Dark Matter in the Galactic dwarf satellites

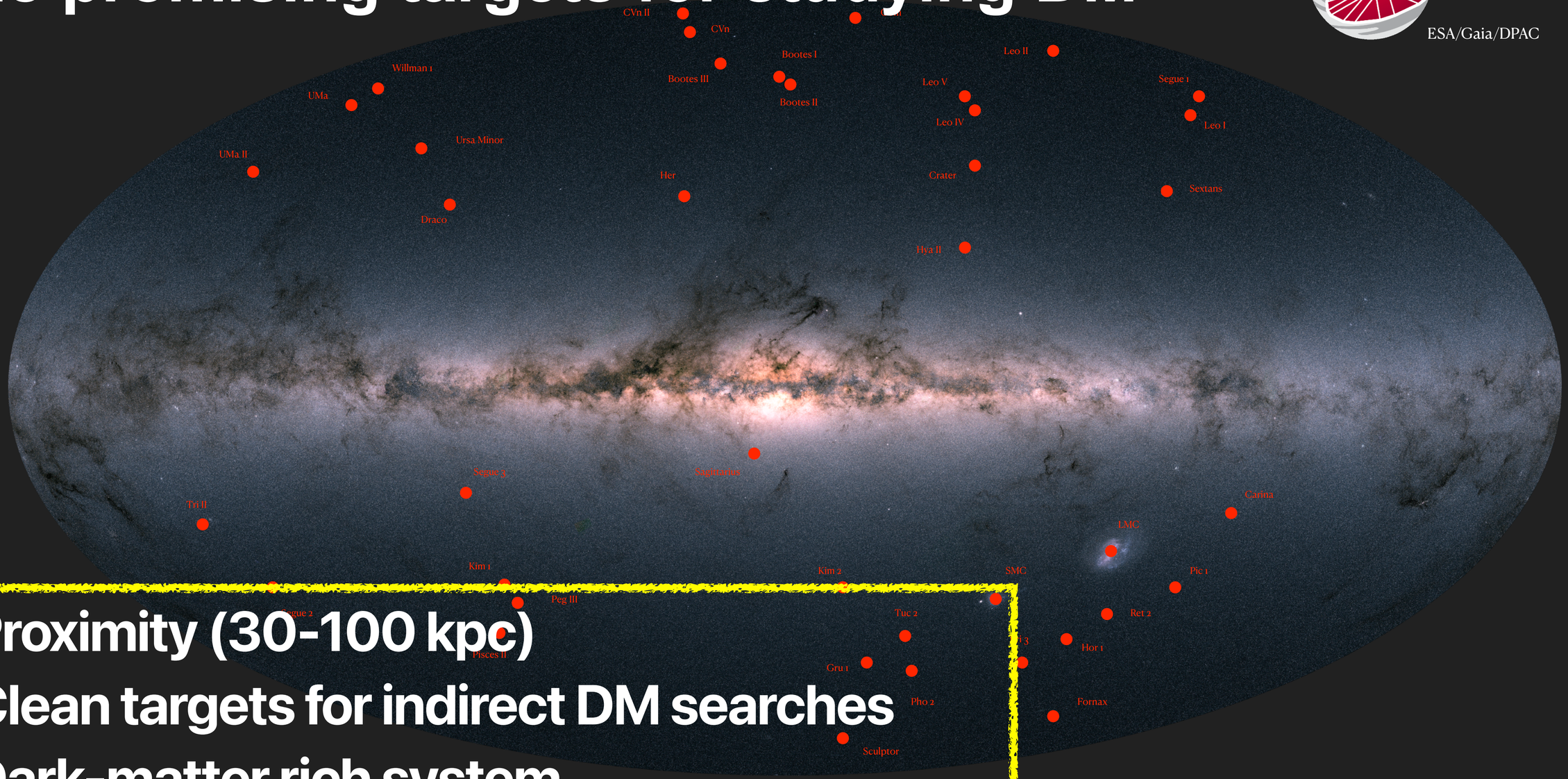
公募研究「すばる望遠鏡による銀河系矮小銀河の網羅的動力学研究とダークマターの正体解明」

Kohei Hayashi (NIT, Ichinoseki College)

Mar. 8, 2023

FY2022 “What is dark matter?”@Kavli IPMU

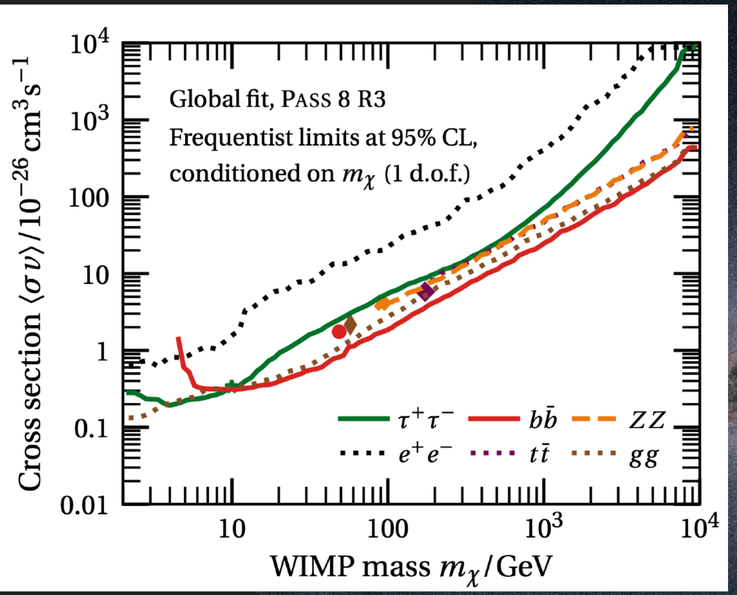
Dwarf spheroidal galaxy (dSph): the promising targets for studying DM



