The Local Dark Matter Density

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

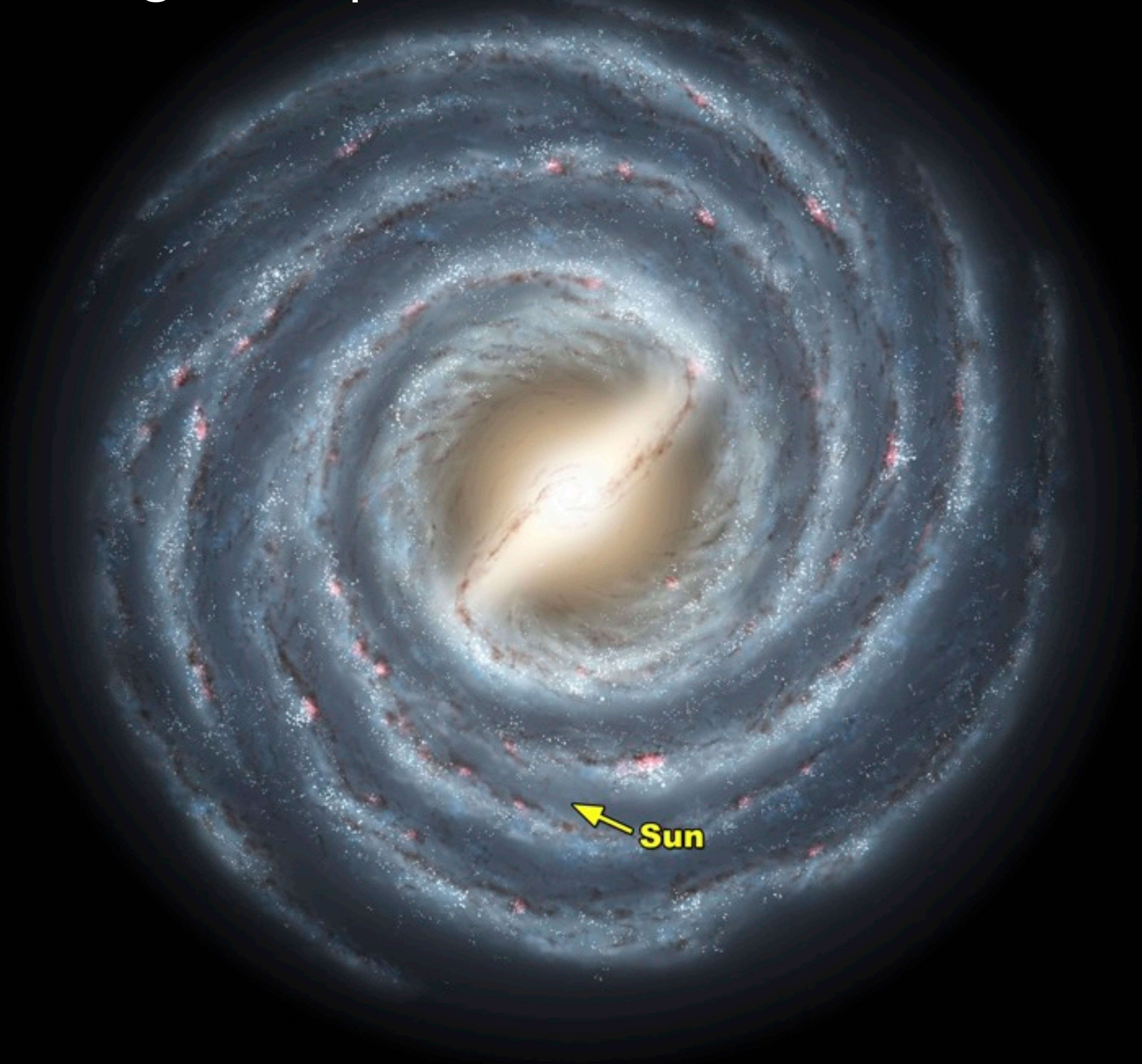
Prof. Justin Read | University of Surrey

Silvia Garbari; George Lake; Greg Ruchti; Oscar Agertz

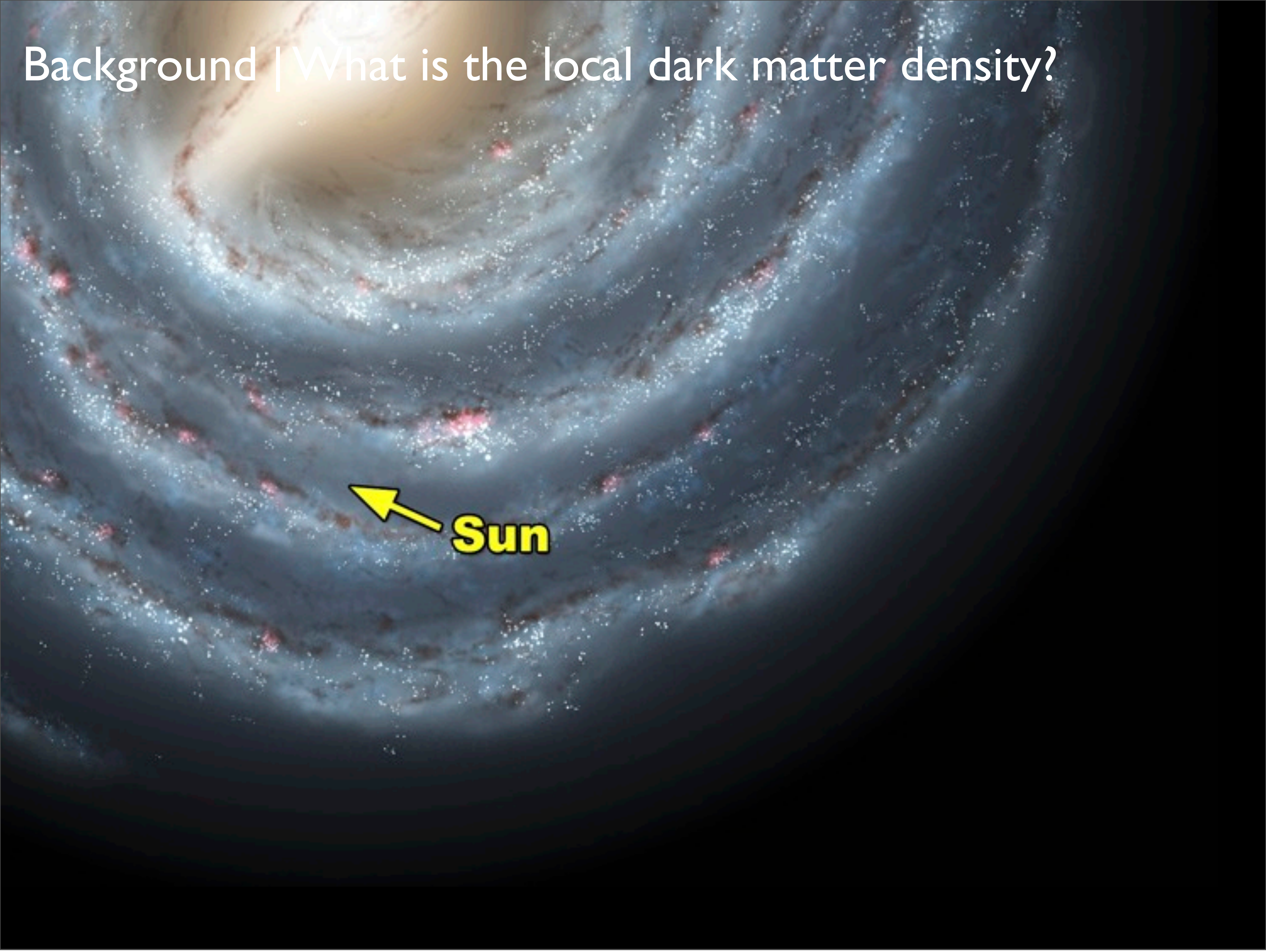
Background

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

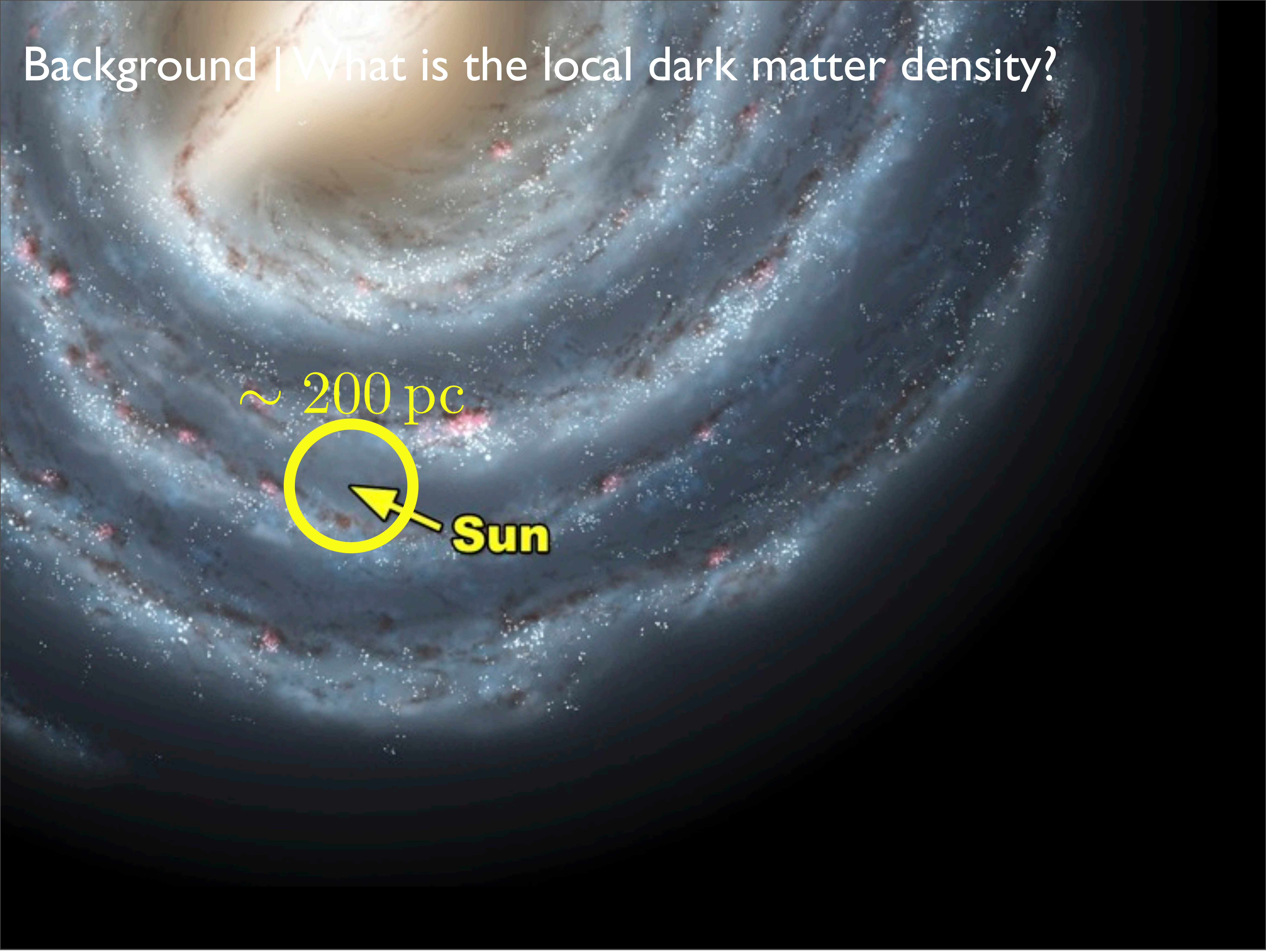
Background | What is the local dark matter density?



Background | What is the local dark matter density?

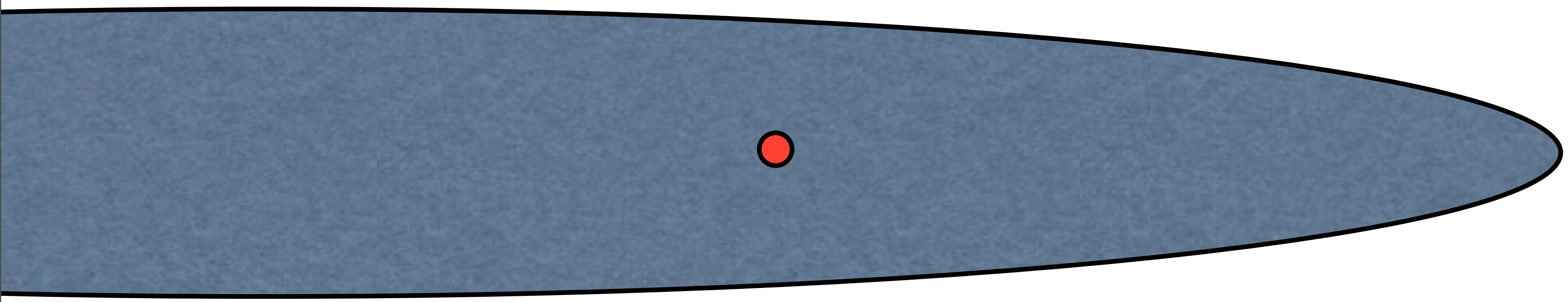


Background | What is the local dark matter density?



Background | How can we measure the local DM density?

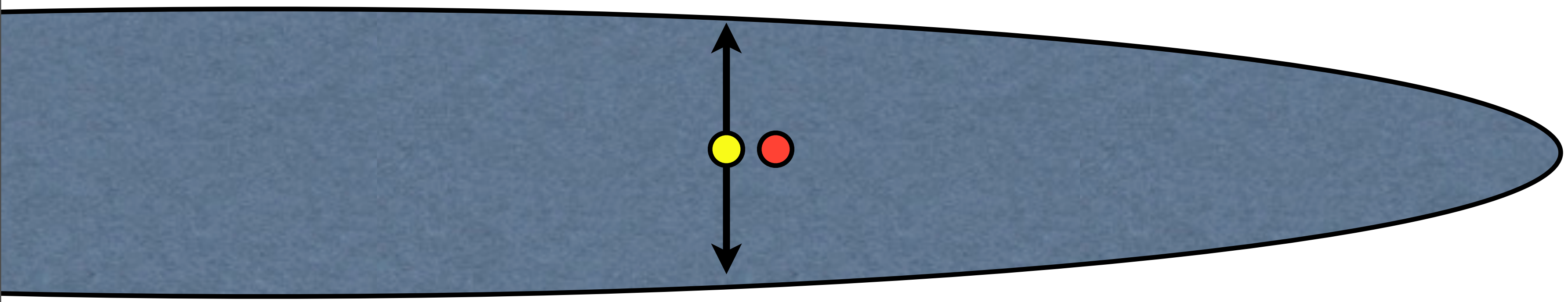
1. Local measure:



$\rho_{\rm dm}$

Background | How can we measure the local DM density?

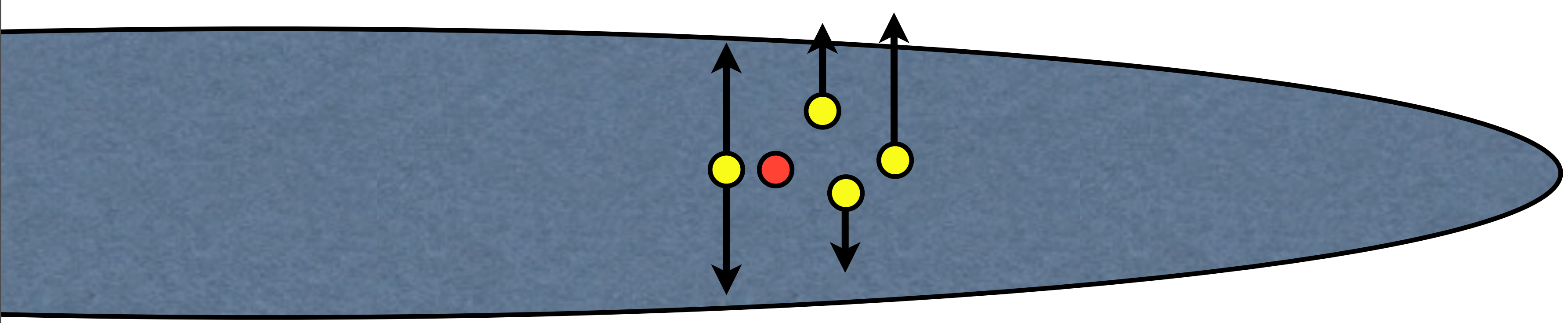
1. Local measure:



ρ_{dm}

Background | How can we measure the local DM density?

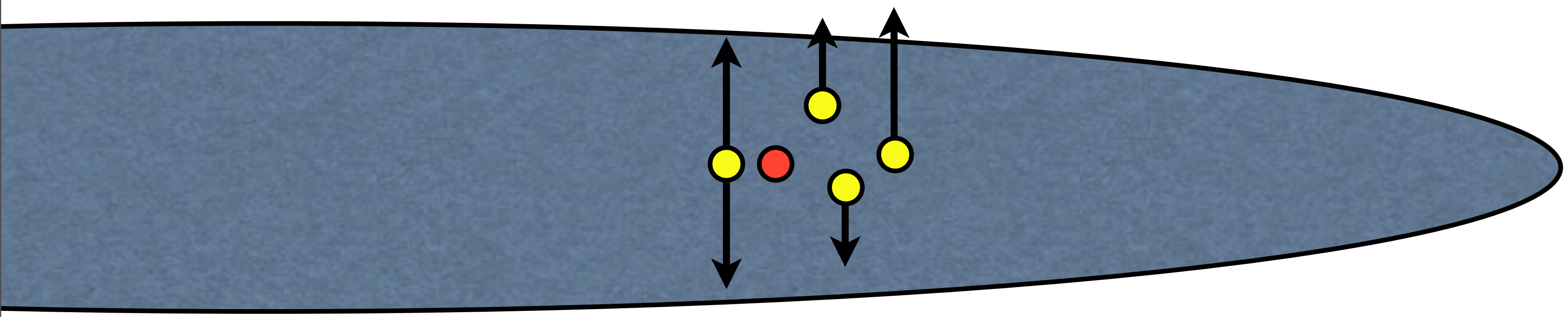
1. Local measure:



$\rho_{\rm dm}$

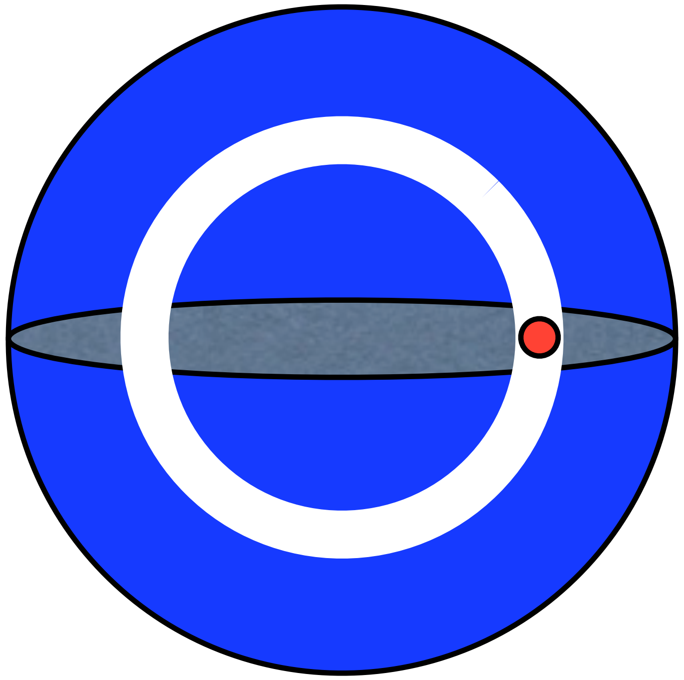
Background | How can we measure the local DM density?

1. Local measure:



$$\rho_{\rm dm}$$

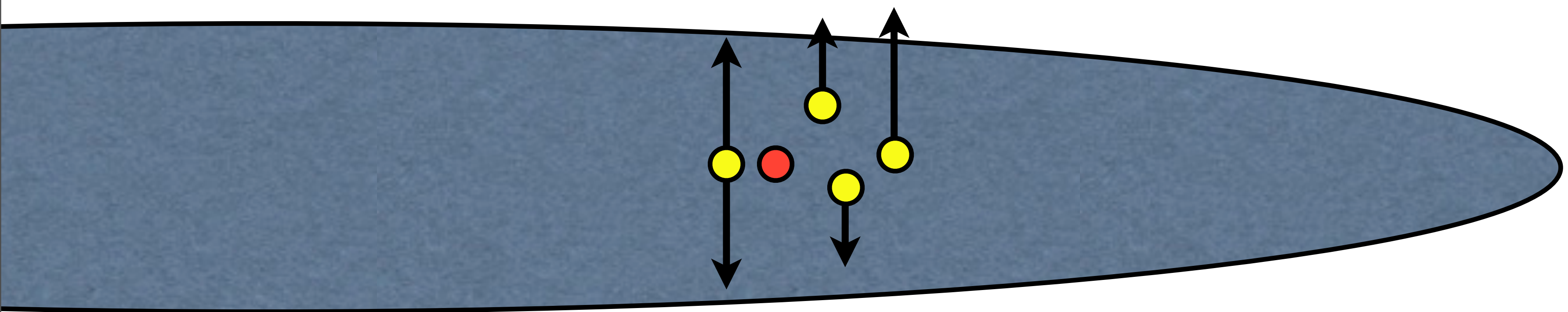
2. Global measure:



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

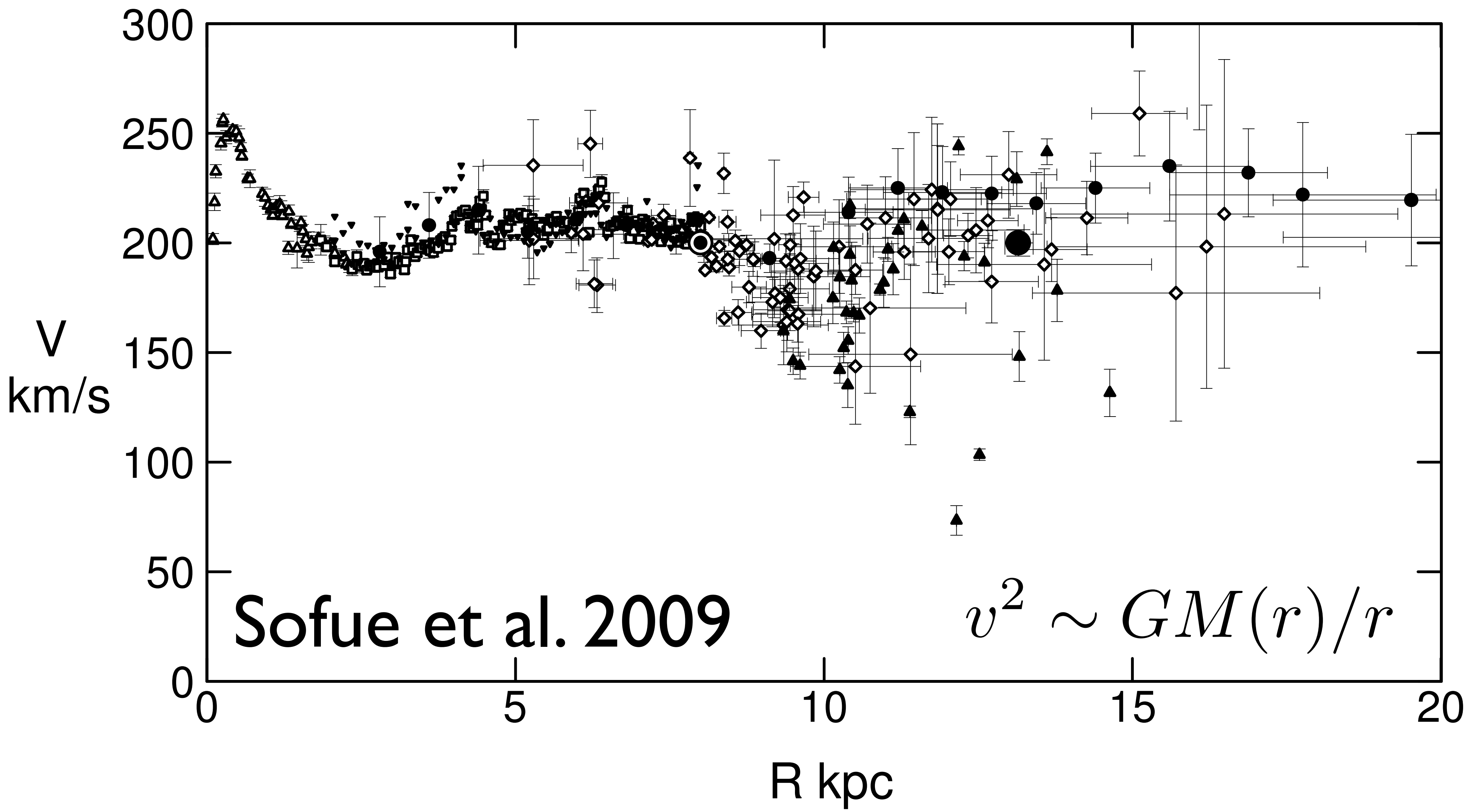
Background | How can we measure the local DM density?

1. Local measure:



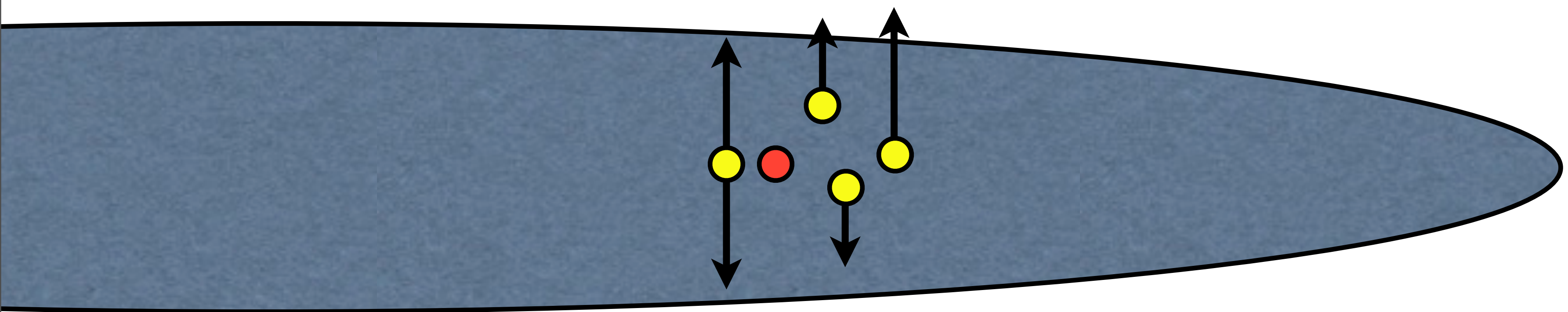
$\rho_{\rm dm}$

2. Glc



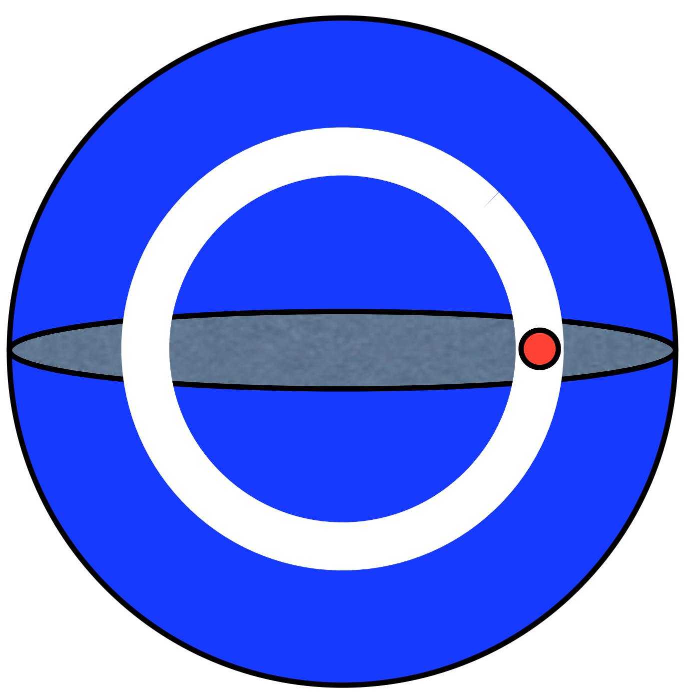
Background | How can we measure the local DM density?

1. Local measure:



$\rho_{\rm dm}$

2. Global measure:

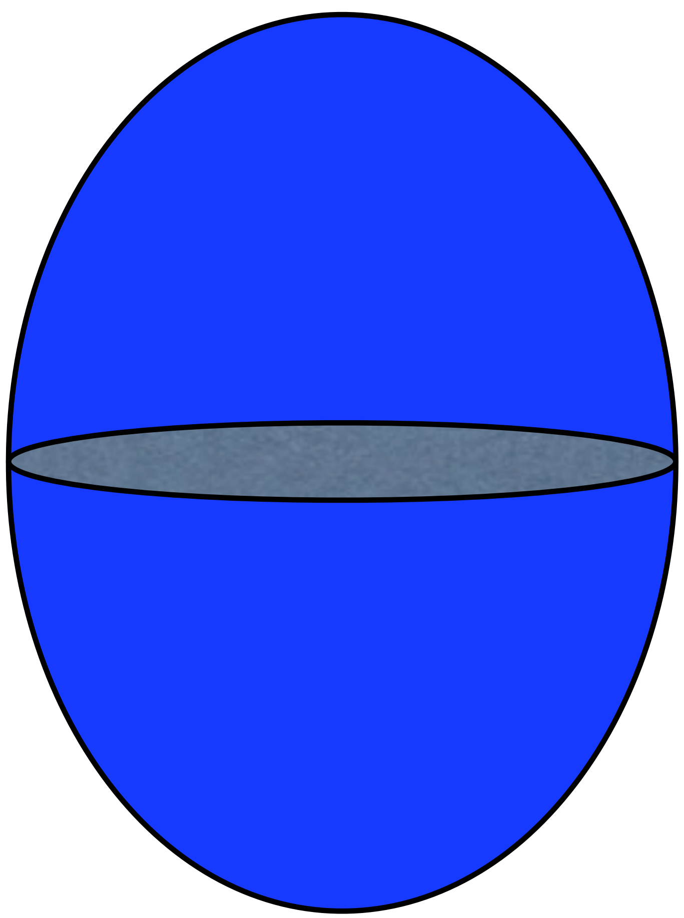


$\rho_{\rm dm,ext}$

Background | Why measure the local dark matter density?

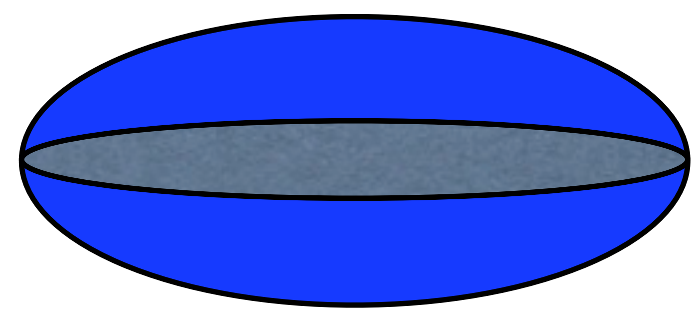
1. Halo shape ...

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



Prolate

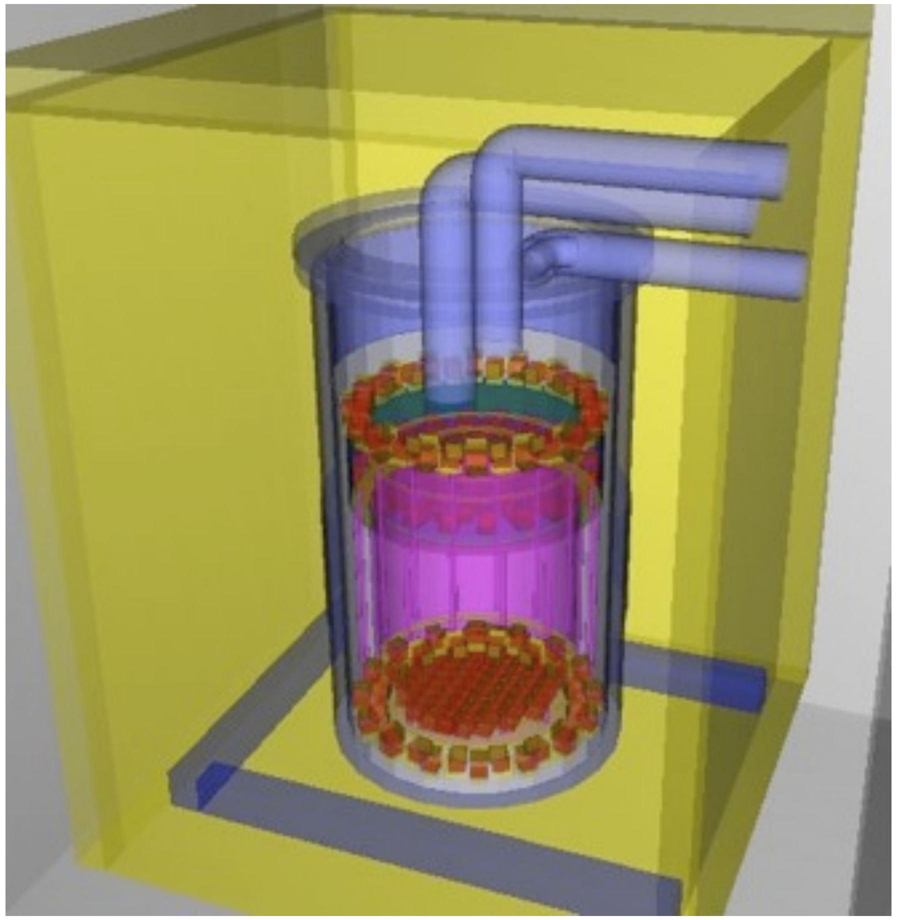
$$\rho_{\rm dm} > \rho_{\rm dm,ext}$$



Oblate/dark disc

Background | Why measure the local dark matter density?

