Spitzer Space Telescope

Observation Planning Cookbook
Version 5.0

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Revision History

- Version 5.0: November, 2005. New chapters 12 and 13 added, outlining how to prepare Time Series and Target of Opportunity (TOO) observations. Existing chapters revised to reflect new releases of Spot and Leopard software, Reserved Observations, instrument sensitivities, and Cycle-3 Call for Proposals.

- Version 4.0: December 13, 2004. New chapters 7, 11, and 12 added, describing the new IRS Peak-Up Imaging (PUI) AOT, the relatively new MIPS Spectral Energy Distribution (SED) AOT, and the proposal submission process, respectively. Existing chapters revised to reflect new releases of Spot and Leopard software, instrument sensitivities, Reserved Observations, Cycle-2 Call for Proposals, and general "lessons learned" to date.

- Version 3.0: January 26, 2004. Updated all chapters with post-launch information from IOC/SV. Was targeted with a December 30, 2003 release date – delayed due to safe modes affecting MIPS instrument characterizations, and updates released to SSC website on Jan 20, 2004.

- Version 2.6: August 22, 2003. Revised background estimation for moving targets to reflect new capabilities within SPOT.

- Version 2.5: July 25, 2003. Revised PCRS peak-up section.

- Version 2.4: July 21, 2003. Added explanation of how to use PCRS GSC. Updated IRS peak-up example to use 3C273 as target. Clarified entry of proper motions. Updated IRS figures and text for SPOT 7.5.

- Version 2.3: May 1, 2003. Updated with info from current Call for Proposals. Improved figure quality. Minor edits.

- Version 2.2: November 22, 2002. Replaced IRS chapter with 2 new IRS examples: staring mode, and spectral mapping observations.

- Version 2.0: November, 2002. Updated sensitivities.

- Version 1.0: April 15, 2002.

Acknowledgements

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Chapter 1

Introduction

Welcome to observing with the Spitzer Space Telescope! The purpose of this "Observer's Cookbook" is to provide complete, detailed, worked examples of how to set up observations for the Spitzer Space Telescope. As such, it is written as a "How-To" manual, based around the following concrete examples of typical observations one can do with Spitzer:

- **Small area, deep imaging:** See §3 for imaging from $3.6 - 8.0$ μm with IRAC, and §4 for coordinated $24 - 160$ μm MIPS imaging (covering the same area, and the same position angle, with both instruments).

- **Wide-field, shallow imaging:** See §8 for $24 - 160$ μm imaging, and §9 for coordinated imaging from $3.6 - 8.0$ μm.

- **Staring mode spectroscopy:** See §5.

- **Spectral mapping:** See §6.

- **Peak-up imaging:** See §7.

- **Moving object photometry:** See §10.

- **Spectral energy distribution:** See §11.

- **Time series observations:** See §12.

- **Target of opportunity observations:** See §13.

The structure of this manual is based around the worked examples listed above. Each detailed example is presented in a separate chapter. Each example observation is preceded by a short summary of how to design the program, both to provide a road map for observers to find the information they require later in the chapter, and to provide a unified, comprehensive overview of the program for observers who do not require the detail that follows. The overview is followed by an in-depth discussion about all aspects of the observation design process, as well as abundant screen captures of the observation planning software entry windows, hints, and detailed instructions.

Many of the details presented in each chapter are common to all of the observation programs developed here. Nevertheless, we have opted to repeat much of the information in each chapter (e.g., the target entry process within the Spot), so that each example can serve as a stand-alone document, with complete information on the observation design process.

Designing observations with Spitzer is easy! There is a custom-built software tool for designing Spitzer Space Telescope observations ("Spot"; see §2.3 and §2.4 for an overview). Spot is versatile, easy-to-use, and includes a host of convenient features, including the ability to resolve object names, calculate target availability (visibility windows), and visualize observations as an overlay on a user-specified image (which you can provide, or grab from the Digitized Sky Survey, 2MASS, etc).

We also include within this Cookbook some background information which might prove useful to Spitzer observers in general:

- **Overview of preparing Spitzer Space Telescope observations:** See §2.

- **Best practices - A step-by-step guide to submitting your proposal:** See §14.

- **Observation planning FAQs:** See §15.

- **Unit Conversion:** See Appendix A.

A few caveats:

1. **What this Cookbook is NOT:** a one-stop source of technical information about the Observatory, or its instruments. Several other good resources exist as definitive references (for example, the Spitzer Observer's Manual, and observatory web pages; see:

http://ssc.spitzer.caltech.edu/

to get started). However, we have attempted to include some technical information with each worked example, where we felt it was particularly useful to develop the logic of the observations.

2. **Updates to technical information:** at the time of writing of this edition of this Cookbook, we are approximately two years into flight with the mission. For the most accurate and up-to-date information re: instrument sensitivity, performance, behavior etc we encourage observers to check the Spitzer website, particularly the instrument web pages. And feel free to contact the Spitzer Helpdesk (mailto:help@spitzer.caltech.edu) if you have any questions!

3. **Spot version:** Please do ensure you are running the latest version of Spot! (v13.0 available mid-November 2005) See §2.3 for information on obtaining Spot. You may notice slight differences between what appears on your screen and the screen-grabs that appear in this cookbook, since some of the screen-grabs were generated using an earlier version of Spot. You may also notice slight differences in Spot's estimation of the duration of the observations or in the instrument sensitivities from the values quoted in this document.

4. **Notice anything weird?:** Although we've done our best to make sure that this document is 100% correct at time of publication, undoubtedly there are small errors. If you notice anything, please let us know at the helpdesk (mailto:help@spitzer.caltech.edu) and we'll correct it in a future edition.

If you prefer to view this document in its entirety, we have prepared a monolithic postscript file, and a PDF version; the output might not look great on your computer screen, but it prints just fine. These are available from the SSC Observer Support webpage:

http://ssc.spitzer.caltech.edu/ost/

So, without further ado, let's get to it! In the next chapter (§2) we provide some background information needed before we begin designing observations for the Spitzer Space Telescope.

Chapter 2

Getting Started

Before launching into designing, developing, creating and massaging a Spitzer Space Telescope observation, we will first need to gather the tools we will need, and dispense of a few preliminaries.

A good place to start to look for information of all kinds is at the Spitzer Science Center (SSC) webpage:

<div align="center">http://ssc.spitzer.caltech.edu/</div>

There we find Spitzer observing rules, manuals, documentation, lists of approved observations, and Spot software (the software observers use to prepare observations and submit proposals). Links on this page will lead to general Spitzer information, instrument webpages, observer information, bulletins, and so on.

We won't attempt to be comprehensive here, but we would suggest you have a look at the following (at minimum):

- **Spitzer Observer's Manual:**

    <div align="center">http://ssc.spitzer.caltech.edu/documents/som/</div>

- **Spot User's Guide:**

    <div align="center">http://ssc.spitzer.caltech.edu/documents/spot/</div>

- **Proposal submission guide:**

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http://ssc.spitzer.caltech.edu/documents/propsubmission.html

- **Proposal kit webpage:**

  http://ssc.spitzer.caltech.edu/propkit/

- **Instrument Support Team webpages:**

  – IRAC: http://ssc.spitzer.caltech.edu/irac/

  – IRS: http://ssc.spitzer.caltech.edu/irs/

  – MIPS: http://ssc.spitzer.caltech.edu/mips/

- **Infrared Compendium:**

  http://ssc.spitzer.caltech.edu/documents/compendium/

Note: if the links above change, this document will be updated ASAP. However, if for some reason any of the links referenced in this manual appear to be outdated or not functioning, please look at the main SSC website (http://ssc.spitzer.caltech.edu/) and follow the links therein.

If you can't find the information you need on any of these websites, or if a link is outdated, please feel free to contact the ever-friendly Spitzer Helpdesk (mailto:help@spitzer.caltech.edu).

2.1 Proposing Observations for the Spitzer Space Telescope

The third General Observer (GO) call for Spitzer proposals was issued November 1, 2005. The deadline for receipt of GO proposals is February 16, 2006, 1:00 PM (Pacific Standard Time). Investigators worldwide are eligible to apply for Spitzer Space Telescope time.

There are several important changes for Cycle-3.

- **Cycle-3 Call for Proposals:**

  http://ssc.spitzer.caltech.edu/propkit/currentcp.html

We summarize the most important changes here: For full details please refer to the Cycle-3 Call for Proposals.

- **Legacy Programs** will be accepted. These programs require > 50 hours of Spitzer time and have no proprietary data rights. In addition to having strong science goals they also promise to return enhanced data products to the astronomical community. In addition to the formulaically determined research funds awarded, eligible Legacy programs will be awarded funds specifically for the creation and delivery of the enhanced products. More details may be found in the CP.

- **Collaborative Spitzer-HST Proposals** which were solicited in Cycle-2 are not offered in Cycle-3. This proposal category required large commitments of time from both HST (> 100 orbits) and Spitzer (> 50 hours) to reach their science goals. Joint Spitzer-HST/NRAO/NOAO/Chandra observing proposals will continue to be offered.

- **Constrained Observations**. In Cycle-2 constrained observations were limited to a maximum of 20% of the total observing time offered. In Cycle-3 the percentage of constrained observations will be unlimited. However, constraints placed on proposed observations must be explicitly stated and accompanied by a compelling justification. The SSC does encourage observers to use loose constraints when this substantially enhances the science. Programs with heavily constrained AORs will be identified as difficult to schedule by the SSC, and their evaluation will be affected accordingly. More details may be found in the CP.

- **IRAC Stellar Mode:** The IRAC AOT now includes a stellar mode that allows different frame times to be used for the shorter and longer wavelength arrays.

- **MIPS campaigns** will be organized into "warm" or "cold" (telescope held at 5.7K) observations, in order to maximize Spitzer's cryogenic lifetime. Programs requiring 160 micron observations must justify this specifically in the proposal and ensure the "160 micron required" checkbox is selected in the AORs. More details may be found in the CP.

- **IRS Long-High Observations**: As a result of the continual increase in the number of degraded pixels in the IRS Long-High Module due to the effects of cosmic rays, the IRS Instrument Support Team strongly encourages that all Long High (LH) observations of sources with equivalent point source flux densities of 2.0 Jy or less at 25 microns be accompanied by off-source background measurements. More details may be found in the CP.

Archival Research Proposals are solicited to work on any data available by December 31, 2006. We anticipate that all of the original six Legacy Science Programs will be available by that time.

In order to apply for observing time with Spitzer, proposers are required to submit three items in their proposal: cover sheet information, scientific and technical justifications in PDF format, and a set of Astronomical Observation Requests (AORs) – which provide the targets and the mode of operation for each of the observations being requested. All three items and the AORs should be submitted through Spot.

For archival/theoretical proposals a cost plan must also be included in the proposal PDF file. Institutionally endorsed hard copies of the cost plans must also be sent to the SSC by February 24, 2006.

See Chapter 14 for a step-by-step guide to submitting your proposal.

2.2 Preliminaries

Designing observations for Spitzer is, in many ways, a familiar process; the necessary steps to follow are common to creating any observing proposal. Assuming you have settled on the science goals of your proposal, the preparatory work includes, at minimum:

1. Select targets for observation (including a duplication check against the Reserved Observations Catalog database using Spot/Leopard to verify that desired targets have not already been observed, or approved for observations, with Spitzer).

2. Determine IR background at the target locations.

3. Estimate instrument sensitivity.

4. Calculate the exposure time required to reach the desired signal-to-noise (S/N) ratio.

5. Design the observations.

While the focus of this Cookbook is to provide detailed examples of the last step, in the next section we will provide some background information to make some of the preliminary work easier to accomplish.

2.2.1 Are the targets available for observations with Spitzer?

Assuming you have targets selected for observations with Spitzer, you will need to be armed with a bit of information before launching into designing the observations themselves: first, can Spitzer view your targets?

The short answer is that all locations in the sky will be observable by Spitzer for at least ~ 80 days per year, even if Bright Object Avoidance is needed near the ecliptic. However, if there are any timing constraints on your program in addition to the visibility windows allowed by this general Sun-pointing constraint (for example, you require a certain position angle for the observations), you will need to make sure that they are consistent with the windows of visibility allowed by the Sun-pointing angles. For example, if your observations are highly sensitive to slit orientation, there might be only a few days in the year when the geometry of the spacecraft will give the desired slit orientation. Or, no days at all (in which case, the observer has to reconsider which slit orientations are required)!

To determine the target's visibility from Spitzer, one can employ the "Visibility/Orientation" button within the "Target window" of the Spot software.

Since the Spitzer Space Telescope has the capability of observing the entire sky at least once per year, your targets will be, at some time, available for observations. Another issue, however, is duplicate observations. In order to ensure the most efficient use of Spitzer, proposed observations that duplicate those already executed, or approved for execution, will not be permitted without the explicit approval of the SSC Director's office. Archival data should be used whenever possible to accomplish the science goals of any proposed investigation. Precisely what constitutes a duplicate observation is defined in the Spitzer Observing Rules document. For all the details see:

http://ssc.spitzer.caltech.edu/documents/rules/

To check for duplicate observations, we need to search the Spitzer **Reserved Observations Catalog** (or ROC, for short) ascii file or use Spot/Leopard to query the database. For more information on Leopard, see §2.3.

http://ssc.spitzer.caltech.edu/documents/leopard/.

For Cycle-2, the CP referred specifically to checking against the ROC. For Cycle-3 we recommend observers check their targets using Spot/Leopard rather than using the ROC. The ROC file is static, and reflects the state of our database at the instant we generated the ROC files. Spot/Leopard talks to our operational databases and thus reflects the real-time state of approved observations.

2.2.2   What is the IR background?

In general, the IR background contribution is a combination of the zodiacal light, interstellar medium, and cosmic background radiation. At the shorter wavelengths, the background is dominated by zodiacal light, while at the longer wavelength end of the Spitzer spectrum, each of the three components may be contributing.

For IRAC and IRS, which lie at the shorter wavelength 'blue' end of Spitzer instruments, the background is dominated by zodiacal light, so a general rule-of-thumb is that the background is (qualitatively) "low" near the ecliptic poles (absolute ecliptic latitude greater than about 60°), "high" if it is in the ecliptic plane (absolute ecliptic latitude less than 30°, say), and "medium" for all other ecliptic latitudes.

For MIPS, which lies at the longer wavelength 'red' end of Spitzer instruments, the ISM dominates near the Galactic plane, and at high Galactic latitudes, observations can be limited by confusion of your target with background sources, the so-called confusion limit.

At present, the SSC has calculated the expected background for three lines of sight, with a range of ecliptic and Galactic latitudes, and quantified the background levels that correspond to the qualitative labels of "low," "medium," and "high" introduced above. The results are tabulated and plotted at:

http://spitzer.caltech.edu/obs/bg.html

As we will see in §2.4, we can obtain a quantitative estimate of the background for any target position either within Spot, or with IRSKY. How to do this is described in detail in the worked examples in the chapters that follow. See §8.5.1 in particular.

2.2.3   What is the instrument sensitivity?

To determine the instrument sensitivity we need to look at the documentation for each instrument separately. For all of the instruments, the sensitivity has been estimated for the qualitative background characterizations given in the previous section. See:

- **IRAC:** http://ssc.spitzer.caltech.edu/irac/sens.html

- **IRS:** http://ssc.spitzer.caltech.edu/irs/sens.html

- **MIPS:** http://ssc.spitzer.caltech.edu/mips/sens.html

An online Performance Estimation Tool (PET) has been developed that returns sensitivities for user-configured observing parameters. See:

$$http://ssc.spitzer.caltech.edu/tools/.$$

2.2.4   What is the required exposure time?

Having a qualitative characterization of the background, based on the target ecliptic/Galactic latitude, and an estimate of the instrument sensitivity, all we need now is the target flux in order to calculate the time required to reach a desired S/N. If you have this in-hand for one of the Spitzer passbands, you are (almost) in business. If not, you will need to use some other mechanism, and we provide some suggestions for that in a moment.

First, though, what is the flux in the Spitzer passbands? For photometry, Spitzer is following the same calibration methodology as used with IRAS (Beichman 1988), COBE/DIRBE (Hauser 1988) and ISO (Siebenmorgen 1999). See the instrument Data Handbooks for more discussion, because IRAC and MIPS calculate color corrections differently!

With IRAC, we quote flux densities at some nominal wavelengths that are accurate for sources with a flat spectrum

$$\nu \, F_\nu = \text{constant}. \tag{2.1}$$

For other sources, we need to calculate the color correction.

For IRAC, we can proceed as follows. Define K as

$$K = \frac{\int \left(F_\nu/F_{\nu_0}\right) R_\nu \, d\nu}{\int \left(v/v_0\right)^{-1} R_\nu \, d\nu} \tag{2.2}$$

where ν_0 is the nominal frequency where we will quote flux densities (see the IRAC Data Handbook), and R_ν is the system response function. The form of R_ν is tabulated on the SSC webpages. For IRAC, see:

http://ssc.spitzer.caltech.edu/irac/spectral_response.html

Finally, then, the quoted flux density (in Spitzer units), F_ν^{quot} for a source with intrinsic flux density F_ν will be

$$F_\nu^{\mathrm{quot}} = K \, F_\nu. \tag{2.3}$$

More details may be found in the IRAC and MIPS Data Handbooks.

What does this all mean? Well, suppose you wish to do photometry on an object and you know its flux density, F_ν. To estimate exposure times, etc., you should convert this to the Spitzer system by calculating the color correction, K, for the passband in question.

Now what if you don't have an estimate for the object's flux density, but instead have a magnitude? If you are like the authors of this Cookbook (coming from an optical astronomy background), flux densities (for which the units are Jy for point sources, and Jy/arcsec^2 for extended sources) are rather nebulous quantities. With this in mind, we have explicitly provided the formalism for converting between the various unit systems in an Appendix of this Cookbook (see Appendix A). As well, the SSC has created an online tool for converting between magnitudes (in various systems) and flux densities; see:

http://ssc.spitzer.caltech.edu/tools/

Now what if you don't have a good estimate of your target flux? For example, suppose you wish to detect high-z star-forming galaxies, but are unsure what is the expected flux at 70 μm? The SSC has developed some tools to help with this. Part of the PET is for extragalactic point source objects. Based on the observed SEDs of some "famous" objects in the Universe, as well as composite SEDs of various classes of objects (e.g., ellipticals, LINERs, starbursts, etc.), this tool can serve as a guide for predicting the expected flux in the Spitzer bands. See the SSC tools webpage:

http://ssc.spitzer.caltech.edu/tools/

2.3   Obtaining Spot

One of the critical tools we will need to design Spitzer observations is Spot. Let's deal with that next.

The SSC has developed a suite of software tools for designing observing programs. The various stages e.g., determining windows for scheduling, visualizing the observations via an overlay on existing imaging, and submission of the proposal itself are all done through one main tool: Spot. Spot is similar to the Astronomer's Proposal Tool for HST (and it is also somewhat similar to the HST Phase 2 proposal software, RPS2). With Spitzer, the proposal and design phase are linked: to create an observing proposal for Spitzer, observers will use the SSC tools to actually design a program that is 'ready-to-fly' on Spitzer, including the determination of visibility windows, constraints, etc. With the Spitzer Space Telescope, this format is created initially using Spot.

In addition to Spot, the SSC has developed Leopard, the Archive Tool, a software package used to download data. Together, these two cats, Spot and Leopard, are referred to as "Spitzer Pride."

The Spitzer Pride package is freely available for download from the Spitzer Science Center website "Proposal Kit" page:

http://ssc.spitzer.caltech.edu/propkit/

Look under the section "Getting the Software" and follow the links to download the software appropriate for your platform.

A few notes about Spot (and Leopard): the software is written in the JAVA programming language, and requires a moderately large memory allocation, and a fast processor, in your computer. See the Spot User's Guide for additional information. The minimum recommended hardware configurations are:

- **Sun Workstations:** Sun Ultra 5 with 256 MB RAM.

- **Windows PC:** Pentium 3 processor with 256 MB RAM.

- **Linux PC:** Pentium 2 processor with 256 MB RAM.

- **Mac PC:** G4 processor with 256 MB RAM.

Even with these minimum requirements, some features i.e., visualizing AORs may be unacceptably slow.

Currently, Spot is supported in a number of operating system configurations, including:

- **UNIX:** Solaris 2.8.

- **Windows:** NT, ME, 2000, XP

- **Linux:** Linux Redhat 8.0+, Fedora Core

- **Mac:** Mac OS X

2.4   Designing the Observations with Spot

How do we design observations for Spitzer? In general, the observer interfaces with the Observatory and the instruments by means of Astronomical Observation Templates (AOTs). An AOT, one for each of the eight Spitzer observing modes, permits the user to unambiguously define the parameters of their observing program. Users fill out these AOTs to create "Astronomical Observation Requests" (or AORs), and submit the AORs with the completed observing proposal.

From an observer's viewpoint, the AOT "Front End" is the electronic form observers fill out to define an experiment to be executed by Spitzer. AORs are the result of filling out an AOT form. The AORs themselves are the fundamental scheduling unit for the Spitzer Space Telescope. An AOR can be thought of as a list of parameters that (when properly interpreted) describe an observation completely.

As noted in §2.3, filling out AOTs to design an AOR is done within Spot. This process consists of entering targets which are individually linked to a desired Spitzer observing mode, or AOT.

To design an observing program for Spitzer with Spot, we will need to:

1. Start the observation planning software, Spot.

2. Enter target information (and, if desired, obtain an IR background estimate at the target location).

3. Fill out an AOT, to create the AORs.

4. Obtain resource estimates.

5. Save AORs, and, when done, submit a full observing proposal (which includes the AORs, together with a coversheet, scientific and technical justifications) to the SSC!

The basic steps in completing an AOR are outlined in the rest of this chapter.

2.4.1   Start Spot

Assuming for the moment that we have some observation program in mind, and we wish to design a Spitzer observation, we are ready to fire-up the software (Spot) to do so.

Under UNIX/LINUX, type **$PATH/spot** (where **$PATH** is the path to where Spot was installed). On a PC, simply double-click on the Spitzer icon.

The start-up Spot window should appear, and is illustrated in Figure 2.1.

2.4.2   Enter Target Information

With *any* Spitzer AOT, the target name and coordinates are entered first. As this step is common to any observing proposal, we will provide a bit more detail on target entry in this chapter.

We first launch Spot and bring up the new target window, either by positioning the mouse over the target icon (the bulls-eye icon on the taskbar; see Fig. 2.1), or by selecting "new target" from the "Targets" menu. The target entry window will appear, with entry dialog as shown in Fig. 2.2.

Several features are accessed from the target entry window. These include:

1. **Resolve the name:** NED/SIMBAD target name resolution. Simply enter the name of the target for which you want the coordinates, select the resolver (NED or SIMBAD), and click "Resolve the Name."

2. **Visibility/Orientation** Determine visibility windows for inertial and moving targets.

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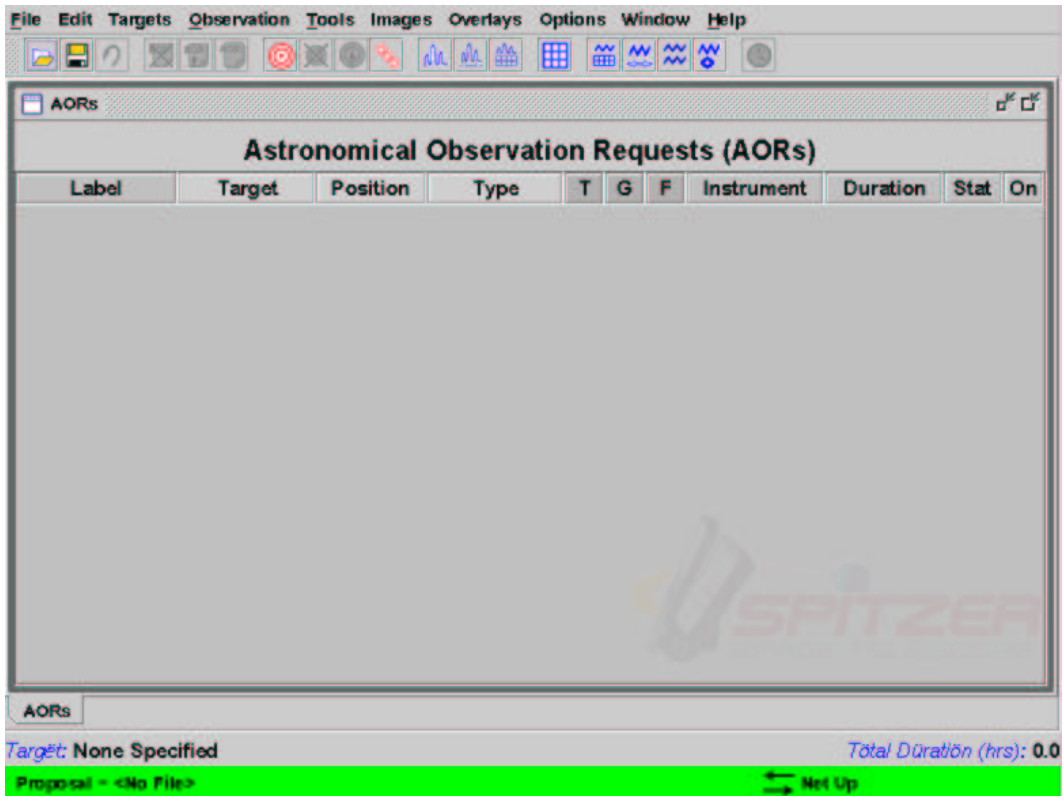
Figure 2.1: The Spot window after initial start-up.

3. **Background:** Sky background estimates for inertial targets. You have the option of specifying the wavelength at which to estimate the background, as well as performing the calculation for a specific date, or over the entire range when the object is visible to Spitzer.

4. Option to avoid **bright moving objects** that might be in the target field. Bright objects to be avoided include both the Earth/Moon and 'Others', which are Mars, Jupiter, Saturn, Uranus, Neptune and the asteroids Vesta, Hebe, Ceres, Iris, and Eunomia. Selecting these options will restrict the observations to preclude times when the target coordinates are within 7° of the Earth and Moon, or within 30′ of the objects on the 'Others' list.

In the target entry dialog, there are two general choices for the *type of target* (fixed or moving), displayed under five tabs. For fixed targets, these
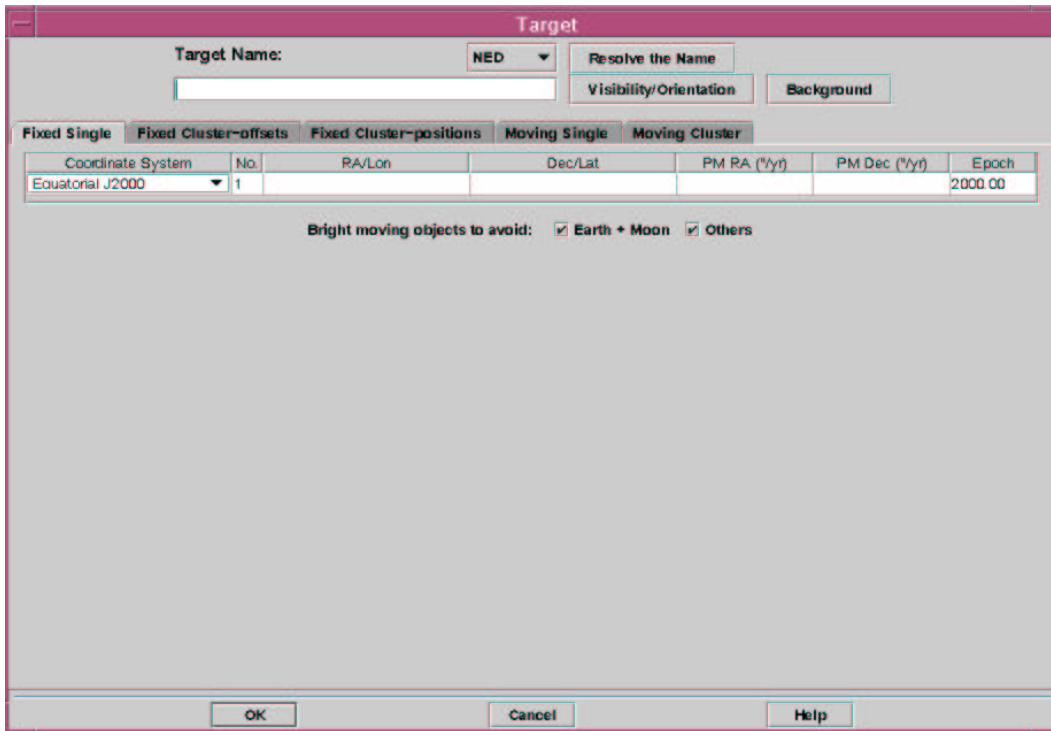
Figure 2.2: The target entry dialog.

are: **Fixed Single, Fixed Cluster, and Fixed Cluster - positions**. For moving targets, these are **Moving Single, and Moving Cluster**. See Fig. 2.2. These are described in more detail below:

1. **Fixed Single:** A fixed-single target is one object or map center outside of the Solar System.

2. **Fixed Cluster:** A Spot 'cluster' does not necessarily mean an astronomical cluster. Rather it defines a group of positions in a region of sky within a radius of 1° to be observed with the same AOT parameters. Targets of this type are sets of objects that have a scientific requirement for observation in close spatial and temporal proximity. By using cluster targets you avoid the per AOR slew tax you might otherwise incur by having separate fixed single targets. The positions are entered as a primary equatorial J2000 right ascension and declination, and the offsets north and east from the primary target. **Note that the east**

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offsets DO NOT follow lines of declination on the celestial sphere. North and east are determined at the primary target position when the observation starts. If it is crucial for your science that you have an exact RA and DEC, you should use a Fixed Cluster - positions target type.

3. **Fixed Cluster-positions:** Defines multiple absolute positions where no two positions are separated by more than $2°$.

4. **Moving Single:** A moving single target is a single object that requires Solar System tracking.

5. **Moving Cluster:** A group of co-moving Solar System targets separated by less than $1°$ to be observed with the same AOT parameters. The positions are entered as a primary target and offsets east and north from that position. The ephemeris for the primary target determines the tracking rate to be used for the entire cluster, but the primary target itself does not have to be observed as part of the cluster.

A few words about overhead and the "cluster" target type: The cluster option has the advantage of saving a significant amount of overhead in some types of programs (e.g., some IRS Peak-Up overheads; see Chapter 5). Any set of observations which can be carried out as a cluster target could also be carried out as a string of observations of Fixed Single targets and a set of AORs. Providing science goals can be met, the "cluster" target allows the user to utilize only one AOR. However, the flight software is built in such a way that doing it as a set of Fixed Single observations can incur additional overhead for each new target (e.g., for target acquisition).

2.4.3   Fill Out an Astronomical Observation Template

Select an AOT from the Observation menu. The instrument configuration and integration time parameters are entered in the AOT form. In Cycle-3 eight distinct AOTs are available for Spitzer observations. We provide complete worked examples of seven AOT types in the chapters that follow. An example of the Total Power AOT may be included in a future edition of the Cookbook.

- **IRAC Mapping:** The IRAC AOT is used for simultaneous imaging at 3.6, 4.5, 5.8 and 8.0 microns, over the two $\sim 5'.2 \times 5'.2$ fields of view. See §3 (deep imaging) and §9 (wide-field, shallow imaging).

- **IRS Staring Mode Spectroscopy:** The IRS staring mode is used for low-resolution, long-slit spectroscopy ($R = 62 - 124$) from 5.3 to 40 microns and high-resolution spectroscopy ($R = 600$) from 10 to 37 microns. It also returns images from the IRS Peak-Up array. See §5.

- **IRS Spectral Mapping:** The IRS Spectral Mapping AOT is used to configure a grid of map positions around a central target position and obtain spectra at each position

- **IRS Peak-Up Imaging:** The IRS Peak-Up Imaging AOT is used to obtain images from the Peak-Up array, which has a field-of-view of approximately 1 arcminute square and two filters covering $13.3 - 18.7\,\mu$m and $18.5 - 26\,\mu$m. See §7.

- **MIPS Photometry/Super Resolution:** The MIPS Photometry and Super Resolution AOT is used for imaging photometry at 24, 70 and 160 microns. See §4.

- **MIPS Scan Map:** The MIPS Scan Map AOT is used for large field maps at 24, 70 and 160 microns. The maps are constructed using slow telescope scanning, combined with motion compensation using a cryogenic scan mirror. Maps are built up of 5.1 arcminute wide strips (2.5 arcmin for full coverage at 70 microns) between 0.5 and 6 degrees in length. See §8.

- **MIPS Spectral Energy Distribution:** The MIPS Spectral Energy Distribution AOT is used for very low resolution ($R \sim 20$) spectroscopy covering 55-95 microns using the MIPS 70 micron Ge:Ga array. See §11.

- **MIPS Total Power Mode:** The MIPS Total Power Mode AOT provides zero-level-reference observations at 24, 70, and 160 μm for absolute brightness of extended sources.

2.4.4   Obtain Resource Estimates

As noted in §2.4, the fundamental unit of Spitzer observing is the Astronomical Observation Request (AOR). An AOR can not be subdivided, will not be

interrupted for other activities (such as downlinks), and will be handled as a unit by Spitzer. Because an AOR will be executed as a unit, and the need for the Observatory to perform certain activities (such as calibrations, detector anneals, downlinks), there is a maximum duration for an AOR: three hours for IRS and MIPS AORs, and six hours for IRAC AORs . AORs that would require longer time-blocks to execute must be divided into separate requests (i.e., shorter duration AORs).

At any time within Spot, you can check how long an AOR (or series of AORs) will take to execute. From the main Spot window (see Fig. 2.1), look in the "Tools" pulldown menu and select "Recompute All Estimates." You will be greeted with a pop-up menu asking you to select what you want to recompute. Most often, you will select "Current AOR," "Selected AORs" or "All AORs." Spot will then churn away in the background, and return you to the main Spot window, with the "Duration" field filled in the lower right-hand corner of the Spot window, and duration estimates listed for each AOR.

To obtain more detailed information about how the total duration is shared among actual integration on-sky, telescope slew time, settle time, and so on, use the "Calc. Obs. Time" button within each AOT entry dialog. See §4.5 for a detailed example within a MIPS Photometry/Super Resolution observation.

2.4.5 Save AORs

Save the AORs! Save the targets! You can do both independently from the "File" pulldown menu in the main Spot window. (Note – you do not have to save your targets separately from the AORs.) Do this not just after you've completely filled out your AOR, but rather do it early, and often! After all, the Big One may hit and a power disruption might mean the end of a beautiful Spitzer program-to-be...

When you are finally ready to actually submit a proposal, make sure that you are submitting a clean set of AORs. If you've been playing around with options and alternate targets, make sure to delete those AORs entirely before submitting your proposal. All the AORs in your Spot window at the moment you submit your proposal will be submitted to the SSC with the other proposal parts.

We explain how to submit a proposal in more detail in §14.

Chapter 3

Deep Imaging of Five Clusters of Galaxies at 3.6 - 8.0 micron using IRAC

In this chapter (and the next), we document the full procedure one might follow in developing a Spitzer observing proposal. We will design a deep imaging observation that covers a relatively small area of sky. This example will illustrate how to perform a deep, small area imaging campaign, coordinating observations between two Spitzer instruments: IRAC $(3.6 - 8.0 \ \mu\text{m})$, and MIPS $(24 - 160 \ \mu\text{m})$. The IRAC observations are described in this chapter, and the complementary MIPS program is developed in §4. You may notice slight differences between what appears on your screen and the screen-grabs that appear in these chapters, since some of the screen-grabs were generated using an earlier version of Spot. You may also notice slight differences in Spot's estimation of the duration of the observations or in the instrument sensitivities from the values quoted here.

In order to mimic more closely the complete procedure an observer might follow, we develop a test case "real observation." The science background is as follows:

The goal is to survey selected regions of the sky to study the formation and evolution of normal galaxies to redshifts $z \gtrsim 3$, and probe the high-z population of star forming galaxies. We will choose well-studied regions of the sky, where deep spectroscopy has been obtained from 10m class telescopes, and observations are extant in the radio, optical and X-ray. The objective will be to obtain deep IR imaging to $\simeq 1.7 \ \mu\text{Jy} \ (1\sigma)$ at 8 microns. This will

enable us to address a number of science goals. For example, Spitzer imaging to this depth, combined with spectroscopic data (obtained elsewhere), would allow us to construct a luminosity function for normal galaxies at $z \simeq 3$.

Such a program has been performed, e.g., in the Spitzer GTO program ("The IRAC Deep Survey," PI: G. Fazio[1]) by imaging a wide area (multiple fields) in the Groth strip. Here we describe a complementary approach to image a smaller total area of the sky, but to greater depth, using the magnification by foreground clusters to probe deeply into the IR sky. We will coordinate two Spitzer instrument campaigns to obtain photometry from $3.6 - 8.0$ μm (§3) and $24 - 160$ μm (§4).

The gravitational lensing by a massive, low-z cluster magnifies background sources, and hence galaxies that would fall below the sensitivity limit of blank field observations are boosted above the detection threshold. For simplicity we ignore this effect for this example.

In the remainder of this chapter, we develop the observations in the 3.6 - 8.0 micron range using the InfraRed Array Camera (IRAC). The longer wavelength ($24-160$ μm) observations using MIPS are discussed in §4. IRAC is the four-channel camera that provides simultaneous $\sim 5{.}'2 \times 5{.}'2$ images at 3.6, 4.5, 5.8, and 8 microns. The pixel size is $\simeq 1{.}''2$ in all bands and all four detector arrays in the camera are 256×256 pixels in size. IRAC is the instrument for imaging observations at the "bluest-end" of the Spitzer wavelength coverage.

3.1   Overview of the Program

In this section, we summarize the steps followed to design the deep imaging IRAC program. This will serve both as a one-stop resource for those requiring only an overview of how to do such a program, and also as a roadmap of where to find more detailed information later in this chapter.

IRAC is a four-channel camera that provides simultaneous $5{.}'2 \times 5{.}'2$ images at 3.6, 4.5, 5.8 and 8 microns. Two adjacent fields of view are imaged in pairs (3.6 and 5.8 microns; 4.5 and 8.0 microns) using a dichroic beamsplitter. All four detector arrays in the camera are 256 x 256 pixels in size, with a pixel size of $1{.}''2$.

Observing programs with IRAC are designed with the IRAC Mapping AOT, supporting both mapping and dithering schemes, a choice of full, sub-

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[1]see http://ssc.spitzer.caltech.edu/geninfo/gto/abs/pid8 for details.

array, stellar or high dynamic range modes, and a selection of frame times, ranging from 2-100 sec in full-array mode, 0.02-0.4 sec in subarray mode, and 12-100 sec in high dynamic range mode. Users can design single pointing observations, or a mosaic, subject only to the constraint that each AOR must have a duration of less than 6 hours; longer duration programs must be split into separate AORs.

- **Target Selection:** For this example, we observe in the fields of rich, low- to moderate-z galaxy clusters. After a duplication check using Leopard (http://ssc.spitzer.caltech.edu/documents/leopard/) we see that these fields already have scheduled observations with Spitzer, and hence we would need to carefully design observations so as not to violate the Spitzer Duplicate Observation Rule. See §3.2.

- **Background Estimate:** We use Spot to obtain a background estimate at each of the target positions. In general, the background is characterized qualitatively by three levels (low, medium and high), and for these targets, the IR background is low/medium/high for the targets. We compare these estimates with what we see in IRAS Sky Survey Atlas images of the target field. See §3.4.

- **Exposure Time Estimate:** Armed with the background characterization above, we look at the IRAC sensitivities for low, medium and high backgrounds, respectively. This enables an estimate of the required exposure time to reach a desired signal-to-noise ratio for point source detection. In this case, for medium background, to reach $\simeq$ 1.7 μJy (1σ) in the 8.0 micron band, we require $t_{\text{tot}} \simeq 50 \times 100$ sec. See §3.5.

- **Filling out the IRAC AOT:** The observations themselves are designed within Spot. We complete the IRAC Mapping AOT, and a screen capture of the completed AOT is shown in Figure 3.14. For each target, we observe the cluster central region in all four passbands, and hence select **both the** 3.6/5.8 μm **and** 4.5/8.0 μm **fields of view**. The objects we wish to detect are intrinsically faint, so we select **bright object avoidance**, and read-out in **full array mode**; see §3.6.1. To reach the desired depth with the integrations, we require $\simeq 5000$ sec total integration. We select a **frame time of 100 sec.**, and a **50-point**

Target	z	ra	dec	in ROC?
		J2000	J2000	
Abell 2218	0.176	16:35:53.99	+66:13:00.2	Yes
ZwCl0024.0+1652	0.4	00:26:36.01	+17:08:36.1	Yes
Abell 665	0.18	08:30:45.19	+65:52:55.3	Yes
Abell 1689	0.18	13:11:34.20	-01:21:55.5	Yes
AC 114	0.31	22:58:52.34	-34:46:54.6	Yes

Table 3.1: The targets for the coordinated IRAC/MIPS deep imaging program.

dither using the **cycling dither pattern**, with **medium scale factor**; see §3.6.4. To image the central region, we explore the possibility of using either a **simple map** (1 column, 2 row array coordinates map, with row/column spacing of $410''.2$), or **no mapping** with both fields-of-view selected; see §3.6.3.

- **Duration:** The total time required, per target, to execute these observations is 11125 seconds, which is less than the limit of 6 hours for an IRAC AOR. See §3.7.

- **Visualization:** We visualize the observations via an overlay of the IRAC fields-of-view on Digital Sky Survey images of the clusters; see §3.8.

3.2 Target Selection: Massive, Intermediate Redshift, Galaxy Clusters

The first task involves the selection of targets for the observations. There are many low-z clusters with existing multiwavelength observations and spectroscopy. Without attempting to be exhaustive in a target list, let us concentrate on the candidates, listed in Table 3.1.

As with all observations, we need to determine if the targets are already scheduled for observations with the Spitzer Space Telescope. To check for duplicate observations, we use the Leopard search tool.

http://ssc.spitzer.caltech.edu/documents/leopard/.

We find that all of the above targets already do have reserved/scheduled/accepted IRAC mapping programs. To propose to observe the targets in Table 3.1 again, we would need to comply with the Spitzer Observing Rules by, for example, reaching to a sensitivity ≥ 3 than the observations already proposed. However, for the purpose of this example, we will not worry about violating the duplicate observation rule, and will proceed as if all targets have not been observed already.

3.3   Target Entry

We start by launching the Spitzer Planning Observations Tool (Spot), and entering the target information.

As described in §2.4.1, we first start Spot and bring up the new target window, either by clicking on the target icon (the bulls-eye icon on the taskbar; see Fig. 2.1), or by selecting "new target" from the target menu.

In this example, we wish to consider observations of the galaxy clusters listed above, at a single position, with small dithers for cosmic ray rejection, which we will configure in a moment. Hence we choose the "Fixed Single" target type. We enter the first target, Abell 2218, and hit the "Resolve the name" button. Spot finds the RA/Dec of the cluster center (16:35:53.99, +66:13:00.2, J2000 for Abell 2218. Note that this seems to be somewhat offset from the optical center of the cluster, but we will accept it anyway for the purposes of this example).

Since we will be looking for faint, high-z galaxies, we select also the boxes to avoid bright moving objects during the observations (both the Earth/Moon and 'Others', which currently includes Mars, Jupiter, Saturn, Uranus, Neptune and the asteroids Vesta, Hebe, Ceres, Iris, and Eunomia). This choice will restrict the observations for scheduling to preclude times when the target coordinates are within $7°$ of the Earth and Moon, or within $30'$ of the objects on the 'Others' list). The completed entry dialog is shown in Fig. 3.1.

After entering the target name, coordinates, and clicking 'OK', we are returned to the main Spot menu (see Fig. 3.2). A few features to notice: in the bottom banner, the selected target name is displayed "abell 2218," with target type "Fixed Single."

Repeat this procedure for the other targets in the list.
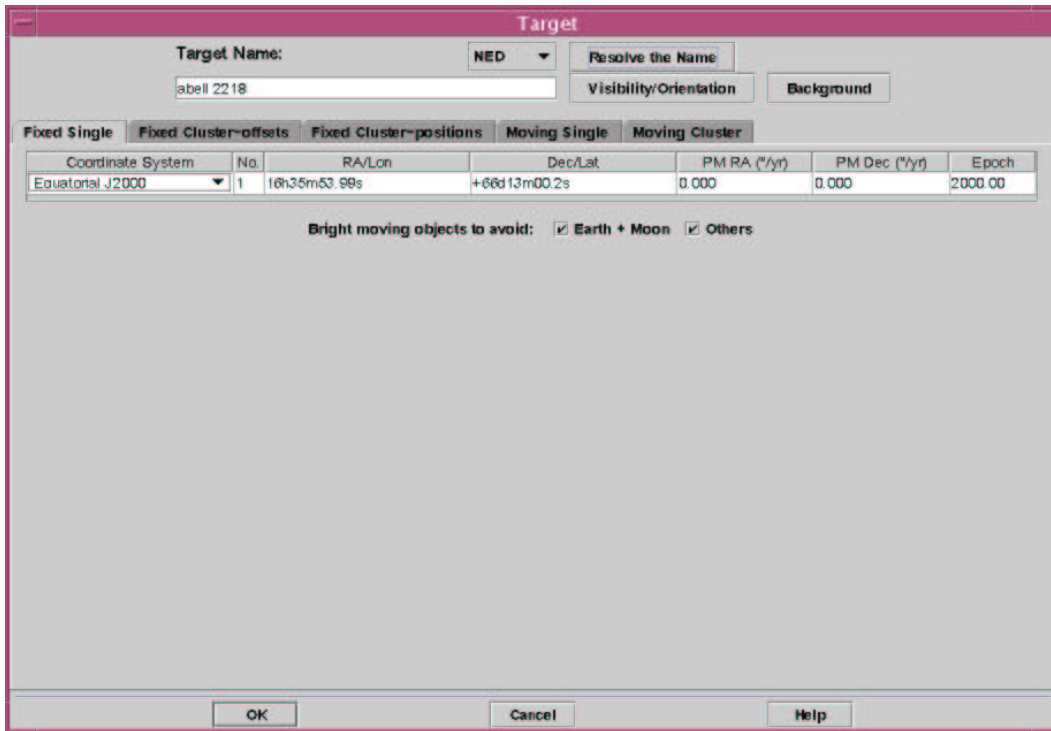
Figure 3.1: The target entry dialog.

3.4   Background Estimate

As with all observations, we will need to determine the IR background at the location of the targets. In general, the IR background contribution is a combination of the zodiacal light, interstellar medium, and cosmic background radiation. At IRAC wavelengths, the background is dominated by zodiacal light, so a general rule-of-thumb is that the background is "low" near the ecliptic poles (absolute ecliptic latitude greater than about 60°), "high" if it is in the ecliptic plane (absolute ecliptic latitude less than 30°), and "medium" for all other ecliptic latitudes.

We obtain a more quantitative estimate through the Spot Target entry dialog. Within the target entry/modification window, clicking on "Background" (see Figure 3.1), brings up the "Background Dialog" window, which we display in Figure 3.3.

We enter 8.0 microns as the wavelength to do the estimate, leave the "Calculate Range When Visible" button selected, and click "Do Estimate."
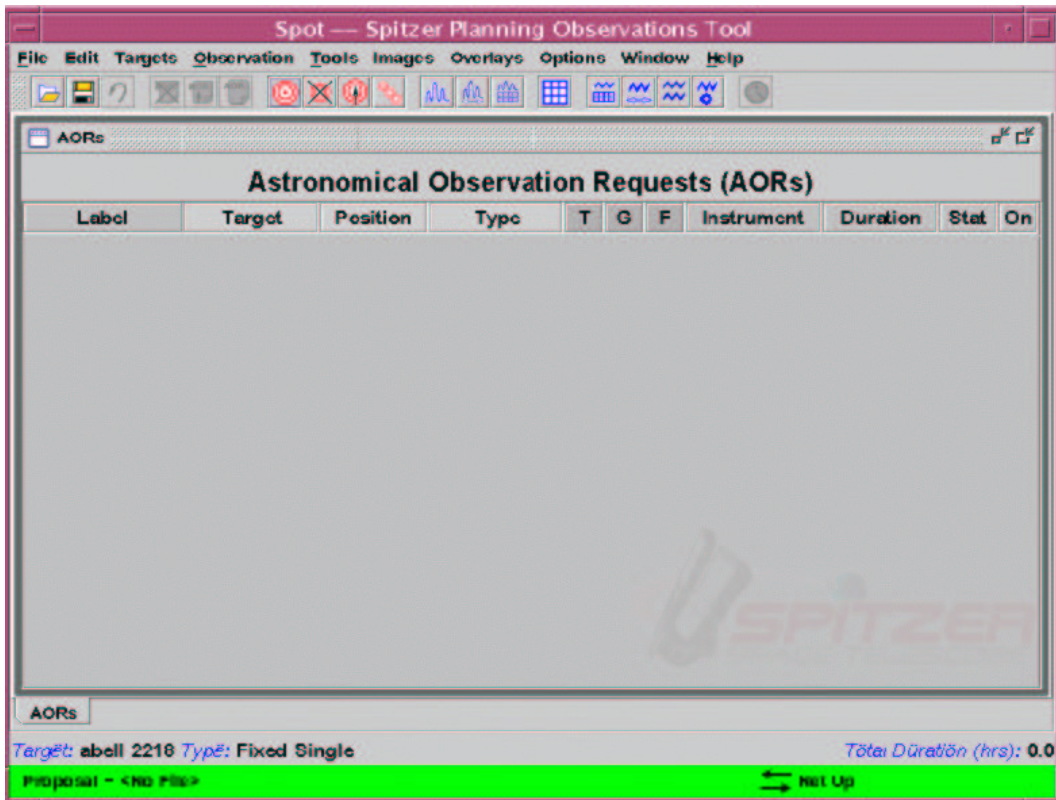
Figure 3.2: Spot menu after Abell 2218 target entry.

A screen capture of the results for Abell 2218 is shown in Figure 3.4, and the results for all of the targets are given in Table 3.2. The 8 micron maximum backgrounds vary by a factor of three (5.678 MJy/sr for Abell 2218, to 16.372 for Abell 1689), and are classified by the SSC as "low" to "high" backgrounds respectively[2].

It is a good idea to verify the background estimate provided by Spot with a visual check of observations provided by IRAS. To do this, we first retrieve the IRAS Sky Survey Atlas (ISSA) image of the target field (in this case, we do it for Abell 2218). To do this, select "ISSA image..." from the "Images" pulldown menu. The ISSA image retrieval pop-up window, shown in Figure 3.5, will appear.

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[2]see: http://ssc.spitzer.caltech.edu/obs/bg.html for plots of the IR background at various Galactic latitudes, and the SSC's classification of low/medium/high backgrounds.
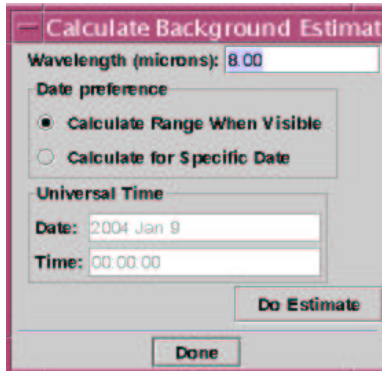
Figure 3.3: The background dialog entry dialog.
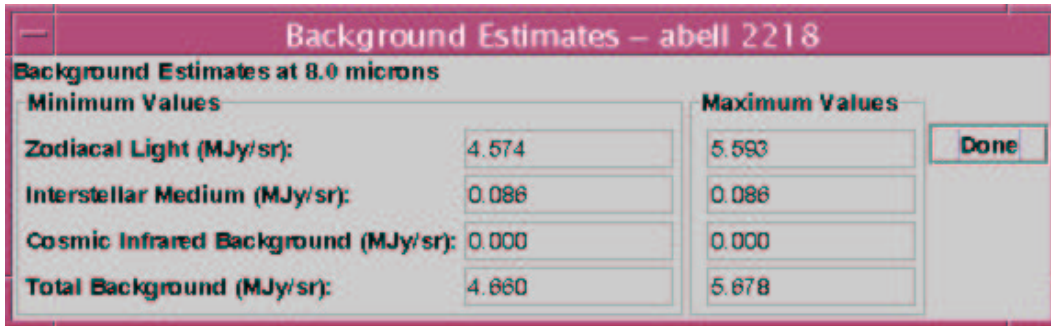
Figure 3.4: The 8.0 micron background at the Abell 2218 central position.

We select all wavelengths (12, 25, 60 and 100 micron), choose a 1 degree FOV, put all plots in a current frame, no zoom, and hit "OK." When Spot has retrieved the images, you will note that there are now large black arrows and a slider bar in the upper right; see Figure 3.6. This is how you can flip between images loaded into the same window. If you load fewer than four images into the same window, then the slider only includes those images as options.

Putting the slider on 12 microns (closest to the IRAC bands), and increasing the zoom (by hitting the magnifying glass icon with the "+" sign on the left hand side of the main Spot window), allows us to examine the structure of the IR emission in the target field. Now the ISSA pixels are $90''$, so the resolution is only a few pixels per IRAC FOV. Nevertheless, we see no evidence of very bright spots in the emission, and the flux is $\simeq 1$ MJy/sr at 12 microns, somewhat below the estimates at 8 microns returned by Spot.

Target	Maximum Background [MJy/sr]	Background Level
Abell 2218	5.678	Low
Abell 1689	16.372	High
AC 114	11.620	Medium
Abell 665	8.591	Medium
cl0024+16	13.982	High

Table 3.2: The 8.0 micron background at the target positions.

Why is there a difference between Spot's estimates and that seen in the ISSA maps? Ignoring the slight difference in wavelength, there are some differences in how the background is estimated with Spot that may be important for your science. For a detailed discussion, see §8.5.1.

3.5   Sensitivity and Exposure Time

Armed with the characterization of the background level (see §3.4), we can proceed to estimate the required exposure time. The first stop is the IRAC webpage for the instrument sensitivity. See:

$$http://ssc.spitzer.caltech.edu/irac/$$

For IRAC, the current estimate of the confusion limit is $\simeq 0.6$ μJy (this does not represent a hard sensitivity limit, but rather indicates where source confusion affects the reliability of source extractions; see the IRAC chapter of the SOM for more information). At 3.6 microns, we reach the limit quickly: with a single cycle of the 100 sec frame time for low background. The longest IRAC waveband, 8 microns, reaches the confusion limit last, requiring $>$ 260×100 sec total integration (for low background) to be confusion limited. See the SOM for more information.

We determine the exposure time required for this proposal to reach $\simeq$ 1.7 μJy (1σ) at 8 microns. For medium background, with a 100 sec frame time[3], the 1σ IRAC point-source sensitivity is $0.73, 1.4, 9.3$, and 12.0 μJy for the 3.6, 4.5, 5.8 and 8.0 micron bands respectively. For long frame times, the

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[3]In Cookbook v3.0 and earlier, this calculation was performed using 200 sec frame times. The calibration of 200 sec frames is no longer supported - See the SOM.
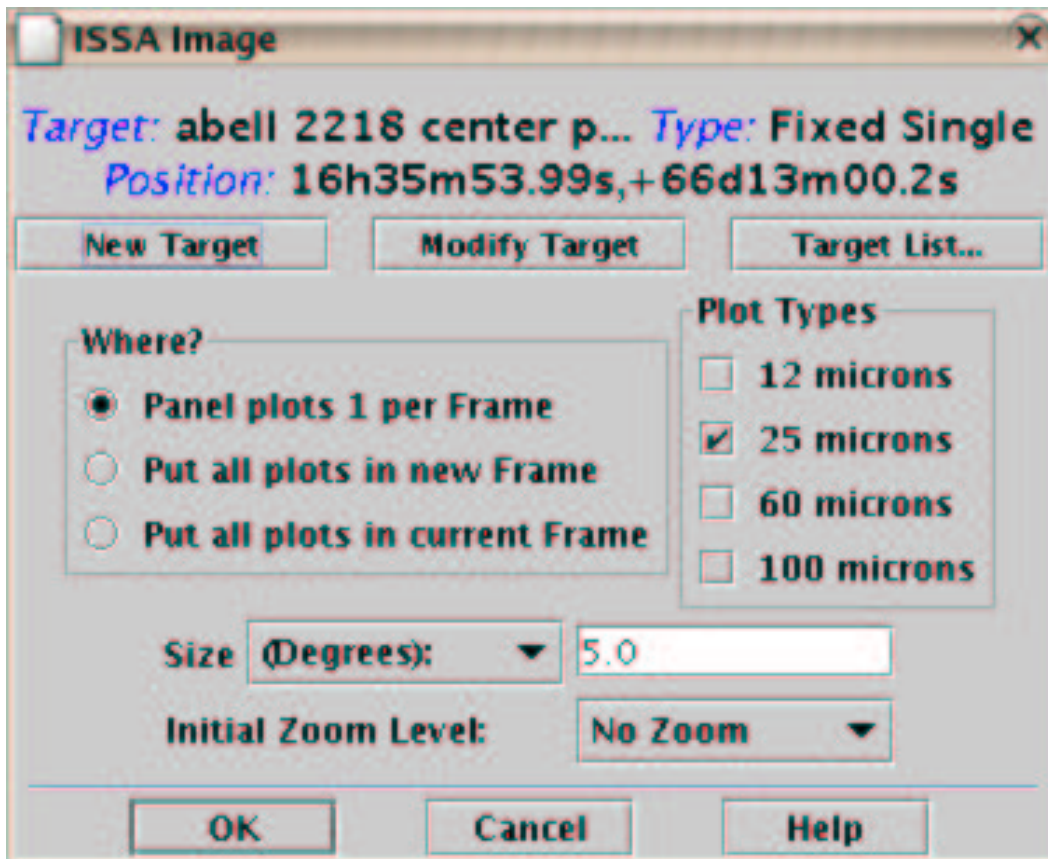
Figure 3.5: The ISSA image retrieval entry dialog.

noise essentially scales with $t^{-1/2}$. Hence, to reach $\simeq 1.7$ μJy (1σ) in the 8.0 micron band, we require 49×100 sec.

One word of caution however: while our science goal is to probe deeply at 8 microns, the 3.6 and 4.5 micron arrays will be well below the confusion limit with $t_{tot} \simeq 49 \times 100$ sec. Since the 3.6 and 5.8 arrays are paired (data are obtained in both arrays simultaneously), and similarly for the 4.5 and 8 micron arrays. So, if we also want (for whatever scientific reasons) the deep 5.8 micron data from 49 repeats of the 100 sec frame time, we must be aware that we will not be increasing the S/N as $\propto \sqrt{t}$ in the 3.6 micron data once the confusion limit is reached in that waveband. A similar argument applies for 4.5 micron data, while we collect the deep 8 micron data.
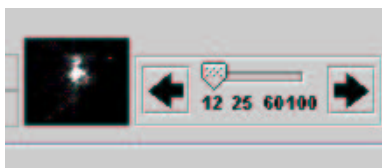
Figure 3.6: Flipping between 12, 25, 60, and 100 μm images.

3.6 Filling out the IRAC AOT

We now fill out the IRAC AOT, starting with selecting the AOT type. This is accomplished either by selecting "IRAC Mapping" from the "Observation" pull-down menu, or by clicking on the "Infrared Array Camera $3.6 - 8.0$ μm imaging of single or multiple fields" icon (the blue checkerboard icon, sixth from the right on the icon taskbar). The IRAC Mapping AOT entry window will appear as illustrated in Fig. 3.7.

The IRAC AOT itself consists of an (optional) dither pattern superposed on an (optional) rectangular-grid raster. In this section, we will discuss each of the AOT entry options, and the activities that the spacecraft and telescope will perform when the specified AOR is executed. Let us consider these in turn.
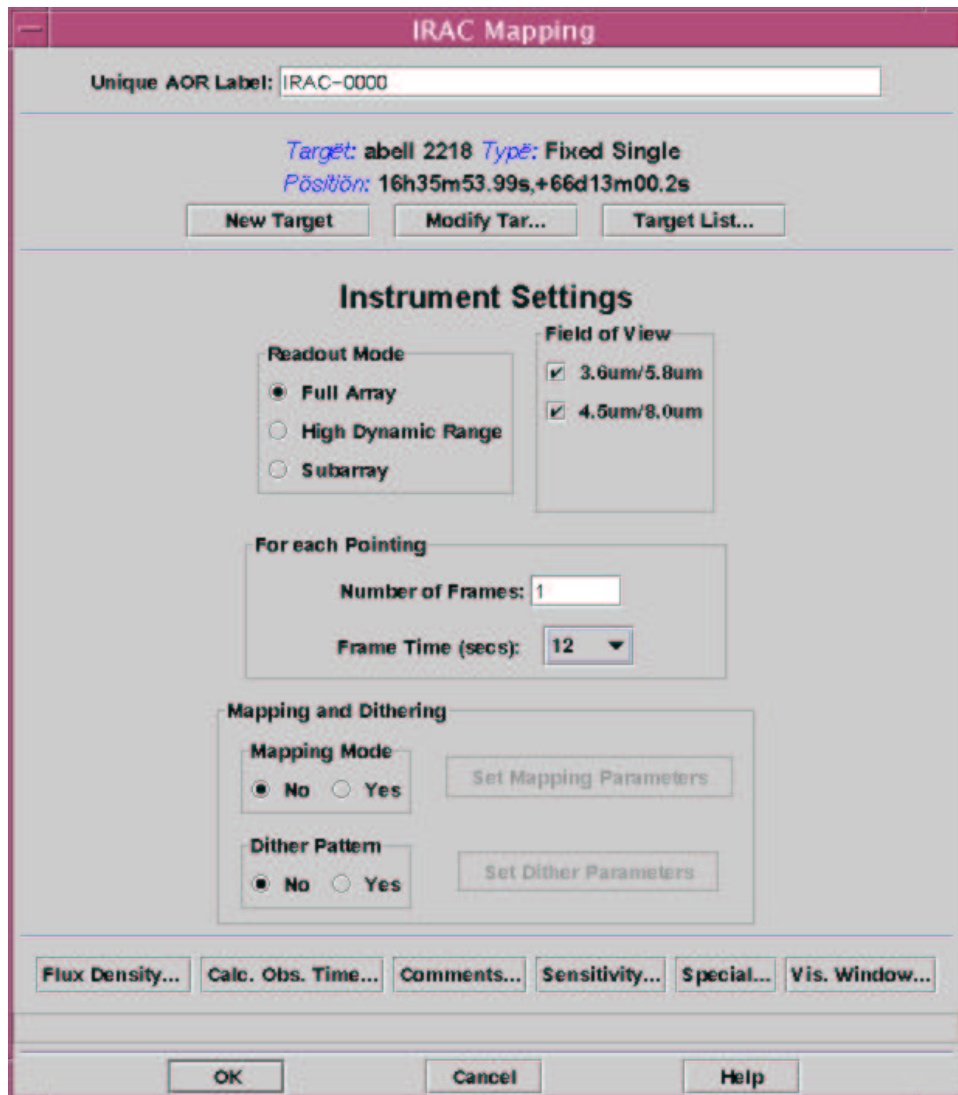
Figure 3.7: The IRAC Mapping AOT entry dialog.

3.6.1 Readout Modes and Frame Times

For most observations, each of the 256 x 256 arrays is read out in its entirety; this is the full array mode. In full array mode, there are four selectable frame times: 2, 12, 30, and 100 sec (the 200 sec frame time is not supported by calibration measurements and we strongly discourage its use).

In this example, we are searching for intrinsically faint objects, hence we choose full read-out mode, and, for each pointing, the 100 seconds frame time. Now to reach our desired depth at each pointing, we calculated above that we need 49 repeats. Therefore we *could* enter "49" in the "Number of Frames" dialog box. However, to do this would be a very bad idea indeed!!. This would mean that the observations would be executed with no offsets. In almost all observing scenarios, to obtain a good quality final image it is *essential* to have at least small offsets between exposures, for cosmic ray rejection, for mitigation of scattered light and long- and short-term latents, and for image artifact masking. We thus use the dithering option, as described in §3.6.4, and set "1" in the "Number of Frames" dialog box; see Fig. 3.14.

3.6.2 Field of View

The four IRAC arrays are fed by two entrance apertures, which are located one above the other in the focal plane with a gap of about 1.5 arcmin. For the subarray mode, there are four separate fields of view (FOVs), corresponding to the subarray section of each of the four arrays.

The observer can select a primary group of detectors for the observation by checking one, or both, of the field-of-view (FOV) boxes, which are labeled by the wavelengths of the detectors in each group. In subarray mode, there are four FOVs, because the subarray portions of the detectors do not overlap on the sky.

Note: the way the AOR will be executed depends *both* upon the map and field of view choices (i.e., they are co-dependent). For the moment, let us leave aside the choice of field of view and discuss the mapping implications.

3.6.3 Mapping
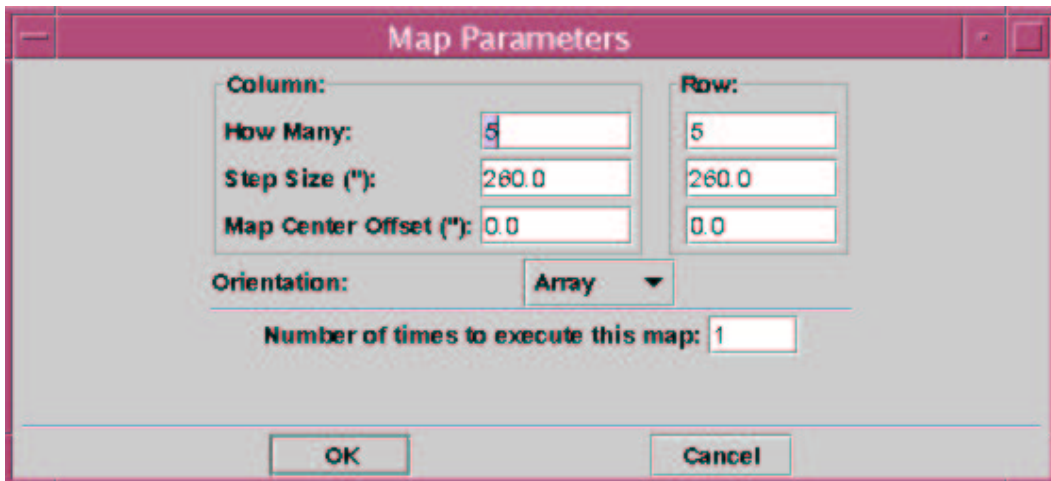
The choices for mapping and field of view are co-dependent. Selecting one of the fields of view as primary ensures that the map you define will be centered on the target coordinates in your primary field of view. All four fields of view

collect data, however, so an offset map will be imaged by the other field of view.

For example, for a single pointing observation (i.e., no mapping), by selecting the 3.6/5.8 μm field of view as primary, the specified target will be imaged with the 3.6/5.8 μm field of view, while a nearby portion of sky will be covered with the 4.5/8.0 μm FOV. By selecting both fields-of-view (still with no mapping), we request that the same piece of sky be covered by *each* array, and in this case, there will be 'offset' fields that are imaged only by either the 3.6/5.8 μm or 4.5/8.0 μm FOVs.

In mapping mode, selecting both fields of view *does not guarantee that the same sky is covered at all four wavelengths.* If you select the celestial coordinates map, the map grid is executed once with the 3.6/5.8 field of view centered on the map positions, and then again with the 4.5/8.0 field of view. This can lead to significant redundancy, as the same area of sky is imaged more than once by the same aperture. If you select array coordinates and both fields of view, then the map will be centered on the point midway between the two IRAC fields of view.

Confused? A few examples are in order. From the main IRAC AOT entry window (see Fig. 3.7), under the "Mapping and Dithering" section, clicking the "Yes" radio button under "Mapping Mode" brings up the mapping entry dialog in Figure 3.8.

Figure 3.8: The IRAC Mapping AOT map parameter entry dialog.

We have choices of the number of rows and columns of the map, the map

spacing, and the coordinate system for the offsets: array or celestial. As alluded to above, how maps are executed depends upon the field of view selection, as we illustrate below. For this example, all choices will be done with the rectangular grid.

- **Case 1: no mapping.** The easiest case first. If both fields of view are selected, the observations are executed with the target in each aperture successively. With either the 3.6/5.8 or 4.5/8.0 field of view selected, the target is centered in the chosen aperture only. A simple illustration of these three cases is shown in Figure 3.9, where the 'X' marks the target location, and the two apertures are shown as the squares.

- **Case 2: single position (1x1) map.** A tricky thing can happen if you choose both fields of view, and do a 1 row, 1 column map in array coordinates. In this case, the target is placed midway between the two fields of view. Choosing one or the other field of view only centers the target coordinates at the center of that field of view. This is illustrated in Figure 3.10.

- **Case 3: simple map.** Let's consider a map consisting of 2 rows, 1 column, with offsets $= 260''$ in array coordinates. This should be sufficient to illustrate more complex mapping strategies. Choosing both fields of view centers the target in the middle of the overlap region of both fields of view. Conversely selecting one of the 3.6/5.8 and 4.5/8.0 micron fields of view centers the map in the center of the overlap region for that field of view. The maps are illustrated in Figure 3.11.

No mapping

Both FOVs   3.6/5.8 FOV   4.5/8.0 FOV
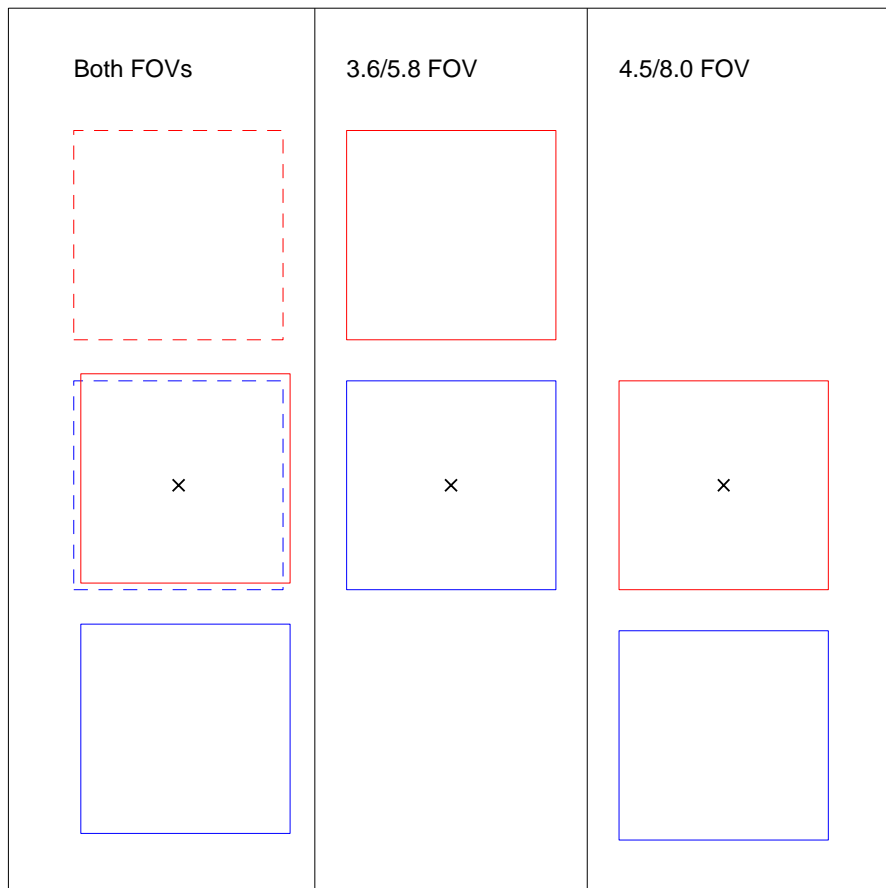
Figure 3.9: **No mapping.** The dependence of the sky area covered in no-map mode on the field of view selection. The "x" marks the target position in each case, and the squares show the 3.6/5.8 and 4.5/8.0 micron apertures. In the first panel, the second pointing has been shown as dashed lines, to aid in the visualization.

Figure 3.10: **Single position map.** The dependence of the sky area covered with a single position (1 column, 1 row) array coordinates map. The "x" marks the target position in each case, and the squares show the 3.6/5.8 and 4.5/8.0 micron apertures.

Simple map: 1 column, 2 rows, offsets = 260"
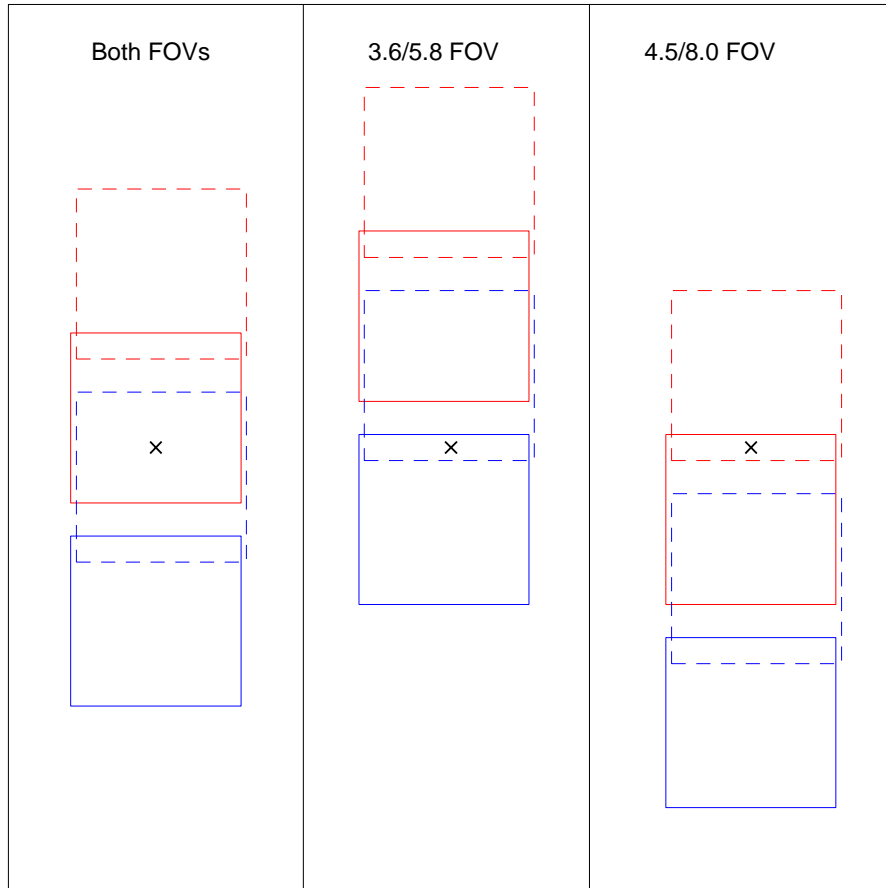
Figure 3.11: **Simple map.** The dependence of the sky area covered with a simple map (1 column, 2 rows with offsets = $260''$ in array coordinates). The "x" marks the target position in each case, and the squares show the 3.6/5.8 and 4.5/8.0 micron apertures.

So, what does this all mean? You should choose a map scheme such that you obtain sky coverage in the passbands you wish, obviously. What about if you want exactly the same sky to be covered in both apertures? This is possible, although at the added expense of constraining when your observations can be performed. The Spitzer Space Telescope has a restricted roll angle, such that it must be positioned so that the solar shield offers protection from the Sun. Hence to 'flip' the relative orientations of the 3.6/5.8 and 4.5/8.0 micron apertures, effectively we must wait $\simeq$ six months for the observatory to be on the other side of the Sun. You can do this with Timing Constraints, or, equivalently, by creating two AORs with position angle constraints. However, **do so at your own risk**! The more constrained a program is, the less likely it can be scheduled. **The preferred method is to make a map large enough so that there is sufficient overlap in both fields of view without constraining the observations.**

For the purposes of the example we are developing in this chapter, we could do one of the following (which are equivalent). The first way is the simplest: do the observations with no mapping, but select both fields of view. The sky coverage is given as in the left panel of Figure 3.9.

An equivalent way to implement this using mapping is to perform a 1 column, 2 row array coordinates map. We adjust the offsets to be one array width + the spacing between the arrays $\simeq 310 arcs + 90'' = 400 arcs$, and select both fields of view. This will mean that the second pointing places the 4.5/8.0 micron aperture at the position of the 3.6/5.8 micron aperture in the first pointing. The end result is uniform coverage over a $5.'2\square$ FOV in 3.6, 4.5, 5.8, and 8.0 microns, with flanking fields imaged for half as much time in either 3.6/5.8, or 4.5/8.0 microns. The resulting sky-coverage map is illustrated in Figure 3.12.
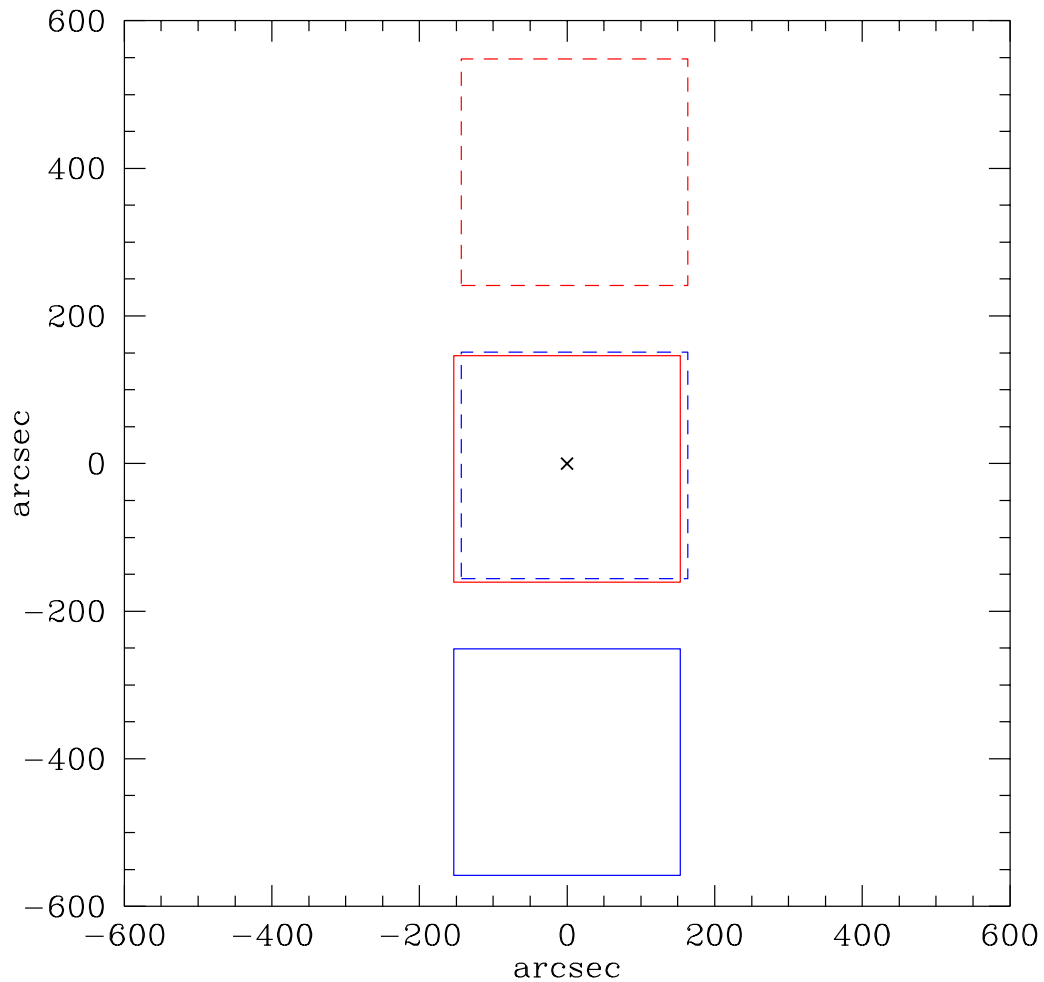
Figure 3.12: The sky area covered either with no mapping, selecting both fields of view, or a simple map: 2 columns, 1 row, offsets 410 arcseconds in array coordinates, and both fields of view selected as primary. The "x" marks the target position, and the squares show the 3.6/5.8 and 4.5/8.0 micron apertures. The second pointing in the map has been shown as a dashed line, and offset slightly in the x-direction, to aid in visual recognition of each pointing.

