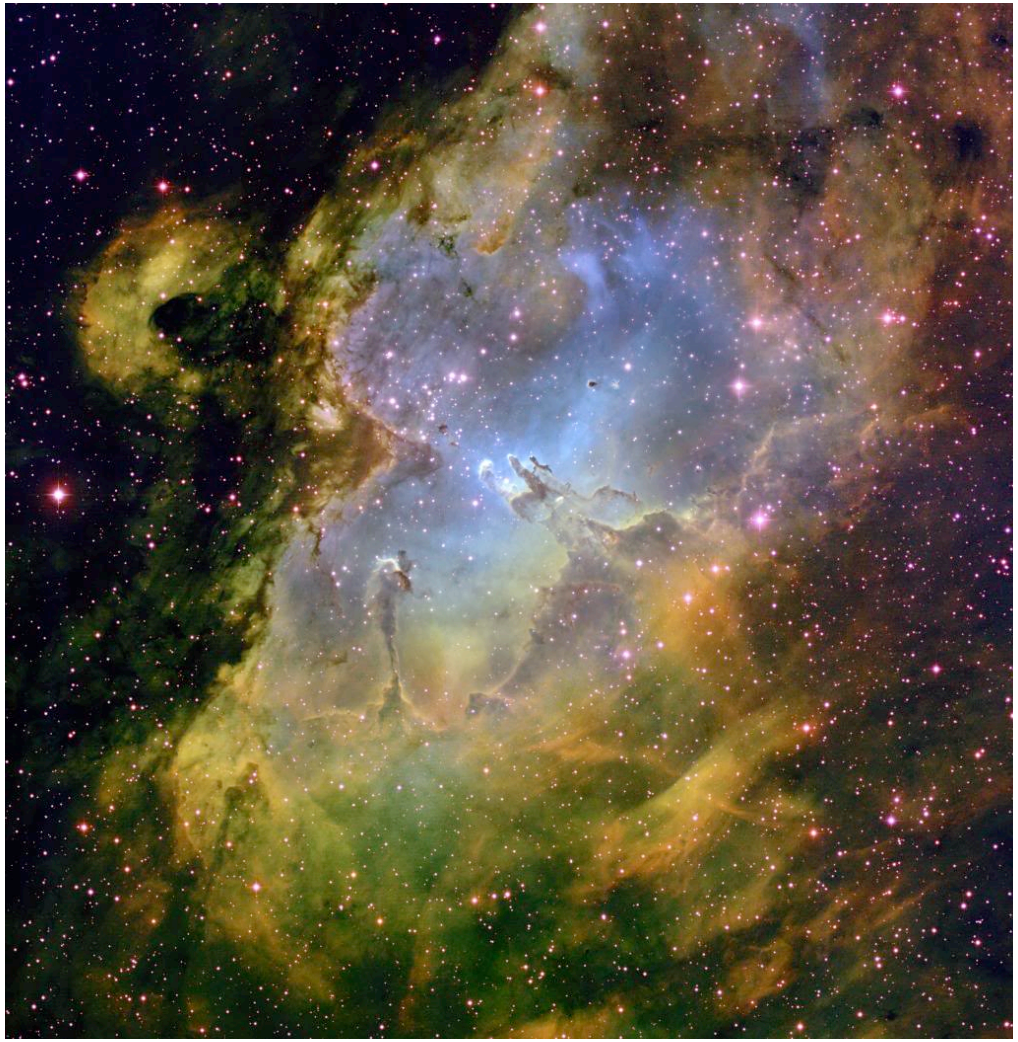
The dark matter attractor: origin and implications



Steen H. Hansen,
Dark Cosmology Centre,
Niels Bohr Institute,

Ascona

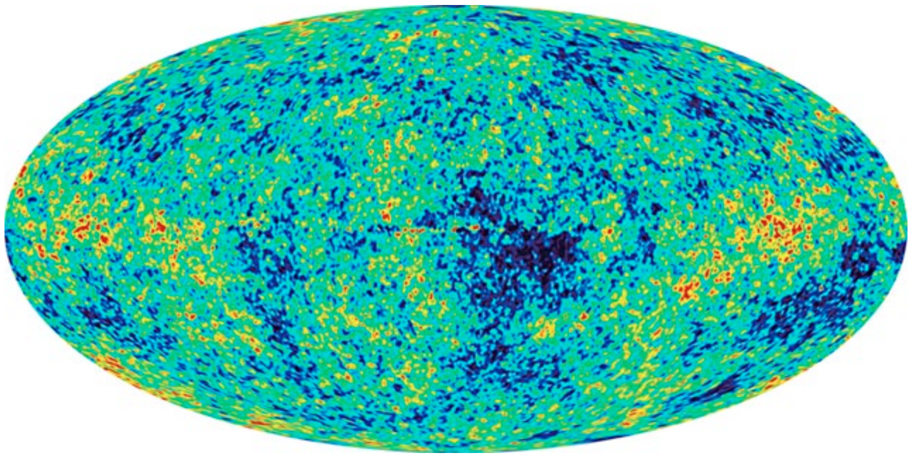
July, 2012

Dark Cosmology Centre

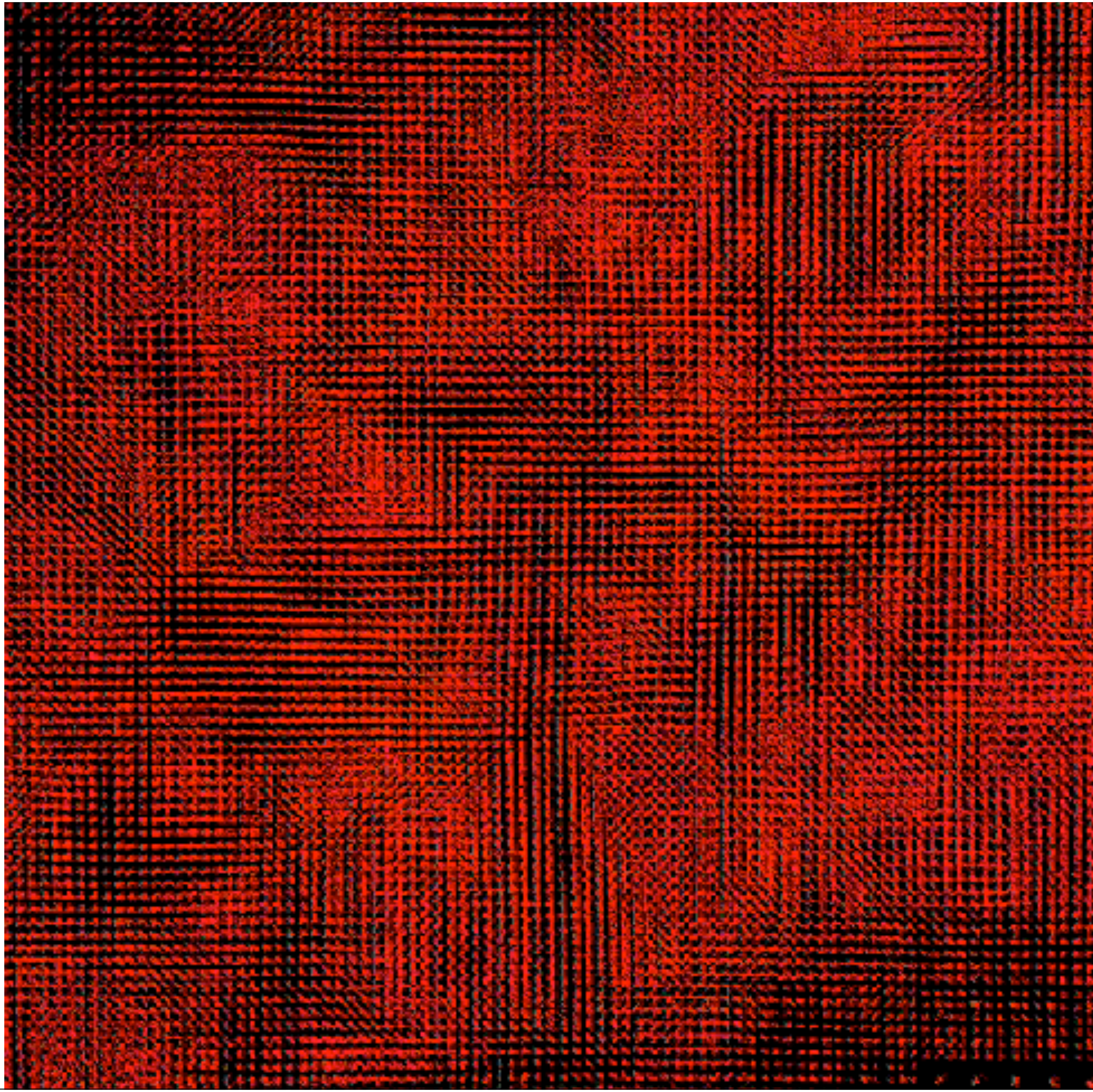
what many people have been discussing here

what i will be discussing

A numerical simulation



Initial conditions from the very young universe



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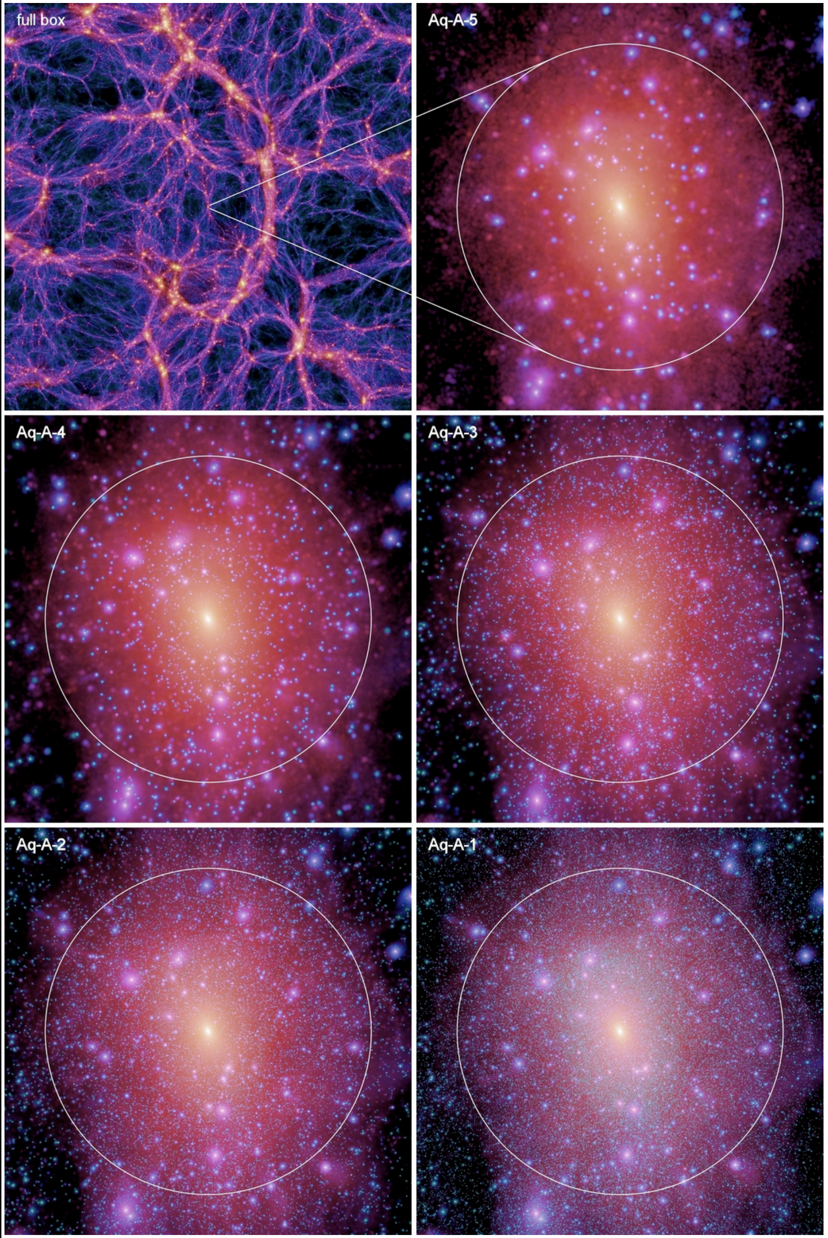
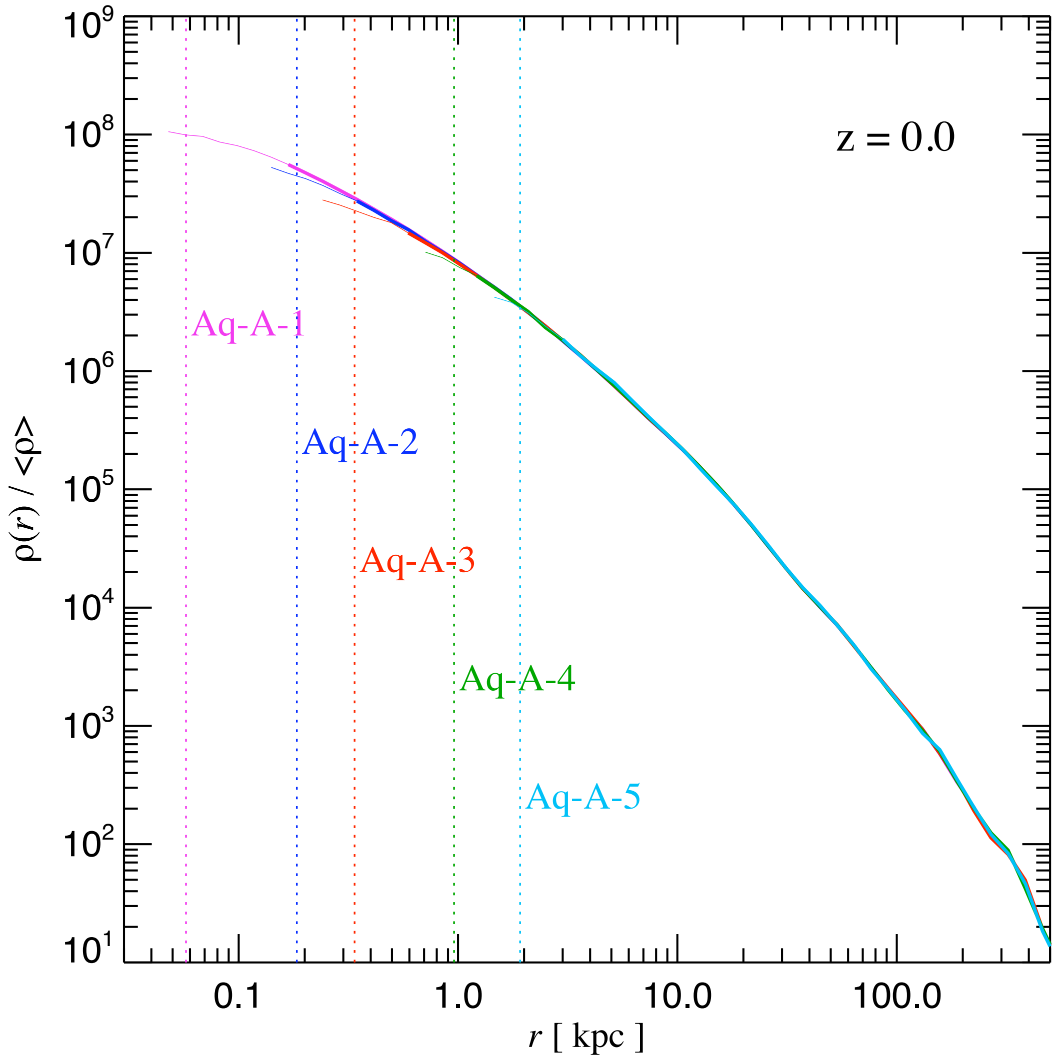
Simulated density-profiles





