Measurement of the dark matter velocity anisotropy in galaxy clusters

Ole Høst, Dark Cosmology Centre, NBI, Copenhagen

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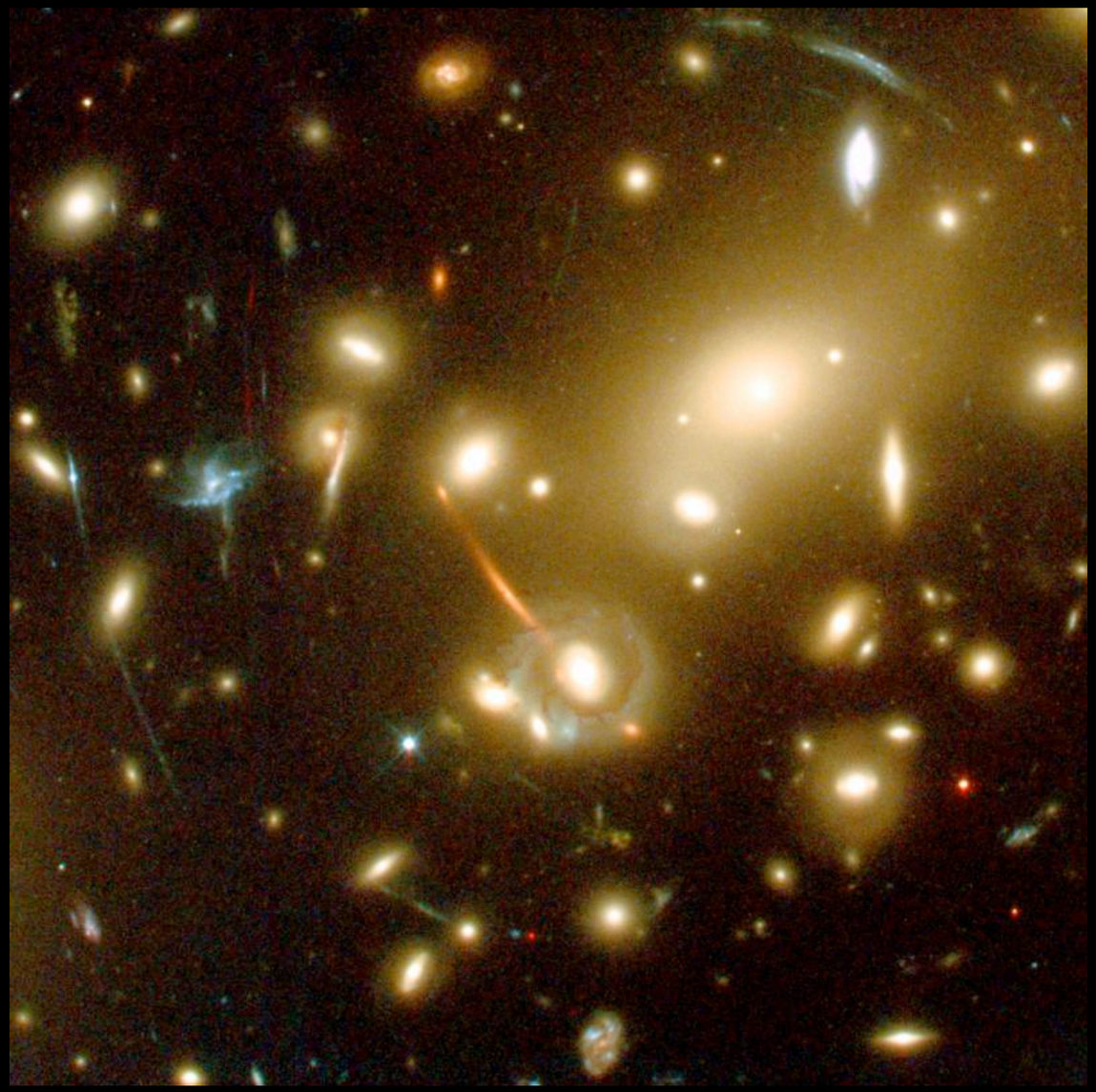
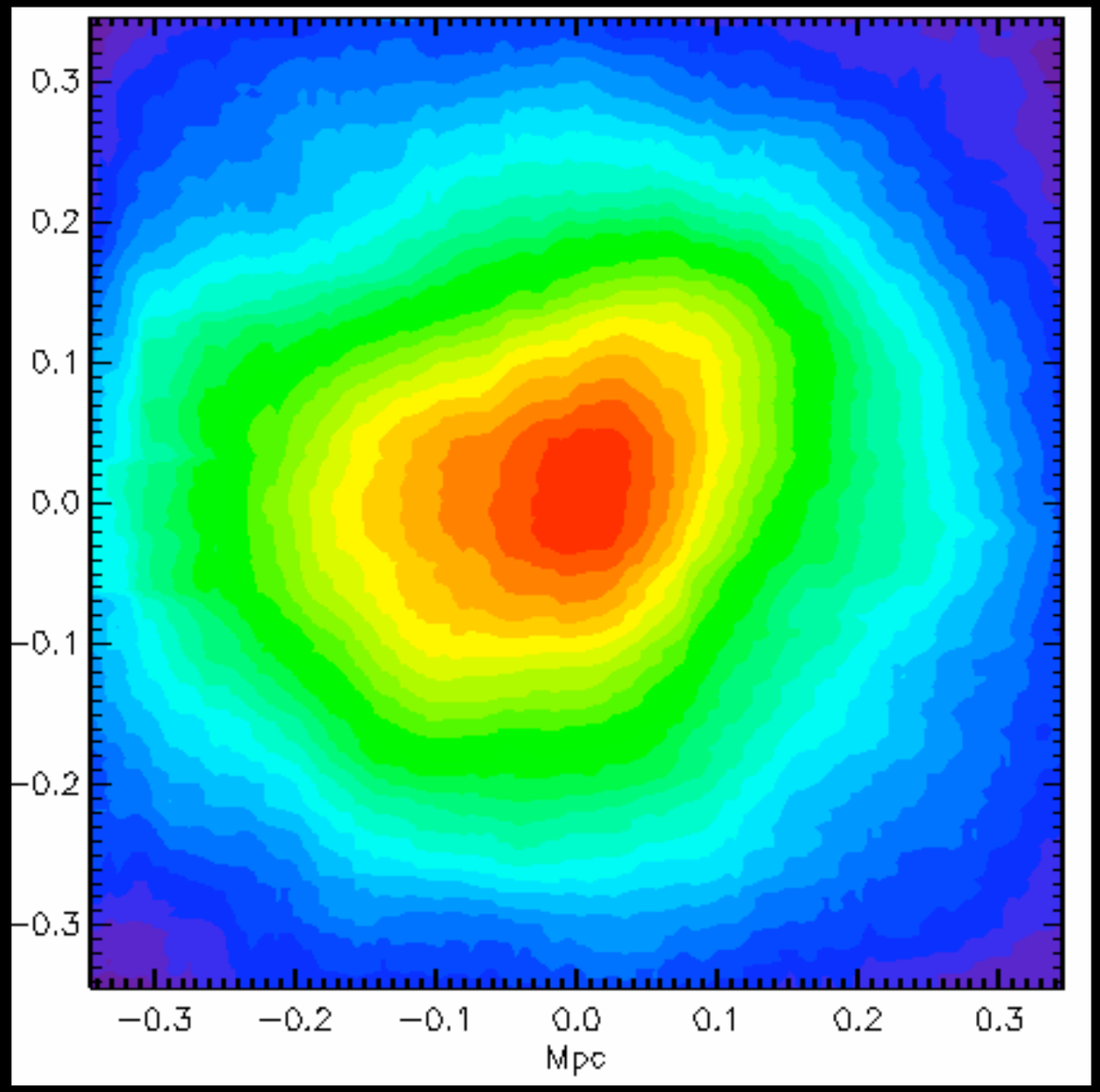
Dark Cosmology Centre

