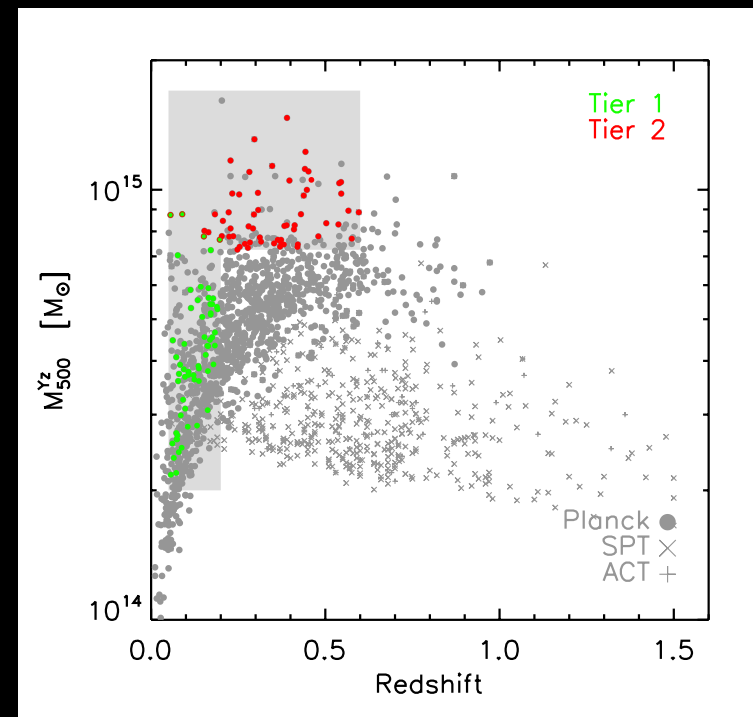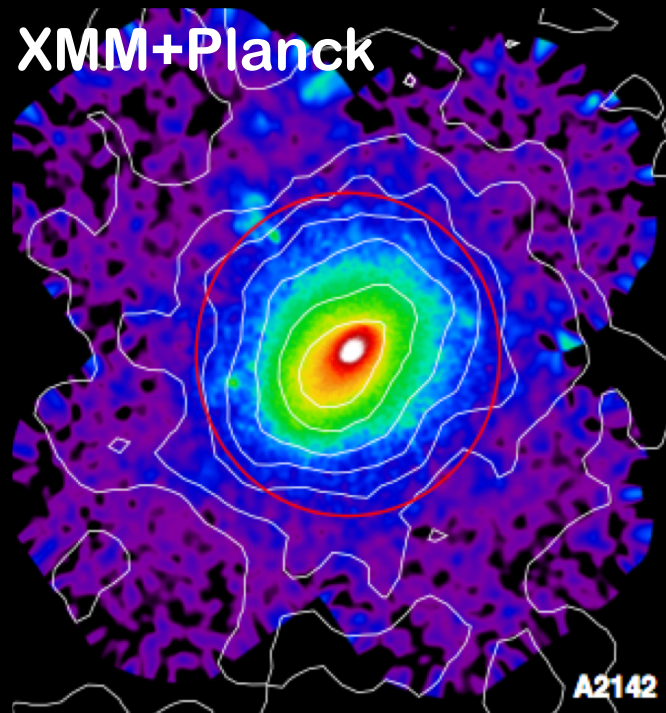# The Galaxy Clusters in the Hot Universe (MA 1.2)

OAS: **S. Ettori**, **M. Sereno** (Dec 2018), **M. Meneghetti**, *Giovani Ric 2018*, V. Ghirardini (PhD 2015-18)

IRA: G. Brunetti, R. Cassano et al.
DIFA: A. Bonafede, F. Brighenti, M. Gitti, L. Moscardini, C. Nipoti, C. Giocoli, F. Marulli, F. Vazza, *M. Roncarelli*

Main lines of research:
## cosmology & astrophysics with the thermal component of galaxy clusters

- **Mass (baryonic & dark) distribution in galaxy clusters** from X-ray (*Chandra, XMM*) data to constrain cosmological parameters (*2 master theses in 2017; 0.5 postdoc*)

- **Galaxy cluster M_{tot} from scaling relations** with X-ray, SZ & optical proxies: use, limits & implications for future surveys (from *XXL* & *eROSITA* to *Euclid* & *Athena; 0.5 postdoc*)

- **Turbulence & coherent motion of the ICM**: new window on the plasma physics through high resolution spectroscopy with next generation X-ray instruments (*XRISM, Athena; 0.5 postdoc*)

- **Properties of the galaxy cluster outskirts**, where most of the mass is and accretion is taking place: constraints from present X-ray (*ROSAT, XMM*) & SZ (*Planck*) data and from hydro-simulations (*1 PhD*)

Main lines of research:
cosmology & astrophysics with the thermal component of galaxy clusters

- ➢ Italian (INAF -Bo, Mi, Fi, Ts-, Tor Vergata) & international (CH, D, F, UK, J, US) network

- ➢ *Projects*: CLASH-VLT, CLUMP-3D, XXL, BUFFALO, WEAVE, ***XMM Heritage***, Euclid, Athena

- ➢ ~80 refereed papers in the last 3 years

R$_{500}$ - limit for XMM/Chandra
R$_{200}$ - limit for Suzaku (LEO)
3R$_{500}$ - limit for Planck SZ stack

