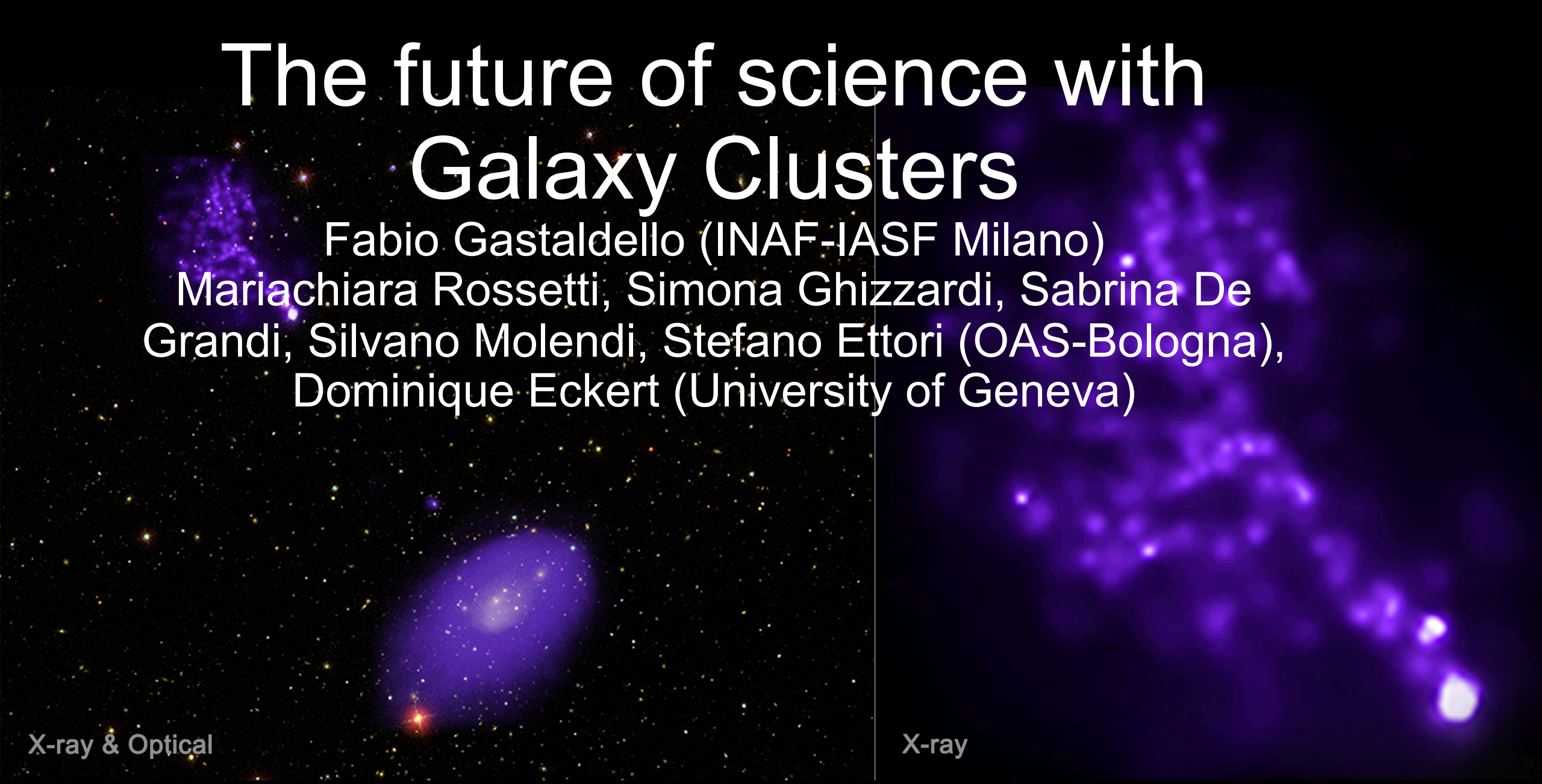
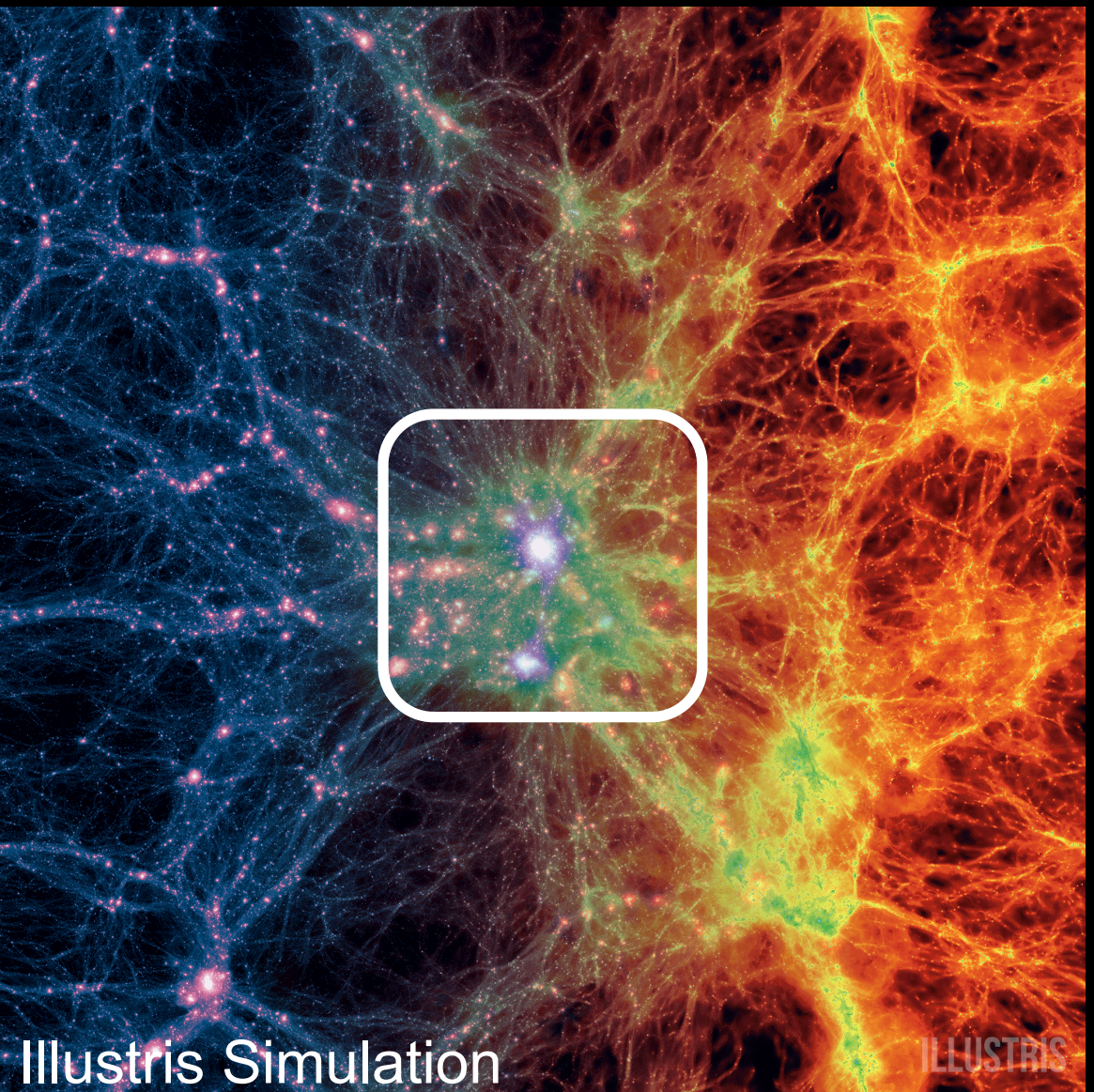
The future of science with Galaxy Clusters

Fabio Gastaldello (INAF-IASF Milano)
Mariachiara Rossetti, Simona Ghizzardi, Sabrina De Grandi, Silvano Molendi, Stefano Ettori (OAS-Bologna), Dominique Eckert (University of Geneva)



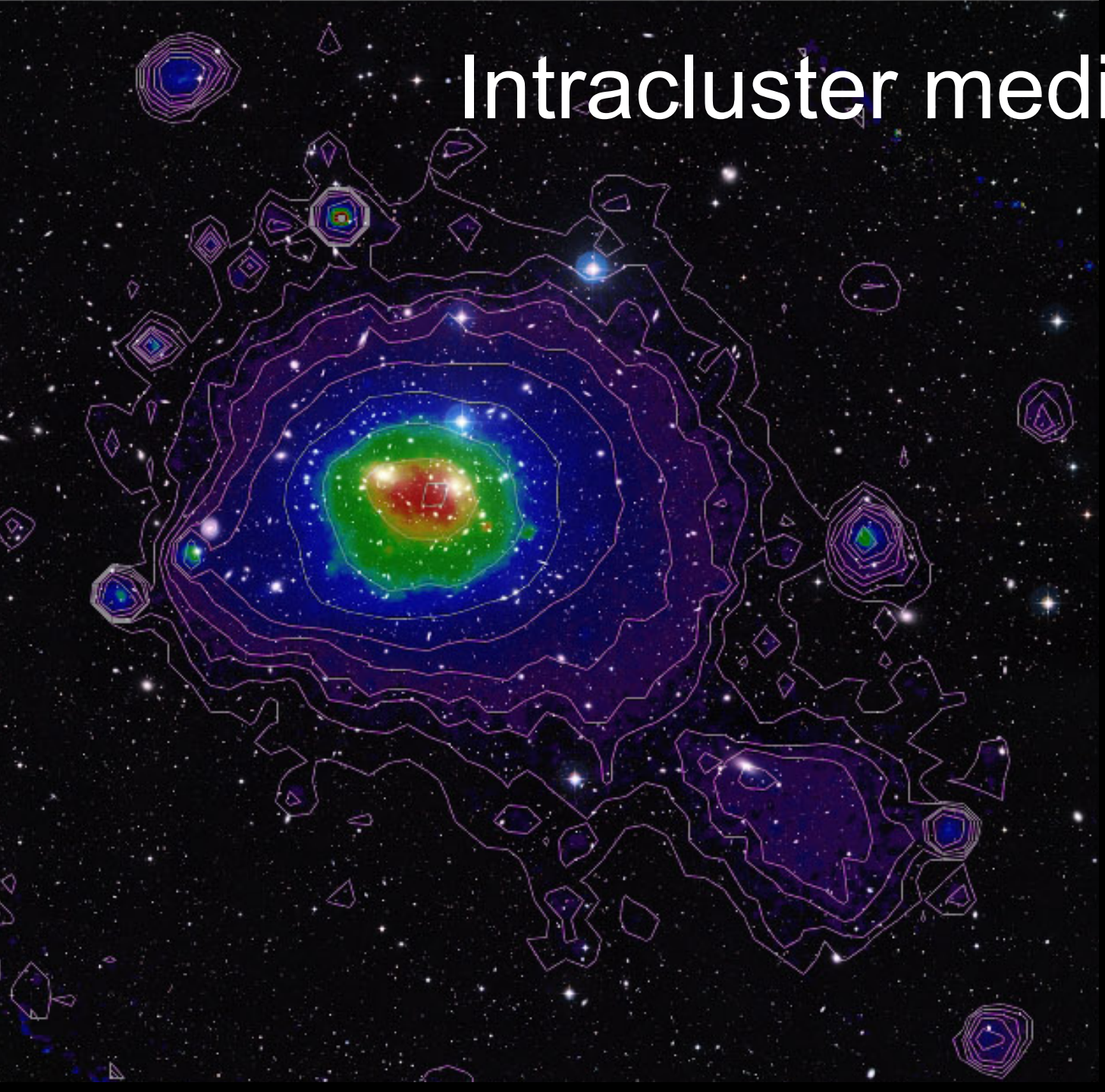
Clusters of galaxies



Illustris Simulation

- They form at the intersection of the cosmic web
- The greatest strctures to decouple from the Hubble flow
- Dimension of the order of the Mpc
- Masses 10^{14}-10^{15} M_{sun} (75-90% Dark Matter)

Intracluster medium (ICM)



Basic properties:

