AGN feedback and structure formation processes: From groups to clusters

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Constraining AGN feedback in galaxy groups

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R. Seppi, A. Finoguenov, F. Gastaldello, E. O'Sullivan, ...

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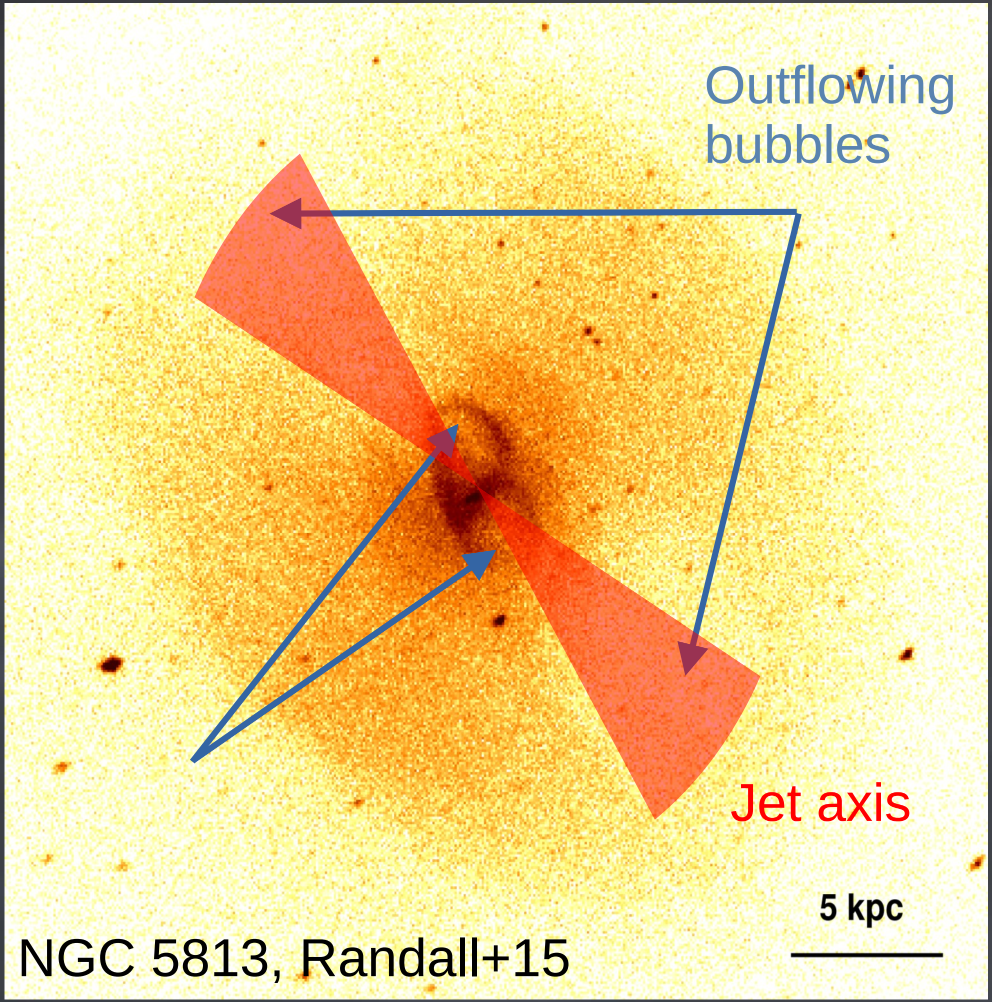
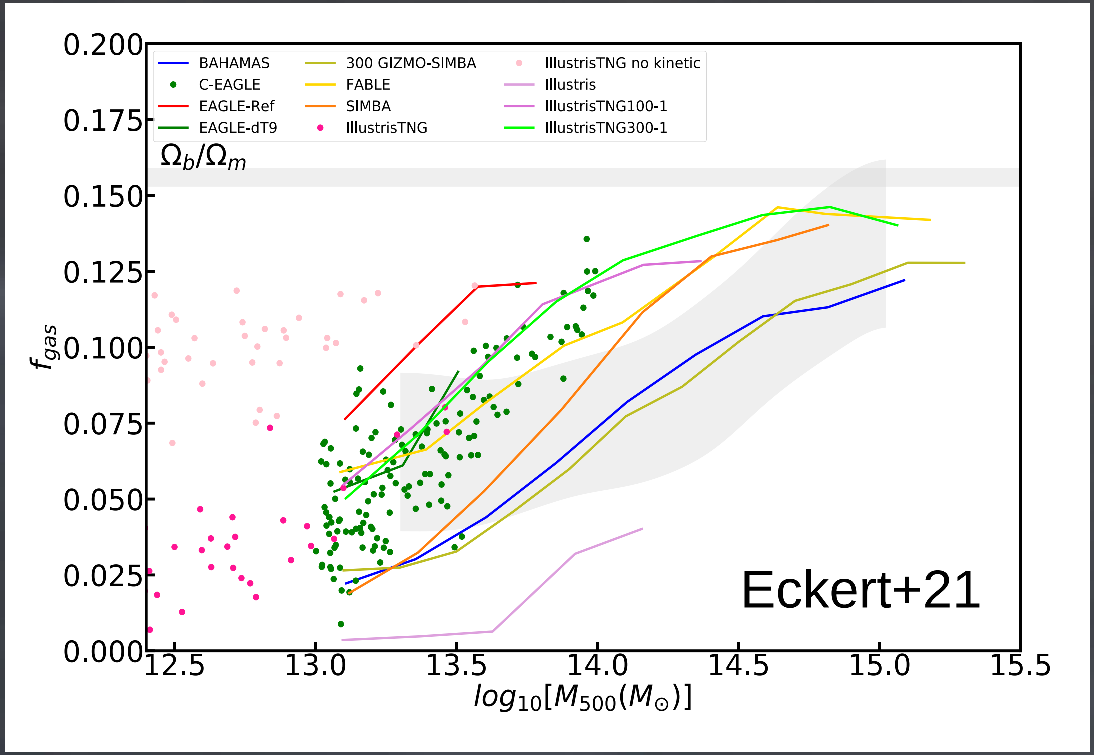
Impact of AGN feedback on hot atmospheres



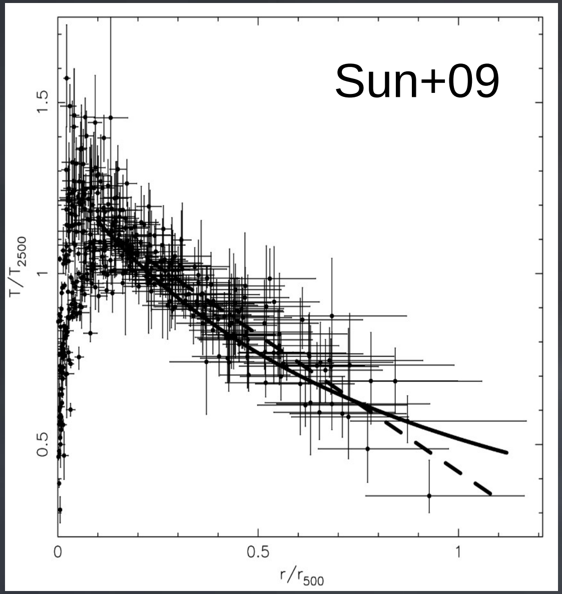
Gas fractions as a probe of AGN feedback

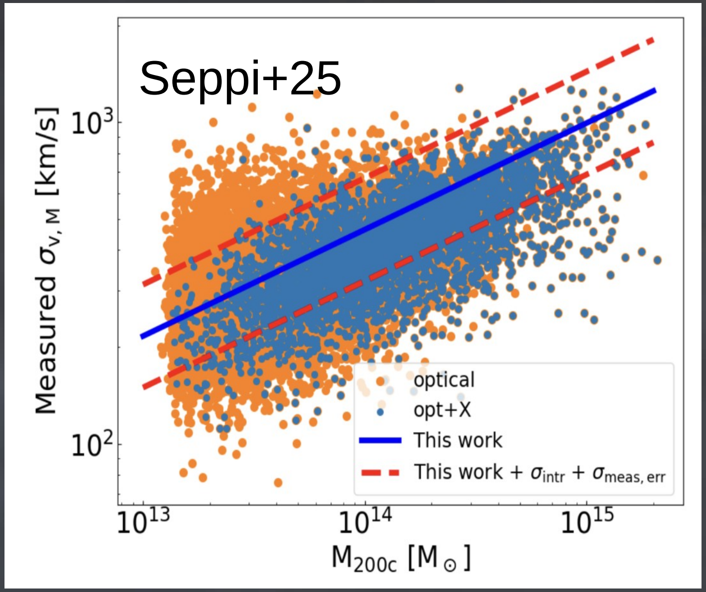
- AGN feedback leads to ejection of gas from halos, decreasing f_{gas}
- Many recent simulations (e.g. FLAMINGO) are calibrated on gas fractions

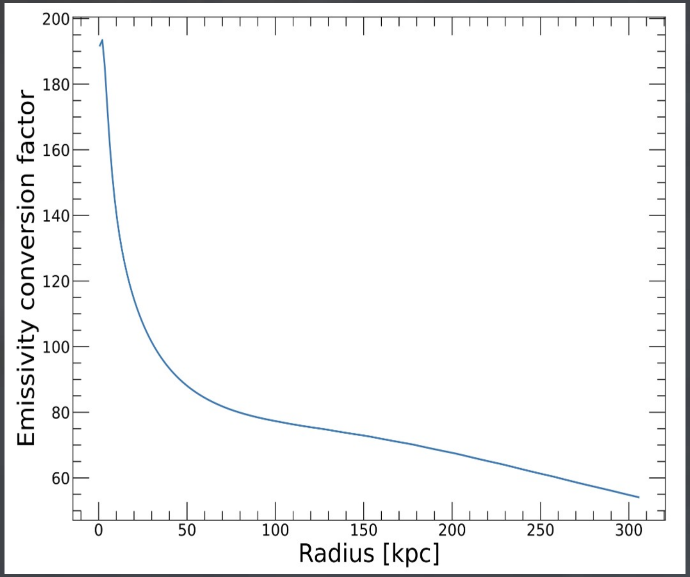


Why gas fractions ?

- Measuring gas fractions is hard…





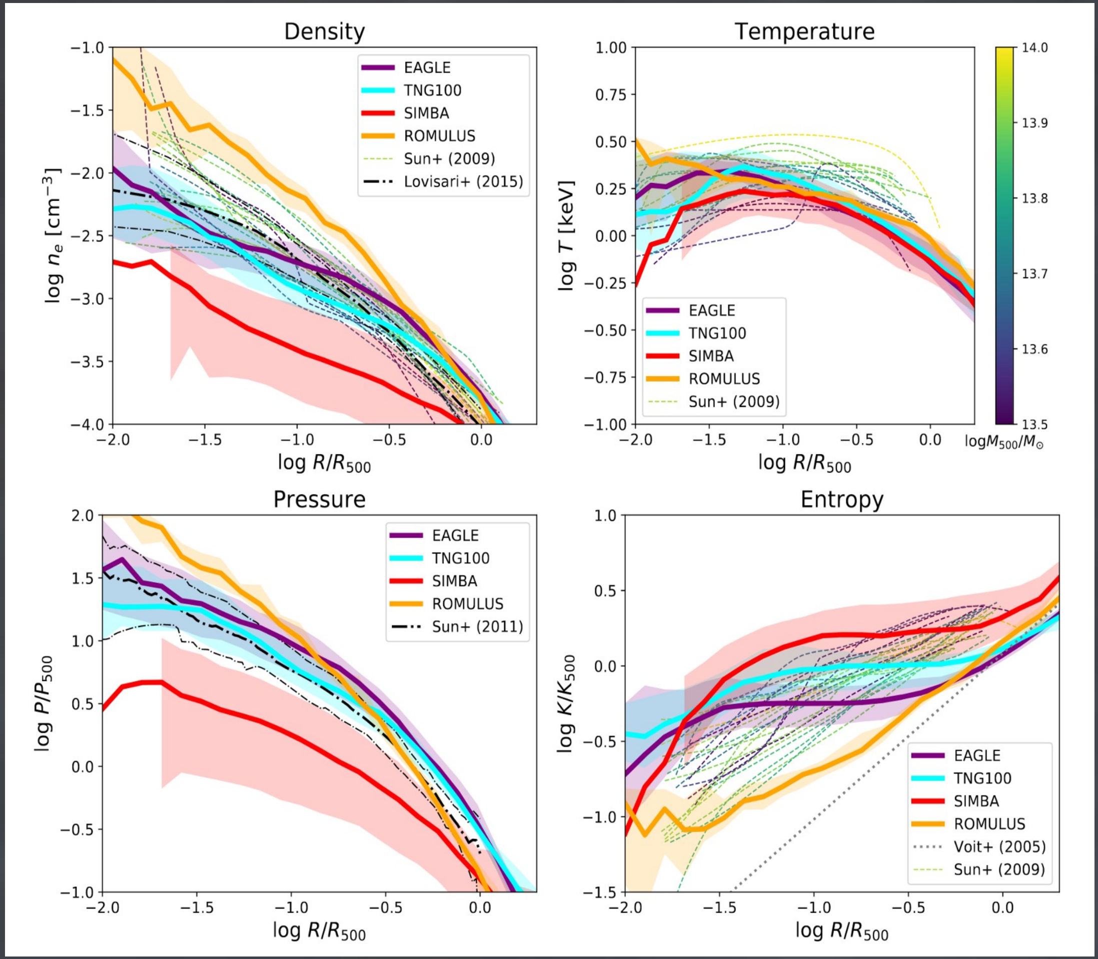


- … But do we really need to ?

