Monitoring with TESS photometers for Light Pollution studies

An introduction to TESS photometers and how to use the data

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Ground-based Monitoring with TESS photometers

This presentation aim to help citizens and researchers to get scientific results from TESS photometers observations.

TOPICS

1. STARS4ALL TESS photometers
2. Monitoring with TESS photometers
3. TESS-W photometer network
4. STARS4ALL dashboards
5. Cloud estimate
6. Archived data
7. New TESS photometer models
8. Open software

(1) STARS4ALL TESS-W photometer

(1)

One of the aims of the STARS4ALL H2020 European Project was to build a European network of Night Sky Brightness monitoring stations. This is why we designed a **low cost photometer** with some additional features that improve the well known SQM photometer.

Our main concern was to archive the data for open use. Most of the observations of Night Sky Brightness were obtained by citizens and stored in their own computers. On the other hand the spectral response of the SQM is too short in the red and does not completely cover the sodium HPS spectral lines.

We decide to design a new low cost photometer for citizen science but without compromising the scientific quality.

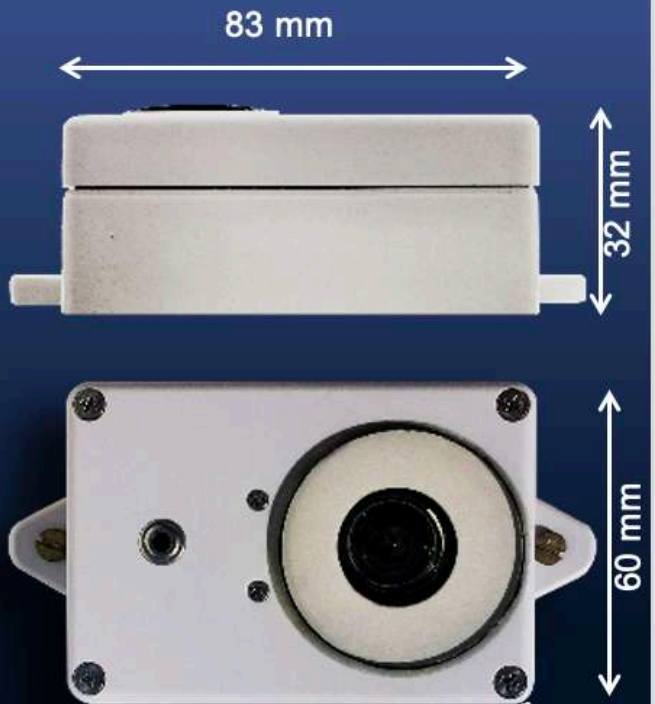
The next slides explain the TESS-W features

Why to design a new photometer ?

- One of the aims of the H2020 European Project was to build a European network of Night Sky Brightness monitoring stations.
- We designed a **low cost photometer** with some additional features that improve the well known SQM photometer.
- TESS-W is open hardware and software, and was designed to share the data (**OPEN DATA**).
- TESS-W is a user friendly **research photometer for citizen science**.

TESS-W night sky brightness photometer

- TESS-W was designed to **monitor** zenith ***Night sky brightness*** every night
- Compact photometer mounted inside a ***weatherproof enclosure***
- Wherever there is **electricity and WIFI** you can install it and **share measures**.
- Scientific results and **open data**
- Internet of Things IoT '**Connect, (register) and forget**'
- ***Extra features.*** Anti-condensation heating, cloud detector...



Open data

Open hardware

STARS4ALL

European Commission

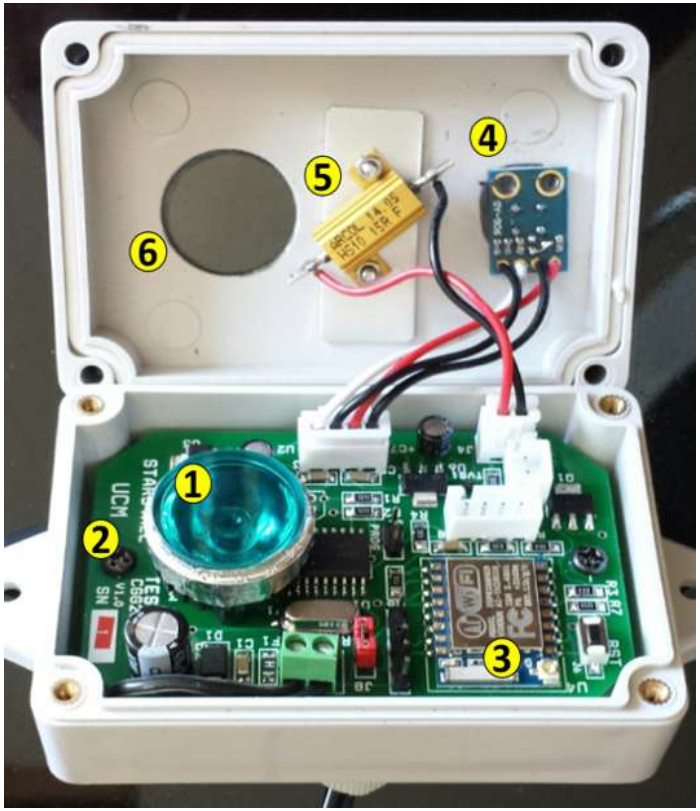
Horizon 2020
European Union funding
for Research & Innovation

TESS-W description

Open Hardware

- Dichroic filter
- Light collector
- Light sensor
- Weatherproof enclosure box
- Clear glass window
- Heater
- Custom printed circuit board
- Infrared thermometer
- WIFI + microcontroller chip
- 5V 2A power supply with 10m wire
- Extra ports for connecting modules

TESS-W description



The photometer is enclosed into a weather proof box that contents the custom made electronics and optical parts. TESS has a custom made Printed Circuit Board (PCB) with an ESP8266 (low-cost WIFI chip with full TCP/IP stack and microcontroller capability.

The electronic is used to reads the frequency provided by the TSL237 light sensor (for night sky brightness data) and also the MLX90614ESF-BA Infrared thermometer module (for cloud cover information).

The sky brightness detector is a TSL237 photodiode that converts light to frequency. It is the same sensor used by the SQM photometers. However, the bandpass is more extended to the red range with the use a dichroic filter with respect to the BG38 color filter of the SQM.

The light from the sky is collected with the optics that includes a dichroic filter to select the bandpass.

(1) The filter fully covers the collector.

(2) The sensor (not seen in this picture) is located on a printed circuit board along with the custom-made electronics.

(3) The WIFI module with an antenna inside the box that extends the WIFI range.

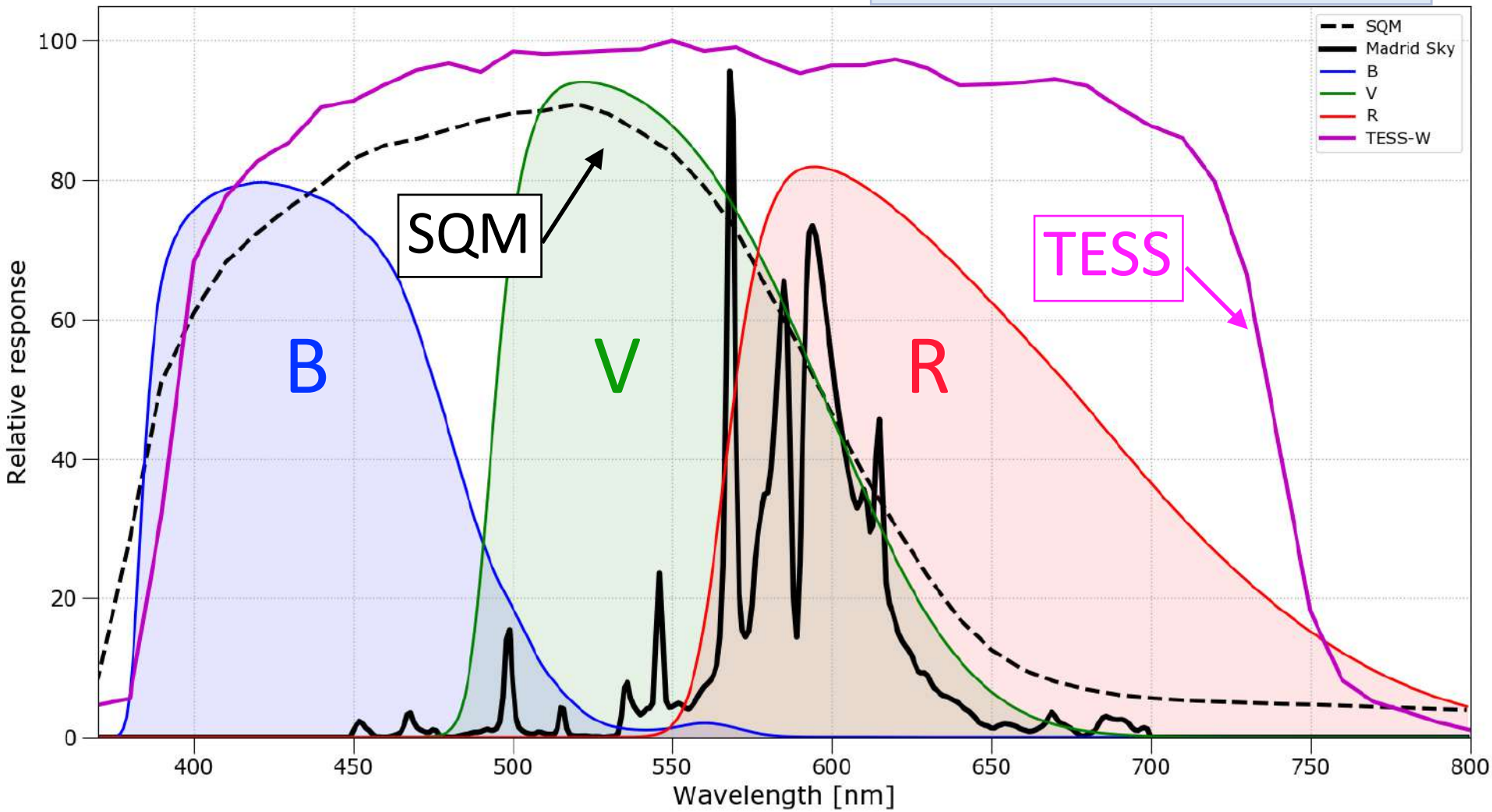
(4) A near-infrared sensor is used to measure sky temperature.

(5) The heater is switched on when needed to get rid of condensation on the window or even to melt the ice or snow (6).

The field of view (FoV) is FWHM=17 degrees.

TESS-W spectral response extended to the red

SQM, Johnson B, V, R and TESS-W and Madrid night sky spectrum

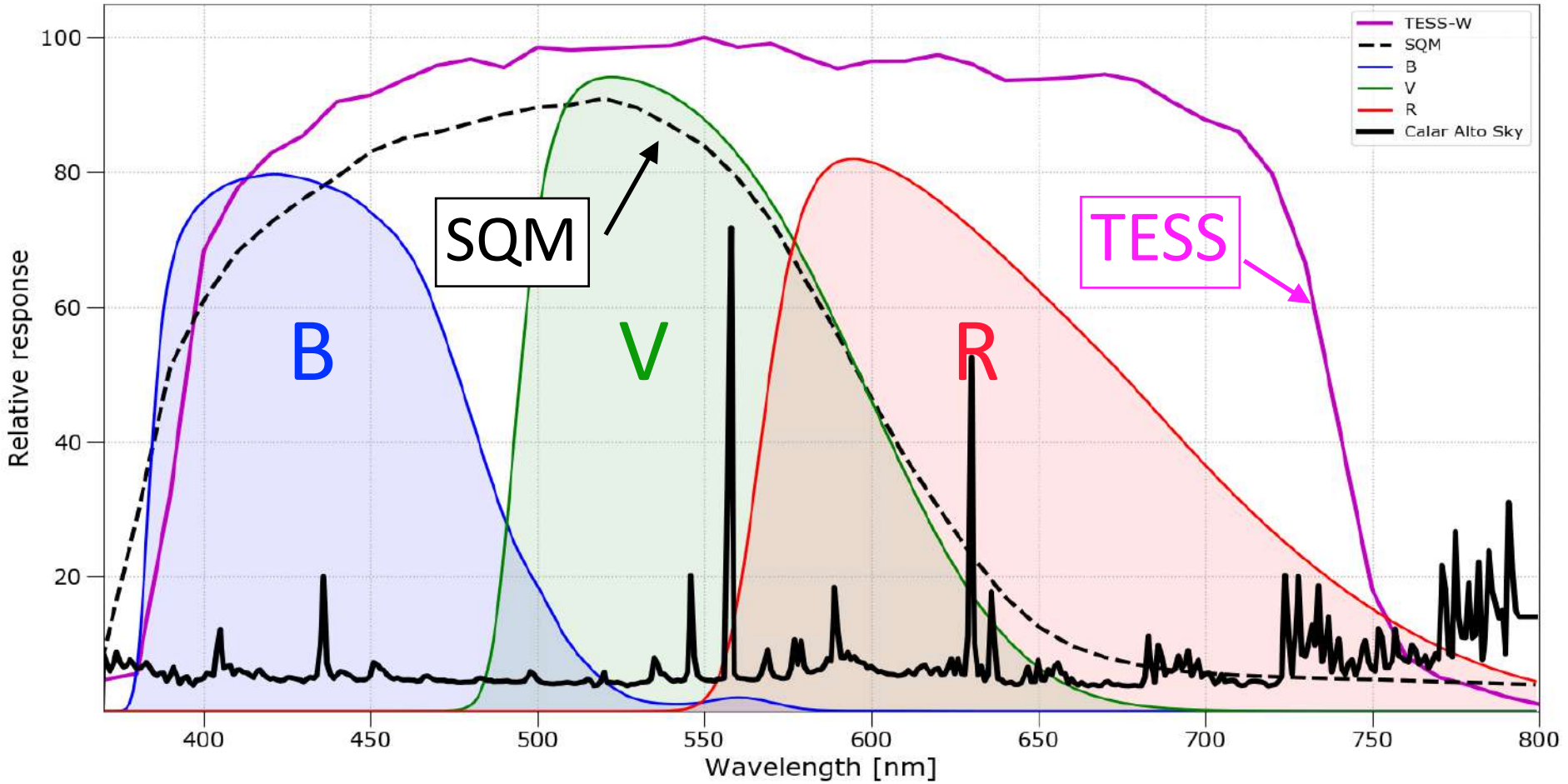


While SQM spectral response covers the blue and green the TESS-W response expands to the red part of the spectrum.

This feature is necessary in locations with HPS street lights as Madrid.

TESS-W spectral response extended to the red

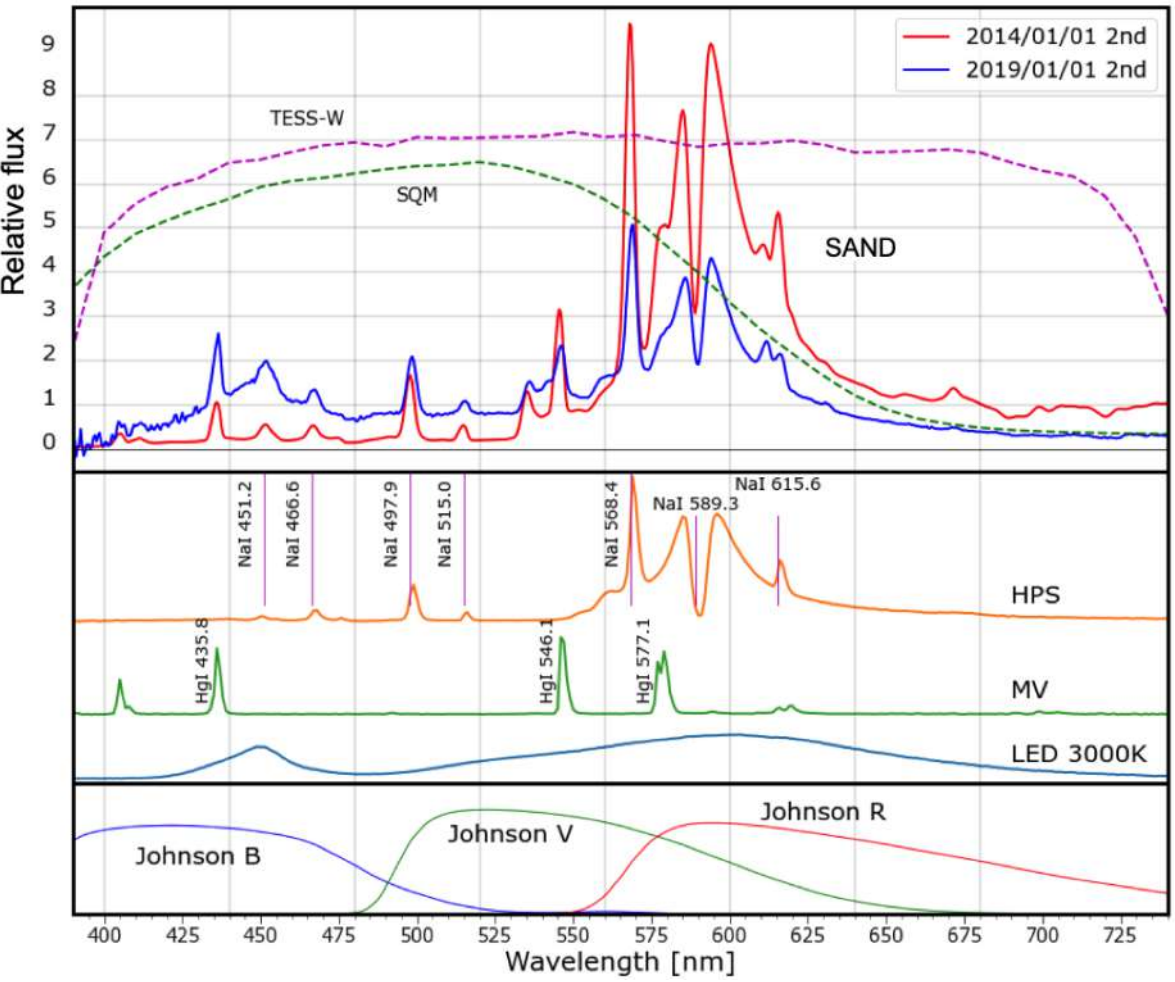
SQM, Johnson B, V, R and TESS-W and Calar Alto night sky spectrum



In the night sky spectrum of a dark astronomical observatory there is a lot of auroral lines.

"The Night Sky at the Calar Alto Observatory". S. F. Sánchez *et al* 2007 *PASP* **119** 1186
https://iopscience.iop.org/article/10.1086/522378

TESS-W spectral response extended to the red



Night sky spectra for Madrid after midnight in January of 2014/01 and 2019/01 (blue and red solid lines; upper panel).

The 2019 spectrum shows the blue component of the LED spectrum that peaks at 450 nm.

The upper panel also shows the TESS-W and Sky Quality Meter (SQM) spectral responses.

Some prominent emission lines of typical lamps are labeled in the middle panel.

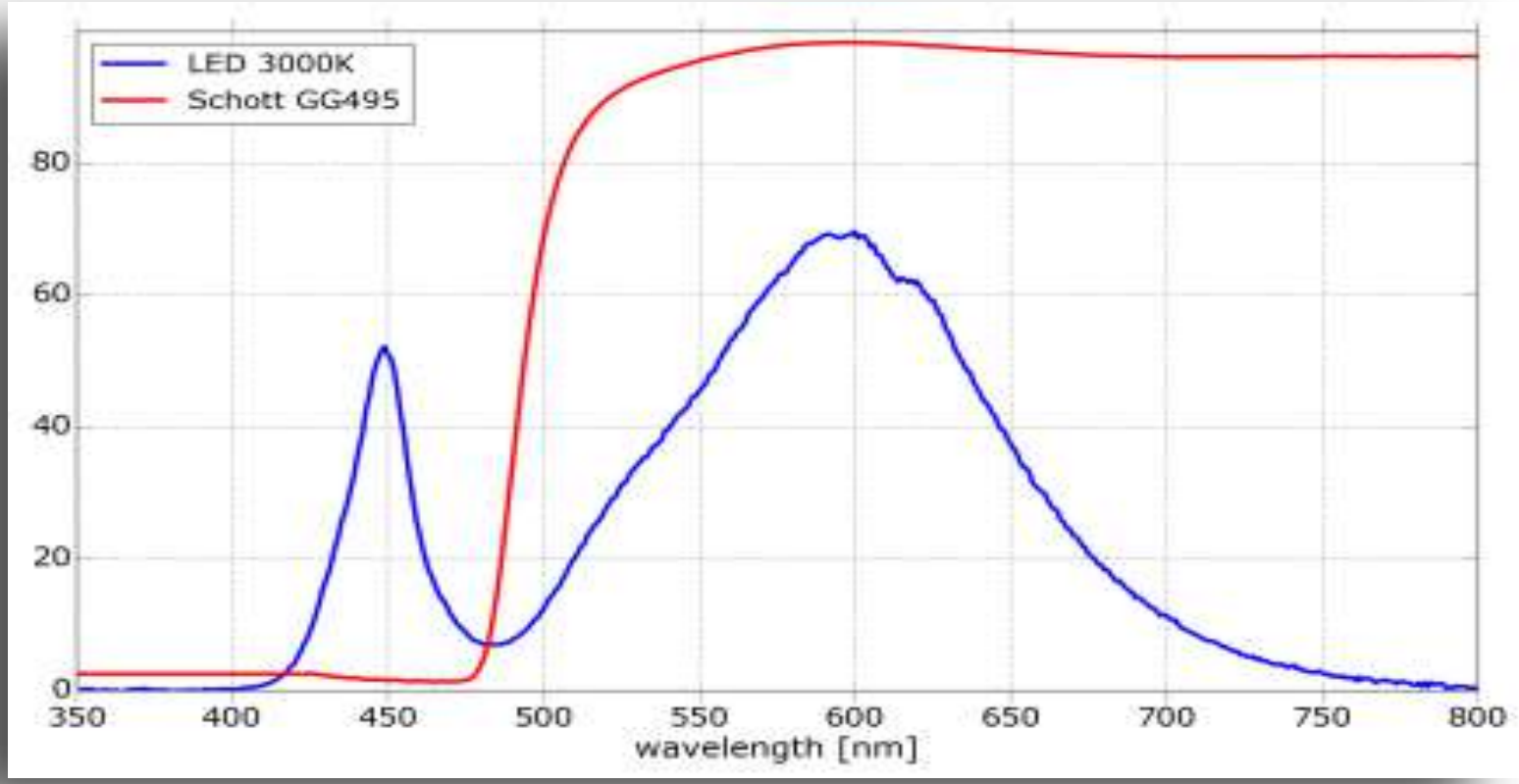
The Johnson B, V, and R photometric bands are plotted in the lower panel.

The spectrum of the night sky contents the signatures of the spectrum of the street light lamps. Emission lines from HPS and Mercury Vapor and more recently the continuum from LED are present in the Madrid night sky spectrum.

"Evolution of Brightness and Color of the Night Sky in Madrid".
Robles et al. *Remote Sens.* **2021**, *13*(8), 1511;https://doi.org/10.3390/rs13081511

TESS-W can accommodate an extra filter

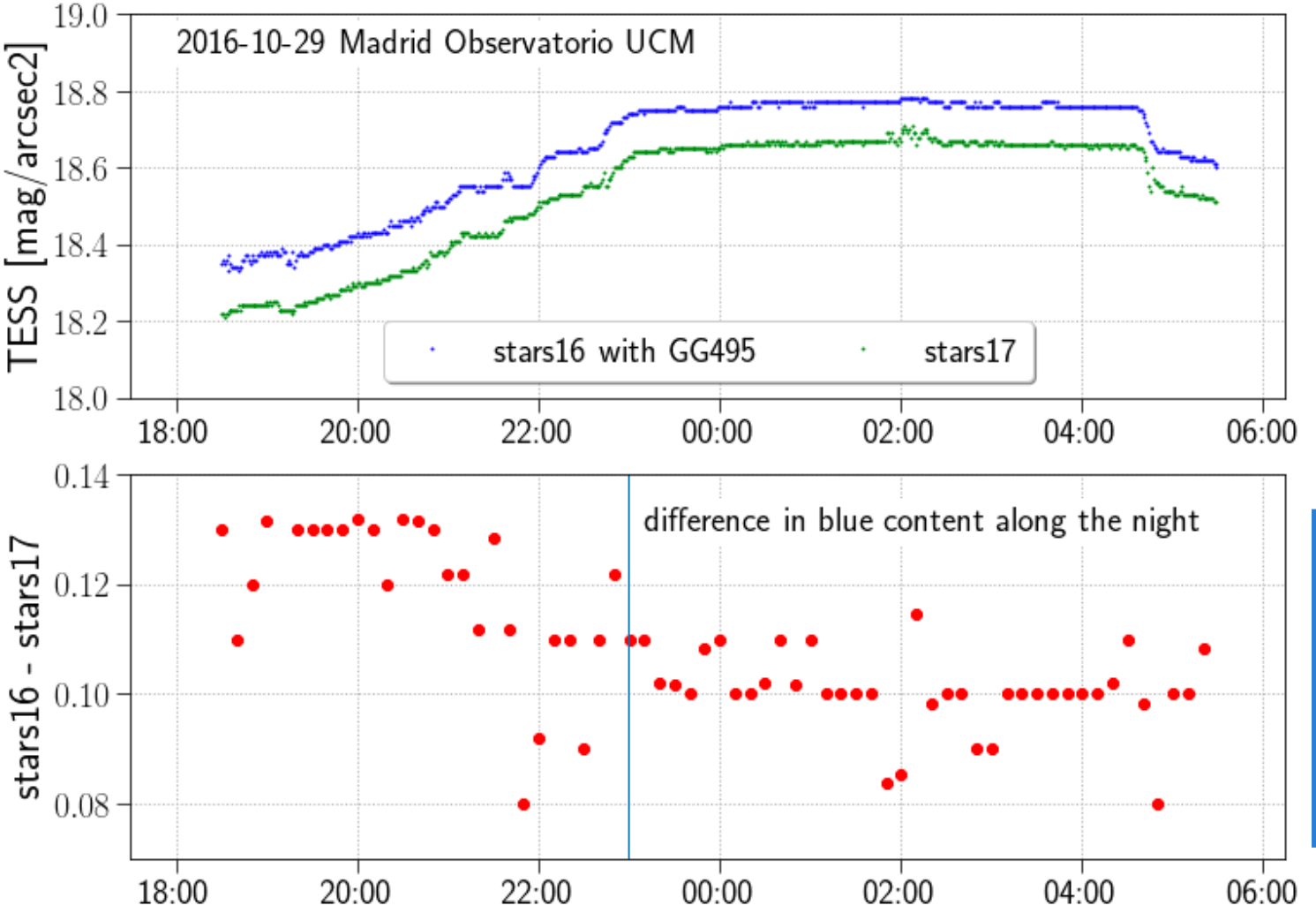
TESS-W designed with room for an extra filter inside the enclosure



Detection of blue light from LEDs using two photometers,
one of them with a long pass filter rejecting blue light.

It is possible to select your favorite passband with a filter.
In this case a yellow filter (Schott GG495, transmission curve in red)
rejects the blue part of the spectrum below 495 nm.

Color detection with 2 TESS-W



Color variation along the night measured with two photometers
with different passband: full TESS-W band and with GG495 yellow filter.
The sky is bluer in the first part of the night and darker in the second part of the night

(2) Monitoring with STARS4ALL TESS-W photometers (2)

One of the effects of the light pollution is the brightening of the nocturnal sky. We can use the night sky brightness (NSB) as a proxy to estimate the light pollution in a certain location.

It is simple and easy to set up a monitoring station with a TESS-W photometer. By continuously monitoring the night sky brightness one can study the light pollution and check whether there is an evolution.

