BINARY "POST–AGB" STARS

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Abstract. In this contribution we report on our radial-velocity monitoring of optically bright, high-latitude supergiants that appear to be in a post–AGB evolutionary stage. Binarity is a widespread phenomenon among our sample stars. More precisely: *all* objects with a near-IR excess in their energy distribution turn out to be binaries while the fraction of binaries in our program stars with only a far-IR excess is very small. The orbital periods, the often non-zero eccentricities, and the sometimes large mass functions set strong constraints on the previous evolution in which mass transfer must have been an important ingredient. We have accumulated observational evidence that the presence of a circum-binary dusty disk has an important dynamical and sometimes even chemical influence on the binary and its evolution. Some objects with a high mass function still defy an explanation.

1. Introduction

Systematic searches for post–AGB stars of low initial mass have concentrated mainly on optically bright objects with an IR excess due to circumstellar dust (Hrivnak et al. 1989; Pottasch & Parthasarathy 1988; Oudmaijer et al. 1992). This IR excess, the high or intermediate galactic latitude, the on average low metal content, and in some cases the high space motion are observational indications for the old and evolved population of these objects. Detailed studies of the spectral energy distribution (SED) have

R.F. Wing (ed.), The Carbon Star Phenomenon, 285-291.

https://doi.org/10.1017/S0074180900002515 Published online by Cambridge University Press

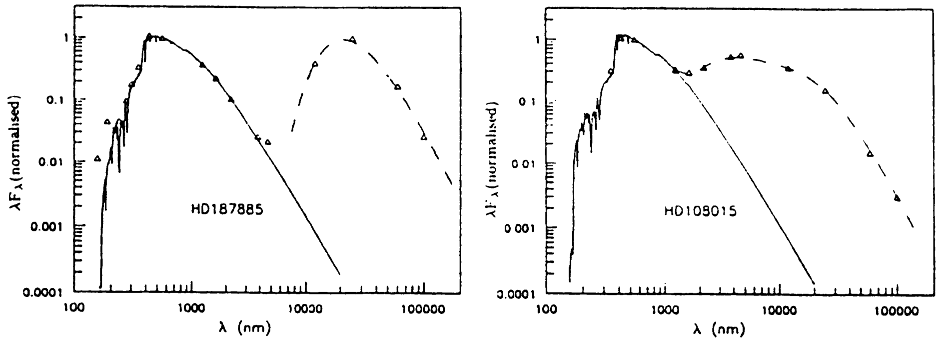

Figure 1. The SEDs of representatives of the two classes of optically bright post-AGB stars: HD 187885 shows the presence of only cold dust, while HD 108015 has hot dust as well.

shown that the objects can be divided into two groups depending on the shape of the IR excess (e.g. Trams et al. 1991; van der Veen et al. 1994; Bogaert 1994). Sources with an IR excess starting already at the near-IR have both hot and cool dust in their circumstellar dust shells, while others with only a far-IR excess show the presence of only cool dust (Figure 1).

In this contribution we report on our ongoing radial velocity monitoring and strengthen the earlier suggestions (Waters et al. 1993b) that *all* objects with a near-IR excess are binaries. We will focus on observational evidence that the presence not only of a companion but also of a circum-binary dust-disk has important influence on the stellar evolution.

2. Orbital Parameters

We have been accumulating radial velocity measurements using the CORAVEL spectrometer at ESO and OHP complemented with observations obtained with the CES at ESO, La Silla. A detailed report of this ongoing program will be published elsewhere; here we limit ourselves to the most important results. In Table 1 we list the objects for which we have found conclusive evidence of binarity. The orbital periods, eccentricities and mass-functions are given for the objects for which we have enough data-points to analyze the radial-velocity curve in detail. In the last column we indicate whether the circumstellar environment is carbon or oxygen rich. For none of the stars with only a far-IR excess in our sample (6 stars in total) did we find evidence for a binary companion in our radial velocity data!

Most of the periods we found are of the order of one to a few years. Noticeable exceptions are SAO 173329 with a period of only 116 days (!) and the RV Tauri stars HD 131356, AC Her and U Mon which have longer

TABLE 1. Overview of the orbital elements

Name	Period (d)	e	F(M) ($M_\odot$)	CS chemistry
Chemically peuliar				
HR 4049[1]	429	0.31	0.143	C-rich
HD 44179[1]	318	0.39	0.049	C-rich
HD 52961[1]	a few years	> 0	?	C-rich
BD +39°4926[2]	775	?	?	-
HD 213985	259	0	0.97	C-rich
HD 46703[3]	610	> 0	?	?
SAO 173329	115.9	0	0.026	?
89 Her[4]	288.4	0.19	0.00083	O-rich
HD 108015	938	?	0.0029	?
HD 95767	± 2050	?	± 0.3	?
HD 131356	1150	?	± 0.52	?
AC Her	±1230	?	?	?
U Mon[5]	2597	0.43	?	?

