Thermally-pulsing asymptotic giant branch stars in the Magellanic Clouds

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Abstract. We present the latest results of a theoretical project aimed at investigating the properties of thermally-pulsing asymptotic giant branch (TP-AGB) stars in different host systems. For this purpose, we have recently calculated calibrated synthetic TP-AGB tracks — covering a wide range of metallicities \((0.0001 \leq Z \leq 0.03)\) up to the complete ejection of the envelope by stellar winds (Marigo & Girardi 2007) — and used them to generate new sets of stellar isochrones (Marigo et al. 2008). The latter are converted to about 25 different photometric systems, including the mid-infrared filters of Spitzer and AKARI as the effect of circumstellar dust from AGB stars is taken into account. First comparisons with AGB data in the MC field and stellar clusters are discussed.

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1. Introduction

Owing to their intrinsic brightness and distinctive spectral features, TP-AGB stars play an important role in many properties of their host systems. For instance, the TP-AGB contribution to the total luminosity of single-burst stellar populations reaches a maximum of about 40% at ages from 1 to 3 Gyr (Frogel et al. 1990), and account for most of the bright-infrared objects in resolved galaxies, as clearly demonstrated by DENIS, 2MASS, SAGE, S\(^3\)MC, and AKARI IRC data (Cioni et al. 1999; Nikolaev & Weinberg 2000; Blum et al. 2006; Bolatto et al. 2007; Ita et al. 2008) for the Magellanic Clouds (MC). Despite its large relevance, the description of the TP-AGB phase in evolutionary models of galaxies has always been far from detailed and physically accurate.

Our goal is to provide complete sets of TP-AGB models useful for the evolutionary population synthesis of galaxies — both resolved and unresolved into stars — taking into consideration all the processes and physical inputs which are known to be critical in determining the evolution along this phase, and reproducing its basic observables. The Magellanic Clouds play a key role in our project, as we can rely on rich and complete samples of well-observed TP-AGB stars, to be used in the calibration of the basic model parameters.
3. From stellar tracks to synthetic samples of AGB stars

The TP-AGB evolutionary tracks were attached to the Girardi et al. (2000) tracks for the previous evolutionary phases, and used to build the Marigo et al. (2008) isochrones. They consider the reprocessing of radiation by dust in the circumstellar envelopes of mass-losing stars. The web interface in http://stev.oapd.inaf.it/cmd provides these isochrones — and their derivatives, such as luminosity functions and integrated magnitudes — for more than 25 optical-to-far-infrared photometric systems, including those more useful to the study of MC AGB stars (e.g., OGLE, DENIS, 2MASS, Spitzer IRAC+MIPS, and AKARI).
Figure 2. Comparison between 2MASS and Spitzer near- and mid-infrared data for the LMC (left panels), and the simulated photometry without (middle panels) and with (right panels) the effect of AGB circumstellar dust. Predicted carbon stars are marked with black points.

In the process of building the isochrones, we have used the sequences of synthetic C star spectra from Loidl et al. (2001). These cover well the $T_{\text{eff}}$ range of C stars in the Magellanic Clouds and in the Milky Way galaxy, but not the wide intervals of surface gravities and C/O ratios expected for such stars. Moreover, they have been computed for C stars of initial solar metallicity. We are now extending the database of C star spectra, using the COMARCS code (Lebzelter et al. 2008), so as to cover the complete parameter space expected from the evolutionary tracks (Aringer et al., in preparation).

This set of theoretical models have been included in the TRILEGAL code (Girardi et al. 2005) for simulating the photometry of resolved stellar populations. The code has been adapted (Girardi & Marigo 2007b) so as to deal with the luminosity and temperature variations driven by thermal pulse cycles, and to consider additional variables such as the pulsation period of LPVs, the mass loss rate, the optical depth of circumstellar dust, etc. This allows us to simulate complete samples of AGB stars together with their main optical-to-infrared properties, for any history of star formation and chemical enrichment.
Figure 3. Comparison between predicted period-luminosity relations (in the K-band) for LPVs in the MCs (right panels) and the observed data (left panels; Ita et al. 2004). The models contain the fundamental and first overtone modes only. The faint plume at longer periods leaking from the $P_0$ sequence consists of models with $\dot{M} > 10^{-6}$ M$_\odot$ yr$^{-1}$, i.e. corresponding to dust-enshrouded stars.

