Non-thermal pressure support in galaxy clusters: current constraints and perspective

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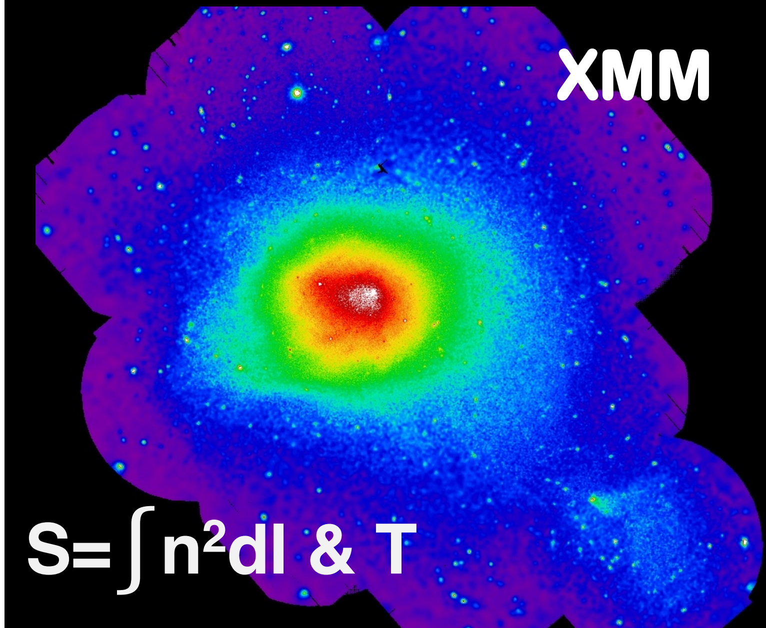
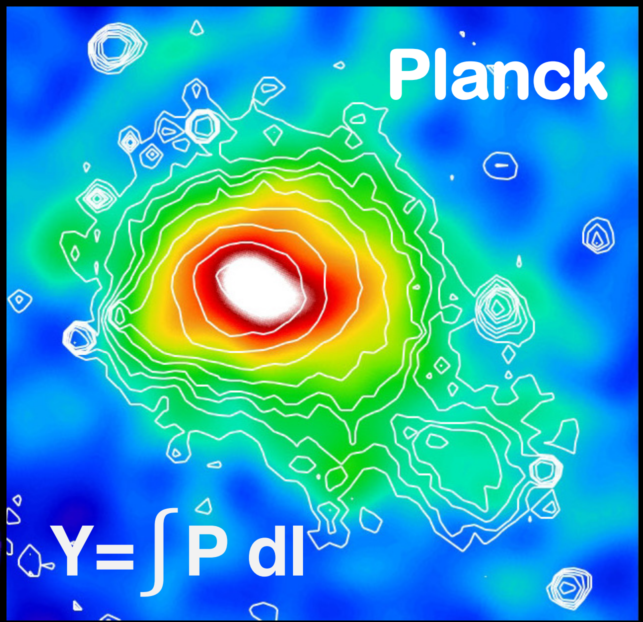
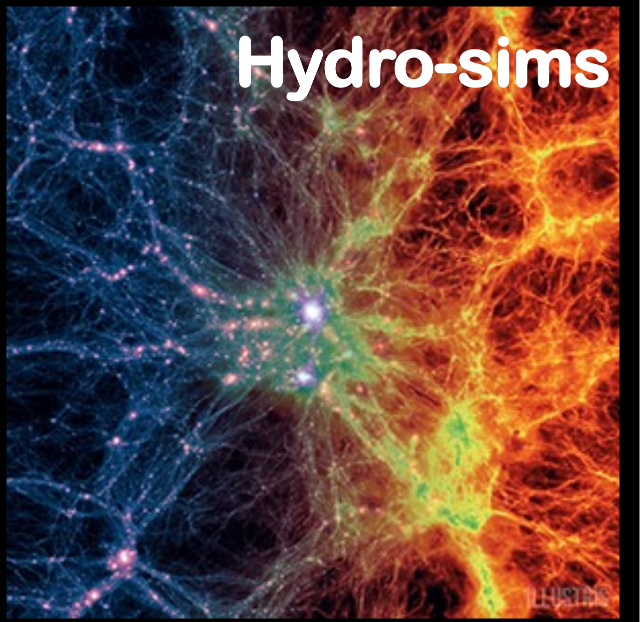
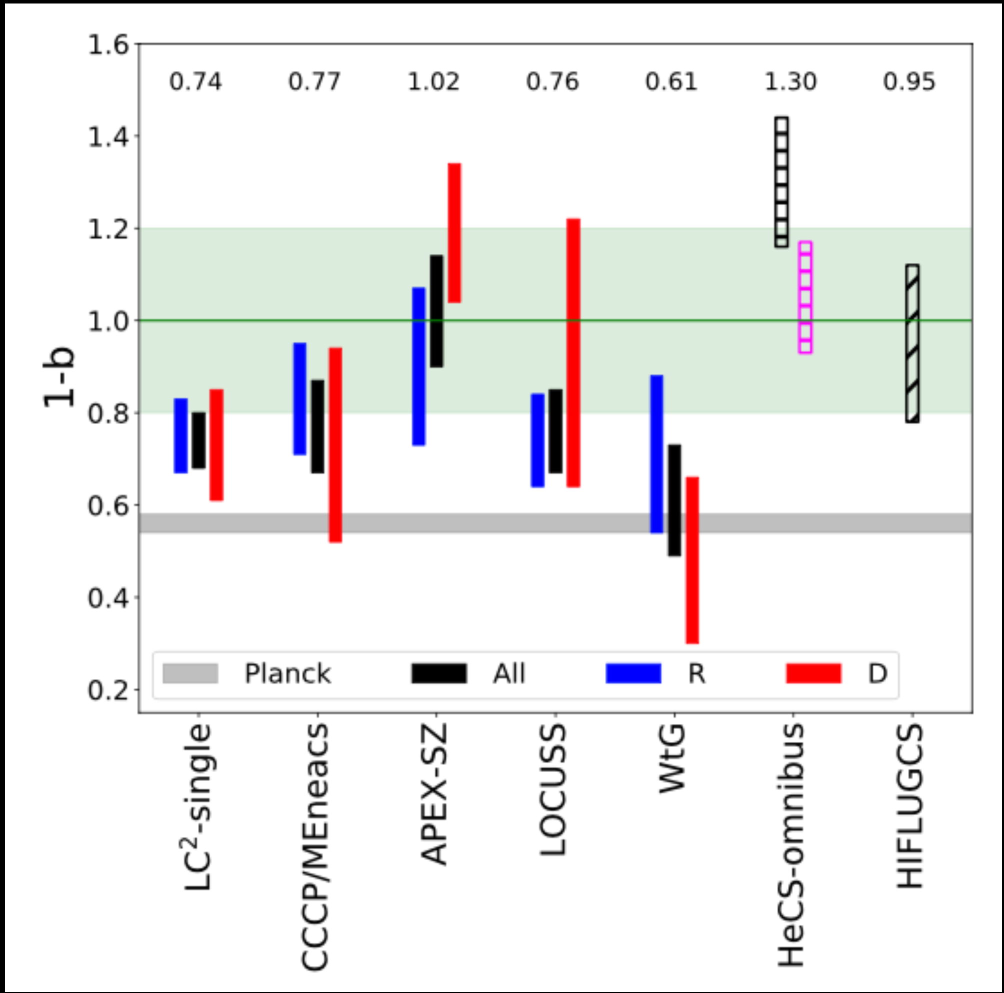
Ettori, *Eckert 2022 A&A 657L 1*
Ettori, *Lovisari, Eckert 2023 A&A 669 133*
Ettori, *Lovisari, Sereno 2020 A&A 644 111*

