Mem. S.A.It. Vol. 77, 937

Memorie della

On the luminosity of AGB stars as observed in the infrared from space and from the ground

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Abstract. As a part of a reanalysis of galactic Asymptotic Giant Branch stars (hereafter AGB stars), we discuss here two samples for which photometry in the near- and mid-infrared and distance estimates exist. Whenever possible we searched also for mass loss rates. Spectral energy distributions were always up to 20 μm and for the best observed sources up to 45 μm. For the first sample (carbon-rich stars) we present rather complete results, while for the second sample (S stars) we give only the preliminary results. In particular, for carbon stars the wide wavelength coverage allows us to obtain reliable bolometric magnitudes. Moreover, we show that mid-IR fluxes are crucial to estimate the magnitudes of stars with dusty envelopes. The resulting brightness of C stars is relatively high (brighter than $M_{bol} = -4.8$), so that the long-claimed luminosity problem of C-rich stars does not appear to exist. We examine the different properties of the carbon rich stars according to their type of variability and find that the relevance of Miras and Semiregulars varies with evolution, with Miras dominating the final stages. We present here also the first results of a similar analysis that we are doing for a sample of galactic S stars. Finally, we show here a first comparison between mid-IR measurements made by space observatoriess (ISO, MSX) and ground observations performed by us with the IR camera TIRCAM2.

Key words. Stars: AGB and post-AGB – Luminosity – Mass Loss – Infrared Photometry

1. Introduction

Stars of low and intermediate mass (all those below M = 7-8 $M_{\odot}$) terminate their evolution through the so-called Asymptotic Giant Branch phase (Busso et al. 1999), in which they lose mass efficiently thanks to stellar winds powered by radiation pressure on dust grains (Habing 1996). After this stage, they generate planetary nebulae and start a blueward path, which ultimately gives birth to a white dwarf. Moreover, winds from AGB stars replenish the Interstellar Medium with about 70% of all the matter returned after stellar evolution; this is done with the formation of circumstellar envelopes through the processes of mass loss (Winters et al. 2002). As AGB stars radiate most of their flux at long wavelengths, large surveys of infrared (IR) observations play a fundamental role in studying their luminosity and their mass loss (see e.g. Habing 1996; Epchtein 1999).

We do not have yet a quantitative description of AGB winds, though attempts at modelling them are a few decades old (Salpeter 1974; Knapp & Morris 1985). More recently,

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hydrodynamical and phenomenological studies of pulsating stellar atmospheres and of the associated mass loss have undergone important improvements. Also, observational works have become more quantitative, using new data at long wavelengths from space and from the Earth (see e.g. Le Bertre et al. 2001, 2003; Groenewegen et al. 2002a,b), as well as improved knowledge of stellar distances (e.g. Van Eck et al. 1998; Bergeat & Chevallier 2005).

A real step forward would be to derive realistic formulae, linking the efficiency of stellar winds to the luminosities, colours and chemical properties of AGB stars, to be adopted as inputs for stellar models, thus avoiding free parameterizations. This kind of studies has become quantitative only recently (van Loon et al. 2005), while previous attempts (Vassiliadis & Wood 1993) suffered from large uncertainties. A good knowledge of absolute magnitudes, through improved distances is also required to reduce those uncertainties.

Therefore, we plan to make a reanalysis of AGB luminosities and mass loss: this is actually the main scientific scope of our project for putting an IR telescope (the International Robotic Antarctic Infrared Telescope) in Antarctica, at the Italian-French base of Dome C (Tosti et al. 2004). It will permit an extensive study of AGB sources in Magellanic Clouds and in the southern Milky Way up to 20 μm (and possibly beyond, given the unique characteristics of the Antarctic atmosphere). This analysis is part of the preliminary works necessary to define the key projects for the telescope.

We are therefore considering, in a series of works, all types of AGB stars, using existing catalogues of IR observations and compiling a homogeneous list of luminosities, distances, mass loss rates, looking for correlations between them and the IR data. We start with C-rich AGB stars (see Guandalini et al. 2006); next steps will analyze MS-S giants, where C- and *s*-element enrichment becomes observable, and finally the more disperse family of M giants. In this note we present the current status of our research.

