UNIVERSITY OF SURREY

The Local Dark Matter Density

New constraints on the Milky Way's dark disc and the shape of the halo

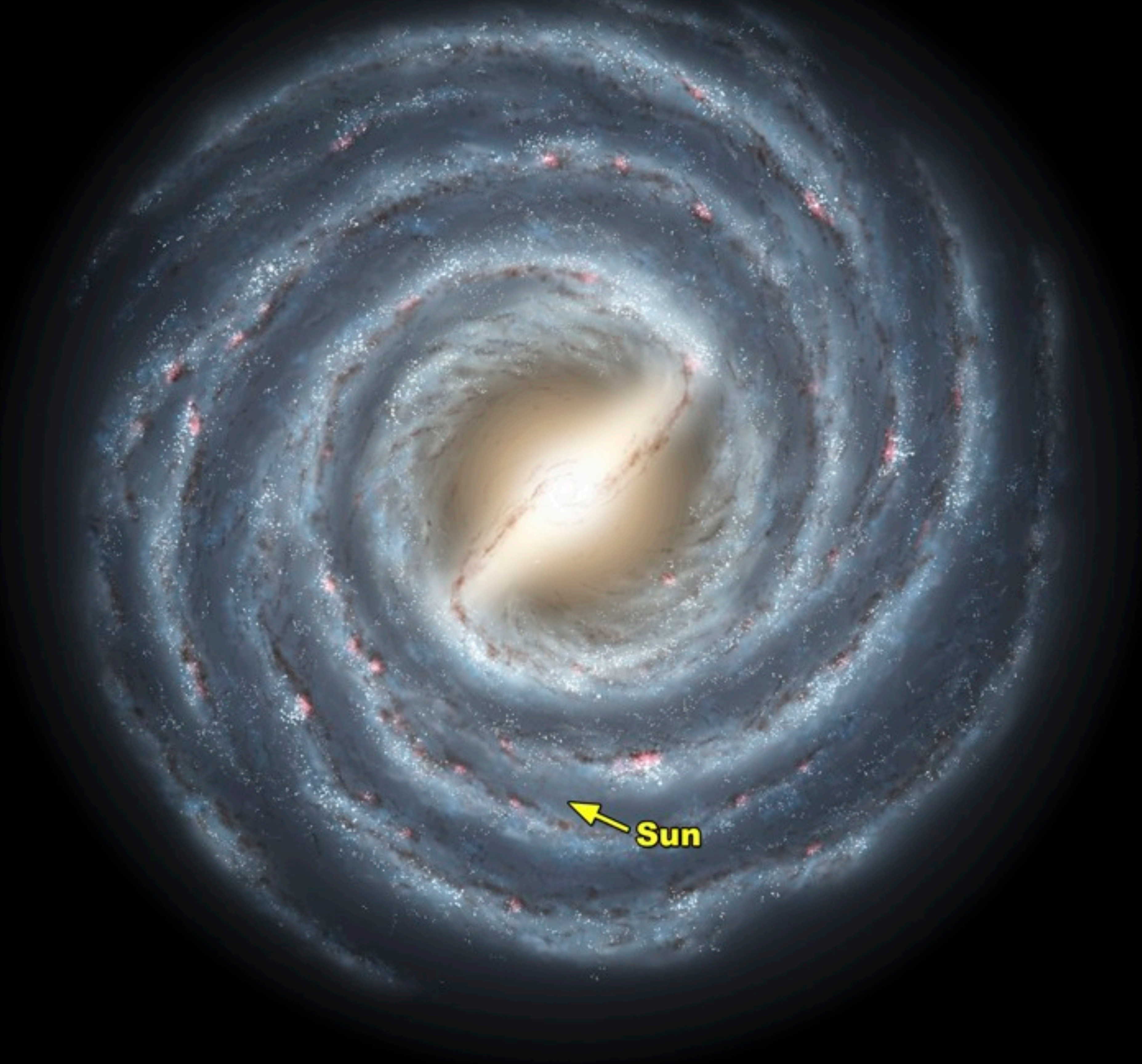
Prof. Justin Read | University of Surrey

Silvia Garbari; George Lake; Greg Ruchti; Oscar Agertz

Background

[What is ρ_{dm}? How do we measure it? Why is it interesting?]

Background | What is the local dark matter density?



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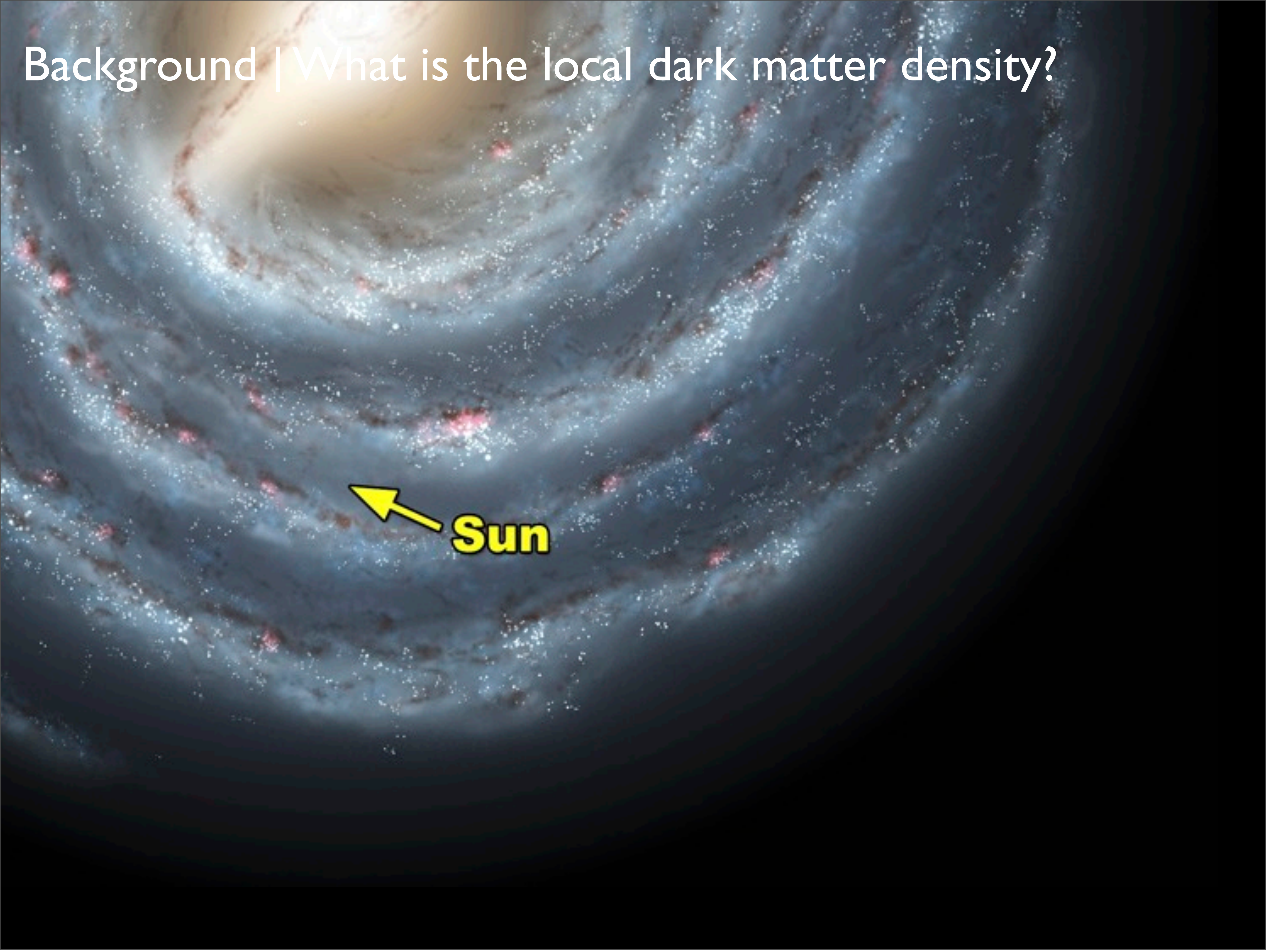

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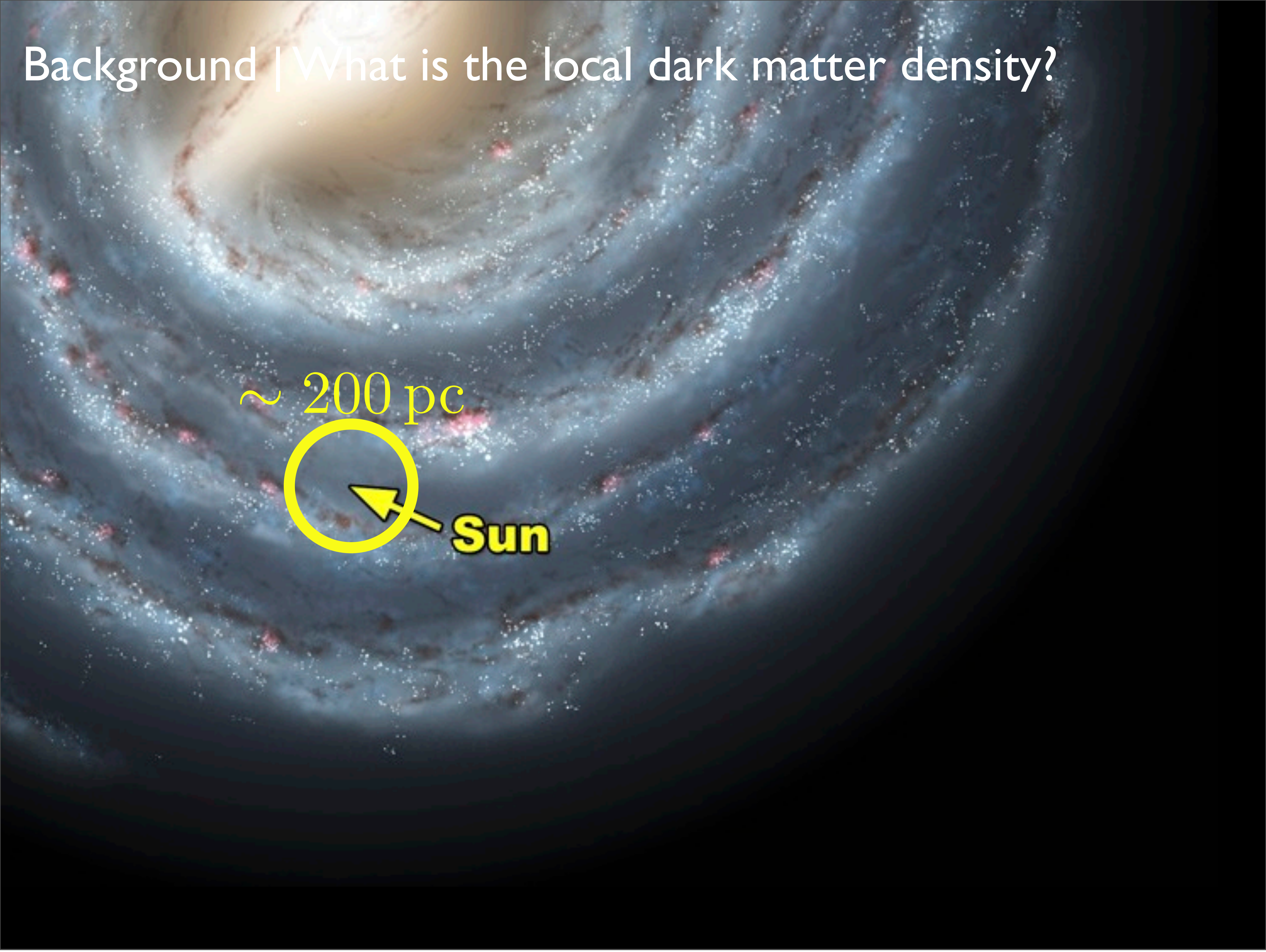
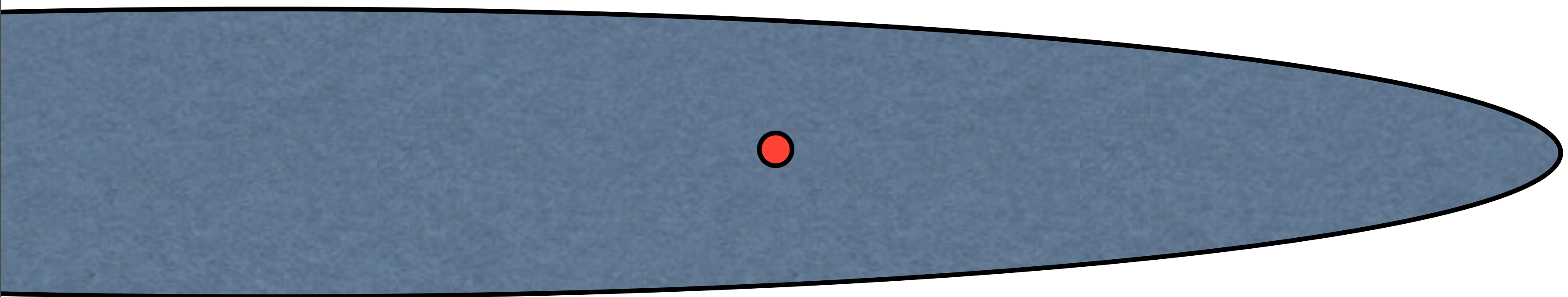


Background | How can we measure the local DM density?

1. Local measure:



$\rho_{\rm dm}$

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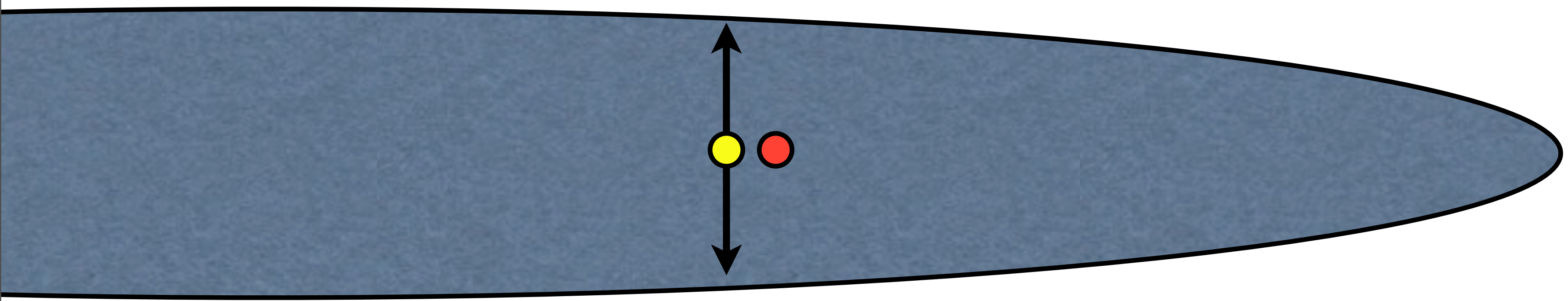

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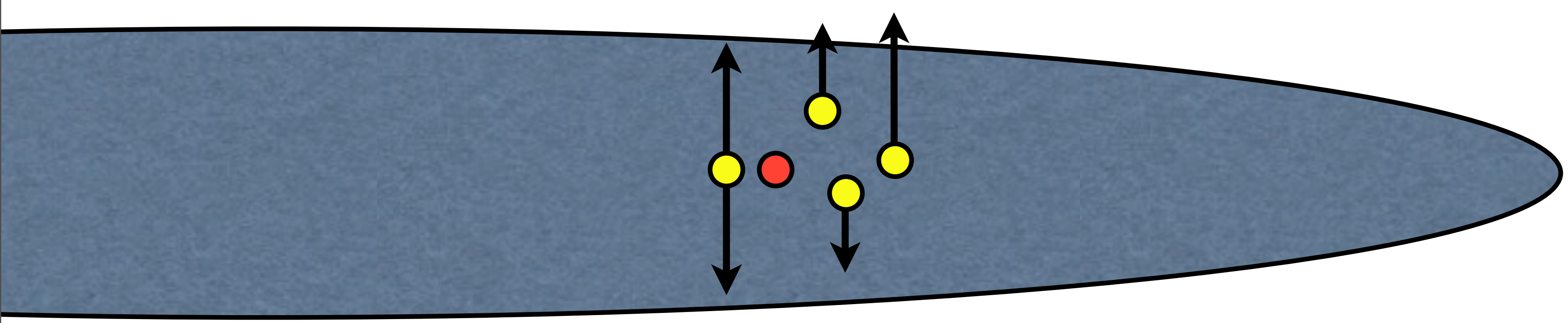

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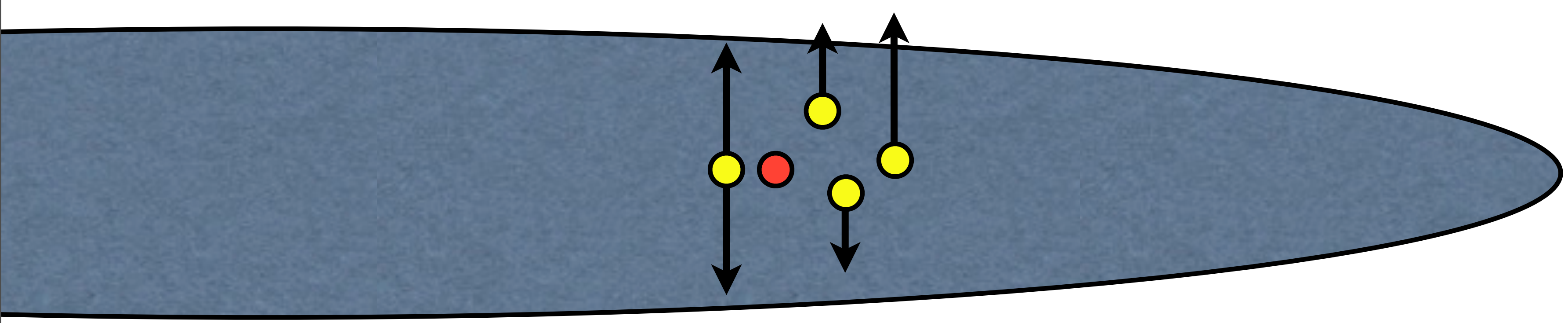
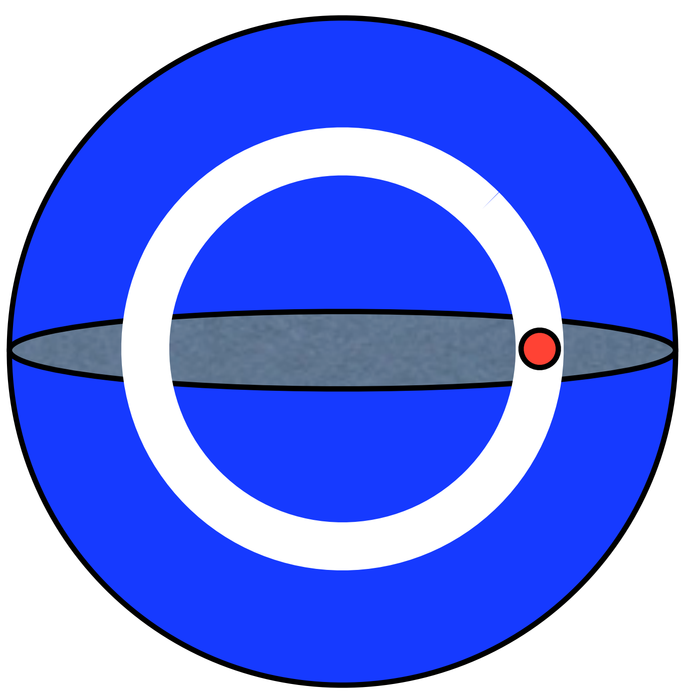


$\rho_{\rm dm}$

2. Global measure:



$\rho_{\rm dm,ext}$

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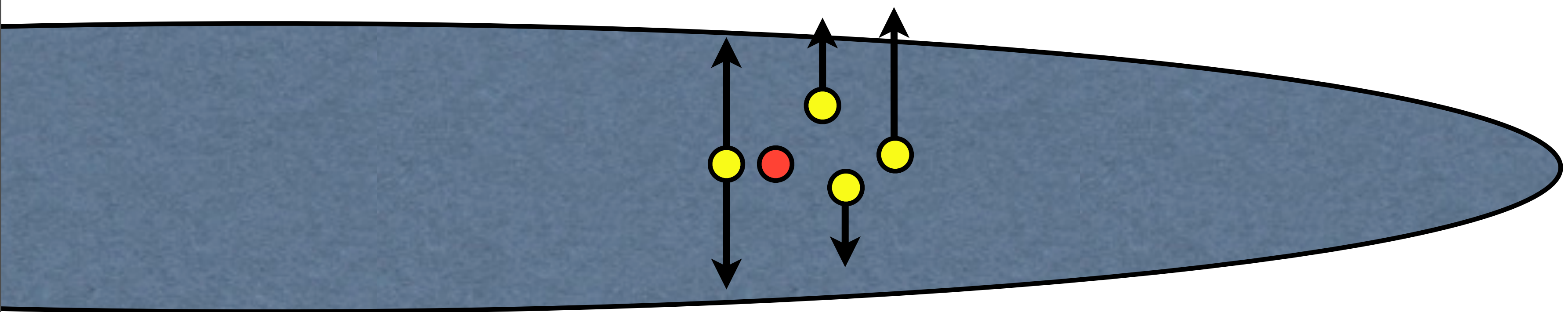
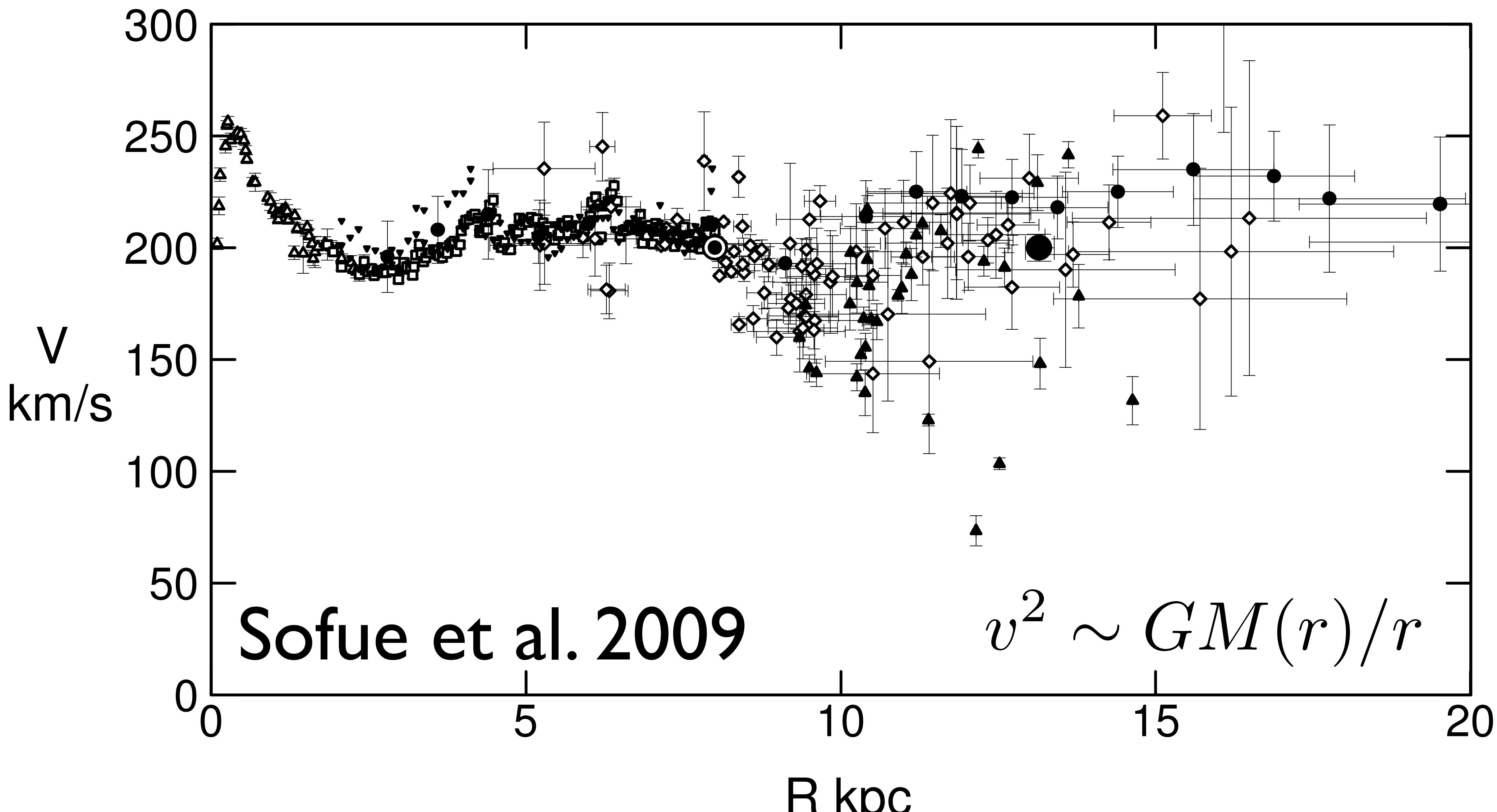


$\rho_{\rm dm}$

2. Glc



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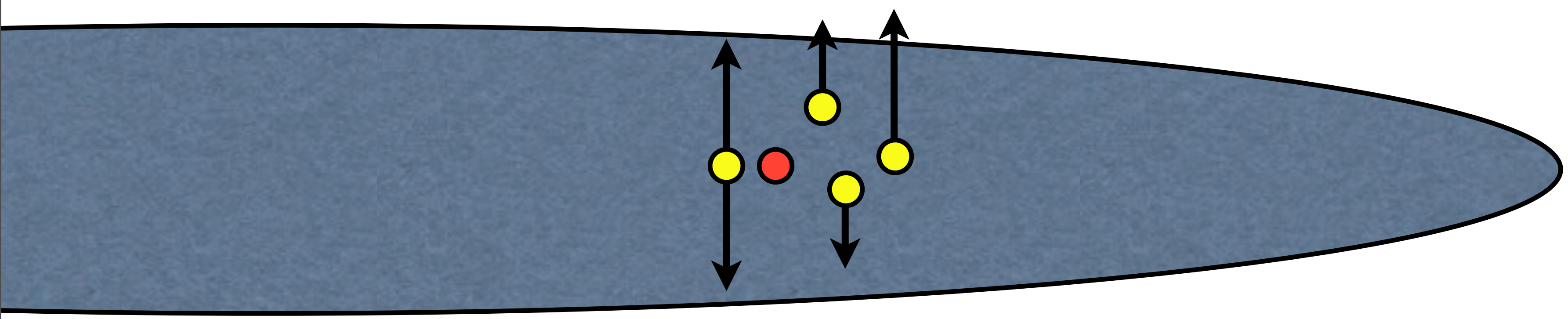

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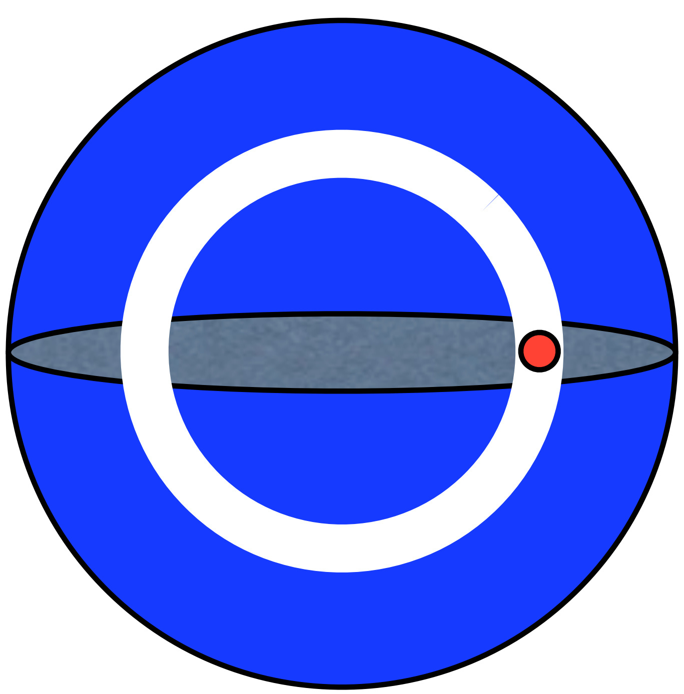
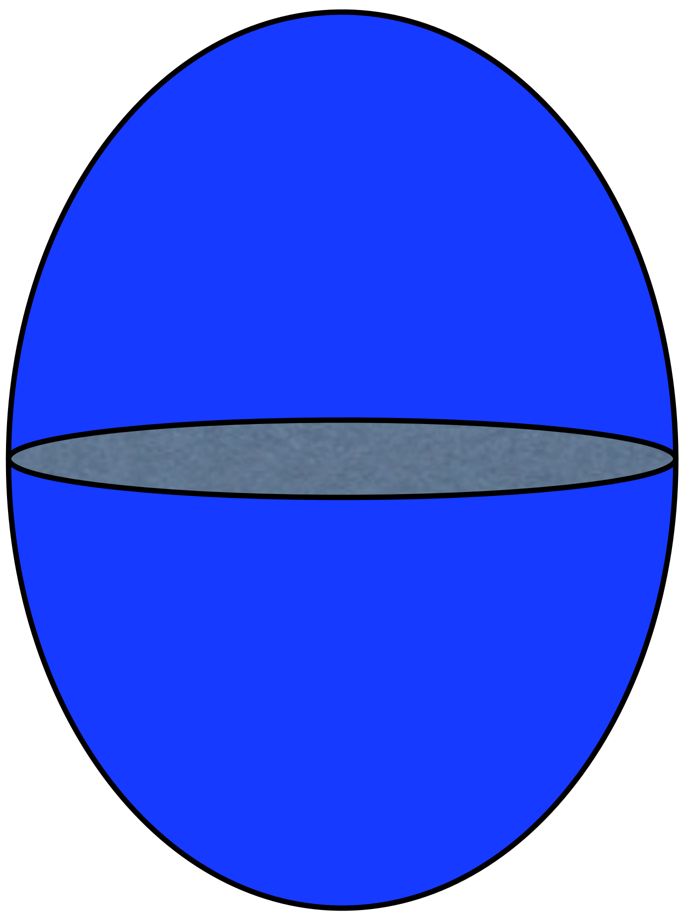


$\rho_{\rm dm,ext}$

Background | Why measure the local dark matter density?

