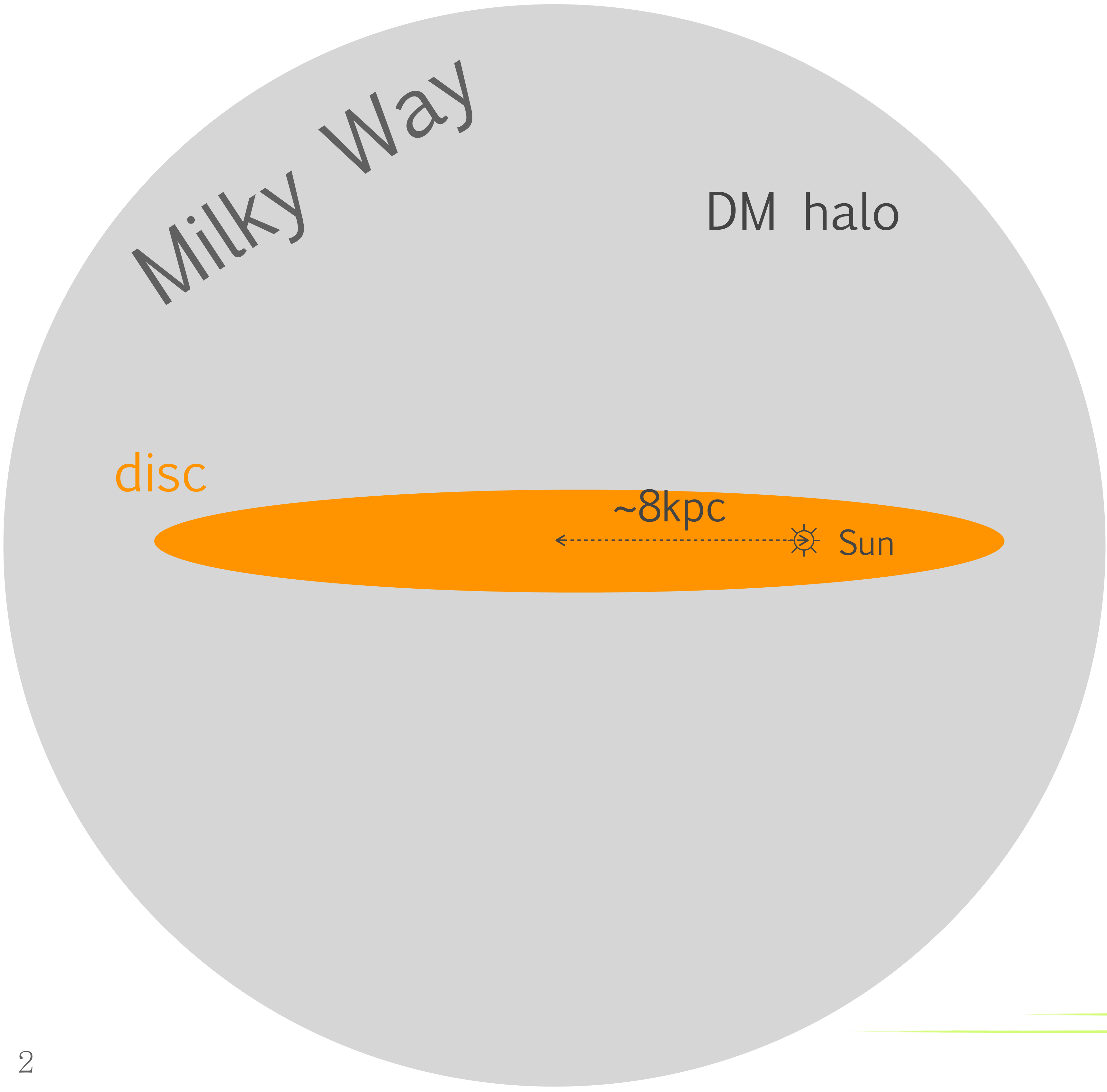
Institute for Theoretical Physics
University of Zurich

A new measurement of $\rho_{DM}(R_\odot)$ from the kinematics of K dwarfs

Silvia Garbari
with Justin Read, George Lake and Chao Liu

DARK ATTACK, Ascona 2012

Measuring the local dark matter density $\rho_{DM}(R_{\odot})$



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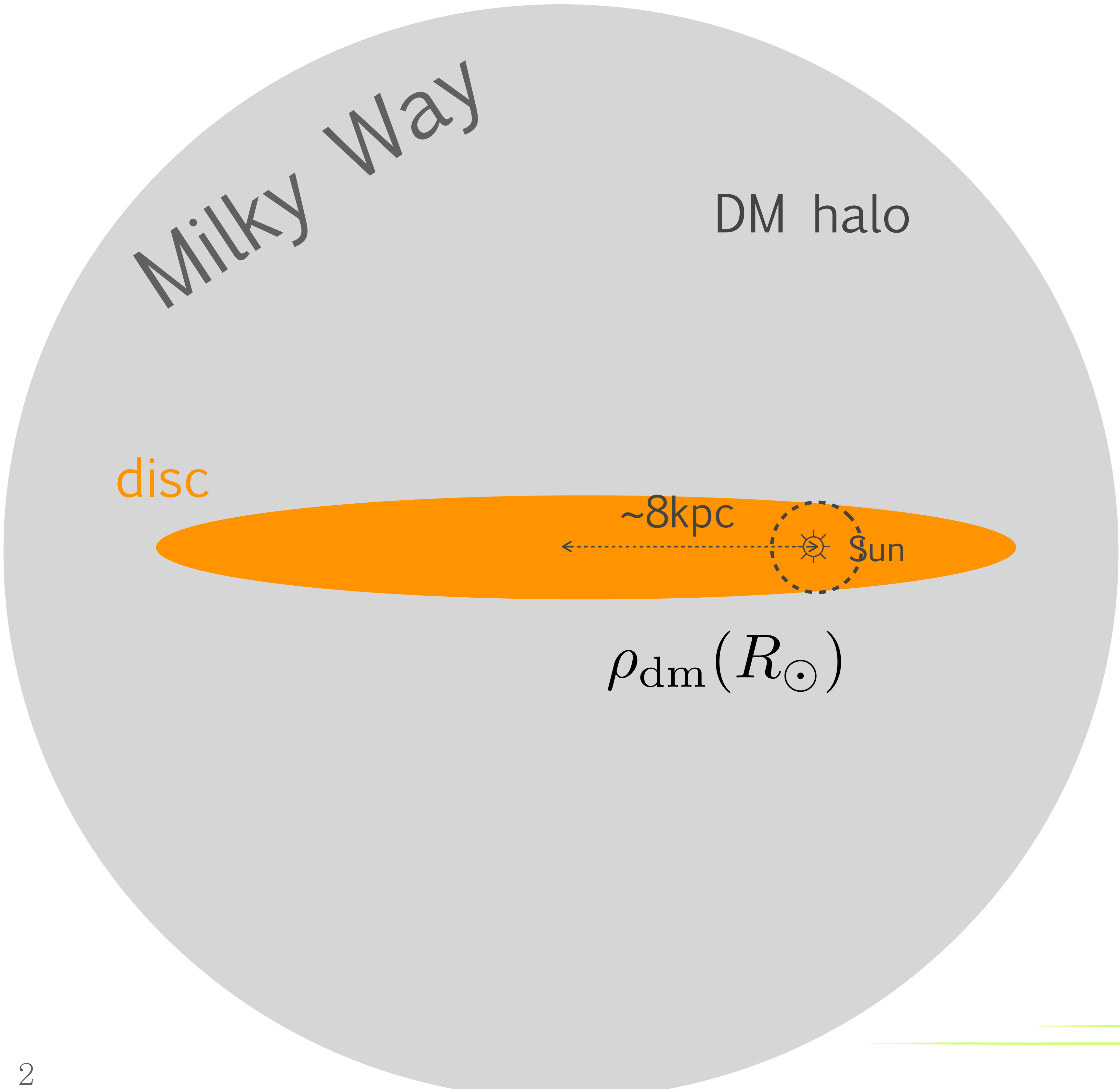

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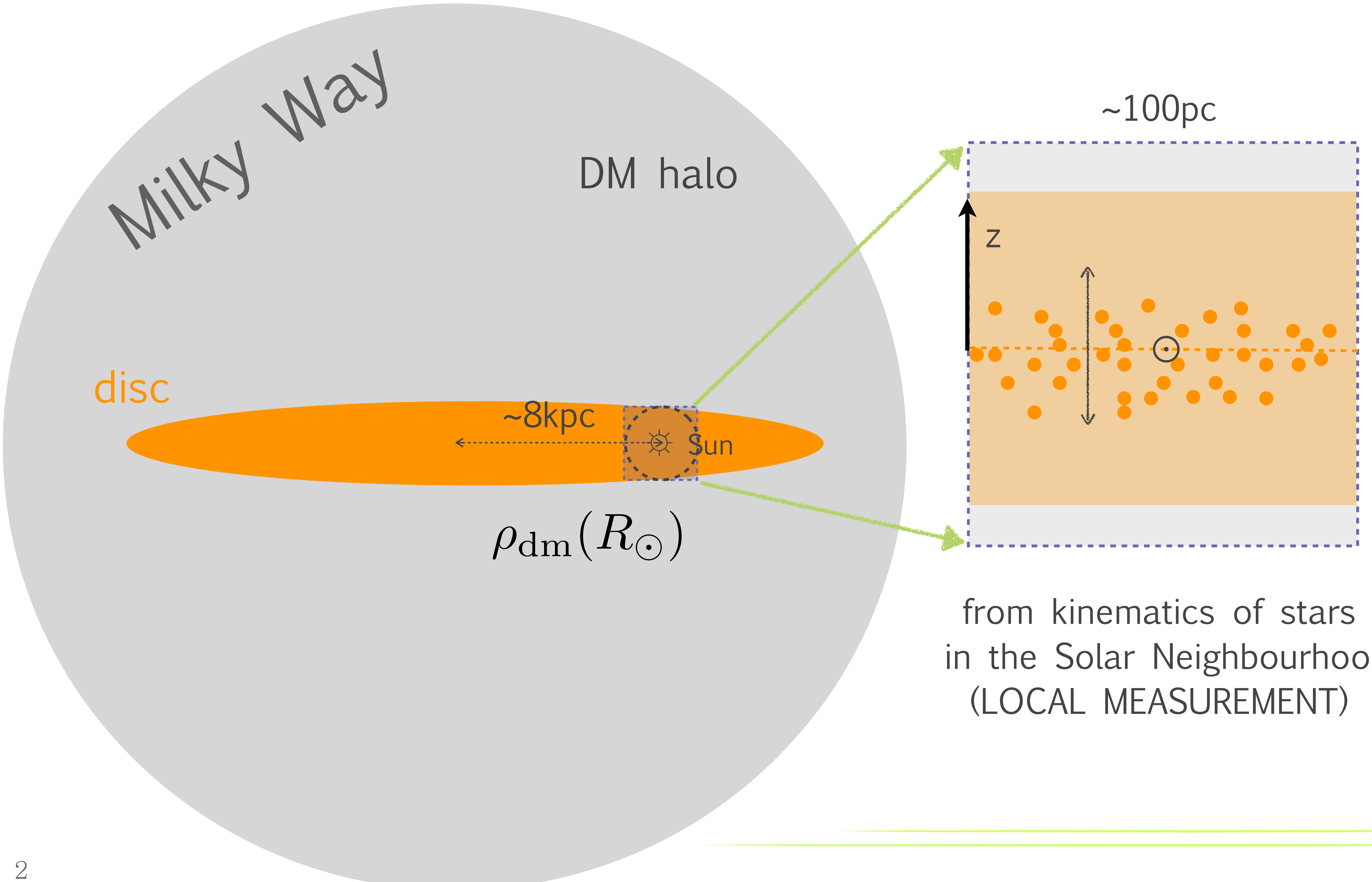
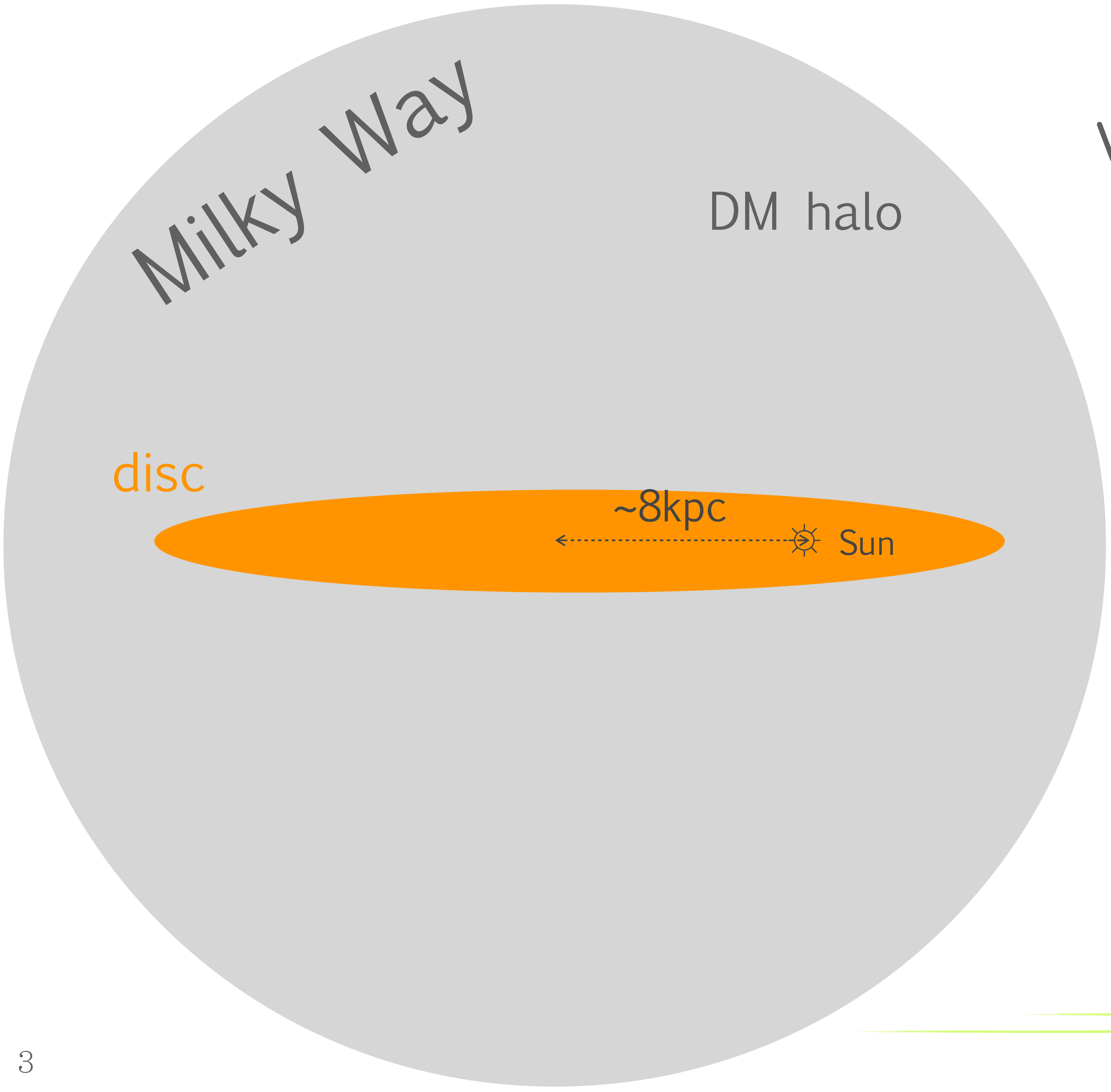
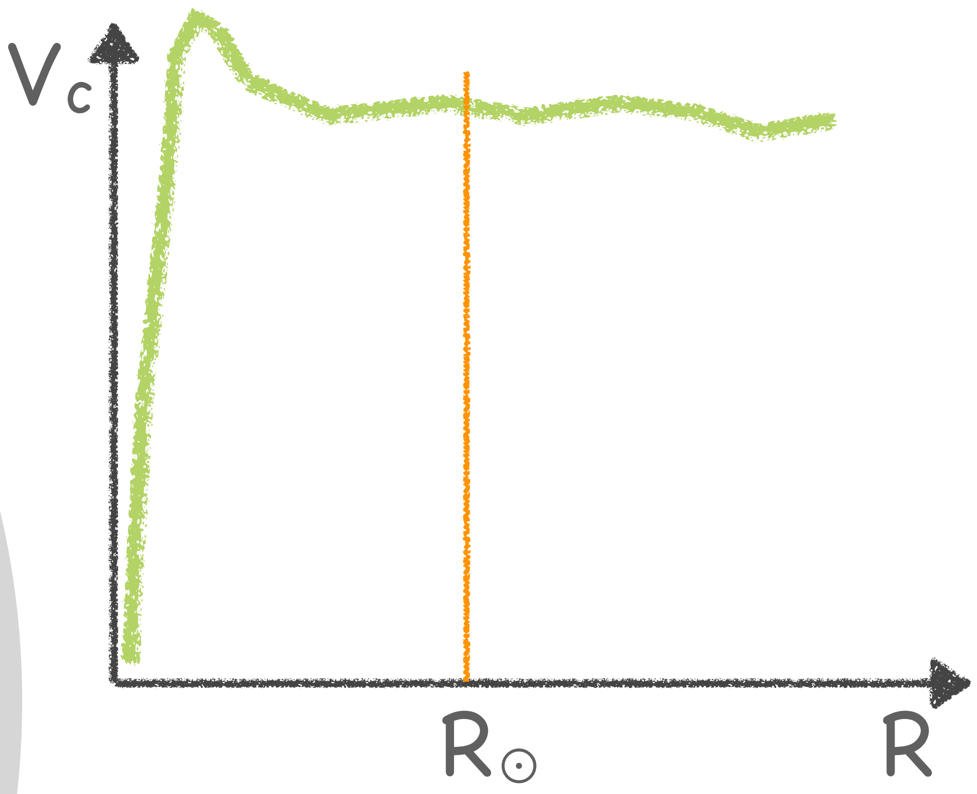