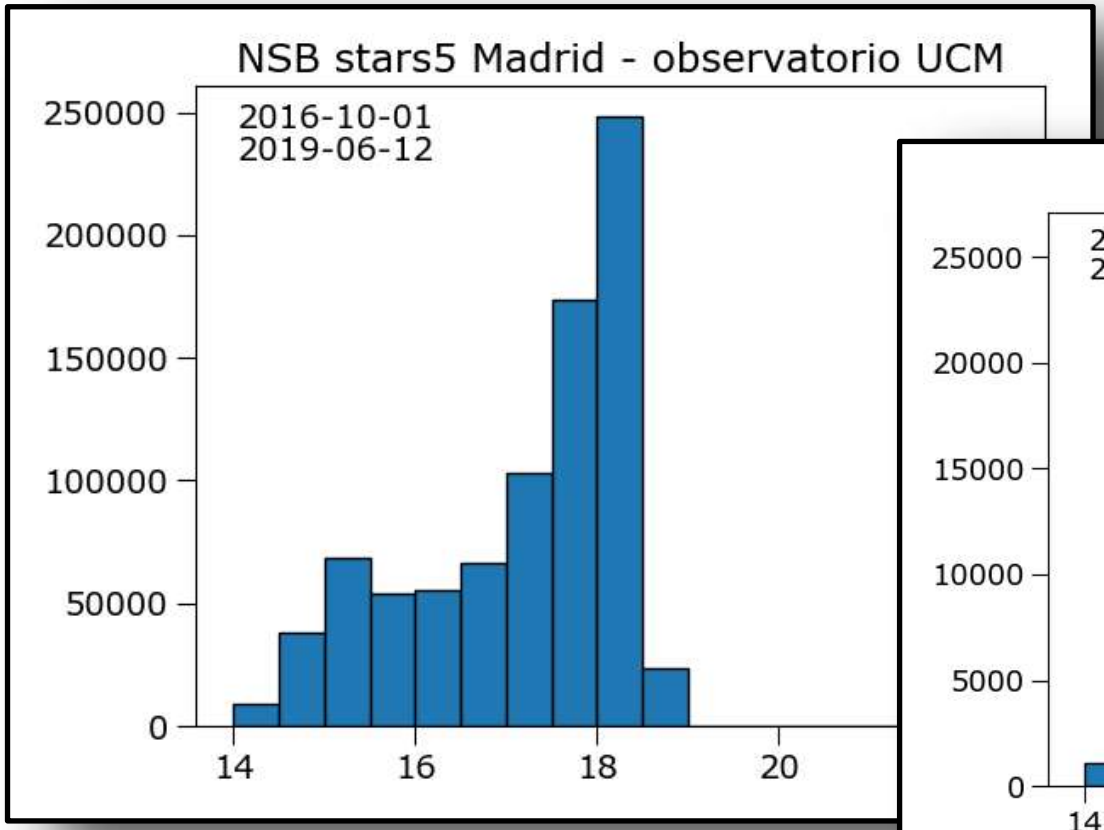
The NSB is measured in the astronomical units of mag/arcsec2. It is worth noting that the astronomical scale of magnitudes is inverse (the higher the darker) and logarithm.

After obtaining observations for as many nights as possible we can perform statistics to better understand the light pollution at the monitoring station.

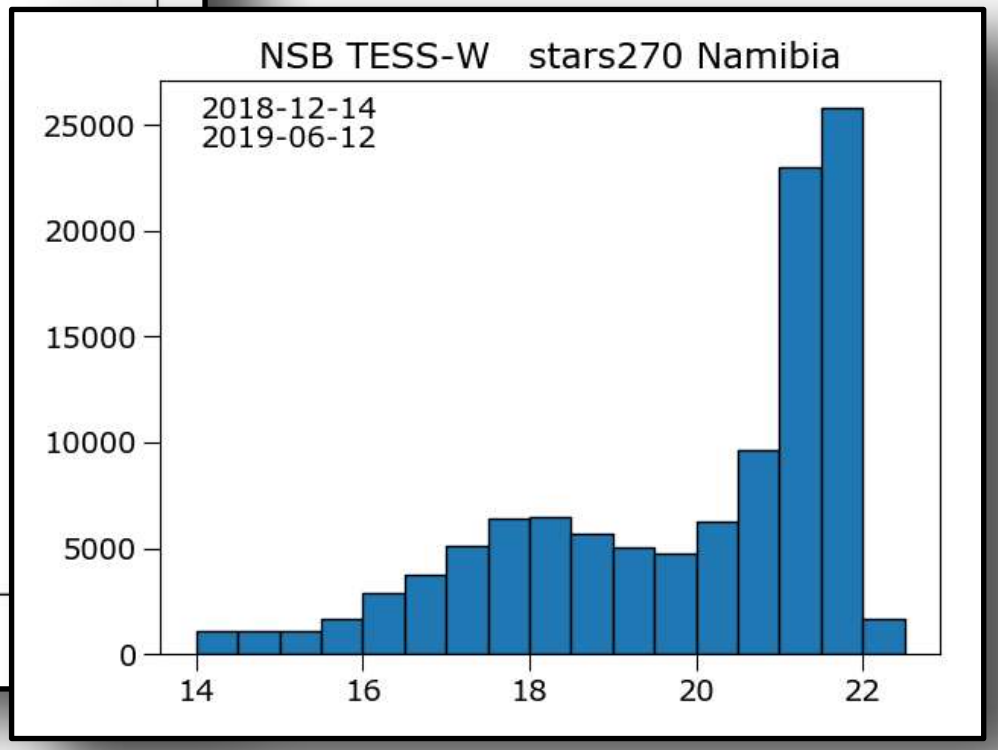
The next slides show and explain examples of night data plots, histograms and record graphs and how extract useful information.

Why monitoring ?

Urban area

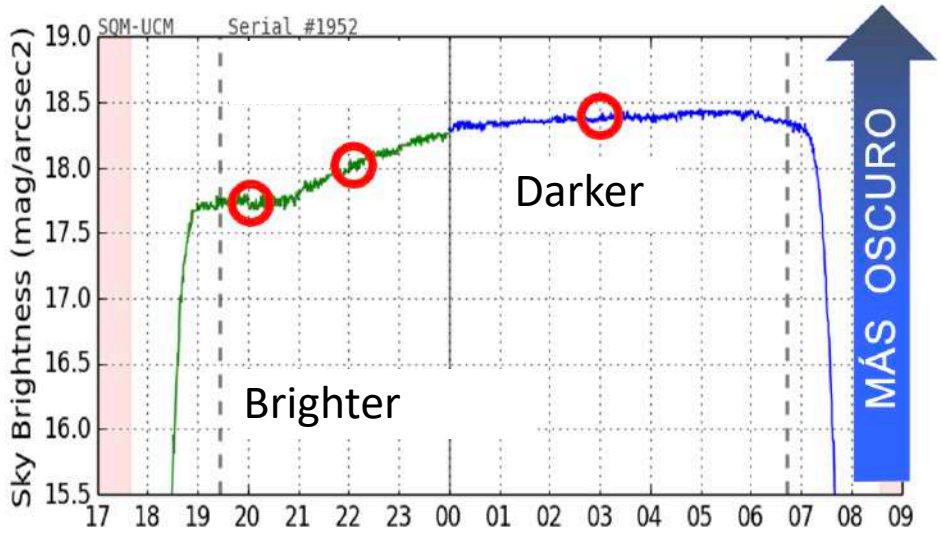


Natural area

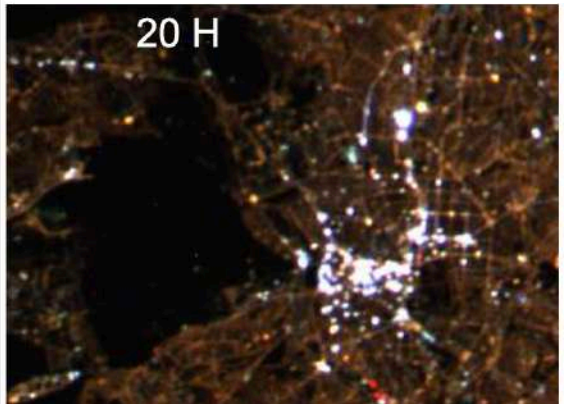


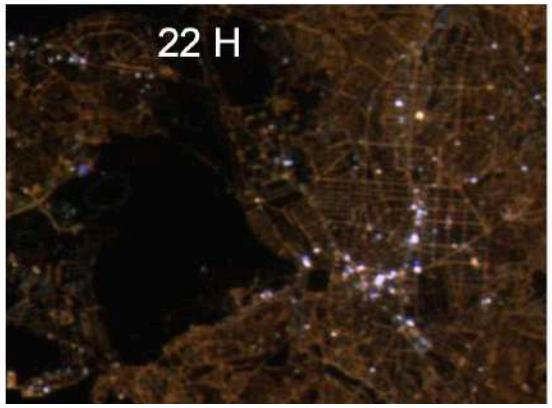
- Studies on Light Pollution and its evolution based on **statistics** could be made after **monitoring** the Night Sky Brightness.
- Night Sky Brightness measures are key for light pollution models.
- "*Night Sky Brightness should be treated as another weather parameter*" (Salvador Bará)

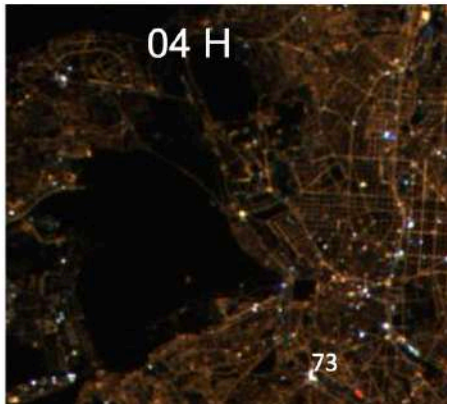
Night Sky Brightness along the night



The sky is darker in the second part of the night (Madrid).



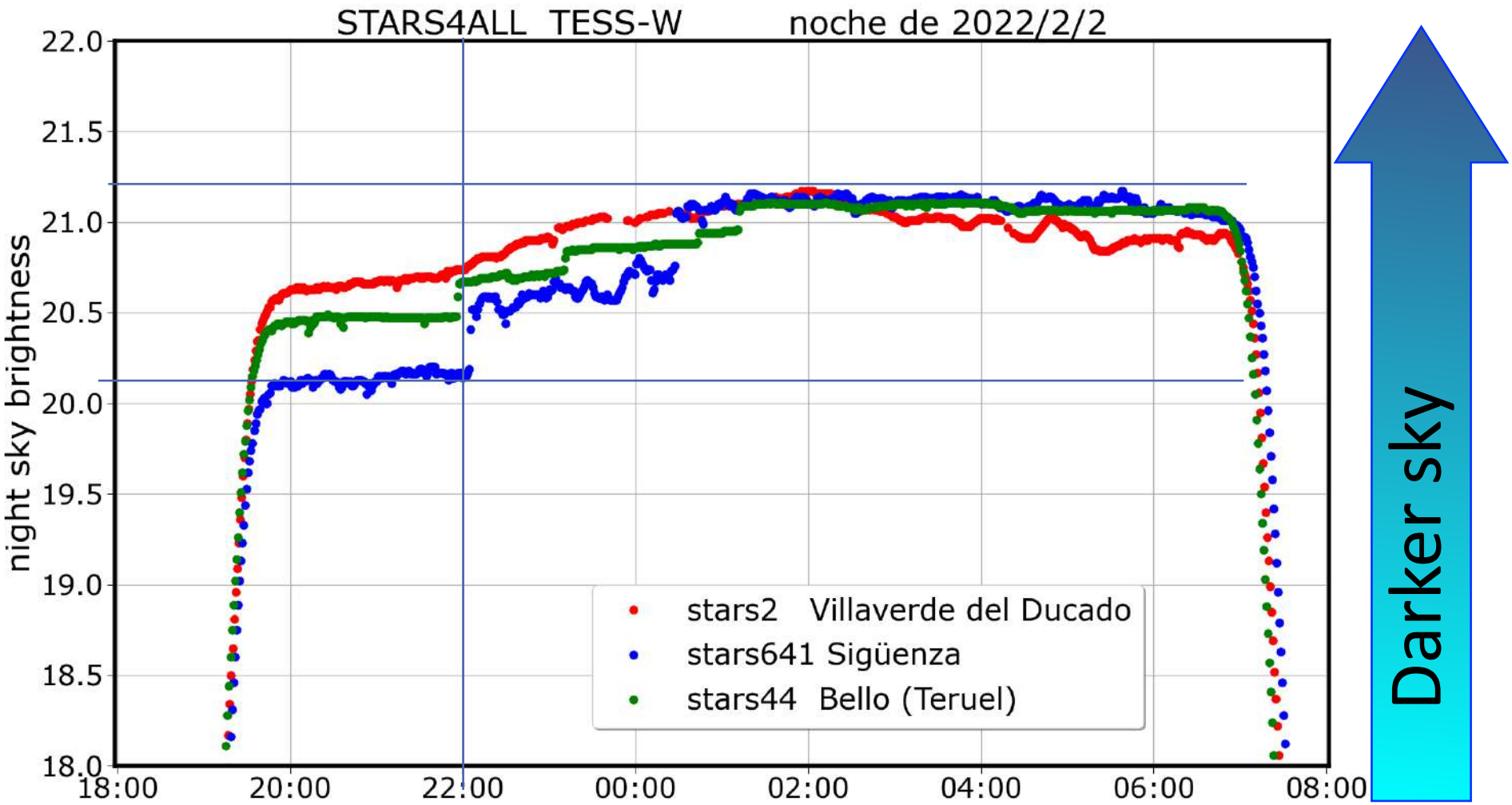




Night Sky Brightness measured along one night in Madrid using a SQM.

- The pictures from the International Space Station at different times show a decrease of light pollution.

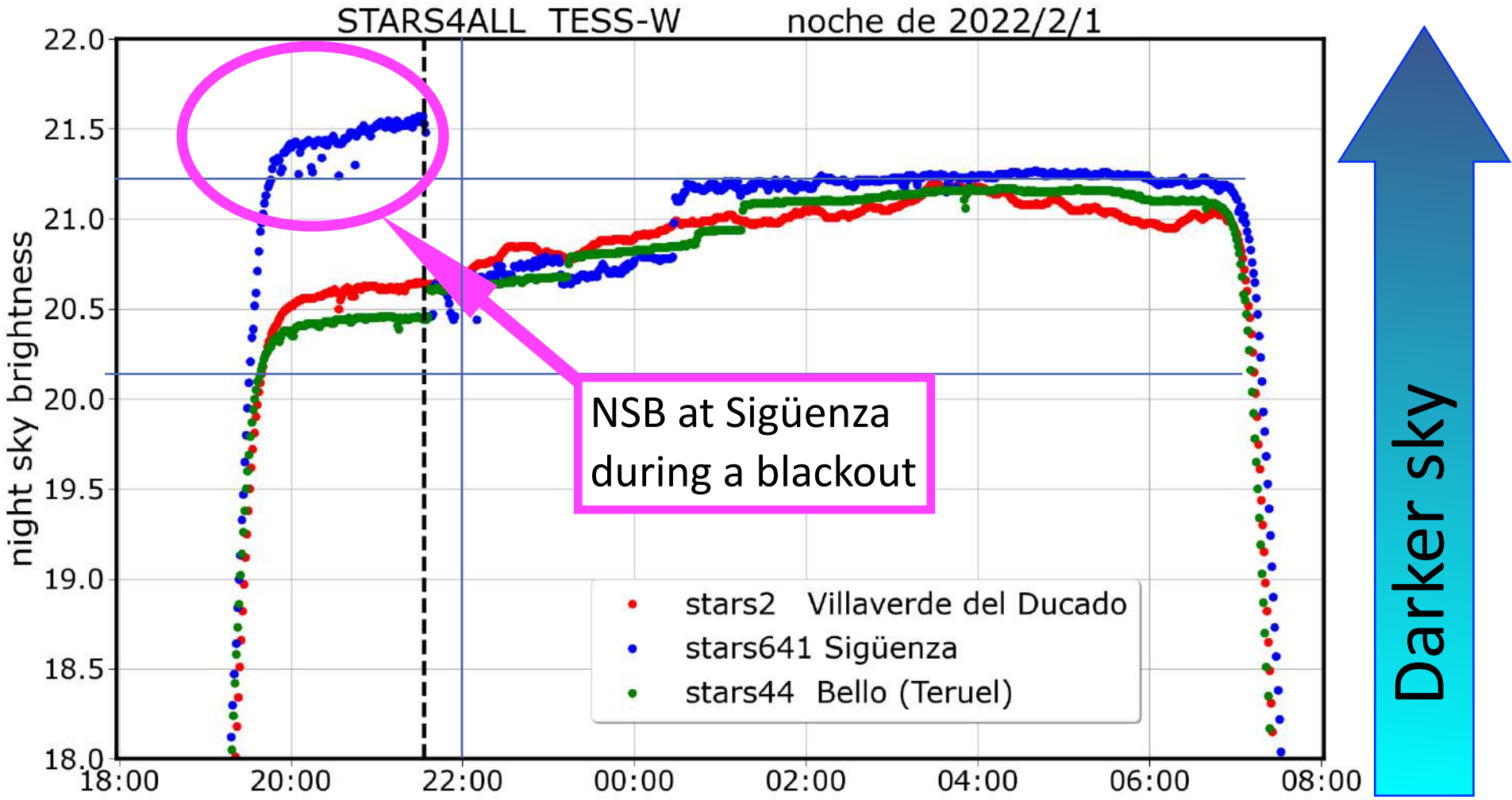
Night Sky Brightness along the night



Night Sky Brightness measured along one night in several locations in Guadalajara (Spain)

- Night sky brightness varies along the nights and from night to night.
- The brightness of the sky varies according to the street light power regulation (see step change at 22:00 UT in Sigüenza).

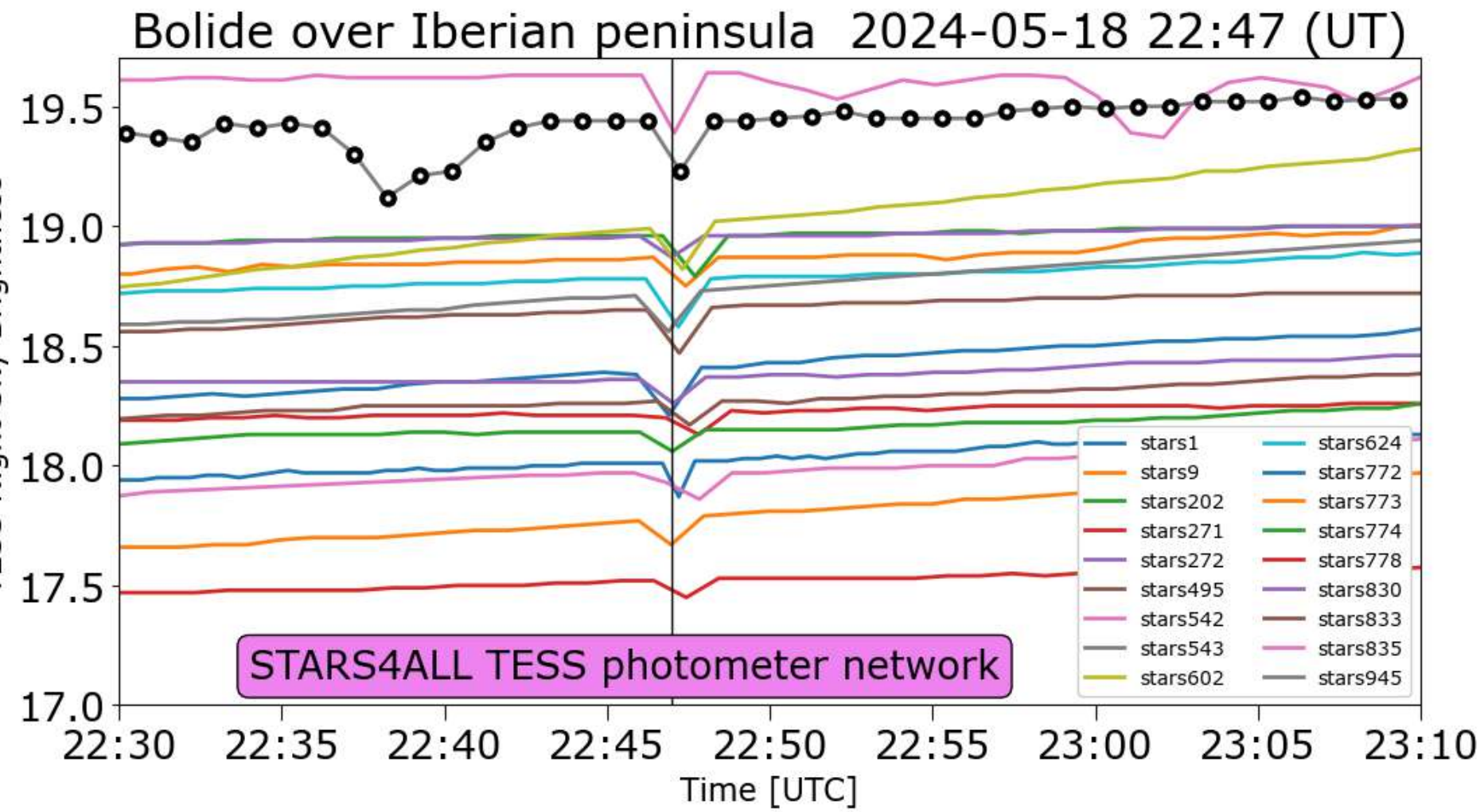
Night Sky Brightness along the night



Night Sky Brightness measured along one night in several locations in Guadalajara (Spain)

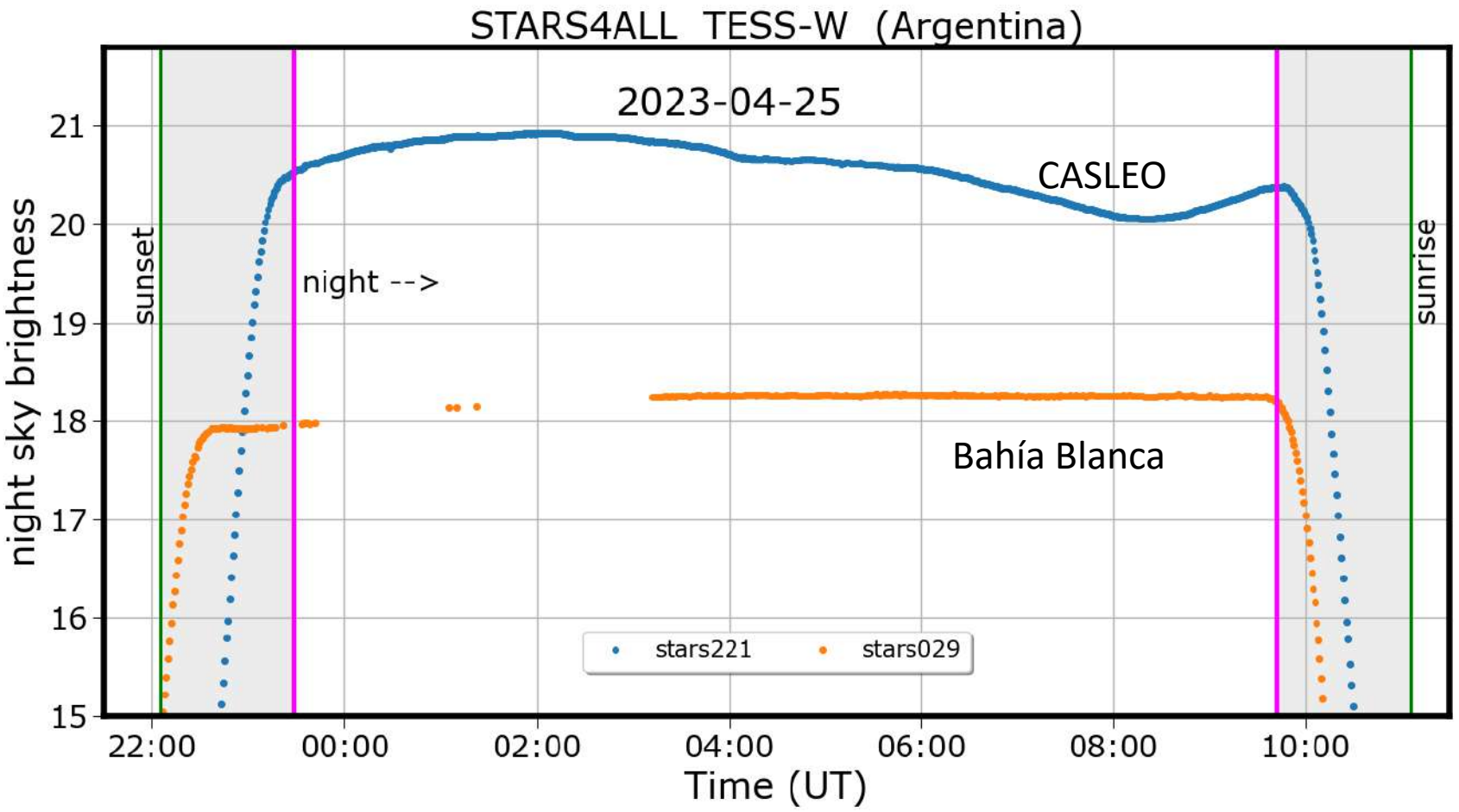
- During a blackout it is posible to measure the NSB without local light pollution.
- In this case the NSB at Sigüenza is 21.5 mag/arcsec^2.

Why monitoring ? Bolide over Iberian Peninsula



Night Sky Brightness measured at several TESS-W monitor stations that detected the brightening of the night sky due to a bolide.

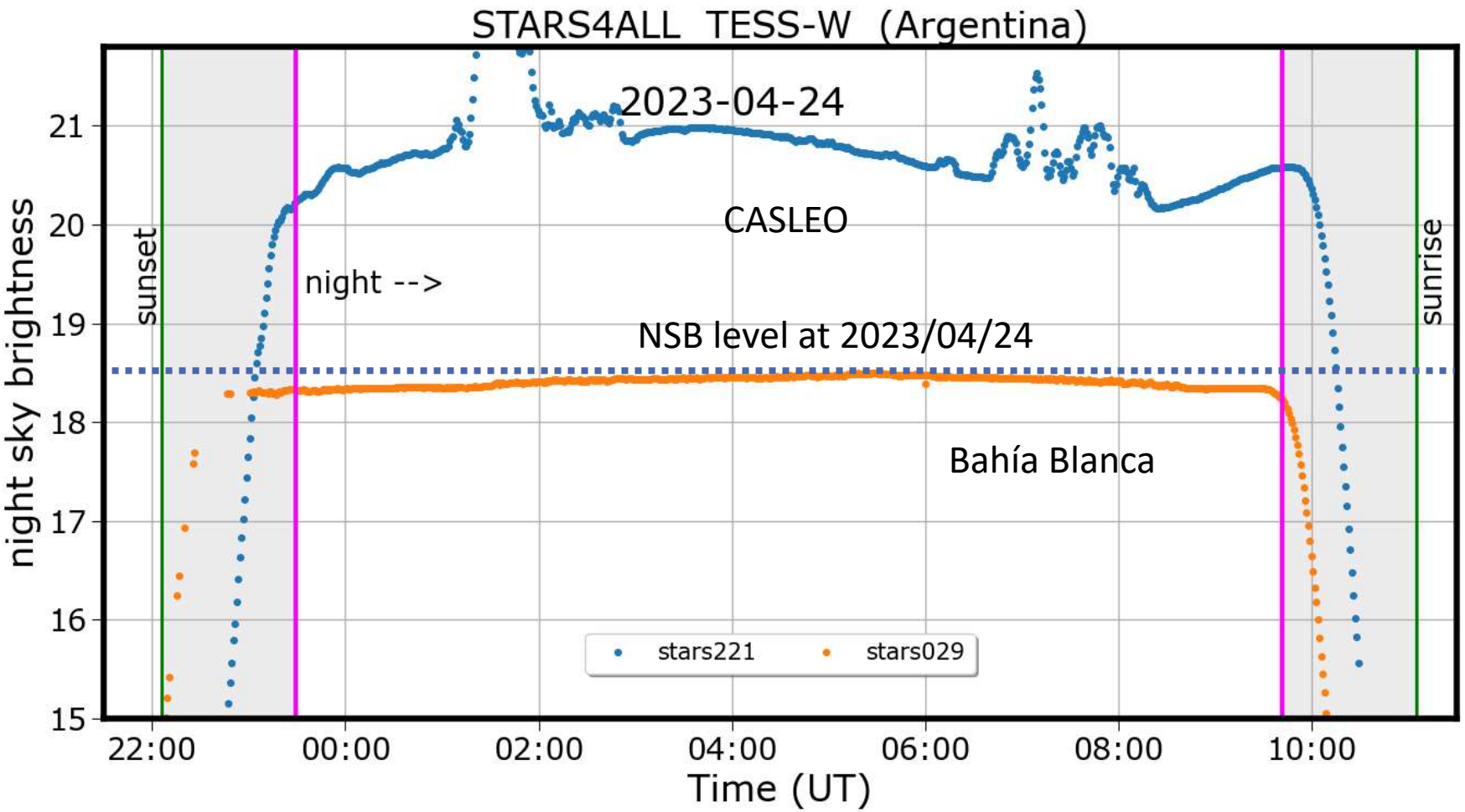
Why monitoring ? Night Sky Brightness night plot



Night Sky Brightness measured along one night in two locations in Argentina.

