A Stellar Library for Evolutionary Synthesis Modeling Including Variable AGB Stars.

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Abstract. A self-consistent spectrophotometric modelling of intermediate age post-starburst requires accurate stellar ingredients taking into account a principal feature of the stars dominating the near-IR emission during this phase: the variability of the AGB stars. A new library of stellar spectra based on averages of the empirical spectra of variable AGB stars is presented. This library is designed for convenient use in the population synthesis models. We discuss meaningful ways to compute these averages, and the non-trivial connection with the theoretical stellar parameters. Our library covers the near infrared wavelength range between 0.5\(\mu\)m and 2.5\(\mu\)m and exhibits fundamental differences when compared to the standard libraries using only static giants.

1. Introduction

Evolutionary population synthesis predictions depends strongly on the stellar inputs. One of them is the library of stellar spectra used to compute the integrated population spectrum. To interpret the integrated light of post-starburst galaxies in the near-IR, where the bulk of the energy of luminous evolved stars is emitted, one needs to introduce in some way the spectral signatures of such stars (essentially molecular absorption bands). Asymptotic giant branch stars (AGB stars) are characterized by low temperatures as well as high luminosity. The third dredge-up phenomenon on the AGB, due to the recurrent penetration of the convective envelope into the carbon-rich layers, brings the products of the helium burning nucleosynthesis to the surface (see Mowlavi, 1998, for a review), and is responsible for the eventual conversion of some M stars to carbon stars. This process is highly efficient in metal-poor systems, where the C stars can dominate the AGB stars population luminosity at low metallicity (Groenewegen 1998). Another particularity of the most evolved AGB stars is their high rate of mass loss ($\dot{M} \sim 10^{-7} - 10^{-4} M_\odot yr^{-1}$, Zijlstra 1998). These stars, surrounded by a dusty envelope, emit most of their energy at wavelengths from a few to a few hundred microns. They can be missed in optical surveys, and accounting for circumstellar extinction reduces the predicted emission of the AGB population even in the near-IR spectral region (see Habing, 1996, for detailed review).

For intermediate age populations one must take into account all the AGB properties pointed out above. The different libraries used in the literature, empirical or synthetic ones, (Terndrup et al. 1990, Lançon & Rocca-Volmerange
1992, Fluks et al. 1994, Lejeune et al. 1998) have introduced cool static giant stars, but they are not appropriate to distinguish between red giant stars and AGB stars. Bressan et al. (1998) have taken the presence of the AGB stars into account in their modelling of the intermediate age population by assigning, to each point of an isochrone, parameters of a dusty envelope model and performing radiative transfer calculations to correct the spectra of static giant star. This method is promising but it takes into account only the effects of the circumstellar shells around AGB stars. Our principal motivation is to recognise the presence of AGB stars in the integrated near-IR spectrum of a stellar population and to introduce all the effects pointed out above to be able to interpret accurately the spectrophotometric properties of intermediate age stellar populations. The scope of this paper is to construct a new stellar library taking into account the relevant processes affecting the near-IR spectra of AGB stars.

2. Data

The spectra of our sample (Lançon & Wood, 1997) cover a broad spectral range (0.5 – 2.5 \( \mu \text{m} \)) quasi-instantaneously, i.e. with no phase mixing. This sample consists of a wide range of cool objects: 35 O-rich Miras and 6 C-rich Miras, with various periods (between 90 and 450 days, corresponding to different luminosities), observed 3 times or more on different phases (up to 8 times). For reference and comparison, the sample also includes spectra of non-variable M-type giants, supergiants, LMC and galactic Bulge variables, and OH/IR and C/IR. The near-IR spectra, taken at 2.3m ANU Telescope at Siding Spring Observatory, have a resolution of 1100 and are connected with overlapping low resolution optical spectra, taken at Mt Stromlo Observatory. The quality of the spectra is good; the S/N per resolved element usually reaches \( \sim 100 \) in atmospheric windows and the typical uncertainty on (I-K) is \( \leq 0.2 \text{ mag} \).

The data confirm that the long period variables display much deeper near-IR molecular absorption bands than the cool and luminous static stars (Bessell et al. 1996).

3. Constructing stellar library

To estimate the luminosity of our spectra, we have used the L\(_K\)-P relation of Kanbur et al. (1998), and an instantaneous bolometric correction, obtained from the individual spectra themselves (Mouhcine et al. in preparation).

The effective temperature (T\(_{\text{eff}}\)) determination is more problematic (see Haniff et al. 1995 for the essential reasons, which we cannot discuss in enough detail here), and will strongly affect in the synthetic integrated spectra. The shape of the spectral energy distribution of the O-rich long-period variables (LPVs) is similar at most phases to that of static M giants (Fig. 1). Alvarez et al. (in preparation) find that the optical spectra of LPVs can be fitted well with static giant model atmospheres. This might be interpreted as an indication that the T\(_{\text{eff}}\) scale of the LPVs and static giants are equivalent. A large grid of static giant spectra was used to determine the effective temperatures of the spectra of our sample. Feast (1996) has derived an alternative temperature scale for LPVs using a data set grouping M Mira and non-Mira stars. The colour-T\(_{\text{eff}}\) relation
Figure 1. Comparison between static giant and long period variable spectra. We see clearly how we can separate the two populations on the basis of the H$_2$O bands (1.4 and 1.9 $\mu$m) and how the difference is function of the spectral type (e.g. temperature). Dips around 0.95 $\mu$m may be artifacts.

derived is steeper than the one derived using the static giants models: cool Mira spectra are assigned lower T$_{\text{eff}}$ values. This relation could be biased since the T$_{\text{eff}}$ used in Feast’s fit are derived from angular diameter measurements, who are interpreted using uncertain models both to correct for limb-darkening and to convert a monochromatic radius to the effective radius (Rosseland optical depth 2/3 or 1.0). The situation is complicated by the uncertainties about the pulsation mode of some LPVs. In addition, the T$_{\text{eff}}$ derived can be biased if there is some scattering source (dust?) in the upper atmospheres of LPVs that makes them appear bigger than they are (Wood, private communication).

To be conservative we have constructed two different libraries considering the two different T$_{\text{eff}}$-(J-K) relations.

Schematically, the thermal pulses move stars up and down in luminosity along the evolutionary tracks, while the LPV pulsations (periods of $10^2 - 10^3$ days) occur perpendicular to the tracks (large T$_{\text{eff}}$ shifts), deeply modifying the spectral type, the shape of the global energy distribution and the spectral signatures of the stars. The evolutionary tracks represent the evolution of static parent stars of the pulsating long period variables. How do we deal with this problem? How to determine the stellar spectrum to associate with each point of the evolutionary tracks? There are two approaches to adopt. One is to obtain properly weighted averages of the phase dependent spectra of individual stars, for various masses and evolutionary stages. This approach is, in principle, correct, but needs a huge amount of data or large pulsating model grids, which makes this approach very hard practically. The second approach, which was adopted, is to average the instantaneous spectra by temperature bin, disregarding phase and the pulsation properties. This approach is supported by the fact that, in our sample, no systematic correlation between the molecular indices and the luminosity or amplitude was found. In addition, this approach needs much less data.

Our library also contains carbon stars. Using interferometric angular diameters,
in combinaison with bolometric flux, Dyck et al. (1997) have found that there is small range of effective temperatures for C-stars over a large range in spectral type, and derived that $T_{\text{eff}} = 3000 \pm 200$ K. Finally, the library includes 5 OH/IR and several observations of 1 C/IR star.

4. Conclusion

This library of averaged spectra is constructed for population synthesis modelling. It should become public before the end of the year.

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