Compact Red Galaxies at z = 2..

Ay 211, 10/16/2009
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.. and today?

van Dokkum 2008, Kriek 2006
Observing galaxies @ z= 2-3

- Surface brightness dimming
- To compare to optical morphology, need NIR observations
- Angular size comparable to PSF of Hubble
- Stellar mass estimates from spectral synthesis modeling
  - Degeneracies between age and mass
  - Depends on template (e.g. Bruzual & Charlot, Maraston)
van Dokkum et al 2008

- 9 objects, $2 < z < 2.7$
- NICMOS + GNIRS spectra
- $M > 10^{11} \, M_\odot$
- $0.5 < R_e < 2.4 \, \text{kpc}$
- 5 times smaller than local SDSS with same mass
van Dokkum et al 2008

- 180 x local density inside effective radius
- Conclusion: 100 (-11)% of massive galaxies @z>2 compact
Buitrago et al 2008

NICMOS H-band, 82 objects with $1.7 < z < 3$, $M > 10^{11} \, M_\odot$

Ellipticals
- $R_e \sim 1$ kpc at $z \sim 2.3$
- 4.3 x smaller than local

Spirals
- $R_e \sim 2$ kpc at $z \sim 2.3$
- 2.6 x smaller than local
Cappellari et al. 2009

- 9 objects, 1.4 < z < 2
- 202 h VLT spectra
- Different mass estimates
  - Virial
  - Dynamical
  - Stellar populations
    Agree within factor 2

Confirm galaxies are massive, more dense than local counterpart
Damjanov et al 2009

NICMOS GDDS, 19 objects with $1.2 < z < 2$, $z_f \sim 4$
Damjanov et al 2009

Galaxies of comparable mass 3x smaller at $z = 1.5$
Can’t explain normalization of Kormendy relation ($z_f \sim 4$)
Observations: Summary

• Compact massive galaxies observed by many groups, using different instruments and techniques
• Number density $\sim 2 \times 10^{-5} \text{ Mpc}^{-3}$ at $z \sim 2$, locally $3 \times 10^{-8}$
• Need $\sim 5$ x increase in radius since $z \sim 2.5$ to evolve into local counterparts

Forming them is easy: early formation time + gas rich progenitor lead to compact star formation (e.g. Cox 2006)
Local Counterparts?

At fixed mass more compact ellipticals older (van der Wel 09)
Physical (not effective) surface density of $z > 2$ objects
similar to cores of local ellipticals (Bezanson 09, Hopkins 09)
Evolution: possible processes

• (Adiabatic) expansion caused by feedback
• Dry mergers
  – Equal mass \( \frac{r_{i+2}}{r_i} \approx \frac{M_{i+2}}{M_i} \)
  – Minor mergers (Khochfar & Silk 2006, Naab 2009)
    larger progenitor survives, builds up extended envelope

Hopkins 2009, Bezanson 2009
Evolution: possible processes

- Evolution mainly through major mergers produces too many massive galaxies today.
- Evolution mainly through expansion implies only no mass growth since $z \sim 2$; compact red galaxies evolve into $\sim 7\%$ of today’s massive galaxies. What about the progenitors of the other 90%?
- Observed (minor) merger rate too small for account for everything (?)
- Probably a bit of everything + observational effects
Minor mergers + a bit of everything, in a cosmological context

Populate merger tree of early forming spheroid with hydrodynamic simulations and “observe” (Hopkins 2009, also Naab 2009)

Probably not yet the full story, but rapid progress