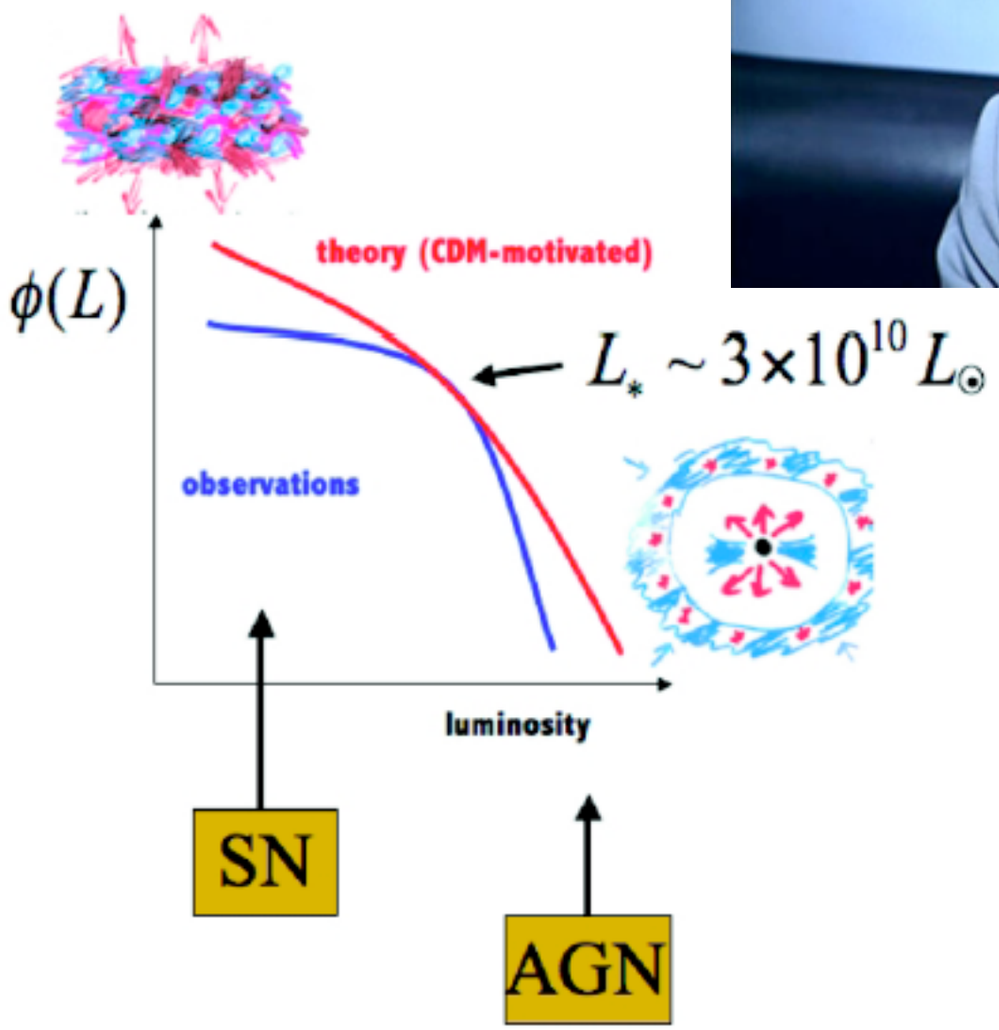
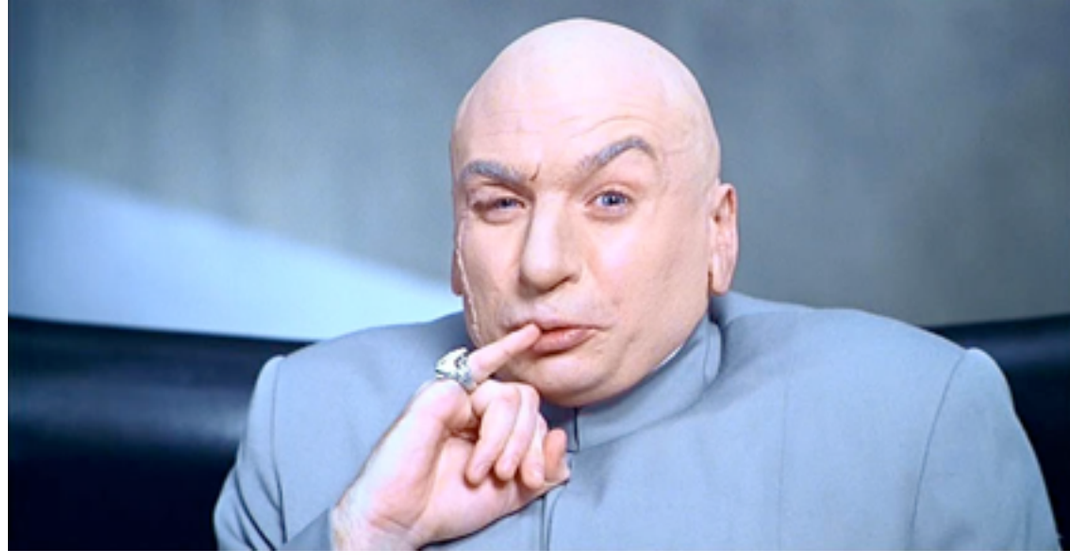
Scaling relations

missing satellite problem

final?

Feedback





Need non-linear mapping between properties of dark matter halos and observed, luminous galaxies

It does not work to make the obvious assumption

$$M_{tot} \propto L$$

One infers the presence of numerous dark sub-halos

Not all sub-halos host proportionately luminous galaxies

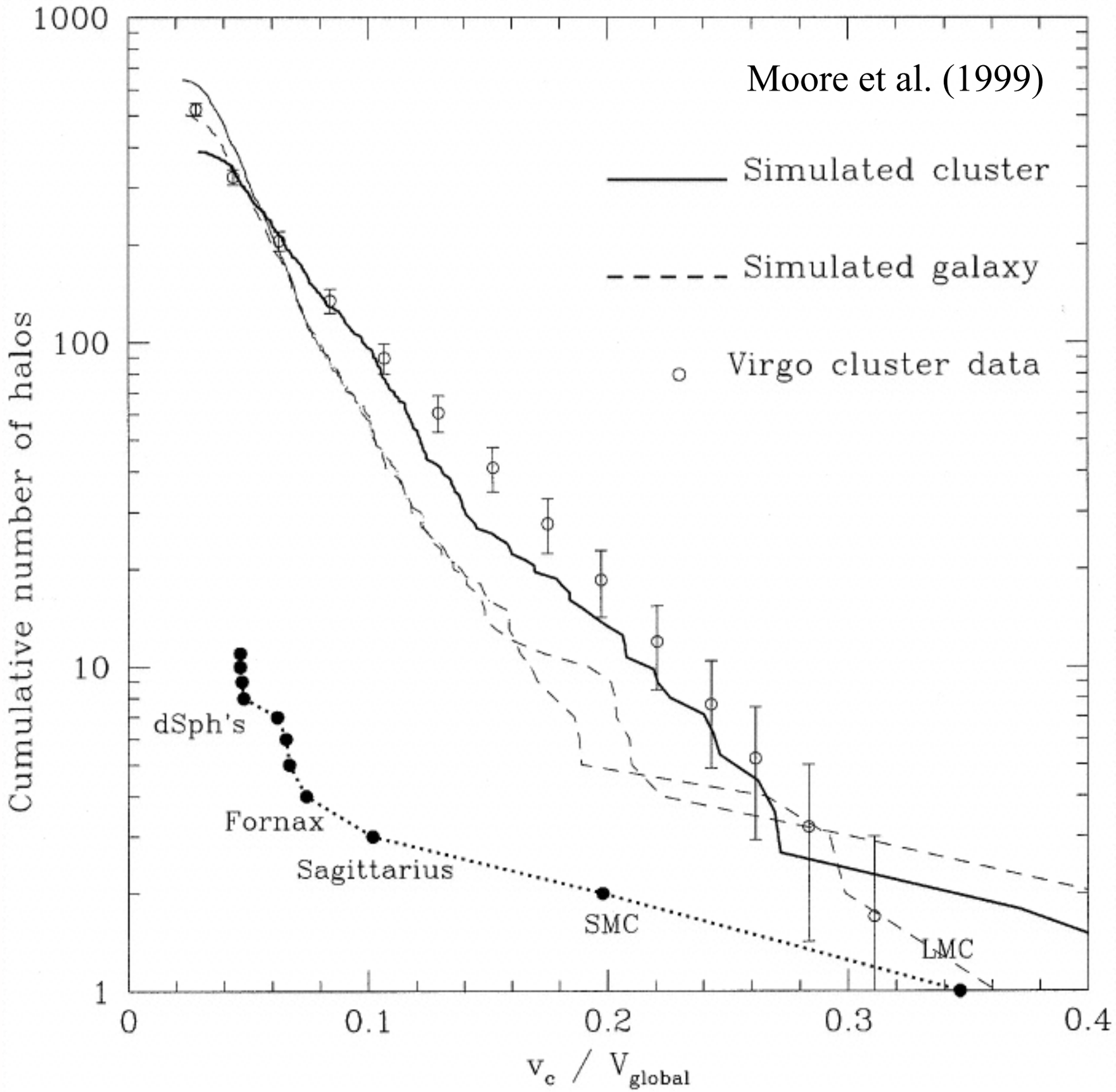
CDM is scale free

Moore et al. (1999)

