ORBITAL ELEMENTS OF A SAMPLE OF S STARS: TESTING THE BARIUM – S EVOLUTIONARY CONNECTION

A. JORISSEN[1] and M. MAYOR[2]
[1] European Southern Observatory, Garching bei München, Germany
[2] Observatoire de Genève, Switzerland

ABSTRACT. Orbital elements for 8 non-Mira S stars (derived from CORAVEL observations and from Griffin 1984) are compared with those of barium stars. In all but one case, the mass functions are compatible with white dwarf companions. No periods shorter than 600 d are found, while the 5 orbits with $600 < P(\mathrm{d}) < 900$ all have $e \leq 0.1$, in contrast with the situation prevailing for barium stars. It is suggested that the hypothesis of an evolutionary link between barium and non-Mira (no Tc) S stars can be reconciled with these differences provided that these S stars are low-mass stars populating the first giant branch instead of the asymptotic giant branch, as usually thought.

1. THE INCIDENCE OF BINARITY AMONG S STARS

Several recent works (see Johnson, this volume, for a review) have suggested that S stars should be divided into two distinct classes: *intrinsic* and *extrinsic* S stars. The former class includes S stars showing the unstable element Tc in their spectra; they are believed to be thermally-pulsing stars on the asymptotic giant branch (AGB), involved in the evolutionary sequence M – S – C. On the contrary, extrinsic S stars neither exhibit Tc nor show large light variations, and are likely all spectroscopic binaries. Their chemical peculiarities are thus probably related to some mass transfer episode in the binary system, exactly as for their hotter counterparts, the barium stars. Since orbital elements are now available for S stars as well, the hypothesis of an evolutionary link between barium and extrinsic S stars can be tested on a more quantitative basis.

2. THE CORAVEL RADIAL VELOCITY MONITORING

A CORAVEL radial velocity monitoring of 10 non-Mira S stars was initiated in 1984. The main selection criterion was the absence of any variable star designation in Stephenson's (1984) *General Catalog of S Stars*. Although the Tc content is not known for all of our S stars (but will be investigated in a forthcoming paper), the absence of large light variations makes the presence of Tc unlikely (see Little-Marenin et al. 1987).

A detailed discussion of the radial velocity variations can be found in Jorissen & Mayor (1988, 1991). After 7 years of monitoring, the situation regarding binarity is as follows: 5 SB1 orbits are available, 3 stars have periods longer than 2000 d and the remaining two stars display a statistically significant jitter but no evidence for binarity.

3. THE MASS FUNCTIONS

The mass functions for 4 among the 5 orbits derived from our CORAVEL measurements, as well as that from Griffin (1984), are compatible with a white dwarf (WD) companion ($0.028\ \mathrm{M}_\odot \leq f(M) \leq 0.043\ \mathrm{M}_\odot$). A rough estimate of the mass functions for two among the three long-period systems yields values in the range 0.015 to 0.020 $\mathrm{M}_\odot$. In fact, the cumulative distribution of the mass functions for S stars does not differ significantly from that of barium stars. In the latter case, Webbink (1986; see also McClure & Woodsworth 1990 and Eggleton, this volume) showed that this

Y. Kondo et al. (eds.), Evolutionary Processes in Interacting Binary Stars, 407–410.
© 1992 *IAU. Printed in the Netherlands.*

https://doi.org/10.1017/S0074180900122594 Published online by Cambridge University Press

cumulative distribution is compatible with orbits of mass ratio $Q \equiv M_2^3/(M_1 + M_2)^2$ in the range 0.04 ± 0.01 $M_\odot$ seen at random orbital inclinations. Such mass ratios are those expected for systems consisting in a WD of mass $0.5 \leq M_2/M_\odot \leq 0.6$ and a red giant of mass $1.2 \leq M_1/M_\odot \leq 2$.