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

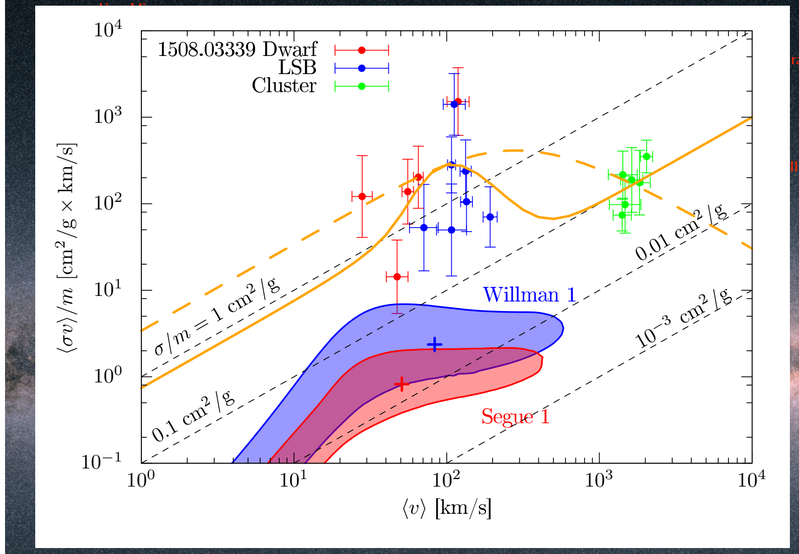
Dwarf spheroidal galaxy (dSph): the promising targets for studying DM

WIMP



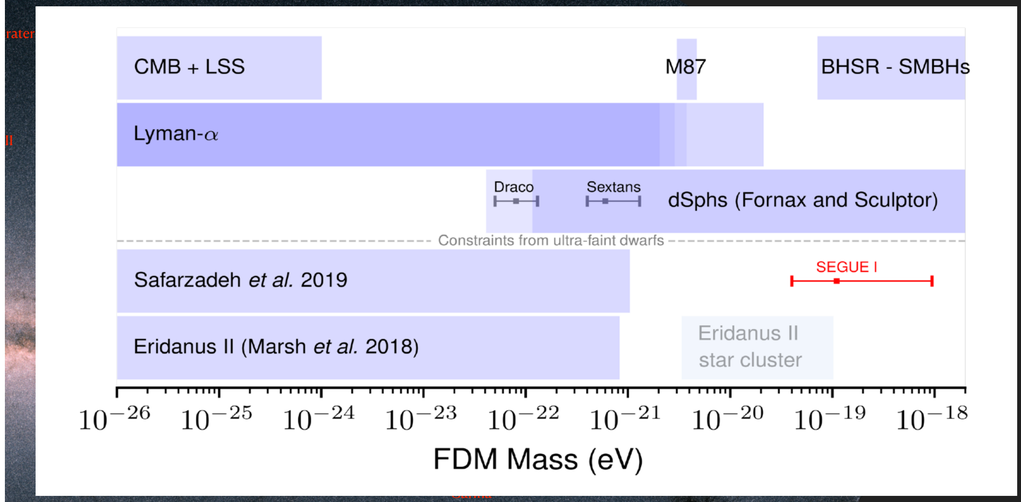
Hoof+ (2020)

SIDM



Hayashi+ (2021)

FDM



Hayashi+ (2022)

- Proximity (30-100 kpc)
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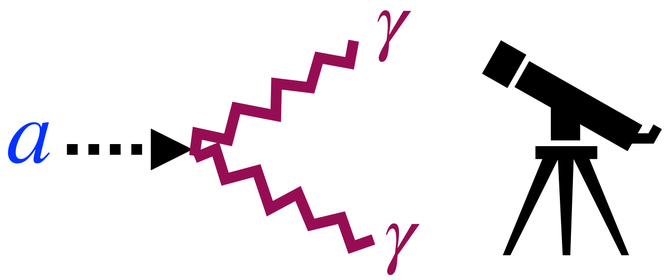
Indirect detection of eV DM with Subaru-IRCS

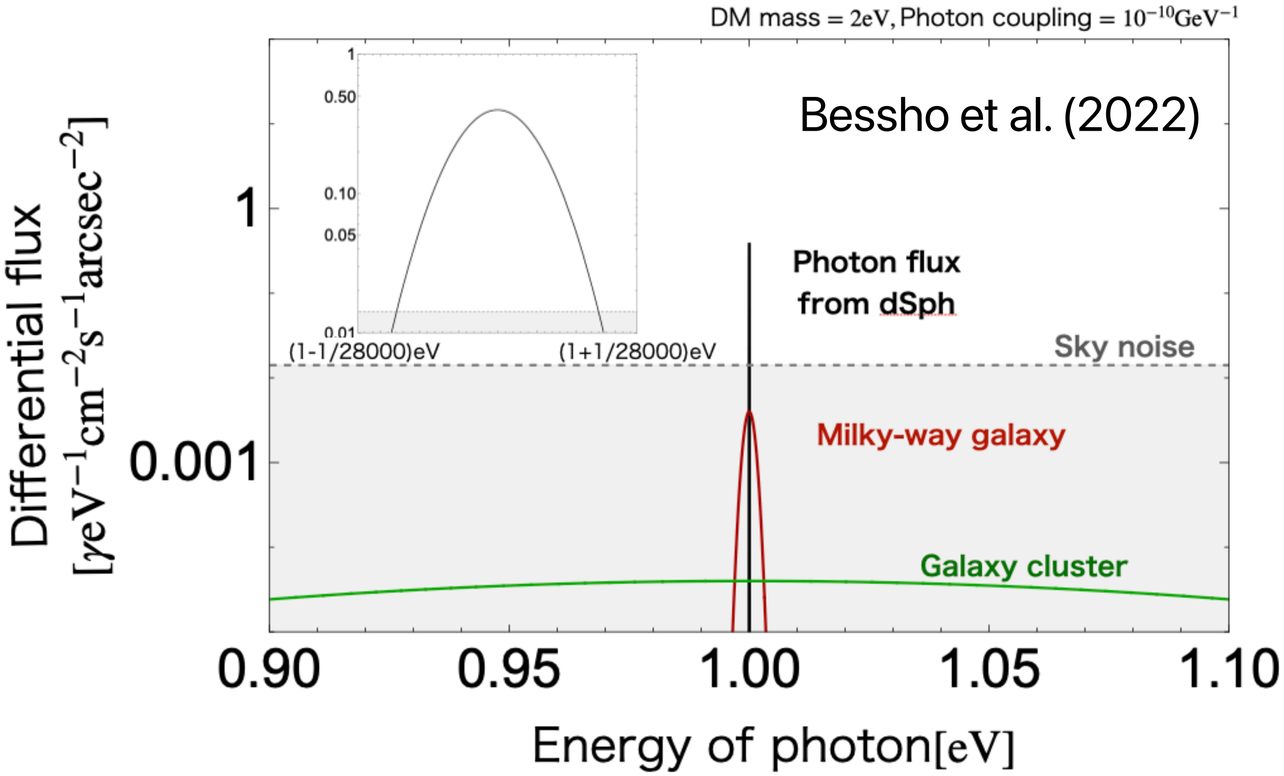
KH and W. Yin (in prep.)

