Highlights of Spanish Astrophysics VIII, Proceedings of the XI Scientific Meeting of the Spanish Astronomical Society held on September 8–12, 2014, in Teruel, Spain. A. J. Cenarro, F. Figueras, C. Hernández-Monteagudo, J. Trujillo Bueno, and L. Valdivielso (eds.)

Red supergiant identification and classification

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Abstract

The interest for red supergiants has grown in the past few years, as these objects are being used for a number of different studies. In spite of this, their spectral identification and classification still present several problems and limitations that we expose in this work. To bring light to this topic, we have homogeneously observed and classified the largest sample of red supergiants to date. We are using this data to develop a system of identification and classification for these objects through the atomic and molecular features in the infrared Calcium Triplet spectral region. Also, our method will allow the identification and classification of the cool bright stars observed by *Gaia* without resorting to TiO bands, as none of their bandheads is inside the *Gaia* spectral range.

1 Introduction

When stars with initial masses between ∼8 and $\sim 25\ M_\odot$ [10] leave the main sequence, they evolve quickly, expanding their atmospheres to hundreds (sometimes, more than one thousand) solar radii. This process seems to happen at constant luminosity and, therefore, the atmosphere expansion is compensated by a temperature drop. The result are red supergiants (RSGs), high luminosity stars, $\log(L/L_\odot) \sim 4.5-5.8$ [13], with late (K and M) spectral types (SpTs).

As the typical ages of RSGs range from 8 Myr to 20 Myr [10], these stars are good tracers of recent star formation. Moreover, these stars have a clear observational advantage with respect to young and hot high-mass stars: due to their low temperature, their emission peaks in the near infrared (nIR). Therefore these stars can be observed through heavy extinction, while the hot high-mass stars become difficult to observe, because they have their emission peak in the ultraviolet.

The high-mass stars which will evolve to RSGs are preferentially born in high-mass clusters. Clark et al. [3] estimated that a cluster must have a minimum initial mass approaching $10^4\ M_\odot$ to guarantee the presence of $2-4$ RSGs at a given time. Therefore, RSGs are very useful massive stellar formation tracers. In fact, in the past few years many RSGs clusters have been discovered in the inner galaxy [4, 5, 6, 8, 24], revealing the massive stellar formation in those regions.

Beyond their role as massive stellar formation tracers, RSGs are an essential key to understand high-mass stellar evolution. About 80% of the high-mass stars pass through the RSG phase at some point in their evolution, but only spend there about 10% of their lifetime. In consequence, models are very sensitive to the physical conditions of this stage, as the mass-loss during it may change drastically the subsequent evolution [10].

Finally, as RSGs are easily observable even at intergalactic distances, they have also been used to study the high-mass population and evolution in other galaxies [13, 21, 19, 20, 1], as well as to trace abundances [7].

Because of the reasons exposed above, RSGs are interesting objects but also elusive ones. Their photometric characteristics are pretty much the same as those of the ubiquitous red giants. The main difference is their high luminosity, but when we are looking through the galactic plane, we have no information about the distance or the extinction. Therefore photometric criteria only allow the selection of RSG candidates, but they cannot separate them effectively from other red stars. In consequence, spectroscopic observations are needed in order to confirm the nature of the candidates selected.

2 Spectral identification and classification of red supergiants

The identification of RSGs through spectroscopy is not an easy task. Firstly, there are very few RSG standards. There are two reasons for this. The first one is the small number of these stars optically accessible in our Galaxy. Moreover, standards only exist for the early-M spectral subtypes; there are no luminosity class I standards later than M4, but in fact there are supergiants with later spectral types (see for example [26]). The second one is that long-period spectral variability is common among RSGs. Even some of the established standards present variability.

Secondly, at low temperatures molecular bands (mainly TiO) become prominent in the spectra. These bands were used to define the spectral subtypes for M-stars, but as these bands grow in depth, they erode all the other spectral features, even erasing the weaker lines. In consequence, the ratios of atomic lines used to determine the Luminosity Class (LC) become useless for late SpTs.

Even though the RSG classification is used in many works, it is poorly characterized. The main criteria for SpTs were developed using photographic plates, before the CCD era ([27] and references therein), and are defined for the optical range. However, the optical range is not the most adequate for modern studies. As the emission peak of RSGs is around the nIR, this spectral range is easier to observe and less affected by interstellar extinction.

There are works from the CCD era [18, 12, 2] that study the spectral features in the infrared Calcium Triplet (CaT) spectral range (from ~ 8400 to ~ 9000 Å). In fact, the CaT itself is a powerful luminosity indicator [9]. However, RSGs are just marginally studied in these works: they use a very low number of SGs, and all are earlier than M SpT. As most

RSGs in our galaxy are of M type, these works are not useful for them. Moreover, the CaT become useless for LC classification (because of the effects of TiO bands) for stars later than ∼M3 [25].

Finally, there is a critical factor that has not been studied until now: how metallicity affects the spectral features used for classification in RSGs.

3 Work outline and objectives

We are working to circumvent the problems and lacks exposed before, providing a detailed spectral study of RSGs. To achieve this, we are applying the following the work-path:

1 Observe a statistically significant sample of RSGs in both the nIR and optical ranges.

2 Perform exhaustive spectral and luminosity classifications, using the classical criteria for the optical range.

3 Measure the spectral features from the nIR (around Ca Triplet).

4 Study the correlation between the optical classifications and the value of spectral features from the nIR.

This work will provide a large RSG catalogue, homogeneously classified (González-Fernández et al. 2015, submitted), from which we will derive clear criteria to classify both spectral type and luminosity class, independently of the effect of rising TiO bands. Moreover, these result will be applicable to the *Gaia* spectral range.

