Candidate red supergiants from Gaia DR3 BPRP spectra: From the Perseus to the Scutum-Crux spiral arms

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Outline

- Introduction
- New cRSGs from Gaia-DR3 and 2MASS catalogs
- XY distribution
- Summary

Introduction

- Red supergiant stars (RSGs) are massive stars in a late stage of evolution, crucial for understanding stellar life cycles and Galactic structure.
  - Mass: between $\approx 8\ M_\odot$ and $\approx 40\ M_\odot$
  - Effective temperatures: from ~3500 to 4500 K
  - Low gravity: $\log(g) < 0.7$ cm s^{-2}
  - Metal-rich: $-0.5 < [Fe/H] < 0.5$ dex
  - Luminous: $\log(L/L_\odot) \geq 4$
  - Young ages: from 4.5 to 30 Myr
- RSGs are usually found in large molecular complexes, which populate the spiral arms of the Milky Way; only a small fraction of them (about 10%) are associated with stellar clusters (e.g., Messineo et al. 2017; Messineo & Brown 2019; Smith & Tombleson 2015).
- However, a search for individually selected RSGs is more complex than in stellar clusters, because of dust obscuration and little knowledge of distances, and RSGs are often mistaken for asymptotic giant branch stars (AGBs) because they have similar colors and magnitudes.

Introduction

- In the last decade, significant progress has been made in identifying RSGs; this is thanks to Gaia data, which provide the parallactic distances and optical stellar energy distribution (SED) of millions of stars, and the availability of photometric time series.
- In the coming years, spectroscopic data at a resolution higher than 10,000 will become available from the GALAH, Gaia DR4 RVS, and 4MOST surveys, providing metallicity for millions of stars. In order to prepare for the upcoming spectroscopic era, lists of bona fide late-type stars with high luminosities are required.
- The catalog of Messineo & Brown (2019) collected and analyzed stars previously reported in the literature as stars of K-M type and class I. Unfortunately, a significant portion of the gathered late-type stars turned out to be faint giants, and the parallactic distances revealed that most of the classes collected from past literature are not reliable.

Introduction

- Following the division of the theoretical diagram of luminosity values versus temperatures in areas, Messineo & Brown (Gaia DR2 2019) and Messineo (2023, Gaia DR3) kept those ≈400 out of 1725 stars analyzed, located in areas A and B, as highly probable RSGs. Healy et al. (2024) report 638 candidate RSGs (cRSGs) in the Gaia DR3 catalog, exceeding the number of bona fide stars of Messineo & Brown (2019).
- This number is still too low to account for the Galactic population. Here, we publish an additional list of candidate RSGs (cRSGs) and examine the determination of the extinction and luminosity of about 300 cRSGs.

New cRSGs from Gaia-DR3 and 2MASS catalogs

- We preselected 2,167,423 data points with the extinction-free magnitude $K_S - 1.311 \times (H - K_S - 0.2) < 8$ mag from the 2MASS catalog (470,992,970 entries) (Messineo 2024).
- By using their 2MASS IDs we retrieved 1,941,750 Gaia DR3 matches (Gaia Collaboration et al. 2023), of which 1,880,040 were assigned distances in the catalog by Bailer-Jones et al. (2021).
  - $\frac{\varpi}{\sigma_\varpi} > 4$: 851,612
  - 2MASS J, H, and Ks data (all three bands): 850,926
- Following the diagnostics described in Messineo (2023), RSGs appear to be preferentially located in a narrow range of colors between 0 and 1 mag.
- In the M_K versus the extinction-free color $W_{RP,\,BP-RP} - W_{K_S,\,J-K_S}$ diagram, two curves are drawn to roughly select RSGs.

$W_{RP,BP-RP} = G_{RP} - 1.3(G_{BP} - G_{RP})$,
$W_{K_S,J-K_S} = K_S - 0.686(J - K_S)$ (Abia et al. 2022)

New cRSGs

- Two curves: Messineo (2023)
- 730 cRSGs with $M_K < -8.5$ mag are located in the cone enclosed by these two curves. As 315 cRSGs are already included in the list of Messineo & Brown (2019), 415 stars remain.
- We searched for available spectral types of the 415 cRSGs in the catalog by Skiff (2014) and in SIMBAD and retrieved it for 279 stars – 185 stars are M-type stars, 22 K-type stars, 20 C-rich stars, 32 S-type stars, 14 F-G types, and seven early-type stars.
- The B-A-F-G type, C-rich, and S-type stars were dropped from the sample, which remains composed of 342 O-rich stars, of which 207 with known KM spectral types and 135 previously unclassified.

