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How Massive is the Milky Way?

See also:

Klypin et al. (2002)
Simon's talk

Matthias Steinmetz
Astrophysical Institute Potsdam

Overview

- Spectroscopic Surveys of the MW
 - ◆ Geneva-Copenhagen, SDSS, 
- Mass estimates
 - ◆ Using cosmological simulations for data interpretation
- Do we have consistency between different mass estimates?



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Unveiling the Mass
Kingston, June 15-19, 2009

GCS, and SEGUE are complimentary

SEGUE

- selected pointings
- deep exposures
- low resolution (R=2000)
- large wavelength coverage
- northern hemisphere
- no repeats

Geneva-Copenhagen Survey

- volume limited, F & G stars
- 3 repeats for each star
- stars with Hipparcos parallaxes
- RVs via correlations



- wide angular coverage
- intermediate depth
- medium resolution (R=7500)
- limited wavelength coverage
- southern hemisphere
- 10% repeats

The **RAVE** survey

RAVE: RADIAL VELOCITY EXPERIMENT

- Spectroscopic high latitude survey of the MW
 - ◆ $9 < l < 13$
- 350.000 spectra for 300.000 stars
- GAIA spectral range and resolution
 - ◆ Ca triplet region (8400-8800Å)
 - ◆ $R_{\text{eff}}=7500$
- Scheduled operation: 2003 – 2011
 - ◆ 6dF MOS on UKST at Siding Spring
 - ◆ 7 nights per lunation up to 8/2005
 - ◆ 25 nights per lunation since 8/2005
- Goal: 1 Million spectra
- Typical RV error: 2 km/s
- 50% of the stars have 3D velocity errors better than 20 km/s



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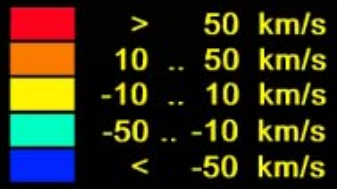
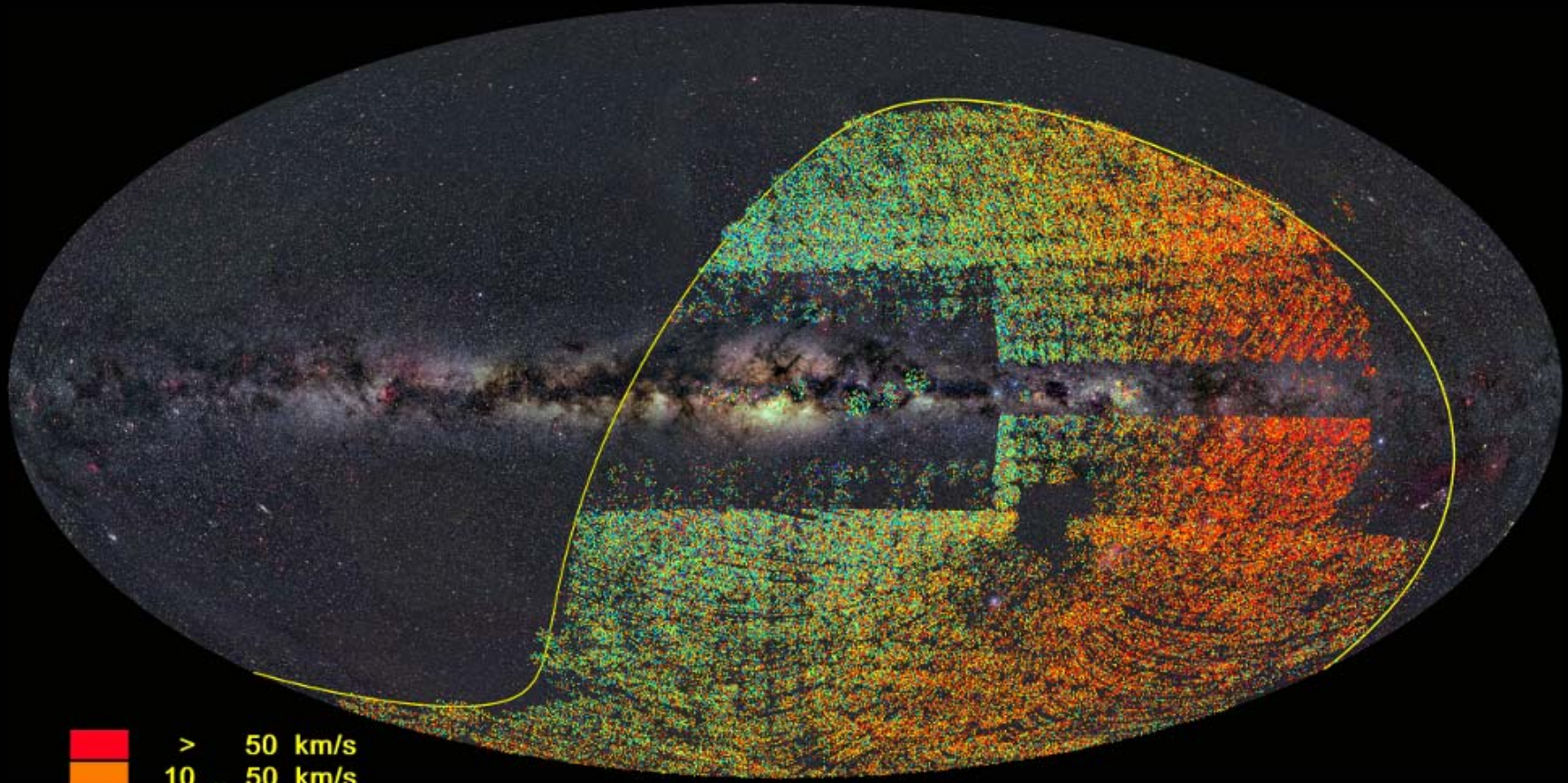
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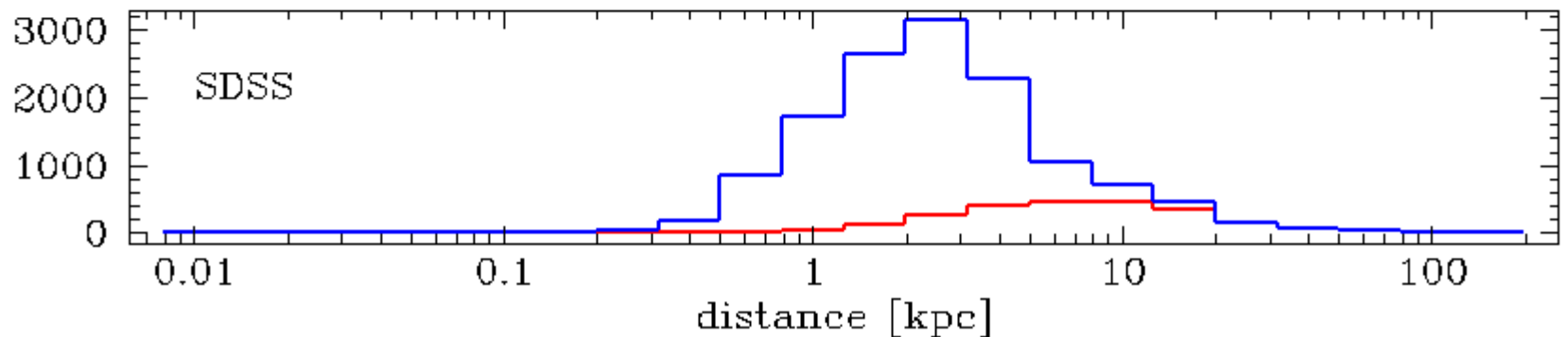
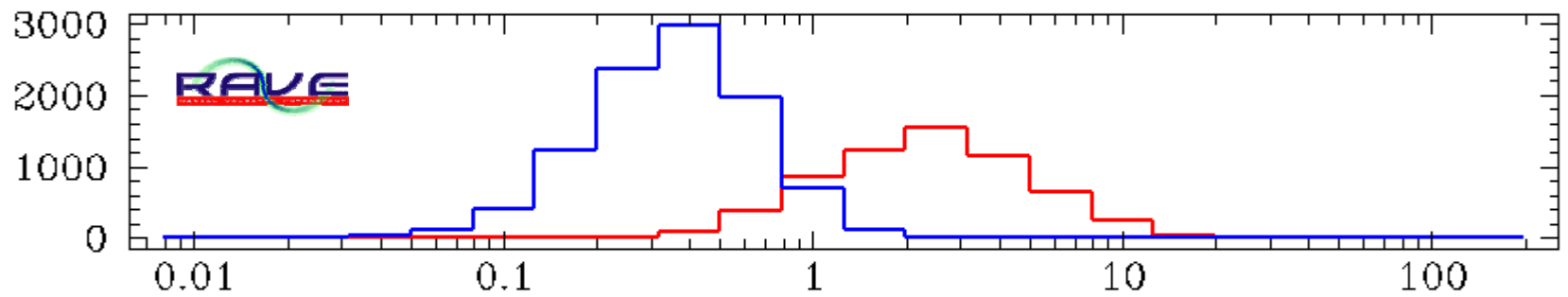
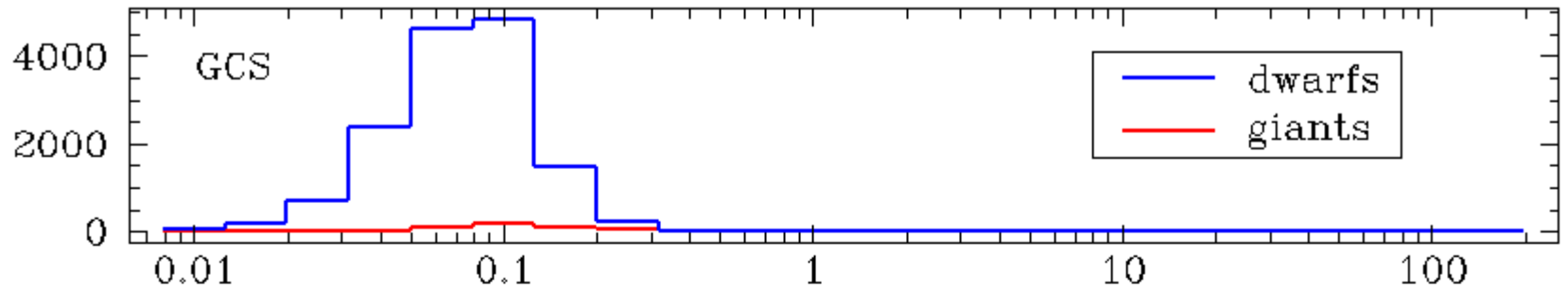


