First measurement of the r-process abundance at the Galactic Center using a hyper velocity star

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s, i & r Element Nucleosynthesis (sirEN) Conference @ Giulianova/Italy

Outline

1. Introduction: origin of the nuclear star cluster (NSC) investigated using a hyper-velocity star (HVS)

2. Near-infrared (NIR) high-R spectroscopy w/Magellan/WINERED
   (Hattori, **DT** et al. 2025, arXiv:2502.20266; accepted yesterday!)

3. Optical high-R spectroscopy w/Gemini-S/GHOST
   (**DT** et al. in prep.)

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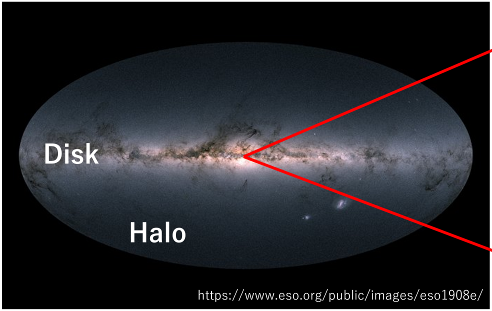
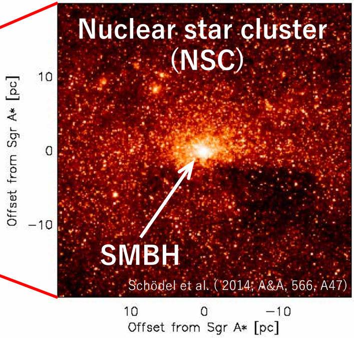
Nuclear star cluster (NSC)

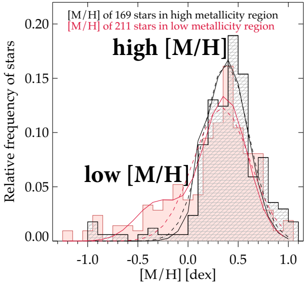
- The Galactic Center region of the Milky Way hosts Nuclear Star Cluster (NSC).
- NSC's formation history is still a matter of debate.

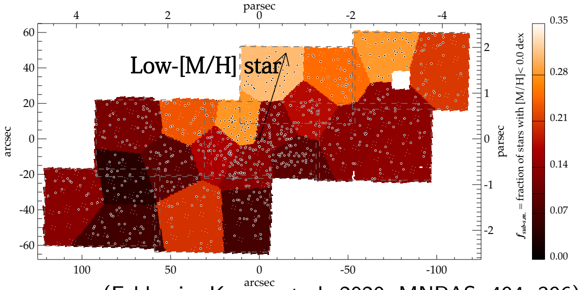




Formation of NSC: in situ v.s. accreted

- **High-[M/H]**: maybe in situ
- **Low-[M/H]**: in situ? accreted?
    - Spatial asymmetry supports accreted scenario.
    - If so, globular cluster? dwarf galaxy?
- Detailed chemistry (e.g., [r/Fe]) is required!

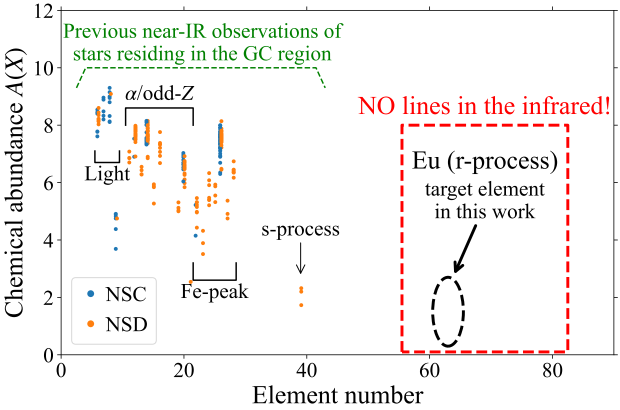




(Feldmeier-Krause et al. 2020, MNRAS, 494, 396)

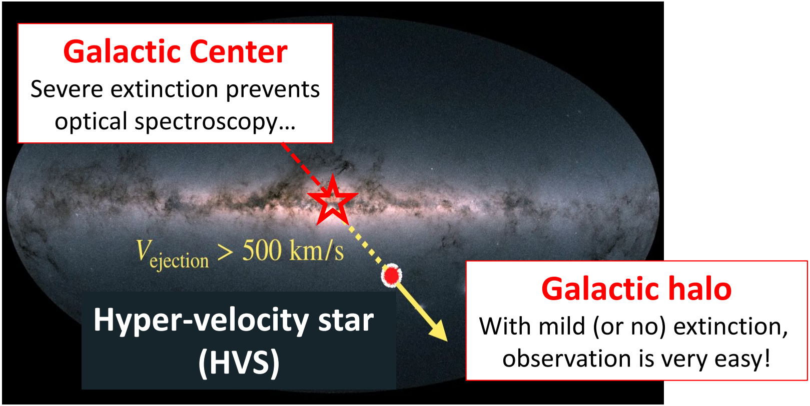
Optical observation is difficult!

