Chemically Tagging Remnants of Accreted Low-Mass Dwarf Galaxies Using r-process Enhanced Stars

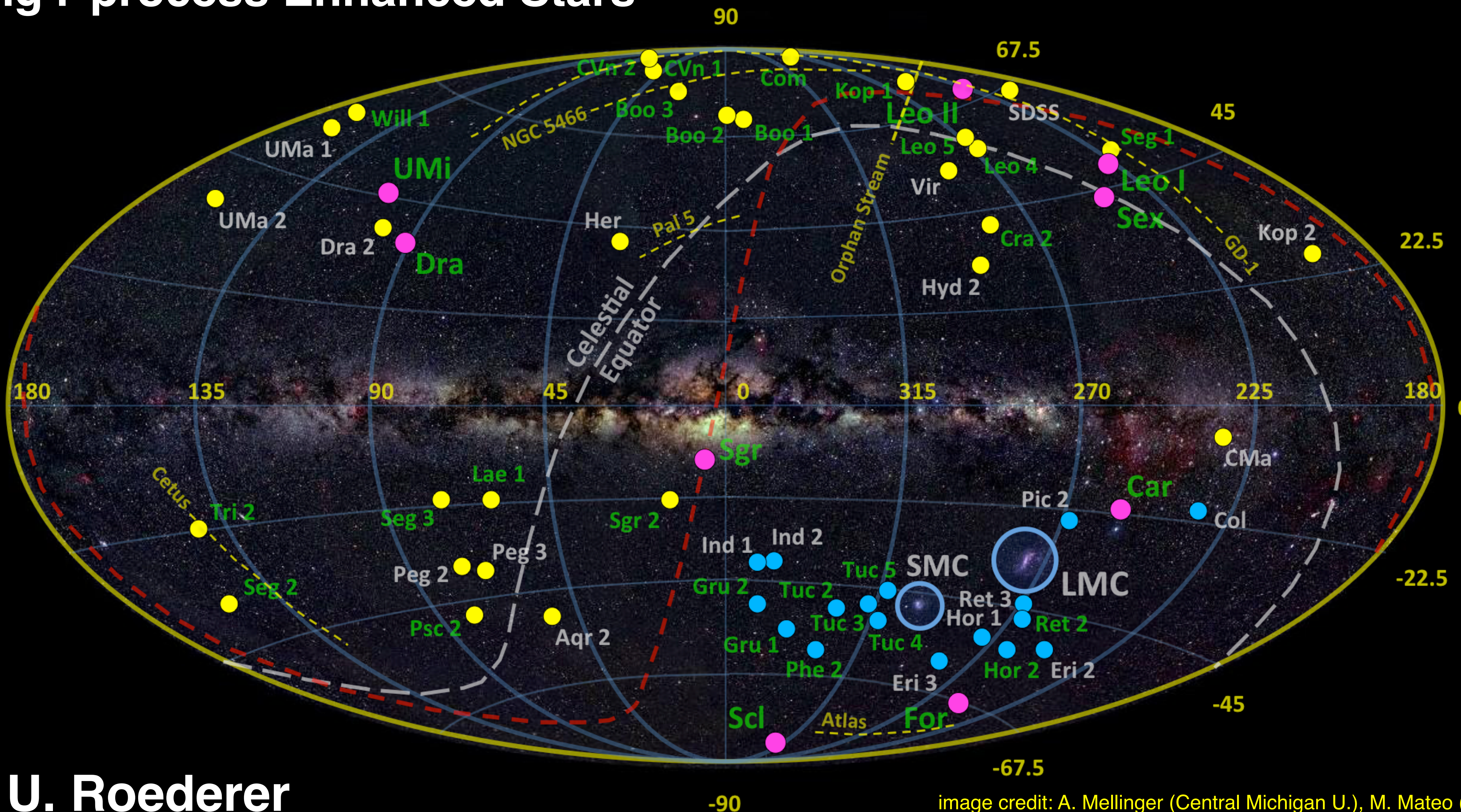

image credit: A. Mellinger (Central Michigan U.), M. Mateo (U. Michigan)

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and
Joint Institute for Nuclear Astrophysics — Chemical Evolution of the Elements

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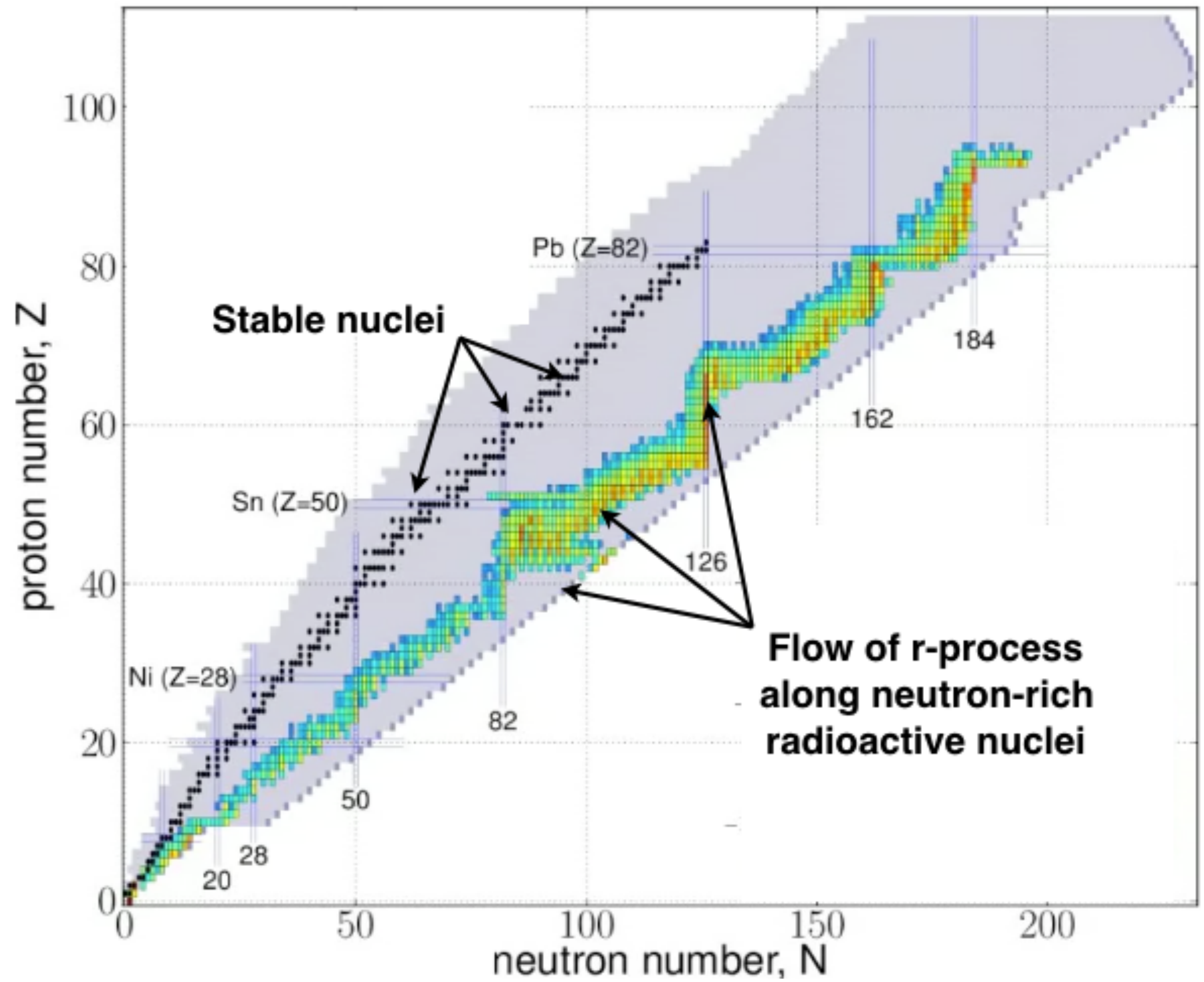
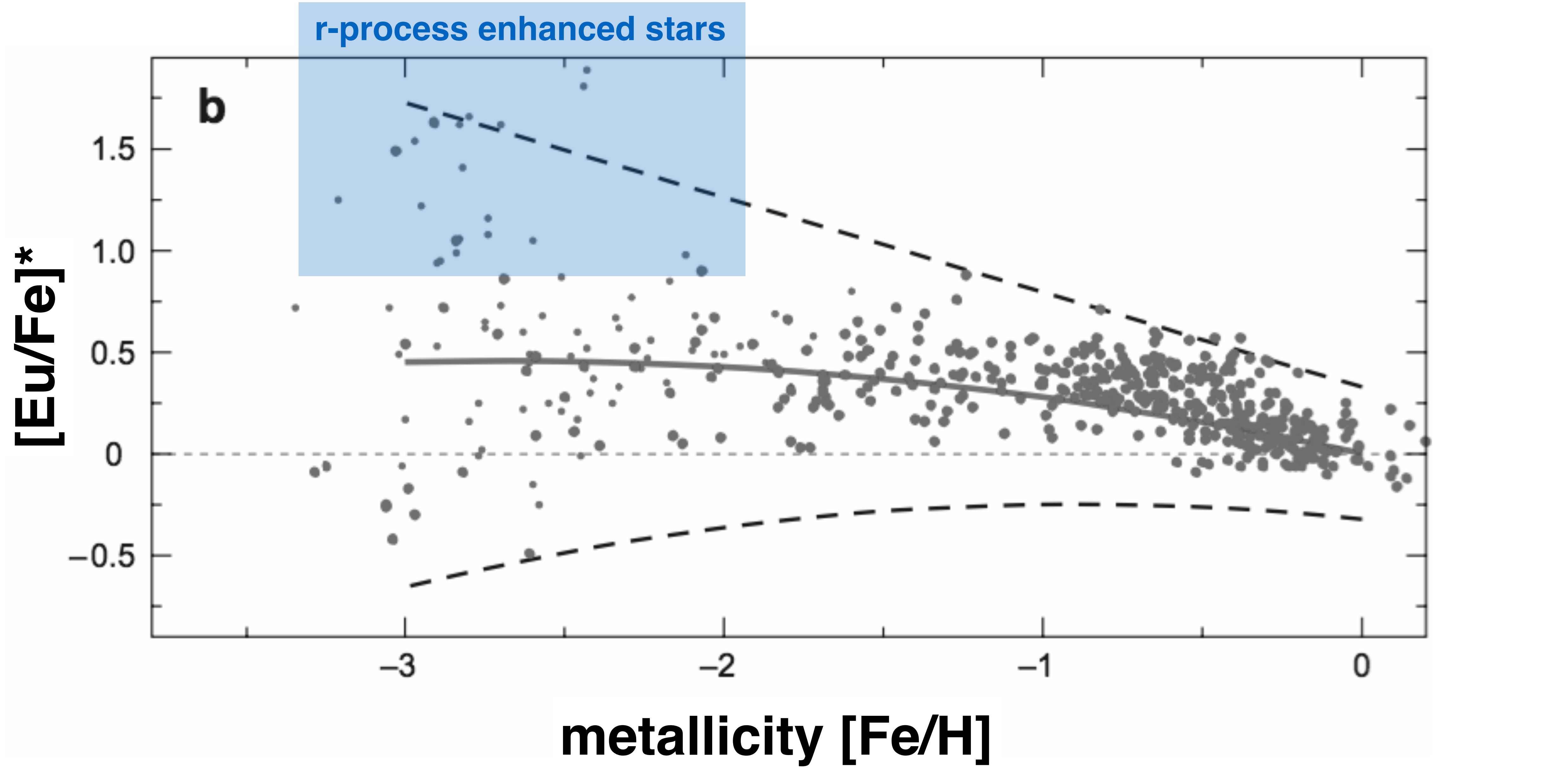
The **r-process** is one of the fundamental ways that stars produce heavy elements.

