

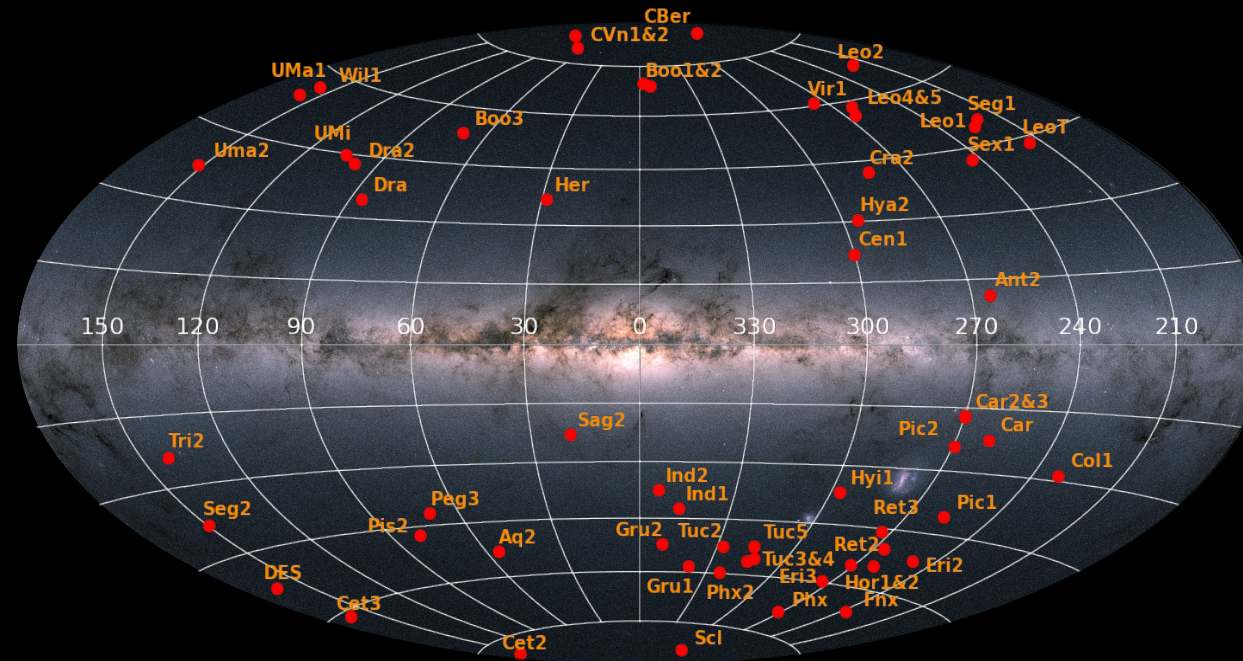
Small-scale stellar haloes: detecting extended substructure in the outskirts of Milky Way dwarf galaxy satellites