Springel et al. 2008

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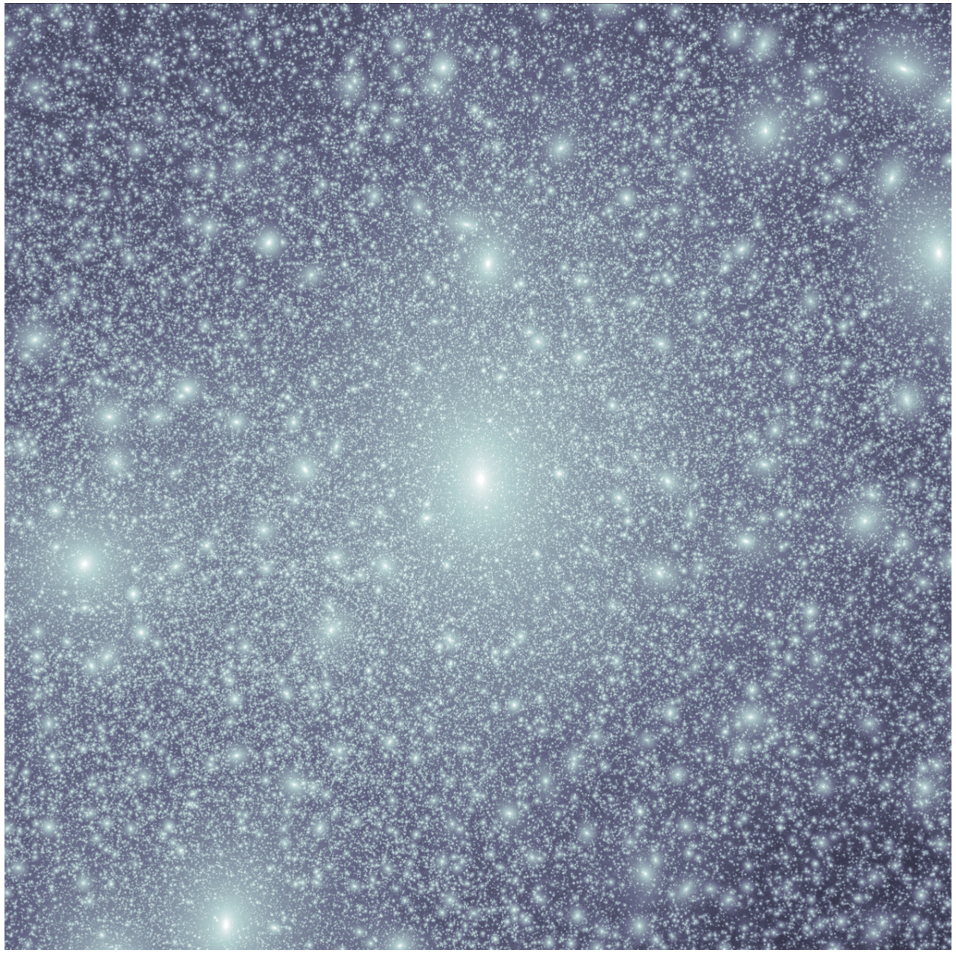
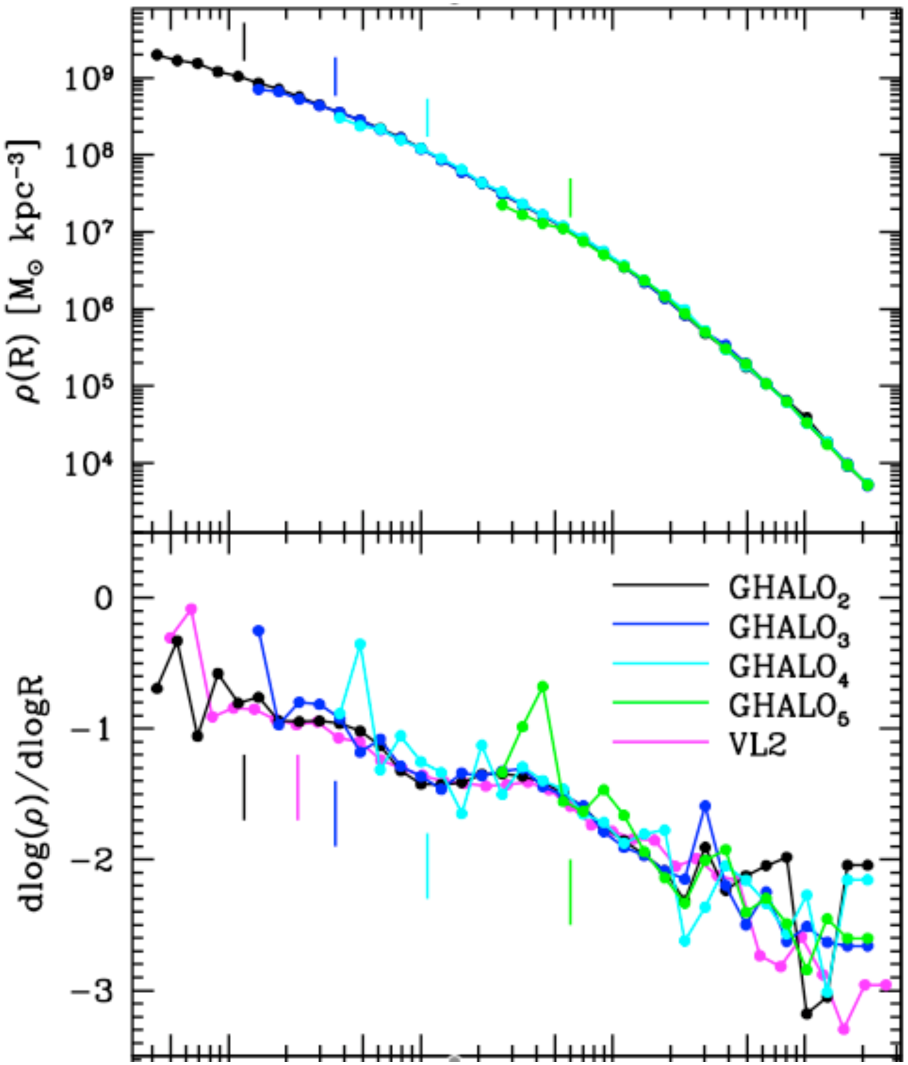
Simulated density-profiles





Stadel et al. 2008

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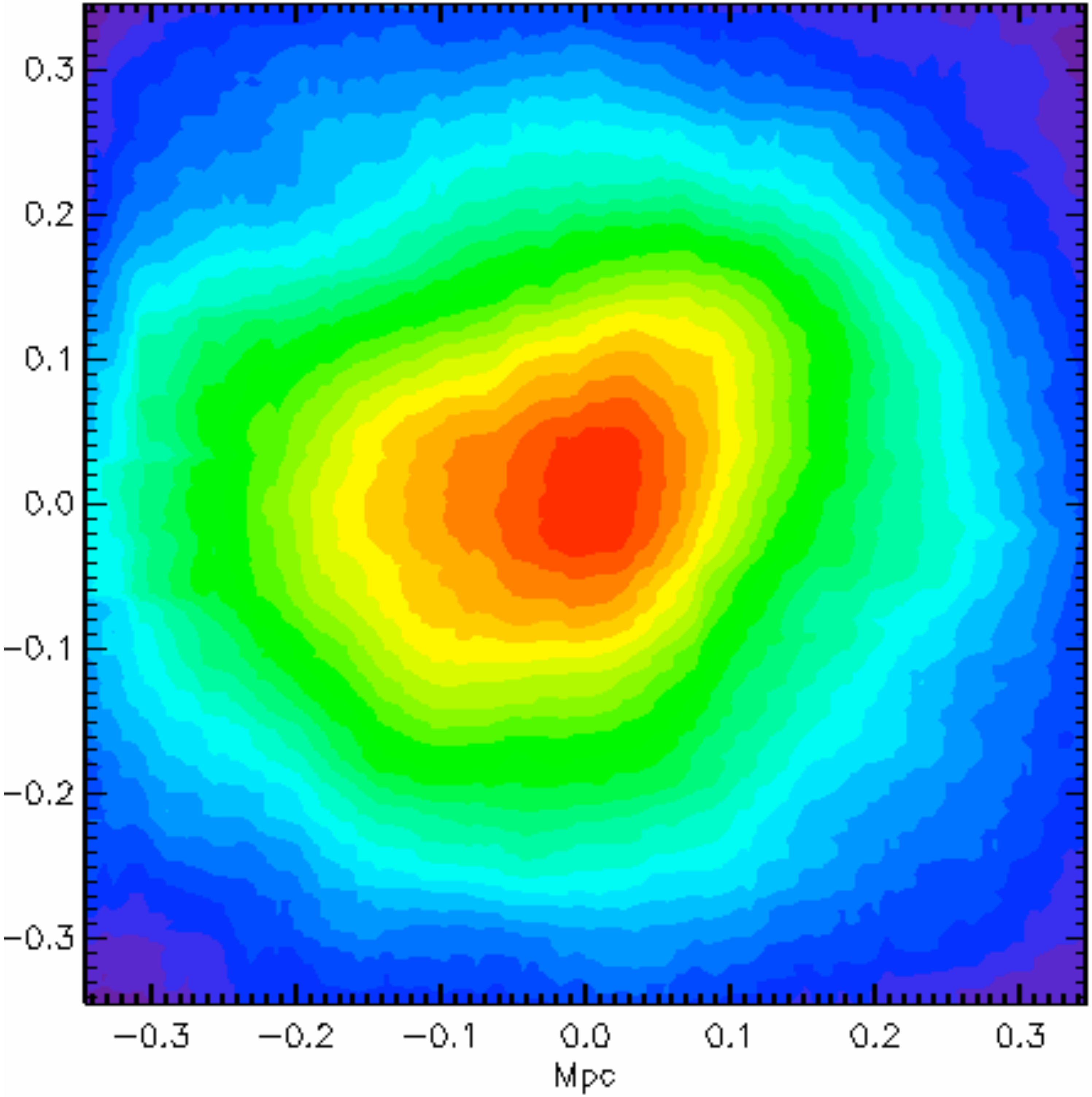
Observed galaxy cluster



