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Disentangling massive AGB stars and red supergiants

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Abstract. The difference between AGB stars and RSGs lies in physical processes within. However, this difference is not very noticeable on the surface of these stars: their colours are pretty much the same and their spectra are very similar, especially when low luminosity RSGs and AGB stars are compared. Therefore, to separate RSGs from high-luminosity giants is an open issue. Due to the limitations of classical criteria and the analysis of individual stars, we decided to use statistical methods. For this, we performed a spectroscopic study of a significantly large sample of RSGs and AGB stars from the Magellanic Clouds. In total, we observed and analysed more than 600 RSGs and AGB stars, covering wide ranges in SpT (from G0 to M9), luminosity (M_{bol} from −9 to −4 mag), and in metallicity (as we observed targets from both Magellanic Clouds). From the analysis of our sample, we find that high and mid-luminosity RSGs (LC Ia and Iab) present a behaviour intrinsically different from those of low luminosity (LC Ib or Ib – II) and luminous giants (LC II). We also used the spectral information in the Ca Triplet range to develop through statistical analysis a method for the discrimination of luminous giants and supergiants. These results have major implications for any work about AGBs and RSGs in low metallicity galaxies, but also provide a statistical context when these populations are studied at higher metallicities.

Key words. Stars: Supergiants – Stars: AGBs – Galaxies: Magellanic Clouds – Stars: statistics

1. Introduction

Stellar evolutionary theory separates the luminous late-type population of stars in two different groups: red supergiants (RSGs) and asymtotic giant branch (AGBs) stars, depending on their evolutionary pathways and their predicted death. What differentiates evolved high-mass stars with late types (known as RSGs) from luminous red giants is the behaviour of their cores. However, it is not possible to observe their inner processes directly. Thus, we need other ways to discriminate RSGs from luminous red giants.

The use of criteria based on colours is a typical method to select specific types of stars, but it is not useful in this case. Red giants and RSGs have in common many of their atmospheric characteristics: both groups have cool extended atmospheres, significant mass-loss rates and share the same range of temperatures. In consequence, they have the same colors in many cases (e.g. González-Fernández et al., 2015).

Luminosity is an obvious difference. Most RSGs are more luminous than most red giants. This criterion is useful to identify mid- and high-luminosity RSGs. However, low luminosity RSGs and high luminosity giants (in the AGB phase) share the same luminosity range (e.g. González-Fernández et al., 2015). In addition, this method is only useful when distances are known, which is not usually the case.

The spectral features classically used to distinguish RSGs from red giants, are those related to luminosity. However, in many cases it is not possible to determine if a target is a high-mass star or not using the spectral classification, because the luminosity class (LC) is not indicative of the inner processes; it is only morphological. In consequence, classical criteria identify as high-mass many stars which are in fact intermediate-mass stars (Dorda et al., 2016a).

Variability provides a more reliable method than those explained above. Although most RSGs present photometric and spectral variability (Dorda et al., 2016a, and references therein), it is much less extreme than in the case of AGB stars. However, some supergiants have extreme variations (Humphreys et al., 1972; Humphreys, 1974), and the only way to distinguish them from giant stars is the luminosity. In addition, this method requires observing periods of several hundreds of days (Wood et al., 1983).

As alternative, we present here our methods, based on statistical analysis of large samples, and the results we obtained with them. The full details of our work can be found in González-Fernández et al. (2015); Dorda et al. (2016b,a), as in two upcoming works: Tabernero et al. in prep. and Dorda et al. in prep.

2. Sample selection and observations

The objective of our work was the study of the RSGs in the MCs. For this, we took a list of previously known RSGs from Elias et al. (1985); Massey (2003); Neugent et al. (2010). We also added a large number of candidates to RSGs, which were selected through photometric criteria using the infrared free reddening parameter $Q_{\rm IR}$ (see González-Fernández et al., 2015, for details). We had several hundreds of targets. Thus, we decided to observe them using the AAOmega spectrograph, which is mounted on the 3.9 m Anglo-Australian Telescope. This fiber-fed dual-beam spectrograph can observe up to 400 targets at the same time in both the optical and the infrared Calcium Triplet (CaT) spectral ranges. For the CaT range we used grating 1700D, which provides a resolving power of $R = \lambda/\delta\lambda \sim 10\,000$, while for the optical range we used the gratings 580V ($R \sim 1300$) and 1500V ($R \sim 3700$).

We classified all the observed targets through their optical spectra, using classical criteria. In addition, we removed from our sample those targets having radial velocities incompatible with being part of the Magellanic Clouds (for details see González-Fernández et al., 2015). Finally, we calculated the bolometric magnitudes for those targets from the MCs. For this, we used the 2MASS photometry and the bolometric correction proposed by Bessell & Wood (1984). For details, see Dorda et al. (2016b).

In total, we observed more than 500 hundred RSGs (González-Fernández et al., 2015). In addition, we found about 40 luminous giant or AGB stars among our observed targets. It must be remarked that our objective was to observe RSGs. In consequence, our exposures were not deep enough to have a large number of red giants. However, those which we have, are those which pass our selection criteria and which are luminous enough to be easily identified as RSGs.

3. Results

3.1. Spectral type and bolometric magnitude

When we plotted the diagram of SpT against absolute bolometric magnitude for our sample, we found that there is a clear trend between SpT and luminosity (see Fig. 1). This trend is composed mostly by mid- to high-luminosity RSGs (blue colors), while most of the stars outside the trend were classified as low luminosity RSGs (Ib – II) or luminous giants (II).

