SOME HIPPARCOS RESULTS FOR LATE-TYPE STARS

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ABSTRACT

We present first results on late-type stars based on Hipparcos data for 42 stars that have their distances determined to better than 50 per cent. Luminosities are calculated from modelling the spectral energy distributions, or using a bolometric correction.

For the two Miras in the sample first overtone pulsation can be excluded and the pulsation mode is the fundamental one. For three Semi Regular (SR) variables fundamental mode can be excluded. For all SRs first overtone pulsation always fits the observed periods better. For two SRs there may be evidence for pulsation in a higher mode. The periods and luminosities of the 2 Miras are consistent with the $P-L$ relation determined for the LMC, when shifted by a distance modulus of 18.5.

There are 5 R-type carbon stars in the sample. The brightest has a luminosity of 170 $L_\odot$. This confirms the low luminosity of these stars known previously from statistical parallax studies.

Six stars in the sample show the ^{99}Tc line, and six do not. We find that the borderline luminosity above which most stars show Tc lies at 1500–2000 $L_\odot$.

Bias of the Lutz-Kelker type may affect these conclusions.

Key words: stars: carbon – stars: distances – stars: evolution – stars: AGB.

1. INTRODUCTION

The Hipparcos Catalogue (ESA 1997) provides trigonometric parallaxes obtained by fitting an astrometric model of stellar motion to a set of measurements obtained between 1989 and 1993. Systematic errors in the astrometry have been estimated to be less than 0.1 mas (Arenou et al. 1995, Lindegren 1995).

In 1992 we submitted a research proposal to obtain early data access. At that time we selected from various catalogues about 400 AGB and post-AGB stars of all spectral types, judged to be within 500 pc based on optical magnitude and color criteria. In the competition with other proposers, we eventually obtained results from the Hipparcos Catalogue for 107 stars.

We discuss some research topics related to late-type stars that can be addressed when accurate distances are available, in particular the long-standing problem about the pulsation mode of Mira and semi-regular (SR) variables, the luminosity of the peculiar R-type carbon stars, and the relation with the unstable isotope ^{99}Tc, the presence of which indicated that third dredge-up on the AGB occurred recently.

2. THE SAMPLE

We restrict ourselves in this paper to those 42 stars that have their distances determined to better than 50 per cent. Table 1 (available at http://www.mpa-garching.mpg.de/~groen/groen.html) contains the objects and lists in the first seven columns the identifier, spectral type, variability type and pulsation period, HIP number, parallax with its error, and the distance and its error. The identifier is the variable star name, when available, or the number in the S-star and C-star catalogues (Stephenson 1984, 1989). The spectral types come from the SIMBAD database or from the two Stephenson catalogues. Variability type and period are from the General Catalogue of Variable Stars (Kholopov et al. 1985). The HIP number, the parallax and its error are from the Hipparcos Catalogue; from these, the distance and its error were computed.

The most interesting quantity that can be derived once the distance is known is the intrinsic luminosity of the stars. To this end the apparent bolometric magnitude has to be derived.

Photometry was collected from Gezari et al. (1993) and by scanning the literature listed by the SIMBAD database. B, V and I magnitudes are taken from the Hipparcos Catalogue. Additionally, Drs. Laney and Kerschbaum provided infrared data for V810 Cen, and GY Vel and BO Mus, respectively. Furthermore, IRAS fluxes were collected. For several sources there are only poor, or no, IRAS data available, and in those cases we used the GIPSY software package (Assendorp et al. 1995) to analyse the 12 and 25 μm survey data in the IRAS data base. The following improved, or new, IRAS fluxes are derived: HIP 53810 (S_{12} = 0.27 ± 0.03 Jy, S_{25} < 0.2 Jy), HIP 54806 (S_{12} = 0.41 ± 0.02 Jy, S_{25} = 0.11 ± 0.02 Jy), HIP 57175 (S_{12} = 1.79 ± 0.09 Jy, S_{25} < 6 Jy), HIP 98958 (S_{12} = 0.21 ± 0.02 Jy, S_{25} = 0.08 ± 0.01 Jy), HIP 101859 (S_{12} = 0.23 ± 0.02 Jy, S_{25} = 0.046 ± 0.019 Jy).

Apparent bolometric magnitudes are derived by two methods. One is using a bolometric correction, the other is model fitting of the entire spectral energy distribution (SED). The former method is applied to some carbon stars. The reason is that accurate bolometric corrections for arbitrary photometric bands are available based on model fitting of SEDs of 48 carbon stars (Groenewegen 1997). The bolometric correction at K as a function of $J-K$ is used.

For all M and S stars and most carbon stars the SED is modelled using the dust radiative transfer model of Groenewegen (1993a). The central stars are represented by model atmospheres from Fluks et al. (1994). Sometimes, model atmospheres corresponding to spectral types slightly different from those listed in Table 1 gave better fits to the observed photometry. For carbon stars blackbodies are used. For M-stars without known spectral type the model atmosphere was adjusted to give the best fit to the colors. As most of the stars in the present sample have no dust (as evidenced by the LRS spectra, when available), the observed SED and colors are determined by the underlying central star. In the fitting, emphasis is put on reproducing the near-infrared data (when available) as the effect of variability is smaller there then in the optical. The effective temperatures are listed in Table 1.

