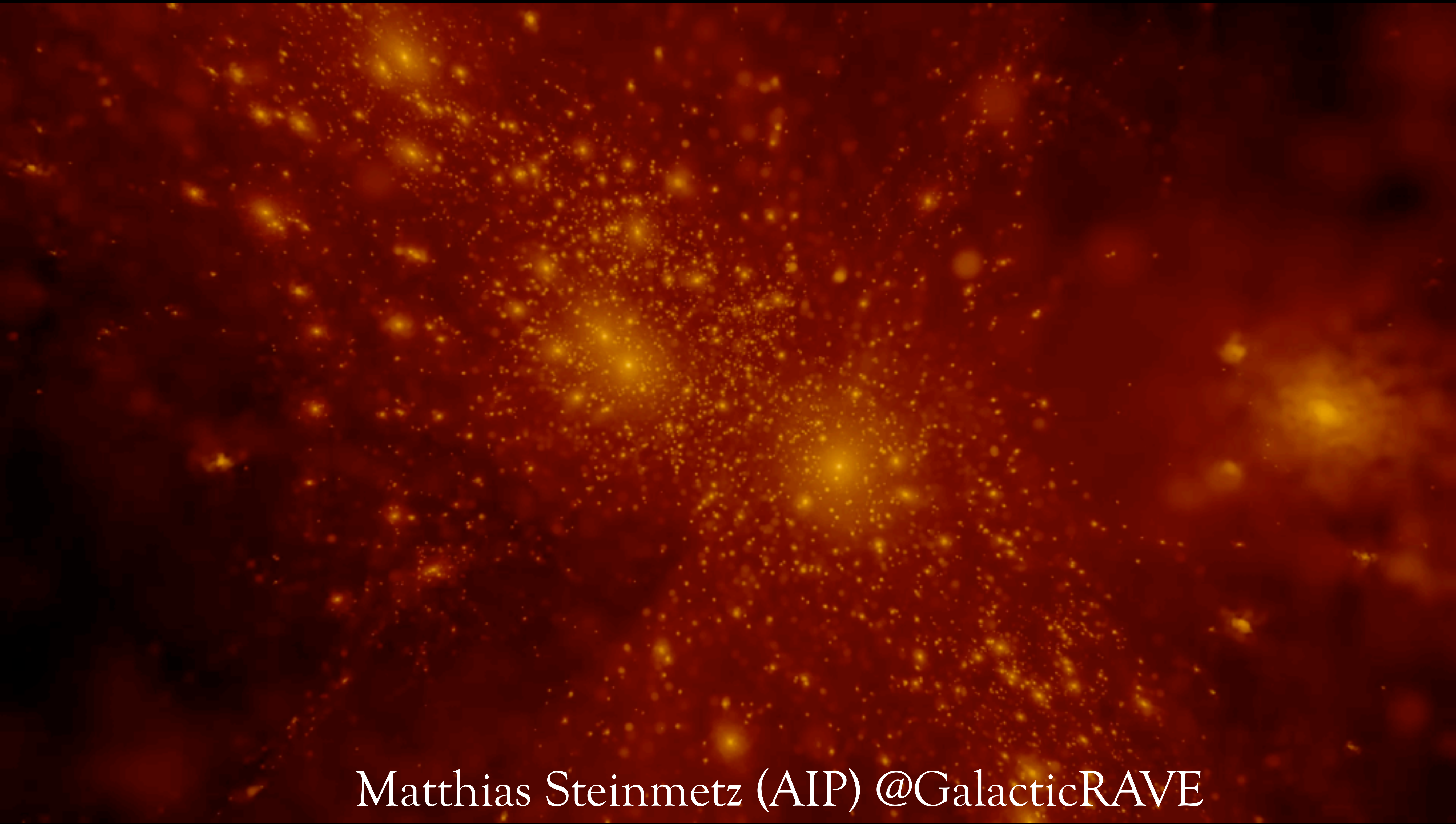
Constraints on dark matter in the Milky Way and the Local Group

AIP



Matthias Steinmetz (AIP) @GalacticRAVE

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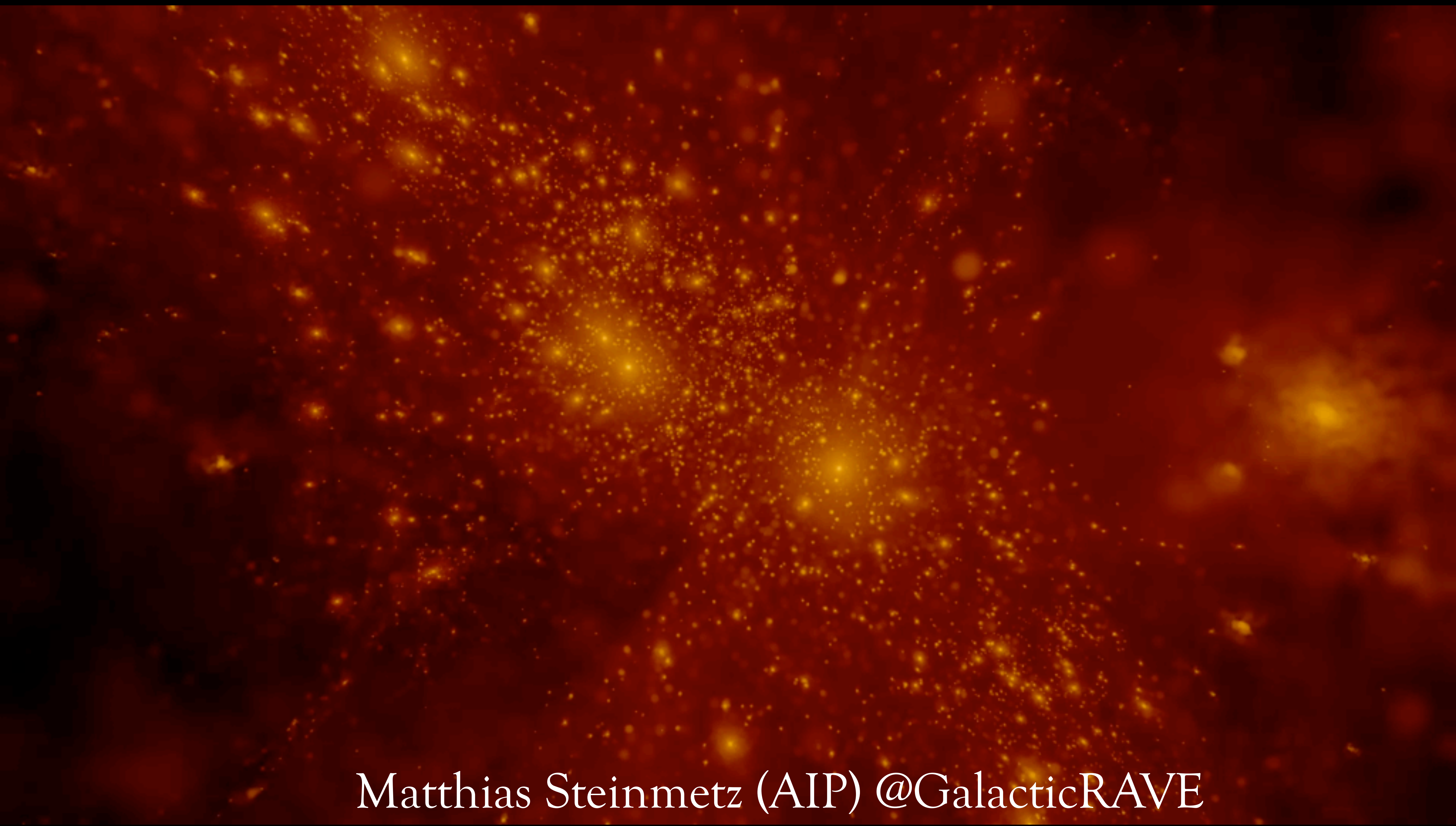

