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Variable Red Giants - the MACHO view

Stefan C. Keller and Kem H. Cook (IGPP, LLNL)

Introduction

The MACHO microlensing project has produced an unprecedented database with which to investigate stellar variability. In this proceedings we present a study of the variability characteristics of the red giant population of the Large Magellanic Cloud.

We have searched for periodic behavior amongst the population of bright red stars using a PDM-based method. Approximately 51% are periodic variables: 16489 have one period, 7690 have two and 926 have three. We have cross-correlated the MACHO variables with the 2MASS catalogue. This provides J, H, and K magnitudes for 44458 variables out of 49256. In Figure 1 we show the period-K luminosity diagram for the sample.

Period-Luminosity Relations

Fig. 1 shows six distinct period-luminosity sequences; five above the minimum luminosity for thermally pulsing AGB and another extending down to the minimum luminosity of our variable search.

Interpretation:

A–D: Sequences A–C are populated by low amplitude ($\Delta V \sim 0.^{m}05$-$0.^{m}3$) semi-regular variables. Sequence D is comprised of Mira and large amplitude ($\Delta V \sim$ 0.3-3 mag.) semi-regular variables. Vassiliadis & Wood (1993) showed that the Mira sequence can be modeled assuming fundamental mode pulsation. Sequences A–C can then be understood as higher order sequences (i.e. 1st, 2nd and 3rd overtones). The period ratios for multiple periodic stars is an additional constraint (Fig. 3). Models match some of the structure seen in Fig. 3 – improvement requires a better understanding of envelope structure than those evoked through the use of mixing-length theory.

E: These stars all have two distinct periods with period ratios of 5-13 (Fig. 3). The higher frequency variation belongs to sequence B. The long secondary period is characterized by 0.1-1.0 "fading" events of irregular amplitude (see Fig. 2). If D is due to the fundamental mode then pulsation is ruled out as the mechanism for the long period in E stars. The "fading" events seen in these stars suggests a dust κ-mechanism in the circumstellar envelope.

F: Sequence F light curves are easily distinguished amongst the other LPVs by their regularity (typical amplitudes $\Delta V = 0.^{m}1$). The regularity of the light curves suggests a binary mechanism in which the red giant is accompanied by a close companion. These binaries lie on the first giant branch or at the red end of the core-He burning loops of intermediate mass stars where they make up $\sim 0.5\%$ of the stars within 1 mag. of the TRGB.

Luminosity functions: Pulsation at the tip of the First Giant Branch

The luminosity function of sequences A–E is shown in Fig. 4. For sequences A,B, and E we see a prominent peak associated with the immediate vicinity of the tip of the RGB (TRGB) with a sharp drop above the TRGB. Sequences C and D do not suffer this cutoff. They show a peak at $K \sim 11.3$ which is also seen in A,B, and E. Standard evolutionary tracks show no feature of AGB evolution at the luminosity of the TRGB which could explain the peak we observe. We ascribe the peak in the luminosity functions of sequences A, B, and E to the presence of variability on the RGB which sits atop the luminosity function of the AGB variables (as described by sequences C and D).

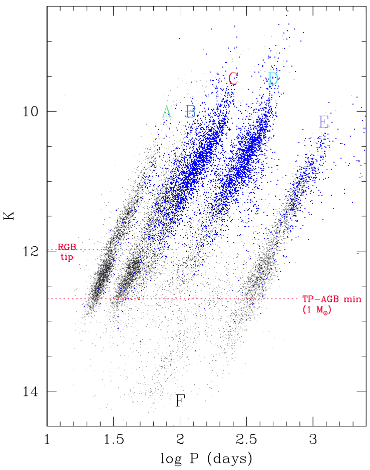
This is the first clear indication of pulsational instability on the first giant branch (FGB). Our results imply 8% of the RGB within a magnitude of the TRGB exhibit this variability. Notice that the period-luminosity relationships A, B and F are not disjoint across the evolutionary boundary between FGB and AGB stars. This implies that the envelopes of these two populations are remarkably alike.