Interstellar extinction was estimated from Neckel & Klare (1980), Burnstein & Heiles (1982) and/or the Parenago (1940) formula (see Groenewegen et al. 1992 for the exact formula). The adopted value for A_V is listed in Table 1. At other wavelengths the extinction was derived from Cardelli et al. (1989). The exact value of the extinction does not influence the results of this paper.

Table 1 lists the derived value of the apparent bolometric magnitude. The error is estimated to be of the order of 0.1 magnitudes. It depends e.g. on the amount of available photometry for the model fit. The luminosity is based on the apparent bolometric magnitude, combined with the best distance estimate. The error includes the error in the apparent magnitude and the error in the distance, which dominates.

The luminosities listed are *not* corrected for bias of the Lutz-Kelker (LK) type (Lutz & Kelker 1973). Given the error on the individual parallaxes, these corrections could be important in most cases, but the exact value depends on the distribution of stars in space and the luminosity function. Also the error on the correction itself is large (see e.g. Turon Lacarrieu & Crézé 1977, Smith 1987, Koen 1992).

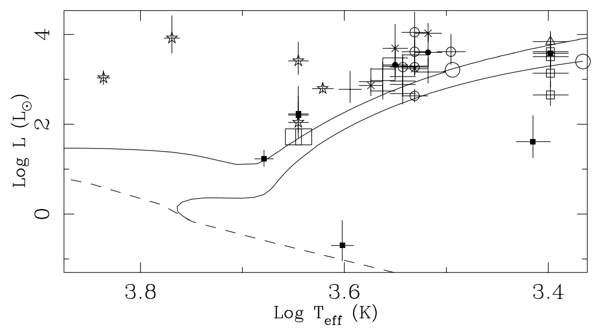

Figure 1. The Hertzsprung-Russell diagram. Symbols are as follows: ○ = M-type SRs, △ = S-type SRs, □ = C-rich SRs, • = O-rich Miras, × = other O-rich stars, (no symbol, only error bars) = other S-stars, ■ = other C-stars, ⋆ = non-MSC stars. The main-sequence and evolutionary tracks for 1 and 2 $M_\odot$ Pop I stars are indicated. Big open circles mark the tip of the RGB, and big open squares the location of the clump (helium core burning phase) phase. The AGB is hardly distinguishable from the RGB for luminosities between the clump phase and the tip of the RGB, hence for simplicity we show composite RGB/AGB tracks. The absolute calibration of the effective temperature in the models depends on the adopted mixing length parameter. A shift of 0.02 dex cannot be excluded.

3. DISCUSSION

3.1. HR Diagram

Figure 1 shows the HR diagram. An error of 100 K in the effective temeprature is assumed which corresponds to about one spectral subclass for M stars. The main sequence and some evolutionary tracks are indicated (Wagenhuber 1996). All stars in our sample are post-MS stars.

3.2. Stellar Diameters

Stellar diameters have been determined for HIP 82038 (3.24 ± 0.24 mas; Ridgway et al. 1979), and for HIP 91781 (7.76 ± 0.18 mas; Di Benedetto 1993). Both measurements have been made in the near-infrared from a lunar occultation. For the former star this leads to a radius of 81^{+35}_{-21} $R_\odot$ (the error includes the error in diameter and distance), and to an effective temperature of 3374 ± 77 K. Although the spectral type by SIMBAD is listed as K5II, the best fit to the SED is obtained with the model atmosphere of an M4 star which has a (model) effective temperature of 3490 K. For HIP 91781 the observed diameter leads to a radius of 310^{+199}_{-90} $R_\odot$, and to an effective temperature of 3355 ± 40 K. The spectral type of the star is listed as M4 but the best fit to the SED is obtained with the model atmosphere of an M5 star which has a (model) effective temperature of 3397 K. In both cases the agreement between the two effective temperature estimates is satisfactory.

3.3. Technetium

The presence of the unstable isotope ^{99}Tc indicates that third dredge-up occurred less than 2×10^5 years ago. Table 1 includes information on whether Tc was detected or not (Jorissen et al. 1993; Little et al. 1987; Little & Little-Marenin 1979). The three highest luminosities of the stars without Tc are in descending order 2100, 1150, 940 $L_\odot$. The three lowest luminosities of the stars with Tc are in ascending order 920, 1460, 1960 $L_\odot$. Although the sample is relatively small (six stars without Tc, six stars with Tc) this suggests that the borderline above which most, if not all, stars have Tc lies approximately at 1500–2000 $L_\odot$, and that the borderline below which stars seldom or never show Tc lies approximately at 1000–1200 $L_\odot$. The stars with Tc are all of spectral type S, and 4 out of 6 are known variables. The stars without Tc contain 4 S stars, one M star and one R-type carbon star. Except one, none is known to be variable. The one exception interestingly is a Mira and is the star with the highest luminosity among the stars without Tc. The interpretation of the S stars without Tc is that they acquired their peculiar abundance pattern through mass transfer in a binary system (e.g. Groenewegen 1993b, Jorissen et al. 1993).

