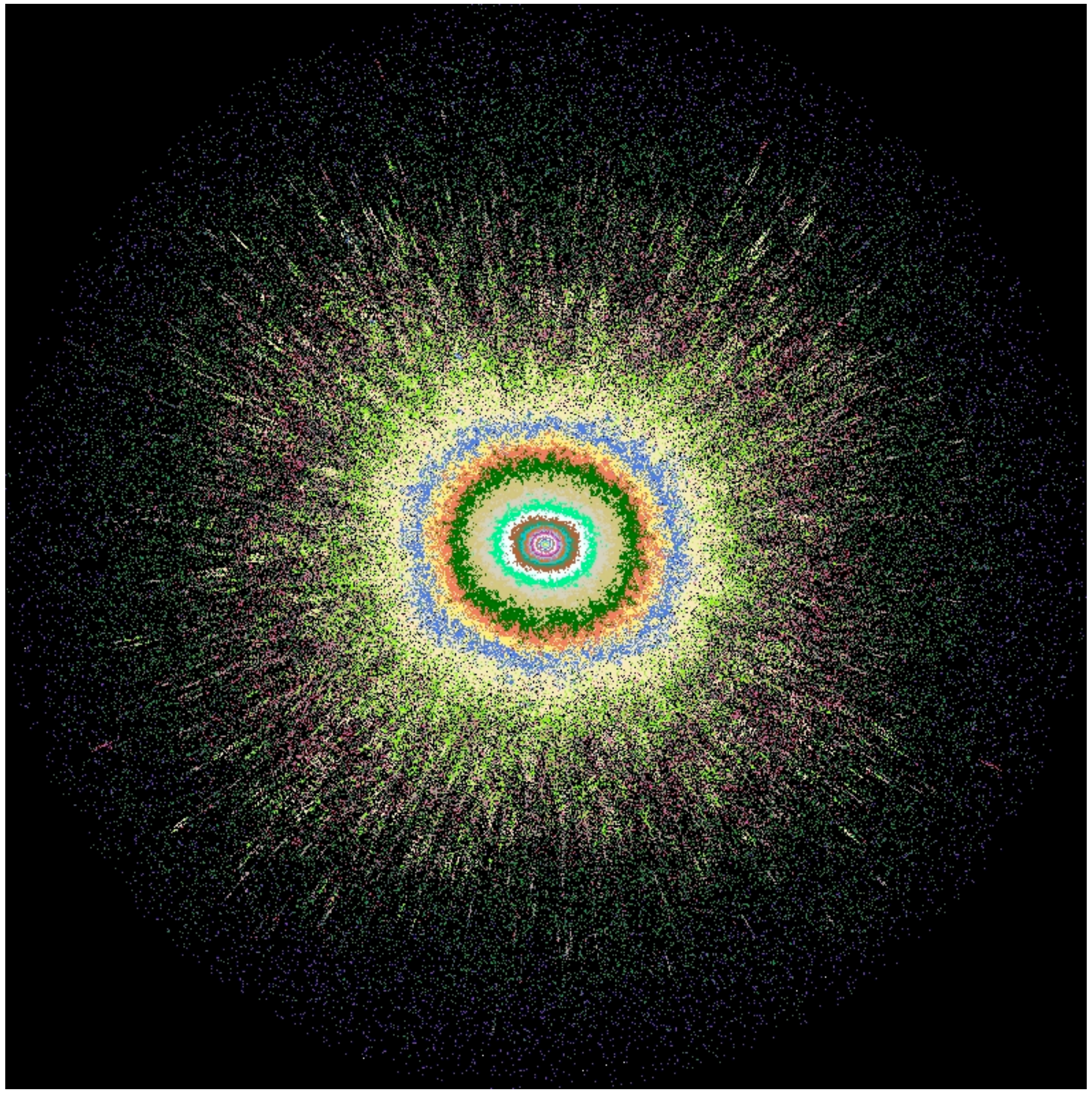
Dark Matter velocity anisotropy - observations and theory



Steen H. Hansen,
Dark Cosmology Centre, NBI
Cargese, Corsica
SW3, April, 2009

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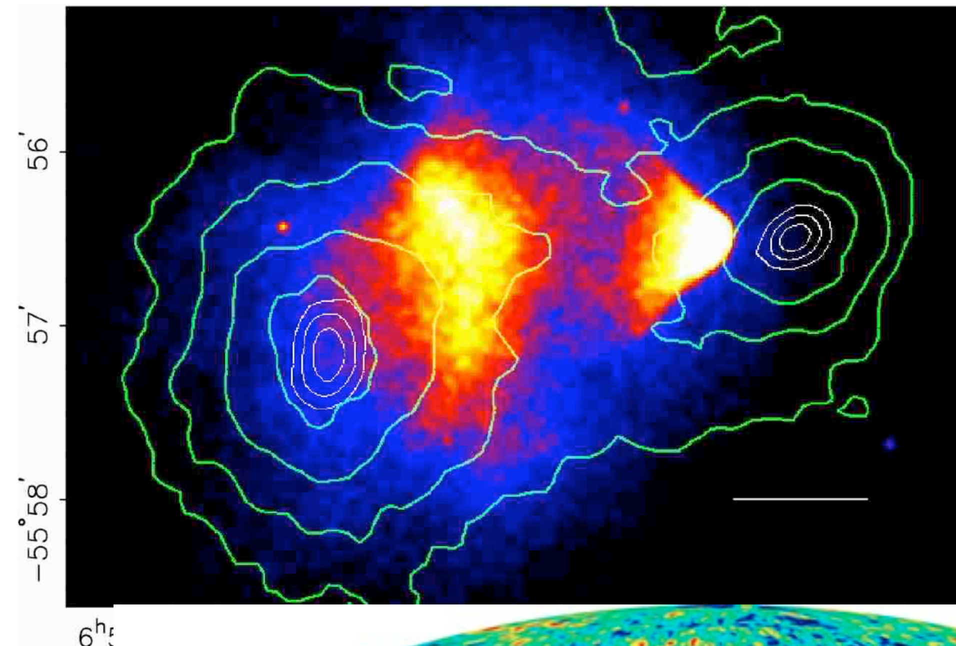
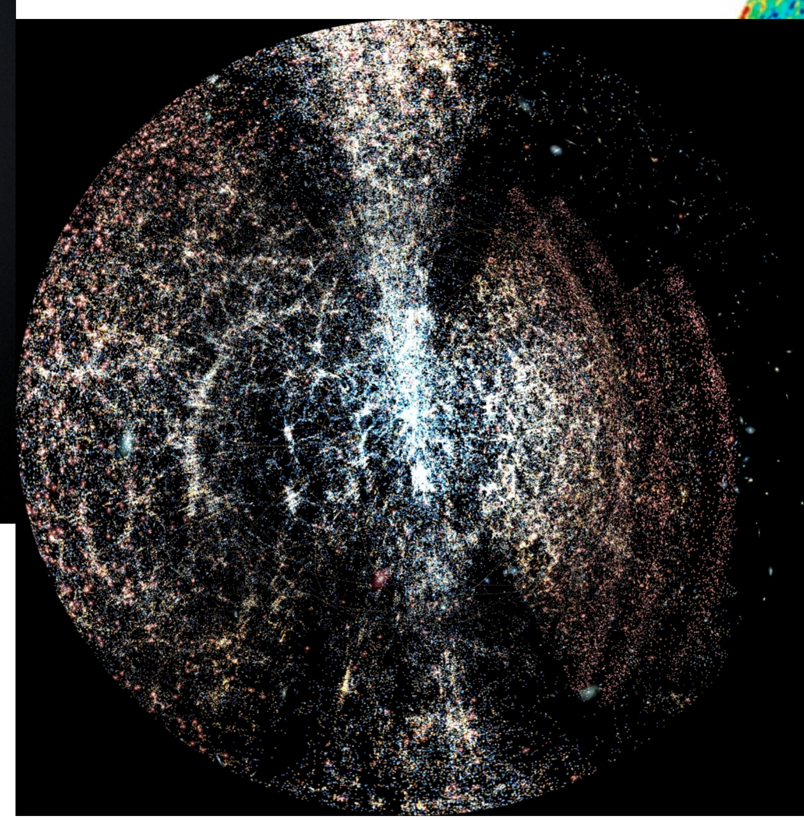
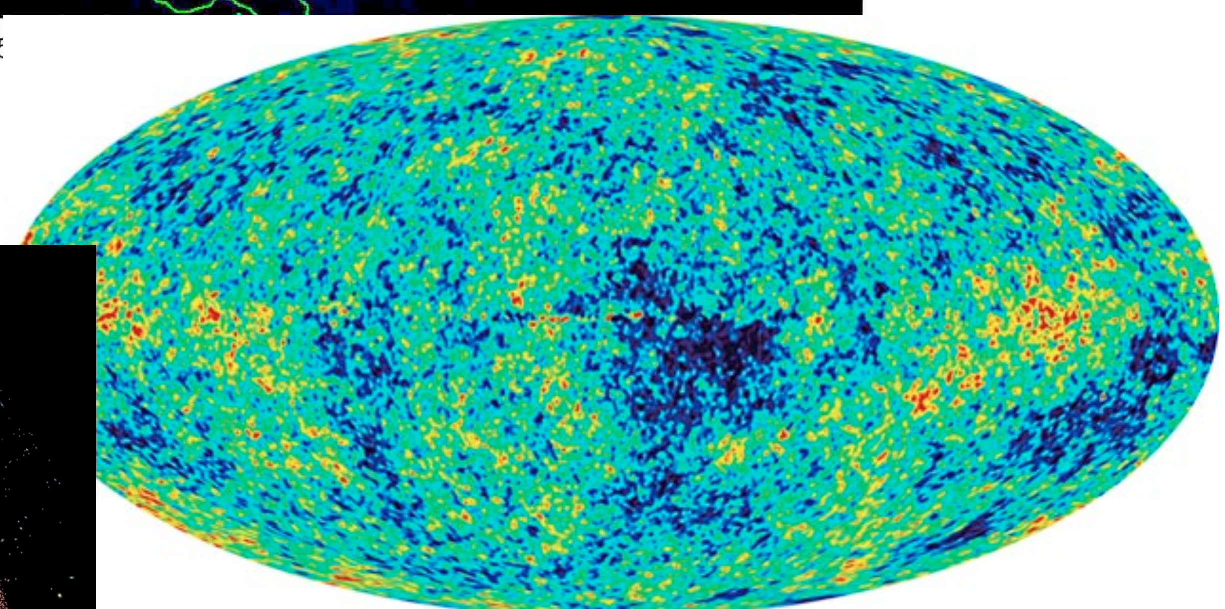
Dark matter observations







