

THE BINARY NATURE OF THE BARIUM STARS

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ABSTRACT

We present radial-velocity spectrometer observations that indicate that Ba II stars are binary systems. The secondary stars of these systems have low masses, consistent with their being degenerate objects which have lost mass onto their primaries in a previous stage of evolution. It is suggested that the Population II equivalents, the CH stars, may also be binary systems. This may be related to the fact that they are found only in globular clusters of the lowest central concentration.

Subject headings: stars: Ba II — stars: binaries — stars: evolution

I. INTRODUCTION

Considerable effort has been expended in trying to explain the mixing event which could cause the anomalous compositions of the Ba II and CH stars. It is usually assumed that the carbon and *s*-process elements in their atmospheres have been mixed to the surface from the deep interiors of the stars. To date, however, theoretical models of core flashes and shell flashes have been unable to produce a mixing event which is capable of producing the anomalies satisfactorily (e.g., Scalo 1976).

The present *Letter* describes observations that indicate that all Ba II stars (excluding marginal cases) are binary systems. Although this does not in itself explain the event responsible for the abundance peculiarities, it is most unlikely that these stars can be explained without incorporating their binary nature in the theory. Therefore, although our results at this point are preliminary, it is most important that they be published quickly. The observations described here span more than 1 year, but the periods of most of these systems are such that considerably more time is needed to determine accurate orbital information in order to obtain a more reliable knowledge of the mass ratios of the stars involved.

II. THE OBSERVATIONS

Most of the velocities were measured with a radial-velocity spectrometer attached to the 9682M (2.4 Å mm⁻¹) coude spectrograph of the Dominion Astrophysical Observatory (DAO) 1.2 m telescope. This instrument resembles the Palomar 5 m spectrometer described by Griffin and Gunn (1974). The principal difference in the DAO instrument is that the scanning in velocity is accomplished by moving the spectrum mask rather than by tilting a plane-parallel glass block in the beam. In addition, a comparison spectrum is incorporated in the mask, so the zero-velocity position can be monitored by direct measurement of an iron argon discharge spectrum. A few of the early velocities were also obtained from photographic spectra taken with the 21121 spectrograph (15 Å mm⁻¹) on the 1.8 m telescope. The time period spanned by all the observa-

tions is about 1.3 years, although for the spectrometer observations, which are considerably more accurate, the time spanned is about 10 months.

The sample of Ba II stars we have observed includes most of the stars in MacConnell, Frye, and Upgren's (1972) list that are brighter than $V = 8.5$ mag and located in the northern sky. Three stars that Williams (1975) suggested have enhanced barium, on the basis of a photometric index, were also included in the program. In addition to the Ba II stars, a random sample of 20 K giant stars was monitored to obtain a better knowledge of the frequency of spectroscopic binaries among giant stars, and of our ability to detect these with our spectrometer. This sample includes all *Bright Star Catalog* (Hoffleit 1964) K stars of luminosity class III with right ascension between 13^h and 18^h and declination greater than +50°.

III. THE RESULTS

Table 1 is a summary of the velocity data we have obtained. Column (2) contains the standard deviation of the velocities, and column (3) lists the number of velocities measured for each star. These data are based on the spectrometer data only, the 1.8 m telescope velocities being less accurate. We have not listed the absolute velocities at this time since we wish to make more standard star and asteroid measurements to ensure that our system zero point is correct.

Since this is the first large observing program attempted with the DAO radial-velocity spectrometer, it is necessary to discuss the precision of the velocities obtained before we can make an estimate of the frequency of spectroscopic binaries among our sample. This can be done by examining the velocities of the random K giant sample as well as the standard velocity stars which were observed repeatedly during the program. We find that three of our randomly selected K giant stars are definitely spectroscopic binaries, and we have possibly detected velocity variations in four others. The velocity curves for these candidates are shown in Figure 1. Although one of these, HD 124547 is a well-

known spectroscopic binary (Young 1927; Scarfe 1971), we include it because it fits our simple selection criteria for our random sample. If we assume the four *possible* variables truly are varying in velocity, then the frequency of spectroscopic binaries found here is in excellent agreement with that found by Gunn and Griffin (1979), who state that 30% of the field giant stars they