Stellar Heliocentric Radial Velocities



© The RAVE collaboration, background: ©2000 Axel Mellinger

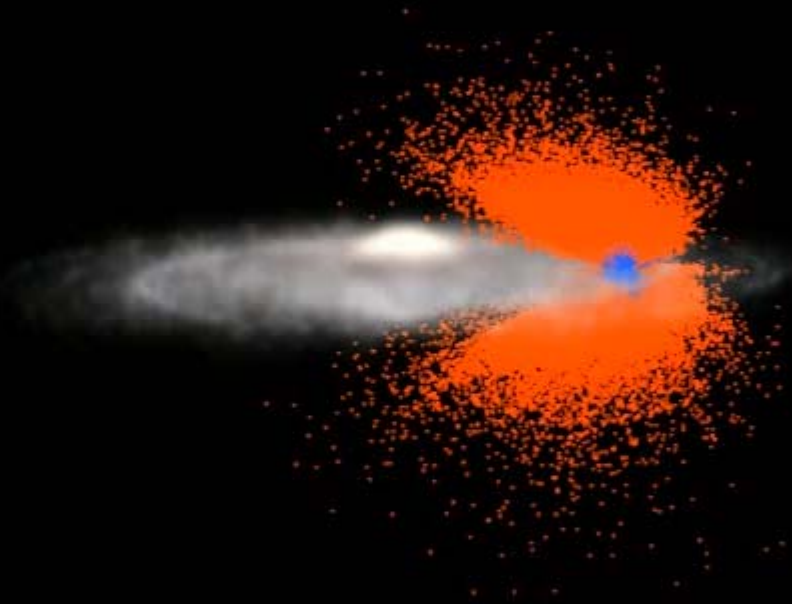
Comparison of RV-surveys



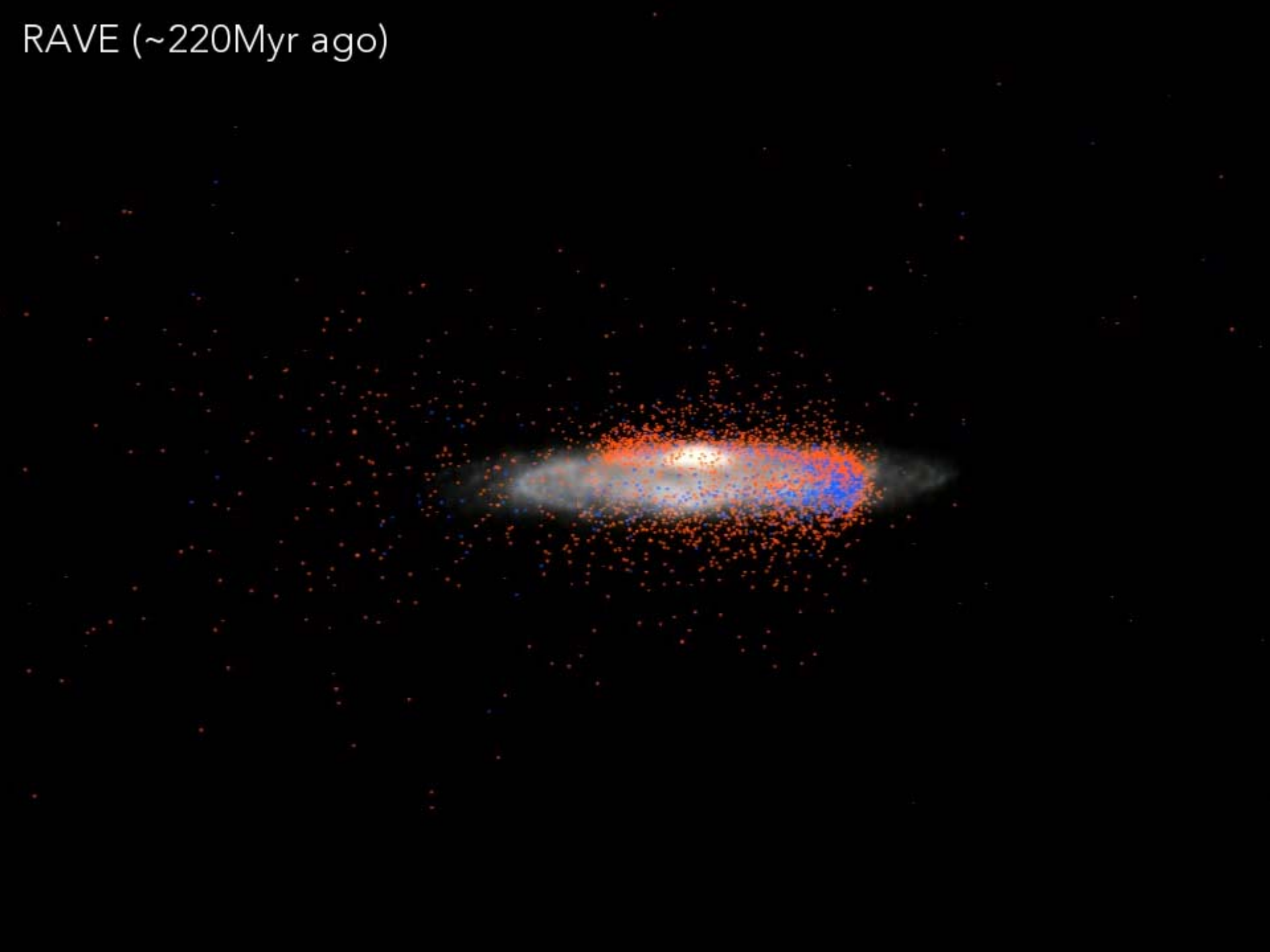
Geneva-Copenhagen



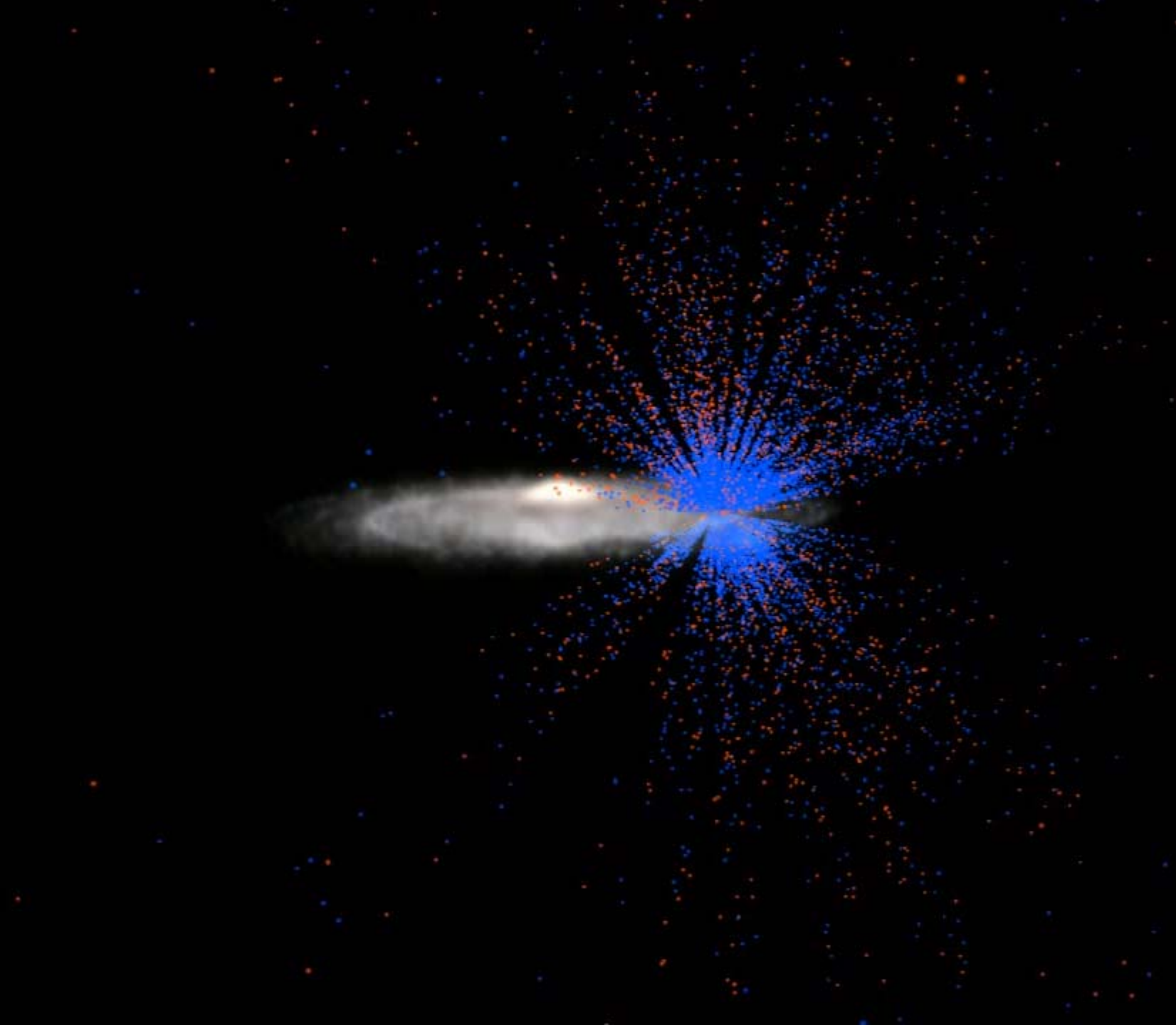
RAVE



RAVE (~220Myr ago)



