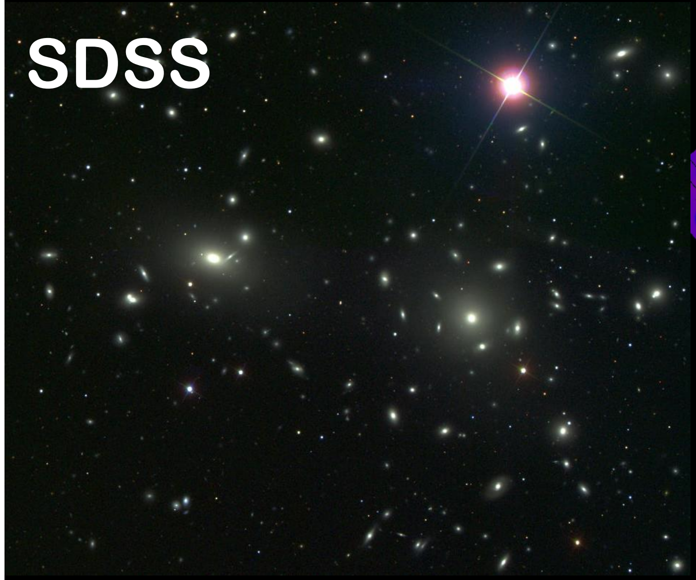
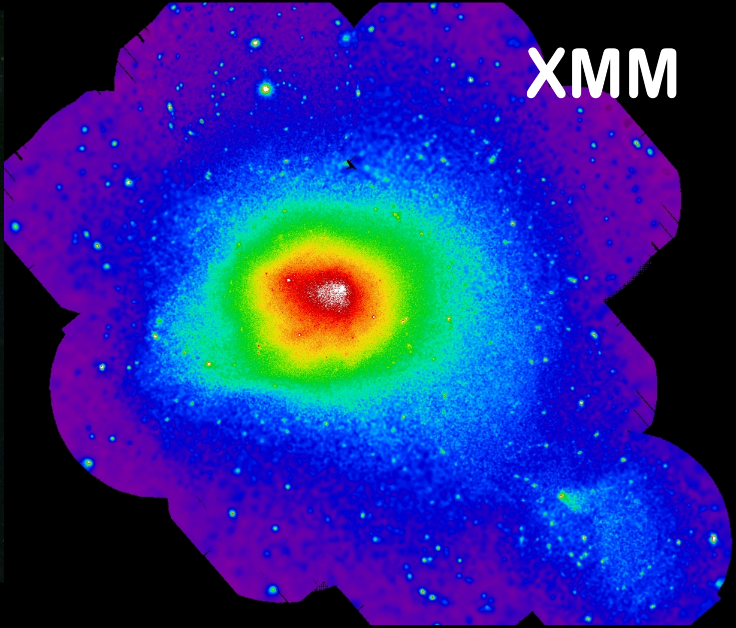
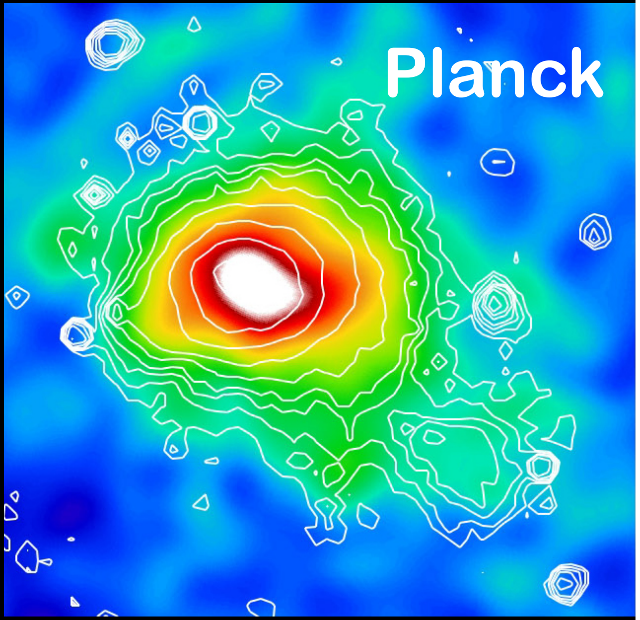
X-ray, SZ & dark matter in Galaxy Clusters

Stefano Ettori
INAF-OA / INFN Bologna

(Main) collaborators: D. Eckert, **V. Ghirardini,** M. Roncarelli, M. Sereno







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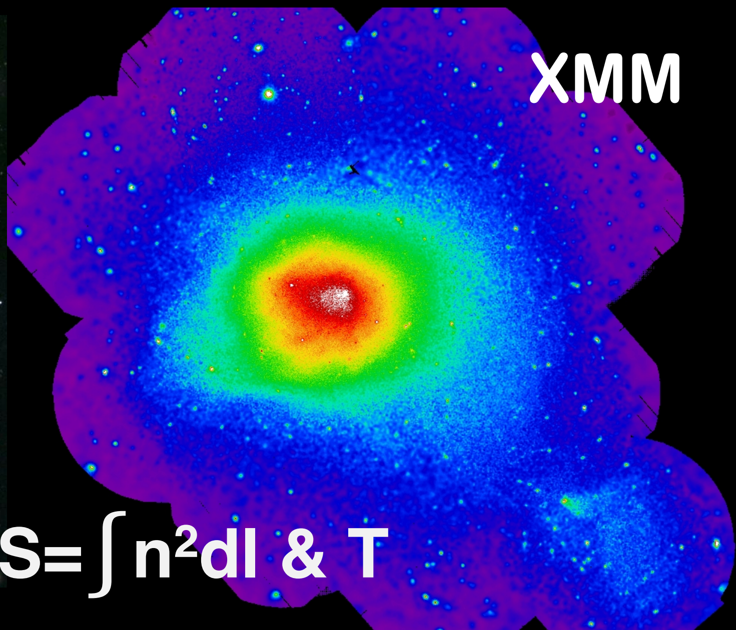
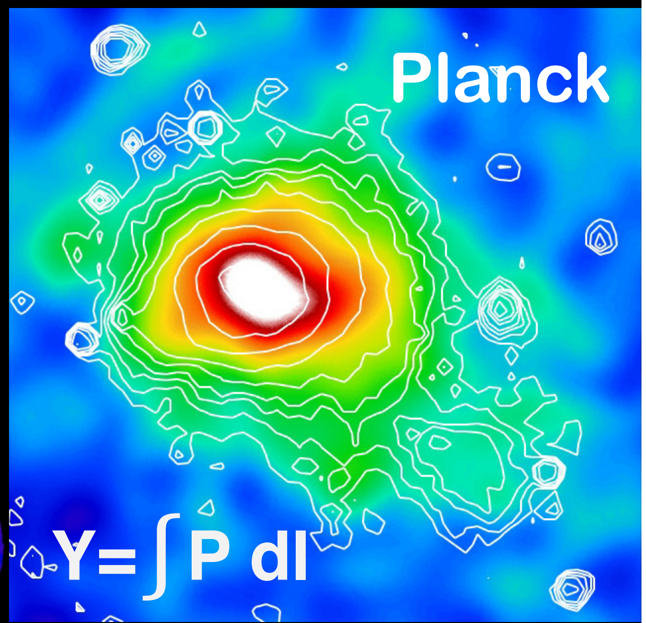
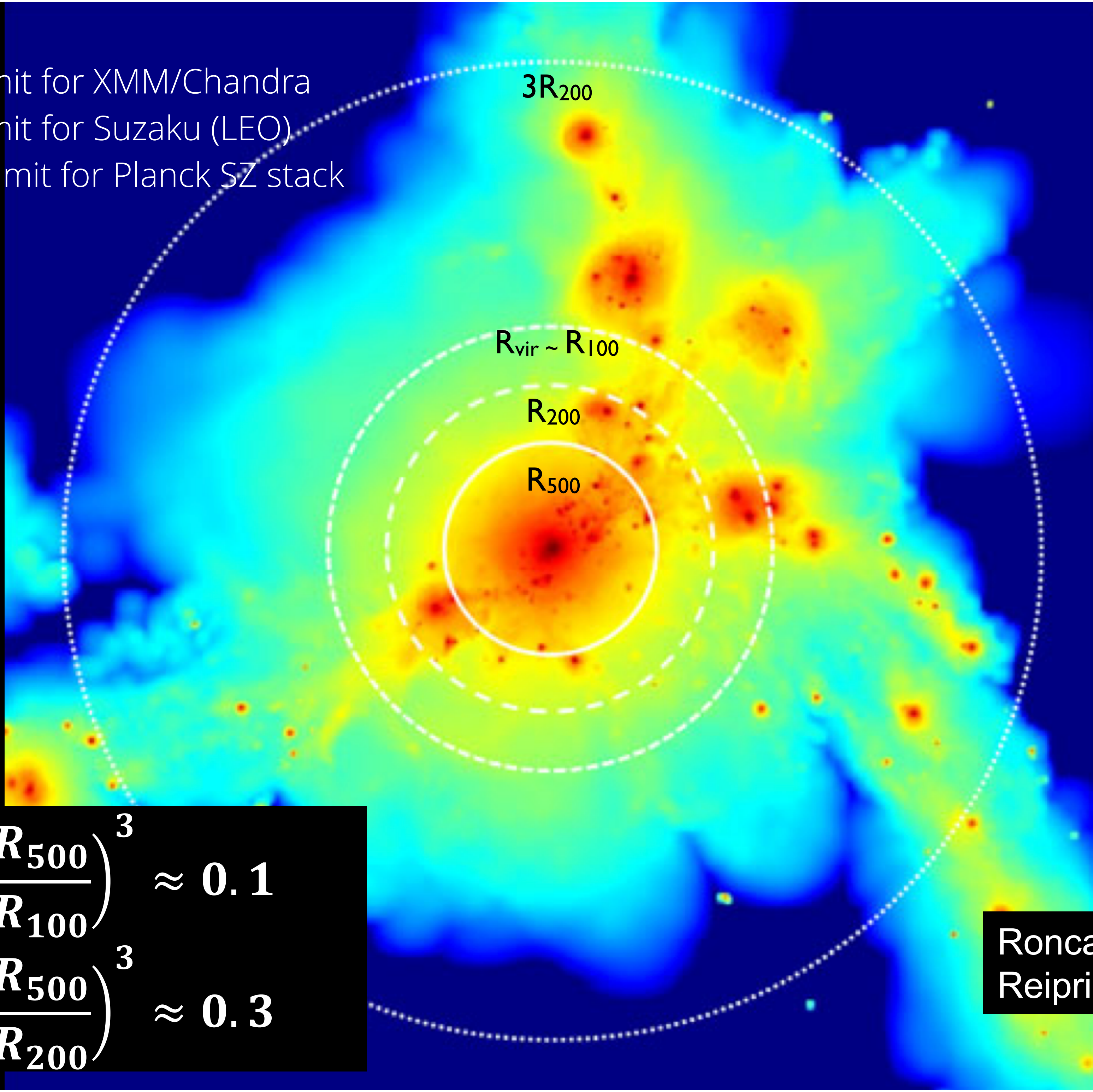




R_{500} - limit for XMM/Chandra

R_{200} - limit for Suzaku (LEO)