Group thermodynamics as a probe of AGN feedback

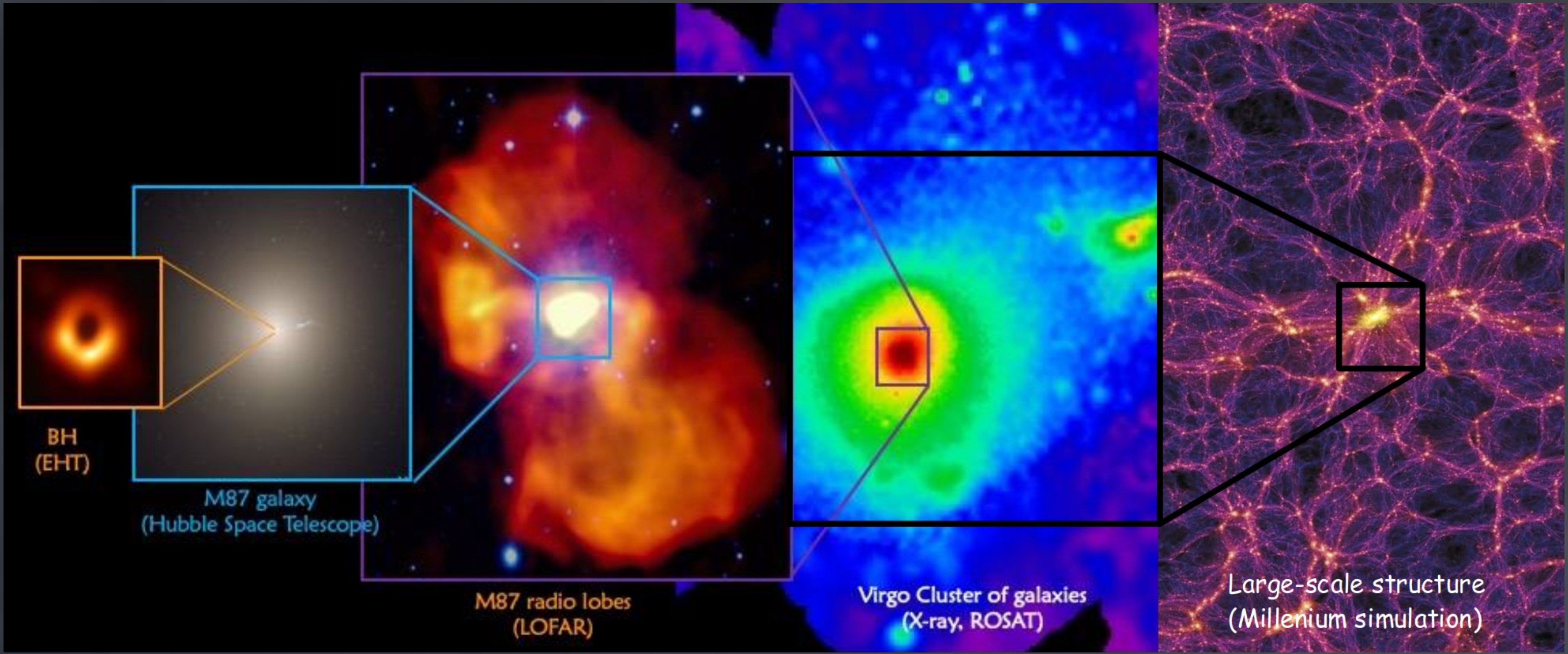
- The feedback scheme implemented in simulations has a large impact in thermodynamic properties of groups

- Thermodynamic profiles encode the same information as gas fraction, and much more !



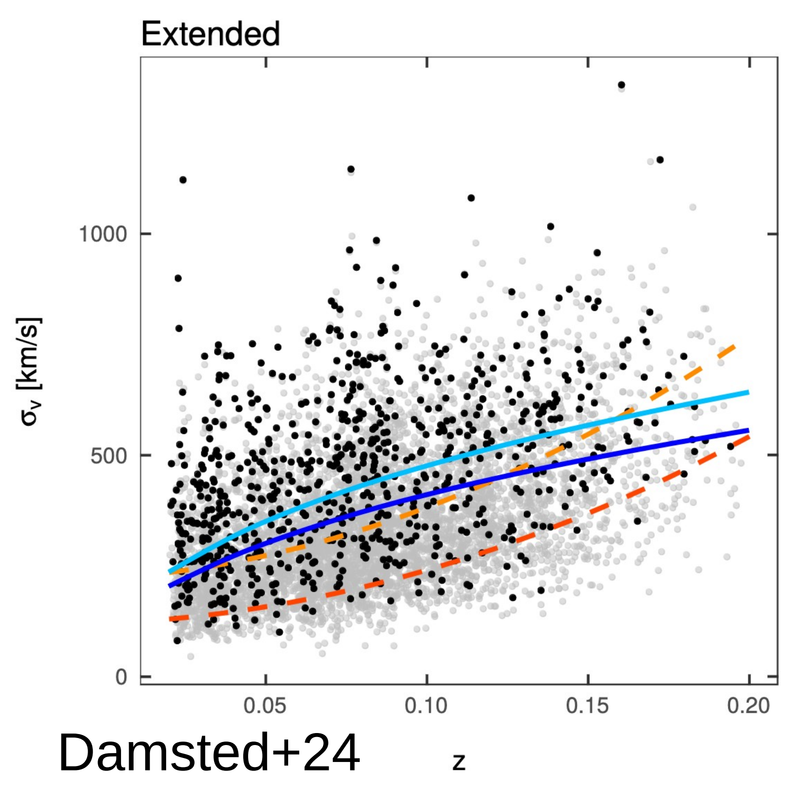
Oppenheimer+21

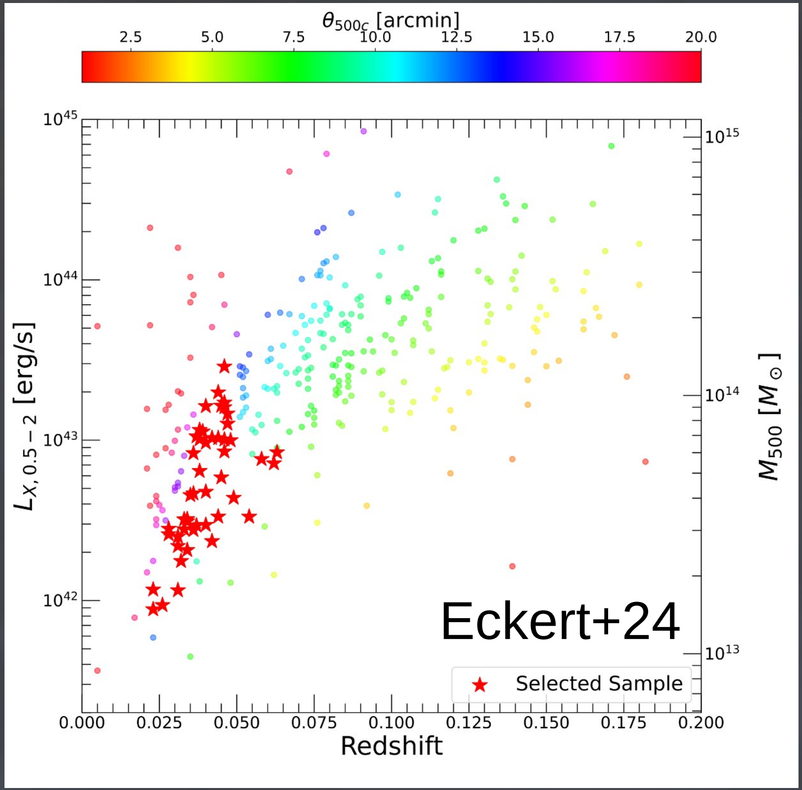
AGN feedback : a multi-scale problem



The XMM Group AGN Project (X-GAP)

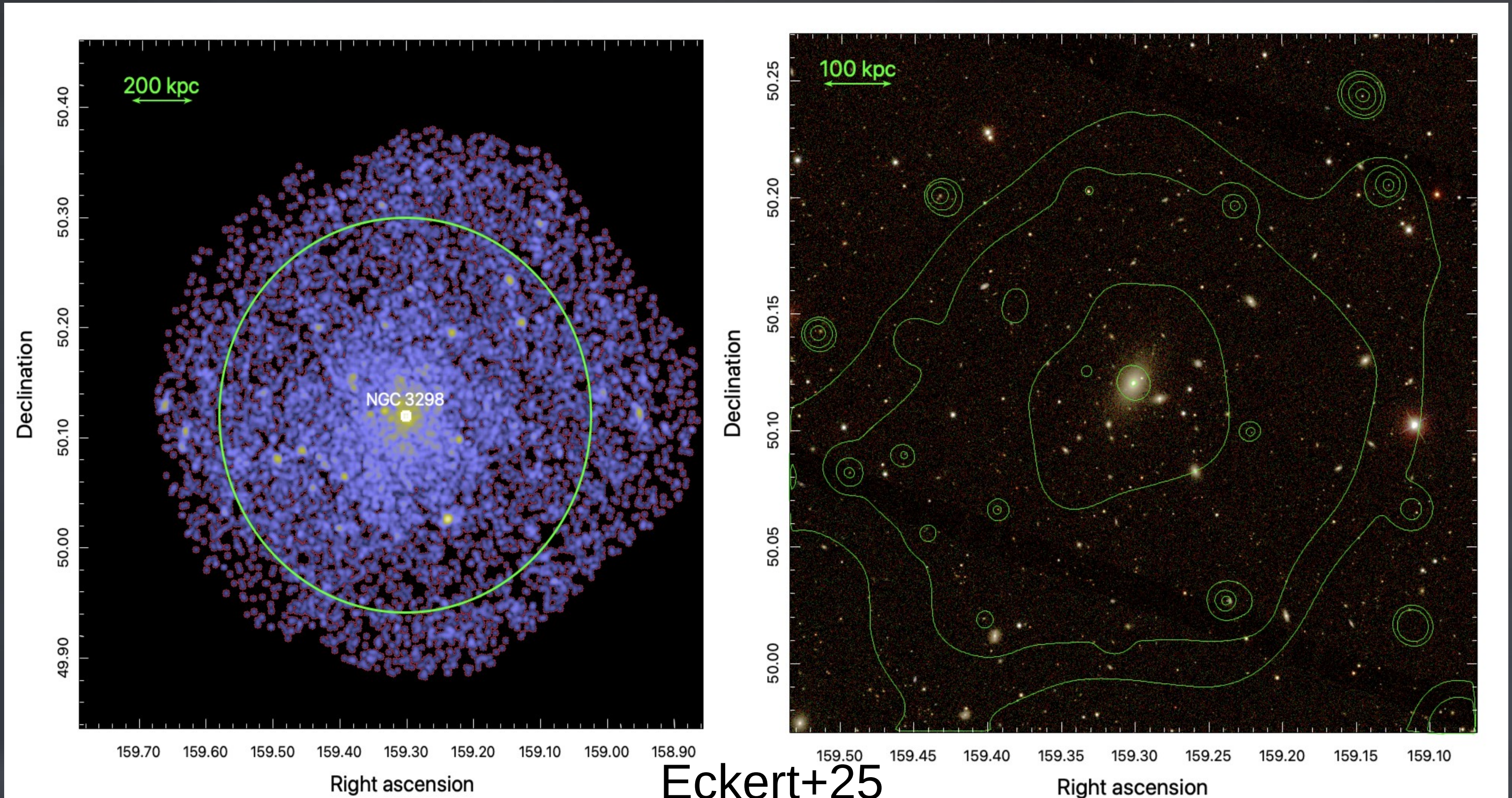
- X-GAP is a complete group sample extracted from SDSS FoF spectroscopic groups cross-correlated with RASS X-ray photons





Extreme feedback in SDSSTG 4436

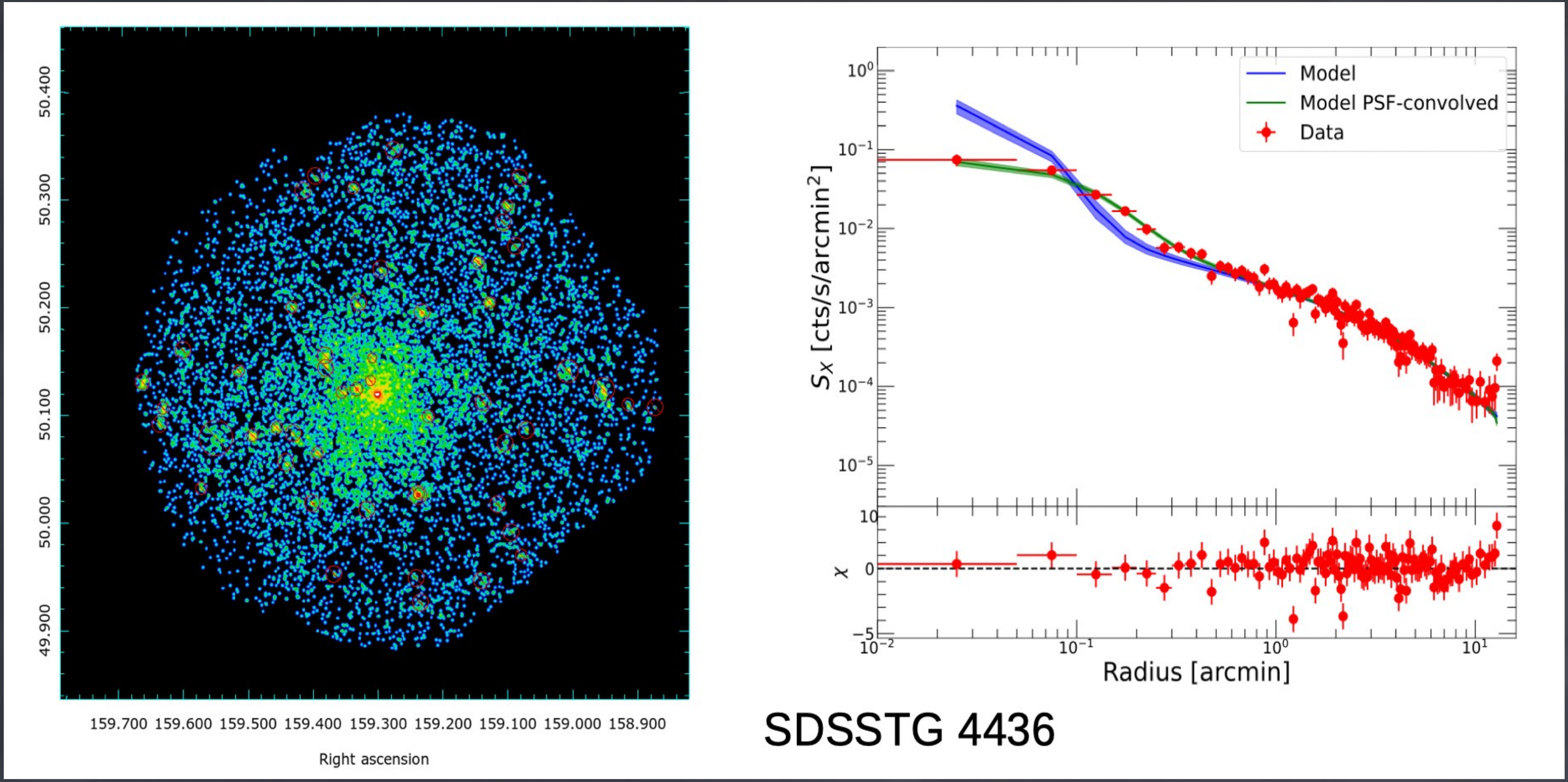
- SDSSTG 4436 (z=0.046) is a fossil group with relaxed X-ray morphology centred on the massive elliptical NGC 3298 (log M* = 11.5)