- Due to the severe extinction, infrared observation is required.
- However, there is no r-process line in the infrared!



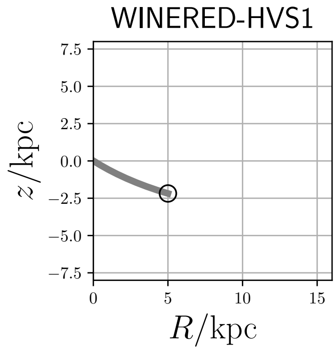
Our solution: hyper-velocity star (HVS)

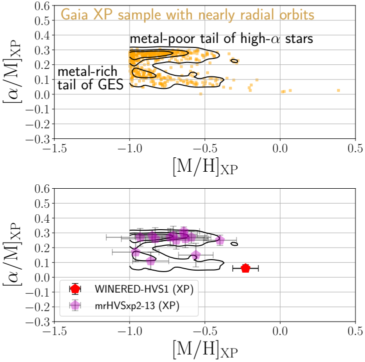
- Hyper velocity star (HVS): stars ejected from the Galactic Center through the Hills mechanism (Hills 1988, Nature, 331, 687)
- HVSs can be easily observed with optical spectroscopy.



WINERED-HVS1: first late-type HVS

- Using *Gaia* DR3, we searched for late-type stars with:
  - whose orbit is traced back to the Galactic Center.
  - whose *Gaia* XP [M/H] is inconsistent with halo stars.
- We found one candidate, named "WINERED-HVS1".





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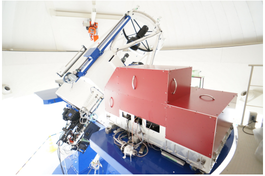
Why near-infrared (NIR)?

Simply because we had access to observing time.
Nothing more...

NIR high-res observation w/WINERED



(Ikeda et al. 2022, PASP, 134, 015004)

- NIR: z', Y, J bands (0.90–1.35 µm)
- High resolution ($R \sim 28,000/70,000$)
- High throughput ($> 50\%/> 40\%$)

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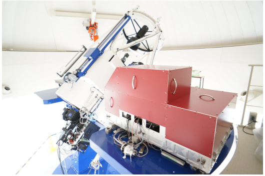

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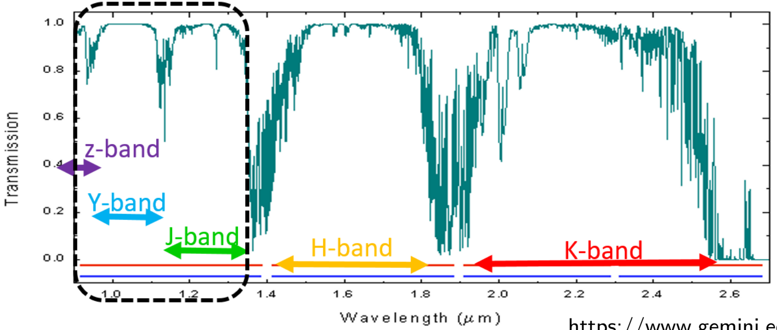

https://www.gemini.edu/

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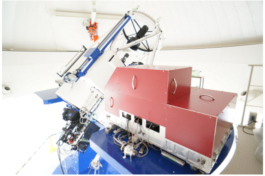

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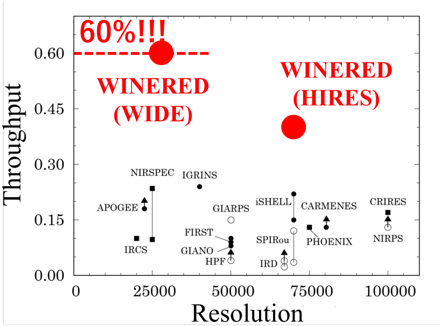

