Linking the Galactic and extragalactic chemical abundances using red supergiants

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Based on Taniguchi et al. 2021 (*MNRAS*, **502**, 4210); Taniguchi et al. in prep.

1. Abstract—Metallicity measurements of red supergiants (RSGs)

Thanks to recent large spectroscopic surveys of the Galactic-disk stars such as APOGEE, it is now well known how the chemical abundance distribution changes over the Galactic disk. A natural step forward is to turn our eyes to nearby external galaxies; measuring the abundances of individual stars, rather than mean abundances. However, spectroscopic observations of such far stars are usually hard.

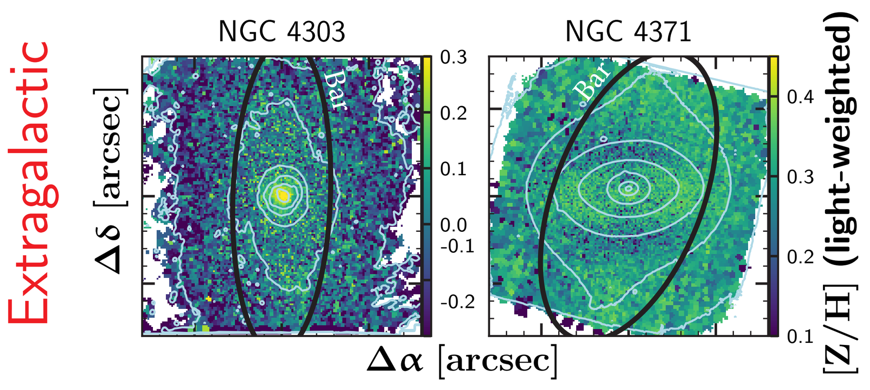
To overcome this difficulty, it has recently been proposed to use red supergiants (RSGs) as a luminous ($10^4 L_\odot$) tracer of chemical abundances; RSGs at large distances, such as M31/M33 (0.8 Mpc), can be observed with recent high-throughput high-resolution spectrographs such as WINERED/Magellan and CRIRES+/VLT. Therefore, RSGs can be a good tracer to connect the chemical structures of the Milky Way and external galaxies.

As a pilot study, we observed four RSGs located at around the Galactic bar end and ten Solar-neighbor RSGs with a near-infrared high-resolution spectrograph (*YJ* bands; 0.91–1.35 µm). This wavelength range has an advantage of the weakest strengths of molecular lines contaminating to atomic lines. We have derived the chemical abundances of the RSGs including amongst others Fe, Mg, Si, Zn, Ge, and Y. We find that the bar-end RSGs have metallicities of ~ 0.0 dex, which is lower than expected from the radial metallicity gradient of the Galactic disk ($\gtrsim +0.3$ dex). This low metallicity indicates the existence of an efficient inflow of metal-poor gas toward the bar-end from, e.g., halo or outer disk. Moreover, this sample sets a base line for comparing with the chemical abundances of RSGs in external galaxies.

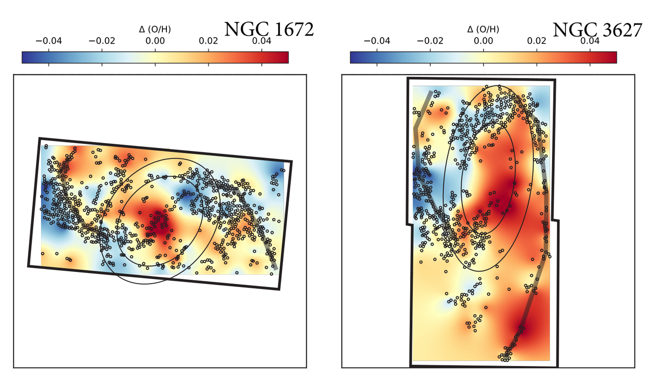
2. Introduction1—2D Metallicity distribution