TABLE 1
VELOCITY DATA

Star (HD) (1)	σ (2)	n (3)
Random K Giants		
113092.....	0.80	12
118536.....	0.29	12
123977.....	0.43	11
124547.....	5.03	11
127700.....	0.35	11
129245.....	0.32	11
131507.....	0.35	11
131873.....	0.54	9
134493.....	0.25	11
136726.....	0.27	12
137759.....	0.46	9
139669.....	0.53	11
148293.....	0.29	12
150275.....	0.44	9
150449.....	0.29	9
154391.....	0.14	8
159966.....	0.58	8
163588.....	0.48	8
164058.....	0.30	8
166207.....	1.65	8
Standard Vel Stars		
26162.....	0.31	14
35410.....	0.50	5
66141.....	0.46	9
92588.....	0.25	3
107328.....	0.33	6
161096.....	0.48	5
186791.....	0.43	5
212943.....	0.44	5
223311.....	0.31	3
Ba 1 Stars		
11658.....	0.18	11
67447.....	0.42	9
77912.....	0.36	11
104979.....	0.30	9
139195.....	0.21	10
199394.....	0.26	12
Ba 2-Ba 5 Stars		
16458.....	1.82	13
37487.....	2.50	10
46407.....	8.54	9
49641.....	1.16	9
77247.....	5.78	13
101013.....	1.37	16
178717.....	0.64	8
196673.....	0.77	12
199939.....	5.86	11
205011.....	1.07	10
223617.....	0.21	8

have observed over the years are variable with amplitudes of a few km s^{-1} and time scales of a few years.

For the remaining 13 stars of our random sample, the rms scatter is 0.32 km s^{-1} . This compares with an rms scatter of 0.39 km s^{-1} for the standard velocity stars for which we have at least three observations. We conclude that the internal precision of the spectrometer is $\pm 0.35 \text{ km s}^{-1}$ rms for the observational methods we have employed. Note that we have relied entirely on the iron-argon comparison spectrum for our zero-velocity calibration. It may be possible, although we have little evidence of this, that the precision can be improved by determining the zero-velocity point from observations of a standard object. We are now observing asteroids each night to investigate this and to better determine any absolute velocity error the system may have.

The sample of Ba II stars has been divided into two categories based on the classification system devised by Warner (1965). This denotes the strength of barium on a scale of 1-5 in order of increasing strength of the lines. We include in the Ba 1 category the three stars from Williams's (1975) list, HD 67447, HD 77912, and HD 104979, as well as HD 11658 which does not have a published barium strength on this system. Our 1.8 m spectra suggest that these are marginal Ba II stars, and can certainly be classified no more extreme than Ba 1.

Examination of Table 1 shows that we have detected no significant radial-velocity variations among the Ba 1 group, the least extreme of the Ba II stars. The rms

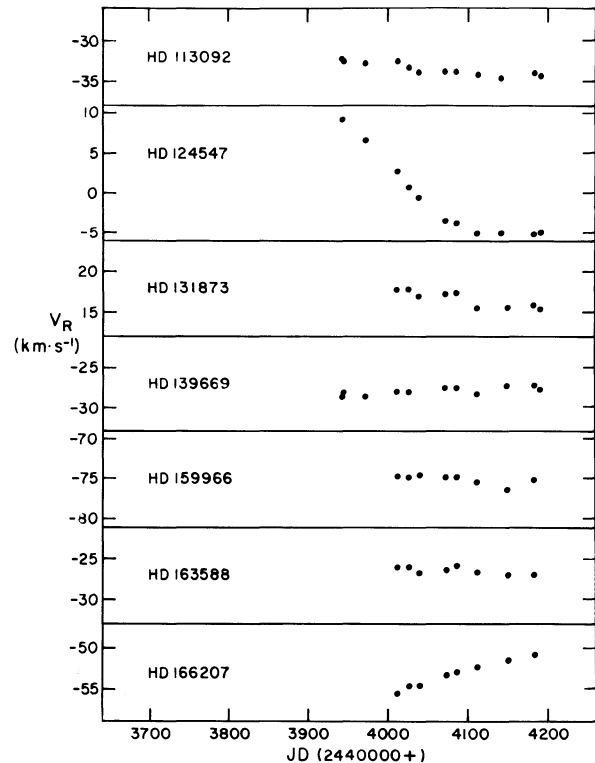


FIG. 1.—Radial velocity versus Julian date for members of the random K giant sample that are possible spectroscopic binaries.

scatter for these is almost identical to the random K giants and standard velocity stars discussed above. The situation for Ba 2–Ba 5 stars is very different, however. Nine out of 11 of these have standard deviations more than twice the value of the precision of measurement with the spectrometer. It is highly unlikely that these large variations are due to the faintness of the stars. They are not near the limit of observation with the spectrometer. The limiting magnitude of the sample was chosen to ensure that photon statistics would not enter into the errors of the observations. In fact, to ensure that seeing noise was overcome, the brightest stars observed in this program needed integration times about as long as the faintest ones (1–2 minutes). Furthermore, the large standard deviations for the Ba 2–Ba 5 stars are not random, but rather show trends over the course of the year's observing.