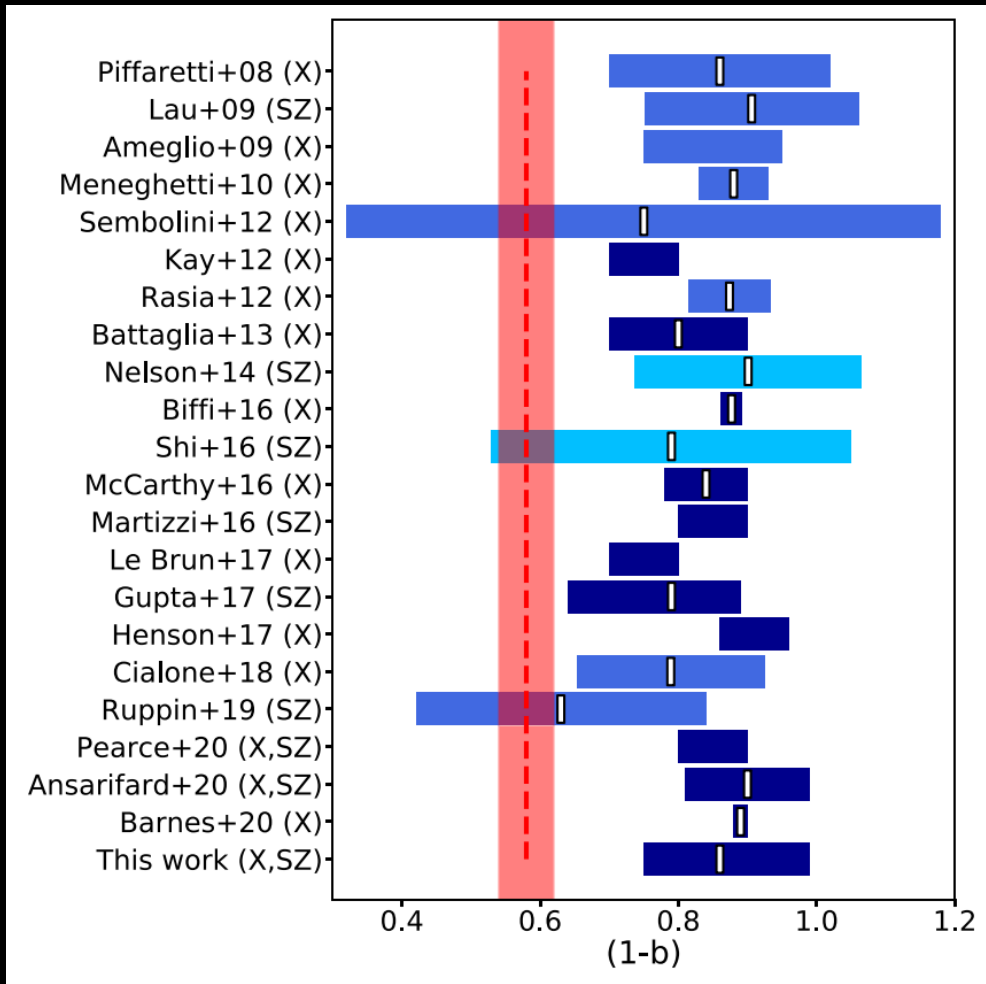






Hydrostatic bias: (1-b) = M_X/M_{500}





Planck ESZ sample (120 obj;
Lovisari, Ettori+20)

Gianfagna+21

The Mass of Galaxy Clusters:

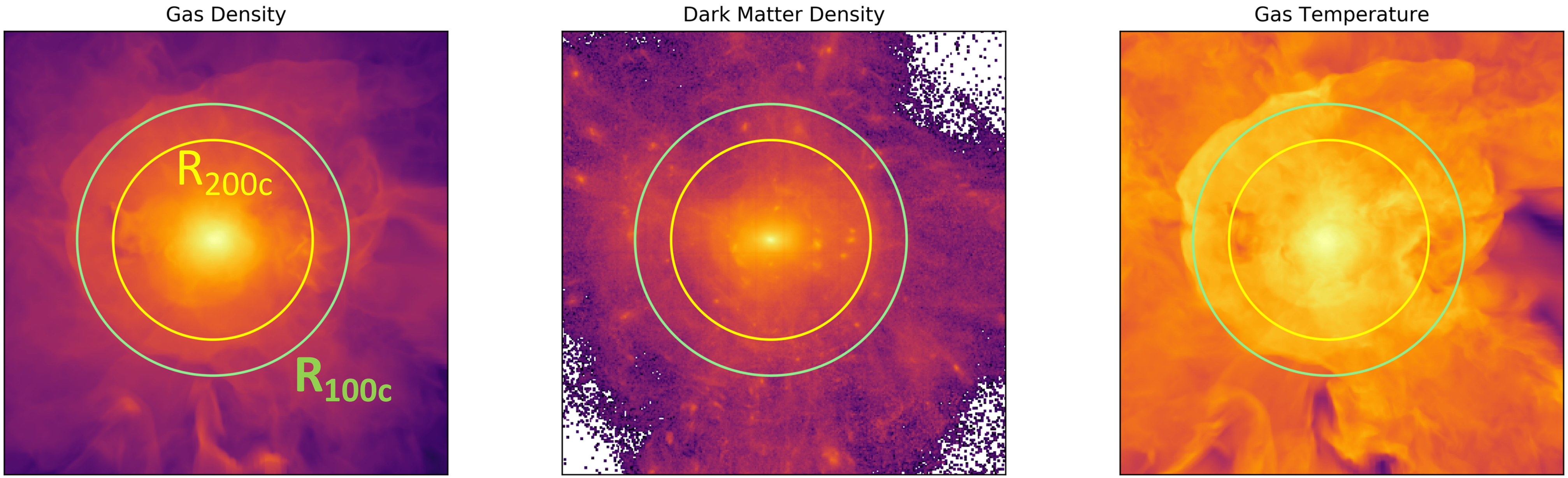
fundamental quantity, but systematically biased with current X-ray/SZ data

$$\boxed{\frac{G\,M_{HE}(<r)}{r^2} = -\frac{dP_g}{dr}\frac{1}{\rho_g}}$$

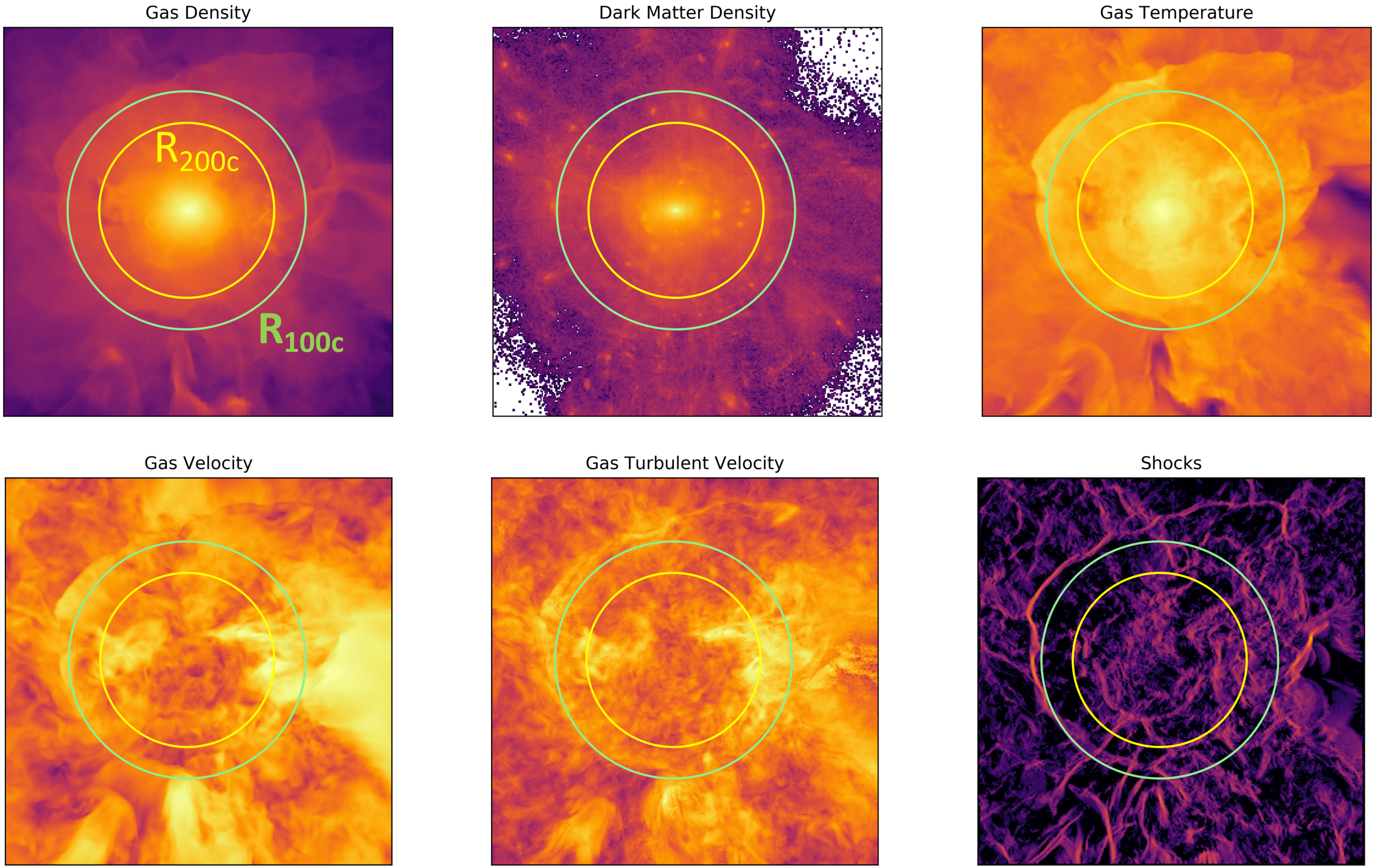
$$\frac{G\,M_{tot}(<r)}{r^2} = -\frac{dP_g}{dr}\frac{1}{\rho_g} - \frac{d\boldsymbol{v}}{dt}$$

$$\ldots = -\frac{d(P_g+P_{NT})}{dr}\frac{1}{\rho_g} = -\frac{dP_{tot}}{dr}\frac{1}{\rho_g}$$