- Hot with temperatures 10^7-10^8 K o 1-10 keV)
- Low density (10^{-2}-10^{-4} particles/cm^3)
- Mainly H and He completely ionized. Chemically enriched with heavy elements (C, O, Si, Fe)
- Dominant baryonic component

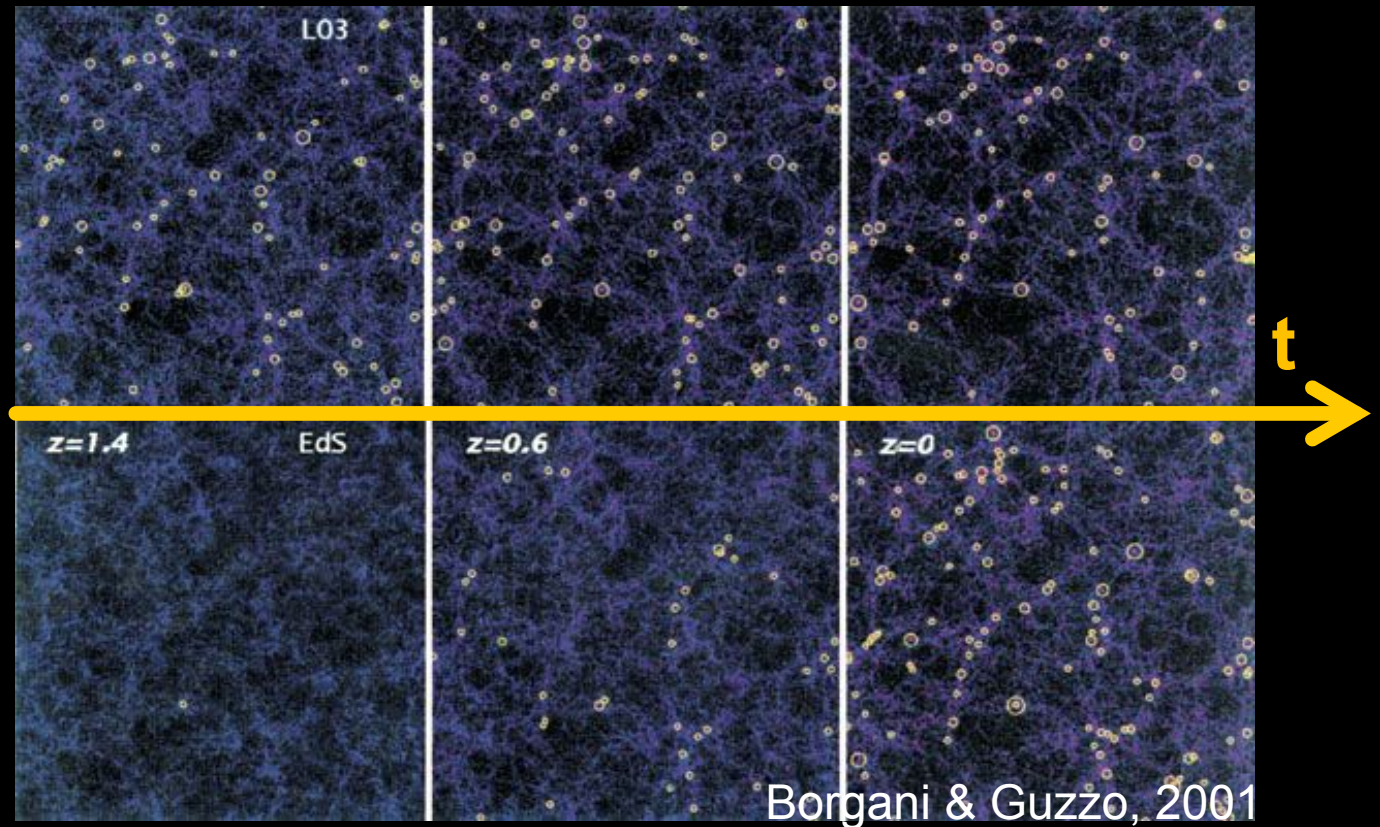
Why Galaxy Clusters ?

- Clusters as cosmological probes: structure formation and cosmological parameters estimate
- Clusters as astrophysical laboratories: plasma physics and DM properties

Clusters as cosmological probes

Ω_M=0.3
Ω_Λ =0.7

Ω_M=1
Ω_Λ =0



N(M,z): Number of clusters of galaxies depends on the cosmological parameters

Clusters as astrophysical probes

A2142
Immagine XMM-Newton
Rossetti et al. (2013)

- ICM is «the best proton-electron plasma in the Universe ever» (Cavaliere & Lapi 13) because of its large kinetic energy compared to the electrostatic energy

- Ideal to study the properties of DM

The Hot Universe and Athena

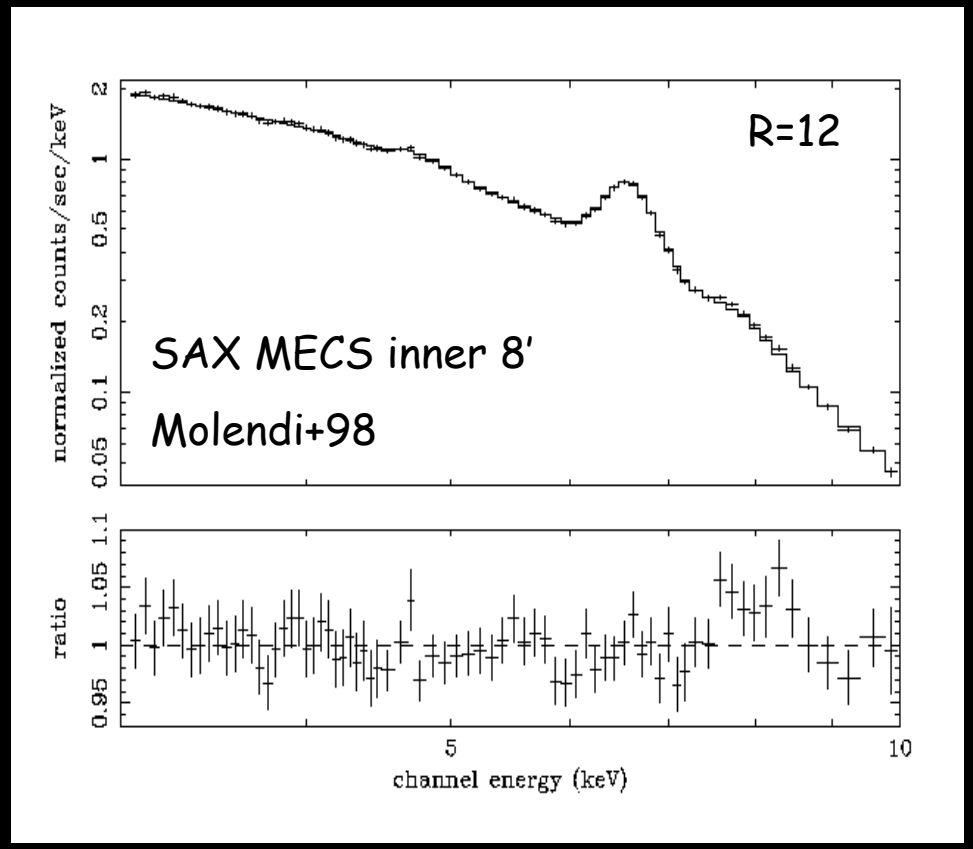
How does ordinary matter assemble into the large-scale structures we see today?

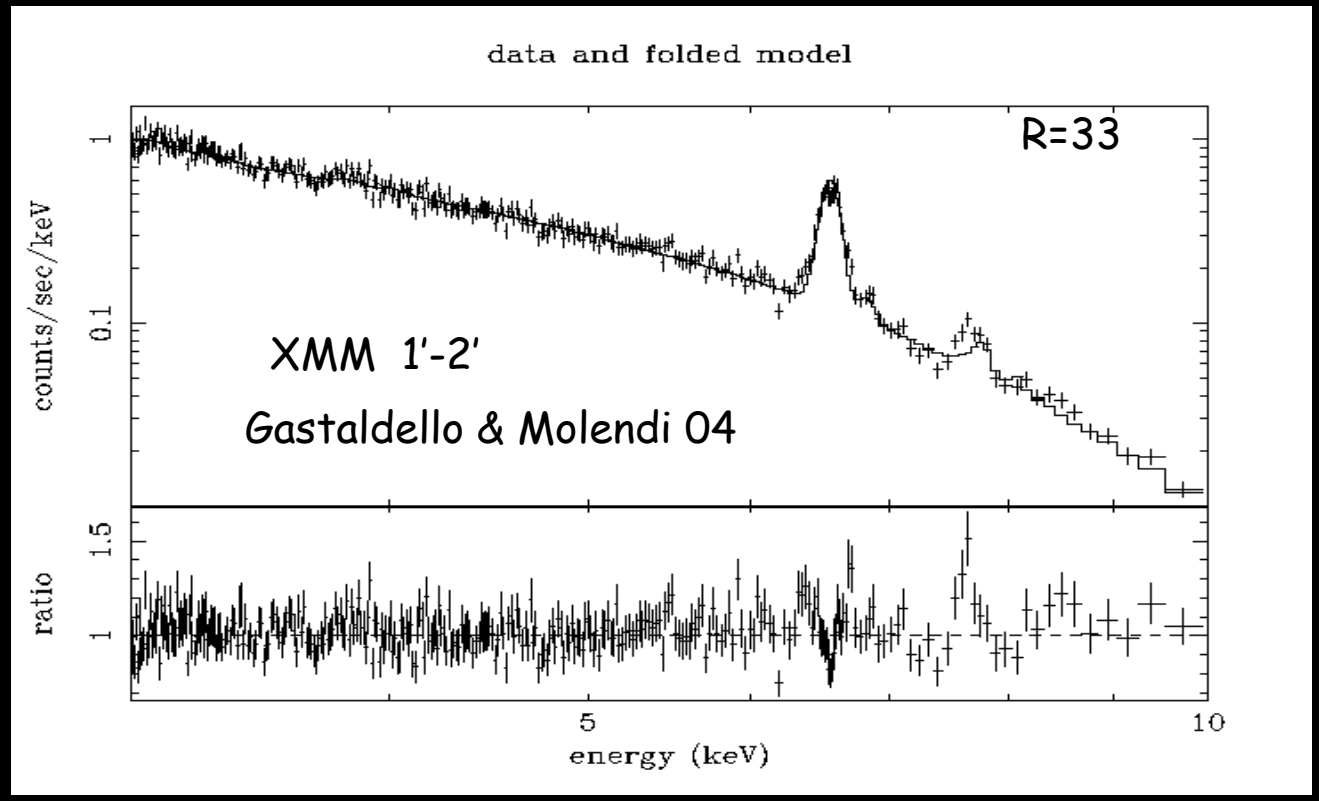
How do diffuse hot baryons accrete and dynamically evolve in the dark matter potential?

How and when was the energy in the ICM generated and distributed?

