Galaxies and Clusters Across Cosmic Time

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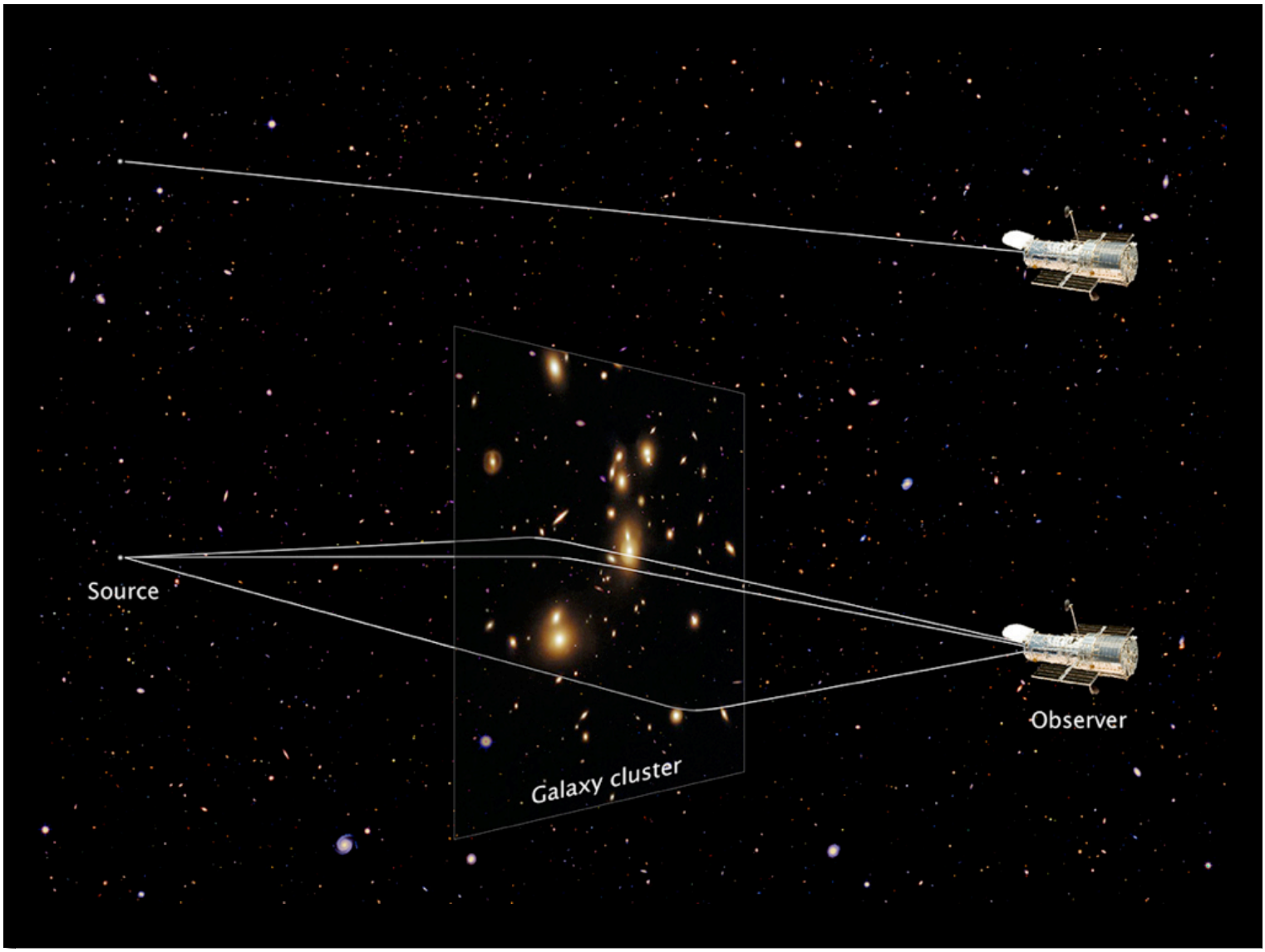