Eckert+25

Central density «kink»

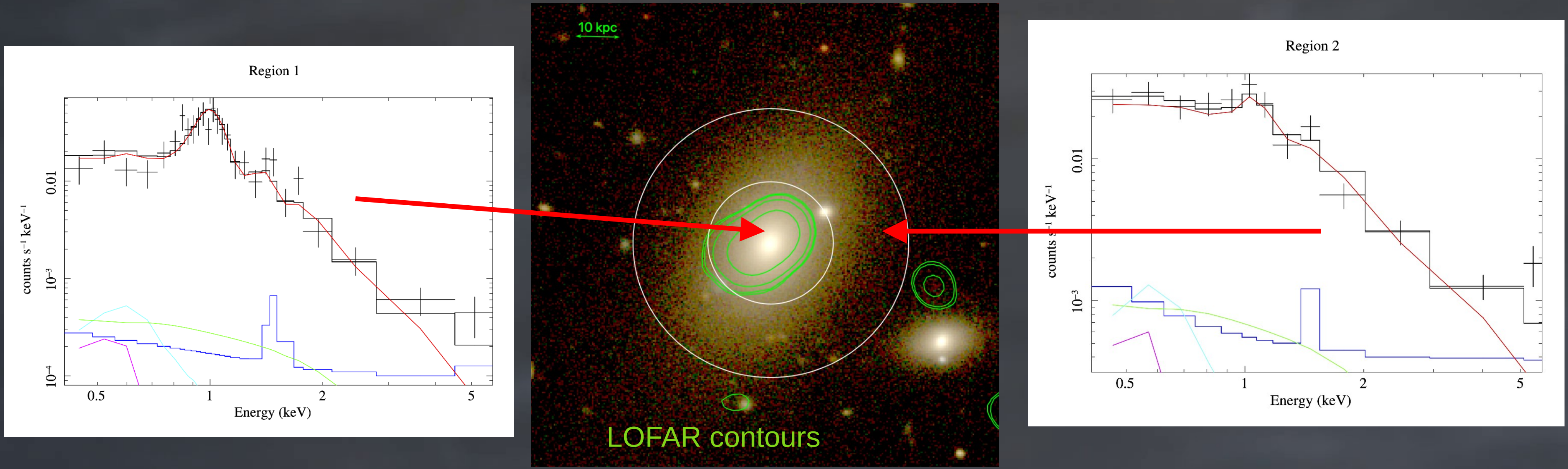
- The group exhibits a bright, compact core and a flat profile beyond ~10 kpc



SDSSTG 4436

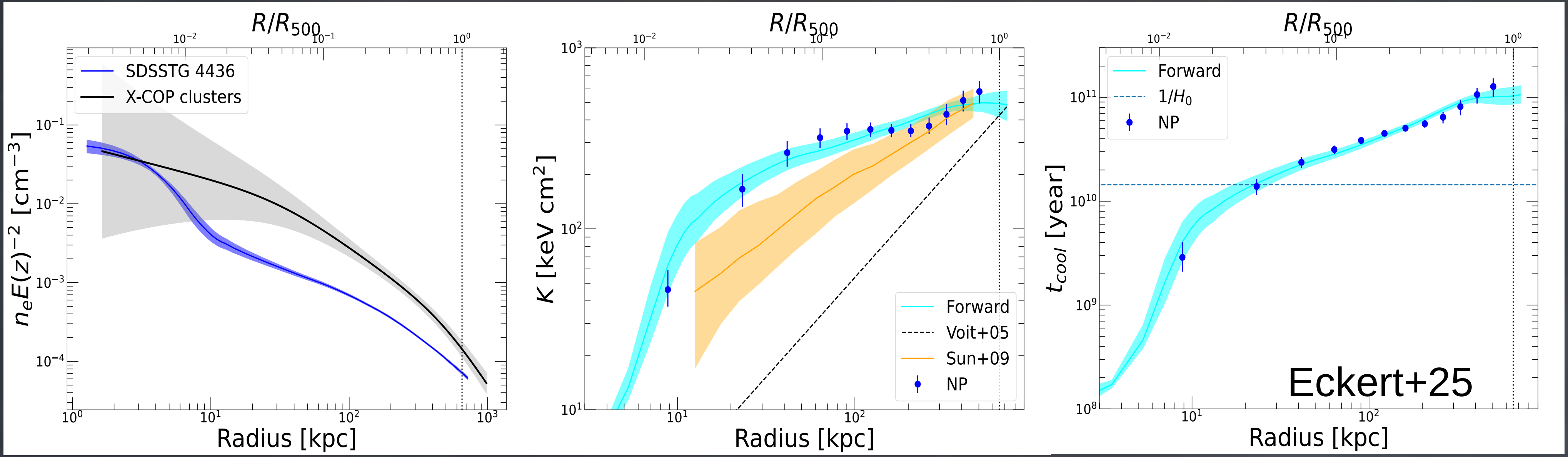
Compact core

- The emission from the core is fully thermal (no evidence for AGN); high metallicity
- The mass of the compact core (< 10 kpc) is only ~ 1% of the stellar mass Consistent with replenished gas from stellar mass loss



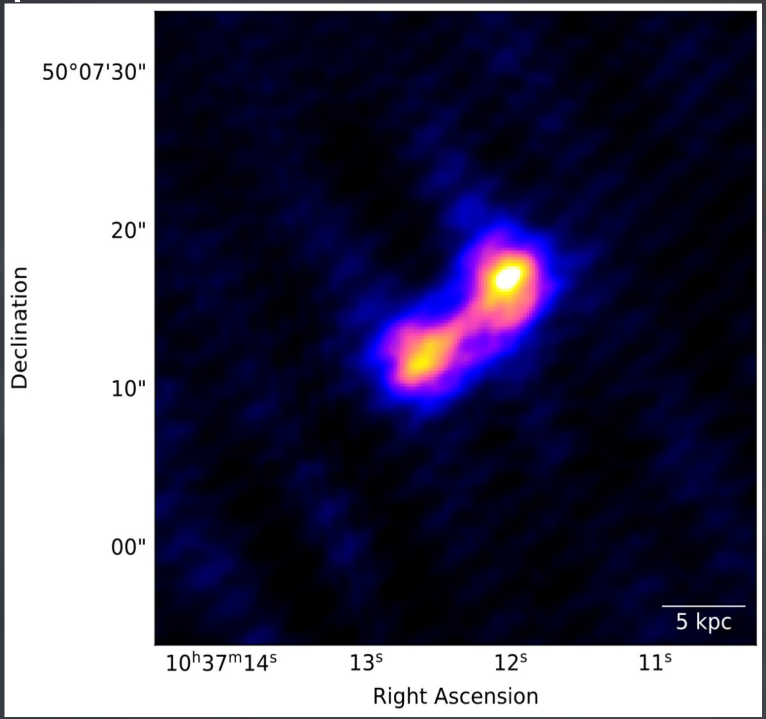
Over-heated atmosphere

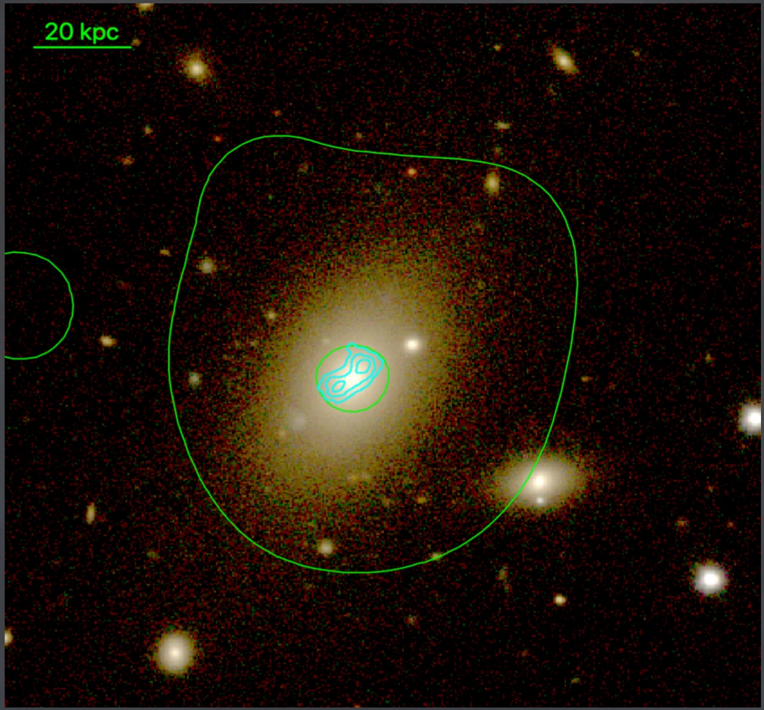
- Beyond the central corona (< 10 kpc size) the entropy exceeds the gravitational collapse expectation by a factor ~ 20!
- The cooling time sharply rises to the Hubble time at ~15 kpc



Radio jets

- The current radio jets have low power and are confined within the compact core





- Little energy is currently being injected inside the large-scale halo !

Energetics

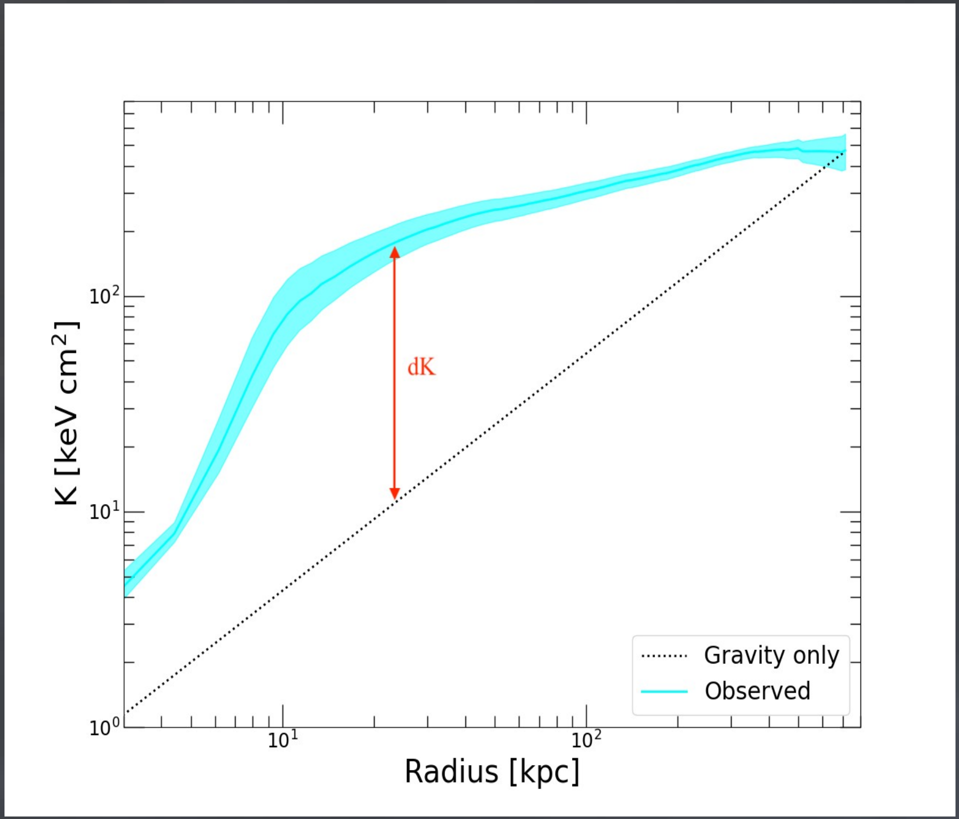
- The total feedback energy can be estimated from the excess entropy over the baseline gravitational entropy profile

- The heat needed to raise the entropy from K to K + dK is

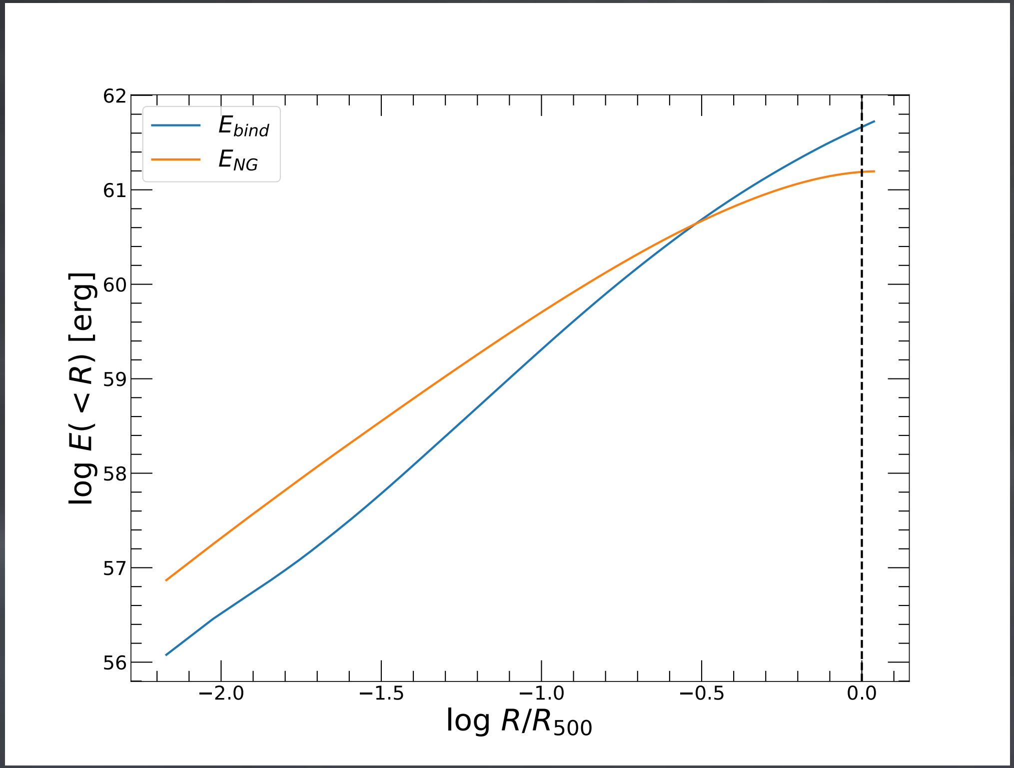
$$dQ = T\,dS \approx \frac{kT}{\gamma-1}\,\frac{K_{obs}-K_{grav}}{K_{obs}}$$