- The night of 2023/04/25 was clear (no clouds) in both locations.
- The sunset and twilight are marked for stars221 in a dark astronomical observatory.
- The stars29 photometer is located in a light polluted region.

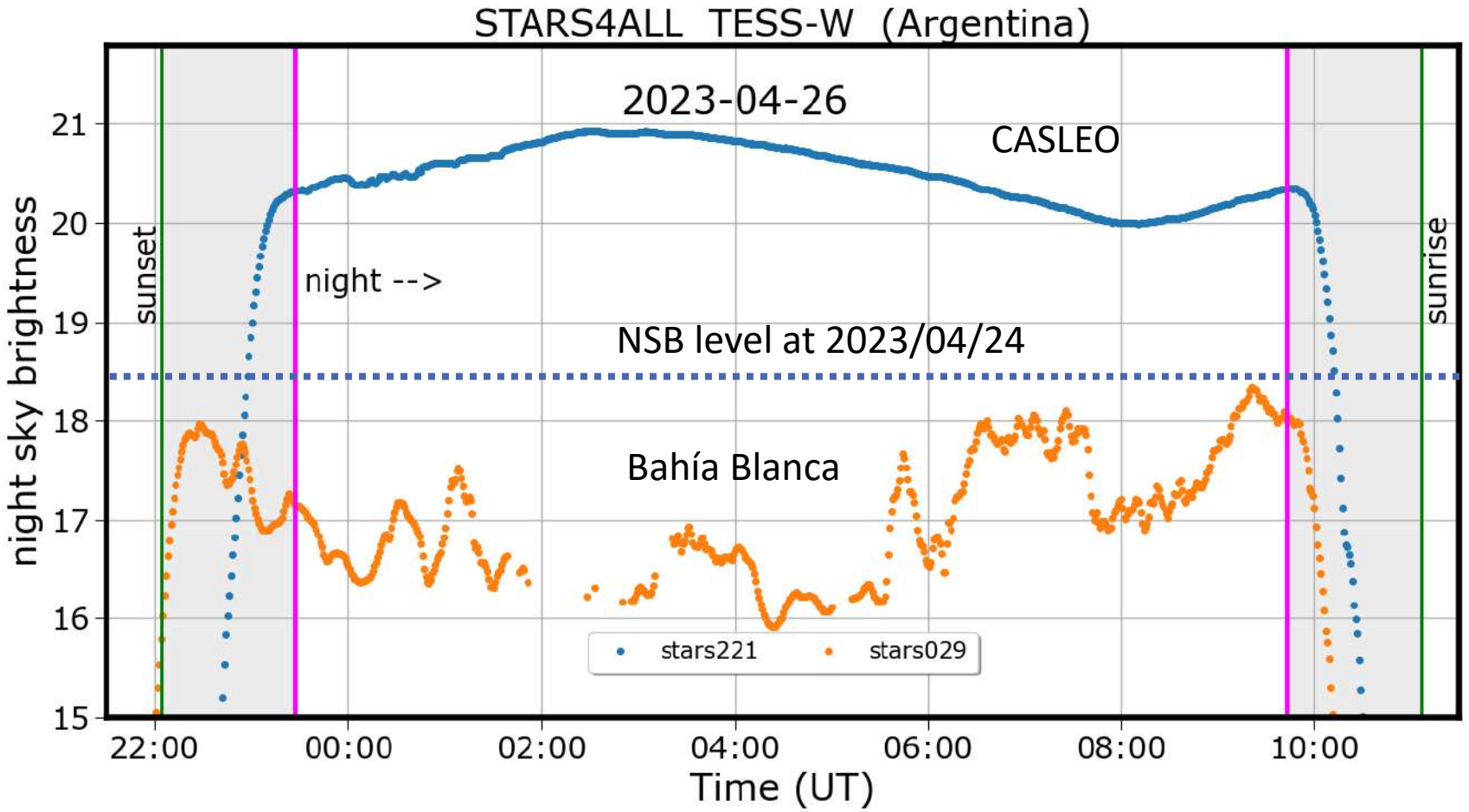
Why monitoring ? Night Sky Brightness night plot



Night Sky Brightness measured along one night in two locations in Argentina.

- The night of 2023/04/24 was not clear at CASLEO.
- Note that the sky is darker when the clouds are passing. This darkening indicates that the place in not very light polluted.
- Green and magenta lines mark sunset and astronomical night (Sun below -18 degrees)

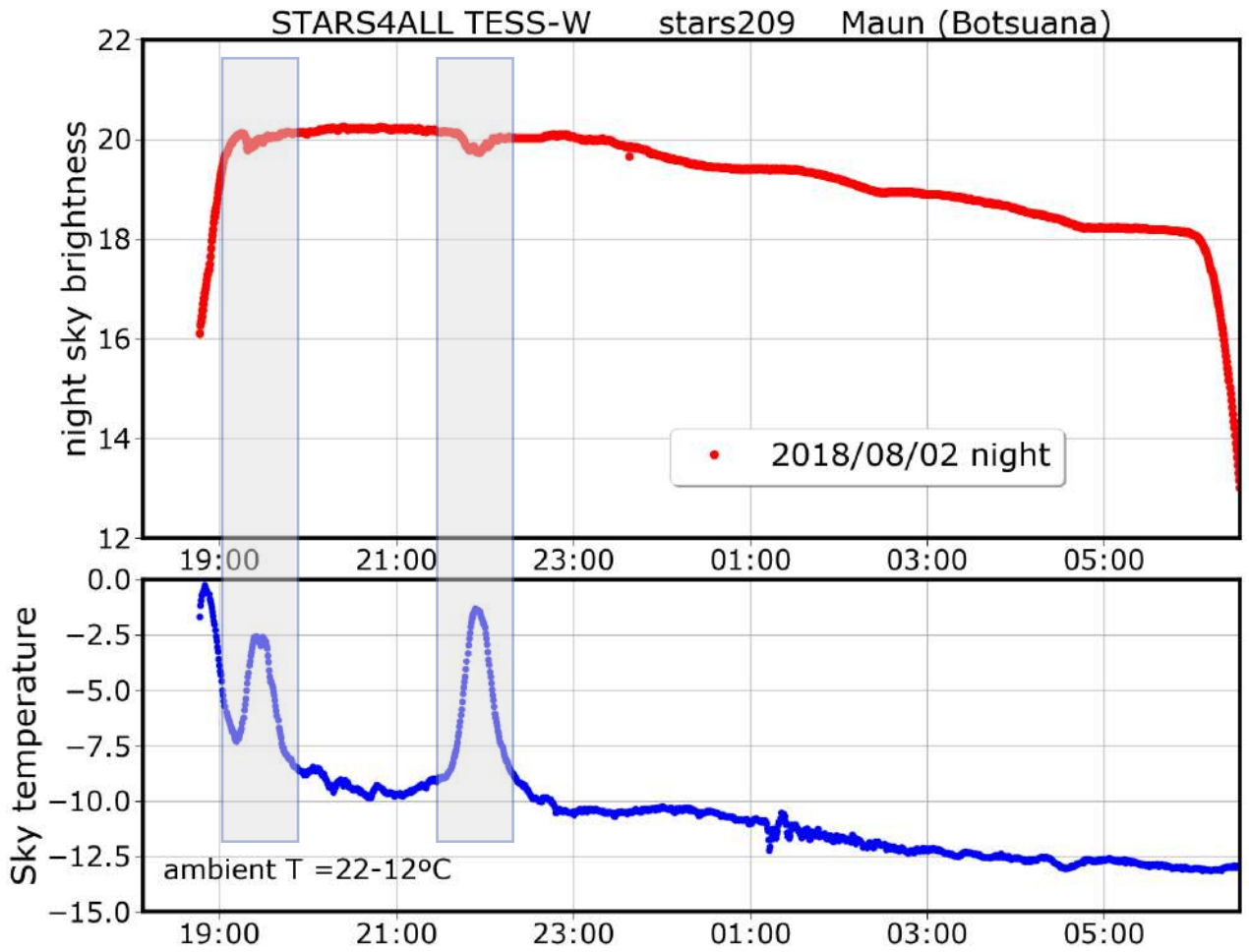
Why monitoring ? Night Sky Brightness night plot



Night Sky Brightness measured along one night in two locations in Argentina.

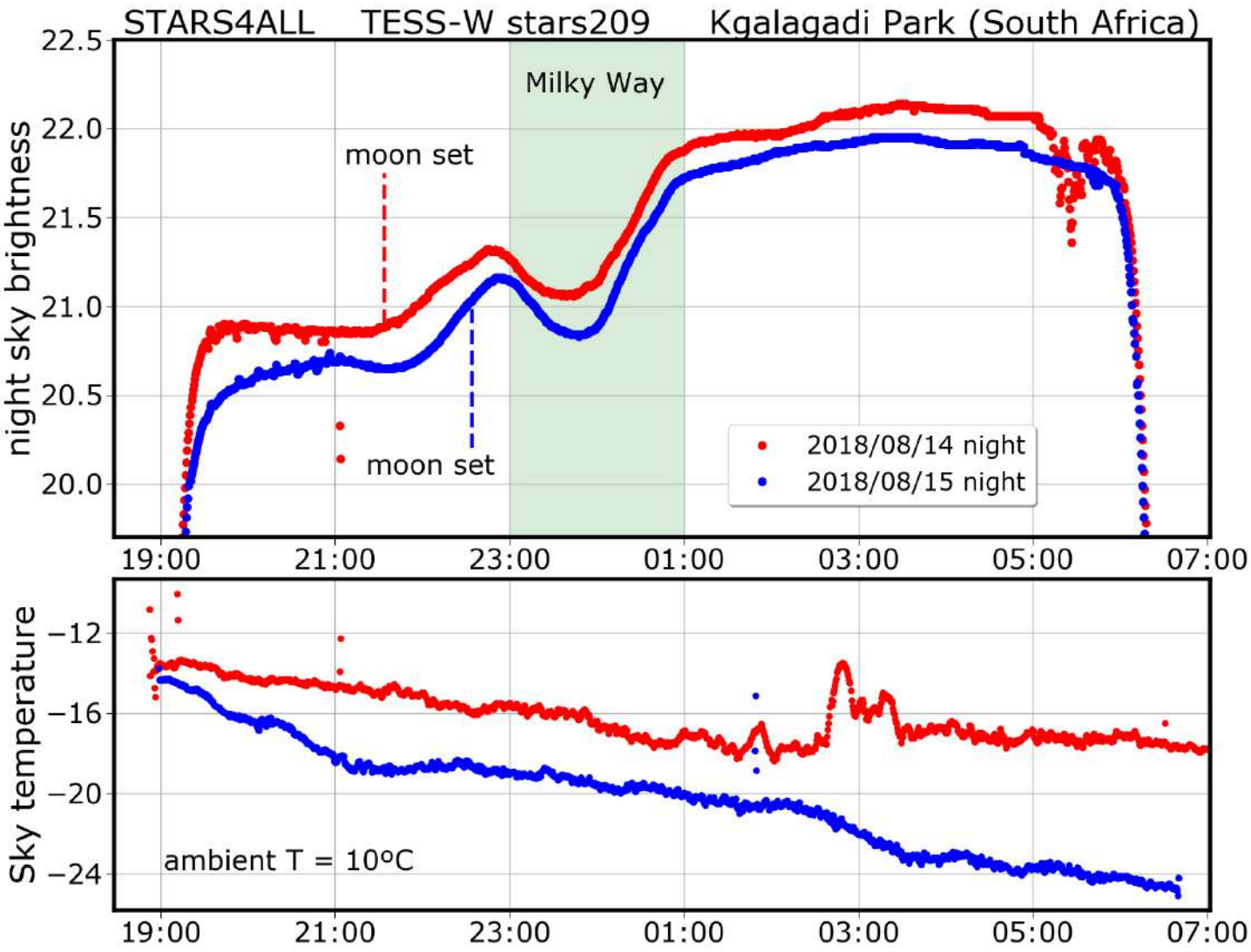
- The night of 2023/04/26 was cloudy at Bahía Blanca.
- Note that the sky is brighter at Bahía Blanca when the clouds are passing.
- This darkening indicates that the place is polluted by light which reflected by the clouds.

Night Sky Brightness night plot example (2)



Night Sky Brightness measured along one night. The lower panel shows the sky temperature.
- Note the brightening of the sky at 21:30 due to clouds as shown by the increasing of the sky temperature.

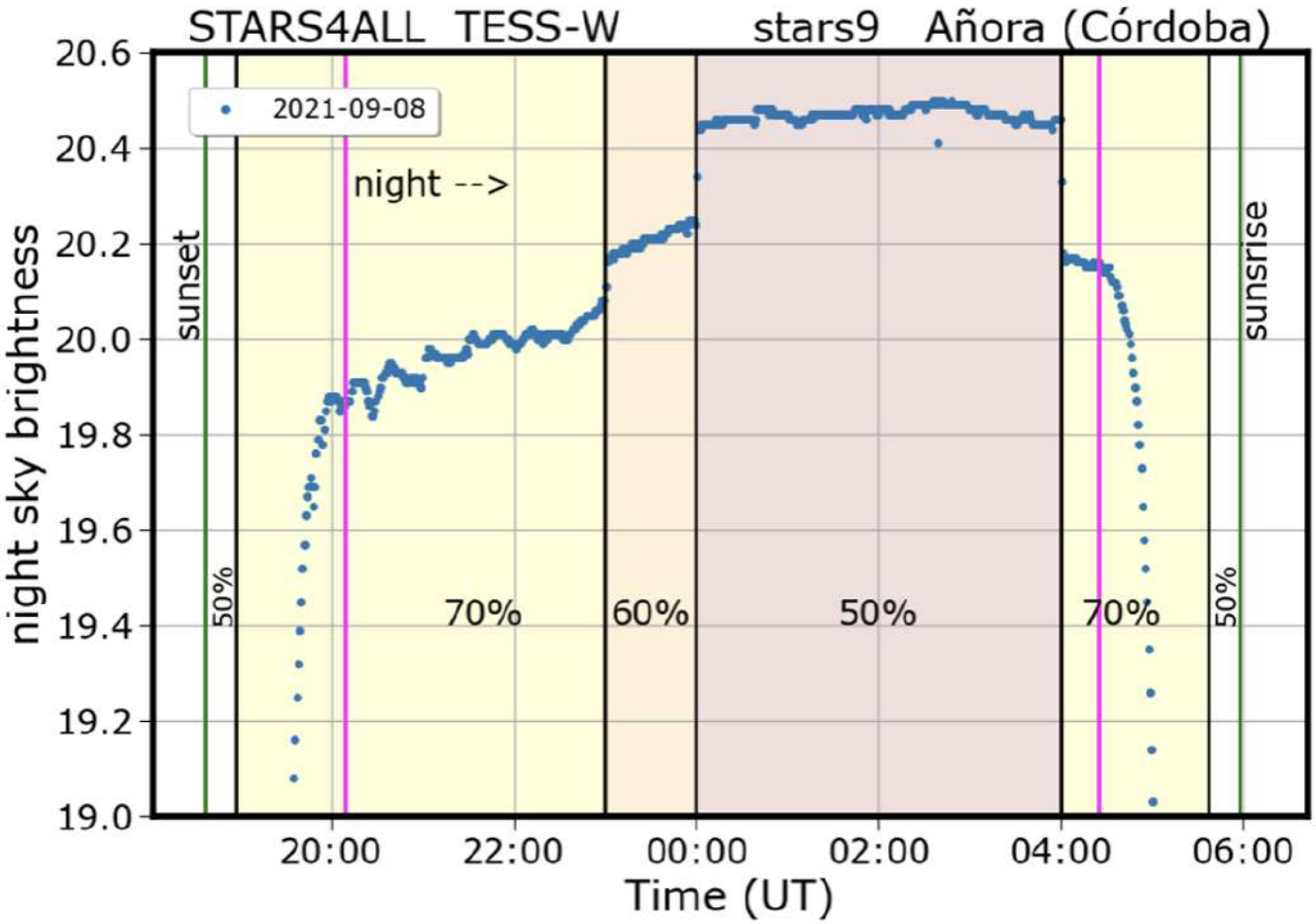
Night Sky Brightness night plot example (3)



Night Sky Brightness measured along two consecutive nights.

- Note the brightening of the sky at 23:00-01:00 due to Milky Way at the zenit.
- First night was darker but the sky was not so cold indicating cirrus.

Night Sky Brightness night plot example (4)

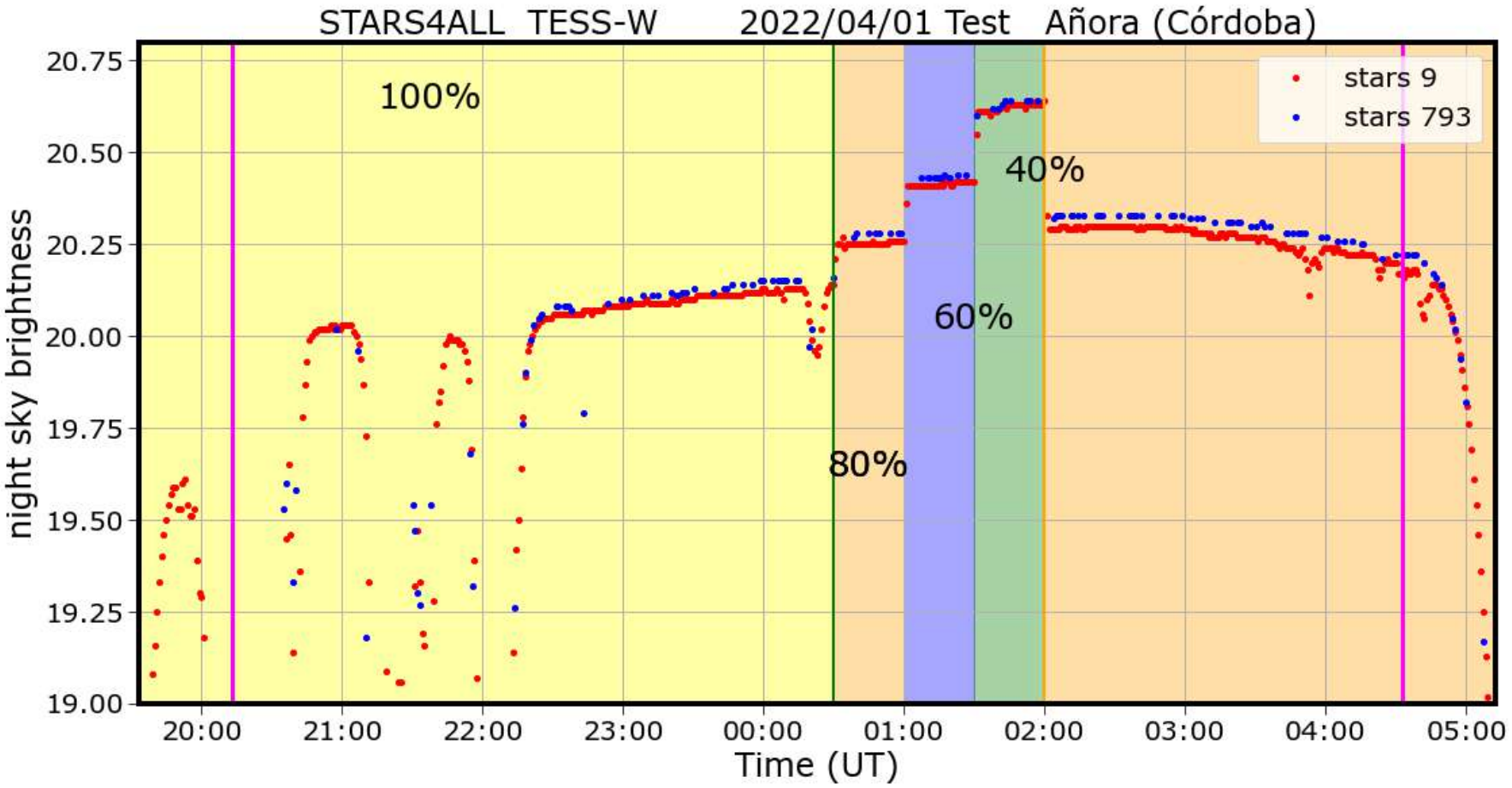


Night Sky Brightness measured along 2021/09/08 in Añora (Córdoba, Spain).

- The NSB changes as the public lighting changes (in % of total power).
- Sunset and sunrise marked with green vertical lines.
- Beginning and end of the astronomical night marked with magenta lines

"Controlling the artificial radiance of the night sky: The Añora urban laboratory" Journal of Quantitative Spectroscopy & Radiative Transfer 296, 108454, February 2023https://doi.org/10.1016/j.jqsrt.2022.108454

Night Sky Brightness night plot example (4)

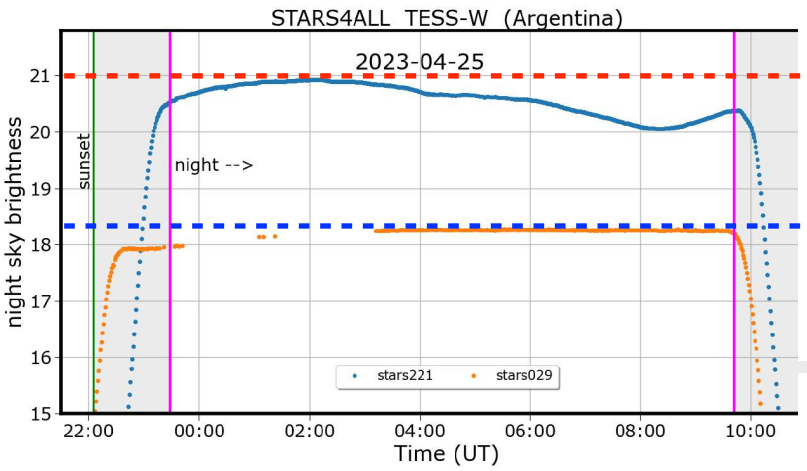


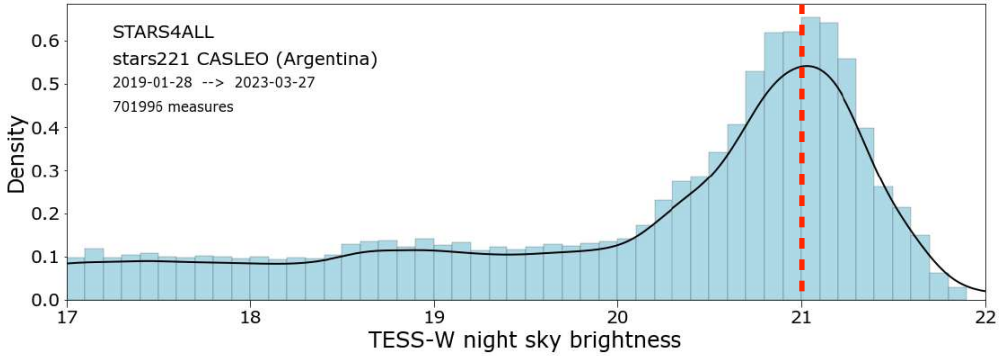
Night Sky Brightness measured along 2022/04/01 in Añora (Córdoba, Spain).

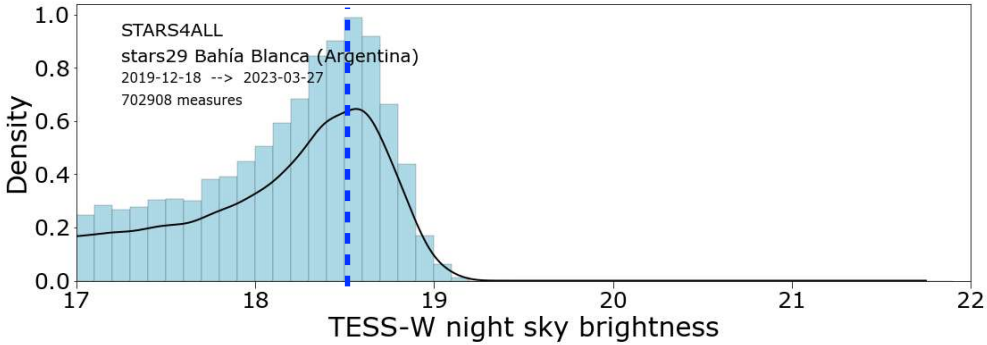
- Some clouds at the beginning of the night brighten the sky.
- The NSB changes as the public lighting changes (in % of total power).

"Controlling the artificial radiance of the night sky: The Añora urban laboratory" Journal of Quantitative Spectroscopy & Radiative Transfer 296, 108454, February 2023https://doi.org/10.1016/j.jqsrt.2022.108454

Why monitoring ? Night Sky Brightness histogram







Histogram of Night Sky Brightness measured in two locations in Argentina.

