Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
Proceedings IAU Symposium No. 380, 2024
T. Hirota, H. Imai, K. Menten, & Y. Pihlström, eds.
doi:10.1017/S1743921323001965

Nascent planetary nebulae: new identifications and extraordinary evolution

Roldán A. Cala[1], José F. Gómez[1] & Luis F. Miranda[1]

[1]Instituto de Astrofísica de Andalucía, CSIC, Glorieta de la Astronomía s/n, E-18008 Granada, Spain. email: rcala@iaa.es

Abstract. Planetary nebulae (PNe) harbouring masers of H_2O (H_2OPNe) and/or OH (OHPNe) are thought to be nascent PNe. They are extremely scarce, and so far only eight members are know to date. Here we explain our current effort to identify new H_2OPNe and/or OHPNe. We report IRAS 07027−7934 as a new bona fine OHPN. Its 1612 MHz OH spectrum seems to be changing from double- to single-peaked since the redshifted emission has vanished almost completely, and the 1667 MHz OH maser emission has disappeared. For the OHPN Vy 2-2, we found that its central star is unexpectedly carbon (C)-rich, has a low-mass progenitor, and could be a post-common envelope binary system. Moreover, we confirm Vy 2-2 as a nascent PN. We speculate that low-mass C-rich central stars in post-common envelope systems could be a common end of H_2OPNe and OHPNe.

Keywords. masers, planetary nebulae: general, stars: AGB and post-AGB, stars: carbon, stars: Wolf-Rayet

1. Introduction

The Sun and stars with initial masses (M_i) ≤ 8 $M_\odot$ are expected to form a planetary nebula (PN) before their end as white dwarfs. Complex shapes of PNe may result from the interaction between binaries or multiples stellar systems (de Marco *et al.* 2022). To understand the entire evolution of a star or stellar system in the PN phase, both the circumstellar envelopes and central stars of PNe require to be characterized.

PNe harbouring masers of H_2O (H_2OPNe) and OH (OHPNe) are considered to be extremely young or nascent PNe (Zijlstra *et al.* 1989; Miranda *et al.* 2001; Gómez *et al.* 2018). This is because, after the AGB phase, H_2O and OH masers seem to disappear in timescales of 10^2 and 10^3 yr, respectively (Lewis 1989; Gómez *et al.* 1990), while, simultaneously, the PN phase starts in timescales of 10^3-10^4 yr, depending on the initial mass of the star (Miller Bertolami 2016). Therefore, even though both intermediate- (4–8 $M_\odot$) and low-mass ($\leq$1.5 $M_\odot$) stars can develop an oxygen (O)-rich envelope, necessary for H_2O and OH maser emission being present, it has been proposed that progenitors of maser-emitting PNe should be of intermediate mass, because they evolve faster during the post-AGB phase. Currently, there are only eight bona fide H_2OPNe and/or OHPNe confirmed to date (e.g. Uscanga *et al.* 2012, 2014; Qiao *et al.* 2016), and the onset of the PN phase remains poorly understood.

This contibution aims to present our current effort to increase the known members of H_2OPNe and OHPNe, as well as their characterization as a group.

2. New identifications

New H_2OPNe and OHPNe candidates can be identified by cross-matching the interferometric positions of maser and radio continuum emitters, considering that radio continuum