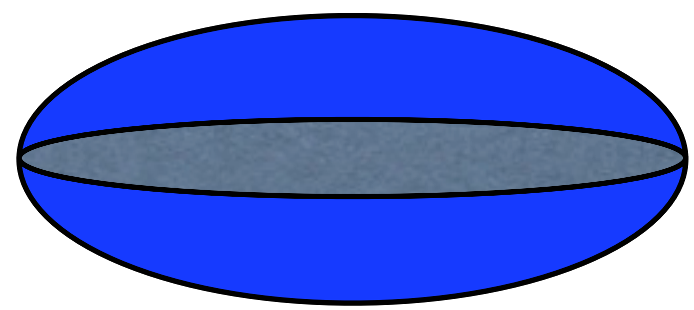
1. Halo shape ...

$$\rho_{\rm dm} < \rho_{\rm dm,ext}$$



Prolate

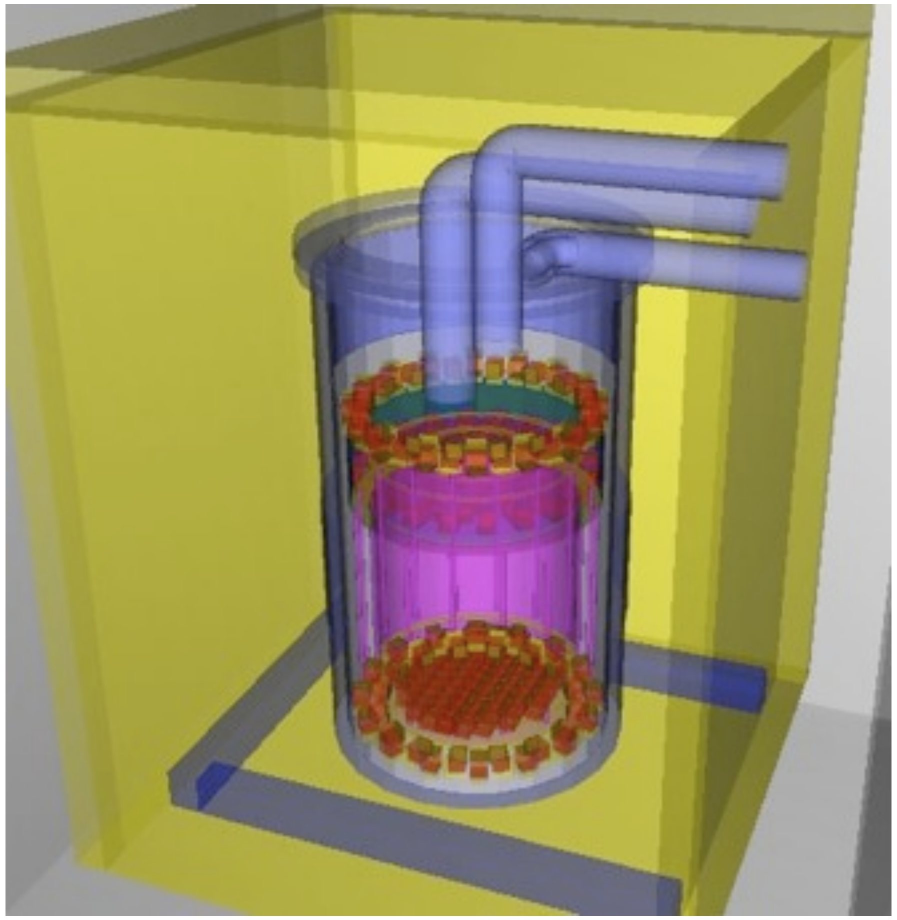
$$\rho_{\rm dm} > \rho_{\rm dm,ext}$$



Oblate/dark disc

Background | Why measure the local dark matter density?

2. Detecting dark matter



- Big tub of inert material
- Deep underground
- Wait for rare event
- Need to know very local phase space distribution

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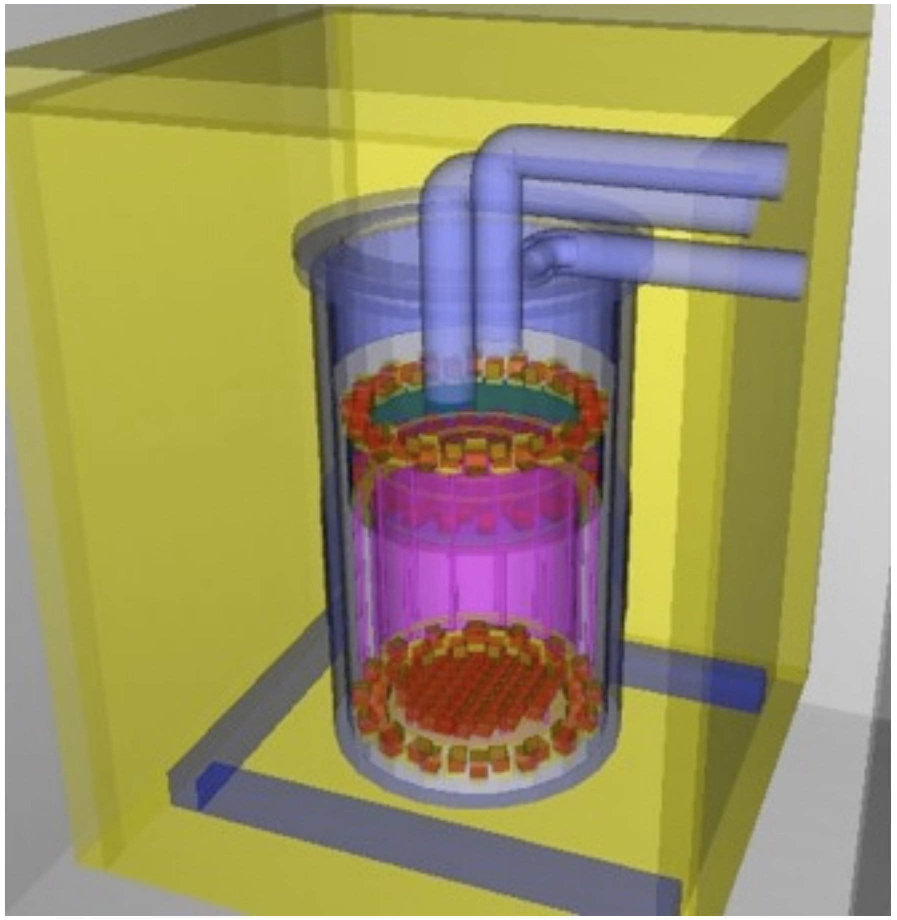

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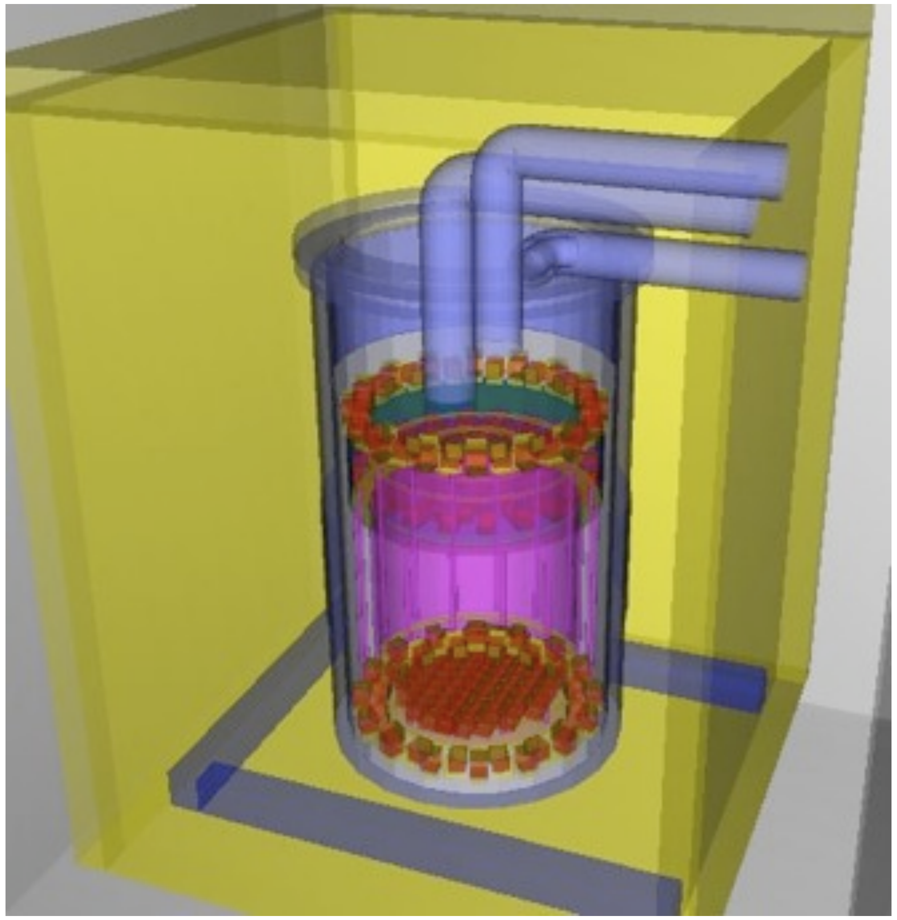

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Particle physics

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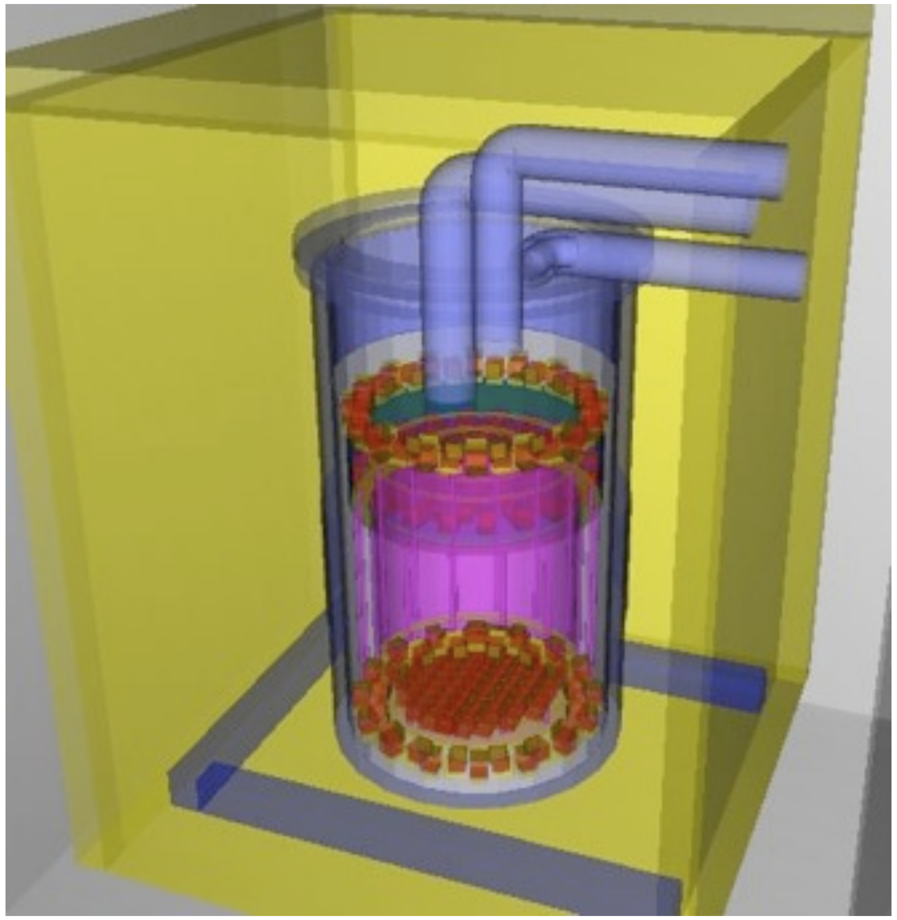

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Particle physics | Astrophysics

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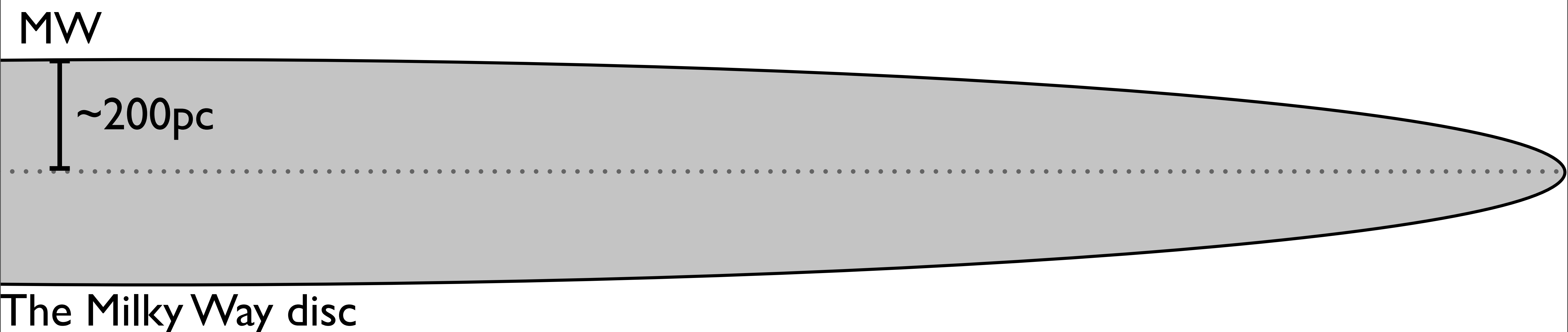

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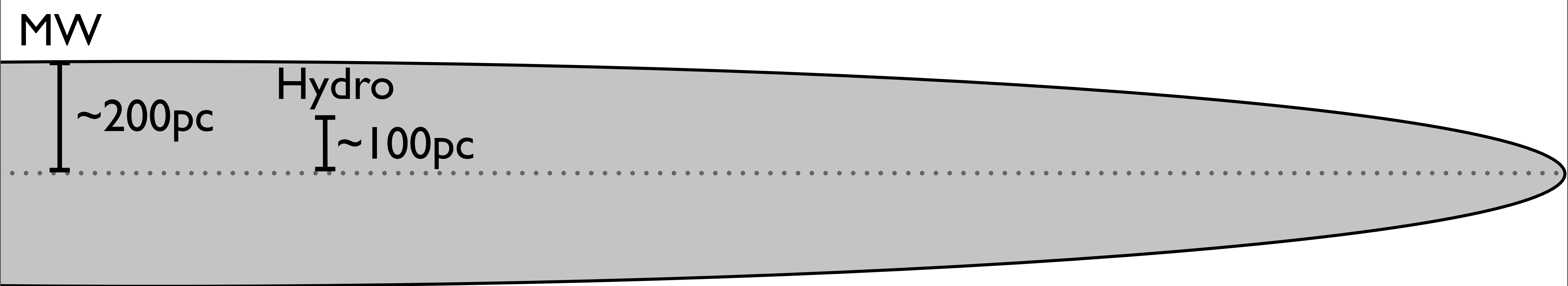

The Milky Way disc

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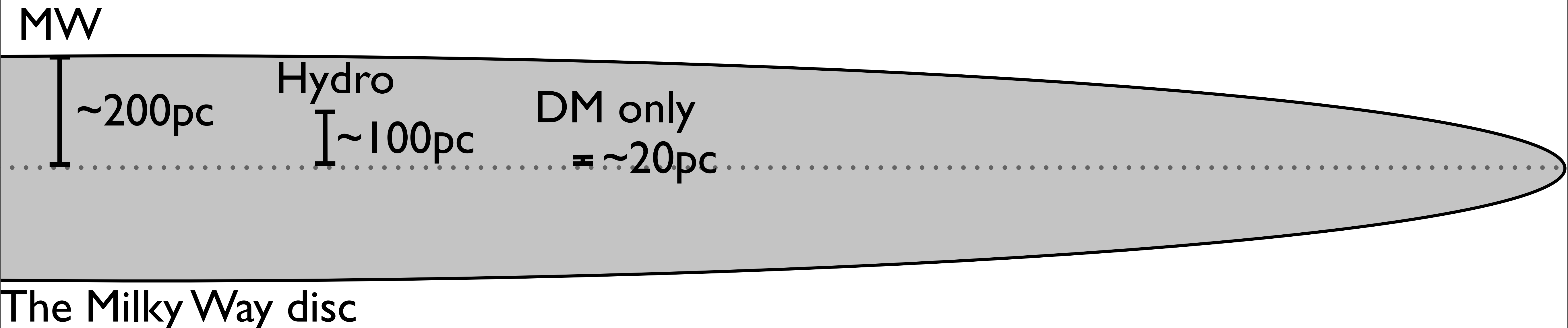

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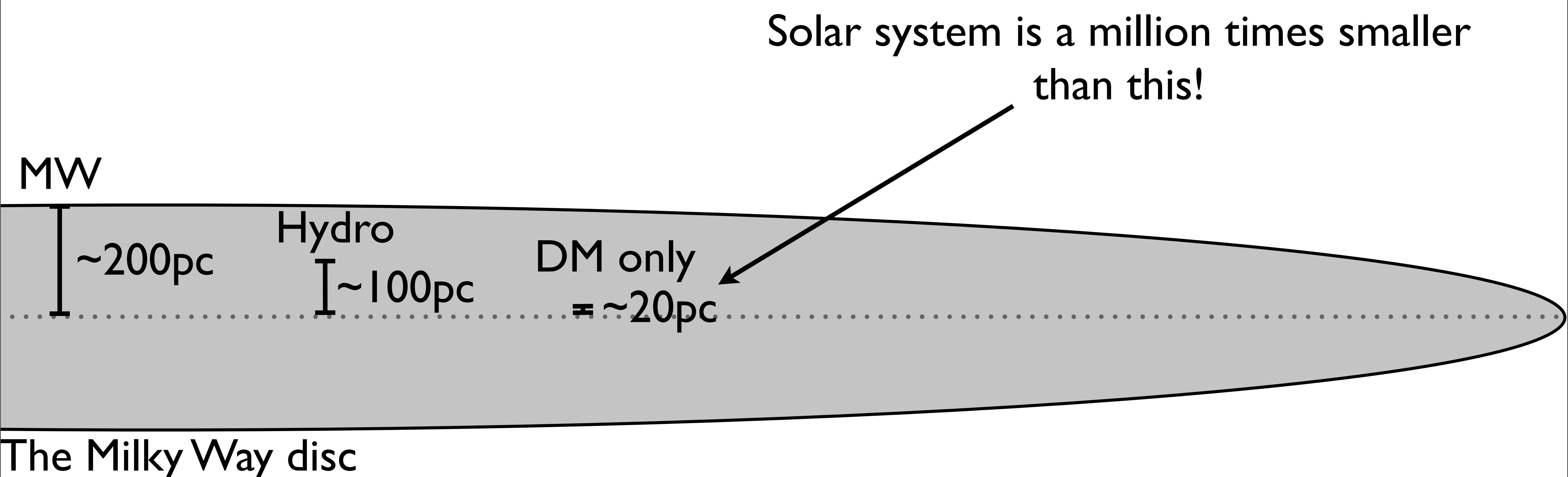

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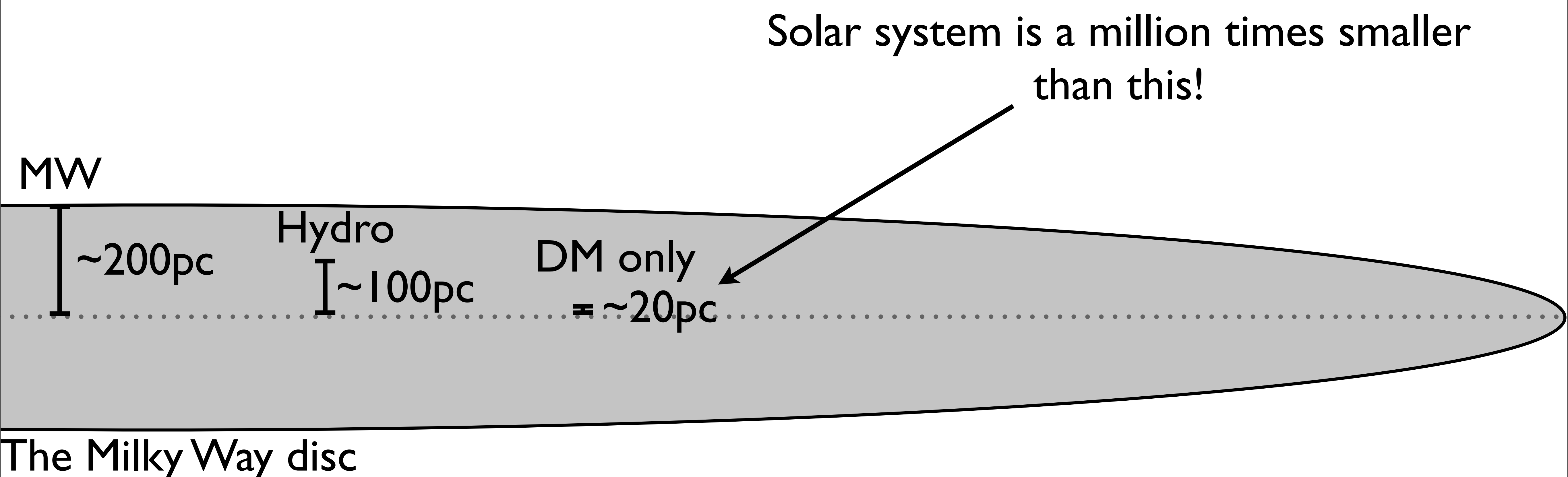