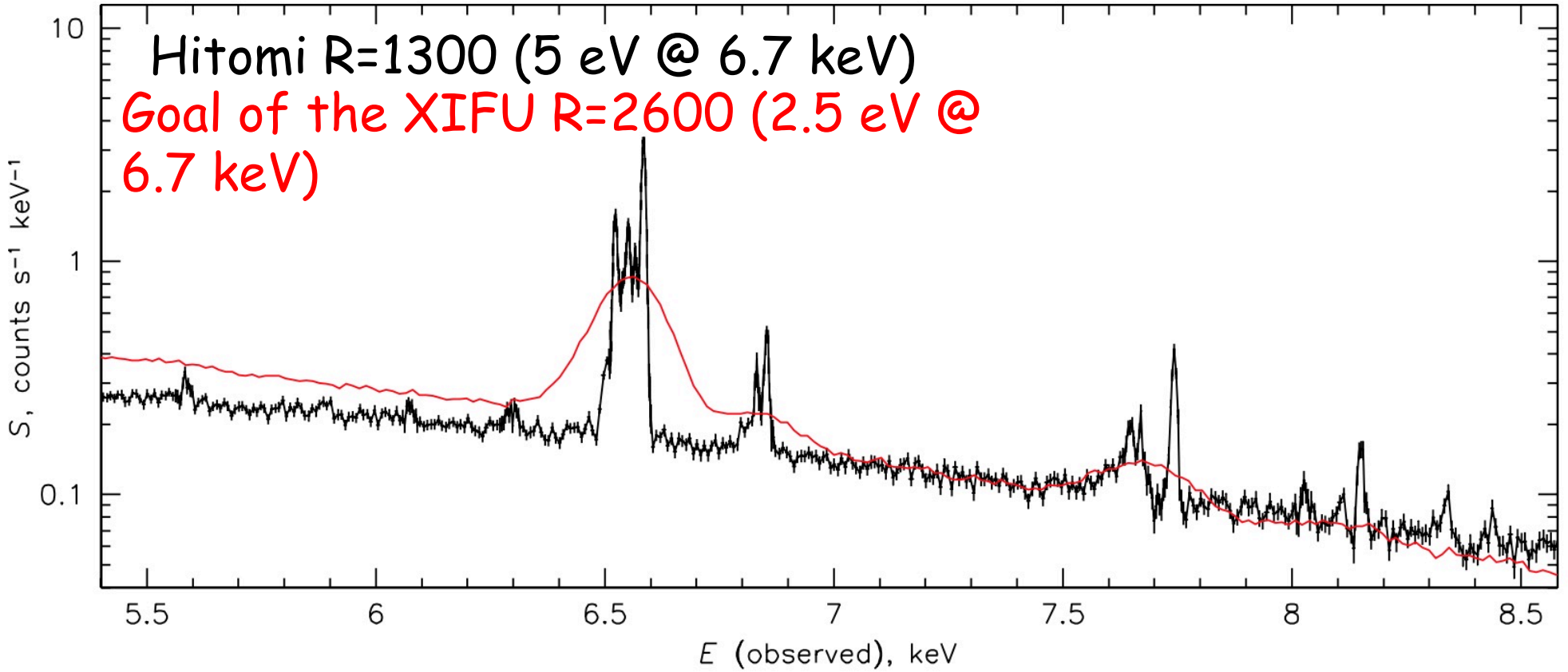
When and where are heavy elements produced and how are they circulated?

X-ray spectroscopy





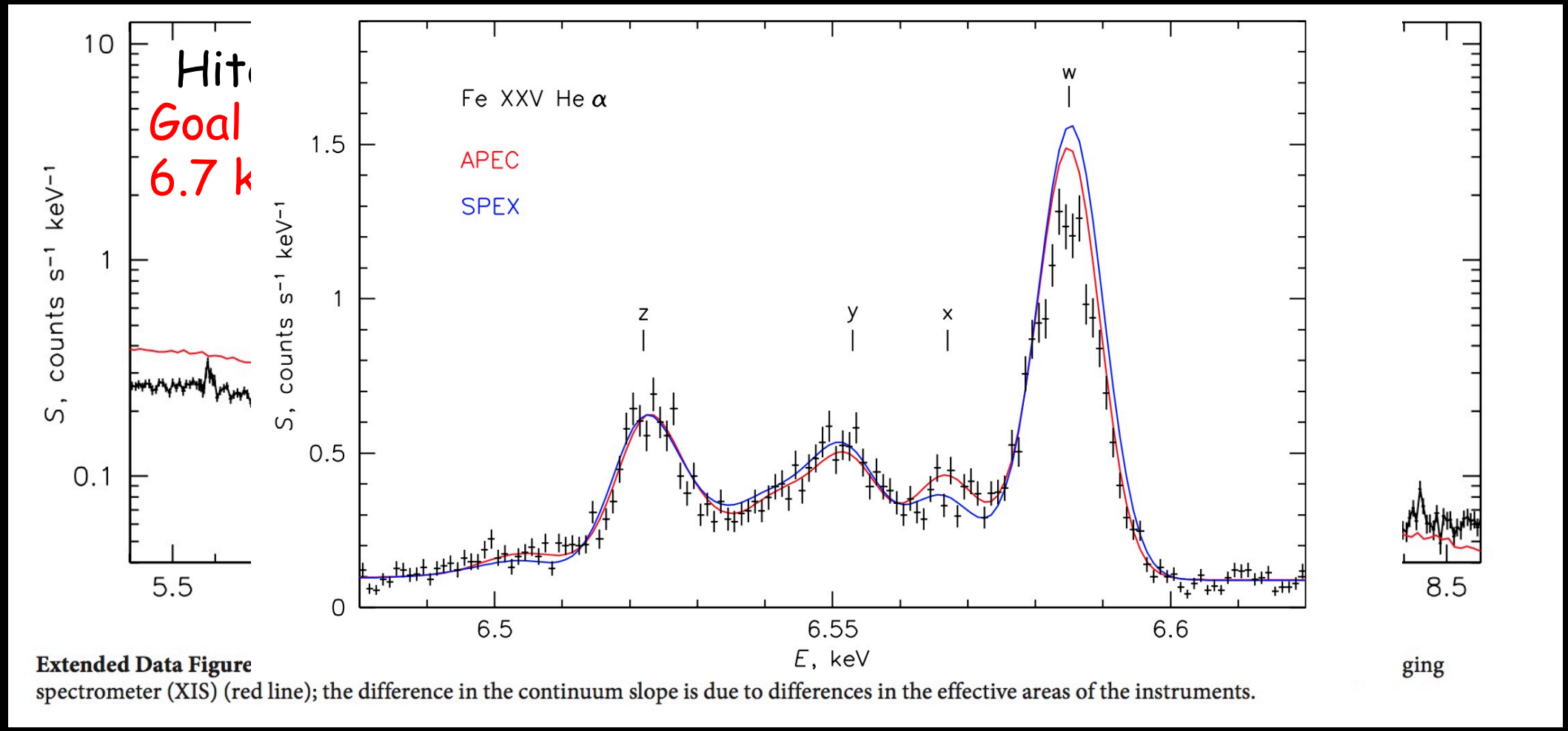
High resolution X-ray spectroscopy



Extended Data Figure 1 | SXS spectrum of the full field overlaid with a CCD spectrum of the same region. The CCD is the Suzaku X-ray imaging spectrometer (XIS) (red line); the difference in the continuum slope is due to differences in the effective areas of the instruments.

Hitomi collaboration 16

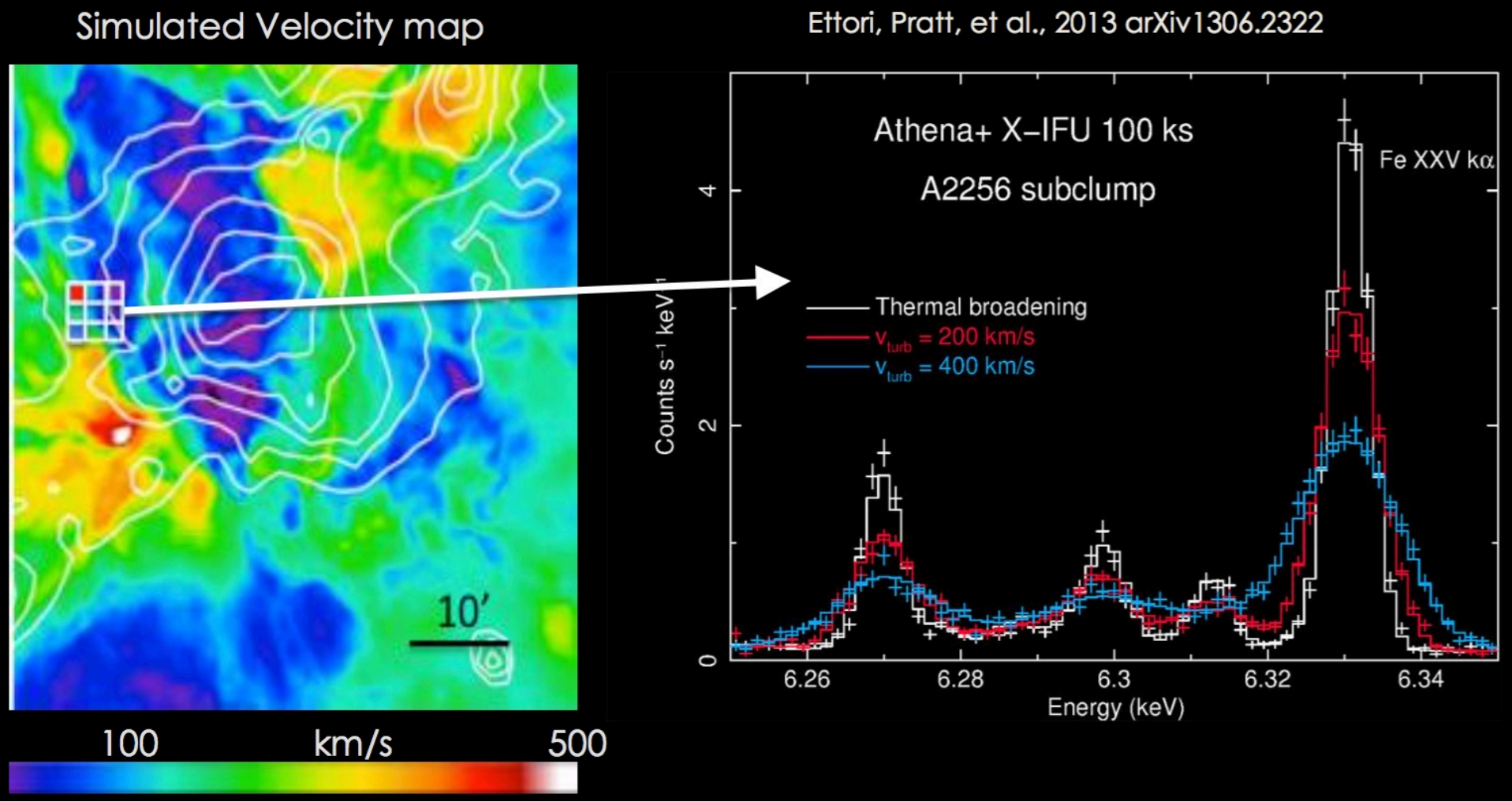
High resolution X-ray spectroscopy



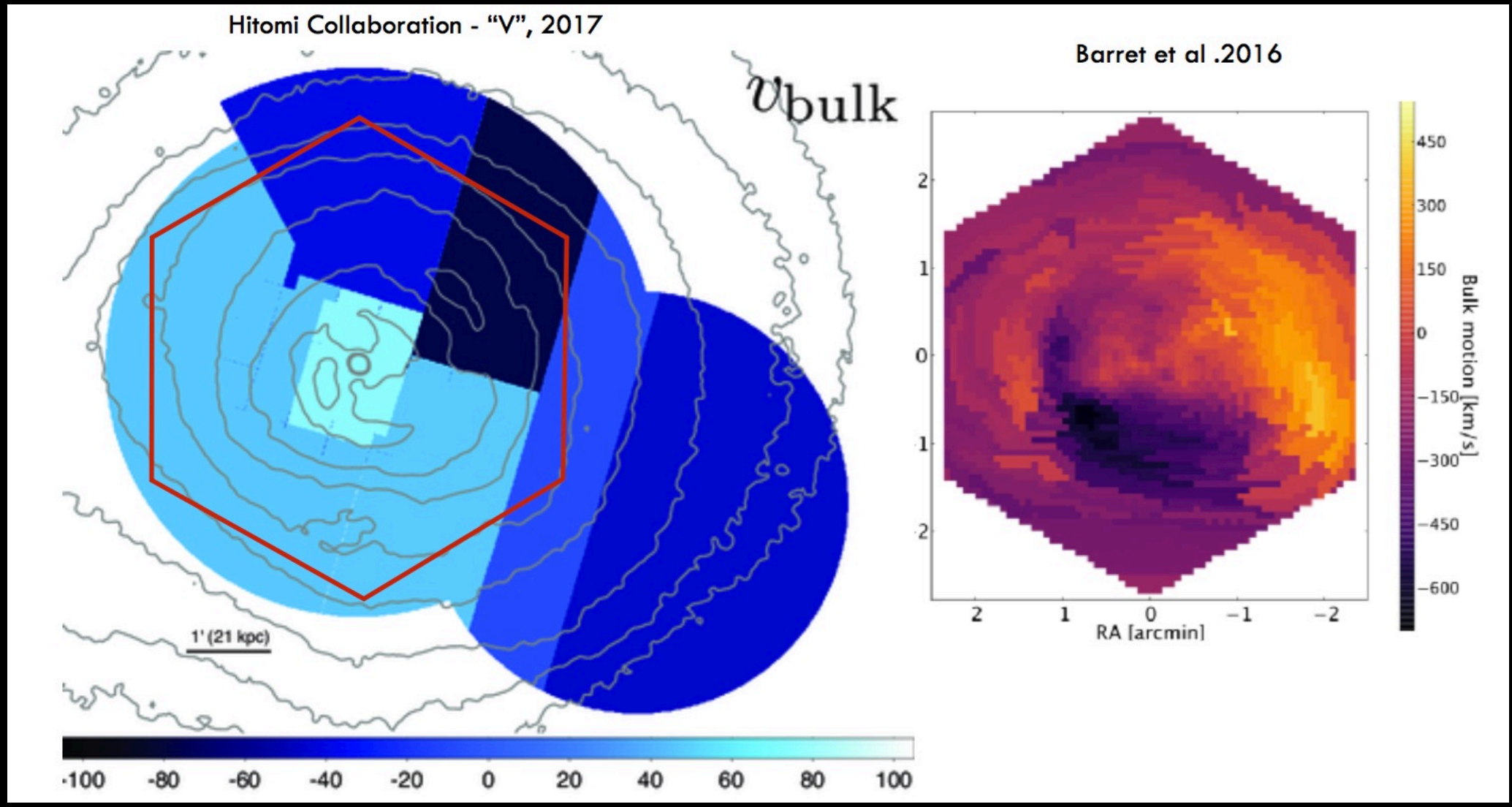
Extended Data Figure ging
spectrometer (XIS) (red line); the difference in the continuum slope is due to differences in the effective areas of the instruments.