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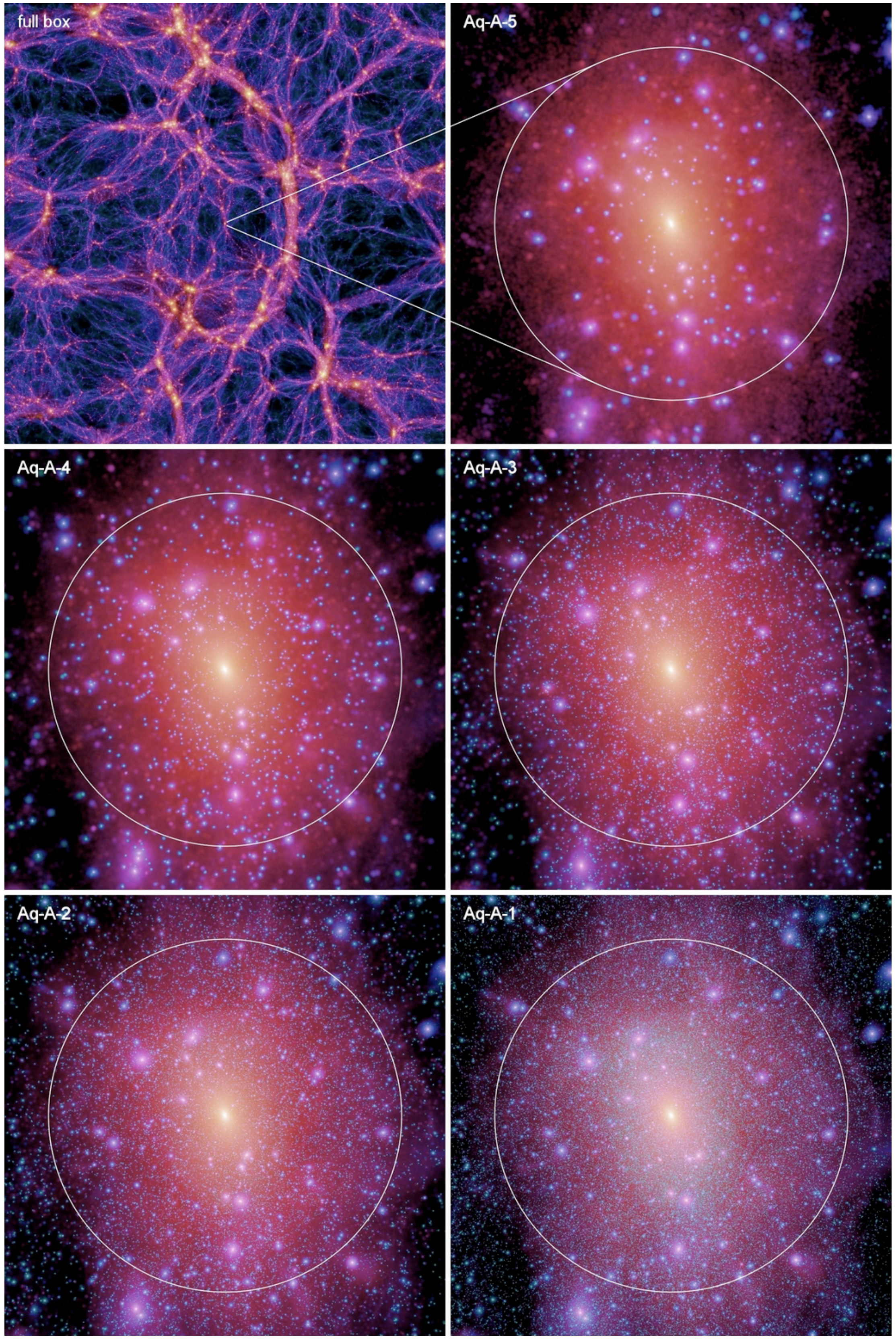
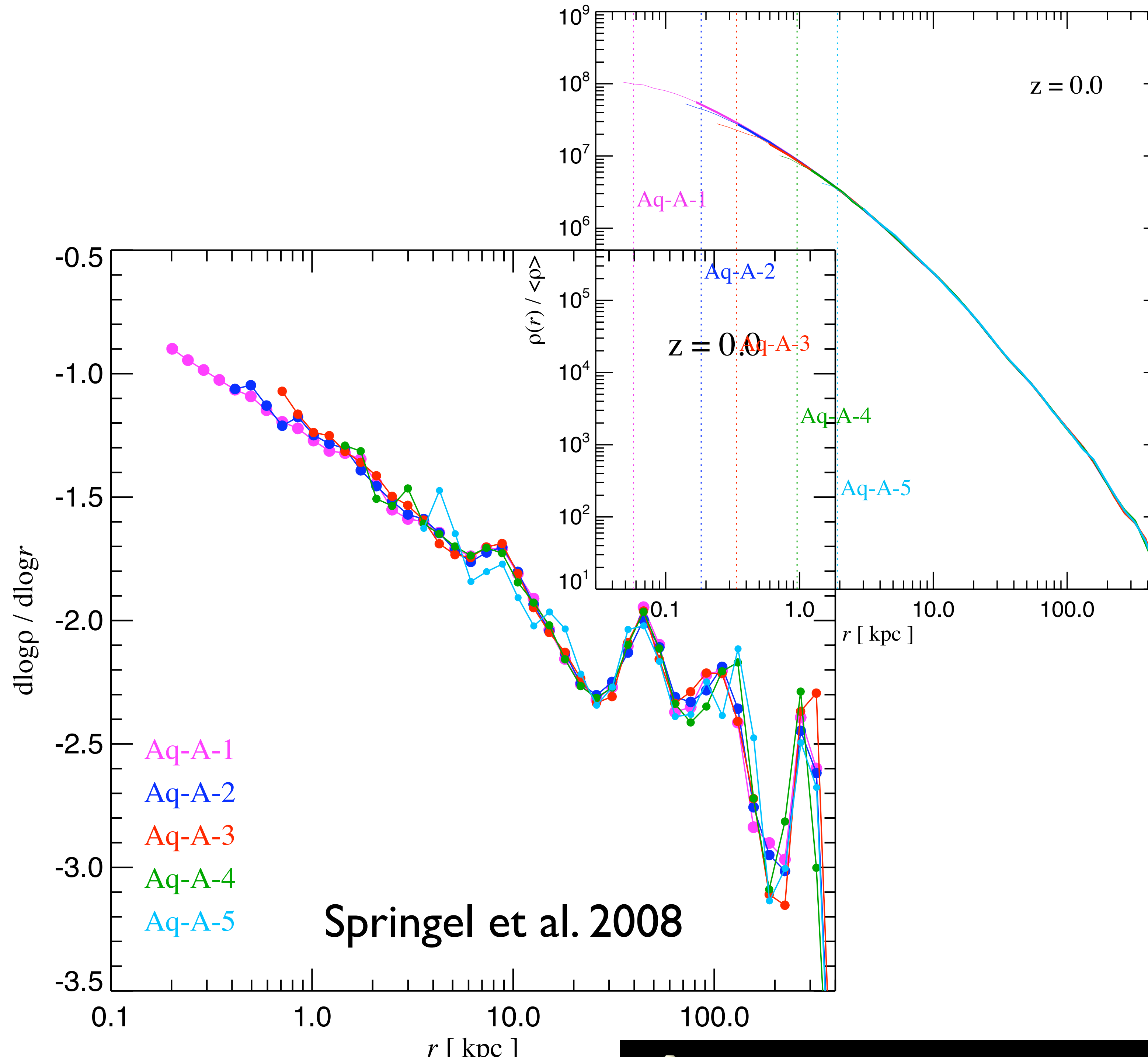
Simulated density profiles





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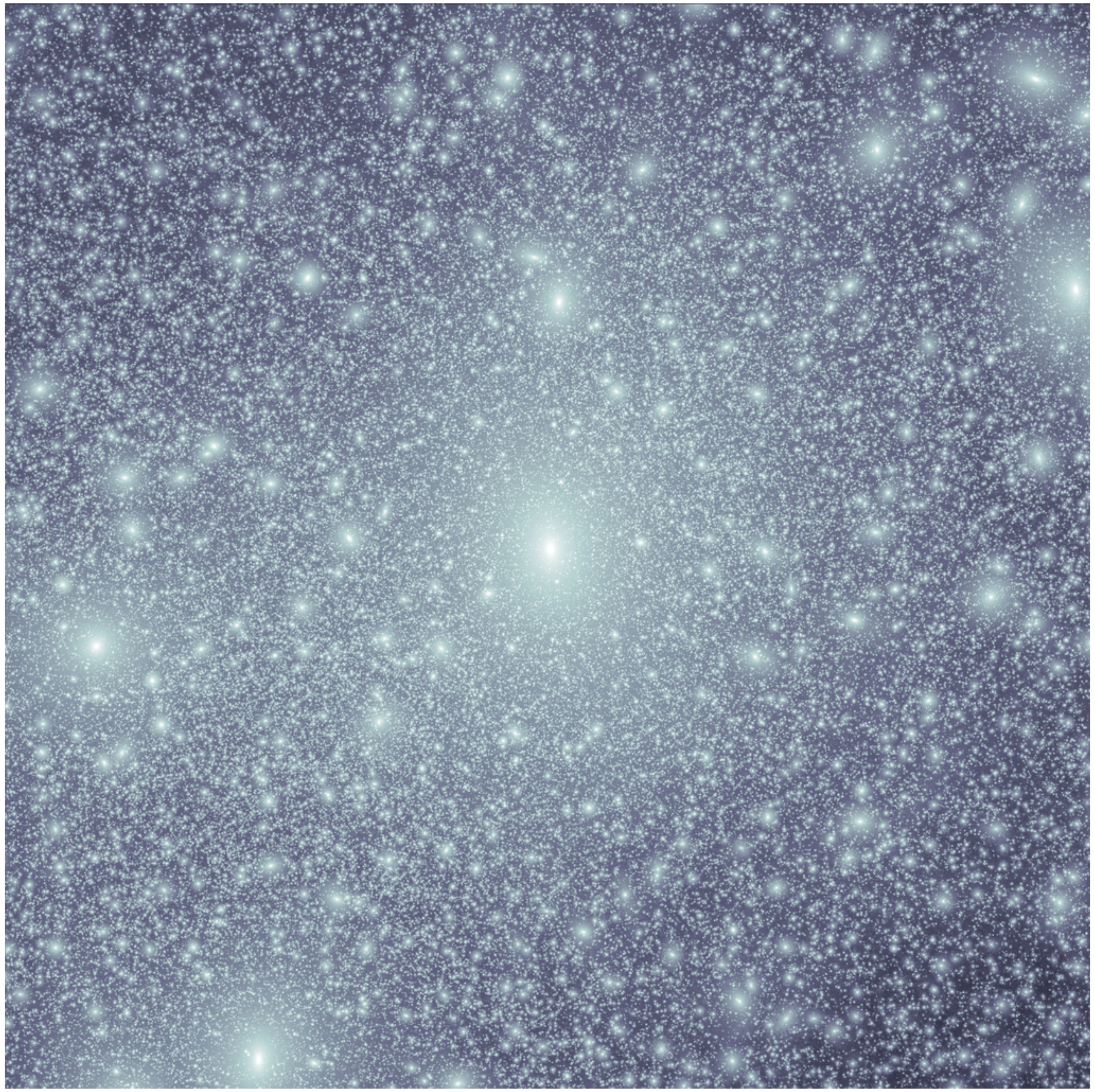
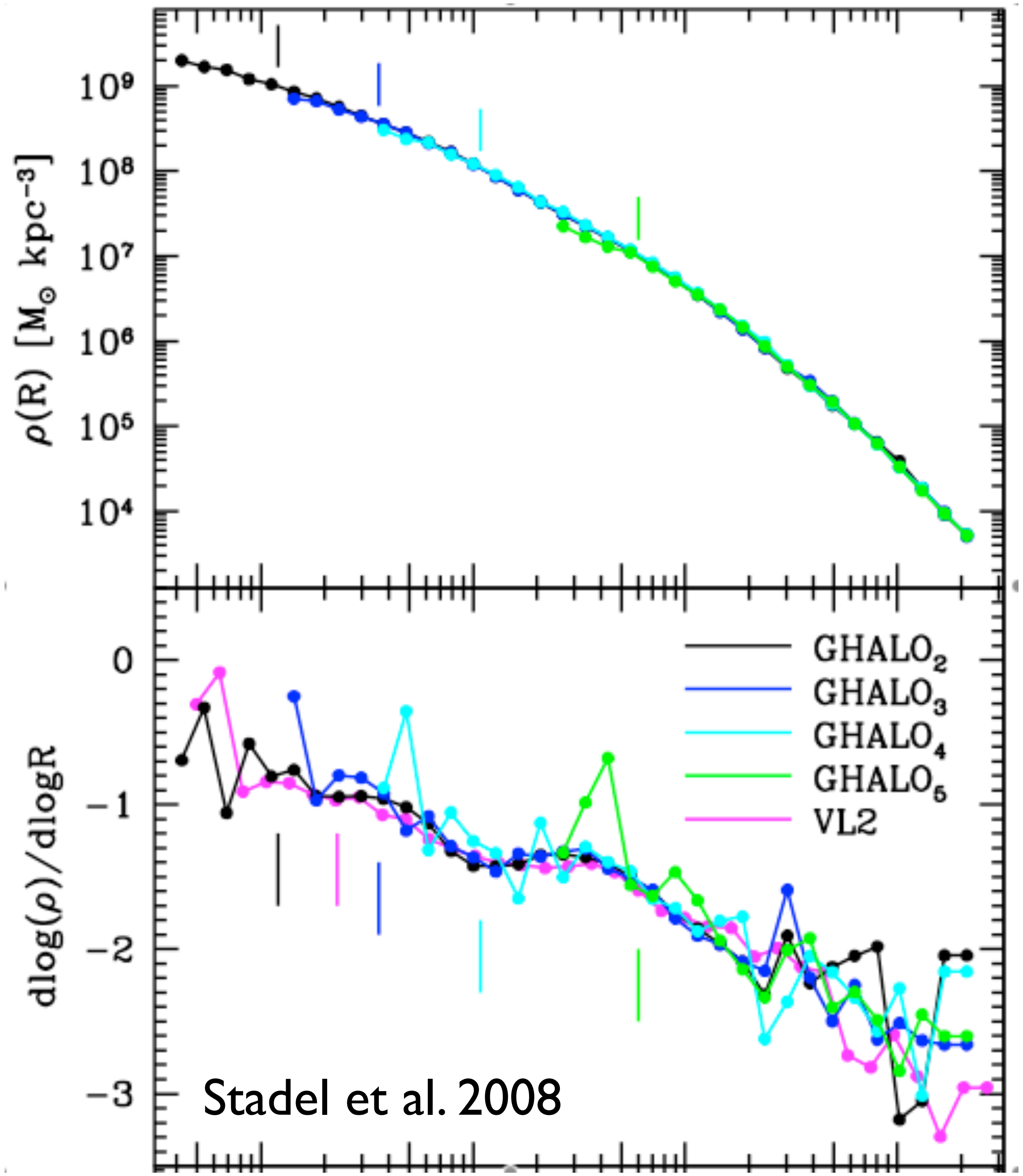
Simulated density profiles