Our observations provide a straightforward mechanism for mass loss in the vicinity of the TRGB. Mass loss prior to the helium flash must be invoked in order to explain a host of features of Pop. II stars, in particular the existance of extreme horizontal branch stars and the pulsational masses of RR Lyraes. A quarter of the variable population near the TRGB exhibit E behaviour indicative of episodic mass loss.

Summary

We present a study of the MACHO red variable population in the Large Magellanic Cloud. Our study reveals six period-luminosity relations amongst the red variable population. Only two of these were known prior to MACHO. Our results are consistent with Mira pulsation in the fundamental mode. A sequence comprising 26% of the red variable population can not be explained by pulsation. We propose a dust κ-mechanism in the circumstellar environment is responsible for the long period variation of these objects.

The luminosity function of the variables shows a sharp edge at the tip of the red giant branch (TRGB). This is the first clear indication of a population of variable stars within the immediate vicinity of the TRGB. Our results indicate this population amounts to 8% of the RGB population near the TRGB.



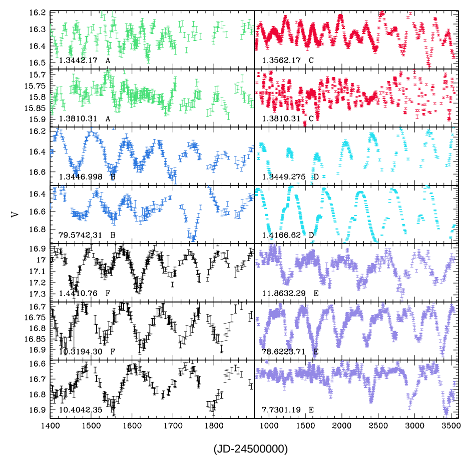
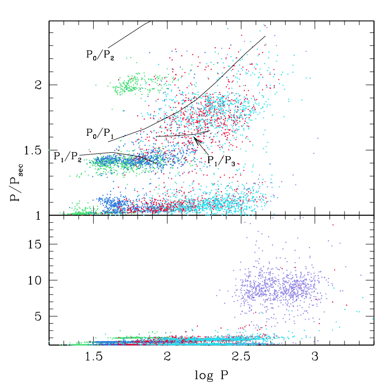


Figure 1 (l): The period-luminosity relation for variable LMC red giants. The presence of only two sequences was known prior to MACHO. Also shown is the tip of the first giant branch (TRGB: Cioni et al. 2001) and the minimum luminosity for $1M_{\odot}$ thermally pulsing AGB (TPAGB: Vassiliadis & Wood 1993). Carbon stars, shown in blue, are identified on the basis of their IR colors.

Figure 2 (r): Examples of light curves from the six sequences seen if Fig. 1. The color coding refers to the colors of sequence labels in Fig. 1. An example of a multi-mode pulsator is seen in the second right panel. Note the shorter time interval of the left column.



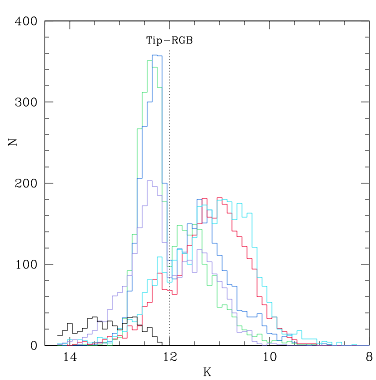


Figure 3 (l): The period ratio (longest/shortest) plotted against longest P for objects showing multiple periods. The lines correspond to period ratios predicted by Vassiliadis & Wood (1993). While pulsation mechanisms can plausibly explain sequences A-D they can not explain sequence E which possesses a long secondary period superimposed on a shorter (B,C -like) pulsation.

Figure 4 (r): The K luminosity function for the sequences in Fig. 1. Sequences A, B, & E possess a two peak structure with a sharp edge feature formed at the TRGB, while sequences C & D do not. This the first clear indication of a population of variables in the vicinity of the TRGB.

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