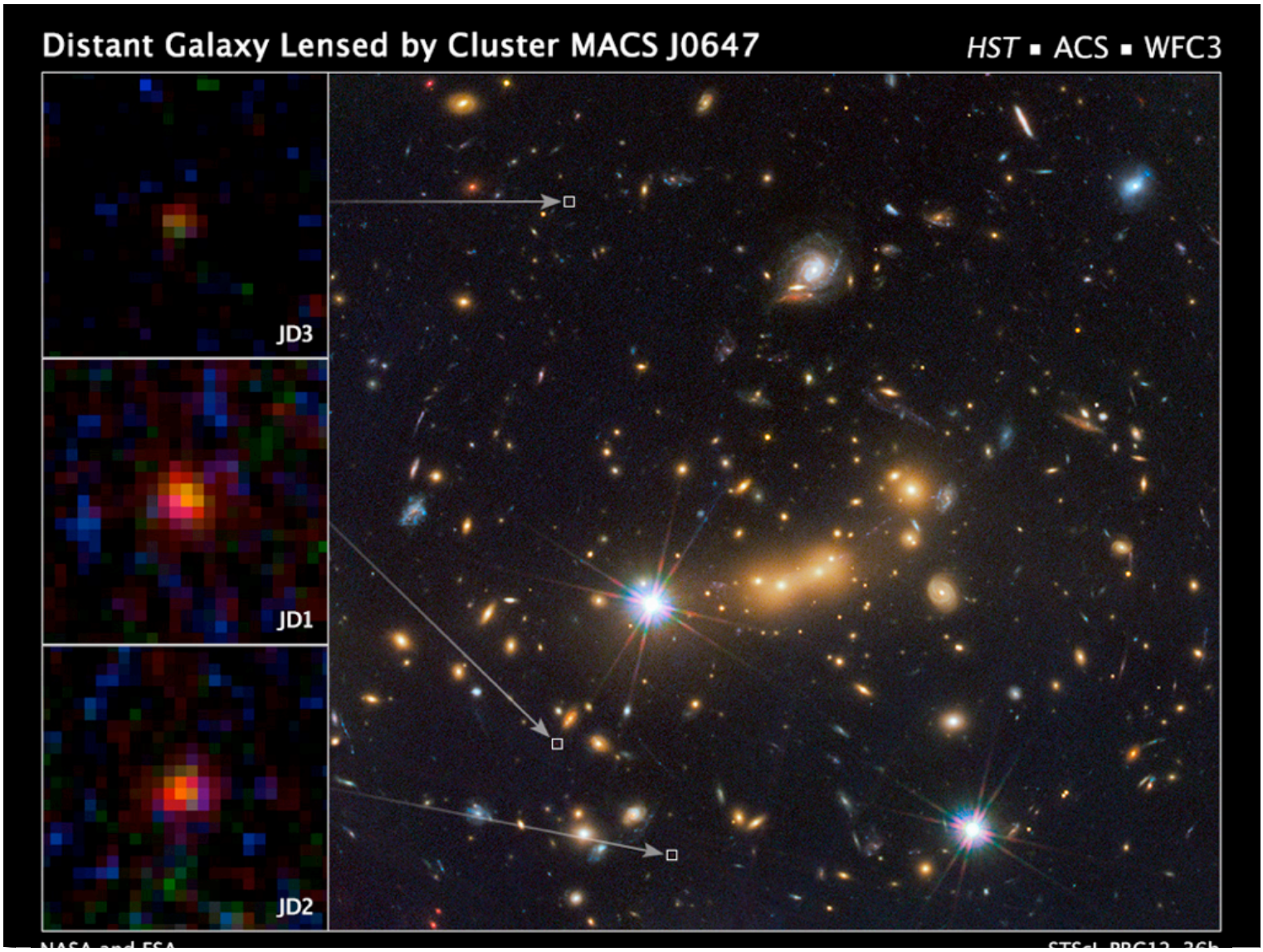
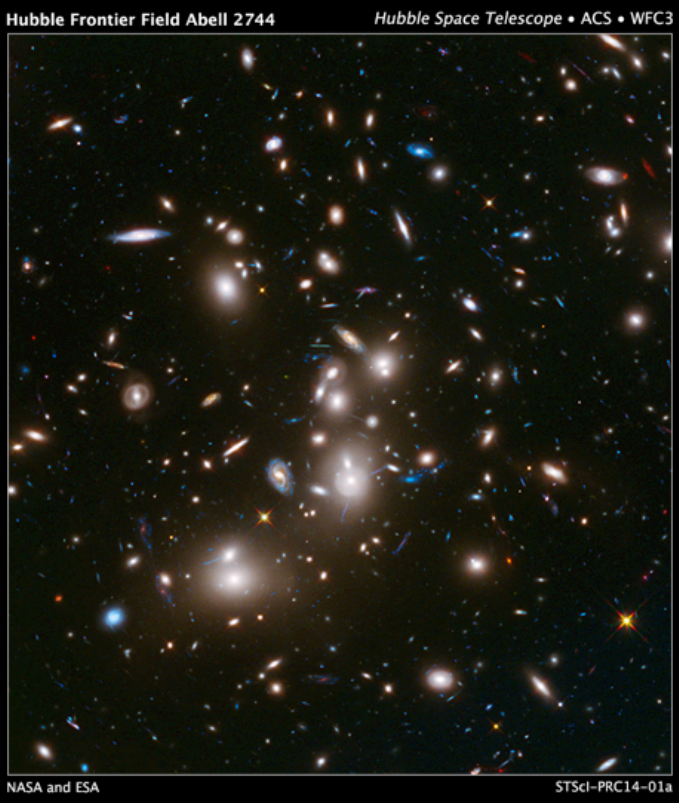
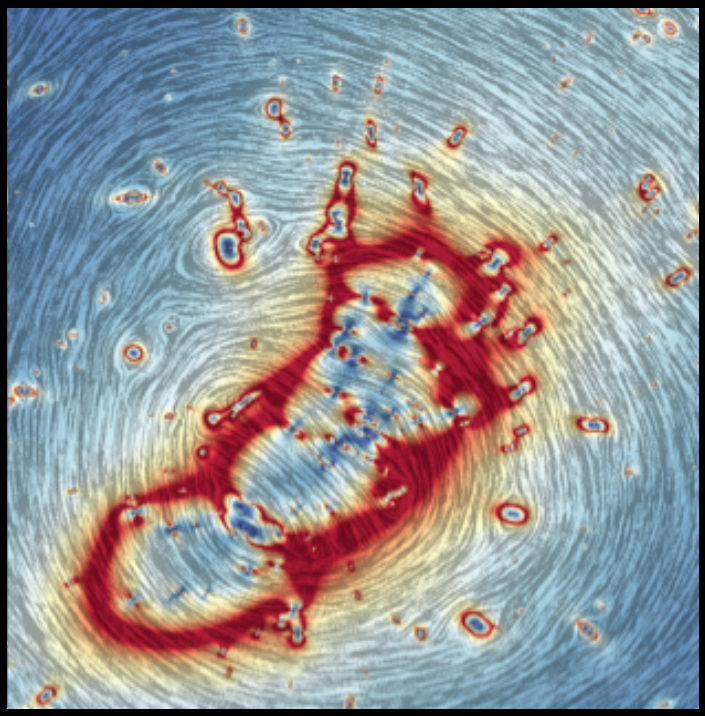
The universe turned up to 11


