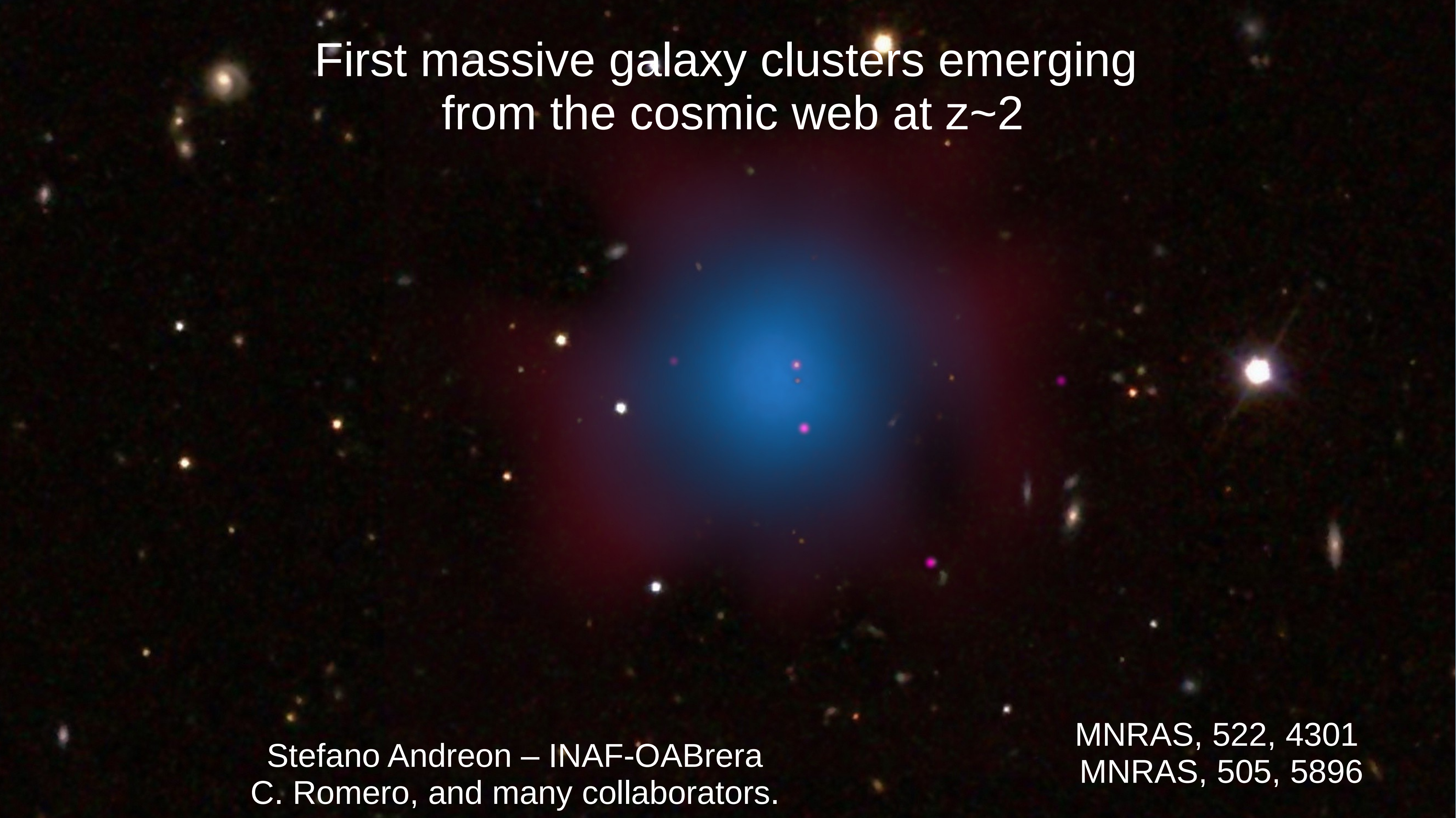


First massive galaxy clusters emerging from the cosmic web at z~2

Stefano Andreon – INAF-OABrera
C. Romero, and many collaborators.

MNRAS, 522, 4301
MNRAS, 505, 5896

Outline

- Introduction
  - Focus on the cluster growth and pressure evolution in the last 10 Gyr
  - Similarity of pressure profiles at z=0
  - Pressure profile determination from SZ data
- JKCS041 (z=1.803) and IDCSJ1426 (z=1.75)
  - JKCS041 is extremely faint, also for its mass
  - Their likely evolution
  - Both are just emerging from the cosmic web

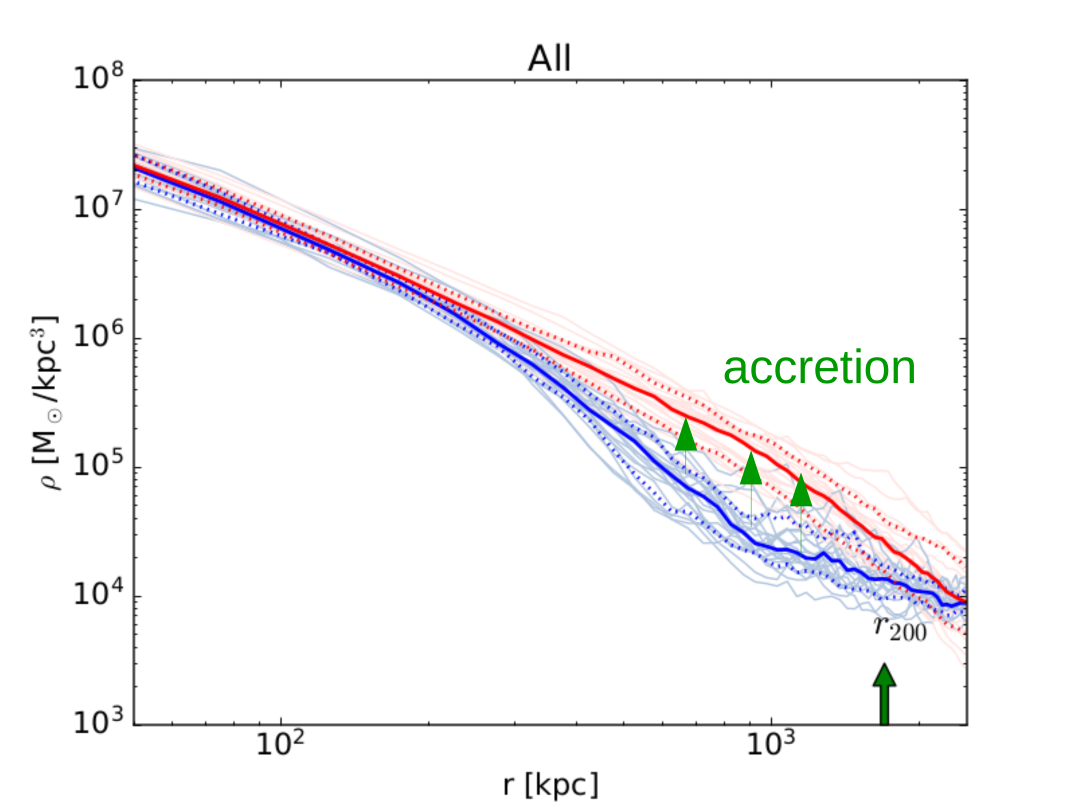
Why galaxy clusters?

- **Cosmology:** the comparison of the observed and predicted abundance of clusters as f(M,z) allows us to infer cosmological parameters (counts have an exponential sensitivity to some cosmological parameters)
- **Astrophysics:** interesting laboratories, the physics of processing going on in the ICM

Two stage cluster growth

the core sets early, the remaining part grows later, mostly from the cosmic web (not spherical infall)

Outer regions == last to come



Magneticum (i.e. with full gas physics), 25 most massive clusters at z=1.71

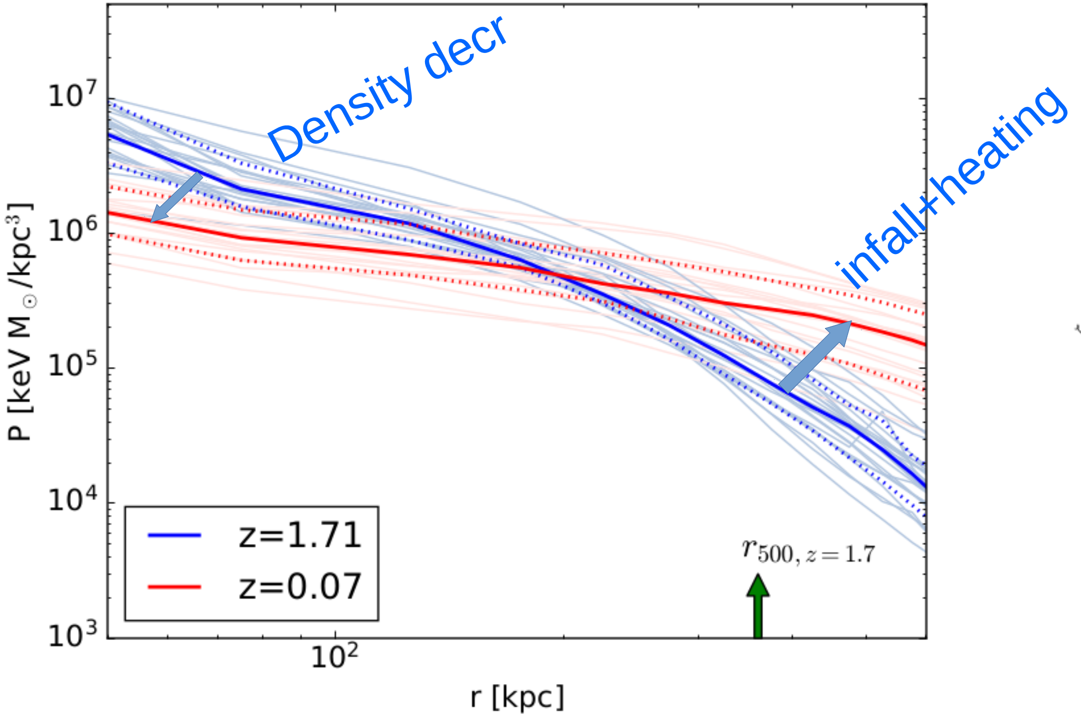
Light curves: individual objects
Solid and dotted: mean and std

SA+21

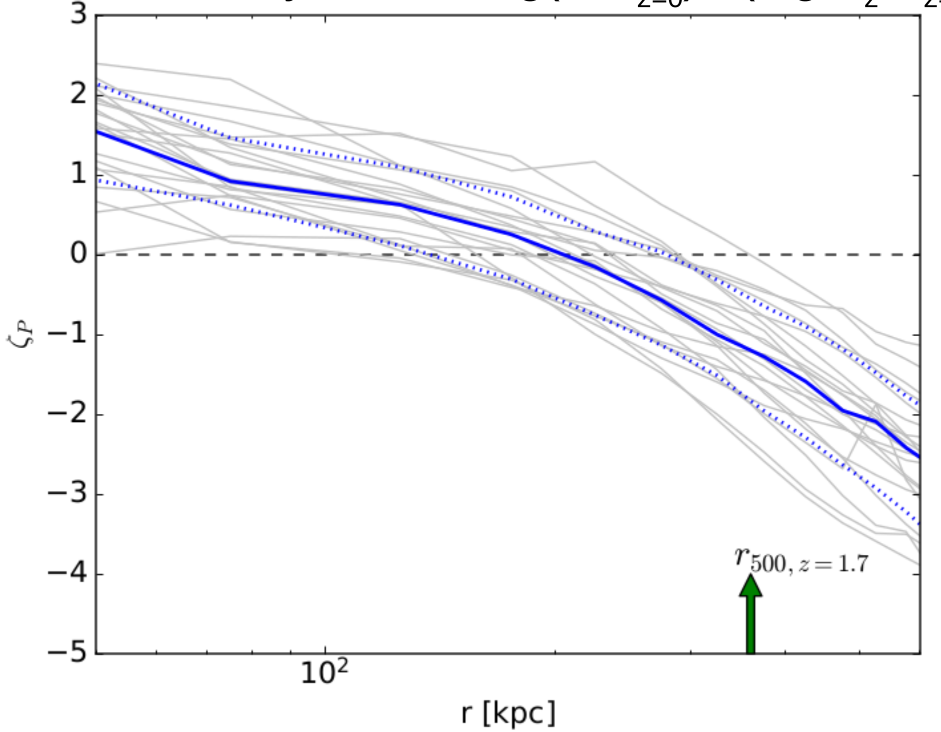
In Magneticum simulations, at z=1.7 clusters have central parts with larger P and outer regions with lower P

(SA+21)