3.6.4 Dithering

Finally, we wish to implement a dither scheme. At each of the positions defined by the single position, map, or cluster in the target specification section, the telescope is pointed to a series of offset positions that define the dither pattern. The purpose of the dither is to minimize the effect of pixel-to-pixel gain variations, help with cosmic ray identification and removal, and aid in removal of image artifacts on the detector. Several pre-packaged dithering options are available in either the full array or subarray readout modes. Clicking on dither pattern "yes" brings up the dither selection dialog illustrated in Fig. 3.13.
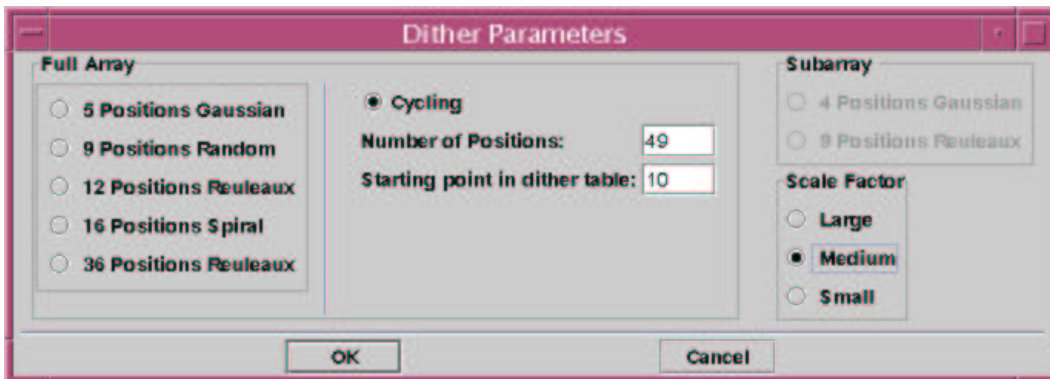
Figure 3.13: The IRAC Mapping dither pattern dialog.

The dither patterns for IRAC in full array mode currently include a five-position Gaussian pattern, two sizes of Reuleaux triangle, a 9-point random, a 16-point spiral, and a cycling dither pattern; see the IRAC chapter in the Spitzer Observer's Manual for more information.

For the Gaussian, Random, and Reuleaux patterns, the same dither pattern is performed at each map grid position. The "cycling" pattern consists of a table of 311 unique offsets, drawn at random from a Gaussian-normal distribution; for each dither, the observations are obtained at the next entry position in the table. The dither pattern can vary quite a bit depending on the number you choose as the "starting point in the dither table," so if you don't like any given pattern, try changing that number and re-visualize the observation.

For the Cookbook example we are developing here, in the dither selection dialog window (Fig. 3.13), selecting "Cycling," with "Number of Positions"

set to "49," and "Starting point in dither table" set to, for example, 10 would mean that at the first map position, exposures are taken with dither-offsets 10-58. At the second map position, exposures are taken with dither-offsets 59-107 in the dither table.

In addition, the selected dither patterns may be scaled using one of the "large, medium, small" options, which select pre-determined scalings of the dither patterns, which for cycling dithers are 5:2:1. The offsets in the Gaussian-normal distribution that generates the cycling pattern can be as large as $\simeq 160$ pixels from the (0.0) position. In general, well-dithered observations will mitigate much of the effect of latents, scattered light, and image artifacts, and so we select the "medium" scaling option.

3.7   Duration

The completed AOT is displayed in Fig. 3.14.
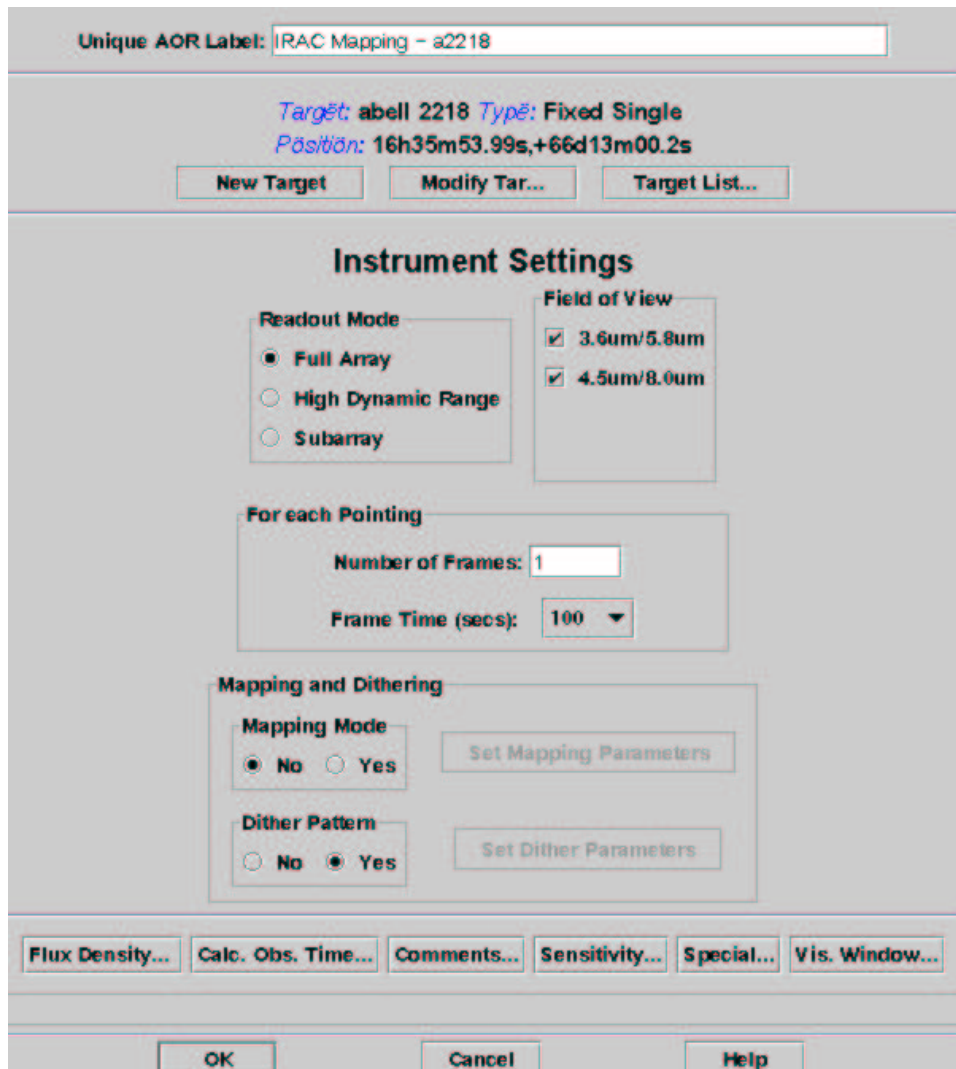
Figure 3.14: The completed IRAC AOT for Abell 2218.

Hitting "OK" on the AOT entry dialog window returns us to the main Spot window, as shown in Figure 3.15.
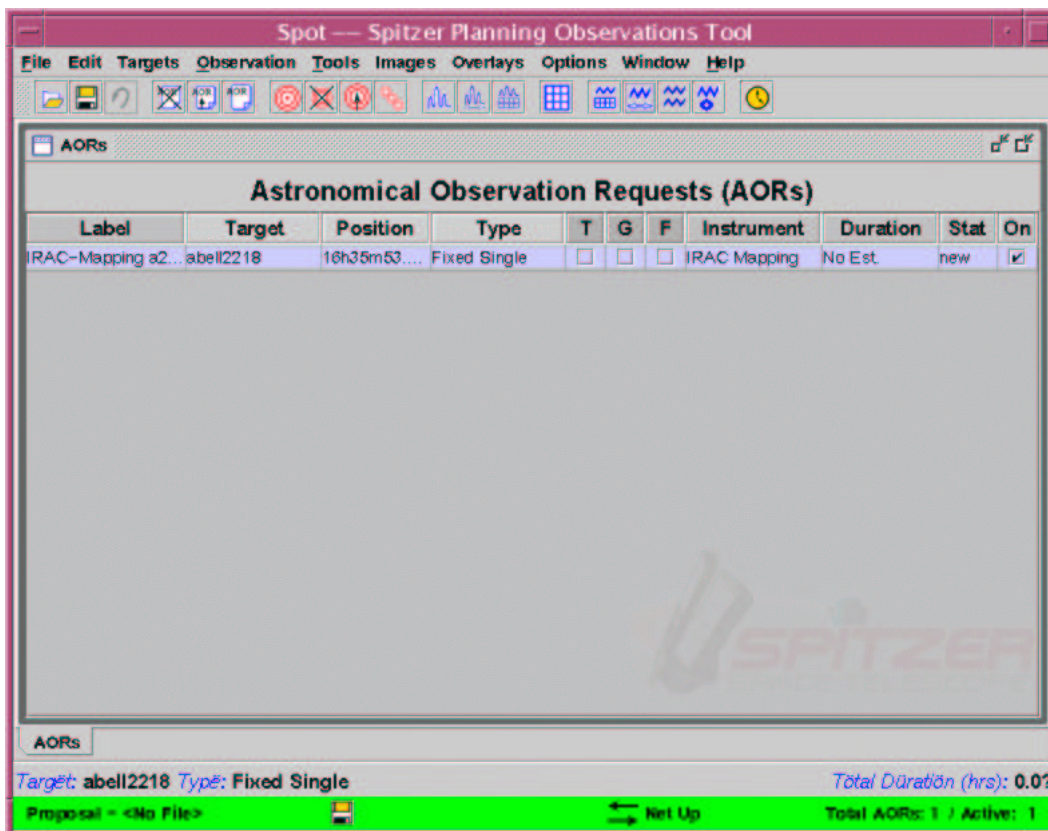
Figure 3.15: The Spot menu after the IRAC AOT parameters have been entered.

> **Hint:** in this example, we gave the AOR the title "IRAC mapping - a2218." Note that all alpha-numeric characters are not permitted in the AOR name. Periods and colons are not allowed. Also, make sure to give each AOR a unique, short and yet insightful name. The AOT entry dialog will assign a label by default, but we highly recommend changing this to more reflect the nuances of your observations.

A feature to notice: under duration, there is no estimate of time required to execute this AOR. Easy enough to fix: under the "Tools" pulldown menu

of the main Spot window, select "Recompute All Estimates." You will be greeted with a pop-up menu asking you to select what you want to recompute. Select "Current AOR." Spot will then churn away in the background, and return you to the main spot window, with the "Duration" field now filled (11124.8 seconds, for this example). Also the Total Duration report on the bottom right of the Spot window will be filled. In this example, we use 3.1 hrs, which is less than the maximum of six hours per AOR allowed for IRAC observations. A screen capture of the Spot menu with the duration estimates included is shown in Fig. 3.16.
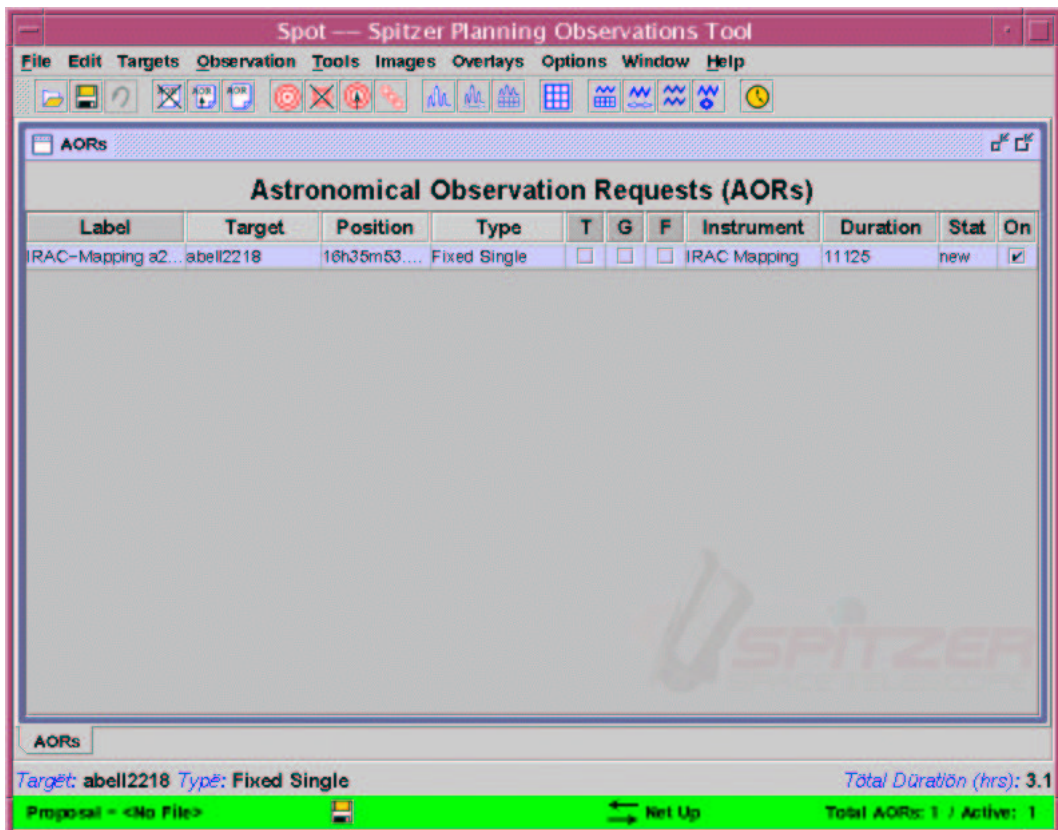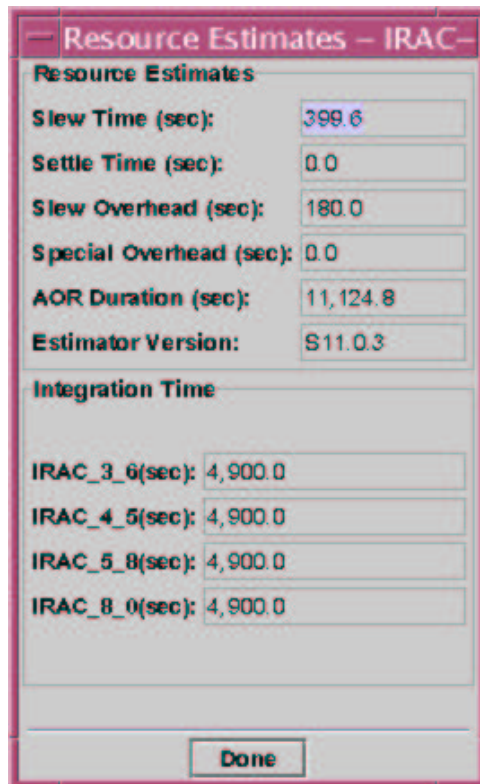
Figure 3.16: The Spot menu after the Abell 2218 IRAC AOT parameters have been entered, and the AOR duration computed.

> **Hint:** an alternative way of obtaining the AOR duration is to click on the "Calc. Obs. Time" button from within the main

AOT entry window (see Fig. 3.14). The duration estimate returned will now include a breakdown of slew time required, settle time, total AOR duration, and the integration depth in seconds, per pixel, for each of the passbands. See Figure 3.17 for a screen capture.

Figure 3.17: The AOR duration calculated from within the AOT entry window.

3.8 Visualization

We have a completed AOR for one of our targets, determining the background and hence the sensitivity of the instrument, calculating and specifying within Spot the required exposure (frame) time, a dither pattern, and number of repeats. We calculated the total duration of this program, and it is less than the maximum allowed per AOR. So what next?

We will use this AOR as a template for the other targets in the list. However, first, we might want to visualize the observations with an overlay on the optical or infrared sky.

First, we need to obtain or specify an image to use for the overlay. We can obtain ISSA, 2MASS, MSX, or DSS images through Spot. Click on the "Images" tab on the toolbar, and, for example, select "DSS Image." You will see a pop-up window, asking you to specify the parameters for the image; a screen capture in shown in Fig. 3.18. After clicking "OK," Spot will work away, and return with an image in the main window.

To place the overlay on the image, click on the "Overlays" tab, and select "AORs on current image." You will be prompted for an observation date. Choose anything reasonable (this will be more important for constrained observations; however, since we have placed no timing or orientation constraints on the AOR, we can simply choose whatever dates are available to get a visualization of the observations). The resulting overlay (after zooming out) is shown in Fig. 3.19.
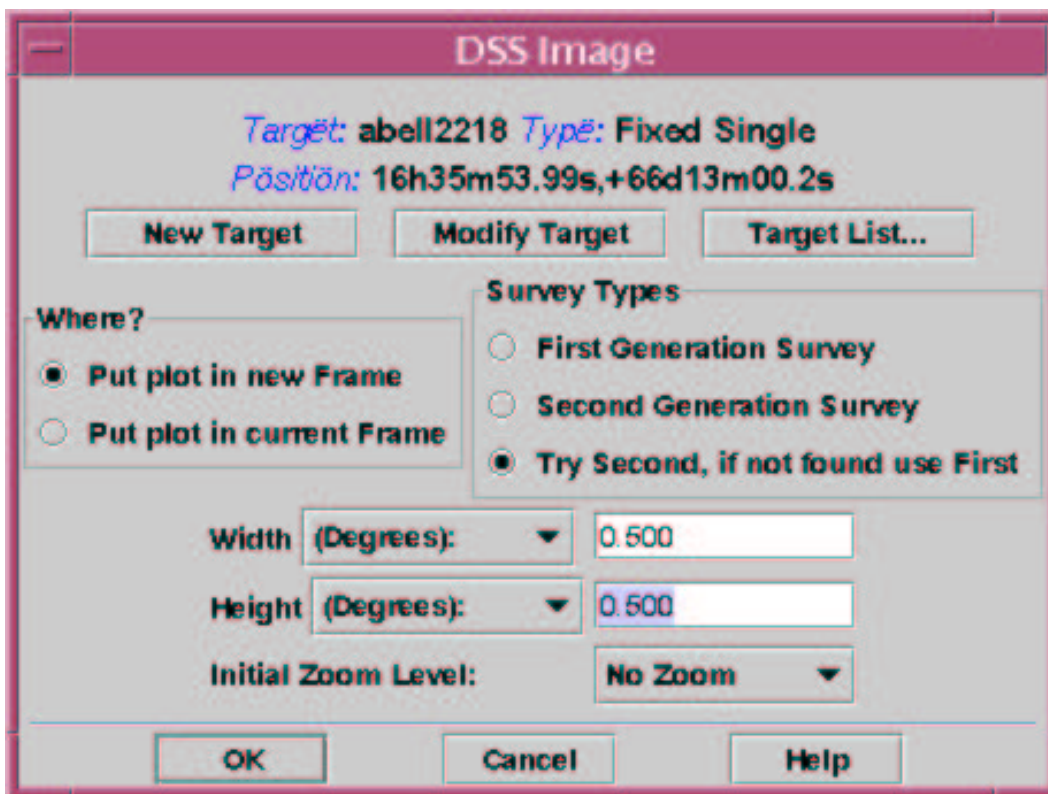
Figure 3.18: The Spot image menu dialog.
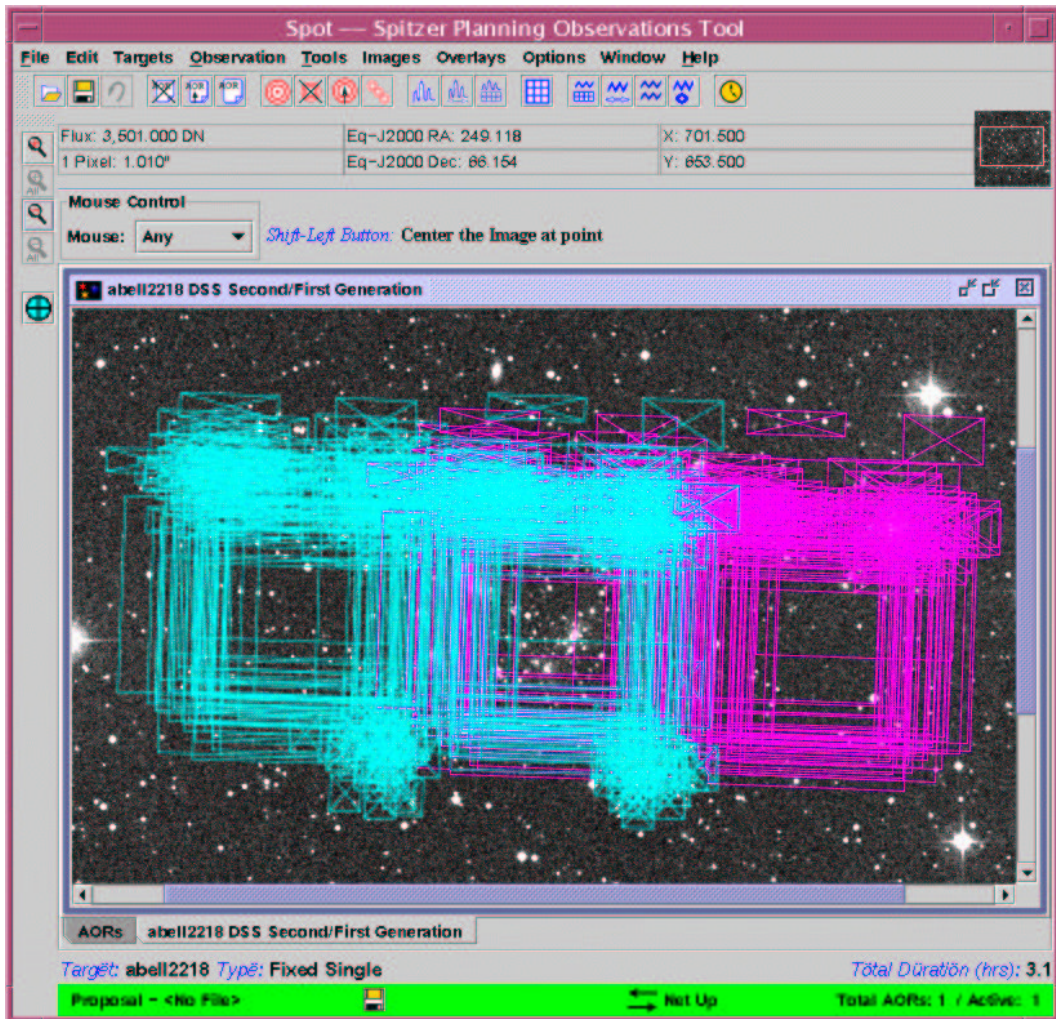
Figure 3.19: The overlay of the IRAC mapping observations on the Abell 2218 field.

The overlay shows that the central position has been observed twice, once with the 3.6/5.8 μm field of view (large, light blue squares), and once with the 4.5/8.0 μm FOV (large, purple squares). There are a few neat visualization aids which we highlight here: Firstly click on the "Show Side Bar on Current Frame" under "Options." This will bring up a sidebar with "IRAC-Mapping" and "Base-Image Options" if it is not already visible. Look under "IRAC-Mapping" and you will see four buttons, including one that looks a bit like a tiny grid with red lines. Click that and you will see a pop-up window with options to animate the overlay on an image-by-image basis, animate with a trail, showing the cumulative observations, and the opportunity to select only a subset of the dithered pointings to overlay on the image.

> **Hint:** the visualization tool within Spot is a great, simple way of understanding what all of the AOT options really mean. For example, the various mapping/field of view options described in §3.6.3 can be easily sorted out simply by selecting various combinations of options, and seeing what the resulting visualization looks like. Combined with the detailed duration tool from within the AOT entry window, you are presented with a unified picture of how the sky is mapped with your observations, and what depth, per pixel, you are obtaining.

> **Hint:** in the visualization, you will notice a few small squares with containing X's, approximately one arcminute from the main fields of view. These are the scattered light boxes, highlighting locations where bright point sources will scatter light into the IRAC FOVs. If a bright star falls in one of those boxes, it is recommended that the observations be adjusted to move the object out of the troublesome regions by e.g., constraining the date of the observations. Well-dithered observations will also mitigate scattered light problems.

A similar exercise can be done to examine the local IR sky at the target position. Instead of selecting a DSS image from the "Image" pulldown tab, select 2MASS or ISSA instead.

For another way to get a feel for the IR background around the target position, we can place the ISSA image on the DSS image, viewing both simultaneously. To do this, click on the "Overlays" pulldown tab, and follow

"Image Overlays" to "ISSA Image overlaid on current image...." Bringing up a 1 degree image, at 12 microns, and overlaying the current AOR on the image, gives the result shown in Figure 3.20.
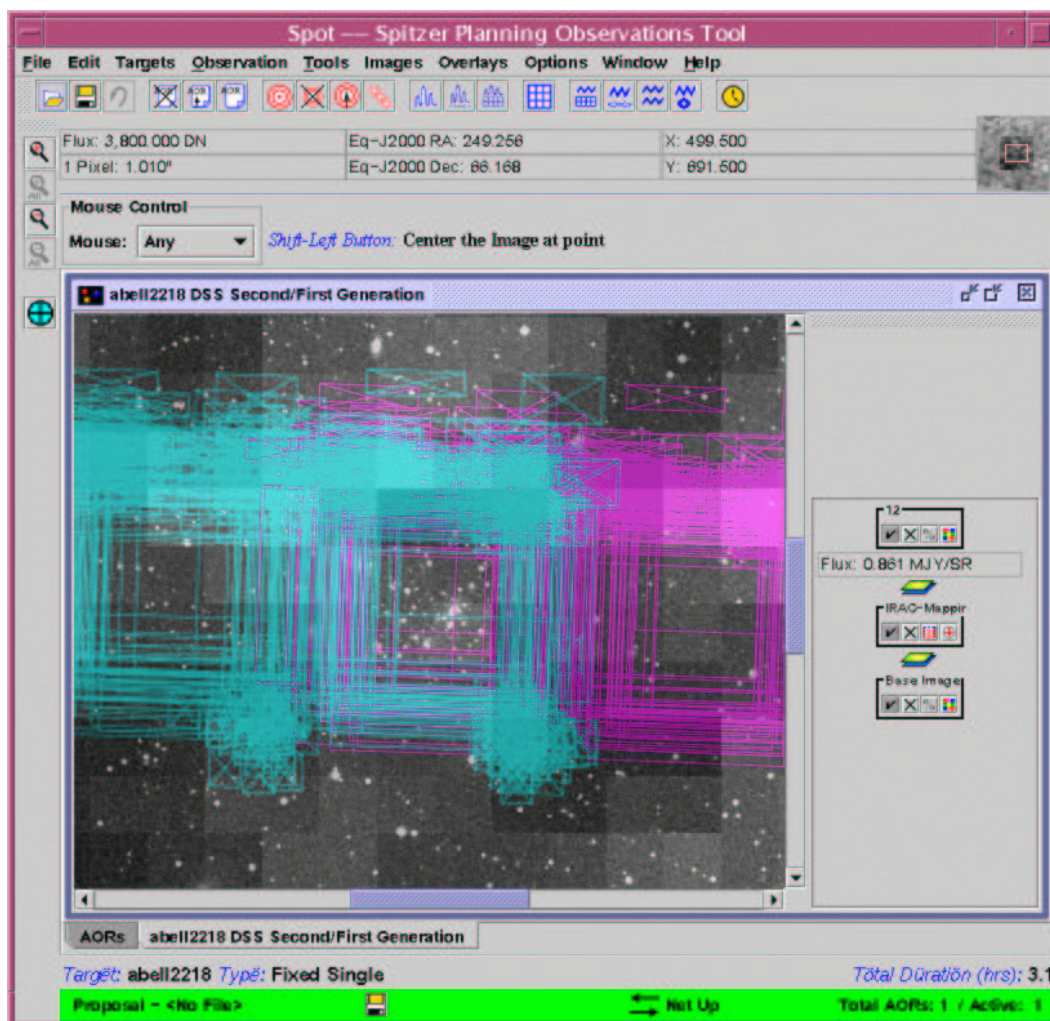
Figure 3.20: The overlay of the IRAC mapping observations on the Abell 2218 field. The checkerboard pattern is the ISSA image.

3.9   Duplicating the A2218 AOR to Design the Complete Program

Finally, we need to duplicate this AOR for all of our other targets. To do this we can use the AOR replication tool. Click on the "Edit" tab, and select "Copy current AOR." In the main Spot window, a second AOR, appearing to be exactly the same as the first we just created, will appear. Double click on it to edit, and the IRAC Mapping AOT entry dialog will appear. We need to change the target for this AOR, so we click on "Target List" which brings up a pop-up window with the list of targets we entered earlier (see §3.3). Select, for example "Abell 1689." Also, adjust the AOR Label to whatever you like (e.g., "IRAC Mapping: a1689 central position"). Hitting "OK" returns you to the main Spot window with the new AOR listed.

We repeat this procedure for all of the targets in the list and recalculate the duration necessary for the entire program. A screen capture of the main Spot window after all of this has been completed is shown in Figure 3.21.

That's it! Don't forget to save both the target and AOR list (otherwise all of this work will be lost when you exit Spot). For reference, we show the raw text .aor file for this set of observations (as well as the companion MIPS observations, developed in the next chapter) in Appendix B. For reference, the raw text .aor file for this set of observations is available at the SSC website:

http://ssc.spitzer.caltech.edu/documents/cookbook/aors/

In the next chapter (§4) we describe how to develop a complementary observing program to image the same fields from 24 to 160 microns, using the Multiband Imaging Photometer for Spitzer.
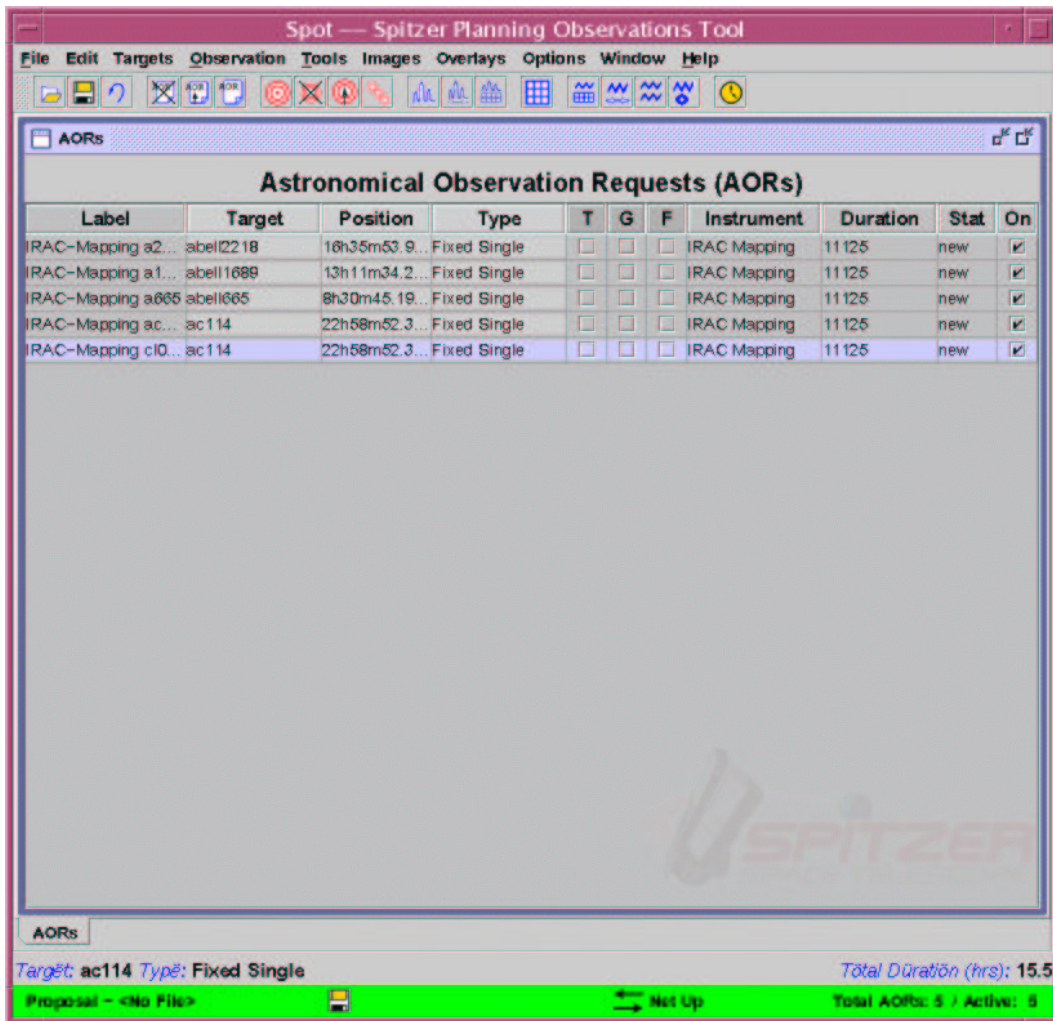
Figure 3.21: The main Spot screen after the complete IRAC imaging program has been designed.

Chapter 4

Deep Imaging of Five Galaxy Clusters at 24 - 160 microns using MIPS

In the previous chapter, we described the procedure to develop a deep, small area, imaging campaign using IRAC, covering the 3.6 - 8.0 micron range. In this chapter, we describe a complementary project to image the same regions of sky, in the 24 - 160 micron wavelength range, using the Multiband Imaging Photometer for Spitzer (MIPS).

MIPS is designed to provide the Spitzer Space Telescope with diffraction limited imaging capability, with noise performance limited by natural sources, over the wavelength range from 20 to 180 microns. The instrument utilizes three detector arrays. These arrays provide photometric bands centered at 24, 70, and 160 microns respectively and a low-resolution spectroscopy mode covering 55 to 95 microns.

The MIPS Photometry and Super Resolution Mode allows accurate photometric measurements of sources using multiple and precise sampling of the 24, 70, and 160 micron MIPS bands employing a sequence of inertially fixed pointing positions. Super Resolution is enabled through precise fractional pixel pointing offsets in the standard dither patterns, and by the optional fine pixel scale optical path to the 70 micron array.

The 24 micron array enjoys a 5.4×5.4 field of view (128×128 pixels, with 2.55 per pixel). The 70 micron array large field has an instantaneous field of view of $\simeq 5.2 \times 2.6$ ($\simeq 32 \times 16$ pixels, 9.98 per pixel), not including the noisy side B of the 70 micron array (see SOM, § 8.1.2.1), while the 160 micron

band has an effective, unfilled field of $0\rlap{.}'5 \times 5\rlap{.}'3$ (2×20 pixels, $16\rlap{.}''0$ per pixel) that has a $0\rlap{.}'25$ gap down the middle. In practice, scan mirror motions are used to fully sample the PSF at 160 microns.

The scan mirror can also deflect the beam to provide two alternate functions for the 70 micron array. In one position, a different set of re-imaging optics provides a higher magnification, with a field of $2\rlap{.}'7 \times 1\rlap{.}'35$; the improved pixel sampling will be used to achieve "super resolution" (i.e., to exceed the traditional Rayleigh criterion of resolution) through data processing. The pixel scale is $5\rlap{.}''20$ per pixel in super resolution mode (compared with $9\rlap{.}''98$ per pixel in default mode). In another position, the beam is sent to the low resolution spectrometer (SED mode). The observer can choose to observe in one, two, or all three bands.

4.1   Overview of the Program

In this section, we summarize the steps followed to design the deep imaging MIPS program. This will serve both as a one-stop resource for those requiring only an overview of how to do such a program, and also as a roadmap of where to find more detailed information later in this chapter.

- **Target Selection:** This program is tied to a complementary IRAC program, developed in the previous chapter (§3). We use the same targets as were selected for that program. See §3.2 for further details.

- **Background Estimate:** We use Spot to obtain a background estimate at each of the target positions. In general, the background is characterized qualitatively by three levels (low, medium and high), and for these targets, the IR background in the MIPS wavelength regime is low/medium. See §4.2.

- **Exposure Time Estimate:** Equipped with the background characterization above, we look at the MIPS sensitivities for low, medium and high backgrounds, respectively. This enables an estimate of the required exposure time to reach a desired signal-to-noise ratio for point source detection.

  For MIPS, the 1-sigma confusion limit is $\simeq 1$ mJy at 70 microns and $\simeq 15$ mJy at 160 microns (Xu et al., 2001, ApJ, 562, 179; Franceschini et al., 2002, astro-ph/0202463; Dole et al., 2002, ApJ, 585, 617).

For the 70 micron array, the low background sensitivity is approximately 1.2 mJy (1σ) in 500s for the default pixel scale. Similarly, for the 160 micron array, the low background sensitivity is approximately 3 mJy (1σ) in 500s. Hence, adopting a goal of imaging to the confusion limits in these passbands, we will require $\simeq 500$ sec at 70 microns, and $\simeq 20$ sec at 160 microns.

At 24 microns, and finite observation times, the confusion limit is effectively never reached in regions of low background. In 500 seconds, with low/medium background, the 1σ sensitivity is $\simeq 20$ μJy. See §4.3.

- **Filling out the MIPS Photometry/Super Resolution Imaging AOT:** See §4.4 for details, and Figures 4.8 and 4.9 for screen captures of the completed AOTs.

  - For the **24 micron array**, we select the **large field size**, with a minimal offset to the sky field; this, in effect, doubles our exposure time at the target position, and covers a $\sim$5 arcminute square FOV, with 24 exposures per pointing; see §4.4.1. We use an **exposure time** of 30 seconds, and one cycle. This yields 375.4 s on each of the science and sky fields, which are the same, and so an effective total exposure time of 751 s on our target field; see §4.4.2.

  - For the **70 micron array**, we select the **default pixel scale** and **small field of view**, and use a Fixed Cluster-offsets target, observe the offsets only, with offsets $(0, 80'')$, and $(0, -80'')$ in array coordinates. This again covers a $\sim$5 arcminute square FOV, with 10 exposures per cycle on the target; see §4.4.1. We use an **exposure time** of 10 seconds, and 5 cycles. This yields 545 seconds on target; see §4.4.2.

  - For the **160 micron array**, we select the **large field of view**. This also covers a $\sim$5 arcminute square FOV, with one exposure per cycle on the target; see §4.4.1. We use a **exposure time** of 10 seconds, and 4 cycles. This yields 41.9 seconds on target; see §4.4.2.

- **Duration:** The total duration for this and the IRAC program developed in the last chapter is 22 hours. See §4.5.

Target	24 μm [MJy/sr]	Bkgd Class	70 μm [MJy/sr]	Bkgd Class	160 μm [MJy/sr]	Bkgd Class
Abell 2218	17.194	Low	4.906	Low	4.712	Low
Abell 1689	60.157	High	17.457	Low	7.571	Low
AC 114	37.018	Med	10.083	Low	4.810	Low
Abell 665	24.974	Med	7.135	Low	7.150	Low
cl0024+16	46.638	High	13.584	Low	9.779	Low

Table 4.1: The maximum background levels in the MIPS passbands as returned by Spot.

- **Constraints:** In order to constrain the MIPS and IRAC observations to have the same (or similar) PA, we place a group-within constraint so that the IRAC and MIPS observations occur within 14 days of each other. See §4.6.

- **Visualization:** We visualize the observations as an overlay of the MIPS arrays on Digital Sky Survey and IRAS images of the clusters; see Figures 4.4, 4.7 and 4.5 .

4.2   Background Estimate

We obtain a quantitative background estimate through the Spot Target entry dialog. Within the target entry/modification window, clicking on "Background" (see Figure 3.1), brings up the "Background Estimate" window.

Enter 24.0 microns as the wavelength to do the estimate, leave the "Calculate Range When Visible" button selected for the moment, and click "Do Estimate." We repeat this calculation at 70.0 and 160 microns for all of the targets in the target list. The calculated background levels are tabulated in Table 4.1.

As with IRAC, the SSC has characterized backgrounds as "low," "medium" and "high," depending primarily upon the distance from the ecliptic, and determined the sensitivities for these quantized background levels. See:

http://ssc.spitzer.caltech.edu/obs/bg.html.

Especially with MIPS, it is a very good idea to verify the background estimate provided by Spot with a visual check of observations provided by

IRAS. To do this, we first retrieve the IRAS Sky Survey Atlas (ISSA) image of the target field (in this case, we do it for Abell 2218). To do this, select "ISSA image..." from the "Images" pulldown menu. The ISSA image retrieval pop-up window, shown in Figure 4.1, will appear.
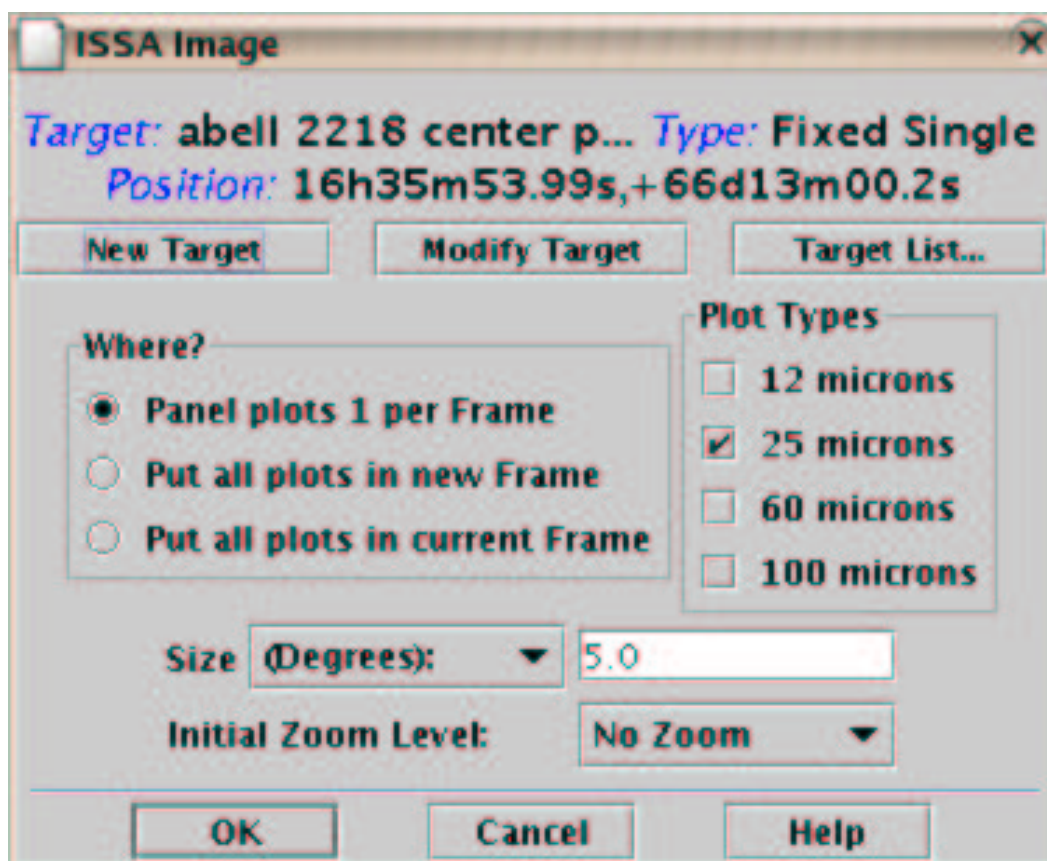
Figure 4.1: The ISSA image retrieval entry dialog.

We select all wavelengths (12, 25, 60 and 100 micron), choose a 1 degree FOV, put all plots in a single frame, no zoom, and hit "OK." When Spot has retrieved the images, you will note that there are now large black arrows and a slider bar in the upper right; see Figure 4.2. This is how you can flip between images loaded into the same window. If you load fewer than four images into the same window, then the slider only includes those images as options.

Examining the 25, 60 and 100 micron images, we see that the maximum
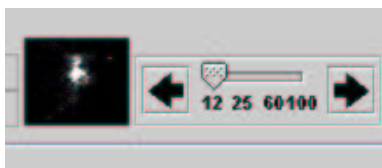
Figure 4.2: Flipping between 12, 25, 60, and 100 μm images.

surface brightness at any of these wavelengths on the sky covered by the Abell 2218 observations is $\simeq 4$ MJy/sr, centered on the giant, foreground spiral galaxy to the northeast of the cluster center. Note that this is different than what Spot reported for the background. For more discussion on background issues, please see §8.5.1.

4.3   Exposure Time

Armed with the characterization of the background level (see §4.2), we can proceed to estimate the required exposure time. As before, the first stop is the webpage for the MIPS instrument sensitivity. For the latest updates, see:

http://ssc.spitzer.caltech.edu/mips/

> **Note:** sensitivity plots are available in the Spitzer Observer's Manual (SOM), and online, at the web address given above. The latest updates for CP-3 were posted on the webpages on November 1, 2005, and should be consulted for planning observations in response to the third call for proposals.

The required total integration time depends on the instrument sensitivity. For the 70 micron array, the low background sensitivity is approximately 1.2 mJy (1σ) in 500s. Similarly, for the 160 micron array, the low background sensitivity is approximately 3 mJy (1σ) in 500s.

Now, especially for MIPS, one needs to consider the confusion limits. For MIPS, the confusion limits are $\simeq 1$ mJy at 70 microns and $\simeq 15$ mJy at 160 microns. See:

http://ssc.spitzer.caltech.edu/mips/sens.html

Hence, adopting a goal of imaging to the confusion limits at 70 and 160 microns, we will require integrations of $\simeq$ 500 sec at 70 microns, and $\simeq$ 20 sec at 160 microns.

At 24 microns, and finite observation times, the confusion limit is effectively never reached in regions of low background. In 500 seconds, with low/medium background, the 1σ sensitivity is $\simeq$ 20 μJy. See §4.3.

> **Note:** the confusion limits shown on the low background sensitivity plots are lower limits to the actual position dependent on-sky confusion. The lower limits shown on the low background sensitivity charts are for regions of *lowest expected confusion at high Galactic latitudes and on clean sky.* The observer should consider the local confusion caused by background sources when planning observations. Confusion likely will be more important in higher background regions, and can limit the sensitivity that can be achieved. Local sources of confusion, such as cirrus and the stellar background, are highly variable and can be very localized. For all MIPS observations, the sky background should be considered carefully in the observation planning. See the MIPS chapter of the Spitzer Observer's Manual for more information.

> Furthermore, redundancy is vital for MIPS, and hence imaging beyond the confusion limit will often be necessary to, e.g., fill in the full FOV at 160 microns (see SOM, v6.0, § 8.2.1.2.6).

4.4 Filling out the MIPS Photometry/Super Resolution Imaging AOT

Since we have already entered the targets for the IRAC observations, let's select a2218 as the first target, and begin by bringing up the MIPS Photometry/Super Resolution AOT entry dialog, either from the "Observation" pull-down menu, or by clicking on the "Multiband Imaging Photometer 24, 70, 160 μm pointed imaging" icon (the blue squiggly line over a blue checkerboard icon, fifth from the right on the icon taskbar). The pop-up entry window will appear, as illustrated in Figure 4.3. Be sure that the correct target info appears in the AOT.

We'll do the 24 and 160 μm micron observations first (we will need to change our targeting strategy for the 70 micron observations to compensate
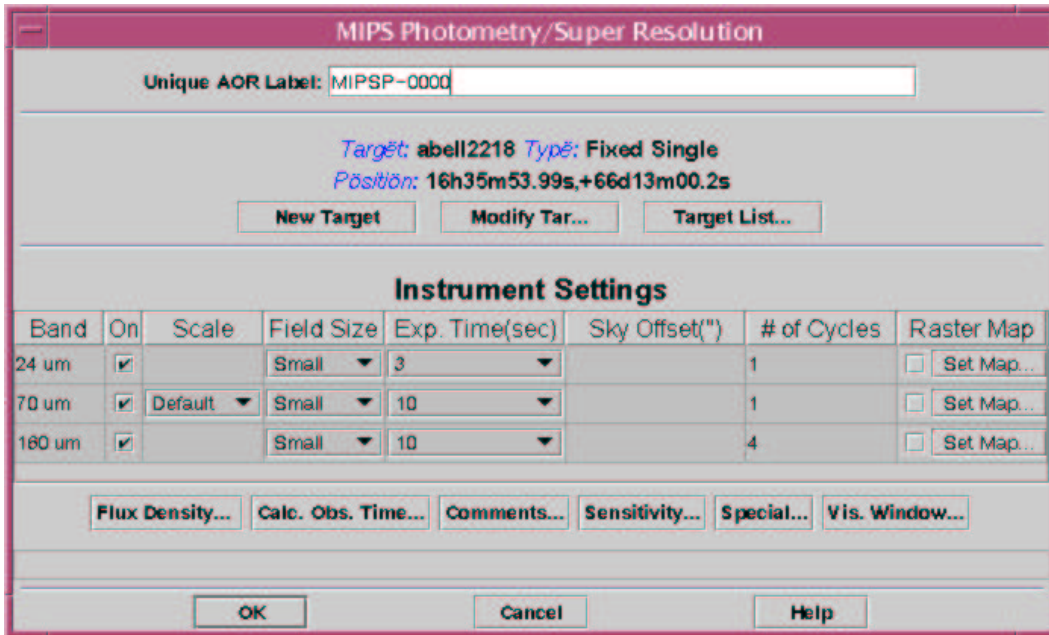
Figure 4.3: The MIPS 24, 70, 160 micron pointed imaging AOT entry dialog.

for the noisy side B electronics. This discussion follows). Click-on the 24 and 160 μm buttons to obtain data in the two passbands, assuming for the moment that our AOR will not exceed the three hour MIPS AOR time limit; more on that later. There are several fields to fill, and we discuss each in turn.

4.4.1 Field Size and Resolution

MIPS photometry observations are taken as a series of exposures on the prime science target, and at offset "sky" fields. The 'field size' option in the AOT entry dialog refers to the amplitude of the offsets that will be applied to sample the sky, and also has some consequences on how large the dithers will be for the on-field images.

In general terms, the basic idea in the design of the field size option is that the "small" field size is appropriate for imaging sufficiently compact target objects so that taking an exposure offset from the target by $\simeq 1/2$ array is sufficient to determine the sky. For large sources, the "large" field size is required to sample the sky, and, for the 24 micron array, the offset

can be specified manually. How large is large, and how small is small? A generic rule-of-thumb is that objects smaller than about $2'$ should be imaged with the "small" field size; objects with size $2' - 4'$ are observed with the "large" field size, and objects larger than about $4'$ should be observed using the raster map option, or the MIPS Scan Map AOT.

This works well for objects that are extended. However, for this example, we are looking essentially for point sources (for the pixel scale of the MIPS arrays anyway). That is to say that the sky will be sampled with the science images themselves, and so both the on-source and sky images are useful for scientific purposes. Our choice for field size will simply determine the overlap of the "science" and "sky" images.

The IRAC observations in §3 covered a $\sim 5.'2\Box$ FOV uniformly at 3.6, 4.5, 5.8 and 8.0 microns, with offset fields imaged once in either of the 3.6/5.8 or 4.5/8.0 micron arrays, respectively. We will design the MIPS observations to image the same central area in all of the MIPS bands, and use the MIPS offset (sky) fields to image the part of flanking fields viewed in the IRAC observations.

To accomplish this, we will use the "large" field size for both MIPS 24 and 160 micron wavebands, and manually configure the offsets to the sky images, where appropriate. Let's describe in detail how the observations will be carried out in each array:

- **24 micron array:** The basic 24 μm large field photometry observations acquires 10 separate images of a source, dithered around the center of the array. The nominal pattern is a 1×5 set of images along the scan direction, separated by 1.5 pixels $= 3.''83$ for each, followed by a cross-scan spacecraft offset of 4.5 pixels ($11.''48$), and a repeat 1×5 set of images. This 10-point imaging sequence is also executed for the offset sky field. In addition, for calibration purposes, two extra exposures will be obtained at both the object and sky positions per AOR (as opposed to per cycle). The details of this pattern are given in the Spitzer Observer's Manual (in v6.0, see § 8.2.1.2.2):

  http://ssc.spitzer.caltech.edu/documents/som/

  Thus, for the 24 micron band large field observations, entering a small offset for the sky observations, say $10''$, will mean that for a single cycle

observation, 24 images will be taken centered on the target position. For N cycles, the total number of on-source exposures will be

$$N_{\mathrm{exp}} = 2 \times [(N \times 10) + 2] \tag{4.1}$$

where, since the sky and science fields are effectively the same, we effectively get double the depth (and hence the factor of 2 at the front of equation 4.1.

A visualization of these observations (arbitrary frame time) on a DSS + IRAS 12 micron image (see § 3.8) of the Abell 2218 field is shown in Figure 4.4.

- **160 micron array:** Imaging the field at 160 microns is straightforward. Selecting the 160 micron array with large field size will yield a complete, uniform coverage map over a $\simeq 4' \times 5'$ field. Note that this large-source AOT cycle provides only one fully sampled image of the field. Observers are *strongly* encouraged to specify at least four cycles so that the redundancy can be used to reject artifacts in the images.

  The overlay on the Abell 2218 field (4 cycles, arbitrary frame time) is shown in Figure 4.5.

  Hint: Keeping track of the number of exposures on-source is somewhat complicated within the MIPS Photometry and Super-Resolution AOT; a good summary table of the frames/cycle and the integration time per pixel per cycle is given in the SOM (in v6.0, see Table 8.11).

- **70 micron array:** With the 70 μm array, because of the smaller effective size of the array compared to pre-flight expectations, there is a recommended work-around to image a $\simeq 5\square'$ FOV: first, we create a **Fixed Cluster-offsets target** with offsets of $(0'', 80'')$, $(0'', -80'')$ in array coordinates observing "offsets only" (see Figure 4.6). Then, we use the MIPS Photo/Super-Resolution AOT, select the 70 micron array, default pixel scale, and small field size. See § 8.2.1.2.4 of the SOM, v6.0.

  The result is 10 exposures "on-source," covering the 5 arcminute field around the target. A visualization of this on a DSS image of the Abell 2218 field is shown in Figure 4.7.

  We need to do this manually for each of the targets on our program.
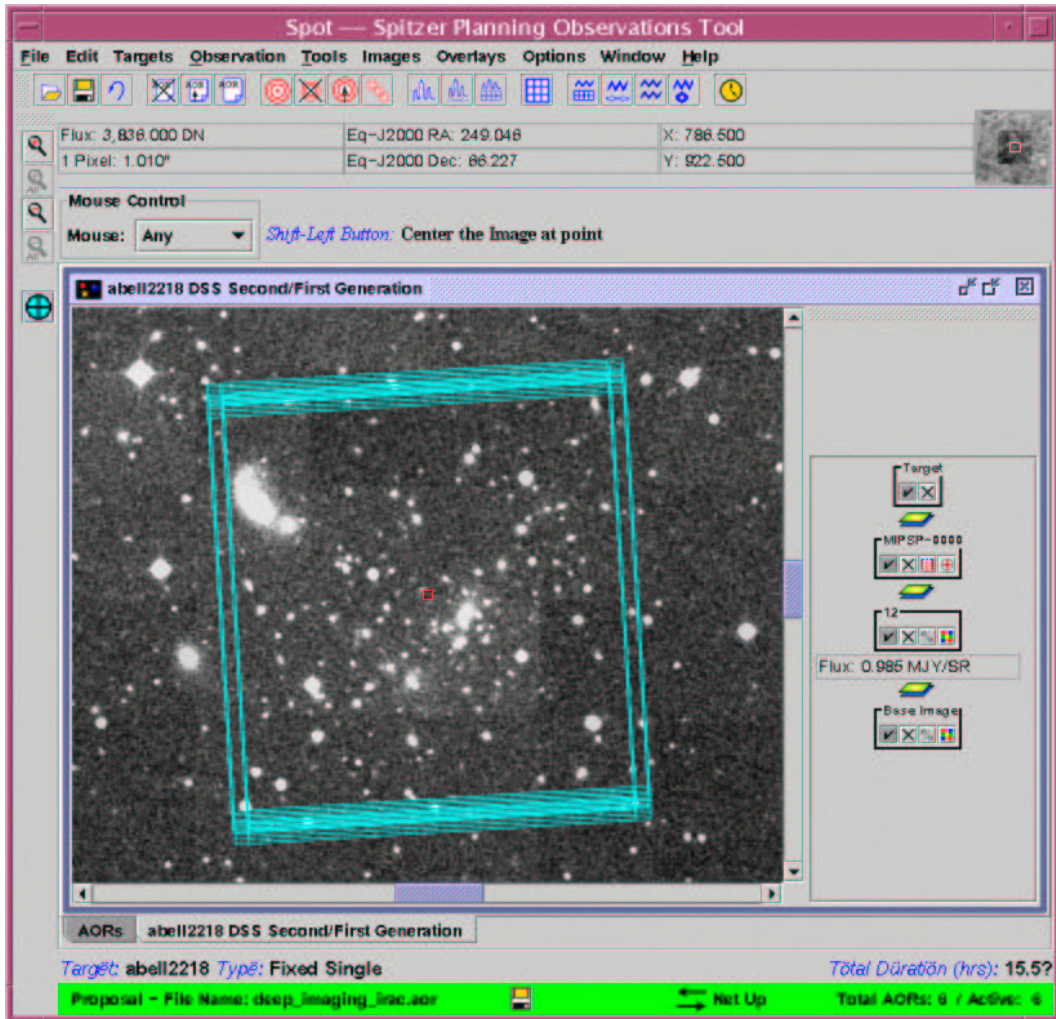
Figure 4.4: The overlay of the MIPS 24 micron, large field Photometry/Super
Resolution observations on the Abell 2218 field. One cycle of the 30 second
frame time was observed, with sky offset of 10 arcseconds.
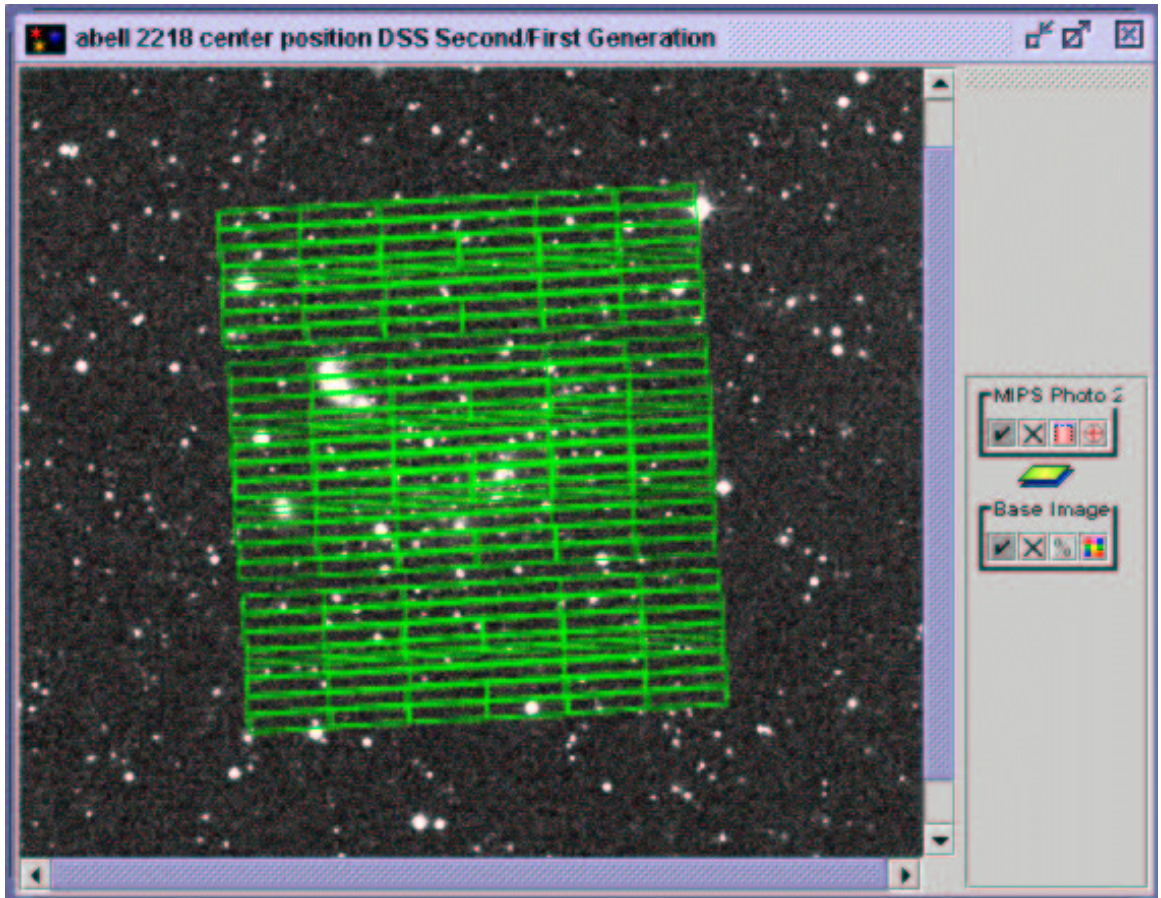
Figure 4.5: The overlay of the MIPS 160 micron, large field Photometry/Super Resolution observations on the Abell 2218 field.
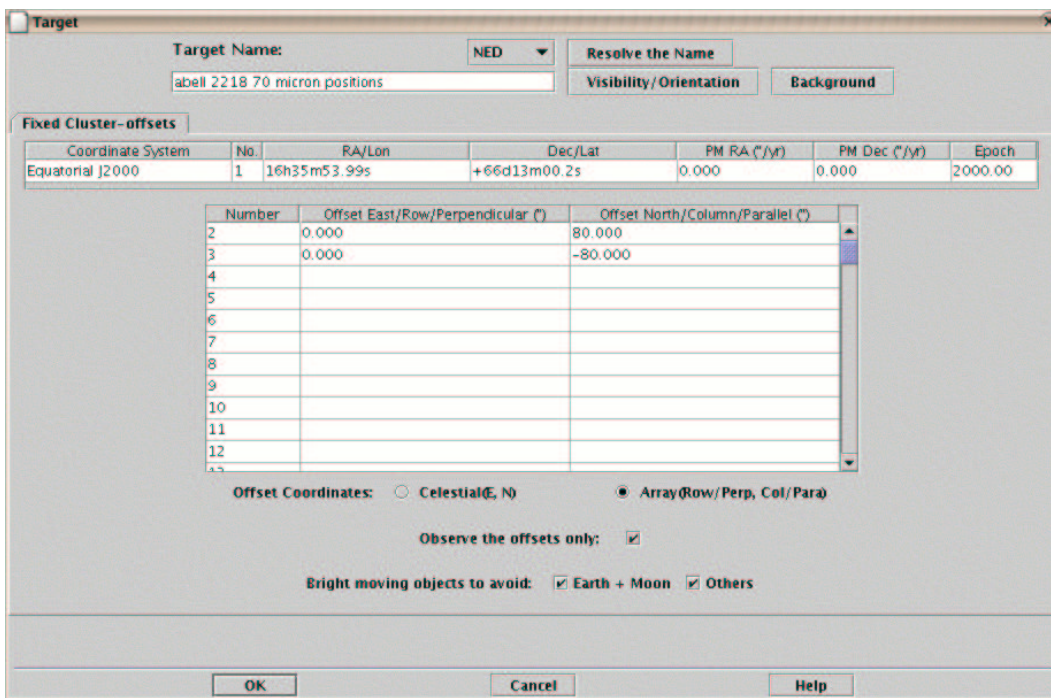
Figure 4.6: The "cluster offsets" target for the 70 micron Photometry/Super Resolution observations on the Abell 2218 field.
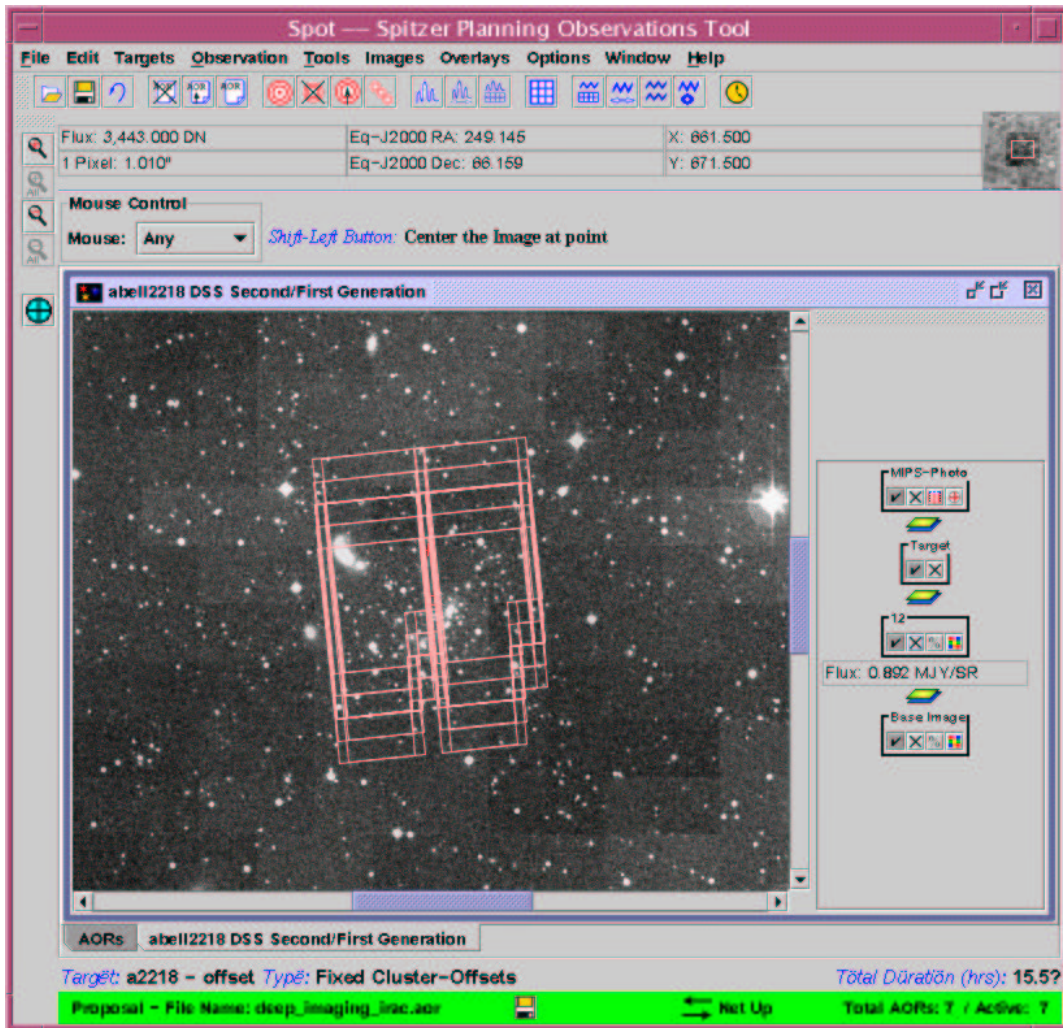
Figure 4.7: The overlay of the MIPS 70 micron, small field, default pixel scale for "cluster offsets" target and the Photometry/Super Resolution observations on the Abell 2218 field.

4.4.2 Frame Times

Having set our field of view, and pixel scale, all that remains is to set the total integration time. The observer sets a frame (exposure) time, and number of repeats.

- **24 micron array:** there are three selectable exposure times: 3, 10 and 30 seconds. For this example, since we are searching for intrinsically faint objects, we take the longest frame time, 30 seconds, and build up our desired total integration time as follows:

  Accounting for the 10 pointings per exposure with the 24 micron array and large field size, plus some housekeeping factors which introduce two extra exposures per AOR, the total integration time is

  $$t = [(N \times 10) + 2] \times (\text{Exposure Time}) - 2 \sec \qquad (4.2)$$

  where N is the number of cycles (i.e., the number of times the exposure sequence is executed). This is the exposure time on the science field. However, since we selected our sky field to be only very slightly shifted ($10''$), these images effectively double the depth.

  Hence to reach a 1-sigma sensitivity of better than 20 μJy, which requires 500+ seconds integration, we use 1 cycle of the 30 second frame time (yielding a total on-source integration of 720 seconds). However, just to make things confusing, the timing in MIPS has been adjusted to be synchronous with the computer oscillator, and other potential sources of synchronous noise. Hence a MIPS second is 5% longer than a conventional one. Hence the total time on target in conventional seconds will be slightly larger than the estimate here. The time estimates returned by Spot are in real seconds.

- **70 micron array:** The goal is to obtain 500s total integration. One cycle yields 10 exposures on the science field. Hence selecting the 10 second frame time, we require $\simeq 5$ cycles to reach the required depth.

- **160 micron array:** one cycle of the large field, 160 micron array AOT yields 10 exposures, with depth unity, covering a $4' \times 5'$ area on the science field. Hence the reach a depth of 20 seconds, with the 10 second frame time, requires two cycles. However, the SSC *strongly* recommends at least four cycles redundancy with this AOT, for artifact

removal, etc., and hence we will set the number of cycles to be four. See SOM, v6.0, § 8.2.1.2.6.

4.5 Duration

Let's review what we've done so far:

First, for the Abell 2218 field, we designed observations with MIPS 24 and 160 passbands, with the large field size for both wavebands. At 24 microns, we used the 30 second frame time, 1 cycle, and a sky offset of $10''$. For 160 microns, we used 4 cycles of the 10 second frame time.

At 70 microns, we covered a $\simeq 5' \times 5'$ FOV by using a Fixed Cluster-offsets target with offsets of $(0'', 80'')$, $(0'', -80'')$ in array coordinates observing "offsets only." We chose a frame time of 10 seconds, and requested 5 cycles.

Screen captures of the completed MIPS Photometry/Super Resolution AOT entry dialogs are shown in Figure 4.8 and 4.9.
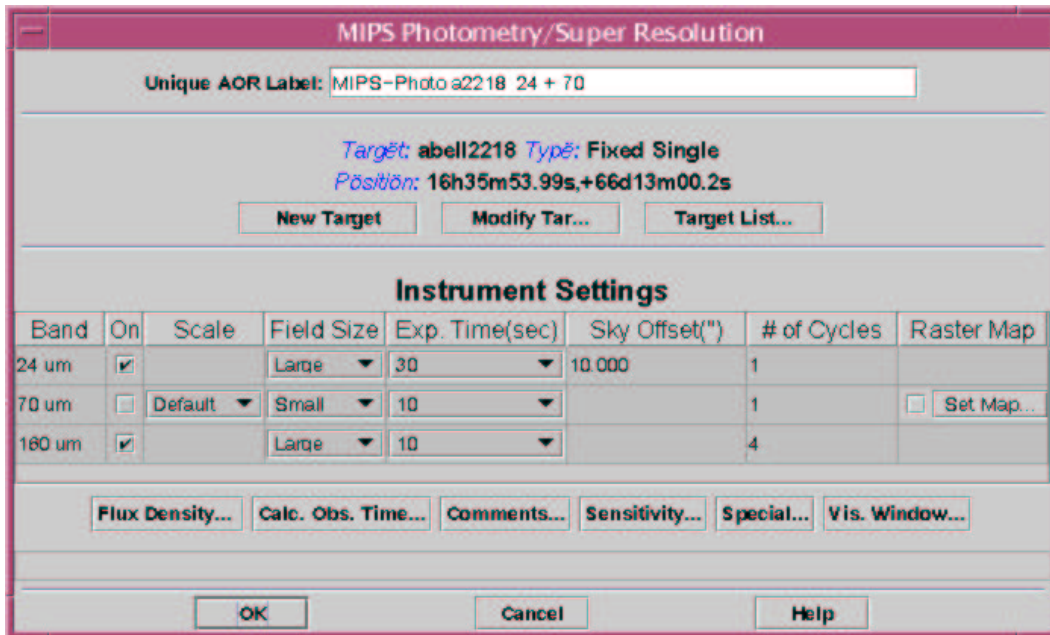
Figure 4.8: The completed MIPS Photometry/Super Resolution AOT for 24 and 160 micron imaging of Abell 2218.
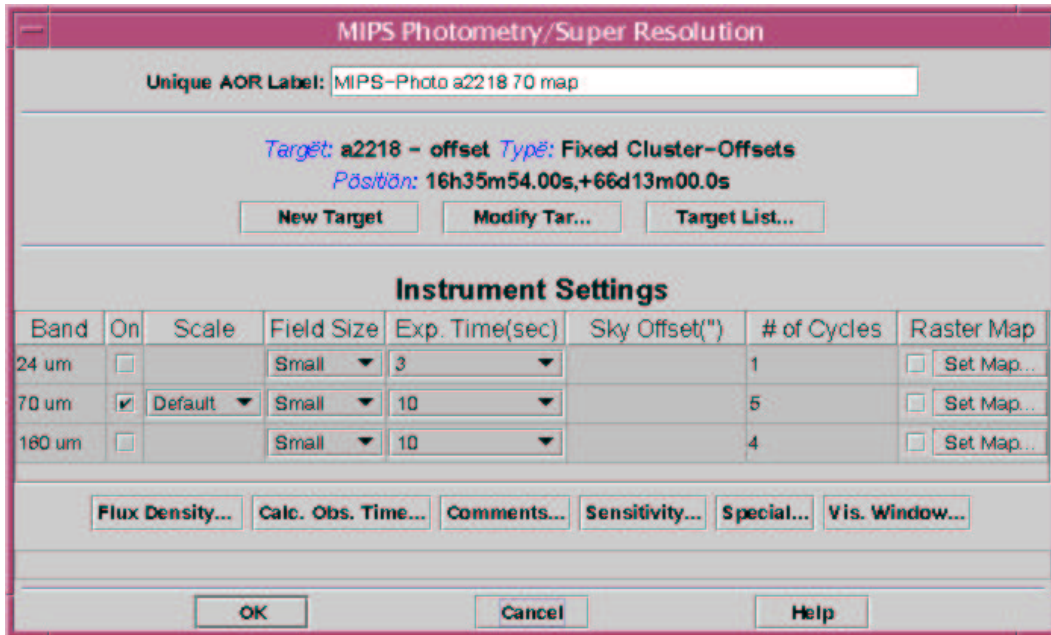
Figure 4.9: The completed MIPS Photometry/Super Resolution AOT for 70 micron imaging of Abell 2218.

How long do these AORs take to execute? For the 70 micron observations, Spot returns a duration of 1731.3 s, including overheads (545.3 s integration), while the 24 + 160 micron observations take 3039.6 s, including overheads (2 x 375.4 s integration on-source for 24 microns, and 41.9 s at 160 microns).

The (next to) last step we need to do is clone these AORs for the other targets in the target list. We'll get to that in a moment. First we will consider how to constrain these observations so that both the IRAC observations (see §3) and those obtained with MIPS (this chapter) have the same (or similar) position angle.

4.6   Constraining the Observations

Due to positioning constraints on the observatory, Spitzer does not have the freedom to view any piece of the sky at any time at any position angle. This is because of hard pointing constraints of the spacecraft, required to keep the solar shield positioned to protect the telescope and instruments, as well

as to provide power through the solar panels. Therefore, the orientation of the Spitzer detector arrays will depend upon when the observations are scheduled. It is worth noting as well that some position angle (PA) selections may never be possible to achieve (for example, for objects in the ecliptic, Spitzer has an extremely narrow range of permissible PAs).

We have developed in this chapter, using MIPS, and in the previous chapter, using IRAC, imaging campaigns to image the central region in five galaxy clusters. It is worth emphasizing again that the PA of the MIPS and IRAC observations will depend upon when these AORs are scheduled for observations. For this example, it doesn't really matter what PA we use, but it would be preferable that both the IRAC and MIPS observations are taken with the same (or at least similar) position angle. We accomplish this by imposing constraints on the observations as follows:

In the main Spot window, under the "Tools" pulldown menu, select "Group/Follow-on Constraints." This brings a constraint editor window, as shown in Figure 4.10.

Figure 4.10: The constraint editor entry dialog.

We select "Add Group Within" constraint, and the "Group Within Parameters" pop-up window will appear. We will fill the parameters in a moment. But first, what is a "group-within" constraint?

A group within constraint means that the AORs constrained will all be executed within a selected period of time, pre-determined by the observer. Before entering any numbers, we have to be careful here, because of the way Spitzer functions.

At any given time, only one instrument will be on, and will operate in "campaigns" of duration 7-14 days, before a switch is made to one of the other instruments. The switch-over itself takes some time, for the telescope to be adjusted to the required temperature, instrument calibrations to be performed, and so on. All of this is to say that selecting a very short timescale for a group within parameter will mean that your observations may very well become unschedulable. Of course, the flipside is that using a very long time for the group of observations means that the PA could vary significantly within the group.

A generic rule-of-thumb is that the default PA changes by $\simeq 1°/$day at high ecliptic latitude, and $\simeq 0.5°$ per day for mid-latitude regions. For this example, we select 14 days for the group within parameters; this will mean that the PA will vary by no more than $14°$ for the MIPS/IRAC observations, which seems acceptable, and yet the observations are not so tightly constrained to pose scheduling difficulties. A screen capture of the completed "Group Within Parameters" pop-up window is shown in Figure 4.11.
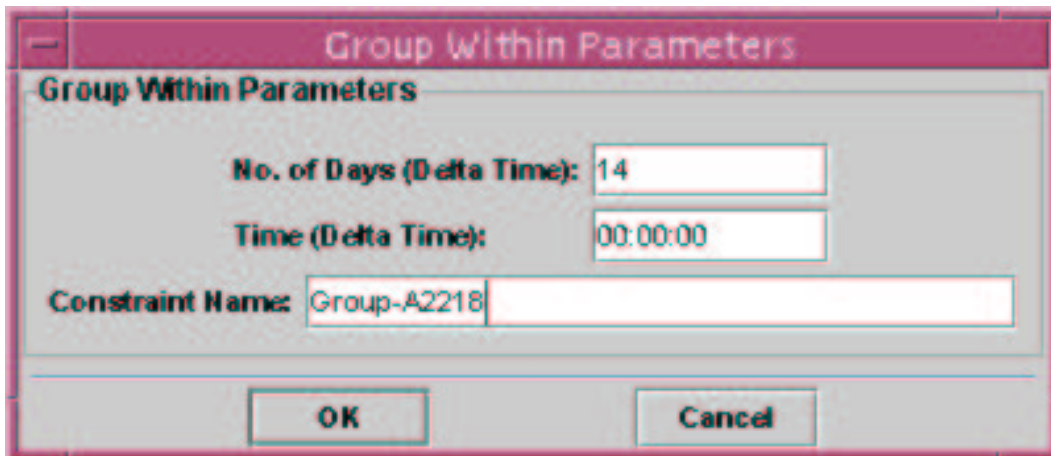
Figure 4.11: The group within parameter entry dialog.

