Estimation of phase space density in dwarf galaxies

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Motivation

- So far only astronomical observations support the DM hypothesis and augment the data pointing at the lack of gravitational potentials at various spatial scales and late cosmological epochs.

- Dwarf spheroidal galaxies are excellent systems to probe the nature of fermionic dark matter due to their high observed dark matter phase-space density.

- Any stable (at cosmological time scale), electrically neutral, almost collisionless particles, produced in the early Universe and decoupled from primordial plasma well before recombination, may serve as dark matter particle.

- Sterile neutrinos being Majorana fermions, carring o charges (hence sterile) with respect to the SM gauge group and mixing with the SM neutrinos providing them with masses and mixing angles required to explain the neutrino oscillation phenomena.

Bounds from Liouville's theorem

Liouville's theorem: For a collisionless and dissipationsless particle species the maximum of fine-grained distribution function cannot increase throughout the cosmological evolution.

$$F_{initial}^{max} \geq F_{final}^{max}$$

We assume that the initial sterile neutrino distribution is approximately thermal:

$$F_{initial} = F_{FD}\,(x,p) = \frac{gN}{(2\pi)^3}\frac{1}{e^{p/T_{dec}}+1} \Rightarrow F_{initial}^{max} = \frac{gN}{2(2\pi)^3}$$

$$n = \frac{3}{4}N\frac{g\zeta(3)}{\pi^2}T_\nu^3 \Rightarrow \rho_{DM} = mn = \frac{3}{4}N\frac{g\zeta(3)}{\pi^2}T_\nu^3$$

$$\Downarrow$$

$$F_{initial}^{max} = \frac{1}{2(2\pi)^3}\frac{11.16eV}{m}$$

Bounds from Liouville's theorem

Assuming Maxwellian velocity distribution in the final state:

$$F_{final} = F_{Maxwell}(x,p) = \frac{\rho(r)}{(2\pi)^{3/2} m^4 \sigma_r \sigma_\tau^2} \exp\left(-\frac{1}{2}\left(\frac{v_r^2}{\sigma_r^2} + \frac{v_\varphi^2}{\sigma_\tau^2} + \frac{v_\theta^2}{\sigma_\tau^2}\right)\right) \Rightarrow F_{final}^{max} = \frac{1}{(2\pi)^{3/2} m^4}\left(\frac{\rho(r)}{\sigma_r \sigma_\tau^2}\right)_{max}$$

$$m^3 \geq \frac{2(2\pi)^{\frac{3}{2}}}{11.16\ eV}\left(\frac{\rho(r)}{\sigma_r \sigma_\tau^2}\right)_{max}$$

Problems:

- Maxwell phase-space density function has no local maximum, monotonously decreasing with radius instead
- Search for more strict limitations

Advantages:

- Explicit equation for mass bound

Bounds from EMF function

Excess Mass Function(EMF):

$$D(f) = \int (F(x,p) - f)\Theta(F(x,p) - f)dxdp$$

$$D_{initial}(f) \geq D_{final}(f) \quad \forall f$$

$$V_{initial} \int (F_{Fermi}(p, m) - f)\,\Theta(F_{Fermi}(p, m) - f)dp \geq \int (F_{Maxwell}(x, p, m) - f)\Theta(F_{Maxwell}(x, p, m) - f)dxdp$$

Problems:

- Maxwell phase-space density function has no local maximum, monotonously decreasing with radius instead
- Implicit equation for mass bound

Advantages:

- More strict limitations

Numerical analysis

Radial Jeans equation:

$$\frac{\partial}{\partial r}(\rho\sigma_r^2) + \frac{2\beta}{r}\sigma_r^2 = -G\frac{M(< r)}{r^2}$$

