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Close binary central stars of planetary nebulae and V458 Vul

Romano L.M. Corradi[1,2]

[1] Instituto de Astrofísica de Canarias, E-38200 La Laguna, Tenerife, Spain
[2] Departamento de Astrofísica, Universidad de La Laguna, E-38206 La Laguna, Tenerife, Spain e-mail: rcorradi@iac.es

Abstract. I briefly review our current knowledge of binarity in the central stars of planetary nebulae. Their number is significantly increased in the last years; this allows discussion of their main statistical properties, and of their relevance to understand the planetary nebula formation as well as poorly known processes such as the common-envelope phase.
The case of V458 Vul, showing a nova inside a planetary nebula, is discussed in some more details. Together with other double-degenerate central stars of planetary nebulae, it is a potential SNIa candidate.

Key words. planetary nebulae – binaries: close – stars: winds, outflows – ISM: jets and outflows – SNe Ia

1. Introduction

The importance of binarity in the formation and evolution of planetary nebulae (PNe) has long been recognized. There are several compelling reasons for that. Perhaps the most debated one is the amazing variety of shapes displayed by PNe, which includes collimated, high velocity, and precessing outflows which can hardly be produced by single stars (e.g. Balick & Frank 2002). Another important constraint comes from the the observation of fast collimated winds in the early post-AGB phase (e.g. Sahai et al. 2007), when such winds are not expected as the central star is not yet hot enough to produce significant radiative-driven fast winds. Another important property is the large momentum measured in the molecular outflows of pre-PNe, which is largely in excess of what luminosity-driven mass loss can provide (Bujarrabal et al. 2001). On the other hand, interactions in binary stars and the abundant energy reservoirs contained in these systems, can easily provide the formation of fast collimated outflows at any stage of the PN development, the extra source of momentum, and several mechanisms able to break the spherical symmetry of mass loss at the end of the AGB (De Marco 2009).

In spite of this, until recently the number of PNe with known binary central stars was only a dozen, out of ∼3000 PNe now known in the Galaxy (Bond & Livio 1990). The main limitation in their discovery is that PN central stars (PNCSs) are generally faint, the ionizing sources are hot so that their energy peak is shifted to the UV region which is difficult to access, and in the most promising cases (e.g. in highly aspherical nebulae) the detection of the

Send offprint requests to: R.L.M. Corradi

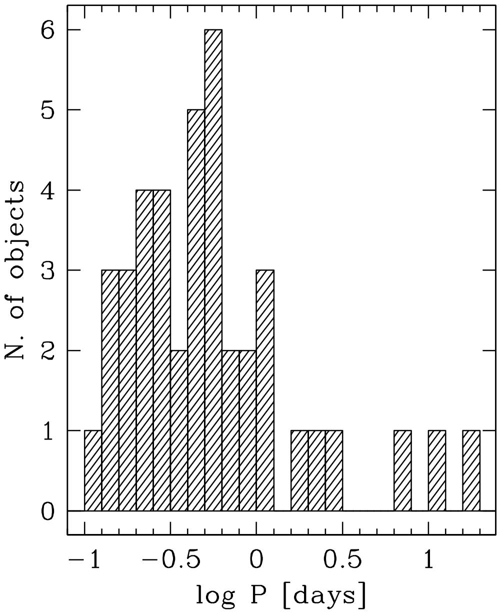

Fig. 1. Orbital period distribution of 41 binary PNCSs.

stars is severely affected by obscuring circumstellar dust and dense ionized gas.

The situation has significantly improved in the last three years, thanks to the discovery of a number of new binary PNCSs which have raised the number of known sources to more than 40 (Miszalski et al. 2009a). Most of them are detected by means of photometric monitoring which reveals light modulation by irradiation, ellipsoidal effects and/or eclipses. The increased number of binary PNCS allows some of their general properties to be investigated. They are briefly presented in the following sections. The very special case of V458 Vul is discussed in some more details.

2. Close binary PNCS

The period distribution of the known binary PNCSs is shown in Fig. 1. The vast majority of sources have a period of less of one day, which is partly a consequence of the discovery method, limited to systems that are close enough that irradiation or tidal distortion of the secondary have measurable effects. Even so, a lack of source with P>1 days is certainly intrinsically present (Miszalski et al. 2009a).

