Dark Matter Distributions in the dwarf spheroidal galaxies in the Subaru-PFS era

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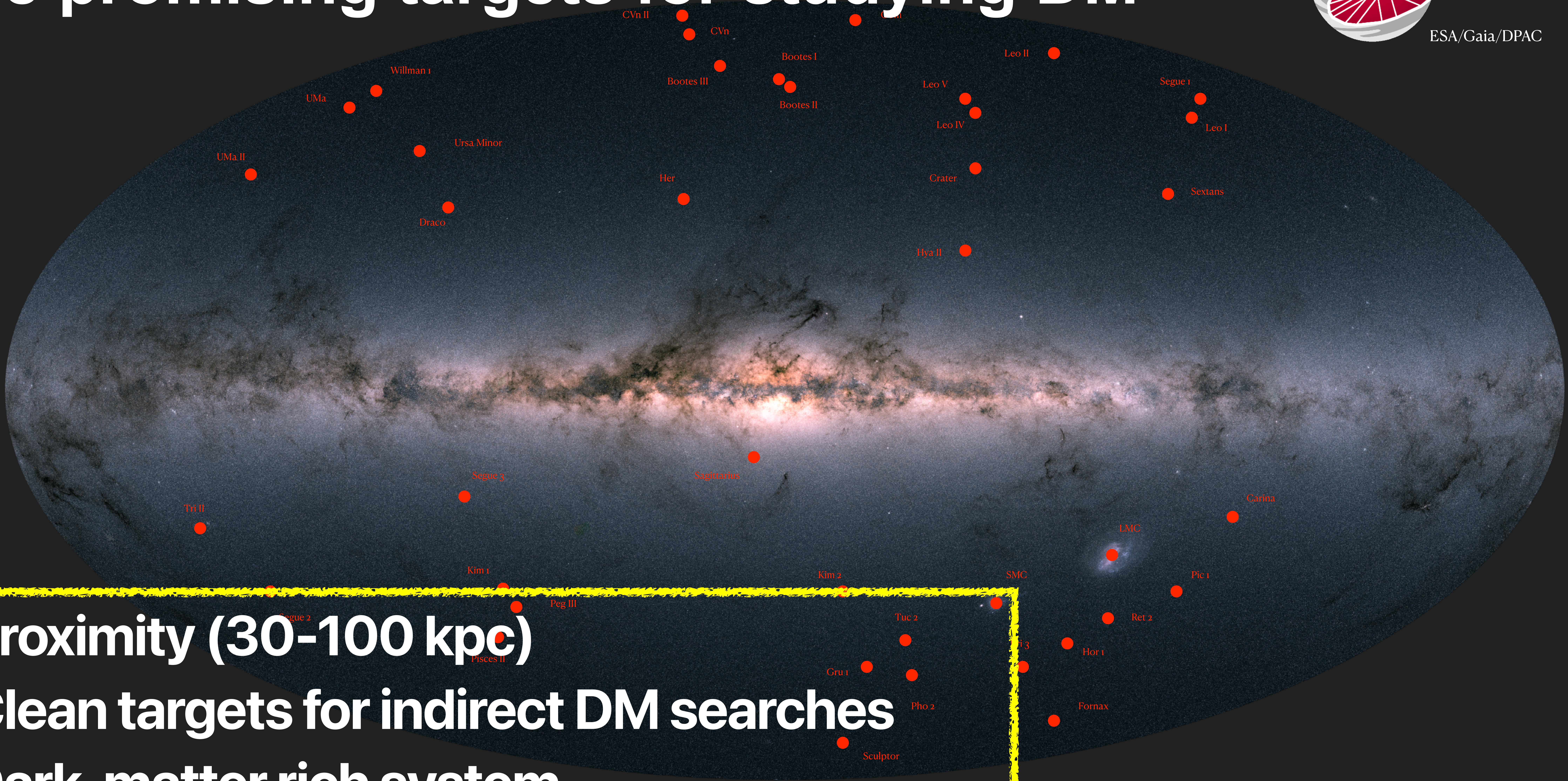
SIDM workshop: Models, Simulations and Signals

Dwarf spheroidal galaxy (dSph): the promising targets for studying DM

ESA/Gaia/DPAC

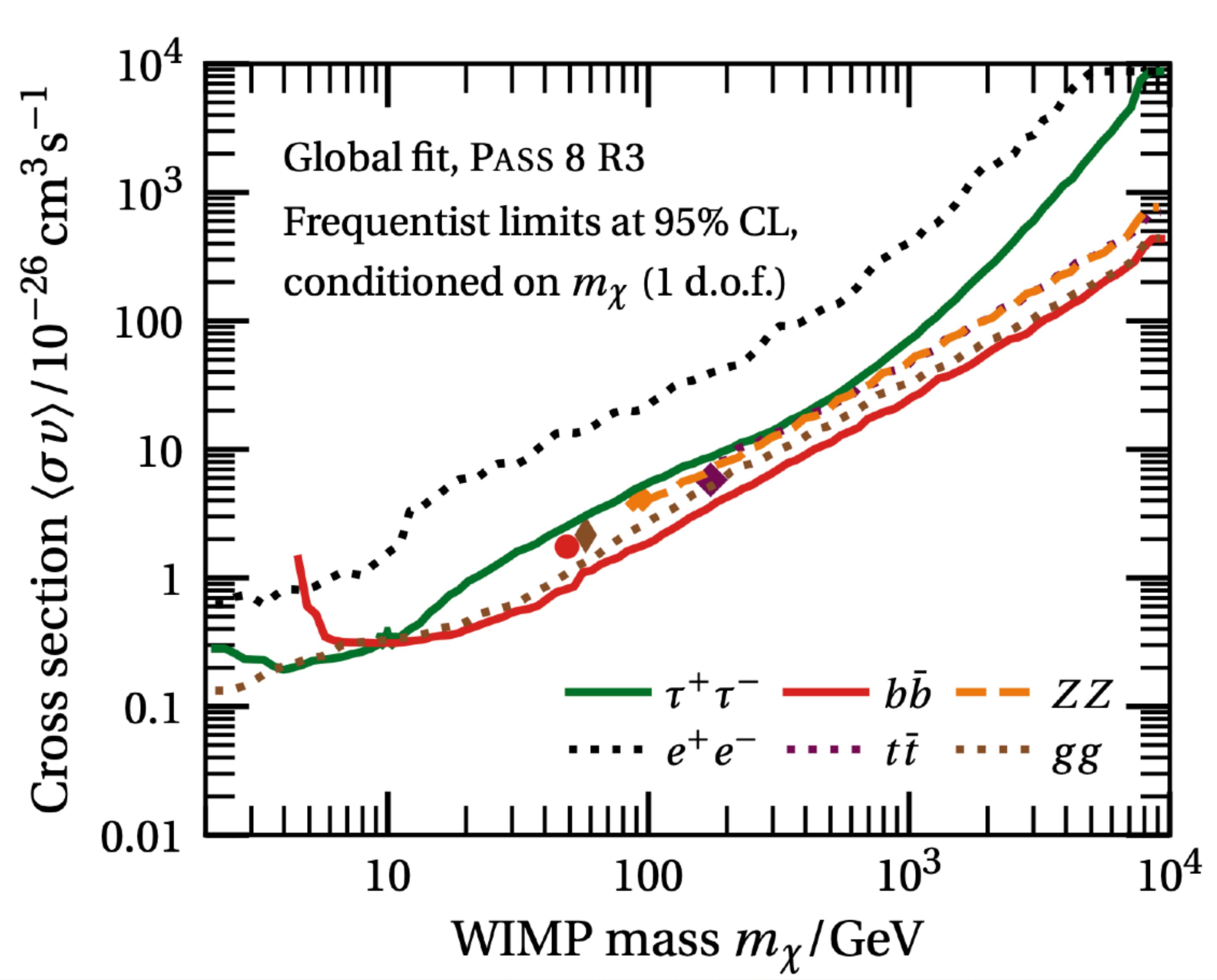


- Proximity (30-100 kpc)
- Clean targets for indirect DM searches
- Dark-matter rich system

Dwarf spheroidal galaxy (dSph): the promising targets for studying DM

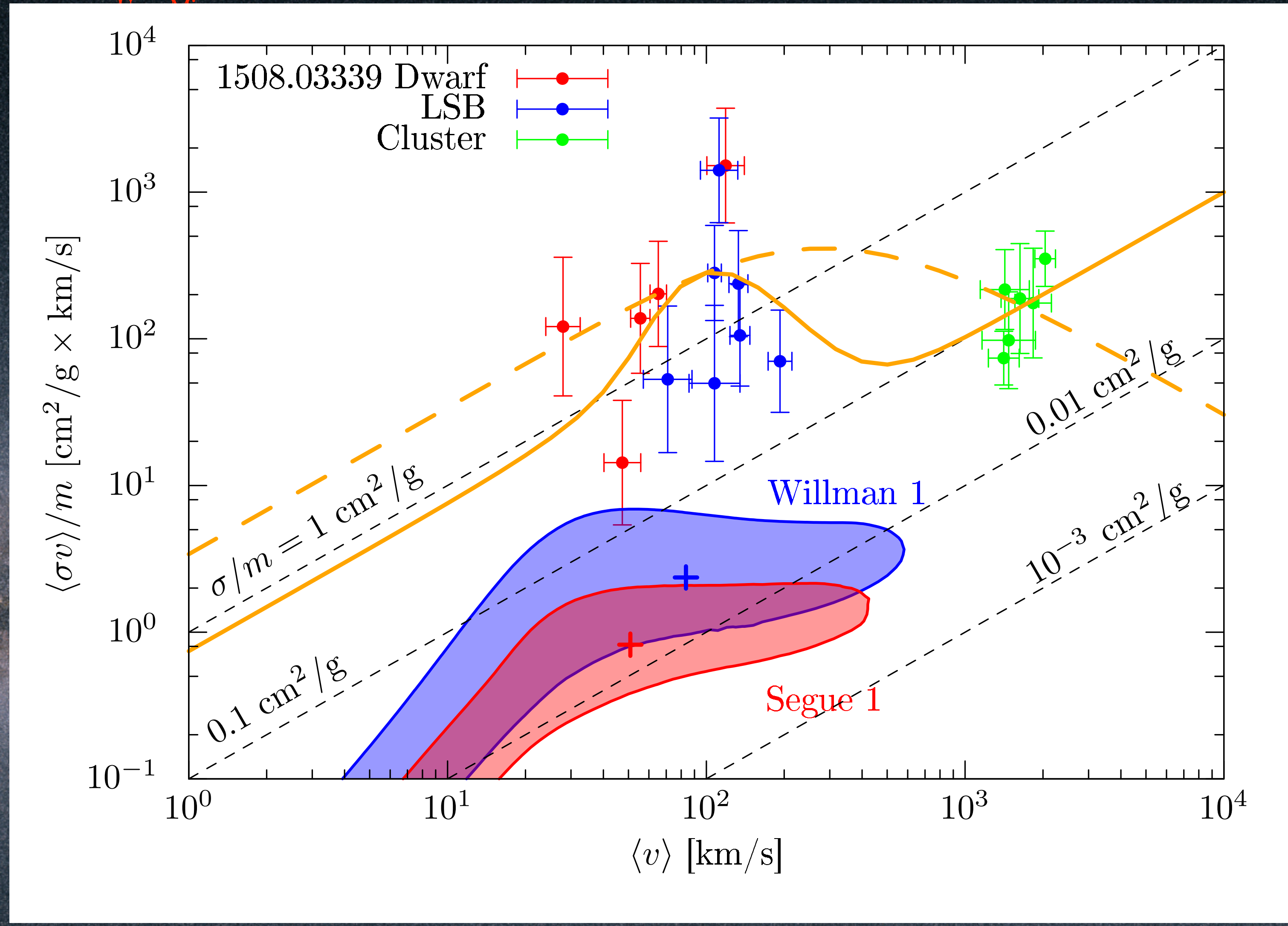
ESA/Gaia/DPAC

WIMP



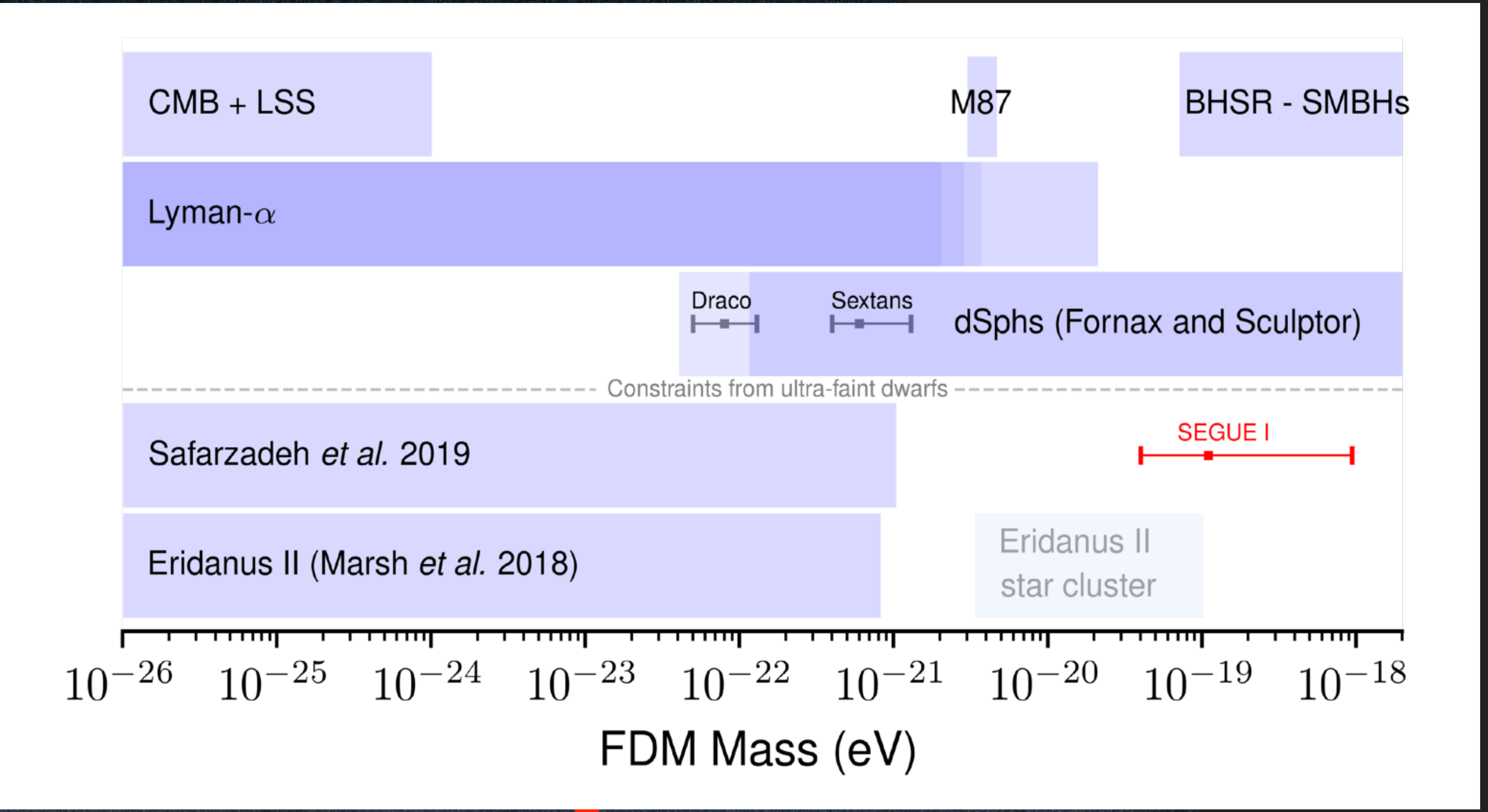
Hoof+ (2020)

SIDM



Hayashi+ (2021)

FDM



Hayashi+ (2022)

- Proximity (30-100 kpc)
- Clean targets for indirect DM searches
- Dark-matter rich system

Dwarf spheroidal galaxy (dSph): the promising targets for studying DM

To gain insight into the properties of dark matter from the Galactic dwarf spheroidals

it is *necessary* to place tighter constraints on their dark matter density *profiles*.