$3R_{500}$ - limit for Planck SZ stack

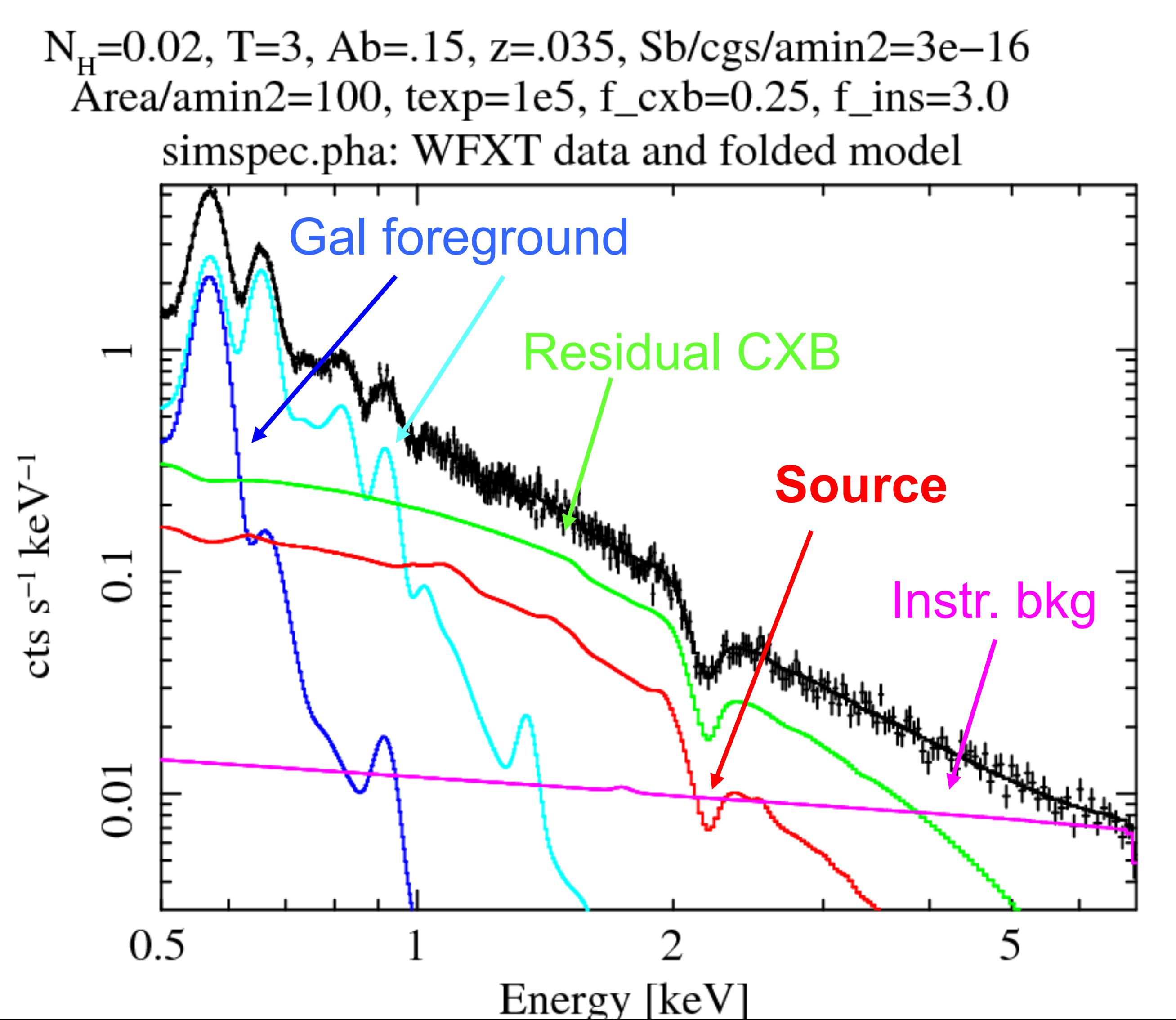


$$\left(\frac{R_{500}}{R_{100}}\right)^3 \approx 0.1$$

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

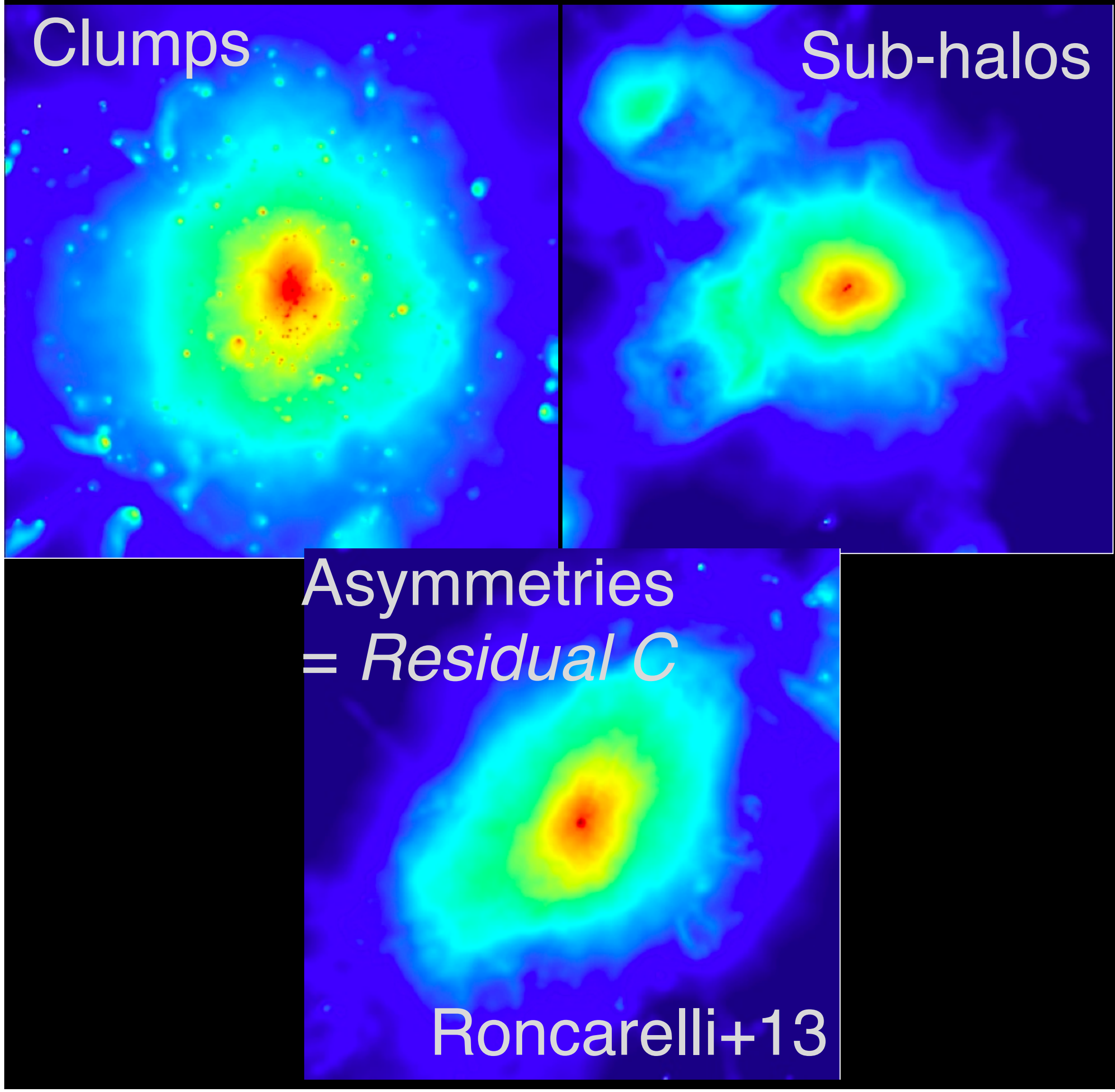
Roncarelli+06
Reiprich+13

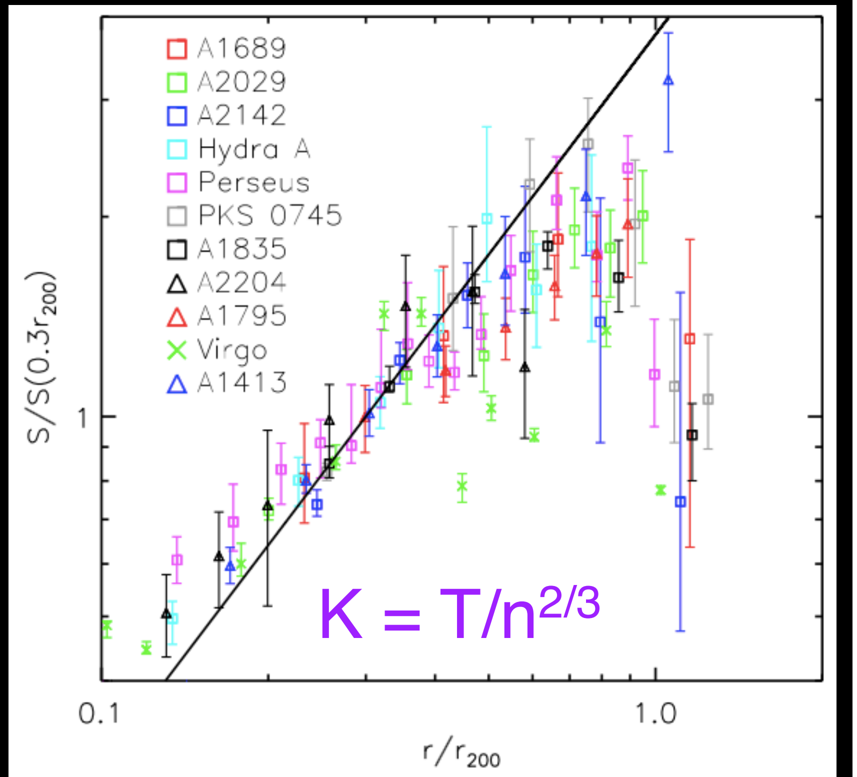
Problem #1: bkg dominates



Simulation for 3keV cluster @ R200 (Ettori & Molendi arXiv:1005.0382)

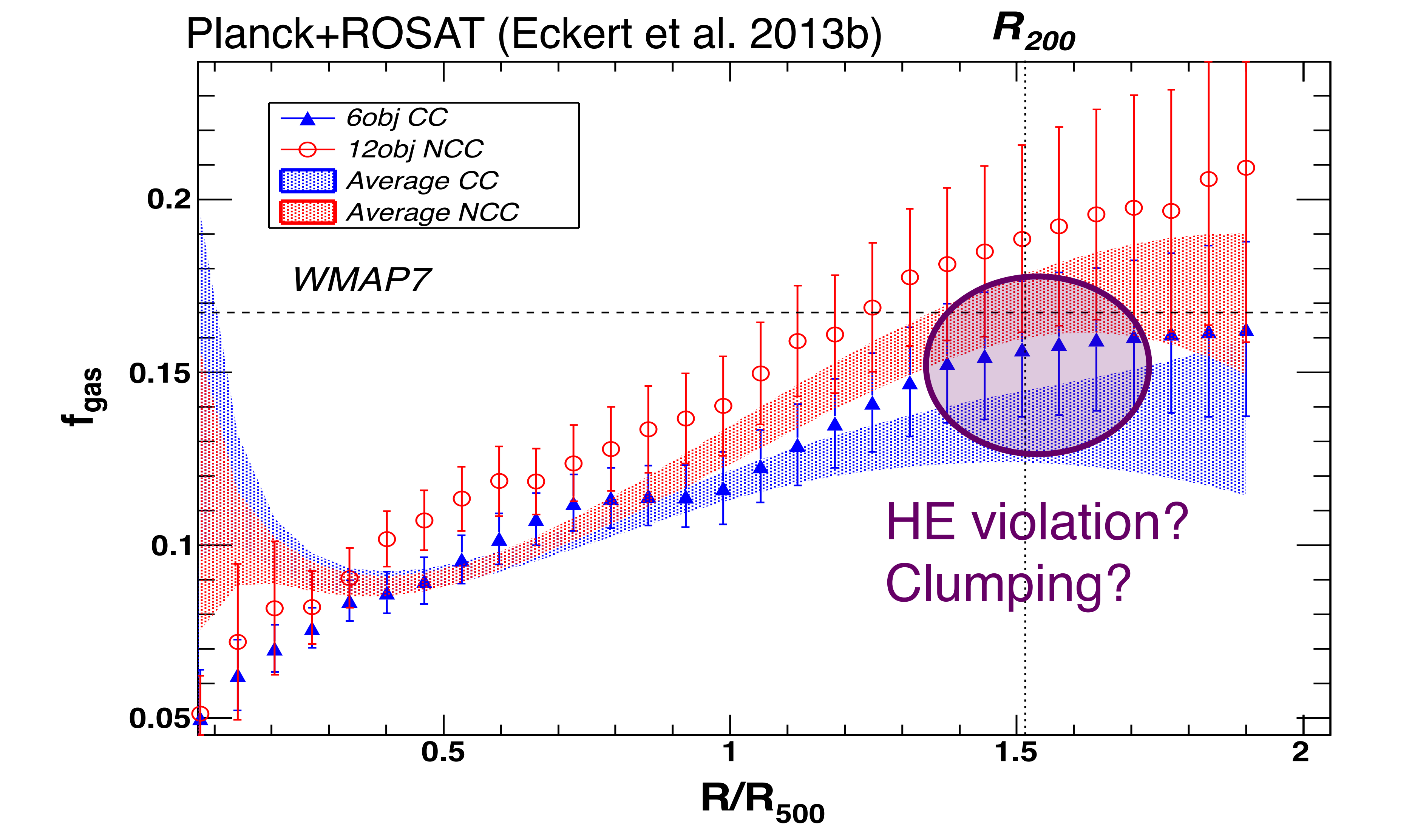
Problem #2: n_{gas} (from X-ray) $= deproj(S_b)^{1/2} / C^{1/2}$