- **r**apid addition of neutrons
- explosive site
- high n density (~$10^{22\text{-}28}$ n cm^{-3})
- prolific (~10^{-2} $M_\odot$ per event)
- rare (~10^{-3-4} per SN)



Burbidge, Burbidge, Fowler, & Hoyle, Rev. Mod. Phys., 29, 547 (1957)   Korobkin et al., Mon. Not. Roy. Astron. Soc., 426, 1940 (2012)

A small fraction of metal-poor stars are highly enhanced in r-process elements.



Sneden, Cowan, & Gallino, Ann. Rev. Astron. Astrophys., 46, 241 (2008)

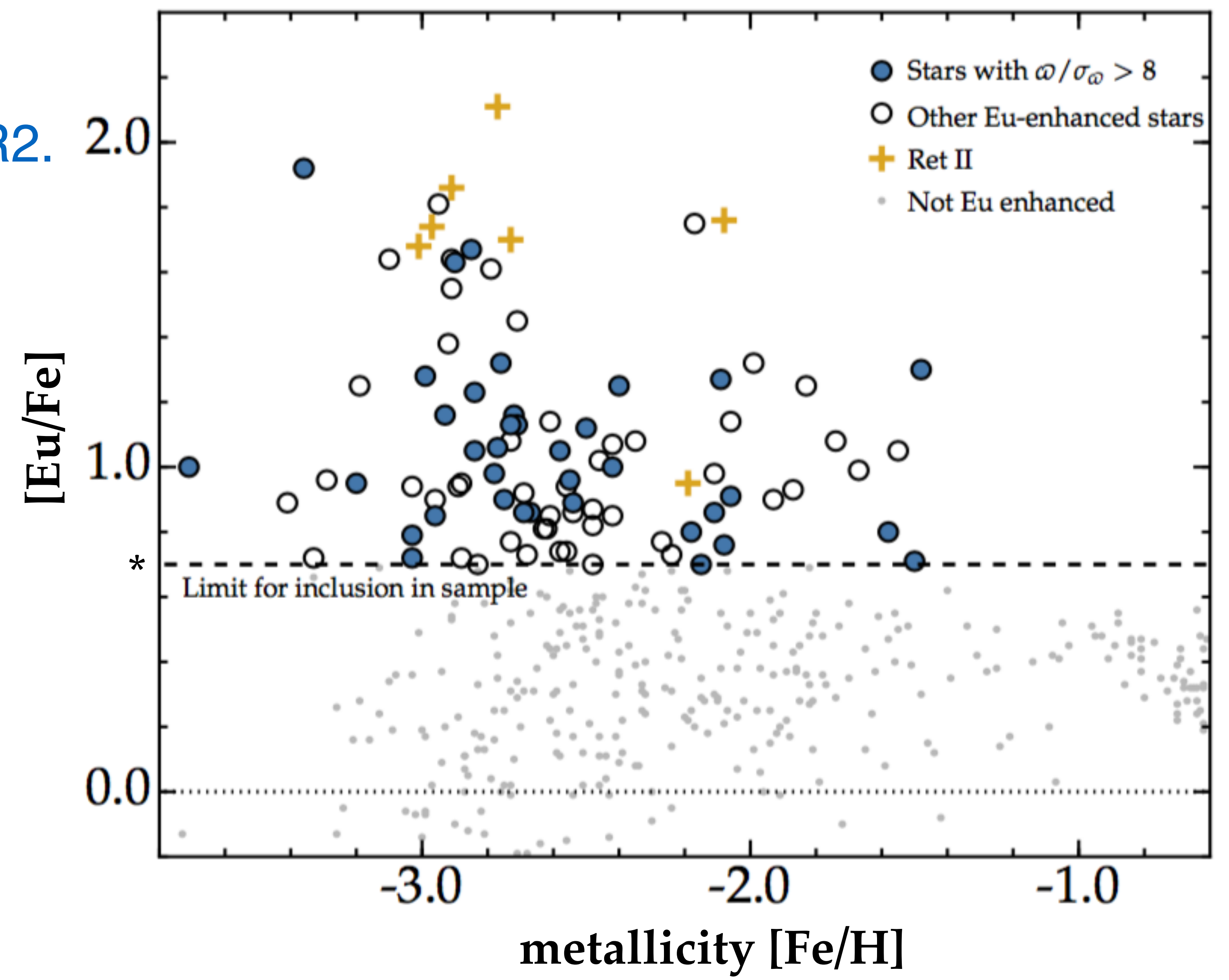
* $[\mathrm{Eu/Fe}] = \log_{10}(N_{\mathrm{Eu}})_{\mathrm{STAR}} - \log_{10}(N_{\mathrm{Eu}})_{\mathrm{SUN}} - [\mathrm{Fe/H}]$
(think of this as the level of r-process enhancement in a star)

europium
63
Eu
151.96

There are 83 r-process-enhanced stars ([Eu/Fe] > +0.7)* known in the Milky Way field.