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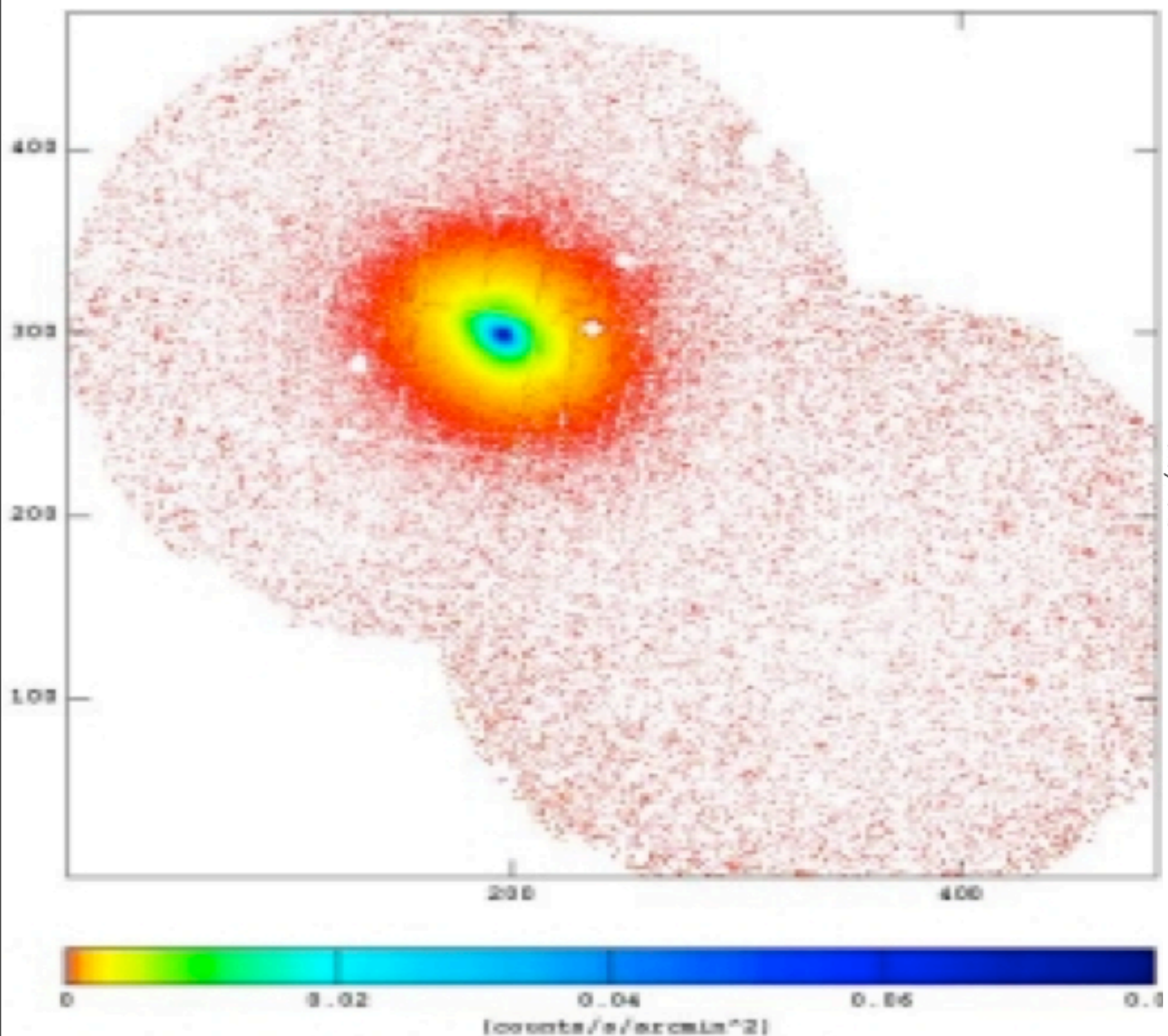
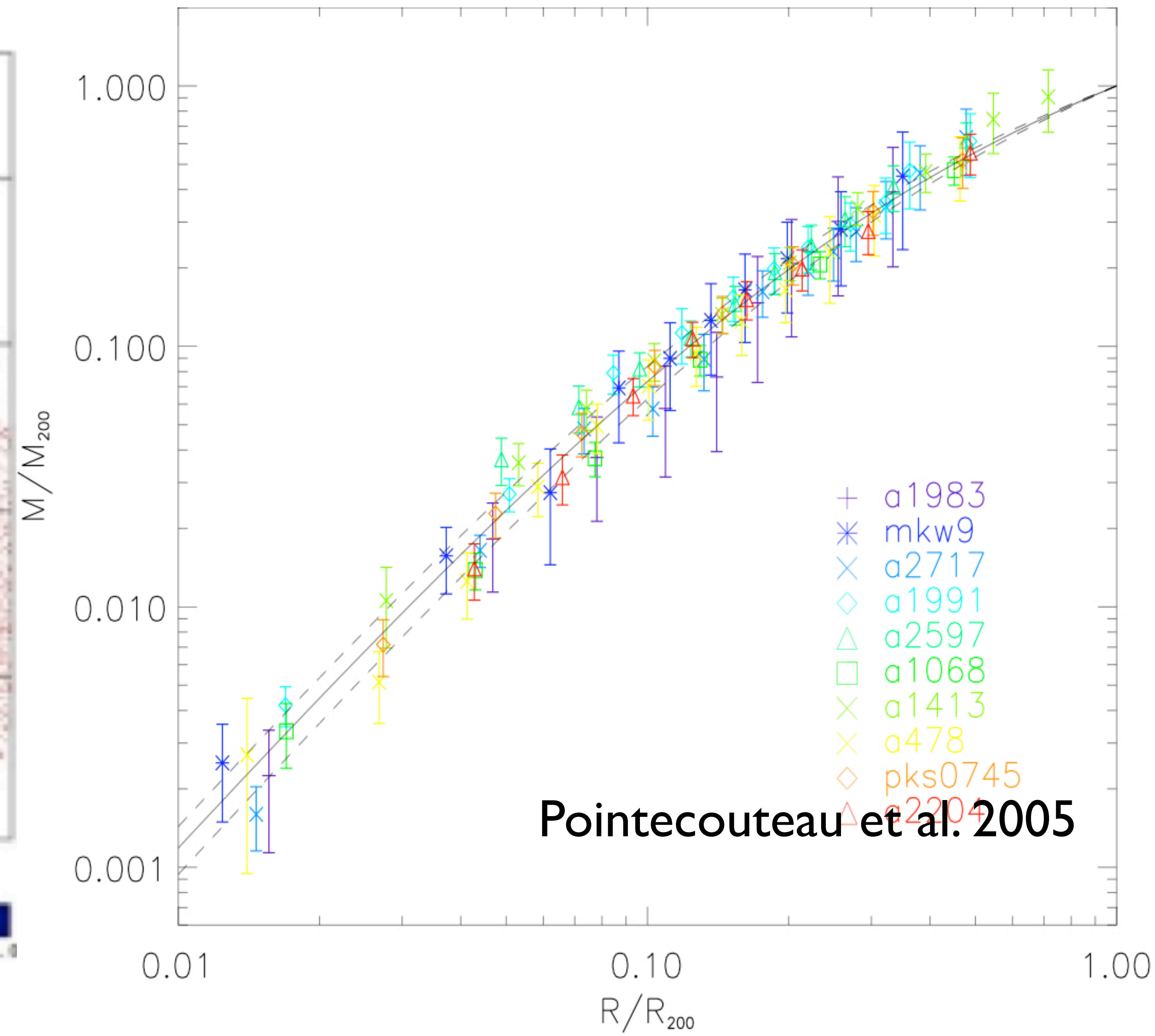
Observed density profile

X-ray observations





Pointecouteau et al. 2005

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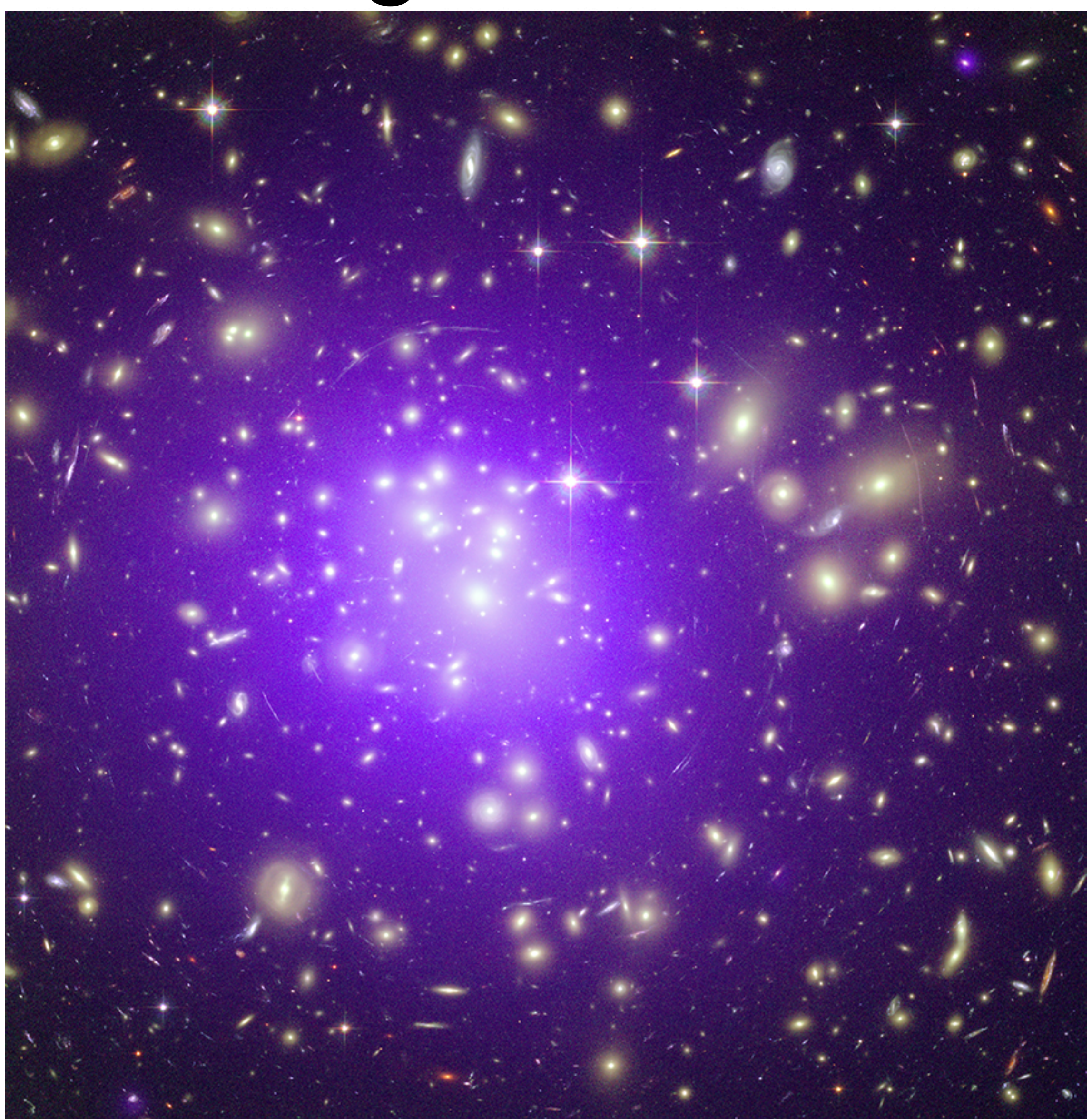
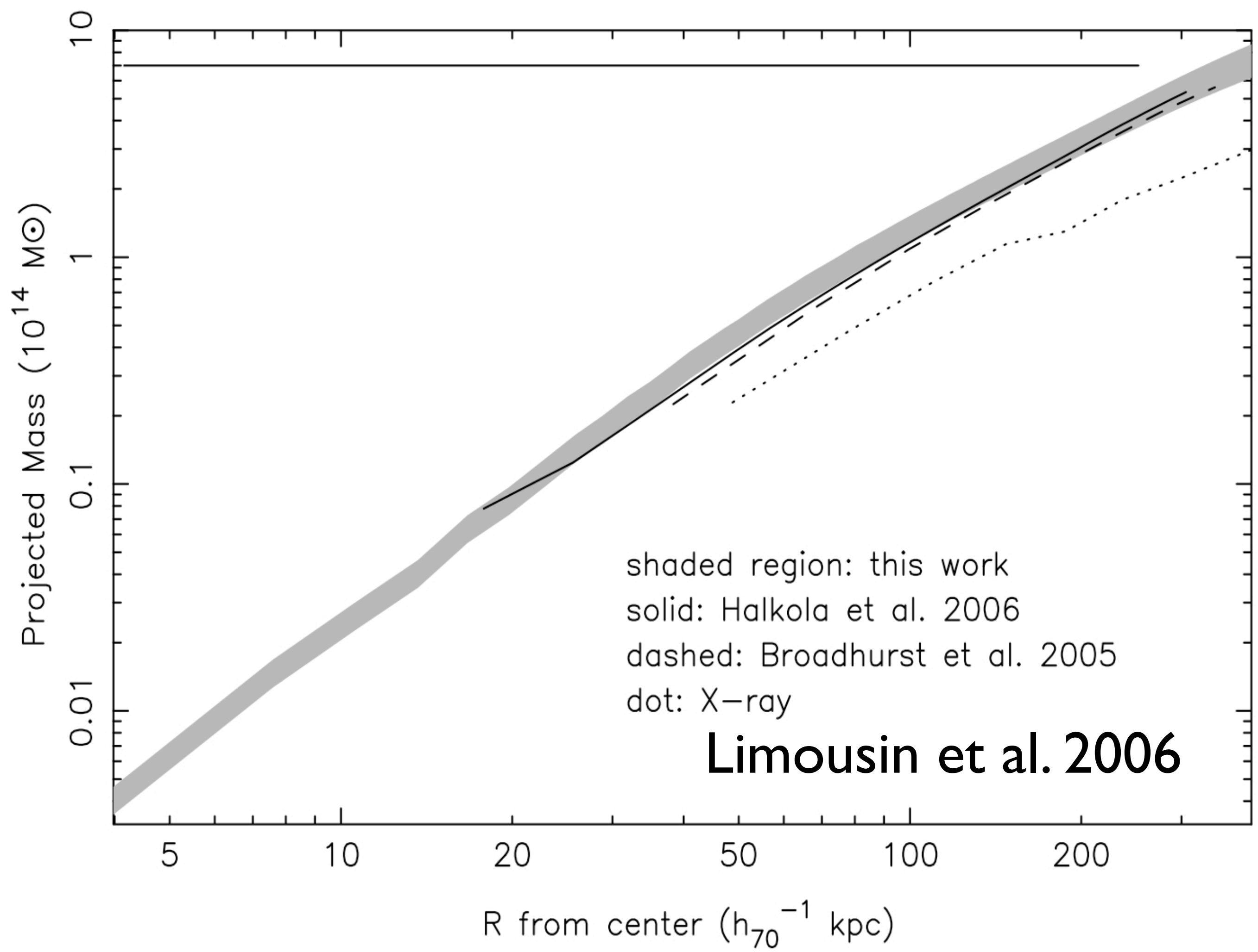
Observed density profile

