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# New radio detections of molecular and atomic emission towards C-rich planetary nebulae

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## Abstract

Planetary Nebulae (PNe) are known to host an energetic radiation environment that does not avoid the simultaneous presence of different types of molecules and single atoms. For this reason, PNe appear to be a unique laboratory where simple and complex molecules coexist. We will present our recent very sensitive and high-resolution mm observations of PNe IC 418 and NGC 7027, which have provided us a nice mm database of the atomic and molecular content of these objects. In our aim to study the complex organic molecules in mm frequencies, we have found for the first time very weak radio recombination lines (RRLs) of several neutral and ionized atoms never observed before. These new detected RRLs together with the molecular content give useful information about their circumstellar envelopes as well as the complex organic chemistry taking place in this kind of astrophysical environments.

## 1 Introduction

Millimeter (mm) observations are sensitive to the rotational emission lines produced by species with dipolar moment. Detecting these lines provides crucial information to unambiguously identify molecules in space. Since the detection of the first molecule in space (CH, 1937), hundreds of molecules have been observed in a large variety of astrophysical sources

[1]. However, the number of species formed in astrophysical environments is so large that the available information of state-of-the-art observations is not enough. The formation processes remain pretty unknown even for small molecules. As molecules become more complex, their rotational emission lines are weaker, so it is difficult to clearly distinguish them from the noise level of past observations. More accurate and sensitive observations must be made to detect new molecular species and to understand the formation mechanisms of complex molecules.

High-sensitivity mm observations significantly reduce the noise of the spectra, combining long exposure times with large dishes, equipped with high-resolution receivers. Such low noise spectra may reveal the presence of weak features never resolved before. The detection of these hidden lines will provide the necessary clues to identify the chemical pathways that lead to the formation of (complex) molecules in space.

## 2 Observations and data reduction

The PN IC 418 is an elliptical nebula surrounded by various low surface brightness structures and haloes (see e.g., [2, 3]). Its IR spectrum reveals aliphatic and aromatic molecular bands, unidentified infrared features (UIRs) [4, 5], and $C_{60}$ emission bands [6]. Only radio recombination lines (RRLs) have been detected at mm frequencies up to date [7].

The bipolar/multipolar PN NGC 7027 has a very rich molecular content despite of the high effective temperature of the central star ($T_{\rm eff} = 200\,000\,{\rm K}$), which results in strong UV and X-ray emission capable to photo-dissociate and ionize this molecular component [8, 9, 10]. In the IR range, the presence of both aliphatic and aromatic species and UIRs [5, 11] is confirmed. At sub-mm frequencies, molecular emission as well as H and He RRLs have been extensively observed (see e.g., [12, 13, 14, 15]).

We present new very sensitive spectra on these two PNe obtained using the IRAM-30m and Yebes 40m[1] radio telescopes. The good weather conditions and receiver setup allowed a sensitivity of $\sim 1\,{\rm mK}$ [$T_{\rm a}^*$] and a spectral resolution of $2.5\,{\rm kms}^{-1}$ and $5-7\,{\rm kms}^{-1}$ for the 30m and the 40m observations, respectively. Here we present our results on the RRLs, a necessary first step prior for the identification of weak lines produced by new molecular species.

## 3 Results

We calculated the RRLs frequency for light atoms in the observed ranges using the Rydberg approximation. All coincidences up to the noise level where fitted with Gaussian profiles and then modeled with the Code for Computing Continuum and Radio-recombination Lines (Co$^3$RaL , Sánchez-Contreras et al. in preparation), a code specialized in the interpretation of both the line and continuum emission of the free-free radiation from the ionized gas.

[1] Operated by the Spanish Geographic Institute (IGN, Ministerio de Transportes, Movilidad y Agenda Urbana - MITMA).