Pressure=ρ*T

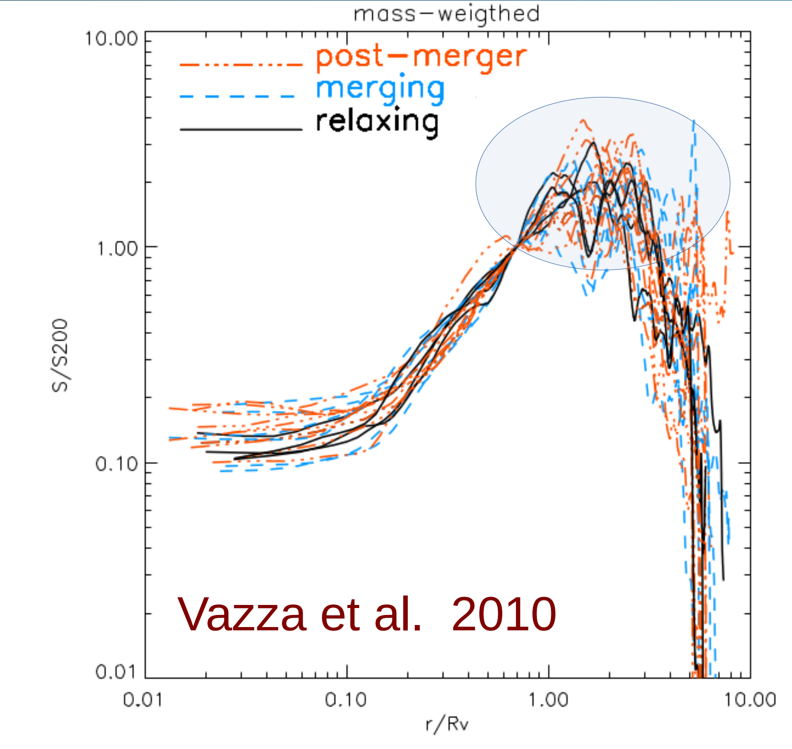


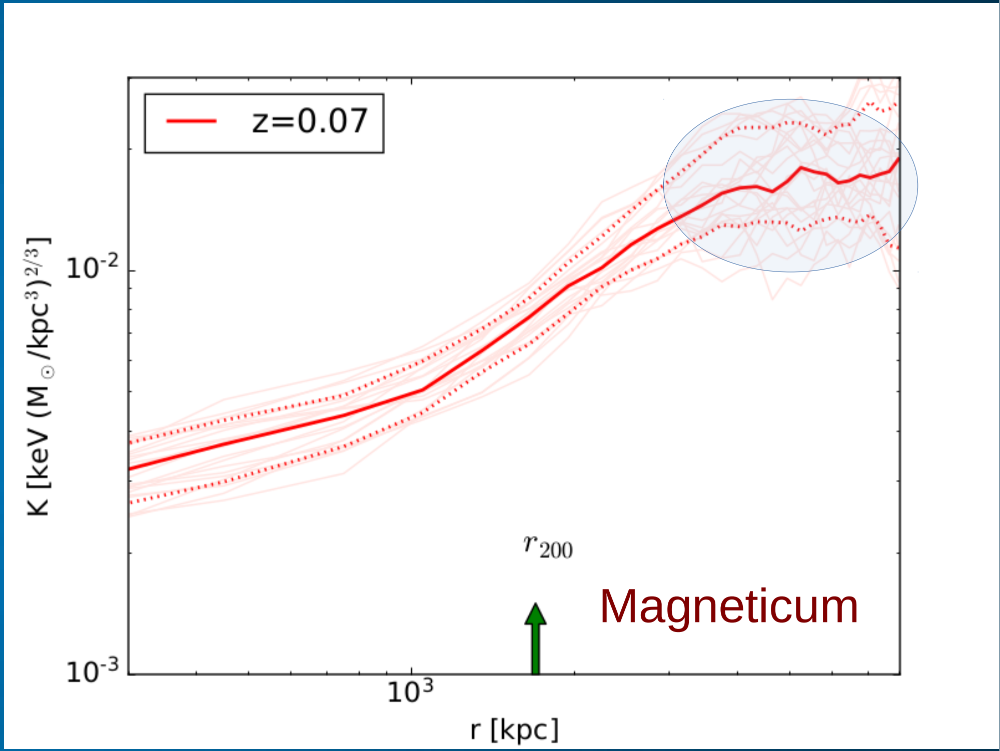
Evolutionary rate $\zeta = \log(P/P_{z=0}) / (\log E_z/E_{z=0})$



Simulations differ in detail (e.g. entropy flattening not at the same radius)

$S==K=P/n_e^{5/3}$





Redshift ~2 is the key epoch

because we expect that at this epoch clusters start to emerge from the cosmic web and because feedback from AGN and SF is maximal (peak there!)

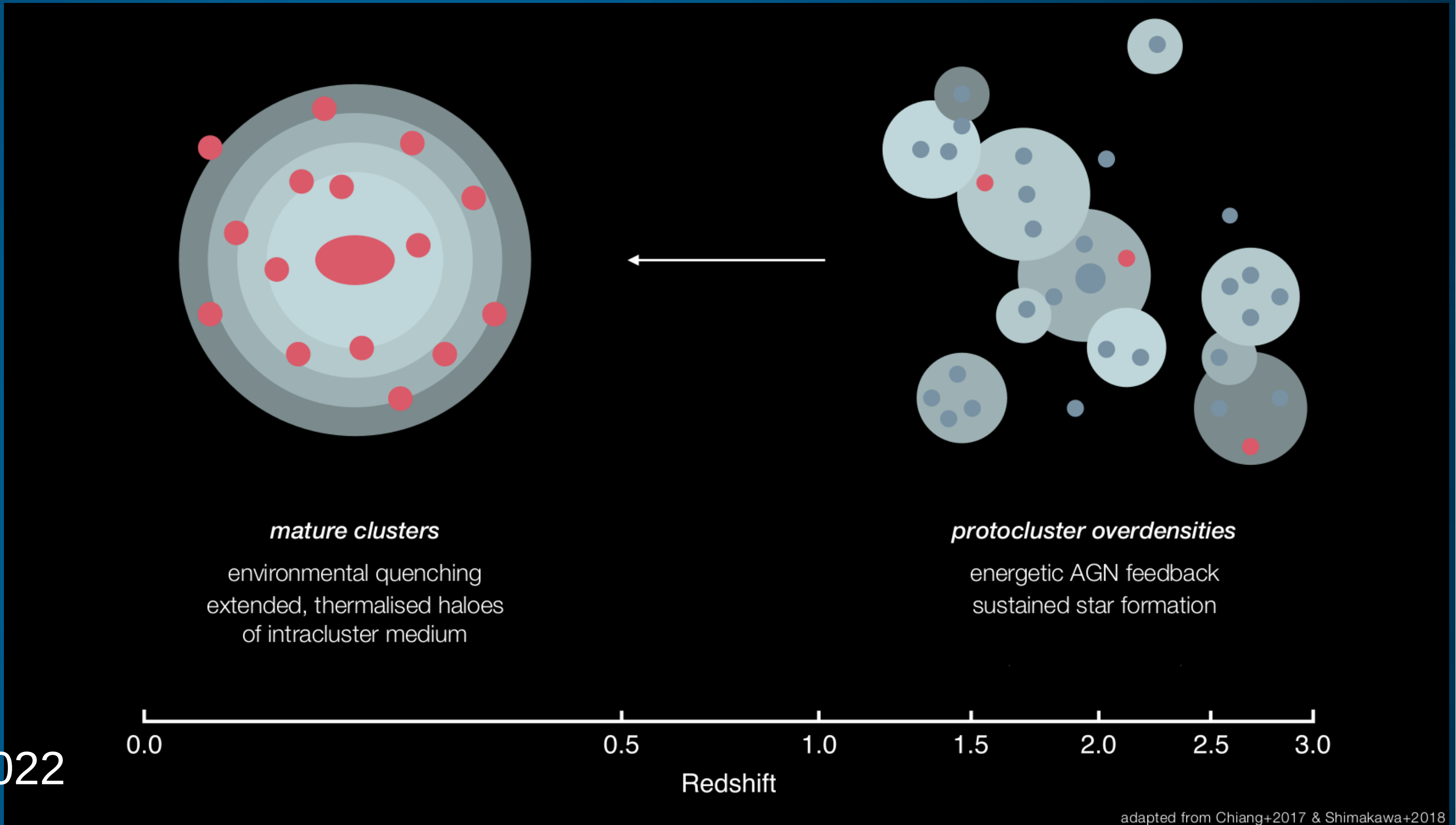


Figure credit: Di Mascolo 2022

Yet, z~2 is observationally almost un-sampled

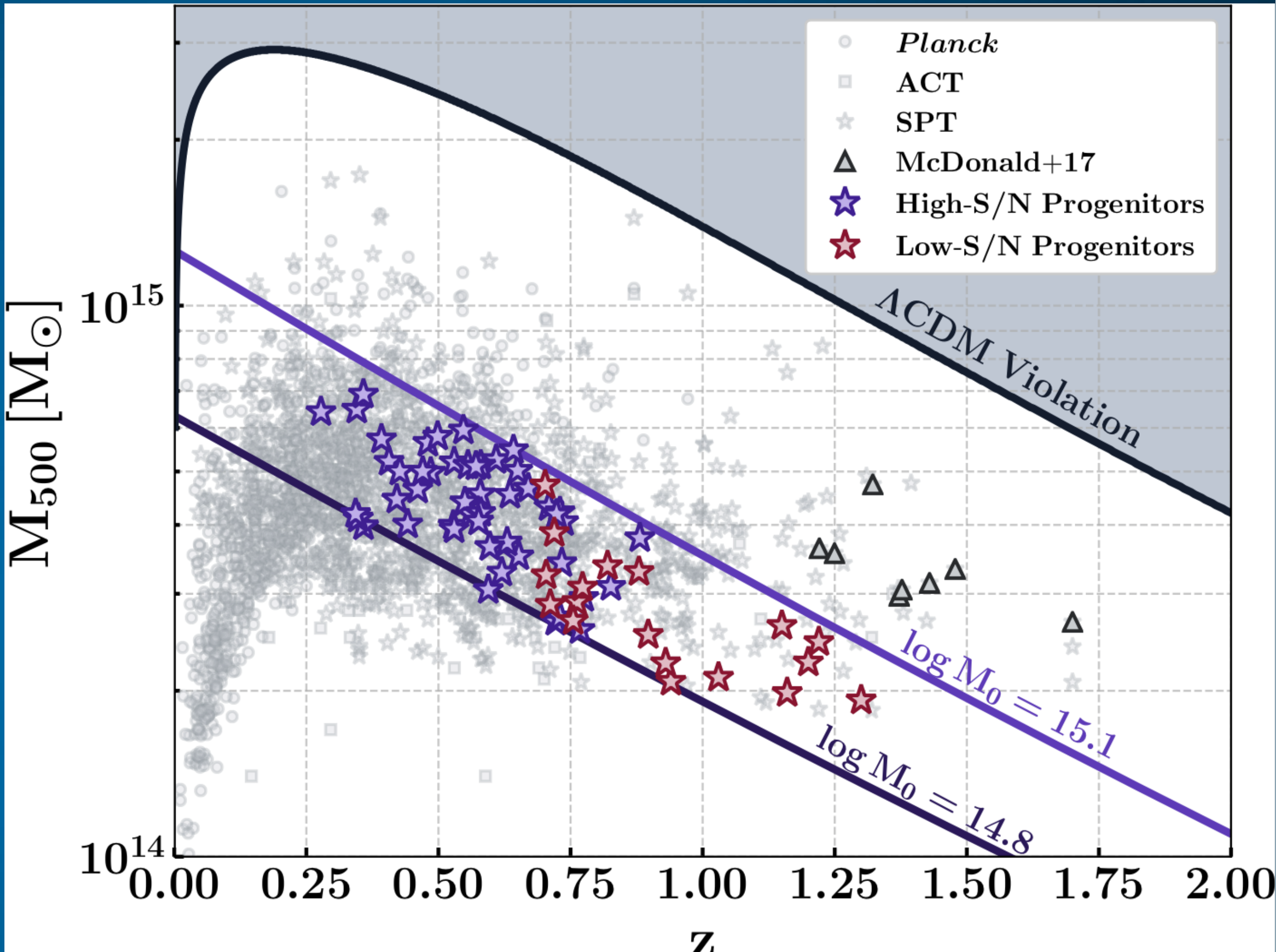
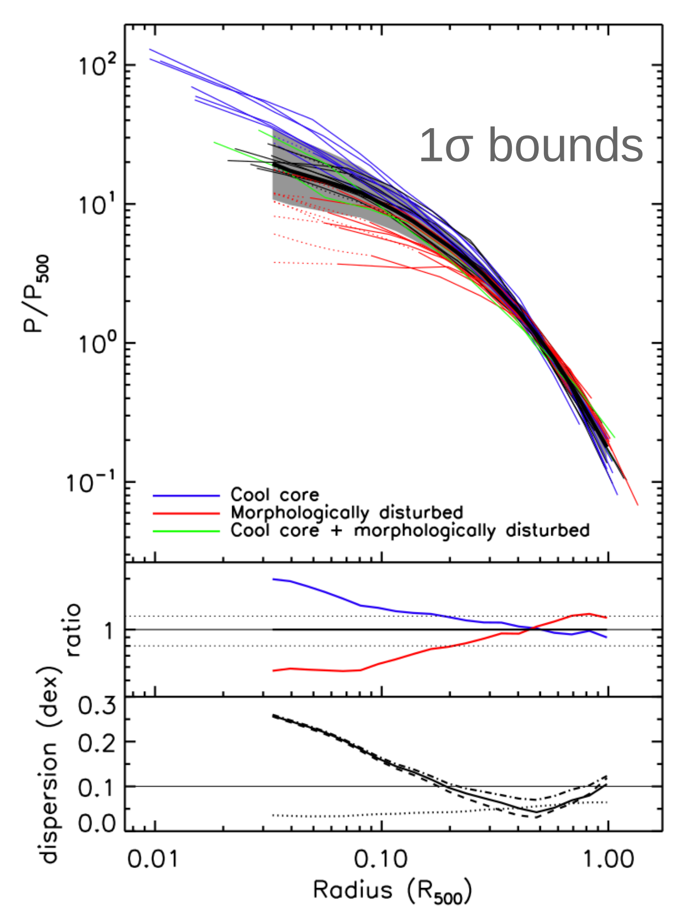