Source
Galaxy cluster
Observer


Distant Galaxy Lensed by Cluster MACS J0647
HST ▪ ACS ▪ WFC3
JD3
JD1
JD2

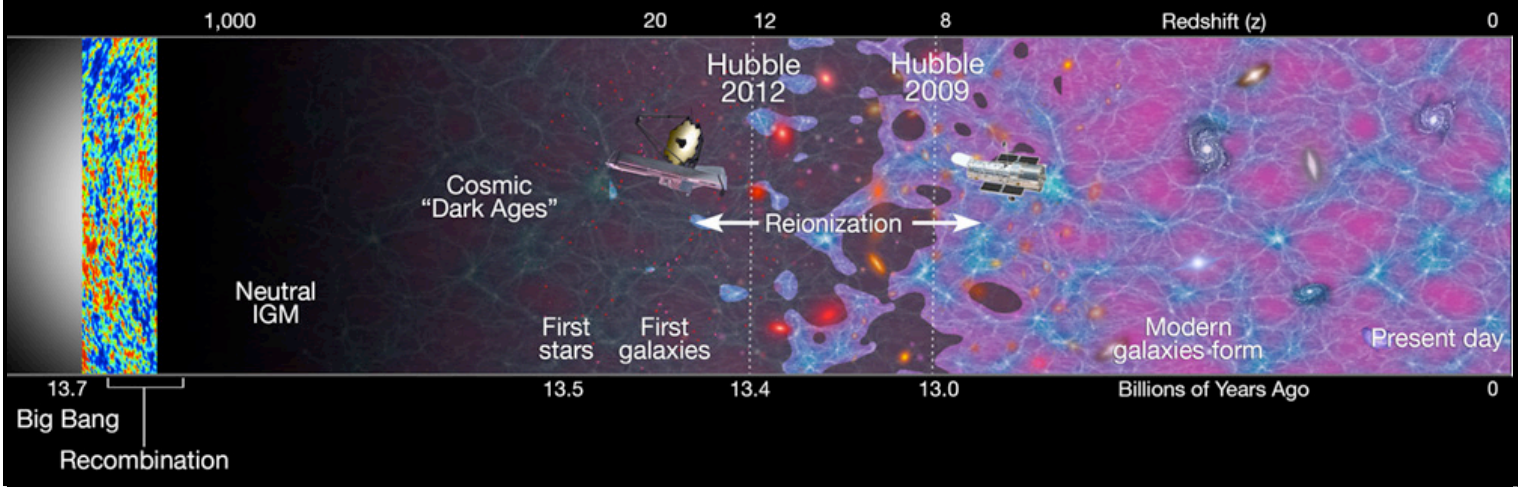




Abell 2744 and lensing model

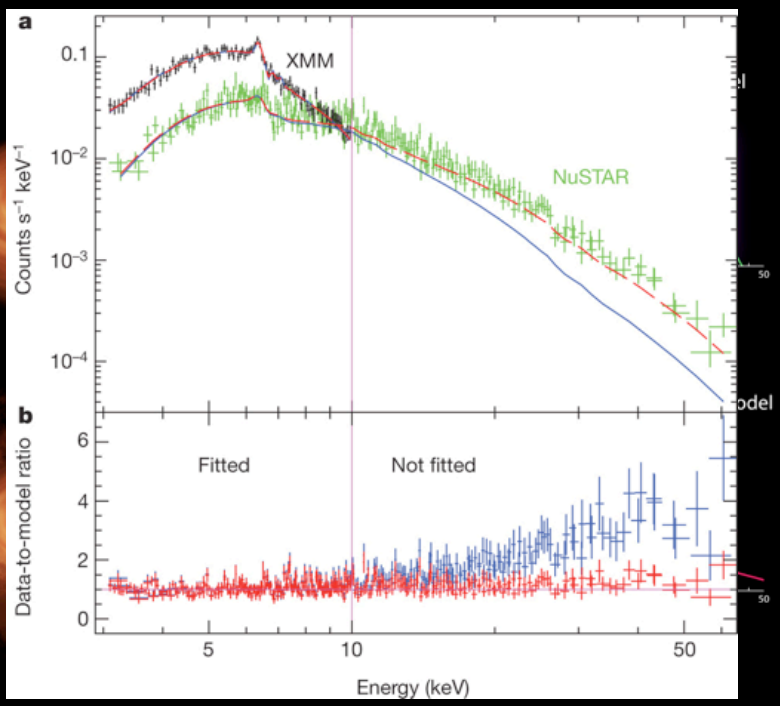
Reionization

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



Black Hole Spin in AGN

AGN Spin



NuStar+XMM

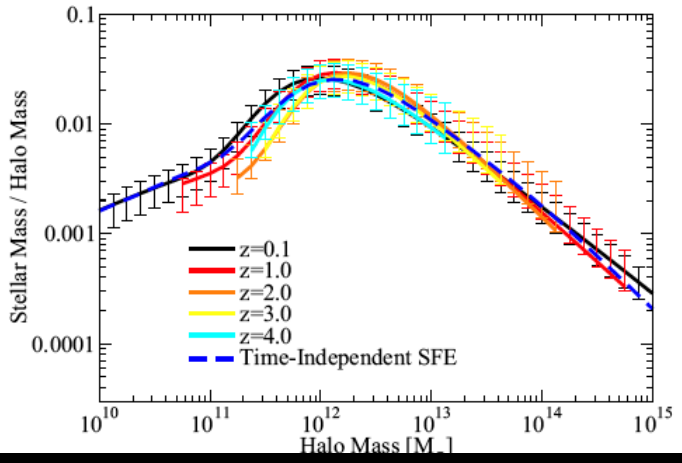
Risalti+2013 Nature

SMBH NGC1365

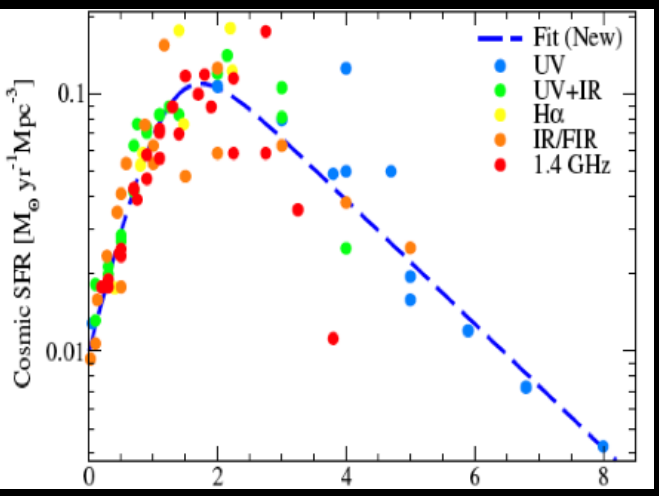
SF through cosmic time

Abundance matching and SF history

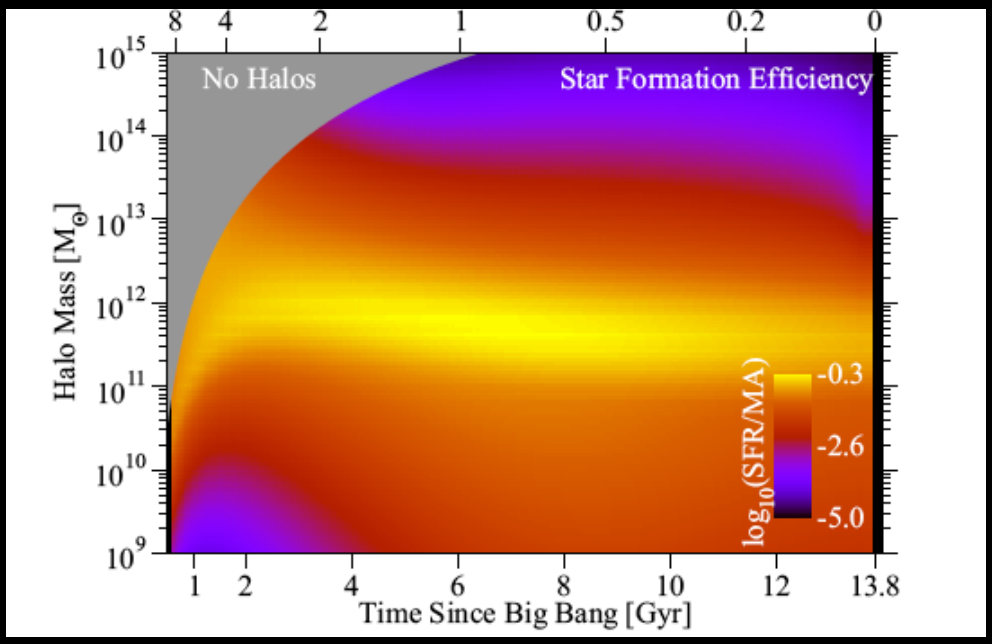
Why does the stellar mass fraction peak at $M_{halo} \sim 10^{12}$ solar?



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)



Color: SFR/mass accretion rate

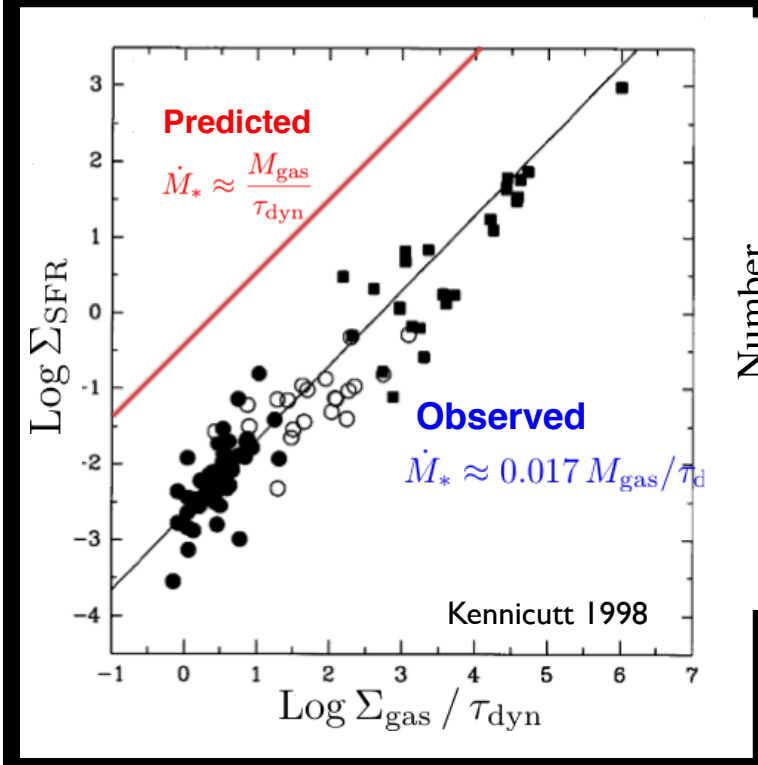
Behroozi+2013a

SF efficiency peaks at $M_h \sim 10^{12}$ solar masses independent of redshift ($z<4$)