Non-spherical dynamical mass models

Non-spherical dark matter density profile

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

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

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

Axisymmetric Jeans equations

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

$\overline{v_R^2}$ is unknown parameter as

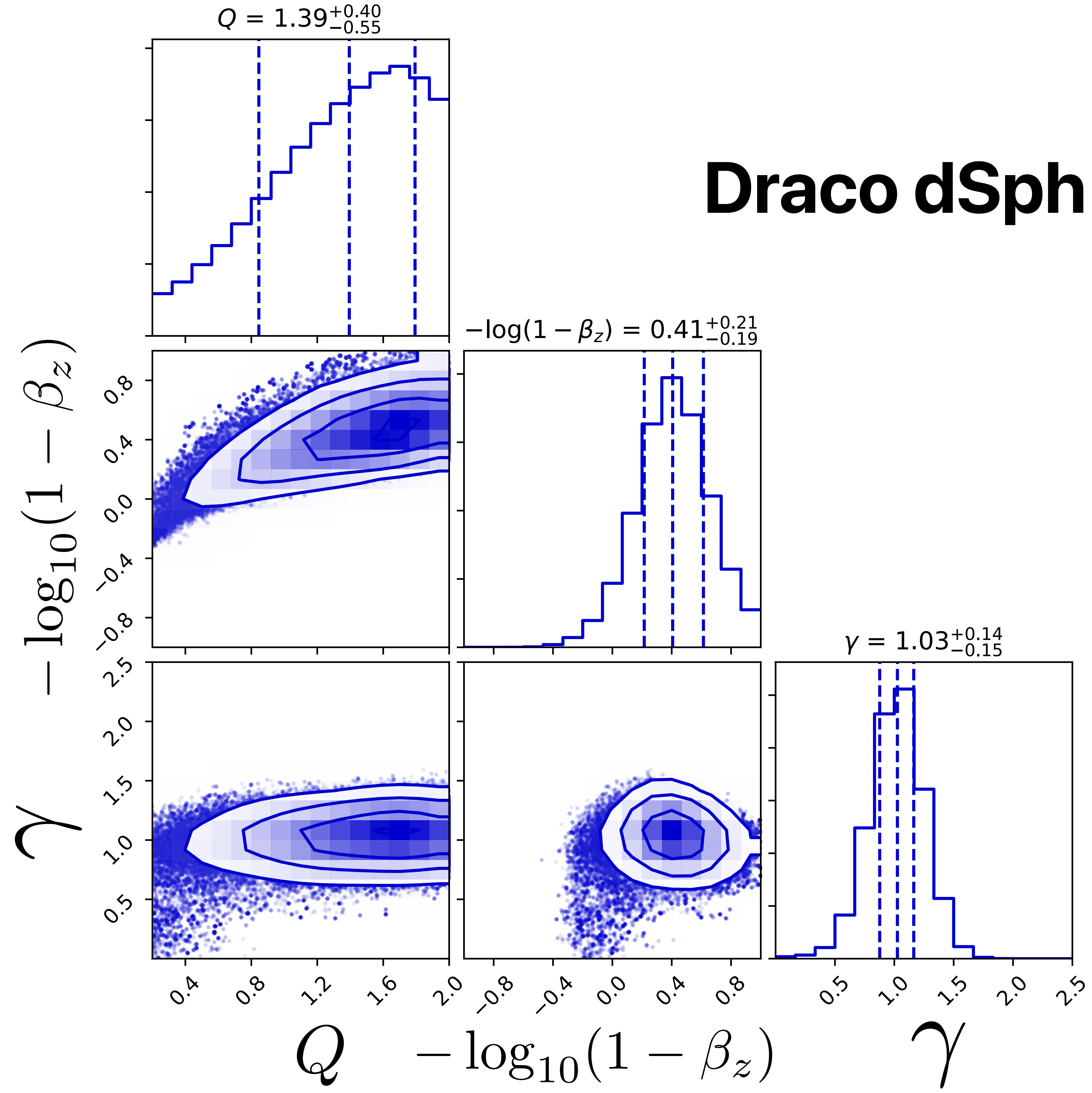
$$\beta_z = 1 - \overline{v_z^2}/\overline{v_R^2}$$

$$\sigma^{\rm th}_{\rm l.o.s}(x,y)$$

FIT

$$\sigma^{\rm obs}_{\rm l.o.s}(x,y)$$

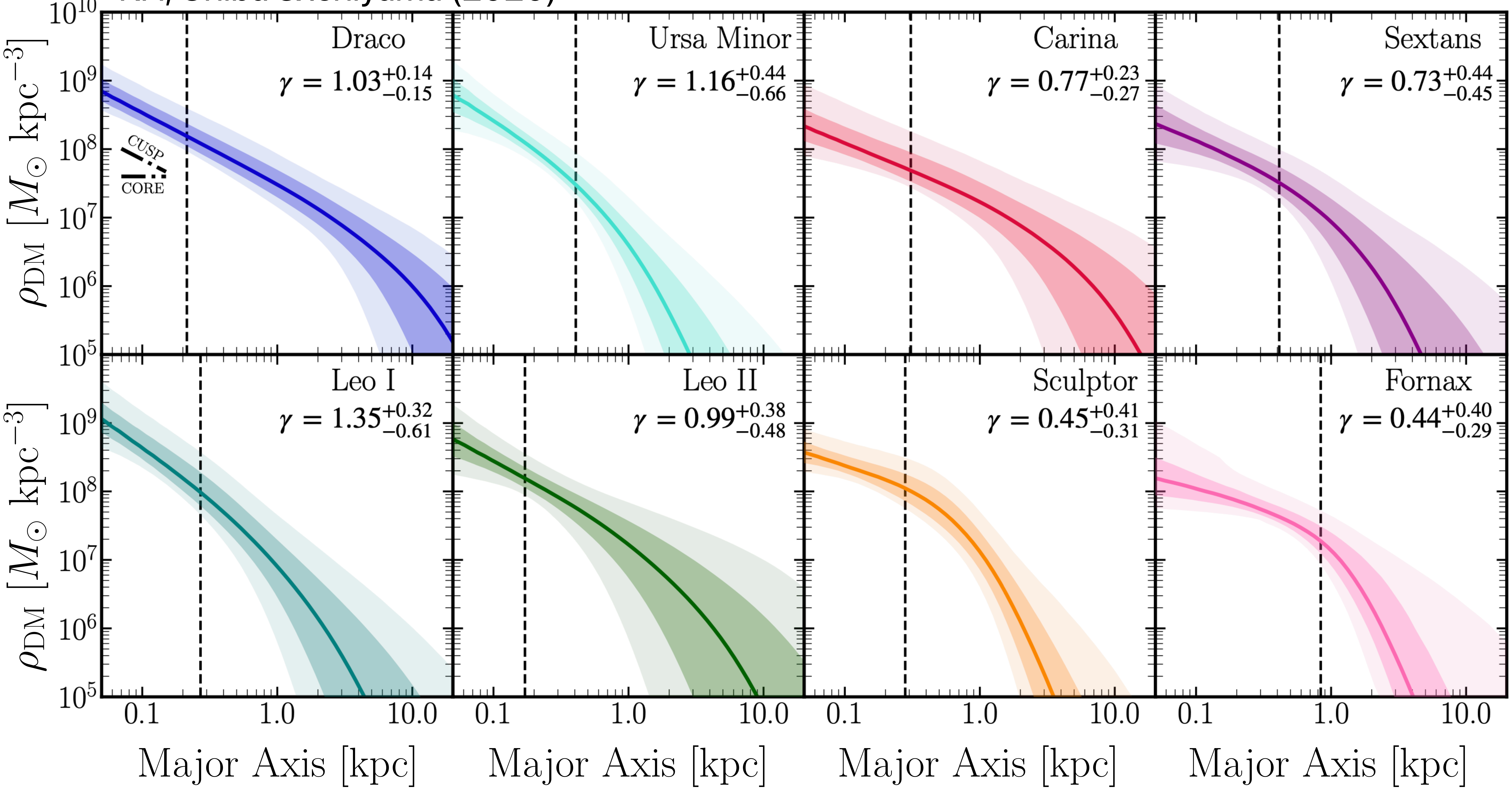
Draco dSph



Dark matter density profiles: Classicals

KH, Chiba & Ishiyama (2020)

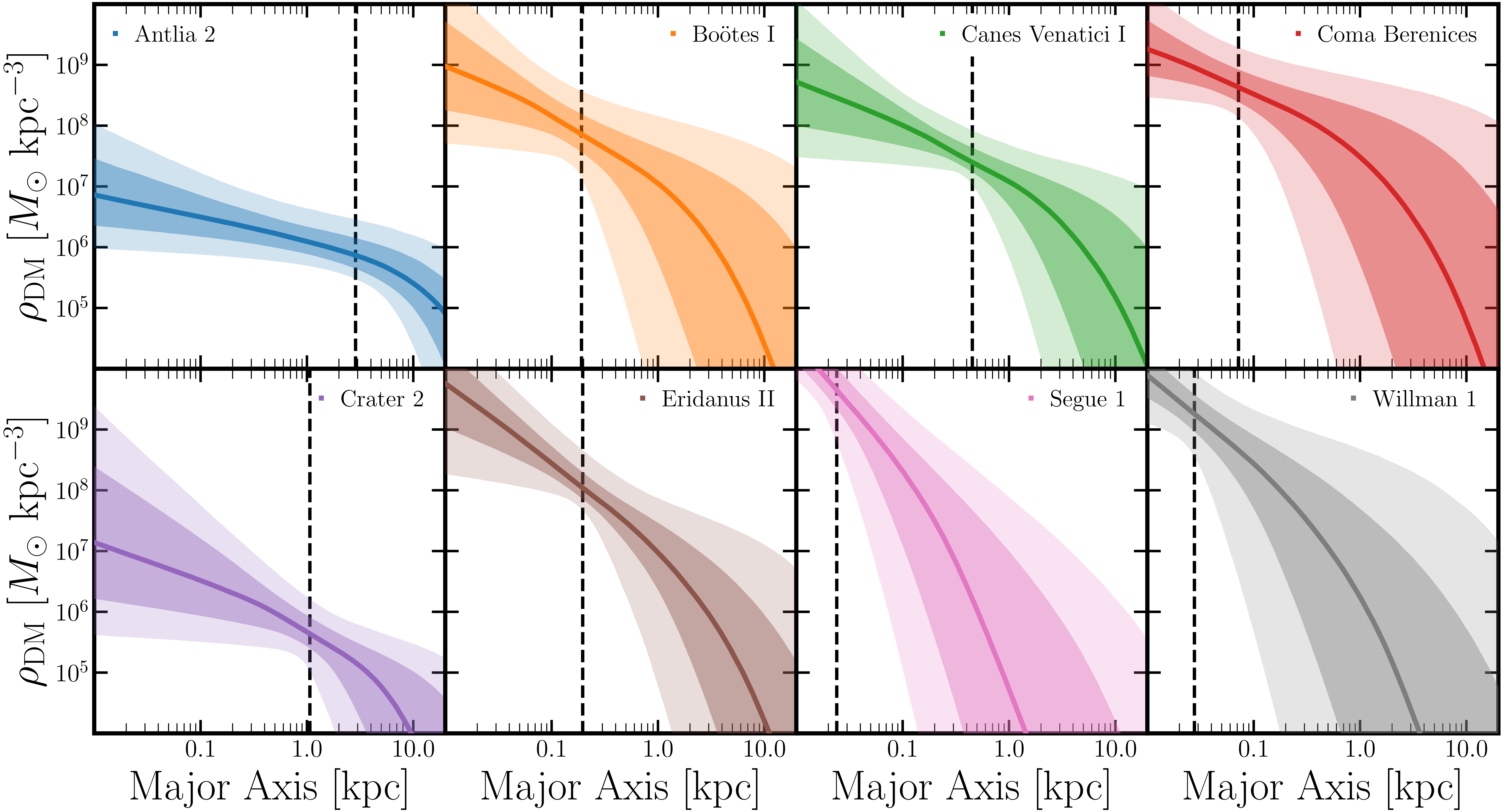
$(0.0 \leq \gamma \leq 2.0)$



Dark matter density profiles: UFDs

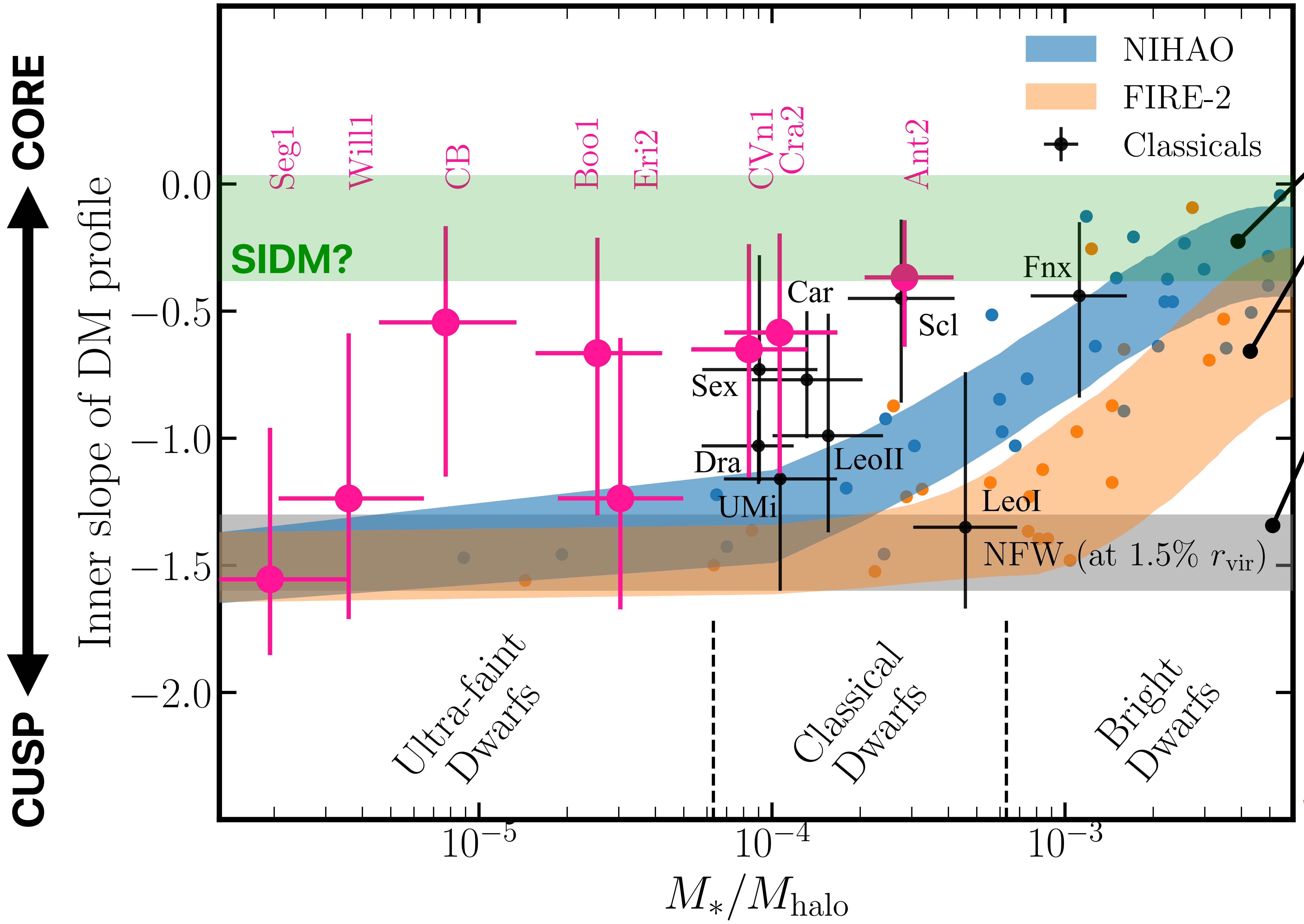
KH, Hirai, Chiba & Ishiyama (2022)

$(0.0 \leq \gamma \leq 2.0)$



Diversity of the DM distributions?