- Steen H Hansen, DARK
- Rocco Piffaretti, SISSA, Italy
- Andrea Morandi, DARK
- Stefano Ettori, Bologna, Italy
- Scott T Kay, Manchester, UK
- Riccardo Valdarnini, SISSA, Italy

Galaxy clusters





Baryons and dark matter in clusters

- Hydrostatic equilibrium of baryonic gas

$$\frac{k_B T}{\mu m_H}\left(\frac{d\ln T}{d\ln r}+\frac{d\ln n_e}{d\ln r}\right)=-\frac{GM(r)}{r}$$

- Jeans equation of collisionless dark matter

$$\sigma_r^2\left(\frac{d\ln \sigma_r^2}{d\ln r}+\frac{d\ln \rho}{d\ln r}+2\beta\right)=-\frac{GM(r)}{r}$$

Velocity anisotropy

$$\beta = 1 - \frac{\sigma_t^2}{\sigma_r^2}$$

- Zero for isotropic velocity dispersion - e.g. collisional gas
- Non-zero for dark matter according to numerical simulations

β: A bloody nuisance

- Decisive parameter for collisionless systems - stars, galaxies, dark matter
- So far not probed by data
- MUST be tested if we want to eventually understand DM structures

Baryons and dark matter in clusters

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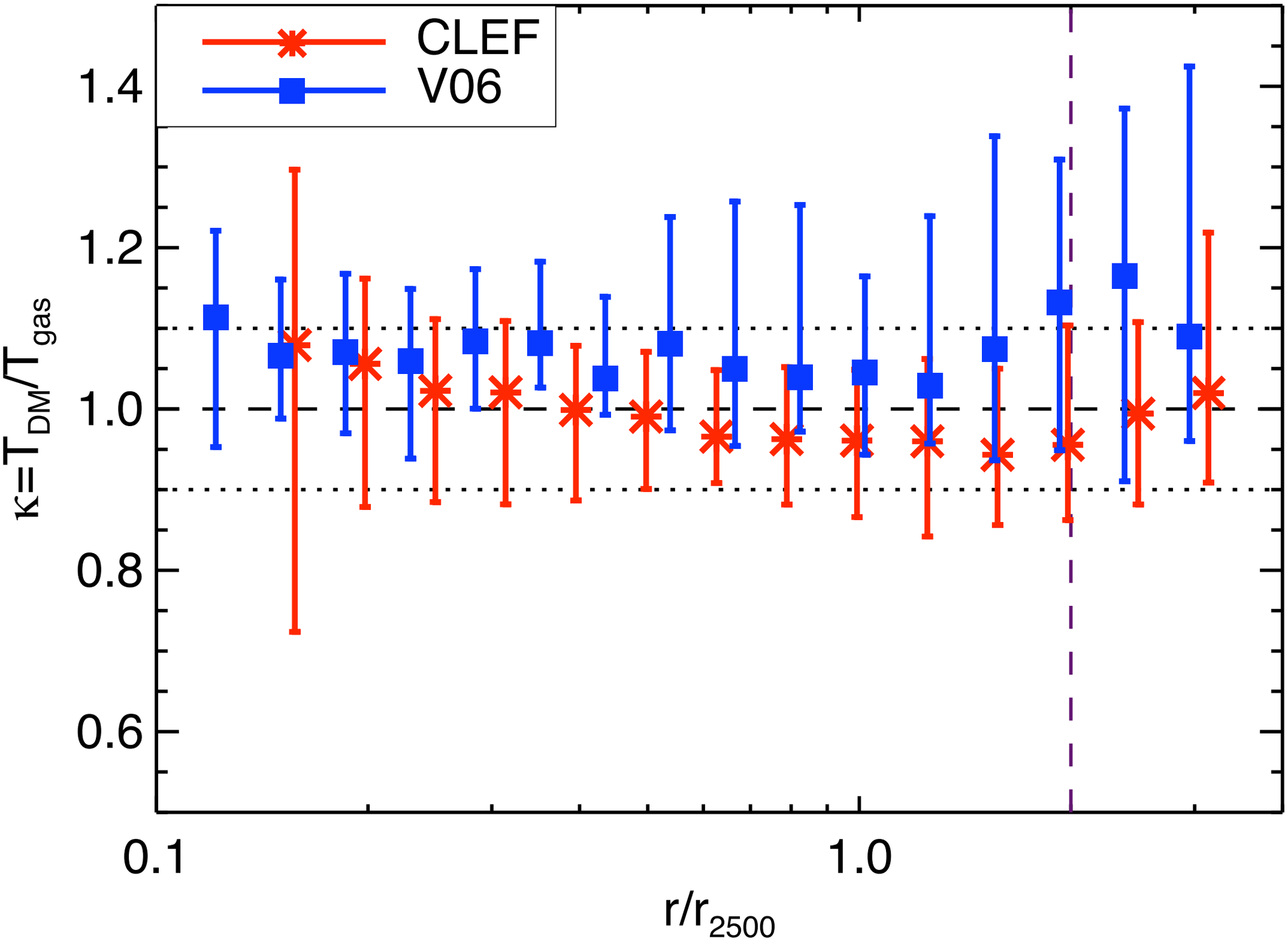
Specific energies

