Galaxies and Clusters
Across Cosmic Time
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The universe turned up to 11
Abell 2744 and lensing model
Reionization

- Quasar GP (e.g. SDSS 2001) ends, $z \sim 6$  
  ($z= 5.5-7$ Becker+2015)
- Planck+ : starts, $z \sim 11$ (Planck 2013)
- 21-cm work (theory and experiment) in progress (SKA)
Black Hole Spin in AGN
AGN Spin

NuStar+XMM

Risalti+2013 Nature

SMBH NGC1365
SF through cosmic time
Abundance matching and SF history

Why does the stellar mass fraction peak at $M_{\text{halo}} \sim 10^{12}$ solar?

Why does the SFR peak at $z=2$ then plummet?

Behroozi, Wechsler, Conroy 2013ab; consistent with other abundance-matching efforts (e.g. Moster+2010,2013,Reddick+2012)
SF efficiency peaks at $M_h \sim 10^{12}$ solar masses independent of redshift ($z<4$)
Stellar and AGN Feedback: Simulations
ΛCDM + Gravity + Hydro + Cooling: not done yet...
WHY IS STAR FORMATION SO INEFFICIENT?

Predicted
\[ \dot{M}_* \approx \frac{M_{\text{gas}}}{\tau_{\text{dyn}}} \]

Observed
\[ \dot{M}_* \approx 0.017 M_{\text{gas}}/\tau_{\text{dyn}} \]

Kennicutt 1998

Elmegreen 77, Larson 81, & many since

No Feedback

Observed

Rees 77, Dekel & Silk 87, & many since
State of the Art Today
STAR FORMATION & GALAXY FORMATION TOGETHER AT LAST

FIRE: Feedback in Realistic Environments

- High-resolution (~pc),
  molecular/metal cooling (~10 K),
  SF at $n_H > 1000 \text{ cm}^{-3}$

- Energy/Mass/Metals:
  - SNe (II & Ia)
  - Stellar Winds (O & AGB)
  - Photoionization (HII)
  - Photo-electric
  - Radiation Pressure (IR & UV)
  - Cosmic Rays

- all with…
  - Magnetic fields
  - Cooling, chemistry
  - Conduction, viscosity, etc.

230 Myr
Gas

1 kpc

e.g. Hopkins+ 10, Agertz+ 13, Wadsley+ 14
Low-mass galaxies are regulated by stellar feedback. Stellar feedback alone fails to regulate SF in massive galaxies.
AGN in clusters and galaxies
Nature’s version

“That’s all well and good but I don’t see that in my simulations.”
- Anonymous

$M_{\text{gas}} \sim 10^{12} M_{\odot}$

13.7 Gyr

but star formation rate $<< 10^2 M_{\odot} \text{yr}^{-1}$
AGN balance radiative cooling in clusters
PDS 456 Quasar winds

Nardini+2015 Science
$10^{12}$ solar mass halo with a former AGN?
BCGs, AGN, and star formation

CLASH clusters
AGN feedback is fueled by CGM

*Multiphase threshold in the CGM*
Voit+ 08, Cavagnolo+ 08, Rafferty+ 08

Core Entropy Index = \( K_0 = kTn_e^{-2/3} \)
Star Formation in BCGs

Donahue et al. 2015

Simulated precipitation around AGN in a BCG, 50x50 kpc

Li et al. 2014

CLASH rest-frame UV 50x50 kpc
Two Kinds of Massive Ellipticals
Werner+ 12, Werner+ 14

Single-Phase
NCG 1399

Multiphase
NGC 5044

30 kpc
Quenching of Ellipticals

Voit+ 15 (ApJL)

Single-phase ellipticals: Supernova sweeping at > 1 kpc
Multiphase ellipticals: Precipitation-driven feedback at > 1 kpc
NCG 4261: 100x Bondi power boost from chaotic cold accretion
AGN Feedback Landscape

- AGN feedback is required to explain properties of massive systems.

- AGN feedback affects stellar fractions, metallicity, and the CGM/ICM scaling relations: cosmological models are still working on this.

- The mode of AGN feedback affects the answer: “thermal” feedback differs from “jets”.

AGN Feedback Landscape