The Extended Stellar Distribution in the Outskirts of the Ursa Minor Dwarf Spheroidal Galaxy

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Introduction

How did galaxies form and evolve in the early Universe?

Formed by other smaller systems like dwarf galaxies

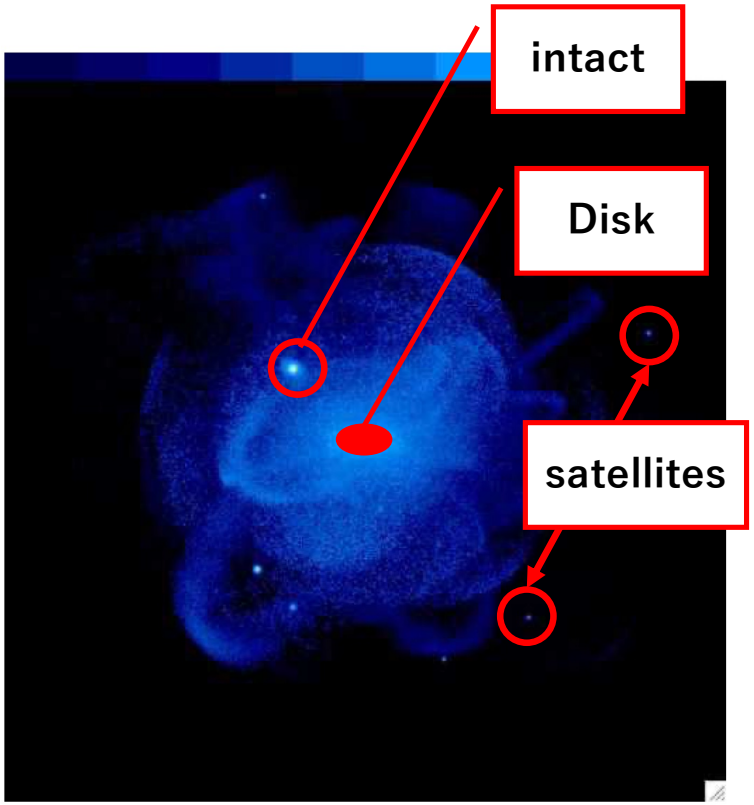
Hierarchical clustering

Smallest building blocks in ΛCDM theory

Investigation of Galactic dwarf galaxy

How to form and evolve dwarf galaxies?

We want to know the formation mechanism of the first galaxy



Milky Way (MW) like galaxy in cosmological simulation (Bullock & Johnston 2005)

Introduction

Survivor candidates of First Galaxies

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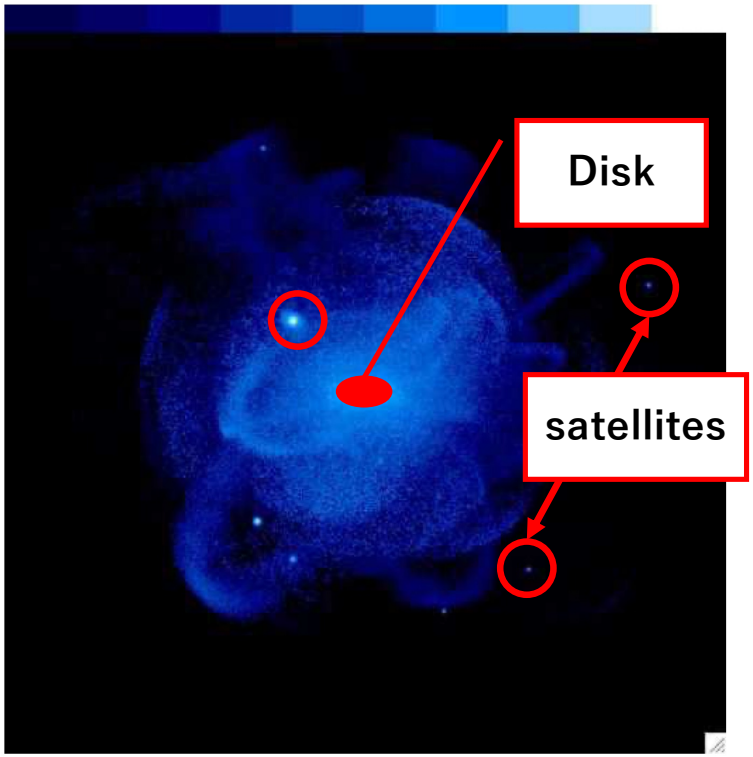
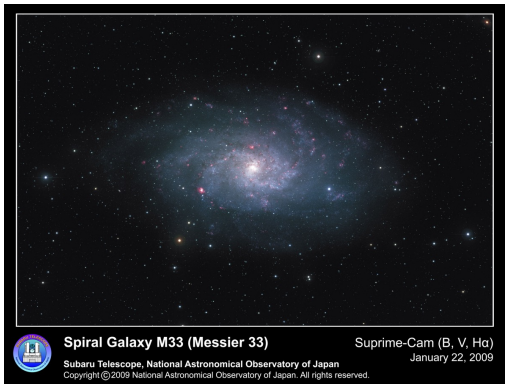


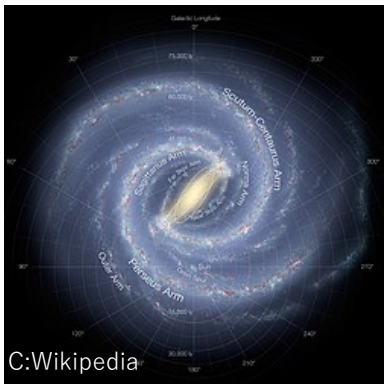
Milky Way (MW) like galaxy in cosmological simulation (Bullock & Johnston 2005)

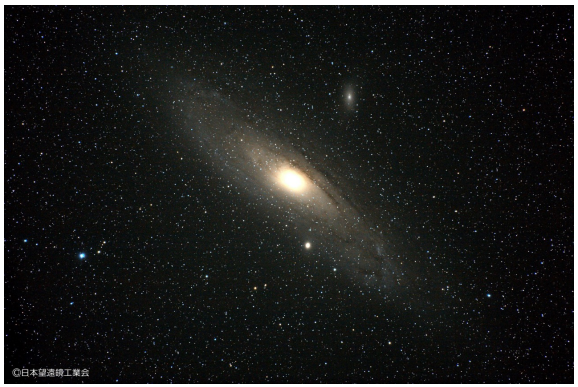
Introduction
Stellar halo

Stellar halo only detected only in large galaxies(e.g. M31, Milky Way)

Does low mass ($\leq 10^8$) dwarf galaxies have stellar Halo ??