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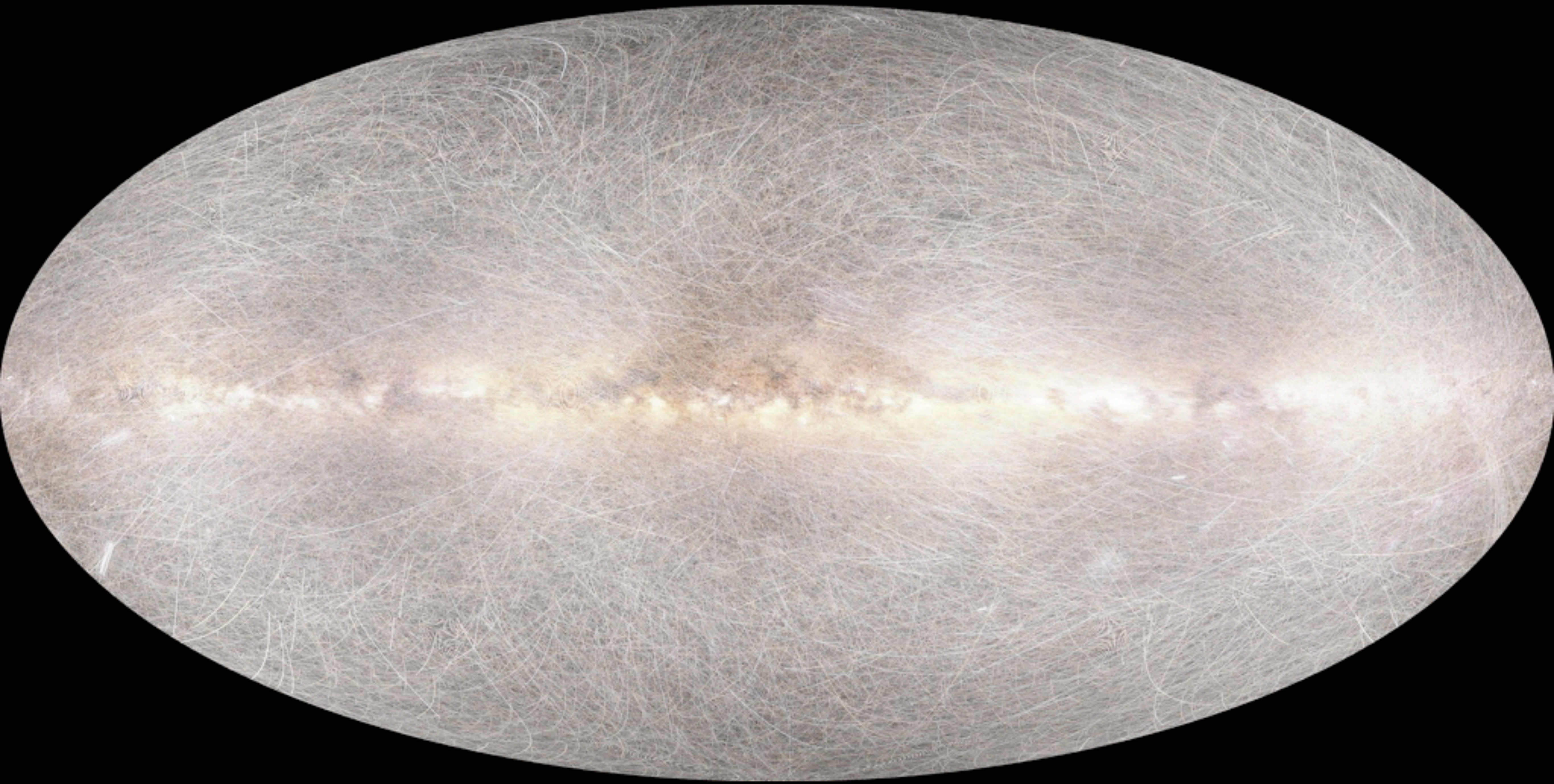
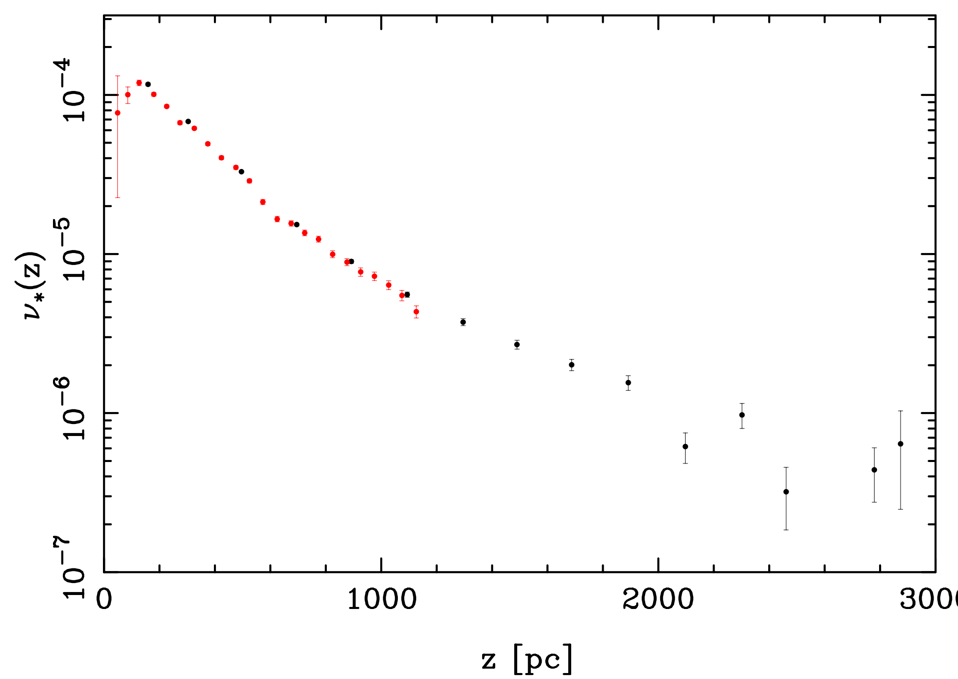
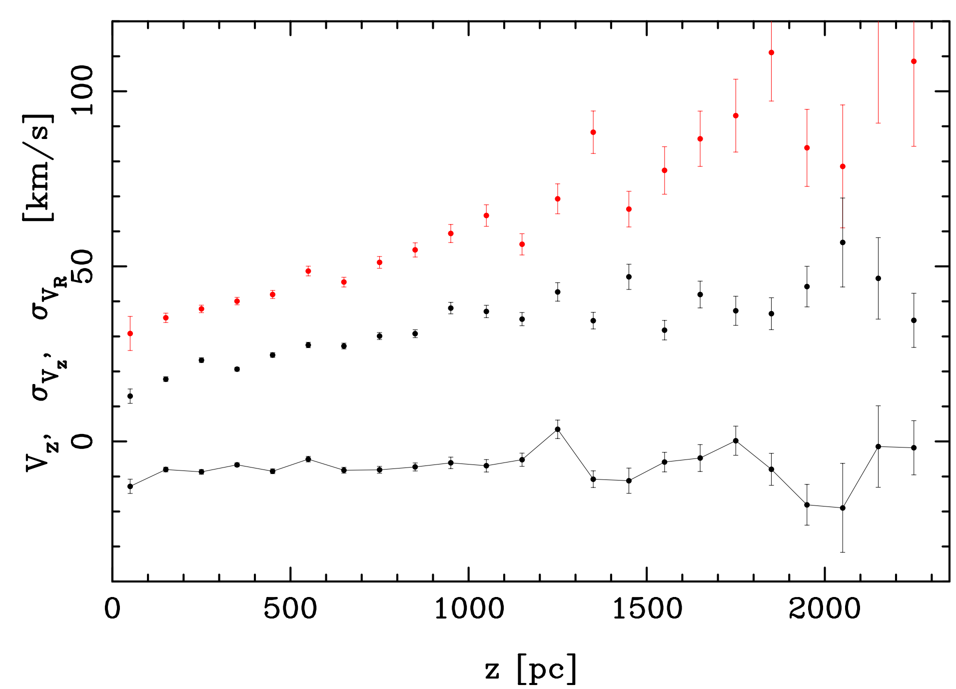


Determining the local density by the K_z force

- basically following the idea of Oort in the 1930s
- Take a sample of stars in a towards the Galactic Poles up to a certain distance from the Galactic Plane.
- subset of red clump stars gives good distances.
- Change in kinematics with vertical distances gives total vertical force (in simplest approximation proportional to surface density)
- number counts of stars gives baryonic mass distribution





Bienaymé et al., 2014

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$$\varrho_{\rm DM} \approx 0.01 M_\odot\, {\rm pc}^{-3} = 0.38 {\rm GeV\, cm}^{-3}$$

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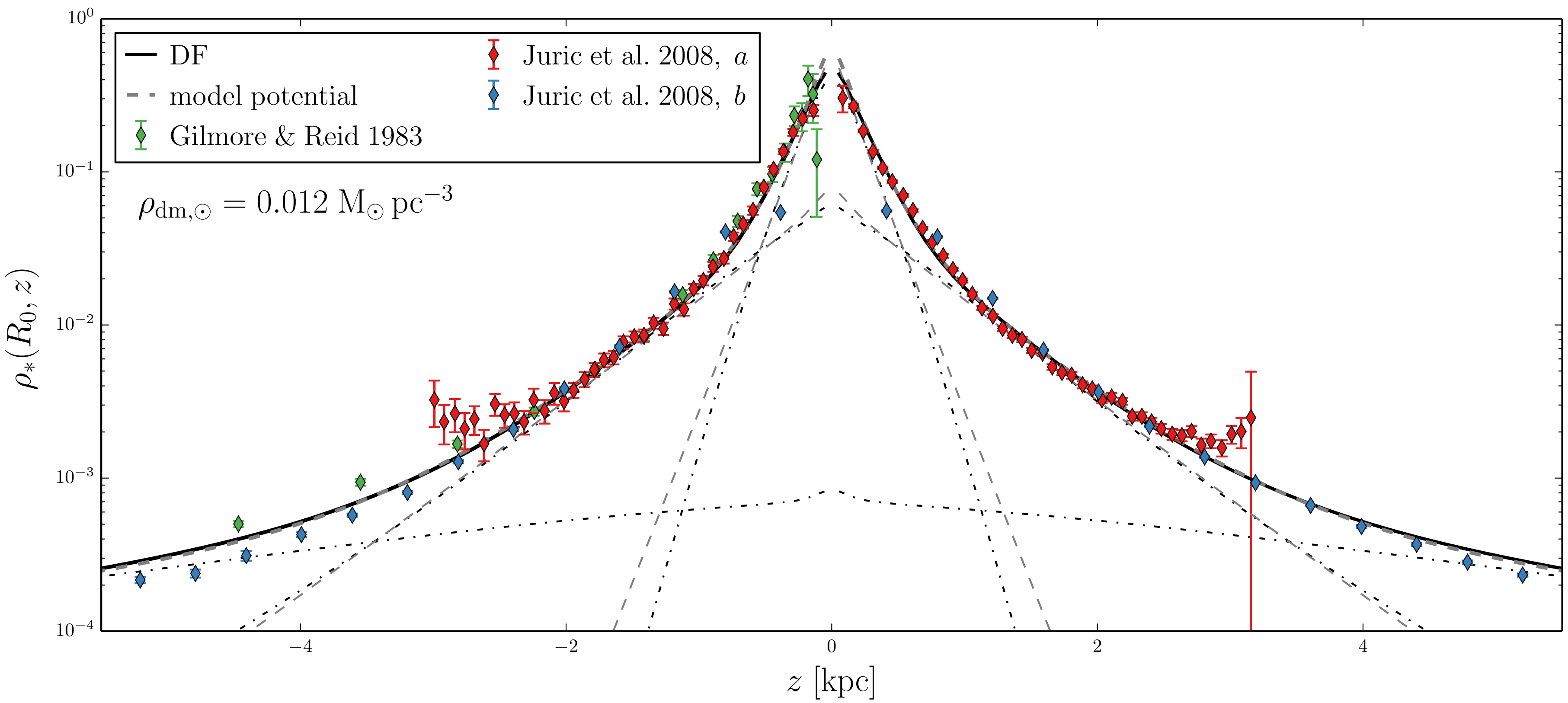
  - Hagen & Helmi: $\varrho_{\rm DM} \approx 0.018 M_\odot\, {\rm pc}^{-3}$
- but in particular HH18 use a smaller scale height for the thin disk of 0.27kpc (with 0.31kpc as in McMillan the would get 0.012 $M_\odot$ pc^{-3})

Parameters from Galaxy models

- Mass Model:
  - three exponential disks
  - flattened bulge
  - NFW dark matter halo
- Binney 2012 model for kinematics (incl. stellar halo)
- Model fit to vertical RAVE data
- see e.g. Bovy & Rix 2013, **Piffl et al 2014**, McMillan 2016