Figure credit: F. Ruppin webpage

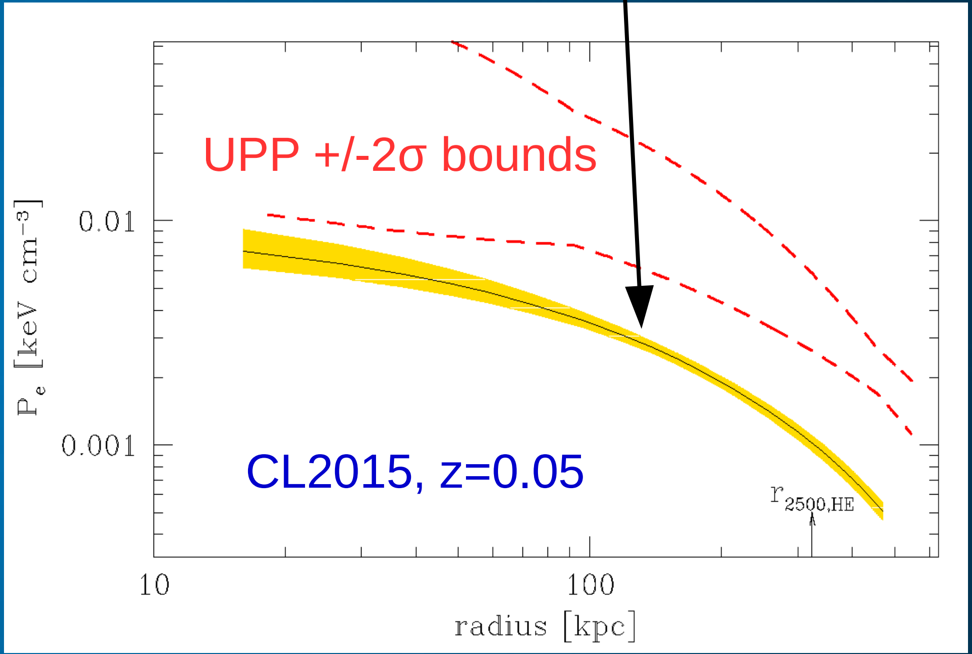
At low z: low scatter around the Universal Pressure Profile

Arnaud et al. 2010



exploited to detect clusters in SZ surveys or to estimate cluster mass from them.

Outliers start to be found (SA et al. 2016, 2017a, 2017b, 2019)



y is a quasi-direct measurement of P

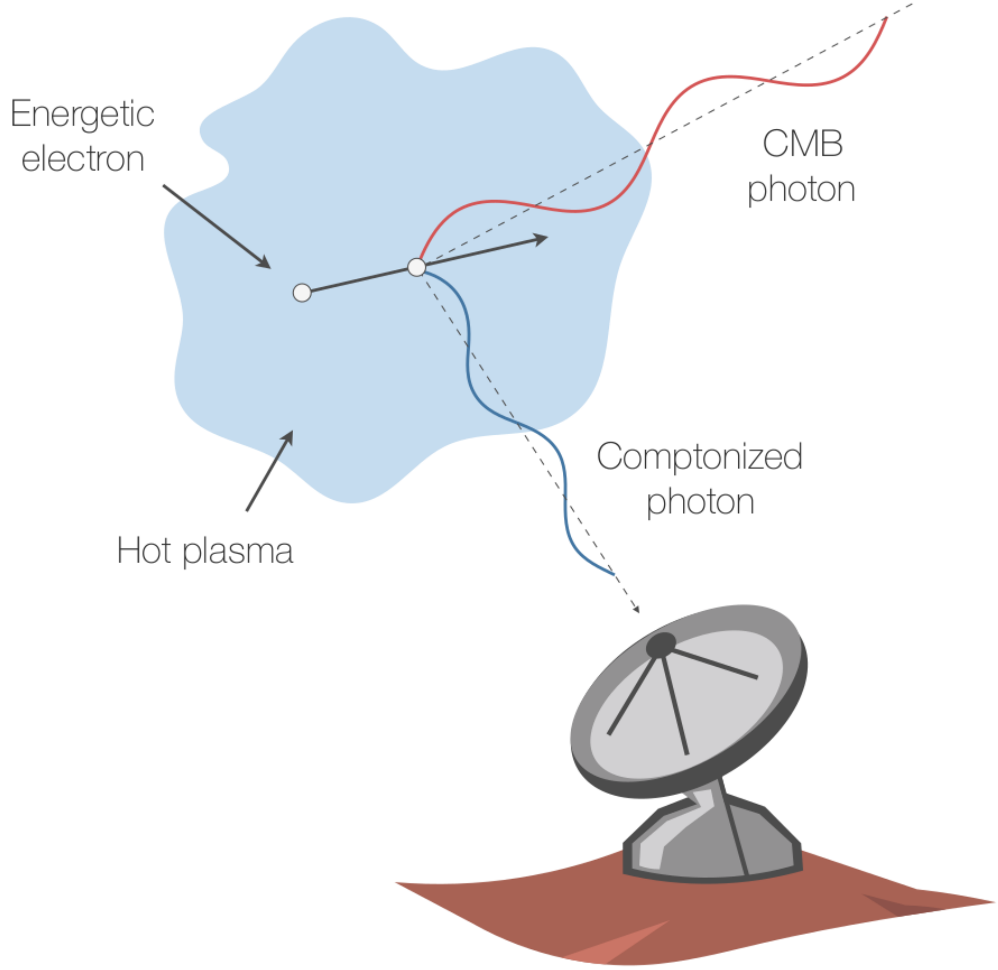
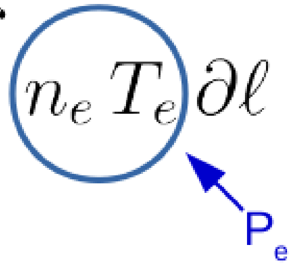


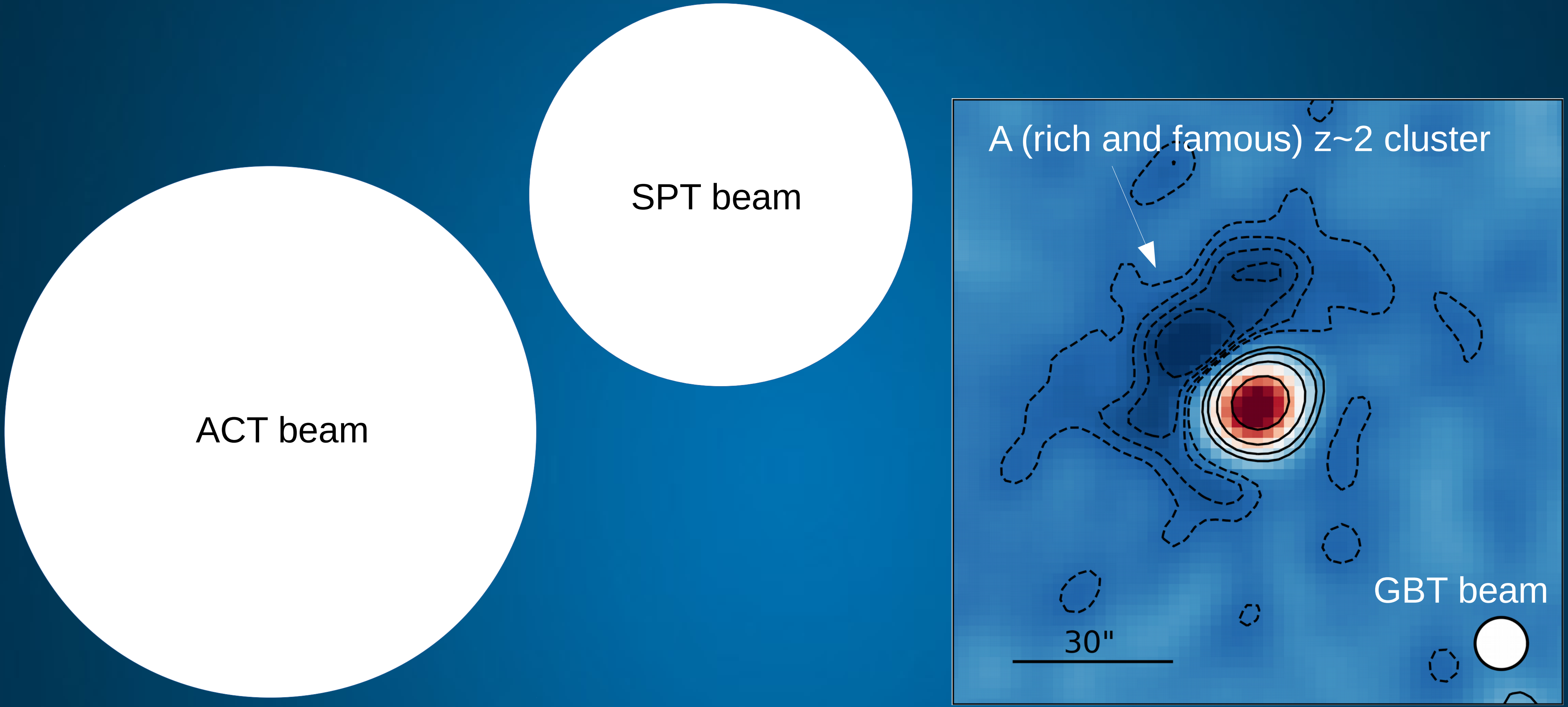
Figure credit: Mroczkowski 2019

Not subject to cosmological dimming → hi-z accessible

$$y \propto \int n_e T_e \partial \ell$$



SZ is wonderful, but … sizes of many telescopes are unsuitable to look inside the clusters



JKCS041

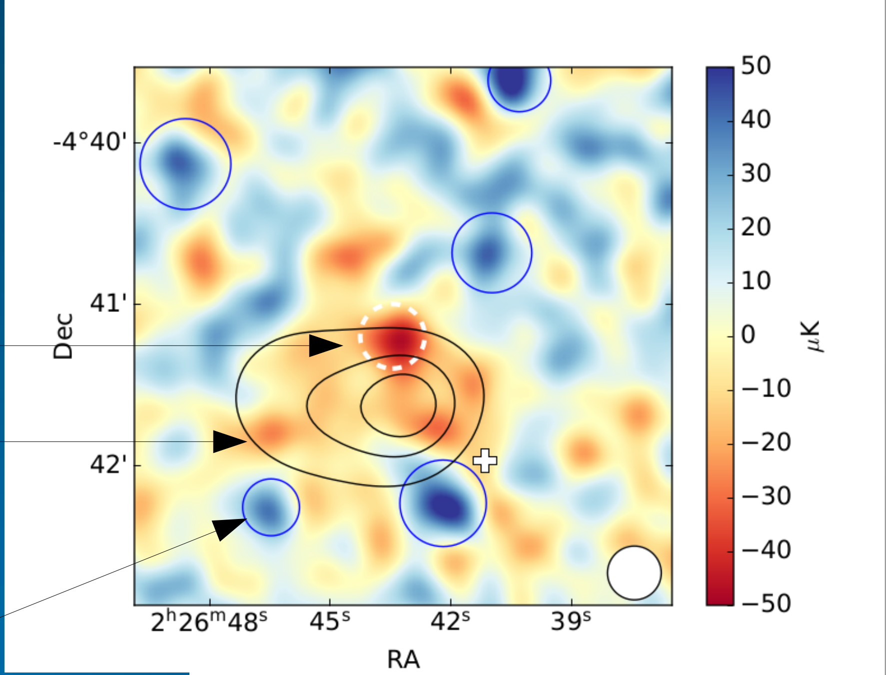
z=1.803, $M_{200,wl}$~4.7 10^{14} M_{sol}, massive at this z (Kim+23)

