Non-sphericity of ultralight axion dark matter halos in the Galactic dwarf satellites

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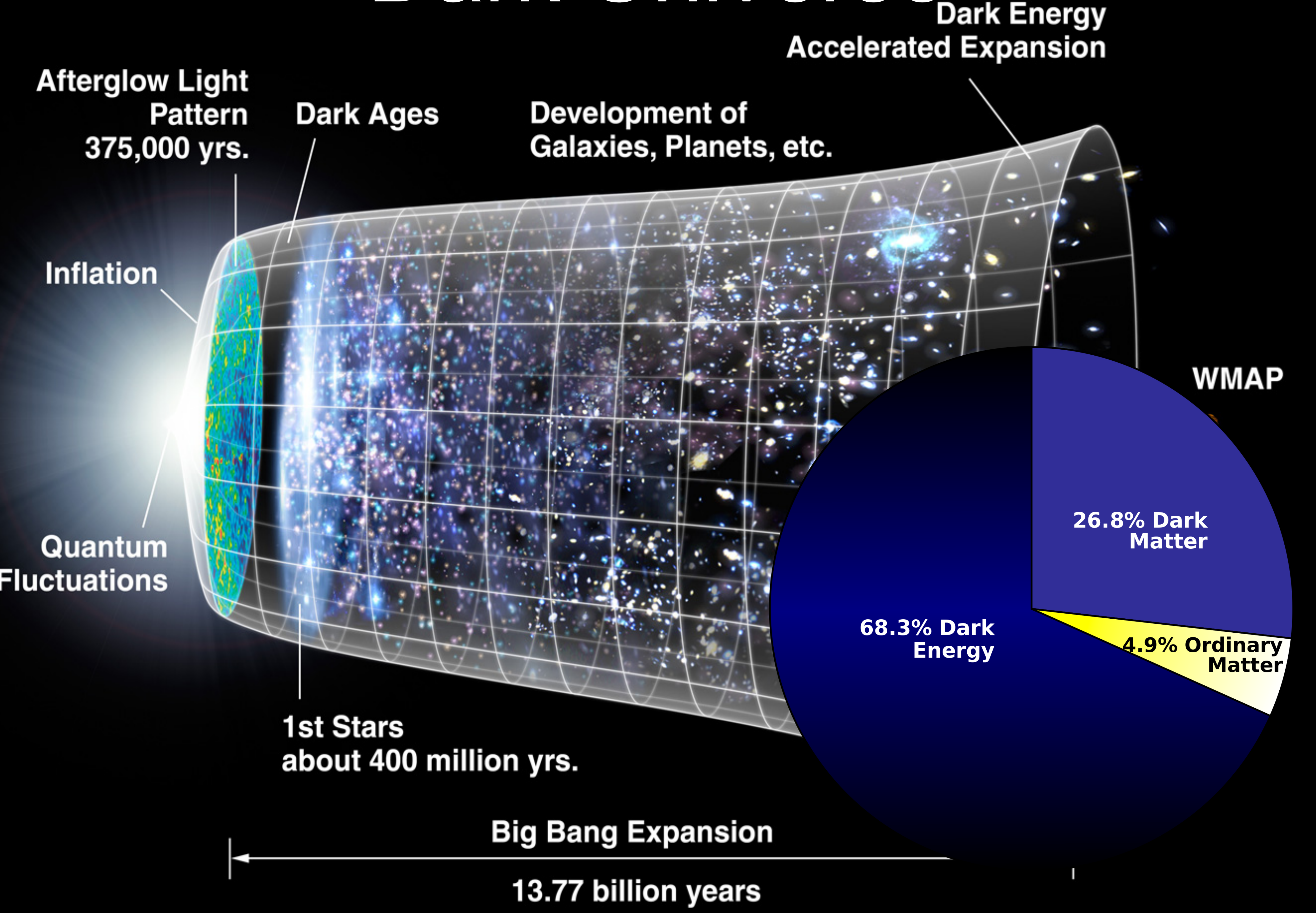
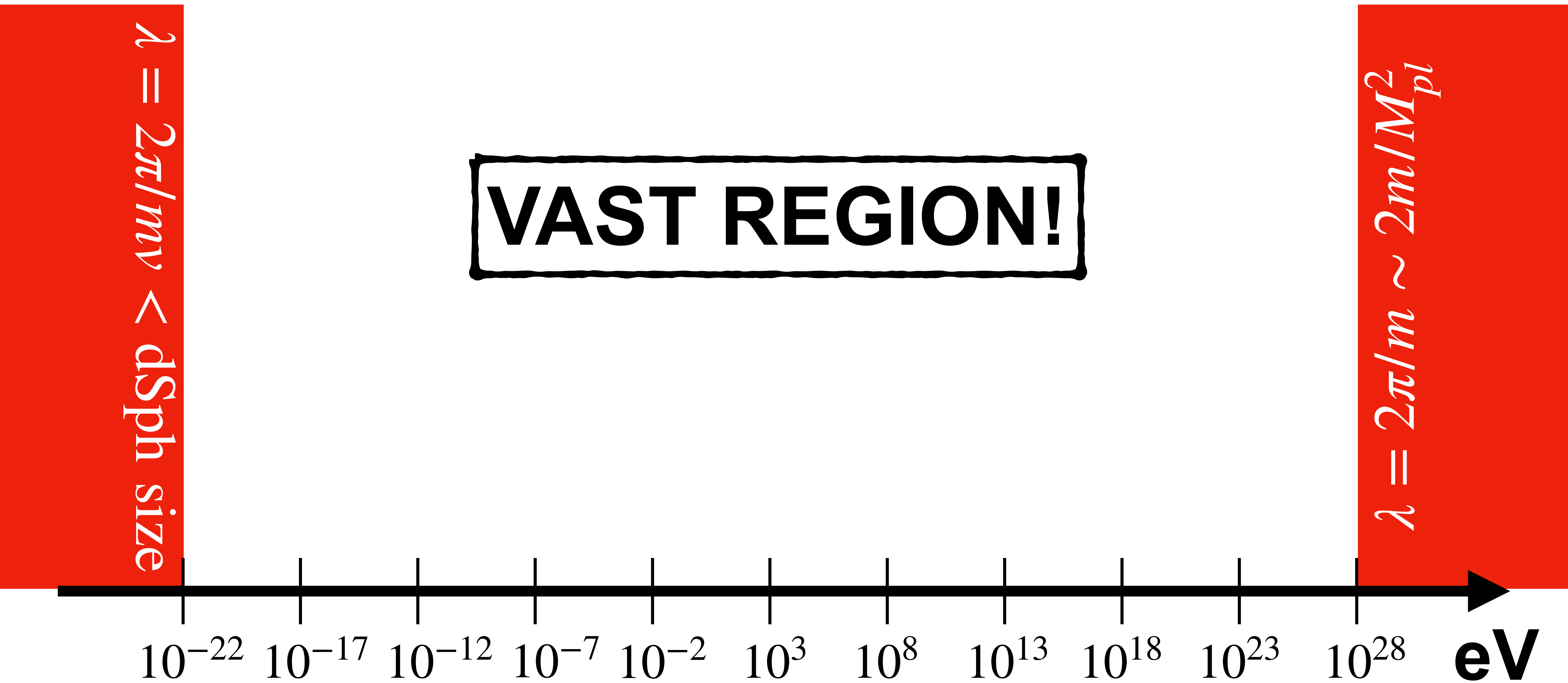
Hayashi and Obata (2019), arXiv: 190203054

Dark Universe



Particle Dark Matter Mass Range



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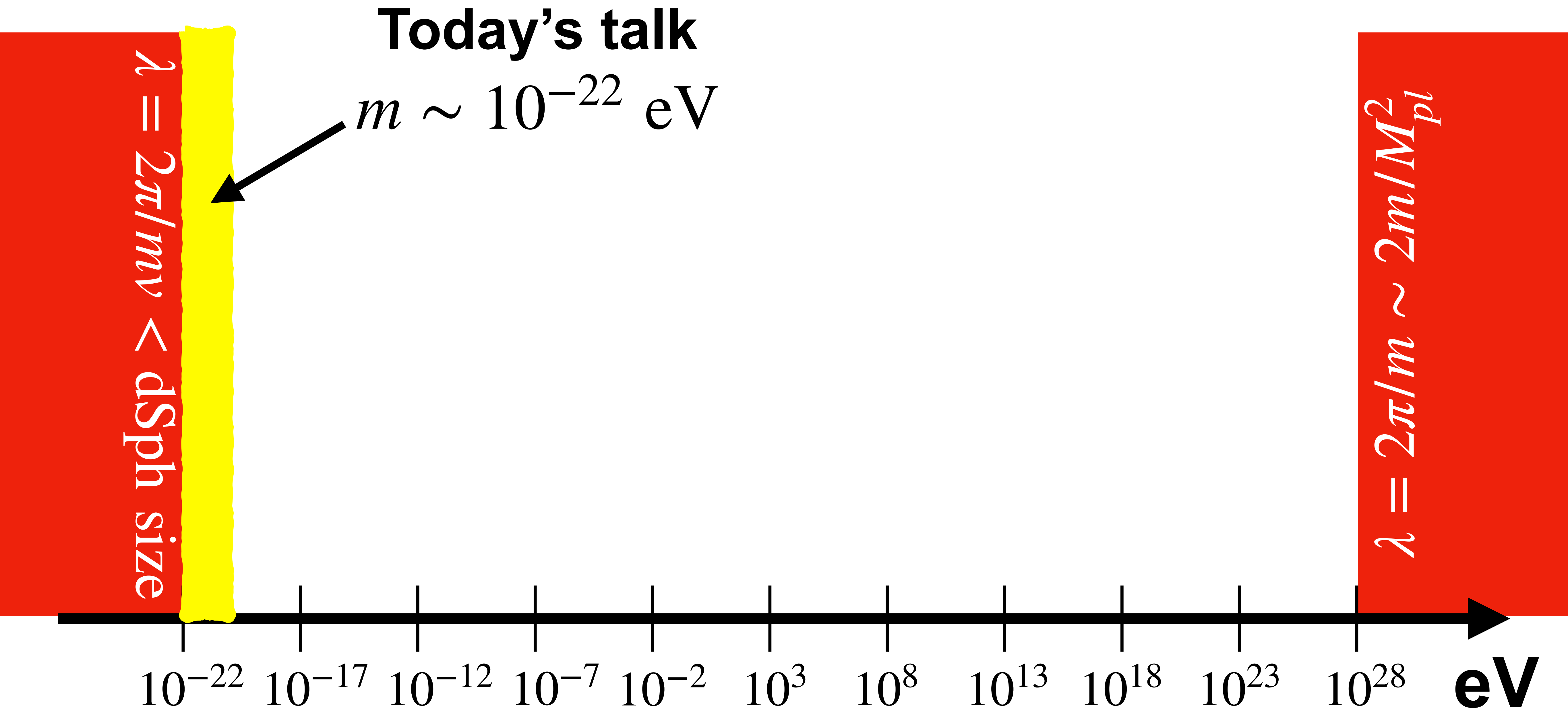