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Galaxy Stellar Haloes

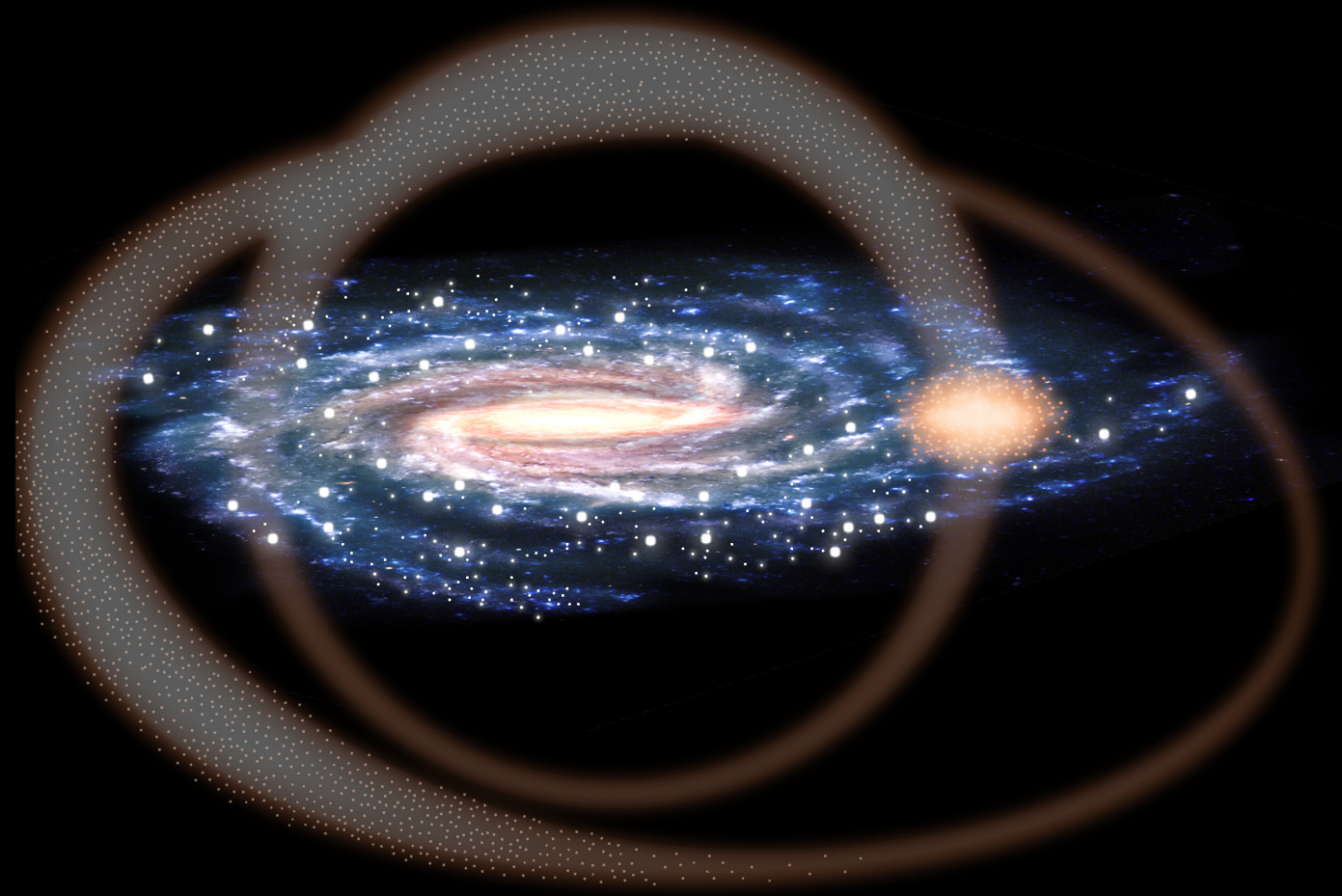
- As galaxies are accreted into systems like the Milky Way, evidence of their disruption is scattered throughout the stellar halo.



Milky Way dwarf galaxy satellites;
ESA/Gaia stellar density map

Outskirt Stars of Dwarf Galaxies

- Competing hypotheses for stars at large radial distances to their dwarf satellite:
 1. **Tidal interactions imparted by the host**
 - Stripped stars of a satellite may be moved to large radius.