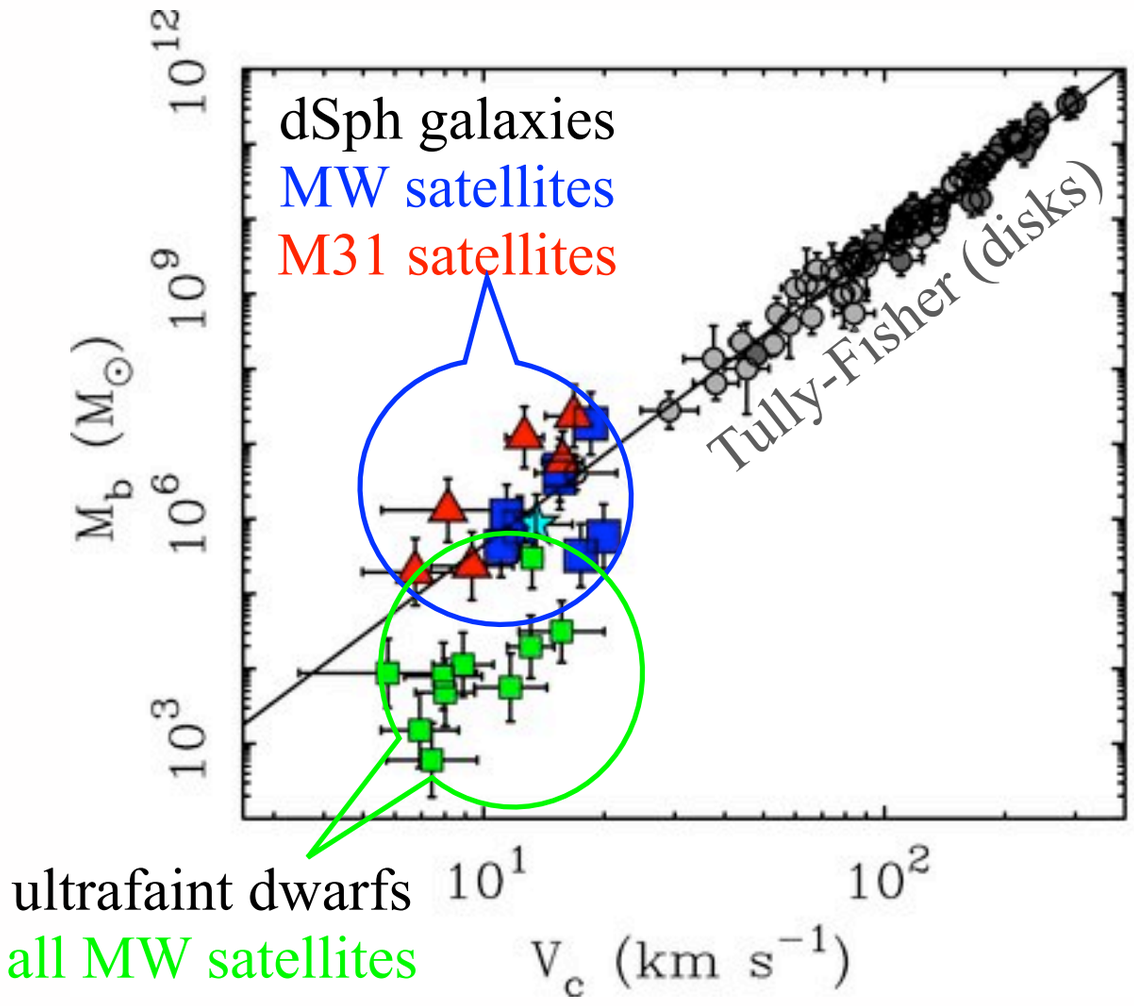
Density of dark matter within a cluster halo of mass $5 \times 10^{14}\,M$ (*top*). The edge of the box is the virial radius, 2000 kpc for the cluster (with peak circular velocity 1100 km s^{-1}).

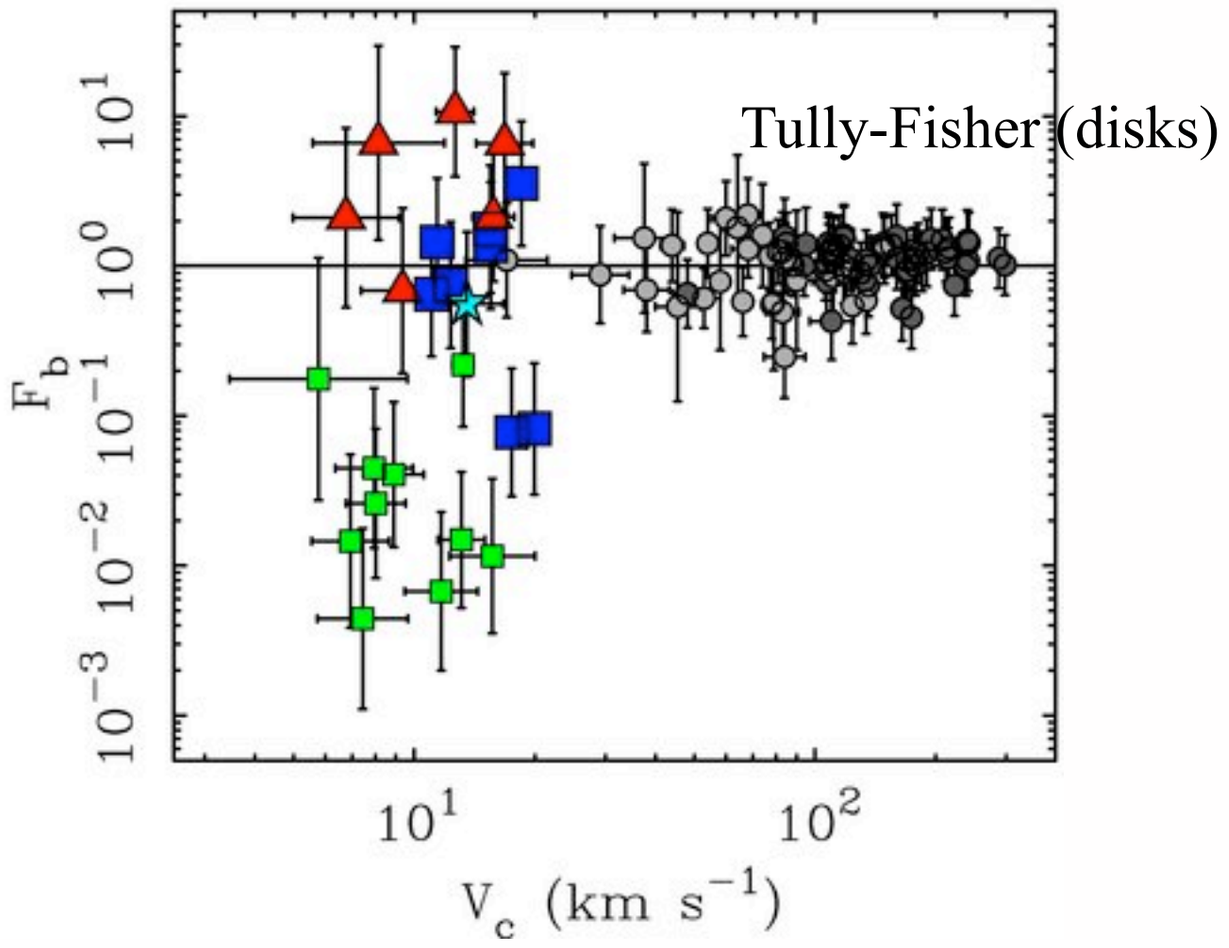
Density of dark matter within a galaxy halo of mass $2 \times 10^{12}\,M$ (*bottom*). The edge of the box is the virial radius, 300 kpc (with peak circular velocity of 200 km s^{-1}).