2. Need $f(\mathbf{v}, t)$

Simulations | "DM-only" simulations

Potter 2006; Springel 2008; Stadel 2009; Vogelsberger et al. 2009

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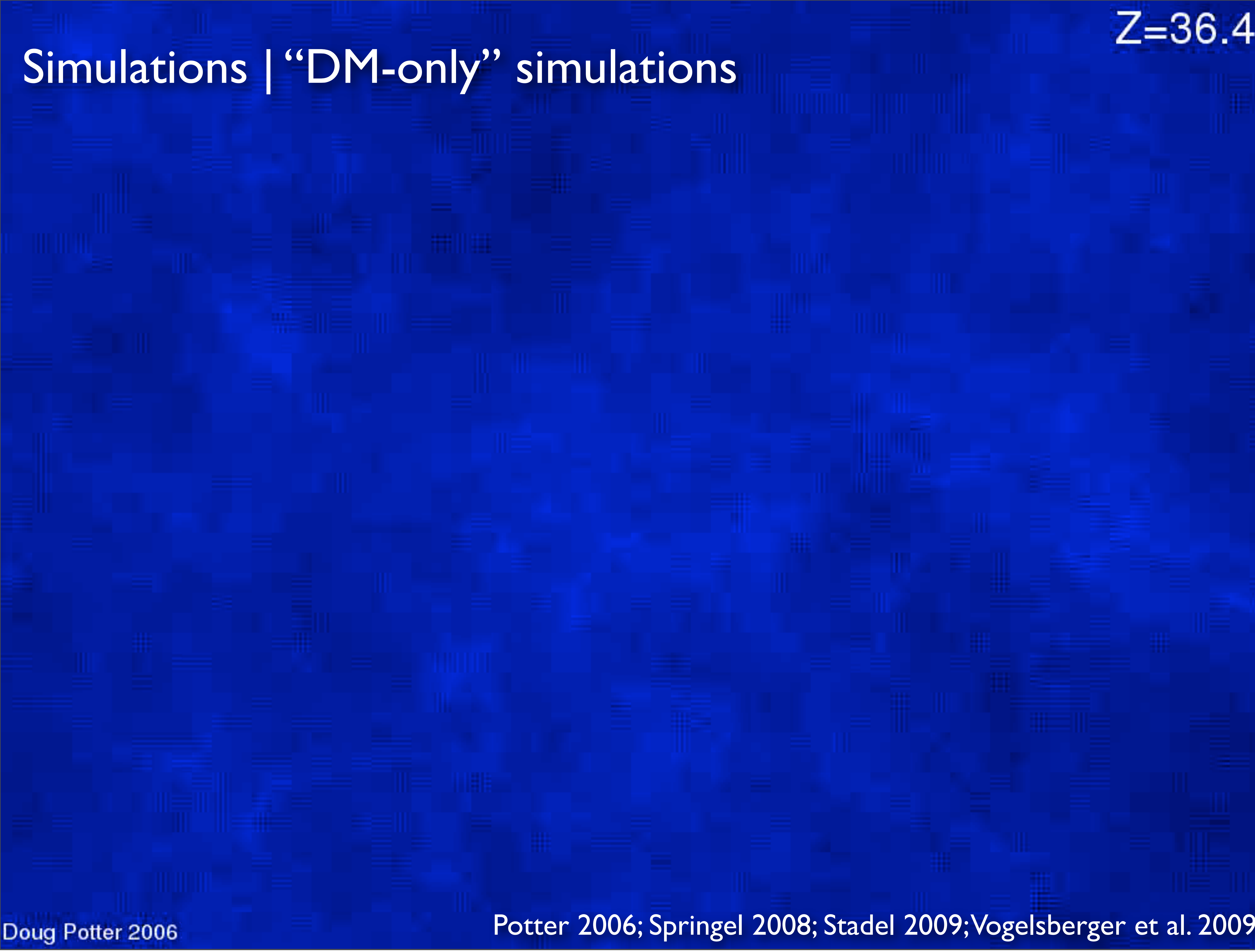

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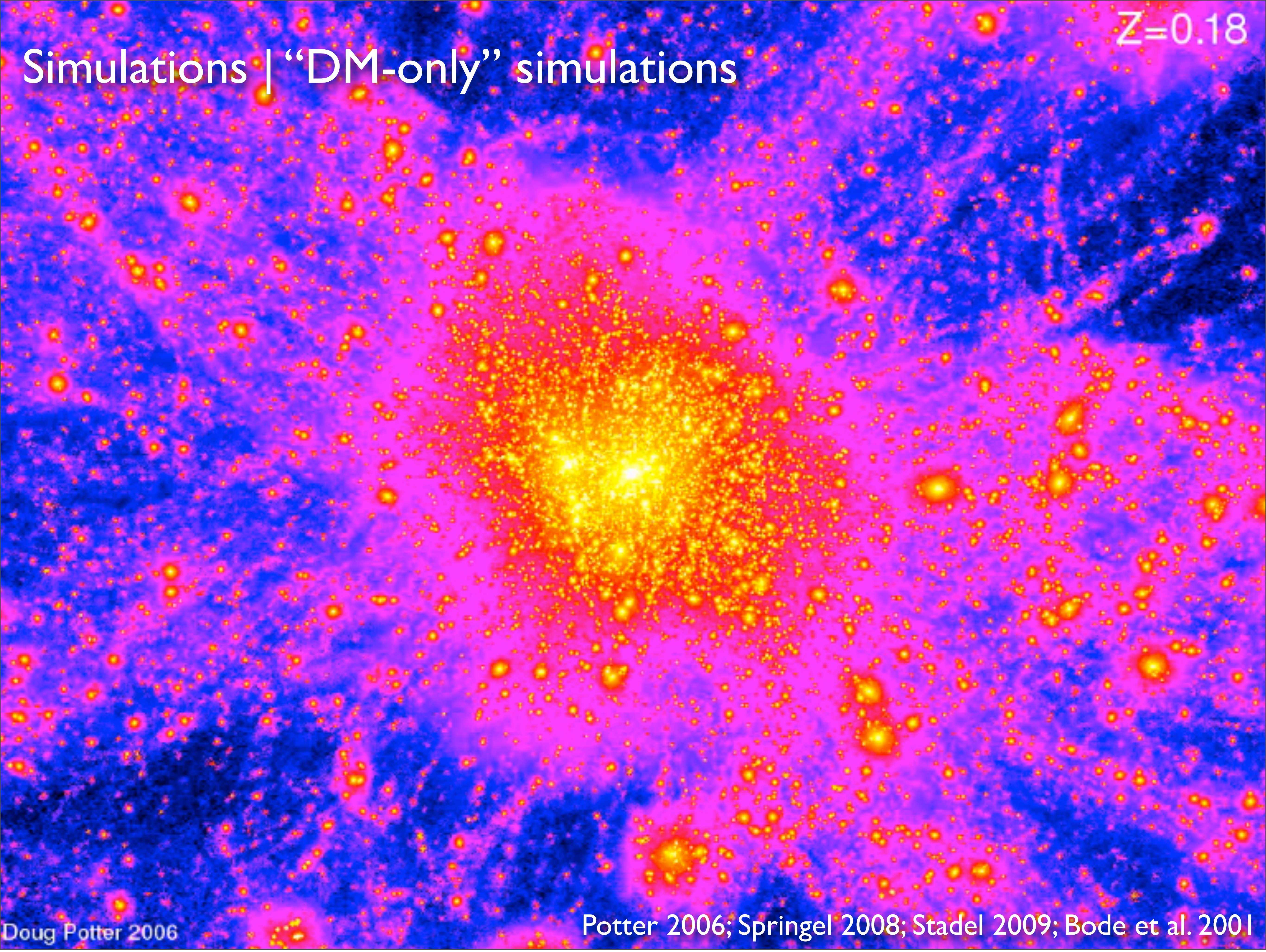

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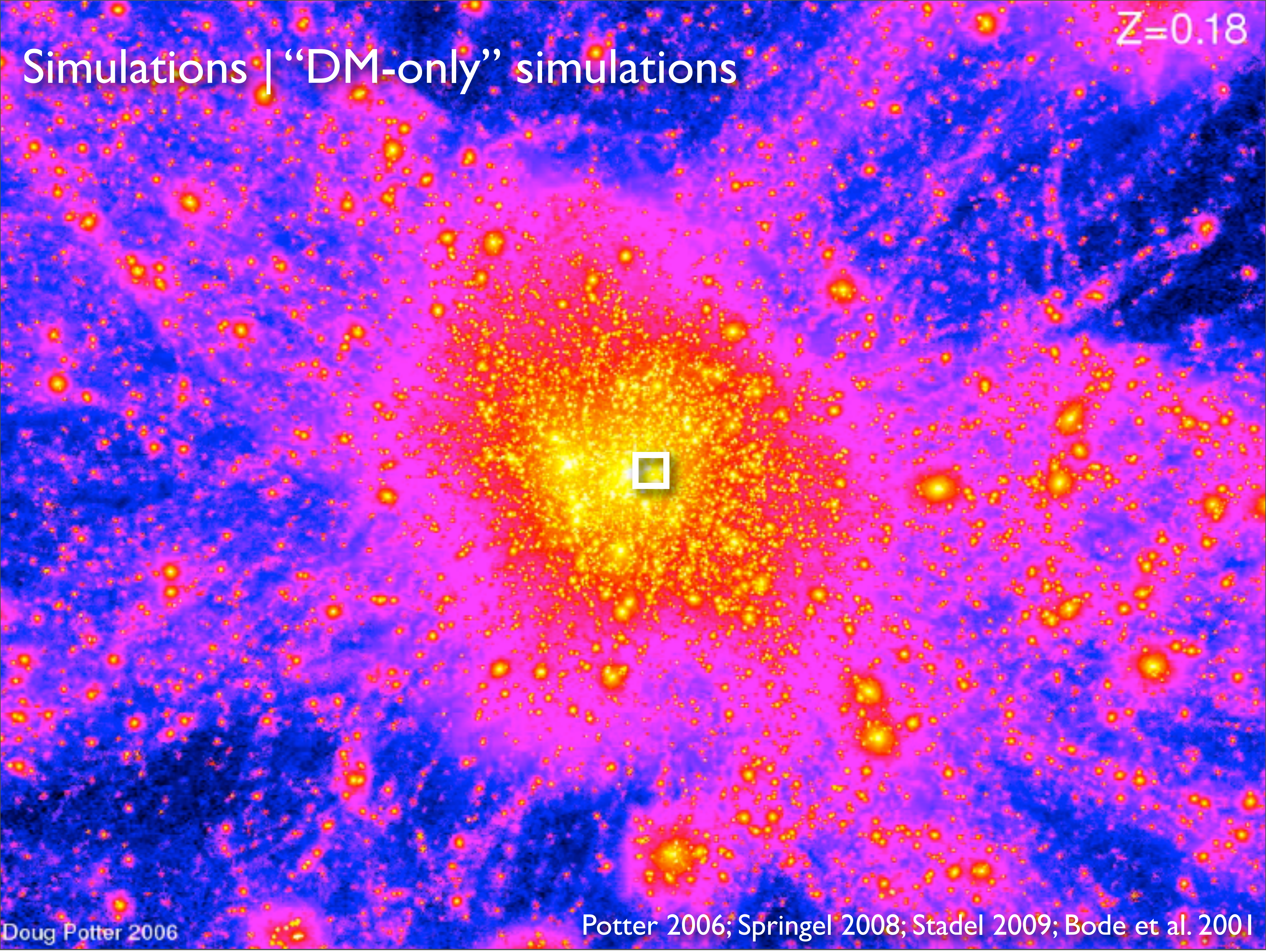

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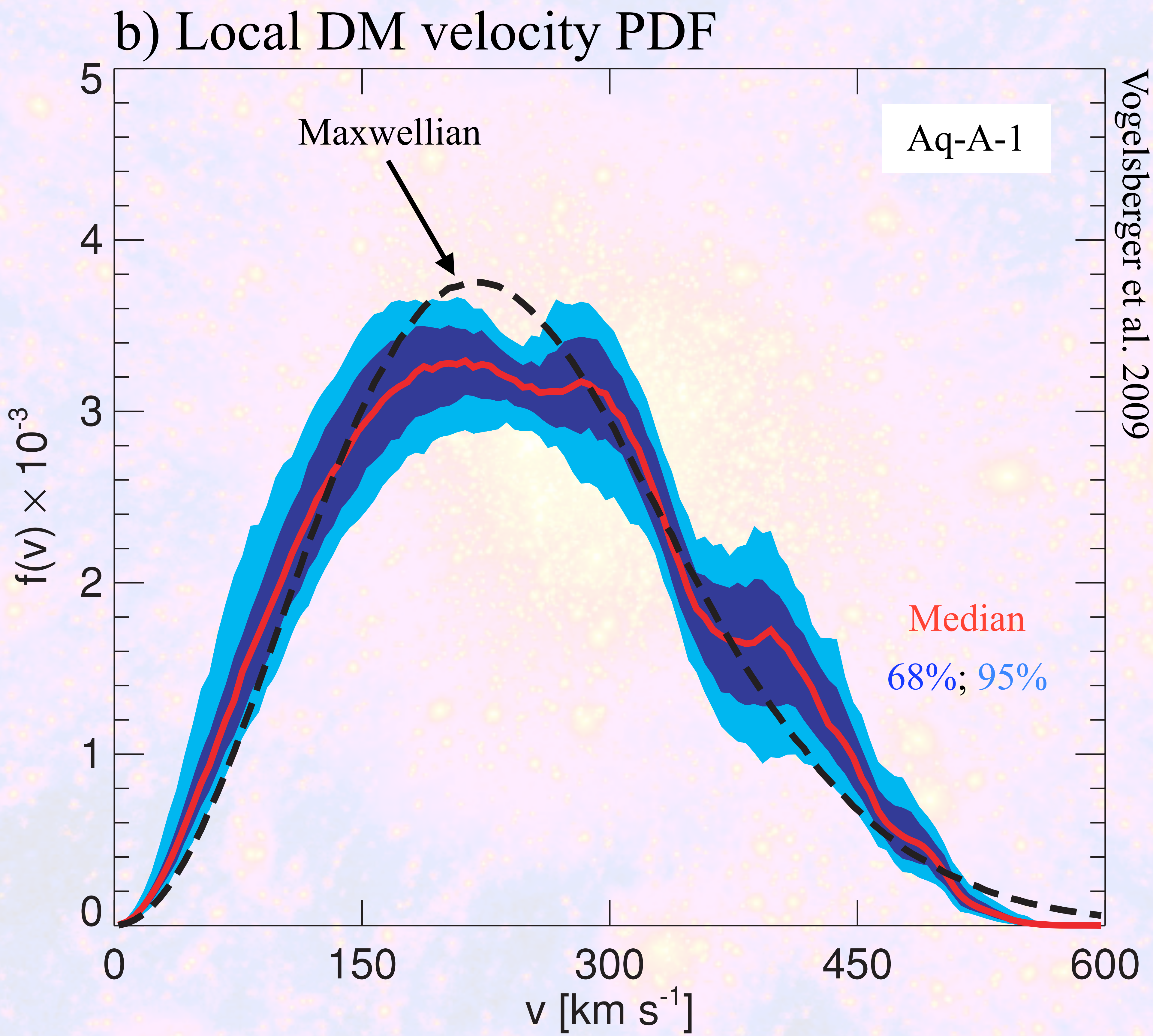

Z=0.18

Doug Potter 2006

Simulations | “DM-only” simulations | Fine structure

- Unresolved substructure | not likely important
  [Vogelsberger et al. 2009; Zemp et al. 2009; Kamionkowski et al. 2008]

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$$\rho_{\mathrm{dm}} \Rightarrow \rho_{\mathrm{lab}}$$

~600 light years ~metres

Simulations | The importance of baryons

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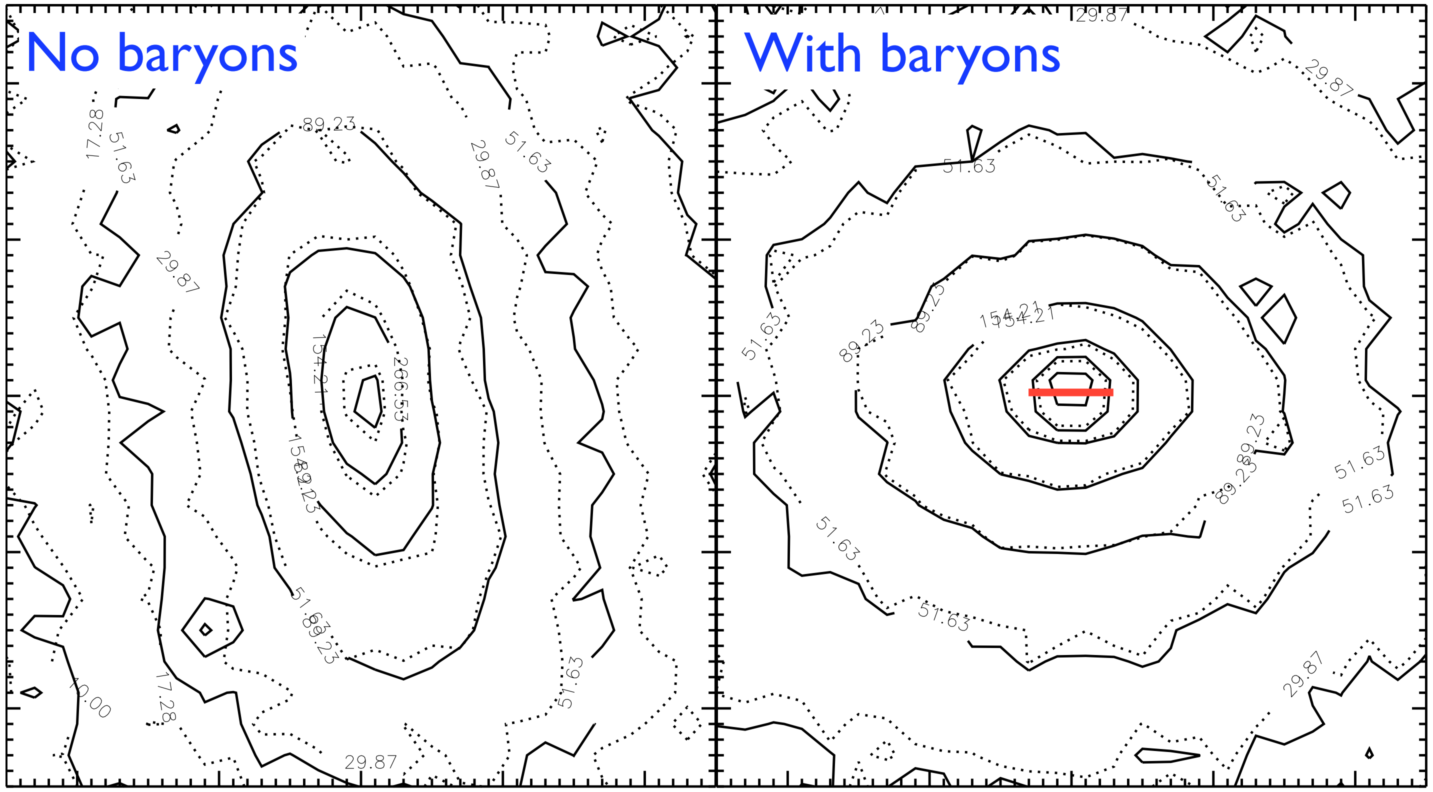
Shape change



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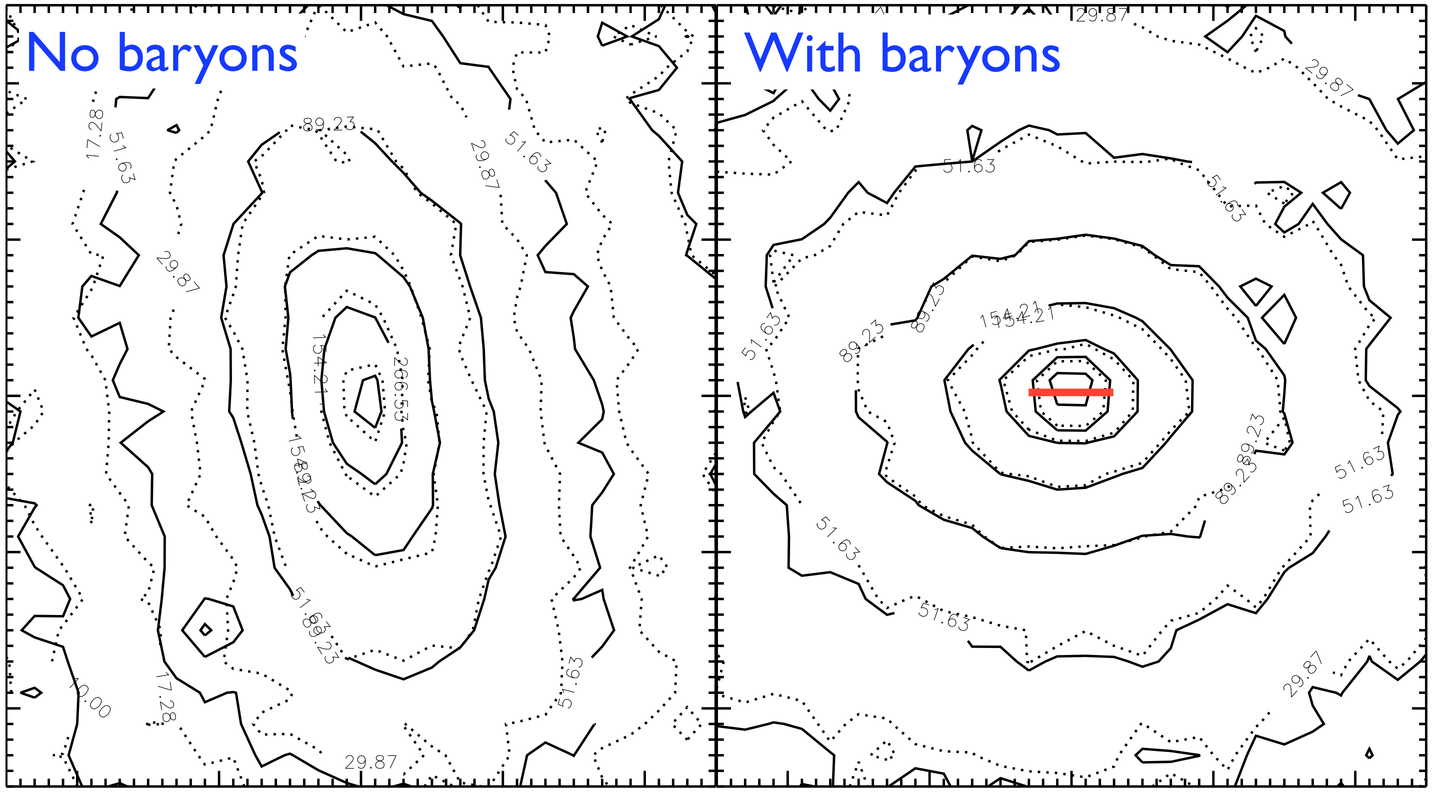

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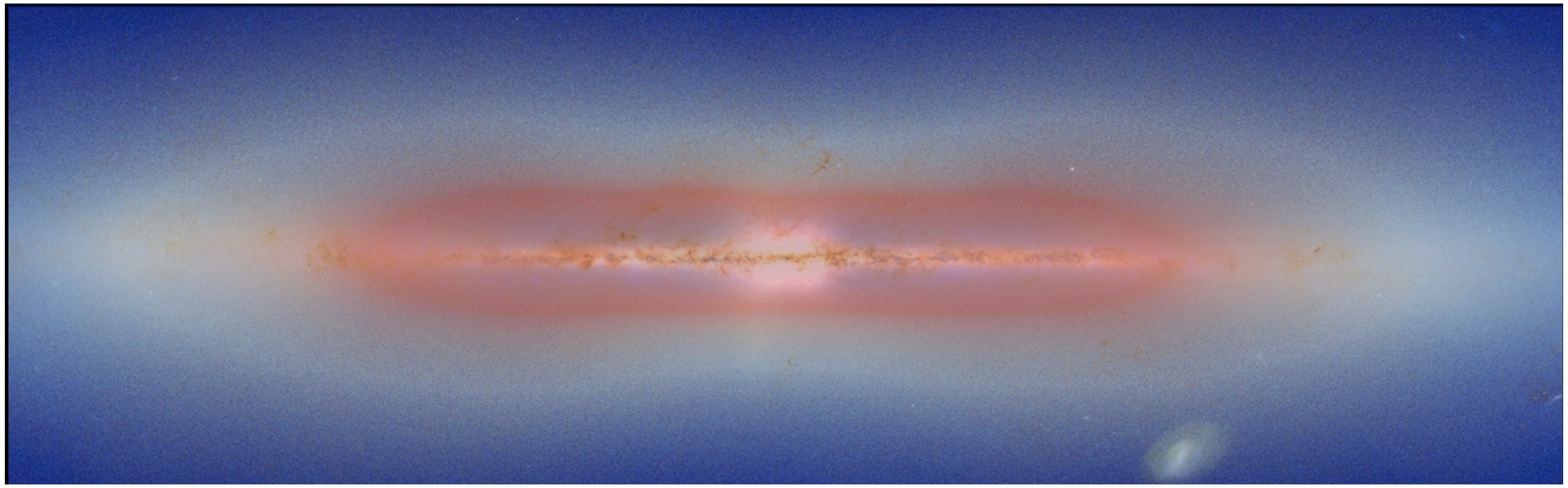
Dark discs



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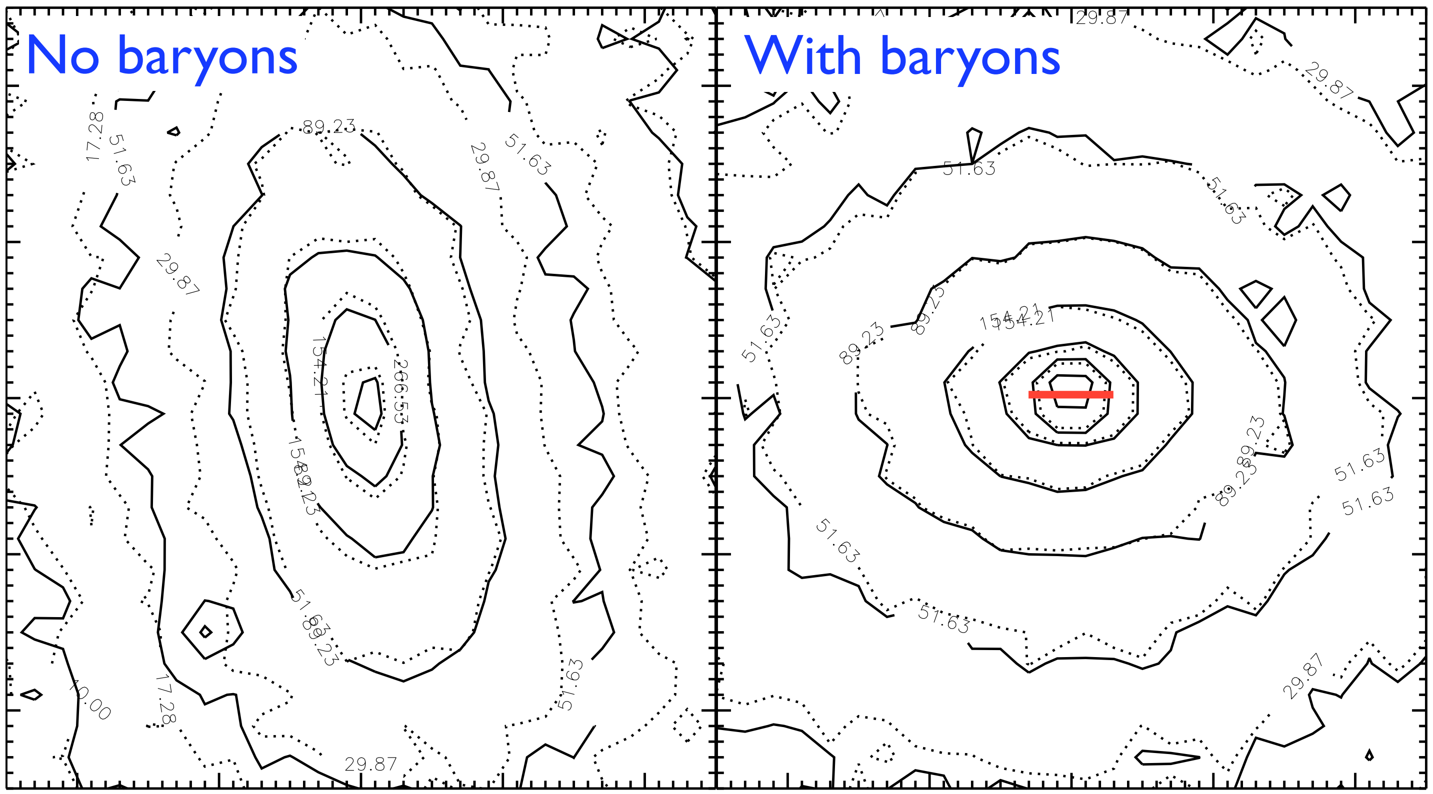