from kinematics of stars
in the Solar Neighbourhood
(LOCAL MEASUREMENT)

Measuring the local dark matter density $\rho_{DM}(R_\odot)$





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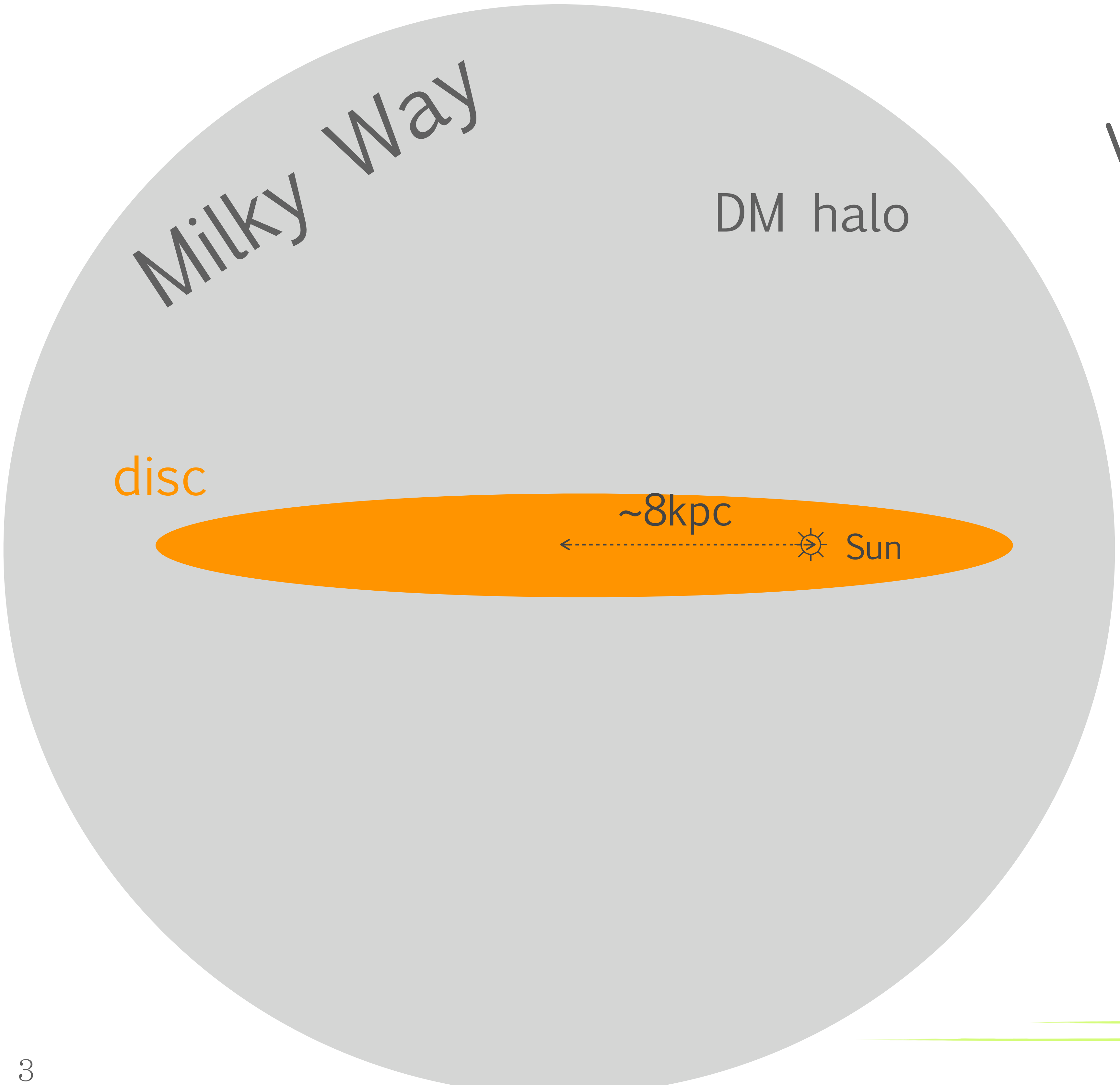

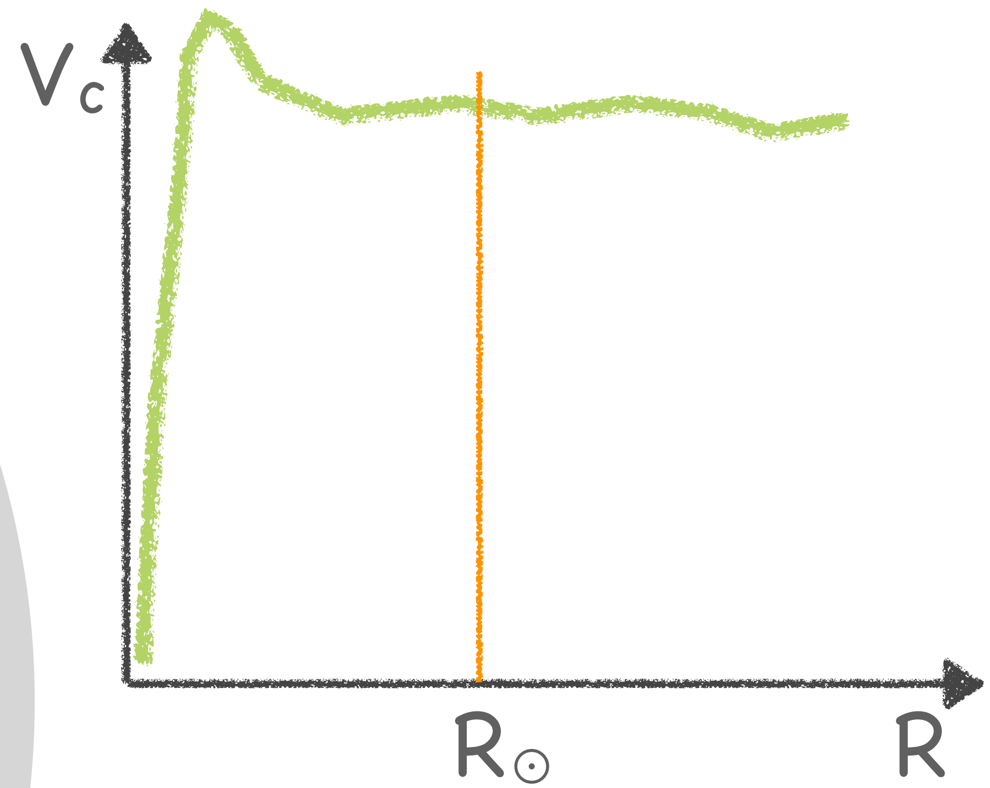

assumptions
on the halo shape

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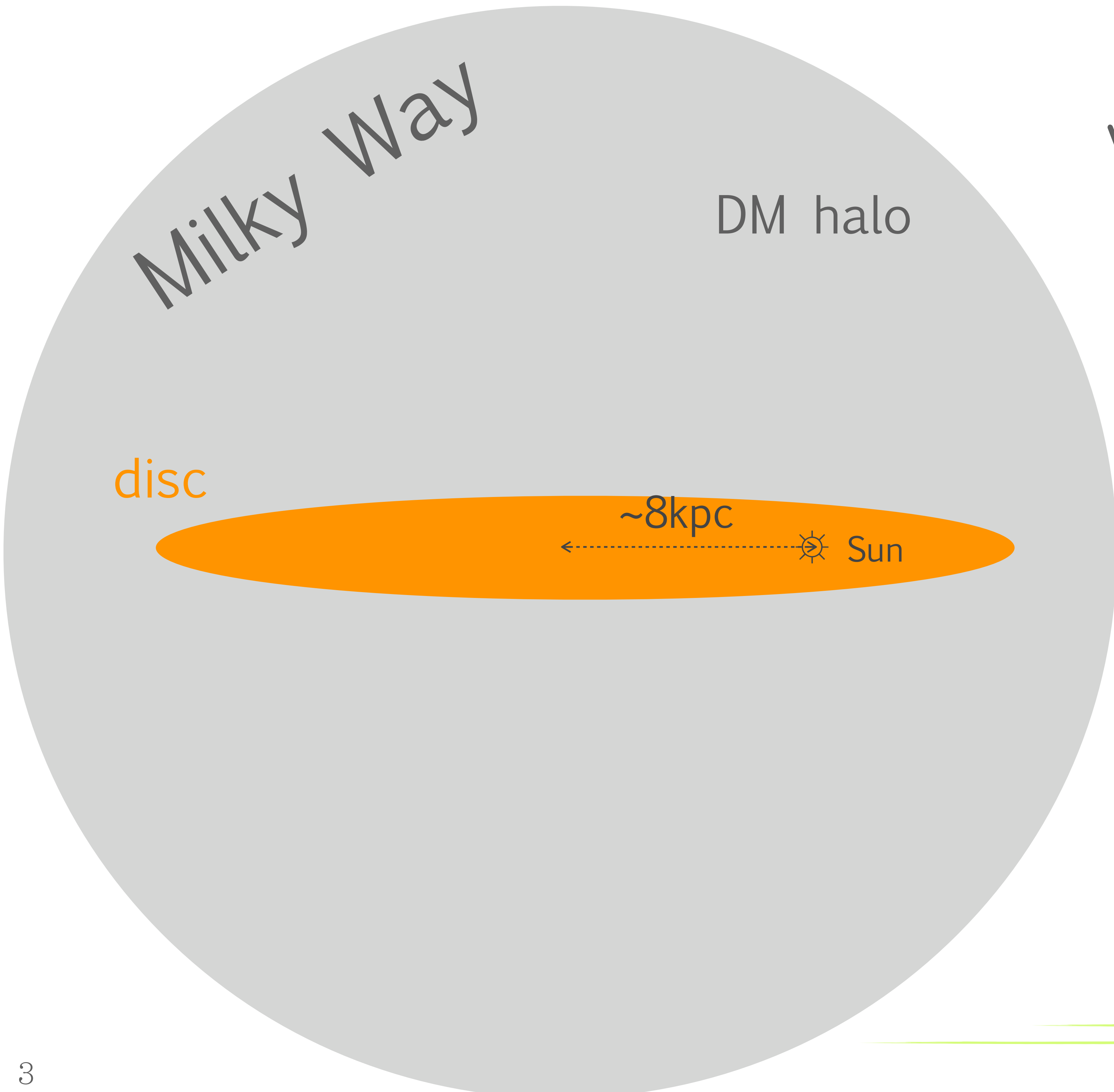