Dwarf galaxies

$M_* = 10^3 \sim 10^8\ M_\odot$

$M_{*,halo} = ?$

M33

$M_* = 3.2\times10^9\ M_\odot$

$M_{*,halo} = ?$, shallow slope

Milky Way

$M_* = 6.1 \pm 1.1\times10^{10}\ M_\odot$

$M_{*,halo} = 4 - 7\times10^8\ M_\odot$

M31

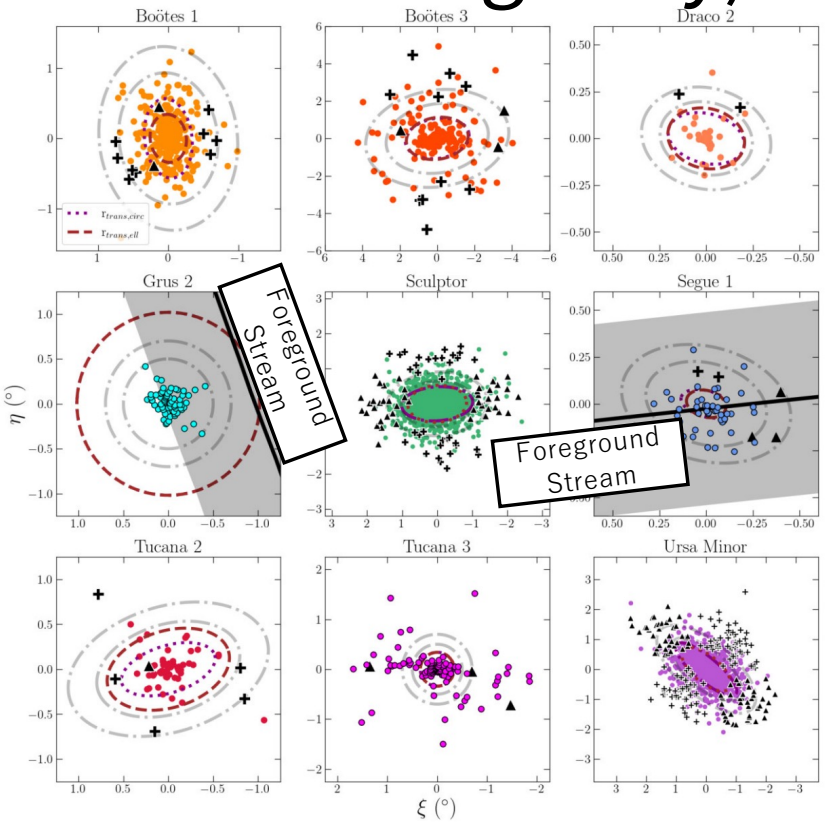
$M_* = 10.3 \pm 2.3\times10^{10}\ M_\odot$

$M_{*,halo} = 1.1\times10^{10}\ M_\odot$

Small scale ← Large scale

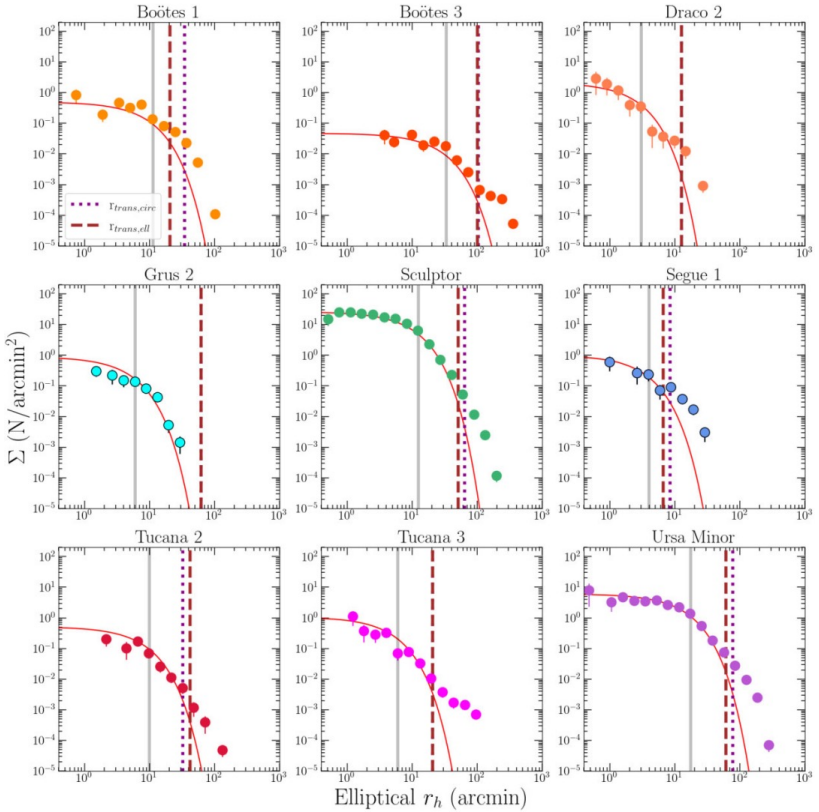
How does the Hierarchical formation scenario in a low mass scale?