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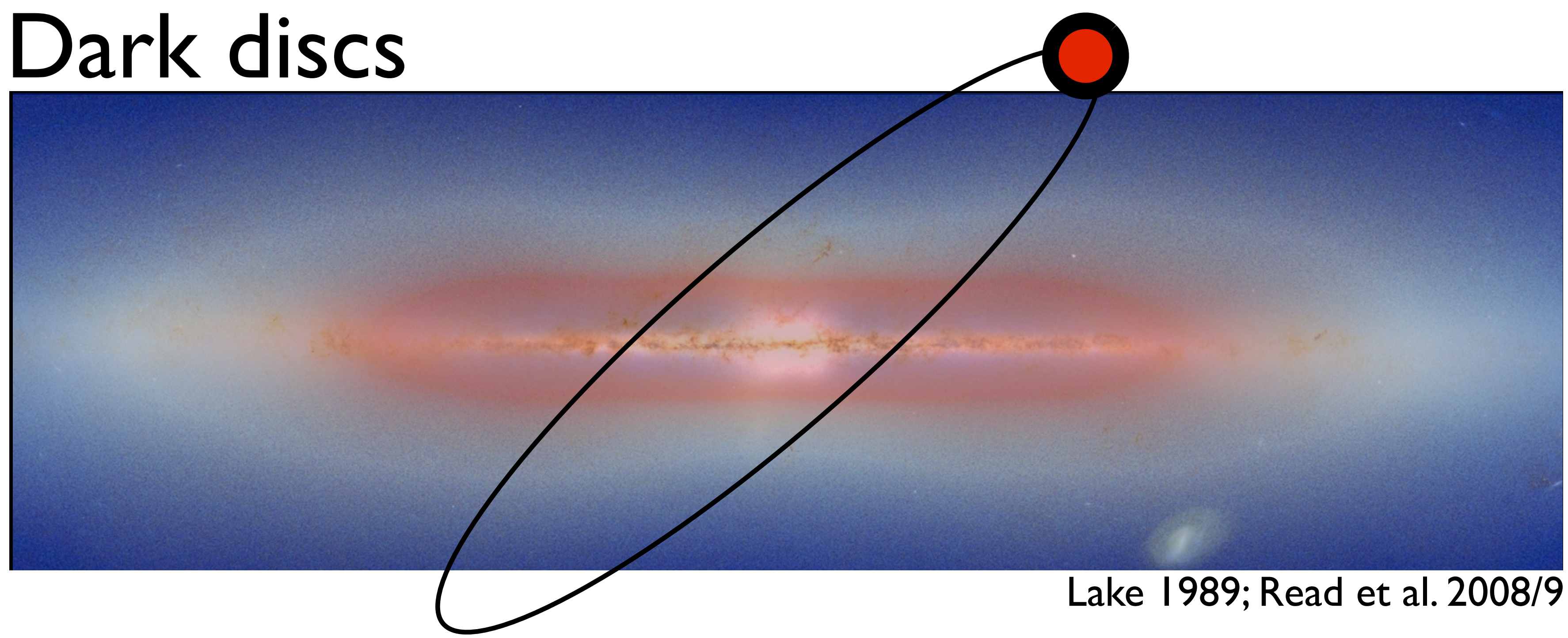

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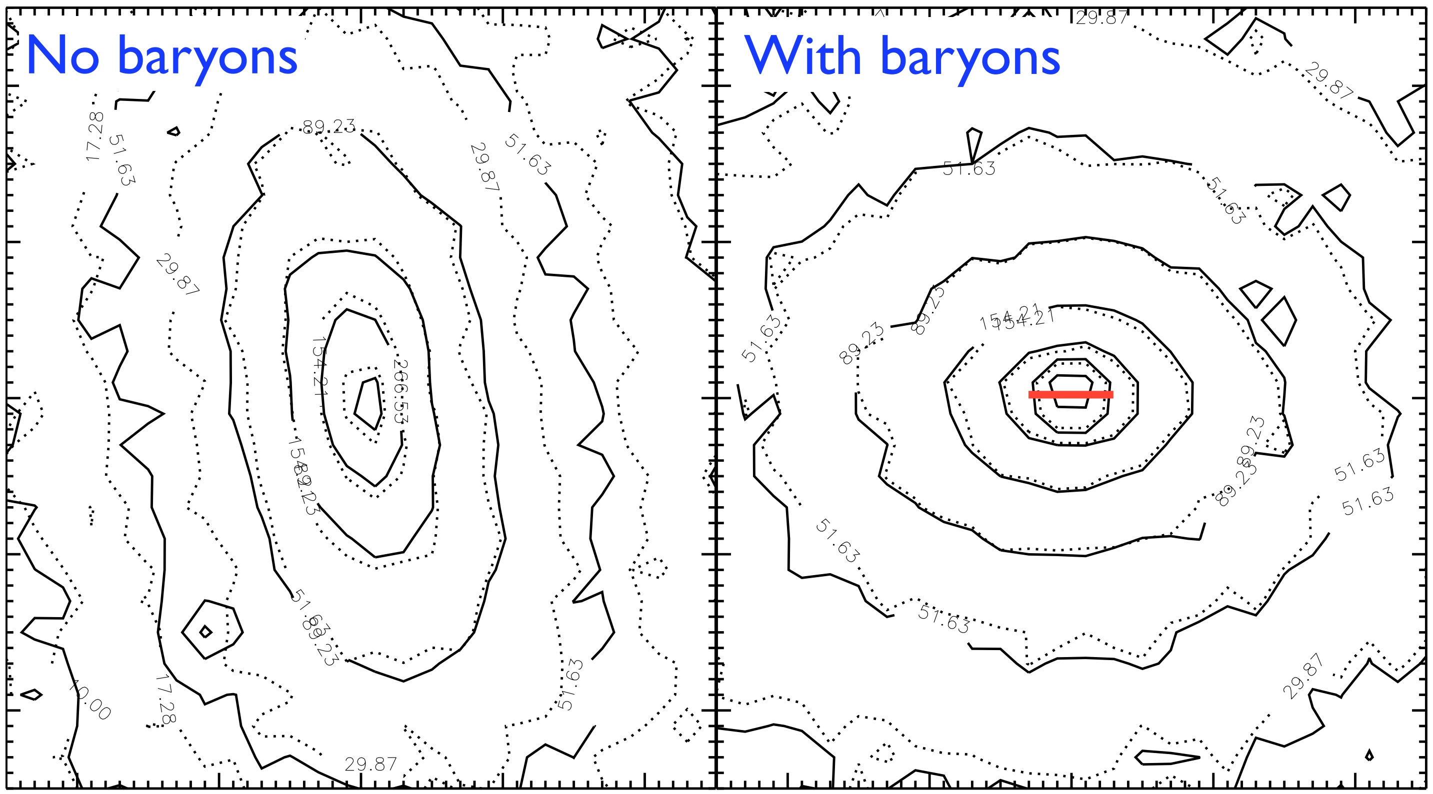

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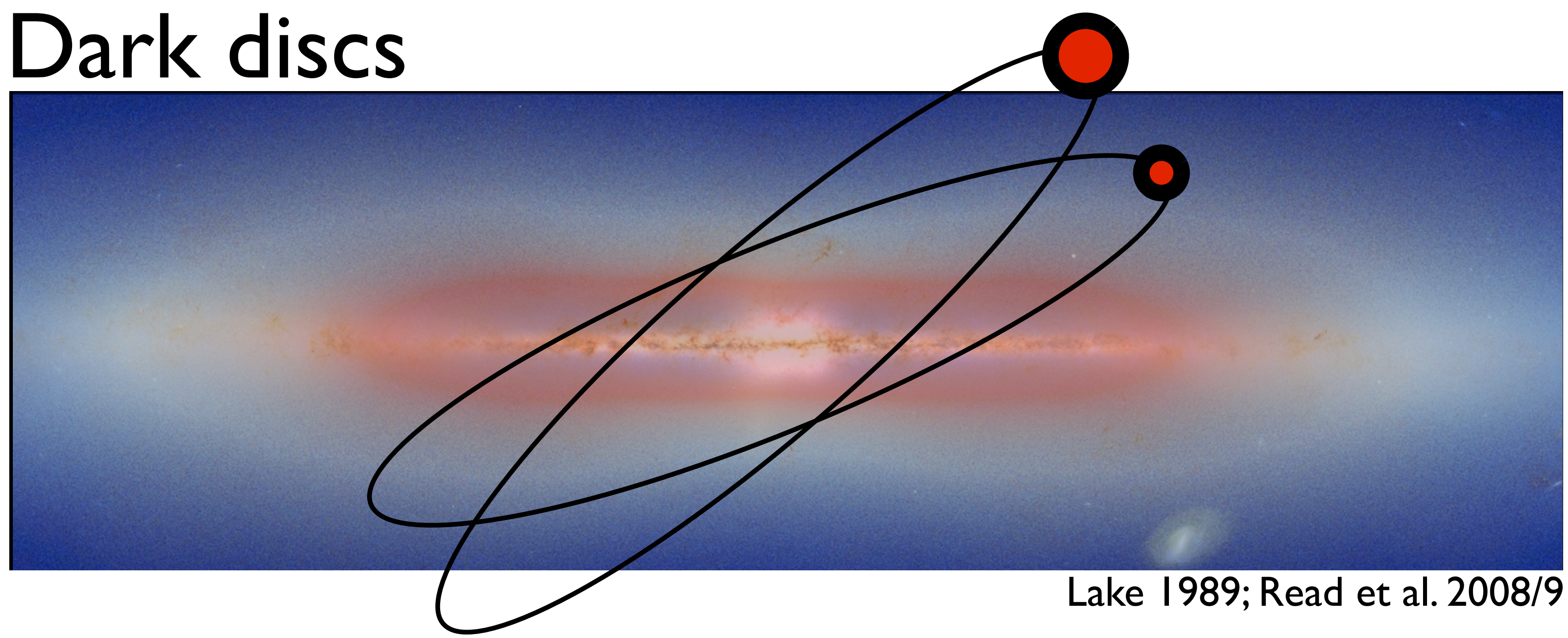

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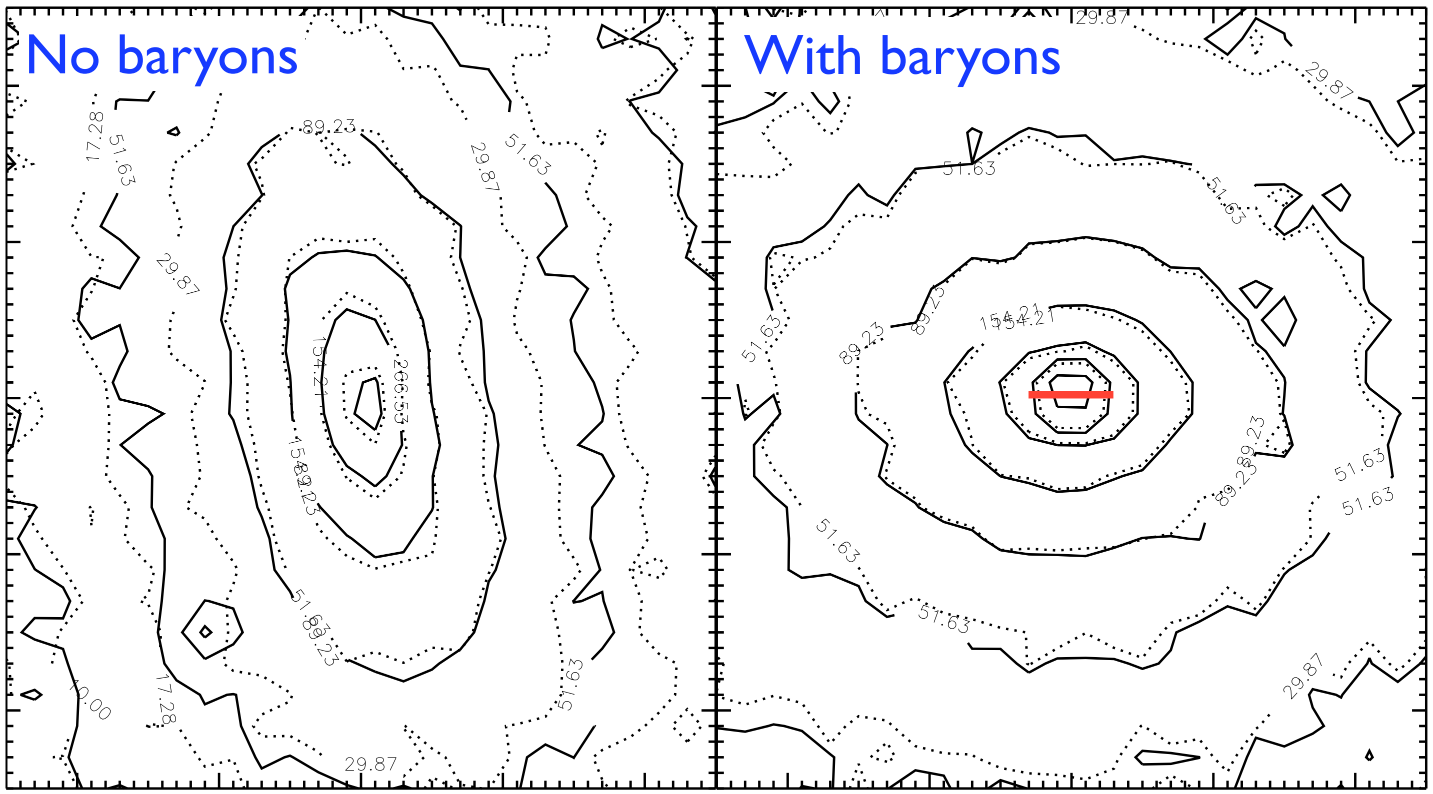

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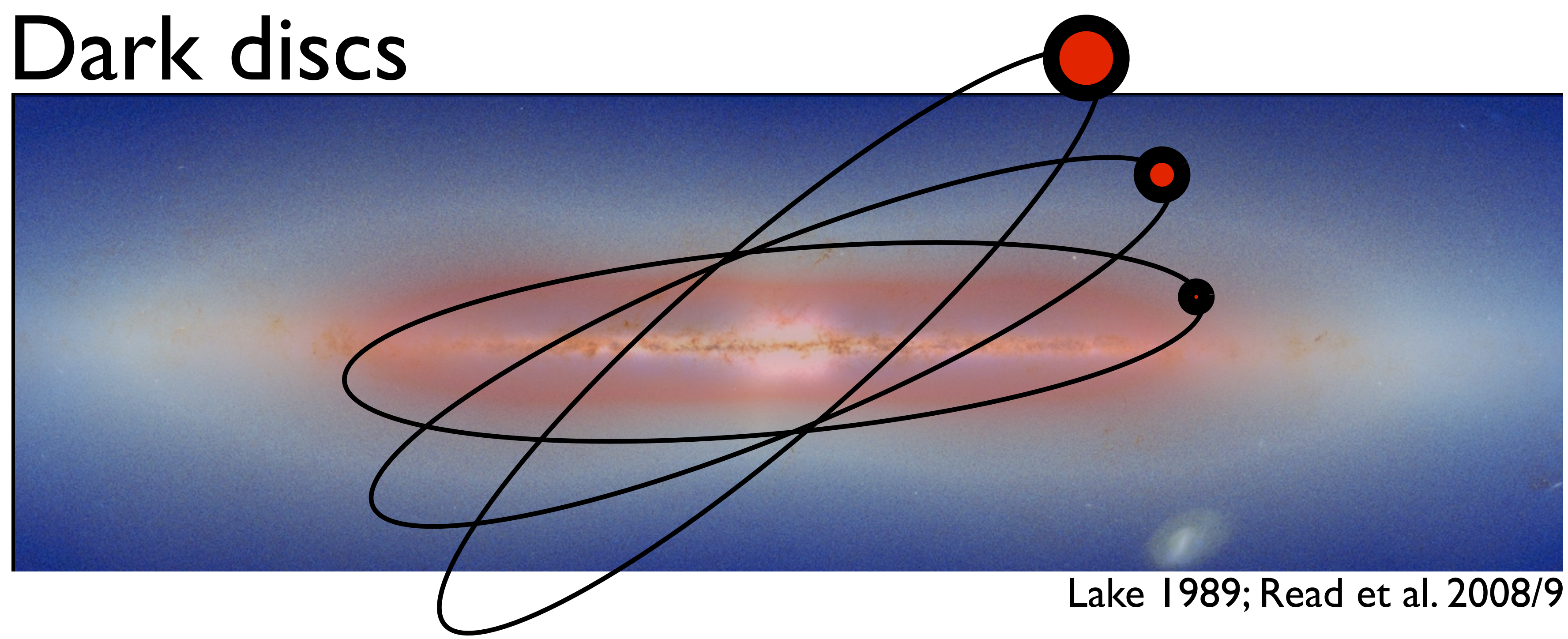

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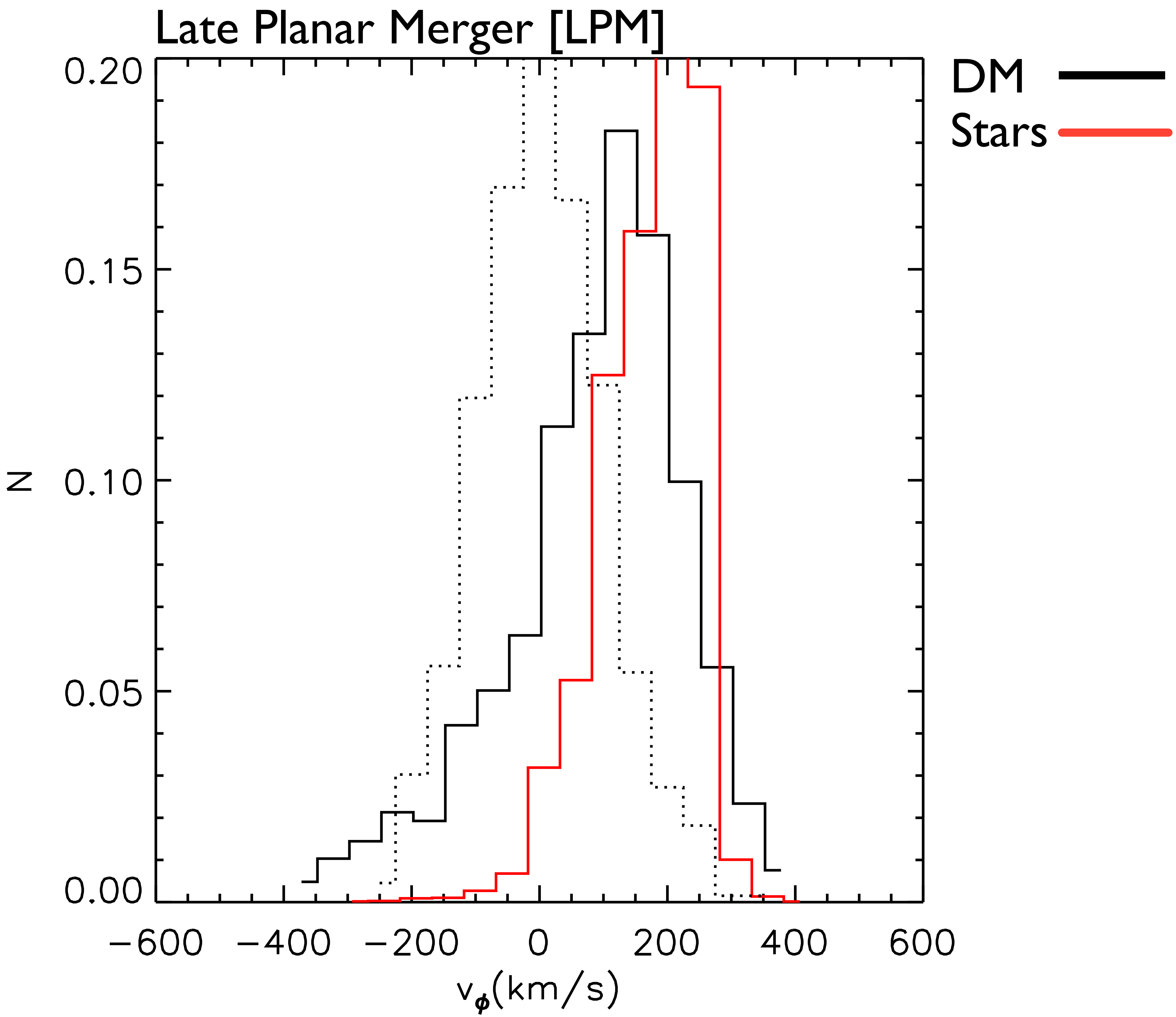
Simulations | Dark discs

Stellar disc

ERIS | Guedes et al. 2011

Simulations | Dark discs



Read et al., 2008/9; Bruch et al. 2009a/b.

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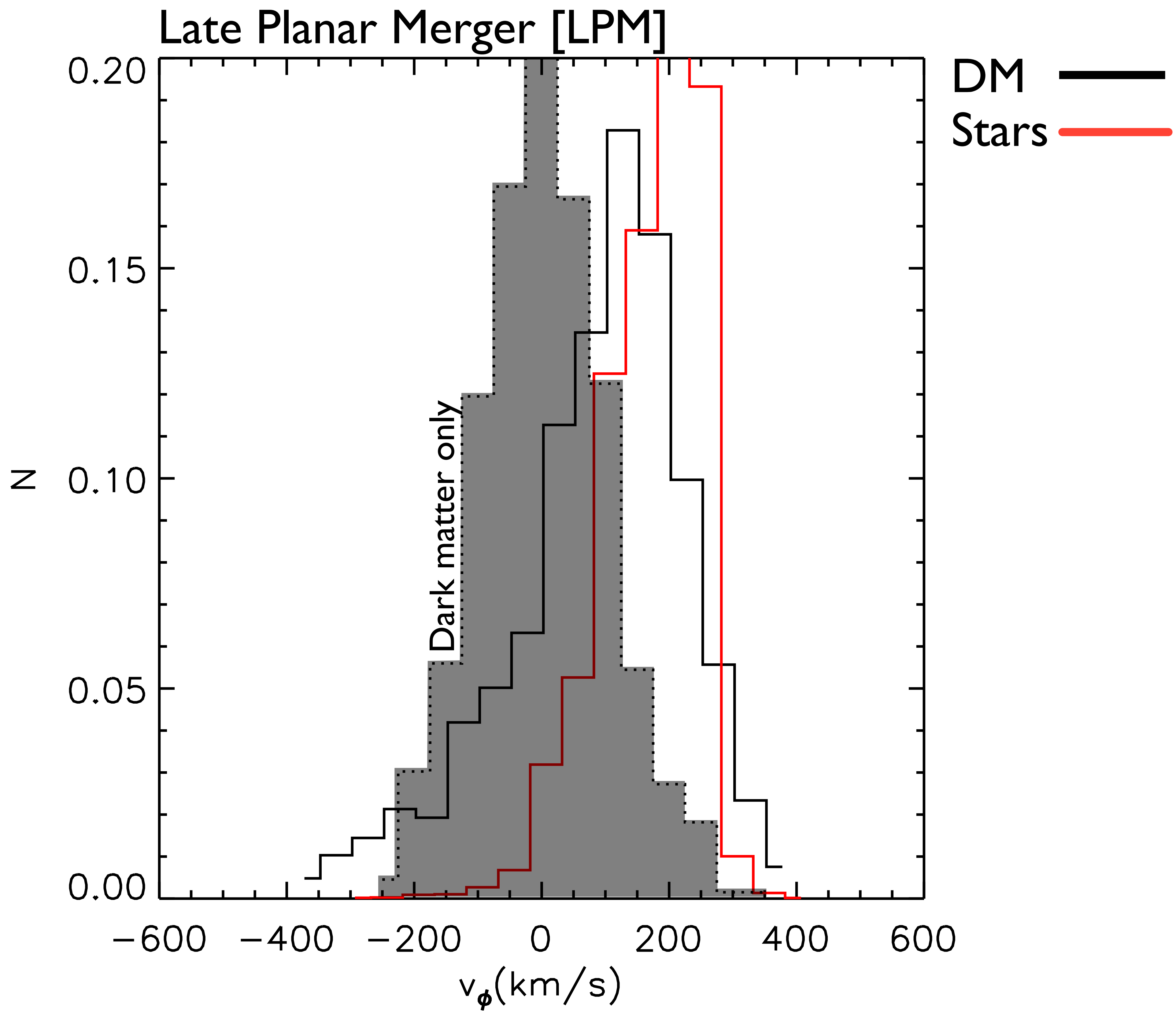