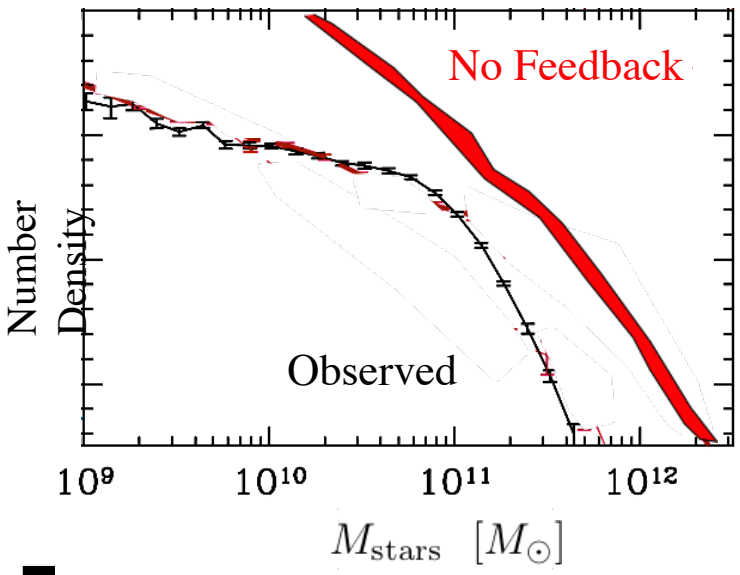
Stellar and AGN Feedback: Simulations

ΛCDM + Gravity + Hydro + Cooling: not done yet...

WHY IS STAR FORMATION SO INEFFICIENT?



Elmegreen 77, Larson 81,
& many since



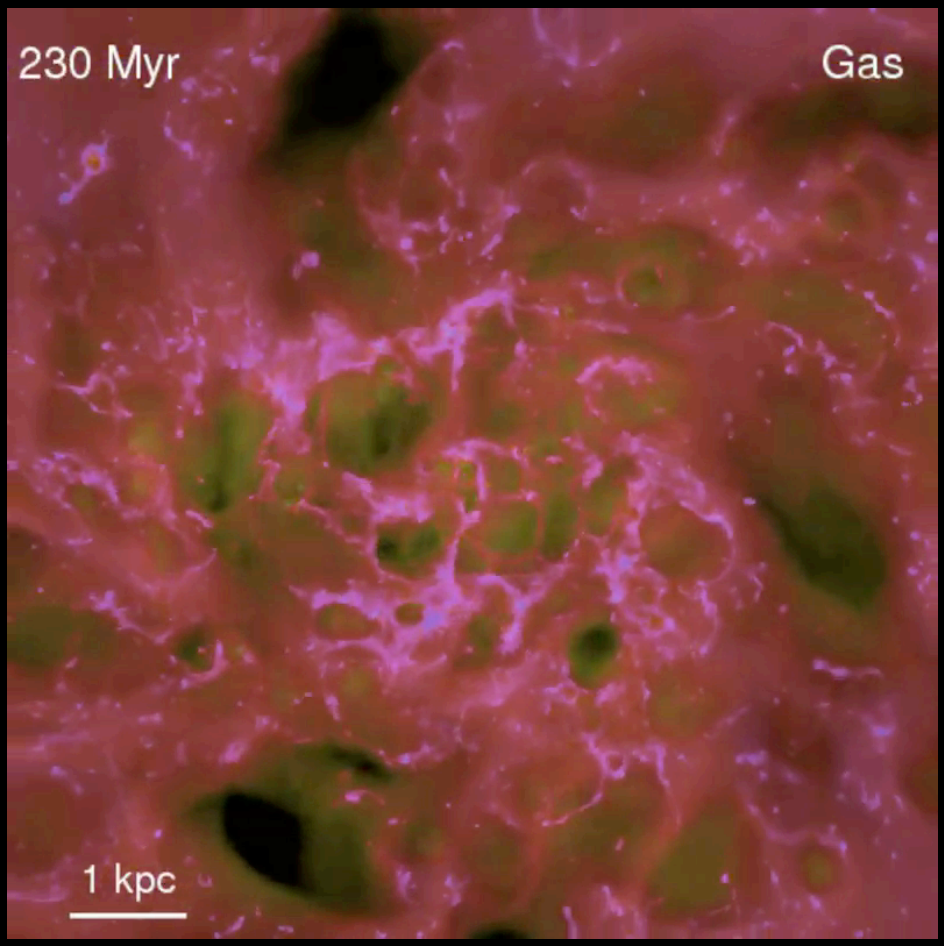
Rees 77, Dekel & Silk 87,
& many since

State of the Art Today

STAR FORMATION & GALAXY FORMATION TOGETHER AT LAST

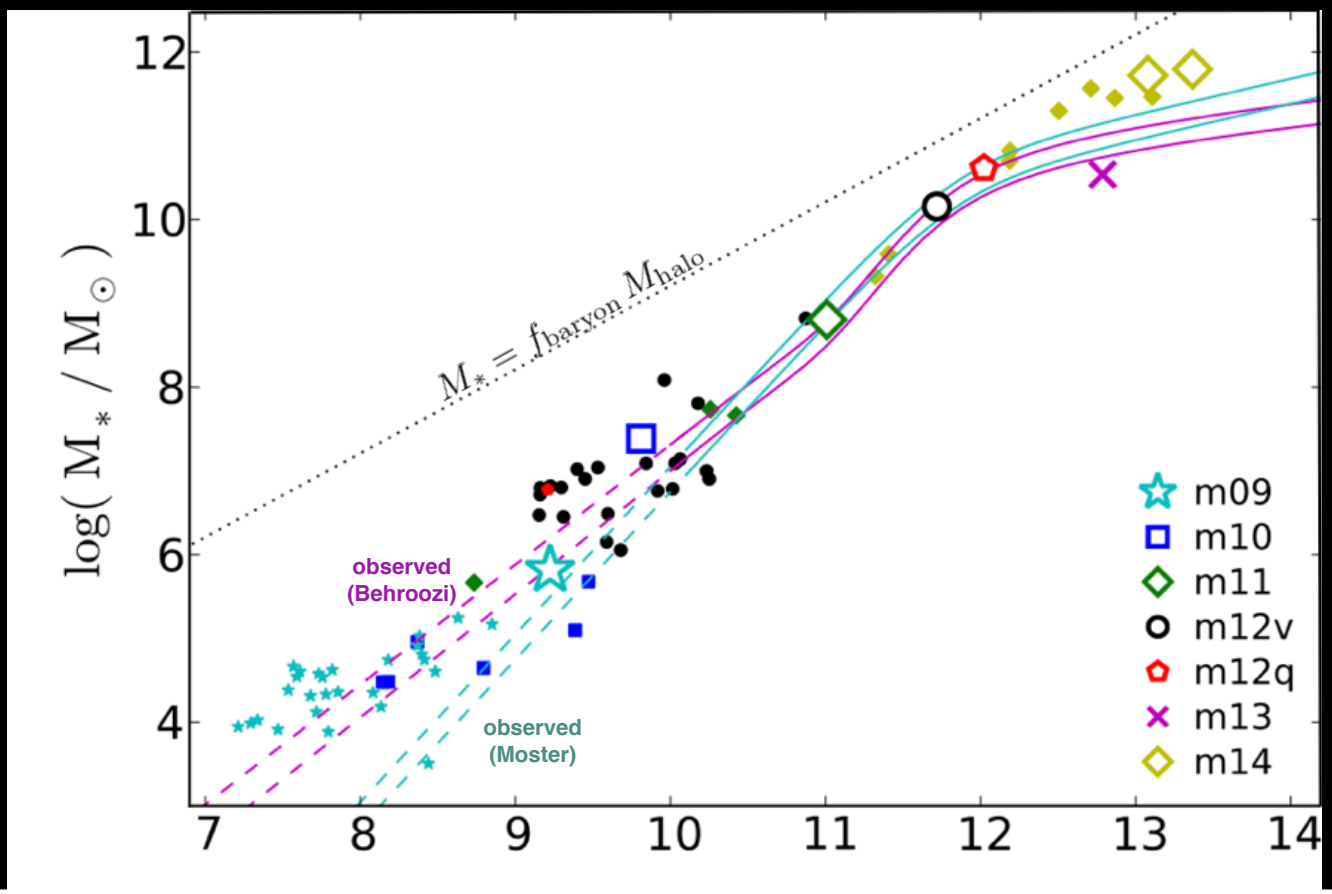
FIRE: Feedback in Realistic Environments