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After clicking "OK" we are returned to the main constraint editor window. Now all we need to do is specify which AORs will be grouped within this constraint. We will do this by dragging and dropping the AORs we have already created.

From the main Spot window, click and hold the left mouse button on the "IRAC mapping: a2218 center position" AOR. Then drag the AOR into the constraint editor window and drop in the constraints sub-window. Repeat this for the "MIPS Photo a2218 24+160" and "MIPS Photo a2218 70 map" AORs. A screen capture of the resulting constraint editor window is shown in Figure 4.12.
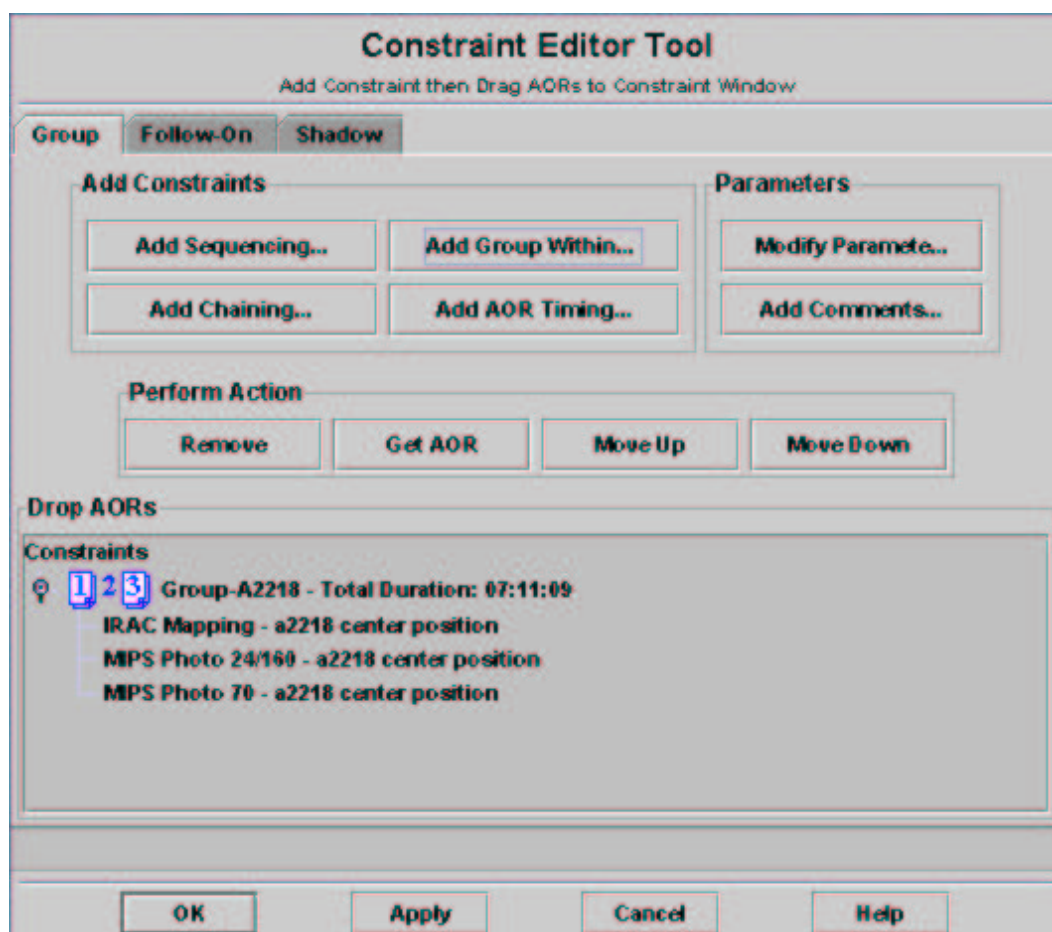
Figure 4.12: The completed constraint editor dialog, with A2218 IRAC and MIPS observations constrained with a group-within constraint of 14 days.

Clicking "OK" returns us to the main Spot window, and we see that the boxes under the "G" column are checked for the three AORs, indicating that a group constraint has been applied.

That's it. Save your AORs and targets. Then do some copying and editing (within Spot) to develop the grouped AORs for the other targets. A screen capture of the constraint editor window with all of the targets entered is shown in Figure 4.13.

The main Spot window after the complete, constrained IRAC and MIPS campaign has been designed is shown in Figure 4.14.

That's the entire program! Don't forget to save both the target and AOR list. For reference, the raw text .aor file for this set of observations is shown in Appendix B. For reference, the raw text .aor file for this set of observations is available at the SSC website:

http://ssc.spitzer.caltech.edu/documents/cookbook/aors/

The total program time to execute this series of AORs is 22.2 hours. For CP-3, this would be classified as a "small program" ($\leq$ 50 hrs). May the TAC be with you...

Figure 4.13: The completed constraint editor dialog, with all targets having their IRAC and MIPS observations constrained with a group-within constraint of 14 days.
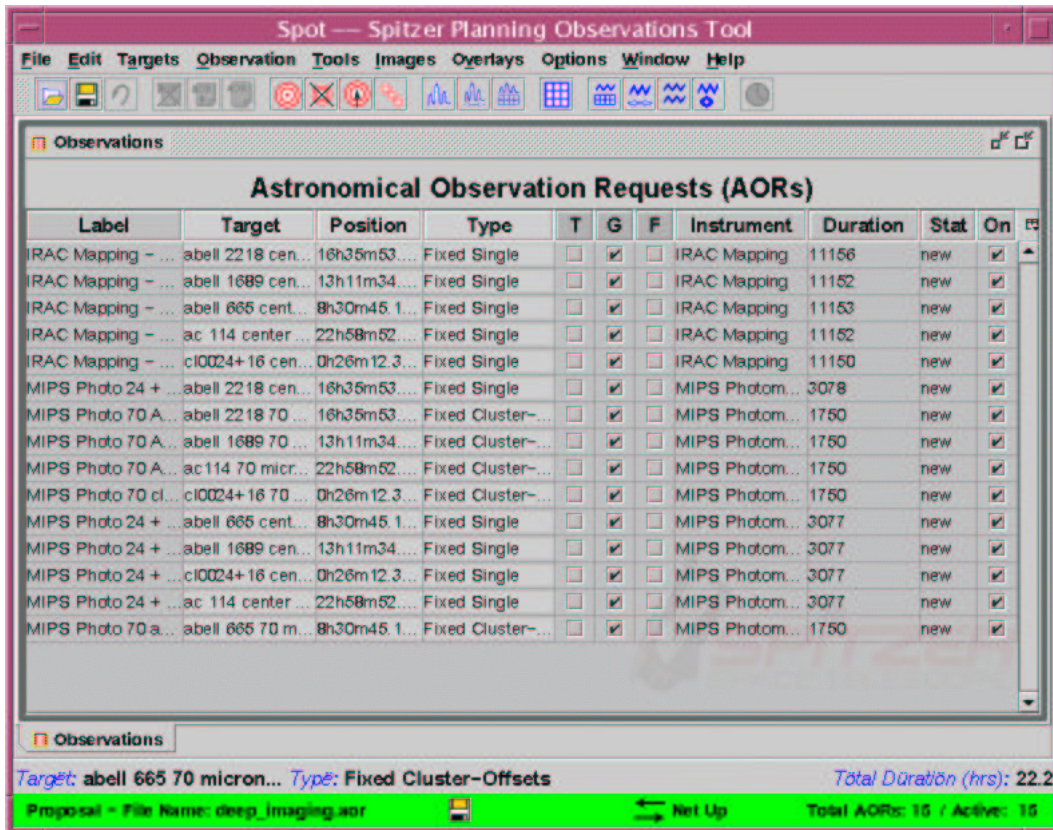
Figure 4.14: The Spot menu after the IRAC and MIPS AOT parameters have been entered for all of the targets, and the group within constraints imposed.

Chapter 5

High Resolution Staring Mode Observations at 10–37 microns with the IRS

In this chapter, we illustrate use of the Infrared Spectrograph (IRS) to obtain high-resolution spectra of a point source target. We will utilize the Short-High (SH) and Long-High (LH) modules of the IRS. This detailed example of an IRS Staring Mode observation expands the basic example given in the IRS chapter of the Spitzer Observer's Manual (SOM). The goal of this observation is to detect (or establish upper flux limits for) polycyclic aromatic hydrocarbon (PAH) lines at 13.1 and 24.5 μm (redshifted from 11.3 and 21.2 μm) in the well-known quasar 3C 273. Additional dust and atomic spectral features in the $20 - 30$ μm range (e.g., Moutou et al. 1996, A&A, 310, 297) could also be investigated with these IRS data.

   Note that this example is intended to demonstrate the operational modes of the IRS and how to propose for IRS observations, but not to present a rigorous scientific case for the observations described herein.

5.1   Introduction to the IRS

The IRS provides the Spitzer Space Telescope with spectroscopic capabilities at two different resolutions spanning the wavelength range from 5.2 to 38 μm. The IRS is composed of four separate spectroscopic modules, with two of the modules providing "low" spectral resolution of R $\sim 64 - 128$ over "short" and

"long" wavelength ranges of $5.2 - 14.5$ μm and $14.0 - 38$ μm, respectively. The other two modules provide "high" spectral resolution of R ~ 600 over "short" and "long" wavelength ranges of $9.9 - 19.6$ μm and $18.7 - 37.2$ μm, respectively.

Each module has its own entrance slit in the Spitzer focal plane. The low-resolution modules employ long slit designs that allow both spectral and one-dimensional spatial information to be acquired simultaneously on the same detector array. The high-resolution modules use a cross-dispersed echelle design that yields both spectra and limited spatial measurements on the same detector array. A small imaging array (the peak-up array) in the Short-Low (SL) module is used to place objects accurately into any of the IRS entrance slits. A more detailed description of the IRS is available in the SOM. An example of how to use the peak-up array may be found in Chapter 7 of this document.

5.2   Summary of the Observing Program

In this section, we summarize the basic steps followed to design a Spitzer observing program that uses the SH and LH modules of the IRS to obtain spectra of 3C 273, which is a bright ($V \approx 12.9$ mag), nearby ($z = 0.158$) quasar, located at RA = 12:29:06.7, DEC = +02:03:08.6 (J2000), ecliptic latitude = $+4.7°$ (this will affect the signal-to-noise ratio estimate below). The design process for this example is presented in more detail in the remainder of this chapter.

- **Target Selection and Duplication Check:** Checking the Spitzer Reserved Observations Catalog shows that the field around 3C 273 already has observations planned with the IRS. In particular, GTO observations in program PID 105 will use both the SH and LH modules. If we were considering to write a new Spitzer observing proposal, then this could preclude obtaining new observations at the specified target position. According to the Spitzer Duplicate Observations Rules, new observations would need to be designed in such a way that: (1) the integration time per pixel for each observation differs by more than a factor of three in sensitivity, and (2) the target positions are separated by more than one-half of the slit length of the relevant IRS module. See §5.3 for additional details.

- **Exposure Time Estimate:** Requesting exposures of 1×120 seconds and 1×240 seconds for the SH and LH slits, respectively, will yield a signal-to-noise ratio of S/N ≈ 8 in each spectrum from both modules for a target line flux of 5×10^{-18} W m^{-2}. (Note that because two spectra with the requested exposure time are automatically obtained at two different positions of the source within the slit in IRS Staring Mode observations, the signal-to-noise ratio can be increased by combining these spectrum pairs, to yield S/N ≈ 12 in the final combined spectrum from each module.) See §5.7 for additional details. Although in this particular example we have used 1 cycle per slit, it is strongly recommended that the observers provide a minimum of two cycles per slit. This provides greater redundancy against cosmic rays and variability in the pixels.

- **Filling in the IRS Staring Mode AOT:** We select one cycle using the 120-second and 240-second ramp durations for the SH and LH slits, respectively. We present examples of configuring offset IRS and PCRS peak-ups for 3C 273, using stars selected from the 2MASS Point Source Catalog or the Pointing Calibration and Reference Sensor (PCRS) Guide Star Catalog, respectively. (In addition, the procedure for configuring a peak-up on the science target itself is discussed.) See §5.9 for additional details.

5.3   Target Selection and Duplication Check

When planning a Spitzer observing proposal, the first consideration is whether the intended target has already been observed, or approved for observations, with Spitzer. To determine this, we visit the Spitzer Reserved Observations Catalog (ROC) at

<div align="center">

http://ssc.spitzer.caltech.edu/roc/

</div>

and look for any instances of 3C 273 (or other observations at, or near, the target coordinates of RA = 12:29:06.7, DEC = +02:03:08.6). The ROC shows that our target is already selected for observation with the IRS in GTO program PID 105; the abstract for this program can be viewed at

<div align="center">

http://ssc.spitzer.caltech.edu/geninfo/gto/abs/pid105,

</div>

and with MIPS in GTO program PID 82, which can be viewed at

http://ssc.spitzer.caltech.edu/geninfo/gto/abs/pid82.

The PID 105 observations are of most interest in determining potential conflicts with any new IRS program: these GTO observations at our target coordinates are planned to utilize both the SH and LH modules.

If we were considering to write a new proposal for Spitzer observations, then these approved GTO observations could preclude new observations at the specified target position. In order to avoid being in conflict with these previous observations, as per the Spitzer Duplicate Observations Rules, which are available at

http://ssc.spitzer.caltech.edu/documents/rules/,

new observations would have to be designed in such a way that: (1) the integration time per pixel for each observation differs by more than a factor of three in sensitivity, and (2) the target positions are separated by more than one-half of the slit length of the relevant IRS module. Nevertheless, for the purpose of developing this Cookbook example, we will continue without worrying further about these considerations.

5.4   Target Entry

The Spitzer observing proposal process is started by launching the Spitzer Planning Observations Tool (Spot) and entering the target information. As described in §2.4.1, we first start Spot and bring up a new Target window, either by selecting "New Target" from the "Targets" pull-down menu, or by clicking on the target icon (the "bullseye"), from the left on the taskbar (see Figure 2.1). The completed Spot Target window for this example is shown in Figure 5.1; the steps for filling in the Target window as shown are described below.

In this example, we wish to obtain spectra at a single position, of a non-moving target. Hence, we choose the "Fixed Single" tab in the Target window. Type "3C 273" in the "Target Name" entry box, and enter the RA and DEC in the target table. Options to resolve the coordinates of a named target using NED or SIMBAD can be accessed from Spot's Target window.
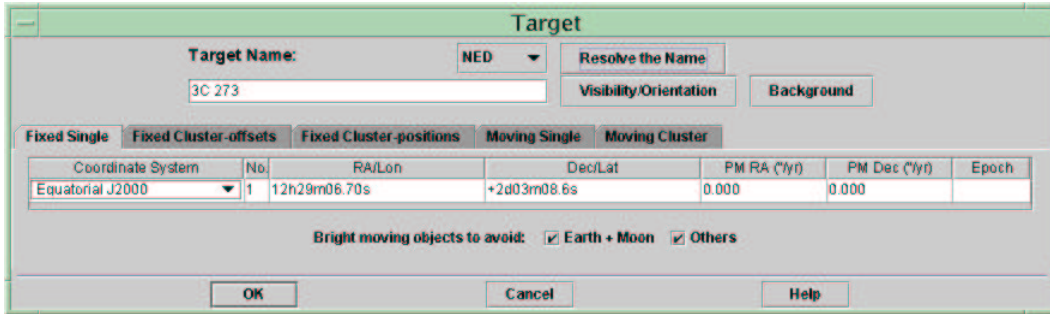
Figure 5.1: Completed Spot Target window.

However, the proposer should confirm that the returned coordinates are accurate and represent the desired location for the observation (especially in the case of extended targets). If the target's proper motion is non-negligible, then these values should also be entered in the target form. Although the field of view is small through any of the IRS slits, we select the boxes to avoid bright moving objects during the observations (both "Earth+Moon" and "Others"; the latter includes Mars, Jupiter, Saturn, Uranus, Neptune, and the brightest asteroids currently visible to Spitzer. This will prevent the observations from being made when the target coordinates are within 7° of the Earth and Moon, or within 30′ of the objects in the "Others" list.

5.5 Checking Slit Orientation

Because Spitzer is constrained to point within ≈ 35° of the perpendicular to the Sun at all times, most of the sky can be observed for only part of the calendar year. All locations in the sky will be observable by Spitzer for at least ∼ 80 days per year even if Bright Object Avoidance is enabled. Target visibilities range from ∼ 80 days per year for targets in the ecliptic plane, to ∼ 120 days per year at ±45° ecliptic latitude, to year-round visibility very near the ecliptic poles. To check a target's Spitzer visibility, click on the "Visibility/Orientation" button in the Spot Target window (see Figure 5.1) to bring up the Visibility Windows window (see Figure 5.2, left panel).

If, for scientific purposes, a specific slit orientation is required, then an iterative process must be performed to determine the dates within the Spitzer visibility windows when that orientation is available. Start by typing a date that lies within one of the visibility windows into the "Observation Date"
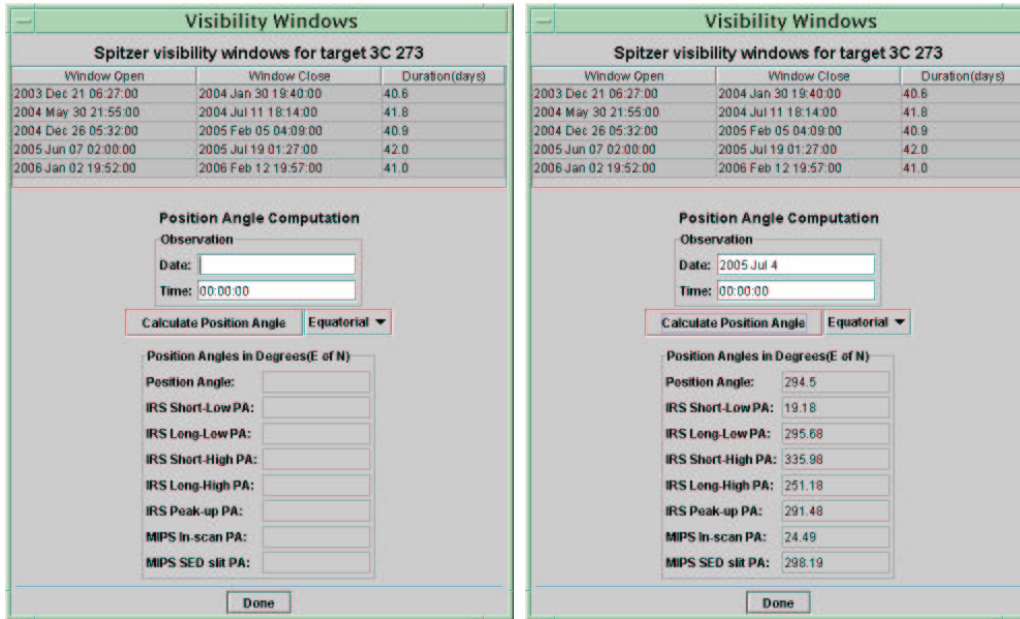
Figure 5.2: Spitzer Space Telescope visibility windows for 3C 273, showing the default configuration of Spot's Visibility Windows window (left) and the configuration after requesting the IRS slit orientations for 2005 July 04 (right).

entry box (located mid-way down the Visibility Windows window) and click on "Calculate Position Angle." For example, entering "2005 Jul 04" returns the IRS slit orientations on that date (see Figure 5.2, right panel).

Additional dates can be checked in the same fashion to determine the range of dates during which the desired orientation is achieved. Note that the slit orientations are a function of the calendar date and cannot be requested as a special maneuver. Spitzer does not perform roll maneuvers. **The only way to obtain a specific slit position angle is to constrain the proposed observations to be obtained on the date(s) during which the current spacecraft position produces the desired slit orientation.** All requests for specific slit orientations following from Astronomical Observation Requests (AORs) with timing constraints must be thoroughly and rigorously justified in the text of the accompanying observing proposal. While it is recognized that some scientific goals can only be accomplished by using specific slit orientations, proposers are encouraged to design their

programs to use as few constraints on the timing of observations as possible. Constraining observations to occur with a certain position angle requires adding a timing constraint to the AOR – this procedure is discussed in the IRS Spectral Mapping chapter of this Cookbook (see Ch. 6).

5.6 Saturation

The point source saturation levels for the IRS are as follows (Figure 7.23 of the SOM):

- Short-Low Module: ~ 5.5 Jy at 10 μm in 6 seconds.

- Long-Low Module: ~ 10 Jy at 25 μm in 6 seconds.

- Short-High Module: ~ 65 Jy ($\sim 2.6 \times 10^{-14}$ W m^{-2} for an unresolved emission line using equation 7.7 in the SOM) at 12.5 μm in 6 seconds

- Long-High Module: ~ 70 Jy ($\sim 1.4 \times 10^{-14}$ W m^{-2} for an unresolved emission line) at 25 μm in 6 seconds.

These saturation values assume that the incident light falls onto 4 pixles (in a 2×2 grid). Since, for example, the SL module pixels have linear sizes of 1″8, the SL module will saturate in 6 seconds when a total of 5.5 Jy illuminates 4 pixels, corresponding to an angular region of 13 square arcseconds. Pixel sizes for the other IRS modules are: 5″1 for Long-Low (LL) and LH (corresponding to 104 square arcseconds for a 4-pixel region), and 2″3 for SN (corresponding to 21.2 square arcseconds for a 4-pixel region). For the most up-to-date information about saturation of the IRS see:

http://ssc.spitzer.caltech.edu/IRS/sat.html.

The IRAS fluxes for a given target can be used to estimate if that target will saturate the IRS. IRAS fluxes (if available) can be found, for example, by using the SIMBAD or NED (for extragalactic objects) online databases, or by searching in the Infrared Science Archive (IRSA) database, at

http://irsa.ipac.caltech.edu/.

The target for this example, 3C 273, was observed with IRAS and has flux densities of 0.55 Jy and 0.94 Jy at 12 and 25 μm, respectively. For the IRS high resolution modules, these flux density values are well below the saturation limits.

5.7 Sensitivity and Exposure Time Estimate

The sensitivity of the IRS is a function of the background which at these wavelengths is primarily from the cirrus and zodiacal light. The background for any target can be obtained as a function of observation date in Spot, by entering the target and then clicking "Background" in the target window. Plots illustrating the sensitivity of the IRS for high, medium and low background are given in the IRS chapter of the SOM and can also be viewed at

http://ssc.spitzer.caltech.edu/IRS/sens.html.

High background corresponds to positions close to the ecliptic plane; low background, to positions close to the ecliptic pole; and medium background, to intermediate ecliptic latitudes. See also

http://ssc.spitzer.caltech.edu/obs/bg.html.

This information can also be obtained using the Spitzer Spectroscopy Performance Estimation Tool (SPEC-PET) available at

http://ssc.spitzer.caltech.edu/tools/specpet/.

Note, however, that the SPEC-PET only supplies the same information available from the IRS sensitivity plots in the SOM. Note also the following: For each cycle of the IRS Staring mode AOT, two exposures are obtained. The sensitivity quoted by the SPEC-PET assumes that both exposures have been combined, and that the sensitivity of the combined image has scaled as $1/\sqrt{2}$ times the sensitivity of the individual images. Similarly, for multiple cycles, the sensitivity quoted assumes that the sensitivity of the combined image has scaled as the 1/(square root of the number of cycles). The sensitivities given in the SOM (section 7.2.1.2) are for a single exposure.

The sensitivity plots in the SOM show that a single, 120-second exposure will yield signal-to-noise ratio of unity (S/N $\approx$ 1) in the SH module for an unresolved emission line having flux of approximately 6.0×10^{-19} W m^{-2} at 15 μm. Similarly, a 240 sec exposure will provide S/N $\approx$ 1 in the LH module for an unresolved emission line having flux of approximately 7.0×10^{-19} W m^{-2} at 25 μm. By comparison with observations of Seyfert galaxies, the emission features in our target are expected to have fluxes of $\approx 5 \times$

10^{-18} W m^{-2} each. Using exposures of 1×120 seconds and 1×240 seconds for the SH and LH slits, respectively, and recalling that each cycle in staring mode automatically obtains two spectra with the requested exposure time (per slit at two slit positions), results in S/N$\approx$12 in each of the combined spectra from SH and LH for the target line fluxes. **Despite the adequate S/N of 1 cycle, we strongly recommend decreasing the ramp time and having a minimum of two cycles for each slit.** This provides greater redundancy against cosmic rays and variability in the pixels.

Strictly speaking, these signal-to-noise estimates, like the IRS sensitivity curves in the SOM, assume that the target is in the faint source limit (i.e., the shot noise from the target is negligible compared to other sources of noise). For a target in the Bright Source Limit (BSL), we would have to also consider the shot noise of the target itself. In this example, however, the expected line fluxes are well below the BSL for the IRS high resolution modules (see the SOM for IRS sensitivity curves and examples of calculating S/N for faint and bright targets).

5.8   Long-High Sky Background Observations

As a result of the continual increase in the number of degraded pixels in the IRS Long High module due to the effects of Cosmic Rays, it is strongly recommended that observations of sources with equivalent point source flux densities of 2.0 Jy or less at 25 microns be accompanied by off-source background measurements. Examination of the properties of Long High warm, or "rogue" pixels (pixels with abnormally high dark current that vary unpredictably with time), shows that the rogue dark current can be reduced substantially by subtracting a nearby background spectrum taken within a few hours of the science spectrum. Improvements in the signal-to-noise in the extracted spectrum can be substantial, up to 80% when averaged over an entire order of Long High and when the integration time is split evenly between target and background, since for faint sources the dark current in the rogue pixels is the dominant source of noise.

This recommendation applies chiefly to those observers using IRS Staring mode. Observers who are mapping their sources may only need one additional background observation (if all their map positions fall on the target of interest), or none (if at least one of the map positions falls on blank sky).

If an observer has to split out the LH/background observation into an-

other AOR because the current AOR has other slits selected, the cost of splitting the observation into another AOR (i.e. the 215 sec overhead charged to each AOR) will not be charged to the observer. However, the duration of the background measurement must come out of the observer's allocation. The LH background AOR should have no peakup, should replicate the cycles and ramp durations of the LH science AOR, and should be chained to the LH science AOR.

5.9   Filling Out the IRS Staring Mode AOT

We now fill out the IRS Staring Mode Astronomical Observation Template (AOT) in Spot, starting with selection of the AOT type. This is accomplished either by selecting "IRS Staring" from the "Observation" pull-down menu in Spot, or by clicking on the single-spectrum icon (the wiggly blue line), ninth from the right on the taskbar. The IRS Staring Mode AOT entry window appears as shown in Figure 5.3. It includes a choice of peak-up (target acquisition) options, slit configurations, exposure times, and repeats (cycles). In this section, we discuss each of the AOT entry options, and the activities that the spacecraft and telescope will perform when the specified AOR is executed. Let us consider these in turn.

5.9.1   Naming the AOR

It is recommended that proposers give unique names to their Astronomical Observation Requests (AORs; i.e., completed AOTs) to aid in identifying a particular AOR after proposal submission. When a new AOT window is opened, Spot assigns a default name derived from the instrument and observing mode, and a sequence number. This default label is shown at the top of the AOT entry window (see Figure 5.3). For example, "IRSS-0000" indicates an IRS Staring Mode observation with sequence number 0000 (the sequence number is incremented each time a new AOT is opened in a Spot session). Rename this AOT to "IRS_cookbook-example1" by selecting the default text in the "Unique AOR Label" box and typing the new name.
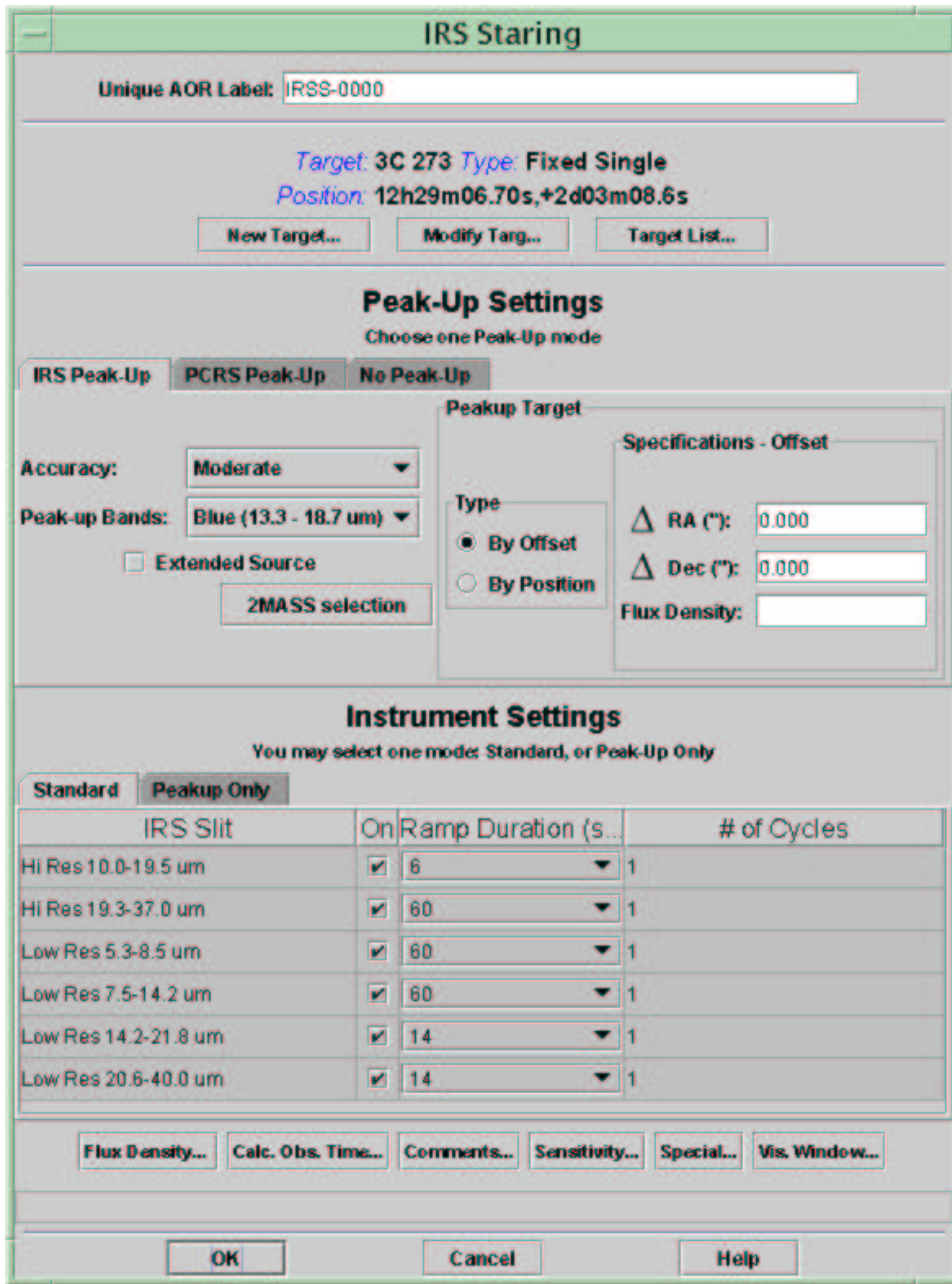
Figure 5.3: IRS Staring Mode AOT entry dialog window in its default state.

5.9.2 Choosing the Best Peak-up Option

"Peaking up" is at the heart of Spitzer's target acquisition process for the IRS, and partly determines the basic feasibility of a particular AOR. Configuring the peak-up for an IRS AOR should be done with care, as a failed or imprecise peak-up can lead to the subsequent science exposure not meeting the desired accuracies for target placement and photometric flux calibration. During the peak-up process, on-board software views either a $\sim 1' \times 1'$ (for the IRS peak-up imaging arrays) or a $40'' \times 40''$ area (for the PCRS imaging array), whichever is chosen, and determines the position of peak brightness in this field of view. The software then assumes that the position of peak brightness corresponds to the "peak-up target" that the proposer has specified via Spot. (There is, of course, no separate target acquisition if blind pointing – i.e., "No Peak-Up" – is requested.)

The peak-up target may be either the science target itself (not recommended for extended objects) or an offset target. In either case, after the software has identified the point of peak brightness, it then directs the spacecraft to move so that the science target is precisely placed in the desired IRS slit. The peak-up arrays occupy different parts of the Spitzer focal plane from the IRS slits and from each other (see Fig. 4.5 of the SOM). One peak-up array is integrated into the IRS SL module, while Spitzer's Pointing Calibration and Reference Sensor (PCRS) is used as the other peak-up array. The IRS peak-up array is actually composed of two sub-arrays that are sensitive to slightly different IR wavelength regions (see "Option 1" below). An IRS peak-up images the peak-up target in one of these two IR bands, while a PCRS peak-up images the peak-up target in an optical band (see "Option 2" below).

The peak-up process introduces an overhead of several minutes; the exact length depends on the requested accuracy (with higher accuracy requiring longer overhead). For an IRS peak-up, Low, Moderate, and High accuracies yield target placements within $2''\!.0$, $1''\!.0$, and $0''\!.4$, respectively. Each of these peak-up accuracies corresponds to a level of uncertainty in the photometric flux calibration of the resultant IRS spectrum (with a higher accuracy peak-up corresponding to smaller photometric uncertainty; see the IRS chapter of the SOM for more details). The nominal initial pointing accuracy of Spitzer, as measured during the In-Orbit Checkout (IOC), is $\approx 1''$; thus, the use of a peak-up in situations requiring Low accuracy is not strictly necessary if the target coordinates are well-known and if the set of peak-up images is not

needed. Use of the Moderate accuracy peak-up for observations that require a pointing accuracy of $1''$ (in order to obtain the associated photometric uncertainty) is still advisable. This is especially true when multiple IRS modules are selected for use. PCRS peak-up accuracy is comparable to a High accuracy IRS peak-up. It is also possible to request that no peak-up be done.

When filling out an IRS AOT with Spot, unless the "No Peak-Up" option is chosen, the proposer always needs to consider the following:

- Peak-up Mode: Either IRS peak-up or PCRS peak-up?

- Is the peak-up object a point source or an extended source?

- What is the peak-up target brightness in the relevant wavelength band?

- What is the offset distance between the peak-up and science targets?

Additionally, if "IRS Peak-Up" is selected, then the proposer must consider:

- Peak-up Filter: Red or Blue? This determines which of the two IRS peak-up sub-arrays is actually used.

- Peak-up Accuracy: Which pointing accuracy is needed (Low, Moderate, or High)? Each of these carries a successively better photometric calibration accuracy and longer associated overhead time.

An IRS peak-up has at least one advantage over a PCRS peak-up. During an IRS peak-up, 3 images of the peak-up target at the nominal spacecraft pointing, and an additional 3 images centered on the peak-up array "sweet spot," are obtained. These images are delivered to the observer (along with 2 combined, "cleaned" images constructed from each set of 3 raw images). Thus, if the science target is used as the IRS peak-up target, then "free" IR images of the science target are gained. Note that although useful for viewing, e.g., the source's morphology, these images are only coarsely calibratible. If you require calibratible images, then you should use the IRS peak-up imaging AOT.

Option 1: IRS Peak-up

The IRS peak-up array images in the IR, in contrast to using optical imaging as in the PCRS peak-up option. It provides two modes of operation. A bright, IR target whose absolute coordinates are known only to within $\sim 10 - 15$ arcseconds, but which is well isolated from other bright IR sources, can be located by the peak-up software and placed on the IRS slit(s). Alternatively, a faint IR target whose location relative to a bright, nearby (within $30'$) IR source is accurately known can be observed by peaking up on the bright object and performing an offset to the science target.

If an IRS peak-up is selected, then the proposer must specify which of the two peak-up sub-arrays to use. The IRS "Blue" peak-up sub-array covers $13.3 - 18.7$ μm, while the IRS "Red" peak-up sub-array covers $18.5 - 26$ μm. Only one peak-up sub-array (Blue or Red) can be selected per AOR. A Blue peak-up requires ~ 2 minutes less than a Red peak-up. On the other hand, Red can be used with brighter peak-up targets than Blue without saturating. Generally, Blue is preferable if a peak-up target can be found that works with either sub-array, and Red is a second-choice backup in the event that either the peak-up target is very much fainter in the Blue waveband than in the Red or the only available peak-up target saturates in the Blue, but not in the Red. In general, the following process is recommended for identifying a suitable IRS peak-up target.

Consider the science target itself: If the science target satisfies all of the following conditions, then it is probably a good IRS peak-up target.

(i) It is a point source.
(ii) It is brighter than 5 mJy (Blue) or 15 mJy (Red), but fainter than 150 mJy (Blue) or 340 mJy (Red). (Targets fainter than 10 mJy in either band require increased overhead time during the peak-up process.)
(iii) It is not in a region of extended and/or bright IR emission.

3C 273 is effectively a point source, so satisfies condition (i). However, recall that the 12 and 25 μm IRAS flux densities of 3C 273 are 550 and 940 mJy (see §5.6), which violates condition (ii) by exceeding the allowed IRS peak-up flux limits for both the Blue and Red sub-arrays, respectively. Thus, we can already conclude that 3C 273 cannot itself be used as an IRS peak-up target. For the sake of completeness in this example, condition (iii) can be qualitatively checked by using the "ISSA Image" option in Spot's "Images" pull-down menu to download the 12, 25, and 100 μm IRAS images of the
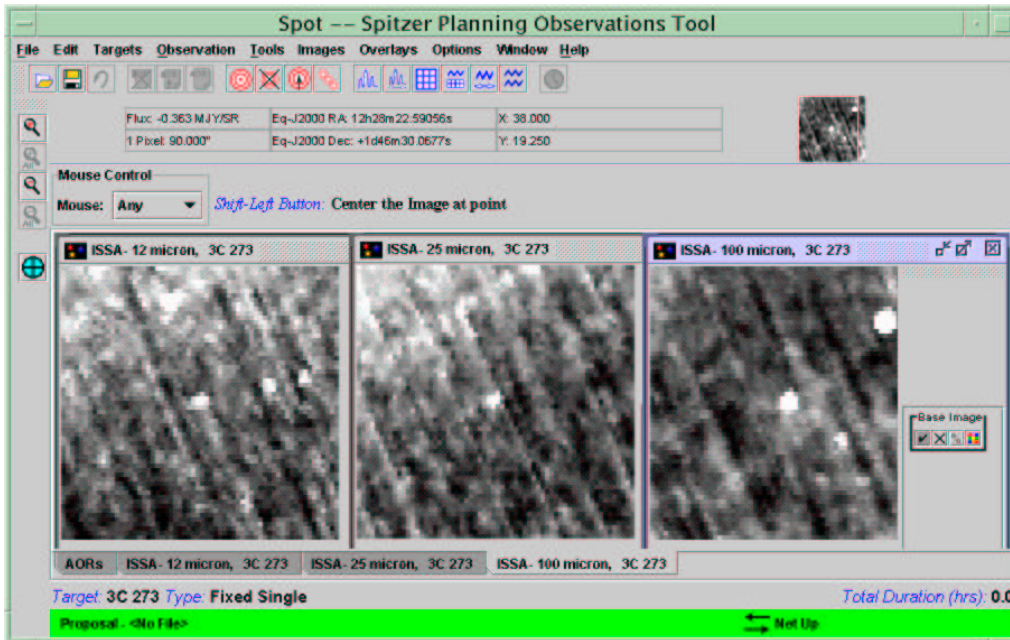
Figure 5.4: IRAS 12 (left), 25 (middle), and 100 μm (right) images of a 1.5°
field around 3C 273 (bright white spot at the center of each image), displayed
in Spot using the "Images → ISSA Image" menu.

region around the target (see Figure 5.4). This shows that 3C 273 is not
located amidst bright, extended IR emission.

A quantitative estimate of the local background level can be made us-
ing the "Background" option in the Spot Target window (see Figure 5.1).
To access this feature, first click on the "No Peak-Up" tab[1] and then on
"OK" in the IRS Staring Mode AOT entry window to dismiss it (this win-
dow can be recalled at any time by pressing the modify-AOR icon – a sheet
of paper labeled "AOR" with an arrow – fifth from the left on the taskbar,
or by selecting "Modify current AOR" from the "Edit" pull-down menu).
Next, recall the Target window by pressing the modify-target icon (a bulls-
eye with an arrow in it), ninth from the left on the taskbar, or by selecting
"Modify Target" from the "Targets" pull-down menu. Finally, click on the
"Background" button in the Target window. In the Background Estimate

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[1]This is necessary because the flux density for a peak-up target has not yet been entered,
which is required before storing the AOR in Spot's memory – we will return to this soon.
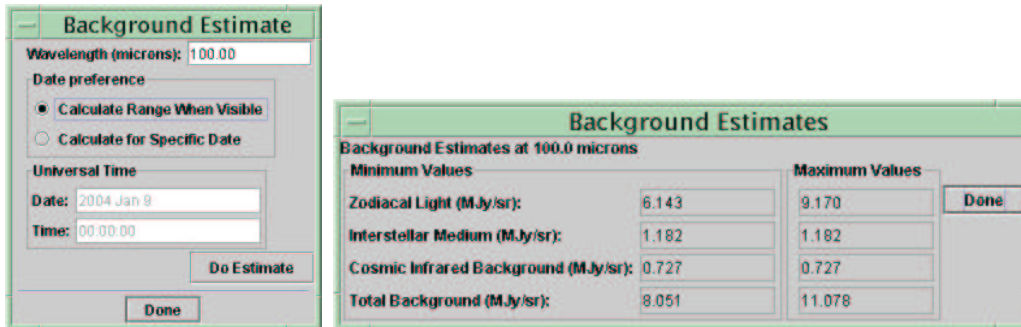
Figure 5.5: (left) Spot Background Estimate entry window, which is available from the Target entry window. (right) Result of Spot's background estimate for 3C 273.

pop-up window, set a wavelength of 100 μm and select the "Calculate Range When Visible" option, then click on the "Do Estimate" button (see Figure 5.5, left panel). This returns a table showing the breakdown of estimated 100 μm background components during the range of target visibility windows (see Figure 5.5, right panel). The ISSA IRAS images should not be used to determine the background level, as the zodiacal light component has been removed from these images. In the case of 3C 273, Spot estimates the total local background surface brightness at 100 μm to be between $\approx 8 - 11$ MJy sr^{-1}.

This can be compared to the plot of 100 μm IR cirrus brightness vs. minimum peak-up source flux density in the IRS chapter of the SOM (Fig. 7.40), which shows that objects with flux densities of at least ≈ 5 or 10 mJy in the Blue or Red wavelength ranges, respectively, are acceptable against this level of cirrus background. The IR flux densities of 3C 273 (see above) would clearly satisfy condition (iii); however, 3C 273 has already been excluded from serving as its own peak-up target by exceeding the flux limits of condition (ii).

Try a 2MASS Star: If the science target is not a good peak-up target, then another peak-up target within 30$'$ must be located. It is recommended that the proposer first approach this problem by using the Spot feature that searches for suitable IRS peak-up targets from the 2MASS Point Source Catalog (2MASS-PSC). In the IRS Staring Mode AOT entry window, click on the "2MASS selection" button under the "IRS Peak-Up" tab. This will display a window (see Figure 5.6) asking for the local surface brightness at 100 μm (in order to facilitate selecting the largest possible number of
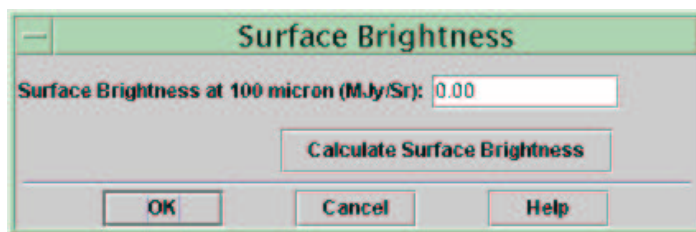
Figure 5.6: Spot Surface Brightness window, which is the first step in performing a search for valid IRS peak-up stars from the 2MASS-PSC.

2MASS peak-up stars that are bright enough against the local background). Either enter a known maximum local surface brightness (e.g., as estimated previously – see Figure 5.5) or click on the "Calculate Surface Brightness" button (which performs the same operation as the "Background" option in the Spot Target window). When complete, click on "OK" to dismiss the Surface Brightness window and initiate the 2MASS search.

> **Warning:** Clicking on "OK" in the Surface Brightness window while the surface brightness is still set to the default value of 0.00 MJy sr^{-1} will cause Spot to return all available 2MASS stars brighter than 10 mJy. Many of these will not actually be usable against the true, non-zero background level. If a surface brightness larger than 50 MJy sr^{-1} is entered (or calculated), then Spot displays a warning that the surface brightness must be between 0.0 and 50.0 MJy sr^{-1}. This limit is imposed because non-uniform structure accompanying backgrounds higher than 50 MJy sr^{-1} will confuse the peak-up algorithm. In this case, available peak-up stars can still be obtained by setting the surface brightness to exactly 50.0 MJy sr^{-1}; however, the success of the peak-up algorithm using any of these stars is not guaranteed. It is recommended that an initial "Peak-up Only" observation be used to confirm the success (or failure) of the peak-up before attempting the spectrum exposure on the science target.

When the 2MASS search is complete (this can take a few seconds to several minutes), Spot returns a table of "Peakup Candidates" (see Figure 5.7). The candidates are noted as either "GOOD for Blue" or "Acceptable." The former are optimum targets for use in an IRS Blue peak-up, while the

Figure 5.7: Spot's recommended IRS peak-up point sources from the 2MASS database. The selected peak-up target is highlighted.

latter are, as the label implies, acceptable (but not optimum) for peak-up. ("GOOD for Red" candidates might also be listed, if available, but these should only be used if an IRS Red peak-up has been selected.) The remaining columns in the table give the 2MASS J2000 coordinates of the candidates, their spectral types (based on the 2MASS colors), their flux densities (in mJy) at 16 and 22 μm (estimated from the spectral type), and the 2MASS observation epoch.

Among multiple "GOOD" peak-up targets, preference should be given to the target that is, first, closest to the science target and, second, brightest among approximately equidistant peak-up targets. In this example, the more nearby of the two "GOOD" peak-up targets available for 3C 273 has been assigned by selecting it in the "Peakup Candidates" window and then clicking on "OK." When we do this, the coordinates, epoch and flux density are automatically transferred to the "Peakup Target" box in the "Peak-Up Settings" portion of the IRS Staring Mode AOT window (Figure 5.7). However, the 2MASS database does **not** contain proper motions. It is **essential** that the observer click on "View/Modify Peak-up Target" and enter the proper motion of the peak-up star (see Figure 5.8). In general, selecting a peak-up star with small proper motion will lead to better results from the peak-up process (especially when a high accuracy peak-up is desired). In order to avoid using high proper motion stars for peak-up, the proper motion of the selected peak-up star should be verified. In all cases, the correct proper motion values should be entered into the "Peak-up Settings" section of the AOT entry window.

Accurate proper motions for a large number of stars can be found, for example, in the Tycho-2 catalog, which is a new reduction of measurements obtained by the *Hipparcos* satellite combined with ground-based data. Tycho-2 can be searched interactively at the CDS-VizieR web site, at

http://vizier.u-strasbg.fr

(or one of the local mirror sites available at that site). SIMBAD also often provides proper motions, although they have sometimes been obtained from catalogs with larger uncertainties than Tycho-2. If a given peak-up star is not listed in the Tycho-2 catalog, then every effort should be made to obtain the best-known proper motion (and position – see below) information from another literature source. If high accuracy astrometric information is not available from other sources, then it might be prudent to select a different peak-up star that *is* listed in the Tycho-2 catalog, if available.

Another important factor to consider is that the coordinates in the 2MASS-PSC, although given for the standard epoch J2000.0, do not include the cumulative displacement, due to proper motion between the time when the image of a given object was obtained and J2000.0. **As a general rule of thumb when using an offset peak-up, the combined uncertainty in the coordinates of the science target and peak-up target (including any unaccounted proper motion between the epoch of the coordinates and J2000.0) should be no larger than 1/3 of the desired positional accuracy.** While this does not present an especially rigorous challenge for a Low or Moderate accuracy peak-up, special care must be exercised when planning a High accuracy peak-up. The "Peak-up Only" observing mode for IRS allows testing and verification of the success of a questionable peak-up before the actual spectroscopic exposure is obtained. The trade-off for this, of course, is a potentially significant addition to the total time required to complete the observing program.

Ideally, the coordinates used for the selected peak-up star should correspond precisely to the standard epoch J2000.0. Most often, the coordinates for a 2MASS peak-up star are not the standard epoch and possess an unaccounted proper motion offset. Unlike previous versions of Spot, the current Spot (v11) can handle any non-standard epoch value in the peak-up settings section of the AOR. It is no longer necessary manually to adjust the 2MASS coordinates to epoch J2000.0; this is now done automatically within Spot. The example IRS 2MASS peak-up star is HD 108473, a $V = 9.28$
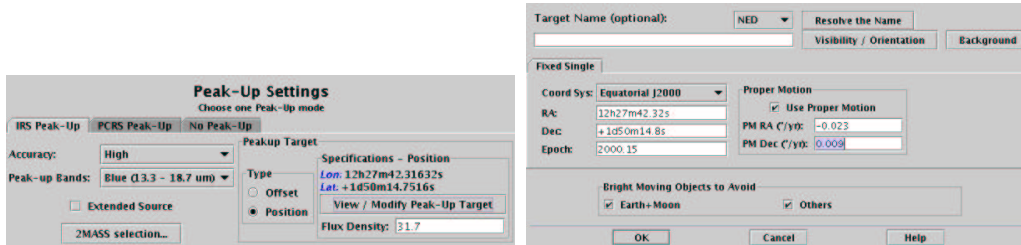
Figure 5.8: Completed "Peak-Up Settings" portion of the IRS Staring Mode AOT for an IRS peak-up using a star selected from the 2MASS-PSC.

and $K_s = 6.84$ mag G5 star. This star was actually observed by 2MASS on epoch 2000.15, with the equinox 2000.0 coordinates, RA=12:27:42.32, DEC=+01:50:14.8, shown for it in Fig. 5.7. Although Spot corrects the star's epoch, you will still need to manually input the proper motions for the peak-up star. The Tycho-2 catalog gives proper motions of $\mu_\alpha = -22.9$ mas yr^{-1} and $\mu_\delta = +9.5$ mas yr^{-1}. These proper motions can now be entered into the "Peakup Target" box, keeping in mind that Tycho-2 gives proper motions in mas per year, but Spot requires them to be entered in arcseconds per year. The RA proper motions from Tycho-2 are expressed in 2-dimensional, or "linear," arcseconds (which differ by a factor of the cosine of the declination from 3-dimensional, or "curved," arcseconds on the celestial sphere. Recent releases of the Tycho-2 catalog have the RA proper motions already multiplied by the cosine of the declination). This is the format required for entry into Spot. To reiterate, Spot expects the RA proper motion to have been converted from seconds per year to arcseconds per year as follows:

$$\mu_\alpha \, [\text{arcseconds year}^{-1}] = 15.0 * \cos(\text{DEC}) * \mu_\alpha \, [\text{seconds year}^{-1}].$$

Proper motion uncertainties from Tycho-2 are 2.5 mas year^{-1}, so we will typically not have to worry about this correction over the Spitzer mission lifetime (e.g., the maximum combined positional error accumulated in 7 years amounts to only 0.″025). Figure 5.8 shows the completed "Peak-Up Settings" section of the IRS Staring Mode AOT window configured for a High accuracy, Blue IRS peak-up on HD 108473, which was selected from the 2MASS-PSC.

The peak-up algorithm assumes that the brightest object within the peak-up array field-of-view ($\approx 1' \times 1'$) is the intended peak-up target, so it is also a good idea, after selecting a peak-up target, to examine the DSS, 2MASS, and/or IRAS images around the peak-up target to ensure that this condition
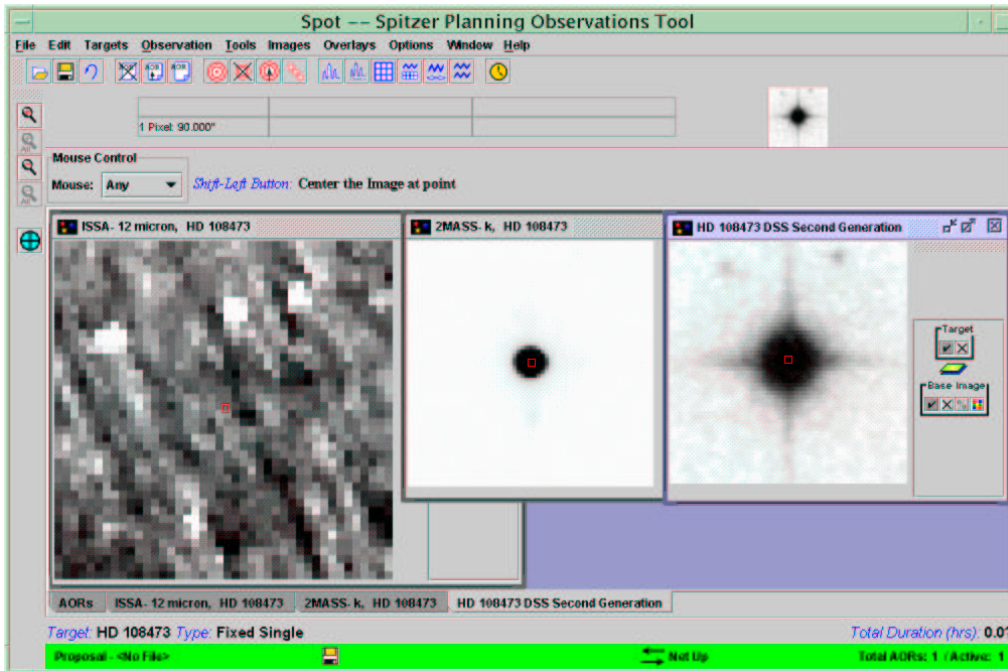
Figure 5.9: IRAS 12 micron (left), 2MASS K_s (middle), and DSS optical (right) images of the peak-up star HD 108473, obtained using Spot's "Images" menu. The 2MASS and DSS images are displayed in reverse greyscale.

is met (a reminder to do this is given in the "Peakup Candidates" window – see Figure 5.7). Both SIMBAD (via Aladin) and Spot (via the "Images" menu) offer means of doing this. Recall that the Blue IRS peak-up operates in the $13.3-18.7$ μm range, so it is useful to examine the IRAS 12 μm image. Figure 5.9 shows the IRAS 12 μm, 2MASS K_s, and DSS optical images of the field around the selected peak-up star, obtained using Spot's "Images" menu (this was accomplished by creating a new "dummy" target using the coordinates of the selected peak-up star – see §5.4).

The 2MASS and DSS images shown in Figure 5.9 cover $1' \times 1'$, which is the approximate size of the IRS peak-up array field-of-view, and clearly show that there is no brighter object within this area. The IRAS image covers $1° \times 1°$. The peak-up star (located in the small box at the image center) is too faint to have been detected by IRAS (and the IRAS spatial resolution is too poor to show a 1 square arcminute field) but, at least, there is no overwhelmingly bright IR source (like the distant objects near the top

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of the IRAS image) located close to the peak-up star that would confuse the peak-up algorithm.

Find another peak-up star: If the science target is not a good peak-up target, and there is no "GOOD" or "Acceptable" star available from 2MASS, then another usable IRS peak-up object must be manually located. Care should be taken to ensure that the selected target meets all of the criteria described above; namely, that it is located within $30'$ of the science target, is the brightest object within $1'$ of itself in the selected peak-up passband, has flux levels within the acceptable range for the selected peak-up, and is also bright enough against the background of local IR cirrus. **Only when all attempts to locate a point source peak-up target have failed should an extended source be used for the peak-up target.**

Option 2: PCRS Peak-up

A PCRS peak-up utilizes Spitzer's Pointing Calibration and Reference Sensor. The PCRS is sensitive at 5050–5950 Å, and can find the centroid of a star with $V = 7.0 - 10.0$ mag[2]. As with an IRS peak-up, either the science target or an offset star can be used as the peak-up target. However, because the PCRS obtains images in a very different wavelength region from that of the IRS, **it is strongly recommended that only an object with a known visual magnitude be used as a PCRS peak-up target.** At $V \approx 12.9$ mag, 3C 273 is itself too faint to act as a PCRS peak-up target.

The accuracy of target placement in an IRS slit for a PCRS peak-up is comparable to a High accuracy IRS peak-up ($0\rlap{.}''4$). As described previously for selecting an IRS peak-up target, the PCRS peak-up target should be the brightest object in the $40'' \times 40''$ field-of-view of the PCRS array. Also, because the PCRS pixels are quite large ($10''$), it is important that the peak-up target does not have a close, bright companion. In general, in order to minimize the detrimental effect on the measurement of peak-up target position, the angular separation between a peak-up target and companion star must be larger for brighter companion stars. A quantitative expression of this condition exists, but cannot be provided here[3].

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[2]This bright magnitude limit of $V = 7.0$ is 0.5 mag brighter than that given in v2.6 and earlier of this Cookbook, and reflects a revision to the PCRS peak-up procedure based on in-orbit tests.

[3]Like much of the documentation related to Spitzer's PCRS, dissemination of this information is restricted by the International Traffic in Arms Regulation. Please contact

Although any method of identifying a star in the allowed PCRS peak-up brightness range can be utilized, we recommend that proposers consult the PCRS Guide Star Catalog (PCRS-GSC), which is available at

http://ssc.spitzer.caltech.edu/pcs/.

This web page provides important notes on the limitations and use of the catalog (also see the Explanatory Document available from the PCRS-GSC web page for detailed descriptions of the data columns in the catalog table). The proper motions listed in the PCRS-GSC are in mas year^{-1} (as in the Tycho-2 catalog), and the RA proper motion has been "linearized" (i.e., it includes a factor of the cosine of the declination). However, the coordinates in the PCRS-GSC are the J2000.0 coordinates corrected for proper motion to J2004.5. Before entering the coordinates into Spot, this proper motion correction must be removed. Tests by the PCRS team have shown that using a simplified method of merely subtracting 4.5 times the proper motions from the listed coordinates (after dividing the RA proper motion by the cosine of the declination) gives results that are generally good to within 1 mas compared to those derived using spherical trigonometry.

Future versions of Spot will automatically search the PCRS-GSC for available peak-up targets (like "2MASS Selection" for IRS peak-ups). In the meantime, an IDL routine ("pcrsfind.pro") is available from the PCRS-GSC web page that finds all usable PCRS peak-up stars around a given target position, and corrects their coordinates to epoch J2000.0. Proposers should keep in mind that there is no advantage to choosing a PCRS peak-up star that is at the bright end of the allowed range over choosing one at the faint end. The "pcrsfind.pro" routine also reports the quality grade of the positional accuracy for each star from the PCRS-GSC. Grade-A stars have smaller 1σ radial position errors than grade-B stars. In general, the best results will be obtained by choosing the star within the allowed magnitude range that is located closest to the science target and/or has the better quality grade.

As located by "pcrsfind.pro," the PCRS-GSC contains one suitable PCRS peak-up target within 30′ of 3C 273: star 282-374-1 (the PCRS-GSC uses the Tycho-2 designations) has a magnitude of $V = 9.27$ and is located 24′.73 away at epoch J2000.0 coordinates of RA = 12:27:42.31 and DEC = +01:50:14.7. A SIMBAD search around the coordinates of this star confirms that, by

the Spitzer Helpdesk at help@spitzer.caltech.edu if you are concerned about a nearby companion to a potential PCRS peak-up target star.
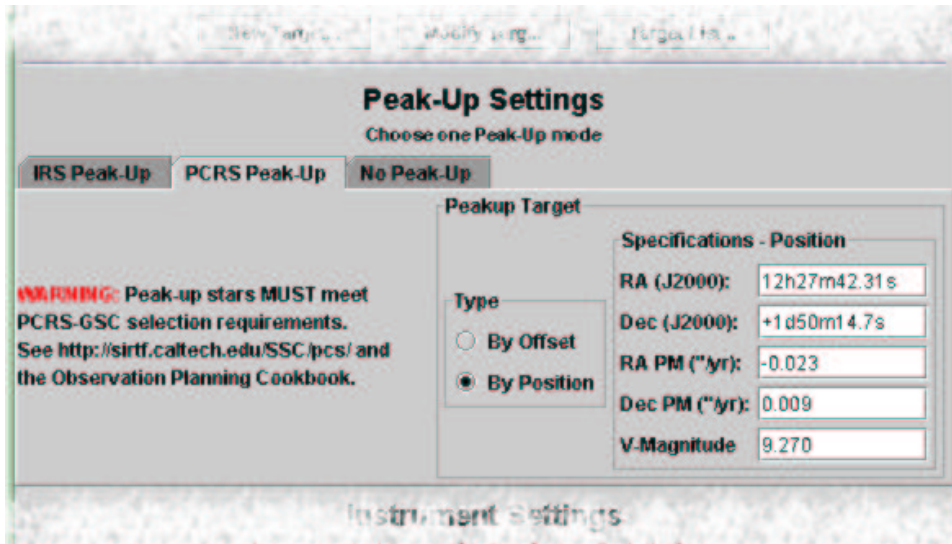
Figure 5.10: Completed "Peak-Up Settings" portion of the IRS Staring Mode AOT for a PCRS peak-up using a star selected from the PCRS-GSC.

coincidence, it is HD 108473, the same star identified earlier as a suitable IRS peak-up target. Figure 5.10 shows how the finished "Peak-Up Settings" section of the IRS Staring Mode AOT entry window would look if configured for a PCRS peak-up on the star selected from the PCRS-GSC.

The PCRS-GSC contains $\sim 2 \times 10^6$ stars and was, therefore, necessarily constructed via an automated process that relied primarily on star catalogs. Although the best effort has been made to ensure the validity of the objects in the PCRS-GSC, it is estimated that $\lesssim 5\%$ might be questionable. Future versions of the catalog will remove these as they are discovered; in the meantime, it is advisable to check for nearby neighbors and/or overlapping (extended) background objects. This can be accomplished using the process described above for searching for bright, nearby neighbors to IRS peak-up stars selected from the 2MASS-PSC. If you find a star in the PCRS-GSC that is *not* a valid peak-up target, please notify the Spitzer Helpdesk, at

help@spitzer.caltech.edu.

Before constructing AORs using PCRS peak-up stars selected from the PCRS-GSC, please check for updated versions and/or information about the catalog at the web address shown above, or revisions to the procedures described in the Observation Planning Cookbook at

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Option 3: No Peak-up

In some cases, it might not be strictly necessary to perform a peak-up and incur the requisite overhead time (although **performing a peak-up is almost always recommended**). The only obvious examples are an observation using the IRS Spectral Mapping mode (see Chapter 6 of this Cookbook) when the starting point within an extended region does not need to be precisely specified (to better than the nominal intrinsic pointing accuracy of Spitzer), or when the photometric calibration uncertainty associated with Low accuracy is sufficient, the target coordinates are well-known, and the observer does not need the set of peak-up images (see §5.9.2). However, the proposer should keep in mind that each pointing movement of the telescope introduces a cumulative, random positional error on the order of 0.″2. Thus, spectral mapping observations using many steps and/or cycles can accumulate large pointing errors.

5.9.3 IRS Peak-up Array Saturation and Droop Correction

When the IRS arrays are read non-destructively in RAW ("sample up the ramp") mode, they suffer from "droop," which is the addition of a voltage to each pixel proportional to the total charge summed over the entire array. Droop is a detector artifact, not a true signal, and is present in all of the IRS arrays. The standard IRS science pipeline corrects all exposures for droop; however, this correction is underestimated for a given array (hence, the spectrum flux will be overestimated) if a large number of pixels on that array are saturated. This especially affects the SL array, which includes the broad-band IRS peak-up imaging sub-arrays. These arrays are also exposed during the SL spectrum exposure, so if a bright source happens to be incident on either of the peak-up sub-arrays, then it can quickly saturate a large number of SL array pixels (see Figure 5.11). This effect must be considered for any SL exposure, even if an IRS peak-up is *not* being used prior to the spectrum exposure.

The IRS Instrument Support Team at the Spitzer Science Center (SSC) has made calculations of this effect based on achieving better than 4% radiometric accuracy on unmeasurable droop in a bright SL spectrum (i.e.,
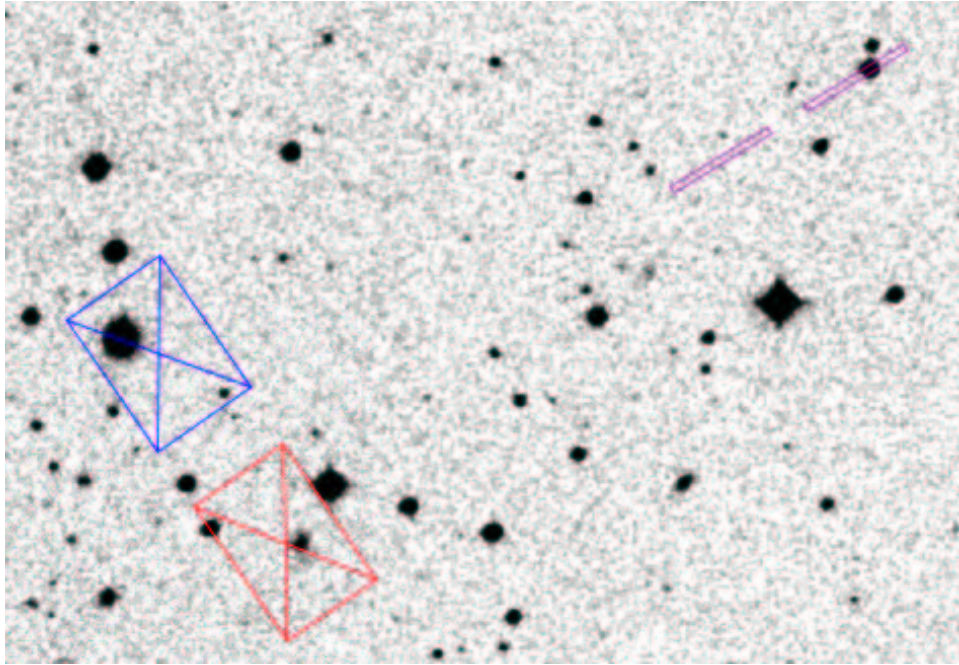
Figure 5.11: Visualization overlay showing a science target (not 3C 273) in one subslit of the IRS SL module (small boxes on right), with the simultaneous position of the IRS peak-up arrays (large boxes on left). The bright point source in the Blue peak-up array field-of-view might be cause for concern with regard to the droop correction for the SL array.

one which fills 50% of the available maximum ramp capacity in a single, 240-second exposure). The following recommendations pertain to serendipitous sources illuminating the IRS peak-up arrays during an SL spectrum exposure:

- Point sources should not exceed a flux density of 41 Jy in the wavelength range of the IRS peak-up arrays ($\approx 13 - 26$ μm).

- Spatially uniform (i.e., extended or background) sources should not exceed an illumination of 114 MJy sr^{-1}. (This is larger than the brightest expected signal due to zodiacal light.)

One means of mitigating the effect of serendipitous bright sources in the IRS peak-up arrays is to use a shorter SL spectrum exposure time. Another

would be to constrain the observations to occur at such a time that the spacecraft roll prevents any bright objects from illuminating the peak-up arrays during the SL exposure (although this method is not recommended unless absolutely necessary due to the limit on the number of constrained AORs that will be allowed in GO Cycle-2 – see §5.5). Spot includes an overlay in the visualization tools that automatically shows the location of the IRS peak-up arrays during any SL exposure. This allows direct verification that no bright sources are located in the peak-up array field-of-view.

5.9.4 Ramps and Cycles

For each of the four IRS slits (there are six "slits" if we count the two spectral orders available in each of the two low resolution modules), in addition to selecting which slit(s) to be used, the proposer must specify in the IRS Staring Mode AOT window two aspects of the actual exposure: the duration of ramps and the number of cycles for each ramp. The ramp duration is the time between the first and last non-destructive reads of the array. It corresponds to an individual exposure time. Ramp durations range from 6 to 480 seconds, with a limited set of discrete choices available for each IRS module. A cycle is a repetition of the exposure with all other parameters (ramp duration, slit selection, observing mode) unchanged and without moving the telescope. Since the IRS observes each ramp at two slit positions in Staring Mode, choosing a single cycle will result in two independent spectral ramps. Choosing two cycles will obtain four independent ramps, with two at the first slit position, then two at the second slit position, and so on.

For our target, we determined that using exposures of 1×120 seconds and 1×240 seconds for the SH and LH slits, respectively, will result in S/N ≈ 12 in both sets of spectra for the target line flux of 5×10^{-18} W m^{-2} (see §5.7). Additional ramp cycles (e.g., 2×120 seconds) could be used to acquire spectra that could be combined to yield higher S/N. To continue the set-up for the 3C 273 observations, refer to the "Instrument Settings" portion of the IRS Staring Mode AOT window. Make sure that only the "Hi Res" slits have been checked "On." Use the "Ramp Duration" pull-down menus to set the ramps for the SH slit ("Hi Res $9.9 - 19.6$ μm") to 120 seconds and the ramps for the LH slit ("Hi Res $18.7 - 37.2$ μm") to 240 seconds. Finally, enter the "# of Cycles" as "1" for the SH slit and "1" for the LH slit. The AOT window up to this point (including peak-up settings for a high accuracy, Blue filter IRS peak-up) is shown in Figure 5.12. Now, we will add

the LH sky background observation. We can either add the background as a separate AOR or as a fixed cluster offset.

5.9.5   LH Background

Adding LH Background as a separate AOR

Create a new AOR following the steps that you took for 3C273 i.e. Click on "Observation"$->$"IRS Staring". Modify the target position to be offset from that of your source. For a point source, the position of the sky observations should be greater than 60 arcsecs from the source. For an extended source, the sky observations should be offset by an amount substantially larger than the angular extent of the source. Always ensure by visualizing your AORs, if the position of your sky observation is blank i.e. no bright serendipitous sources fall in your slit during the sky observation. For this particular source, we pick 12h20m06.3s, +2d02'06.9" (J2000). Disable peak-up by selecting "No peak-up". Select same ramp duration for the background as you selected for the sky, in this case 1×240s. Figure 5.13 shows the complete AOR for the sky background.

Now chain your sky background AORs and target AORs which results in them being executed as a single uninterrupted observing sequence. This can be done by Clicking on Tools$->$Group/Follow-on constraints. The Constraint Editor Tool pops up (Figure 5.14). Click on Add Chaining and enter a name for the Chain. The click on each AOR you want to chain and drag and drop the two AORs into the Constraint Editor Tool so that it looks like Figure 5.14. Then Click Apply and OK.

Your background AOR has now been chained to the target AOR. The "G" column has a check mark to indicate the Grouping of the two AORs.

Adding LH background as a fixed cluster offset

You can also add a sky background observation as a fixed cluster offset to your AOR. This is an alternative only if you plan to take your sky observation within 1 degree in radius of your target. The Fixed Cluster mode also results in the observing parameters of the sky being exactly the same as that on the target. In the example given, since SH and LH observations are in the same AOR, selection of fixed cluster offset will result in SH **and** LH sky background observations being taken at the sky position. The cluster offsets

Figure 5.12: IRS Staring Mode AOT window for 3C 273 showing target, peak-up, slit, ramp, and cycle settings.

can be either specified by coordinates or by relative offsets.

To create a fixed cluster target, click on Observation− >IRS Staring− >New Target Then select either "fixed cluster-positions" or "fixed cluster" depending on whether you will provide absolute coordinates or relative offsets for the sky position. Then enter the coordinates of the target and the sky in each row of the fixed cluster window. Figure 5.15 shows the target window for fixed cluster-positions with the position of 3C273 and the sky observations entered.

Then select the peak-up star exactly as shown earlier and enter the proper motion. Click ok. When you visualize your AOR, you will notice that the sky observation is performed both for SH and LH as expected, for the fixed cluster mode. If you do not want to invest time to take a sky for the SH position, then you will either have to remove the SH observations from this AOR or take the LH background as a separate AOR as illustrated in the previous example.

5.10   Completing the Program: Duration Calculation and Proposal Submission

Now that the IRS Staring Mode AOT entry dialog to obtain high resolution spectra of 3C 273 is complete, we can perform the final steps necessary to finish the AOR and submit the associated proposal. First, click on "OK" in the IRS Staring Mode AOT window to store the AOR in Spot's memory, then refer to the main Spot window. The observation will now be listed in the "Astronomical Observation Requests (AORs)" table (see Figure 5.16, top panel). Notice that the "Duration" column says "No Est." and the "Total Duration" field in the lower right corner of the Spot window says "0.0?". This is because Spot has not yet been instructed to estimate the total duration of the AOR, which includes ramp durations and overhead times associated with array conditioning, telescope slew and settle, telescope movements within the AOR, and peak-up.

Estimating the AOR duration can be accomplished in two ways. The simplest method is to select "Recompute All Estimates" under the "Tools" menu. Spot will ask "Recompute what?" – select "All AORs." The AOR table and "Total Duration" field in the main Spot window will now be updated to list the total estimated duration of the AOR, as shown in the bottom
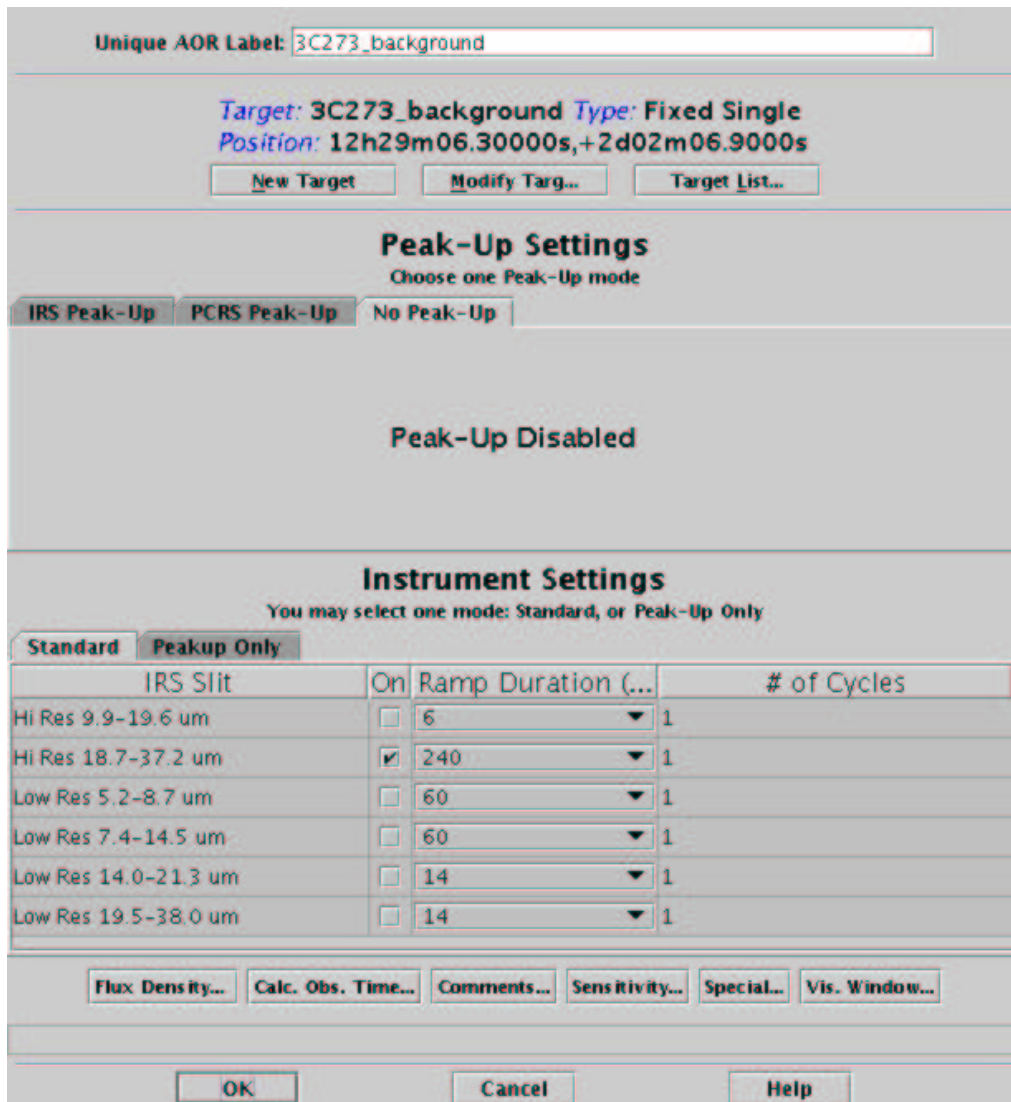
Figure 5.13: Illustration of a separate AOR for LH sky background observations

panel of Figure 5.16 (remember that the maximum allowed duration of any one IRS AOR is 6 hours).