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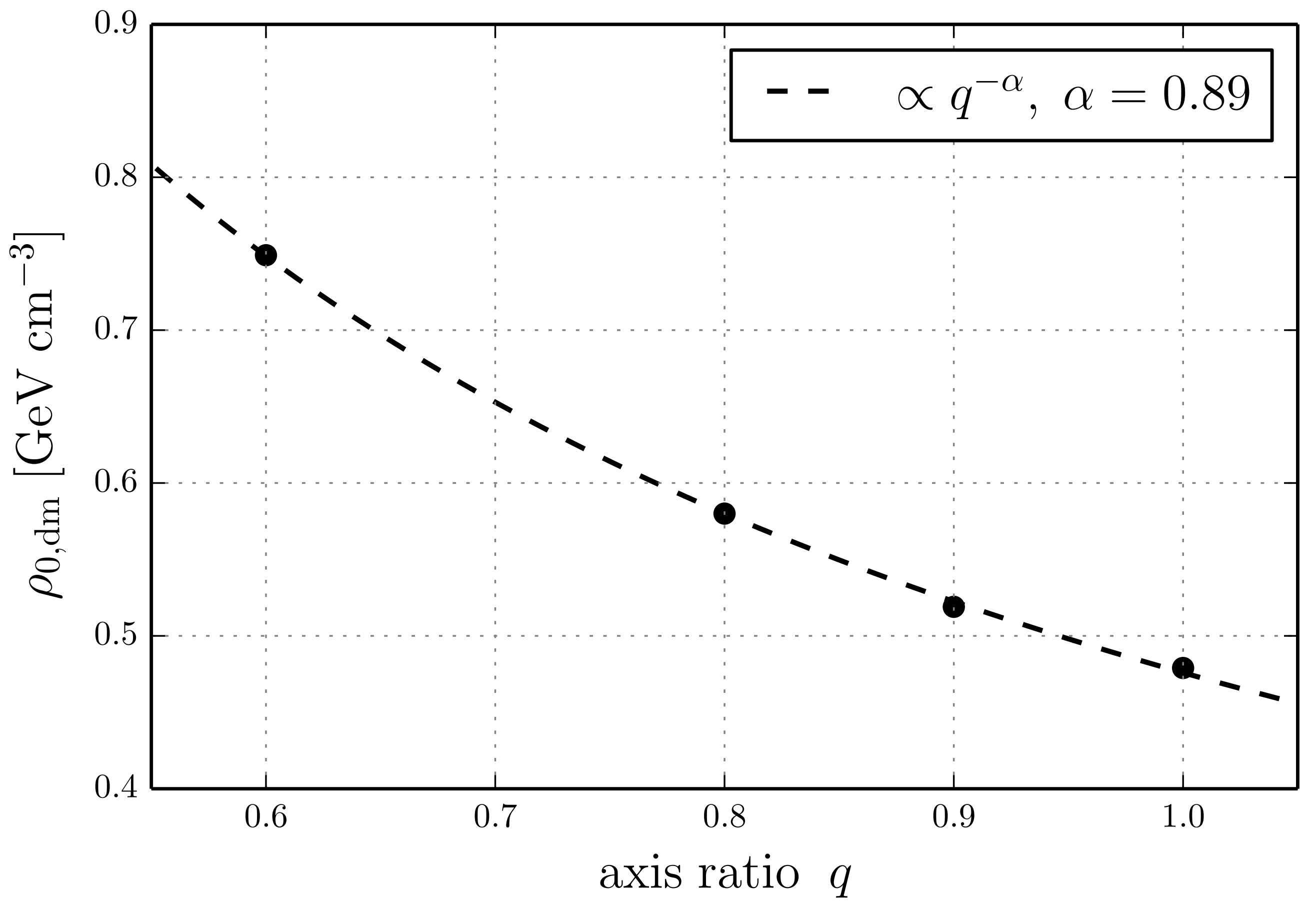
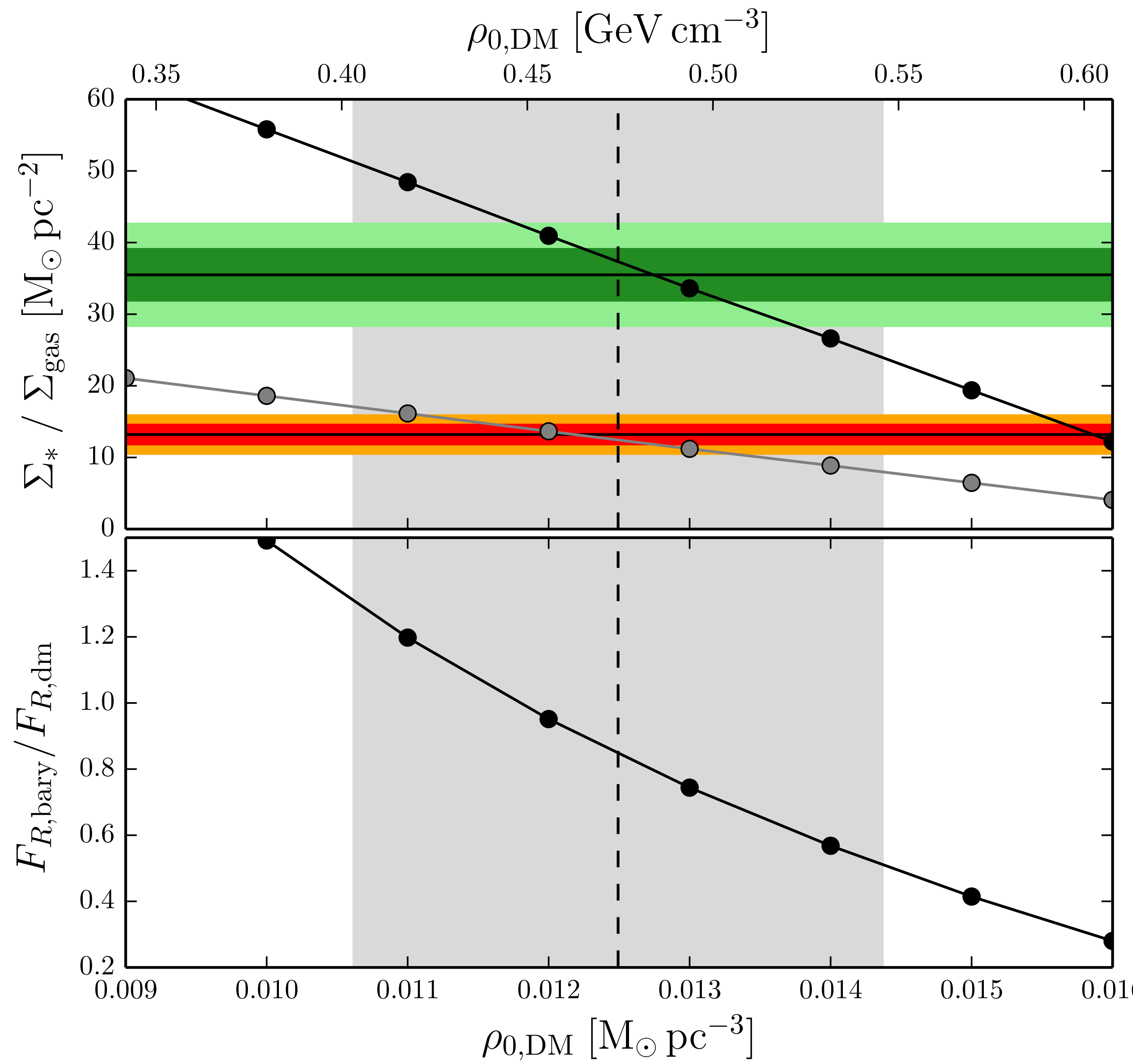
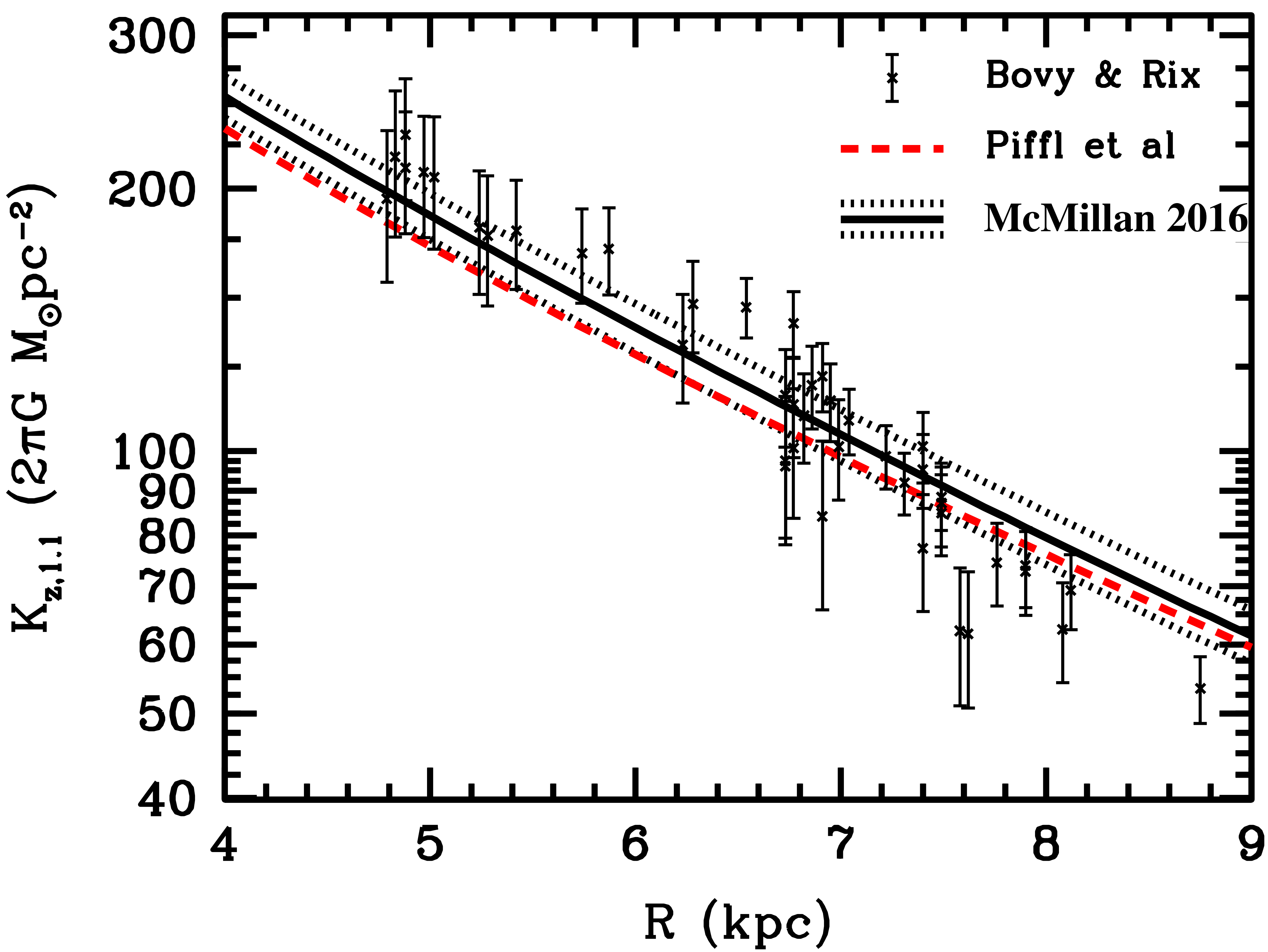




$$\varrho_{\mathrm{DM}} = 0.0126 \times q^{-0.89} \mathrm{M}_\odot\, \mathrm{pc}^{-3} \pm 10\%$$

$$\Sigma_{\mathrm{tot}}(< 0.9\mathrm{kpc}) = 69 \pm 10\, \mathrm{M}_\odot\, \mathrm{pc}^{-2}$$

Rix&Bovy 2013: non-local measurements



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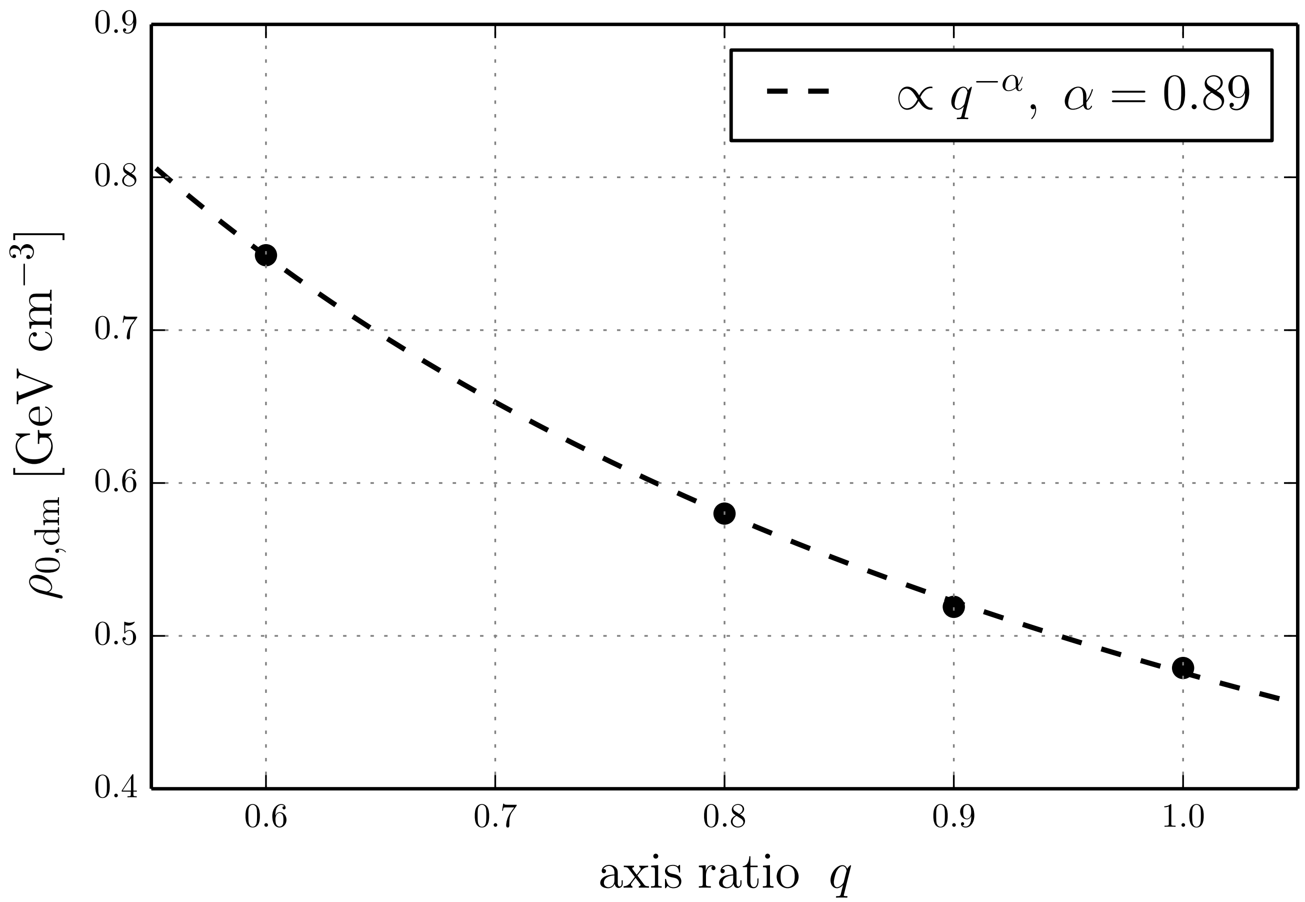