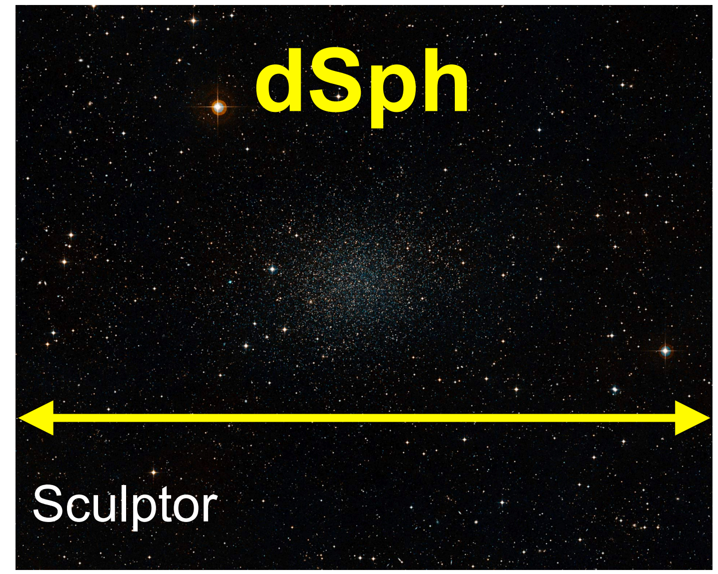
Ultralight axion dark matter (ULADM)

- The lightest particle among dark matter candidates ($m_\psi \sim 10^{-22}$ eV)

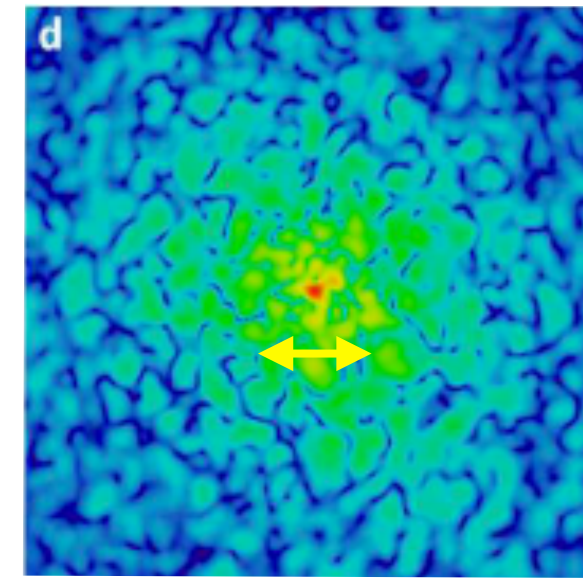
- Create a core (~kpc) comes from quantum pressure

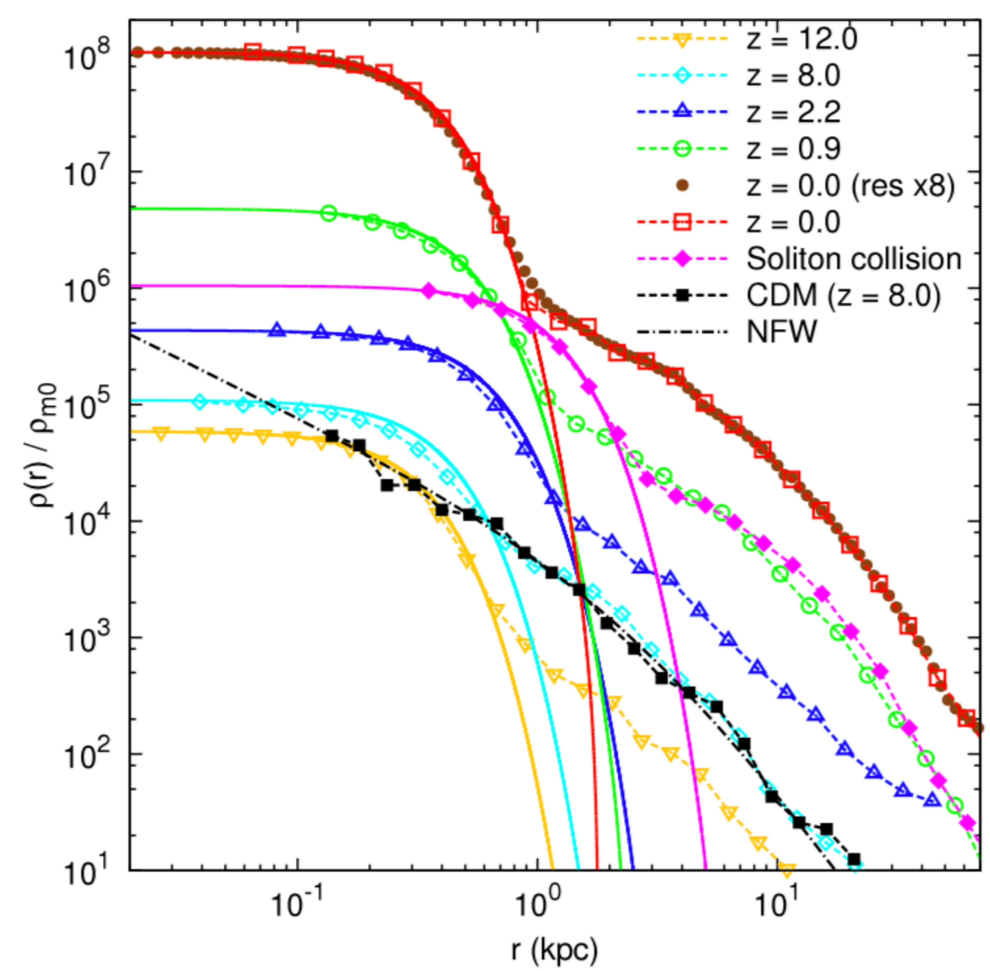
$$r_{\rm core} \sim \lambda_{\rm dB} \equiv \frac{h}{m_\psi v}$$

- central soliton core + outer NFW DM profile

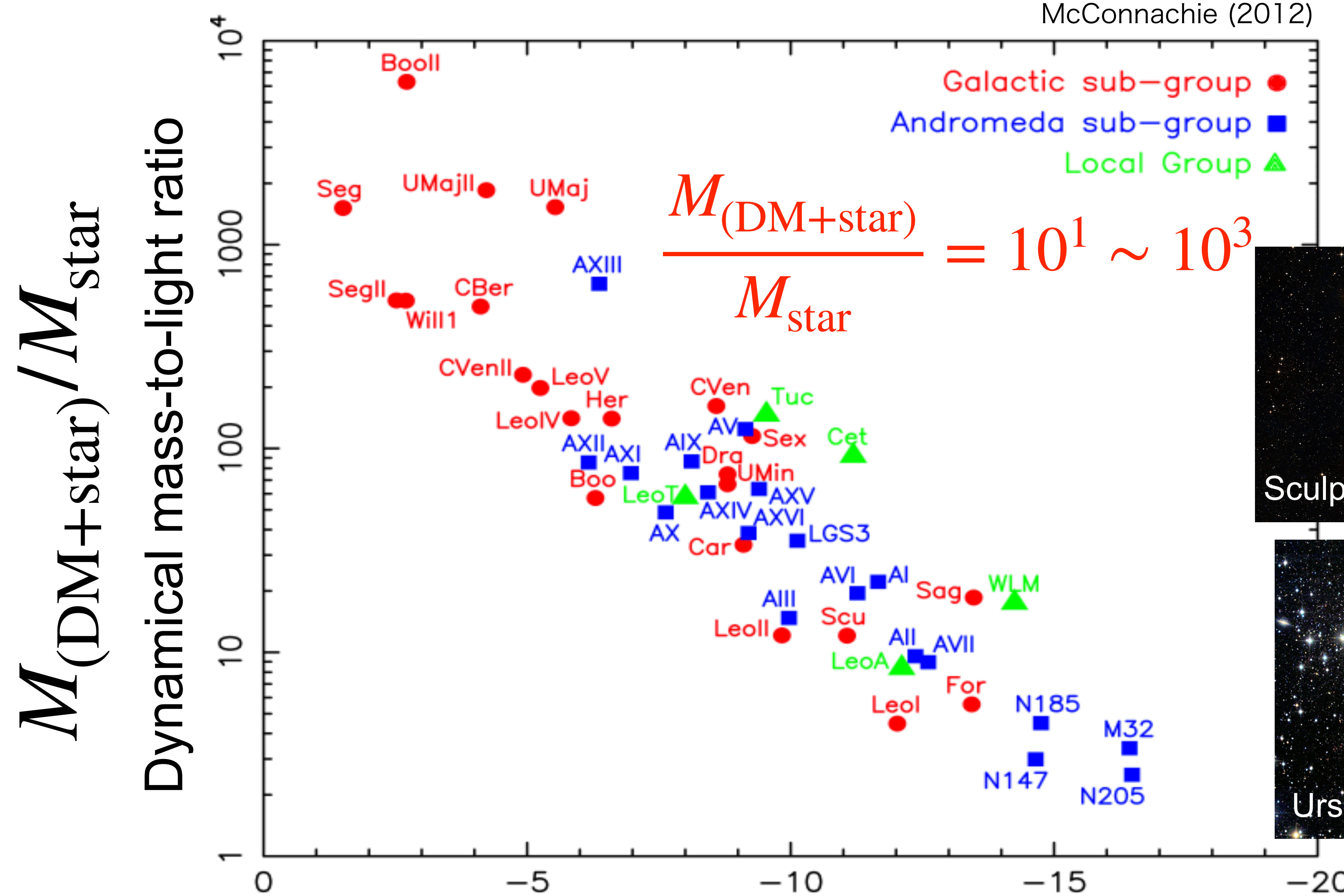


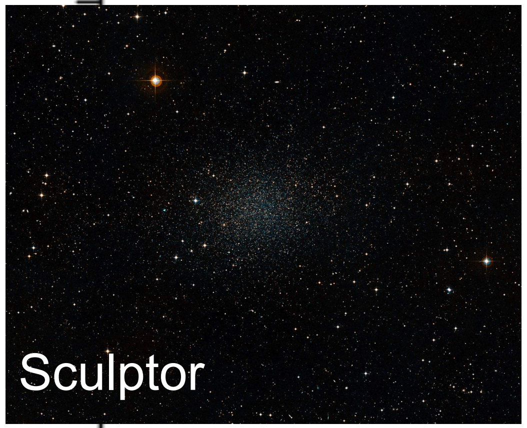
Schive et al. (2014)





dSphs: dark-matter dominated system





DSphs are ideal sites for studying the nature of DM!