Missing satellite problem



dwarf Spheroidal galaxies (satellites of the Milky Way)

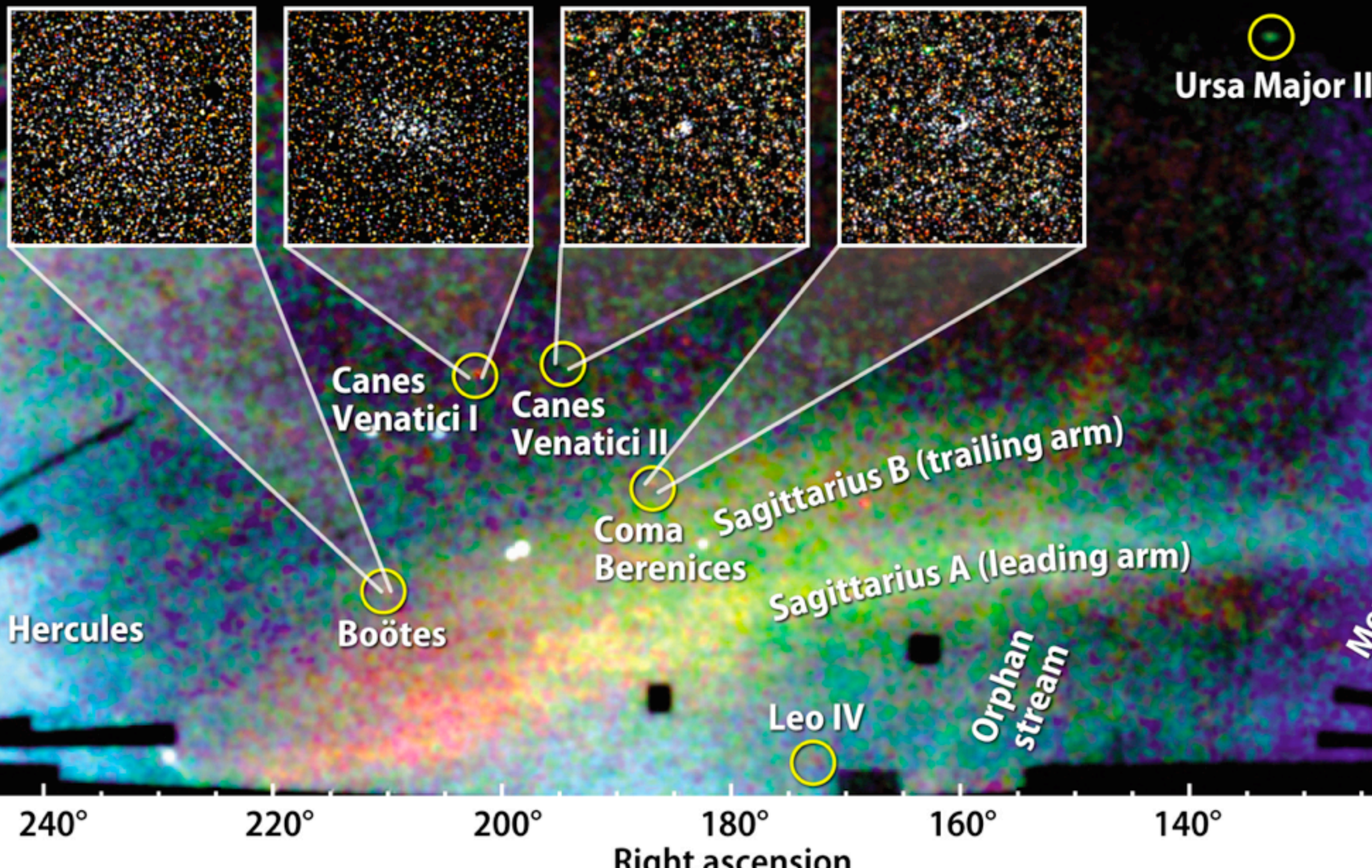


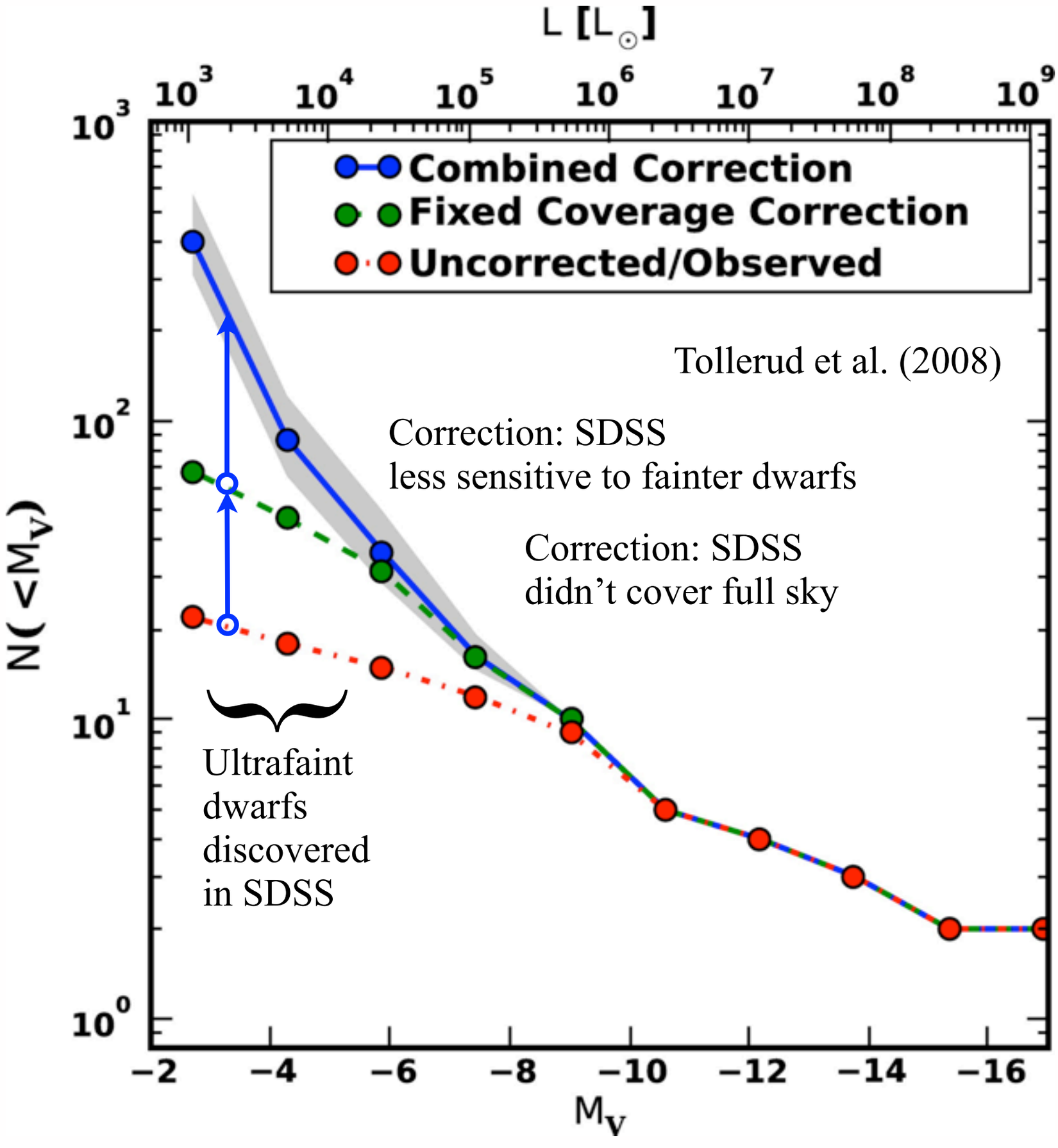


"Classical" dSph galaxies $10^5 < L < 10^7\ L_\odot$

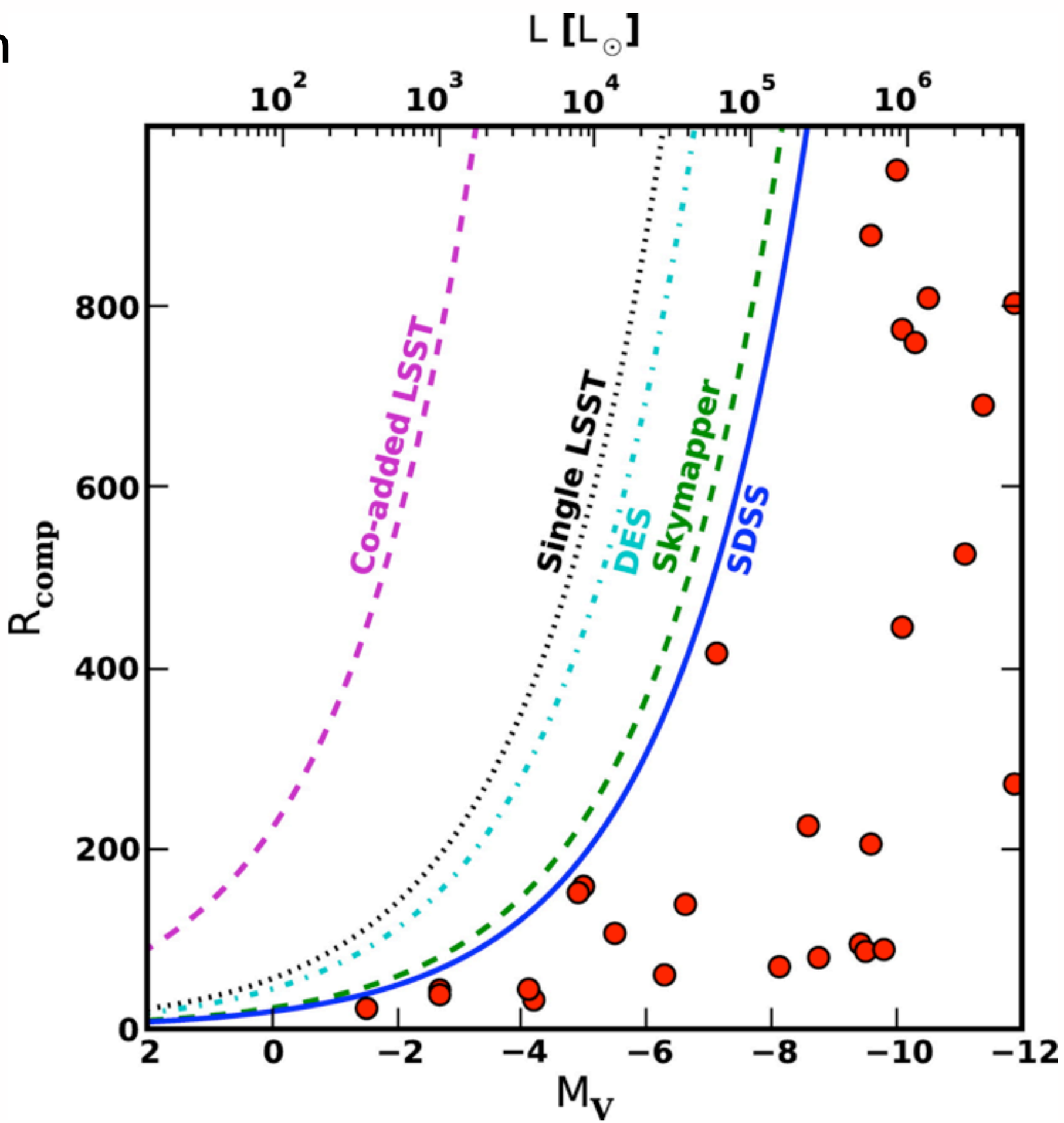
ultrafaint dSph galaxies $L < 10^5\ L_\odot$

Ultrafaint dwarf satellite galaxies discovered by SDSS