4. Comparison with basic observables in Magellanic Cloud fields

We are presently dealing with simulations of the fields in the LMC and SMC, using published SFHs and age–metallicity relations (e.g., Harris & Zaritsky 2004; Javel et al. 2005; Pagel & Tautvaišienė 1998). Figs. 2 and 3 presents the typical results regarding the photometry and LPV periods of the sample. The models do a reasonable job in reproducing the number counts, magnitudes and colors of AGB stars in the Magellanic Clouds, which is no surprise since the evolutionary models have been originally calibrated using MC data. Looking at the quantitative details, however, we are accumulating several hints on the aspects of the models which need to be improved. One of the most obvious deficiencies is in the description of the pulsation periods for C stars (Fig. 3), which requires more reliable pulsation models (e.g., computed with the right molecular opacities, as in Lebzelter & Wood 2007) than we have used so far. Moreover, although our models describe well the sequences of mass-losing stars in mid-infrared CMDs (Fig. 2), they fail to describe the detailed color distributions. This likely means that we have to adjust the mass loss prescriptions, which, in turn, would imply the recalculation and recalibration of the TP-AGB tracks. We are implementing such iterative process, which is however not simple and quite demanding in terms of CPU time. No doubt the final target is well worth of the effort.

5. Comparison with basic observables in 47 Tuc

The old globular cluster 47 Tuc is of particular interest to us, thanks to the detailed information available for its AGB stars, and to its metallicity which is comparable to those found in young and intermediate-age populations of the MCs. Figure 4 presents the period-luminosity diagram of 47 Tuc LPVs (Lebzelter & Wood 2005). They
Figure 4. Comparison between predicted period–luminosity relations (right panel) for LPVs in 47 Tuc (actually simulated for a much more massive cluster), and the Lebzelter & Wood (2005) data (left panel). Starred symbols correspond to TP-AGB models with \( M > 10^{-7} \ M_\odot \ yr^{-1} \).

Figure 5. Theoretical CMDs for 47 Tuc simulated in the AKARI filters, without (left panel) and with (right panel) the effect of AGB circumstellar dust. TP-AGB stars are plotted with black dots, and those with \( M > 5 \times 10^{-7} \ M_\odot \ yr^{-1} \) are marked with starred symbols.

clearly distribute on two sequences, with the switch from the first overtone to the fundamental mode occurring at \( K \sim 6.7 \) mag. Our models show the same transition, but at \( K \sim 7 \) mag.

Moreover, our simulations (Fig. 5) reproduce the behavior of the mid-IR colors that has been recently measured by AKARI (Ita et al. 2007): the only stars that present a prominent mid-IR excess are those at the very tip of the AGB (see also van Loon et al. 2006; Lebzelter et al. 2006). This reinforces the idea that the bulk of dust formation occurs at the end of the AGB, with the role of RGB stars being quite marginal, if not negligible (see also Boyer et al. 2008, for \( \omega \) Cen).

6. Other perspectives

In addition to the detailed work allowed by the MCs and by 47 Tuc, we are involved in different projects aiming at the calibration of the TP-AGB tracks at lower and higher
metallicities. In particular, it has become clear that dwarf galaxies provide a useful testbed for the models at small metallicities, using either near-infrared observations of nearby dwarfs (such as Leo II and Leo I; Gullieuszik et al. 2008, and work in preparation) or HST photometry of more distant dwarfs (Dalcanton et al. 2008, and work in preparation). Moreover, the Spitzer mid-infrared spectrum of Virgo ellipticals clearly shows the signatures of mass-losing AGB stars (Bressan et al. 2006; Clemens et al. 2009). The detailed modelling of all these galaxies will eventually help us to constrain the AGB evolution over a wide range of metallicities.

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References