1) Van Winckel, et al. 1995, *A&A*, 293, L25
2) Kodaira, K., et al. 1970, *ApJ*, 159, 485
3) Hrivnak & Lu 2000 (these proceedings)
4) Waters, et al. 1993, *A&A*, 269, 242
5) Pollard, K. R. 1995, ASP Conf. Ser., 83, 409

periods. For the RV Tauri stars this is probably a selection effect as the shorter period orbits are very hard to detect due to the large pulsational velocity amplitudes.

The objects are thought to be post-AGB objects: their kinematics point to low masses, the CS dust (for some objects C-rich!) and high luminosity suggest a terminal phase of evolution. Current evolutionary tracks suggest then a post-AGB stage of evolution. However, for the shorter period binaries (periods smaller than a few years), the orbit is too small to accommodate an AGB star. On the AGB, an object with the same luminosity and orbital parameters would experience severe Roche-lobe overflow leading not only to circularization of the orbit, but also to spiral-in. This would result in a circular short period binary, contrary to what is observed. Note that the same problem is encountered in the short period Ba stars and Tc-poor S stars (see Jorissen & Van Eck 2000); these stars are also post-AGB objects since the actual white dwarf has been an AGB star in the past.

Most remarkable are, however, the non-zero eccentricities in certainly 3 of the shorter period objects (HR 4049, HD 44179 and 89 Her). As can be

https://doi.org/10.1017/S0074180900002515 Published online by Cambridge University Press

seen on the e–log$P$ diagram shown by Jorissen & Van Eck (2000), evolved binaries with orbital periods in the range of our program stars have circular orbits due to dissipative processes during red giant and asymptotic giant evolution. We can conclude that especially these shorter period binaries do not follow standard stellar evolution.

3. Circumbinary Disk

For a thorough review of the observational evidence for the presence of a circumbinary disk around these binaries we refer to Waters et al. (1993a,b) and Waelkens et al. (1991, 1996). We stress that the best evidence comes from the three objects (HR 4049, HD 44179 and HD 213985) where the photometric brightness and color variations we observe are in phase with the orbital motion. This behavior can best be explained by variable extinction by a thick circumbinary dust-disk that is viewed at a certain inclination: when the supergiant is nearest to us the obscuration by the dust ring is maximal so that the light is minimal and reddest (Waelkens et al. 1991).

With the dust trapped in a Keplerian thick disk around the system, it is prevented from cooling down rapidly. The dust in the inner part of the disk will remain in thermal equilibrium with the radiation field of the binary and remains hot. This gives a natural explanation for the correlation between the presence of hot dust and the binary nature of the objects. How such disks are formed in the wide period range given in Table 1 is still an open question.

4. Binary-Disk Interactions

4.1. CHEMICAL

In the top part of Table 1, the chemically peculiar objects are listed. In these extremely metal-deficient objects (with iron abundances as low as [Fe/H] $= -4.8$) the photospheric chemical patterns are acquired by accretion of pure circumstellar gas, separated from the dust (see Waters et al. 1992, and references therein). Recently other evolved objects have been found that display the same, albeit less extreme, chemical patterns (see Giridhar 2000). Some of them are again known to be binaries.

There is growing evidence that the presence of a disk is essential for the fractionation process to be effective. According to Waters et al. (1992), a stationary disk offers the best environment for two essential conditions to be fulfilled: a density low enough for the drag of the dust grains on the gas to be minimal, and a slow accretion rate.

4.2. DYNAMICAL

It is interesting to note that Artymowicz et al. (1991) concluded that the binary eccentricity distribution on the main sequence is determined in the pre-main-sequence phase of evolution by tidal interaction between the binary and the circum-binary dust disk, which is present as a relic from the star formation process. They conclude that for stars with a mass ratio smaller than five, and a small but non-zero eccentricity, a resonant interaction between the binary and the circum-binary disk can cause very rapid eccentricity growth. Very similar conditions are now present in the short-period stars of Table 1: these objects are also surrounded by a thick dusty circumbinary disk. It may be then that resonant behavior between the circum-system disk and the binary has caused rapid eccentricity growth leading to high eccentricities. Clearly this process should be explored in more detail.