SZ (negative) peak

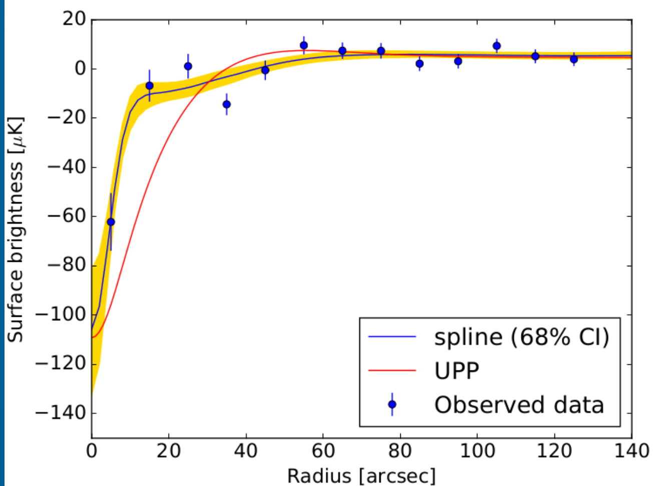
Chandra X-ray contours

26(±3) arcsec, 220 kpc, SZ X-ray offset
First indication of a major merger

mm point sources



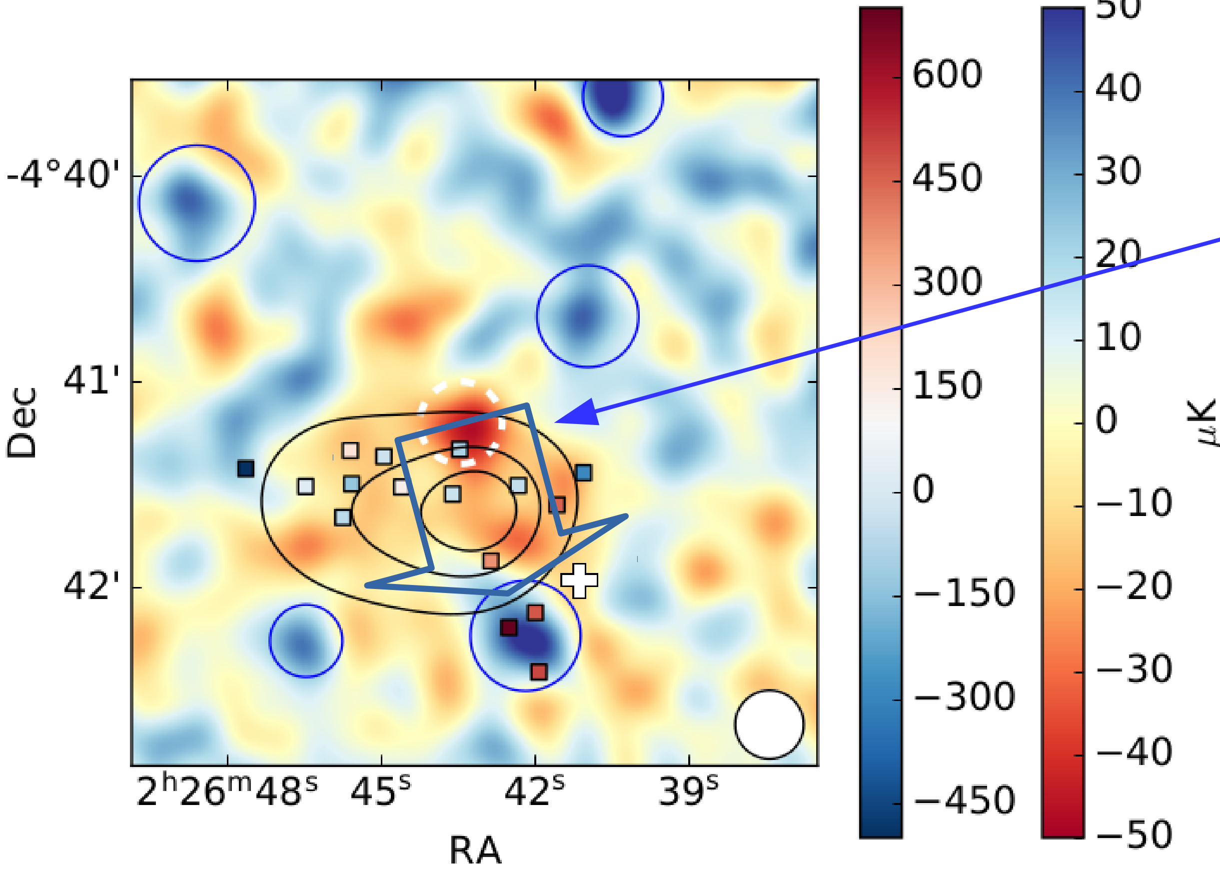
Presence (absence) of undetected mm point sources constrained by observations at shorter (SCUBA2) and longer (JVLA) wavelengths (and <0.5 are expected vs >4 needed)



28h GBT Mustang2 integration

Major merger of two massive sub-clusters

JKCS041



Velocity offsets

Direction of the SZ-X-ray offset and of the galaxy velocity gradient

Spatial offset (220 kpc) gives time after pericentric passage (~0.5 Gyr, Zhang et al. 2014). Tailored simulations being analysed -> merging of 0.8 and 1.2 10^{14} M_{sun} (Felix et al, in prep).

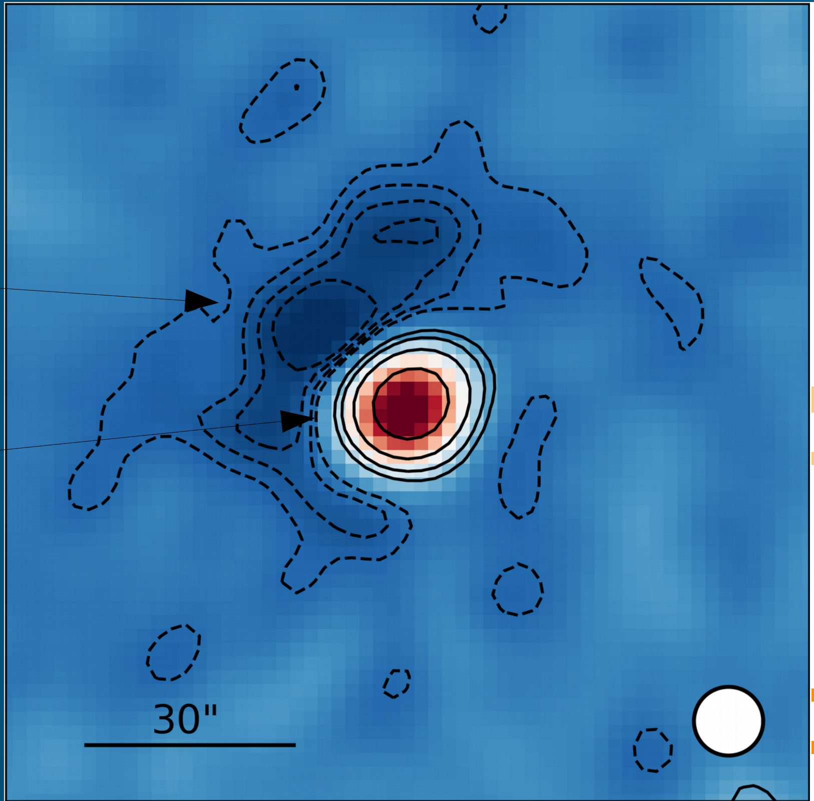
IDCS J1427.5+3508

z=1.75, $M_{200,wl}$~2.2 10^{14} M_{sol}, massive at this z (Jee+17)

