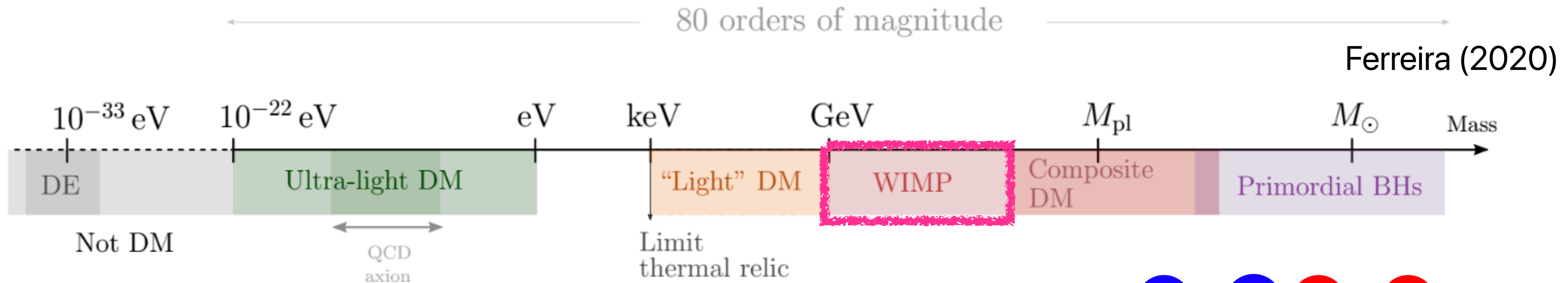


Beyond Spherical Assumptions: CTAO Sensitivity to Dark Matter in Dwarf Spheroidal Galaxies

Kohei Hayashi (NIT, Sendai college)

In collaboration with Nagisa Hiroshima (YNU) and Tomohiro Inada (Kyushu Univ.)

Dark matter: one of the greatest mysteries in modern physics

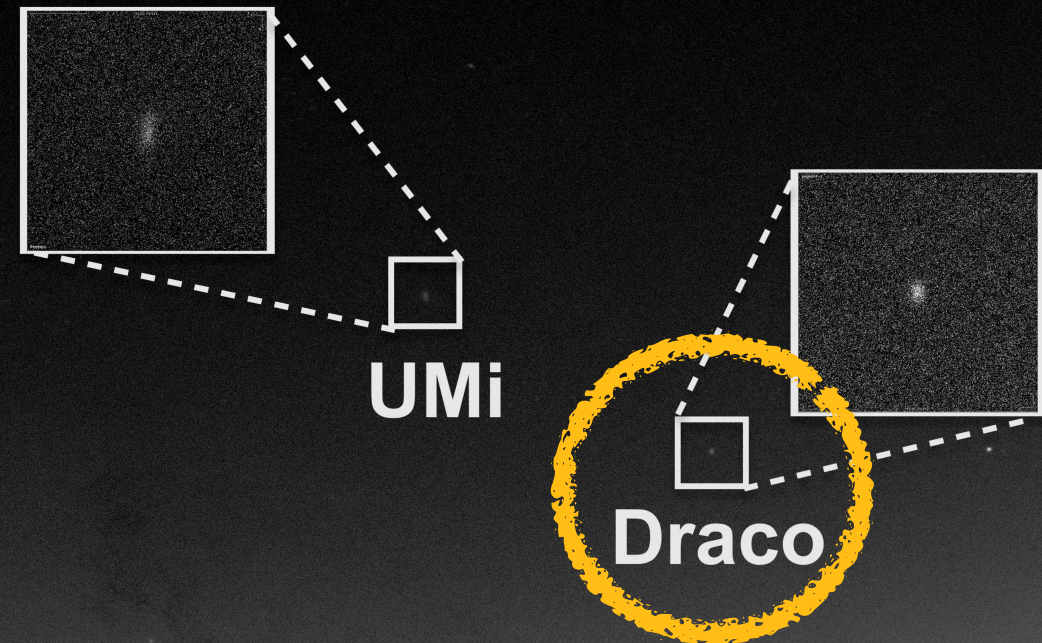


- Its existence has been confirmed through various astronomical observations.
- Yet, it remains an unknown substance - we don't even know its mass.
- It offers an enormous discovery space waiting to be explored.
- WIMPs are among the leading candidates for DM.



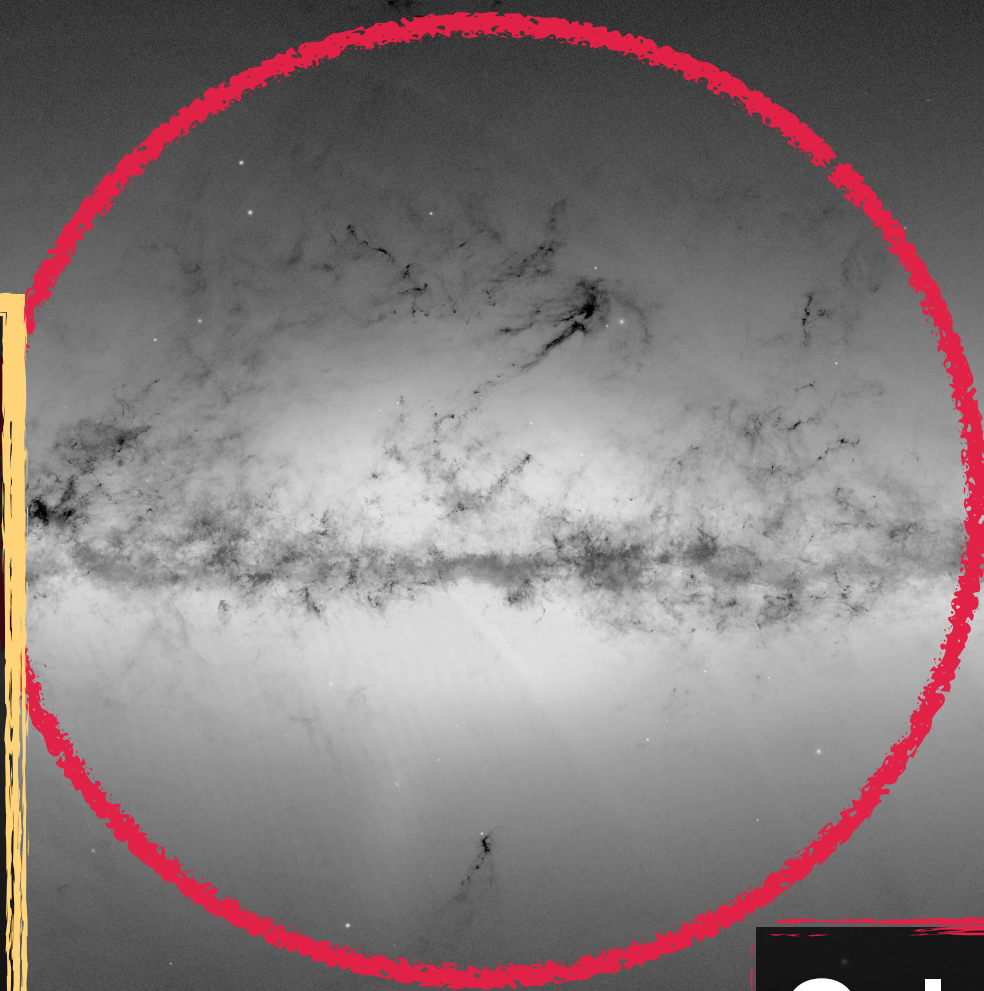
Bertone & Tait (2018)

The Milky Way as a unique target for indirect DM searches



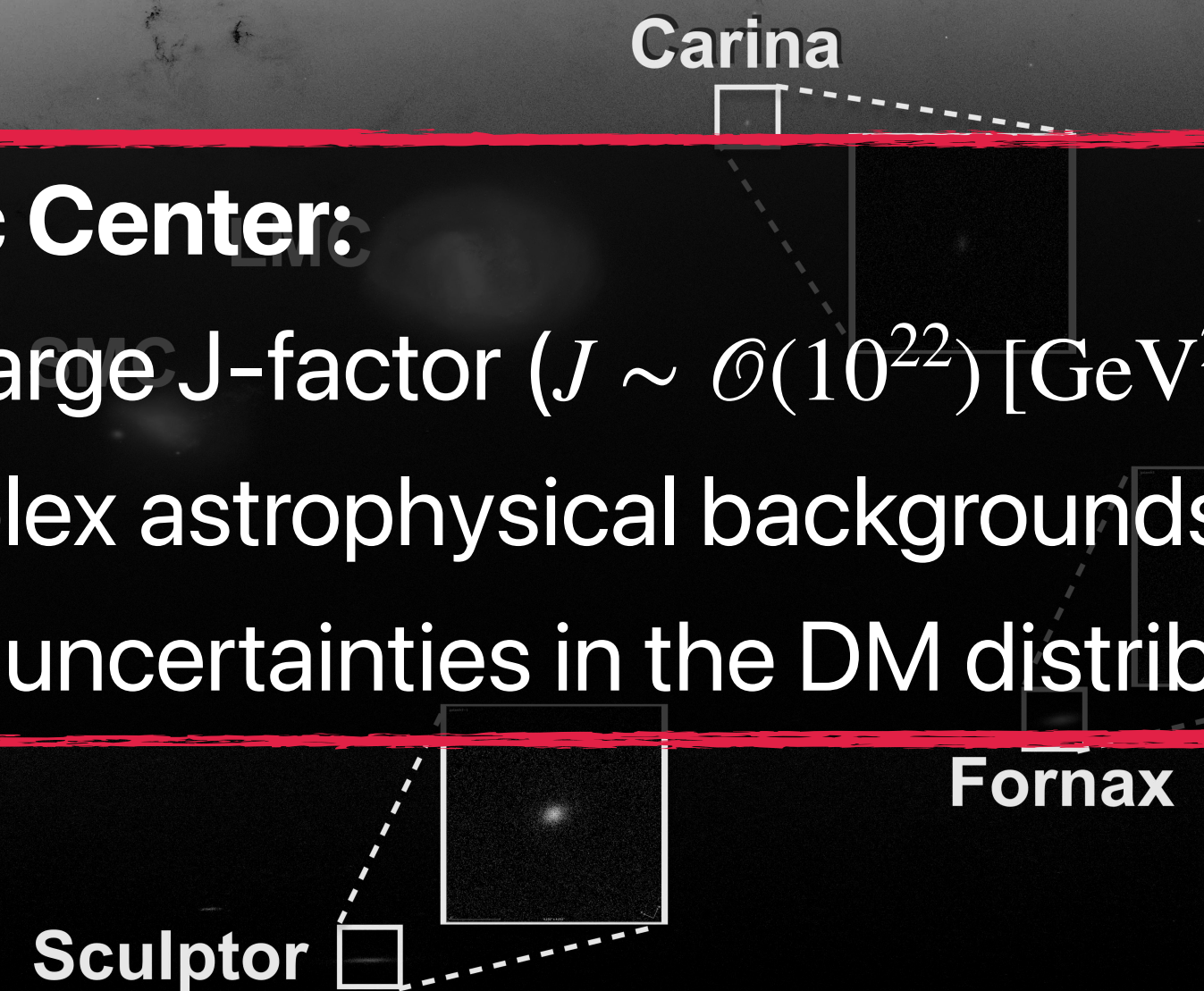
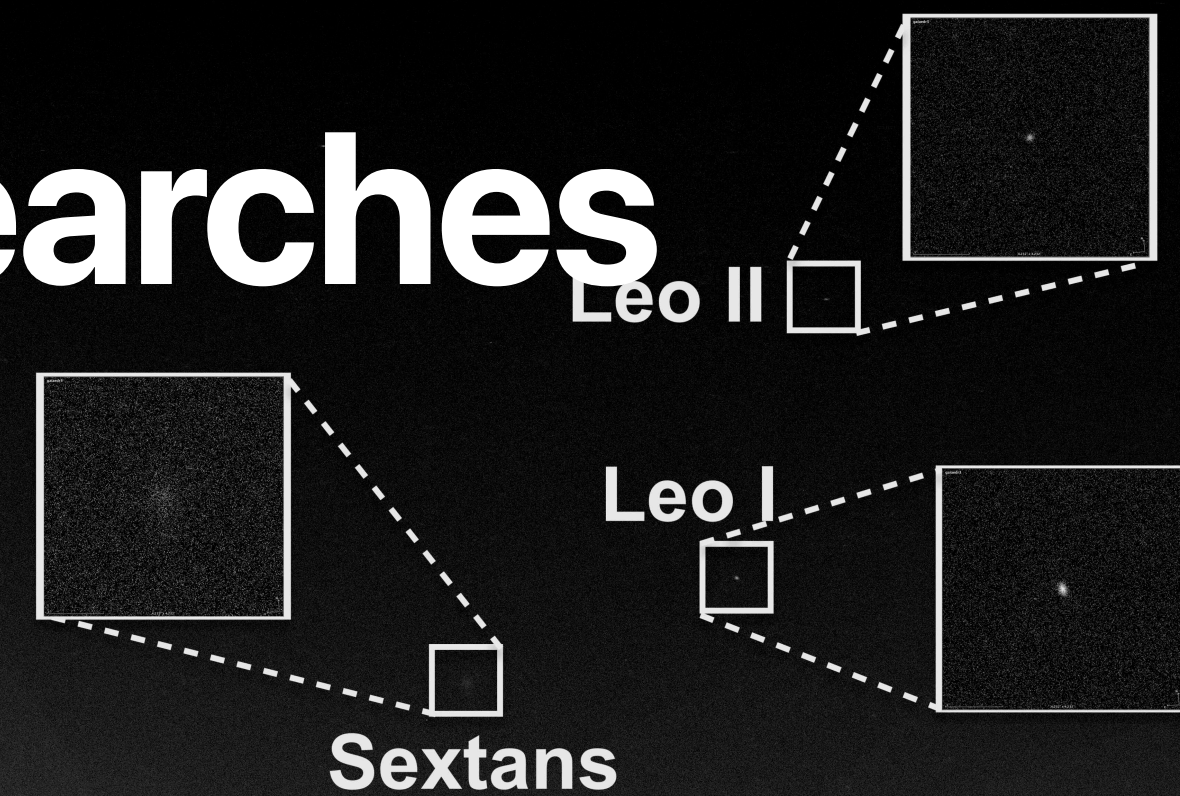
MW dSphs:

- Large J-factor ($J \lesssim \mathcal{O}(10^{19}) [\text{GeV}^2/\text{cm}^5]$)
- Clean astrophysical environments
- DM distributions constrained by stellar kinematics

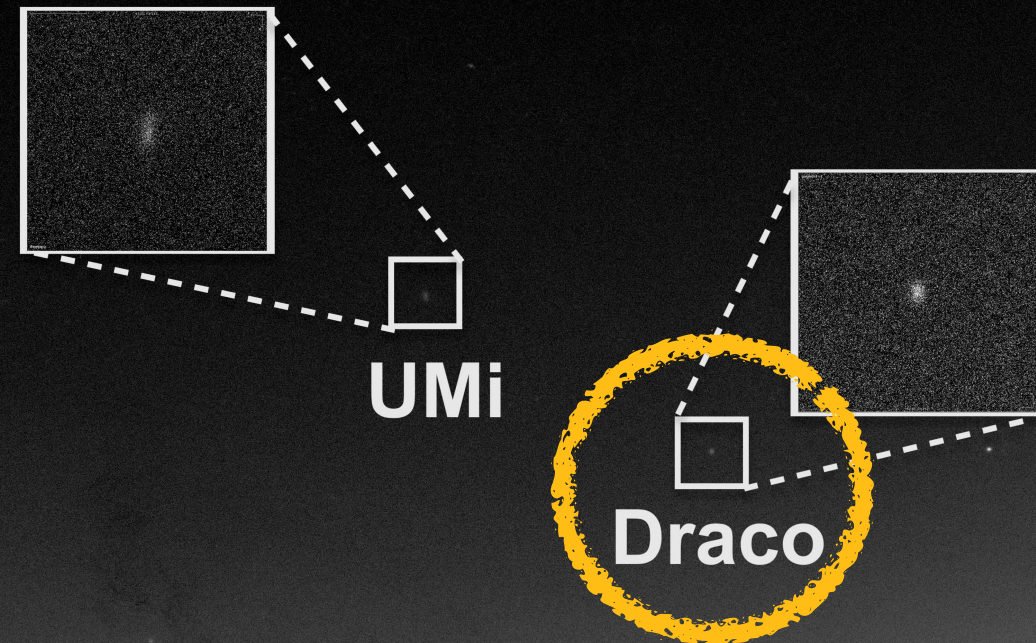


Galactic Center:

- Very large J-factor ($J \sim \mathcal{O}(10^{22}) [\text{GeV}^2/\text{cm}^5]$)
- Complex astrophysical backgrounds
- Large uncertainties in the DM distribution



The Milky Way as a unique target for indirect DM searches



MW dSphs:

- Large J-factor ($J \lesssim \mathcal{O}(10^{19}) [\text{GeV}^2/\text{cm}^5]$)
- Clean astrophysical environments
- DM distributions constrained by stellar kinematics

Key Question of my talk:

How sensitive are estimates of the DM annihilation cross section with CTAO to non-spherical DM distributions in dSphs?

Galactic Center:

- Very large J-factor ($J \sim \mathcal{O}(10^{22}) [\text{GeV}^2/\text{cm}^5]$)
- Complex astrophysical backgrounds
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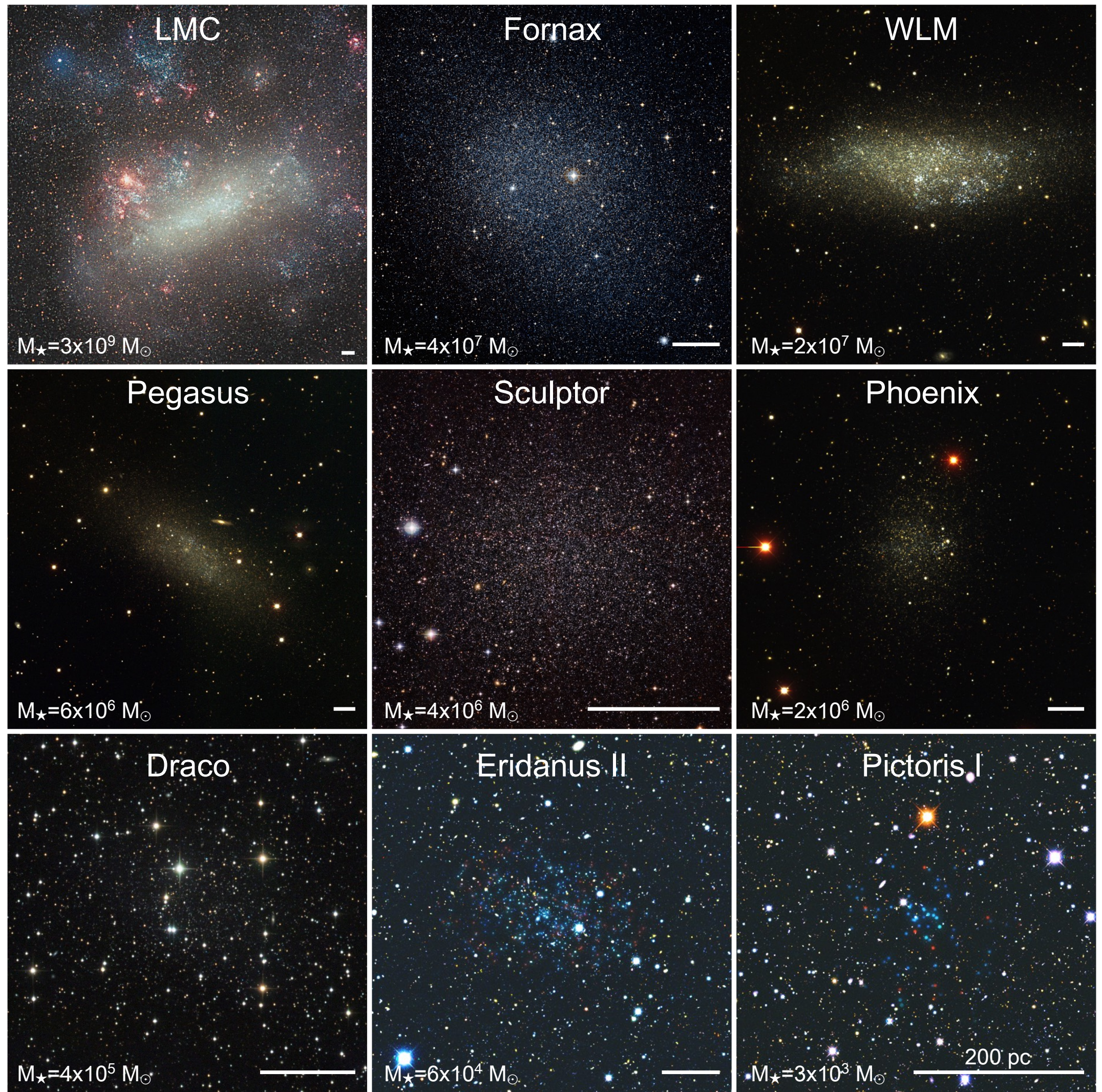


Why non-spherical?