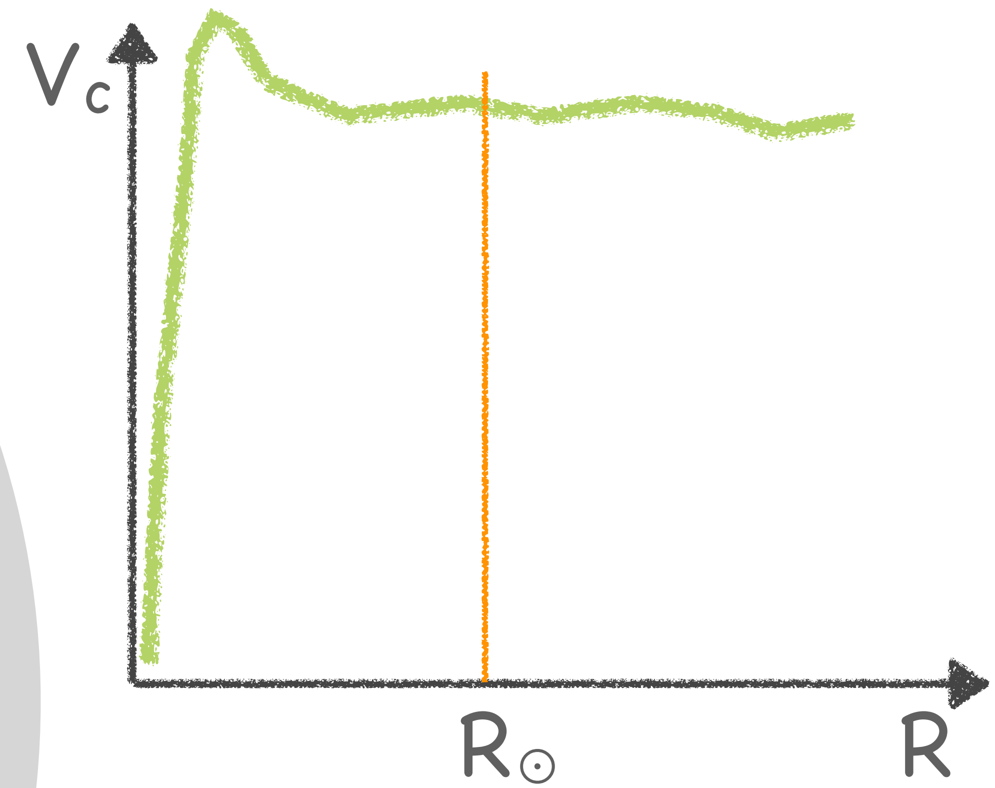

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$$V_c^2(R) = \frac{GM}{R}$$

spherical

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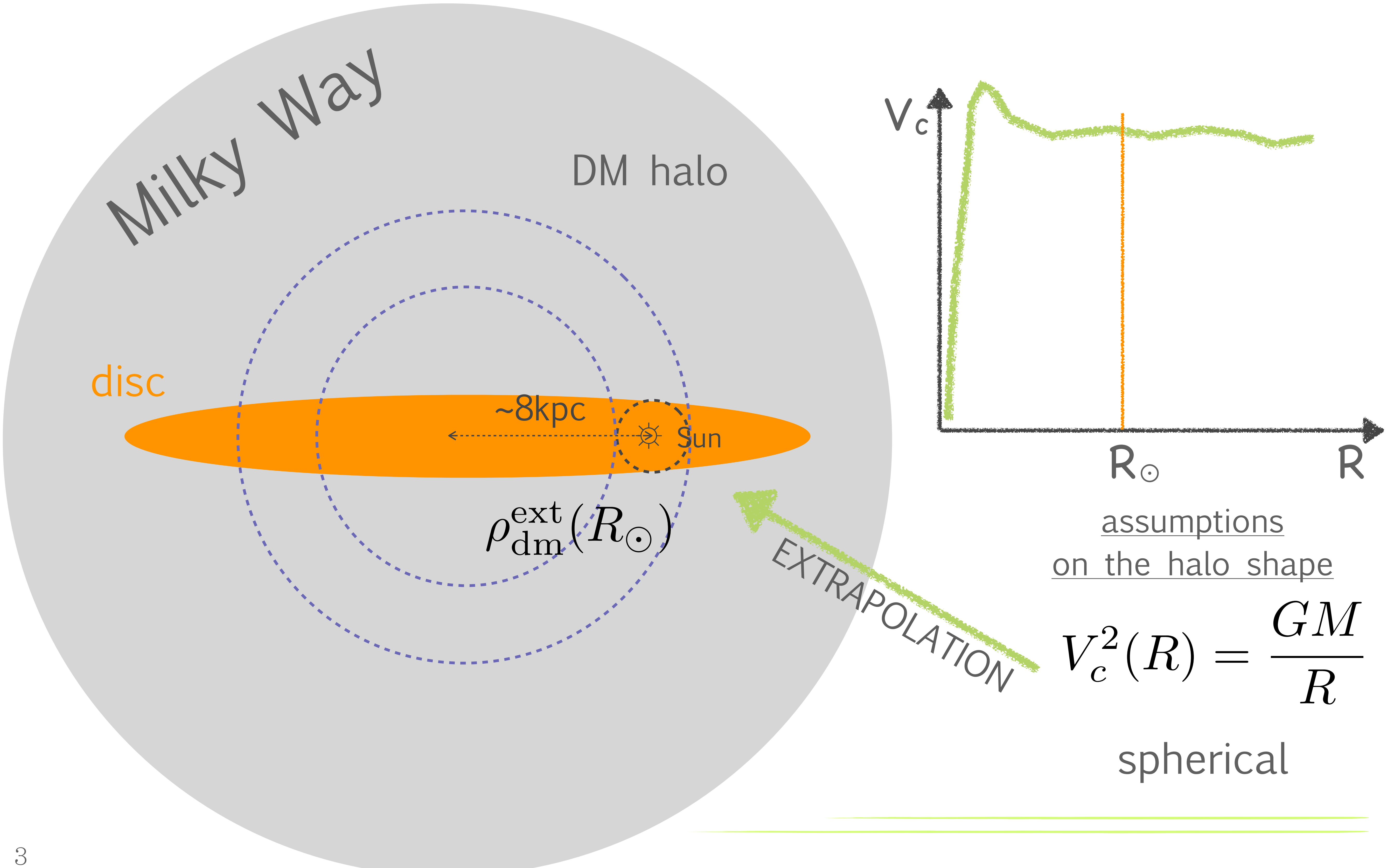

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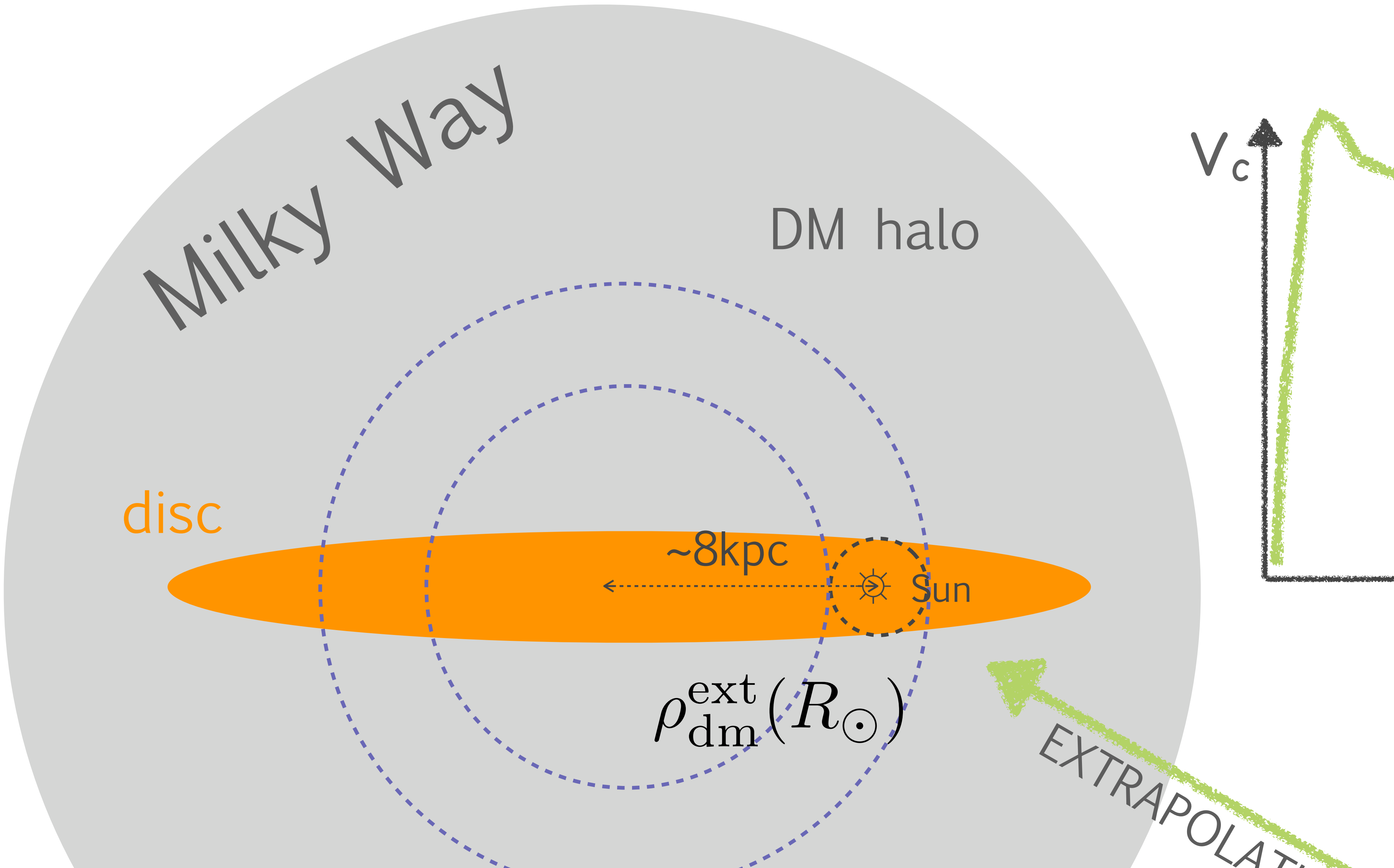

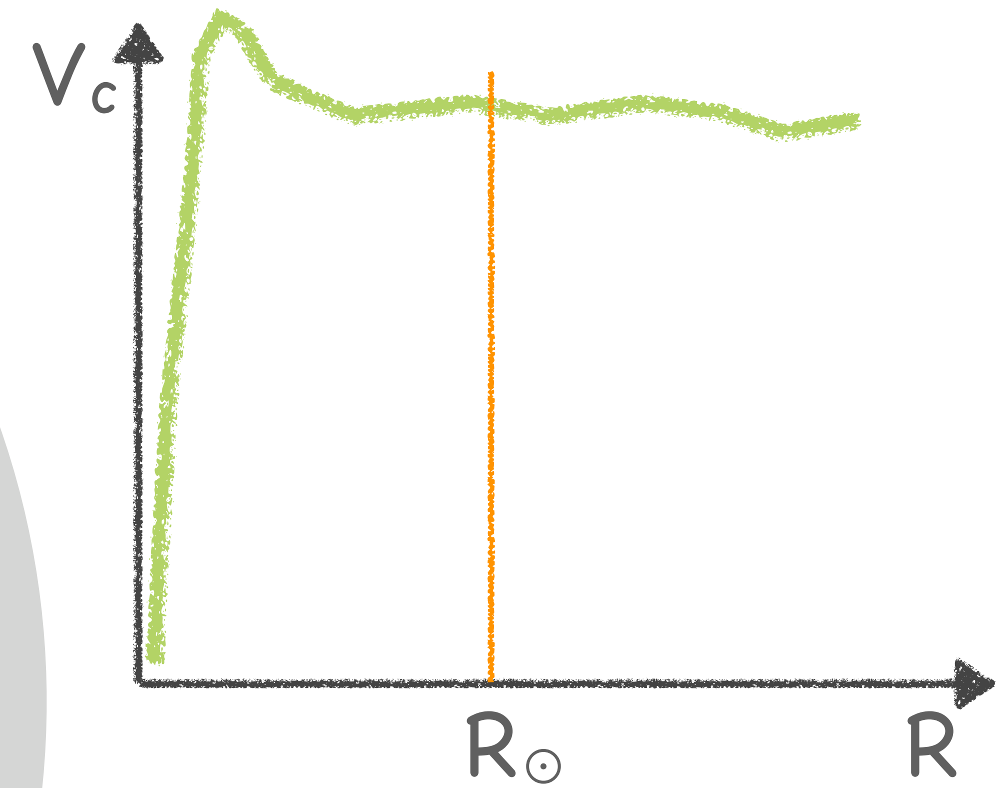

assumptions on the halo shape

$$V_c^2(R) = \frac{GM}{R}$$

spherical

$$\rho_{\rm dm}^{\rm ext}(R_\odot) \simeq 0.01 {\rm M}_\odot/{\rm pc}^3$$

visible: $\rho_{\rm s}(R_\odot) \simeq 0.1 {\rm M}_\odot/{\rm pc}^3$

Why is $\rho_{DM}(R_\odot)$ interesting?