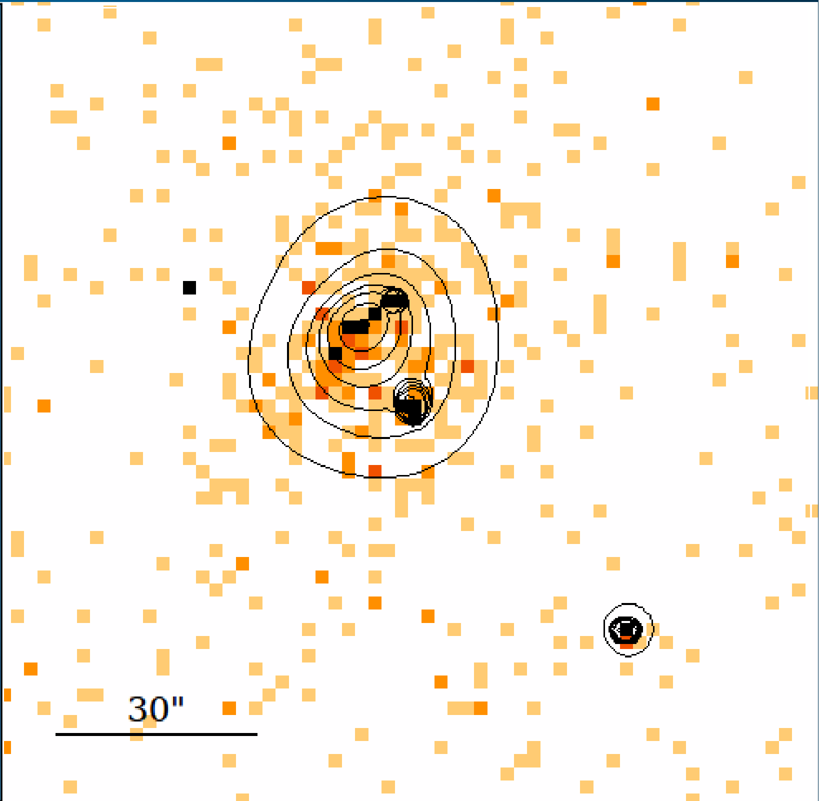
Mustang2@GBT

SZ (negative) emission

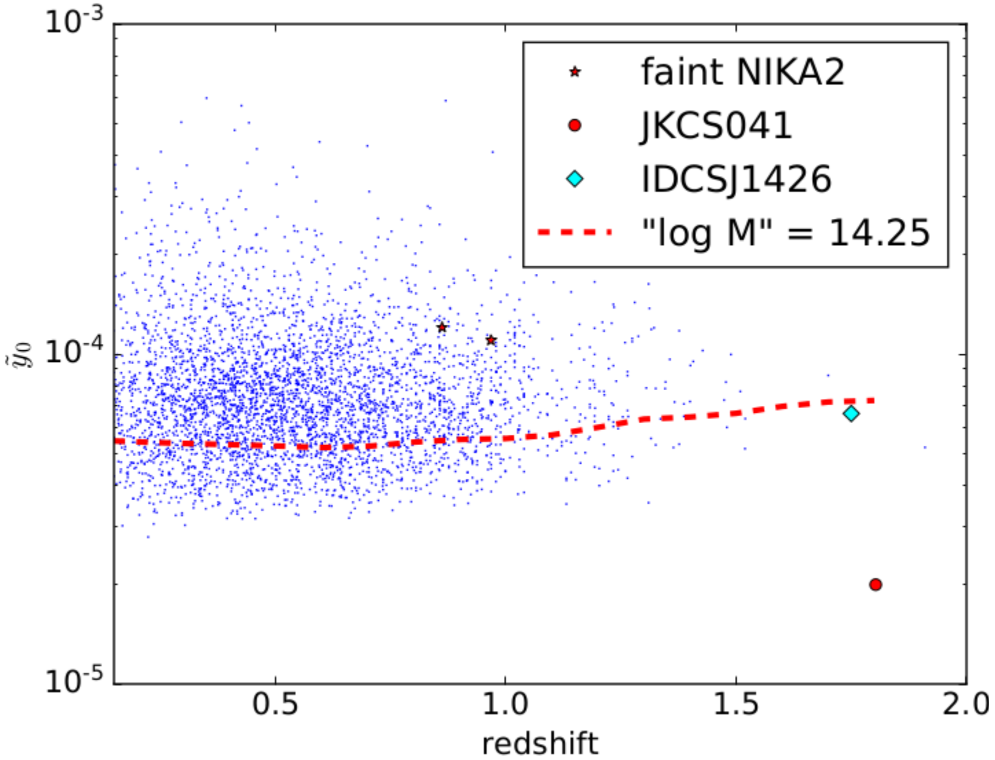
mm point source

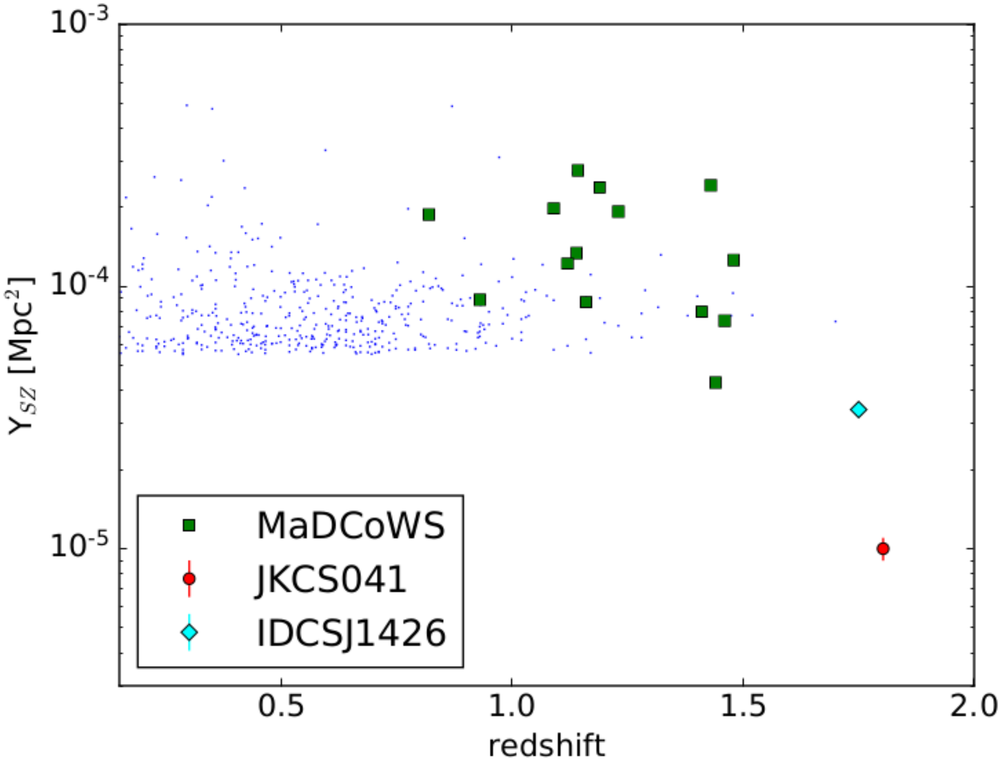


Chandra



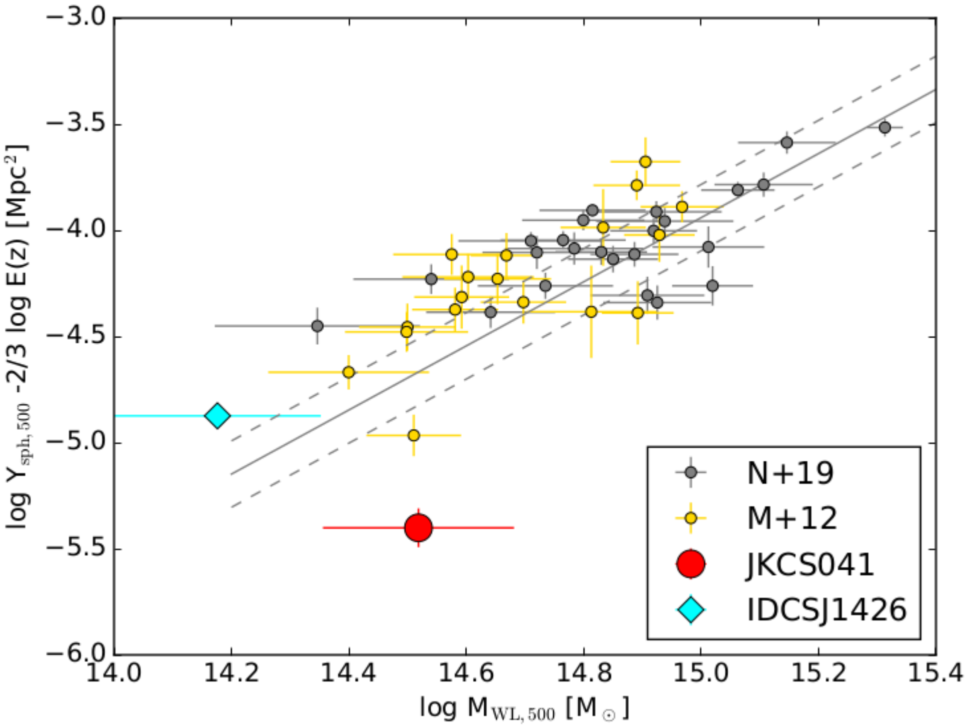
JKCS041 is very faint



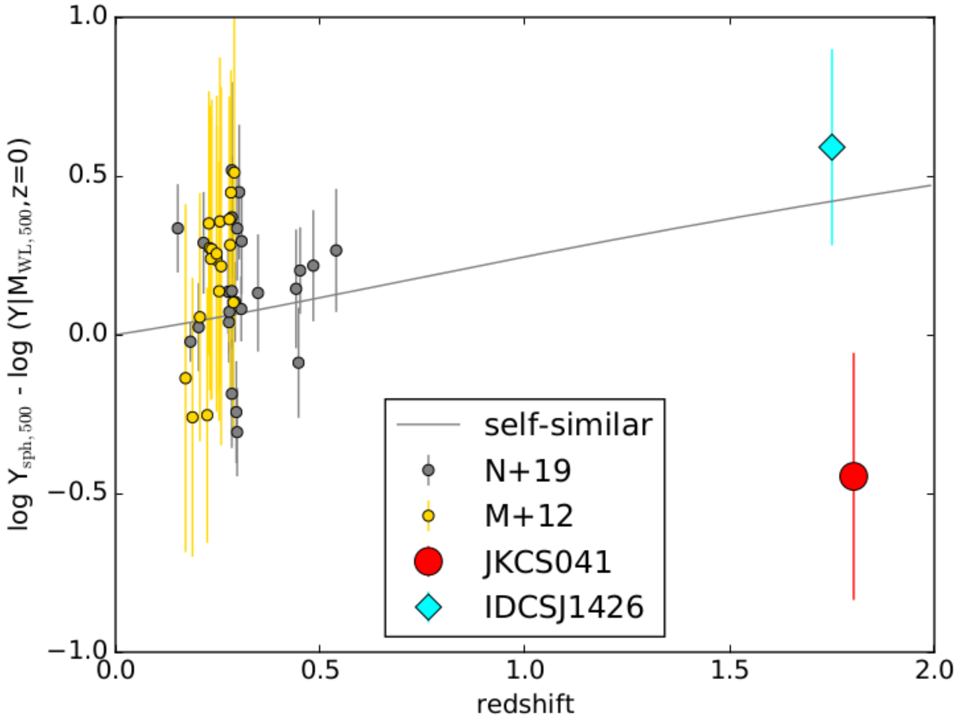


Faint != less massive (i.e. Y_{SZ} !=mass)

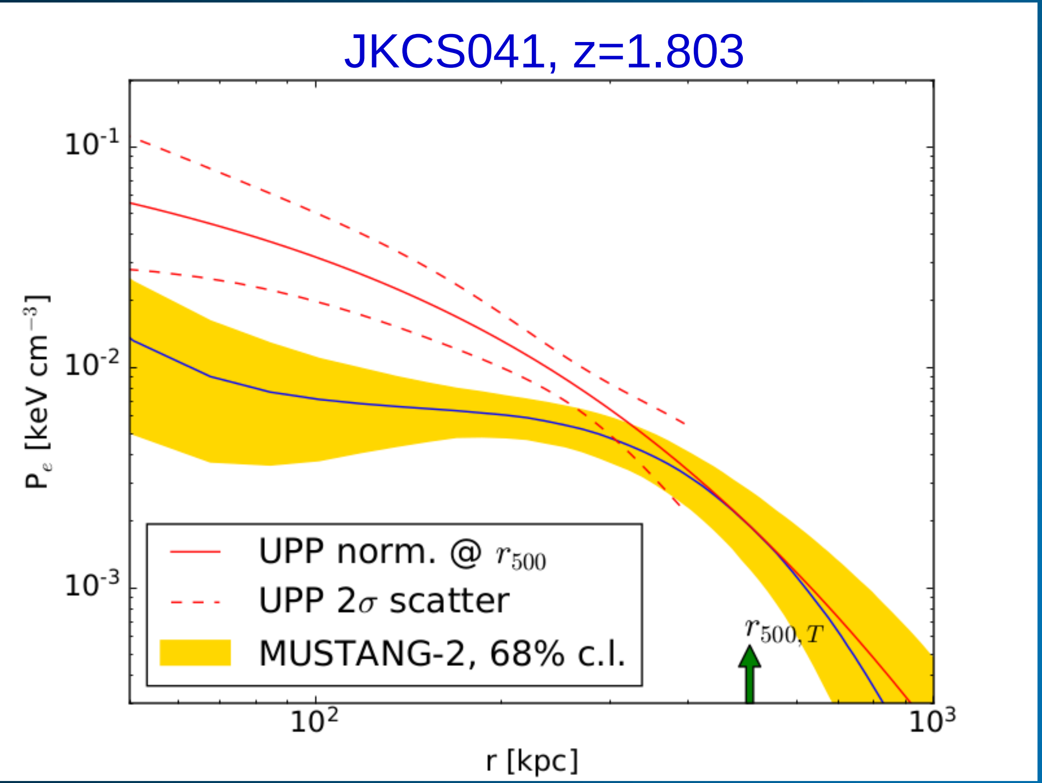
During major merger expected down-scatter (Wik+08, Krause+12); hi-z is a period of enhanced merger activity -> we expect many massive clusters to be SZ-weak