- The total injected energy is thus

$$E_{NG}(<R) = \int_0^R \frac{kT}{(\gamma-1)\mu_e m_p}\,\frac{K_{obs}-K_g}{K_{obs}}\,4\pi r^2 \rho_{gas}\,dr$$

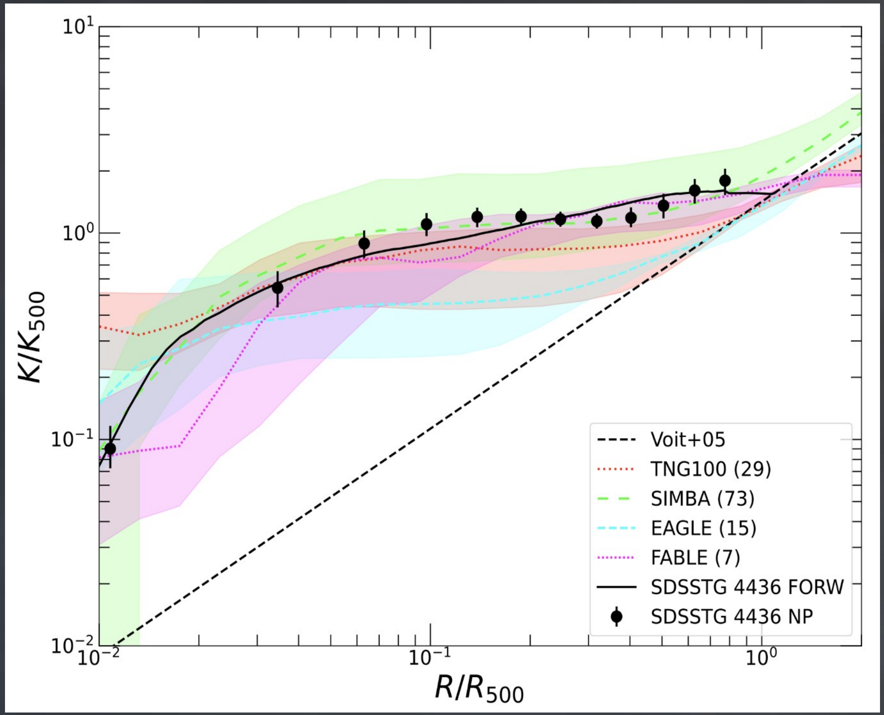


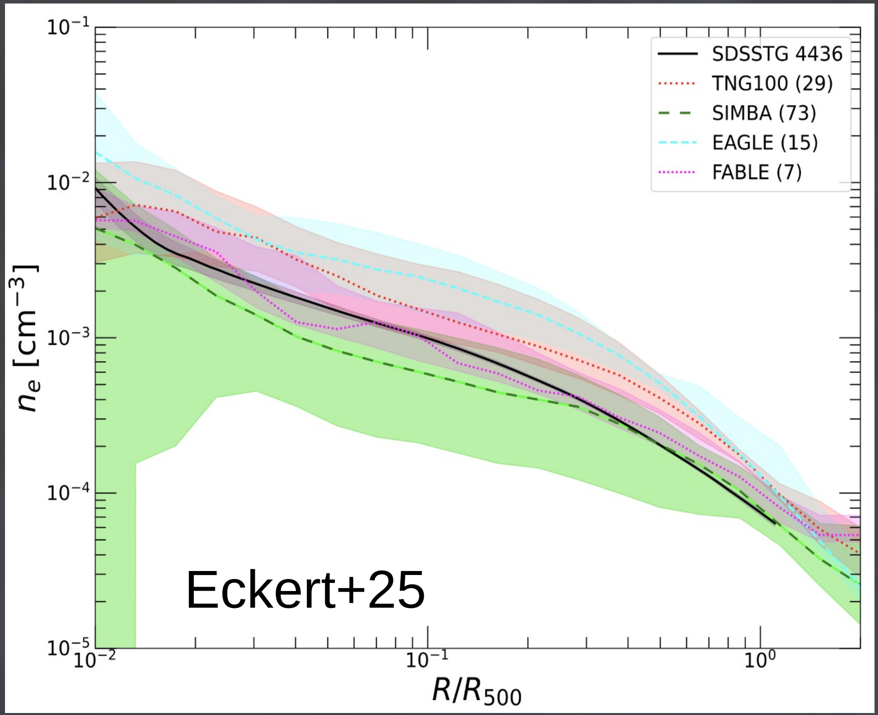
AGN vs binding energy



- The total non-gravitational energy within R_{500} is > 1.5×10^{61} erg
- The feedback energy is sufficient to unbind the core out to ~ $0.3R_{500}$

Comparison with simulations

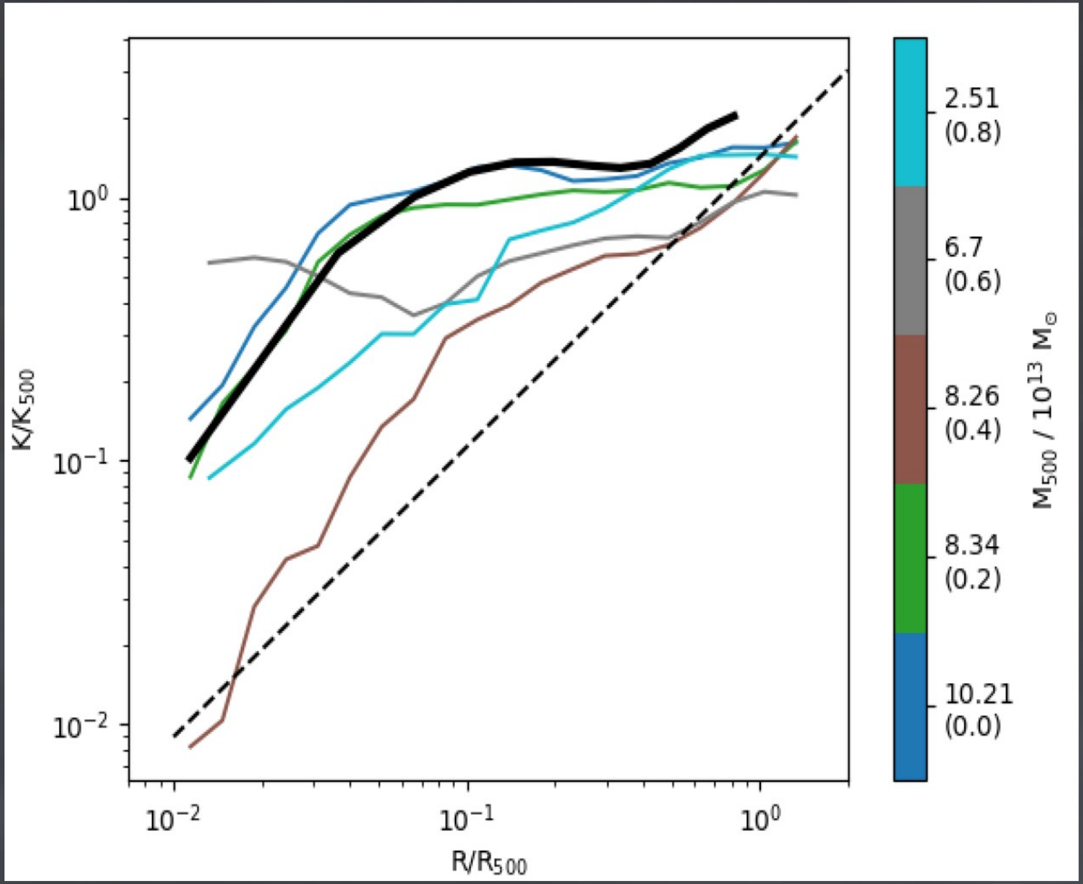




- SDSSTG 4436 corresponds to the most extreme systems in TNG and FABLE
- In SIMBA there are many such systems and some are much more extreme
- No such system exists in EAGLE

Entropy evolution in FABLE analogs

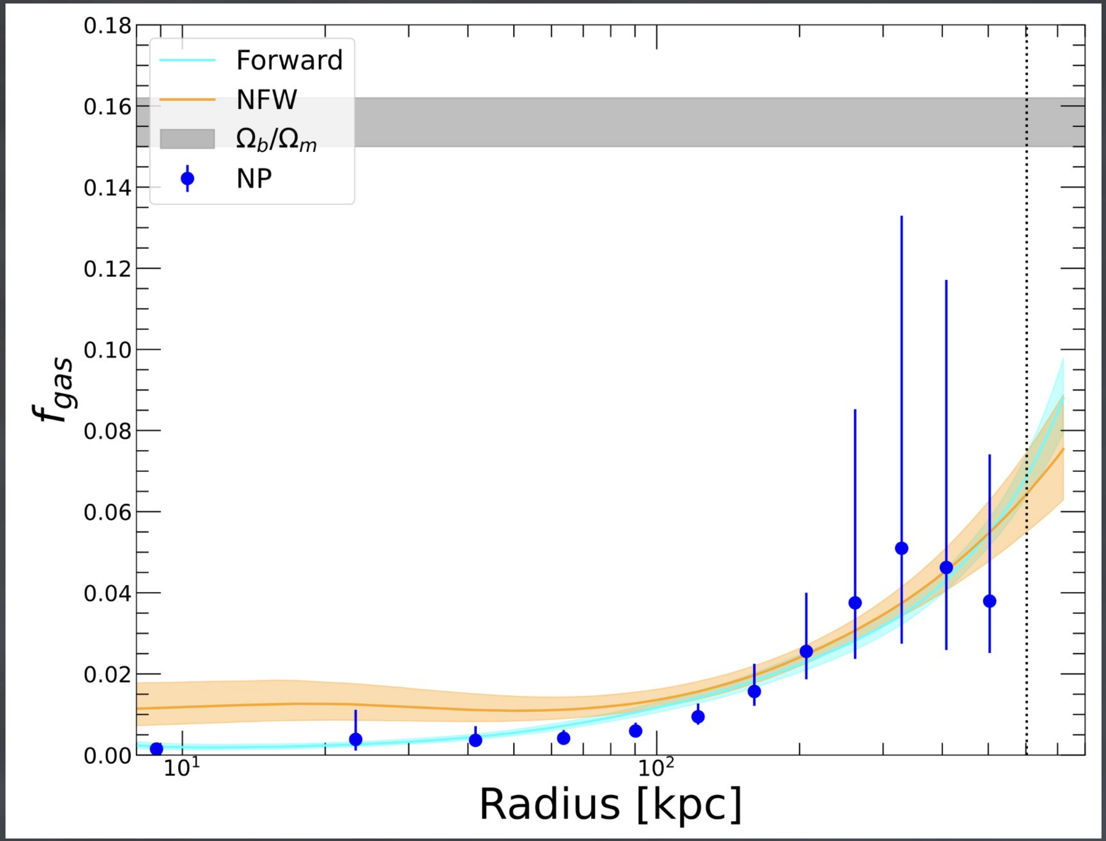
- We studied the evolution of entropy profiles for the FABLE halos that most closely resemble SDSSTG 4436
- The entropy in these systems was injected **recently** (z<0.4)
- We should see a strong evolution of entropy profiles and traces of past outbursts



Credit M. Bourne

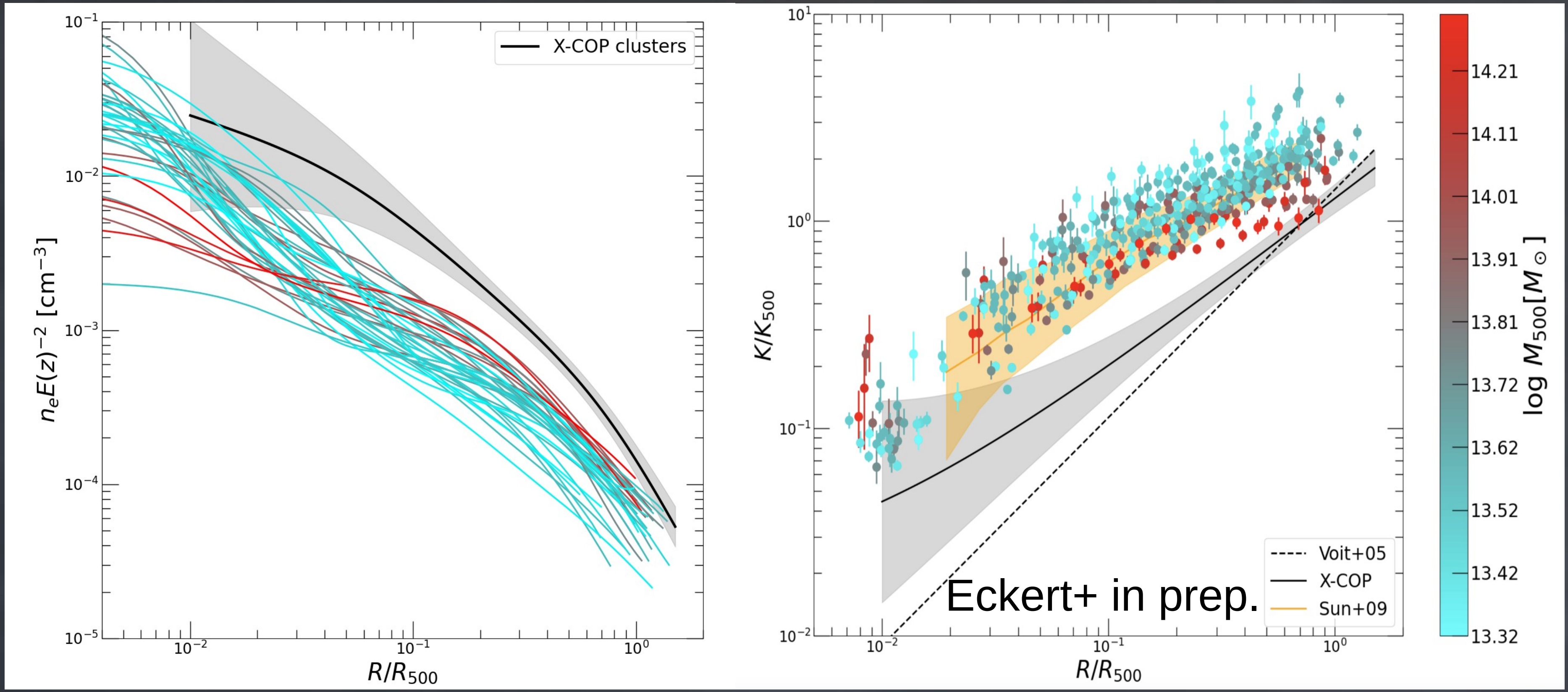
But what about f_{gas} ?