Walker+12
(but *Suzaku*'s PSF~2'
vs *XMM*'s PSF~15")

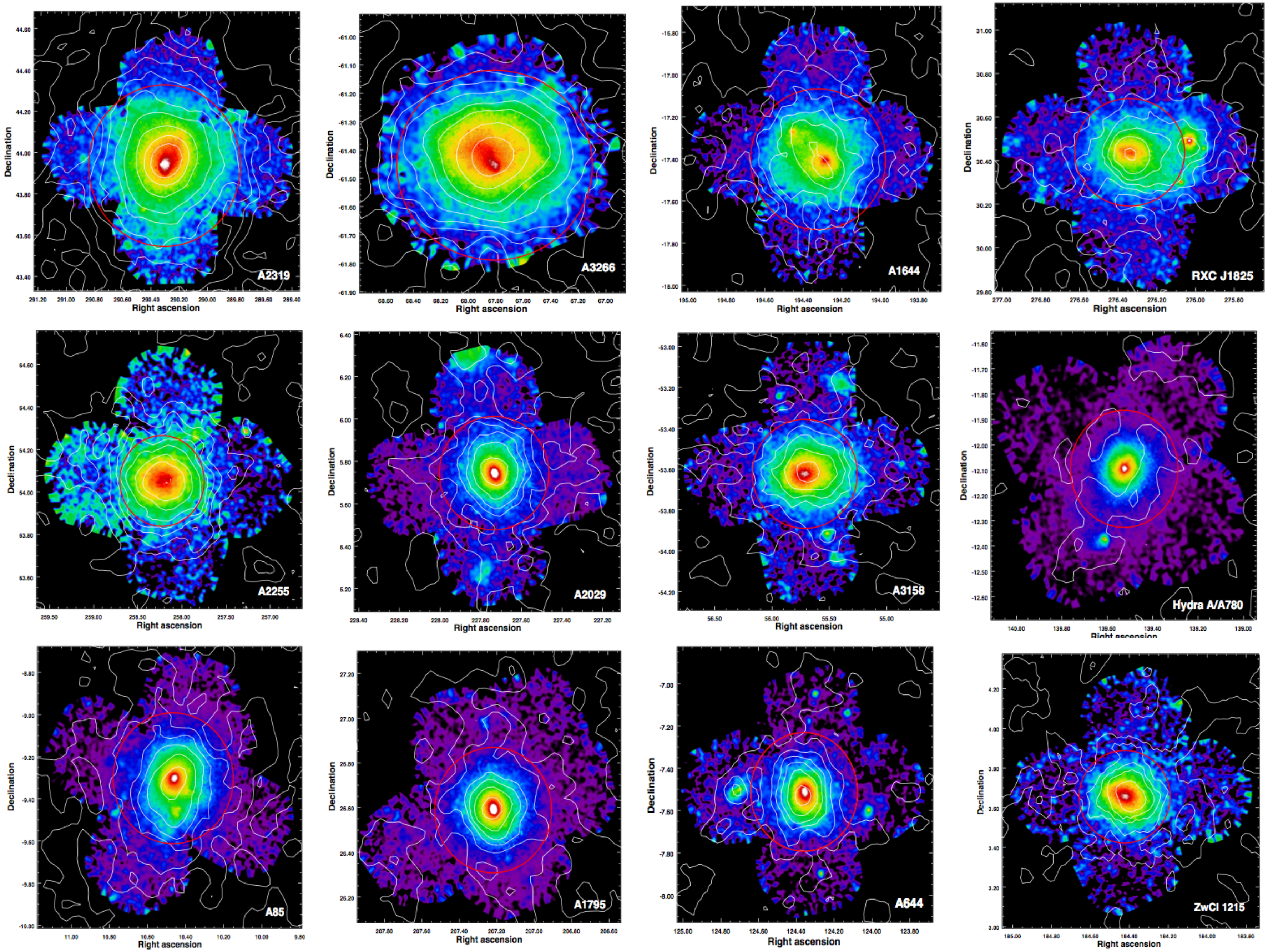
Problem #3: $P_{non\text{-}thermal}$



X-COP
The XMM Cluster Outskirts Project

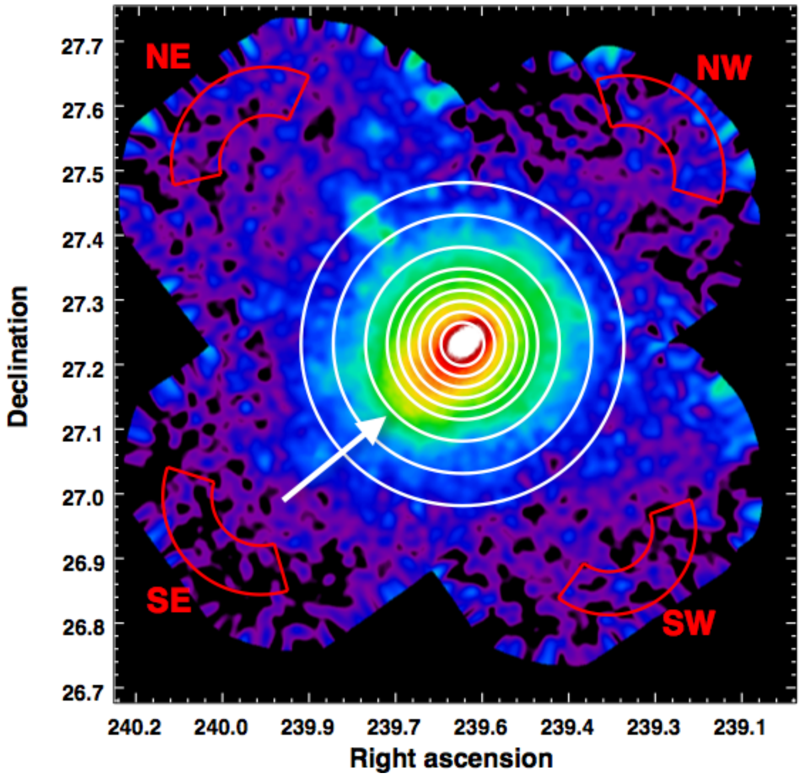
- X-COP is a ***very large program*** (PI: Eckert), approved in *XMM-Newton* AO-13 for a total observing time of 1.2 Msec; co-I: Ettori, Molendi, Pointecouteau, Gastaldello, Hurier, Vazza, Roncarelli, Rossetti, Kneib, Paltani, Ghizzardi, De Grandi, Bartelmann Tchernin
- X-COP targets the outer regions of a sample of 13 massive clusters ($M_{500} > 3 \times 10^{14}\ M_{\odot}$) in the redshift range 0.04-0.1 at uniform depth. The sample was selected based on the signal-to-noise ratio in the *Planck* Sunyaev-Zeldovich (SZ) survey with the aim of combining high-quality X-ray and SZ constraints throughout the entire cluster volume

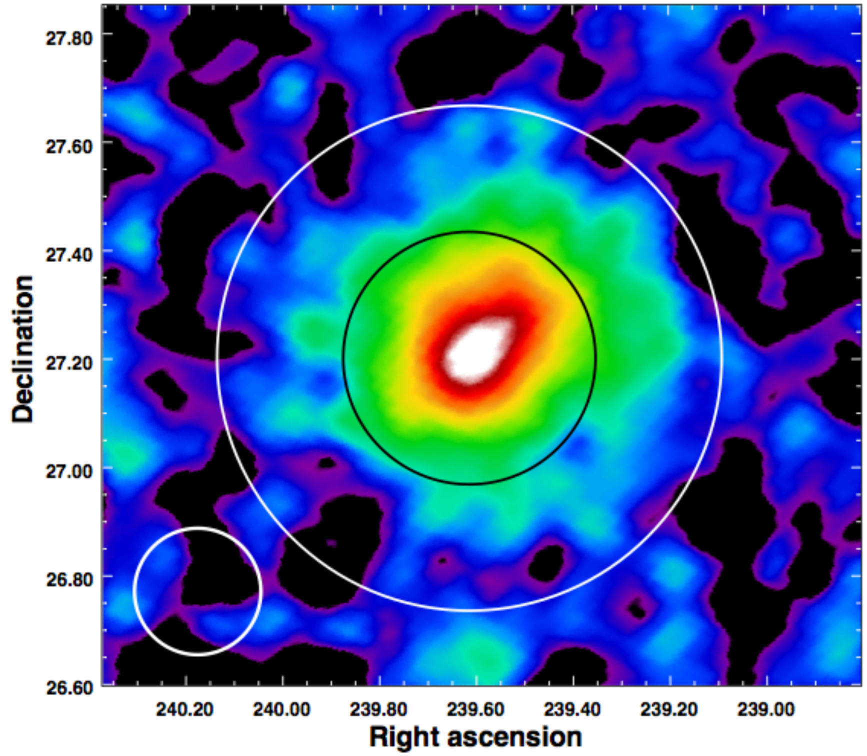
X-COP



A2319
A3266
A1644
RXC J1825
A2255
A2029
A3158
Hydra A/A780
A85
A1795
A644
ZwCl 1215
Declination
Right ascension

X-COP: A2142 (Tchernin+16)

