FROM IJK TO M_{BOL} IN AGB STARS

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1. Abstract

DENIS and 2MASS will discover on the order of 10^8 objects. In this paper I discuss the possibilities and problems of discriminating AGB stars against other red objects, like M-dwarfs, T Tauri stars and He Ae/Be stars based on IJK and JHK color-color plots.

In addition I discuss the bolometric corrections necessary to convert K-magnitudes into apparent bolometric magnitudes for AGB stars.

2. The database

In order to construct IJK (DENIS) or JHK (2MASS) color-color-diagrams I could have opted for the possibility to collect the necessary data from the literature. However, there is the problem of the different photometric systems, most I and near-infrared observations are not simultaneous, and most AGB stars are variable. Instead I chose a different approach to fold theoretical models of observed spectral energy distributions (SEDs) of AGB stars with the filter response curve and apply the zero point to get synthetic magnitudes. This approach can be applied if the zero point of a given magnitude system and the filter response are known.

For the DENIS system I used the filter response curves provided by N. Epchtein (priv. comm.) and estimated the zero points by folding the response curves with a theoretical model for a A0 dwarf and comparing them to the magnitudes obtained when folding the standard Cousins I and the ESO J and K filter response curves with the same model atmosphere. The adopted flux densities (in W m^{-2} μm^{-1}) for a zero magnitude star on the DENIS system are I = 1.26 10^{-8}, J = 3.34 10^{-9}, K' = 4.46 10^{-10}. The estimate for the I band is probably the most uncertain. For the 2MASS system no filter response curves are available to me and the JHK magnitudes given in this paper when referring to 2MASS are on the ESO system.

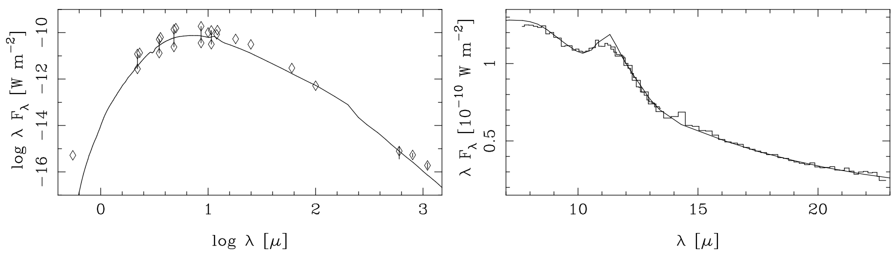

Figure 1. Fit to the spectral energy distribution and LRS spectrum of the carbon star AFGL 2494. In the sub-mm region error bars are given. In the near infrared values at maximum and minimum light are connected.

The radiative transfer models that are used to fit the observed SEDs are taken from several papers of mine. In these, the fits were used to derive physical quantities like the dust mass loss rate of a star, the inner dust radius or the amount of silicon carbide. Fits to 48 carbon stars are used: Groenewegen & de Jong (1994; S Sct), Groenewegen (1995; infrared carbon stars), Groenewegen (in prep.; carbon Miras with pulsation periods < 400 days). Fits to 18 oxygen-rich stars are used: Groenewegen (in prep; M-stars with 60 μm excess), Groenewegen (1994; OH32.8-0.3, OH44.8-2.3), Groenewegen et al. (1995; GM103, TRM60, OH138) and Groenewegen et al. (in prep.; AGB stars in the LMC). For all these stars synthetic DENIS IJK, and ESO JHK colors were computed based on the best fitting radiative transfer models to the observed SEDs of these stars. An example of such a fit is shown in Fig. 1 for the carbon star AFGL 2494.

With respect to other red objects which potentially could occupy the same region in IJK or JHK color-color plots as the AGB stars the following sources were considered.

- Galaxies. Typical IJHKL colors for 5 classes of galaxies are taken from Yoshii & Takahara (1988). DENIS data on Galaxies presented by Mamon et al. at this meeting appear to agree with these colors.
- T Tauri stars. From Myers et al. (1987) 8 stars are taken. An additional 17 which have simultaneous optical and NIR data and were detected by IRAS as well are taken from Rydgren et al. (1984).
- Herbig Ae/Be stars. From Hillenbrand et al. (1992) 34 are taken.
- M-dwarfs. Six are taken from Jones et al. (1994), including GD165B. Note that it became apparent during this meeting that brown dwarfs are not necessarily redder than these M-dwarfs (see Guerrero; Hawkins; Baraffe & Chabrier; this meeting).

For these stars no effort was made to put them on the DENIS or ESO system or to correct for interstellar extinction as the aim is to get a rough idea where these stars are located in the color-color plots.