- Gas and dark matter must have same specific potential energy

- Simplest assumption is they also have the same specific kinetic energy

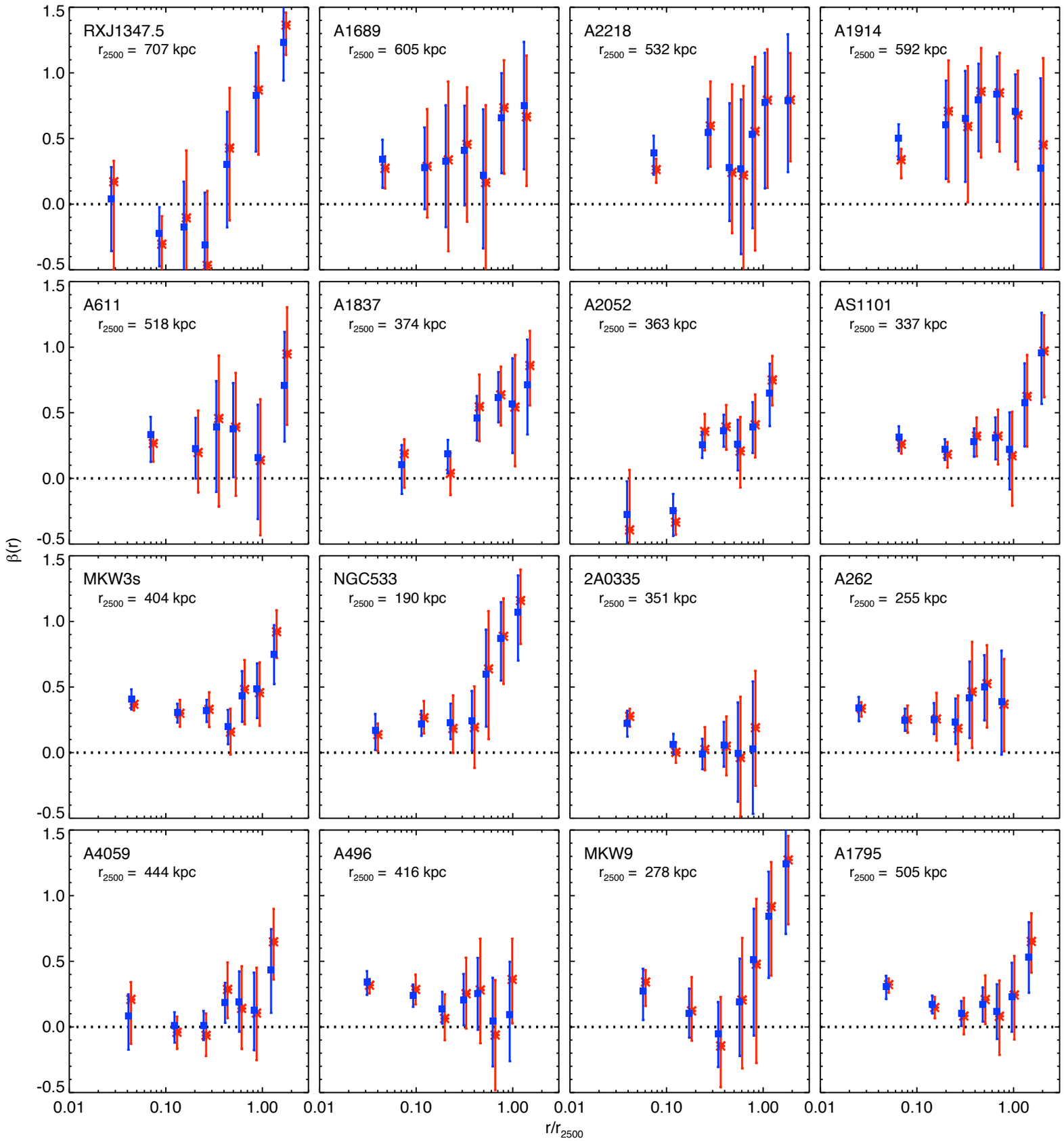
$$\sigma^2_{\rm DM} = \kappa \frac{3 k_B T}{\mu m_H}$$