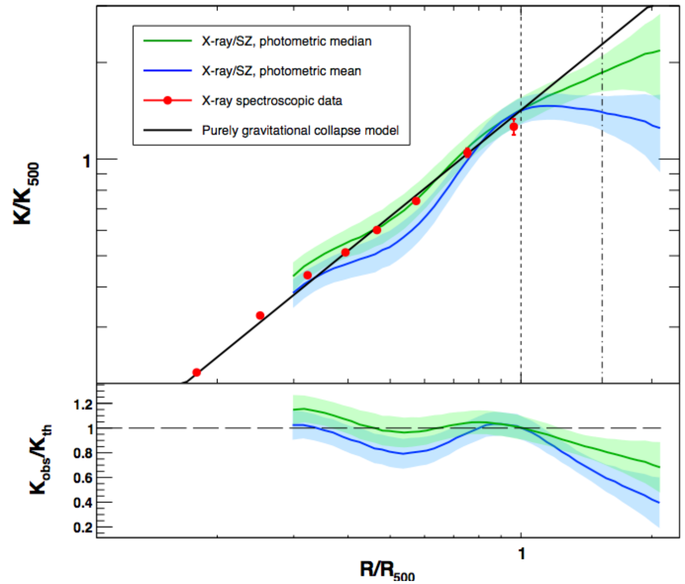


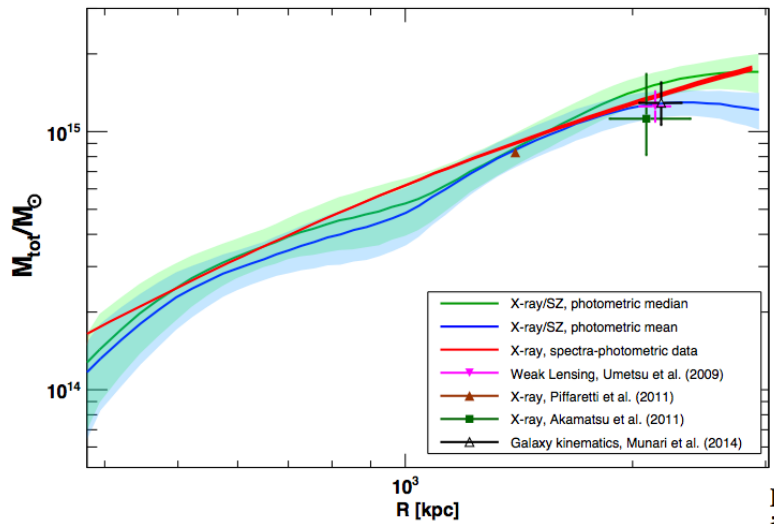


$T = P/n$

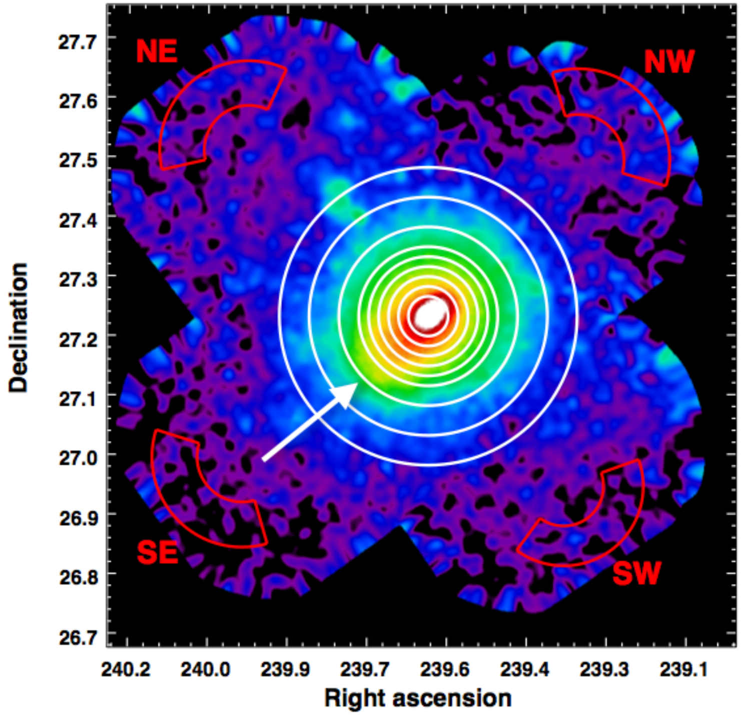
$K = P/n^{5/3}$

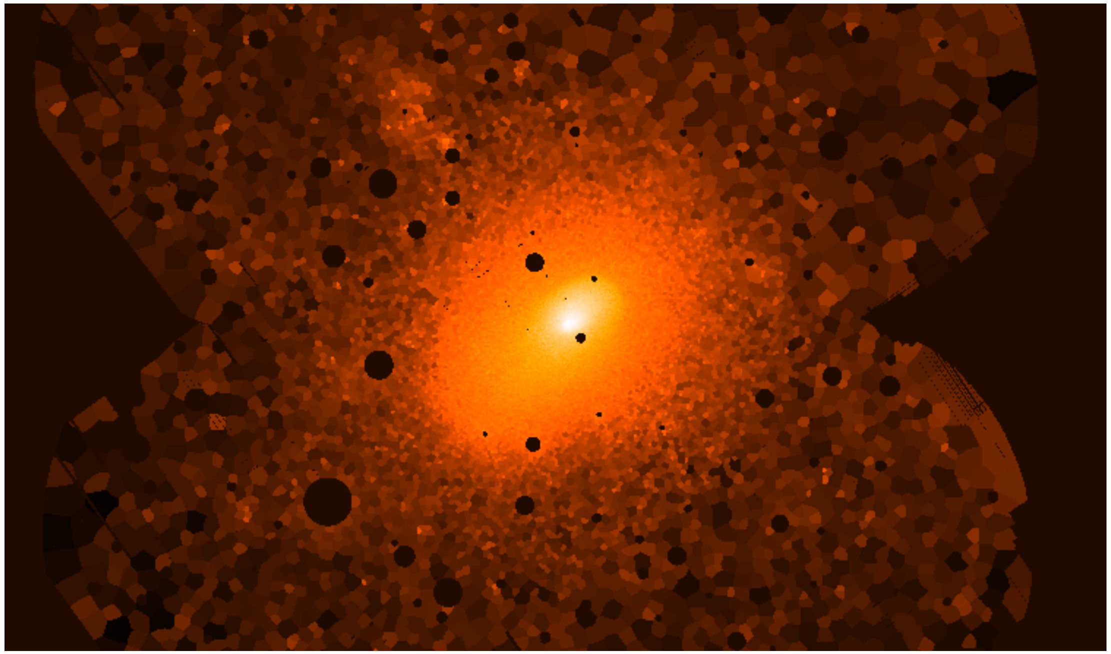
$M \sim -\frac{r^2}{n}\frac{dP}{dr}$



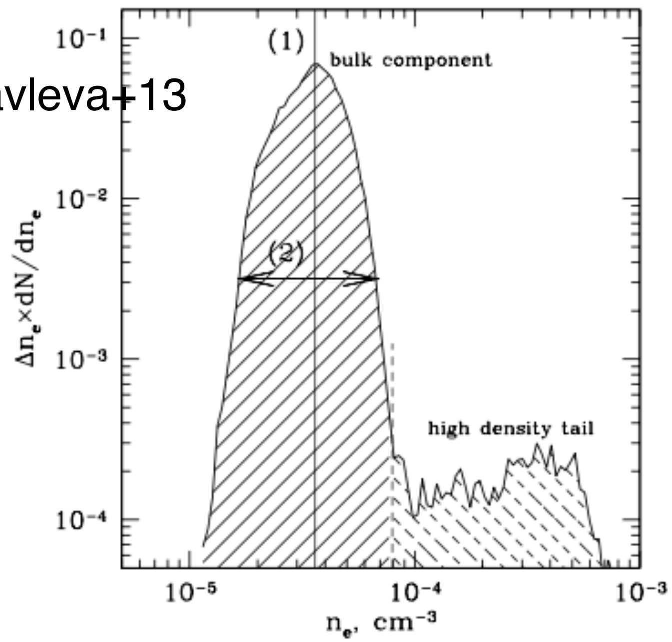


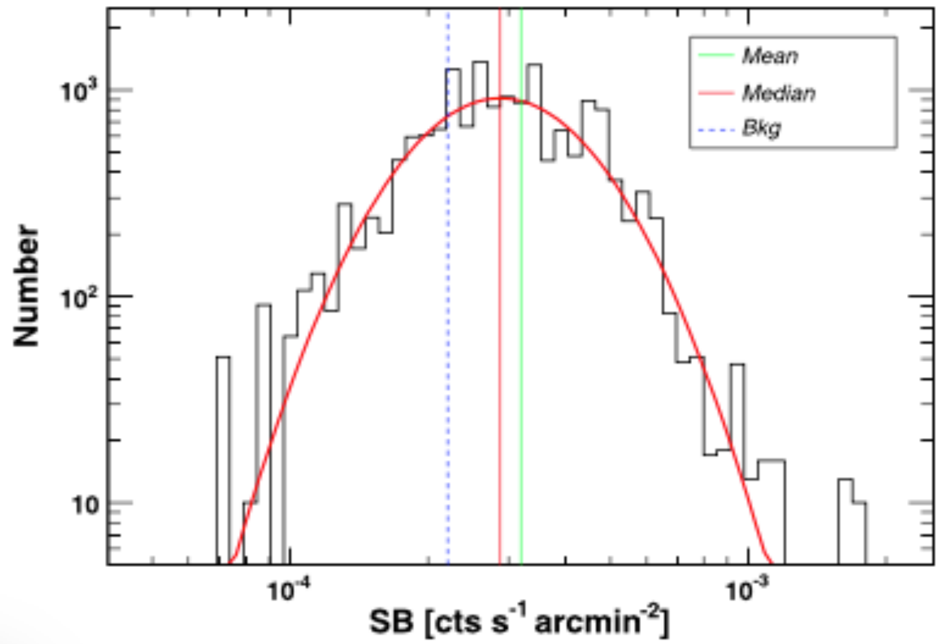
X-COP: A2142 (Tchernin+16)