Hitomi collaboration 16

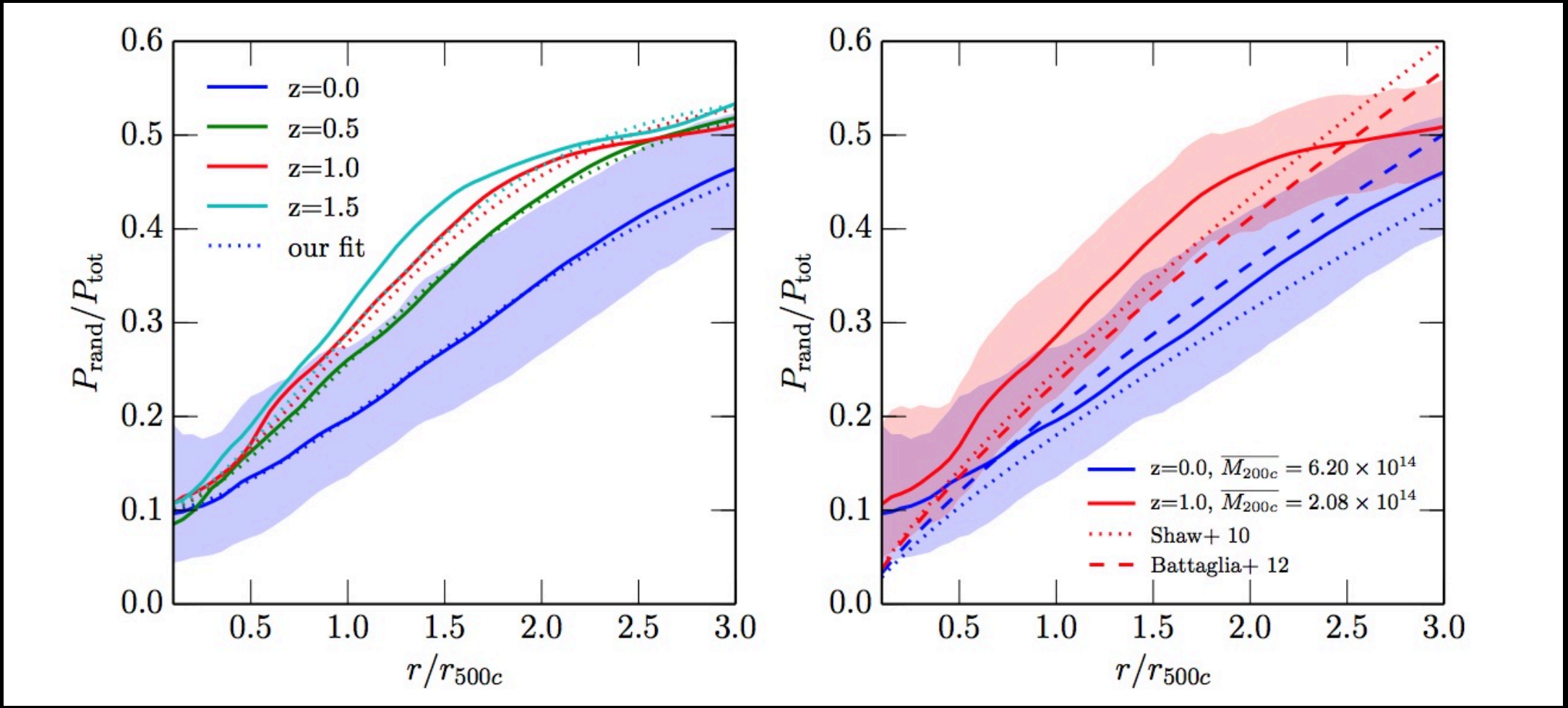
Dynamical assembly of clusters



Dynamical assembly of clusters

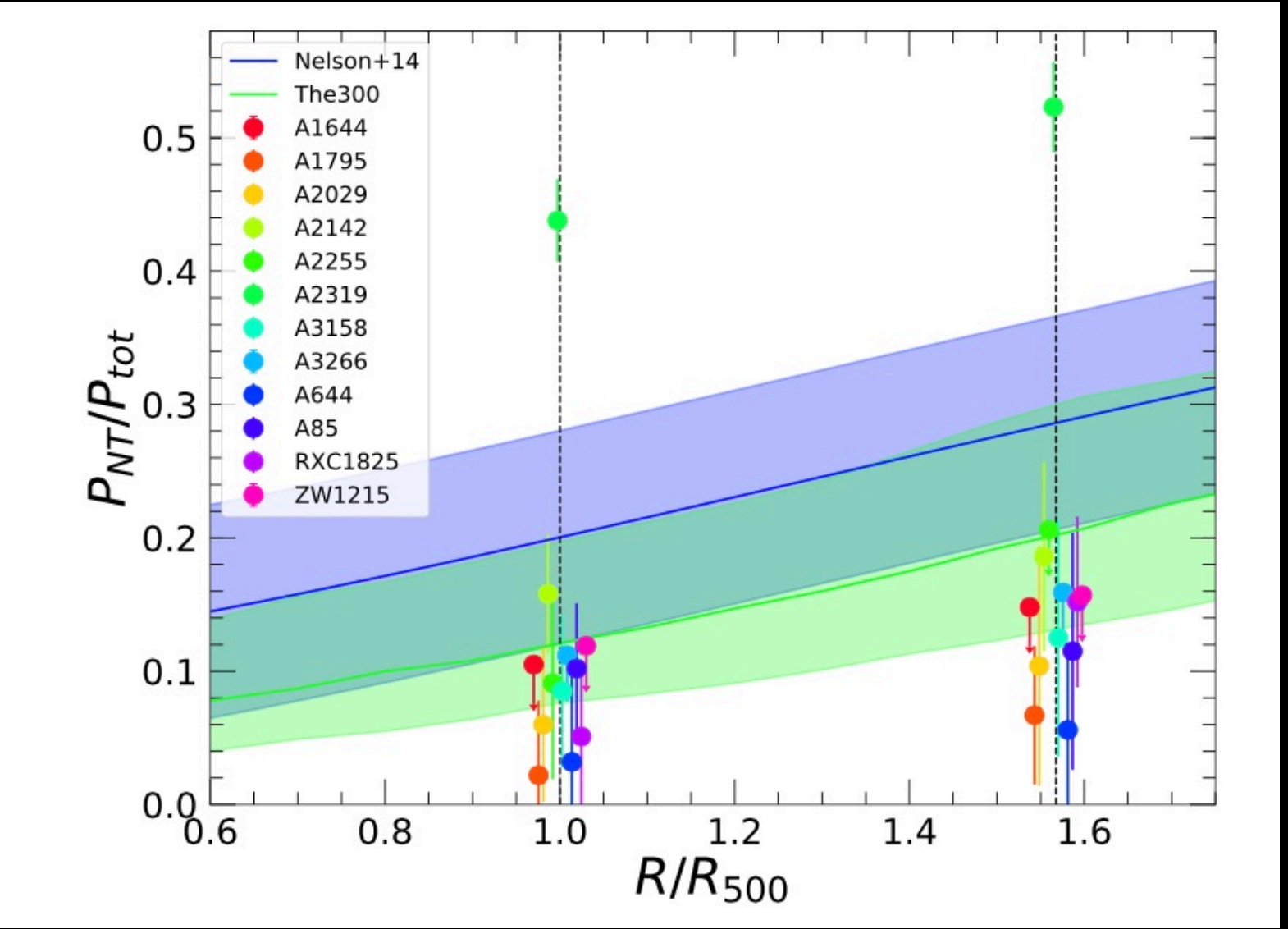


Constraints on HE mass bias



Nelson+14

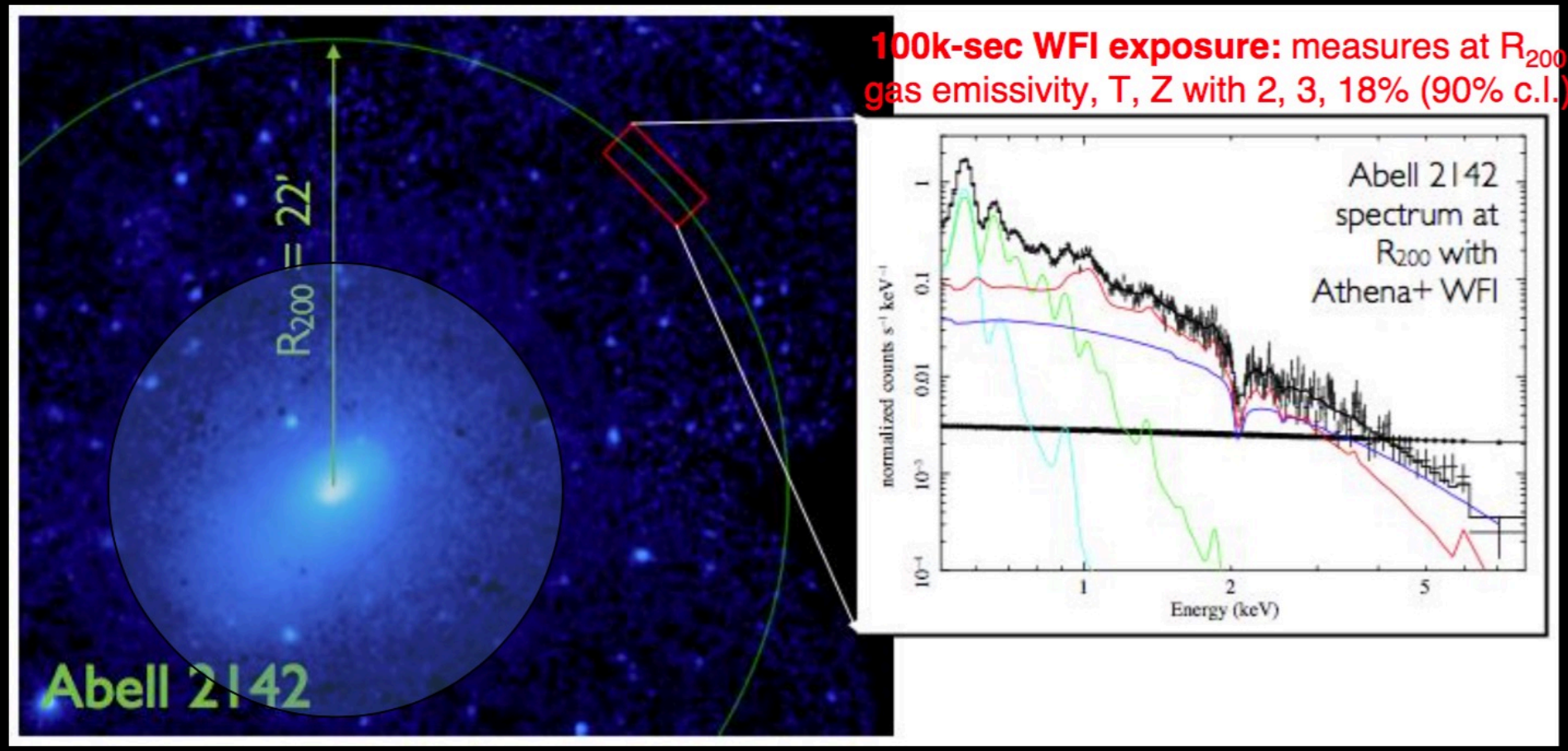
Constraints on HE mass bias



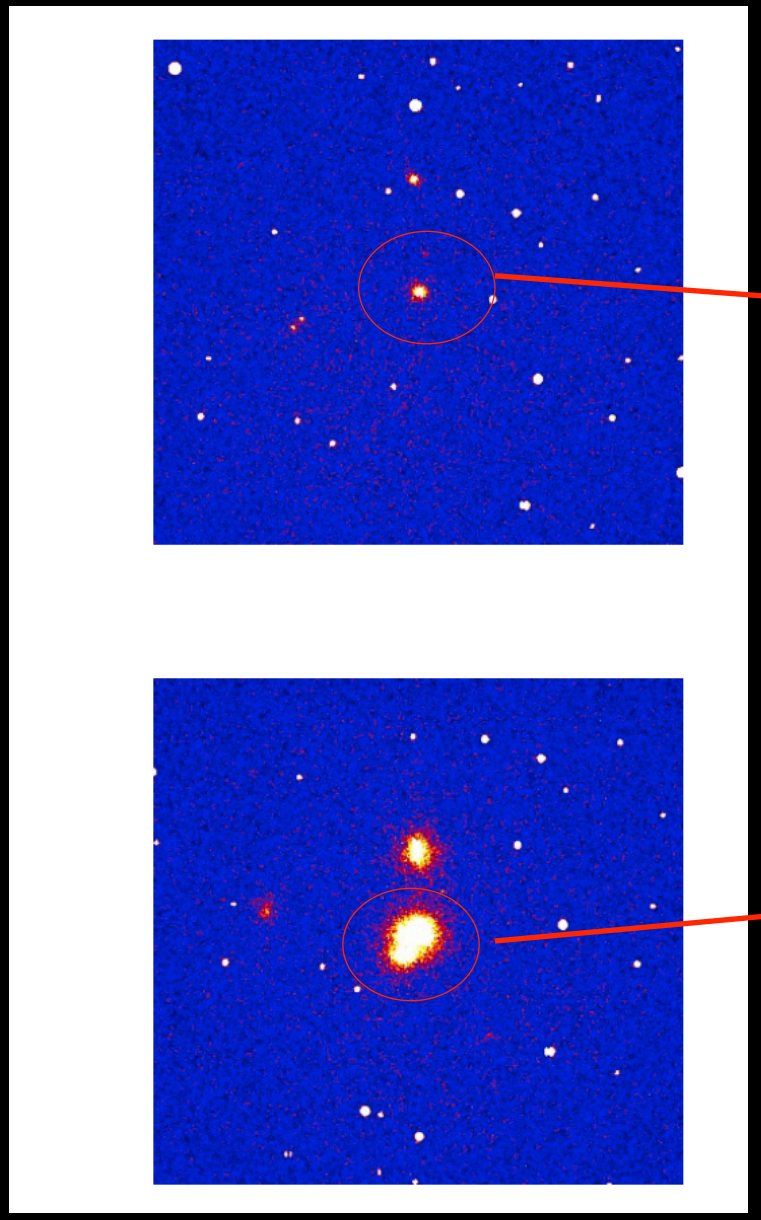
Eckert+19

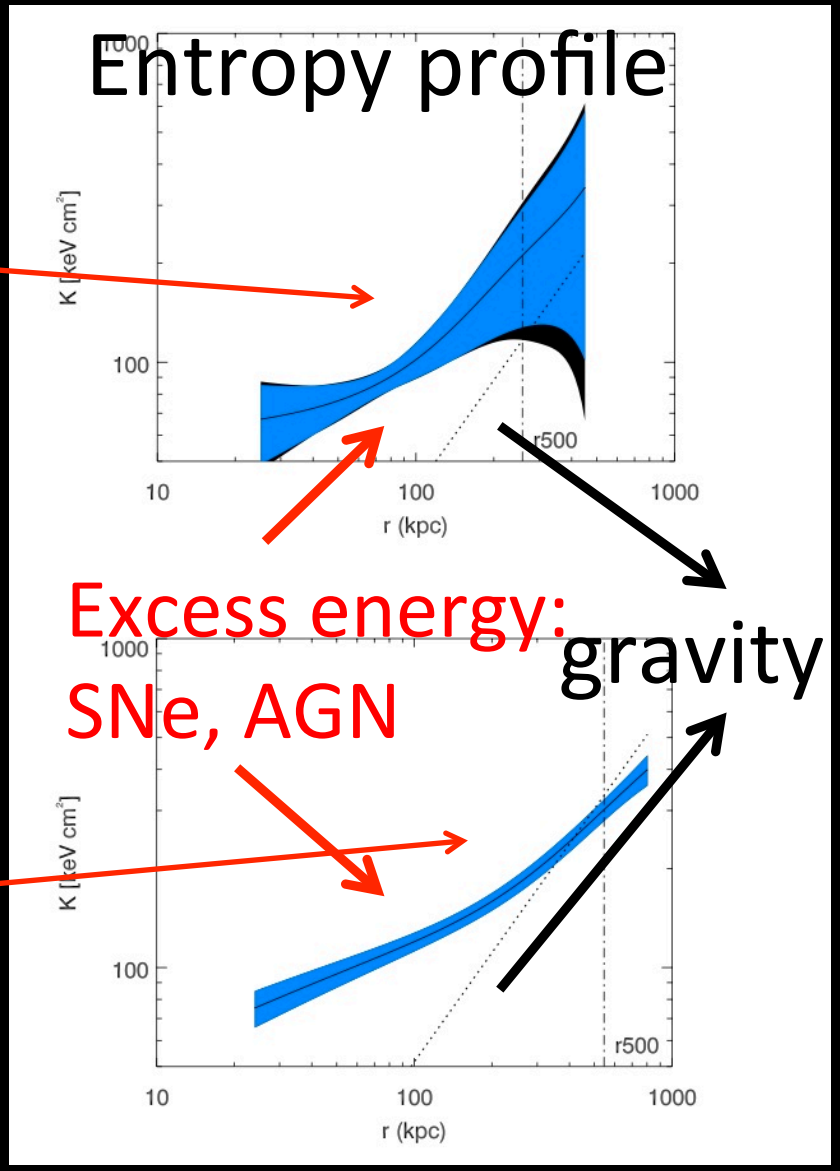