Outskirt Stars of Dwarf Galaxies

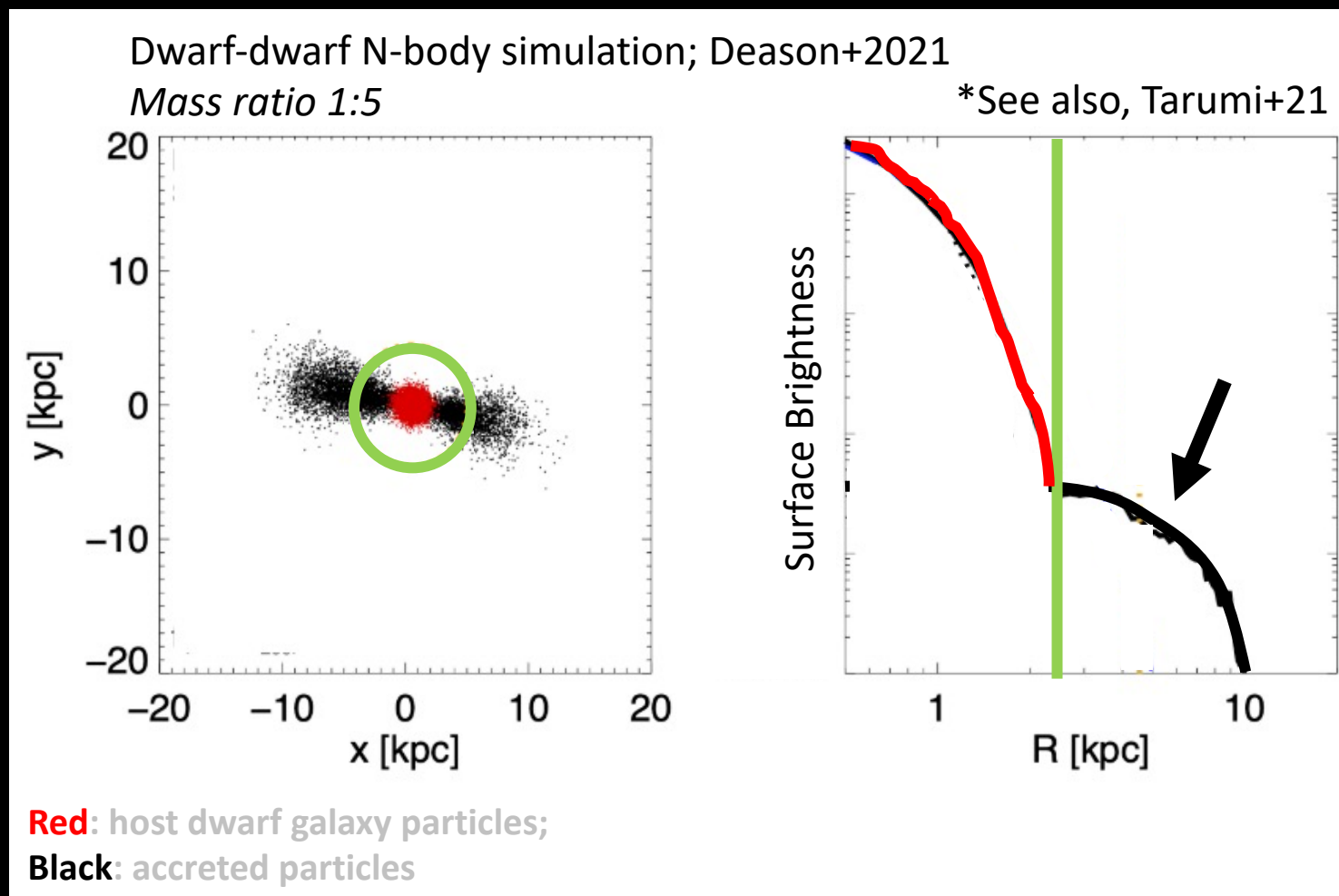
- Competing hypotheses for stars at large radial distances to their dwarf satellite:

1. **Tidal interactions imparted by the host**

- Stripped stars of a satellite may be moved to large radius.

2. **Dwarf-dwarf mergers**

- Member stars in the outskirts may likely be from past accretions!