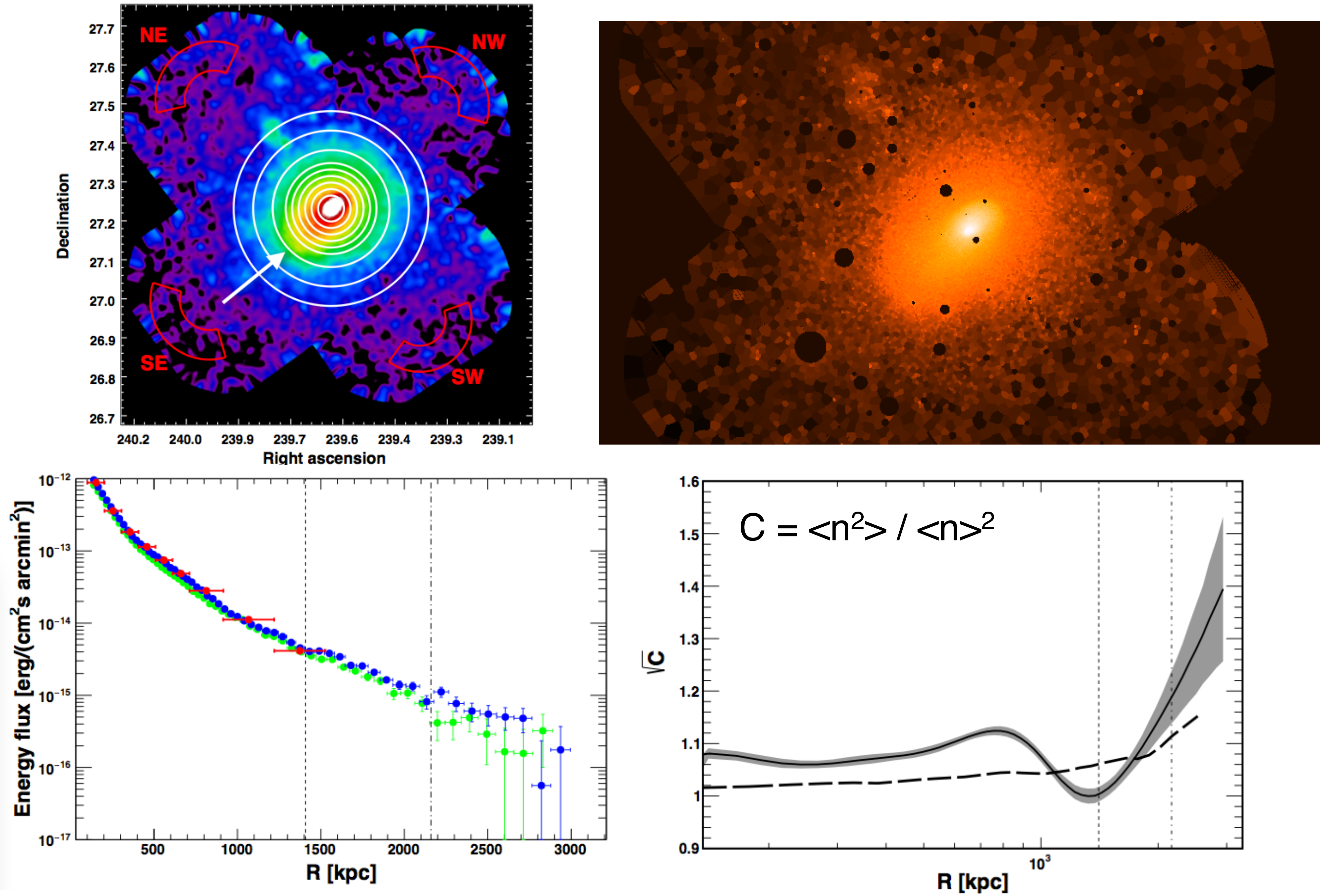


Zhuravleva+13

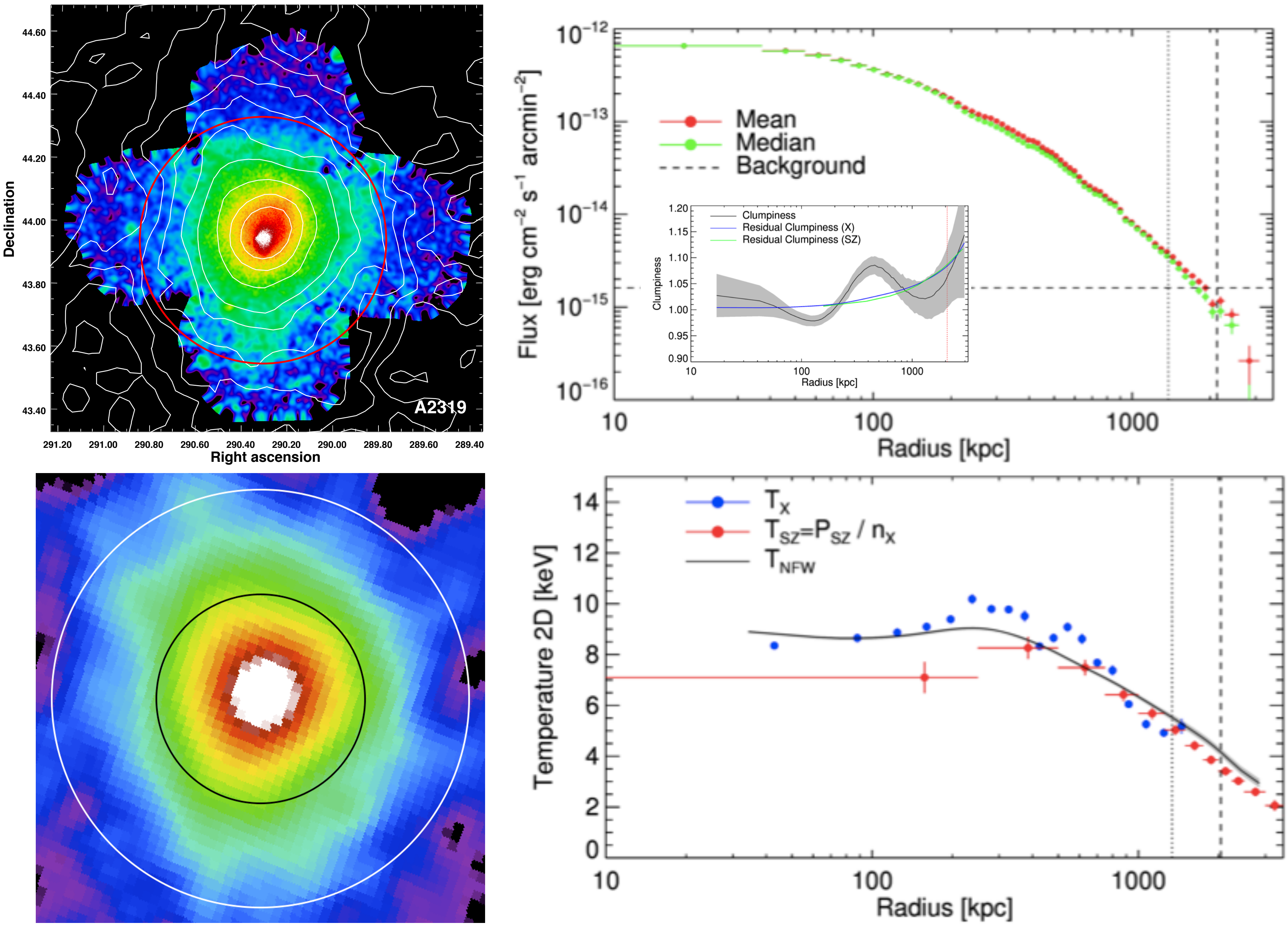




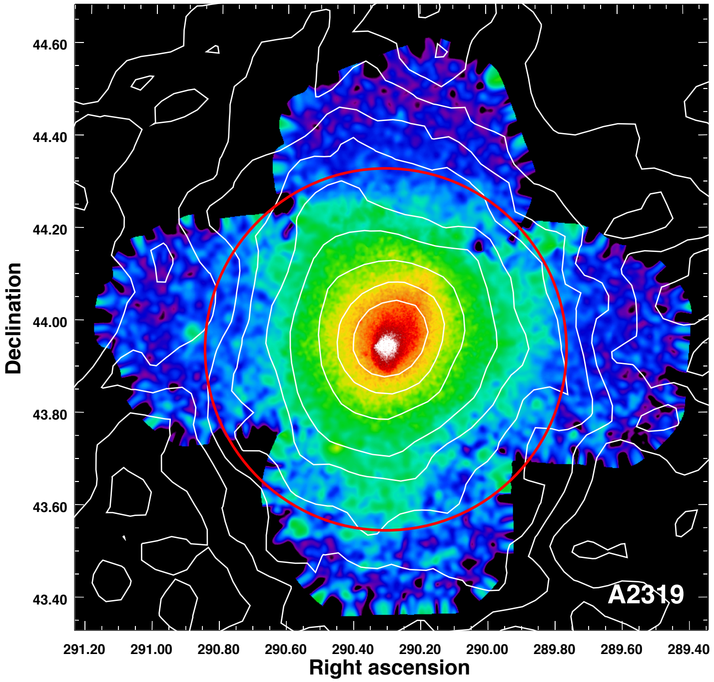
X-COP: A2142 (Tchernin+16)

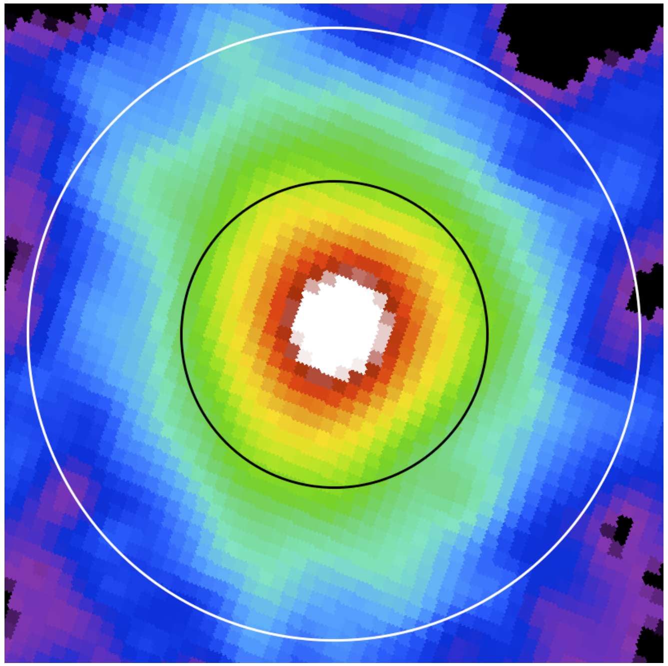


X-COP: A2319 (Ghirardini+17 to be subm)



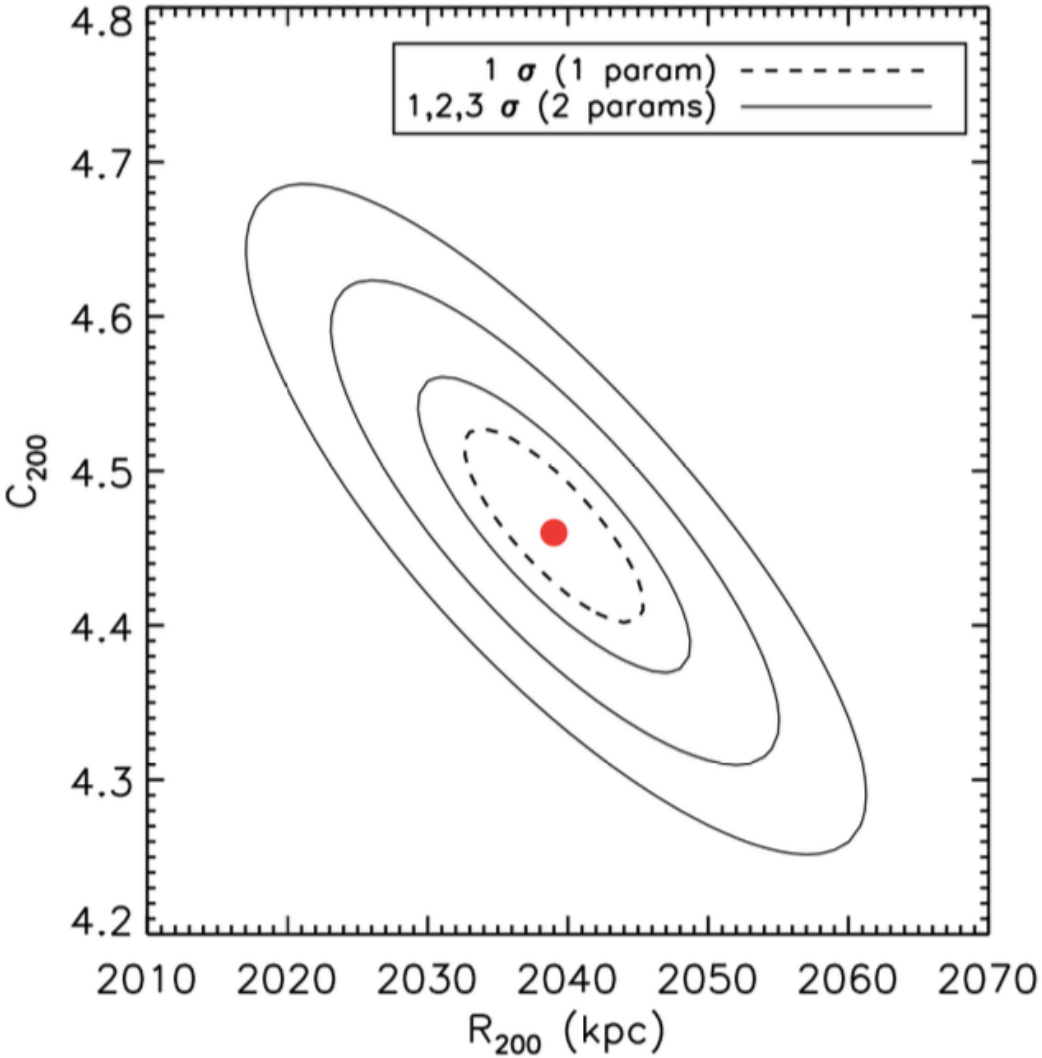
X-COP: A2319 (Ghirardini+17 to be subm)