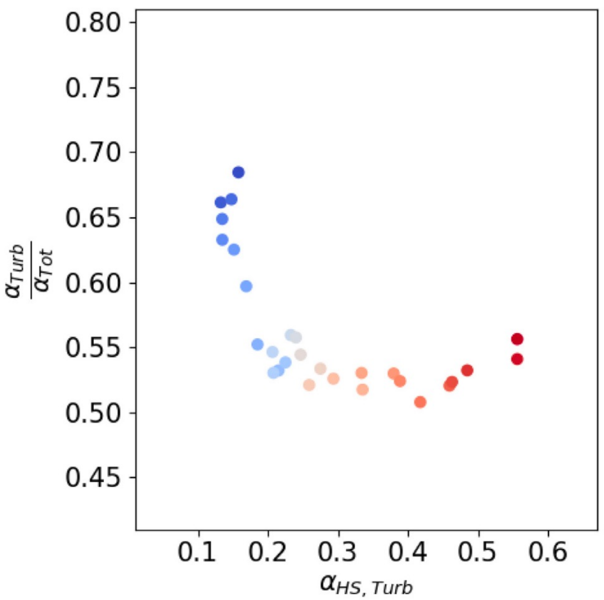
$$M_{HE}\,/(1-b) = \; M_{tot} \sim T^{3/2} \sim M_{gas} \sim L^{3/4} \sim Y^{3/5}$$

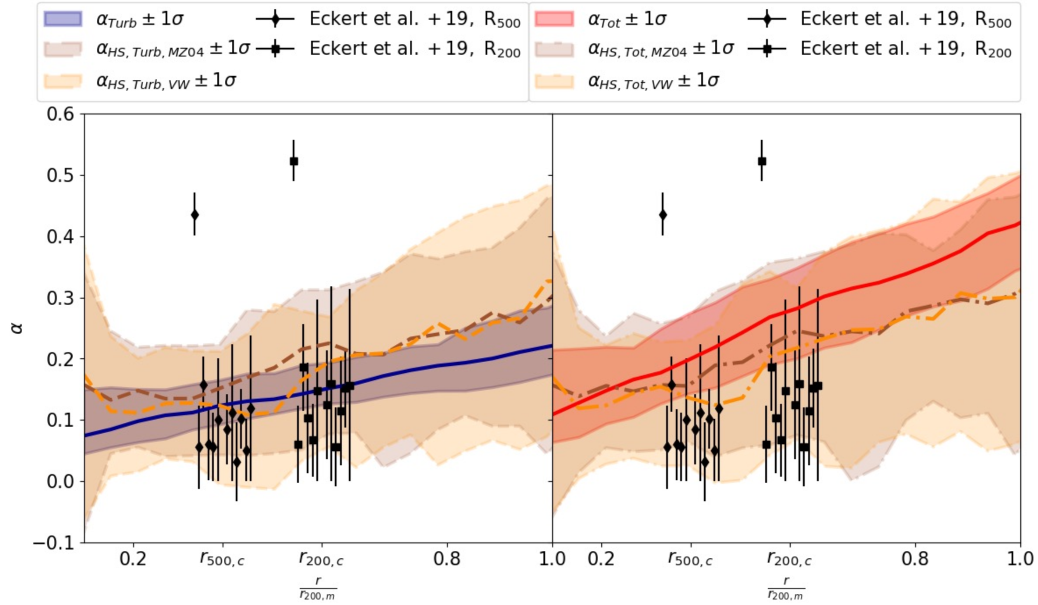


Angelinelli, Vazza + 20



Angelinelli, Vazza + 20

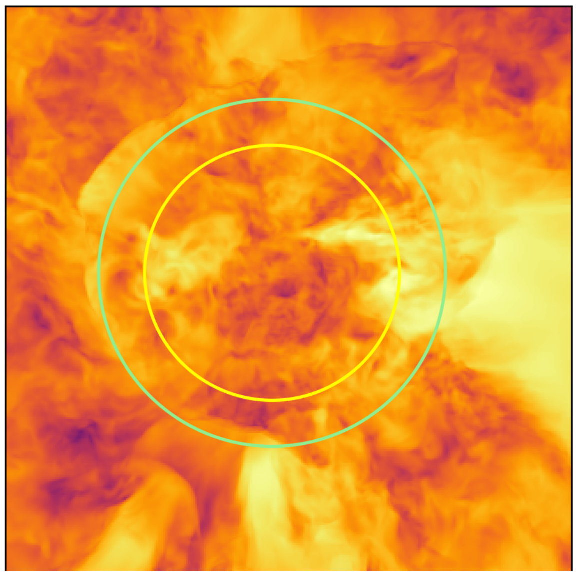




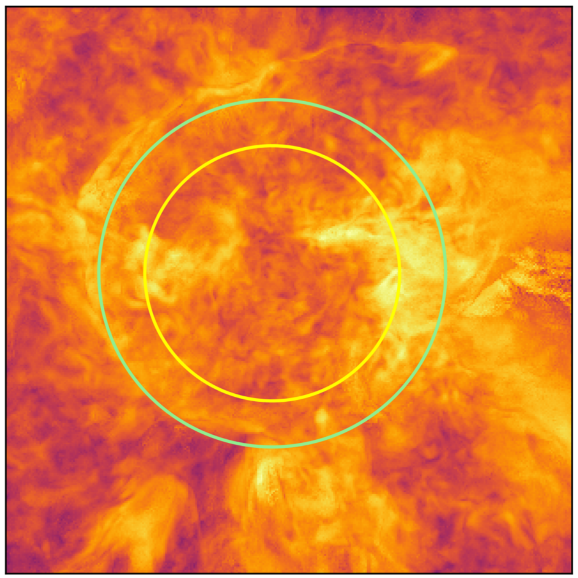
$$\boxed{\alpha = \frac{P_{NT}}{P_{\rm tot}}}$$

$$\alpha_{\rm Turb}(r) = a_0 \times \left(\frac{r}{r_{200,m}}\right)^{a_1} + a_2$$