Old stars | **Young objects**

Extragalactic

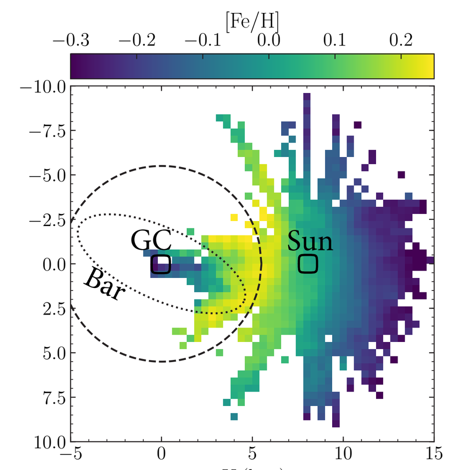


(Neumann et al. 2020, A&A, 637, A56)

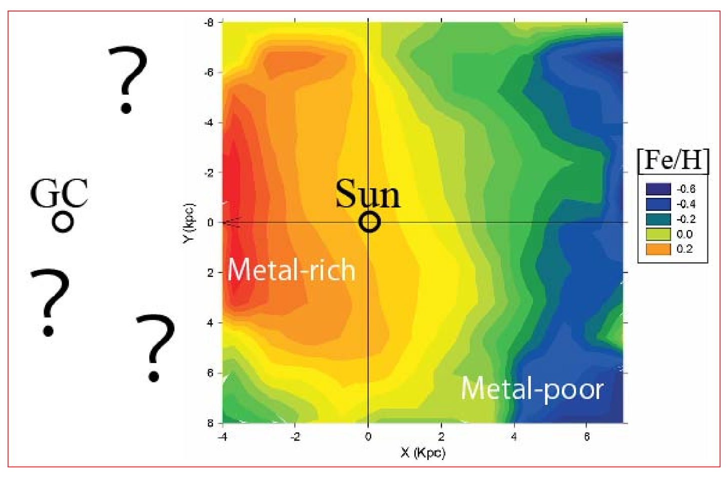


(Kreckel et al. 2019, ApJ, 887, 80)

Galactic



(Bovy et al. 2019, MNRAS, 490, 4740)



(Luck & Lambert 2011, AJ, 142, 136)

3. Introduction2—RSGs as a metallicity tracer

- Metallicity distribution in the Milky Way and nearby galaxies are important research targets in understanding the (chemical) evolution of galaxies (e.g. Pagel 1997).
- Young: ~20–70 Myr
- Extremely bright: $M_{\rm bol} < -5$ mag
- With recent very high throughput near-infrared high-resolution spectrographs (e.g. WINERED/Magellan, CRIRES+/VLT), far RSGs can be observed:
  - Large area in the Galaxy
  - Local galaxies (~ 1 Mpc)

