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Binary post-AGB stars

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Abstract. An overview is given on the observational characteristics of some individual post-AGB stars in binary systems, which inspired us to start a systematic search for binarity in a sample of post-AGB stars. In this contribution a preliminary report is presented of this search. One of the fundamental ingredients in the evolution of the systems discussed here is the creation of a circumbinary dusty disc, probably during the AGB evolutionary phase. There is observational evidence that the discs are Keplerian and that they have important impact on the systems' (chemical) evolution. We discuss briefly the relation to other evolved binary classes, in which one of the components went through the AGB evolution.

Key words. Post-AGB stars – binary evolution

1. Introduction

Post-AGB stars are in a very fast evolutionary phase: in a mere few times 10 000 years, the central star is crossing the HR-diagram from a molecular opacity dominated AGB photosphere, to the ionising temperature of the central star of a Planetary Nebulae (PNe). Post-AGB stars are therefore rare and not many are known (e.g. Szczerba et al., 2001; Van Winckel 2003). In recent years it became clear that binarity is not uncommon and in this contribution an overview is given on the observational characteristics of the objects, for which there is direct proof of the binary nature by radial velocity measurements. Note that in more embedded post-AGB stars, for which the central star is too obscured to be subject to radial velocity monitoring, binarity is often suspected on the basis of morphological or kinematical properties of the outflow (Balick & Frank 2002).

An overview of the possible binary interactions during the late evolution of one of the components, and the whole zoo of specific types of objects resulting from these interactions, is given in these proceedings by Onno Pols. In this contribution the focus is on post-AGB binaries in which one of the components has post-AGB signatures and the other is likely unevolved.

2. Depletion

The chemical composition of an evolved star is usually understood as being the initial composition of the star, modulated by dredge-up enrichements during specific evolutionary phases. In the case of post-AGB stars, the chemical composition is an important constraint on the possible evolutionary status of the individual star, but it is also an ideal tool to study AGB nucleosynthesis in general.

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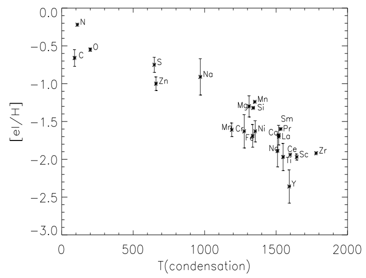

Fig. 1. The photospheric chemical composition of AC Her is showing the effect of a depletion process in which refractory species are deficient. Figure from Van Winckel et al. (1998).

In post-AGB stars, however, the photospheric composition is sometimes determined by a *chemical* process called 'depletion': elements with a high condensation temperature have low photospheric abundances, while elements with a low condensation temperature show higher abundances (see Figure 1). The photospheric abundance patterns mimic the gas phase abundances of the ISM. There is general agreement that this is the result of gas-dust separation in the circumstellar environment, followed by selective re-accretion of the gas, devoid of refractories (e.g. Waters et al. 1992). This gives these specific abundance pattern (Fig 1). Note that at first sight, the large [C/Fe] ratio may be mistaken for an indication of 3^{rd} dredge-up enhancement and it is only when the whole photospheric abundance pattern is available, that one can differentiate between depletion and internal nucleosynthesis evidence.

3. Individual objects

Detailed multispectral studies of individual binary post-AGB stars showed that there is a large variety of observational properties. A general characteristic is, however, that the circumstellar dust is (partly) trapped in the system forming a presumably Keplerian disc.

3.1. HD 44179

Since its discovery by Cohen et al. (1975), the Red Rectangle (RR) and its central star HD 44179 has often been used as an archetypical example of a C-rich post-AGB object. But it is now generally accepted that many of the remarkable phenomena and the peculiar morphology of the nebula (for an overview see Cohen et al. 2004), are closely related to the presence of a stable circumbinary disc around the binary central star. The longevity of the disc was dramatically confirmed by the detection of cool O-rich crystalline silicate dust grains in the disc (Waters et al. 1998). The mixed chemistry is best explained assuming the formation of the O-rich disc predated the more recent C-rich transition of the central object. The disc is resolved in ground-based high spatial-resolution imaging at optical and near-IR wavelengths (Men'shckikov et al. 2002) as well as in HST optical images (Cohen et al. 2004). Recently, the disc was also resolved in interferometric CO(2-1) maps, and the Keplerian kinematics of the disc were directly detected (Bujarrabal et al. 2003). The dust properties as well as the presence of large grains (Jura et al. 1997) and even macrostructures (Jura et al. 1998) are distinct characteristics and can best be explained by the long-term processing in the disc.