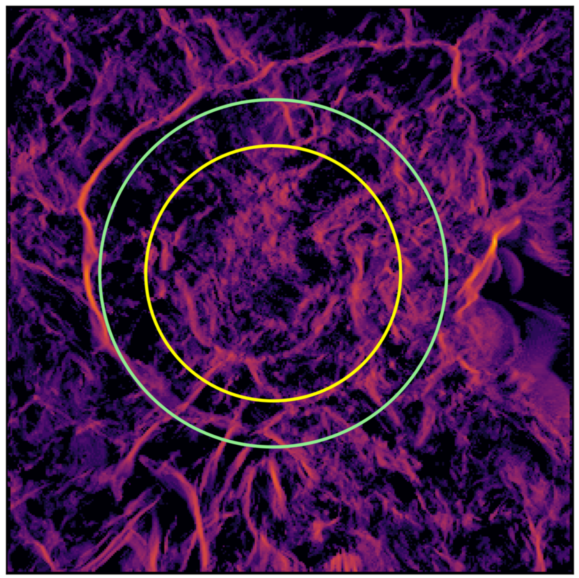
Gas Velocity



Gas Turbulent Velocity

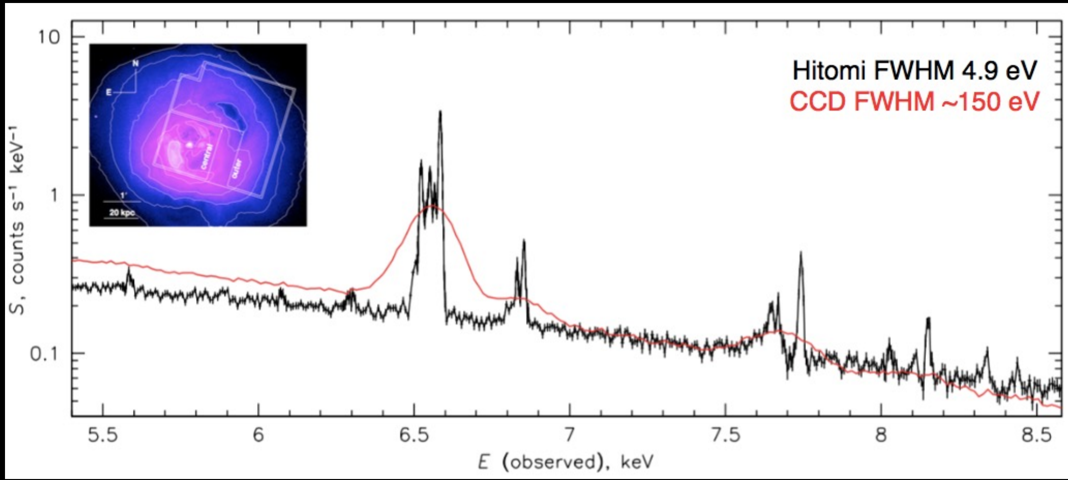


Shocks

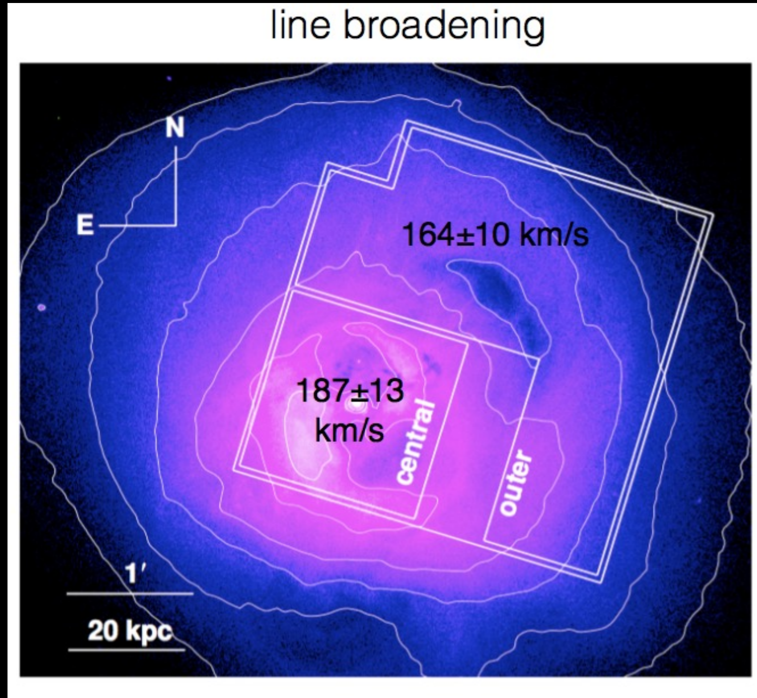


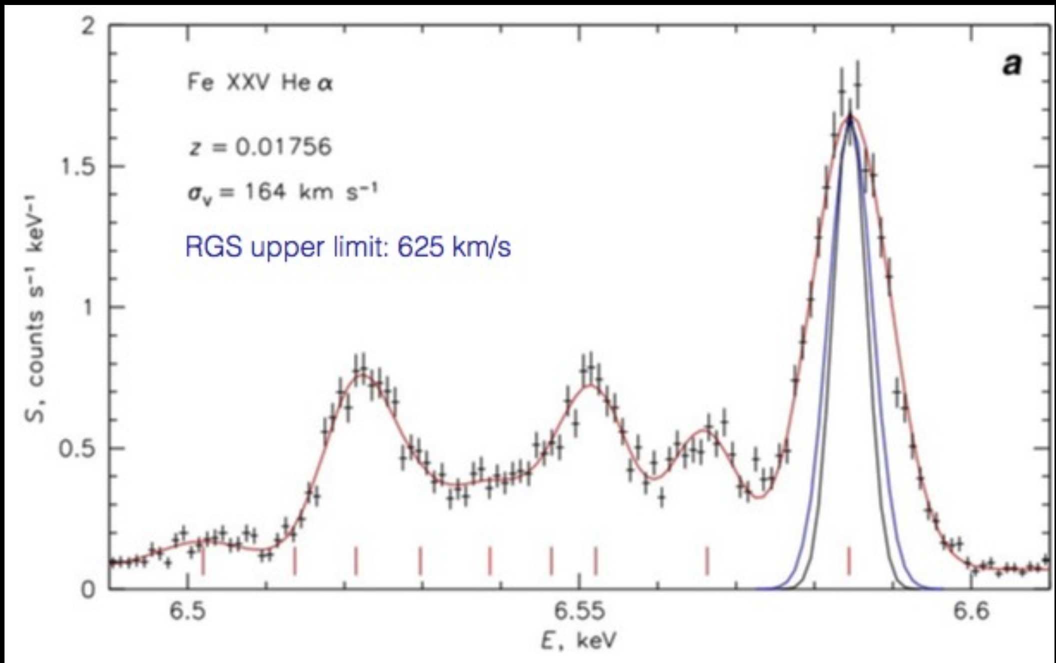
Angelinelli, Vazza + 20

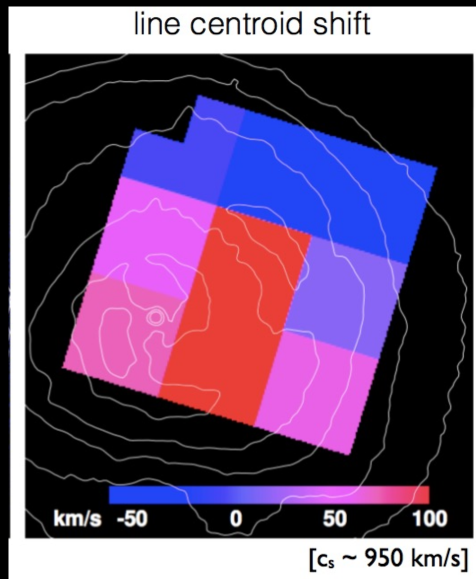
Turbulence in the ICM



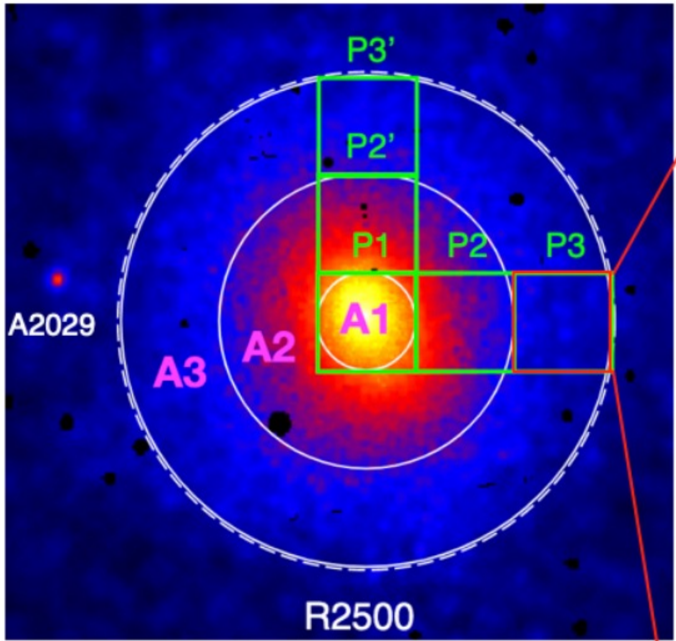
Hitomi collaboration, Nature 2016

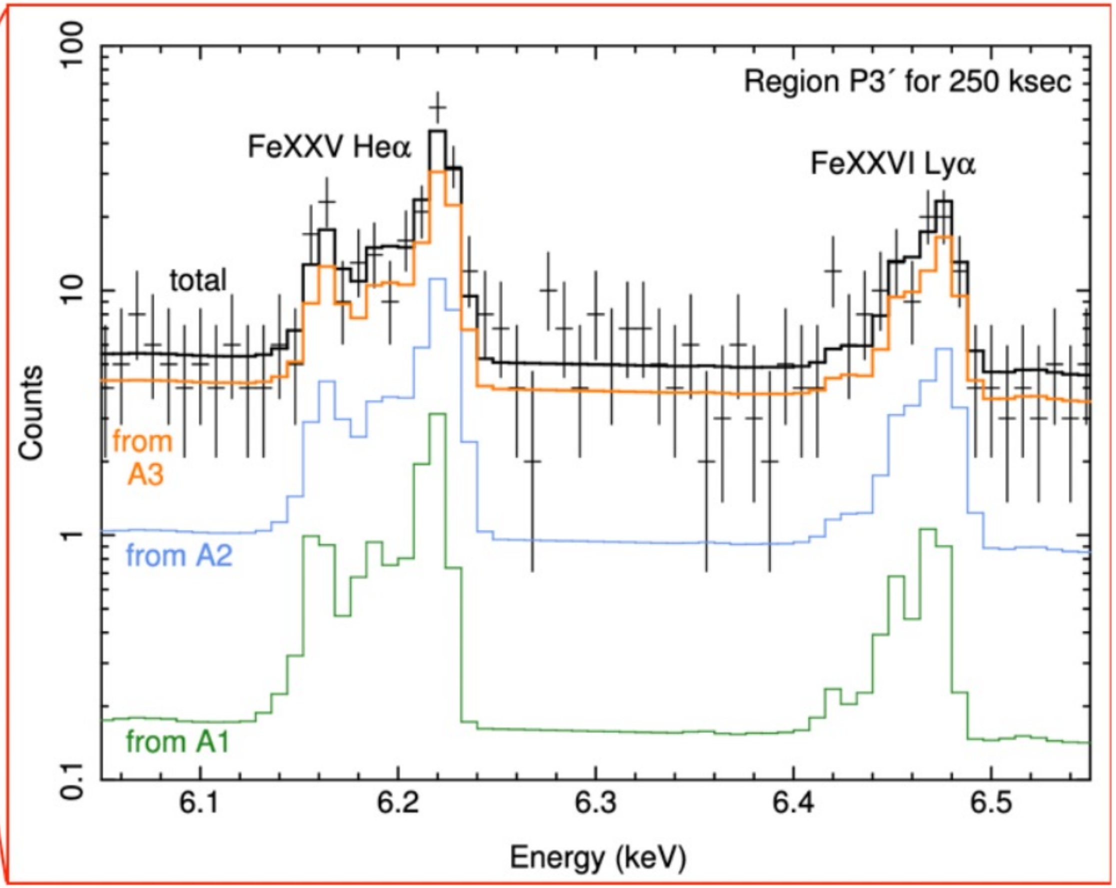






Turbulence in the ICM





A2029: simulated
Resolve spectrum from the region around R2500 shows strong Fe lines broadened by turbulence