- Note that the sky is brighter at Bahía Blanca with magnitude mode around 18.5.
- In CASLEO the typical NSB in clear nights is around 21.1 mag/arcsec^2.
- Using more than 700 k observations from 2019/01/28 to 2023/03/27

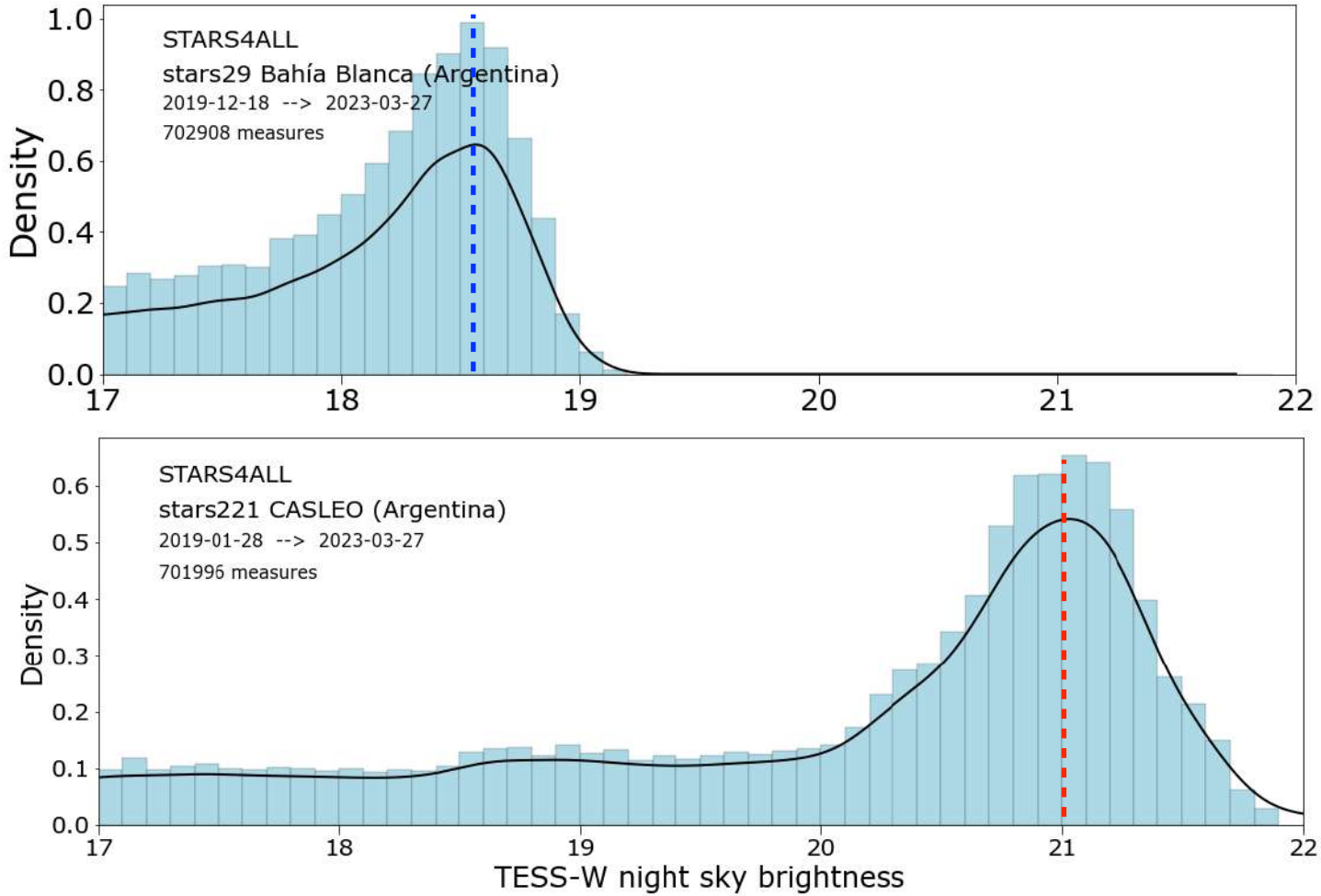
Read for instance:

"Monitoring Long-Term Trends in the Anthropogenic Night Sky Brightness"

Salvador Bará, Raul C. Lima, and Jaime Zamorano

Sustainability 2019, 11(11), 3070; https://doi.org/10.3390/su11113070

Why monitoring ? Night Sky Brightness histogram



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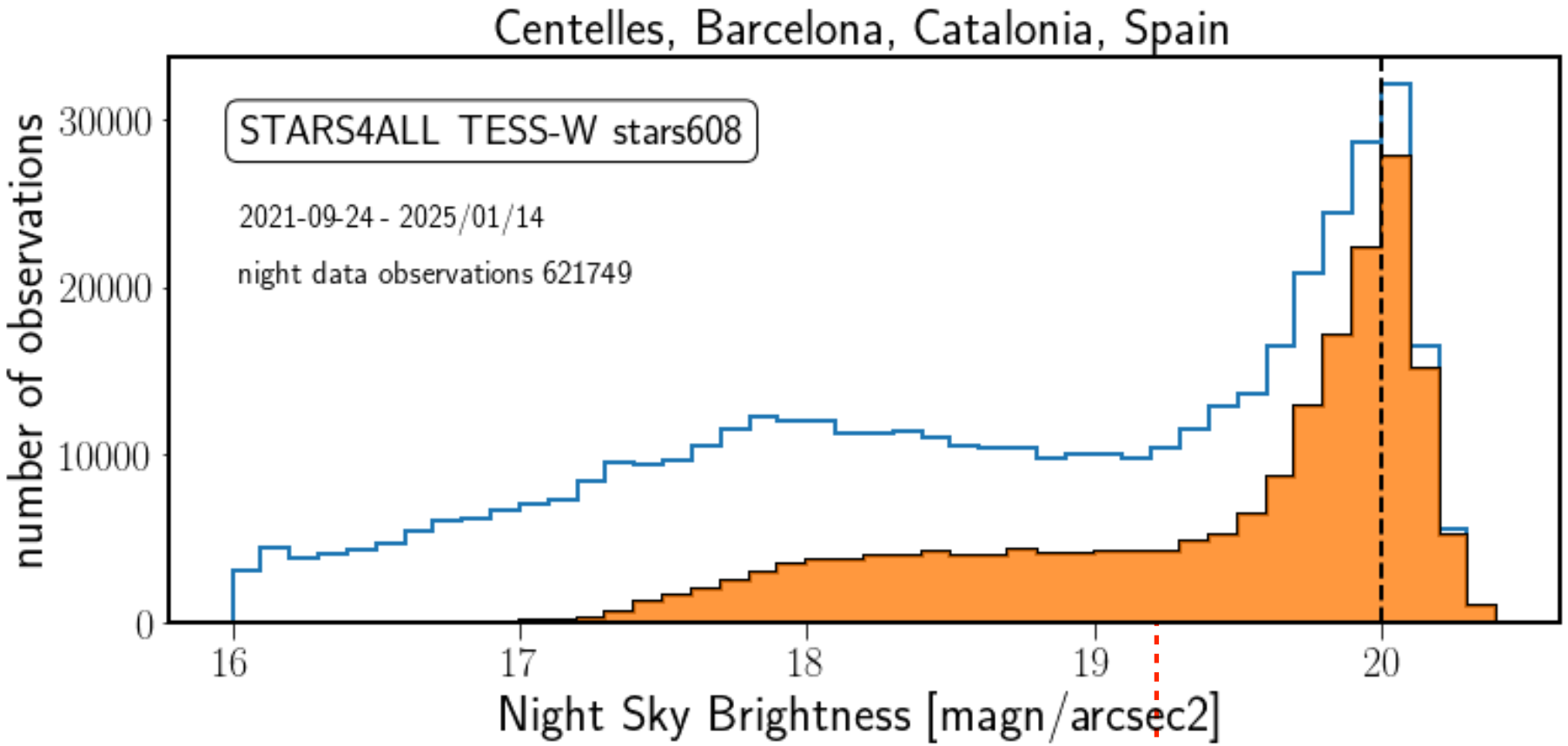
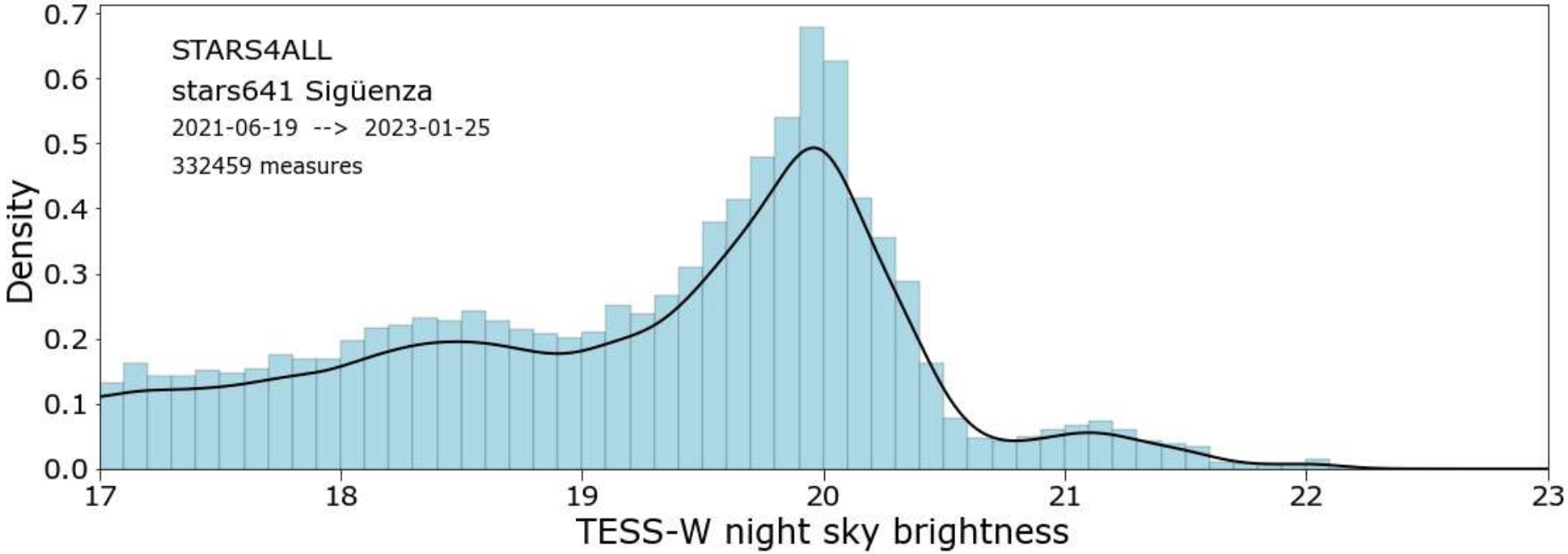
Why monitoring ? Night Sky Brightness histogram



Histogram of Night Sky Brightness measured in Centelles.

- Blue line corresponds to all observations. Orange shadow to those when the Moon is bellow the horizon and the Sun below -18 degrees to avoid the twilight data.
- The distribution tail (left of the mode) belongs to data with clouds that brighten the sky in a light polluted location.
- Most of the observations gather around the mode (20 magn/arcsec2)
-

Why monitoring ? Night Sky Brightness histogram

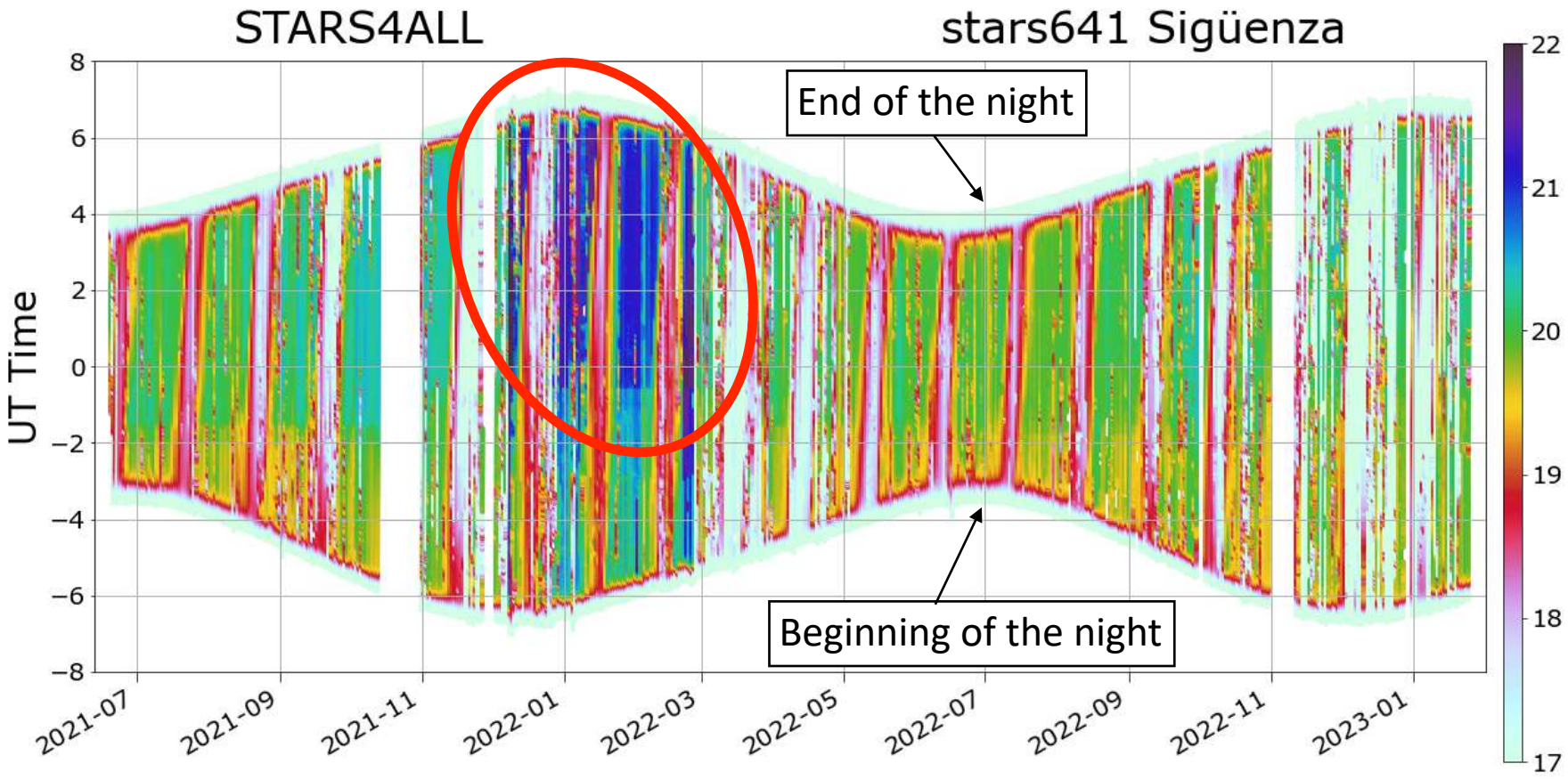


Night Sky Brightness measured at Sigüenza (Spain).

The observation time range is the same that the next graph.

- The mode of NSB is around 20 with a secondary peak at 21.2.
  These darker values correspond to winter 2022 (see next graph)

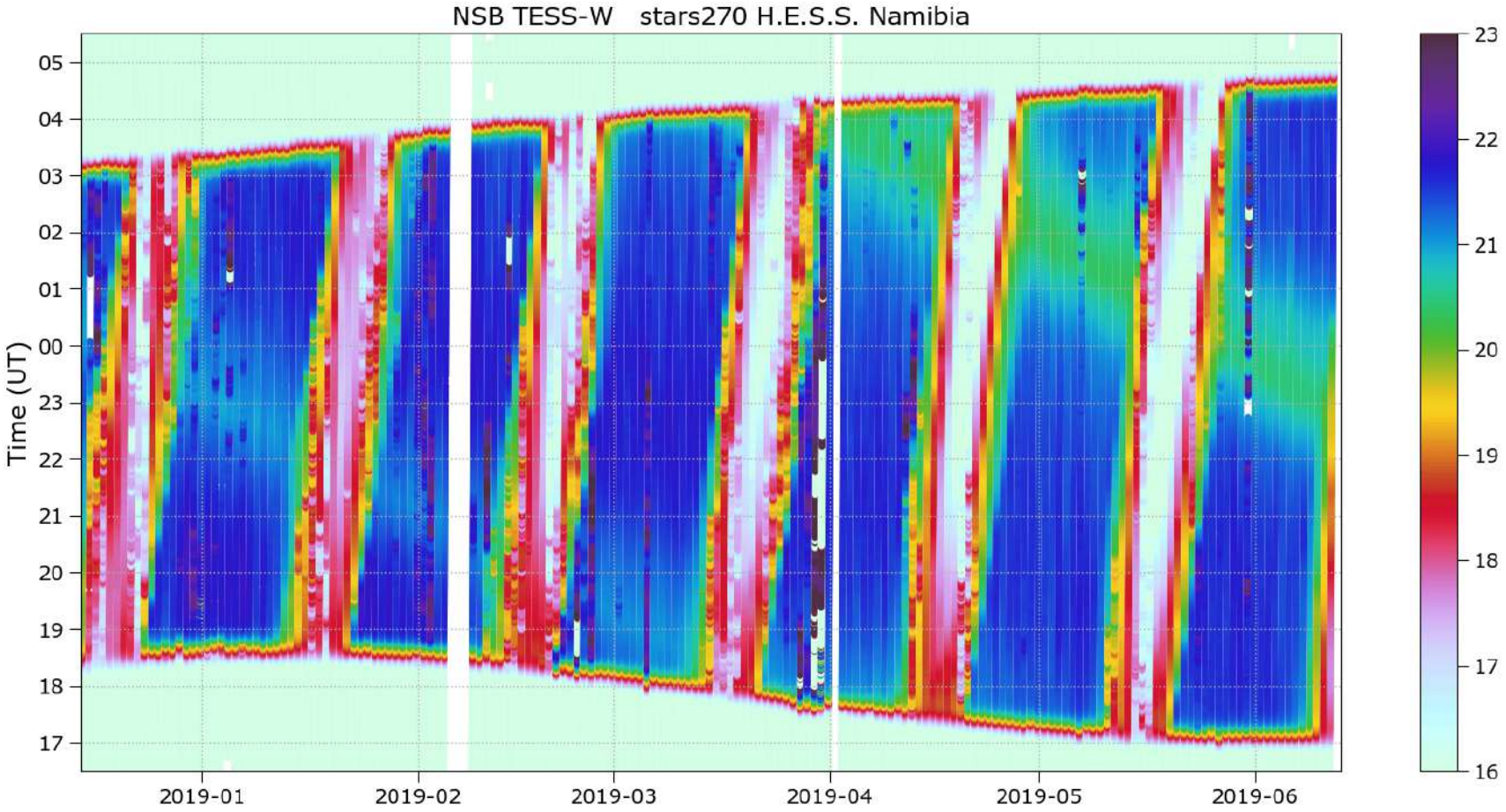
Why monitoring ? Night Sky Brightness evolution graph



Evolution along the time of Night Sky Brightness measured at Sigüenza (Spain).
The observations are color coded according to NSB value.

- Each vertical line corresponds to observations along one single night.
- The nights are short at summer time (see date at x-axis).
- The second part of the night in winter 2022 are darker than in 2023.

Why monitoring ? Night Sky Brightness evolution graph

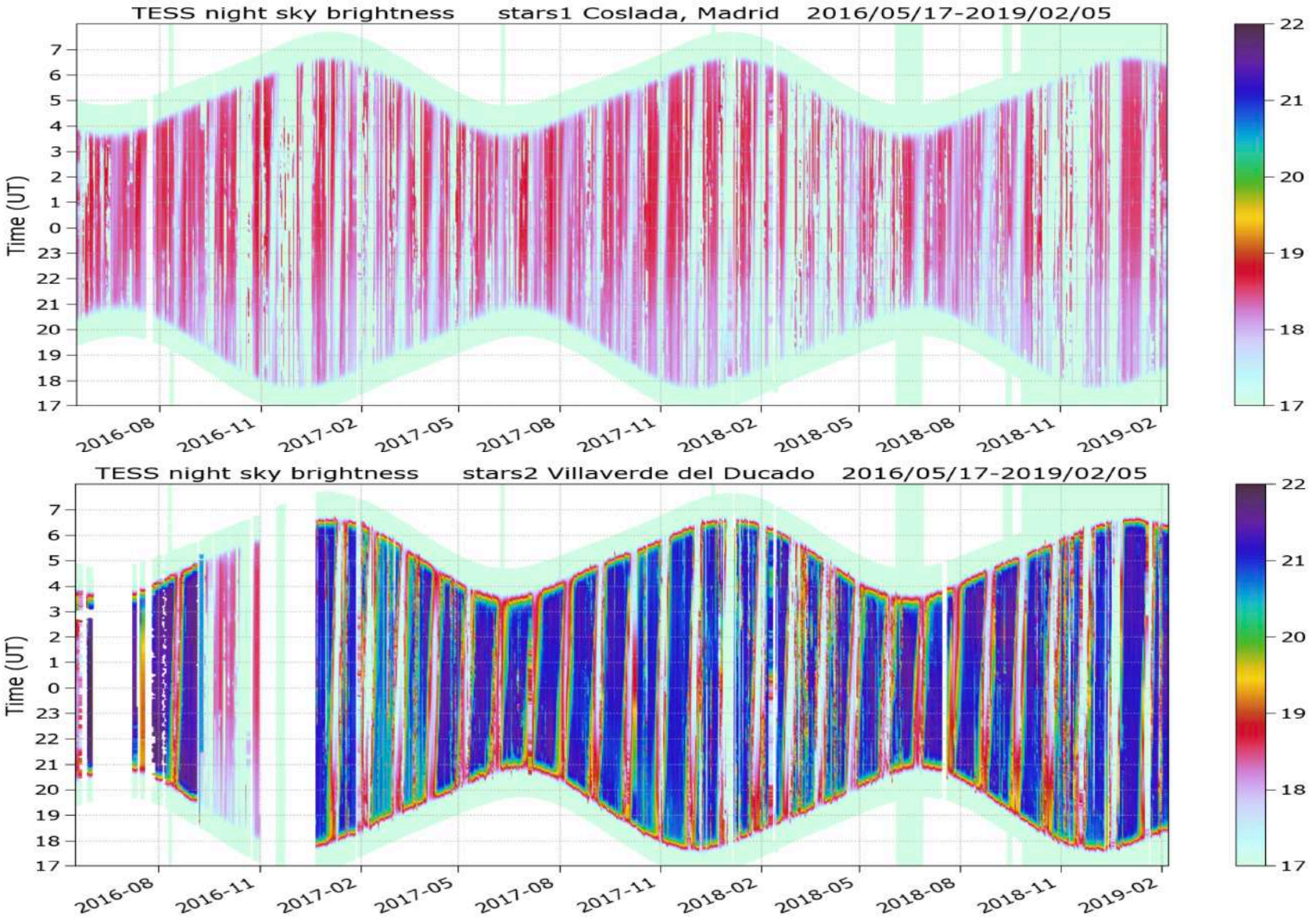


Evolution along the time of Night Sky Brightness measured at H.E.S.S. (Namibia).
The observations are color coded according to NSB value.

- The brightening due to the Milky Way is visible as green bands.
- The white bands are observations when the Moon is over the horizon at night

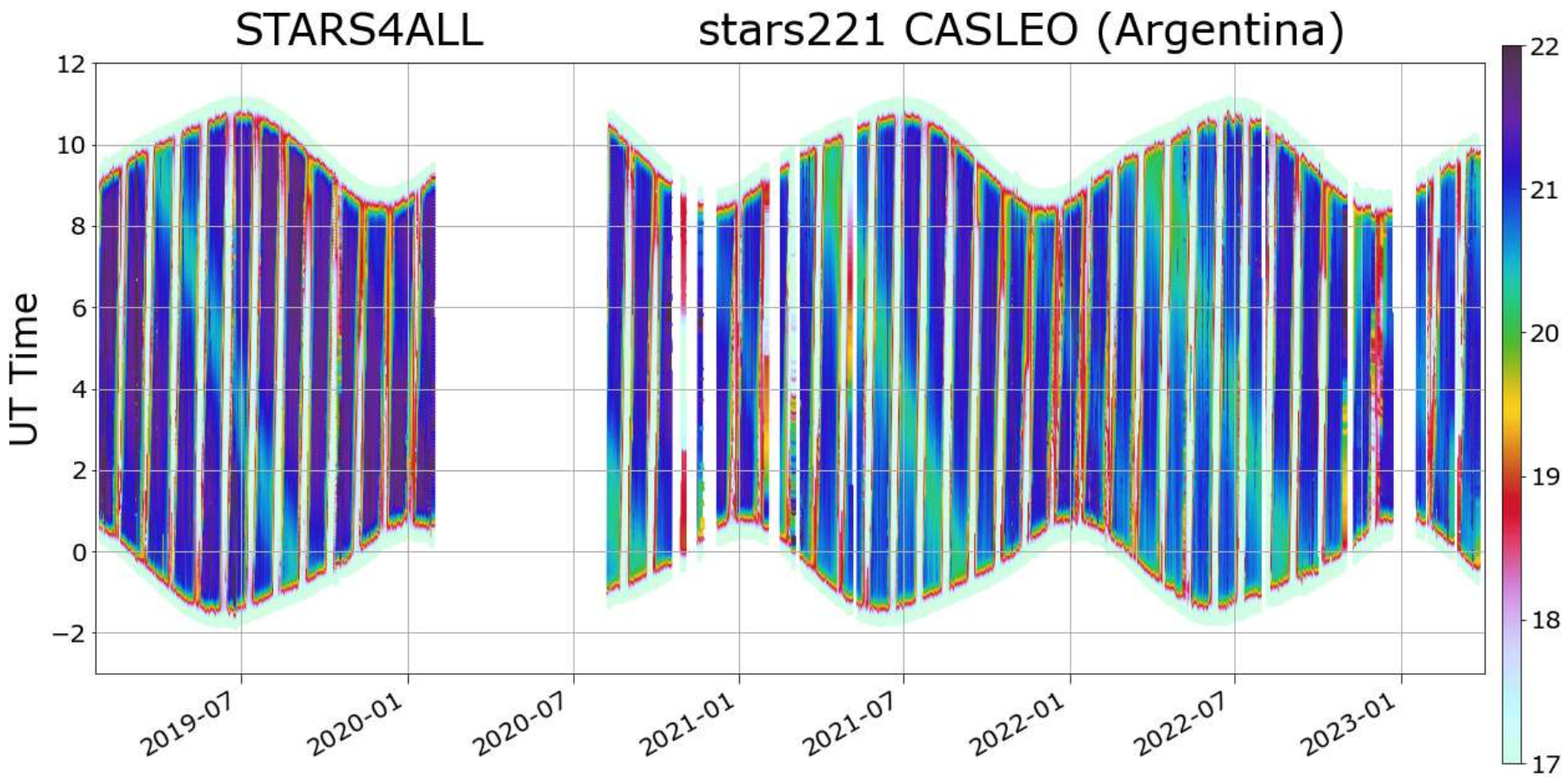
"Night Sky Brightness should be treated as another weather parameter" (Salvador Bará)

Why monitoring ? Night Sky Brightness evolution graph



Evolution along the time of Night Sky Brightness measured at Coslada (Madrid urban area) and Villaverde del Ducado (rural area in Guadalajara, Spain).

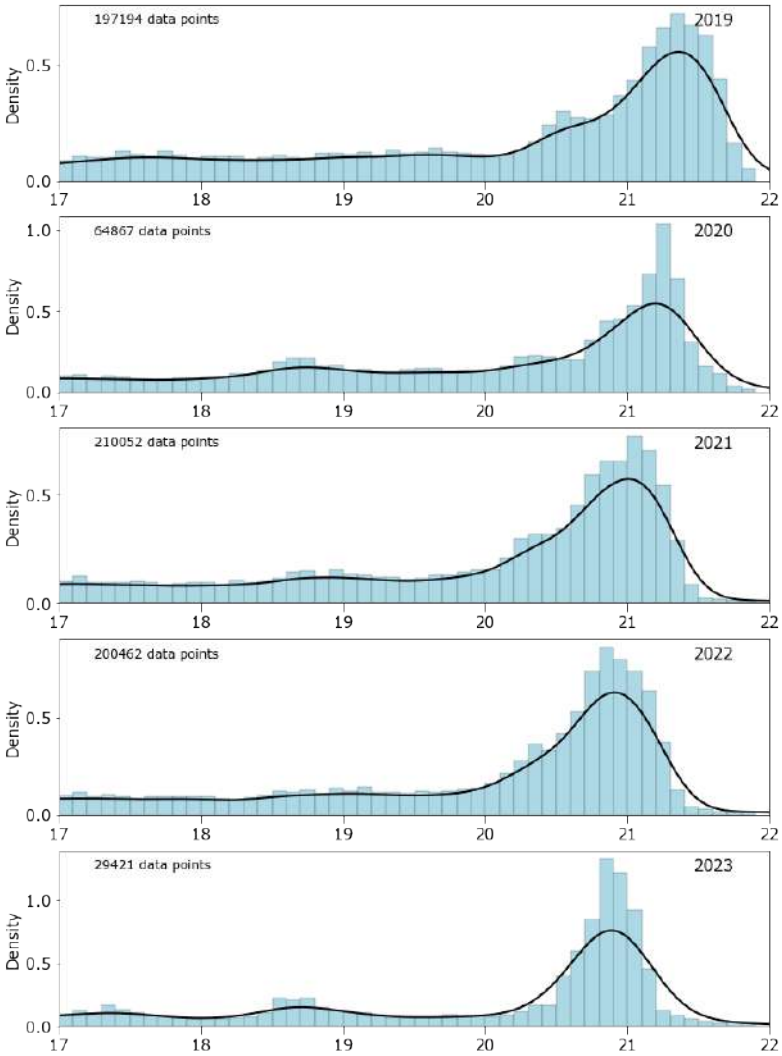
Why monitoring ? Night Sky Brightness evolution graph



Evolution along the time of Night Sky Brightness measured at CASLEO (Argentina).
The observations are color coded according to NSB value.

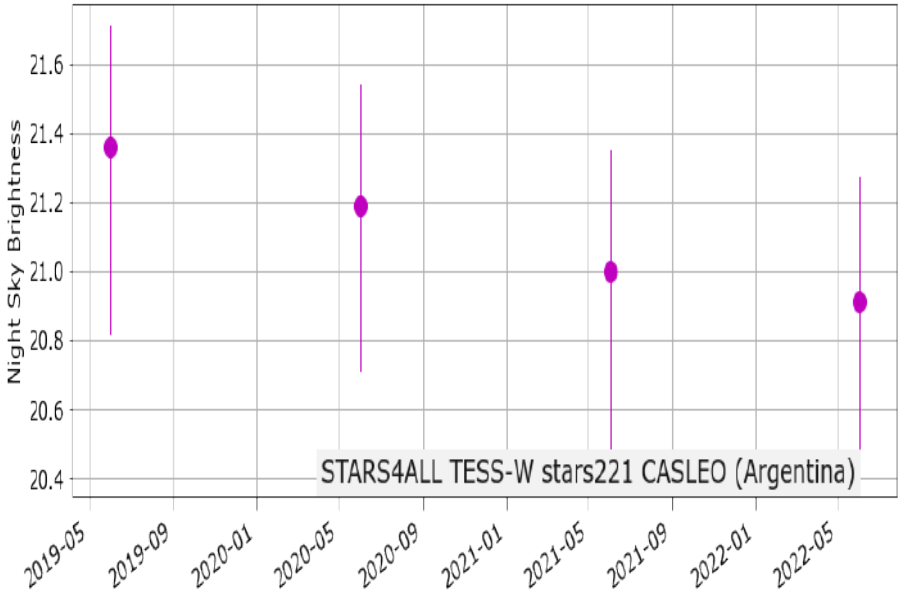
- The brightening due to the Milky Way is visible as green bands.
- Note the shorter nights at December because is in the Southern Hemisphere.

