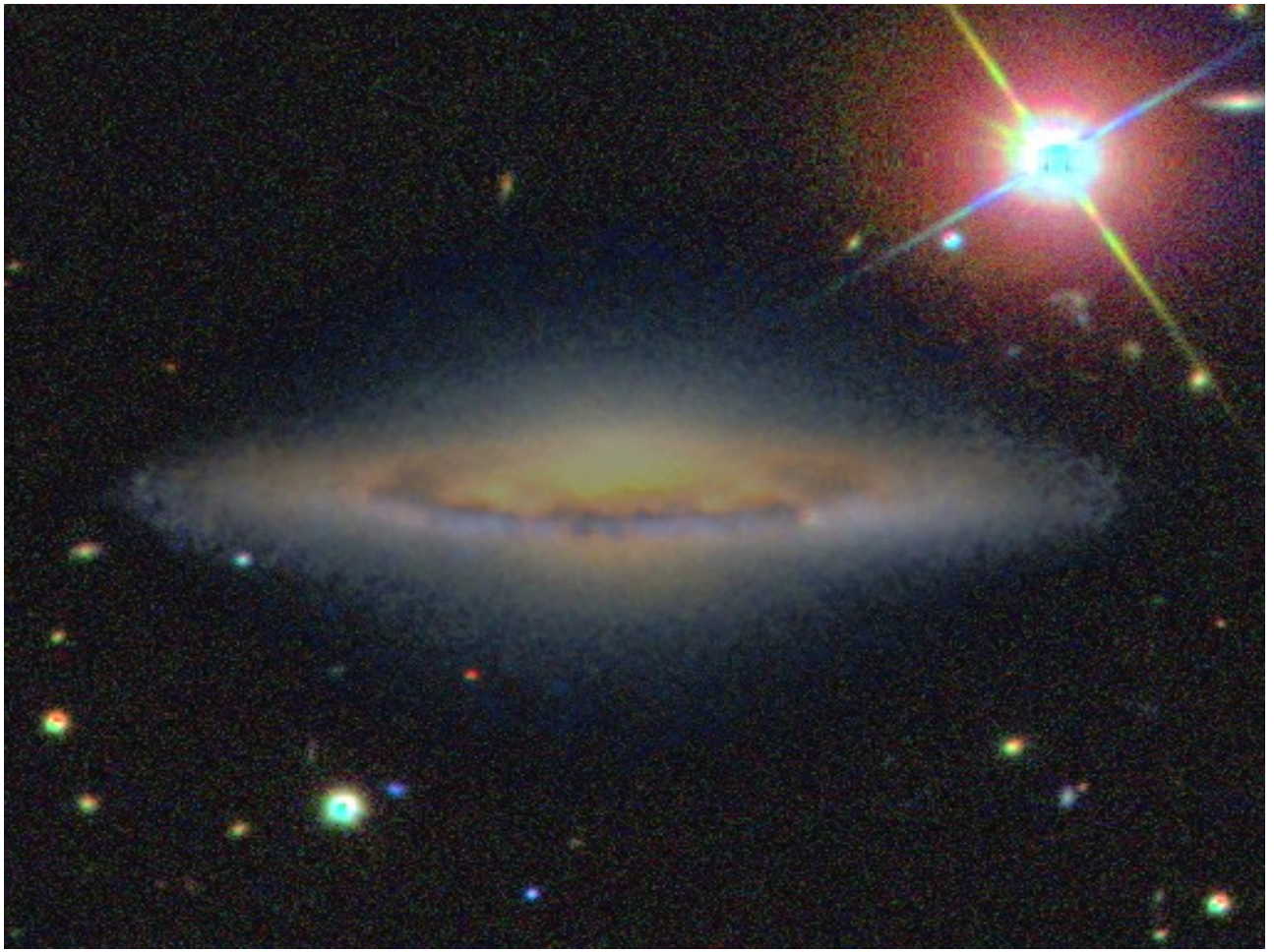
Structure formation in a CDM Universe



Thomas Quinn, University of Washington

Greg Stinson, **Charlotte Christensen**, Alyson Brooks
Ferah Munshi

Fabio Governato, **Andrew Pontzen,** Chris Brook,
James Wadsley

Microwave Background Fluctuations

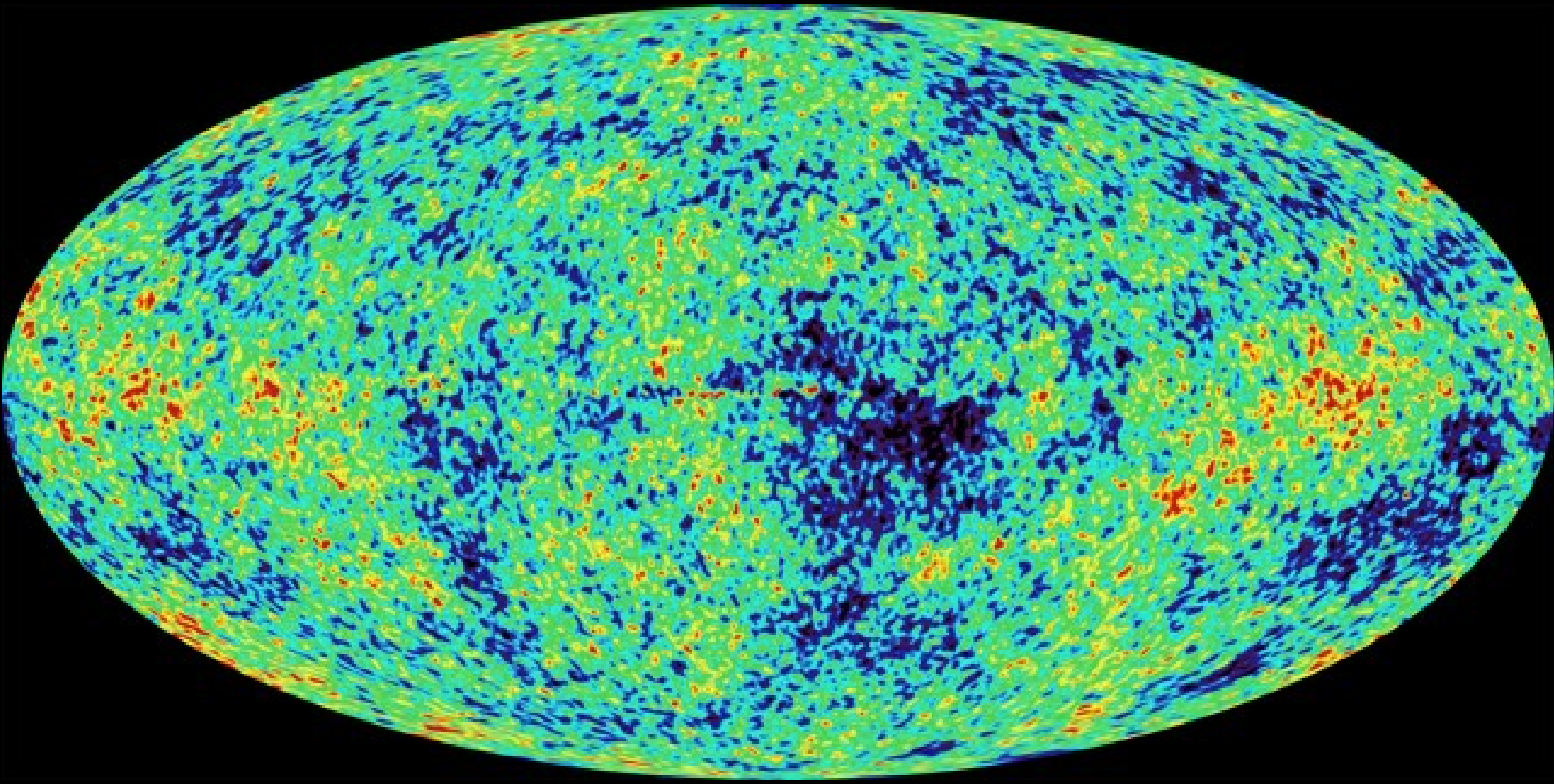
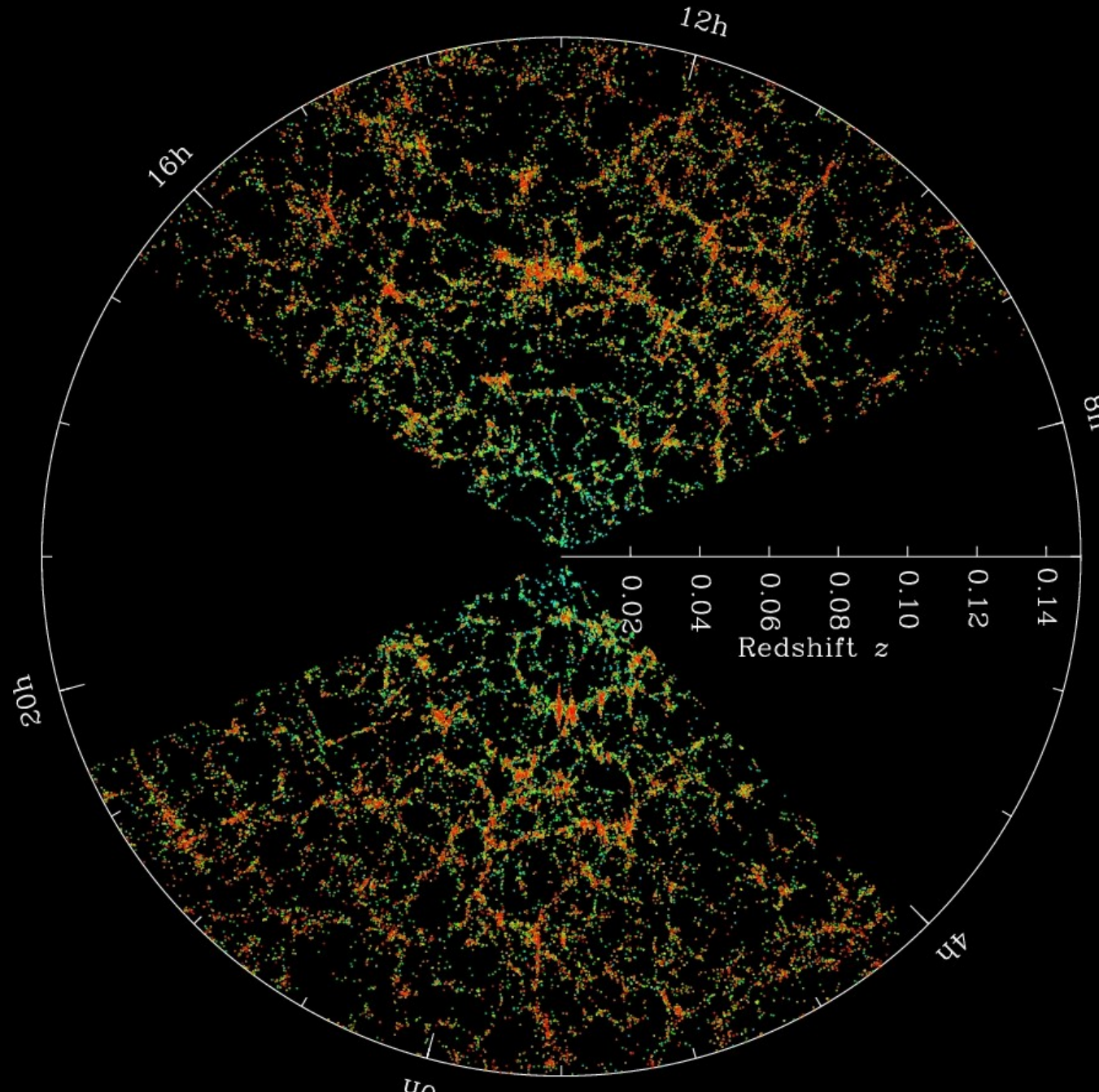
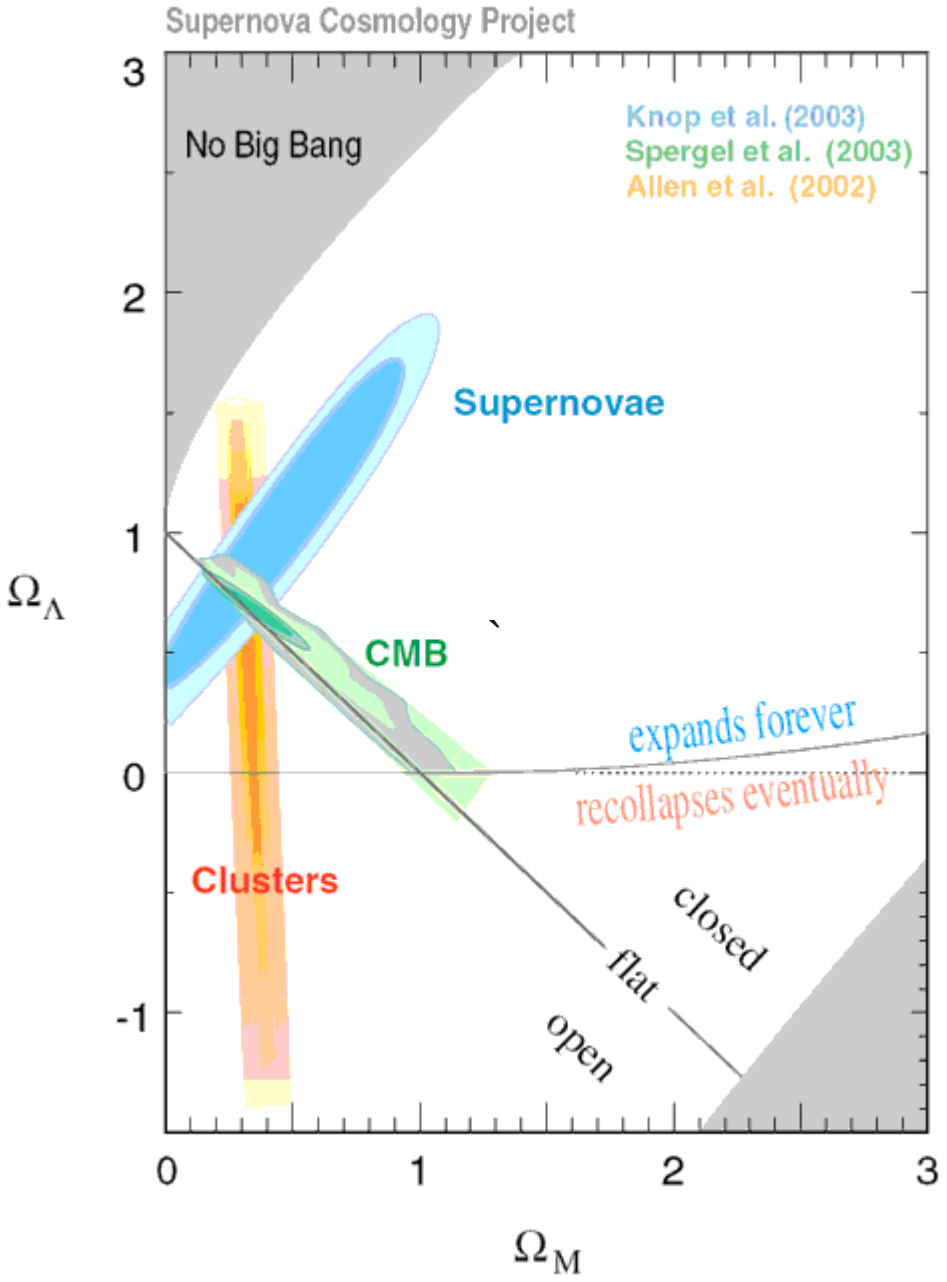