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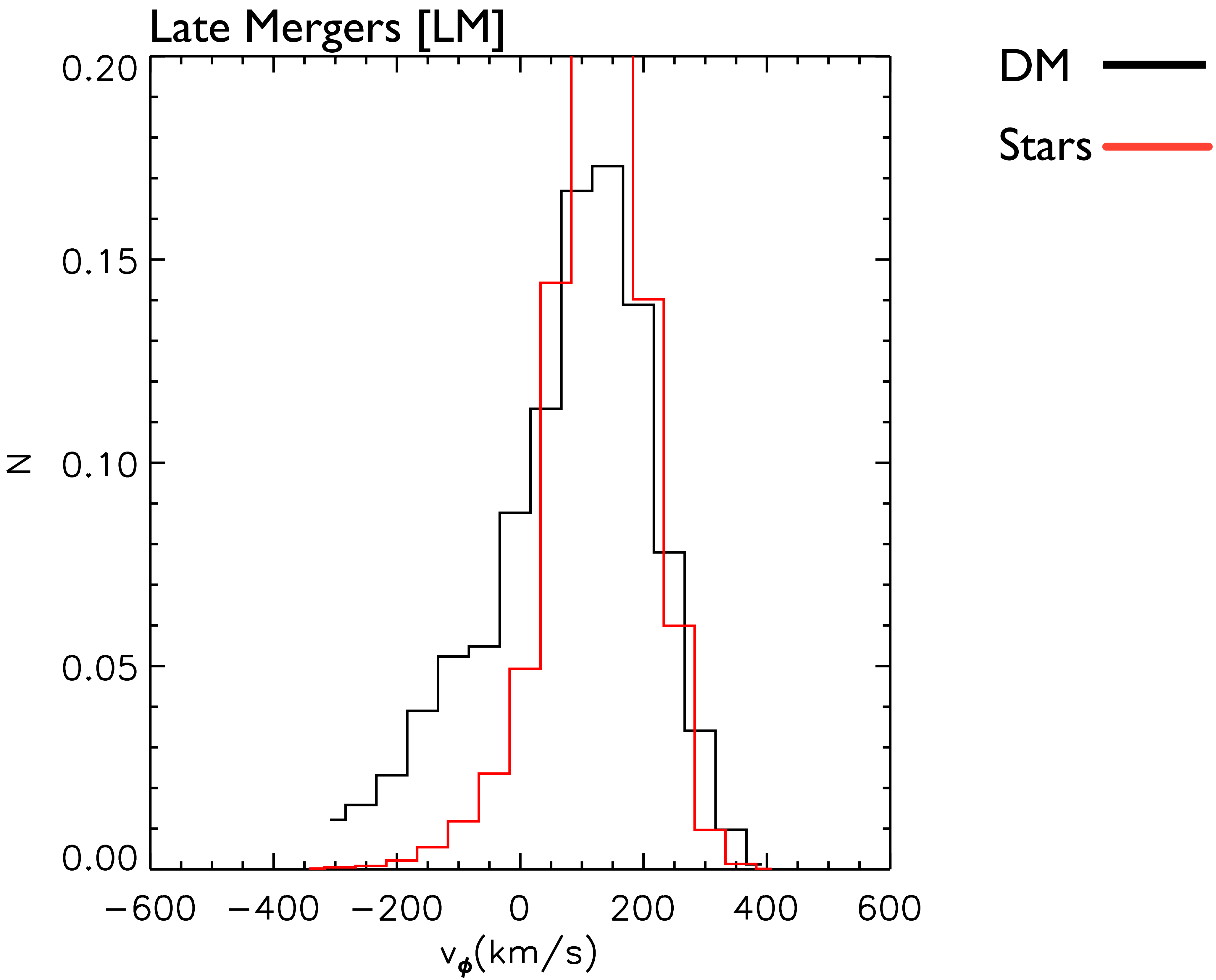

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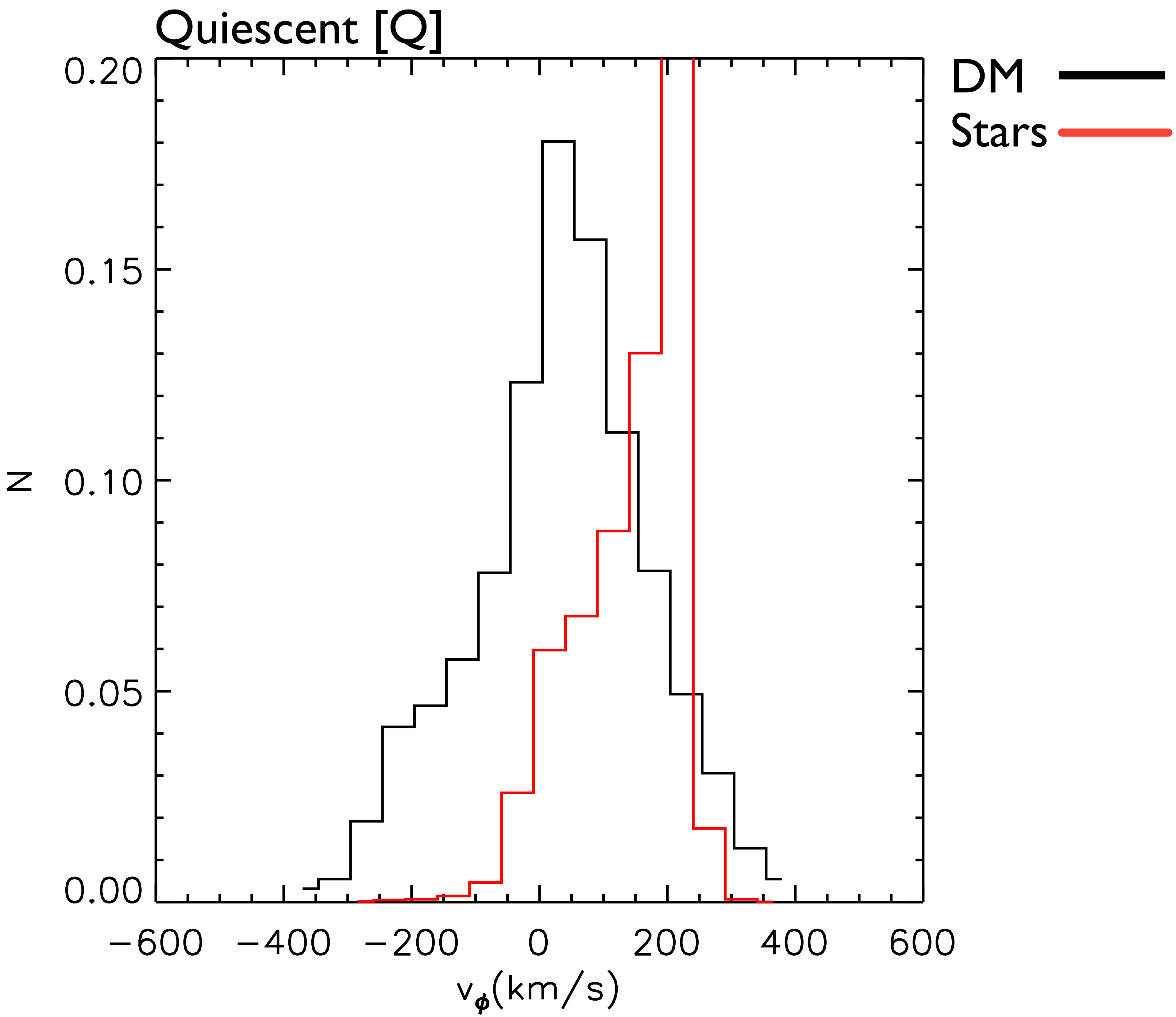

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Measurement

[ρ_{dm}; the local halo shape; and the MW's dark disc]

Measurement | Theory

Bahcall 1989; Garbari et al. 2011/12

Measurement | Theory

$$\frac{df}{dt} = 0 = \frac{\partial f}{\partial t} + \mathbf{v} \cdot \frac{\partial f}{\partial \mathbf{r}} - \nabla\Phi \cdot \frac{\partial f}{\partial \mathbf{v}}$$

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But! hard to measure $f(\mathbf{r}, \mathbf{v})$

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$$\frac{1}{R}\frac{\partial}{\partial R}\left(R\nu_i \overline{v_R v_z}\right) + \frac{\partial}{\partial z}\left(\nu_i \overline{v_z^2}\right) + \nu_i \frac{\partial \Phi}{\partial z} = 0$$

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"tilt term"

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$\propto \Sigma_z(z)$

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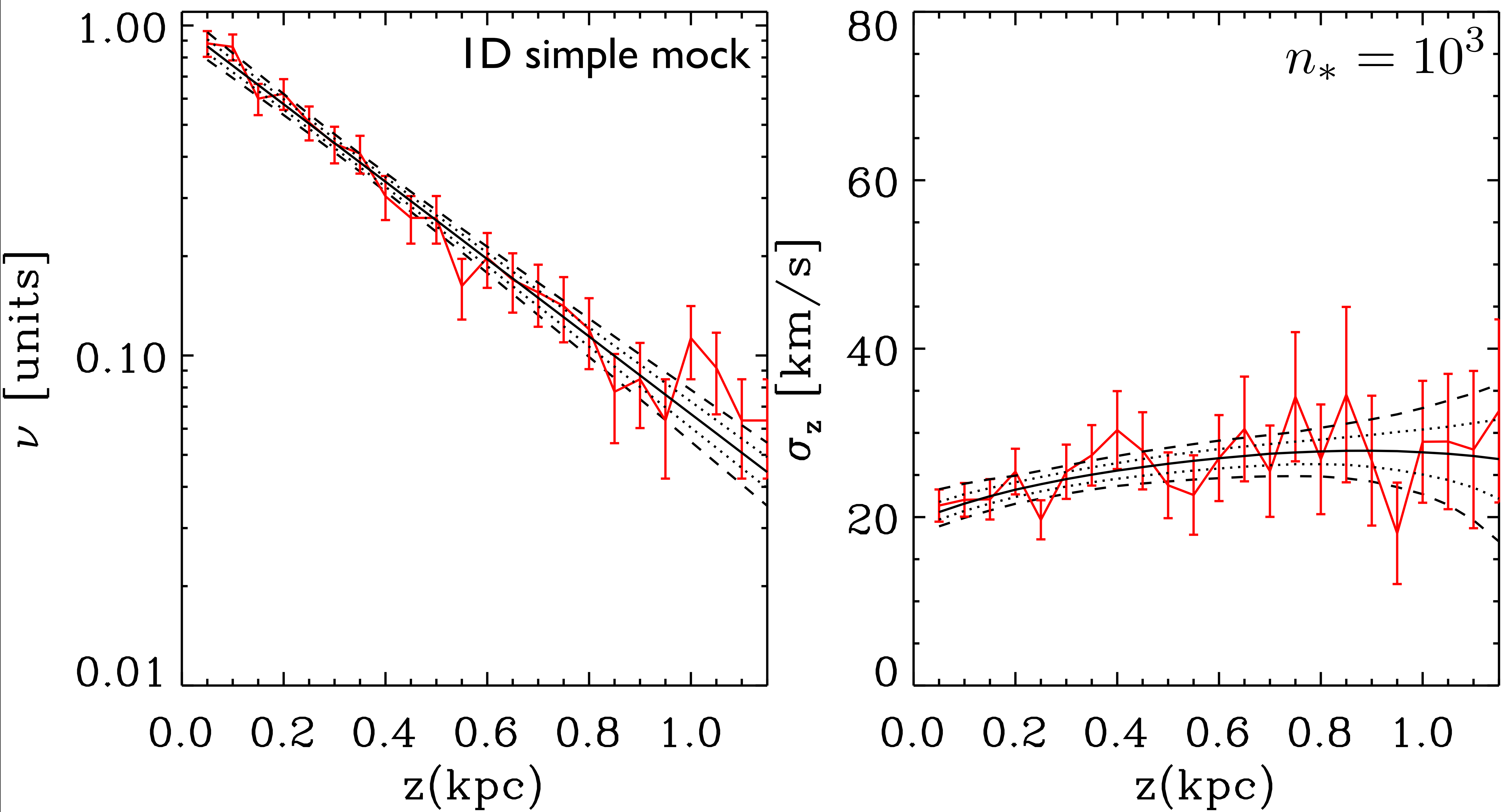
Measurement | Mock data



Read 2014

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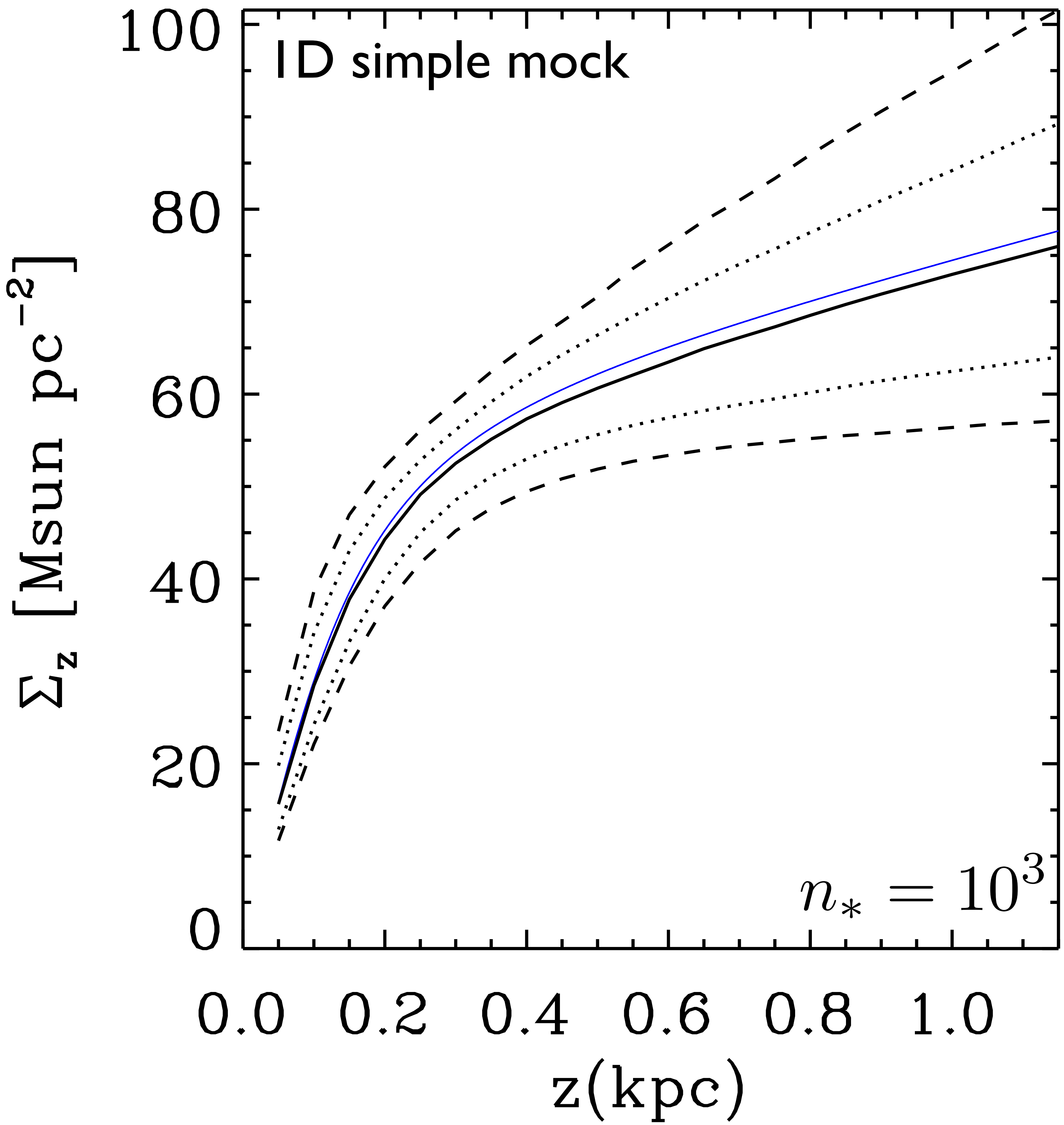

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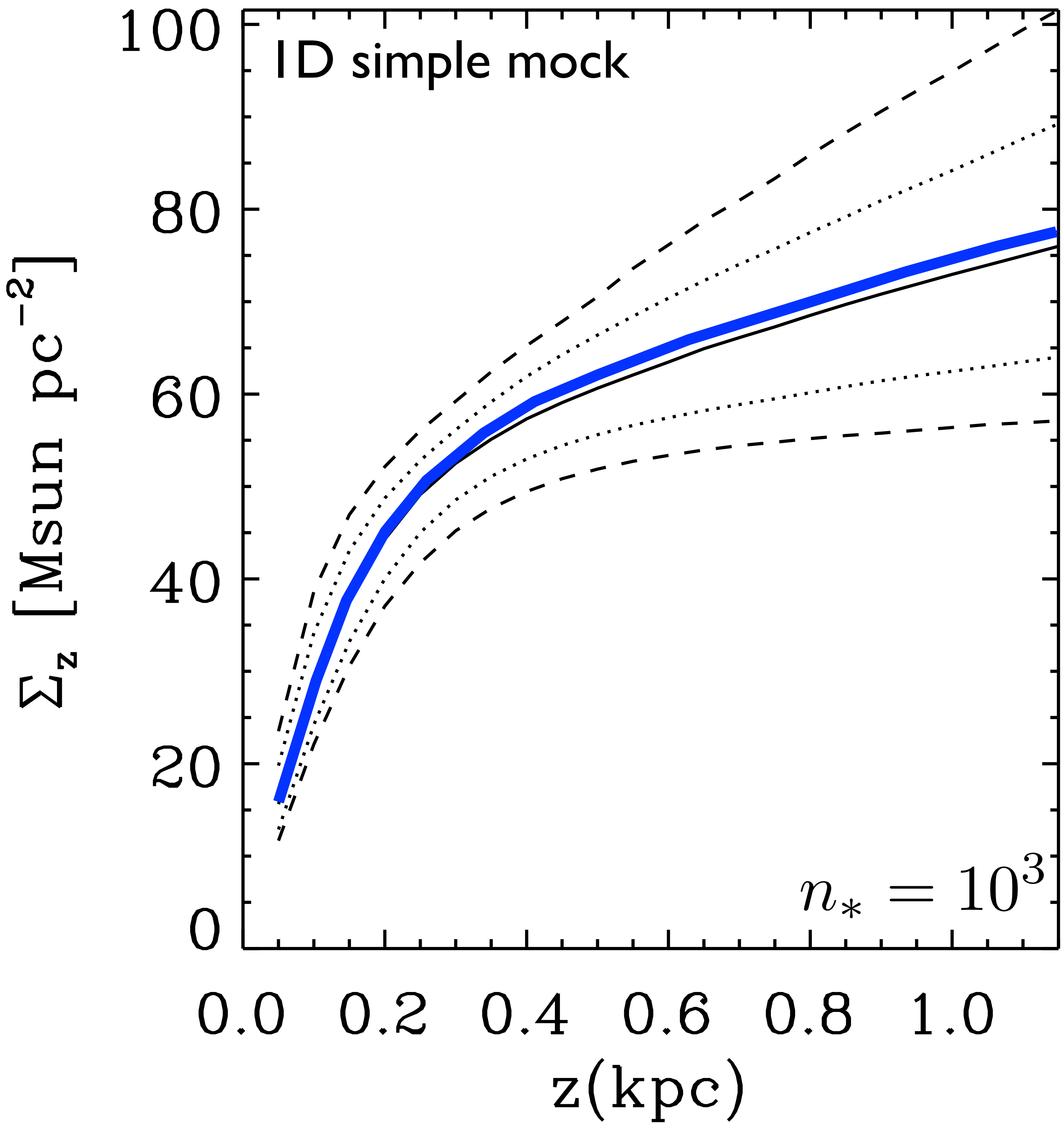

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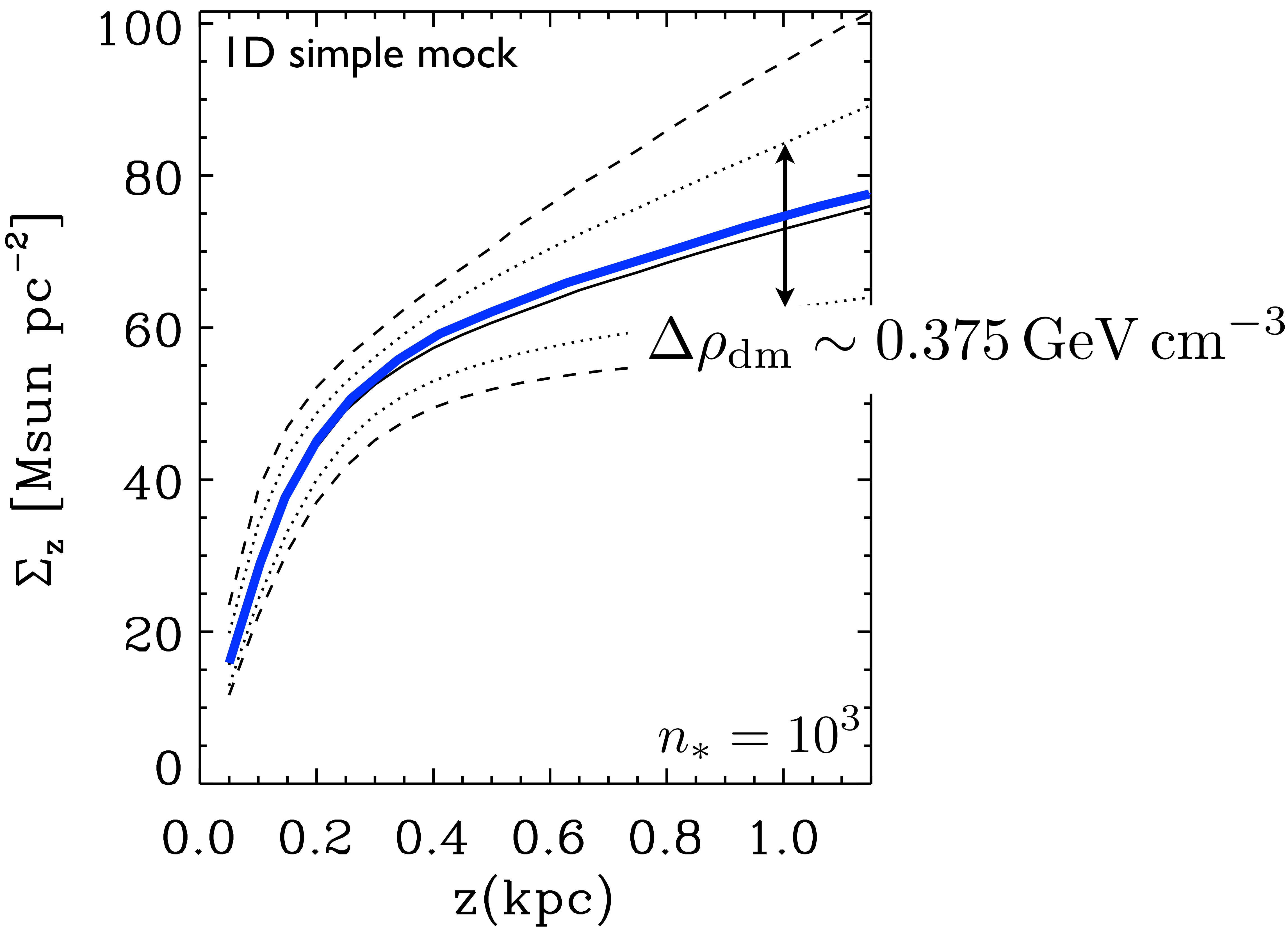

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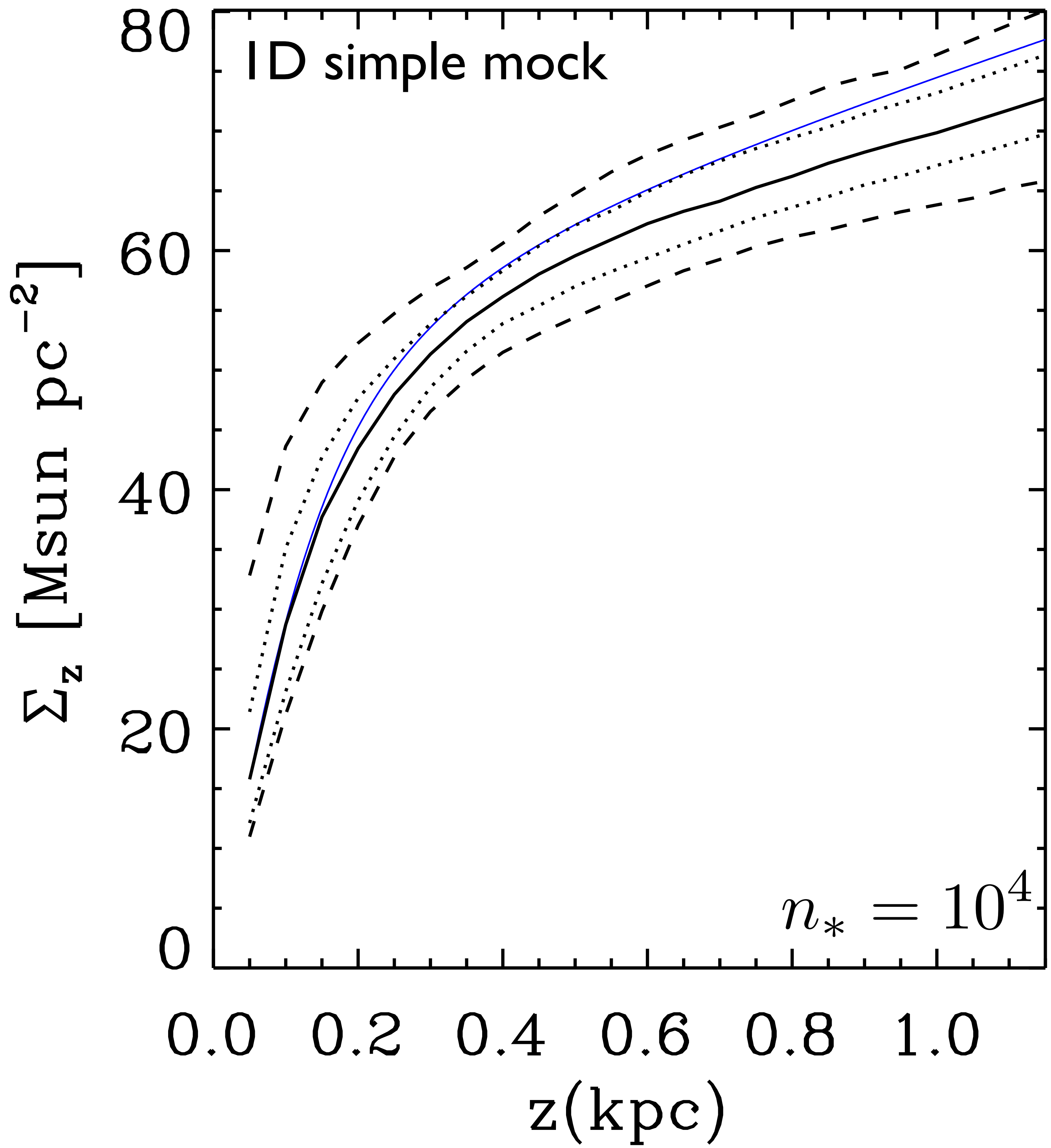