Introduction
(case of dwarf galaxy)



Spatial distribution of 9 dwarf galaxies
with member stars (probability P>10%). (Jensen+2024)

↓ Red line: one component exponential

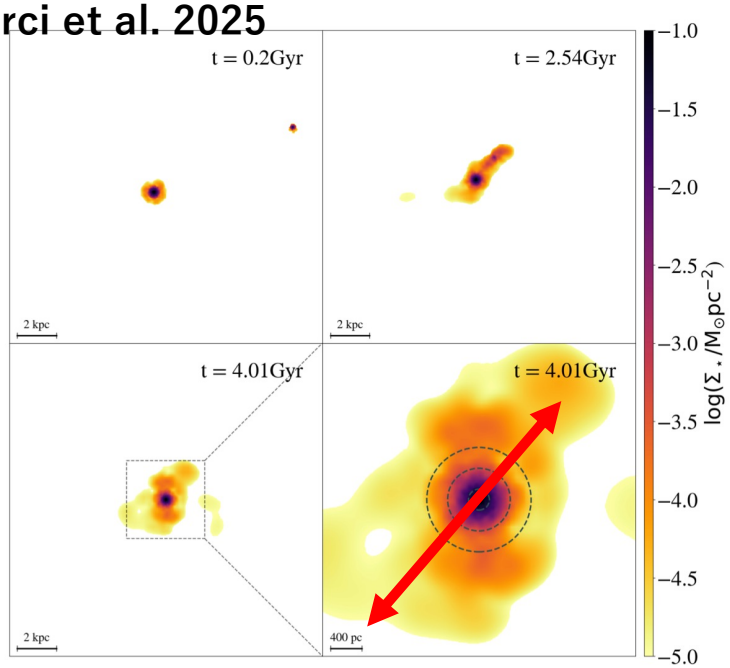


Radial profiles of 9 dwarf galaxies,
which has an extended structure. (Jensen+2024)

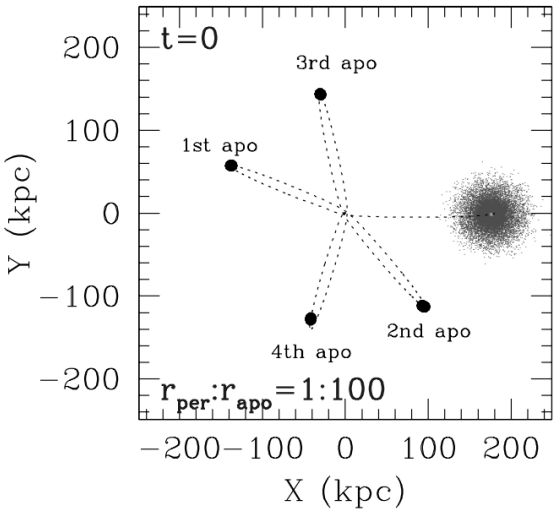
Extended structures in 9 dwarf galaxies were found among 60 targets using Gaia DR3 data.

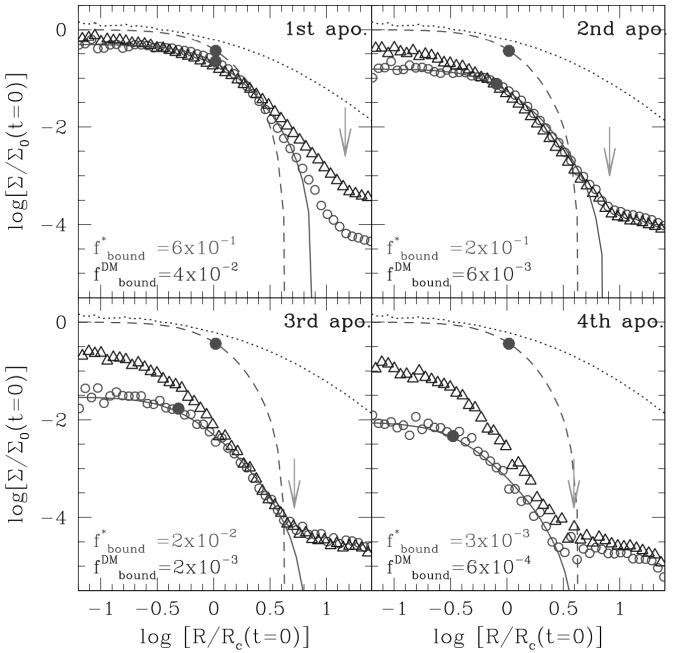
Introduction
Origin of the Extended Structure of dwarf galaxies

Querci et al. 2025



Spatial density distribution
of merging dwarf galaxy.



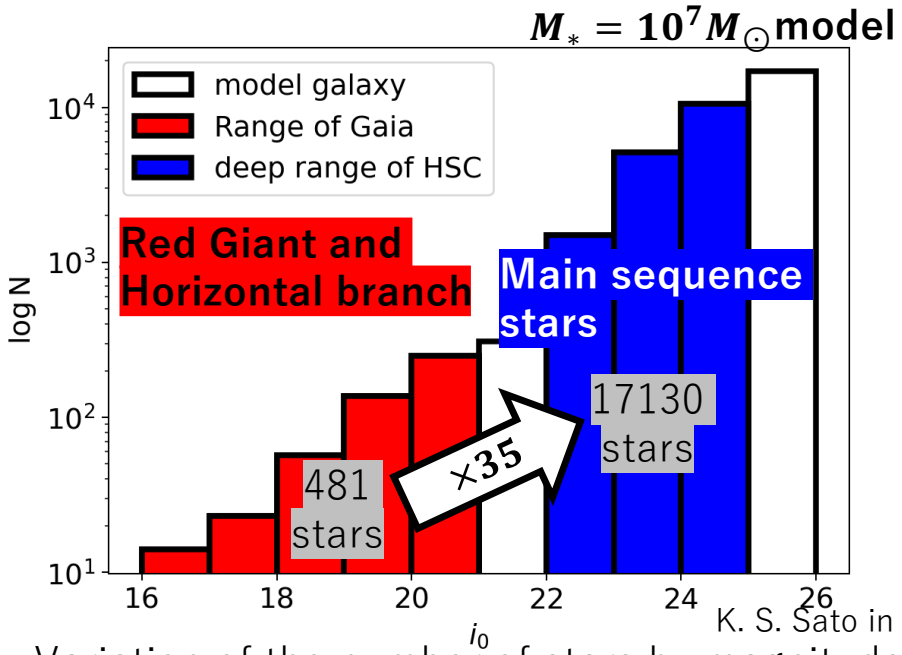


Orbit of the satellite and the radial profile (Peñarrubia+2008).