Energy deposition in the ICM

Ettori, Pratt et al., 2013 arXiv1306.2322



Energy generation in the ICM

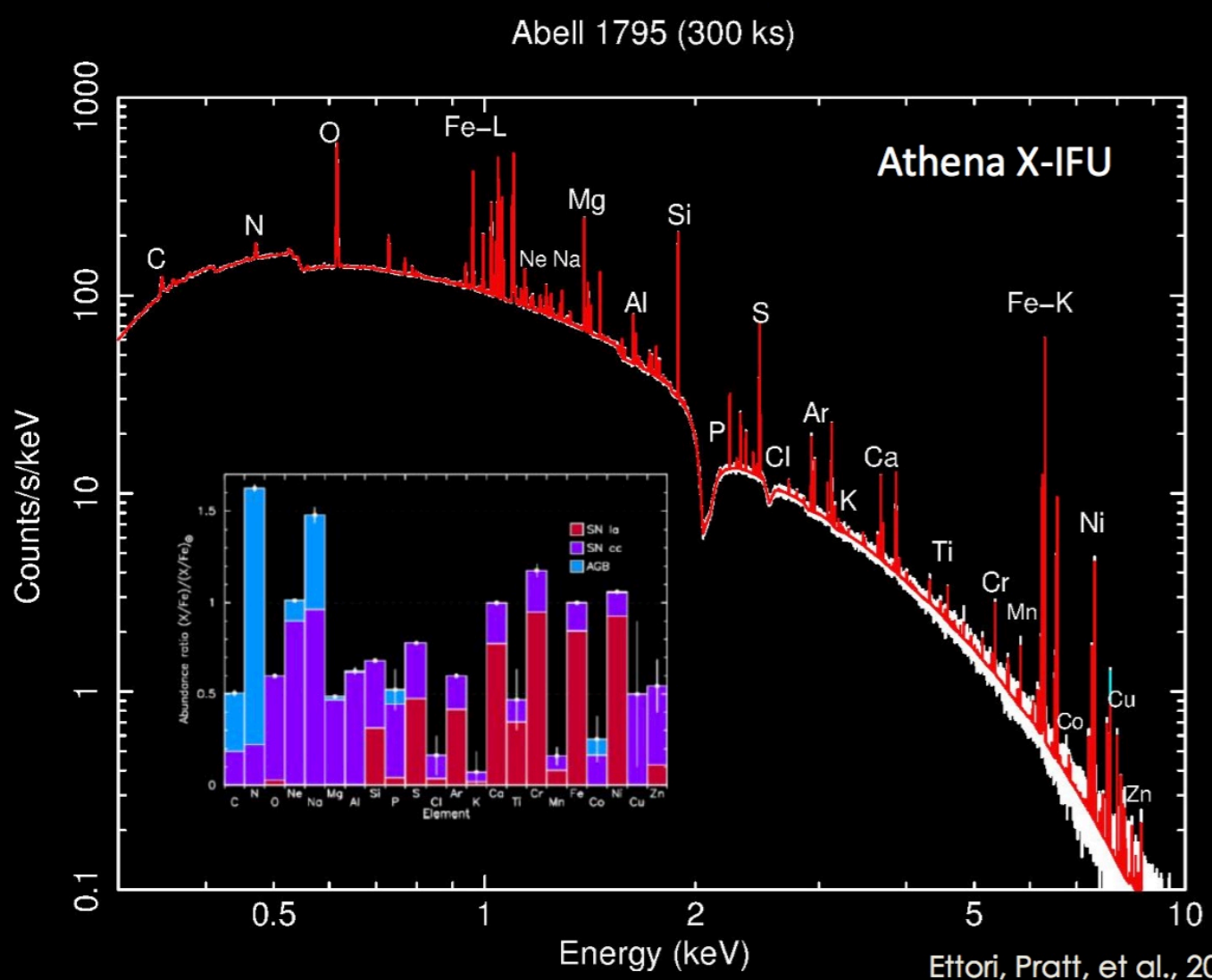




z=2

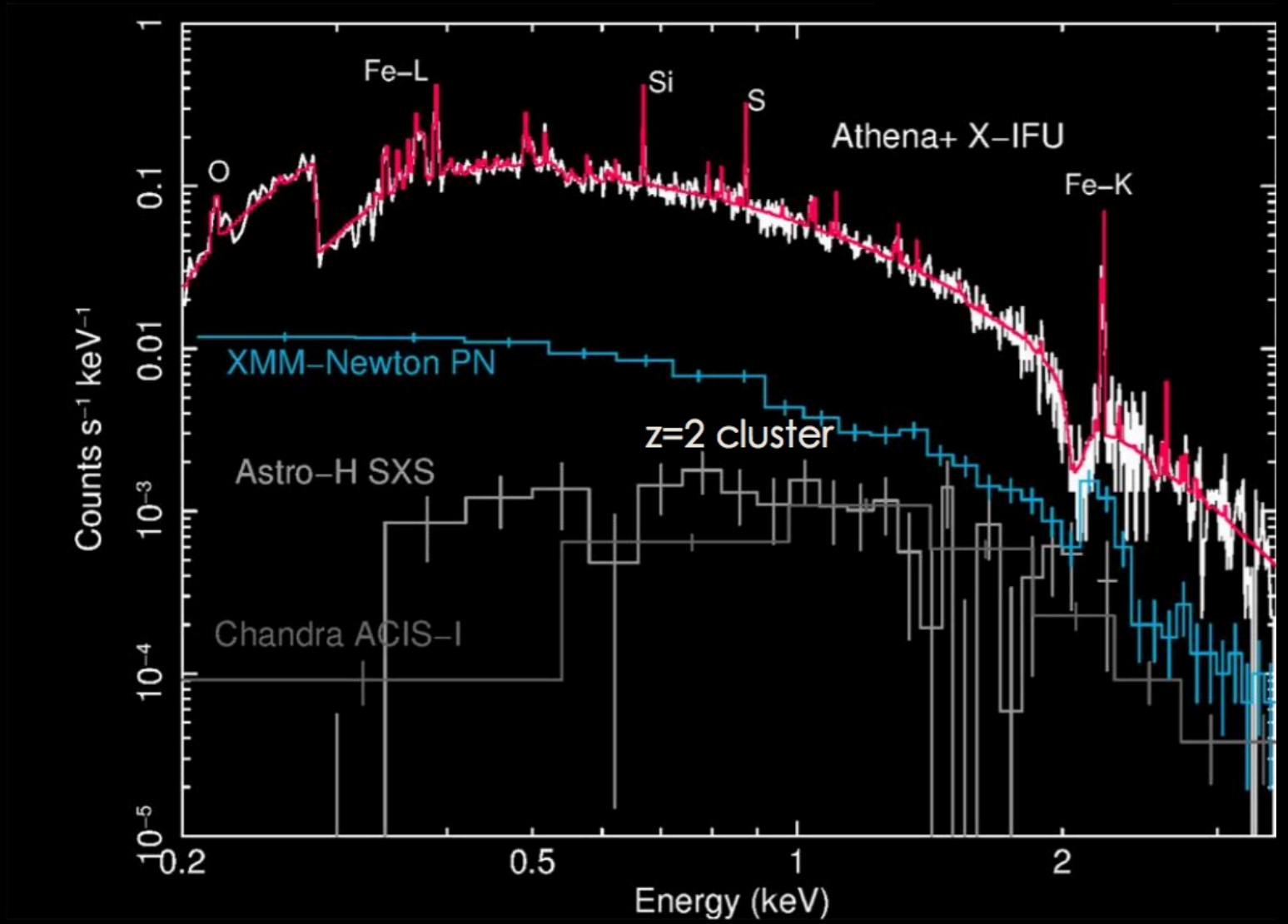
z=1

Chemical evolution of the ICM



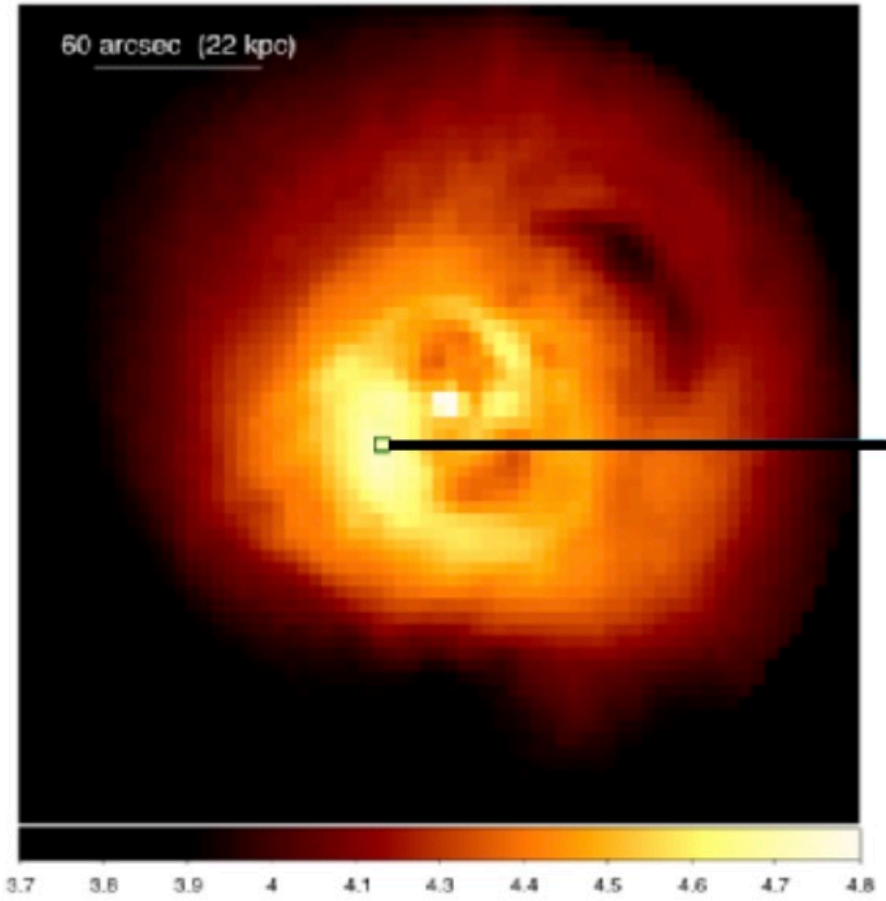
Ettori, Pratt, et al., 2013 arXiv1306.2322

Chemical evolution of the ICM

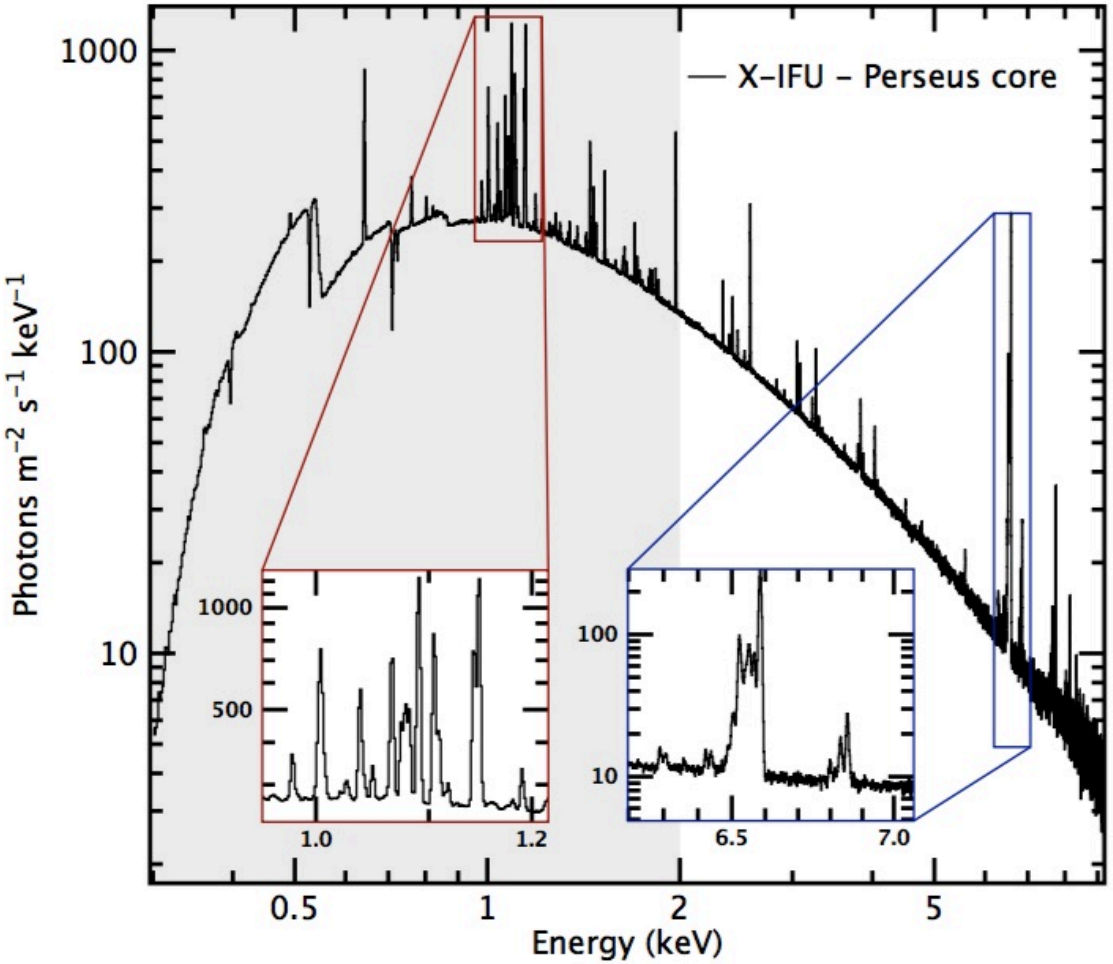