XRISM: **Priority A**: 3 pointings, 320 ks in total [North P3 (15:10:56.03, +05:50:39.3): 250 ks; North P2 (15:10:56.03, +05:47:39.3): 50 ks; Center P1 (15:10:56.03, +05:44:39.3): 20 ks]

Priority C: 2 pointings, 300 ks in total [West P3 (15:10:32.15, +05:44:39.3): 250 ks; West P2 (15:10:44.09, +05:44:39.3): 50 ks]

Non-thermal P & hydrostatic bias b

(Ettori & Eckert 22)

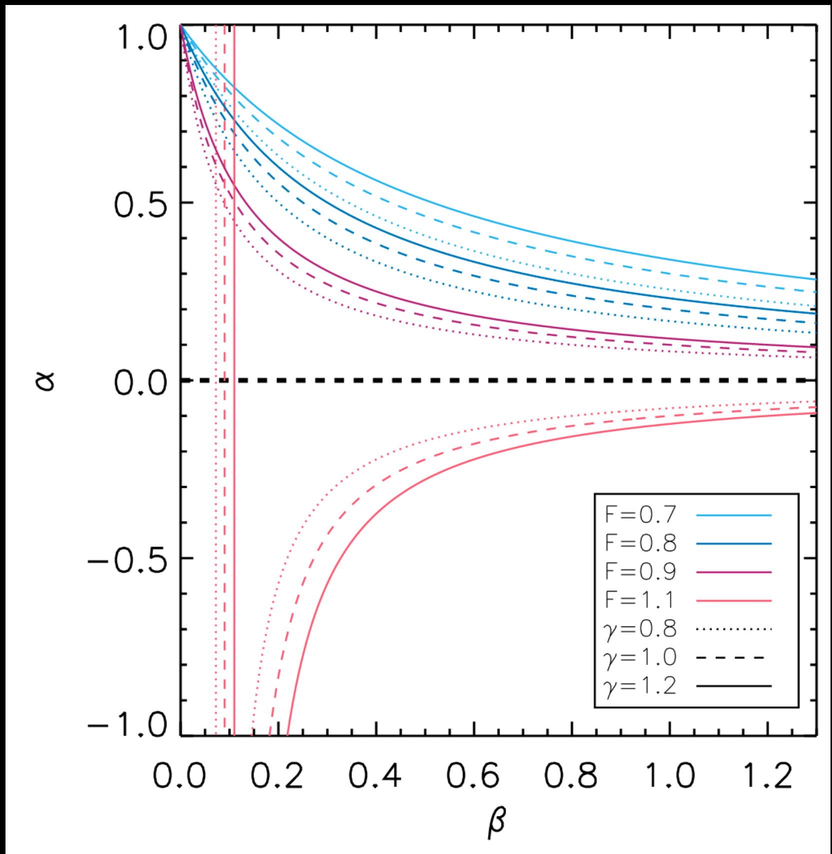
$$\boxed{\alpha = \frac{P_{NT}}{P_{\rm tot}}}$$

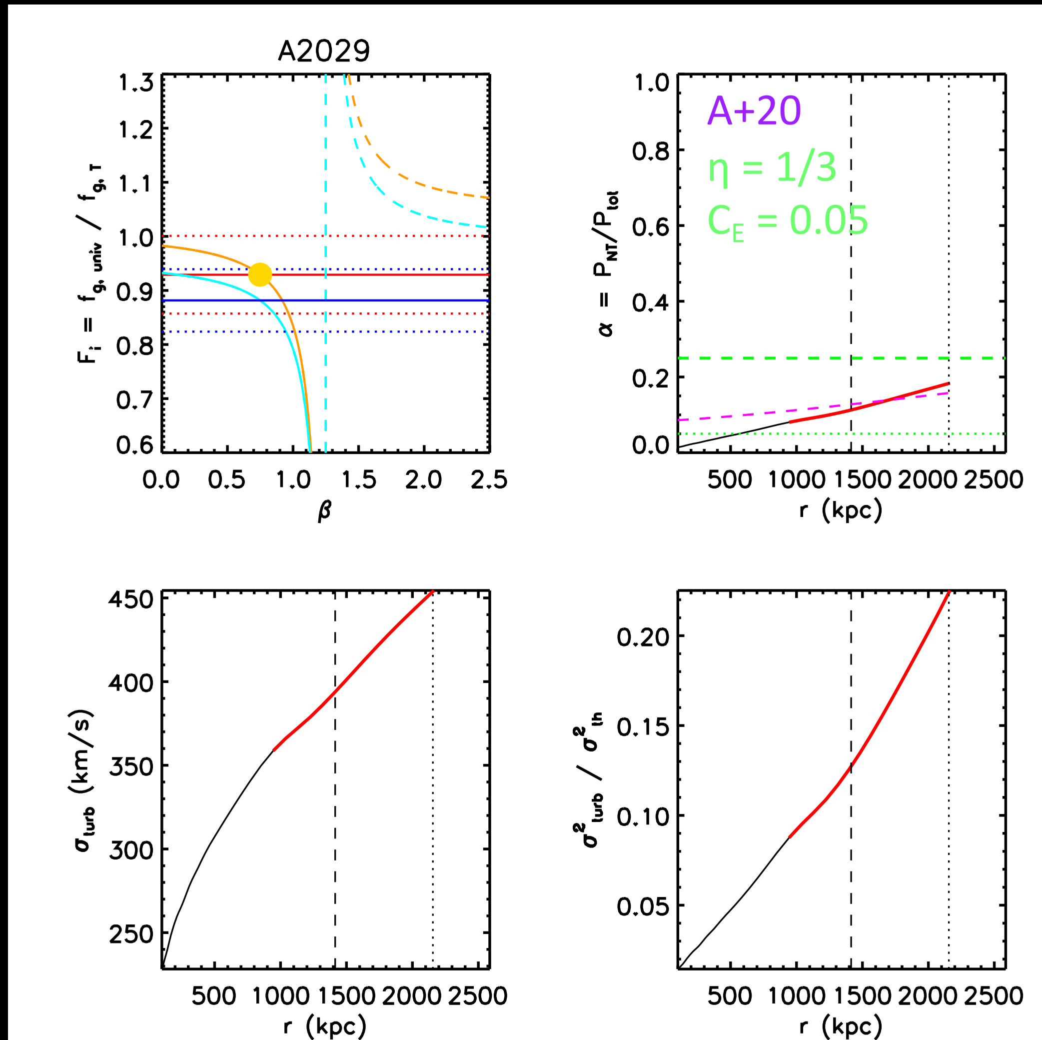
$$P_T = P_{o,T}\left(\frac{n}{n_0}\right)^{\gamma}$$

$$\boxed{F_i = f_{g,\,Univ}/f_{g,\,thermal}}$$

$$\begin{cases} F_1 = \dfrac{1-\alpha_1}{1+\alpha_1(\beta-\hat{\gamma})/\hat{\gamma}} \\ F_2 = \dfrac{1-\alpha_2}{1+\alpha_2(\beta-\hat{\gamma})/\hat{\gamma}} \end{cases}$$

$$P_{NT} = P_{o,NT}\left(\frac{n}{n_0}\right)^{\beta}$$



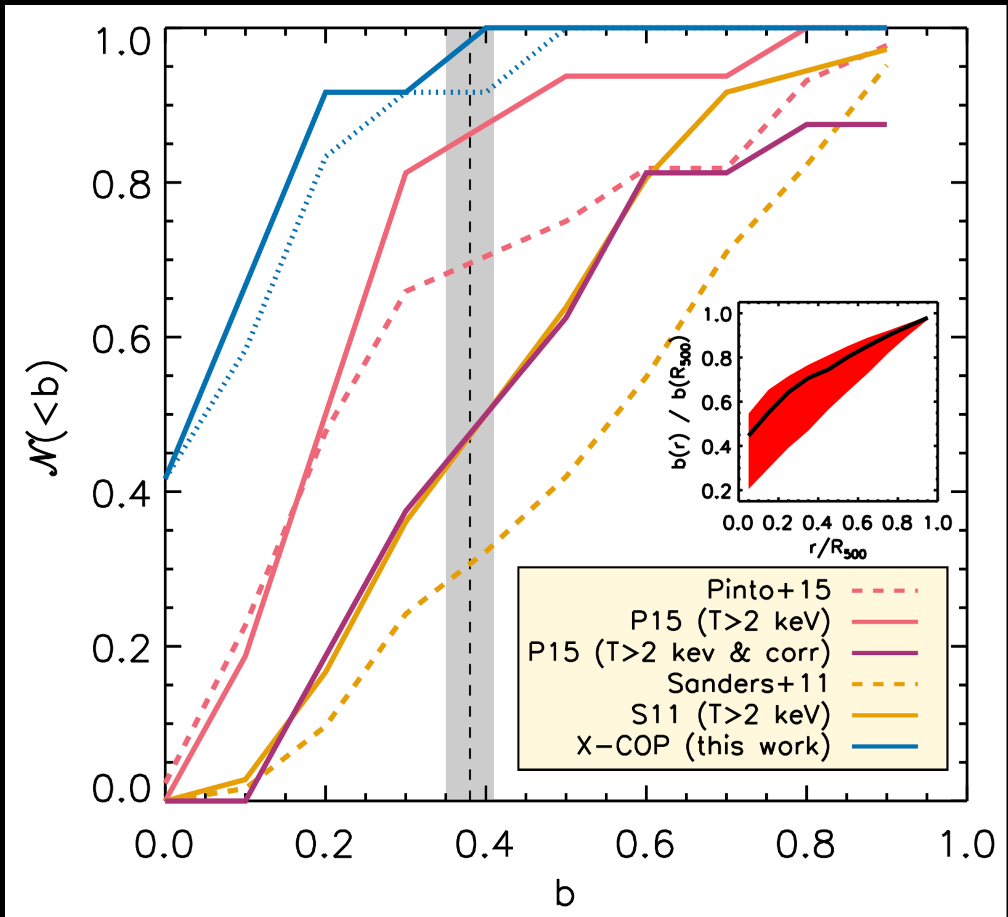


Non-thermal P & hydrostatic bias b

(Ettori & Eckert 22)