Merger and/or Tidal interaction?

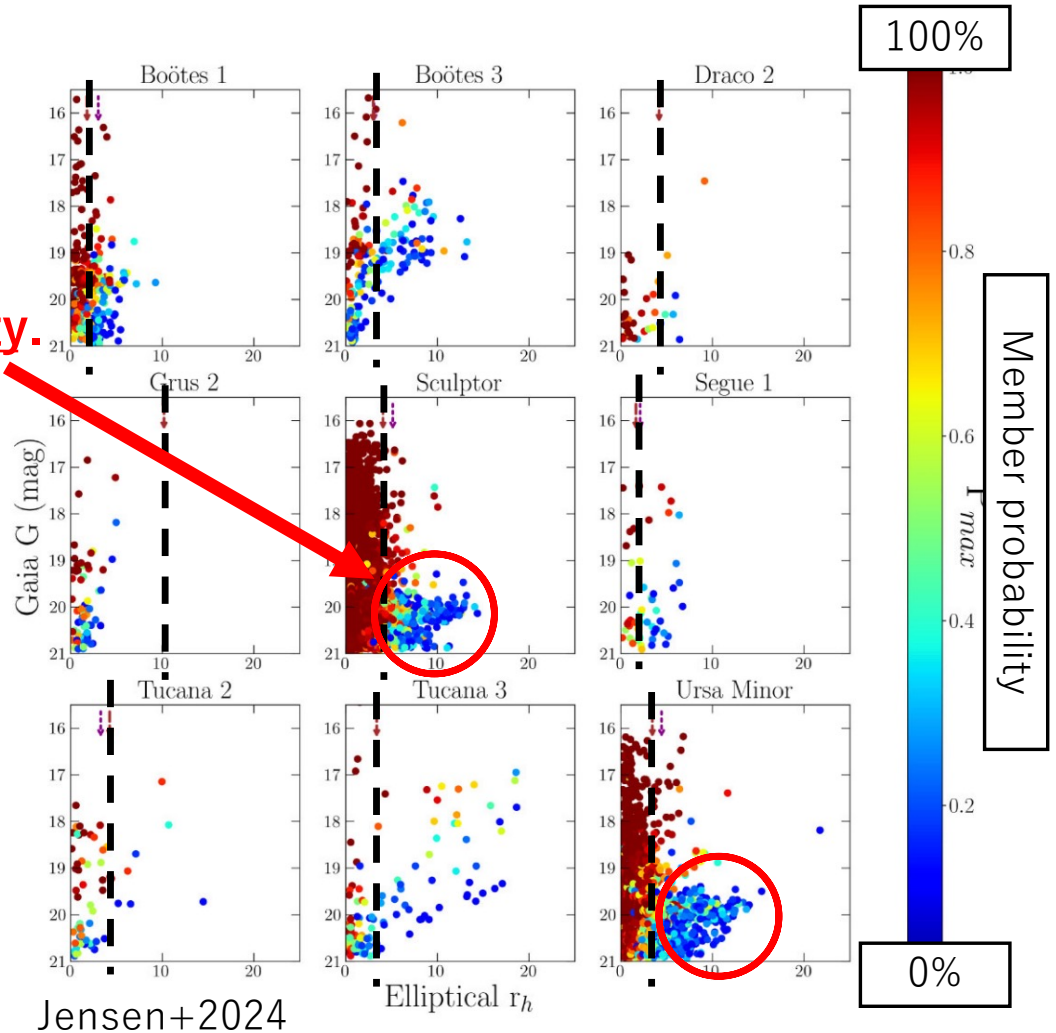
Introduction (case of dwarf galaxy)

- Gaia DR3 data are shallow.
- The **faint and outer stars** **have** **low probability**.
- Jensen+2024 only uses a small number of Red Giants and Horizontal Branch stars.