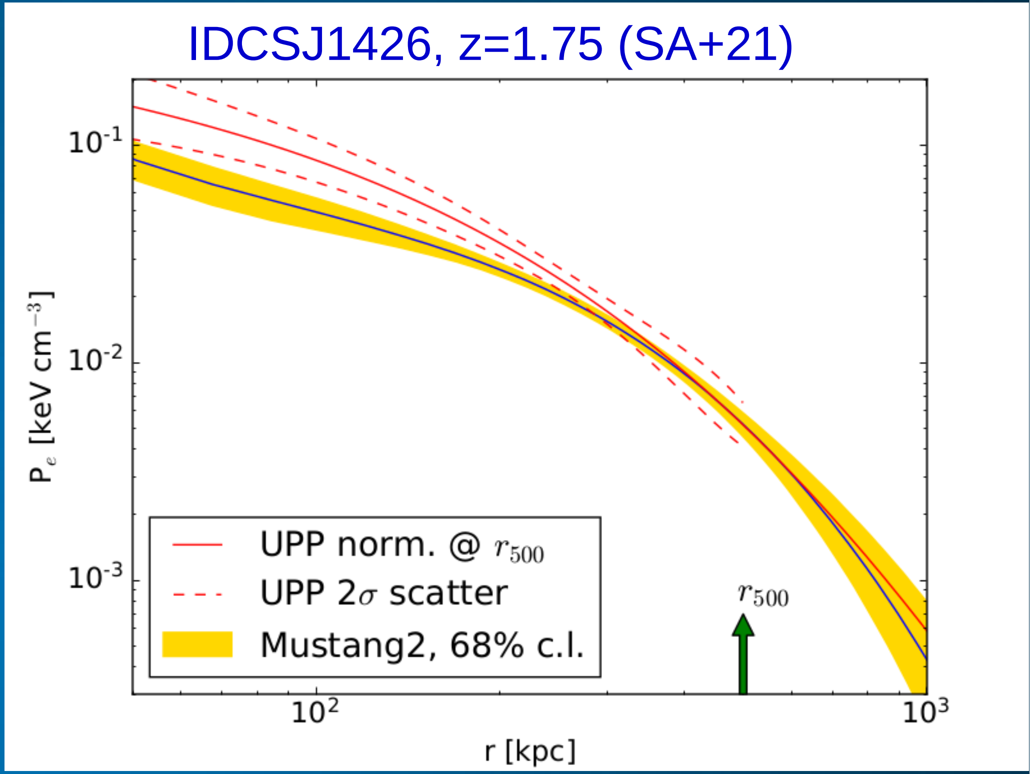


Evolution



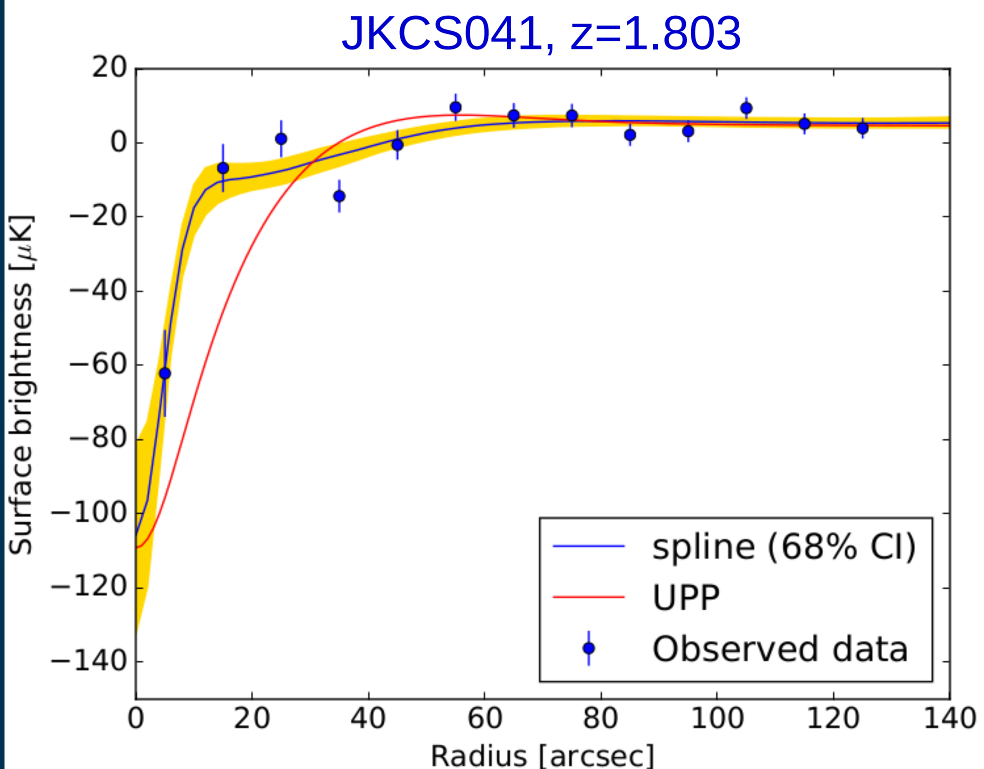
Depressed (for the today standard) pressure profiles

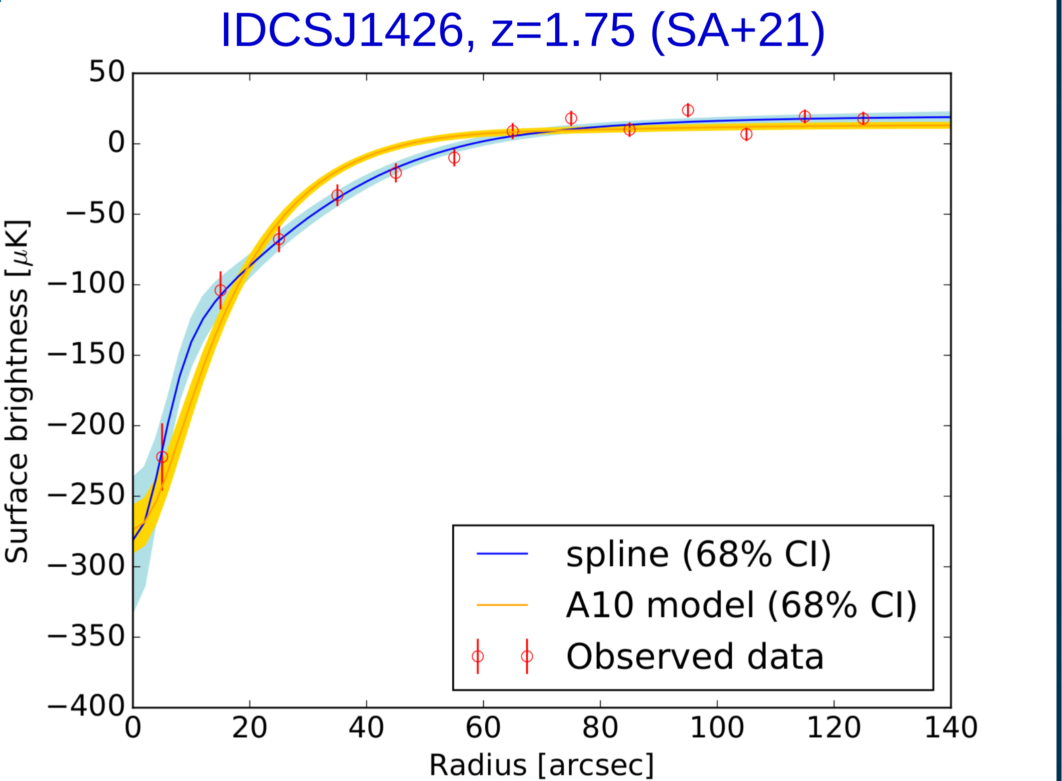




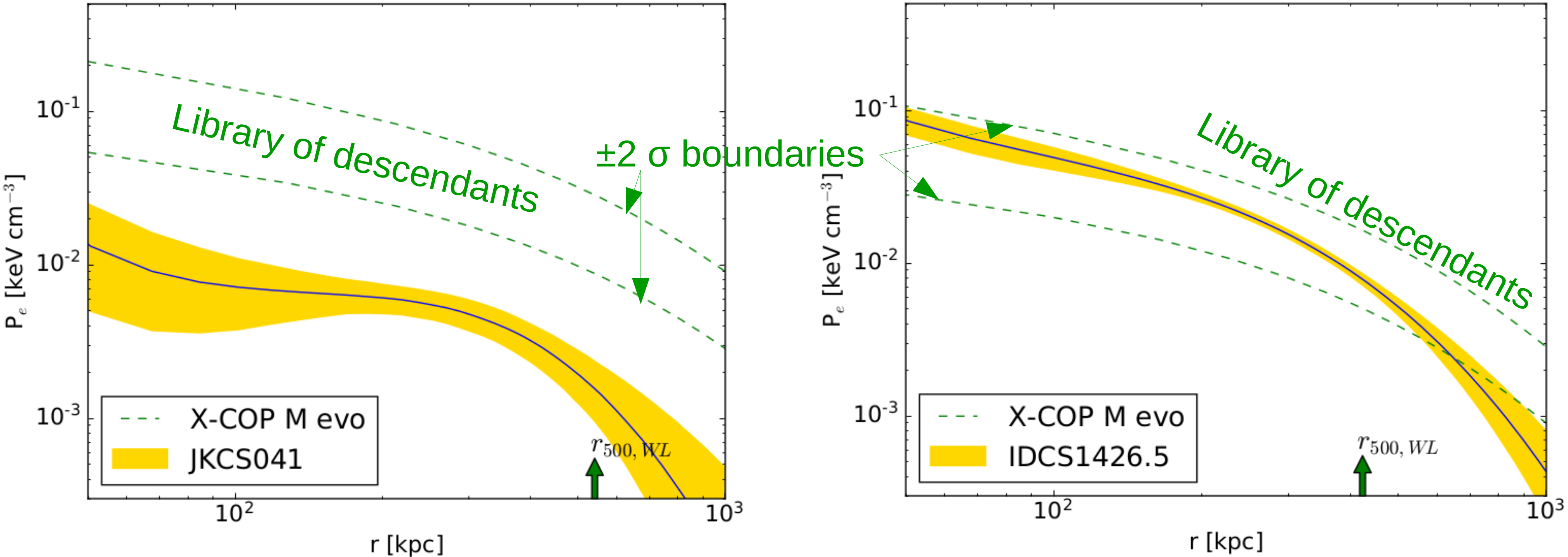
Relevant for cosmology

affect detectability and mass estimate





Evolution

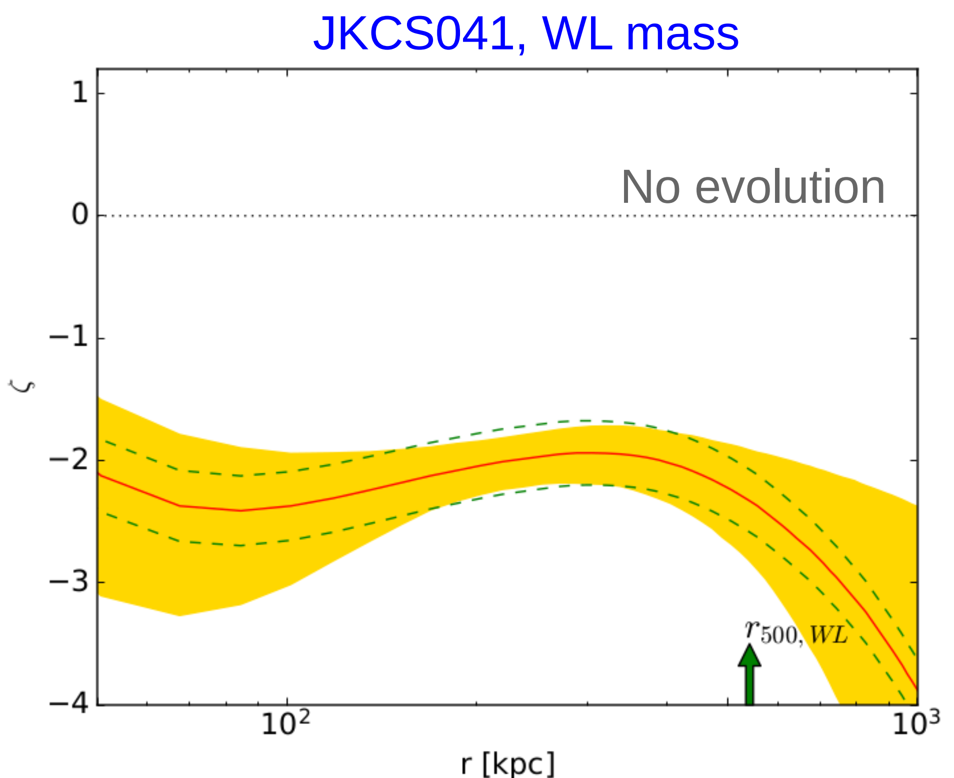


Library of descendants
±2 σ boundaries
Library of descendants
10-1
10-2
10-3
P_e [keV cm^-3]
X-COP M evo
JKCS041
IDCS1426.5
r500, WL
10^2
10^3
r [kpc]

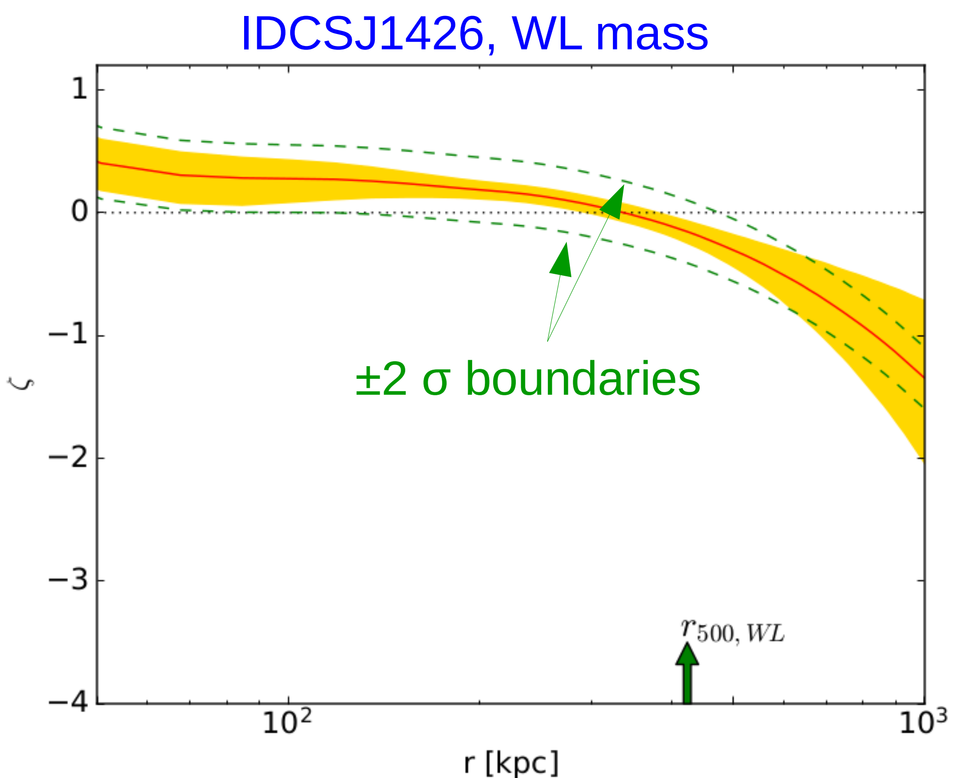
Relevant for evolution

Dramatic evolution at all radii

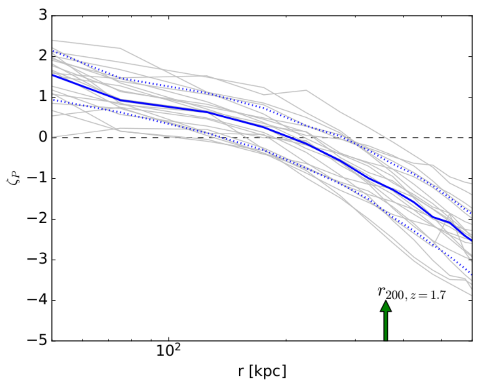
Core in place, detailed constraints on evolution at other radii (SA+21 and SA+ in prep.)