Image courtesy NASA/WMAP

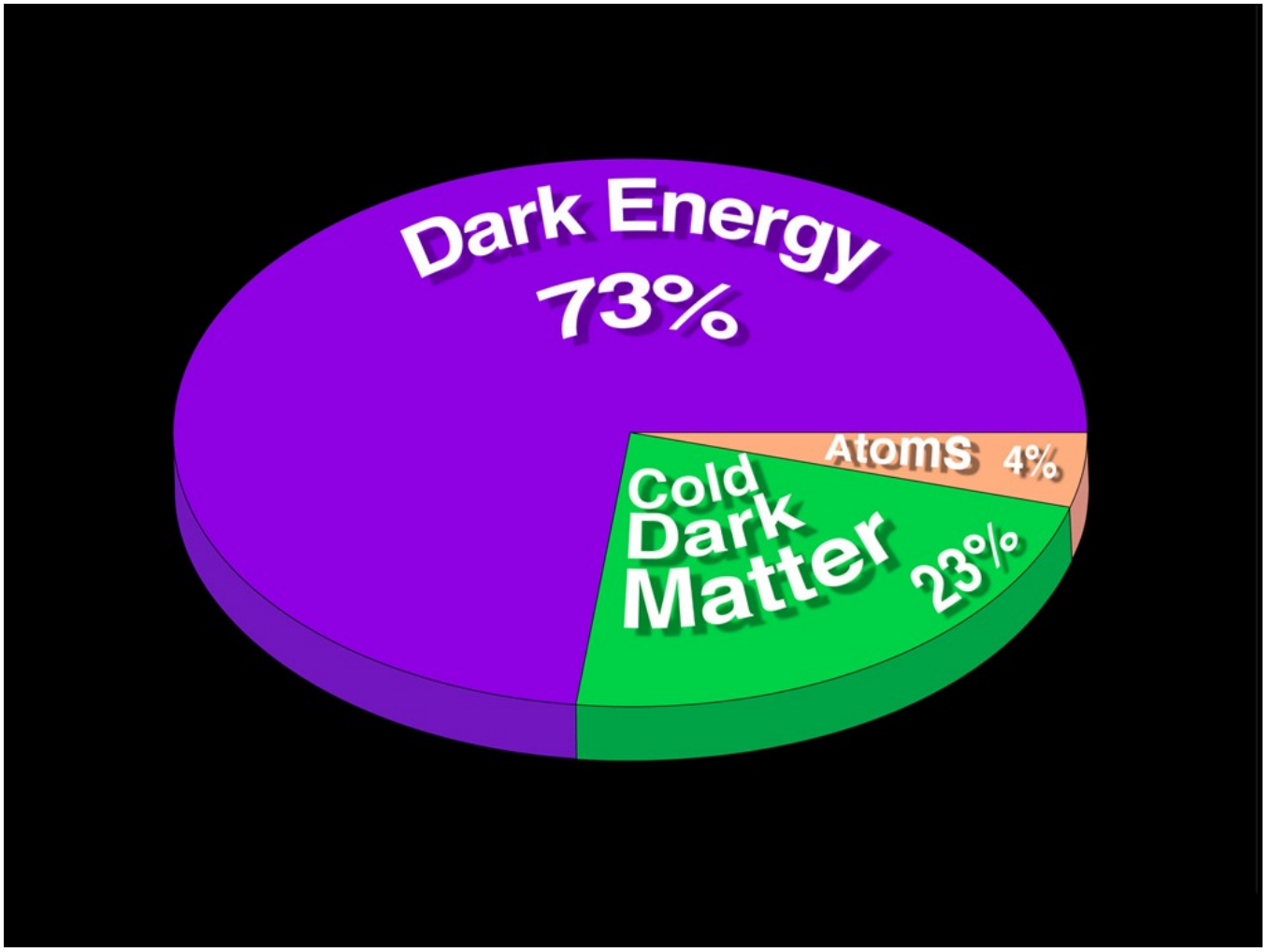
Large Scale Clustering



A well constrained cosmology



Contents of the Universe

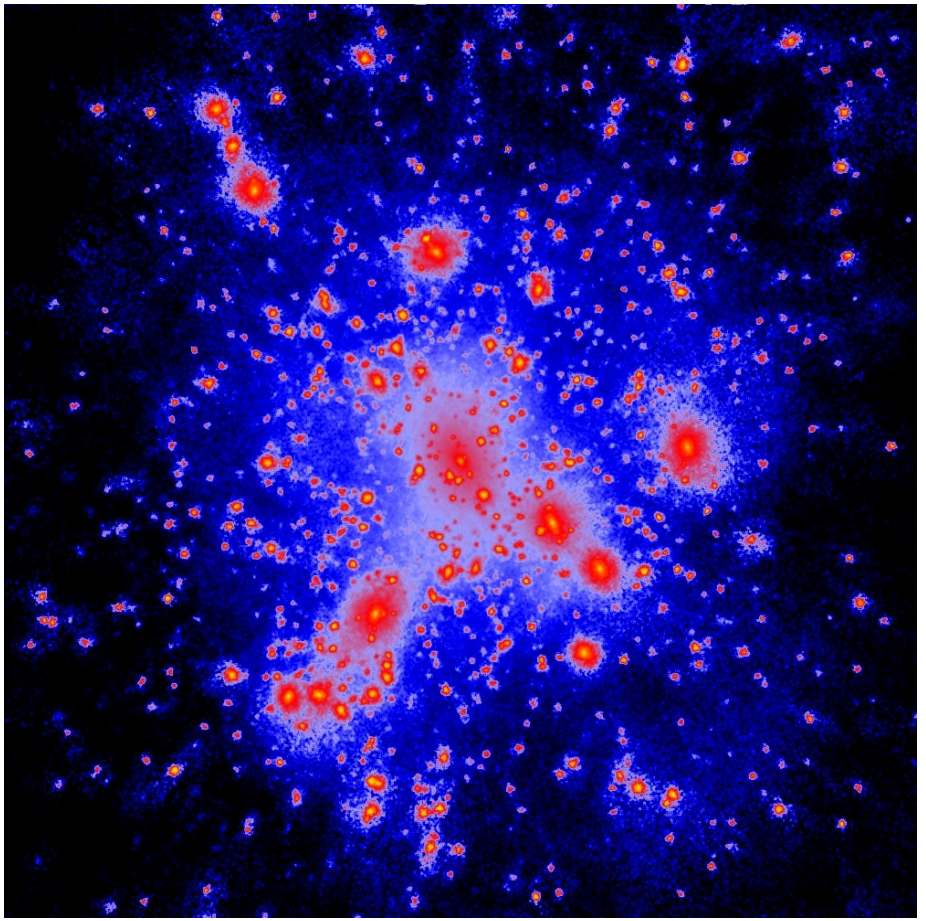


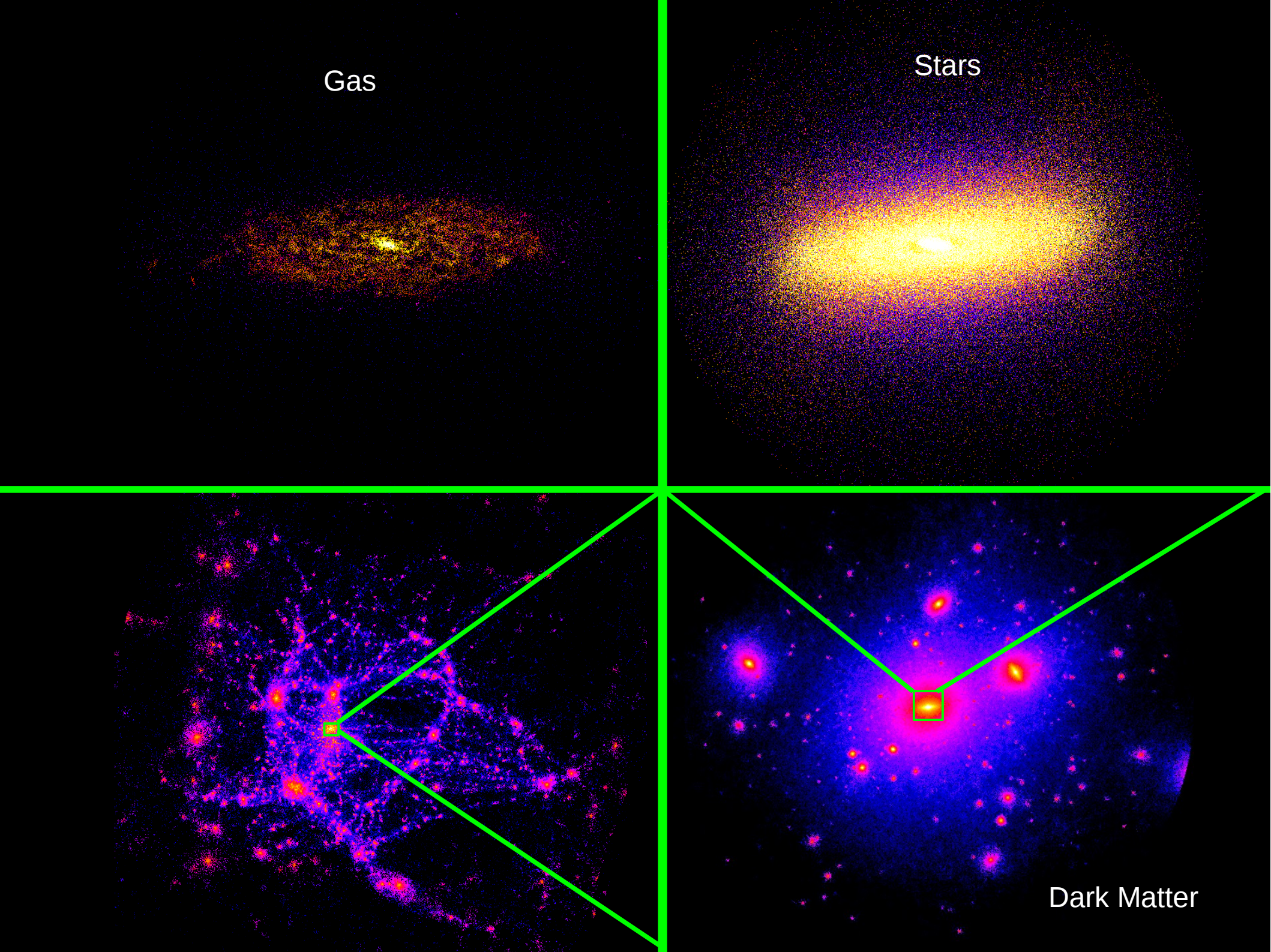
Can it make one of these?