3R$_{200}$

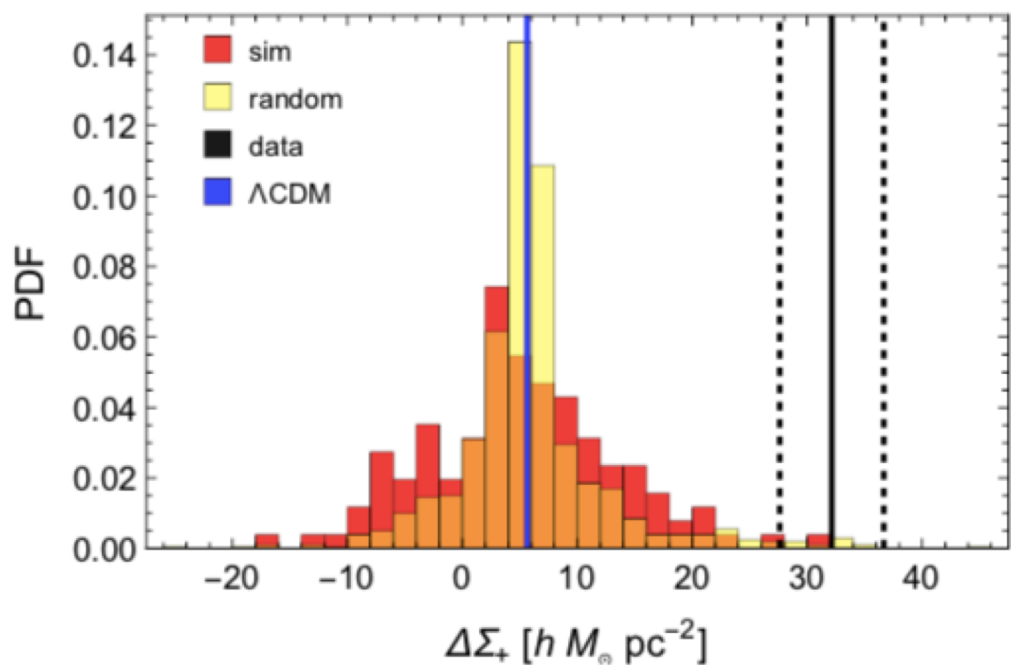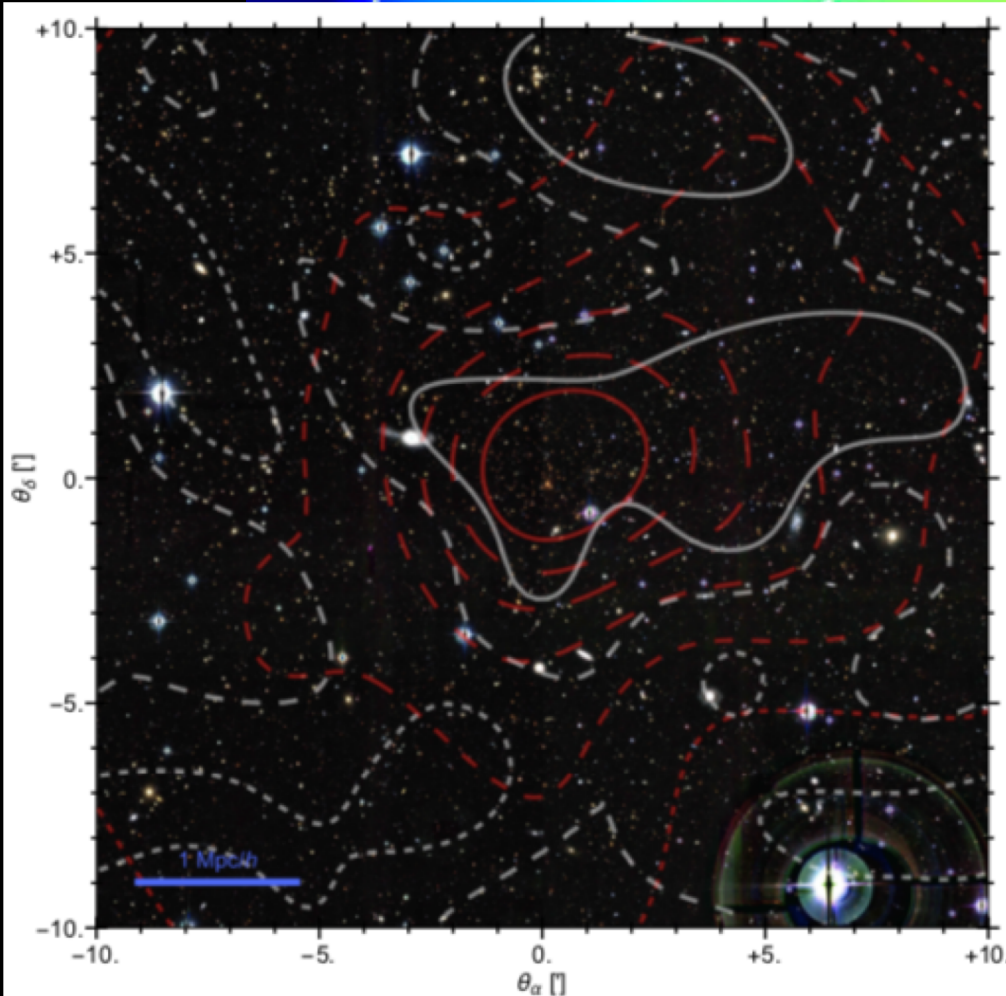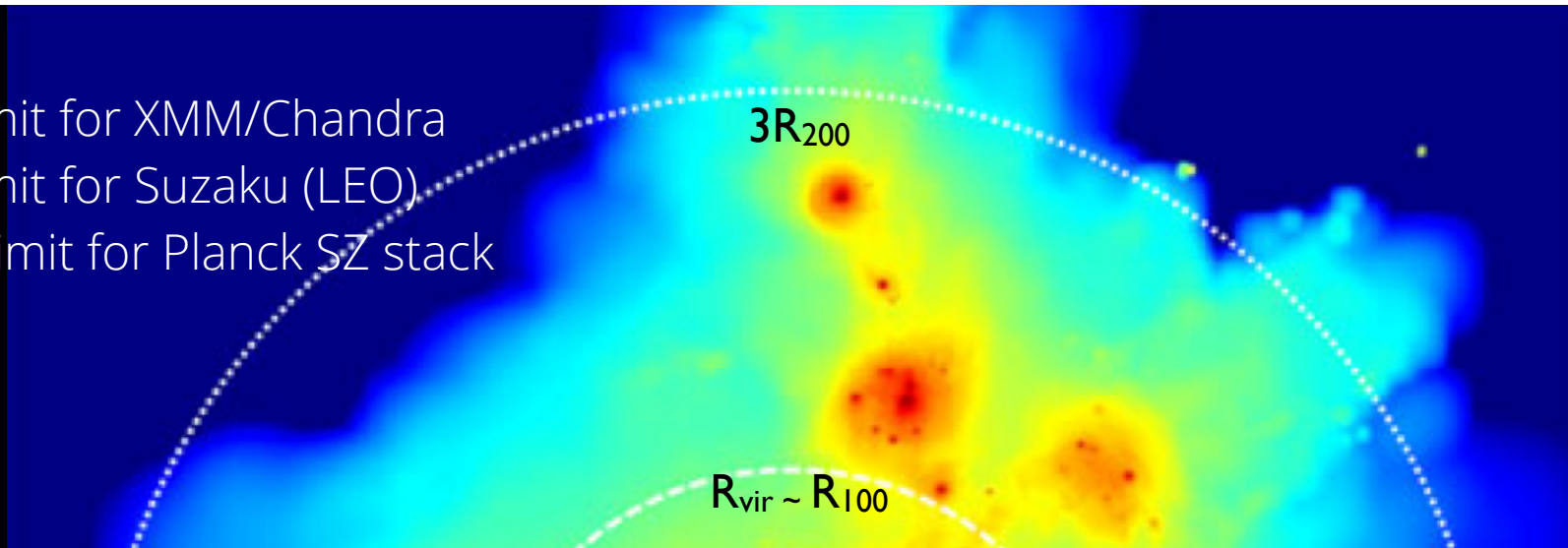R$_{vir}$ ~ R$_{100}$
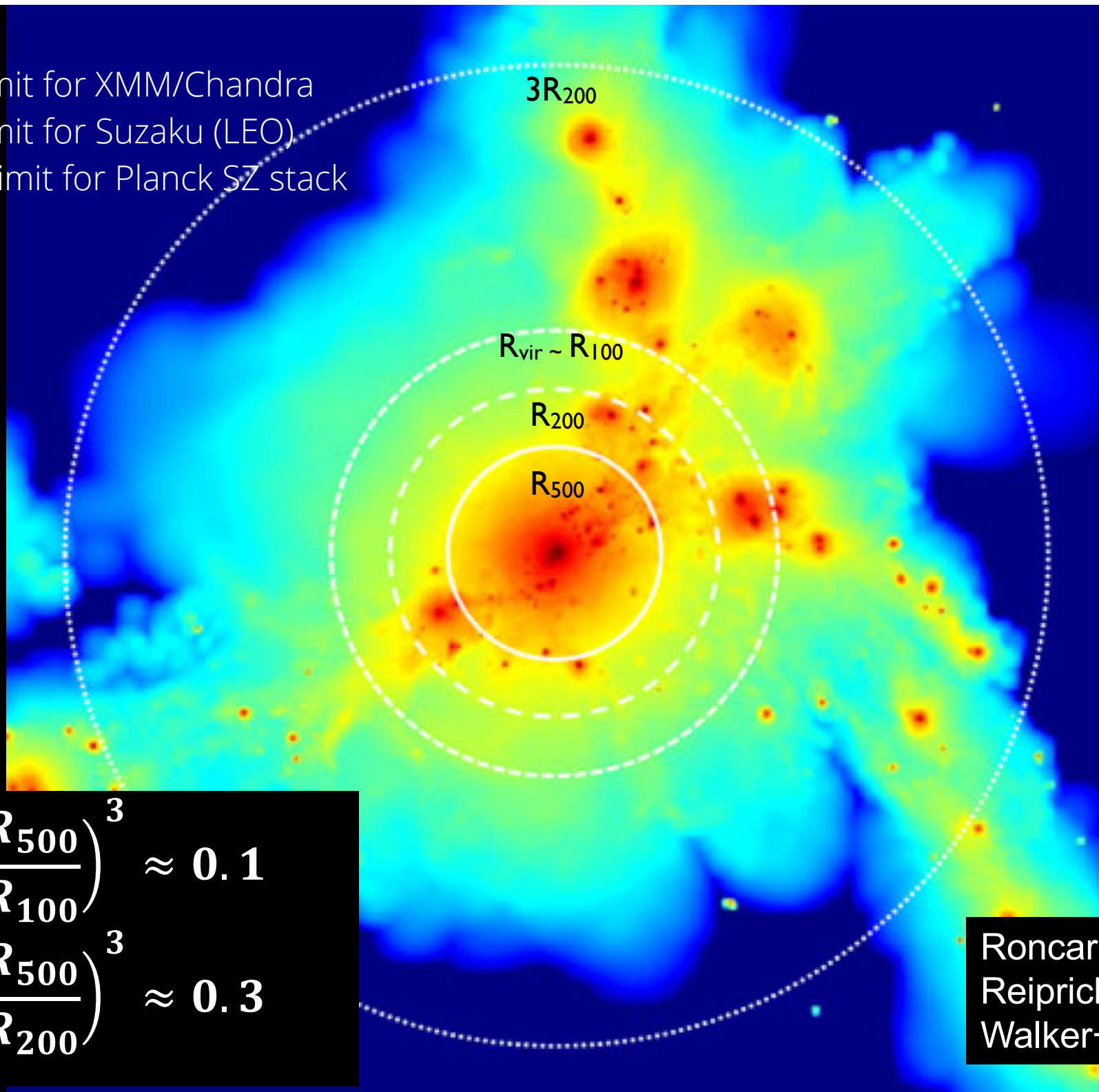
R$_{200}$