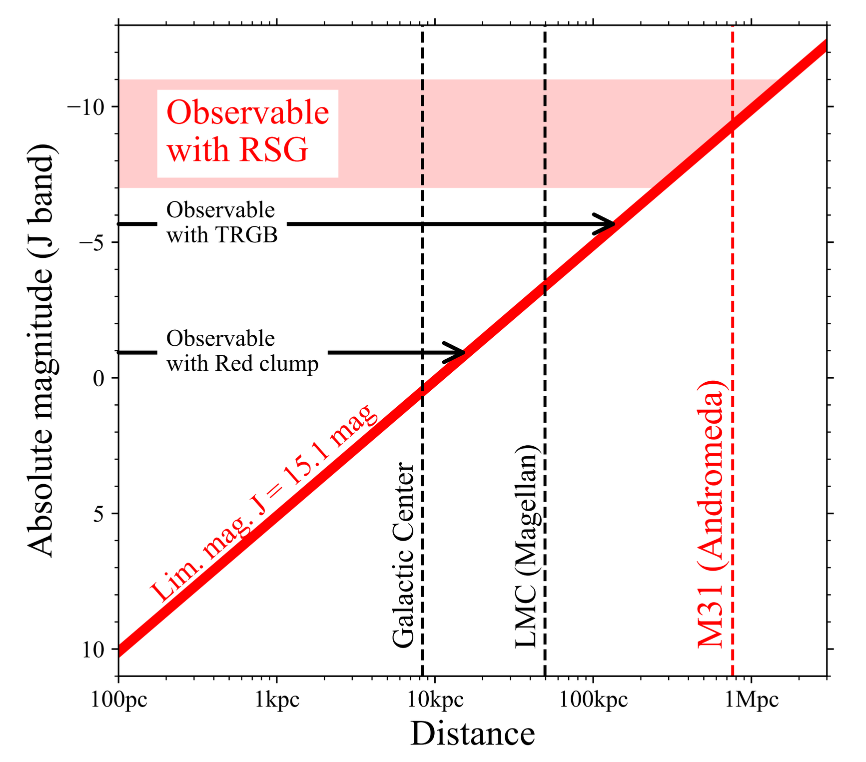


Figure 1: Limiting magnitude of WINERED spectrograph attached to Magellan 6.5 m telescope ($J = 15.1$; Ikeda et al. 2022,).

4. Observation—RSGs at the Galactic bar end

- NIR: *z'*, *Y*, *J* bands (0.90–1.35 µm)

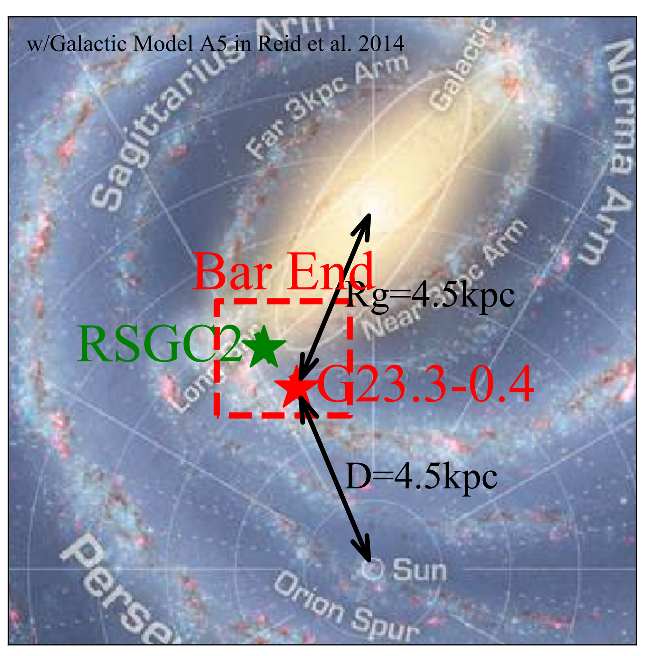


Figure 2: Target of this work: bar end region.

