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Velocity Observations of Multiple Mode AGB Variable Stars

Francis C. Fekel[1], Kenneth H. Hinkle[2], Richard R. Joyce[2], and Thomas Lebzelter[3]

Abstract. Numerous infrared spectroscopic observations were obtained of eight AGB field M giants that have multiple periods of light variability. Each semiregular variable has light changes with a short period of several months, which is typical of low-amplitude pulsation for stars on the AGB, as well as a long period of 1-3 years. For six of the eight giants we found radial-velocity periods that confirm the long-period light variability. Those periods are significantly longer than the predicted fundamental-mode pulsations for these stars. Although we consider the possibility that the velocity variations result from orbital motion, we conclude that the long-period velocity changes in most, if not all of our sample stars, likely result from pulsation rather than duplicity. The location of these stars in the AGB period-luminosity relation is discussed.

1. Multimode AGB Variable Stars

A number of late-type giant variables have been found to have at least two periods. These were first commented on by Houk (1963). Wood et al. (1999) demonstrated that in the LMC these multimode variables are definitely on the asymptotic giant branch (AGB). Period ratios divide the multi-period AGB variables into two groups. One group consists of stars with period ratios of roughly 1.8. It is possible that this group actually includes most semiregular (SR) variables (Mattei et al. 1997). The period ratio for these stars is marginally consistent with mode switching between the fundamental and first overtone, a ratio of $\sim$2.2 in linear pulsation analysis.

The second group of multi-period AGB variables has period ratios ranging from about 5 to 13 with the short period typical for a SR or Mira variable. The Wood et al. (1999) LMC period-luminosity diagram shows the extraordinary significance of these objects. They largely fall on a sequence in the period-luminosity diagram that is parallel to the sequence believed to be that of the fundamental-mode pulsators but at *longer* periods ranging from 250 to over 1000 days. Wood et al. (1999) have labeled this period-luminosity sequence 'D'. Since

[1]Tennessee State University, Center of Excellence in Information Systems, 330 10th Avenue North, Nashville, TN 37203

[2]National Optical Astronomy Observatory, P.O. Box 26732, Tucson, AZ 85726-6732

[3]Institute for Astronomy, Türkenschanzstrasse 17, A1180 Vienna, Austria

classical pulsation theory does not allow a period of radial pulsation longer than the fundamental mode, the nature of the long periods is unknown.

We have investigated field M giants in our galaxy that have multiple modes with ratios of 5 to 13, and thus, are presumably sequence 'D' members. While some of these stars have been the targets of recent detailed photometric work by other observers, our investigation is spectroscopic. In particular we were interested in determining if the long periods indicate that the giants are binaries. The full details of our investigation can be found in Hinkle et al. (2002). A summarized discussion is presented here.

2. Observations

Eight semiregular AGB variable stars were added to an observing list that included a large group of symbiotic stars. Our secondary sample (Table 1) was drawn from Houk (1963), whose list was taken from the 1958 edition of the General Catalogue of Variable Stars and its 1960 supplement. Only stars with large period ratios (i.e. sequence 'D' variables) that are very bright in the near infrared were included in our program.

Spectra were obtained with the Kitt Peak National Observatory coudé feed telescope and spectrograph. The detector, NICMASS, was a 256 x 256 HgCdTe near infrared array with a cold narrow blocking filter. The spectra have a resolution of ~44,000 at a central wavelength of 1.623 μm.