Utility of Gaia & Resolved Stars

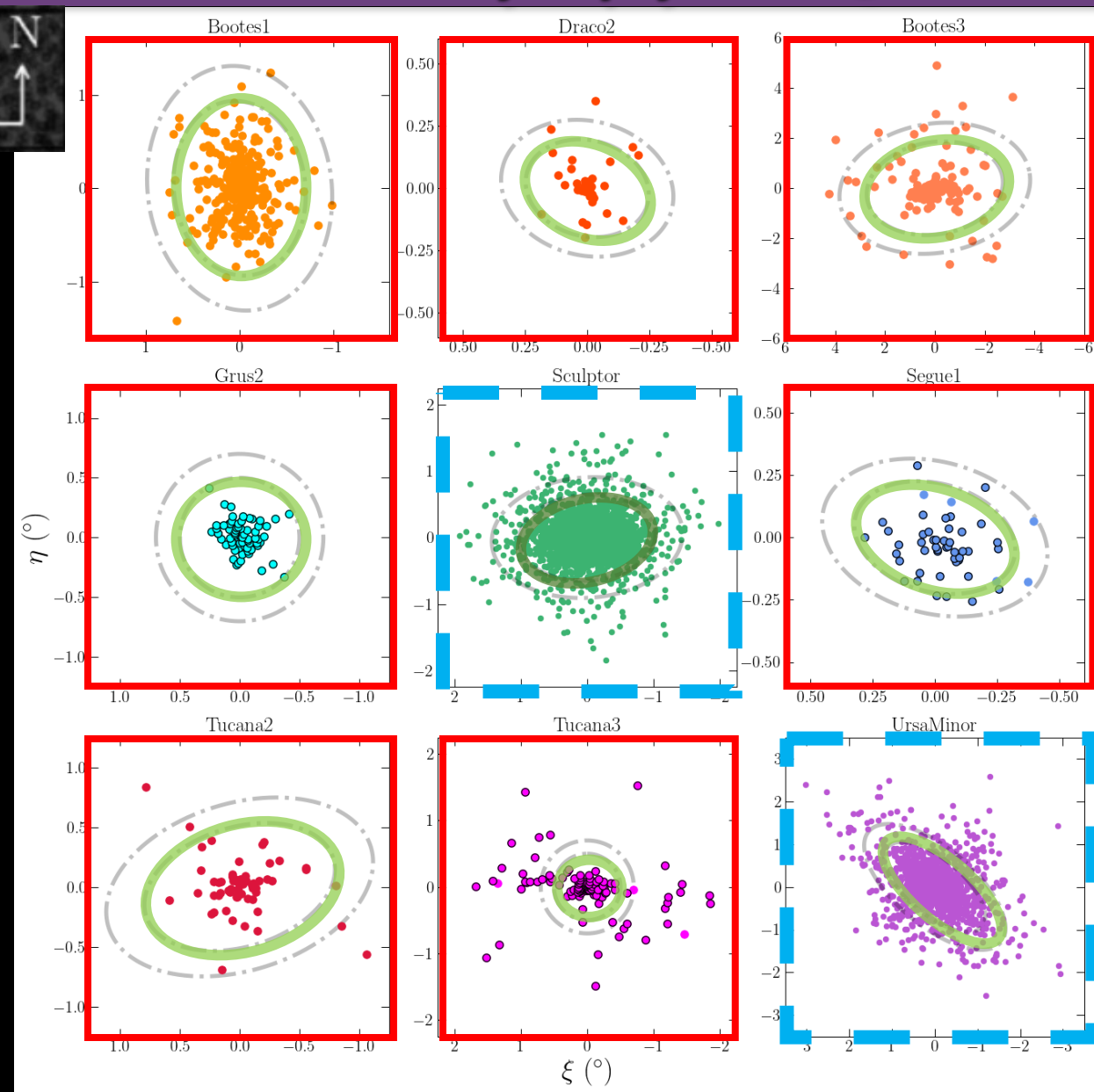
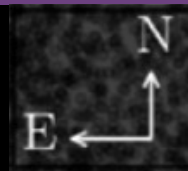
- *Our goal: to identify individual member stars in dwarfs, particularly those most radially distant.*
- The Milky Way's (MW's) satellites are the best laboratory to explore the stellar haloes of dwarf galaxies, and Gaia is the best dataset to probe resolved stars in these systems!
- We developed an algorithm for determining:
 - a) The probability that a star in a given field is a member of its nearby satellite, and
 - b) **Which dwarf galaxies exhibit signatures of extended stellar profiles**

Results!

