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Early r-process Enrichment and Hierarchical Assembly Across the Sagittarius Dwarf Galaxy

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Introduction

- **Dwarf galaxies** provide a unique window into the early stages of galactic chemical evolution, particularly **through their metal-poor stars**
- The measurements of europium (Eu) , which is the indicator of r-process and provides us the galaxy formation history and early star formation, remains sparse in dwarf galaxies.
- They focus on **Sagittarius (Sgr) dwarf galaxy** and its associated stellar stream.
  - Sgr dwarf galaxy has undergone significant tidal stripping due to the Milky Way over the past ~ 5Gyr.
  - The core of Sgr is located ~ 25kpc away.
- They collected a low-metallicity sample of stars in **the Sgr core and stream**.

Target Seletion and Observations

- Gaia DR3 proper motions.
- SkyMapper DR2 (Onken et al. 2019) and synthetic photometry derived from Gaia XP spectra.

→ A sample of **~200 metal-poor stars** in the Sgr core and the stream was acquired.

- follow-up high resolution spectroscopy of ~20 stars in the stream and ~40 stars in the core by the Magellan Inamori Kyocera Echelle spectrograph at the Magellan Clay 6.5m Telescopes.
  - R ~ 28000/22000 for the blue/red arm, covering 3200-5000Å / 4900-10000Å
- Cross-correlating their spectra against a template spectrum of HD122563.

→ the final sample consists of **37 stars.**

- They examined radial velocities to complete the 6D kinematics.

→ **22 stars in the Sgr core, 15 stars in the tidal streams**

Stellar Parameters and Chemical Abundance Anaysis

- They estimated the stellar parameters (T_{eff}, $\log g$, $[Fe/H]$, v_t) by **spectroscopic** analysis. They used ATLAS model atmospheres, with α enhancement.

→ They reaffirmed these stars belong to Sgr, not being the foreground contamination.

- Then, they proceeded to determine **photometric** stellar parameters.
  - Spectroscopic approach typically underestimates T_{eff} and $\log g$ due to non-local thermodynamic equilibrium effects in FeI.

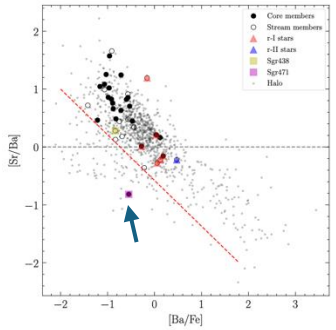


Figure 5. bottom

- The procedure of estimating photometric stella parameters

$[Fe/H], v_t$ → T_{eff} by Gaia DR3 G-RP colors with color-$[Fe/H] - T_{eff}$ relations from Mucciarelli et al. (2021)

T_{eff}, $[Fe/H]$ → $\log g$ by low-metallicity Dartmouth isochrones of the red giant branch (Dotter et al. 2008) (Figure 1.)

T_{eff}, $\log g$ → $[Fe/H], v_t$ by FeI lines

They iterated these calculations. They obtained $[Fe/H]$ **for each stars** eventually.

- The elemental abundances were derived by using
  - The 1D LTE stellar atmosphere models from (Castellli & Kurucz 2003)
  - The radiative transfer code MOOG
  - SMHR for spectral analyses
  - Linelist from the works of the R-Process Alliance with updated log gf values (Roederer et al. 2018)
  - linemake code

→ **Up to 20 elements** were measured by spectra.

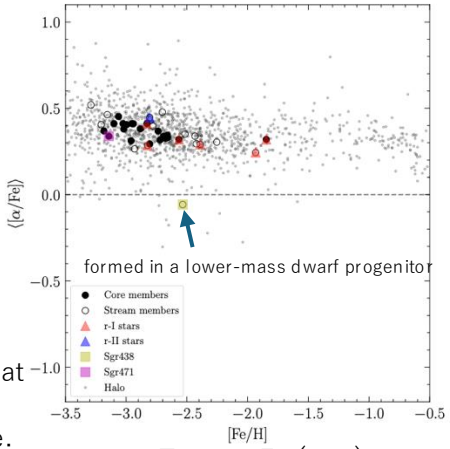


Figure 5. (top)

Discussion and Interpretation

- (4.1) Most stars in the sample exhibit elevated [α/Fe] ratios at low metallicities (Figure 5. top)

→ consistent with rapid enrichment by core-collapse supernovae.

- (4.2) Fewer fractions of CEMP (carbon-enhanced metal-poor, [C/Fe]>0.7) stars (1/37~3%) in the Sgr than in Milky Way halos (20~40%)

→ **a significant lack of faint SNe progenitors** dominating the enrichment of its early gas.