Table 1. BASIC PARAMETERS OF THE PROGRAM STARS

Variable Name	HD	Spectral Type	Var. Type	P_1 (Days)	P_2 (Days)	P_3 (Days)	P_l/P_1
SS And	218942	M7 II:	SRc	152.5	650	···	4.3
RR CrB	140297	M3	SRb	61	377	···	6.1
RS CrB	143347	M7	SRa	69.5	183	331	4.8
AF Cyg	184008	M4	SRb	93	163	921	9.9
X Her	144205	M8	SRb	102	178	746	7.3
g Her	148783	M6 III	SRb	62	90	888	14.3
V574 Oph	165510	M4	SRa	71.5	500	···	7.0
BI Peg	···	M9	SRa	60-80	500	···	7.1

3. Analysis

To determine radial velocities, the program-star spectra were cross correlated with the spectra of velocity standards. Usually, more than 20 velocities were obtained per star over a period of more than 4 years. In Figure 1, a typical time series of velocity observations is shown that is overplotted with photometric observations obtained with an automatic photometry telescope (Percy et al. 2001).

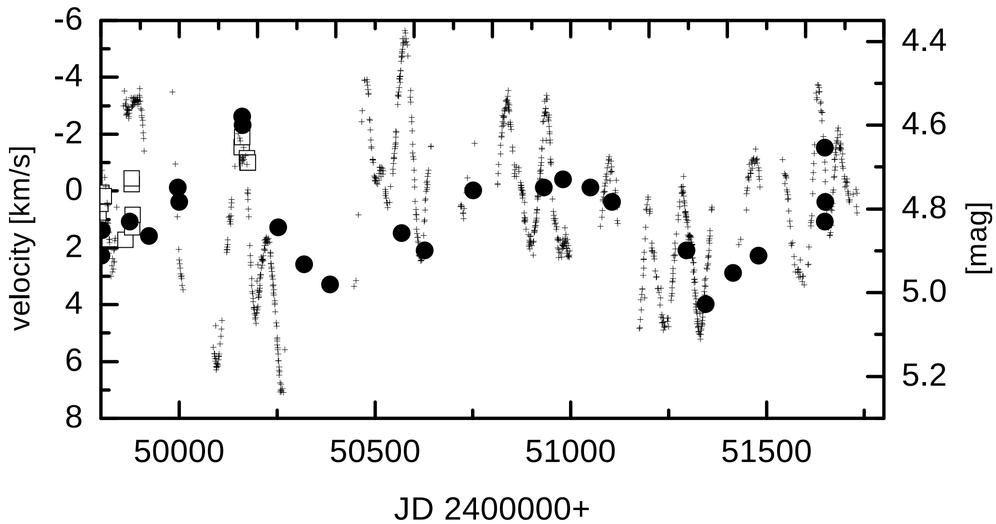

Figure 1. Velocity measurements for g Her compared with its light variations (Percy et al. 2001). Filled circles mark measurements from the current investigation, open boxes denote data from Lebzelter (1999). The velocities have been plotted with the most negative velocity at the top.

As noted previously, each program star has light variations with both a short and a long period. The short periods are in agreement with overtone stellar pulsation, and we have not investigated them further. A period search of the radial velocities was carried out for each program star, and a long period similar to that of the light variations was found for six stars. For each of these six the long period from the velocities was adopted as the orbital period, and orbital elements were computed (Table 2). As an example, our velocities of g Her are compared to the computed orbit in Figure 2. By fitting an orbit to the velocities we do not necessarily imply that these stars are spectroscopic binaries. Rather, this is an analysis technique to examine the nature of the velocity variations.

Table 2. "ORBITAL" ELEMENTS

Name	P (days)	γ (km s^{-1})	T (HJD)	K (km s^{-1})	e	ω (°)	f(m) ($M_\odot$)
RS CrB	328.3	−80.9	2,451,770.9	2.4	0.35	251	0.0004
AF Cyg	926.3	−14.8	2,451,224.6	1.8	0.08	58	0.0006
X Her	658.3	−90.3	2,451,770.9	1.6	0.32	319	0.0002
g Her	843.7	1.2	2,451,918.2	2.3	0.37	246	0.0009
V574 Oph	690.0	−35.7	2,451,540.0	1.7	0.33	251	0.0003
BI Peg	548.4	−28.2	2,451,368.9	3.1	0.36	240	0.0013

