Hot Baryons in Deep Potential Wells

Hot Gas in Galaxies, Groups, and Clusters of Galaxies

Megan Donahue
Chair: Christine Jones
Keith Arnaud, Andi Mahdavi, Kazuhiro Nakazawa, Paul Nulsen, Scott Randall, Mateusz Ruszkowski, Jan Vrtilek

Science Questions

- How did galaxies grow?
  - What role did AGN play in galaxy formation?
- What is the universe made out of?

Scaling Relations and Cosmolgy: Why do we want to understand clusters?

+ Accurate empirical relations between cluster virial mass and observables are key.

+ A physical model allows us to self-calibrate (cross-check assumptions)

+ A physical model that works gives confidence to the method

- A physical model that falls short casts doubt on the method.

big picture issues

- Gravity physics: testing at largest scales
  - hierarchical structure formation & CDM
  - dynamical tests of dark energy models
- Astrophysics: IGM > Galaxies > IGM
  - ICM & IGM metallicity and entropy
  - Gas properties at r_{virial} and beyond
  - Feedback modes: cold/hot, "bouncer"/"velvet rope" (coined by Neal Katz)

Hot gas in clusters and groups

- 85% of baryons are intergalactic, and never have been or will be in stars: clusters and groups are where this matter shines.
- X-ray spectroscopy + imaging: where and how much dark matter there is, from temperature and density gradients.
- Measurements of ICM metallicity and entropy outside the core provide clues to history of feedback from galaxies.
- Measuring AGN output: cavity volume & pressure, ICM core entropy, velocities, and temperatures provide clues to on-going AGN feedback.

The role of IXO

- We need better cluster models and better empirical determinations of ICM mass-observables (to higher z, and to constrain scatter and evolution of scatter) to inform cosmological constraints.

- We need better and different measurements of ICM, to test and inform models of clusters: velocities, line widths, accurate abundances of hot gas, hard X-ray emission.

- We need better information about low surface brightness emission: group outskirts, clusters near the virial radius.

The bullet cluster: a picture of 10^{63-64} ergs

- Shocks and cold fronts
- Magnetic field and relativistic particles (with radio observations)
- Velocities: flows and turbulence