We show velocity curves for these stars in Figure 2. These give a good indication of the type of velocity variations we have observed. However, note that we have spanned a complete or nearly complete period for only two of the stars so far. For these two stars, HD 77247 ($P \sim 80^d$; $K \sim 10 \text{ km s}^{-1}$) and HD 199939 ($P \sim 500^d$; $K \sim 7 \text{ km s}^{-1}$), we find a mass function of the order of 0.01–0.02. This implies a mass ratio of two or more, depending on the primary mass and orbital inclination. Although these results are very preliminary, it seems likely, because of the small amplitudes of the velocity variations in all these systems, that the secondary stars must be very low-mass objects.

IV. DISCUSSION

It is not unreasonable to conclude that Ba II stars are all binaries with low-mass secondaries consisting of degenerate objects. It is possible that these systems are such that mass has been lost from a more massive evolving star and deposited onto the present primary, the secondary having now evolved to the white dwarf stage. The carbon and *s*-process elements in this case could be dumped onto the present primary-star atmosphere. The separations we are finding for the components of the binaries are large (several AU). Therefore, if normal binary mass-transfer has taken place, the evolving star would originally have been rather massive. Iben's (1975) mechanism for convective mixing in a thermally pulsating intermediate mass star may work in this case.

The original impetus for this project (see McClure 1979) was the observation that among globular clusters which have been surveyed for peculiar stars, CH stars are found only in the very low concentration clusters ω Cen, M22, and M55, but not in more highly concentrated ones (McClure and Norris 1977; McClure 1979). It is possible that these relatively loose systems either form binaries or retain binaries more easily than other clusters. The CH stars, which are probably the Popula-

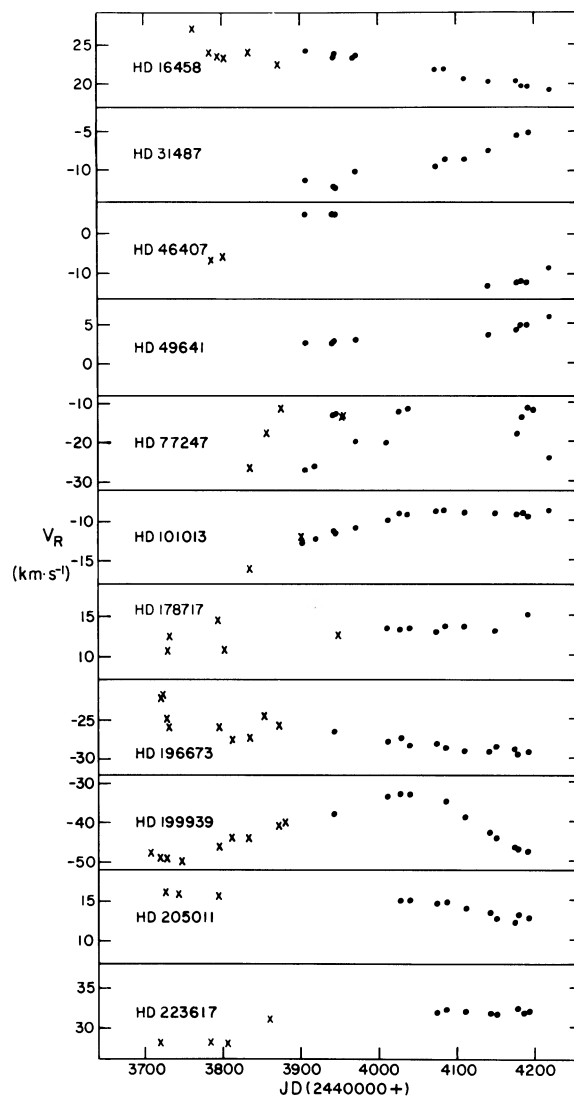


FIG. 2.—Radial velocity versus Julian date for the Ba 2–Ba 5 stars.

tion II equivalents of Ba II stars may also, by implication, be binaries. We have added a sample of CH stars to the program and hope to gain a better knowledge of this in a few months' time. If they prove to be binaries, then their existence will be of considerable importance in interpreting the peculiar abundance anomalies existing in several globular clusters.

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