Parameter region:

$$\text{DM mass} \sim \text{eV}, \quad \text{DM} - \text{photon coupling} \sim 10^{-11} - 10^{-10}\text{GeV}^{-1}$$



Serious sky/thermal noise can be overcome by high-resolution of infrared spectrographs.



Indirect detection of eV DM with Subaru-IRCS

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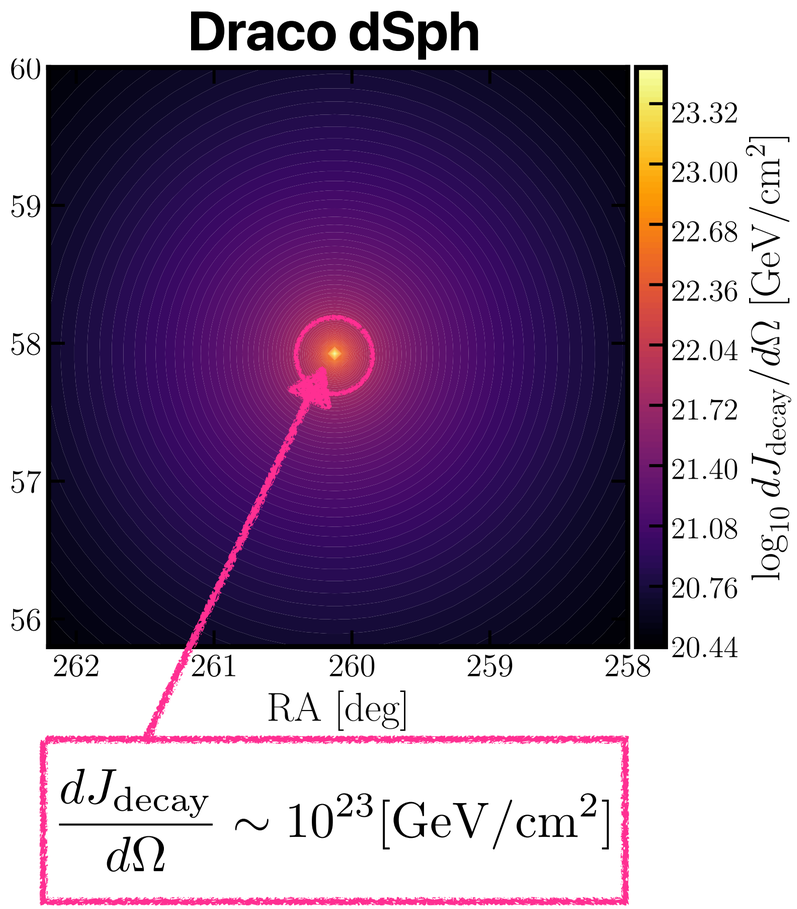
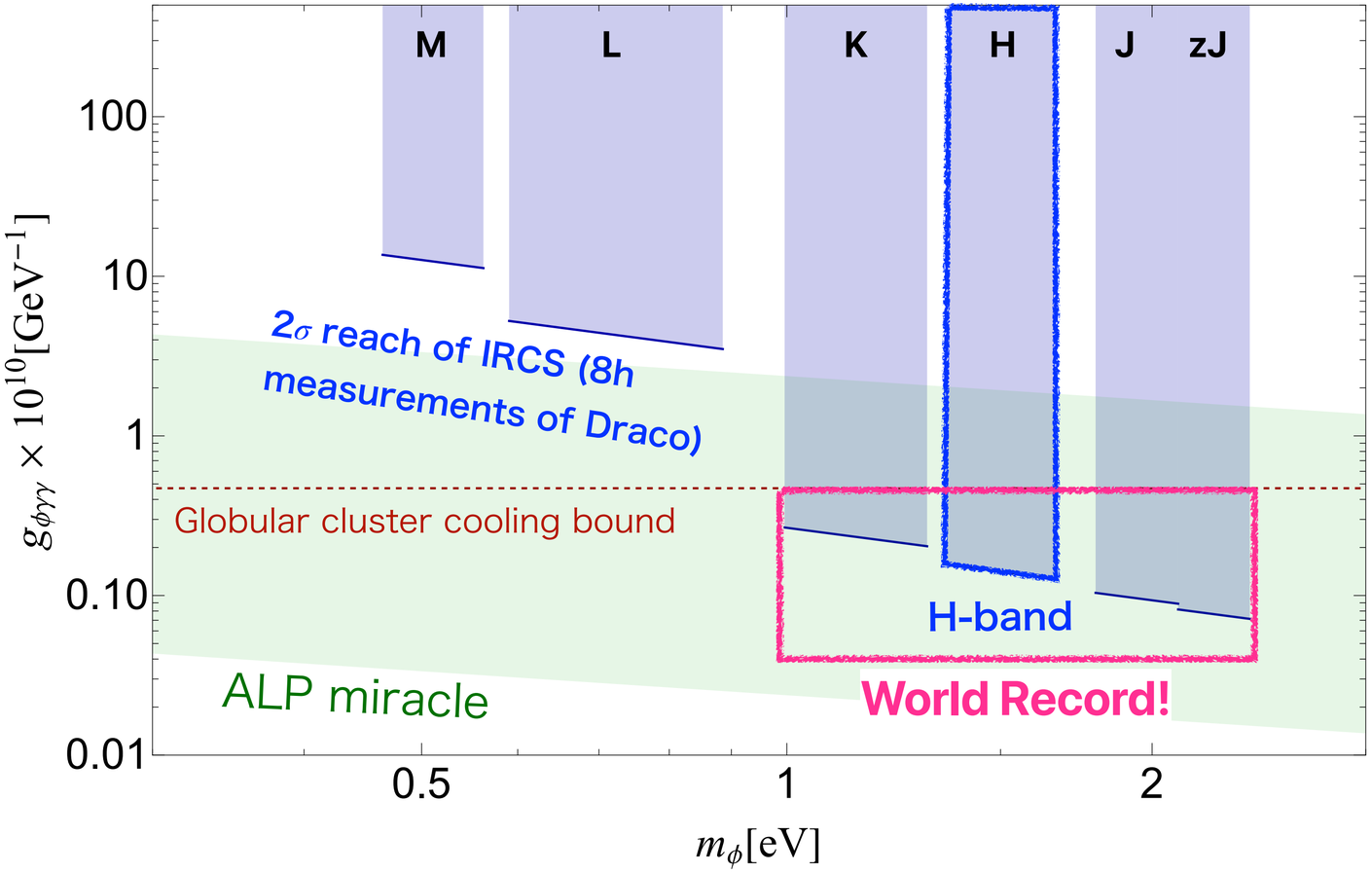
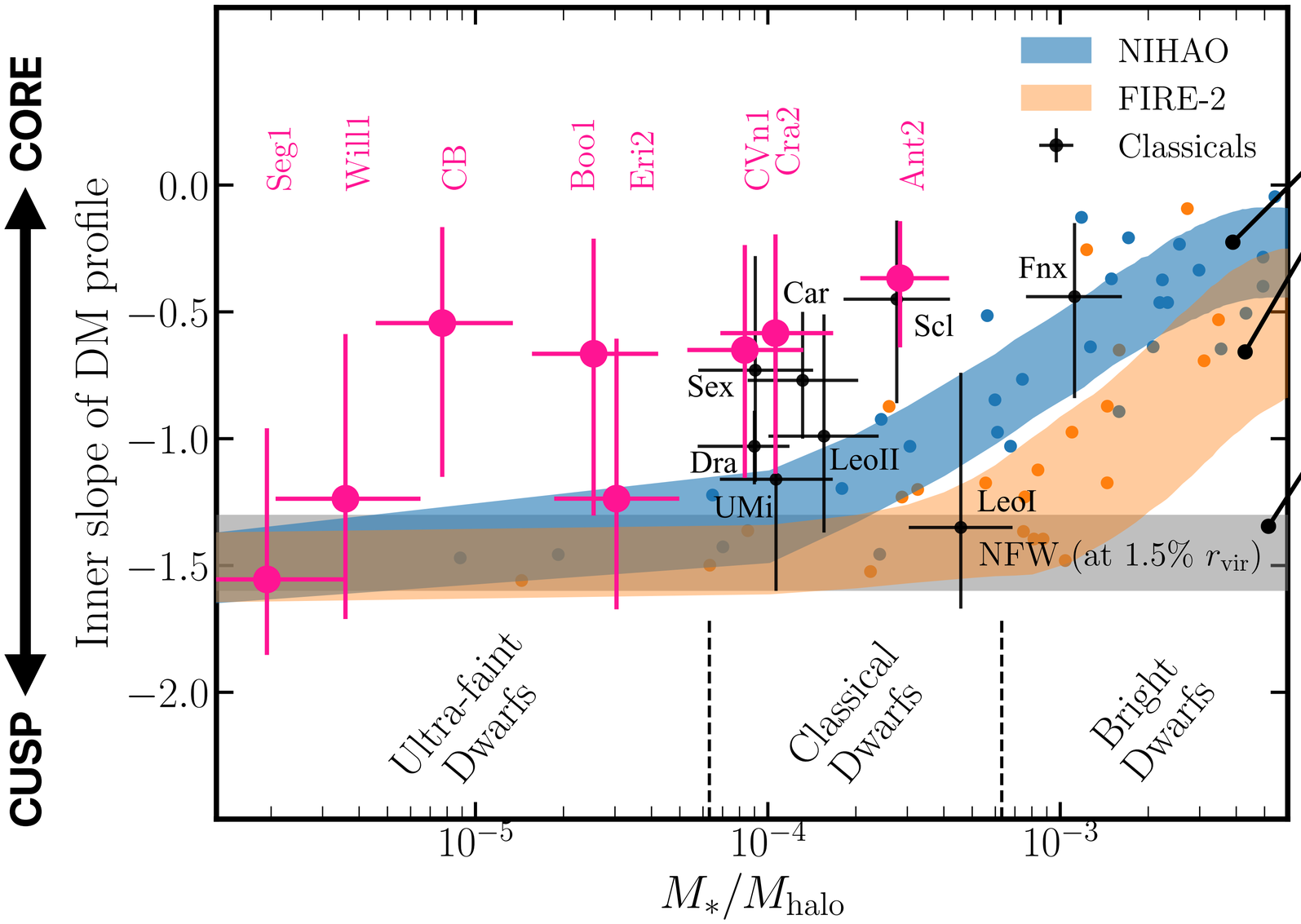
Subaru-IRCS observation can place more stringent constraints on $g_{\phi\gamma\gamma}$ of eV DM than the GC cooling.