Structure formation issues

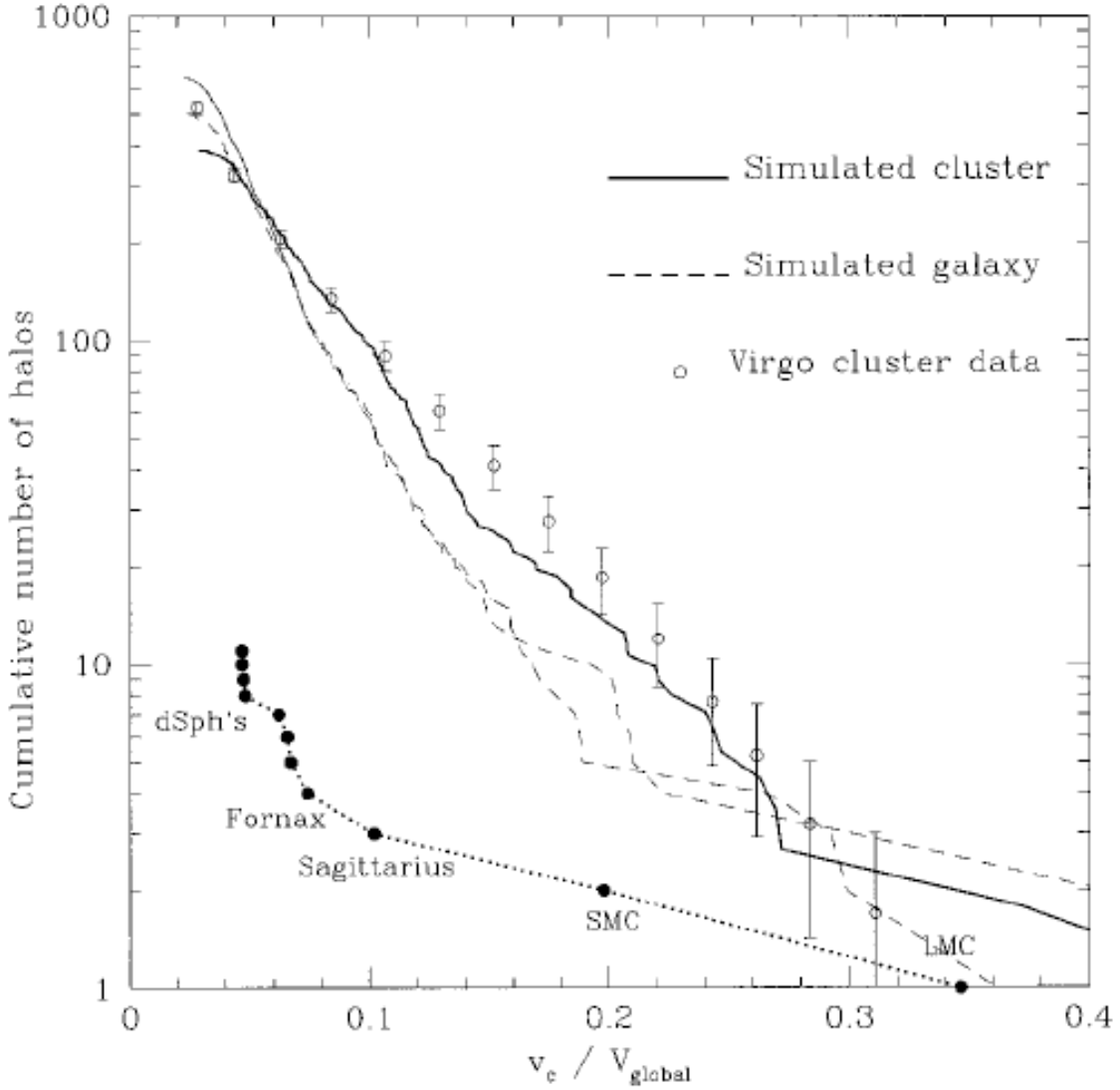
- The substructure problem
- The angular momentum problem
- The cusp problem