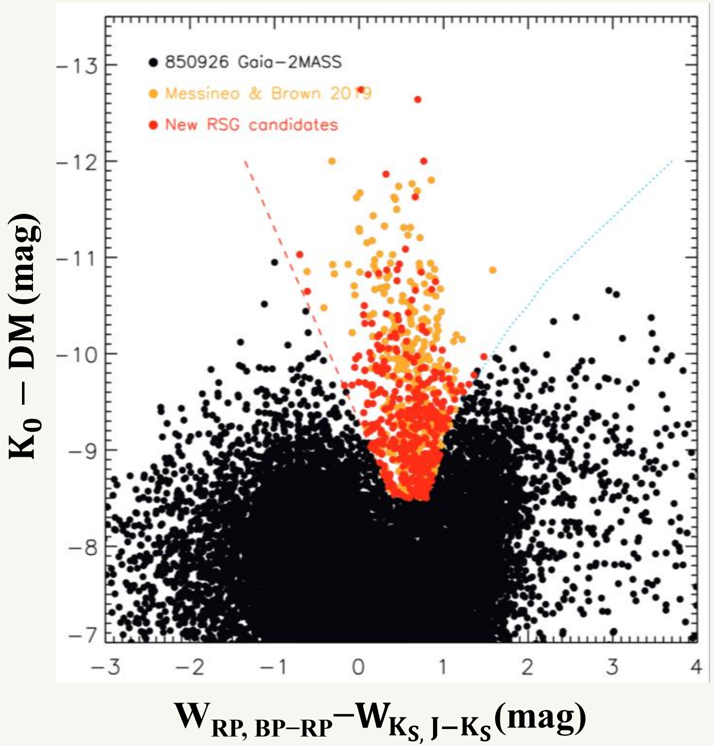


Fig. 1. M_K versus $W_{RP,BP-RP} - W_{K_S,J-K_S} < 4$ colors of 2MASS stars brighter than $K_s - 1.311 \times (H - K_s - 0.2) < 8$ mag and with good Gaia parallax. Selected cRSGs (in red and orange) lie in the cone enclosed by the two curves. The dotted cyan curve indicates a rough separation between O-rich AGB stars and C-rich AGB stars (to the right). The long-dashed red curve separates RSGs from O-rich AGBs and S-type stars. Stars included in the catalog of Messineo & Brown (2019) are colored in orange.

New cRSGs

Spectral types

- The sample contains 135 previously unknown late-type stars, which we classified solely using the Gaia DR3 BPRP spectra.

- We analyzed the BPRP spectra to estimate KM types of the newly selected 342 O-rich stars. 327 BPRP spectra were available, but four were excluded because of poor quality, and four stars had spectra typical of G-types. Among the 15 stars without BPRP spectra, three do not have types in SIMBAD. In conclusion, a clean sample of 335 bright K- and M-type stars was produced.

- Spectral types were inferred by matching the de-reddened BPRP spectra of the target stars with those of reference stars, as described in Messineo (2023). The optical extinction curve by Cardelli et al. (1989), extrapolated to the near-infrared with a power law of index -2.1, was used to deredden the BPRP spectra.