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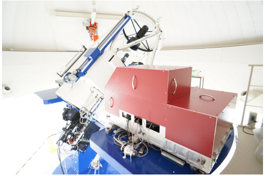
NIR high-res observation w/WINERED

- With Magellan Clay 6.5 m telescope
- 40 min exposure on June 6th 2023
- $J = 12.7$, S/N ~ 50 per pixel



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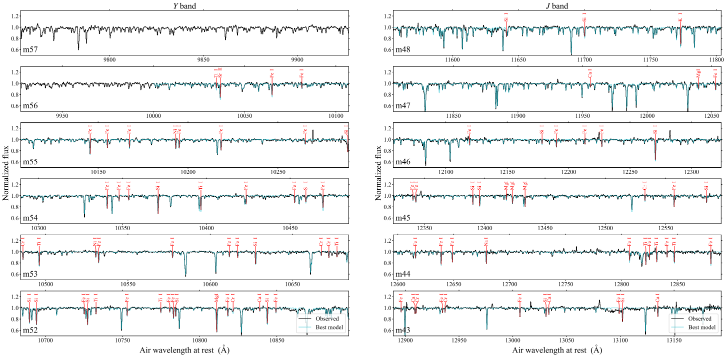
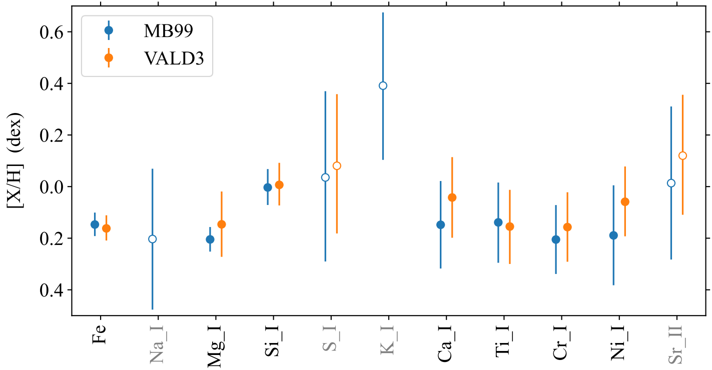


NIR abundance analysis: procedure

- **A (standard?) method for near-infrared spectroscopy**
- **Effective temperature (T_{eff})**
  - Line-depth ratio method with Fe I lines
    (Gray & Johanson 1991, PASP, 103, 439; **DT** et al. 2021, MNRAS, 502, 4210)
- **Surface gravity ($\log g$)**
  - Stefan-Boltzmann's law
- **Microturbulence and [Fe/H]**
  - Fitting of individual Fe I lines
    (Kondo et al. 2019, ApJ, 875, 129; **DT** et al. 2025, A&A, 693, A163)
  - Atmosphere: ATLAS9-APOGEE (Mészáros et al. 2012, AJ, 144, 120)
  - Line list: MB99 (Meléndez & Burbuy 1999, ApJS, 124, 527) and VALD3

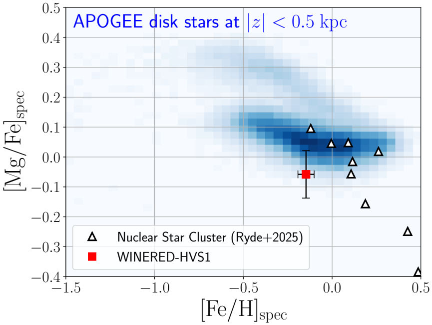
NIR results: no dependence on linelist

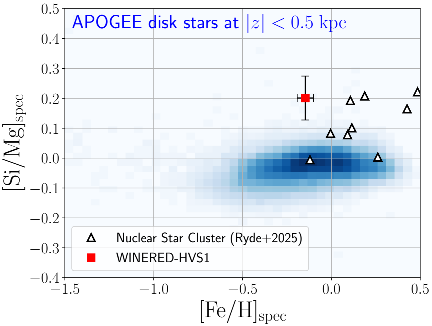
- We measured the abundances of α, odd-Z, Fe-peak, and s-process elements.
- Two linelists gave consistent results.



NIR results: comparison with disk chemistry

- Abundances are consistent with NSC stars.
- [Mg/Fe] is also consistent with thin-disk stars.
- BUT, [Si/Mg] is inconsistent with disk stars.
  →Rejecting the possibility of the disk origin.





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