- High-resolution (~pc), molecular/metal cooling (~10 K), SF at $n_H > 1000$ 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.



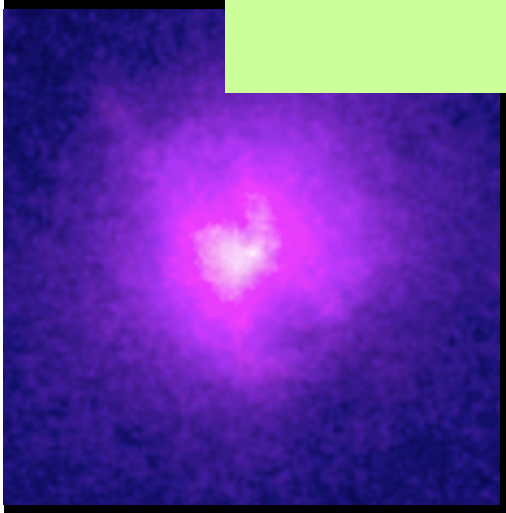
e.g. Hopkins+ 10, Agertz+ 13, Wadsley+ 14

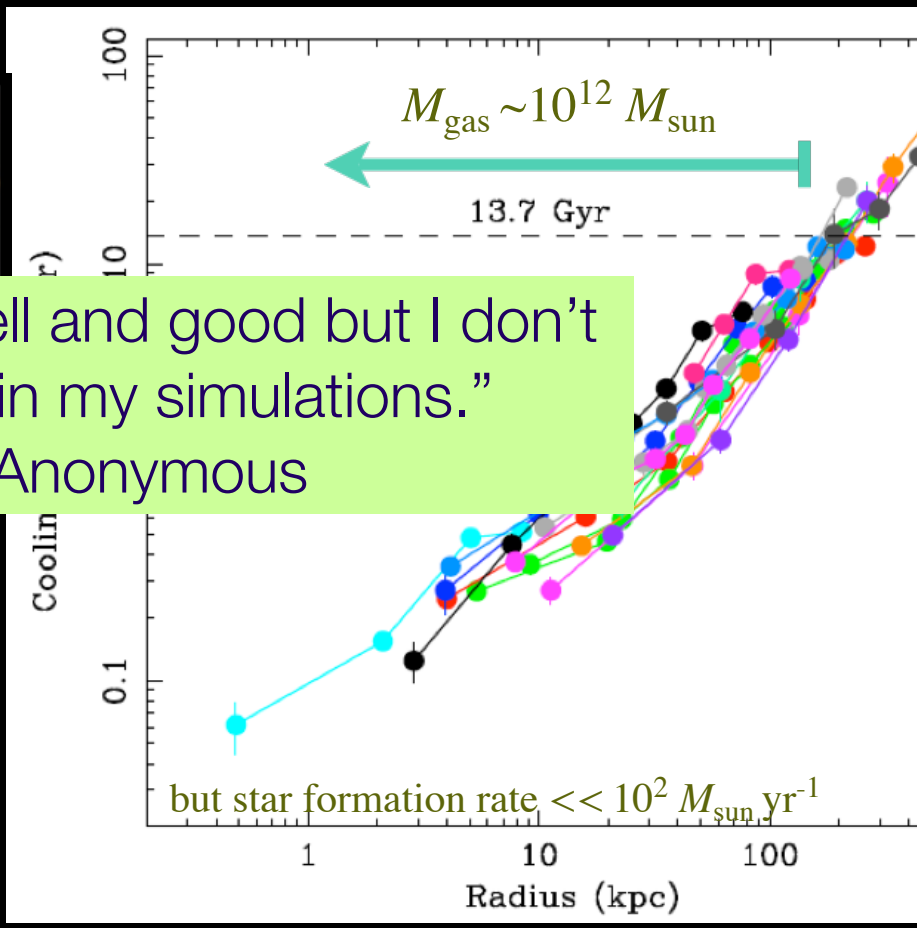
Low-mass galaxies are regulated by stellar feedback. Stellar feedback alone fails to regulate SF in massive galaxies.