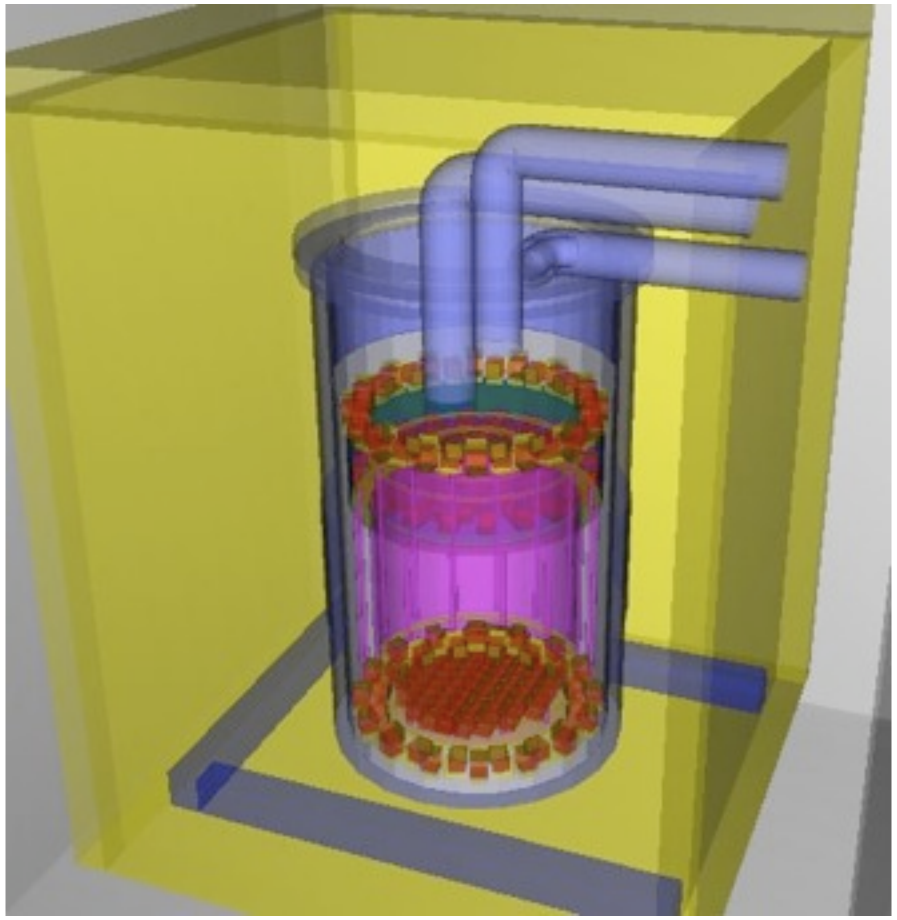
2. Detecting dark matter



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

Background | Why measure the local dark matter density?

2. Detecting dark matter

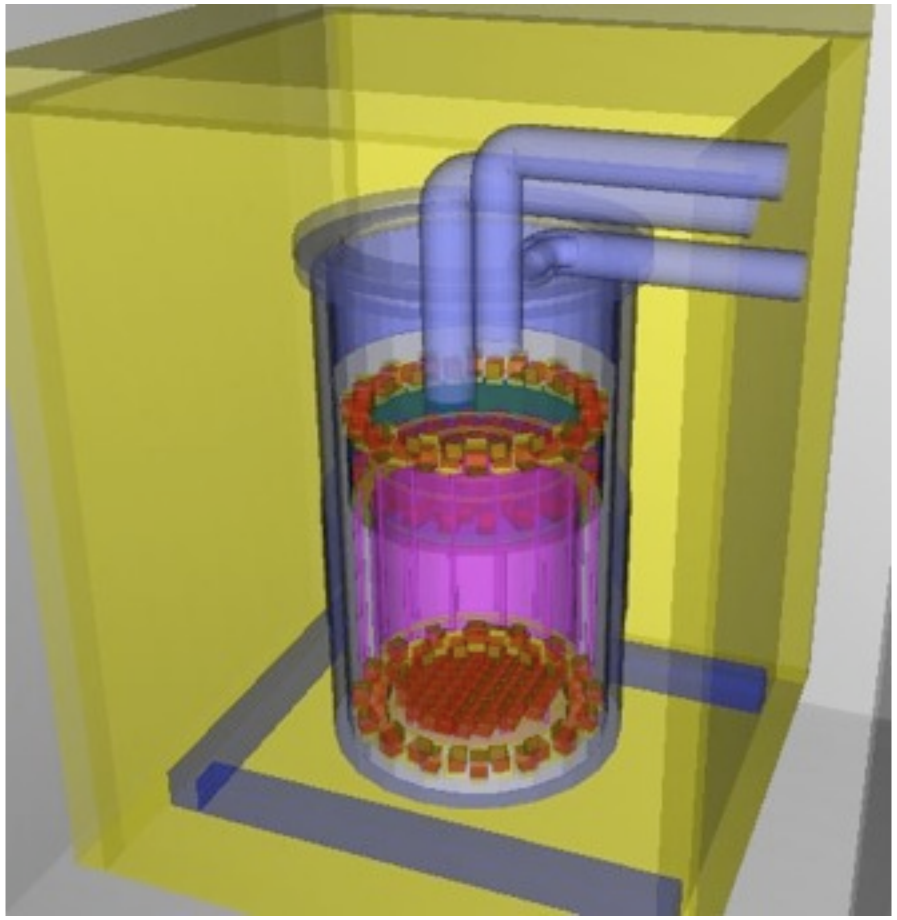


- Big tub of inert material
- Deep underground
- Wait for rare event
- Need to know very local phase space distribution

$$\frac{dR}{dE} = \frac{\rho\sigma_{\rm wn}|F(E)|^2}{2m\mu^2}\int_{v>\sqrt{ME/2\mu^2}}^{v_{max}} \frac{f(\mathbf{v},t)}{v} d^3v$$

Background | Why measure the local dark matter density?

2. Detecting dark matter



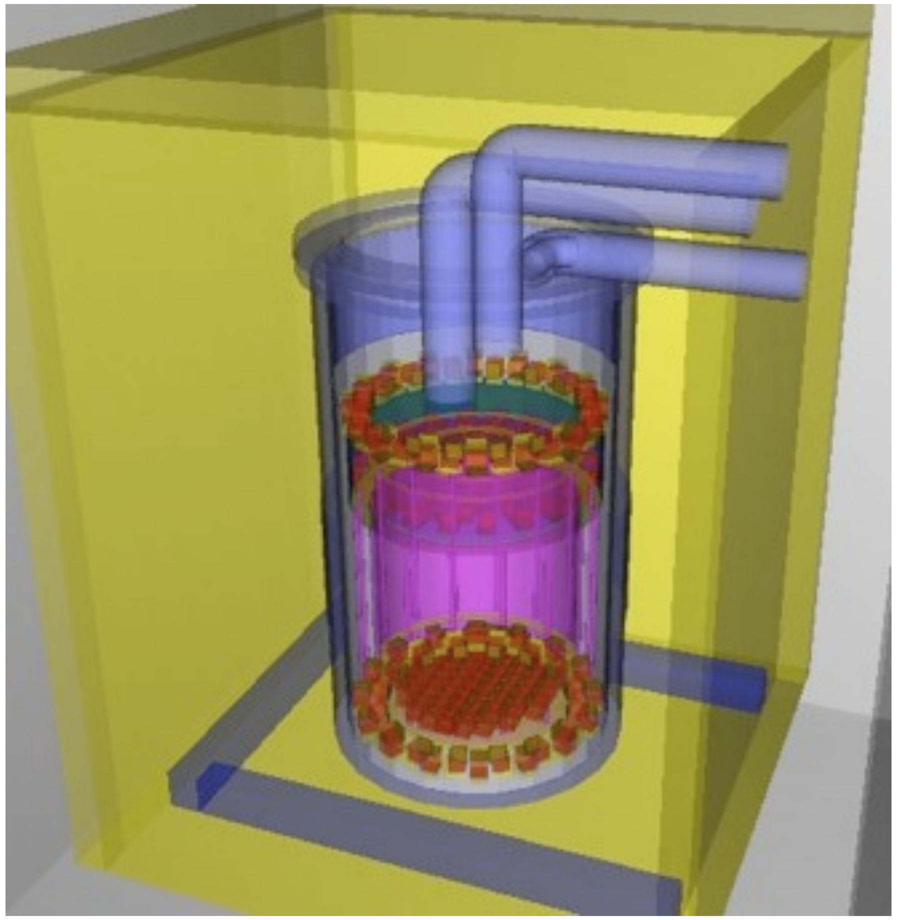
- Big tub of inert material
- Deep underground
- Wait for rare event
- Need to know very local phase space distribution

$$\frac{dR}{dE} = \frac{\rho\sigma_{\rm wn}|F(E)|^2}{2m\mu^2}\int_{v>\sqrt{ME/2\mu^2}}^{v_{max}} \frac{f(\mathbf{v},t)}{v} d^3v$$

Particle physics

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

$$\frac{dR}{dE} = \frac{\rho\sigma_{\rm wn}|F(E)|^2}{2m\mu^2}\int_{v>\sqrt{ME/2\mu^2}}^{v_{max}} \frac{f(\mathbf{v},t)}{v} d^3v$$

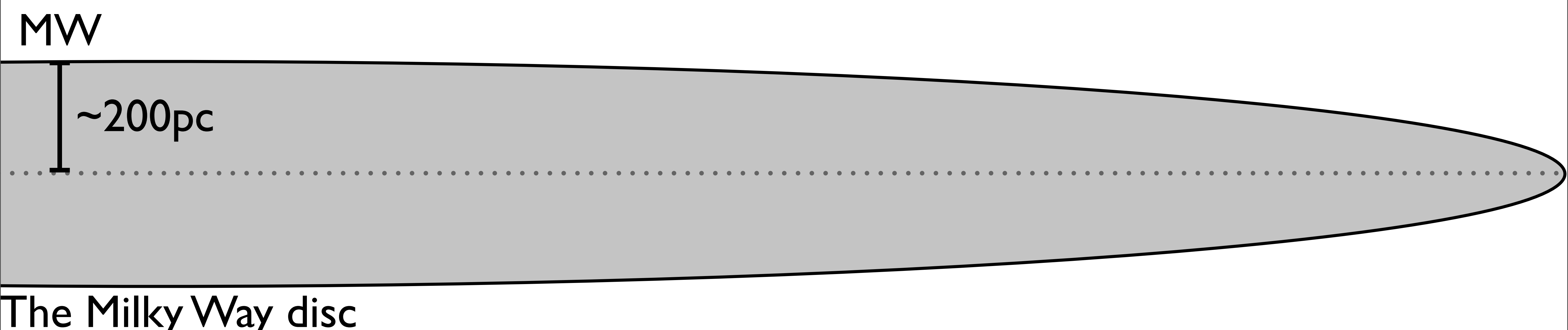
Particle physics | Astrophysics

Background | The need for simulations

1. $\rho_{\rm lab} \neq \rho_{\rm dm}(< 1\,{\rm kpc})$

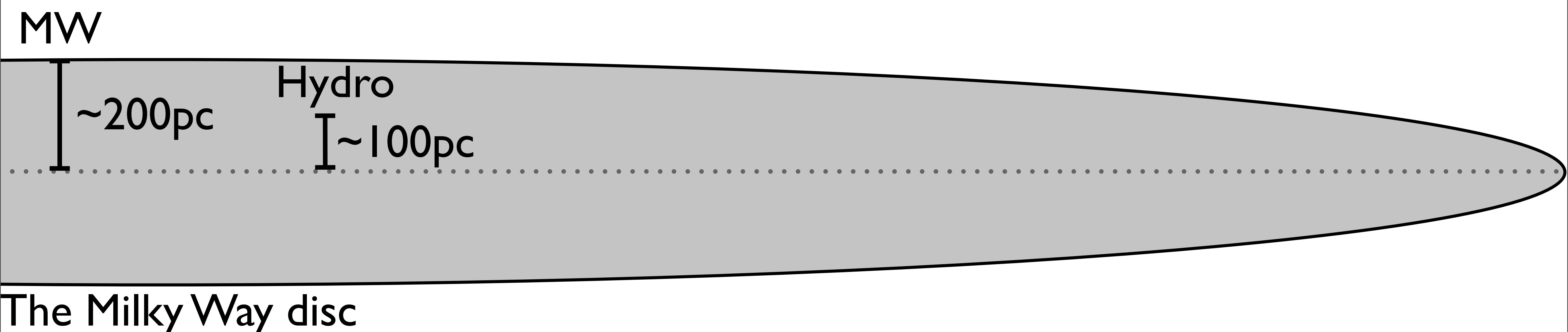
Background | The need for simulations

1. $\rho_{\rm lab} \neq \rho_{\rm dm}(< 1\,{\rm kpc})$



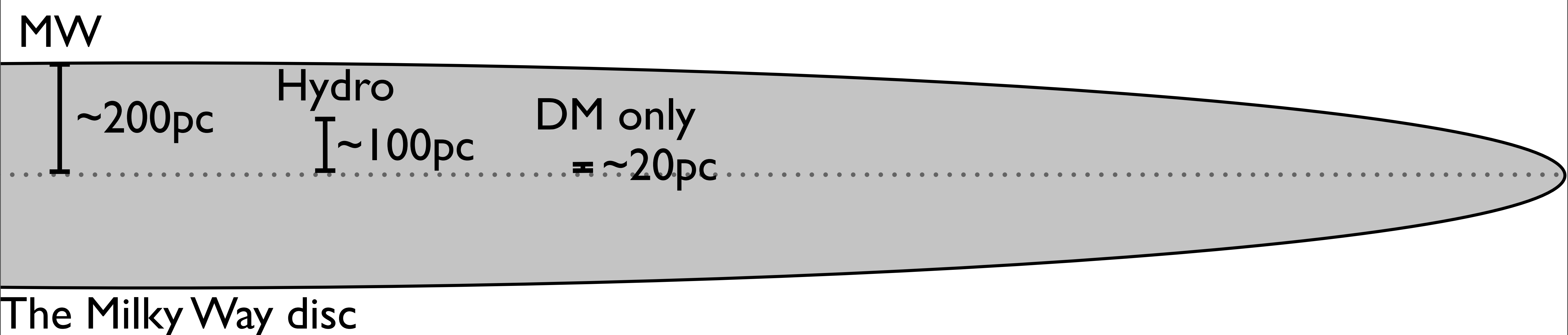
Background | The need for simulations

1. $\rho_{\rm lab} \neq \rho_{\rm dm}(< 1\,{\rm kpc})$



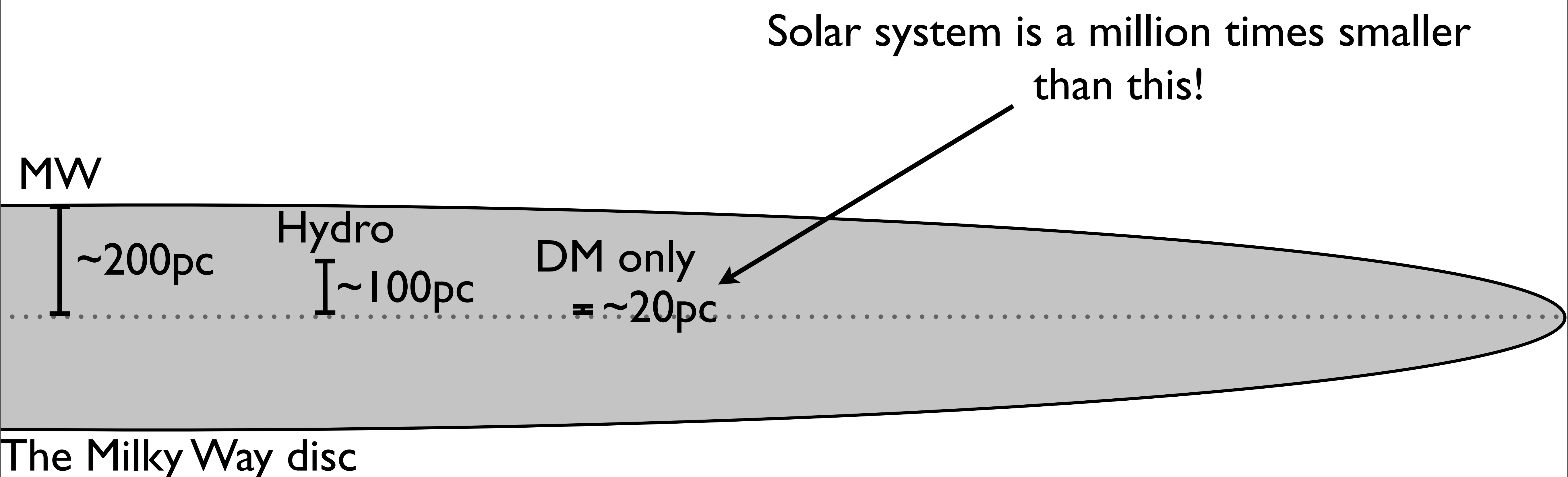
Background | The need for simulations

1. $\rho_{\rm lab} \neq \rho_{\rm dm}(< 1\,{\rm kpc})$



Background | The need for simulations

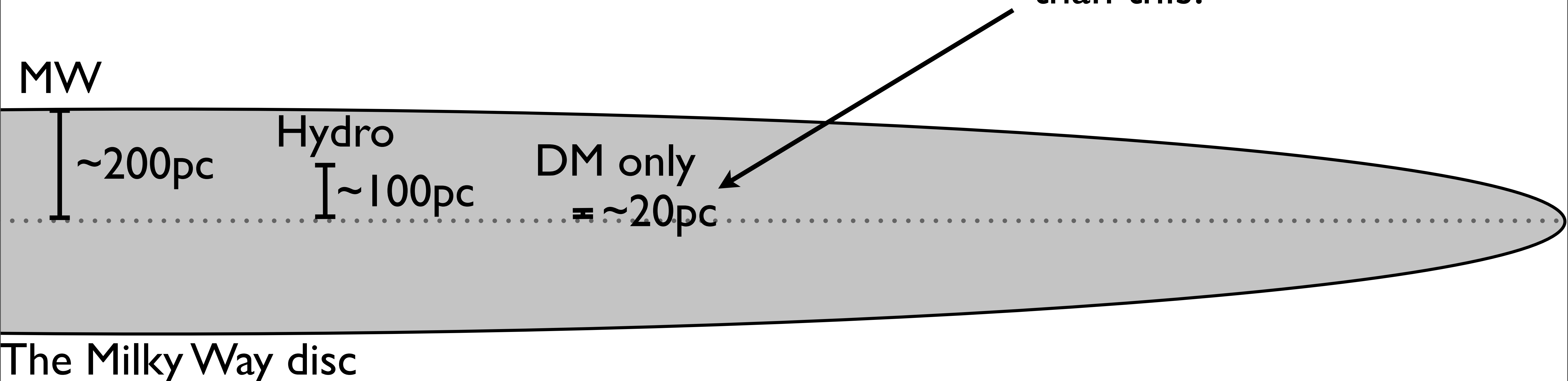
$$1.\ \rho_{\rm lab} \neq \rho_{\rm dm}(< 1\,{\rm kpc})$$



Background | The need for simulations

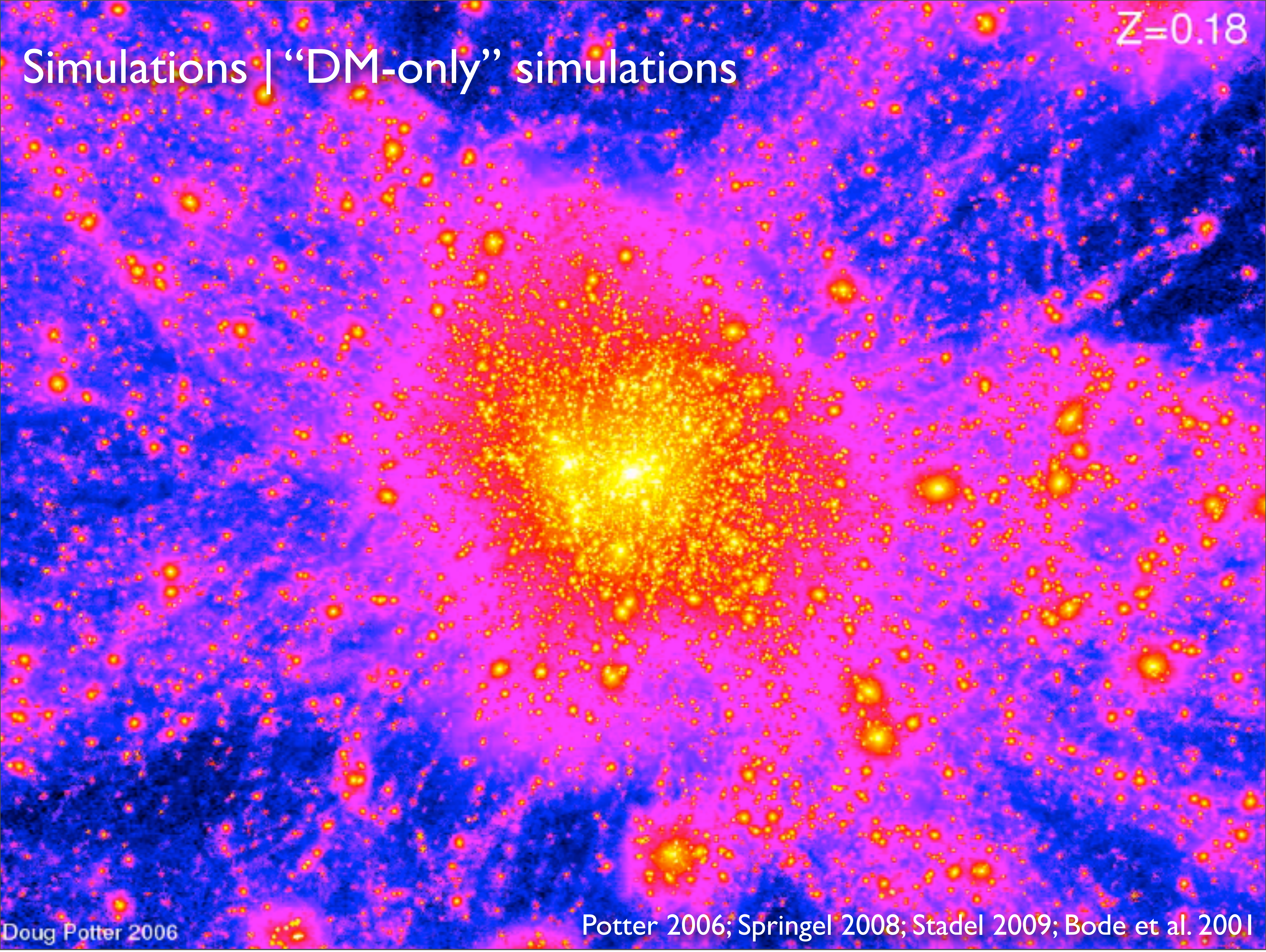
1. $\rho_{\mathrm{lab}} \neq \rho_{\mathrm{dm}}(< 1\,\mathrm{kpc})$

Solar system is a million times smaller than this!



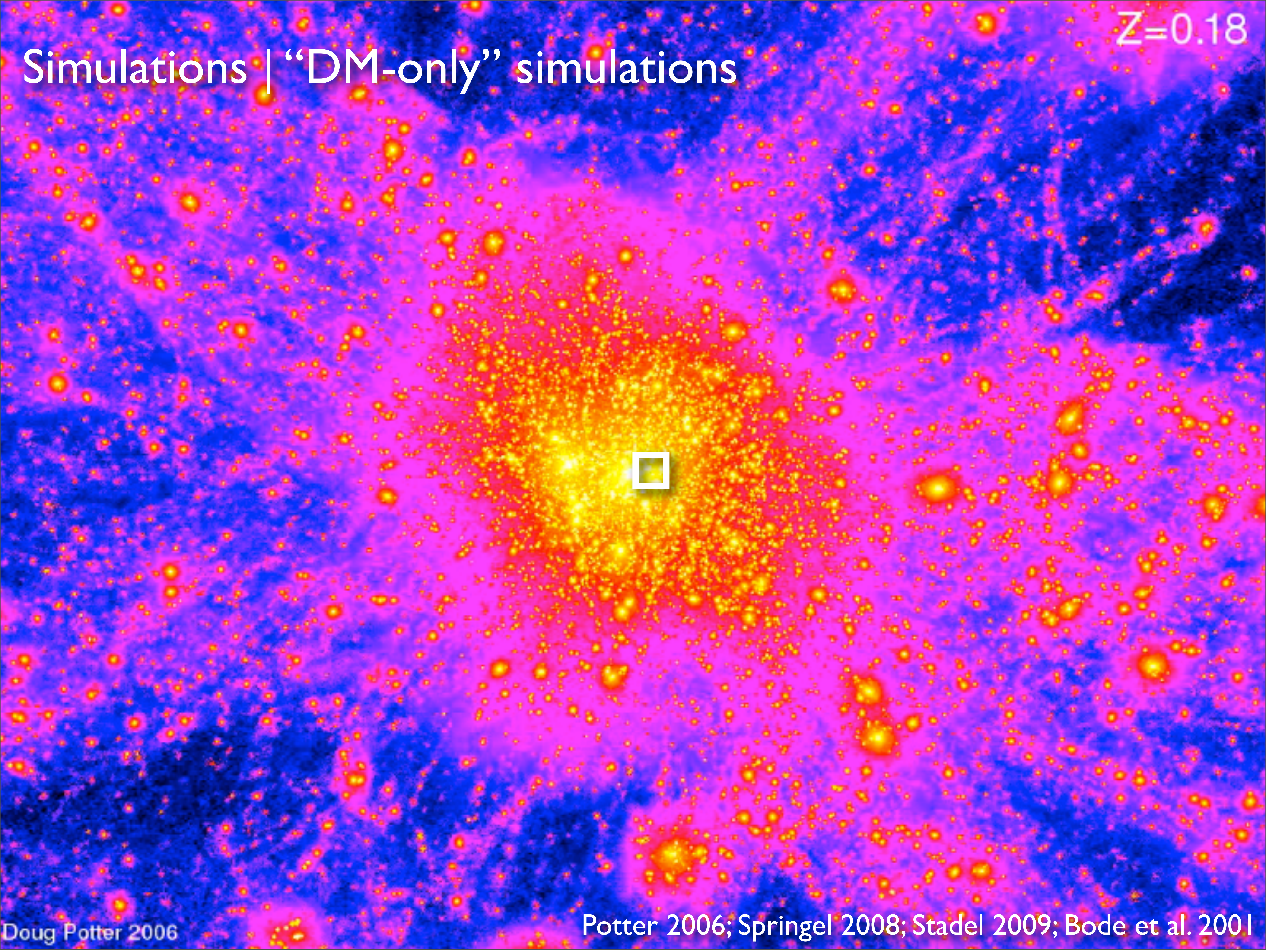
2. Need $f(\mathbf{v}, t)$

Simulations | “DM-only” simulations



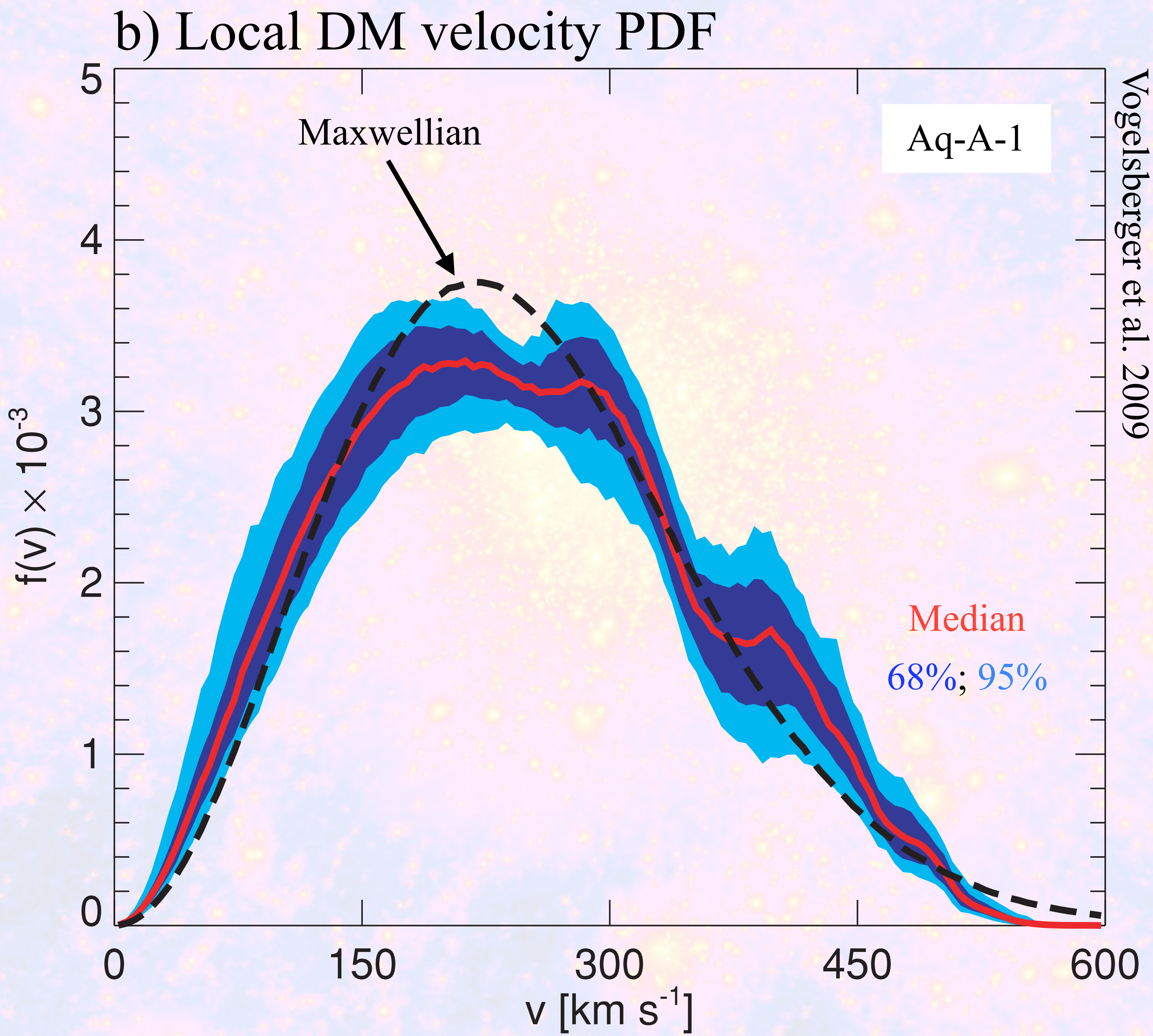
Potter 2006; Springel 2008; Stadel 2009; Bode et al. 2001

Simulations | "DM-only" simulations



Potter 2006; Springel 2008; Stadel 2009; Bode et al. 2001

Simulations | "DM-only" simulations



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]

- Unresolved streams | not likely important
  [Vogelsberger et al. 2011; Fantin et al. 2011]

- Solar system | not likely important
  [Peter 2009]

Simulations | “DM-only” simulations | Fine structure

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

- Unresolved streams | not likely important
  [Vogelsberger et al. 2011; Fantin et al. 2011]

- Solar system | not likely important
  [Peter 2009]

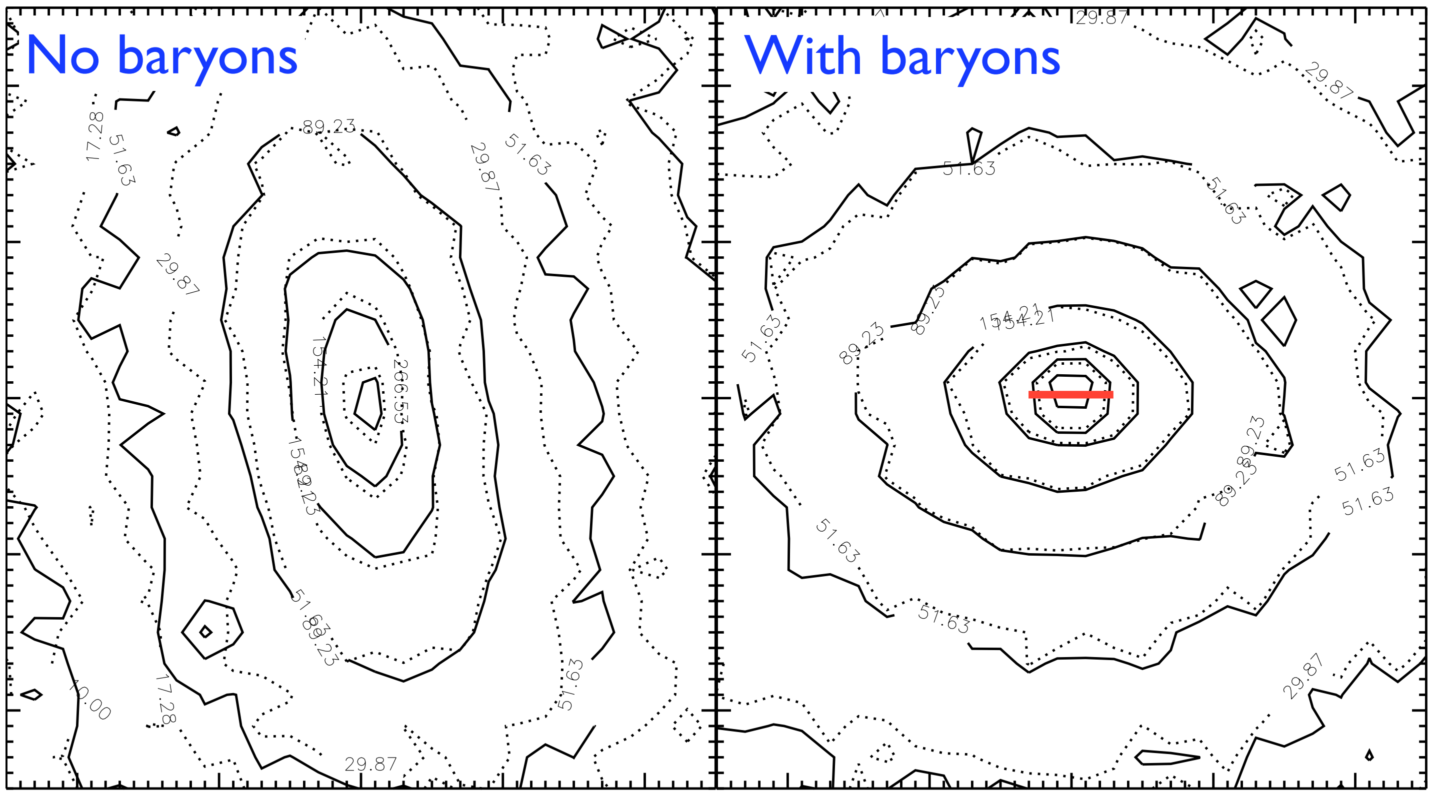
$$\rho_{\rm dm} \Rightarrow \rho_{\rm lab}$$