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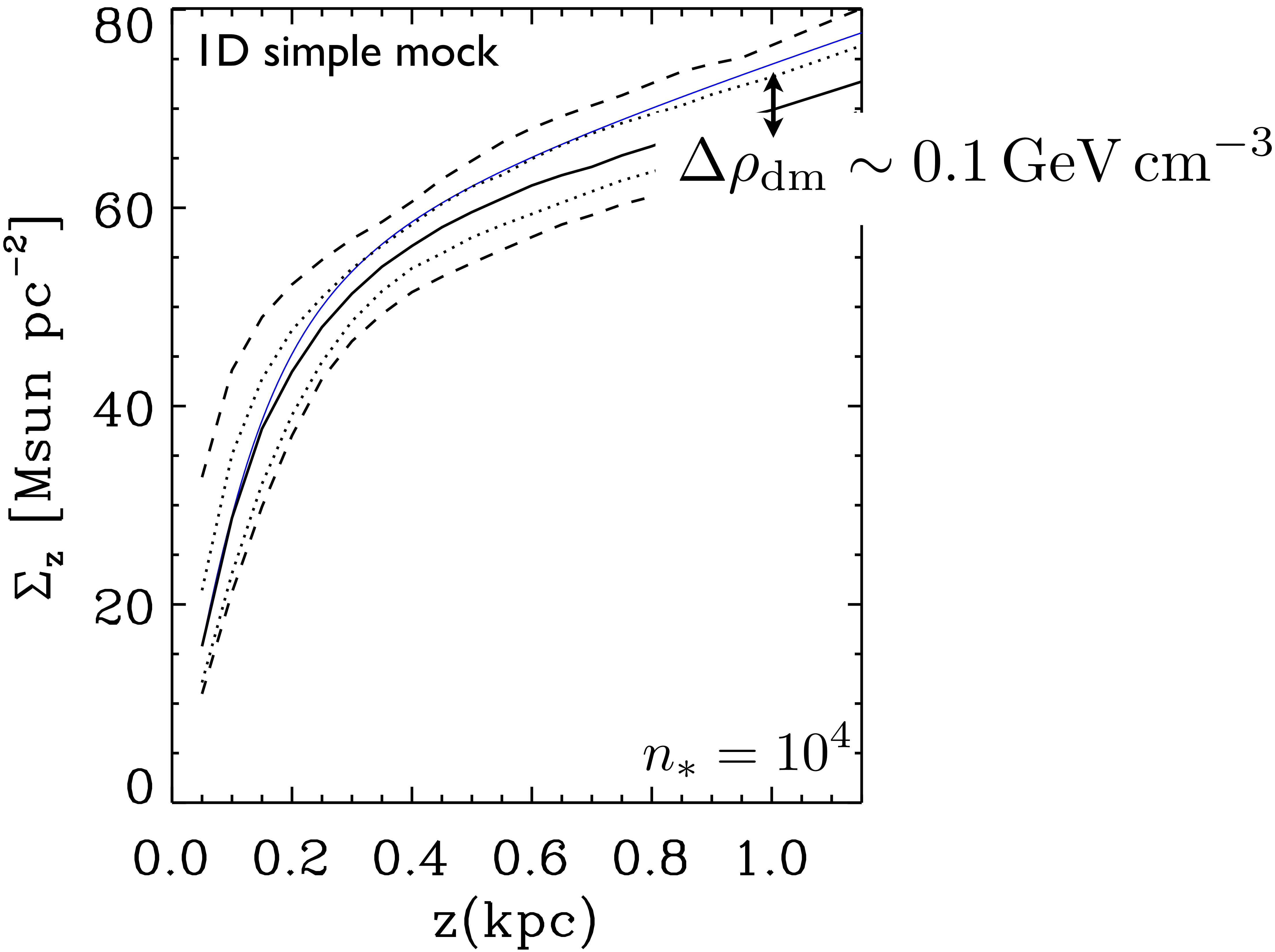

Read 2014

Measurement | Real data

Need a good tracer:

Read 2014

Measurement | Real data

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- Well mixed ⇒ equilibrium
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- Volume complete (helpful)
- Velocity data (v_z)
- Good distances

Read 2014

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Volume Complete
[Kuijken & Gilmore 1989]

Read 2014

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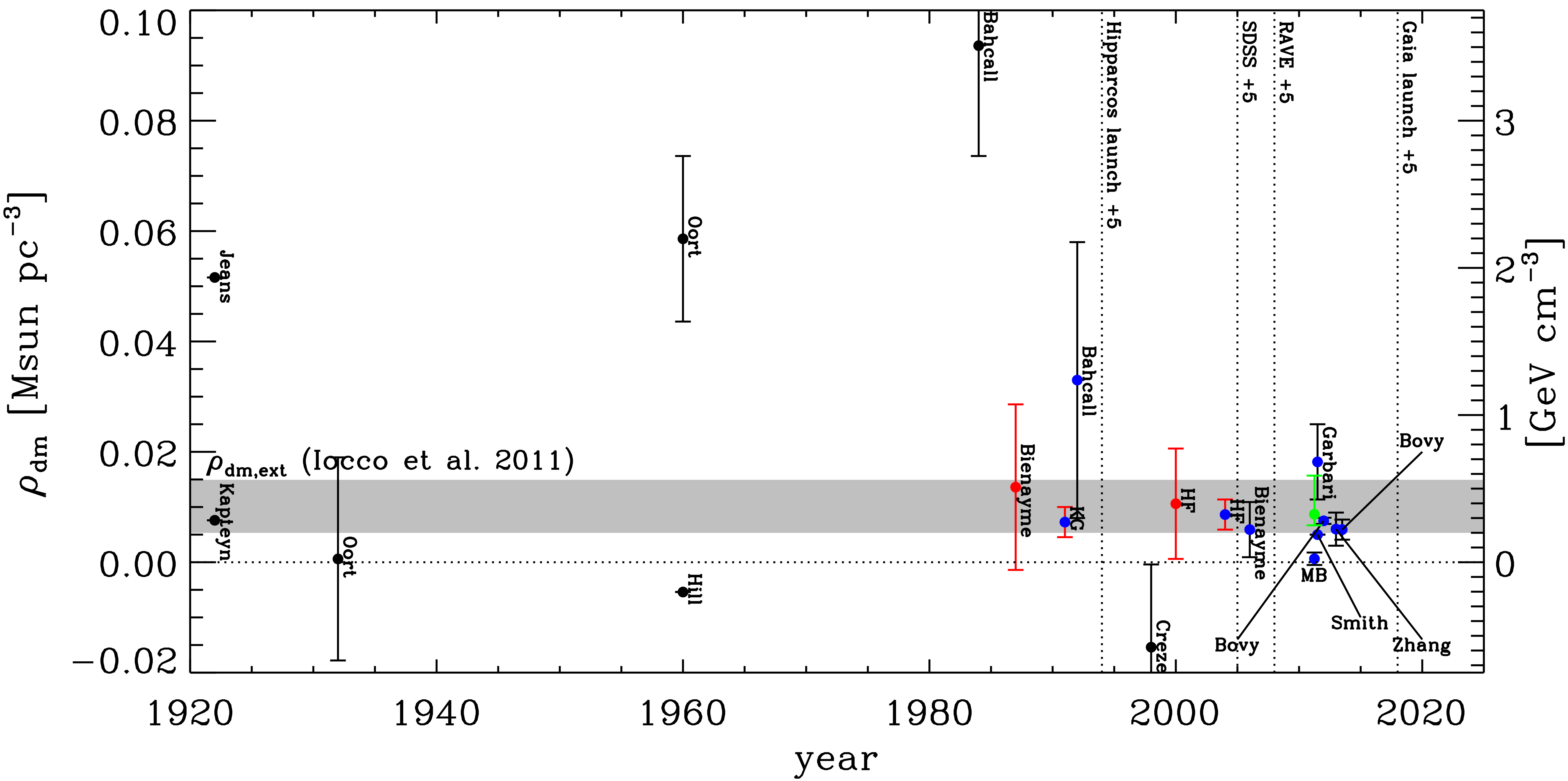
Volume Complete
[Kuijken & Gilmore 1989]

b) 10,000 stars
Complex SF
[Zhang et al. 2013]

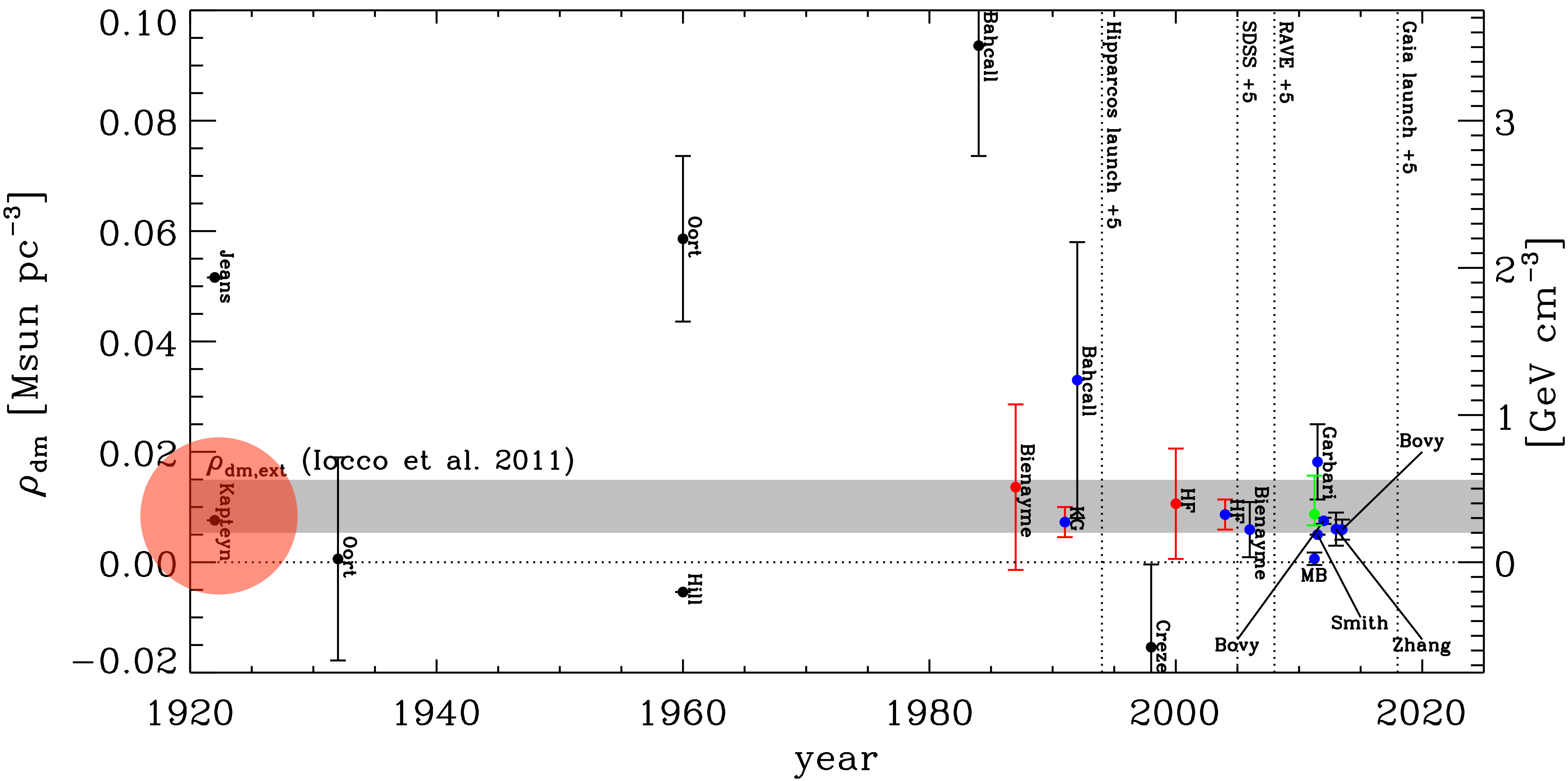
Read 2014

Measurement | Historic measures



Read 2014

Measurement | Historic measures



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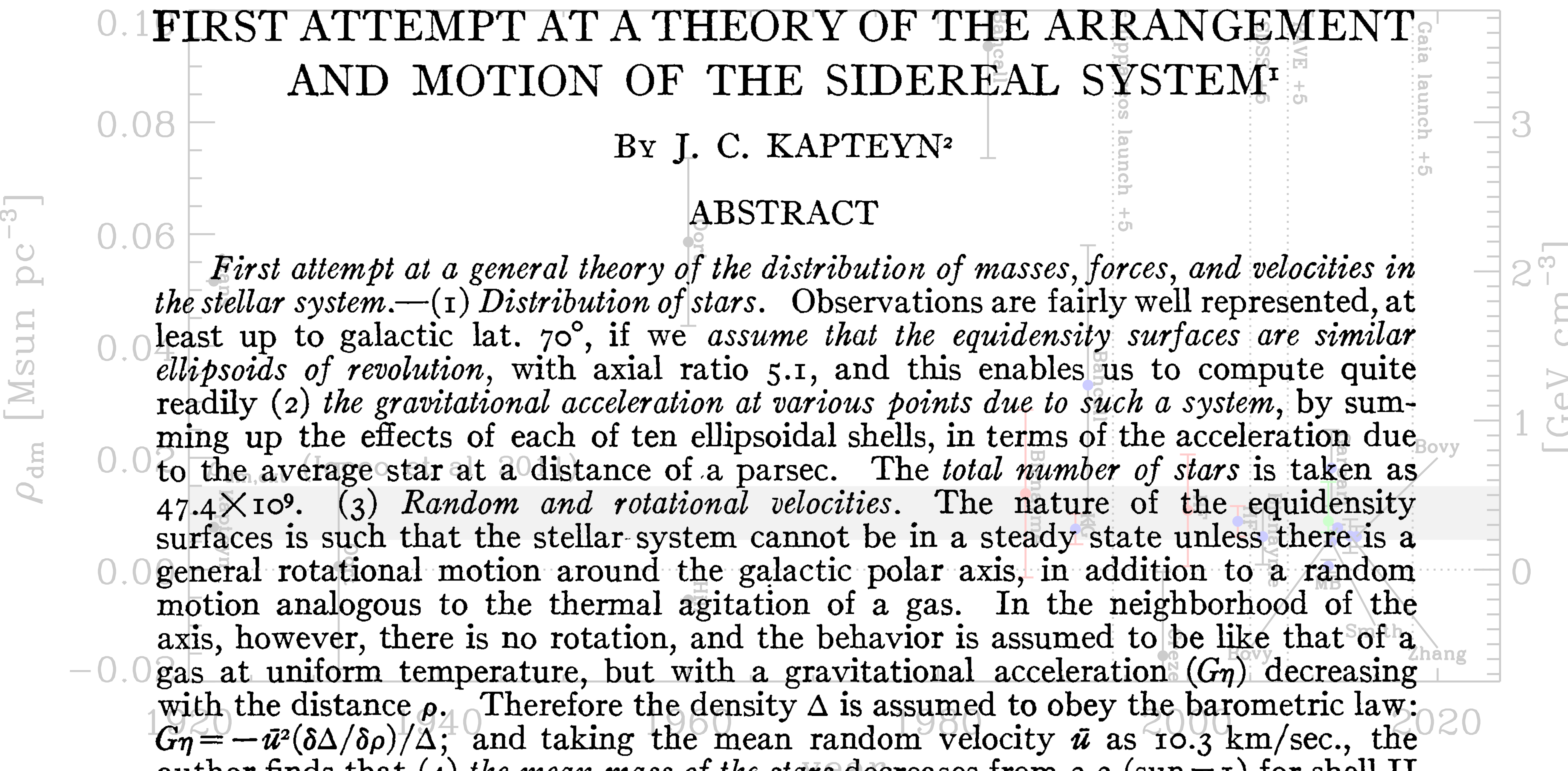

FIRST ATTEMPT AT A THEORY OF THE ARRANGEMENT AND MOTION OF THE SIDEREAL SYSTEM[1]

BY J. C. KAPTEYN[2]

ABSTRACT

First attempt at a general theory of the distribution of masses, forces, and velocities in the stellar system.—(1) *Distribution of stars.* Observations are fairly well represented, at least up to galactic lat. 70°, if we *assume that the equidensity surfaces are similar ellipsoids of revolution*, with axial ratio 5.1, and this enables us to compute quite readily (2) *the gravitational acceleration at various points due to such a system*, by summing up the effects of each of ten ellipsoidal shells, in terms of the acceleration due to the average star at a distance of a parsec. The *total number of stars* is taken as 47.4×10^9. (3) *Random and rotational velocities.* The nature of the equidensity surfaces is such that the stellar system cannot be in a steady state unless there is a general rotational motion around the galactic polar axis, in addition to a random motion analogous to the thermal agitation of a gas. In the neighborhood of the axis, however, there is no rotation, and the behavior is assumed to be like that of a gas at uniform temperature, but with a gravitational acceleration $(G\eta)$ decreasing with the distance ρ. Therefore the density Δ is assumed to obey the barometric law: $G\eta=-\bar{u}^2(\delta\Delta/\delta\rho)/\Delta$; and taking the mean random velocity $\bar{u}$ as 10.3 km/sec., the author finds that (4) *the mean mass of the stars* decreases from 2.2 (sun = 1) for shell II to 1.4 for shell X (the outer shell), the average being close to 1.6, which is the value independently found for the average mass of both components of visual binaries. In the galactic plane the resultant acceleration—gravitational minus centrifugal—is again put equal to $-\bar{u}^2(\delta\Delta/\delta\rho)/\Delta$, $\bar{u}$ is taken to be constant and the average mass is assumed to decrease from shell to shell as in the direction of the pole. The angular velocities then come out such as to make the linear rotational velocities about constant and equal to 19.5 km/sec. beyond the third shell. If now we suppose that part of the stars are rotating one way and part the other, the relative velocity being 39 km/sec., we have a quantitative explanation of the phenomenon of star streaming, where

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Jacobus Cornelius Kapteyn
[1851 - 1922]

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1. *Equidensity surfaces supposed to be similar* … —In *Mount Wilson Contribution* No. 188[3] a provisional derivation was given of the star-density in the stellar system. The question was

Measurement | Historic measures

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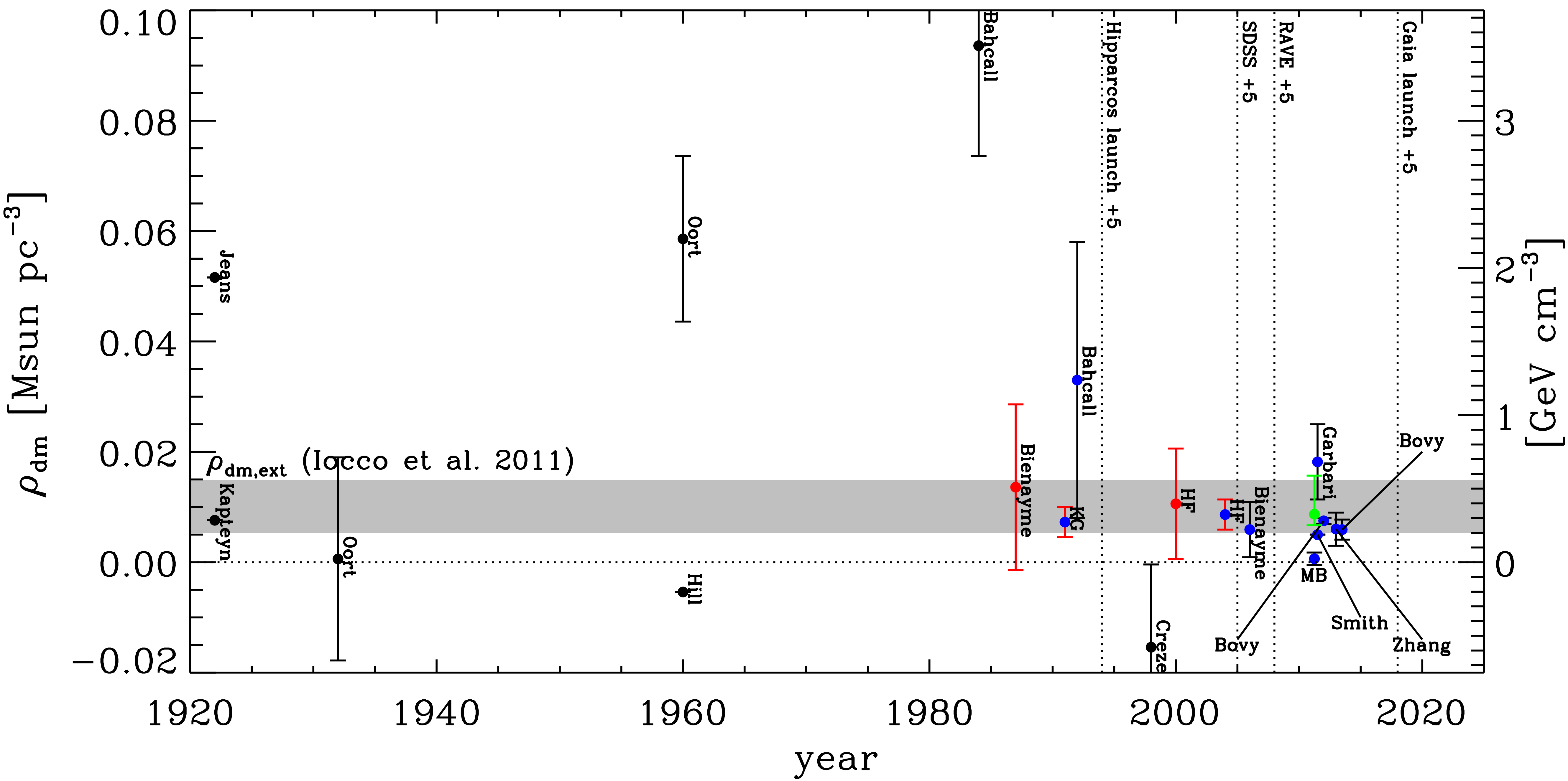
Measurement | Comparison of recent measures



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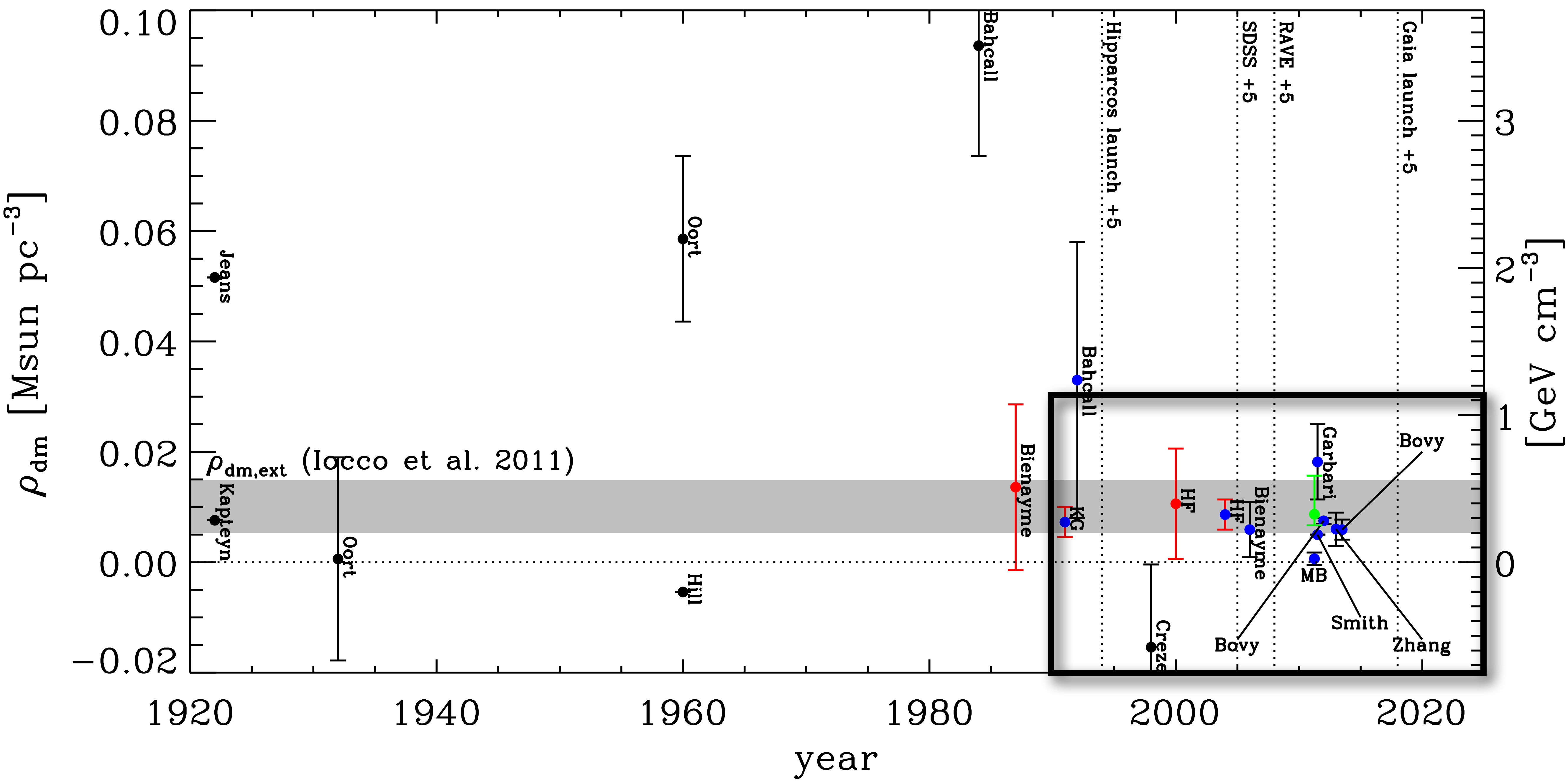