AGN feedback in the ICM

Sanders , Croston et al. 2013



Barret et al .2016



Challenges

National meetings started, Cluster I and Cluster II: clearly there are investments to be made to exploit the future data:

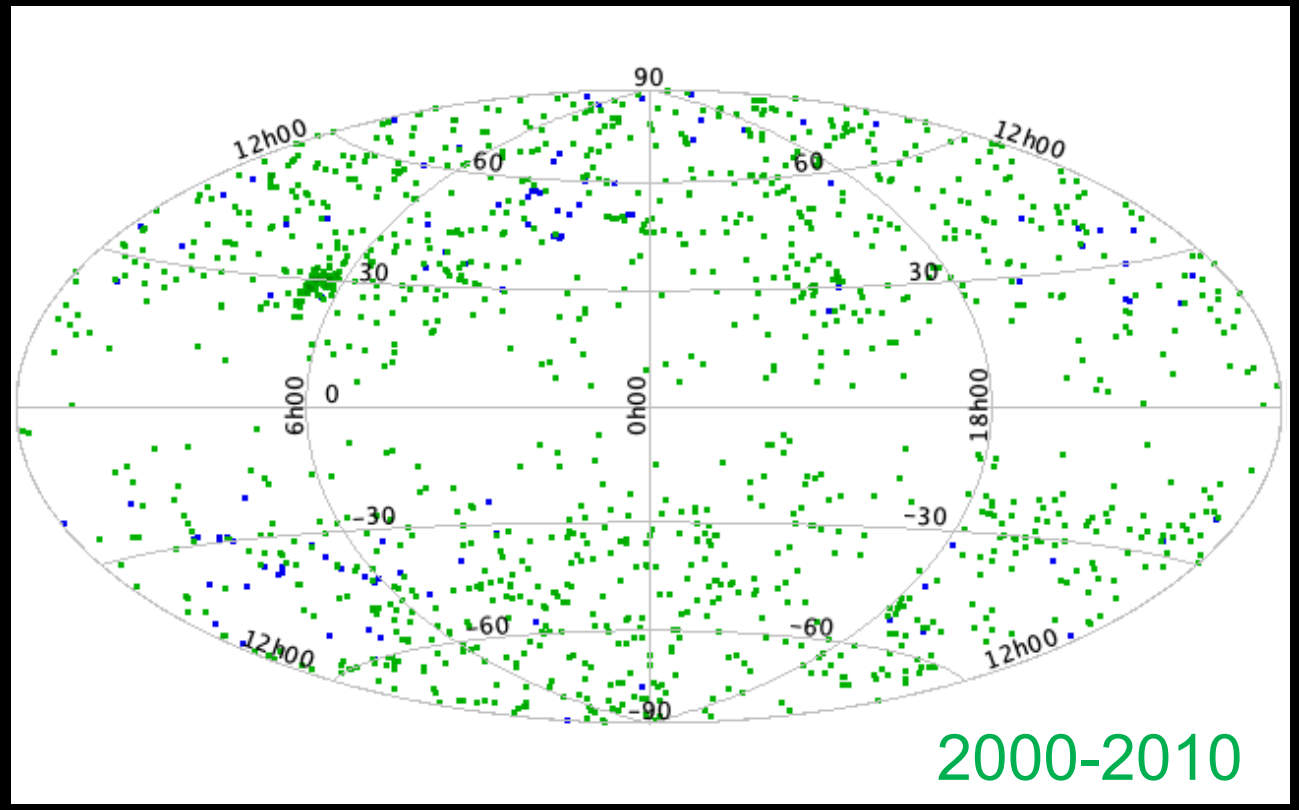
- PLASMA PHYSICS
- HIGH RESOLUTION SPECTROSCOPY, both in terms of novel data analysis methods and laboratory measurements