Light vs CDM structure




Gas
Stars
Dark Matter

The CDM Substructure Problem

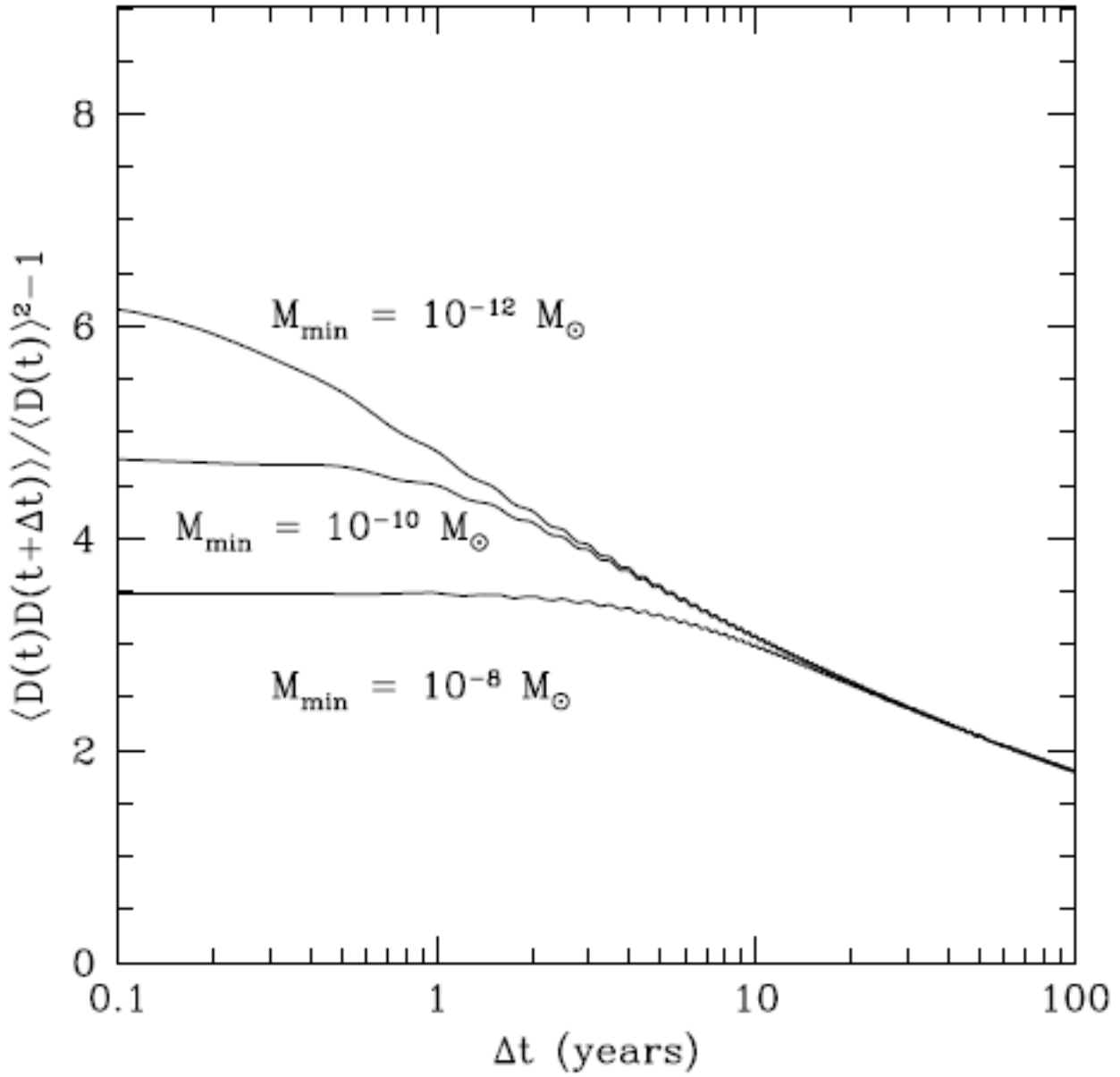


Moore et al 1998

Substructure down to 100 pc

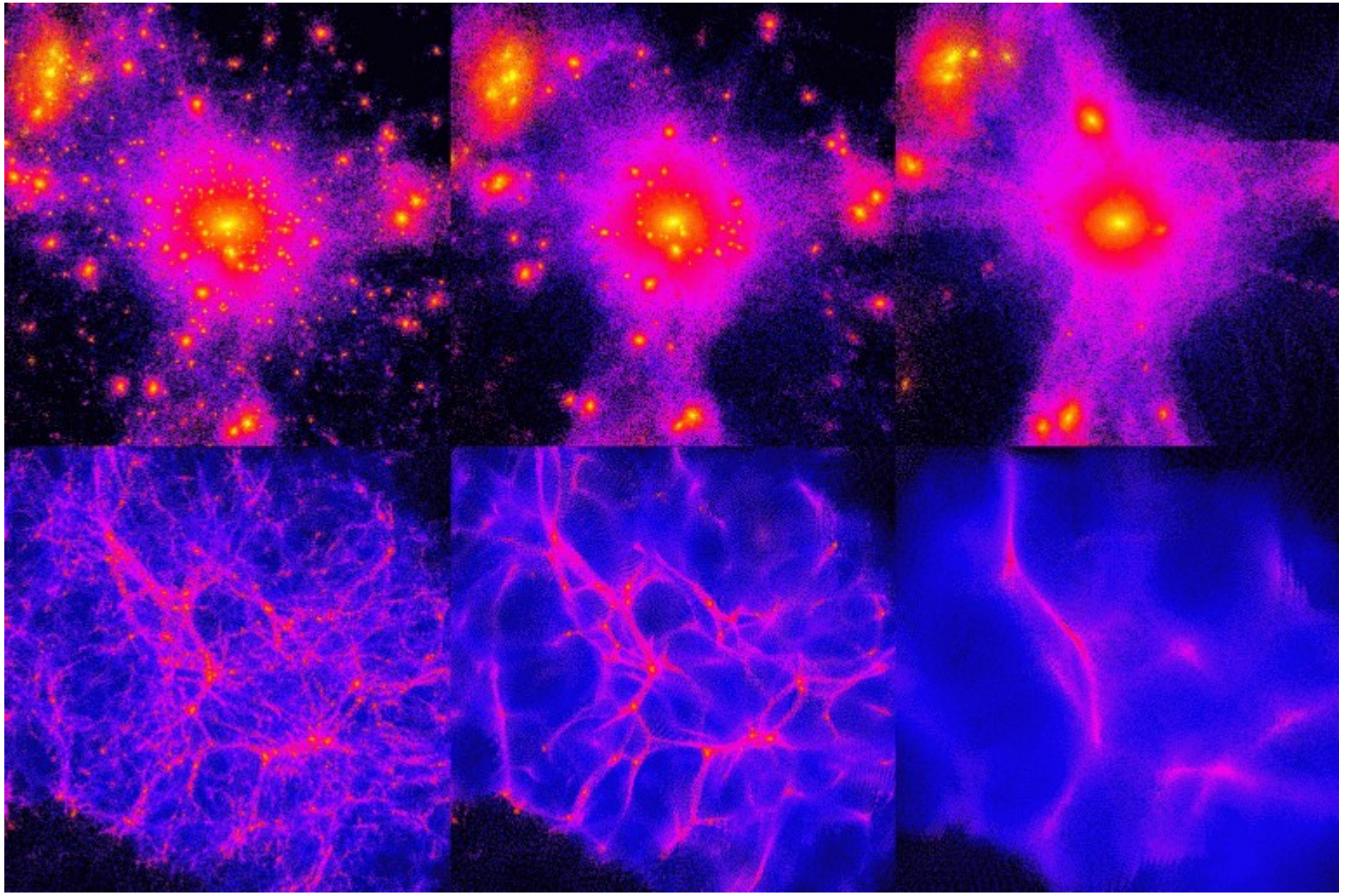
Stadel et al, 2009

Consequences for direct detection



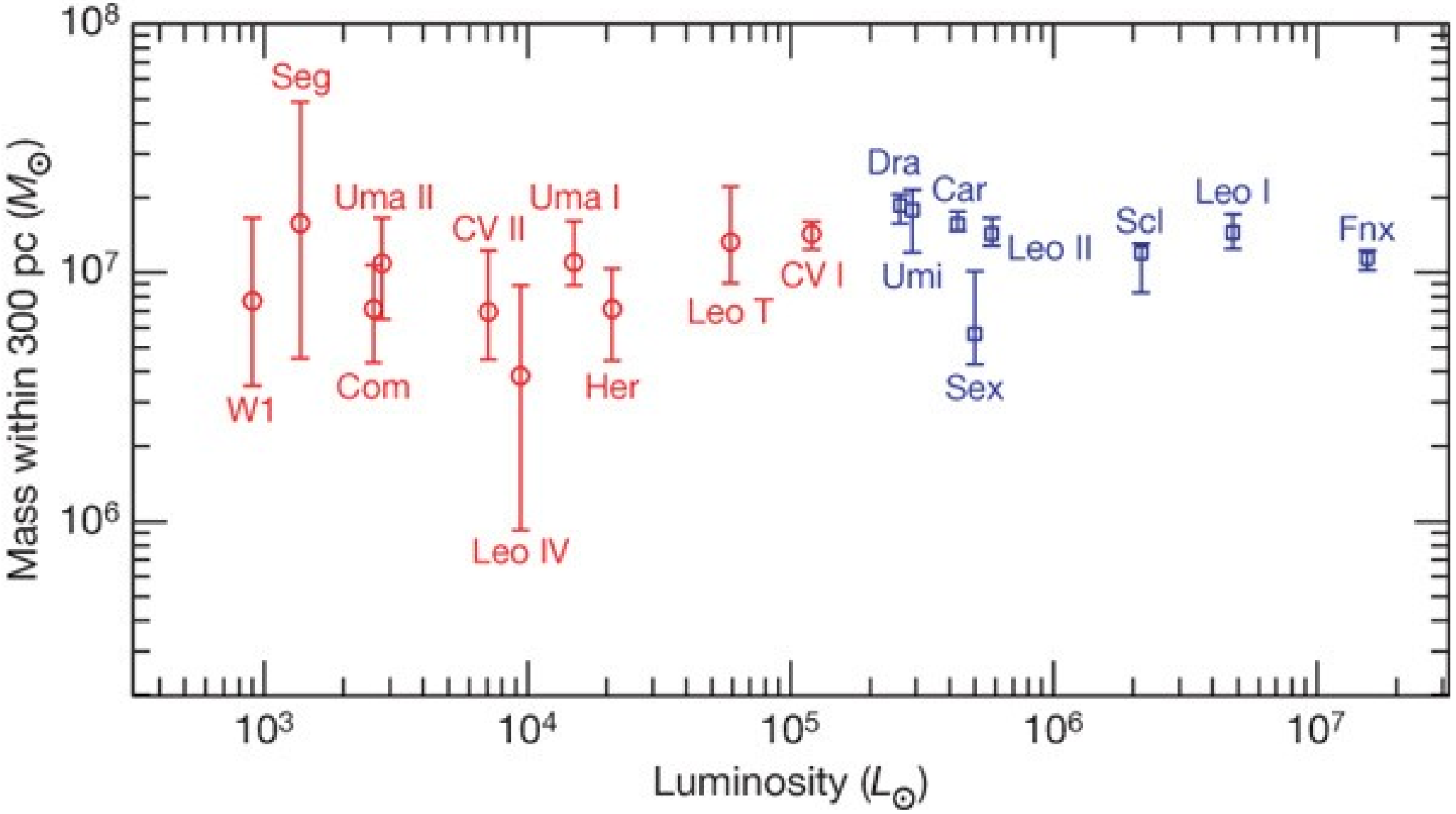
Afshordi etal 2010

Warm Dark Matter



cold warm hot

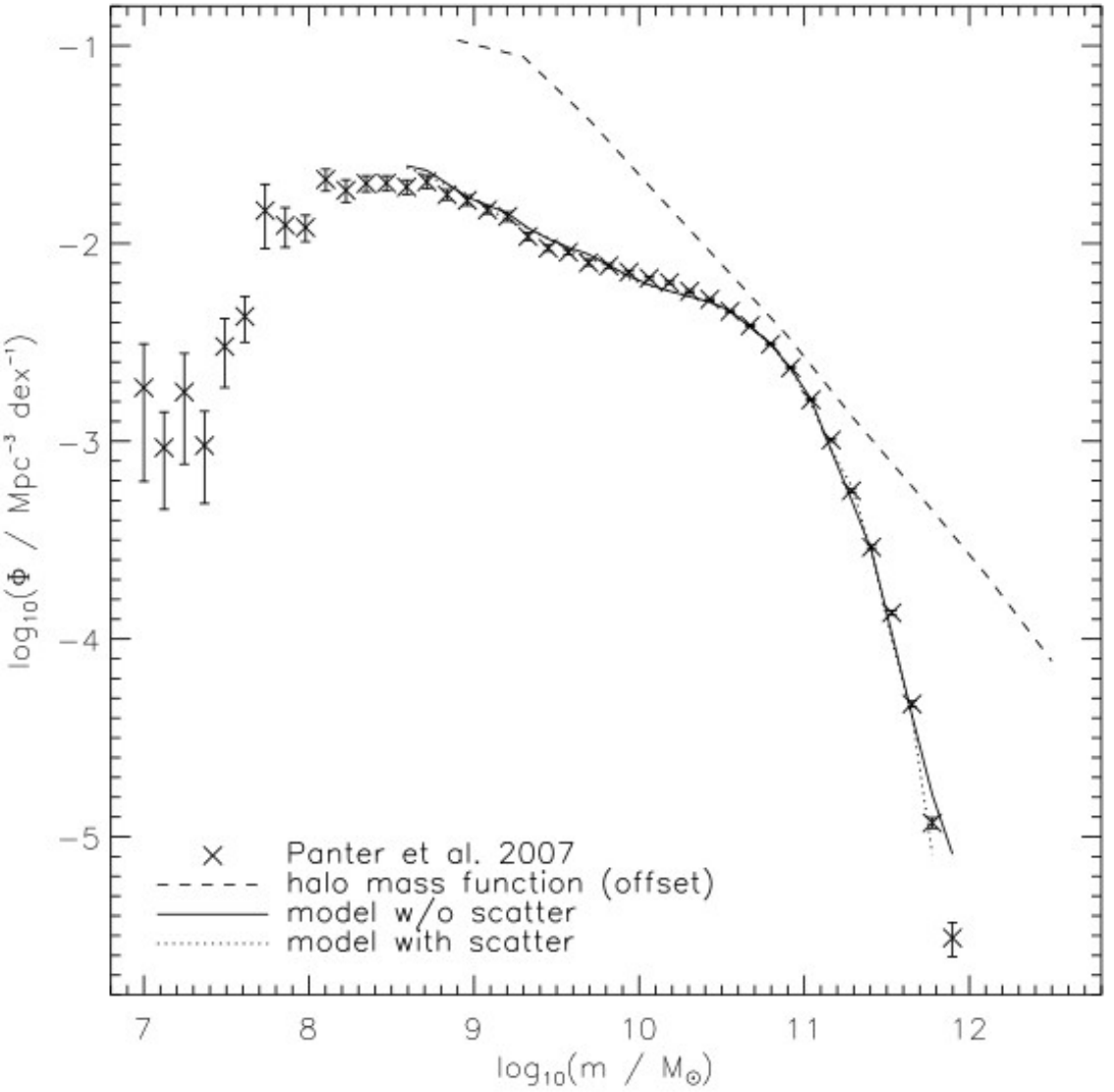
Constant Core Mass



Strigari et al 2008

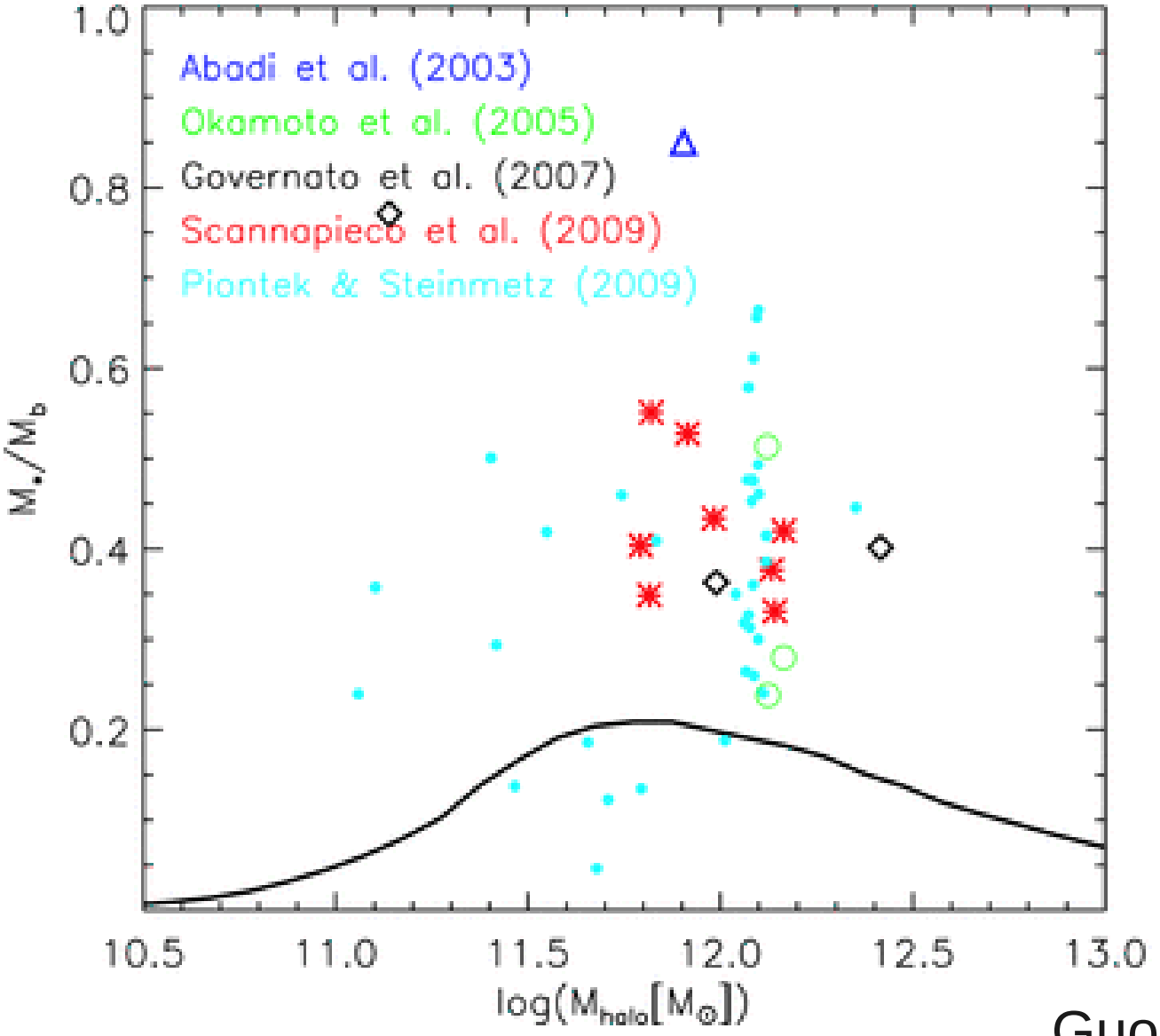
Light vs Mass

Number density



log(halo or galaxy mass)

Simulations of Galaxy formation



Guo e tal, 2010

Origin of Galaxy Spins

- Torques on the collapsing galaxy

  (Peebles, 1969; Ryden, 1988)