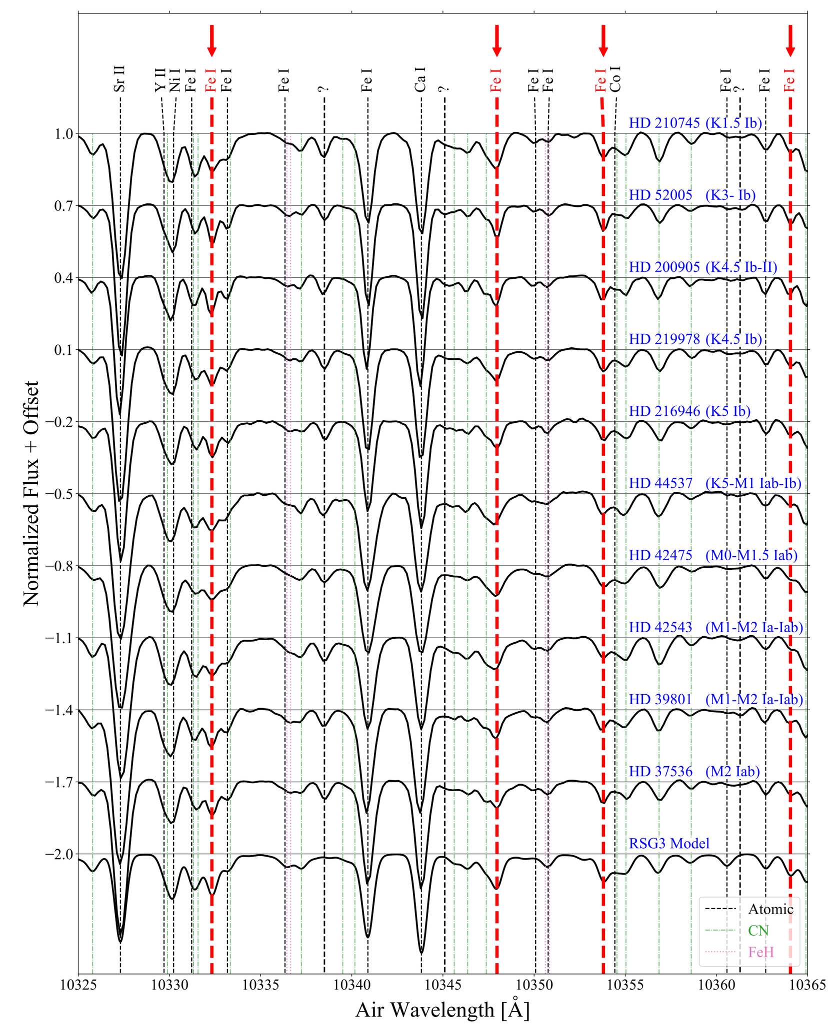


Figure 3: Sample spectra of RSGs.

Table 1: Bar-end RSGs.

Name	SpType	*J*mag	ExpTime	ObsDate
GMC22.3−0.4 region				
ID39	K5I	7.36	1200	2015-08-15
ID42	K3I	8.79	2400	2015-08-15
RSGC2 cluster				
No.3	M4I	7.27	1107	2014-10-07
No.6	M5I	7.72	3860	2014-09-11

Table 2: Solar-Neighbor RSGs.

Name	Sp. Type	*J*mag	ObsDate
ζ Cep	K1.5Ib	0.97	2015-08-08
41 Gem	K3–Ib	2.92	2015-10-28
ξ Cyg	K4.5Ib–II	0.93	2016-05-14
V809 Cas	K4.5Ib	2.16	2015-10-31
V424 Lac	K5Ib	1.87	2015-07-30
ψ^1 Aur	K5–M1Iab–Ib	1.51	2013-02-22
TV Gem	M0–M1.5Iab	2.16	2016-01-19
BU Gem	M1–M2Ia–Iab	2.17	2016-01-19
Betelgeuse	M1–M2Ia–Iab	−3.00	2013-02-22
NO Aur	M2Iab	2.09	2015-10-28

5. Method and results—Metallicity gradient

- Effective temperature: line-depth ratio (LDR) method (Taniguchi et al. 2021)
  1. Calibrating LDR–$T_{\rm eff}$ relations of Fe I lines using red giants with well-known $T_{\rm eff}$.
  2. Applying these relations to target RSGs.
- Surface gravity: stellar evolutionary model and Stefan-Boltzmann's law
- Microturbulence velocity: requiring that $\log \varepsilon_{\rm Fe}$ does not depend on the line strength

- Metallicities of RSGs near the Sun are consistent with those of Cepheids, which is expected because of their young ages ($\lesssim$200 Myr).
- Bar-end RSGs have metallicities lower than expected from the metallicity gradient, as has been suggested by previous studies (Davies et al. 2009; Origlia et al. 2019).
- This low metallicity in a wide area near the bar end (~1 kpc) suggests the Galactic bar may reduce the metal content around the bar end.

