Planetary Nebulae: An Eye to the Future
Proceedings IAU Symposium No. 283, 2011
A. Manchado, L. Stanghellini & D. Schönberner, eds.
© International Astronomical Union 2012
doi:10.1017/S1743921312011222

Herschel/HIFI observations of molecular lines from young planetary nebulae

Valentín Bujarrabal[1], Miguel Santander-García[1,2], Javier Alcolea[3], Rebeca Soria[3] and the HIFISTARS team

[1]Observatorio Astronómico Nacional, Ap. 112, E-28803 Alcalá de Henares, Spain
email: v.bujarrabal@oan.es

[2]Centro de Astrobiología, INTA-CSIC, Madrid, Spain; Instituto de Astrofsica de Canarias, Tenerife, Spain; and Dpto. de Astrofísica, Universidad de la Laguna, Tenerife, Spain

[3]Observatorio Astronómico Nacional, C/ Alfonso XII 3, E-28014 Madrid, Spain

Abstract. We present results from systematic Herschel/HIFI observations of molecular lines in the FIR/sub-mm from young planetary nebulae. The high spectral resolution provided by the hetorodyne spectrometer HIFI allows properly studying the line profiles, whose structure corresponds to the various kinematics of the most massive nebular components, including fast bipolar outflows and slow shells. In particular, we have studied the excitation properties of the high-velocity (dense) flows. In some cases we find typical temperatures of the fast gas over 100-200 K, though in others it remains cool, $\lesssim$ 30K. We argue that the thermodynamics of the molecule-rich bipolar outflows is driven by fast radiative cooling, after the passage of the shock that accelerated it.

Keywords. planetary nebulae: general, stars: AGB and post-AGB, submillimeter

---

Low-J molecular transitions, in the mm-wave domain, have been often observed in protoplanetary nebulae (PPNe) and young planetary nebulae (PNe), using ground-based telescopes. These transitions are very useful to study the nebular structure, mass distribution, and dynamics. Very massive components, representing most of the nebular material (~ 1 $M_\odot$), are often detected, including fast bipolar outflows. Molecule-rich bipolar outflows, which are thought to result from shock interaction, carry large amounts of mass (0.1–0.3 $M_\odot$) and are the basic phenomena in the formation and evolution of PNe. However, low J transitions cannot properly probe the excitation state of this molecule-rich gas, mainly when its temperature is higher than about 100 K, because of the very low excitation required by those lines. To study this warm, intermediate-excitation gas, observations of intermediate-excitation transitions are necessary, which have in general frequencies, in the submm or FIR. Warm molecule-rich components are particularly important in our case because they include the fast dense outflows.

We have performed systematic observations of high-J molecular lines in PPNe and young PNe using HIFI, the high-resolution spectrometer on board Herschel, as part of the Herschel guaranteed time key project HIFISTARS. We have observed a total of ten nebulae in transitions of ^{12}CO and ^{13}CO (J=6−5, 10−9, and 16−15) and H_2O ($1_{1,0}$–$1_{0,1}$, $1_{1,1}$–$0_{0,0}$, $3_{2,1}$–$3_{1,2}$, $3_{1,2}$–$2_{2,1}$, $4_{2,2}$–$4_{1,3}$, and $7_{3,4}$–$7_{2,5}$), as well as rotational lines of NH_3 and OH, and lines of $C^{18}O$, $H_2{}^{18}O$, vibrationally excited H_2O, SiO, HCN, CN, etc.

The high sensitivity and spectral resolution of the instrument allowed an accurate study of the complex line profiles, whose structure corresponds to the various kinematics of the nebular components, particularly the fast bipolar outflows and slow shells. See examples in the figure. In our first works, we have focused in deriving the excitation state of the high-velocity bipolar outflows. Detailed modeling have been carried out in

Downloaded from https://www.cambridge.org/core. IP address: 3.236.212.116, on 17 Sep 2021 at 07:43:11, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S1743921312011222

Table 1. Characteristic temperatures of the fast outflows derived from our data; the lifetime of the fast outflows and their characteristic densities are also given.

source	T_{k}	flow lifetime	n_{tot}
CRL 618	200 K	$\lesssim$ 100 yr	5 10^6 cm^{-3}
CRL 2688	100 K	200 yr	$\sim 10^6$ cm^{-3}
OH 231.8+4.2	30 K	1000 yr	$\sim 2\ 10^5$ cm^{-3}
NGC 6302	40 K	$\lesssim$ 800 yr	2 10^4 cm^{-3}
Frosty Leo	60 K	$\sim$ 1700 yr	10^4 cm^{-3}
IRAS 17436+5003	60 K	$\sim$ 500 yr	$\sim 10^6$ cm^{-3}

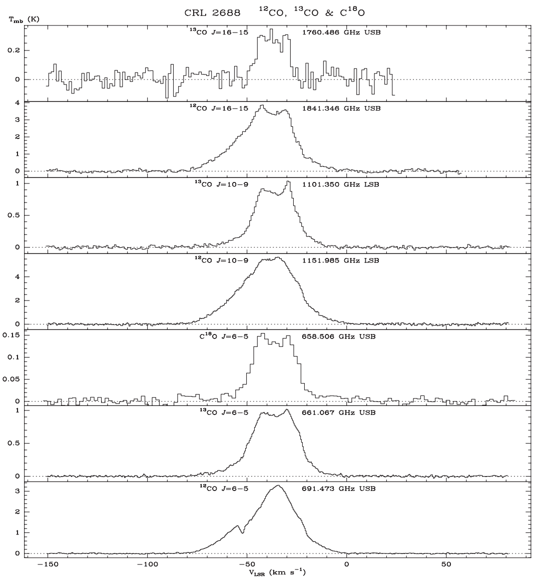

Figure 1. Observations of CO lines in the PPN CRL 2688.

the best studied sources; for others a more general analysis was performed. In some cases, notably for the well-known nebula CRL 618, we detect the presence of fast gas components with temperatures higher than 200 K (Bujarrabal *et al.* 2010). In other cases, e.g. OH 231.8+4.2, the fast-flowing gas is found to remain cool, under $\sim$ 30 K (Alcolea *et al.* 2012). Results for some objects are summarized in the table (see general discussion and other cases in Bujarrabal *et al.*, 2012), together with other properties of the flows. We find that the temperature of the fast outflows in our sources falls with the time elapsed since the acceleration took place. For instance, the lifetime of the fast molecule-rich flow in CRL 618 is shorter than about 100 yr, while that of OH 231.8+4.2 is about 1000 yr. Some dependence with respect to the density is also found, denser gas being in general cooler. Both results strongly suggest that the thermodynamics of the massive fast outflows in PPNe is mostly driven by fast radiative cooling after the passage of the shock responsible for their acceleration.

References

Alcolea, J., Bujarrabal, V., Soria-Ruiz, R., *et al.* 2012, *A&A*, in preparation
Bujarrabal, V., Alcolea, J., Soria-Ruiz, R., *et al.* 2010, *A&A*, 521, L3
Bujarrabal, V., Alcolea, J., Soria-Ruiz, R., *et al.* 2012, *A&A*, 537, A8

Downloaded from https://www.cambridge.org/core. IP address: 3.236.212.116, on 17 Sep 2021 at 07:43:11, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/S1743921312011222