SDSS

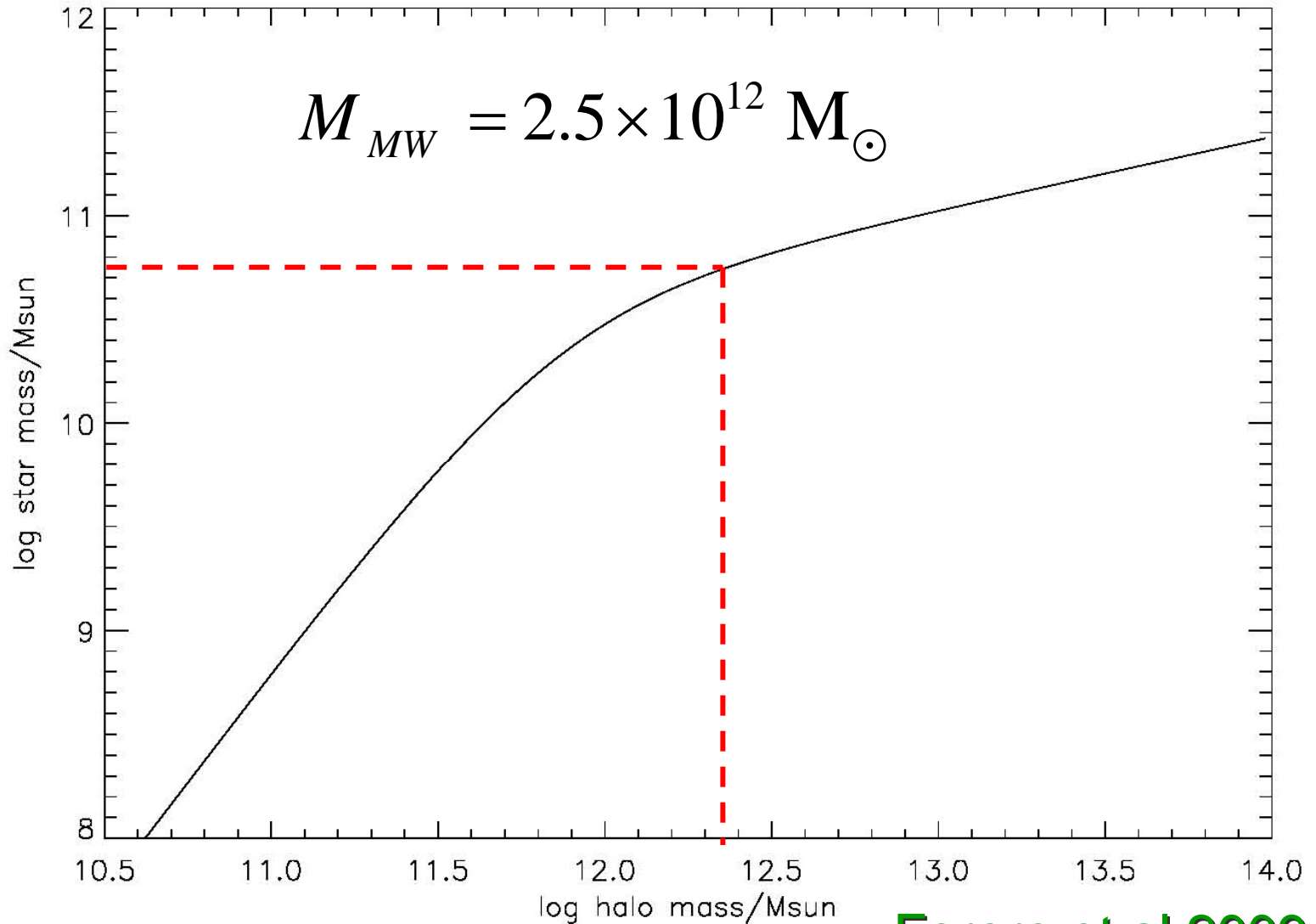




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Compare SDSS stellar mass function with DM halo mass function