Alternatively, the Staring Mode AOT window can be reopened by selecting "Modify Current AOR" from the "Edit" pull-down menu or by clicking the modify-AOR icon (the sheet of paper labeled "AOR" with an arrow),

Figure 5.14: Figure illustrating the chaining of a LH sky background AOR to the target LH observations.

fifth from the left on the taskbar. Then, in the Staring Mode AOT window, click on the "Calc. Obs. Time" button. This method is more informative since Spot will produce a Resource Estimates window showing a breakdown of the various time components (see Figure 5.17). Notice that the reported integration times for each module are slightly longer than what we have requested (i.e., 2 slit positions $\times$ 1 cycle $\times$ 120 seconds = 240 seconds for SH, and 2 slit positions $\times$ 1 cycle $\times$ 240 seconds = 480 seconds for LH). This is because the IRS electronics clock uses seconds of a slightly different
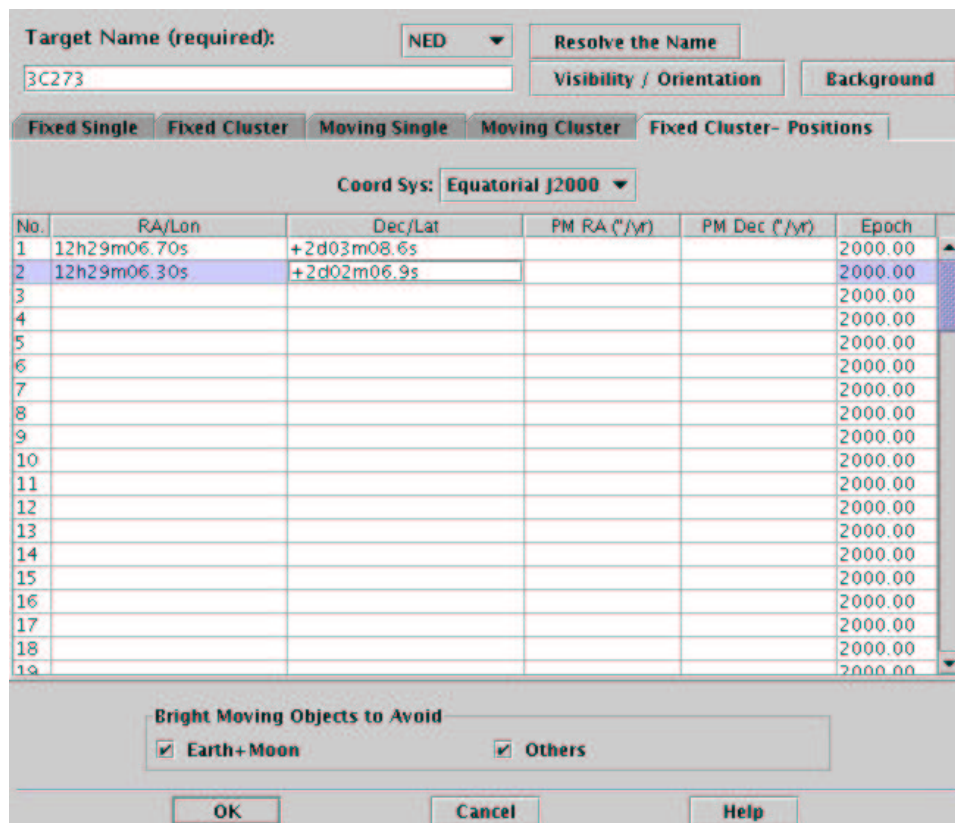
Figure 5.15: Illustration of a LH sky background observation added as a fixed cluster offset.

length than "real" seconds. However, the duration estimates reported by Spot are in "real" seconds – these are the times that are used in the final, submitted proposal. Press "Done" to dismiss the Resource Estimates window. The AOR entry for the observation in the main Spot window will now show the correct duration (see Figure 5.16, bottom panel). The AOR is now completely finished!

Before continuing on to the proposal submission stage, it is a good idea to save the target list and AOR to a local computer disk. This can be accomplished by selecting the "Save AOR(s) and Target(s)" option under the "File" pull-down menu, or by clicking on the save icon (the floppy disk), second from the left on the taskbar. Target lists and AORs must be saved separately – be sure to select the correct save format in the Save AOR(s) and
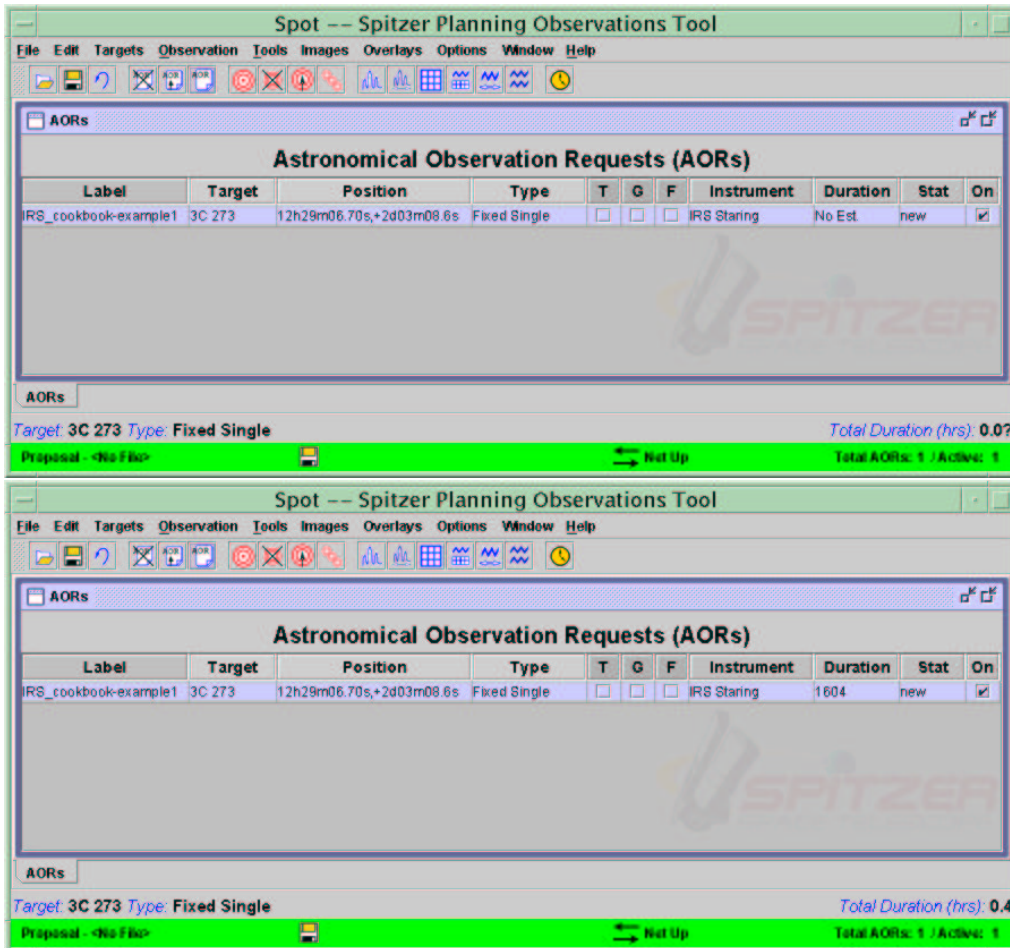
Figure 5.16: Main Spot window, showing the example observation of 3C 273 listed in the AOR table without (top panel) and with (bottom panel) a computed duration. To avoid confusion, the LH sky background AOR is omitted from these windows.

Target(s) window.

To complete the proposal submission process, follow the instructions given in §2.1: use the "Proposal Tool" option in the "Tools" menu to create a cover sheet for the proposal with contact information and an abstract, and attach the saved AOR(s) and a portable document format (pdf) file of the scientific justification. **The Spitzer proposal submission process occurs entirely through the Spot interface.**
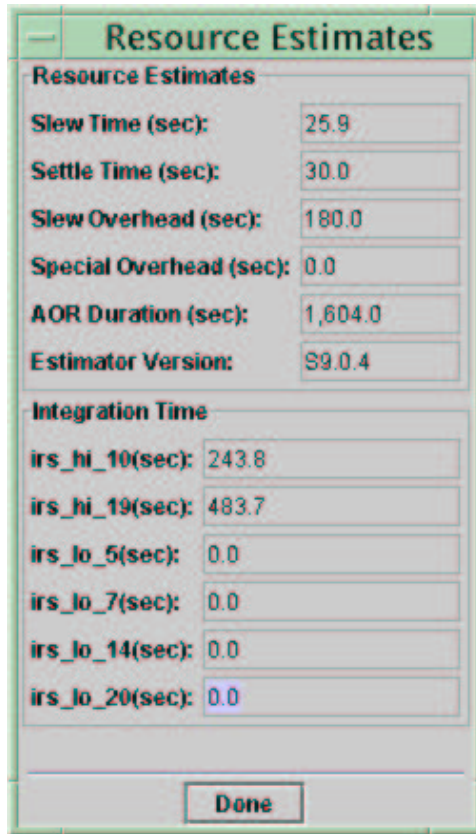
Figure 5.17: Resource Estimates window for the IRS Staring Mode AOR.

5.11   Reference Material

For reference, the raw text of the AOR file for this example (irs_staring.aor) is available in electronic form at the SSC web site:

http://ssc.spitzer.caltech.edu/documents/cookbook/aors/

and is reproduced in Appendix C here.

Chapter 6

Low Resolution Spectral Mapping at 5–14 microns with the IRS

In this chapter, we illustrate use of the Infrared Spectrograph (IRS) to obtain a low-resolution spectral map of an extended target. We will utilize both orders of the IRS Short-Low (SL) module. This detailed example of an IRS Spectral Mapping Mode observation expands the basic example given in the IRS chapter of the Spitzer Observer's Manual (SOM). The target is the Ring Nebula, a well-known planetary nebula located at RA = 18:53:35.16, DEC = +33:01:43.2 (J2000) (Galactic latitude ∼+55). The goal of this observation is to compare spectra of opposite sides of the Ring Nebula in order to look for differences in spectral features and continuum shapes. Some of the information and steps used in preparing this observation are substantially similar (or identical) to those described in Chapter 5 for an IRS Staring Mode observation. We describe those steps only briefly (or not at all) in this chapter; instead, we concentrate on material specific to the IRS Spectral Mapping Mode.

Note that this example is intended to demonstrate the operational modes of the IRS and how to propose for IRS observations, but not to present a rigorous scientific case for the observations described herein.

6.1 Summary of the Observing Program

In this section, we summarize the basic steps followed to design a Spitzer observing program that uses the SL module to construct a low resolution spectral map of the Ring Nebula, a planetary nebula located at RA = 18:53:35.16, DEC = +33:01:43.2 (J2000). The design process for this example is presented in more detail in the remainder of this chapter.

- **Target Selection and Duplication Check:** Checking the Reserved Observations Catalog using Leopard shows that the target does not already have approved or completed Spitzer observations using IRS. Thus, a new observing proposal using IRS will have no conflicts as specified in the Spitzer Duplicate Observations Rules. See §6.2 for additional details.

- **Slit Orientation and Timing Constraints:** The "Calculate Position Angle" function in Spot's Visibility Windows window is used to determine the subset of the Spitzer visibility windows during which the IRS SL slit position angle is within $\pm 10°$ of perpendicular to the major axis of the Ring Nebula. These timing constraints are then recorded in an AOR Timing window. See §6.4 for additional details.

- **Laying Out the Spectral Map:** Spot's visualization tool is used to overlay slit templates for a given AOR configuration onto an image of the target. This allows determination of the optimum spectral map layout parameters that achieve the observational goals. The layout is controlled by specifying a number of steps of a given size in each direction parallel or perpendicular to the long axis of the slit. For the spectral map of the Ring Nebula, we specify 2 parallel steps of size 51″ and 11 perpendicular steps of size 3″.6 (i.e., the width of the SL slit) for each of the 1st and 2nd order subslits of the SL module. This produces a closely sampled map. See §6.7.3 for additional details.

- **Filling in the IRS Spectral Mapping Mode AOT:** In addition to timing constraints and map layout parameters, the individual ramp durations and numbers of map and/or ramp cycles must be specified. Although only one mapping cycle will be performed, two ramp cycles will be obtained at each pointing position in the map. This will facilitate combining the individual spectra at each map pointing in order to

improve signal-to-noise ratio (S/N) and to provide redundancy against cosmic ray hits. In addition, the "2MASS Selection" function is used to configure a moderate accuracy, Blue IRS peak-up on HD 175291, a K type star with $V = 8.3$ mag. The estimated duration for the spectral mapping observation does not exceed the 3-hour time limit for an IRS AOR. See §6.7, §6.7.2, and §6.7.3 for additional details.

6.2 Target Selection and Duplication Check

As described in more detail in Chapter 5, the first consideration in planning a Spitzer observing proposal is whether the intended target has already been observed, or approved for observations, with Spitzer. In this case, searching the Spitzer **Reserved Observations Catalog** by querying Leopard

http://ssc.spitzer.caltech.edu/documents/leopard/.

reveals that the Ring Nebula (NGC 6720) is selected for observation with IRAC in GTO program PID 68, and with MIPS in PID 77, either of which can be downloaded using Spot (from the File menu, choose "View Program," and enter either PID). However, the Ring Nebula is not currently scheduled for IRS observations. Thus, there are no target duplication conflicts with the proposed example observations of the Ring Nebula.

6.3 Target Entry

The Spitzer observing proposal process is started by launching Spot and entering the target information. This is accomplished exactly as described in Chapter 5, and results in the completed Target window shown in Figure 6.1.

6.4 Slit Orientation and Timing Constraints

Because Spitzer is required to point within $\approx 35°$ of the perpendicular to the Sun at all times, most of the sky can be observed for only part of the calendar year. To check a target's Spitzer visibility, click on the "Visibility/Orientation" button in the Spot Target window (see Figure 6.1) to bring up the Visibility Windows window (see Figure 6.2, left panel).
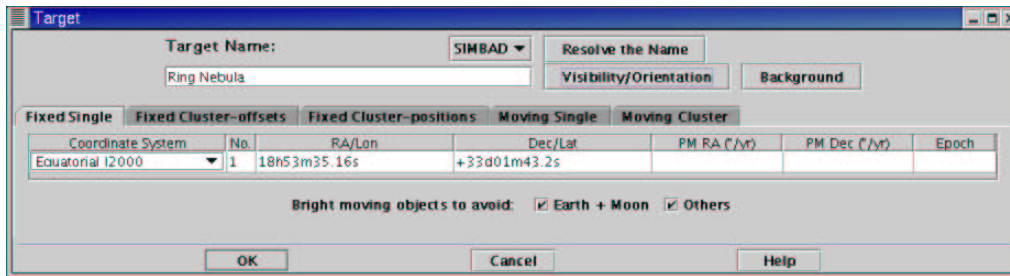
Figure 6.1: Completed Spot Target window.
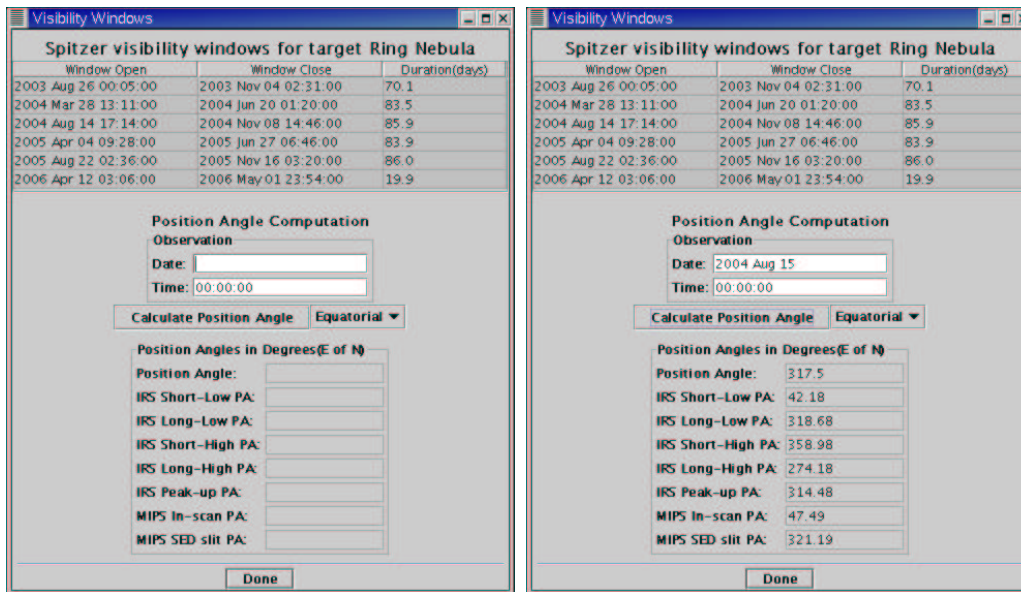
Figure 6.2: Spitzer visibility windows for the Ring Nebula. The left panel shows the default configuration of Spot's Visibility Windows window, while the right panel shows the configuration after requesting the IRS slit orientations for 2004 Aug 15 and selecting "Calculate Position Angle."

Note that the slit orientations are a function of the calendar date and cannot be requested as a special maneuver. Spitzer does not perform roll maneuvers. **The only way to obtain a specific slit position angle is to constrain the proposed observations to be obtained on the date(s) during which the current spacecraft position produces the desired slit orientation.** While it is recognized that some scientific goals can only

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be met by using a specific slit orientation, proposers are encouraged to design their programs to use as few constraints on the timing of observations as possible. All requests for specific slit orientations following from Astronomical Observation Requests (AORs) with timing constraints must be thoroughly and rigorously justified in the text of the accompanying observing proposal. Because of the limits to the range of allowed pointings of Spitzer as a function of time (as discussed in the SOM), in some cases it may *never* be possible to achieve a desired slit orientation for a particular location in the sky.

For illustrative purposes in this example, we will constrain the IRS slit orientation for our observation of the Ring Nebula to be within $\pm 10°$ of perpendicular to the major axis of the nebula (which is indicated in Figure 6.3). This will produce a spectral map that "slices" the nebula perpendicularly along its major axis. The Ring Nebula's major axis is oriented at a position angle (PA) of approximately 66° (measured in the usual fashion, eastward of PA = 0° at due north). Thus, the SL slit must be oriented at

$$PA = 156° \pm 10° = 146° \text{to} 166°$$

during the spectral mapping observation. Because the slit is symmetric, a position angle rotated by 180° will work as well, so

$$PA = 336° \pm 10° = 326° \text{to} 346°.$$

can also be used.

Finding the range of dates when a desired slit orientation on a given target is available requires an iterative examination of the Spitzer visibility windows for that target. There are a total of six visibility windows reported by Spot for the Ring Nebula (see Figure 6.2). Henceforth, we refer to these as "Window 1," "Window 2," and so on, in order of earliest (top) to latest (bottom).

We begin by typing the approximate start date of Window 3 into the "Observation Date" entry box (located mid-way down the Visibility Windows window), and then clicking on "Calculate Position Angle." For example, entering "2004 Aug 15" returns the slit orientations for the various IRS modules on that date (see Figure 6.2, right panel). Notice that the different IRS slits are *not* aligned. If we were using more than one IRS module, and desired to have the same slit orientation in all modules, then the observations for each module would have to be performed on different dates (keeping in
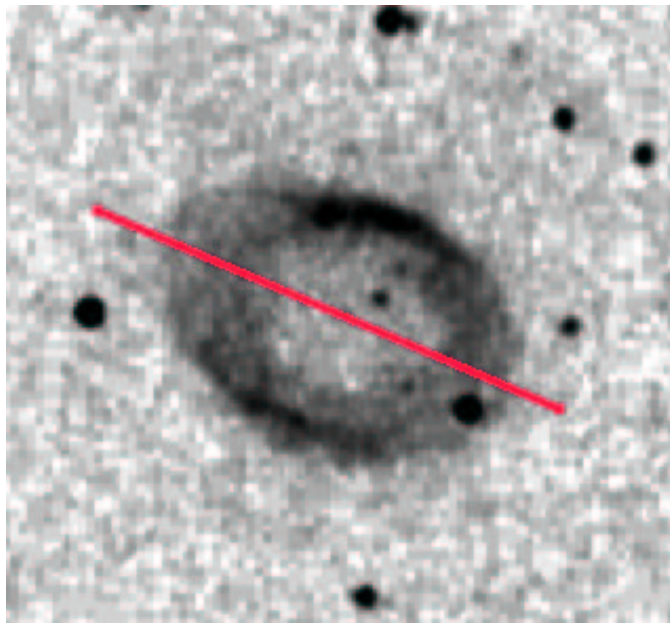
Figure 6.3: 2MASS K_s band image of the Ring Nebula. The major axis of the nebula is indicated with a grey (red) line. The roughly elliptical nebula measures $59''$ across its minor axis and $89''$ across its major axis. North is at the top of the image; east is to the left.

mind that for some targets it may be impossible to ever attain a given slit orientation with multiple, or even *any*, slits).

In this particular case, the orientation of the SL slit on the selected date ($42°$) does not fall into either of the acceptable ranges ($146° − 166°$ or $326° − 346°$). The Spitzer PA changes (decreases) by approximately 0.5–1.0 degrees per (increasing) day depending on the ecliptic latitude of the target. Thus, we estimate that the SL module PA will enter the first of our desired ranges about 56–112 days later than 2004 Aug 15. On 2004 Oct 10 (i.e., 56 days later), Spot reports a PA of $352°$, indicating that this date is still slightly earlier than the first day on which Spitzer enters the desired PA range. Checking the days immediately after 2004 Oct 10 reveals that a PA of $346°$ is first achieved on 2004 Oct 17 – this is the start of the first PA-constrained visibility window. A similar process performed using dates near the end of Window 3 reveals that the PA never quite reaches the other end of the desired range ($326°$) before the end of the visibility window on

Table 6.1: PA-constrained SL Visibility Windows

Visibility Window	Start Date	PA (deg)	End Date	PA (deg)
3	2004 Oct 17	346	2004 Nov 03	333
4	2005 Apr 20	166	2005 May 14	146
5	2005 Oct 25	346	2005 Nov 11	333
6	2006 Apr 27	166	2006 May 01	163

2004 Nov 8. Repeating this process for Windows 4–6 yields the information shown in Table 6.1. Note that Windows 3, 5, and 6 do not reach the minimum acceptable PA ($146°$ or $326°$) before those visibility windows for the Ring Nebula end. In order to be implemented, these timing constraints have to be recorded in Spot as part of an AOR. This cannot be accomplished until after the AOR is completely configured, and the procedure is discussed in §6.8.1.

6.5   Saturation

Approximate point source saturation levels for the IRS are given in the SOM and Chapter 5 of this Cookbook. These values assume that incident light is distributed over 4 pixels (in a 2×2 grid). Saturation levels for extended source surface brightnesses can be estimated by using the formulae given in equation 7.8 and 7.9 of the SOM (section 7.2.1.2.1) where PSSC is in mJy and PSSL is in W/m^2. We divide the point source saturation values by the angular size of a region of sky corresponding to 4 detector pixels in each IRS module (keeping in mind that 1 sr $= 4.2545 \times 10^{10}$ square arcseconds).

1. Short-Low Module ($1''8$ pixel^{-1}): $\sim 1.36 \times 10^4$ MJy sr^{-1} ($\sim 4.4 \times 10^{-5}$ W m^{-2} sr^{-1}) at 10 μm in 6 seconds for the continuum in an extended source.

2. Long-Low Module ($5''1$ pixel^{-1}): $\sim 3.1 \times 10^3$ MJy sr^{-1} ($\sim 4.0 \times 10^{-6}$ W m^{-2} sr^{-1}) at 25 μm in 6 seconds for the continuum in an extended source.

3. Short-High Module (2''3 pixel^{-1}): $\sim 9.8 \times 10^4$ MJy sr^{-1} ($\sim 3.9 \times 10^{-5}$ W m^{-2} sr^{-1} for an unresolved emission line in an extended source) at 12.5 μm in 6 seconds.

4. Long-High Module (4''5 pixel^{-1}): $\sim 2.7 \times 10^4$ MJy sr^{-1} ($\sim 5.5 \times 10^{-6}$ W m^{-2} sr^{-1} for an unresolved emission line in an extended source) at 25 μm in 6 seconds.

The saturation levels in parentheses were calculated per resolution element, assuming resolving powers ($R = \lambda/\Delta\lambda$) of $R = 90$ and $R = 600$ in the low and high resolution modules, respectively. For further information about saturation of the IRS (including more accurate numbers when they become available), see the SOM and

http://ssc.spitzer.caltech.edu/IRS/sat.html

The IRAS fluxes for a given target can be used to estimate whether that target will saturate the IRS. The IRAS fluxes (if available) can be found, for example, by using the SIMBAD or NED (for extragalactic objects) online databases, or by searching in the Infrared Science Archive (IRSA) database, at

http://irsa.ipac.caltech.edu/

Surface brightnesses in the IR can be examined directly from the IRAS images available for download in Spot (via the "ISSA Image" option in the "Images" pull-down menu). The surface brightness at the cursor position in the downloaded ISSA IRAS image is reported in the main Spot window. (Note, however, that the ISSA IRAS images have had the zodiacal light component subtracted, so they should not be used to make estimates of the local IR background surface brightness. Instead, use the "Background" option in the Spot Target window, as discussed in §5.9.2.) The target for this example was observed with IRAS and has an integrated flux density of 1.04 Jy and a peak surface brightness of ≈ 2.4 MJy sr^{-1} ($\approx 6.0 \times 10^{-7}$ W m^{-2} sr^{-1}) at 12 μm. The "Background" option in the Spot Target window gives an estimate of the total local background at 12 μm (including zodiacal light) of $\approx 11 - 19$ MJy sr^{-1}. The total expected surface brightness is well below the saturation limit for the IRS SL module.

6.6   Sensitivity and Exposure Time Estimate

Plots illustrating the point source sensitivity of the IRS are given in the IRS chapter of the SOM and can also be viewed at

http://ssc.spitzer.caltech.edu/IRS/sens.html.

This information can also be obtained using the Spitzer Spectroscopy Performance Estimation Tool (SPEC-PET) available at

http://ssc.spitzer.caltech.edu/tools/specpet/.

Note, however, that the SPEC-PET only supplies the same information available from the IRS sensitivity plots in the SOM.

These point source sensitivity values can be converted to extended source sensitivities using the provisional relations (which yield results with uncertainty of $\approx 20\%$) that are given in the IRS chapter of the SOM. The sensitivity plots show that a single, 60-second exposure will yield signal-to-noise ratio of unity (S/N ≈ 1) in the SL module for a point source with a flux density of ≈ 0.2 mJy at 10 μm; this converts to an extended source with a surface brightness of ≈ 0.49 MJy sr^{-1} at 10 μm. Compared to the 12 μm surface brightness of the Ring Nebula, we can estimate that an exposure of 60 seconds or 240 seconds would achieve a S/N value of approximately 5 or 10, respectively. (This S/N calculation correctly assumes that the target is in the faint source limit for 60- and 240-second exposures in the SL module, which is true for flux densities $\lesssim 10$ mJy or extended source surface brightnesses $\lesssim 25$ MJy sr^{-1}. See the IRS Staring Mode chapter of this Cookbook and Section 7.2.1 of the SOM v6g.0 for more details.)

Unlike the IRS Staring Mode, in Spectral Mapping Mode only *one* spectrum (at one slit position) is obtained per exposure. However, the entire mapping cycle can be repeated (up to the 3-hour time limit on individual IRS AORs). For example, repeating the mapping over 2 cycles of 240-second exposures each would increase the S/N of the combined spectrum at each map position to $\gtrsim 14$ (as well as providing redundancy against cosmic ray hits). In general, it is strongly recommended to have at least 2 cycles per position to provide greater redundancy against varying pixels and cosmic rays. Note that the sensitivity values quoted here and in the SOM were calculated assuming the lowest possible IR background level (i.e., at the ecliptic poles).

If we wanted to be very conservative, we might consider using medium backgrounds simply because of the ecliptic latitude. However, in this case, the difference between the medium and low background levels is negligible. In general, observations with the IRS, especially those obtained through the long, low resolution slits, will typically have to contend with higher background levels, resulting in reduction of the obtained S/N.

6.7 Filling Out the IRS Spectral Mapping Mode AOT

A new IRS Spectral Mapping Mode AOT entry window is accessed in Spot in much the same way as the IRS Staring Mode AOT window. Either select the "IRS Spectral Mapping" option from the "Observation" pull-down menu, or click on the spectral-mapping icon (the blue wiggle with a "chain" under it), eighth from the right on the taskbar. The IRS Spectral Mapping Mode AOT entry window will appear as illustrated in Figure 6.4. The IRS Spectral Mapping AOT is very similar in appearance to the IRS Staring AOT; only the "Instrument Settings" section is substantially different. We now consider each of the AOT sections (remember to rename the AOR as described in the IRS Staring Mode chapter of this Cookbook, and to fill in any timing constraints as described in §6.4 of this chapter).

6.7.1 Droop Correction Considerations

Because we are using the SL module, it is important to consider the possibility of serendipitous placement of bright targets into the IRS peak-up array field-of-view during the spectrum exposures. As described in §5.9.3 in the IRS Staring Mode chapter of this Cookbook, this can result in underestimating the droop correction for the SL array, which, in turn, causes the flux of the SL spectrum to be overestimated. Refer to §5.9.3 for details about how to mitigate this effect.

6.7.2 Peak-up Settings

In principle, selection of a peak-up target for an extended source can be accomplished in basically the same manner as described for a point source
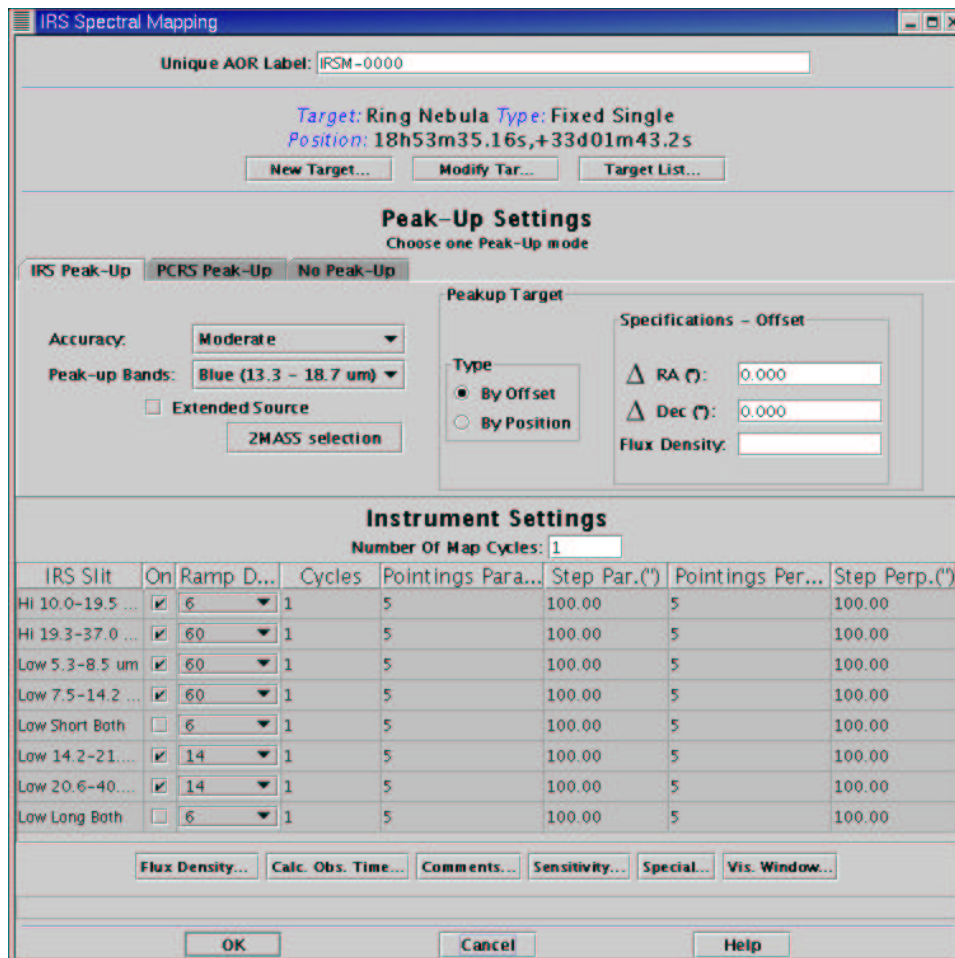
Figure 6.4: Default configuration of the IRS Spectral Mapping Mode AOT entry dialog window.

in Chapter 5 of this Cookbook – see that chapter for details of the peak-up configuration process. If a large region is being mapped, it may not be necessary to perform a peak-up at all (if the nominal pointing accuracy of Spitzer, $1\rlap{.}''0$, is sufficient to place the selected slit on the target with adequate precision). However, it should be kept in mind that each movement of the telescope introduces a random, cumulative pointing error of order $0\rlap{.}''2$. Thus, maps composed of large numbers of individual pointings may accumulate large positional errors by the end of a mapping cycle, and might benefit from

a peak-up at the start of the cycle. In any case, peak-up is performed only once per mapping cycle, at the start of each cycle.

For this example, a Moderate accuracy IRS peak-up is selected, since a relatively large number of individual pointings will be used in the layout of the spectral map (see §6.7.3). Peaking-up on an extended source should be avoided unless there is no other option, so we will not try to use the Ring Nebula itself as a peak-up target. (In addition, the flux distribution of the Ring Nebula, which lacks a central, brightest peak, would exclude it as even a suitable extended peak-up target.) Instead, we will use one of the "GOOD for Blue" stars returned by the "2MASS Selection" function. This star has a flux density of 120 mJy in the Blue peak-up passband.

A SIMBAD search on the coordinates of the 2MASS peak-up star reveals that it is HD 175291, a K type star with $V = 8.3$ mag. Searching the Tycho-2 catalog, as described in §5.9.2 in the IRS Staring Mode chapter of this Cookbook[1], yields accurate epoch J2000.0 coordinates of RA = 18:53:15.84 and DEC = +33:28:28.1, and proper motions of $\mu_\alpha = -15.8$ mas yr^{-1} and $\mu_\delta = +13.8$ mas yr^{-1}. This information can be used to update the default values in the "Peakup Target" specification window in the AOT entry window (after converting from milliarcseconds yr^{-1} to the units of arcseconds yr^{-1} that are used by Spot). This star has a magnitude in the range $7.0 < V < 10.0$, so, in principle, it could also be used as a PCRS peak-up target.

Examination of the DSS, 2MASS, and IRAS images of HD 175291 shows that no brighter object is located within $1'$. Spot's "Background" option (in the Target window) yields a local 100 μm background surface brightness of $7.1 - 7.8$ MJy sr^{-1} (including zodiacal light). The plot of the 100 μm IR cirrus brightness vs. minimum peak-up source flux density in the IRS chapter of the SOM confirms that an object with a flux density of at least ≈ 5 mJy in the Blue passband is an acceptable IRS peak-up target against this level of IR background.

6.7.3 Instrument Settings

Slit Selection

There are four IRS slits, or six "slits" if we count the two spectral orders available in each of the two low resolution modules. In addition, the IRS

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[1]Please see that section if you have not already, because it includes important information about a factor of $\cos\delta$!

Spectral Mapping Mode AOT offers two additional slit choices, "Low Short Both" and "Low Long Both," which select both orders of the indicated module (however, see below). Because of their two-order configuration, the use of the low resolution slits deserves further description.

If only one order of one or both low resolution slit(s) is selected, then the IRS will also simultaneously obtain a spectrum in the unselected order of the slit(s); however, the latter spectrum will not be centered on the target. If both orders of one or both low resolution slit(s) are selected, then spectra will be obtained in both orders for all pointings, and each pointing will be repeated with each order subslit centered on the target. Finally, if either of the "Both" options is selected, then spectra from both orders of the selected slit(s) will be obtained with the entire slit centered on the target position (i.e., neither order subslit will be centered exactly on the target coordinates). The "Both" options should be used with caution since they can result in neither order obtaining a spectrum of the target. The various slit configurations are illustrated in Figure 6.5.

Laying Out the Spectral Map: Pointings and Step Sizes

We must now consider how to lay out the spectral map pointings in order to obtain the desired coverage of the Ring Nebula; namely, we wish to "slice" the nebula perpendicularly along its major axis, and obtain both 1st and 2nd order SL spectra of opposite sides of the "ring." The map layout is controlled by the pointing number ("Pointing") and step size ("Step") parameters. One pair of these parameters specifies pointings parallel to the long axis of the slit and a second pair specifies pointings perpendicular to the long axis of the slit. In both cases, the step size is the distance between successive slit positions. The following steps outline a method that can be followed in preparing a spectral map layout.

Step #1: Download a 2MASS K_s band or DSS image of the target using the "Images" pull-down menu. For the Ring Nebula example, we download a $500'' \times 500''$ 2MASS K_s image. Center the target in the image by clicking the light blue "cross-hairs" icon on the left side of the main Spot window. Adjust the size (by "dragging" a corner of the window, or by clicking on the expansion icon in the upper right corner of the image window), magnification (using the plus and minus "magnifying glass" buttons on the left frame of the main Spot window), and color scale of the image as desired; the color
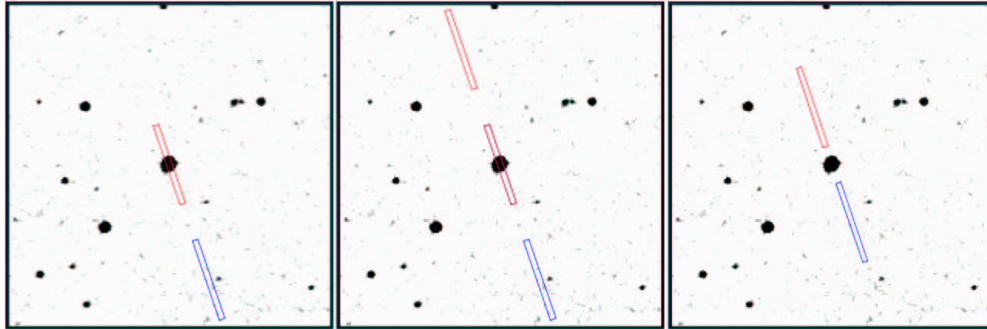
Figure 6.5: Comparison of order selection using the SL module. The left panel shows the result of selecting only the 1st order – one spectrum spanning both orders is obtained, but only the selected order subslit is centered on the target (the bright star at the center of the image). The middle panel shows the result of selecting both 1st and 2nd orders – two spectra spanning both order subslits are obtained, with the target centered in the 1st order subslit for one spectrum and in the 2nd order subslit for the other spectrum. The right panel shows the result of selecting the "Low Short Both" option – one spectrum spanning both orders is obtained, with the full slit centered on the target (in this case, the target ends up in neither order subslit). In all panels, the 1st order subslit is at the top (red) and the 2nd order subslit is at the bottom (blue). In the middle panel, the "slit" in the middle (purple) is the overlapping 1st and 2nd order subslits from successive exposures.

scale controls are accessed using the small "rainbow checkerboard" button on the right border of the image window. Figure 6.6 shows the image window layout with the color table of the 2MASS image set to "Reverse Grey scale."

Step#2: If the current AOT entry window is not open, then reopen it for editing using the "Modify Current AOR" option under the "Edit" pulldown menu, or by clicking on the modify-AOR icon (the sheet of paper labeled "AOR" with an arrow), fifth from the left on the taskbar. At this point, only the AOR name and the peak-up settings have been modified – the "Instrument Settings" should still have their default values, as shown in Figure 6.4.

Step#3: Since we want to obtain spectra in both 1st and 2nd orders of the SL module, we first examine the possibility of using the "Low Short

125
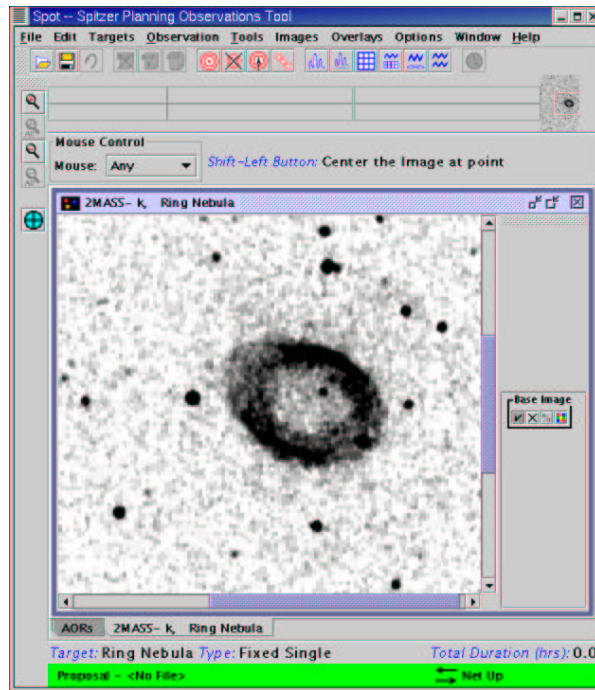
Figure 6.6: Main Spot window with an image display window showing the 2MASS K_s band image of the Ring Nebula.

Both" option. Click in the "On" boxes next to the "IRS Slit" column in the "Instrument Settings" so that only "Low Short Both" is turned on. Set both of the "Pointings" columns to values of 1. Finally, click on "OK" in the AOT entry window to store these changes. This will also dismiss the window, but it can be recalled at any time using the instructions in Step #2.

Step#4: In the main Spot window, select the "Current AOR on current image" option under the "Overlays" pull-down menu. Spot will request a date for the overlay; use "2004 Oct 30," which is one of the dates when the SL module PA is exactly aligned perpendicular to the major axis of the Ring Nebula. Spot will create a projection of the slit positions on the downloaded 2MASS image of the Ring Nebula. In this case, the slit is centered around the target coordinates at the center of the Ring Nebula (see Figure 6.7, left panel). Use of this option will probably not be optimum, since, by coincidence, the size of the Ring Nebula is comparable to the separation of the two orders of the SL slit. Thus, opposite sides of the "ring" cannot be
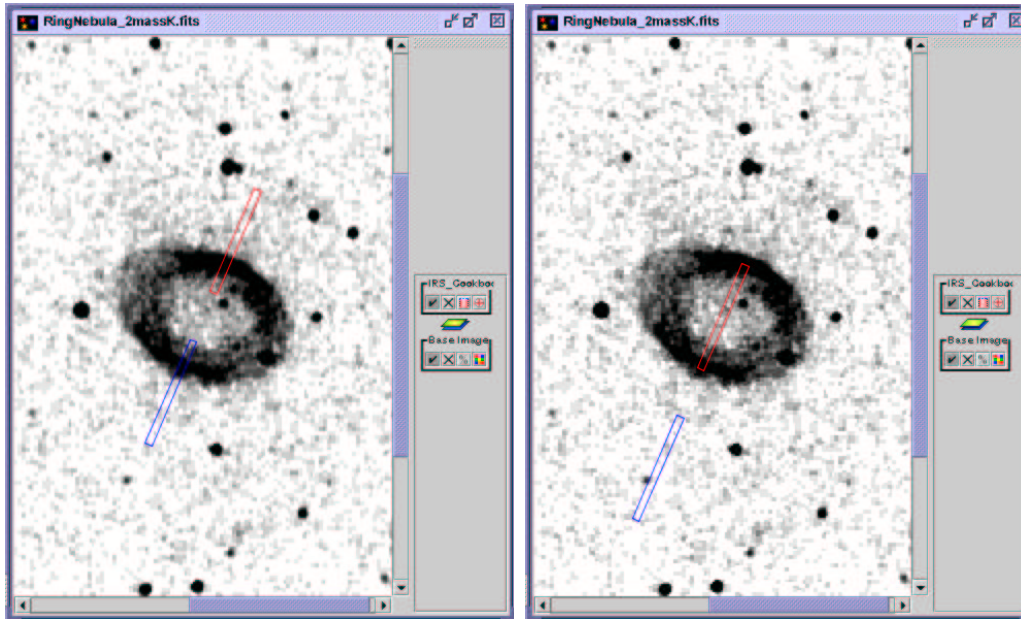
Figure 6.7: Spot's image display window, showing the 2MASS K_s band image of the Ring Nebula with an overlay of (left) the "Low Short Both" slit option and (right) the SL 1st order $(7.4 - 14.5 \ \mu\text{m})$ option.

centered in the two subslits at the same time. If we were mapping a larger region, then using the "Low Short Both" option might be a viable alternative.

> **NOTE:** For the figures in this chapter of the Cookbook, the following slit overlay color scheme has been used: the red (upper) subslit is SL 1st order $(7.4-14.5 \ \mu\text{m})$, and the blue (lower) subslit is SL 2nd order $(5.2-8.7 \ \mu\text{m})$. The default slit colors in the Spot overlays may differ from those used here.

Step#5: Recall the AOT entry window using the instructions in Step #2. Deselect "Low Short Both" and turn on the 1st order SL slit ("Low 7.4 − 14.5 μm") instead. Again, set both corresponding "Pointing" columns to values of 1. Now overlay the slit visualization on the 2MASS image using the instructions in Step #4. This is also not optimum since the 1st order slit is now centered on the empty middle of the Ring Nebula instead of the actual "ring" as desired (see Figure 6.7, right panel).

127
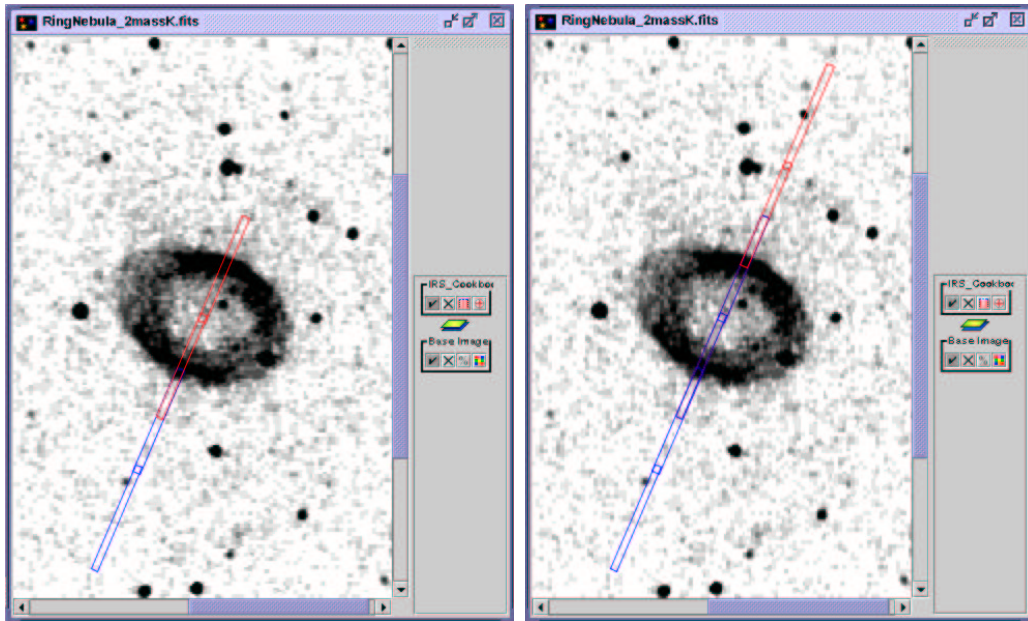
Figure 6.8: Spot's image display window, showing the 2MASS K_{s} band image of the Ring Nebula with an overlay of (left) 2 parallel pointings of the SL 1st order ($7.4 - 14.5~\mu$m) subslit, offset by $51''$, and (right) 2 parallel pointings of the SL 1st and 2nd order subslits, offset by $51''$.

Step#6: We now take advantage of a property of IRS Spectral Mapping layout that is described in the IRS chapter of the SOM. When an odd number of steps (in either or both of the parallel or perpendicular directions) is used, then the middle pointing will always be centered on the target coordinates. However, when an even number of steps is used, then *no* pointing will be exactly centered on the target coordinates. The separation of the midpoints of the Ring Nebula annulus along its minor axis is approximately $51''$, so we reopen the AOT entry window (Step #2) and set the number of parallel pointings to 2, with a step size of $51''$. Re-visualizing the AOR onto the 2MASS image (Step #4) now shows that opposite sides of the nebula annulus are nicely centered in two pointings of the 1st order slit (see Figure 6.8, left panel). The 2nd order slits are also shown, but they are off the target at both pointings.

Step#7: We now repeat the procedure in Step #6 with both the 1st and 2nd order subslits of the SL module turned on. This will produce four indi-

vidual pointings, with two having opposite sides of the Ring Nebula annulus centered in the 1st order subslit, and the other two having opposite sides of the annulus centered in the 2nd order subslit.

The AOR visualization is now somewhat confusing, because there are several overlapping sequential slit positions displayed simultaneously (see Figure 6.8, right panel). The "Pointings Table" feature can be used to clarify this situation. Click on the small "table" icon, third from the left in the top row of icons on the right of the image window. This will open the Pointings Table window (see Figure 6.9), which contains one row for each slit position currently scheduled in the AOR (notice that it also contains one row for each scheduled peak-up exposure, barely at the edge of the 500×500 arcsecond image).

The corresponding overlays in the image window can be turned on or off by selecting any of these rows (using the check-mark boxes in the "On" column). The two "Animation" buttons are also useful – these produce cartoon movies showing the sequence in which the pointings will be obtained by Spitzer. Experiment with the Pointings Table, and convince yourself that the current configuration of the Instrument Settings does indeed produce the desired pointings as described at the beginning of this step.

Step#8: We are now ready to configure the second axis of the map, the perpendicular "slices" along the major axis of the Ring Nebula. First, reopen the AOT entry window. We would like the map grid to be closely spaced, so set the size of the perpendicular steps for both the 1st and 2nd order subslits to the width of the SL slit, $3''\!.6$. A more sparsely sampled map using fewer pointings could be obtained by setting the size of the perpendicular steps to be larger than the SL slit width. A few iterations of setting the number of perpendicular pointings and visualizing the slit overlay on the 2MASS image shows that 11 perpendicular pointings completely sample the opposite sides of the Ring Nebula "parallel" to the nebula's major axis.

The complete spectral map coverage is shown in Figure 6.10. Notice that many spectra of essentially empty regions around the nebula are obtained. These are a normal result of the fact that 1st and 2nd order spectra of the same slit are always obtained, even if only one of the orders is selected. When mapping a large region, this can often be advantageous; however, the proposer is not penalized for any "extraneous" spectra resulting from a carefully designed spectral map. (It may prove advantageous for the Ring Nebula also, since the additional spectral map coverage could reveal as yet
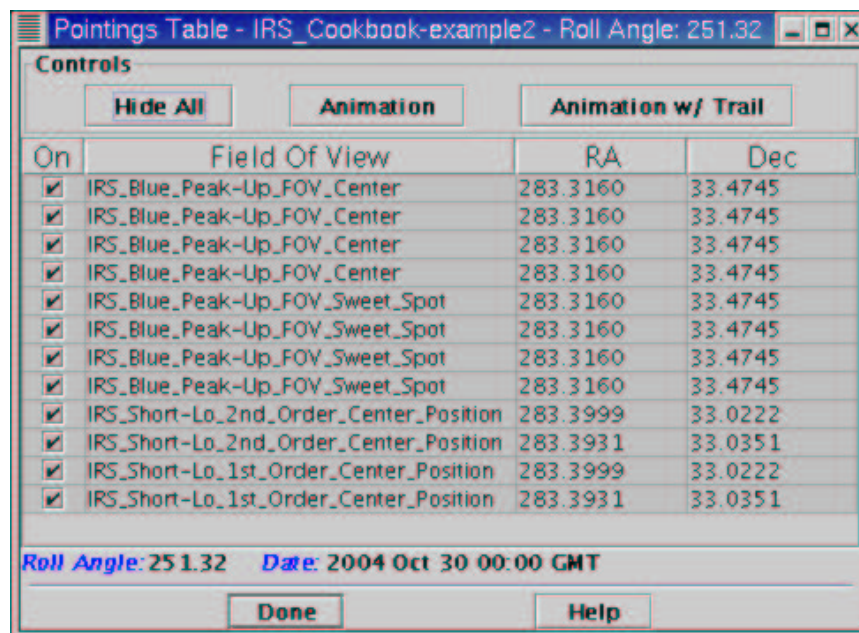
Figure 6.9: Pointings Table window for the observation shown in Figure 6.8, right panel.

unknown, extended IR structure of the nebula, or provide spectra for sky subtraction.)

The right panel of Figure 6.10 shows one pointing from each of the parallel steps (at a different perpendicular step position), in order to clearly illustrate the slit position at each parallel step. The spectra will be obtained starting with the first 2nd order subslit exposure in one corner, then proceeding to the other for the 11 perpendicular steps. Next, the offset to the second 2nd order subslit parallel step is made, and the perpendicular pointings proceed back towards where we started. This process is then repeated for the 1st order subslit pointings. The order in which spectral map pointings are carried out is also described in the IRS chapter of the SOM, and can be demonstrated in Spot using the "Animation" buttons in the Pointings Table window.

Ramp Cycles vs. Map Cycles

For this example, we select a basic ramp duration of 60 seconds. However, in order to increase the S/N of the resultant spectra and provide redundancy
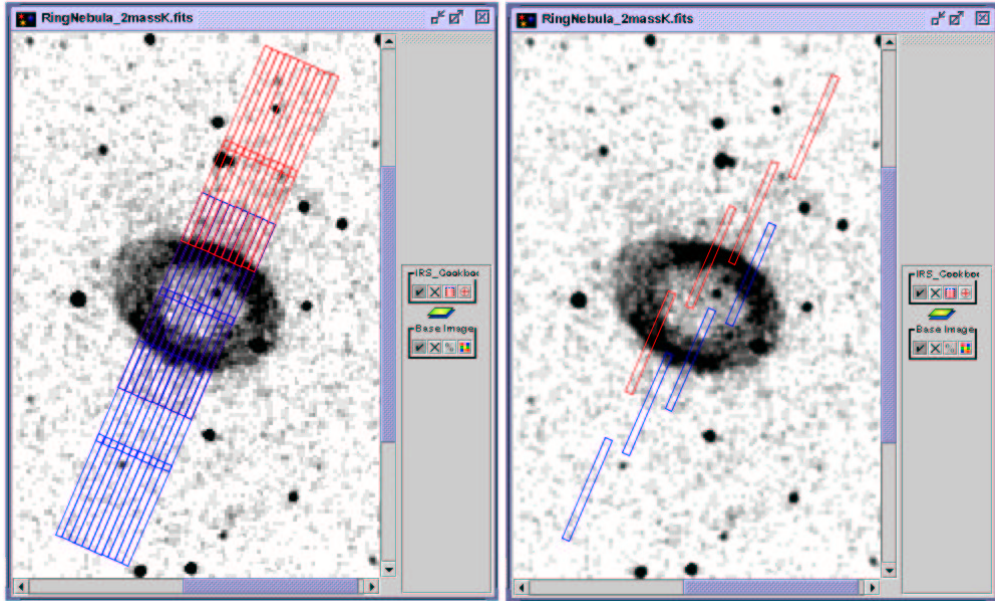
Figure 6.10: Complete spectral map coverage of the Ring Nebula. The left panel shows the full extent of the spectral map coverage. The right panel shows one pointing from each of the parallel steps (at different perpendicular steps) to illustrate the positions of individual pointings in the map.

against cosmic ray hits, we will repeat each ramp two times (to obtain a total exposure time of 120 seconds at each pointing in the spectral map). There are two means of repeating ramps. The first is to set a number of "Cycles" for each ramp. This will repeat the selected ramp in succession, without moving the telescope. The second is to set a number of "Map Cycles." This will repeat the ramp at each pointing only after finishing all of the pointings in the preceding cycle through the spectral map.

Multiple ramp and map cycles can be used in combination (as long as the total AOR time does not exceed the 3-hour limit for IRS AORs). Because the absolute positions of pointings will not exactly repeat from one map cycle to another (due to the small, cumulative, and random errors associated with all movements of Spitzer), the best choice in this example is to set the number of ramp cycles to 2, and the number of map cycles to 1. This will produce the following result: at each map pointing, the IRS makes 2 successive exposures without moving the telescope, then moves to the next

map pointing and makes 2 successive exposures, and so on, until the complete map has been observed once. This ensures that the two spectra obtained at each pointing sample exactly the same spatial region of the nebula. If we were interested in exploring time variability in the spectra (rather than achieving the highest S/N spectrum at each map pointing), then obtaining one ramp at each pointing over a number of map cycles might have been a better strategy.

6.8   Completing the Program

The completed IRS Spectral Mapping Mode AOT entry window is shown in Figure 6.11. The final steps necessary to finish the AOR and submit the associated proposal can now be performed.
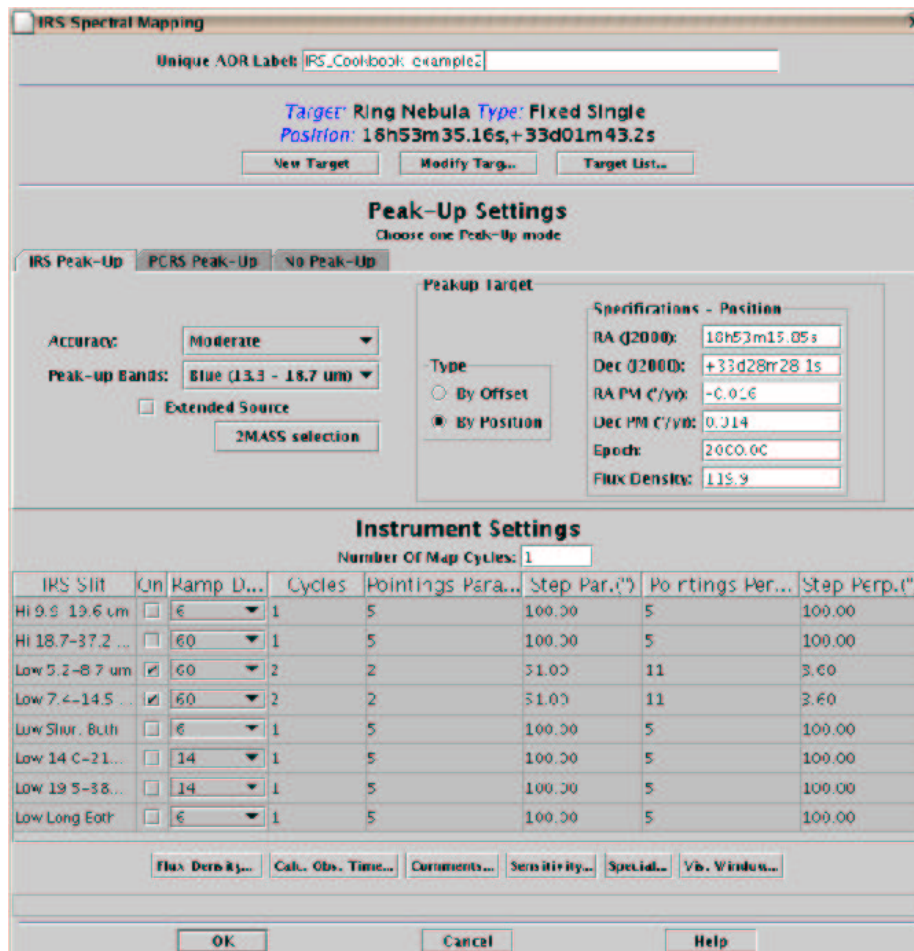
Figure 6.11: Completed IRS Spectral Mapping AOT.

6.8.1 Timing Constraints

The timing constraints determined in §6.4 must now be recorded as part of the IRS AOR. This step cannot be accomplished until after an IRS AOR has been configured and stored in Spot's memory (see §6.7). The process is relatively simple. After completing the IRS AOR, make sure it is highlighted in the AOR Table in the main Spot window, and then select the "Timing Constraints" option under the "Tools" pull-down menu. This will open the AOR Timing window, which displays the full range of available visibility windows for the target, and includes a table where the start and stop dates for the PA-constrained visibility windows can be entered. The completed timing constraint table is shown in Figure 6.12. Note that the exact start and stop dates for the visibility windows are slightly different than shown in Figure 6.2. This is because Spot refines the visibility windows based on the AOR configuration, to ensure that the desired observations can be completed. Because Spot's knowledge of Spitzer's orbit can change slightly in time, these visibility windows may change slightly in the future. Timing constraints that are made as loose as possible have the best chance of being successfully integrated into Spitzer's observing schedule. If we specify slightly larger timing windows than the visibility windows as now calculated, Spot will let us know that we've done that, but will allow us to do so. The observations, obviously, will not be scheduled when the object is not visible to Spitzer.

6.8.2 Duration Calculation

Next, click on the "Calc. Obs. Time" button in the AOT window to estimate the total duration of the AOR, which includes ramp durations and overhead times associated with array conditioning, telescope slew and settle, telescope movements within the AOR, and peak-up. Keep in mind that there is a 6-hour (21600-second) time limit for an individual IRS AOR. If the total duration exceeds the 6-hour limit, we would have to reduce the number of individual pointings, individual ramp durations, and/or number of cycles at each pointing. Alternatively, the observation could be split into two or more AORs.

Recall from the discussion in Chapter 5 of this Cookbook that the estimate of the total AOR duration can also be accomplished after the AOT entry window has been closed, by selecting "Recompute All Estimates" un-
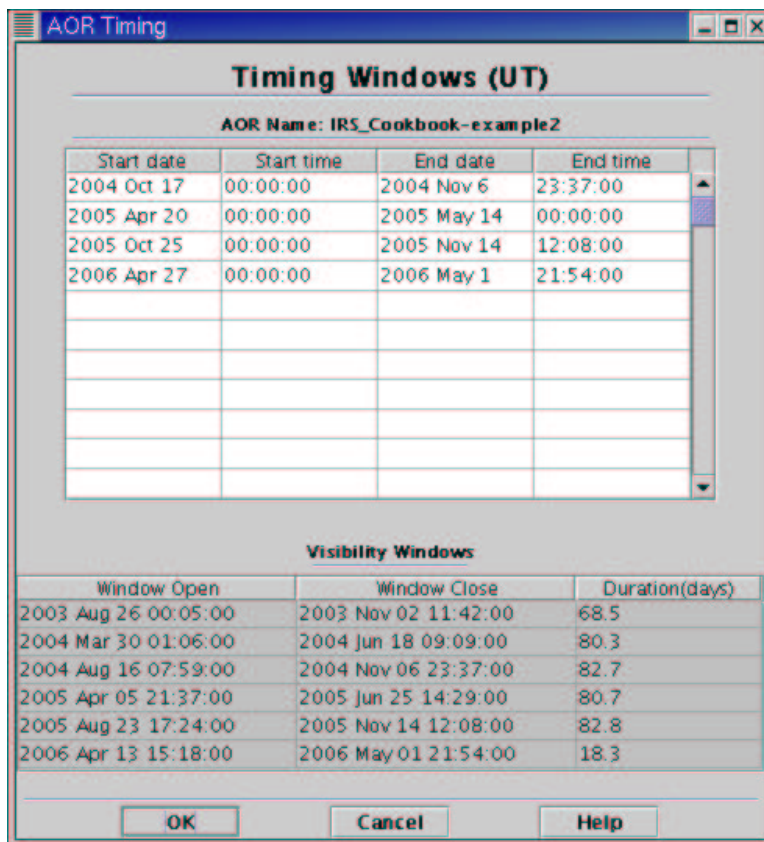
Figure 6.12: AOR Timing window showing the completed timing constraints table.

der the "Tools" pull-down menu. Spot will ask "Recompute what?" – select "All AORs." Finally, click "OK" in the IRS Spectral Mapping AOT window to store the completed AOT in Spot's memory, then refer to the main Spot window. The observation will now be listed in the "Astronomical Observation Requests (AORs)" table (see Figure 6.13). Notice that the "T" box is checked, indicating that this AOR has timing constraints.

Before continuing on to the proposal submission stage, it is a good idea to save the target list and AOR to a local computer disk. This can be done by selecting "Save AOR(s) and Target(s)" under the "File" pull-down menu, or by clicking on the save icon (the floppy disk), second from the left on the taskbar. Target lists and AORs must be saved separately – be sure to select the correct save format in the Save AOR(s) and Target(s) window.
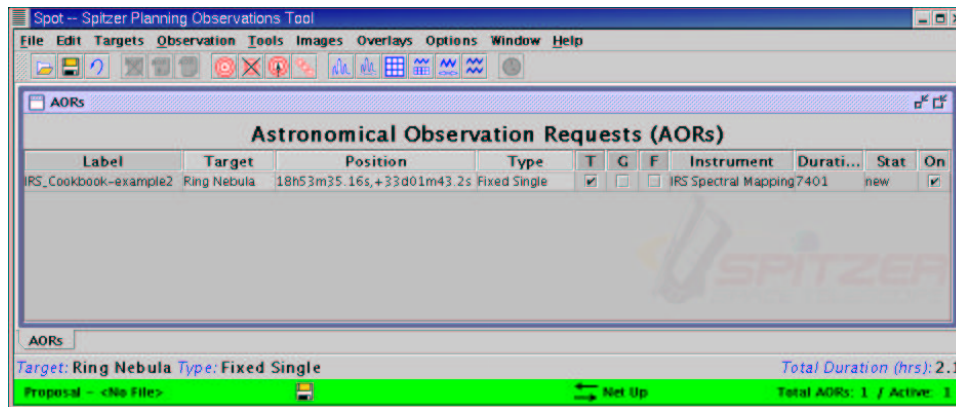
Figure 6.13: Main Spot window showing the completed AOR (with computed duration).

6.8.3 Proposal Submission

To complete the proposal submission process, follow the instructions given in Chapter 14: use the "Proposal Tool" option in the "Tools" menu to create a cover sheet for the proposal with contact information and an abstract, and attach the saved AOR(s) and a portable document format (pdf) file of the scientific justification. **The Spitzer proposal submission process occurs entirely through the Spot interface.**

6.9 Reference Material

For reference, the raw text of the AOR file for this example (irs_spectral_mapping.aor) is available in electronic form at the SSC web site:

http://ssc.spitzer.caltech.edu/documents/cookbook/aors/

and is reproduced in Appendix D here.

Chapter 7

16 Micron Imaging of Five Clusters of Galaxies using IRS

In chapters §3 and §4, AORs were developed to obtain deep imaging of five galaxy clusters. In this chapter, we describe how to construct a complementary survey using the IRS Peak-Up Imaging (PUI) mode.

PUI allows the observer to obtain photometric-quality images in two filters, one centered at 16 microns, and the other centered at 22 microns. Both Red (22 micron) and Blue (16 micron) Peak-Up images are obtained simultaneously, but at slightly different fields of view.

The Peak-Up capability is primarily intended for target acquisition. This means that the imaging field of view is small and the detector is less sensitive to the faintest sources. Nonetheless, the PUI mode at 16 microns fills in a wavelength gap between the longest wavelength of IRAC (8 microns) and the shortest wavelength of MIPS (24 microns).

PUI mode observations are taken in a ~50 arcsecond by 80 arcsecond field of view, with a pixel scale of 1.8 arcseconds per pixel. Images are diffraction-limited, implying a FWHM of 2 pixels at 16 microns. In the example we develop in this section, the Blue image is of primary scientific interest. The Red image overlaps with MIPS observations already planned above in Chapter 4.

7.1 Overview of the Program

- **Target Selection**: This program is designed to be complementary to

the IRAC and MIPS programs developed in previous chapters. We use some of the same targets.

- **Background Estimate**: We use Spot to obtain background estimates. In general, we consider backgrounds to be low, medium or high (see discussion in earlier chapters).

- **Exposure Time Estimate**: Based on the background regime in question, we can determine PUI sensitivity (see Table 7.6 in the SOM). All PUI observations are background limited, so we can simply infer the required exposure time from the measured sensitivity. The small field of view of the PUI mode leads to a large overhead in surveying any extended area. As a result, it is important to keep the size of the target in mind when considering signal-to-noise vs. exposure time trade-offs.

- **Filling in the AOT using Spot**: The PUI mode allows both Dithering and Mapping, and we employ both in order to obtain deep imaging of the target field. In most cases, we use the longest exposure time (30 seconds) because the science targets are intrinsically faint and saturation is not a concern. However, in the highest background region, we will consider using the 14 second exposure time instead.

- **Duration**: The total duration for all PUI imaging AORs considered here is ∼6 hours.

- **Constraints**: The IRAC and MIPS observations were constrained to ensure similar rotations. We must decide whether such a constraint is necessary in this case as well.

7.2   Target Selection

Our goal is to observe many of the same targets chosen in chapters §3 and §4 for the IRAC and MIPS programs. First, we must determine if the targets are already planned for Spitzer imaging at the PUI wavelengths. We consult the online Reserved Object Catalog (ROC) using the Leopard Search Tool:

http://ssc.spitzer.caltech.edu/documents/leopard/.

Please be aware:

Potential Duplications can occur between PUI 22 μm **Imaging and MIPS** 24 μm **Imaging.** So when preparing a proposal for PUI observations, it is important to check both for PUI *and* MIPS in the ROC. If a duplication exists, your proposal may be rejected outright based on those grounds. Alternatively the entire dataset (including the non-duplicated 16 μm portion of the data) may be embargoed until the end of the proprietary period for the reserved observation. *Proposers should note in the text of their proposal any potential duplication with MIPS and justify the need for the new observation.* Note that in some cases the 22 μm PUI data may be so much shallower than MIPS observations that they will not technically be a duplication. Observations are duplications if the integration time per pixel for each observation agrees to within a factor of nine (corresponding to a factor of ∼three in sensitivity).

7.3   Background Estimates

We obtain an estimate of the (primarily zodiacal light) background using Spot. On the Target Entry dialog, we choose the "Background" button, which brings up the estimation window. We enter 16 microns as the desired wavelength, and choose "Calculate Range When Visible." PUI observations will saturate in a 30 second exposure when observing a surface brightness flux of ∼ 90 MJy/sr (see the SOM for more discussion).

Source	16μm MJy/sr	Bkgd class
Abell 2218	18	low
Abell 1689	60	high
AC 114	38	med
Abell 665	26	low
cl0024+16	48	med

7.4   Exposure Time and Survey Design

We consult either the online SENS-PET or Table 7.7 in the SOM to calculate the required exposure time. The MIPS observations in the program reach a

$1 - \sigma$ sensitivity of less than 20 μJy. To reach that same level at 16 microns in low background, we find that we need at least 7×30 second exposures. In medium background it would take ~ 10 exposures to reach the same sensitivity level. In high background, we should consider using a shorter exposure time to keep the detector away from the nonlinear regime; a 30 second exposure on Abell 1689 would lead to 2/3 full well. Using the 14 second exposure time, we require 36 repetitions. Finally, in order to cover a single IRAC/MIPS $5' \times 5'$ field of view will take ~ 24 PUI positions.

Thus, we can see that it may be quite expensive in observing time to fully cover the IRAC and MIPS survey fields. In low background, we would require 24 map positions of 7×30 second exposures, or a total AOR duration of 2.5 hours. **There is a six hour limit on the duration of individual IRS AORs** which allows the maps to be performed as a single AOR.

IRAC and MIPS together require 22 hours for the survey of the five clusters. They obtain 7 bands between them. So we must ask how much time we want to devote to adding the 16 μm band. We can obtain complete PUI coverage of the two low-background clusters in 5 hours, and then add more specific imaging of the other clusters for a few hours more.

7.5 Filling in the AOT using Spot

We begin with the two target fields with low background. We go through the AOT for Abell 2218 in detail, and then we can simply copy it for Abell 665. Then we will use *fixed cluster targets* to specify a few individual pointings in each of the medium background galaxy clusters; again, we will go through one in detail. The other would be very similar. Finally, we will do a single, deep pointing in the high background cluster. Note that in each case we only select 16 μm imaging, but 22 μm data will also be obtained at a spatially offset field. These extra data are not useful in this case, as there will be deeper MIPS coverage, but they might be important to other programs (or cause duplication problems for our program, see above).

The AOR file is listed in the Appendix here and is also available on the website, ready to be loaded into Spot:

<div align="center">

http://ssc.spitzer.caltech.edu/documents/cookbook/

</div>

7.5.1 Mapping Abell 2218

In this region of low background, we use the longest exposure time (30 seconds). We check only the box for 16 μm imaging. We observe only one cycle per position, and dither for artifact rejection; see Figure 7.1.

We want to map the $5' \times 5'$ region to match the IRAC/MIPS coverage. Using the PUI mapping function requires 6×4 positions. Because the array is not square (54×80 arcseconds), we are not using the same number of rows as columns. We need very little overlap between map positions, so we use step sizes of 50 and 75 arcseconds. At each position, we want to dither. We choose the overlaps such that we maintain contiguous coverage regardless of position angle and therefore observing date. In the previous section, we determined that it would take 7 exposures per position to reach the required depth. We could settle for five position and use the fixed pattern dithers, or we can use the cycling pattern and get the 7 positions we really want. We choose the latter.

Figure 7.1 shows the completed AOT page and Figure 7.2 shows the overlay map on a DSS image. We can use a similar map for the other low background target. Together they require ~5 hours to complete.
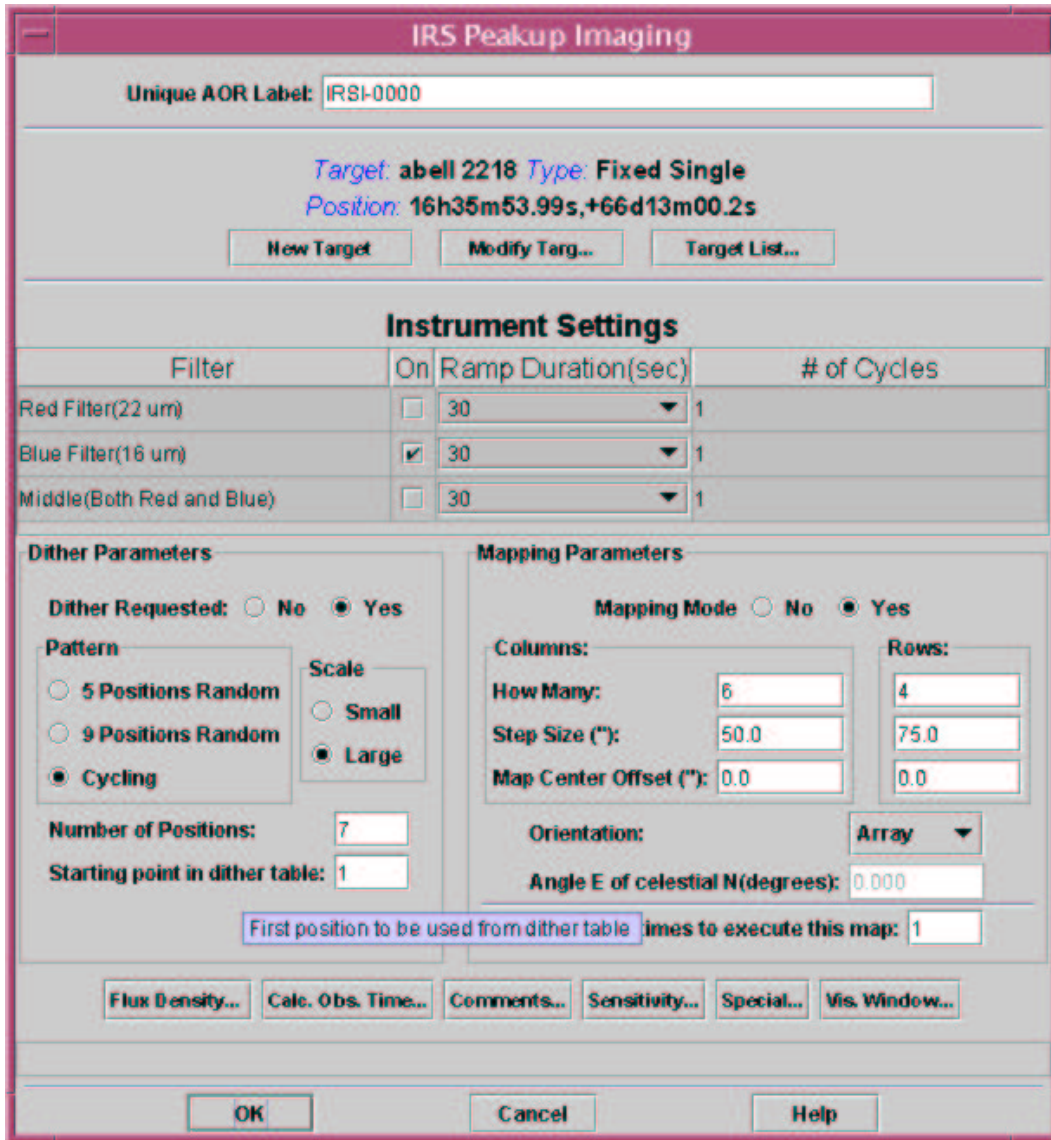
Figure 7.1: The completed PUI AOT for mapping Abell 2218.
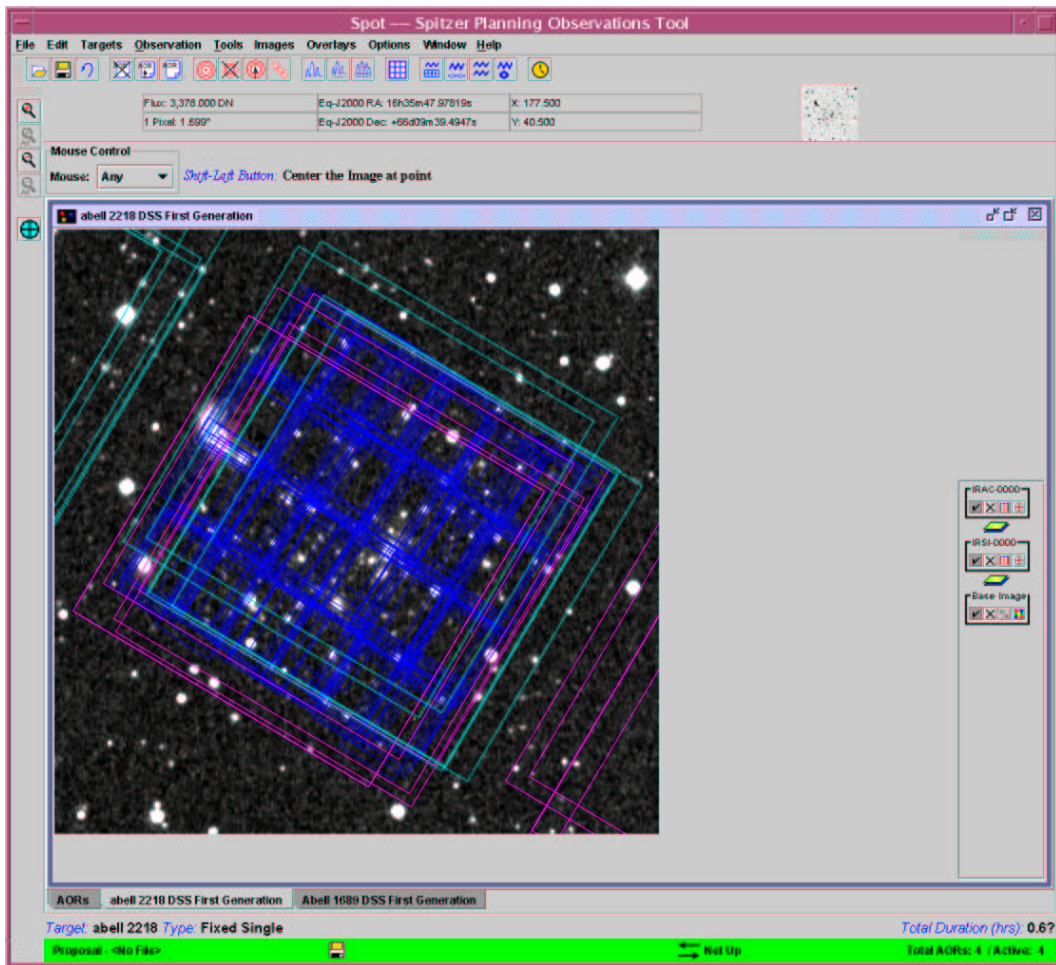
Figure 7.2: The overlay of the PUI observation of Abell 2218 on the IRAC overlap region. This illustration assumes constant roll angle for the two observations, which is unlikely to be the case.

7.5.2 Fixed Cluster Targets

For Cl0024+16, the background is in the medium range. As we discussed above, this makes it harder to survey the entire field in a short amount of time. Instead, we choose to obtain just a few targeted PUI observations. From the NED catalog (http://nedwww.ipac.caltech.edu/) we find that there are three objects at $z > 0.7$ in the field. We target each one individually using the "Fixed Cluster" target definition on the "Target" dialog. We enter the RA and Dec of each explicitly (see Figure 7.3). By experimenting with the online SENS-PET, we find that, to reach the same depth as before, we require ten 30 second exposures. One way to accomplish this depth is to choose the 5-point Random dithering pattern and obtain two cycles at each position. Again, we check only the 16 μm box. Figure 7.4 shows the completed AOT and Figure 7.5 shows the overlay.