~600 light years ~metres

Simulations | The importance of baryons

Simulations | The importance of baryons

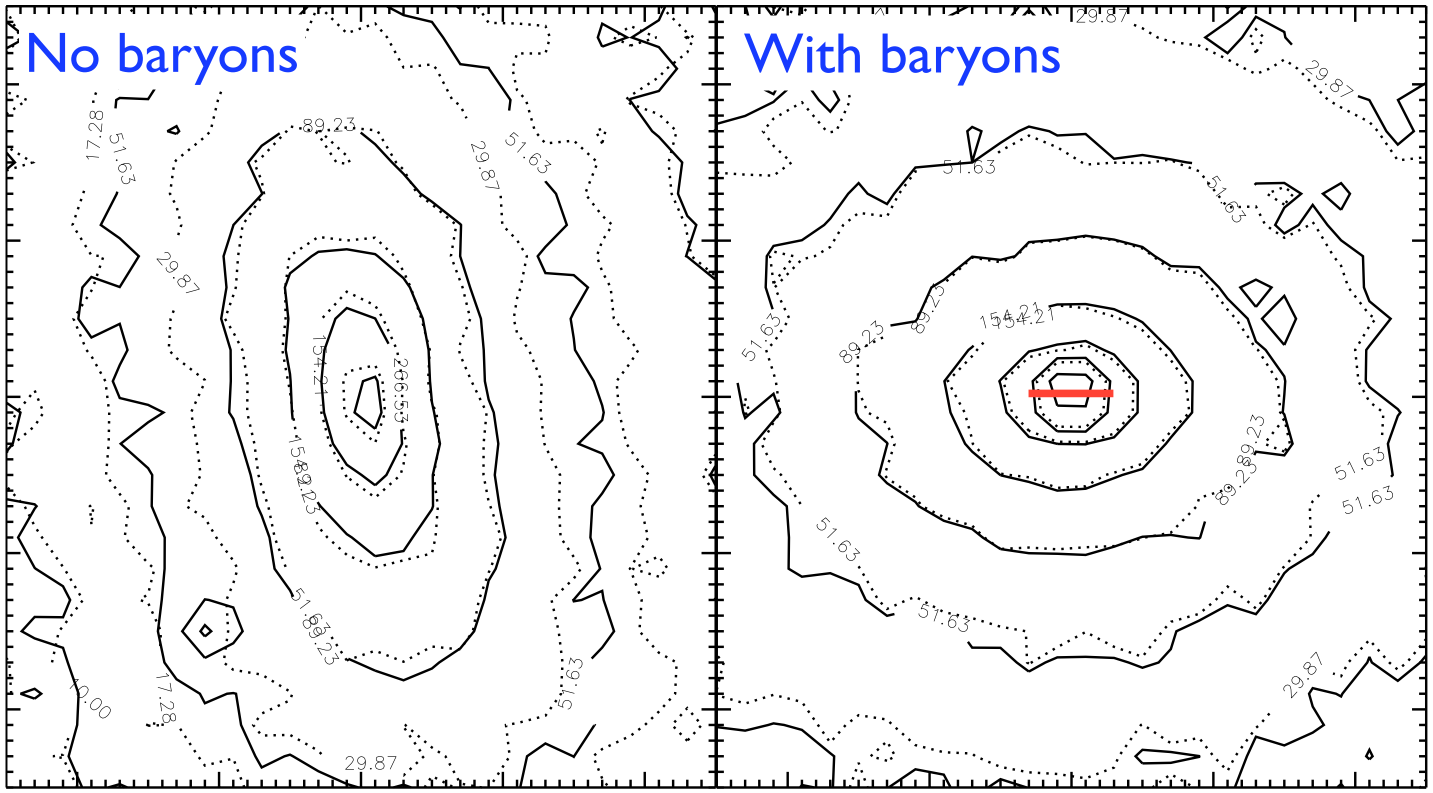
Shape change



Katz & Gunn 1991; Dubinski 1994; Debattista et al. 2008; Read et al. 2009

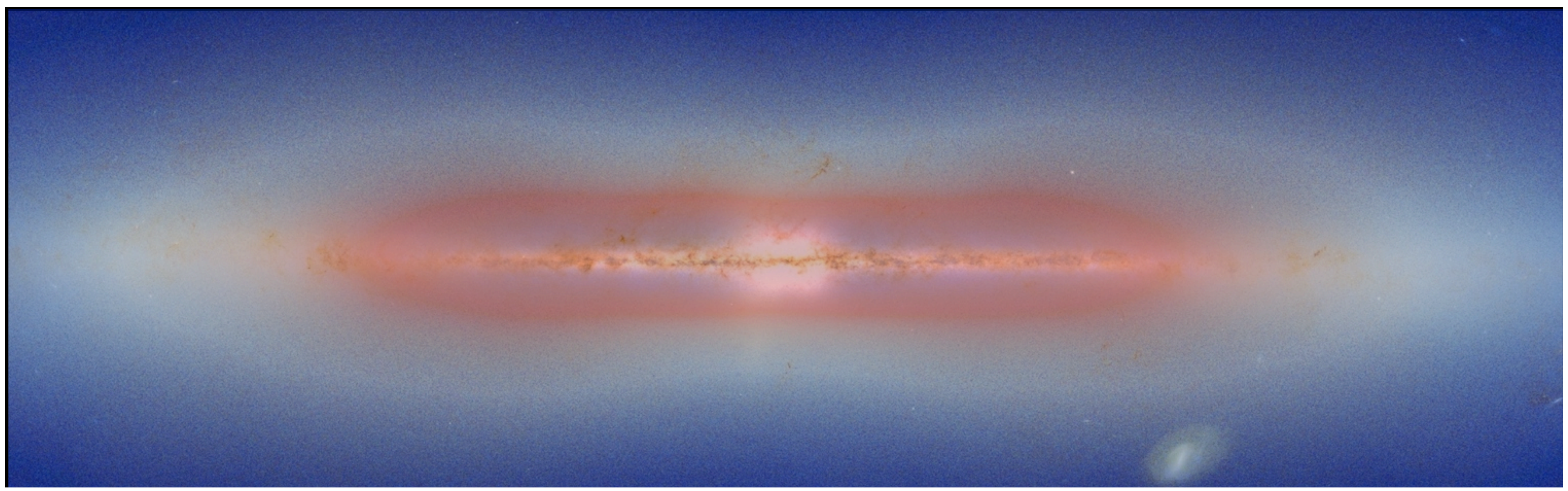
Simulations | The importance of baryons

Shape change



Katz & Gunn 1991; Dubinski 1994; Debattista et al. 2008; Read et al. 2009

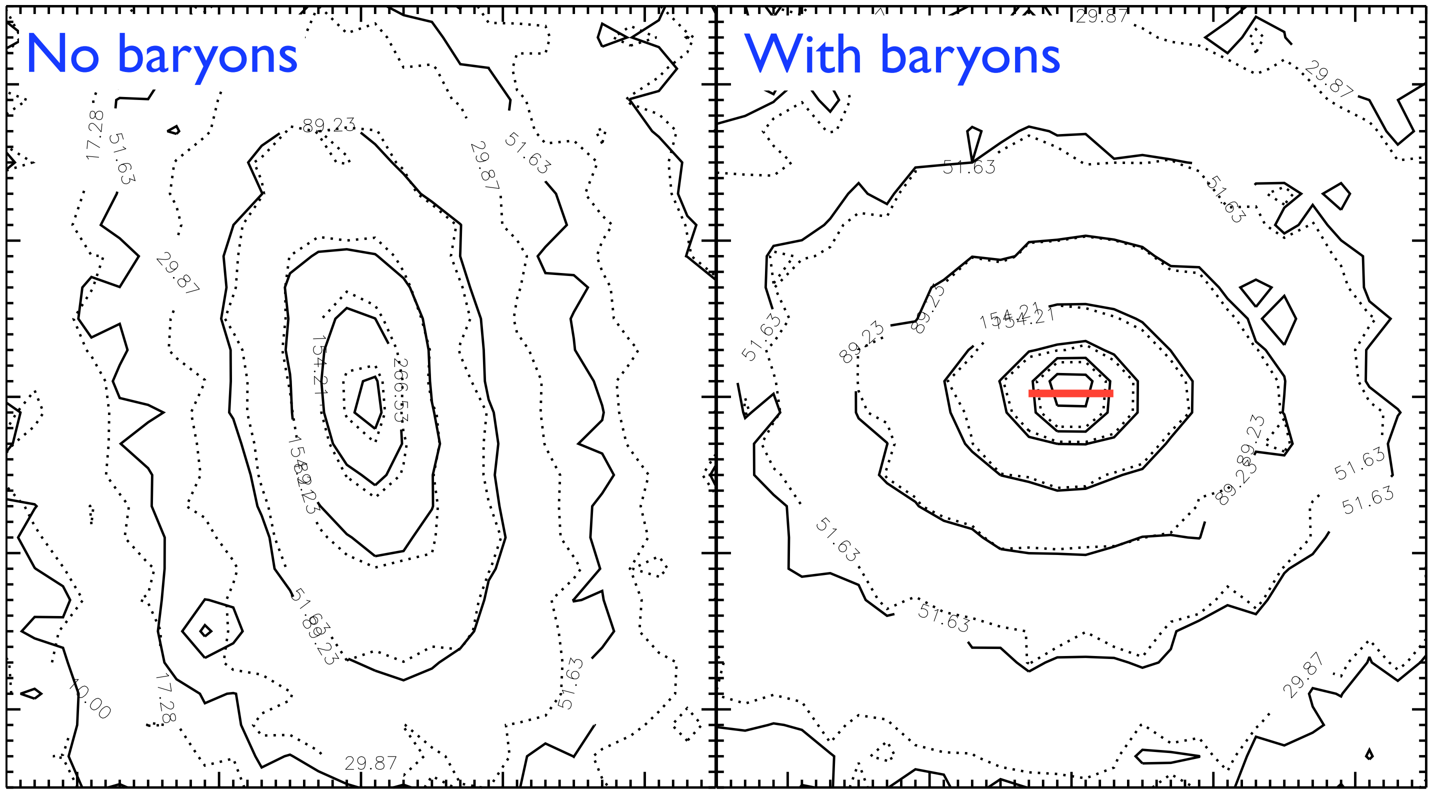
Dark discs



Lake 1989; Read et al. 2008/9

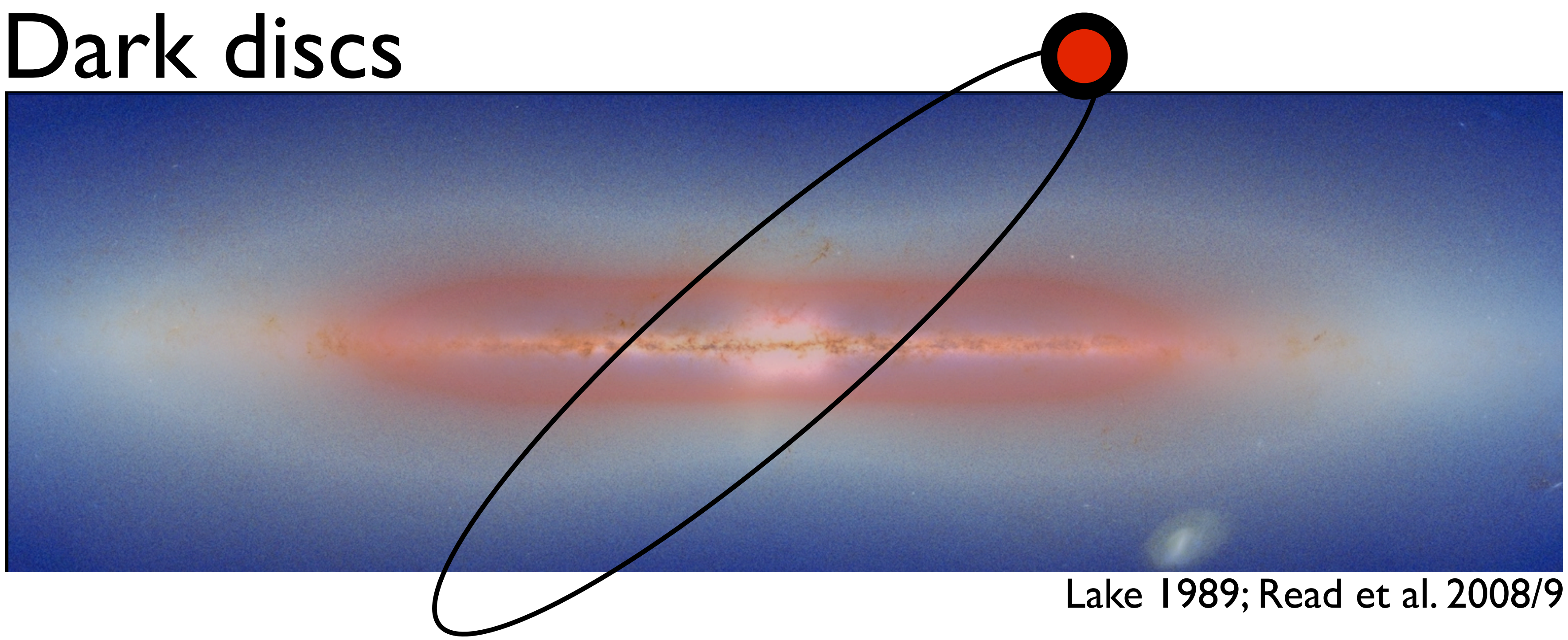
Simulations | The importance of baryons

Shape change



Katz & Gunn 1991; Dubinski 1994; Debattista et al. 2008; Read et al. 2009

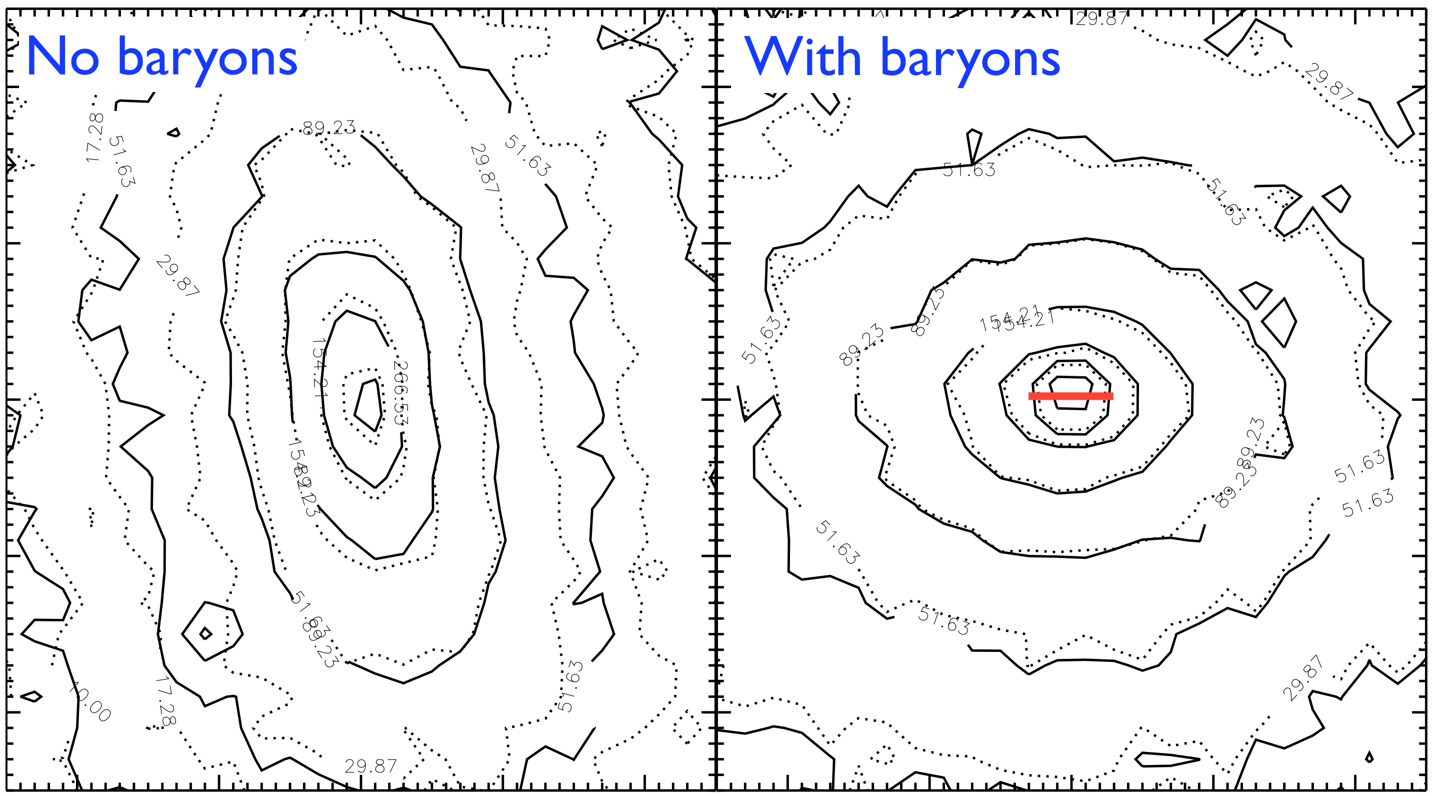
Dark discs



Lake 1989; Read et al. 2008/9

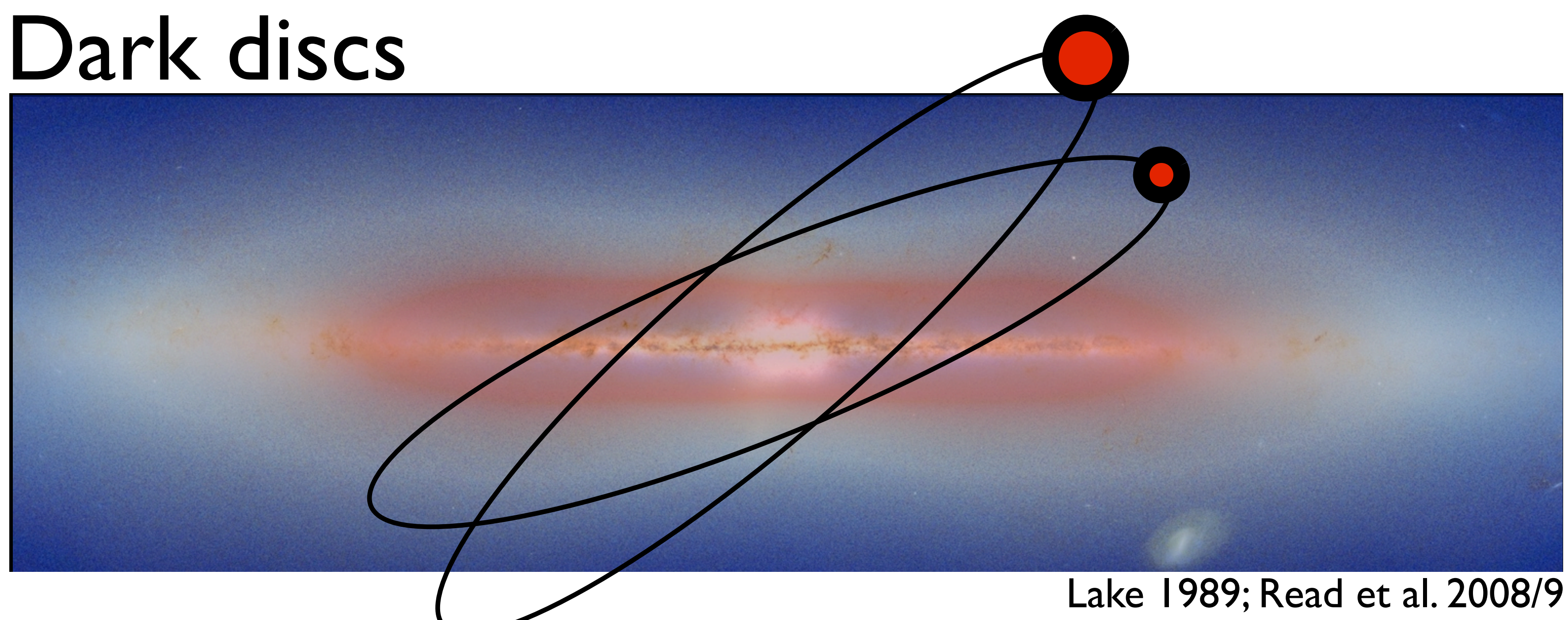
Simulations | The importance of baryons

Shape change



Katz & Gunn 1991; Dubinski 1994; Debattista et al. 2008; Read et al. 2009

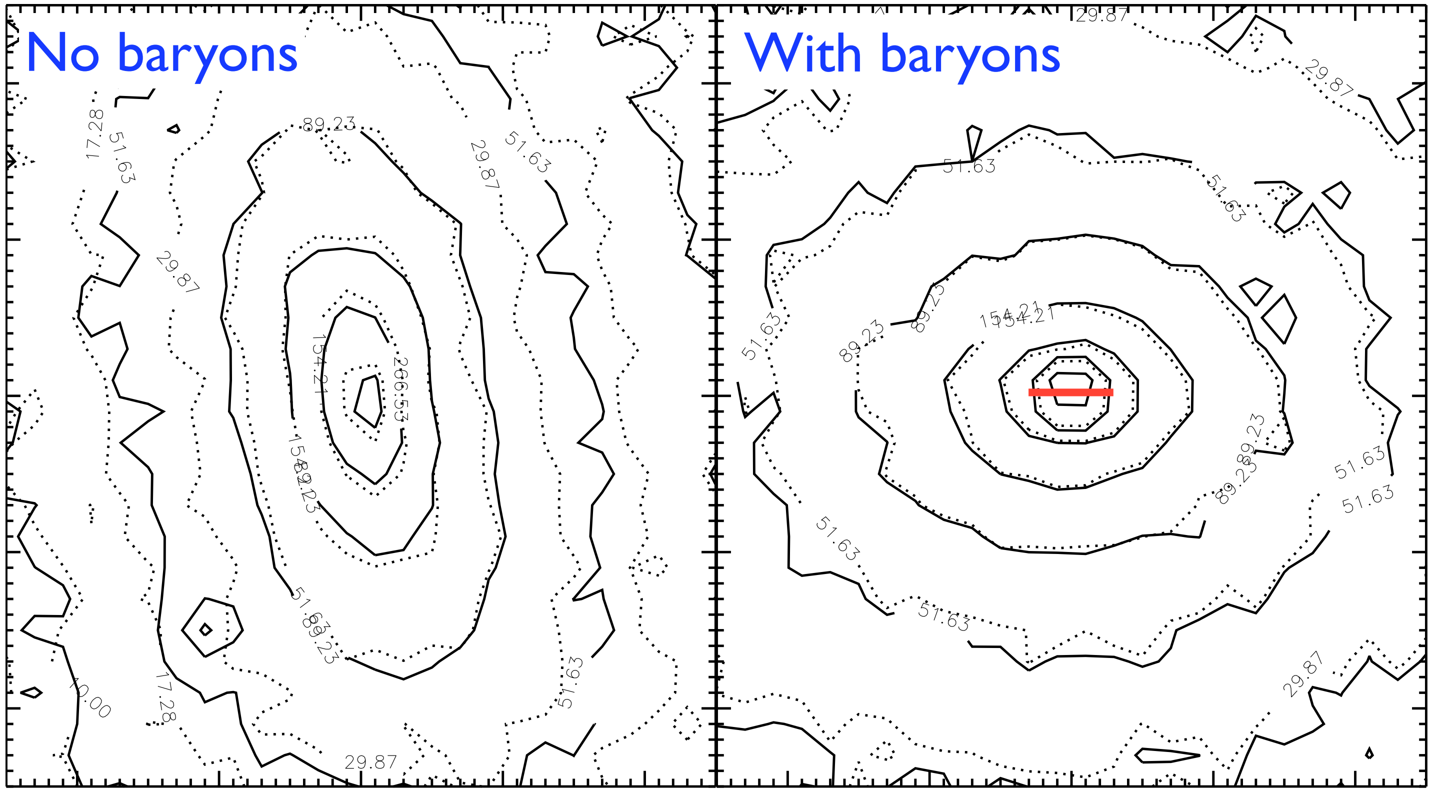
Dark discs



Lake 1989; Read et al. 2008/9

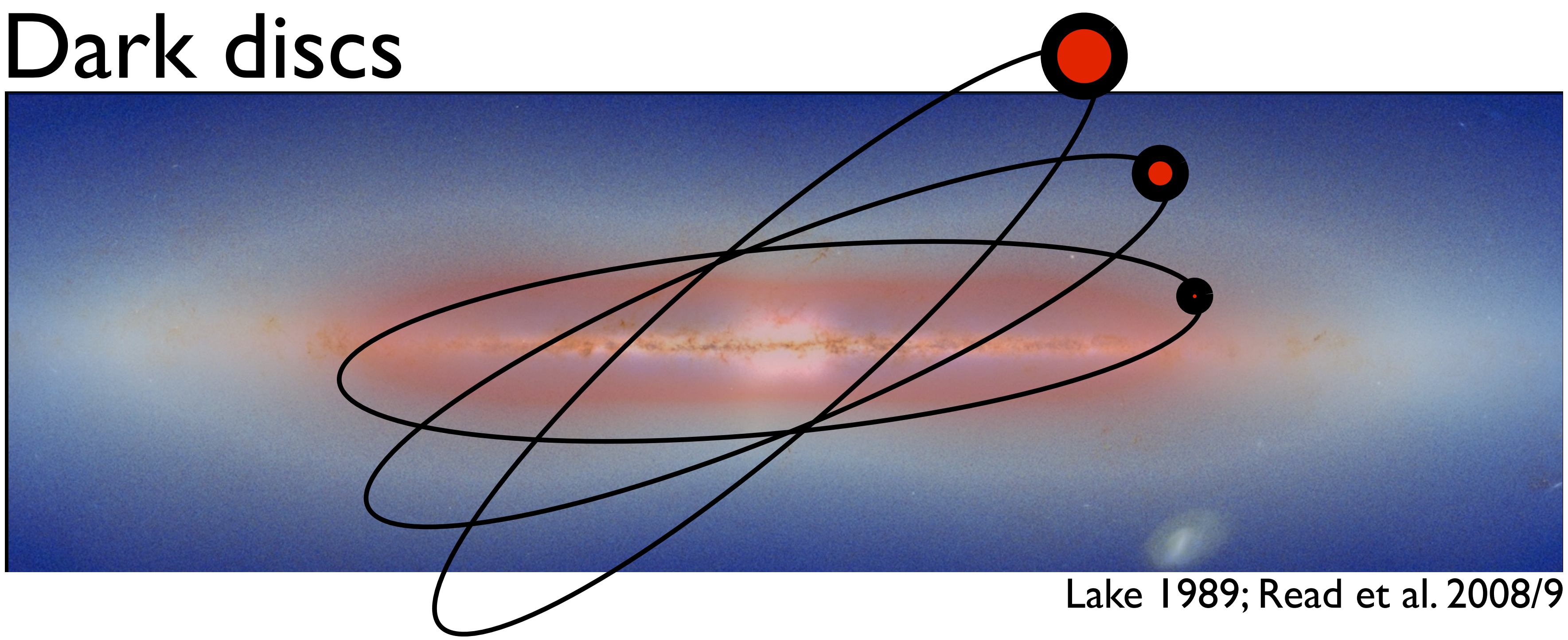
Simulations | The importance of baryons

Shape change



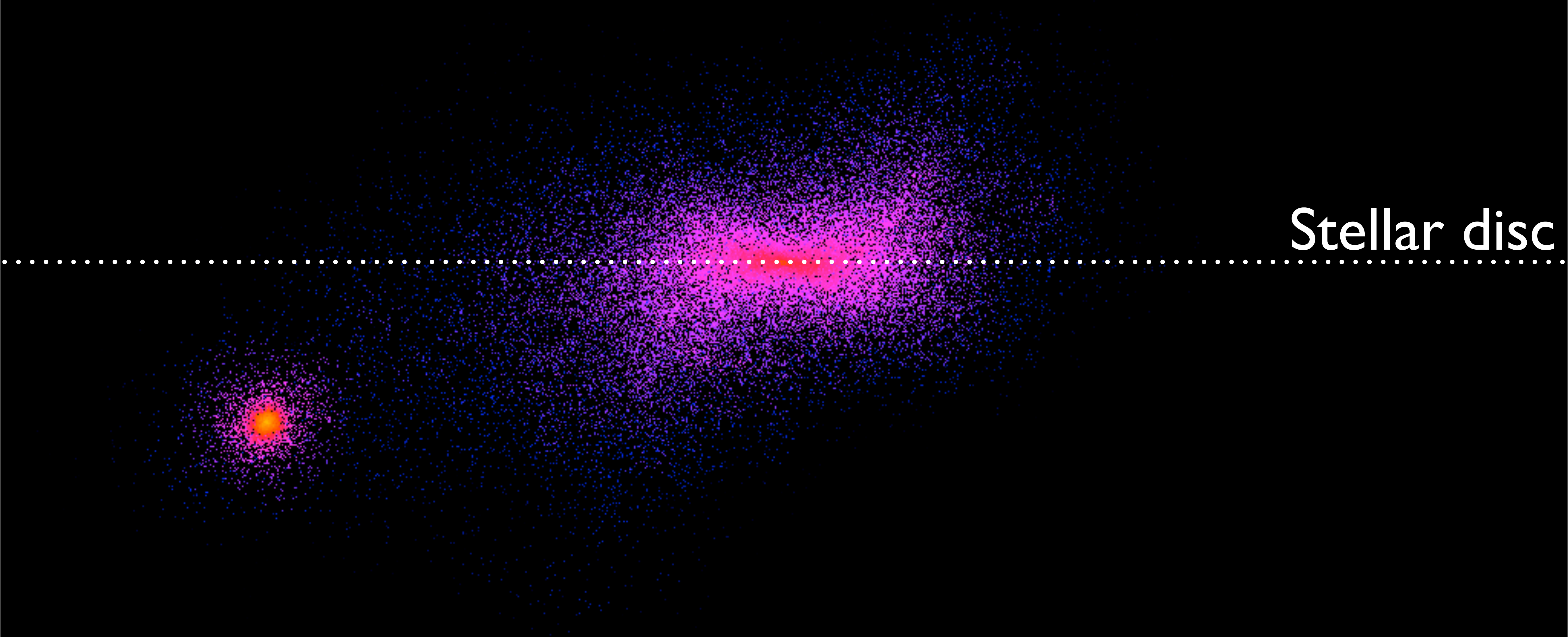
Katz & Gunn 1991; Dubinski 1994; Debattista et al. 2008; Read et al. 2009