- For a mass of ~8e13 $M_\odot$ (T=1.85 keV), the gas fraction is not that low (~7 %)
- This is still much more than the *mean* of eROSITA stacks at this mass…
- Important : f_{gas} is a very difficult measurement and **all** measurements should be taken with caution

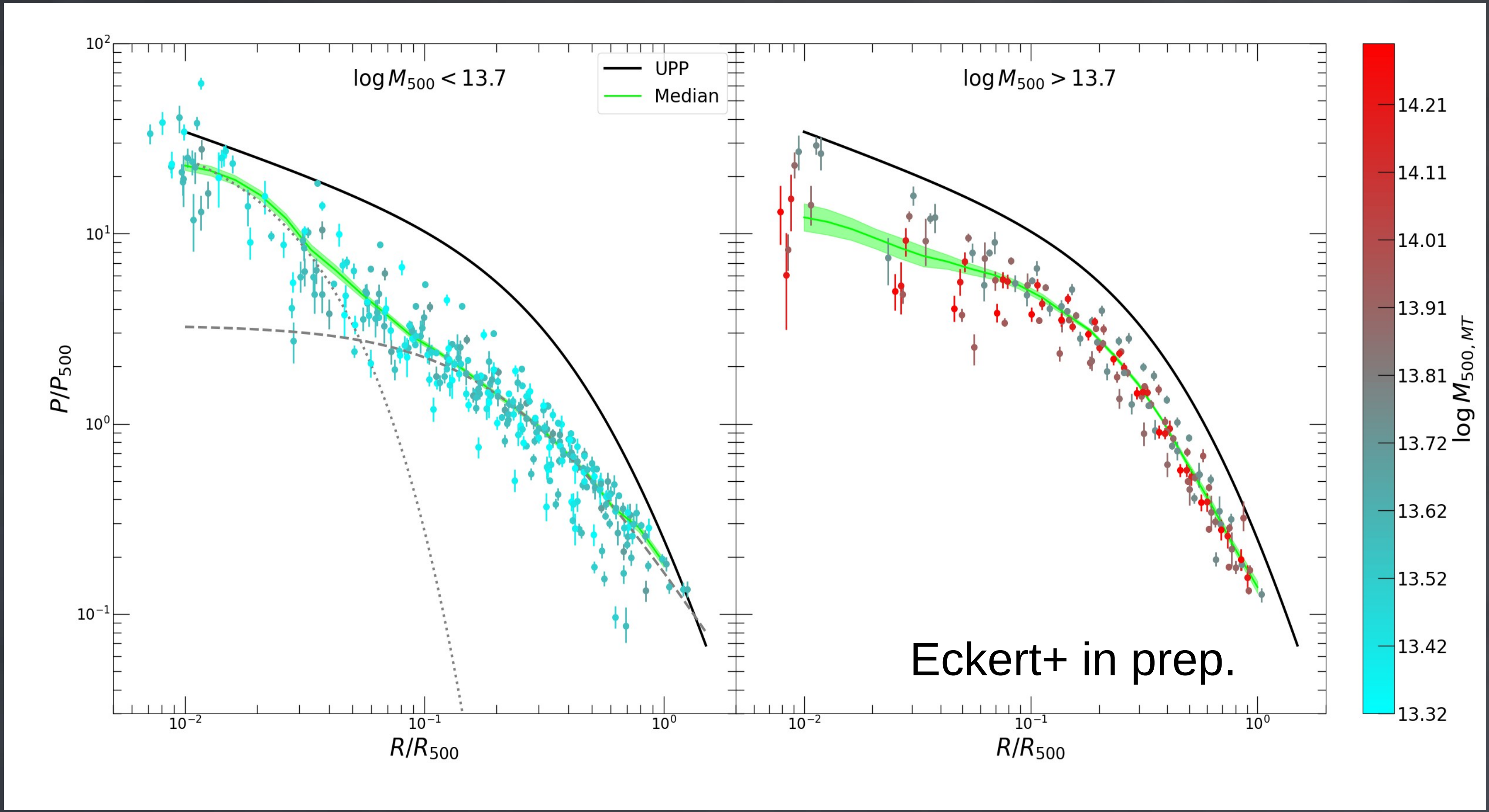


Thermodynamic profiles for the sample

- Clear trend of decreasing entropy and increasing density with halo mass



Pressure profiles

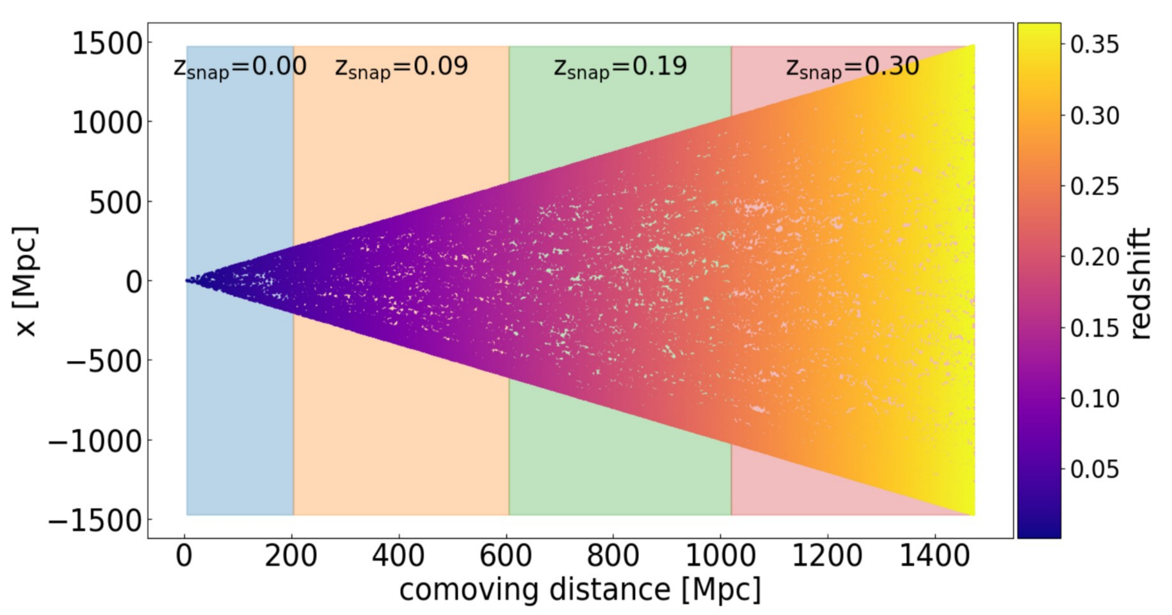


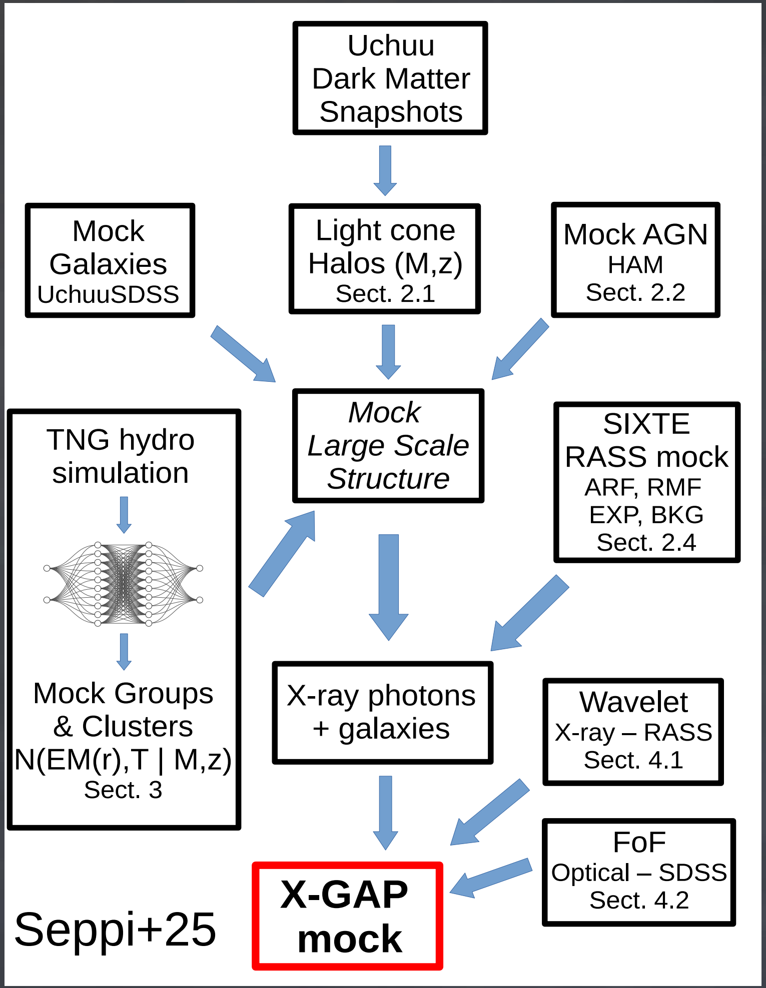
Gas fractions

Mocking the X-GAP selection function

Riccardo Seppi

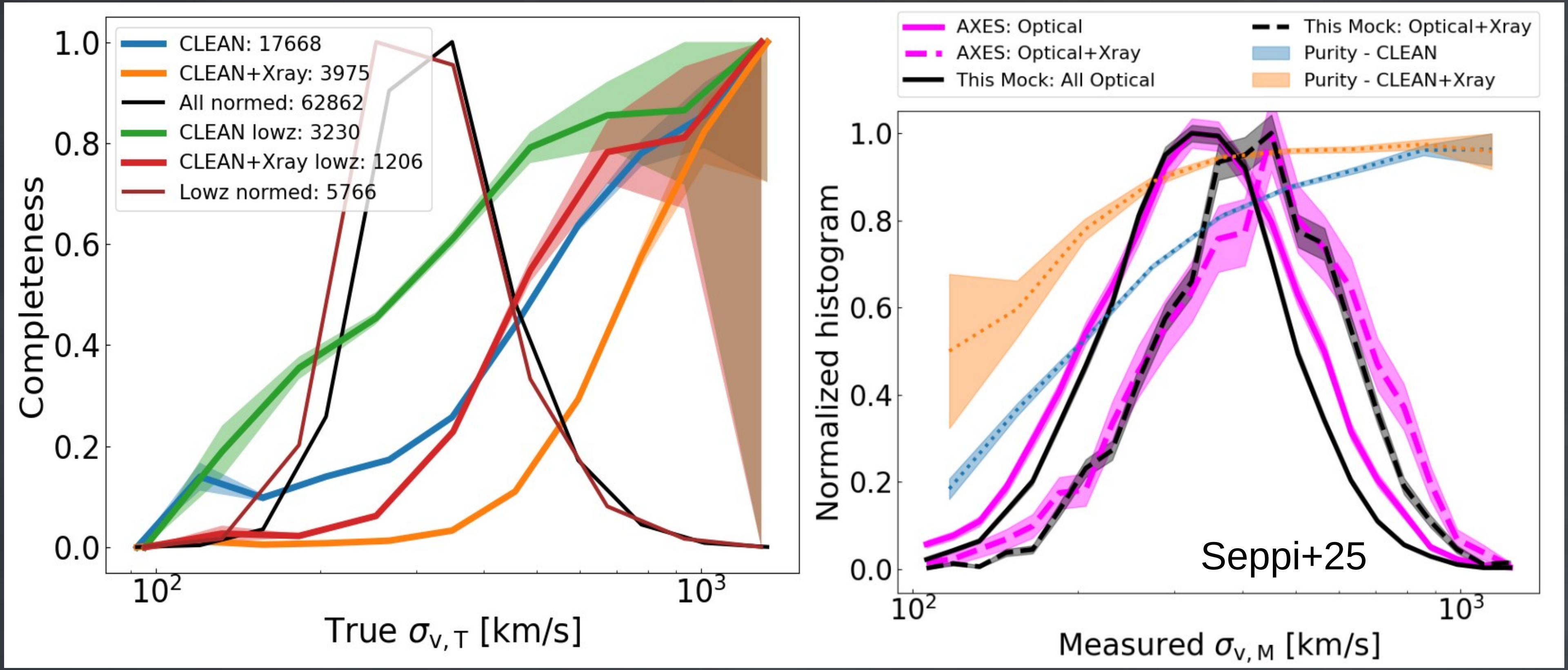
- Uchuu (Ishiyama+21): 2.0 Gpc/h, Mp = 3.27e8 Msun/h
- Mock galaxies: UchuuSDSS (Dong-Paez+22): abundance matching + SDSS colors
- Mock AGN from HOD modeling (Comparat+19)