1. Constraints on the shape of the DM Halo of the MW

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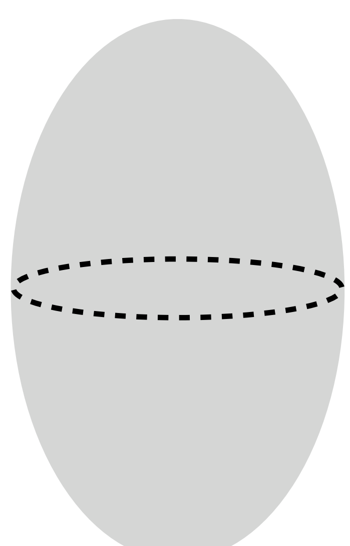
prolate halo



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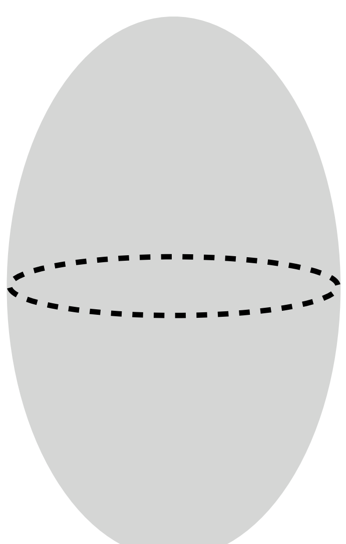
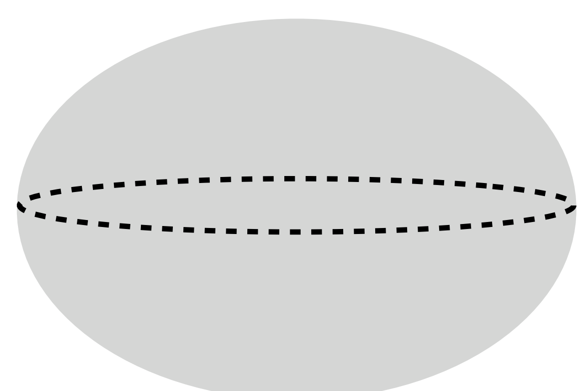
$$\rho_{\rm dm}(R_\odot) < \rho_{\rm dm}^{\rm ext}(R_\odot) \qquad \rho_{\rm dm}(R_\odot) > \rho_{\rm dm}^{\rm ext}(R_\odot)$$

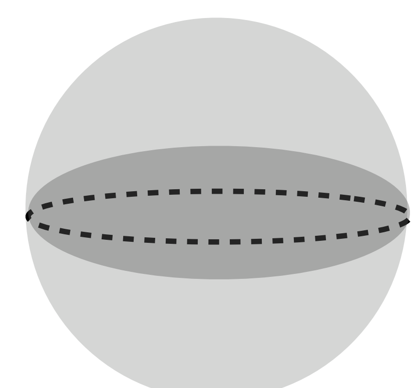
prolate halo



oblate halo

(or/and dark disc [Read 2008,2009])





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2. WIMPS detection experiments

if DM=WIMP (Weakly Interacting Massive Particles)

direct detection:

nuclear recoil caused by a WIMP scattering within the detector

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what we want to measure

Minimal Assumption Method

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

[Garbari, Read, Lake (2011) MNRAS 416, 2318]

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hyp. 1: the system is in equilibrium (steady state)

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Moments = Jeans equations

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

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hyp. 2: tilt term is negligible

⇆ $z_d << R_d$ [Bahcall, 1984; Binney&Tremaine 2008]

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$$\frac{\nu_i(z_*)}{\nu_i(0)} = \frac{\overline{v_{z,i}^2}(0)}{\overline{v_{z,i}^2}(z_*)}\exp\left(-\int_0^{z_*}\frac{1}{\overline{v_{z,i}^2}(z)}\frac{d\Phi}{dz}dz\right)$$

[Garbari, Read, Lake (2011) MNRAS 416, 2318]

Minimal Assumption Method

Tracer population:

$$\frac{\nu_i(z_*)}{\nu_i(0)} = \frac{\overline{v_{z,i}^2}(0)}{\overline{v_{z,i}^2}(z_*)} \exp\left(-\int_0^{z_*} \frac{1}{\overline{v_{z,i}^2}(z)} \frac{d\Phi}{dz} dz\right)$$

Poisson: matter density

$$4\pi G(\rho_{\rm s} + \rho_{\rm dm}) = \frac{\partial^2 \Phi}{\partial z^2} + \frac{1}{R}\frac{\partial}{\partial R}\left(R\frac{\partial \Phi}{\partial R}\right)$$

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hyp. 3: ρ_dm independent of z

$$\rho_\mathrm{dm}(z) = \rho_\mathrm{dm}(0)$$

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negligible

$$\frac{1}{R}\frac{\partial}{\partial R}\left(R\frac{\partial \Phi}{\partial R}\right) = \frac{1}{R}\frac{\partial V_c^2}{\partial R} = 2(B^2 - A^2)$$

[Garbari, Read, Lake (2011) MNRAS 416, 2318]

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MCMC

[Garbari, Read, Lake (2011) MNRAS 416, 2318]

HF method [Holmberg & Flynn, 2000]

hyp. 5: the distribution function is separable

$$f = f_{R,\theta}(v_R, v_\theta, R) \times f_z(v_z, z)$$

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$$f(v_z(z), z)$$

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$f(v_z(z), z)$ ← $f(v_z(0), 0)$ observed

$\Phi(z)$ calculated

Testing the methods with simulations

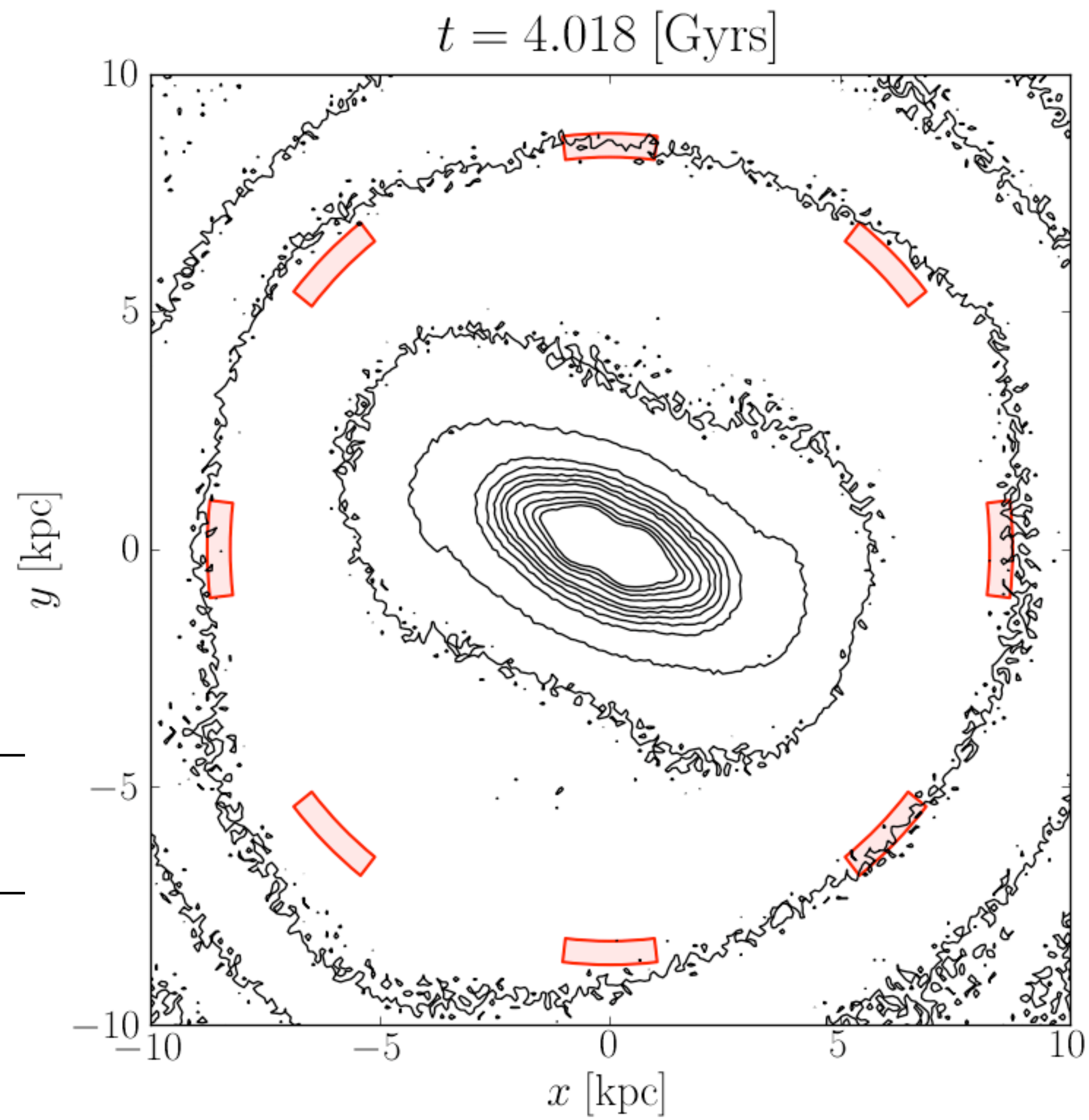
simulation

	N (10^6)	M (10^{10} M$_\odot$)	ε (kpc)	$R_{1/2}$ (kpc)	$z_{1/2}$ (kpc)
Disc	30	5.30	0.015	4.99	0.17
Bulge	0.5	0.83	0.012	–	–
Halo	15	45.40	0.045	–	–

Milky Way

	M (10^{10} M$_\odot$)	$R_{1/2}$ (kpc)	$z_{1/2}$ (kpc)
Thin disc	3.5–5.5[a]	3.35–9.24	∼0.14–0.18
Thick disc	–	5.04–7.56	0.49–0.84
Bulge	∼1	–	–
Halo	∼40–200	–	–

[a]Total disc mass.



Garbari, Liu, Read & Lake accepted for publication in MNRAS

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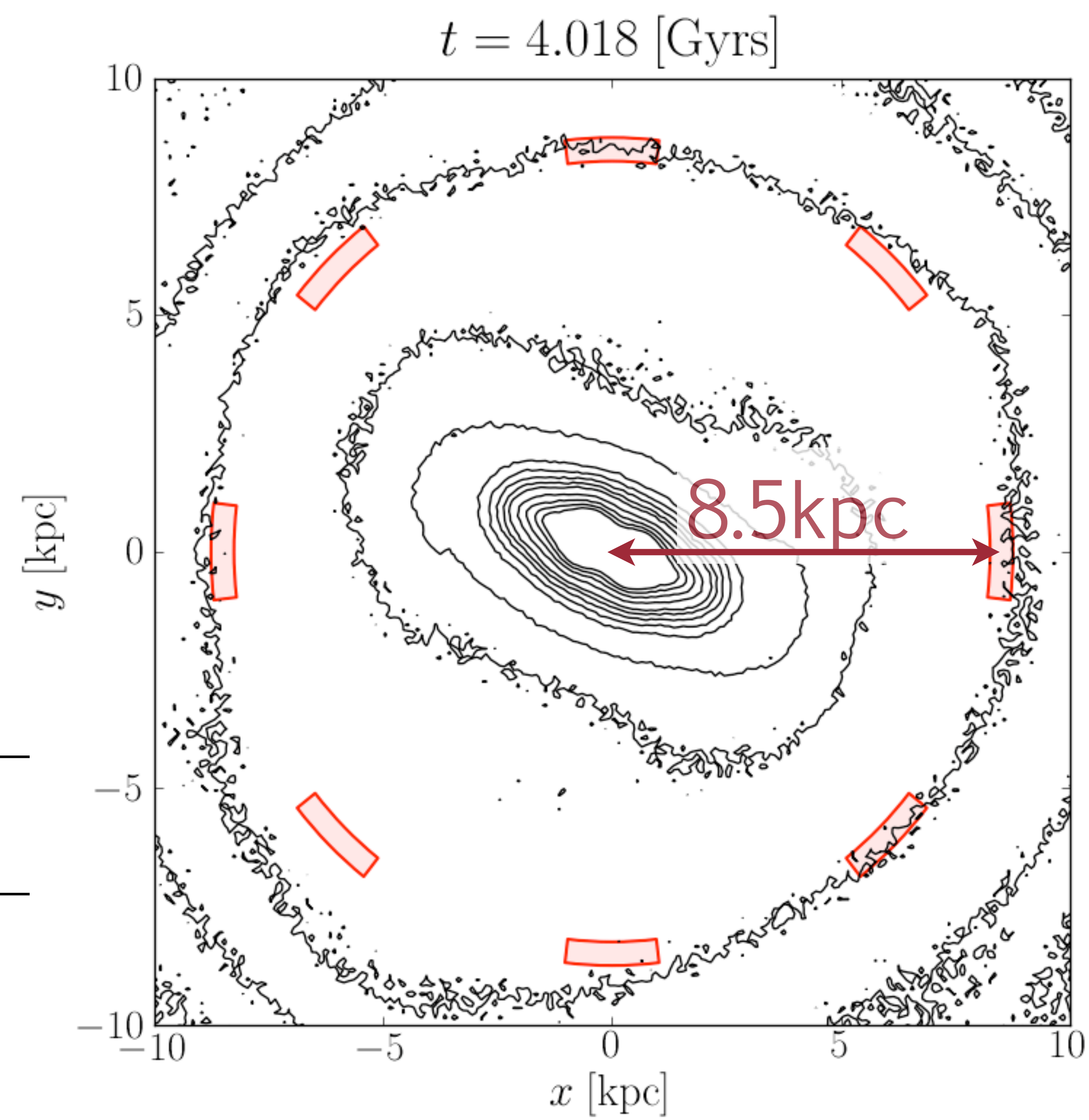