Dark discs



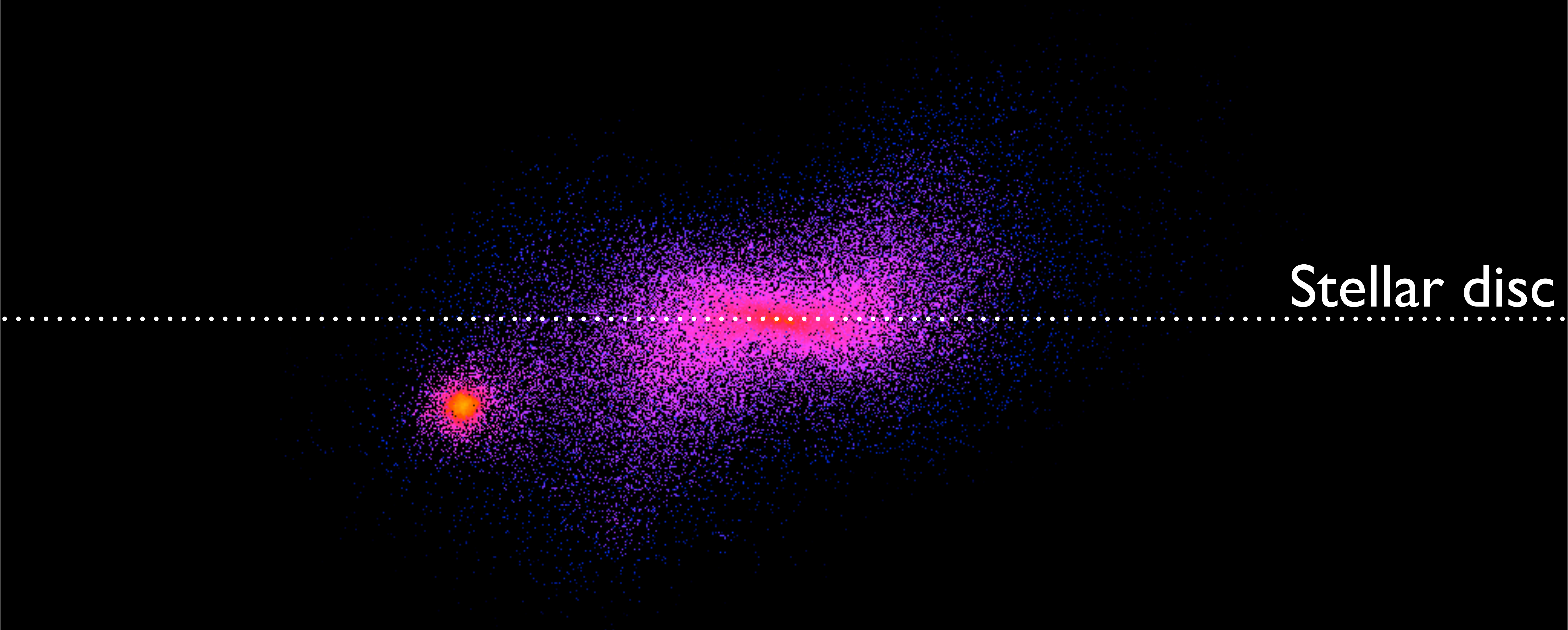
Lake 1989; Read et al. 2008/9

Simulations | Dark discs



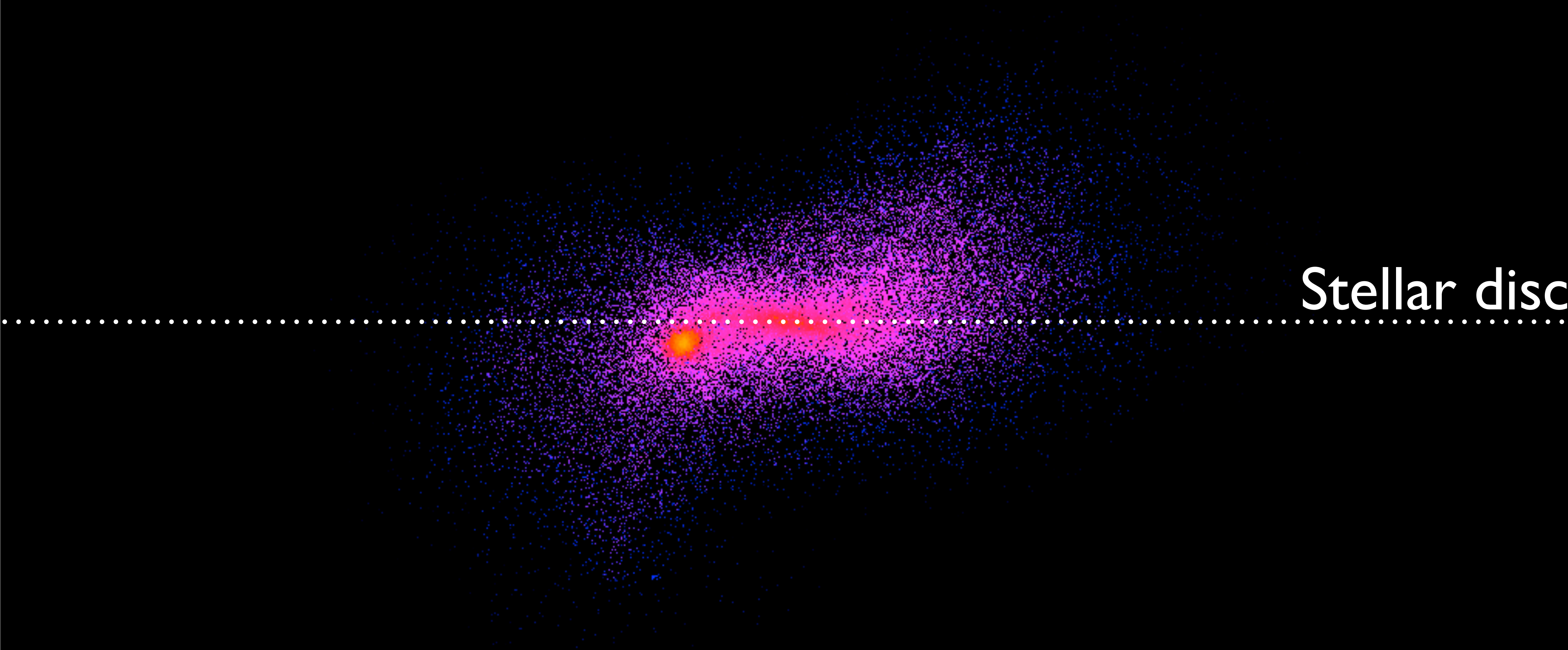
ERIS | Guedes et al. 2011

Simulations | Dark discs



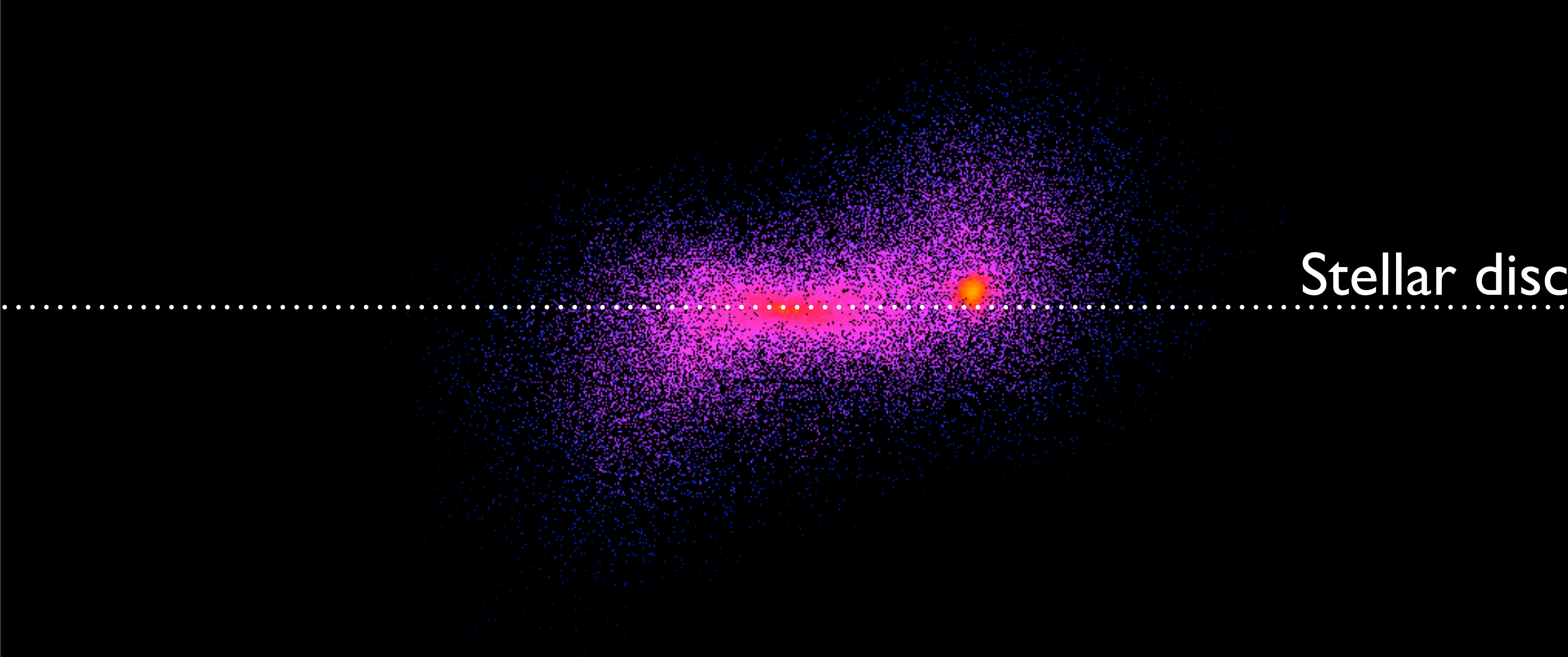
ERIS | Guedes et al. 2011

Simulations | Dark discs



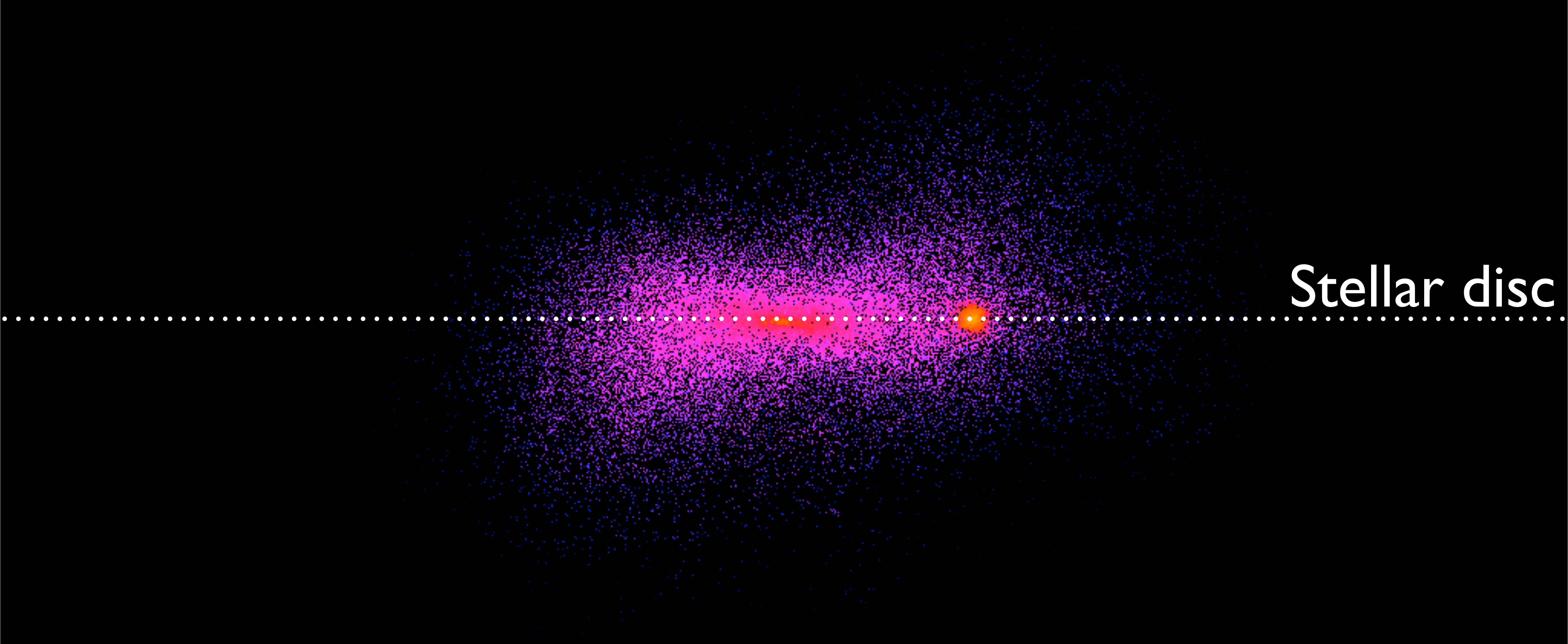
ERIS | Guedes et al. 2011

Simulations | Dark discs



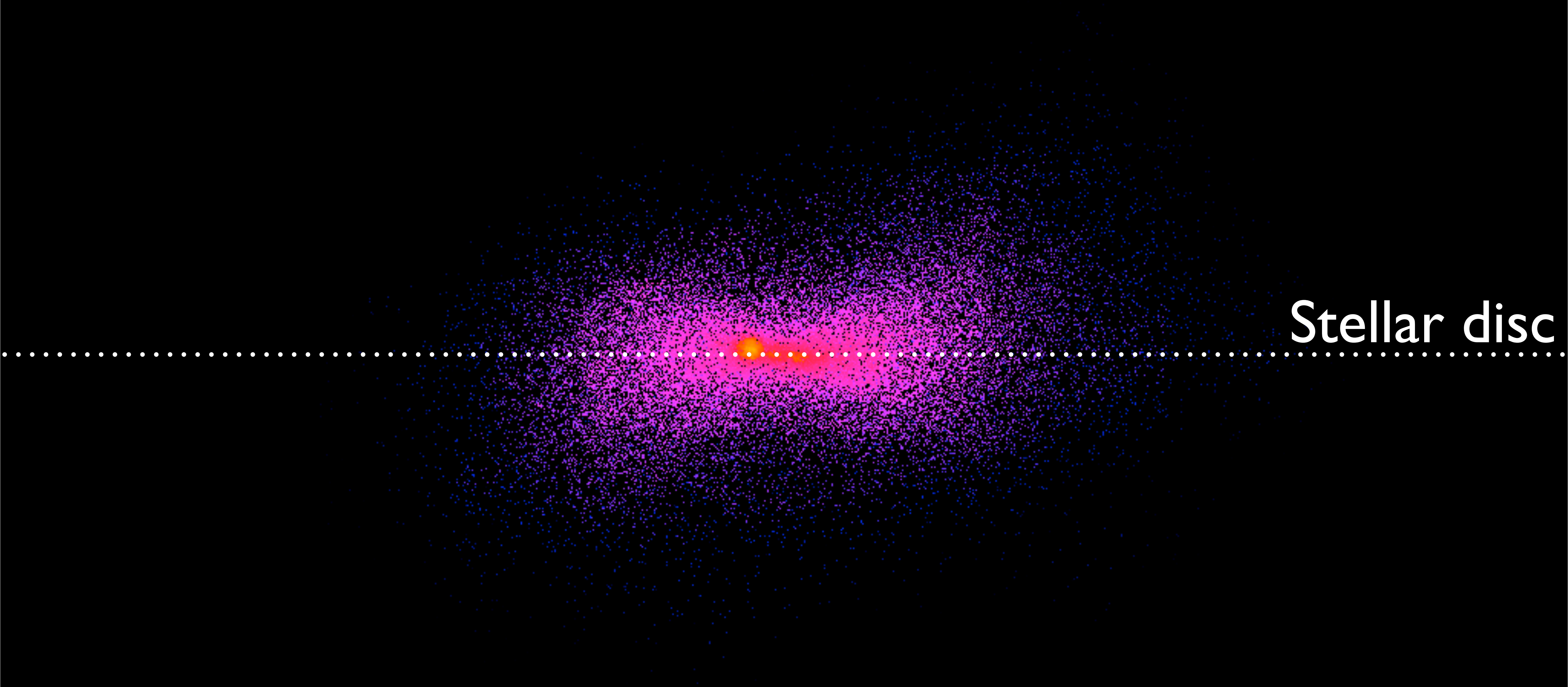
ERIS | Guedes et al. 2011

Simulations | Dark discs



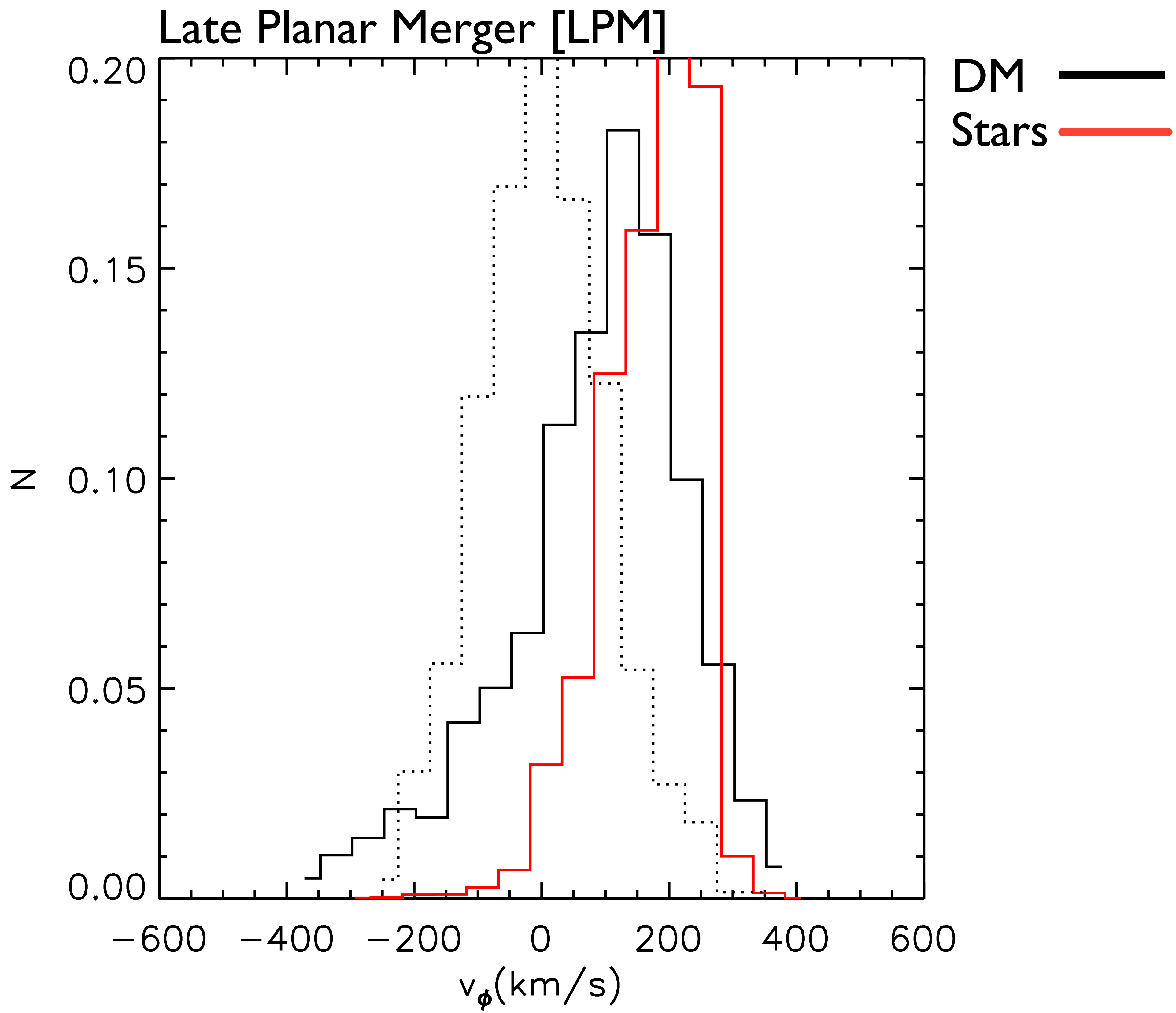
ERIS | Guedes et al. 2011

Simulations | Dark discs



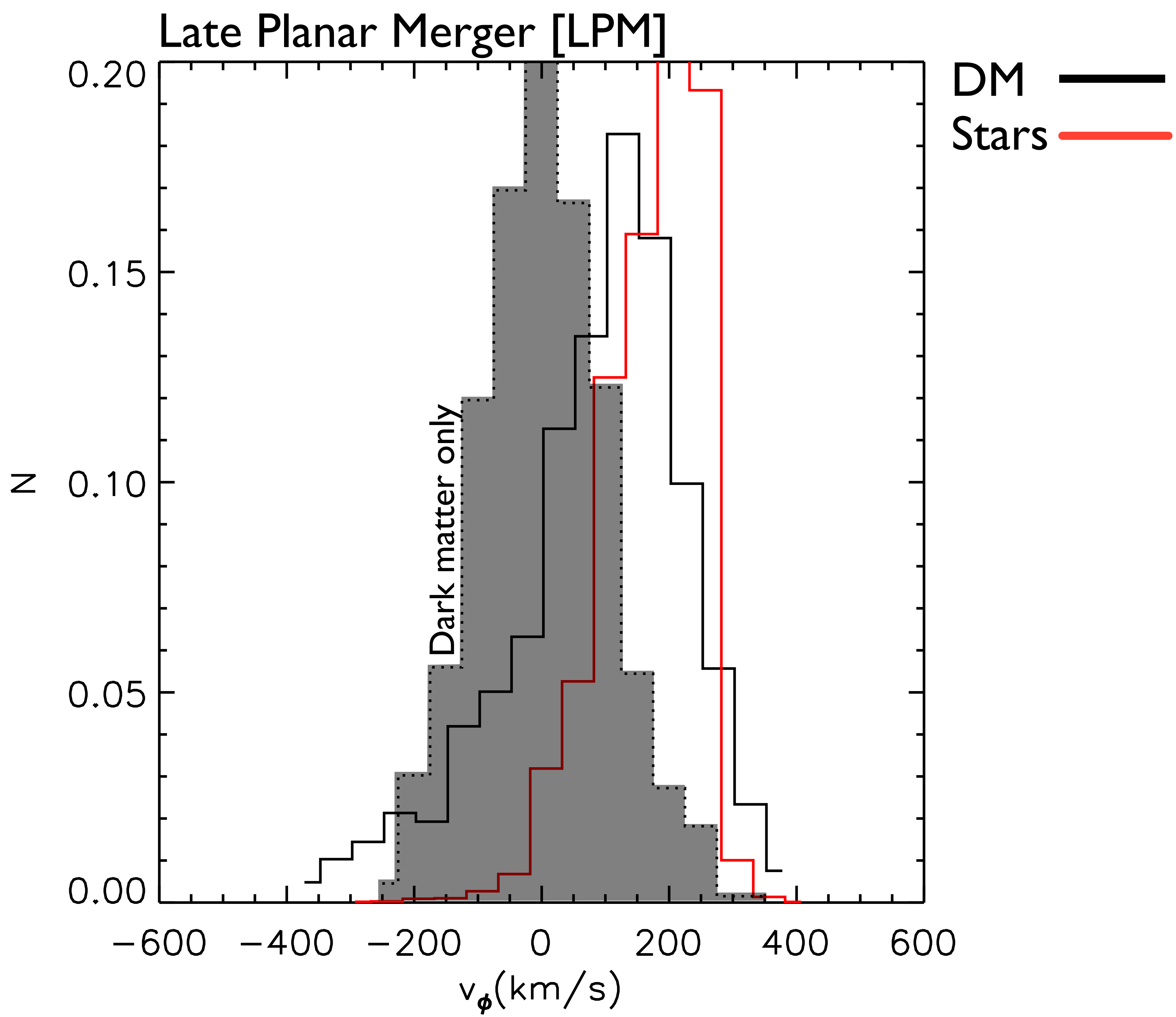
ERIS | Guedes et al. 2011

Simulations | Dark discs



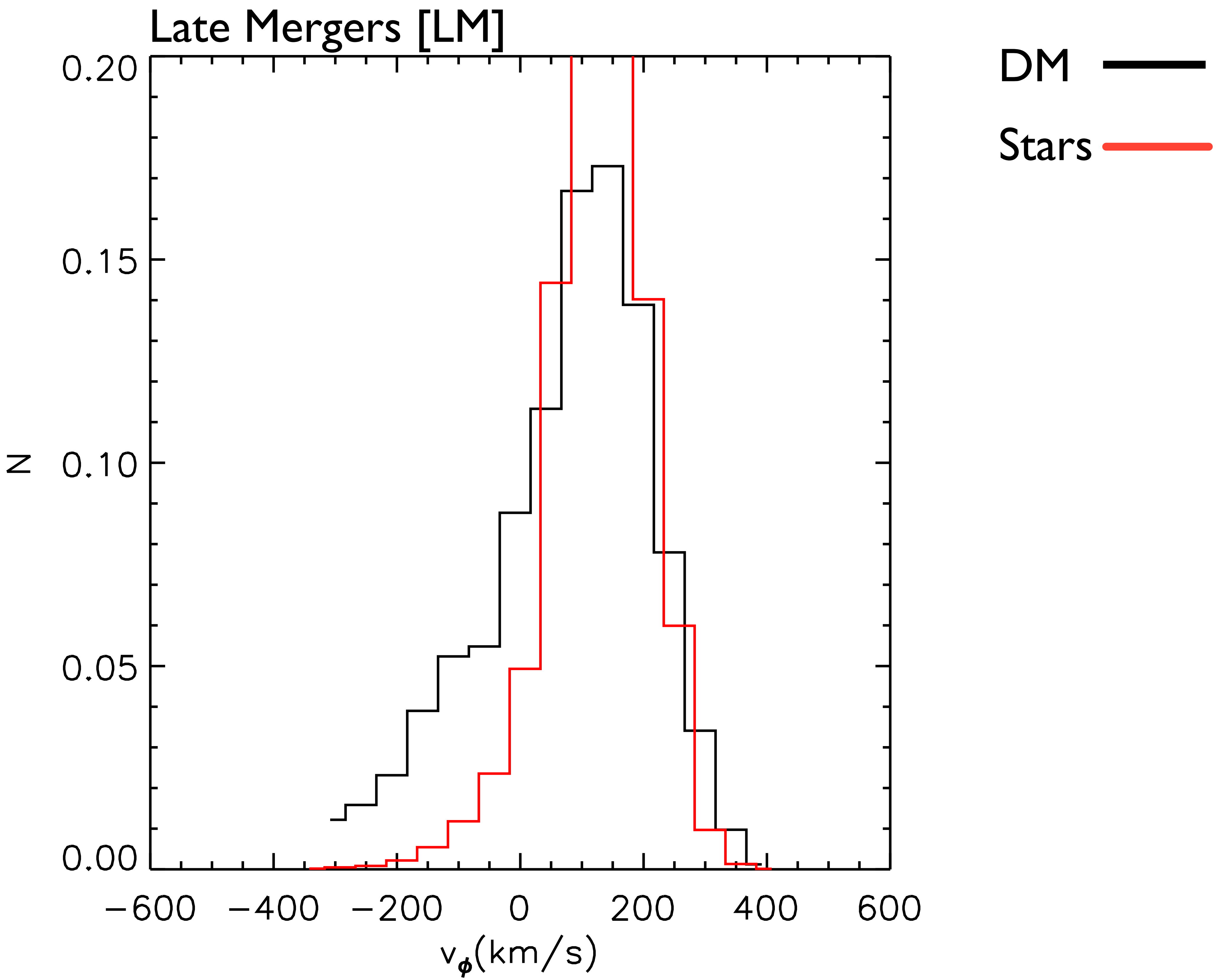
Read et al., 2008/9; Bruch et al. 2009a/b.

Simulations | Dark discs



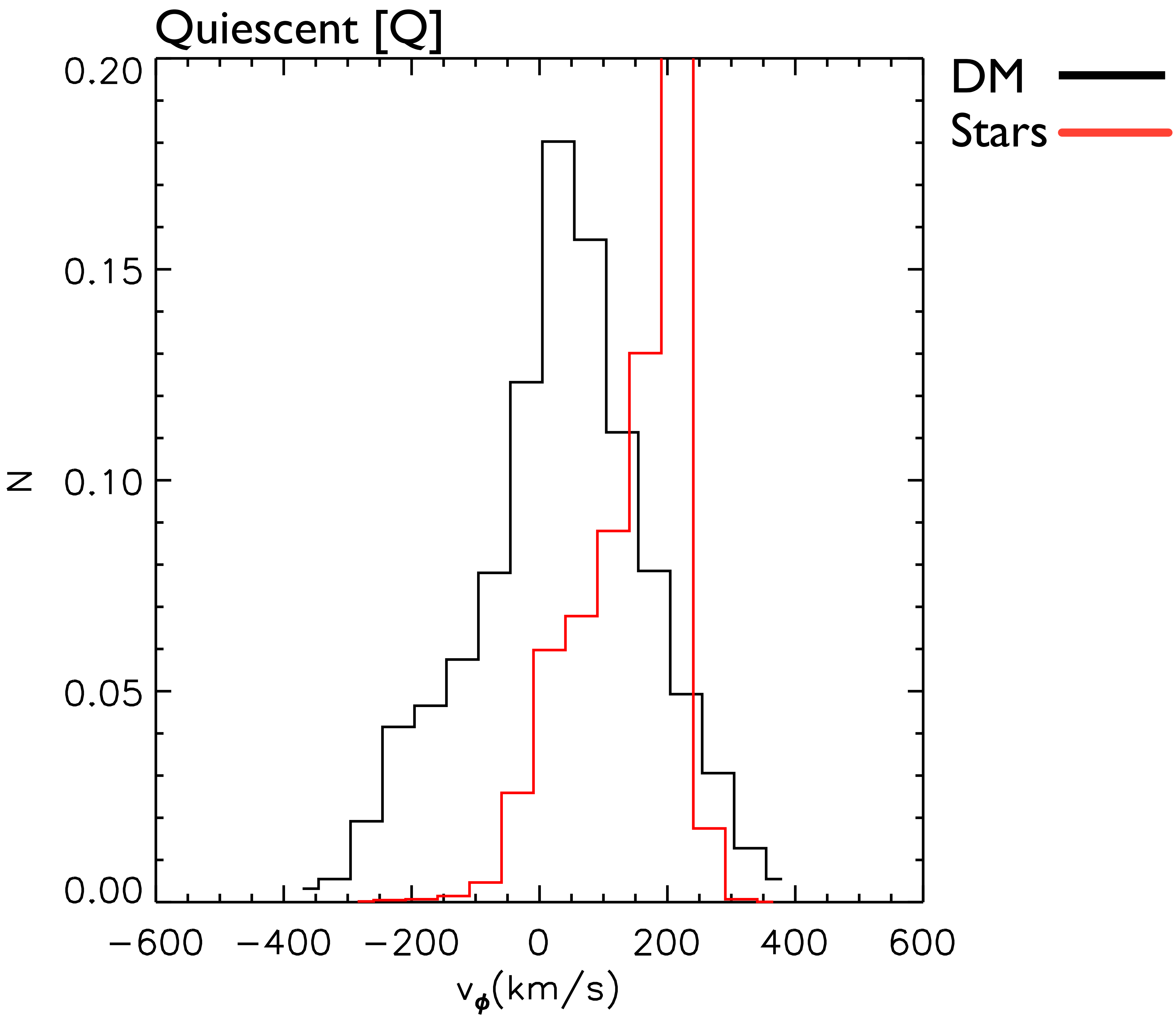
Read et al., 2008/9; Bruch et al. 2009a/b.

Simulations | Dark discs



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

Simulations | Dark discs



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

Measurement

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

Measurement | Theory

Bahcall 1989; Garbari et al. 2011/12

Measurement | Theory

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

Bahcall 1989; Garbari et al. 2011/12

Measurement | Theory

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

Steady state

Bahcall 1989; Garbari et al. 2011/12

Measurement | Theory

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

Steady state

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

Bahcall 1989; Garbari et al. 2011/12

Measurement | Theory

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

Steady state

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

Moments ⇒
Jeans equations

Bahcall 1989; Garbari et al. 2011/12

Measurement | Theory

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

Steady state

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

Moments ⇒
Jeans equations

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

Bahcall 1989; Garbari et al. 2011/12

Measurement | Theory

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

Steady state

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

Moments ⇒
Jeans equations

"tilt term"

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

$h \ll R_d$

Bahcall 1989; Garbari et al. 2011/12

Measurement | Theory

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

Steady state

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

Moments ⇒
Jeans equations

$\propto \Sigma_z(z)$

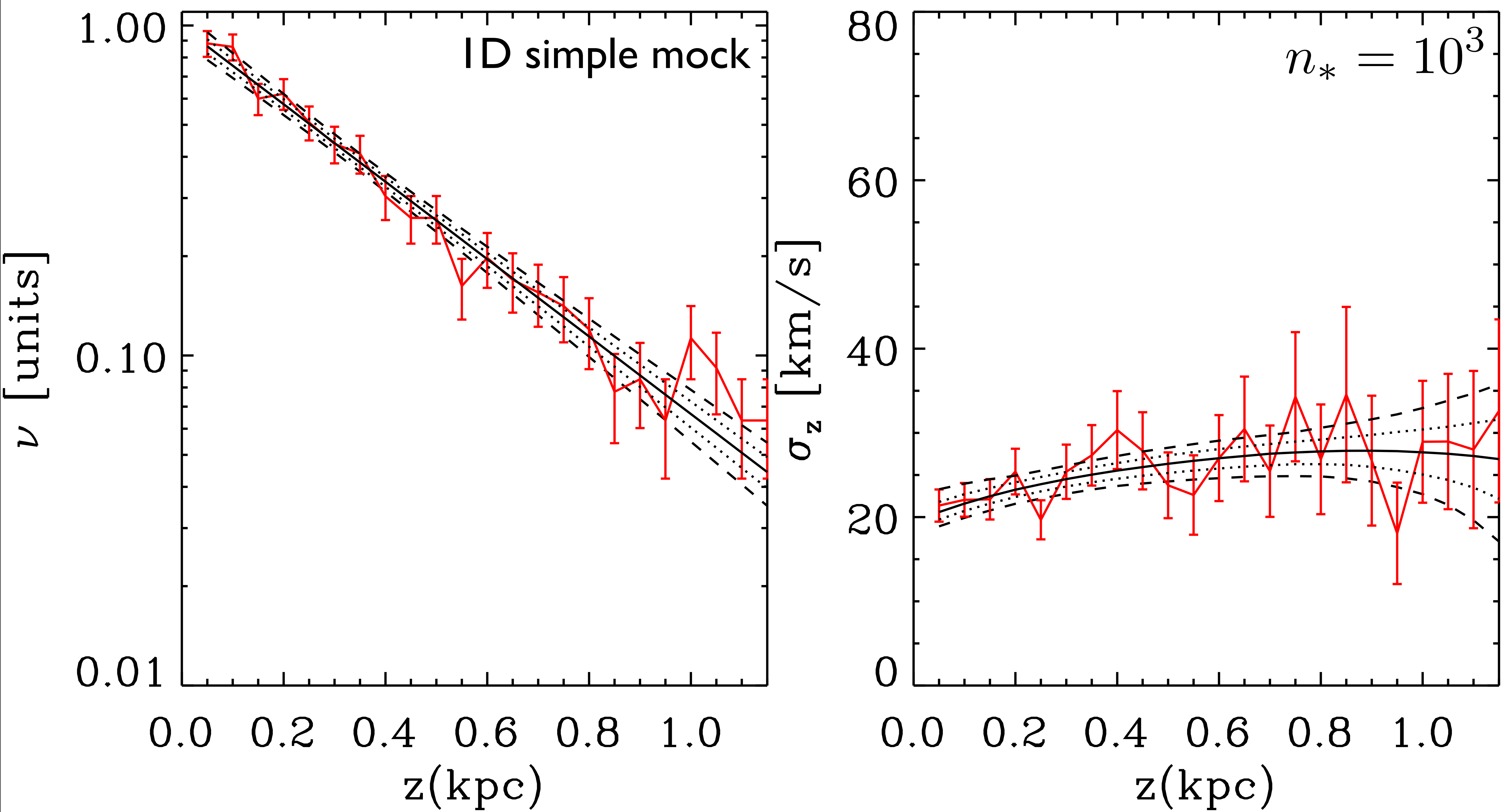
"tilt term"