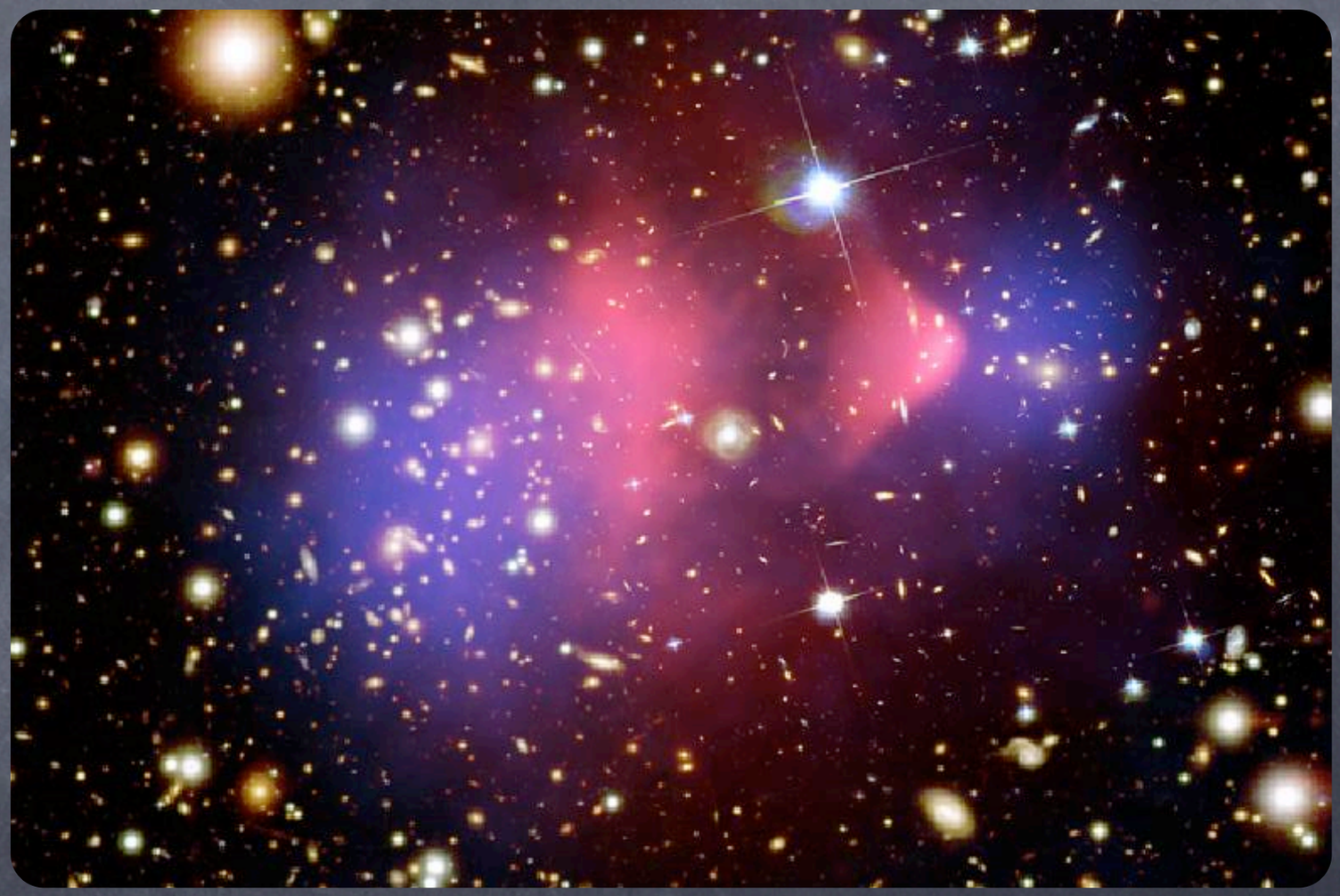