R$_{500}$

$$\left(\frac{R_{500}}{R_{100}}\right)^3 \approx 0.1$$

$$\left(\frac{R_{500}}{R_{200}}\right)^3 \approx 0.3$$

Roncarelli+06
Reiprich+13
Walker+19

R$_{500}$ - limit for XMM/Chandra
R$_{200}$ - limit for Suzaku (LEO)
3R$_{500}$ - limit for Planck SZ stack

3R$_{200}$

R$_{vir}$ ~ R$_{100}$

Figure 3. Averaged differential surface density of PSZ2 G099.86+58.45. Shown is the differential surface density $\Delta\Sigma_+$ in the radial range $10 < R < 25$ Mpc h^{-1}. The histograms show the theoretical predictions, as obtained from numerical simulations (red) or the signal from random pointings added to the expected value (yellow). The black vertical lines mark the observed value for PSZ2 G099.86+58.45 (full black) and the 68.3 per cent confidence region (dashed). The blue line marks the ΛCDM prediction.
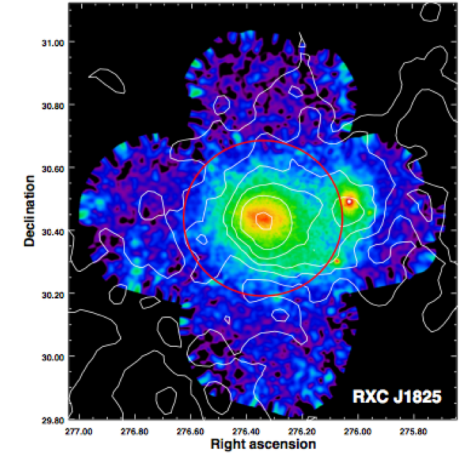
Sereno+18 Nat. Astr.