KH, Chiba & Ishiyama (2020)
KH, Hirai, Chiba & Ishiyama (2022)



Prediction from LCDM based N-body+hydro sims.

Prediction from LCDM based pure N-body sims.

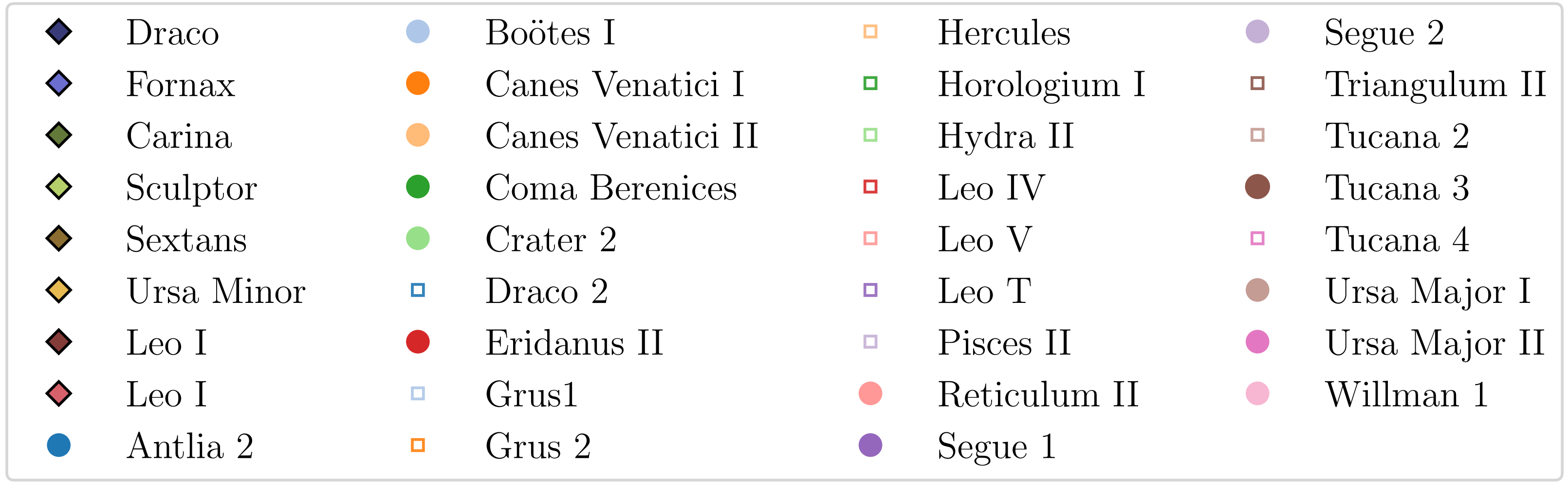
- Several dSphs (Dra, UMi, Seg1, Will1) favor cusped DM central profiles
- **The diversity of the DM density profiles in the dSphs.**
- There are still **<u>large uncertainties on their inner slopes</u>**.

The main reasons:

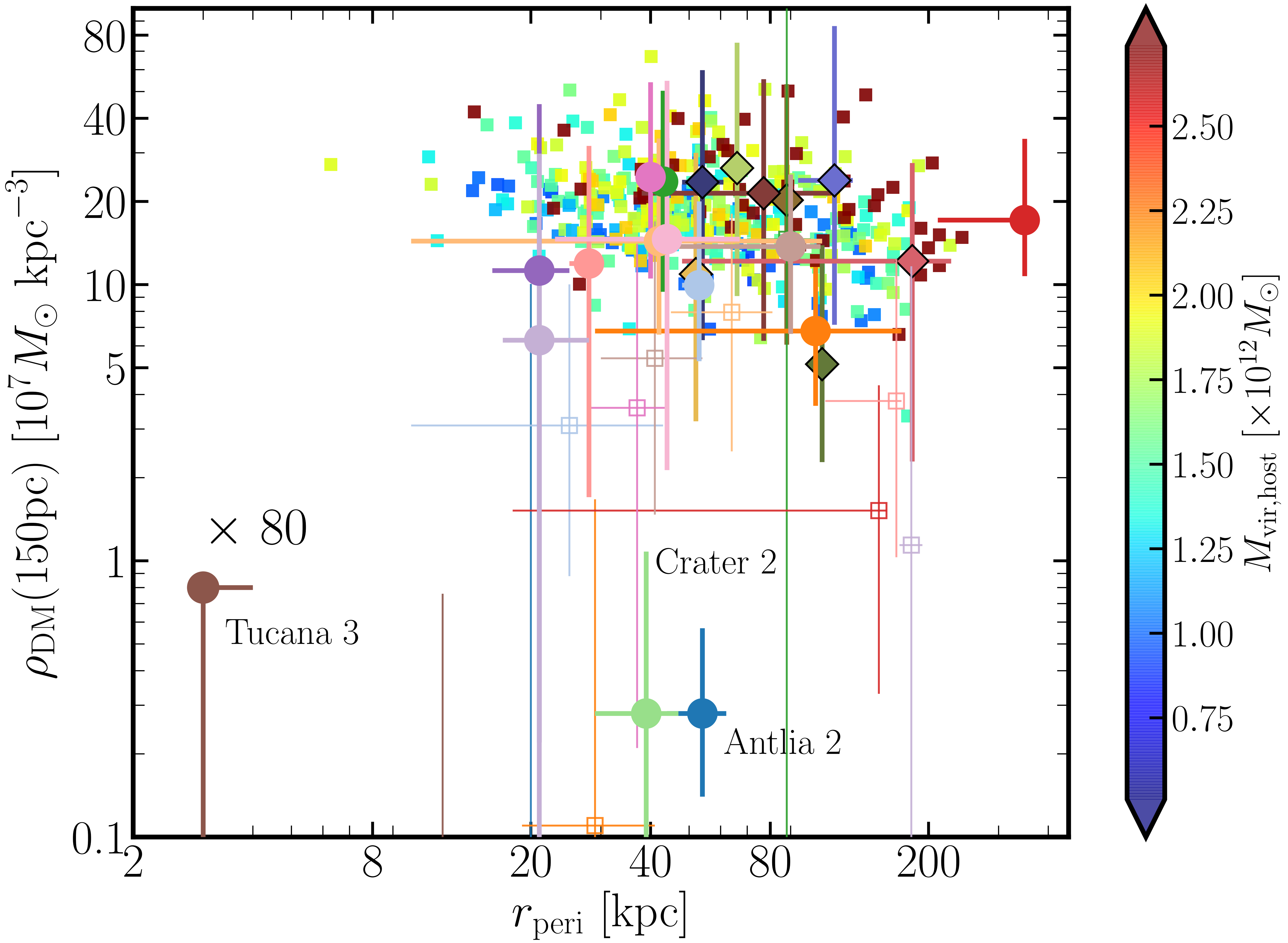
1. Insufficient number of velocity data
2. Outer regions of the dSphs have not been observed yet.
3. Mass modelings

DM densities at 150 pc

Motivated mainly by Kaplinghat et al. (2019)

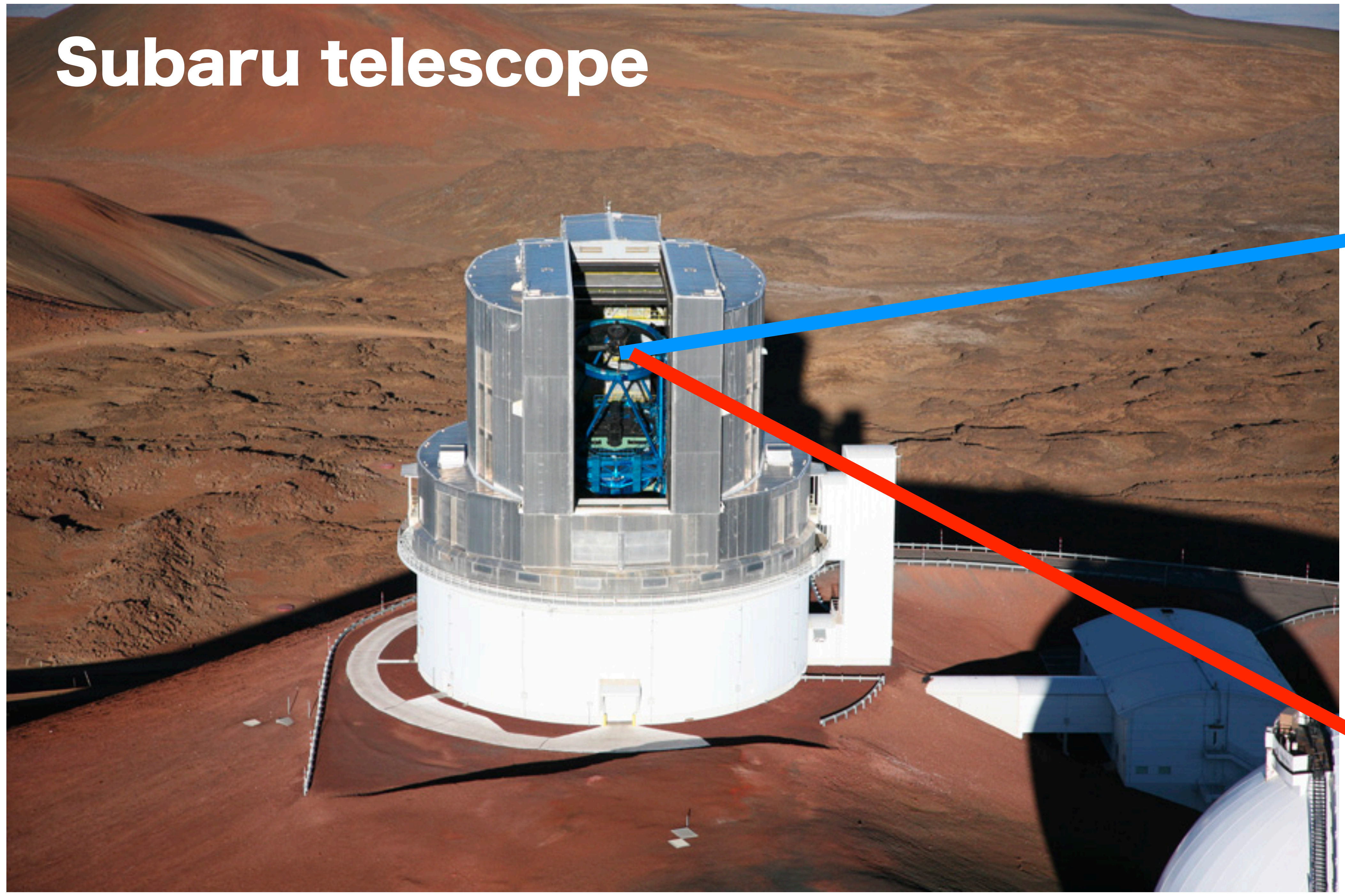


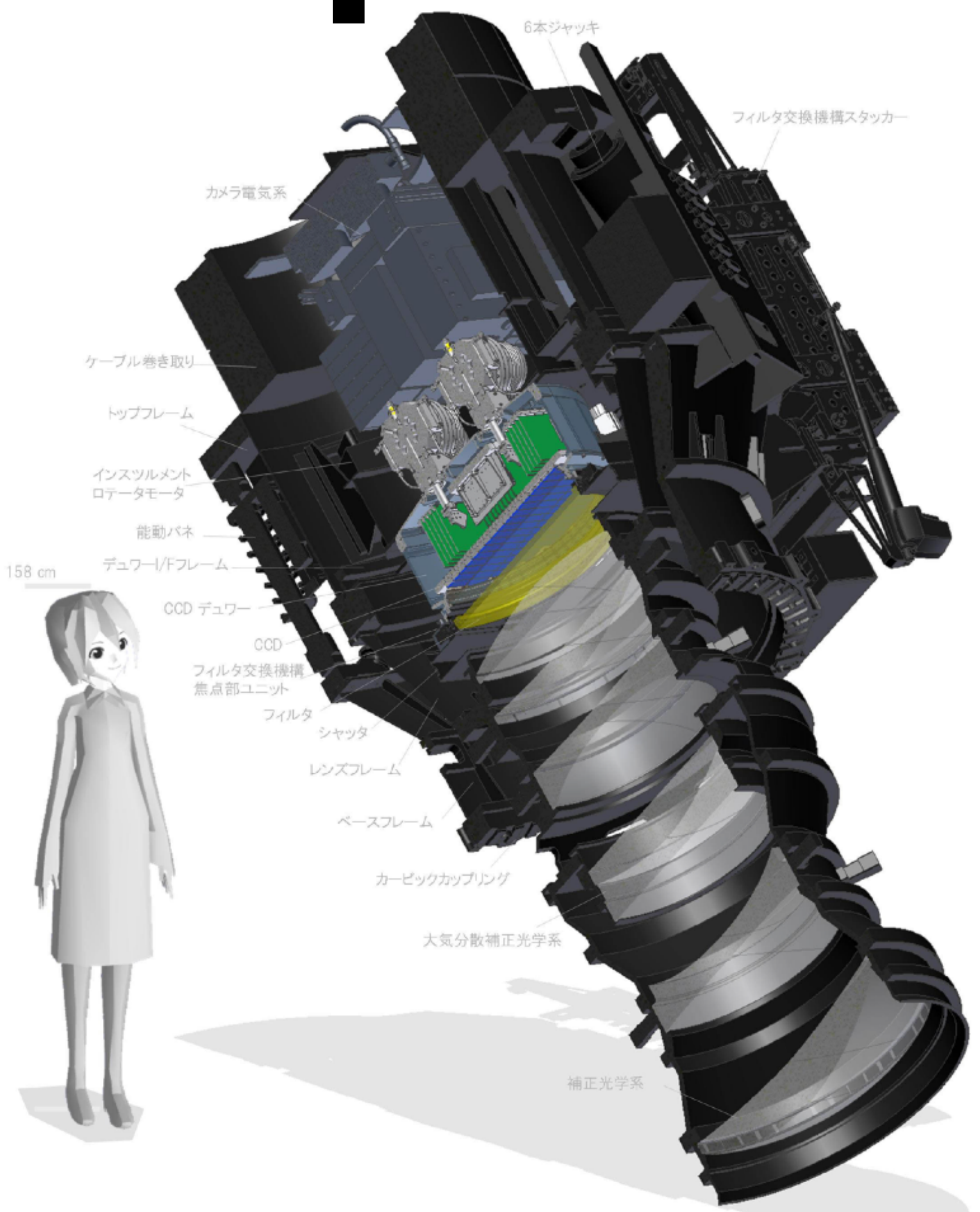
- The dwarf satellites are widely distributed on this plane.
- For comparison, LCDM based subhalos (Vpeak>25km/s) are also plotted.
- The dwarfs are reasonably consistent with subhalos, except for **Ant2, Cra2, and Tuc3** which deviate significantly from the simulations.
- This deviation ***cannot*** be explained by the CDM subhalos detected by commonly-used subhalo finders.