4 Object selection and Observations

We selected a large sample of RSGs and photometric candidates in the Magellanic Clouds (MCs), because these galaxies present clear advantages. Firstly, the extinction is very low along the line of sight to the MCs, allowing easy observation of both the optical and nIR spectral range. Secondly, the physical properties of the MCs, such as their intrinsic radial velocities, metallicities and distances, are well established; thanks to this, we can easily check the membership to the MCs for our observed stars and determine their absolute magnitudes. Finally, each of these galaxies hosts about a hundred known RSGs, providing a sample that shares common parental environment properties. Thus, we obtain two samples, each one pretty homogeneous in their properties, but with clear differences between them. Table 1 summarizes our observations.

Our samples were observed with AAOmega, a fibre-fed multi-object spectrograph, at the Anglo-Australian Telescope (AAT). This instrument can allocate up to 400 fibres in a 2 degree field. The light of each fibre is split and dispersed by two different grisms, providing two different spectra covering at the same time the optical (4000 to 5800 Å, at R ∼1300) and the nIR (8400 to 8900 Å, at R ∼10000) spectral ranges. Therefore, it is the ideal instrument for our work.

Table 1: Objects observed for this work. The details about the photometric selection and spectral classification are explained in González-Fernández et al. 2015 (submitted)

	Known SG		Candidates		
Galaxy	Red SGs	Yellow SG	SG	carbon stars	other stars
Large MC	103	3	125	48	112
Small MC	110	54	162	10	238

5 Results and future work

We have performed the classification of all stars from our samples using classical criteria [22, 11, 14, 15, 16, 23, 28, 17] for the optical spectral range, while we have measured 21 pseudo equivalent widths (EWs) from the main atomic and molecular features. In this way, the characterization of the CaT done using the features measured is independent of the spectral and luminosity classifications.

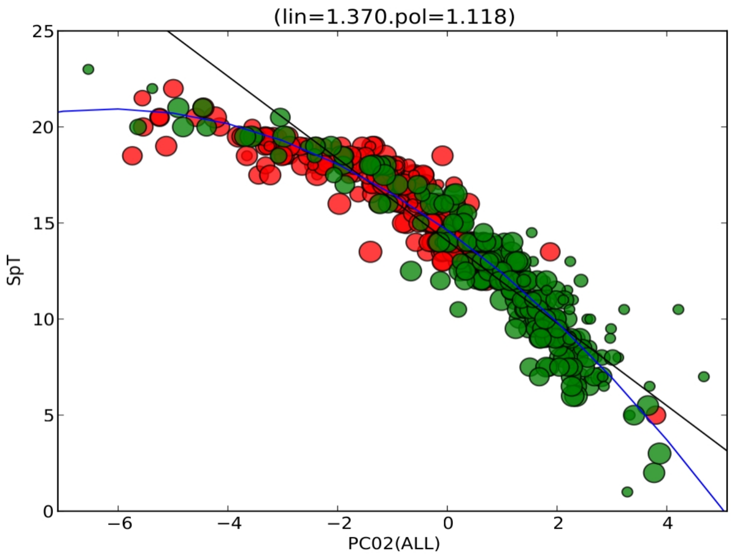

Figure 1: This image shows the relation between the SpT assigned in the optical range and the value obtained from the second principal component. The values of SpT were assigned as follows: 0 to G0, 8 to G8, 9 to K0, 14 to K5, 15 to M0 and 23 to M8. The size of the circles is proportional to the luminosity of the stars: the largest circles are LC Ia, and the smallest LC V. The red circles are stars from LMC observations, and green circles from SMC observations. The blue line is the best fit using an order 2 polynomial (with a dispersion of 1.2 spectral subtypes). The black line is a linear fit as a comparison to the polynomial one.

The measurements of EWs were done in a automatic and uniform way. Then, a principal component analysis was performed over the values from all the stars, including all non-supergiant contaminants (except the carbon stars). The preliminary results show a clear correlation between the second principal component and the spectral type (Figure 1), independent of the luminosity and the metallicity, as the samples from both galaxies have the same trend. Moreover, this SpT classification is independent of the depth of TiO bands in the CaT spectral range. This is a result of high interest for *Gaia*, as its spectral range (~ 8470 to ~ 8740 Å) does not cover the TiO bandheads around the CaT, making impossible a reliable spectral and luminosity classification for M stars. However, our results still require further analysis to find a rational and reliable method to classify the RSGs.

In addition, we have obtained the largest cool SG catalogue to date, containing a $\sim$70% of previously unknown SGs. Moreover, the whole catalogue has been classified in a homogeneous way using classical criteria for the optical spectral range. We are using this catalogue as a base not only to obtain new identification and classification methods, but also to characterize the RSG population in the MCs, specially among the low-brightness RSGs.

In the future, we will use all these methods to study two Galactic samples that we have already observed, one around the base of the Scutum arm, and the other along the Perseus arm.

Acknowledgments

This research is partially supported by the Spanish Ministerio de Economía y Competitividad (Mineco) under grant AYA2012-39364-C02-02. The work reported on in this publication has been partially supported by the European Science Foundation (ESF), in the framework of the GREAT Research Networking Programme.

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