Night Sky Brightness histogram evolution



Night Sky Brightness measured at CASLEO (Argentina).
The observation time range is one year for each plot.

- The mode of NSB varies along the time.



Comparing histograms of NSB during one year it is possible to detect evolution along the time.

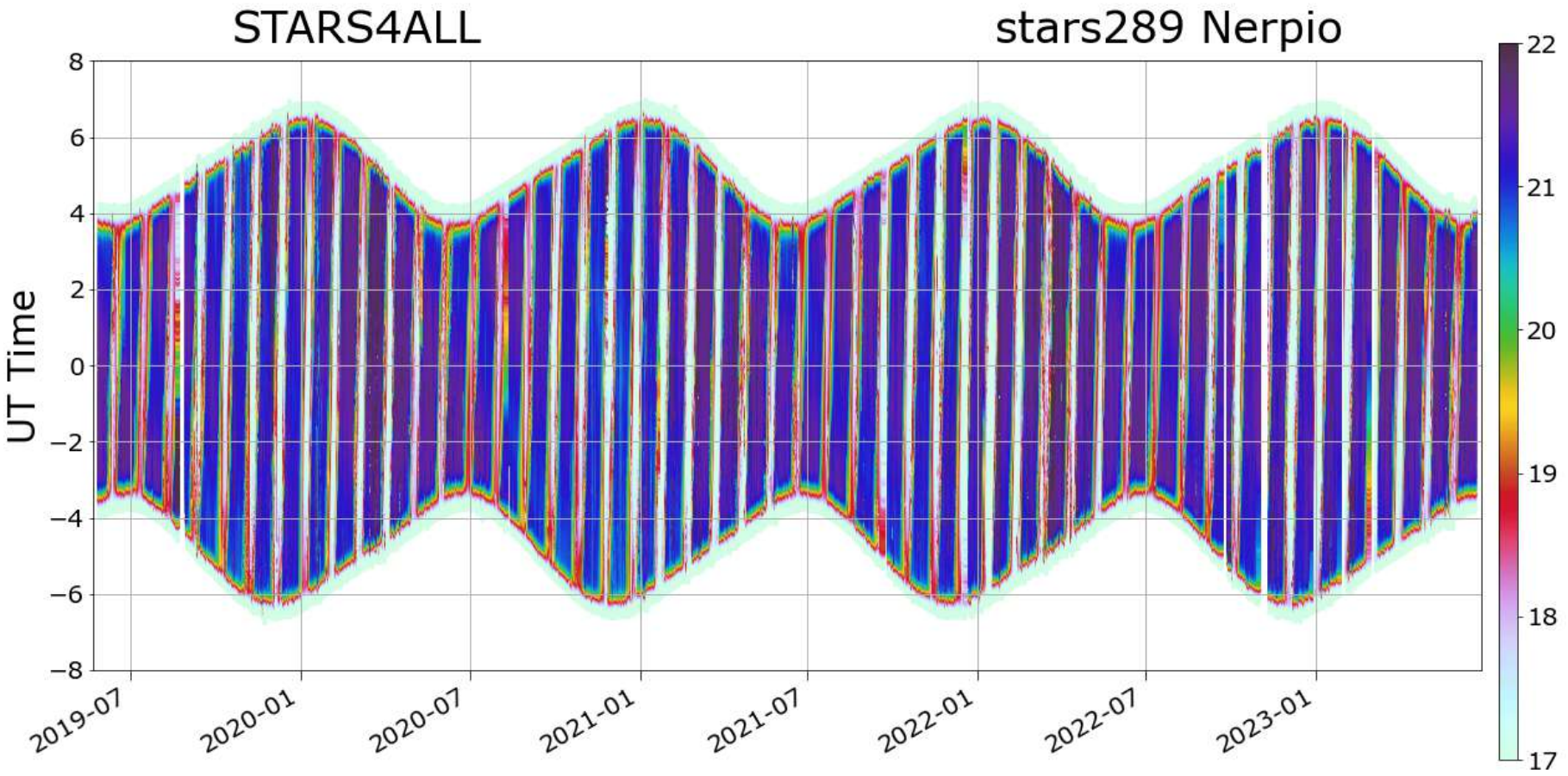
Read for instance:

"Monitoring Long-Term Trends in the Anthropogenic Night Sky Brightness"

Salvador Bará, Raul C. Lima, and Jaime Zamorano

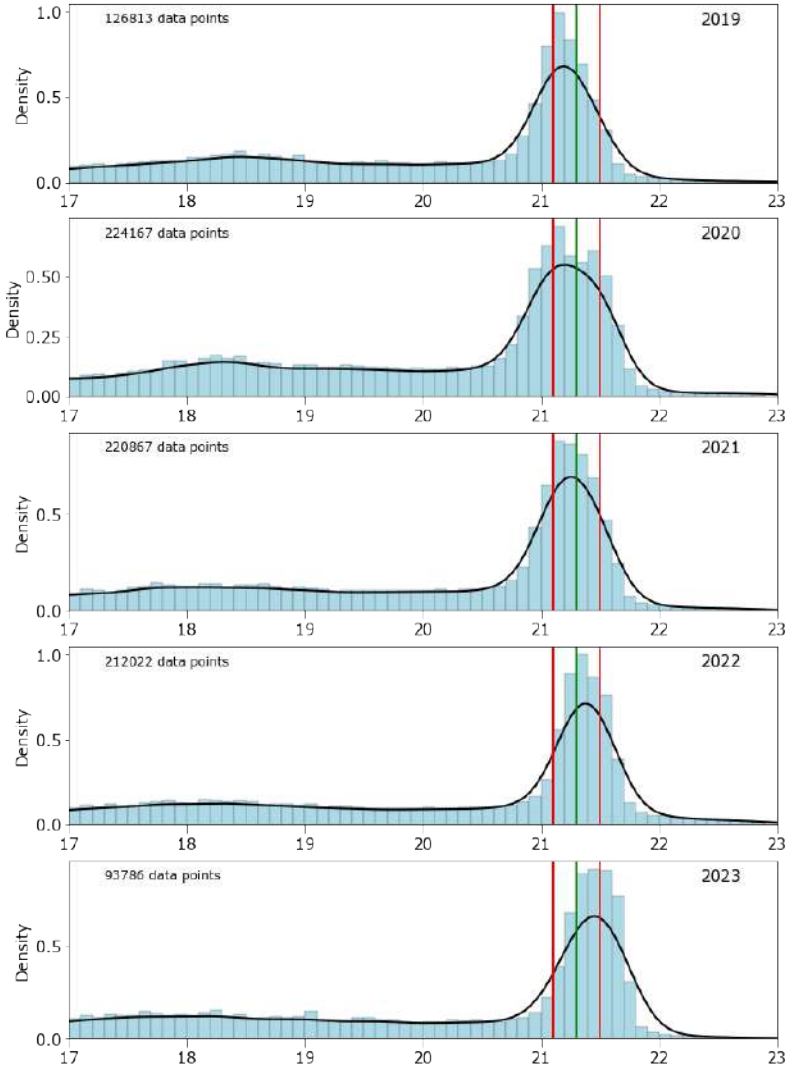
Sustainability 2019, 11(11), 3070; https://doi.org/10.3390/su11113070

Night Sky Brightness evolution example (2)



Evolution along the time of Night Sky Brightness measured at Nerpio (Spain).
The observations are color coded according to NSB value.

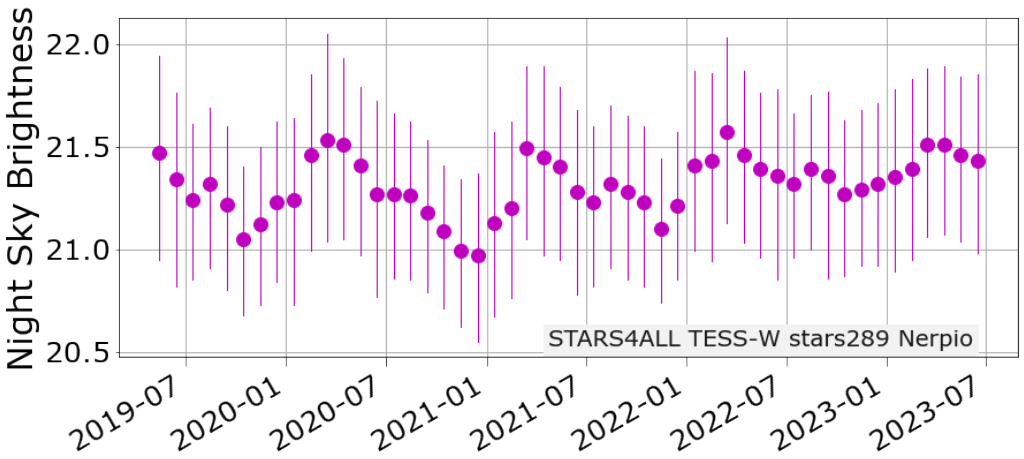
Night Sky Brightness evolution example (2)



Night Sky Brightness measured at Nerpio (Spain).

The observation time range is one month for each plot.

- The mode of NSB varies along the time.



Note the wider histogram at 2020 indicating a possible change in light pollution.

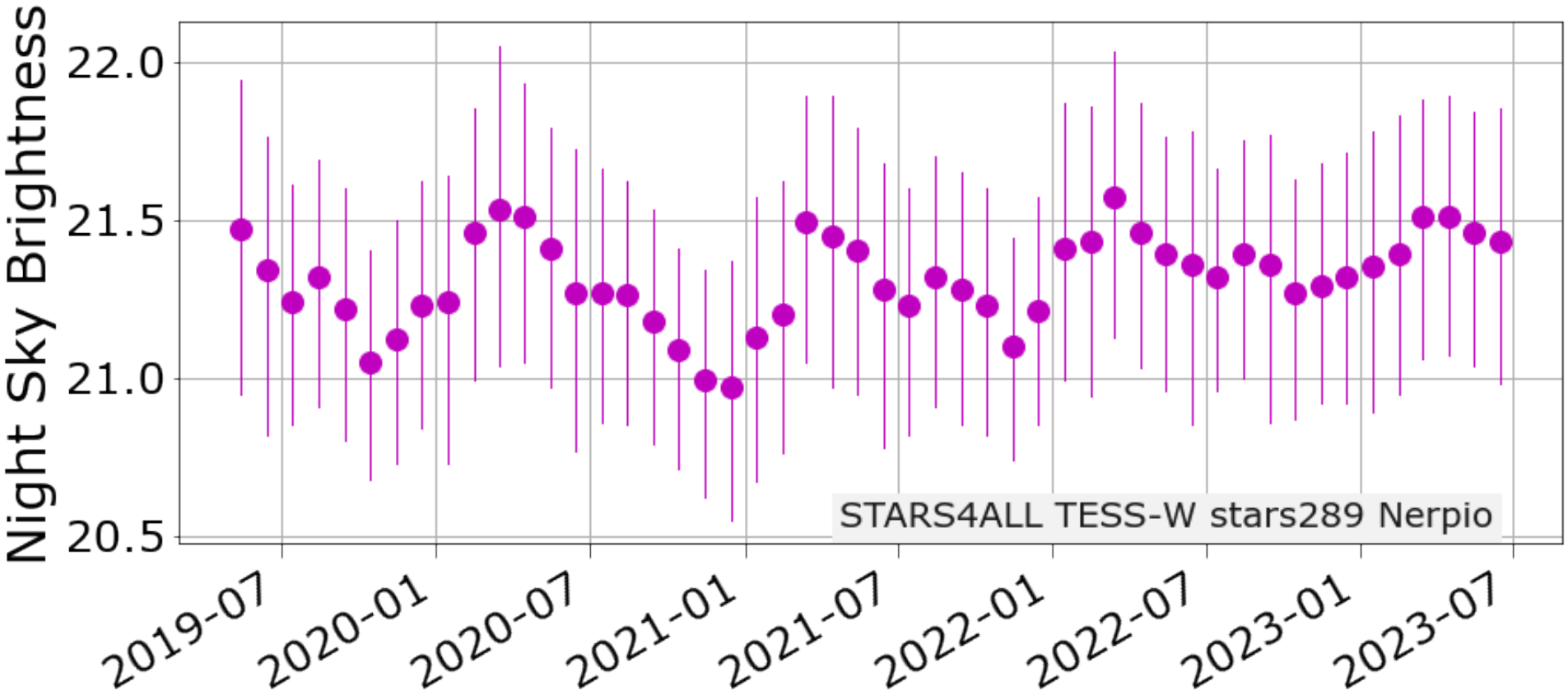
Read for instance:

"Monitoring Long-Term Trends in the Anthropogenic Night Sky Brightness"

Salvador Bará, Raul C. Lima, and Jaime Zamorano

Sustainability 2019, 11(11), 3070; https://doi.org/10.3390/su11113070

Night Sky Brightness evolution example (2)



Night Sky Brightness measured at Nerpio (Spain).

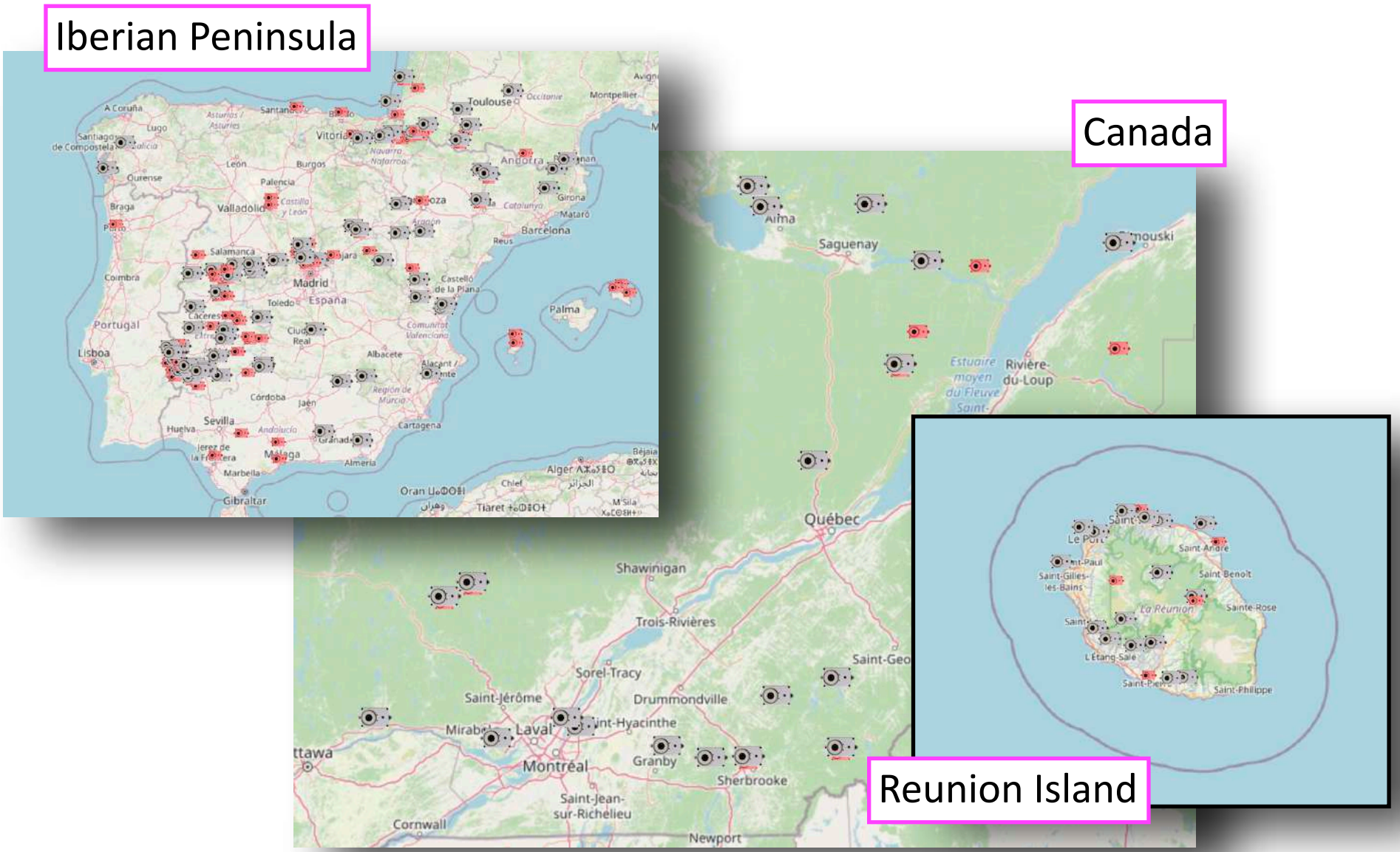
The observation time range is one month for each point in the evolution plot.

- There is a seasonal variation

Using the histogram of NSB in monthly bins it is possible to detect seasonal evolution.

(3) STARS4ALL TESS-W photometer network

(3)



Locations of some monitoring stations along the world.

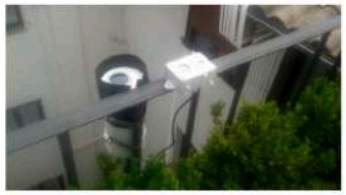
https://tess.dashboards.stars4all.eu/d/tess_network_map/map?orgId=1

Examples of monitoring stations along the world


Coslada (Spain) - stars1


Villaverde del Ducado (Spain) - stars2


UCM Madrid (Spain) - stars5 & stars85

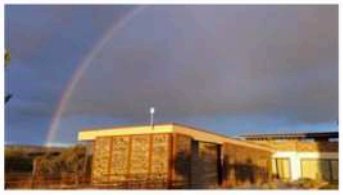

Pamplona (Spain) - stars7


Añora (Spain) - stars9


Oukaimeden (Morocco) - stars27


Ajdovščina (Slovenija) - stars35


Huércal de Almería (Spain) - stars52


Monfragüe (Spain) - stars66

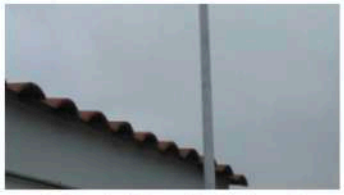

Saõ Vicente (Cape Verde) - stars79


Helechosa de los Montes (Spain) - stars202


Hoegaarden (Belgium) - stars209


Wellington (New Zealand) - stars214


Mount Martha (Australia) - stars215


La Roca de la Sierra (Spain) - stars218


Pierre Auger Observatory, Malargüe (Argentina) - stars220

IES Caballero Bonald, Jerez de la Frontera


Parco Astronomico Lilio (Italy) - stars232


Badajoz (Spain) - stars233

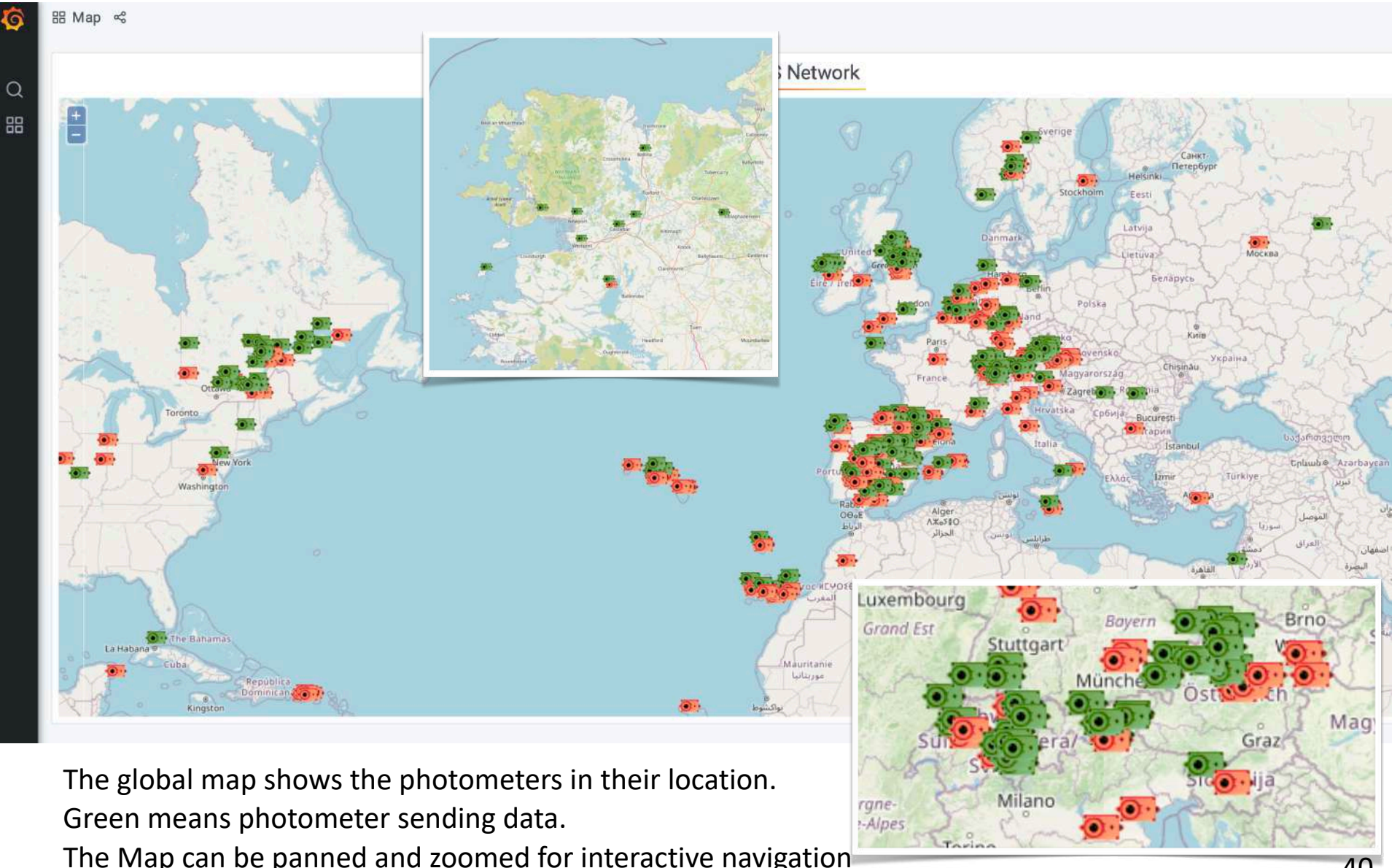

Hong Kong (China) - stars238

TESS-W needs electrical power and wifi connection.

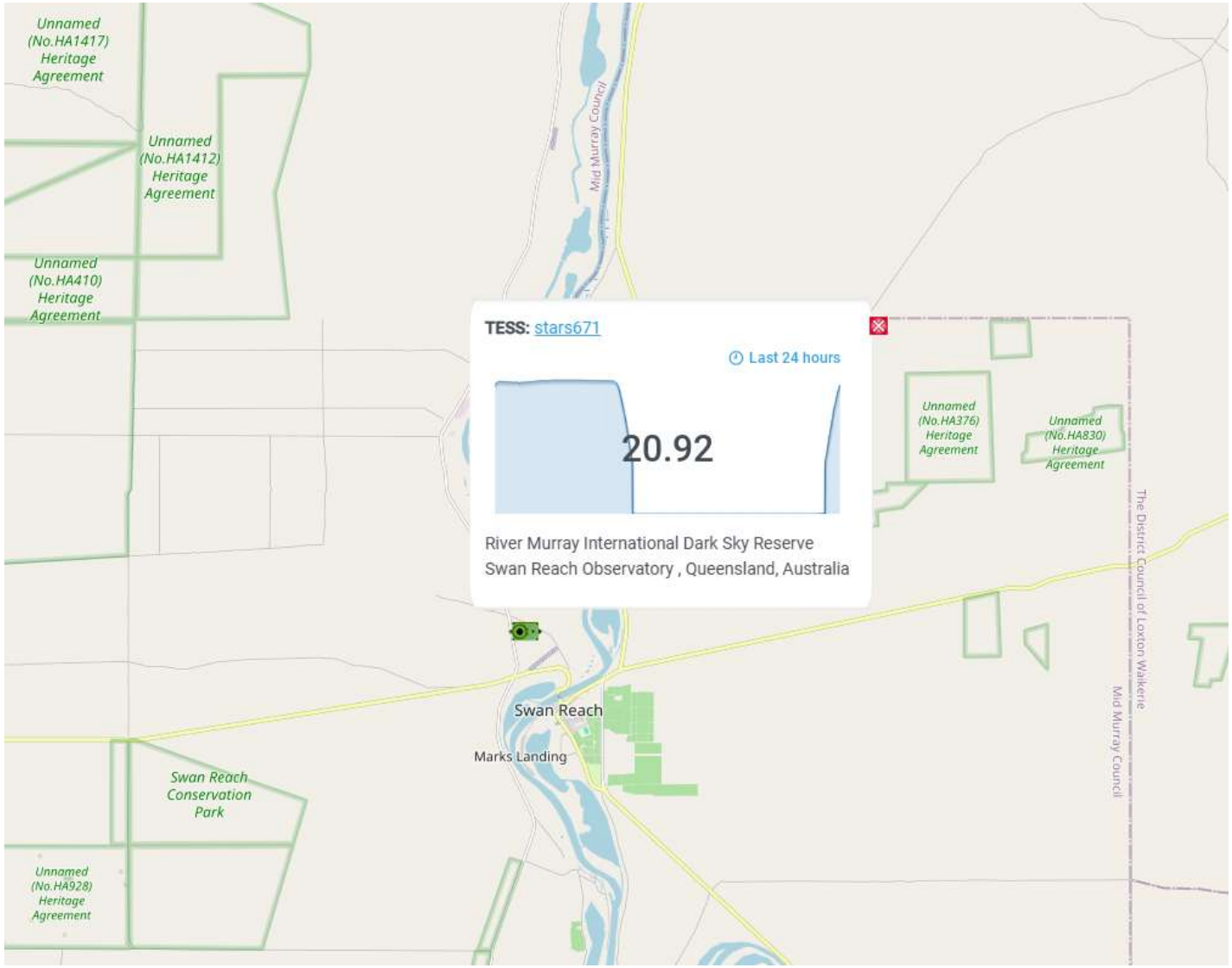
(4) STARS4ALL network Dashboards

(4)

https://tess.dashboards.stars4all.eu/d/tess_network_map/map?orgId=1



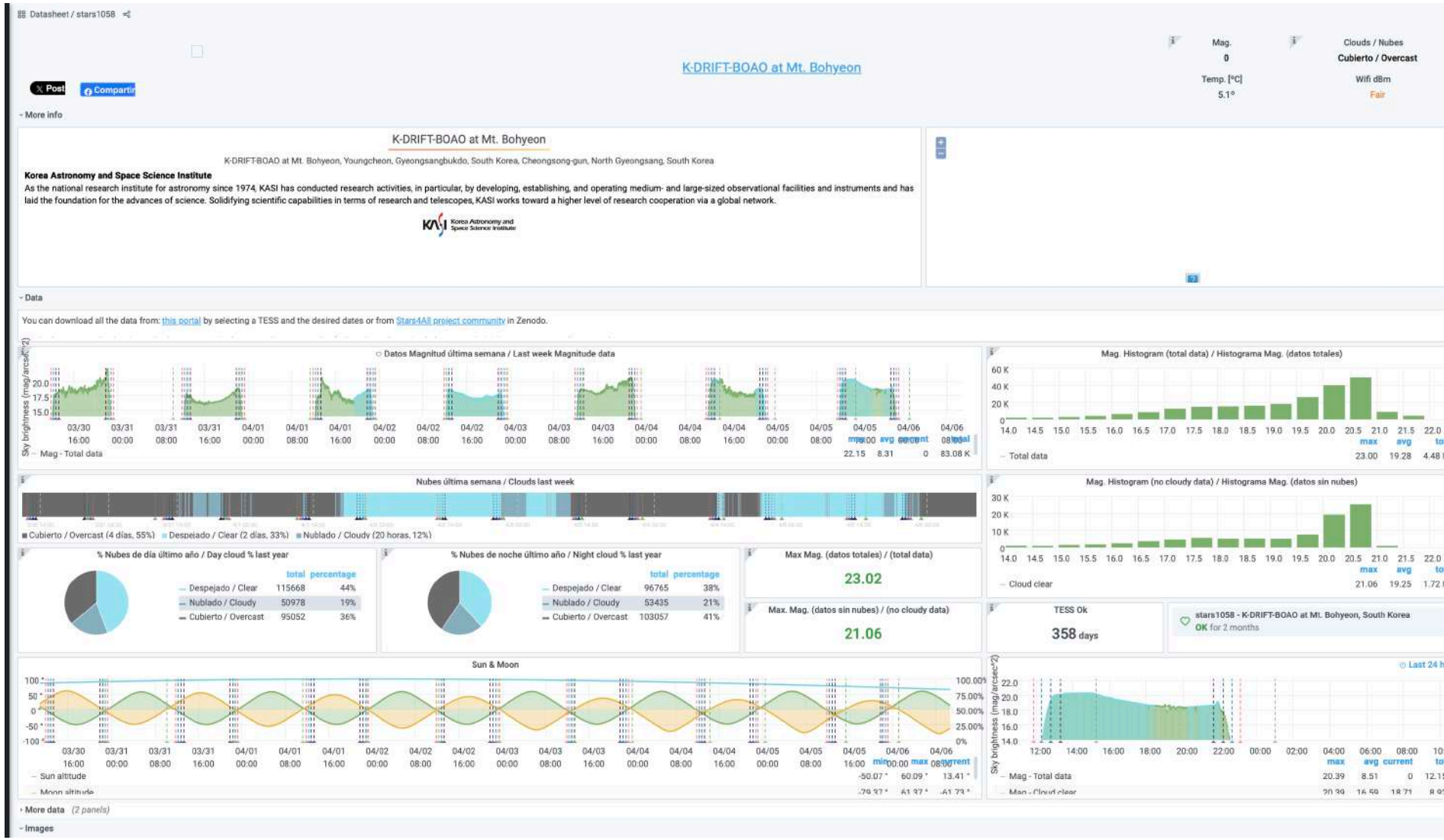
The global map shows the photometers in their location.
Green means photometer sending data.
The Map can be panned and zoomed for interactive navigation



From the global map one can reach the photometers in their location.
After clicking the name and last 24h NSB plot is displayed.