X-COP (*XMM LP +Planck; PI: Eckert, coI: Ettori*)
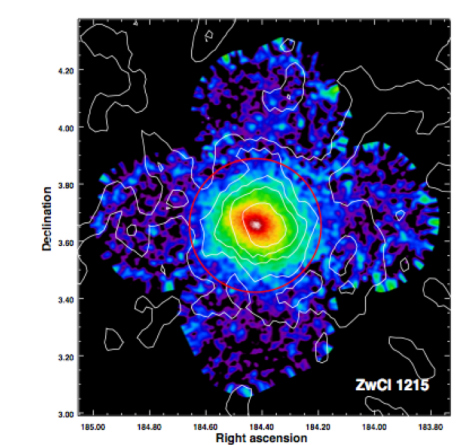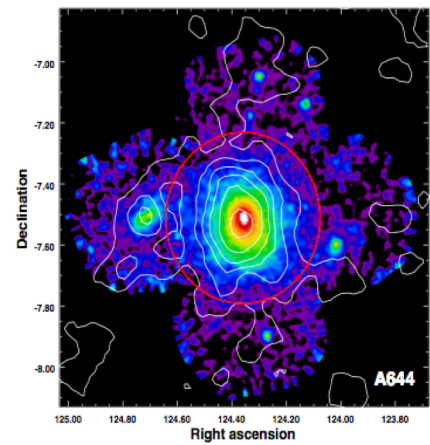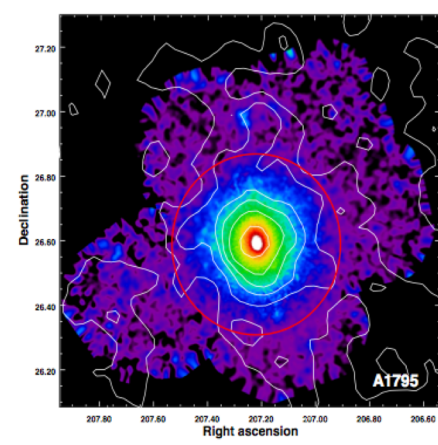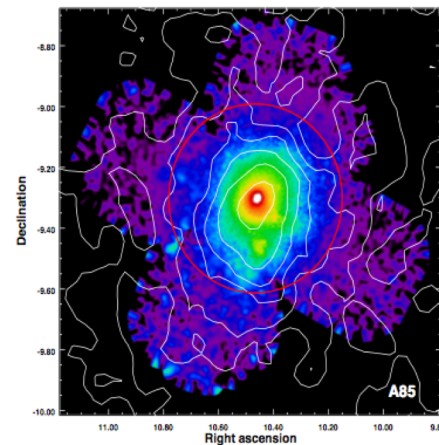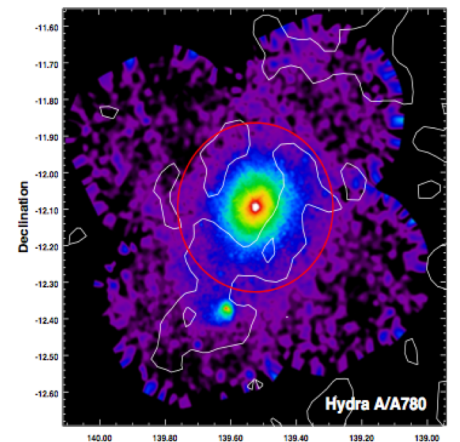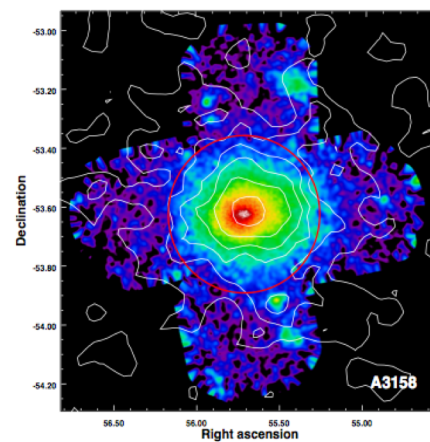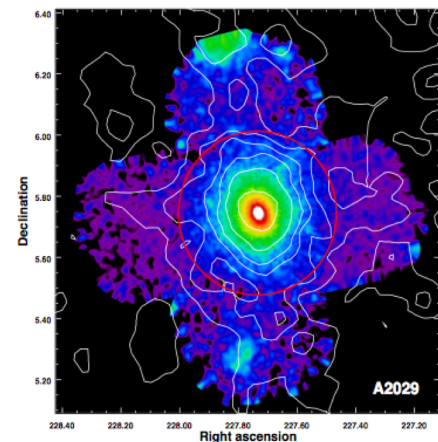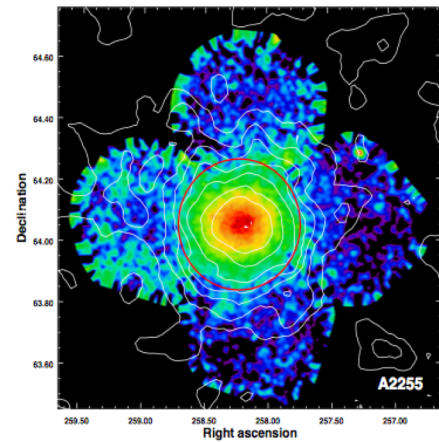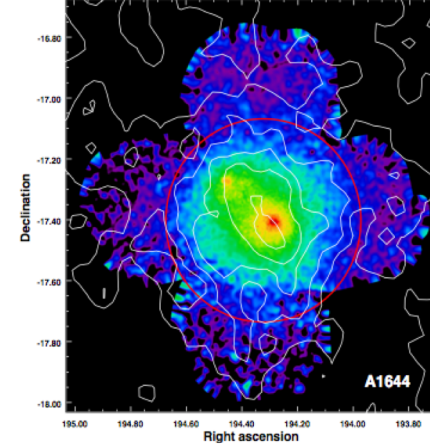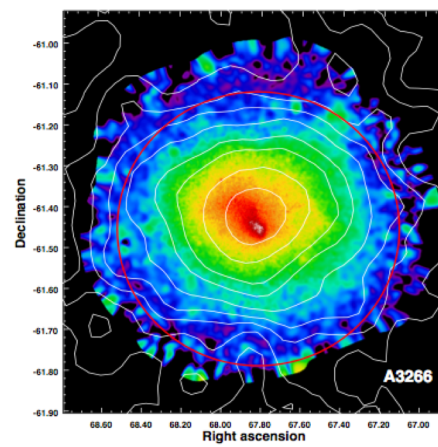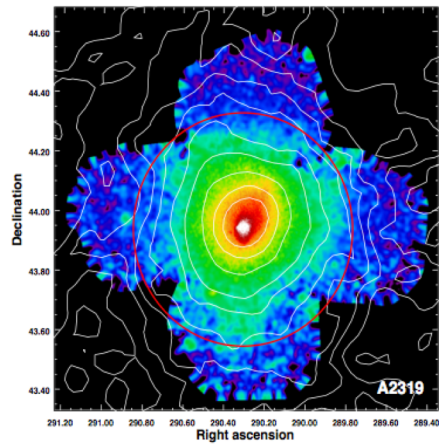
X-COP: the sample
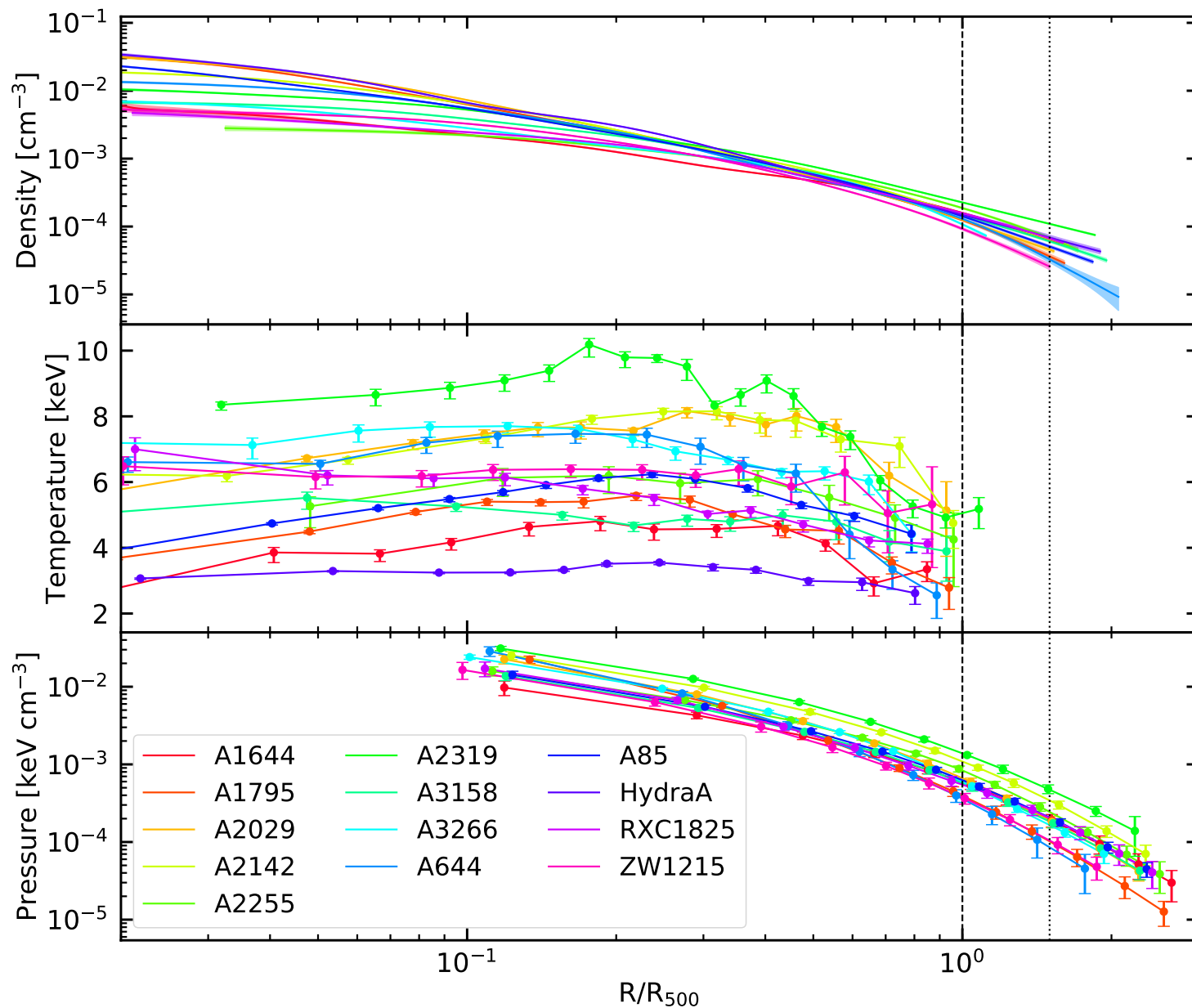
$$T = P/n$$

$$K = P/n^{5/3}$$

$$M \sim -r^2/n \, dP/dr$$

Main results in
Ghirardini+18 / on universal profiles;
Eckert+18 / on non-thermal P;
Ettori+18 / on mass profiles