Dwarf *spheroidal* galaxies are **not spherical but spheroidal!**

Stellar distributions

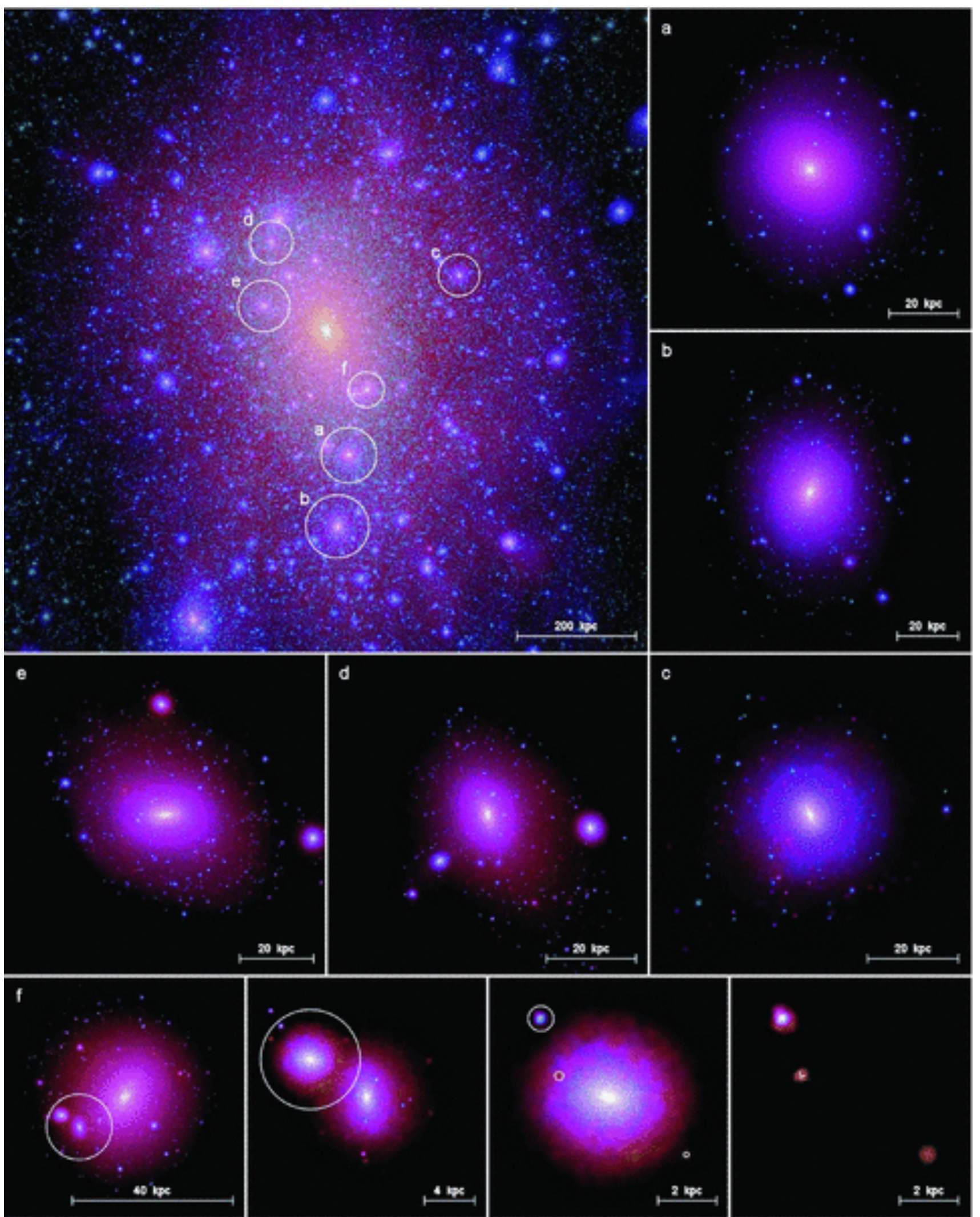
$0.4 \lesssim q_* \lesssim 0.8$



Bullock & Boylan-Kolchin (2017)

Predicted DM distributions

$0.6 \lesssim q_{DM} \lesssim 0.8$



Springel et al. (2008)

Non-spherical dynamical mass models

Non-spherical dark matter density profile

$$\rho_{\text{DM}}(r) = \frac{\rho_s}{(r/r_s)^\gamma [1 + (r/r_s)^\alpha]^{(\beta-\gamma)/\alpha}}$$

$$r^2 = R^2 + \frac{z^2}{Q^2} \quad \text{DM halo axial ratio}$$

Non-spherical stellar profile

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

$$r_*^2 = R^2 + \frac{z^2}{q^2} \quad \text{Stellar axial ratio}$$

Axisymmetric Jeans equations

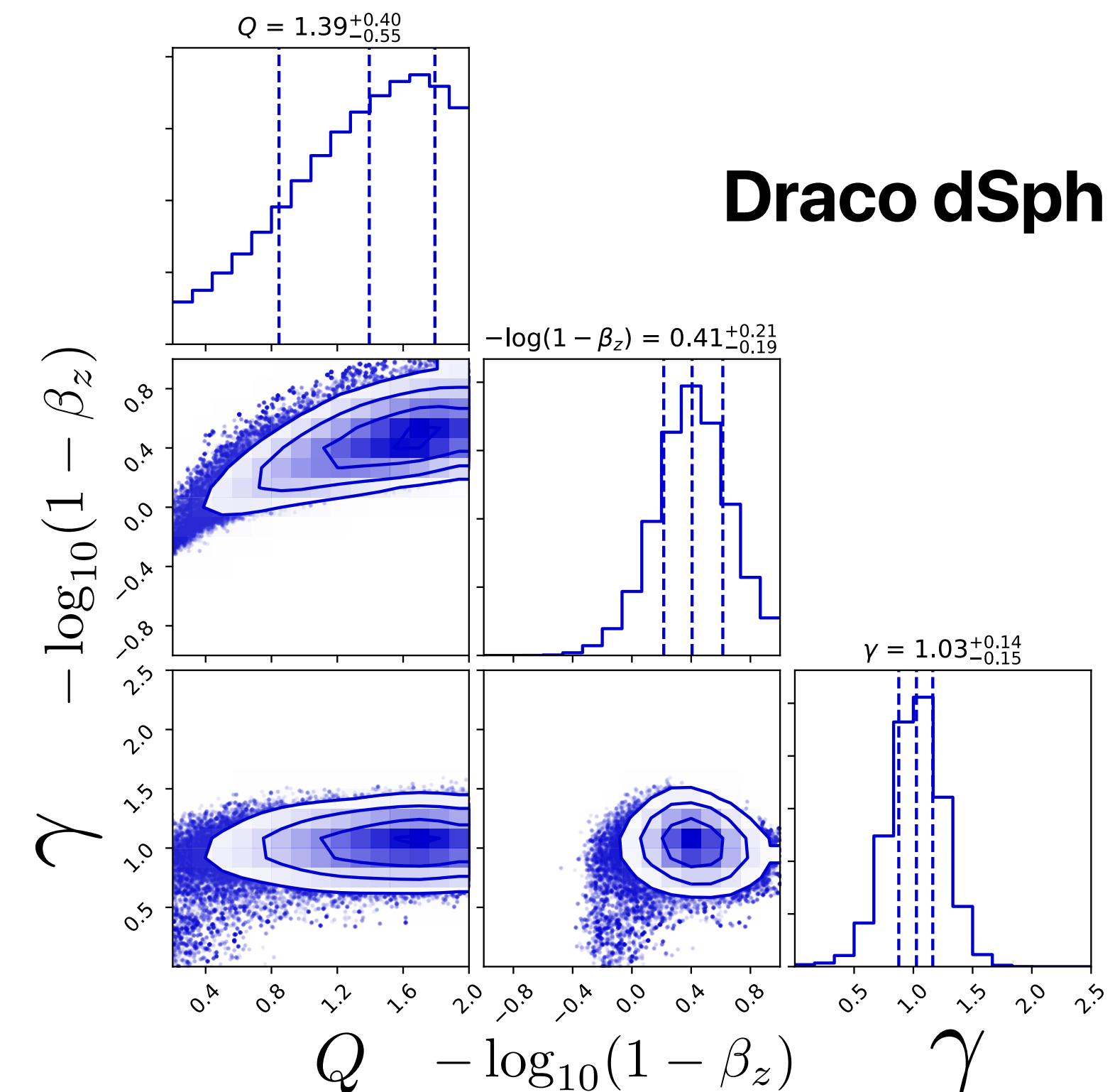
$$(\overline{v_z^2}, \overline{v_\phi^2})$$

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

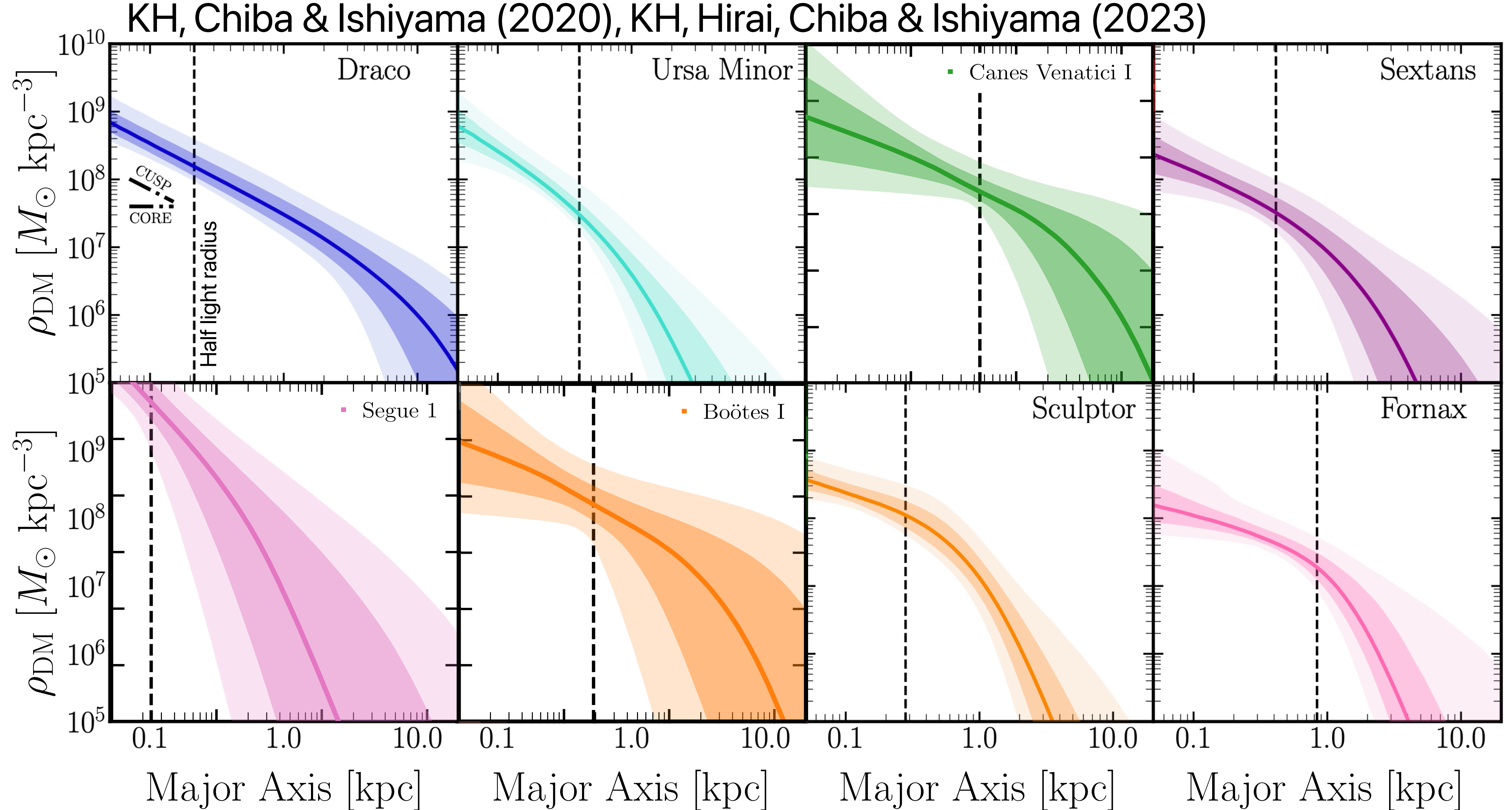
$$\sigma_{\text{l.o.s}}^{\text{th}}(x, y)$$