New cRSGs

Spectral types

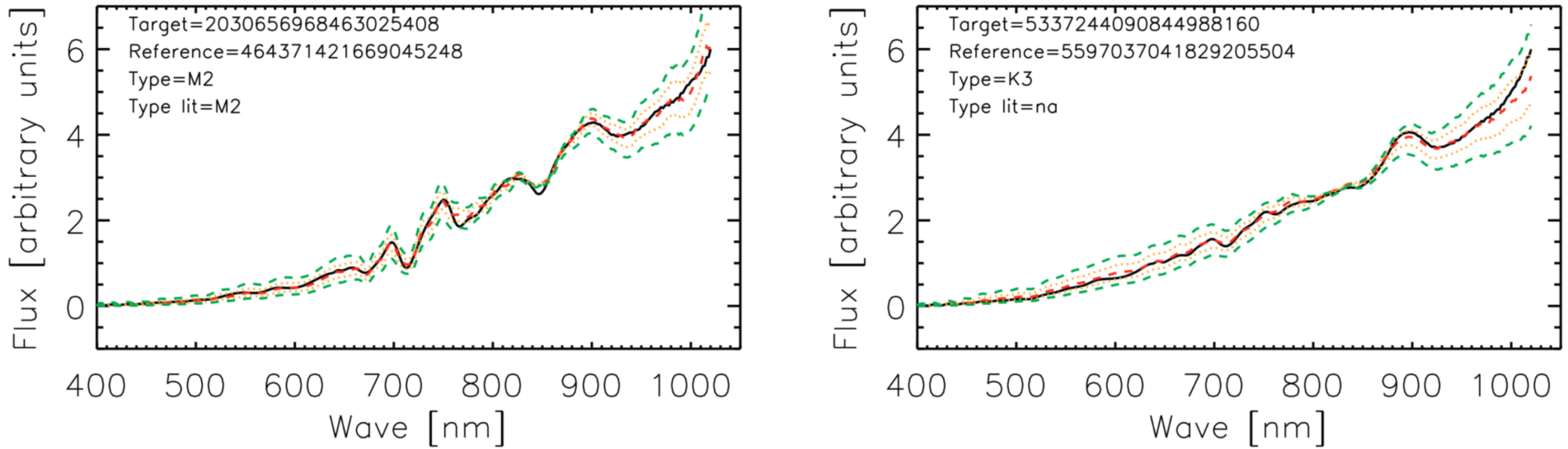


Fig. 2. Two examples of BPRP spectra. The target spectrum is shown with a black curve, and the reference spectrum with the dashed red curve. The reference spectrum was brought to the target′s extinction, which is estimated in the infrared. Extinction variations of $\Delta A_{K_S} = \pm 0.05$ mag and ± 0.10 are indicated with orange dotted and green dashed curves, respectively.

New cRSGs

Temperatures and Luminosities

- By using models of stellar atmospheres (such as the MARCS models) and a fitting technique, Levesque et al. (2005) established a TiO-based temperature scale. They used the TiO bands to determine temperatures.

- Luminosities were obtained using the de-reddened 2MASS Ks, the Gaia distances of Bailer-Jones et al. (2021), the temperature scale, and the BCK of Levesque et al. (2005).

- For the bulk of stars, the derived luminosities are consistent with those of RSGs, as shown in Fig. 6. They are mostly located in areas A and B of the luminosity-versus-temperature diagram.

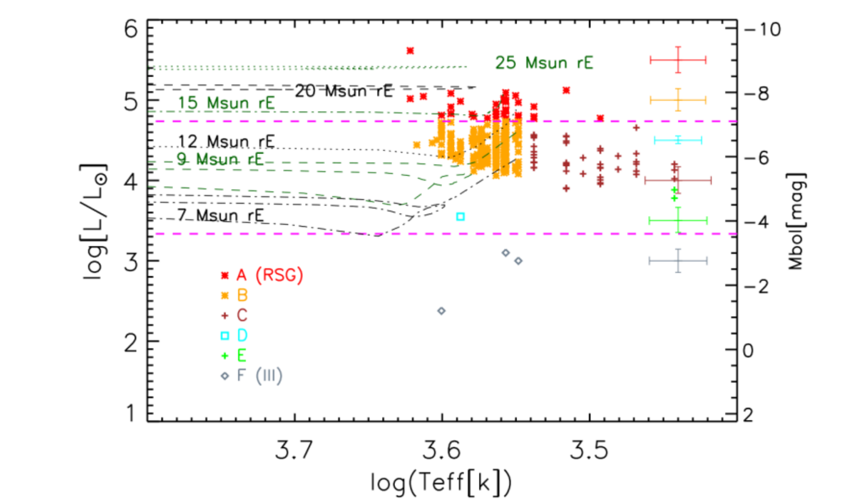


Fig. 6. Luminosities versus $T_{\rm eff}$ of newly selected stars. Evolutionary tracks with solar metallicity and rotation by Ekström et al. (2012) are over-plotted.

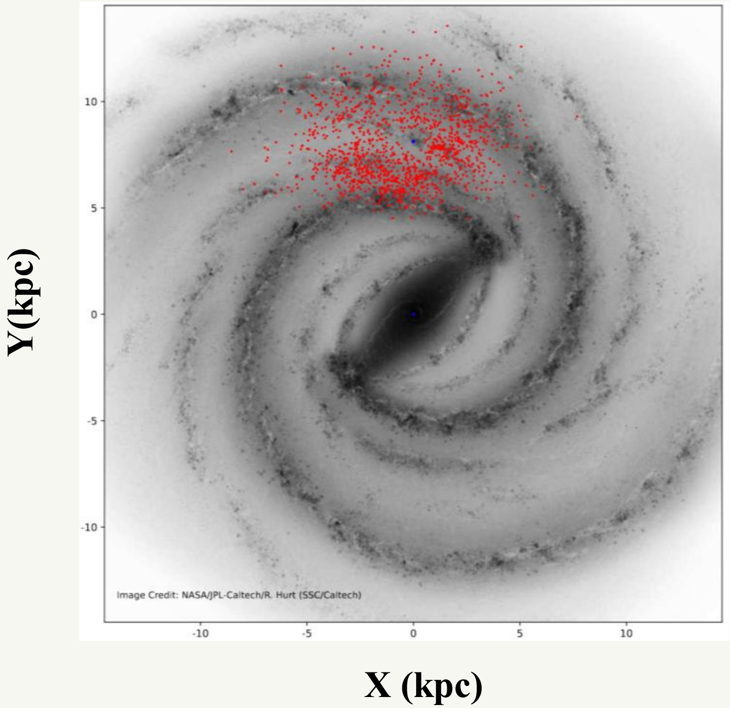
[3] As in Messineo & Brown (2019), Area A is defined as $M_{bol} < -7.1$ mag, which is the AGB limit. Area B is coded as $-7.1 < M_{bol} < -5.0$ mag and $L/L_\odot > 51.3 - 13.33 \times log(T_{\rm eff})$, with $\log(T_{\rm eff}[K]) > 3.548$.