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nology Centre

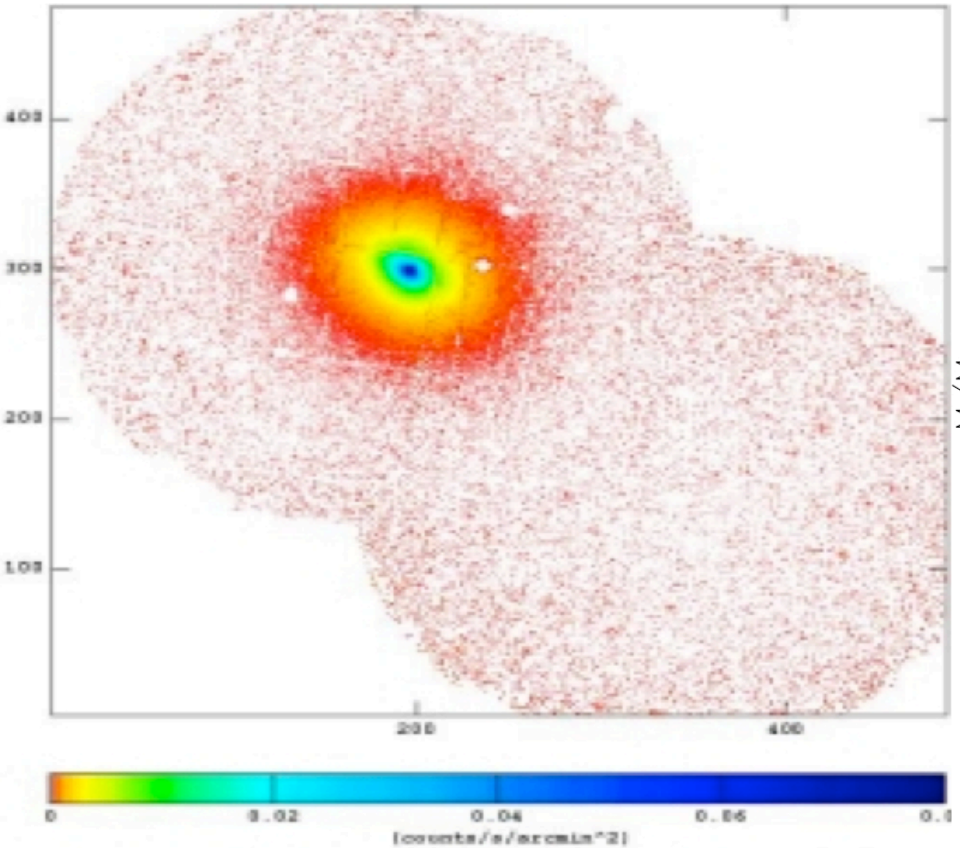
X-ray is easy

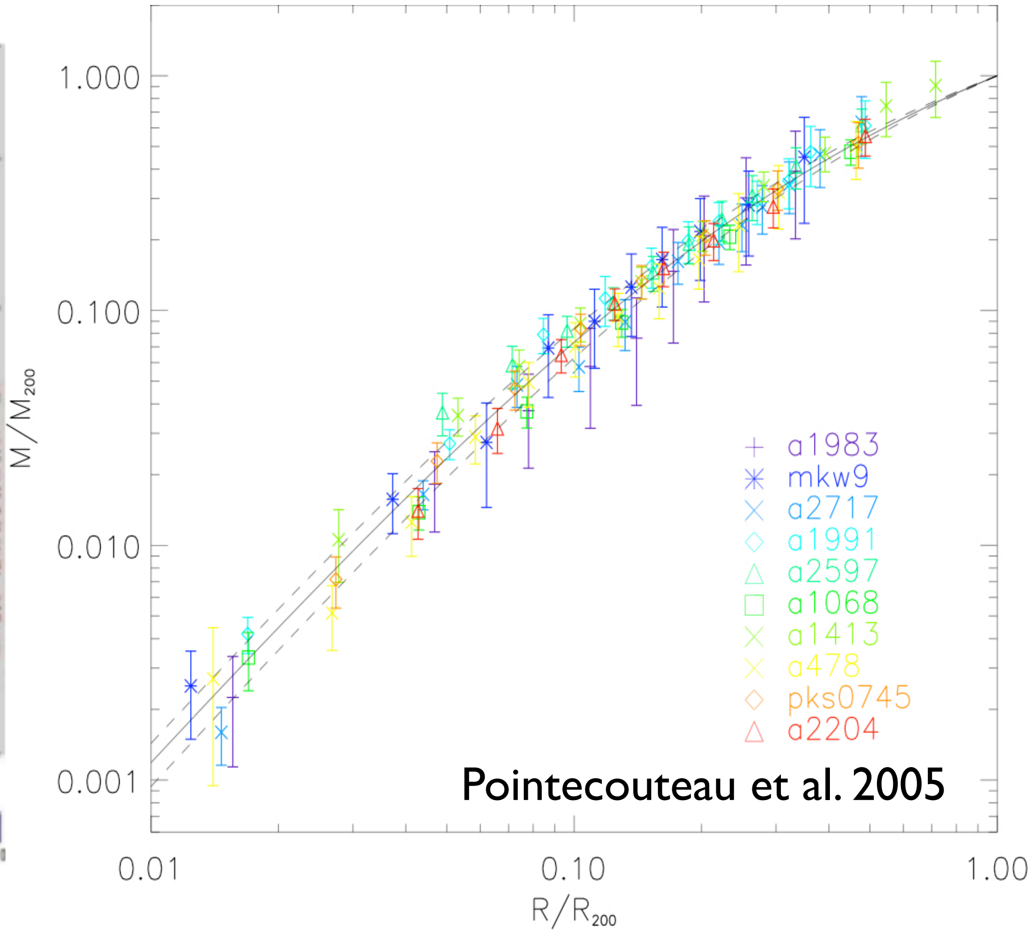
Hydrostatic equilibrium

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

Observed mass-profiles

X-ray





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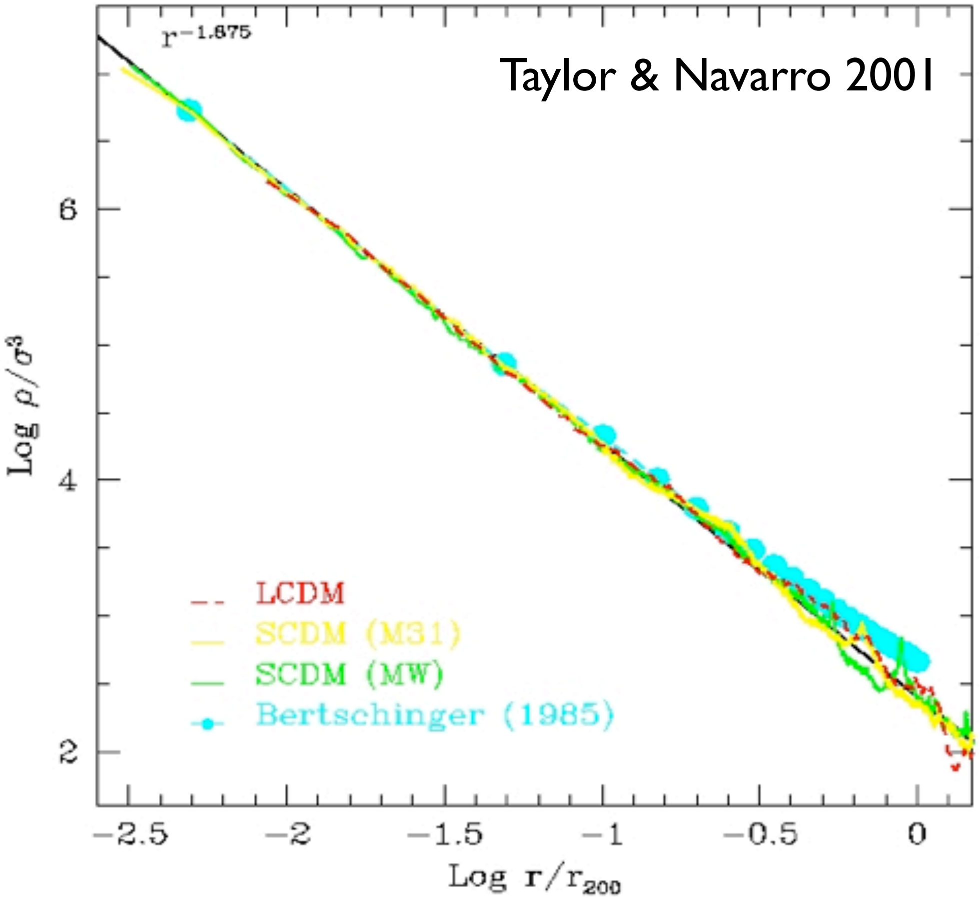
Collisionless particles

Jeans equation (dark matter, stars)

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

dark matter has **no** equation of state
...pretty hard to solve (impossible?)

Theoretical density profiles



Assumption

Phase-space density = power law in radius

$$\rho/\sigma_r^3 \sim r^{-\alpha}$$

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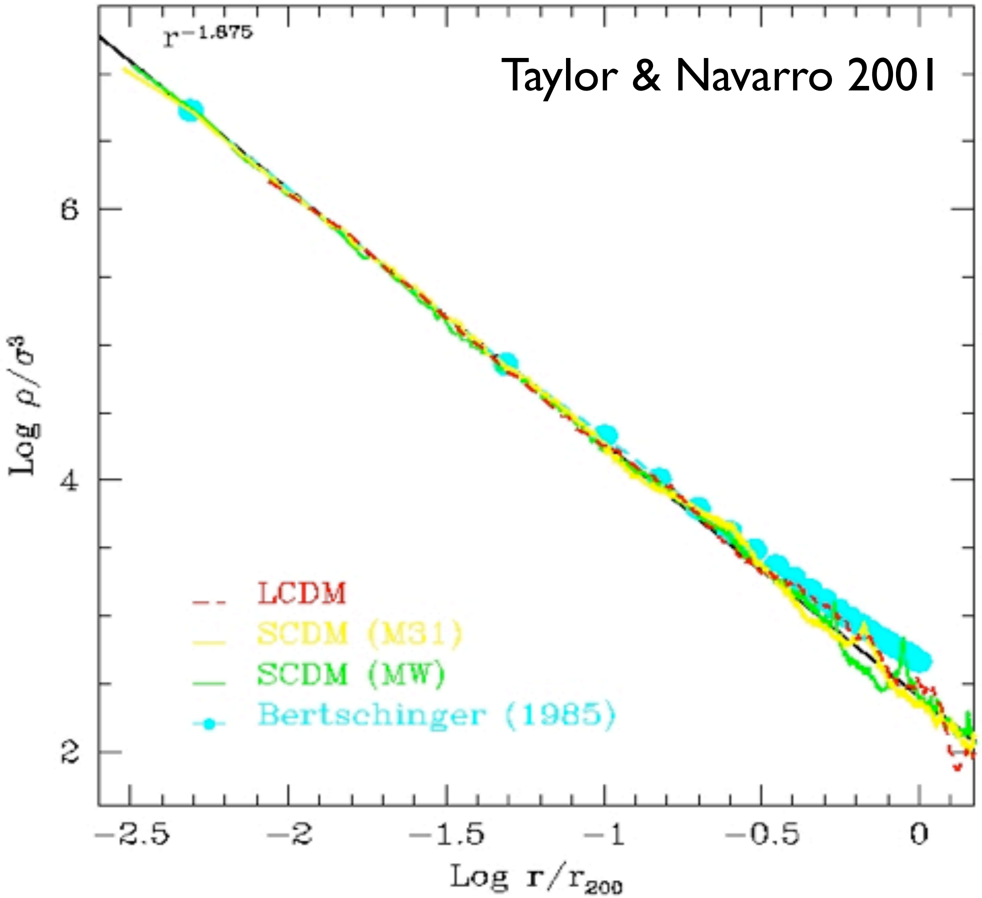
Theoretical density profiles



Assumption

Phase-space density = power law in radius

$$\rho/\sigma_r^3 \sim r^{-\alpha}$$

Solution to Jeans equation

$$\rho(r) = \frac{1}{r^{7/9}(1+r^{4/9})^6}$$

Hansen 2004
Austin et al. 2005
Dehnen & McLaughlin 2005

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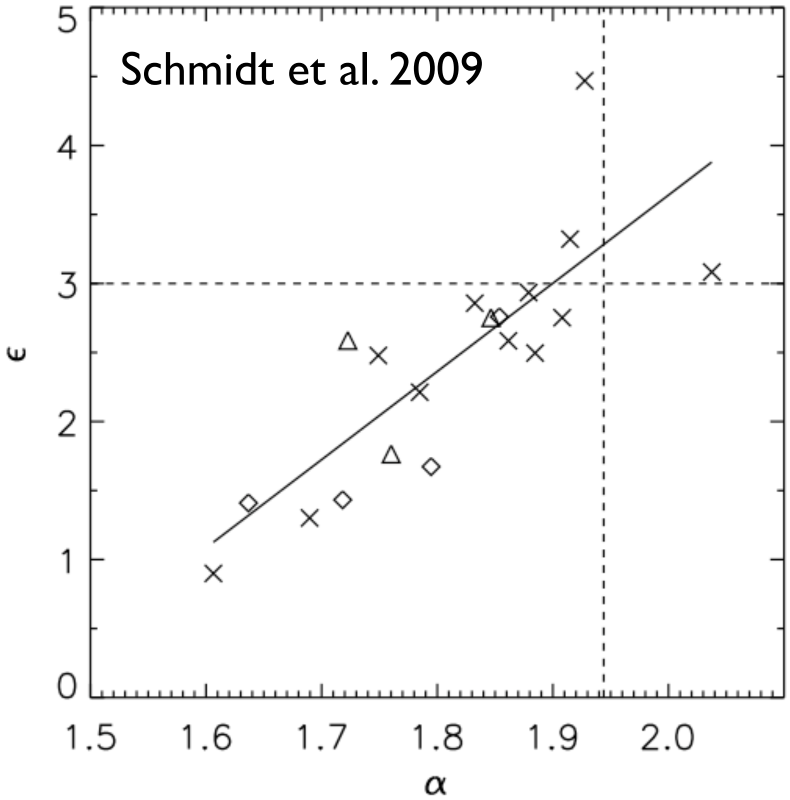
Theoretical density profiles

The phase-space density argument does unfortunately not work, because different structures are fit with different forms



$$\rho/\sigma_d^{\epsilon} \sim r^{-\alpha}$$

learning to love beta...