$$\beta = 1 - \frac{\sigma_\tau^2}{\sigma_r^2}$$

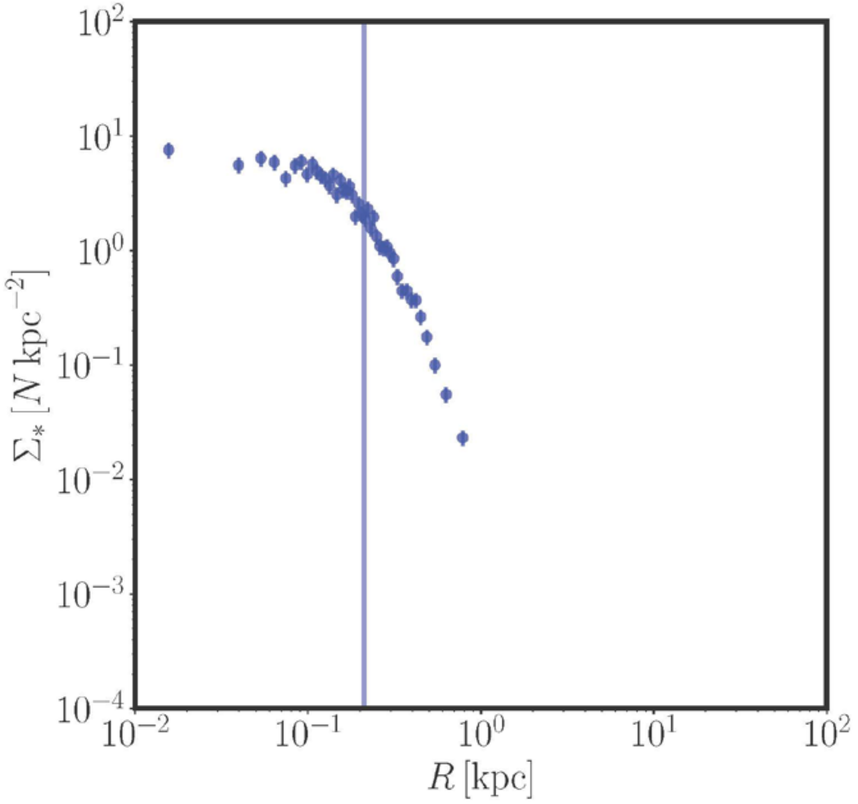
Equation above can be solved using GravSphere code:

- Fitting stellar ρ & σ_{LOS}^2 ⟶ Obtain $M(< r)$ ⟶ Obtain $\rho(r)$

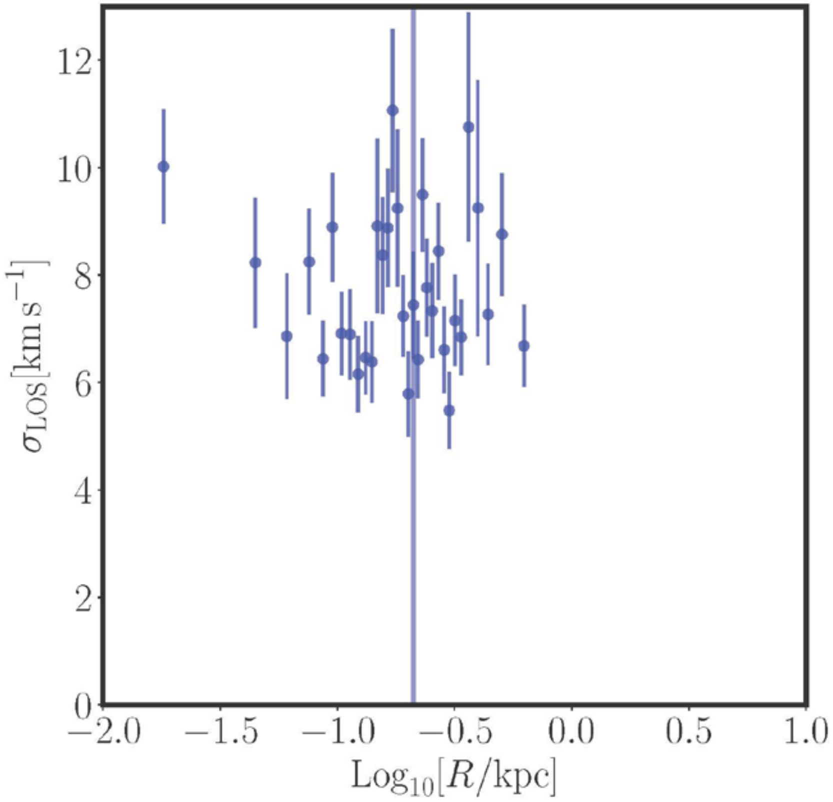
We adjust Gravsphere code for DM velocity dispersion calculation:

