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Post–AGB binaries in an evolutionary perspective: a HERMES monitoring programme

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Abstract. We give a status report on our project to exploit the properties of our self-built high-resolution spectrograph HERMES to study binary evolutionary channels. Our large programme focuses on the wide variety of distinct (suspected or proven) classes of binary stars with evolved components. By combining high S/N single observations with low S/N time series, we aim to quantify the orbital and chemical characteristics of every distinct subgroup. The suspected orbital periods range from days (sdB stars, PNe) to years (post-AGB, Ba star family, J-type silicate stars etc.) so the sampling rate is tuned to the expected behaviour. The ultimate goal of this long programme is to connect the zoo of different objects into a sound evolutionary picture which accounts for the chemical peculiarities and the dynamical constraints set by the orbital distribution and binarity rates.

Key words. Stars: abundances – Stars: AGB and post-AGB – Stars: binaries: spectroscopic – Instrumentation: spectrographs – Techniques: radial velocities

1. Introduction

An important issue which governs the discussion of our theoretical uncertainties of the final evolution of low- and intermediate-mass stars is the impact of binarity on our global understanding of this late evolution. Confirmed or suspected classes of evolved binaries are so prominent that our global understanding of the final phases of single stars may very well be biased too.

A rich zoo of peculiar evolved objects are born from the interactions between the loosely bound envelope of a (super)giant and the gravitational pull of a companion. The balance between the equipotential surfaces (Roche lobes) and the stellar radii are the key ingredients in theoretical channels but, owing to the strong radiation pressure of the giant star with its loosely defined radius, the classical Roche potential is no longer valid and the ratio of the radiation pressure force to the gravitational attraction becomes a critical ingredient in the theoretical models (Pols et al. 2003; Bonačić Marinović et al. 2008; Dermine et al. 2009).

The wide range of binary interactions are not understood from first principles and the

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theoretical tracks are therefore subject to many unproven assumptions or poorly constrained parameters, such as the efficiency of envelope ejection, the postulated increase of the mass-loss prior to contact, the physical description of the common-envelope phase, the accretion efficiency on to the companion, possible orbital-phase dependent mass loss rates etc. Moreover, there is no general consensus on how to explain several important observational characteristics such as the building of a range of chemical peculiarities (depletion of refractory elements, extrinsic *s*-process overabundances), the creation of stable circumbinary discs, the existence of wide often eccentric orbits of post-Asymptotic Giant Branch (post-AGB) stars despite the likely strong interaction on the AGB etc. The significant shortcoming of binary evolution population synthesis predictions and theoretical binary evolutionary channels is that the many parameters involved are not well constrained by systematic observational data and the goal of our research initiatives is to bring the different classes of (suspected) evolved binaries into an, as yet undisclosed, evolutionary connection.

We start this contribution with an overview of the specific characteristics of Galactic binary post-AGB stars and conclude that there is ample observational evidence that, in most objects, circumstellar material must be trapped in a stable, likely Keplerian, dusty disc. The orbital elements imply that severe binary interaction must have taken place during the evolution of the primary (Sect. 2). This inspired us to use our newly developed fibre-fed spectrograph HERMES (Sect. 3) in a long-term project to disclose not only the orbital characteristics of a significant sample of suspected binary post-AGB stars but, additionally, study systematically the orbital characteristics of the wide variety of distinct (suspected or proven) classes of binary stars with evolved components (Sect. 4). We end in Sect. 5 by summarising the goal of this project which has only just started. The slides which accompany this report might be found on the web-site of the organisers.

2. Binary post-AGB stars

Based on the distinct characteristics of the spectral energy distribution (SED) of a few individual cases, a more systematic search for candidate post-AGB stars was launched (De Ruyter et al. 2006). The objects all show a broad IR-excess, pointing to the presence of both cool and hot dust around the system, irrespective of the spectral type of the evolved central stellar photosphere and the total reddening. The whole sample, of about 70 objects, is by now a significant fraction of all known post-AGB stars in the Galaxy (Szczerba et al. 2007). Recently we found similar objects in the Large Magellanic Cloud (Reyniers & Van Winckel 2007) and the results of a more systematic search are presented by van Aarle in these proceedings.