$M_{200} = 10.2 \times 10^{14} M_\odot$

2% stat, 5% syst



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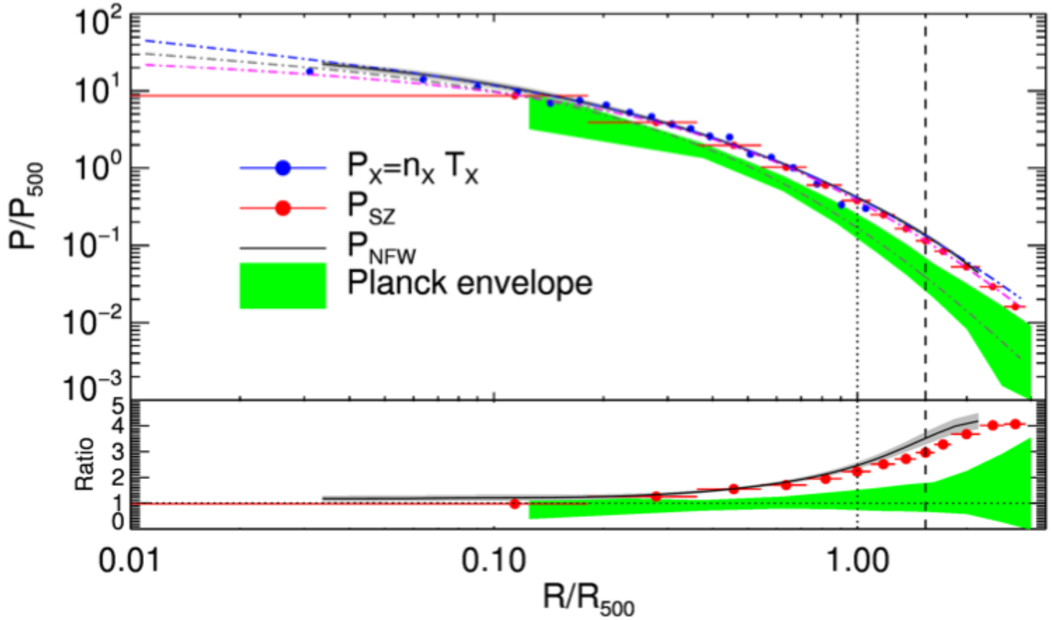
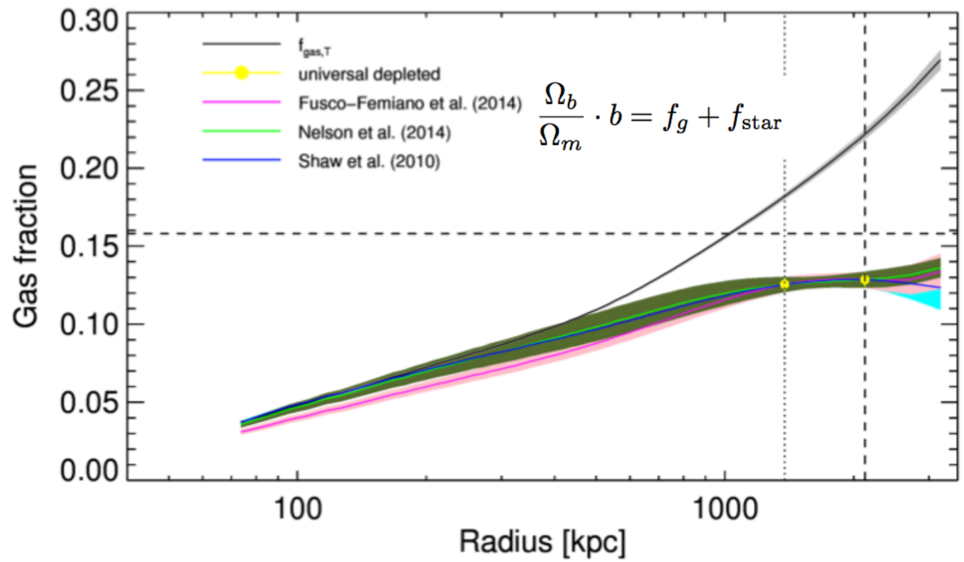
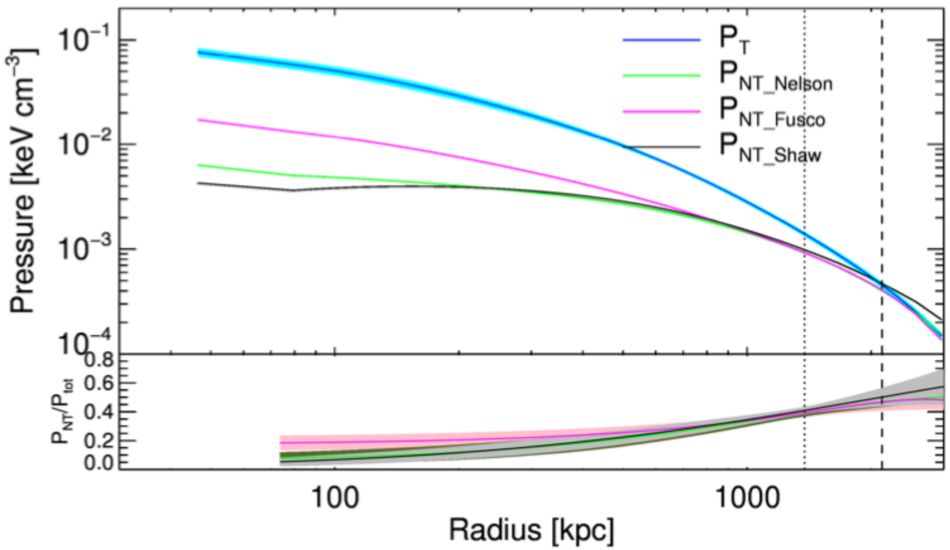




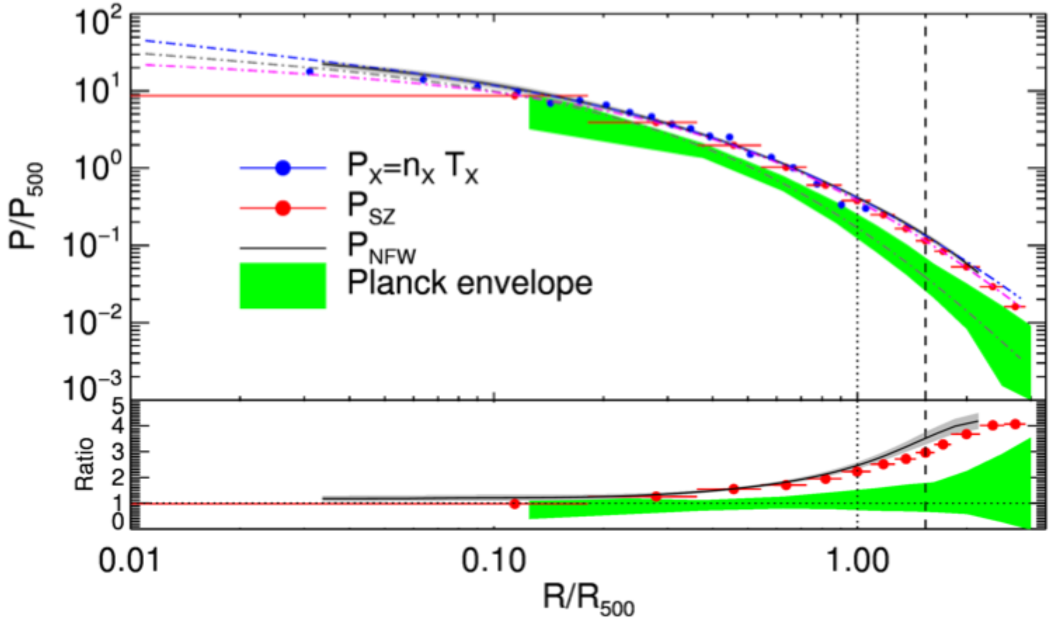


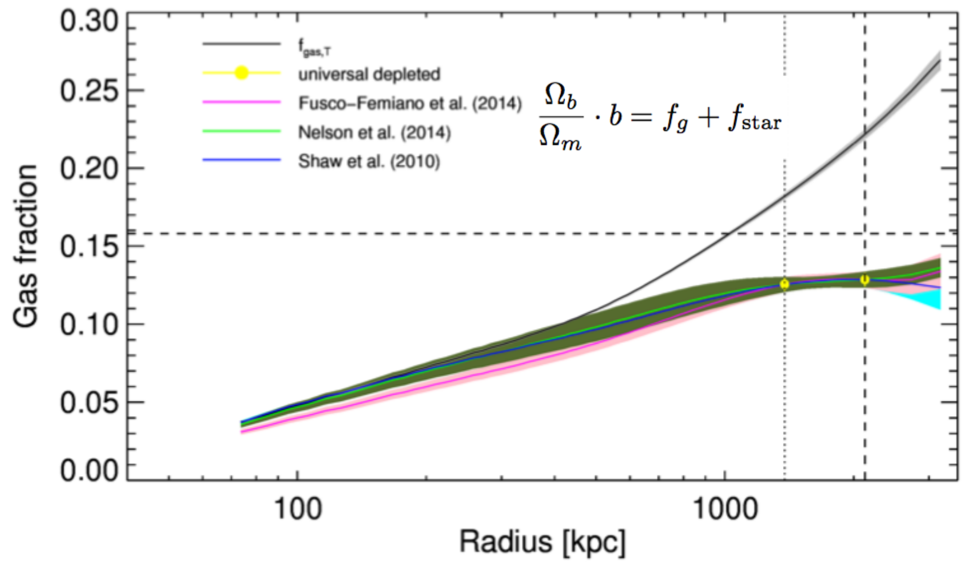
$$\frac{1}{\rho_g}\left(\frac{dP_T}{dr} + \frac{dP_{NT}}{dr}\right) = -\frac{G}{r^2}\left(M_T + M_{NT}\right)$$

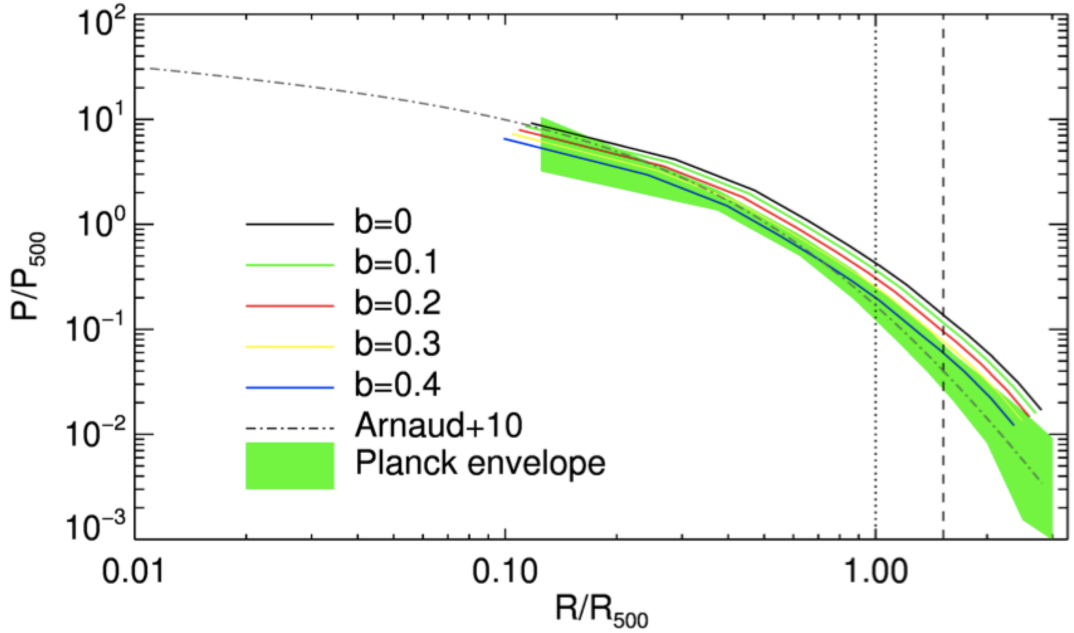
$$f_g = \frac{M_g}{M_T + M_{NT}} = \frac{M_g}{M_T\left(1 + \frac{M_{NT}}{M_T}\right)}$$

$$= \frac{f_{g,T}}{1 + \alpha - \frac{P_T r^2}{G M_T \mu m_p n_e}\frac{d\alpha}{dr}}$$