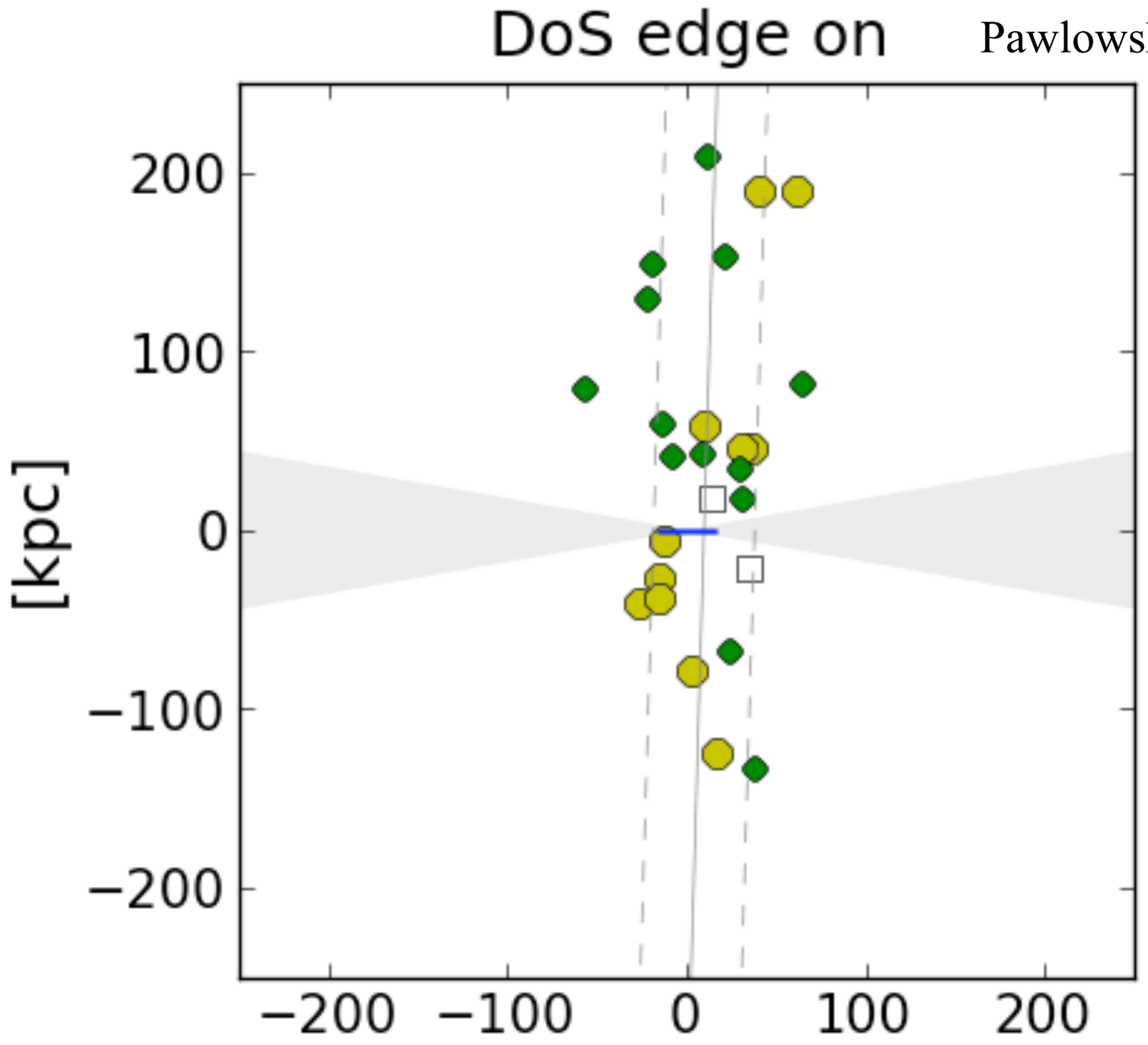



L [L⊙]
10^3
10^4
10^5
10^6
10^7
10^8
10^9
Combined Correction
Fixed Coverage Correction
Uncorrected/Observed
Tollerud et al. (2008)
Correction: SDSS
less sensitive to fainter dwarfs
Correction: SDSS
didn't cover full sky
Ultrafaint
dwarfs
discovered
in SDSS
N(<M_V)
10^2
10^1
10^0
−2
−4
−6
−8
−10
−12
−14
−16
M_V