Lensing observations





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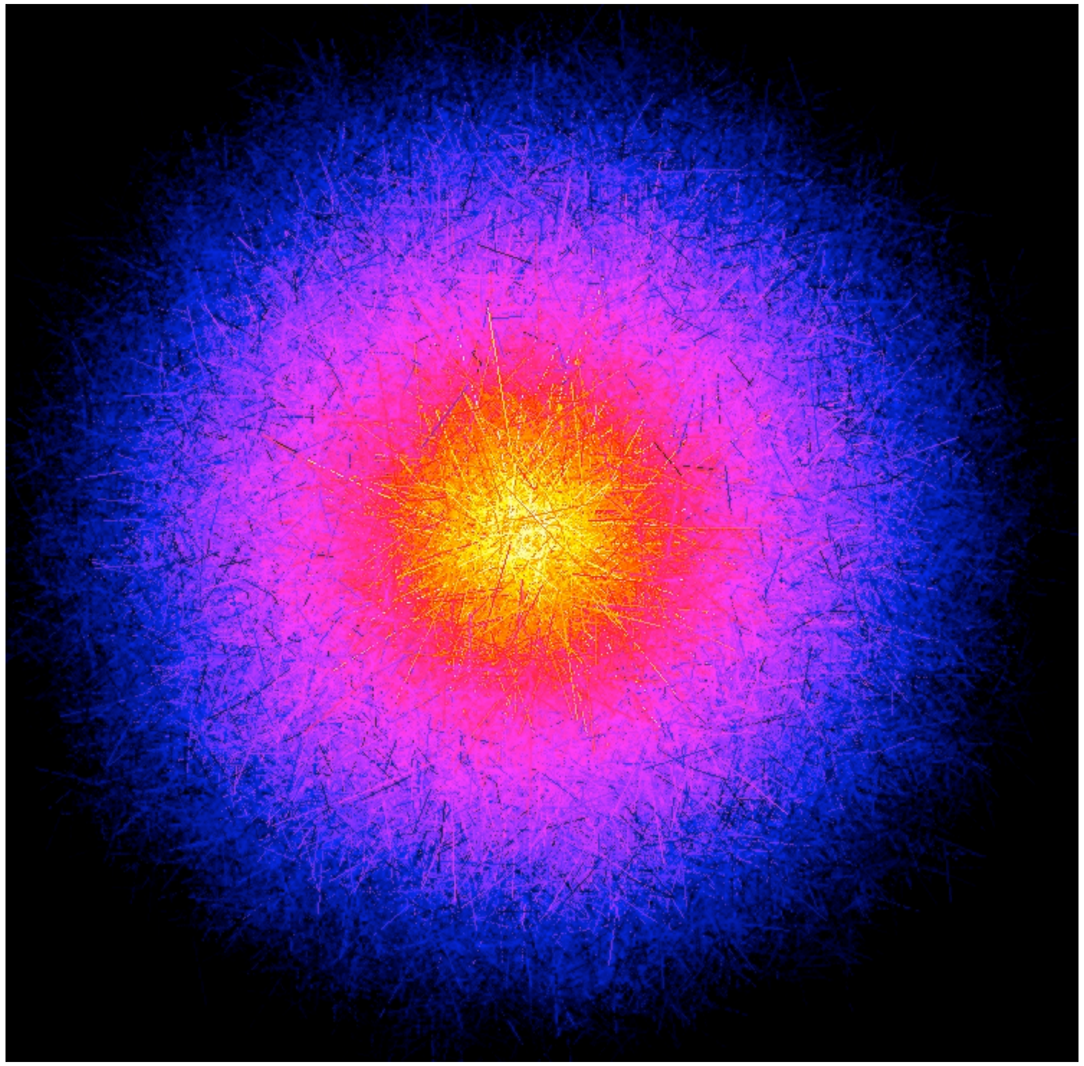
Velocity anisotropy profiles

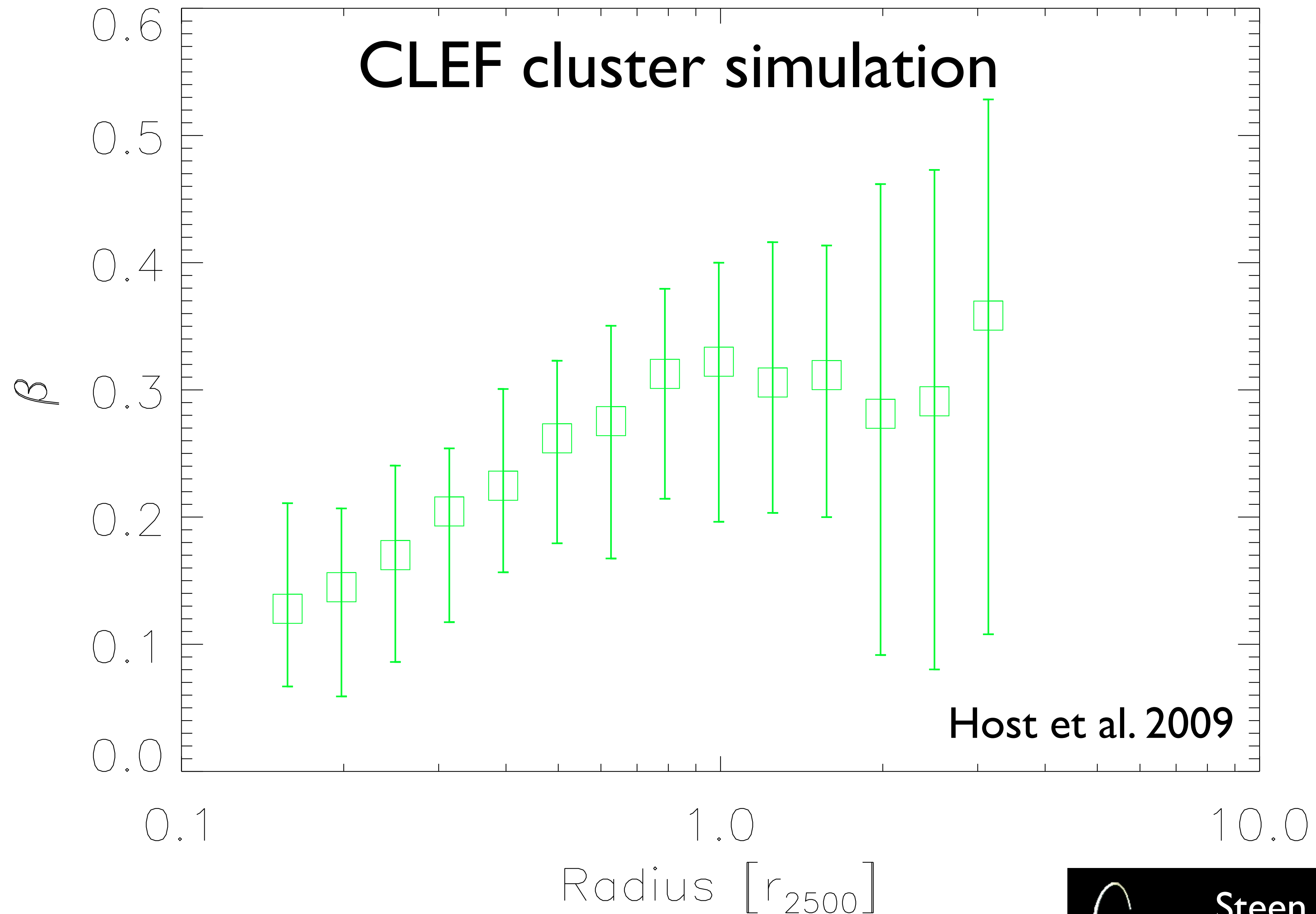
Velocity anisotropy = different "temperature" in different directions

$$\beta = 1 - \frac{\sigma_{\rm tan}^2}{\sigma_{\rm rad}^2}$$



Must be zero for a gas

Simulated velocity anisotropy



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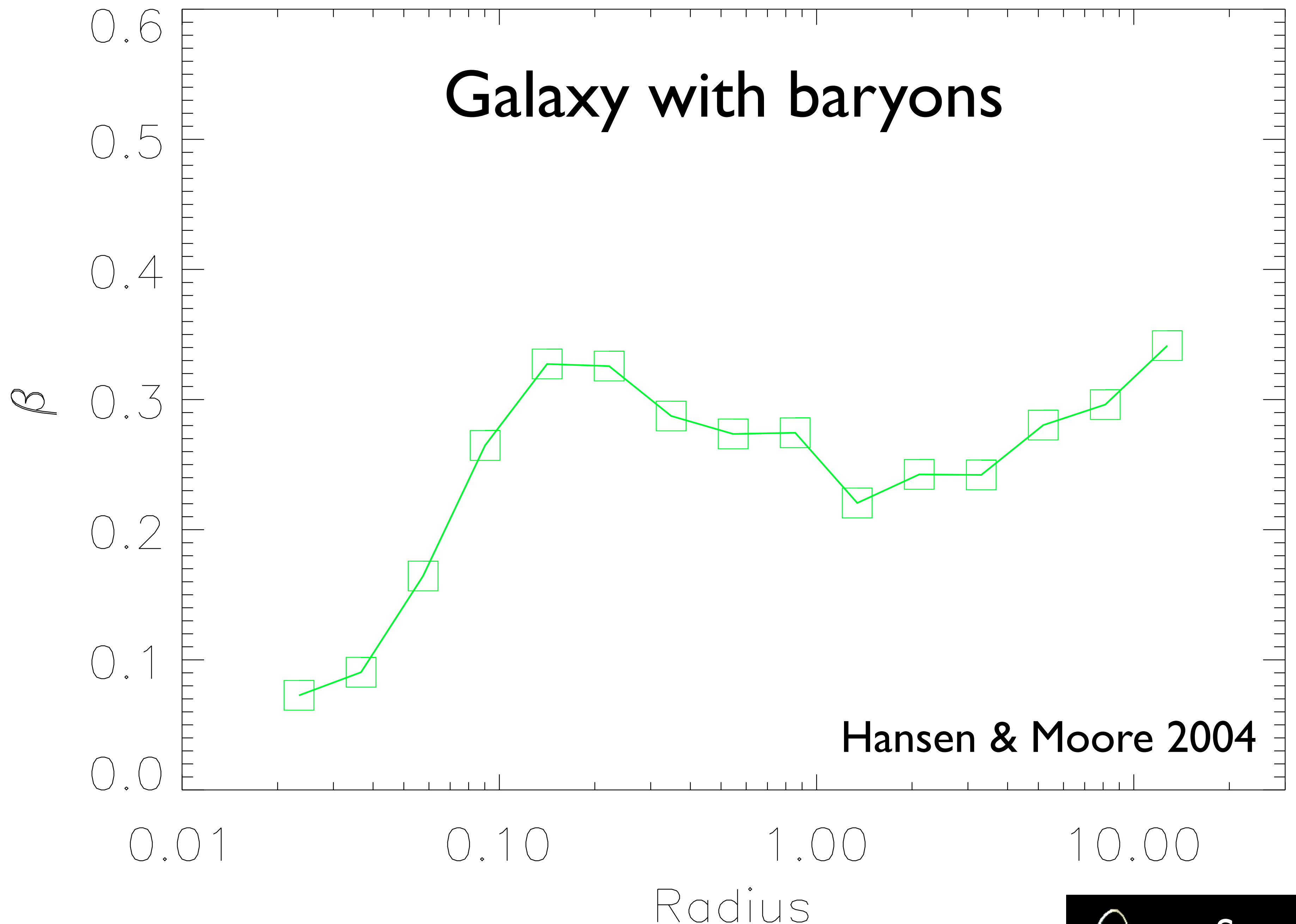
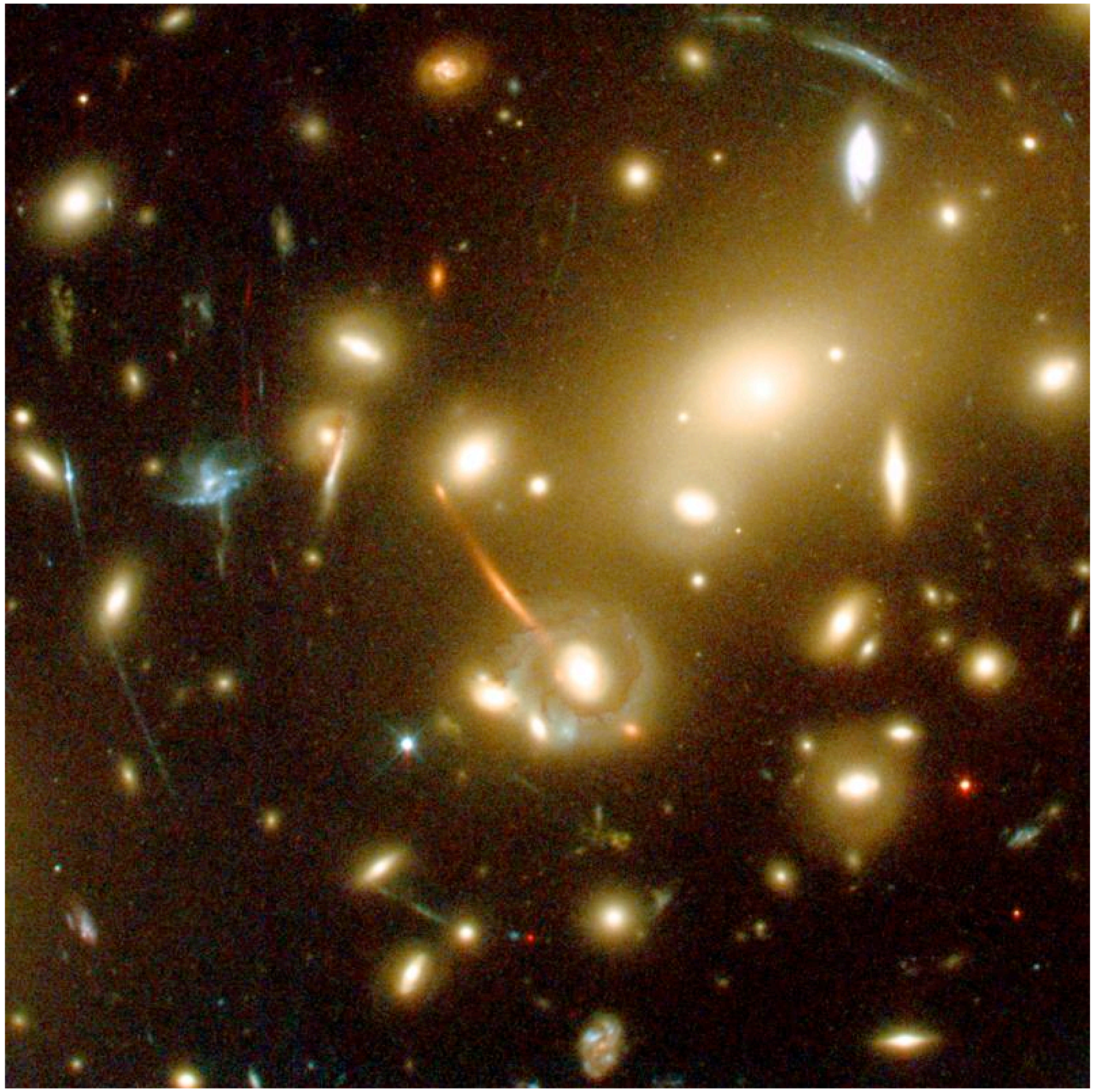
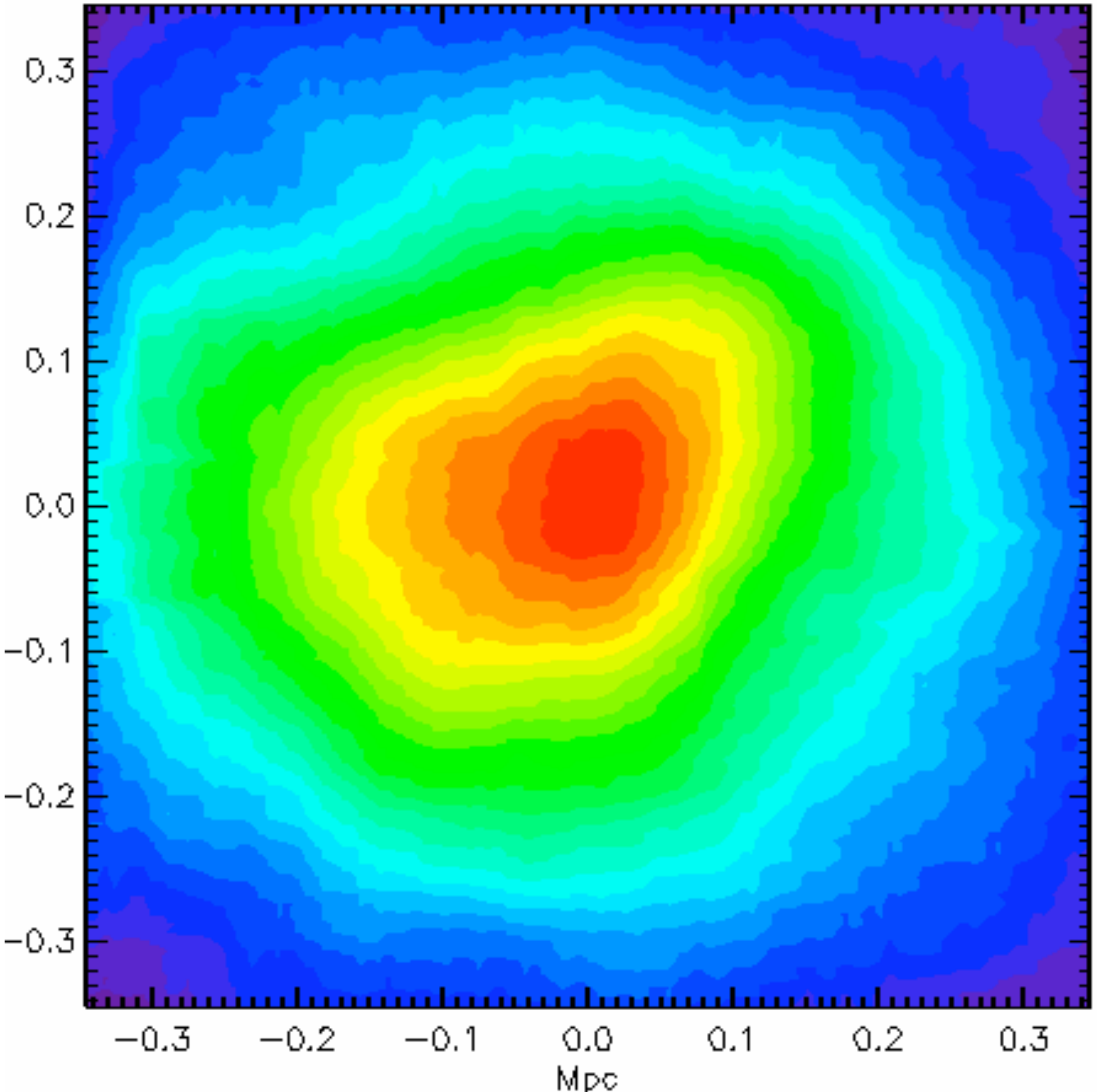
Simulated velocity anisotropy