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.

- Based on axisymmetric Jeans analysis, we found **the diversity of the DM density profiles in the dSphs**.
- There are still **large uncertainties on their inner slopes**.

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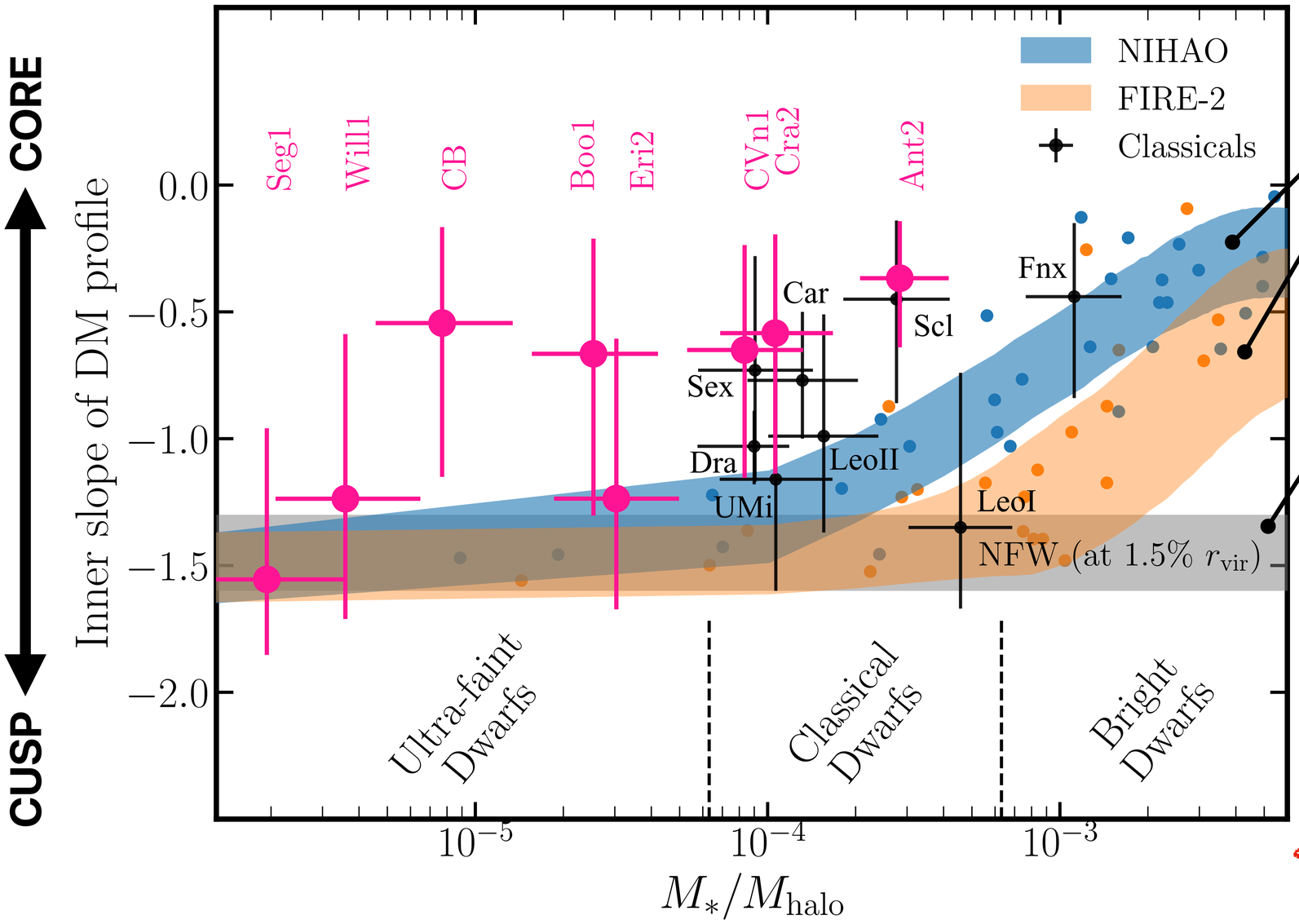