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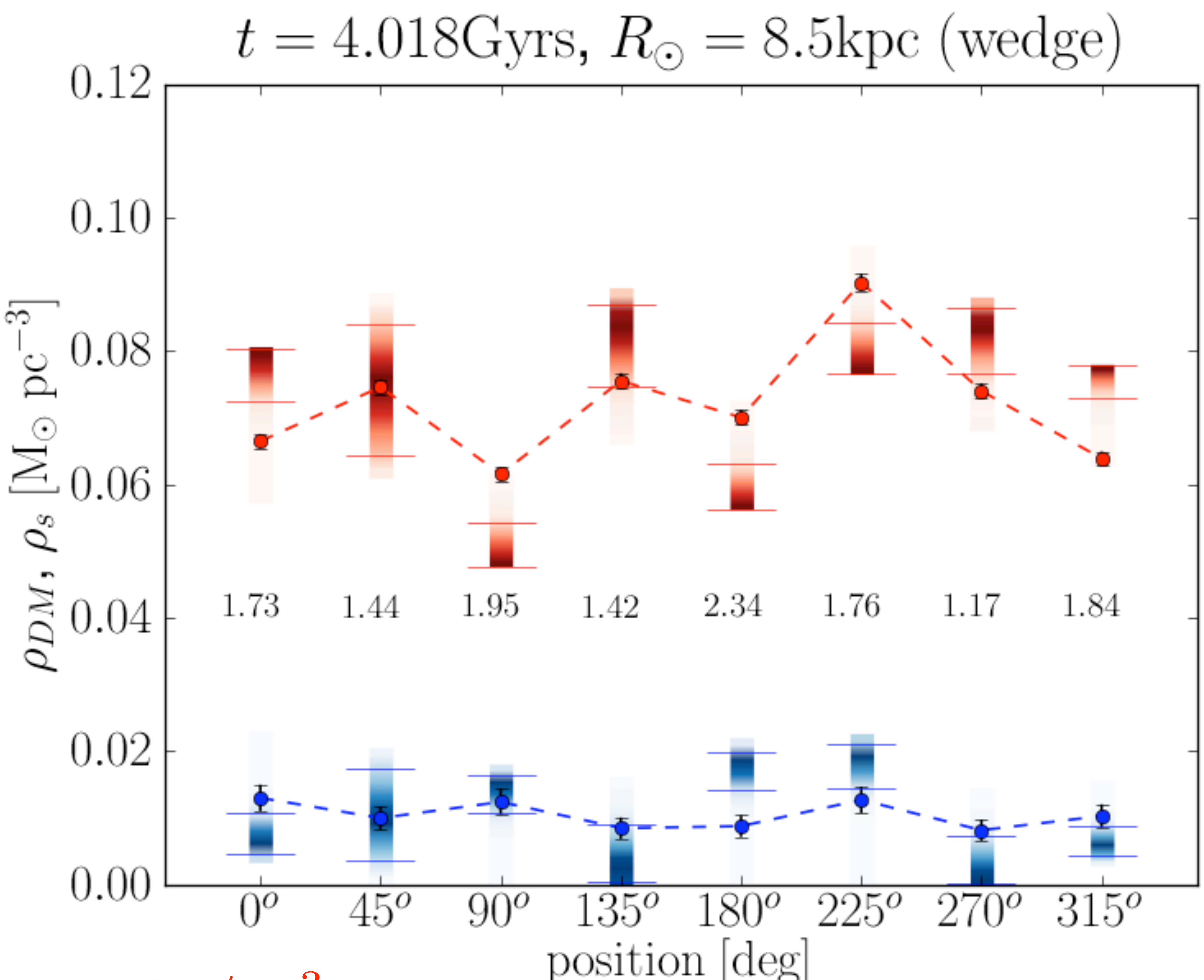
Evolved sim: HF vs MA method

HF method



ρS

ρDM

$\Delta\rho_s = \pm 0.014 M_\odot/pc^3$

[Garbari, Read, Lake (2011) MNRAS 416, 2318]

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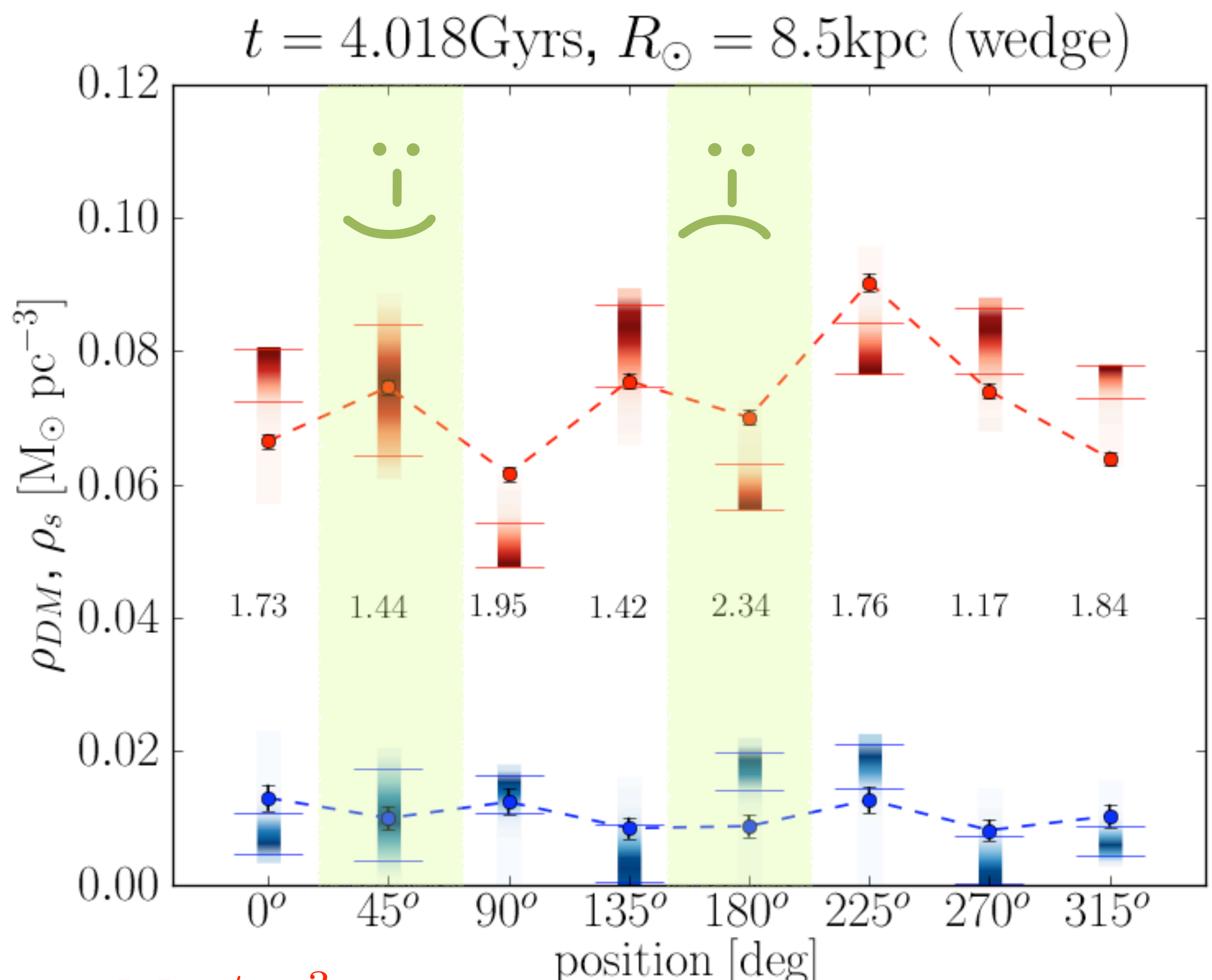

ρ_S

ρ_{DM}

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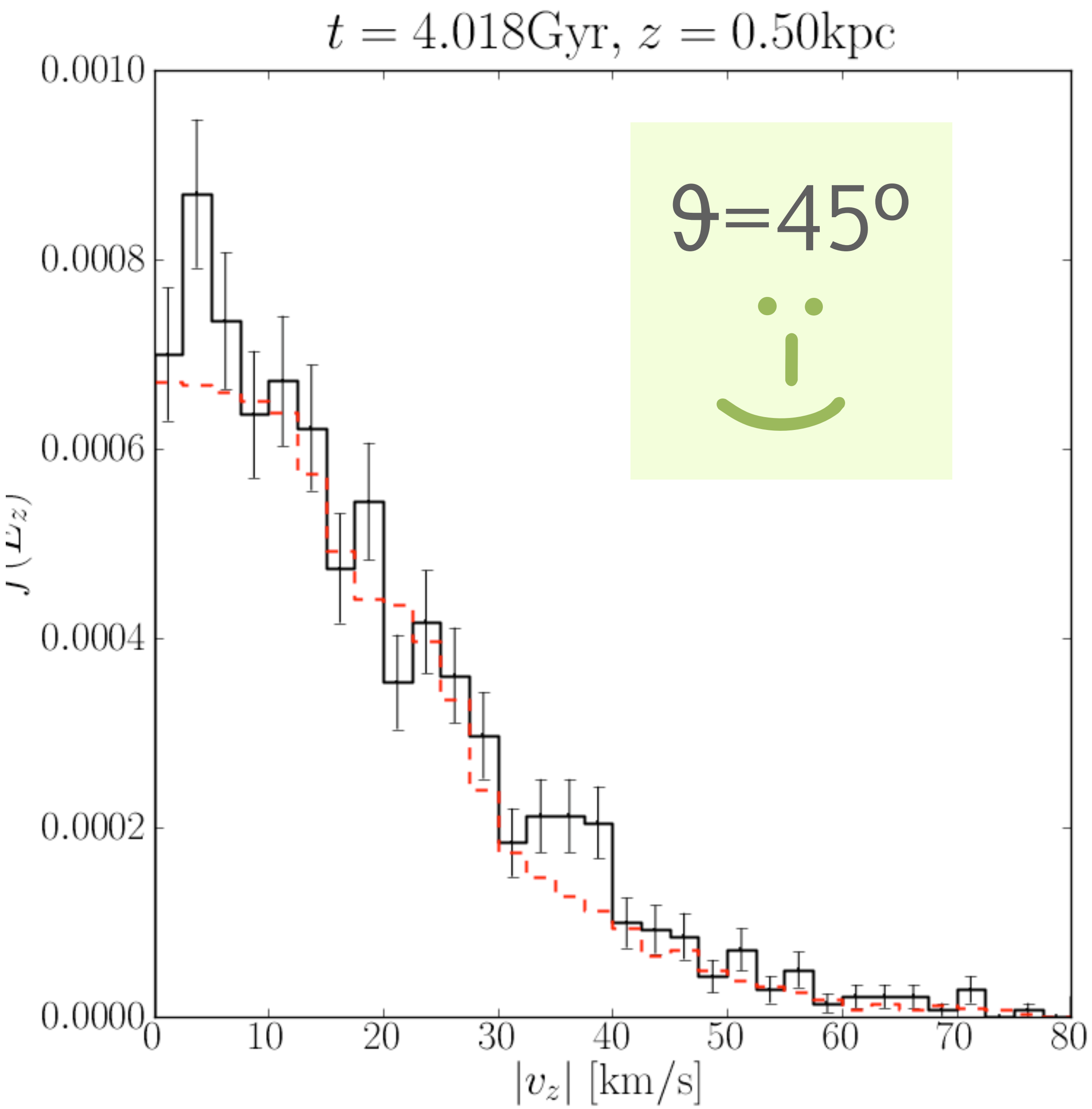
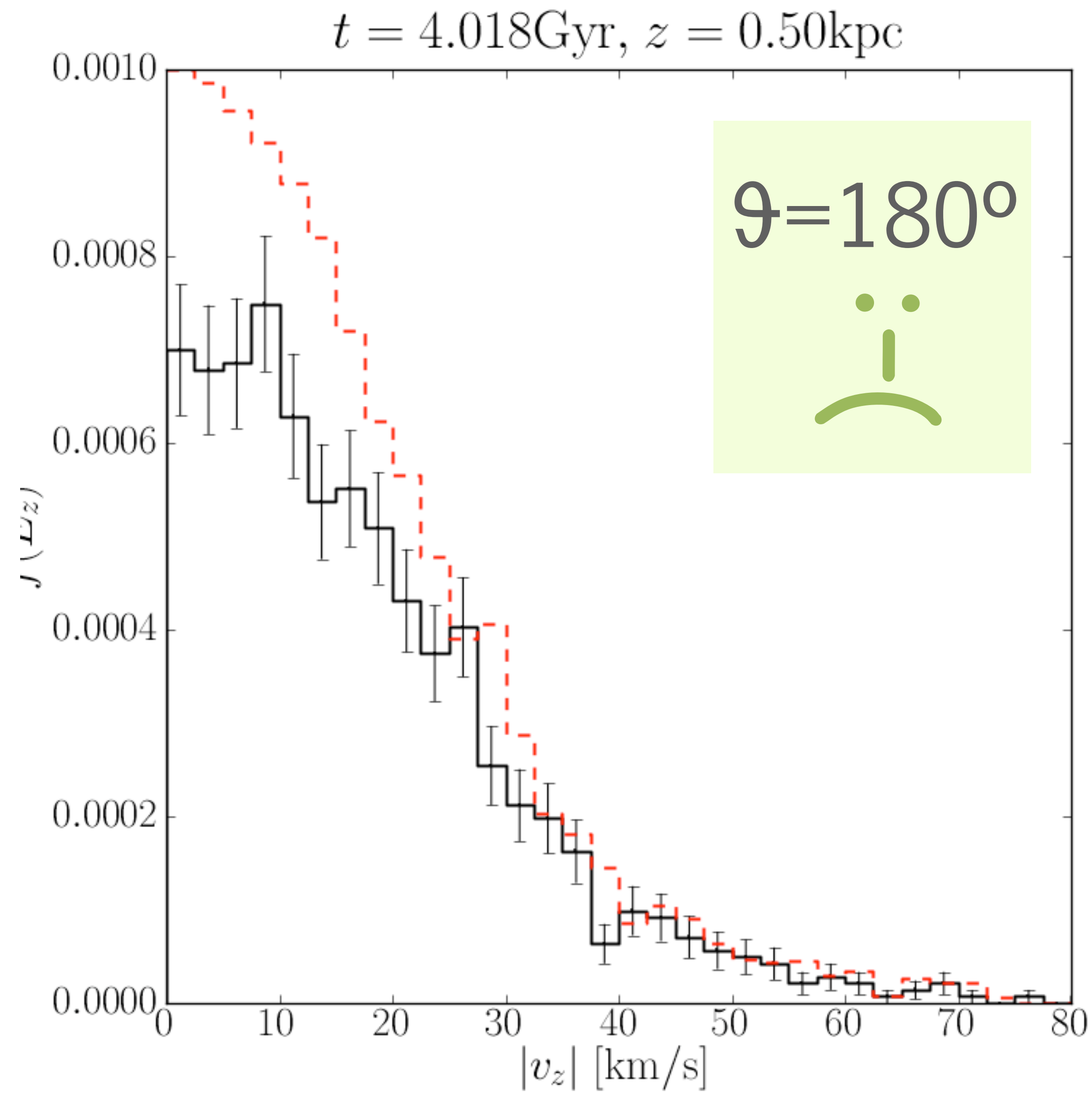
Evolved sim: distribution functions



