Towards simulating the photometry, chemistry, mass loss and pulsational properties of AGB star populations in resolved galaxies

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Abstract. Extended and updated grids of TP-AGB tracks have been implemented in the TRILEGAL population synthesis code, which generates mock stellar catalogues for a galaxy given its mass, distance, star formation history and age-metallicity relation, including also the Milky Way foreground population. Among the stellar parameters that are simulated, we now include the surface chemistry, mass-loss rates, pulsation modes and periods of LPVs. This allows us to perform a series of consistency checks between AGB model predictions and observations, that we are just starting to explore. We present a few examples of model–data comparisons, mostly regarding the near-infrared and variability data for AGB stars in the Magellanic Clouds.

1. Introduction

Synthetic evolutionary models play an important role in the study of TP-AGB stars. The synthetic approach allows the computation of evolutionary grids covering wide age and metallicity intervals, and the easy testing of different input prescriptions (like the mass loss rates and dredge-up efficiency) so as to reproduce basic observational constraints. Due to these characteristics, they are suitable for population synthesis of galaxies, i.e. to the modelling of their resolved stars, and of their integrated light.

Since the work by Groenewegen & de Jong (1993), the carbon star luminosity functions (CSLFs) in the Magellanic Clouds (MCs) have been used to calibrate the onset and efficiency of third dredge-up events in synthetic TP-AGB models. Nowadays, many more observables potentially useful to the calibration process of synthetic models can be individuated. Suffice it to recall that for a few regions of the MCs, we dispose of optical plus near-IR photometry of all stars above the RGB-tip (OGLE, DENIS, 2MASS), spectroscopic C/M classification, variability data (EROS, OGLE, MACHO), mid-IR photometry and spectra (ISO, Spitzer), a good hint of their star formation history from deep HST data, plus the [Fe/H] distribution of red giants from ground-based spectroscopy. The simulation of such observables starting from grids of AGB tracks – and taking into account biases, errors, incompleteness, etc. – should allow us to make many specific tests on their processes of nuclear burning, mixing, mass-loss and pulsation, and test correlations between quantities (e.g. \(L, T_{\text{eff}}\),

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Therefore, we aim at a more complete testing and exploitation of TP-AGB evolutionary tracks, by means of comparisons of mock catalogues with real data for Local Group galaxies. To this aim, the TRILEGAL code has been adapted to deal with sophisticated TP-AGB tracks (Sect. 2.) and to simulate more observables in addition to the photometry – including the spectral classification, mass loss rates, and pulsational properties of AGB stars (Sect. 3.). A few preliminary applications are presented in Sect. 4.

2. Grids of TP-AGB tracks and isochrones

The TRILEGAL code (Groenewegen et al. 2002; Girardi et al. 2005; Vanhollebeke et al., this meeting) is a complex tool to produce mock catalogues for both the Milky Way and external galaxies. It stands on a series of routines that efficiently construct sample of stars by interpolating within grids of evolutionary models, and then it attributes a photometry to each star by consulting into tables of bolometric corrections. Presently, there is a quite good calibration for the Milky Way geometry in TRILEGAL, and external galaxies like the MCs can be easily simulated for a fixed distance and foreground reddening. An interactive web interface to TRILEGAL is available at http://trilegal.ster.kuleuven.be

Figure 1. Two of the isochrone sets already in use in TRILEGAL: the Marigo & Girardi (2001; left) ones which use scaled-solar opacities for the TP-AGB, and the latest Marigo et al. (in prep.; right) using variable opacities.

TRILEGAL uses the low- and intermediate-mass stellar tracks by Girardi et al. (2000) up to the end of the early-AGB. These are complemented with synthetic TP-AGB tracks from various sources: (i) The same ones as described in Girardi & Bertelli (1998), relying on an extremely simplified formalism, without any dredge up and hot-bottom burning; this naive approach was justified as initial applications of TRILEGAL were not dealing with AGB stars. (ii) Marigo et al. (1999) tracks calibrated on the CSLFs in the MCs, computed with – as
so far standard in the field of stellar evolution – the erroneous approximation of solar-scaled opacities; the corresponding isochrones were published by Marigo & Girardi (2001). (iii) Tracks computed for studying the SFH in the Magellanic Clouds (Cioni et al. 2006ab), now adopting consistent low-temperature opacities for C-rich mixtures (the so-called $\kappa$-var case in Marigo 2002). (iv) Finally, a newly computed set of $\kappa$-var tracks (Marigo & Girardi, in prep.) calibrated not only on the CSLFs but also on the lifetimes derived from the C- and M-star counts in MC star clusters (Girardi & Marigo 2006).