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

$h \ll R_d$

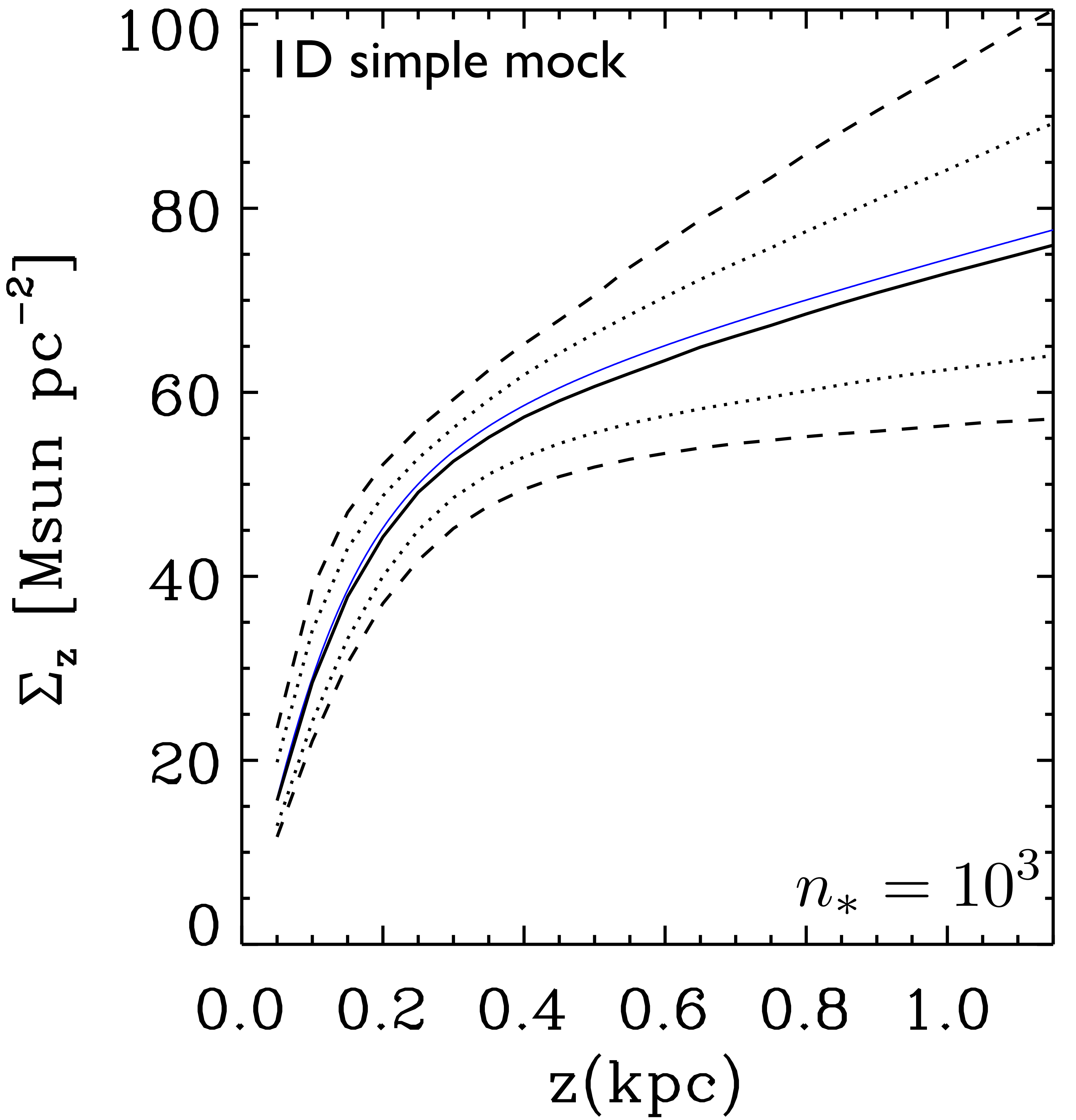
Bahcall 1989; Garbari et al. 2011/12

Measurement | Mock data



Read 2014

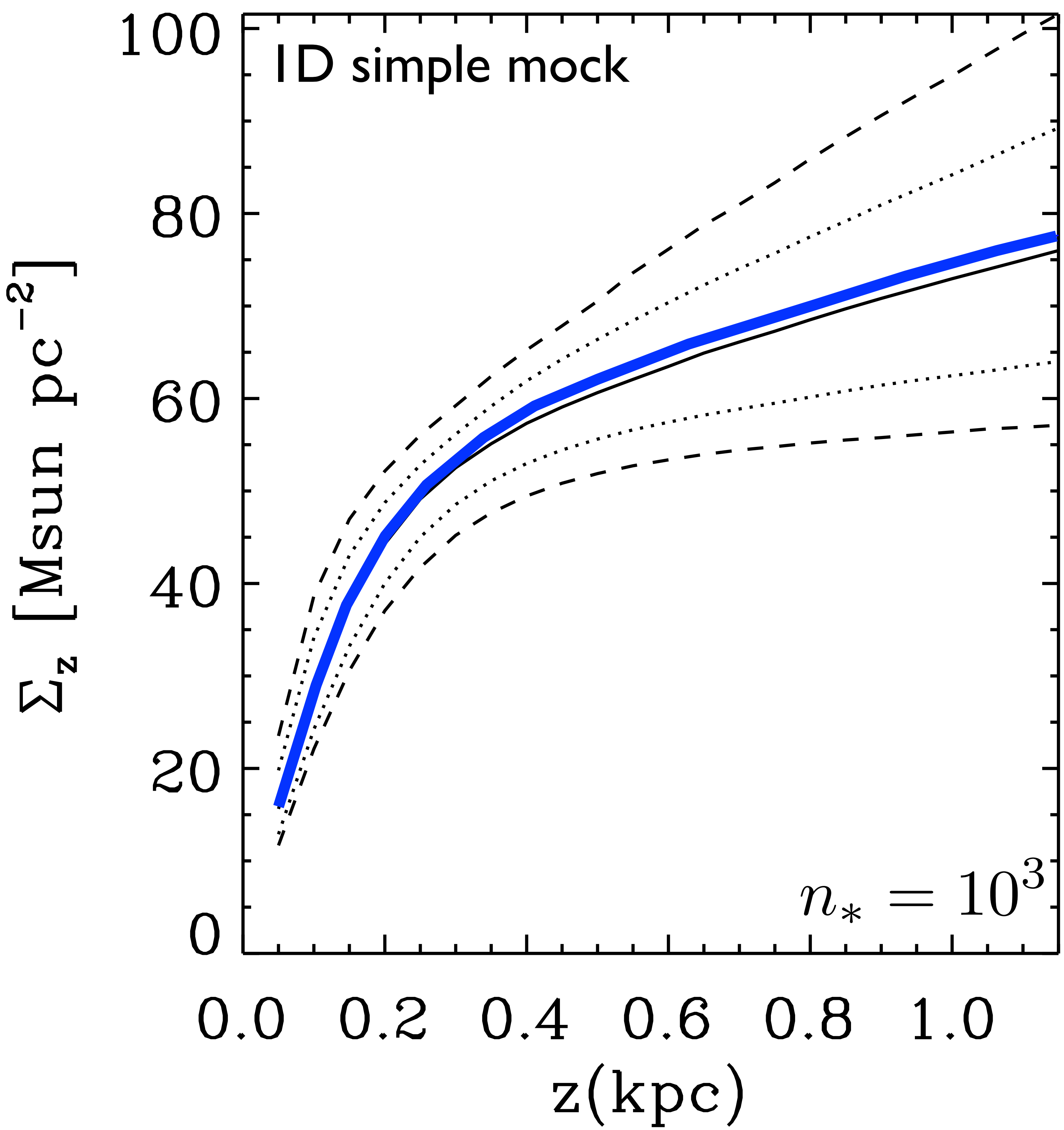
Measurement | Mock data



Read 2014

$\rho_{\rm dm} \sim 0.01\,{\rm M_\odot\,pc^{-3}}$

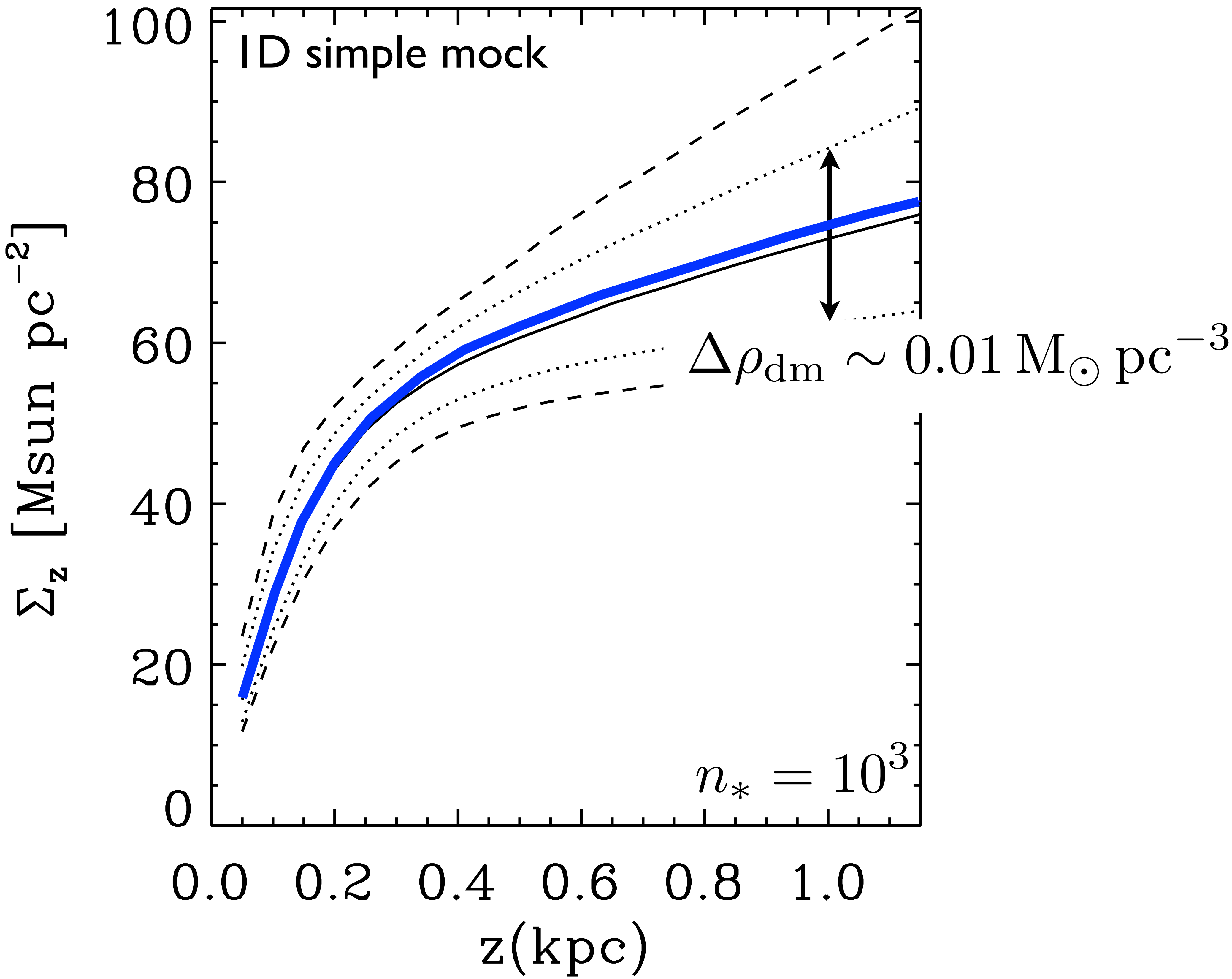
Measurement | Mock data



Read 2014

$\rho_{\rm dm} \sim 0.01\,{\rm M_\odot\,pc^{-3}}$

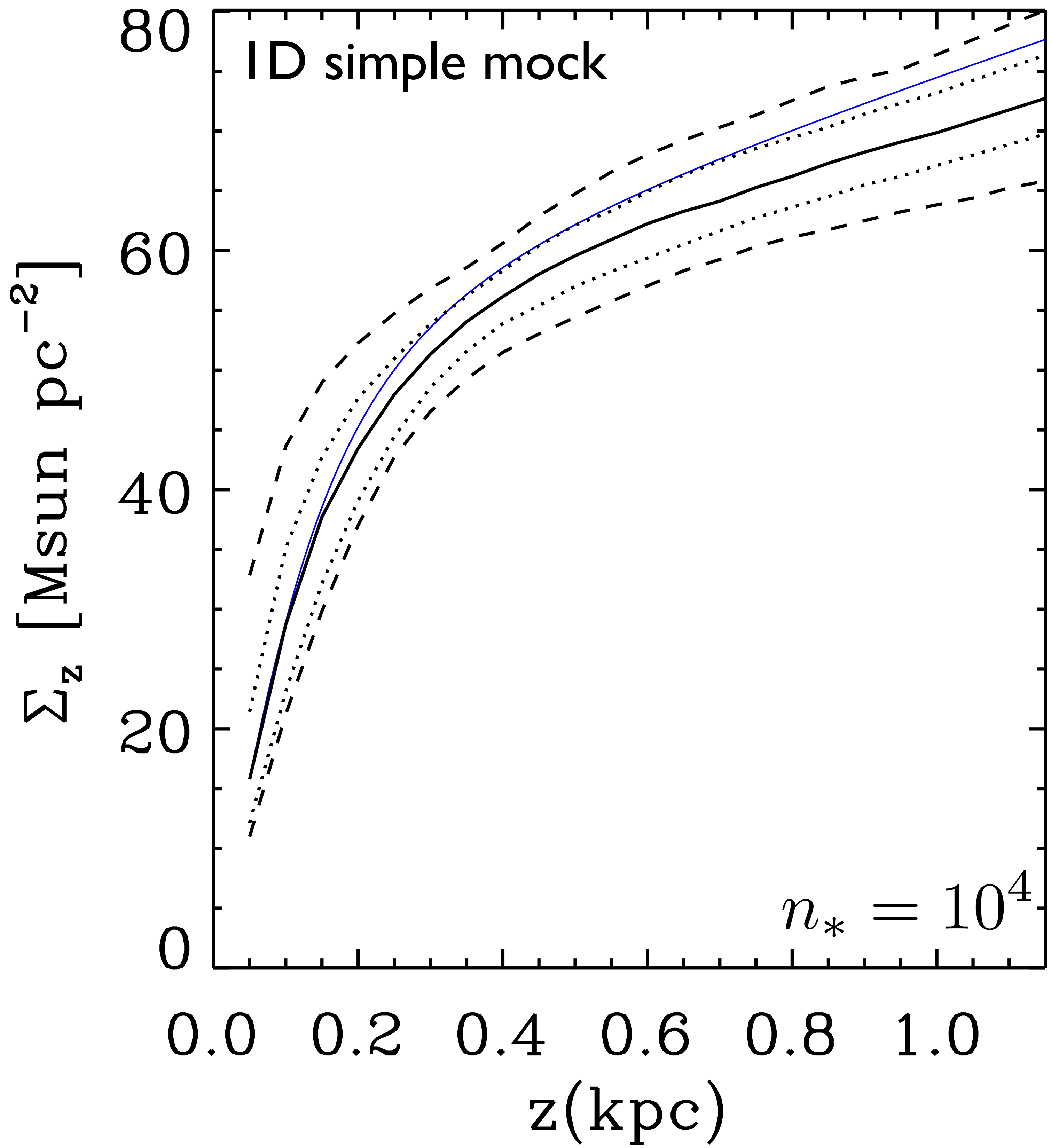
Measurement | Mock data



Read 2014

$\rho_{\rm dm} \sim 0.01\,{\rm M}_\odot\,{\rm pc}^{-3}$

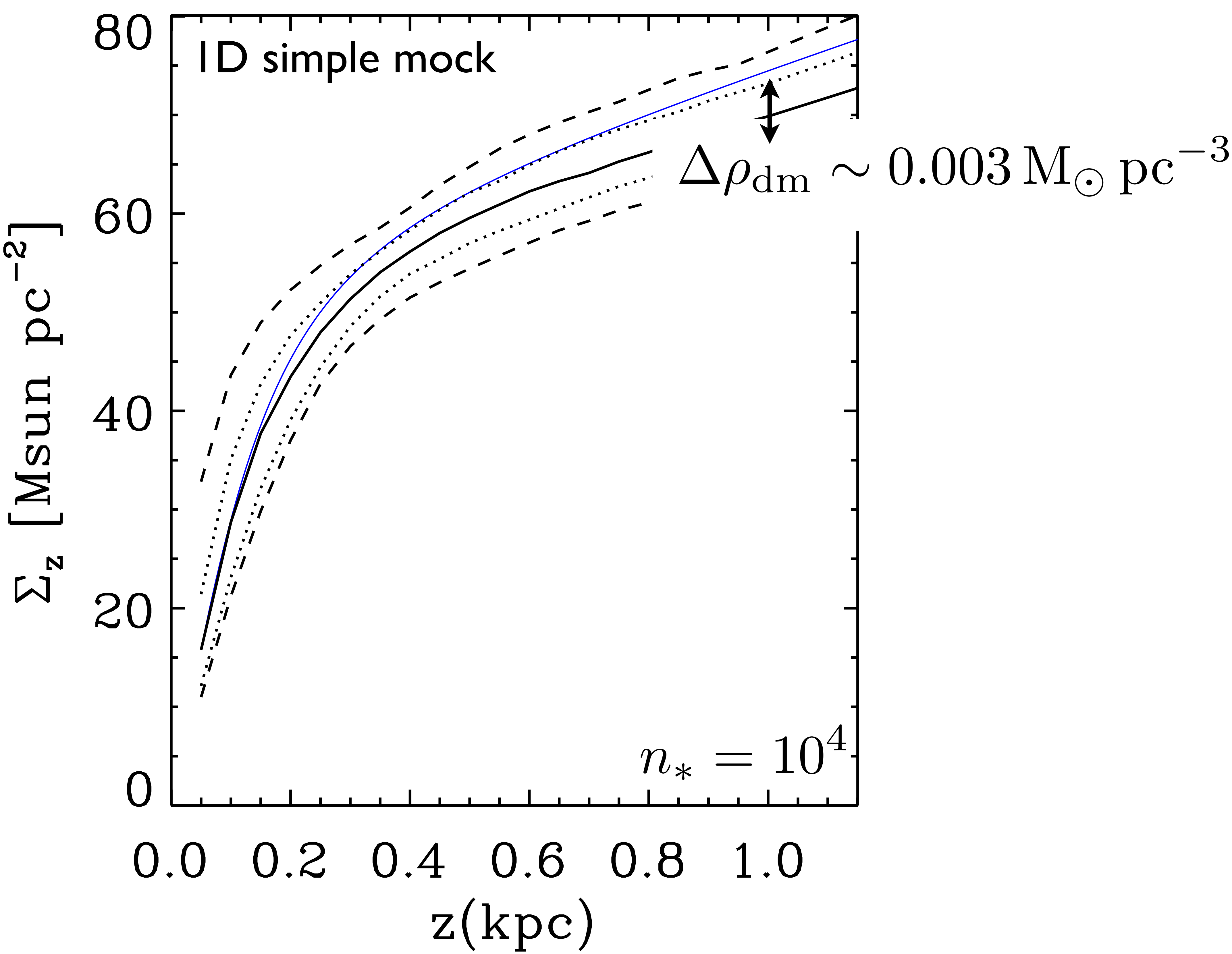
Measurement | Mock data



Read 2014

$\rho_{\rm dm} \sim 0.01\,{\rm M_\odot\,pc^{-3}}$

Measurement | Mock data



Read 2014

$\rho_{\rm dm} \sim 0.01\,{\rm M_\odot\,pc^{-3}}$

Measurement | Real data

Need a good tracer:

Read 2014

Measurement | Real data

Need a good tracer:

- Well mixed ⇒ equilibrium
- Well populated ⇒ good statistics (at high z!)
- Volume complete (helpful)
- Velocity data (v_z)
- Good distances

Read 2014

Measurement | Real data

Need a good tracer:

- Well mixed ⇒ equilibrium
- Well populated ⇒ good statistics (at high z!)
- Volume complete (helpful)
- Velocity data (v_z)
- Good distances

a) 2000 stars
Volume Complete
[Kuijken & Gilmore 1989]

Read 2014

Measurement | Real data

Need a good tracer:

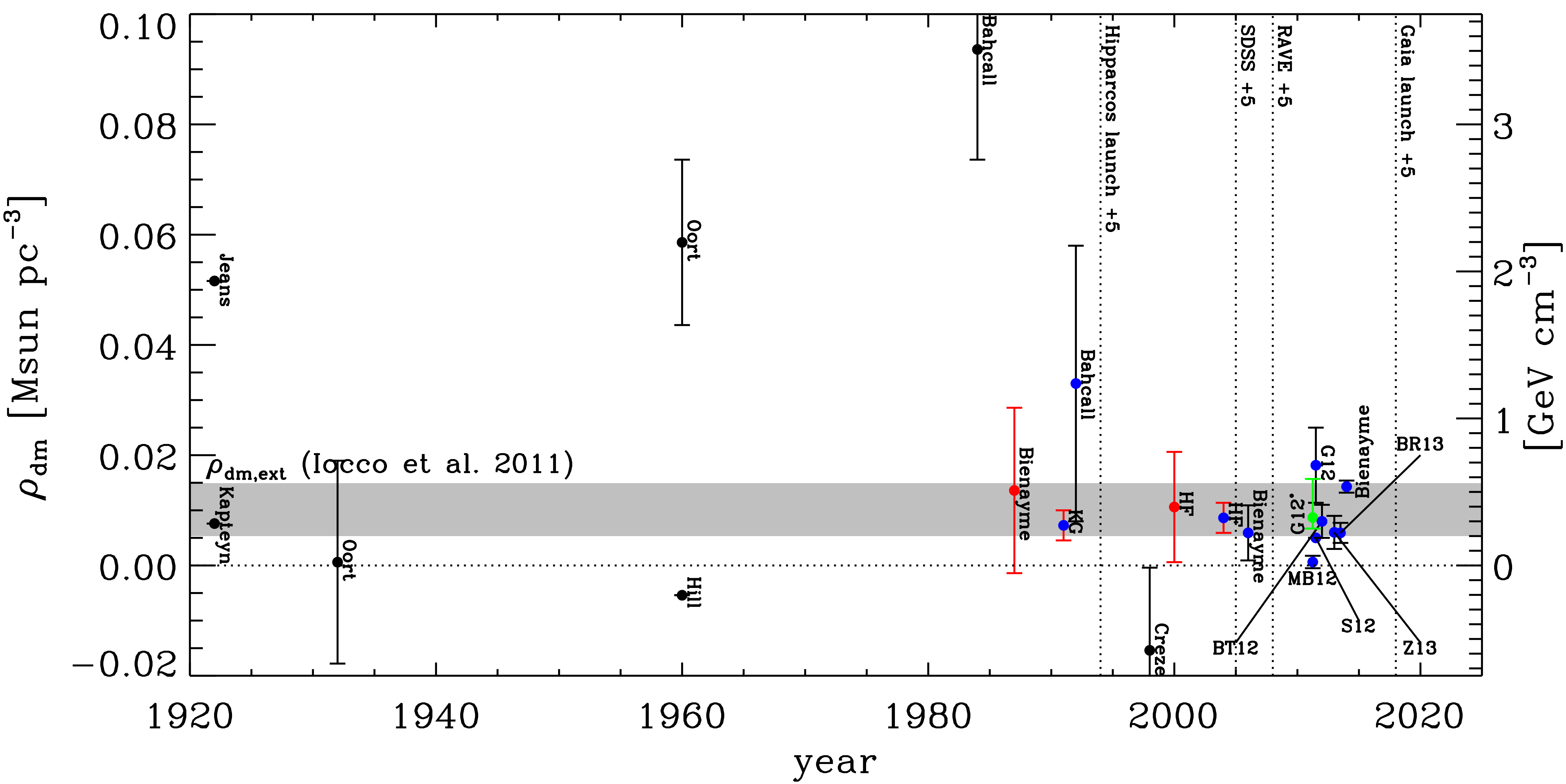
- Well mixed ⇒ equilibrium
- Well populated ⇒ good statistics (at high z!)
- Volume complete (helpful)
- Velocity data (v_z)
- Good distances

a) 2000 stars
Volume Complete
[Kuijken & Gilmore 1989]

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

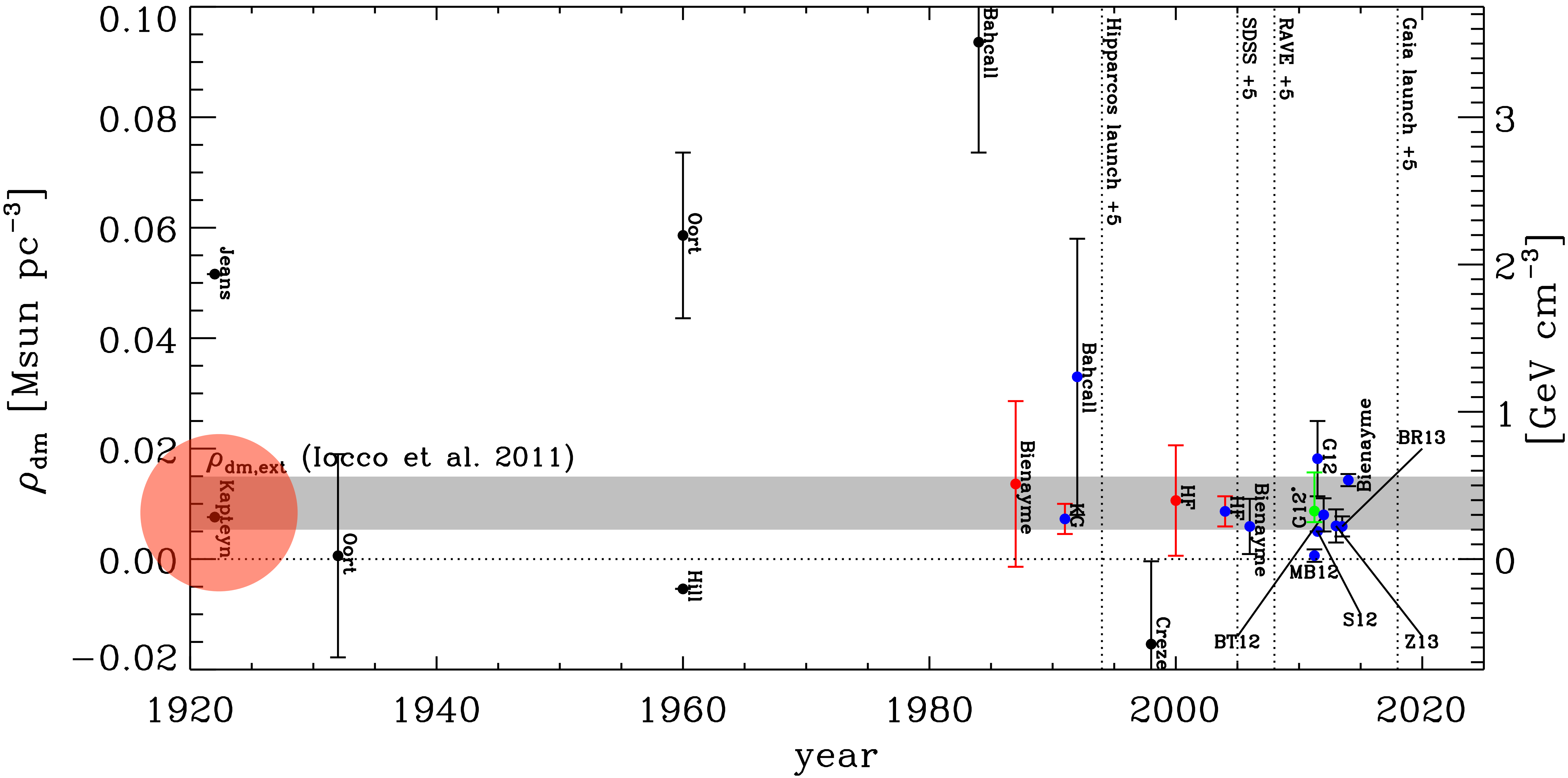
Read 2014

Measurement | Historic measures



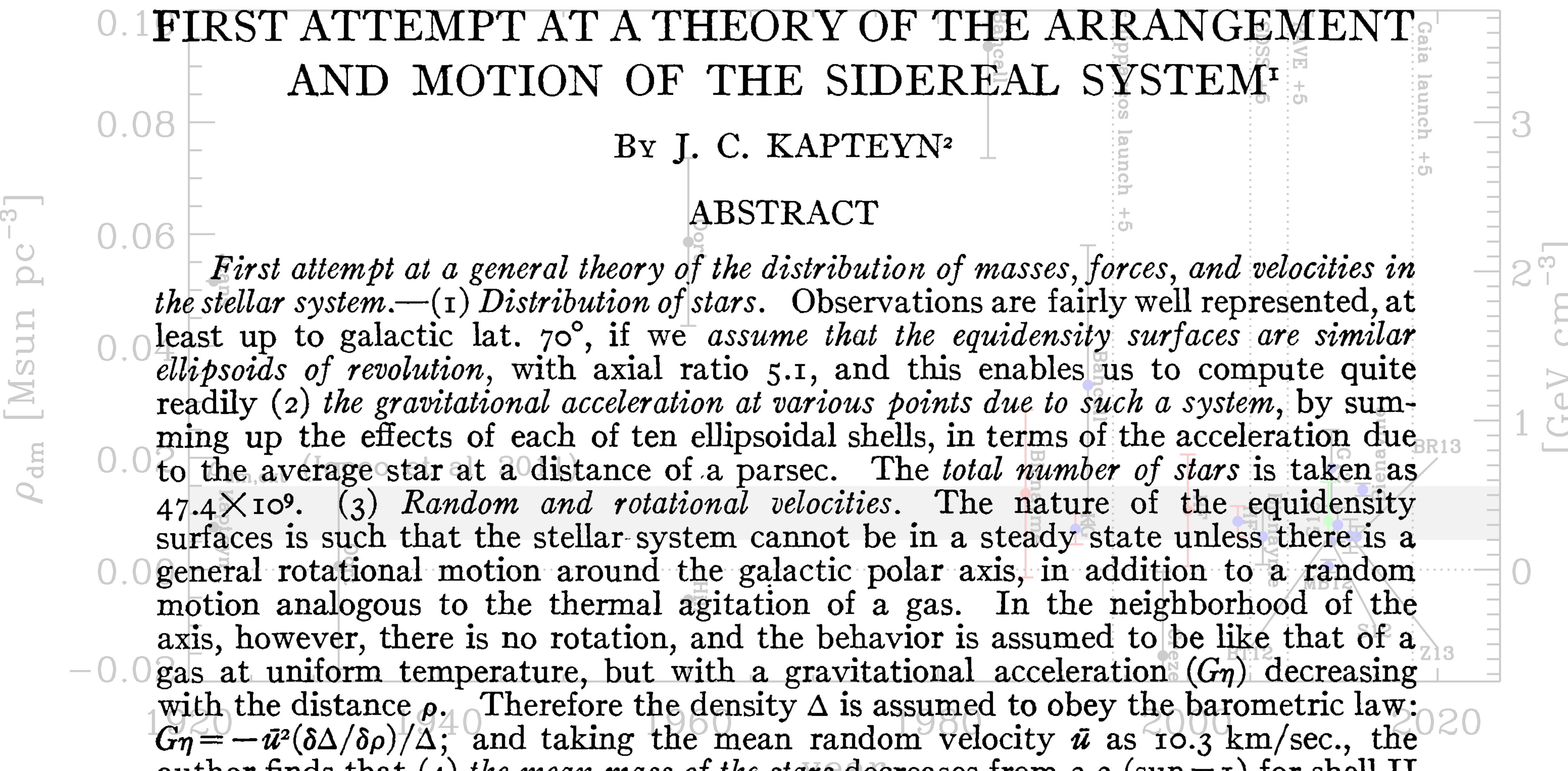
Read 2014

Measurement | Historic measures



Read 2014

Measurement | Historic measures



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

Read 2014

Thursday, June 4, 2015

Measurement | Historic measures

FIRST ATTEMPT AT A THEORY OF THE ARRANGEMENT
AND MOTION OF THE S

BY J. C. KAP

ABSTRAC

First attempt at a general theory of the distri
the stellar system.—(1) *Distribution of stars.* Obs
least up to galactic lat. 70°, if we *assume t*
ellipsoids of revolution, with axial ratio 5.1,
readily (2) *the gravitational acceleration at vario*
ming up the effects of each of ten ellipsoidal
to the average star at a distance of a parsec.
47.4×10⁹. (3) *Random and rotational veloc*
surfaces is such that the stellar system canno
general rotational motion around the galacti
motion analogous to the thermal agitation c
axis, however, there is no rotation, and the b
gas at uniform temperature, but with a grav
with the distance ρ. Therefore the density Δ
$G\eta = -\bar{u}^2(\delta\Delta/\delta\rho)/\Delta$; and taking the mean ra
author finds that (4) *the mean mass of the stars*
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

Jacobus Cornelius Kapteyn
[1851 - 1922]

Read 2014

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 the relative velocity is also in the plane of the Milky Way and about 40 km/sec. It is incidentally suggested that when the theory is perfected it may be possible to determine *the amount of dark matter* from its gravitational effect. (5) The *chief defects of the theory* are: That the equidensity surfaces assumed do not agree with the actual surfaces, which tend to become spherical for the shorter distances; that the *position of the center of the system* is not the sun, as assumed, but is probabl… …oint some 650 parsecs away in the direction galactic long. 77°, lat. −… …age mass of the stars was assumed to be the same in all shells in d… …ula for the variation of $G\eta$ with ρ on the basis of which the variati… …ass from shell to shell and the constancy of the rotational velocity w… …nce either the assumption or the conclusions are wrong; and that no … …een made between stars of different types.

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

Read 2014

Measurement | Historic measures

It is incidentally suggested that when the theory is perfected it may be possible to determine *the amount of dark matter* from its gravitational effect.

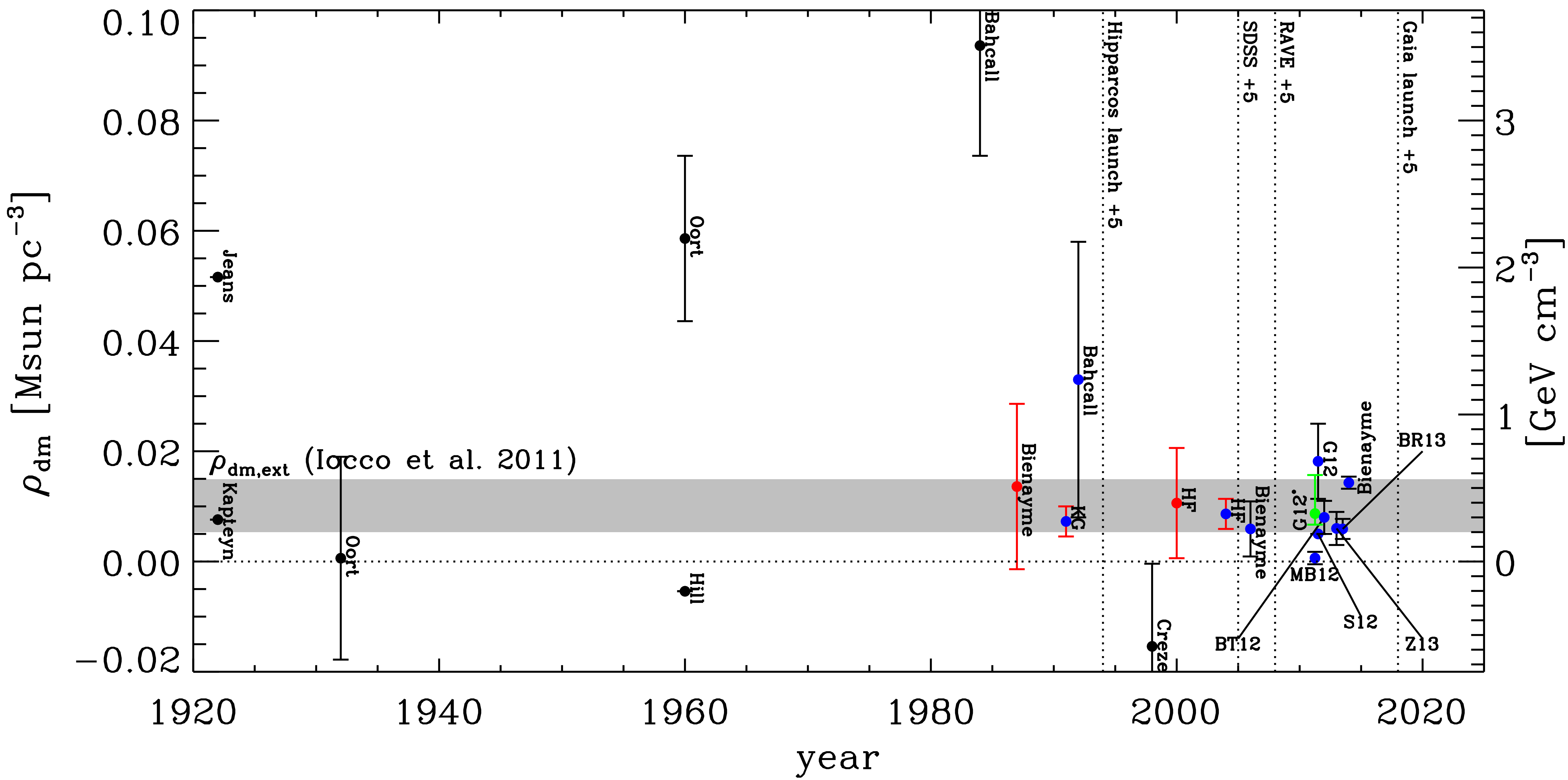
Read 2014

Measurement | Historic measures

It is incidentally suggested that when the theory is perfected it may be possible to determine *the amount of dark matter* from its gravitational effect.