Constraining particle mass of ULADM

Soliton-core dark matter density profile

$$\rho_{\rm soliton}(r) = \frac{\rho_c}{[1+0.091(r/r_c)^2]^8}$$

$$\rho_c = 1.9\times10^{12}\left(\frac{m_\psi}{10^{-23}\ \mathrm{eV}}\right)^{-2}\left(\frac{r_c}{\mathrm{pc}}\right)^{-4}\ [M_\odot\ \mathrm{pc}^{-3}]$$

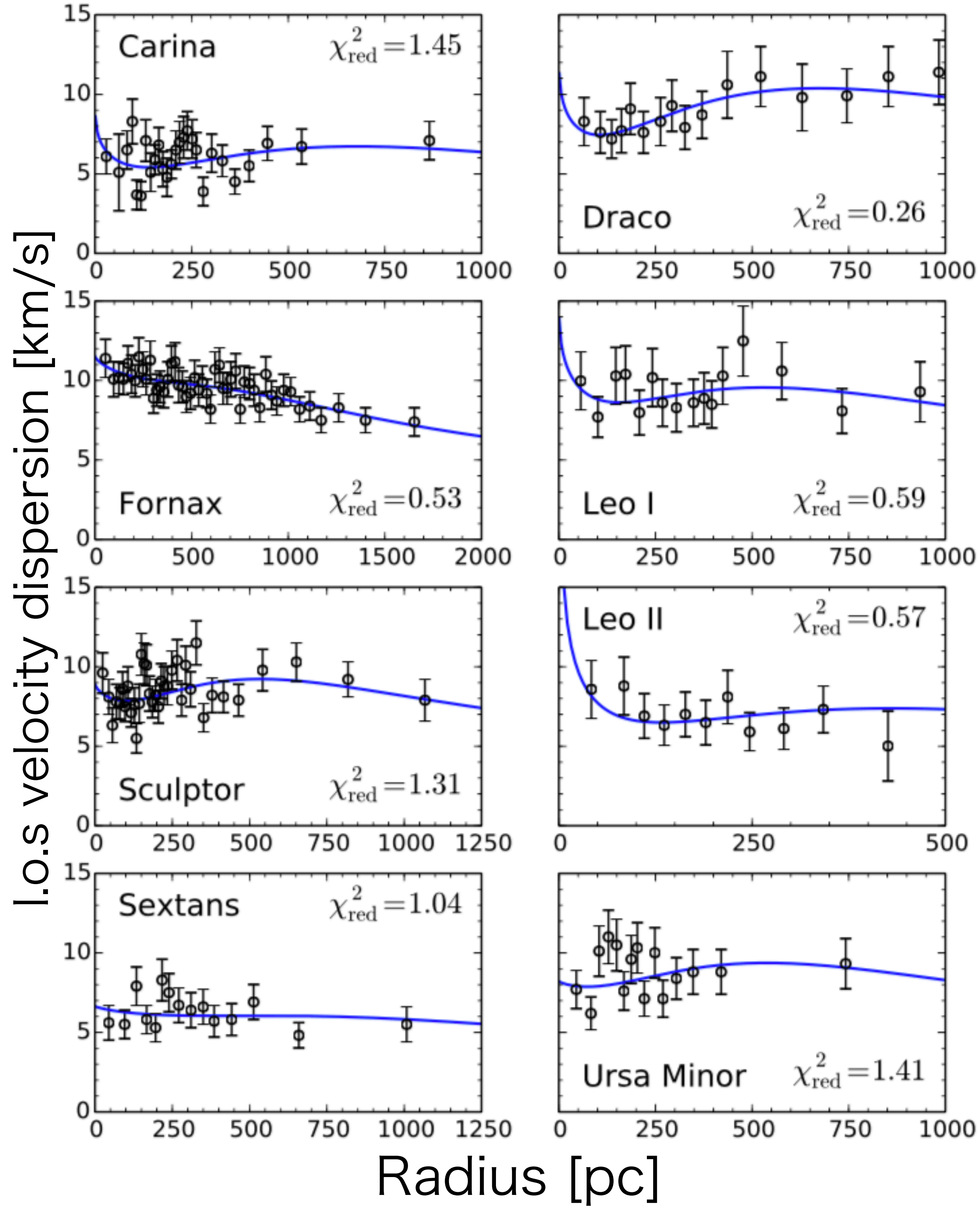
Dynamical models for stars
ex) Spherical Jeans equation

$\sigma_{\rm l.o.s}^{\rm (Theory)}$ **FIT** $\sigma_{\rm l.o.s}^{\rm (obsrved)}$

- Current constraint from Spherical mass models

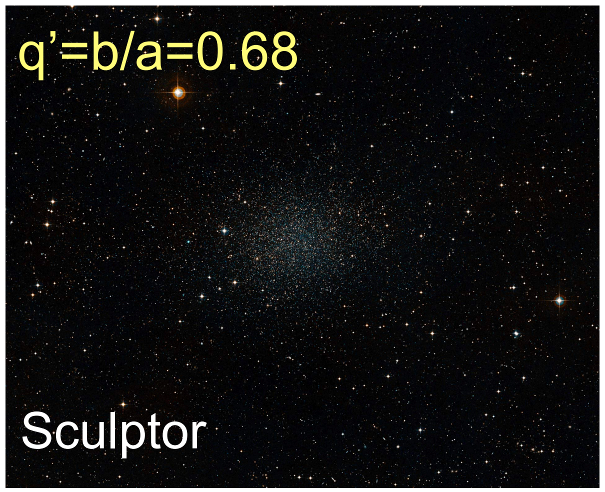
$$m_\psi = 1.79^{+0.35}_{-0.33}\times10^{-22}\ \mathrm{eV}\ (2\sigma)$$

Chen et al. (2009)

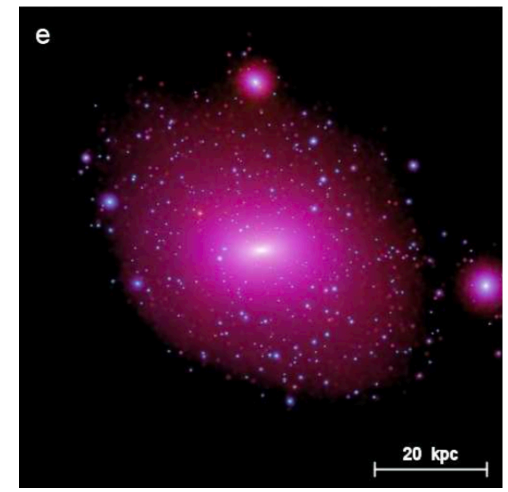


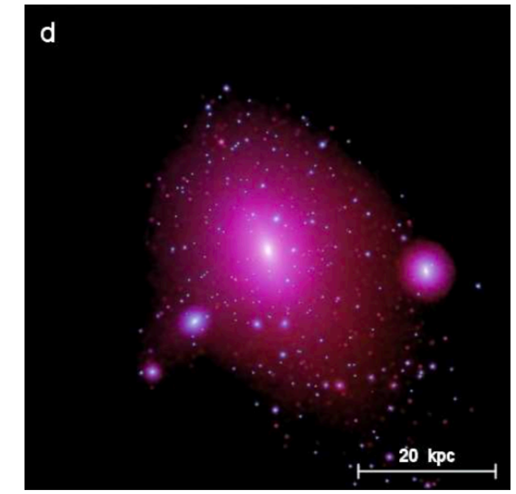
Major systematic uncertainty: Spherical Symmetry

1. Observed dSphs are
NOT spherical shape



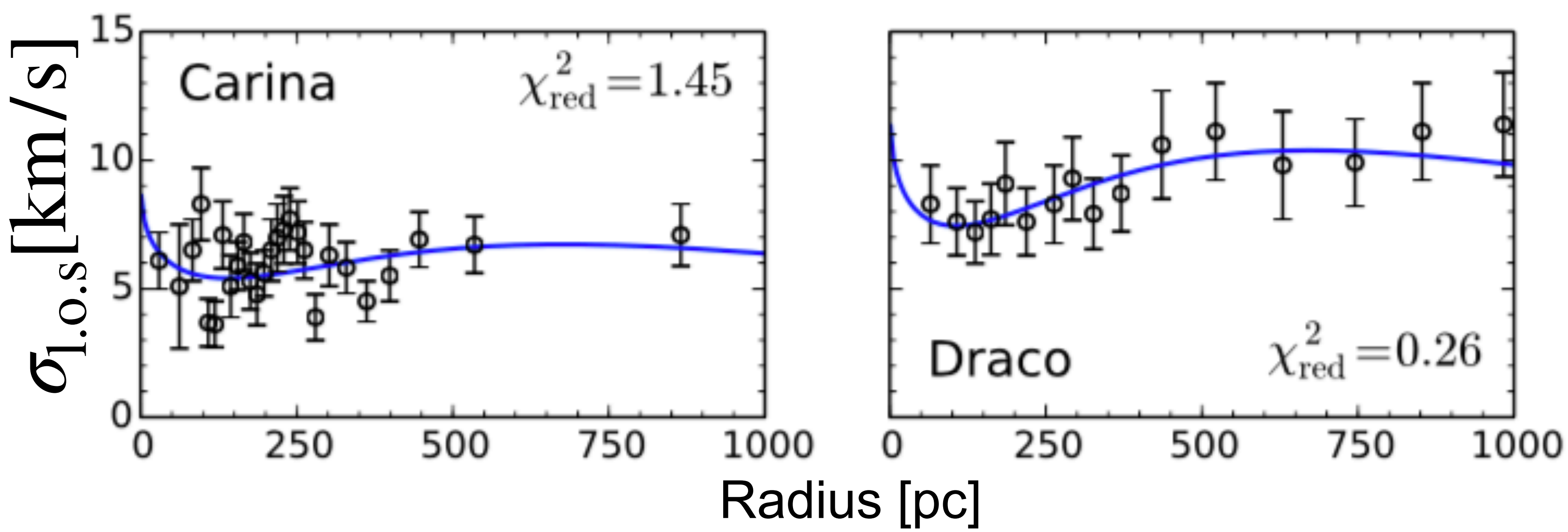
2. DM models predict
NON-spherical DM halo





credit: Aquarius project

3. 1D spatial information



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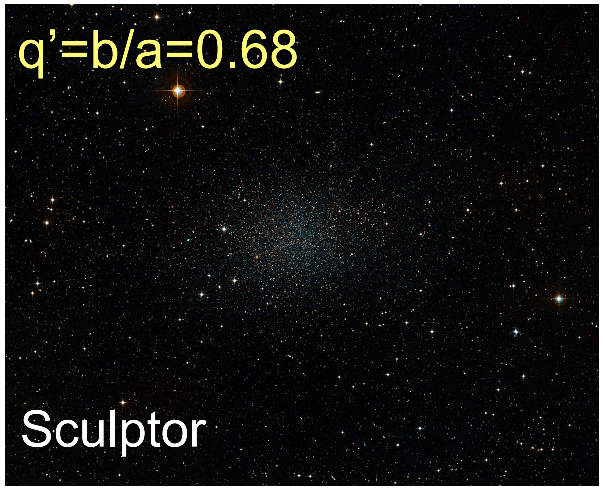

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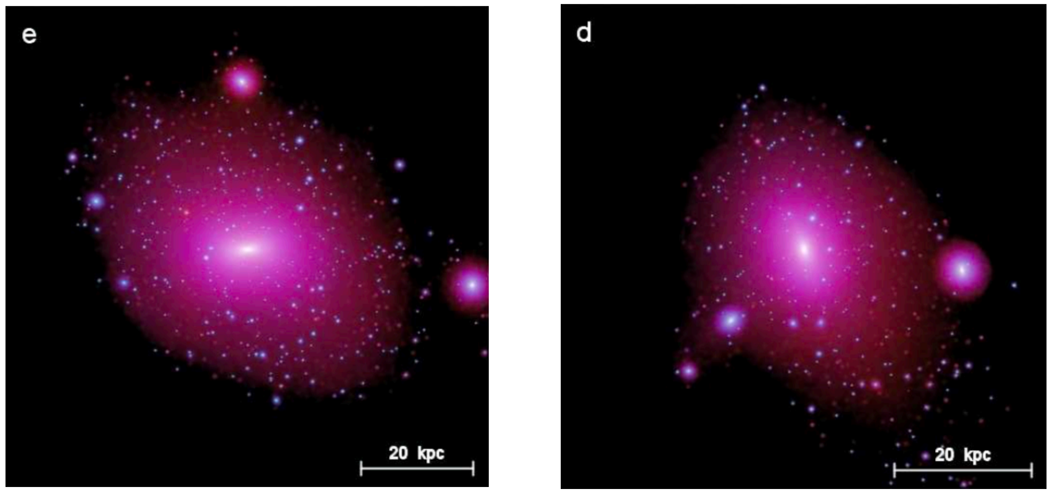