K. S. Sato in prep

Variation of the number of stars by magnitude

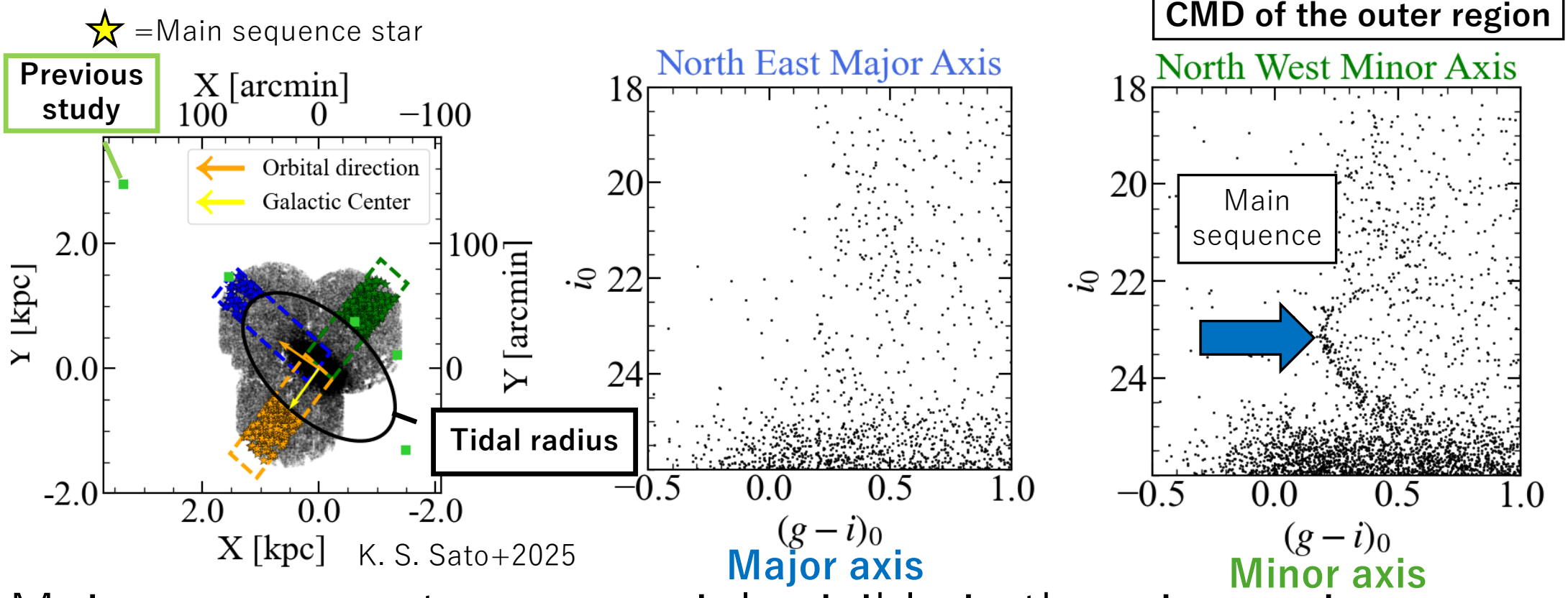


Jensen+2024

Member probability distribution in the magnitude vs distance from the center.

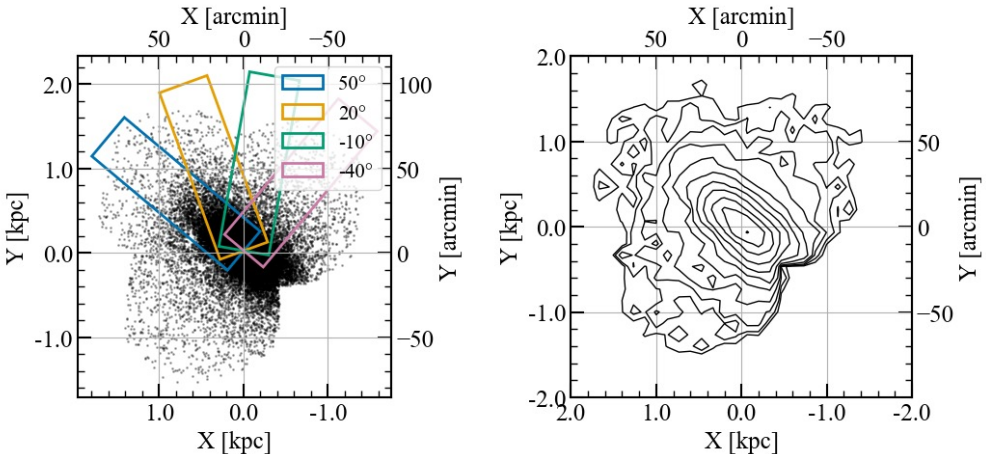
Main sequence stars are powerful.

Result: Main sequence stars in the outskirts



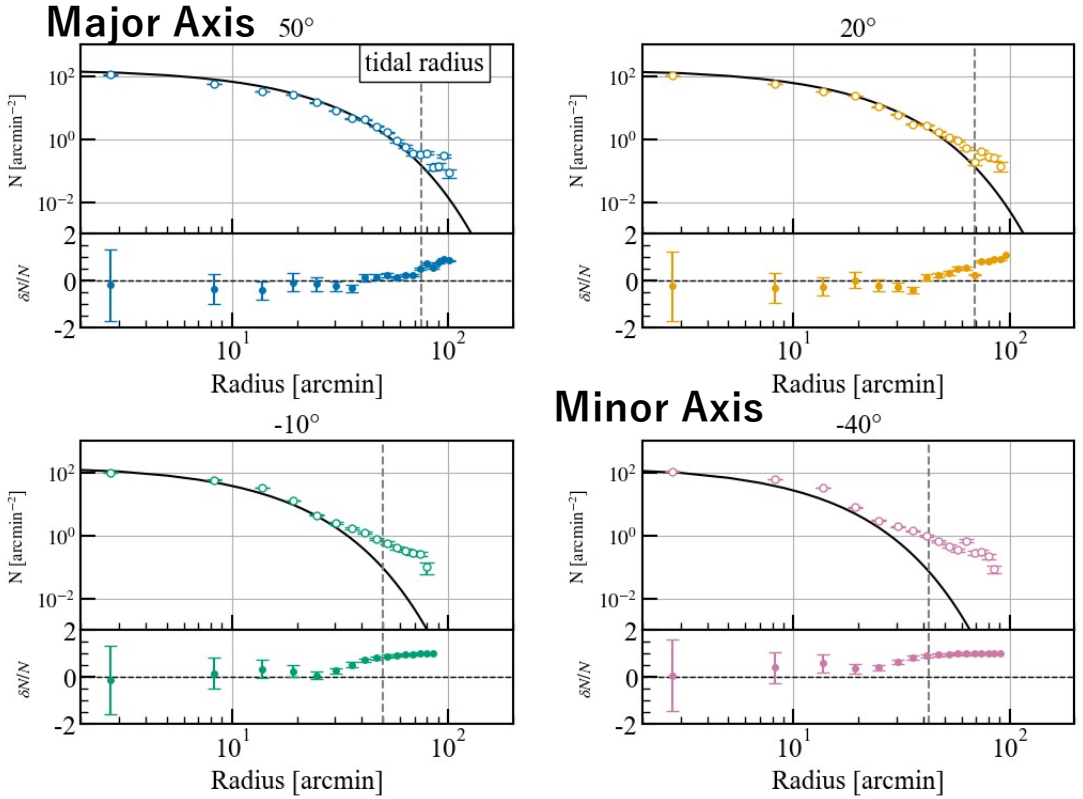
Main sequence stars are mainly visible in the minor axis even considering the difference in area.