STARS4ALL network Dashboards

Share information to register your photometer using the register form. https://forms.gle/uGZRMpdHZfpMnN3W9

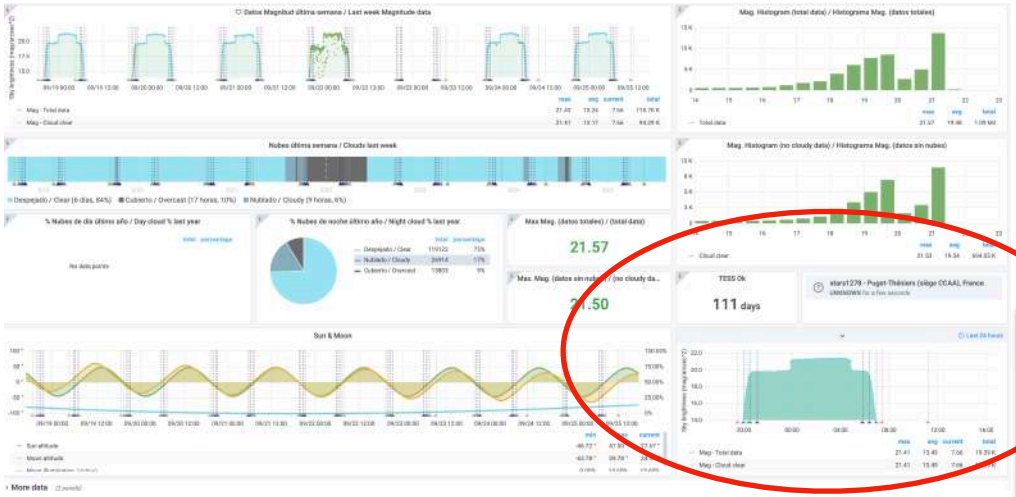


After registering a dedicated webpage with dashboards is open for your photometer.

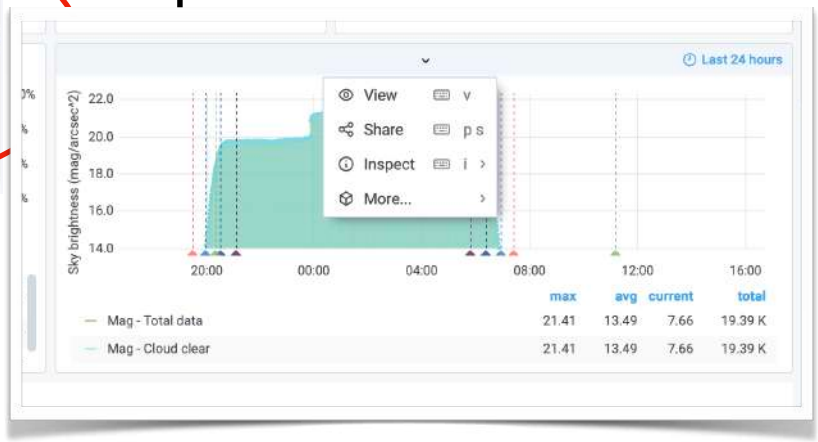
How to insert a grafana panel in your own webpage

1 Open the webpage

https://tess.dashboards.stars4all.eu/d/datasheet_stars1278/stars1278?orgId=1. (Example)



Open menu on selected



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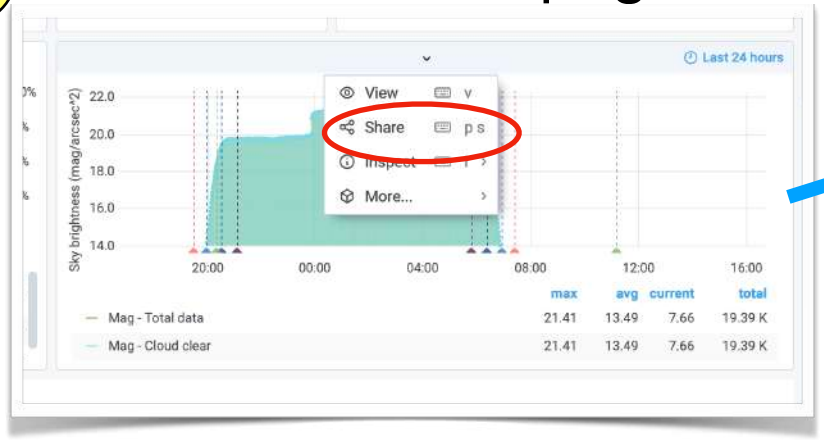
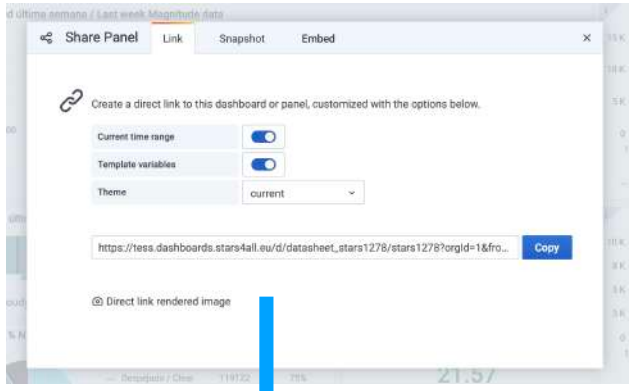
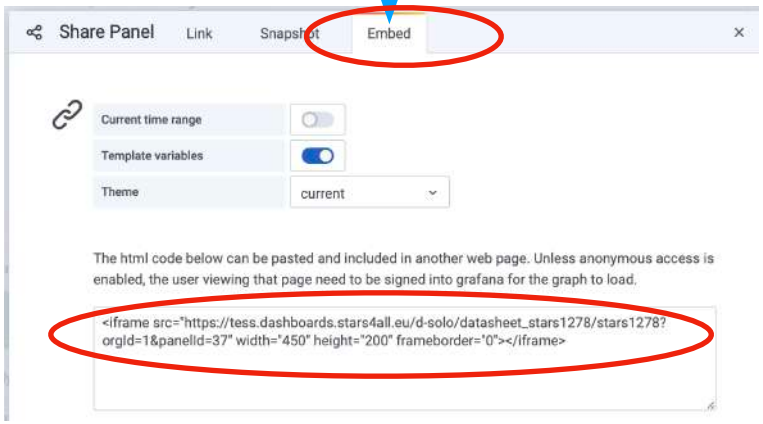
2 Create the webpage code





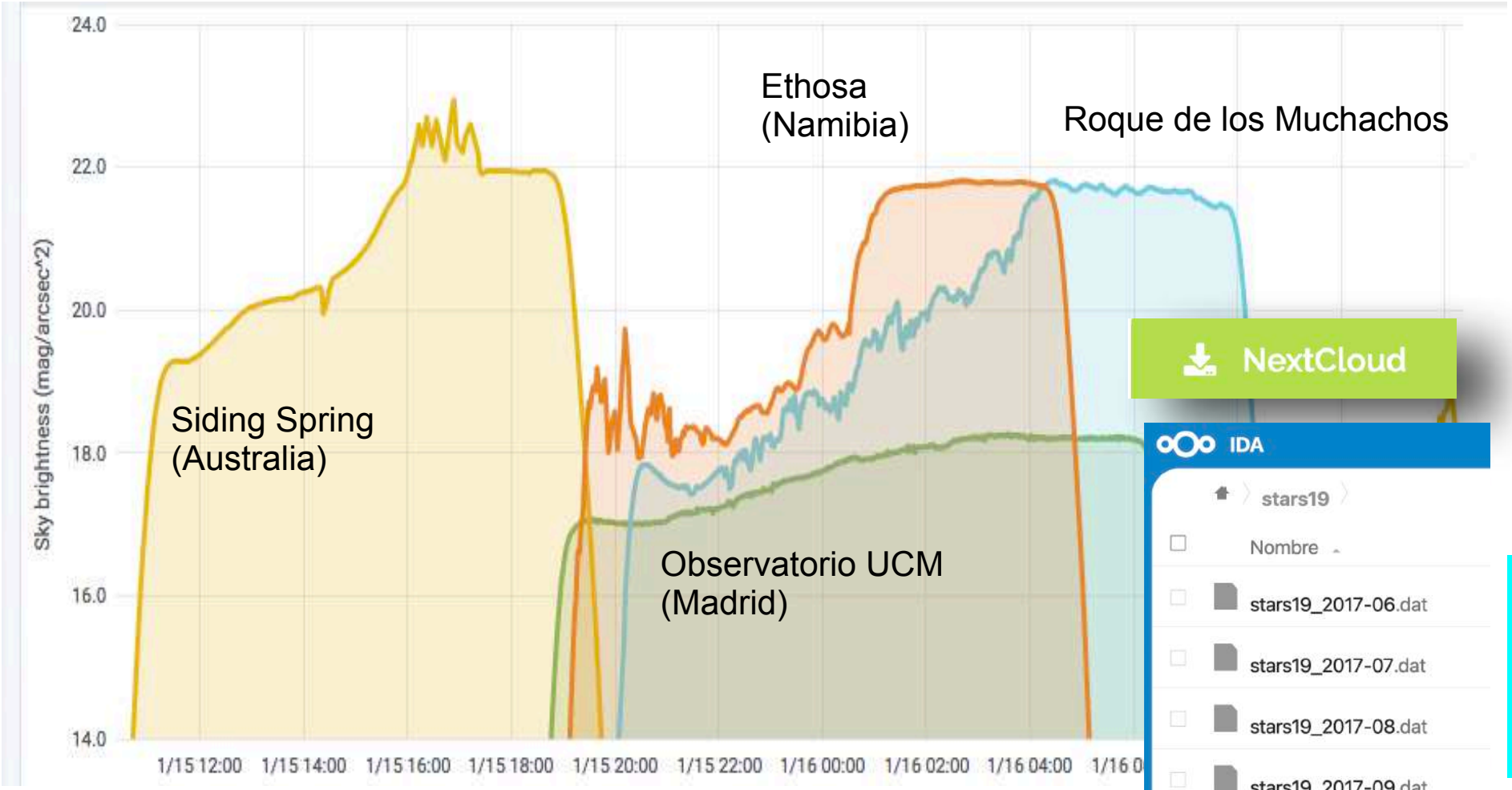


- Select ‘Share’
- Select ‘Embed’
- Copy the html code

```
<iframe src="https://
tess.dashboards.stars4all.eu/d-solo/
datasheet_stars1278/stars1278?
orgId=1&panelId=37" width="450"
height="200" frameborder="0"></iframe>
```

44

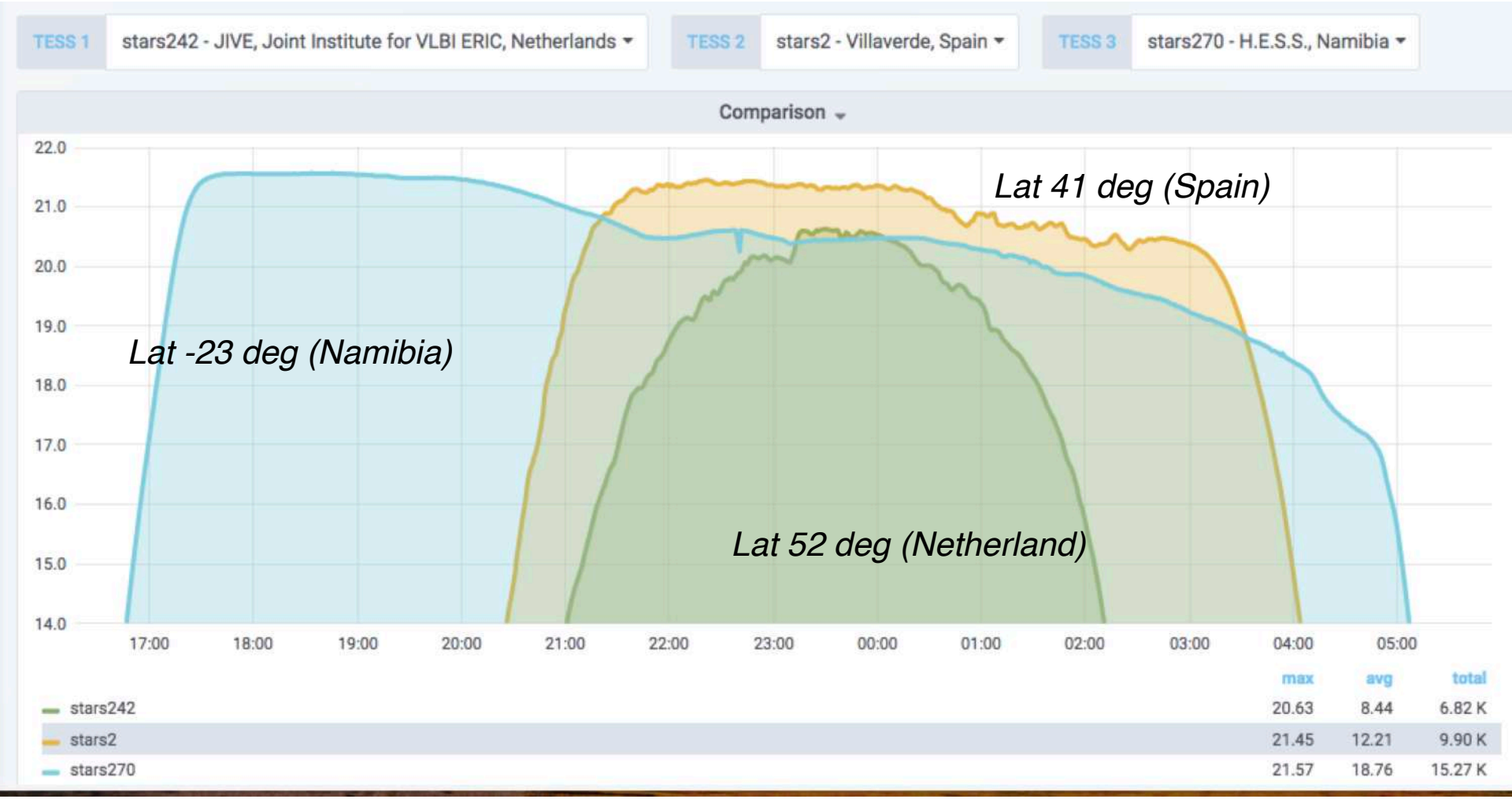
TESS-W photometer network. Real time data



TESS open data is available online in real time (grafana panels)
https://tess.dashboards.stars4all.eu

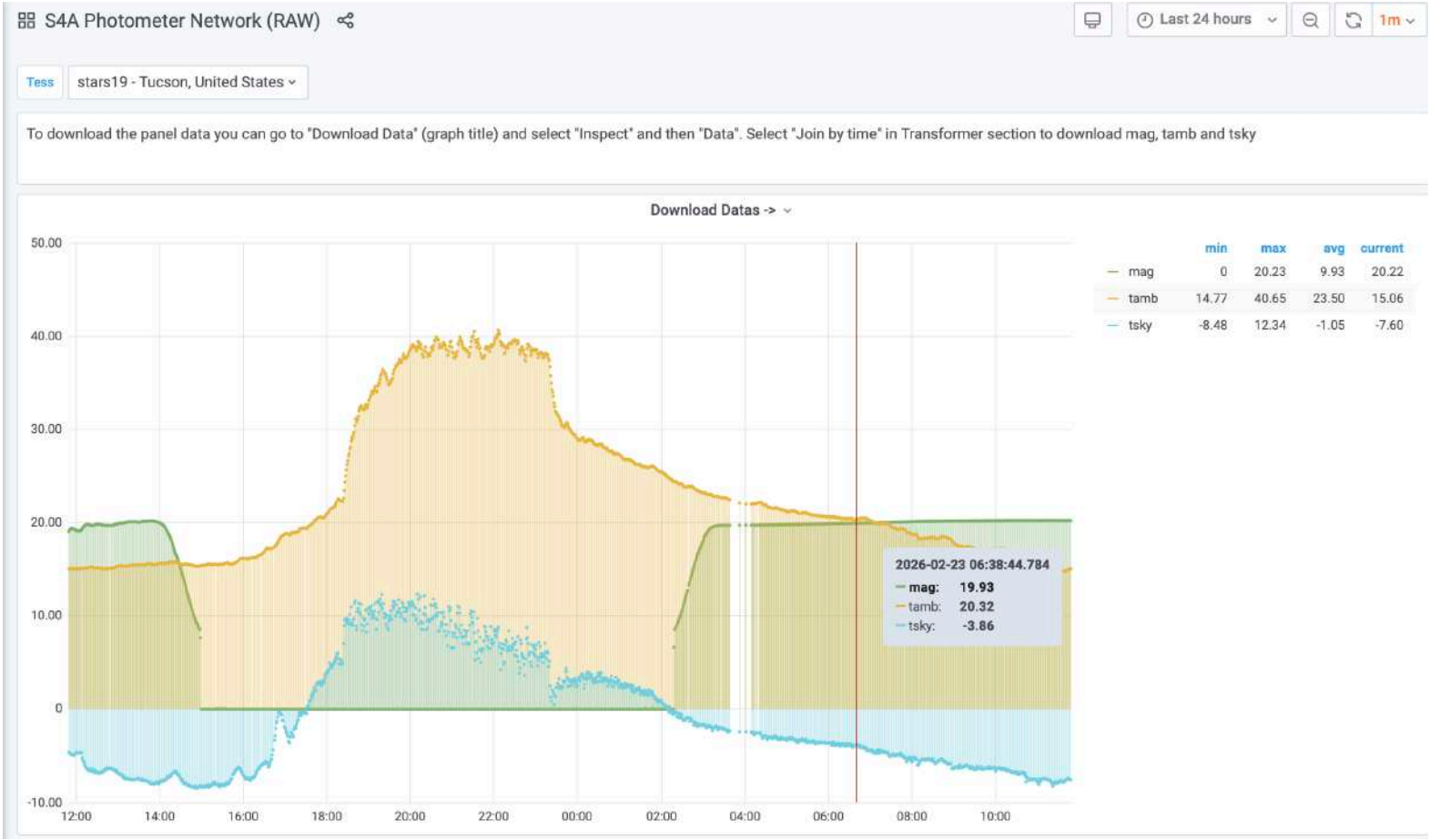
Open data is archived in IDA-IAU format monthly files.
Archived data at https://fta-cloud.fis.ucm.es/index.php/s/Gr9DAbfiX8Pdm86

TESS-W photometer network. Longitude and latitude



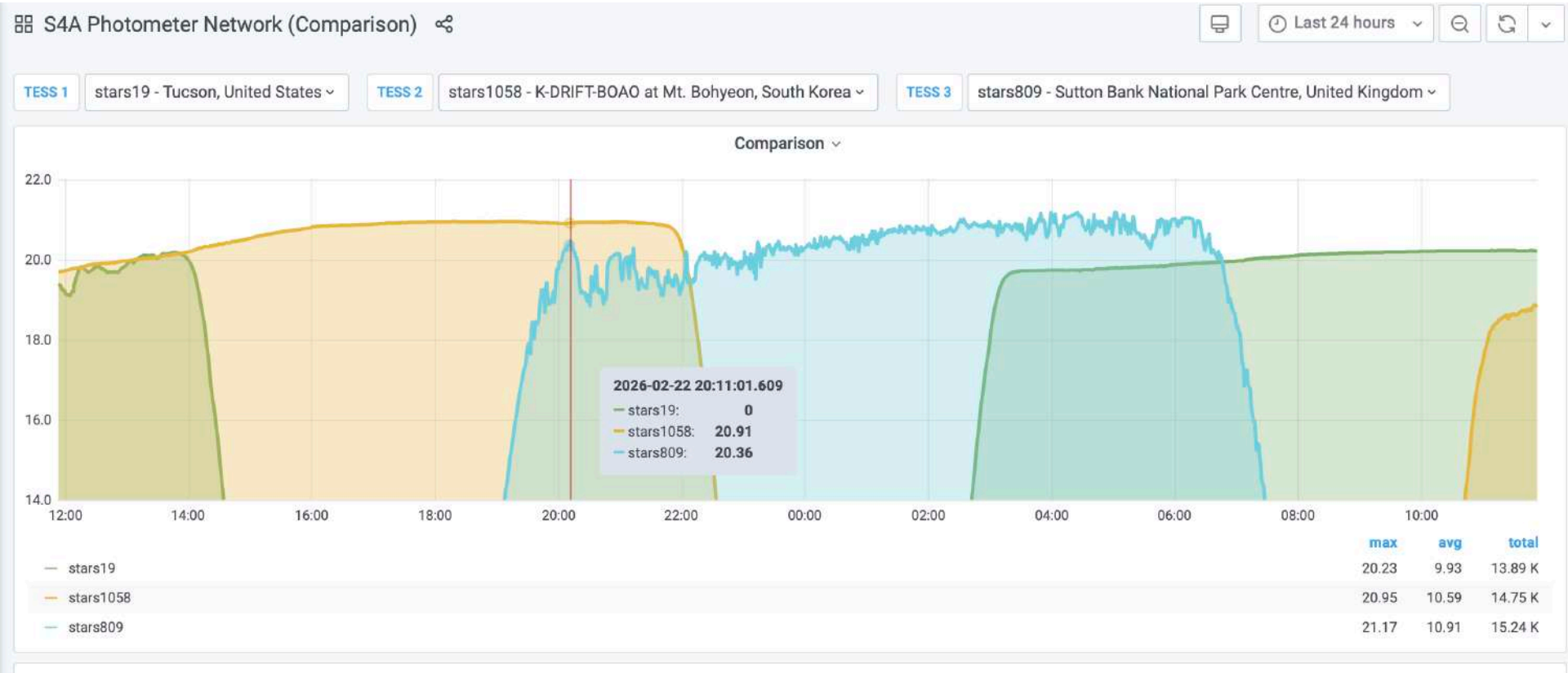
Comparison Grafana panels are useful to learn astronomy.
In this case the length of the night varies with latitude on Earth as shown in the night graphs of three photometers.
https://tess.dashboards.stars4all.eu/d/tess_comparison

- Real time data of one photometer.
  https://tess.dashboards.stars4all.eu/d/tess_raw/s4a-photometer-network-raw?orgId=1&refresh=1m&var-Tess=stars19



Useful to check whether the data from your photometer is arriving to the data repositories. You can select photometer and time range.

- Real time data of three photometers.
  https://tess.dashboards.stars4all.eu/d/tess_comparison/s4a-photometer-network-comparison?orgId=1&var-Tess_1=stars19&var-Tess_2=stars1058&var-Tess_3=stars809



Useful to compare night sky brightness from 3 photometer.
You can select photometers and time range.

- Real time data of four photometers. https://tess.dashboards.stars4all.eu/d/tess_comparison_4/s4a-photometer-network-comparison-x-4?orgId=1&var-Tess_1=stars75&var-Tess_2=stars1&var-Tess_3=stars9&var-Tess_4=stars489&from=now-18h&to=now-4h

Useful to compare night sky brightness from 4 photometer. You can select photometers and time range. Note in this case the time range stands from now-18h to now-4h.

- Real time data of 8 photometers.
  https://tess.dashboards.stars4all.eu/d/tess_comparison_8/s4a-photometer-network-8x-comparison?orgId=1&var-Tess_1=stars541&var-Tess_2=stars542&var-Tess_3=stars543&var-Tess_4=stars602&var-Tess_5=stars1&var-Tess_6=stars1192&var-Tess_7=stars9&var-Tess_8=none

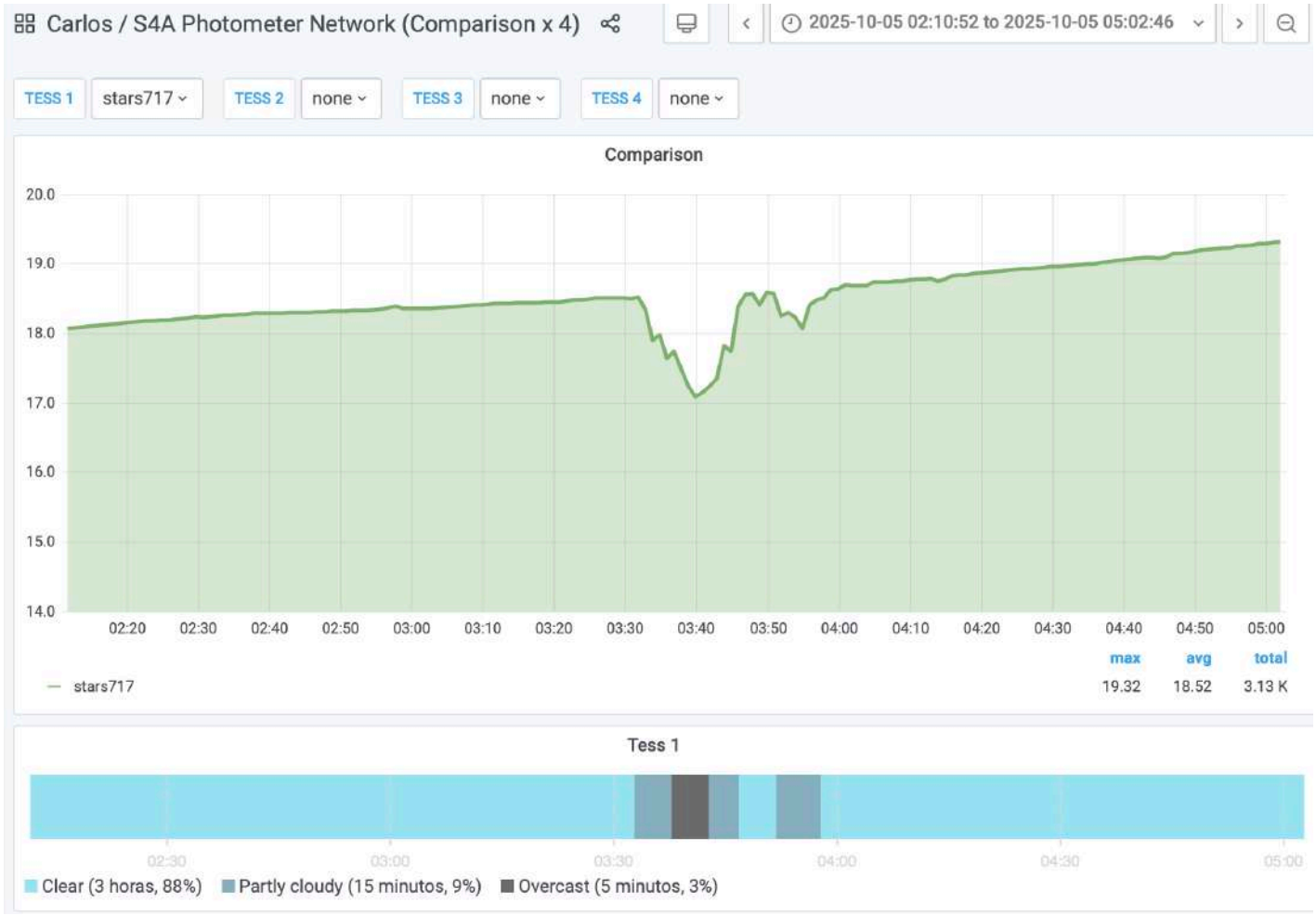
Useful to compare night sky brightness from 8 photometer.
You can select photometers and time range.