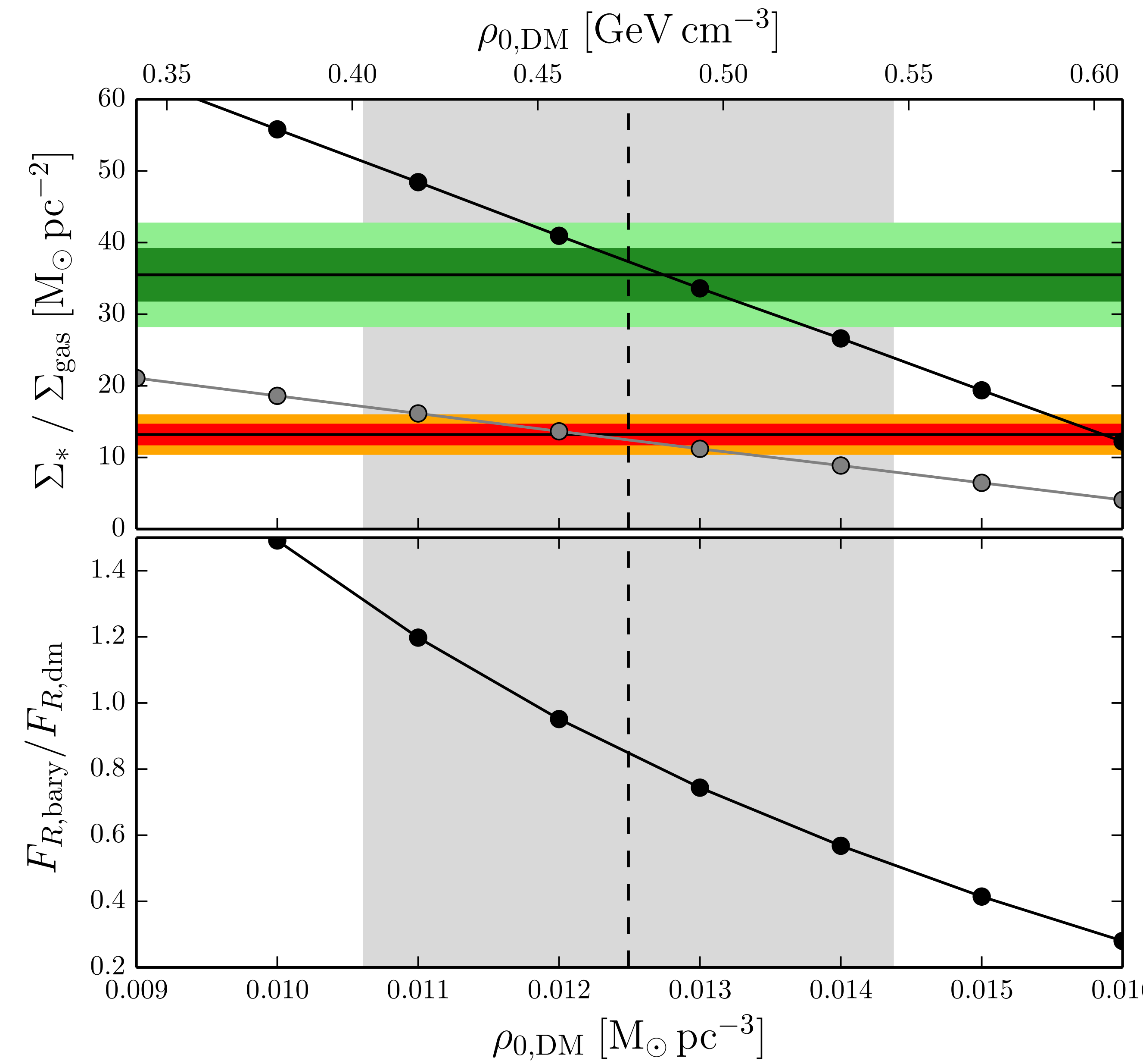

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$$M_{\mathrm{DM}}(< R_0) = (6.0 \pm 0.9) \times 10^{10}\,\mathrm{M}_\odot$$

$$M_{\mathrm{vir}} = (1.3 \pm 0.1) \times 10^{12}\,\mathrm{M}_\odot$$

- 46% of the radial force acting on the Sun provided by baryons

Escape speed of the Milky Way at the Solar Circle

- Leonard & Tremaine (1990):
  - consider distribution function f(E)
  - $f \rightarrow 0$ as $E \rightarrow \Phi(r_{vir}) \Rightarrow n(v) \propto (v_{esc}-v)^k$

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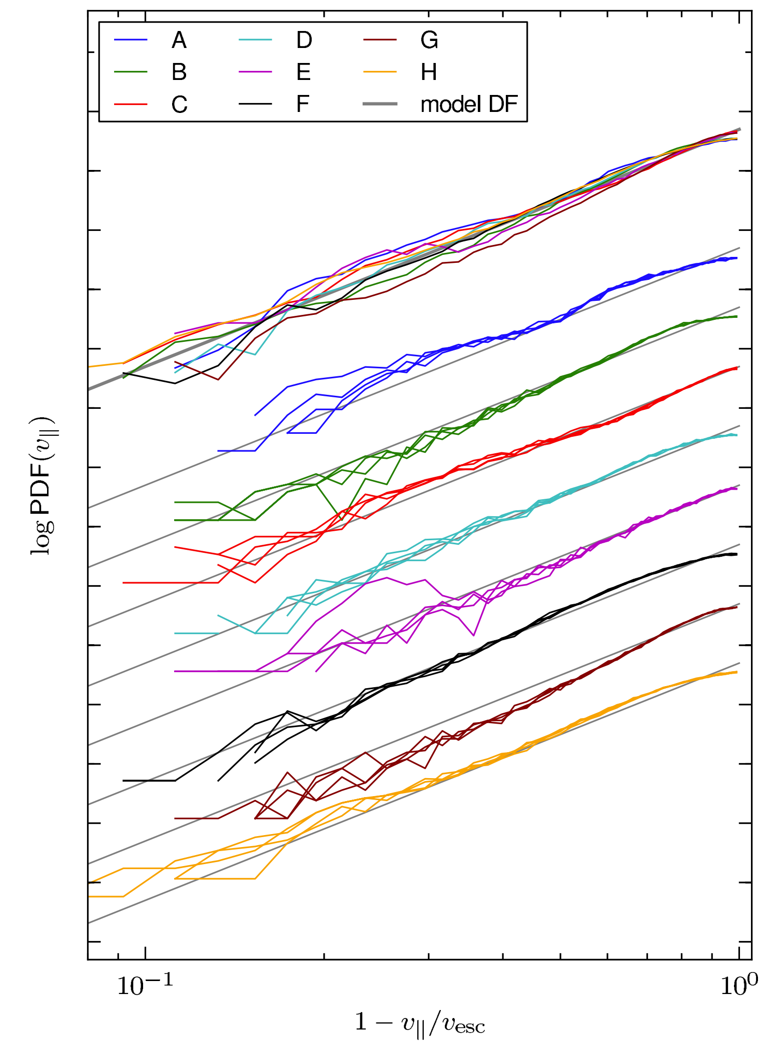

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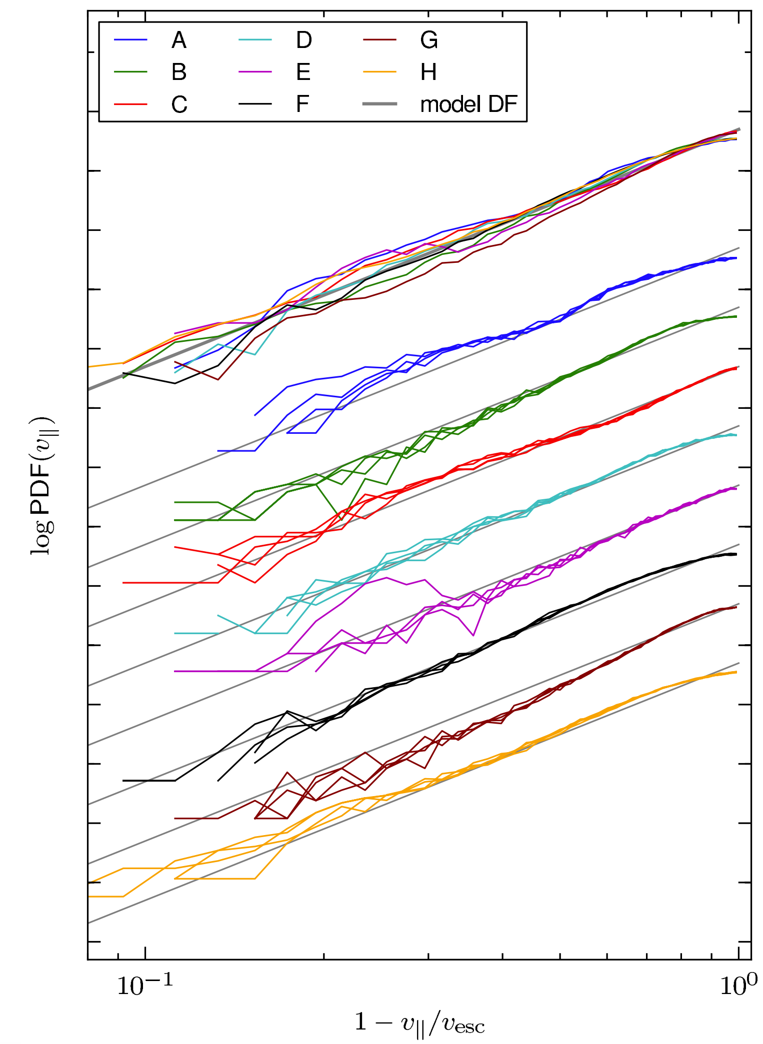