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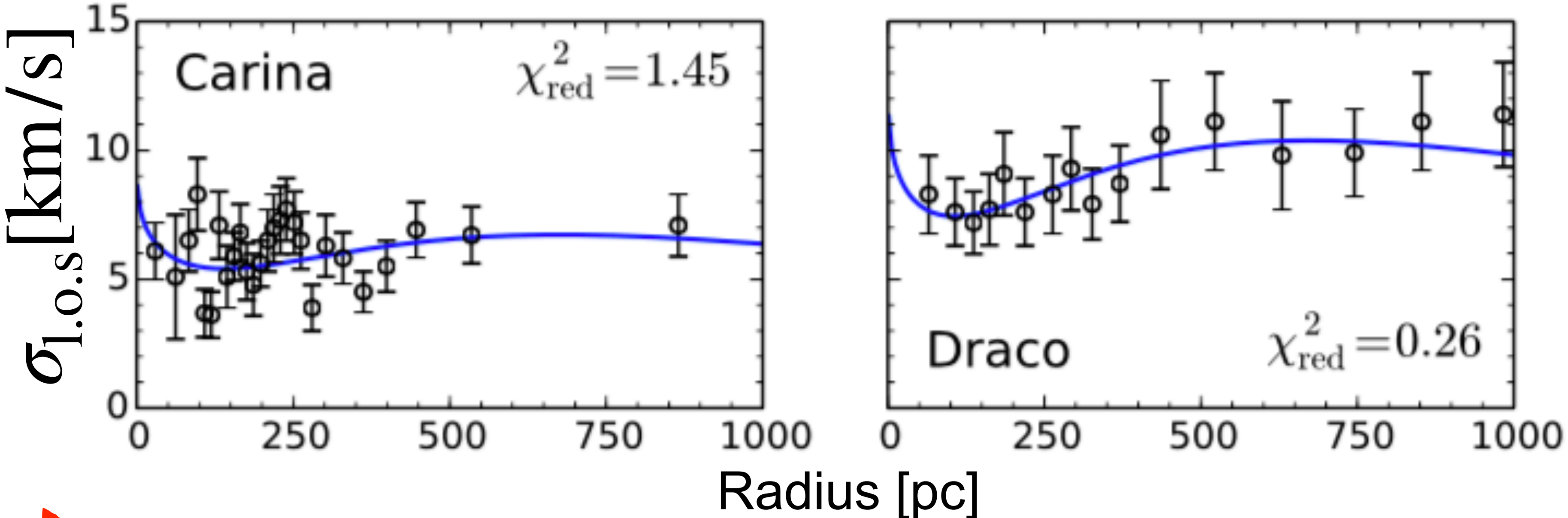

Non-spherical mass model

Non-spherical dynamical mass models

Unobservable

Non-spherical dark matter density profile

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$$\rho_c = 1.9\times10^{12}\left(\frac{\boxed{m_\psi}}{10^{-23}\ {\rm eV}}\right)^{-2}\left(\frac{\boxed{r_c}}{\rm pc}\right)^{-4}\ [M_\odot\ {\rm pc}^{-3}]$$

$$r^2 = R^2 + \frac{z^2}{\boxed{Q^2}}$$

DM halo axial ratio

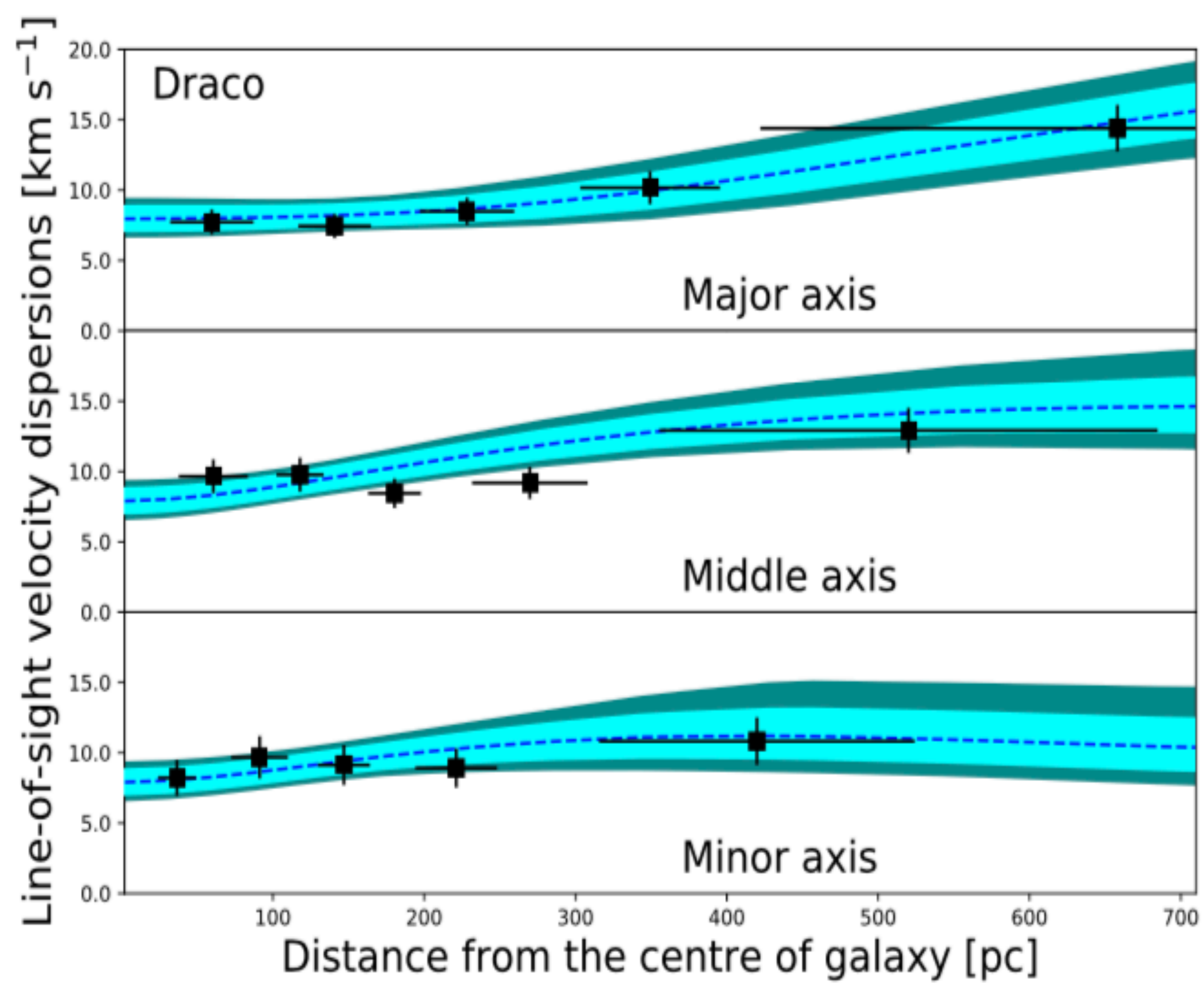
Non-spherical stellar profile

$$\rho_*(r_*) = \frac{3L}{4\pi r_p^3}\left[1+\frac{r_*^2}{r_p^2}\right]^{-5/2}$$

$$r_*^2 = R^2 + \frac{z^2}{q^2}$$

stellar axial ratio

Draco dSph



Axisymmetric Jeans equations

$$\rightarrow (\overline{v_z^2}, \overline{v_\phi^2})$$

$\overline{v_R^2}$ is unknown parameter as $\boxed{\beta_z} = 1 - \overline{v_z^2}/\overline{v_R^2}$

$\sigma_{\rm l.o.s}^{\rm (theory)}$ **FIT** $\sigma_{\rm l.o.s}^{\rm (obsrved)}$

Constraints on ULADM

Hayashi & Obata (2019), 1902.03054

- Constraint on ULADM mass (combined with 8 dSphs)

$$m_\psi = 1.05^{+4.98}_{-0.80} \times 10^{-22} \text{ eV}$$

Constraints on ULADM

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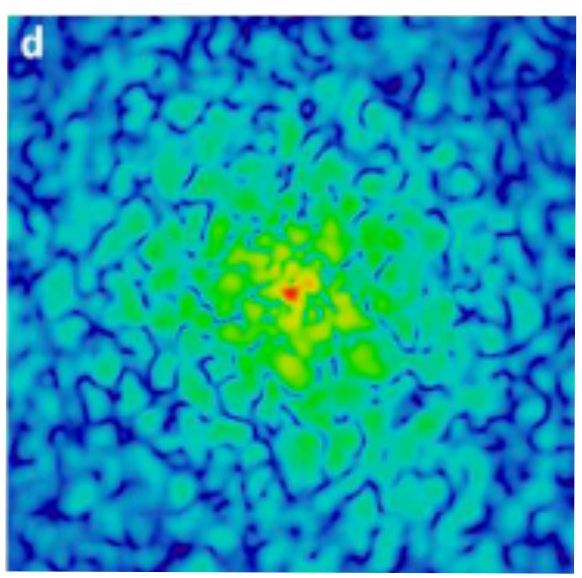
Stellar & DM halo axial ratio of Draco

$$q = (b/a)_{\rm star} = 0.69$$

$$Q = (b/a)_{\rm DM} = 0.21$$



$Q \sim 1.0$

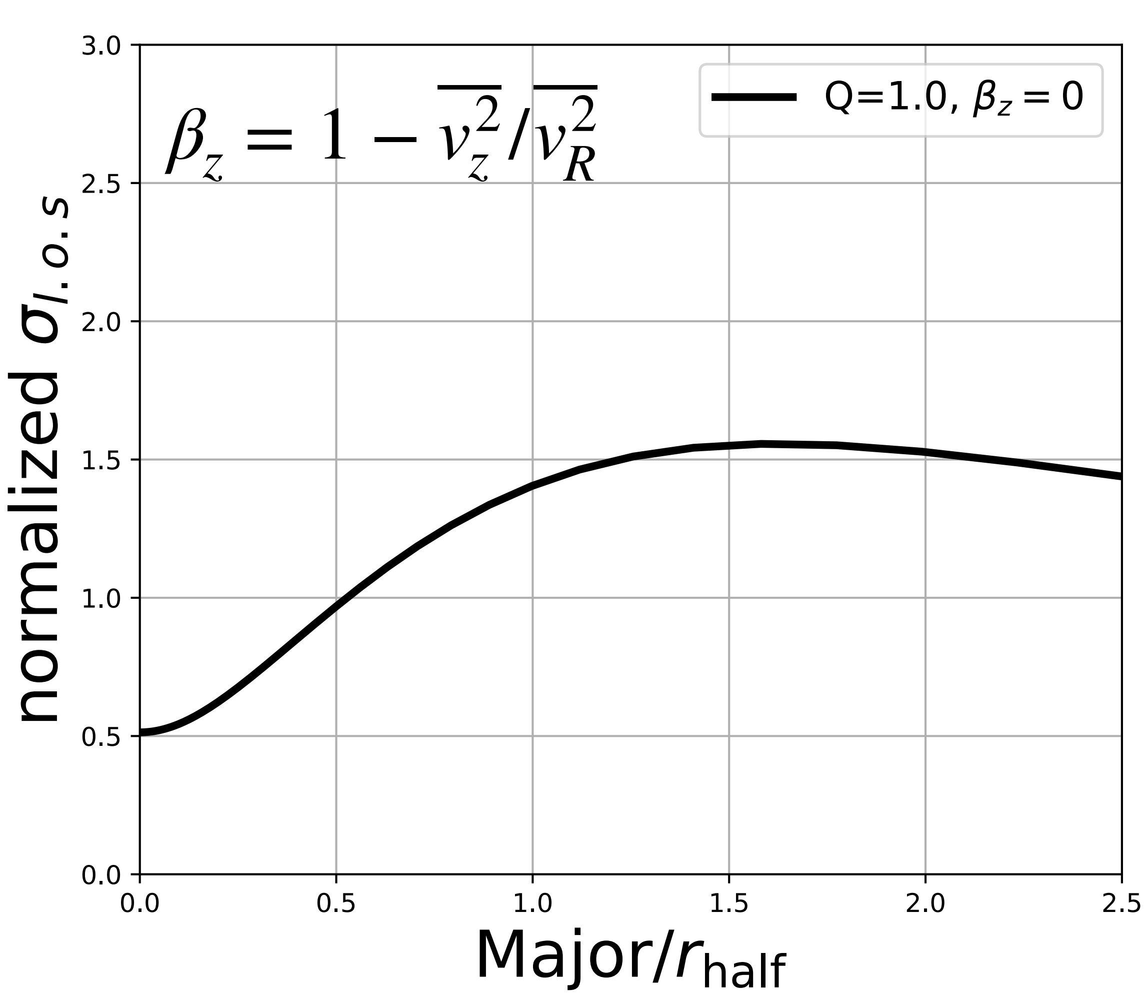
Schive et al. (2014)