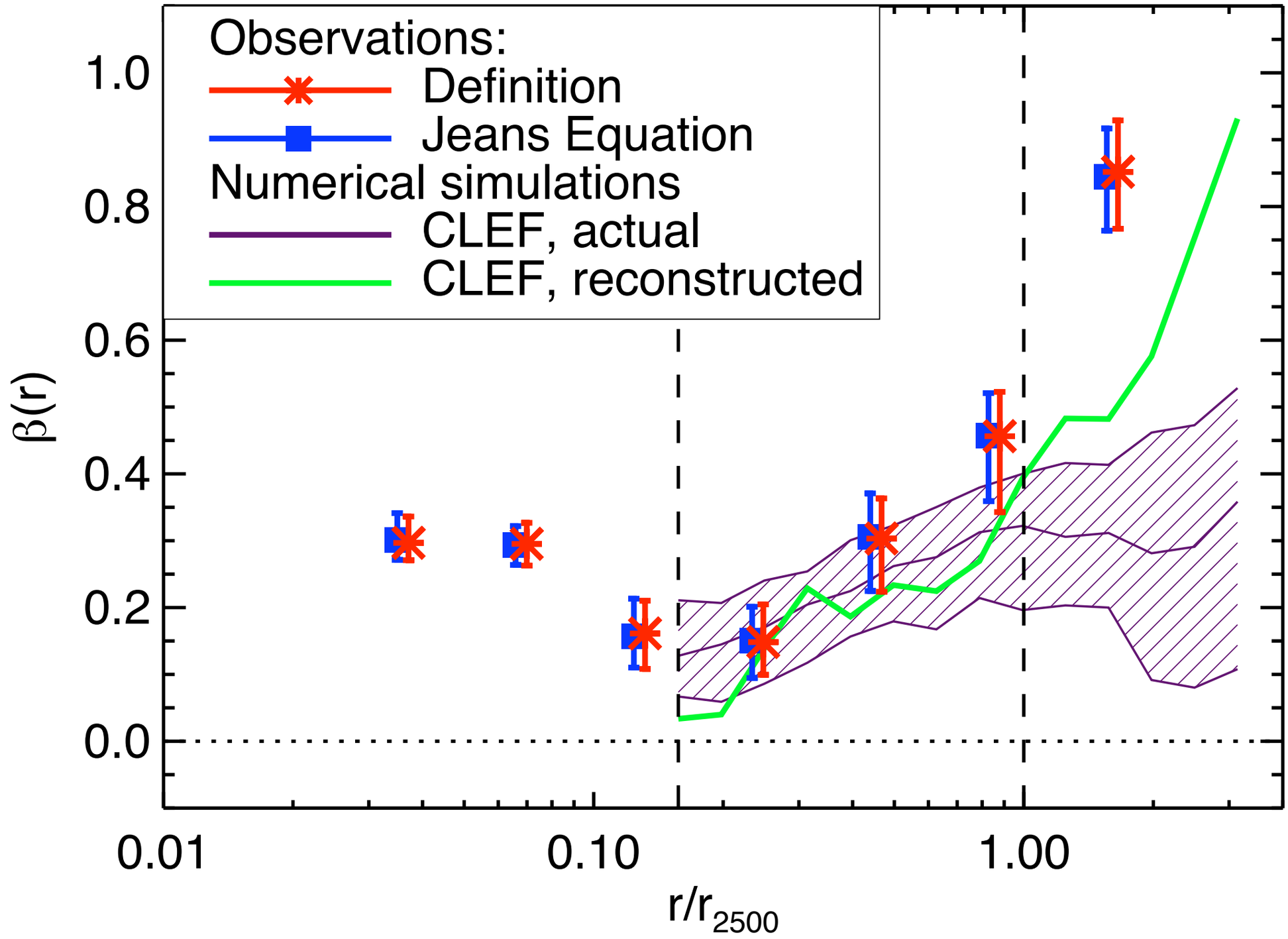
Hansen & Piffaretti, 2007


CLEF
V06
1.4
1.2
1.0
0.8
0.6
κ=T_DM/T_gas
0.1
1.0
r/r_2500

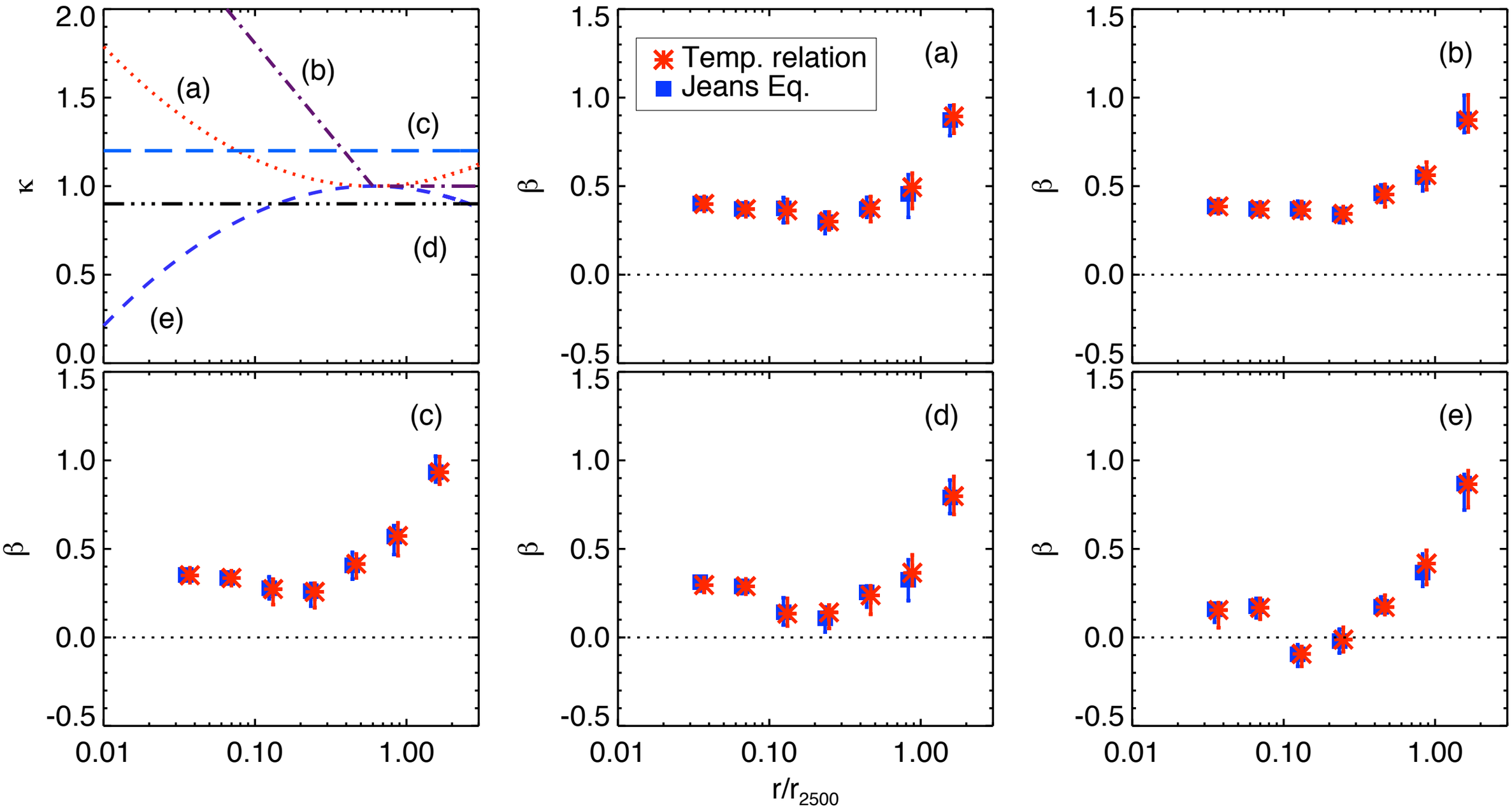
Cluster sample

- 16 clusters at low and intermediate redshift
- Radial gas density and temperature profiles obtained in earlier work (Kaastra et al. 2004, Morandi et al. 2007)
- Selected to appear close to round and have smooth density and temperature profiles