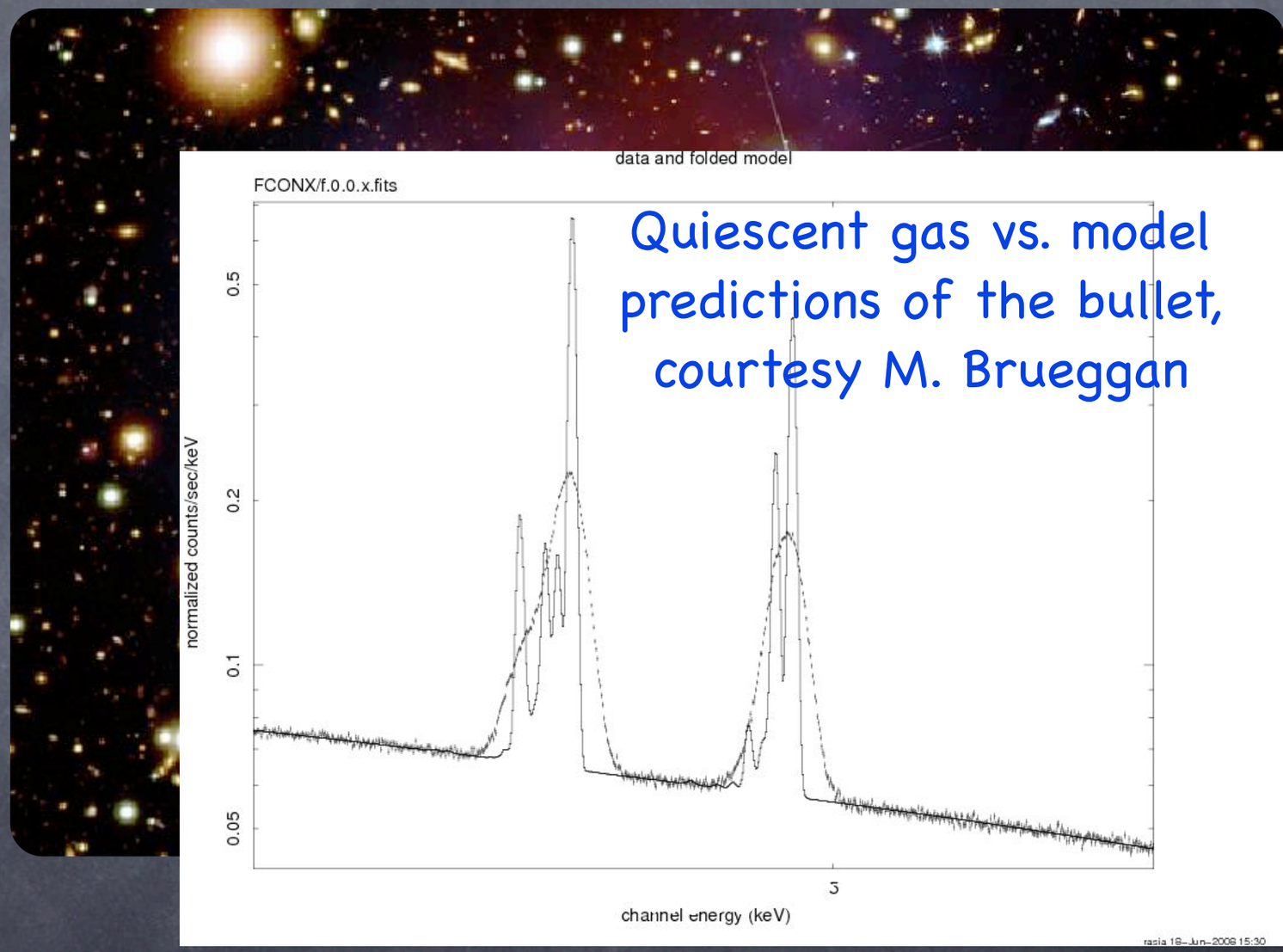