Azimuthal variation



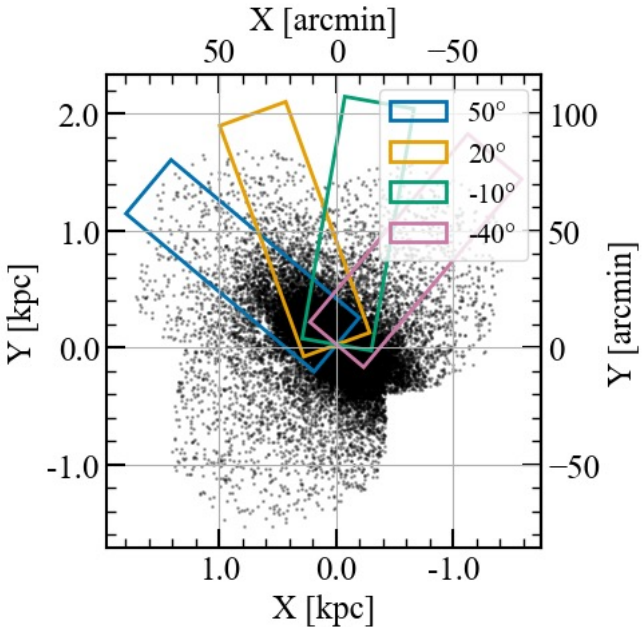
- We compare the profiles for azimuthal variation.
- Extended structures exist in all directions.
- This result suggests that it could potentially spread in any direction.

K. S. Sato+2025

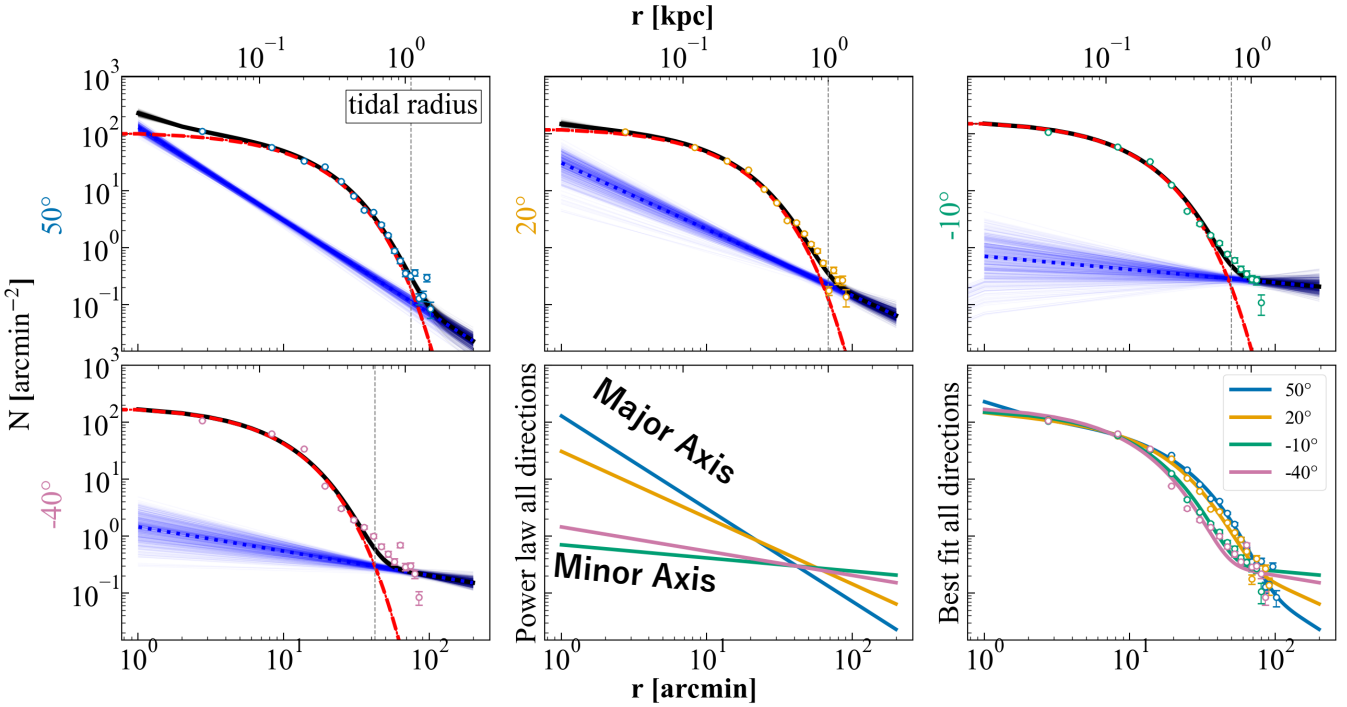


Radial profiles in azimuthal variation

Profile anisotropy



Spatial distribution
and selected regions.