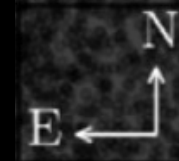
Systems identified in our work, whose density profiles suggest an extended outer component:

- 2 Classical systems
 - Sculptor, Ursa Minor
- 7 Ultra-Faint Dwarfs
 - Boötes 1, Boötes 3, Draco 2, *Grus 2*, Segue 1, Tucana 2, Tucana 3

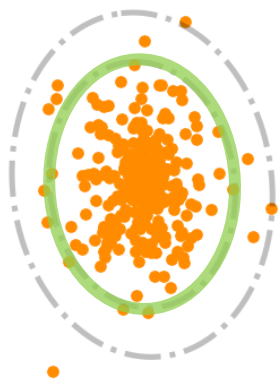
--Green ellipse highlights $5r_h$



Systems with Known/Suspected Tidal Tails



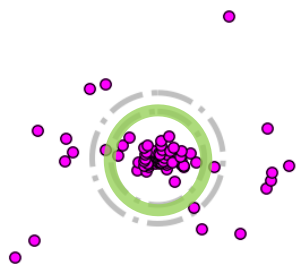
Boötes 1



Boötes 1 (Longeard+22)

- Stars observed up to $4r_h$; we find members up to $\sim 9r_h$!
- See Fletcher Waller's poster! GRACES follow-up of some outskirt members.

Tucana 3



Boötes 3 (Carlin & Sand 18)

- No spectroscopically confirmed members of stream (yet!)

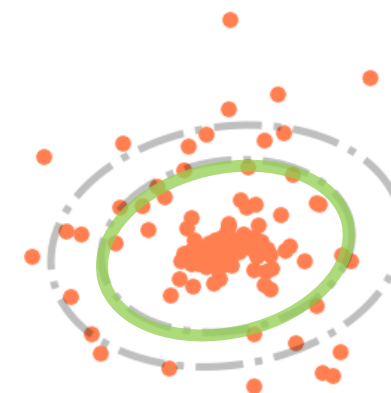
Tucana 3 (Drlica-Wagner+15)

- Tails ~ 4 deg on sky, confirmed spectroscopic members

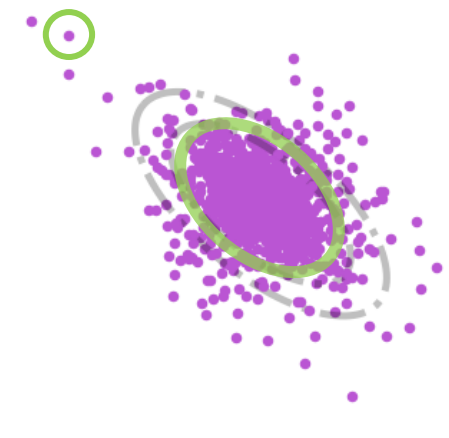
Ursa Minor (Palma+03)

- S-shape isophote contours
- GRACES follow-up (Sestito+23, submitted)

Boötes 3



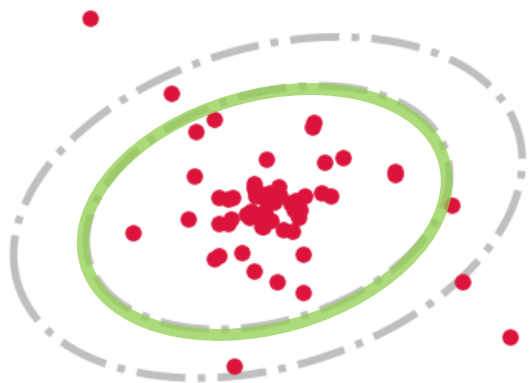
Ursa Minor



--Green ellipse highlights $5r_h$

Systems with Suspected Extended Haloes

Tucana 2



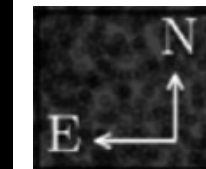
--Green ellipse highlights $5r_h$

Tucana 2 (Chiti+21)