4. Conclusions

The six SR variables for which we have found long-period velocity variations have periods between 328 and 926 days and a mean near 670 days. The same six stars have short periods with an average near 80 days and hence a mean period ratio $P_l/P_s \sim 8$. The periods and the mean period ratio are similar to those found for the multiple-period stars in the LMC (Wood et al. 1999). For four of these six stars (RS CrB, AX Cyg, X Her, and g Her) there are *Hipparcos* parallaxes (ESA 1997). The logarithm of the period and absolute K-band magnitude of these four stars are in the range (2.52, −6.2) through (2.95, −7.3). Even with the relatively large uncertainties of field star luminosities, the luminosities and periods strongly connect the program stars with the sequence 'D' variables identified by Wood et al. (1999) in their LMC period-luminosity diagram. The short-period variations of these stars are normal SR variations and are on sequences 'A' or 'B' of the Wood period-luminosity diagram.

Perhaps one of the most significant remaining doubts about the velocity curves presented here is concern that these periods are aliases resulting from severe undersampling. Mattei et al. (1997) noted this possible effect in discussing the light curves of these systems. While the velocity data are indeed severely undersampled, there can be no question that long periods are present in these stars. Wood et al. (1999) detected similar long periods in well sampled *MACHO* data and the long period light variations in g Her have now been detected in well sampled APT data (Percy et al. 2001). Furthermore, the long periods from the velocity data match the long periods of the light variations.

Five of the six SR variables for which we found a long-period velocity variation have nearly identical values of K, e, and to a lesser extent of ω in the orbital fit (Table 2). This strongly suggests that the velocity changes of these variables do not result from orbital motion. The existence of close binary companions to these stars also seems unlikely on the basis of the mass functions and the properties of the light curves. The similar shapes of the velocity curves imply that some, as yet unknown, type of pulsation is responsible for the velocity variations. Wood (2000) identified theoretically a family of "strange" pulsation modes that occur because of the interaction of stellar oscillations and convective energy transport. In his analyses the modes were highly damped, but other treatments of convection might produce unstable modes with periods similar to those found here.

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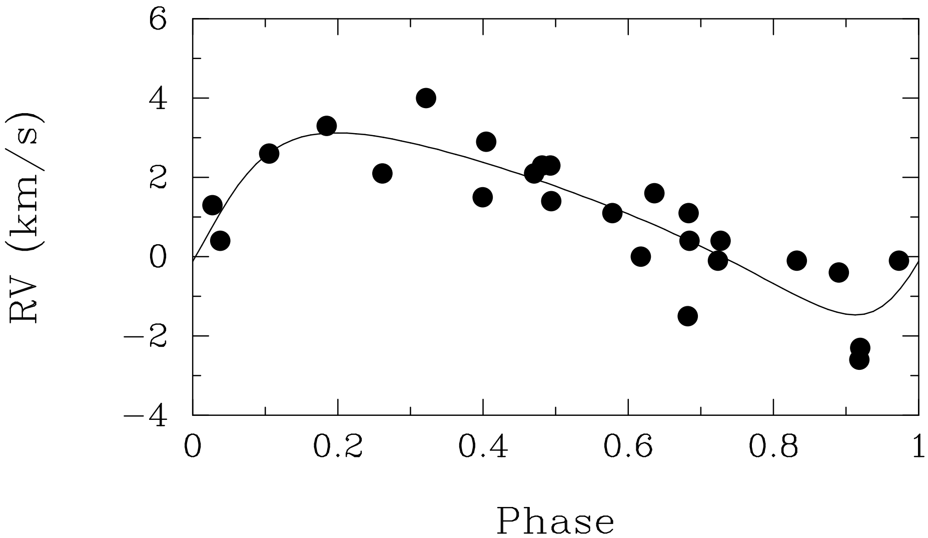

Figure 2. Velocities of g Her phased with a period of 843.7 days. The solid curve is the computed “orbit”.

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