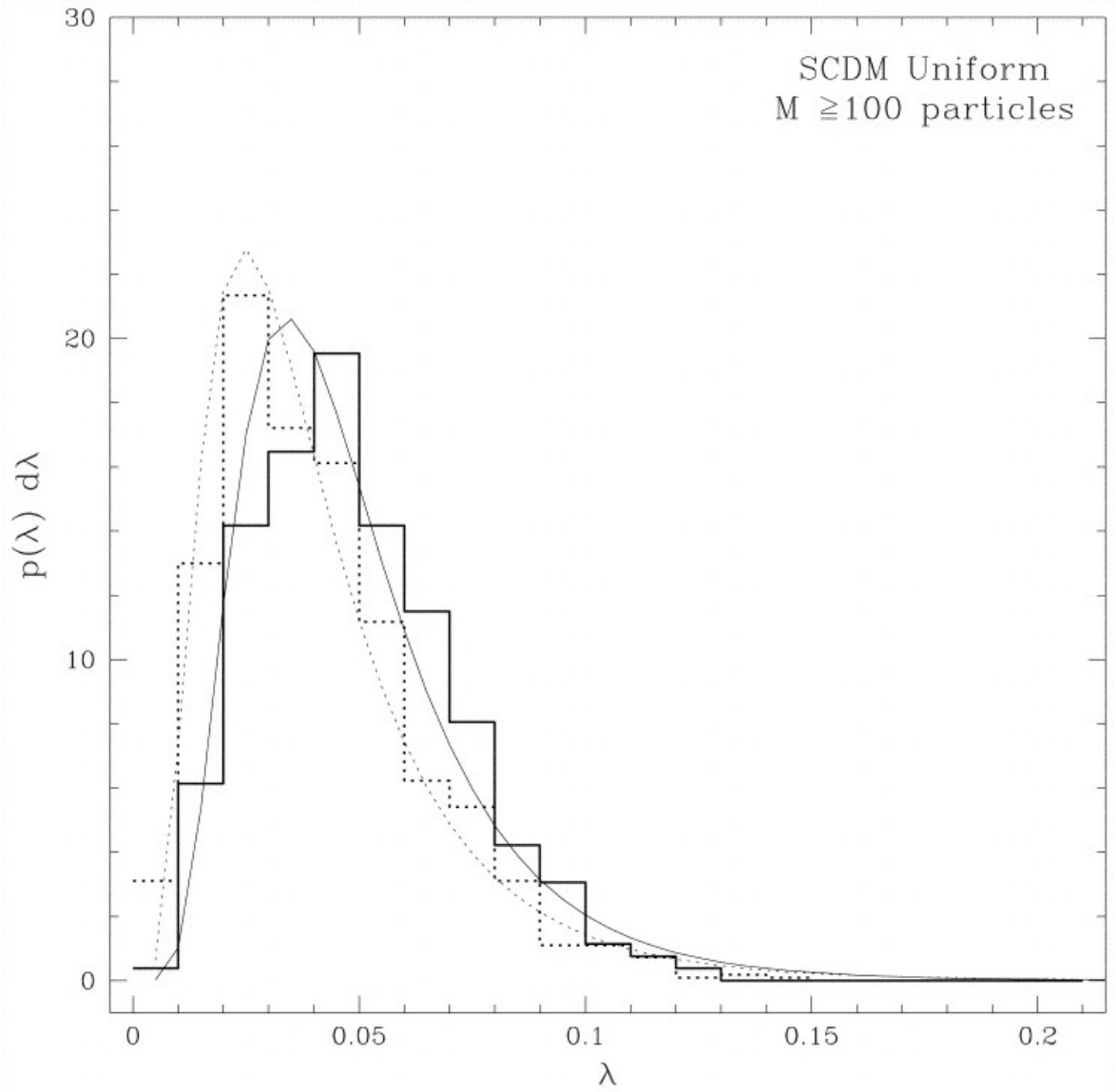
$$\boldsymbol{\tau}(x) = -\frac{GM_{\rm sh}}{4\pi}\int \epsilon(\boldsymbol{x})\boldsymbol{x} \times \nabla\Phi(\boldsymbol{x})d\Omega$$

$$\langle|\boldsymbol{\tau}|^2\rangle = 3\left(\frac{4\pi}{5}G\right)^2 \sum_{m=-2}^{2}\sum_{n=-2}^{2} mn\langle a_{2m}(x)a_{2n}^*(x)q_{2m}^*(x)q_{2n}(x)\rangle$$

$\lambda \equiv L\, E^{1/2}/GM^{5/2} \approx 0.09$ for galaxies

Distribution of Halo Spins

f(λ)



$\Lambda = LE^{1/2}/GM^{5/2}$

Gardner, 2001

Angular momentum Problem

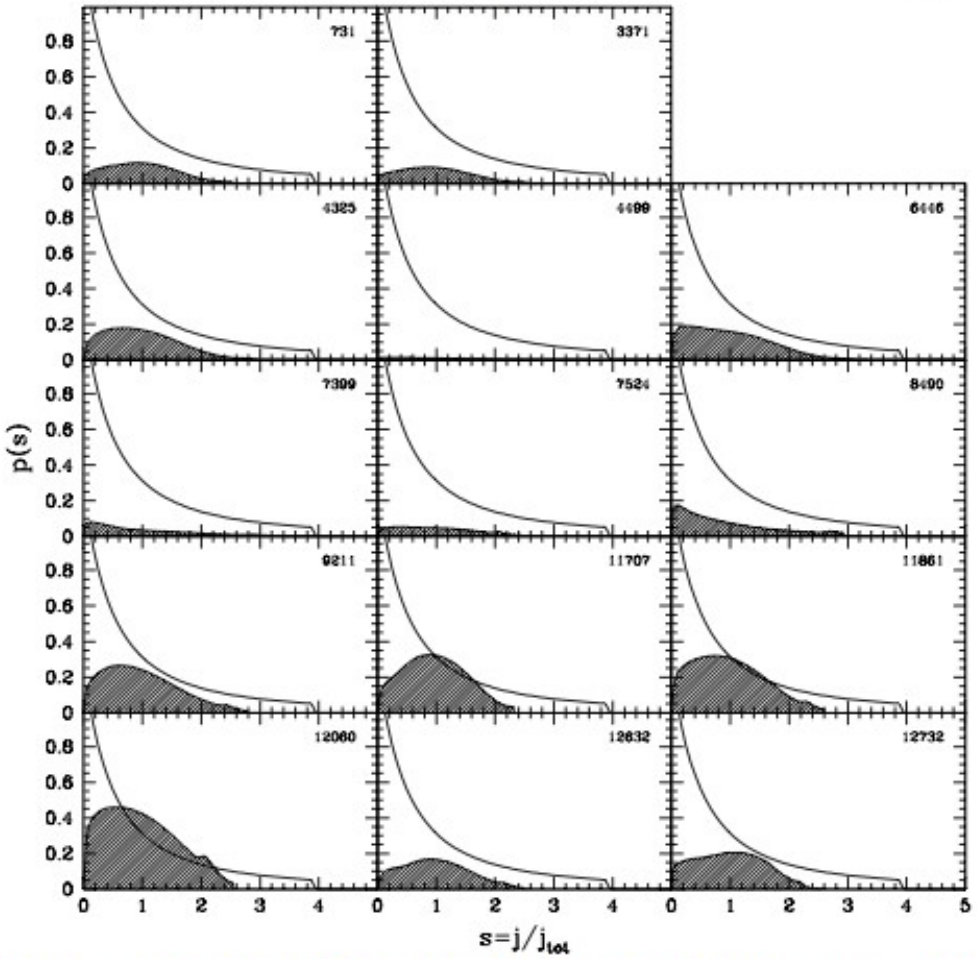
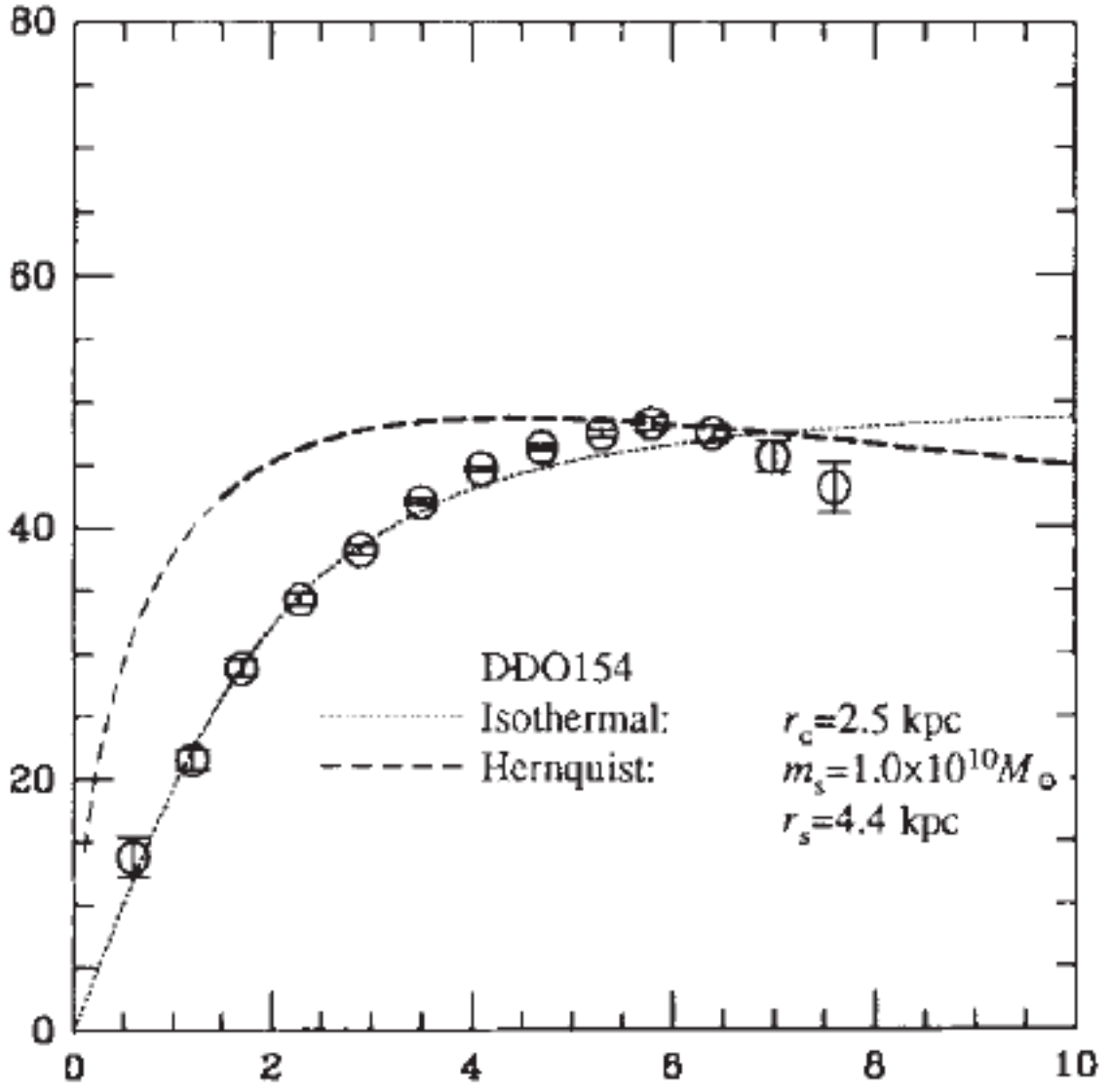


Figure 4. The shaded areas indicate the $p(s)$ of the AMDs for the 14 disc galaxies in our sample, normalized to $f_{\rm disc}/f_{\rm bar}$. For comparison we plot $p(s)$ of equation (11) with $\mu = 1.25$ (normalized to unity), and which represents the median of the AMDs of ΛCDM haloes. Under the standard assumption that baryons conserve their specific angular momentum the difference between the two distributions reflects the AMD of the baryonic matter that is not incorporated in the disc. Note that it is preferentially the baryonic matter with both the highest and the lowest angular momenta that is absent in the discs.