Read 2014

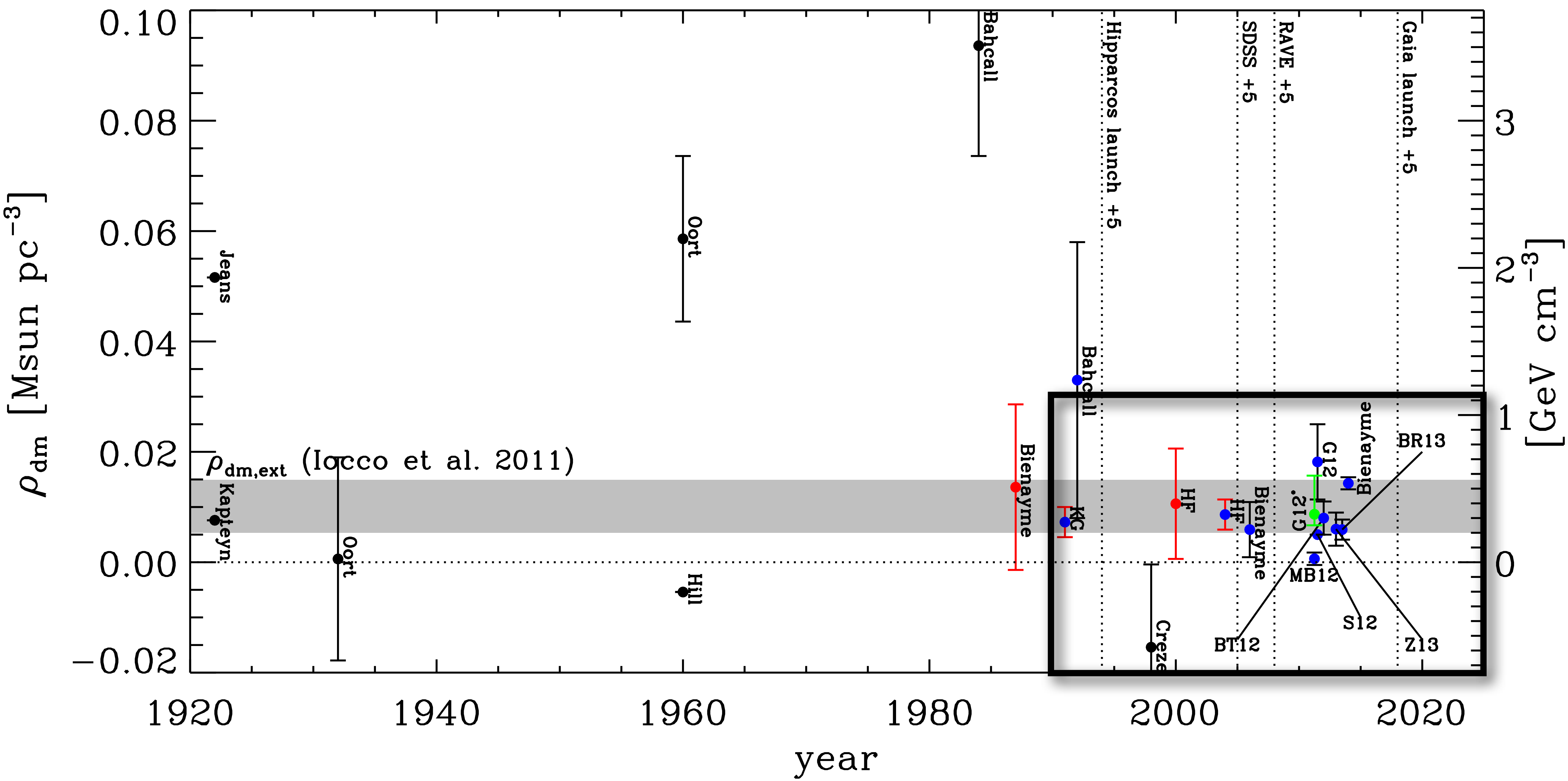
Measurement | Comparison of recent measures



Read 2014

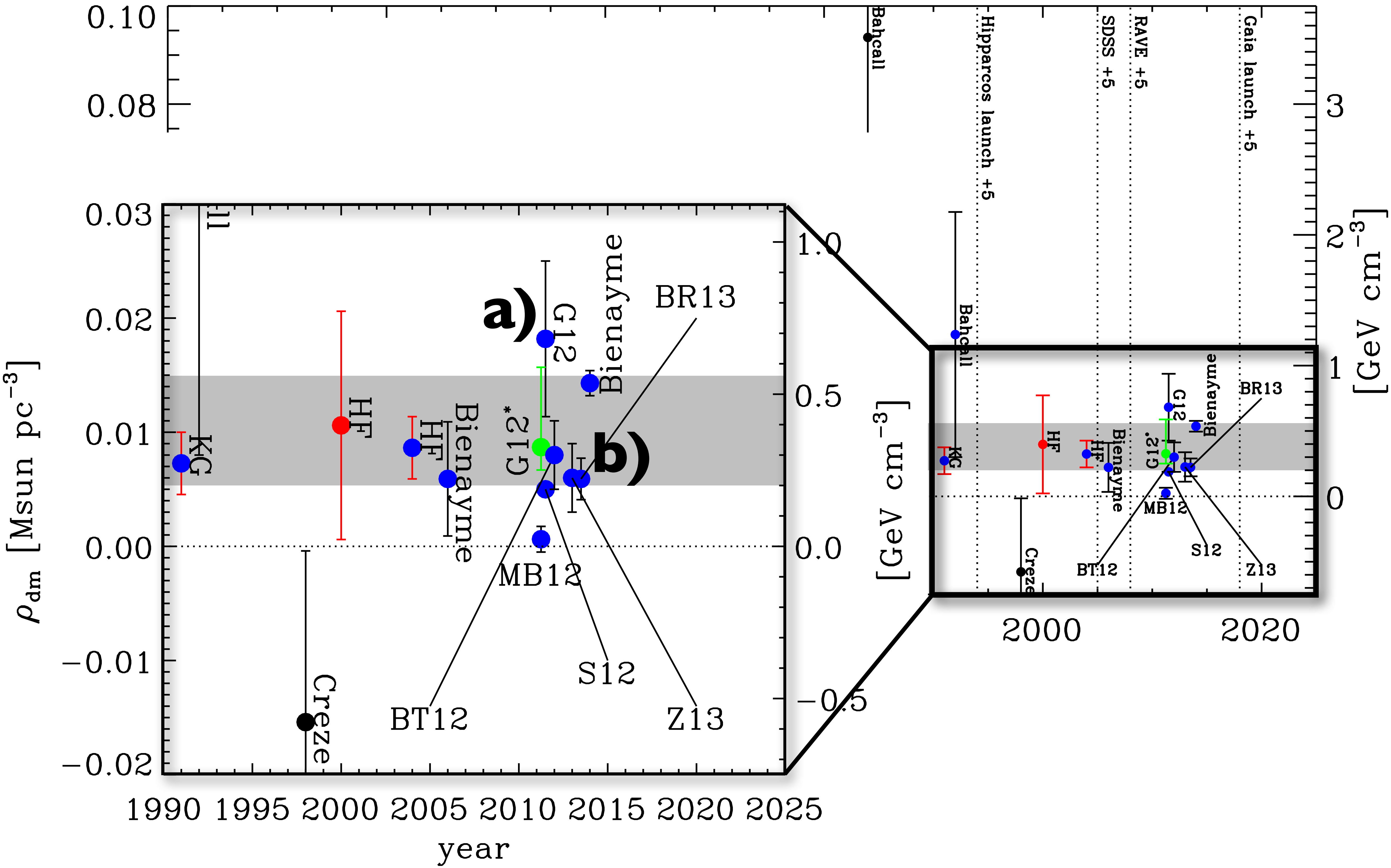
Thursday, June 4, 2015

Measurement | Comparison of recent measures



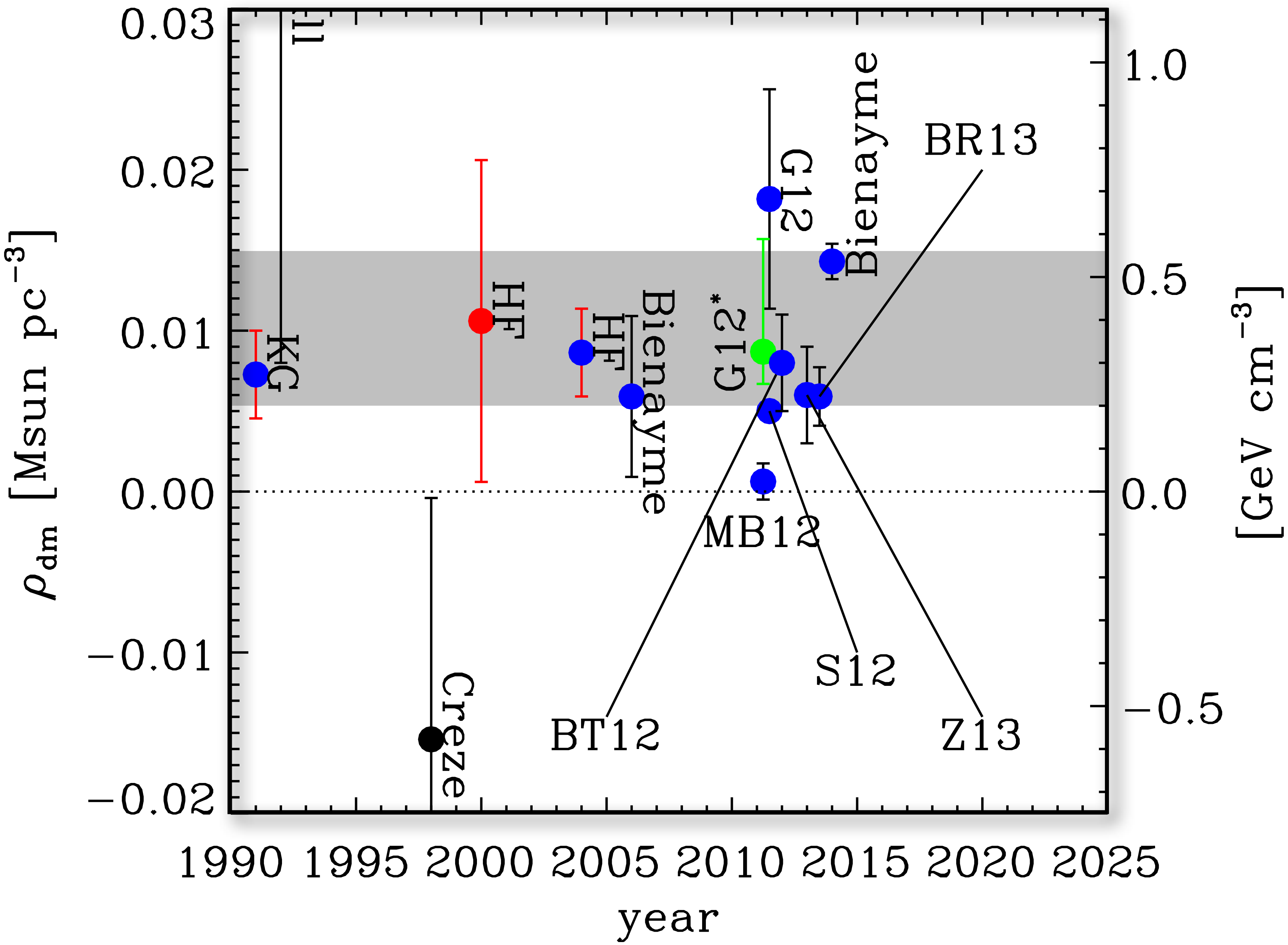
Read 2014

Measurement | Comparison of recent measures



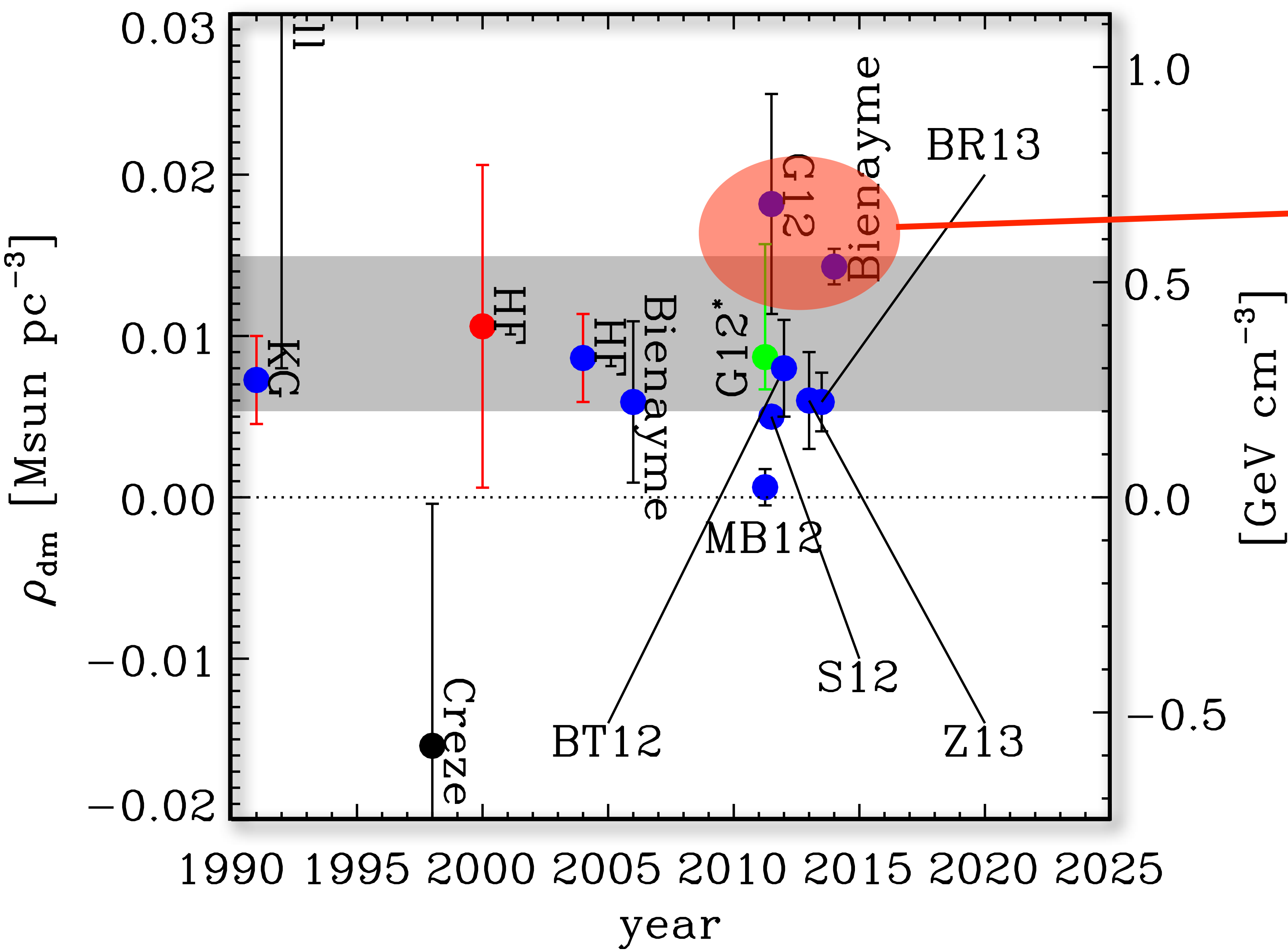
Read 2014

Measurement | Comparison of recent measures



Read 2014

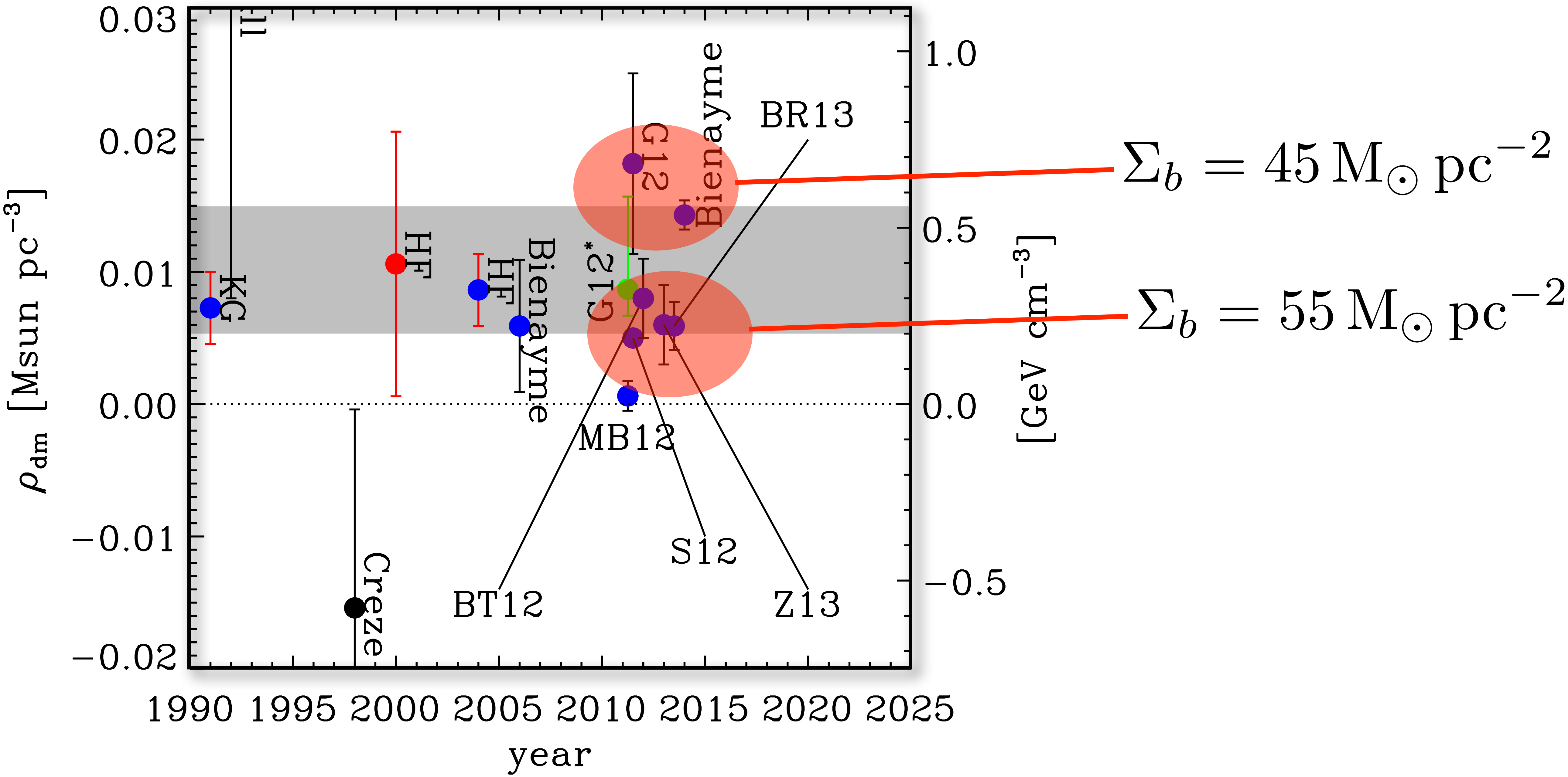
Measurement | Comparison of recent measures



$$\Sigma_b = 45\,\mathrm{M}_\odot\,\mathrm{pc}^{-2}$$

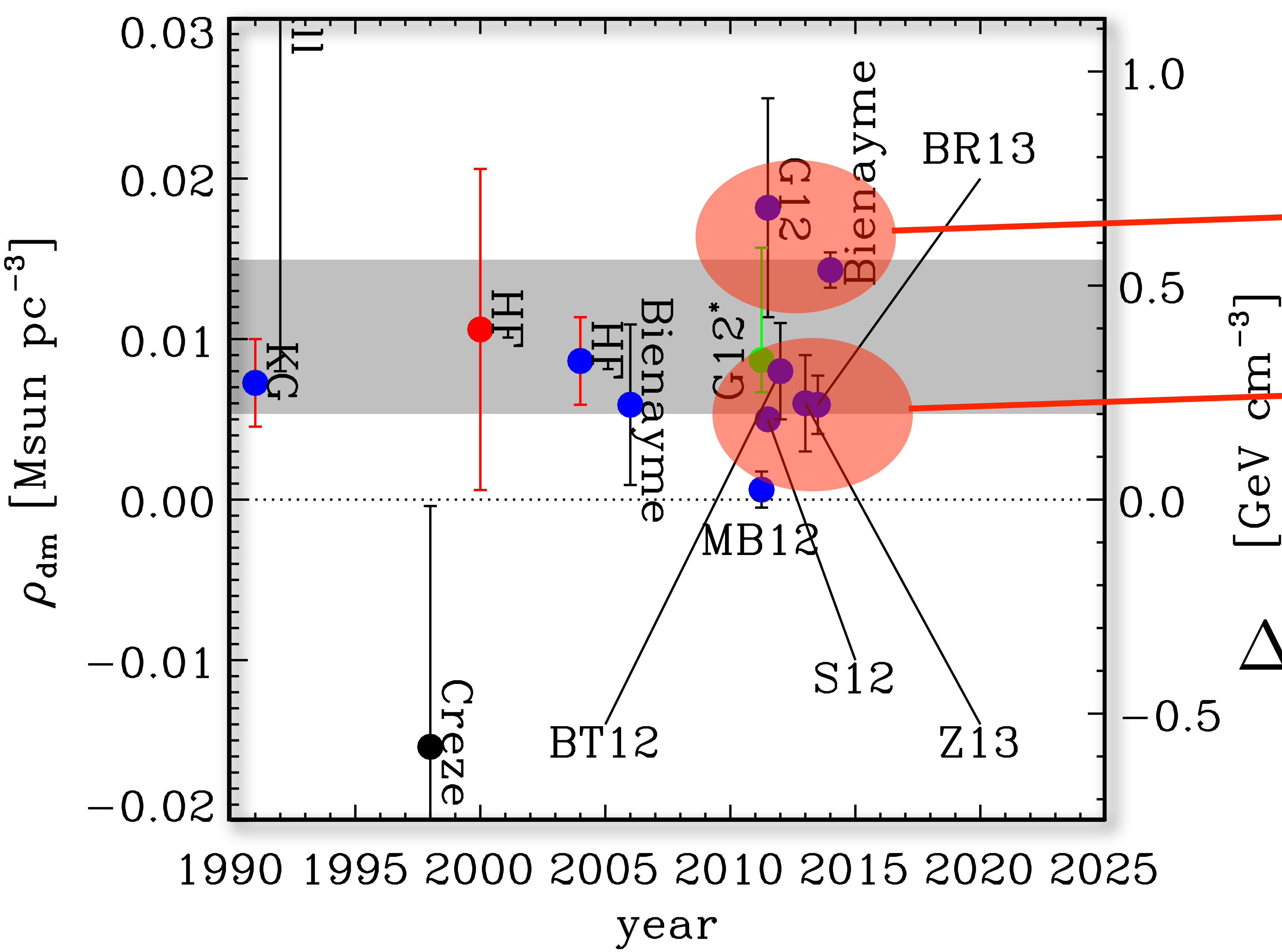
Read 2014

Measurement | Comparison of recent measures



Read 2014

Measurement | Comparison of recent measures



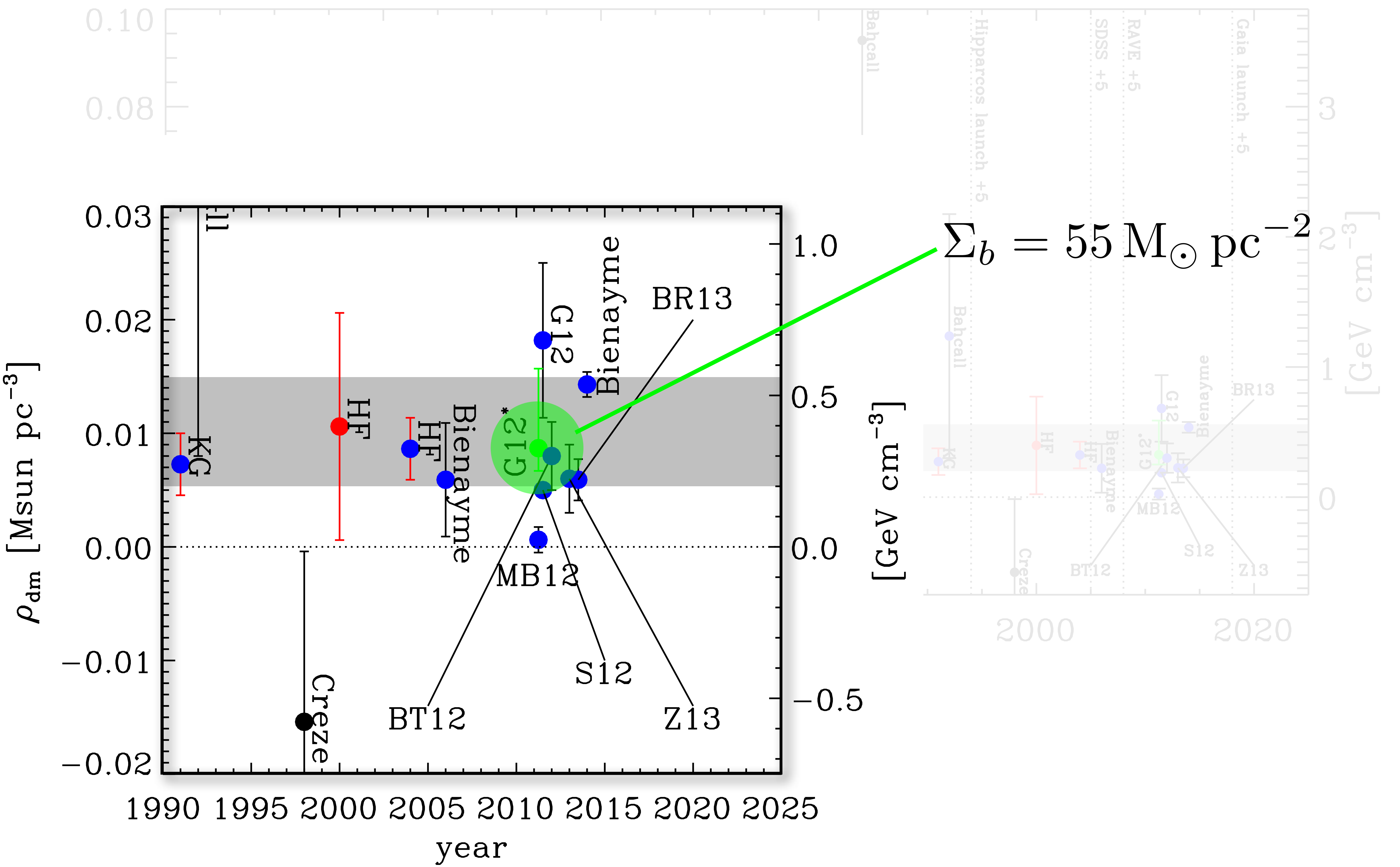
$$\Sigma_b = 45\,{\rm M_\odot\,pc^{-2}}$$

$$\Sigma_b = 55\,{\rm M_\odot\,pc^{-2}}$$

$$\Delta\rho_{\rm dm} \sim 0.005\,{\rm M_\odot\,pc^{-3}}$$

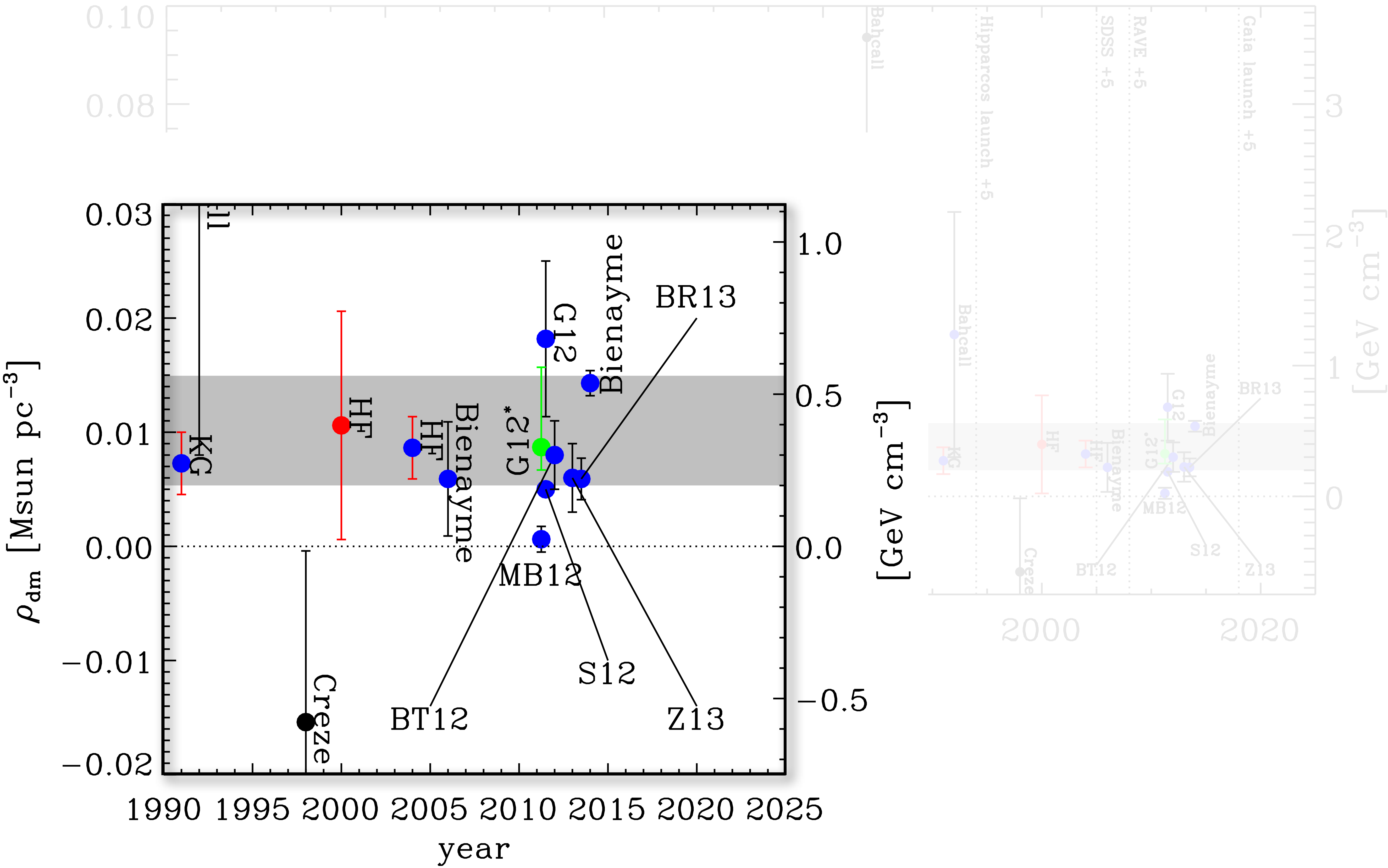
Read 2014

Measurement | Comparison of recent measures



Read 2014

Measurement | Comparison of recent measures



Read 2014

Thursday, June 4, 2015

Measurement | Comparison of recent measures

A new compilation of Σ_b

Component	$\Sigma_i [\mathrm{M}_\odot\,\mathrm{pc}^{-2}]$	Reference
Σ_{HI}	12.0 ± 4.0	Kalberla & Dedes (2008)
$\Sigma_{\mathrm{H_2}}$	3.0 ± 1.5	Flynn et al. (2006)
$\Sigma_{\mathrm{Warm\ gas}}$	2.0 ± 1	Flynn et al. (2006)
Σ_*	30 ± 1	Bovy et al. (2012)
$\Sigma_\bullet$	7.2 ± 0.7	Flynn et al. (2006)
Σ_b	54.2 ± 4.9	This compilation

Read 2014

Measurement | Comparison of recent measures

A new compilation of Σ_b

Component	$\Sigma_i [\mathrm{M}_\odot\,\mathrm{pc}^{-2}]$	Reference
Σ_{HI}	12.0 ± 4.0	Kalberla & Dedes (2008)
$\Sigma_{\mathrm{H_2}}$	3.0 ± 1.5	Flynn et al. (2006)
$\Sigma_{\mathrm{Warm\ gas}}$	2.0 ± 1	Flynn et al. (2006)
Σ_*	30 ± 1	Bovy et al. (2012)
$\Sigma_\bullet$	7.2 ± 0.7	Flynn et al. (2006)
Σ_b	54.2 ± 4.9	This compilation

Read 2014

Measurement | Comparison of recent measures

A new compilation of Σ_b

Component	$\Sigma_i [\mathrm{M}_\odot\,\mathrm{pc}^{-2}]$	Reference
Σ_{HI}	12.0 ± 4.0	Kalberla & Dedes (2008)
$\Sigma_{\mathrm{H_2}}$	3.0 ± 1.5	Flynn et al. (2006)
$\Sigma_{\mathrm{Warm\ gas}}$	2.0 ± 1	Flynn et al. (2006)
Σ_*	30 ± 1	Bovy et al. (2012)
$\Sigma_\bullet$	7.2 ± 0.7	Flynn et al. (2006)
Σ_b	54.2 ± 4.9	This compilation

Read 2014

Measurement | Comparison of recent measures

A new compilation of Σ_b

Component	$\Sigma_i [\mathrm{M}_\odot\,\mathrm{pc}^{-2}]$	Reference
Σ_{HI}	12.0 ± 4.0	Kalberla & Dedes (2008)
$\Sigma_{\mathrm{H_2}}$	3.0 ± 1.5	Flynn et al. (2006)
$\Sigma_{\mathrm{Warm\ gas}}$	2.0 ± 1	Flynn et al. (2006)
Σ_*	30 ± 1	Bovy et al. (2012)
$\Sigma_\bullet$	7.2 ± 0.7	Flynn et al. (2006)
Σ_b	54.2 ± 4.9	This compilation