In the case of HDE 332077 ($V = 9.2$, S3,1), the mass function of 1.2 $M_\odot$ clearly forbids, however, the companion to be a WD: the minimum mass $M_1 \sim 0.2$ $M_\odot$ for the S star (corresponding to the minimum mass for the He-core of a post-main sequence star of initial mass ≥ 1 $M_\odot$) implies $M_2 > 1.4$ $M_\odot$ for the companion. Constraints on a main sequence companion were obtained from an IUE spectrum (no signal recorded at the level 2.4 10^{-14} erg cm^{-2} Å^{-1} s^{-1}) and from the normal $B-V$ index of the S star: as discussed in Jorissen & Mayor (1991), the only solution satisfying these constraints seems to consist in a (post-mass transfer) A-type main sequence companion remaining hidden in the system because the S star is brighter than $M_v = -2$. This high luminosity is well in line with the broad lines exhibited by HDE 332077, although part of the line broadening may be due to a rapid rotation resulting from the synchronization with the orbital motion.

The main difficulty with this solution resides, however, in the absence of Tc at the surface of HDE 332077. This S star thus appears to belong to the extrinsic class, but the absence of WD companion makes it difficult to account for the abundance anomalies. A triple hierarchical system (the companion being a close WD/main sequence pair) may perhaps be invoked, or an intrinsic S star with extinct Tc. This last possibility calls for the spectroscopic abundance determinations of Zr, Nb, Mo and Ru in that star, which can be used to probe its s-process history (Smith & Wallerstein 1983, Mathews et al. 1986). Of particular interest would be the determination of the ^{93}Zr/^{93}Nb ratio, which may still reveal the presence of the unstable ^{93}Zr, because its lifetime is about 10 times longer than the one of ^{99}Tc (at the stellar surface).

It is interesting to note that HD 191589 (Johnson, this volume) is another case of a S star having a main sequence companion but no Tc. If it were not for the absence of Tc in the S star, these two systems consisting in a S star with an A or F-type main sequence companion might well constitute the "missing link" between the intrinsic S stars and the barium/extrinsic S stars. At least in the case of HDE 332077, the reversed mass ratio clearly attests that the (intrinsic?) S star dumped matter on its main sequence companion which will eventually become a barium/extrinsic S star.

4. THE (e, $\log P$) DIAGRAM

The (e, $\log P$) diagram of the sample of S stars is displayed on Fig. 1. The clustering of $600 \leq P(\mathrm{d}) \leq 900$ orbits around $e = 0.1$ is especially appealing. It should be mentioned that these orbits have been tested against circularity according to Lucy & Sweeney's (1971) criterion. All but one (corresponding to the poorest orbit, however) are truly eccentric, at a significance level better than 10% (better than 1% in two cases). These eccentricities are probably not spurious, like in semi-detached systems as a result of the ellipsoidal shape of the Roche lobe-filling component, because ω is neither equal to 90° nor to 270° (Sterne 1941).

The (e, $\log P$) diagram of S stars contrasts with that of barium stars, whose 600 – 900 d orbits have larger eccentricities, on the average. Furthermore, if real, the lack of $P < 600$ d orbits among S stars is puzzling, because such short periods are found among barium stars (Note that there is no selection effect against short-period orbits, since their velocity amplitude is large).

5. EXTRINSIC S STARS = LOW-MASS STARS ON THE RGB?

We suggest that the hypothesis of an evolutionary link between barium and extrinsic S stars can be reconciled with the differences observed in their respective (e, $\log P$) diagrams, provided that *extrinsic S stars are low-mass stars populating the first red giant branch (RGB) where tidal effects and Roche lobe overflow (RLOF) shape their (e, $\log P$) diagram.*

This assumption is supported by the kinematical properties of non-Mira S stars, which are typical of $M_1 \leq 1.3$ to 1.5 $M_\odot$ stars (Feast 1989, Jorissen & Mayor 1991). On the contrary, barium stars appear to involve somewhat more massive stars as well (Hakkila 1989). If extrinsic S stars indeed

https://doi.org/10.1017/S0074180900122594 Published online by Cambridge University Press

