Post-AGB Binaries

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Abstract. The specific characteristic of the SED of serendipitously discovered post-AGB binaries, allowed us to launch a very extensive multi-wavelength study of evolved objects, selected on the basis of very specific selection criteria. Those criteria were tuned to discover more stars with circumstellar dusty discs. The observational study includes radial velocity monitoring, high spectral resolution optical studies, infrared spectral dust studies, sub-mm bolometric observations and high spatial resolution interferometric experiments with the VLTI. In this contribution, we will review the preliminary results of this program showing that the binary rate is indeed very high. We argue that the formation of a stable circumbinary disc must play a lead role in the evolution of the systems.

Key words: stars: AGB and post-AGB, stars: binaries: spectroscopic, stars: evolution, infrared: stars, stars: circumstellar matter

1. INTRODUCTION

It takes a post-AGB star only about $10^4$ years to evolve from a molecular dominated AGB photosphere up to a stage where the central star is hot enough to ionise the surrounding material. During this short transition time, the star and circumstellar envelope must undergo fundamental and rapid changes in structure, mass-loss mode and geometry, which are still badly understood. The debate on which physical mechanisms are driving the morphology changes, gained even more impetus with the finding that also resolved but cool post-AGB stars display a surprisingly wide variety in shapes and structure. Inspite of intense debate between proponents of binary models and single-star models for bipolarity and asphericity in general (see Zijlstra these proceedings), there is still no good understanding on the physical processes involved. One of the reasons is that, due to the very short evolutionary phase, not many objects are known. Very detailed studies of individual objects prevail while a systematic study is still lacking.

The discussion also relates in a broader context to the uncertainties involved in the models of late stellar evolution in binary systems (see Frankowski and Podsiadlowski, these proceedings). The meeting emphasized once more that there is, for the moment, also no clear picture what the evolutionary relation is (if any) between the different classes of evolved binaries like Ba stars, S-type symbiotics, D-type symbiotics and post-AGB binaries.
This contribution focuses on binary post-AGB stars. The first binary post-AGB stars were serendipitously discovered and in Sect. 2, a few well studied examples are given. This limited sample turned out to have distinct observational characteristics (Van Winckel 2003) which include a broad IR excess, often starting already at H or K. We started a systematic search for binary post-AGB stars based on a sample selected by the properties of the IR-excess (Sect. 3). The preliminary results of our ongoing radial velocity monitoring program is given in Sect. 4 and 5. In Sect. 6 we give a small overview on the photospheric chemical signatures observed. Sect. 7 concerns the probing of the circumbinary disc as mayor structure element in the systems. In Sect. 8 we end with a short discussion and highlight the mayor findings in the context of the conference.

2. ILLUSTRIOUS ILLUSTRATIVE POST-AGB BINARIES

1.1. The Red Rectangle

One of the more famous proto-planetary nebulae is certainly the Red Rectangle and its central star HD 44179. The system has outstanding properties in almost all wavelengths in which it is studied so far (Men’shchikov et al. 2002, Van Winckel 2003, Cohen et al. 2004 and references therein). The central object is not seen directly at UV and optical wavelengths, but only in the scattered light that escapes from the polar regions of the thick disc into the line-of-sight.

The best observational evidence that this disc must be stable comes from the CO interferometric position-velocity maps which show that the inner disc is indeed rotating and Keplerian speeds (Bujarrabal et al., 2005, Bujarrabal these proceedings). Moreover, the dust in the inner disc is oxygen rich (Waters et al. 1998) while it is generally accepted that the carrier of the molecular emission of the nebula (the extended red emission) is carbon rich. The object is also one of the strongest source of the infrared bands which are associated with PAHs. The likeliest scenario for O-rich material in this C-rich environment is that silicates in the long-lived circumbinary disc antedate a recent C-rich phase of HD 44179 during which the C-rich nebula was expelled (Waters et al. 1989).

There is now general agreement that many of unique nebular characteristics of the Red Rectangle are born during phases of strong binary interaction. The actual eccentric orbit of 318 days, is too small to accommodate a full grown AGB star (Waelderens et al. 1996) and the object cannot have evolved on a single star evolutionary track.

1.2. HR 4049

Another serendipitously detected binary is HR 4049, again with an orbit which is too small to accommodate an AGB star (Waelderens et al. 1991). The SED of this star shows a significant dust infrared excess, but with a very peculiar temperature distribution: from J up to 850 $\mu$m, the dust excess is consistent with a single black-body temperature of about 1150 K. While the central star of 7500K is no longer in a dust production phase, the high dust temperature leads to the conclusion that the dust reservoir must be very close to the central object. The detailed modelling of the SED showed that the disc in this object must be extremely optically thick. The
significant scale height of the disc, which is needed to account for the redistribution of stellar flux into the infrared, is a natural consequence of the gas pressure in the inner rim of the disc (Dominik et al. 2003).