By now, we could indeed prove the suspected binarity nature by a time-series of accurate radial velocity data and this for all low-amplitude pulsators accessible from the south (e.g. Van Winckel et al. 2009, and references therein). Our data sampling was not good enough to disentangle radial velocity variations due to pulsations or due to orbital motion for the large amplitude pulsators. The systems with orbital data are now not in contact but they are too small to accommodate a full grown AGB star: the orbital periods range from 100 to about 2000 days with remarkably high eccentricities. The companion stars are likely to be unevolved main-sequence stars, which do not contribute significantly to the energy of the objects.

The specific SED characteristic was interpreted as a signature of the presence of a gravitationally bound dusty disc rather than an outflow (e.g. Van Winckel 2003). Using the available interferometric instrumentation on the VLTI at ESO, we resolved this compact dust reservoir around eleven systems. We found that the dust is trapped in a stable disc which is likely in hydrostatic equilibrium. The typical diameter of the disc is only some 40 au in the mid-IR (N-band) and also the outer radius must be quite small (some 500 au). Quantitatively we say the dust disc starts where it can, at the sublimation radius, where it receives head-on radiation. The inner part is therefore strongly puffed-up (Deroo et al. 2006, 2007; Gielen et al. 2009a). The energetics are determined by the radiation from the central object and no other energy source need be invoked to fit the (interferometric) data. Because the physical processes governing the disc structure seem to be similar to those governing the discs around young stellar objects, we tuned the models developed for young stars (Dullemond & Dominik 2004) to study quantitatively the radiative transfer in these discs. A specific theoretical study of the full parameter space is in preparation by the PhD student Edgardo Vidal Perez (UGent, Belgium).

The resemblance between the passive, irradiated discs around dying stars and the planet-forming discs around young stellar objects is found in the mineralogy as well. The submillimeter fluxes point to the presence of large grains (up to mm sized, De Ruyter et al. 2005) and the Spitzer Infrared Spectra show very strong crystalline features of silicates with profiles typical of grain sizes which are much larger that what is seen in outflow sources (Gielen et al. 2007, 2008, 2009a). Dust processing in the discs is very high indeed. All discs studied with infrared spectroscopy are mainly oxygen rich with, in some cases, some evidence for PAH emission too (Gielen et al. 2009a).

Another well documented effect of these discs is that the photospheric chemical content of the central star can be strongly influenced by gas accretion (e.g. Giridhar et al. 2005; Maas et al. 2005; Gielen et al. 2009b, and references therein). The observed chemical pattern is the result of gas-dust separation followed by photospheric reaccretion of the gas only. This gas is poor in refractory elements. The photospheres then become deficient in refractories like Fe and Ca, while the non-refractories are much less affected. Photospheric depletion is surprisingly common in post-AGB stars and the efficiency of the process is likely to be very closely linked to the presence of a circumbinary disc.

The global picture that emerges is that a binary star evolves in a system which is too short to accommodate a full grown AGB star. During a badly understood phase of strong interaction, a circumbinary dusty disc forms but the binary system does not suffer dramatic spiral in. What we observe now is an F/G/K supergiant in a binary system, which is surrounded by a circumbinary dusty disc in a bound orbit. Given the numbers, the range of orbital periods and quantified mass functions, the conclusion is that disc formation must be a mainstream process in the late evolution of a very significant binary population! It is therefore relevant to study in detail different classes of (suspected) evolved binaries and their possible evolutionary connections with the binary post-AGB stars.

3. The HERMES spectrograph

Our research project is embedded in the science exploitation of the HERMES spectrograph of the Flemish 1.2m Mercator telescope (www.mercator.iac.es) installed in the Roque de los Muchachos observatory. The spectrograph began regular science exploitation in April 2009.