X-COP: A2319 (Ghirardini+17 to be subm)







$$\frac{1}{\rho_g}\left(\frac{dP_T}{dr}+\frac{dP_{NT}}{dr}\right) = -\frac{G}{r^2}\left(M_T + M_{NT}\right)$$

$$f_g = \frac{M_g}{M_T + M_{NT}} = \frac{M_g}{M_T\left(1+\frac{M_{NT}}{M_T}\right)}$$

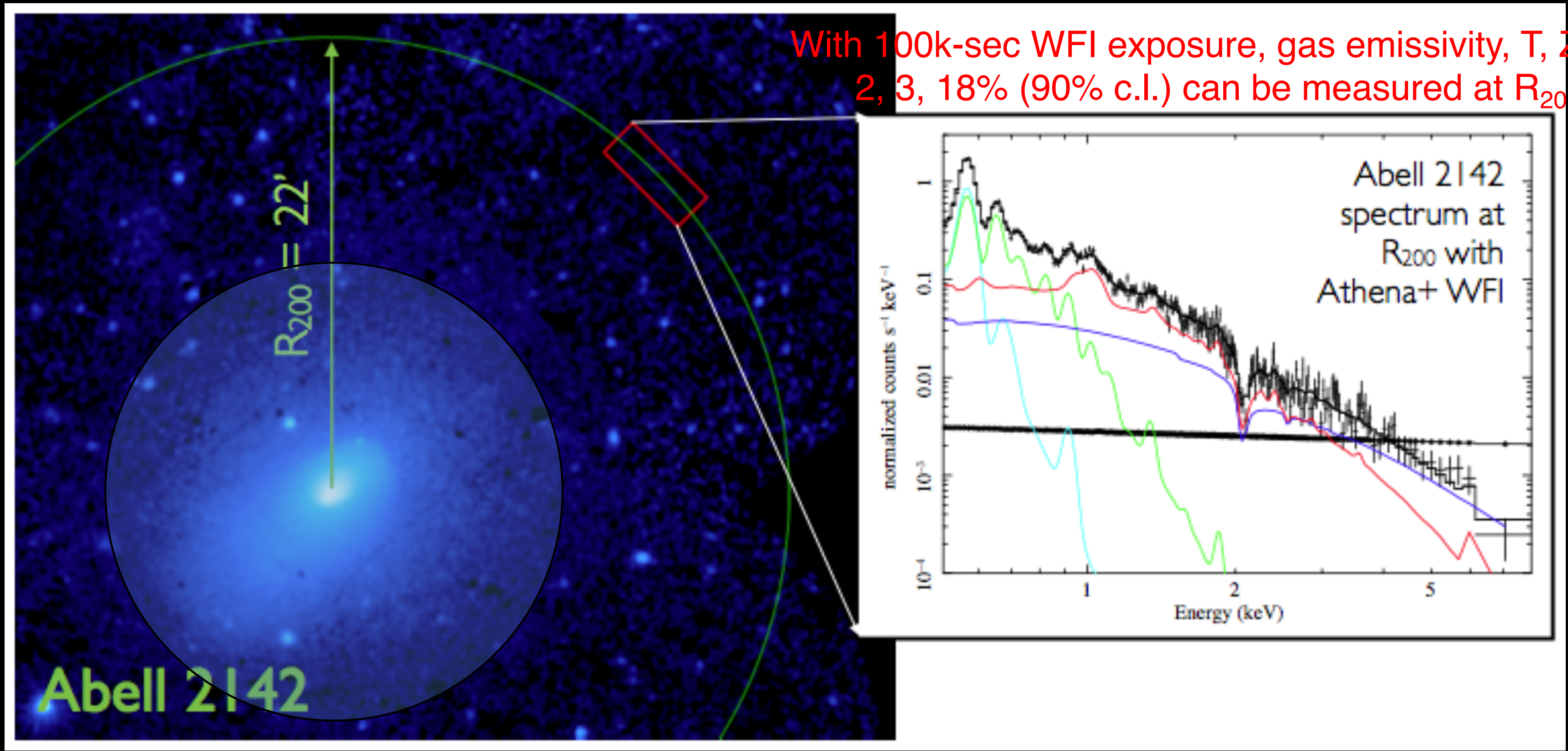
$$= \frac{f_{g,T}}{1+\alpha-\frac{P_T r^2}{G M_T \mu m_p n_e}\frac{d\alpha}{dr}}$$

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



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

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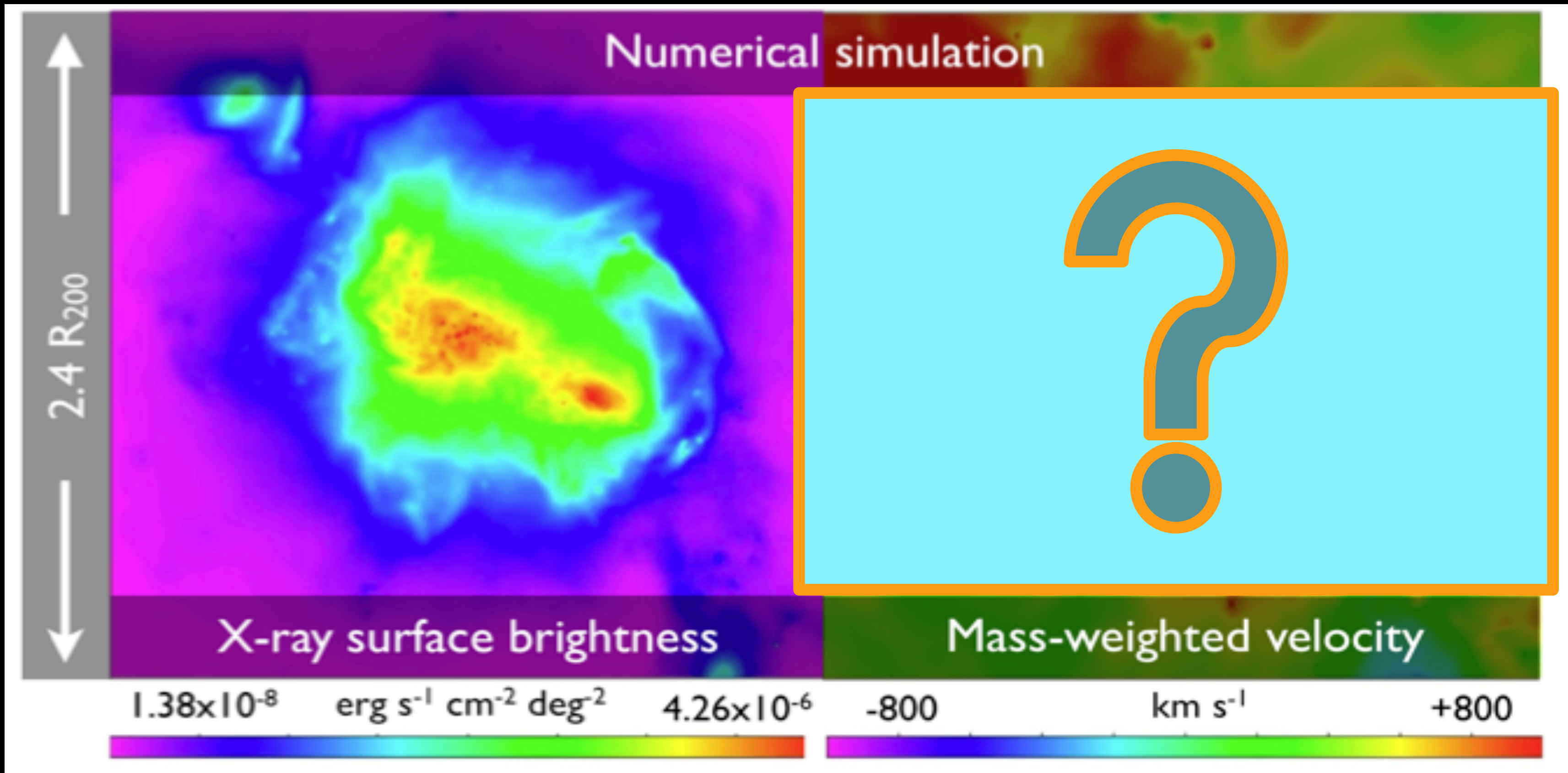