Some of these isochrone sets are illustrated in Fig. 1 (and are available in http://pleiadi.oapd.inaf.it). The procedure for changing the set of TP-AGB tracks is straightforward so that any future set of tracks can be immediately included and tested. Notice that the isochrones of Fig. 1 have been constructed using the quiescent stages of H-burning along the TP-AGB. This simplification is necessary to speed up the interpolations inside grids of TP-AGB tracks. Individual tracks instead have been computed with a detailed description of $L$ and $T_{\text{eff}}$ variations during thermal pulse cycles.

3. Adapting TRILEGAL to the TP-AGB

A few features have been added to TRILEGAL, in order to face the challenges posed by AGB populations:

First of all, in producing mock catalogues we re-introduce the $L$ and $T_{\text{eff}}$ variations driven by thermal pulses in AGB stars. This is performed by generating a random phase of the pulse cycle for each simulated star, then computing the $\Delta L$ variation with Wagenhuber & Groenewegen’s (1998) formulas, and then converting it into a $\Delta T_{\text{eff}}$ by using the slopes in the HR diagram previously derived from envelope integrations. This is performed separately for C- and M-type stars, which present very different $\Delta L/\Delta T_{\text{eff}}$ slopes.

Second, we properly derive quantities such as the mass loss rates, pulsation modes and periods for the interpolated stars. Our experience is that this cannot be simply performed by interpolating between the tracks, due to the recurrent switch of pulsation mode along the pulse cycles. These quantities, instead, have to be re-derived from other ones such as the stellar mass, radius, C/O ratio, etc., which are now included into the tracks and isochrone tables.

Third, we need to properly deal with bolometric corrections for C-stars, and for all AGB stars with dusty envelopes. This step is presently under development. At the stage of this writing, we are using empirical bolometric corrections and $T_{\text{eff}}$-colour relations for C-stars (cf. Marigo et al. 2003).

4. A few results

Marigo et al. (2003) already used some of these adaptations of TRILEGAL to demonstrate that TP-AGB models with variable molecular opacities do naturally produce the “red tail” of C-stars observed in $K$ vs. $J-K$ diagrams of the MCs. Moreover, Cioni et al. (2006ab, and this meeting), used it to map variations of mean metallicity and age across the MCs. Figure 2 and 3 present additional simulations for the stellar populations in the MCs and in the Milky Way disk, that mostly regard the mass loss rates and pulsation periods.
Figure 2. Left panel: Observed (top; data from Le Bertre & Winters 1998) and predicted (bottom) distribution of Galactic M-type Miras in the mass loss vs. period diagram. Right panel: The same for C-type Miras (the data is from Groenewegen et al. 1999). The dashed line in the bottom panels represent the empirical relation by Vassiliadis & Wood (1993).

Figure 3. Observed (left, data from Groenewegen 2004) and predicted (right) distribution of LMC TP-AGB stars in period–luminosity diagrams (either in the K-band, or in $M_{\text{bol}}$). The observed sample has been limited in amplitude so that just the sequences B, C and D are well delineated. The simulation includes stars in both first overtone and fundamental mode, that correspond to the observed sequences B and C, respectively.

Figure 2 shows the predicted distribution of mass-loss rates for galactic M- and C-type Miras, as compared to observations. It is interesting to note that the dispersion of $\dot{M}$ at given period in this diagram is a consequence of using Bowen & Wilson’s (1991) and Wachter et al.’s (2002) prescriptions for the mass loss (for M- and C-type stars, respectively), and it would be absent if we were using simple fits to the empirical data, like the relation provided by Vassiliadis & Wood (1993). On the other hand, tracks computed with Reimers’ (1975) mass loss formula would fail to reproduce the observed values at the high end. With
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this kind of simulations, one can really test whether present-day prescriptions for mass loss (either theoretical or empirical) are consistent with the observed distributions, taking into account also the completeness of observed samples.

Figure 3 compares observed and simulated P–L sequences of LPVs. So far, we have included just the first overtone and fundamental modes of LPVs, that correspond to the B and C sequences observed in microlensing surveys of the Magellanic Clouds. We plot only the stars falling inside the LPV instability strips (Gautschy 1999). Comparing with the data compiled by Groenewegen (2004), we are able to reproduce some of the observed features, such as the slopes of the sequences, the trend of C stars being more luminous than M ones in sequences B and C, and the higher fraction of C stars in sequence C (fundamental mode) than in B (first overtone). However, first overtone periods are smaller than observed in sequence B, and the detailed number counts in both sequences suggest us that a small upward shift is needed to the “critical luminosities” that define the transition from first overtone to fundamental mode. Adjustments made to fix these problems would have a moderate impact on the mass loss rates used in the models, that on the other hand would affect properties like lifetimes and star counts. It becomes then clear that more detailed comparisons of this kind are worth being pursued.

In summary, we are ready to make statistically significant comparisons between predictions of TP-AGB models, and observations of AGB star samples in Local Group galaxies. These comparisons are no longer limited to just the photometry, but now include other crucial properties such as the mass loss rates, surface chemical composition, and pulsation periods.

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