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- Based on axisymmetric Jeans analysis, we found **the diversity of the DM density profiles in the dSphs**.
- There are still **large uncertainties on their inner slopes**.

The main reasons:

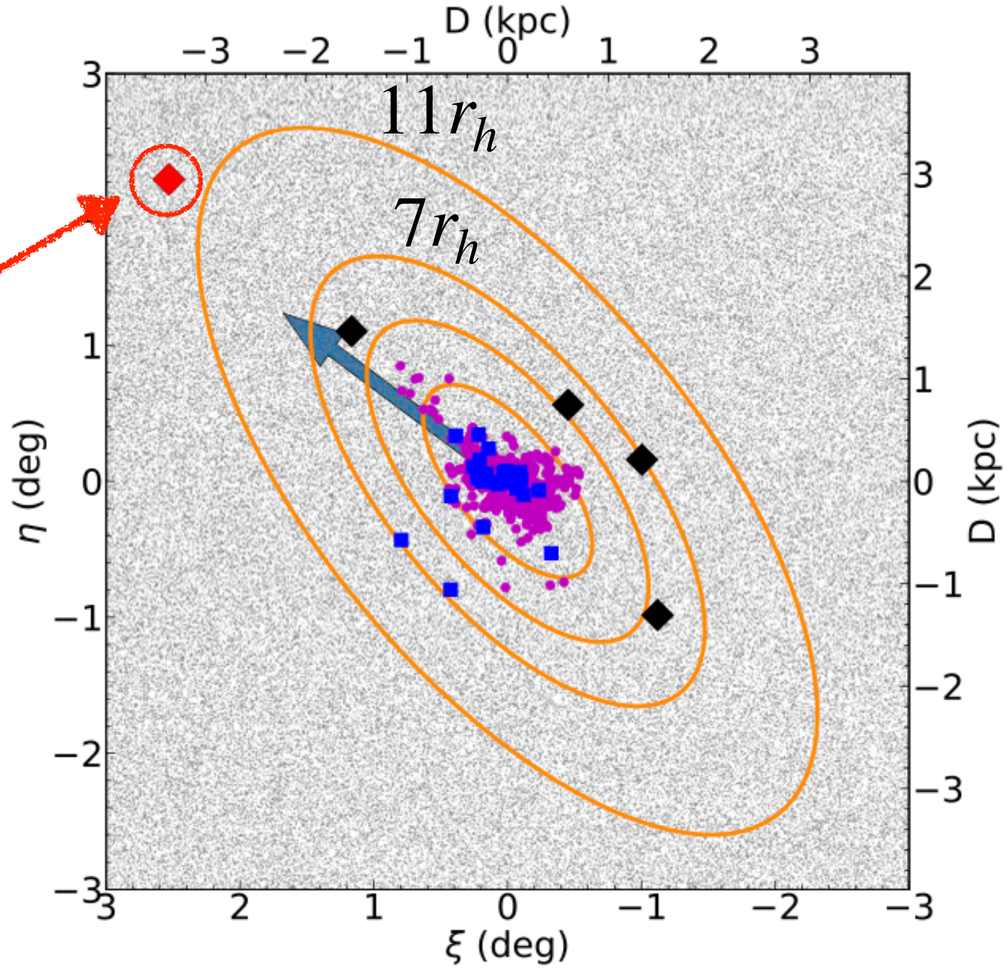
1. Insufficient number of velocity data
2. Outer regions of the dSphs have not been observed yet.