3. SYSTEMATIC SEARCH FOR POST-AGB BINARIES

Inspired by the disc geometry of some binary objects, we launched a more systematic search for evolved binaries with specific selection criteria tuned to discover more objects with stable dusty reservoirs. The total sample and selection criteria are given in (De Ruyter et al. 2006). The IR-based selection is such that evolved objects with a hot dust component are preferentially selected. Apart from the known binary post-AGB stars, the sample consists of dusty RV Tauri pulsators and newly identified post-AGB stars which occupy the same IRAS colour-colour region as the RV Tauri stars (LLoyd Evans 1999). Our sample is biased towards southern objects since our radial velocity monitoring telescope is in La Silla, Chile.

In total we selected 51 objects (De Ruyter et al. 2006), which is a fair number compared to the about 300 post-AGB stars known in the Galaxy (Szczepkow et al., 2001). One of the main results is that in all objects, irrespective of the effective temperature of the central star, the dust excess starts at or near sublimation temperature (De Ruyter et al. 2006, Fig.4 of that paper), which is typically < 10 A.U. from the central object. In most objects, the infrared excess is a significant fraction of the total available luminosity.

4. RADIAL VELOCITY PROGRAMME

In order to be able to test our suspicion that the infrared selected stars are binaries, we have set-up an extensive radial velocity monitoring campaign. Thanks to the Flemish-Swiss collaboration in exploiting the twin telescopes Mercator-Euler, we have access to the CORALIE radial velocity spectrograph mounted on the Swiss 1.2m Euler telescope for about 3 runs of 10 nights per semester. We obtain spectra of limited signal-to-noise but using optimised cross-correlation masks, we are able to derive accurate radial velocity measurements in a limited amount of telescope time. The line masks are tuned for every individual star on the basis of the high signal-to-noise spectra obtained for our photospheric chemical studies (Maas et al. 2005). We refer to the results on individual objects for more information on the method used (Maas et al. 2002, Maas et al. 2003).
Fig. 1. Left we depict the orbital solution of the star IRAS 17038-4815 after we cleaned the radial velocity from the pulsation. On the right the radial velocity is given after cleaning of the orbital motion and folded on the pulsation period. Note the strong shock around pulsation phase 0.5. During this phase, strong line-splitting makes the determination of the radial velocity impossible. The orbital period is $1381 \pm 16$ days with a significant eccentricity of $0.56 \pm 0.05$.

One of the major difficulties we encounter is that most objects are photometric variables with significant amplitudes, also in radial velocity. The disentangling of the photospheric motion and the orbital motion (if present) is not straightforward and does require a good sampling and a long monitoring baseline in time. The objects with the largest pulsations amplitude are the RV Tauri stars and in Figure 1 we show that a positive detection of the orbit is possible, despite the large amplitude radial velocity variations due to pulsations.

Selecting only those objects with a small pulsational amplitude (of maximal 0.25 magnitudes in the V-band), we found a binary rate of 100% on six objects. The orbital periods of this sub-sample range from 120 to 1800 days with four objects showing non-circular orbits (Van Winckel et al., in prep.). In Figure 2, two examples are given.

Fig. 2. Two radial velocity curves of objects in our sample with only small amplitude photometric pulsations. The objects are clear binaries and the radial velocities are folded on the orbital periods. IRAS19125+0343 (left panel) has a period of $517 \pm 3$ days and a significant eccentricity of $0.22 \pm 0.03$. IRAS15469+5311 (right panel) has a period of $387 \pm 1$ day and a circular orbit.
5. ORBITAL CHARACTERISTICS OF POST-AGB BINARIES

In Figure 3 the e-log(P) diagram is shown of all the orbits of post-AGB stars known to date. It is an update of the figure shown in Van Winckel (2003) which now includes all the new orbits found by our radial velocity monitoring program. In total 28 orbits are quantified while orbital motion of some others are suspected but no full orbit has been sampled yet. Not the whole sample of De Ruyter et al. (2006) is subject to our radial velocity monitoring with the Chilian telescope due to either too faint or in the Northern Hemisphere. We are building a spectrograph HERMES (Raskin et al. 2006) for our Mercator telescope so also the northern sample will be subject to a detailed monitoring study in the near future.