FIT

$$\sigma_{\text{l.o.s}}^{\text{obs}}(x, y)$$

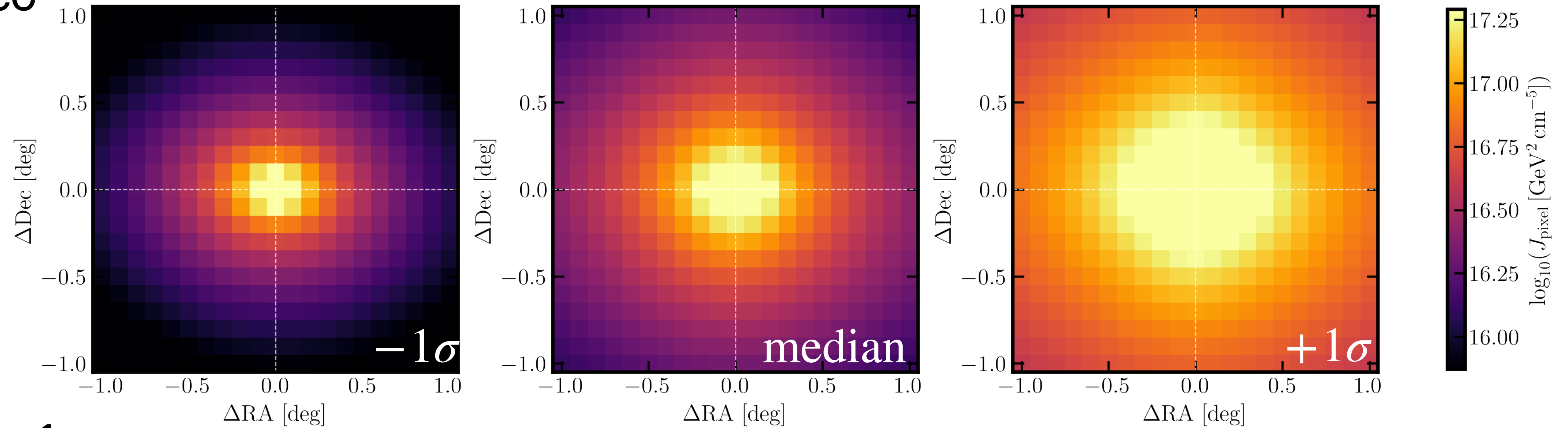


Dark matter density profiles: Classicals & UFDs

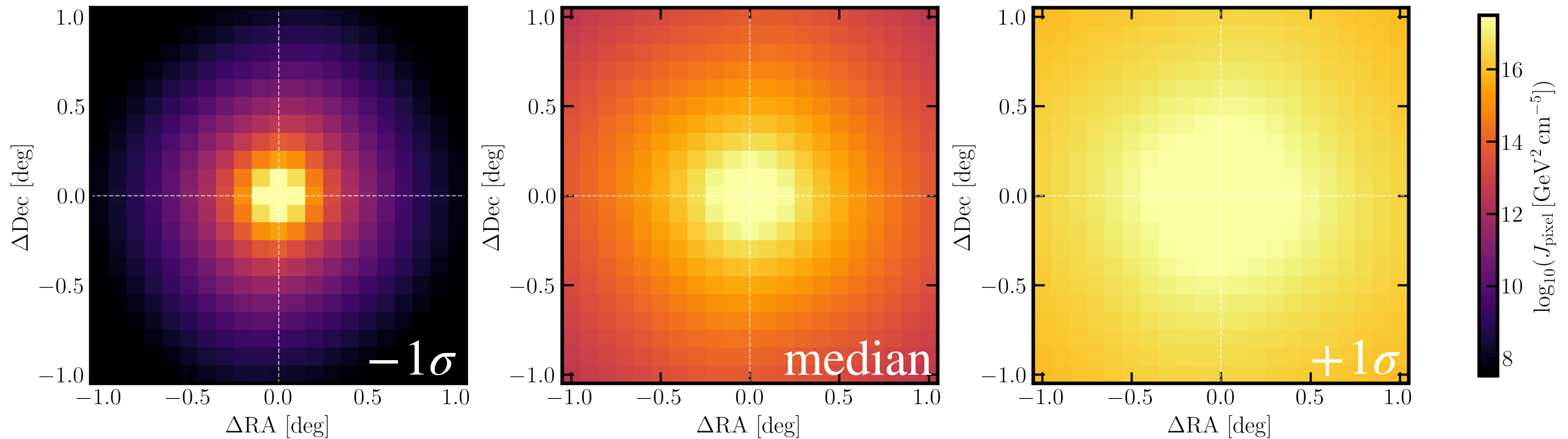


J-factor map:

Draco



Segue 1



Gamma-ray data analysis with CTAO

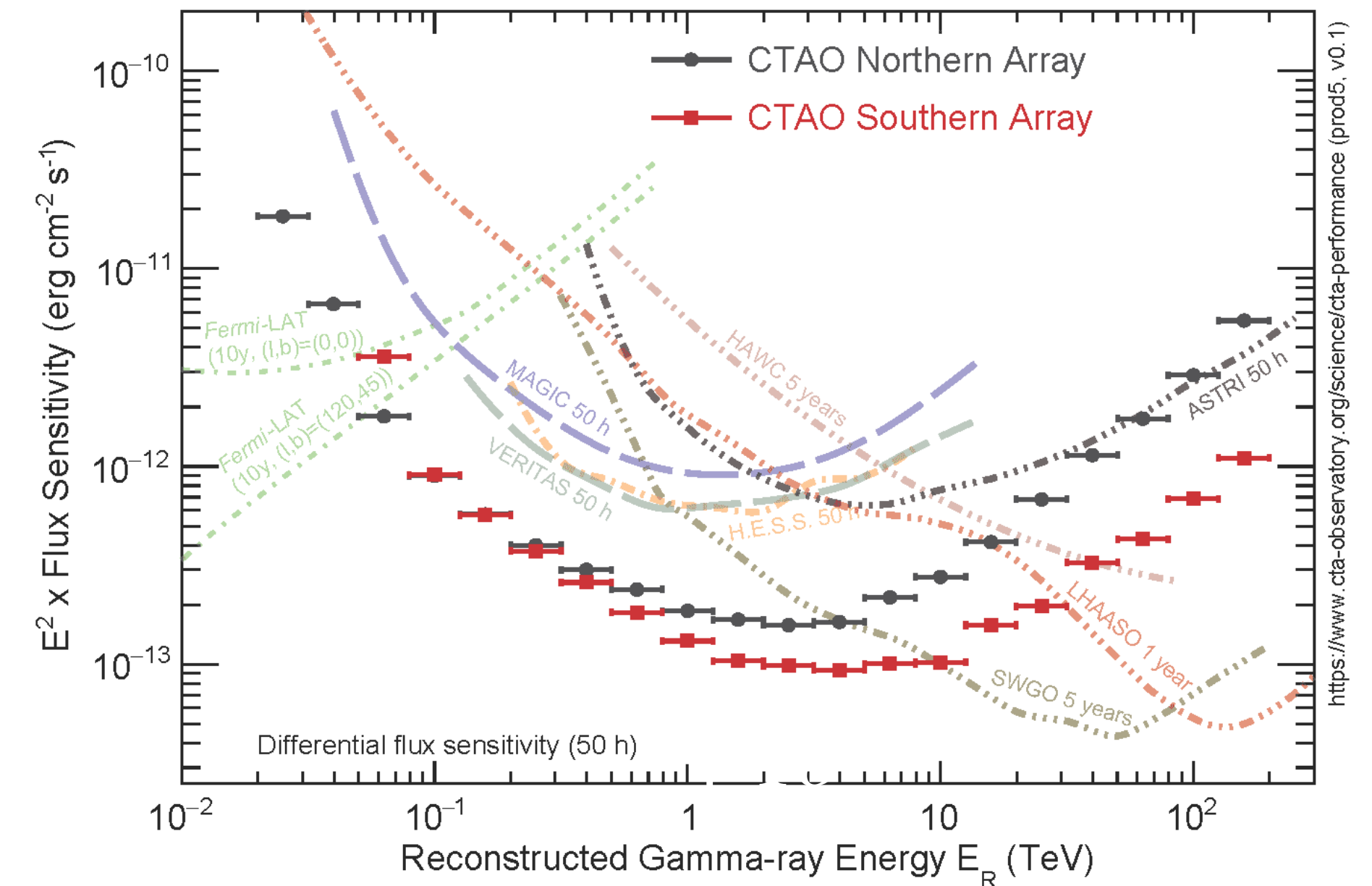
- 100hrs for each dSph (18 objects)
- 60 seeds, bkg only, $2^\circ \times 2^\circ$ for each dSph
- Template model: axisymmetric DM distribution
- Spectrum models: $b\bar{b}$, W^+W^- , $\tau^+\tau^-$, 2γ
- Obs. at zenith angle: $20^\circ - 60^\circ$
- $E_\gamma = [0.02, 150]$ TeV
- Likelihood analysis with Gammapy-ver2.1
- CTAO IRF Prod5-ver.0.1

Classicals:

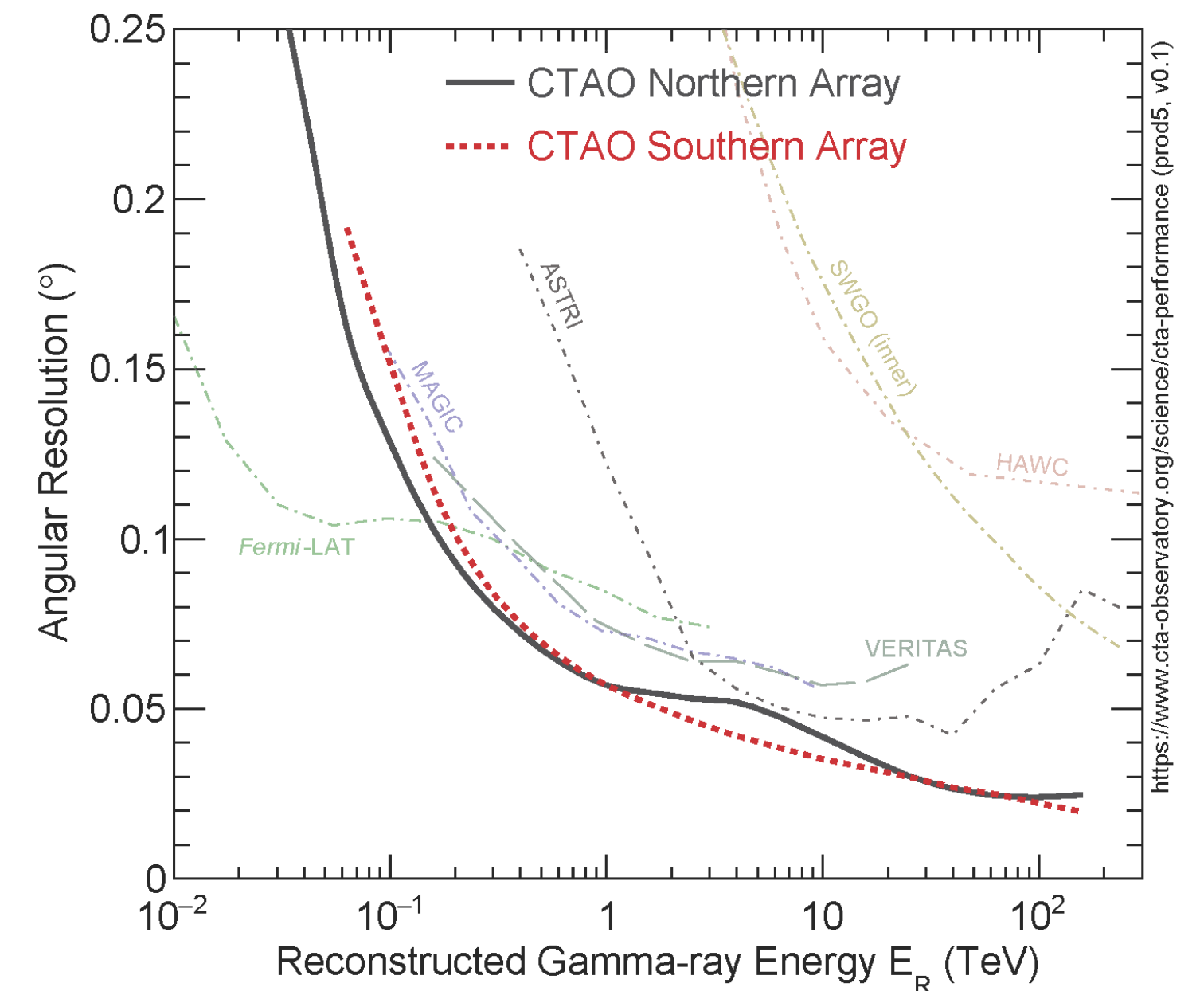
Draco, Fornax, Carina, Sculptor, Sextans, Ursa Minor, Leo I, Leo II

UFDs:

Bootes I, Coma Berenices, Reticulum II, Segue 1, Segue 2, Tucana 2, Tucana 4, UrsaMajor I, UrsaMajor II, Willman 1