Photo credit: Bill Forman

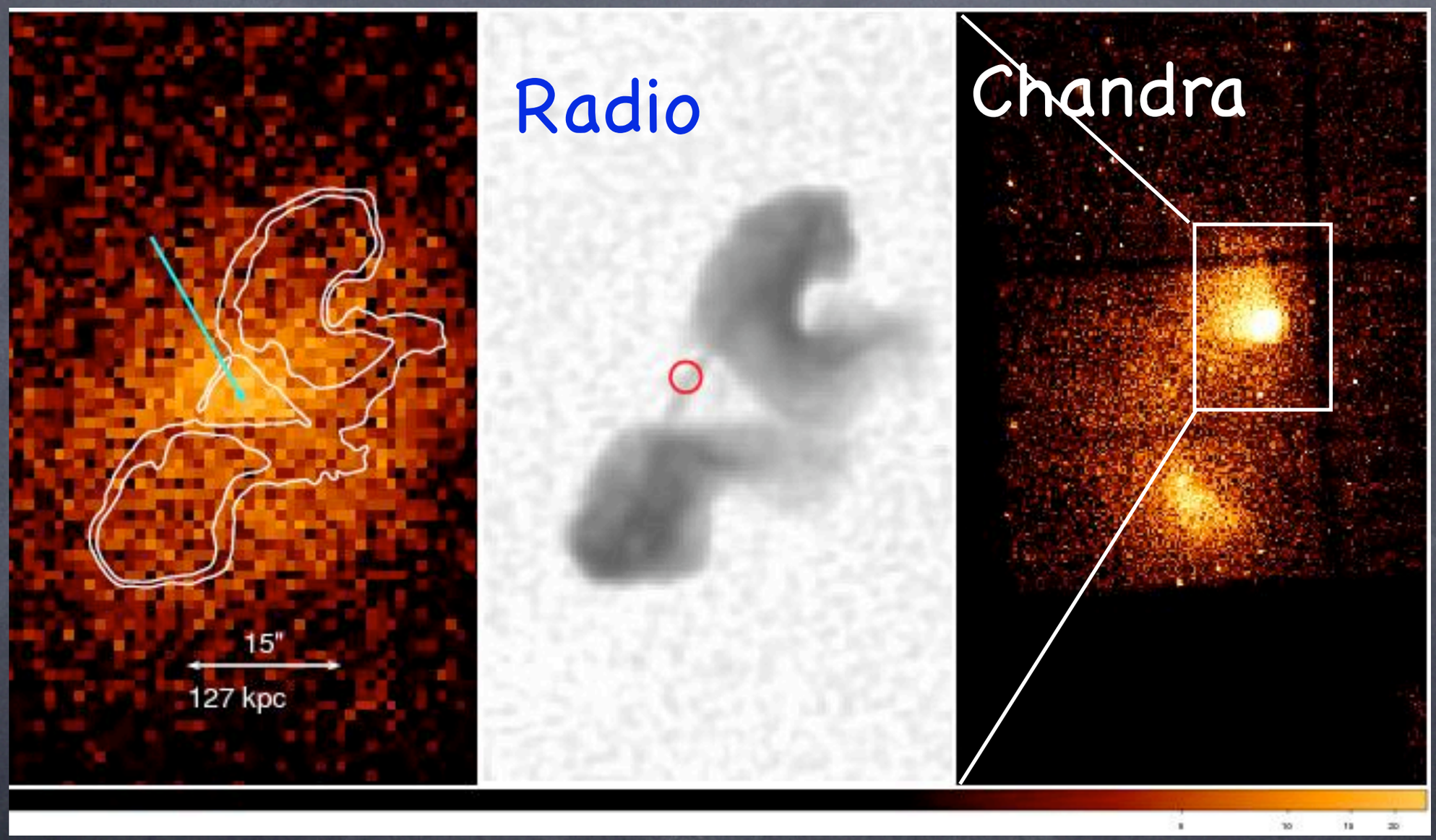
The bullet cluster: a picture of 10^{63-64} ergs

- Shocks and cold fronts
- Magnetic field and relativistic particles (with radio observations)
- Velocities: flows and turbulence