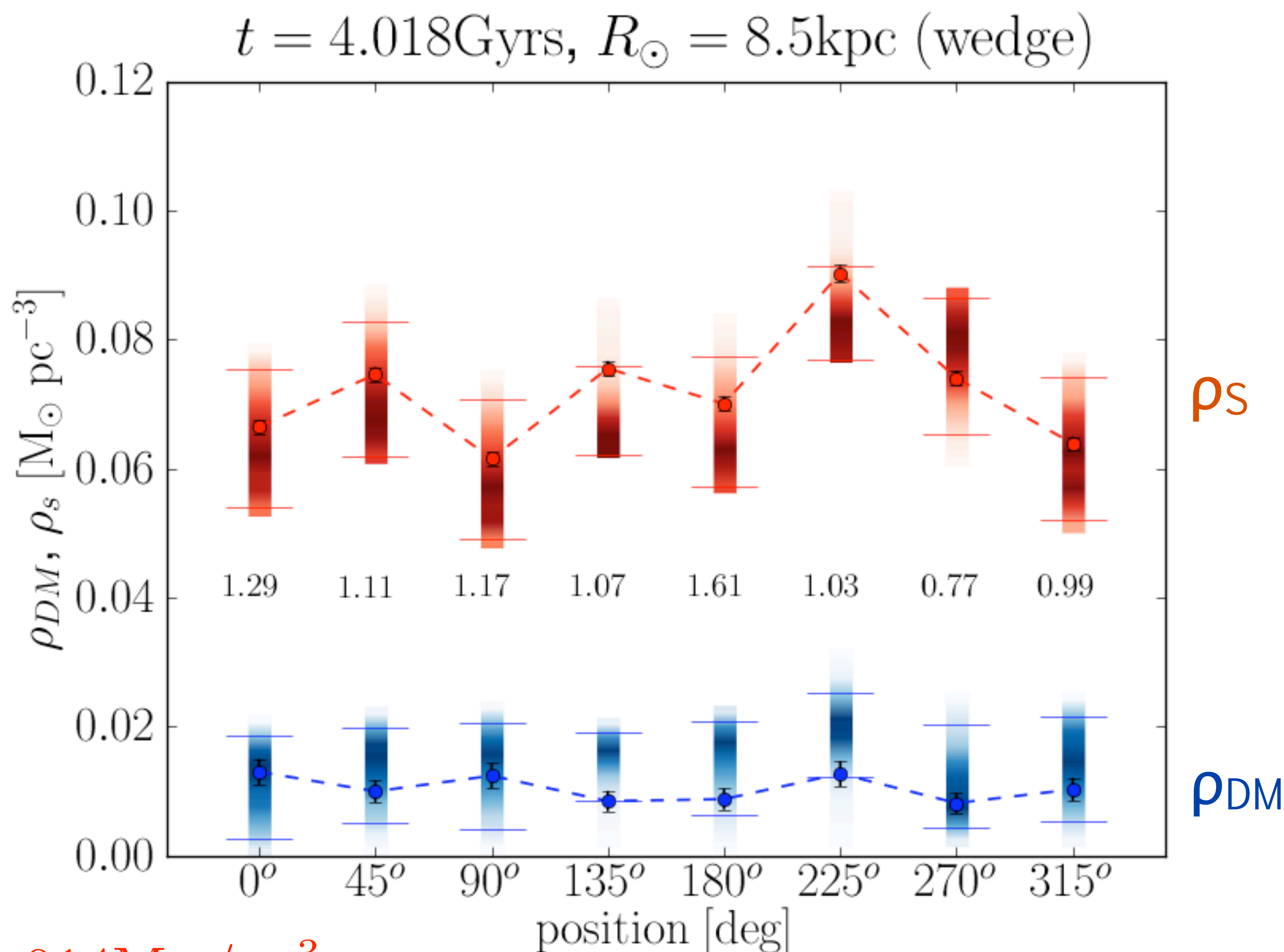


Evolved simulation

[Garbari, Read, Lake (2011) MNRAS 416, 2318]

Evolved sim: HF vs MA method

MA method



$\Delta\rho_s = \pm 0.014 M_\odot/pc^3$

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Tracer population

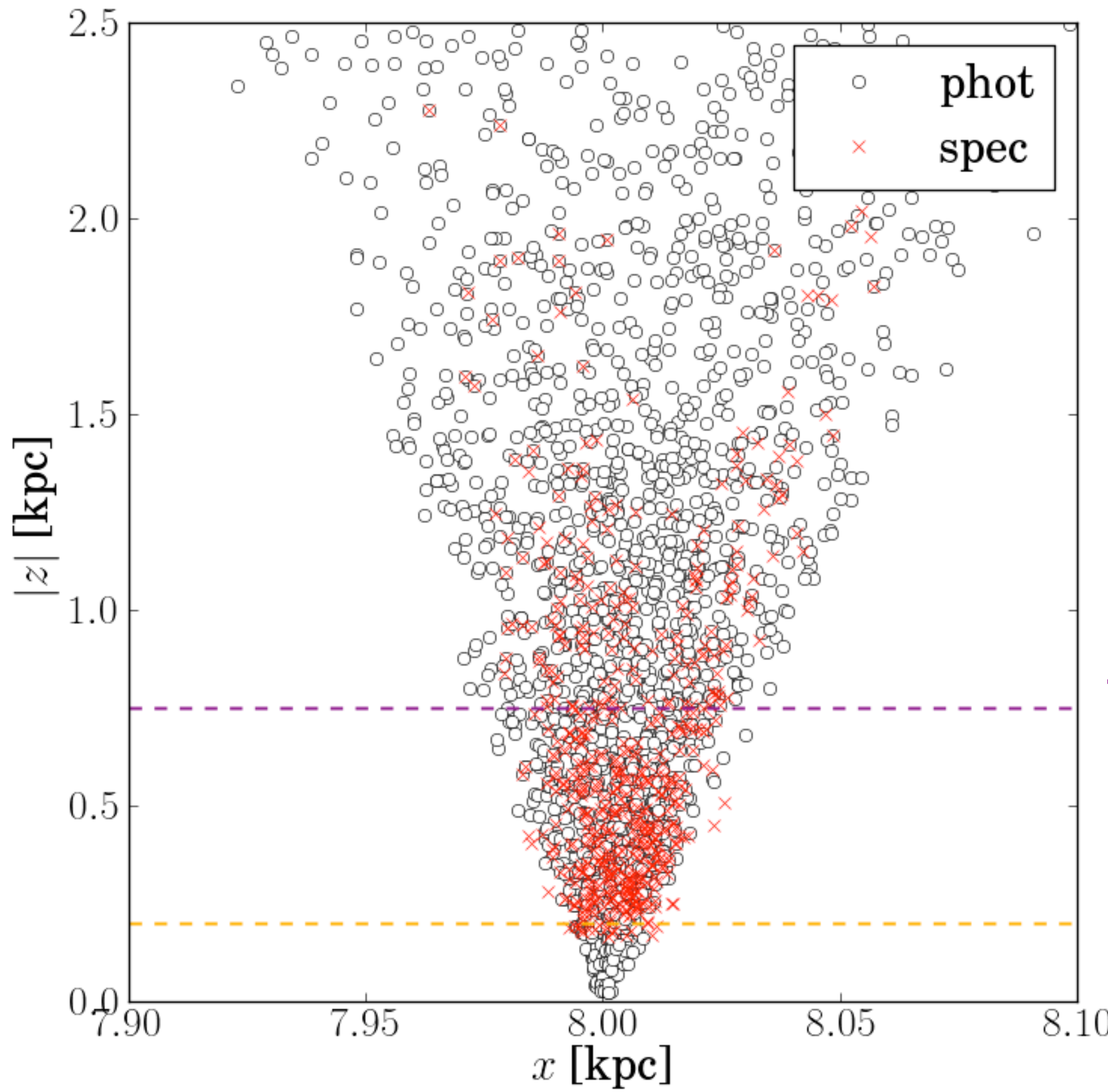
MUST BE:

* in dynamical equilibrium with the Galactic potential.
* common stars (to allow useful statistical precision in the result).
* in a volume complete sample.
* with reliable distances and vertical velocity available.

DATA: from Kuijken & Gilmore 1989 - K dwarfs

photometric sample ~2000 stars

spectroscopic sample ~600 stars



target z

Hipparcos

Garbari, Liu, Read & Lake arXiv:1206.0015 (accepted for publication in MNRAS)

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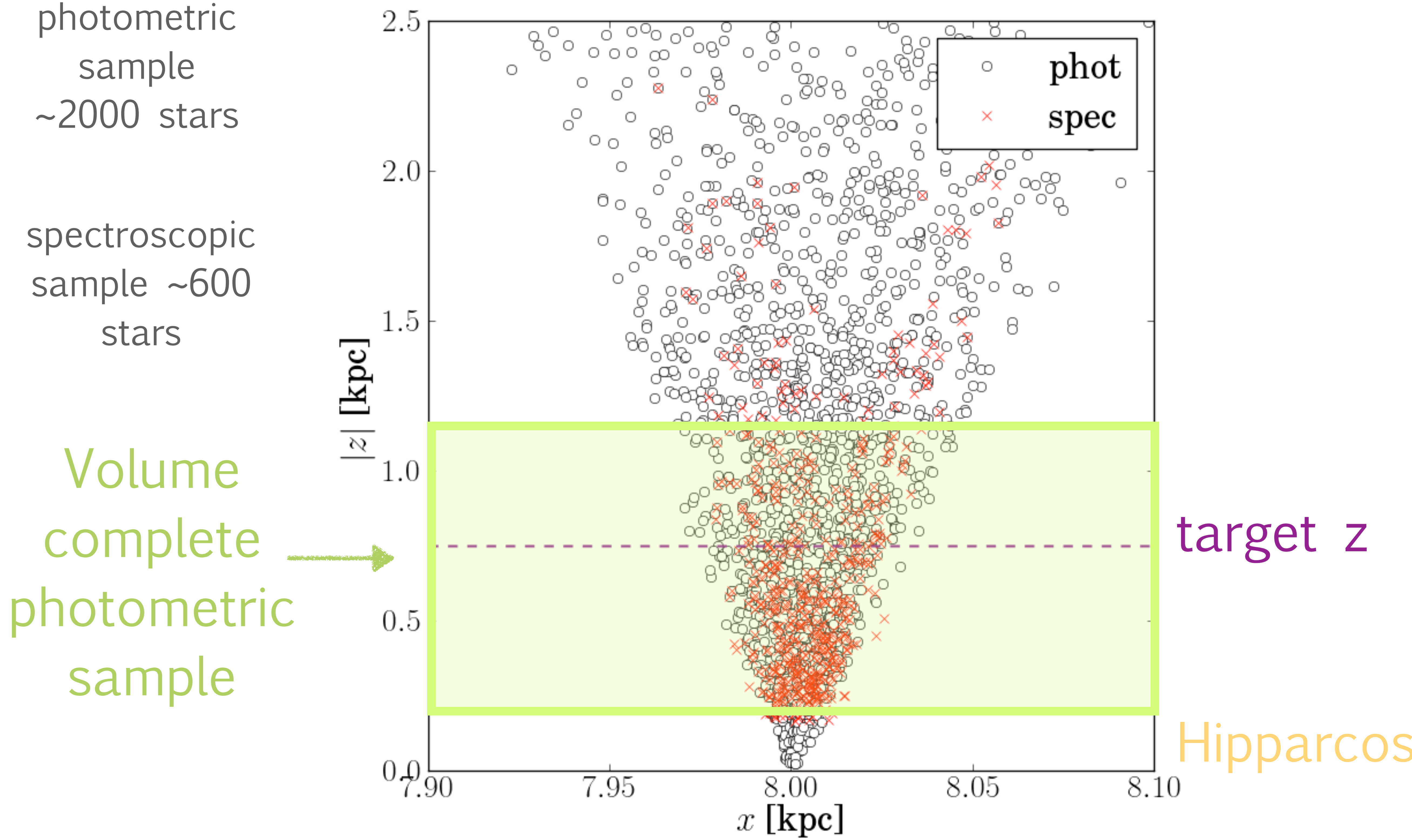