β

It's there - deal with it!

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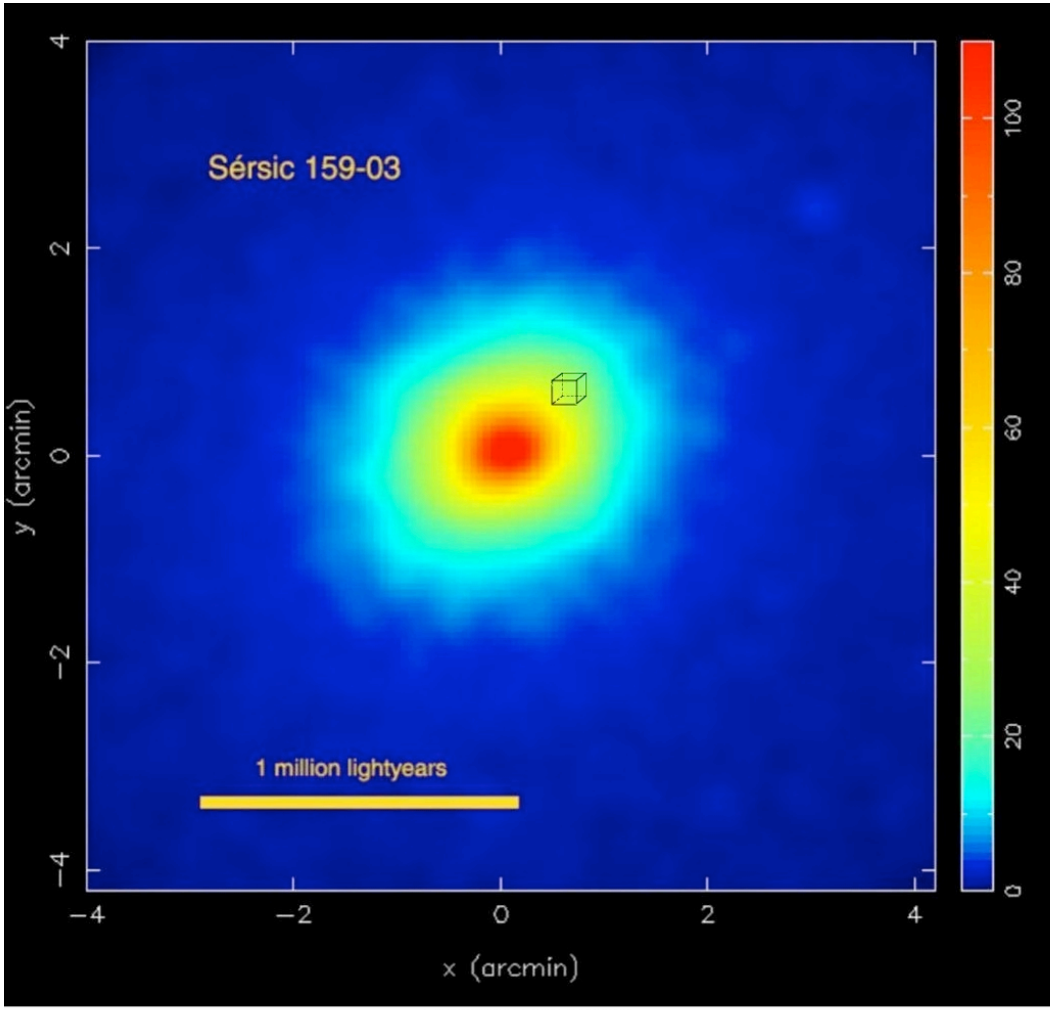
velocity anisotropy profiles

velocity anisotropy =
"different temperature
in different directions"

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

Must be 0 for a gas!



Abell S1101 (=Sersic 159-03)

Image courtesy of J. Kaastra, SRON, Utrecht, NL

European Space Agency

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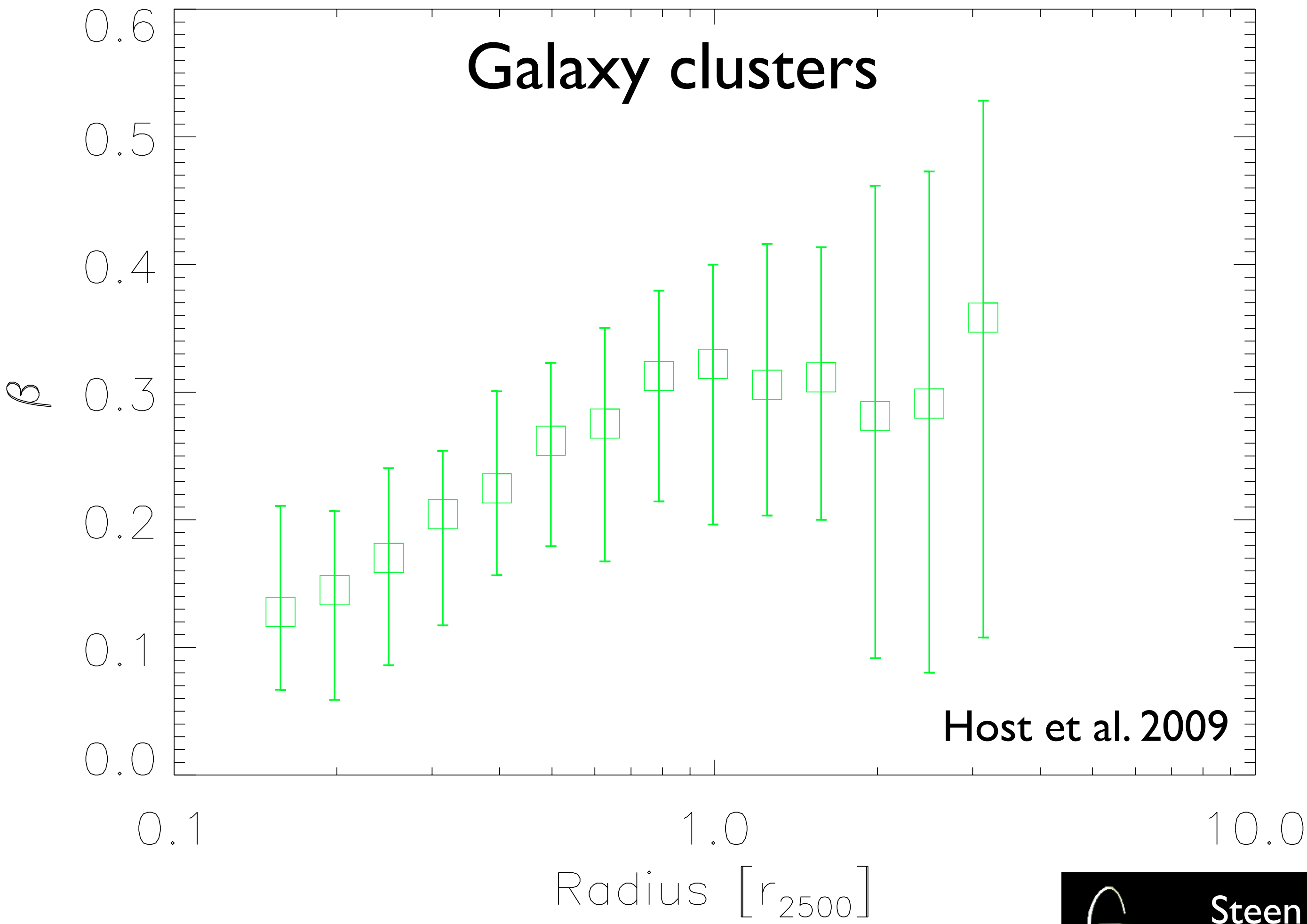
Simulated velocity anisotropy



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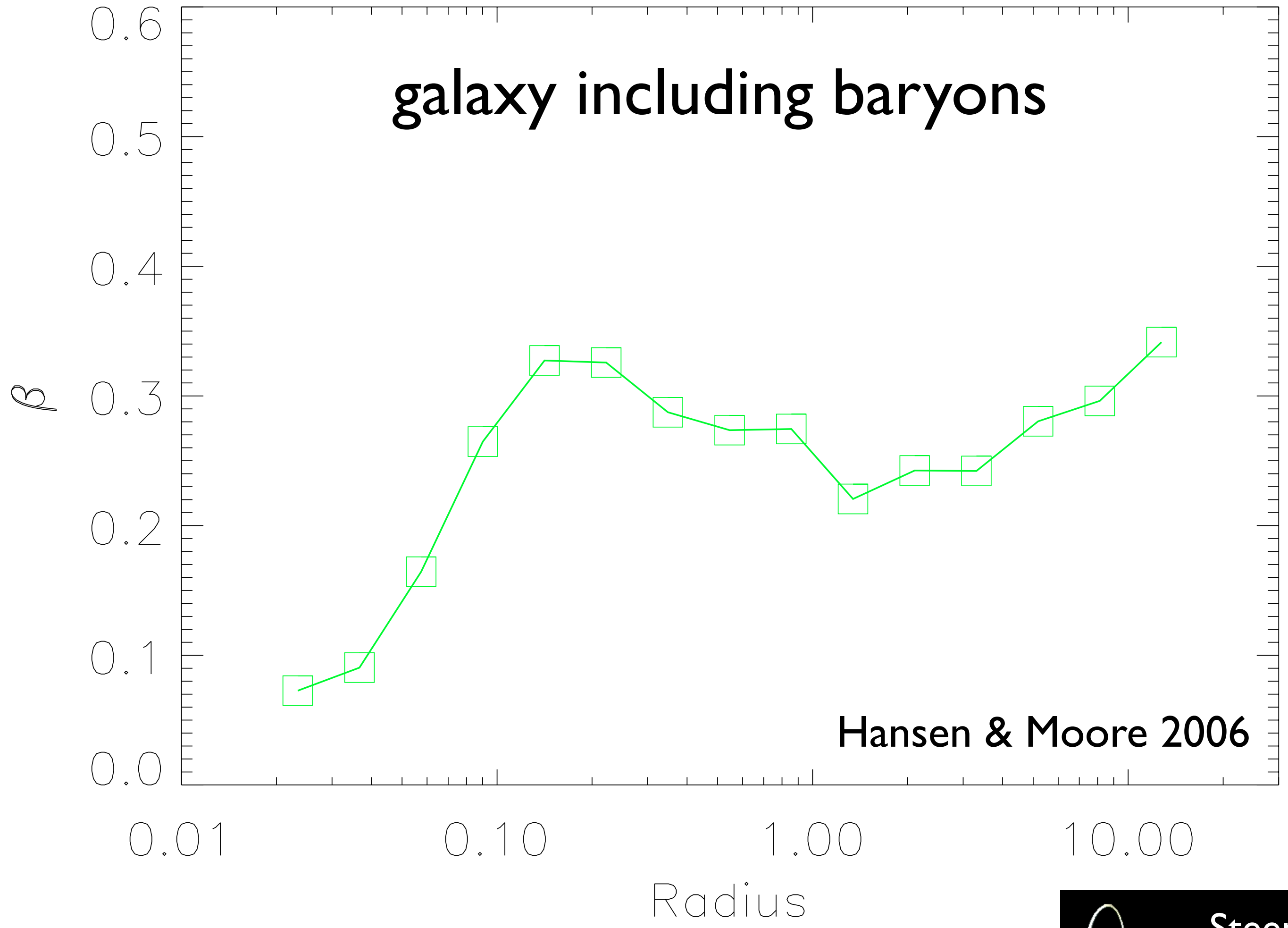
Simulated velocity anisotropy