Evolutionary rate

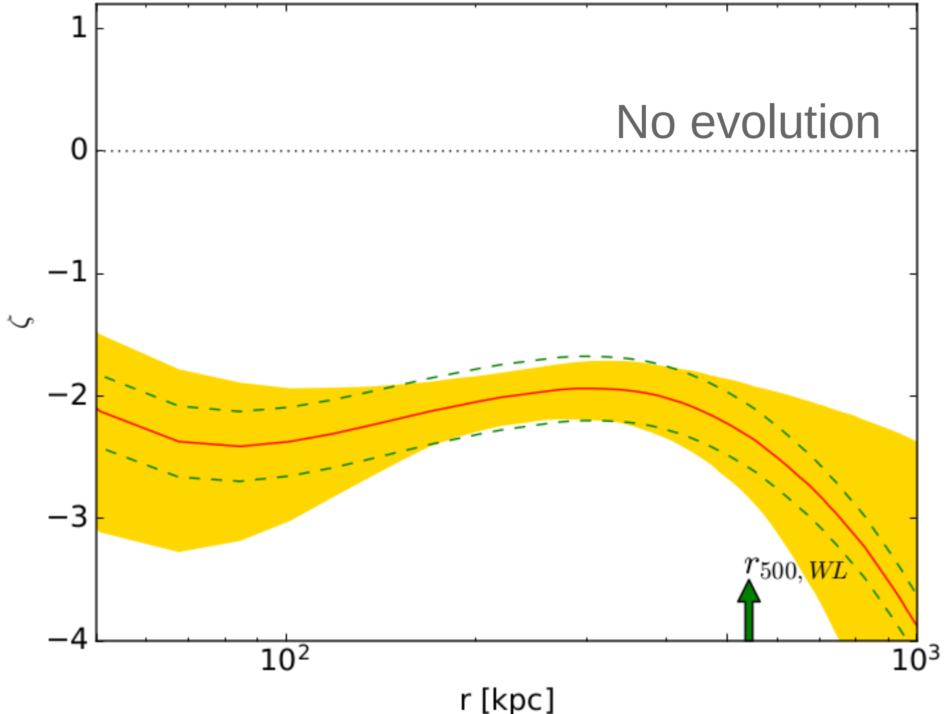


Simulations

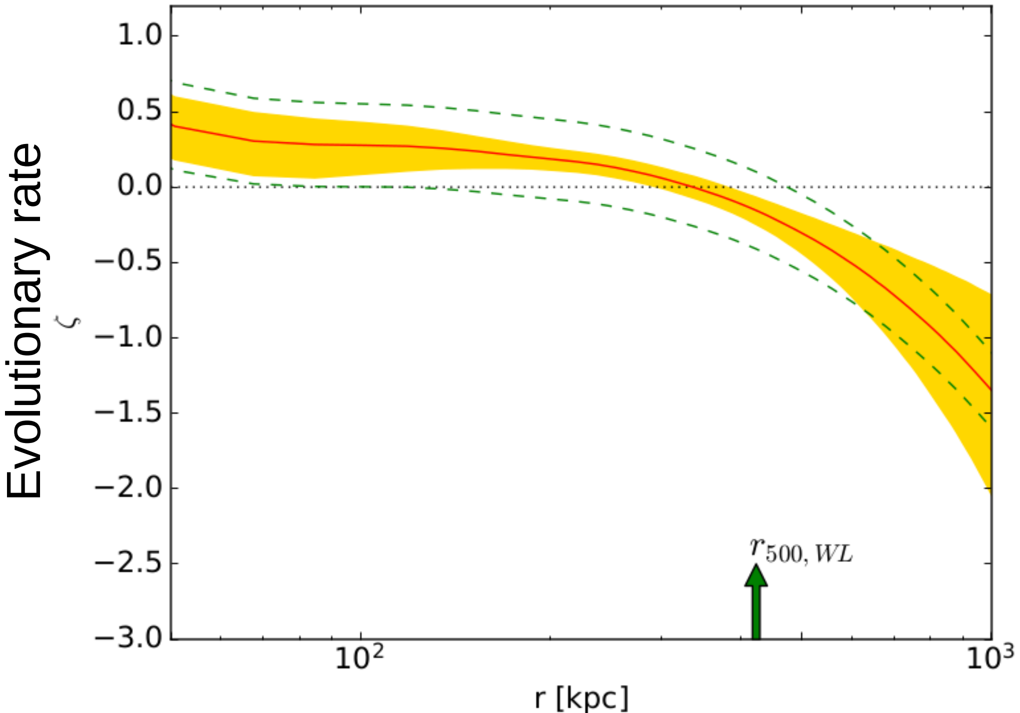


Tailored simulations being run (Felix et al., in prep)

JKCS041, WL mass



IDCSJ1426, WL mass



Summary:

- IDCSJ1426: at small radii is close to (not so far from) the likely final status, is far at large radii. In the act of
- JKCS041: far away from the final status at all radii because observed ~0.5 Gyr after a major merger of massive clusters. Not even the center (which one? X-ray or SZ?) is close to the end status.
- JKCS041 has low Y_{SZ} |M, enhanced scatter at z~2 expected (and Y_{SZ} is not M!)
- Two studied clusters, two different cases. A third cluster, XLSSC122 (z=1.98, van Marrewijk+23, this conference) is a major merger too. z~2 is a period of enhanced (AGN, SFR, cluster, merging) variety!

A postdoc position will offered early this fall (write me if you dont want to miss it)

IDCSJ1426 supplement

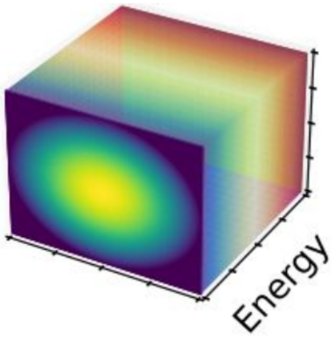
X-ray and SZ centers coincide. I can derive thermodynamic profiles (we need a common deprojection center!)

SZ+X-ray methods:

One per energy band

$$S_X \propto \int n_e^2 \, T_e^{1/2} \, \partial\ell$$

X-ray
Bremsstrahlung emission



$$y \propto \int n_e T_e \, \partial\ell$$

P_e

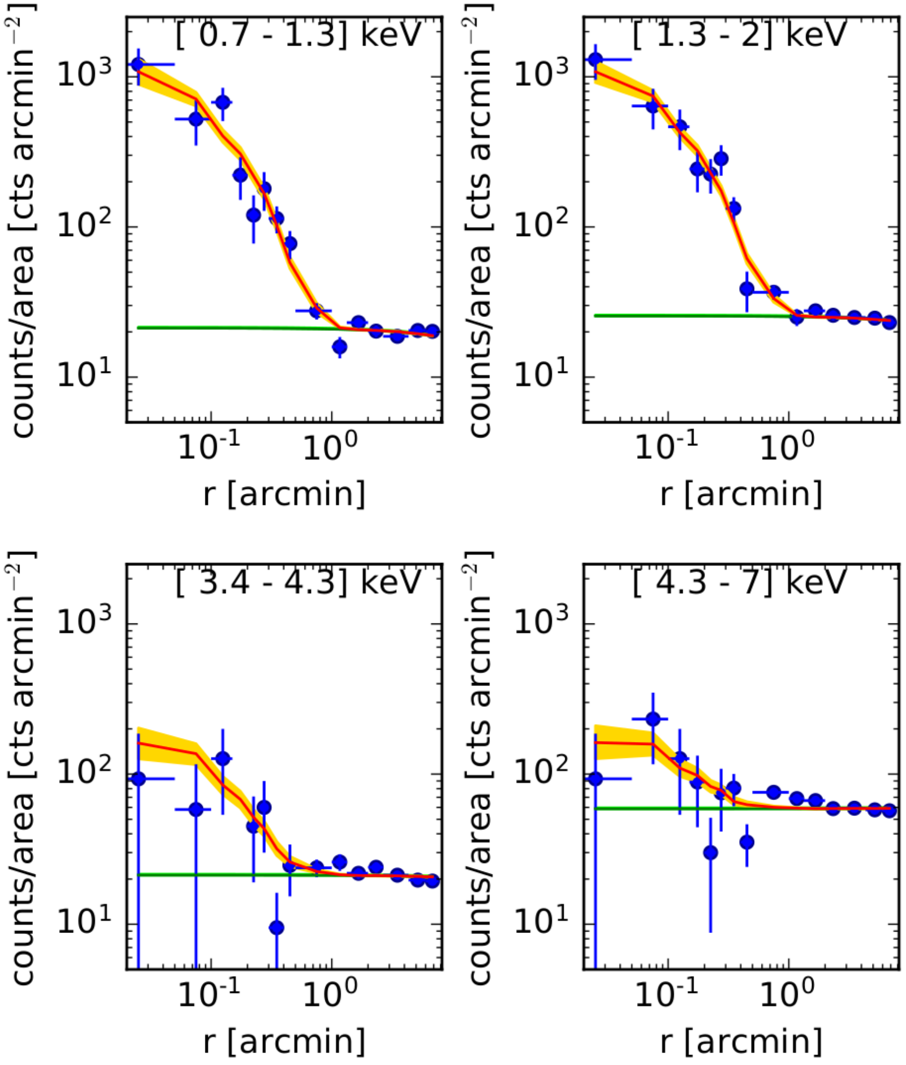
mm
Sunyaev-Zeldovich effect

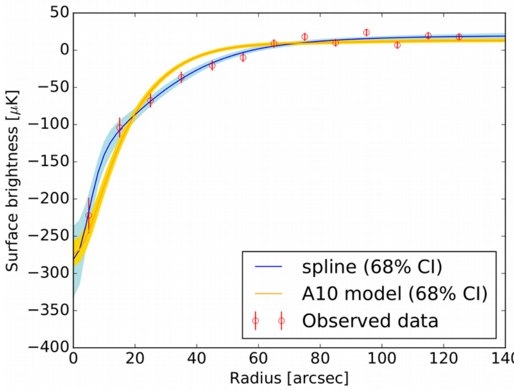
2 equations in two unknowns ($n_e(r)$,$T_e(r)$) with >>2 constraints. See Castagna & SA (2020,2022)

fcastagna / JoXSZ

Added wl fit, multi-object fit, severless computing

Data co-added for presentation purposes



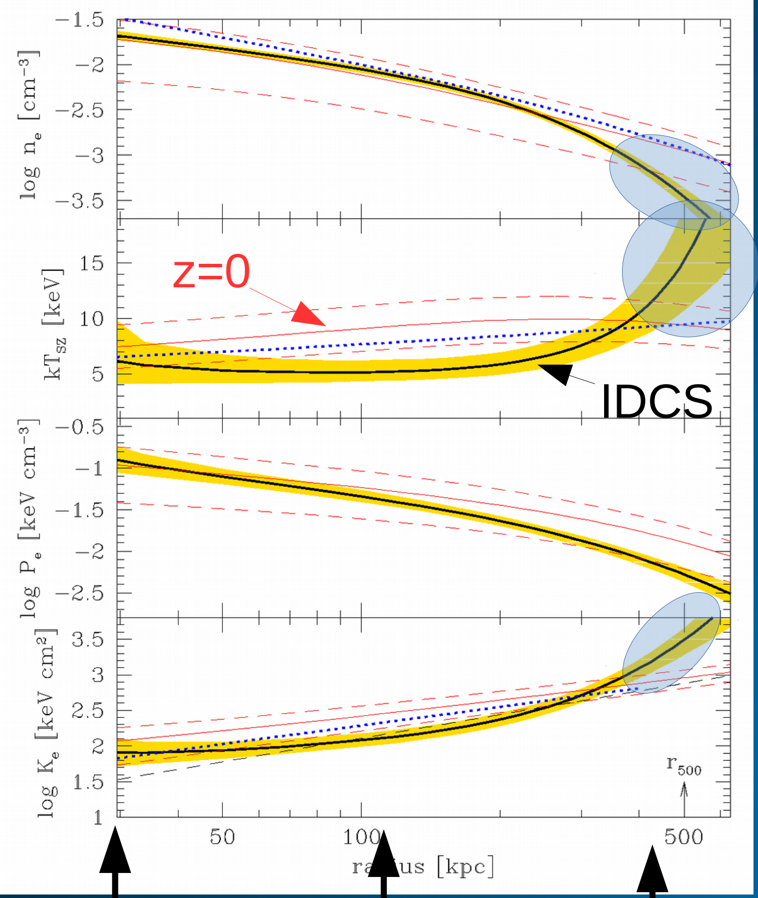


X-ray profiles & fit

Fitted cube
==520 net photons,
150x2 data points
== 15x2 spectra
with 10 data point each
== 10x2 bands with
15 radial bins.