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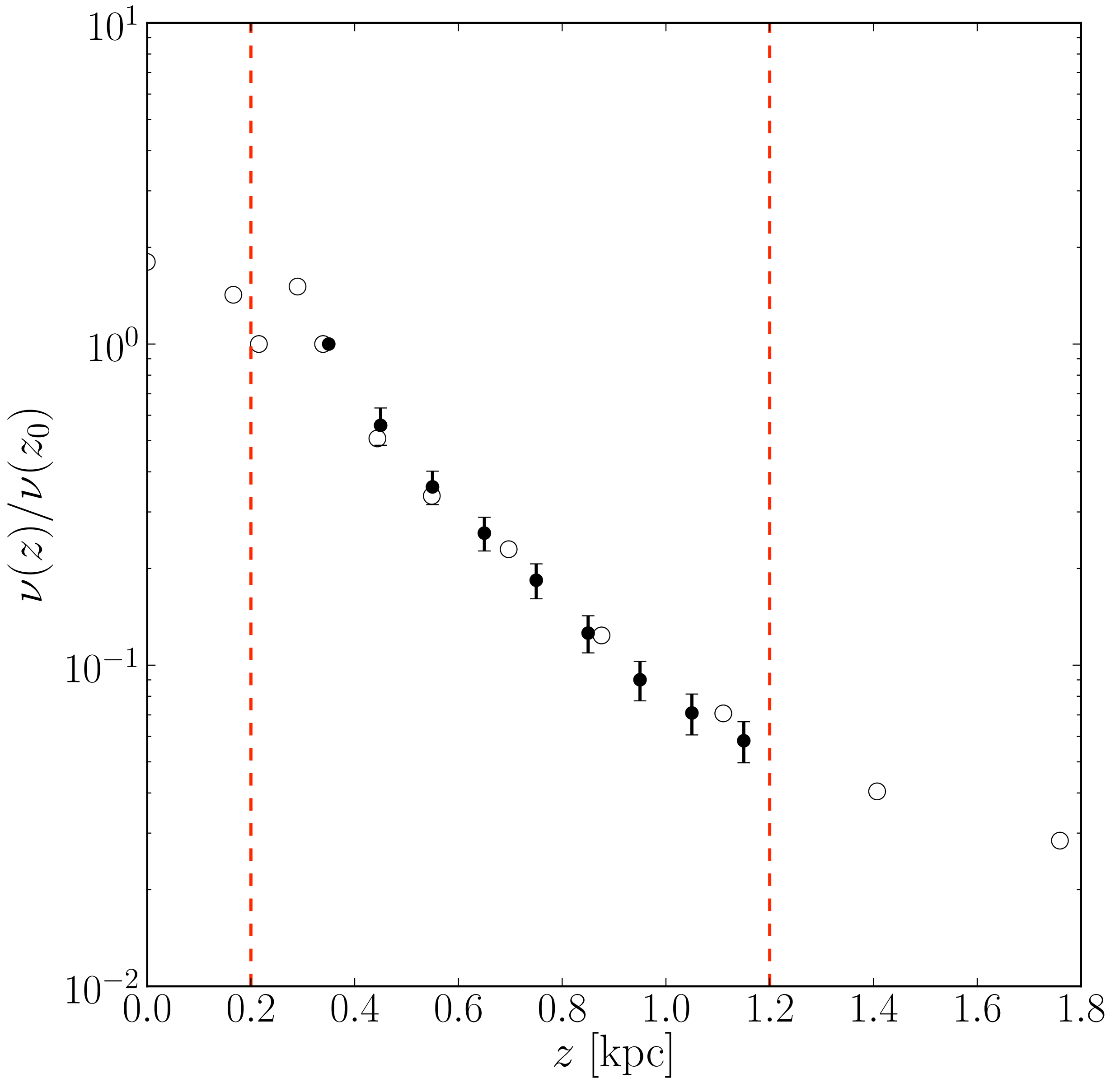
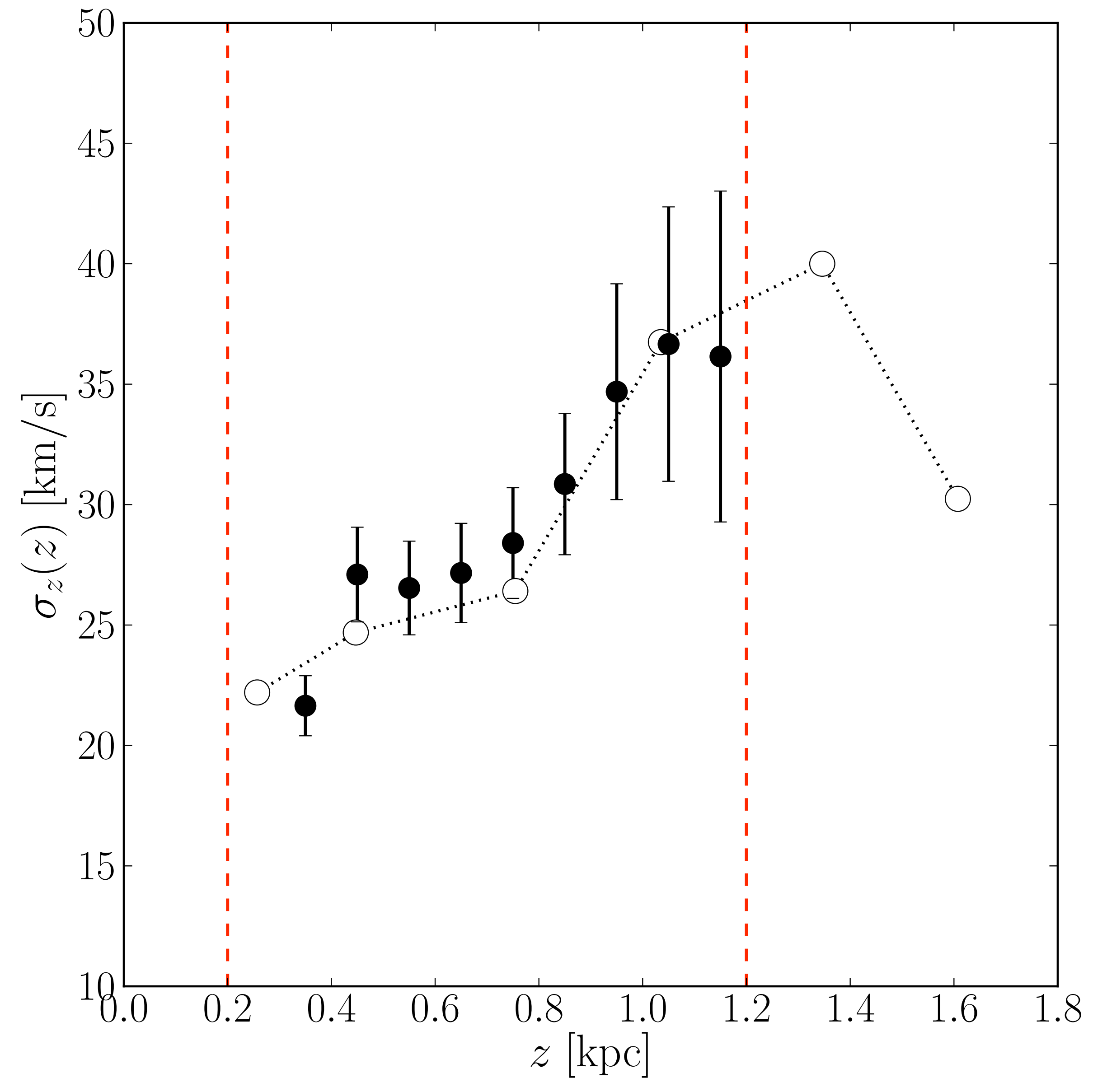


photometric sample
~2000 stars



spectroscopic sample
~600 stars

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Visible mass model by Flynn et al 2006

$$\rho_s(z) = \sum_i \nu_{i,0} \exp\left(-\frac{\Phi(z)}{\overline{v^2_{z,i}}}\right)$$

Component	$\nu_{i,0}(0)$ [M⊙/pc^3]	$\overline{v^2_{z,i}}(0)$ [km/s]
H_2^*	0.021	4.0 ± 1.0
HI(1)*	0.016	7.0 ± 1.0
HI(2)*	0.012	9.0 ± 1.0
Warm gas*	0.0009	40.0 ± 1.0
Giants	0.0006	20.0 ± 2.0
$M_V < 2.5$	0.0031	7.5 ± 2.0
$2.5 < M_V < 3.0$	0.0015	10.5 ± 2.0
$3.0 < M_V < 4.0$	0.0020	14.0 ± 2.0
$4.0 < M_V < 5.0$	0.0022	18.0 ± 2.0
$5.0 < M_V < 8.0$	0.007	18.5 ± 2.0
$M_V > 8.0$	0.0135	18.5 ± 2.0
White dwarfs	0.006	20.0 ± 5.0
Brown dwarfs	0.002	20.0 ± 5.0
Thick disc	0.0035	37.0 ± 5.0
Stellar halo	0.0001	100.0 ± 10.0

density errors:
Stars: 10-20%;
Gas*: 50%

Garbari, Liu, Read & Lake arXiv:1206.0015 (accepted for publication in MNRAS)

Visible mass model by Flynn et al 2006

$$\rho_s(z) = \sum_i \nu_{i,0} \exp\left(-\frac{\Phi(z)}{\overline{v_{z,i}^2}}\right)$$

Component	$\nu_{i,0}(0)$ [$M\odot/pc^3$]	$\overline{v_{z,i}^2}(0)$ [km/s]
H_2^*	0.021	4.0 ± 1.0
HI(1)*	0.016	7.0 ± 1.0
HI(2)*	0.012	9.0 ± 1.0
Warm gas*	0.0009	40.0 ± 1.0
Giants	0.0006	20.0 ± 2.0
$M_V < 2.5$	0.0031	7.5 ± 2.0
$2.5 < M_V < 3.0$	0.0015	10.5 ± 2.0
$3.0 < M_V < 4.0$	0.0020	14.0 ± 2.0
$4.0 < M_V < 5.0$	0.0022	18.0 ± 2.0
$5.0 < M_V < 8.0$	0.007	18.5 ± 2.0
$M_V > 8.0$	0.0135	18.5 ± 2.0
White dwarfs	0.006	20.0 ± 5.0
Brown dwarfs	0.002	20.0 ± 5.0
Thick disc	0.0035	37.0 ± 5.0
Stellar halo	0.0001	100.0 ± 10.0

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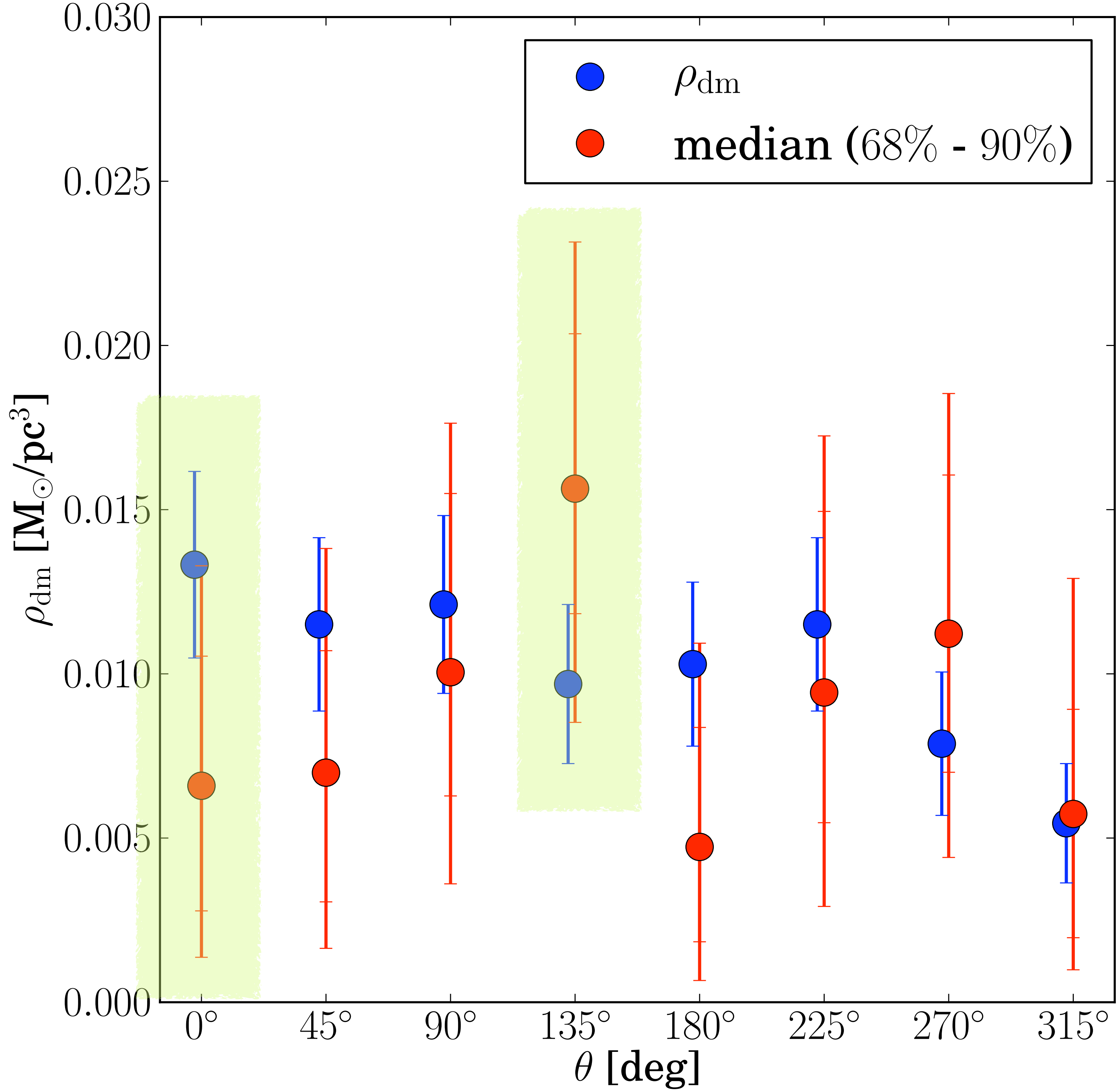
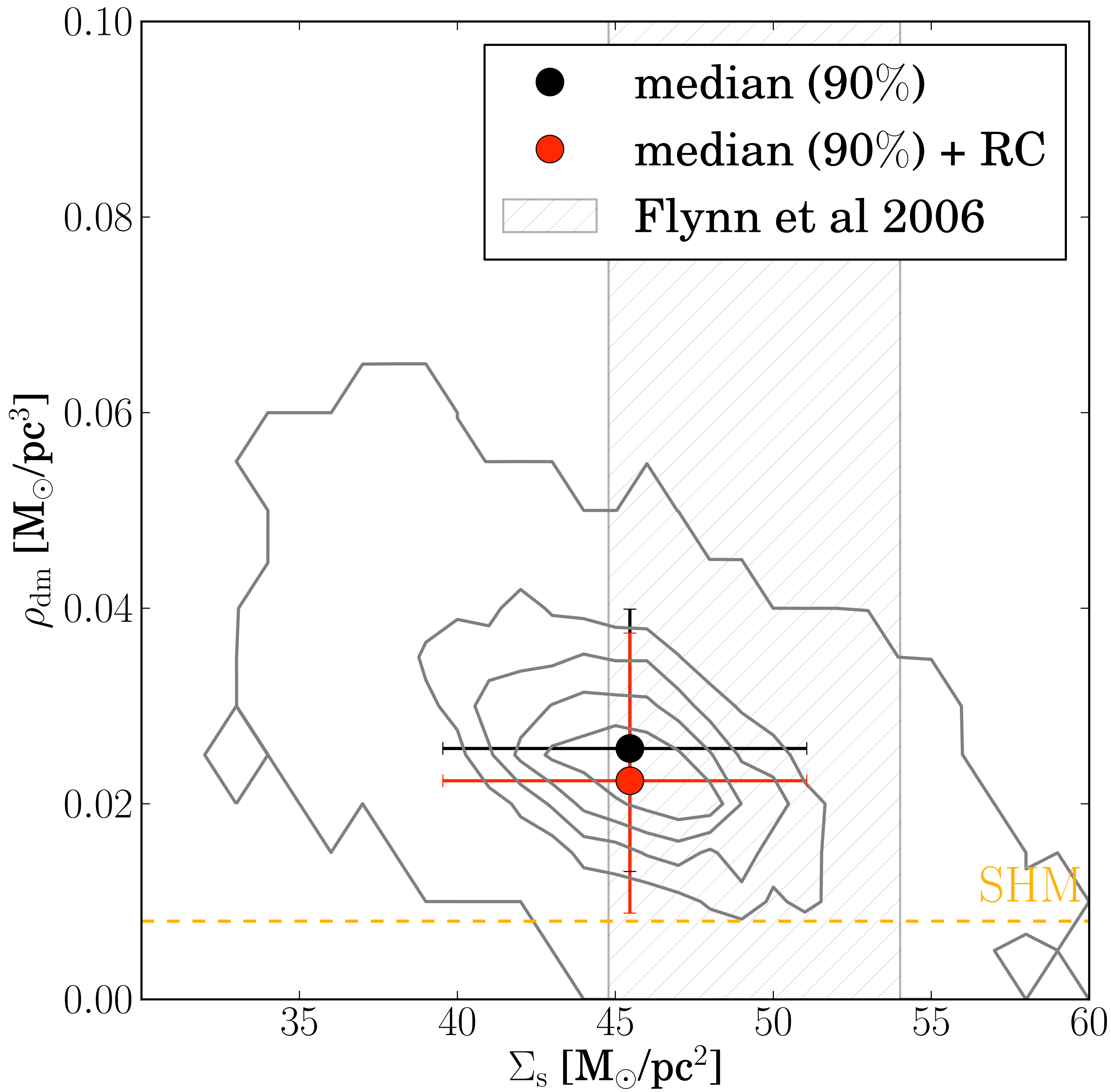
Test on the simulation: MA method