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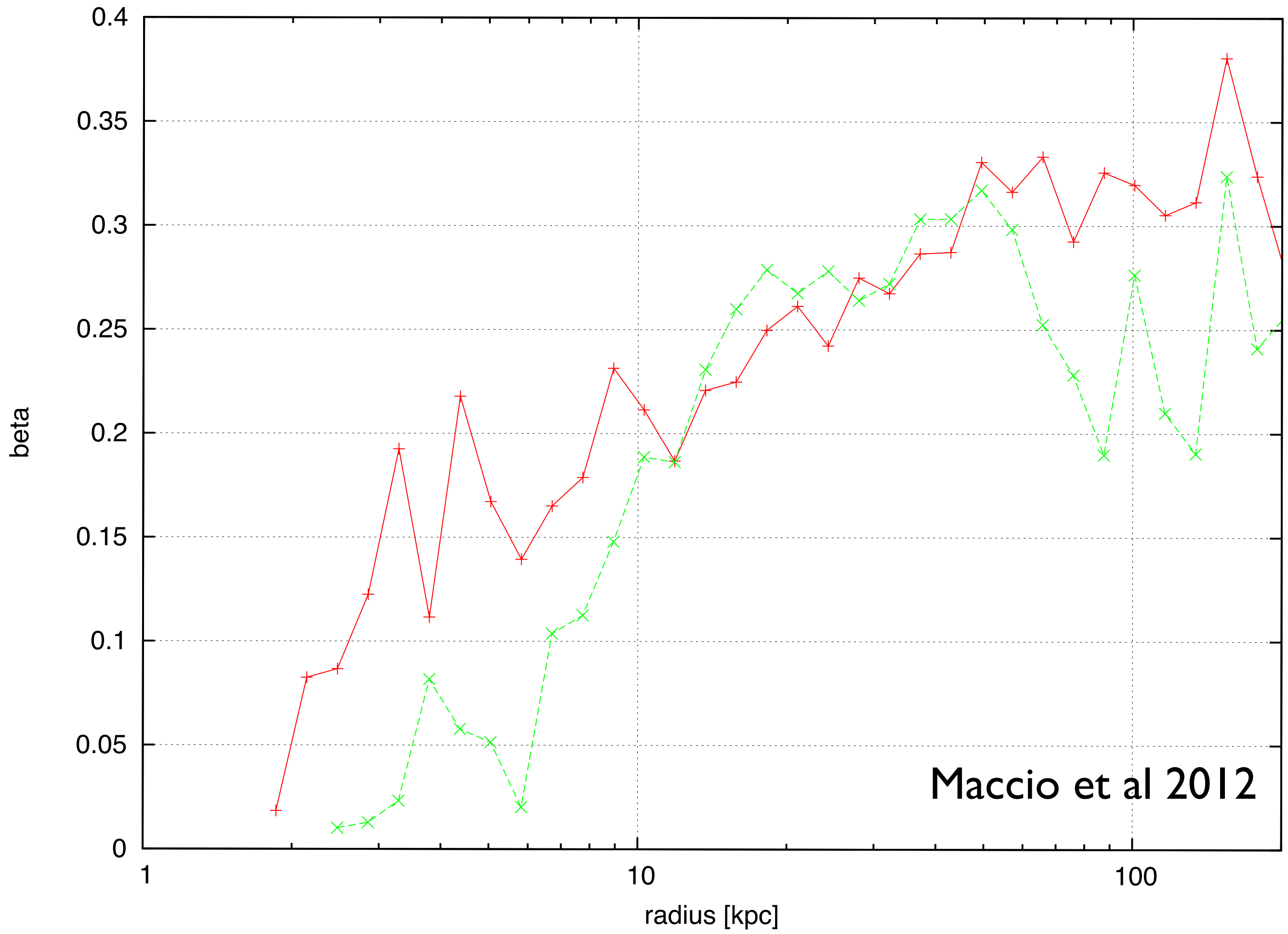
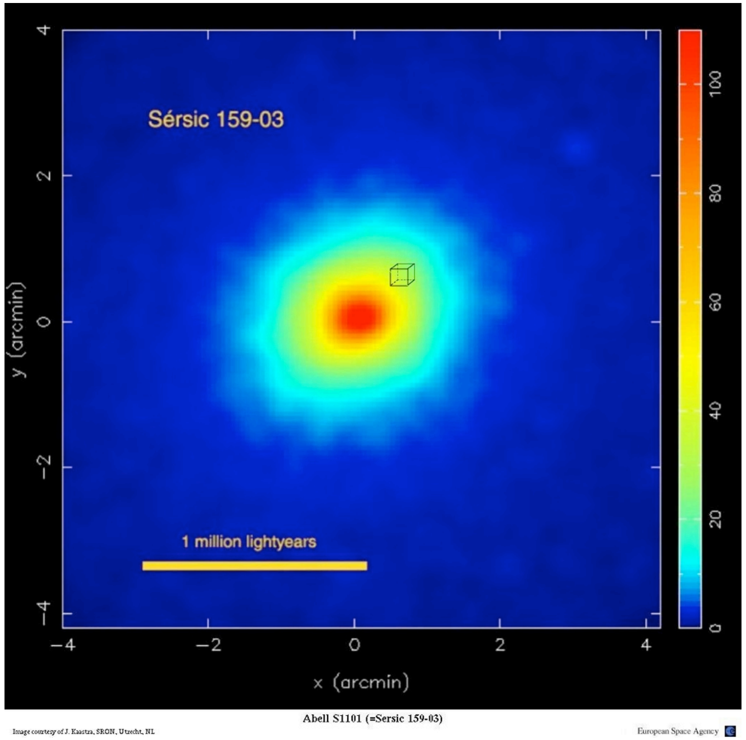
“Most realistic galaxy ever”

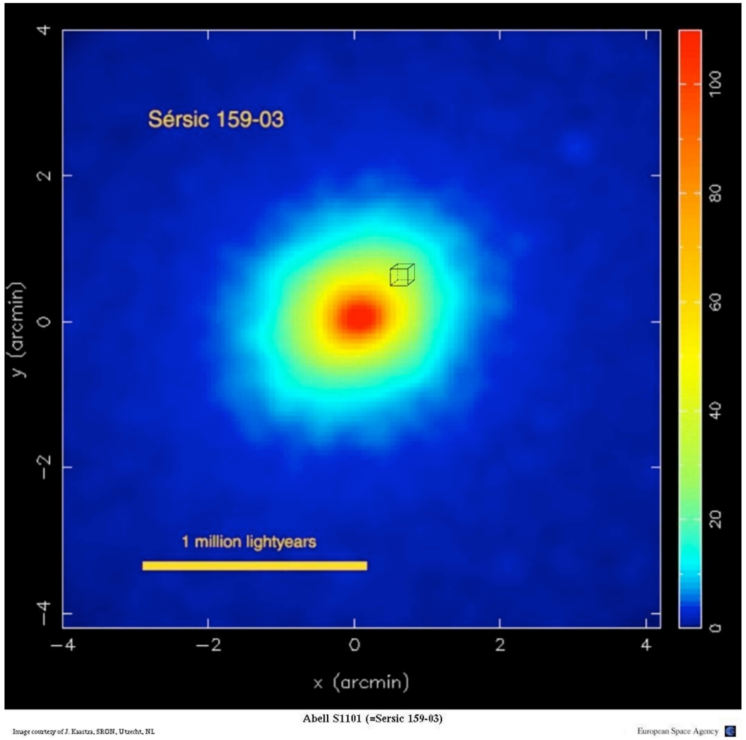


Gas **has** an equation of state



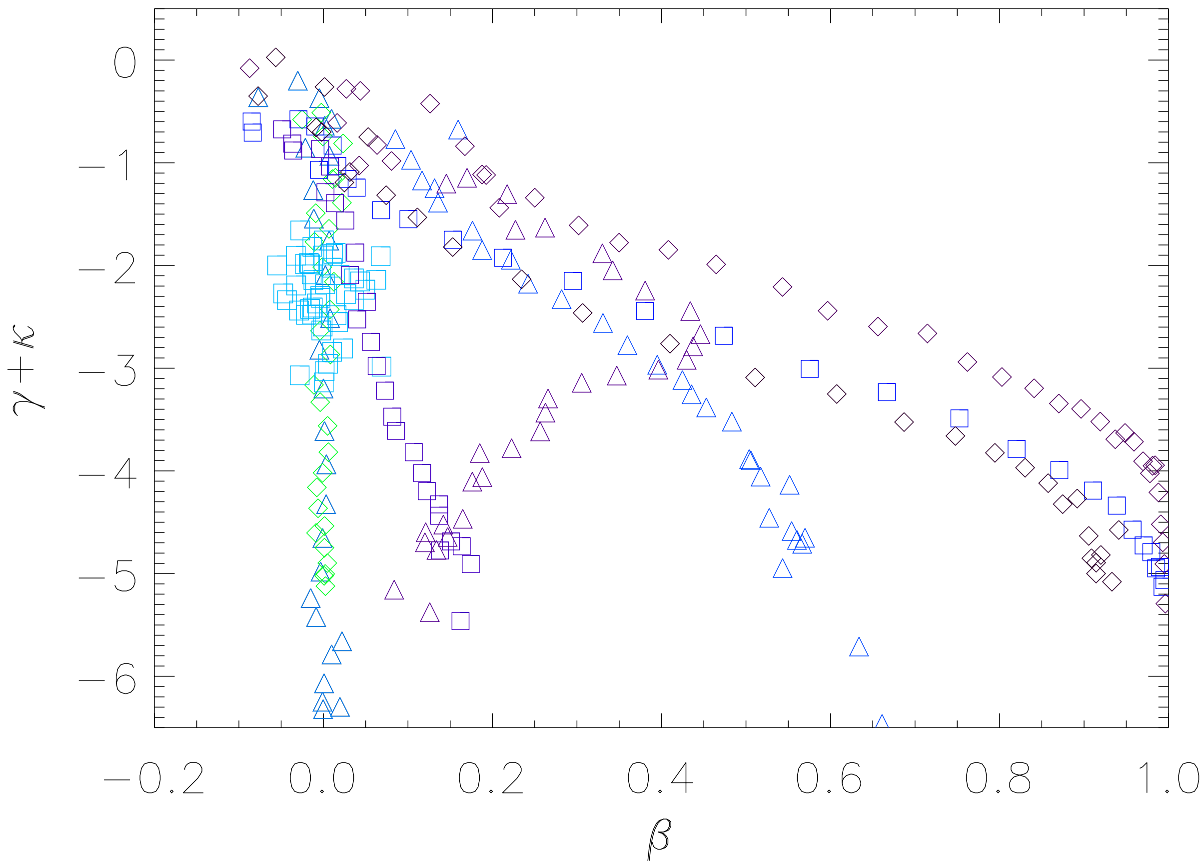
$$\frac{GM_{\rm tot}}{r} = -\frac{k_B T}{\mu m_p}\left(\frac{d\ln T}{d\ln r} + \frac{d\ln n_e}{d\ln r}\right)$$

and yet there are many solutions to hydrostatic equilibrium



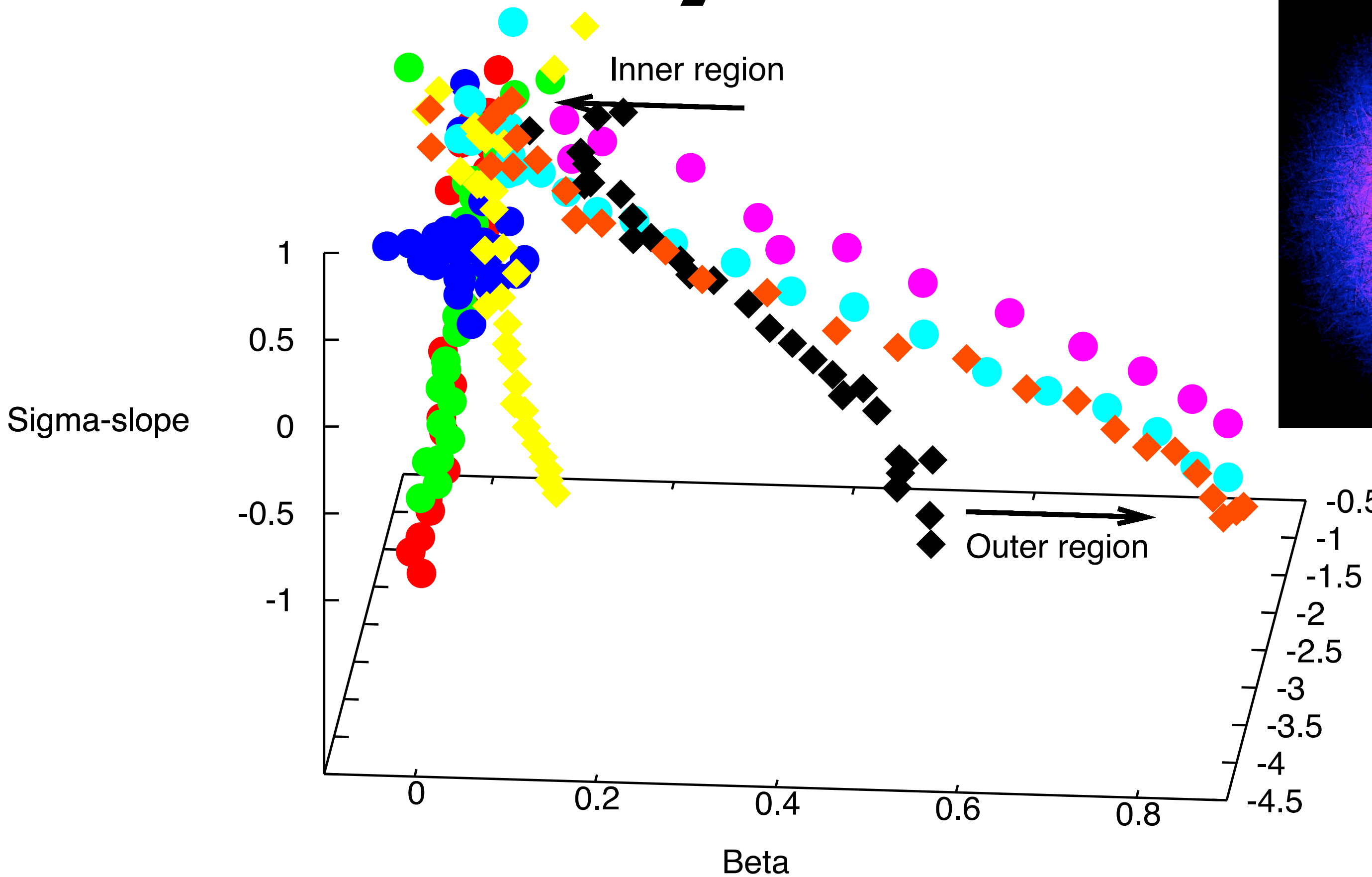
$$\frac{GM_{\rm tot}}{r} = -\frac{k_B T}{\mu m_p}\left(\frac{d\ln T}{d\ln r} + \frac{d\ln n_e}{d\ln r}\right)$$

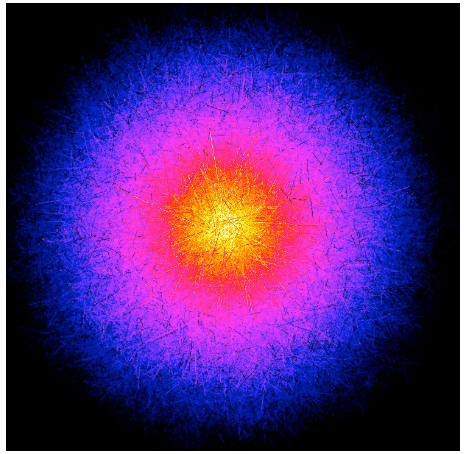
DM structures have many **many** solutions



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

DM structures have many **many** solutions

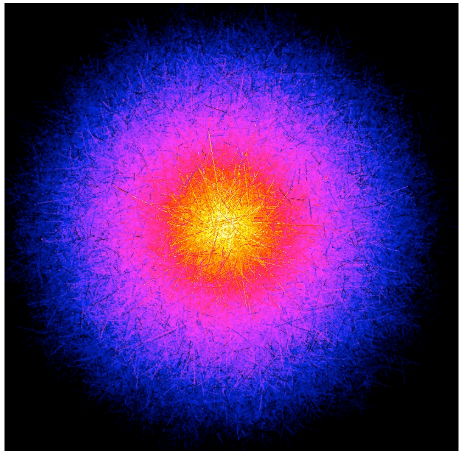




$$\frac{GM_{\rm tot}}{r} = -\sigma_r^2 \left(\frac{d\ln\sigma_r^2}{d\ln r} + \frac{d\ln\rho}{d\ln r} + 2\beta \right)$$

Are all these structures stable to small perturbations?