$$b = \left(\frac{\alpha - A}{1 + A}\right) = \left(\frac{\sigma_{th}^2}{\sigma_{turb}^2} + 1\right)^{-1}$$

$$A = P_{tot}\left(\frac{d\alpha/dr}{dP_T/dr}\right)$$



- Current upper limits from turbulent velocity in local galaxy clusters: 50% with b<0.2 (80% with b<0.33)
- X-COP *(~relaxed massive nearby systems): b*<0.03 in 50% of the objects, and b<0.17 in 80% of them
- All these values are below the amount of bias required to reconcile the observed cluster number count in the cosmological framework set from Planck (b=0.38 ± 0.03)

- ICM can be described by "***universal***" profiles (ie *thermodynamic radial profiles that should be equal -within the intrinsic scatter- once rescaled by halo **mass** and **red**shift*)

- ***But, it is still missing*** a consistent picture that links these **universal radial profiles** and the **integrated values** of the ICM thermodynamical quantities, also quantifying the deviations from the *standard self-similar gravity-driven scenario*

i(cm)z

a semi-analytic model of the ICM
matching ***observed*** both spatially-resolved
& integrated quantities
(Ettori, Lovisari, Eckert 2023; arxiv:2211.03082)

i(cm)z

or a recipe to prepare an ICM that matches ***observed*** spatially-resolved & integrated quantities

- an "universal" $P = P_{500}\, P_0 / (c_{500}\, x)^c / [1 + (c_{500}\, x)^a]^{(b-c)/a}$
- a (c-M-z) relation, $c_{200} = A\, M_{200}^B\, (1+z)^C$
- stir them together in hydrostatic equilibrium
- then add a bit of 3 further ingredients:

(i) $f_T = T(R_{500})/T$, (ii) $f_g = C^{0.5}\, f_{gas}$, (iii) hydrostatic bias b_{HE}

$$\begin{cases} f_{T,\mathrm{ESZ}} = 0.697(\pm 0.103) \times (T/5\,\mathrm{keV})^{0.15(\pm 0.06)} \\ f_{g,\mathrm{ESZ}} = 0.121(\pm 0.045) \times (T/5\,\mathrm{keV})^{0.45(\pm 0.09)} \\ C_{\mathrm{ESZ}} = (<1.4) \times (T/5\,\mathrm{keV})^{1.0(\pm 0.5)} \end{cases}$$

& constraints on b_{HE}

→ ***Ettori, Lovisari, Sereno*** (2020 A&A 644 111)

i(cm)z

or a recipe to prepare an ICM that matches ***observed*** spatially-resolved & integrated quantities

- an "universal" $P = P_{500}\, P_0 / (c_{500}\, x)^c \,/\, [1 + (c_{500}\, x)^a]^{(b-c)/a}$
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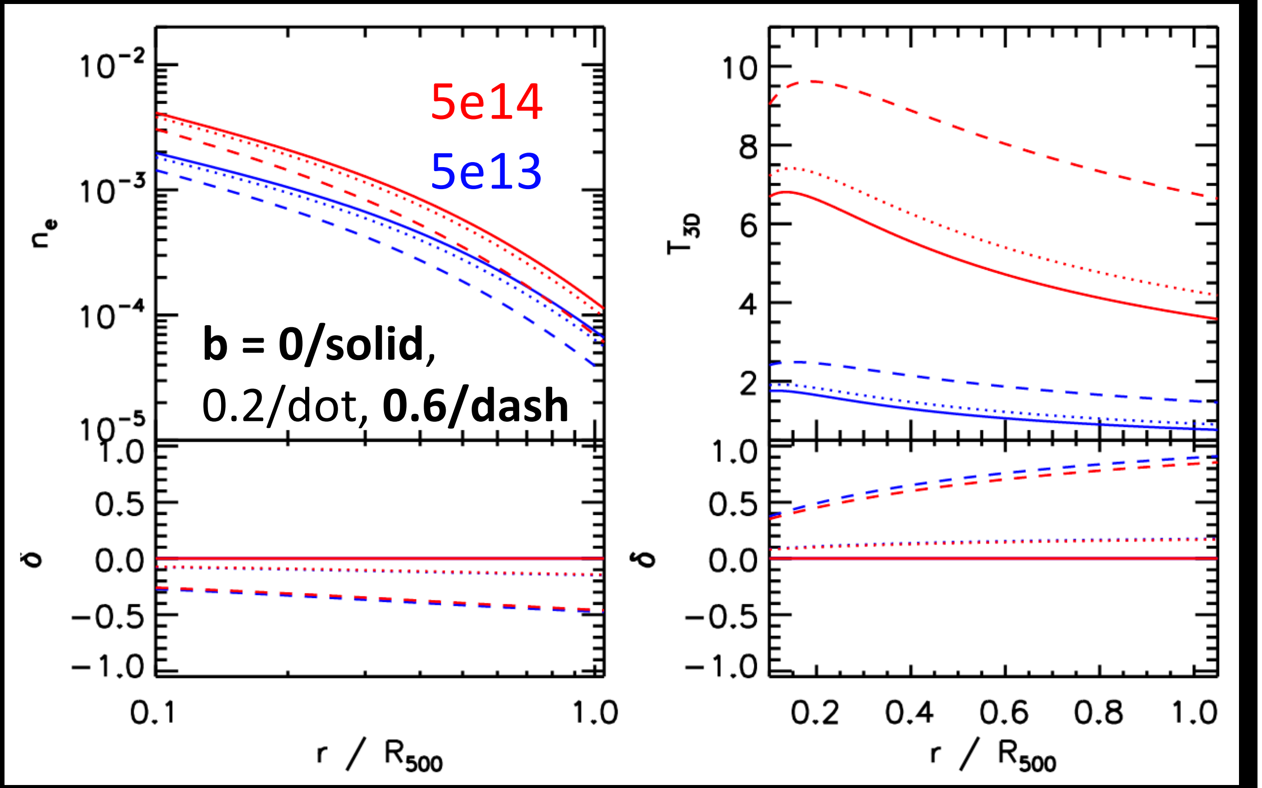
- stir them together in hydrostatic equilibrium
- then add a bit of 3 further ingredients:

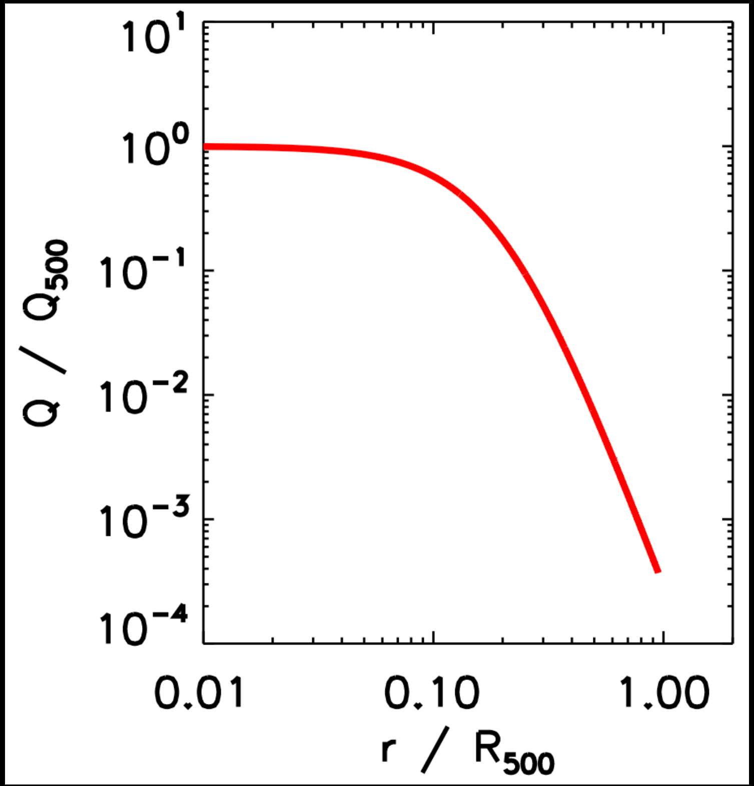
(i) $f_T = T(R_{500})/T$, (ii) $f_g = C^{0.5}\, f_{gas}$, (iii) hydrostatic bias b_{HE}