The design, building and integration of this luminous, high-resolution spectrograph were joint efforts of the Belgian institutes at the universities of Leuven (KULeuven, co-I C. Waelkens) and Brussels (ULB, co-I: A. Jorissen) together with the Belgian Royal Observatory (co-I: H. Hensberge) with smaller contributions from the Geneva observatory and Landessternwarte Tautenburg, Germany (co-I: H. Lehmann). Our institute has taken up the management of the project: both the project engineer (G. Raskin) and the PI (H. Van Winckel) are working at the IvS.

The fibre-fed spectrograph is designed to be optimised both in stability as well as in efficiency. It samples the whole optical range from 380 to 900 nm in one shot, with a spectral resolution of 90 000 for the high-resolution science fibre. This fibre has a 2.5 arcsec aperture on the sky and the high resolution is reached by mimicking a narrow slit using a two-sliced image slicer. Light loss is minimal, despite the high spectral resolution. At 10th magnitude in V a SNR of 110 is reached in a one hour exposure. At the faint limit a star of 14th magnitude will give a spectrum with a SNR of 12 after one hour and under good sky conditions. The dedicated tailored pipeline is made to ensure efficient data reduction as well as spectral cross-correlation routines to obtain accurate radial velocity data. More information can be found on `http://www.mercator.iac.es/`.

The MERCATOR-HERMES combination is precious because it guarantees regular telescope time. This is needed for our monitoring programme and the operational agreement reached by all consortium partners is optimised to allow efficient long-term programming, which is indispensable for this programme.

4. Evolved objects in binaries: the evolutionary connection

The goal of our project is to study the different classes of (suspected) evolved binaries systematically. We do so with a detailed radial velocity monitoring programme based on low S/N but high spectral-resolution data, coupled with detailed photospheric studies based on high S/N data. The different types of suspected wide binaries include several types of star.

* Post-AGB stars with hot dust: This sample consists of suspected binaries (De Ruyter et al. 2006) introduced in Sect. 2.

* Post-AGB stars with outflows: HST data has revealed that asymmetry and bipolarity in proto-planetary envelopes is much more widespread than anticipated (Balick & Frank 2002). Kinematic data shows that (molecular) jets are common (Bujarrabal et al. 2001) and binarity is often postulated. This is the first large binary rate experiment on a subsample of these objects.

* Planetary Nebulae central stars: There is growing evidence that binary interaction mechanisms are responsible for a large fraction of asymmetrical nebular morphologies (Moe & De Marco 2006; de Marco 2009). Direct observational evidence for binarity in PNe is weak and observational techniques are sensitive either to spiraled-in systems (Miszalski et al. 2009a,b) or very wide systems. Our telescope–spectrograph combination is only sensitive enough to monitor a limited sample of brightest objects.

* Silicate J-type carbon stars: Despite their discovery a long time ago by IRAS, silicate J-type stars remain poorly understood. There is now general agreement that the silicates must be trapped somewhere in the system (circumbinary or circumcompanion, Jura & Kahane (1999) and consequently the objects are postulated to be binaries (e.g. (e.g. Evans 1990)). No velocity time series are found in the literature and, up to now, no orbits are available but indirect evidence for duplicity has been found in some of them (Izumiura et al. 2008). Our velocity sets will provide strong constraints on possible binarity.

* J-type carbon stars: An estimated 10% of all carbon stars are of J-type which means that they are genuine carbon stars (C/O) but display a very low ^{12}C/^{13}C ratio in combination with a lack of *s*-process element overabundances (Morgan et al. 2003). Till now there is no theoretical model able to explain these abundances. Also, for this class, binarity is often postulated but never firmly established. This is the first velocity survey which will prove or falsify the binary hypothesis.

* sdB objects from stable Roche Lobe overflow: Subdwarf B (sdB) stars are core helium burning objects with an envelope too thin to sustain shell hydrogen burning (Heber 2009). They are thought to form when a strong binary interaction phase on the RGB removes almost the entire envelope, either through common envelope ejection or through stable Roche-Lobe overflow. We focus here on wide orbit objects that are formed by the latter channel. These are a group of objects that have received very little observational attention to date. These objects will never reach the AGB phase but will evolve directly into white dwarfs when their core helium runs out. The goal is to determine the orbital parameters for these objects as a group, thereby constraining this evolutionary channel in connection with the objects in binaries that could reach the AGB. Only the brightest members are bright enough for our spectrograph.