1. Create structure in equilibrium

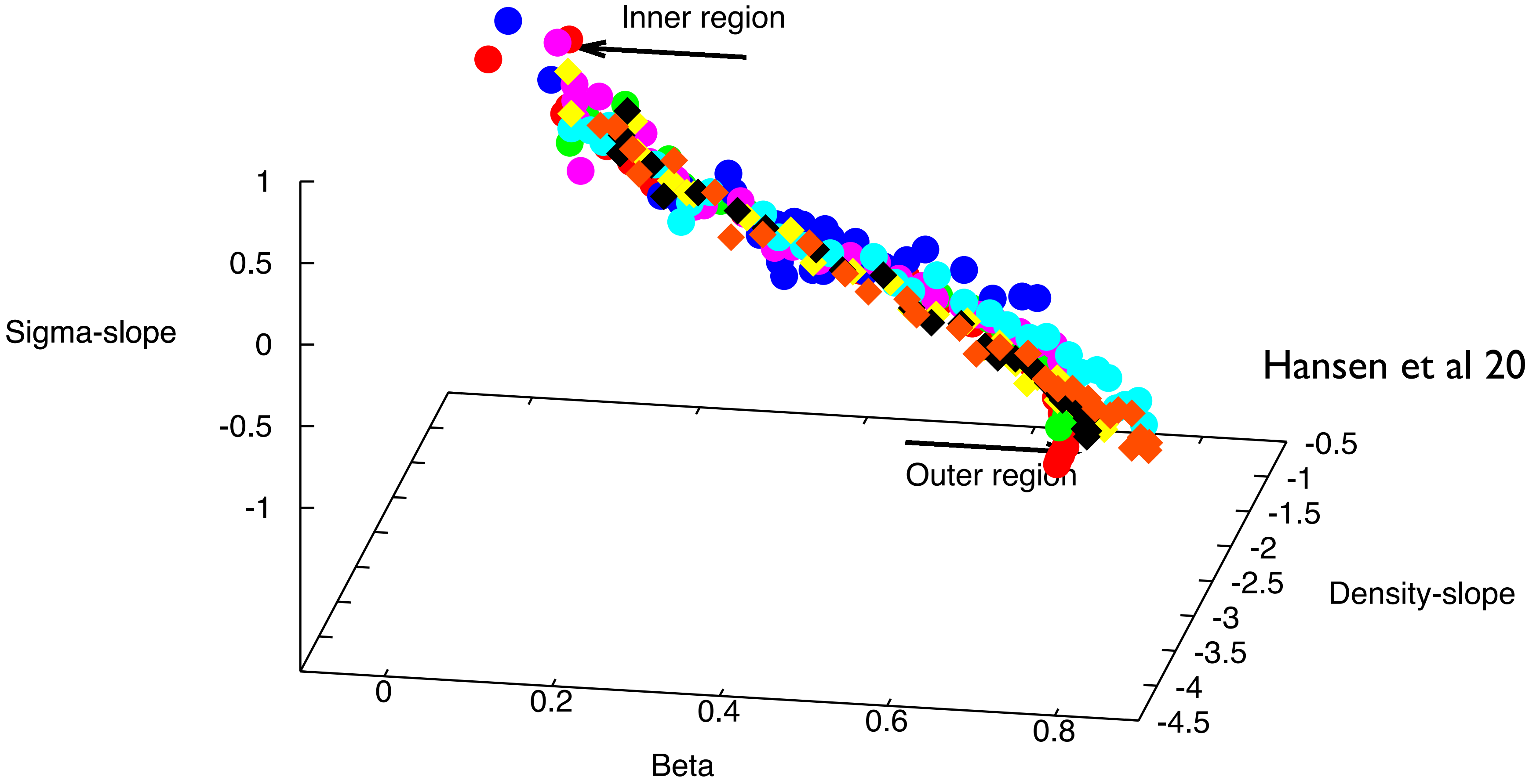


2a. Perturb structure

2b. Let structure relax

Repeat till happy

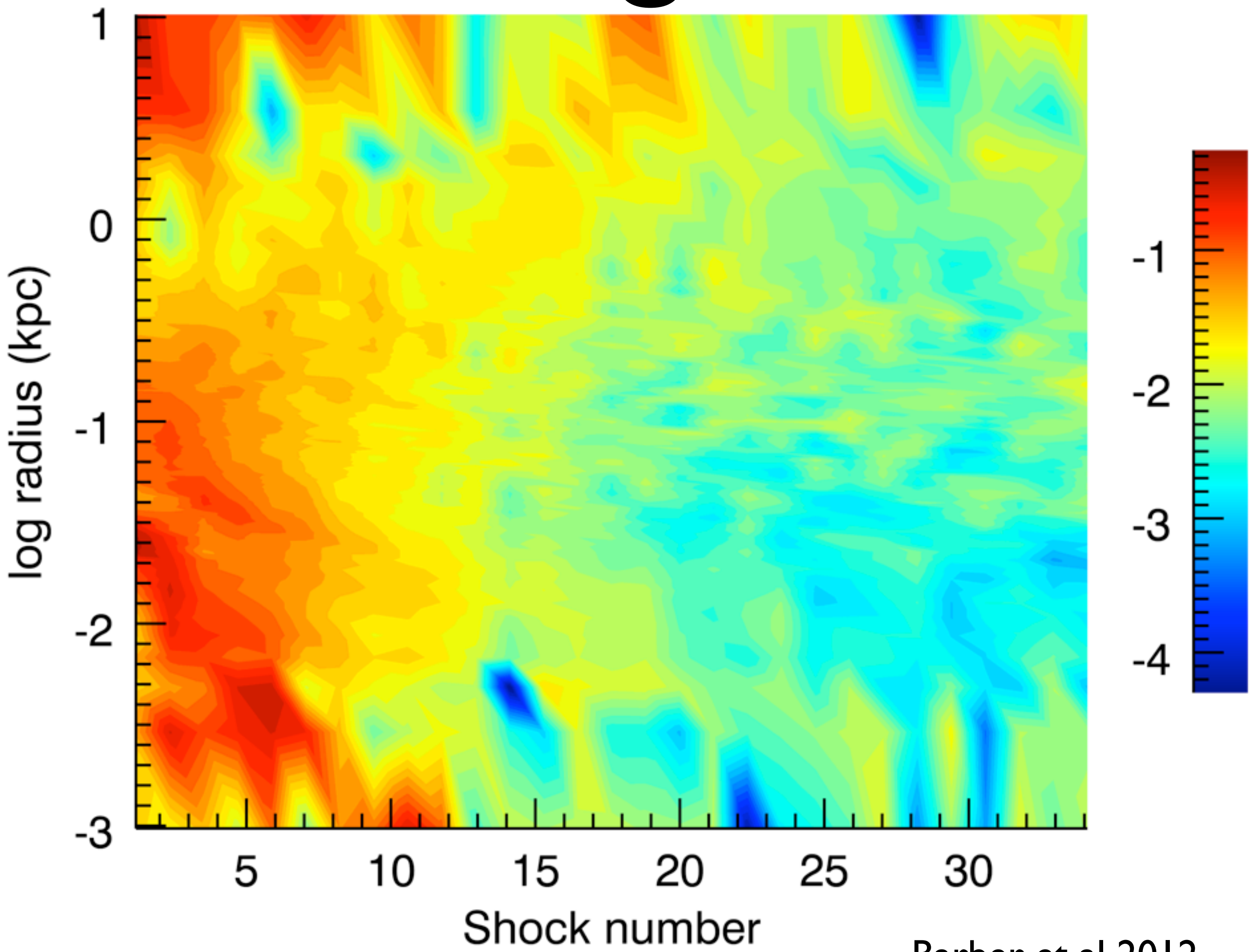
One attractor



Hansen et al 2010

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

Convergence?

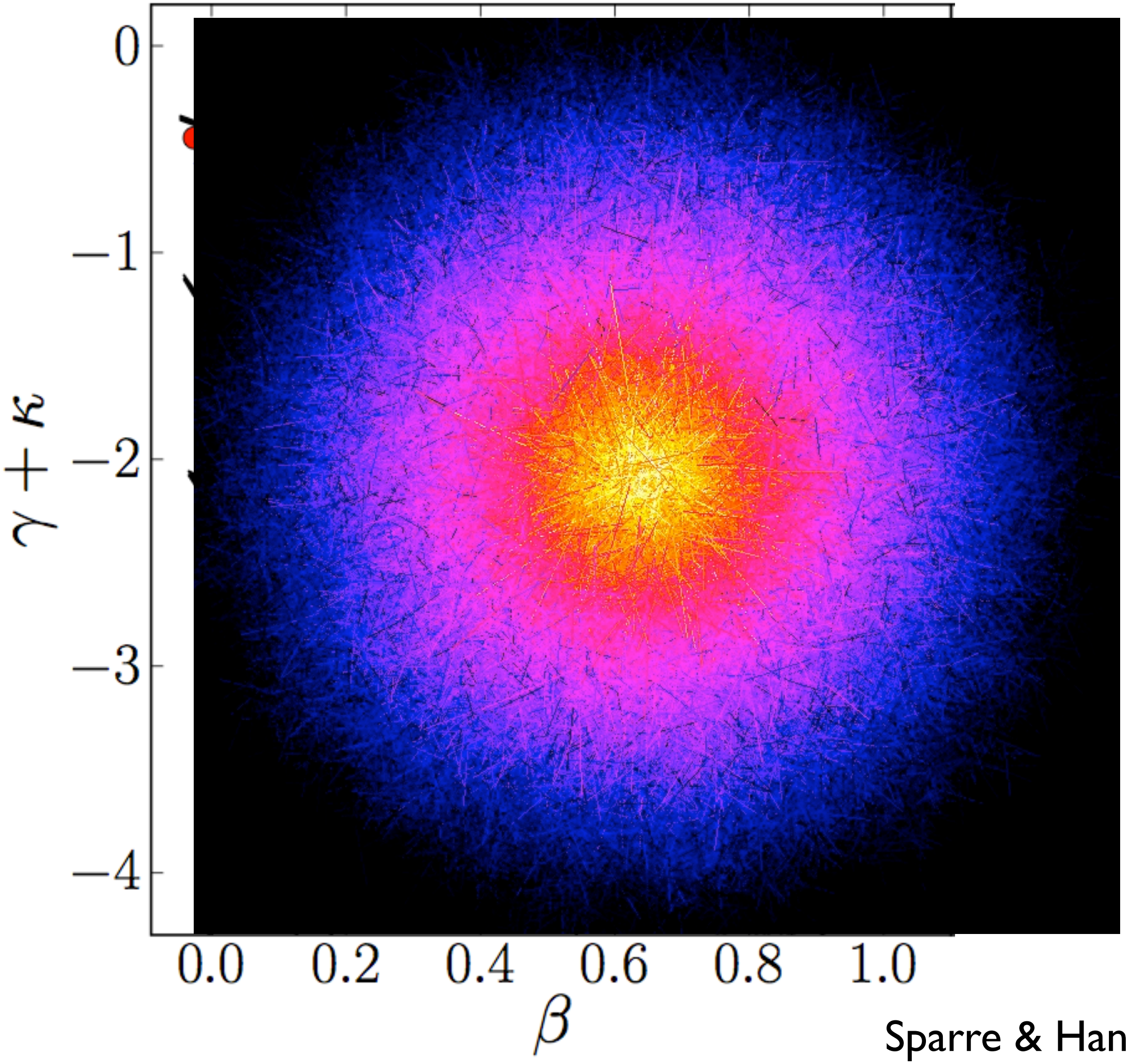


Barber et al 2012

What does this mean?