Highlights from last 3 years

- ***Cosmology***: Sereno+18 (Nat.Ast.) on lensing signal out to 30 Mpc in a galaxy cluster marginally in tension with LCDM predictions; Corasaniti+18 on DM halo sparsity

- **X-COP**: a XMM VL program to study the galaxy cluster outskirts (6 +1 papers; main activity of the INAF PhD student Ghirardini)

Highlights from last 3 years

- **_Cosmology_**: Sereno+18 (Nat.Ast.) on lensing signal out to 30 Mpc in a galaxy cluster marginally in tension with LCDM predictions; Corasaniti+18 on DM halo sparsity

- **X-COP**: a XMM VL program to study the galaxy cluster outskirts (6 +1 papers; main activity of the INAF PhD student Ghirardini)

- **CoMaLit** (Sereno, Ettori et al. series of 5 papers): we present a general method to infer the mass and the redshift dependence, and the time-evolving intrinsic scatter of the mass–observable relations

- **CLUMP-3D** (Sereno et al.): a multi-probe 3D analysis of the gas and DM halo

- **CLASH**: several papers, including few that address the X-ray mass distribution and morphology of these 25 massive galaxy clusters

- **XXL Survey**: the largest XMM program totaling ~2.9 (+4) Msec to map homogeneously 50 deg^2 & involving an international consortium of roughly 100 members (13 +22 papers accepted on Nov 15 & 18; _press releases from ESA, ESO, INAF_)

- **XMM Heritage Cluster Project**

XMM Heritage Cluster Project
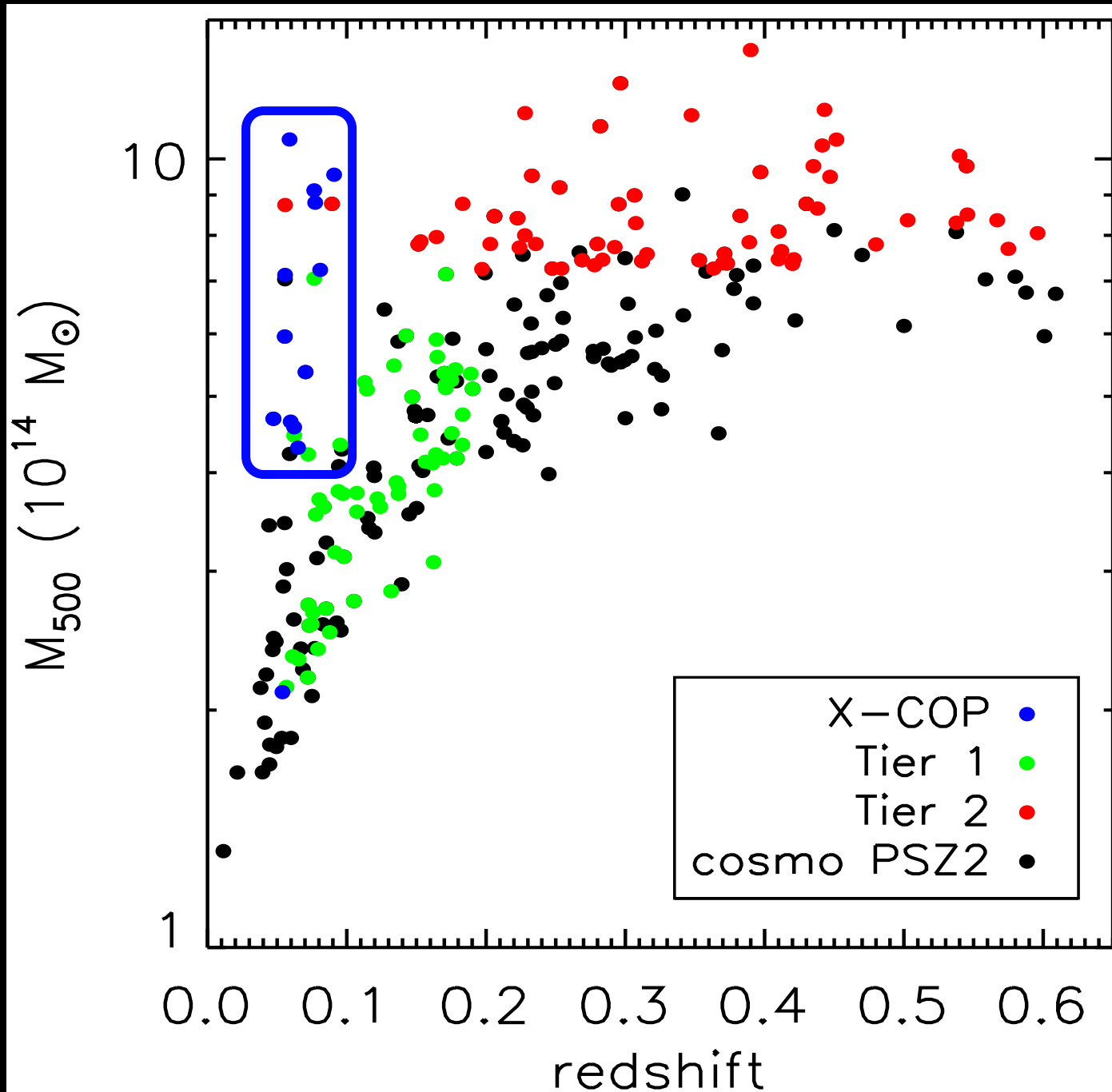
3 Msec *XMM-Newton* observing time obtained in the 2017 call (PI: *M. Arnaud & S. Ettori*) to study the culmination of cosmic structure formation with **the ultimate sample of 118 *Planck* SZ-selected objects**:
(i) the population of clusters at the most recent time (z < 0.2);
(ii) the most massive objects to have formed thus far in the history of the Universe.