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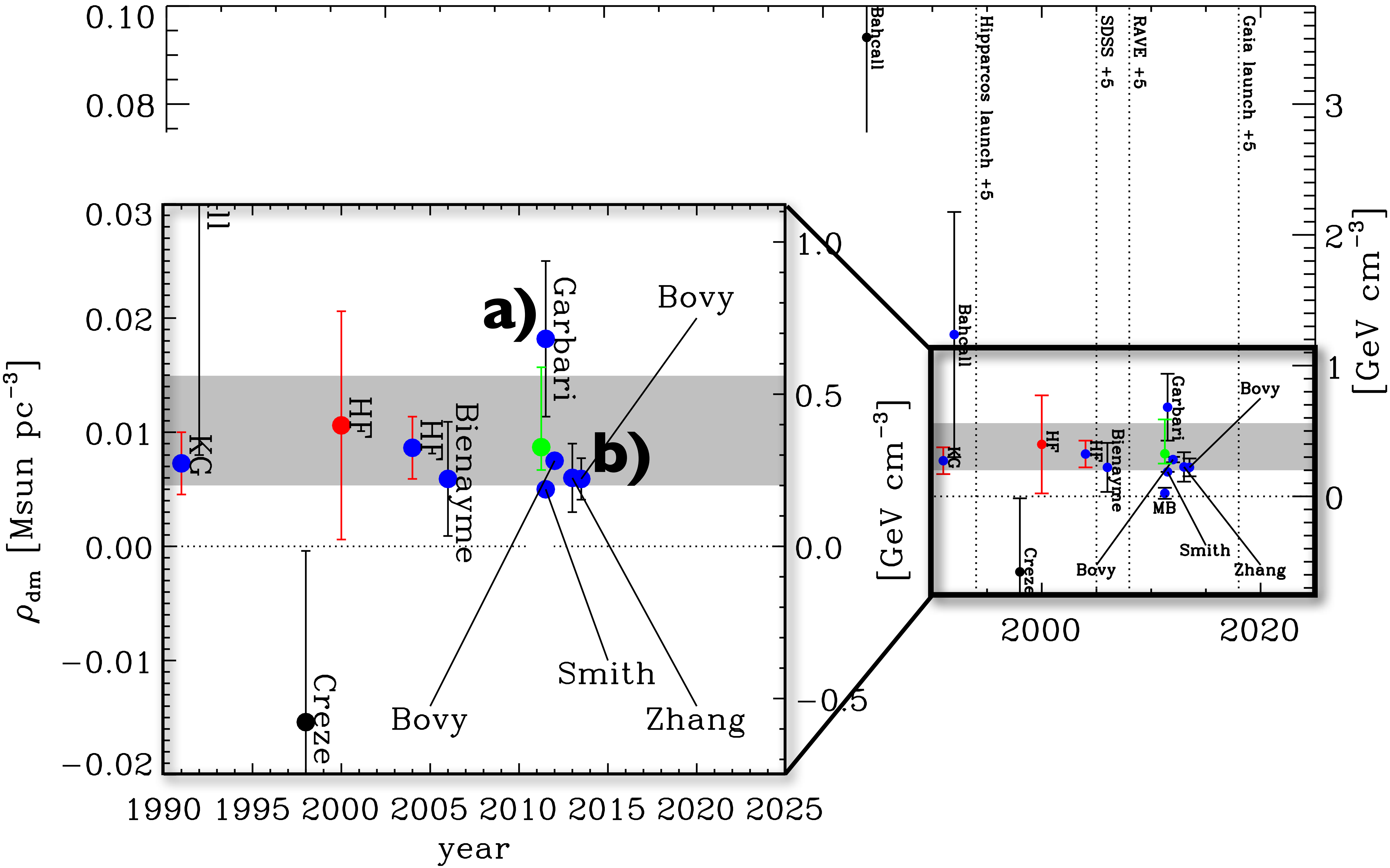
Measurement | Comparison of recent measures



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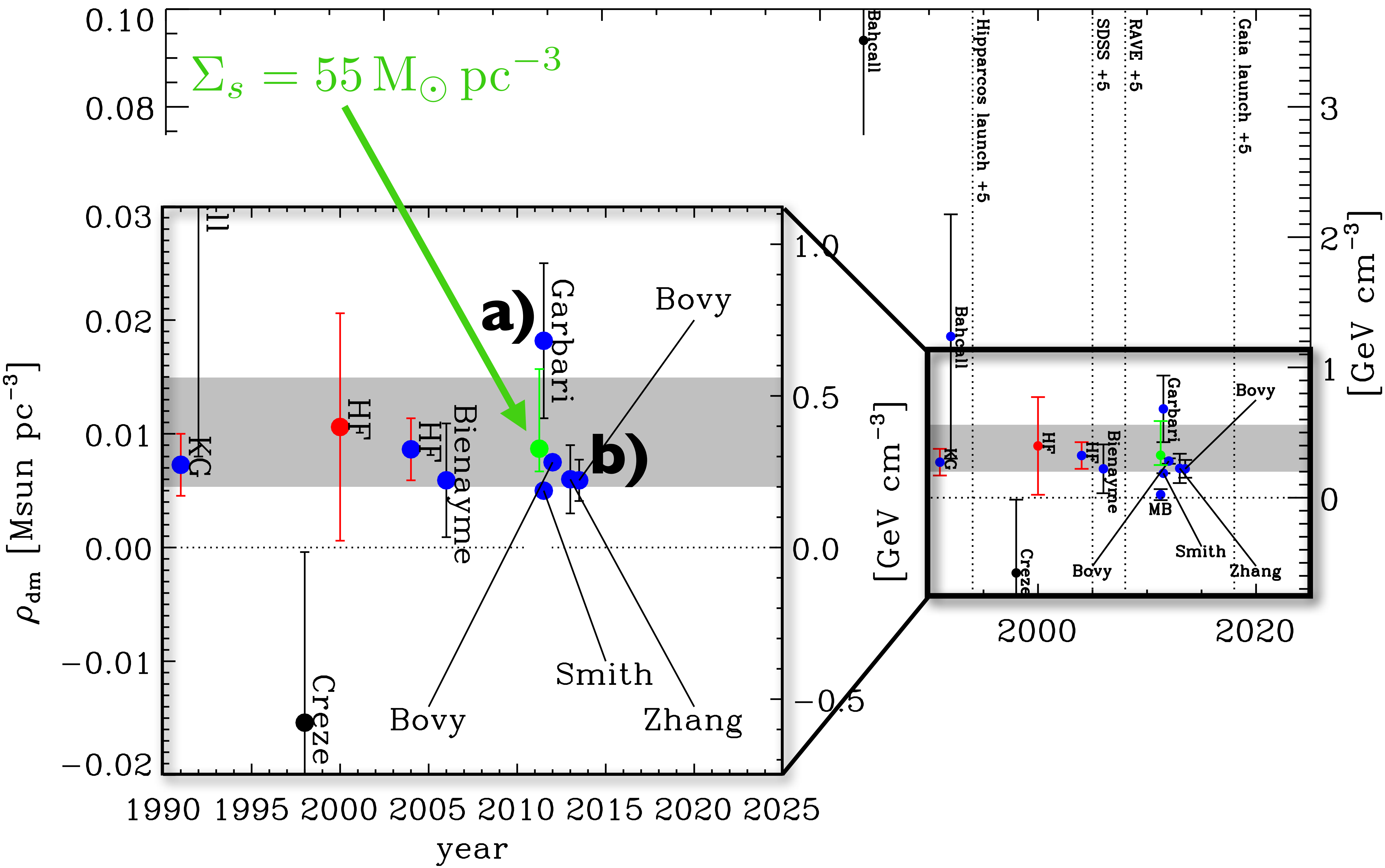

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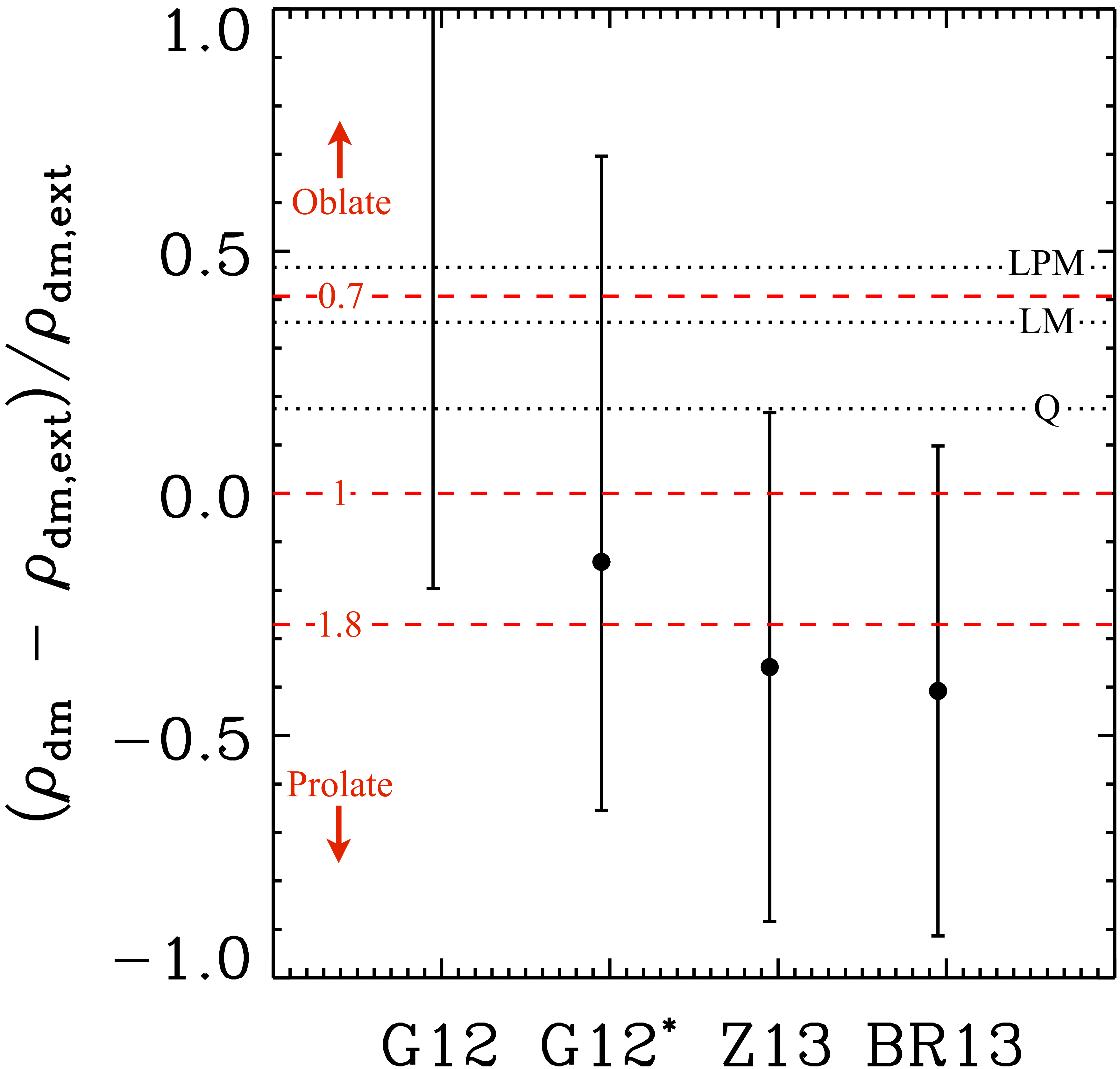
Measurement | The dark disc



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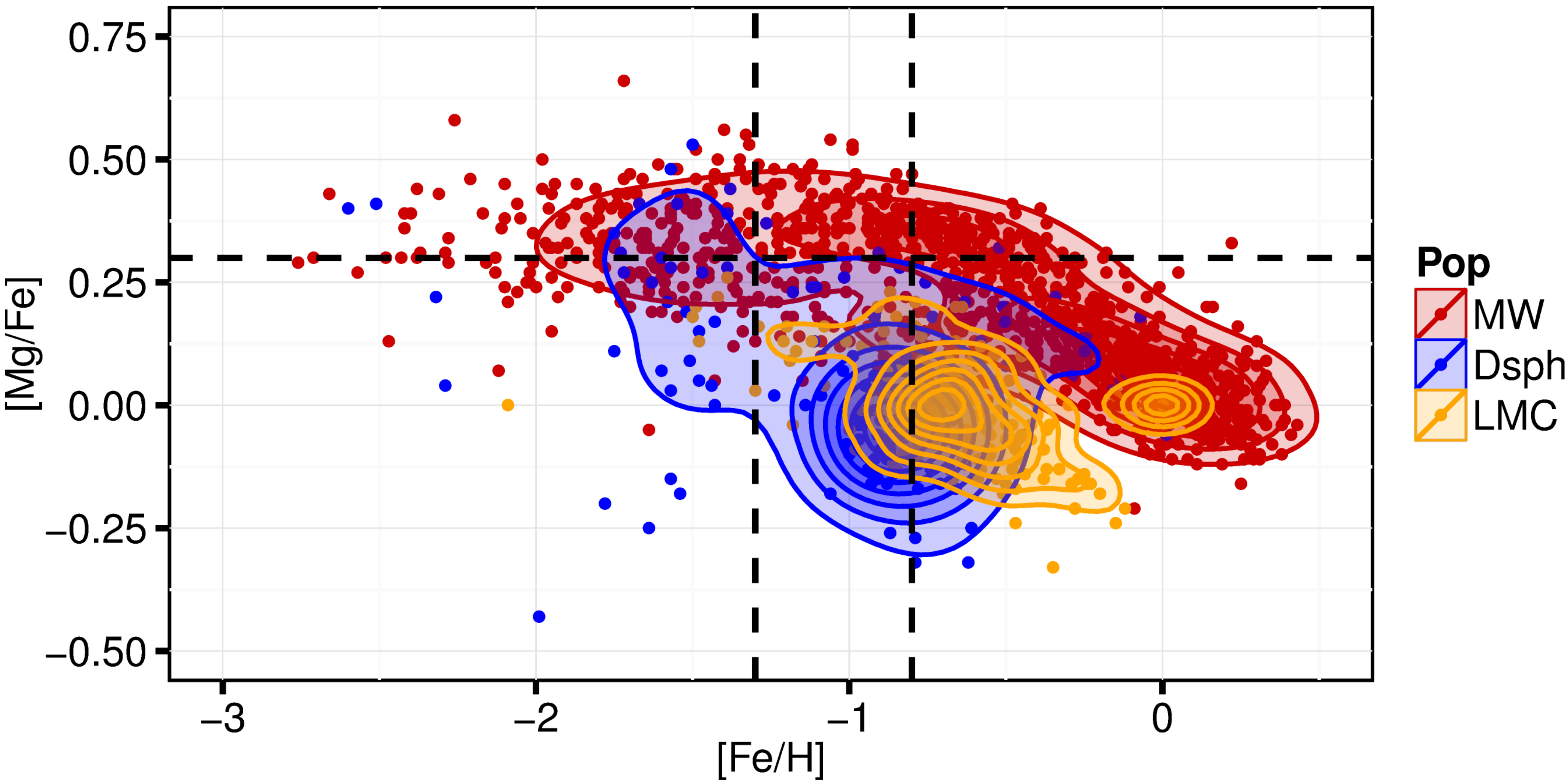
1. A chemical template ...

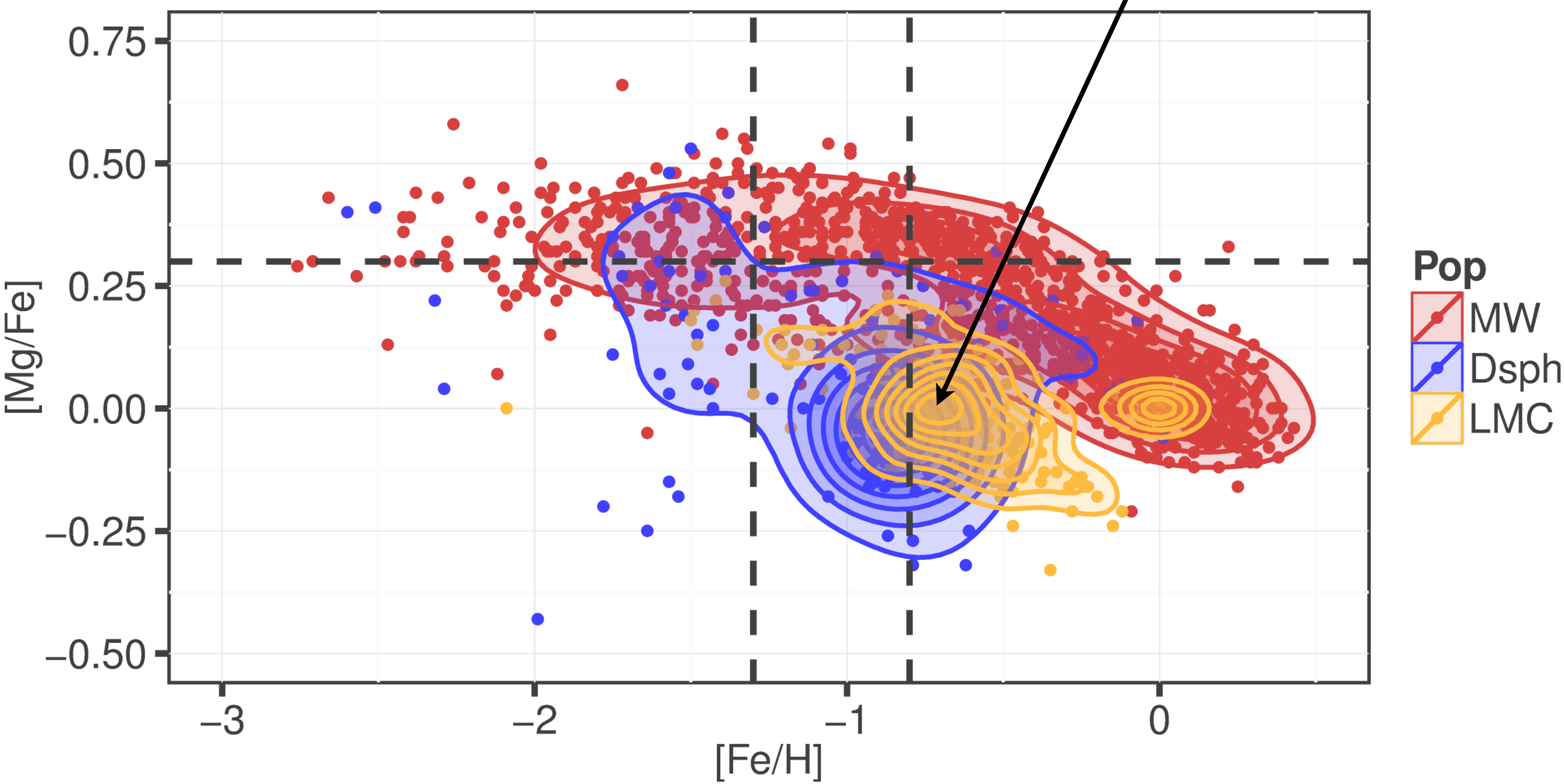


Ruchti, Read et al. 2014, submitted

Measurement | The dark disc | The hunt for accreted stars

1. A chemical template ...

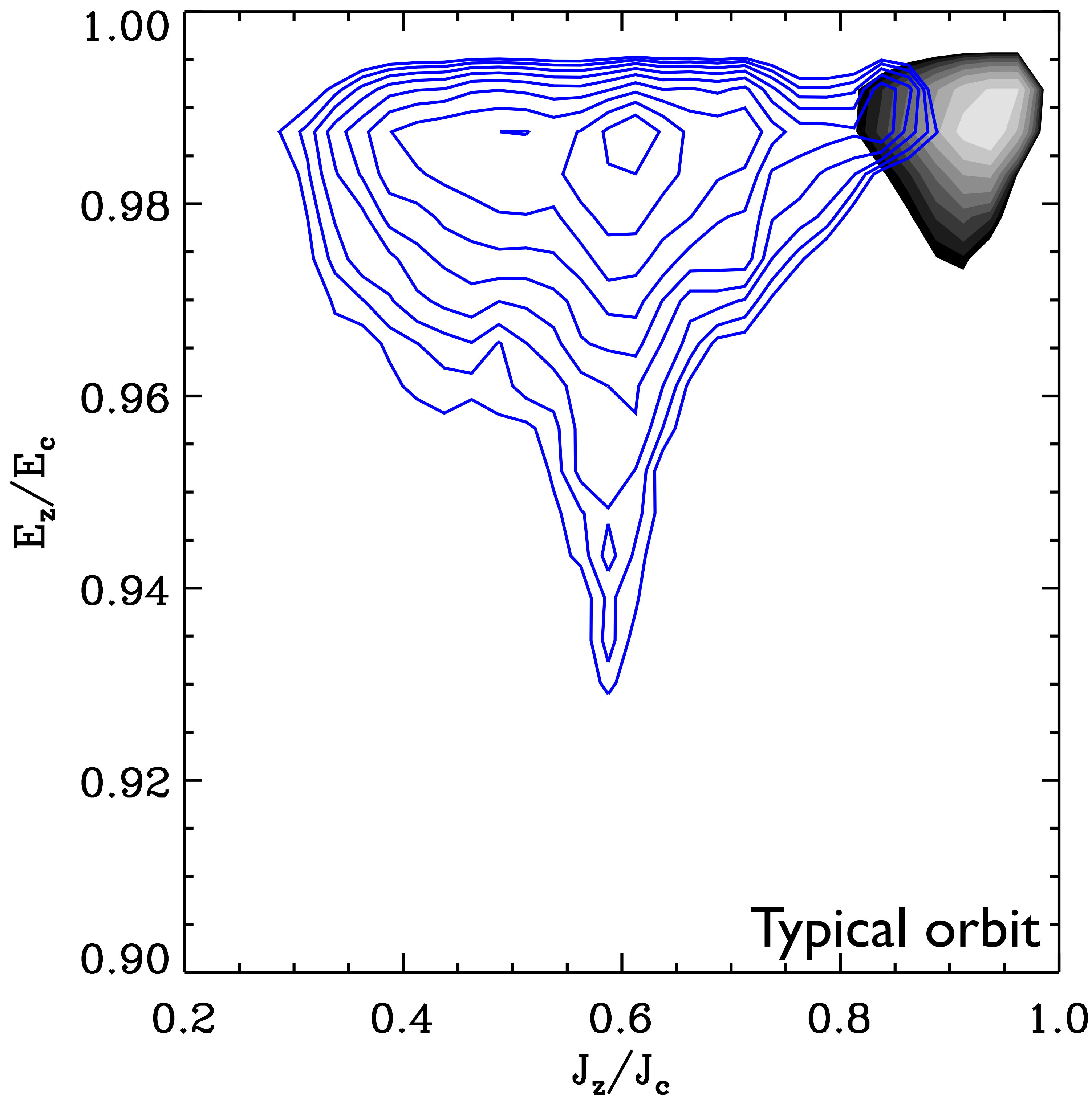
Born in dwarf or outer disc



Ruchti, Read et al. 2014, submitted

Measurement | The dark disc | The hunt for accreted stars

2. A kinematic template ...



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Measurement | The dark disc | The hunt for accreted stars

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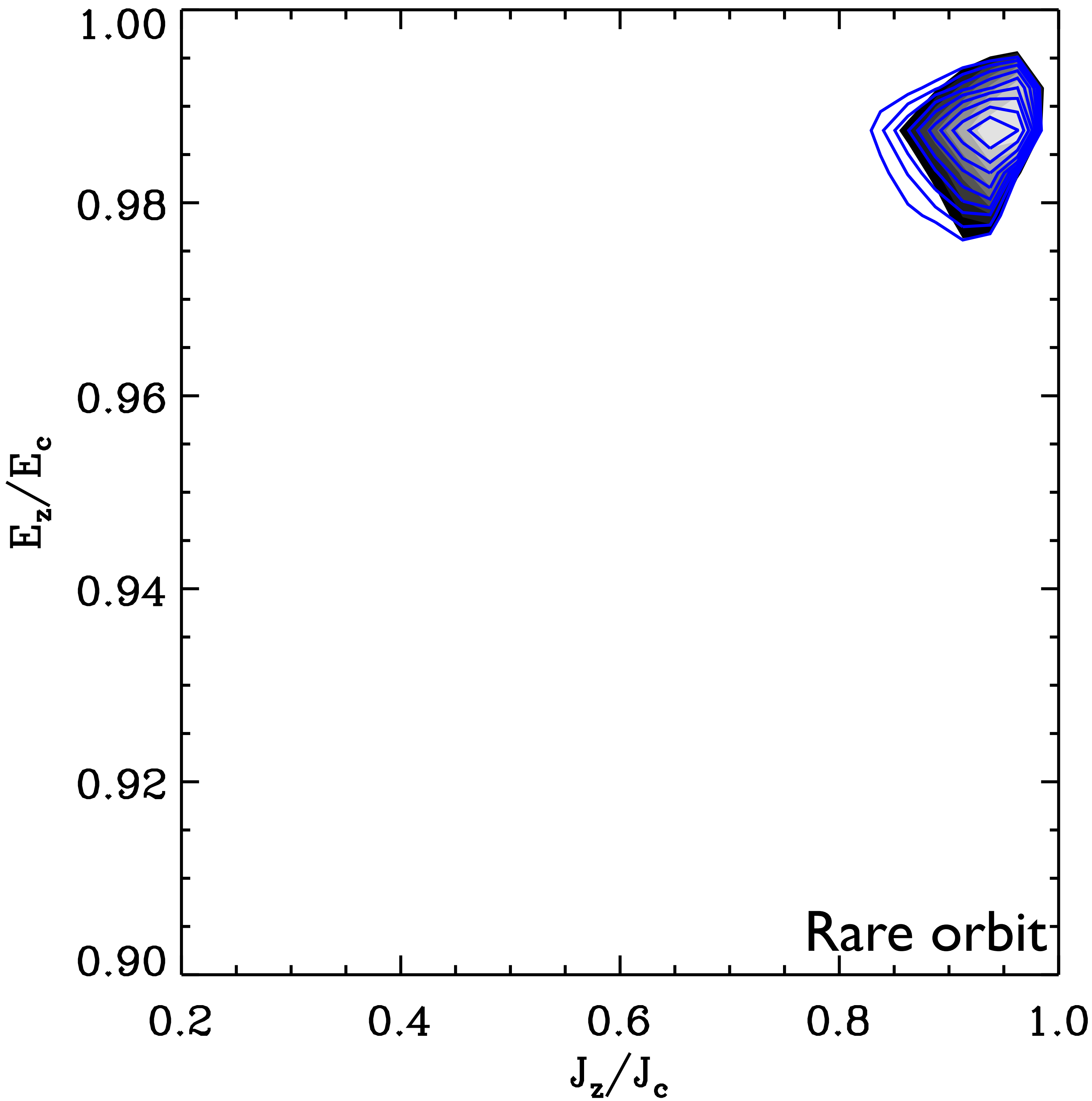