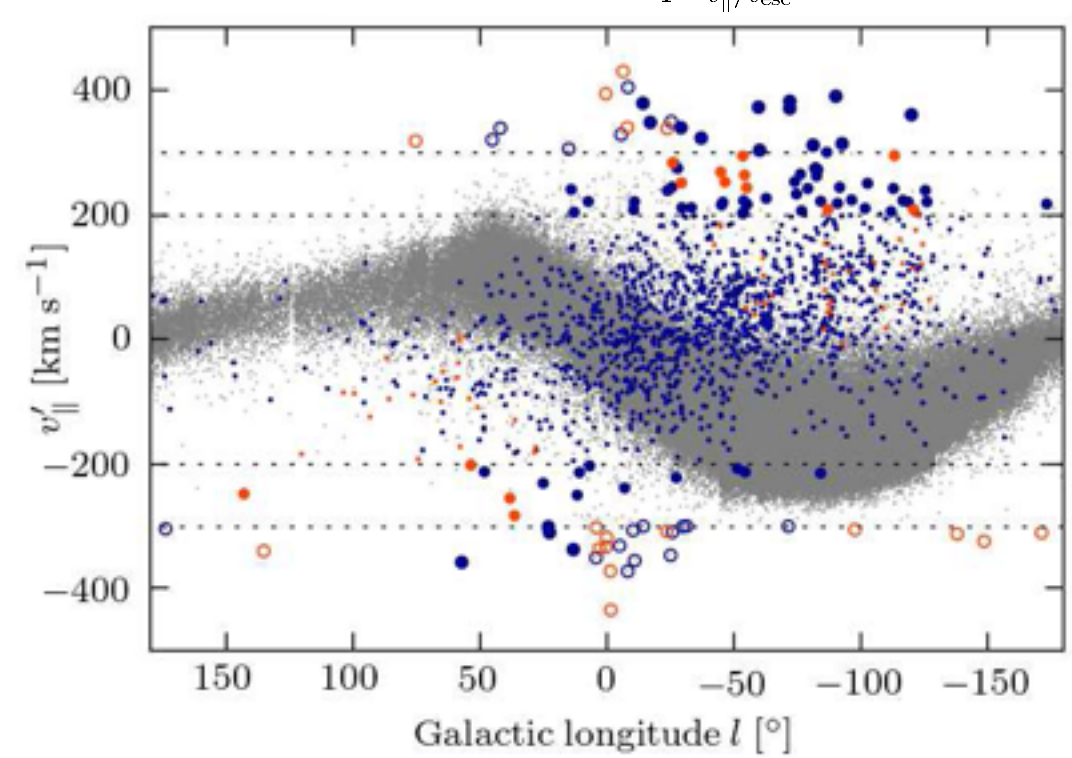

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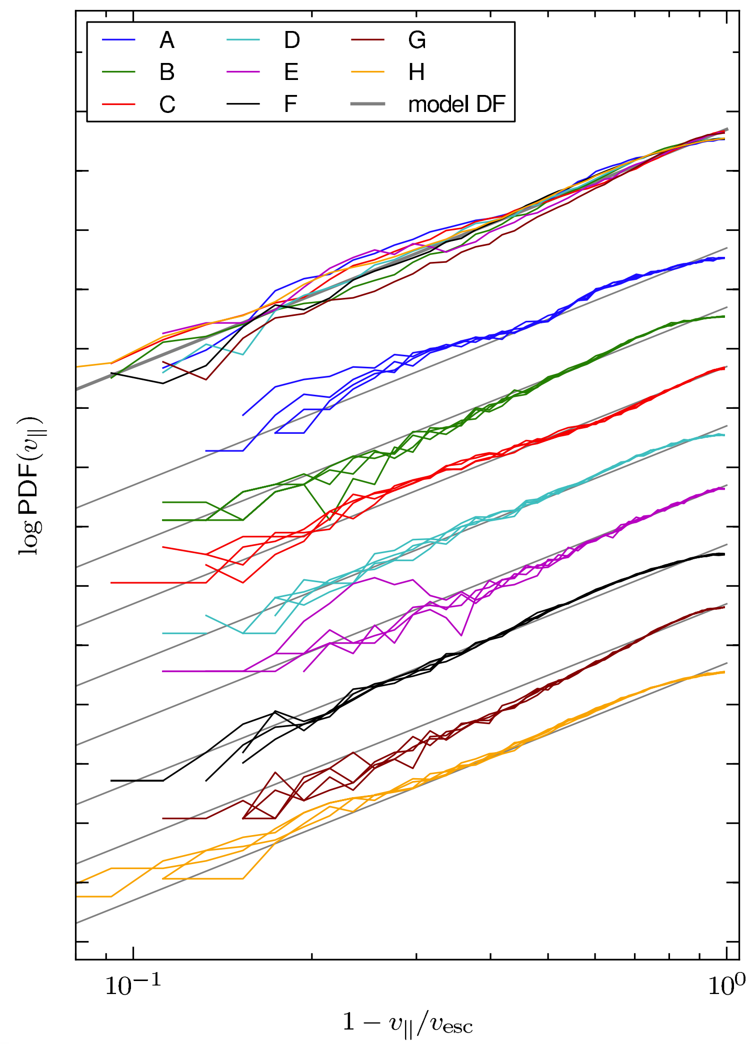

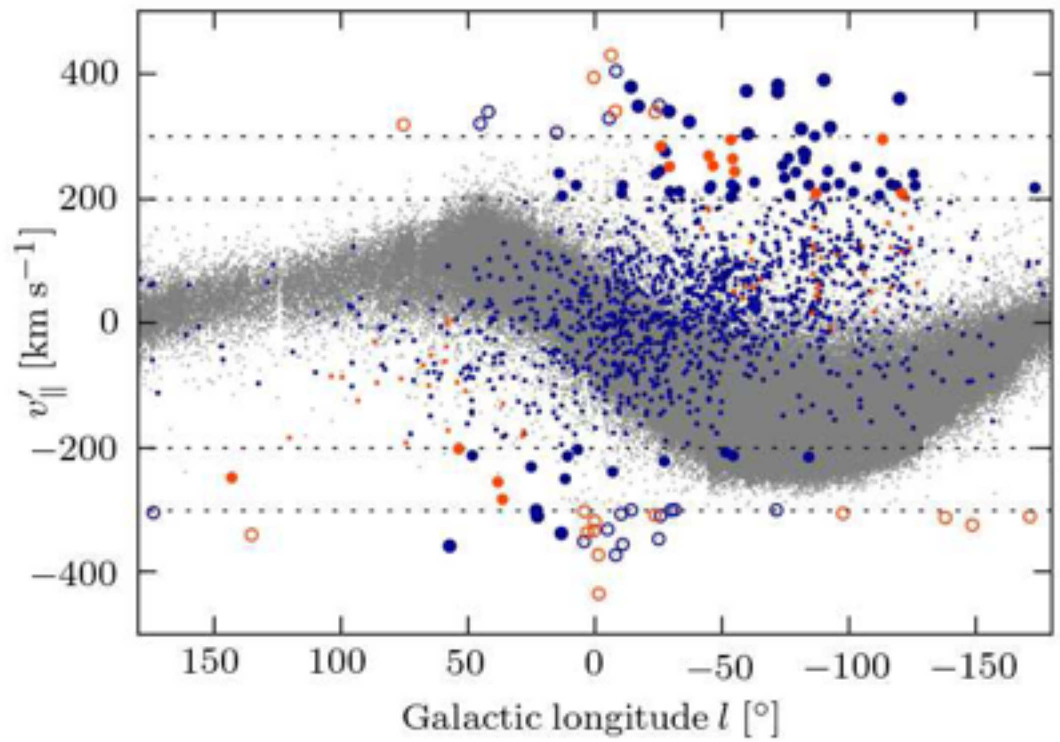

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- Smith + RAVE (2007):
  $498\text{km/s} < v_{esc} < 608\text{km/s}$
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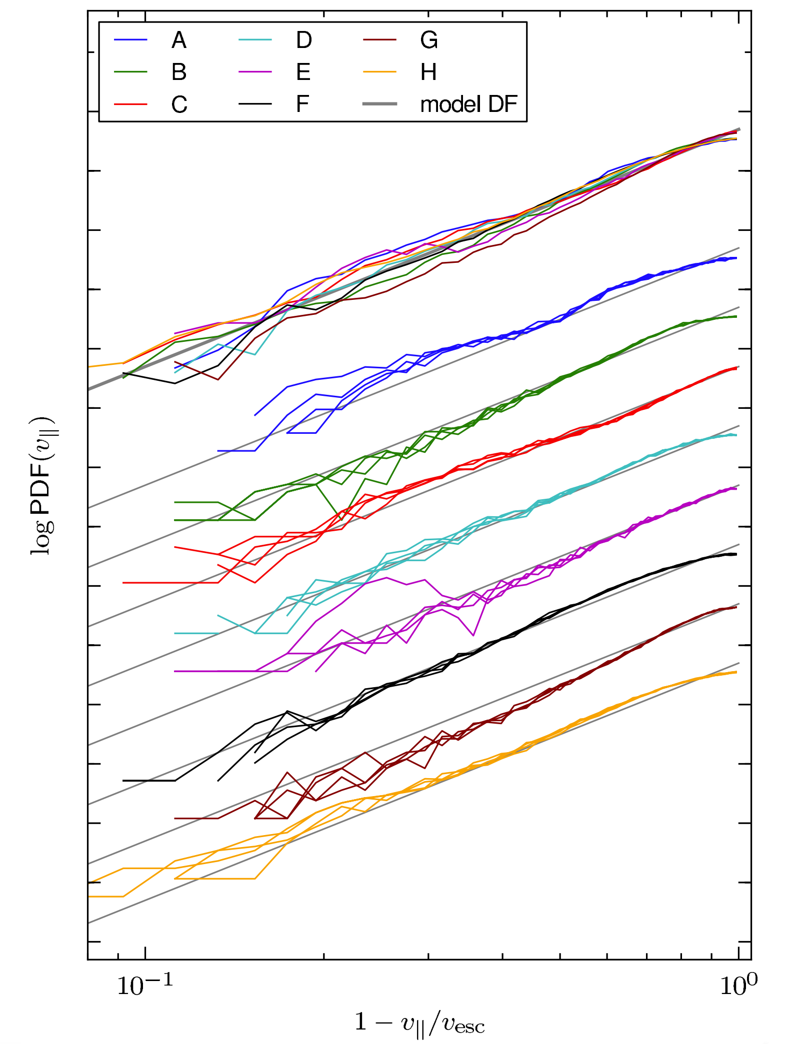