- Stars with good distances from *Gaia* DR2.

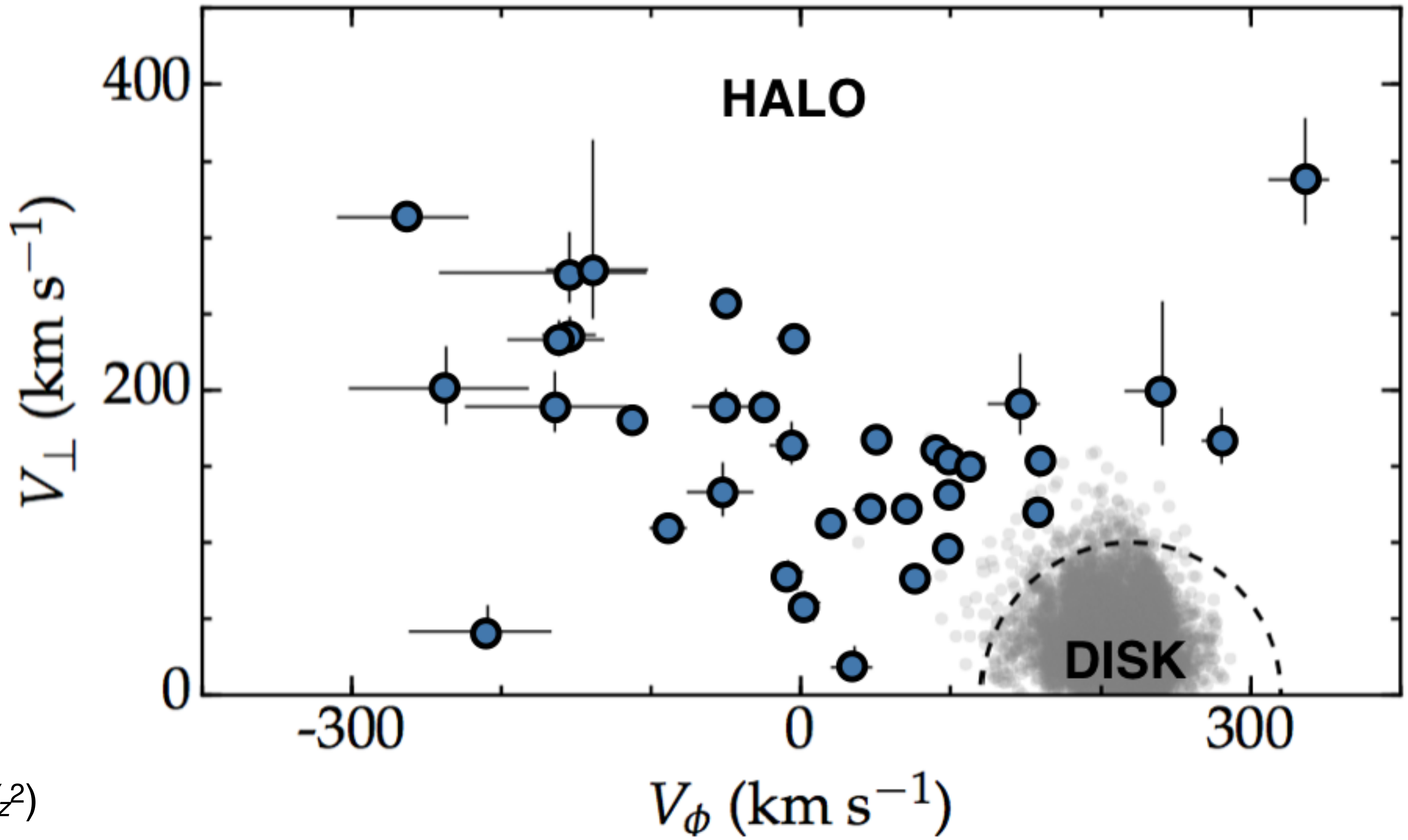
- calculate 6D positions and velocities
- adopt a Milky Way potential
- compute orbits, angular momenta, specific energies, etc.



Roederer, Hattori, & Valluri, Astron. J., 156, 179 (2018)

* I think [Eu/Fe] > +0.7 is a more meaningful discriminant of “r-process enhanced” than [Eu/Fe] > +1.0.

Highly r-process-enhanced stars are not part of the Milky Way disk.