Targets of the Heritage Project

Selection for the 3 Msec *program:*

SNR>6.5;   z ∈ [0.05, 0.6];   M$_{Tier-2}$>7.25e14

- Assess the relative importance of gravitational and non-gravitational processes in shaping cluster properties
- Probe the dynamical collapse of the gas on different scales
- Construct a consistent picture of cluster mass estimates
- Provide a unique reference for evolution studies and numerical modelling
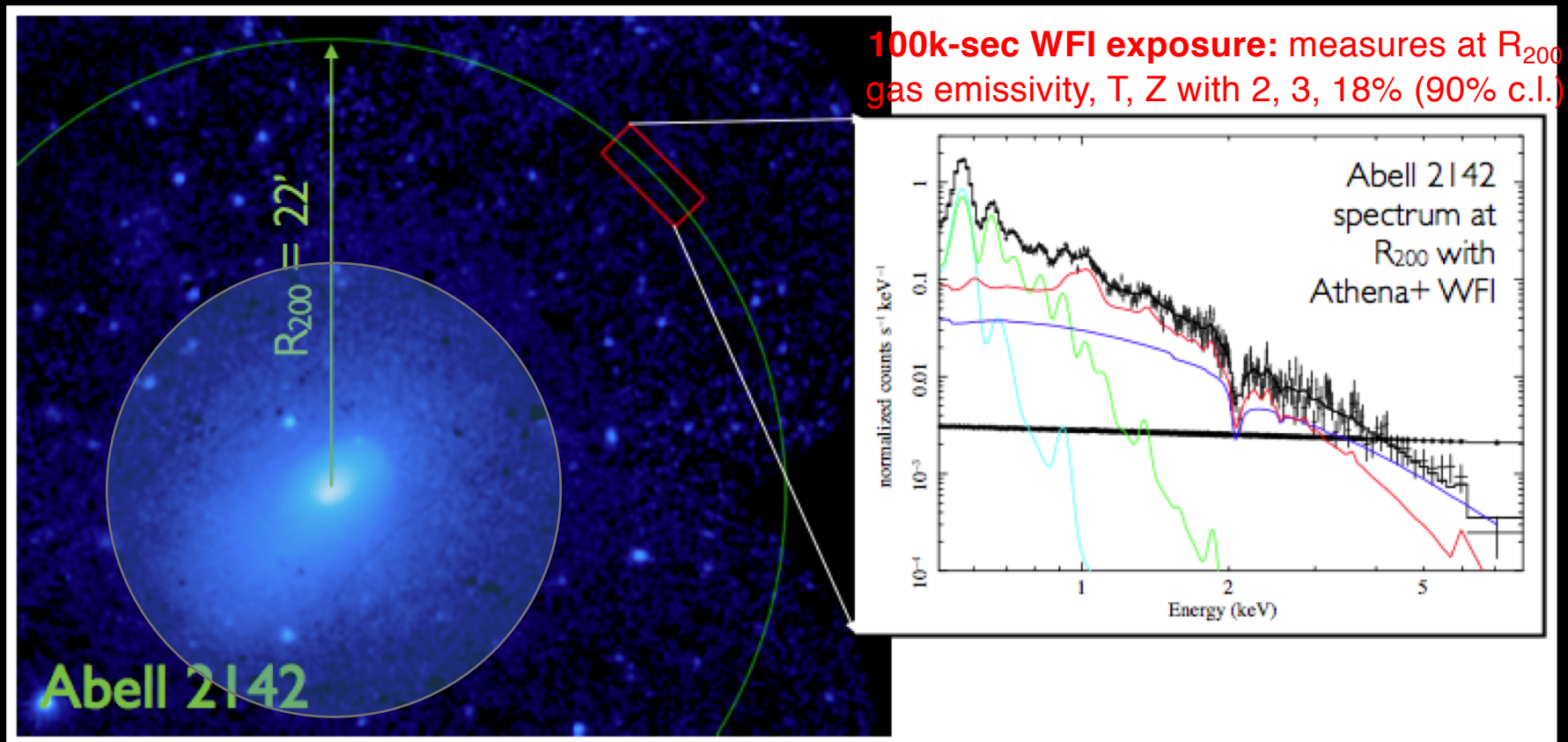- Legacy for Next Generation missions
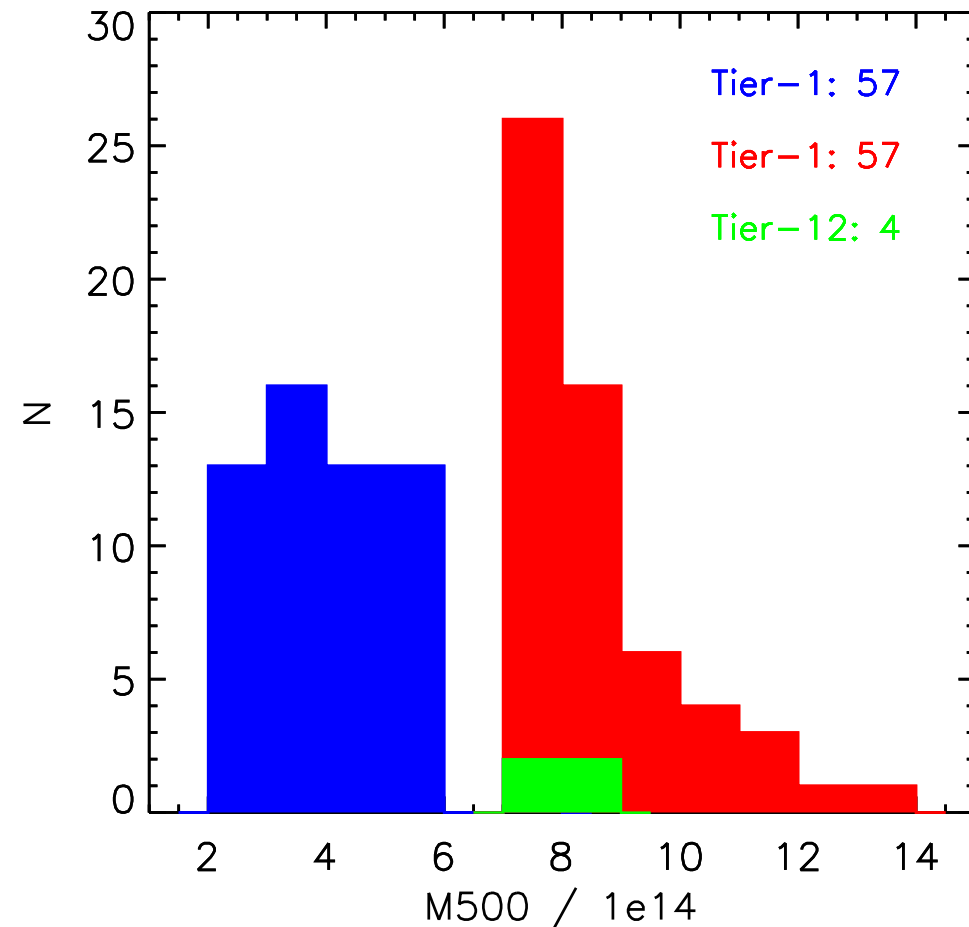
ATHENA

