# Elemental abundances of red supergiants measured with near-infrared high-resolution spectra

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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)

Red supergiants are a class of young, luminous stars with complicated spectra rich in molecular lines. However, their brightness makes them one of the excellent tracers for metallicity distribution in the Milky Way disk, and thus there is a demand for examining the systematic errors in the derived abundances of red supergiants in detail. To examine the systematics, we analyzed the near-infrared high-resolution spectra of ten nearby red supergiants observed with the WINERED spectrograph (0.97–1.32 μm, $R = 28,000$). As a result, we find that the metallicities of red supergiants determined in this work are in good agreement with well-established results of Cepheids. Therefore, our measurement method for red supergiants is as reliable as methods for Cepheids assuming that young stars ($\mathrm{age} < 200\,\mathrm{Myr}$) in the Solar neighborhood have homogeneous elemental abundances, which are represented by those of gas.

## 2. Introduction1—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: $\sim$20–70 Myr
- Extremely bright: $M_{\mathrm{bol}} < -5\,\mathrm{mag}$
- 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 ($\sim 300\,\mathrm{kpc}$)

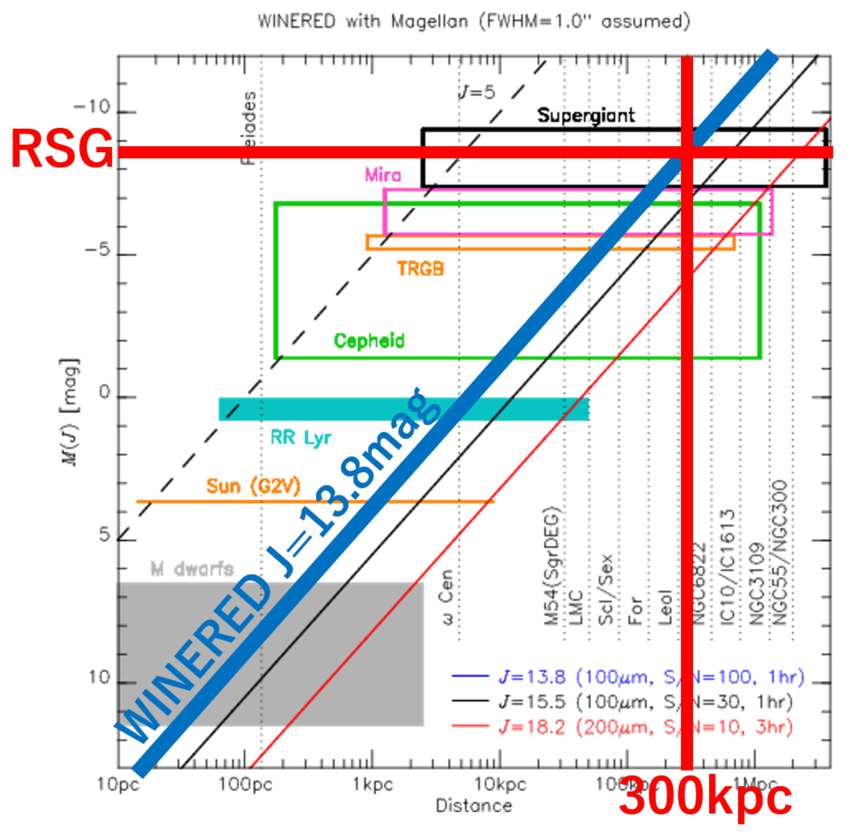


Figure 1: Limiting magnitude of WINERED spectrograph attached to Magellan 6.5 m telescope ($J = 13.8$; Ikeda et al. 2022).

## 3. Introduction2—Molecular blending in RSGs' spectra

- Blending by molecular lines is severe in RSGs' spectra. →Needs of choosing atomic lines free from the blending.
- Near-infrared *YJ* bands is least affected by molecular lines.
- There are many atomic lines of e.g. Fe, Mg, Si, Sr, and Dy in the *YJ* bands (Matsunaga et al. 2020).