Read 2014

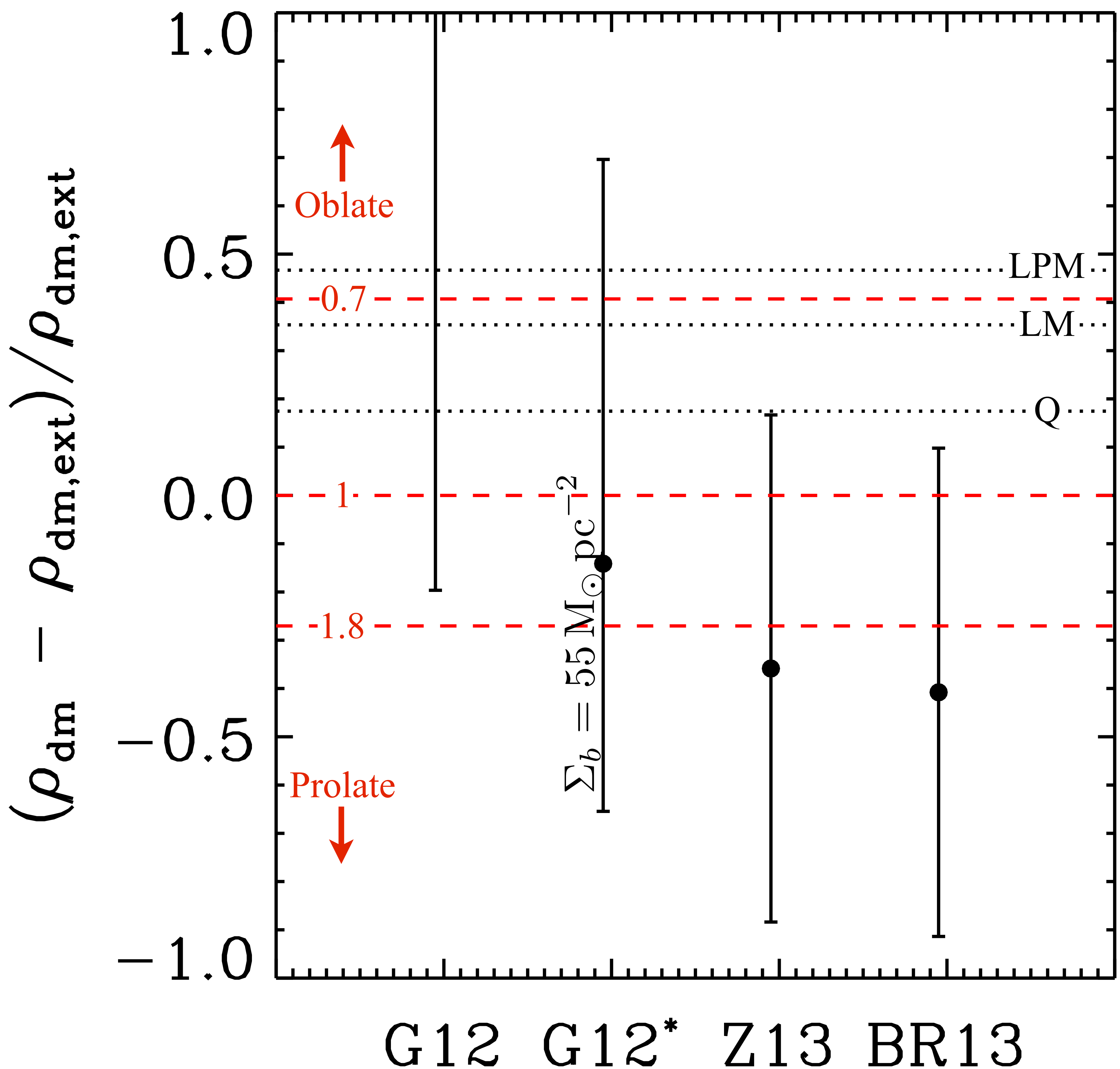
Measurement | Comparison of recent measures

A new compilation of Σ_b

Component	$\Sigma_i [\mathrm{M}_\odot \, \mathrm{pc}^{-2}]$	Reference
Σ_{HI}	12.0 ± 4.0	Kalberla & Dedes (2008)
$\Sigma_{\mathrm{H_2}}$	3.0 ± 1.5	Flynn et al. (2006)
$\Sigma_{\mathrm{Warm\ gas}}$	2.0 ± 1	Flynn et al. (2006)
Σ_{*}	30 ± 1	Bovy et al. (2012)
$\Sigma_{\bullet}$	7.2 ± 0.7	Flynn et al. (2006)
Σ_b	54.2 ± 4.9	This compilation

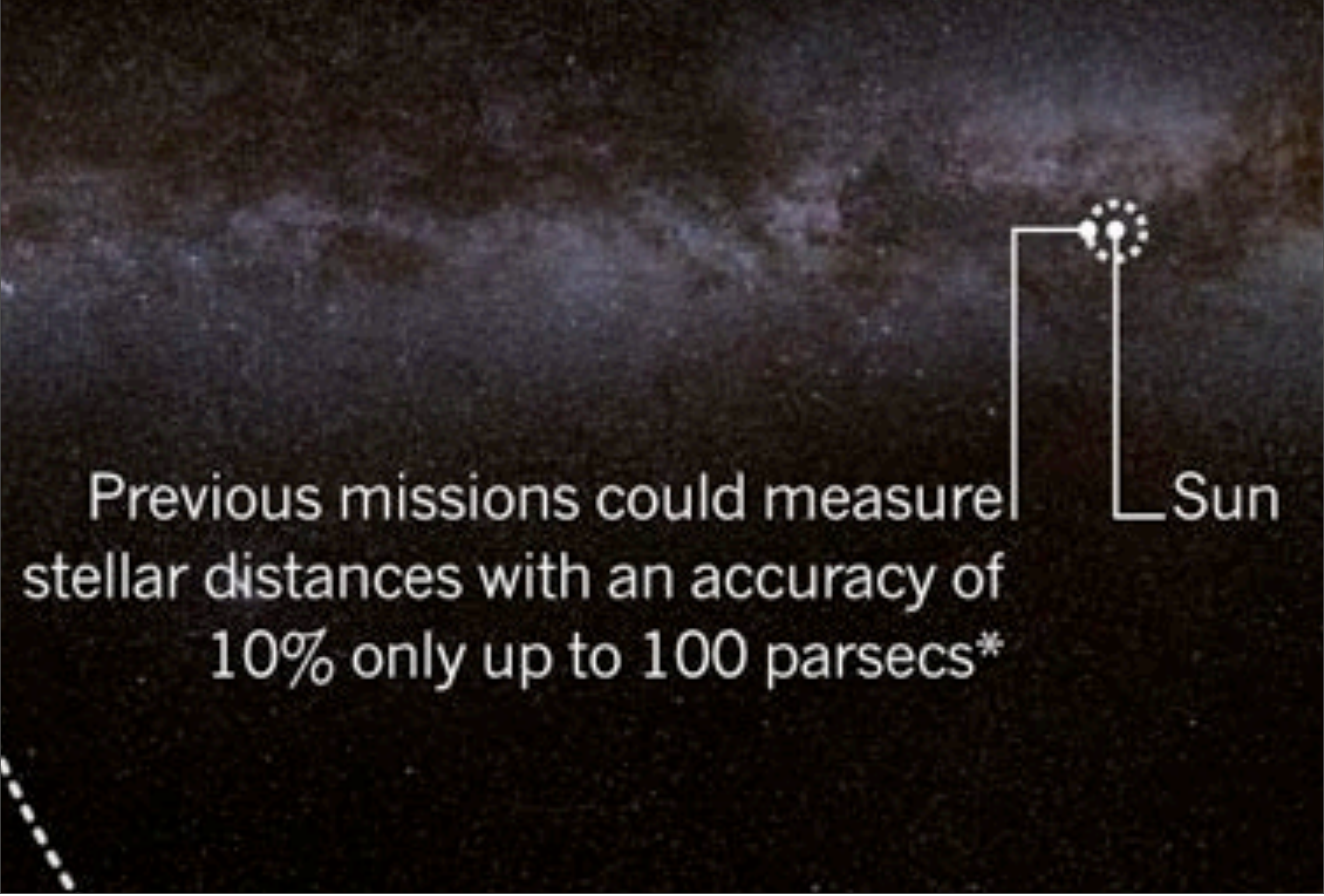
Read 2014

Measurement | The dark disc

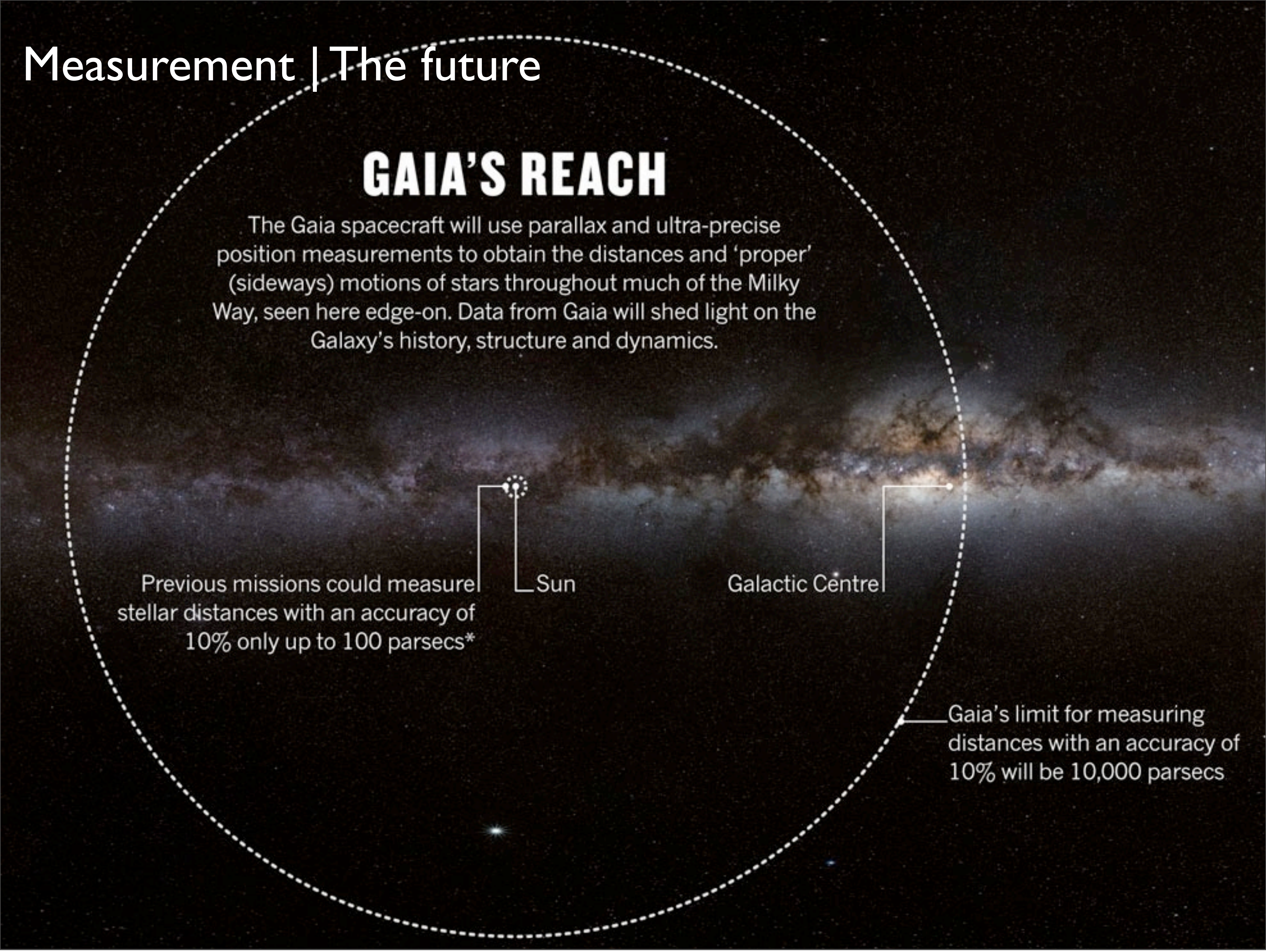


Read 2014

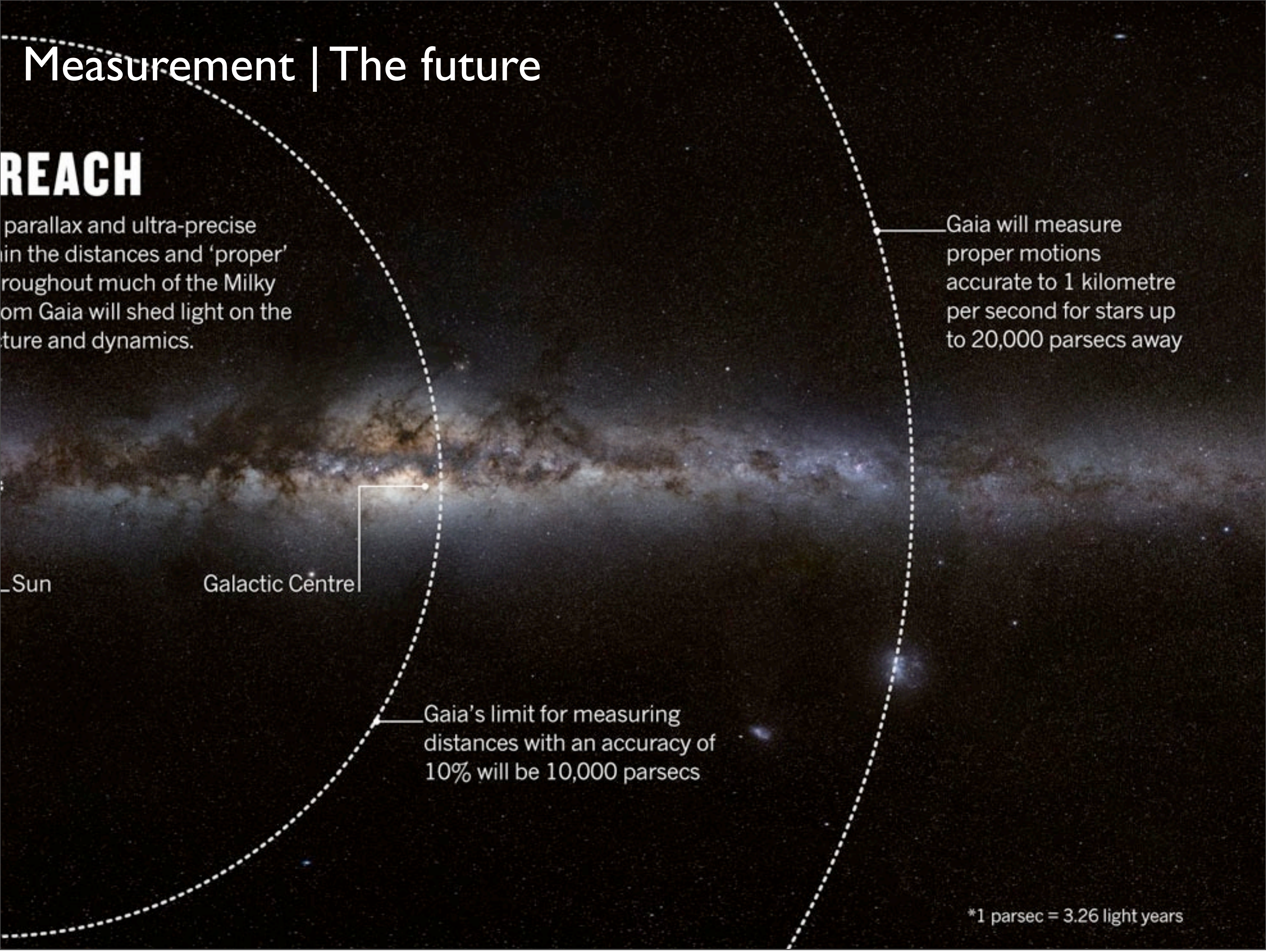
Measurement | The future



Measurement | The future

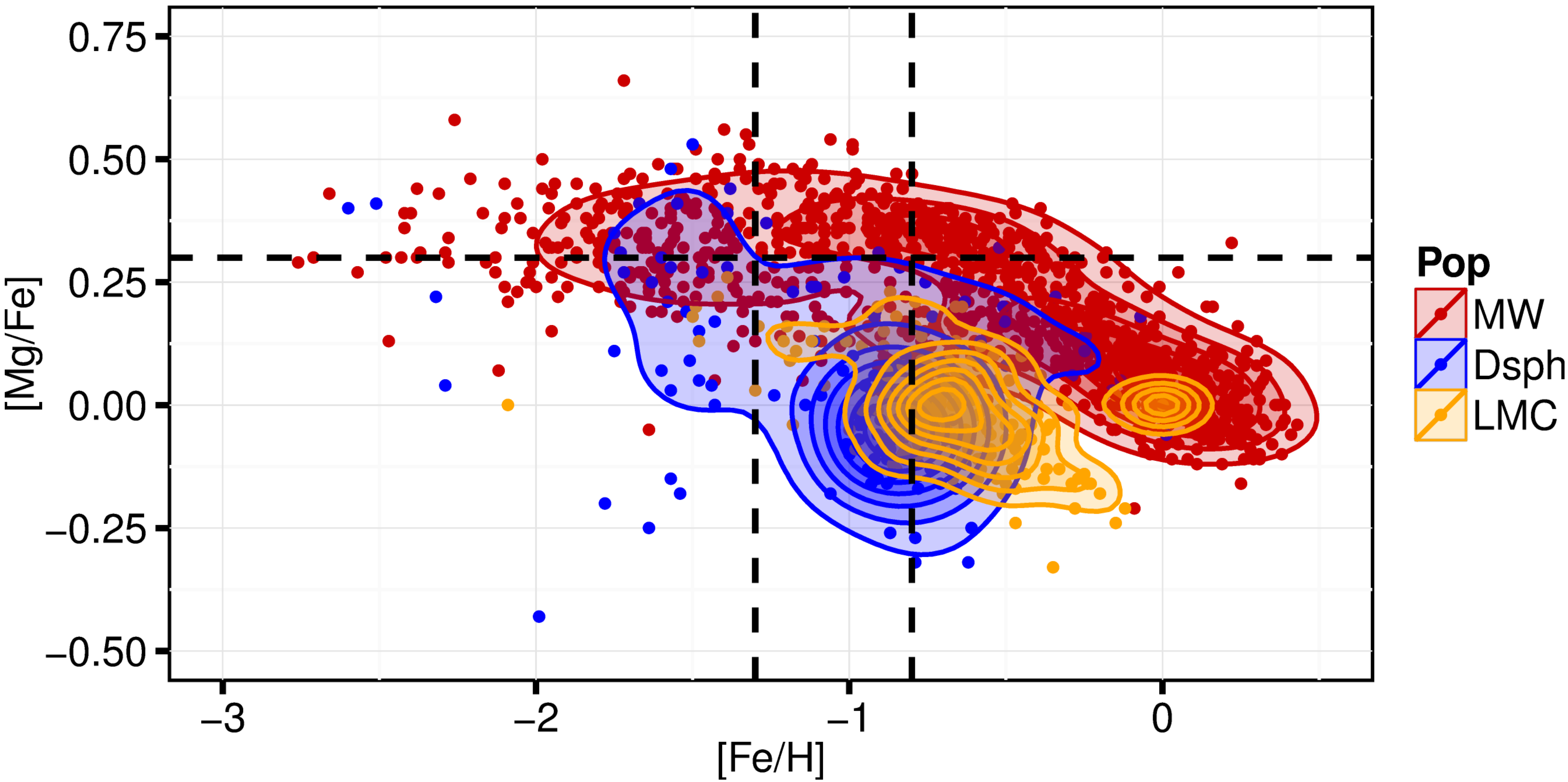


Measurement | The future



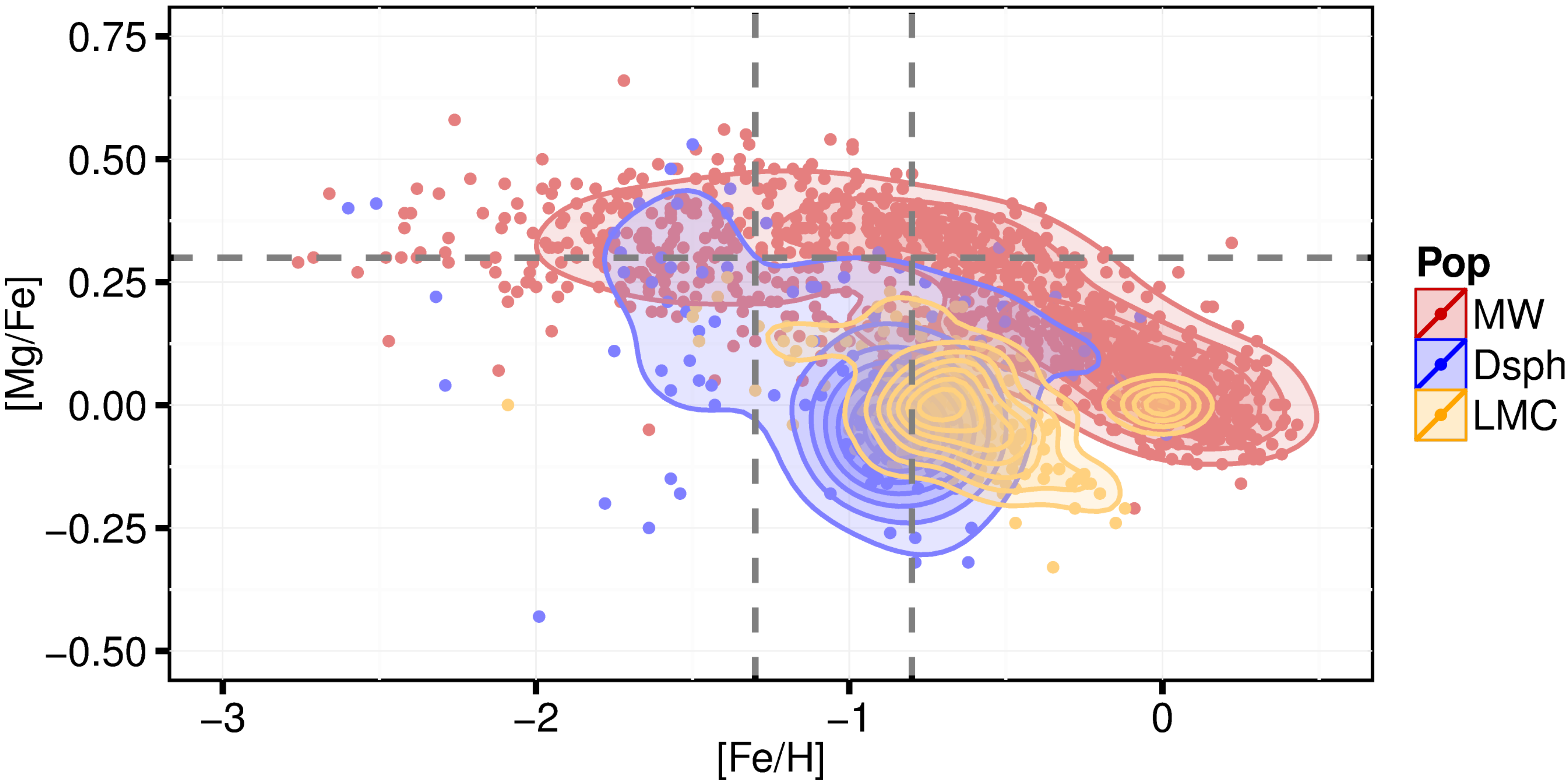
The accreted ‘dark disc’