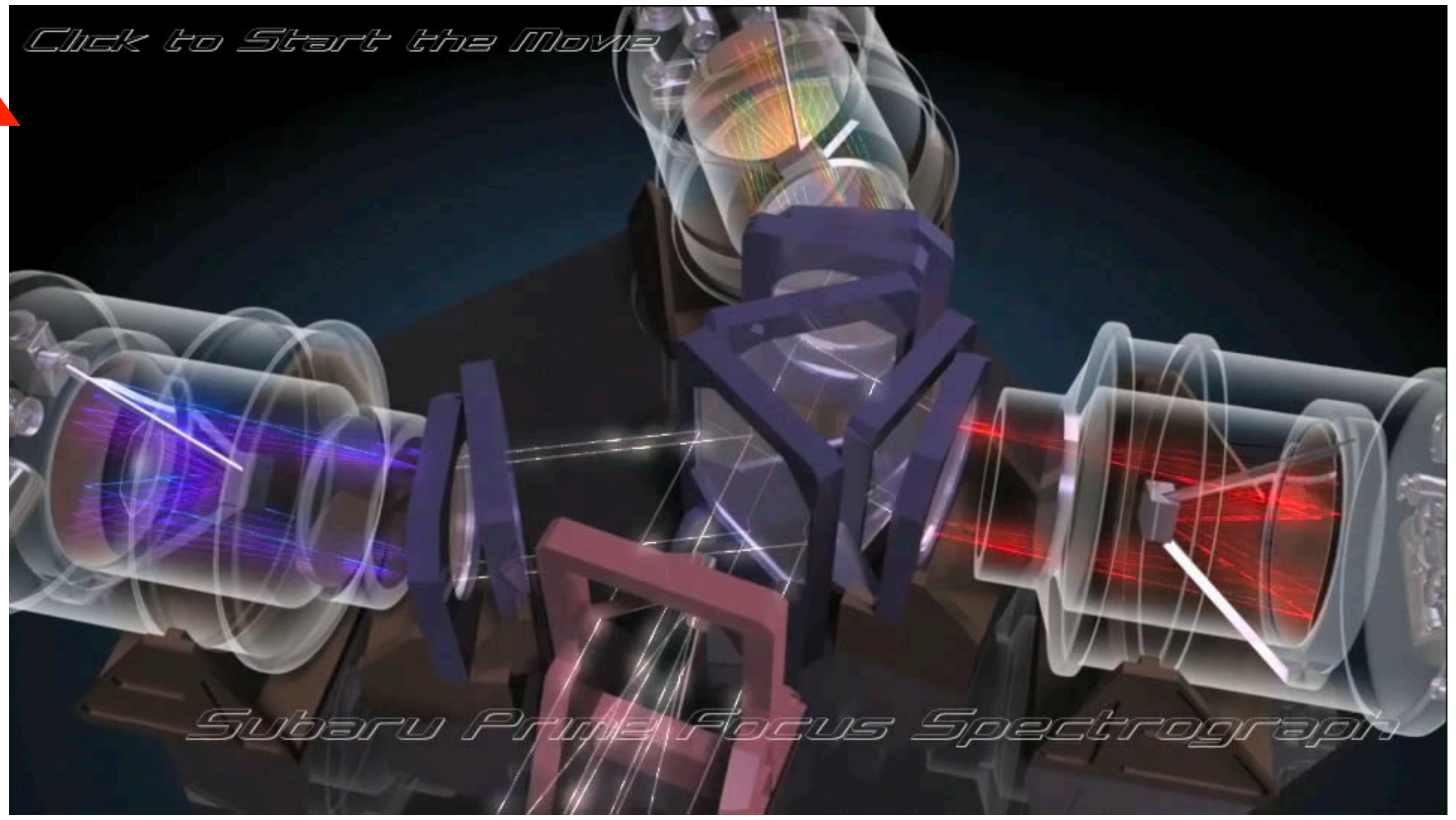
Toward Subaru-PFS era

Subaru-HSC/PFS: deep & wide photo. & spec.



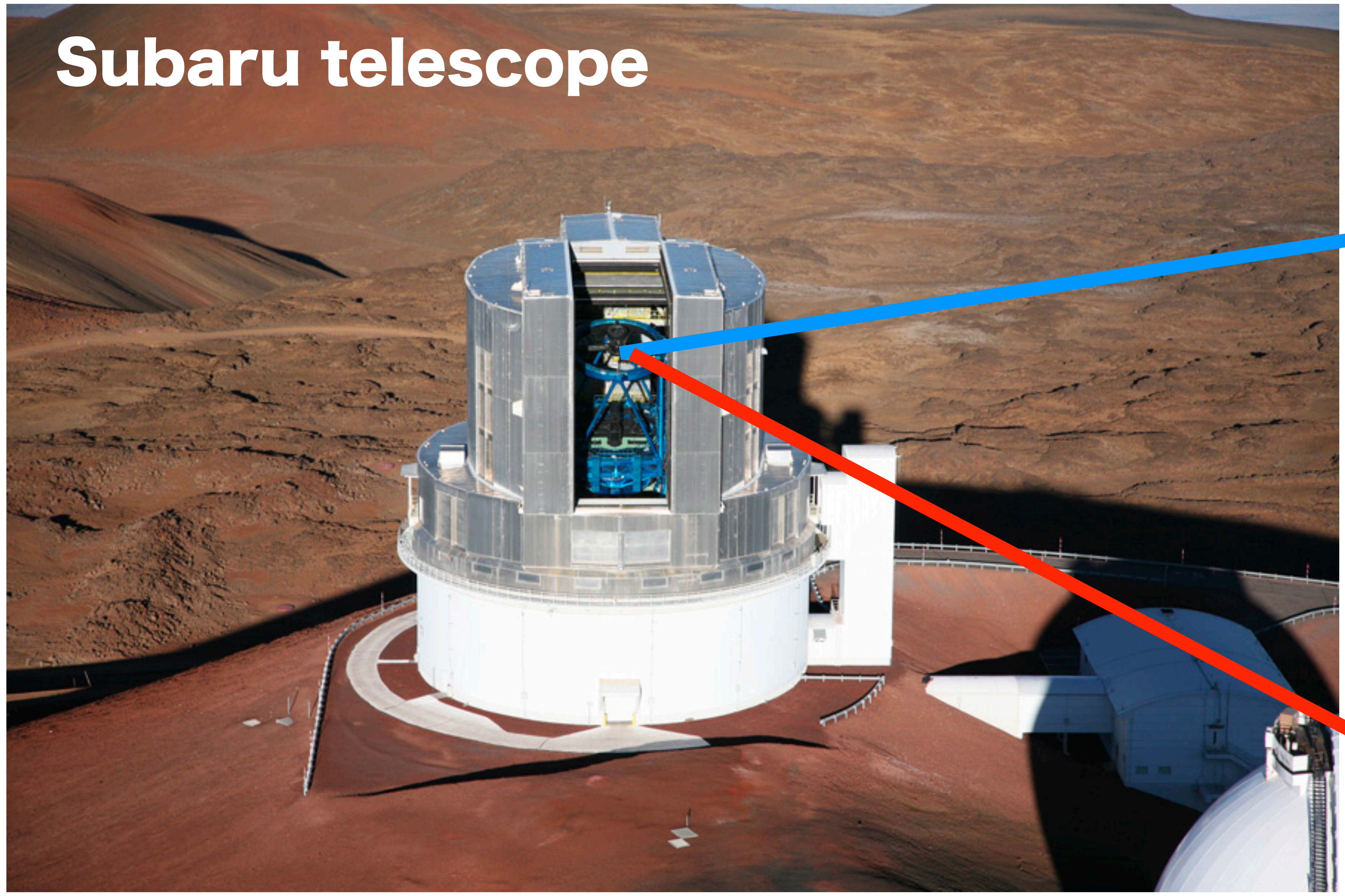


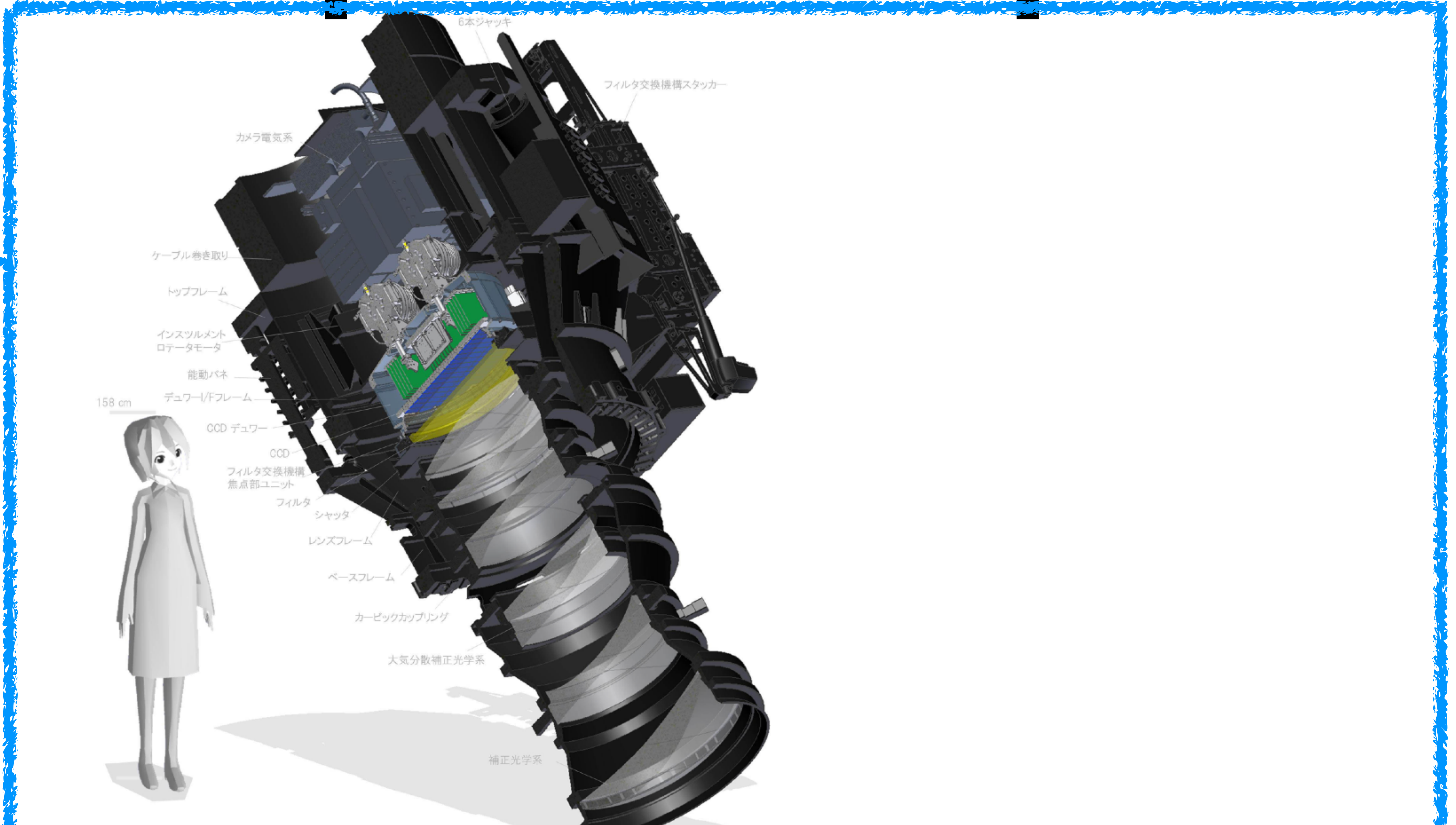
Hyper Suprime Cam



Prime Focus Spectrograph

Subaru-HSC/PFS: deep & wide photo. & spec.





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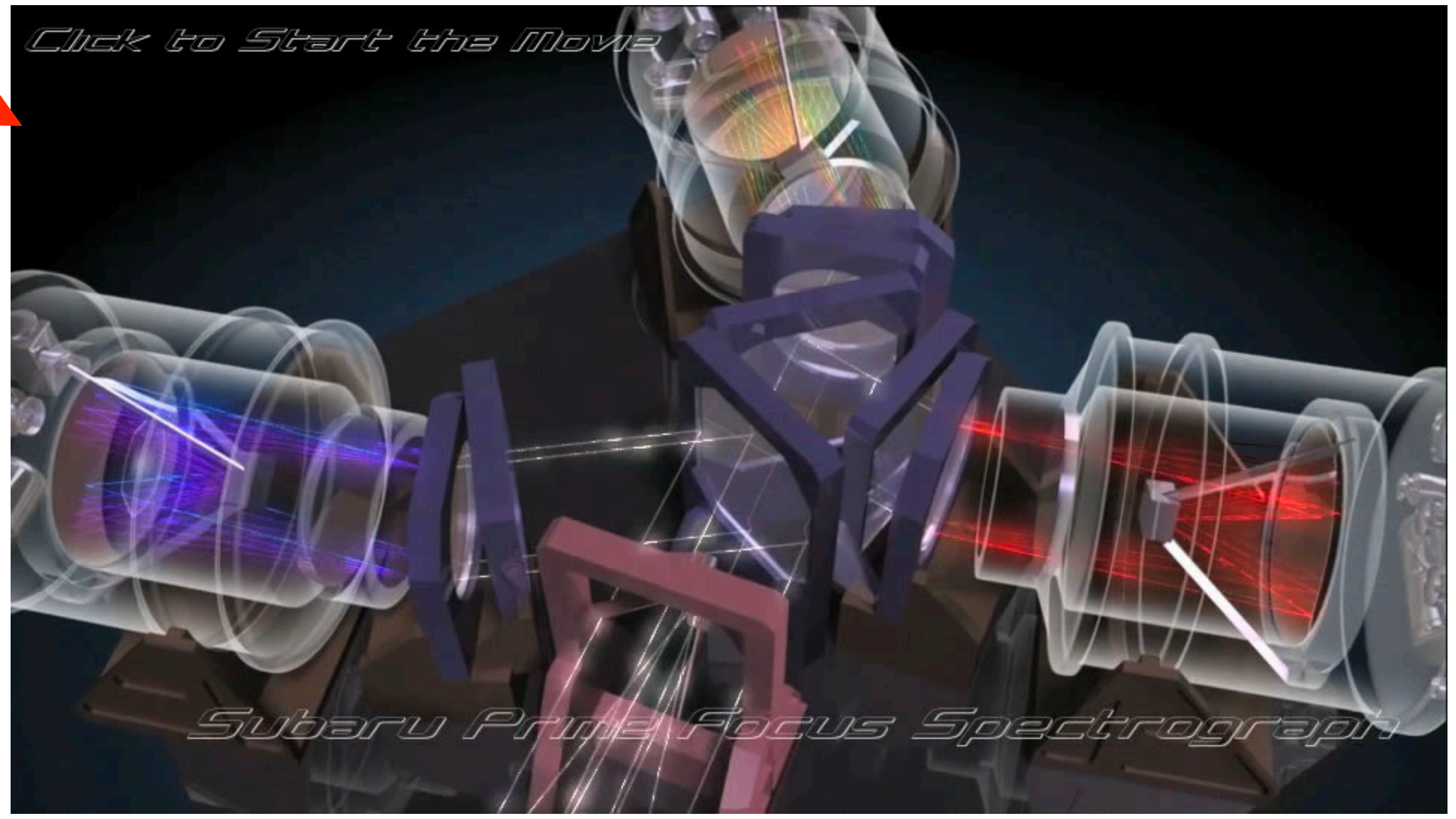
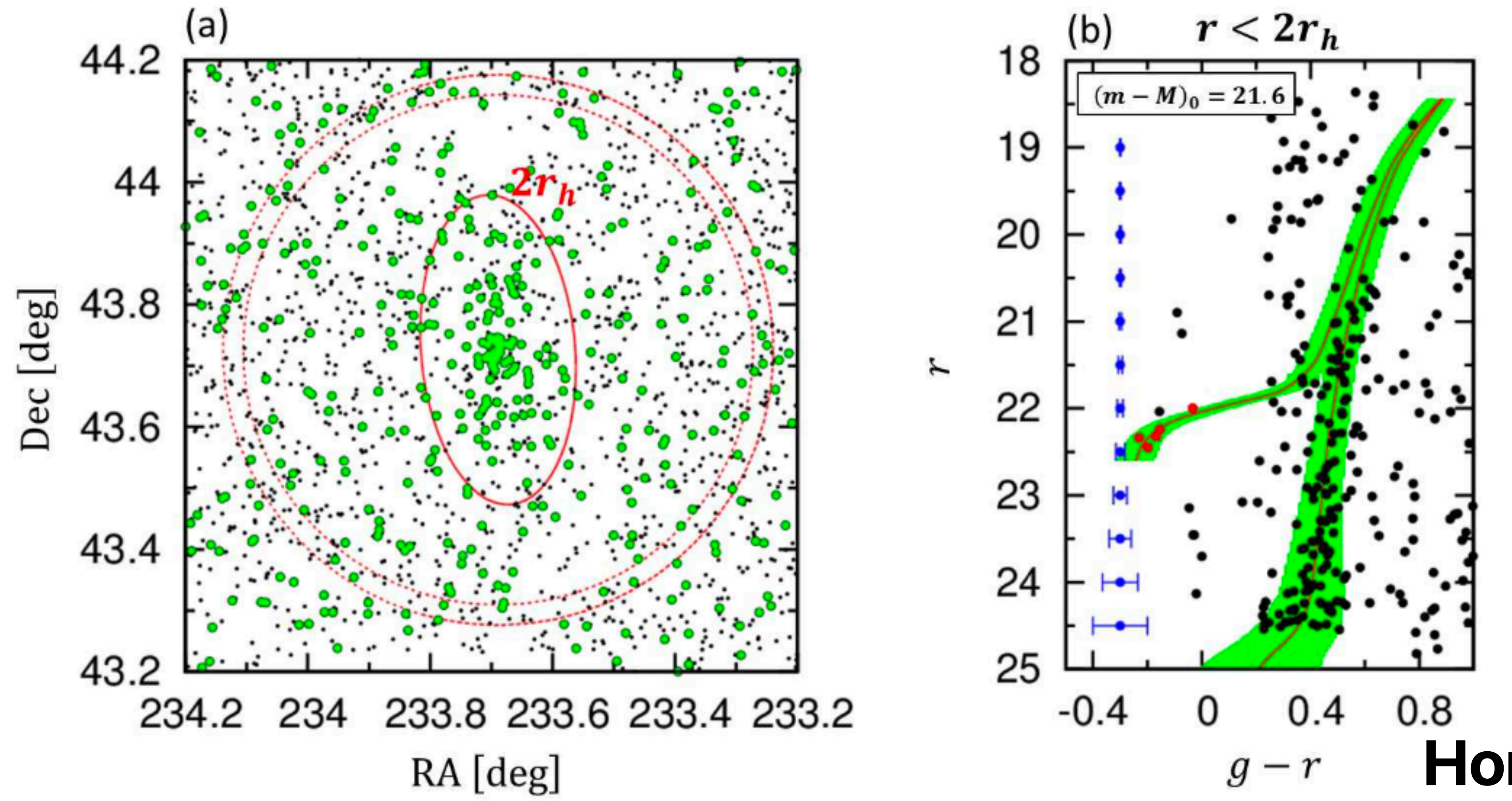