Observed velocity anisotropy





Consider an equilibrated galaxy cluster

Observed velocity anisotropy

Hydrostatic equilibrium (gas)

$$\frac{GM_{\mathrm{tot}}}{r} = -\frac{k_B T}{\mu m_p}\left(\frac{d\ln T}{d\ln r} + \frac{d\ln n_e}{d\ln r}\right)$$

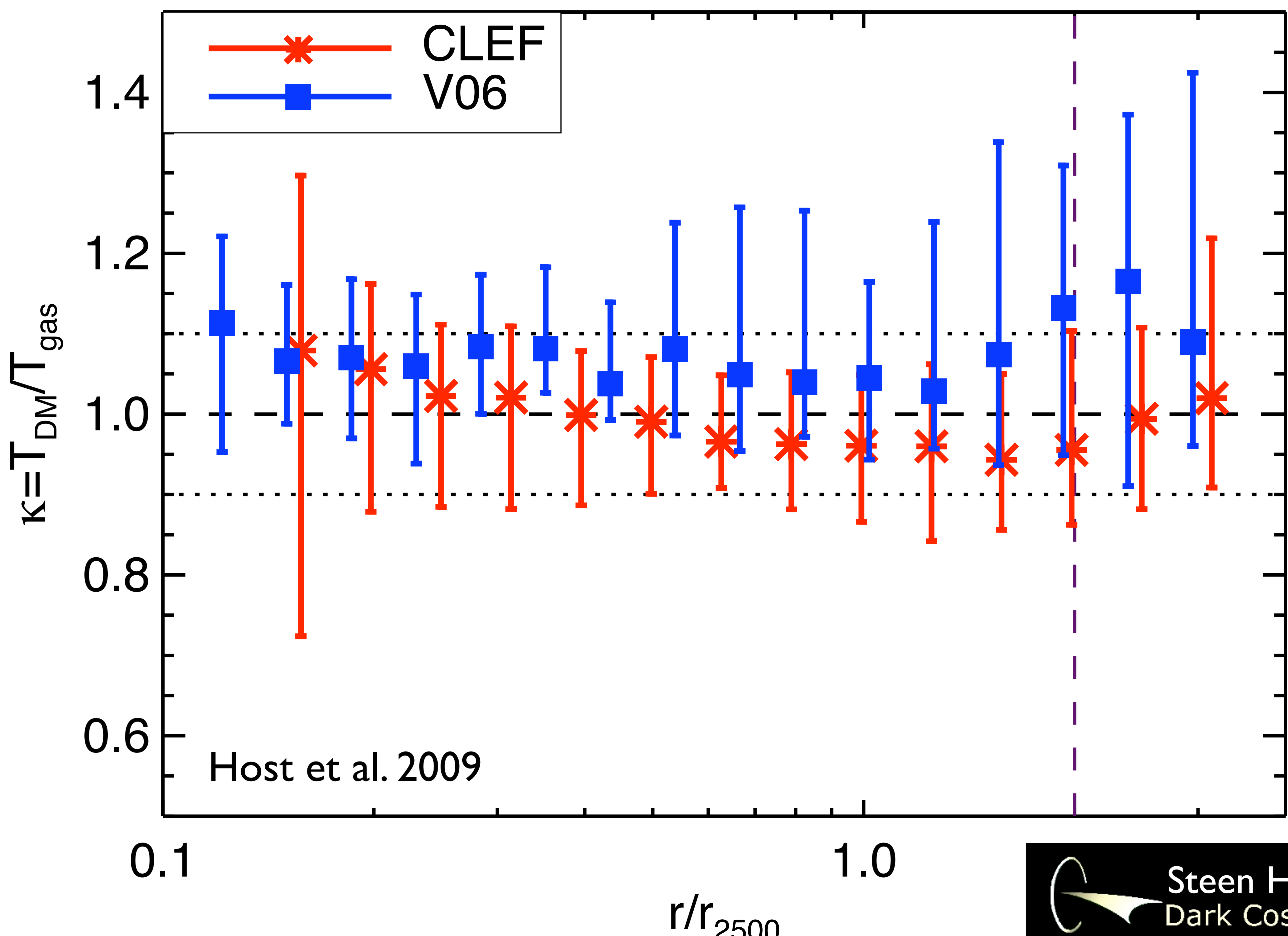
Jeans equation (dark matter)

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

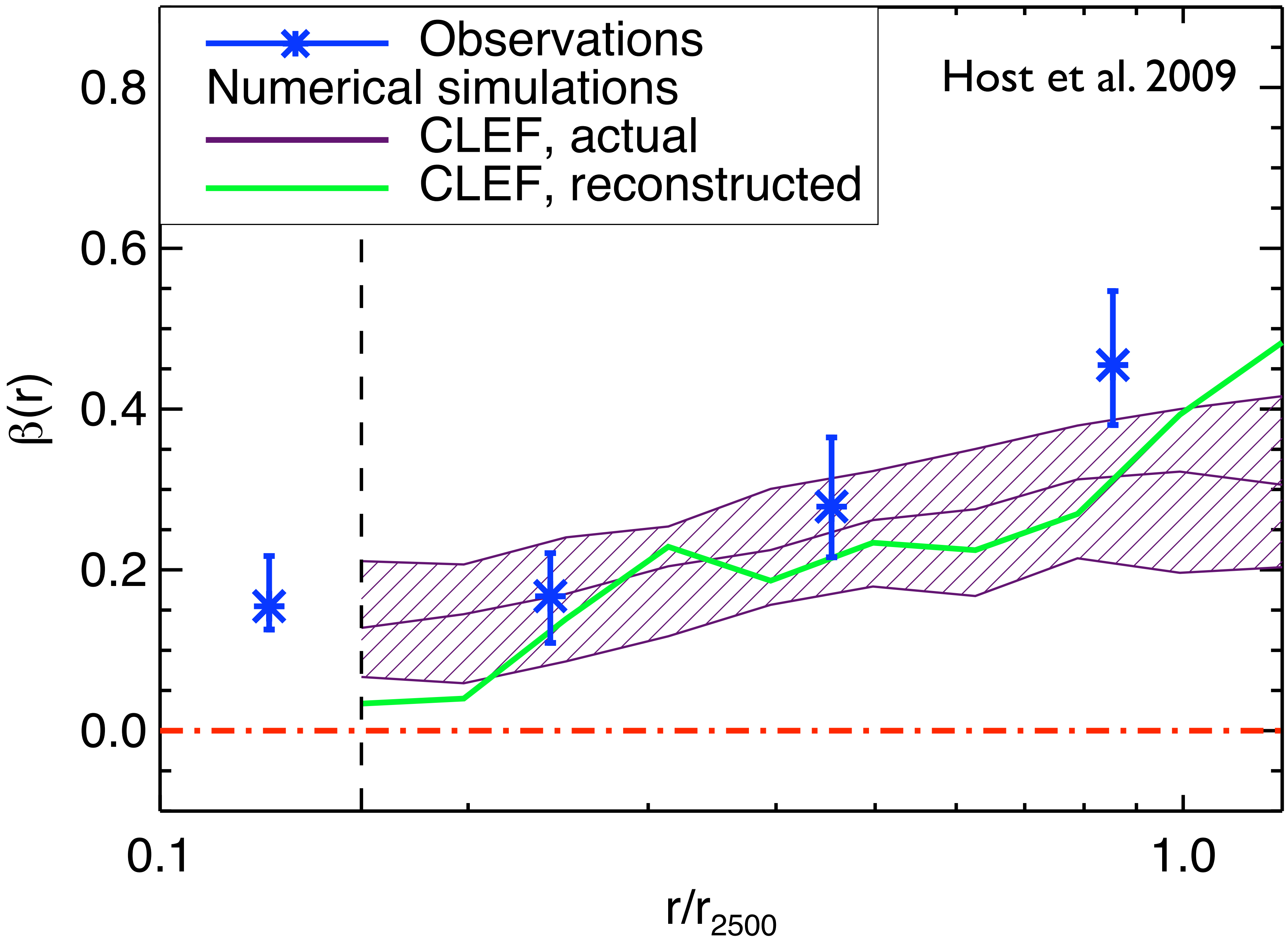
If $\frac{T}{\sigma_{\mathrm{tot}}^2} \approx 1$, then we can solve for β