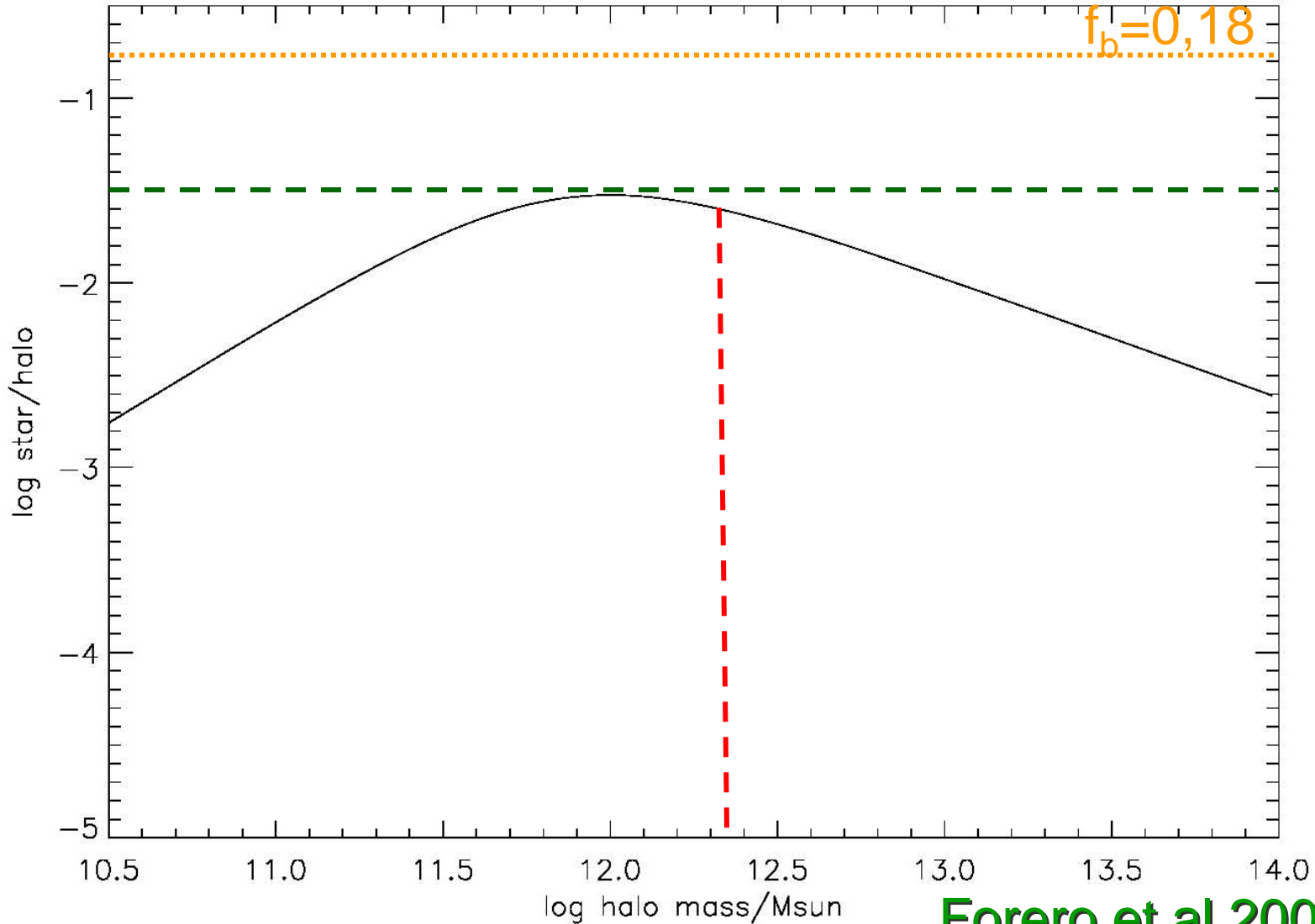




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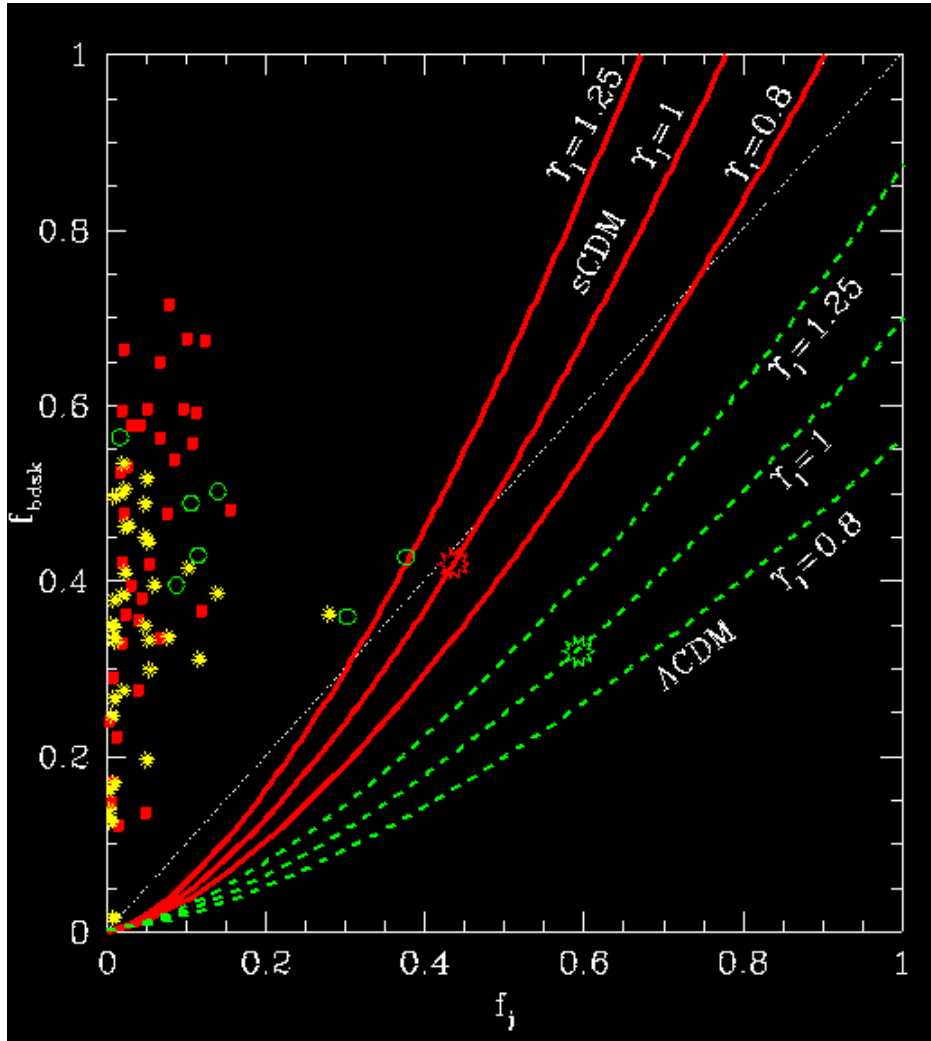
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Compare K-band luminosity function with DM halo mass function



TF + mass-ang.-momentum-relation

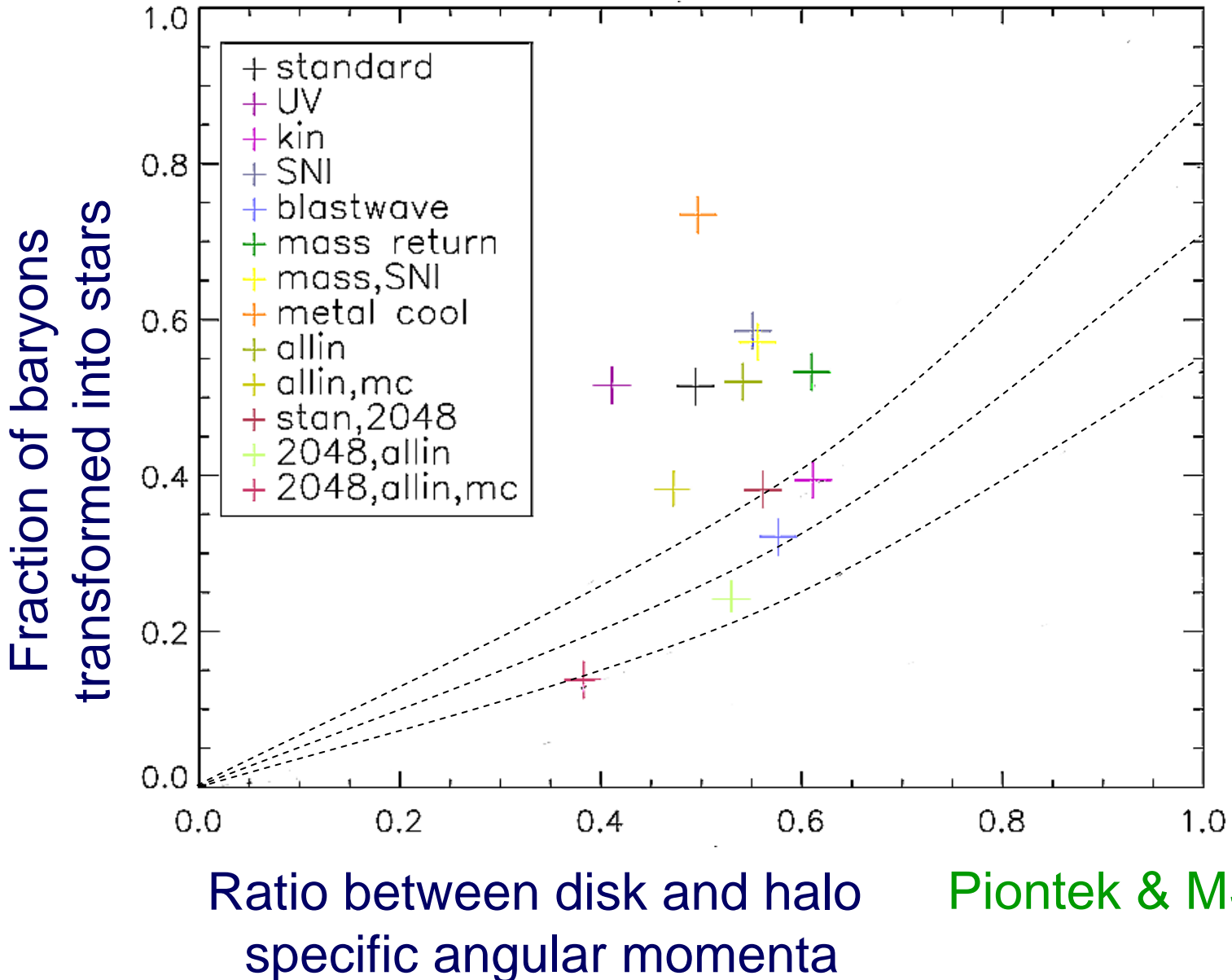
Fraction of baryons transformed into stars



In Λ CDM halos, disks contain a larger fraction of the total specific angular momentum than of baryon mass!

Ratio between disk and halo specific angular momenta Navarro & MS 2000

TF + mass-ang.-momentum-relation

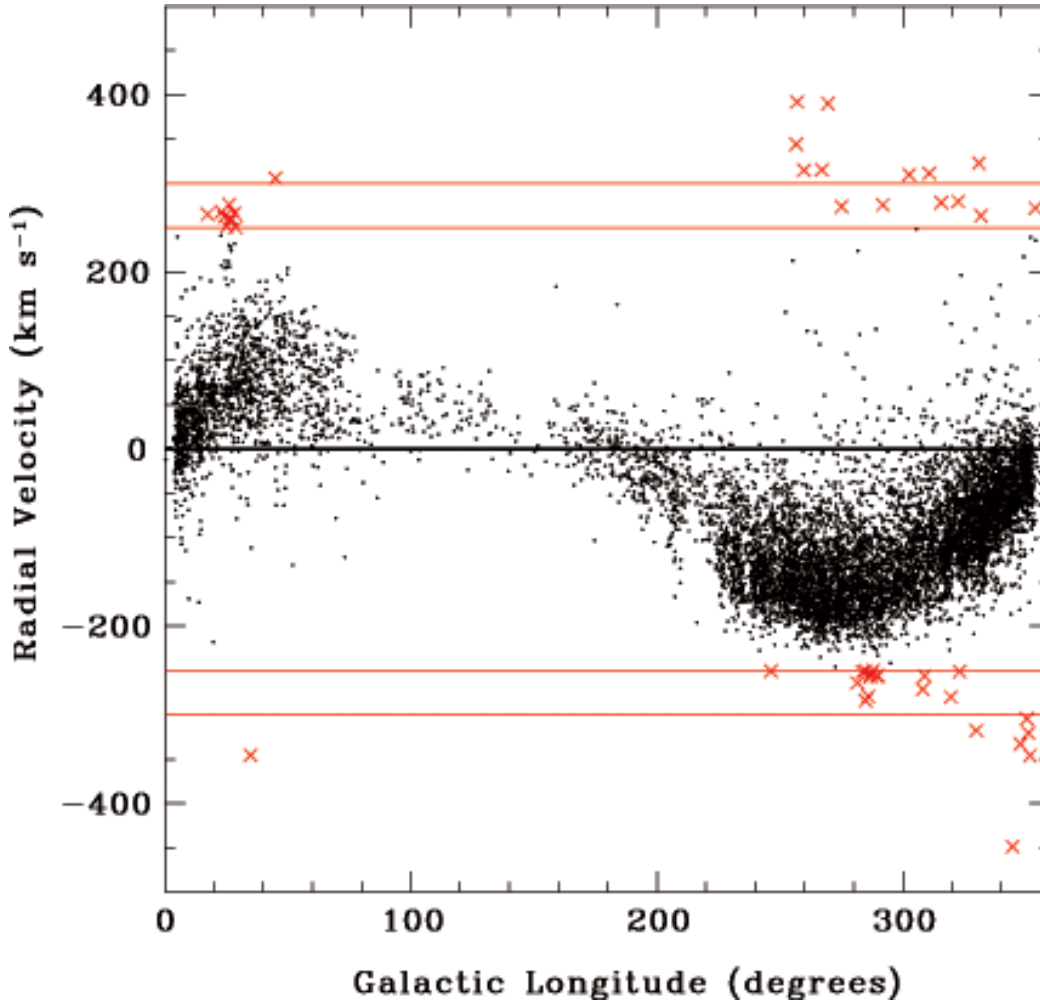


Piontek & MS 2009



The Escape Speed of the Milky-Way

Smith, et al 2007



Leonard & Tremaine (1990):