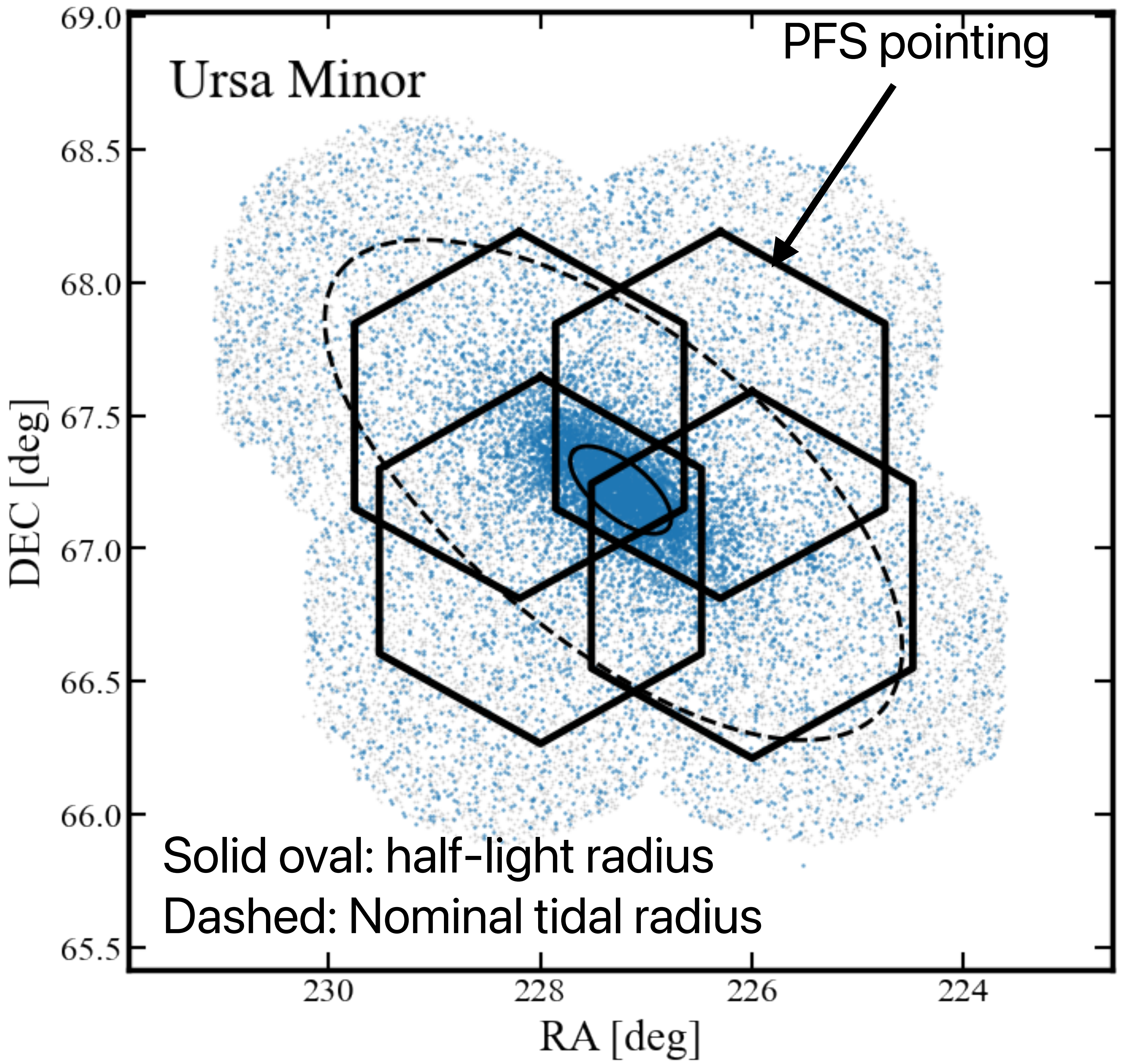
Prime Focus Spectrograph



Homma et al .(2016)