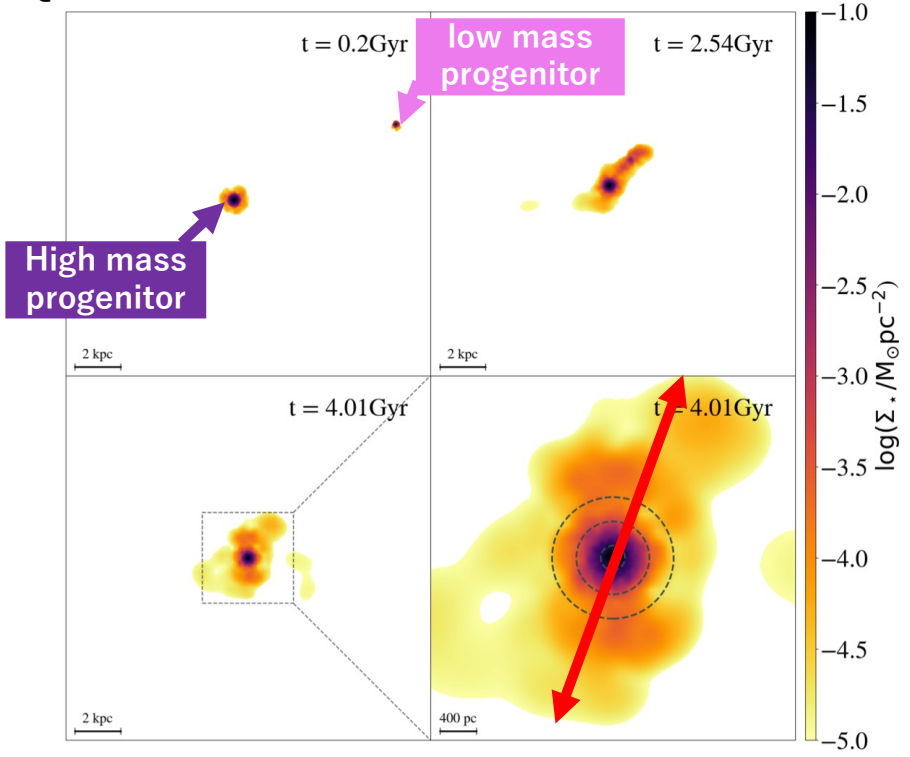


Radial number density distribution for directions (K. S. Sato+2025).

The minor axis tends to have a shallower slope than the major axis.

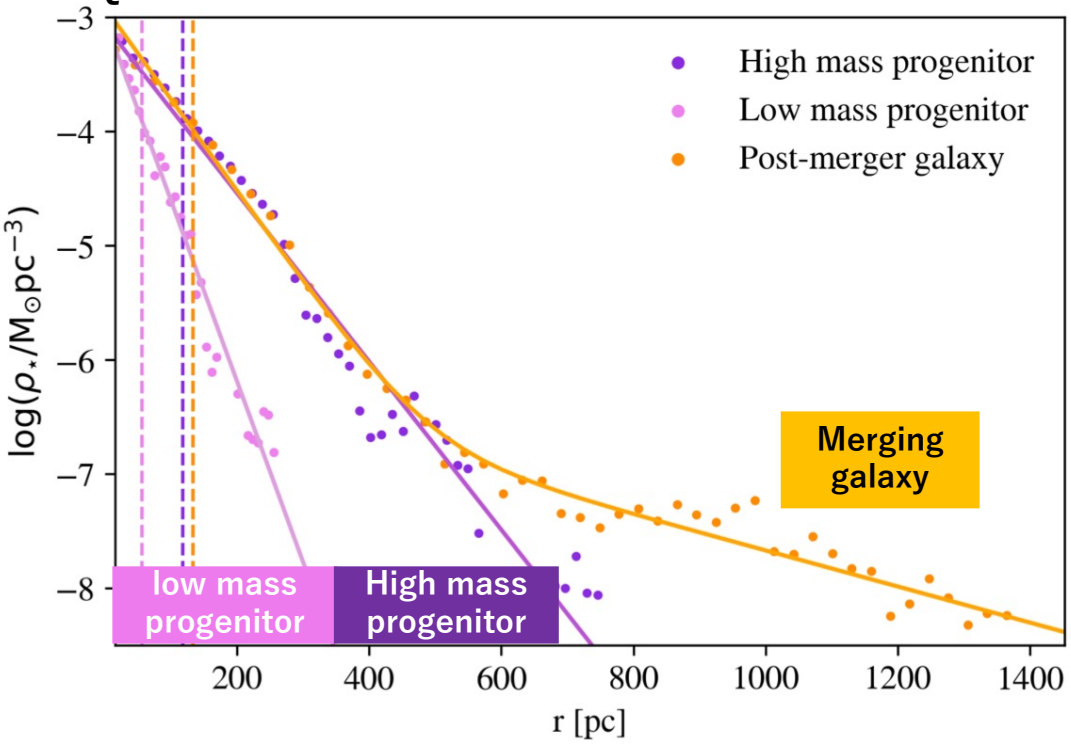
Discussion
Dwarf-dwarf merger makes stellar halo

Querci et al. 2025



Spatial density distribution

Querci et al. 2025



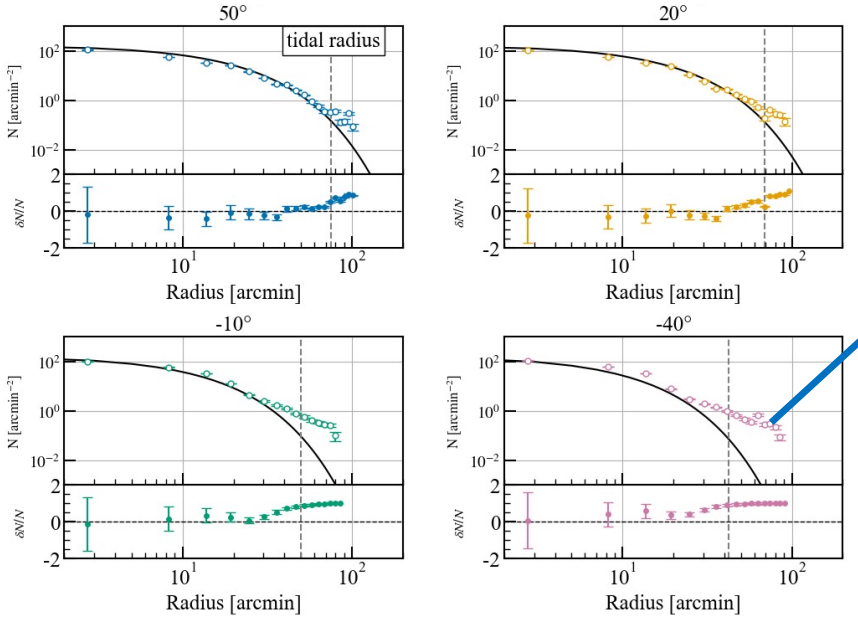
Radial profile

Merging events form the asymmetric stellar distribution.