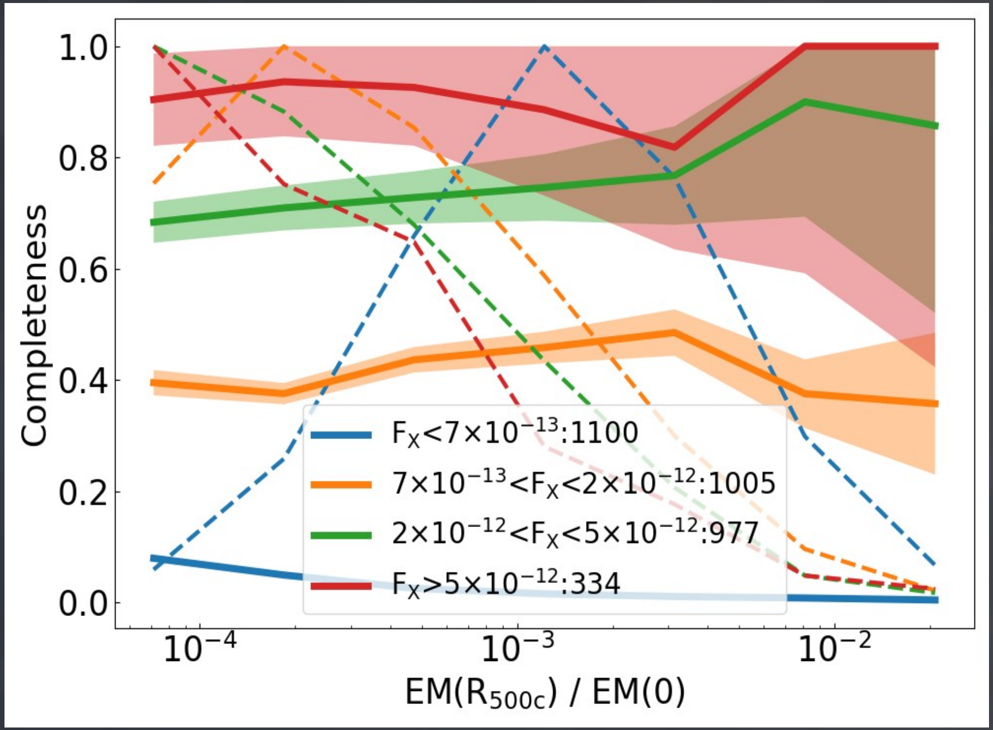
Purity and Completeness

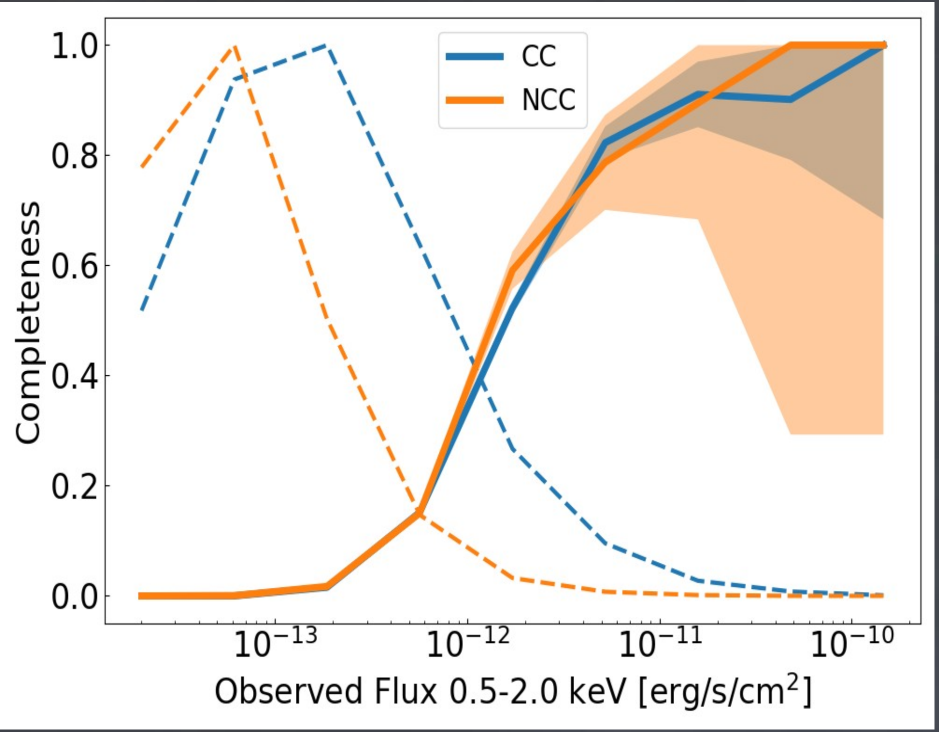
- Optical catalogue (Tempel+17) cleaned with X-ray detection (AXES, Damsted+24)
- Optical groups are more contaminated at low redshift (lower Mstar cut)
- AXES is 50% complete at veldisp=450 km/s and 93% pure



Dynamical state

- Cool core bias: relaxed clusters with peaked SB are easier to detect (Eckert+11)
- Our selection method (wavelet) has no preferential selection for CC

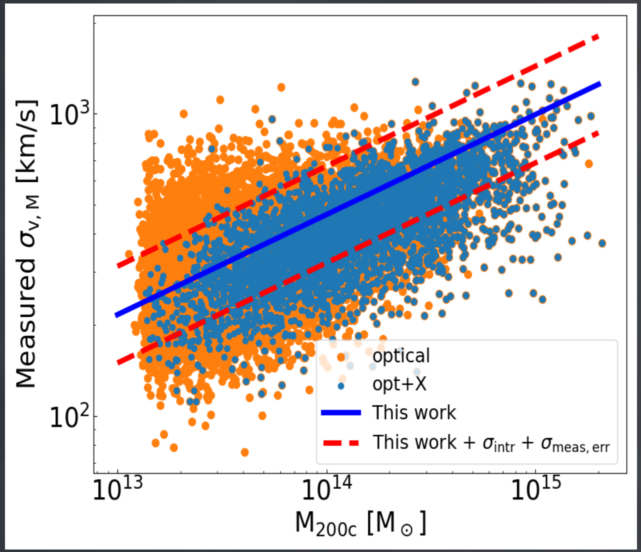


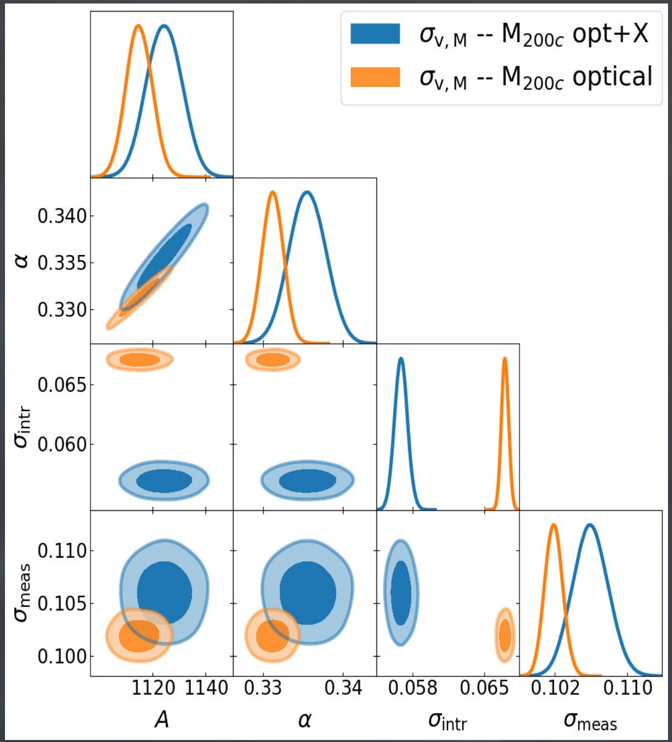


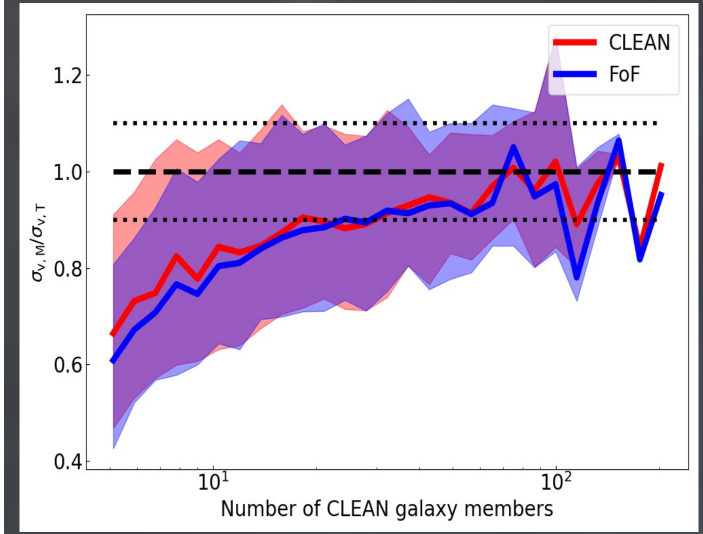
Seppi+25

X-GAP mock: velocity dispersion

- The velocity dispersion is a noisy, but well understood mass proxy
- For low N_{gal} the velocity dispersion retrieved from the galaxies is biased low
- We calibrated the relation between measured σ_v and halo mass



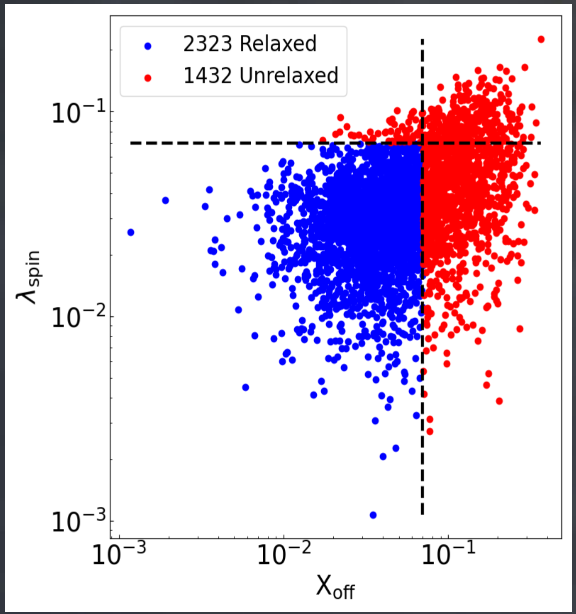


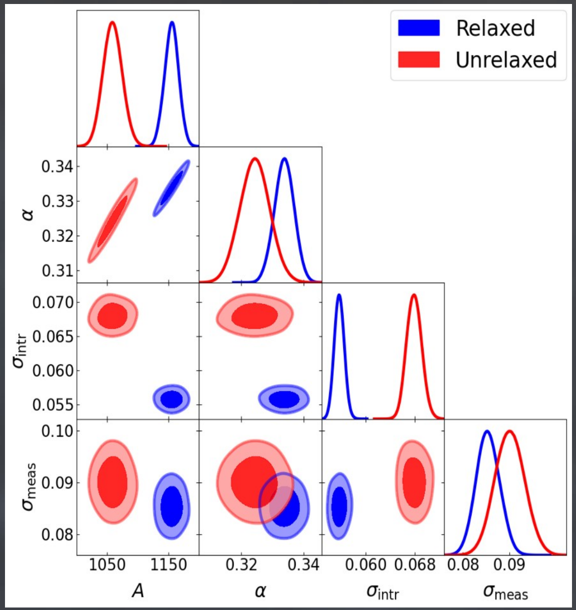


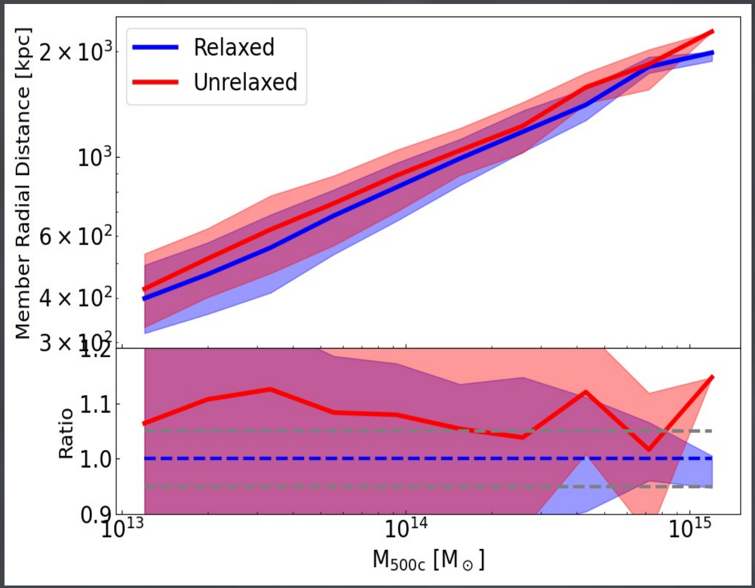
Seppi+25

Impact of dynamical state on velocity dispersion

- The dynamical state has an impact on the σ_v-M_h relation
- The normalization is higher for **relaxed** clusters !
- The member galaxies are on average closer to the center in relaxed groups