- Solving for DM ρ & β_{DM} ⟶ Obtain σ_{DM}^2

Observed parameters

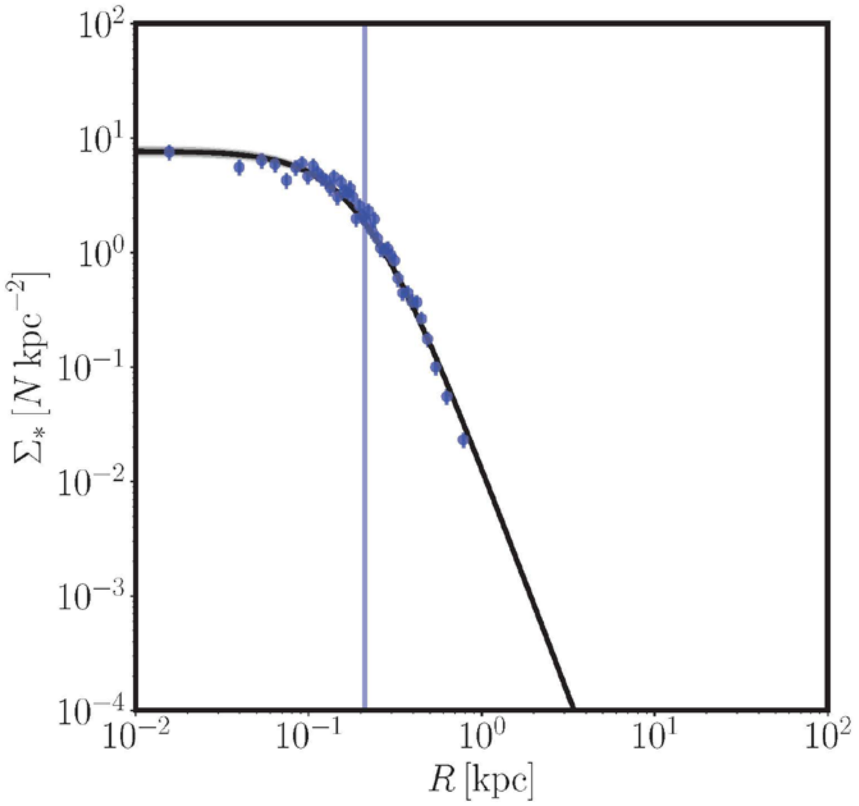


Normalized stellar surface density as a function of projected radius
(Sculptor Dwarf Galaxy)

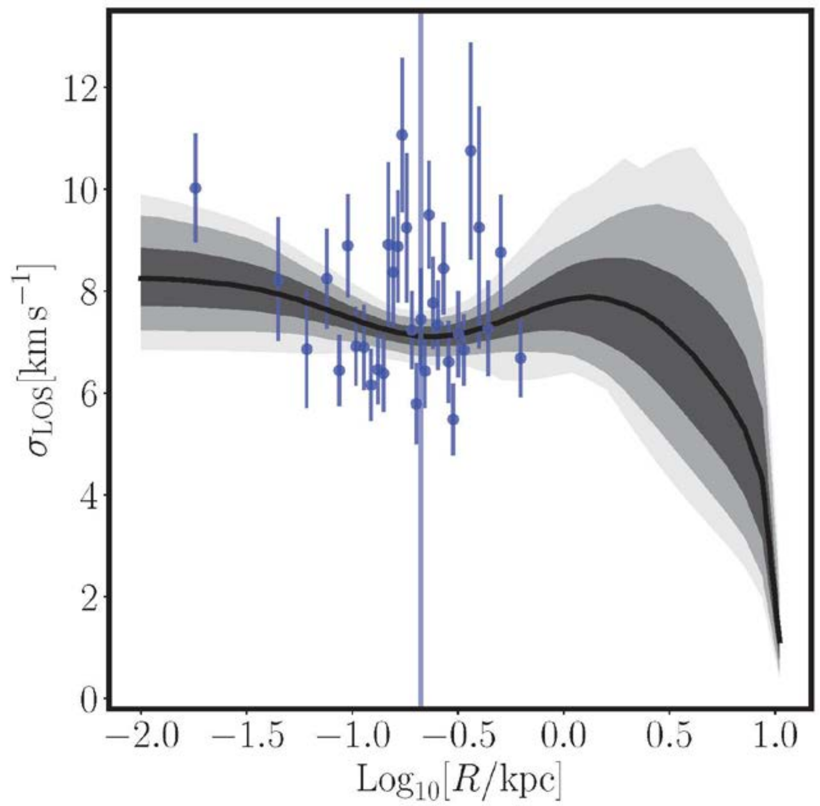


Projected stellar velocity dispersion as a function of projected radius
(Sculptor Dwarf Galaxy)