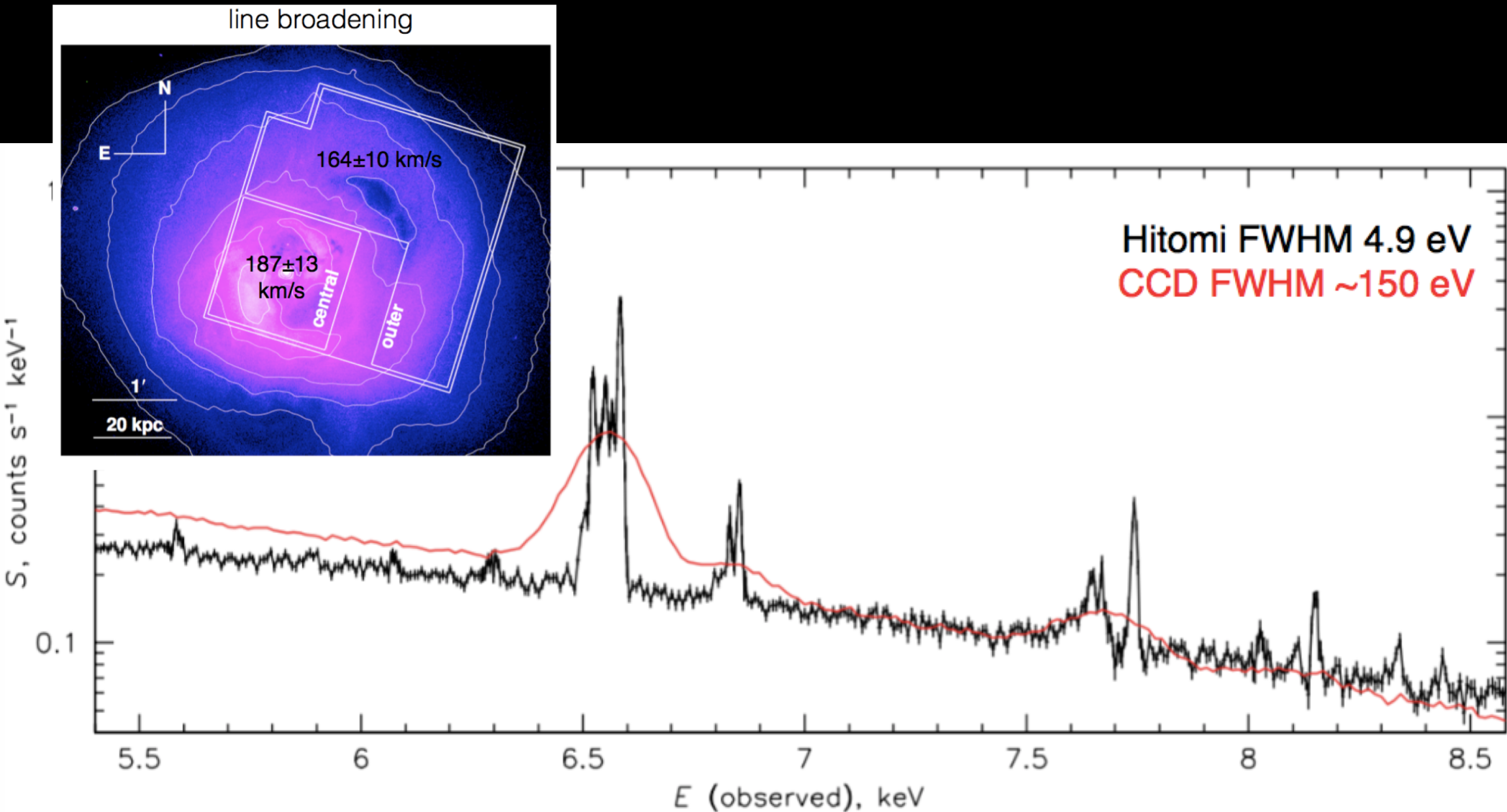# The formation and evolution of clusters and groups of galaxies

How and when was the energy contained in the hot intra-cluster medium generated?

Ettori, Pratt et al., 2013 arXiv1306.2322

100k-sec WFI exposure: measures at R_{200} gas emissivity, T, Z with 2, 3, 18% (90% c.l.)

R_{200} = 22'

Abell 2142

Abell 2142 spectrum at R_{200} with Athena+ WFI

normalized counts s^{-1} keV^{-1}

Energy (keV)

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

Turbulence in the ICM
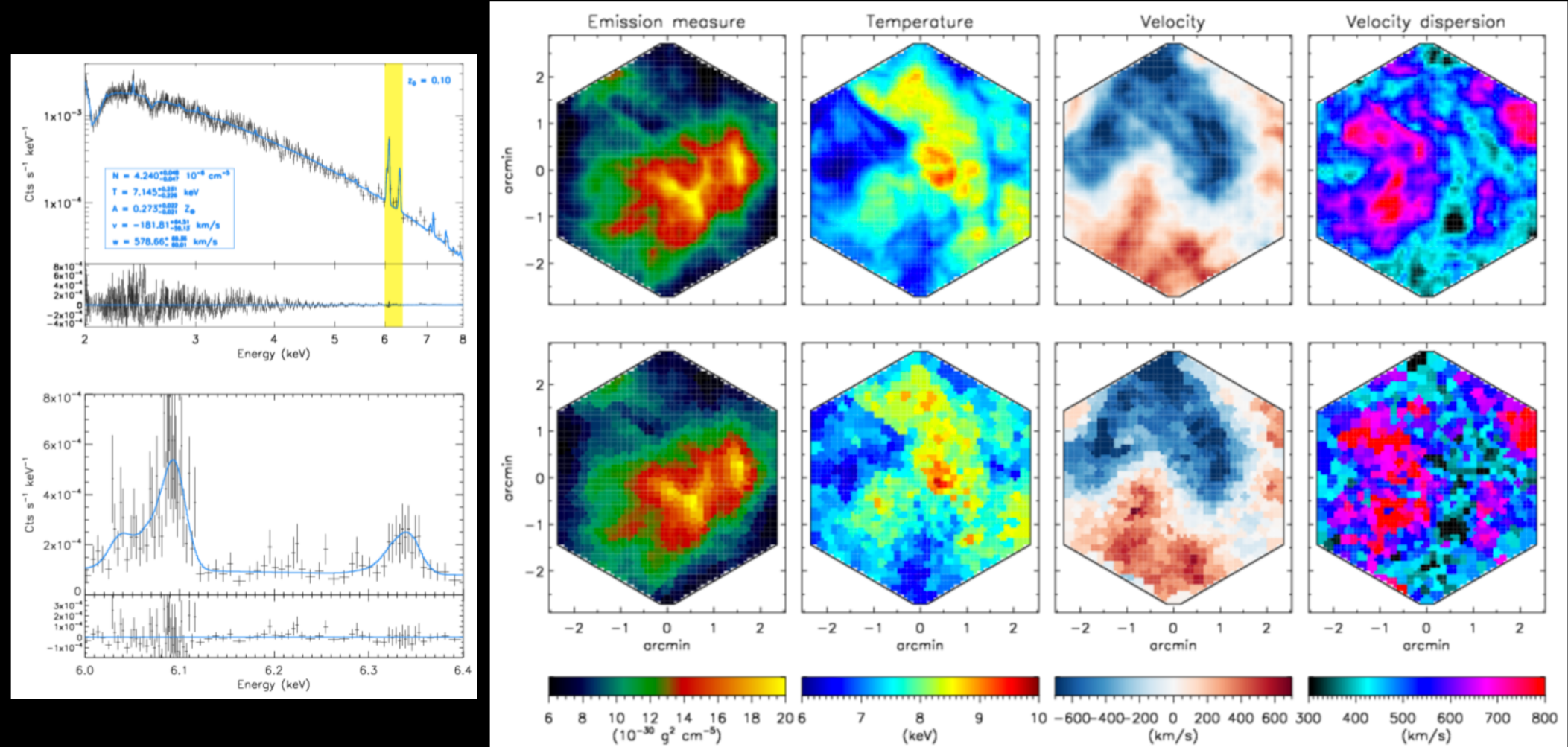
ATHENA

The formation and evolution of clusters and groups of galaxies

How and when was the energy contained in the hot intra-cluster medium generated?