How TESS-W network estimate cloudiness for dashboards:

The cloud parameter we are using is cloud = 100 - 3 * (Tambient - Tsky) # nominal

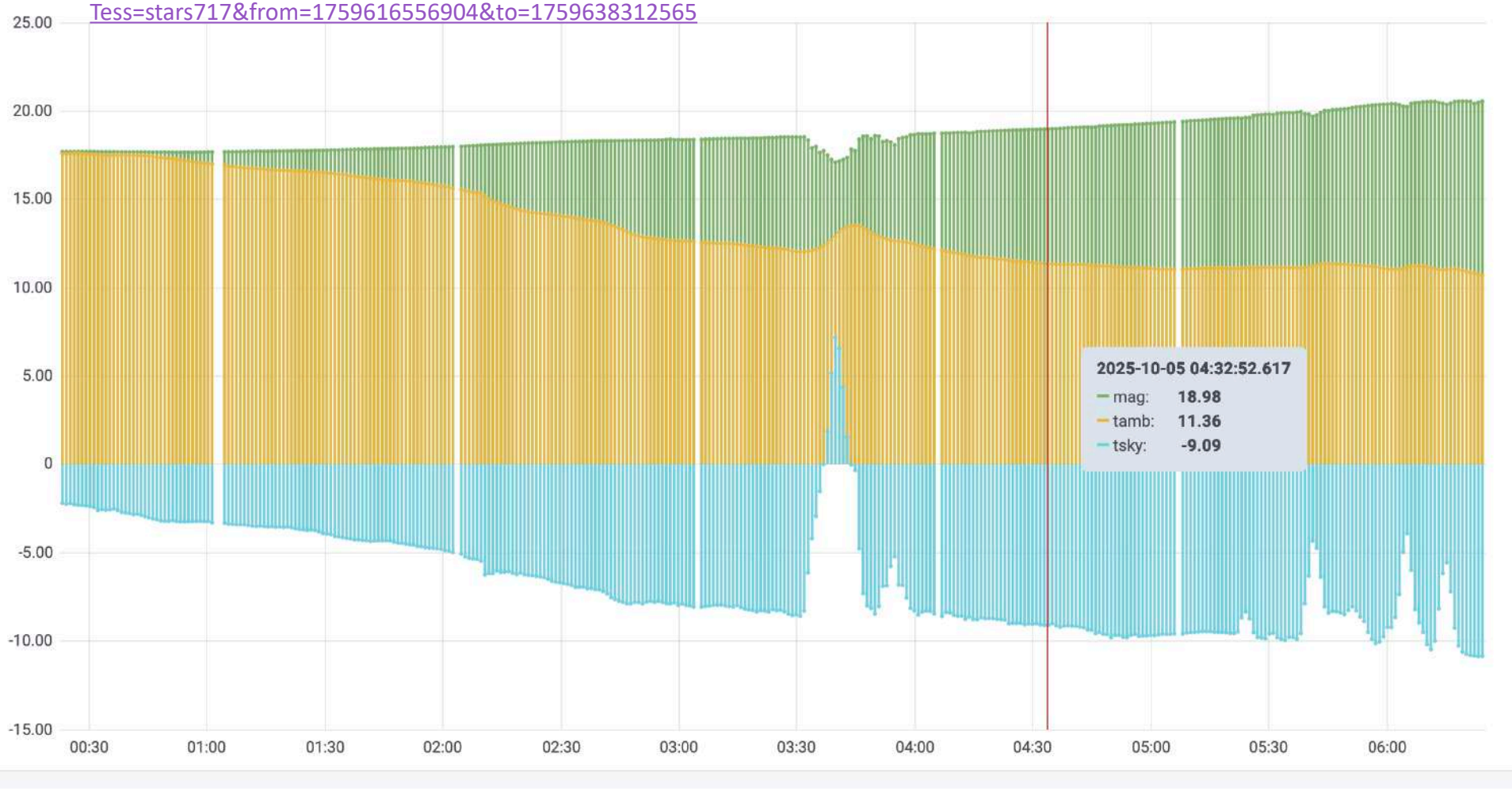
And assign the estimate as

Clear	cloud < 40
Partly cloudy	40<cloud >70
Cloudy	cloud > 70



STARS4ALL network Cloud estimate

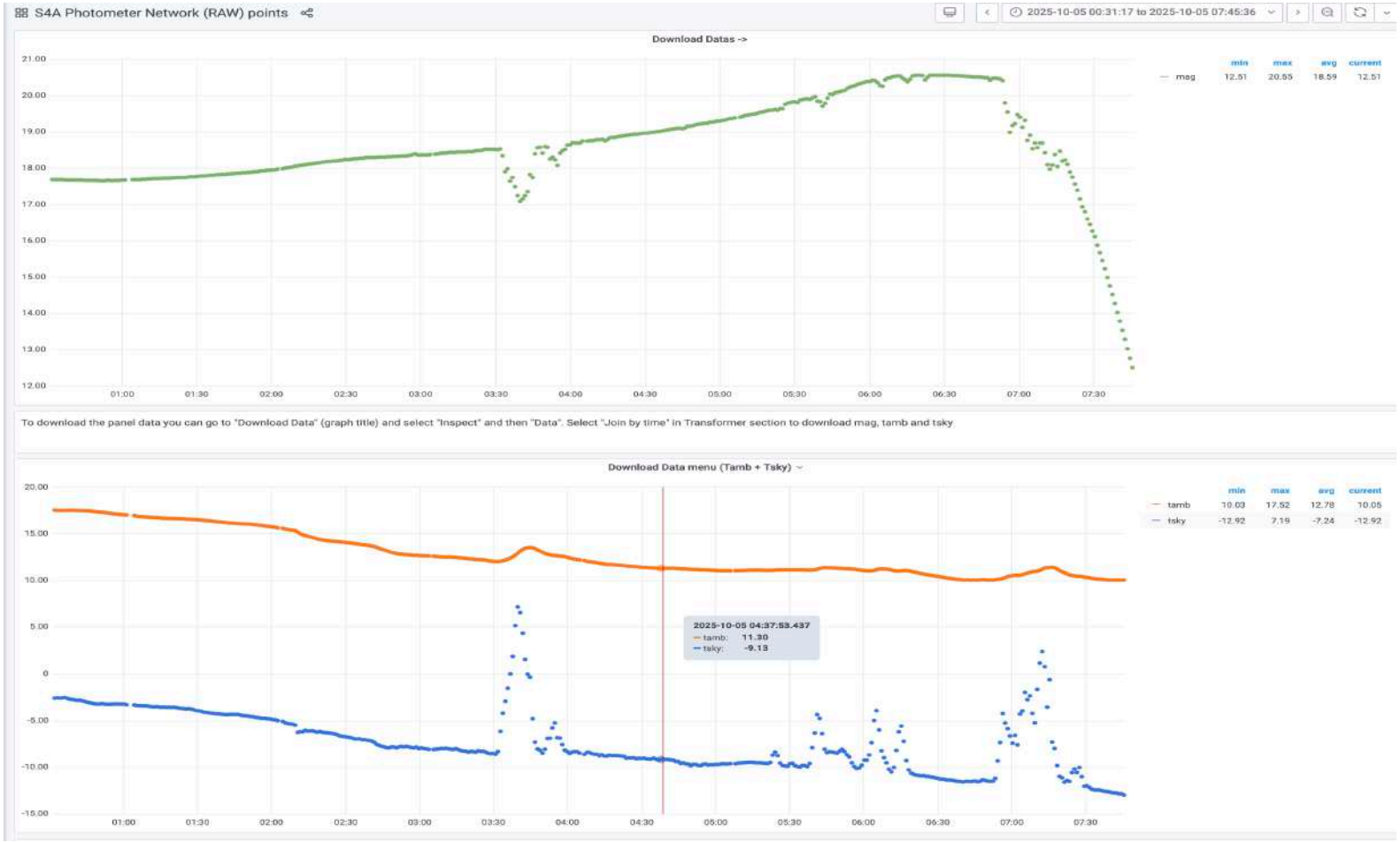
https://tess.dashboards.stars4all.eu/d/tess_raw/s4a-photometer-network-raw?orgId=1&var-Tess=stars717&from=1759616556904&to=1759638312565



Some clouds passing after 3:30 are detected as a rise in the Tsky (blue line).
The Night Sky Brightness value drops (green line) indicating brighter sky during to clouds.
Similar drops at from 5:20 on.

STARS4ALL network Cloud estimate

https://tess.dashboards.stars4all.eu/d/6024eOQ7z/s4a-photometer-network-raw-points?orgId=1&var-Tess=stars717&from=1759617077340&to=1759643136046



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How TESS-W network estimate cloudiness for dashboards:

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And assign the estimate as

Clear	cloud < 40
Partly cloudy	40<cloud >70
Cloudy	cloud > 70

Please note:

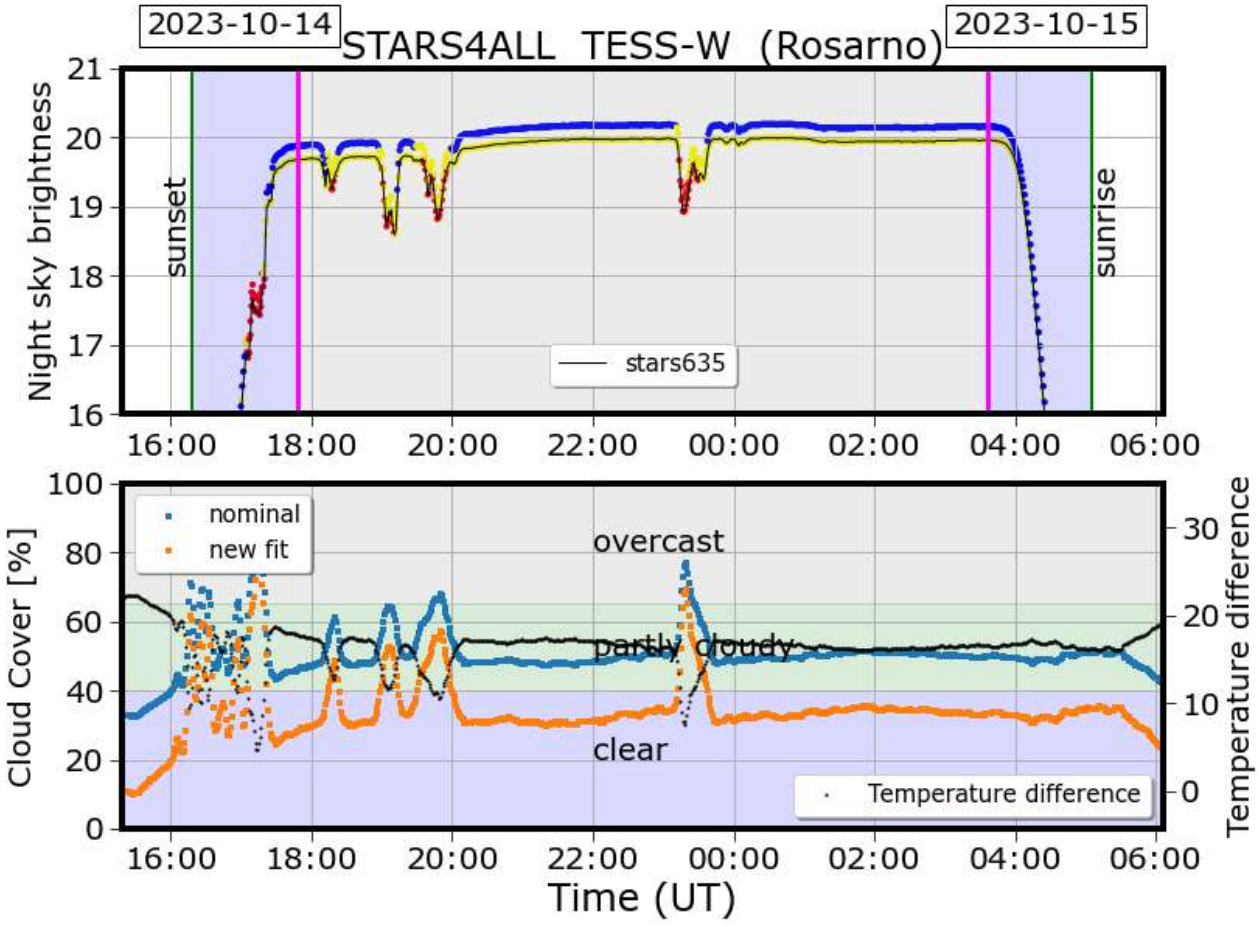
- The **IR sensor** provides the *apparent temperature of the sky*, often called the "**sky temperature**" is the effective temperature a black body would need to emit the same infrared radiation measured from the atmosphere.
- Tsky is a measure related with the water vapor content of the atmosphere (vapor column).
- The difference with ambient temperature gives us a hint of the cloud cover.
- We use the sensor temperature as ambient temperature but the temperature of the sensor is measured inside the photometer and can be higher than the actual ambient temperature. When T inside the enclosure is below 10 degrees celsius a resistance heat the photometer to prevent fog and/or ice in the optical window.
- We do not have angular resolution, i.e. this parameter can not map the cloud cover. This is a wide field average value.
- The IR sensor window should be free of dust.
- Cloud reflects light pollution in polluted areas and the sky brightness increases (magnitude plot drops)
  In very dark areas the sky is darker when cloudy and the magnitude plot goes up.
  Remember that the magnitude plot is also very useful to determine the presence of clouds.
- This formula is not valid for every location and every time. Can be different in different seasons, for instance.
  It also depends of the height of the observatory.

If you wish to obtain your own calibration:

(a) Create a file with the temperatures for some nights and add a new row with a code indicating cloudiness.
You should determine this parameter from meteorological observations or images from an all-sky night camera.

(b) With this information you can derive a better formula that fits your data.

Example for an astronomical observatory where the cloud estimate do not fit the actual cloud cover.
The magnitude plot shows that it was a typical night with some clouds passing but most of the night is clear.



Lower panel shows the temperature difference (blue) and cloud cover in % black line.

According to our calibration (nominal, blue line) most of the night was covered (partly cloudy region, green band) but it is not the case.

Using a new (ad hoc) calibration

cloud = 100 - 4 * (Tambient - Tsky)
(New fit, note 4 instead of 3)

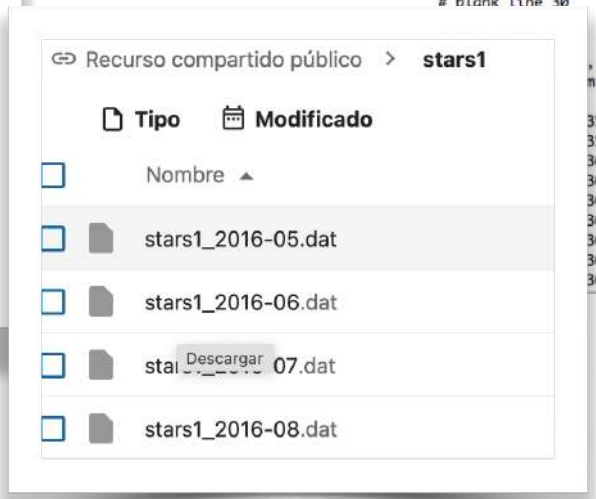
we can plot an orange line that lies in the clear region (purple band) for most of the night.

Upper Panel is the TESS NSB plot. The points are color coded according to cloud estimate.
Using the new fit most of the points are blue (no cloud) and only some posts are red (clouds).
The NSB plot on top (offset of 0.2 mag for viewing purposes) is the new calibration using 4 and not 3.

IDA-IAU monthly files

The Standardized Format (IDA-IAU) was developed to allow for the archival and exchange of data from Night Sky Brightness photometers as SQM or TESS-W.

The format typically includes timestamp (UTC), NSB reading, instrument temperature, sky temperature, and geographic coordinates.
NSB is recorded in magnitudes per square arcsecond (mag/arcsec2).




```
# Definition of the community standard for skyglow observations 1.0
# URL: http://www.darksky.org/NSBM/sdf1.0.pdf
# Number of header lines: 35
# This data is released under the following license: ODbL 1.0 http://opendatacommons.org/licenses/odbl/summary/
# Device type: TESS-W
# Instrument ID: stars273
# Data supplier: Alexei Pace / Unknown
# Location name: Ir-Rabat/Unknown/Malta - Ir-Rabat
# Position: 35.8768, 14.3958, 201.0
# Local timezone: Europe/Malta
# Time Synchronization: timestamp added by MQTT subscriber
# Moving / Stationary position: STATIONARY
# Moving / Fixed look direction: FIXED
# Number of channels: 1
# Filters per channel: UVIR
# Measurement direction per channel: 0.0, 0.0
# Field of view: 17.0
# Number of fields per line: 6
# TESS MAC address: 5C:CF:7F:76:67:EE
# TESS firmware version: 1.0
# TESS cover offset value: 0.0
# TESS zero point (latest):  20.43
# Comment:
# Comment:
# Comment:
# Comment:
# Comment:
# Comment:
# Comment:
# blank line 30
, Local Date & Time, Temperature, Sky Temperature, Frequency, MSAS, ZP
m:ss.fff;YYYY-MM-DDTHH:mm:ss.fff;Celsius;Celsius;Hz;mag/arcsec^2;mag/arcsec^2

35.000;2019-05-01T14:00:35.000;32.7;-5.67;50000.0;0.0;20.43
35.000;2019-05-01T14:01:35.000;33.17;-5.11;50000.0;0.0;20.43
36.000;2019-05-01T14:02:36.000;33.33;-4.76;50000.0;0.0;20.43
36.000;2019-05-01T14:03:36.000;33.14;-4.89;50000.0;0.0;20.43
36.000;2019-05-01T14:04:36.000;33.15;-5.16;50000.0;0.0;20.43
36.000;2019-05-01T14:05:36.000;33.05;-5.67;50000.0;0.0;20.43
36.000;2019-05-01T14:06:36.000;32.75;-5.87;50000.0;0.0;20.43
36.000;2019-05-01T14:07:36.000;32.82;-5.81;50000.0;0.0;20.43
36.000;2019-05-01T14:08:36.000;33.06;-5.68;50000.0;0.0;20.43
```

Open data is archived in IDA-IAU format monthly files.

Archived data at UCM GUAIX cloud

UNIVERSIDAD COMPLUTENSE MADRID

New TESS photometer models

(7)

TESS-W
mainly for fixed monitoring stations

TESS-P
Handheld
Portable

TAS
All-sky
Auto scan

TESS-4C
Four channels
Fixed station

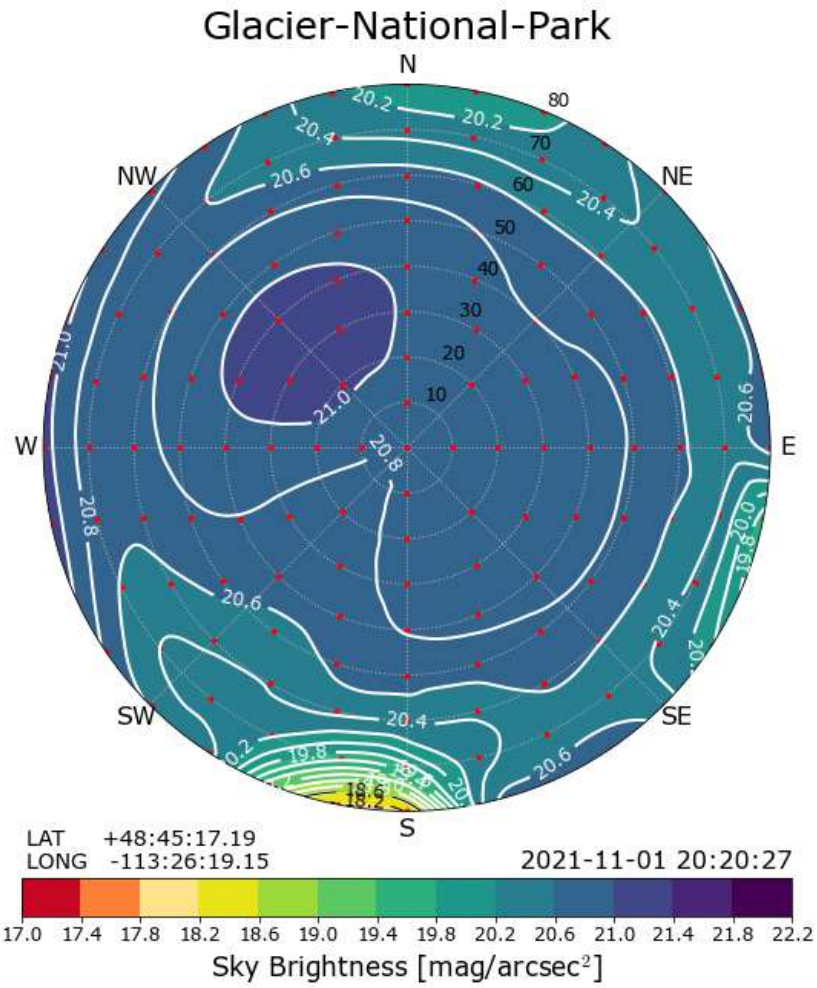
- TESS-W (new version with better weather resistant enclosure)
- TESS-P portable with battery and display, connects to mobile device for recording
- TAS for all night sky brightness maps
- TESS-4C with 4 photometric bands

TAS for all-sky brightness maps

Full automatic scan (144 points)

NSB all-sky maps on the fly

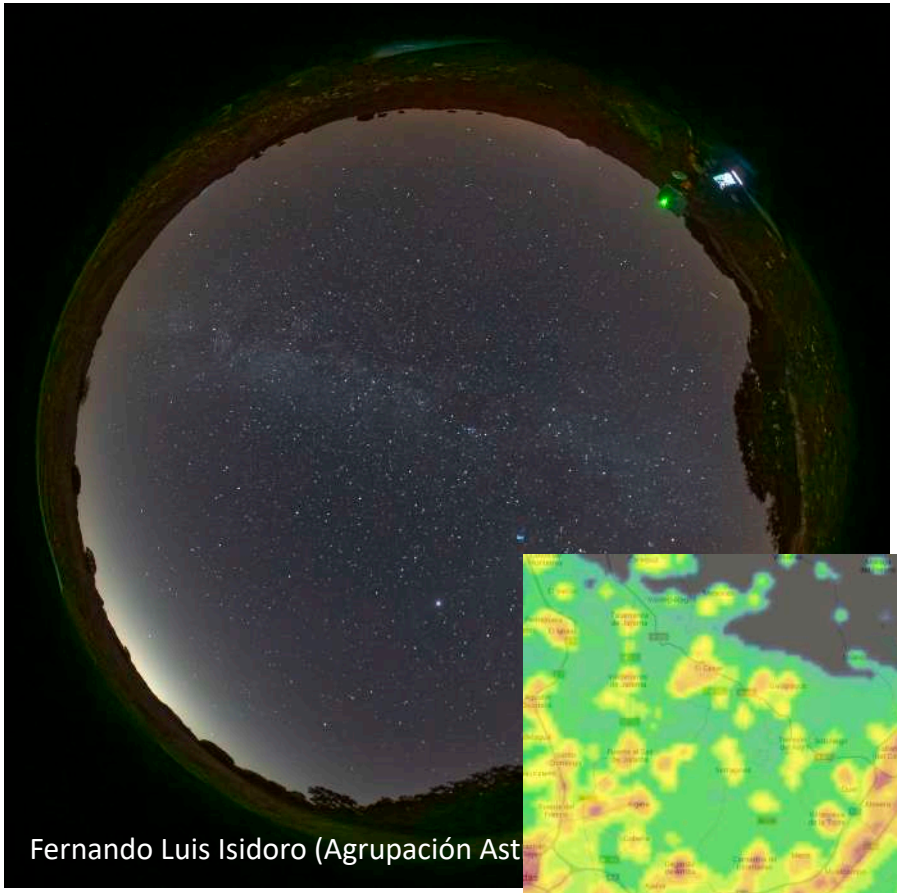
TAS for all-sky brightness maps (Nixnox project)

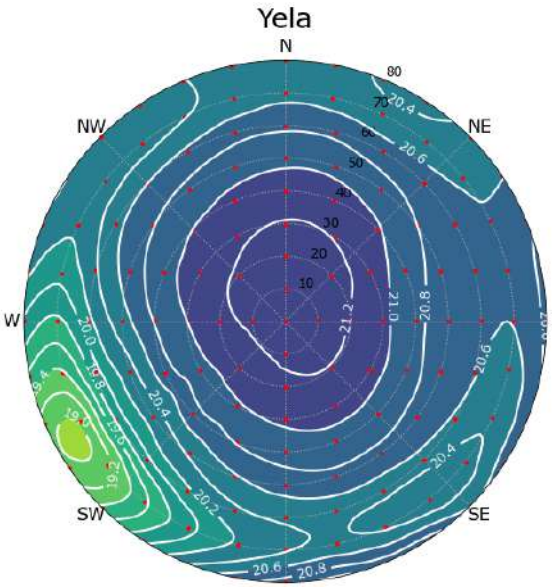


This fisheye picture (www.nps.gov/glac/learn/nature/night-sky.htm) shows the Milky Way, the visitor center and the aurora north of Glacier National Park (USA). The Nixnox map made with TAS data displays these lights at the celestial vault and north horizon (natural) and the artificial light at the building.

https://nixnox.ucm.es/

TAS for all-sky brightness maps (Nixnox project)

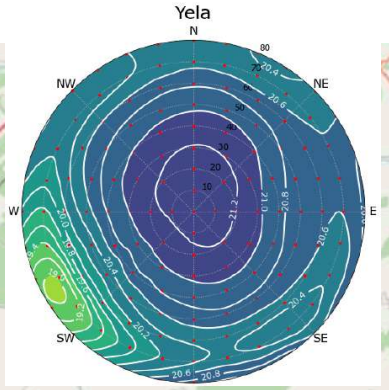


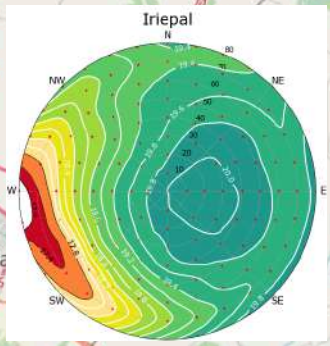


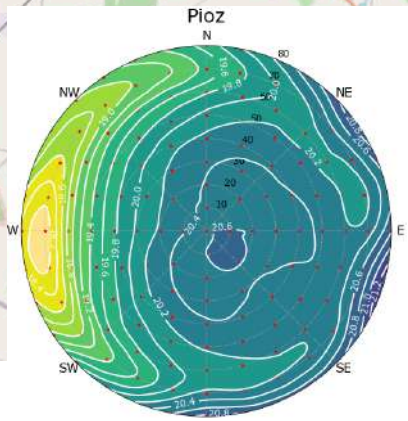
All-sky picture and Nixon map after TAS observation showing Light Pollution from WSW. TAS measurements at red dots in the map.

TAS for all-sky brightness maps (Nixnox project)

NixNox night sky brightness maps show the azimut of the Light Pollution sources.