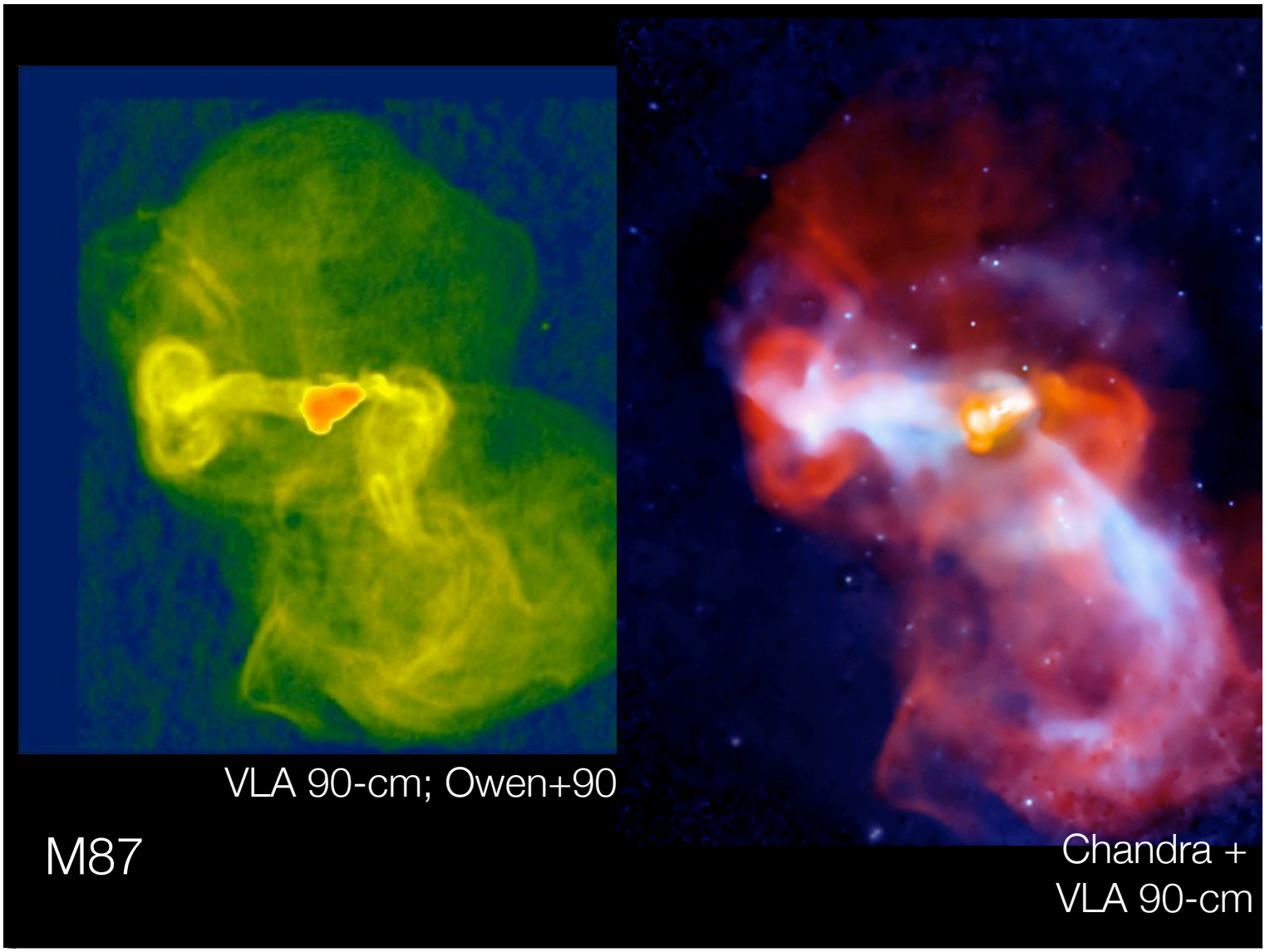
AGN in clusters and galaxies

Nature's version

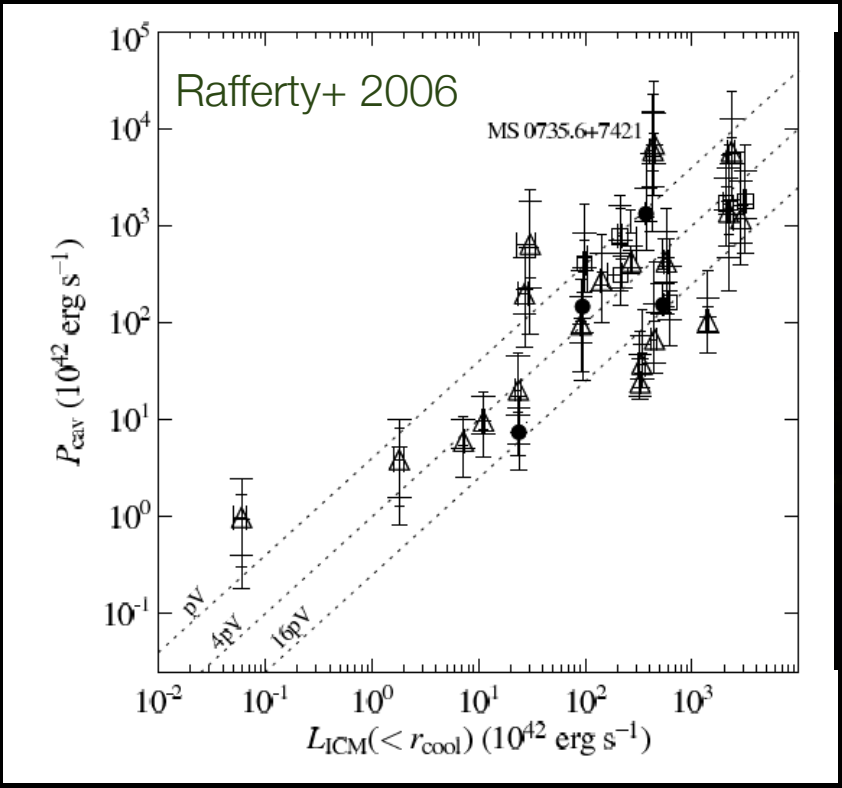


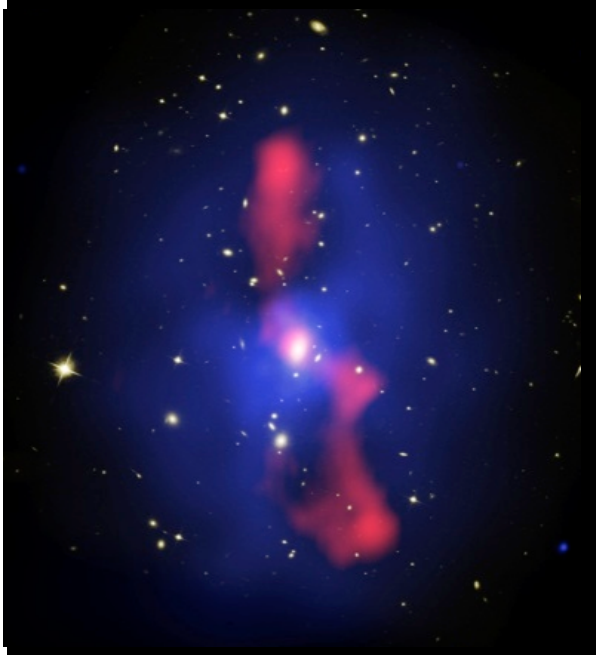


"That's all well and good but I don't see that in my simulations."
- Anonymous


VLA 90-cm; Owen+90
M87
Chandra +
VLA 90-cm

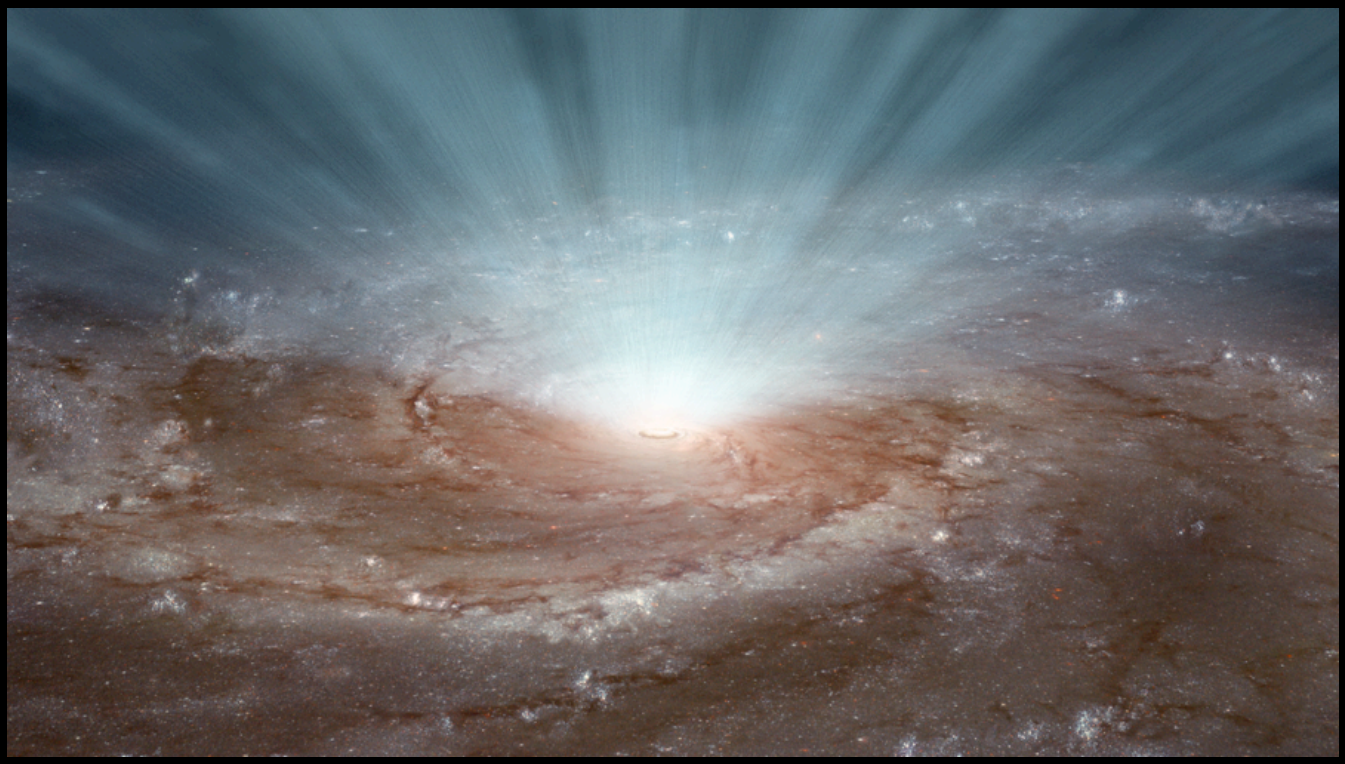
AGN balance radiative cooling in clusters





