PLANETARY NEBULAE: THEIR EVOLUTION AND ROLE IN THE UNIVERSE
IAU Symposium, Vol. 209, 2003
S. Kwok, M. Dopita, and R. Sutherland, eds.

NIR Fabry-Perot Imaging Spectroscopy of PNe

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Abstract. In this work we report the radial velocity field of the molecular hydrogen in five planetary nebulae, obtained from scanning Fabry-Perot interferometer observatins at the near-infrared vibrationally excited line H_2 S(1) 1-0 at 2.122 μm. Direct images of the nebulae in both transitions of molecular hydrogen S(1) 1-0 and S(1) 2-1 are used in order to discriminate between shocks and fluorescence as the excitation mechanism of the H_2. Finally, some physical parameters are derived.

1. Introduction

Recent observations of planetary nebulae (PNe) have evidenced the presence of important amounts of neutral material in this kind of objects. Since the detections of molecular hydrogen in PNe are dominated by the bipolar nebula type, it has been proposed that is very likely that each and every H_2 emitting nebula possesses bipolar structure (Kastner et al. 1994) and therefore ring-like PNe with molecular emission are expected to be nebulae with a high inclination of the polar axis respect to the line of sight. Another important problem concerning the hydrogen molecular emission in PNe, is the process that excites the gas. For the H_2 gas, two types of mechanisms can populate the upper levels of the transitions arising from excited vibrational-rotational states: shock excitation or radiative cascades following the UV pumping in photo-dissociation regions (PDRs). These mechanisms result from very different conditions and can, in principle, be distinguished by examining the relative intensities among the different transitions.

2. Observations

The images were obtained at the 2.1m telescope of the Observatorio Astronómico Nacional at San Pedro Mártir, B.C. (México) using the infrared Fabry-Perot Interferometer PUMILA (Salas et al. 1999; Rosado et al. 1999) and the CAMILA infrared spectrograph (Cruz-González et al. 1994). The main characteristics of this interferometer are interference order of 1181, spectral resolution of 24 km s^{-1}, and free spectral range of 255 km s^{-1}. Sets of images or cubes were obtained at 26 etalon positions that scan a single order at 9.82 km s^{-1}.

3. Results

From the Fabry-Perot data, we derived velocity maps from which integrated radial velocity profiles were extracted. When one or more velocity peaks are present, the heliocentric radial velocity of each component can be obtained by a Gaussian profile fitting. We have tried to reproduce the kinematical data using a 3-D geometry. The best adjusts results when we take a double ellipsoidal shell with a law for the expansion velocity proportional to the distance to the star. The tilt of the polar axis is one of the parameters of the model. Also, We obtained direct images of the PNe in the molecular hydrogen emission lines at 2.122 μm and 2.248 μm, corresponding to the S(1) 1-0 and S(1) 2-1 transitions respectively. The S(1) 2-1 emission is weak in all the cases. It is common to use the ratio of these two lines to discriminate between the two types of mechanisms that produce the emission. In the case of fluorescence a value of about 0.5 is expected for the intensity ratio of the S(1) 2-1 line to the S(1) 1-0 line. By the other hand, this ratio is typically 0.1 in shocked regions and tends to a limiting value of 0.3 for strong shocks. For the PNe reported here we found that the line ratio has values between 0.08 and 0.15 for the regions with stronger emission, indicative of shock excitation. Then, we can estimate the density of the molecular hydrogen using a relation beetween the intensity of the S(1) 1-0 emission line, the shock velocity V_s and the preshock density n_o (Kwan, 1977). If we assume a double ellipsoidal shape and a density law that decreases with the distance to the central star as r^{-2}, as in the case of NGC 2346 (Arias et al. 2001) then we can derive an estimate for the mass. Table I resumes the derived parameters for the five PNe.

Table 1. Derived Parameters

PN	**Tilt angle**	$\mathbf{V_{sh}}$ km s^{-1}	**S(1) 1-0** ergs $s^{-1}cm^{-2}sr^{-1}$	$\mathbf{n_o}$ cm^{-3}	$\mathbf{H_2}$ **mass** $M_\odot$
NGC 6720	25	20	$9.24\ 10^{-3}$	$1.3\ 10^4$	0.3
NGC 6781	23	13	$1.02\ 10^{-4}$	$2.7\ 10^4$	0.2
NGC 3132	30	24	$2.19\ 10^{-4}$	$3.5\ 10^4$	0.4
NGC 2346	65	16	$6.25\ 10^{-5}$	$7.0\ 10^3$	0.8
NGC 7048	20	15	$1.25\ 10^{-5}$	$2.5\ 10^3$	0.1

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