We could make similar choices for the other medium background fields. Together these medium-background AORs require about one hour to complete.

7.5.3 Single Target

In the high background field of Abell 1689, it is expensive in total elapsed time to cover even a small area. Consequently, we choose a single deep pointing centered on the center of the cluster. We will use the 14 second exposure time to avoid saturation. We select the 9-point dither pattern, with 4 cycles at each position. Figure 7.6 shows the completed AOT and Figure 7.7 shows the overlay. This observation will take 19 minutes.
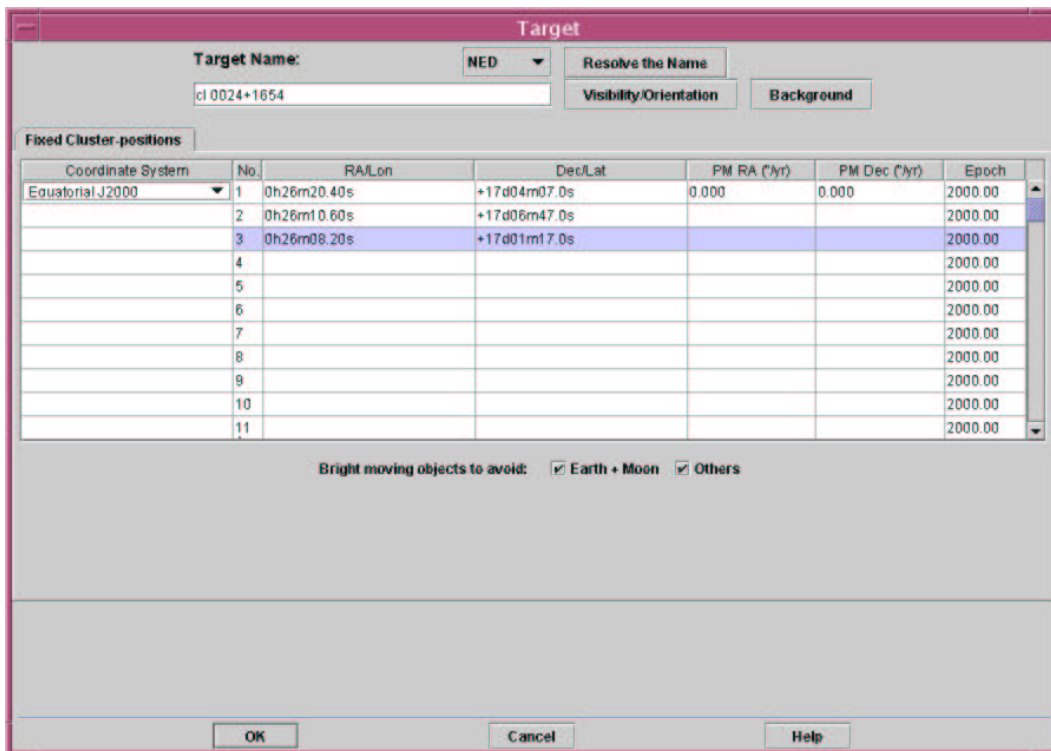
Figure 7.3: The Target dialog for Cl0024+16. We have entered the position of the three intermediate redshift objects in the field.
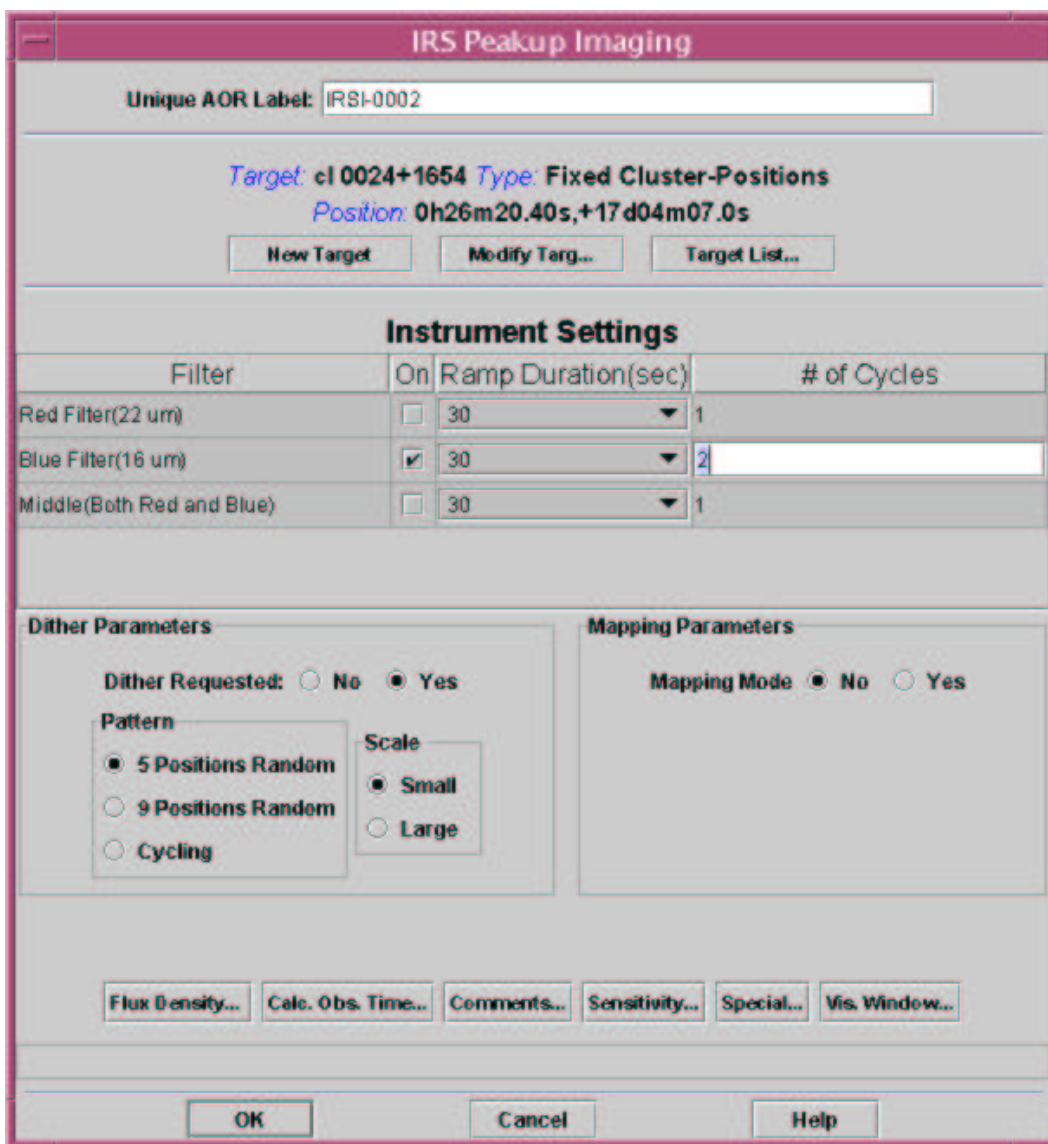
Figure 7.4: The completed PUI AOT for mapping the CL0024+16
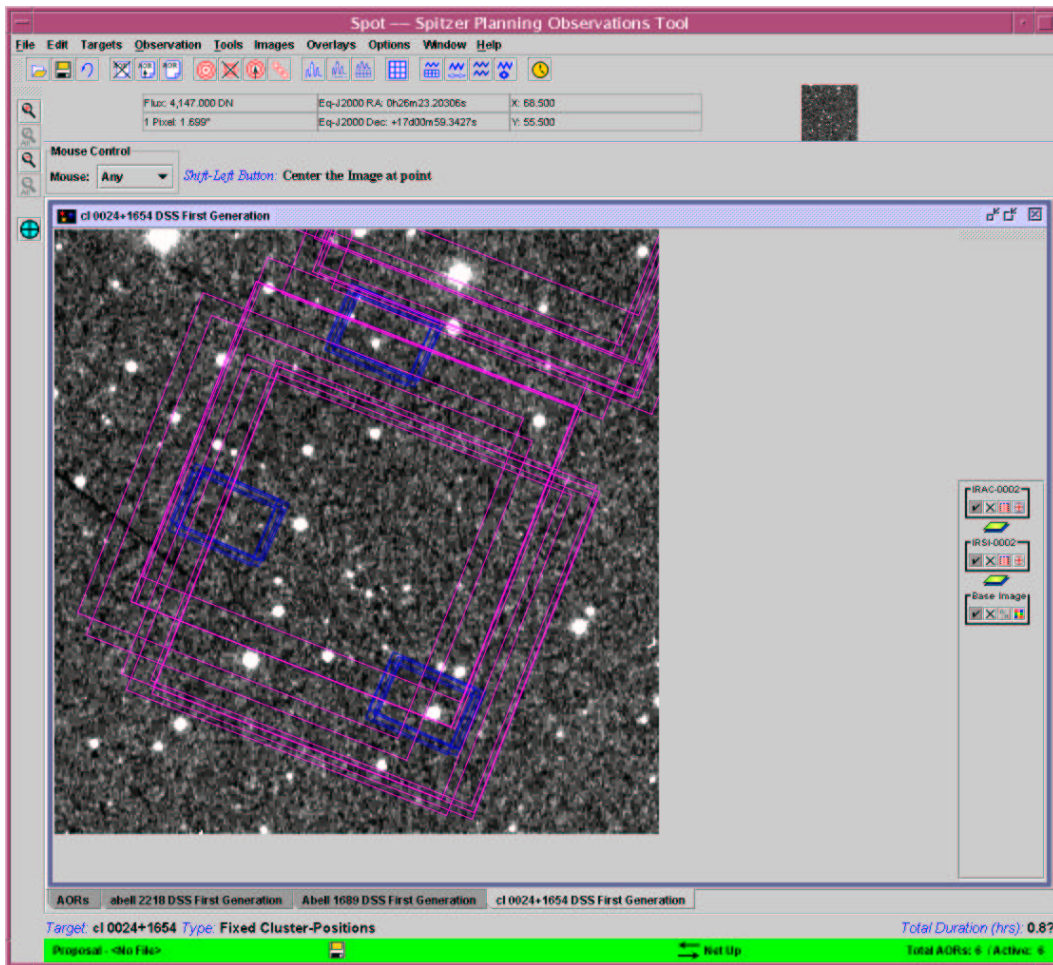
Figure 7.5: The overlay of the PUI observation of CL0024+16 on the IRAC overlap region. For clarity, we only a small subset of the IRAC survey.

Figure 7.6: The completed PUI AOT for mapping Abell 1689.
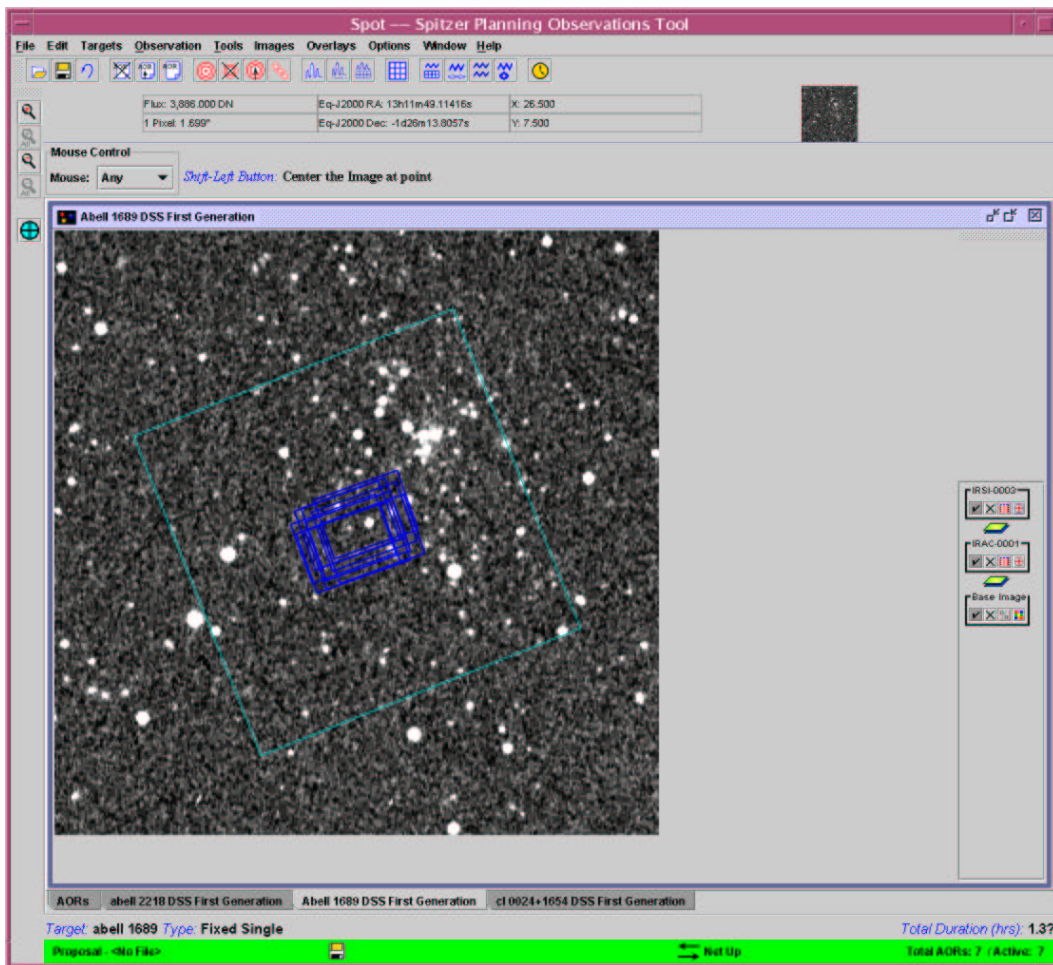
Figure 7.7: The overlay of PUI observation on the IRAC overlap region for Abell 1689.

Chapter 8

Large-Area Mapping in the Trapezium at 24 - 160 microns using MIPS

We're going to design an observation that will cover a relatively large area of sky. This example will illustrate how to do a large area imaging survey, coordinating observations between IRAC ($3.6 - 8.0$ μm) and MIPS ($24 - 160$ μm). The MIPS observations are described in this chapter, and the complementary IRAC program is developed in §9.

For this project, we will use MIPS and IRAC to survey the Orion Nebula Cluster (ONC), which surrounds (and includes) the Trapezium. Our goal is to survey this region and obtain photometry for G stars therein. This region is well-studied at many wavelengths ranging from IRAS to Chandra, and is expected to produce a *very* high flux in the specific Spitzer bands, particularly at the longer wavelengths. In fact, it is likely to be rather blindingly bright, as many Galactic star-forming regions are.

The GTOs, not surprisingly, have snapped up the ONC region with all the instruments already. However, because we would like to demonstrate certain specific features, and even though similar observations of the cluster are already in the ROC (and are likely to be saturated at least in part), we will plunge ahead in this example anyway; the authors of this cookbook, at least, found this exercise useful, specifically because we are coming from an optical background, and Spitzer infrared considerations (sensitivity and backgrounds in particular) can be significantly different from those of optical observations.

In planning these observations, we will use Spot to grab images from IRAS and 2MASS to aid in estimating background and exposure times. We will take into account possible detector saturation and latency effects.

This example can be applied to wide-field mapping of nearly any Galactic star-forming region and/or regions of high background.

8.1 Overview of the Program

In this section, we summarize the steps followed to design this wide-area MIPS imaging program. This will serve both as a one-stop resource for those requiring only an overview of how to do such a program, and also as a roadmap of where to find more detailed information later in this chapter.

- **Target Selection:** We check the Reserved Observations Catalog (ROC) using Leopard before planning any observations. Unfortunately, the Trapezium region has pretty thoroughly been covered in all of the Spitzer instruments already with GTO observations. However, for purposes of this example, we will carry onward nevertheless. See §8.2 for a discussion of target selection.

- **Background Estimate:** Since we are observing an HII region, we need to use IRAS images, Spot, and IRSKY to estimate background levels. See §8.5.1.

- **Scan Rate/Exposure Time:** We can obtain full sky coverage in all three wavelengths at the medium scan map rate, but since the 160 μm array will be saturated in any case, we opt for a fast scan map rate, and ignore the 160 μm data. See §8.5.4.

- **Map Grid Specifications:** The basic inputs here are scan leg length and scan leg offset. The fast scan rate, with minimal overlap between scan legs, ultimately covers a relatively large area. And, we still come in under the maximum AOR duration for MIPS observations of three hours.

- **Durations:**
  - A single cycle of a medium scan of a $1° \times 0.5°$ region (with $160''$ cross-scan steps), including overhead, can be done in a little less than three hours. See §8.5.4.

– A single cycle of a fast scan of a $1° \times 0.5°$ region (with $160''$ [half-array] cross-scan steps), including overhead, can be done in 1.5 hours. A single cycle of a fast scan of a $1° \times 1°$ region (with $160''$ cross-scan steps), including overhead, can be done in a little less than three hours. See §8.5.4.

- **Visualization:** We overlay the planned AORs on an ISSA image of the Trapezium. This helps us verify that we are really doing what we think we are doing! See §8.5.6.

- **Constraints:** Since each of the one degree square maps takes about three hours, and the field of view rotates in time, we need to constrain these AORs to occur as close together in time as possible. We use a "group within" constraint, with a time frame of 7 days.

- A screen capture of the completed AOT entry dialog is displayed in Figure 8.10.

8.2   Target Selection: Orion Nebula Cluster

Technically we should check the Reserved Observations Catalog (ROC) using Leopard (http://ssc.spitzer.caltech.edu/documents/leopard/) before planning any observations. As a new feature in release v13 Spot can help search also. Enter your target and choose "search programs" from the file menu.

We find that the Trapezium region has pretty thoroughly been covered in IRAC, MIPS, and even IRS already. Had this been a real proposal, the next step should have been checking the Duplicate Observations Rule to see if the specific proposal idea we have in mind qualifies as a new observation– perhaps we would like to go deeper or over a larger area than previous observations, in which case our observation might not be considered a duplicate.

However, for purposes of this example, we will plunge onward nevertheless with a shallow, large-area survey of the Trapezium. The Trapezium is very bright and as a new feature in release v13 Spot can help us find objects which are officially classified as "bright". More on this below.

8.3   Target Entry

Start up Spot on your platform of choice (see §2.4.1). Enter a new target either by clicking on the bulls-eye target icon on the taskbar, or selecting "New Target" from the "Targets" menu.

As shown in Figure 8.1, we type "Trapezium" into the target name box, select SIMBAD for name resolution (since this is a Galactic object), and click on "Resolve the Name." We should leave the boxes checked that avoid all bright moving objects; as in other examples here, this restricts the observations to avoid times when the targets are within 7° of the Earth or Moon, or within 30′ of other bright Solar System objects.

The default "Fixed single" target type is fine. It might appear that since we're doing a map of a large region that what we really want instead is a "Fixed Cluster-offsets" or "Fixed Cluster-positions." However, those options are more appropriate for people who are, for example, mapping a small region of space or chasing down a set of specific young stellar objects (YSOs) scattered through the cloud; rather than submitting each specific pointing or YSO as a separate AOR, submitting the set as offsets from a center results in much less slew overhead. But, in our current case, the scan mode takes care of assigning the offsets we want, and the target type we should use is "Fixed Single."

After entering this information, we click "OK" and we return to the main Spot screen. Note that the bottom of the Spot screen now tells us which target and target type we have entered. We might save our target list now, just in case.

8.4   Image Retrieval

In several of the sections below, we will need to examine images of our selected region in other wavelengths and/or from other surveys. Spot has some built-in features to allow us to do this easily. Via Spot's "Images" menu, we can retrieve images of our target from several surveys, including the IRAS Sky Survey Atlas (ISSA) and 2MASS. Here we will walk through retrieving images from ISSA and 2MASS, both of which will be needed below.
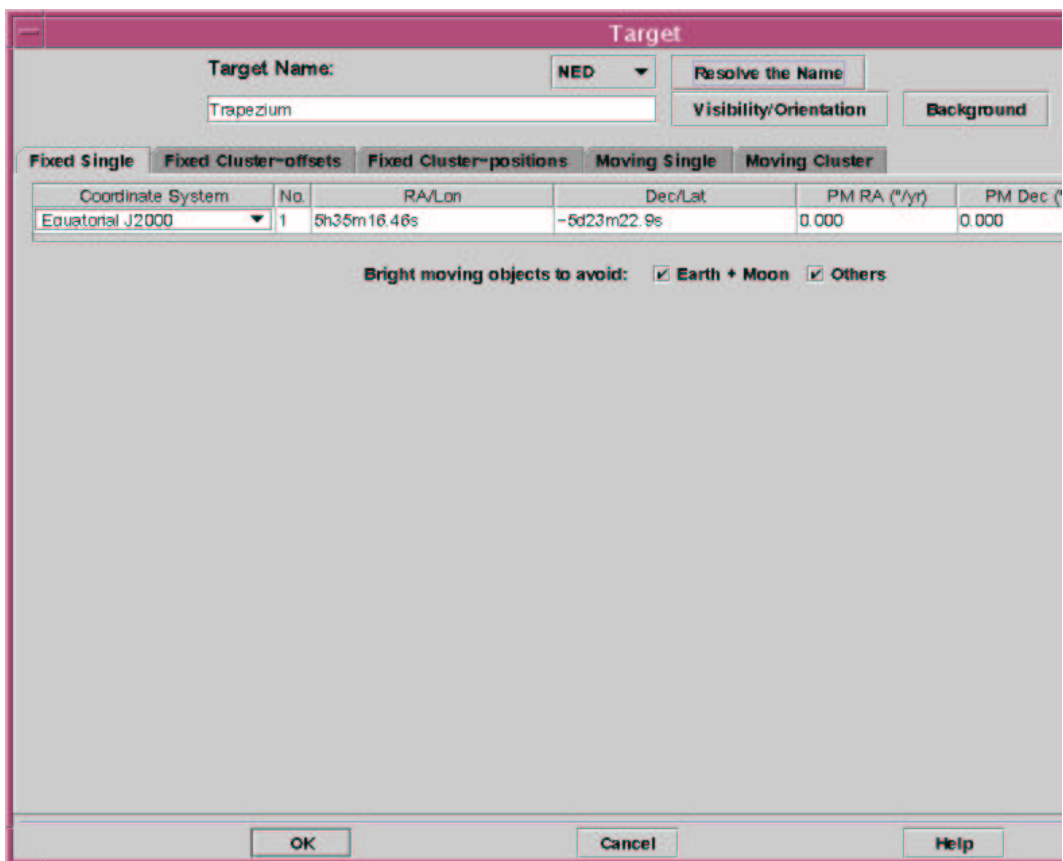
Figure 8.1: The target window after entering Trapezium.

8.4.1 ISSA

Select "ISSA" and you will get the dialog box shown in Figure 8.2.

Our whole region will fit in one retrieval of an ISSA image; Spot limits ISSA image retrievals to between 1° and 12.5°, with a default value of 5°. We can select more than one wavelength, and we can select whether or not these images are opened in one frame (with an option to cycle through them interactively) or in separate frames. Here, we choose all of them, 12, 25, 60, and 100 μm, put all plots in a single frame, 5° on a side, no zoom. In release v13 of Spot, we could choose to combine three of these wavelengths together into an RGB composite image.

When Spot has retrieved the images, you will note that there are now
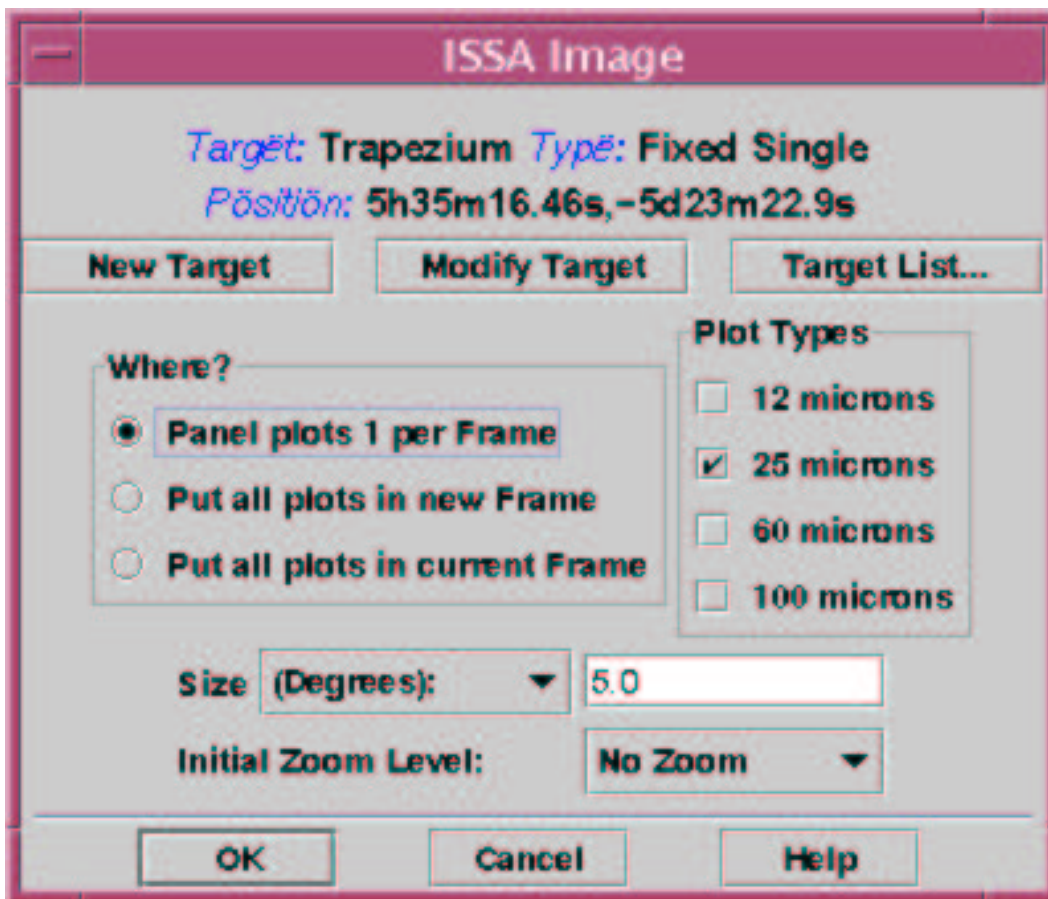
Figure 8.2: Retrieving an image from ISSA.

large black arrows and a slider bar in the upper right; see Figure 8.3. This is how you can flip between images loaded into the same window. If you load fewer than four images into the same window, then the slider only includes those images as options.
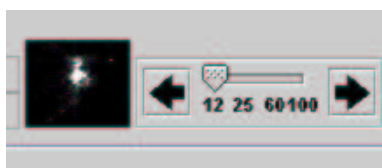
Figure 8.3: Flipping between 12, 25, 60, and 100 μm images.

The default color table is black and white; to better see gradations, we can change the color table. Click on the color grid button (looks vaguely like a Rubik's Cube) which has now appeared on the right of the image window, to obtain the window shown in Figure 8.4. From the color table pull-down menu, we pick "a trip around a color cube," click "apply color to all plots," then click Apply and OK.
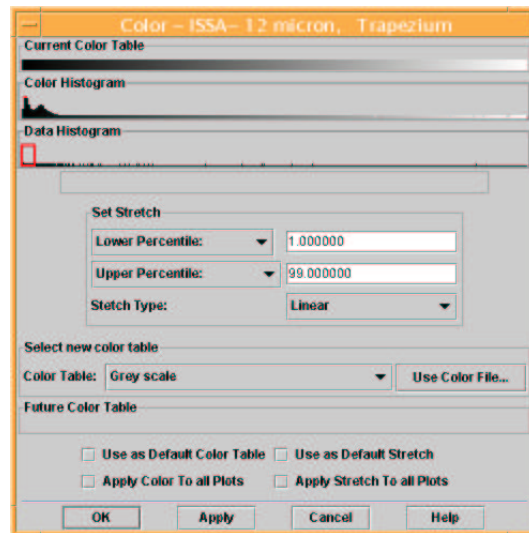
Figure 8.4: Color table selection.

8.4.2   2MASS

Similarly, using the "Images" menu, we can retrieve an image from 2MASS. Select "2MASS" from the menu and you will get the dialog box shown in Figure 8.5. Note that, as with any of the 2MASS images retrieved through Spot, these are gifs only, and for actual science on 2MASS images, you should go to the original 2MASS archive:

http://www.ipac.caltech.edu/2mass/ or http://irsa.ipac.caltech.edu/

The map that we will eventually construct below will cover a larger region than Spot will allow us to retrieve from 2MASS; it limits image selection to between 50 and 500 arcsec. We still want to check stellar density, so we still want to download images. We select all three bands (J, H, and K), put
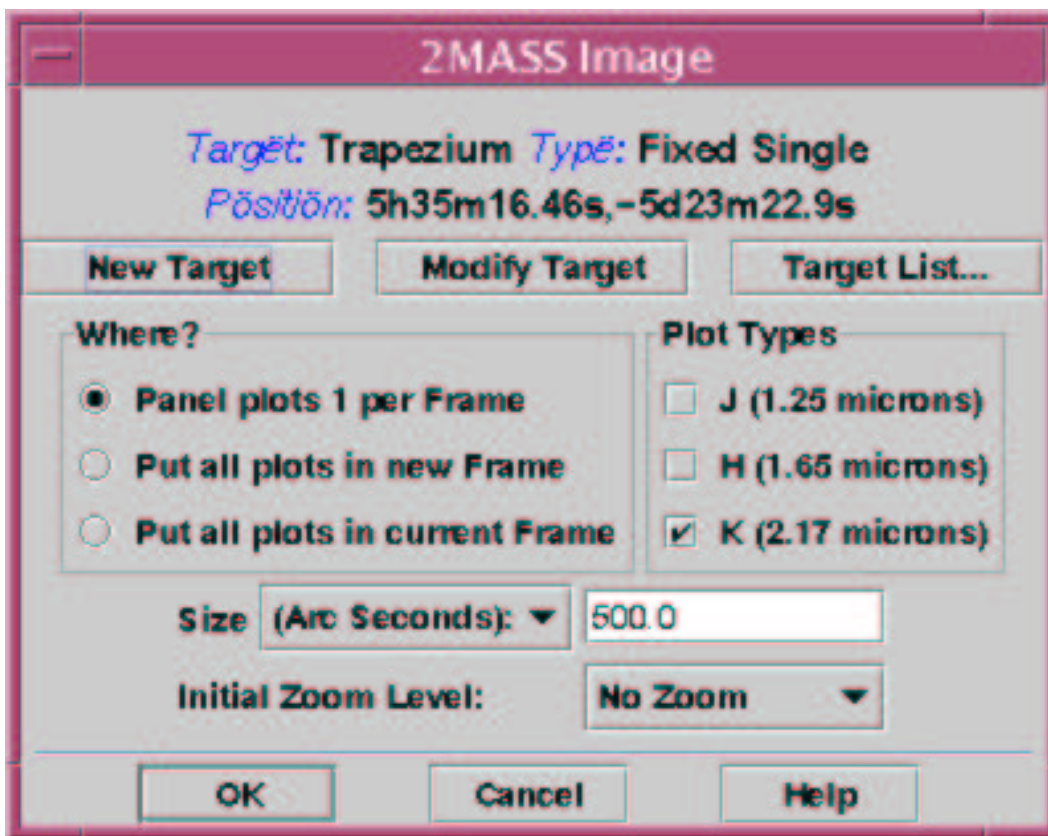
Figure 8.5: Retrieving an image from 2MASS.

them in a new frame, and select the largest possible region (500 arcsec), no zoom. Note that any color table changes selected above carry over to these new images. If you would like to alter the color table for these images, click on the color table icon and pull up the corresponding color table window for these images (like Fig. 8.4).

8.5 MIPS Scan Map

MIPS' photometric bands are at 24, 70, and 160 μm. It has diffraction-limited imaging capability, with noise performance that may be limited by natural sources, e.g., zodiacal dust at 24 & 70 μm, and confusion with distant galaxies at 160 μm. In the case of the ONC, the nebula itself is going to be

brighter than the zodiacal dust or distant galaxies! We are going to have to be careful about background estimates. We will then select a mapping mode and fill out the AOT for this observation.

8.5.1   Background Estimates

Especially in the ONC with the long wavelengths of MIPS, background is really going to matter. There are three ways for us to obtain an estimate of the background, through (1) Original IRAS ISSA plates, (2) Spot, and (3) IRSKY. There is another effective source of background to worry about - effective instrumental backgrounds introduced by bright objects.

IRAS Data

When in doubt (or when starting out), it's always best to go back to actual data. We retrieved IRAS images of the ONC region above. As we move the mouse over the image, we get a readout of pixel position (x, y), sky position (α, δ), and flux, in MJy/sr. This calibrated flux value, specifically, is the number we need to care about. IRAS observations at 25, 60, and 100 microns are reasonably close to MIPS wavelengths at 24, 70, and 160 microns, and will give us a sense of what to expect. Indeed, the ISM is very bright here! At 100 microns, peak flux values are $\sim 24,000$ MJy/sr! *(Note for users where ISM does not dominate: the ISSA plates have had the Zodiacal light already removed from them. See below and the moving target chapter for more information.)*

For any given target, not just the ONC, other sources of background flux may be much more significant. So, we next look at other ways of getting a background estimate.

Spot's Estimates

From within Spot, there are two ways to get a background estimate. First, while entering the target (as above) we can click on the "Background" button, producing a window like Figure 8.6. Alternatively, once a series of targets are entered, we can get a complete list of targets via either the "Targets/Target List" menu or the bulls-eye icon on the toolbar; see Figure 8.7. In the target list window, we can click on "calculate background for all" then "show background" and get the same window as in Figure 8.6.
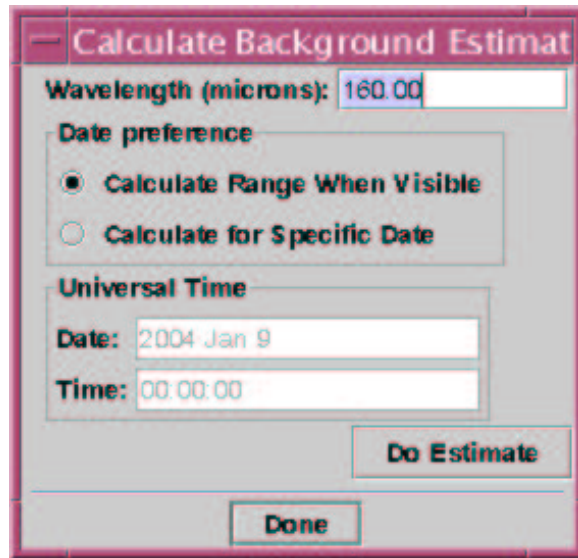
Figure 8.6: The background estimation window.

Figure 8.7: The target list window.

MIPS' longest wavelength is 160 μm, and the one most likely to suffer here, so we start with that by entering "160" in the wavelength box in the "calculate background estimates" dialog box in Figure 8.6. We don't need to constrain these observations to be at a specific date, so we will allow Spot to calculate the range of background estimates when our target is visible. Click
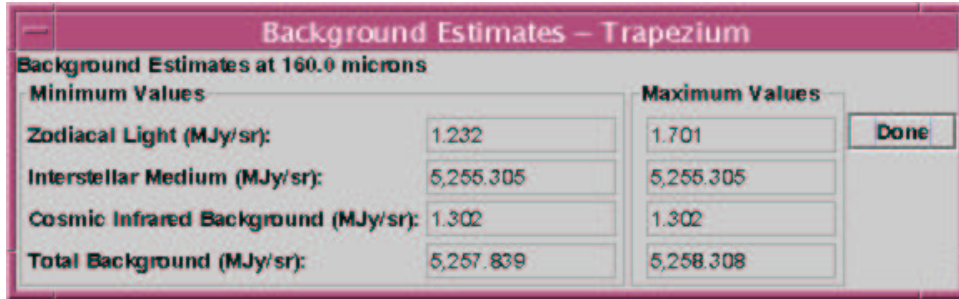
Figure 8.8: The output of background estimation for the Trapezium at 160 microns.

Table 8.1: ONC MIPS and IRAC background levels from Spot.

wavelength (μm)	ISM (MJy/sr)	total range (MJy/sr)
3.6	5.4	5.5
4.5	7.4	7.6-7.8
5.8	30	31-32
8	175	180-185
24	108	130-140
70	795	805
160	5255	5260

on "Do estimate" (not "Done," a common mistake) to actually calculate it. Spot works in the background and notifies us when complete. It tells us the minimum and maximum contributions separately for Zodiacal light, interstellar medium (ISM), and the cosmic infrared background; see Figure 8.8. In this case, again, the ISM clearly dominates! The flux expected in 160 μm from the ISM alone is returned as $\sim$ 5260 MJy/sr! We should repeat this Spot estimate for each of the MIPS photometric bands (and IRAC, for that matter, since we'll need these later). See Table 8.1 for the results.

Spot is working specifically at the exact coordinates we gave it, e.g., right on top of the center of the Trapezium (θ Ori). For purposes of background estimates, Spot doesn't care whether we are taking a single "snapshot" or a $5° \times 5°$ map, it evaluates the background specifically at the RA and Dec entered in the Targets list. However, we know from the ISSA image we retrieved above that the ISM is very patchy in this region, and brightest

near the Trapezium. We could try sending Spot coordinates offset by a few IRAS pixels ($4 - 5'$/pix), but we will instead try with IRSKY in the next section.

For more information on comparing various background estimates, see the "IRAS vs. Spot vs. IRSKY" discussion below.

IRSKY's Estimates

Since we know the background nebulosity is highly variable near the Trapezium, we would like to also make some background estimates with IRSKY. IRSKY will tell us, among many other things, the mean background over $30' \times 30'$. (We could change the size of that box, but that is the default output.)

IRSKY can be found here:

http://www.ipac.caltech.edu/ipac/services/irsky.html

It also exists with a batch file interface, called IBIS, should we want to submit a list of targets:

http://www.ipac.caltech.edu/ipac/services/ibis/ibis.html

To log into IRSKY, do this:

ssh irsky.ipac.caltech.edu -l irskyssh

and enter the password ssh!irsky. The program is self-documenting, with many help options as we go along. At the end of the session, we are given the option to have our results sent to us by email. The results of a session looking at the 24, 70, and 160 μm fluxes is in Appendix G and summarized in Table 8.2. As expected, the 160 μm background decreased, but somewhat surprisingly, the 70 μm background levels increased. See the next section for more on this.

IRAS vs. Spot vs. IRSKY: Which one should you use?

For some overview information on infrared backgrounds, see the Infrared Compendium, a web-based reference at the SSC website:

http://ssc.spitzer.caltech.edu/documents/compendium/

Table 8.2: ONC MIPS background levels from IRSKY (averaged over $30' \times 30'$).

wavelength (μm)	ISM (MJy/sr)
24	241
70	3200
160	2370

Specifically, there is a page on backgrounds under the overview section, along with pages on resolution, diffraction, and confusion issues.

For a detailed description of exactly what Spot is doing, see this document:

http://ssc.spitzer.caltech.edu/documents/background/

In brief, this is what Spot does:

1. Takes a smooth empirical function fit to IRAS and DIRBE data (from Schlegel et al. 1998, ApJ, 500, 525), and derives a brightness distribution.

2. Employs a "standard" ISM spectrum (or rather, ratios of fluxes at Spitzer and IRAS wavelengths), scaled to the right intensity as just derived, and infers fluxes at the Spitzer wavelengths.

3. Adds above to a 3-d model of the zodiacal dust based on DIRBE data, also derived for Spitzer-specific wavelengths.

Thus, Spot is:

1. Using a model based on data from more than one mission.

2. Trying to compensate for the fact that Spitzer's view of the zodiacal light is changing in time as it moves away from the Earth (in fact, literally through clumps of dust).

3. Making an educated guess as to the brightness at Spitzer (rather than IRAS) wavelengths.

The first point suggests that one should also consult the IRAS images, as (a) model assumptions may in reality be incorrect, (b) the model will smooth out sharp variations in the real data in confused or complex regions of sky, and (c) Spot has assumed a single temperature for the ISM (the "standard" ISM spectrum), which breaks down in HII regions such as the ONC. The second point is particularly important if observations of your target(s) are likely to be dominated by zodiacal dust; Spot knows specifically where Spitzer will be as a function of time, and this can matter a great deal– there is an Earth-trailing blob of zodiacal dust, and Spitzer is going right through it. For the true novice, the third point may be specifically valuable, but it is also important (specifically in this chapter's case of the ONC where the ISM is very bright) to remember that one should always check the IRAS images to see actual data for the region in question. In the example we have here, the ISM clearly dominates, but in other regions this may not be the case. *The ISSA plates have had the zodiacal light subtracted out* so if you are worried about background in the ecliptic plane but not the Galactic plane, this may affect you. See the chapter on moving targets for more on some of these issues.

IRSKY is a big workhorse of a program that has been used for years and does a lot of things. The background estimator that is in IRSKY spits back quite a bit of output. It gives you an average over a region of sky of the IRAS data at each wavelength (and interpolates to arbitrary wavelengths using a somewhat tricky method). It returns estimates of brightness from IRAS and COBE data after having subtracted off a zodiacal light model (based on IRAS data) with known limitations, certainly not taking into account Spitzer's position as a function of time. And, it does not understand point sources; a bright point source can distort the mean brightness in a region. Going to a bigger region might give a better idea of the diffuse emission. A median would perhaps get rid of a giant point source. An average would include the point source and not give a measure of the diffuse emission. It would just go down as the inverse square of the aperture until the point source is no longer important, unless there is lots of structured emission, in which case it is hard to even define what the background means, as is likely the case in the ONC. In the case of the ONC, it's all one big smear!

Spot helpfully returns separate contributions for each of the major sources of background so you can pick and choose what you want to take from it. For example, if you are worried about the contribution from the ISM (if the ISM is very bright, like > 100 MJy/sr, you *should* be worried), pull the

zodiacal light estimates alone out of Spot and add them to the estimates from your cursor position on ISSA images in Spot (your best option) or estimates from IRSKY (assuming you understand what is resolved and what is not), or experiment with sending slightly different RA and Dec coordinates to Spot.

In the end, though, keep the original IRAS images in mind. These are actual data, and nothing beats actual data! Depending on where your target is, you could also consult Midcourse Space Experiment (MSX) data, which were taken in and near the Galactic plane at 8.28, 12.13, 14.65, and 21.3 microns. Spot will allow us to download MSX images of a target (obviously, only if it is in the region mapped by MSX). Alternatively, we can retrieve MSX data (or any other data, including our own) as FITS files from the web (e.g., from http://irsa.ipac.caltech.edu/), and load those into Spot to play with them. For IRAC wavelengths, starlight originating from stars merging together and becoming confused in the Galactic plane may also be an issue. For this, consult (actual data again!) 2MASS or DSS images, or if necessary, a star-count model, to determine if it is a problem for any given region.

If our proposed region resembles any other region already observed and released into the archive, we can even load actual Spitzer data into Spot, and then investigate and scale it appropriately for our proposed target. You can read more details about the observations which are currently available (e.g. First Look Survey, Legacy etc), by downloading the archive tool (Leopard) and accessing the Spitzer Archive. Additional information may be found at:

http://ssc.spitzer.caltech.edu/archanaly/archive.html

In the current example, a contribution from starlight is expected on top of the contribution from the ISM, given the images we retrieved from 2MASS above. The contribution from the ISM still dominates, however.

8.5.2   Bright Objects and Instrumental Backgrounds

Bright objects with MIPS leave latents in the arrays, so when planning observations near bright objects, we must also worry about the effect that the bright objects have on our observations (and the ones that come after us). As a new feature in release v13 Spot can help us figure out how many bright objects may affect our observations. After entering the AOR parameters (see below) and obtaining an image (above), we can choose from the Overlays menu the option to overlay "Spitzer bright objects for AOR." This will show us all of the objects that might cause latents in the arrays. We then

Table 8.3: MIPS Saturation limits.

	24 μm	70 μm (default scale)	160 μm
point srcs (1 sec)	4.1 Jy	23 Jy	3 Jy
extended srcs (10 sec)	260 MJy/sr	101 MJy/sr	TBD (pre-launch 14 MJy/sr)

need to specifically explain in our proposal why we would like to do this observation anyway, how we will deal with the latents, and how this additional background affects our science. In this example, at least 20 bright objects are displayed, and our proposal would definitely have to include such a discussion.

8.5.3 Exposure Time

Saturation

OK, so we have some whopping huge ISM background contributions, especially at 70 and 160 μm. Are we going to saturate the detectors? Probably. Saturation is not a good thing; saturation on one exposure over an extended region will affect the detector response for several subsequent exposures. In the case of the Si detectors, the pipelines at this point do NOT remove latent images (although they are flagged in the mask file), so it's best to avoid them if possible.

We should check at the SSC MIPS website for the very latest saturation estimates:

http://ssc.spitzer.caltech.edu/mips/

The MIPS saturation limits for point sources are summarized in Table 8.3. (You should check the MIPS website to be sure that you have the most recent numbers.) According to the numbers we derived using Spot and IRSKY above, the 70 and 160 μm detectors will be saturated from ISM alone in a 10 second exposure.

> **Note:** Remember that any point sources will be added on top of the signal from the ISM, so if the background is 130 MJy/sr in 24 μm, after 10 seconds, 75% of the dynamic range is left available for any point sources, and the stimulator (or "stim") flash that is an inherent part of the MIPS observing sequence. The stim flash

Table 8.4: MIPS Scan Map Integration times *per pixel* (note that only 1/2 of map region covered by 160 microns in one scan leg at the fast scan rate).

scan rate	24 μm	70 μm	160 μm
slow	100 s	100 s	10 s
medium	40 s	40 s	4 s
fast	15 s	15 s	3 s

Table 8.5: MIPS Scan Map Integration times *per exposure.*

scan rate	24 μm	70 μm	160 μm
slow	10 s	10 s	10 s
medium	4 s	4 s	4 s
fast	3 s	3 s	3 s

by itself takes up 1/3rd of the dynamic range, so, for calibrated data, the total flux entering the telescope ought to take up no more than 2/3rds of the available dynamic range.

Map Modes

Our goal is to cover a large region. The mode we would therefore like to use is one of the survey Scan Map Modes– MIPS is very efficient at covering area in scans. We have three scan rate choices, slow ($\sim 2\rlap{.}''6$/sec), medium ($\sim 6\rlap{.}''5$/sec), and fast ($\sim 17''$/sec). As is discussed in the SOM or on the MIPS website, the fast scan rate will leave gaps in the 160 μm areal coverage, but will be complete in the other two wavebands.

From the SOM, we can look up the Scan Map integration time per pixel, reproduced in Table 8.4. Note that this is the total integration time *per pixel* at the end of the day, after everything is processed. During slow and medium scan maps, every source is observed 10 times in a single pass with the 24 and 70 μm arrays; during a fast scan, these arrays see every source five times. For 160 μm, during a medium or slow scan, every object is observed once; a quick scan observes "stripes" on the sky, due to the unfilled nature of the 160 micron array. Therefore, the integration time *per exposure* is different than per px (at least for the 24 and 70 μm data), which is summarized in Table 8.5.

Note: As described above, in scan modes the 24 and 70 μm arrays see every patch of sky several times, whereas the 160 μm array sees every patch only once (or every other patch once). For highest-quality 160 μm data of an extended object, it is recommended that we plan four images of any given patch of sky with the 160 μm arrays. If there is an object such as an asteroid moving through the field of view, we will need to plan for multiple observations to identify and remove the object.

From this information, combined with the background estimates above, we learn that we certainly shouldn't do a slow scan, because that is likely to saturate (at least) two of the detectors. A medium-speed scan will allow saturation limits 2.5× higher than the last row of Table 8.3, and a fast scan will allow limits 3.3× higher.

However, under fast scan, there is an additional "160 μm fast reset" option. We can choose to reset the 160 μm detectors twice as rapidly as normal for fast scan, giving an effective exposure time of 1.5 s for 160 μm (or limits 6.7× higher than the last row of Table 8.3). (Note that this "fast reset" option only applies to fast scans.)

According to these numbers, then, for medium and fast scans, the 24 μm detector will be fine for the most part. The 70 μm detector will probably be okay. The 160 μm detector is likely to saturate.

In an important change for Cycle-3, MIPS campaigns will be divided into "warm" or "cold" (telescope held at 5.7K) observations, in order to maximize Spitzer's cryogenic lifetime. Programs requiring 160 micron observations must justify this specifically in the proposal and ensure the "160 micron required" checkbox is selected in the AORs. These AORs will be more difficult to schedule given that every MIPS campaign will not be "cold". For full details please refer to the Cycle-3 Call for Proposals.

Since 160 μm is likely to saturate in this example we should state this explicitly in our proposal. Since we cannot justify 160 μm observations in this case, we ensure that the 160 μm box is unchecked in the AORs and concentrate on the 24 and 70 passbands only.

Final Decision on Exposure Time

We could try for complete sky coverage at all wavelengths using as short exposures as possible via the medium scan rate. We note, though, that

saturation and therefore calibration could be a real problem in these data. So a better option is fast scan. We will get full sky coverage at 24 and 70 μm using this scan rate .

Using the online SENS-PET, we determine the $1 - \sigma$ sensitivities of a single fast scan pass to be (for point srcs, high background) 358 and 14500 microJy at 24 and 70 microns, respectively. This is sufficient to reach our goal of detecting some G stars; if we wished to go deeper, we could plan for multiple scan passes until the desired sensitivity is reached (see below).

Because it takes time for the detectors to recover from saturation, subsequent observations that are not saturated will not be as easy to calibrate as they would otherwise. If we expected to get anything viable on the edges of the field, we could break this observation up into pieces such that the places where viable observations are possible are separated in time from those where the detectors will be saturated. See §8.6 for details on tiling a region with individual AORs. Given the bright and complex background, if well calibrated data are desired on the edges, then we should be sure to obtain enough off-cloud background to allow the stims to do their job and calibrate the data e.g., ask for longer scans including fainter regions than the core area. (See the MIPS Data Handbook under "extrapolated stims" for more information on this issue.)

8.5.4   Filling in the AOT

Now, we're ready to fill in the AOT in Spot. We can either look under the Observation Menu and select "MIPS Scan Map," or click on the MIPS Scan Map icon (fourth from right) on the toolbar. We obtain the window in Figure 8.9.

Basic Identification

Working from the top, we can enter our own "Unique AOR label" or it will create one for us. To ensure sanity when we go back to this a year or 6 from now, it makes sense to pick a label that is actually descriptive and not just something like "number 463205sprime." Note that we should not use underscores or colons in the label.

If we have more than one target entered, we should verify that the target it has selected is indeed the Trapezium, and that it is a "Fixed single" target
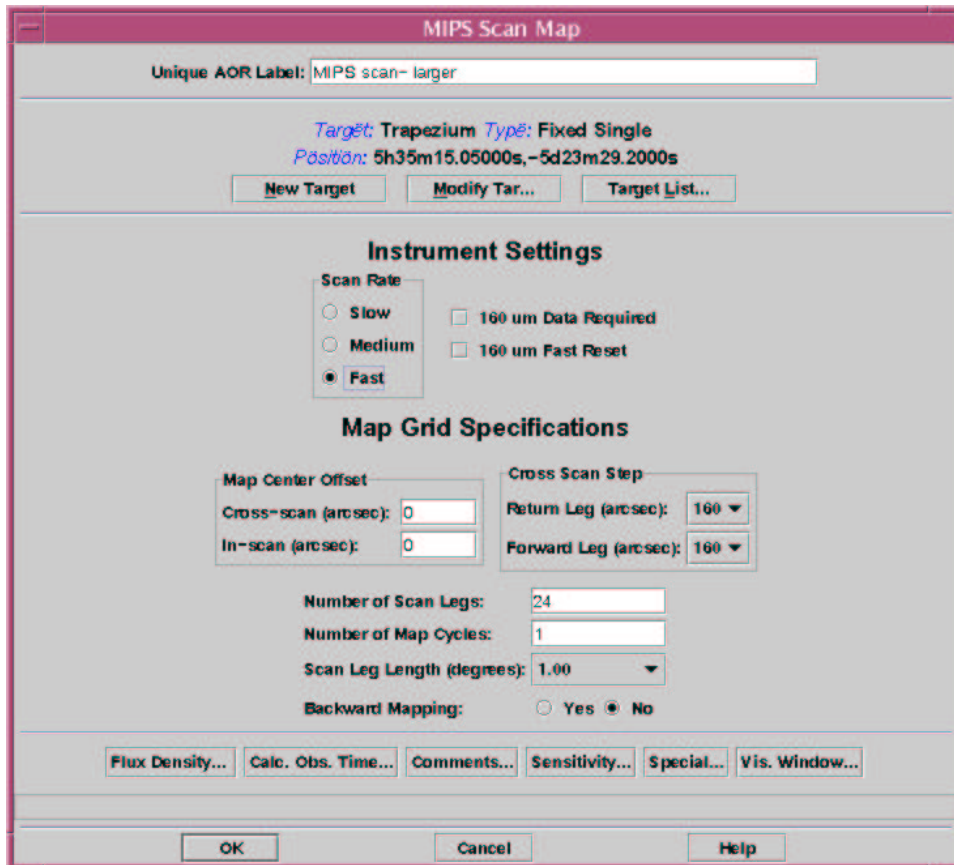
Figure 8.9: MIPS Scan Map AOT window, default values.

type. (If you need to change the target, click on "target list," and if you need
to change the target type or position, click on "modify target.")

Instrument Settings

Under Instrument Settings, we click on "fast" scan rate. Since 160 μm ob-
servations are not required, we should ensure the 160 μm box is unchecked,
loosening constraints on the observation, and making scheduling the obser-
vation much easier. Note that the telescope is always cold enough for 24 and
70 μm observations (as long as the cryogen lasts).

Map Grid Specifications

The basic inputs here are scan leg length and scan leg offset. "Scan legs" are a strip of sky observed by the scan mirror and telescope moving in a complementary fashion; see the SOM for details. A leg is defined as one direction on the sky only; an "up-and-back" scan is composed of two scan legs. The target coordinates we submit are the *center* of the final map. The observatory will cover the map region in all three wavebands; since the three detectors see slightly different regions of sky, there will be overscan of about $20'$ at either end of the map that has data at only one or two of the three wavelengths. The scan leg length specified by the observer refers to the region imaged at all three wavelengths.

MIPS can generally make scan legs of lengths $0.5°$ to $6°$, e.g., one single scan pass in one direction, forward or reverse. Typical scan legs are $0.5°$ to $5°$; the minimum leg length in fast scan mode is $1°$. These legs are essentially linear. The scan leg offsets in the cross-scan direction set how much overlap there is between scan legs. Given the on-orbit realities of the MIPS fields-of-view, we should step in the cross-scan direction by at most $1/2$ array steps, or even at most $1/4$ array steps for the highest S/N possible.

We can also consider orientation on the sky. The orientation is going to be a function of exactly when during the visibility window the observations are scheduled. Conversely, selecting a specific orientation may make it difficult or even impossible for the observation to be scheduled. Since it is always better to put as few constraints as possible on the observations, and since constraints will only be accepted for scientifically compelling reasons, we will not put any timimg constraints on the particular observations we are planning here.

Finally, if it is a particularly large map, we have to make sure that the total length of time to execute the AOR is less than the three-hour-limit on MIPS AOR duration. If our current observations take longer than this three hour limit, we need to break them up into more than one AOR; see §8.6 below for an example.

We know from consulting other Spitzer manuals (e.g., the SOM) that a single cycle of a basic medium scan of a $1° \times 0.5°$ region (with $160''$ cross-scan steps), including overhead, can be done in a little less than three hours. This results in complete coverage, avoiding the bad readouts/sides of the Ge arrays. It ultimately covers a relatively large area. Surely, then, a fast scan of the same region, same step size, will be under the maximum AOR duration

for MIPS observations of three hours; we might even be able to get much more area covered in three hours.

In this example, we can start with exactly this, a fast scan of a $1° \times 0.5°$ region with with $160''$ cross-scan steps; see Figure 8.10. The map center offsets "cross-scan" and "in-scan" values should be left at 0 arcsec, select 12 scan legs, 1 map cycle and 1.00 degrees scan leg length, and set it to cross-scan step of 160 arcsec [half-array] each forward and return leg.

Save your AOR(s) early and often. Now would be good.

> **Note:** Want to cover a larger area? By entering different parameters into Spot, asking it to calculate total time, and/or visualizing the AOR, we can experiment to see how much area is covered for any given AOR. See more below!

8.5.5   Time Estimates

To ensure that we have planned an observation that comes in under the 3-hour MIPS time limit for one AOR, we should get an estimate of total time.

There are two ways to do this, both of which require a live network connection to the SSC (note the "Net Up" icon in the green bar at the bottom of the Spot screen). (1) Under the "Tools" menu in Spot, select "Recompute All Estimates." After thinking for a while, it will place the final best estimates on the main Spot AOR screen under "Duration." To see a breakdown of where most of this time is coming from, again from the "Tools" menu in Spot, select "Show Current Estimates." (2) Alternatively, in the AOT window (which you can retrieve from the main AOR listing in Spot by double-clicking on the relevant row), you can click on "Calc. Obs. Time." This latter option is particularly useful for interactively playing with the mapping parameters if you so choose.

In either case, the breakdown of where the time estimates are coming from are shown in Figure 8.11[1]. We indeed come in well under the 3-hour limit.

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[1]Careful readers will note that the total time for the AOR is not equal to the sum of the times given here. There are "hidden" overheads, e.g., the time devoted to taking stim flashes. We as observers have no control over the frequency or duration of the stim flashes, or anything else in the "hidden" overheads. We do, however, have control over all the overheads shown here – e.g., by varying the scan rate, the slew and settle times
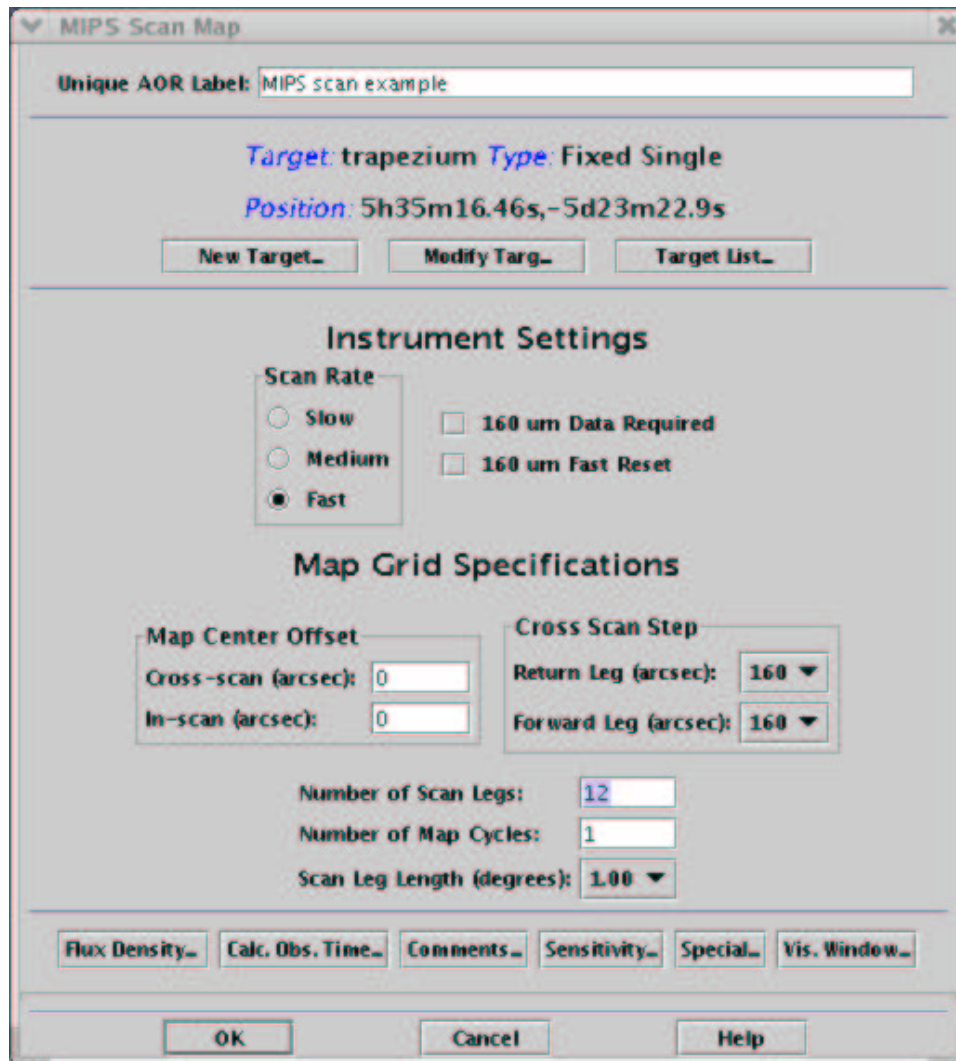
Figure 8.10: MIPS Scan Map AOT window, filled out with values for the planned observation.

Note that it also tabulates for us the total integration time, in seconds, per pixel. If you are one of the folks who have, with much dedication, read every word of the MIPS chapter of the SOM, you know that MIPS has seconds that

change; by reducing the number of AORs in the program, the total slew overhead can be reduced.

are slightly different from real seconds. Spot tabulates times in real seconds, not MIPS seconds.
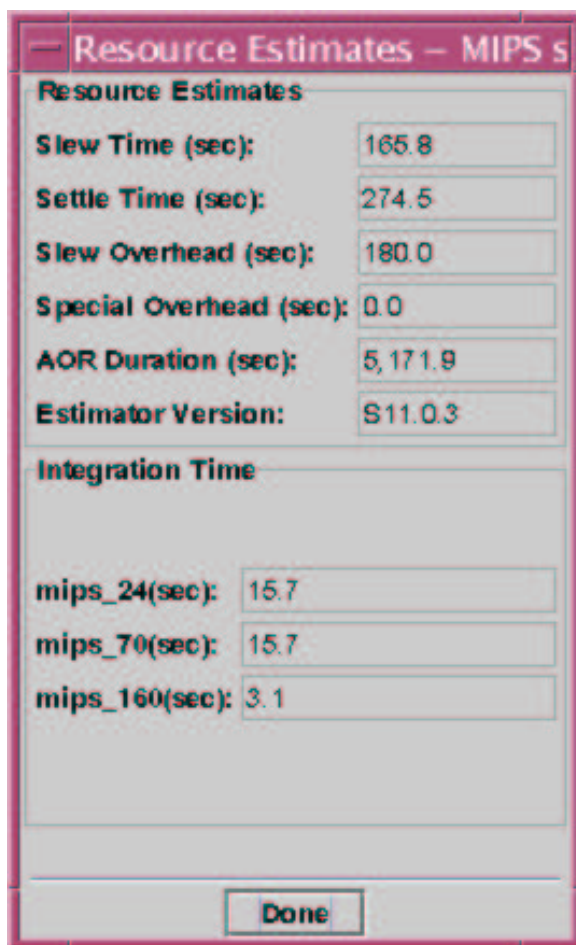
Figure 8.11: MIPS Scan Map Resource Estimates window. Integration time is in units of real seconds (not MIPS seconds), total time per pixel.

8.5.6   Visualization

We can and should use Spot's visualization tools to verify that the observation is doing what we think it is doing. Our whole region will fit in one retrieval of an ISSA image; see §8.4 for instructions on image retrieval.

After retrieving an ISSA image (or any other image), to visualize the observations we have planned, highlight the AOR, go to the "Overlays" menu and select "Current AOR on current image." It will calculate visibility windows and ask when you want to visualize; pick any time where the ONC is visible. It will then overlay the map on the region you have selected. (To avoid common errors during this process, be sure that you have retrieved an image of the desired target as opposed to a different target in your list, then be sure that you have selected the appropriate AOR such that the "current AOR" refers to the target whose image you have retrieved.)

Because this particular map is so large and dense, it is likely to take some time for Spot to render it. While this visualization is turned on, the rest of Spot could be sluggish. Be patient! See Figure 8.12 for what it should display. Note that on the right hand side of the image window, when we added the overlay, a layer appeared with the label of the AOR. The symbols are, from left to right, a check mark (to turn on and off), a × (to remove the overlay entirely), a small red and blue table (to get a listing of each pointing), and a crosshairs (to turn on and off the visualization of each wavelength).

The three wavelengths are represented by blue (24 μm), green (70 μm) and pink (160 μm). The overscan regions discussed above can clearly be seen on the edges of the map. By clicking on the crosshairs icon on the right side of the ISSA window, we get a dialog box enabling us to turn off and on the visualization for each wavelength. Be patient; it may take a little while for the computer to respond.

If we have a lot of computer RAM, we can try animating the scan to see exactly what it's doing. In order to do this, we click on the small red-and-blue table icon on the right edge of the ISSA image window to get a listing of each pointing. Select "Animation" or "Animation with Trail" to watch it step through the mapping procedure. Note that specifically for MIPS scan maps, this is not for the impatient or those with limited RAM ("faint of RAM"?). To turn off the visualization (or animation) after verifying that it's doing what we think it's doing, click on the × under the name of the observation in the ISSA window. Note how much faster Spot runs now!

> **Note:** Had this been an observation in which we expected to get 160 μm data, because it is an extended object, we should have requested three more passes in two sets of two pairs (for a total of 4) to make sure that the 160 μm data are high-quality and includes no asteroids. Moreover, since it is a bright extended

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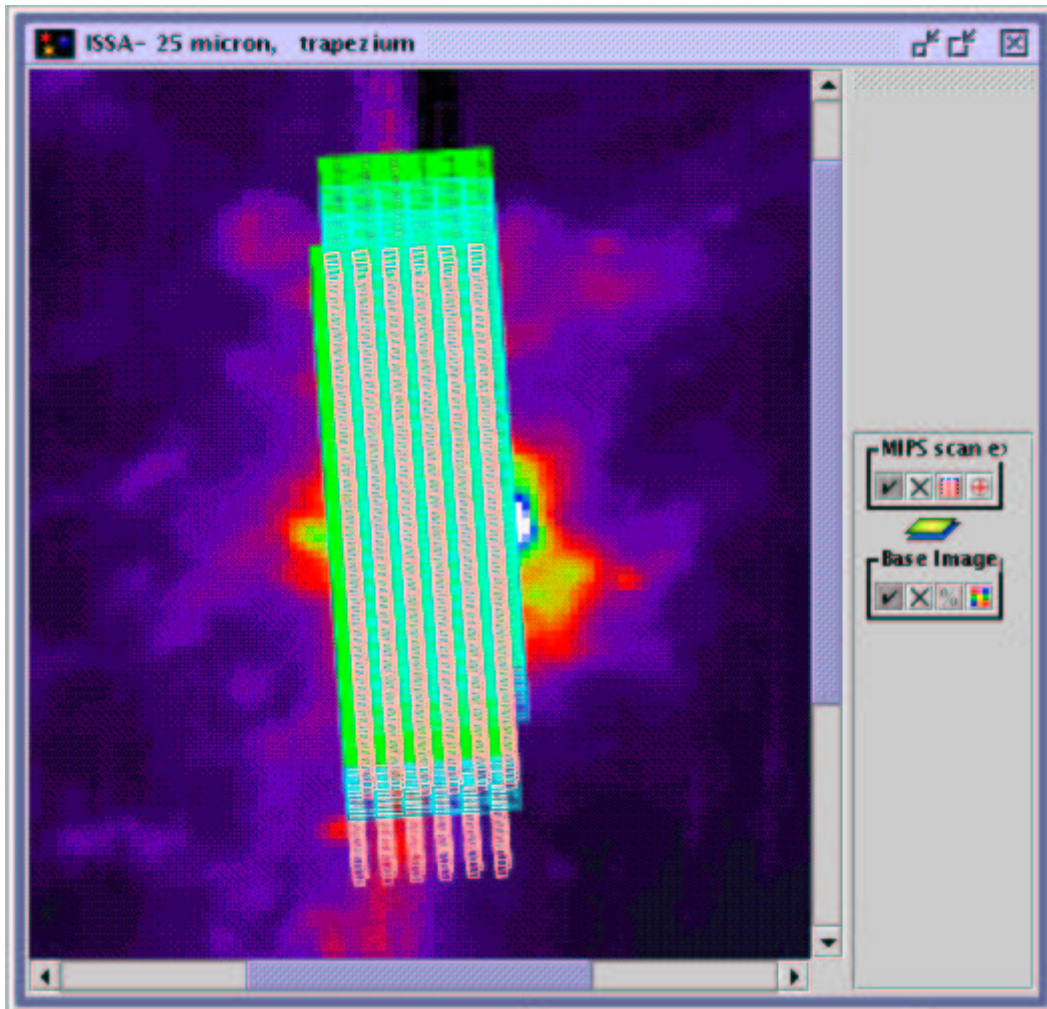
Figure 8.12: Visualization of MIPS observation.

object, we should be sure to have sufficient low background observations before and after the object to ensure a good calibration; see "extrapolated stims" section in the MIPS Data Handbook for more information.

The observation as currently designed takes about 1.5 hrs, and we can go up to three hours in a single MIPS AOR. We might want to design an AOR to cover a larger area. We can play with the values in the AOT window, hitting "Calc. Obs. Time" after each change. If we design an observation that

exceeds 3 hours, Spot will tell us. In order to figure out the area covered by the AOR, we can use the tools within Spot. Under the "Overlays" menu, there is a "distance tool" option. By clicking and dragging, we get the distance measured in arcseconds. (The measurement appears near where you clicked before dragging. Click on the little red and blue "table" icon to change the display color or units of the measurement.) By following this general process, we discover that we can make a $1° \times 1°$ map that takes less than 3 hours; see Figure 8.13.

Now, we're done with the MIPS part of the survey, and we should move on to IRAC. Before we do, though, let's consider another option for the MIPS scan map, covering an even larger region.

8.6 Another MIPS Scan Map Option: Tiling a Larger Region

Here is another example - what if we wanted to cover a larger region, say a $2° \times 2°$ map? Even at fast scan rates, mapping this region in one AOR will take longer than the three-hour limit. Since we already know a $1° \times 1°$ fast scan rate map takes about three hours (Figure 8.13), we can tile the region with four $1° \times 1°$ tiles with minimal overlap, and constrain the observations to be done closely spaced in time, e.g., roughly consecutively with plenty of gaps for necessary spacecraft and instrument activities. In order to do this, we would have to return to target entry as above and enter four map centers set at appropriate coordinates around the main map center, in this case θ Ori, e.g., in units of offsets from θ Ori, $(+0.5°,+0.5°)$, $(-0.5°,+0.5°)$, $(-0.5°,-0.5°)$, and $(+0.5°,-0.5°)$. Then, we could duplicate the above simple AOR for each of these four map centers.

There are other ways to do this as well. Note that you can't use the fixed target offsets option with the MIPS scan map AOT. However, we can use the "Map Center Offset" parameters in the AOT window (see Figure 8.10) to literally offset the map by more than one field of view. This doesn't save us anything in slew overhead, and conceptually, at least one of the authors of this cookbook thinks it is clearer to separate them entirely with different target IDs, so this is what we do in the following. However, note that with respect to field rotation (see below), using map center offsets may in fact shortcut some of the potential rotation problems.
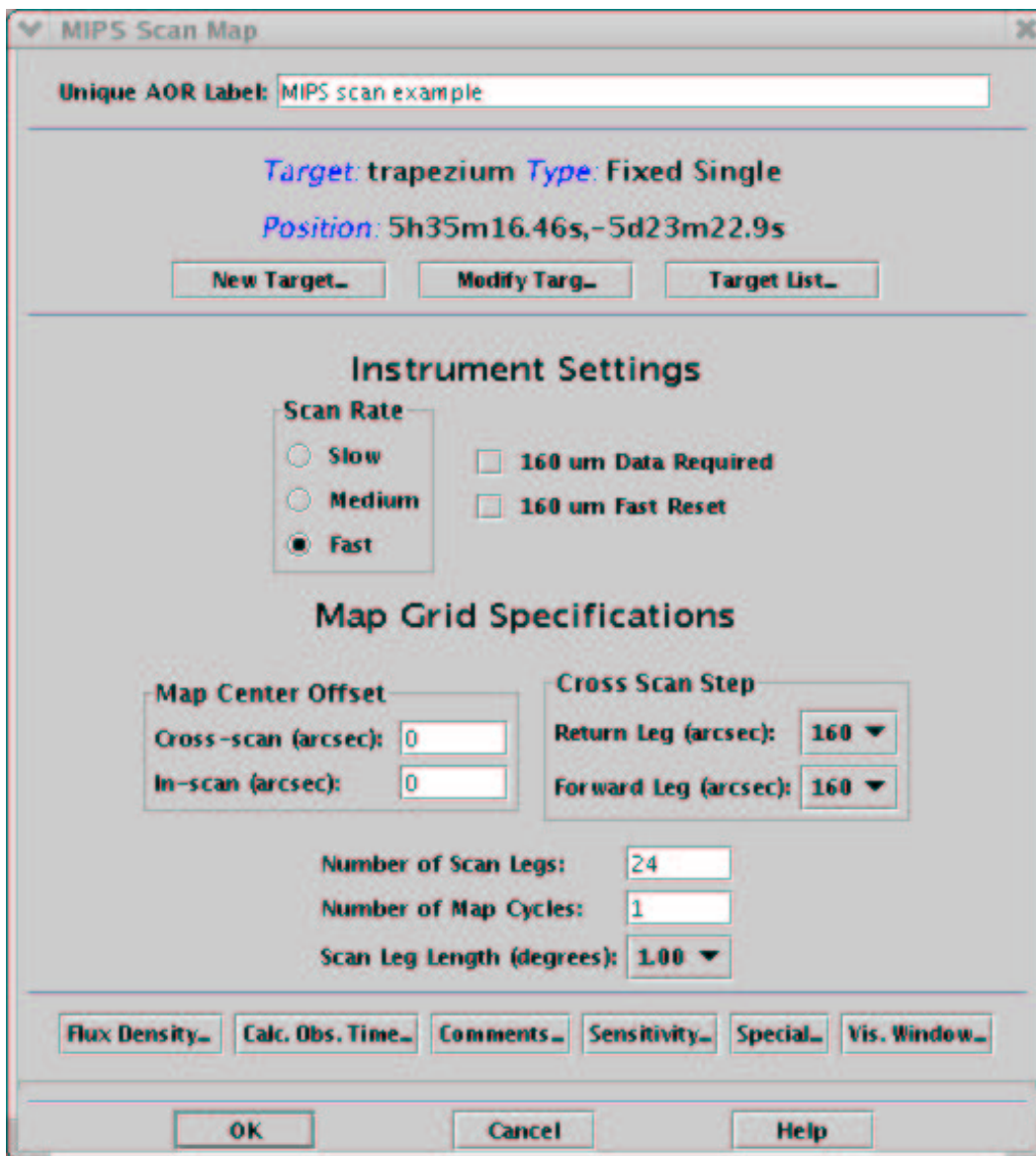
Figure 8.13: MIPS Scan Map AOT window, final values for the planned observation.

Briefly, then, this is how we could do this observation.
Step 1: Enter targets for each field of view; see Figure 8.14.
Step 2: Fill AOT for each target. We could individually repeat entry

Target	Position	Equinox	Type
Trapezium NE	5h33m18.59s,-4d53m28.6s	J2000	Fixed Single
Trapezium SE	5h33m18.59s,-5d53m28.6s	J2000	Fixed Single
Trapezium NW	5h37m17.33s,-4d53m28.6s	J2000	Fixed Single
Trapezium SW	5h37m17.33s,-5d53m28.6s	J2000	Fixed Single
trapezium	5h35m15.05s,-5d23m29.2s	J2000	Fixed Single

Figure 8.14: Target list for alternate MIPS Scan Map scenario.

of each AOT separately for each of the four targets, but a more efficient use
of time would be to be sure the original Trapezium map AOR is highlighted,
then click on the "Copy AOR" button on the toolbar. After copying, double-
click on the new row that is a copy of the original AOR, and update it
accordingly by changing its label as well as clicking on "target list" and
choosing the new target. Repeat for each of the four new fields. Calculate
the total time required for each AOR.

Step 3: Verify this with visualization if you have enough RAM and
have quit out of all other memory hogs (e.g., Netscape). We will need to use
an ISSA image, as no other available (Spot-retrieved) image is large enough
to handle the large field of view now covered by our observation.

Step 4: Enact constraints. This is a new topic for this chapter, so it
will be covered here in more depth than the other steps, in its own subsection
(next).

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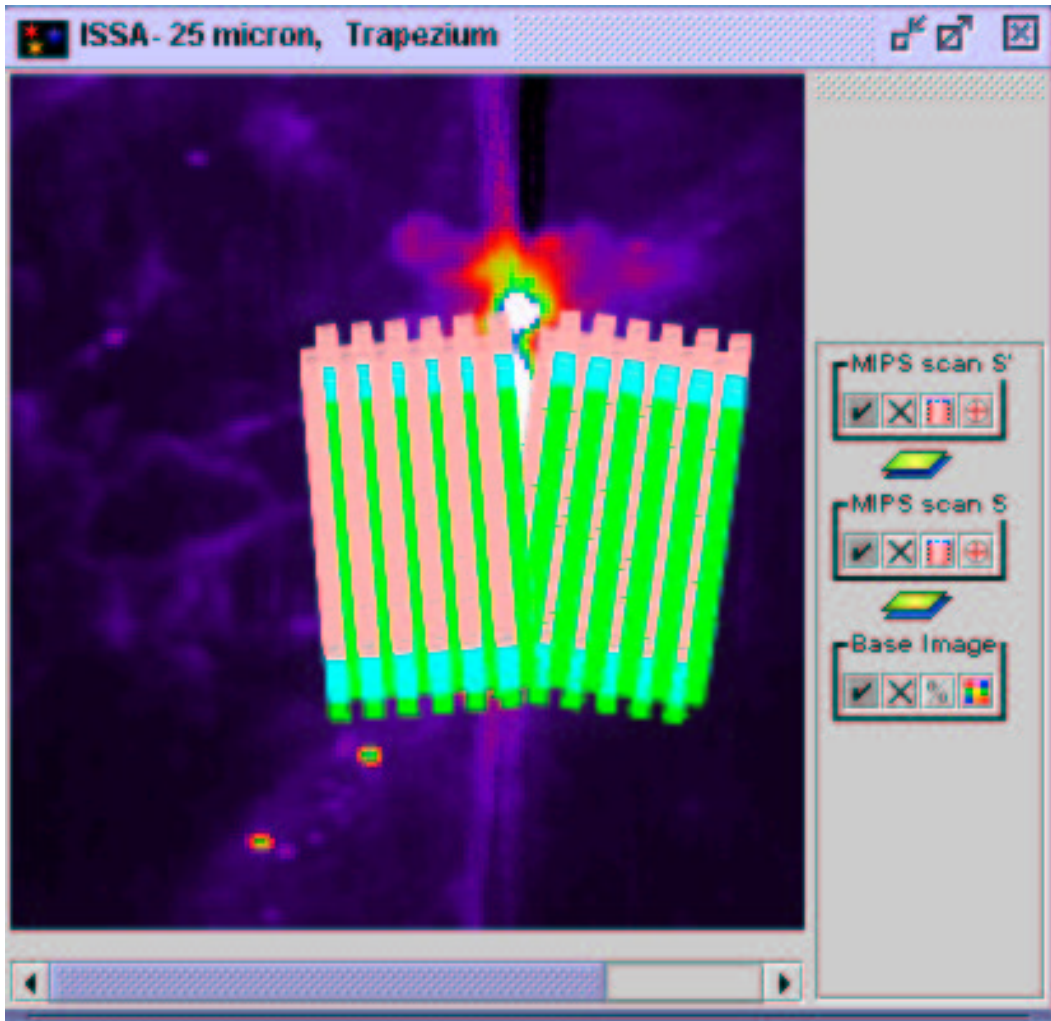
Figure 8.15: Visualization of alternate MIPS Scan Map scenario: what we don't want to happen. Note the wedge of missing wavelength coverage between the SW and SE maps.