Selection Limits

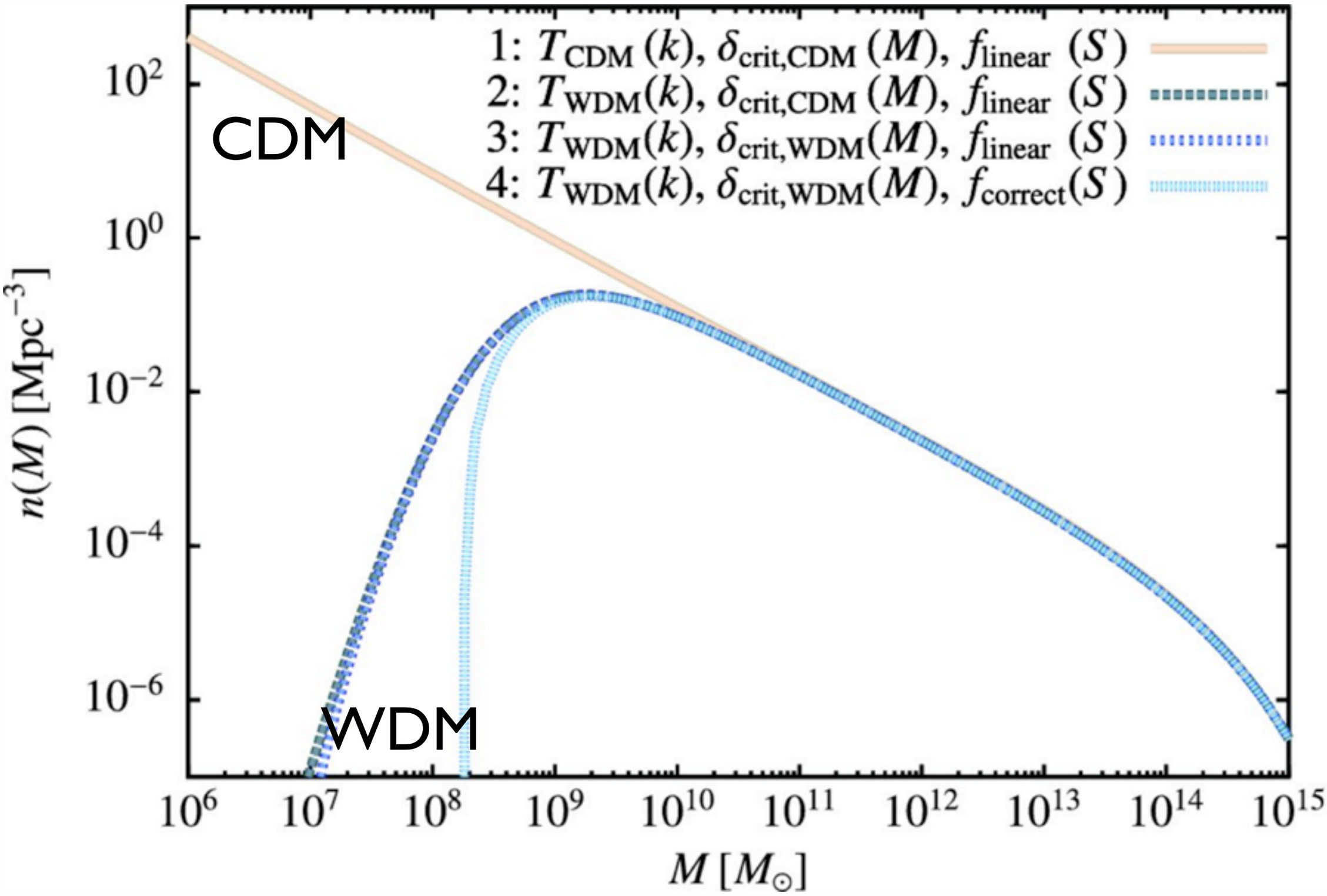


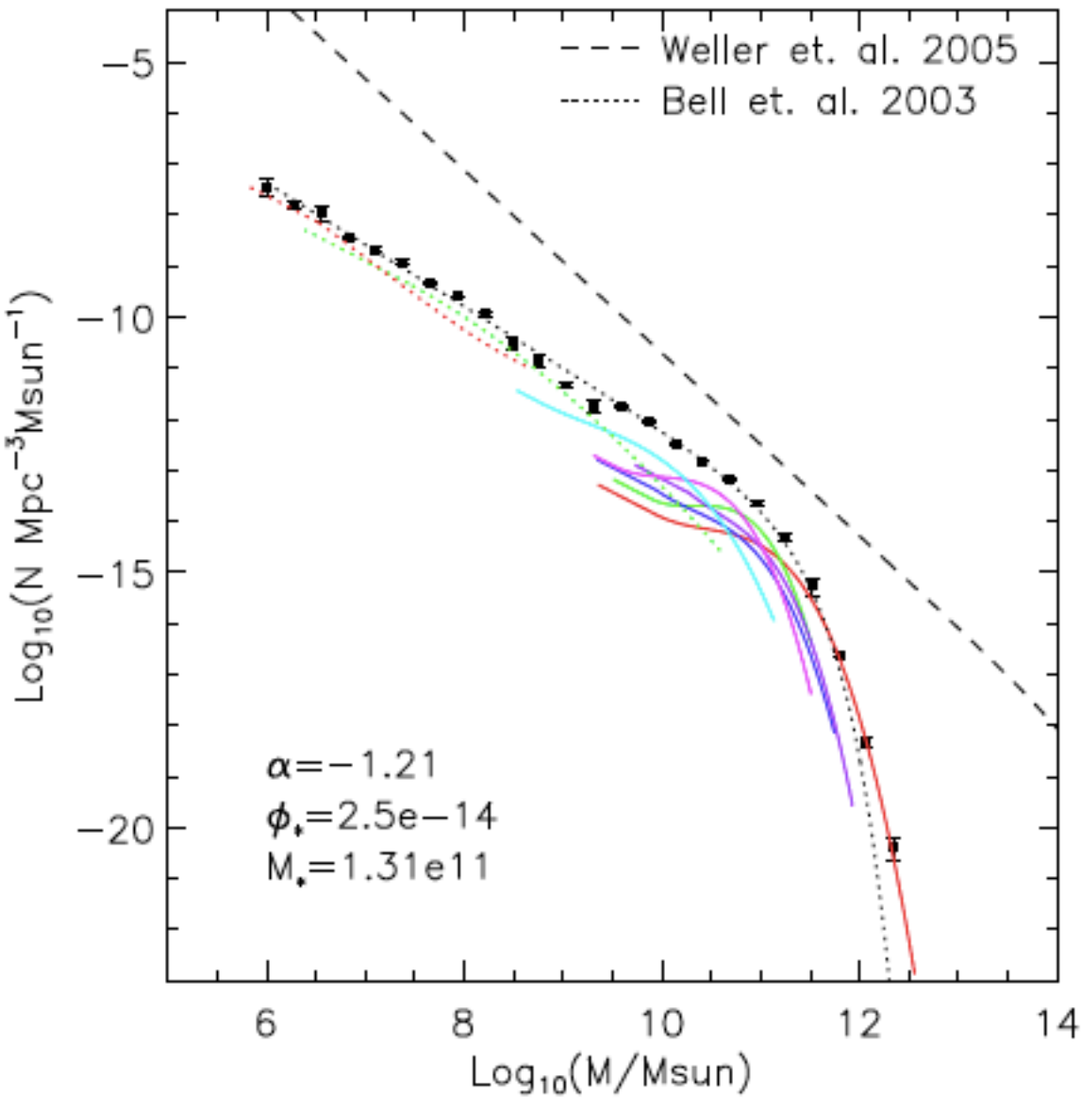
Is sky coverage correction appropriate?
dwarf satellites appear primarily to reside in a polar plane.



Pawlowski et al. (2012)

Benson et al (2013)