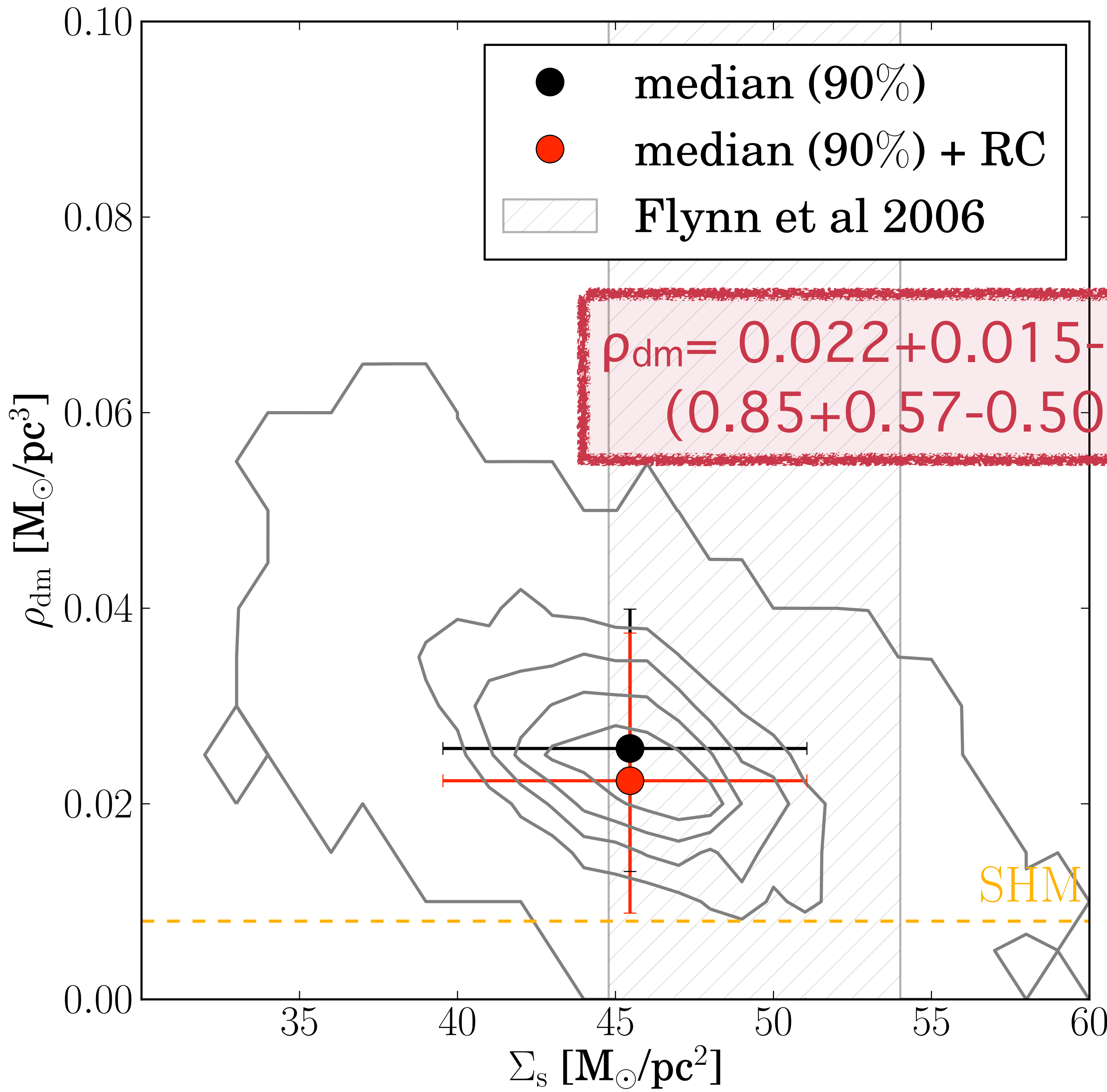
Garbari, Liu, Read & Lake arXiv:1206.0015 (accepted for publication in MNRAS)

data from Kuijken & Gilmore 1989 - K dwarfs



Garbari, Liu, Read & Lake arXiv:1206.0015 (accepted for publication in MNRAS)

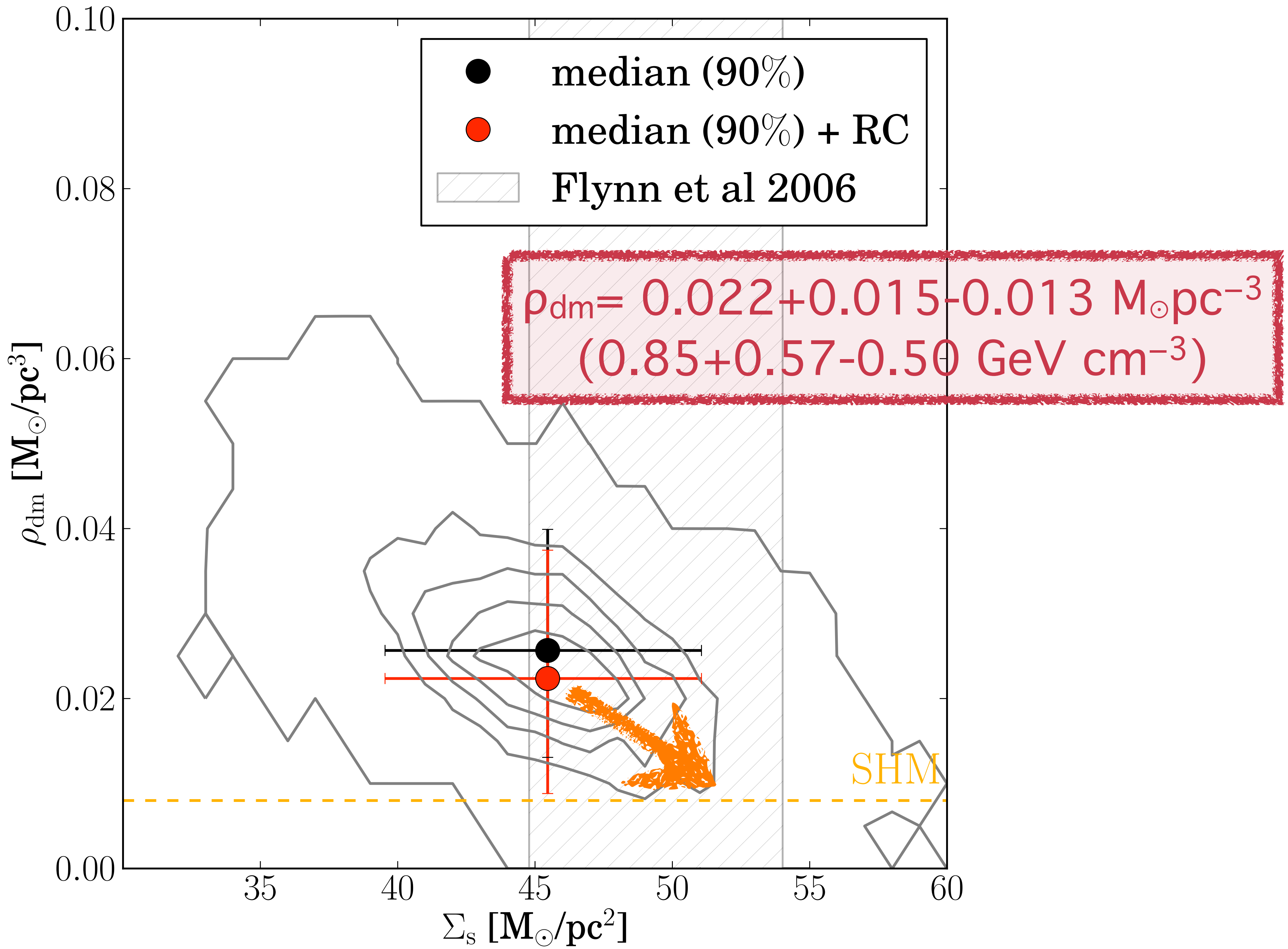
data from Kuijken & Gilmore 1989 - K dwarfs



ρ_{dm}= 0.022+0.015-0.013 $M_\odot pc^{-3}$
(0.85+0.57-0.50 GeV cm^{-3})

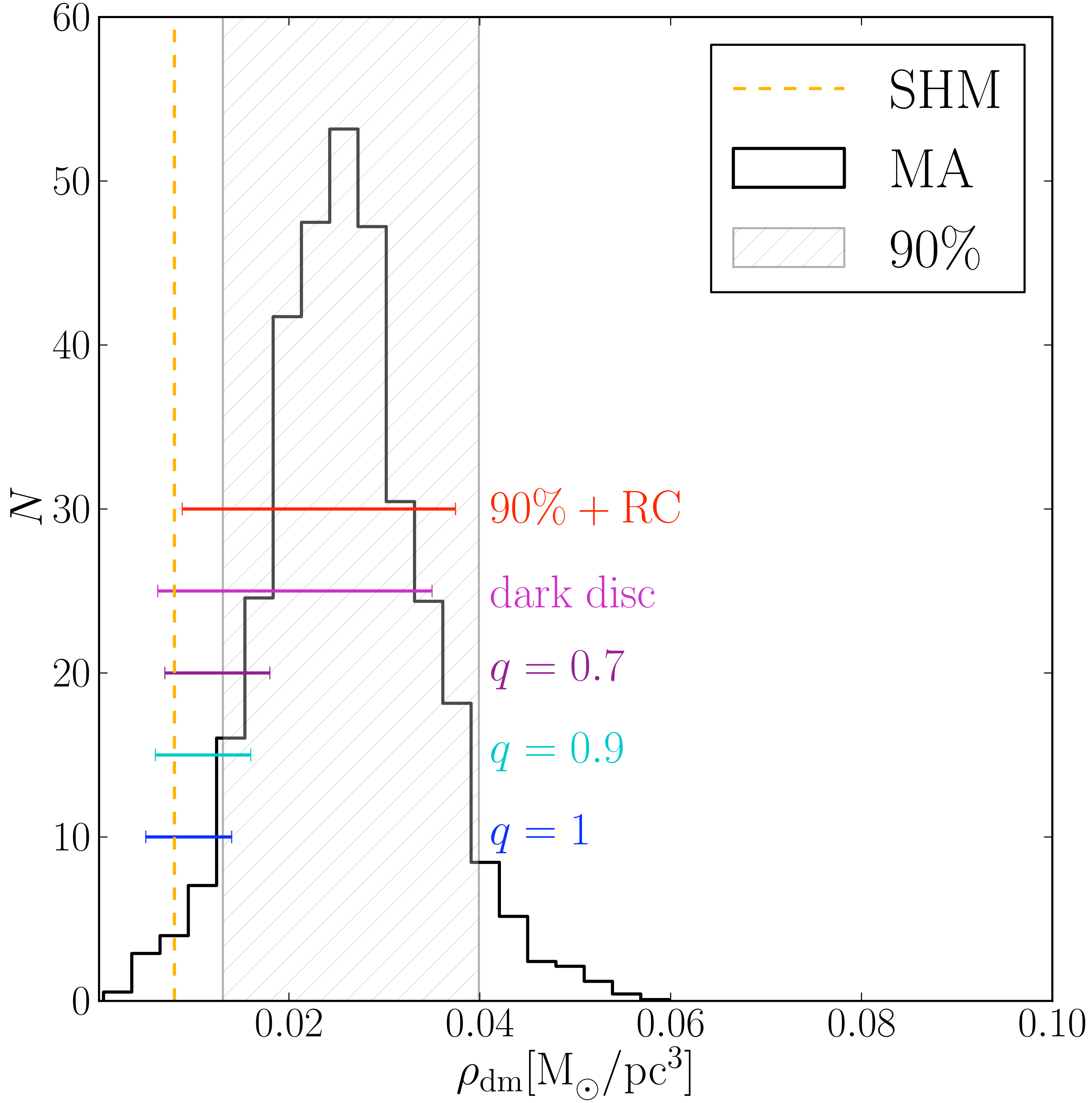
Garbari, Liu, Read & Lake arXiv:1206.0015 (accepted for publication in MNRAS)

data from Kuijken & Gilmore 1989 - K dwarfs



Garbari, Liu, Read & Lake arXiv:1206.0015 (accepted for publication in MNRAS)

data from Kuijken & Gilmore 1989 - K dwarfs



Garbari, Liu, Read & Lake arXiv:1206.0015 (accepted for publication in MNRAS)

Conclusion

✳We present a new method to measure ρ_{dm} from the vertical kinematics local tracers. It relies on a minimal set of assumptions and

- uses a MCMC to marginalise over the uncertainties
- does not require any prior on the MW rotation curve
- does not require any assumption on the tracers' distribution function

✳We use hi-res simulations as a mock data set to test our method.

✳ We obtain a new measurement of the local dark matter density: $\rho_{dm} = 0.022{+0.015}{-0.013}\ M_{\odot} pc^{-3}$ ($0.85{+0.57}{-0.50}$ GeV cm^{-3}).

✳Our median value of the local dark matter density is larger at 90% confidence than the Standard Halo Model value of $\rho^{SHM}_{dm} = 0.008\ M_{\odot}\ pc^{-3}$ (0.30 GeV cm^{-3}). If confirmed by future data (GAIA), it has interesting implications:

- for direct detection experiments: it implies a larger flux of dark matter particles and therefore a greater chance of detection.
- it suggests that the halo of our Galaxy is oblate and/or that we have a disc of dark matter.