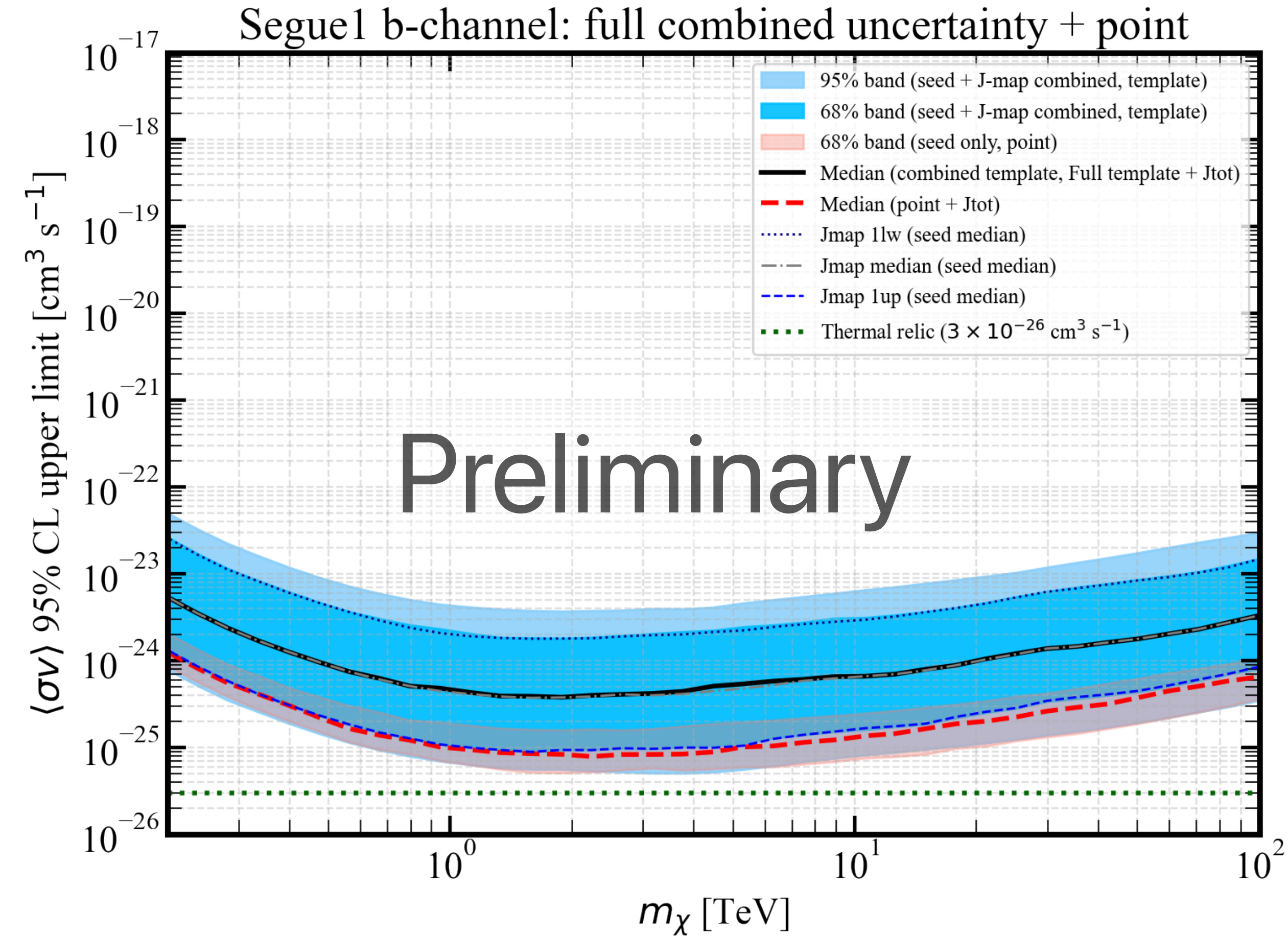
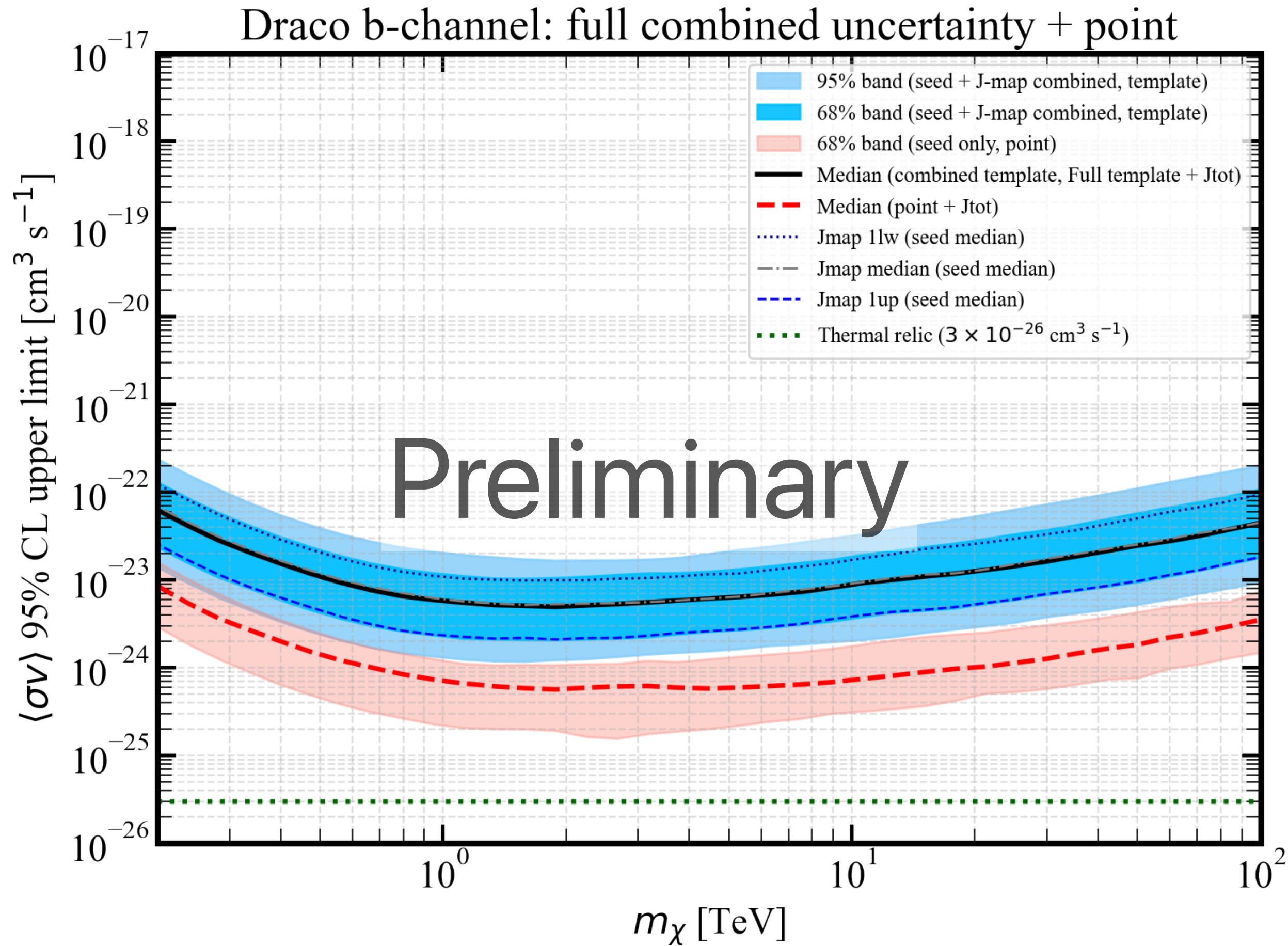