Challenges

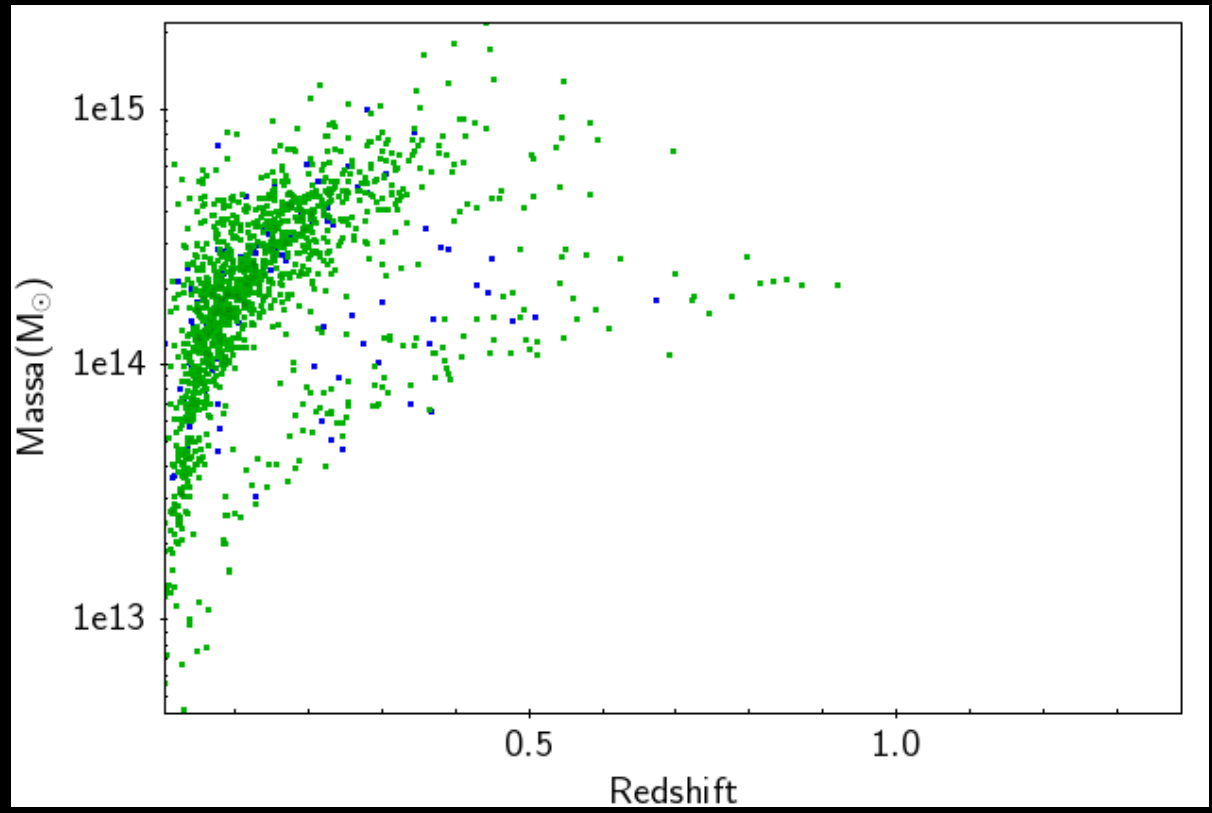
Technological challenges:

- Mirrors
- Calibration
- Background: strategies to minimize and increase its reproducibility INAF key role: IAPS (Macculi, Lotti) OAS (Fioretti) IASF-MI (Marelli, Gastaldello, Molendi, Ghizzardi, Rossetti, De Luca) IASF-Palermo (Mineo, Amato)