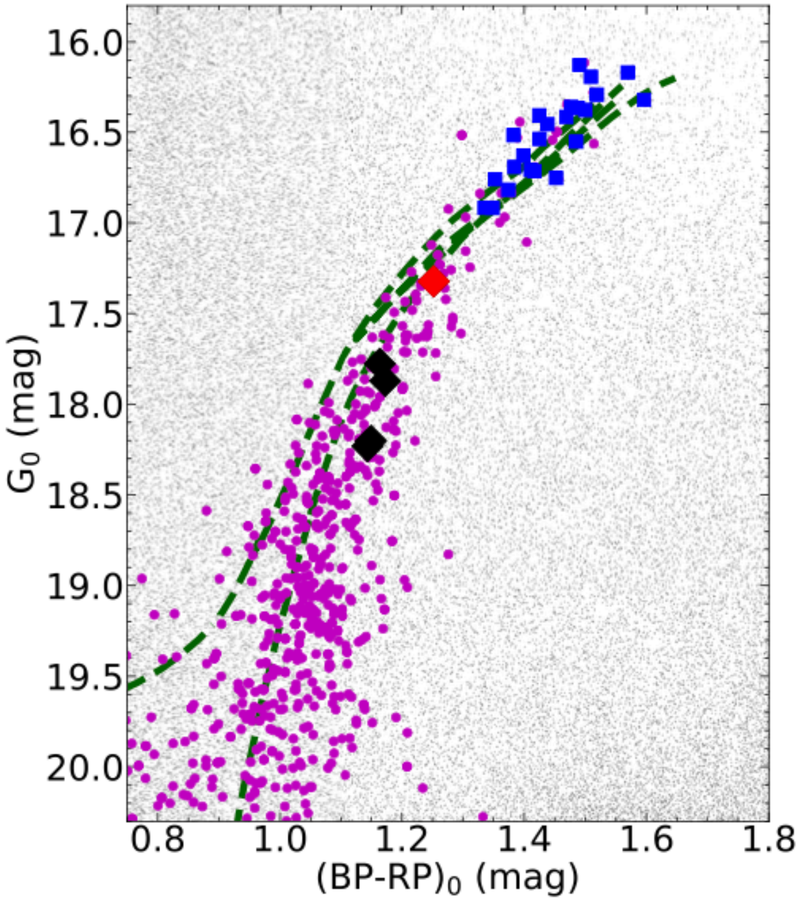
Why need new spec. data in outer region?

Ursa Minor dSph has member stars far away from its center (Sestito+2023).

Red and black diamonds are new targets.

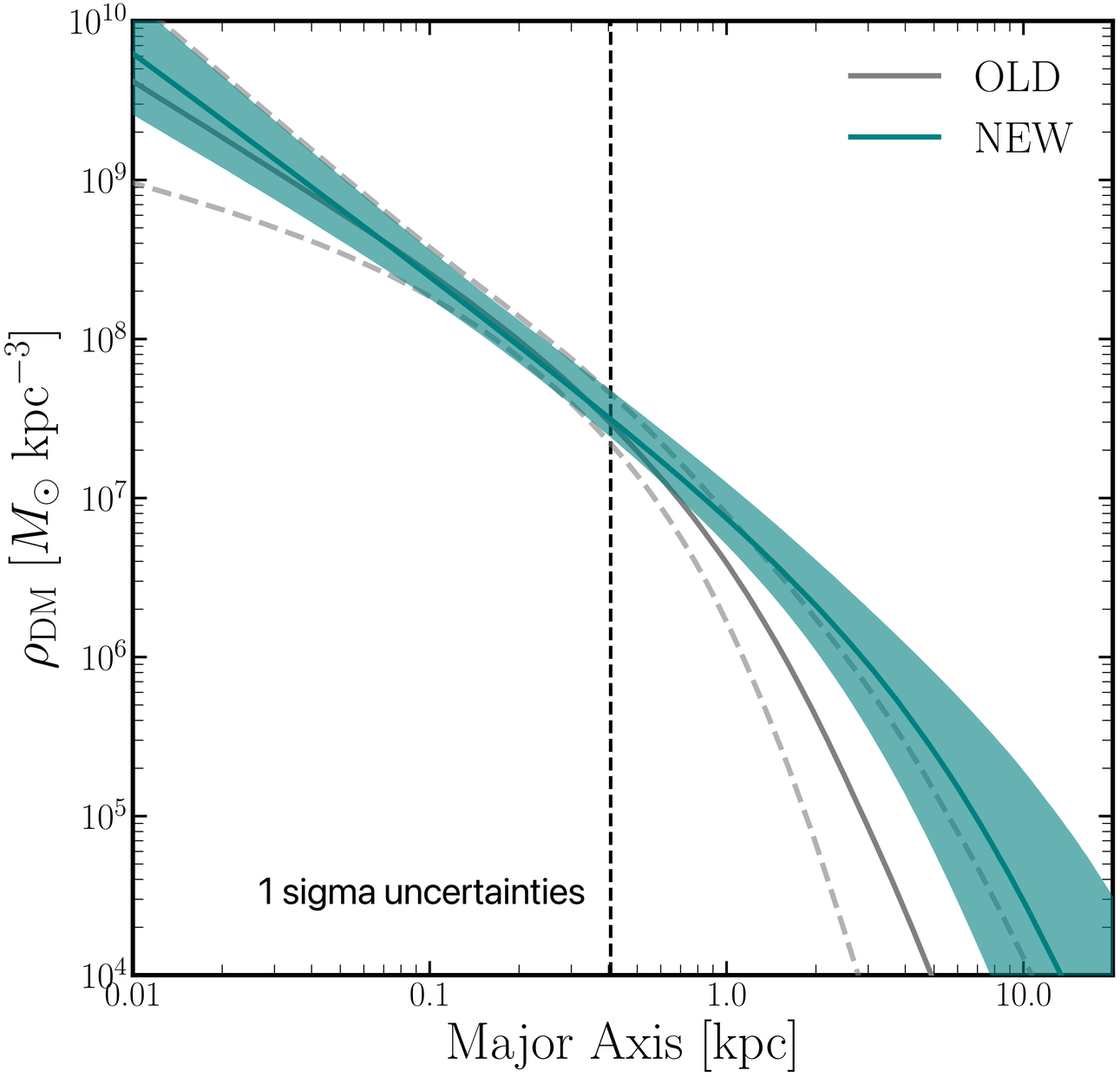
The star is located at 4kpc from the center!





Why need new spec. data in outer region?

KH et al. (in prep.)