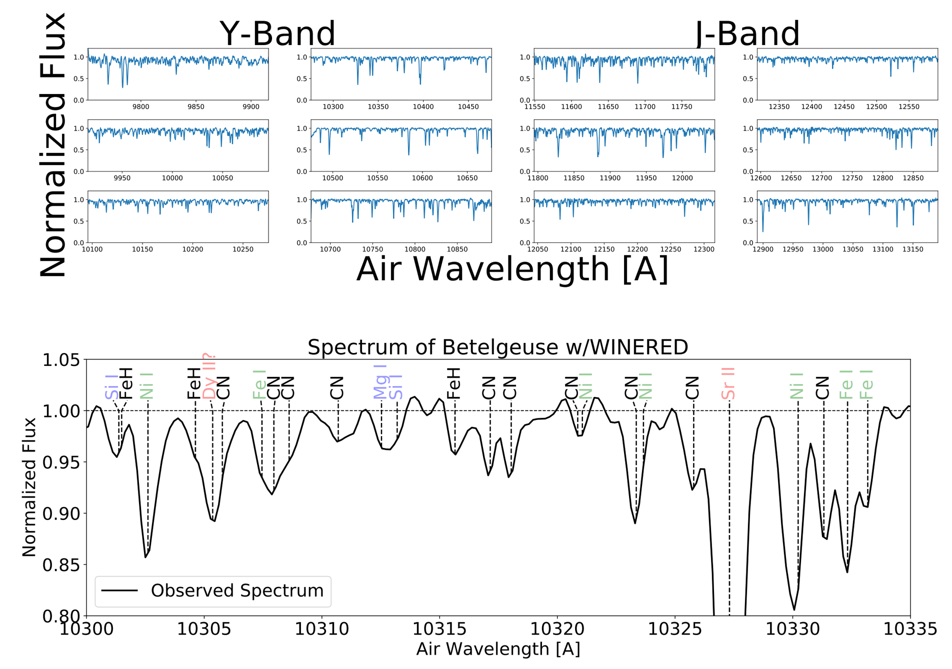


Figure 2: Spectra of Betelgeuse observed with the WINERED spectrograph.

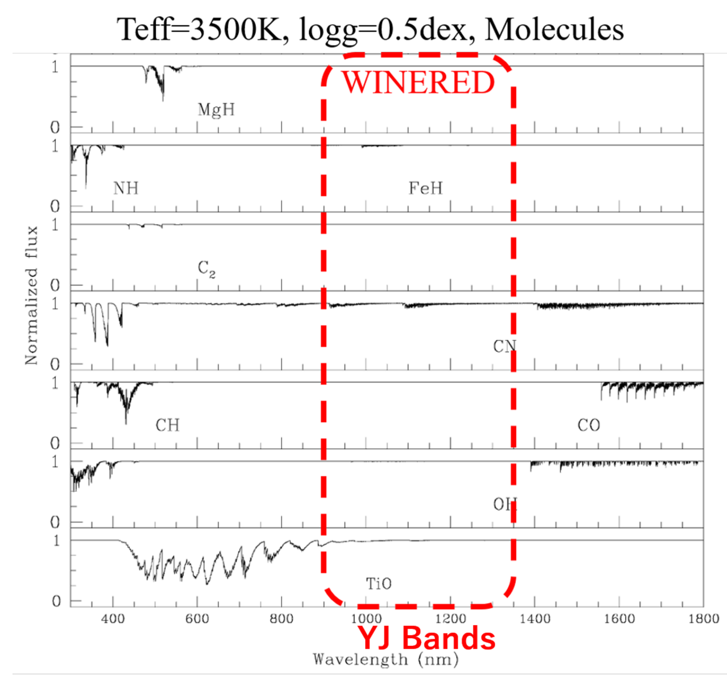


Figure 3: Molecular absorptions in a RSG's model spectrum (Coelho et al. 2005).

## 4. Observation with the WINERED spectrograph

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

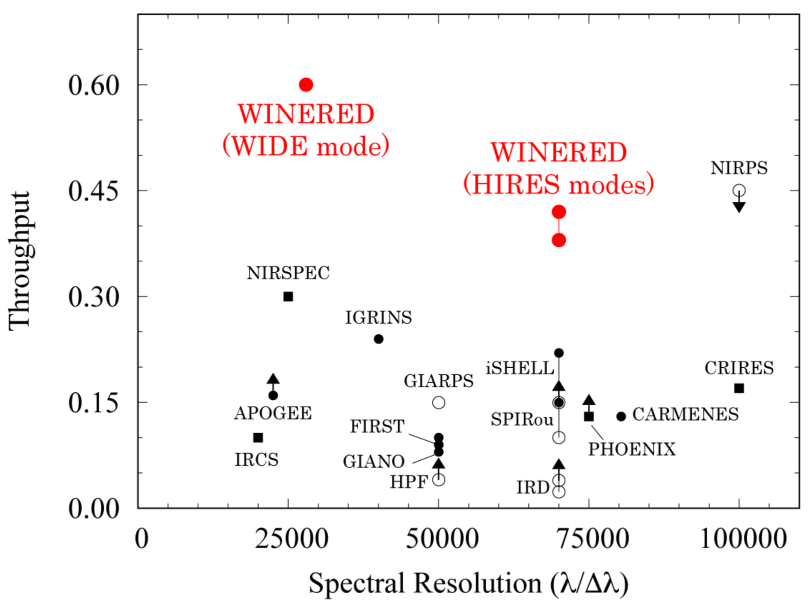


Figure 4: Performance of NIR high-resolution spectrographs (Otsubo et al. 2016; Ikeda et al. 2022).