Too few low-J baryons

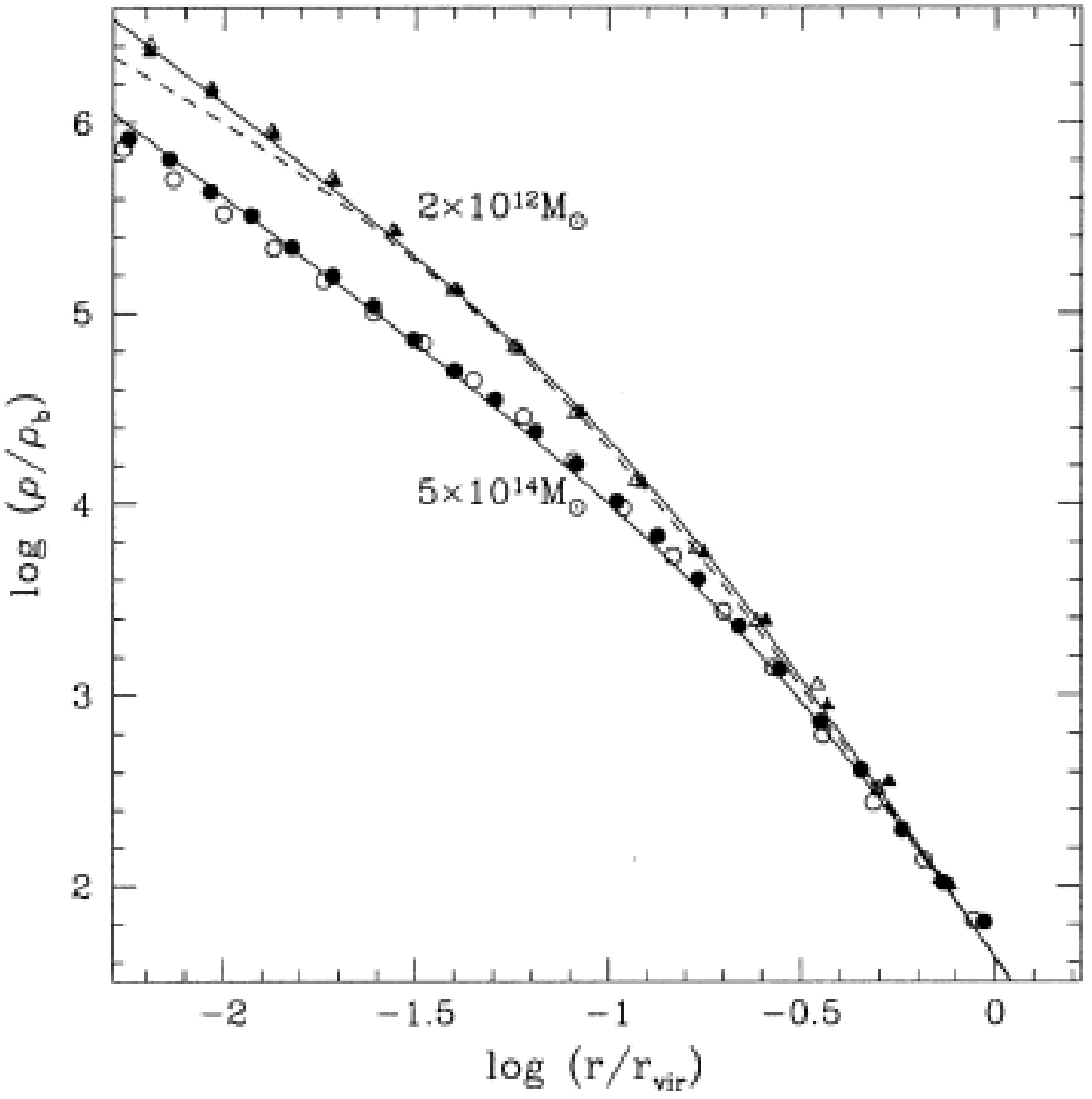
Van den Bosch 01
Bullock 01

Core/Cusps in Dwarfs



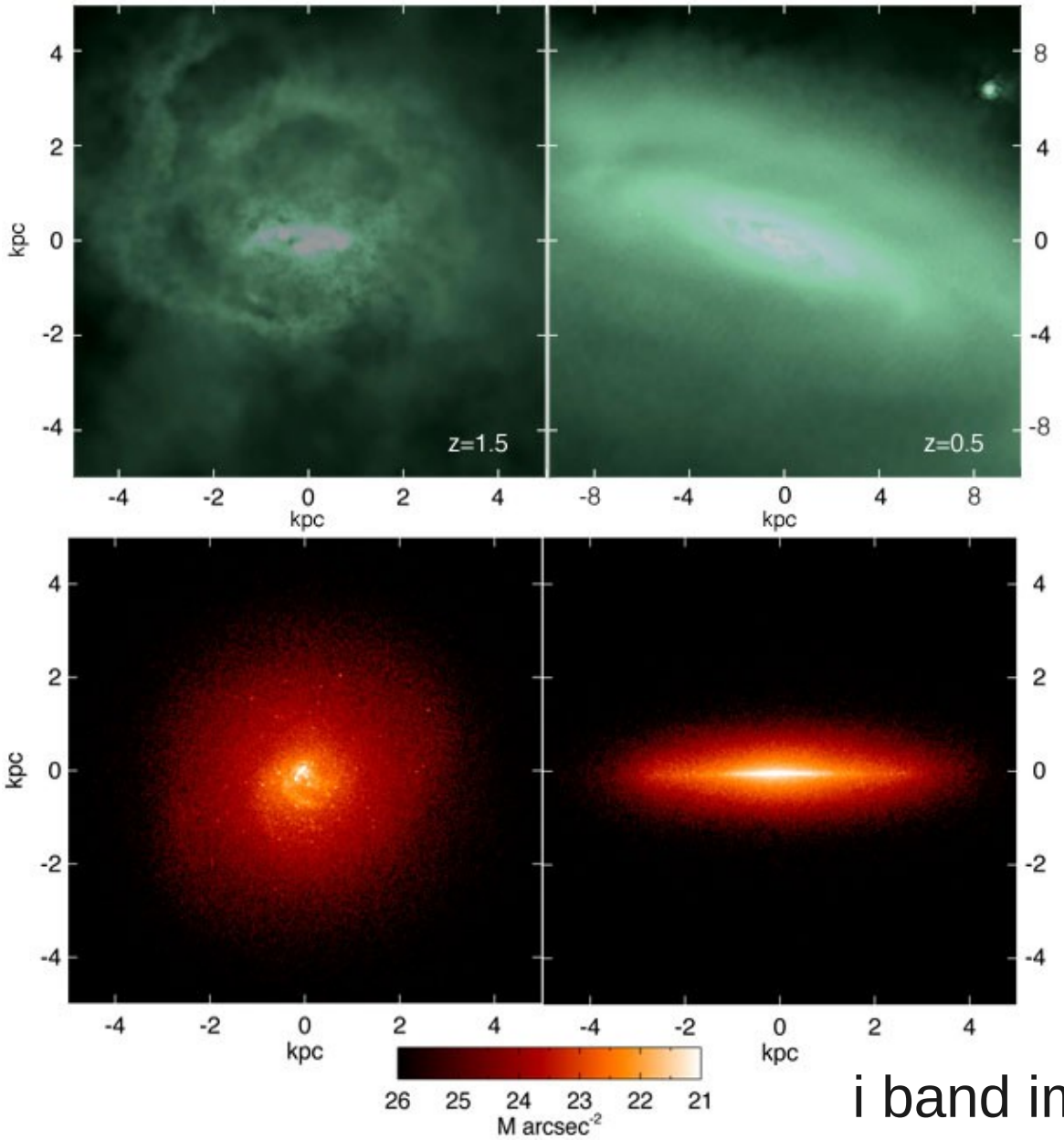
Moore 1994

Warm DM doesn't help



Moore et al 1999

Dwarf simulated to z=0



Stellar mass = 5e8 $M_{sun`}$

M_i = -16.8

g - r = 0.53

V_{rot} = 55 km/s

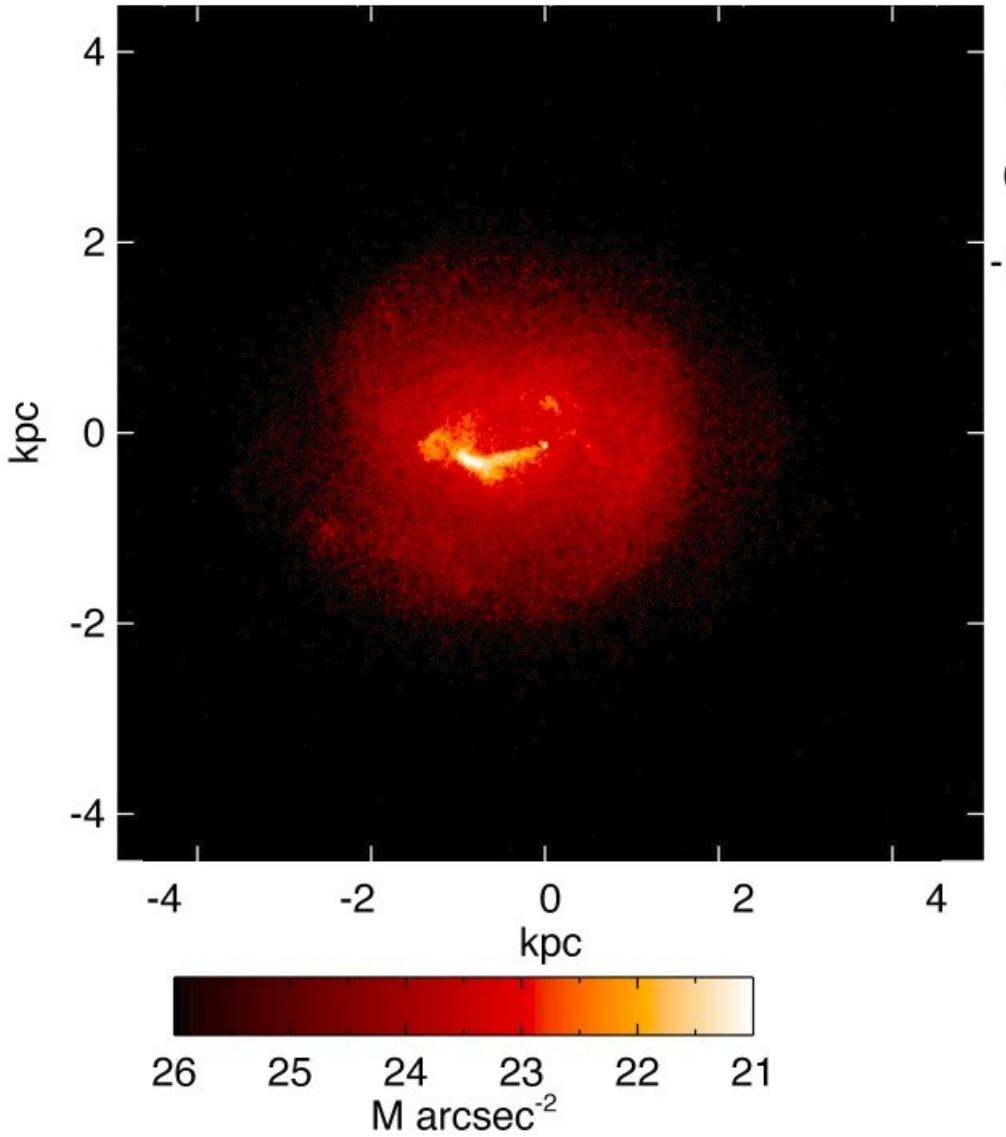
R_d = 1 kpc

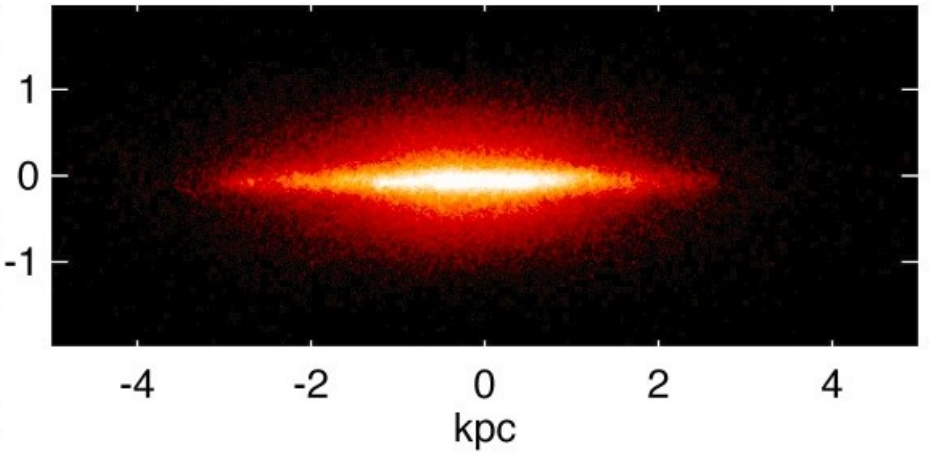
M_{HI}/M_* = 2.5

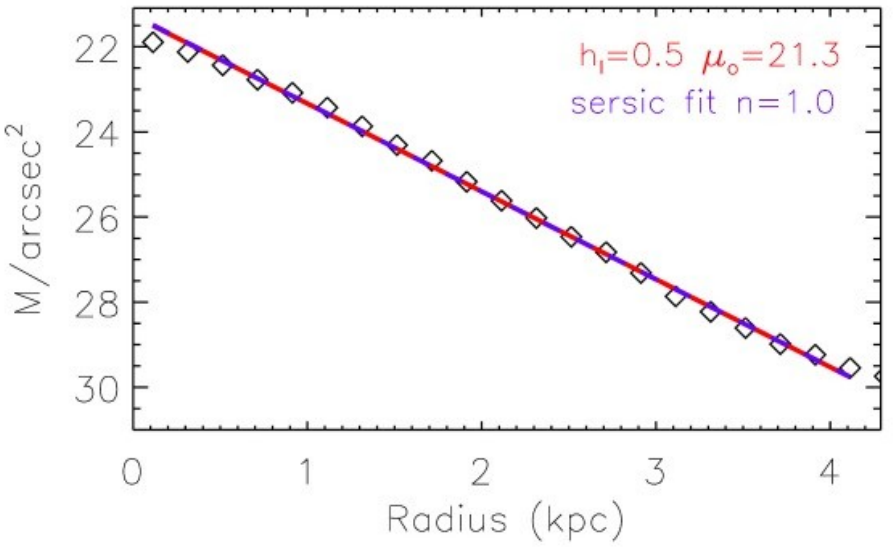
f_b = .3 f_b cosmic

i band image