4.3. TIDALLY ENHANCED MASS-LOSS

Also for HD 213985 the period is much too short to accommodate an AGB star. For this object with a C-rich circumstellar environment, we have the best evidence that severe mass transfer occurred since the (probably) unevolved secondary has a mass which is larger that the main-sequence mass of the primary (the mass function is high). It is, however, not clear how the system avoided spiral-in on the AGB. It could be that severe mass transfer took place, but only after the system reversed its mass-ratio. In that case, Roche-lobe overflow (RLO) is stable. Tout & Eggleton (1988) and Han et al. (1995) describe a scenario where the mass-ratio of a binary system can be reversed before RLO occurs due to a tidally enhanced stellar wind. These authors invoke this scenario in order to explain the existence and the period distribution of several groups of binaries. Observational evidence that such an enhanced mass-loss mechanism exists is, however, difficult to find. SAO 173329 may be in this respect a most interesting object: it shows a strong P-Cygni Hα line-profile with an expansion velocity of some 300 km s^{-1} which is highly remarkable for a F–type object. At the same time, the object turned out to be a binary star with the shortest period of our sample, only 116 days. The short orbital period and the high mass loss rate may be related: SAO 173329 may the best observational evidence that the companion can induce a high mass-loss rate by a tidally enhanced wind.

5. Conclusions

The optically bright post–AGB stars with a near IR-excess have turned out to be binaries. The observed periods, eccentricities and mass-functions

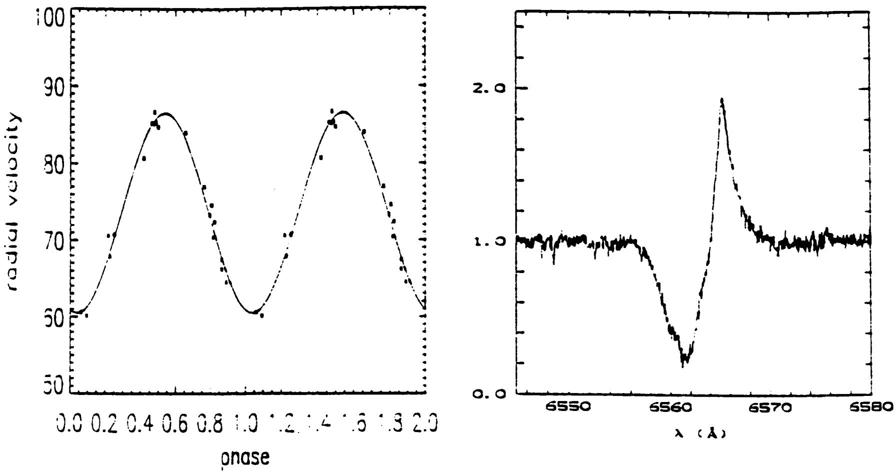

Figure 2. *Left*: The radial velocity curve of SAO 173329 folded on the 115.9–day period. *Right*: The Hα line profile.

imply that they do not follow standard evolutionary scenarios and non-standard phenomena connected to the specific binary nature have to be invoked in order to understand these systems.

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Discussion

Giridhar: You mentioned mass transfer in the case of HD 213985. Would you like to elaborate on it?

Van Winckel: The mass function is high, and if we adopt a typical mass for a post–AGB star of $0.6\,M_\odot$, the companion must be around $2\,M_\odot$ or even higher, depending on the inclination. The mass of the secondary is then higher than the main-sequence mass of the actual high-latitude supergiant primary.

Giridhar: Is the binarity of U Mon confirmed on the basis of radial-velocity variation?

Van Winckel: Yes. In the paper of Pollard, the radial velocity measurements are shown with a long-timescale trend which they interpret as due to orbital motion.

Molster: Is there enough mass in the circumbinary disk to increase the eccentricity of the orbit?

Van Winckel: Yes. The amount of mass is not too important in this scenario of Artymowicz. The location of the dust shell is, however, crucial.

Bakker: The star BD +39°4926 is in your sample of post–AGB binaries but does not exhibit an infrared excess. Could you comment on this?

Van Winckel: This star is more distant than the others. For example, an IR excess similar to what IRAS measured for HR 4049 would be below the detection limit for BD +39°4926. We have a proposal in for ISO to try to detect the star and see whether there is still circumstellar material.

Linsky: Do you have an estimate for the mass-loss rate of SAO 173329 from the profile of the Hα line? Will this mass-loss rate alter the evolution of the binary system?

Van Winckel: It is about $10^{-7}\,M_\odot$/year. It is the only star in our sample of F supergiants with a P-Cygni profile and such a high mass-loss rate. Increased mass loss in the post–AGB phase will speed up the evolution drastically. We believe this star is very good evidence that tidally enhanced mass loss indeed exists and can be very efficient. It might be crucial to flip over the mass ratio of the binary system, before Roche-lobe overflow.