2. The samples and the data

In this note we present the results of an analysis performed on two different samples of AGB stars. The sample of C-stars is fully described in Guandalini et al. (2006), in this paper we present some of its main results. The sample of S stars is made of more than 600 sources and here we show the first preliminary results.

A detailed exposition of the methods used to obtain the revised estimates of mass loss used in this paper can be found in Guandalini et al. (2006). We have collected photometric data in near- and mid-infrared filters from the catalogues of the ground-based observations of 2MASS and DENIS and from the databases of two space-borne observatories, ISO (Infrared Space Observatory) and MSX (Midcourse Space eXperiment). We have reduced these observations through a rebinning of the spectra made over the response curves of mid-infrared photometric filters that were chosen according to our needs. A detailed presentation of all these proceedings can be found in Guandalini et al. (2006).

3. Discussion

3.1. Carbon stars

In figure 1 there are two HR diagrams with a different colour baseline. They show the different behaviour of Carbon stars according to their variability type and at the same time a substantial agreement of the observed luminosities with model predictions can be seen; a more detailed analysis of these diagrams can be found in Guandalini et al. (2006).

Our figure 2 shows that the Luminosity Function of galactic C stars is continuous, unique, quite wide and therefore well in agreement with the model predictions (Guandalini et al. 2006). A comparison with the right panel shows that our global distribution looks pretty much as a superposition, with gaps filled, of Luminosity Functions obtained for different samples of C stars in LMC (see for similar results Zijlstra et al. 2006).

In figure 3 the relation between mass loss rates and bolometric magnitudes is shown for irregulars, semiregulars and Miras. One would

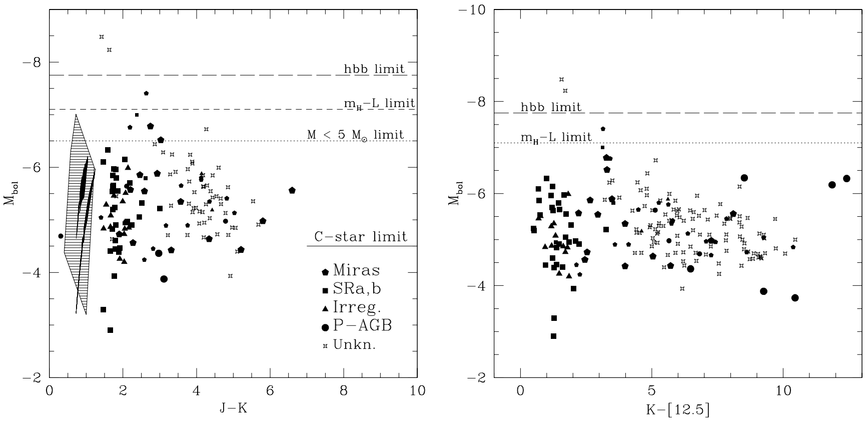

Fig. 1. Left panel: The HR diagram of observed C stars in near-IR, as compared to the area (dashed) covered by canonical stellar models (without Hot Bottom Burning). The minimum limit for C stars occurrence in the adopted models is indicated (Guandalini et al. 2006). Right panel: The HR diagram of observed C stars adopting as a temperature indicator the near-to-mid IR colour K−[12.5], where contributions from both the photosphere and dust are present (see