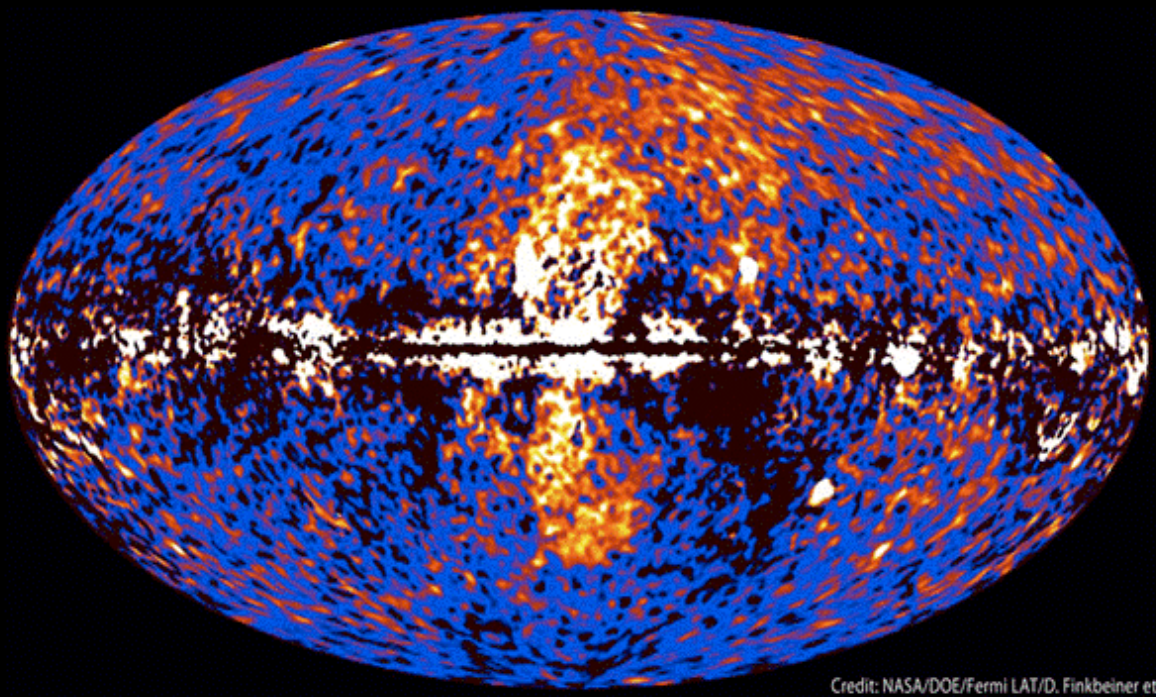
MS0735+74
NASA/ESA/CXC/STScI/NRAO/Birzan/M

PDS 456 Quasar winds



Nardini+2015 Science

10^{12} solar mass halo with a former AGN?



Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.