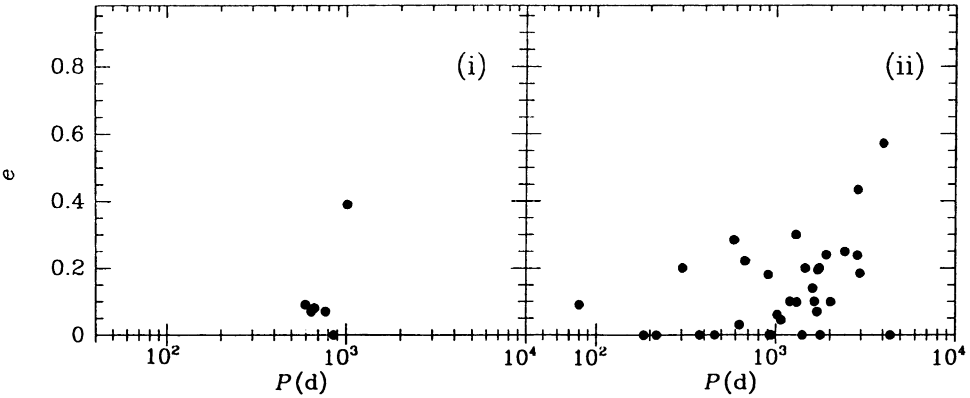

Figure 1: The (e, $\log P$) diagram for S stars (left panel, from Jorissen & Mayor 1991 and Griffin 1984) and barium stars (right panel, from McClure & Woodsworth 1990 and Jorissen & Mayor, in preparation). Preliminary orbits for two among the three S stars with long periods yield P in the range 2000 to 3000 d and e in the range 0.2 to 0.4.

populate the RGB (instead of the AGB), this difference between the kinematical properties of barium and extrinsic S stars simply reflects the fact that only the RGB of low-mass stars ($M \leq 1.8$ $M_\odot$, according to Maeder & Meynet 1989) extends to low enough temperatures for the S-type spectrum to develop ($\log T_{\rm eff} < 3.6$). There is no such natural selection effect for the hotter barium stars (being either early-RGB stars or core He-burning giants).

As will be shown in a forthcoming paper, a further indication (besides evolutionary time scales) that extrinsic S stars populate the RGB rather than the AGB is provided by their position in the IRAS ([12]-[25], [25]-[60]) color-color diagram, since extrinsic S stars do not show IR excesses as do dusty AGB stars like intrinsic S stars (see Habing 1987 for a similar distinction among M stars).

As far as the threshold period – if any – in the (e, $\log P$) diagram is concerned, Fig. 2 shows that it should indeed be of a few hundred days if extrinsic S stars populate the RGB. Binary systems involving a low-mass giant ($M_1 \leq 1.5$ $M_\odot$) and a WD companion of $M_2 \sim 0.6$ $M_\odot$ will in fact undergo RLOF on the RGB if their orbital period is shorter than a few hundred days. The orbits of systems with periods close to this RLOF threshold will moreover be circularized by tidal effects acting on the deep convective envelope of the giant.

On the contrary, short period systems can survive among the more massive barium stars, since they do not reach radii as large as those of S stars when evolving along the RGB. Consequently, the threshold period for RLOF before the onset of core He-burning is shorter (Fig. 2).

In conclusion, the differences observed in the (e, $\log P$) diagrams of barium and S stars do not preclude the existence of an evolutionary link between both families, provided that S stars populate the RGB. However, S stars with main sequence companions but no Tc [HD 191589 (Johnson, this volume) and HDE 332077] are now known, and further studies will be needed to see how these "outsiders" can fit in the current picture of extrinsic/intrinsic S stars.

https://doi.org/10.1017/S0074180900122594 Published online by Cambridge University Press

