Mergers, AGN, and the Evolution of Galaxies

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Bimodal Galaxy Distribution

- Hubble Sequence - morphology shows dynamically distinct populations
- Gas content/integrated colors - different ages and star formation histories
Downsizing of Star Formation

The sites of star formation appear to shift from including high-mass galaxies at early epochs (z~1-2) to only lower-mass galaxies at later epochs.

Top-Down Formation of Ellipticals

The most massive galaxies transform into ellipticals first, with less massive galaxies following later.
Downsizing of Star Formation

The sites of star formation appear to shift from including high-mass galaxies at early epochs (z~1-2) to only lower-mass galaxies at later epochs. The most massive galaxies transform into ellipticals first, with less massive galaxies following later.

Juneau et al. 2005
Downsizing: Red Growth

Increasing abundance

\( z \approx 1.2 \)

\((U-B) > 0.2, \text{ Red}\)

Bundy et al. 2006
Downsizing: Red Growth

Increasing abundance

Bundy et al. 2006
Downsizing: Red Growth

Morphological spheroidals have a similar formation pattern.

(Bundy et al. 2005)

Bundy et al. 2006
Star formation
Quenching (gas)

Major Merger

Quasar

Radio Mode
AGN
Feedback

Spheroidal Formation (morphology)

Major Merger

N-body Simulation

Prevent cold disk formation
Merger Simulations
Trigger

Mechanism

Maintenance

Threshold Halo Mass, $\sim 10^{12} \, M_\odot$

Star formation
Quenching
Quenching even at low densities

Environment - ram pressure, strangulation?

Quasar

Radio Mode AGN Feedback

Major Merger

Prevent cold disk formation

Spheroidal Formation (morphology)

Major Merger

N-body Simulation

How to build S0 bulges?

Environment - S0 formation?
Trigger

Star formation (gas)
Quenching

Mechanism
Major Merger
Quasar

Maintenance
Radio Mode AGN Feedback

Spheroidal Formation (morphology)

Prevent cold disk formation

N-body Simulation

1.

2.
Quenching and AGN (Quasar) Feedback

Does the frequency of AGN activity match the rate of quenching?
AGN Frequency vs. Quenching Rate


AEGIS: DEEP2 + Palomar + Chandra

- Chandra: 200 ks in EGS, 0.5-10 keV
- 241 X-ray selected AGN hosts, $L_{\text{X-ray}} > 10^{42}$ erg/s
- ~50% more could be X-ray absorbed.
- Stellar masses and colors mostly unaffected by AGN
AGN Host Mass Function

Number Density

Log \( \frac{dN}{dM} \left[ \text{Mpc}^{-3} \cdot \text{dex}^{-1} \right] \)

Log \( M_{\ast}h_{70}^{-2}/M_\odot \)

Host Stellar Mass

\( z \sim 0.6 \)

\( 0.40 < z < 0.70 \)

\( 0.75 < z < 1.00 \)

\( 1.00 < z < 1.40 \)

\( z \sim 1.2 \)
AGN Host Mass Function

Number Density vs. Host Stellar Mass

AGN Hosts
AGN Host Mass Function

AGN Hosts

trigger rate = \frac{\text{no. density}}{\text{timescale}}

Bundy et al. 2008
Quenching Rate
Quenching Rate

Red Fraction
Quenching Rate

Red Fraction

Cosmic Age (Gyr)

Lowest $M_*$
- Log $M_*$ $\sim$ 10.5
- Log $M_*$ $\sim$ 10.8
- Log $M_*$ $\sim$ 11.1
- Log $M_*$ $\sim$ 11.4
- Log $M_*$ $\sim$ 11.7

Highest $M_*$
Quenching Rate

Cosmic Age (Gyr)

Log M* ~ 10.5
Log M* ~ 10.8
Log M* ~ 11.1
Log M* ~ 11.4
Log M* ~ 11.7

Bundy et al. 2008
Quenching vs. AGN Triggering

$0.40 < z < 0.70$

- $\tau = 0.6$ Gyr, Hopkins
- $\tau = 0.9$ Gyr, Marconi

$0.75 < z < 1.00$

Effect of $\epsilon \sim 0.7$
Quenching and AGN (Quasar) Feedback

- Does the frequency of AGN activity match the rate of quenching?
  Yes

- Do AGNs live in quenched or at least quenching galaxies?

Nandra et al. 2006
Accretion Efficiency

Also see Silverman et al. 2008

Bundy et al. 2008
Alison Coil’s DEEP2 Clustering Measurements

Quasars cluster like blue galaxies, X-ray AGN like red ones.

Coil et al. 2007

Coil et al., in prep
Also see Georgakakis et al. 2008.
Quenching and AGN (Quasar) Feedback

- Does the frequency of AGN activity match the rate of quenching? Yes

- Do AGNs live in quenched or at least quenching galaxies? Not always…

- Is this physics correct? Probably not…

AGN activity is associated with quenching, but probably not the cause.