Gray:
Without five stars
(the same as Hayashi+2020)
# of stars: 313

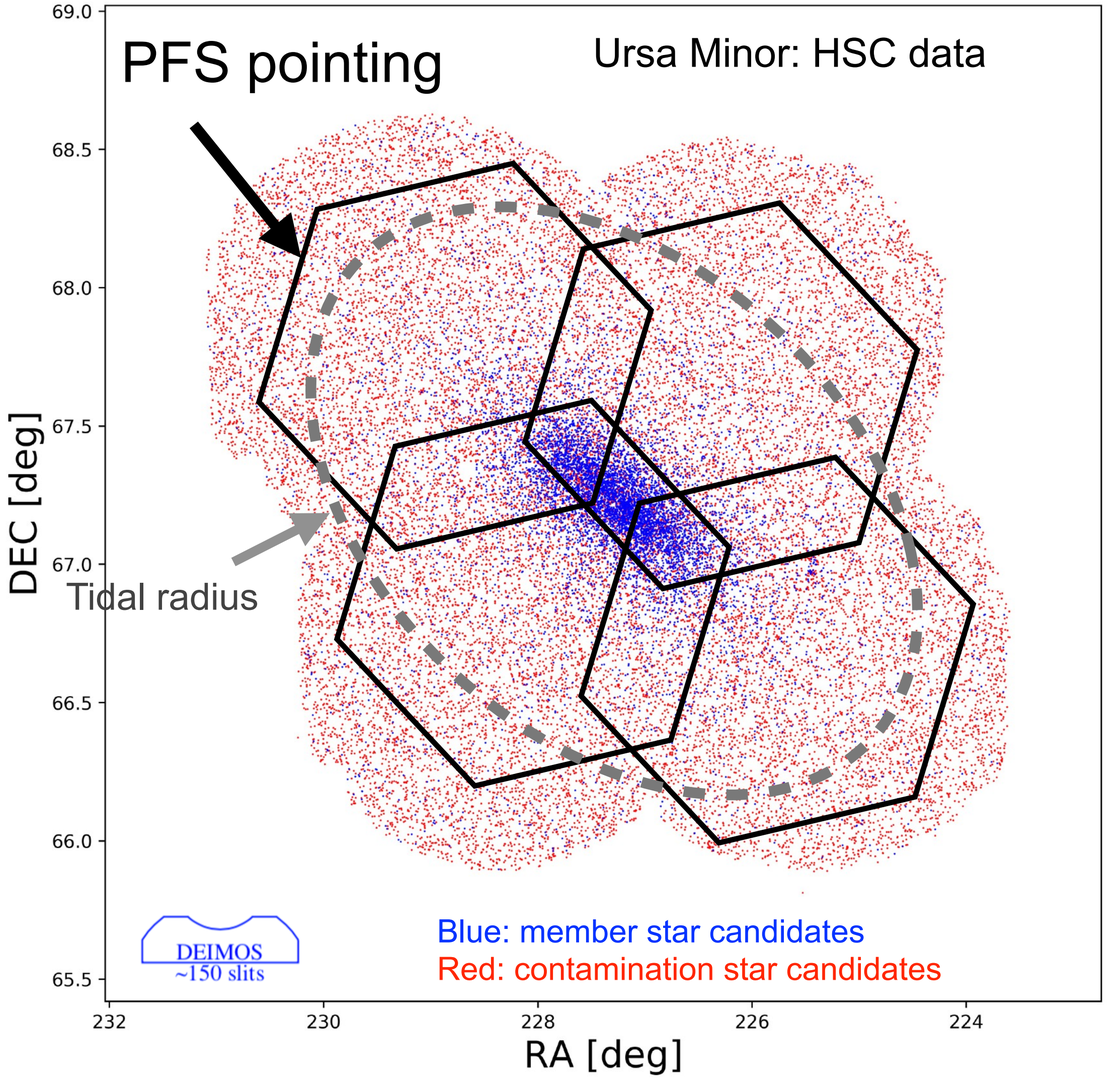
Green:
With five stars
# of stars: 313+5

The DM density profile can be improved by adding only five outermost stars.

Good motivation for PFS!

Subaru-PFS is coming soon.

KH and PFS-GA science WG



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.

- **Combining a huge data volume and dynamical analysis can place severe constraint on their DM distributions.**
- **There are many kinds of dynamical analysis models.**

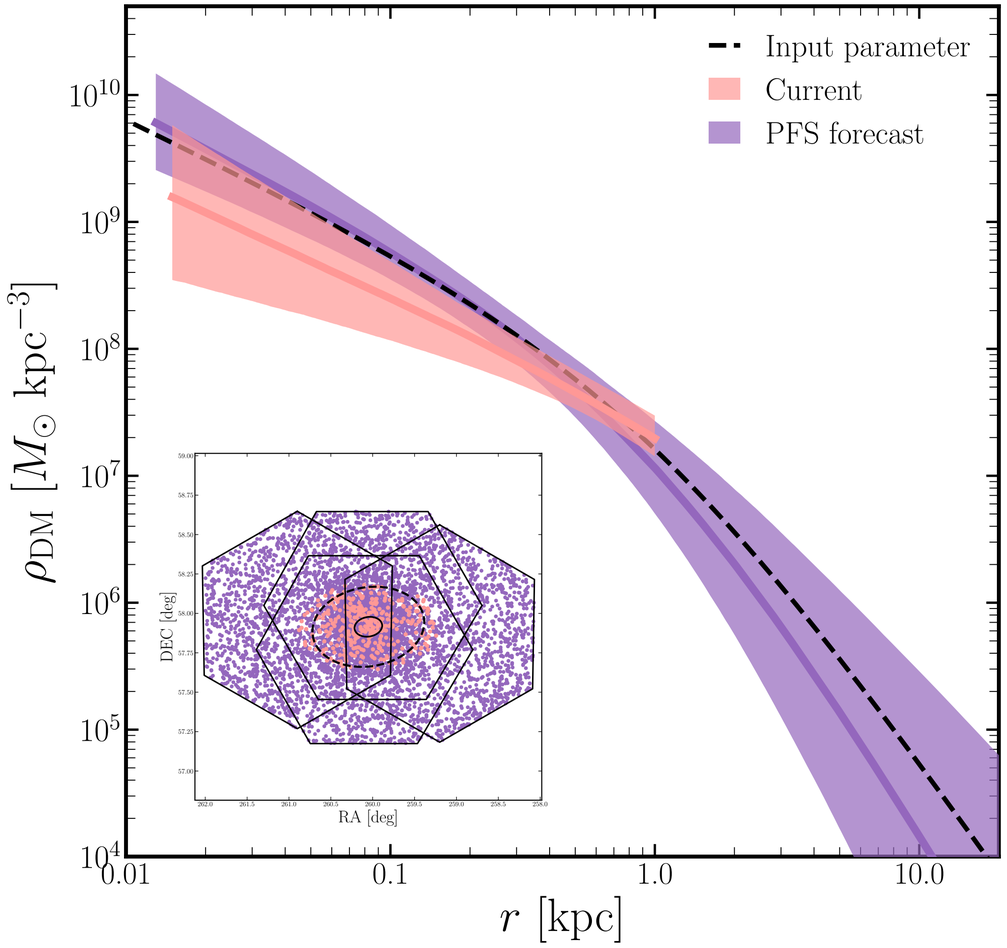
Main goals:

1. Develop more than one dynamical modelings
2. Compare quantitatively the estimated DM density profiles from developed independent methods.