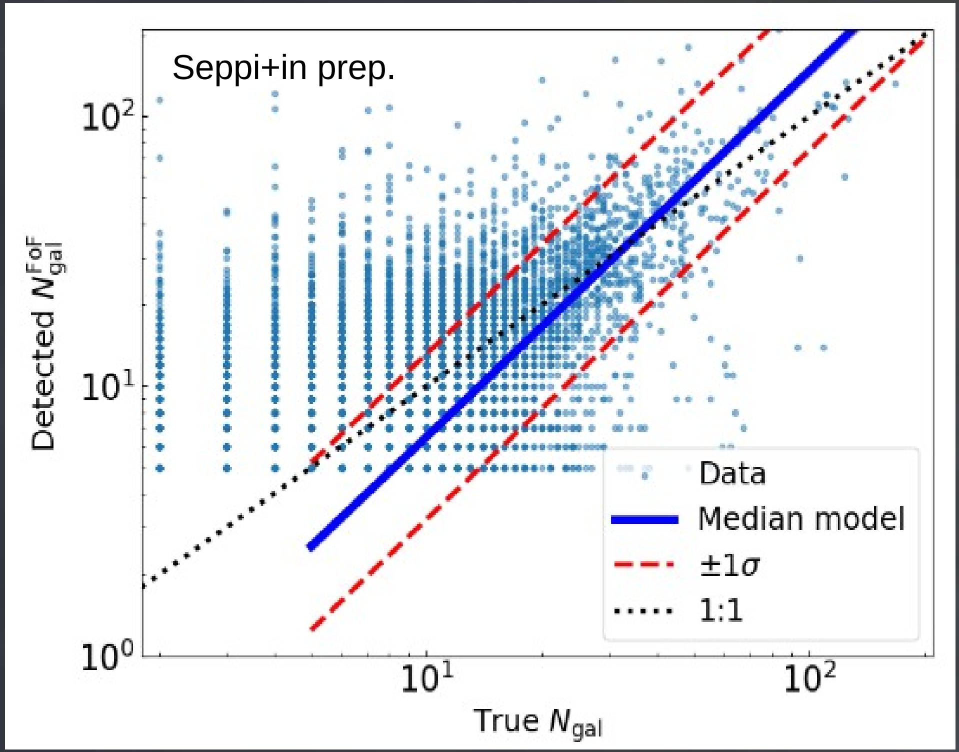


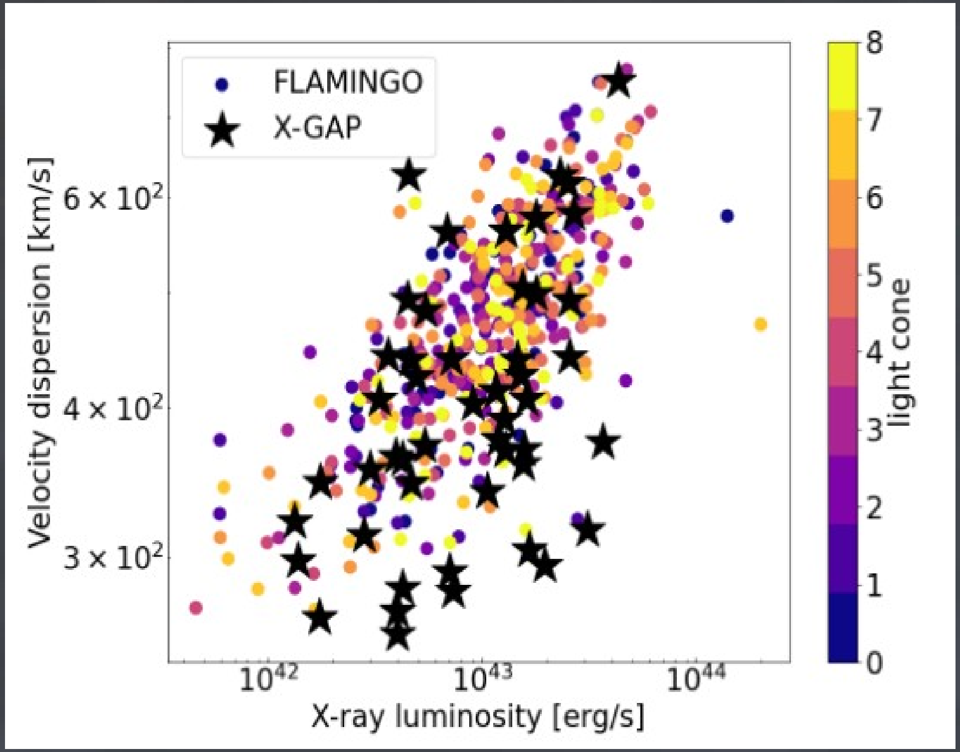




FLAMINGO x X-GAP

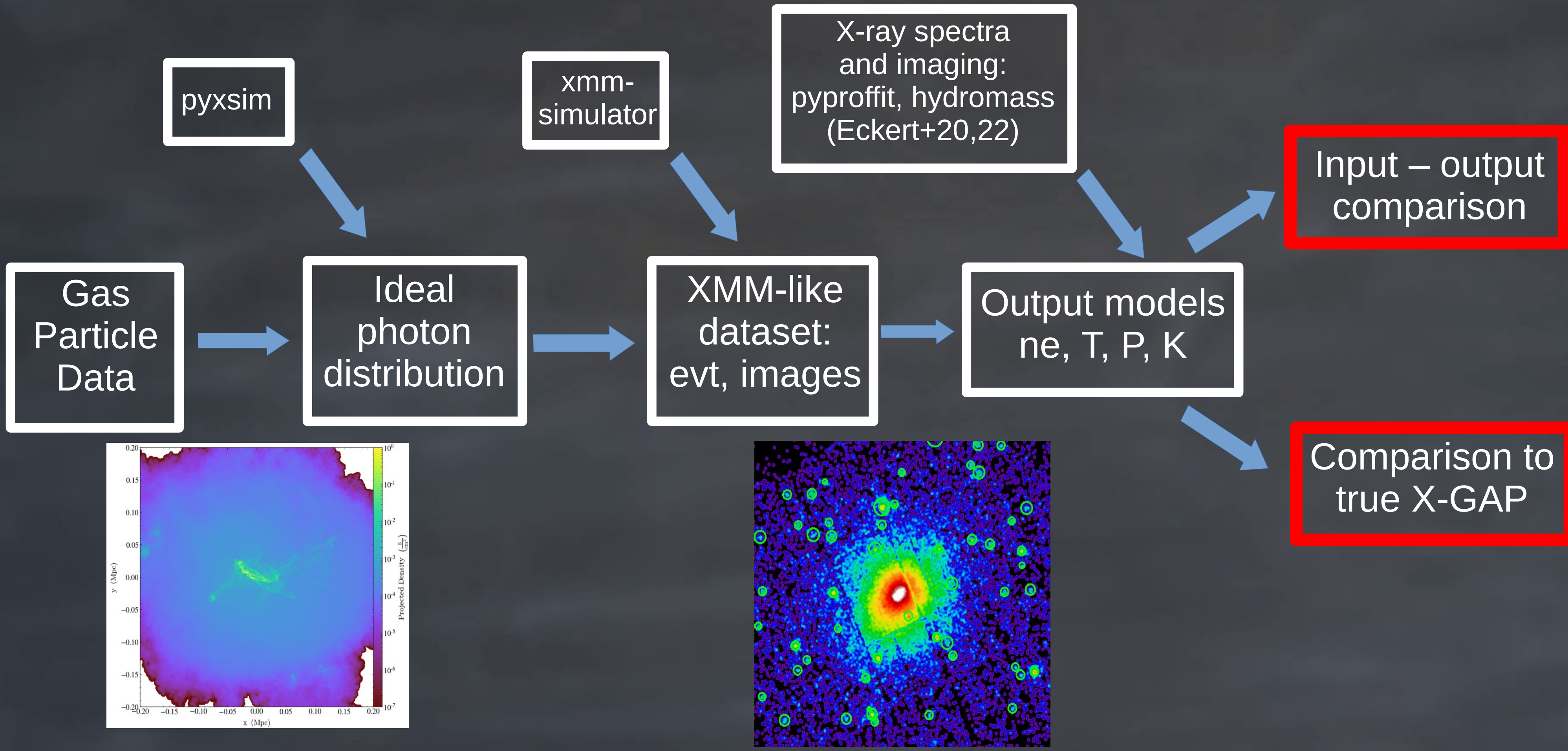
- We forward model the group selection in FLAMINGO
- The high-resolution run resolves all SDSS member galaxies
- Correction model for Nmembers vs Nsubhalo following Seppi+25
- Apply Selection Function with rejection sampling





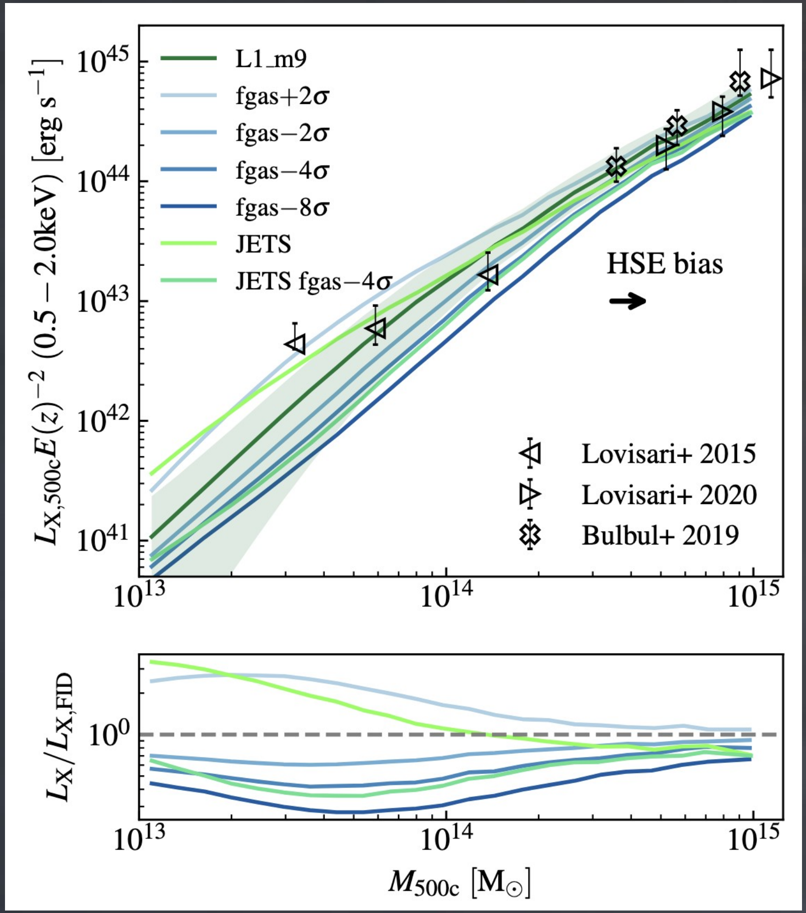
Forward modeling X-GAP

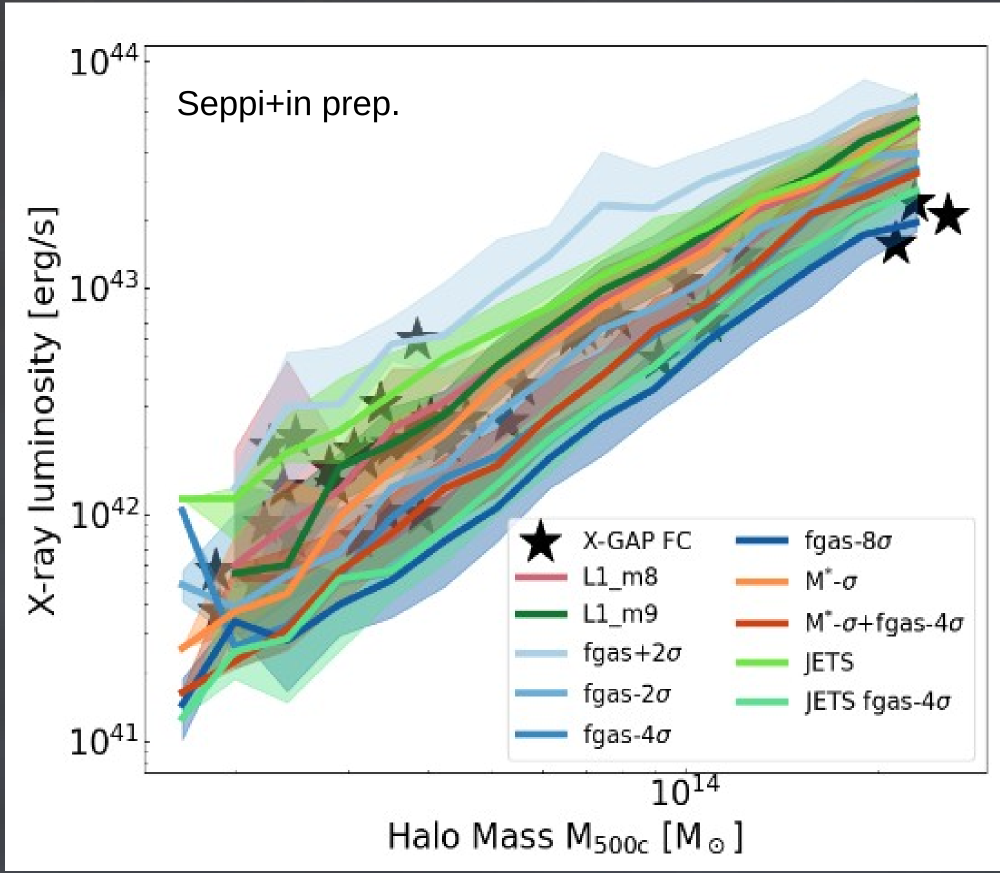
- Goal: compare thermodynamical gas profiles (ne, T, P, K) to hydro-models (feedback)
- Select twin systems (with selection function)



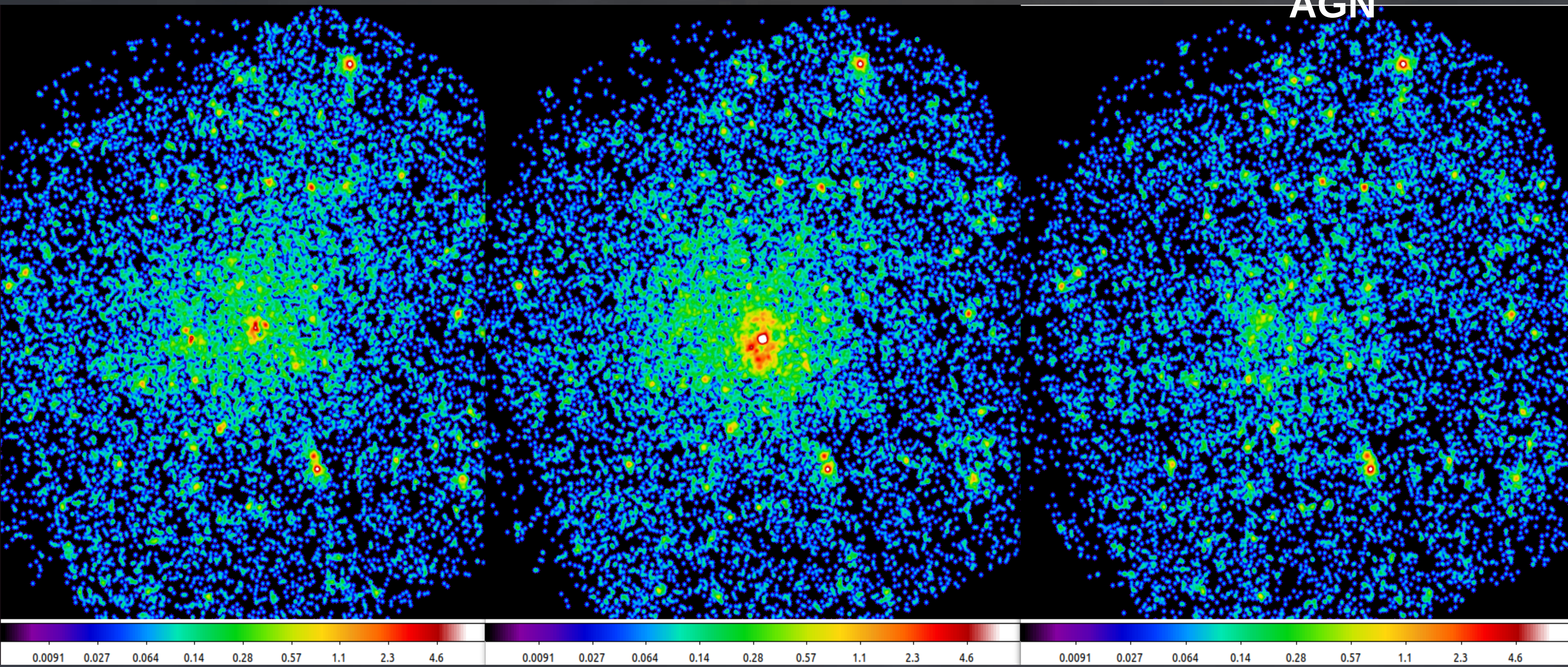
FLAMINGO x X-GAP

- Apply the selection on the high resolution run
- Study how the same halo behaves with different hydro-models