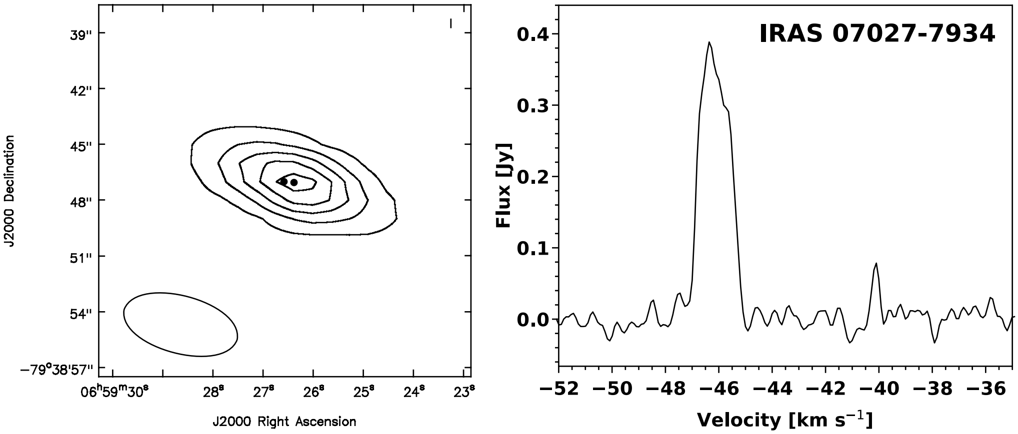

Figure 1. Contour map (left) of the radio continuum emission at 2.1 GHz of IRAS 07027−7934. The contours are 5, 15, 25, 35 and 45×1-σ (where $\sigma = 0.13$ mJy beam^{-1} is the rms of the map). The beam is shown in the bottom left corner. Black dots represent the positions of the 1612 MHz OH maser features observed in the spectrum (right). The relative positional accuracy between maser and continuum emission is ∼0.5 arcsec.

emission is a common characteristic of PNe (e.g. de Gregorio-Monsalvo *et al.* 2004; Uscanga *et al.* 2012). Hence, we are carrying out a comprehensive search for new H_2OPNe and OHPNe based on radio continuum and spectral line data obtained from simultaneous interferometric observations.

We have started with the Southern Parkes Large-Area Survey in Hydroxyl (SPLASH; Dawson *et al.* 2022), which was initially carried out with single-dish observations. We have processed all the continuum data associated with the interferometric follow-up of SPLASH (see Qiao *et al.* 2020), which was carried out with Australia Telecope Compact Array. We found three previously identified bona fide OHPNe, and four new OHPNe candidates (Cala *et al.* 2022). The new OHPNe candidates present characteristics that are similar to those observed in bona fide OHPNe (see Cala *et al.* 2022). We aim to confirm the new OHPNe candidates as bona fide PNe by means of optical/infrared spectroscopy.

For this contribution we report that the single dish 1612 MHz OH maser emission detected towards the PN IRAS 07027−7934 (Zijlstra *et al.* 1991) has been interferometrically confirmed, as it presents spatial coincidence with the radio continuum emission at 2.1 GHz (Fig. 1, left). The OH spectrum at 1612 MHz displays two different spectral components (Fig. 1, right). The redishifted component (at −40 km s^{-1}) has significantly weakened with respect to the Zijlstra *et al.* (1991) observations. A possible explanation is that the (background) redshifted emission is being progressively absorbed by an expanding, optically thick photoionized nebula. Furthermore, the only component observed in the single dish 1667 OH MHz maser spectrum has also disappeared in our observations. We speculate that this variability of the OH spectra could be a usual evolutionary feature of these objects as they enter the PN phase.

3. Extraordinary evolution

To characterize maser-emitting PNe as a group, we have started studying Vy 2-2, the first OHPN identified (Seaquist & Davis 1983). Vy 2-2 consists of a very bright, compact shell of radius ∼0.24 arcsec and a faint bipolar formation of ∼2 arcsec in size (Christianto & Seaquist 1998). All available information indicates that the ejected matter from the central star in the AGB/post-AGB phase is O-rich ($C/O < 1$) because OH masers, silicate dust, and water ice coexist in an environment with undetectable silicon

https://doi.org/10.1017/S1743921323001965 Published online by Cambridge University Press

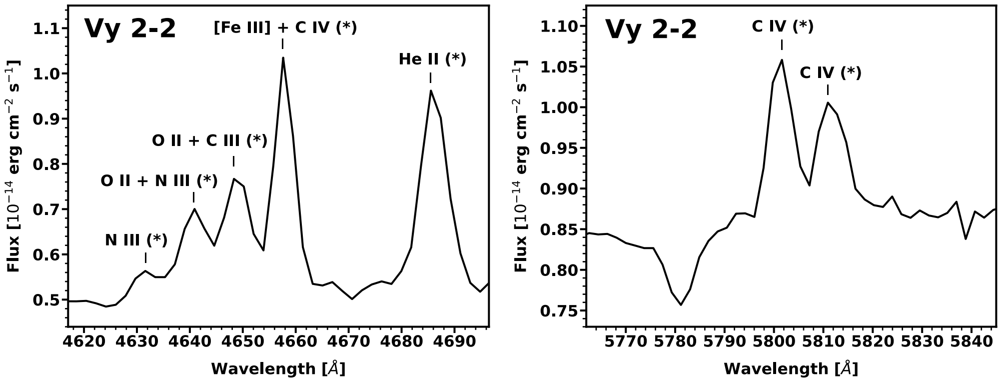

Figure 2. Optical spectra of V 2-2 in two spectral ranges. Weak stellar (*) and nebular emission lines are indicated.

carbides and polycyclic aromatic hydrocarbons (e.g. Molster *et al.* 2002; Rinehart *et al.* 2002). Furthermore, the photodissociation region (PDR) of Vy 2-2 has been detected and presents an abundance ratio C/O < 1 (Liu *et al.* 2003).