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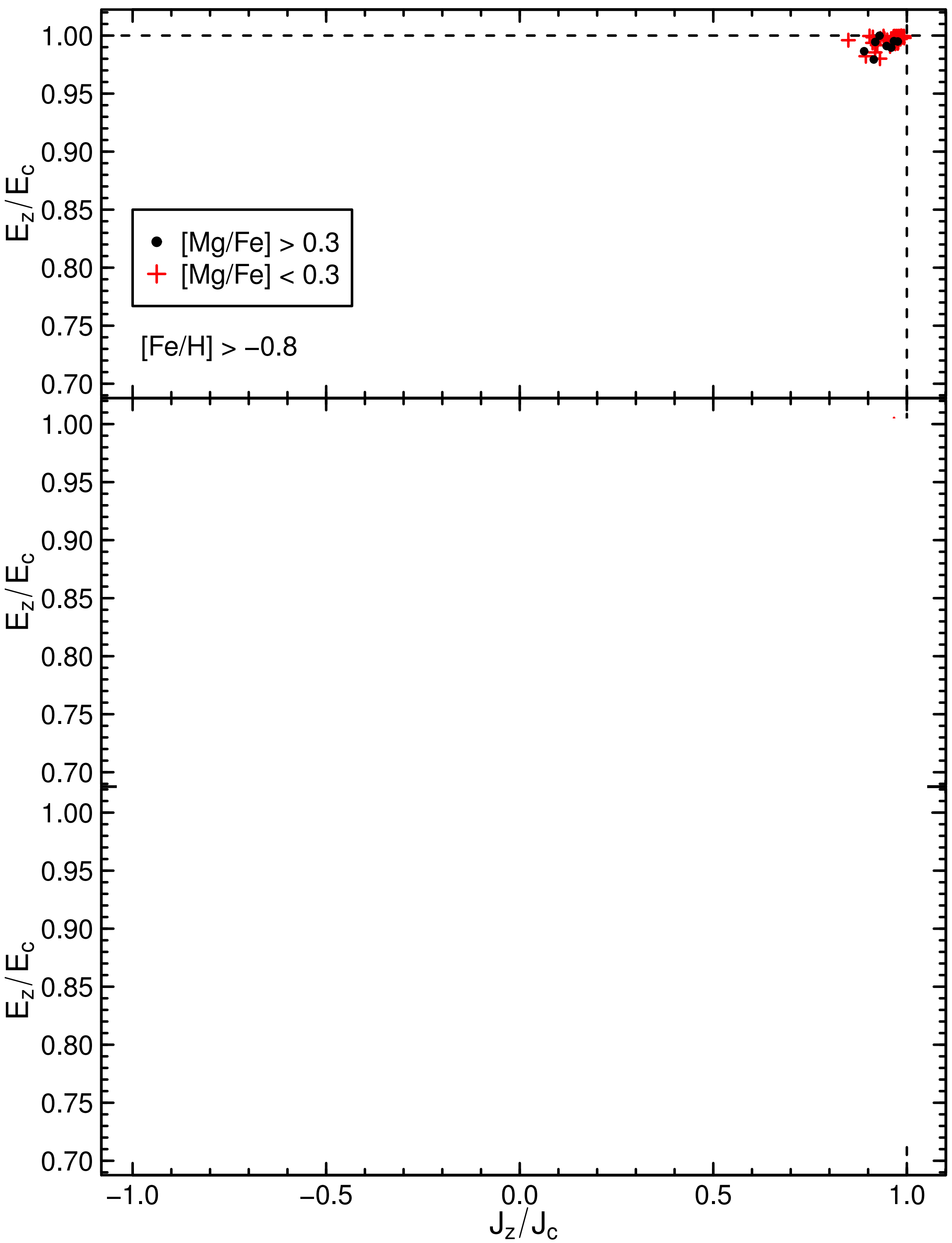
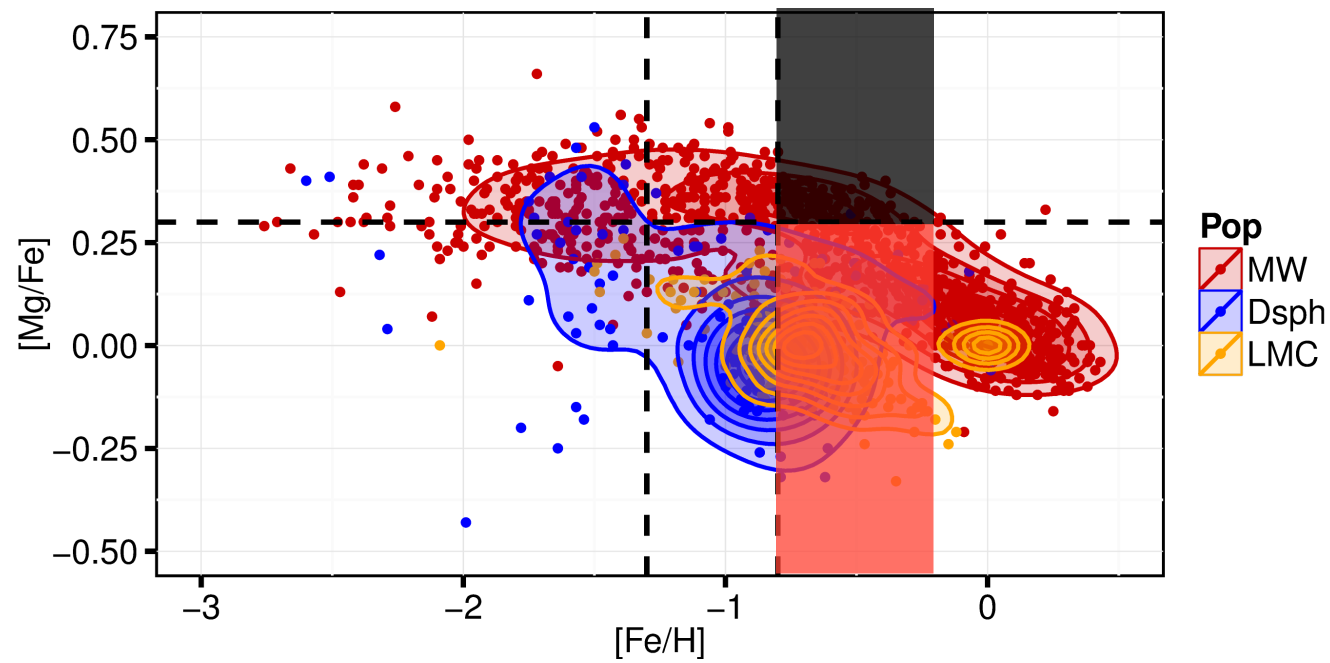
Measurement | The dark disc | The hunt for accreted stars

Real data [Ruchti et al. 2014 submitted]





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Measurement | The dark disc | The hunt for accreted stars

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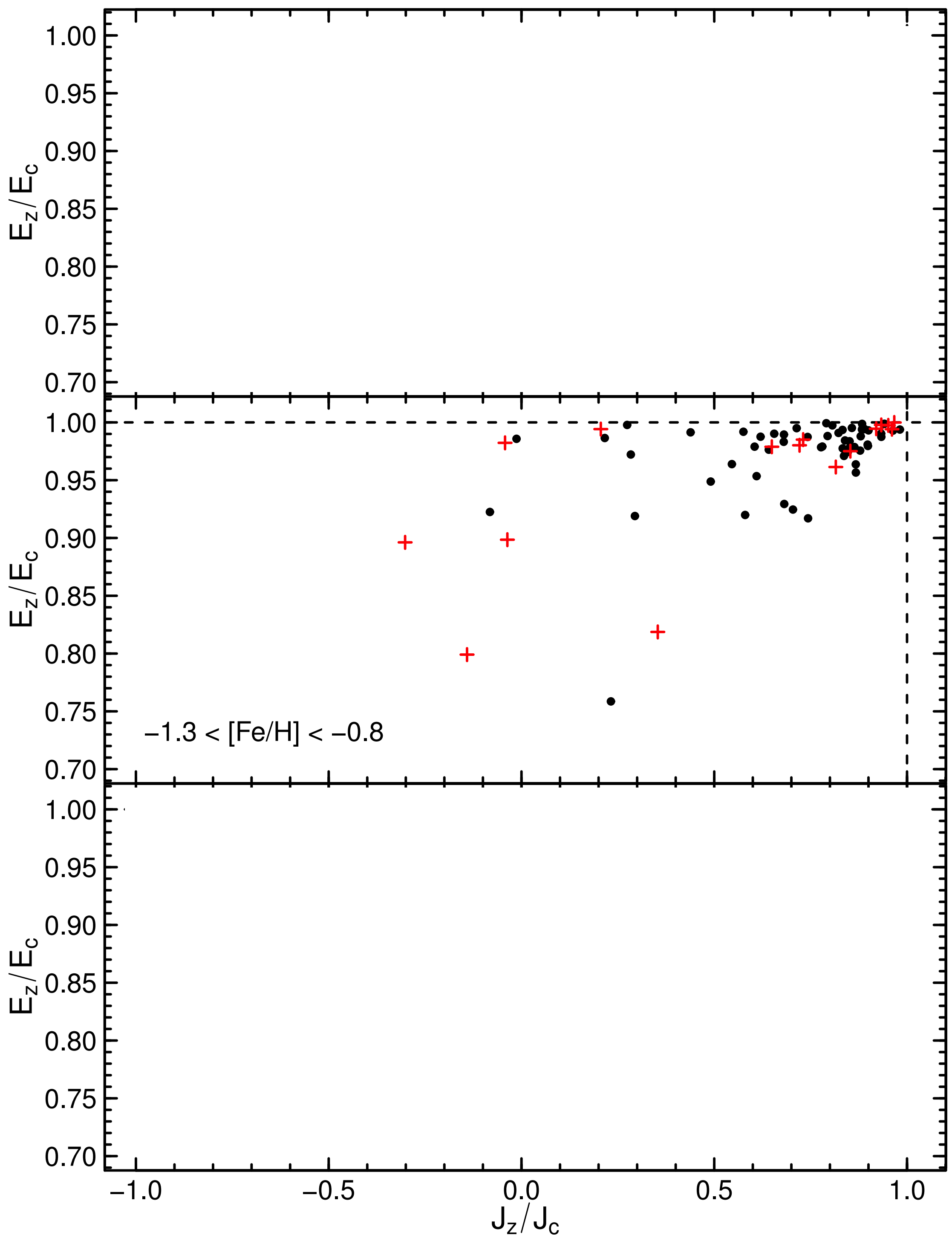

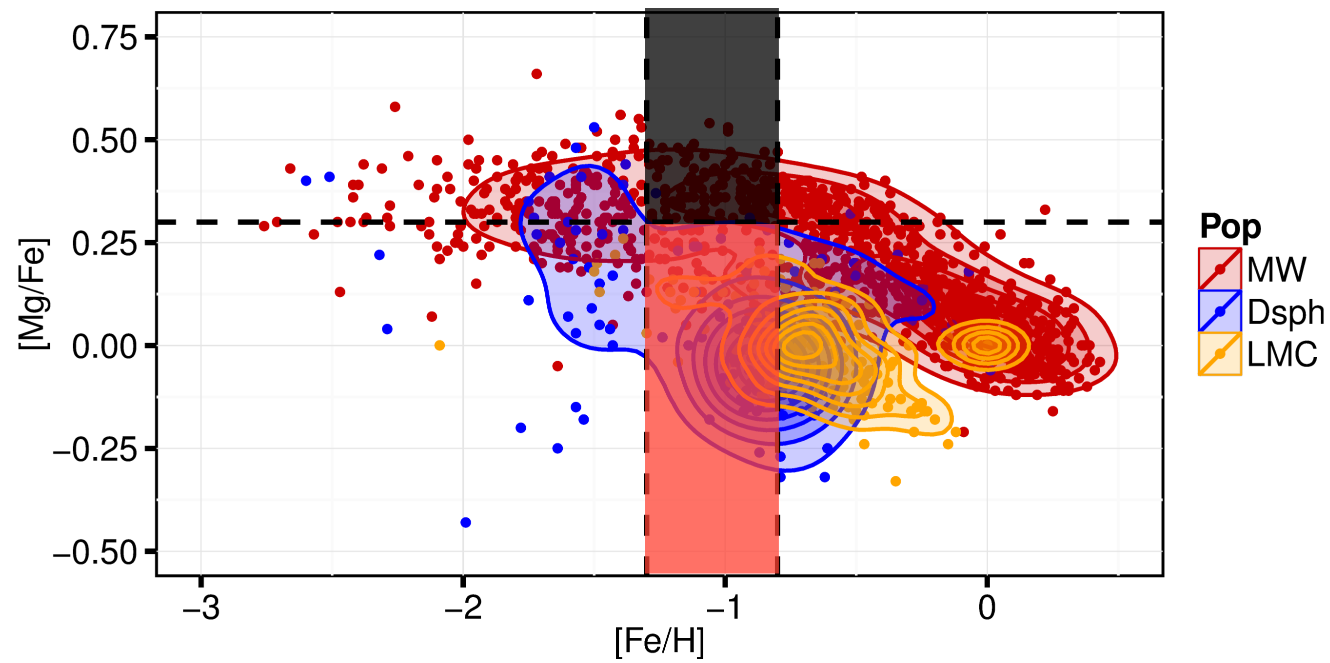

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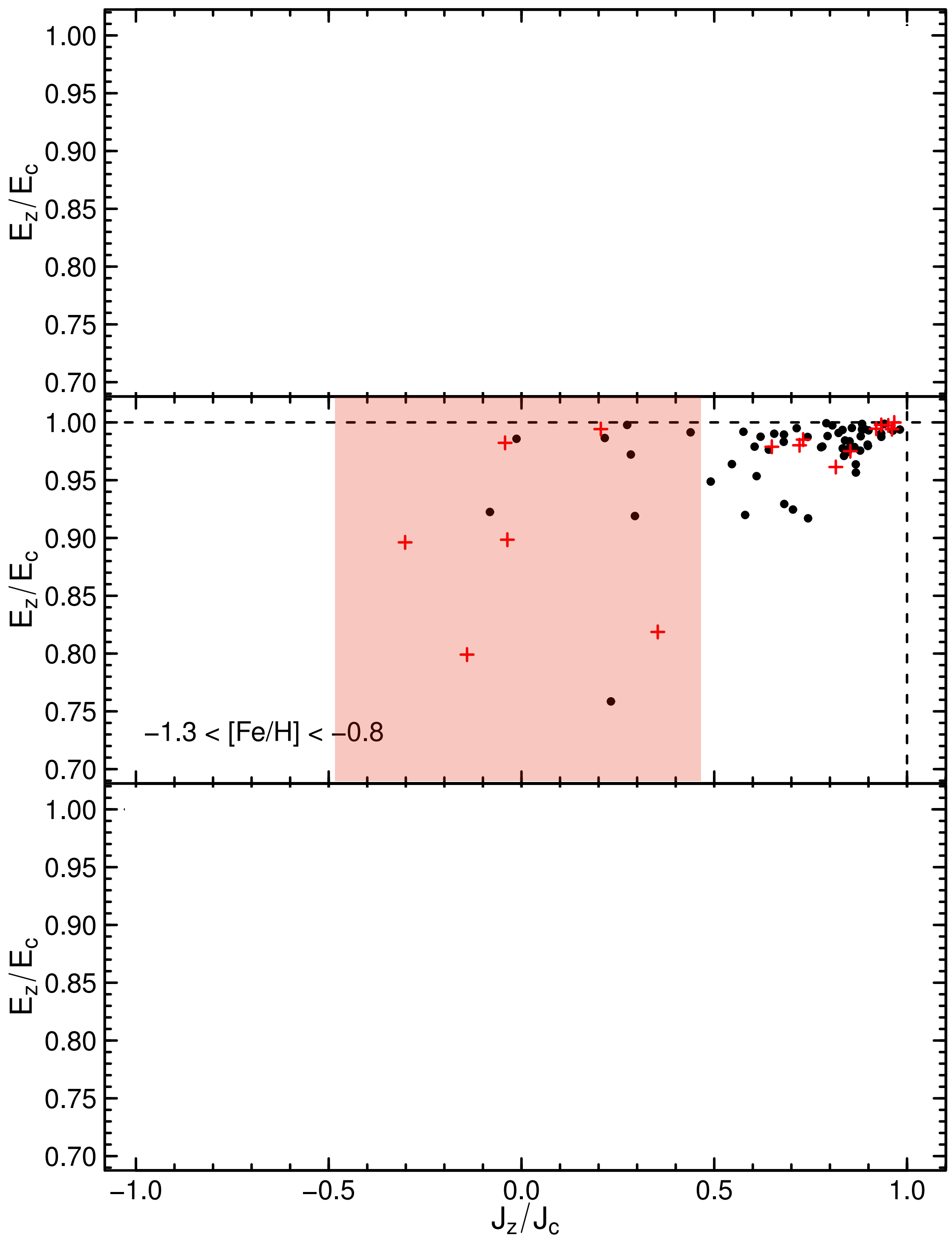

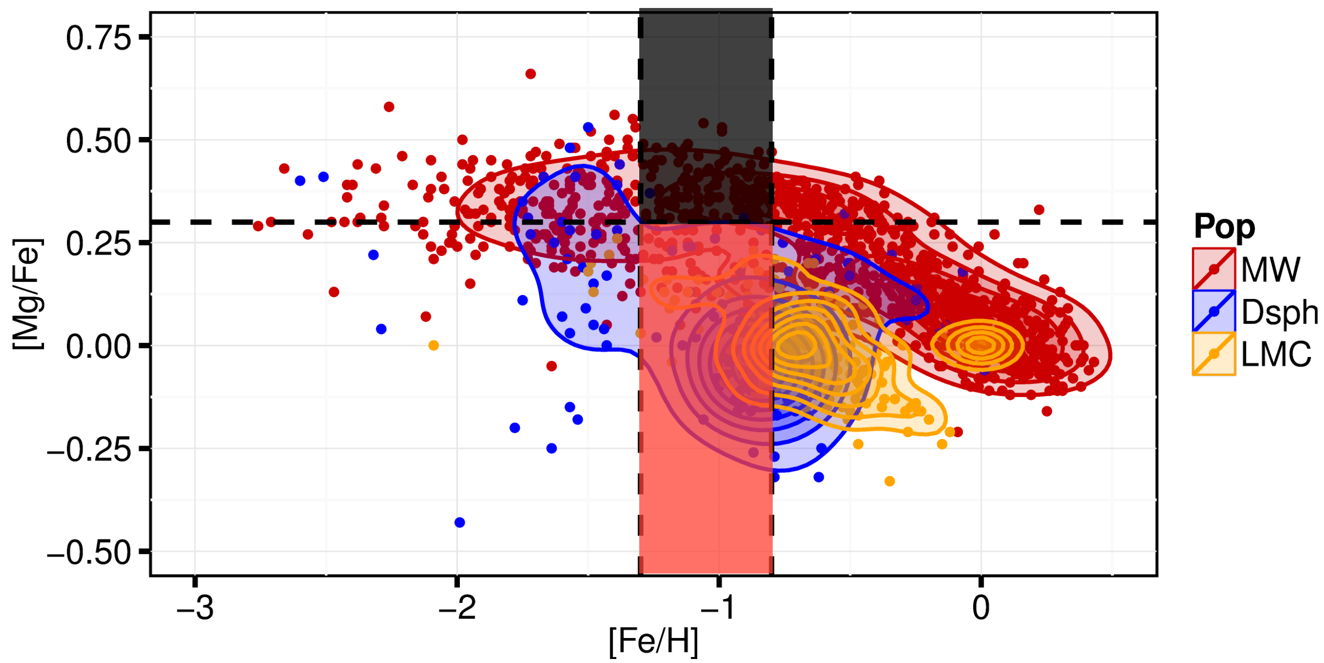

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Measurement | The dark disc | The hunt for accreted stars

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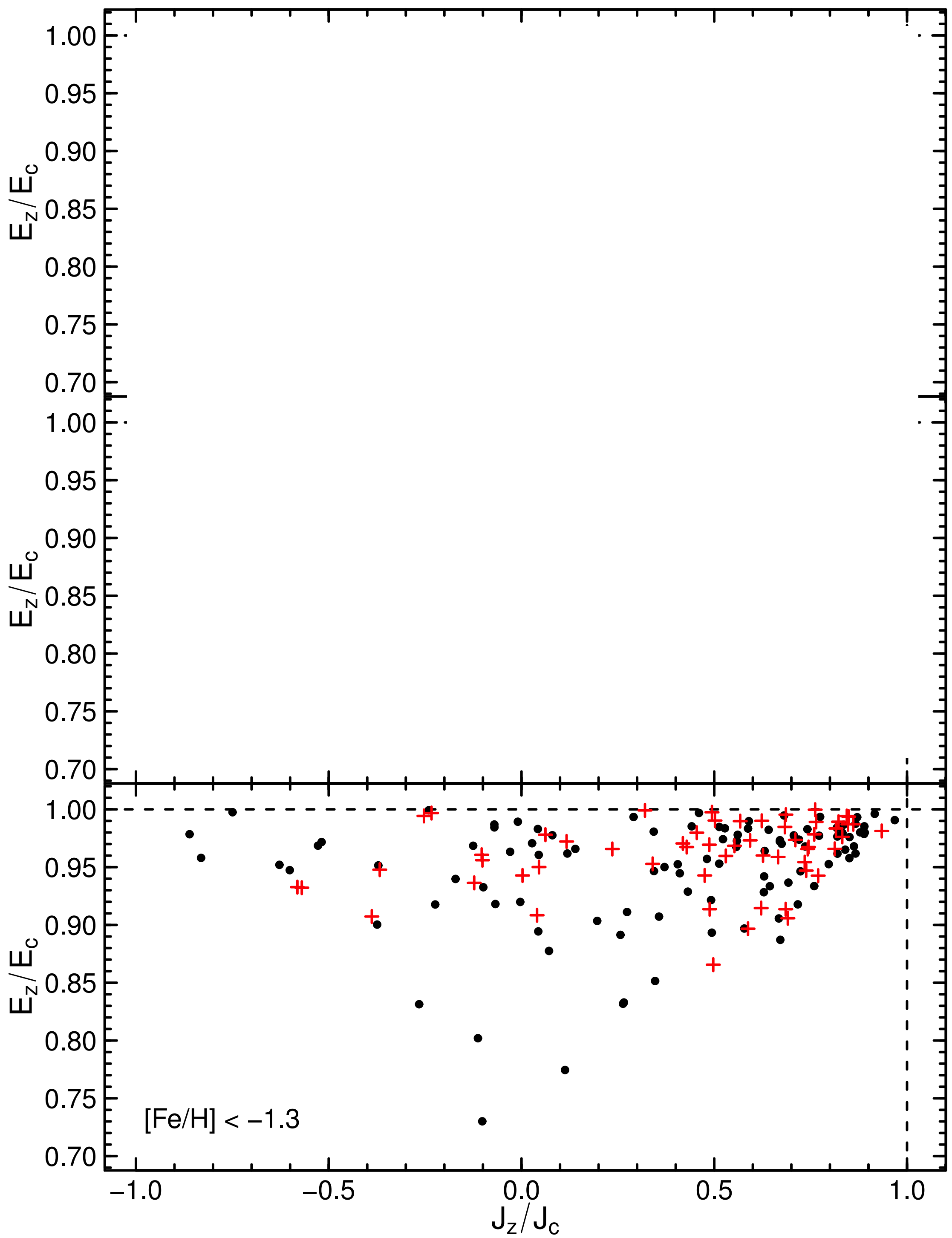

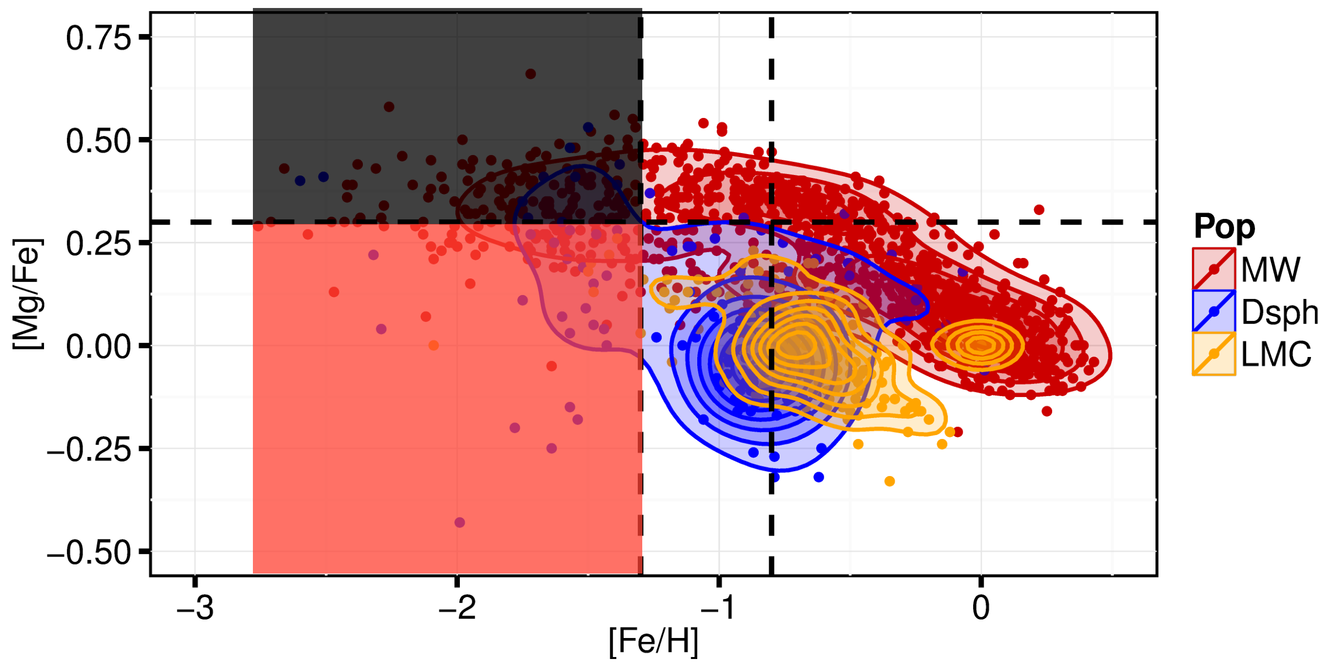

Ruchti, Read et al. 2014, submitted

Conclusions

- The latest constraints on the local dark matter density give:

$$\rho_{\rm dm} = 0.33^{+0.26}_{-0.075}\,{\rm GeV\,cm^{-3}} \qquad \rho_{\rm dm} = 0.25 \pm 0.09\,{\rm GeV\,cm^{-3}}$$

[volume complete; G12*;R14] [SDSS; Z13]

- Comparing these with the rotation curve implies a near-spherical MW halo at ~8kpc, little dark disc, and a quiescent merger history.

- We have searched for stars accreted along with the dark disc, finding none so far; this supports the "quiescent MW" scenario.

- Gaia will move us into the realm of truly precise measurements of the Local Dark Matter Density.

Garbari et al. 2012; Zhang et al. 2013; Read 2014; Ruchti, Read et al. 2014, submitted