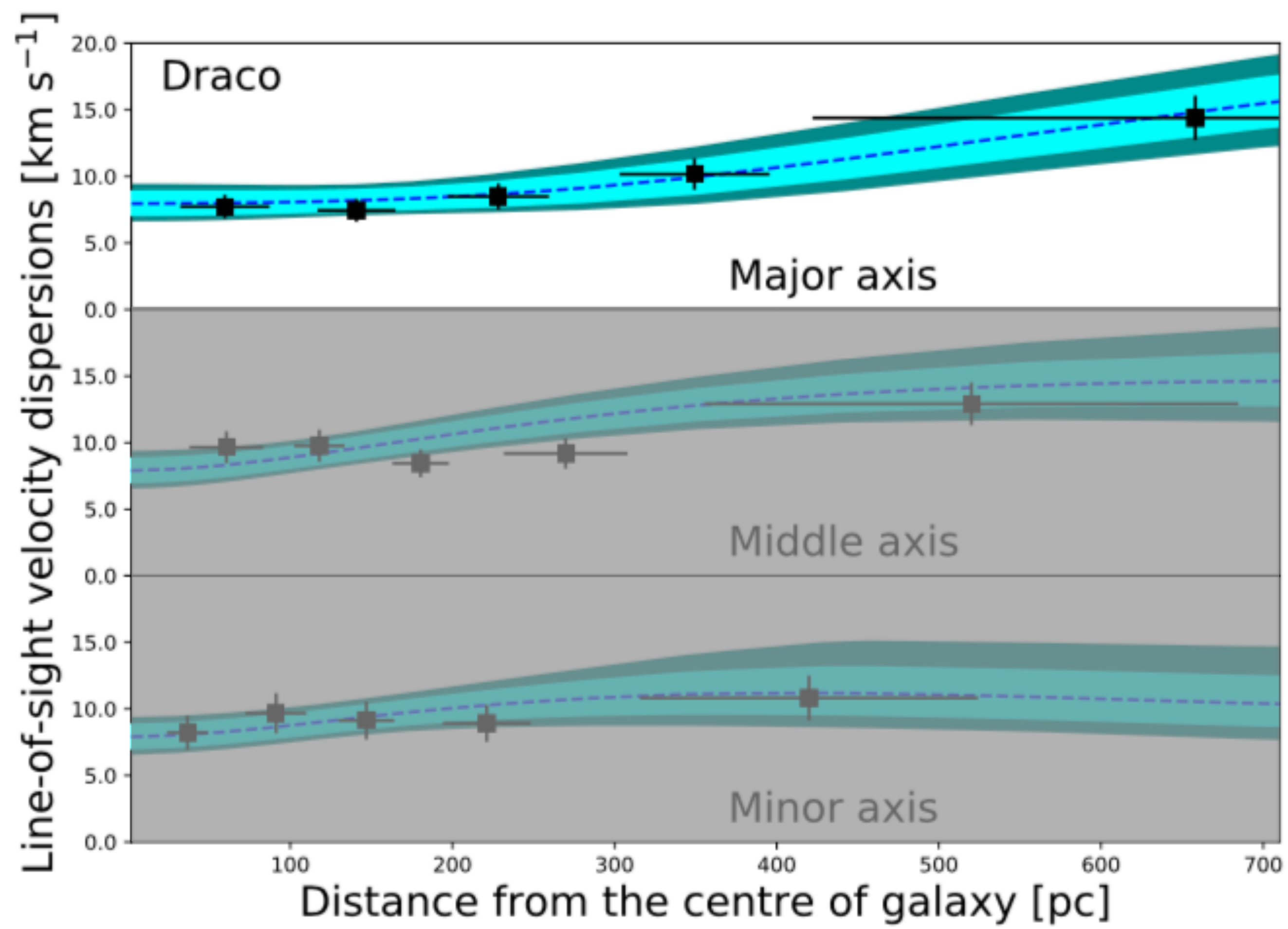
- Constraint on ULADM mass (combined with 8 dSphs)

$$m_\psi = 1.05^{+4.98}_{-0.80} \times 10^{-22}\ \mathrm{eV}$$

- Draco has strongly elongated dark halo, **Q~0.2**.
- Draco's ULADM halo is **much more flattened** than N-body predictions.
- Further understanding of baryonic and DM physics should be needed.

Why does Draco have very flattened dark halo?





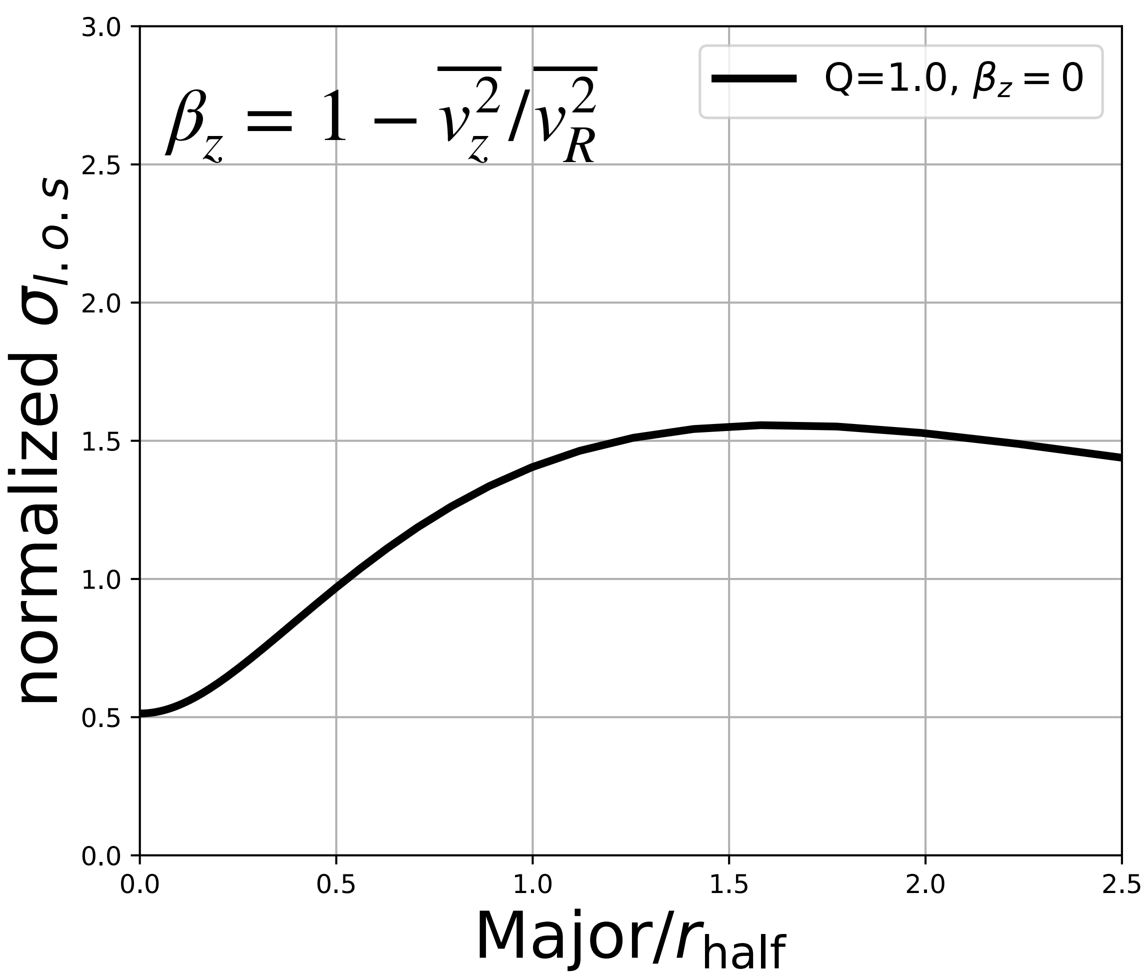
Setting:

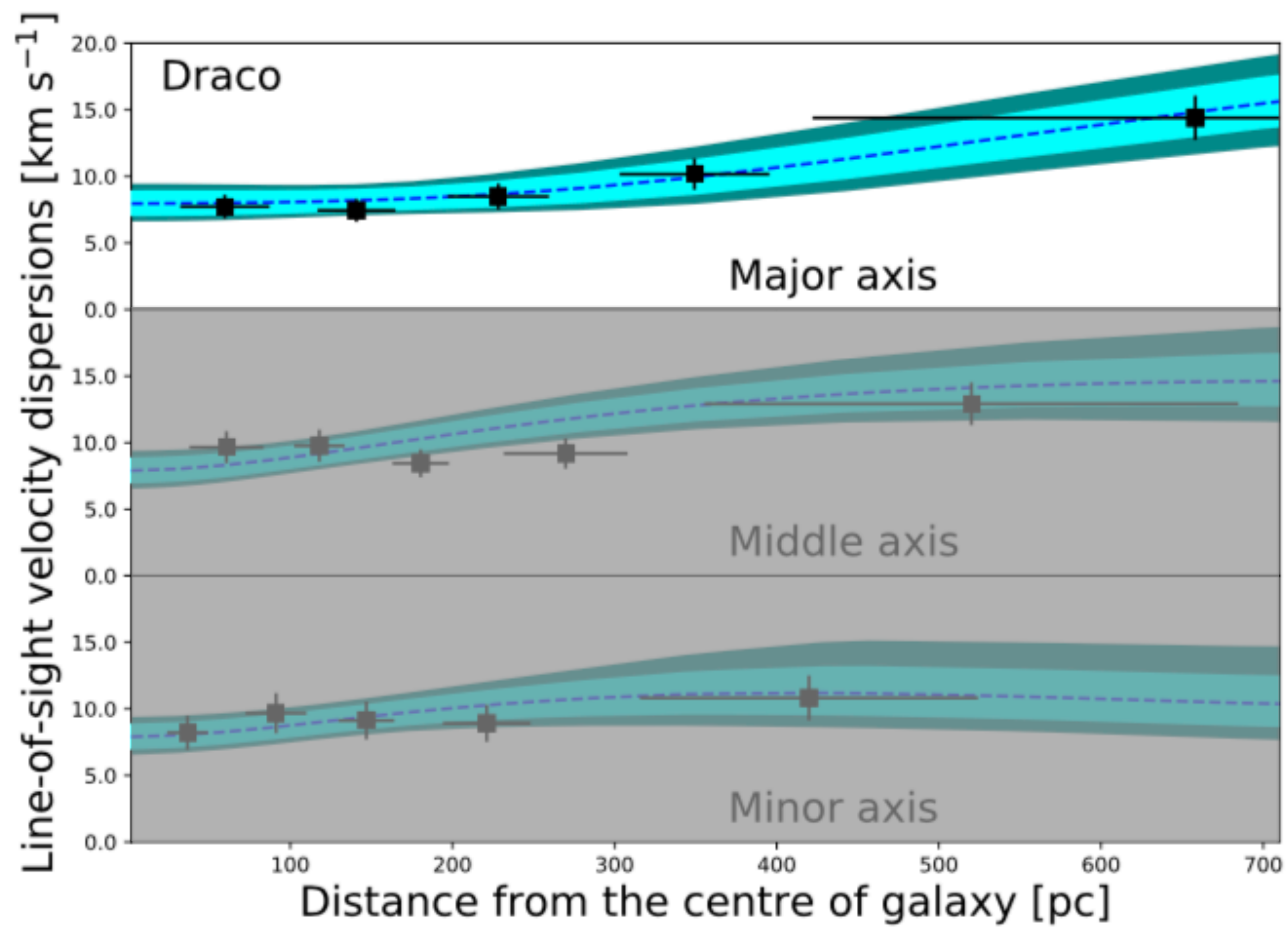
- m_psi = 10^{-22} eV
- stellar axial ratio, q=0.7
- r_c = 2×r_half

Why does Draco have very flattened dark halo?

The three ways to increase velocity dispersion in inner parts

1. **small Q**
2. **radially-biased velocity ellipsoid**
3. **steeper inner slope**





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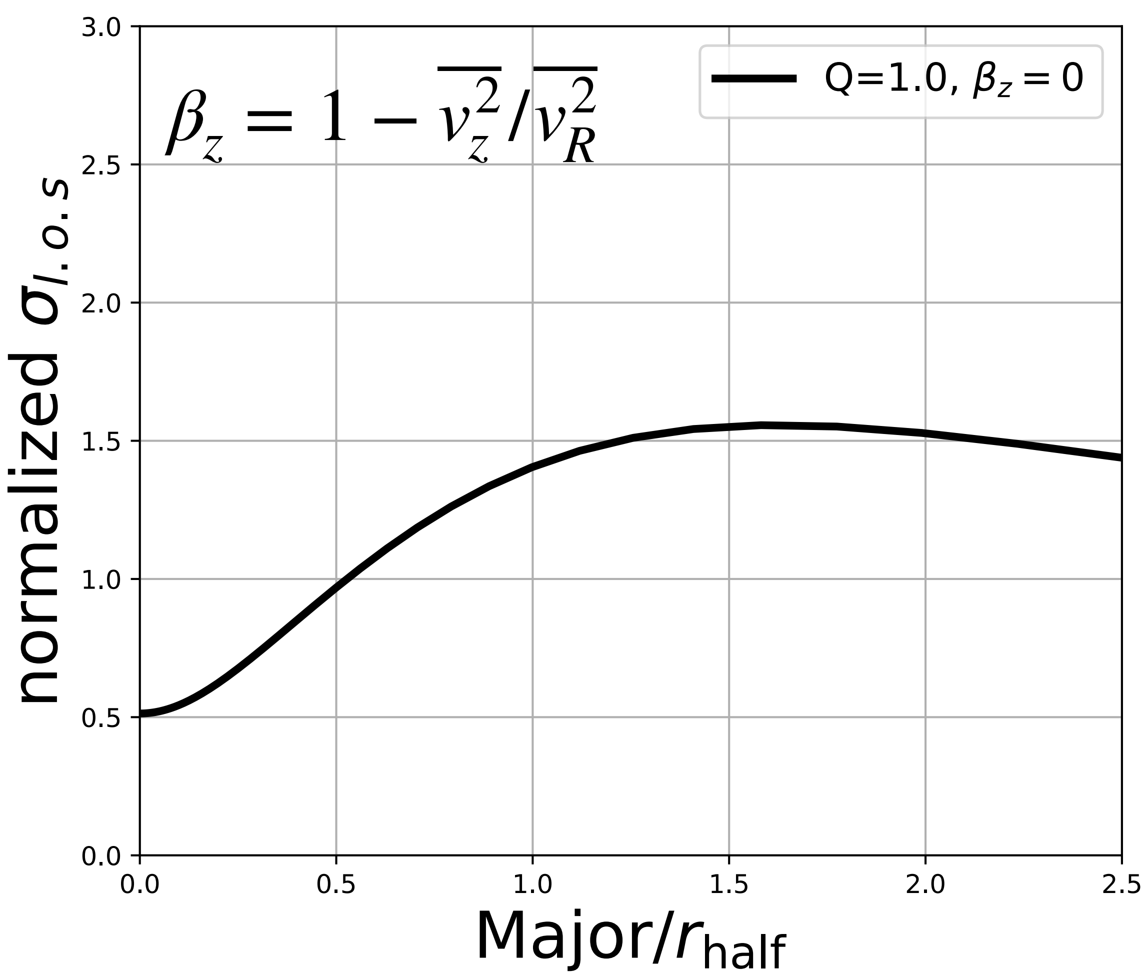