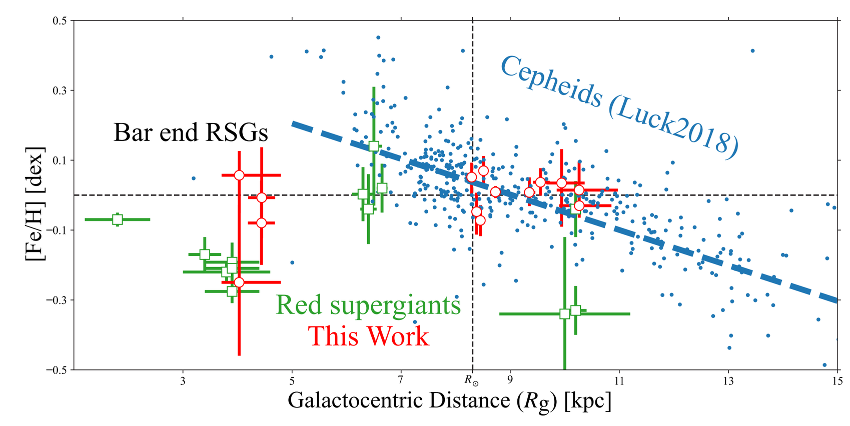


Figure 4: The Galactic metallicity gradient of young stars. Blue dots represent the metallicities of Cepheids (Luck 2018), while green symboles represent those of RSGs (squares for RSGs by previous works, and circles for RSGs by our group).

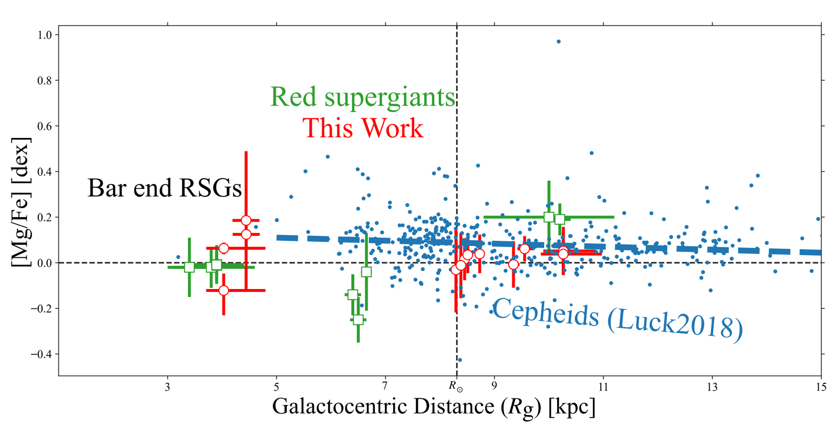


Figure 5: [Mg/Fe] of young stars.

- [Mg/Fe] ratios of RSGs near the Sun are also consistent with those of Cepheids.
- Bar-end RSGs have almost Solar-scaled [Mg/Fe], which does not contradict to the thin-disk chemistry.

- Ongoing/future surveys of RSGs in the Galactic/extragalactic disks would help us understand the chemical structure of galactic disks.
- Especially, comparison between the Milky Way and nearby galaxies (e.g. M31) is important for determining whether the Milky Way is an "usual" galaxy.

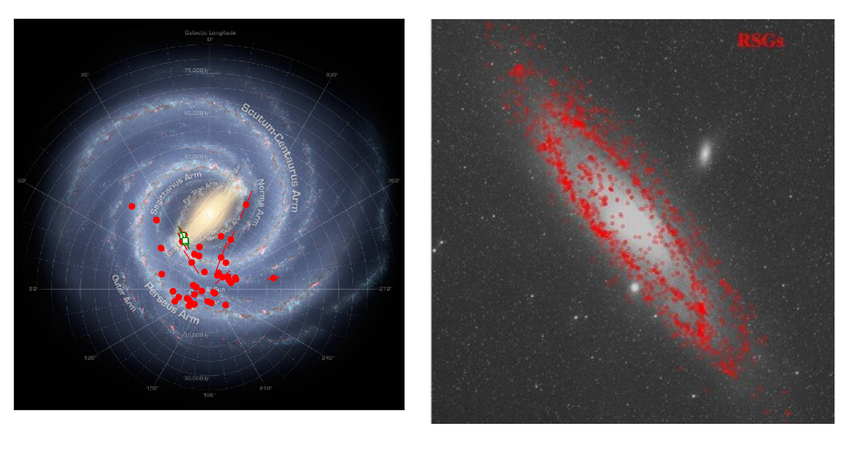


Figure 6: RSG samples in galactic disks. (Left) compilation of RSGs in clusters from literature. (Right) RSGs in M31 (Massey et al. 2021).

References

[1] Taniguchi, D., et al. 2021, *MNRAS*, **502**, 4210
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