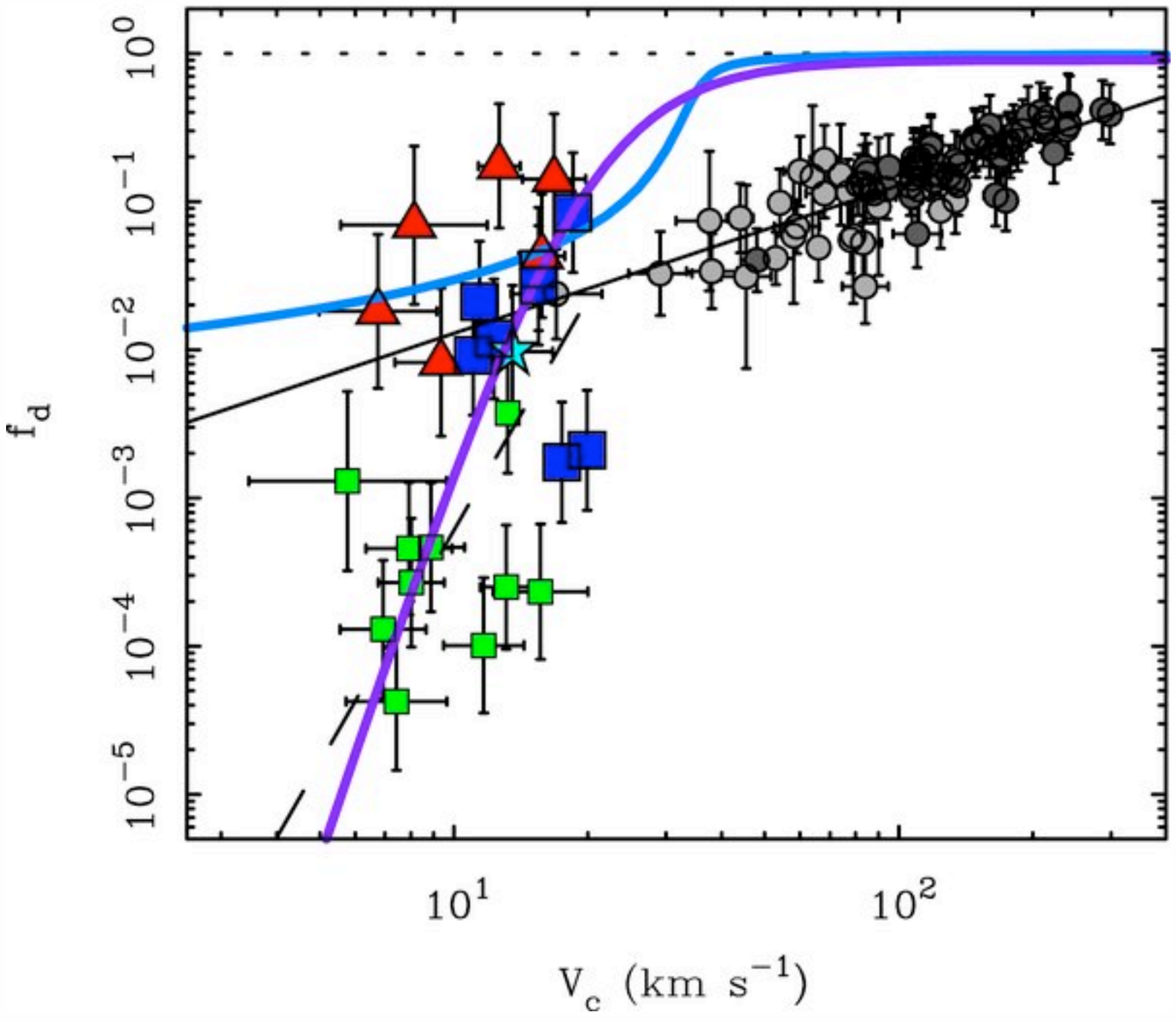


Slopes are mismatched everywhere, so it isn't obvious that WDM helps

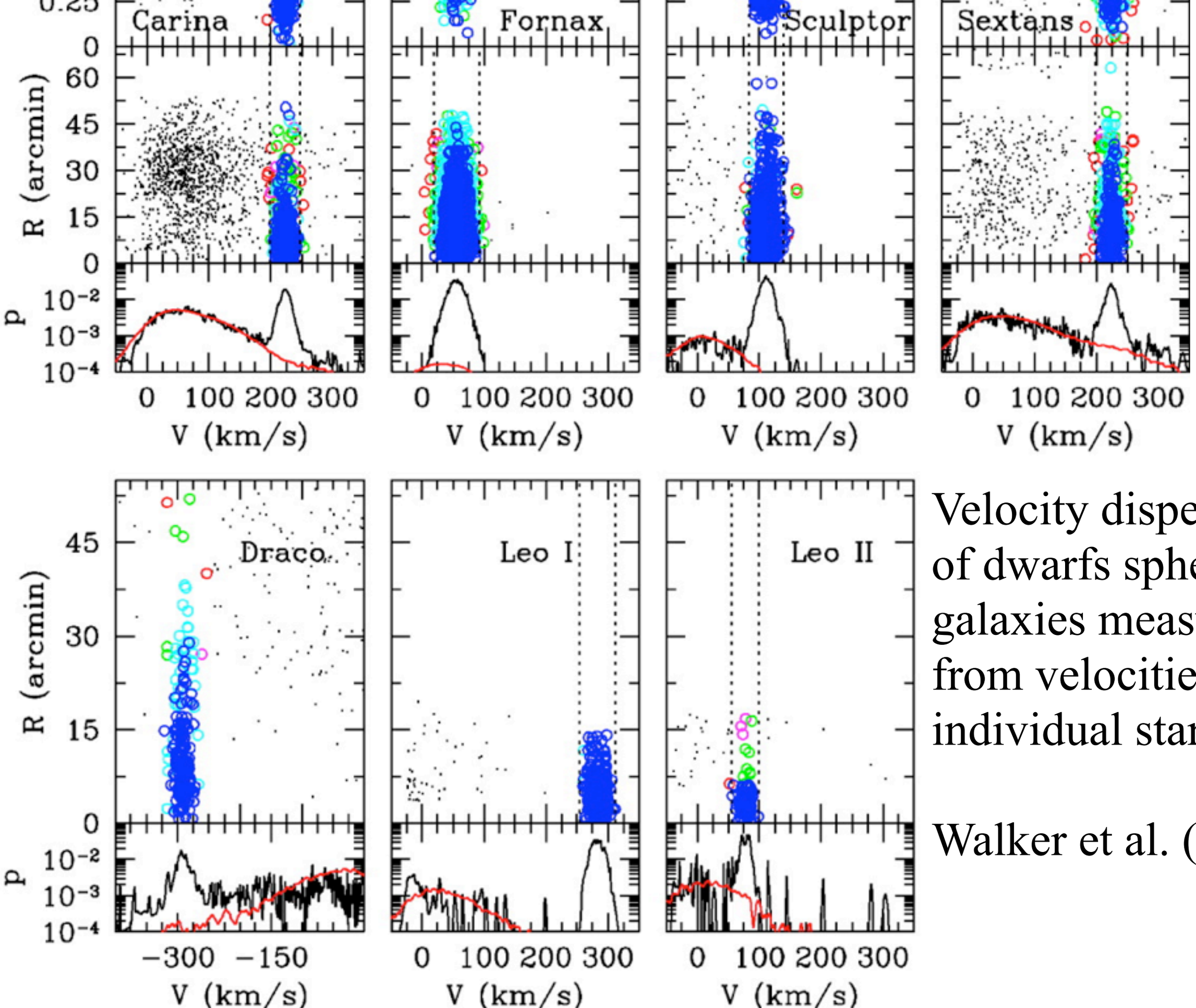
Figure 4. The field galaxy baryonic mass function. The data points are for all galaxies, while the lines show spine fits by Hubble Type. The lines are as in Figure 2. The CDM mass spectrum from the numerical simulations of Weller et al. (2004) is also shown. Overlaid are parameters for a Schechter fit to the total mass function.

Too Big to Fail?

Many models can be invoked to suppress galaxy formation in small dark matter halos; is harder to prevent in mid-size halos.



e.g., Reionization models illustrated here are good for explaining the smallest galaxies, but not ~40 km/s halos, which are too big to fail.