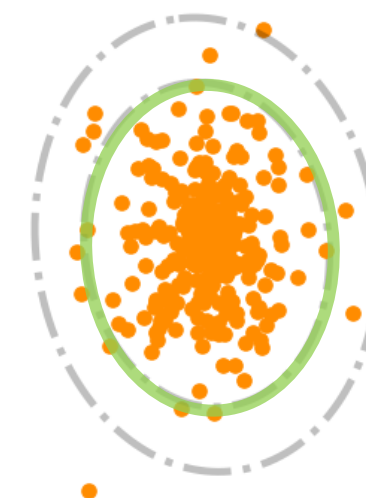
- Dwarf-dwarf merger suggested from stars up to $9r_h$
- We find additional stars at opposite side of the halo at roughly same radii

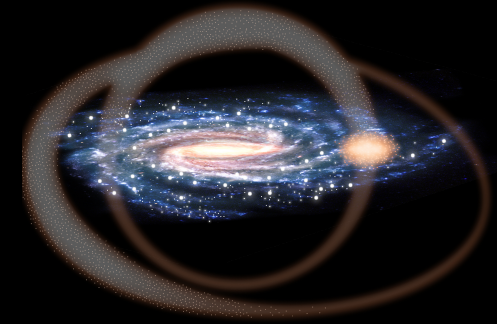
Boötes I (Longeard+22)

- Metallicity gradient only comparable to Tuc2 (an argument as to a dwarf-dwarf merger scenario in Chiti+21)

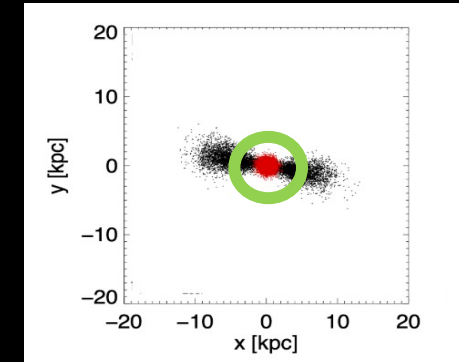


Boötes 1





Ruling out a Tidal Scenario



Evidence *for* tides:

- Morphology
- Velocity gradient
- Close (< 30 kpc) pericenter in orbit
 - Low density ratio ($\rho(<r_h) / \rho_{MW, peri}$; Pace+22)
- Member stars located beyond a break radius (Peñarrubia+09)
- Chemically similar

Evidence *contrary* to tides:

- Extended features perpendicular to orbit
- No velocity gradient
- Possible (steep) metallicity gradient
- Large break radius (beyond main body of system)
- A separate $[\alpha/Fe]$ chemical sequence in outskirts

Future Work with GHOST: the Gemini High-resolution Optical SpecTrograph

- Spectroscopic follow-up for extended candidates – radial velocities & abundances will allow us to constrain a star's membership & origin
- GHOST specs:
 - 75,000 resolution in single object mode
 - Radial velocity precision of 10 m/s
 - Coverage from ~360 – 950 nm



Summary

- We have developed an algorithm to identify member stars in each MW dwarf satellite (observed in Gaia eDR3), and additionally probe each system for extended stellar profiles.
- *We identified 9 dwarf satellites which we argue show evidence of an extended stellar halo/indications of tidal features. *Future spectroscopic campaigns* (e.g., GHOST) joined with *dynamical models/R_{break} radii* will be necessary to confirm the origins of these distant outskirts stars (late minor merger/tidal).*