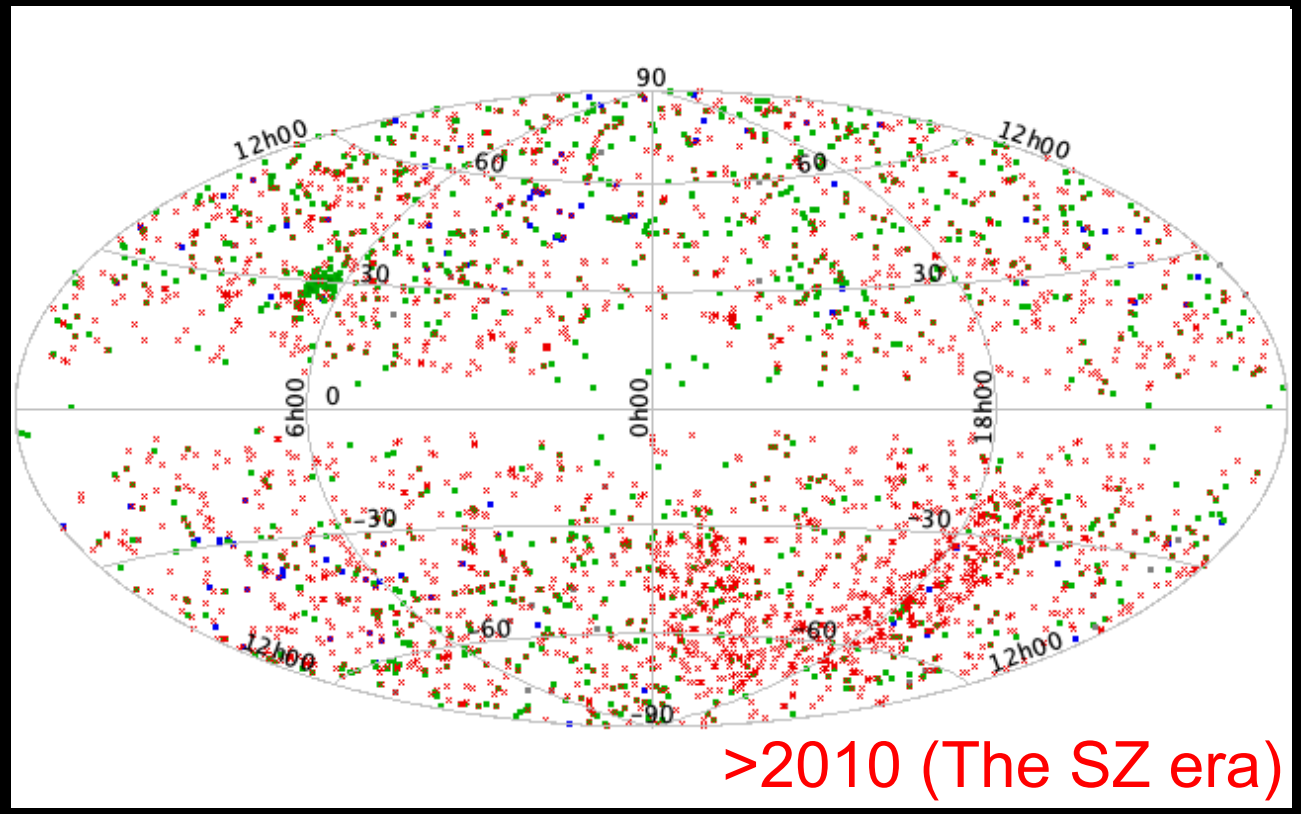
Known clusters



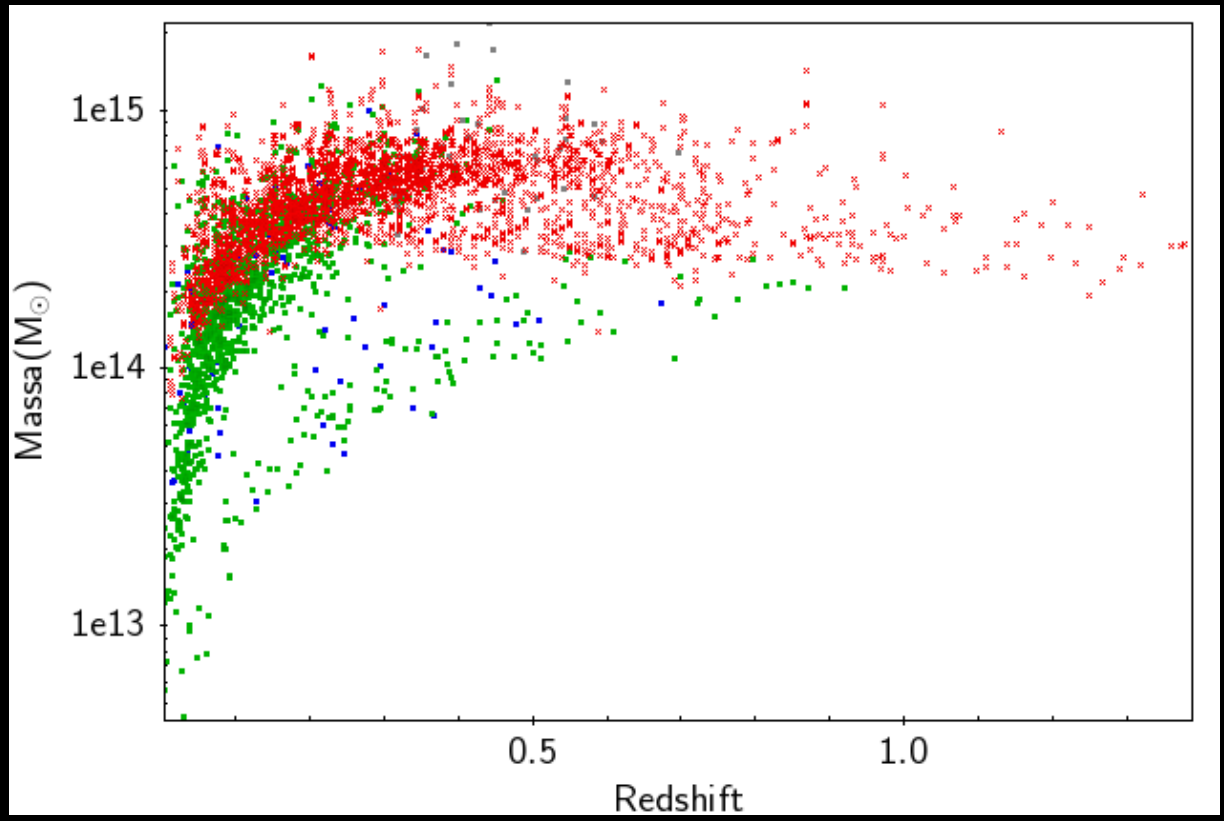
2000-2010



Known clusters



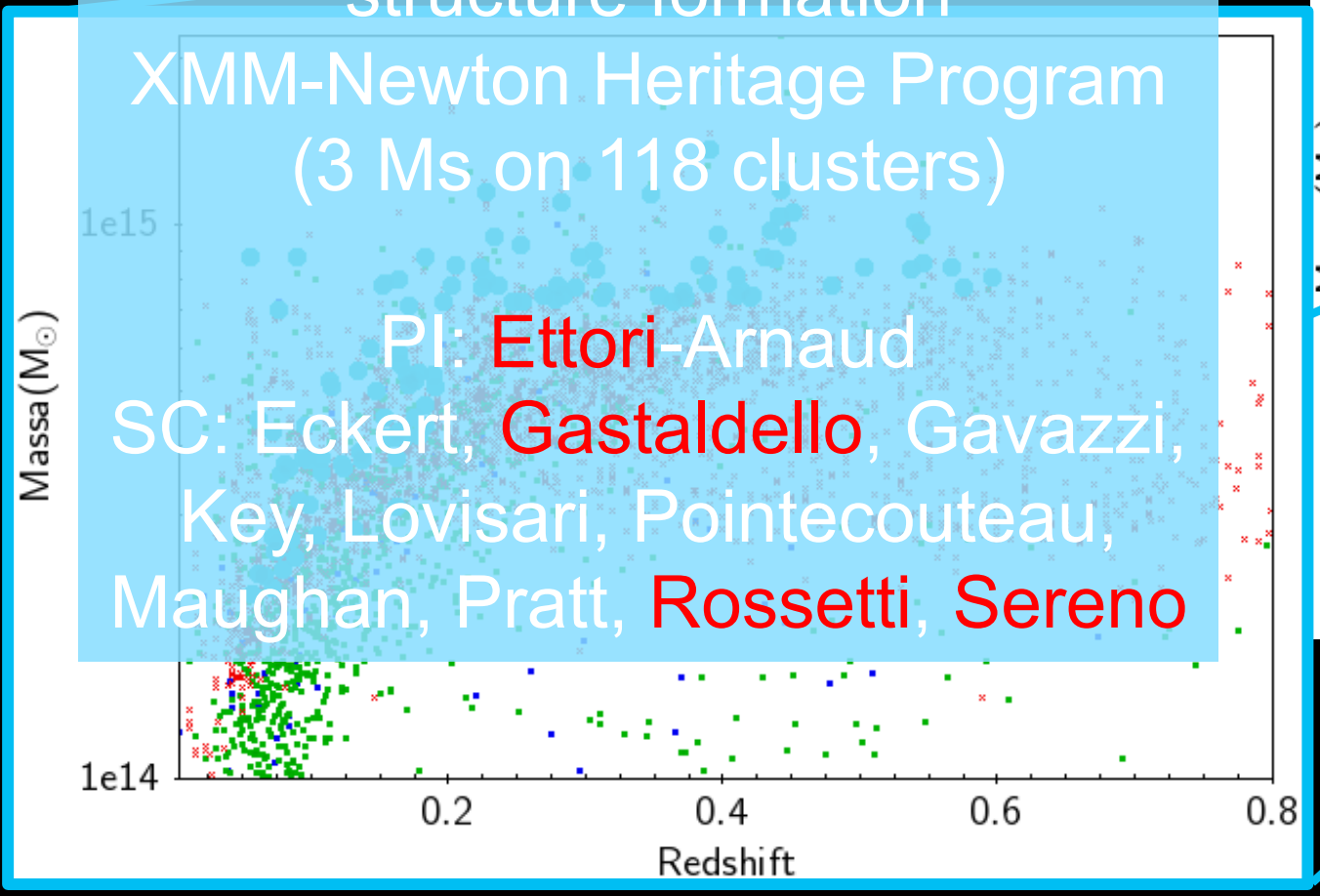
>2010 (The SZ era)

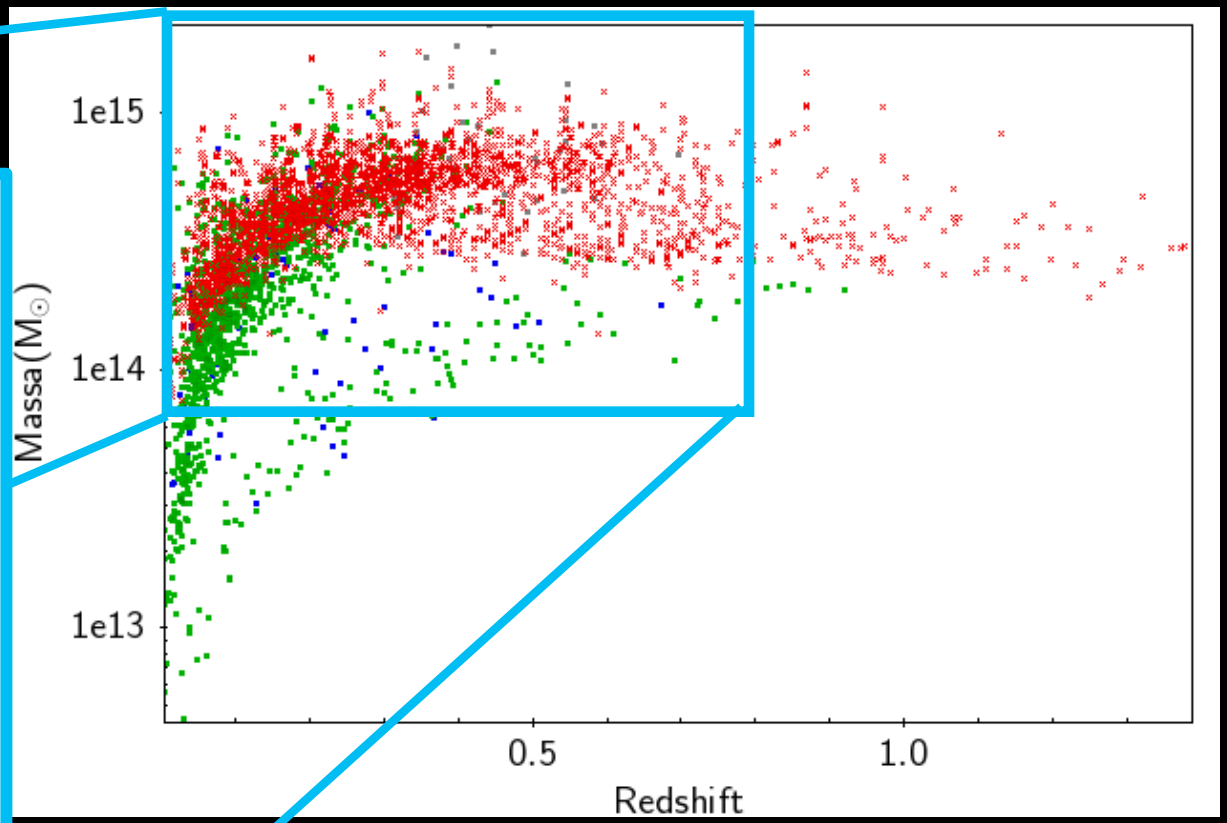


Known clusters

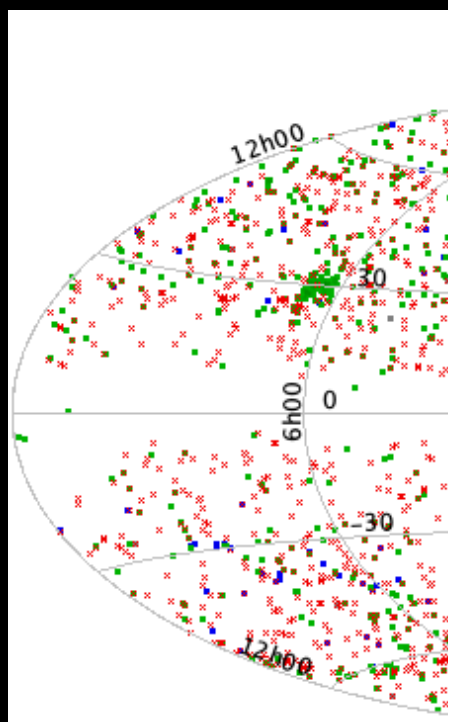
Witnessing the culmination of structure formation
XMM-Newton Heritage Program
(3 Ms on 118 clusters)

PI: Ettori-Arnaud
SC: Eckert, Gastaldello, Gavazzi, Key, Lovisari, Pointecouteau, Maughan, Pratt, Rossetti, Sereno

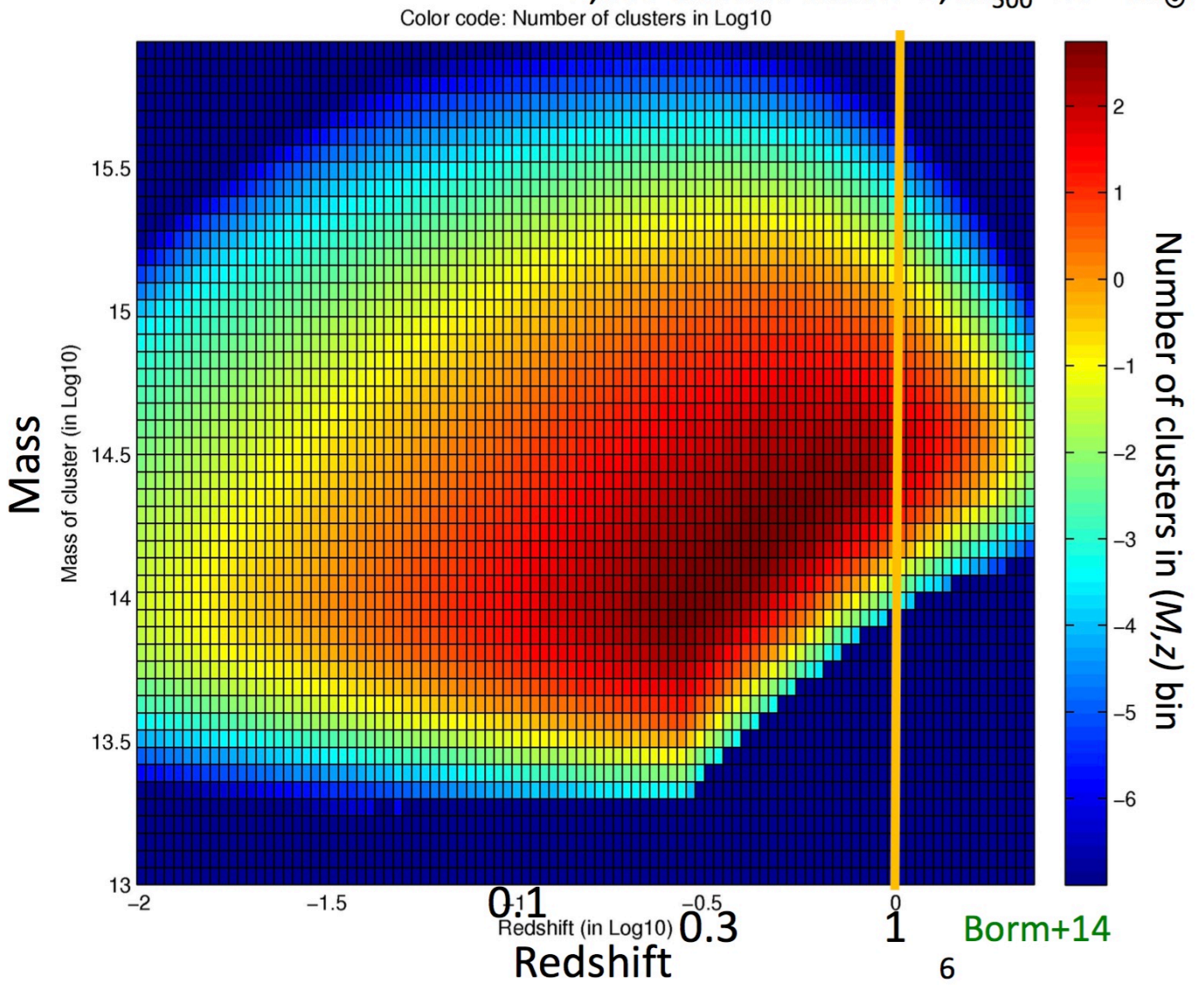




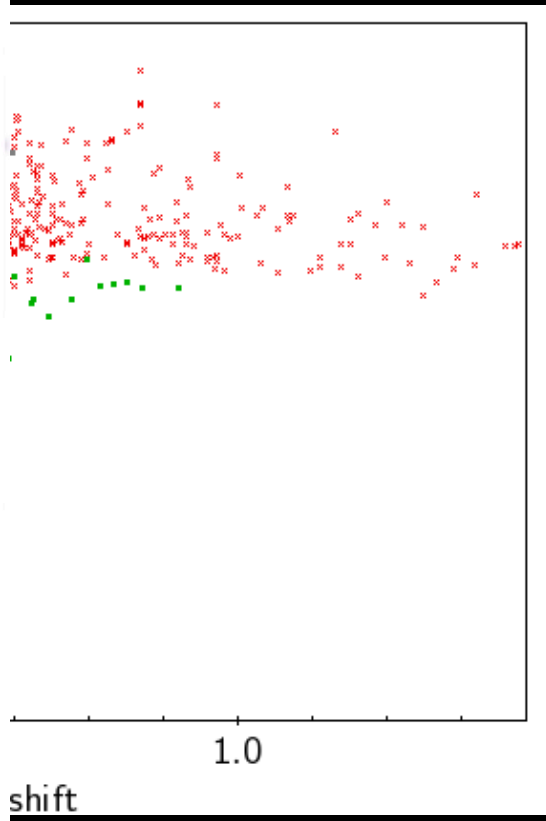
eROSITA - Cluster Demography



~1,000 clusters with $z>1$, $M_{500}>10^{14}$ $M_\odot$.



Borm+14



The future is (X-ray) bright!

June 2019

2021

2030

eROSITA