3.2. HR 4049

HR 4049 is a binary with an orbital period of 430 days with a remarkable high eccentricity of e=30. The star is extremely depleted with a [Fe/H]=−4.8, making the strongest Fe II multiplet number 42 almost completely invisible. The photometry is modulated with the orbital period due to variable circumstellar extinction in the line of sight. The star is redder and fainter at inferior conjuction. The wavelength dependence of the circumstellar material in the UV is enigmatic (Monier R & Parthasarathy M., 1999). Also in this object, the circumstellar material shows a mixed chemistry with both carbon rich and oxygen rich features. Weird O isotopic ratios are found with $^{16}O/^{17}O$ =

8.3 ± 2.3 and $^{16}O/^{18}O$ = 6.9 ± 0.9 (Cami & Yamamura 2001). These ratios are as yet unexplained by AGB nucleosynthesis, but may indicate novae nucleosynthesis (Lugaro et al. 2004) rendering the previous evolution of the system even more problematic. The SED of the dust is also very peculiar as it can be fitted with a single black-body of about 1150 K, from 1 μm down to 850 μm. These SED characteristics are very constraining and the best model for the circumstellar material is, that the dust is trapped in a very opaque dust torus at Keplerian rotation (Dominik et al. 2003). It is clear that the dusty disc plays a lead role in the (future) evolution of the system.

3.3. AC Her

RV Tauri stars are quire rare supergiants which occupy the high-luminosity end of the Pop. II Cepheid instability strip. The defining light curve shows alternating deep and shallow minima with periods ranging from 30 to 150 days. They are generally acknowledged to be post-AGB stars because many (but not all) show a considerable amount of circumstellar dust (Jura 1986). AC Her is one of the best studied RV Tauri stars with a very regular pulsation period of 75 days. The star is severely depleted and resides in a binary with orbital period of some 1200 days (Van Winckel et al. 1998). The weak and narrow CO emission (Bujarrabal et al. 1988) points to Keplerian rotation instead of outflow kinematics (Jura et al. 1995). The circumstellar dust particles are larger than in outflows and the strong dust processing signatures in the IR spectral features are typical for disc sources. This is illustrated by Molster et al. (1999) who compare the very similar IR spectrum of AC Her with the one of solar system comet Hale-Bopp. We conclude that also in AC Her there is evidence for the presence of a Keplerian dusty disc in the system.

4. Systematic search for binary post-AGB stars

The presence of a disc seems to be the common ingredient in the well studied individual post-AGB binary stars. For evolved stars the presence of a discs implies binarity. We therefore initiated a systematic search for post-AGB binaries starting from a sample selected only by the IR-colours. A list of candidates was prepared by calculating the colours of all IRAS stars with reliable (quality 3) photometry at 60 μm and selecting those, which were located in a rectangle in the IRAS two-colour diagram tuned to find new RV Tauri stars by Lloyd Evans (1999). The defining rectangle is

$$\begin{cases} [12] - [25] = 1.0 - 1.55 \\ [25] - [60] = 0.20 - 1.0 \end{cases}$$

Moreover, our selection criteria included an observed excess in the L-band, indicative of a dusty disc. Follow-up low-resolution spectroscopic observations were supplemented with photometric monitoring data by Lloyd Evans (1999). Most variable stars of the sample have spectral types in the narrow range occupied by the bulk of the previously-known RV Tauri stars, while those of lesser amplitude are mainly of earlier F subtype. This suggests that many IRAS detected RV Tauri stars of the GCVS are simply those with dusty discs, which happen to be passing through the instability strip of the Type II Cepheids (Lloyd Evans 1999).