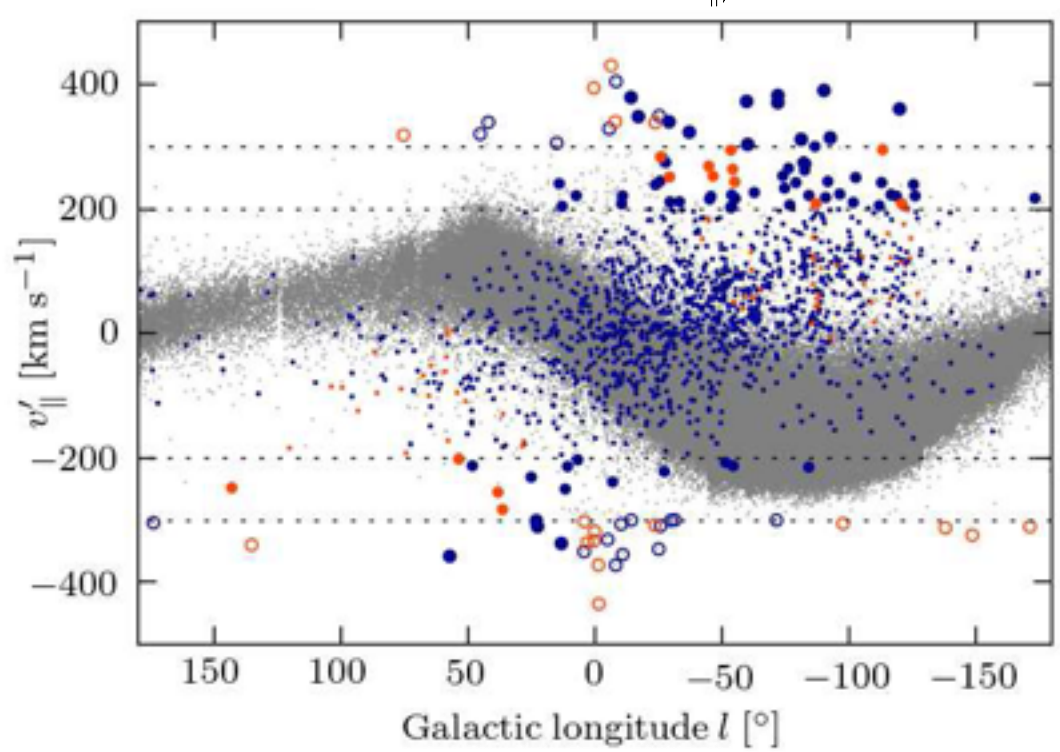

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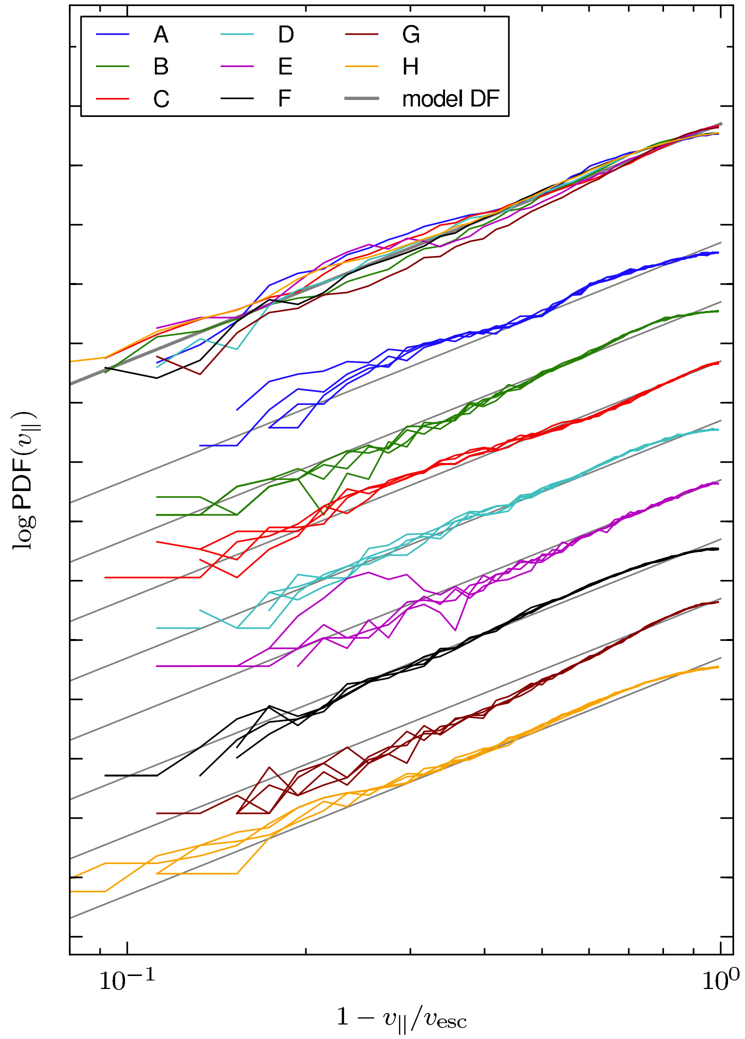
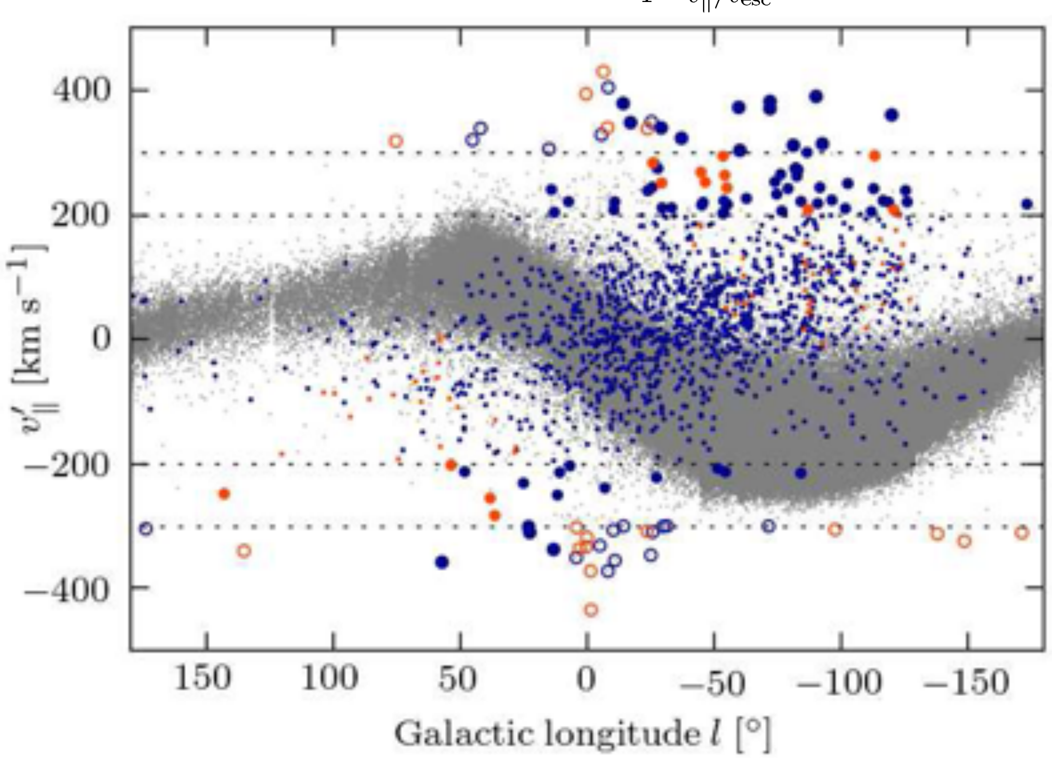
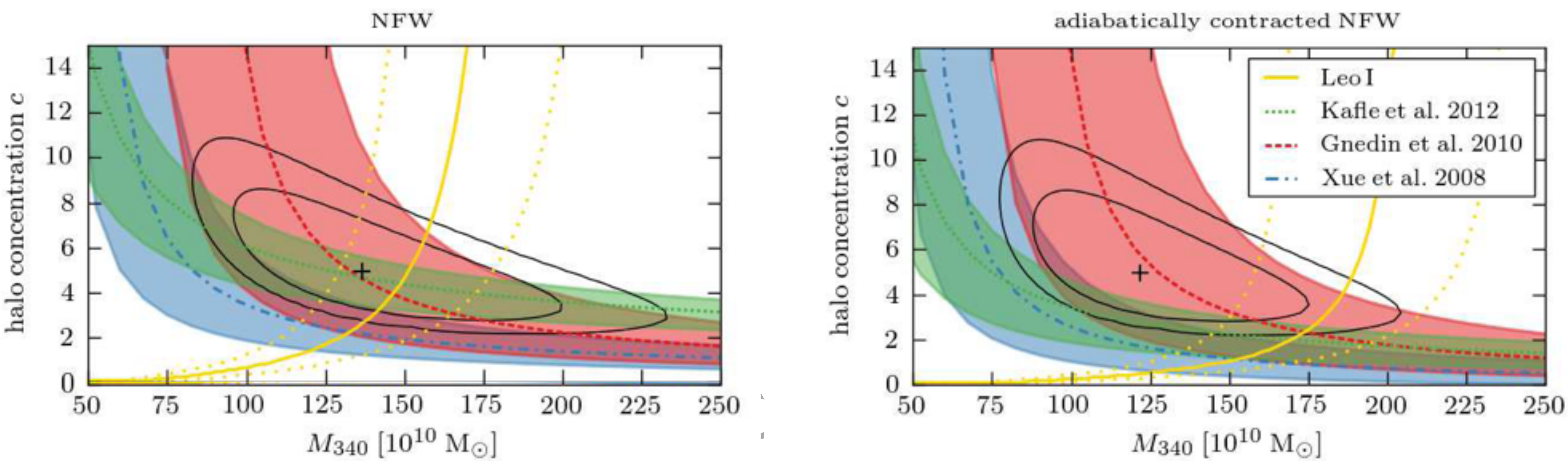
- Piffl + RAVE (2014):
  492km/s < v_{esc} < 587km/s
  $1.2\times10^{12}M_{\odot} < M_{vir} < 2.1\times10^{12}M_{\odot}$