Fitting surface density & velocity dispersion

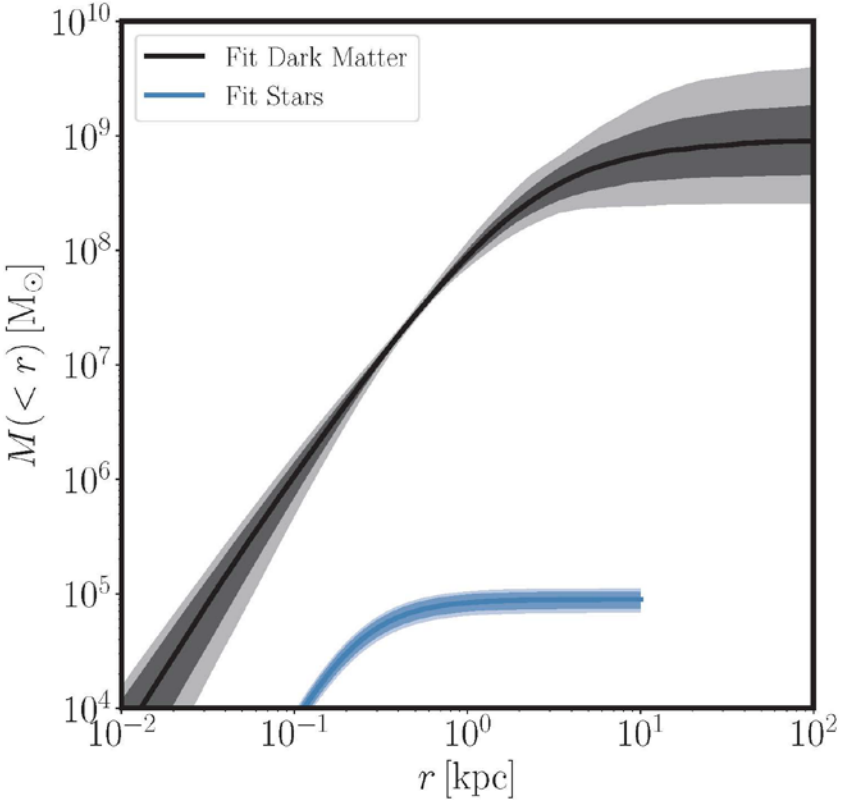


Fitted normalized stellar surface density as a function of projected radius (Sculptor Dwarf Galaxy)

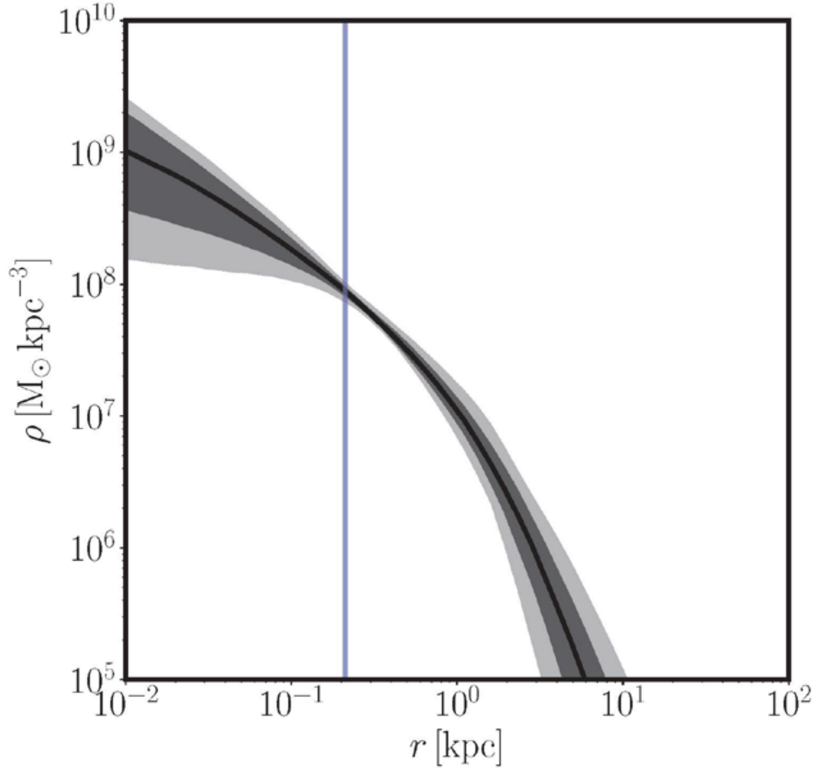


Fitted projected stellar velocity dispersion as a function of projected radius (Sculptor Dwarf Galaxy)