XIFU, SIXTE & simulated Velocity map

Roncarelli, Gaspari, Ettori et al., *arXiv:1805.02577*

Man-power & Funding

- An INAF PhD for the period 2015-2018 (Vittorio Ghirardini)

- Two new staff (M. Sereno -Dec 18; *Giovani Ricercatori*)

- **Funds**

  ➢ ASI-INAF "Data analysis" (few tens kEUR / pre-Heritage);

  ➢ *ISSI Team 2018* to cover meeting of Heritage Steering Committee;

  ➢ NASA ADAP grant (2019-2021; 3-yrs +1.5-yrs US PostDocs)

Man-power & Funding

- An INAF PhD for the period 2015-2018 (Vittorio Ghirardini)

- Two new staff (M. Sereno -Dec 18; *Giovani Ricercatori*)

- **Funds**

  - ➢ ASI-INAF "Data analysis" (few tens kEUR / pre-Heritage);

  - ➢ *ISSI Team 2018* to cover meeting of Heritage Steering Committee;

  - ➢ NASA ADAP grant (2019-2021; 3-yrs +1.5-yrs US PostDocs)

- **Autonomy limited to <1 year** (!):

  - ✓ **ASI supports *poorly* the activities related to Athena's science**

  - ✓ ASI-INAF "Data analysis": 2nd call in Summer 2019

  - ✓ INAF Main Stream on *XMM Heritage* (hw +travel): results?

  - ✓ *PRIN-MIUR* 2017 (beginning of 2019?)

  - ✓ *Co-funding with DIFA is valuable (more coordination?)*

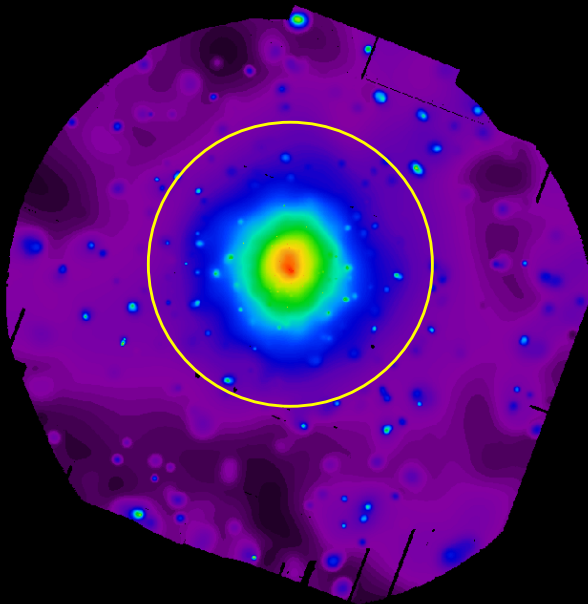# The XMM-Newton Heritage Project
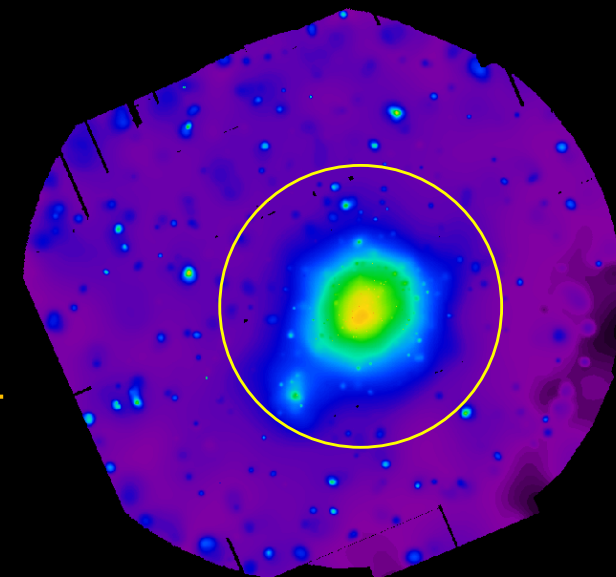
PSZ2G008, **z=0.312**, M_{500}=7.4e14
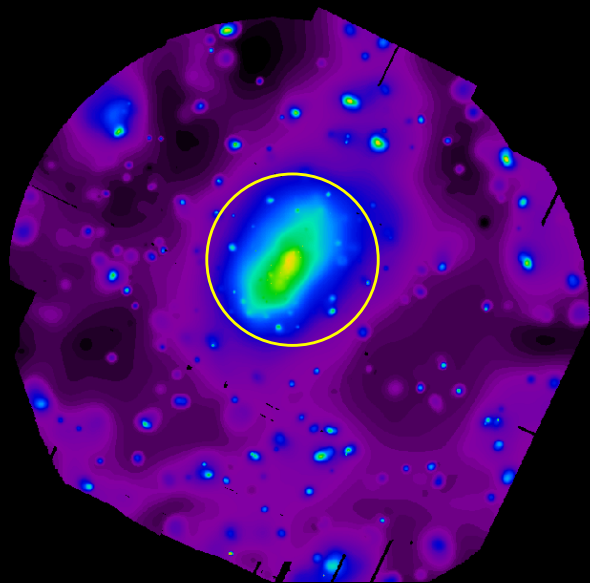
PSZ2G066, **z=0.163**, M_{500}=3.8e14
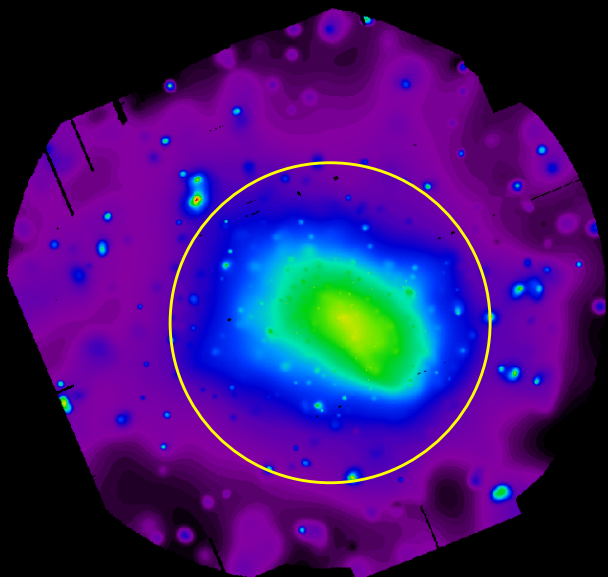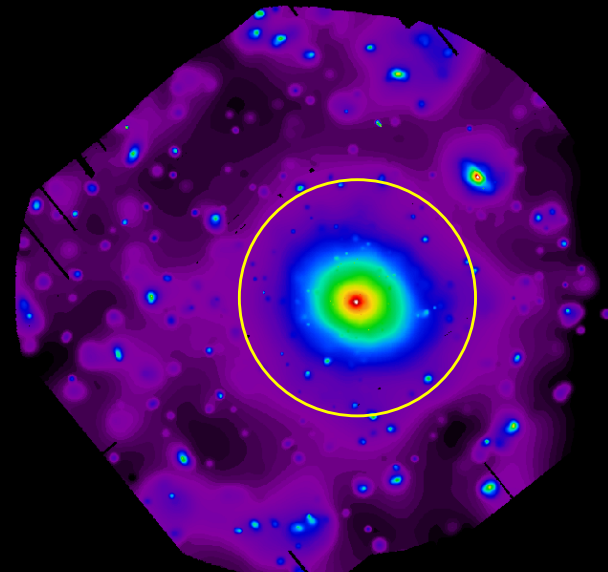
PSZ2G077, **z=0.147**, M_{500}=5e14

PSZ2G273, **z=0.134**, M_{500}=5.5e14

PSZ2G285, **z=0.165**, M_{500}=6.5e14