These short orbital periods imply that these binary systems have gone through a common-envelope (CE) phase right before the PN ejection. They therefore give the opportunity to better understand the CE process and constrain it observationally. The short ages of the PNe ($<10^4$ yr) ensures that the central, post-CE binary is "fresh out of the oven", so that PNCSs provide an opportunity to measure parameters such as the orbital period distribution after the CE phase before any angular momentum loss. The CE ejection geometry, timescale, and efficiency can also be derived by studying the PN properties.

A significant number of longer period (months to hundred of years) binary PNCSs are also expected, but these are extremely difficult to discover. Note that even at a separation corresponding to orbital periods of several hundred of years, some interaction with a companion is expected at the tip of the AGB phase. The case of Mira itself (*o* Ceti), with its compact accreting companion and an estimated orbital period longer than 500 years, clearly demonstrates it (Karovska et al. 1997).

The new observations produced an estimate of the fraction of close binary PNCSs ≥17% (Miszalski et al. 2009a), but other authors have proposed that the *overall binary fraction could be as high as ∼80%* (Moe & De Marco 2006; Soker 2006). If the latter is true, our perspective of PNe would change dramatically, and the common belief that PNe are faithful tracers of the chemistry, luminosity, and dynamics of stellar systems in any type of galaxies would be severely questioned.

3. Binarity vs. morphology

With the increased sample, the first association of binarity with specific nebular morphological features was possible (Miszalski et al. 2009b). Fig. 2 show a selected sample of nebulae with close binary central stars. Structures like rings are widely common among this nebulae. This shows that the CE evolution favours a mass loss geometry strongly enhanced toward an "equatorial" plane. There is evidence