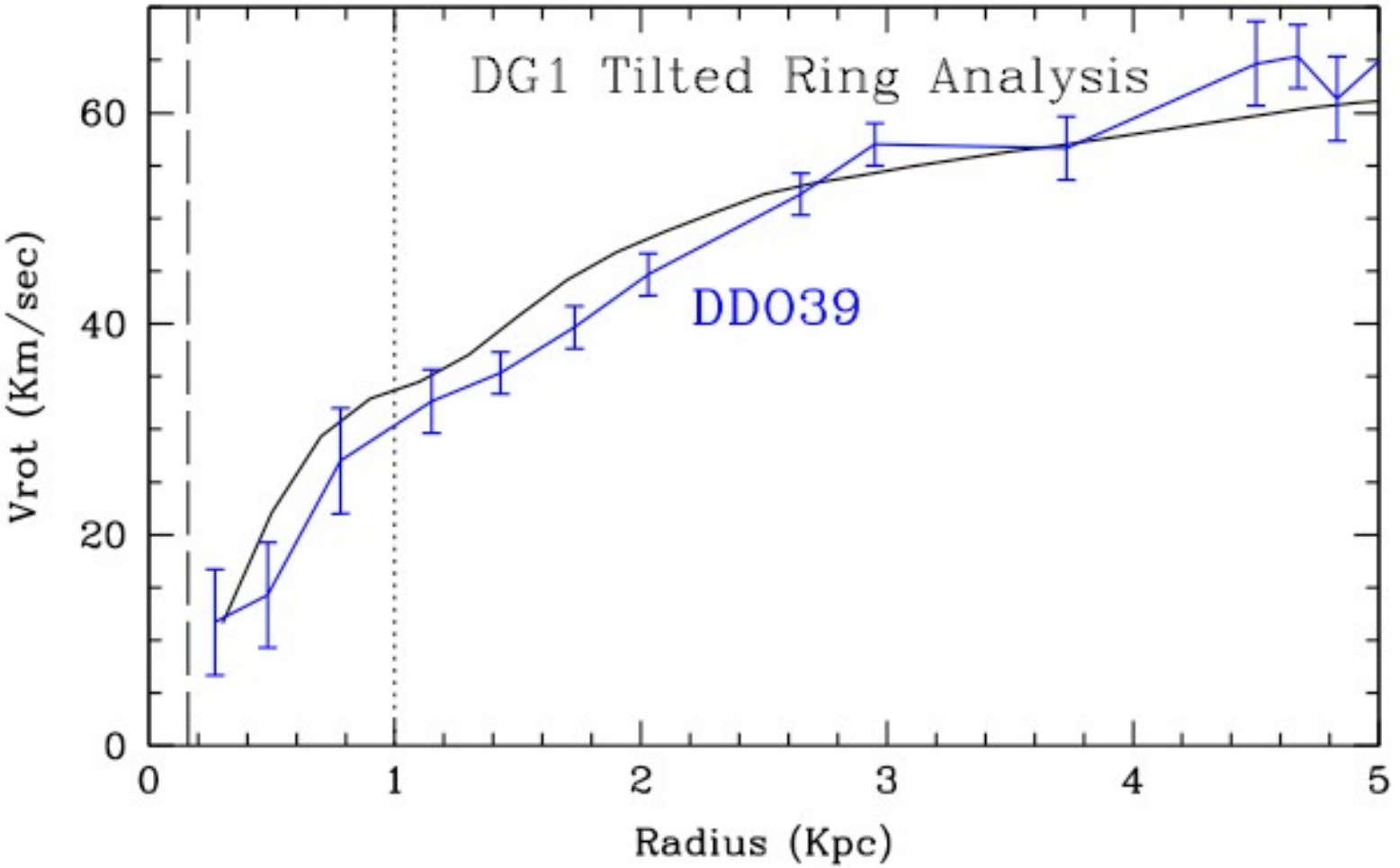
Dwarf Light Profile



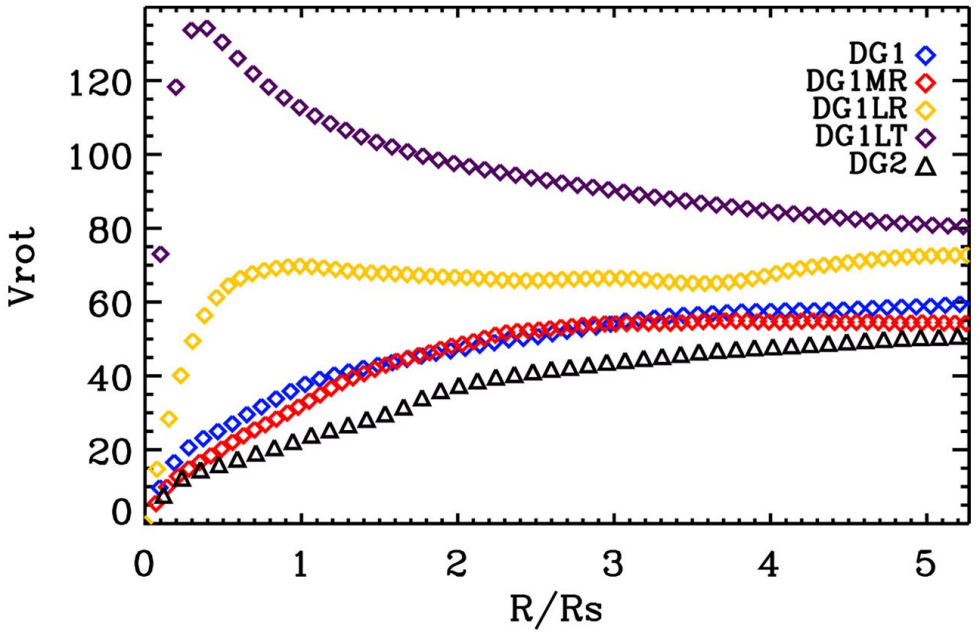


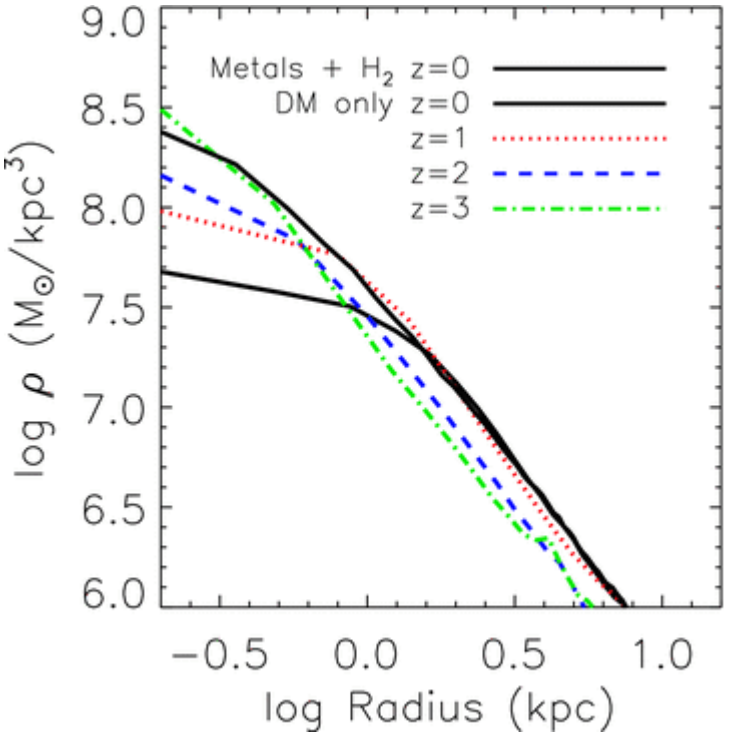


Rotation Curve



Resolution effects

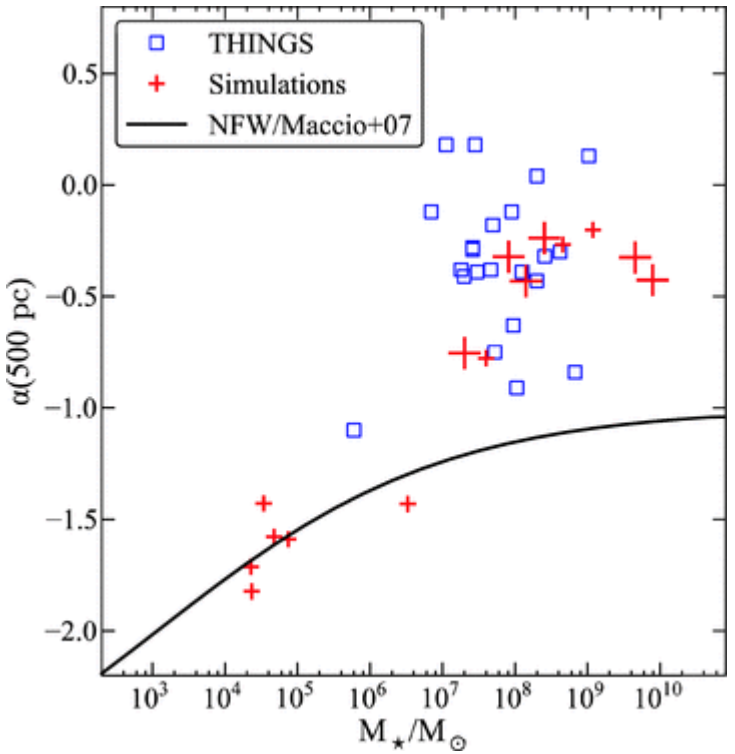


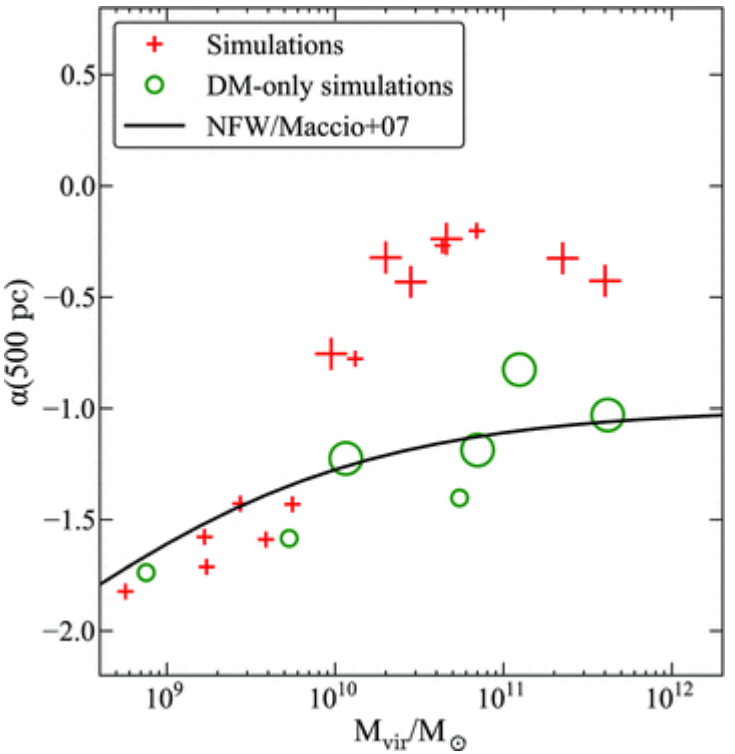


Low resolution: bad

Low resolution star formation: worse

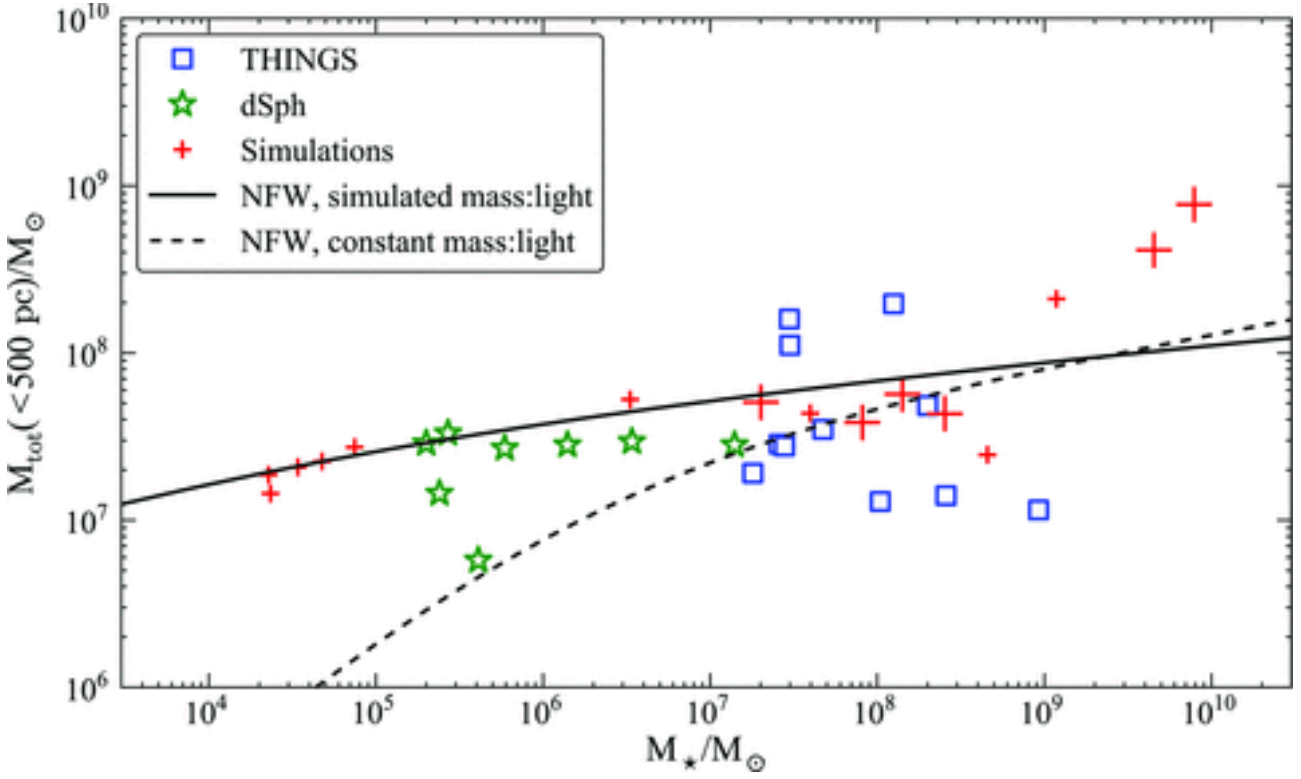
Inner Profile Slopes vs Mass

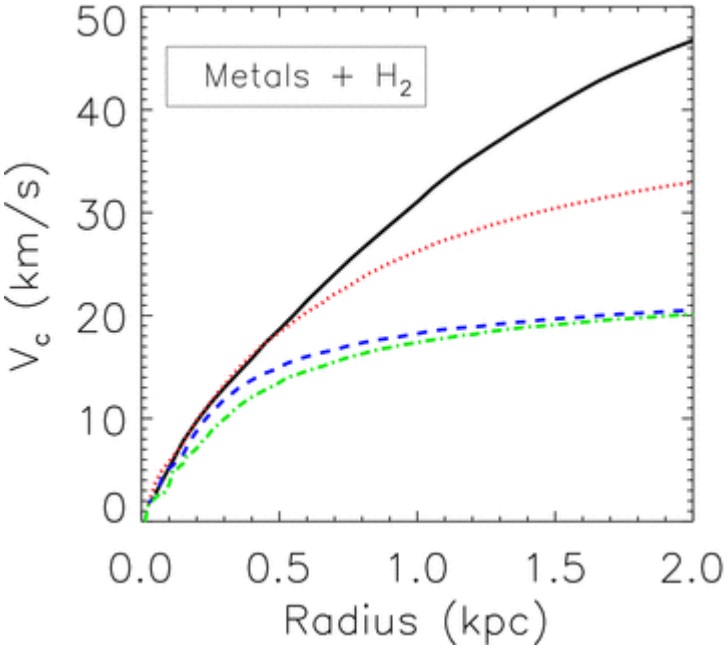




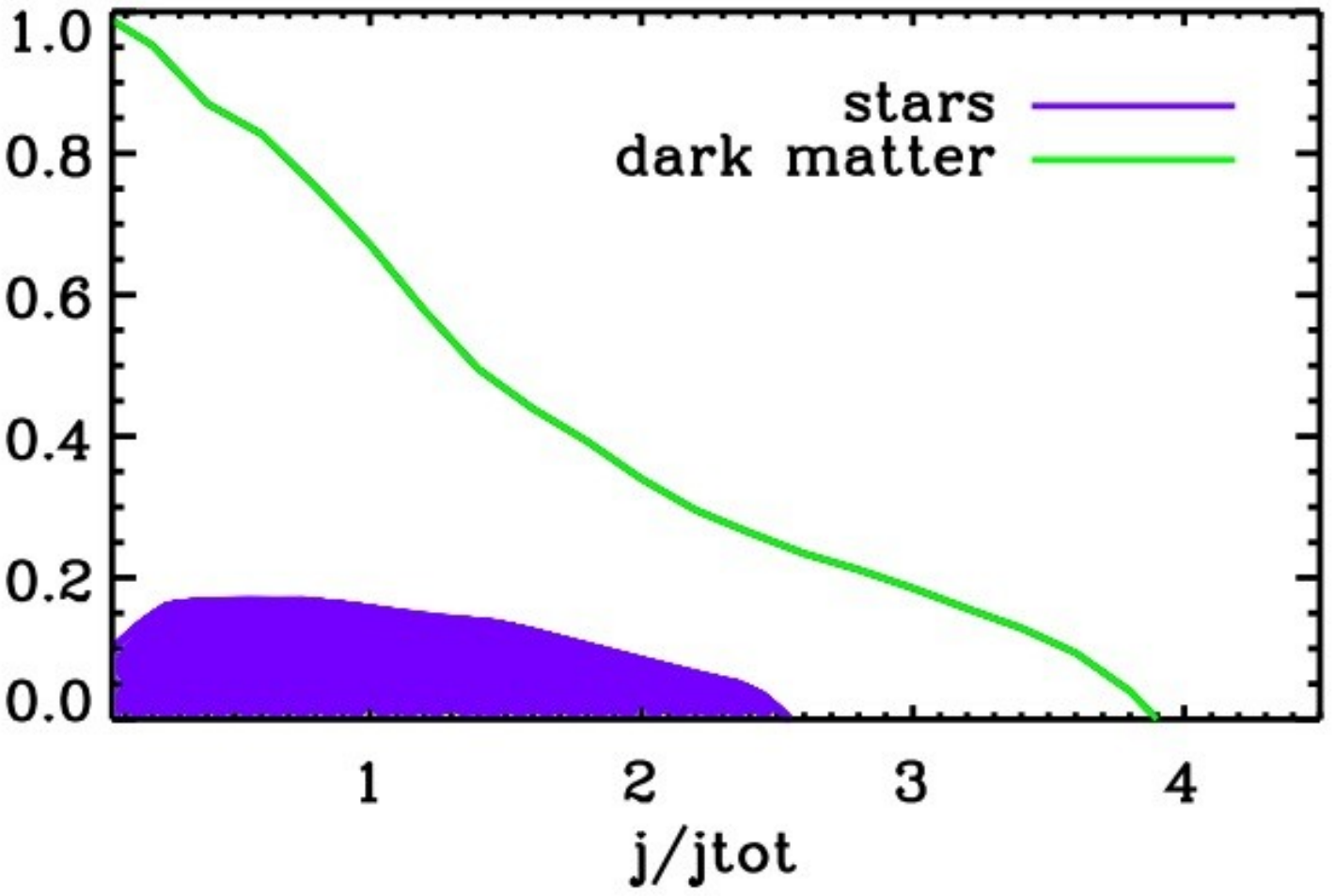
Governato, Zolotov etal 2012