RXJ1347.5
r2500 = 707 kpc
A1689
r2500 = 605 kpc
A2218
r2500 = 532 kpc
A1914
r2500 = 592 kpc
A611
r2500 = 518 kpc
A1837
r2500 = 374 kpc
A2052
r2500 = 363 kpc
AS1101
r2500 = 337 kpc
MKW3s
r2500 = 404 kpc
NGC533
r2500 = 190 kpc
2A0335
r2500 = 351 kpc
A262
r2500 = 255 kpc
A4059
r2500 = 444 kpc
A496
r2500 = 416 kpc
MKW9
r2500 = 278 kpc
A1795
r2500 = 505 kpc
β(r)
r/r2500
1.5
1.0
0.5
0.0
-0.5
0.01
0.10
1.00



- ApJ 690:358-366,2009 - arXiv:0808.2049


κ
(a)
(b)
(c)
(d)
(e)
β
Temp. relation
Jeans Eq.
(a)
(b)
(c)
(d)
(e)
r/r2500

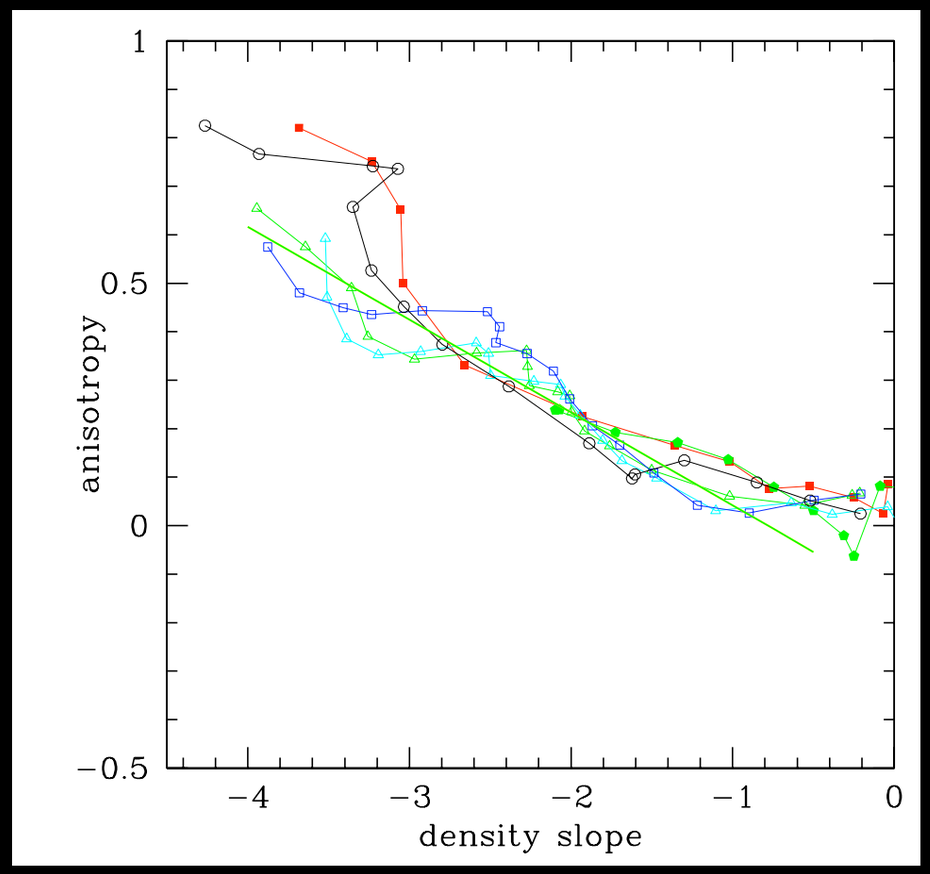
Implications

- Collective behaviour of dark matter fundamentally different from that of a gas
- Dark matter collisionless on timescales of Gigayears
- Agreement between simulations and observations both on static and dynamic properties of halos
- Constraint on self-interaction:

$$\sigma/m \lesssim 1\,\mathrm{cm}^2\,\mathrm{g}^{-1}$$

DM determines gas properties?