We initiated an intensive radial velocity monitoring campaign of a subsample of these objects which are bright enough for the spectrograph CORALIE mounted on the Swiss Euler telescope at ESO, La Silla. High S/N single shot spectra were also obtained to study the chemical composition of the stars. IR spectra were observed to study the chemistry and physical characteristics of the circumstellar dust, while sub-mm data were gatherd to constrain the dust size distribution.

Our regular monitoring of the radial velocity did result in the detection of quite a few binaries. In Figure 2 we show the broad-band SED of one of the newly detected binaries, together with its radial velocity curve. Our monitoring campaigns are still ongoing but we can safely conclude that we indeed found the suspected high binary rate (now about 73%, but some of the objects have pulsational amplitudes which are too large for easy detection of binary motion). Moreover, our single dish CO

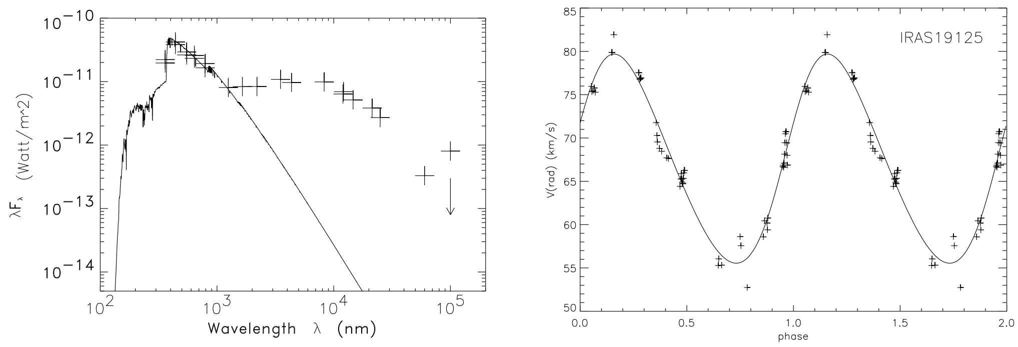

Fig. 2. The broad band SED (left) and the folded radial velocity curve (right) of the newly discovered post-AGB binary IRAS19125+0343. The full line in the SED is the appropriate Kurucz atmosphere model fitted to the dereddened fluxes. The full line in the radial velocity curve is the binary orbit solution (period=508 days; e=0.12; A sin i = 0.56 AU).

data show typical rotation velocities instead of outflows and our sub-millimetre data is consistent with a significant component of large grains. All this supporting the suggestion that stable dusty discs are indeed present. Recent publications of our team on individual objects can be found in (Maas et al. 2002, Maas et al. 2003, Maas et al. 2004, and De Ruyter et al. 2004).

5. The e-log P diagram

In none of the binary post-AGB stars detected so far is there observational evidence for the presence of a hot degenerate companion and the more likely scenario is that the companions are unevolved main-sequence stars. In Figure 3 we show the e-log(P) diagram of all binary post-AGB stars for which orbital periods were known until now. These include our partly unpublished orbits and for references of the others we refer to Van Winckel (2003).

The orbits cluster in the 300-1000 day range. The longer period limit is an observational bias due to the relative recent start of the radial velocity monitoring. It is clear from this figure that significant dynamical interaction has taken place, making the shorter orbits disappear from the diagram. On the other hand it is also most remarkable that from a few hundred days onwards, significant eccentricity is observed, which is not understood in the current binary evolution theory. To illustrate this, we show as a dotted line, a population synthesis result of Pols et al. (2003) tuned to explain the Ba star sample.

To compare the post-AGB binaries with other classes of evolved binary stars, we show in the same figure, the orbits of Ba stars from the compilation of Jorissen et al. (1998). These are the natural successors of the post-AGB stars, since the white dwarf in the Ba star was once a mass losing AGB star (see also contribution of Pols). Note that the orbits of the Ba stars are complete.