The luminosities of the stars with Tc are low. In fact, these stars cannot follow the standard linear core mass-luminosity relation for full-amplitude pulses. Either some stars are in the post-flash luminosity dip, and/or, more likely, they have experienced few thermal pulses so far and 'turn-on' effects of the shells flashes are important (Wagenhuber 1996). In either case a luminosity of 1200–2000 $L_\odot$ corresponds to a core mass of 0.52–0.56 $M_\odot$. This is not consistent with the lower core mass limit of 0.58 $M_\odot$ for third dredge-up to occur derived by Groenewegen et al. (1995).

On the other hand, the LK correction will probably increase this borderline luminosity where Tc and non-Tc stars are separated and hence the discrepancy may disappear when the analysis is repeated using all available stars from the Hipparcos catalogue.

3.4. R-type Carbon Stars

The carbon stars can be divided into two groups based on their luminosities. Five stars are presumably on the TP-AGB with luminosities above 1400 $L_\odot$ (except one case). Four are SR variables. Then there are the five R-type carbon stars with luminosities below 170 $L_\odot$. This is direct evidence for the low luminosities as known previously from statistical parallax studies (see Scalo 1976 and Dominy 1984 for a summary on luminosities and evolutionary status of the R-stars, and references to earlier work). Our new observations do not provide new insight in the origin of the R-stars and the connection with similar low luminosity carbon stars in the galactic bulge (Westerlund et al. 1991) and the SMC (Westerlund et al. 1995)

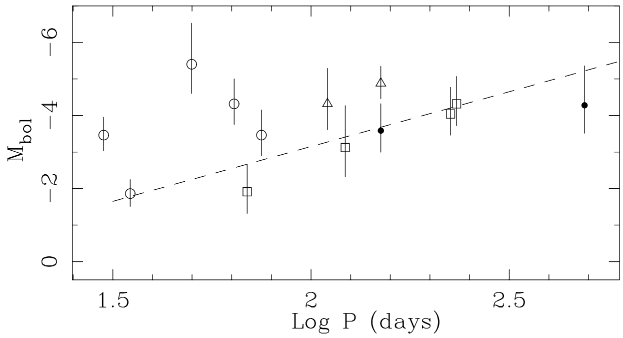

Figure 2. The Period-Luminosity relation. Symbols as in Figure 1. The dashed line is the relation derived for O-rich Miras in the LMC (Feast et al. 1989) shifted by a distance modulus of 18.5, and extrapolated to shorter periods.

3.5. Period-Luminosity Relation

In Figure 2 the periods and luminosities are plotted together with the $P-L$ relation derived for O-rich Miras in the LMC (Feast et al. 1989) and shifted by a distance modulus of 18.5. The supergiant V810 Cen and the RV Tau variable R Sct have not been plotted. The location of the 2 Miras is consistent with the $P-L$ relation. One could argue that all SRs, except one, also seem to obey the same $P-L$ relation. This result must be considered preliminary in view of the possible difference in pulsation mode discussed below.

3.6. Pulsation Mode

Fundamental mode (P_0) and first overtone (P_1) pulsation periods are calculated from luminosity and effective temperature (hence stellar radius) according to Wood (1990) and Wood et al. (1983), respectively. A mass of 0.8 ± 0.2 $M_\odot$ is assumed. The error on the calculated periods includes the error in the mass, an error of 100 K in effective temperature (except for the carbon stars with an assumed effective temperature of 2500 K, for which an error of 200 K is assumed) and the error in luminosity.

The predicted periods are listed in the last columns of Table 1. For both Miras first overtone pulsation can be excluded at the 2.5–3σ level. This is in disagreement with the result for R Leo by Tuthill et al. (1994). Van Leeuwen et al. (1997) use Hipparcos data to find that in a sample of 8 Miras, two are fundamental mode pulsators and the others first-overtone pulsators.

For the non-supergiant SRs the situation may be more complicated. In two cases, V3879 Sgr and π Gru, there may be evidence for pulsation in the second overtone or even higher mode. In the other SRs, first overtone pulsation nearly always fits the observed periods better than fundamental mode, which in three cases can even be excluded at the 1.5–2σ level. This finding is roughly consistent with the findings of Kerschbaum & Hron (1992) and Jura &

Kleinmann (1992) based on scale height and other arguments. All the SRs in our sample are classified as 'blue' in the scheme of Kerschbaum & Hron (1992). Both papers suggest that Miras with periods longer than 100 days pulsate in the fundamental mode. For SRs the situation is less clear and they suggest there may be a mix of fundamental and first overtone pulsators, a situation we cannot exclude.

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