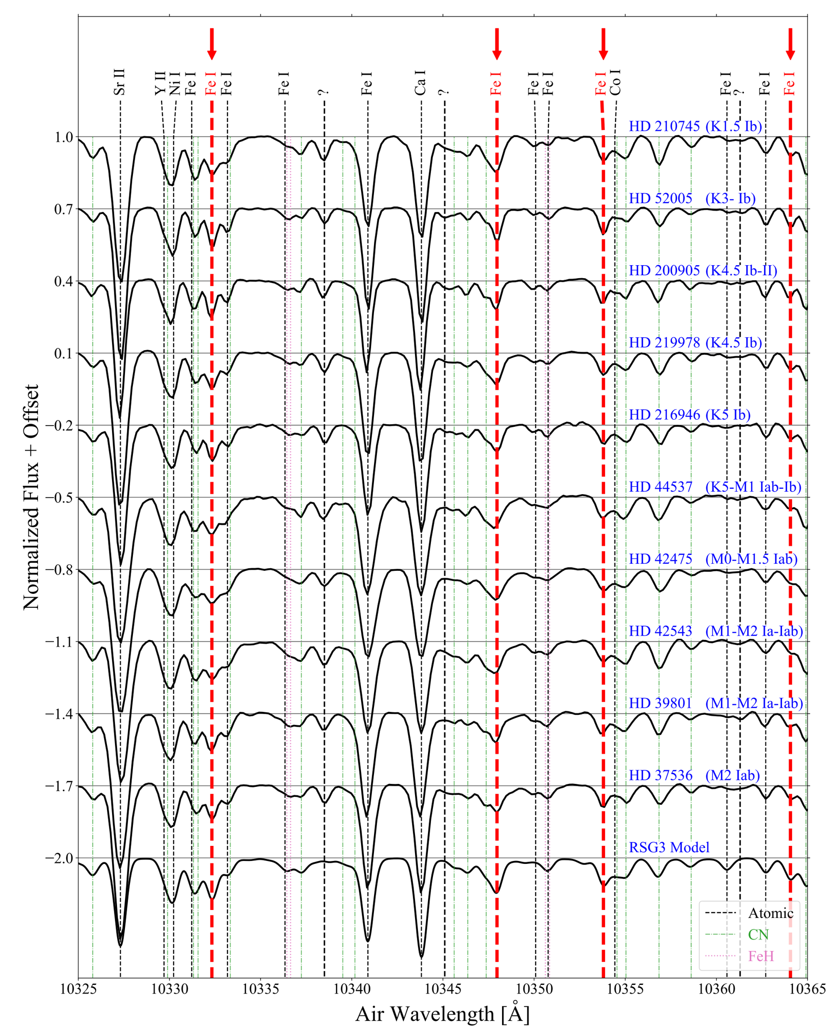


Figure 5: Sample spectra of RSGs.

Table 1: Observation log of red giants.

| Name | Sp. Type | $T_{\mathrm{eff}}$ [K] | *J* mag | Obs. Date |
|---|---|---|---|---|
| ε Leo | G1IIIa | 5398 ± 31 | 1.63 | 2014-01-23 |
| κ Gem | G8III–IIIb | 5029 ± 47 | 2.02 | 2013-12-08 |
| ε Vir | G8III–IIIb | 4983 ± 61 | 1.31 | 2014-01-23 |
| Pollux | K0IIIb | 4858 ± 60 | −0.52 | 2013-02-28 |
| μ Leo | K2IIIbCN1Ca1 | 4470 ± 40 | 1.93 | 2013-02-23 |
| Alphard | K3IIIa | 4171 ± 52 | −0.36 | 2013-11-30 |
| Aldebaran | K5+III | 3882 ± 19 | −2.10 | 2013-02-24 |
| α Cet | M1.5IIIa | 3796 ± 65 | −0.62 | 2013-11-30 |
| δ Oph | M0.5III | 3783 ± 20 | −0.24 | 2014-01-23 |

Table 2: Observation log of 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 |
| $\psi^1$ 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. Analysis and Results: Metallicity measurements

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

- Using the parallax in the *Gaia* DR3 catalogue, we determined the bolometric luminosities of the RSGs.
- On the HR diagram, the distribution of our sample RSGs is well consistent with the latest Geneva's stellar evolution model with the solar metallicity (Ekström et al. 2012).
- A larger sample of RSGs would enable us to test various evolutionary models, incl. metallicity dependence.