- ➢ adding the redshift evolution
- ➢ new calibrations in (M, z) based on >2020 scaling laws & recent thermodynamic profiles
- ➢ new constraints on b_{HE} *(e.g. X-COP)*

➔ ***Ettori, Lovisari, Eckert*** (2023; arXiv:2211.03082)

i(cm)z



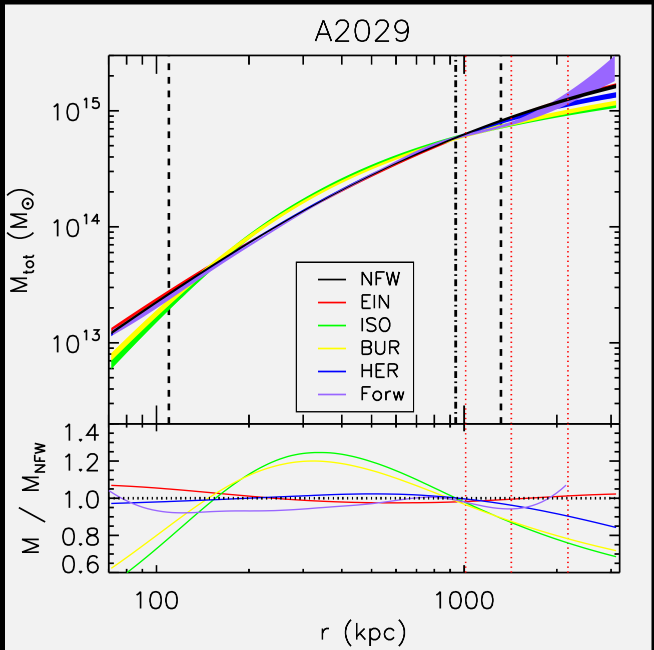


$$M_{HE} = (1 - b)\, M_{tot}$$

$$R_{500} \sim M_{tot}^{1/3}$$

$$Q_{500} = f(M_{tot})$$

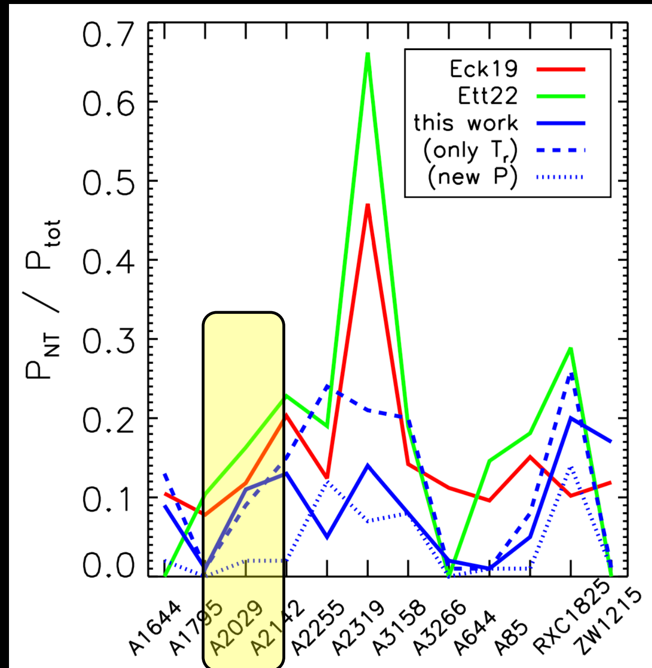
A2029: constraints on *b*

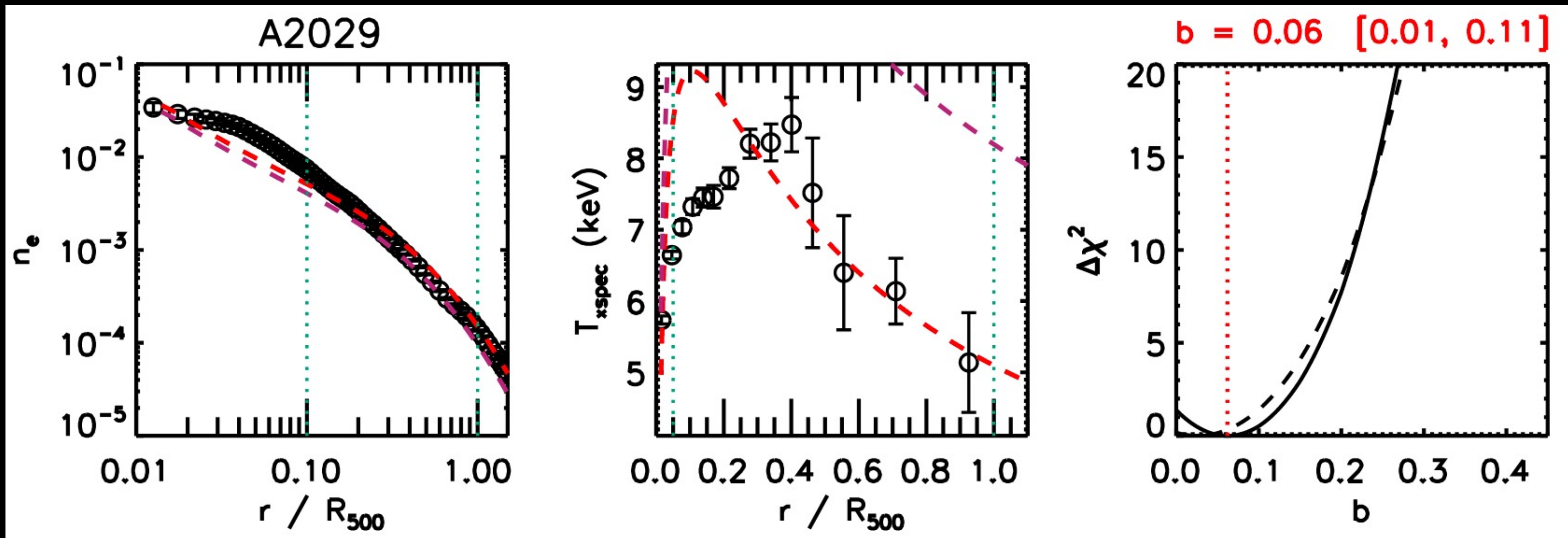


Input:
$\{M_{HE}, z\}$

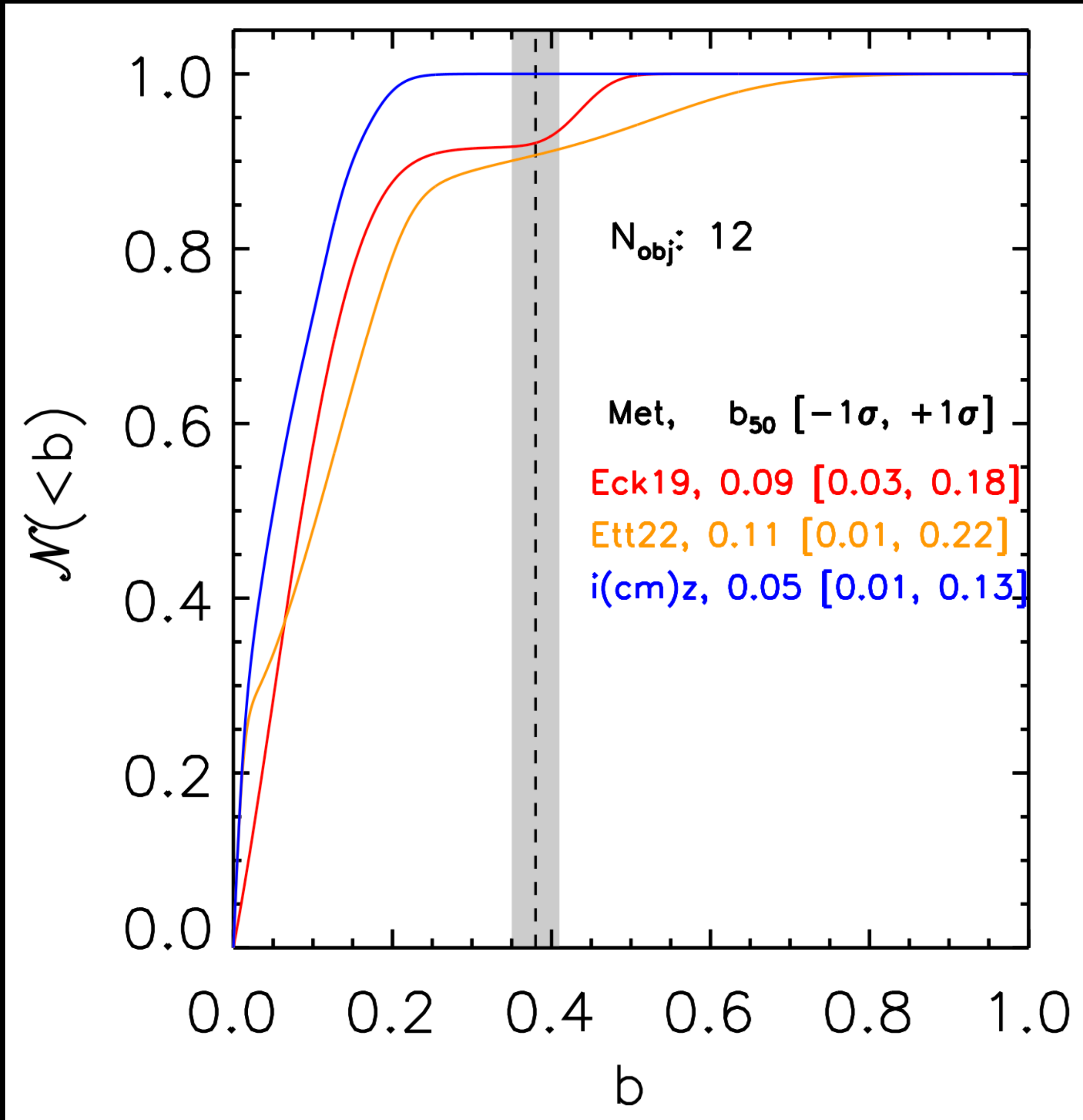
α

i(cm)z



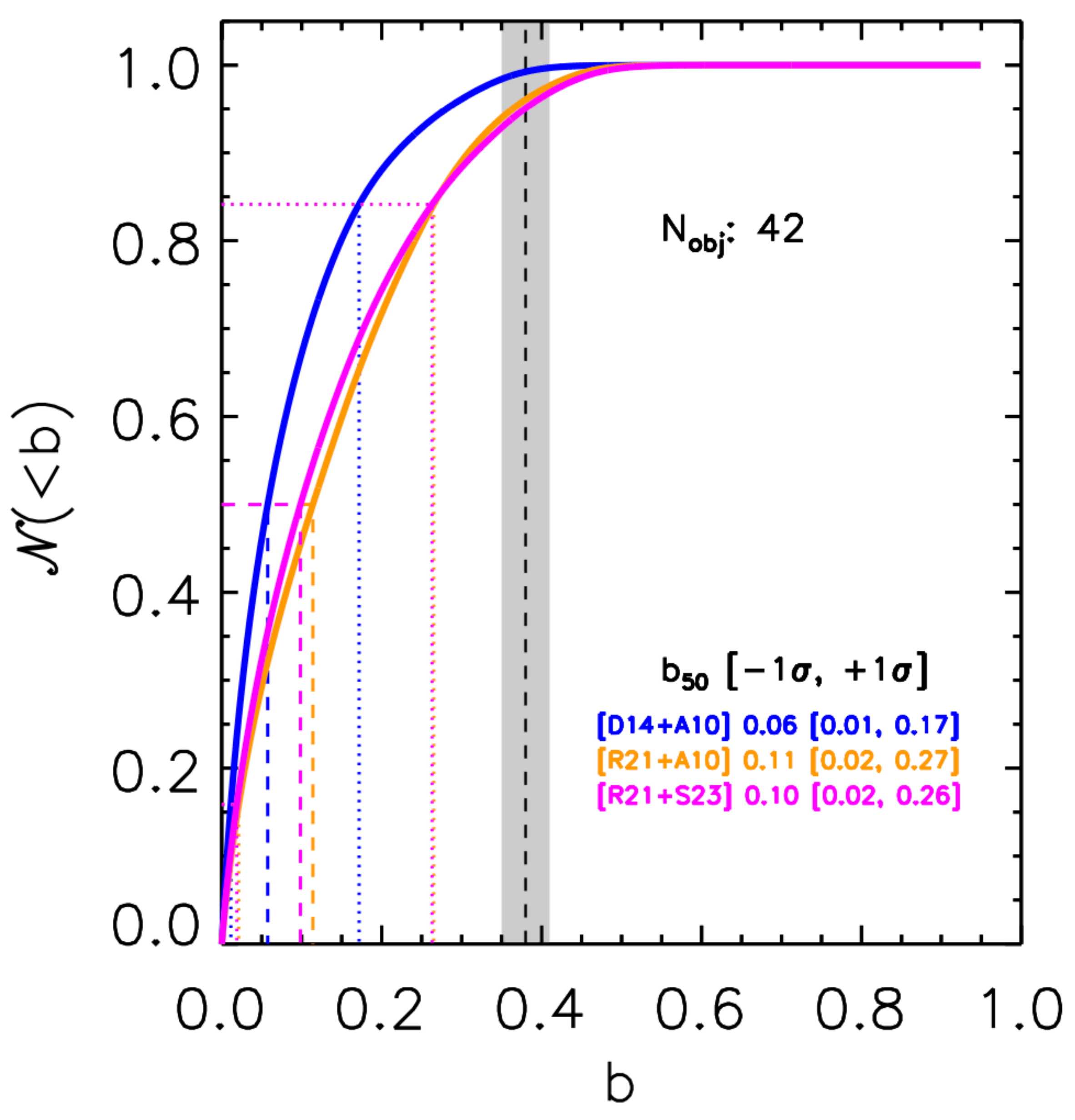


i(cm)z: X-COP

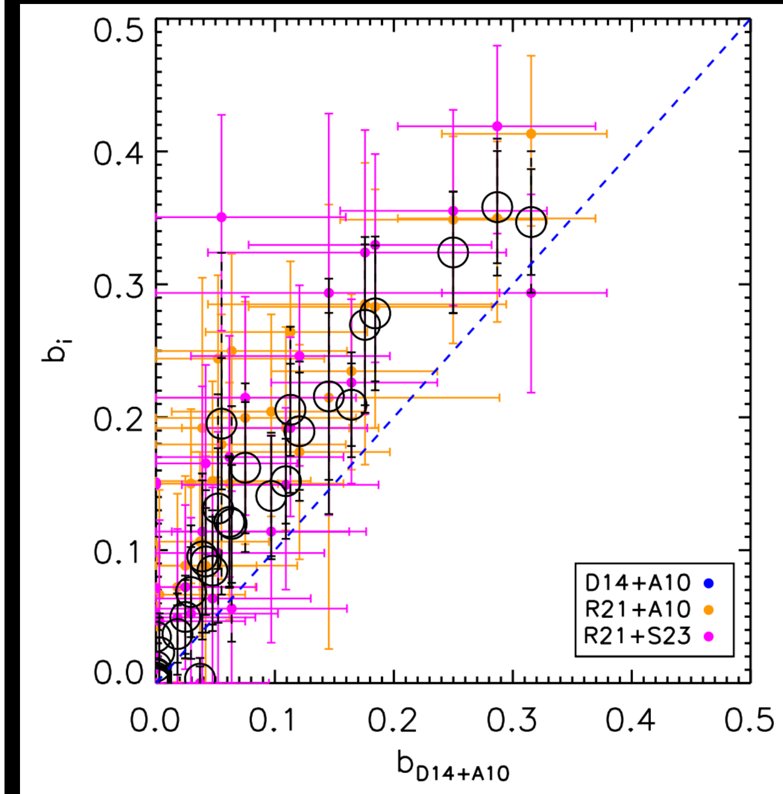


N_{obj}: 12
Met, b_{50} [−1σ, +1σ]
Eck19, 0.09 [0.03, 0.18]
Ett22, 0.11 [0.01, 0.22]
i(cm)z, 0.05 [0.01, 0.13]
$\mathcal{N}(<b)$