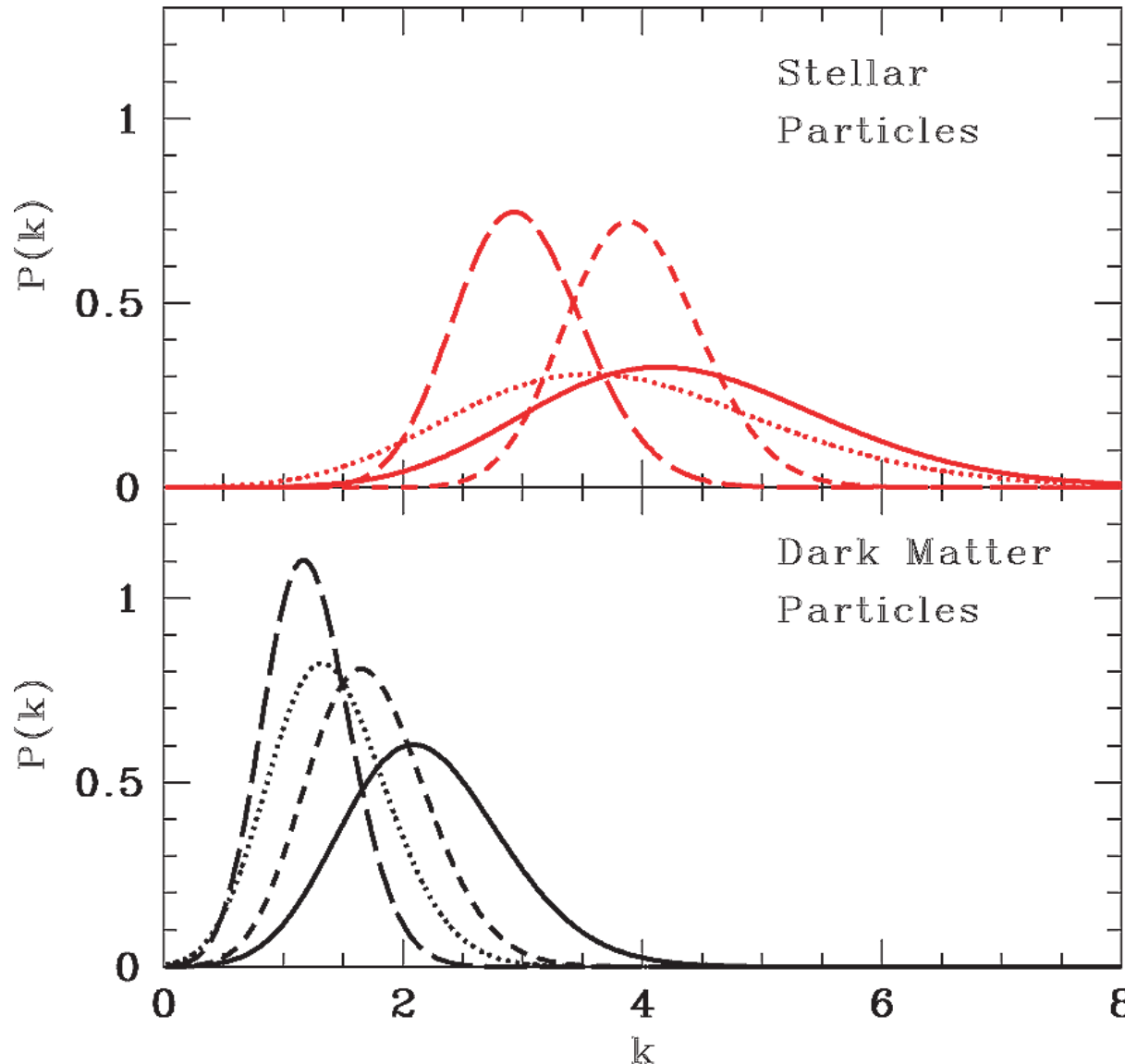
near escape velocity:

$$f(\varepsilon) \propto \varepsilon^k$$

$$\varepsilon = (v_e^2 - v^2)$$

The Mass of the Milky-Way

Smith et al., 2007

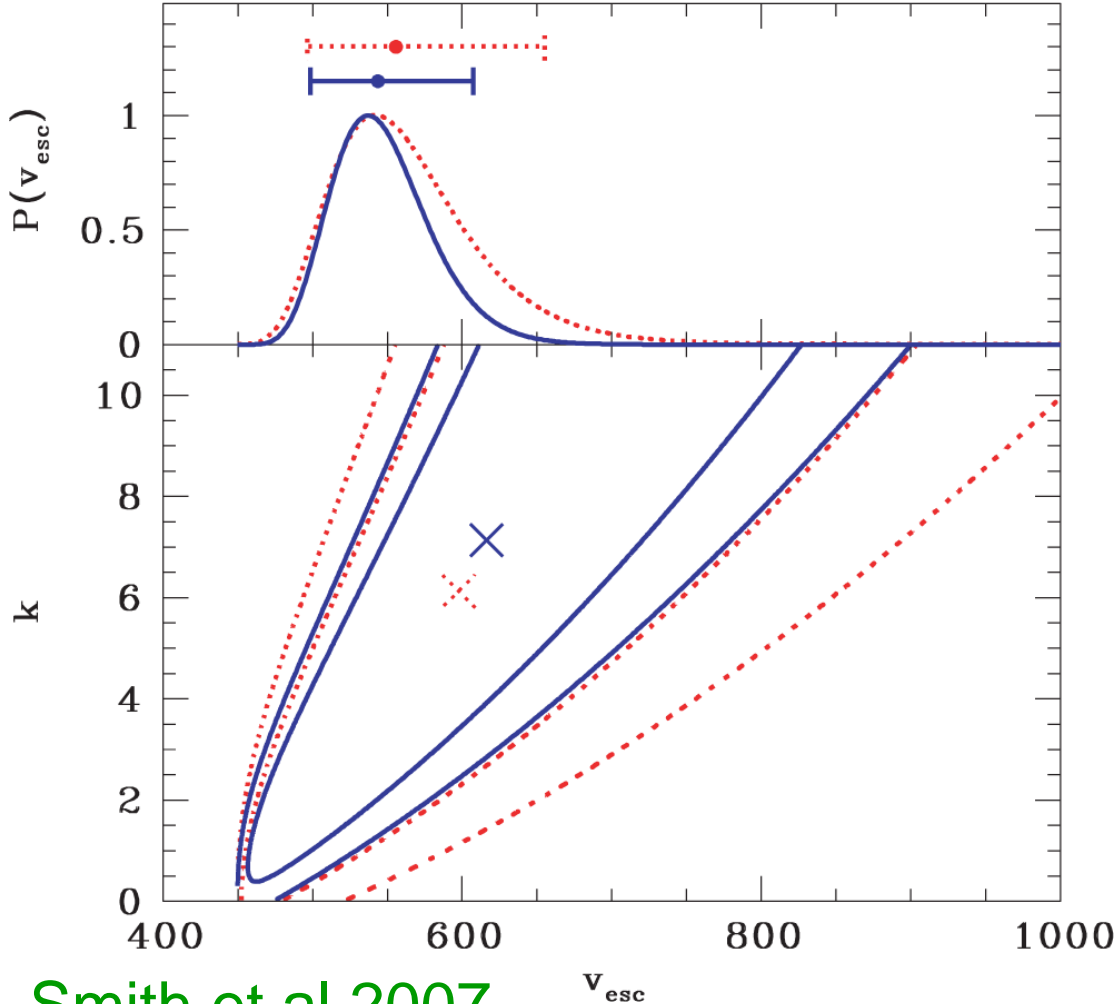


The Escape Velocity of the Milky-Way



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$$498 < v_{\text{esc}} < 608 \text{ km/s}$$



For an adiabatically contracted NFW dark halo:

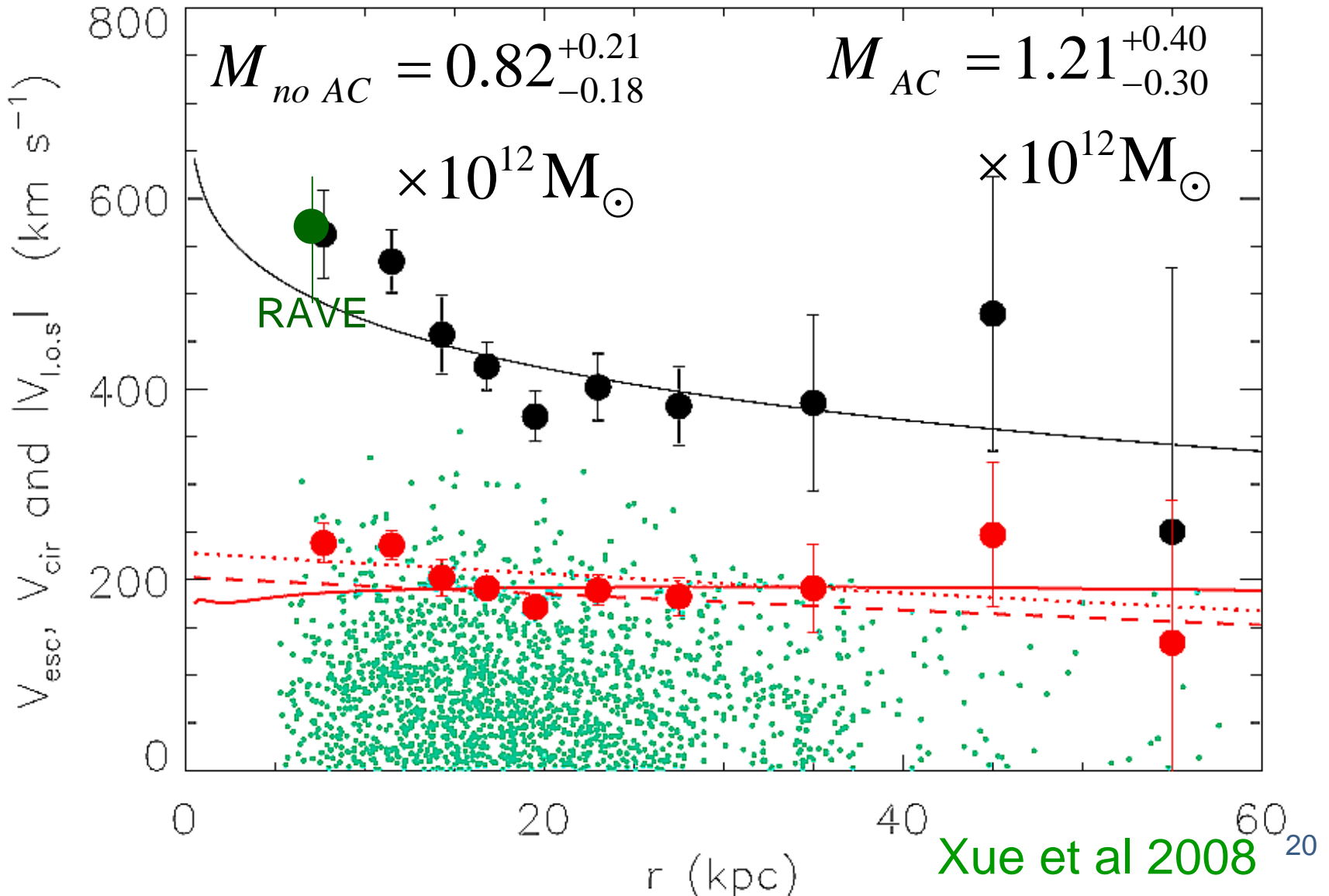
$$M_{MW} = 1.42^{+1.14}_{-0.54} \times 10^{12} M_{\odot}$$

Non contracted NFW dark halo:

$$M_{MW} = 0.85^{+0.55}_{-0.29} \times 10^{12} M_{\odot}$$

V_{circ} and V_{esc} from SDSS

V_{cir} and V_{esc} estimate



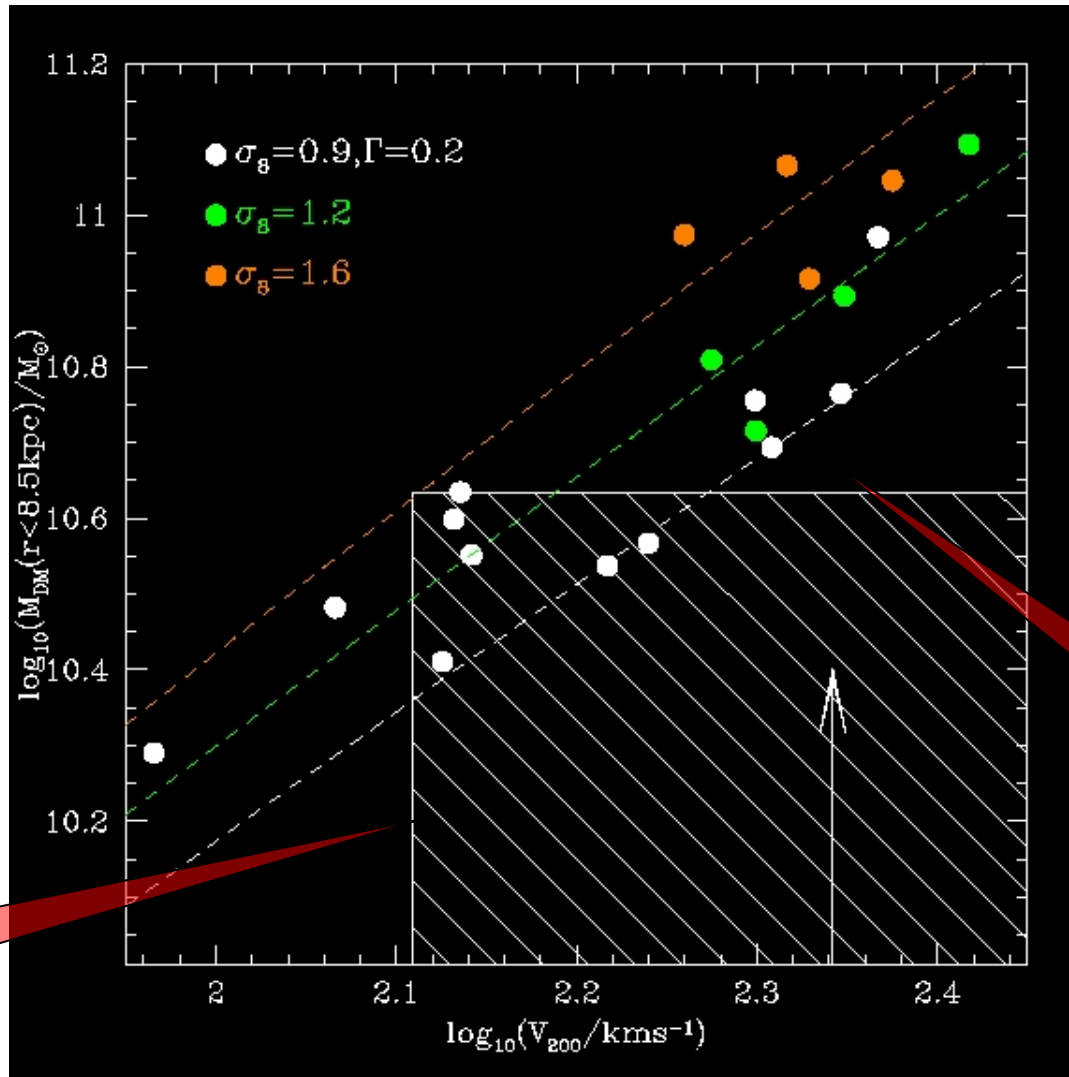
Dark Matter in the Milky Way



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Dark Mass within the Solar Circle



Constraint from universal baryon fraction

Dark mass constraint from Oort limit

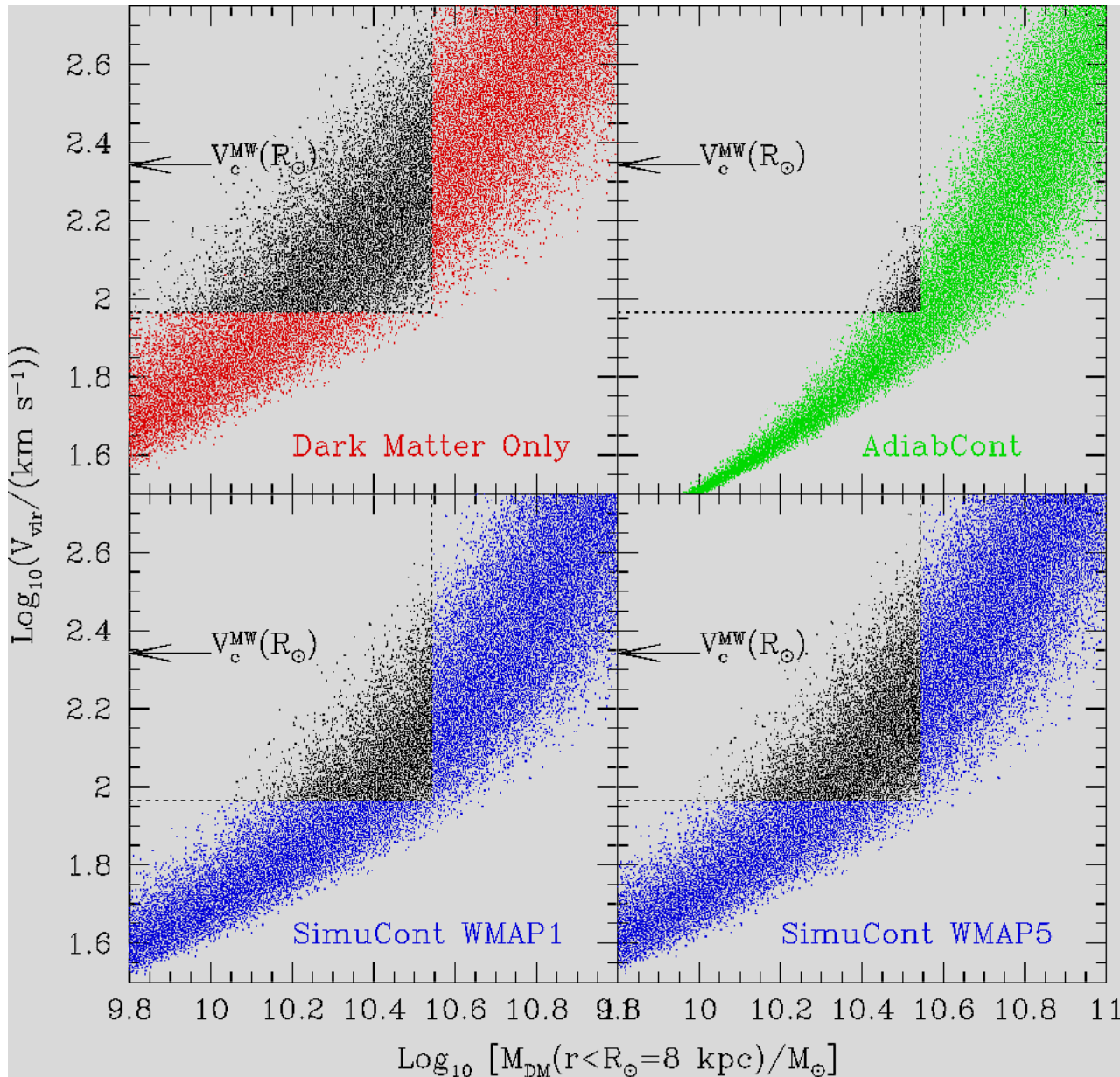
Halo Mass (Circular Velocity)