![Fig. 2. e-log(P) diagram of the detected orbits so far. The older orbits (Van Winckel 2003, and references therein) are supplemented with the most recent results from our monitoring campaigns.](image)

The new orbits confirm our earlier statements (Van Winckel 2003) in which the excess of non-zero eccentricities is a major theoretical challenge and still not well understood. On general, one can say that the actual orbits are too small to accommodate a cool AGB star with similar luminosity. Most systems are too distant to yield significant parallaxes and no direct tracer for their distance is available. From the orbital distribution, it is clear that all objects must have been subject to severe interaction when at giant dimensions.

6. THE PHOTOSPHERIC COMPOSITION

The photospheric composition is often used as a tracer for the internal enrichment and, especially for post-AGB stars, it could give a very good picture of the complete AGB nucleosynthesis and dredge-up history of an object.

The chemical patterns which prevail in this binary sample are, however, determined by a chemical ‘depletion’ process in which the separation of the circumstellar
dust from the circumstellar gas, is followed by a selective reaccretion of only the
gas, which is then rich in non-refractory elements compared to the refractories.
The photosphere will become coated with a layer of clean gas devoid of refractory
species like Fe or Ti. Waters et al. (1992) proposed that the most likely circum-
stance for the process to occur is, when the dust is trapped in a circumstellar
disc.

While this chemical depletion pattern was recognised originally in only a few
binaries (Van Winckel et al. 1995) in which the depletion was very severe (down
the [Fe/H]=−4.8) it turned out that depleted photospheres are in fact rather
common (Giridhar et al. 2005, Maas et al. 2005 and references therein) and often
with only a moderate effect on the metallicity of the object. From the 51 objects
of our sample, many do show indeed depleted photospheres (Maas et al. 2005)
strengthening even more the connection between the presence of a circumbinary
disc and the depletion process.

In an oxygen-rich condensation sequence, also the s-process elements are re-
fractory. To trace eventual AGB enrichment of the s-process elements one should
compare the s-process abundances with abundances of species with similar conden-
sation temperature. In none of the systems studied so far, there is evidence for an
overabundance of s-process elements. In a C-rich environment, the condensation
sequence is expected to be very different.

7. THE CIRCUMBINARY DISC

The compact circumstellar disc is a major structure element in all the objects,
irrespective of the orbital characteristics. The study of the dust in the discs is
a major tool to probe the physical and chemical processes involved. Our ground
based N-band spectra (De Ruyter 2005) as well as the high resolution spectra of
Spitzer (Gielen these proceedings) illustrate the very high degree of dust process-
ing, both with respect to grain growth and crystallisation of the grains. The grain
growth is probed with far-infrared fluxes. There must be a contrib ution of very
large (>0.1mm) grains (De Ruyter et al. 2005) in the few objects for which we
have data so far.

Thanks to the interferometric capabilities at ESO, we are now able to resolve
the discs and study its angular extent. Our first results (Deroo et al. 2006) show
that the discs are indeed compact. Thanks to the spectrally dispersed fringes of
the N-band instrument MIDI, we can probe the radial distribution of the different
dust species. The hot inner rim of the disc is above the glass temperature and
grains will easily crystallise in this environment. In the cooler outer layers, this
is not the case and cool crystalline material can be understood either as due to
a strong radial mixing within the disc, and/or a very different thermal history of
the grains at formation. For some objects there is evidence for a radial decrease in
crystallisation but the picture is far from clear yet (see Deroo these proceedings).

The temperature-density distribution of a disc is very different from the ones in
outflows and calls upon detailed radiative transfer modelling in two and even three
dimensions. The latter is especially needed if the orbital motion of the central
illuminating source is of importance in the interpretation of the interferometric
signal. The discs are likely very optically thick with the hot inner rim beeing
puffed up by gas pressure. In its shadow, the disc is much cooler. Our infrared
spectra show that all matrix resonances of the dust species show up in emission,
illustrating that the surface layer of the disc is likely optically thin at a warmer temperature than the midplane. Detailed models of one object only was presented in Dominik et al. (2003) but we are now in a process to model in detail the very inner structure of the discs in many objects (see also contributions by Baes and Vidal-Pérez and Gielen). The model results are confronted with the detailed analysis of the interferometric data (see also Deroo these proceedings).