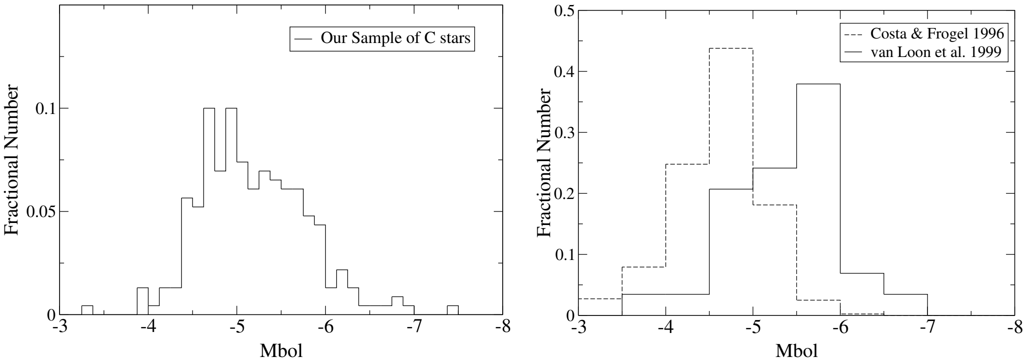

Fig. 2. Left panel: the histogram showing the fractional number of C stars per magnitude interval in the sample from (Guandalini et al. 2006) (230 sources). Right panel: same as before, for the samples of LMC C stars in optical wavelengths (Costa & Frogel 1996, 887 sources) and in the infrared (van Loon et al. 1999, 29 sources), note that the bin size here is the same as used by these authors for their data (see Guandalini et al. 2006, figure 8).

expect that mass loss rates and luminosity be correlated: this is so because, while becoming more luminous, AGB stars become also increasingly cool, their pulsation becomes stronger and both facts should power more intense stellar winds. However, a large scatter is present in figure 3, so that no correlation appears. This should be due to the influence of other parameters, such as the stellar mass, and/or to the fact that different mechanisms might power stellar winds in different evolutionary stages.

A good monitor of the mass loss rate is instead given to us from the IR colours. This is illustrated in figure 4. When IR colours are used as a baseline on the x-axis, especially if includ-

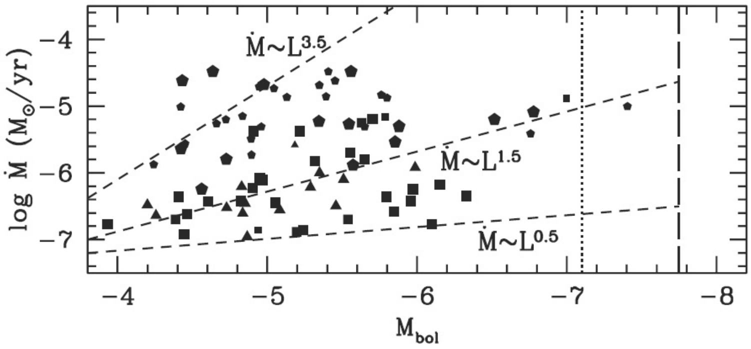

Fig. 3. The bolometric magnitudes for AGB C-rich stars of known variability type, as indicated, plotted as a function of mass loss rates (see Guandalini et al. 2006, figure 11). Symbols are described below in figure 4.

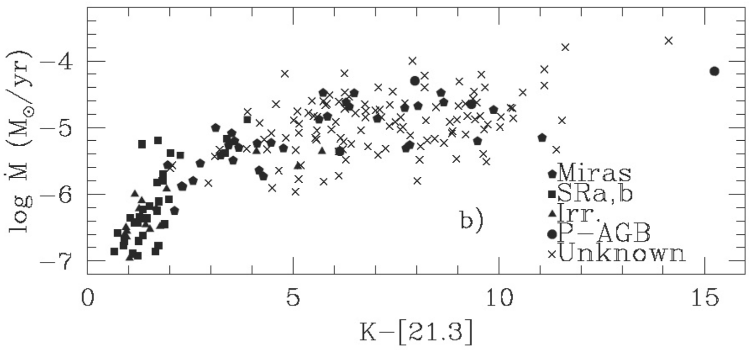

Fig. 4. Relation linking the mass loss rates of C-rich AGB and post-AGB sources to the IR colours up to 21 μm (see Guandalini et al. 2006, figure 12).

ing the 21.3 μm (with the characteristic emission feature of C-rich post-AGB stars), then the variation of mass loss rates with the stellar classes (and with evolution, if the hypothesis that Miras are on average quite evolved holds) is clearly distinguishable. More details on this topic can be found in Guandalini et al. (2006).

3.2. S stars

In figure 5 we show a preliminary HR diagram for a limited sample of MS, S and SC sources (the complete list contains more than 600 stars). The data were treated similarly to the Carbon stars presented in the previous subsection. In this figure one can see that MS and S stars whose "intrinsic" nature is confirmed by detection of Tc, generally occupy the higher part of the plot, as expected. However, before looking for more quantitative correlations much larger statistics must be obtained.