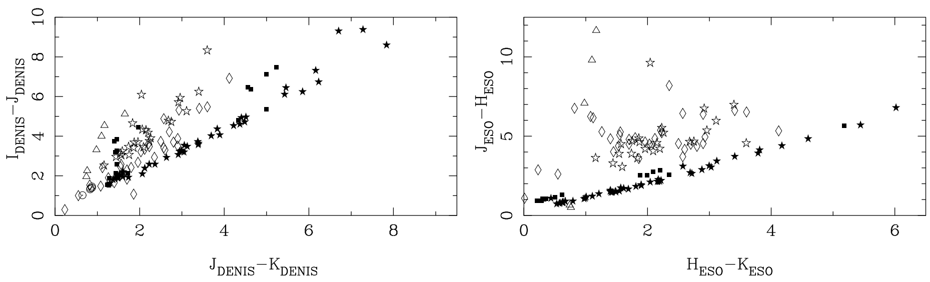

Figure 2. IJK and JHK color-color diagram. Symbols: carbon stars = filled stars; oxygen-rich AGB stars = filled squares; galaxies = open circles; M-dwarfs = open triangles; He Ae/Be stars = open diamonds; T Tau stars = open stars. The limits of the IJK plot are set based on the saturation and 5σ detection limits of DENIS; very red AGB objects outside the plot limits do exist. For the AGB stars the colors are dereddened.

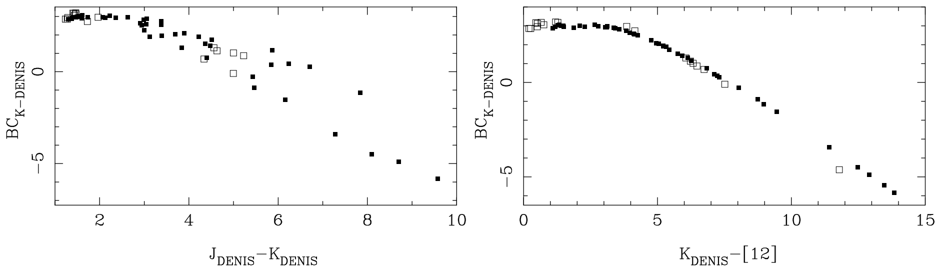

Figure 3. Bolometric correction at K′ versus J–K and K–12. Symbols: carbon stars = filled squares; oxygen-rich AGB stars = open squares.

3. Color-color plots

Figure 2 shows the IJK and JHK color-color diagrams. Note that the sequence for the oxygen-rich AGB stars (the filled squares) appears not to be continuous. This is an artifact of the type of templates used: the M-stars with 60 μm excess have little or no current mass loss and all are relatively blue while the OH/IR stars and the IRAS detected AGB stars in the LMC are all relatively red. Oxygen-rich AGB stars with intermediate colors do exist but are not represented among the template stars used.

4. Bolometric corrections

Figure 3 shows the bolometric correction at DENIS K' against $J - K'$ and $K' - 12$. The bolometric correction is defined as $m_{\rm bol} = m_{\rm K'} + {\rm BC}_{\rm K'}$. There is quite a lot of scatter in the former relation but the latter relation appears to be extremely tight.

5. Discussion

From the IJK color-color plot it is clear that it is virtually impossible to select AGB stars with blue colors $J - K < 3.5$. Between $3.5 < J - K < 4.5$ carbon stars may be selected as they appear to have bluer $I - J$ colors for a given $J - K$. Only for $J - K > 4.5$ do the AGB stars stand out from other red objects.

From the JHK color-color plot it appears that AGB stars stand out from other red objects independent of color. For $J - K$ smaller than about 1.0-1.5 this is misleading as all un- or slightly reddened giants and main sequence stars which are not shown in the figure are located in this region; for every blue AGB star one may expect 100-1000 "normal", possibly slightly reddened, giants which are on the first RGB. On the other hand, it appears that redder AGB stars stand out somewhat more clearly from other red objects than in the IJK color-color plot. The oxygen-rich AGB stars appear to have slightly redder colors than carbon stars for a given $H - K$. However if this is sufficient to discriminate them remains to be seen when photometric errors, reddening and variability "confuse" the color-color diagram of true observations.

Additional informations may be used to discriminate AGB stars, e.g. optical colors when these become available from SUPERCOSMOS, known associations with young stellar objects or star forming regions, and IRAS fluxes.

Although not shown in this contribution for lack of space AGB stars are well separated in color-color diagrams where $[12 - 25]$ is plotted against $J - K$ of $H - K$ (compare Guglielmo et al. 1993). Also oxygen-rich AGB stars and carbon stars separate very nicely. However, this kind of color-color plots can only be used for the sub-set of stars detected by DENIS or 2MASS that were also detected by IRAS.

The color-color diagrams and bolometric corrections shown in this paper are only specific examples. Other can be calculated upon request (contact Martin Groenewegen at groen@mpa-garching.mpg.de).

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