Hansen & Piffaretti 2007

Observed velocity anisotropy



Observed velocity anisotropy



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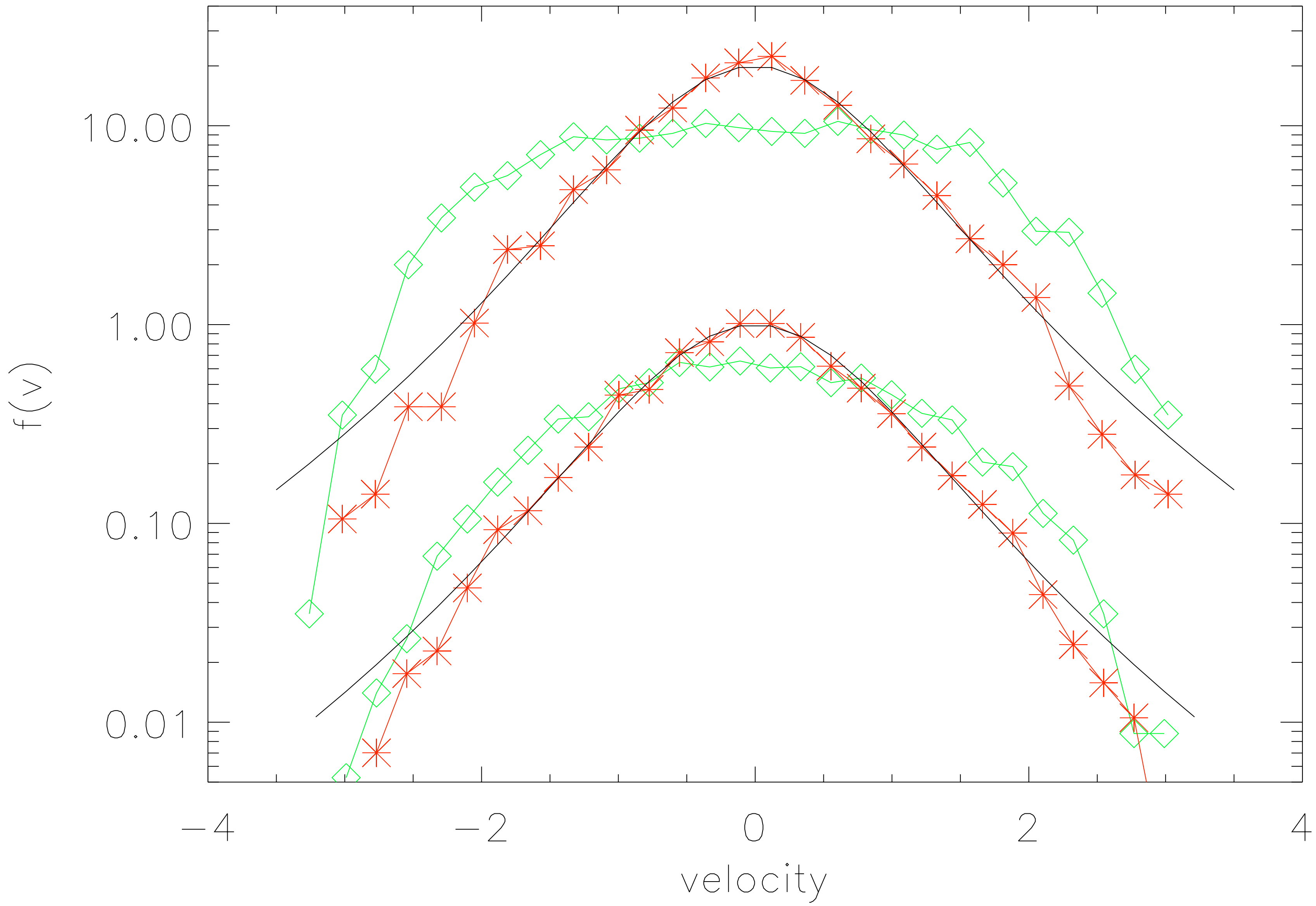
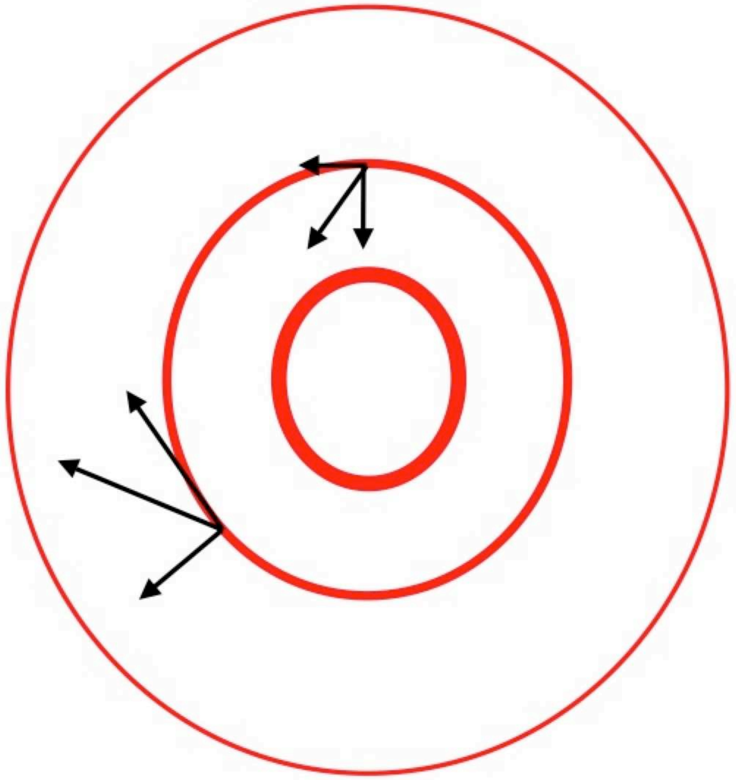
Theoretical velocity anisotropy

If we understand the velocity distribution function - which is exp(-v^2/T) for a gas - then we also understand the integrated things like density, velocity dispersions, velocity anisotropy, ...





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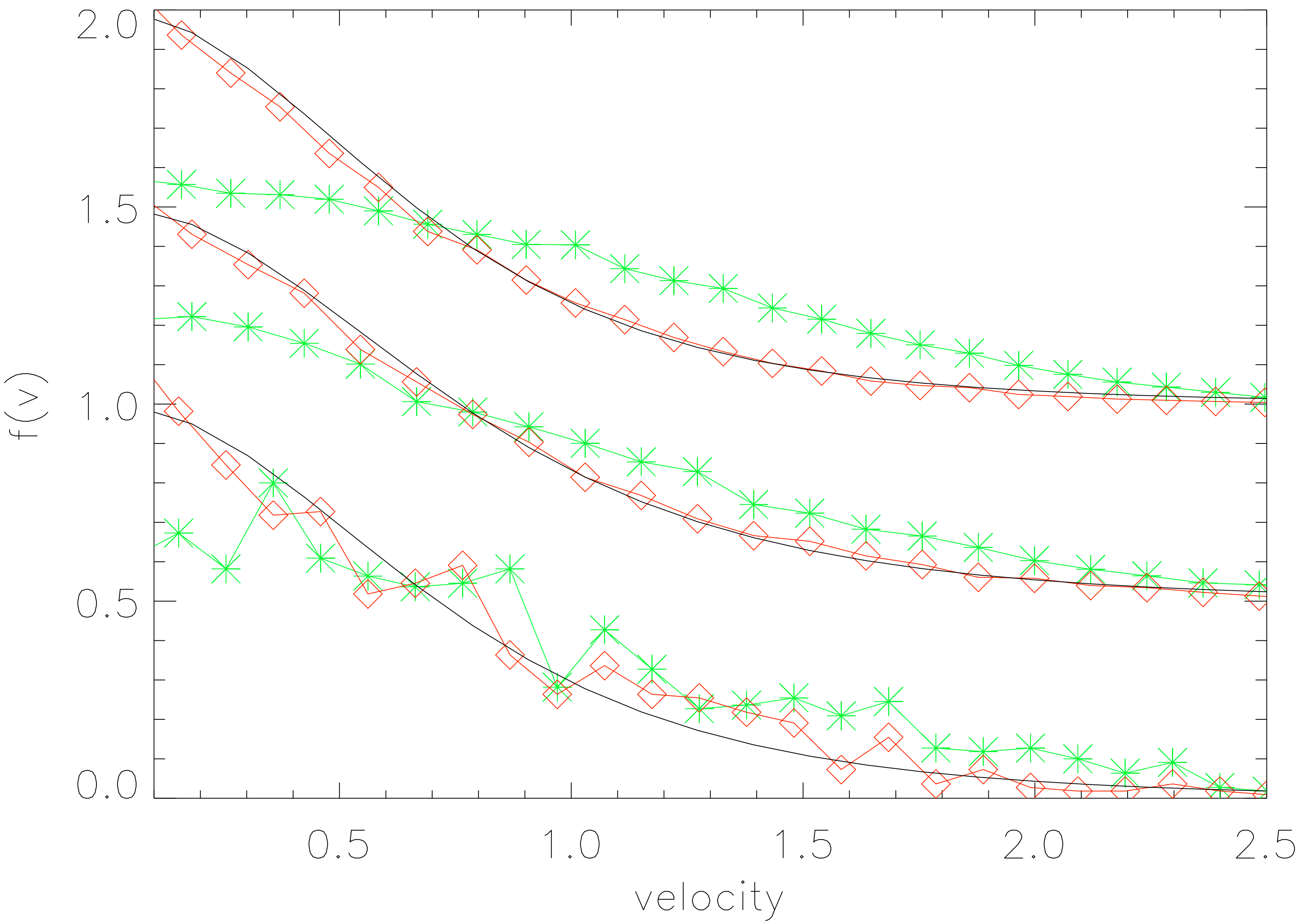
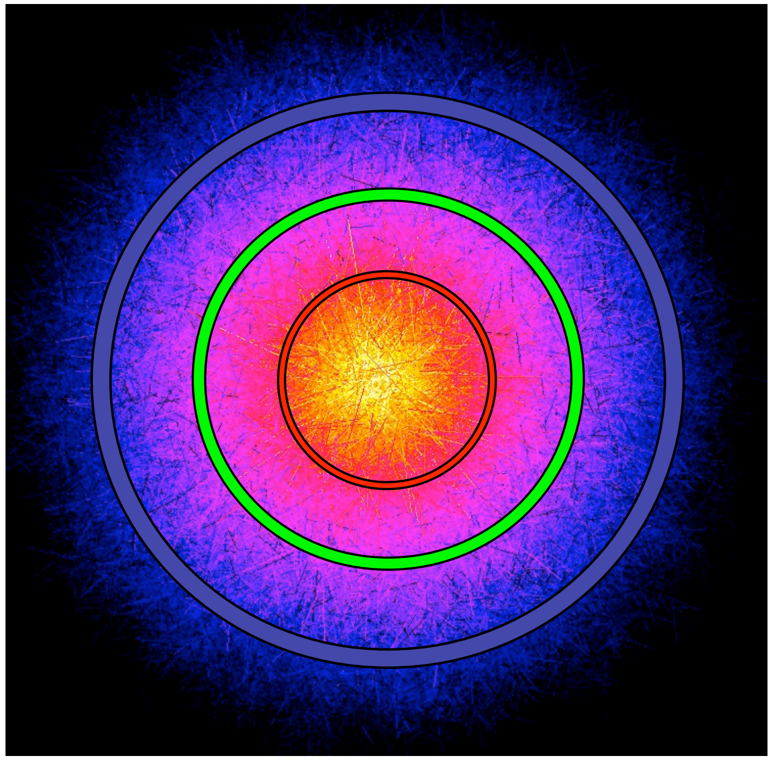
We (almost) know the tangential distribution function





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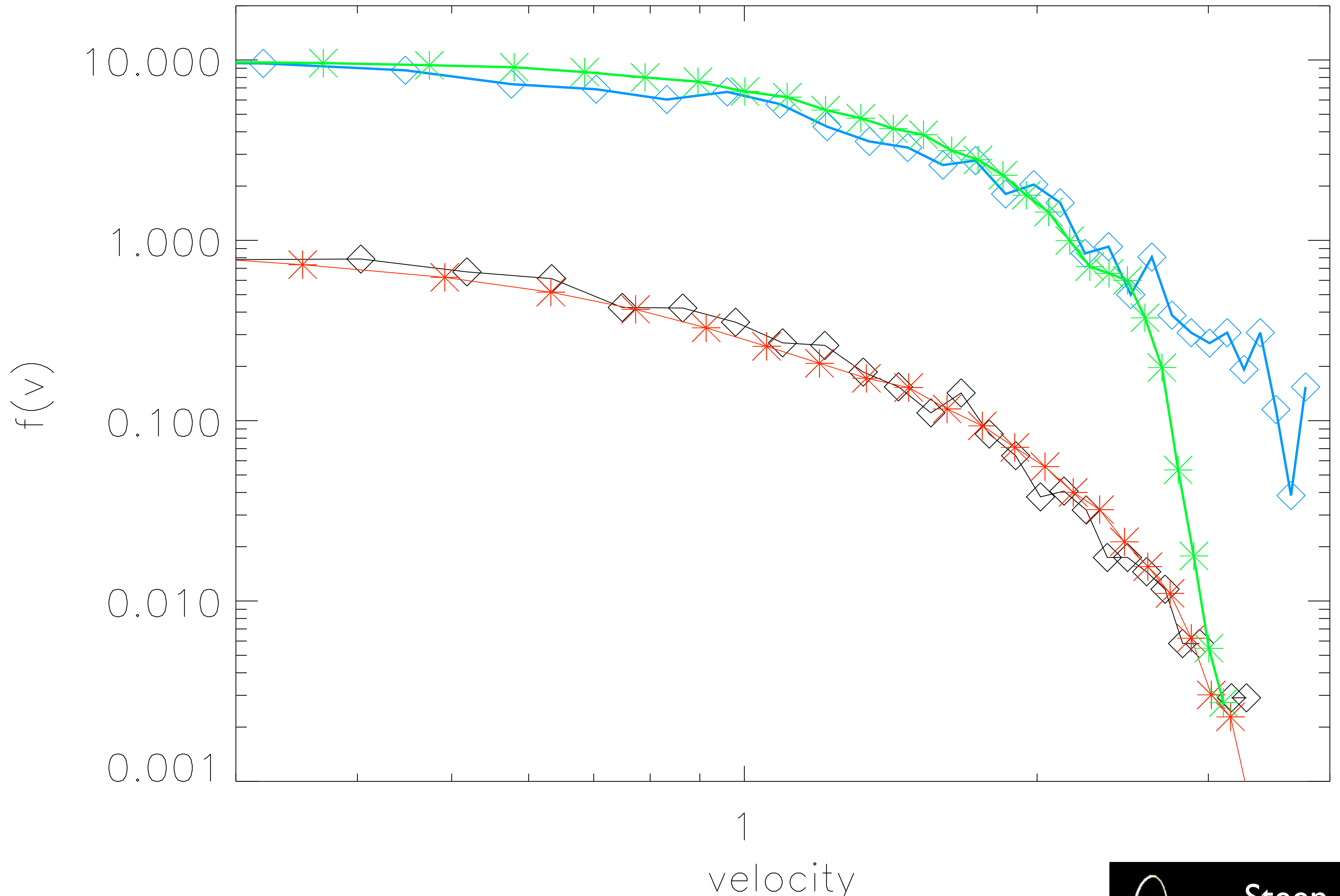
We (almost) know the radial distribution function