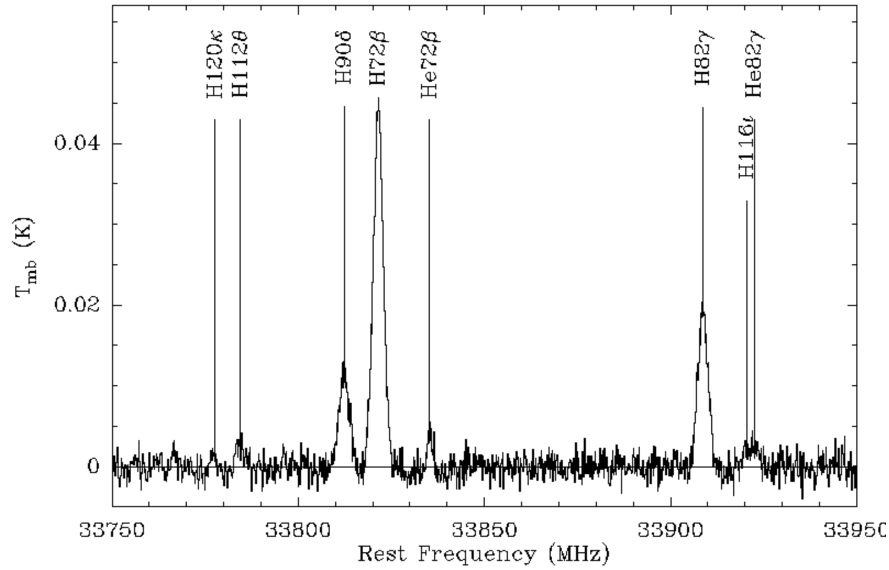


Figure 1: Example of the IC 418 spectrum.

**RRLs catalog of IC 418**

The observations reveal, for the first time, the presence of more than 150 H and He RRLs at 2, 3, and 7 mm (see an example of the spectrum in Fig.1). The $Co^3RaL$ results show a really good agreement for H and He RRLs in the observed ranges. However, $Co^3RaL$ predicts larger full width at half maximum (FWHM) for He lines that are not observed. After a carefull identification of all the RRLs, no traces of emission of known species have been found, confirming the results of past observations. However, we have identified a number of U-features whose origin must necessarily be from yet unknown molecular carriers.

**RRLs catalog of NGC 7027**

We detect more than 150 H, He, and He II RRLs across 2, 3, and 7 mm . The spectra of this PN reveal fewer weak RRLs compared to IC 418. Here again, the model reproduces quite well the peak flux intensity of every line, but it predicts larger FWHM values for He and He II RRLs than the observed ones. After identifying all these RRLs, we also observed emission lines produced by molecules such as $HCO^+$ (at 3 mm ), HCN (at 3 mm ), or $C_2H$ (at 3 mm ), and more species from the ground and vibrational excited states.

# 4 Conclusions

Our high-sensitivity mm observations reveal, for the first time, the presence of hundreds of emission lines in both PNe that are associated with RRLs of H, He,and He II. We have detected He II emission at wavelengths longer than 2 mm, which have not been previously observed in a PN. This also demonstrates that the atomic and molecular content of objects in the same evolutionary stage may be very dissimilar because of the different physical conditions. Curiously, even though the IR spectrum of IC 418 is very rich in molecules, no evidences of known molecular species have been found in our observed bands.

The new RRLs can provide information about the morphology and the physical conditions of the PNe. A deeper inspection on the location of the different RRLs emission should be done for a better understanding of the different FWHM values depending on the atomic species.

The new RRLs catalogs presented here are also an important tool to confirm or discard the detection of new molecular lines in high-sensitivity radio and mm observations. We have shown that RRL emission is more frequent than though, so a carefull inspection has to be done in future observations. To confirm the detection of new weak molecular lines, a previous RRL identification is crucial to avoid miss-identifications.

Our next steps focus on the upcoming publication of these new and unprecedent RRLs catalogs in PNe (Huertas-Roldán et al., in preparation), as well as the use of them to clearly distinguish atomic from molecular emission lines, and to unambiguously identify new molecular lines towards PNe. More interdisciplinary efforts, including new high-sensitivity observations in conjunction with microwave laboratory experiments, and theoretical predictions of the emission of complex molecules, are clearly needed to detect new weak rotational features and unambiguously identify their molecular carriers.

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