3.3. TIRCAM2 observations

Finally, figure 6 presents the comparison between space-borne observations from ISO and MSX and ground-based measurements performed by us with the infrared camera TIRCAM2 in two different mid-IR filters for a sample of AGB stars. The two types of measurements are in substantial agreement and this fact confirms the validity of ground-based mid-IR photometric observations strengthening the IRAIT project. More details on the comparison

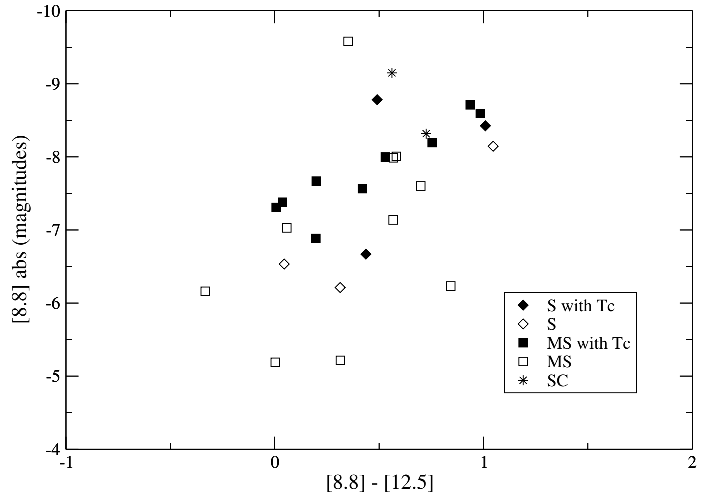

Fig. 5. Relation between luminosity in the 8.8 μm filter and the colour [8.8]-[12.5] for different classes of S stars. Open squares refer to stars for which Tc was not found or not looked for in the literature.

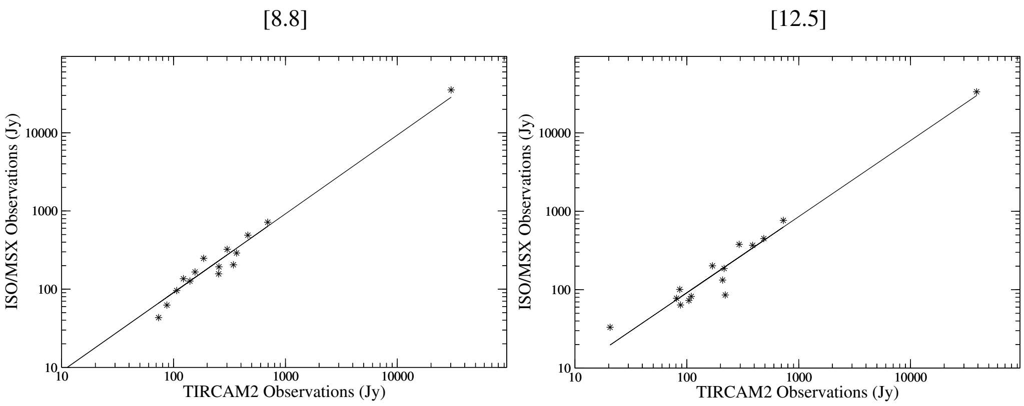

Fig. 6. Comparison for a sample of AGB stars between space-borne observations from ISO and MSX and ground-based measurements performed by TIRCAM2 in two mid-IR filters (Busso et al. 2006).

between these two sets of measurements and on the TIRCAM2 observations can be found in Busso et al. (2006).

4. Conclusions

In conclusion we find that in our analysis the estimates of bolometric magnitude for Galactic AGB C-rich stars are in agreement with the main theoretical models; therefore, the old problem of underluminous C-rich stars is not real according to our results and to recent works on Magellanic Cloud data (Whitelock et al. 2006). Moreover, there is no clear correlation for carbon stars between mass loss and bolometric magnitude. Other physical parameters must be involved but also different mass loss mechanisms are possible. In our preliminary results on Galactic S stars we find an almost linear behaviour in the IR HR diagram for Tc-rich stars. Finally, we show that mid-IR observations from the ground (TIRCAM2) are in substantial agreement with space-borne observations (ISO, MSX) of the same sources.

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