8.6.1 Constraints

Since each of the $1° \times 1°$ maps take about three hours, and the field of view rotates in time, we will need to constrain these AORs to occur as close together in time as possible. For example, we do not want the situation that is depicted in Fig. 8.15; in this case there is an irregularly-shaped wedge of missing wavelength coverage between the maps because one was taken at the beginning of the visibility window, and the other was taken at the end of the window (about 6 weeks later), after the field has rotated.

For future reference, a field of view in the ecliptic plane hardly rotates at all, but a field of view at high ecliptic latitudes rotates quickly. A rule-of thumb is $1°$/day at the poles, and $0.5°$/day at mid latitudes. It's worth noting again that adding constraints to the observations requires compelling scientific justification, and may make it difficult or even impossible for the observations to be scheduled, so an alternative scenario is to place the map field centers close enough (e.g., such that there is sufficient overlap) that this is not a problem.

There are several different kinds of constraints. "Timing constraints" are meant to indicate constraints on specific times, e.g., this comet will be hitting Jupiter on this date and time, and this observation will only be meaningful if obtained at this date and time. These kinds of observations are generally the toughest to schedule, so don't use this unless you really must. This is not what we need here. What we do need are "Relational Constraints." Go to the Spot "Tools" menu and select "Grouping/Follow-On Constraints," which pops up a window like Figure 8.16. There are four relational constraint options:

- Sequencing, a.k.a. ordered, interruptible group. Sequence must be executed in order specified, but may be interrupted by, e.g., a downlink or calibration sequence.

- Chaining, a.k.a. ordered, non-interruptible group. Chain must be executed in order specified and without any kind of interruption. We can't use this here because each of our AORs is already close to the three-hour limit.

- Group within. Like a sequence, but order can be shuffled during a time period of specified length.
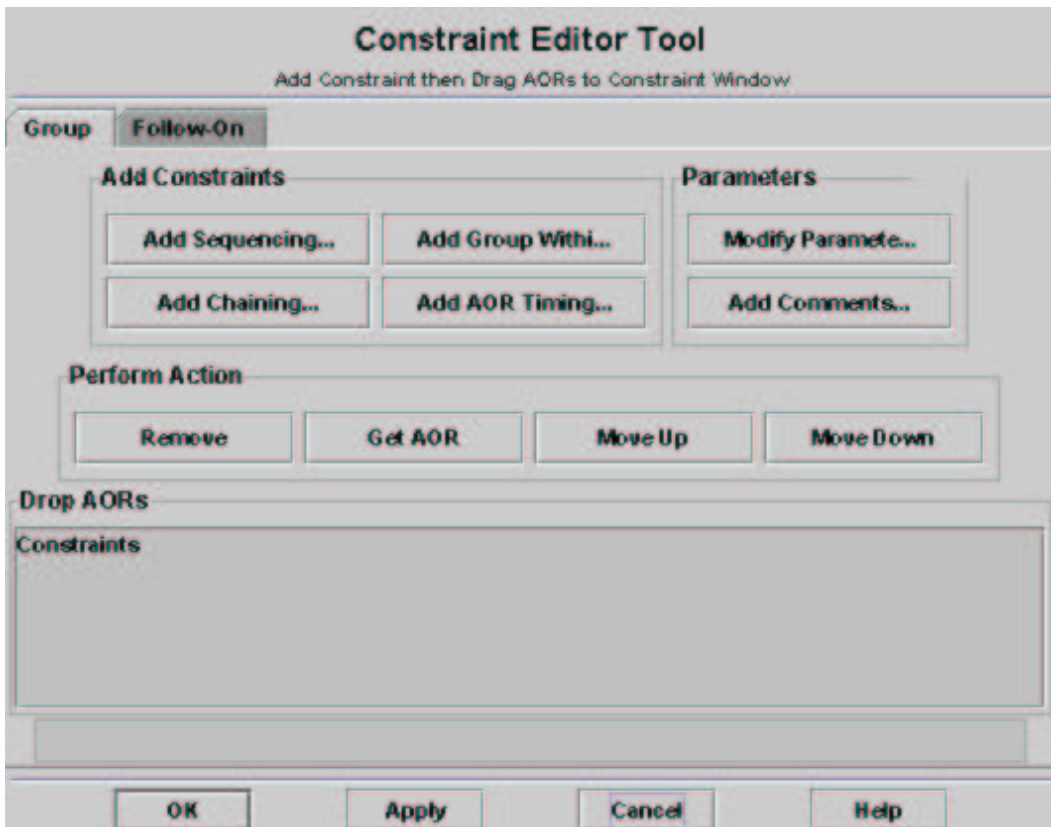
Figure 8.16: Constraint editor tool.

- Follow on. Used to specify scheduling of two AORs separated by a specified time, usually used when the ordering matters. For example, AOR #2 depends on the success or failure of AOR #1, as in we need to make sure we can peak up on a target before exposing for a deep spectrum using IRS. If we had only two AORs, or wanted to break our 4 AORs into two groups, we could use this constraint.

For this project, we want either a sequence or a "group within." We want to be as flexible as possible for ease of scheduling, so we choose "group within." Clicking on that option in the Constraints Editor produces the window in Figure 8.17.

By playing with visualization and timing, we learn that a week is about the upper limit for field rotation before left-right (E-W in this orientation) spatial coverage is compromised. We also learn that the overscan in the up-
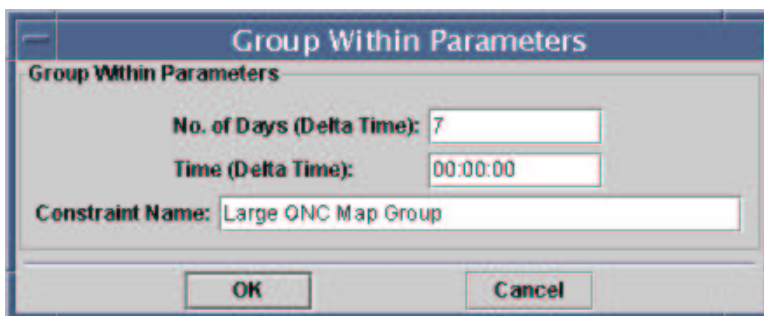
Figure 8.17: Group within parameters.

down (N-S here) direction is such that even the most extreme rotation for this field doesn't compromise the coverage, at least not as quickly as in the left-right/E-W direction.

So, we enter 7 days, 0 hours into the window in Figure 8.17, and click OK. Then click on the constraint and either drag-and-drop the AORs or highlight each AOR and click on "get AOR." For this example, we put all of the AORs in the same group (see Figure 8.18). We could just put the two North fields in one group and the two South fields in another (could instead use follow-on constraint in that case).

> **Note:** Save your AOR(s) early and often. Now would be good. When you finally go to actually submit your proposal, make sure that you are submitting a clean set of AORs. If you've been playing around with options and alternate targets, make sure to delete those AORs and targets entirely before submitting.

OK, now we're really done with MIPS! The file, ready to be loaded into Spot, containing the raw AORs developed in this chapter (and the IRAC observations in the next chapter) can be downloaded from the SSC webpage:

http://ssc.spitzer.caltech.edu/documents/cookbook/

To develop complementary IRAC observations of the same region, see §9.
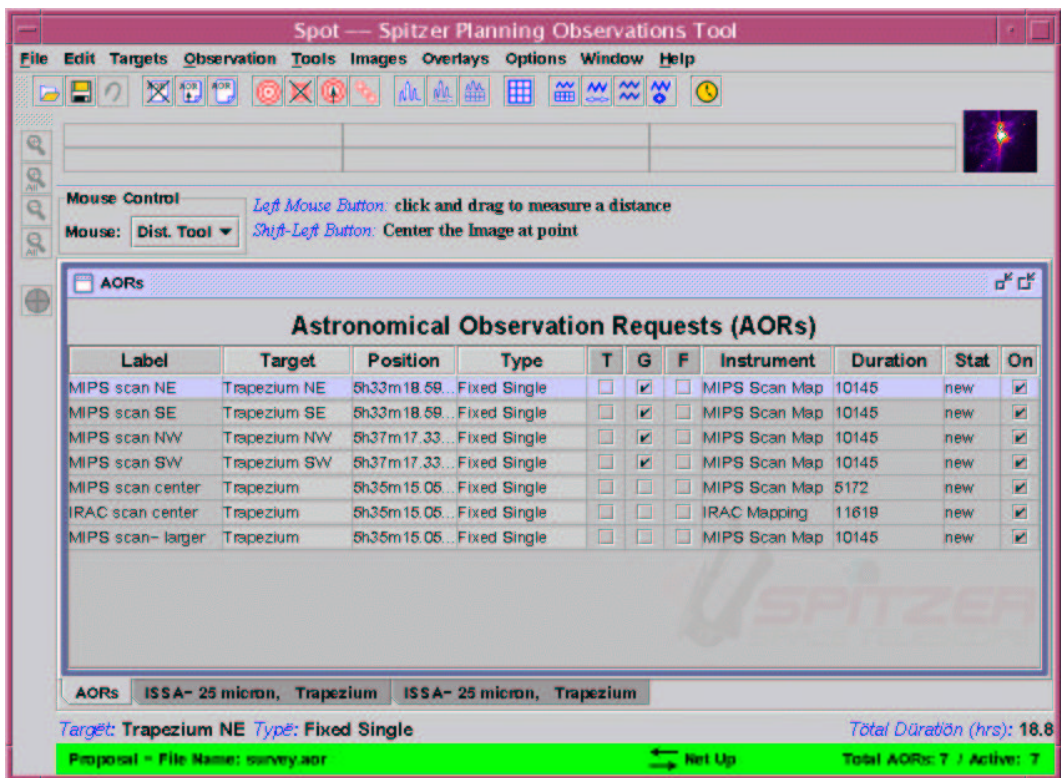
Figure 8.18: Filled-out constraints.

Chapter 9

Large-Area Mapping in the Trapezium at 3.6 - 8.0 microns with IRAC

In the previous chapter, we described the procedure to develop a large-area imaging campaign using MIPS. In this chapter, we develop a complementary project to image the same regions of the sky in the 3.6 - 8.0 micron range using IRAC.

A brief note before we get started: in §3 we designed an IRAC deep imaging campaign. Many of the details of setting up the observations, and the Spot interface, are similar between the example expanded in this chapter, and the deep imaging observation in §3. Therefore, we have provided somewhat less detail here, and refer to §3 for further information.

IRAC's images are at 3.6, 4.5, 5.8, and 8.0 μm, with bandwidths of 0.7, 1.0, 1.4, and 2.9 μm, respectively. Each pixel is $\sim 1''.2$; each image covers a total of $\sim 5'.2 \times 5'.2$. Recall that 3.6 and 5.8 μm share an entrance aperture, as do 4.5 and 8.0 μm.

We want to cover an area comparable to the MIPS survey above (see §8) but still be able to reject cosmic rays, so we'll need to dither, with at least 3 images per patch of sky.

9.1 Overview of the Program

- **Target Selection:** This is a complementary program to the observa-

tions developed for MIPS in the previous chapter. We observe in the Trapezium; see §8.2 for a discussion of target selection, and the implications for this particular object being in Spitzer's Reserved Observations Catalog.

- **Background Estimate:** Since we are developing observations for IRAC, and these wavelengths are all shorter than the IRAS wavelengths, Spot's estimates of background (rather than IRSKY) are preferable here. See §9.2.2.

- **Filling the IRAC AOT:** A screen capture of the completed IRAC AOT entry dialog is shown in Figure 9.4. We require wide-area coverage, so we choose "Full Array" mode. We expect to have bright objects over the whole large area covered here, so we choose "High Dynamic Range" mode. We observe in all four passbands, selecting **both the** 3.6/5.8 μm **and** 4.5/8.0 μm **fields of view**. A $1° \times 1°$ region can be covered by a 14×14 **map** grid, stepping 85% the width of the array, $260''$, and using **dithering** (3 per position, using Cycling); see §9.3.

- **Durations:** It takes 4.1 hours; see §9.4.

- **Visualization:** We overlay the planned AORs on an ISSA image of the Trapezium. Visualization of the planned AOR helps us verify that we are really doing what we think we are doing! See §9.5.

9.2   Exposure Time

In order to decide on an exposure time, we need to consider what the limits of the detectors are, what flux we expect from the background, and what flux we expect from the objects.

9.2.1   Saturation Limits

As with MIPS, to find the instrument saturation levels, we check the SSC IRAC website. See:

<p align="center">http://ssc.spitzer.caltech.edu/irac/</p>

Table 9.1: IRAC Point-Source saturation limits (mJy).

wavelength (μm)	0.02 s (subarray)	0.4 s (subarray)	2 s	12 s	30 s	100 s
3.6	20000	1000	190	32	13	3.8
4.5	17000	820	200	33	13	3.9
5.8	63000	3100	1400	230	92	27
8.0	45000	2300	740	120	48	28

for the very latest in saturation limits for IRAC. These limits are subject to slight changes so please do check the website and/or the Spitzer Observer's Manual for updates.

9.2.2   Background Estimates

When we were calculating the background levels for MIPS wavelengths in §8.5.1, we also made estimates for IRAC wavelengths. See Table 8.1 for the results. The nebula is nowhere near as bright in these wavelengths as it was for MIPS, so it is not as big a concern. Relying on Spot's estimates is better than going to IRSKY in this case, particularly because these wavelengths are all shorter than the IRAS wavelengths.

For comparison to saturation limits, we need to convert the background estimates to mJy/px using IRAC pixel sizes and the conversions from Appendix A; we get 3.4×10^{-11} sr/px.

We note that the contribution from the background alone will not saturate the detectors, but it will eat up dynamic range, leaving less room for counts due to objects. Now, we need a better estimate of counts due to the objects.

9.2.3   Source Count Estimates

Recall that our minimum science goal is to obtain photometry for G stars in the ONC region. A small number of G stars (like four or five) have been measured from the ground to have L (3.4 μm) $\sim$ 9th mag, M (4.8 μm) $\sim$ 7th mag, and N (10 μm) $\sim$ 5th mag. These wavelengths conveniently bracket the IRAC wavebands. Using the conversions in the Spitzer online Mag-to-Jy search tool or in Appendix A, these magnitudes convert to 0.072, 0.27, and 0.36 Jy, respectively.

Now, admittedly the ground-based detections are going to pull off only the very brightest stars. We note that (check the IRAC website!) the point-source saturation limits are given in *milli*Janskys, and even under the high-background conditions, the 1σ sensitivities are measured in *micro*Janskys. Evidently we ought to worry not so much about simply detecting these stars, but about whether or not they will be too bright! Fortunately, we happen to know (from painful personal experience) that there are quite a number of late-type stars in Orion with N magnitudes not detectable from the ground. Even if these four or five stars detected from the ground saturate the detector, we expect that there will be other stars that do not saturate.

9.2.4 Sensitivity Estimates

Now we will use the sensitivity estimator on the Spitzer web pages here, specifically the IRAC portion:

$$\text{http://ssc.spitzer.caltech.edu/tools/}$$

We enter the shortest whole frame (as opposed to subarrays) time with High Dynamic Range (HDR) option, 12 seconds, with 1 repeat and high background. The resulting 1σ sensitivities at 3.6, 4.5, 5.8, and 8.0 μm are 4.8, 7.1, 44, and 52 μJy. Let's say we only believe 5σ detections, e.g., 24, 36, 220, and 260 μJy. Backgrounds have already been included in this estimate. The aforementioned ground-detected stars will obviously be easily detected, assuming they don't saturate the detector. The additional frame from the HDR mode will help us obtain calibrated data for even those brightest stars that will saturate at 12 seconds. If we don't expect to care about those brightest stars, we can use a 2 second exposure instead and save a reasonable amount of time – 0.6 hrs!

9.2.5 Final Decision on Exposure Time

We're still in this to cover as much area as possible, and there are likely to be bright things all over the place. The shortest exposure time available for a full-array readout in HDR mode is 12 seconds, so we will go with that. Note also that the sub-array options are not useful here, as we are aiming to cover a large area.

9.3 Filling in the AOT

Now we're ready to fill in the IRAC AOT. We can either look under the Observation menu and select "IRAC Mapping" or click on the IRAC icon on the toolbar. See Figure 9.1 for the default values.
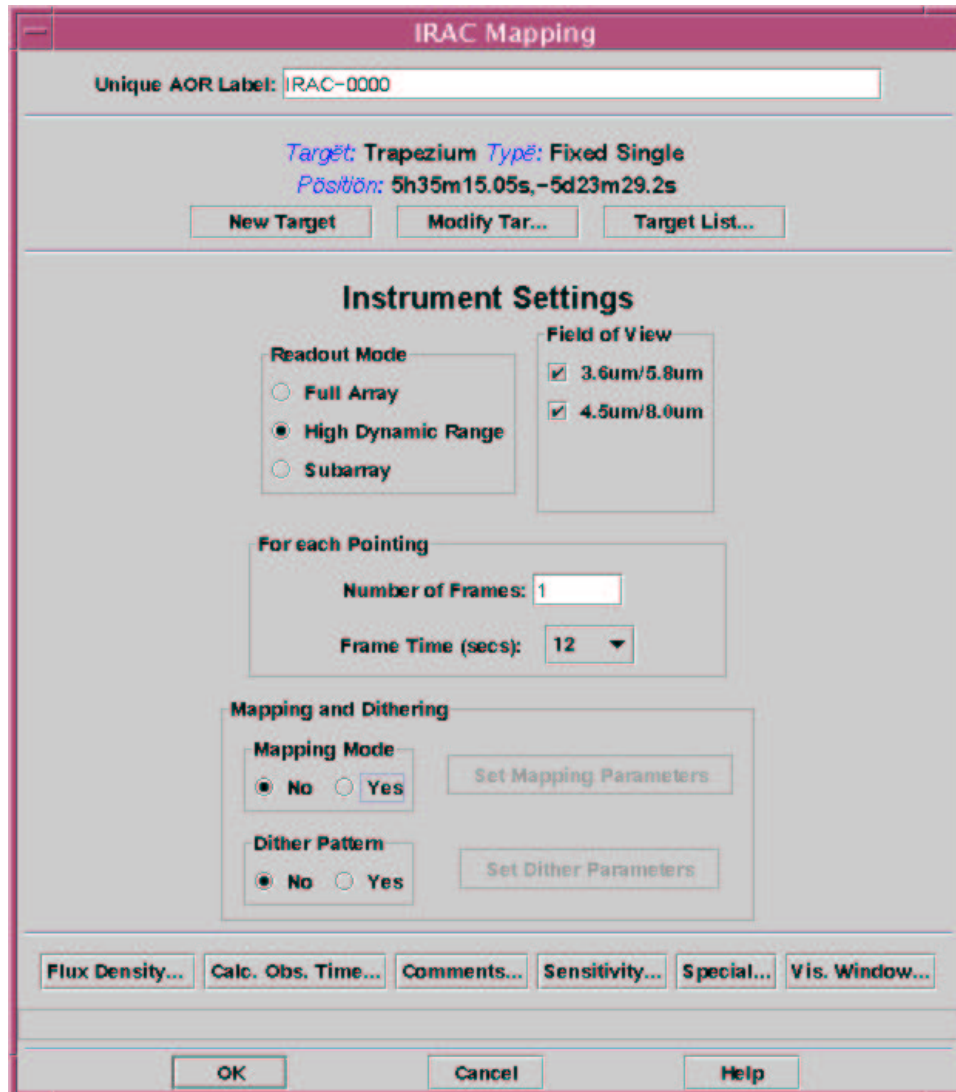
Figure 9.1: IRAC AOT window, default values.

9.3.1 Basic Identification

Note that Spot has pre-assigned an AOR label, as before, but this one starts with IRAC, of course, rather than MIPS as in §8.5.4. As in §8.5.4, to ensure sanity when we go back to this a year or 6 from now, it makes sense to pick a label that is actually descriptive and not just something like "number 463205sprime." Note that we should not use periods or colons in the label.

9.3.2 Instrument Settings

We are going for areal coverage here, so we choose "Full Array" readout mode, and make sure that both fields of view are checked, because we do indeed want all four wavelengths. We also ensure that "HDR" mode is selected. As with MIPS, all four detectors are always taking data, but the fact that we have checked both fields of view affects exactly how the map is executed, in exactly what pattern.

For each pointing, we select 1 frame, with a 12 second frame time.

Figure 9.2: IRAC mapping parameters.

Now, we want to do both mapping and dithering. Clicking "yes" for mapping mode produces the window in Figure 9.2. We obtain more uniform coverage when mapping in array coordinates.

We want to cover as much as we can of the $1° \times 1°$ patch approximately lined up with the MIPS AOR. We'll grid the region, stepping 85% the width

of the array, 260″. This will allow enough overlap to match up the tiles afterward, but still cover the area. In order to do this, we will need a 12×12 grid.[1]

We don't want any map center offset, and we should use array (rather than celestial) orientation; this is because we don't want funny gaps in the map (see the IRAC chapter of the SOM for more discussion). And, finally, we want to execute this map only once. After clicking "OK," now that we have set some mapping parameters, note that the button "set mapping parameters" is now clickable (it used to be greyed out). To retrieve the window from Figure 9.2, click on this button.

> **Note:** We avoided the use of "repeats," which are tantalizingly available as "number of frames" on the IRAC AOT. This option results in multiple observations without moving the telescope and should be avoided. Instead, we want to "dither" to ensure good cosmic ray rejection, mitigation of scattered light, long- and short-term latents, and artifact masking. Do NOT set number of frames to anything other than 1!

Clicking "yes" for dither pattern produces the window in Figure 9.3. We click on the button to enact "Cycling," and choose the recommended minimum of three dither positions from the dither table. (We can let it start any place it wants, it doesn't matter.) Since there is only small overlap between map tiles, we chose a "medium" scale factor. Now we do want to keep the dithers small to keep the coverage as uniform as possible, but, conversely, we also need large dithers to separate large-scale photometric variations from sky variations. A reasonable compromise is "medium" scale dithers.

As with the mapping parameters, after clicking "OK," we have set some dither parameters, and the button "set dither parameters" is now clickable

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[1]Using more grid elements than this (e.g., 14×14) results in an error in Spot – to see the detailed error, we pull up the AOR, increase the grid elements to 14, and explicitly ask Spot to calculate observing time. It checks on the number of commands, the number of strings, the size of the command sequence, and the number of instructions for the spacecraft we're generating via this AOR. We run over on the number of instructions. We can break our AOR up into pieces (see the previous MIPS chapter for an example of this concept), or we can just reduce the size of our map slightly, which is what we have done here. This whole issue may be remedied in a future software release, but for now it's safest to break up the AOR or reduce its size.

Figure 9.3: IRAC dither parameters.

(it used to be greyed out). To retrieve the window from Figure 9.3, click on this button.

9.4 Time Estimates

A screen capture of the completed IRAC AOT is displayed in Figure 9.4.

We calculate the total time to execute this AOR by clicking on "Calc. Obs. Time" in the AOT window or via "Tools/Recompute All Estimates." By doing this, we learn that we come in at about 4 hours for this AOR. Note that unlike MIPS, the limit for an IRAC AOR is six hours, so we're fine. Clearly, if we had opted for the larger MIPS map, we have plenty of time left in this AOR to tile over a larger region with IRAC; we don't need to split it into several AORs and link them with constraints. (Although, see footnote above about "number of instructions.")

Save your AOR(s) early and often. Now would be good.
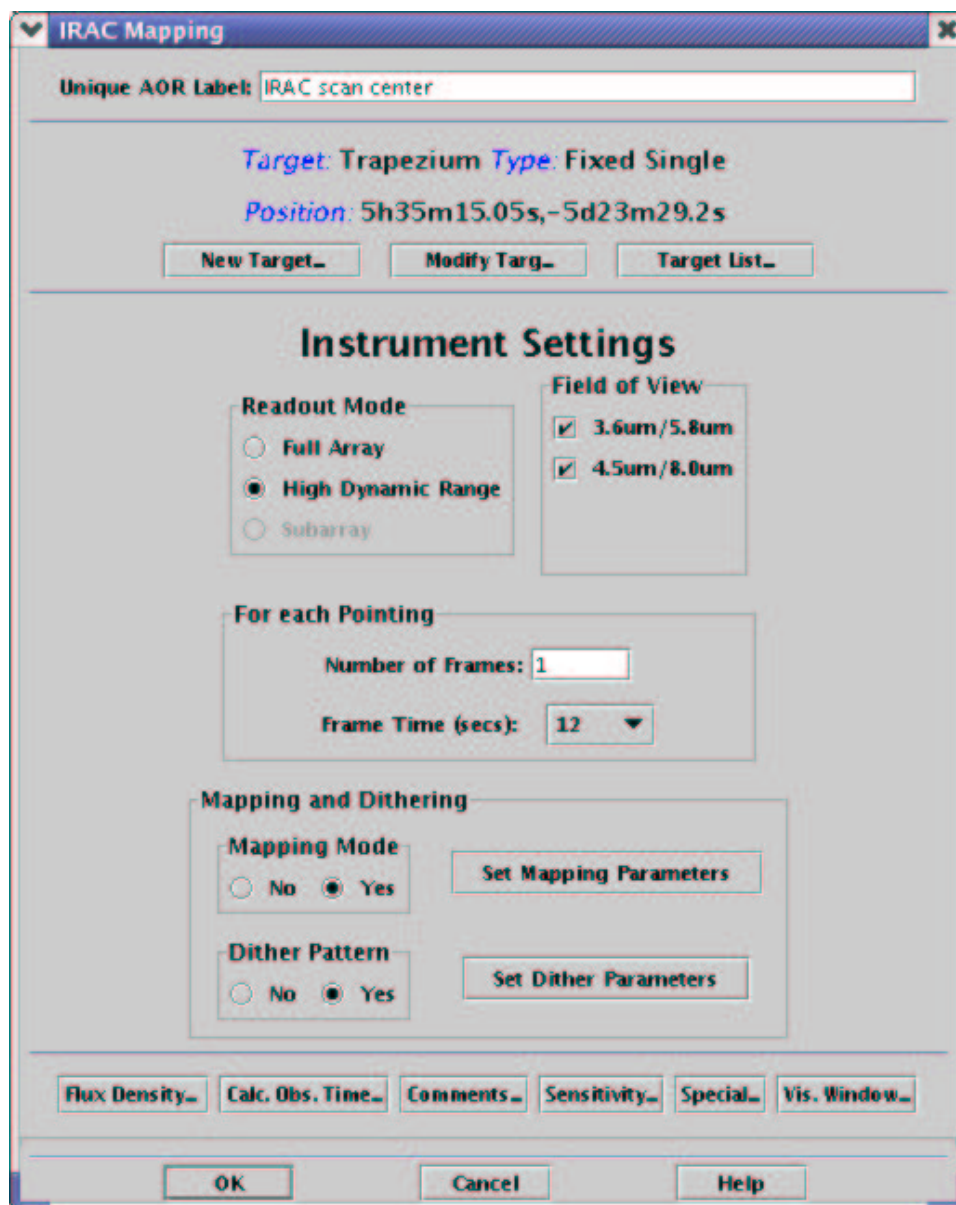
Figure 9.4: The completed IRAC AOT window.

9.5 Visualization

We can overlay this AOR on the ISSA 12 μm image. As with the large MIPS maps, this too may take a while to finish and suck up quite a bit of memory in the process. If you are viewing this document on the web (and it's in color), the fuchsia (pink/purple) is the 4.5/8.0 μm field of view, and the teal (blue/green) is the 3.6/5.8 μm field of view. Note, as in the MIPS map, there are regions at either end where there is incomplete wavelength coverage.
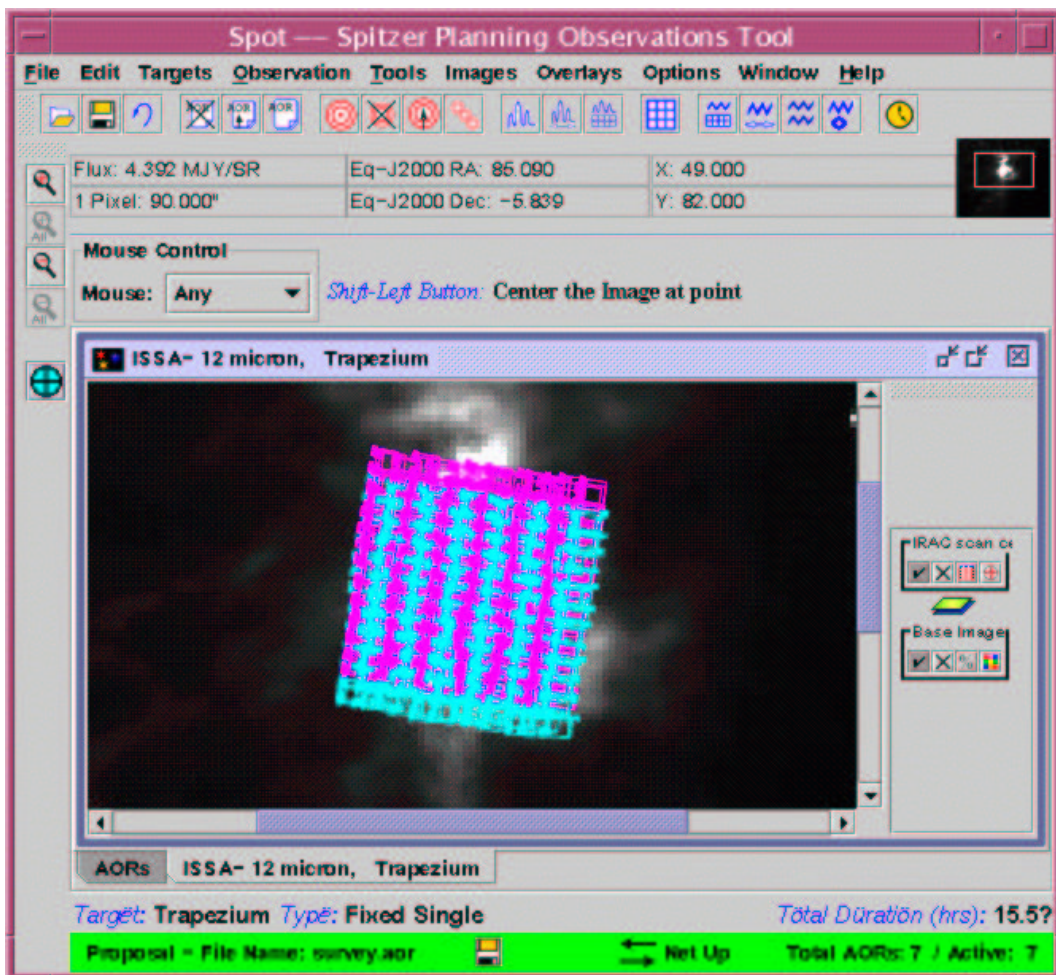
Figure 9.5: Visualization of IRAC observation.

If you dare (and you have enough RAM), select the pointings table (the

red and blue table icon that appears on the right of the ISSA image window when you overlay this AOR) and choose "Animate" to watch it dither three times per pointing. Make sure that it isn't dithering with too large of an amplitude that leaves spaces between tiles. See Figure 9.5. If the spacing isn't what we want, we can change to small (or large) amplitude dithers.

And we're off!! Write a GREAT justification and submit this thing.

> **Note:** When you finally go to actually submit your proposal, make sure that you are submitting a clean set of AORs. If you've been playing around with options and alternate targets, make sure to delete those AORs and targets entirely before submitting. If you had any constraints, be sure to strongly justify those in the proposal as well.

The file, ready to be loaded into Spot, containing the raw AORs developed in this chapter (and the MIPS observations from §8) can be downloaded from the SSC webpage:

http://ssc.spitzer.caltech.edu/documents/cookbook/aors/

Chapter 10

Photometry of Moving Object Centaur 5145 Pholus using MIPS

In this Cookbook, we have not yet tried imaging a moving target. Spitzer can observe Solar System targets, by tracking in linear segments at rate up to $1''$/sec, while superposing any requested mapping motions onto the track. Note that because Spitzer tracks in *linear* segments, if a given source track has significant curvature during a planned AOR, the observation may need to be broken up into smaller AORs. Visualizing the orbital track of your object in SPOT can help you determine whether an observation will need to be split into multiple AORs.

In this chapter, we will describe the steps needed to create an AOR for a moving target. Because imaging with MIPS and IRAC have been covered thoroughly in earlier chapters (see §3, §4, §8 and §9), we will not spend as much time on those aspects of these observations here; this chapter is meant primarily to give an example of observing a Solar System object.

We will plan an observation of the Centaur 5145 Pholus. Centaurs are objects whose perihelion is outside Jupiter's orbit (5 AU) and whose semimajor axis is less than that of Neptune (30 AU). Pholus is thought to have a size of about 190 km and an albedo of about 0.04. When discovered, it was the reddest object in the Solar System, a characteristic that is believed by some to be due to the presence of organic-rich materials on its surface. Observations of these kinds of objects at MIPS wavelengths will help to constrain albedos and diameters. They are too faint for IRAC, except perhaps

at 8μm, the very longest IRAC wavelength.

The collection of Spitzer resources for SSO observers can be found in the Proposal Kit area of the SSC website:

http://ssc.spitzer.caltech.edu/propkit/

This includes (among other things) an overview of things Solar System observers should know about observing with Spitzer, and a document called "Horizons Tips for Spitzer Solar Systems Observers." The JPL Horizons ephemeris tool has been modified to allow specification of Spitzer as a coordinate center. This is valuable, because although Spot can provide basic information on Solar System objects to help you plan, specify, and visualize your observations, it cannot provide detailed object-specific geometric information (such as planet phase, range, solar elongation, ...) which may also be important for planning your observations. Instructions on how to specify and request this sort of detailed Spitzer-centric information for your target can be found in the Horizons Tips document. (Note also that this document includes instructions for a new tool, ISPY, which allows you to query for known Solar System small bodies in your Spitzer data, at a given time).

10.1   Overview of the Observations

- **Target Selection and Suitability:** Before being selected for potential Spitzer observation, targets should be vetted for conflict with previous observations, and for the positional accuracy of the object's ephemeris.

- **Target Entry:** Target ephemerides for Spitzer are specified by providing the object's NAIF ID. See §10.3.

- **Completing the AOT:** With MIPS, to achieve ~ 300 sec integration time, we need 7 basic photometry cycles at 24 μm, and 9 cycles at 70 μm. To get up to 500 sec integration time at 160 μm, we need ~ 80 cycles (we are limited to 20 cycles/AOR, so we create several AORs). The completed AOTs are displayed in Figures 10.13 and 10.14.

- **Constraints**: If scientifically compelling, constraints can be applied to observations. In this case, we'd like some background, or shadow observations, which are treated as a kind of constraint. See §10.5.3.

- **Visualization:** An overlay of the planned AOR on an image helps us not only verify that we are really doing what we think we are doing, but also actually plan the moving object observation itself. See §10.4, 10.5, 10.5.4.

10.2 Target Selection and Suitability: Pholus

As with all other observations, we need to first check the ROC using Leopard. We find that Pholus observations with MIPS have already been taken by another observer. Had this been a real proposal, we could then check the Duplicate Observations Rule to see if the specific proposal idea we have in mind qualifies as a new observation – perhaps we would like to go deeper than previous observations, in which case our observation might not be considered a duplicate. Or perhaps the Solar System target we are planning to observe is known to be time variable, and we feel we could make a good scientific case for why it would need to be observed more than once during the Spitzer mission. However, for purposes of this example only, we will ignore the potential duplication, and continue planning a simple MIPS photometry observation of Pholus.

Another thing that is important to check is the known positional accuracy of your target at the time you propose. Although Spitzer's pointing accuracy is extremely good (typically less than an arcsecond), the position of your Solar System target as a function of time (the ephemeris) may be have a relatively large error. This could either be because the target is newly discovered, and has had relatively few observations made to determine its orbital parameters, or because the object has not been seen for quite some time and/or it is subject to unpredictable, non-gravitational forces, as is the case for comets close to perihelion. It is especially important to check for any available positional accuracy information when planning observation with the IRS, which has relatively small measurement apertures. However, even observations with MIPS and IRAC may have to pay attention to positional errors.

Remember to check for availability of positional error information for the ephemerides for your targets (instructions on how to do this can be found in one of the documents in the Solar System area of the website; there is additional information on this issue in the SOM). We do this for Pholus, and discover that it has 3-σ positional error ellipse of no more than ∼1.3

arcsecond throughout 2004. For our planned MIPS observations with a 5×5 arcmin field, this positional error is insignificant, so we do not need to worry about it. Causes for concern would include 3-σ radial errors that are more than half of the linear size of the measurement aperture, e.g., 2.5 arcminutes, in this case, or a lack of any available error information. However, even with large errors or no available error information, we could still have proposed for this target, on the proviso that we clearly note in the proposal that the object had large errors or no available error information at the time of proposal.

10.3   Target Entry

Start up Spot and enter a new target either by clicking on the bulls-eye target icon on the taskbar, or selecting "New Target" from the "Targets" menu.
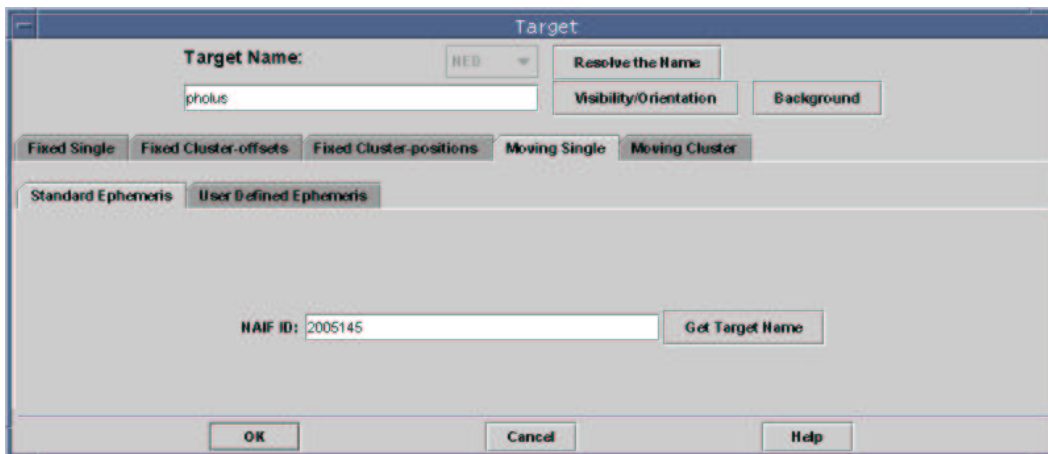
Figure 10.1: The target window after entering Pholus.

Click on the "Moving Single" tab to pull up the window shown in Figure 10.1. Enter "Pholus" in the Target Name box. Note that, unlike in other chapters, we cannot resolve the name using NED or SIMBAD. This time, Spot contacts HORIZONS directly to resolve the NAIF ID. Clicking on "Resolve the Name" in Figure 10.1 fills in the NAIF ID box.

Note that, to be able to return accurate time estimates, or calculate visibility and visualization, Spot needs to have access to that object's ephemeris, and successful name resolution does not automatically mean that we have an ephemeris available. These are two separate steps. Spot has a core set of

ephemerides which are provided with each proposal call. However, this is a small fraction of the well over 100,000 objects with NAIF IDs that can be found in the DASTCOM list. To check whether Spot can already access an ephemeris for your object you can check Spot's list of ephemeris files:

http://ssc.spitzer.caltech.edu/propkit/spot/ephem.html

If the NAIF ID of your favorite Solar System target is not on our list, and you would like to use Spot to generate visibility windows for your object, please contact the Spitzer Help Desk (mailto:help@spitzer.caltech.edu) with the NAIF ID and/or name and type of body for your Solar System target (e.g., asteroid, comet, satellite), and we will update the Spot ephemeris database to include your target. You can request an ephemeris at any time, and it typically takes us less than 3 days to get the ephemeris on-line. However, it's a very good idea to check for availability of ephemerides in the Spot software as soon as possible, and request any objects you are even *thinking* about observing, well in advance of the proposal deadline. Do not leave this to the last minute! To guarantee that you will have your ephemeris to plan your observations, we must receive the request no later than a week before the proposal deadline. Any requests for ephemerides received in the final week before the deadline will be supported on a best effort basis only.

For this example, Spot knows about Pholus and has its ephemeris. So, after entering our target information, we click "OK" and we return to the main Spot screen. Note that the bottom of the Spot screen now tells us which target and target type we have entered. Save your target list, just in case. To retrieve the target list at any time, we can click on the icon that looks like 3 bullseyes on the toolbar.

To find exactly when the target is visible to Spitzer, we can click either on the "Visibility/Orientation" button in the target entry window, or from the target list window, "Calculate Visibility Windows for All" and then "Show Visibility." This shows us a list of the dates when Spitzer can actually observe Pholus. Next, we will visualize Pholus to see where it is on one of those dates.

10.4   Image Retrieval

Image retrieval has been discussed above in detail (e.g., §8.4), but Spot has some extra features for Solar System objects that merit review. Here we will not walk through retrieving images in detail, since that is covered in

earlier chapters (and in the Spot manual). We will use ISSA images since we are planning MIPS observations of this object, and the long-wavelength background is likely to matter.

From the Images menu, we select ISSA, and ask for all four wavelengths in one frame; see Figure 10.2. After clicking OK, Spot will ask what date we would like to visualize, and the number of data points to be distributed along the orbital arc. For purposes of this example, we pick "2004 Jul 30", and the default number of points; see Figure 10.3. Finally, then, we get the images and tracks shown in Figure 10.4. The tracks show Pholus' position as a function of time, as seen from Spitzer.
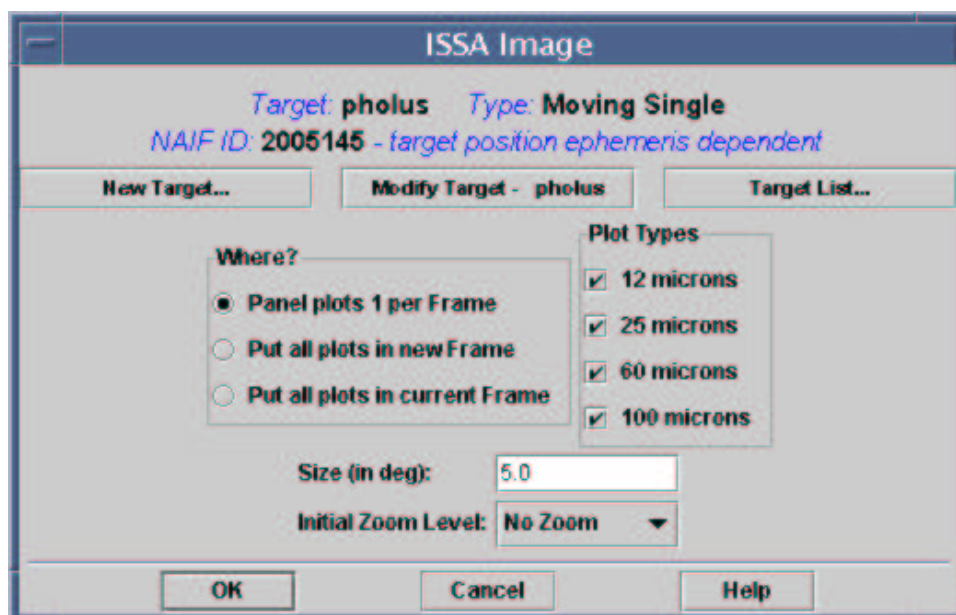
Figure 10.2: Retrieving an image from ISSA.

If we click on the tiny red-and-blue table icon associated with the Pholus orbital track overlay in one of the ISSA images, we produce the window in Figure 10.5, which lists the specific dates associated with each of the points in Figure 10.4.

The controls in this window do several things to the overlay in the corresponding ISSA window. "Hide All Points" or "Show All Points" turns off and on the points in the overlay. "Show All Dates" or "Hide All Dates" turns on and off the dates associated with the specific points in the overlay. The

200
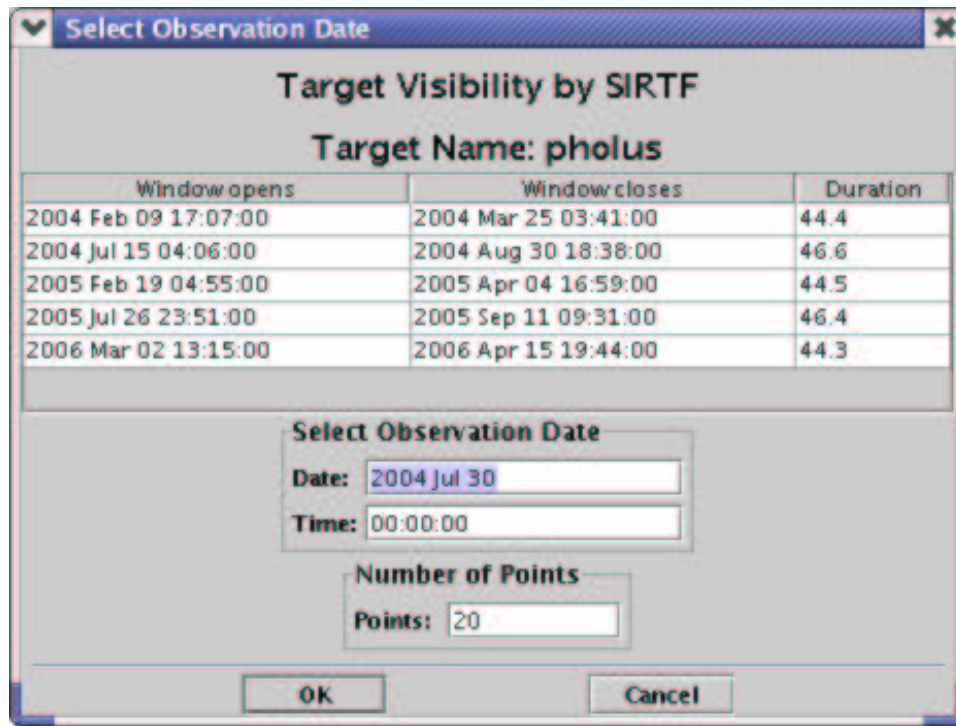
Figure 10.3: Picking the date to visualize.

next option, a pull-down menu, refers to the symbols used in the points in the overlay. "Point color" allows the user to select the point color in several different ways ("swatches," "HSB," and "RGB," just like in Adobe Photoshop or the Gimp). Similarly, "Line Color" allows us to choose the color of the track, and "Hide Path" or "Show Path" turns the track off and on. "Save Table" writes the object's position information as a function of time to an ASCII file. The individual entries for each point can be turned off and on, temporarily highlighted with a different color and symbol ("Hi" column checkboxes), have its shape changed, and have its individual date notation turned off or on. Most of these features will be useful for us in a moment as we consider background contamination.
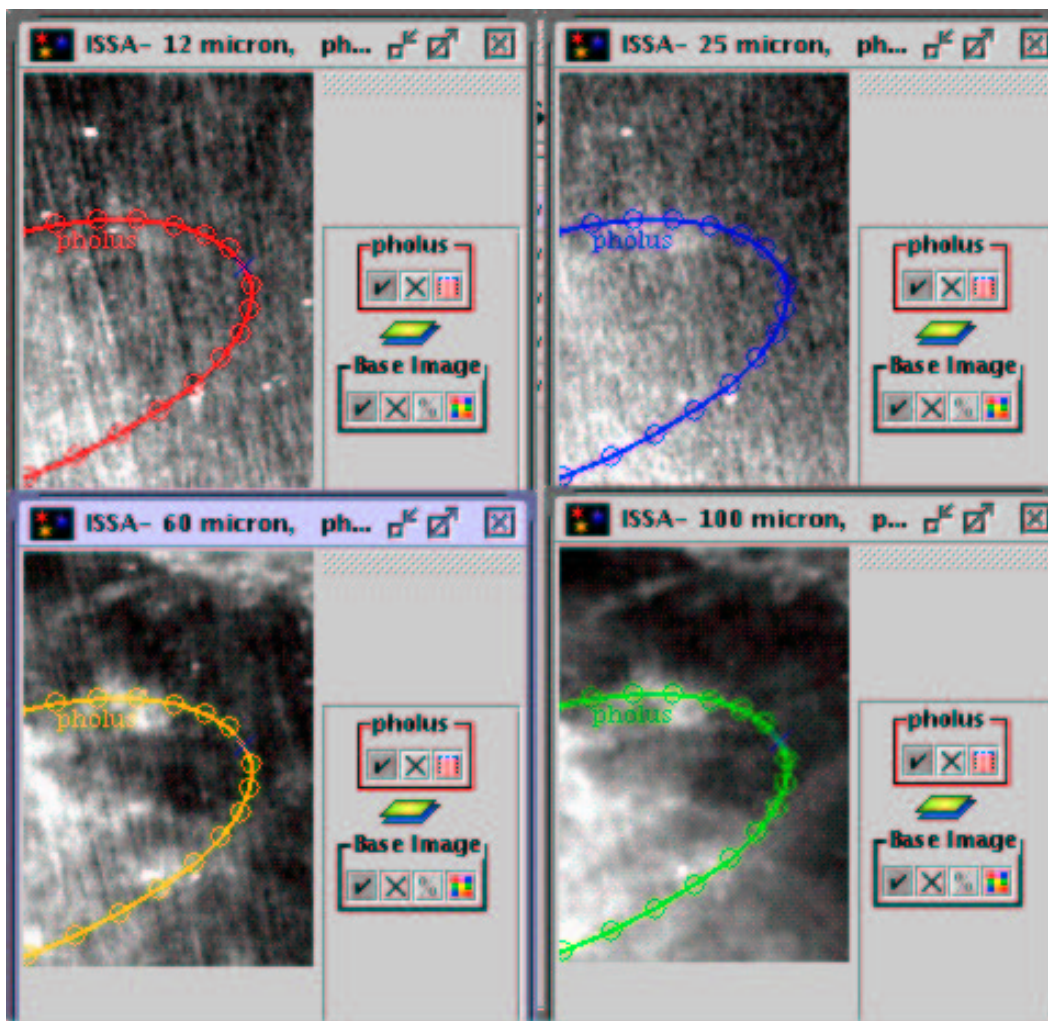
Figure 10.4: Pholus orbital track visualization in all four ISSA bands.

Figure 10.5: Pholus point identifications.

10.5 MIPS Photometry

10.5.1 Exposure Time & Saturation

MIPS is the only Spitzer imaging instrument that really can make observations of these cool, dark things in a reasonable exposure time. To estimate how bright your Solar System target will be, it may often be necessary to use specialized scientific models, such as Standard Thermal Models for asteroids, to estimate the brightness of your target at MIR wavelengths. These models are not provided by the SSC, and must be provided by you (or your carefully chosen collaborators!). For the purpose of this example, we use such a model, and the Spitzer online Performance Estimation tools to determine instrument sensitivities for a given background. With these two tools, we figure that we can detect Pholus with sufficient S/N for our purposes in ~ 300 seconds at both 24 and 70 μm, but to achieve a comparable S/N at 160 μm, we would have to integrate for 3800 seconds! Since 3800 seconds is rather a long integration time, we consider that if we integrate for 500 seconds, we can achieve acceptable (lower) S/N, which we decide is appropriate for our science. Note also, that if we were willing to approximate our target as a blackbody, then the Spitzer extragalactic PET, EX-PET, could have also been used to estimate MIPS sensitivities, saturation limits, and confusion limits. Also see the Infrared Compendium at the SSC website for an introduction to sources of background, including confusion.

These objects are so cool that saturation by these kinds of objects themselves is not a concern. But, they do move across the sky, necessarily in the ecliptic. Zodiacal light and intersection with the Galactic plane can both be a problem.

10.5.2 Background

MIPS is very sensitive, even with the on-orbit reality adjustments for the Ge arrays. Moreover, the stimulator flash that is an inherent part of MIPS data taking occupies up to 1/3rd of the dynamic range, so source+background should take up no more than 2/3rds of the available depth. For these and all of the other reasongs discussed in other chapters, it's really important to get a good estimate of the background flux at the wavelengths we care about for our science goals. Recently, background estimates have become available from within Spot for moving targets; this can be obtained identically as for

fixed targets, discussed above. Although we can calculate background levels for a moving target for a specific date, calculation of background levels over a range of dates is not (yet?) supported. See especially Section 8.5.1 for a discussion about backgrounds in Spot. However, it is also a good idea to make a manual check of the background.

The very first thing we can do is make sure that our object is not in the Galactic plane at a time when we are planning for Spitzer to observe it. We can check to see if any given Solar System object is in the Galactic plane by overlaying the object's location on an all-sky map in Spot. From Spot's Images menu, select "All Sky Images" and select the DIRBE survey for an all-sky image, NOT the ISSA image! Although it seems that Zodiacal light and the Galaxy are clearly visible in both, only the DIRBE image has reliable zodiacal fluxes.
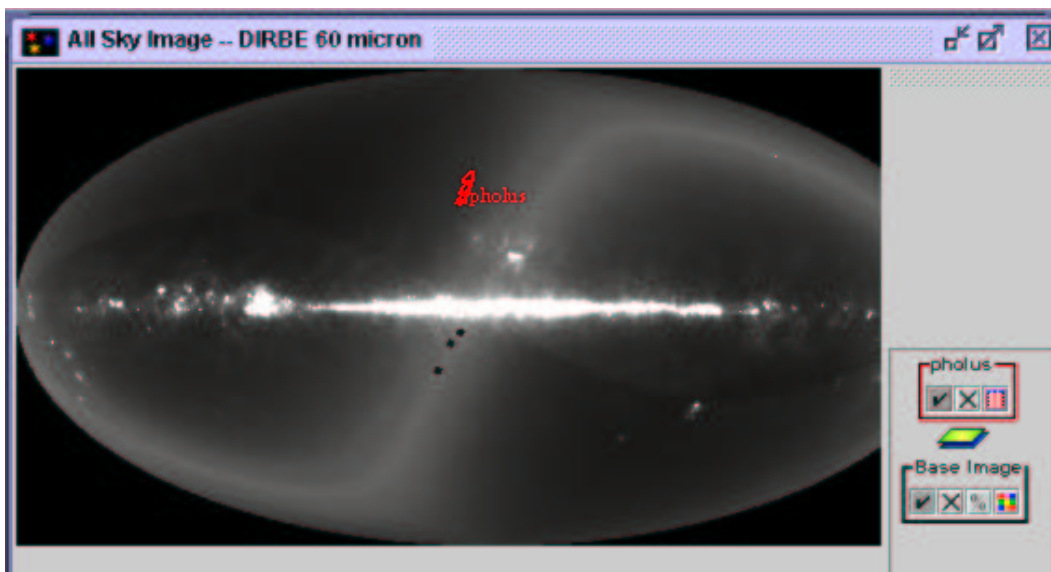
Figure 10.6: DIRBE all-sky image with Pholus overlaid.

Once the all-sky image has been retrieved, from Spot's "Overlays" menu, select "Add Moving Target" and select a target from the Targets window. Spot will calculate visibilities and enquire as to the specific date of observation. It will then overlay the track (with a default of 20 days) points on the all-sky image, often spanning several years; see Figure 10.6. Pholus, fortunately, is not in the Galactic plane, and it's even reasonably far away from

the brightest part of the ecliptic at this point as well. For the sake of example, some readers may also want to plot the position of Chiron on the all sky plot. It should become readily apparent why observations of Chiron will become successively more sensitive over the duration of the Spitzer mission.

If we'd like to use the DIRBE (NOT the ISSA!) all-sky image for background estimates, we can! First, zoom in on the target using the little magnifying glass icons on the left of the Spot window. The DIRBE all-sky image is calibrated, and will give us correct backgrounds, providing our target is at a Solar elongation of 90 degrees. If our object has a Solar elongation of 80 degrees, the zodiacal background could be brighter by 20%, and if it's at a Solar elongation of 120 degrees, the zodiacal background could be fainter by 50%. Since we don't know exactly when Spitzer will schedule our observation, we can't tell *exactly* what the elongation will be, but that's the possible range of backgrounds. Note also that this DIRBE image is at 60 microns, so technically it's only accurate at that wavelength.

There are other ways to estimate background, but importantly, we should NOT try this using the *individual* ISSA images retrieved from IRSA or Spot, because they *already have the Zodiacal light removed.* For moving targets, this is obviously somewhat less than helpful.

We retrieved some ISSA images above for 2004 Jul 30; see Figure 10.4. Although the individual ISSA images have the zodiacal light removed, they still have plenty of cirrus. As we can see in the figure, the ISSA 60 and 100 μm images reveal some patchy cirrus background we need to worry about. By turning on the dates in the overlay display, we learn that Pholus doesn't start to leave the high background region until about June 4, and pretty much after that through Oct 4 is clear, or at least clearer than it was prior to June 4. BUT, we have to also factor visibility windows into this discussion. From Figure 10.3, we can see that the 2004 visibility windows are 2004 Feb 12-2004 Mar 25 (which overlaps with the patch of bright stuff at 60 and 100 μm, with a background of 47 MJy/sr at 24μm, from the background estimator in the SPOT target window) and 2004 Jul 15−2004 Aug 27 (which are in a much clearer patch of sky, with a background closer to 27 MJy/sr at 24um from the SPOT). So, we have a scientifically justified case for constraining these observations to take place during the second visibility window on the basis of background contamination.

10.5.3 Filling in the MIPS Photometry/Super Resolution Imaging AOT

Now we're ready to fill in the AOT in Spot. Click on the MIPS Photometry/Super Resolution icon or select it as an option under the "Observation" menu. We obtain the window in Figure 10.7.

Figure 10.7: MIPS Photometry AOT window, default values.

Basic Identification

Working from the top, we can enter our own "Unique AOR label" or it will create one for us. To ensure sanity when we go back to this a year or 6 from now, it makes sense to pick a label that is actually descriptive and not just something like "number 463205sprime." Note that we should not use underscores or colons in the label.

If we have more than one target entered, we should verify that the target it has selected is indeed Pholus, and that it is a "Moving single" target type. (If you need to change the target, click on "target list," and if you need to change the target type or position, click on "modify target.")

Instrument Settings

We would like to image this object in all three wavelengths. This is a small-field observation, and we do not need to use the fine pixel scale (a.k.a. superresolution) 70 μm scale setting because we don't need the high spatial resolution, and we do need as large a patch of background as we can find for better background subtraction. We will need to visit the object at least twice in 160 μm to ensure we will be able to distinguish our object from background objects (e.g., beat the confusion limit).

Since we're sitting in (or at least close to) the ecliptic plane here, it would seem that deep single integrations would not be wise, due to the likelihood of bright background levels. However, it turns out that for better sensitivity during long total integration times, it is better for the Ge detectors in particular to use longer exposure times. The best available selection is 10 seconds. We need to take into account the fact that the stim flash that is an inherent part of MIPS operations will occupy up to a 1/3rd of the dynamic range, so that plus the other background plus the target hopefully will not saturate immediately. If there are a few samples of the ramp (see discussion of operations in the Spitzer Observing Manual, SOM), then the ramp can be reconstructed even if saturated.

Recall that a single cycle of MIPS photometry is a whole series of images, each at the requested exposure time. We can specify the number of cycles at each wavelength. From the correct table at the Spitzer/MIPS website or in the SOM, we look up that the 24 μm compact source photometry takes 14 frames per observation cycle, which at 3 seconds exposure time per frame, results in about 48 seconds integration time per pixel. Similarly, 1 cycle of 70 μm takes 10 frames, and with 10-sec exposure times, produces 126 seconds integration time per pixel, and 160 μm takes 10 frames in and around the source, but at least 4 cycles are recommended for minimum accuracy, resulting in the end in 83 seconds per pixel on-source.

These considerations mean that, to get about 300 seconds integration time, we need 7 cycles at 24 μm, and 3 at 70 μm. To get up to 500 s integration time at 160 μm, we need, well, *many* cycles! We are limited to selecting in any one AOR 20 cycles at 160 μm, so we do that for this AOR. See Figure 10.8 for these values. We can check the exposure time by clicking on "Calc. Obs. Time," producing Figure 10.9. Note that the 24 and 70 μm are darn close to 300 seconds, whereas the 160 μm is most but not all of what we need.

By clicking on the "Copy AOR" button, we obtain a duplicate AOR. We can modify that AOR to just obtain 160 μm data, for another 10 cycles, for a total 160 μm integration time of $\sim 5 - 600$ seconds.

> **Note:** One AOR contains observations at 24, 70, and 160 μm. We need not separate 24, 70, and 160 photometry into separate AORs unless we've configured things such that one band's observations alone are close to 3 hours in duration.

Save your AOR(s) early and often. Now would be good.
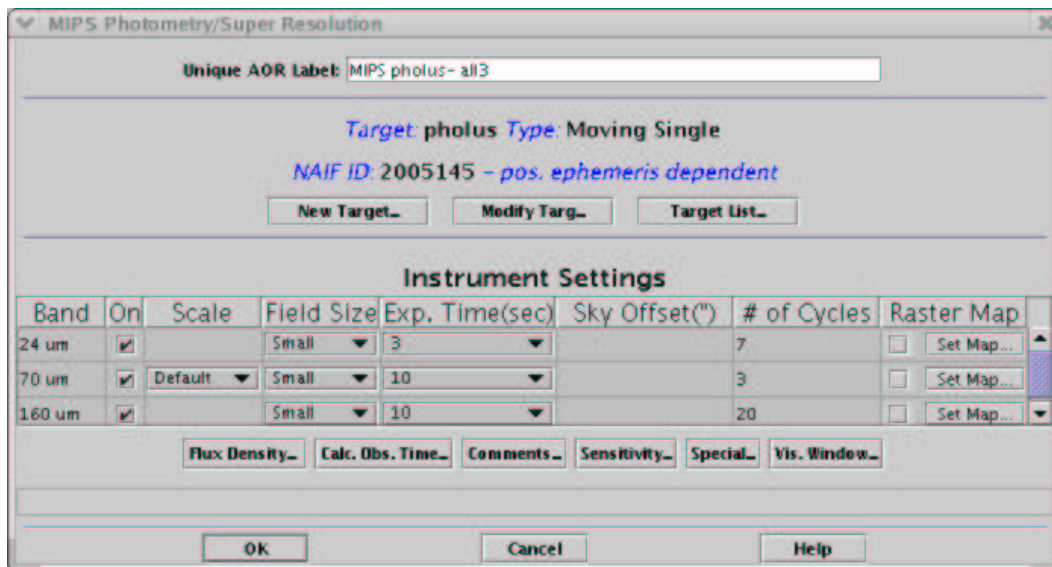
Figure 10.8: MIPS Photometry AOT window, filled values.

Constraints

As we noted above, we need to constrain these observations to be done during the second visibility window in 2004 to avoid the particularly patchy background seen in the ISSA images.

From the "Tools" menu, we select "Timing Constraints," producing Figure 10.10. We really have to be careful to make sure that the times we enter here are consistent with the actual visibility window, which is why there is a handy button allowing you to pull up the visibilities. We verify that 2004
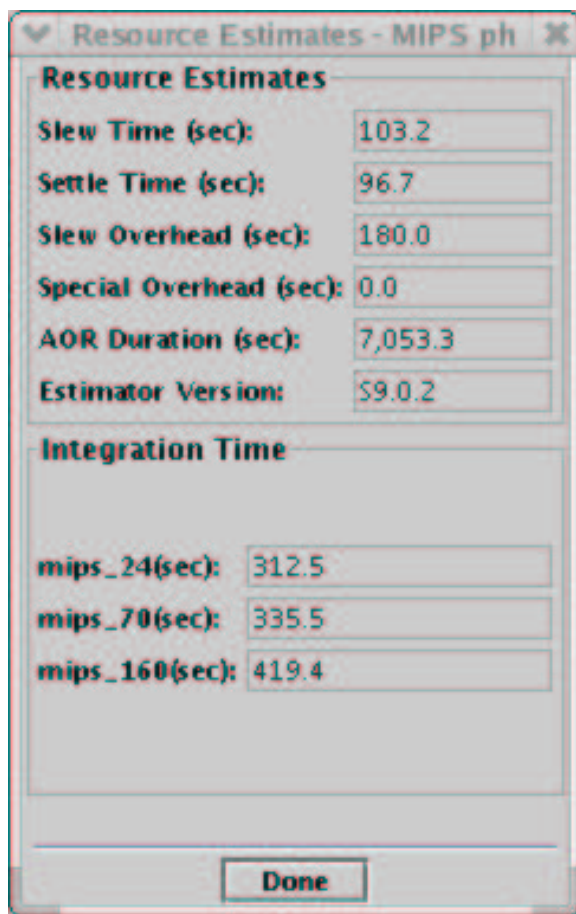
Figure 10.9: The resource estimate for the MIPS SSO observations.

Jul 15 05:00−2004 Aug 30 15:00 is a viable window, and enter that into the constraints window. Note that these constraints have to be entered separately for each AOR, and constraints don't get copied when you copy AORs. *NOTE that you have to click apply*, not just ok for the constraints to actually stick to the AOR. To regain this window in the future, select "Timing Constraints" from the tools window as above.

Shadow Observations

We are not necessarily done yet! If we expect to not have enough sky in the images we obtain, or if we expect a very patchy background, or if we are
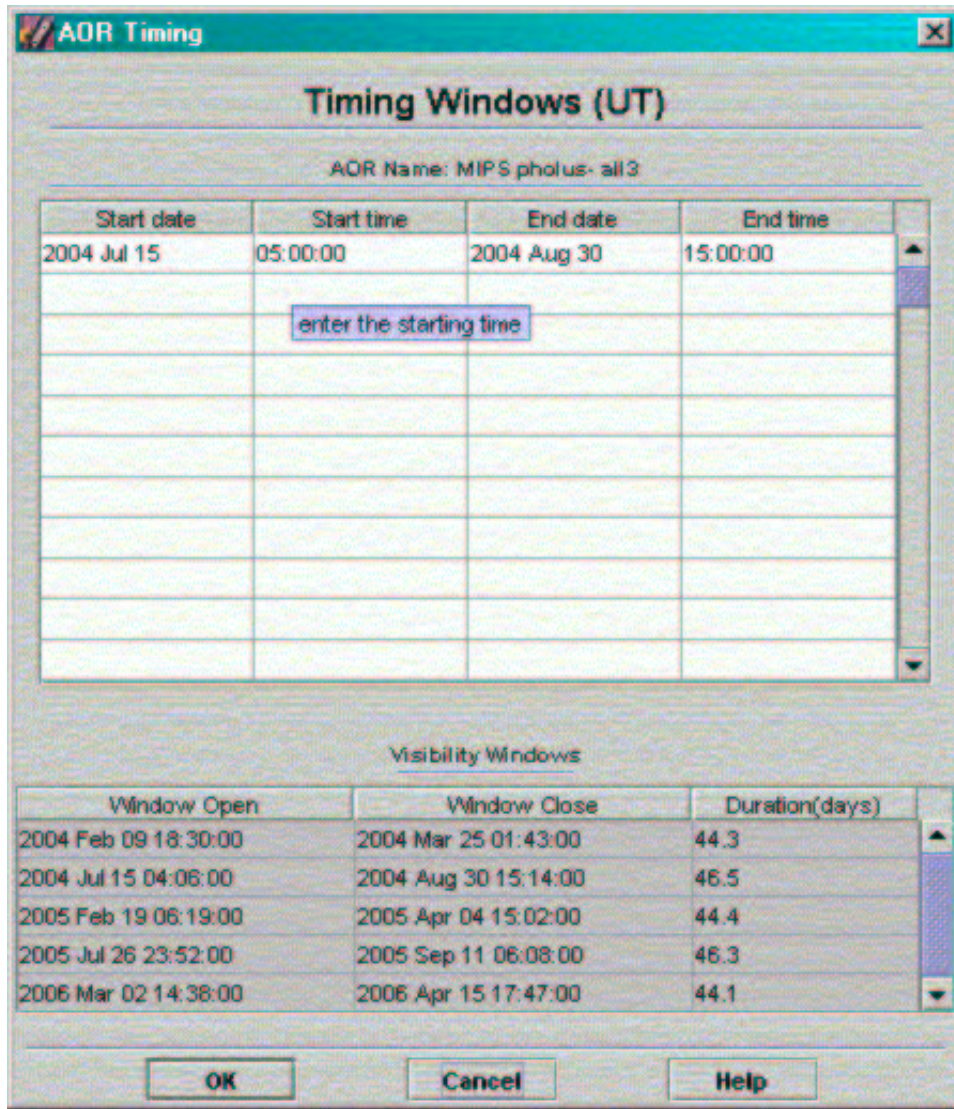
Figure 10.10: Enacting timing constraints.

attempting to distinguish our moving object from extragalactic confusions levels, or if we expect the object to be fuzzy (outgassing?) and therefore need a really good background subtraction to meet our science goals, we can obtain so-called "shadow" observations. Shadow observations are repeated observations of this same field at a later time, without the object (or at least with the object having moved with width of several PSFs), so as to

better subtract off the background. If we request this option, Spitzer follows exactly the same track as it does for the actual observations we have planned of Pholus, just after (or just before) Pholus has already moved on (or gotten there). When using shadow constraints, it is easier to schedule observations if your shadow (background) observation comes AFTER the main observation. If it doesn't matter to your science whether your shadow observation comes before or after the object, put it after. Here we put it after.

Shadow observations are a separate form of constraint, like a group/follow-on constraint. In order to set up a shadow constraint, first we need two identical AORs to link via this constraint. This is true for ALL AORs, including IRS observations of a moving target with peak-up; DO NOT disable the peakup in a moving target shadow observation – the Spot/AIRE software will take care of this behind the scenes. We select our MIPS AOR with all three wavelengths, and then copy it (via the Edit menu or the toolbar icon). Then, having done that, from the Tools menu, we select "Group/Follow-on Constraints" to pull up a dialog box. We select the "shadow" tab to pull up the right options. We then choose "Add Shadow." We want to make these observations enough later in time that Pholus has moved at least the width of several PSFs, but as close as possible in time to minimize changes in the Zodiacal background and the instrument calibration. It is also important to try to specify a shadow interval that is (preferably much) less than a typical instrument campaign – this is good both scientifically and for our scheduling process. For MIPS, campaigns are currently 2 weeks on average. So, we ask for shadow observations to be taken some time between 16 hrs and 3 days after our original observations; see Figure 10.11. We can also choose to have the shadow observations taken before the main observations; see Figure 10.11.

To accept these parameters, we click OK, and then click-and-drag the AOR with all three wavelengths and its new copy into this constraint. We could choose to also add the second 160 micron observation into this constraint, but this will obviously take more observing time, so we have to be sure that we justify this in our proposal (because it will also make it harder to schedule our observation).

To enact the constraint, we click "OK." Having done this, now we see in the AOR list that the Follow-on constraint box ("F") is checked.
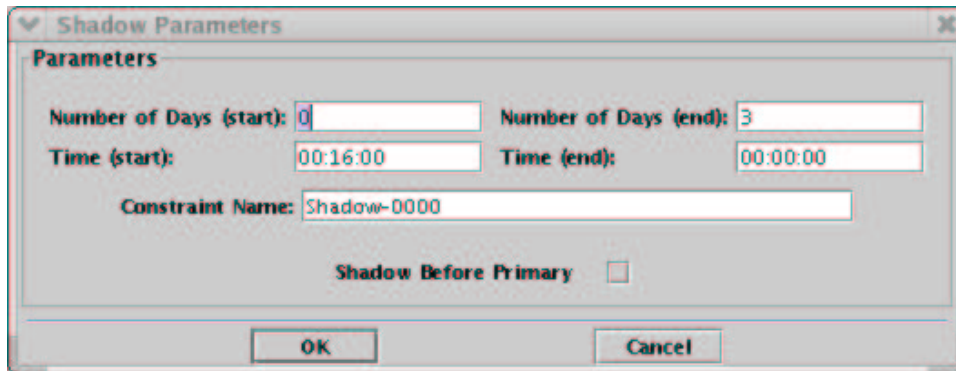
Figure 10.11: The options for Shadow constraints.
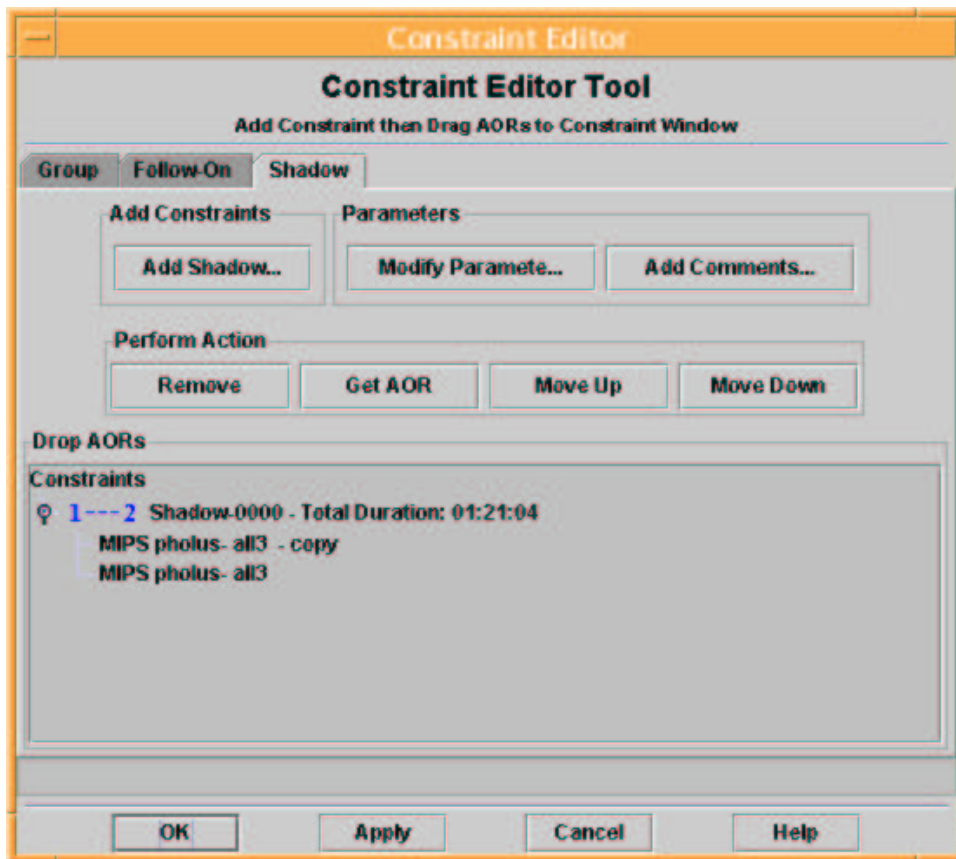
Figure 10.12: The enacted Shadow constraints.

10.5.4 Visualization

The completed AORs are displayed in Figure 10.13 and 10.14.
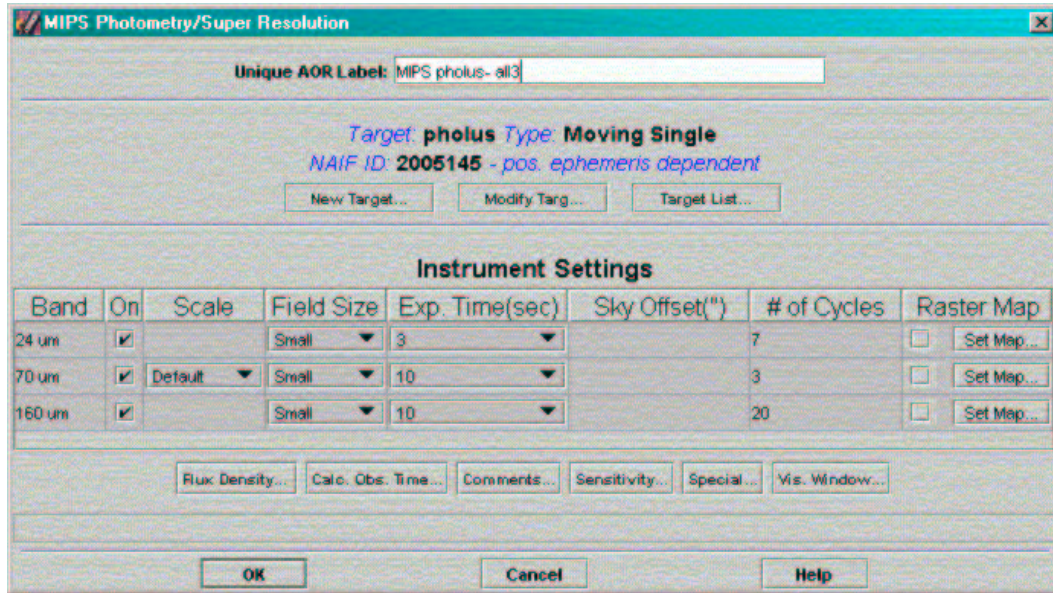
Figure 10.13: The completed AOT window, using all three passbands.

As in all of the earlier chapters, to verify that we are doing what we think we're doing, we can visualize the observation. We retrieved an ISSA image above, and certainly it was useful to examine the background at this location. However, the whole field covered by our MIPS observation is something like only 30 IRAS pixels (5 pixels for the region observed in 160 μm). This is somewhat less than informative, so we can of course also retrieve a DSS or 2MASS image. We have retrieved a DSS image for the following example, but a 2MASS image could also be useful. We then select our AOR, click on the "Overlays" menu, and overlay the current AOR. By choosing the AOR which observes Pholus in all three wavelengths, we obtain Figure 10.15. If this is too confusing, we can select the tiny crosshairs that have appeared with the overlay on the right side of the image window, and selectively turn off and on the individual pointings by wavelength. The visualizations are shown in Figures 10.16, 10.17 and 10.18 for the 24, 70 and 160 μm observations respectively.