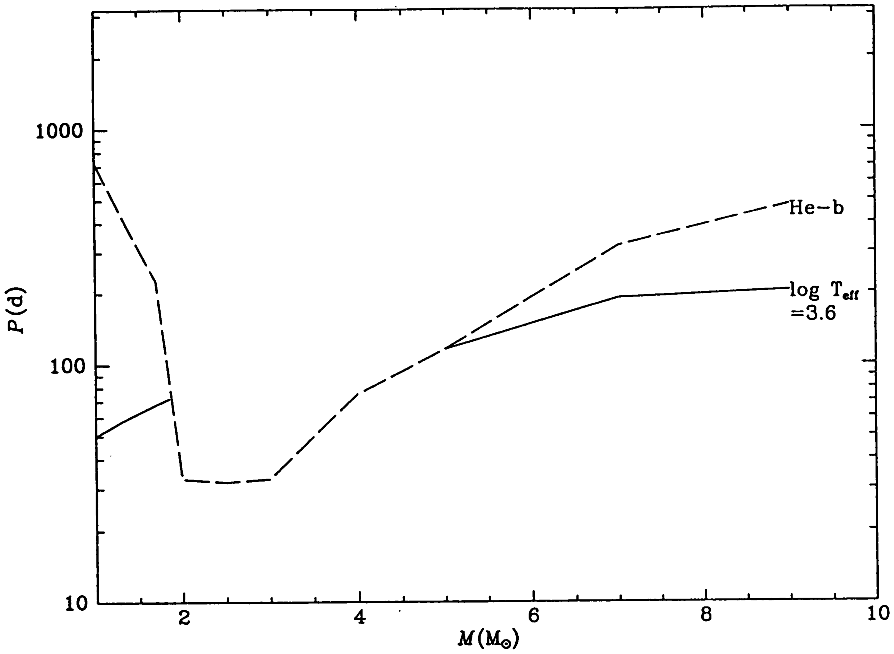

Figure 2: The critical periods for RLOF at the time when $\log T_{\rm eff} = 3.6$ on the RGB (solid line) and at the onset of core He-burning (dashed line), as a function of the mass of the red giant. The red giant radius is deduced from Fig. 15 of Maeder & Meynet (1989), and the companion is assumed to be a WD of mass 0.6 $M_\odot$ in a circular orbit. Red giants in the range $1.9 \leq M_1/M_\odot \leq 5$ ignite He at $\log T_{\rm eff} > 3.6$ and are never cool enough to appear as S stars on the RGB.

6. REFERENCES

Feast, M.W., 1989, in: Evolution of Peculiar Red Giant Stars, eds. H.R. Johnson & B. Zuckerman, Cambridge U.P., p.26

Griffin, R.F., 1984, The Observatory 104, 224

Habing, H.J., 1987, in: Circumstellar Matter (IAU Symp. 122), eds. I. Appenzeller & C. Jordan, Dordrecht, Reidel, p.197

Hakkila, J., 1989, AJ 98, 699

Jorissen, A., Mayor, M., 1988, A&A 198, 187

Jorissen, A., Mayor, M., 1991, submitted to A&A

Little, S.J., Little-Marenin, I.R., Hagen-Bauer, W., 1987, AJ 94, 981

Lucy, L.B., Sweeney, M.A., 1971, AJ 76, 544

Mathews, G.J., Takahashi, K., Ward, R.A., Howard, W.M., 1986, ApJ 302, 410

Maeder, A., Meynet, G., 1989, A&A 210, 155

McClure, R.D., Woodsworth, A.W., 1990, ApJ 352, 709

Smith, V.V., Wallerstein, G., 1983, ApJ 273, 742

Stephenson, C.B., 1984, Publ. Warner & Swasey Observ. 3, 1

Sterne, T.E., 1941, Proc. Nat. Acad. Sc. 27, 168

Webbink, R.F., 1986, in: Critical Observations vs Physical Models for Close Binary Systems, eds. K.C. Leung and D.S. Zhai, New York, Gordon and Breach

https://doi.org/10.1017/S0074180900122594 Published online by Cambridge University Press