8. DISCUSSION

This contribution focuses on the post-AGB objects with hot dust in the system. The global picture which emerges is that there are all binary stars which are born in a system which is too small to accommodate a full grown AGB (or in some cases maybe even an RGB) star. During a badly understood phase of strong interaction, a circumbinary dusty disc was formed, but the binary system did not suffer dramatic spiral in. Moreover, many systems avoided even complete circularisation. What we observe now is a F-G supergiant in a binary system with a dust excess starting at or near sublimation temperature. Given the effective temperature of the central star and its high luminosity, the dust must be circumbinary since all the determined orbits are within the sublimation radius of the dust. The SEDs show that a considerable fraction of the luminosity of the central star is reprocessed towards infrared radiation so the scale height of the discs must be significant. The discs are passive and strongly processed (see also Deroo and Gielen these proceedings).

All the discs are oxygen rich and there is no photospheric evidence that the central star suffered from thermal pulses with dredge-up. Given the detected orbits, the normal chemical AGB evolution was probably shortcut by a phase of strong binary interaction. In none of the systems there is evidence for a hot compact component and we suspect that the companion stars are unevolved main sequence objects.

It is interesting to note that also in symbiotic systems, the actual white dwarf, was not s-process and carbon enhanced when on the AGB (see Mikolajewska these proceedings). The main observational evidence in symbiotics is that no extrinsic s-process overabundances are observed in the cool component. On the other hand, the Ba star family (extrinsically s-process enriched stars) show a very similar spread in orbital periods as the one observed in post-AGB binaries, but they are clearly not the descendents of them, because of the lack of chemical enrichment in the evolved photosphere. For a recent review on the orbital characteristics of the different type of systems we refer to (Jorissen 2003). A major challenge in binary star research is therefore to unravel the different evolutionary channels leading to the different (chemical) classes of evolved binary stars.

We can conclude from this research that the evolved post-AGB stars with a hot dust component are all binaries in which the dust is trapped in a circumbinary stable disc. This disc plays a lead role in the dynamical and chemical evolution of the system. The formation and evolution of that dusty disc is a fundamental ingredient in the final evolution of a significant fraction of binary stars.

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REFERENCES

Bujarrabal V., Castro-Carrizo A., Alcolea J., & Neri R. 2005, A&A, 441, 1031
Cohen M., Van Winckel H., Bond H. E., & Gull T. R. 2004, AJ, 127, 2362
De Ruyter S. 2005, PhD thesis, UGent, Belgium
De Ruyter S., Van Winckel H., Dominik C., Waters L. B. F. M., & Dejonghe H. 2005, A&A, 435, 161
De Ruyter S., Van Winckel H., Maas T., et al. 2006, A&A, 448, 641
Deroo P., Van Winckel H., Min M., et al. 2006, A&A, 450, 181
Dominik C., Dullemond C. P., Cami J., & Van Winckel H. 2003, A&A, 397, 595
Giridhar S., Lambot D. L., Reddy B. E., Gonzalez G., & Yong D. 2005, APJ, 627, 432
Jorissen A. 2003, in Asymptotic Giant Branch Stars, ed. H. Habing & H. Olofsson, A&A Library, Springer, p. 461
Lloyd Evans T. L. 1999, in Asymptotic Giant Branch Stars, eds. T. Le Bertre, A. Lèbre, and C. Waelkens. IAU Symp. 1991, p. 453
Maas T., Van Winckel H., & Lloyd Evans T. 2005, A&A, 429, 297
Maas T., Van Winckel H., Lloyd Evans T., et al. 2003, A&A, 405, 271
Maas T., Van Winckel H., & Waelkens C. 2002, A&A, 386, 504
Men'shchikov A. B., Schertl D., Tuthill P. G., Weigelt G., & Yungelson L. R. 2002, A&A, 393, 867
Raskin G., Van Winckel H., & Lehmann H. 2006, in Ground-based and Airborne Instrumentation for Astronomy, Eds. by I.S. McLean, M. Iye, Proceedings of the SPIE, Volume 6269, p. 81
Szczerba R., Görny S.K., Zalfesso-Jundzi/lo, M., 2001, in Post-AGB Objects as a Phase of Stellar Evolution, Eds. R. Szczerba and S.K. Görny, p. 13
Van Winckel H. 2003, ARA&A, 41, 391
Van Winckel H., Waelkens C., & Waters L. B. F. M. 1995, A&A, 293, L25
Waelkens C., Lamers H. J. G. L. M., Waters L. B. F. M., et al. 1991, A&A, 242, 433
Waelkens C., Van Winckel H., Waters L. B. F. M., & Bakker E. J. 1996, A&A, 314, L17
Waters L. B. F. M., Cami J., de Jong T., et al. 1998, Nature, 391, 868
Waters L. B. F. M., Trams N. R., & Waelkens C. 1992, A&A, 262, L37