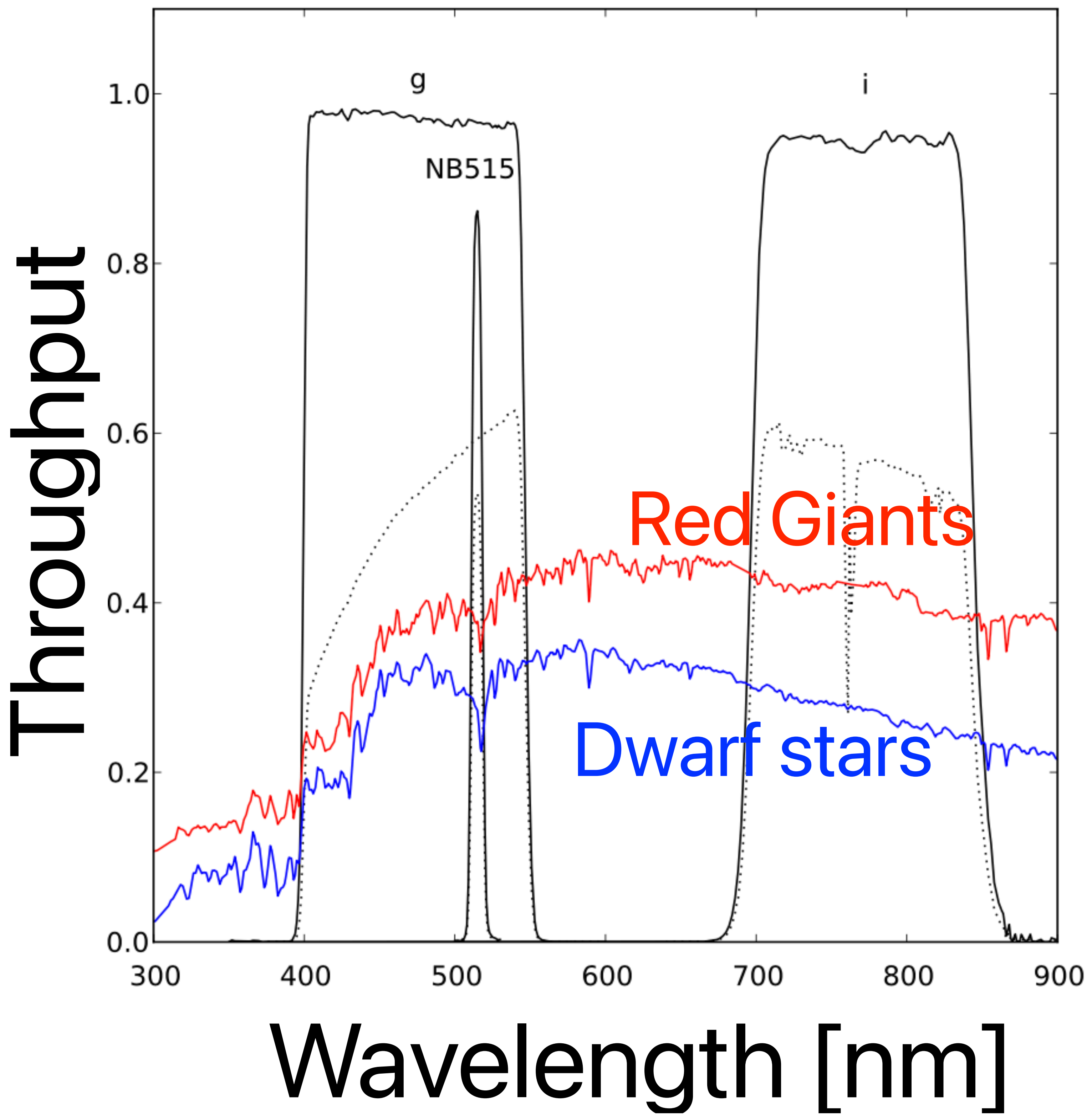
Subaru-HSC: Narrow band selection

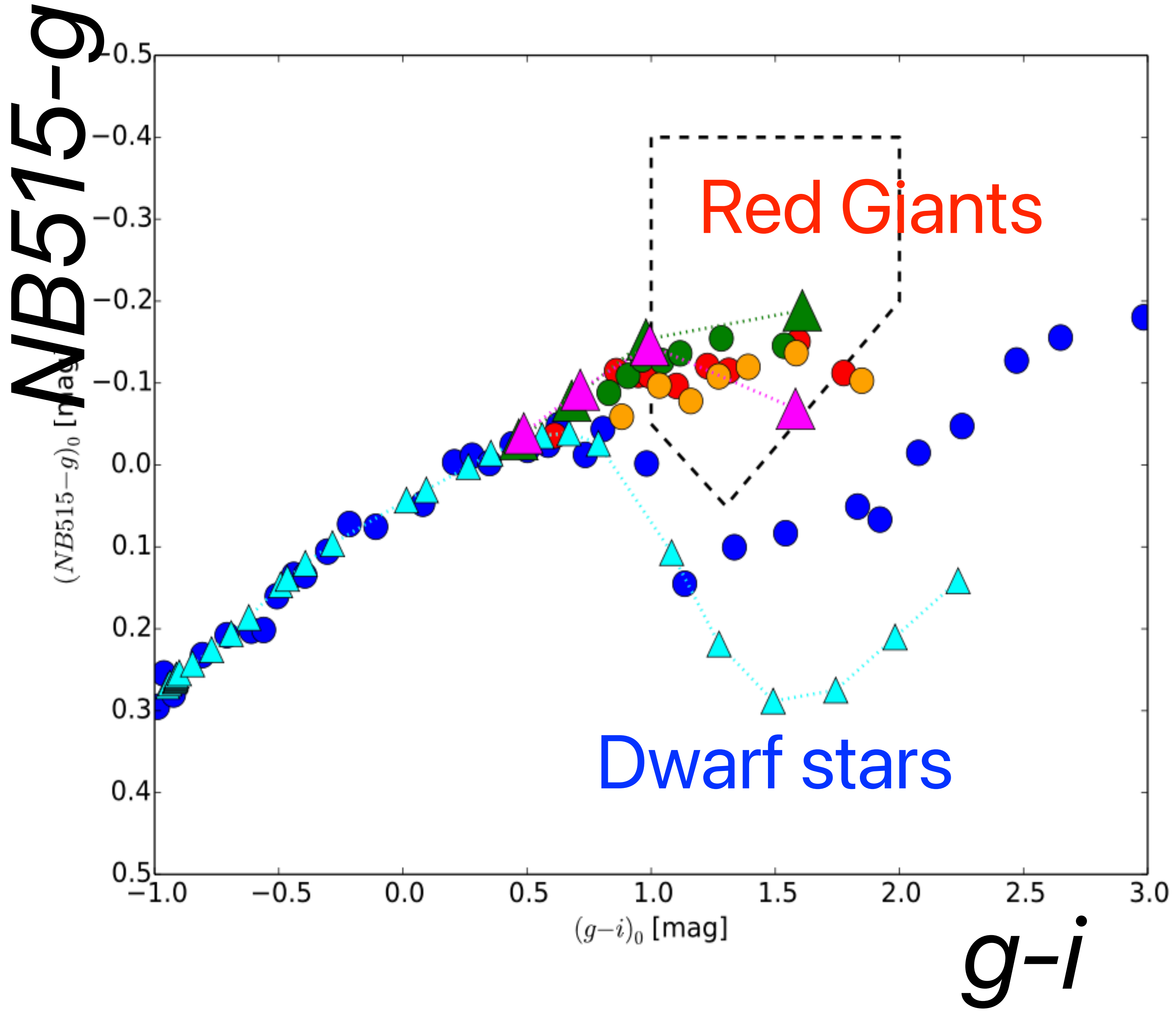
4 pointing HSC data for UMi



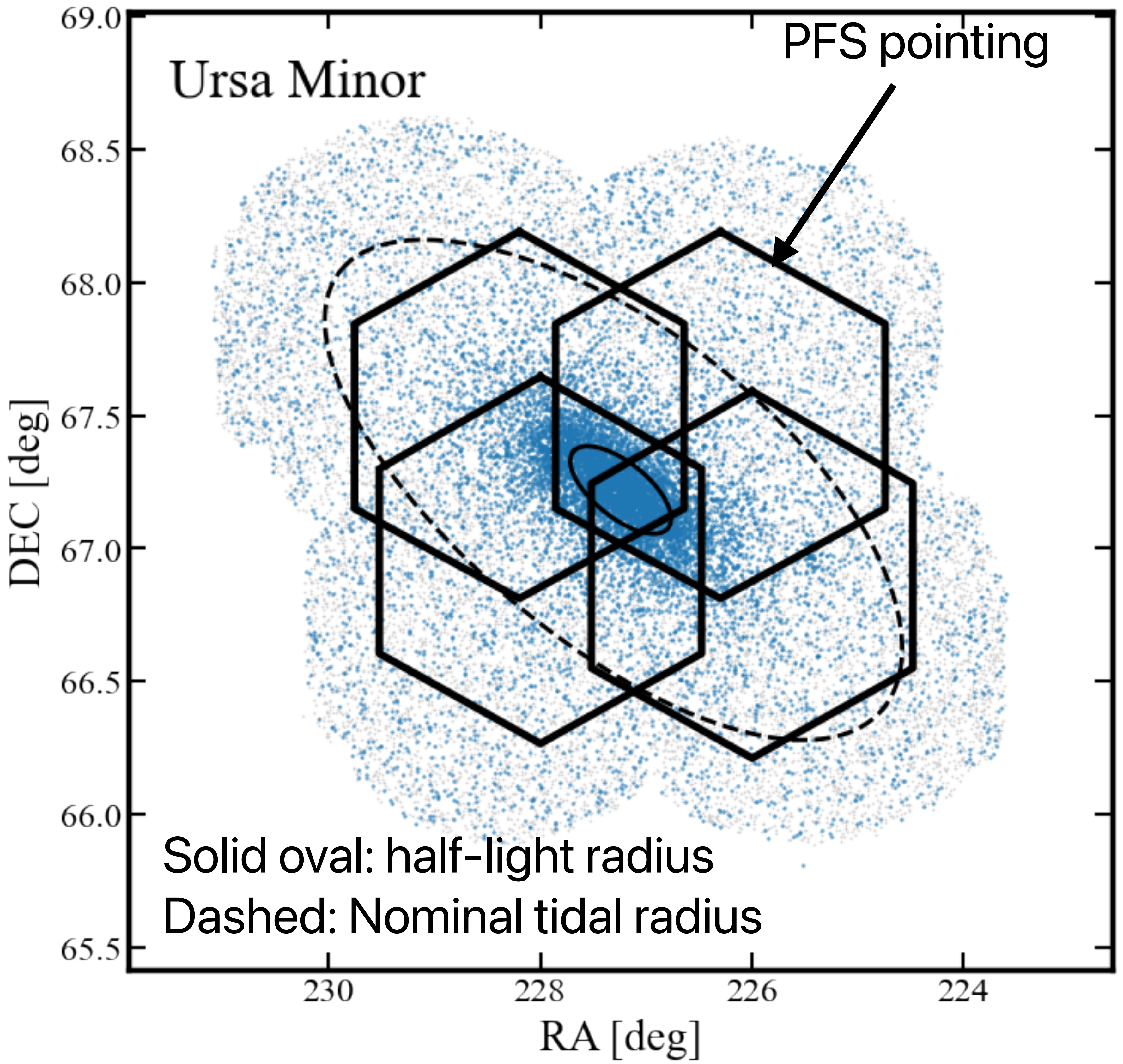
Subaru-HSC: Narrow band selection

Komiyama (incl. KH) et al. 2018



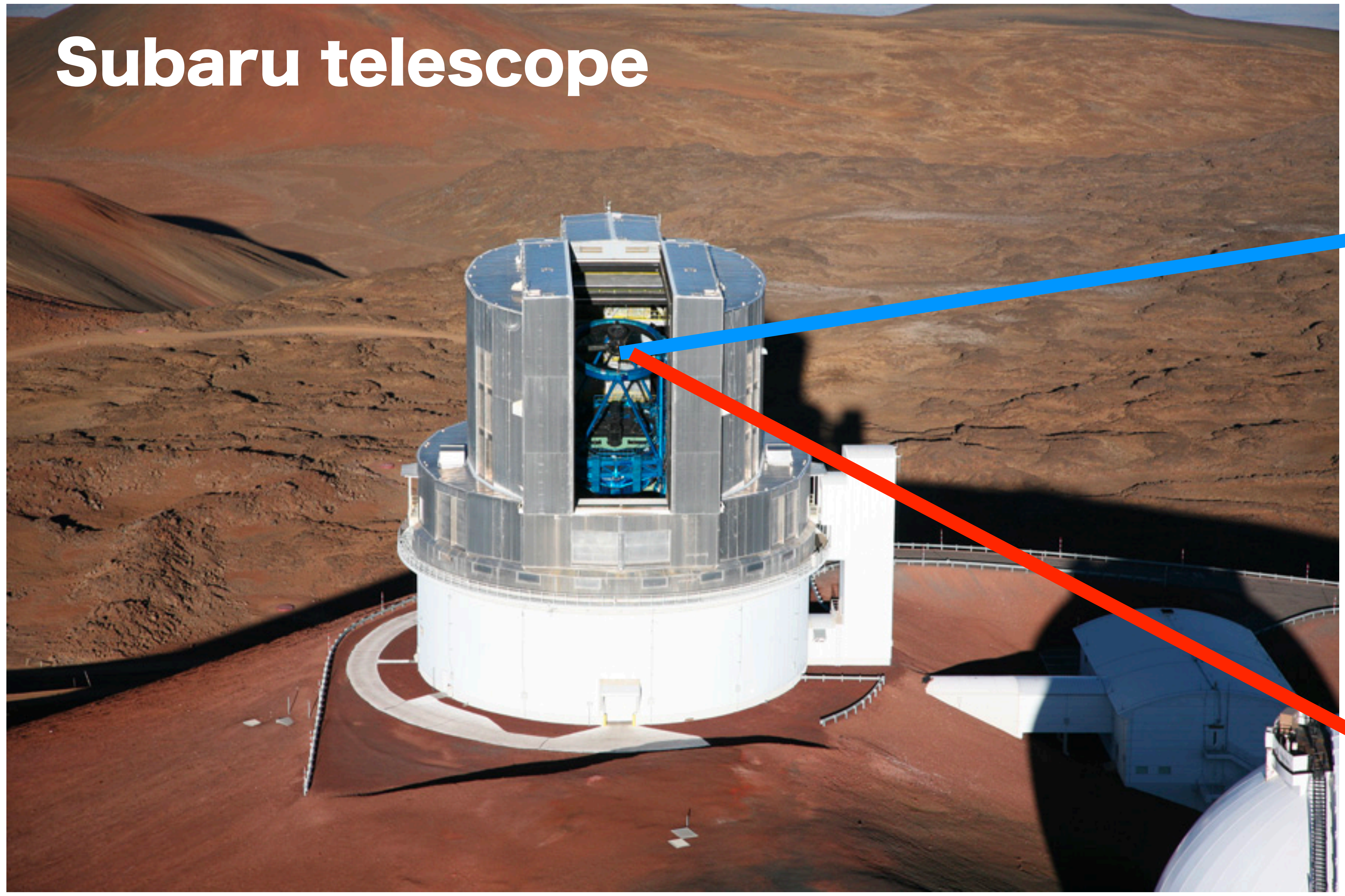


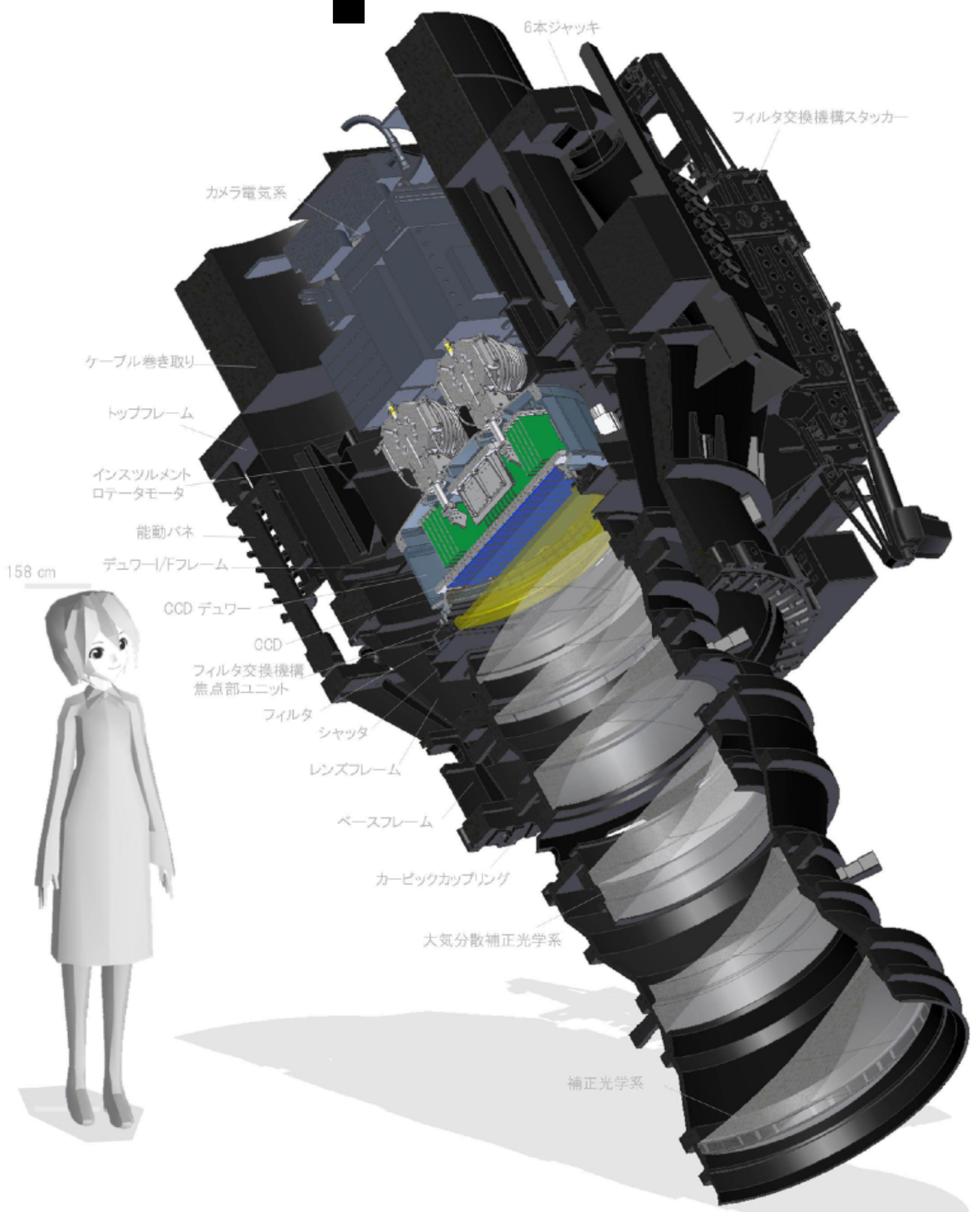
4 pointing HSC data for UMi



NB515 filter can distinguish between (field)dwarf and (dSph's) giant stars based on the depth of stellar surface gravity.

Subaru-HSC/PFS: deep & wide photo. & spec.





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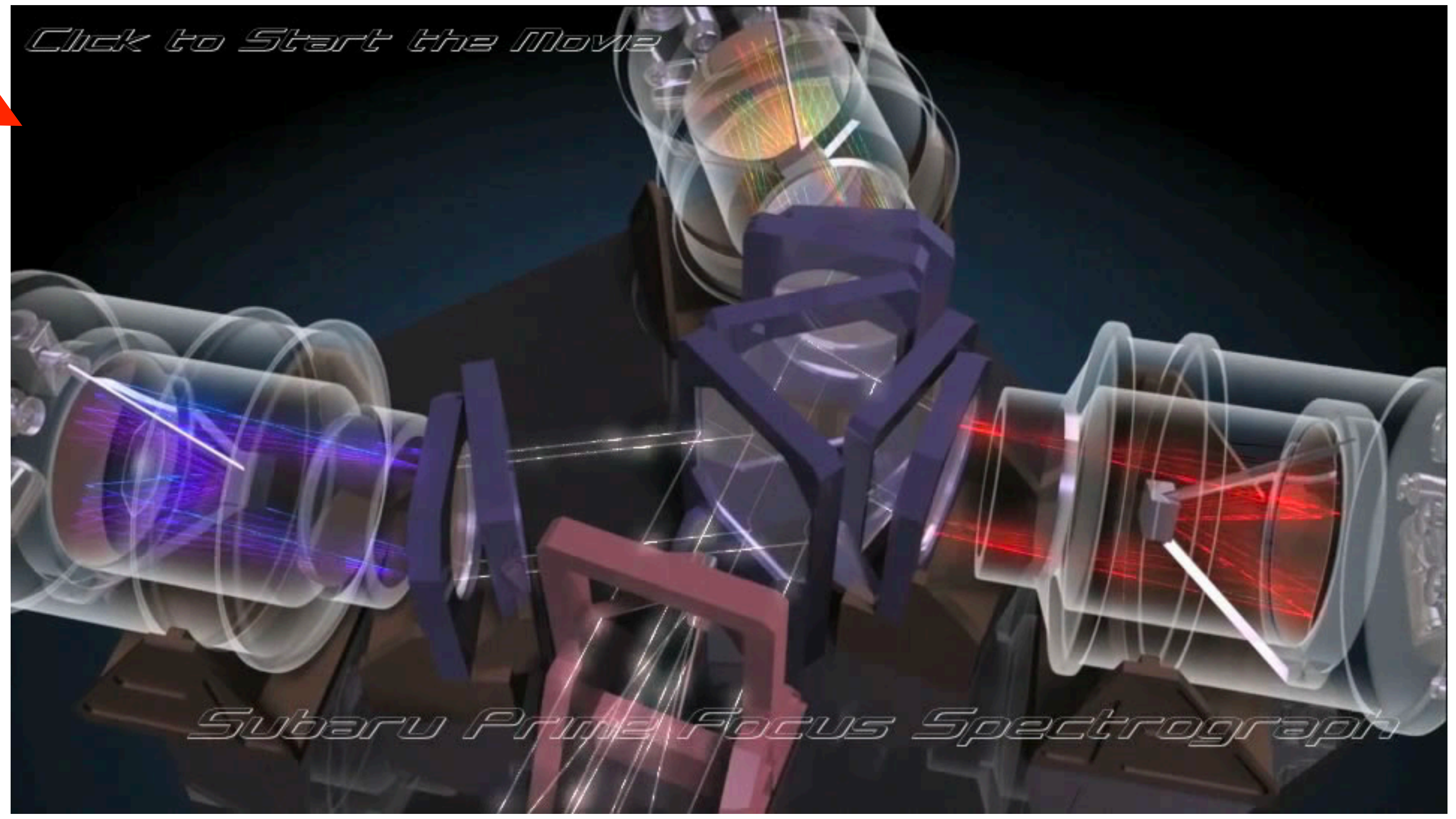
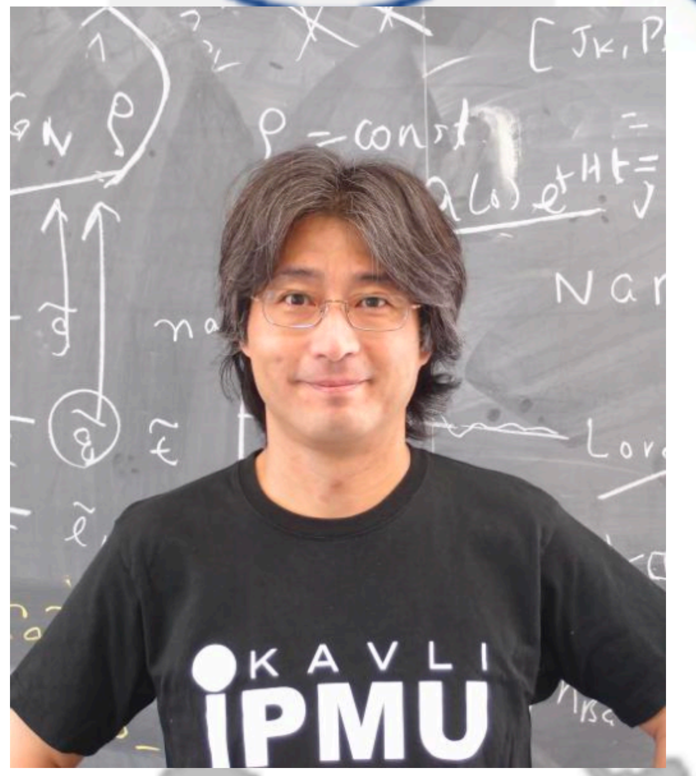