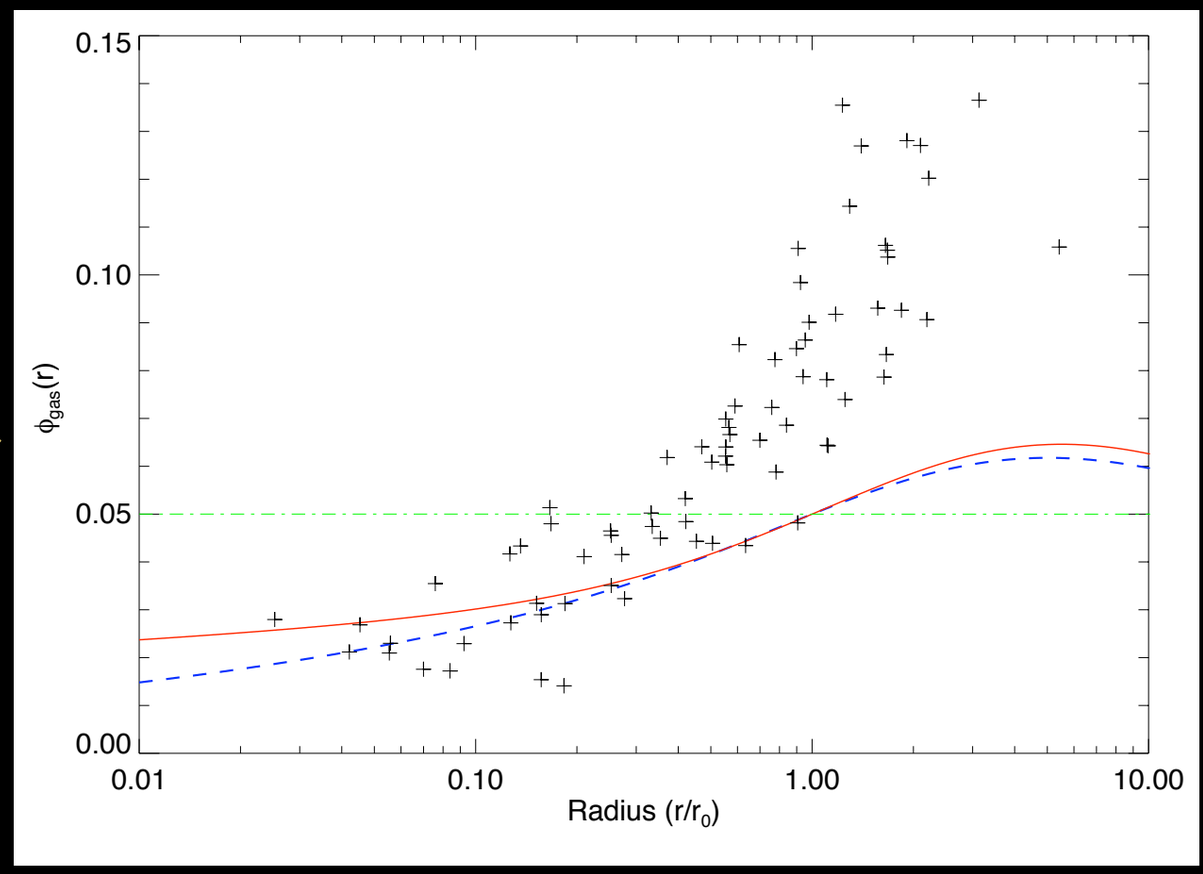
DM-slope correlated with β



Hansen & Stadel 2005

κ=1

Gas fraction



Frederiksen 2009, in prep.

Summary

- Dark matter velocity anisotropy is non-zero in the outer regions of galaxy clusters
- Measurement stable to deviations from $\kappa=1$
- Implies dark matter is effectively collisionless
- "Temperature relation" $\kappa=1$ may yield further insights in cluster modeling