Mass of the Milky Way with additional constraints



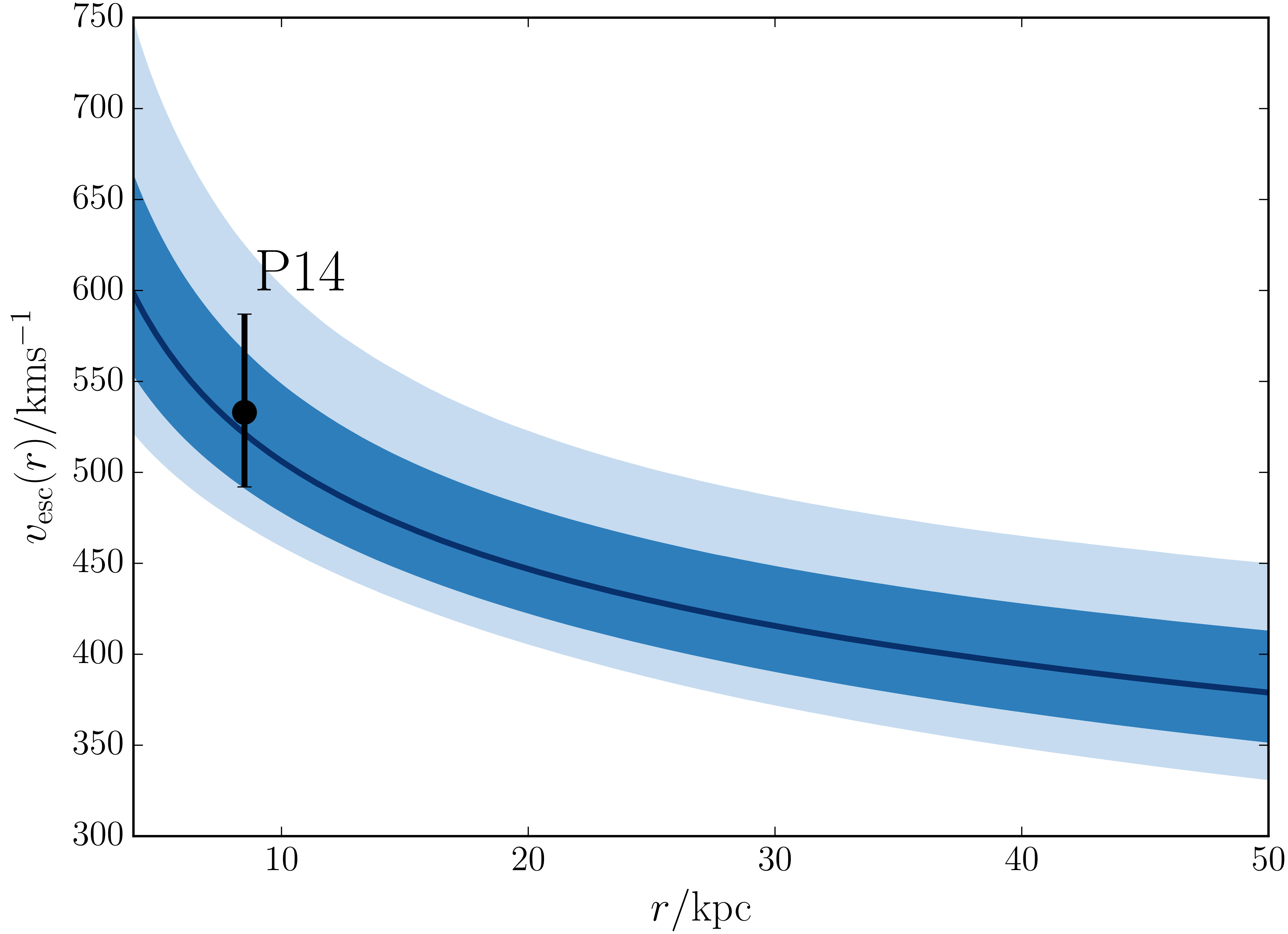
Kafle: Mass within 25kpc

Xue: Mass within 60kpc

Gnedin: Mass within 85kpc

Piffl et al., 2014

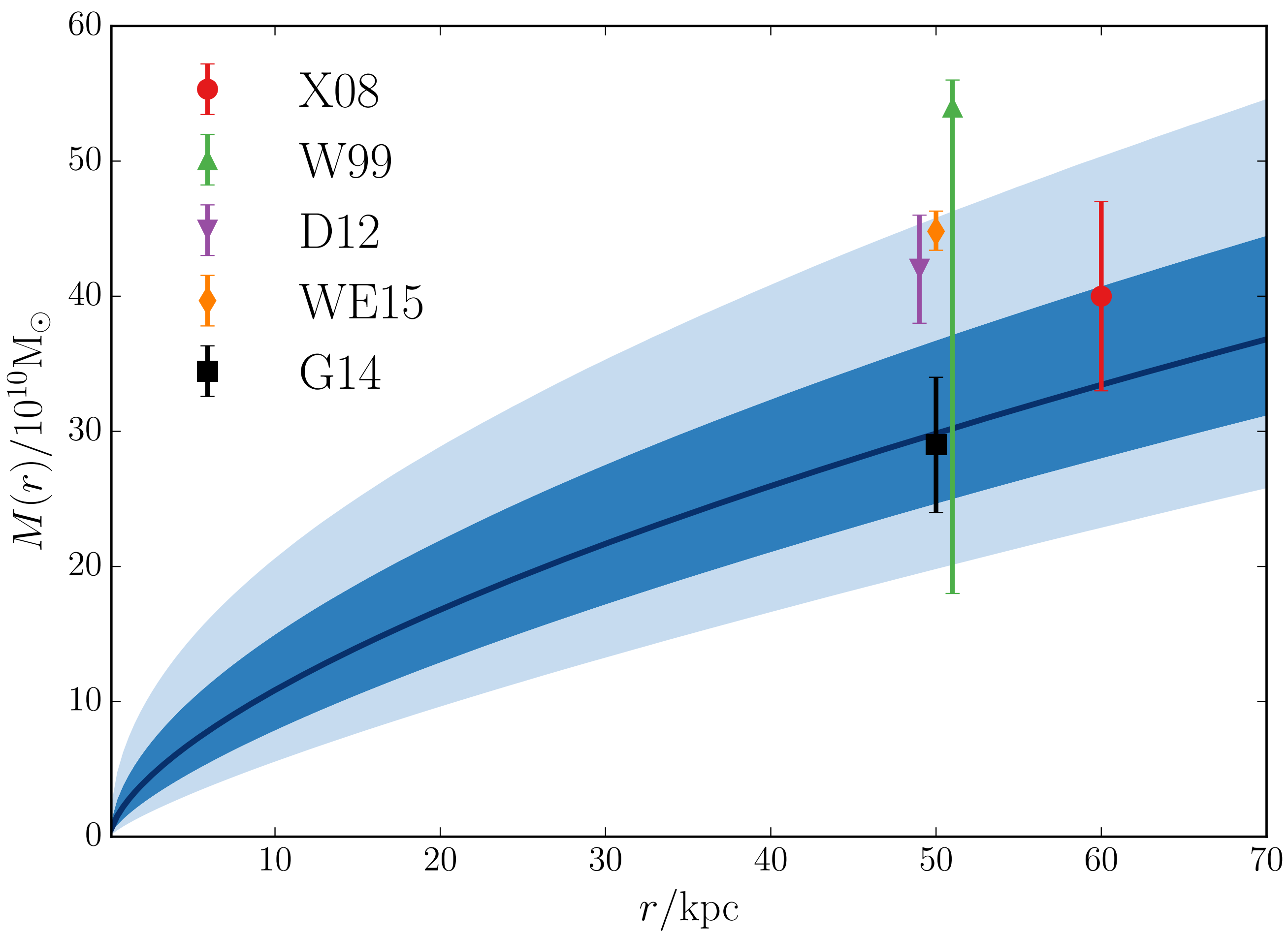
Escape velocity out to 50kpc using SDSS

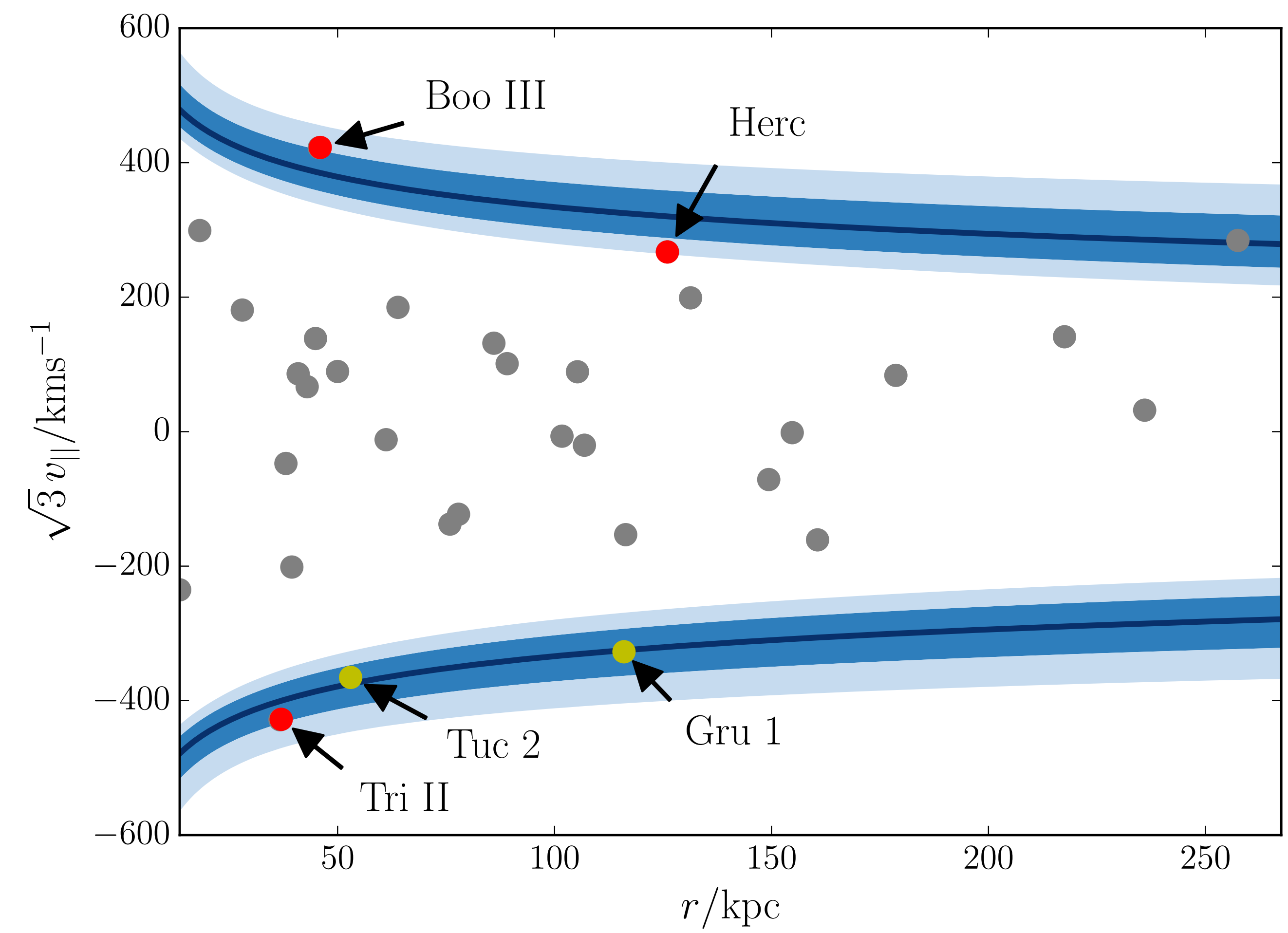


- fairly rapid decline to 376km/s at 50kpc

Williams et al., 2017

Comparison with halo stars and dwarf gals

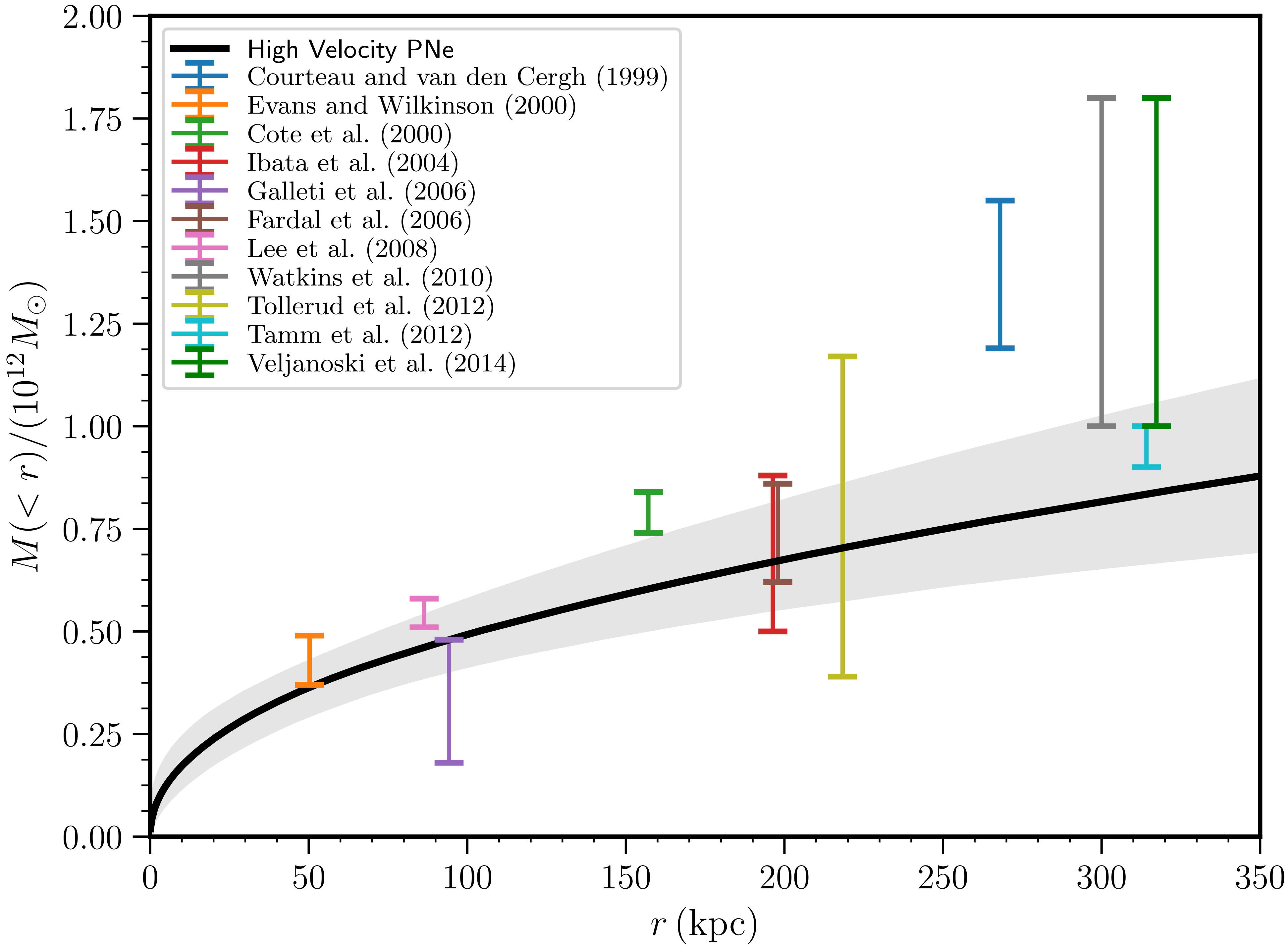




- if tangential velocity of high velocity dwarfs is close to $\sqrt{3}\,v_{\parallel} \Rightarrow$ unbound