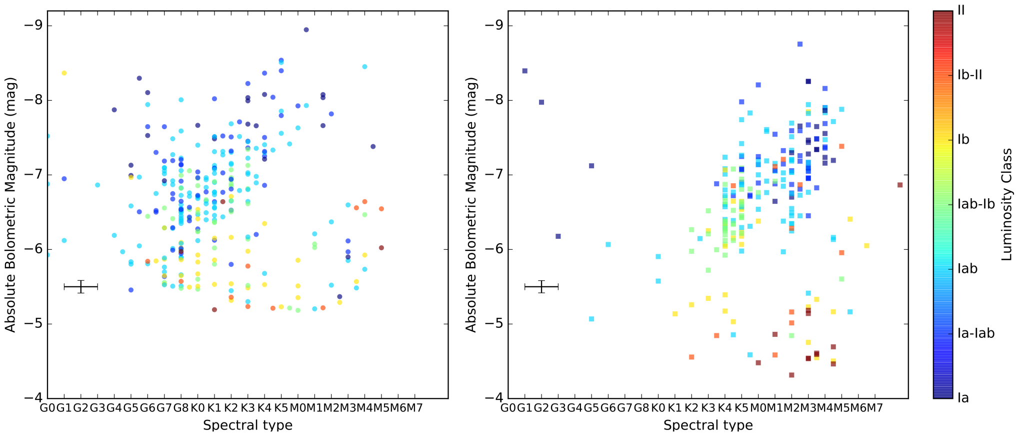

Fig. 1. Spectral type against absolute bolometric magnitude for our two samples: from the SMC (left panel) and the LMC (right panel). The color indicates the luminosity class. The black crosses indicate the median uncertainties in each sample.

We found remarkable that for a given luminosity there is a difference in SpT between the less luminous stars in the trend, and those out of it. The difference is clear in the SMC sample, because the SpTs of RSGs in the low luminosity end of the trend are relatively early. In the LMC, the difference is not so large, but still significant. As the RSGs at the beginning of the trend seem to follow the same behaviour as more luminous RSGs, we think that the difference between them and those stars outside the trend may be a consequence of their different inner physical processes. In other words, stars outside the trend are luminous intermediate-mass stars, instead of high-mass stars, regardless of their luminosity classification (which only attends to the morphology of the spectra).

We also calculated the temperatures of our RSGs through spectral synthesis (for the details, see Tabernero et al., submitted). When we compare our samples with the predictions done by Geneva evolutionary models, we found that those low-luminosity RSGs which do not follow the trend between SpT and luminosity seem to correspond to the track of 9 $M_{\odot}$. Thus, they correspond with the masses expected for very luminous giants. Instead, mid- to high-luminosity supergiants seem to correspond to tracks of higher masses.

Therefore, if the distance of a sample is known, the SpT to Luminosity diagram provides a useful tool to split RSGs and luminous giants. However, as the distances may be unknown in many cases, we developed another method to separate high-mass RSGs from luminous giants.

3.2. PCA analysis

We used a statistical analysis of the spectra from our sample to develop a method that separates supergiants from non-supergiants. For this, we first measured in an automated way the main spectral features in the Ca Triplet spectral range. Then, we performed a Principal Component Analysis (for details see Dorda et al., 2016a). These components concentrate all of the useful spectral information. Finally, to define the boundaries between supergiants and non-supergiants in our sample, we used the Support Vector Machine method.

With this method, we recovered 95% of the stars manually classified as RSGs. In fact, those not identified by this method were low luminosity supergiants, which were detected as different from the main group of mid- to high-luminosity RSGs. For details, see Dorda et al. (2016a)

We applied this method to a problem sample of RSGs candidates that we observed in the Perseus arm. We obtained their spectra in the Ca Triplet spectral range, at a resolution similar to that of the Magellanic Clouds observations. Then, we used the PCA method to split supergiants from non-supergiants. In addition, we performed a classical visual classification of the candidates.

The number of RSGs obtained through each method is substantially different. However, this difference is caused by those stars classified as low luminosity RSGs. The PCA method does not identify them as RSGs, probably because it is detecting subtle differences in their spectra, which is a consequence of being luminous giants or AGB stars, instead of supergiants. Therefore, we think that this method is a powerful tool to split high-mass stars from luminous giant stars. Moreover, as this method only requires the observation of the spectra, it can be used for populations at unknown distances.

4. Conclusions

The identification of the true nature of luminous cool stars is not easy when we are dealing with individual stars. However, the statistical analysis of large samples provides a powerful tool for this task. To illustrate this, we presented two of our main results, which provide a new perspective for the identification of RSGs and AGB stars:

1. We analysed the SpT to luminosity diagram for our sample. We found that most mid- to high-luminosity (LC Iab and Ia) RSGs pressent a behaviour different to most low luminosity RSGs (LC Ib or Ib – II) and luminous giants (LC II). We think these statistical behaviours are indicative of their different inner processes. Thus, this diagram provides a useful tool in the analysis of luminous red stars.
2. We presented a statistical method, which uses the spectral information in the Ca triplet range, to split supergiants from non-supergiants. This method resulted in a very high efficiency identifying Iab and Ia RSGs. However, it identifies many Ib and Ib – II as non-supergiants (high-mass stars), as these stars do not share the same spectral properties as high-mass RSGs. We think that this method is capable to handle the subtle differences present in spectra from stars with different inner processes. However, this idea requires further research.

In conclusion, the statistical analysis over large samples presents a new approach to split high-mass supergiants from intermediate-mass luminous giants. Although our findings need further work, we think these methods have a high potential in the upcoming age of large spectroscopic surveys, with instruments such as Gaia and WEAVE.

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