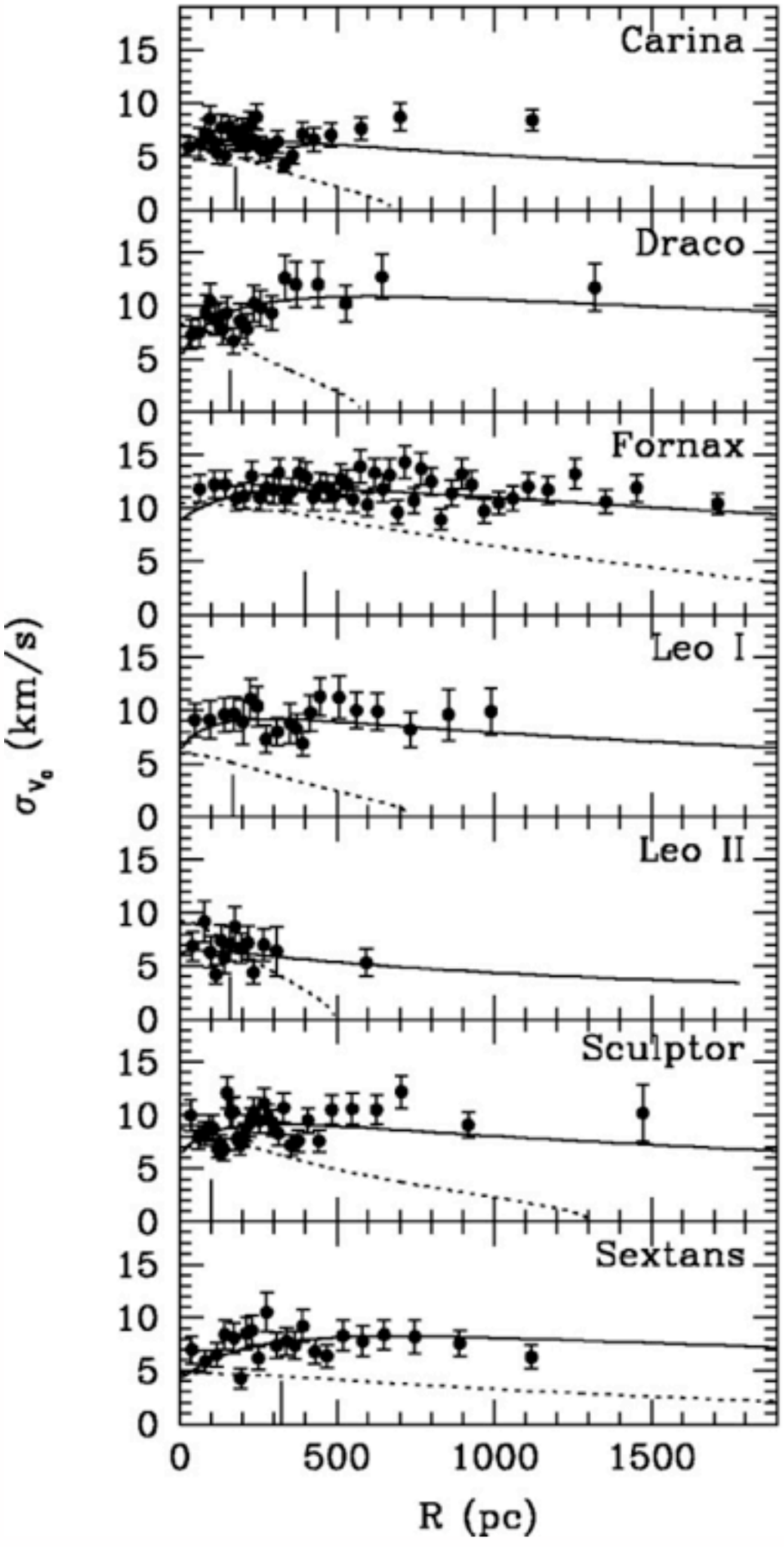


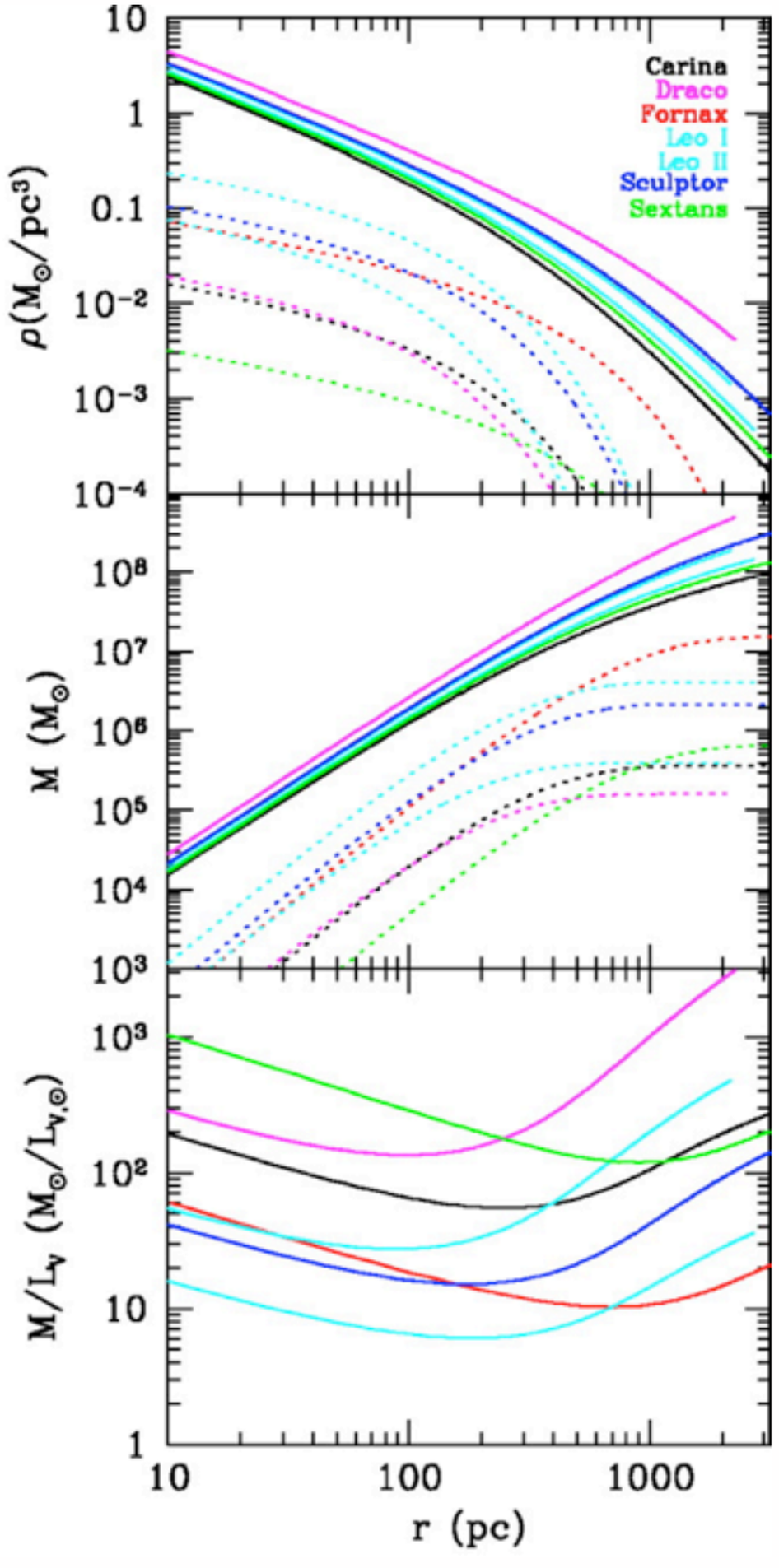
Velocity dispersions of dwarfs spheroidal galaxies measured from velocities of individual stars.

Walker et al. (2007)

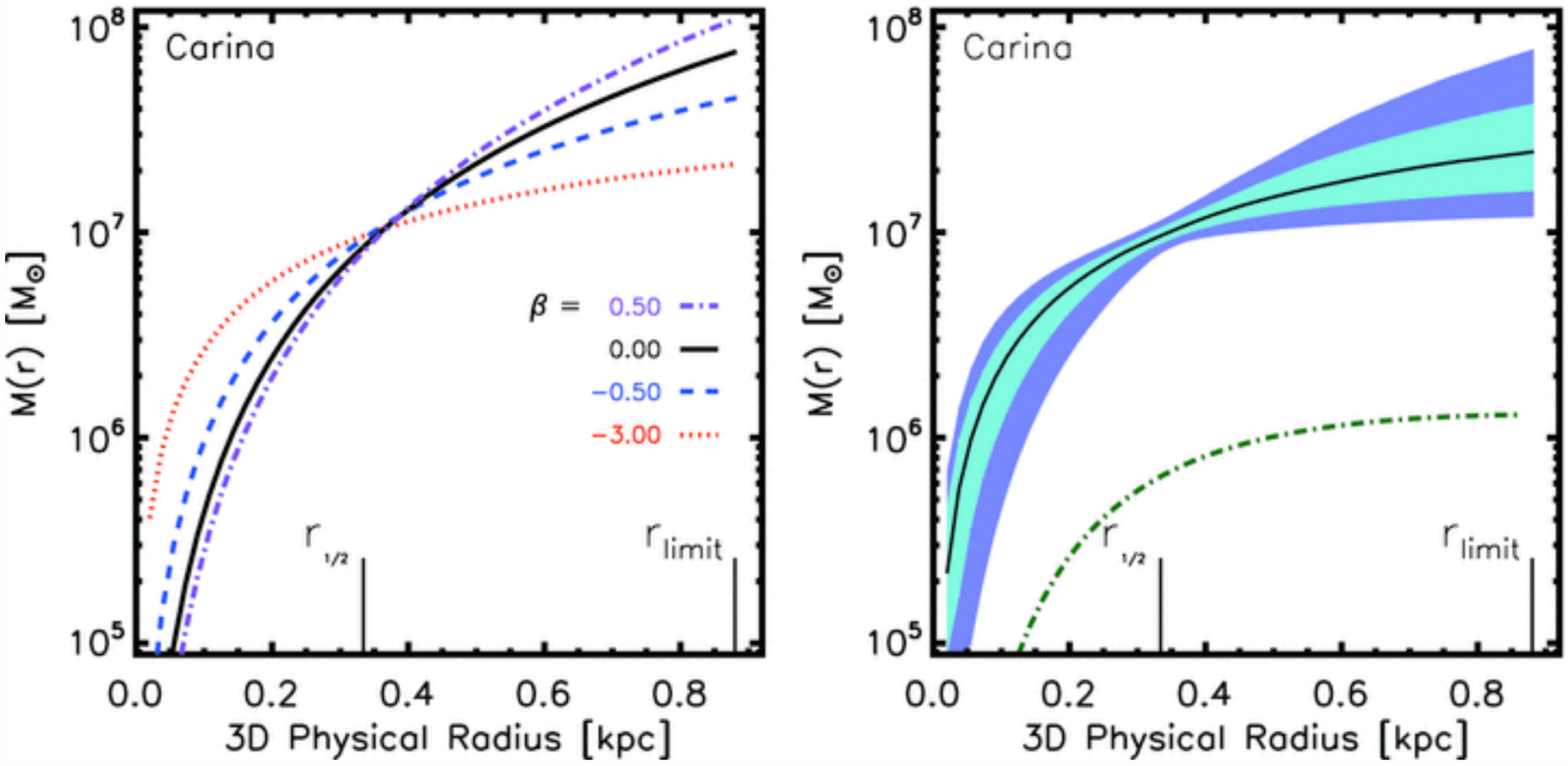
Velocity dispersion profiles of dwarfs spheroidal galaxies approximately flat.