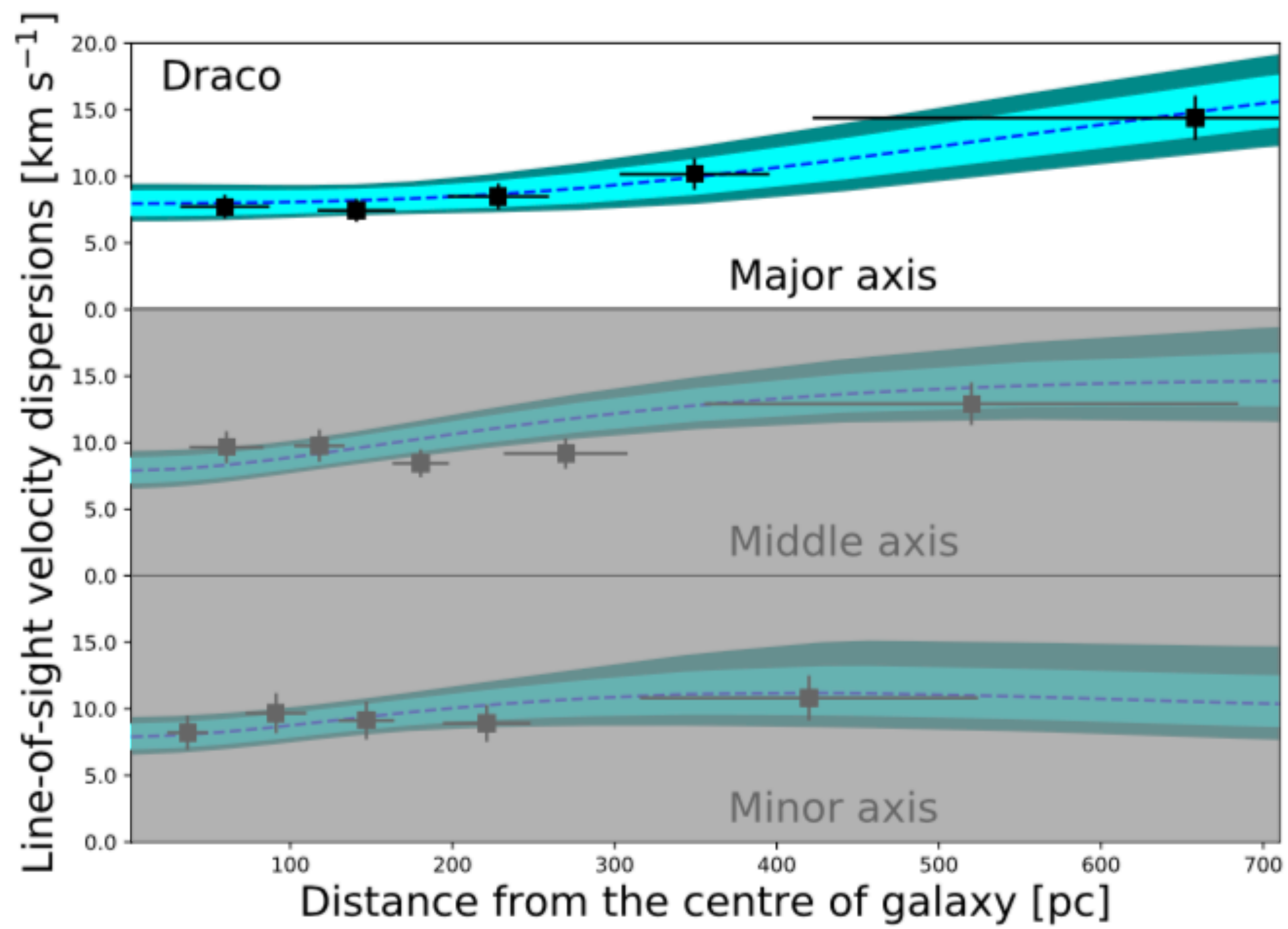

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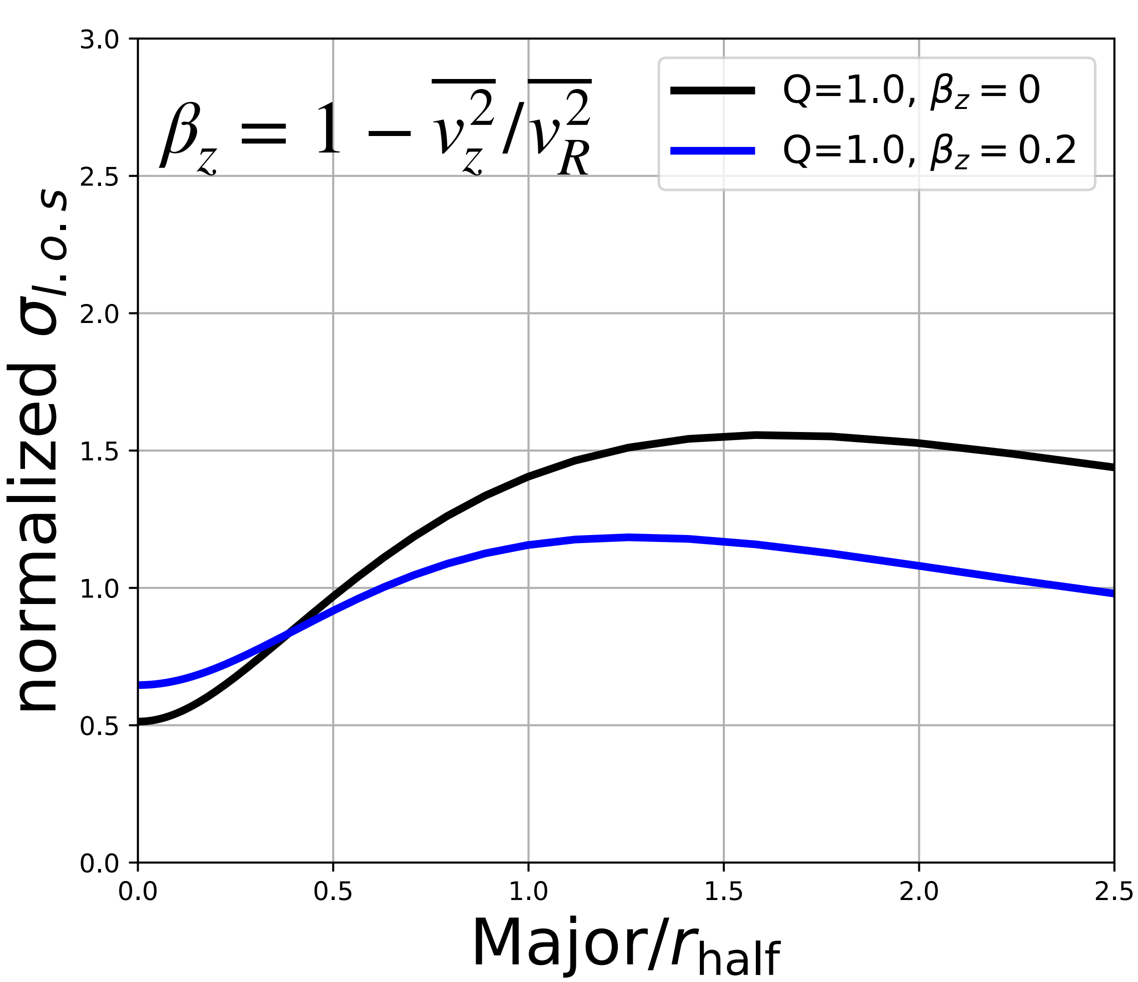

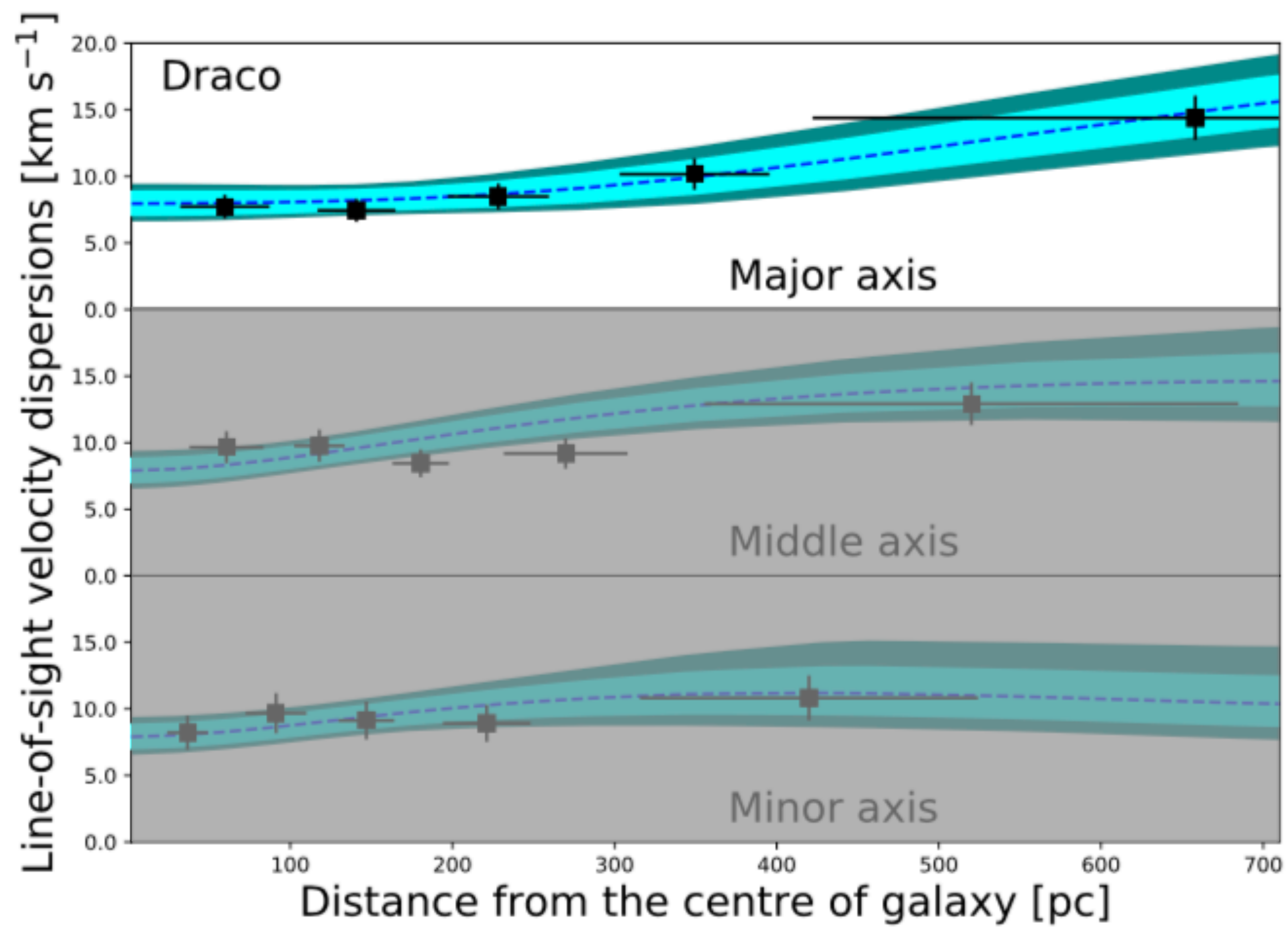

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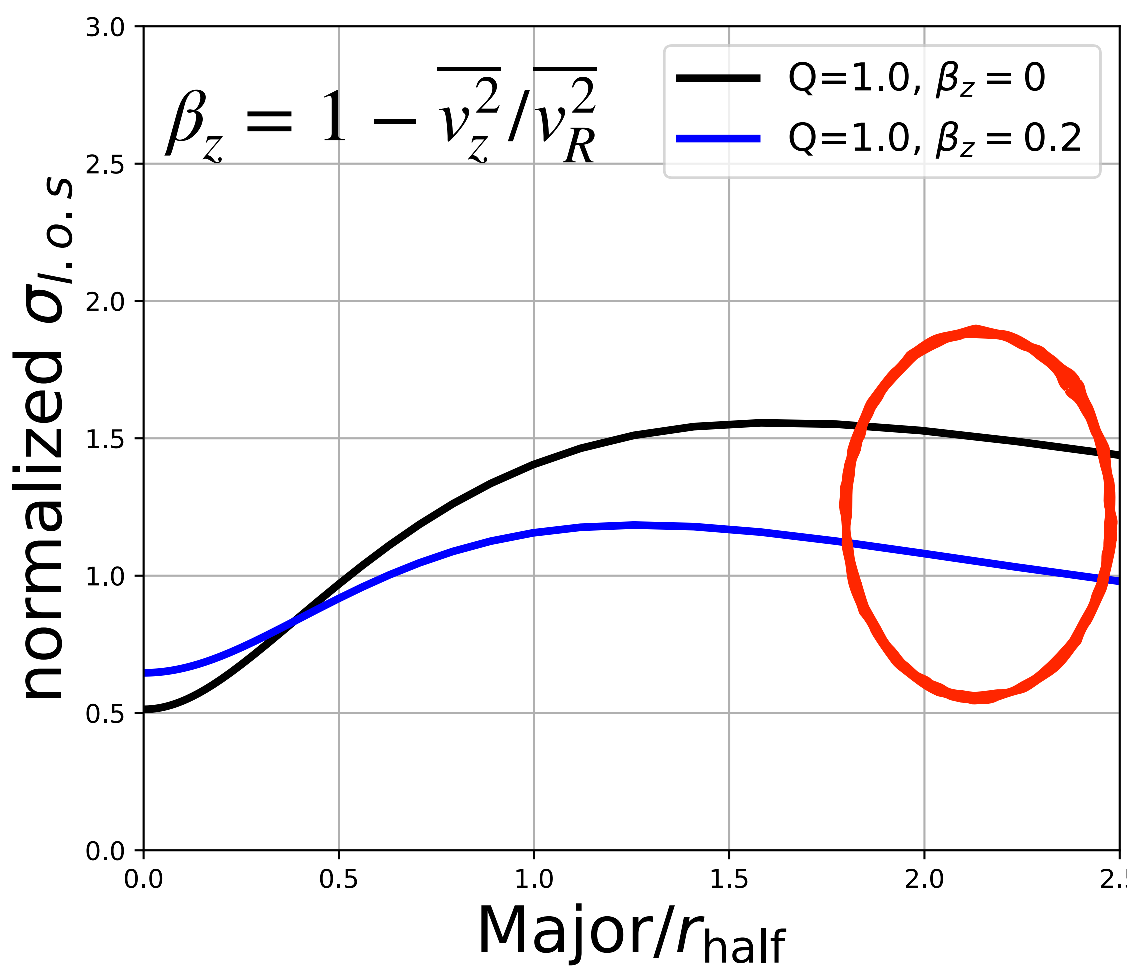