The file, ready to be loaded into Spot, containing the raw AORs developed
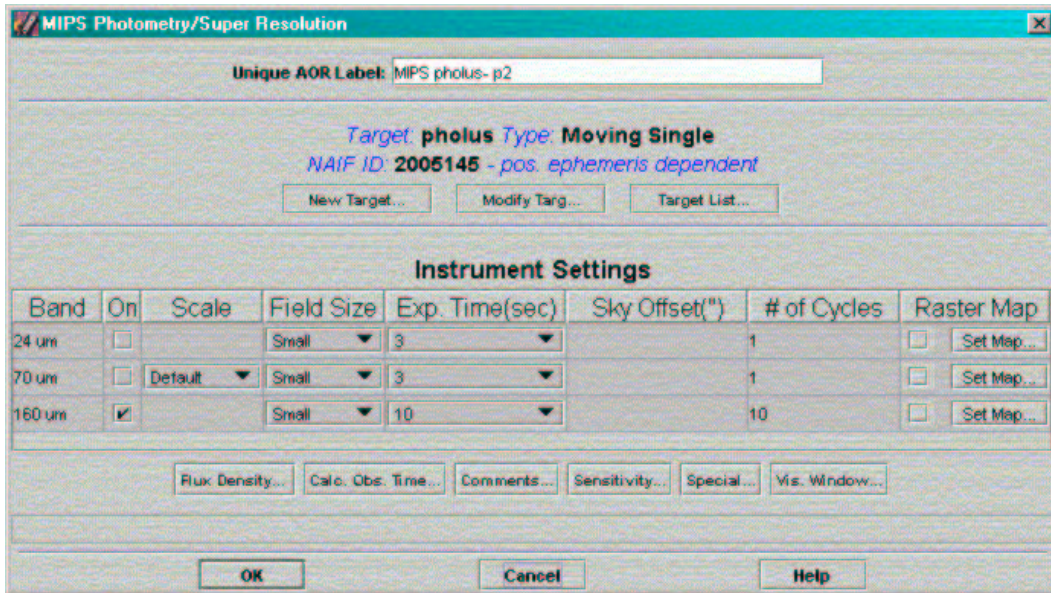
Figure 10.14: The completed AOT window, with the additional 160 micron observations.

in this chapter can be downloaded from the SSC Cookbook webpage:

http://ssc.spitzer.caltech.edu/documents/cookbook/
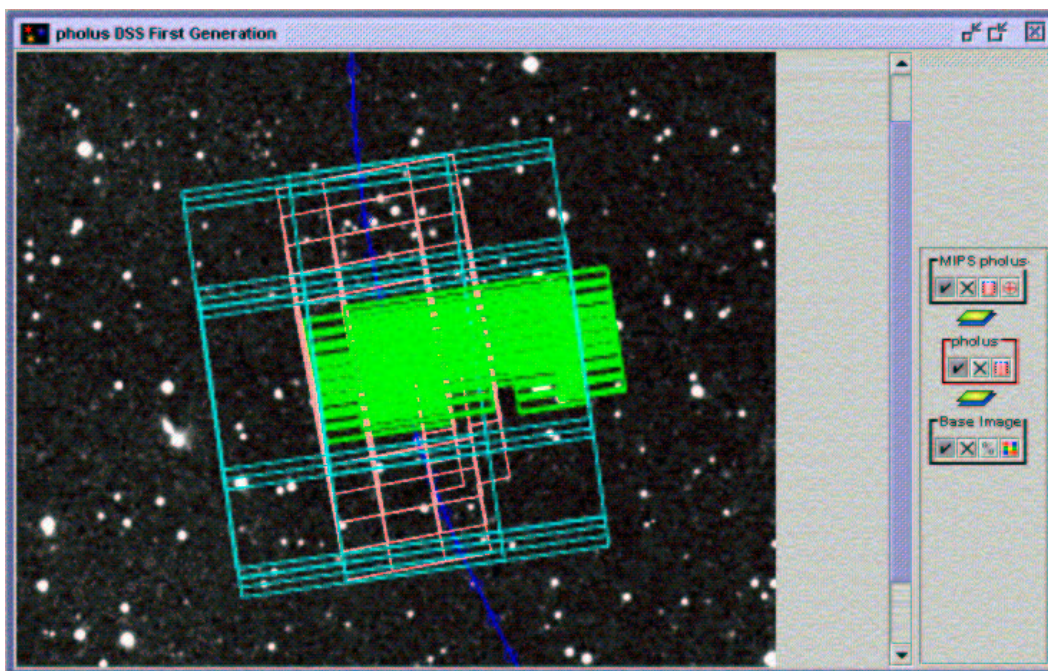
Figure 10.15: The overlay of the MIPS observations on a DSS image of the field.
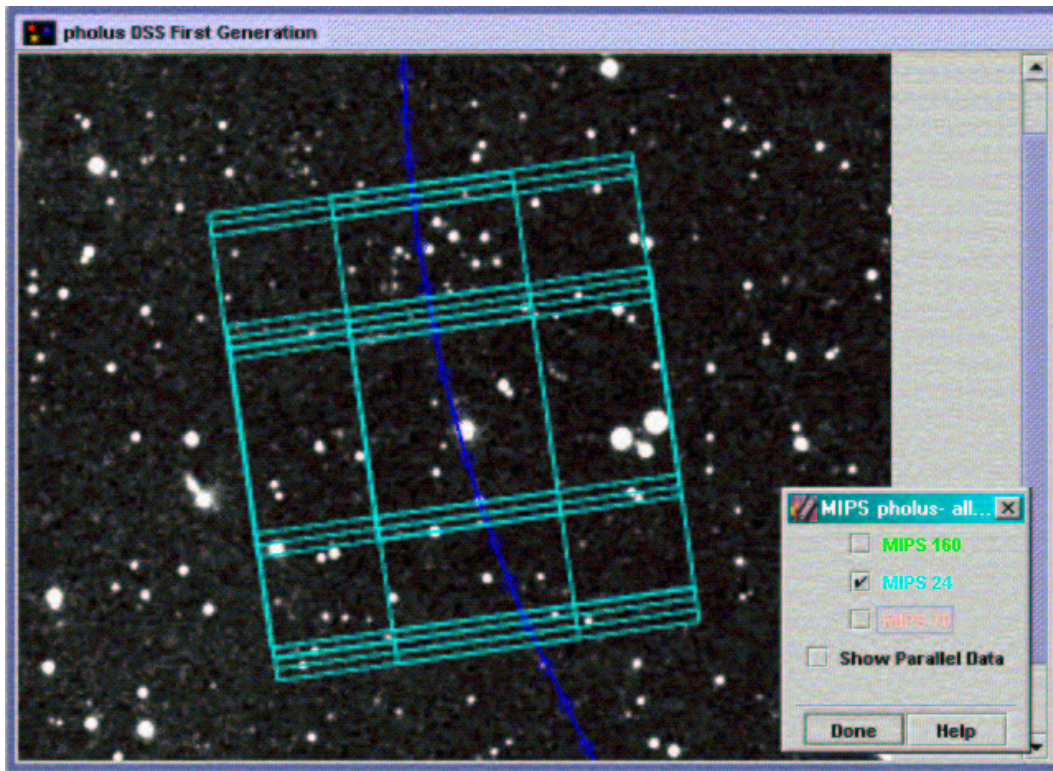
Figure 10.16: The overlay of the 24 micron MIPS observations on the DSS image of the field.
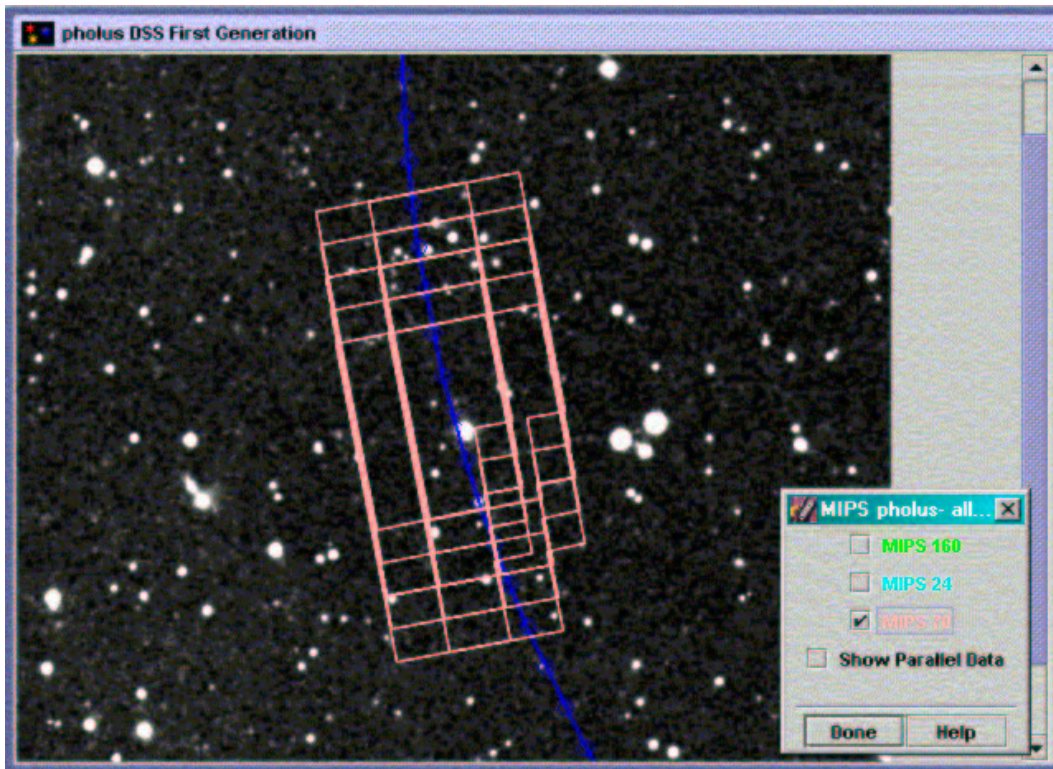
Figure 10.17: The overlay of the 70 micron MIPS observations on the DSS image of the field.
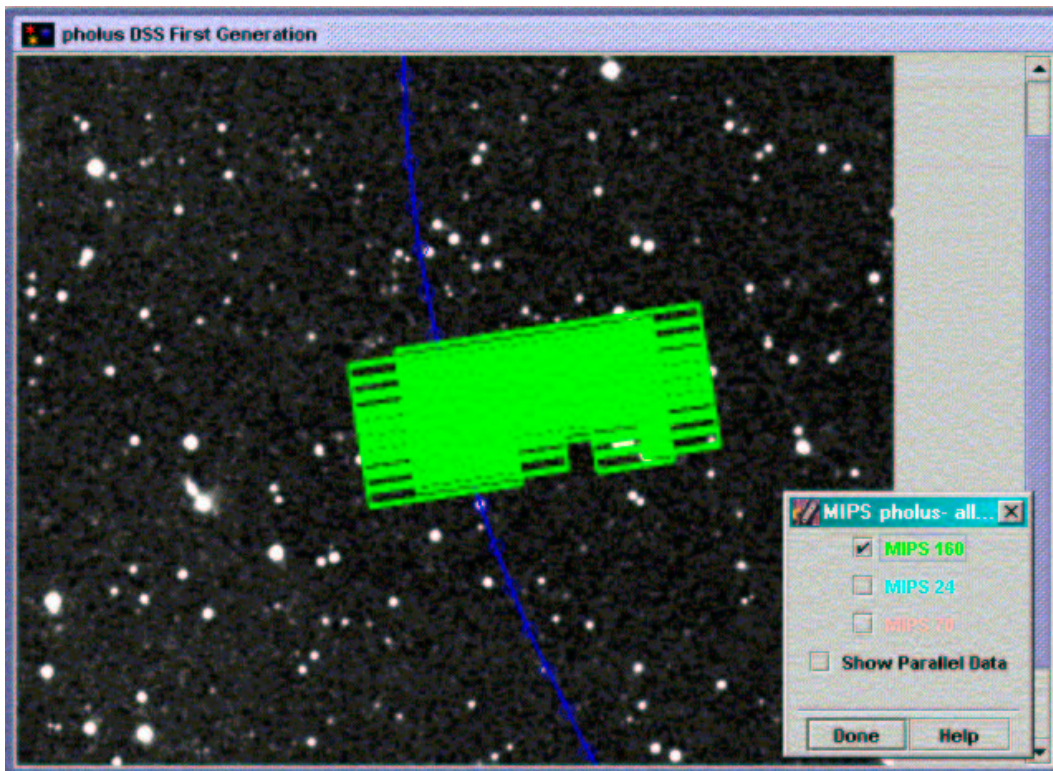
Figure 10.18: The overlay of the 160 micron MIPS observations on the DSS image of the field.

Chapter 11

MIPS Spectral Energy Distribution (SED) Observations of Canopus

11.1 Introduction

The MIPS Spectral Energy Distribution (SED) mode can be used for obtaining long-slit, low-resolution ($R \sim 20$) spectra. The detector array is the same as the one used for the MIPS 70 μm observations. The slit, which is 2 pixels (or ~ 20 arcsec) wide, covers the "good" half (i.e., 16 pixel columns) of the detector array. The spectral dispersion leads to 1.71 microns per pixel and a wavelength coverage of 55 to 95 microns over the 32 detector pixels. Among many scientific uses of this mode are (i) to obtain the far-infrared continuum of an infrared source, and (ii) to determine equivalent widths of interstellar emission lines (e.g., [OI] 63 μm, [OIII] 88 μm, or [NIII] 57 μm).

SED observations provide pairs of data frames between the target position (ON) and a nearby off position (OFF). The scan mirror is used to chop between the ON and OFF positions, and we choose a chop throw of $+3'$, $+2'$, $+1'$, or $-1'$. We can request either a pointed observation or perform an $M \times N$ raster map (with M, N between 1 and 100). We can choose to repeat this basic set by a number of N_c (≥ 1) cycles until be reach the desired signal-to-noise ratio.

As with IRS, we cannot ask for a specific slit orientation on the sky. The actual slit orientation is determined by the date and time when the obser-

vation is carried out. If a particular slit orientation is absolutely necessary, we can request a time constraint on the range of dates, during which the observation should be executed.

As an example, we show here how to design a non-mapping SED observation of star Canopus (HD 45348) with Spot. (A mapping observation consists of a regular grid of $M \times N$ pointed observations).

There are three basic steps in planning any Spitzer observation: (i) select the target and perform duplication check (see §11.3), (ii) estimate the sources fluxes, sky background and the required integration time to reach the desired S/N (see §11.4), and (iii) enter the target position and observing parameters into Spot (see §11.5).

11.2   Overview of the Program

In this section, we summarize the steps followed in designing an SED observation. This will serve both as a one-stop resource for those requiring only an overview of how to do such a program, and also as a roadmap of where to find more detailed information later in this chapter.

- **Target Selection:** We check the Reserved Observations Catalog (ROC) using the Leopard search tool, before planning any observations. As of this writing, there are no SED observations of Canopus in the ROC. See §11.3 for a discussion of target selection.

- **Saturation, Sensitivity, Exposure Time:** We will use 4 cycles of the 10 second exposure times. See §11.4.

- **Durations:** Our total AOR time is 471.3 seconds, including all the overheads. See §11.5.

- **Visualization:** We overlay the planned AORs on a 2MASS image. This helps us verify that we are really doing what we think we are doing! See §11.6.

- A screen capture of the completed AOT entry dialog is displayed in Figure 11.2.

Table 11.1: Relative Counts of a Star as a Function of Offset from the Slit Center

Offset from Slit Center (in units of slit width)	% Relative Flux Count Dither Position 1	% Relative Flux Count Dither Position 2
$-5/8$	43	45
$-4/8$	62	61
$-3/8$	74	75
$-2/8$	88	92
$-1/8$	96	98
0	100	100
$-1/8$	97	93
$-2/8$	91	87
$-3/8$	76	79
$-4/8$	59	60
$-5/8$	44	45

11.3 Target Selection and Duplication Check

The SED slit width (19.8 arcsec) roughly equals the diameter of the Airy disk at 70 micron. If you are observing a point source, make sure that the accuracy of its position (including the proper motion if it is a star) is better than about 5 arcsec. Table 11.1 shows that a star placed at 5 arcsec offset (in the dispersion direction) from the slit center could lead to a measured flux that is 10% too low.

As with all observations, we need to determine if the target is already scheduled for observations with Spitzer . To check for duplicate observations, we look in the ROC by querying Leopard, or using Spot to "search programs" (under the file menu).

We find that (at least as of this writing) there are several calibration issues of the star HD 45348 but we plunge along for this example anyway.

11.4 Saturation, Sensitivity and Integration Time Estimate

11.4.1 Saturations

The best saturation estimates for MIPS may be found at:

http://ssc.spitzer.caltech.edu/mips/sat.html

Our target has an IRAS measured flux of 5.50 Jy at 60 microns, which is far below the saturation level. Using Spot, we estimate that the sky background at the position of our target is also fairly low. Thus, we do not have a saturation issue and will use the 10 sec frames.

If you are observing a bright star on a high background, you need to take into consideration the sum of both flux components if either alone does not saturate the detector. A rough way to do this is to approximate the sky surface brightness by a point-source flux that gives the same surface brightness over the Airy disk.

The SED mode offers two frame times (3 or 10 sec). Since the saturation occurs at fairly high fluxes, the SSC recommends that the 10 sec frame time should be used unless saturation is a risk.

11.4.2 Sensitivities

Some SED sensitivity information is given online here:

http://ssc.spitzer.caltech.edu/mips/sens.html

but for sensitivity estimates the online tool SPEC-PET may be more useful since it interpolates and scales to take into account different background levels, etc.

For low backgrounds, 1 cycle of 10 second exposures, the SPEC-PET returns 1σ sensitivities of 67, 164, and 365 mJy at 60, 75, and 90 microns, respectively.

11.4.3 Integration Time Estimate

Since the spectrum of our target follows more or less the Rayleigh-Jeans law in far-infrared, our star has an estimated flux density of 2400 mJy, and we decide we want to reach S/N = 20 at 90 microns.

We can use the numbers from the SPEC-PET to determine the integration time. One cycle is 60 seconds total integration time on-source. We find a $1 - \sigma$ sensitivity of 258 mJy at 90 microns. Thus, a $10 - \sigma$ detection in that same observation would be 2580 mJy, and a $20 - \sigma$ detection would be 5160 mJy. By empirically trying numbers in the SPEC-PET, in four cycles, we'd reach a $1 - \sigma$ detection of 129 mJy, and a $20 - \sigma$ detection of 2580 mJy, darn close to where we want to be. Five cycles yields a $20 - \sigma$ detection of 2300 mJy. We decide 4 cycles is enough.

11.5   Filling in the MIPS SED AOT

11.5.1   Enter the Target

We first start Spot and bring up the new target window, either by positioning the mouse over the target icon (the bulls-eye icon on the taskbar), or by selecting "new target" from the target menu.

For our example, we choose the "Fixed Single" target type, and enter the target name and hit the "Resolve the name" button using the SIMBAD database. Spot finds the RA and Dec of the target as well as the proper motion of our star. Double check to make sure that the returned position is what you intended to enter, especially the proper motion. Fig. 11.1 shows the result.

Figure 11.1: The Target Info Window.

After entering the target name, coordinates, and clicking 'OK', we are returned to the main Spot menu. We can use Spot at this point to check for existing programs with similar observations - see "search programs" under the file menu.

11.5.2 Specify the Observing Parameters

The next step is to select the SED observing mode for this observation by bringing up the MIPS Spectral Energy Distribution AOT entry dialog, either from the "Observation" pull-down menu, or by clicking on the MIPS "SED" icon (with two wiggling blue lines, near the end of the icon taskbar).

The pop-up AOT window (see Fig. 11.2) should already display the target name and intended position. We then modify the AOT label to something that makes sense to us (and any other observer that might want to use our observations later).

We then set the exposure time (or frame time) to 10 sec. There are four choices for the chop throw (+1, +2, +3 and −1 arcmin). In our case, we simply choose the +1 arcmin chop throw because our target size is small. For a large object (e.g., a nearby galaxy), we may use the +3 arcmin chop throw. Note that the chopping direction is always perpendicular to the slit orientation on the sky.

As we mentioned already, the actual slit orientation on the sky of our observation will depend on when the observation is executed. If your observation requires a certain slit orientation on the sky, you need to constrain when your observation should be carried out.

Next, we set the desired number of cycles to 4 based on our work above in §11.4.3. Since we are doing a non-mapping observation, we choose NO for the mapping mode.

11.5.3 Calculate the Time

To calculate the total time for this observation, we click on the "Calc. Obs. Time" button near the bottom of the window. A pop-up window shows that our total AOR time is 471.3 seconds, including all the overheads.

To finish this AOR, click on the "OK" button at the bottom of the AOT window. This will bring you back to the window that lists all the observations we entered so far.

11.6 Visualization of the Observation

A very useful way to confirm the observation has been designed as we intended is to use the visualization tool in Spot. First, we need to obtain or specify an image to use for the overlay. We can obtain ISSA, 2MASS, MSX,
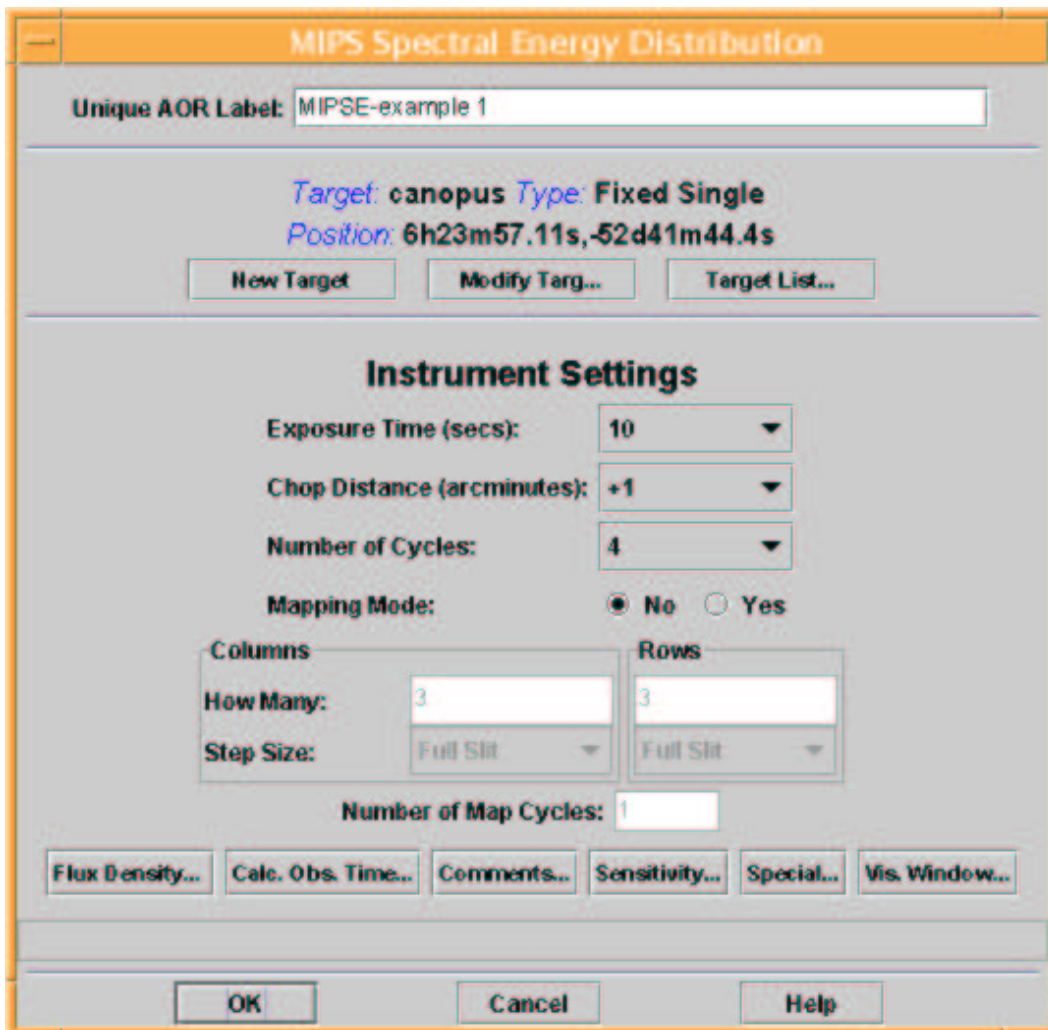
Figure 11.2: The completed SED AOT window.

or DSS images through Spot. Click on the "Images" tab on the toolbar, and, for example, select "DSS Image." We see a pop-up window, asking us to specify the parameters for the image. After clicking "OK," Spot works away, and returns with an image in the main window. In our example, we choose the 2MASS K-band image.

To place the overlay on the image, click on the "Overlays" tab, and select "Current AOR." We are prompted for an observation date. Choose anything

reasonable for an initial visualization. By visualizing the observations, we may discover a reason why we want a particular slit orientation (or a reason to avoid a particular orientation, like a serendipitous source). If we have a strong scientific justification, we can place constraints on the AORs that effectively constrain the slit angle; there are other chapters in this cookbook that cover this topic. We have placed no timing or orientation constraints on this example AOR, so we can simply choose whatever dates are available to get a visualization of the observations. The resulting overlay for a particular date is shown in Fig. 11.3.

To see how the slit is placed spatially in time, click on the "Pointing Table" option, which is one of the options located to the right of the displayed image. This brings up all the MIPS SED frames. We then click the "Animation" or "Animation w/ Trail" option to see the SED observation in real time.

Since the visualization result looks satisfactory to us, we are happy with the AOR we have designed.

The AOR file is listed in the Appendix here and is also available on the website, ready to be loaded into Spot:

<center>http://ssc.spitzer.caltech.edu/documents/cookbook/</center>

11.7 Additional Notes for Consideration

11.7.1 Constraining the Slit Orientation

If your observation absolutely needs a narrow range of slit orientations on the sky, you can play with the visibility tool in Spot to see if you can find dates when the slit is at the "right" orientation.

In the AOT window (see Fig. 11.2), click on the "Visibility/Orientation" button near the bottom right corner after you have entered your target into Spot. The pop-up window displays a list of ranges of dates when your target is visible. Choose a date, and click "calculate Position Angle" to see the slit orientation on that date. You can try different dates to find the "right" orientation.

11.7.2　Mapping Observations

In the AOT window (see Fig. 11.2), select Yes for mapping, then enter the number of columns (1 to 100) and number of rows (1 to 100). The column step size is in units of the length of the slit and the row step size is in units of the width of the slit.

The AOT animation option in the visualization tool can be used to show how the slit in a mapping observation is moved.

11.7.3　Spectroscopic Photometry of Extended Sources

If your target is not a point source (e.g., a galaxy), you may want to also do a 70 μm photometric observation in one of the MIPS photometry modes. The resulting imaging photometry will allow you to make an empirical aperture correction to the SED spectrum.
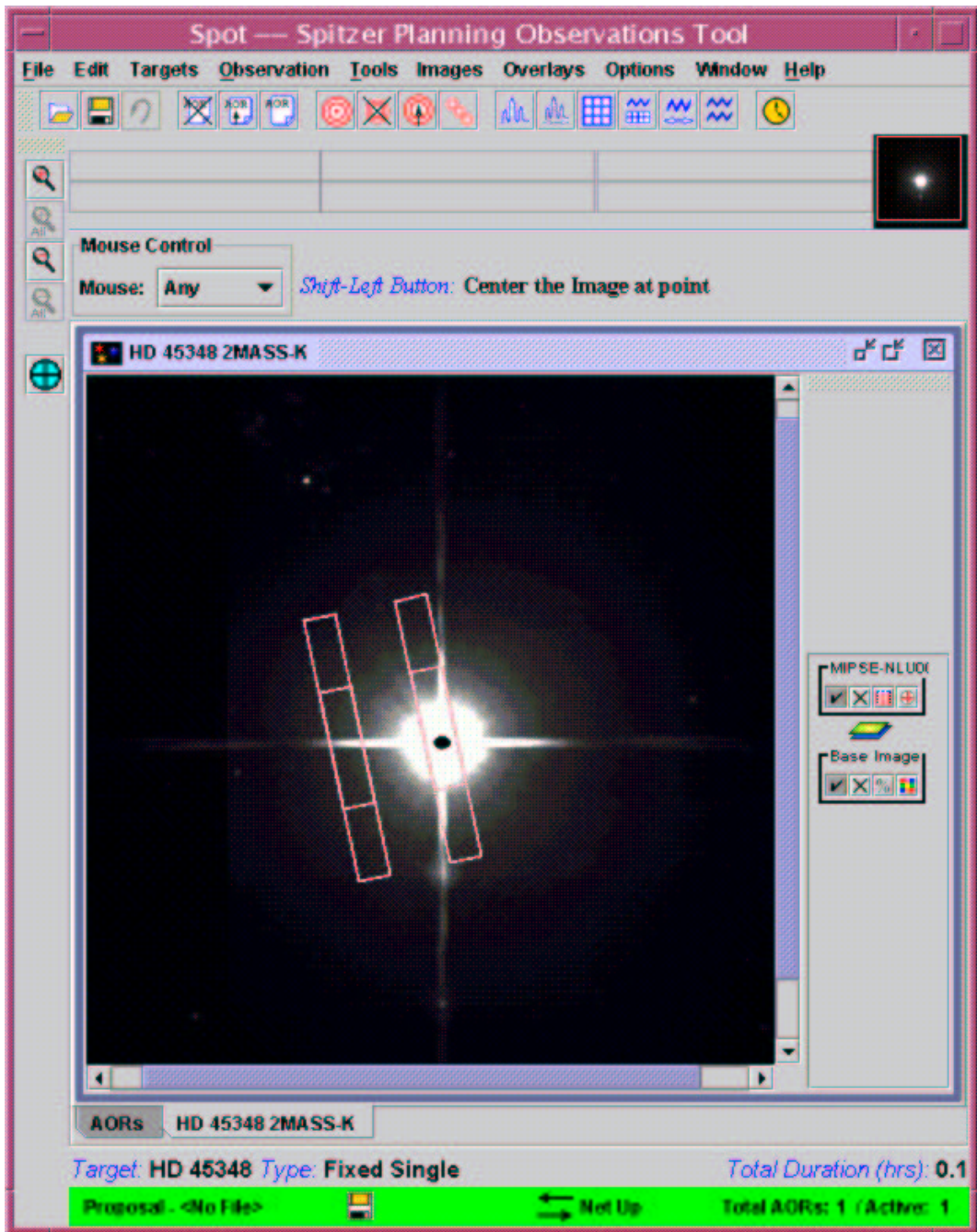
Figure 11.3: Visualization of the observations.

Chapter 12

Time Series Observations

Repeated observations of (inertial) celestial objects that vary with time are becoming ag popular request. For this next cookbook chapter, we use the real-life example found for the observations of TrES-1, from DDT program 227 (Charbonneau). The original AORs for this program can be viewed via Spot (choose "View Program" and enter pid 227), or slightly relabeled and modified (for new slew model) AORs that are functionally the same can be downloaded as part of this cookbook.

Because imaging with MIPS and IRAC have been covered thoroughly in earlier chapters (see §3, §4, §8 and §9), we will not spend as much time on those aspects of these observations here; this chapter is meant primarily to give an example of observing the same object repeatedly, and using Spot to tell Spitzer exactly how you want the observations carried out.

We will plan an observation of the extra-solar planet TrES-1 during the time of secondary eclipse (when the planet passes behind the star). The science learned from these real-life observations is described in Charbonneau et al., 2005, ApJ, 626, 523. The secondary eclipse reveals two key quantities of the planet: its temperature (from the eclipse depth), and its orbital eccentricity (from the eclipse timing).

12.1   Overview of the Observations

- **Target Selection:** Before being selected for potential Spitzer observation, targets should be vetted for conflict with previous observations. See §12.2.

- **Completing the AOT:** With IRAC, we plan the unusual step of 200 repeats, no dithers or mapping, 12 seconds per frame.

- **Constraints**: We enact as broad constraints as possible. We place a timing constraint on the first AOR of the series, and then chain the rest to the first one. See §12.5.

12.2   Target Selection and Suitability

As with all other observations, we need to first check the ROC using Leopard. By looking here, we find that, of course, TrES-1 has already been observed. Had this been a real proposal, we could then check the Duplicate Observations Rule to see if the specific proposal idea we have in mind qualifies as a new observation – perhaps we feel we could make a good scientific case for why it would need to be observed more than it already has during the Spitzer mission. Or, we note that the existing observations are at 4.5 and 8.0 μm and we would like to observe it instead at 4.6 and 5.8 μm – this would not be a duplication. However, for purposes of this example only, we will ignore the potential duplication, and continue planning these time series observations of TrES-1.

12.3   Target Entry

Start up Spot and enter a new target either by clicking on the bulls-eye target icon on the taskbar, or selecting "New Target" from the "Targets" menu.

Click on the "Fixed Single" tab to pull up the window, and enter the coordinates for TrES-1. After entering our target information, we click "OK" and we return to the main Spot screen. Note that the bottom of the Spot screen now tells us which target and target type we have entered. Save your target list, just in case. To retrieve the target list at any time, we can click on the icon that looks like 3 bullseyes on the toolbar.

To find exactly when the target is visible to Spitzer, we can click either on the "Visibility/Orientation" button in the target entry window, or from the target list window, "Calculate Visibility Windows for All" and then "Show Visibility." This shows us a list of the dates when Spitzer can actually observe our target.
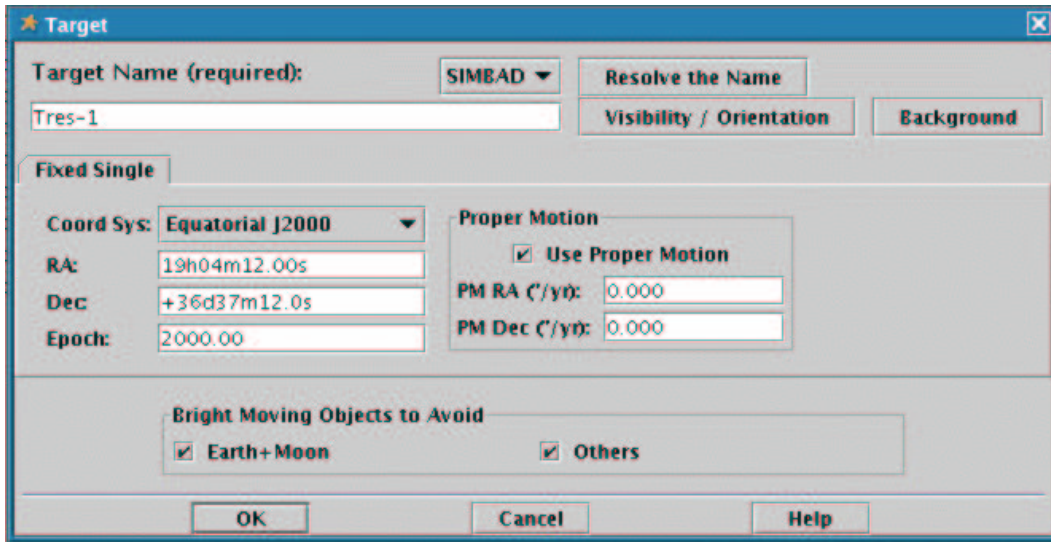
Figure 12.1: The target window after entering TrES-1.

12.4 The IRAC AOR: Exposure Time & Observing Strategy

In this case, we are looking for tiny variations in the signal from the star+planet system. We could be fooled by variations in the placement of the object on the array (pixel position), or by variations in the flat field. In order to limit these effects, we would like the object to stay in the same place on the array, so we have chosen NOT to dither. Instead we use the "repeats" option on the AOT window, located just above the frame time setting. Moreover, in this case, we will take enough frames such that the first frame effect is not as much of a concern as it would be if we were only taking, say, 5 frames. The net result of these decisions is that the relative flux that we measure will be quite good, but the absolute flux might not be as good as it would be had we dithered and not used repeats. Finally, we wish to have as continuous coverage as possible, and that (plus the desire to get the object on exactly the same pixel for the whole series) is more important than multi-wavelength coverage. So, we choose to only use one field of view; we choose 4.5/8 because the planet is likely to be brighter in these wavelengths.

Based on predictions of the star's flux, and based on the considerations above, we enter the information into the AOT window; see Figure 12.2. We

select the full array, just the 4.5/8 μm field of view, and 200 frames of 12 sec each, with no mapping or dithering. We choose "Calc. Obs. Time" to see how long this AOR takes. It's well under the 6 hour limit, and we have not tripped any "number of instructions" errors.

We are planning a time series of 8 observations, 7 more just like this one. After creating the AOR, we choose "copy AOR" 7 times, and change the labels of each one so that we can keep track of which AOR is which. If we did not already calculate the total elapsed time for this program, we should choose "Recompute All Estimates" from the "Tools" menu so that we know how long the total program is.

As in all of the earlier chapters, to verify that we are doing what we think we're doing, we should visualize the observation. Since visualization is thoroughly covered elsewhere in this Cookbook, we do not repeat that information here.

Save your AOR(s) early and often. Now would be good.

12.5   Constraints

In order to accomplish our science, of course we need to ask Spitzer to complete these observations in the "right place" in the planet's orbit, including at the very least when the planet moves behind the star. We go away and calculate when we would like these observations to start. To provide the maximum possible flexibility, we figure out the right time for these observations to start over many possible orbits of the planet. We also need to be sure that the timing windows we give are consistent with when Spitzer can view the object (available through Spot, see below). We should also check, if possible, that the IRAC instrument is scheduled to be on (see the Baseline Instrument Campaign (BIC) on the SSC website). This is especially important for DDT and ToO programs.

NOTE THAT in order to accomplish this observation, we don't have to time-constrain each observation! In fact, it provides the most flexibility for scheduling, and the best possible data quality, if we time-constrain the first AOR in the series, and then chain together the rest of the AORs in the series to be linked to the first.
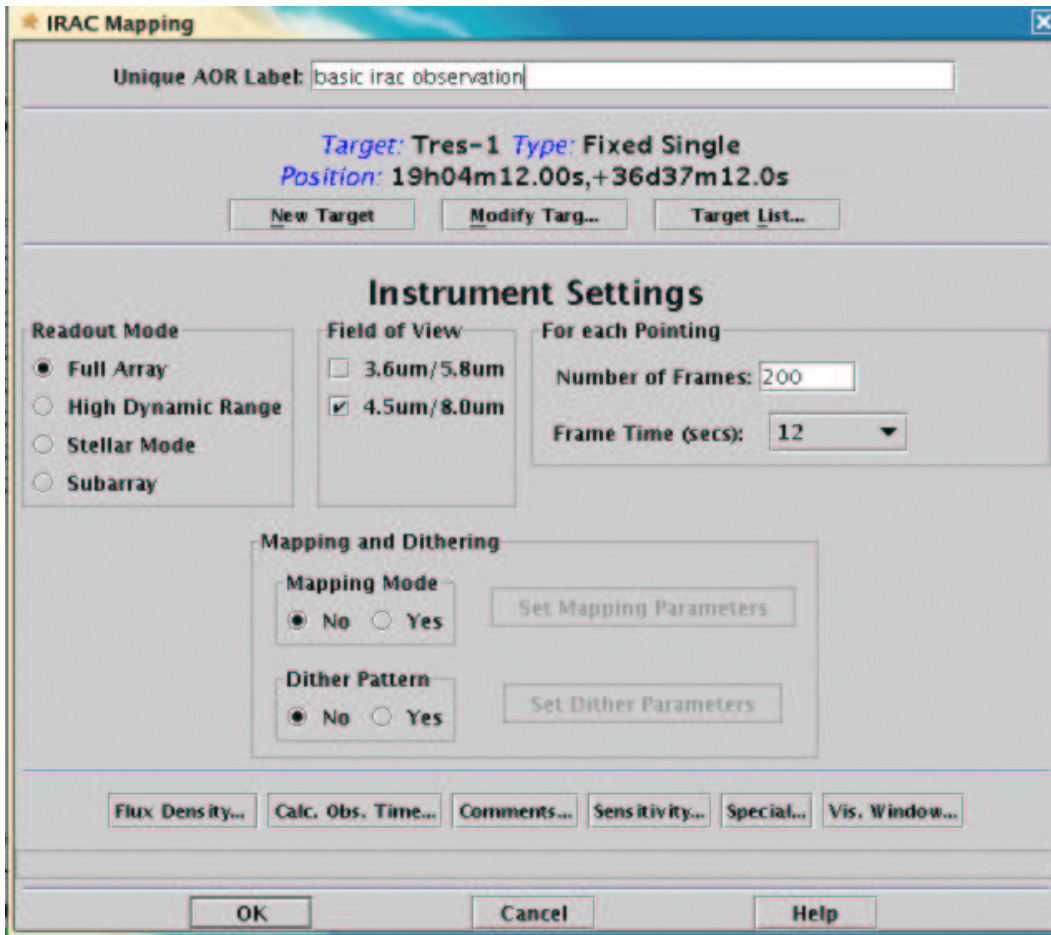
Figure 12.2: IRAC AOT window, filled values.

12.5.1 Timing Constraints

In order to enact a timing constraint on the first AOR, we select the first AOR in the list, and then from the "Tools" menu, we select "Timing Constraints." It helpfully provides us with a list of the visibility windows for this object. We also look at the list of possible TrES-1 orbits and consider the largest possible window when these observations could start.

(Note that this example is based on DDT observations, so there was a short period of time over which the observations were possible; for GO observations in general, the possible window is much larger. For a GO proposal, example time constraints over at least a similar ∼6 week period [if not the

whole cycle] are fine; observer support will work with you if you are accepted and need to enact even more flexible time constraints.)

We then enter a series of start and end dates and times, and then click OK, see Figure 12.3. To regain this window at any time in the future, select "Timing Constraints" from the tools window as above.

In the main Spot window, note that the checkbox is now checked for this AOR under the "T" column.

12.5.2   Chaining AORs

We are not done yet! Next, we need to tell Spitzer that we need to do the rest of these observations in order, without breaks. We would like this series of observations to be done as an ordered non-interruptible group because we need continuous monitoring of this object.

In order to start a chain, we first select "Group/Follow-on Constraints" from the "Tools" menu. The default first tab that appears is the Group tab; we could also select Follow-Ons or Shadows (were this a Solar System target) from this same dialog. We want to enact chaining constraints, so we select "Add Chaining." We get a pop-up asking for a name of the constraint – since we only will have one chain, the default "Chain-0000" is fine. An icon and text now appears in the lower part of this Constraint Editor. It tells you the total duration of this Chained series of AORs. Note that the longest possible uninterrupted group of IRAC AORs is 6 hours.

Now, we select the first AOR in the series and drag-and-drop it into the window. It now appears under the "Chain-0000" entry. Next, we drag-and-drop the second AOR in the series here too. We note that the total duration is keeping track of how long this will take. We repeat this for each of the 8 visits. We then note (Spot helps us notice this if we forget) that the total duration exceeds 6 hours! We will have to fix this, but we can empirically do this.

We click "Apply" to enact this constraint, and Spot reminds us that the chain takes too long. See Figure 12.4

NOTE that you have to click apply, not just ok for the constraints to actually stick to the AOR.

Having done this, now we see in the AOR list that the Group constraint box ("G") is checked. But now we need to get this chain under 6 hours. We double-click on the visit 8 AOR and reduce the number of repeats here. We can empirically iterate this process, selecting "Calc Obs Time" and clicking
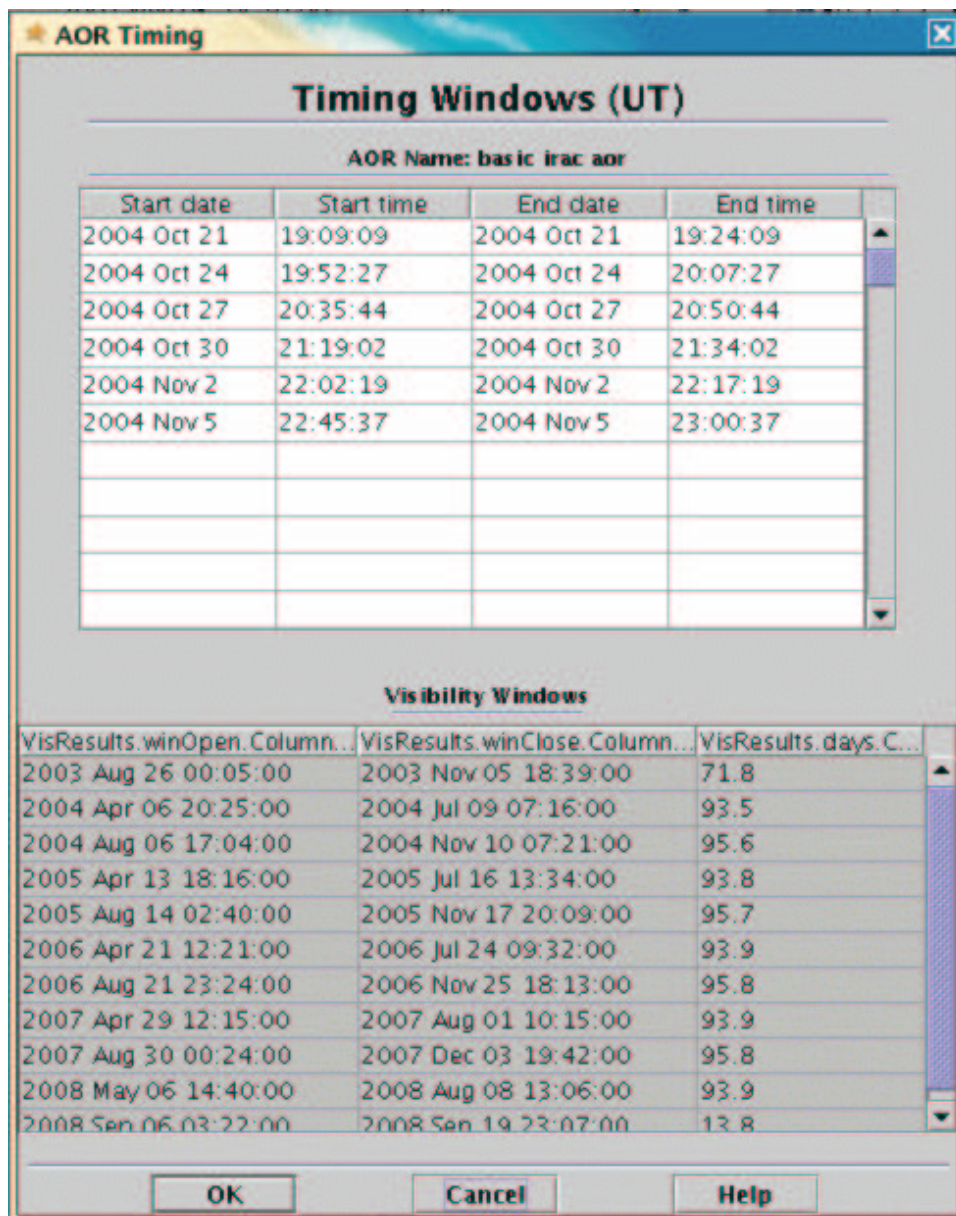
Figure 12.3: Enacting timing constraints.

OK until the chain length is under 6 hours. By doing this, we learn that visit 8 will only be 80 repeats long. This is fine; we will still get 6 hours of essentially continuous observations.
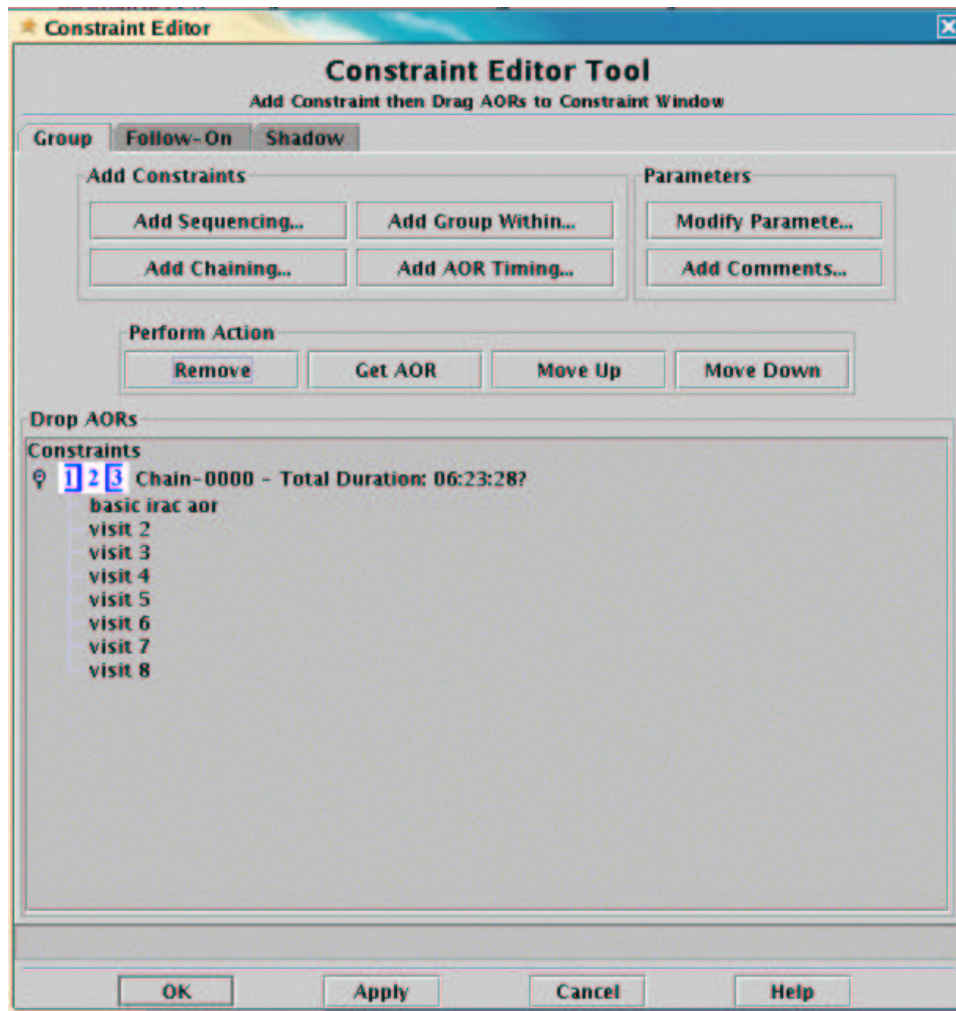
Figure 12.4: The initial enacted chain constraint.

The final chain constraint appears in Figure 12.5.

Now we're done! The AOR file, ready to be loaded into Spot, containing the raw AORs developed in this chapter can be downloaded from the SSC Cookbook webpage:

http://ssc.spitzer.caltech.edu/documents/cookbook/
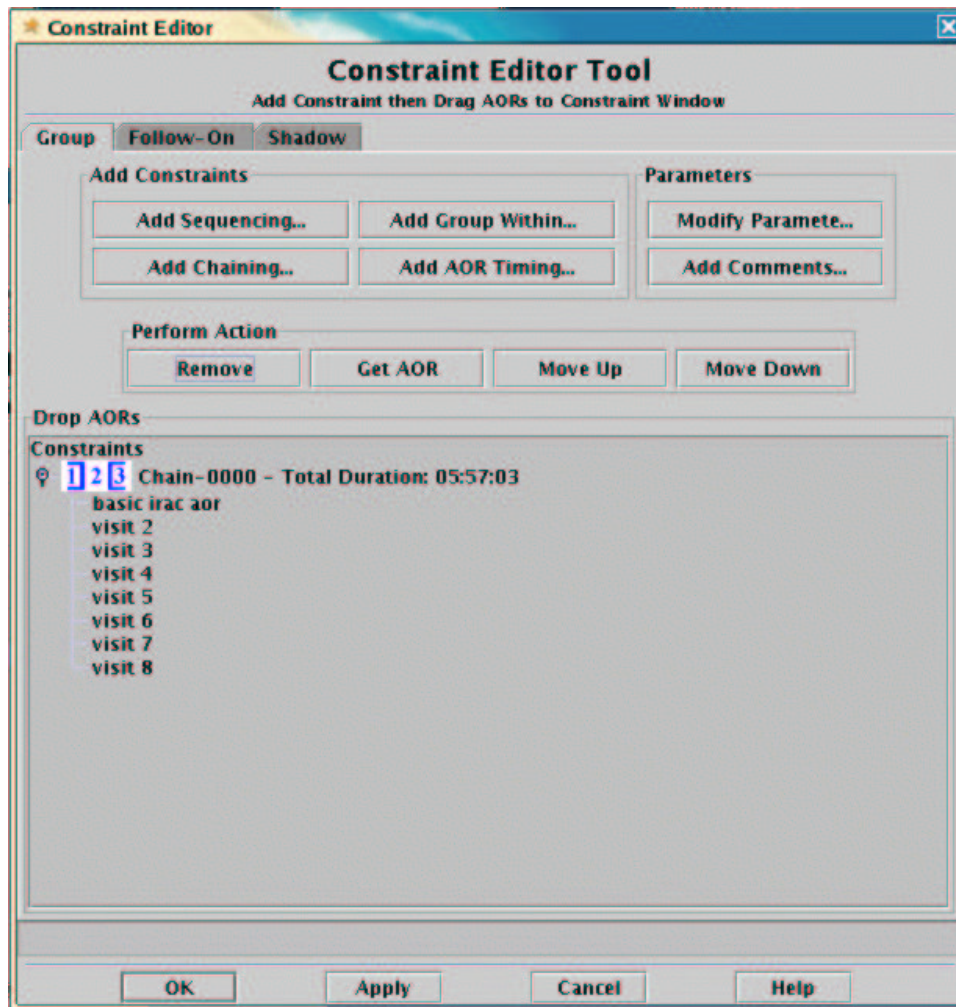
Figure 12.5: The initial enacted chain constraint.

12.5.3 Other kinds of constraints

Note that for other projects, such a strict ordering as found with a chain constraint outlined in this example might not be justified, and a sequence or group-within or follow-on constraint might suffice.

For example, perhaps we would like to monitor a stochastically variable object (e.g., accretion events?). In that case, perhaps the specific start time of the first observation of the series is not terribly important, but perhaps it is important that a small group of IRAC observations are obtained close in time

to some associated MIPS observations. In that case, a "Group Within" constraint of several days would likely do the job . Enacting a "Group Within" from Spot is essentially identical to enacting a Chain as described above, except obviously we would click on "Add Group Within" rather than "Add Chain." This kind of constraint is also appropriate for grouping, e.g., a set of large MIPS scan maps covering a huge region to limit field rotation between map execution times.

Chapter 13

Target of Opportunity (ToO) Observations

Targets of Opportunity (ToO) are transient phenomena whose exact timing and/or location on the sky are uncertain at the time of the proposal submission. They include objects that can be generically identified before the onset of such phenomena (e.g., recurrent novae, variable stars) and objects that cannot *a priori* be specifically identified (e.g., newly discovered comets, novae, supernovae, gamma-ray bursts). Requests for observations of these objects should be submitted through the normal General Observer proposal process.

For this next Cookbook chapter, we design AORs for ToO observations. The AORs for this program can be downloaded as part of this cookbook.

Because imaging with MIPS and IRAC have been covered thoroughly in earlier chapters (see §3, §4, §8 and §9), we will not spend any time on those aspects of these observations here; this chapter is meant primarily to give an example of planning ToO observations, using Spot to tell Spitzer how you want the observations carried out, and keeping track of observing overheads associated with ToO observations.

13.1   Overview of the Observations

- **Completing the AOT – single instrument:** We plan the simplest kind of ToO, using a single instrument.

- **Completing the AOT – multiple instrument:** We plan a more

sophisticated ToO, using multiple instruments.

- **Completing the AOT – single instrument, multiple epoch:** We plan an even more sophisticated ToO, using one instrument, but observing the same object multiple times.

13.2   Target Selection and Suitability

ToOs, by their very nature, are transient events. Thus, the duplication rule "escape clause" applies, and re-observation of an object already in the ROC is likely to be approved because it is intrinsically changing.

13.3   Impact definitions

Targets of Opportunity are categorized by the extent to which the execution of such an observation affects normal Spitzer scheduling and observing procedures. Therefore, as part of the proposal submission, *we must identify in our proposal* each ToO request, based upon the maximum delay – in our judgment – that is scientifically acceptable between the activation of an approved AOR and the execution of the observation.

The normal Spitzer scheduling process begins 6 weeks prior to when a sequence begins execution on the observatory (Since the sequences run from Wednesday to Wednesday, this process usually begins on the Monday of the 6th week in advance).

Therefore, if we choose to activate an approved ToO with comfortably more than 5 weeks' notice, then this is *a low-impact ToO*. In order to truly have no impact on scheduling, the ToO must be activated more than 5 weeks before *the scheduling process for that week begins*, not just 5 weeks before *the desired observation date.*

Spitzer is designed to operate autonomously for periods of about a week, so the schedule is developed in units of weeks. A ToO that is activated less than 5 weeks in advance therefore affects scheduling for not just the *entire week*, but perhaps *the weeks before and after* as well. Because the SSC only communicates with the spacecraft once or twice a day, the fastest possible response for a ToO activation is 48 hours. A ToO that is activated with less than a week's notice requires considerable effort to implement.

Therefore, to summarize,

- High-Impact is < 1 week (normally a minimum 48-hour turnaround)

- Medium-Impact is 1-5 weeks

- Low-Impact is > 5 weeks.

Apart from the overhead burdens applied to all Spitzer observations, the SSC imposes no additional overheads on low-impact ToO observations.

Because of the heavy impact that high-impact ToO observations have on the short- and medium-term Spitzer schedule, **there is a maximum number of medium- and high-impact ToOs permitted per cycle**. Rapid response ToOs that require a ∼6 K telescope when the telescope is not already cold are unlikely to be accommodated.

In general, the more disruptive the ToO observation is to normal Spitzer scheduling and operations, the stronger the scientific justification must be to approve the proposed observation.

13.4   Single Instrument, Medium Impact

For our first example, we will design an IRAC-only observation. We decide, based on our science case, that we can live with a 1-5 week window for activation, so we settle on a medium impact ToO.

First, we design our IRAC observation. The IRAC observation in Figure 13.1 nominally takes 2129 seconds.

Figure 13.1 shows the IRAC AOR that we have designed. But before clicking "OK" (or at any time while editing the AOR), we need to click on the "Special" button in the lower right of the AOT window as indicated in Figure 13.1. Doing so results in a new dialog box. In Figure 13.2, we have selected "Medium Impact Target of Opportunity 1 Instrument.

Before selecting the impact option via the "Special" button, the AOR as designed took only 2129 sec = 35 minutes. But now, having selected the overhead, the AOR takes 11489 sec = 191 min = 3.2 hrs. These 156 "extra" minutes are the special overhead charged to our observing program for having requested a medium impact ToO with one instrument. *The proposal we write using this AOR must ask for 3.2 hours, not 35 minutes.*
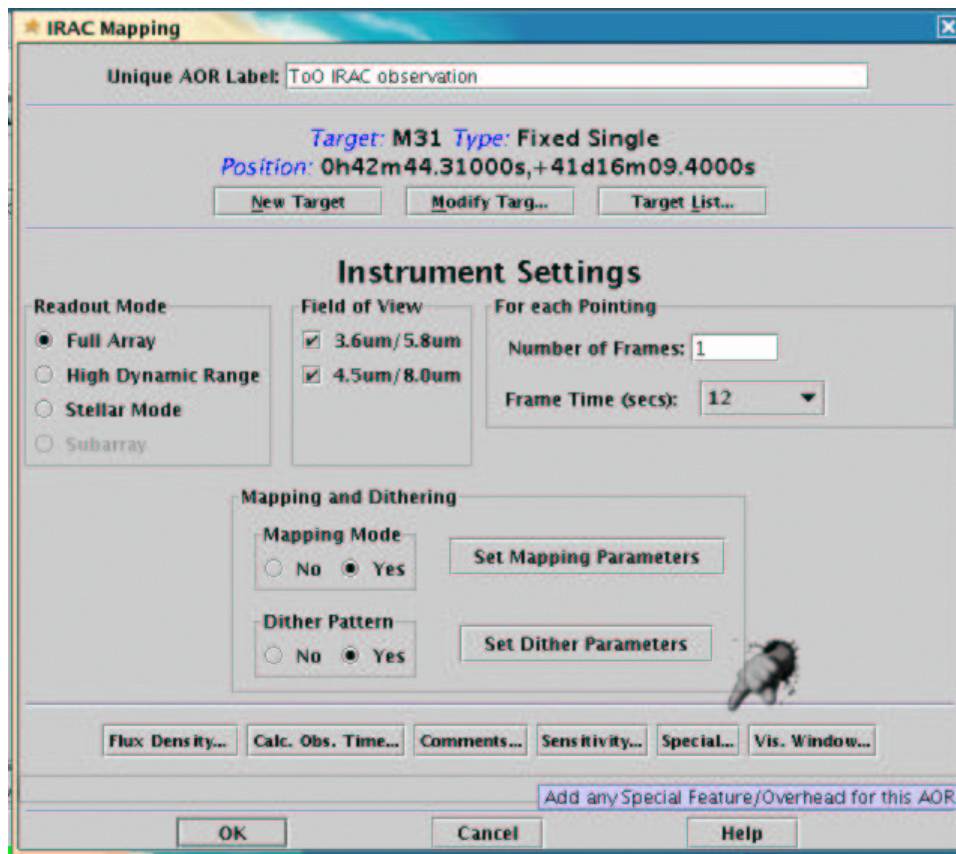
Figure 13.1: The IRAC AOT window ... note the "special" button on the lower right!

13.5 Multiple Instrument, High Impact

Now, we will design an IRAC and MIPS observation of a ToO that we would like to activate with <1 week's notice, a.k.a. a high-impact ToO. We want the observations from the two instruments observed as close as possible in time to each other. (It does take time to shut down one instrument and start up the next, so they won't be one right after the other, but it will be as close as possible in time.)

We design (for purposes of this example) some very simple AORs, one for IRAC and one for MIPS. The IRAC one bears a striking resemblance to the one designed above, e.g., it takes 2130 seconds without any additional
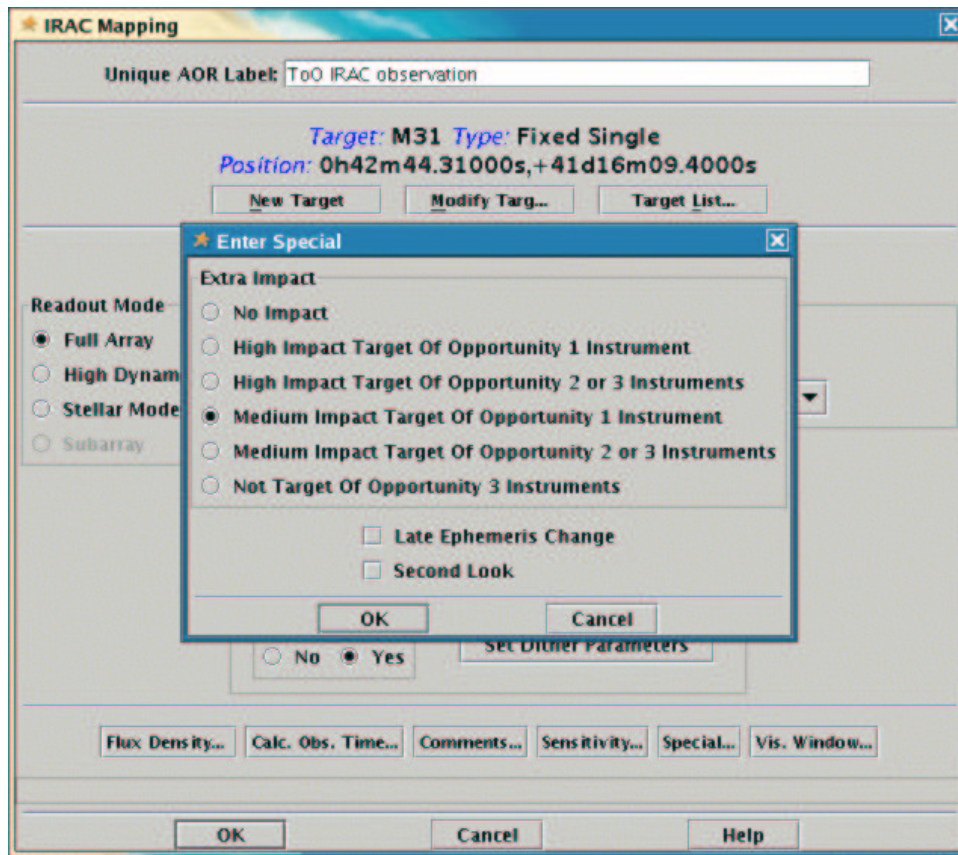
Figure 13.2: The special overhead window acquired in the previous figure.

ToO overhead. The MIPS-photometry observation we design just takes the default options for all three wavelength bands, and thus takes 1403 seconds without any additional ToO overhead.

Now, to charge the overhead properly, we select *either* of the two AORs and click on the "special" button to obtain the dialog box as in Figure 13.1. This time, though, we select "High Impact Target of Opportunity 2 or 3 Instruments." The total time for this AOR now rises to 33810 seconds = 564 minutes = 9.4 hours. The extra 529 minutes are the special overhead charged to our program for using two instruments with a high-impact ToO. Note that the total duration for the MIPS AOR did not change. For this program (two instruments, high-impact), our proposal should ask for 9.8 hours.

For this example, we have selected 160 μm observations. Note that the

telescope is not always at the right temperature to obtain observations at this wavelength. ToOs that request 160 μm observations must justify this in the proposal, and an activation request is unlikely to be approved unless the telescope is already cold.

13.6   Single Instrument, Multiple epoch

What if we want to plan an observation that follows the light curve of a transient event, like a supernova? Maybe we need an observation soon after a SN, then we want another observation a week later, and then 3 weeks after that. In order to do this, **we need to apply the special overhead to *each* AOR in the sequence** because each one of them, on their own, is a high- or medium-impact ToO.

So, we create again (for purposes of this example) some very simple AORs for IRAC; we create three basically identical AORs. Again, they bear a striking resemblance to the ones designed above, e.g., each takes 2130 seconds without any additional ToO overhead.

In order to realize our vision of the first one going as soon as possible after we trigger it, the second going 1 week later, and the third going 3 weeks after that, we need to impose some constraints. More detail on constraints is included in other sections (e.g., §4.6) but we summarize these steps here.

13.6.1   Setting Constraints

The loosest, best constraint to use to accomplish our goals here is the follow-on constraint, e.g., do this second AOR no sooner than time x and no later than time y after the first AOR.

After creating all three of our IRAC AORs, we select the first one and choose "Group/Follow-on constraints" from the Tools menu. We then click on the "Follow-on" tab at the top of the window, then the "Add Follow On" button. For this first window, we want the second AOR to go no sooner than 5 days and no later than 10 days after the first, so we enter that information in the "Follow-On Parameters" pop-up window that appears. We then drag-and-drop the two relevant AORs into the constraint, resulting in Figure 13.3.

We repeat this process, but now we want to link the 2nd and 3rd AORs with a gap of no less than 18 days and no more than 25 days; see Figure 13.4.
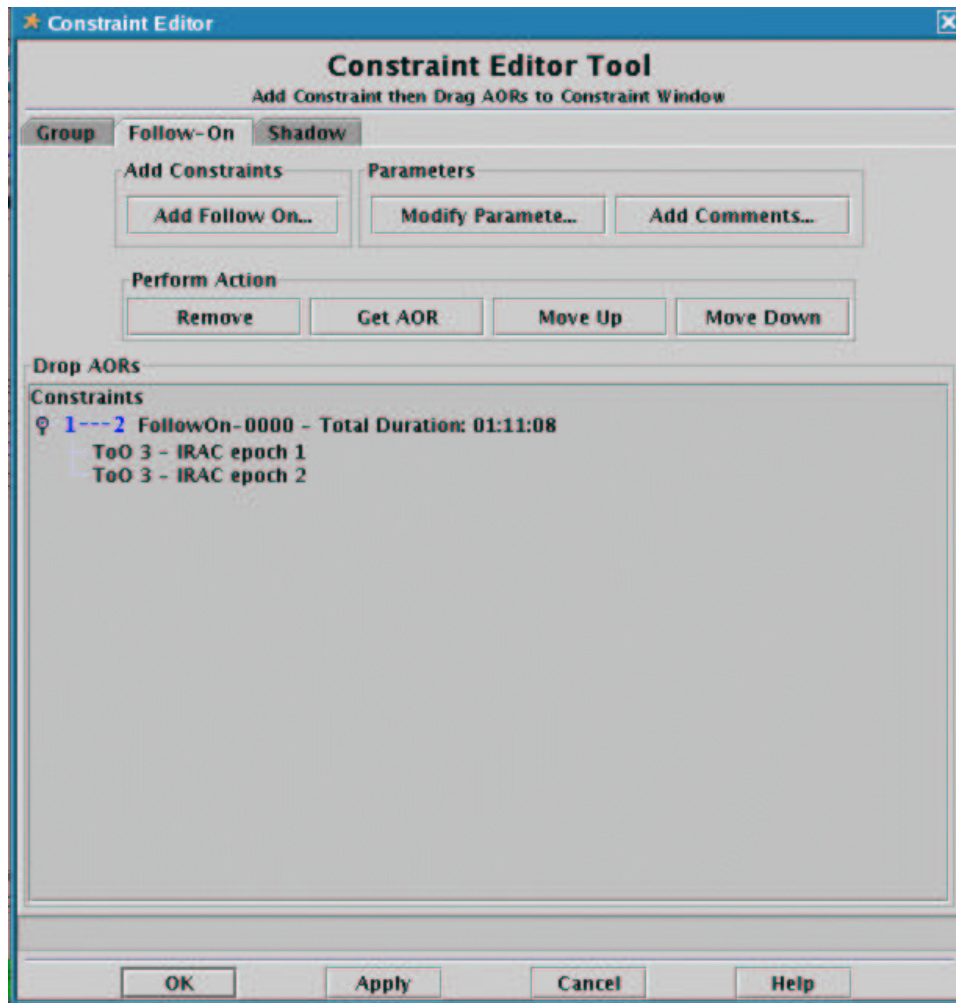
Figure 13.3: The first follow-on constraint

We click "Apply" and then "OK." Note that the boxes under "F" are checked in the main Spot window now.

13.6.2   Special Overhead

Now, note that when we initiate the first AOR in the sequence, we are impacting a schedule with <1 week's notice, a schedule with <2 weeks' notice, and a schedule with <5 weeks' notice. This means that *each* of these AORs
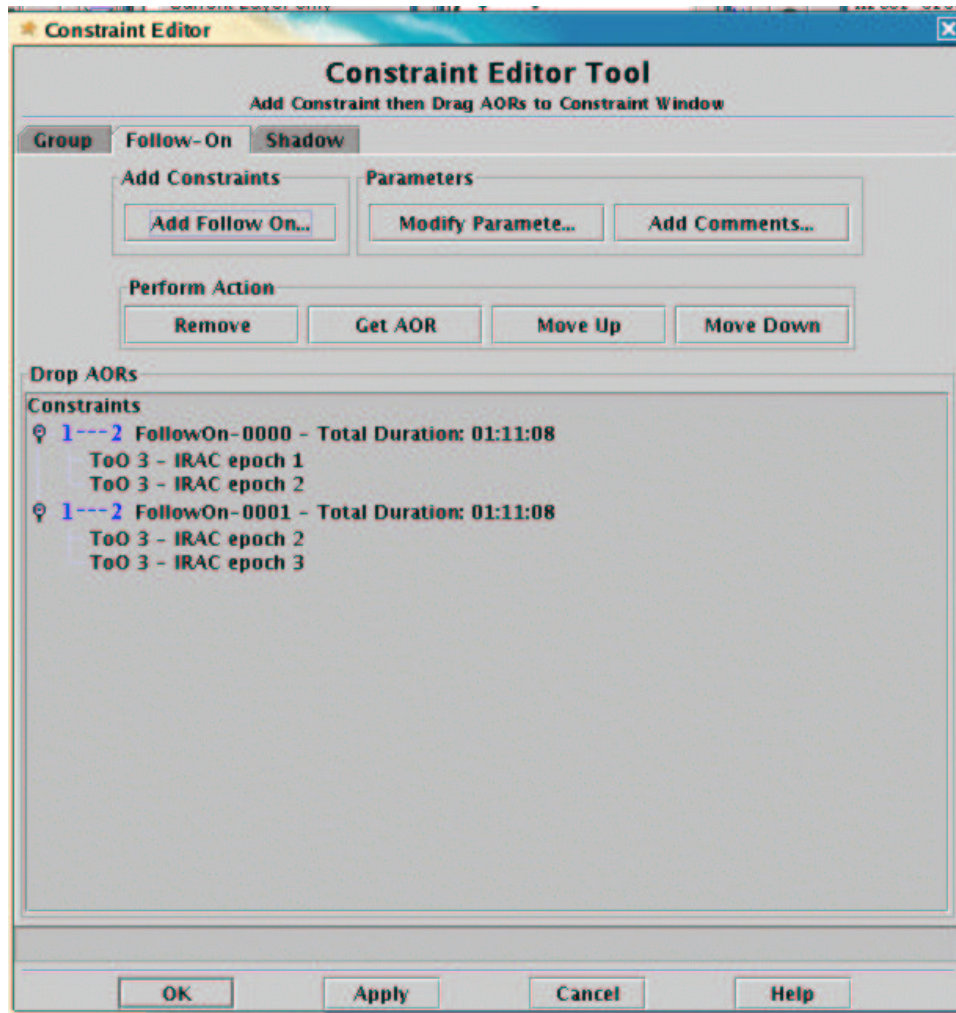
Figure 13.4: The second follow-on constraint

qualifies as a ToO; the first is a high-impact, and the other two are medium impact. We edit the AORs, click the "special" button, and select the corresponding overhead. This program, with all the overheads, comes now to 13.5 hrs.

NOTE that this same series of steps should be followed if we want an IRAC observation followed n days later with a MIPS observation, only in that case (obviously) select "multiple instrument" on the special overhead window.

13.7   Hints and Tips

While writing our ToO proposal, we don't know *when* the observations will be needed. Some programs will know *where* the object is (watching for flaring in a given source), and some will not (gamma ray burst follow-up). In our proposal, we must describe the trigger criteria clearly, e.g., this observation will be triggered if a comet of the right family and size is discovered during this Cycle and is within this distance of the Sun.

Even if we don't know where we will need to point Spitzer, we still need to create representative AORs for each instrument. For example, if we want to observe with all three Spitzer instruments, our proposal should include example AORs for all three instruments, not just one.

The total time we need to request in our proposal is the total time *including* the special overhead, not just the elapsed time of the solitary observations.

The "special overhead" for multiple AORs *occurring as close in time to each other as possible* need only be applied to one of the group of AORs, not to each one.

The "special overhead" for multiple AORs *occurring with a specified number of days between them* need to be applied *to each AOR in the set.*

ToOs that require use of the 160 μm array are unlikely to be accommodated unless the telescope is already cold.

Once our interesting object does whatever we're waiting for it to do, the very first thing we should do is pull up Spot, enter it as a target, and *check the visibility windows.* Calling in an activation request won't do much good if Spitzer can't view the object.

13.8   Obtaining the AOR file

The AOR file, ready to be loaded into Spot, containing the raw AORs developed in this chapter can be downloaded from the SSC Cookbook webpage:

http://ssc.spitzer.caltech.edu/documents/cookbook/

Chapter 14

How to Submit A Spitzer Proposal

The Call for Proposals and the Spot User's Guide, both available on the SSC website, provide important information on many things relevant for proposal submission. The SSC provides a propopsal template; this template is available on the same web page as the Call itself. For Cycle-3, the SSC has added embedded guidelines into the template to aid observers in preparing their proposal. If you read no other documentation be sure to *Read the template instructions and follow them.* That is the best advice we can give for submitting a successful proposal!

A Step-by-step proposal submission guide is available online here:

http://ssc.spitzer.caltech.edu/documents/propsubmission.html

That page has many embedded links to other resources. The content from this website is repeated below, along with some hints and tips for creating good proposals.

14.0.1   Planning Stages

- Think of some spiffy science to be done using Spitzer.

- Read all of the relevant documentation (and there is quite a bit of it). The 5 most essential documents are Call for Proposals (CP), Spitzer Observer's Manual (SOM), Spot User's Guide, Reserved Observations Catalog (ROC), and the Spitzer Observing Rules. Many other helpful

documents are also available for download in the Proposal Kit area of the SSC web site.

- Download and install Spot. Do this early! Get to know your Spot and the Spitzer science instruments well before the deadline of the Call.

- Check the Reserved Observations Catalog (ROC). Avoid duplicating approved observations. Duplications are generally not allowed. See the Observing Rules for more details on duplication of approved observations.

- Check that your favorite target(s) are not too bright or too faint for Spitzer. Remember that the sky background can be significant at some infrared wavelengths. Sensitivity charts are available in the Spitzer Observer's Manual and in the Proposal Kit area (see the Tools page). Observers can use Spot and/or IRSKY to estimate the infrared sky background in regions of interest. See the Infrared Compendium for more details on IR background and estimating background flux levels.

- Use Spot to fill out AOTs to create AORs. (There are lots of examples of how to do this on this site; particularly in the document you are reading now!) Check the visibility of your observations, especially if you need to use an observational constraint (hints and tips about constraints). Use Spot to visualize your AORs. Is it doing what you expected?

- Start writing the scientific and technical justification. This must be in PDF format when submitted as part of the proposal. See the Call for Proposals for details on what to include in the justification. All of this information must be in a PDF file that is less than 10 MB total.

- Early on, open the Proposal Tool in Spot (see more below). Fill in some information and save it to disk. This is the coversheet part of the proposal. Get comfortable editing the information and changing it if needed.

14.0.2 Planning stage Hints and Tips

Spitzer Proposal Submission is a one-phase process (for exceptions, see the CP). Proposers for Spitzer observing time must include the details of their

proposed observations in the form of AORs. By reading this Cookbook, you are well on your way to preparing final AORs to submit with your proposal.

Your scientific and technical justification must be in PDF format. Note that there is a file size limit of 10 MB (see the Call). In practice, what this means is that ultra-high-resolution color figures may not be allowed to be submitted in your proposal! For Cycle-1, most people's proposals were *much* smaller than even 2 MB, so your proposal is also likely to fit very comfortably within 10 MB. If you are having trouble making things fit, note that resolution of any figures need not be more than 300 dpi; also try black-and-white figures rather than color.

Note that your proposal will be provided to the peer reviewers in CD-ROM form. This means that a reasonable fraction of the proposal reviewers will be reading your proposal on a computer screen. There are a few very easy tips for creating screen-readable PDF documents available online here:

http://ssc.spitzer.caltech.edu/documents/makepdf.html

Anyone not reading your proposal on the computer screen will most likely have sent it to a black-and-white printer. Make sure your color figures are also intelligible in black-and-white (which, by the way, also helps color-blind readers decipher your plots).

14.0.3   Proposal Submission

- Think of a nifty shorthand proposal user name (not your personal username) for your proposal. It must be unique within the Spitzer mission. Check the ROC list of science programs for proposal user names other observers have used. Also think of a password. You will need to use this proposal user name and password to update your submitted proposal (possible throughout the Call, see below) and to modify your approved proposal if necessary.

- Start up Spot.