b
0.0
0.2
0.4
0.6
0.8
1.0

i(cm)z: CHEX-MATE

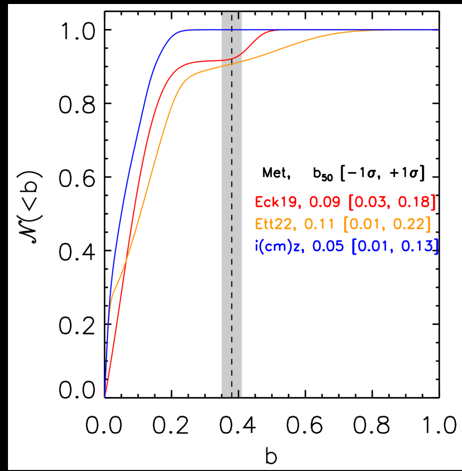


From *quicklook* analysis, using M_{Planck} as input



Take-home messages on P_{NT}

- Analytic model (Ettori & Eckert 22) of P_{NT} ➔ b_{HE}, σ_{turb}
- **i(cm)z** (Ettori+20, 23): a semi-analytic model based on *P_{univ} + cMz;* reproduce spatially-resolved & integrated quantities ➔ forecasting b_{HE} (vel_{bapec})



✓ in relaxed objects (X-COP): *b_{50}~0.1 (<0.2)*
✓ (CHEX-MATE; M_{Planck}): *b_{50}~0.1 (<0.3)*
✓ Required: $b_{Planck} = 0.38 \pm 0.03$

❖ Hydrodynamic simulations (from e.g. Magneticum, the300, ENZO) convolved with SIXTE-like tools are needed to infer correlation between intrinsic and observed properties *(turbulence, bulk motions, structure functions, true b_{HE})*