Fitting DM mass & density

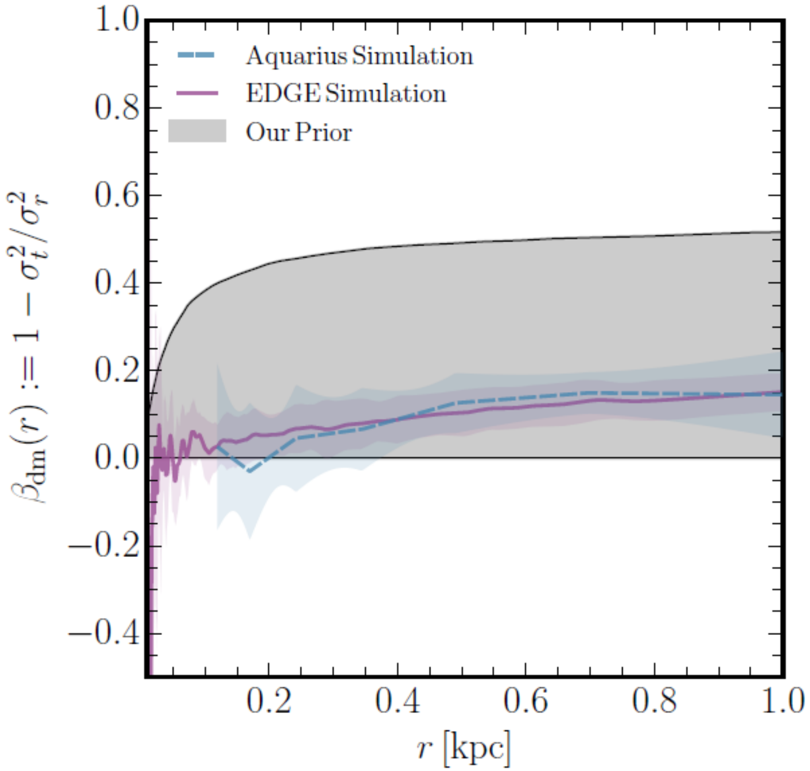


Fitted DM and stellar mass as a function of radius
(Sculptor Dwarf Galaxy)

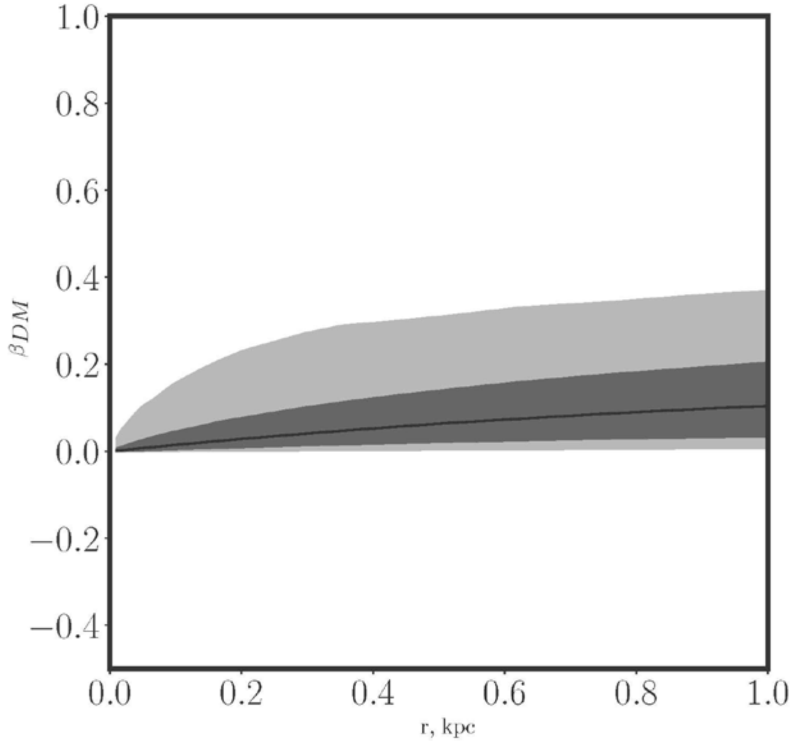


Fitted DM density as a function of radius
(Sculptor Dwarf Galaxy)