Williams et al., 2017

Escape velocity of M31



Kafle et al., 2018

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  - $M_{MW} = (0.85 \pm 0.25) \times 10^{12}\ M_\odot$ (Sag Dwarf included)
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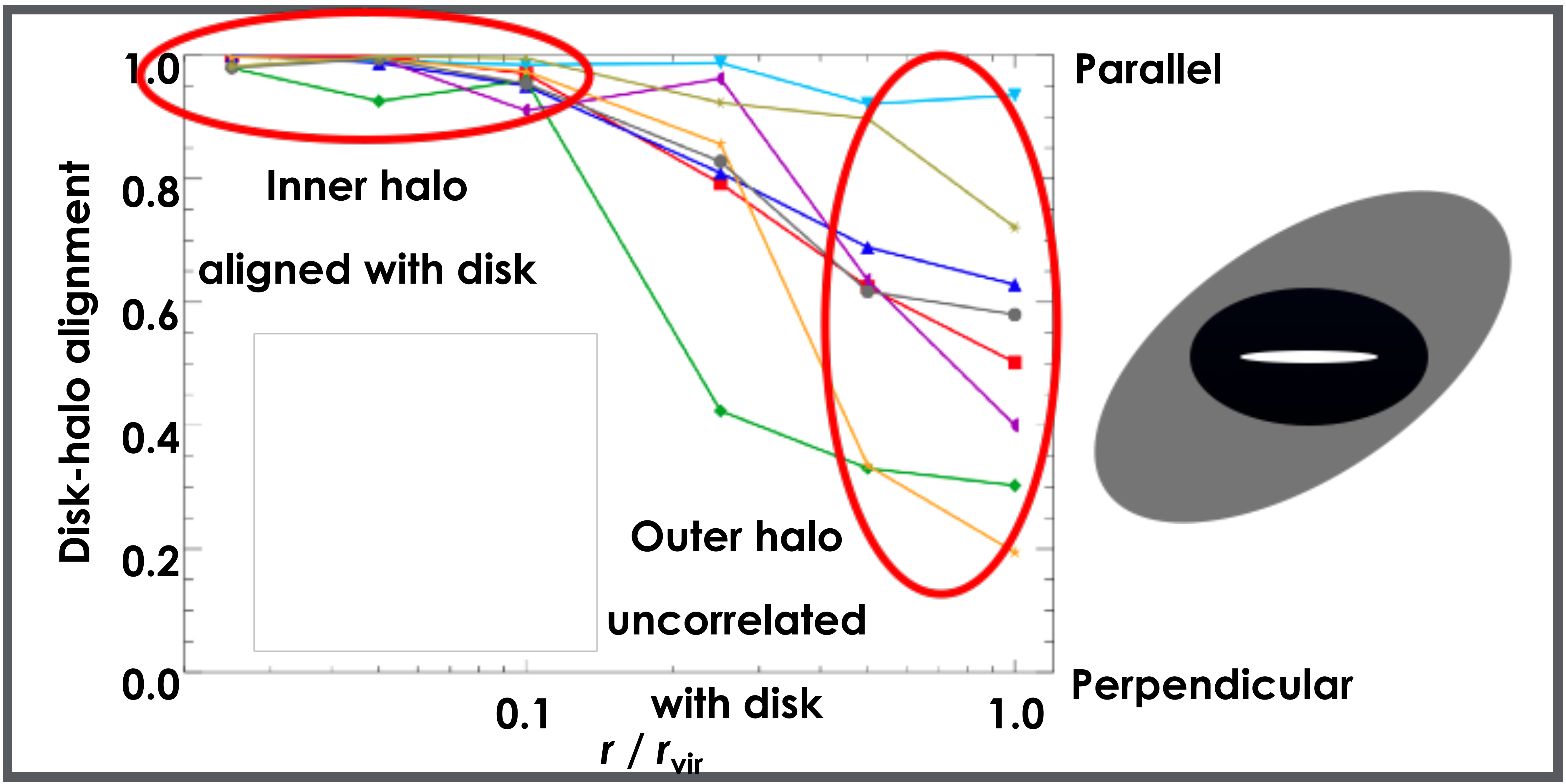
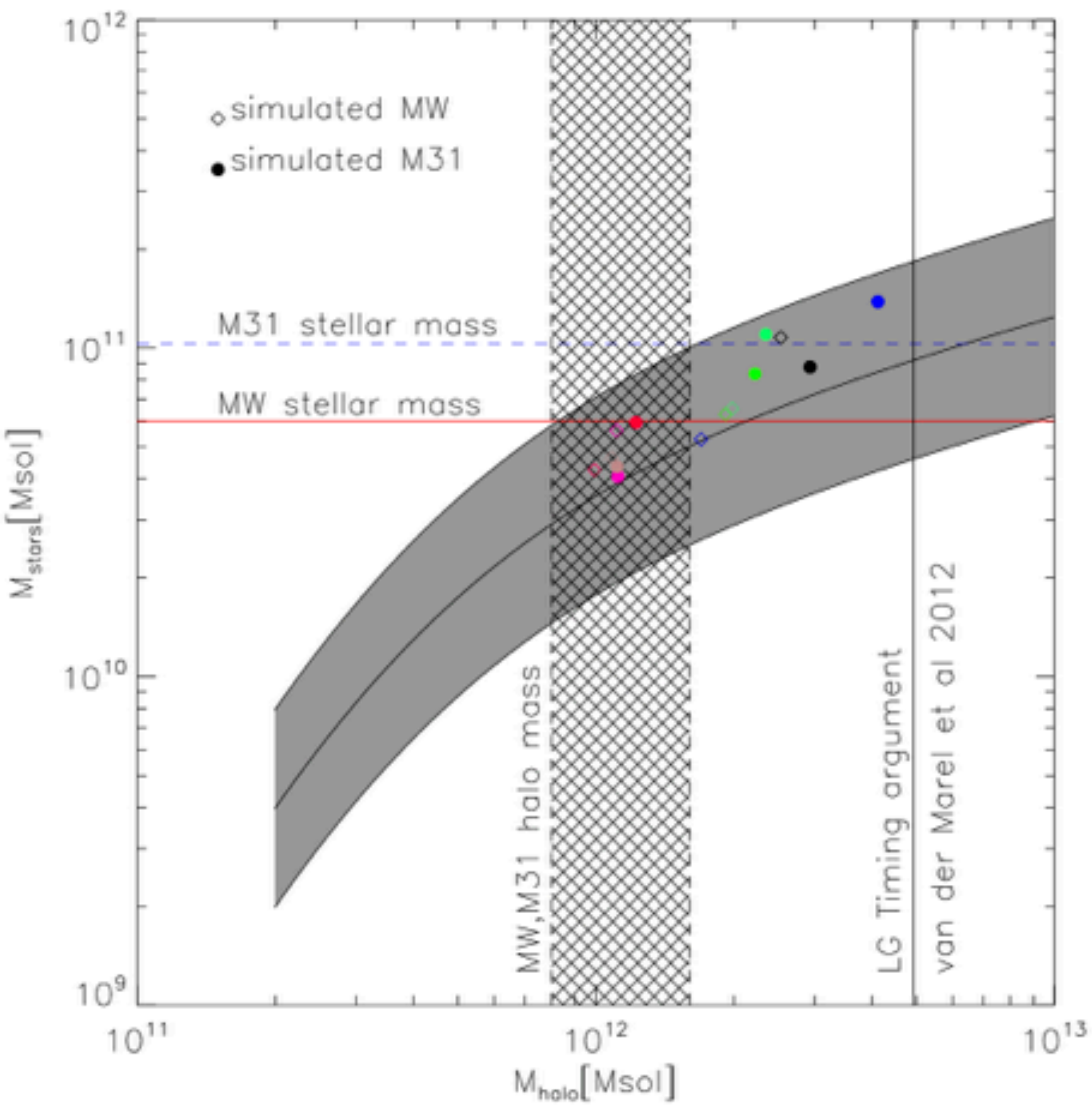
- Kafle etal 2018: compare mass estimates derived from sims: difficult to get better than 15%

Misalignment between disk and halo



Bailin et al., 2005

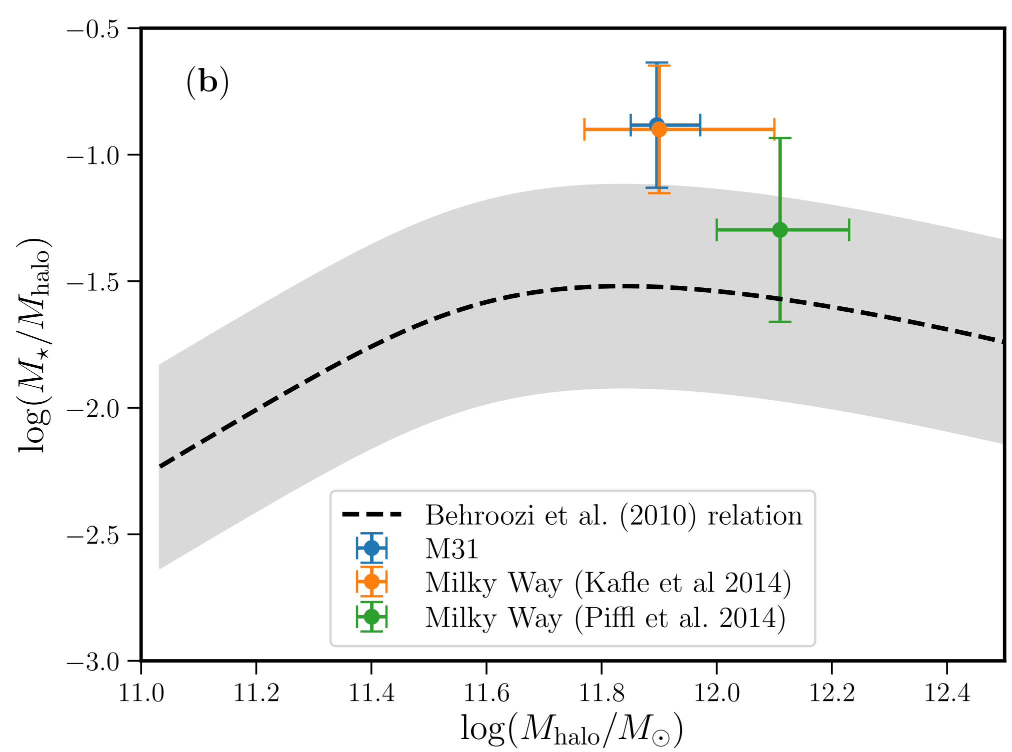
Baryonic vs total mass of MW & M31



Libeskind et al., in prep.

If Mass of the Milky way (or even M31) is below ≈10^{12} $M_\odot$

- MW/M31 unusually efficient in cooling/star formation
- Angular momentum
- local dynamics?
- Where is the mass in the Local Group?



Kafle et al., 2018

Summary

- Local Dynamics: $M_{MW} = 1.3 \times 10^{12}\ M_\odot$
- Dwarf orbits
  - Sag Dwarf included $M_{MW} = 0.85 \times 10^{12}\ M_\odot$
  - Sag Dwarf excluded $M_{MW} = 0.96 \times 10^{12}\ M_\odot$
- Globular Clusters
  - HST PM: $M_{MW} = 1.87 \times 10^{12}\ M_\odot$
  - Gaia PM: $M_{MW} = 1.41 \times 10^{12}\ M_\odot$
  - HST+Gaia PM: $M_{MW} = 1.67 \times 10^{12}\ M_\odot$
- Typical mass for $M_* = 6 \times 10^{12}\ M_\odot$
  - abundance matching $M_{MW} \approx 2 \times 10^{12}\ M_\odot$
- Mass of the Local Group $M_{LG} \approx 4 - 5 \times 10^{12}\ M_\odot$