Constant Core Masses



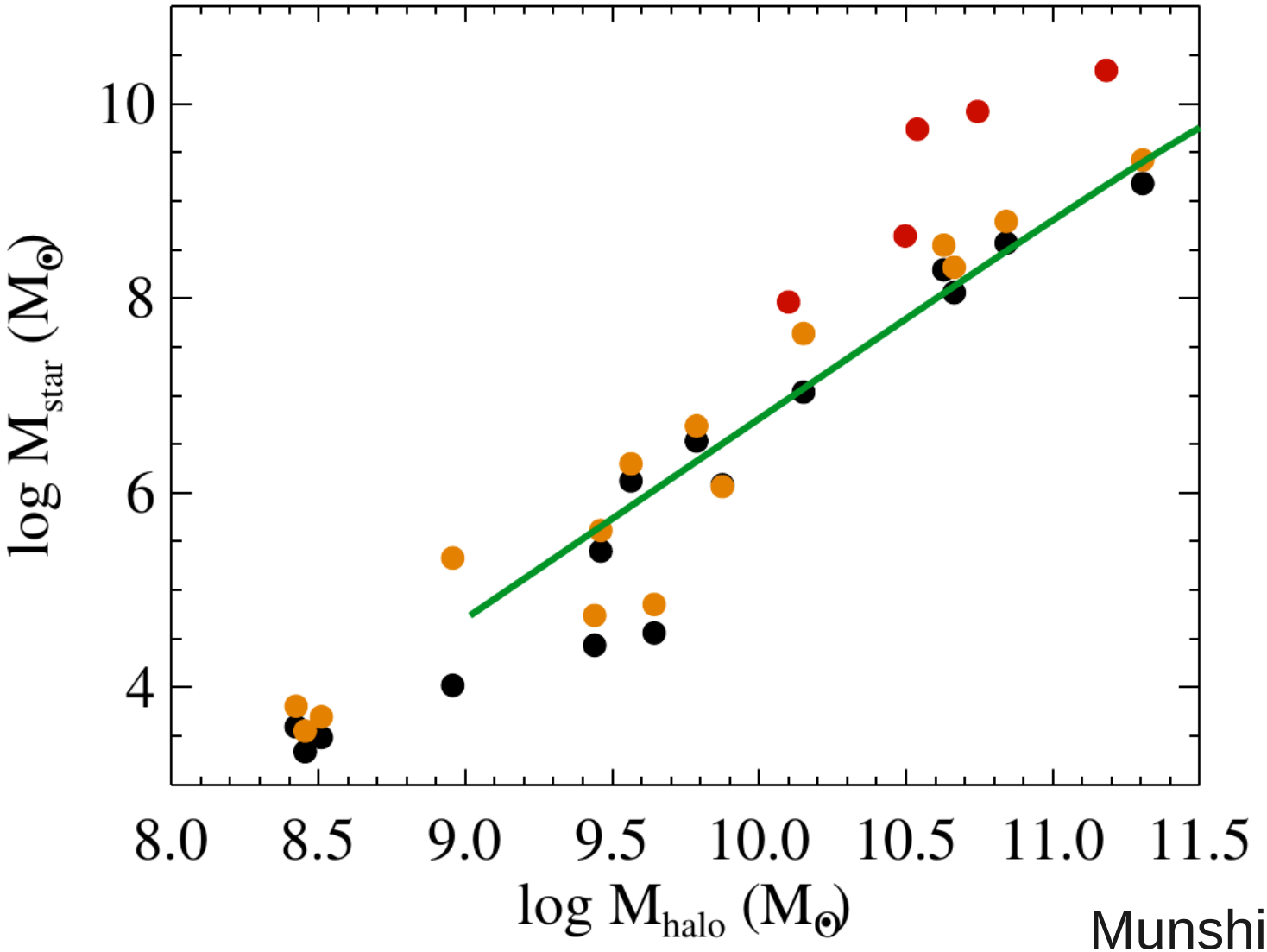


Angular Momentum



Outflows preferential remove low J baryons

Simulation Results: Resolution and H2



Munshi, in prep.

Outstanding Issues

- Profiles of large (Milky Way sized) galaxies still not understood
  - Including satellite galaxies
- Results are dependent on coupling star formation/SNe physics to galactic scales
  - Getting the right answer for the wrong reason?
- Dark matter/baryon is a non-linear dynamical process that needs detailed modeling.