Quiescent gas vs. model predictions of the bullet, courtesy M. Brueggan

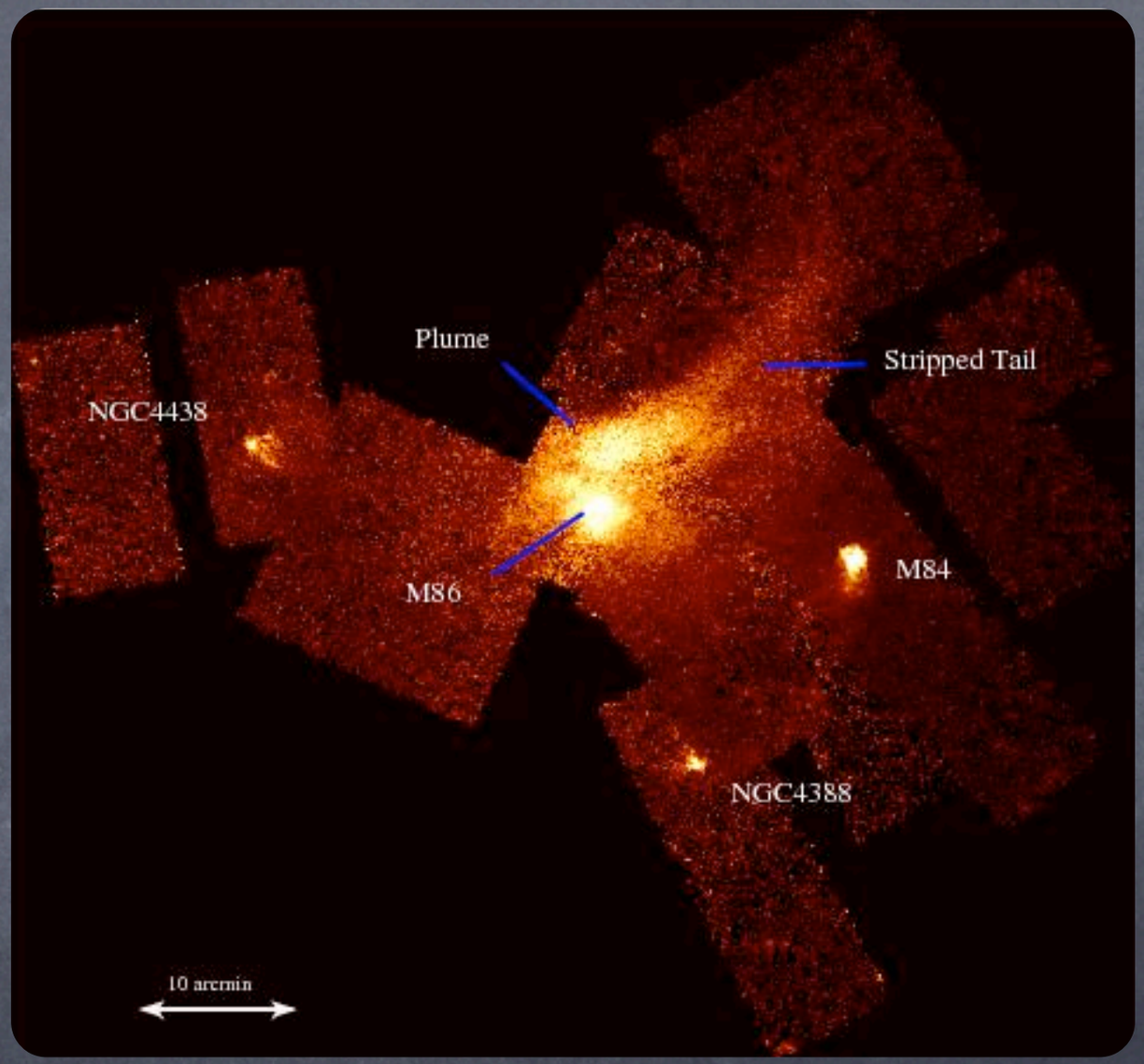
Viscosity



Forman et al 2008

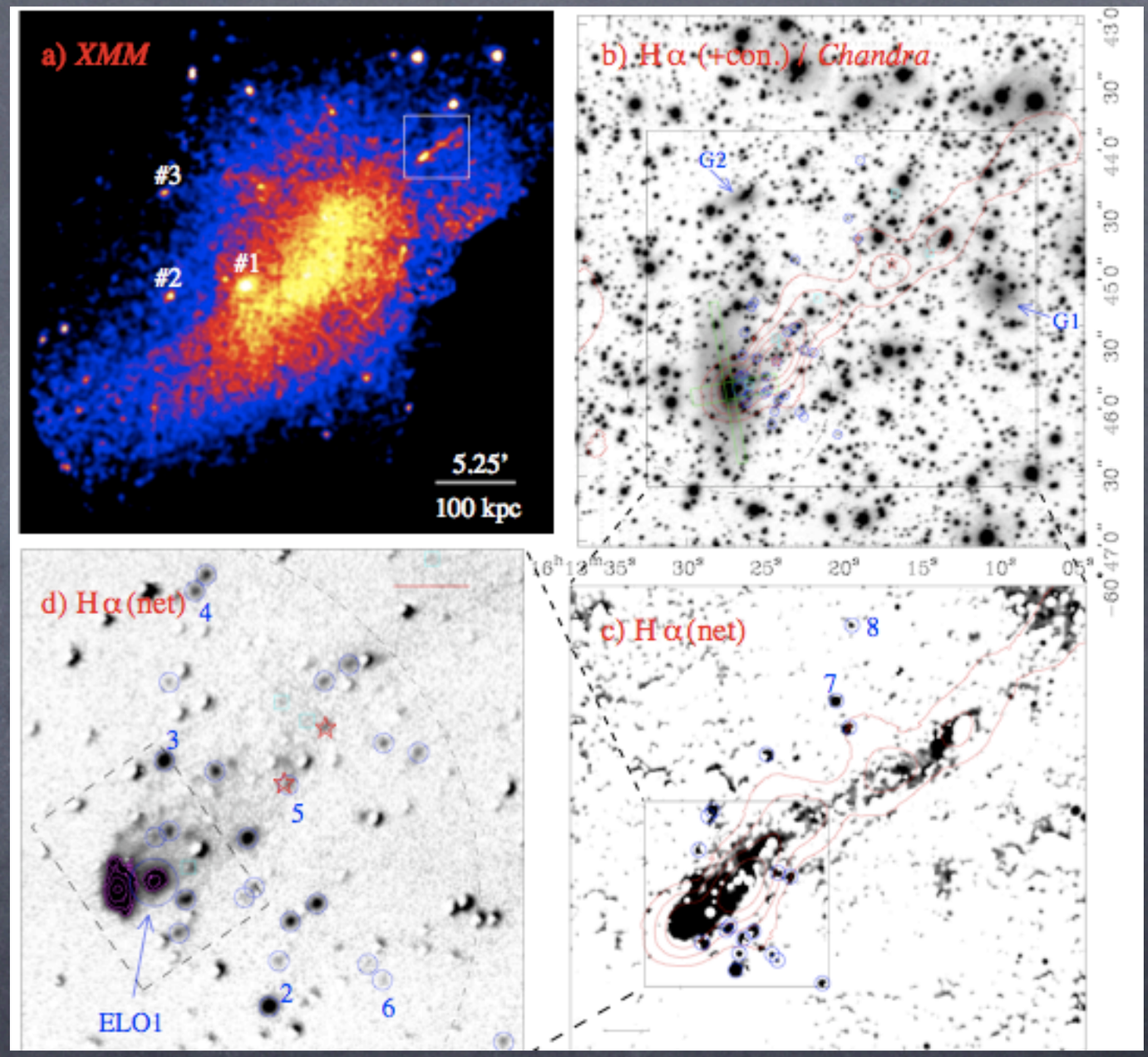
Sloshing and stripping

- Can sloshing heat? (few 10s of km/s required)
- Stripping of ellipticals (M86)
- Metals: stripped ISM, wind-driven ISM.
- Metals: produced by intergalactic stars.



Sloshing and stripping

- Can sloshing heat? (few 10s of km/s required)
- Stripping of ellipticals (M86)
- Metals: stripped ISM, wind-driven ISM.
- Metals: produced by intergalactic stars.