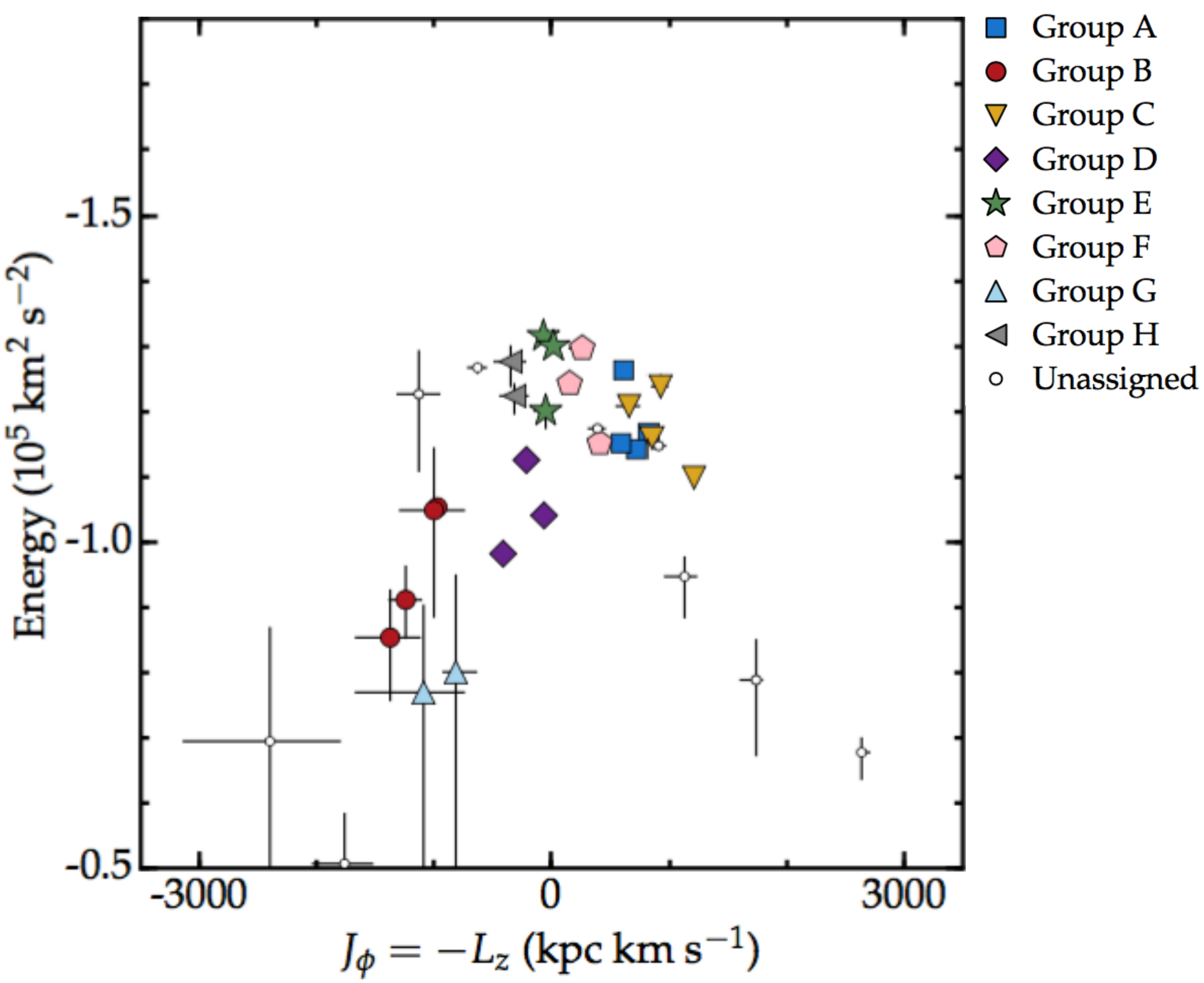


$V_\perp = \sqrt{(V_R^2 + V_z^2)}$

$V_\phi > 0 \longrightarrow$ prograde

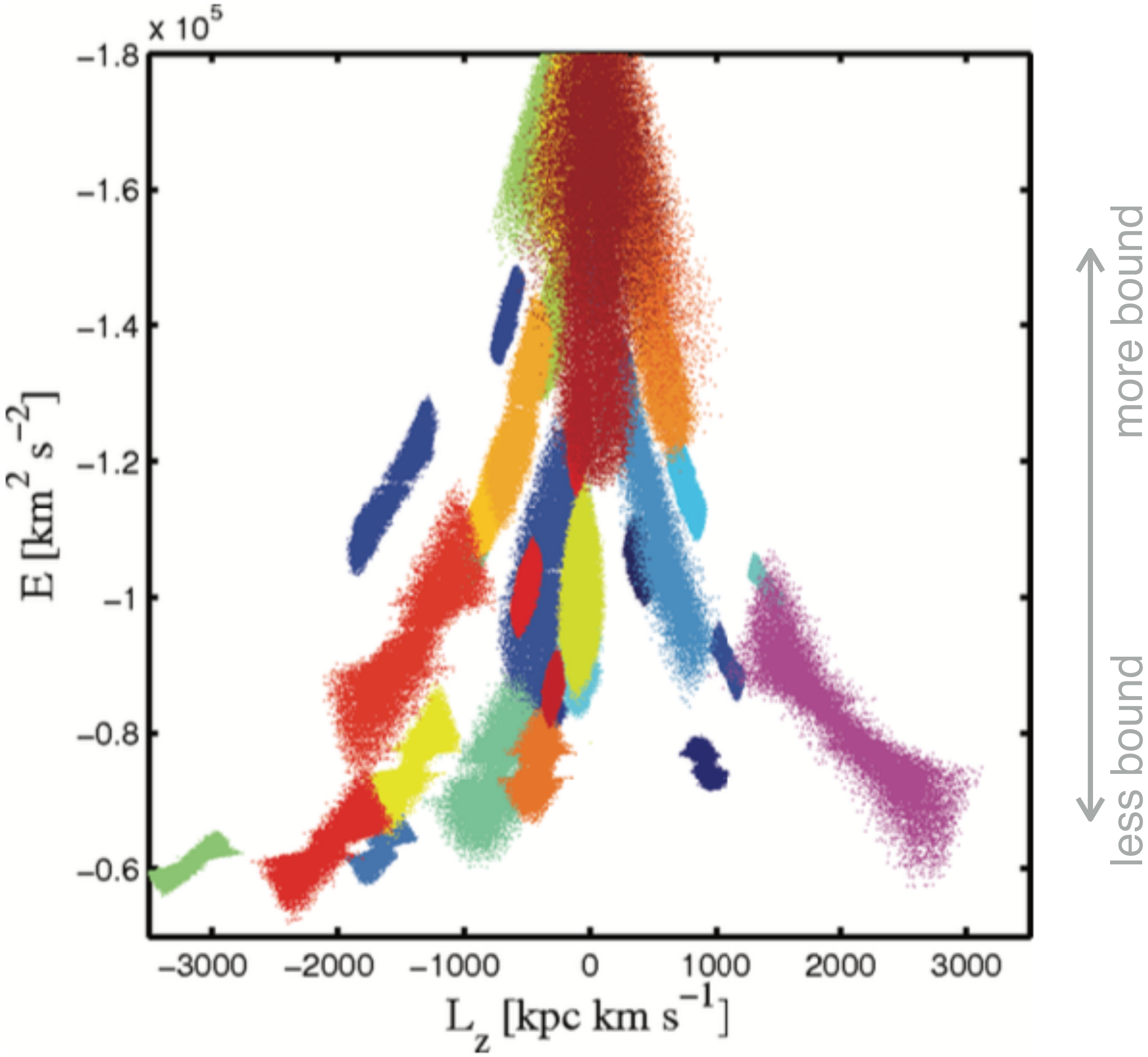
Roederer, Hattori, & Valluri, Astron. J., 156, 179 (2018)

Observations: each symbol/color represents r-process enhanced stars found by three clustering methods applied to the energy (*E*) and integrals of motion (J_R, J_ϕ, J_z)



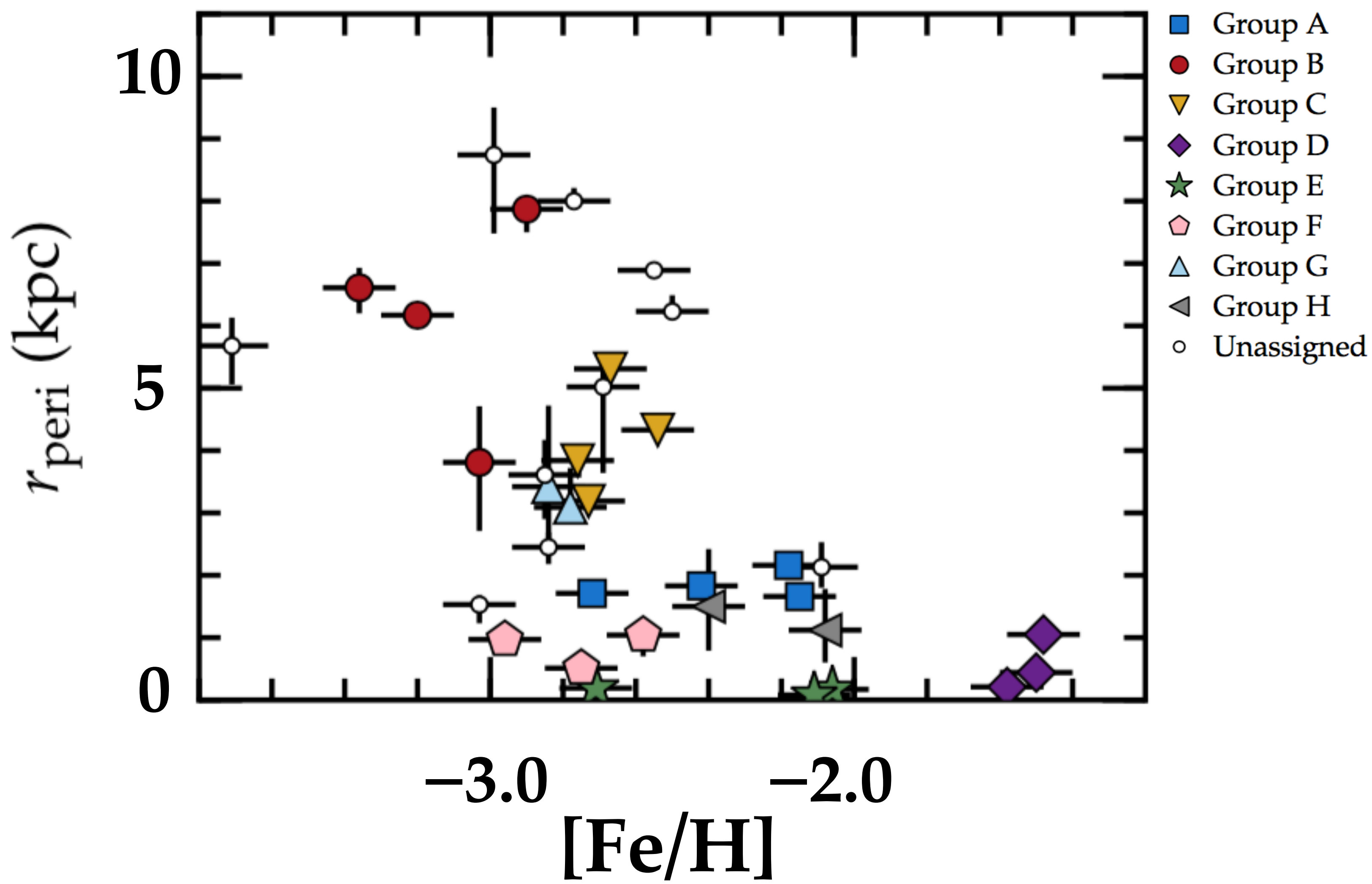
Roederer, Hattori, & Valluri, Astron. J., 156, 179 (2018)