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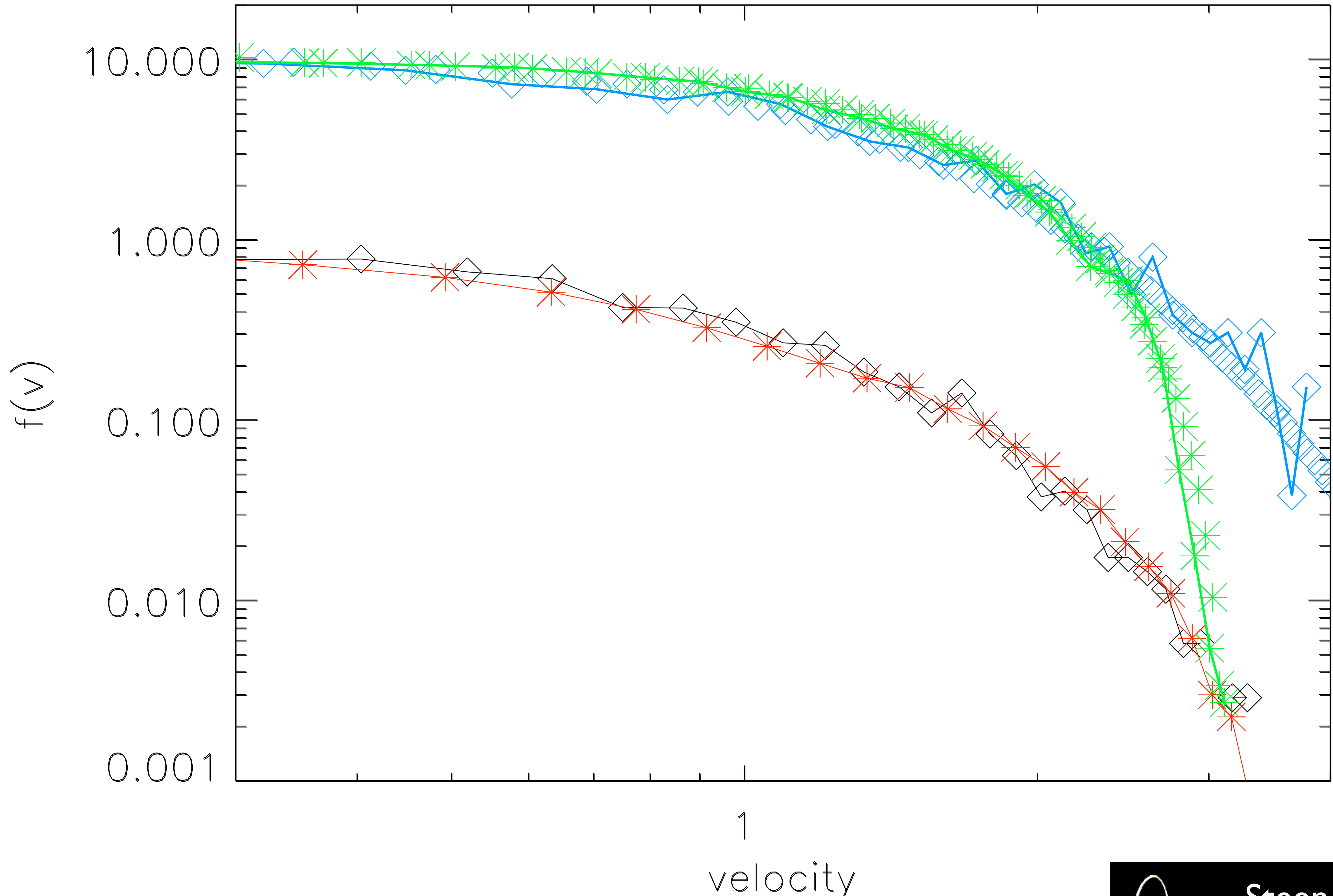
We (almost) know the radial distribution function



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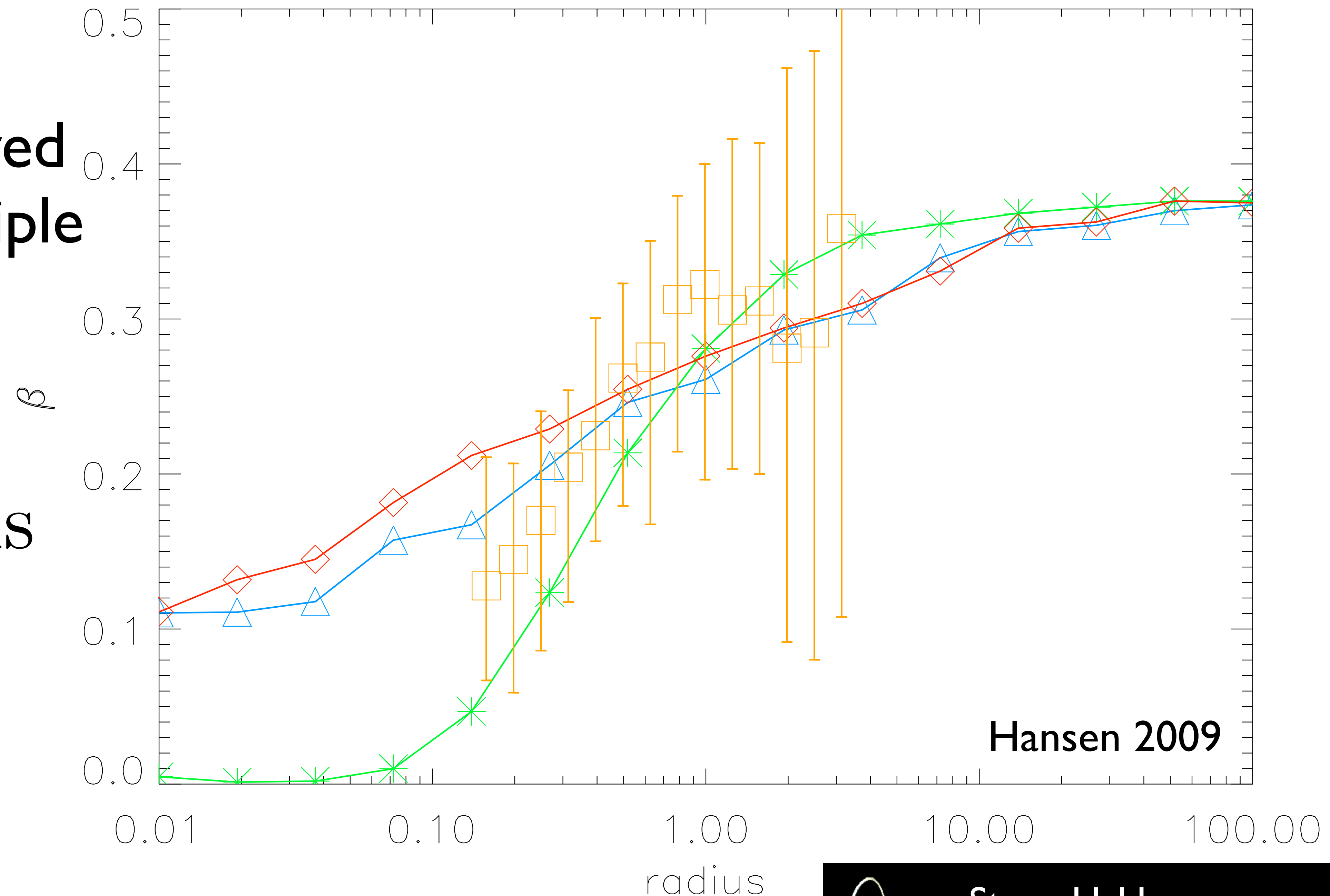
Theoretical velocity anisotropy

Analytically derived from “first” principle

$\beta(r)$ depends only on $\rho(r)$



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Conclusions

Velocity anisotropy

1) Numerical **simulations** show radial variation from about 0 (inner) to about 0.5 (outer)

2) First ever **observations** of this dynamical aspect confirm the predicted behavior

3) The **analytically** derived velocity anisotropy confirms the magnitude and radial variation

4) If this derivation is correct, then the velocity anisotropy is a function only of the density profile. This implies that we can close the Jeans equation

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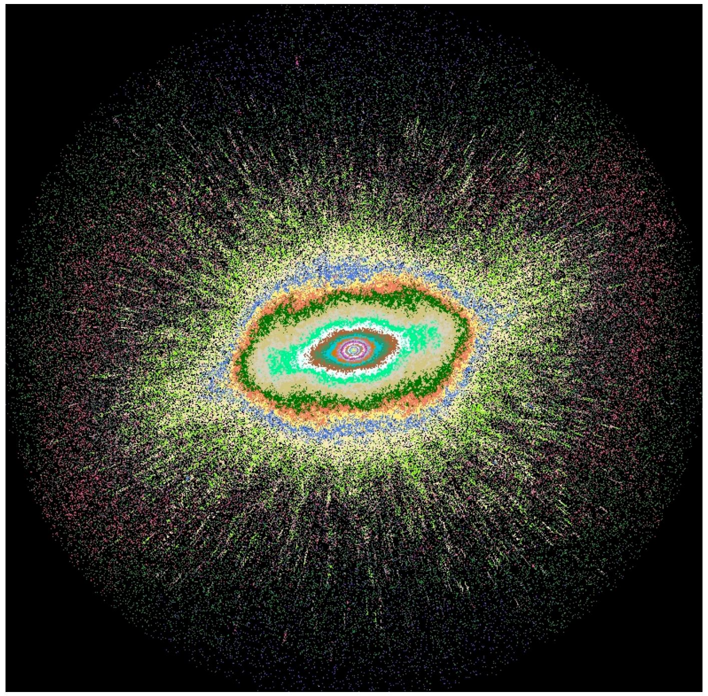
Conclusions - final

We have impressive agreement between numerical simulations, observations and theory concerning the large dark matter structures



Thank you

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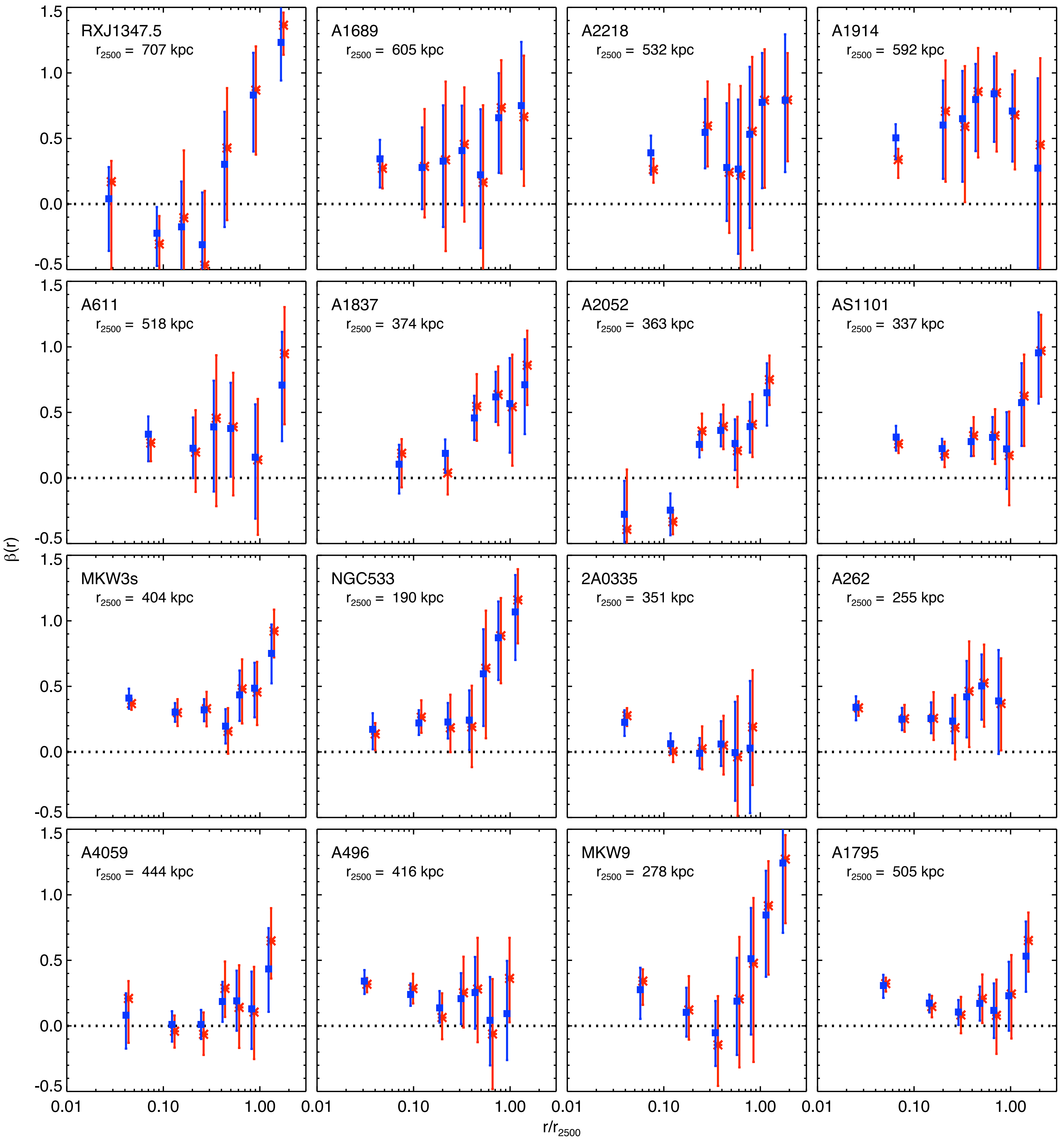
Extra slides