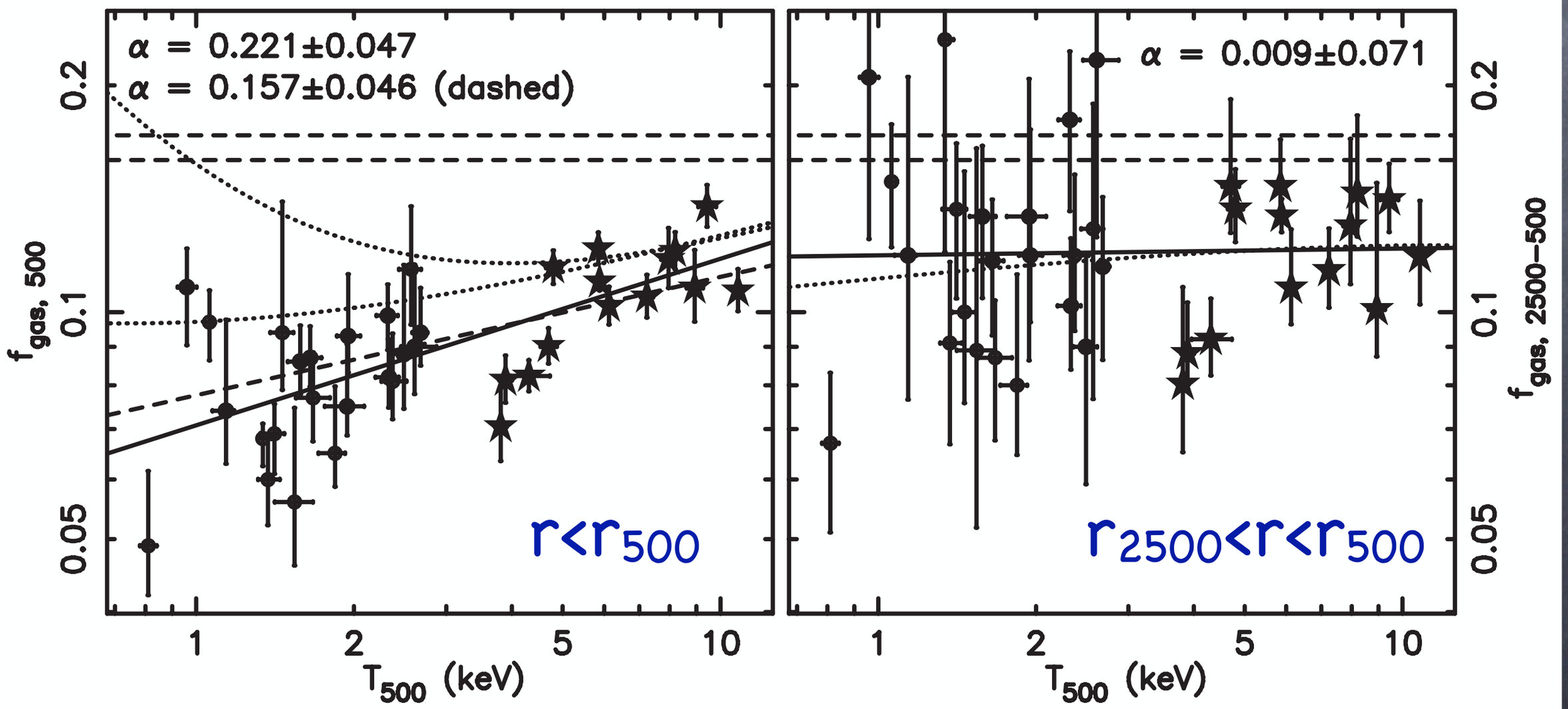


Stripping of spirals (A3627)

Cluster outskirts

- Long cooling time: entropy retains imprint of past events.
- Enrichment: same or different from dense ICM?
- Virial radius: accretion shock(s)?
- Group baryon fraction: between r_{2500}-r_{500} it is the same as clusters? (Sun et al 2008).
- Enrichment mechanism: alpha-Fe ratios?

f_{gas} in groups between r_{2500}-r_{500} is the same as in clusters



Sun et al 2008; Vikhlinin et al 2008

IXO requirements

- Spectral resolution: tens of km/s to resolve redshifts and line widths generated by turbulence(requires a large collecting area as a corollary)
- Spatial resolution: 5" or better required to limit contamination by background AGN. Better resolution needed to image shocks and bubble edges.
- Background: low background, local measurements (flat, well-understood response), independent confirmations. Modeling will be required to be more specific.

Decadal to-do list

- Improve our discussion of simulations: cosmologically realistic hydro simulations: collisions, stripping, AGN interactions, effects of conduction, magnetic fields, turbulence (recruit more theorists?)
- Develop observing programs of groups and clusters assuming realistic backgrounds.
- Coordinate the presentation of cluster working groups: a coherent and compelling science case is present, but hard to develop in isolation.
- Directly connect the observations to big science questions of broad community interest (astronomy and physics).