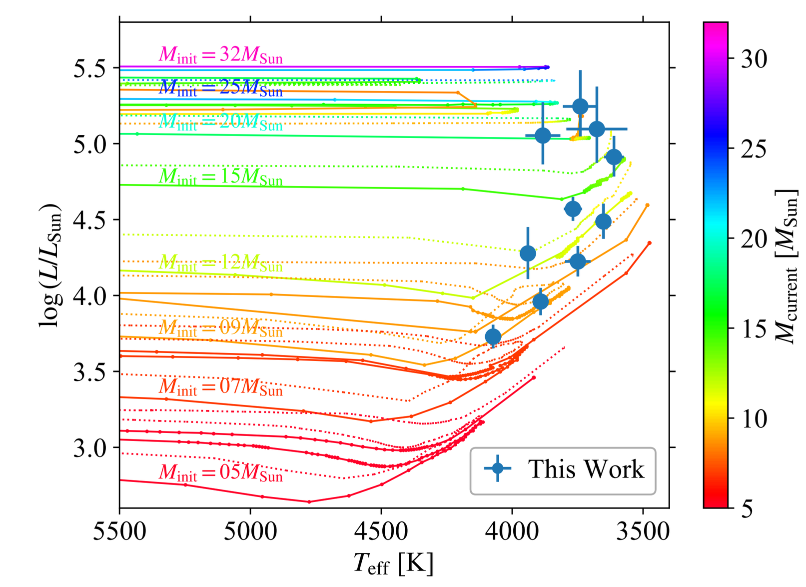


Figure 6: $T_{\mathrm{eff}}$ and $\log L$ of RSGs in this work on the HR diagram.

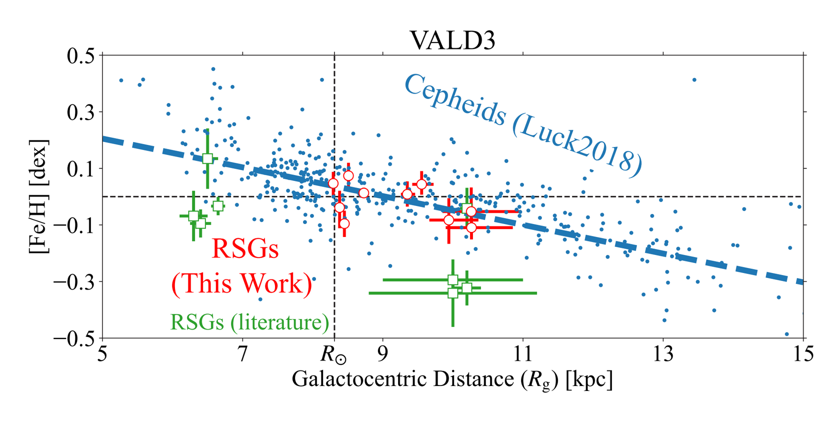


Figure 7: The Galactic metallicity gradient of young stars. Blue dots represent the metallicities of Cepheids (Luck 2018), while other symboles represent those of RSGs (green squares for RSGs in clusters by previous works, and red circles for field RSGs by our group).

- Metallicities of RSGs determined by this work show a good agreement with the radial metallicity gradient of Cepheids. →This fact supports the reliability of our metallicity measurements of RSGs.
- In contrast, metallicities determined by some of previous works show offsets of $\sim 0.3\,\mathrm{dex}$ compared to Cepheids.

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

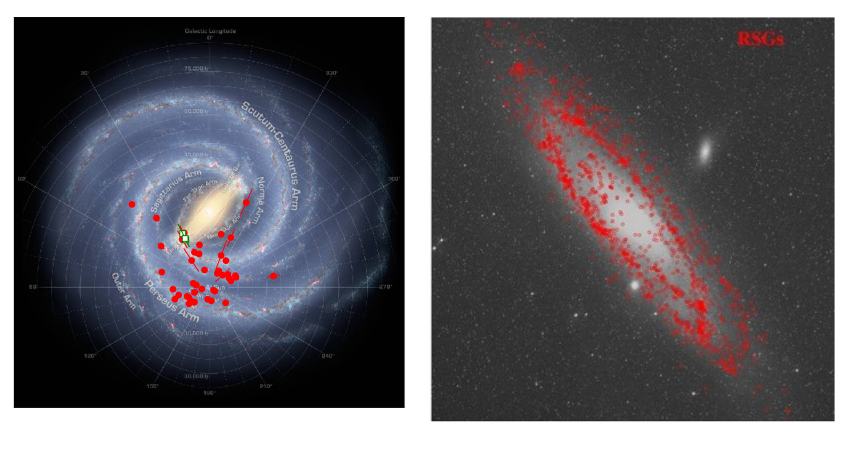

Figure 8: RSG samples in galactic disks. (Left) compilation of RSGs in clusters from literature. (Right) RSGs in M31 (Massey et al. 2021).

## References

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