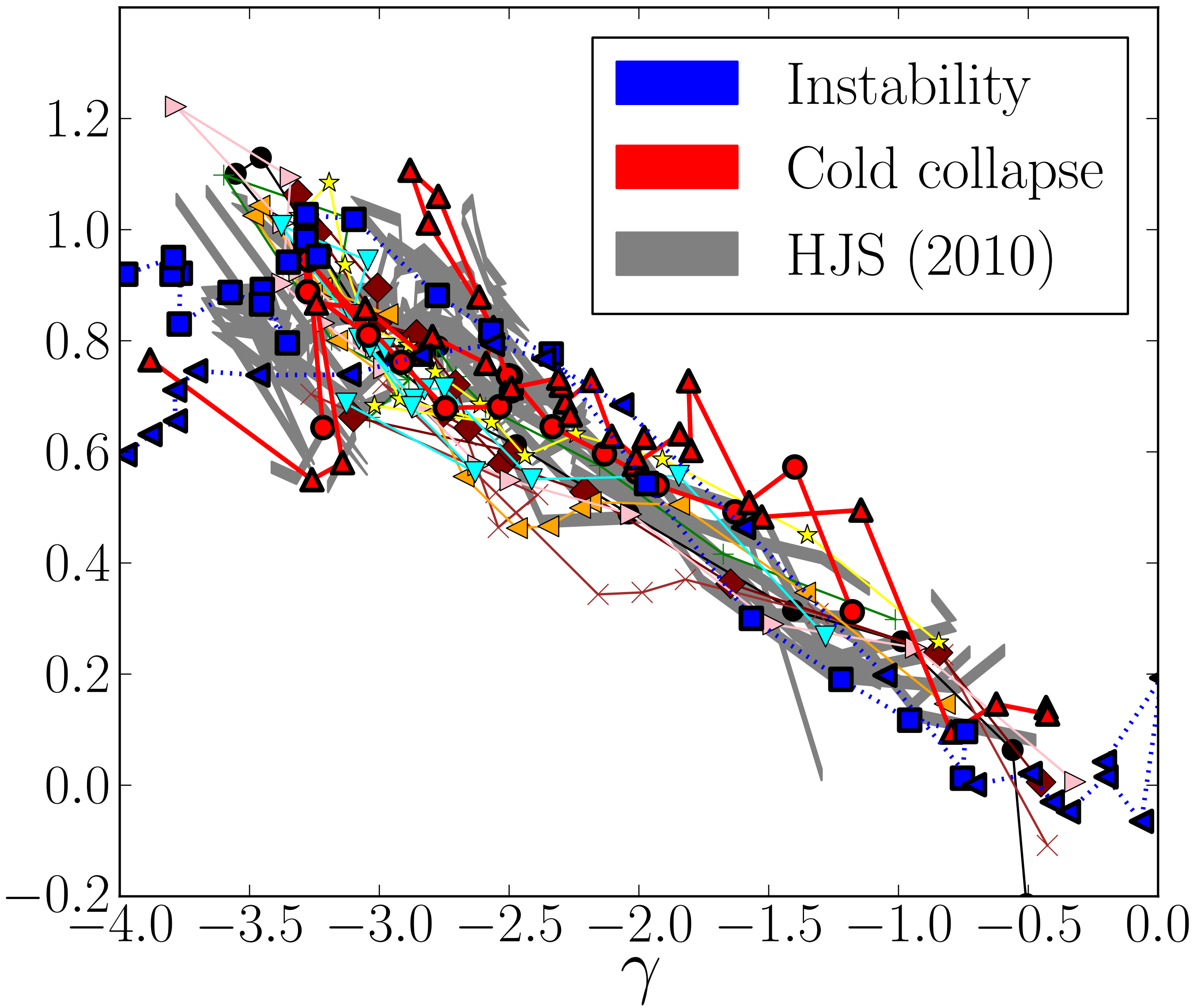
- All structures “want” to follow a connection between sigma, rho and beta (dispersion, density and anisotropy)
- This is almost an **equation of state** for dark matter
- ...if the attractor is real