The accreted disc | A chemodynamic template



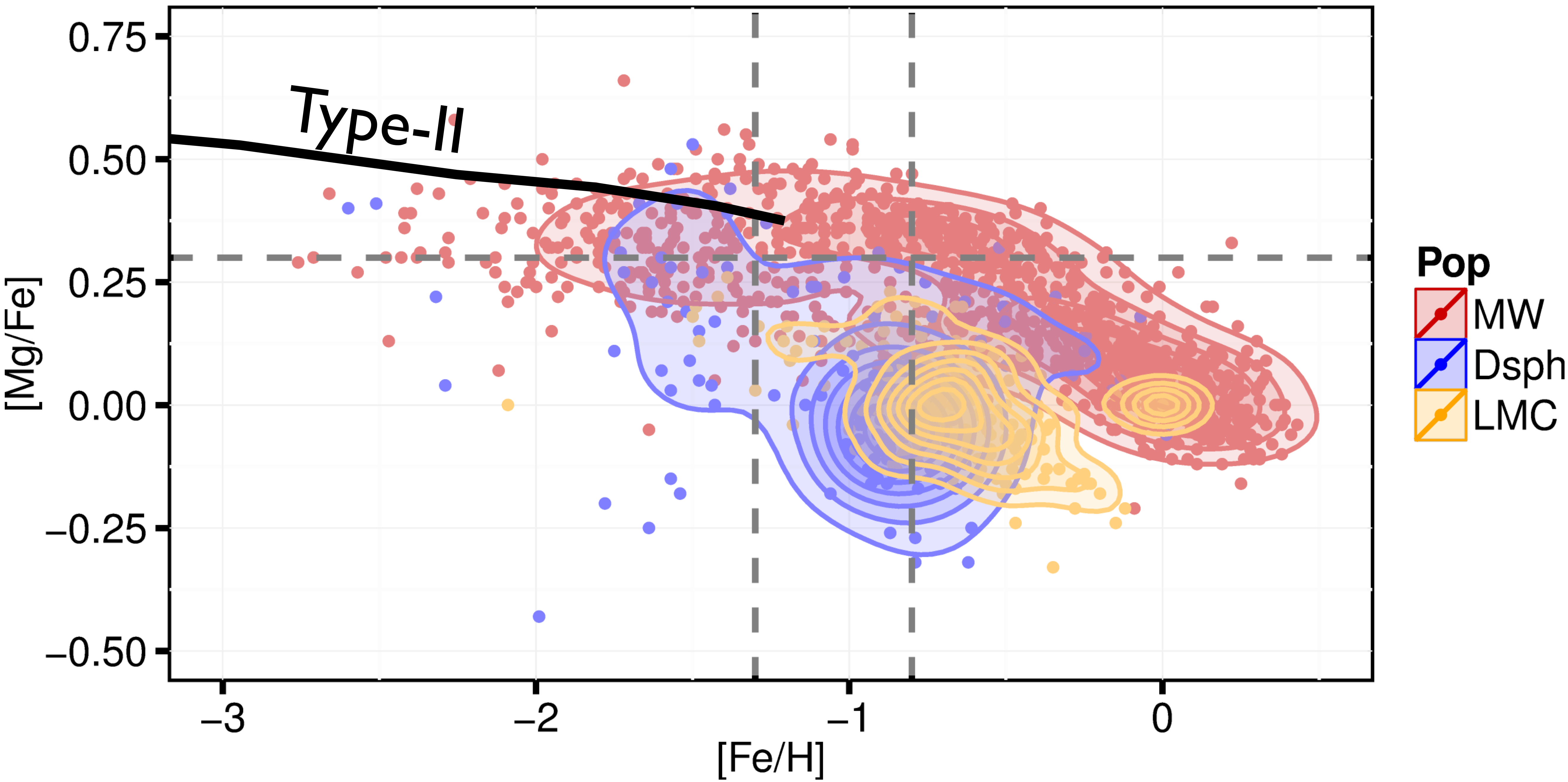
Ruchti, Read et al. 2014

The accreted disc | A chemodynamic template



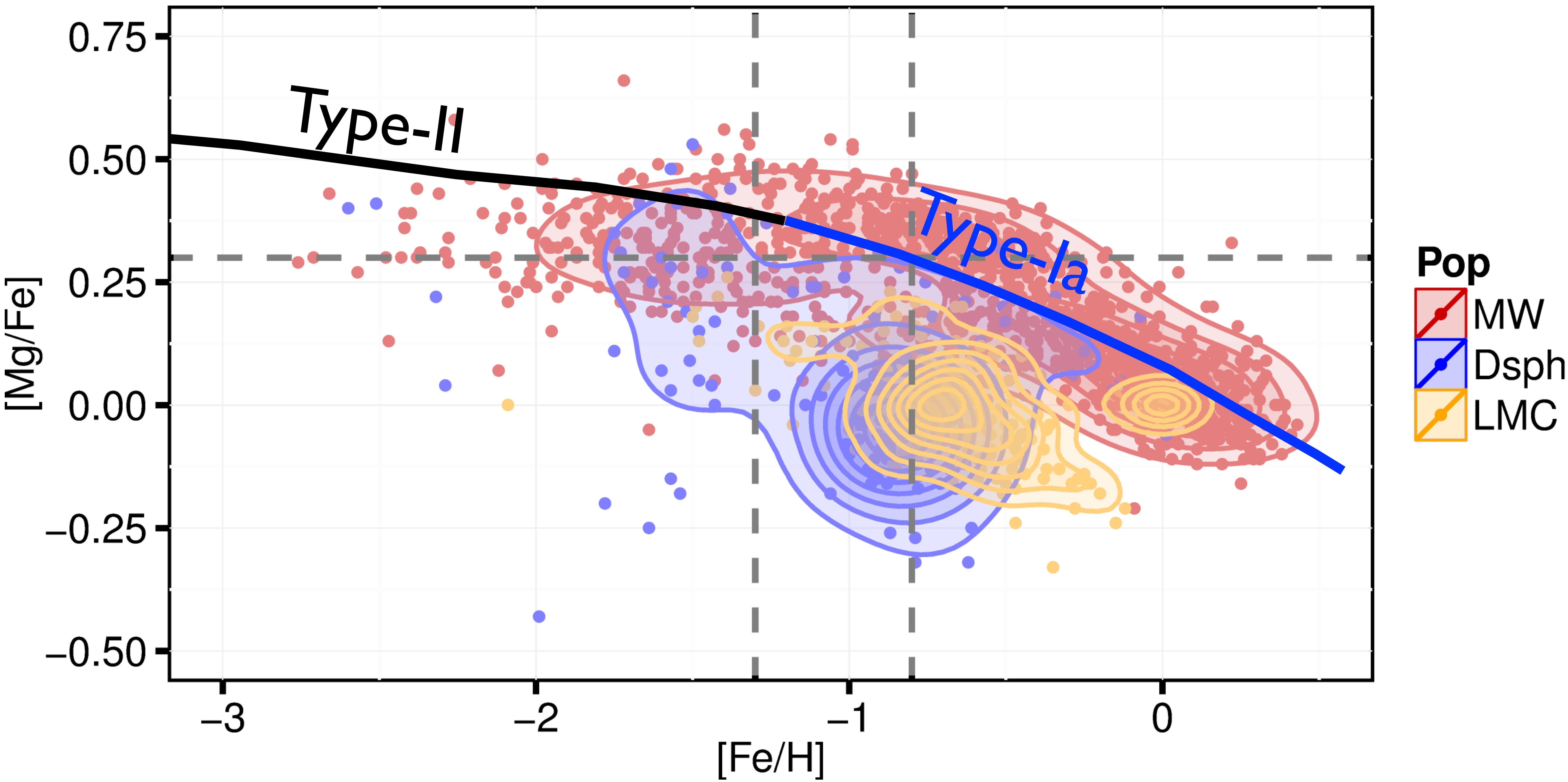
Ruchti, Read et al. 2014

The accreted disc | A chemodynamic template



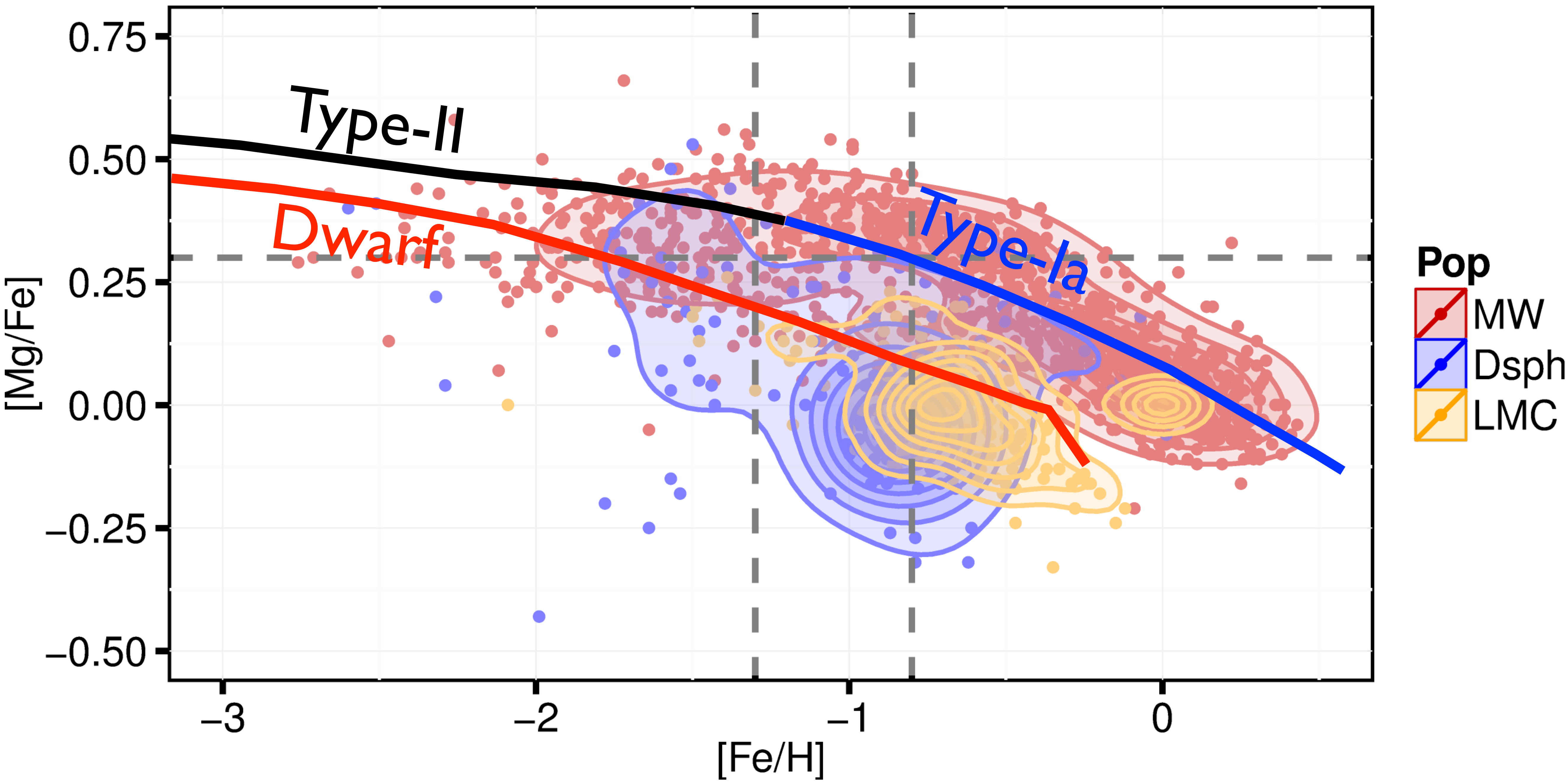
Ruchti, Read et al. 2014

The accreted disc | A chemodynamic template



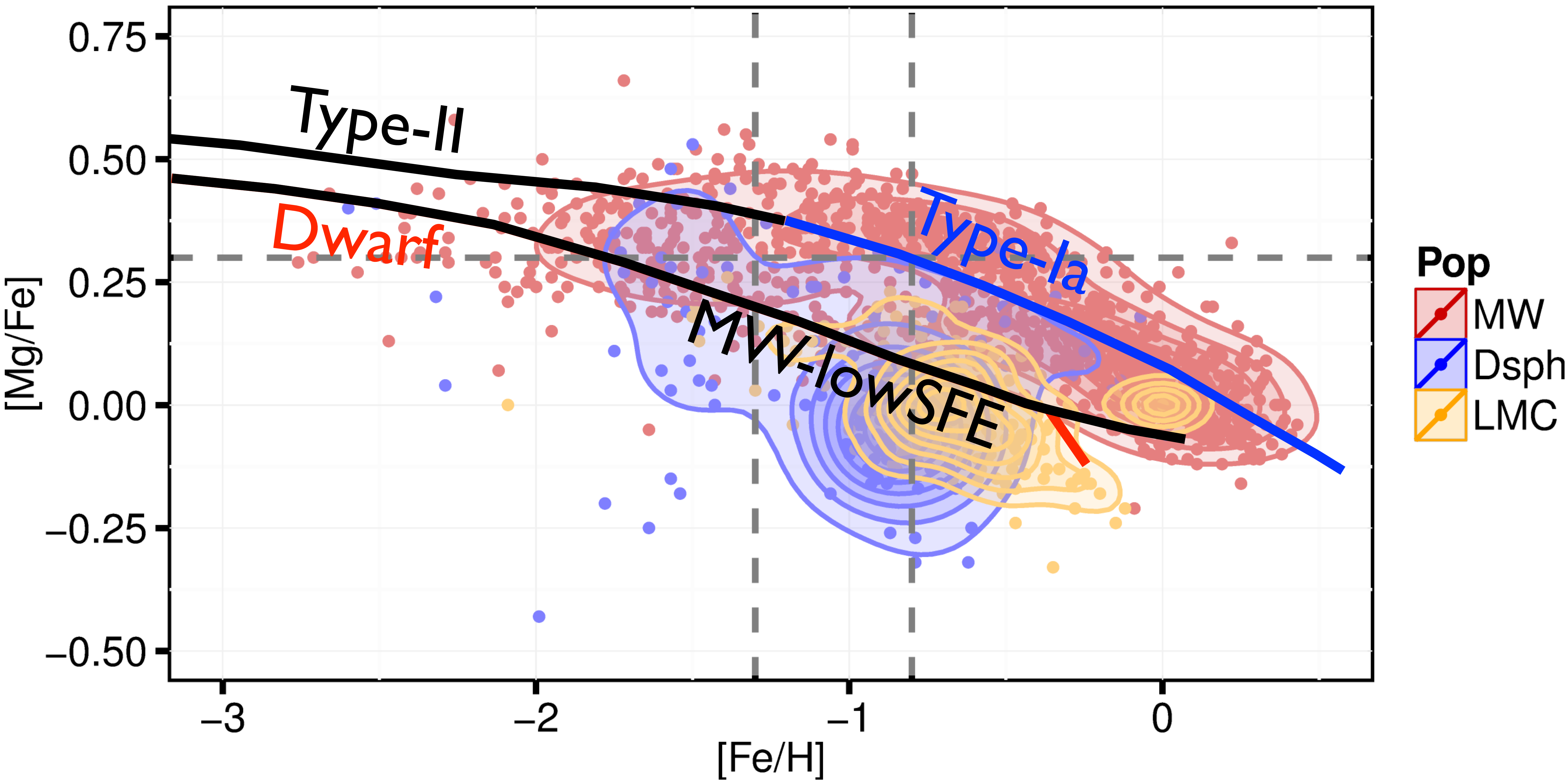
Ruchti, Read et al. 2014

The accreted disc | A chemodynamic template



Ruchti, Read et al. 2014

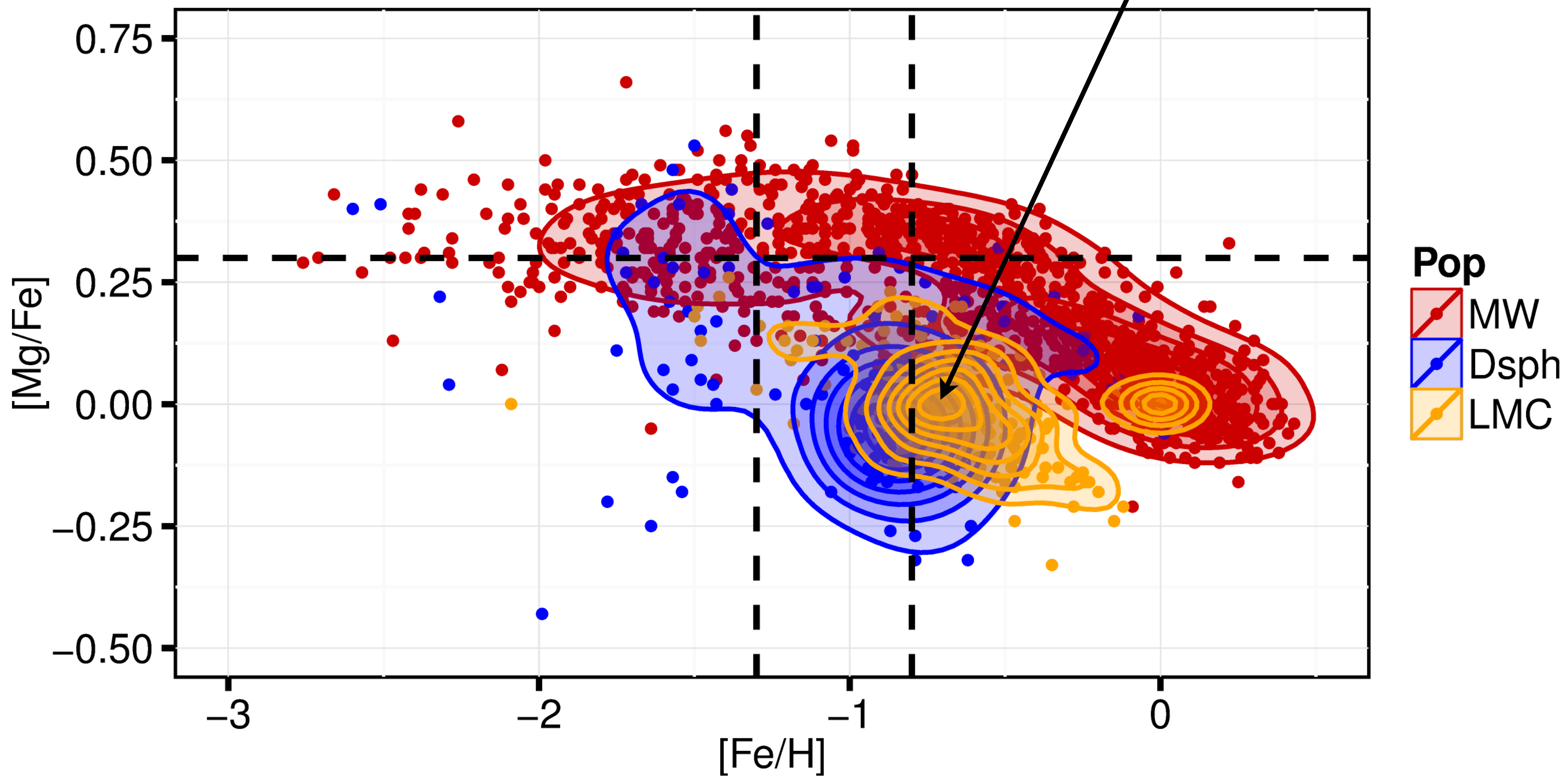
The accreted disc | A chemodynamic template



Ruchti, Read et al. 2014

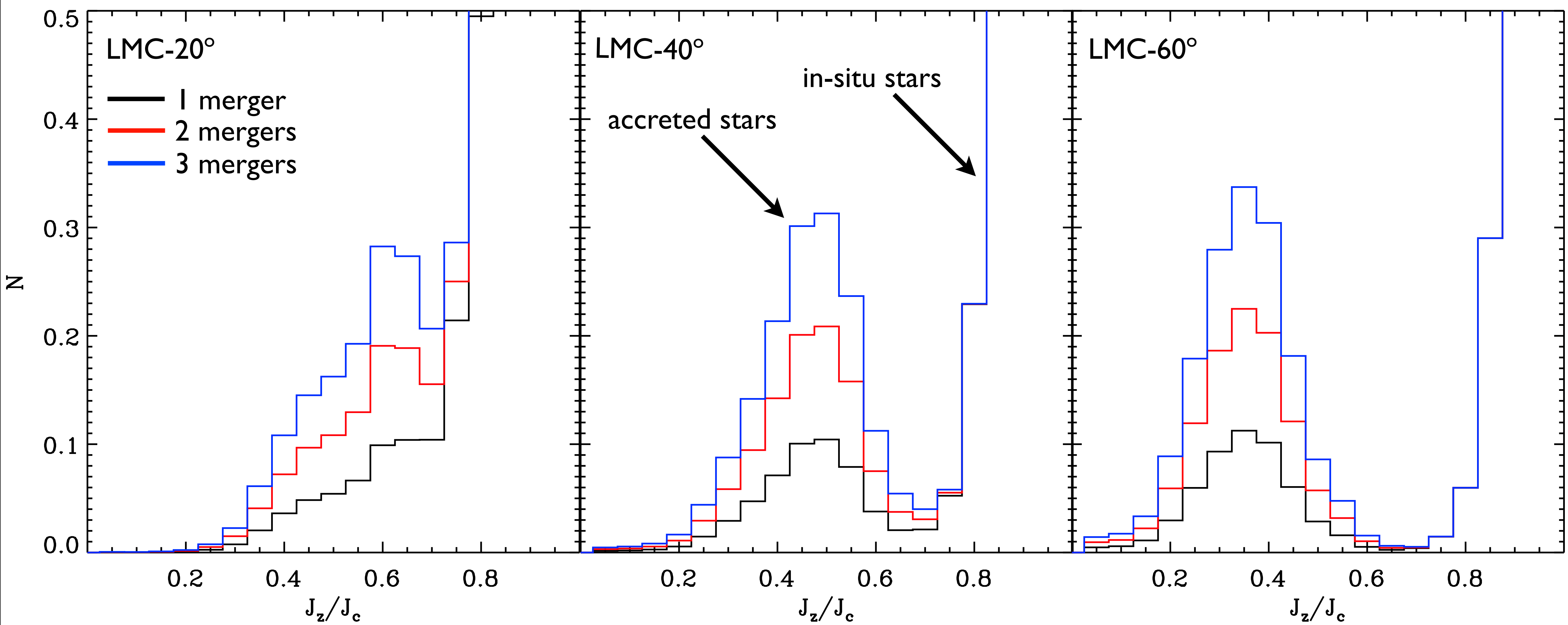
The accreted disc | A chemodynamic template

Born in dwarf or outer disc



Ruchti, Read et al. 2014

The accreted disc | A chemodynamic template



Ruchti, et al. 2015

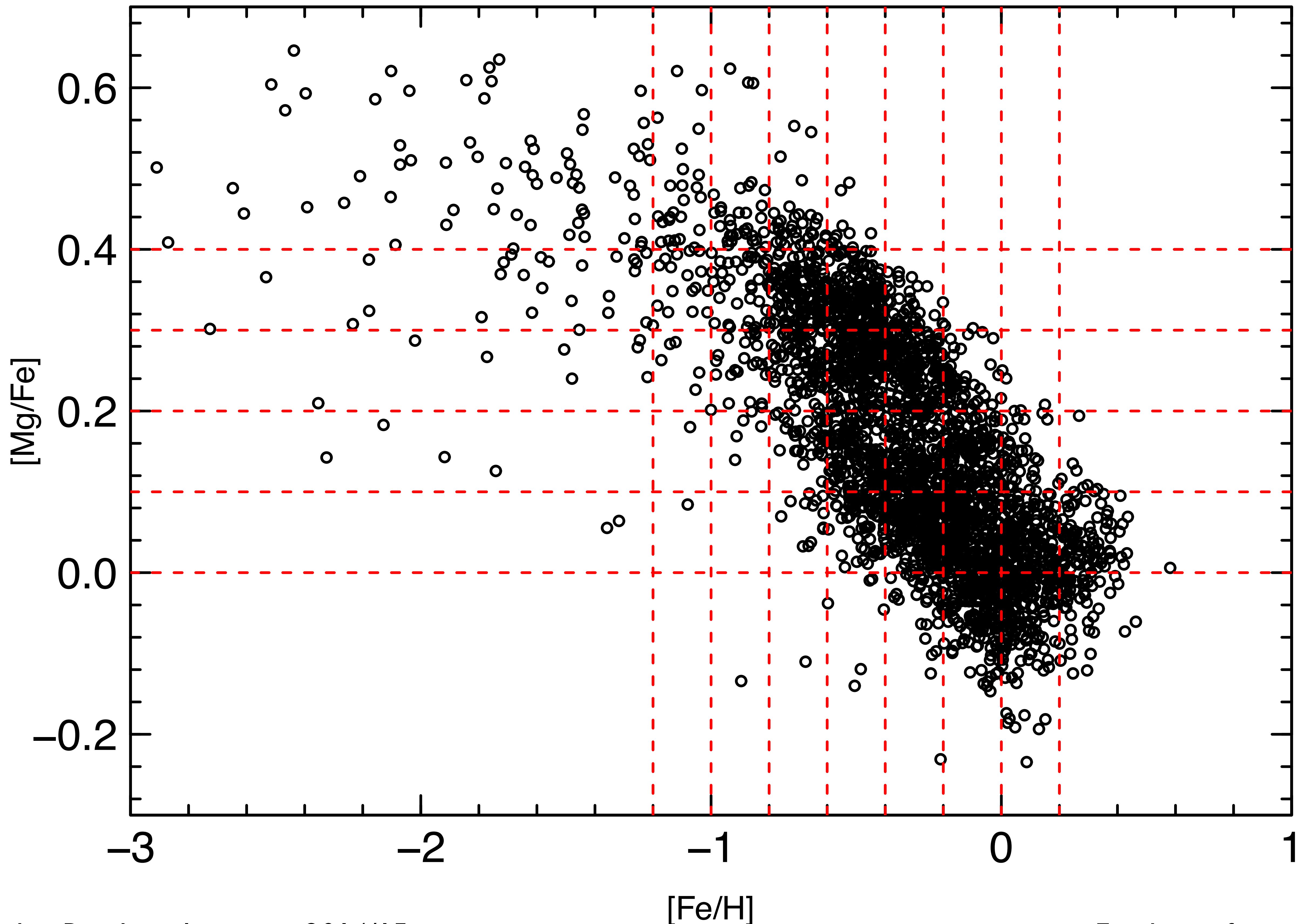
The accreted disc | The Gaia-ESO survey

- Medium resolution (R~18,000) GIRAFFE data.
- S/N > 20.
- Only Milky Way field stars (e.g. no clusters etc.).
- 3015 stars with distances; proper motions + radial velocities.
- Calculate $[E_z/E_c, J_z/J_c]$ for each star assuming a simple Galactic model.

Ruchti, Read et al. in prep. 2014/15

GaiaESO

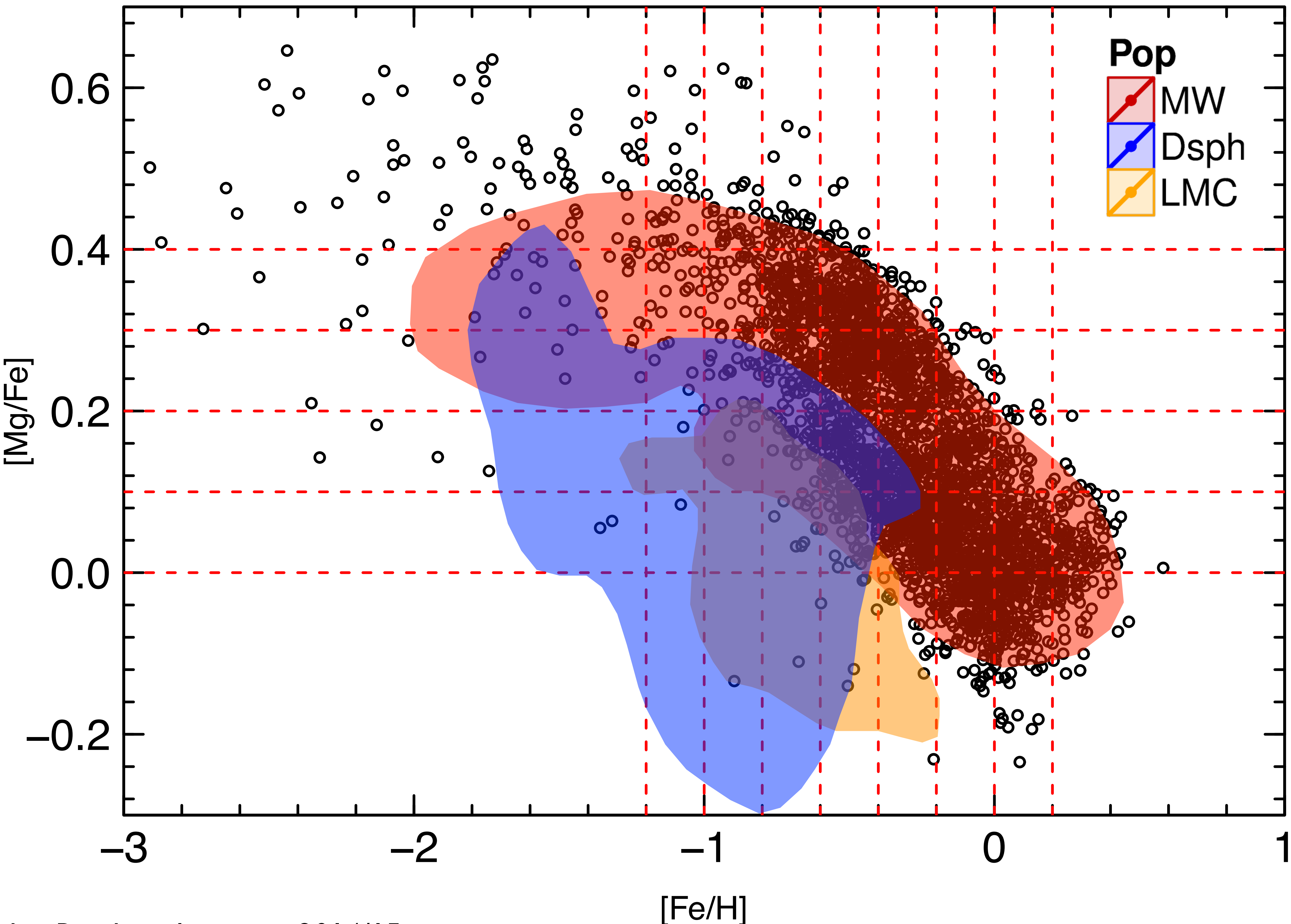
The accreted disc | The Gaia-ESO survey



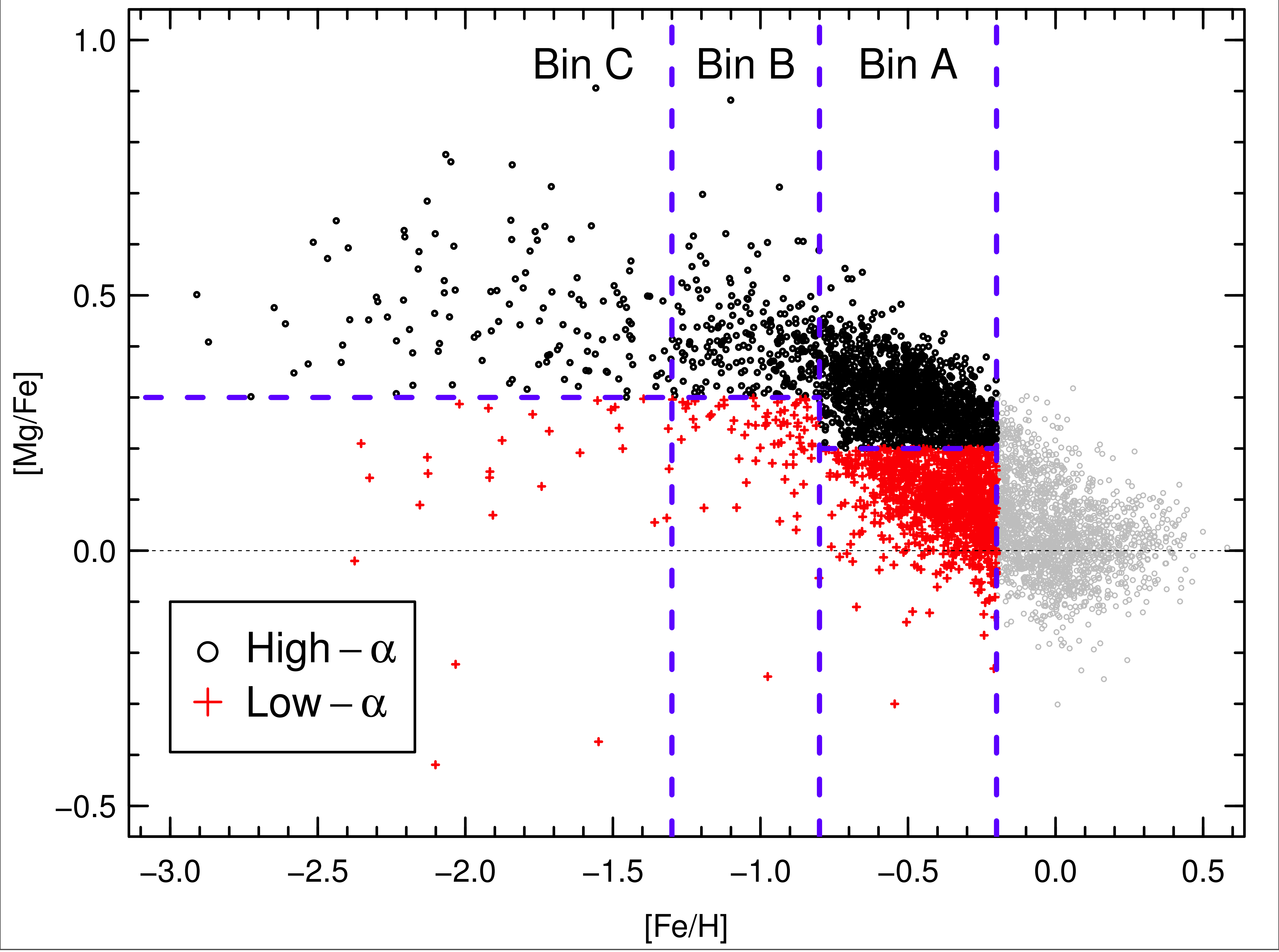
Ruchti, Read et al. in prep. 2014/15

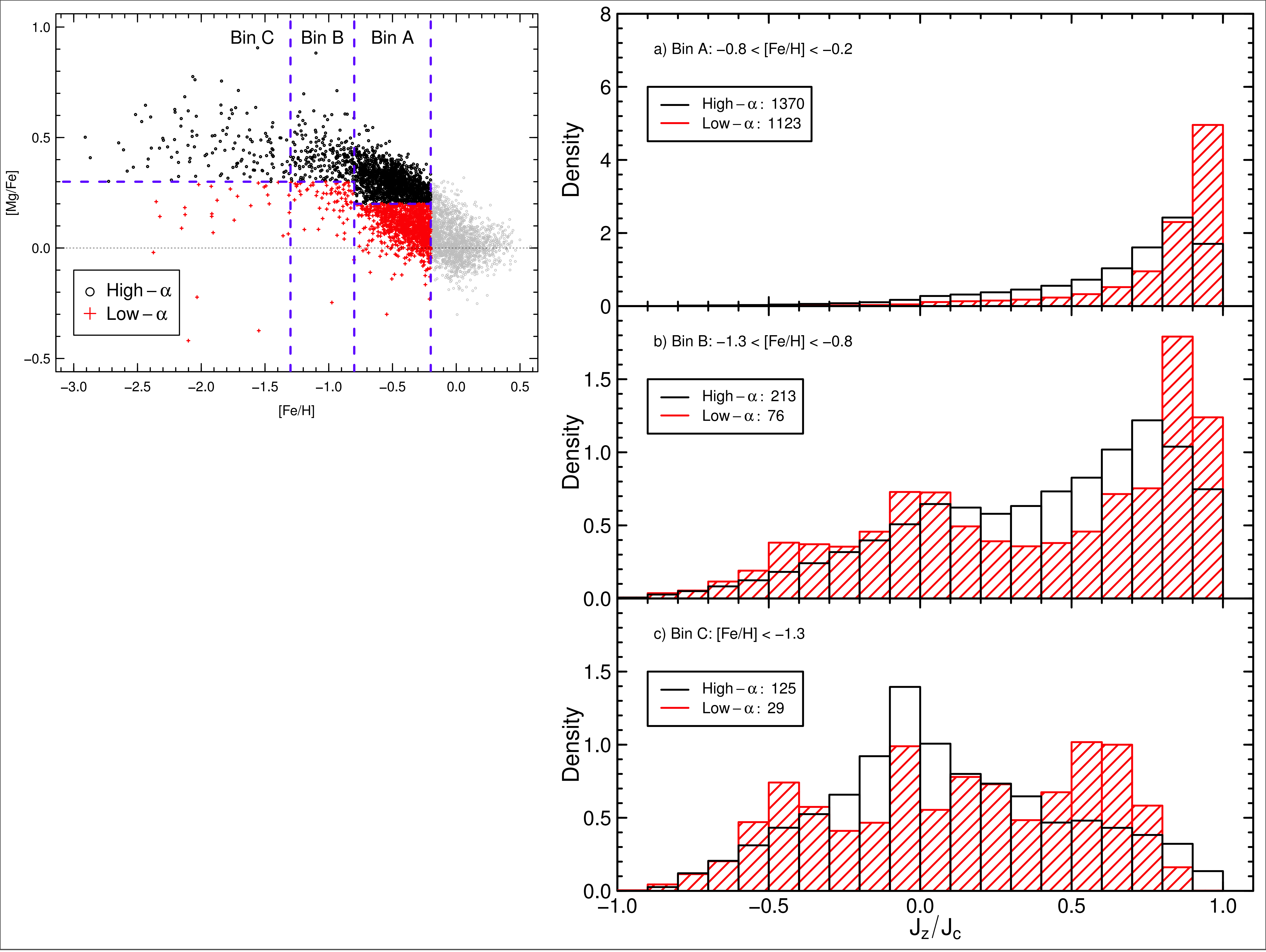
Further information:

The accreted disc | The Gaia-ESO survey

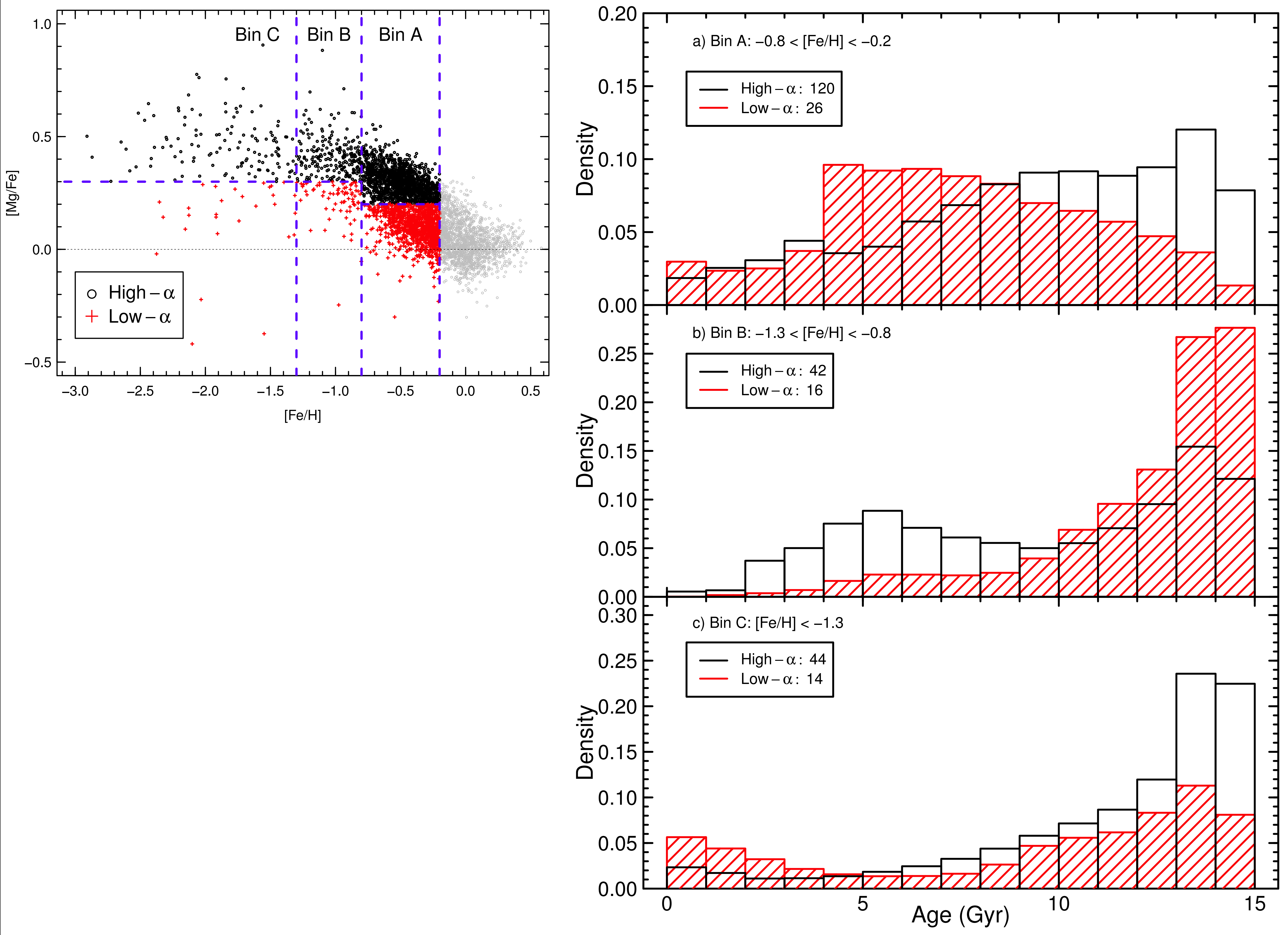


Ruchti, Read et al. in prep. 2014/15


Bin C
Bin B
Bin A
High − α
Low − α
[Mg/Fe]
[Fe/H]
1.0
0.5
0.0
−0.5
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5



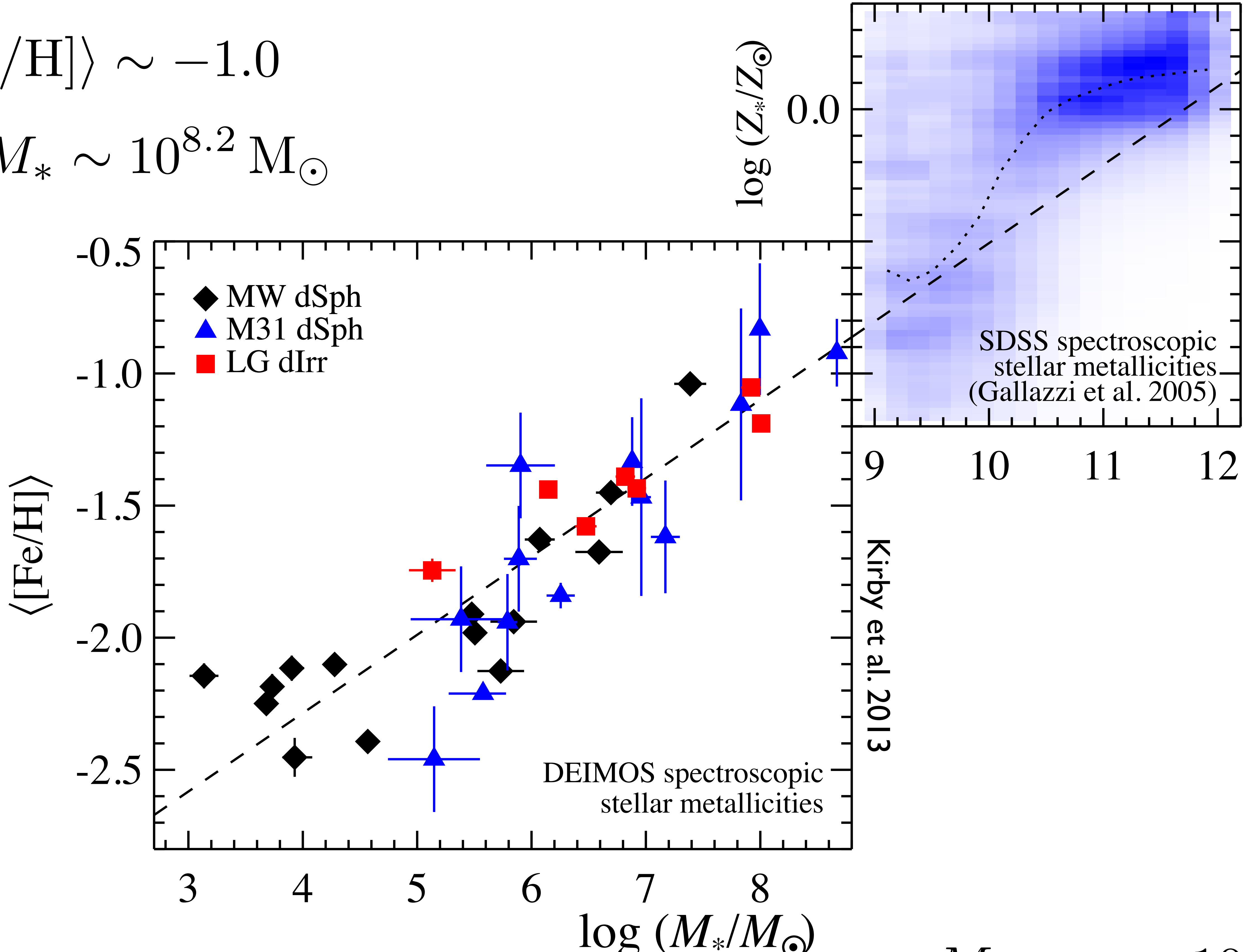
Thursday, June 4, 2015


Bin C
Bin B
Bin A
High − α
Low − α
[Mg/Fe]
[Fe/H]
a) Bin A: −0.8 < [Fe/H] < −0.2
High − α: 120
Low − α: 26
b) Bin B: −1.3 < [Fe/H] < −0.8
High − α: 42
Low − α: 16
c) Bin C: [Fe/H] < −1.3
High − α: 44
Low − α: 14
Density
Age (Gyr)

The accreted disc | The Gaia-ESO survey

$\langle [Fe/H] \rangle \sim -1.0$

$\Rightarrow M_* \sim 10^{8.2}\,\mathrm{M}_\odot$



Ruchti, Read et al. in prep. 2014/15

$M_{*,\mathrm{LMC}} \sim 10^{8.9}\,\mathrm{M}_\odot$

Conclusions

- Latest constraints on $\rho_{\rm dm}$ [assuming $\Sigma_b = 55\,{\rm M}_\odot\,{\rm pc}^{-2}$]:

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

[volume complete; G12*; R14]

$$\rho_{\rm dm} = 0.25 \pm 0.09\,{\rm GeV\,cm^{-3}}$$

[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 [and baryonic] density.