Sensitivity



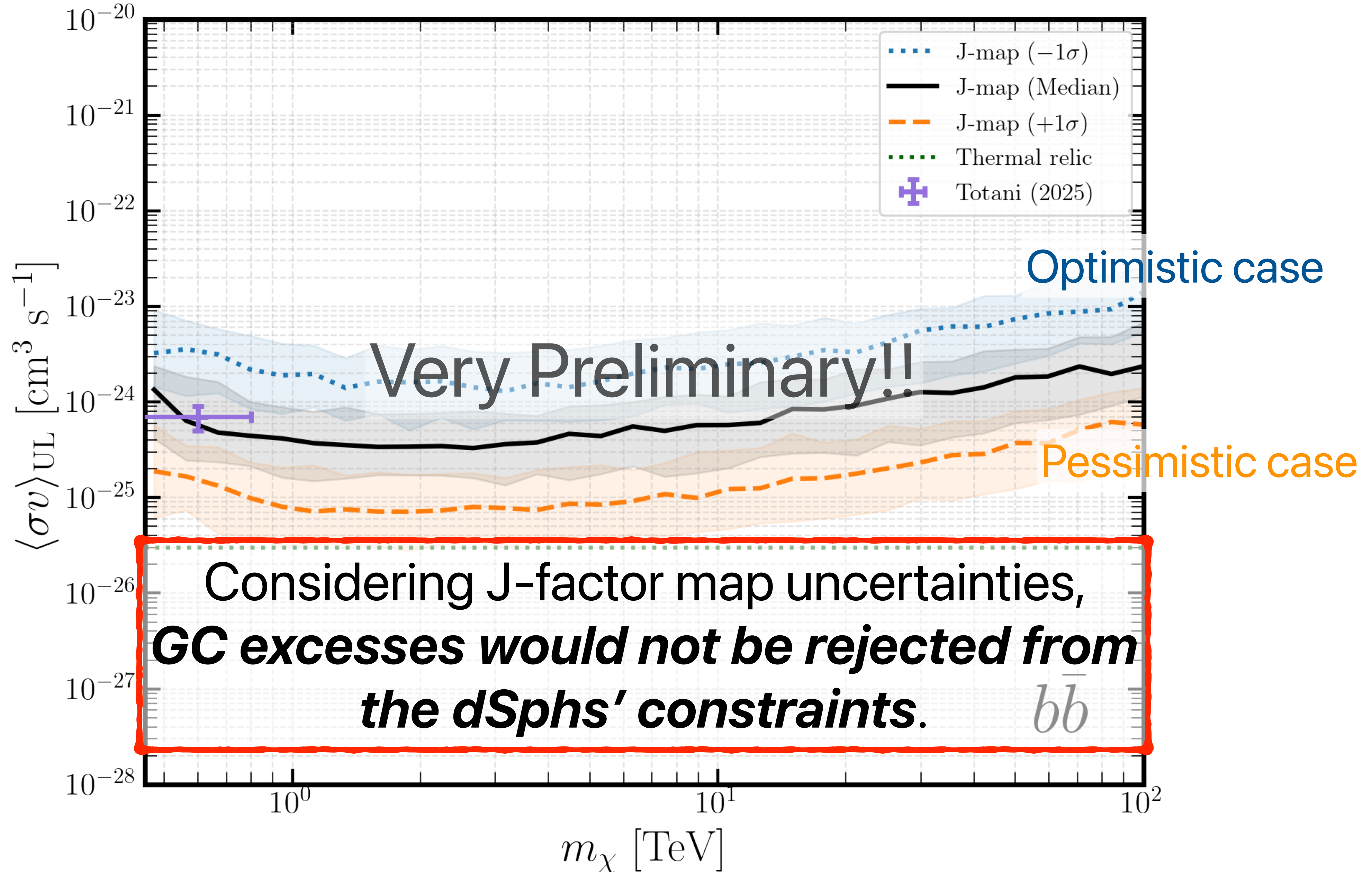
Angular resolution

Results: Sensitivity for individual dSphs

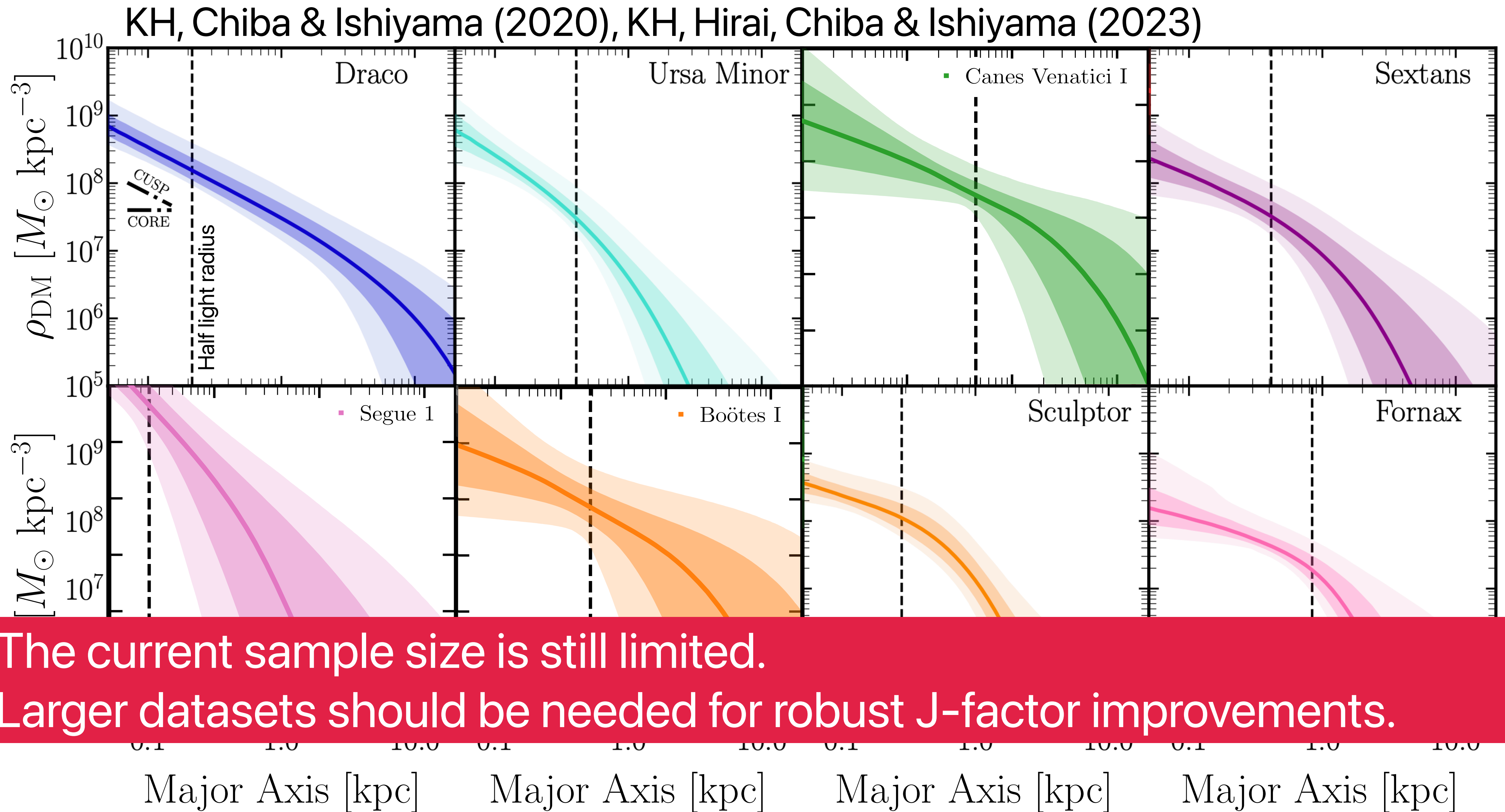


- Point source approximation could overestimate the DM sensitivity
- Systematic (J-factors) and statistical (bkg seeds) errors are included
- *J-factor uncertainties of UFDs are larger than statistical uncertainties.*

Results: Sensitivity for Combined dSphs

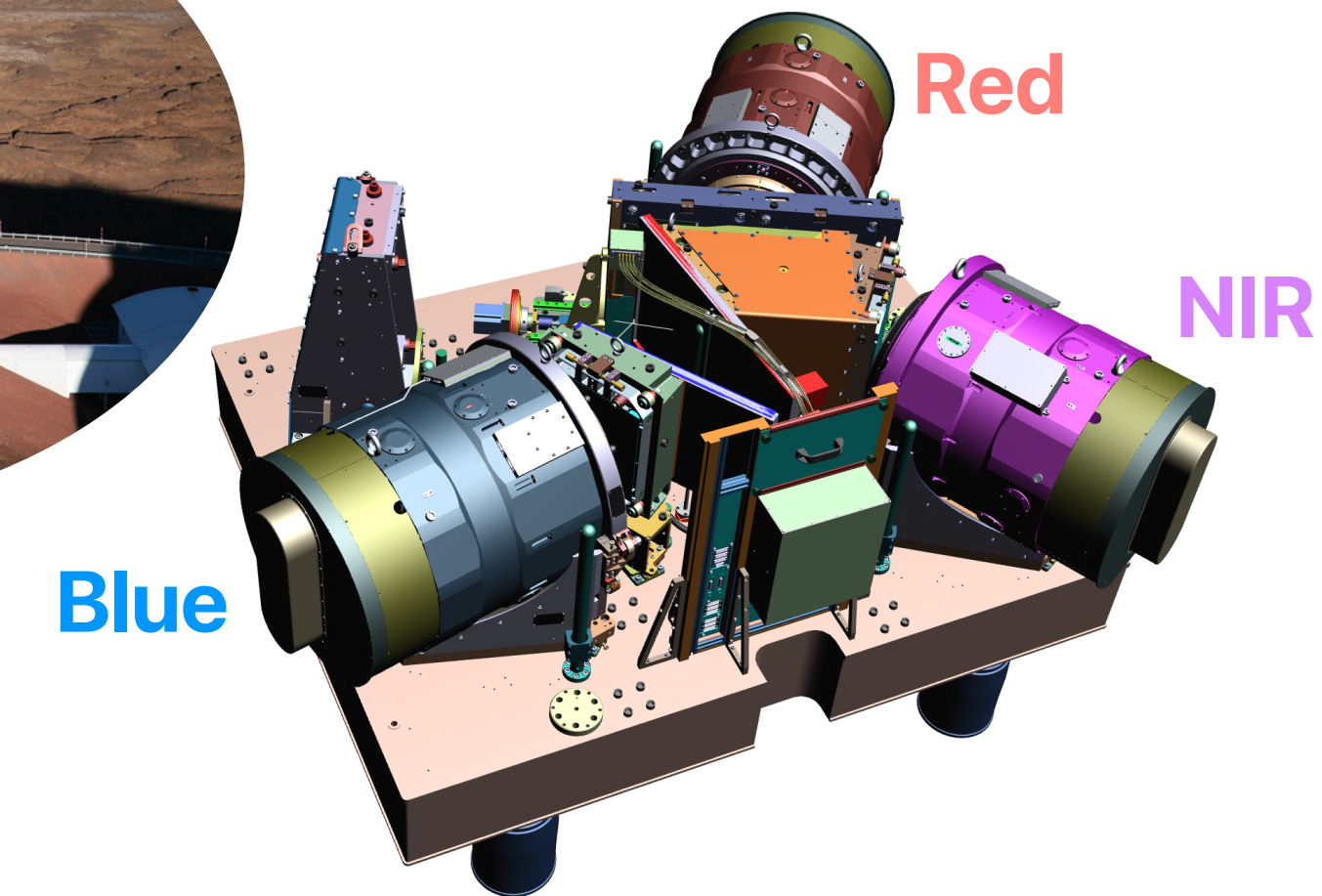
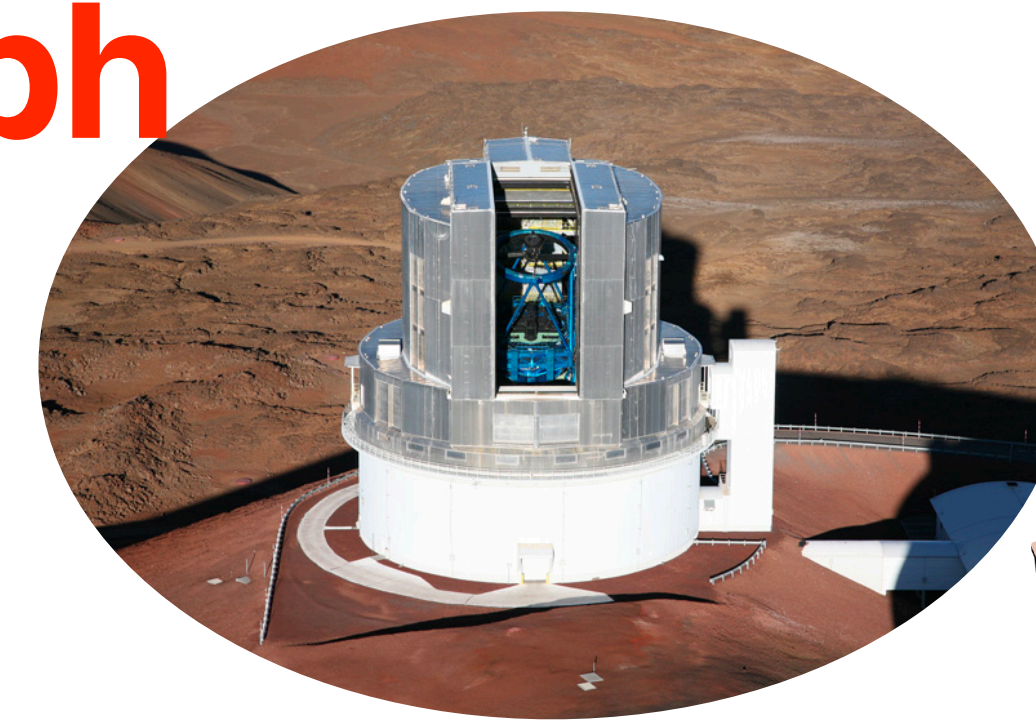
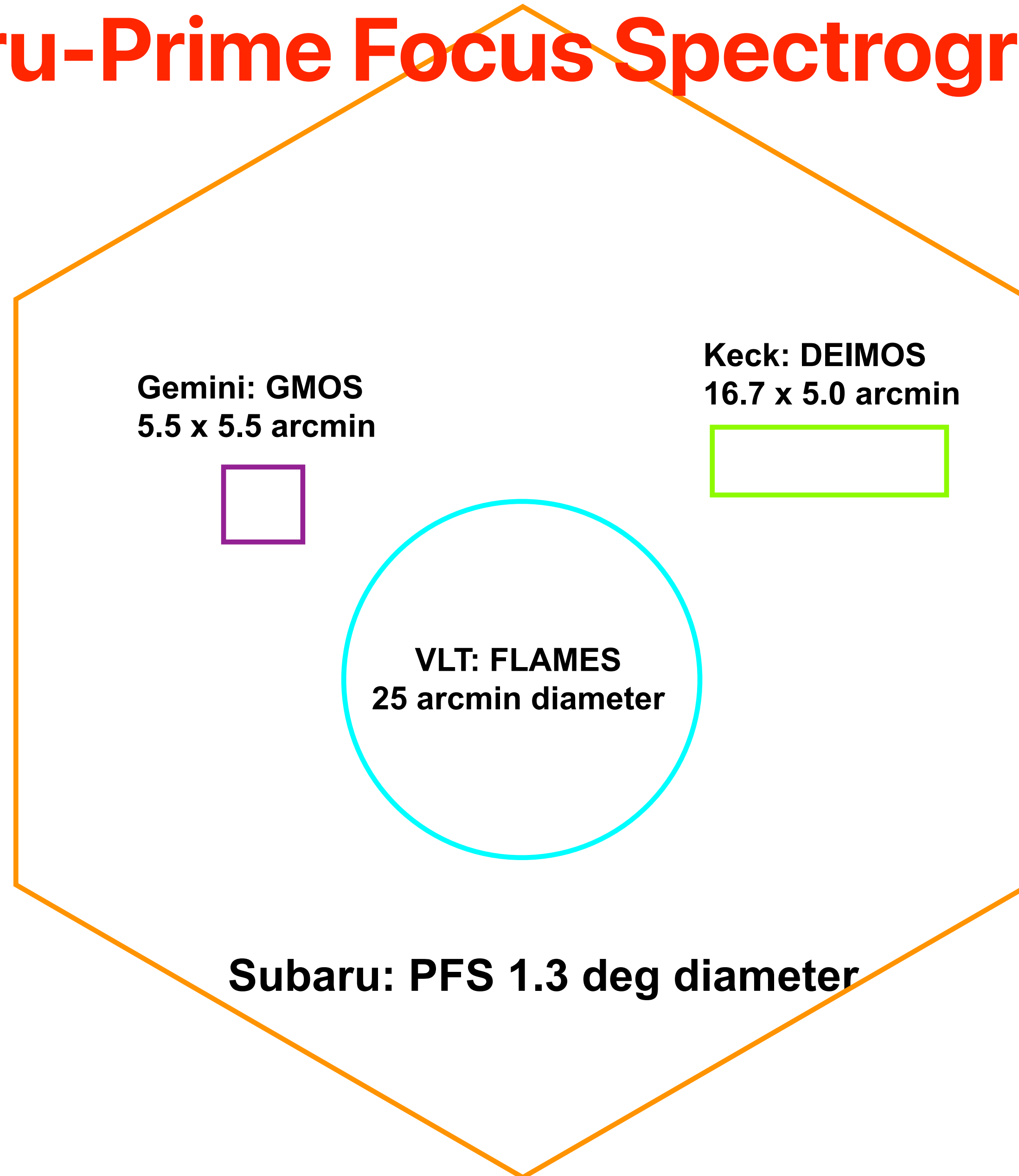