different perturbations

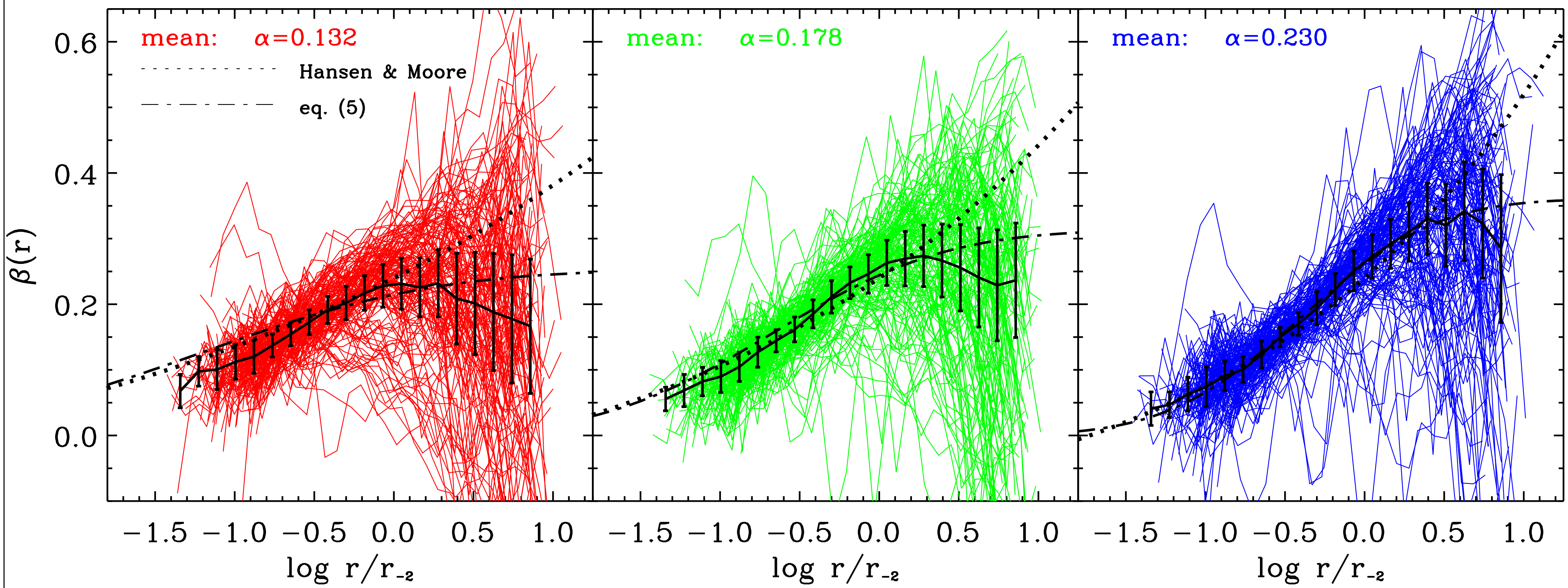


Sparre & Hansen 2012

Cold collapse

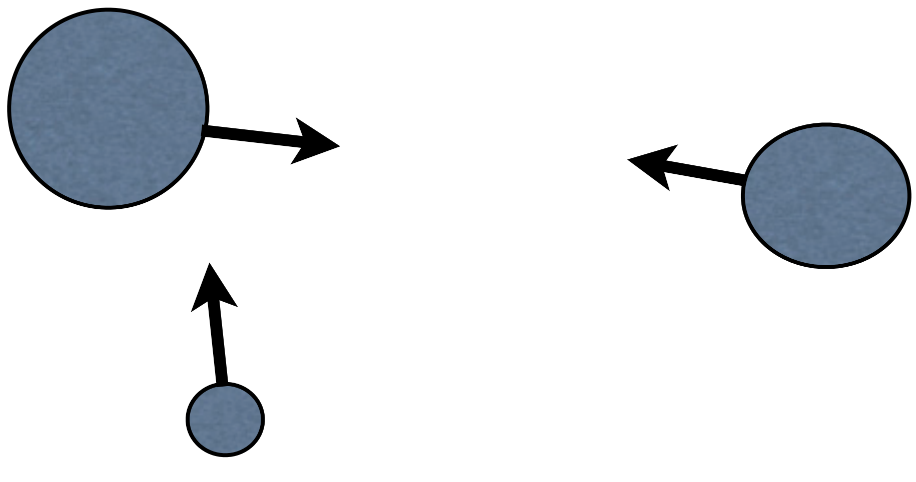


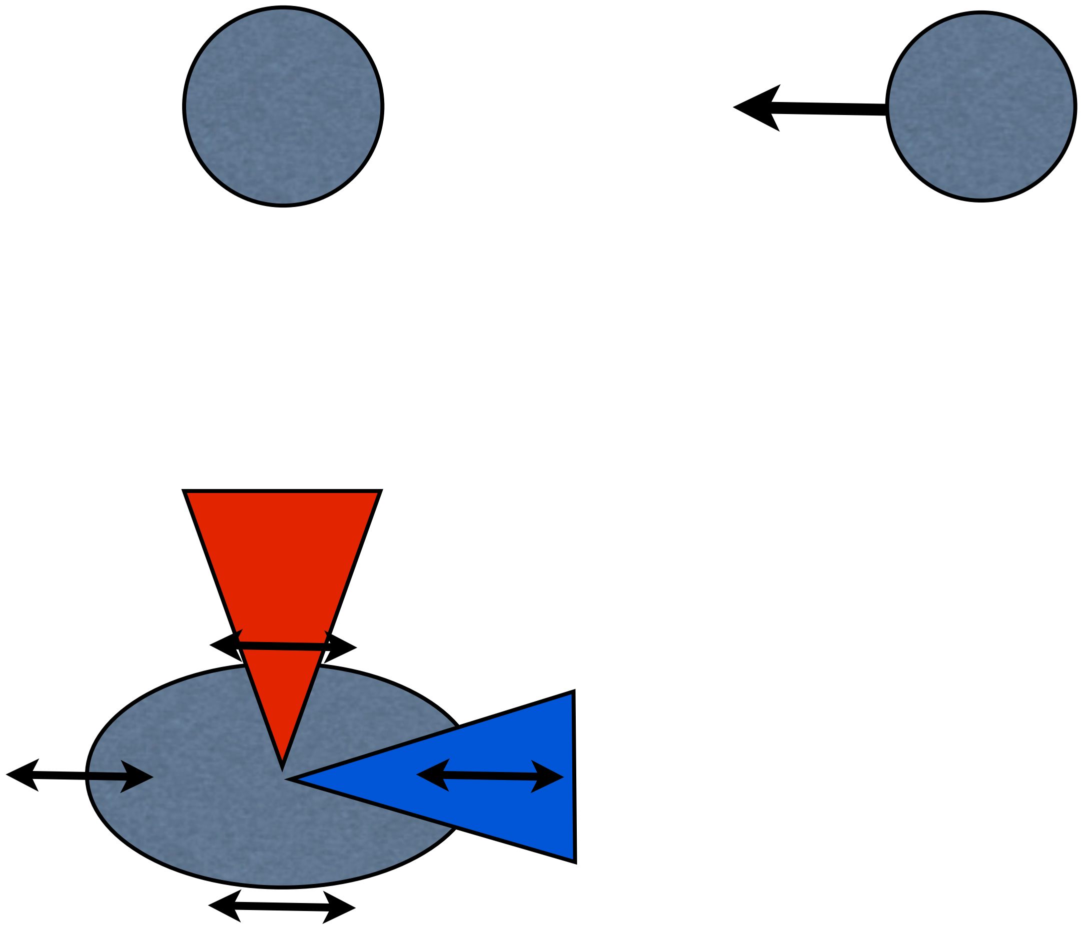
Cosmological simulations

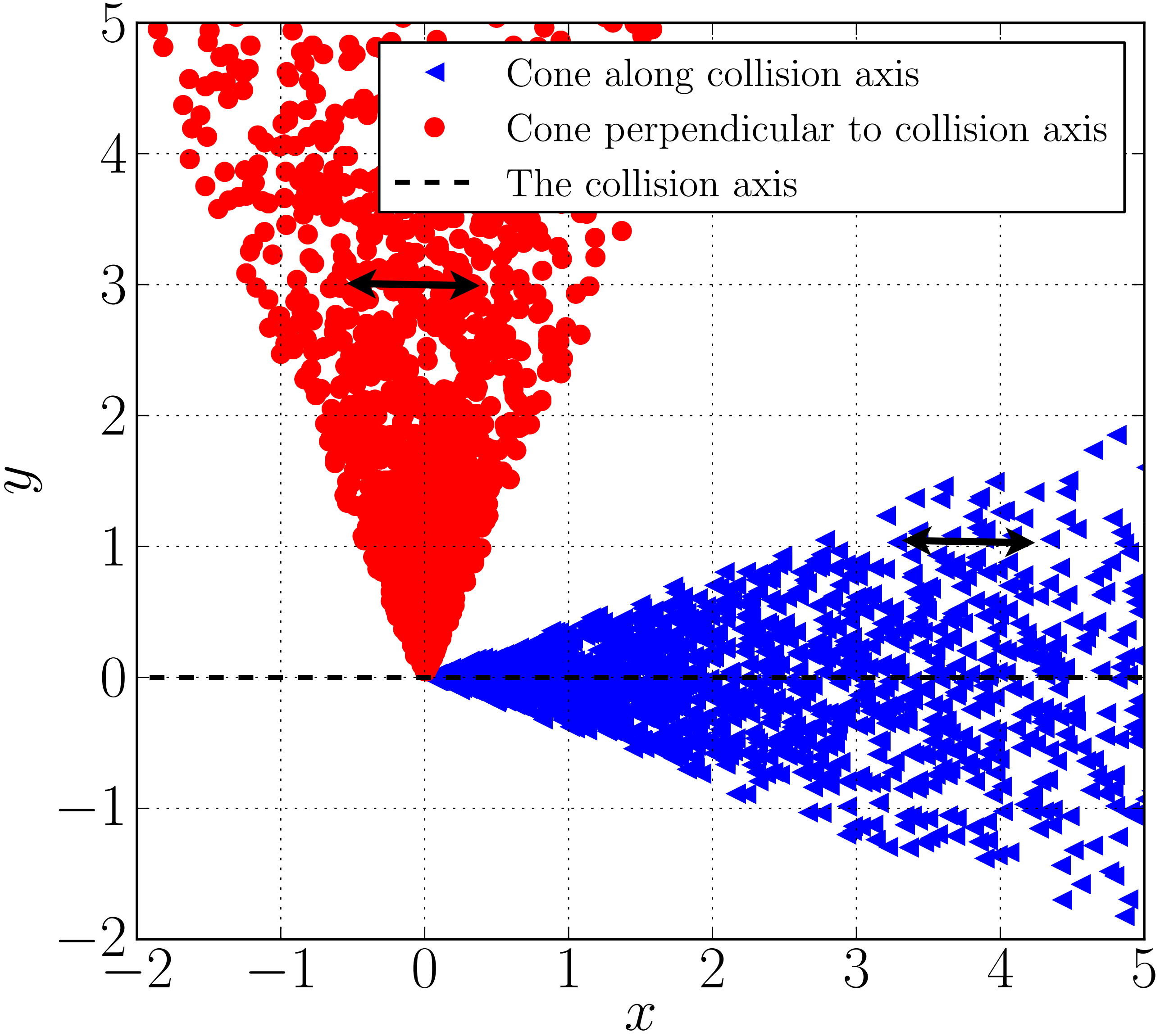


Ludlow et al 2010

the “problem” in the outer part is mergers...

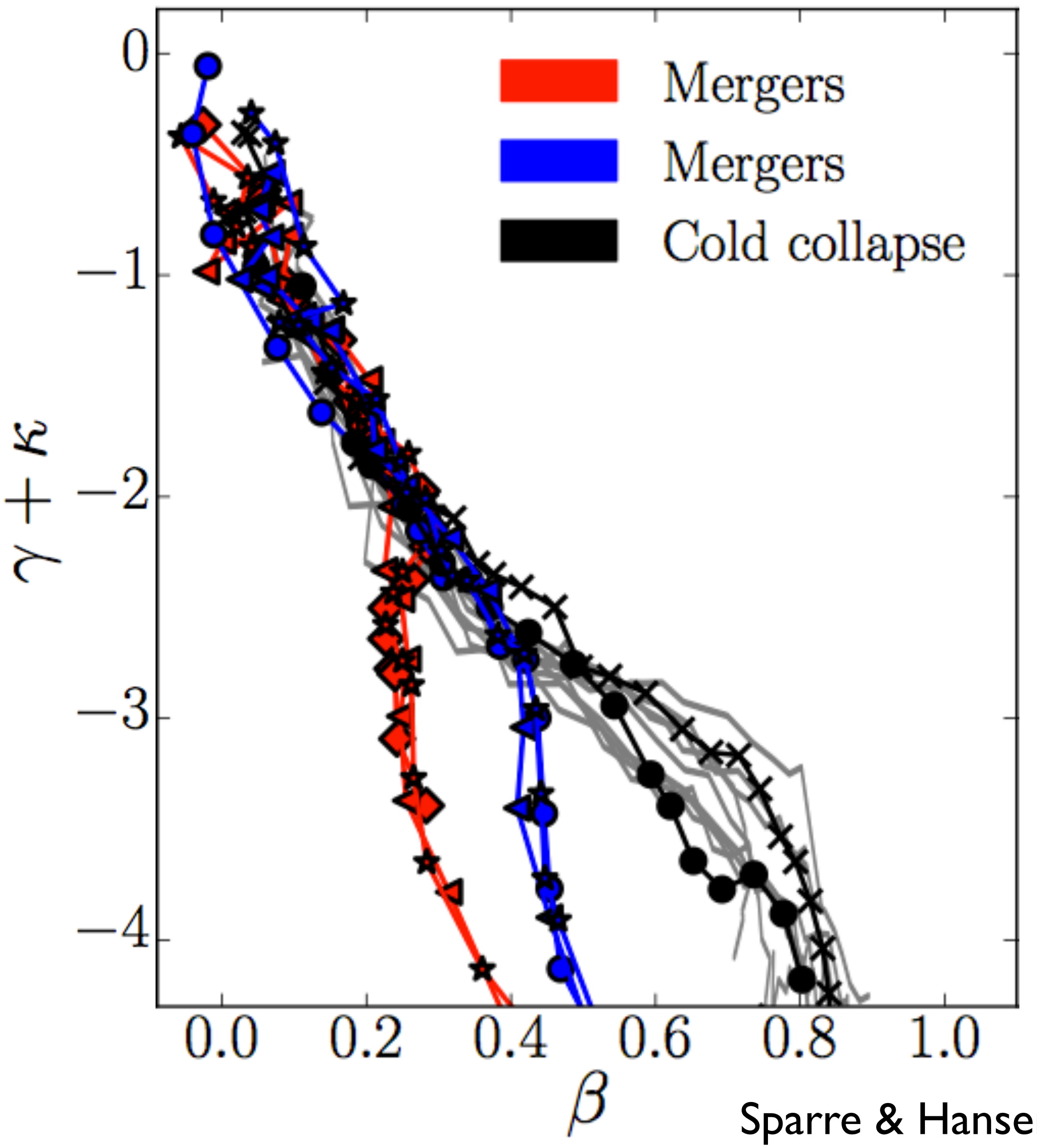






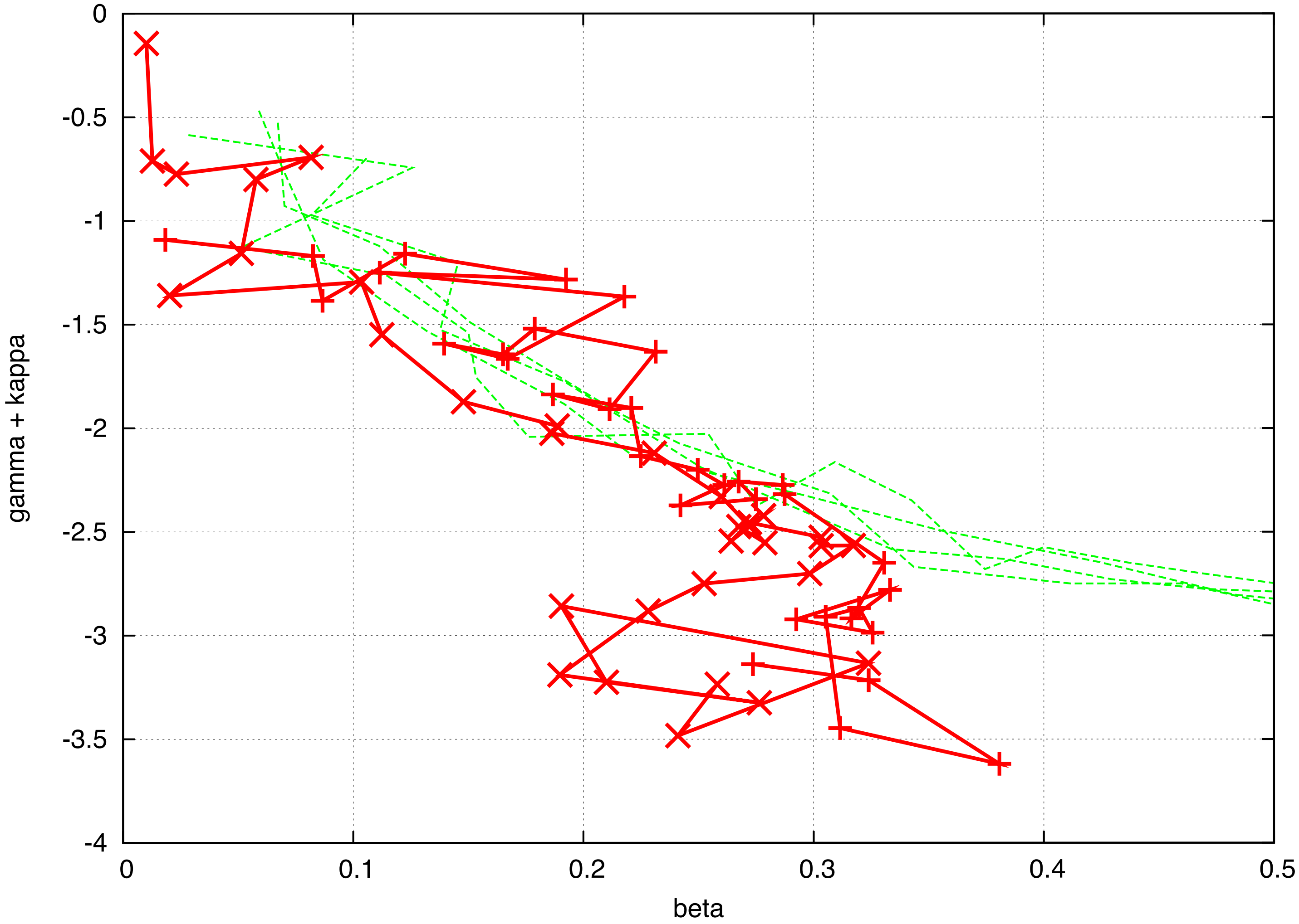
Zemp et al 2009, Sparre & Hansen 2012

Mergers



Sparre & Hansen 2012

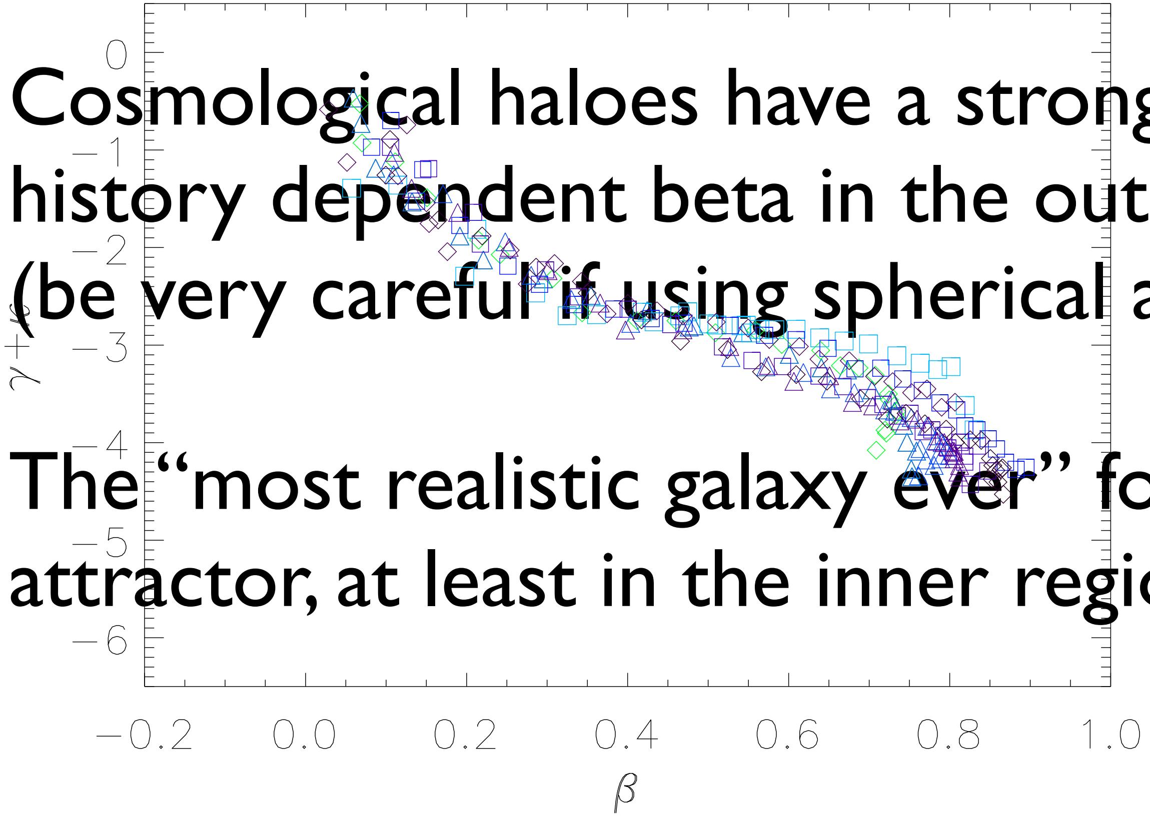
“Most realistic galaxy ever”



Maccio et al 2012

Conclusions

- The attractor provides *a simple prescription for finding **beta*** for equilibrated dark matter structures



- Cosmological haloes have a strong merger history dependent beta in the outer regions (be very careful if using spherical averages)
- The "most realistic galaxy ever" follows the attractor, at least in the inner region

the end...

the end...