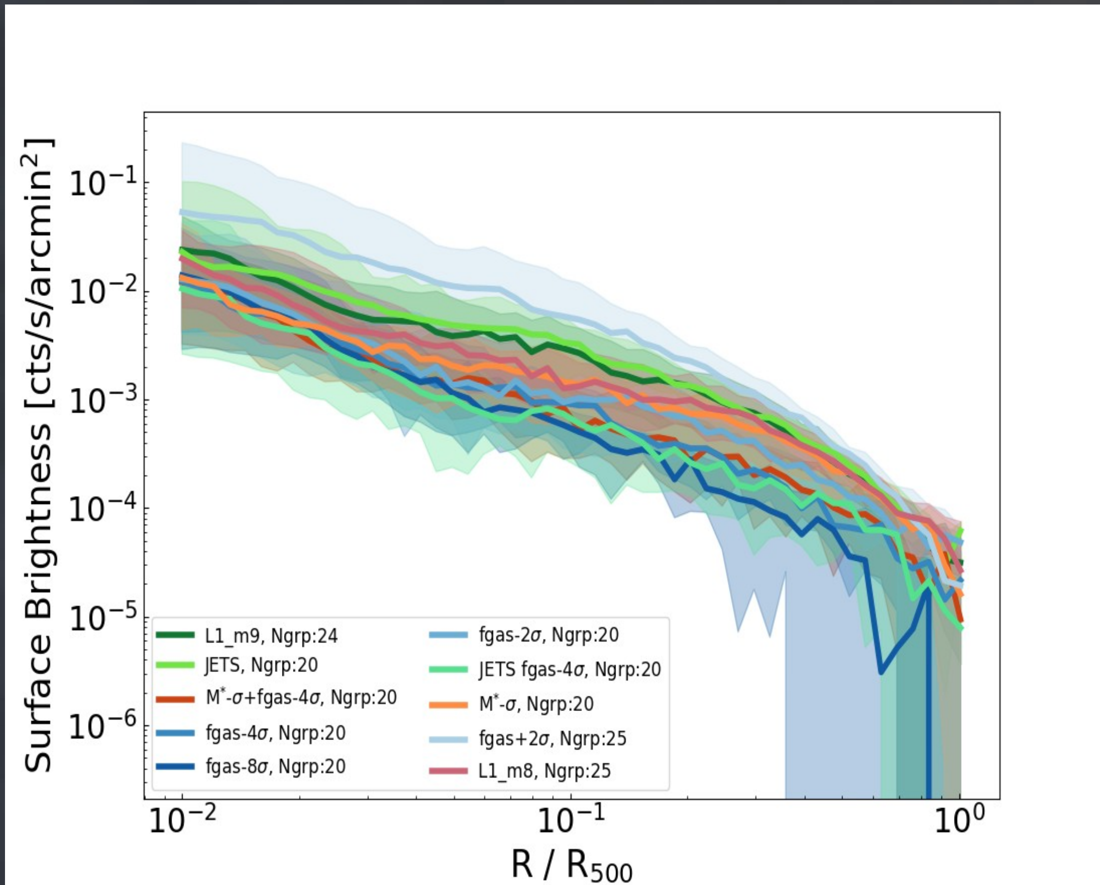


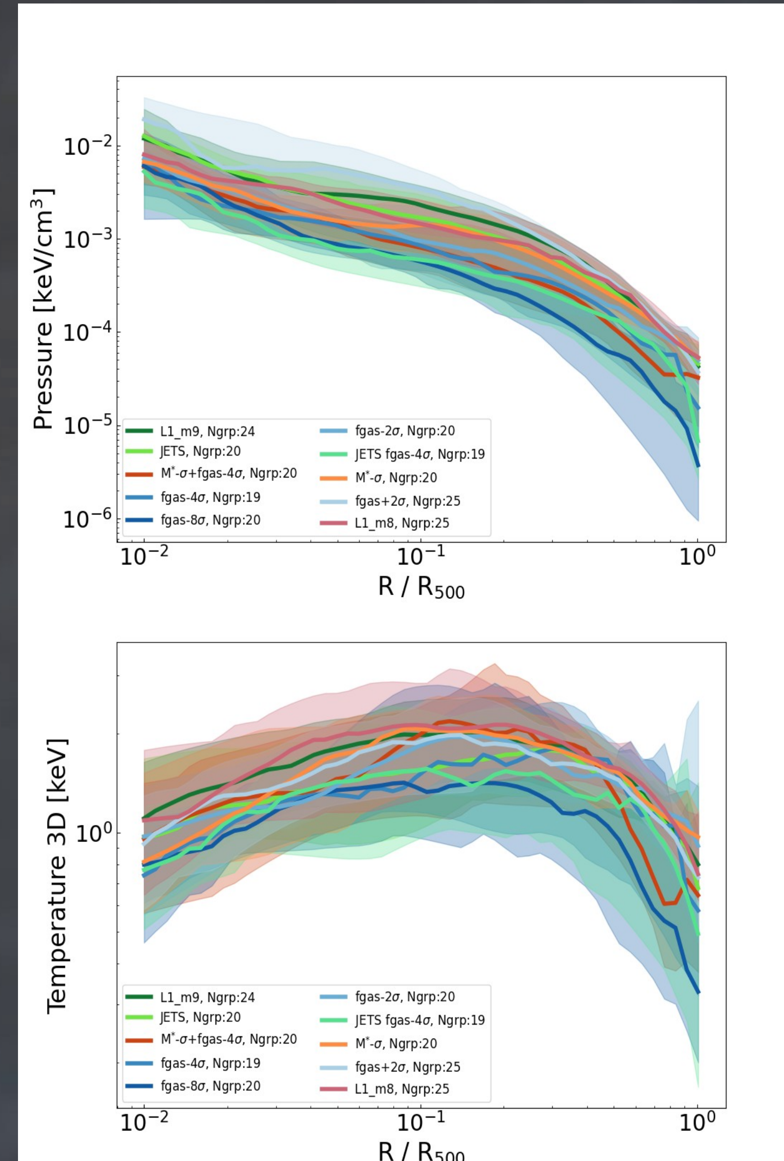
Impact of feedback models



Analysis of FLAMINGO mocks

- AGN get rid of gas (low SB)
- Jets redistribute gas (change P, T)

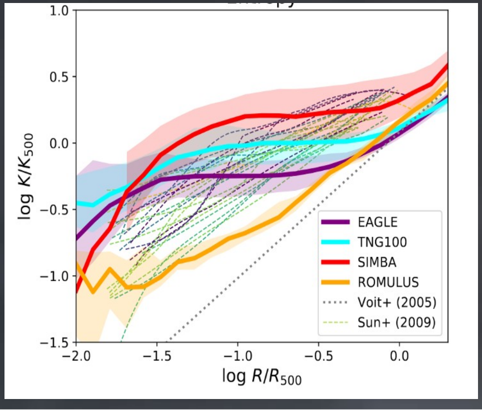




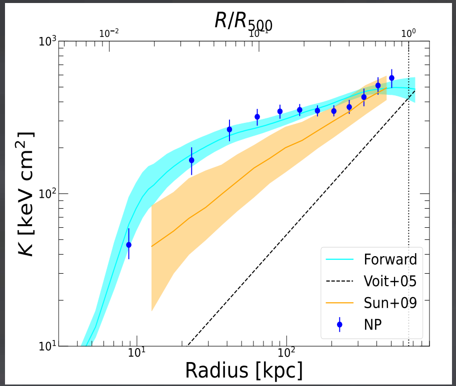
… To be continued

Take home message

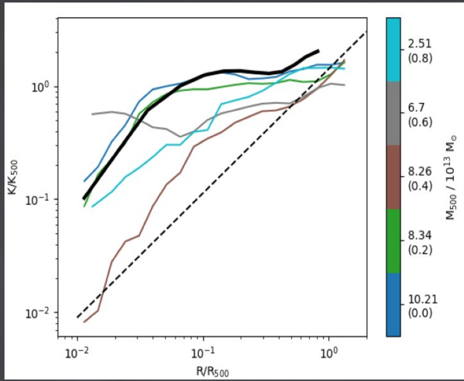
Entropy profiles encode the integrated AGN input



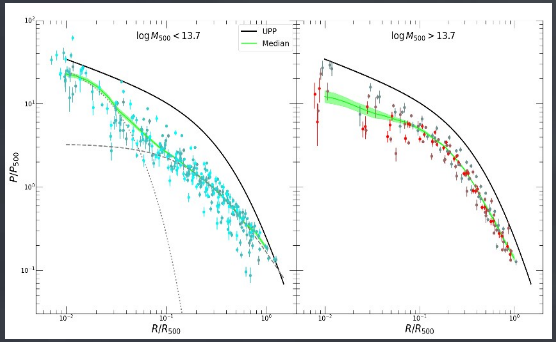
There exists fossil systems with highly elevated entropy



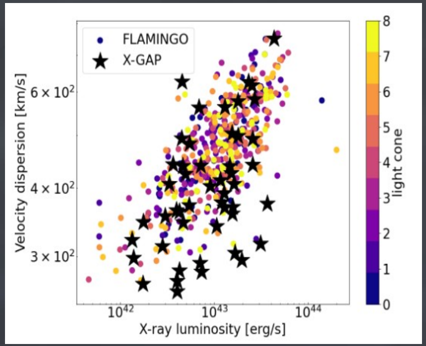
Analogs in FABLE acquired their entropy recently



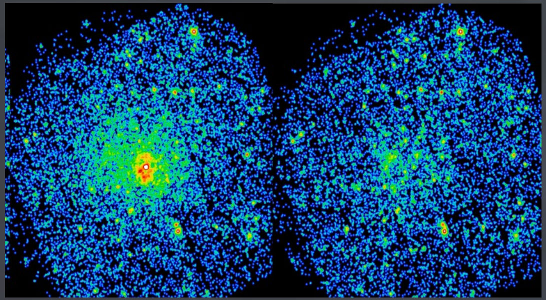
We see clear evolution of pressure profiles with mass



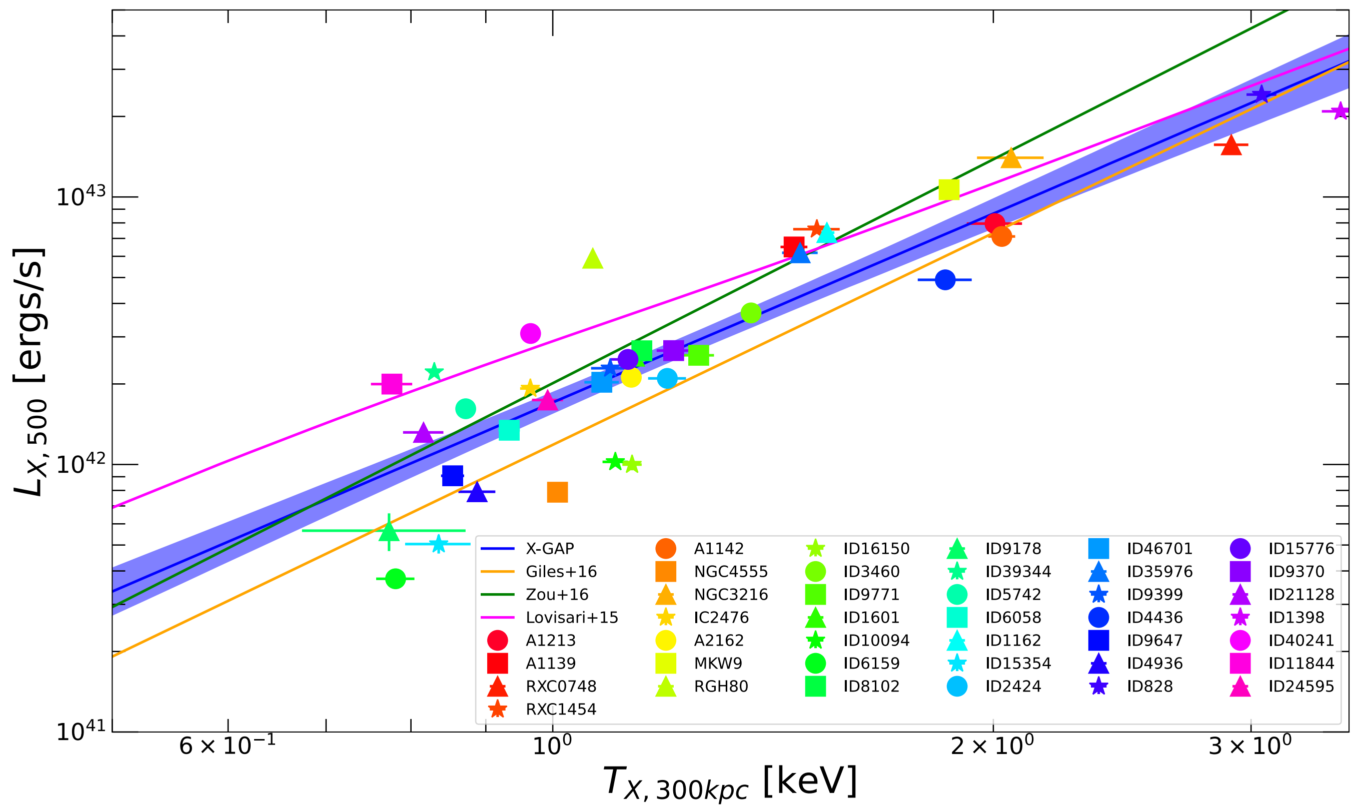
Forward modelling is preferable to comparisons with processed date



X-ray observations of local groups are highly sensitive to feedback implementation



Luminosity-temperature relation



Mass calibration