Near Future Prospect



Toward Better Estimates of DM distributions

Subaru-Prime Focus Spectrograph



Subaru Telescope

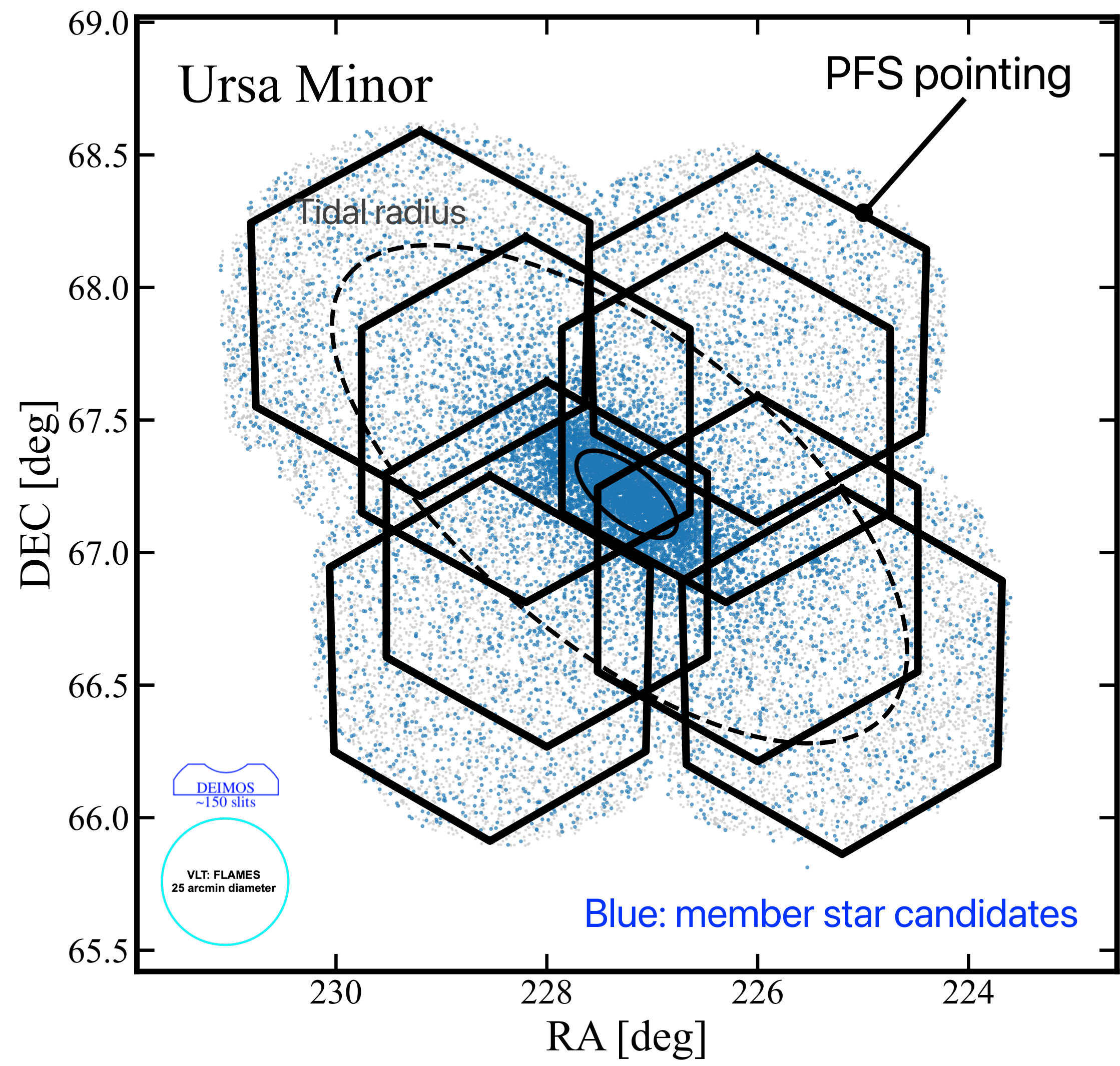
+

PFS

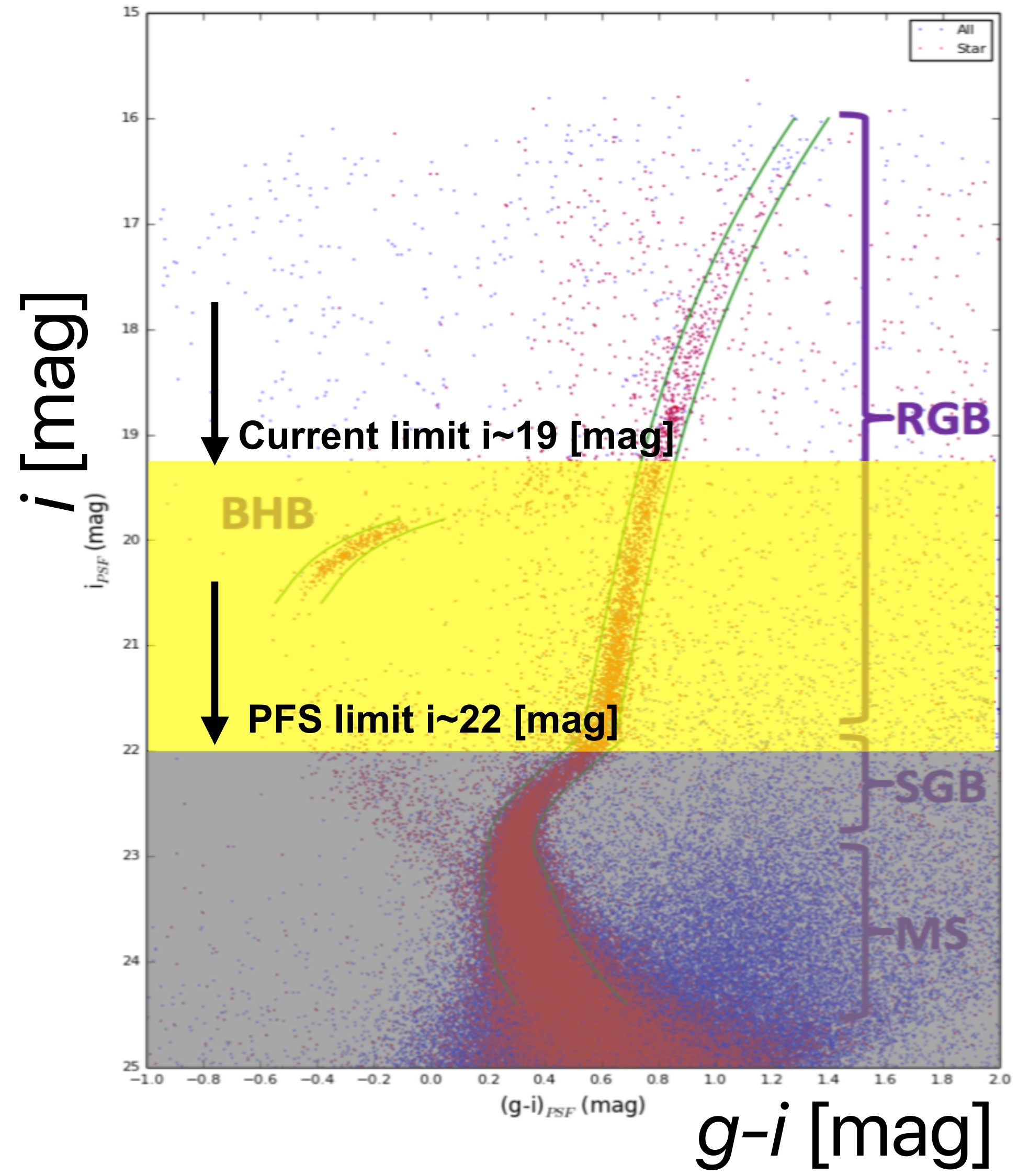
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**Wide and Deep
spec. survey**

Uniqueness of Subaru-PFS



Current
 $N_{\text{spec.}} \sim 1000$ $\Rightarrow$ PFS
 $N_{\text{spec.}} \sim 2500$



Wide & deep PFS survey:

Huge number of line-of-sight velocities of each star out to the outskirts of the Galactic dSphs.

Take Home Messages

- Milky Way dSphs are well-motivated targets for indirect DM searches.
- CTAO will provide powerful probes of DM candidates at high energies ($E \gtrsim \mathcal{O}(1) \text{ TeV}$), with excellent angular resolution.
- With the CTAO angular resolution, non-sphericity of DM distributions in dSphs may have a non-negligible impact on the DM sensitivity.
- Subaru-PFS will provide large samples of stellar line-of-sight velocities extending to the outskirts of dSphs, enabling improved constraints on their DM distributions.