Eke, Navarro & Steinmetz 2001²¹

Mass of the MW dark matter halo

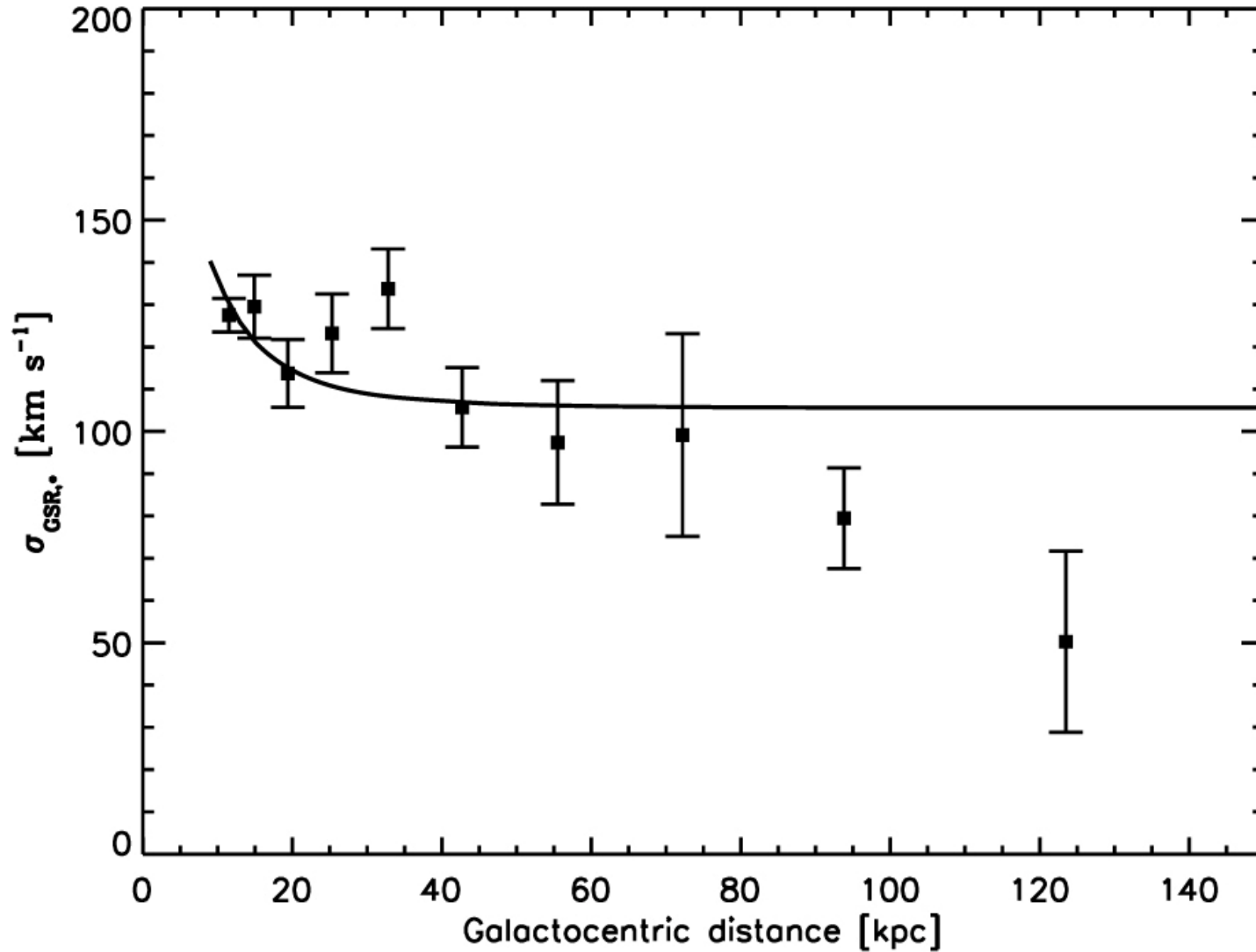


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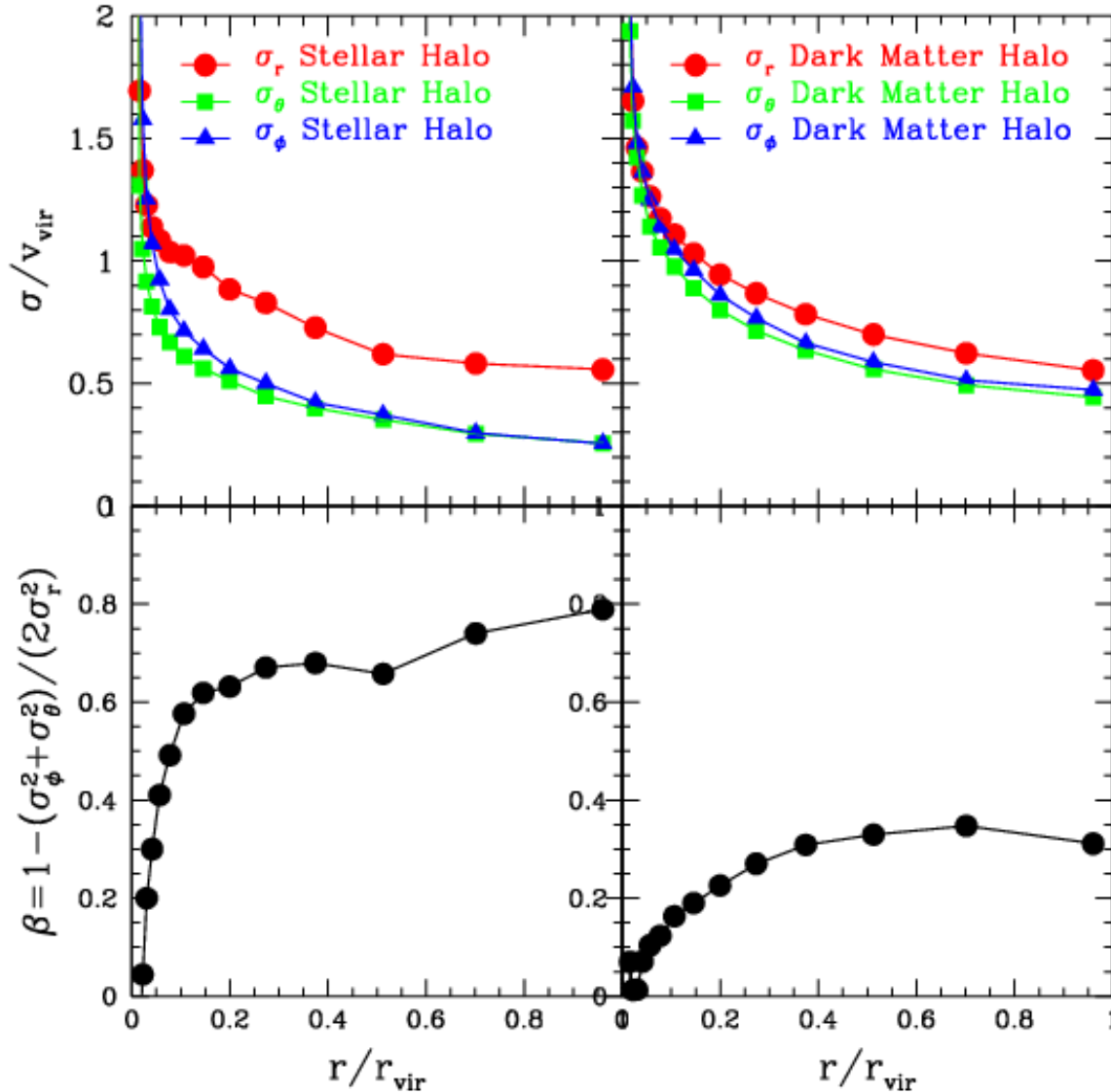