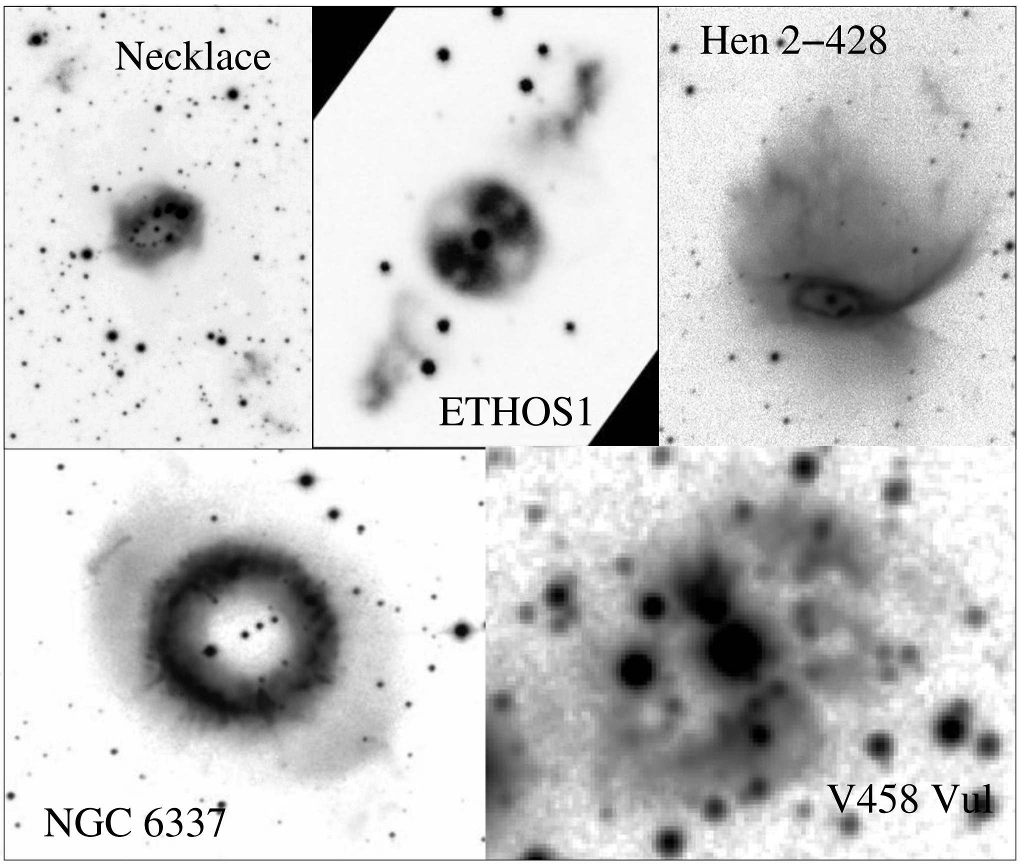

Fig. 2. Images of selected PN with close binary central stars.

that this equatorial plane coincides with the orbital plane (Jones 2011), as expected from some simulations.

Several of these nebulae also show polar outflows (e.g. the Necklace, Corradi et al. (1999) and ETHOS1, Miszalski et al. (2011), see Fig. 2) moving away from the central stars at supersonic speeds $\geq$100 kms^{-1}. These outflows are somewhat different from canonical "jets", as their collimation degree is moderate and they seem to have been ejected during a relatively short lapse of time. In the very few cases studied in details they appear to have kinematical ages shorter than those of the main nebulae. In the simplistic assumption of ballistic motion, therefore, these polar outflows would be produced before the CE phase, at the end of which the AGB envelope is completely lost forming the main body of the PN. These polar outflows could therefore be related to the formation of transient accretion discs before or during the CE phase (Soker 1998; Soker & Rappaport 2000).

4. V458 Vulpeculae

Among binary PNCSs, this is a very special case as its PN escaped detection until the (previously anonymous) central source exploded as a fast nova in 2007. We checked the Hα images taken a few weeks before the nova explosion as part of the IPHAS survey of the Northern Galactic Plane (Drew et al. 2005), detecting that the progenitor star was surrounded by a mildly bipolar ionized nebula (bottom-right panel of Fig. 2). Its study (Wesson et al.

2008) revealed that the nebula is indeed a PN rather than the rest of a former nova explosion. The main arguments are its low expansion velocity (few tens of kms^{-1}), its large ionized mass (0.2 solar masses), and its chemical abundances typical of PNe (solar oxygen content and mild N/O enhancement). Interestingly, subsequent images revealed a rapid increase of the surface brightness in some parts of the nebula, caused by flash ionization by the nova event. Note the relatively large Galactocentric distance of V458 Vul, estimated to be around 11 kpc with a height below the Plane of 0.8 kpc (Wesson et al. 2008).As fast novae are concentrated toward the Galactic plane (z≤100 pc), V458 Vul appears to be unusually located in the Galaxy.

Time-resolved optical spectroscopy obtained during the nova decline has revealed that the orbital period of the system is only 98 min (Rodríguez–Gil et al. 2010). V458 Vul is therefore the binary PNCS with the shortest period known. A plausible scenario is that the system underwent two CE episodes, and is now composed of two degenerate, compact stars. The one that exploded as a nova would then be accreting mass from a post-AGB star which produced the observed PN. It seems more unlikely that the star that produced the nova is also the progenitor of the PN, given the short timescales between the red-giant envelope ejection and the nova explosion (∼14000 years, Wesson et al. (2008)). Theory of fast novae predict that a minimum white dwarf mass around 1 $M_\odot$ is required to trigger the thermonuclear runaway. In addition, the PN photoionisation modelling in combination with the information from the radial velocity curve, results in a mass estimate for the secondary around 0.6 $M_\odot$. This implies that the total mass of V458 Vul may well be ≥1.6 $M_\odot$, i.e. above the critical Chandrasekhar mass. Therefore V458 Vul may become a Type Ia supernova if the white dwarf manages to accumulate mass in the presence of nova eruptions.

Another distinguished case of a double-degenerate PNCS which could potentially explode as a SNIa is TS 01. The detailed study by Tovmassian et al. (2010) provide a quite robust determination of the total mass of the system very close to the Chandrasekhar limit. As more double-degenerate PNCS candidates are known, they should be thoroughly investigated in order to asses the viability and the frequency of this channel of stellar evolution for the production of the cosmologically important SNIa.

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