We have analyzed optical spectra of Vy 2-2 obtained with CAFOS at the 2.2m telescope of the Calar Alto Observatory to study the properties of its photoionized gas. The photoionized shell has a very low value of C/O $\sim$ 0.15, similar to that of $\sim$0.26 (Wesson *et al.* 2005) and consistent with the C/O < 1 in the PDR (Liu *et al.* 2003). Moreover, we obtained a N/O abundance ratio of $\sim$0.39, indicating that *hot bottom burning* has not occurred in the progenitor of the central star. This implies a $M_{\rm i}\leq 1.5$ $M_\odot$ that is contrary to the intermediate-mass stars proposed as progenitors of maser-emitting PNe.

The most intringuing result is that the optical spectra reveal weak stellar emission lines that indicate that the central star of Vy 2-2 is unexpectedly C-rich (C/O > 1; Fig. 2). In particular, its C-rich surface chemistry is inferred from the C IV $\lambda\lambda$5801,5812 recombination lines (Fig. 2, right). The idea of a PN with such low values of C/O and N/O being photoionized by a C-rich central star is extraordinary in the evolution of a low-mass star. Furthermore, we confirm that Vy 2-2 is a nascent PN and could be a post-common envelope binary system (Cala et al. 2023, in preparation).

We investigate if O-rich envelopes photoionized by C-rich central stars could be a common characteristic among H_2OPNe and OHPNe. In IRAS 17347−3139 the H_2O masers trace a circumstellar ring (de Gregorio-Monsalvo *et al.* 2004), while the mid-infrared spectra display emission from both O-rich and C-rich dust (e.g. Jiménez-Esteban *et al.* 2006). Spectra of its (obscured) central star would be crucial to check its possible C-rich nature. In IRAS 18061−2505, the H_2O masers likely trace a circumstellar ring (Gómez *et al.* 2008), mid-infrared spectra show dual dust chemistry, and its central star has been classified as [WC8] (Górny *et al.* 2004). The object has been suggested to be a post-common envelope PN that could have underwent a late or very late thermal pulse (see Miranda *et al.* 2021). Finally, the newly identified OHPN IRAS 07027−7934 (Figure 1) shows dual dust chemistry (Cohen *et al.* 2002), and the central star has been classified as [WC11] (Menzies & Wolstencroft 1990). The formation mechanism and AGB/post-AGB progenitors of [WC] central stars of PNe are still not fully understood. However, taking into account the characteristics of Vy 2-2 and the PNe mentioned above, low-mass C-rich central stars in post-common envelope systems could be a common end of H_2OPNe and OHPNe.

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4. Conclusions

We have presented our efforts to identify new maser-emitting PNe and to characterize them as a group. We have identified four new OHPN candidates that have very similar properties to those of bona fide OHPNe, and confirmed IRAS 07027−7934 as a new bona fide OHPN. We found variability in the OH spectra of IRAS 07027−7934, which could be related to the expansion of a nascent photoionized region consistent with the onset of the PN phase. In the OHPN Vy 2-2, the low values of nebular C/O and N/O abundance ratios, and the low-mass C-rich central star suggest that it is a post-common envelope binary system. Furthermore, at least two more maser-emitting PNe, IRAS 18061−2505 and IRAS 07027−7934, host C-rich central stars. Hence, we speculate that H_2OPNe and OHPNe could be a group of PNe with low-mass C-rich central stars in post-common envelope systems.

This work is partially supported by grant P20-00880 of Junta de Andalucía, grants PID2020- 114461GB-I00, CEX2021-001131-S of MCIN/AEI /10.13039/501100011033, and PRE2018-085518 funded by MCIN/AEI and by ESF Investing in your future.

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