Prime Focus Spectrograph

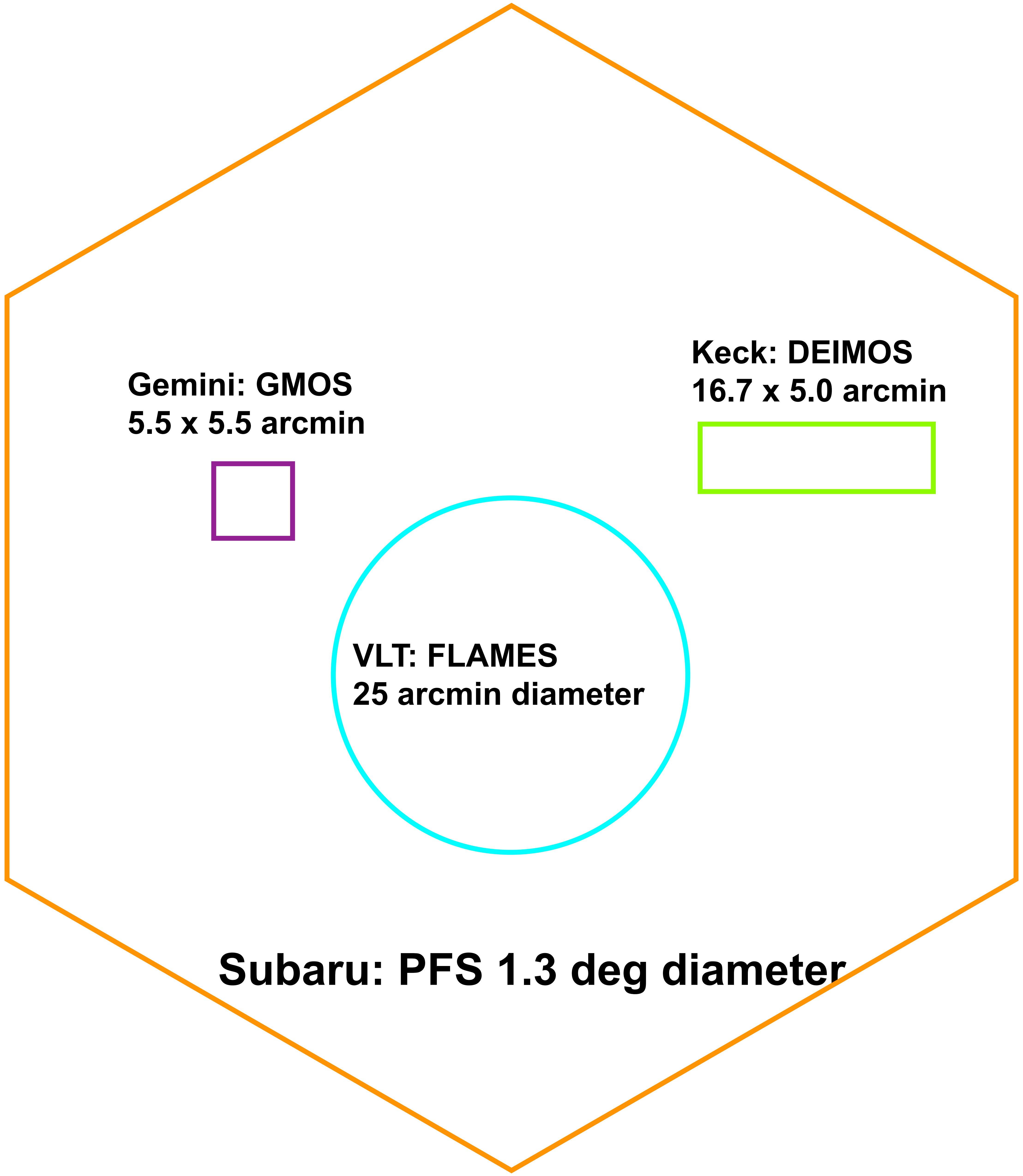
Subaru-PFS: large international collaboration

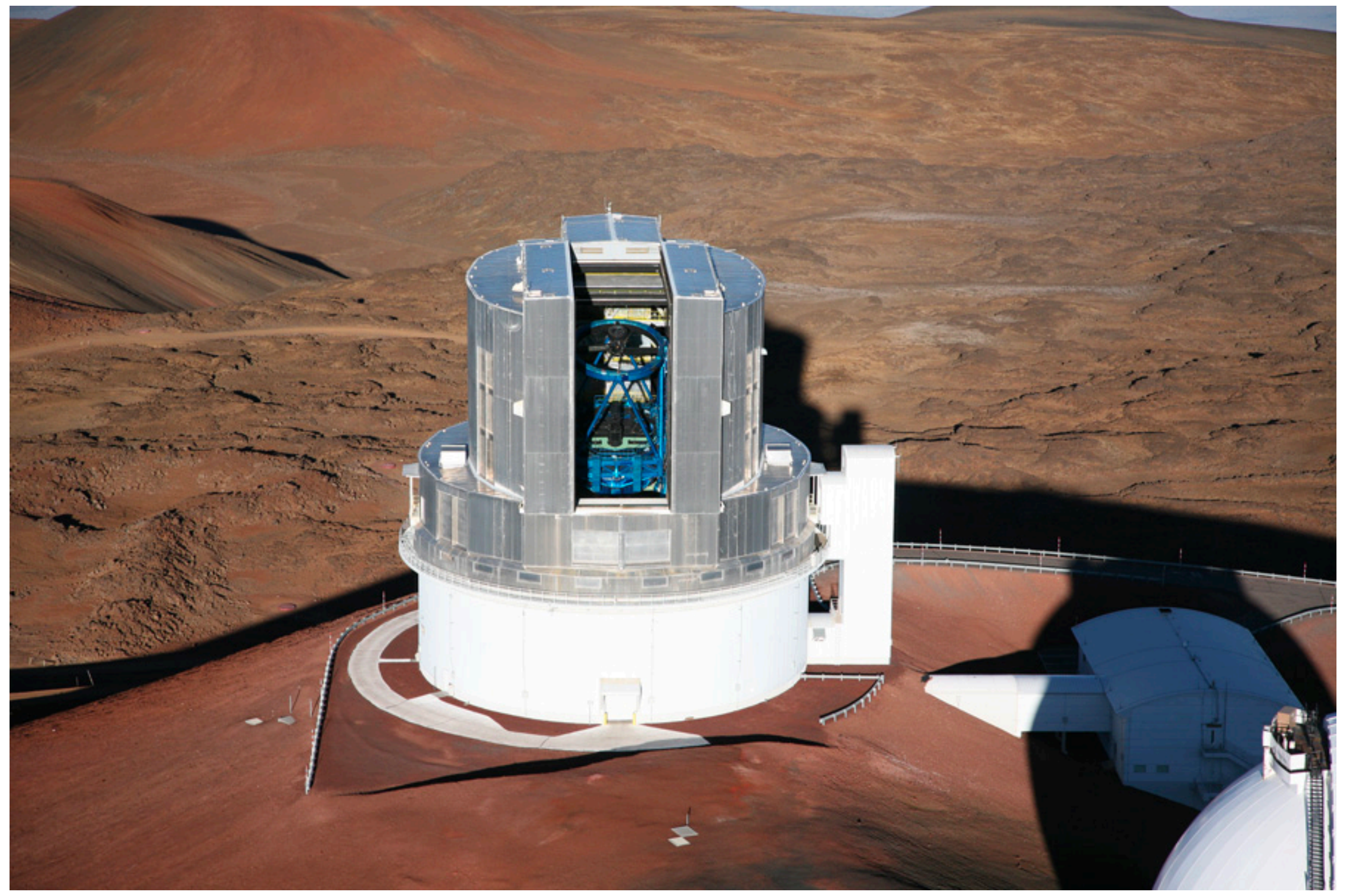


PI: Prof. H. Murayama

- PFS science operation will start from 2024.
- Science team is preparing Subaru Strategic Survey Program (360 nights to be undertaken over 5 years).
- The program makes up three science pillars: cosmology, galaxy evolution, and galactic archaeology

Uniqueness of Subaru-PFS





Subaru Telescope

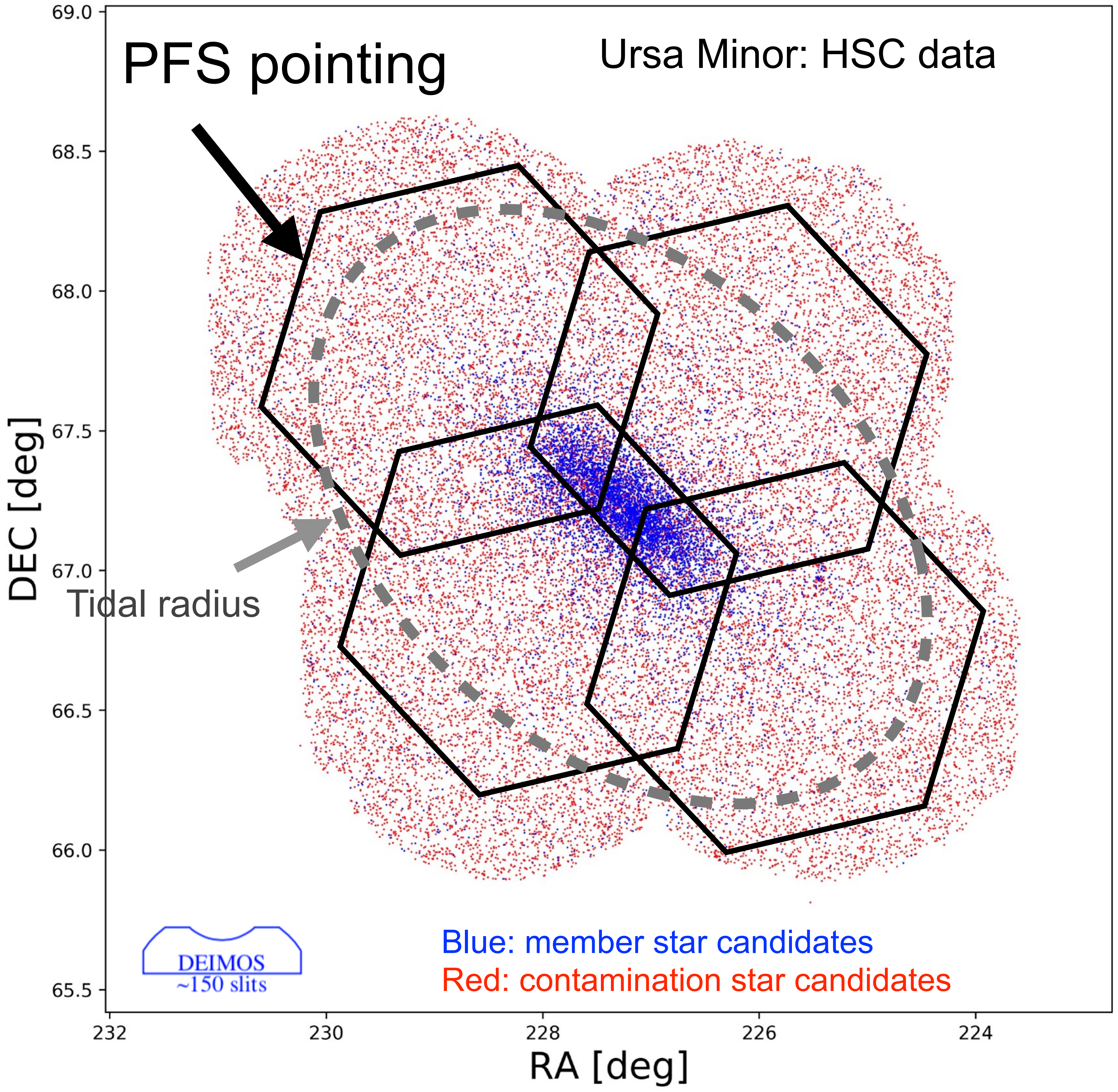
+

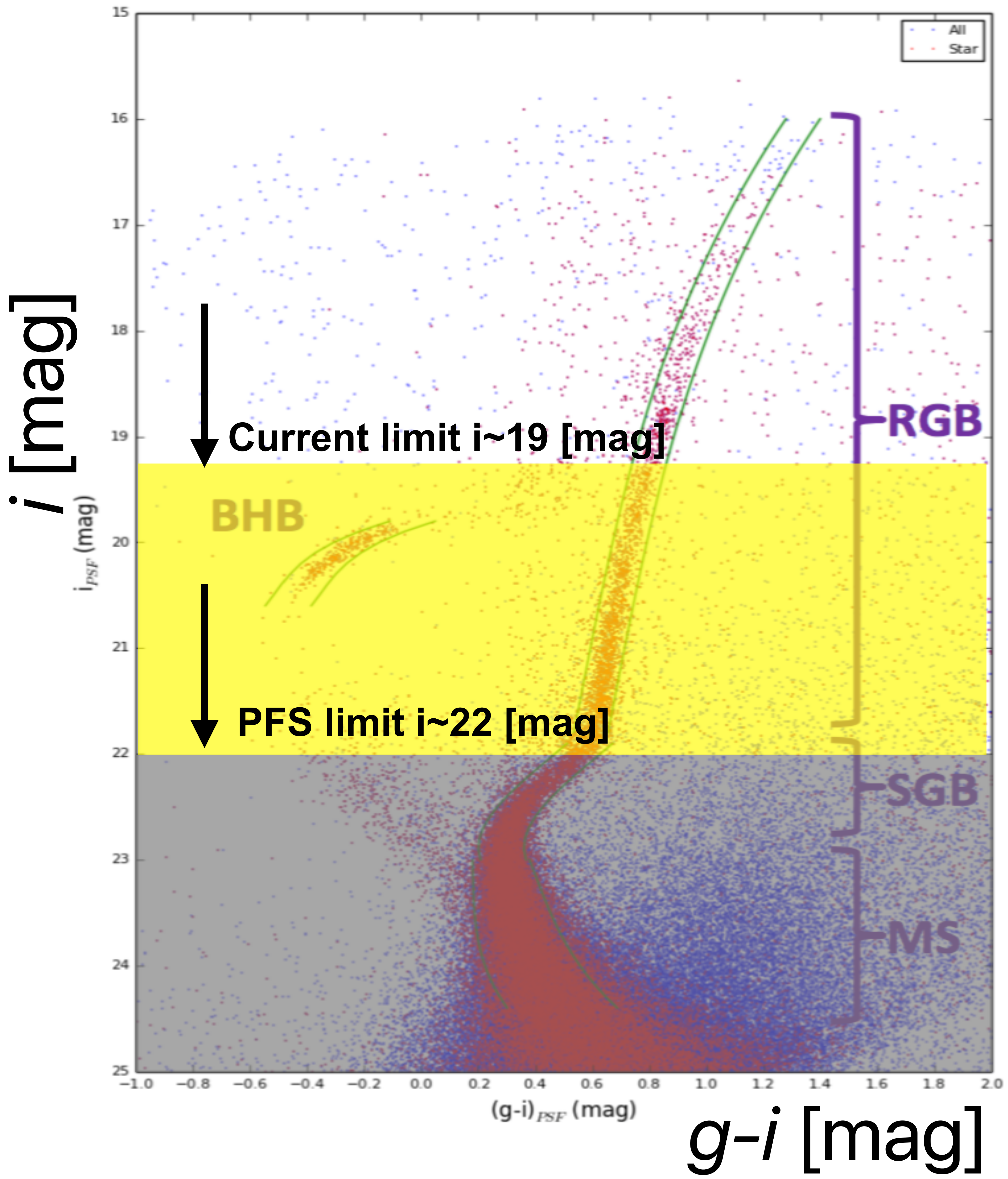
Wide Field of View

||

Wide and Deep spec. survey

Uniqueness of Subaru-PFS





Current $N_{\mathrm{spec.}} \sim 300$ ⇨ PFS $N_{\mathrm{spec.}} \sim 5000$

Wide & deep PFS survey:

Huge number of stellar kinematics out to the outskirts of the Galactic dSphs.