Simulations: each cloud of points represents stars from one disrupted satellite, 10 Gyr later



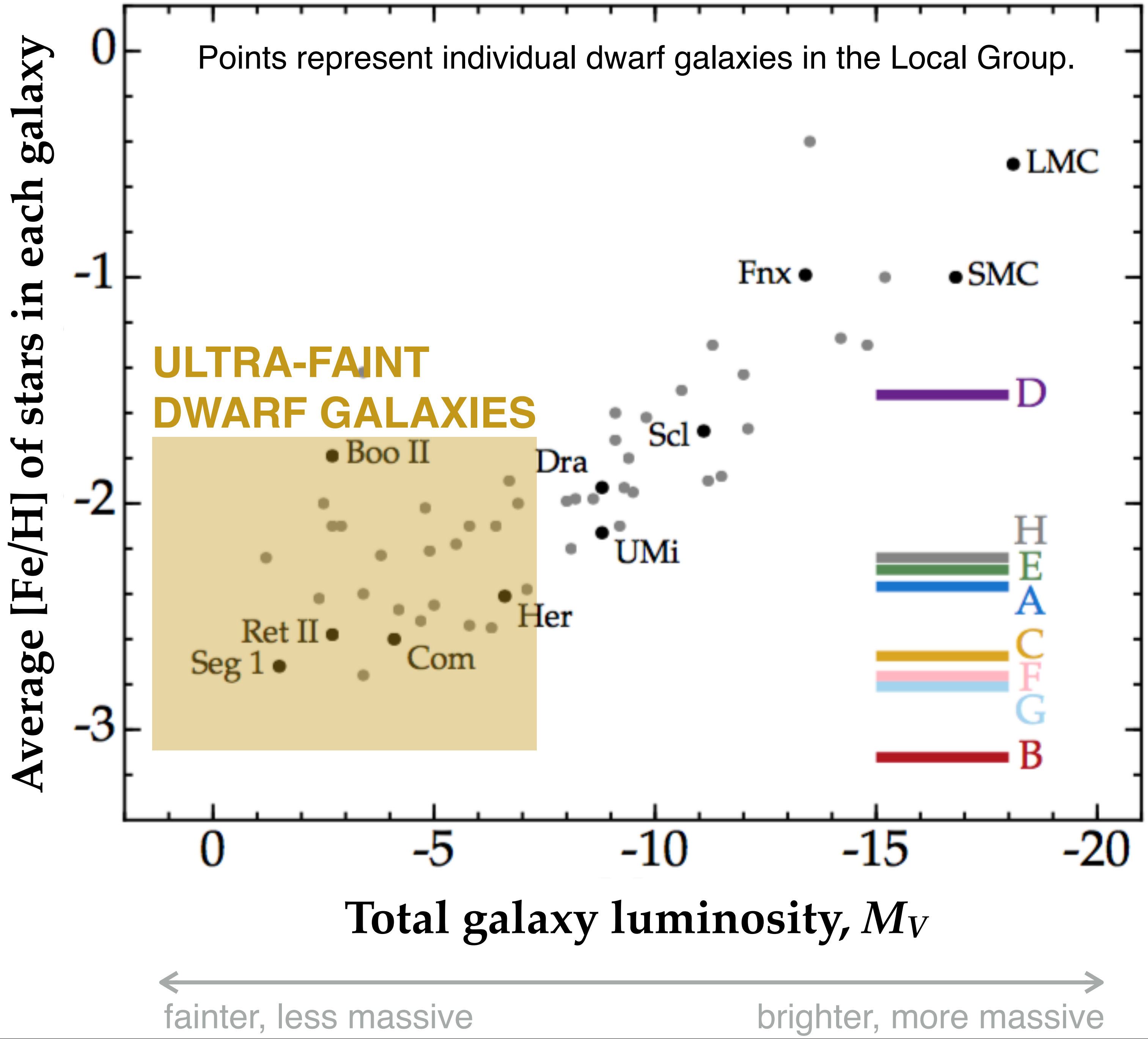
Gómez et al., Mon. Not. Roy. Astron. Soc., 408, 935 (2010)

All candidate groups show a small metallicity dispersion, even though chemistry played no role in the clustering analysis.



Roederer, Hattori, & Valluri, Astron. J., 156, 179 (2018)

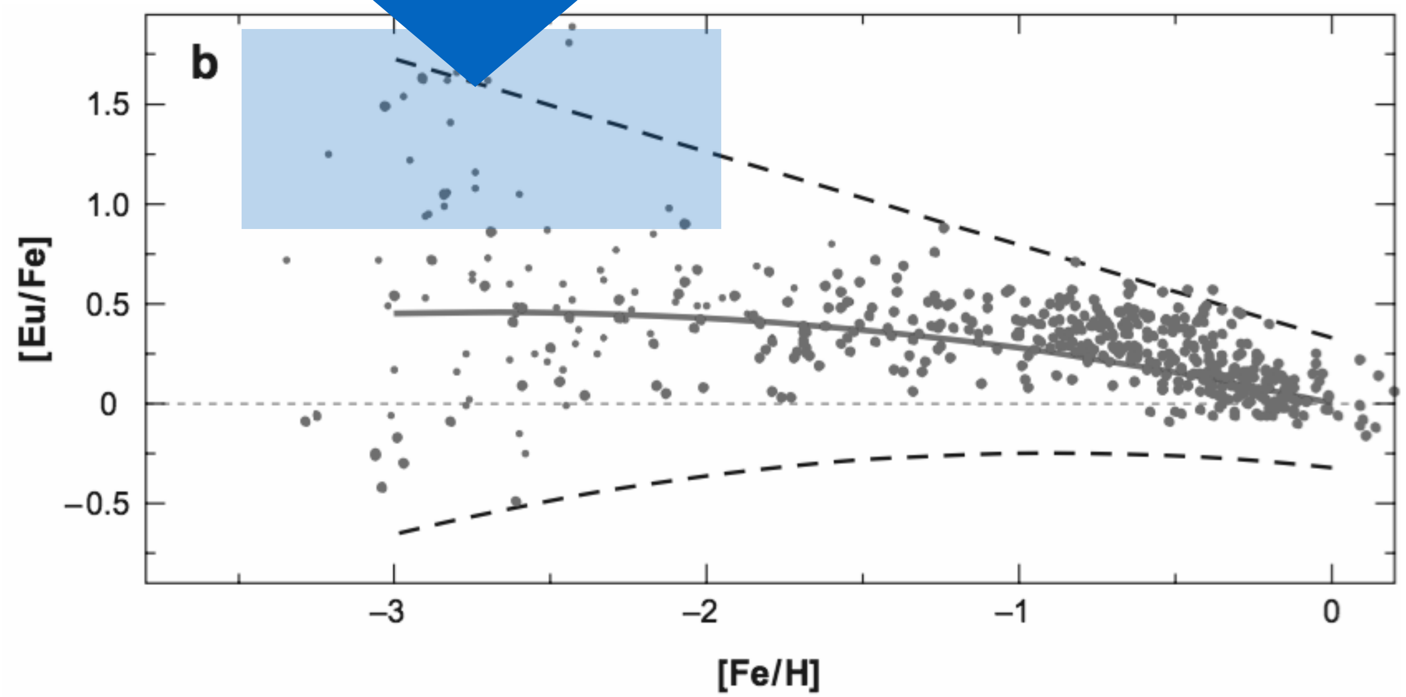
The groups of r-process enhanced stars have low [Fe/H], suggesting they were born in low-mass dwarf galaxies.