Future plan

Now on analysis!!

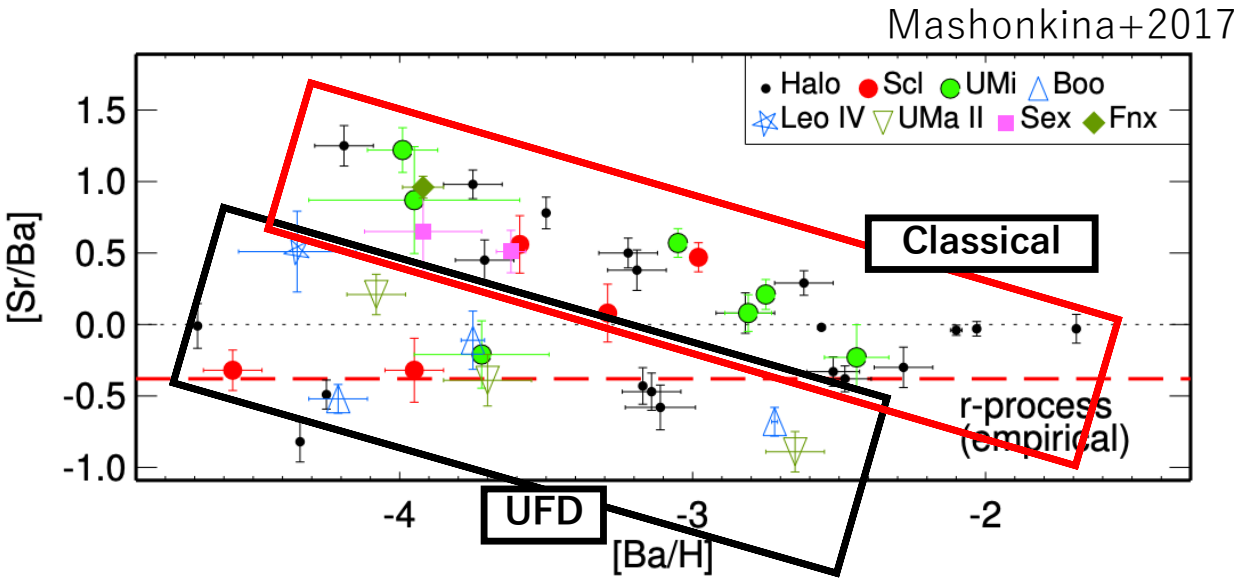
- Subaru/PFS-SSP (Prime Focus Spectrograph) observed the same region that is used in this study.
- PFS gives us the line-of-sight velocity and chemical information.



- **Kinematic information.**
- **More metal-poor stars and different chemical information?**
- Can we find the tracer of the merger remnant ?

Future Plan

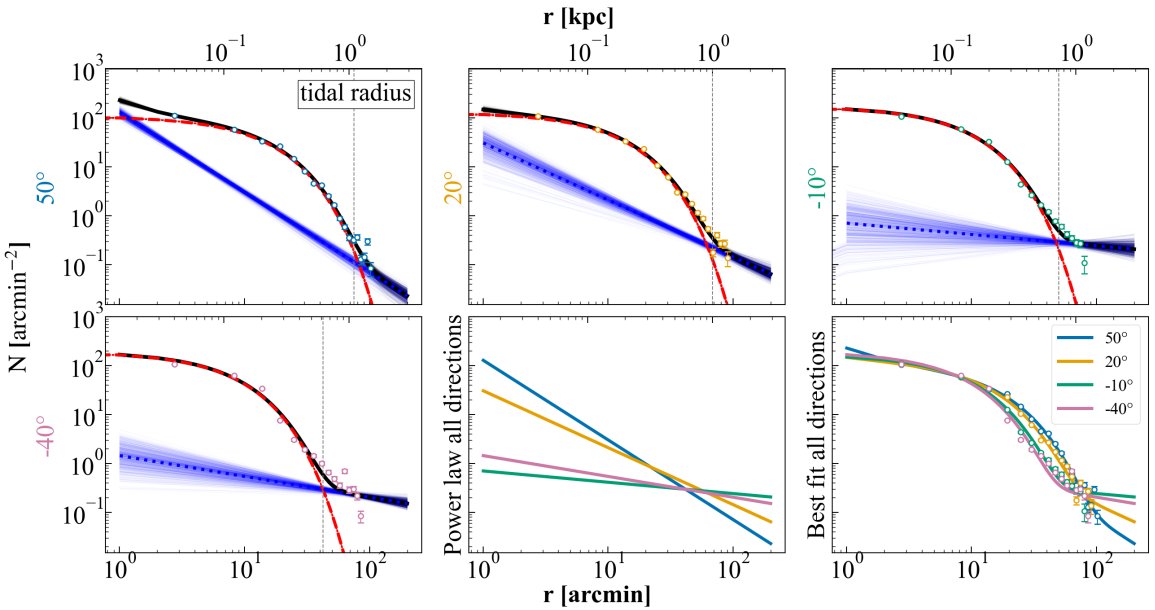
PFS-HR??



- The chemical footprint of classical dSph and UFDs is different in [Sr/Ba] vs [Ba/H], since Ba is mainly produced by the r-process.
- If we can get the information of these elements in the outskirts, we may constrain whether the merging companion of UMi is a UFD or not.

Summary

- The extended structure of dwarf galaxies is important to understand whether their origin is intrinsic or environmental.



- We find the different slopes of main-sequence stars of the Ursa Minor dwarf galaxy along the minor axes using deep Subaru/HSC data.
- Wide-field spectroscopic follow-up has an important role in revealing the origin of extended “Halo-like” structures.