DM velocity anisotropy

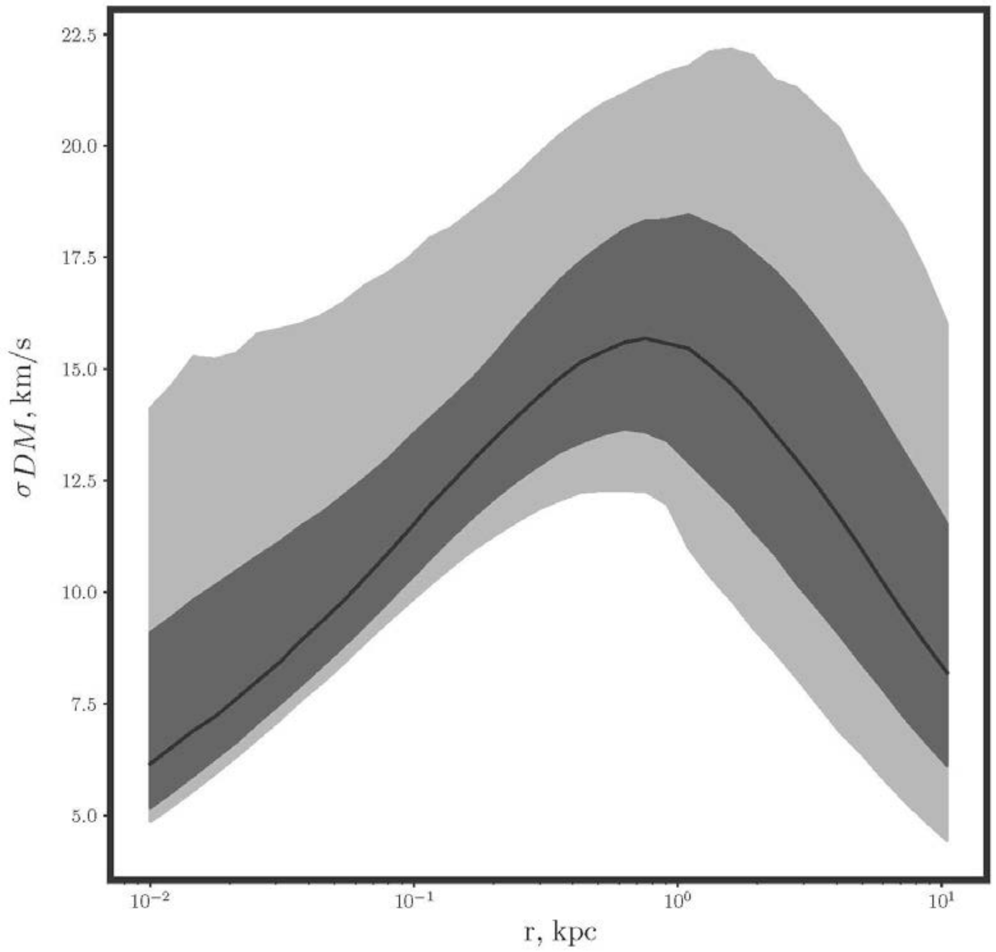


arXiv:2010.03572v2 [hep-ph]



Assumed DM velocity anisotropy

Calculating DM velocity dispersion



DM velocity dispersion as a function of radius
(Sculptor Dwarf Galaxy)

Results

Lower bounds on m_{DM}

Galaxy name	Liouville's theorem keV	EMF keV
Fornax Dwarf Spheroidal	$0.80^{+0.28}_{-0.24}$	$0.84^{+0.34}_{-0.26}$
Sculptor Dwarf Galaxy	$1.78^{+0.40}_{-0.50}$	$1.91^{+0.54}_{-0.60}$
Leo I	$1.11^{+0.16}_{-0.27}$	$1.31^{+0.37}_{-0.36}$
Carina dSph	$1.23^{+0.60}_{-0.54}$	$1.25^{+0.65}_{-0.56}$

Thank you for your attention!