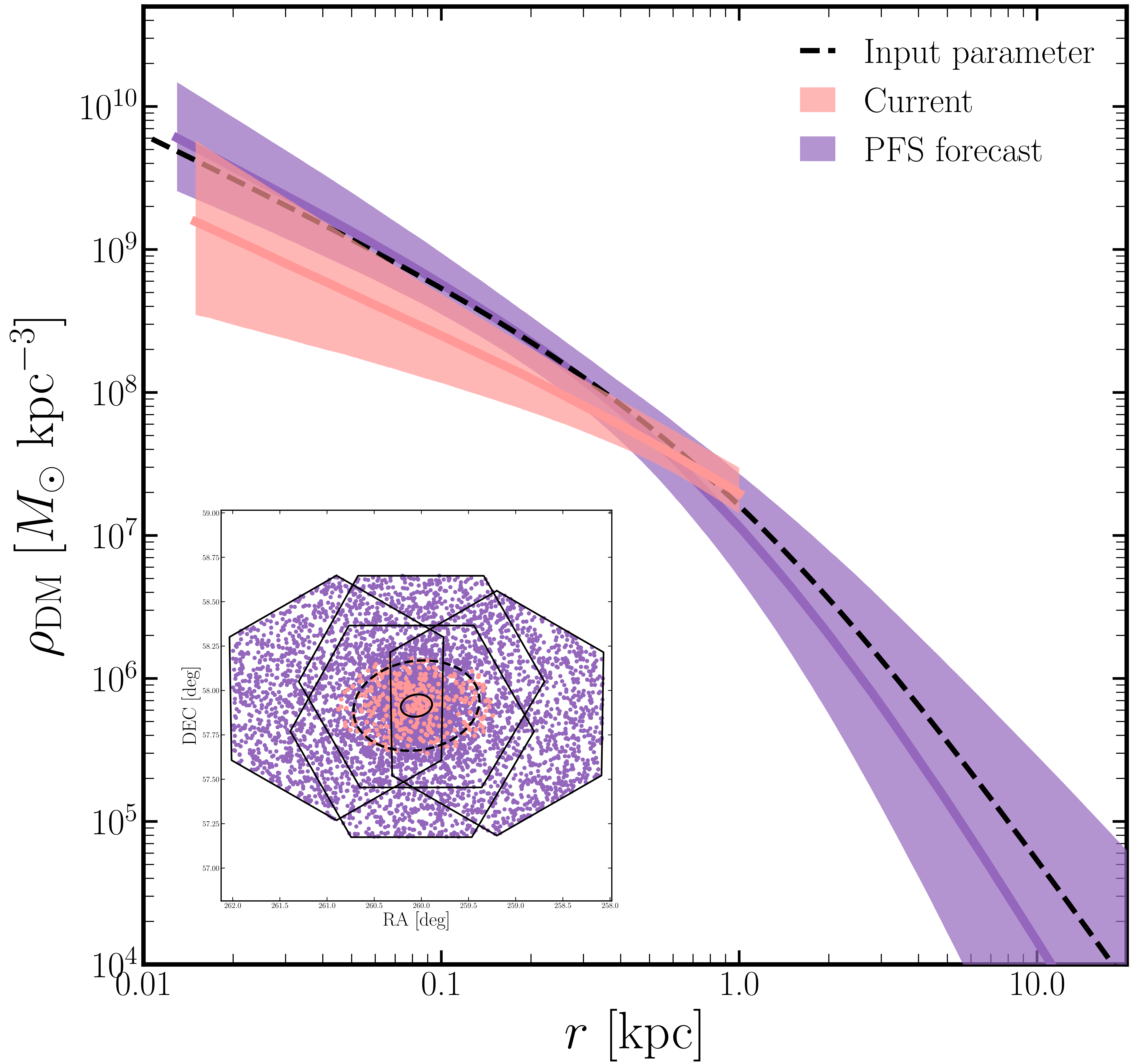
Mock dynamical analysis

I. Axisymmetric Jeans analysis

KH and PFS-GA WG

- Estimated mock DM density profiles from non-spherical Jeans analysis with current small data (pink) and PFS forecast large data volumes (purple).

- From the current analysis, large data volume over wide area by PFS can recover the input density profile from the center to outer parts of a mock galaxy.



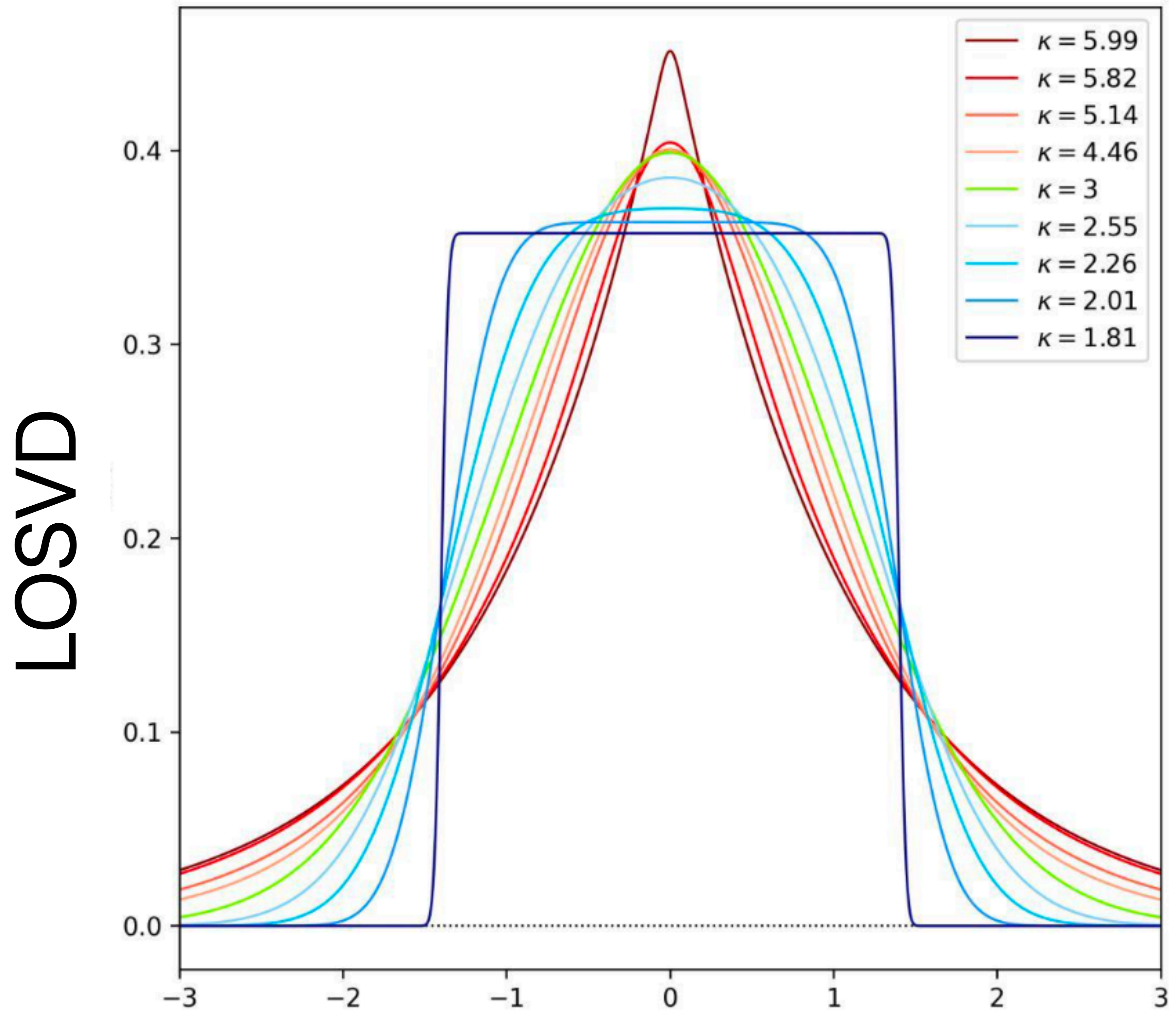
Mock dynamical analysis

II. Higher-order velocity moments (spherical)

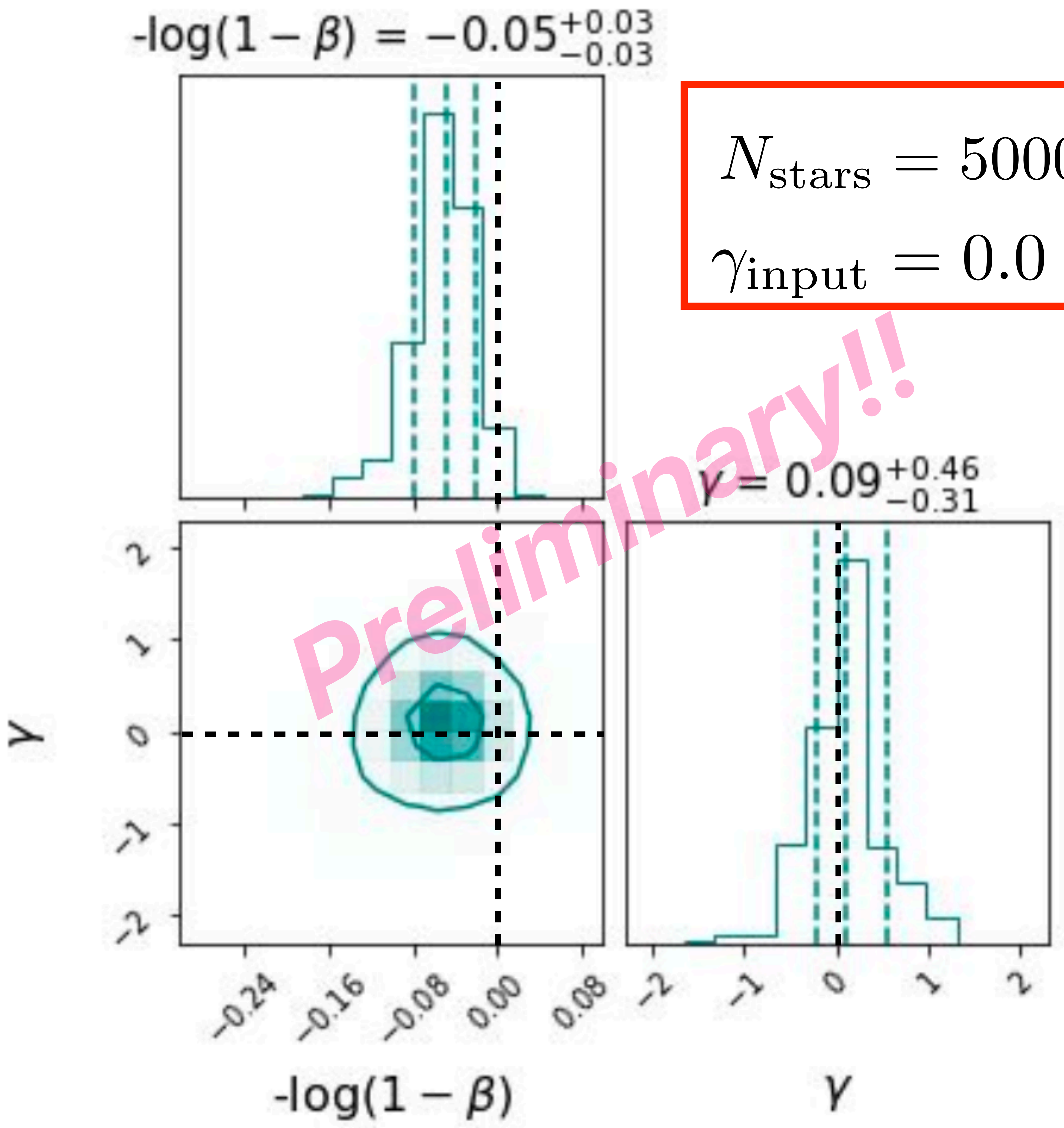
D. Wardana, M. Chiba, and KH (in prep)

Kurtosis:

$$\kappa = \frac{\overline{v^4}}{(\sigma^2)^2}$$



$$w = \frac{v - v_0}{\sigma}$$



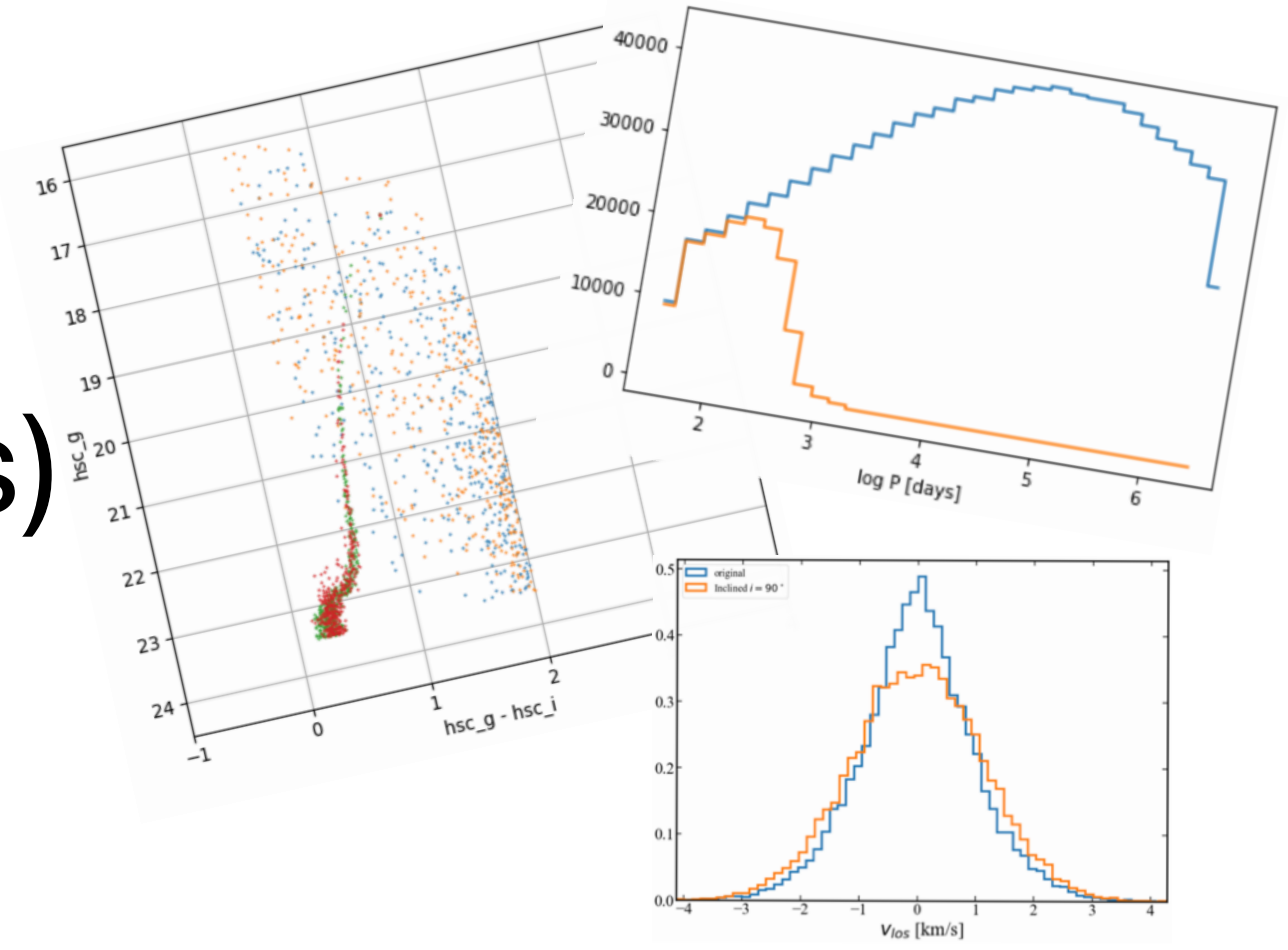
$$N_{\rm stars} = 5000$$

$$\gamma_{\rm input} = 0.0 \ (\rm core)$$

Higher-order velocity moments can break the degeneracy!

Non-trivial effects on dynamical analysis should be considered

- Contamination stars (MW think disk, thin disk, and halo stars)
- Binary stars (Binary system can inflate l.o.s velocity dispersions)
- Tidal forces (Deviation from dynamical equilibrium)



Kinematic info. generated by DM potential × Binary stars × Contamination stars

ME

E. Kirby (Notre Dome)

L. Dobos (JHU)

C. Filion (JHU)

PFS-GA science team

Take Home Message

- The Galactic dwarf spheroidal galaxies are ideal target for studying the basic properties of dark matter.
- The current constraints on their DM density profiles still have large uncertainties, even though several dSphs favor cusped DM halo.
- On the $\rho_{\rm DM,150\ pc} - r_{\rm peri}$ plane, ***Ant2, Cra2, and Tuc3*** deviate significantly from the simulations. This deviation *cannot* be explained by the ΛCDM subhalos detected by commonly-used subhalo finders.
- **Subaru HSC/PFS** enable us to hunt the large number of dSph's stars out to their outskirts, and thereby placing tighter constraints on their DM density profiles.