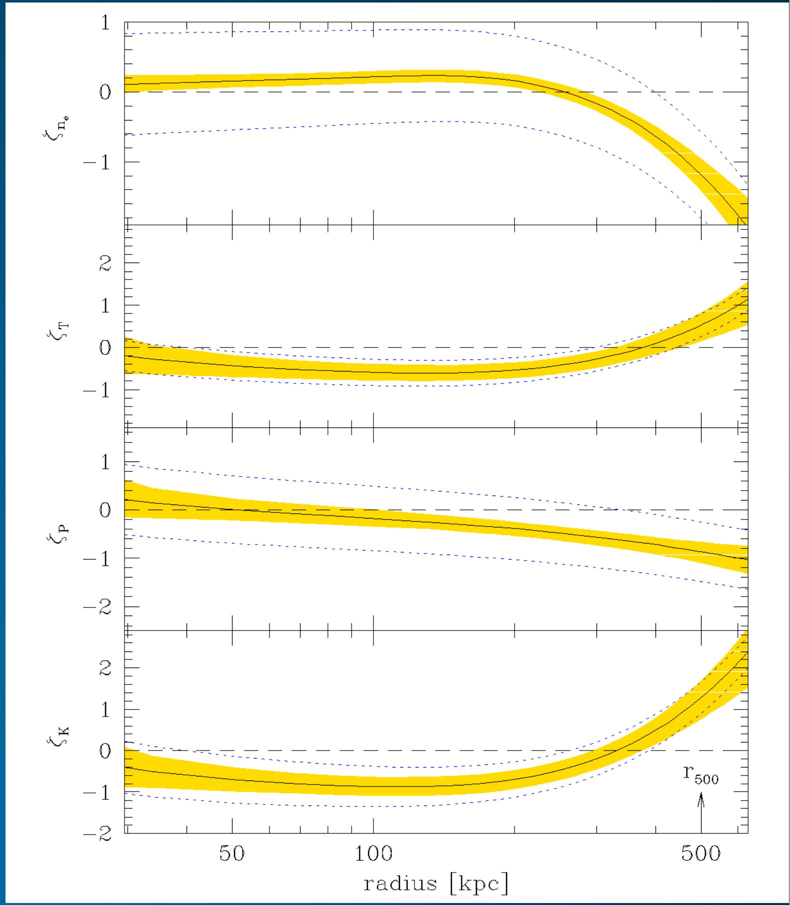
Fully Poisson stats, background modelled, not subtracted

Pointings jointly fitted, not coadded



IDCS J1426

Rates:



$\zeta = d \ln f(r) / d \ln E_z$

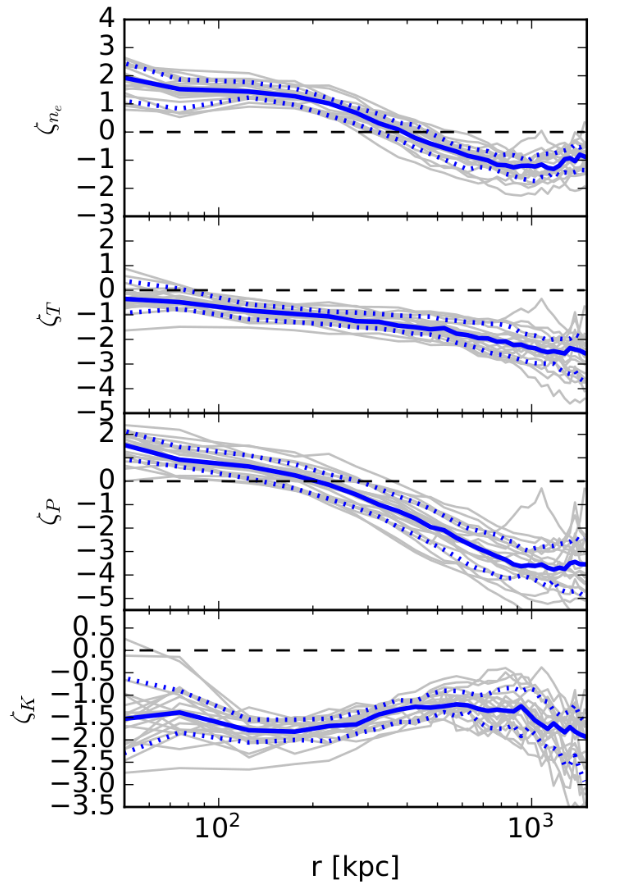
ζ=0 means no-evolution

ζ<0 means lower in the past

No changes at r~30 kpc

At intermediate r, gas will be heated with little net gas transfer

At large radii, heat should be evacuated, gas accumulated and entropy lowered

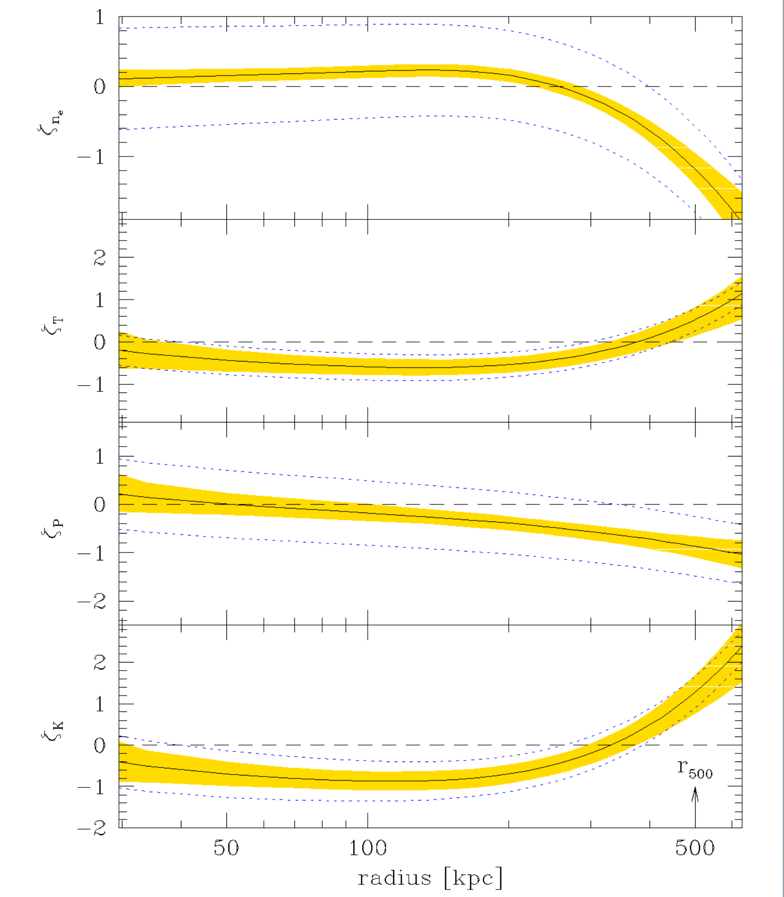


Rates:

$\zeta = d \ln f(r) / d \ln E_z$

⟵ Broad similarity ⟶

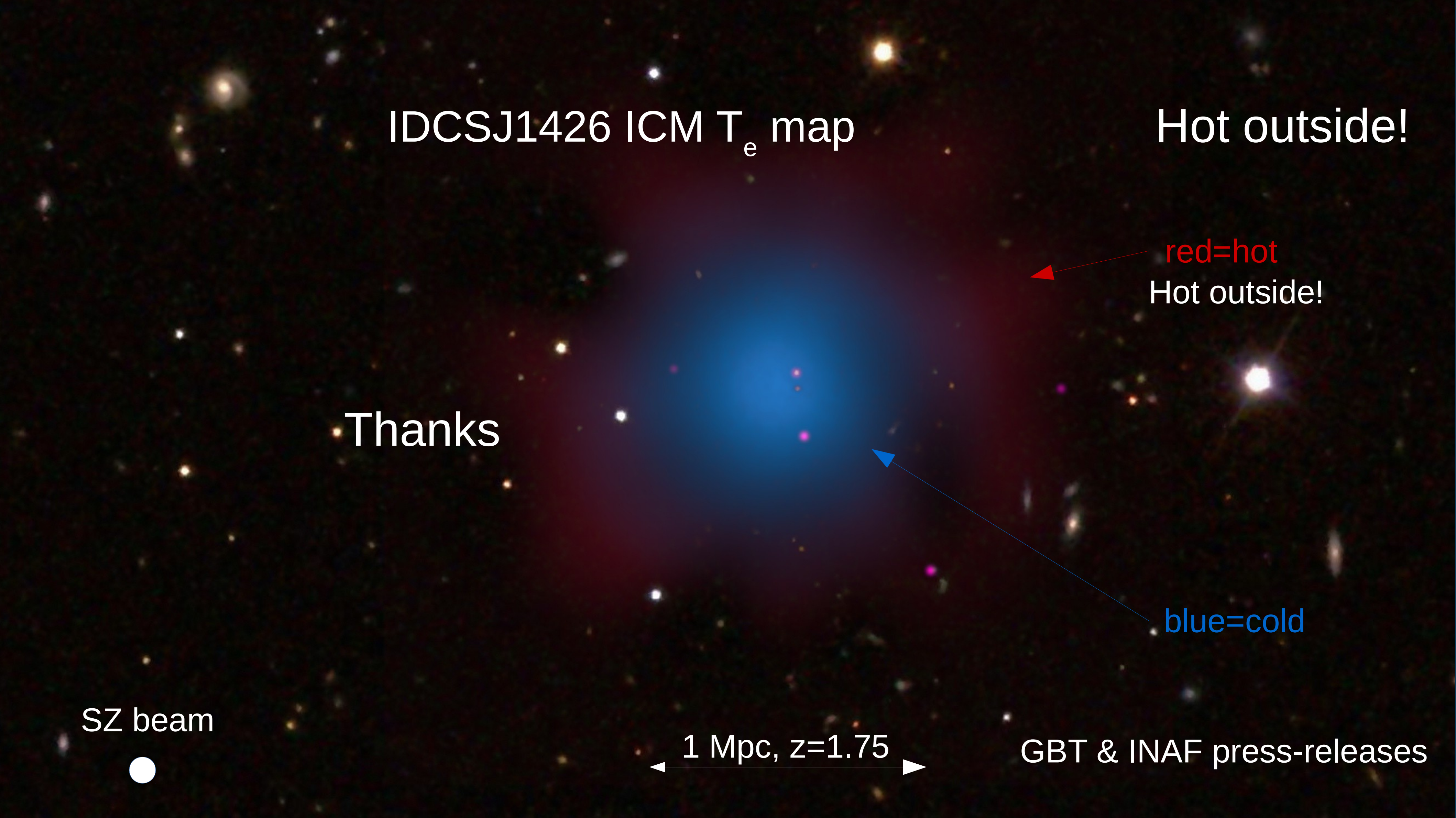
Caveat: qualitative match only



Expected evolution (Magneticum)

Observed

In simulations, bulk motion can be directly seen (not inferred). As for observations, heat and entropy is transferred inward with little net gas transfer at intermediate r, whereas at large r n_e grows by accretion of cold, lower entropy gas.


IDCSJ1426 ICM T_e map
Hot outside!
red=hot
Hot outside!
Thanks
blue=cold
SZ beam
1 Mpc, z=1.75
GBT & INAF press-releases