Back up slides

DM density profile estimation for dSphs

Observable informations are limited to:

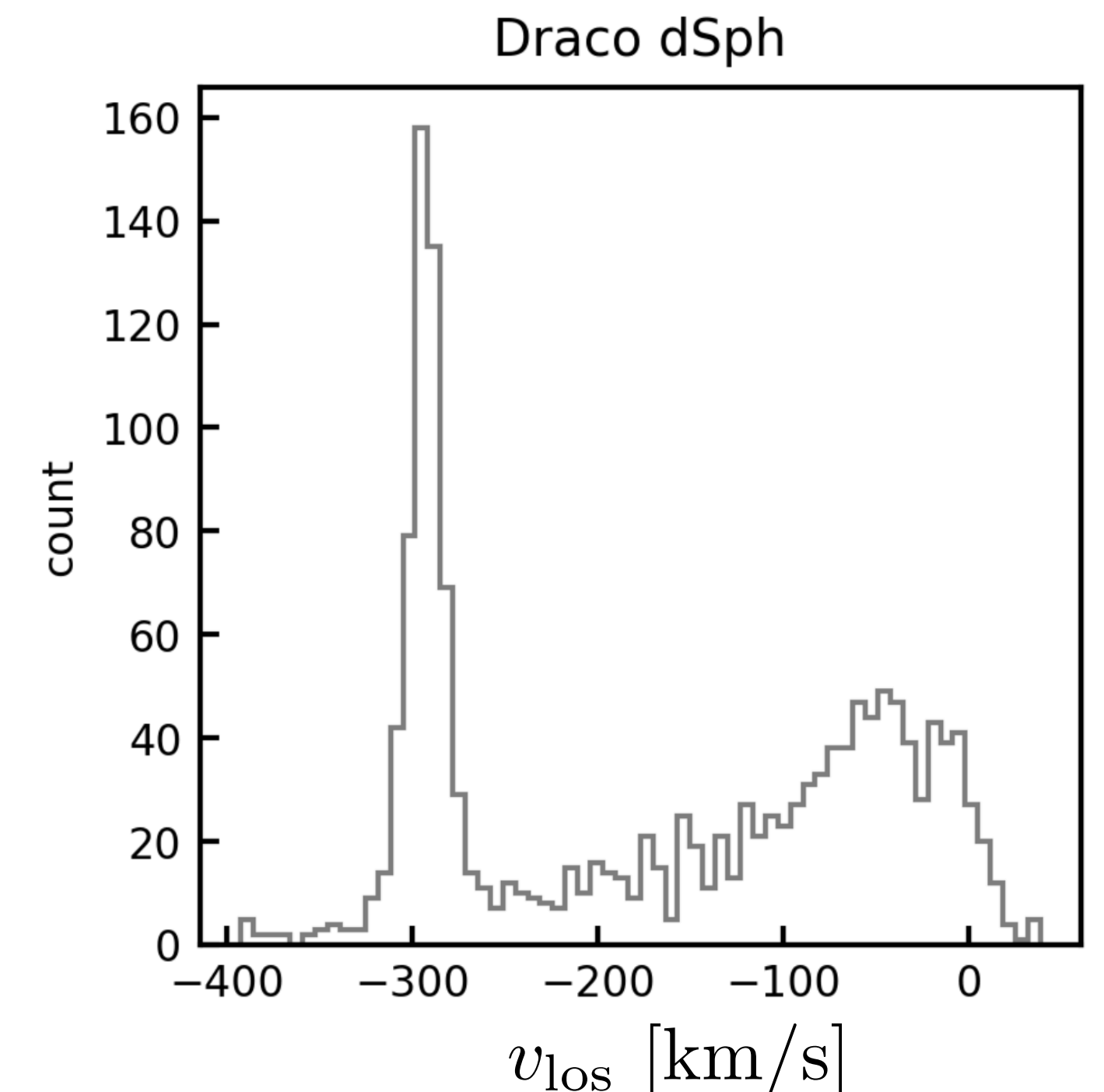
- Celestial coordinate
- Line-of-sight velocity

$$(x, y, z, v_x, v_y, v_z) \longrightarrow (x, y, v_z)$$



Current methods introduce in order to simplify the problem and make it solvable only with limited information:

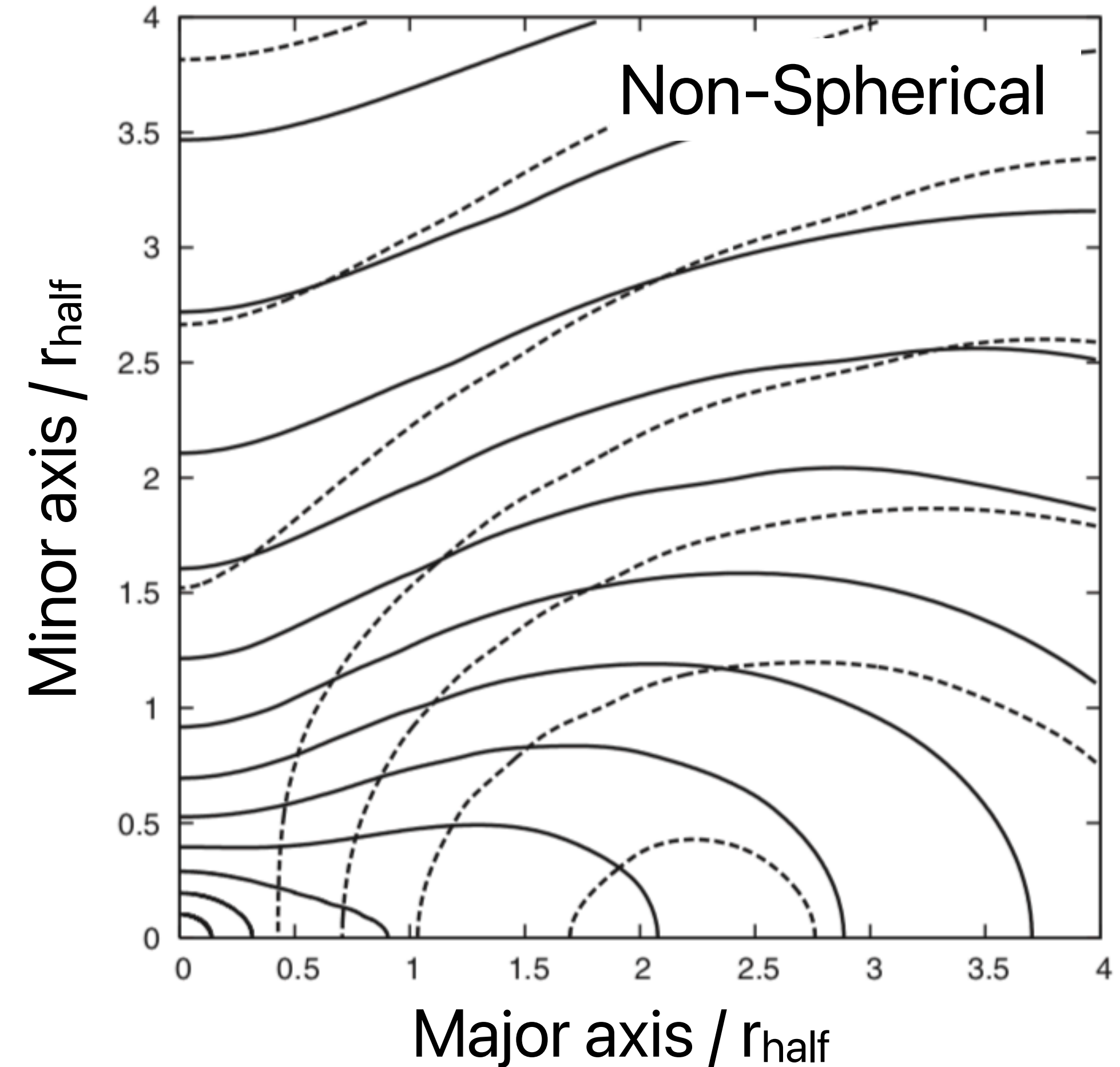
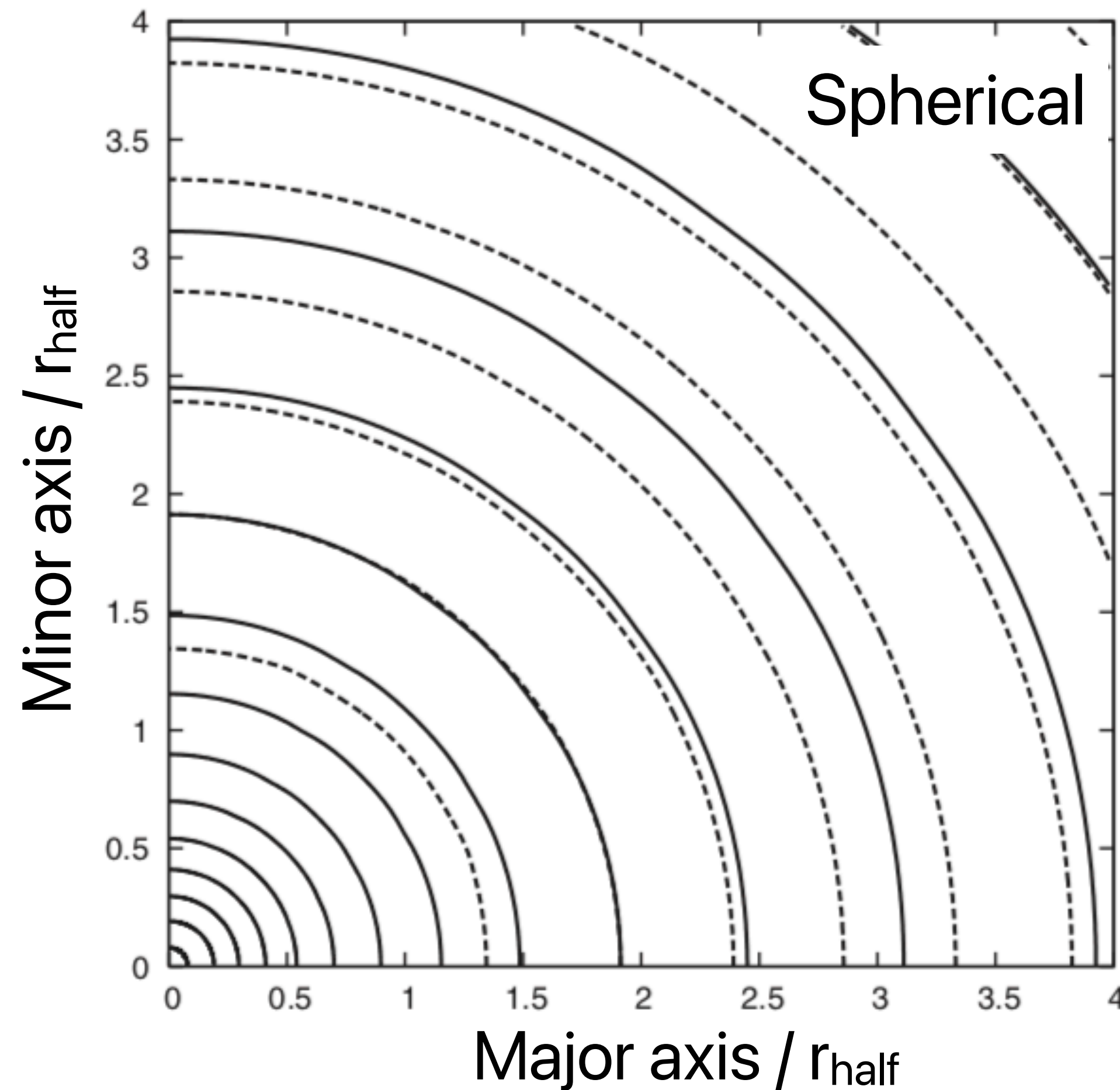
- Symmetry assumptions (e.g., spherical, axisymmetric)
- Parameterized stellar and DM density profiles
- Parameterized velocity anisotropy profile
- Dynamical equilibrium assumption, etc...



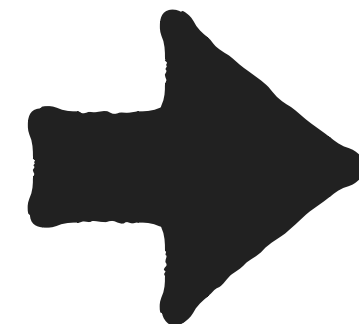
Why non-spherical?

Contours of line-of-sight velocity dispersion (Hayashi & Chiba 2012)

Solid: CUSP
Dashed: CORE



Non-sphericity



**Distinguish between
Cusp and Core**

PFS forecast

- Estimated mock DM density profiles from *non-spherical Jeans analysis* with **current small data (pink)** and **PFS forecast large data volumes (purple)**.
- The **large data volume over wide area by PFS** can recover the input dark matter density profile from the center to outer parts.