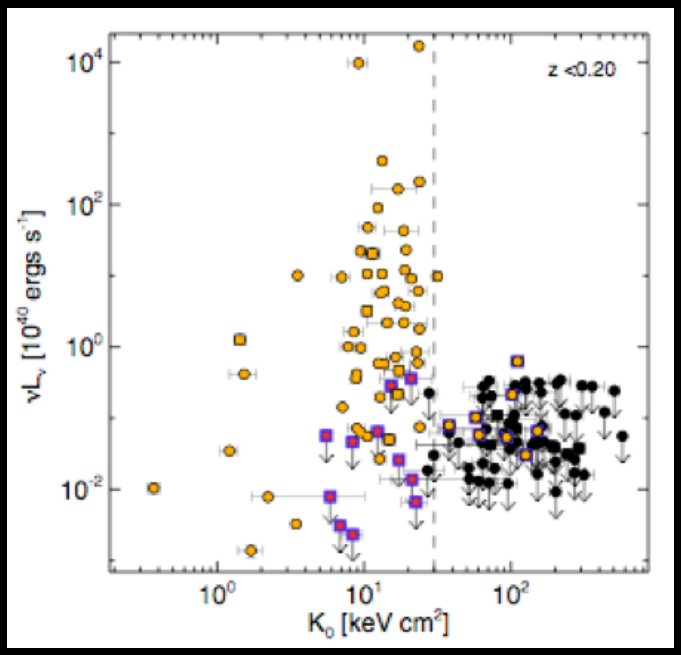
BCGs, AGN, and star formation

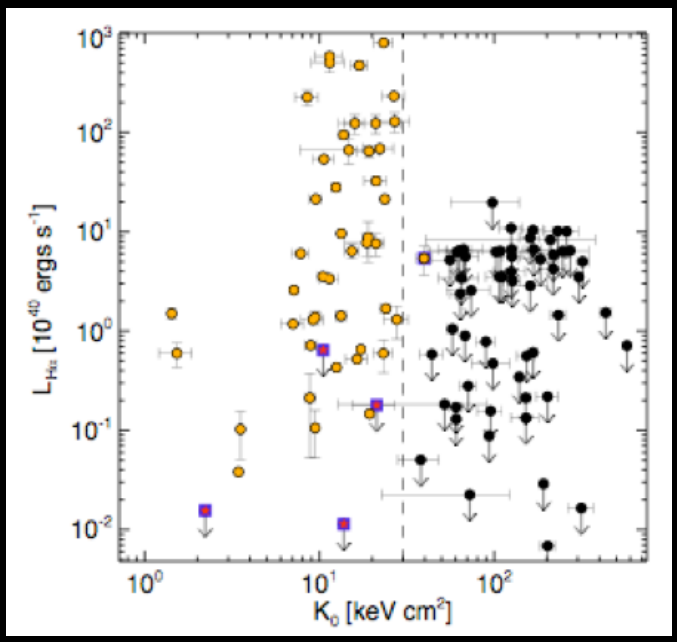
CLASH clusters

AGN feedback is fueled by CGM

Multiphase threshold in the CGM

Voit+ 08, Cavagnolo+ 08, Rafferty+ 08

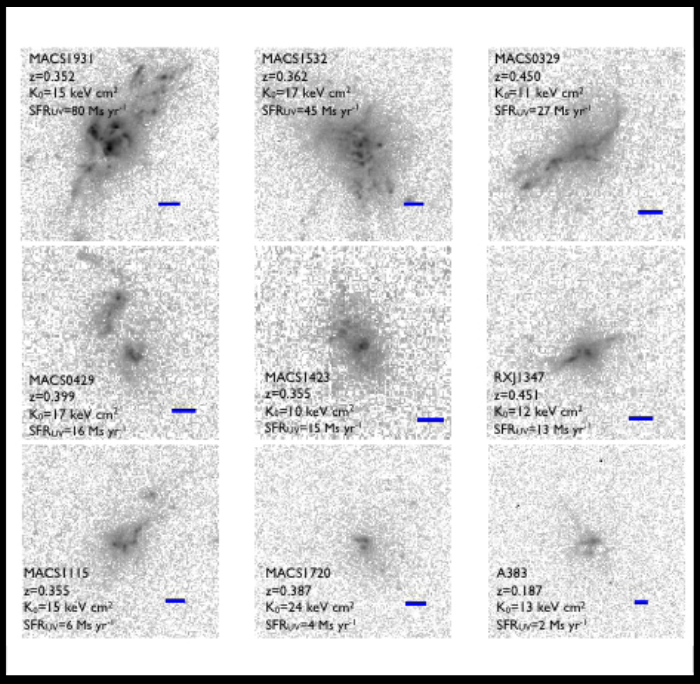




Core Entropy Index = $K_0 = kTn_e^{-2/3}$

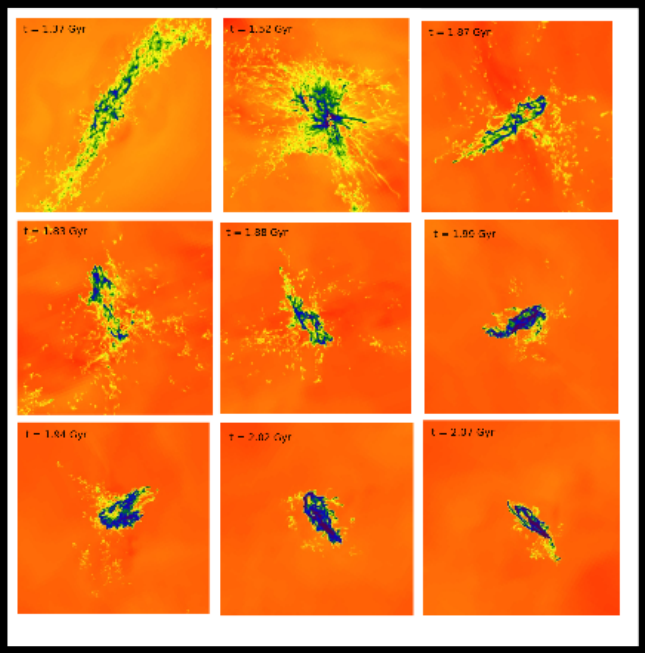
Star Formation in BCGs

Donahue et al. 2015



CLASH rest-frame UV
50x50 kpc

Li et al. 2014



Simulated precipitation around
AGN in a BCG, 50x50 kpc

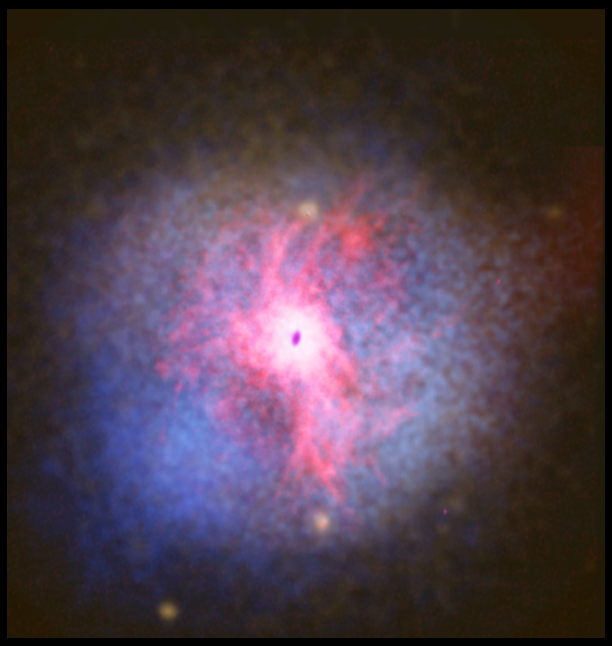
Two Kinds of Massive Ellipticals

Werner+ 12, Werner+ 14

Single-Phase

Multiphase

30 kpc

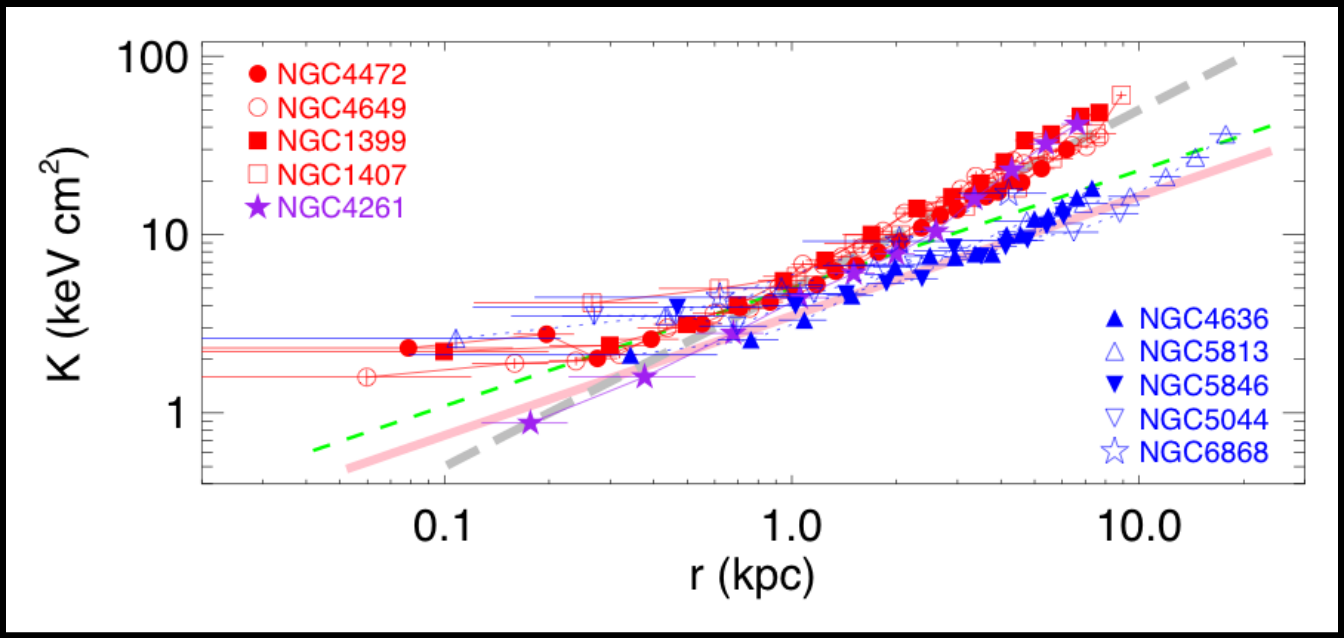


NCG 1399

NGC 5044

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”.