Instead, regular core-collapse SNe may rather have produced the observed carbon

- (4.3) no statistically significant differences of element abundances between the Sgr core and stream populations. (銀河形成の過程で、降着を受けてきた星は、host galaxyの中心から離れている位置するため、streamの方が、[X/Fe]は多い傾向との予想に反して。)

→ The accreted galaxies had a similar chemical enrichment history as the Sgr progenitor, i.e. Sgr experienced limited accretion of chemically distinct systems.

- (4.5) Over half of the sample shows abundance patterns consistent with the scaled solar r-process pattern

→ the Sgr progenitor experienced **efficient r-process enrichment at an early stage of its evolution**.

- (4.4) Sgr 471 exhibits a distinct abundance pattern (low [Sr/Ba]) characteristic of stars that are found in UFDs (Figure 5. bottom).
- They also find eight r-I (0.3<[Eu/Fe]<0.7)and r-II (0.7< [Eu/Fe])stars.
- ~1 may plausibly be accreted from another UFD that was enriched by r-process event.

→ signatures of accretion of low-mass systems into Sgr during its assembly, consistent with hierarchical galaxy formation.

- (4.6) Despite the presence of the early r-process enrichment events, the bulk measured [Eu/Mg] abundances for Sgr in this study are lower than the measurements for GSE star (Figure 8.)

→**Evidence for delayed r-process sources** contributing to the chemical evolution of Sgr

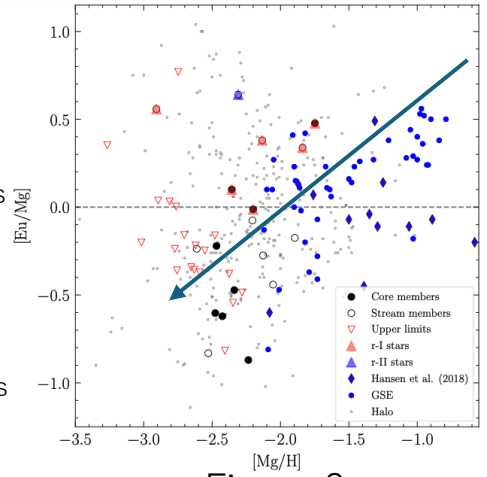


Figure 8.

Figure 7. Heavy element abundance patterns of six r-I stars (Sgr9, Sgr428, Sgr462, Sgr431, Sgr422, Sgr468) and one r-II star (Sgr421), compared to the scaled (normalized to the stellar europium, Eu, abundance) solar *r*-process abundance pattern (black line).