For post-AGB stars, the same period range is observed, although the orbits are significantly more eccentric in the 300-600 day range. Chemically, however, the evolutionary link between both classes if far from clear: many post-AGB binaries are depleted by a circumstellar process (Maas et al. 2004) making eventual AGB nucleosynthesis products difficult to trace. The companion of the post-AGB binaries (the putative future Ba star) is too faint, compared to the primary to be able to observe spectroscopically. The chemistry of the circumstellar material is therefore a good tracer of the chemical history of the object and if the post-AGB binaries are indeed pre-Ba stars, one would expect to observe carbon rich circumstellar material. This is, however, *not* the case

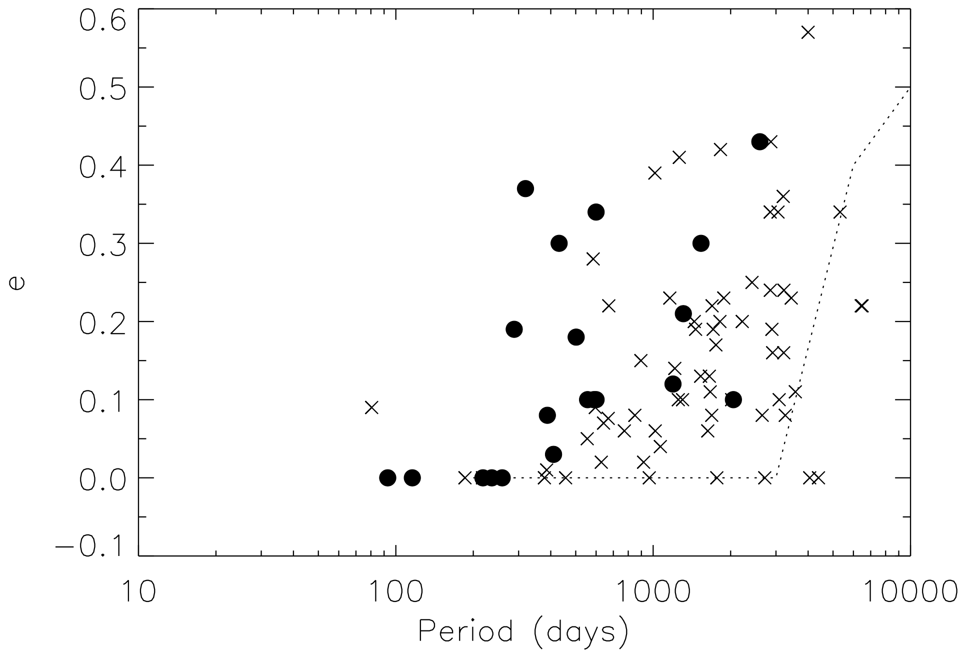

Fig. 3. The e-log(P) diagram of the post-AGB stars for which the orbits are known. Our new results are supplemented with literature orbits (Van Winckel 2003 and references therein). For comparison we show the data of the Ba stars (strong Ba, mild Ba and Tc-poor S-stars) from the compilation of Jorissen et al. (1998). The full line represents a population synthesis model indicating the dividing line below which the Ba population should be present (Pols et al. 2003) Almost all binaries are much more eccentric then expected from theory.

since all discs studied till now are oxygen rich. The binary interaction phase resulting in the formation of the disc, happened therefore when the star was an M-star. It is unclear if the stars discussed here suffered thermal pulses after the creation of the disc.

6. Conclusion

While the first binary post-AGB stars were serendipitously discovered, the distinct characteristics of their broad-band SED allows for a more systematic search for, and multiwavelength study of, binary post-AGB stars and their circumstellar environment.

Since our orbital period range detected till now span a range from 116 days to about 1400 days, it is clear that the formation of a stable orbiting disc in such systems appears more and more to be a key ingredient to understand the evolution of a very significant binary population. In all post-AGB stars studied in detail till now, the disc is clearly oxygen rich. The interaction leading to the creation of the disc must have happened therefore when the star was still an M star. The relation to other evolved binaries like Ba stars is as yet unclear.

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