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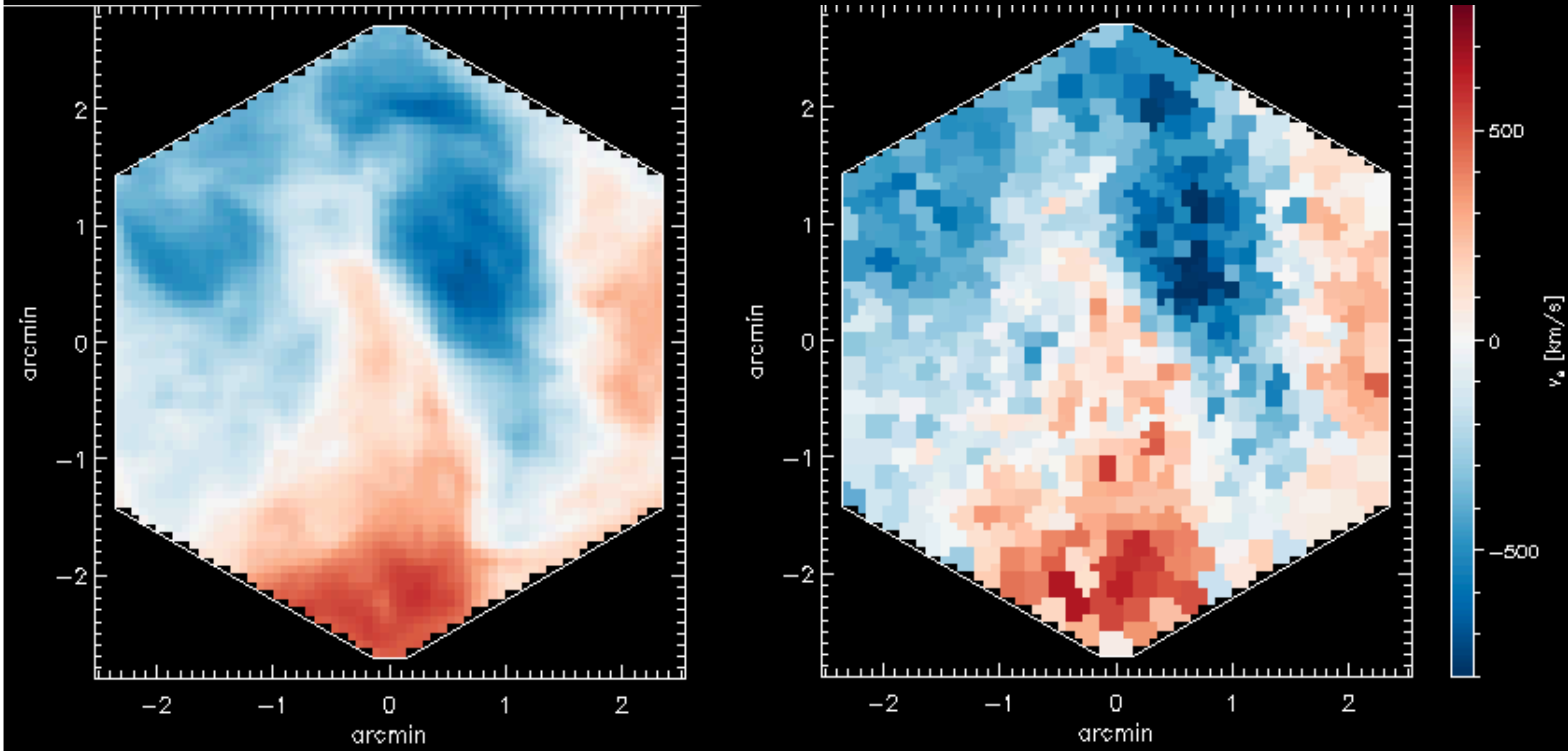
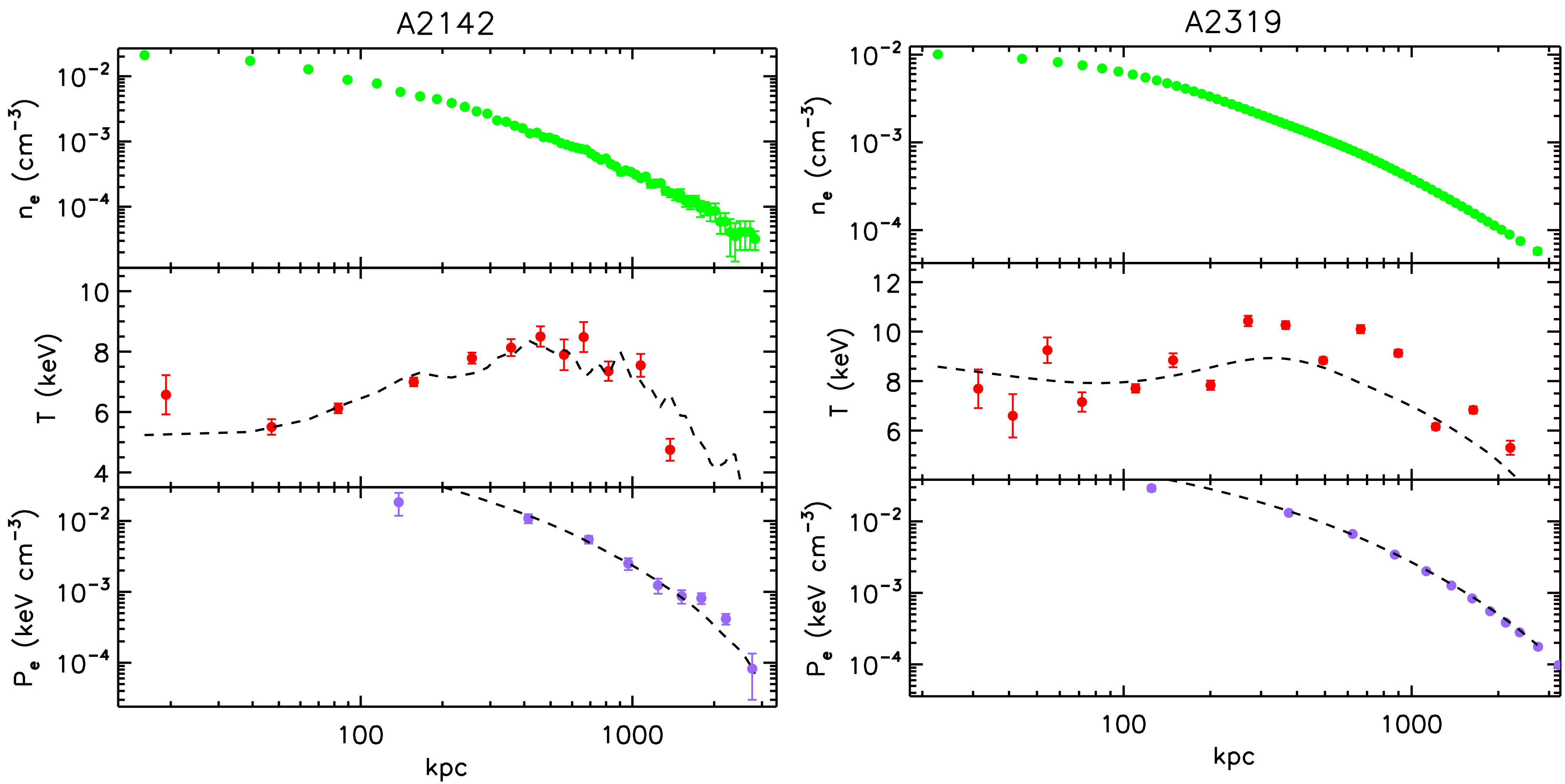
XIFU & simulated Velocity map

Roncarelli, Ettori, Gaspari et al., *in prep*.



X-COP: Emergent Gravity

(Ettori+17)



$$M_{\rm tot}(<r) = -\frac{r\,P_{\rm gas}}{\mu m_{\rm u} G\, n_{\rm gas}} \frac{d\log P_{\rm gas}}{d\log r}$$

X-COP: Emergent Gravity

(Ettori+17)

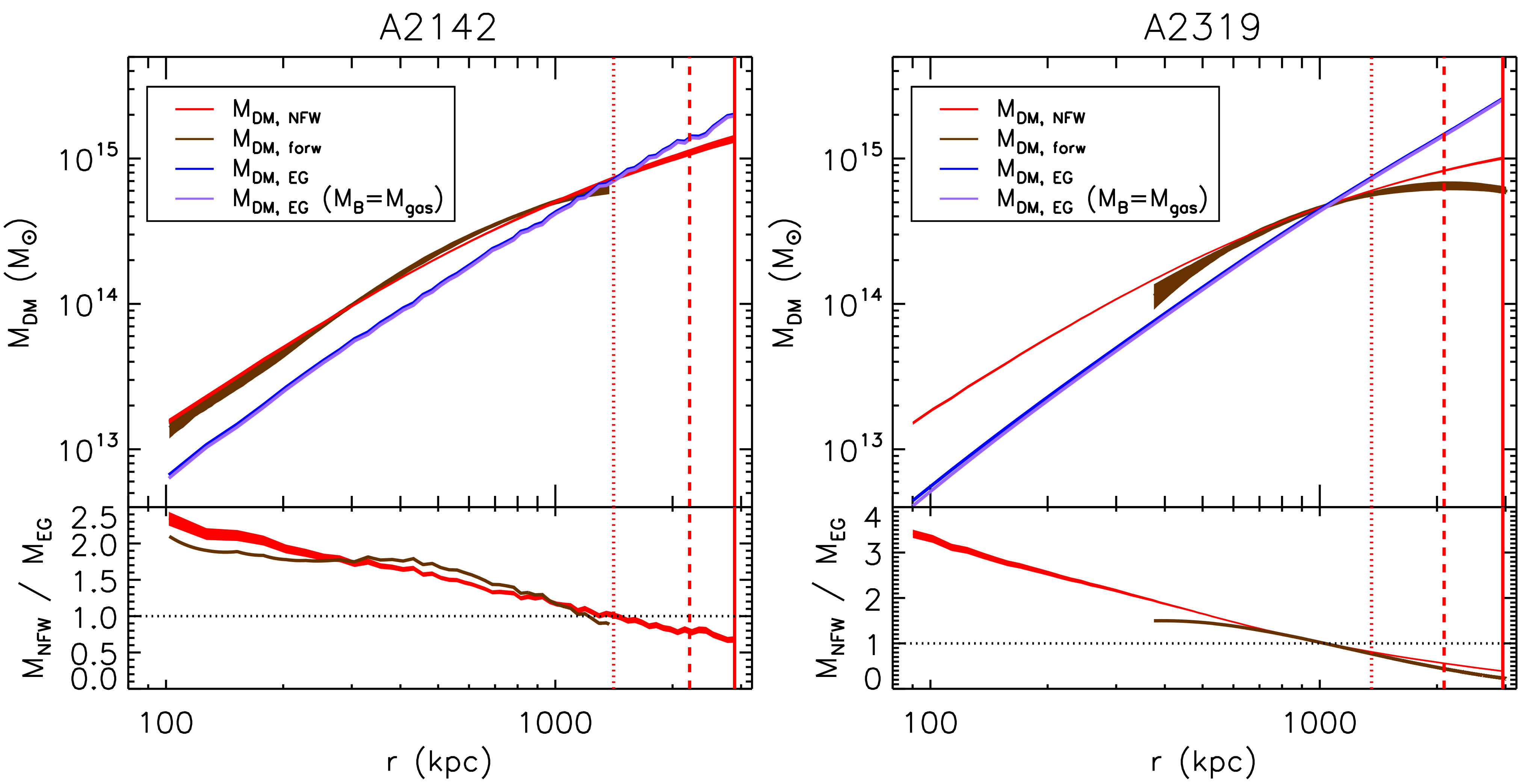
In the ***Emergent Gravity*** (Verlinde 2016),

- *dark energy* dominates our Universe,
- *ordinary matter* only leads to small perturbations,
- *dark matter* appears as manifestation of an additional gravitational force induced from the “elastic” response due to an entropy displacement, and can be described for a spherically-symmetric, static & isolated system as:

$$\int \frac{G\, M_{DM,EG}^2}{r^2} dr = \frac{cH_0}{6} r\, M_B(<r)$$

X-COP: Emergent Gravity

(Ettori+17)



Take-home points

- Combining X-ray+SZ profiles is a promising tool to recover (*clumping-free*) cluster physical quantities out to R_{200}
- Thanks to high-quality data & radial coverage, mass models will be constrained at few % statistical (& systematic) uncertainties
- Under the assumption that f_{gas} is cosmological, we can *assess the level of non-thermal pressure support* *(~0% in A2142, 40% @R_{200} in A2319)*
- More results from ***X-COP*** to come (mean properties & "universal" profiles, clumps & metal distribution, …)

After X-COP, other acronyms that I cannot resist to show…

- ***CLASH-VLT*** (PI: Rosati) extending with VLT/MUSE data strong lensing constraints (***Caminha+17 arxiv:1707.00690*** *–yesterday-* ***on MACS1206***).
- ***CLUMP-3D*** (Sereno, Ettori et al. 17 MN 467 3801) combining S+WL, X-ray & SZ, full 3D analysis of MACS J1206.2-0847, a remarkably regular, face-on, massive obj. ***Analysis of 16 CLASH clusters is in progress***.
- ***CoMaLit*** (Sereno & Ettori 15-17) a Bayesian hierarchical method which deals with statistical errors, selection effects, Eddington/Malmquist biases and time evolution; ***we apply the method to forecast weak lensing calibrated masses of the Planck, redMaPPer and MCXC clusters.***
- ***Generalized/physical-SRs*** (Ettori+13, 15) define a framework for X-ray/SZ scaling laws that permit to reconstruct M with the lowest scatter (up to 50% lower than the one from standard-SRs). The ***self-similar*** prediction on **normalization & slope** can fully explain the ***observed X-SZ SL*** once **{f_g(M), β_P(M), C}** are considered

$$F_z M \sim \beta_P^{\theta} f_g^{-\phi} \, (F_z^{-1} L)^{\alpha} (F_z M_g)^{\beta} T^{\gamma}$$

$$4\alpha + 3\beta + 2\gamma = 3$$

$$\theta = \alpha/2 + \gamma$$

$$\phi = 2\alpha + \beta$$