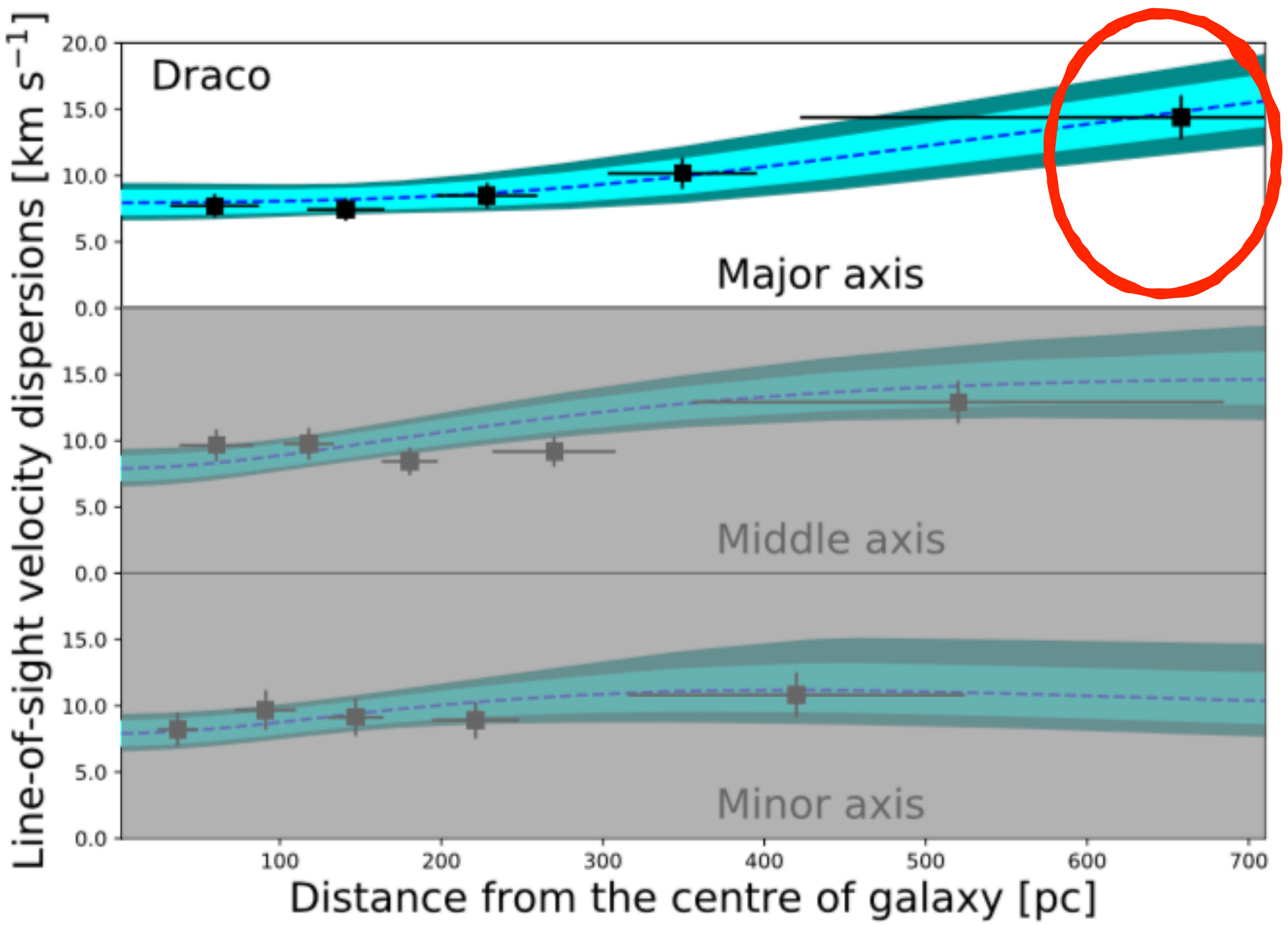

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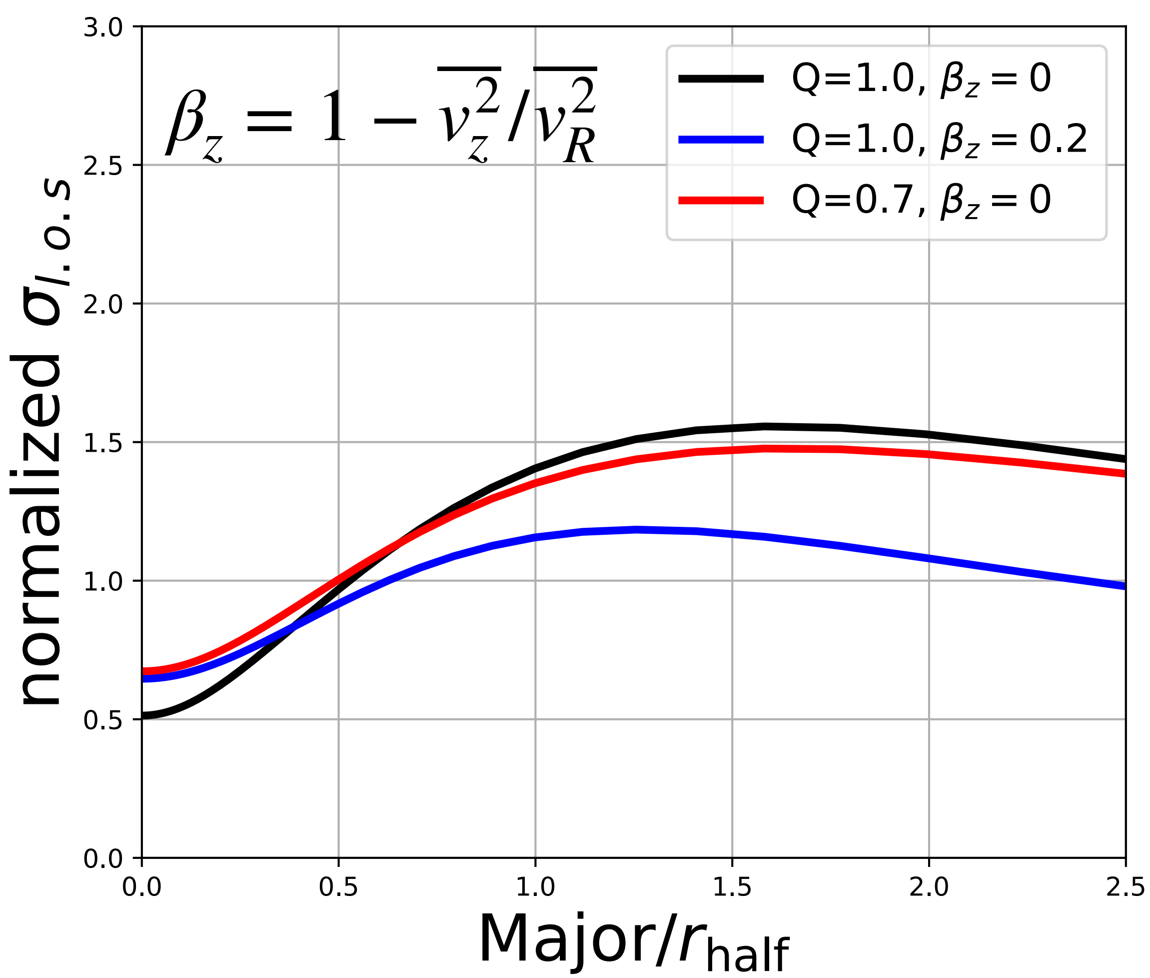

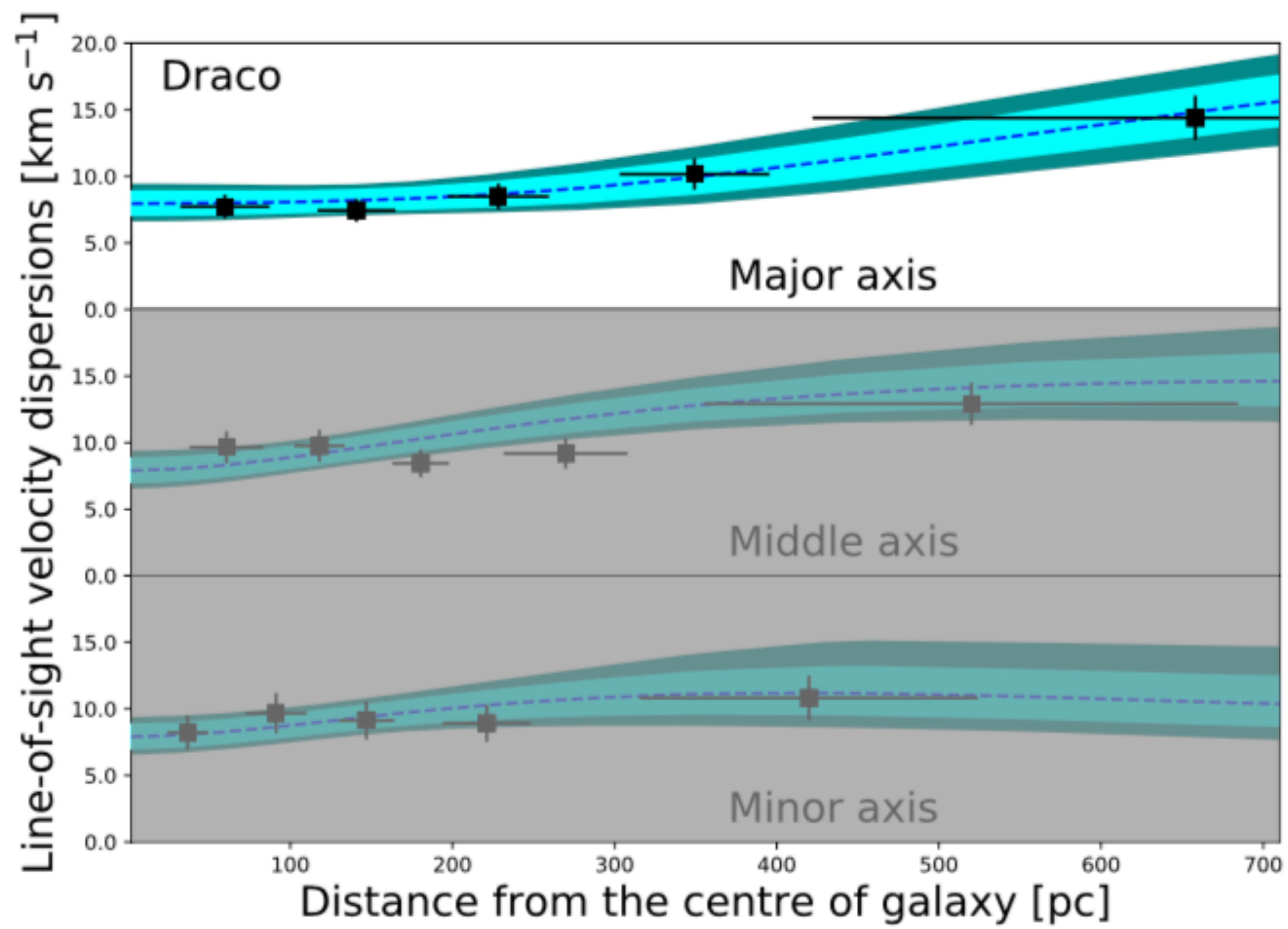

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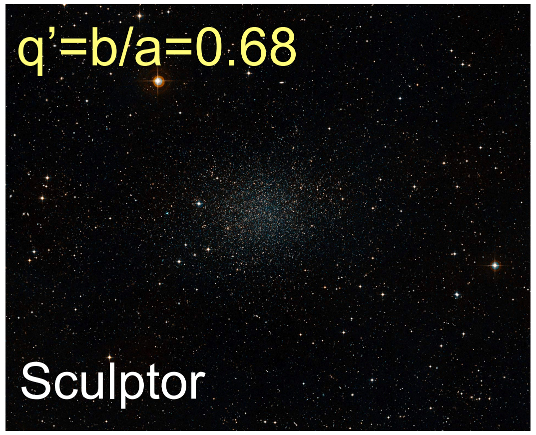
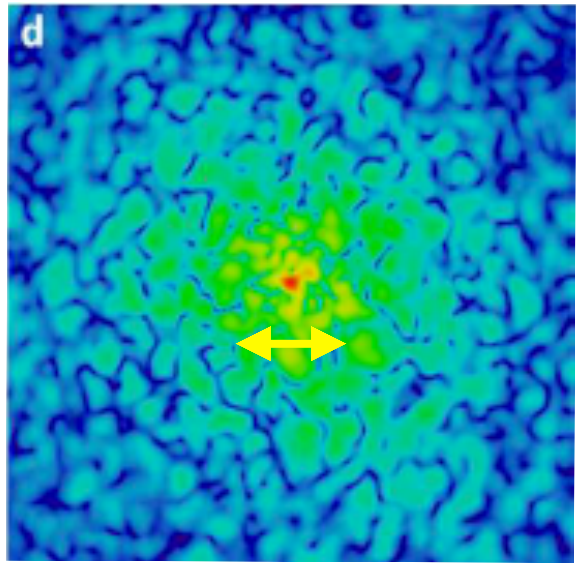
Summary

- Ultralight axion dark matter is one of the dark matter candidates, because it can resolve small scale problems.
- The MW dSphs are excellent test-bed for testing dark matter models.
- Construct dynamical modeling taking into account non-sphericity
- Mass models for the dSphs suggest strongly elongated DM halo.
- Inconsistent with predictions from dark matter simulations





$Q \sim 0.2$