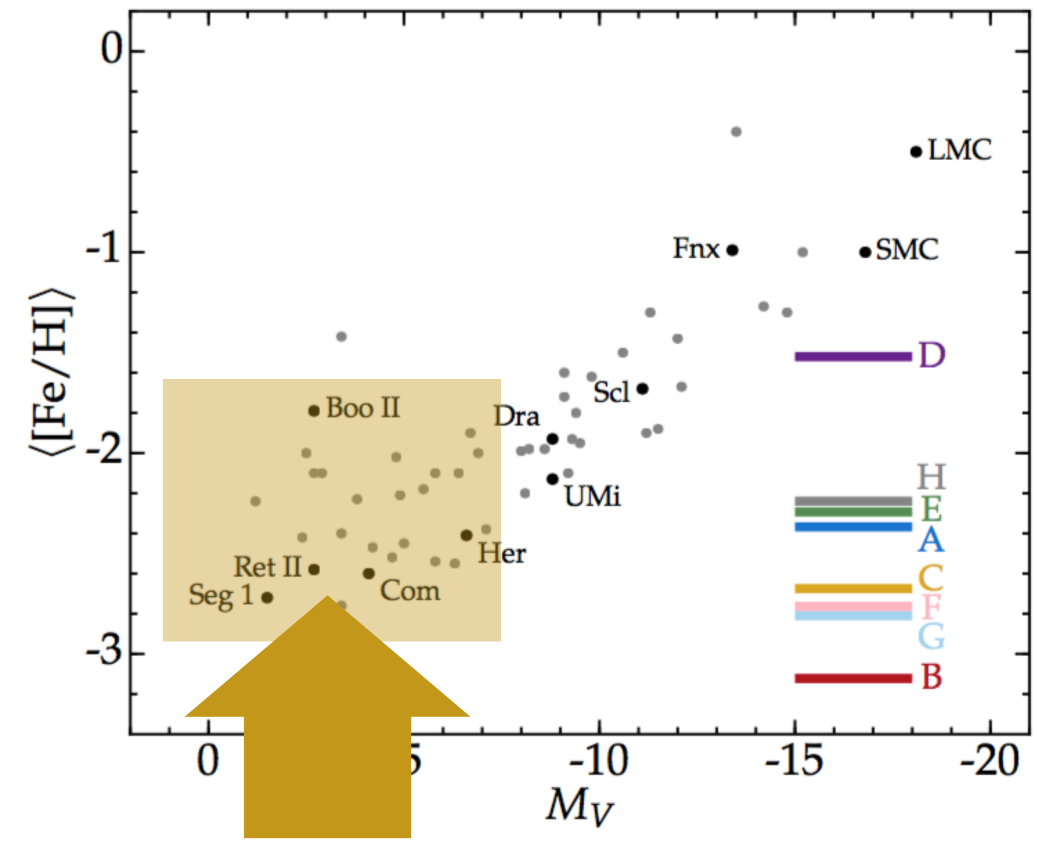


Roederer, Hattori, & Valluri, Astron. J., 156, 179 (2018)

Luminosity-metallicity relation for dwarf galaxies from, e.g.,
Kirby et al., Astrophys. J. Lett., 685, L43 (2008)
Walker et al., Astrophys. J., 819, 53 (2016)

r-process enhanced stars like this…

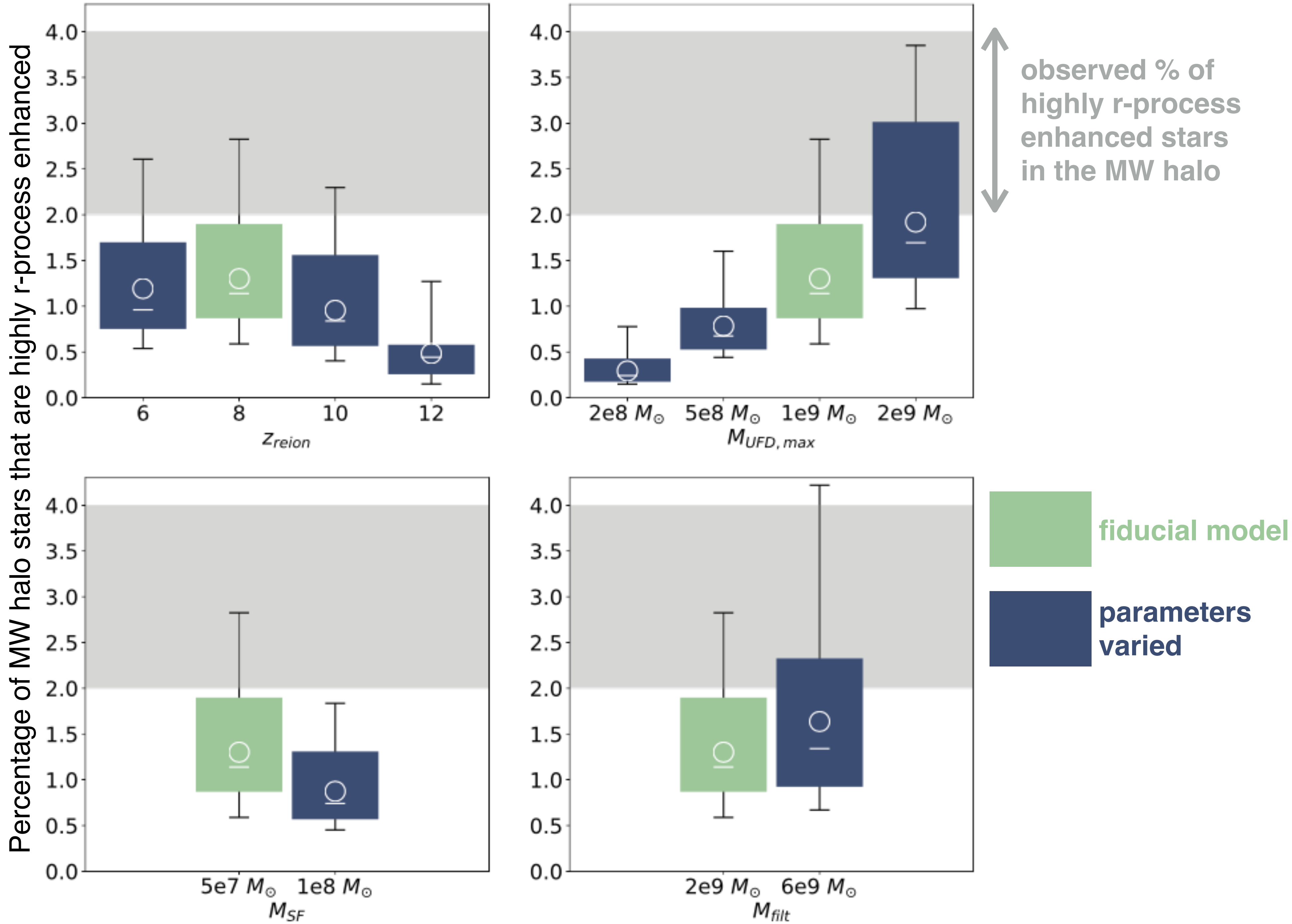




…came from UFD galaxies like this.