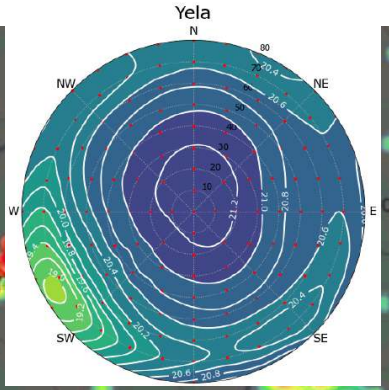


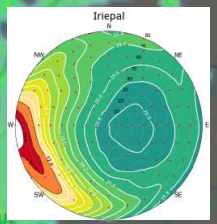
Alcalá de Henares

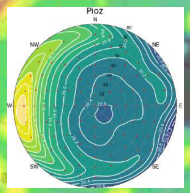
Torrejón

TAS for all-sky brightness maps (Nixnox project)

NixNox night sky brightness maps show the azimut of the Light Pollution sources.







TESS-4C for night sky brightness and color detection

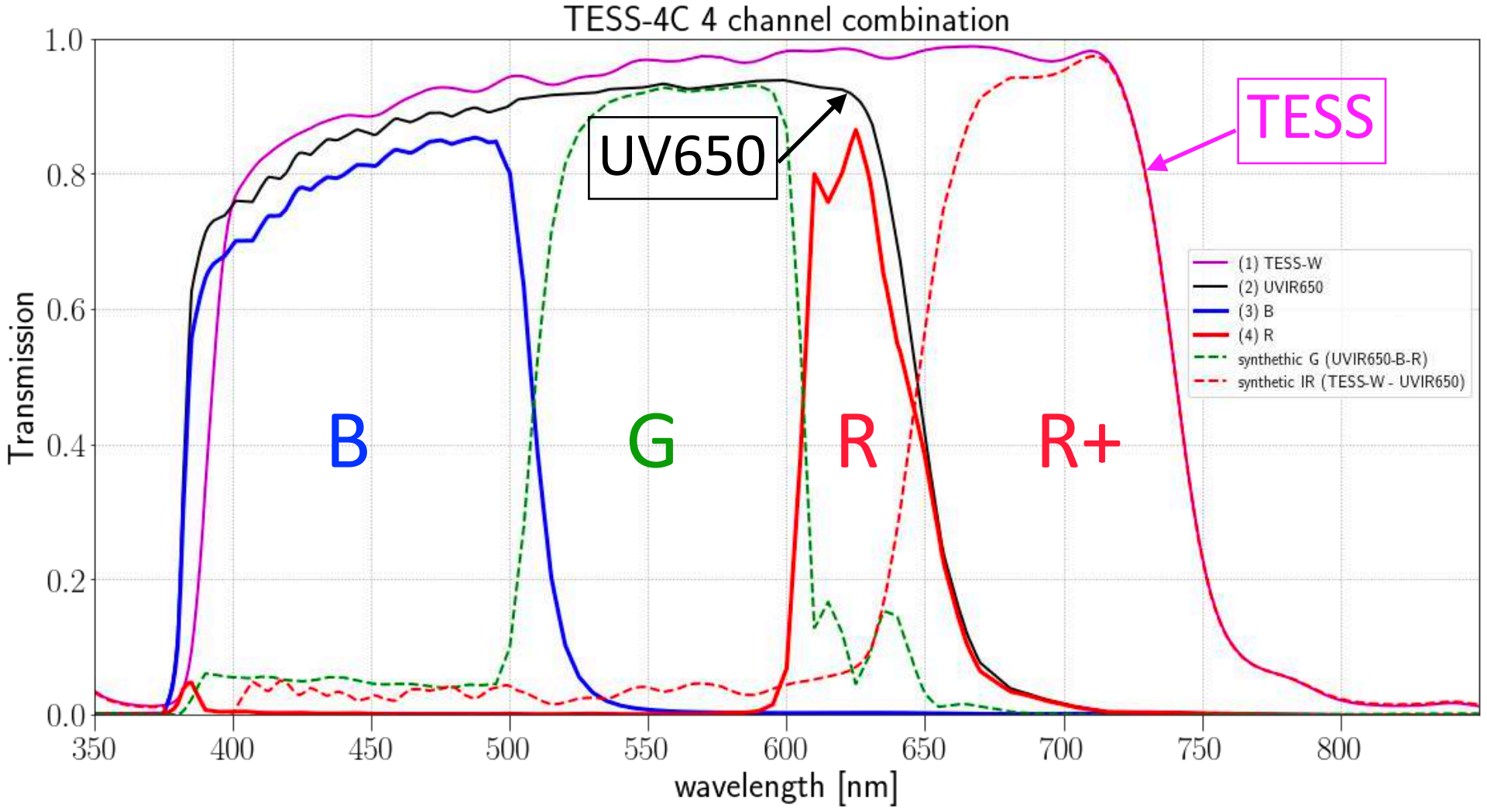
Version 2

Version 1

- Weather resistant to perform monitoring.
- No moving parts.
- 4 channels with interchangeable filters to select the bands.

- Color and brightness detection with a single photometer

TESS-4C for night sky brightness and color detection



- Four channels allow to measure more than 4 bands

TESS-4C for night sky brightness and color detection

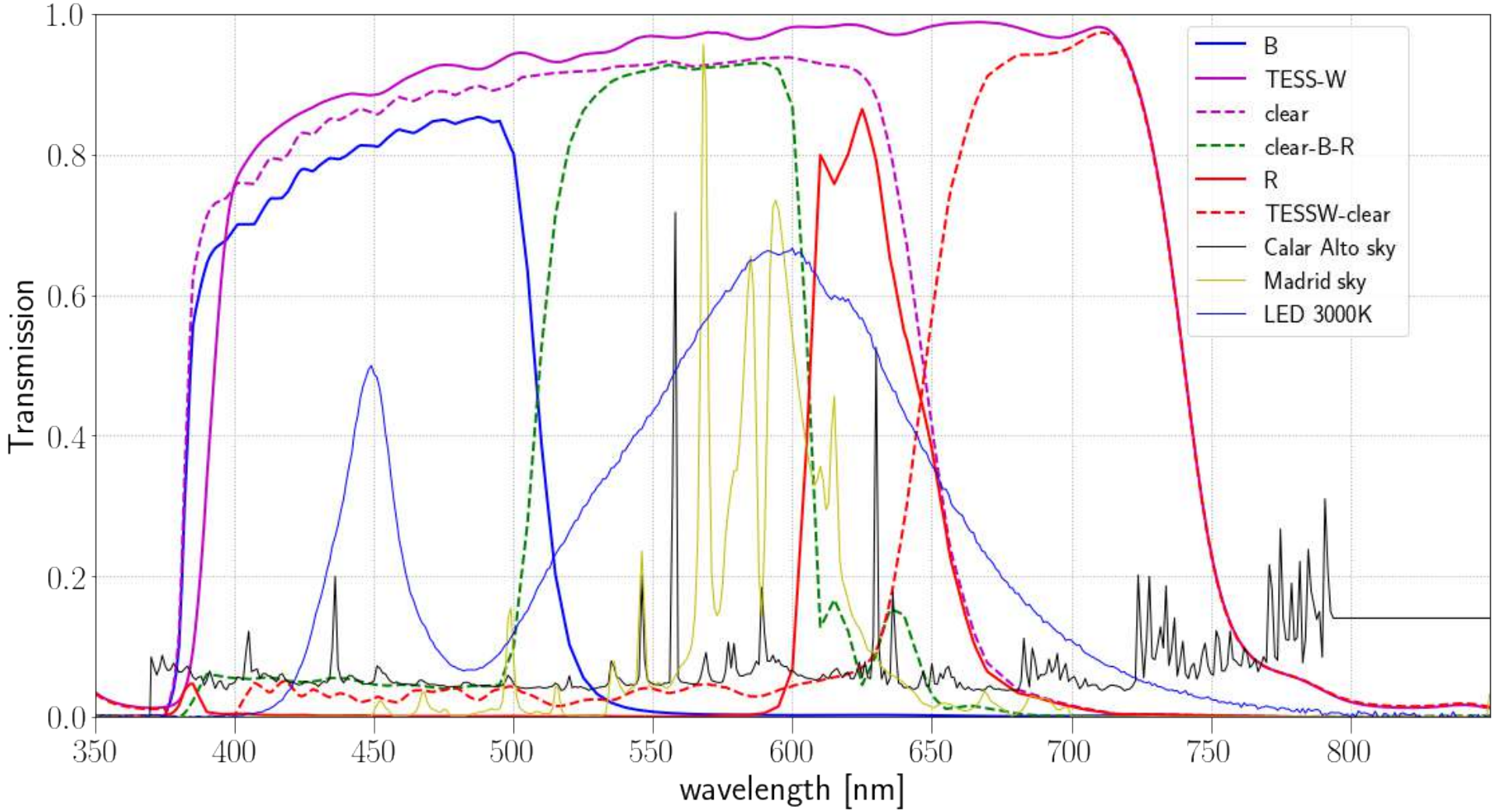


Figure 9. Comparison of the bands and the sky spectrum at Madrid (2014) and at Calar Alto observatory.

TESS-4C for night sky brightness and color detection

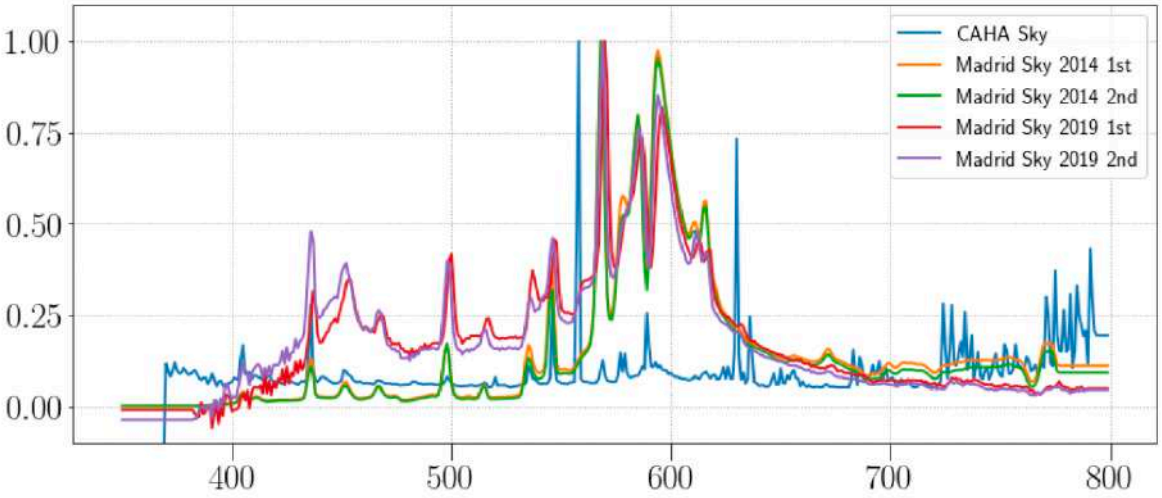


Figure 10. Night sky spectra used for the synthetic photometry. 1st and 2nd refers to the first and the second part of the night respectively.

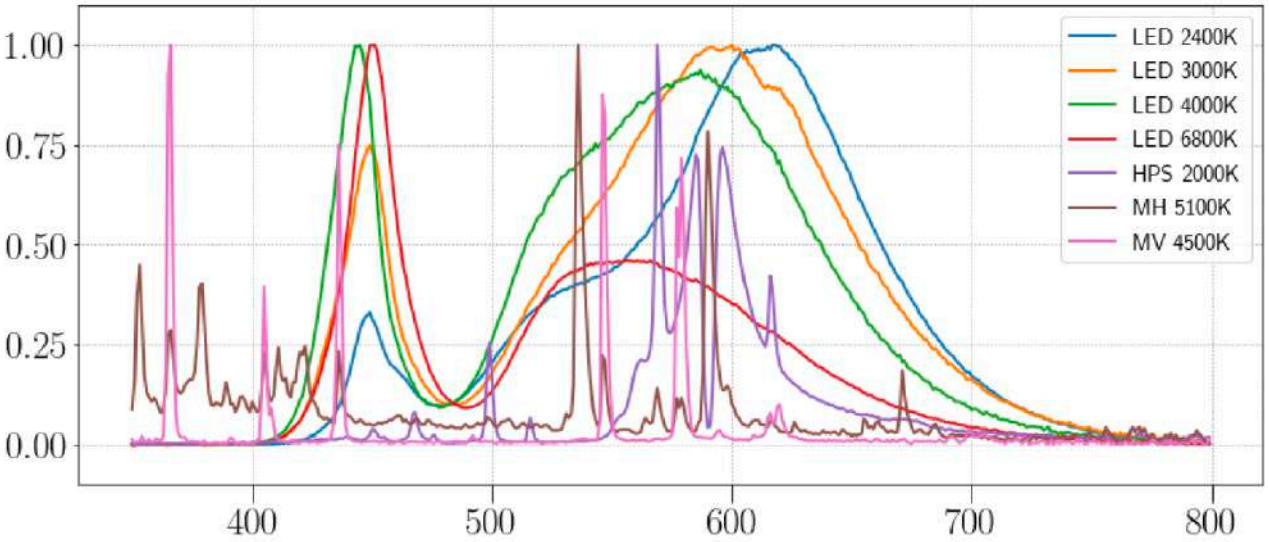


Figure 11. Lamps spectra used for the synthetic photometry.

TESS-4C for night sky brightness and color detection

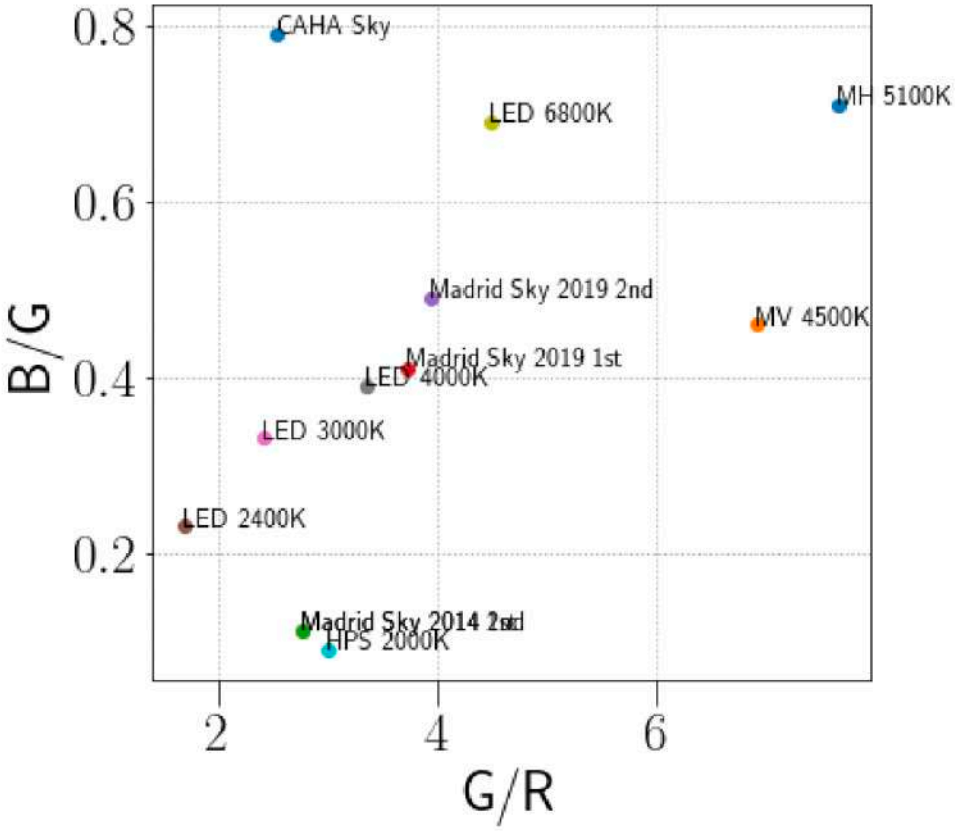
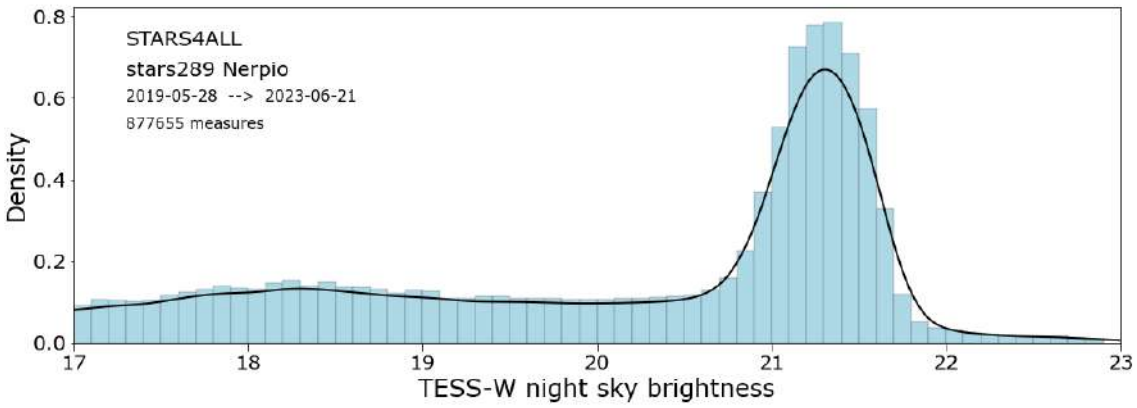
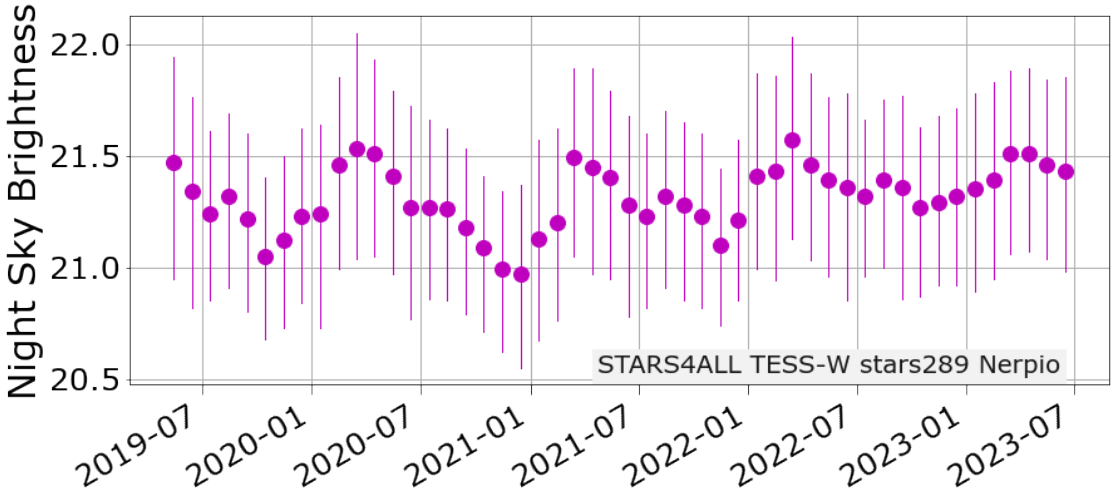


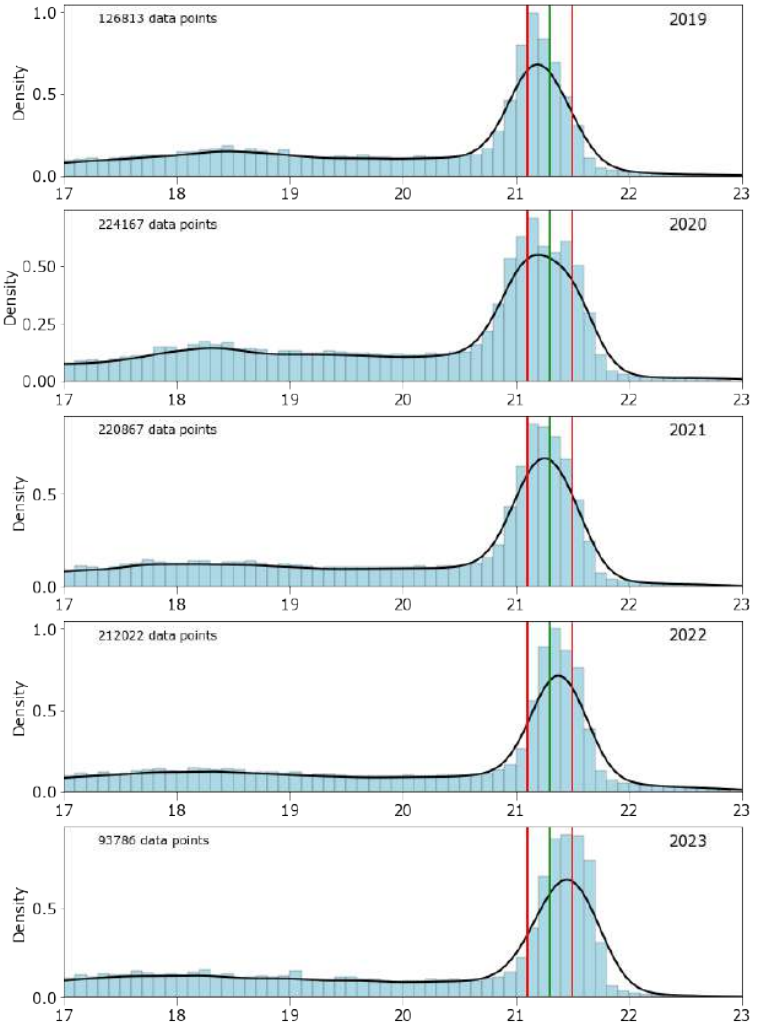
Figure 12. Color-color diagram using the expected output for each channel.

Comparing signal in different bands the color of the night sky can be estimated.
This graph (color-color diagram) shows the expected position for different lamps and selected night skies (Madrid and Calar Alto observatory).
See for instance how the color of Madrid sky has changed with time.

Sky brightness monitoring OPEN SOFTWARE (8)







- Open software to facilitate the analysis and statistics of the Night Sky Brightness series is needed

https://pypi.org/project/tess-ida-tools/
https://github.com/STARS4ALL/TESS-IDA-TOOLS

TESS-IDA-TOOLS is a small pipeline that can be executed as a whole (tess-ida-pipe) or by stages. The stages are:

- tess-ida-get. Download IDA files from published server by some selected criteria.
- tess-ida-ecsv. Converts one or more IDA files to a single, combined ECSV file.
- tess-ida-get --help tess-ida-ecsv —help

Download a single month
Getting a single file

```
tess-ida-get --console single -n stars289 -m 2023-06 -o IDA
```

Download files from photometers near a given location
Downloading files from TESS photometers since last month in a 50 km radius of Madrid, Spain.

```
tess-ida-get --console near -lo -3.703790 -la 40.416775 -ra 50 -o IDA
```

- Open free TESS-IDA-TOOLS software allows you to download and analyze data from archived files in cloud repository.
- IDA monthly files can be converted to '.ecsv' (extended csv files) to facilitate statistics.

From CSV to ECSV

tess-ida-tools 1.1.5

- Tess-ida-tools is using the AstroPy Python Library tables utility to analyze times series data.
- To filter out sky brightness data taken with the Moon of Sun over the horizon we add Moon and Sun data as extra columns to the original files and write them as .ecsv files

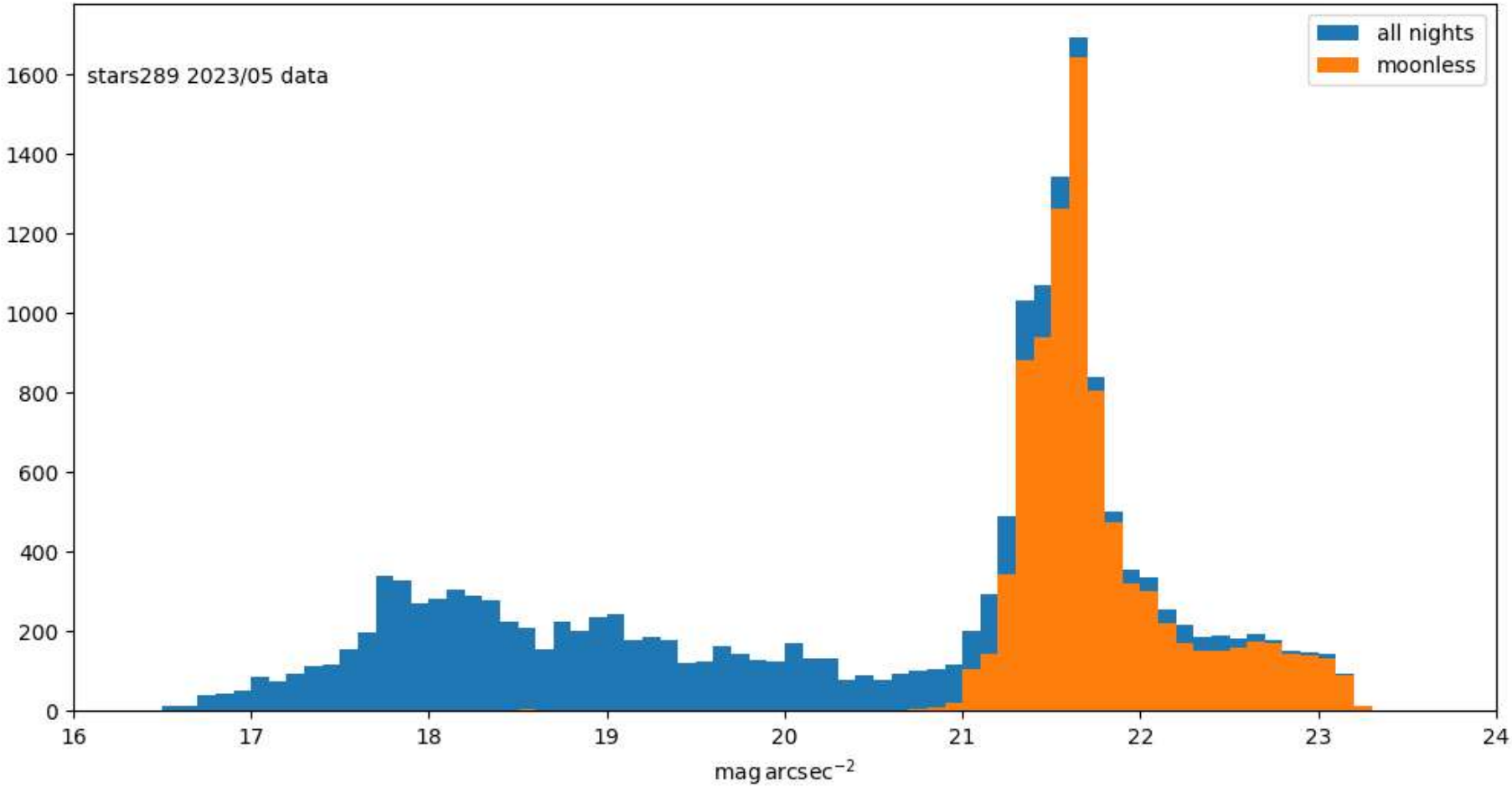
Reading ECSV files

- Using the AstroPy Python Library it is easy to read and analyze times series data.

time	Enclosure Temperature	Sky Temperature	Frequency	MSAS	ZP	Sequence Number	Sun Alt	Moon Alt	Moon Illumination
	deg_C	deg_C	Hz	mag / arcsec2			deg	deg	
Time	float64	float64	float64	float64	float64	int64	float64	float64	float64
2022-03-01T00:00:14.000	0.0	0.0	0.34	21.63	20.45	96365	-59.13	-68.0	0.041
2022-03-01T00:01:14.000	0.0	0.0	0.34	21.64	20.45	96366	-59.16	-68.0	0.041
2022-03-01T00:02:14.000	0.0	0.0	0.34	21.64	20.45	96367	-59.2	-68.0	0.041
2022-03-01T00:03:14.000	0.0	0.0	0.34	21.64	20.45	96368	-59.23	-68.0	0.041
2022-03-01T00:04:14.000	0.0	0.0	0.34	21.64	20.45	96369	-59.26	-68.0	0.041

https://github.com/STARS4ALL/TESS-IDA-TOOLS/blob/main/doc/TESS-IDA-TOOLS-Example.ipynb

Sky brightness monitoring OPEN SOFTWARE



The data can be filtered:

- By Sun altitude (below -18 degrees) —> astronomical night
- By the presence of Moon over the horizon —> moonless

Note that cloudy nights are darker in this low polluted location.