Walker et al. (2007)





Wolf et al. (2010)



$$M(r) = \frac{r\sigma_r^2}{G}(\gamma_* + \gamma_\sigma - 2\beta)$$

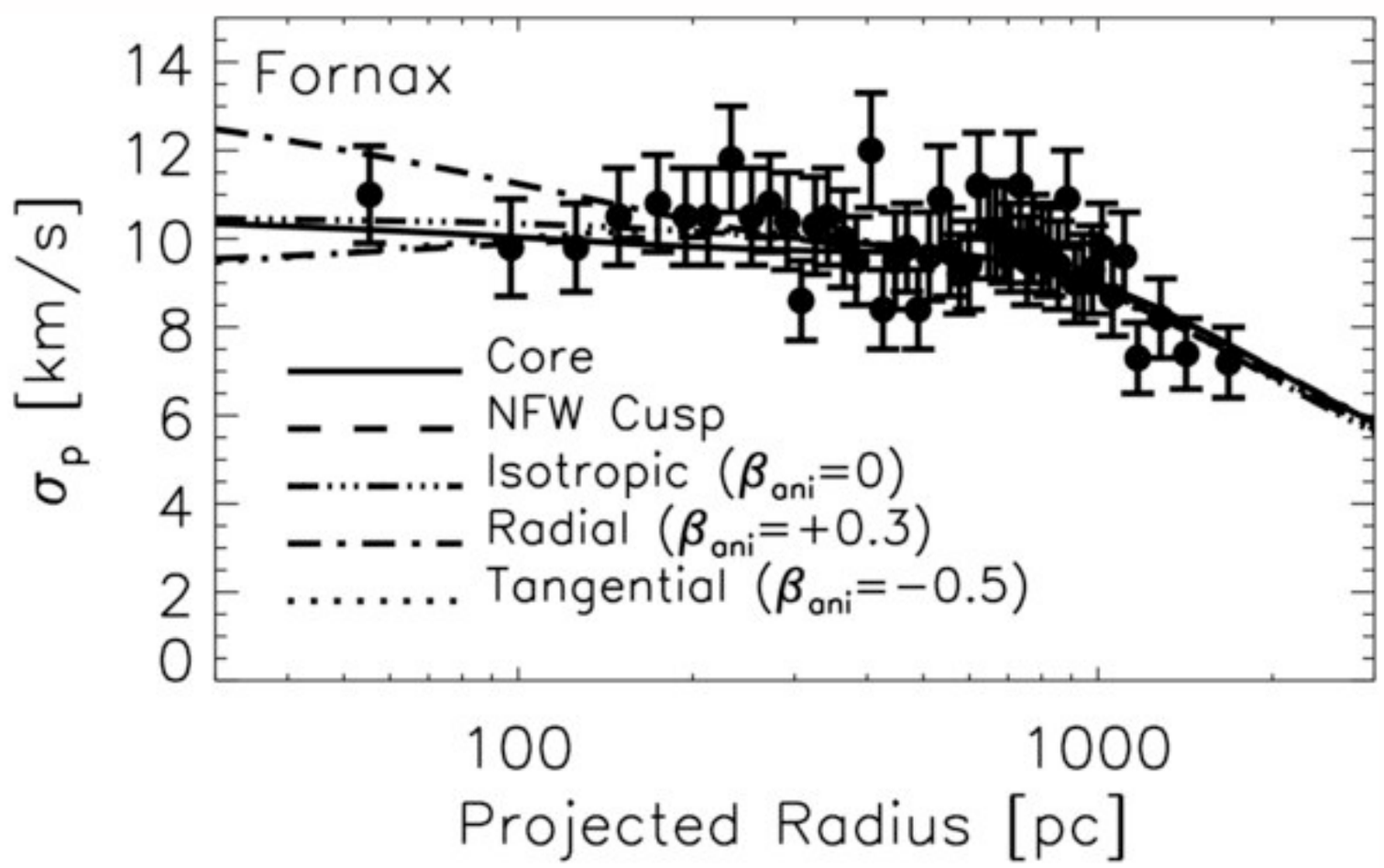
Walker & Panarrubia (2011) find that dSph galaxies suffer the same cusp-core problem as found in rotating low surface brightness galaxies

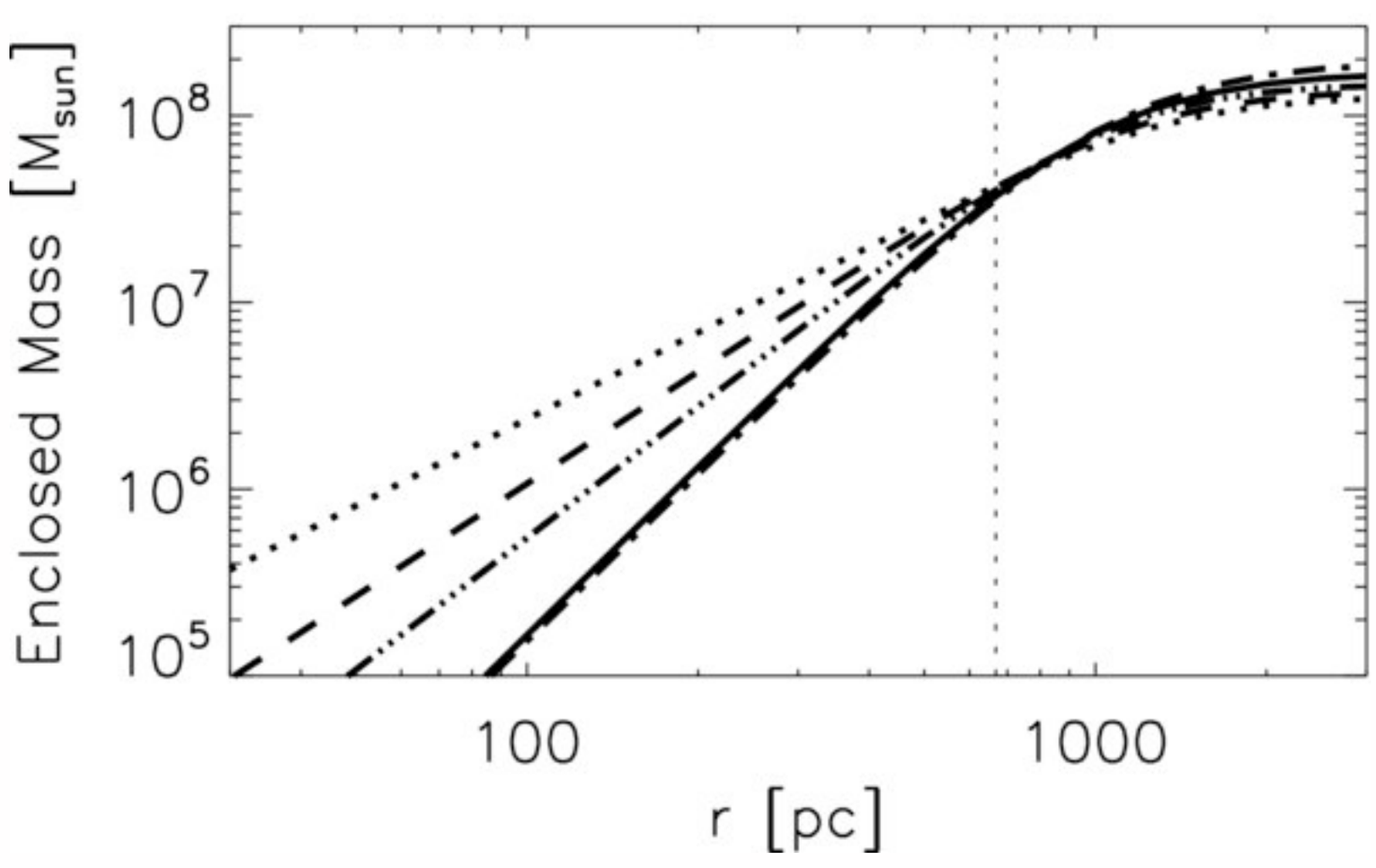
$$\rho \sim r^{-\gamma}$$

$\gamma = 0.39$ Fornax

$\gamma = 0.05$ Sculptor

$$\left[\begin{array}{ll} \gamma = 1 & \text{cusp} \\ \gamma = 0 & \text{core} \end{array}\right]$$





Dwarf spheroidals problematic for CDM in two distinct ways:

- there should be thousands of them rather than dozens (missing satellite problem)

- they have cored dark matter halos (cusp/core problem)