The GOODS NICMOS Survey (GNS) +POWIR/DEEP2

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Motivation: Nearly all massive galaxies are formed by $z \approx 1$ - 1.5

Results from Palomar Observatory Wide-Field Infrared Survey (POWIR) +DEEP2 Redshifts

(Conselice et al. 2007)

Massive galaxies must form at $> 1.5$
Also, there are too many massive galaxies in comparison to models.

Millennium simulation

Prediction for $11 < \log M < 11.5$

Prediction for $\log M > 11.5$

Conselice et al. (2007)

Vast under prediction in models compared to observations
THE GOODS NICMOS SURVEY

180 orbits HST program
NICMOS 3 camera F160W (H) band
Greatest coverage in other bands
60 pointings, 45 arcmin$^2$, > 8000 galaxies in total
Pixel scale 0.1”, PSF ~ 0.3”, Limiting mag. H = 26.8

82 galaxies $\geq 10^{11}M_\odot$ at 1.7 $\leq z \leq$ 3
BzK galaxies (Daddi et al. 2007)
IRAC-selected Extremely Red Objects, IEROs (Yan et al. 2007)
Distant Red Galaxies, DRGs (Papovich et al. 2006)

Can detect log M = 9.5 galaxies to z = 3
To the right is an example of three of our sample of massive galaxies viewed on the left in ACS (rest-frame UV) and on the right in NICMOS (rest-frame optical).

It is clear that many galaxies are visible in the infrared which are invisible in the optical at high z.
Results – Merger Fraction Evolution

This plot shows the redshift evolution of the merger fraction for massive galaxies.

The solid line is a best-fit power law approach:

\[ f(z) = f(0) x (1+z)^\alpha \]

Dotted line is Press-Schectcher power law extended as:

\[ f(z) = f(0)(1+z)^\alpha \exp(\beta(1+z)) \]
Number of Major Mergers

The number of mergers an average massive galaxy will undergo from $z = 3$ to $z = 0$ can be calculated via:

$$N_m = \int_{t_1}^{t_2} \frac{1}{\Gamma(z)} dt = \int_{z_1}^{z_2} \frac{1}{\Gamma(z)} \frac{t_H}{(1 + z)} \frac{dz}{E(z)}$$

For our best fit for $\Gamma(z)$, integrating over the redshift range of our galaxies we obtained:

$$N = 1.7 \pm 0.5$$

(Major mergers / Galaxy)
Size evolution for GNS galaxies

**Disk-like objects**

**Spheroid-like objects**

ALL massive galaxies at z > 2 are compact

Buitrago et al. (2008), ApJ
Galaxy sizes continue to decrease at higher redshifts

Major mergers cannot explain

Buitrago et al.
What is the role of AGN in galaxy formation?

Can investigate with our sample using 508 X-ray selected AGN At 0.4 < z < 6 within the DEEP2/Palomar and GNS fields

Method - find X-ray luminous AGN that are more luminous L_X > 2.35 \times 10^{43} \text{ erg/s} - create volume limited samples

Using X-ray luminosities to calculate the black hole mass

\[ L_E = \frac{4\pi cGM\mu_e}{\sigma_T} = 1.51 \times 10^{38} \frac{M}{M_\odot} \text{ ergs}^{-1} \]

\[ M = \frac{M_E}{\eta} \]
Co-evolution of black hole mass and galaxy mass

If assume that black hole $\eta$ efficiency same at low and high redshift, then black hole mass-galaxy mass relation can only vary by a factor of two.

Bluck et al. (2010)
Can place constraints on time-scales for AGN activity based on $M_{*}$ - $M_{BH}$ relation

\[ \text{Rate} = \frac{\text{time}}{f_{AGN}} \]

Reveals that > 1/4 of Massive galaxies have an AGN > $10^{43}$ erg/s

\[ F_{AGN} = \int_{t_1}^{t_2} \Gamma_{AGN}^{-1}(z) \, dt = \int_{z_1}^{z_2} \Gamma_{AGN}^{-1}(z) \, dz \]

\[ \tau_{max} = \frac{M_{BH}(z = 0) - M_{BH}(z = z')}{\dot{M}} \approx \frac{M_{*}/1000 - M_{E}}{\dot{M}} \]
What drives the evolution of galaxies?

Relation between environment and color at $z < 1$ for a log M > 10.25 sample.
Much stronger relation between color and stellar mass of the galaxy.
Galaxy properties do not strongly depend on the total environment as measured by halo mass of group/cluster.
See at higher redshifts as well for galaxies with $\log M > 9.5$.
Summary

1. Very deep NICMOS/HST imaging to study galaxies at $z > 2$ to connect with galaxies at $z < 1.5$ with POWIR/DEEP2

2. Examination of the major merger history, the AGN history and how environment vs. mass effects the formation of galaxies

3. Massive galaxies become more compact at progressively higher redshifts and over 1/4th of massive galaxies at $z < 3$ have had an AGN. Galaxy stellar mass most important property for understanding galaxy formation