Mock dynamical analysis

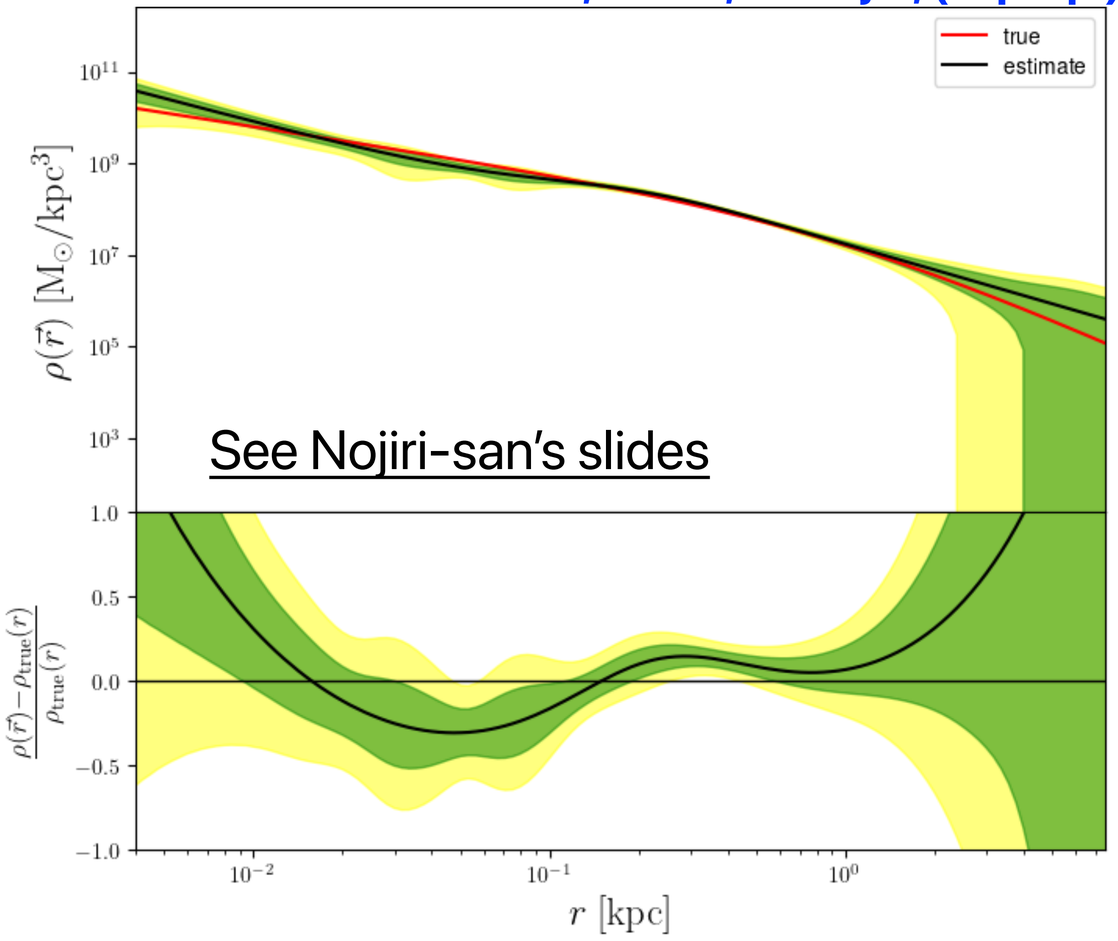
I. Axisymmetric Jeans analysis

KH and PFS-GA WG



II. Spherical Jean eq. Solver by ML

KH, S. Lim, M. Nojiri, (in prep.)



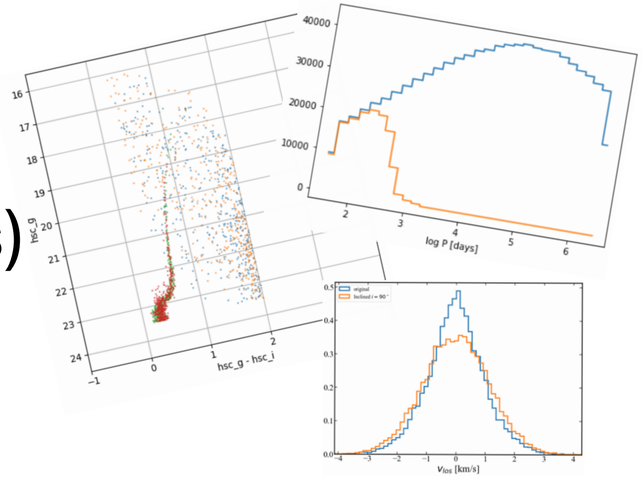
See Nojiri-san's slides

+ III. Higher-order velocity moments (D. Wardana, M. Chiba, KH, in prep.)

See Chiba-san's slides

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

Thank you very much for the support of these papers!

1. “Constraining self-interacting dark matter with dwarf spheroidal galaxies and high-resolution cosmological N -body simulations”, T. Ebisu, T. Ishiyama, **K.H.**, 2022, PRD, 105, 2
2. “Interstellar gas heating by primordial black holes”, T. Volodymyr, **incl. K.H.**, 2022, JCAP, 2022, 017
3. “The diversity of core-halo structure in the fuzzy dark matter model”, J. H.-Y. Chan, **incl. K.H.**, 2022, MNRAS, 511, 943
4. ”Dark matter halo properties of the Galactic dwarf satellites: implication for chemo-dynamical evolution of the satellites and a challenge to ΛCDM”, **K.H.**, Y. Hirai, M. Chiba, T. Ishiyama, 2022 (arXiv: 2206.02821)
5. ”Cosmological prior for the J-factor estimation of dwarf spheroidal galaxies”, S. Horigome, **K.H.**, S. Ando, 2022 (arXiv: 2207.10378) **C02 work**
6. “The Missing Satellite Problem outside of the Local Group. II. Statistical Properties of Satellites of Milky Way-like Galaxies”, M. Nashimoto, **incl. K.H.**, 2022, ApJ, 936, 38

Papers in progress:

1. “Indirect detection of eV DM with Subaru-IRCS”, **K.H.**, Y. Wen
2. “Measuring the dark matter halo of a dwarf spheroidal galaxy through normalizing flows”, **K.H.**, S. Lim, M. Nojiri
3. “Constraints on dark matter distribution in dwarf spheroidal galaxies based on higher-order Jeans analysis”, D. Wardana, M. Chiba, **K.H.**,