Stellar winds, outflows, starbursts are observed (Crystal Martin’s work, Weiner et al. 2008, Erb 2008) and likely can do the job (e.g., Murray et al. 2005).
2. Trigger

Mechanism: Threshold Halo Mass, $\sim 10^{12} \, M_\odot$

Maintenance:
- Major Merger
- AGN?
- Starburst
- Radio Mode AGN Feedback
- Prevent cold disk formation

Star formation
Quenching
(gas)

Spheroidal Formation
(morphology)

N-body Simulation

Major Merger
Are there enough mergers to make spheroidal galaxies?

Merger Rate?
Lin et al. 2004, 2008 (DEEP2); de Ravel et al. 2008 (VVDS), Kartaltepe et al. 2007 (COSMOS), Bell et al. 2006 (COMBO17), Lotz et al. 2007 (morph.), Patton & Atfield 2008 (SDSS)

Challenges

- Must distinguish major mergers.
- Must probe the mass dependence.
- Need complete, mass-limited samples.
Observed Near-IR Galaxy Merger Rate

Subaru K-22 Observations in GOODS-N + ISAAC in GOODS-S

Bundy, Fukugita, Targett, Ellis, Belli, Kodama
Method 2:

**Observed Near-IR Galaxy Merger Rate**

Subaru K~22 Observations in GOODS-N + ISAAC in GOODS-S

Bundy, Fukugita, Targett, Ellis, Belli, Kodama
Observations

- MOIRCS K~22 (Vega), 0.5", GOODS N+S, 0.08 deg²
- K Catalog (17155 sources) matched to ACS data and spec-z surveys.
- ~3000 hosts (60% spec-z), M*>10^{10}M_⊙, 0.4 < z < 1.4
- Additional GOODS-S photo-zs from Grazian et al. 2006 (dz/1+z ~ 0.03). BPZ in GOODS-N (dz/1+z ~ 0.09).

Iichi Tanaka and MOIRCS
Pair Fraction

Count the fraction of galaxies with a fainter companion.

Companion Criteria:

• $5 < r_{\text{sep}} < 20$ kpc

• no fainter than $K_{\text{host}} + 1.5$, ensures major mergers defined as $M_{\text{comp}}/M_{\text{host}} > 1/4$
Contamination Correction

Correction 1:
Subtract background number density.

Correction 2:
Use redshift information, \( \Delta z^2 < \sigma_{\text{host}}^2 + \sigma_{\text{comp}}^2 \).

Then randomize the x,y positions 100 times, subtract the average remainder.
Mass Dependent Pair Fraction

![Graph showing pair fraction vs. redshift for different mass ranges.]

- Log $M^* \sim 11.3$
- Log $M^* \sim 10.3$

Background field correction

Redshift pair correction.
Mass Dependent Pair Fraction

Log $M^*$ $\sim$ 11.3

Log $M^*$ $\sim$ 10.3

Lin et al. 2008

Background field correction

Redshift pair correction.
Mass Dependent Pair Fraction

Background field correction

\[ \log M^* \approx 11.3 \]

\[ \log M^* \approx 10.3 \]

Lotz et al. 2008

Redshift pair correction.

Clustering Prediction \( \triangle \)
Deriving the Merger Rate

Merger efficiency and timescale.

Kitzbichler & White 2007. Find $\tau$ decreases as $M^* - 0.3$

Patton & Atfield 2008. $\tau = 0.5$ Gyr, less efficient at high $M^*$

We use our sample to determine volumetric merger rate.
Volumetric Merger Rate Density, Gyr$^{-1}$ Mpc$^{-3}$

\[0.40 < z < 0.70\]

\[0.70 < z < 0.90\]

\[0.90 < z < 1.40\]
Volumetric Merger Rate

Log Merger Rate Density, Gyr$^{-1}$ Mpc$^{-3}$

0.40 < z < 0.70

0.70 < z < 0.90

0.90 < z < 1.40

Too few mergers!
Elliptical Fraction in semi-analytic models

Data points from SDSS
Benson et al. 2007

Spirals
Ellipticals
S0s

Points: Benson et al, 2007
Dashed: MPA Model
Solid: Durham Model

Parry et al. 2008
Mergers vs. quenching and AGN

0.40 < z < 0.70

- \( \tau = 0.6 \text{ Gyr}, \) Hopkins
- \( \tau = 0.9 \text{ Gyr}, \) Marconi
- \( \tau = 1.8 \text{ Gyr}, \) Granato

0.75 < z < 1.00

Effect of \( \epsilon \approx 0.7 \)

Major Mergers
Trigger

- Star formation
- Quenching (gas)

Mechanism

- Threshold Halo Mass, \(~10^{12} M_\odot\)
- Major Merger
- AGN?
- Starburst (winds, outflows)

Maintenance

- Radio Mode AGN Feedback
- Prevent cold disk formation
- Size growth??

Other

- Spheroidal Formation (morphology)
- Bombardment?
- Disk Instability
- Pseudobulges?
Summary and Conclusions

- AGNs seem to be associated with quenching but are not the cause… Stellar feedback instead?
- There are too few major mergers to understand morphological evolution, quenching, or AGN triggering.
- New triggers are needed: disk instabilities, minor mergers, bombardment…??