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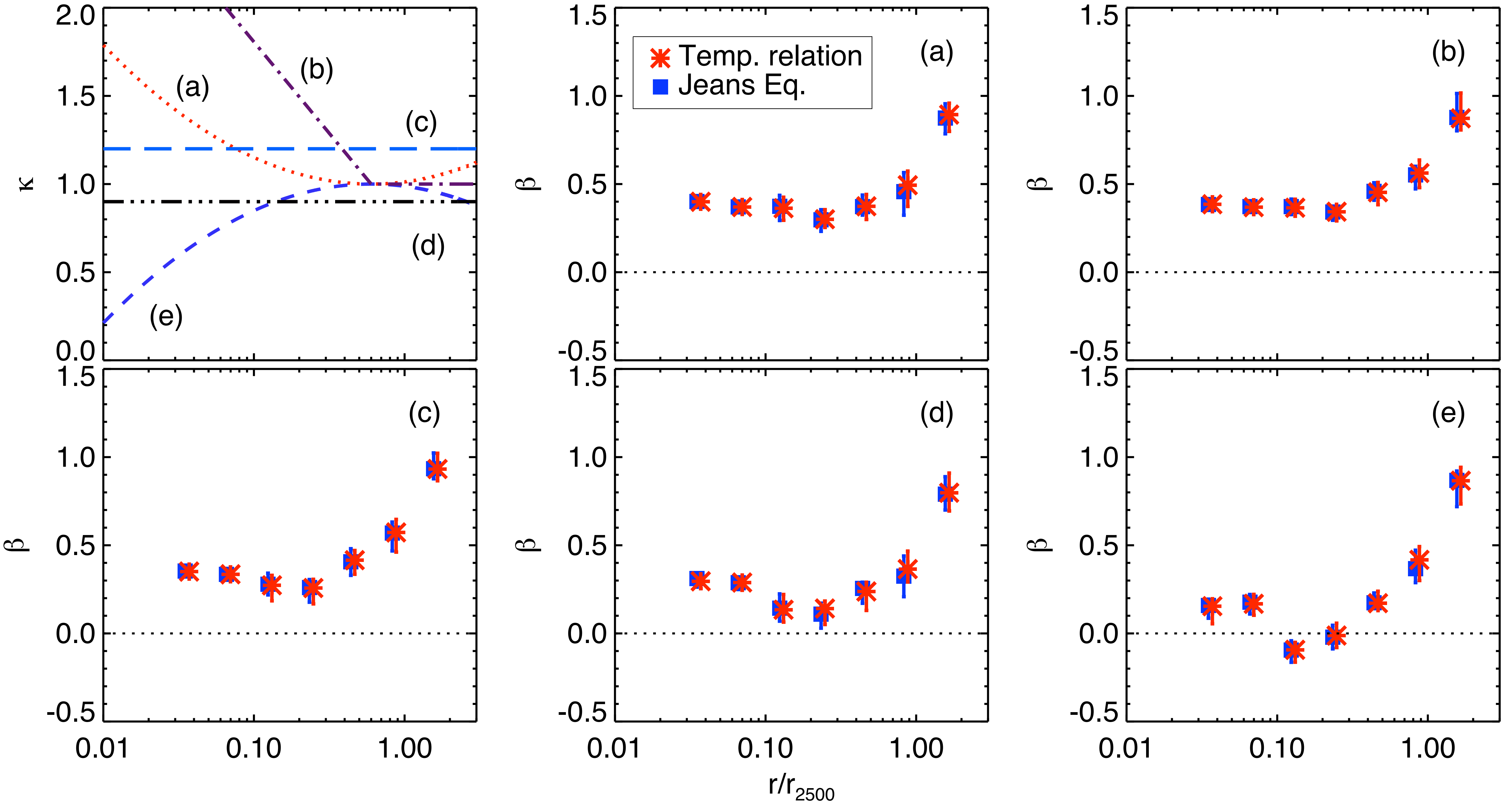

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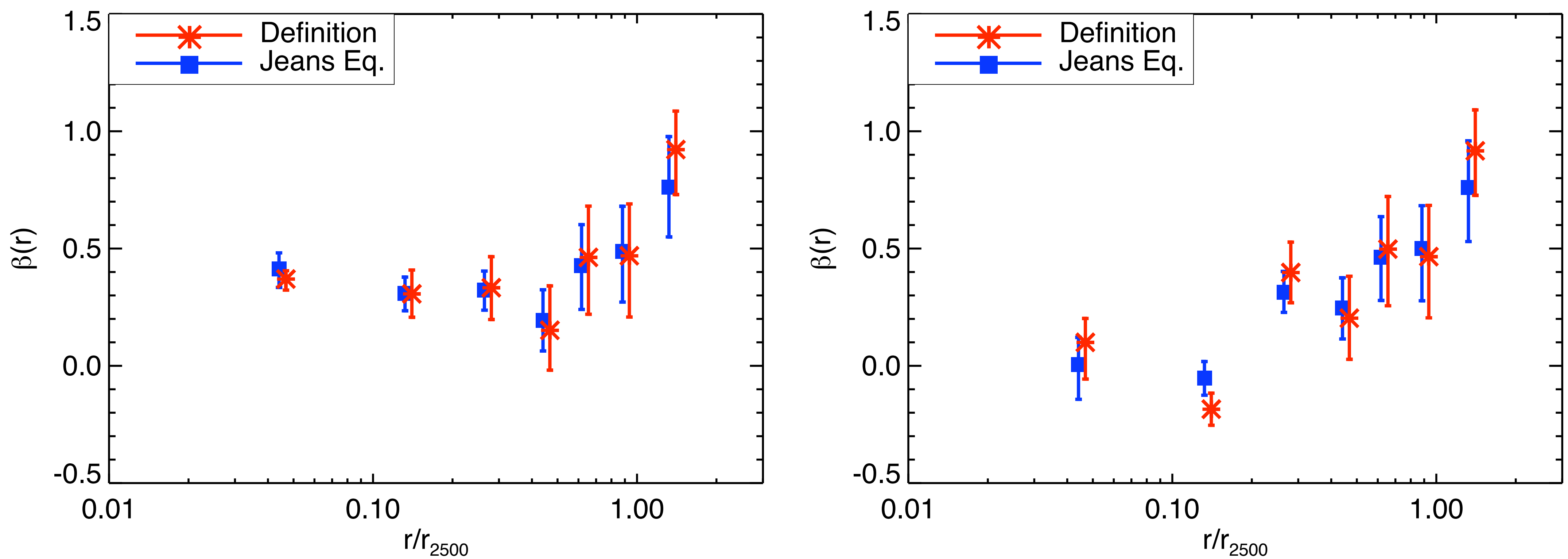
Stellar density profile?



MKW3s - r_{2500} = 404 kpc

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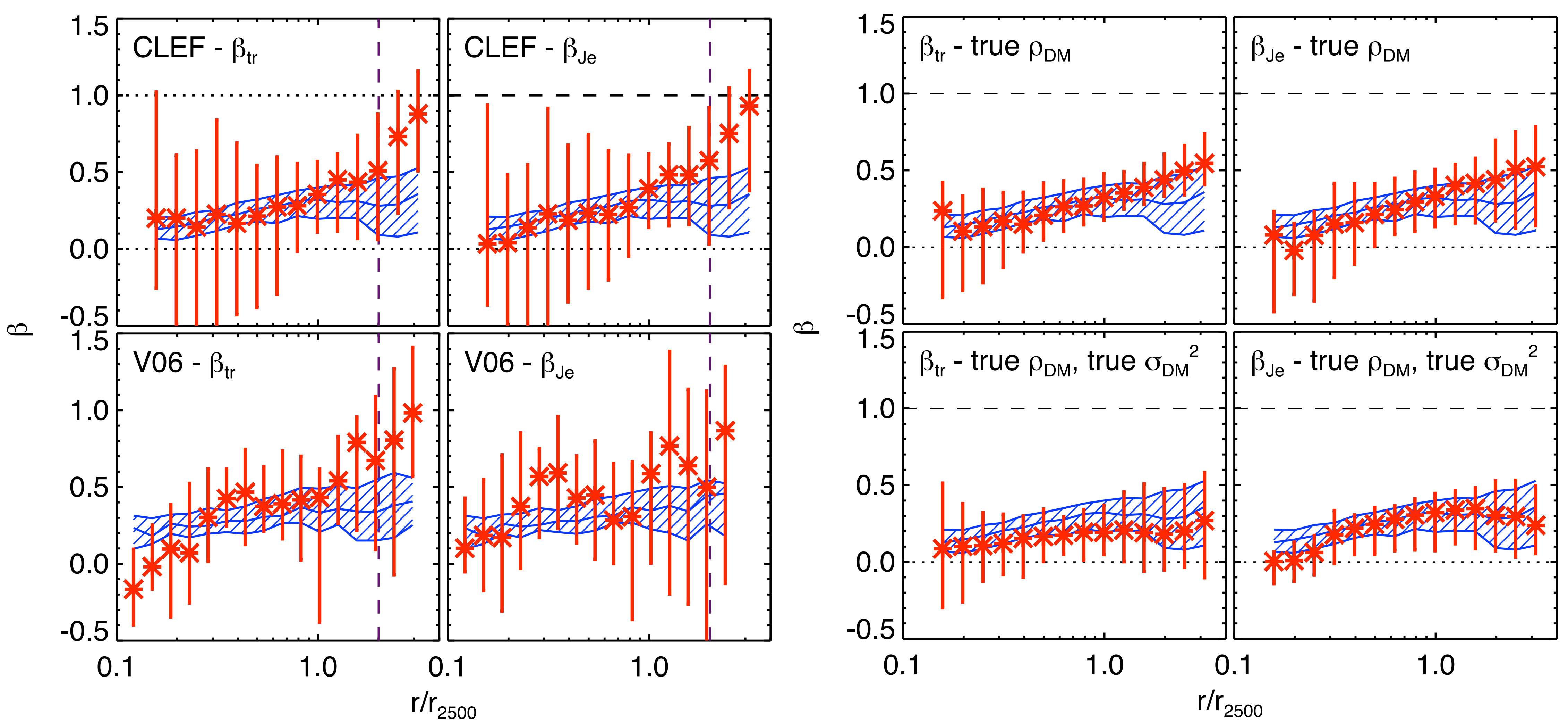
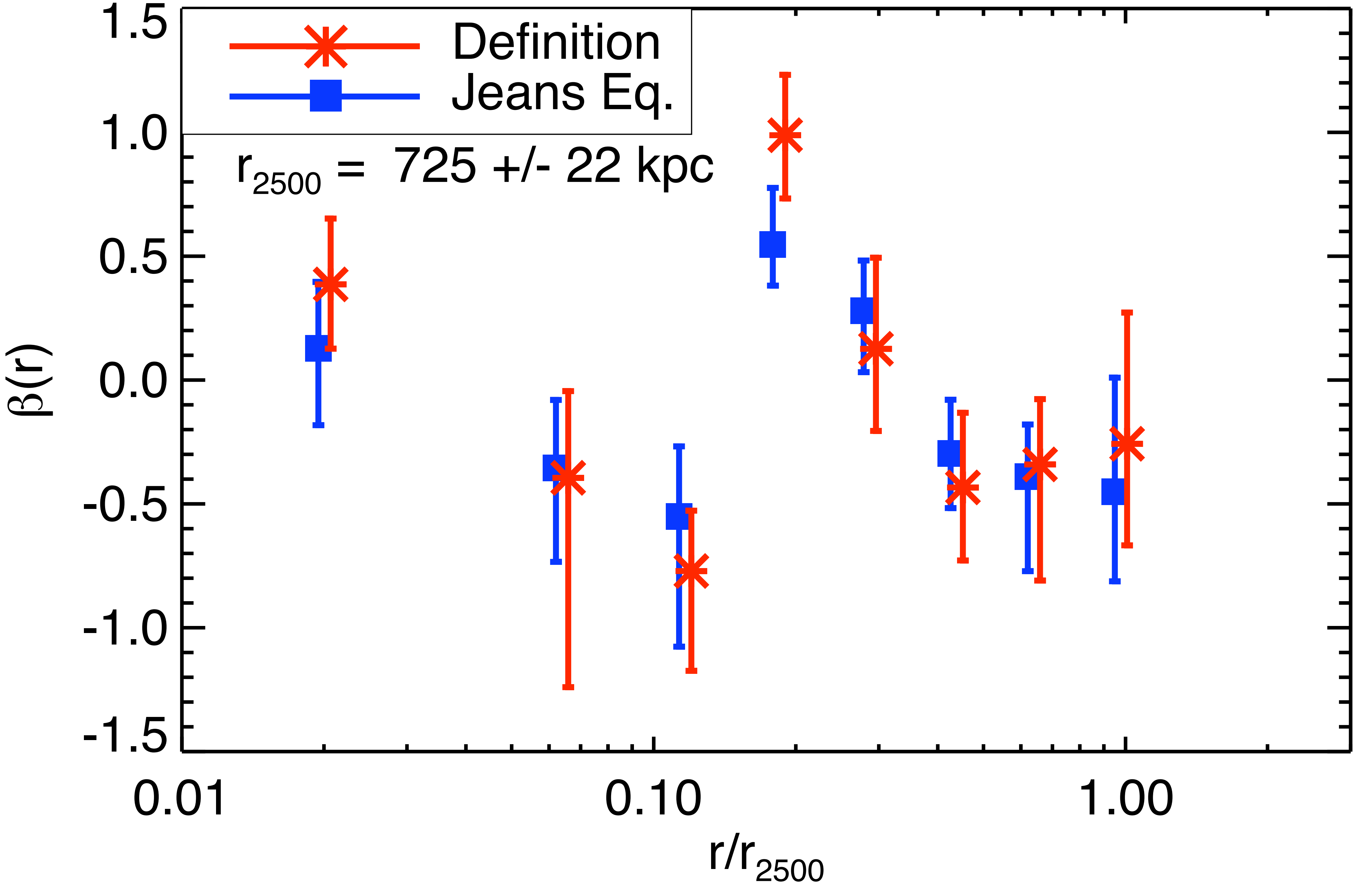
Testing in numerical simulations





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