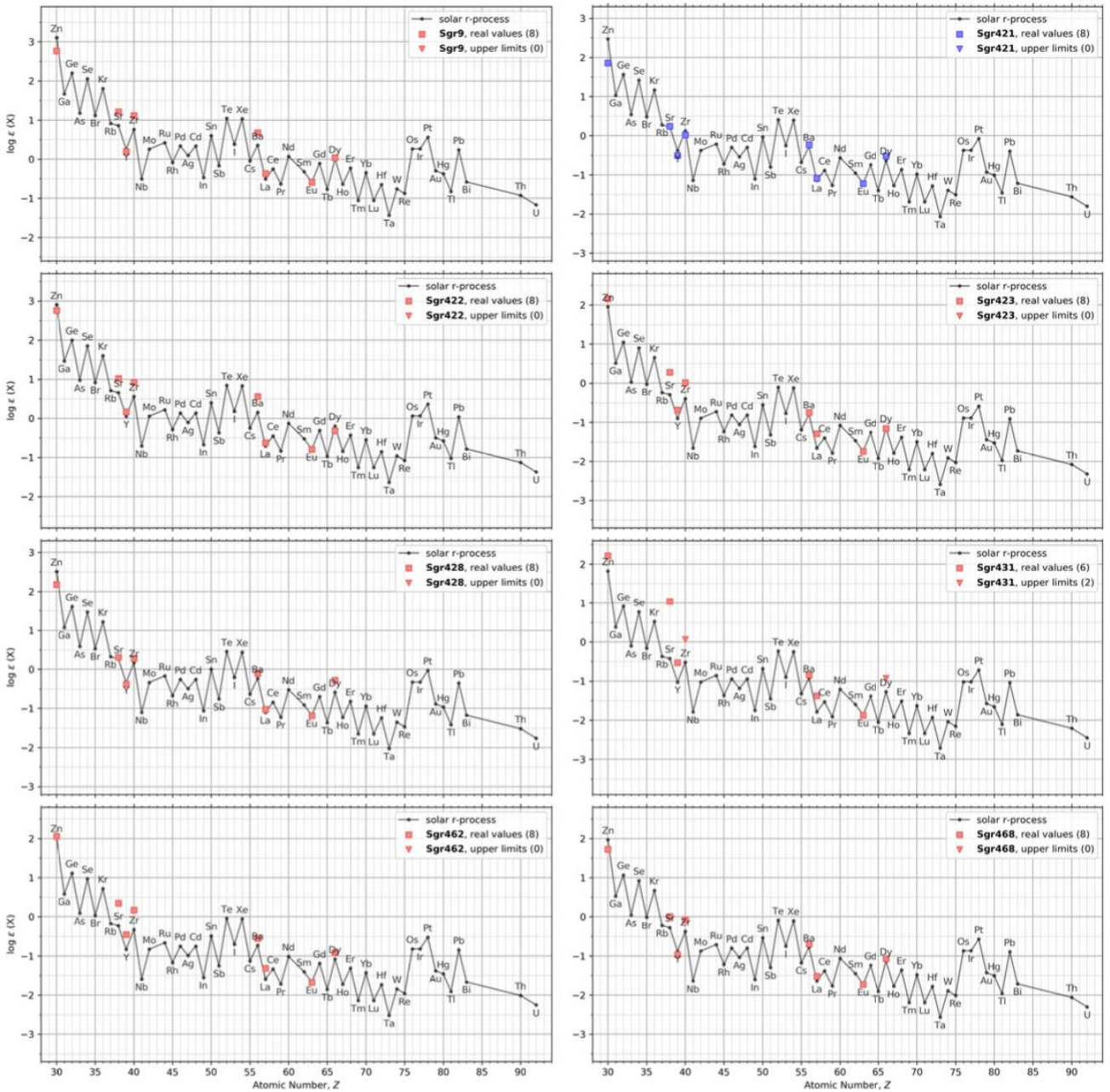
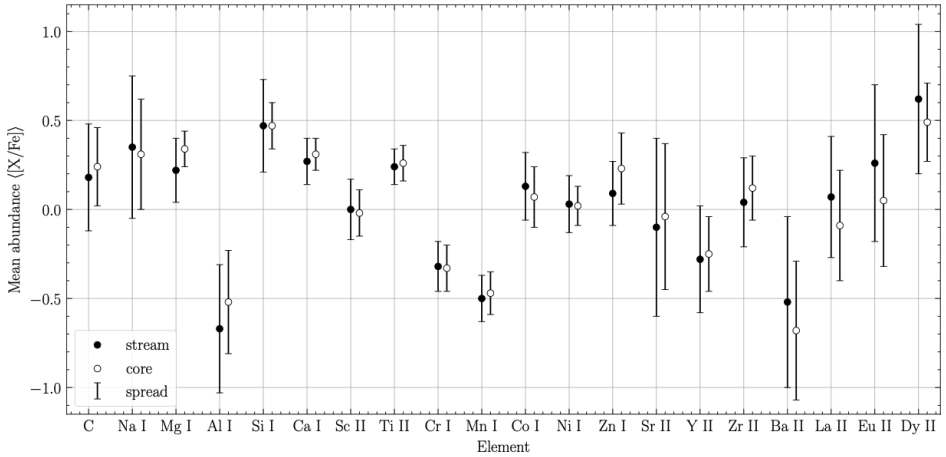


Figure 6. Comparison of means and spreads of various element abundances of all the stars located in the Sgr core and the stream.



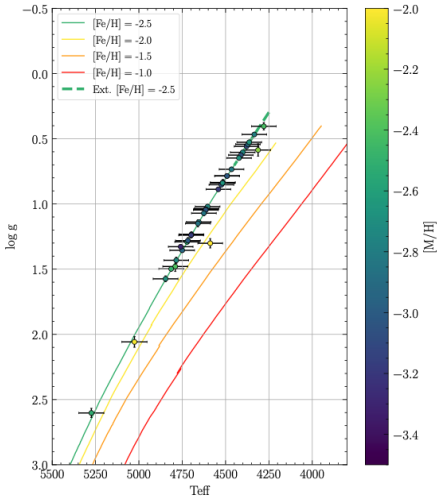


Figure 1. Kiel diagram for the sample with all stars shown in dots. The Dartmouth isochrones are shown in solid lines. The dashed line represents the extrapolated isochrone. Both the stars and isochrones are color-coded by metallicity.