Abadi et al
2009

Velocity dispersion vs radius

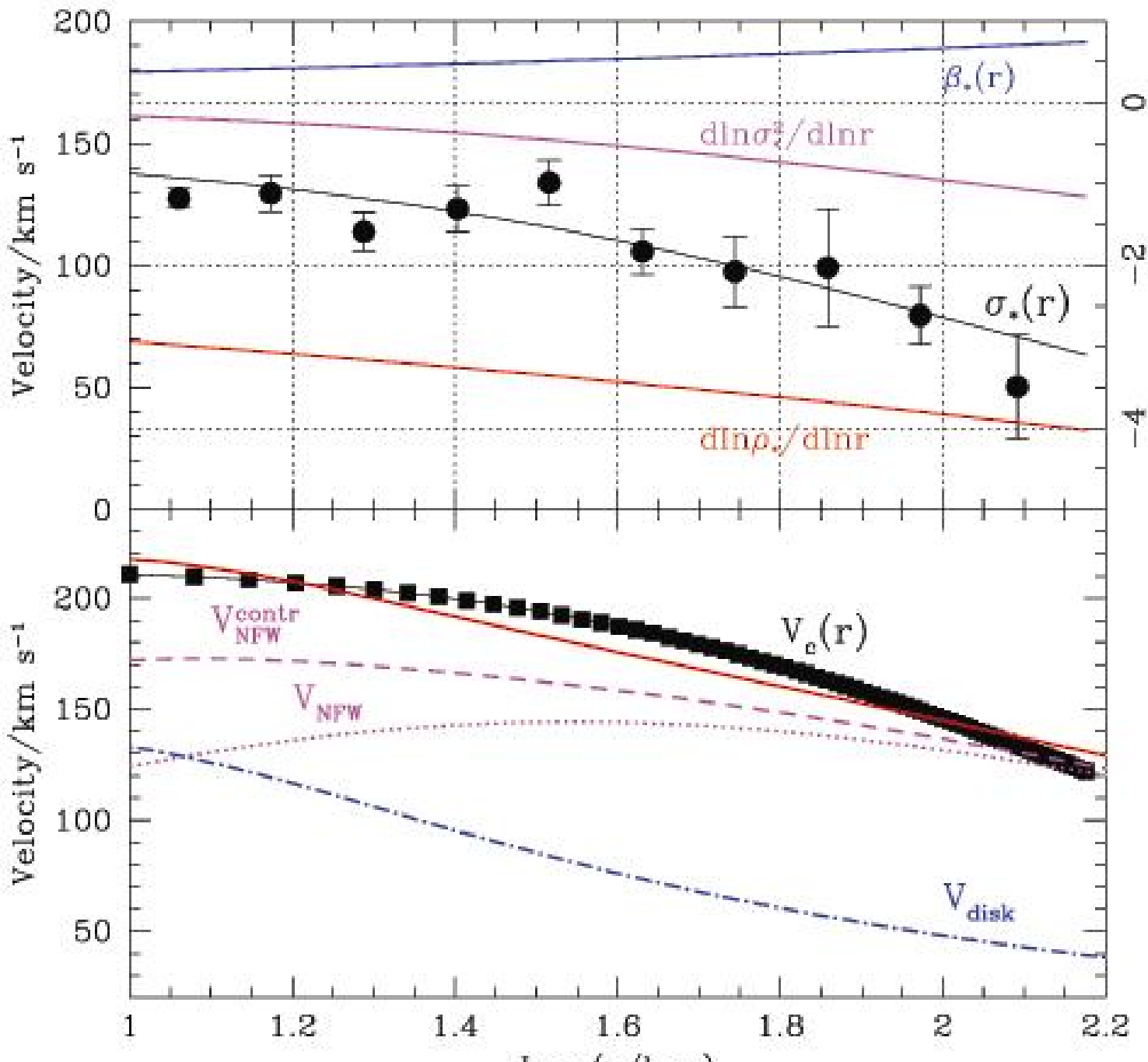


Anisotropy of stellar and DM halo



Dark matter halo and stellar halo exhibit quite different structural properties

Abadi et al
2005



$$V_{200} \approx 0.5 v_{\text{Disk}}$$

Pro

■ Tully Fisher

■ DM in disks

Con

■ Abundance
of disk
galaxies

Abadi et al
2005

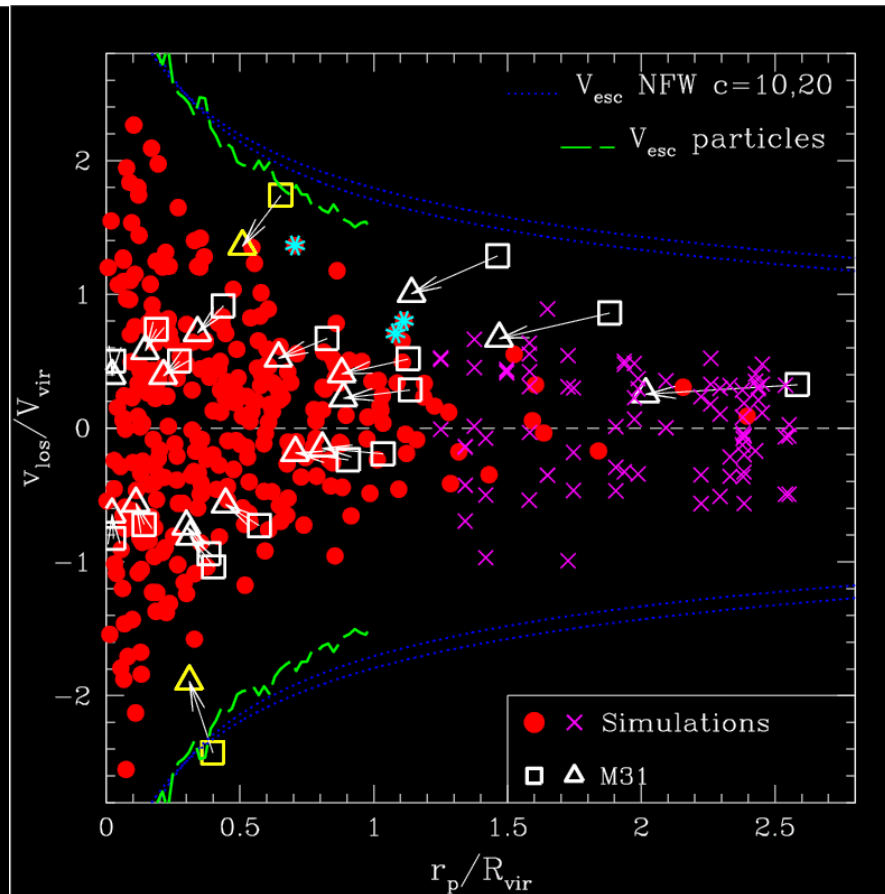
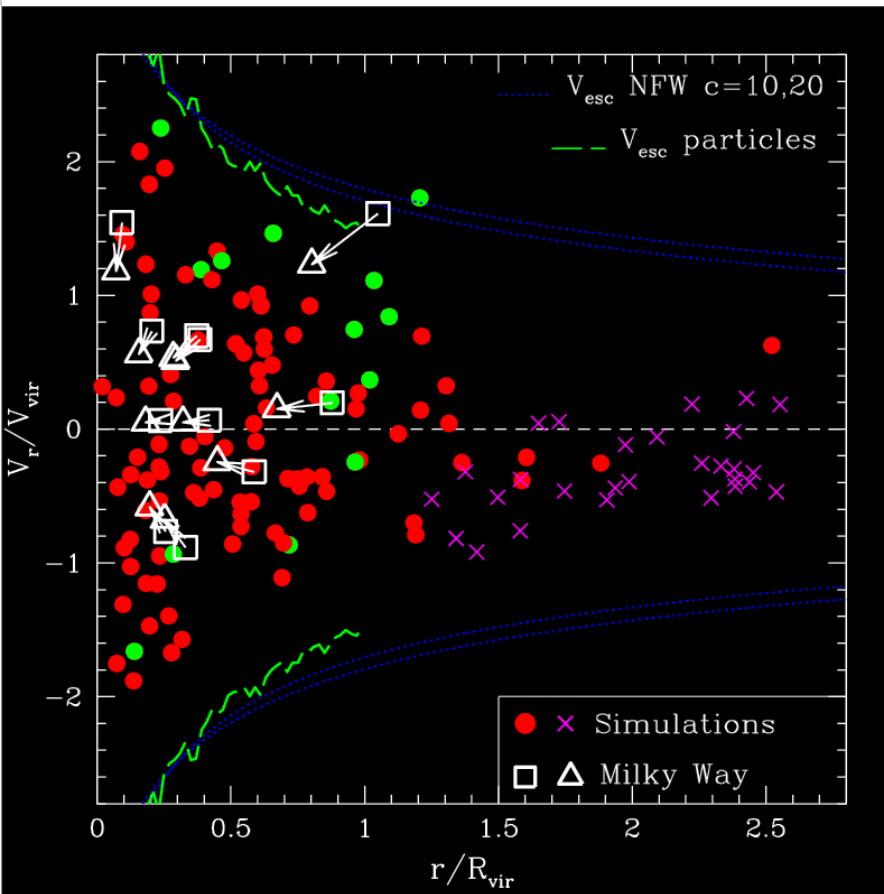
Estimating v_{vir} via satellites



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MW

M31



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What does that mean for the MW as a typical LCDM galaxy?

- Is there an inconsistency between stellar dynamics, timing arguments and statistics?
 - ◆ We need better galaxy formation models
- $M \approx 2.5 \times 10^{12} M_{\odot}$
 - ◆ Only ~20% of halos suitable hosts
 - ◆ >75% of the baryons in the MW are unaccounted for
 - ◆ Disk size: access to the full angular momentum reservoir
- $M \approx 10^{12} M_{\odot}$
 - ◆ MW would rather untypical or over abundant
 - ◆ Local group timing argument