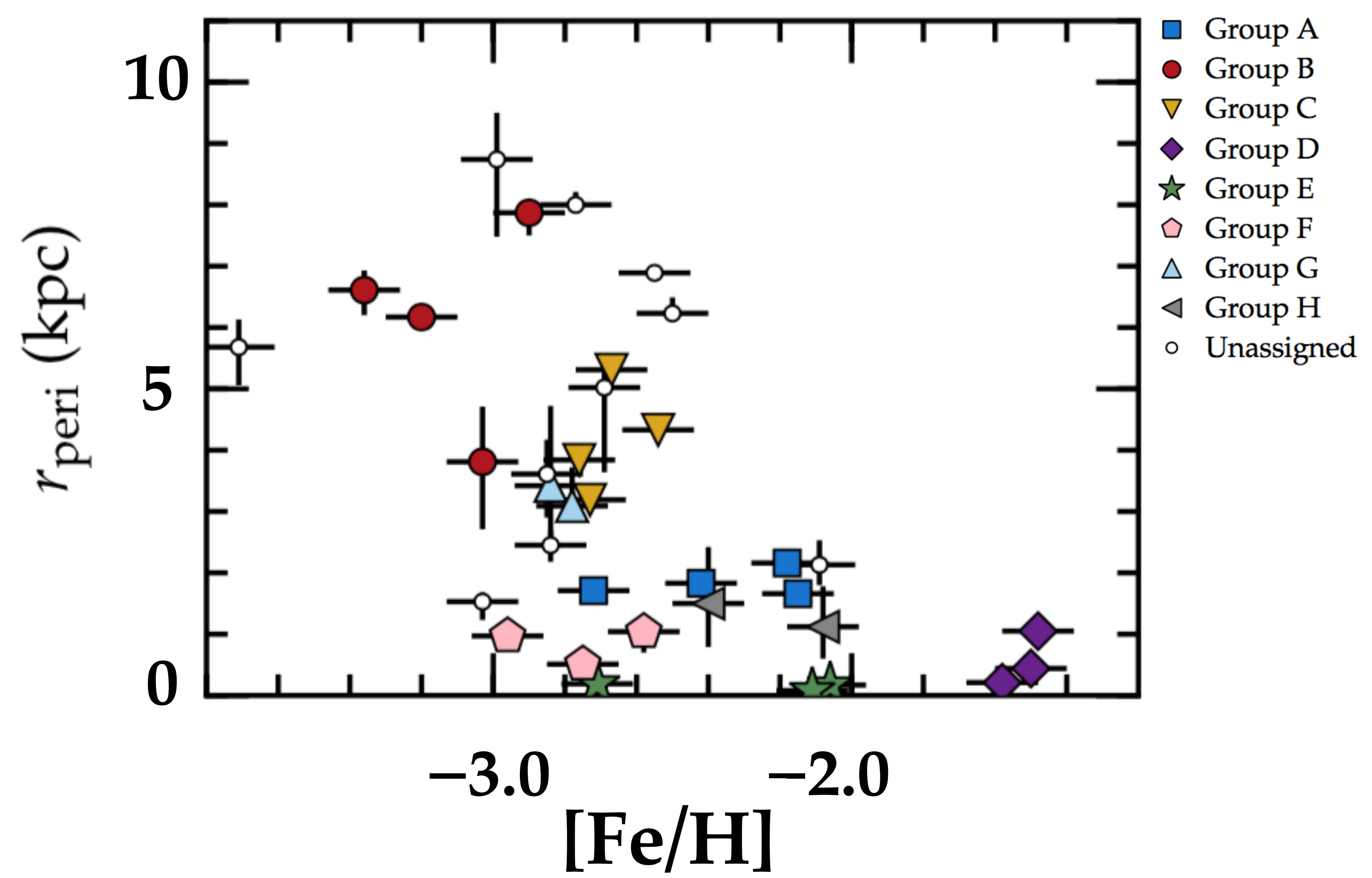
Roederer, Hattori, & Valluri, Astron. J., 156, 179 (2018)

Simulations show that disrupted UFD galaxies can account for most of the highly r-process enhanced stars in the Milky Way halo.



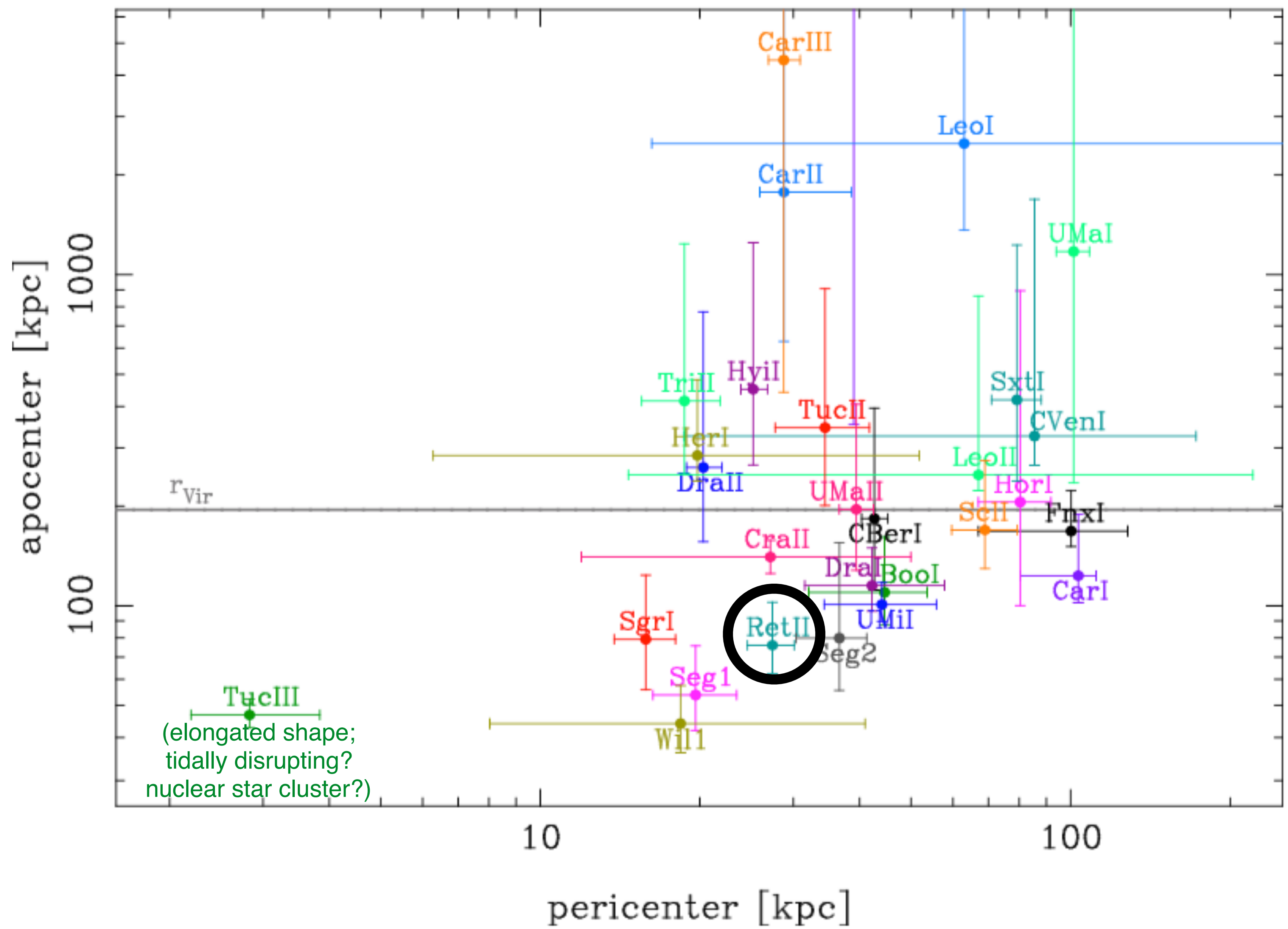
Brauer et al., Astrophys. J., 871, 247 (2019)

The **r-process enhanced stars** have **small** orbital pericenters (< 8 kpc).