XY distribution

- There is approximately one RSG for every burst of 10,000 stars (e.g., Clark et al. 2009a). That is, RSGs are young enough to still mark sites of violent cloud collisions and gas compression, and they populate the spiral arms.

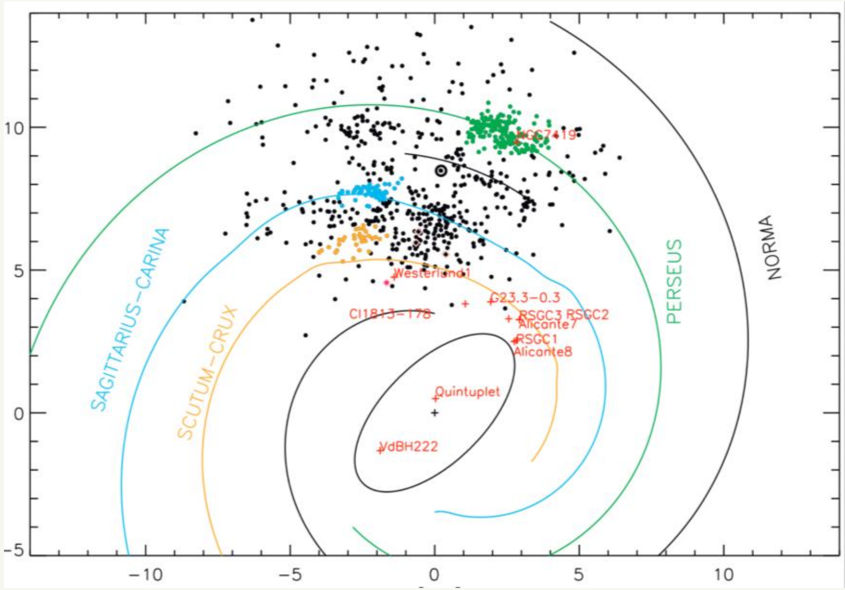
- XY view of stars located in areas A and B of Mbol versus Teff diagram of Messineo & Brown (2019) and newly selected Gaia-2MASS cRSGs, which are also located in areas A and B (red dots).

- The distribution of cRSGs appears far from being homogeneous; indeed, there are several over-densities of cRSGs along the spiral arms, and filaments of cRSGs decorate the inter-arm regions.



XY distribution

- XY view of cRSGs from areas A and B of Messineo & Brown (2019), along with new Gaia-2MASS cRSGs.
- Green filled circles indicate stars located on the large over-density of RSGs of the Perseus arm.
- Cyan filled and Orange-filled circles mark stars corresponding to an apparent concentration of RSGs at the tangent point of the Sagittarius-Carina arm at l≈ −78◦ and the Scutum-Centaurus arm at l≈ −50◦, respectively (Hou & Han 2014).
- Known massive clusters (> 104 M⊙) rich in RSGs are marked in red.



Y(kpc)

X (kpc)

The spiral arms of Cordes & Lazio (2002), taken from the native NE2001p Python code of Ocker & Cordes (2024), are also shown.

Summary

- The work yielded a genuine sample of O-rich late-type stars, and the calculated luminosities confirm that the sample is mostly made of stars brighter than M_{bol}=-5 mag. This new sample represents a 40% increase in the number of highly probable RSGs compared to previous studies.
- A small percentage (18%) of stars are found to be members of stellar clusters. While 58% of the clusters are reported to be younger than 41 Myr old, most have ages below 300 Myr. By extrapolating these percentages to the entire sample, 58% should be true RSGs.
- When looking at the X and Y distribution on the Galactic plane, beside the populous Perseus associations of RSGs and the Sagittarius group of RSGs, a novel population of highly probable RSGs populating the more distant Scutum-Centaurus arm appears.
- In the XY plane, the cRSGs appear to populate inter-arm regions.

Thank you!