- Load the AORs to be submitted into Spot. Be sure there are not any junk or test AORs, just the good ones you want to be executed with Spitzer if your proposal is approved. (AORs are not to be submitted for Archival or Theoretical Research proposals.)

- Open the Proposal Tool from the Tools menu in Spot.

- Load your coversheet file into the Proposal Tool (File → Open Proposal), or input the information that is requested. Double-check that the information looks correct, especially the Hours Requested and the justification file that is to be submitted.

- Click on the Submit menu in the Proposal Tool and select Submit proposal to SSC.

- Save your coversheet file, as requested by Spot. Name it something you will remember like username_submitted_31jan06.cs. Spot will save the file with your chosen proposal user name (that you're about to enter in the next step) included within it. You will need to use this particular saved coversheet file to submit any modifications to your proposal.

- Enter the proposal user name and password and your email address (used by SSC in case a problem is detected during submission).

- Spot will inform you when it has successfully submitted the proposal to the SSC. You will also receive a confirmation via email.

14.0.4   Proposal Submission Hints and Tips

Because you can update your proposal during the Call (see below), and because this process of getting your basic information into the database can take several minutes during periods of extremely heavy load, it will make things easier if you submit a preliminary proposal and get into the database early on.

Don't choose any password you would like to keep ultra secure - don't use a PIN, don't use obscenities. This password will be emailed to the Principal Investigator (PI) and Technical Contact (TC) of your proposal if changes to your program are required.

Are you writing the proposal, but you expect someone else (a grad student? someone who spends less time on travel than you do?) to be doing the nitty gritty work of the program? Put that person in as the Technical Contact (TC) for the program. This may make your life easier later on – for example, only PIs and TCs are authorized to make decisions or changes to accepted programs, and if the SSC later requires a quick decision on something, maybe your TC will be around when you are not.

Spot is very conducive to experimentation when creating AORs. However, all of the AORs in the AOR window are submitted with your proposal. Make sure any junk or test AORs have been deleted from your final set.

Make sure that the total hours requested in the cover sheet is what you expect it to be. This number is NOT automatically grabbed from the Spot window for several very good reasons, not the least of which is that for medium and large Cycle-2 programs, a complete set of AORs is not required. If you discuss other amounts of time in your proposal, these other numbers are likely to be ignored in favor of the number entered here on your coversheet.

Confirmation email is sent to the PI, the TC, and the person self-identifying as submitting the proposal. Make sure there aren't any typos in your email addresses, otherwise you won't get this confirmation email.

14.0.5   Updating your Submitted Proposal

At any time during the Call for Proposals you may modify any aspect of your submitted proposal, except proposal user name and password. You can submit a revised justification, an updated set of AORs, or corrected coversheet information.

- Start up Spot.

- Load in new set of AORs if updating AORs.

- Open the Proposal Tool under the Tools menu in Spot.

- Read in the coversheet file saved from earlier submission (i.e. username_submitted_31jan06.cs) by clicking on File → Open Proposal.

- Make any desired changes to the coversheet information. Be sure the Hours Requested entered is accurate and that the Tool is pointing to the proper justification file (if submitting an updated file).

- Click on the Submit menu and then Update proposal at SSC.

- Enter your password and email address when requested.

- Spot will again require you to save your coversheet file. Call it something useful like username_submitted_1feb05.cs.

- Spot will inform you when it has successfully transferred your updated proposal to the SSC. You will also receive an email confirmation.

- You may submit as many updates as needed prior to the deadline of the Call for Proposals. Submissions after the deadline will be automatically rejected by the software and an error message will be returned by Spot.

14.0.6   Proposal Updating Hints and Tips

At any time during the Call for Proposals you may modify any aspect of your submitted proposal, except proposal user name and password. You can submit a revised justification, an updated set of AORs, or corrected coversheet information.

Because you can update your proposal during the Call, and because this process of getting your basic information into the database can take several minutes during periods of extremely heavy load, it will make things easier if you submit a preliminary proposal and get into the database early on.

Chapter 15

Planning Observations
Frequently Asked Questions

The SSC maintains a list of Spitzer Frequently Asked Questions. (This list changes often reflecting the feedback you send to the Helpdesk.) See:

http://ssc.spitzer.caltech.edu/faq/

Appendix A

Conversion of Units

A number of units are employed in astronomy for photometry, including:

$$\text{magnitude}$$
$$\text{Wm}^{-2}\mu\text{m}^{-1}$$
$$\text{Wcm}^{-2}\mu\text{m}^{-1}$$
$$\text{erg s}^{-1}\text{cm}^{-2}\mu\text{m}^{-1}$$
$$\text{erg s}^{-1}\text{cm}^{-2}\mathring{\text{A}}^{-1}$$

The purpose of this section is to explicitly tabulate the conversion formulae among them.

First, recall that

$$1 \text{ Jy} \equiv 10^{-26}\text{W m}^{-2}\,\text{Hz}^{-1} \equiv 10^{-23}\text{erg s}^{-1}\,\text{cm}^{-2}\,\text{Hz}^{-1}.$$

A.1 Conversion Between Flux Densities

The spectral flux density, F_ν, is defined as the energy per unit area, per unit time, per unit frequency at frequency ν and is related to the object magnitude as

$$F_\nu \equiv dF/d\nu = F_{\nu_0}\, 10^{-0.4m} \tag{A.1}$$

$[F_\lambda]$	a_λ
erg s^{-1}cm^{-2}Å^{-1}	3×10^{-13}
erg s^{-1}cm$^{-2}\mu$m^{-1}	3×10^{-9}
W cm^{-2} μm^{-1}	3×10^{-16}
W m^{-2} μm^{-1}	3×10^{-12}

Table A.1: The conversion between F_ν and F_λ, where $[\lambda] = \mu$m.

λ [μm]	F_{ν_0} [Jy]	F_{λ_0} [erg cm^{-2} s^{-1} μm^{-1}]
3.6	277.5	6.42×10^{-8}
4.5	179.5	2.66×10^{-8}
5.8	116.6	1.04×10^{-8}
8.0	63.1	2.96×10^{-9}

Table A.2: The photometric zeropoints for the Spitzer/IRAC instrument.

where m is the magnitude, and F_{ν_0} is the zero-point flux in a given photo-metric band. In the cgs system, $[F_\nu] = $ Jy. Then

$$F_\lambda \equiv dF/d\lambda = \frac{dF}{d\nu}\frac{d\nu}{d\lambda} = F_\nu \, a_\lambda/\lambda^2. \tag{A.2}$$

The conversion factor, a_λ is not really mysterious; it is simply $1\,\mathrm{Jy} \times c$, the speed of light, expressed in the appropriate units. For completeness, we tabulate a_λ for various unit choices for F_λ. The results are displayed in Table A.1 (where $[\lambda] = \mu$m).

A.2 Converting Between Flux Density and Magnitudes

The conversion between magnitudes and flux density F_ν is given explicitly in equation A.1. All we need is to specify the zero-point flux, F_{ν_0}.

The zero-point flux, F_{ν_0}, is determined for a number of photometric sys-tems. In Table A.2 we tabulate the zeropoints, F_{ν_0} and $F_{\lambda_0} = a_\lambda F_{\nu_0}/\lambda^2$, for IRAC.

Band	$\lambda[\mu m]$	F_{ν_0} [Jy]
J	1.235	1594
H	1.662	1024
Ks	2.159	666.7

Table A.3: The photometric zeropoints in the 2MASS filters.

Band	$\lambda[\mu m]$	F_{ν_0} [Jy]	F_{λ_0} [erg cm^{-2} s^{-1} μm^{-1}]
V	0.56	3540	3.39×10^{-5}
R	0.70	2870	1.76×10^{-5}
I	0.90	2250	8.83×10^{-6}
J	1.25	1670	3.20×10^{-6}
H	1.65	980	1.08×10^{-6}
K	2.2	620	3.84×10^{-7}
L	3.4	280	7.26×10^{-8}
M	4.8	150	1.95×10^{-8}
N	10.1	37	1.09×10^{-9}
Q	20.0	10	7.5×10^{-11}

Table A.4: The photometric zeropoints in the CIT system.

In Table A.3, we display the zeropoints in the 2MASS passbands (see: http://www.ipac.caltech.edu/2mass/releases/second/doc/sec4_5.html).

In Table A.4 we tabulate the zeropoints, F_{ν_0} and $F_{\lambda_0} = a_\lambda F_{\nu_0}/\lambda^2$, adopted for NICMOS, based on the CIT system (Beckwith et al., 1976, ApJ, 208, 390).

In Table A.5, we display the zeropoints in the Johnson UBVRI+ system (see: *Allen's Astrophysical Quantities*, Fourth Edition, 2001, Arthur N. Cox (ed.), Springer-Verlag; Campins, Rieke, & Lebofsky 1985, AJ, 90, 896; Rieke, Lebofsky & Low 1985, AJ, 90, 900).

We have developed an online magnitude $\leftrightarrow$ flux density converter. Check the SSC tools website:

http://ssc.spitzer.caltech.edu/tools/

Band	$\lambda[\mu m]$	F_{ν_0} [Jy]
U	0.36	1823
B	0.44	4130
V	0.55	3781
R	0.71	2941
I	0.97	2635
J	1.25	1603
H	1.60	1075
K	2.22	667
L	3.54	288
M	4.80	170
N	10.6	36
O	21.0	9.4

Table A.5: The photometric zeropoints in the Johnson UBVRI+ system.

A.3   Conversion Among Surface Brightness Units

Typically in IR astronomy, surface brightness is measured in

$$\text{magnitude/arcsec}^2$$
$$\text{Jy/arcsec}^2$$
$$\text{MJy/sr.}$$

The conversion between the latter two is straightforward:

$$S_\nu[\text{Jy/arcsec}^2] = 2.35 \times 10^{-5}\, S_\nu[\text{MJy/sr}]. \qquad (\text{A.3})$$

Converting between Jy/arcsec^2 and magnitude/arcsec^2 is also straightforward. Using equation A.1, we have

$$S_\nu[\text{mag./}\square''] = 2.5 \times \{\log_{10}(F_{\nu_0}) - \log_{10}(S_\nu[\text{Jy/}\square''])\} \qquad (\text{A.4})$$

and hence

$$S_\nu[\text{mag./}\square''] = 2.5 \times \{\log_{10}(F_{\nu_0}) - \log_{10}(S_\nu[\text{MJy/sr}]) + 4.63\}. \qquad (\text{A.5})$$

For example, in the K-band, $F_{\nu_0} = 620$ Jy (see Table A.4) and hence

$$18\ \text{mag./}\square'' = 3.9 \times 10^{-5}\,\text{Jy/}\square'' = 1.7 \times \text{MJy/sr}. \qquad (\text{A.6})$$

Appendix B

Deep Imaging AORs

We include here the raw aors for the deep imaging observations developed in
§3 and 4. The raw file, ready to be loaded into SPOT, can be downloaded
from the SSC website:

http://ssc.spitzer.caltech.edu/documents/cookbook/

```
#  Please edit this file with care to maintain the
#  correct format so that SPOT can still read it.
#  Generated by SPOT on:  12/9/2004      17:39:33



#  Please edit this file with care to maintain the
#  correct format so that SPOT can still read it.
#  Generated by SPOT on:  10/26/2005      10:24:21

HEADER: FILE_VERSION=11.0, STATUS = PROPOSAL

      AOT_TYPE:  IRAC Mapping
     AOR_LABEL:  IRAC Mapping - a2218 center position
    AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  abell 2218 center position
  COORD_SYSTEM:  Equatorial J2000
```

```
        POSITION:  RA_LON=16h35m53.99s,  DEC_LAT=+66d13m00.2s, PM_RA=0.0", PM_DEC=0.
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

        READOUT_MODE: FULL_ARRAY
                ARRAY: 3.6_5.8u=YES, 4.5_8.0u=YES
           HI_DYNAMIC: NO
         STELLAR_MODE: NO
           FRAME_TIME: 100.0
       DITHER_PATTERN: TYPE=Cycling, N_POSITION=49, START_POINT=10
         DITHER_SCALE: medium
 N_FRAMES_PER_POINTING: 1
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=11155.8, SLEW_TIME=399.6, SETTLE_TIME=0.0, SLEW_OVERH
INTEGRATION_TIME: IRAC_3_6=4900.0,IRAC_4_5=4900.0,IRAC_5_8=4900.0,IRAC_8_0=4900.0




        AOT_TYPE:   IRAC Mapping
       AOR_LABEL:   IRAC Mapping - a1689 center position
      AOR_STATUS:   new

  MOVING_TARGET:  NO
    TARGET_TYPE:  FIXED SINGLE
    TARGET_NAME:  abell 1689 center position
   COORD_SYSTEM:  Equatorial J2000
        POSITION:  RA_LON=13h11m34.20s,  DEC_LAT=-1d21m55.5s, PM_RA=0.0", PM_DEC=0.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

        READOUT_MODE: FULL_ARRAY
                ARRAY: 3.6_5.8u=YES, 4.5_8.0u=YES
           HI_DYNAMIC: NO
         STELLAR_MODE: NO
           FRAME_TIME: 100.0
       DITHER_PATTERN: TYPE=Cycling, N_POSITION=49, START_POINT=10
         DITHER_SCALE: medium
 N_FRAMES_PER_POINTING: 1
```

```
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=11152.0, SLEW_TIME=395.8, SETTLE_TIME=0.0, SLEW_OVERH
INTEGRATION_TIME: IRAC_3_6=4900.0,IRAC_4_5=4900.0,IRAC_5_8=4900.0,IRAC_8_0=4900.0




        AOT_TYPE:  IRAC Mapping
       AOR_LABEL:  IRAC Mapping - a665 center position
      AOR_STATUS:  new

  MOVING_TARGET:  NO
    TARGET_TYPE:  FIXED SINGLE
    TARGET_NAME:  abell 665 center position
   COORD_SYSTEM:  Equatorial J2000
        POSITION:  RA_LON=8h30m45.19s,  DEC_LAT=+65d52m55.3s, PM_RA=0.0", PM_DEC=0.0
OBJECT_AVOIDANCE:   EARTH = YES, OTHERS = YES

          READOUT_MODE: FULL_ARRAY
                  ARRAY: 3.6_5.8u=YES, 4.5_8.0u=YES
             HI_DYNAMIC: NO
            STELLAR_MODE: NO
             FRAME_TIME: 100.0
          DITHER_PATTERN: TYPE=Cycling, N_POSITION=49, START_POINT=10
            DITHER_SCALE: medium
 N_FRAMES_PER_POINTING: 1
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=11153.3, SLEW_TIME=397.1, SETTLE_TIME=0.0, SLEW_OVERH
INTEGRATION_TIME: IRAC_3_6=4900.0,IRAC_4_5=4900.0,IRAC_5_8=4900.0,IRAC_8_0=4900.0




        AOT_TYPE:  IRAC Mapping
       AOR_LABEL:  IRAC Mapping - ac 114 center position
      AOR_STATUS:  new
```

```
  MOVING_TARGET:  NO
    TARGET_TYPE:  FIXED SINGLE
    TARGET_NAME:  ac 114 center position
   COORD_SYSTEM:  Equatorial J2000
       POSITION:  RA_LON=22h58m52.34s,  DEC_LAT=-34d46m54.6s, PM_RA=0.0", PM_DEC=0.
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

          READOUT_MODE: FULL_ARRAY
                 ARRAY: 3.6_5.8u=YES, 4.5_8.0u=YES
             HI_DYNAMIC: NO
           STELLAR_MODE: NO
             FRAME_TIME: 100.0
         DITHER_PATTERN: TYPE=Cycling, N_POSITION=49, START_POINT=10
           DITHER_SCALE: medium
 N_FRAMES_PER_POINTING: 1
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=11151.5, SLEW_TIME=395.3, SETTLE_TIME=0.0, SLEW_OVERH
INTEGRATION_TIME: IRAC_3_6=4900.0,IRAC_4_5=4900.0,IRAC_5_8=4900.0,IRAC_8_0=4900.0




       AOT_TYPE:  IRAC Mapping
      AOR_LABEL:  IRAC Mapping - cl0024+16 center position
     AOR_STATUS:  new

  MOVING_TARGET:  NO
    TARGET_TYPE:  FIXED SINGLE
    TARGET_NAME:  cl0024+16 center position
   COORD_SYSTEM:  Equatorial J2000
       POSITION:  RA_LON=0h26m12.38s,  DEC_LAT=+17d03m53.7s, PM_RA=0.0", PM_DEC=0.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

          READOUT_MODE: FULL_ARRAY
                 ARRAY: 3.6_5.8u=YES, 4.5_8.0u=YES
             HI_DYNAMIC: NO
```

```
                    STELLAR_MODE: NO
                     FRAME_TIME: 100.0
                DITHER_PATTERN: TYPE=Cycling, N_POSITION=49, START_POINT=10
                  DITHER_SCALE: medium
     N_FRAMES_PER_POINTING: 1
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=11150.0, SLEW_TIME=393.8, SETTLE_TIME=0.0, SLEW_OVERH
INTEGRATION_TIME: IRAC_3_6=4900.0,IRAC_4_5=4900.0,IRAC_5_8=4900.0,IRAC_8_0=4900.0
```

```
              AOT_TYPE:  MIPS Photometry
             AOR_LABEL:  MIPS Photo 24 + 160 A2218 center position
            AOR_STATUS:  new

     MOVING_TARGET:  NO
       TARGET_TYPE:  FIXED SINGLE
       TARGET_NAME:  abell 2218 center position
      COORD_SYSTEM:  Equatorial J2000
          POSITION:  RA_LON=16h35m53.99s,  DEC_LAT=+66d13m00.2s, PM_RA=0.0", PM_DEC=0.
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

        MICRON_24: FIELD_SIZE = LARGE, EXPOSURE_TIME = 30, SKY_OFFSET = 10.0, N_CYCLES
       MICRON_160: FIELD_SIZE = LARGE, EXPOSURE_TIME = 10, N_CYCLES = 4
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=3078.042, SLEW_TIME=121.0, SETTLE_TIME=203.04195, SLE
INTEGRATION_TIME: MIPS_24=375.3902,MIPS_70=0.0,MIPS_160=41.94304
```

```
              AOT_TYPE:  MIPS Photometry
             AOR_LABEL:  MIPS Photo 70 A2218 map
            AOR_STATUS:  new
```

```
 MOVING_TARGET:   NO
   TARGET_TYPE:   FIXED CLUSTER - OFFSETS
   TARGET_NAME:   abell 2218 70 micron positions
  COORD_SYSTEM:   Equatorial J2000
     POSITION1:   RA_LON=16h35m53.99s,  DEC_LAT=+66d13m00.2s, PM_RA=0.0", PM_DEC=0.
     OFFSET_P2:   EAST_ROW_PERP=0.0",NORTH_COL_PARA=80.0"
     OFFSET_P3:   EAST_ROW_PERP=0.0",NORTH_COL_PARA=-80.0"
OFFSETS_IN_ARRAY:   YES
OBSERVE_OFFSETS_ONLY:   YES
OBJECT_AVOIDANCE:   EARTH = YES, OTHERS = YES

    MICRON_70: IMAGE_SCALE = DEFAULT, FIELD_SIZE = SMALL, EXPOSURE_TIME = 10, N_CY
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=1750.3145, SLEW_TIME=9.8, SETTLE_TIME=20.914473, SLEW
INTEGRATION_TIME: MIPS_24=0.0,MIPS_70=545.2595,MIPS_160=0.0




      AOT_TYPE:   MIPS Photometry
     AOR_LABEL:   MIPS Photo 70 A1689 map
    AOR_STATUS:   new

 MOVING_TARGET:   NO
   TARGET_TYPE:   FIXED CLUSTER - OFFSETS
   TARGET_NAME:   abell 1689 70 micron positions
  COORD_SYSTEM:   Equatorial J2000
     POSITION1:   RA_LON=13h11m34.20s,  DEC_LAT=-1d21m55.5s, PM_RA=0.0", PM_DEC=0.
     OFFSET_P2:   EAST_ROW_PERP=0.0",NORTH_COL_PARA=80.0"
     OFFSET_P3:   EAST_ROW_PERP=0.0",NORTH_COL_PARA=-80.0"
OFFSETS_IN_ARRAY:   YES
OBSERVE_OFFSETS_ONLY:   YES
OBJECT_AVOIDANCE:   EARTH = YES, OTHERS = YES

    MICRON_70: IMAGE_SCALE = DEFAULT, FIELD_SIZE = SMALL, EXPOSURE_TIME = 10, N_CY
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=1750.3146, SLEW_TIME=9.8, SETTLE_TIME=20.91457, SLEW_
```

```
INTEGRATION_TIME: MIPS_24=0.0,MIPS_70=545.2595,MIPS_160=0.0




      AOT_TYPE:  MIPS Photometry
     AOR_LABEL:  MIPS Photo 70 AC114 70 map
    AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED CLUSTER - OFFSETS
   TARGET_NAME:  ac114 70 micron positions
  COORD_SYSTEM:  Equatorial J2000
     POSITION1:  RA_LON=22h58m52.34s,  DEC_LAT=-34d46m54.6s, PM_RA=0.0", PM_DEC=0.
     OFFSET_P2:  EAST_ROW_PERP=0.0",NORTH_COL_PARA=80.0"
     OFFSET_P3:  EAST_ROW_PERP=0.0",NORTH_COL_PARA=-80.0"
OFFSETS_IN_ARRAY:  YES
OBSERVE_OFFSETS_ONLY:  YES
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

    MICRON_70: IMAGE_SCALE = DEFAULT, FIELD_SIZE = SMALL, EXPOSURE_TIME = 10, N_CY
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=1750.3146, SLEW_TIME=9.8, SETTLE_TIME=20.914572, SLEW
INTEGRATION_TIME: MIPS_24=0.0,MIPS_70=545.2595,MIPS_160=0.0




      AOT_TYPE:  MIPS Photometry
     AOR_LABEL:  MIPS Photo 70 cl0024 map
    AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED CLUSTER - OFFSETS
   TARGET_NAME:  cl0024+16 70 micron positions
  COORD_SYSTEM:  Equatorial J2000
```

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```
        POSITION1:  RA_LON=0h26m12.38s,  DEC_LAT=+17d03m53.7s, PM_RA=0.0", PM_DEC=0.0
        OFFSET_P2:  EAST_ROW_PERP=0.0",NORTH_COL_PARA=80.0"
        OFFSET_P3:  EAST_ROW_PERP=0.0",NORTH_COL_PARA=-80.0"
OFFSETS_IN_ARRAY:  YES
OBSERVE_OFFSETS_ONLY:  YES
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

    MICRON_70: IMAGE_SCALE = DEFAULT, FIELD_SIZE = SMALL, EXPOSURE_TIME = 10, N_CY
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=1750.3146, SLEW_TIME=9.8, SETTLE_TIME=20.914602, SLEW
INTEGRATION_TIME: MIPS_24=0.0,MIPS_70=545.2595,MIPS_160=0.0




        AOT_TYPE:  MIPS Photometry
       AOR_LABEL:  MIPS Photo 24 + 160 A665 center position
      AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  abell 665 center position
  COORD_SYSTEM:  Equatorial J2000
      POSITION:  RA_LON=8h30m45.19s,  DEC_LAT=+65d52m55.3s, PM_RA=0.0", PM_DEC=0.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

    MICRON_24: FIELD_SIZE = LARGE, EXPOSURE_TIME = 30, SKY_OFFSET = 10.0, N_CYCLES
   MICRON_160: FIELD_SIZE = LARGE, EXPOSURE_TIME = 10, N_CYCLES = 4
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=3077.055, SLEW_TIME=120.0, SETTLE_TIME=203.05495, SLE
INTEGRATION_TIME: MIPS_24=375.3902,MIPS_70=0.0,MIPS_160=41.94304




        AOT_TYPE:  MIPS Photometry
```

```
      AOR_LABEL:  MIPS Photo 24 + 160 A1689 center position  - copy
     AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  abell 1689 center position
  COORD_SYSTEM:  Equatorial J2000
      POSITION:  RA_LON=13h11m34.20s,  DEC_LAT=-1d21m55.5s, PM_RA=0.0", PM_DEC=0.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

     MICRON_24: FIELD_SIZE = LARGE, EXPOSURE_TIME = 30, SKY_OFFSET = 10.0, N_CYCLES
    MICRON_160: FIELD_SIZE = LARGE, EXPOSURE_TIME = 10, N_CYCLES = 4
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=3076.8733, SLEW_TIME=119.8, SETTLE_TIME=203.07329, SL
INTEGRATION_TIME: MIPS_24=375.3902,MIPS_70=0.0,MIPS_160=41.94304




      AOT_TYPE:  MIPS Photometry
     AOR_LABEL:  MIPS Photo 24 + 160 cl0024+16 center position
     AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  cl0024+16 center position
  COORD_SYSTEM:  Equatorial J2000
      POSITION:  RA_LON=0h26m12.38s,  DEC_LAT=+17d03m53.7s, PM_RA=0.0", PM_DEC=0.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

     MICRON_24: FIELD_SIZE = LARGE, EXPOSURE_TIME = 30, SKY_OFFSET = 10.0, N_CYCLES
    MICRON_160: FIELD_SIZE = LARGE, EXPOSURE_TIME = 10, N_CYCLES = 4
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=3076.9175, SLEW_TIME=119.8, SETTLE_TIME=203.1175, SLE
INTEGRATION_TIME: MIPS_24=375.3902,MIPS_70=0.0,MIPS_160=41.94304
```

```
       AOT_TYPE:  MIPS Photometry
      AOR_LABEL:  MIPS Photo 24 + 160 ac 114 center position
     AOR_STATUS:  new


 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  ac 114 center position
  COORD_SYSTEM:  Equatorial J2000
       POSITION:  RA_LON=22h58m52.34s,  DEC_LAT=-34d46m54.6s, PM_RA=0.0", PM_DEC=0.
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES


     MICRON_24:  FIELD_SIZE = LARGE, EXPOSURE_TIME = 30, SKY_OFFSET = 10.0, N_CYCLES
    MICRON_160:  FIELD_SIZE = LARGE, EXPOSURE_TIME = 10, N_CYCLES = 4
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=3076.8865, SLEW_TIME=119.8, SETTLE_TIME=203.08658, SI
INTEGRATION_TIME: MIPS_24=375.3902,MIPS_70=0.0,MIPS_160=41.94304




       AOT_TYPE:  MIPS Photometry
      AOR_LABEL:  MIPS Photo 70 a665 70 map
     AOR_STATUS:  new


 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED CLUSTER - OFFSETS
   TARGET_NAME:  abell 665 70 micron map
  COORD_SYSTEM:  Equatorial J2000
      POSITION1:  RA_LON=8h30m45.19s,  DEC_LAT=+65d52m55.3s, PM_RA=0.0", PM_DEC=0.0
      OFFSET_P2:  EAST_ROW_PERP=0.0",NORTH_COL_PARA=80.0"
      OFFSET_P3:  EAST_ROW_PERP=0.0",NORTH_COL_PARA=-80.0"
OFFSETS_IN_ARRAY:  YES
OBSERVE_OFFSETS_ONLY:  YES
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES
```

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```
      MICRON_70: IMAGE_SCALE = DEFAULT, FIELD_SIZE = SMALL, EXPOSURE_TIME = 10, N_CY
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=1750.3146, SLEW_TIME=9.8, SETTLE_TIME=20.914534, SLEW
INTEGRATION_TIME: MIPS_24=0.0,MIPS_70=545.2595,MIPS_160=0.0




CONSTRAINT: TYPE=GROUP_WITHIN, NAME=Group-A2218
DELTA_TIME: DAYS=14, TIME=00:00:00
AORS: AOR1=IRAC Mapping - a2218 center position,
      AOR2=MIPS Photo 24 + 160 A2218 center position,
      AOR3=MIPS Photo 70 A2218 map

CONSTRAINT: TYPE=GROUP_WITHIN, NAME=Group-A1689
DELTA_TIME: DAYS=14, TIME=00:00:00
AORS: AOR1=MIPS Photo 70 A1689 map,
      AOR2=MIPS Photo 24 + 160 A1689 center position  - copy,
      AOR3=IRAC Mapping - a1689 center position

CONSTRAINT: TYPE=GROUP_WITHIN, NAME=Group-AC114
DELTA_TIME: DAYS=14, TIME=00:00:00
AORS: AOR1=IRAC Mapping - ac 114 center position,
      AOR2=MIPS Photo 24 + 160 ac 114 center position,
      AOR3=MIPS Photo 70 AC114 70 map

CONSTRAINT: TYPE=GROUP_WITHIN, NAME=Group-cl0024
DELTA_TIME: DAYS=14, TIME=00:00:00
AORS: AOR1=IRAC Mapping - cl0024+16 center position,
      AOR2=MIPS Photo 24 + 160 cl0024+16 center position,
      AOR3=MIPS Photo 70 cl0024 map

CONSTRAINT: TYPE=GROUP_WITHIN, NAME=Group-a665
DELTA_TIME: DAYS=14, TIME=00:00:00
AORS: AOR1=IRAC Mapping - a665 center position,
      AOR2=MIPS Photo 70 a665 70 map,
```

AOR3=MIPS Photo 24 + 160 A665 center position

Appendix C

IRS Staring AORs

We include here the raw aor for the IRS Staring observations developed in
§5. The raw file, ready to be loaded into SPOT, can be downloaded from the
SSC website:

http://ssc.spitzer.caltech.edu/documents/cookbook/

```
#  Please edit this file with care to maintain the
#  correct format so that SPOT can still read it.
#  Generated by SPOT on:  12/11/2004      9:52:50

HEADER: FILE_VERSION=11.0, STATUS = PROPOSAL

      AOT_TYPE:  IRS Staring
     AOR_LABEL:  IRS_cookbook-example1
    AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  3C 273
  COORD_SYSTEM:  Equatorial  J2000
      POSITION:  RA_LON=12h29m06.70s,  DEC_LAT=+2d03m08.6s,
PM_RA=0.0", PM_DEC=0.0", EPOCH=2000.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES
```

```
    IRS_PEAK_UP:  OPTION=HIGH,  FILTER=BLUE,  RAJ2000=12h27m42.31s,
DECJ2000=+1d50m14.7s, PM_RA=-0.023, PM_DEC=0.0090, EPOCH=2000.0,
FLUX_DENSITY=31.7, EXTENDED_SOURCE=NO
          MODE:  STANDARD
      HI_SHORT:  EXPOSURE_TIME=120,  N_CYCLES_SEQ=1
      HI_LONG:  EXPOSURE_TIME=240,  N_CYCLES_SEQ=1
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=1383.7, SLEW_TIME=32.1,
SETTLE_TIME=30.0, SLEW_OVERHEAD=215.0,
SPECIAL_OVERHEAD=0.0, UPLINK_VOLUME=789,
DOWNLINK_VOLUME=2219246, VERSION=S11.0.3
INTEGRATION_TIME:
IRS_HI_10=243.79391,IRS_HI_19=483.65567,IRS_LO_5=0.0,
IRS_LO_7=0.0,IRS_LO_14=0.0,IRS_LO_20=0.0
```

Appendix D

IRS Mapping AORs

We include here the raw aor for the IRS Mapping observations developed in
§6. The raw file, ready to be loaded into SPOT, can be downloaded from the
SSC website:

http://ssc.spitzer.caltech.edu/documents/cookbook/

```
#  Please edit this file with care to maintain the
#  correct format so that SPOT can still read it.
#  Generated by SPOT on:  12/11/2004      9:23:40

HEADER: FILE_VERSION=11.0, STATUS = PROPOSAL

      AOT_TYPE:  IRS Mapping
     AOR_LABEL:  IRS_Cookbook-example2
    AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  Ring Nebula
  COORD_SYSTEM:  Equatorial  J2000
      POSITION:  RA_LON=18h53m35.16s,
DEC_LAT=+33d01m43.2s, EPOCH=2000.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES
```

```
    IRS_PEAK_UP:  OPTION=MODERATE,  FILTER=BLUE,
RAJ2000=18h53m15.85s, DECJ2000=+33d28m28.1s, PM_RA=-0.016,
PM_DEC=0.014, EPOCH=2000.0, FLUX_DENSITY=119.9,
EXTENDED_SOURCE=NO
N_MAP_CYCLES:1
      LO_SHORT5:  EXPOSURE_TIME=60,  N_PARALLEL=2,
STEP_PARALLEL=51.0, N_PERPENDICULAR=11,
STEP_PERPENDICULAR=3.6, N_CYCLES=2
      LO_SHORT7:  EXPOSURE_TIME=60,  N_PARALLEL=2,
STEP_PARALLEL=51.0, N_PERPENDICULAR=11,
STEP_PERPENDICULAR=3.6, N_CYCLES=2

SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK =
NO RESOURCE_EST: TOTAL_DURATION=7467.7, SLEW_TIME=102.9,
SETTLE_TIME=112.0, SLEW_OVERHEAD=215.0,
SPECIAL_OVERHEAD=0.0, UPLINK_VOLUME=2875,
DOWNLINK_VOLUME=43645190, VERSION=S11.0.3
INTEGRATION_TIME:
IRS_HI_10=0.0,IRS_HI_19=0.0,IRS_LO_5=121.89696,IRS_LO_7=121.89696,
IRS_LO_14=0.0,IRS_LO_20=0.0
TIMING1:  START_DATE=2004 Oct 17, START_TIME=00:00:00,
END_DATE=2004 Nov 2, END_TIME=04:08:00
TIMING2:  START_DATE=2005 Apr 20, START_TIME=00:00:00,
END_DATE=2005 May 14, END_TIME=00:00:00
TIMING3:  START_DATE=2005 Oct 25, START_TIME=00:00:00,
END_DATE=2005 Nov 9, END_TIME=16:35:00
TIMING4:  START_DATE=2006 Apr 27, START_TIME=00:00:00,
END_DATE=2006 May 1, END_TIME=21:54:00
```

Appendix E

PUI AORs

We include here the raw aor for the PUI observations developed in §7. The raw file, ready to be loaded into SPOT, can be downloaded from the SSC website:

http://ssc.spitzer.caltech.edu/documents/cookbook/

```
#  Please edit this file with care to maintain the
#  correct format so that SPOT can still read it.
#  Generated by SPOT on:  10/26/2005     11:15:50

HEADER: FILE_VERSION=11.0, STATUS = PROPOSAL

      AOT_TYPE:  IRS Peakup Image
     AOR_LABEL:  IRSI-example 1
    AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  abell 2218
  COORD_SYSTEM:  Equatorial J2000
      POSITION:  RA_LON=16h35m53.99s,  DEC_LAT=+66d13m00.2s, PM_RA=0.0", PM_DEC=0.
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES
```

```
        BLUE:  EXPOSURE_TIME=30,  N_CYCLES_SEQ=1
DITHER_PATTERN: TYPE=Cycling, N_POSITION=7, START_POINT=1
  DITHER_SCALE: large
MAP: ROWS=4, COLS=6, ROW_STEP=75.0, COL_STEP=50.0,
     ORIENT=ARRAY, ROW_OFFSET=0.0,COL_OFFSET=0.0,N_CYCLE=1
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=8902.9, SLEW_TIME=352.3, SETTLE_TIME=1002.0, SLEW_OVE
INTEGRATION_TIME: IRS_RED=0.0,IRS_BLUE=220.20096




        AOT_TYPE:  IRS Peakup Image
       AOR_LABEL:  IRSI-example 2
      AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED CLUSTER - POSITIONS
   TARGET_NAME:  cl0024+1654
  COORD_SYSTEM:  Equatorial J2000
      POSITION1:  RA_LON=0h26m20.40s,  DEC_LAT=+17d04m07.0s, PM_RA=0.0", PM_DEC=0.0
      POSITION2:  RA_LON=0h26m10.60s,  DEC_LAT=+17d06m47.0s, PM_RA=0.0", PM_DEC=0.0
      POSITION3:  RA_LON=0h26m08.20s,  DEC_LAT=+17d01m17.0s, PM_RA=0.0", PM_DEC=0.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

        BLUE:  EXPOSURE_TIME=30,  N_CYCLES_SEQ=2
DITHER_PATTERN: TYPE=5Positions
  DITHER_SCALE: small
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=1611.2963, SLEW_TIME=36.1, SETTLE_TIME=88.09623, SLEW
INTEGRATION_TIME: IRS_RED=0.0,IRS_BLUE=314.57278




        AOT_TYPE:  IRS Peakup Image
```

```
      AOR_LABEL:  IRSI-example 3
     AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  Abell 1689
  COORD_SYSTEM:  Equatorial J2000
       POSITION:  RA_LON=13h11m34.20s,  DEC_LAT=-1d21m55.5s, PM_RA=0.0", PM_DEC=0.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES


         BLUE:  EXPOSURE_TIME=14,  N_CYCLES_SEQ=4
DITHER_PATTERN: TYPE=9Positions
  DITHER_SCALE: large
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=1140.8, SLEW_TIME=15.7, SETTLE_TIME=48.0, SLEW_OVERHF
INTEGRATION_TIME: IRS_RED=0.0,IRS_BLUE=528.4823
```

Appendix F

Survey AORs

We include here the raw aors for the wide-field survey observations developed in §8 and 9. The raw file, ready to be loaded into SPOT, can be downloaded from the SSC website:

http://ssc.spitzer.caltech.edu/documents/cookbook/

```
#  Please edit this file with care to maintain the
#  correct format so that SPOT can still read it.
#  Generated by SPOT on:  12/9/2004     17:43:14

HEADER: FILE_VERSION=11.0, STATUS = PROPOSAL

      AOT_TYPE:  MIPS Scan Map
     AOR_LABEL:  MIPS scan NE
    AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  Trapezium NE
  COORD_SYSTEM:  Equatorial  J2000
      POSITION:  RA_LON=5h33m18.59s,  DEC_LAT=-4d53m28.6s, EPOCH=2000.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES
```

```
     REQUIRE_160: YES
       SCAN_RATE: fast
  FAST_RESET_160: NO
       STEP_SIZE: TURNAROUND=160", FORWARD=160"
     N_SCAN_LEGS: 24
    N_MAP_CYCLES: 1
 SCAN_LEG_LENGTH: 1.0
MAP_CENTER_OFFSET: CROSS_SCAN = 0, IN_SCAN = 0
  BACKWARD_MAP: NO
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=10179.8, SLEW_TIME=343.8, SETTLE_TIME=549.0, SLEW_OVE
INTEGRATION_TIME: MIPS_24=15.7,MIPS_70=15.7,MIPS_160=3.1




        AOT_TYPE:  MIPS Scan Map
       AOR_LABEL:  MIPS scan SE
      AOR_STATUS:  new

  MOVING_TARGET:  NO
    TARGET_TYPE:  FIXED SINGLE
    TARGET_NAME:  Trapezium SE
   COORD_SYSTEM:  Equatorial  J2000
        POSITION:  RA_LON=5h33m18.59s,  DEC_LAT=-5d53m28.6s, EPOCH=2000.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

     REQUIRE_160: YES
       SCAN_RATE: fast
  FAST_RESET_160: NO
       STEP_SIZE: TURNAROUND=160", FORWARD=160"
     N_SCAN_LEGS: 24
    N_MAP_CYCLES: 1
 SCAN_LEG_LENGTH: 1.0
MAP_CENTER_OFFSET: CROSS_SCAN = 0, IN_SCAN = 0
  BACKWARD_MAP: NO
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
```

```
RESOURCE_EST: TOTAL_DURATION=10179.8, SLEW_TIME=343.8, SETTLE_TIME=549.0, SLEW_OVE
INTEGRATION_TIME: MIPS_24=15.7,MIPS_70=15.7,MIPS_160=3.1




        AOT_TYPE:  MIPS Scan Map
       AOR_LABEL:  MIPS scan NW
      AOR_STATUS:  new

  MOVING_TARGET:  NO
    TARGET_TYPE:  FIXED SINGLE
    TARGET_NAME:  Trapezium NW
   COORD_SYSTEM:  Equatorial  J2000
        POSITION:  RA_LON=5h37m17.33s,  DEC_LAT=-4d53m28.6s, EPOCH=2000.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

     REQUIRE_160: YES
       SCAN_RATE: fast
  FAST_RESET_160: NO
       STEP_SIZE: TURNAROUND=160", FORWARD=160"
     N_SCAN_LEGS: 24
    N_MAP_CYCLES: 1
 SCAN_LEG_LENGTH: 1.0
 MAP_CENTER_OFFSET: CROSS_SCAN = 0, IN_SCAN = 0
  BACKWARD_MAP: NO
 SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
 RESOURCE_EST: TOTAL_DURATION=10179.8, SLEW_TIME=343.8, SETTLE_TIME=549.0, SLEW_OVE
 INTEGRATION_TIME: MIPS_24=15.7,MIPS_70=15.7,MIPS_160=3.1




        AOT_TYPE:  MIPS Scan Map
       AOR_LABEL:  MIPS scan SW
      AOR_STATUS:  new
```

```
 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  Trapezium SW
  COORD_SYSTEM:  Equatorial  J2000
      POSITION:  RA_LON=5h37m17.33s,  DEC_LAT=-5d53m28.6s, EPOCH=2000.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES


   REQUIRE_160: YES
     SCAN_RATE: fast
 FAST_RESET_160: NO
      STEP_SIZE: TURNAROUND=160", FORWARD=160"
    N_SCAN_LEGS: 24
   N_MAP_CYCLES: 1
SCAN_LEG_LENGTH: 1.0
MAP_CENTER_OFFSET: CROSS_SCAN = 0, IN_SCAN = 0
 BACKWARD_MAP: NO
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=10179.8, SLEW_TIME=343.8, SETTLE_TIME=549.0, SLEW_OVE
INTEGRATION_TIME: MIPS_24=15.7,MIPS_70=15.7,MIPS_160=3.1




      AOT_TYPE:  MIPS Scan Map
    AOR_LABEL:  MIPS scan center
    AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  Trapezium
  COORD_SYSTEM:  Equatorial  J2000
      POSITION:  RA_LON=5h35m15.05s,  DEC_LAT=-5d23m29.2s, EPOCH=2000.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

   REQUIRE_160: NO
     SCAN_RATE: fast
```

```
 FAST_RESET_160: NO
       STEP_SIZE: TURNAROUND=160", FORWARD=160"
     N_SCAN_LEGS: 12
   N_MAP_CYCLES: 1
SCAN_LEG_LENGTH: 1.0
MAP_CENTER_OFFSET: CROSS_SCAN = 0, IN_SCAN = 0
 BACKWARD_MAP: NO
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=5206.9, SLEW_TIME=165.8, SETTLE_TIME=274.5, SLEW_OVEF
INTEGRATION_TIME: MIPS_24=15.7,MIPS_70=15.7,MIPS_160=3.1




        AOT_TYPE:  IRAC Mapping
       AOR_LABEL:  IRAC scan center
      AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  Trapezium
  COORD_SYSTEM:  Equatorial  J2000
       POSITION:  RA_LON=5h35m15.05s,  DEC_LAT=-5d23m29.2s, EPOCH=2000.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

         READOUT_MODE: FULL_ARRAY
                ARRAY: 3.6_5.8u=YES, 4.5_8.0u=YES
            HI_DYNAMIC: YES
            FRAME_TIME: 12.0
        DITHER_PATTERN: TYPE=Cycling, N_POSITION=3, START_POINT=1
          DITHER_SCALE: medium
 N_FRAMES_PER_POINTING: 1
MAP: TYPE=RECTANGULAR, ROWS=12, COLS=12, ROW_STEP=260.0, COL_STEP=260.0,
     ORIENT=ARRAY, ROW_OFFSET=0.0,COL_OFFSET=0.0,N_CYCLE=1
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=11653.8, SLEW_TIME=2258.2, SETTLE_TIME=0.0, SLEW_OVEF
INTEGRATION_TIME: IRAC_3_6=36.0,IRAC_4_5=36.0,IRAC_5_8=36.0,IRAC_8_0=36.0
```

```
          AOT_TYPE:  MIPS Scan Map
         AOR_LABEL:  MIPS scan- larger
        AOR_STATUS:  new

    MOVING_TARGET:  NO
      TARGET_TYPE:  FIXED SINGLE
      TARGET_NAME:  Trapezium
     COORD_SYSTEM:  Equatorial  J2000
         POSITION:  RA_LON=5h35m15.05s,  DEC_LAT=-5d23m29.2s, EPOCH=2000.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

       REQUIRE_160: NO
         SCAN_RATE: fast
    FAST_RESET_160: NO
         STEP_SIZE: TURNAROUND=160", FORWARD=160"
       N_SCAN_LEGS: 24
      N_MAP_CYCLES: 1
   SCAN_LEG_LENGTH: 1.0
MAP_CENTER_OFFSET: CROSS_SCAN = 0, IN_SCAN = 0
    BACKWARD_MAP: NO
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=10179.8, SLEW_TIME=343.8, SETTLE_TIME=549.0, SLEW_OVE
INTEGRATION_TIME: MIPS_24=15.7,MIPS_70=15.7,MIPS_160=3.1




CONSTRAINT: TYPE=GROUP_WITHIN, NAME=Large ONC Map Group
DELTA_TIME: DAYS=7, TIME=00:00:00
AORS: AOR1=MIPS scan NE,
      AOR2=MIPS scan SE,
      AOR3=MIPS scan NW,
```

```
AOR4=MIPS scan SW
```

Appendix G

IRSKY output for MIPS background near the Trapezium

This is the output of an IRSKY session investigating background levels at 160, 70, and 24 μm near the Trapezium. It was emailed at the end of the IRSKY session.

```
#**********************************************************
  Position (Equatorial B1950)
  Longitude:         5h32m48.98784s 83.204116d
  Latitude :         -5d25m16.2084s -5.421169d
#**********************************************************
#
# ****** BACKGROUND INFORMATION ******
#
# Galactic background estimates are obtained from the
# IRAS Low Resolution Product (LRP) and the
# IRAS Sky Survey Atlas (ISSA).
# Both LRP and ISSA have large scale zodiacal emission removed.
# The LRP has 0.5 degree pixels.
# The ISSA has 1.5 arcmin pixels, and 4--5 arcmin resolution.
#
! Estimates may not be robust outside IRAS wavelengths (12 - 100um)
! Warning: LRP fluxes are not well modeled
! Warning: ISSA fluxes are not well modeled
! Warning: 30x30 fluxes are not well modeled
#
  Epoch 1996    Fluxes in [MJy/sr]
#
```

```
   |um   |Zodiacal| 30'LRP |Zodiacal| 4' ISSA|Zodiacal| 30'x30'| COBE   |
   |     |        |        |        | + LRP  |        |+ ISSA  | mean   |        |
#
   12.00     21.3     218      239 4.67e+03 4.69e+03      69      164
   25.00     40.7     929      969 1.53e+04 1.53e+04     213      991
   60.00     14.8 3.18e+03 3.19e+03 1.69e+04 1.69e+04 2.29e+03 3.75e+03
  100.00     7.33 5.15e+03 5.15e+03 2.47e+04 2.47e+04 3.76e+03 3.43e+03
  160.00     2.94  2.8e+04  2.8e+04 7.09e+04 7.09e+04 2.37e+03  2.9e+03
#
  Brightest 100um ISSA pixel in 0.5 degree square:   2.56e+04 MJy/sr
#
#
# ****** EXTRAGALACTIC CONFUSION NOISE in aperture ******
#
  Aperture  0.0625178  arcmin^2  (5.29e-09 steradian)
#
  At  160.00 um:       0.134 --     0.348  MJy/sr
#
#
# ****** CIRRUS CONFUSION NOISE (1 sigma levels) ******
#
  Aperture  0.0625178  arcmin^2  (5.29e-09 steradian)
  Beam Offset/Aperture Size: 2  (Offset: 33.8562 arcsec)
#
  At  160.00 um:        390 --   1.16e+03  MJy/sr
  using a two component source model.
! At 160.00um the aperture <0.5 Airy disk diameter - Diffraction severe.
#
#
# ISSA STATISTICS for background flux in aperture
# as determined from brightness in Averaging Area and Aperture Size.
# (Zodiacal contribution subtracted)
  Fluxes in [MJy/sr]
#
#             12um          25um          60um          100um
# Averaged    Mean          Mean          Mean          Mean
# Area        (Sigma)       (Sigma)       (Sigma)       (Sigma)
  30x30'           69           213      2.29e+03      3.76e+03
              (    54.6) (     201) ( 2.21e+03) ( 3.38e+03)
  60x60'         20.7          38.3           357           751
              (    13.7) (    31.9) (      337) (      614)
  90x90'         11.8          19.2           149           345
              (    8.46) (    14.2) (      166) (      309)
#
```

```
#**********************************************************
  Position (Equatorial B1950)
  Longitude:        5h32m48.98784s 83.204116d
  Latitude :        -5d25m16.2084s -5.421169d
#**********************************************************
#
# ****** BACKGROUND INFORMATION ******
#
# Galactic background estimates are obtained from the
# IRAS Low Resolution Product (LRP) and the
# IRAS Sky Survey Atlas (ISSA).
# Both LRP and ISSA have large scale zodiacal emission removed.
# The LRP has 0.5 degree pixels.
# The ISSA has 1.5 arcmin pixels, and 4--5 arcmin resolution.
#
! Warning: LRP fluxes are not well modeled
! Warning: ISSA fluxes are not well modeled
! Warning: 30x30 fluxes are not well modeled
#
  Epoch 1996     Fluxes in [MJy/sr]
#
  |um   |Zodiacal| 30'LRP |Zodiacal| 4' ISSA|Zodiacal| 30'x30'| COBE   |
  |     |        |        | + LRP  |        |+ ISSA  | mean   |        |
#
   12.00     21.3      218      239 4.67e+03 4.69e+03      69      164
   25.00     40.7      929      969 1.53e+04 1.53e+04     213      991
   60.00     14.8 3.18e+03 3.19e+03 1.69e+04 1.69e+04 2.29e+03 3.75e+03
  100.00     7.33 5.15e+03 5.15e+03 2.47e+04 2.47e+04 3.76e+03 3.43e+03
   70.00     11.8 3.53e+03 3.55e+03 2.12e+04 2.13e+04  3.2e+03 3.65e+03
#
  Brightest 100um ISSA pixel in 0.5 degree square:    2.56e+04 MJy/sr
#
#
# ****** EXTRAGALACTIC CONFUSION NOISE in aperture ******
#
  Aperture  0.0245817  arcmin^2  (2.08e-09 steradian)
#
  At   70.00 um:      0.0262 --     0.0673  MJy/sr
#
#
# ****** CIRRUS CONFUSION NOISE (1 sigma levels) ******
#
  Aperture  0.0245817  arcmin^2  (2.08e-09 steradian)
  Beam Offset/Aperture Size: 2  (Offset: 21.2296 arcsec)
#
```

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```
  At   70.00 um:         642 --   2.35e+03  MJy/sr
  using a two component source model.
! At 70.00um the aperture <0.5 Airy disk diameter - Diffraction severe.
#
#
# ISSA STATISTICS for background flux in aperture
# as determined from brightness in Averaging Area and Aperture Size.
# (Zodiacal contribution subtracted)
  Fluxes in [MJy/sr]
#
#             12um           25um          60um          100um
# Averaged    Mean           Mean          Mean          Mean
# Area       (Sigma)        (Sigma)       (Sigma)       (Sigma)
  30x30'          69             213      2.29e+03      3.76e+03
             (     54.6)   (      201)   ( 2.21e+03)   ( 3.38e+03)
  60x60'         20.7           38.3           357           751
             (     13.7)   (     31.9)   (      337)   (      614)
  90x90'         11.8           19.2           149           345
             (     8.46)   (     14.2)   (      166)   (      309)
#


#*********************************************************
  Position (Equatorial B1950)
  Longitude:        5h32m48.98784s 83.204116d
  Latitude :        -5d25m16.2084s -5.421169d
#*********************************************************
#
# ****** BACKGROUND INFORMATION ******
#
# Galactic background estimates are obtained from the
# IRAS Low Resolution Product (LRP) and the
# IRAS Sky Survey Atlas (ISSA).
# Both LRP and ISSA have large scale zodiacal emission removed.
# The LRP has 0.5 degree pixels.
# The ISSA has 1.5 arcmin pixels, and 4--5 arcmin resolution.
#
! Warning: LRP fluxes are not well modeled
! Warning: ISSA fluxes are not well modeled
! Warning: 30x30 fluxes are not well modeled
#
  Epoch 1996    Fluxes in [MJy/sr]
#
  |um  |Zodiacal| 30'LRP |Zodiacal| 4' ISSA|Zodiacal| 30'x30'| COBE   |
  |    |        |        | + LRP  |        |+ ISSA  | mean   |        |
#
```

```
  12.00     21.3       218        239 4.67e+03 4.69e+03       69       164
  25.00     40.7       929        969 1.53e+04 1.53e+04      213       991
  60.00     14.8 3.18e+03 3.19e+03 1.69e+04 1.69e+04 2.29e+03 3.75e+03
 100.00      7.33 5.15e+03 5.15e+03 2.47e+04 2.47e+04 3.76e+03 3.43e+03
  24.00     35.8       889        925 1.08e+04 1.08e+04      241       896
#
  Brightest 100um ISSA pixel in 0.5 degree square:    2.56e+04 MJy/sr
#
#
# ****** EXTRAGALACTIC CONFUSION NOISE in aperture ******
#
  Aperture  0.00159544  arcmin^2  (1.35e-10 steradian)
#
  At   24.00 um:  <     0.0516 MJy/sr
#
#
# ****** CIRRUS CONFUSION NOISE (1 sigma levels) ******
#
  Aperture  0.00159544  arcmin^2  (1.35e-10 steradian)
  Beam Offset/Aperture Size: 2  (Offset: 5.4085 arcsec)
#
  At   24.00 um:      4.48 --      23.4  MJy/sr
  using a two component source model.
! At 24.00um the aperture <0.5 Airy disk diameter - Diffraction severe.
#
#
# ISSA STATISTICS for background flux in aperture
# as determined from brightness in Averaging Area and Aperture Size.
# (Zodiacal contribution subtracted)
  Fluxes in [MJy/sr]
#
#               12um            25um            60um            100um
# Averaged      Mean            Mean            Mean            Mean
# Area         (Sigma)         (Sigma)         (Sigma)         (Sigma)
  30x30'             69              213        2.29e+03        3.76e+03
             (      54.6) (         201) (    2.21e+03) (   3.38e+03)
  60x60'           20.7             38.3             357             751
             (      13.7) (        31.9) (         337) (        614)
  90x90'           11.8             19.2             149             345
             (      8.46) (        14.2) (         166) (        309)
#
```

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Appendix H

SSO AORs

We include here the raw aors for the observations of Pholus developed in §10. The raw file, ready to be loaded into SPOT, can be downloaded from the SSC website:

http://ssc.spitzer.caltech.edu/documents/cookbook/

```
#  Please edit this file with care to maintain the
#  correct format so that SPOT can still read it.
#  Generated by SPOT on:  12/9/2004     17:42:33

HEADER: FILE_VERSION=11.0, STATUS = PROPOSAL

      AOT_TYPE:  MIPS Photometry
     AOR_LABEL:  MIPS pholus- all3
    AOR_STATUS:  new

 MOVING_TARGET:  YES
   TARGET_TYPE:  MOVING SINGLE
   TARGET_NAME:  pholus
     EPHEMERIS:  NAIF_ID=2005145, NAIF_NAME=pholus
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = NO

    MICRON_24: FIELD_SIZE = SMALL, EXPOSURE_TIME = 3,
N_CYCLES = 7
    MICRON_70: IMAGE_SCALE = DEFAULT, FIELD_SIZE = SMALL,
```

```
EXPOSURE_TIME = 10, N_CYCLES = 3
    MICRON_160: FIELD_SIZE = SMALL, EXPOSURE_TIME = 10, N_CYCLES = 20
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=5083.866, SLEW_TIME=59.8,
SETTLE_TIME=76.16644, SLEW_OVERHEAD=215.0,
SPECIAL_OVERHEAD=0.0, UPLINK_VOLUME=2231,
DOWNLINK_VOLUME=85240088, VERSION=S11.0.3
INTEGRATION_TIME: MIPS_24=312.47565,MIPS_70=335.5443,
MIPS_160=419.4
TIMING1:  START_DATE=2004 Jul 15, START_TIME=05:00:00,
END_DATE=2004 Aug 30, END_TIME=15:00:00




        AOT_TYPE:  MIPS Photometry
       AOR_LABEL:  MIPS pholus- p2
      AOR_STATUS:  new

  MOVING_TARGET:  YES
    TARGET_TYPE:  MOVING SINGLE
    TARGET_NAME:  pholus
       EPHEMERIS:  NAIF_ID=2005145, NAIF_NAME=pholus
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = NO

    MICRON_160: FIELD_SIZE = SMALL, EXPOSURE_TIME = 10, N_CYCLES = 10
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=2189.022, SLEW_TIME=10.2,
SETTLE_TIME=18.222015, SLEW_OVERHEAD=215.0,
SPECIAL_OVERHEAD=0.0, UPLINK_VOLUME=1022,
DOWNLINK_VOLUME=34306332, VERSION=S11.0.3
INTEGRATION_TIME: MIPS_24=0.0,MIPS_70=0.0,
MIPS_160=209.7152
TIMING1:  START_DATE=2004 Jul 15, START_TIME=05:00:00,
END_DATE=2004 Aug 30, END_TIME=16:00:00
```

```
        AOT_TYPE:  MIPS Photometry
       AOR_LABEL:  MIPS pholus- all3  - copy
      AOR_STATUS:  new

 MOVING_TARGET:  YES
    TARGET_TYPE:  MOVING SINGLE
    TARGET_NAME:  pholus
      EPHEMERIS:  NAIF_ID=2005145, NAIF_NAME=pholus
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = NO

      MICRON_24: FIELD_SIZE = SMALL, EXPOSURE_TIME = 3,
N_CYCLES = 7
      MICRON_70: IMAGE_SCALE = DEFAULT, FIELD_SIZE = SMALL,
EXPOSURE_TIME = 10, N_CYCLES = 3
     MICRON_160: FIELD_SIZE = SMALL, EXPOSURE_TIME = 10,
N_CYCLES = 20
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=5083.866, SLEW_TIME=59.8,
SETTLE_TIME=76.16644, SLEW_OVERHEAD=215.0,
SPECIAL_OVERHEAD=0.0, UPLINK_VOLUME=2231,
DOWNLINK_VOLUME=85240088, VERSION=S11.0.3
INTEGRATION_TIME: MIPS_24=312.47565,MIPS_70=335.5443,MIPS_160=419.4




CONSTRAINT: TYPE=SHADOW, NAME=Shadow-0000, SHADOW_BEFORE_PRIMARY=NO
RANGE_START: DAYS=7, TIME=00:00:00
  RANGE_END: DAYS=14, TIME=00:00:00
      AORS: AOR_PRIMARY=MIPS pholus- all3  - copy, AOR_SHADOW=MIPS
pholus- all3
```

Appendix I

SED AORs

We include here the raw aor for the SED observations developed in §11. The raw file, ready to be loaded into SPOT, can be downloaded from the SSC website:

http://ssc.spitzer.caltech.edu/documents/cookbook/

```
#  Please edit this file with care to maintain the
#  correct format so that SPOT can still read it.
#  Generated by SPOT on:  12/10/2004      11:57:48

HEADER: FILE_VERSION=11.0, STATUS = PROPOSAL

     AOT_TYPE:  MIPS SED
    AOR_LABEL:  MIPSE-example 1
   AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  canopus
  COORD_SYSTEM:  Equatorial  J2000
      POSITION:  RA_LON=6h23m57.11s,  DEC_LAT=-52d41m44.4s,
PM_RA=0.02", PM_DEC=0.024", EPOCH=2000.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES
```

```
SED:  EXPOSURE_TIME = 10, CHOP_DISTANCE = +1, N_CYCLES = 4
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=946.8, SLEW_TIME=3.2,
SETTLE_TIME=5.0, SLEW_OVERHEAD=215.0, SPECIAL_OVERHEAD=0.0,
UPLINK_VOLUME=710, DOWNLINK_VOLUME=12252260,
VERSION=S11.0.3
INTEGRATION_TIME: MIPS_24=0.0,MIPS_70=251.64,MIPS_160=0.0
```

Appendix J

Time Series AORs

We include here the raw aors for the time series observation developed in
§12. The raw file, ready to be loaded into SPOT, can be downloaded from
the SSC website:

http://ssc.spitzer.caltech.edu/documents/cookbook/

```
#  Please edit this file with care to maintain the
#  correct format so that SPOT can still read it.
#  Generated by SPOT on:  9/22/2005      17:54:27

HEADER: FILE_VERSION=11.0, STATUS = PROPOSAL

      AOT_TYPE:  IRAC Mapping
     AOR_LABEL:  basic irac aor
    AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  Tres-1
  COORD_SYSTEM:  Equatorial J2000
      POSITION:  RA_LON=19h04m12.00s,  DEC_LAT=+36d37m12.0s, PM_RA=0.0", PM_DEC=0.
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

         READOUT_MODE: FULL_ARRAY
                ARRAY: 3.6_5.8u=NO, 4.5_8.0u=YES
```

```
             HI_DYNAMIC: NO
           STELLAR_MODE: NO
            FRAME_TIME: 12.0
        DITHER_PATTERN: TYPE=none
 N_FRAMES_PER_POINTING: 200
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=2875.5, SLEW_TIME=0.0, SETTLE_TIME=0.0, SLEW_OVERHEAD
INTEGRATION_TIME: IRAC_3_6=2400.0,IRAC_4_5=2400.0,IRAC_5_8=2400.0,IRAC_8_0=2400.0
TIMING1:  START_DATE=2004 Oct 21, START_TIME=19:09:09, END_DATE=2004 Oct 21, END_T
TIMING2:  START_DATE=2004 Oct 24, START_TIME=19:52:27, END_DATE=2004 Oct 24, END_T
TIMING3:  START_DATE=2004 Oct 27, START_TIME=20:35:44, END_DATE=2004 Oct 27, END_T
TIMING4:  START_DATE=2004 Oct 30, START_TIME=21:19:02, END_DATE=2004 Oct 30, END_T
TIMING5:  START_DATE=2004 Nov 2, START_TIME=22:02:19, END_DATE=2004 Nov 2, END_TIM
TIMING6:  START_DATE=2004 Nov 5, START_TIME=22:45:37, END_DATE=2004 Nov 5, END_TIM


COMMENT_START:
These observations require high (relative) photometric precision. Please do not sc
COMMENT_END:




        AOT_TYPE:  IRAC Mapping
       AOR_LABEL:  visit 2
      AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  Tres-1
  COORD_SYSTEM:  Equatorial J2000
      POSITION:  RA_LON=19h04m12.00s,  DEC_LAT=+36d37m12.0s, PM_RA=0.0", PM_DEC=0.
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

          READOUT_MODE: FULL_ARRAY
```

```
                   ARRAY: 3.6_5.8u=NO, 4.5_8.0u=YES
              HI_DYNAMIC: NO
            STELLAR_MODE: NO
              FRAME_TIME: 12.0
          DITHER_PATTERN: TYPE=none
 N_FRAMES_PER_POINTING: 200
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=2875.5, SLEW_TIME=0.0, SETTLE_TIME=0.0, SLEW_OVERHEAD
INTEGRATION_TIME: IRAC_3_6=2400.0,IRAC_4_5=2400.0,IRAC_5_8=2400.0,IRAC_8_0=2400.0




          AOT_TYPE:  IRAC Mapping
        AOR_LABEL:  visit 3
       AOR_STATUS:  new

  MOVING_TARGET:  NO
    TARGET_TYPE:  FIXED SINGLE
    TARGET_NAME:  Tres-1
   COORD_SYSTEM:  Equatorial J2000
        POSITION:  RA_LON=19h04m12.00s,  DEC_LAT=+36d37m12.0s, PM_RA=0.0", PM_DEC=0.
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

           READOUT_MODE: FULL_ARRAY
                   ARRAY: 3.6_5.8u=NO, 4.5_8.0u=YES
              HI_DYNAMIC: NO
            STELLAR_MODE: NO
              FRAME_TIME: 12.0
          DITHER_PATTERN: TYPE=none
 N_FRAMES_PER_POINTING: 200
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=2875.5, SLEW_TIME=0.0, SETTLE_TIME=0.0, SLEW_OVERHEAD
INTEGRATION_TIME: IRAC_3_6=2400.0,IRAC_4_5=2400.0,IRAC_5_8=2400.0,IRAC_8_0=2400.0
```

```
        AOT_TYPE:  IRAC Mapping
       AOR_LABEL:  visit 4
      AOR_STATUS:  new

  MOVING_TARGET:  NO
    TARGET_TYPE:  FIXED SINGLE
    TARGET_NAME:  Tres-1
   COORD_SYSTEM:  Equatorial J2000
        POSITION:  RA_LON=19h04m12.00s,  DEC_LAT=+36d37m12.0s, PM_RA=0.0", PM_DEC=0.
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

           READOUT_MODE: FULL_ARRAY
                   ARRAY: 3.6_5.8u=NO, 4.5_8.0u=YES
              HI_DYNAMIC: NO
            STELLAR_MODE: NO
              FRAME_TIME: 12.0
         DITHER_PATTERN: TYPE=none
 N_FRAMES_PER_POINTING: 200
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=2875.5, SLEW_TIME=0.0, SETTLE_TIME=0.0, SLEW_OVERHEAD
INTEGRATION_TIME: IRAC_3_6=2400.0,IRAC_4_5=2400.0,IRAC_5_8=2400.0,IRAC_8_0=2400.0




        AOT_TYPE:  IRAC Mapping
       AOR_LABEL:  visit 5
      AOR_STATUS:  new

  MOVING_TARGET:  NO
    TARGET_TYPE:  FIXED SINGLE
    TARGET_NAME:  Tres-1
   COORD_SYSTEM:  Equatorial J2000
        POSITION:  RA_LON=19h04m12.00s,  DEC_LAT=+36d37m12.0s, PM_RA=0.0", PM_DEC=0.
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES
```

```
          READOUT_MODE: FULL_ARRAY
                 ARRAY: 3.6_5.8u=NO, 4.5_8.0u=YES
             HI_DYNAMIC: NO
           STELLAR_MODE: NO
             FRAME_TIME: 12.0
         DITHER_PATTERN: TYPE=none
 N_FRAMES_PER_POINTING: 200
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=2875.5, SLEW_TIME=0.0, SETTLE_TIME=0.0, SLEW_OVERHEAD
INTEGRATION_TIME: IRAC_3_6=2400.0,IRAC_4_5=2400.0,IRAC_5_8=2400.0,IRAC_8_0=2400.0




              AOT_TYPE:  IRAC Mapping
             AOR_LABEL:  visit 6
            AOR_STATUS:  new

        MOVING_TARGET:  NO
          TARGET_TYPE:  FIXED SINGLE
          TARGET_NAME:  Tres-1
         COORD_SYSTEM:  Equatorial J2000
             POSITION:  RA_LON=19h04m12.00s,  DEC_LAT=+36d37m12.0s, PM_RA=0.0", PM_DEC=0.
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

          READOUT_MODE: FULL_ARRAY
                 ARRAY: 3.6_5.8u=NO, 4.5_8.0u=YES
             HI_DYNAMIC: NO
           STELLAR_MODE: NO
             FRAME_TIME: 12.0
         DITHER_PATTERN: TYPE=none
 N_FRAMES_PER_POINTING: 200
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=2875.5, SLEW_TIME=0.0, SETTLE_TIME=0.0, SLEW_OVERHEAD
INTEGRATION_TIME: IRAC_3_6=2400.0,IRAC_4_5=2400.0,IRAC_5_8=2400.0,IRAC_8_0=2400.0
```

```
         AOT_TYPE:  IRAC Mapping
        AOR_LABEL:  visit 7
       AOR_STATUS:  new

   MOVING_TARGET:  NO
     TARGET_TYPE:  FIXED SINGLE
     TARGET_NAME:  Tres-1
    COORD_SYSTEM:  Equatorial J2000
        POSITION:  RA_LON=19h04m12.00s,  DEC_LAT=+36d37m12.0s, PM_RA=0.0", PM_DEC=0.
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

            READOUT_MODE: FULL_ARRAY
                   ARRAY: 3.6_5.8u=NO, 4.5_8.0u=YES
              HI_DYNAMIC: NO
            STELLAR_MODE: NO
              FRAME_TIME: 12.0
          DITHER_PATTERN: TYPE=none
 N_FRAMES_PER_POINTING: 200
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=2875.5, SLEW_TIME=0.0, SETTLE_TIME=0.0, SLEW_OVERHEAD
INTEGRATION_TIME: IRAC_3_6=2400.0,IRAC_4_5=2400.0,IRAC_5_8=2400.0,IRAC_8_0=2400.0




         AOT_TYPE:  IRAC Mapping
        AOR_LABEL:  visit 8
       AOR_STATUS:  new

   MOVING_TARGET:  NO
     TARGET_TYPE:  FIXED SINGLE
     TARGET_NAME:  Tres-1
    COORD_SYSTEM:  Equatorial J2000
```

```
        POSITION:  RA_LON=19h04m12.00s,  DEC_LAT=+36d37m12.0s, PM_RA=0.0", PM_DEC=0.
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

     READOUT_MODE: FULL_ARRAY
            ARRAY: 3.6_5.8u=NO, 4.5_8.0u=YES
        HI_DYNAMIC: NO
      STELLAR_MODE: NO
        FRAME_TIME: 12.0
    DITHER_PATTERN: TYPE=none
 N_FRAMES_PER_POINTING: 80
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=1290.5, SLEW_TIME=0.0, SETTLE_TIME=0.0, SLEW_OVERHEAD
INTEGRATION_TIME: IRAC_3_6=960.0,IRAC_4_5=960.0,IRAC_5_8=960.0,IRAC_8_0=960.0




CONSTRAINT: TYPE=CHAIN, NAME=Chain-0000
AORS: AOR1=basic irac aor,
      AOR2=visit 2,
      AOR3=visit 3,
      AOR4=visit 4,
      AOR5=visit 5,
      AOR6=visit 6,
      AOR7=visit 7,
      AOR8=visit 8
```

Appendix K

Target of Opportunity (ToO) AORs

We include here the raw aors for the target of opportunity observation developed in §13. The raw file, ready to be loaded into SPOT, can be downloaded from the SSC website:

http://ssc.spitzer.caltech.edu/documents/cookbook/

```
#  Please edit this file with care to maintain the
#  correct format so that SPOT can still read it.
#  Generated by SPOT on:  9/30/2005     15:8:33

HEADER: FILE_VERSION=11.0, STATUS = PROPOSAL


      AOT_TYPE:  IRAC Mapping
     AOR_LABEL:  ToO 1- IRAC only observation
    AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  M31
  COORD_SYSTEM:  Equatorial J2000
      POSITION:  RA_LON=0h42m44.31000s,  DEC_LAT=+41d16m09.4000s, PM_RA=0.0", PM_D
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES
```

```
            READOUT_MODE: FULL_ARRAY
                   ARRAY: 3.6_5.8u=YES, 4.5_8.0u=YES
               HI_DYNAMIC: NO
             STELLAR_MODE: NO
               FRAME_TIME: 12.0
          DITHER_PATTERN: TYPE=Cycling, N_POSITION=3, START_POINT=1
            DITHER_SCALE: large
 N_FRAMES_PER_POINTING: 1
MAP: TYPE=RECTANGULAR, ROWS=5, COLS=5, ROW_STEP=260.0, COL_STEP=260.0,
     ORIENT=ARRAY, ROW_OFFSET=0.0,COL_OFFSET=0.0,N_CYCLE=1
SPECIAL: IMPACT = medImpactToo1, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=11489.2, SLEW_TIME=456.6, SETTLE_TIME=0.0, SLEW_OVERH
INTEGRATION_TIME: IRAC_3_6=36.0,IRAC_4_5=36.0,IRAC_5_8=36.0,IRAC_8_0=36.0




           AOT_TYPE:   IRAC Mapping
          AOR_LABEL:   ToO 2- IRAC part
         AOR_STATUS:   new

    MOVING_TARGET:   NO
      TARGET_TYPE:   FIXED SINGLE
      TARGET_NAME:   M42
     COORD_SYSTEM:   Equatorial J2000
         POSITION:   RA_LON=5h35m17.30000s,  DEC_LAT=-5d23m28.0000s, PM_RA=0.0", PM_DE
OBJECT_AVOIDANCE:   EARTH = YES, OTHERS = YES

            READOUT_MODE: FULL_ARRAY
                   ARRAY: 3.6_5.8u=YES, 4.5_8.0u=YES
               HI_DYNAMIC: NO
             STELLAR_MODE: NO
               FRAME_TIME: 12.0
          DITHER_PATTERN: TYPE=Cycling, N_POSITION=3, START_POINT=1
            DITHER_SCALE: large
 N_FRAMES_PER_POINTING: 1
MAP: TYPE=RECTANGULAR, ROWS=5, COLS=5, ROW_STEP=260.0, COL_STEP=260.0,
```

```
        ORIENT=ARRAY, ROW_OFFSET=0.0,COL_OFFSET=0.0,N_CYCLE=1
SPECIAL: IMPACT = highImpactToo23, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=33810.1, SLEW_TIME=457.5, SETTLE_TIME=0.0, SLEW_OVERH
INTEGRATION_TIME: IRAC_3_6=36.0,IRAC_4_5=36.0,IRAC_5_8=36.0,IRAC_8_0=36.0




        AOT_TYPE:  MIPS Photometry
       AOR_LABEL:  ToO 2 - MIPS part
      AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  M42
  COORD_SYSTEM:  Equatorial J2000
       POSITION:  RA_LON=5h35m17.30000s,  DEC_LAT=-5d23m28.0000s, PM_RA=0.0", PM_DE
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

     MICRON_24: FIELD_SIZE = SMALL, EXPOSURE_TIME = 3, N_CYCLES = 1
      MICRON_70: IMAGE_SCALE = DEFAULT, FIELD_SIZE = SMALL, EXPOSURE_TIME = 10, N_CY
    MICRON_160: FIELD_SIZE = SMALL, EXPOSURE_TIME = 10, N_CYCLES = 4
SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=1402.5184, SLEW_TIME=39.4, SETTLE_TIME=43.218437, SLE
INTEGRATION_TIME: MIPS_24=48.234497,MIPS_70=125.82912,MIPS_160=83.88608




        AOT_TYPE:  IRAC Mapping
       AOR_LABEL:  ToO 3 - IRAC epoch 1
      AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  m81
```

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```
    COORD_SYSTEM:  Equatorial J2000
        POSITION:  RA_LON=9h55m33.17000s,  DEC_LAT=+69d03m55.1000s, PM_RA=0.0", PM_D
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

        READOUT_MODE: FULL_ARRAY
                ARRAY: 3.6_5.8u=YES, 4.5_8.0u=YES
            HI_DYNAMIC: NO
            STELLAR_MODE: NO
            FRAME_TIME: 12.0
        DITHER_PATTERN: TYPE=Cycling, N_POSITION=3, START_POINT=1
            DITHER_SCALE: large
 N_FRAMES_PER_POINTING: 1
MAP: TYPE=RECTANGULAR, ROWS=5, COLS=5, ROW_STEP=260.0, COL_STEP=260.0,
     ORIENT=ARRAY, ROW_OFFSET=0.0,COL_OFFSET=0.0,N_CYCLE=1
SPECIAL: IMPACT = highImpactToo1, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=25533.5, SLEW_TIME=460.9, SETTLE_TIME=0.0, SLEW_OVERH
INTEGRATION_TIME: IRAC_3_6=36.0,IRAC_4_5=36.0,IRAC_5_8=36.0,IRAC_8_0=36.0




        AOT_TYPE:  IRAC Mapping
        AOR_LABEL:  ToO 3 - IRAC epoch 2
        AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  m81
  COORD_SYSTEM:  Equatorial J2000
        POSITION:  RA_LON=9h55m33.17000s,  DEC_LAT=+69d03m55.1000s, PM_RA=0.0", PM_D
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

        READOUT_MODE: FULL_ARRAY
                ARRAY: 3.6_5.8u=YES, 4.5_8.0u=YES
            HI_DYNAMIC: NO
            STELLAR_MODE: NO
            FRAME_TIME: 12.0
```

```
        DITHER_PATTERN: TYPE=Cycling, N_POSITION=3, START_POINT=1
          DITHER_SCALE: large
 N_FRAMES_PER_POINTING: 1
MAP: TYPE=RECTANGULAR, ROWS=5, COLS=5, ROW_STEP=260.0, COL_STEP=260.0,
     ORIENT=ARRAY, ROW_OFFSET=0.0,COL_OFFSET=0.0,N_CYCLE=1
SPECIAL: IMPACT = medImpactToo1, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=11493.5, SLEW_TIME=460.9, SETTLE_TIME=0.0, SLEW_OVERH
INTEGRATION_TIME: IRAC_3_6=36.0,IRAC_4_5=36.0,IRAC_5_8=36.0,IRAC_8_0=36.0




        AOT_TYPE:  IRAC Mapping
       AOR_LABEL:  ToO 3 - IRAC epoch 3
      AOR_STATUS:  new

 MOVING_TARGET:  NO
   TARGET_TYPE:  FIXED SINGLE
   TARGET_NAME:  m81
  COORD_SYSTEM:  Equatorial J2000
       POSITION:  RA_LON=9h55m33.17000s,  DEC_LAT=+69d03m55.1000s, PM_RA=0.0", PM_D
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

          READOUT_MODE: FULL_ARRAY
                 ARRAY: 3.6_5.8u=YES, 4.5_8.0u=YES
            HI_DYNAMIC: NO
          STELLAR_MODE: NO
            FRAME_TIME: 12.0
        DITHER_PATTERN: TYPE=Cycling, N_POSITION=3, START_POINT=1
          DITHER_SCALE: large
 N_FRAMES_PER_POINTING: 1
MAP: TYPE=RECTANGULAR, ROWS=5, COLS=5, ROW_STEP=260.0, COL_STEP=260.0,
     ORIENT=ARRAY, ROW_OFFSET=0.0,COL_OFFSET=0.0,N_CYCLE=1
SPECIAL: IMPACT = medImpactToo1, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
RESOURCE_EST: TOTAL_DURATION=11493.5, SLEW_TIME=460.9, SETTLE_TIME=0.0, SLEW_OVERH
INTEGRATION_TIME: IRAC_3_6=36.0,IRAC_4_5=36.0,IRAC_5_8=36.0,IRAC_8_0=36.0
```

```
CONSTRAINT: TYPE=FOLLOW_ON, NAME=FollowOn-0000
RANGE_START: DAYS=5, TIME=00:00:00
  RANGE_END: DAYS=10, TIME=00:00:00
      AORS: AOR_FIRST=ToO 3 - IRAC epoch 1, AOR_SECOND=ToO 3 - IRAC epoch 2


CONSTRAINT: TYPE=FOLLOW_ON, NAME=FollowOn-0001
RANGE_START: DAYS=18, TIME=00:00:00
  RANGE_END: DAYS=25, TIME=00:00:00
      AORS: AOR_FIRST=ToO 3 - IRAC epoch 2, AOR_SECOND=ToO 3 - IRAC epoch 3
```

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