* Strong–Mild Ba stars: There is general acknowledgement that Ba stars are binaries in

which the RGB star was enriched in heavy elements by a companion which is now a cool WD. The sample is to finalise the binary monitoring done earlier (e.g. Jorissen & Mayor 1988) to characterise also the very wide systems and to investigate the orbital characteristics in connection with the sometimes mild pollution factors.

* Metal-deficient Ba stars: The puzzle with these metal-deficient Ba stars is why they are not exhibiting symbiotic activity as do the yellow symbiotics (Jorissen et al. 2005), which have similar properties in terms of metallicity and barium overabundances. Deriving the orbital elements will allow us to check the hypothesis that the discriminating property between yellow symbiotics and metal-deficient barium stars is the orbital period (longer for the metal-deficient Ba stars?).

* M giants in binaries: M stars in binaries are the likely progenitors of the many other systems discussed here (Jorissen et al. 2009). The sample aims at completing the orbits of the wide systems and at improving the binary-frequency statistics for stars requiring many radial-velocity data because they suffer from intrinsic radial-velocity jitter.

* Symbiotic systems: Symbiotics are RGB or AGB giants with WD companions and are classified as either S (stellar) or D (dusty). The D types are known to have very wide orbits. The rare D types have hotter primaries. The binary nature is well established and the limited sample is proposed is to complete the binary statistics (Mikołajewska 2007). A subset have carbon-star and S-star primaries which are likely extrinsic but no orbits are known (yet).

* RCrB: RCrB stars are strongly carbon-enhanced, hydrogen-poor evolved objects for which the light curves are characterised by erratic dust obscuration episodes (Clayton 1996). The theoretical models include either a binary evolutionary channel, or RCrB stars are the result of a very late thermal pulse. This limited sample is mainly to test the binary evolution channel.

* AGB stars with a suspected companion: While post-AGB binaries are common as well as more evolved progeny of AGB binaries (like Ba stars), not many AGB stars with a companion are known (e.g. Nicholls et al. 2010). The main reason is that AGB stars are often variable with a large amplitude, preventing the detection of their binary nature. The sample proposed was selected on the basis of indirect evidence for binarity (like dust-temperature distribution, UV excess emission or a composite spectrum).

* CEMP stars: Carbon-Enhanced Metal-Poor stars are acknowledged to be polluted stars of a very old population (see Pols' contribution to these proceedings). Their surface abundances are witnesses of the very first AGB stars in the Galaxy. They are known to be chemically very diverse. Some have no *s*-process enhancements, while others show *s*-only or both *s*- and *r*-process elemental pollution. The orbital characteristics are not known and will be combined with the chemical peculiarities already known.

* R stars: These stars did not show any radial-variations during a 16 yr monitoring programme (McClure 1997). This programme will secure one more radial-velocity measurement to expand the time span to about 30 yr. The spectra will be used to perform abundance analyses of these enigmatic and not well-studied objects.

* S stars: Abundances of extrinsic (post-mass-transfer) and intrinsic S stars will be compared in the framework of the preparation of a large grid of model atmospheres for S stars (e.g. Van Eck & Jorissen 2002).

5. Conclusion

Regular sampling of (potential) evolved binary stars has just begun and, because the periods of the wider systems are several years, we plan to present results at the next Torino workshop. The ultimate goal of our programme is to confront the obtained orbital distributions, mass functions, binary rates and chemical characteristics with tailored binary evolutionary models, which account for the internal and external chemical enrichment. This systematic approach will hopefully allow us to derive a coherent picture of how binaries evolve and how the different samples are (or cannot) be connected by evolutionary channels and, by doing so, we aim to put strong constraints on the different proposed interaction mechanisms.

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