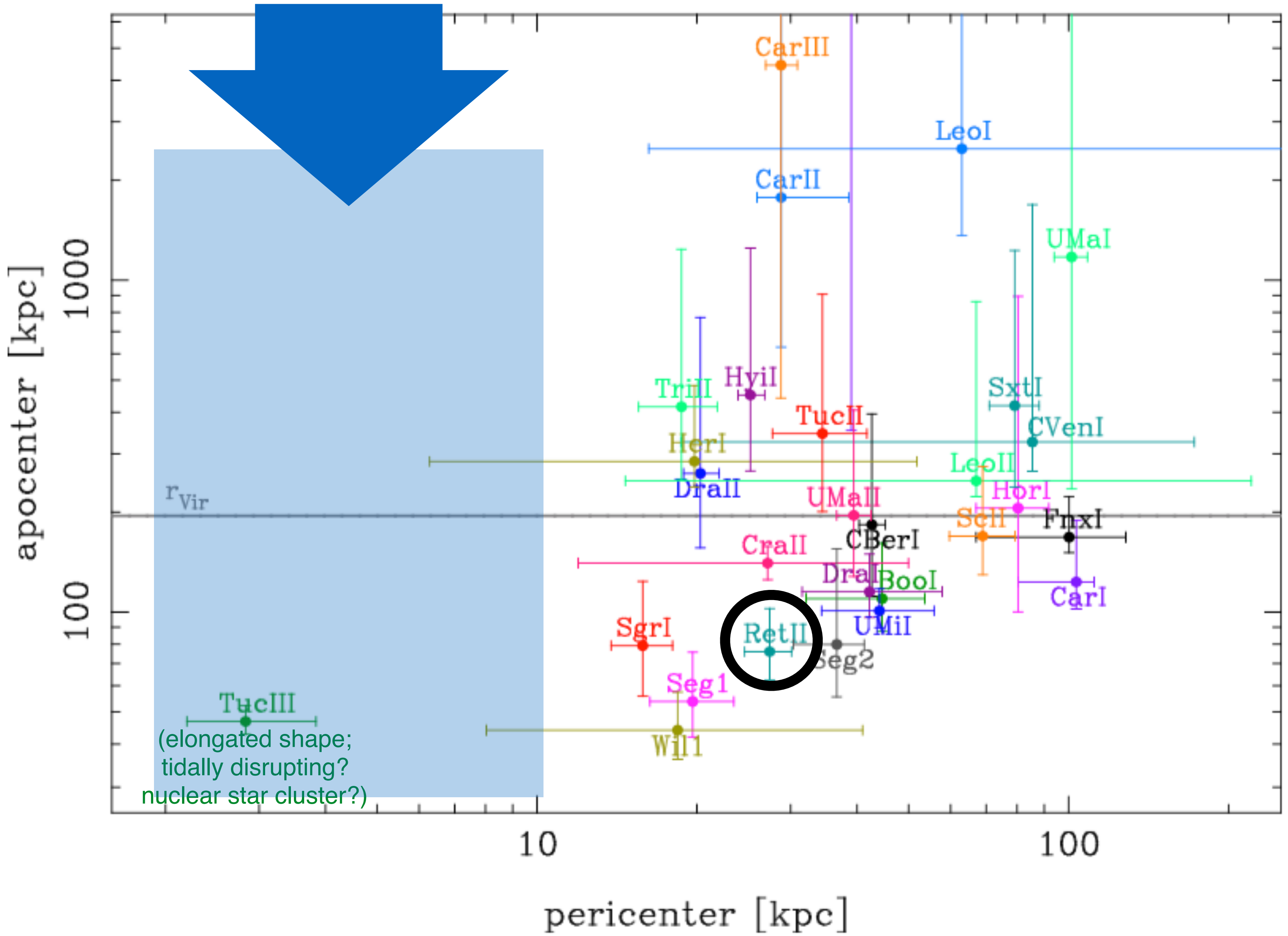
Roederer, Hattori, & Valluri, Astron. J., 156, 179 (2018)

The **surviving UFD galaxies** all have **large** orbital pericenters (> 20 kpc).



Fritz et al., Astron. Astrophys., 619, A103 (2018)

HYPOTHESIS: the **r-process enhanced UFD galaxies** with small orbital pericenters became the **r-process enhanced field stars** of today.



Fritz et al., Astron. Astrophys., 619, A103 (2018)

R-Process Alliance

The RPA is a multi-stage, multi-year effort to provide observational, theoretical, and laboratory constraints on the nature and origin of the astrophysical r-process.

Tim Beers (Notre Dame)
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Kaitlin Rasmussen (Notre Dame)
Ian Roederer (Michigan)
Charli Sakari (San Francisco St.)
Rafael Santucci (U. F. de Goiás)
Chris Sneden (Texas)
Sandro Villanova (Concepción)
Devin Whitten (Notre Dame)
+ others (the list is growing!)

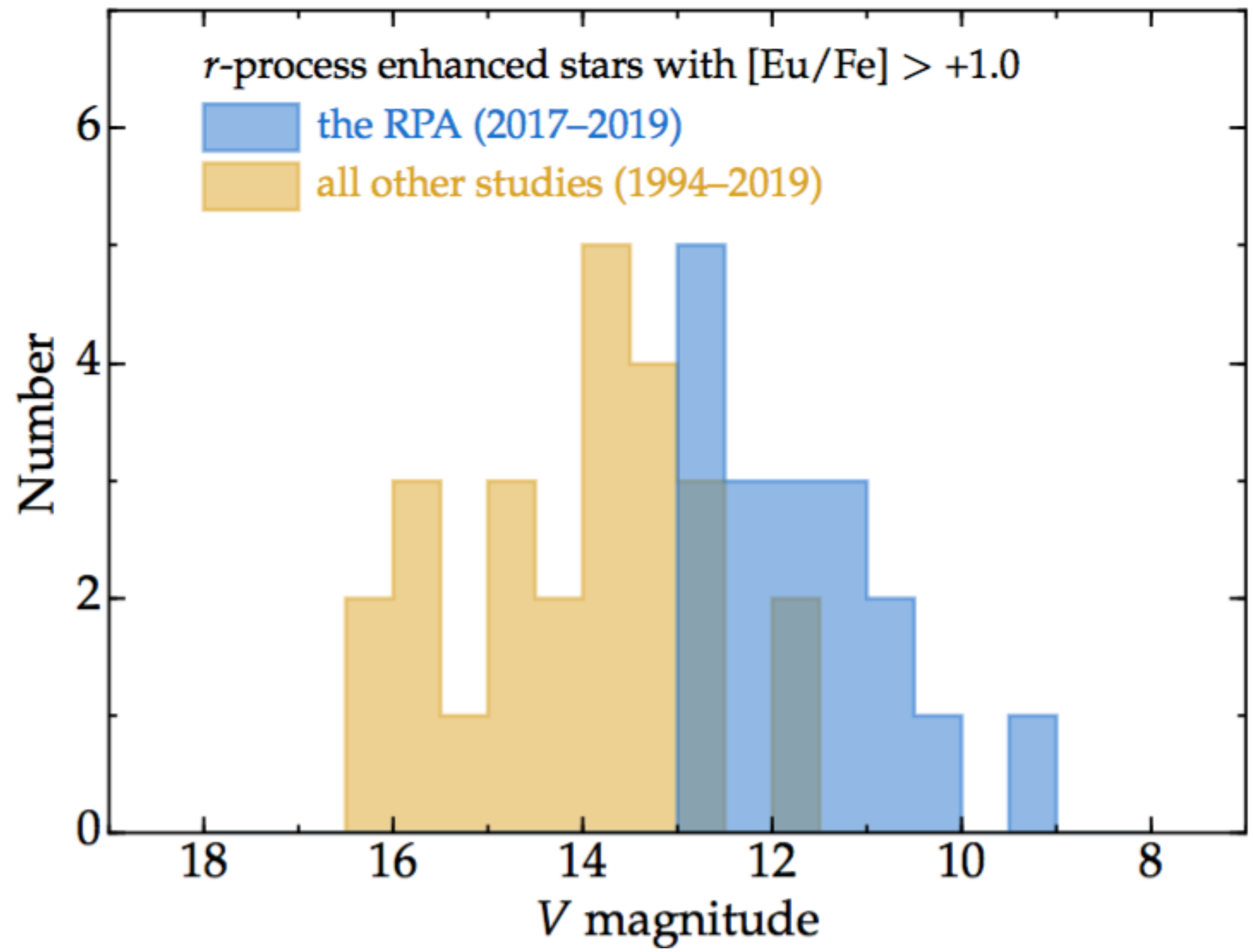

figure: IUR, unpublished