

# Molecular Hydrogen Jets, Filaments, and Haloes in Planetary Nebulae

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**Abstract.** We present deep H<sub>2</sub> images of planetary nebulae obtained with the CFHTIR camera of the *Canada-France-Hawaii Telescope*. Molecular hydrogen emissions are seen in the equatorial torus, bipolar lobes, as well as in extended haloes. Radial equatorial jets are also detected in a number of bipolar nebulae.

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## 1. Introduction

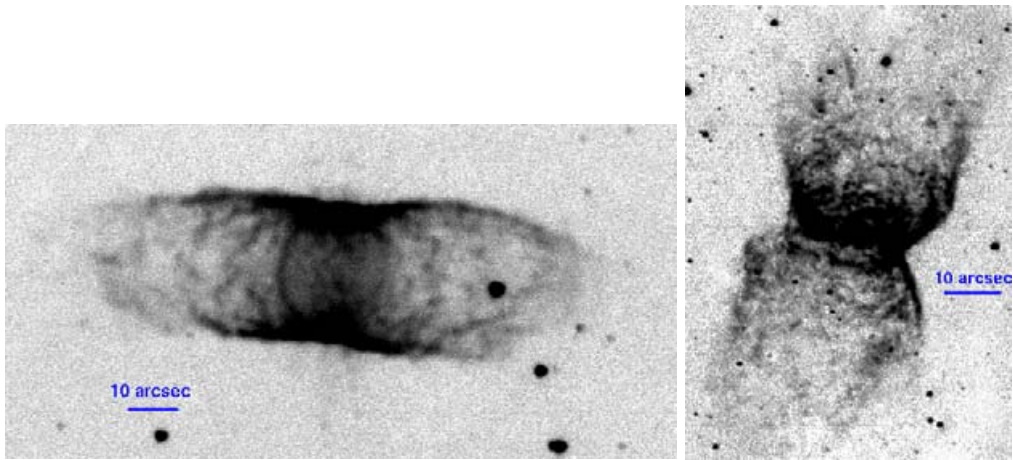
Molecular hydrogen (H<sub>2</sub>) imaging of planetary nebulae (PNe) is a powerful tool for pinpointing the regions of dynamical interactions. Deep imaging in H<sub>2</sub> has been demonstrated to reveal extended emission in PNe haloes (Guerrero *et al.* 2000). In this paper, we report the preliminary results of an imaging survey of PNe with H<sub>2</sub> and Br $\gamma$  filters using the CFHTIR camera of the *Canada-France-Hawaii Telescope*.

## 2. Observations

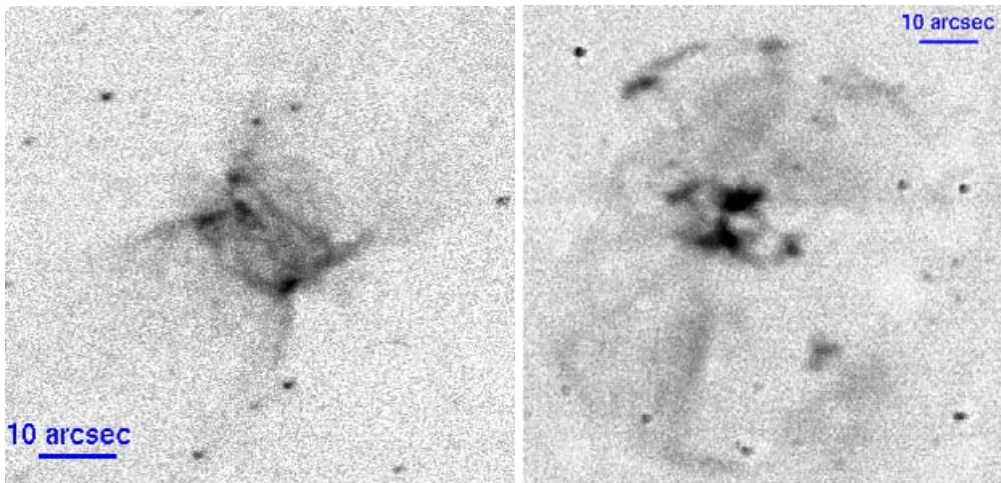
CFHTIR is a 1024  $\times$  1024 array camera providing a large field of view of 3.6 square arcmin on a pixel scale of 0.2 arcsec. Images with an H<sub>2</sub> filter (central wavelength 2.122  $\mu$ m) and *K'* filters were obtained for nine PNe (Frosty Leo Nebula, IC 4406, K3-72, M2-9, NGC 2346, NGC 2392, NGC 2440, NGC 6210, NGC 6543) with photometric calibrations. Continuum-subtracted (H<sub>2</sub>-*K'*) images are constructed from co-added short exposures that were individually sky-background subtracted and flat fielded.

## 3. Results

Strong H<sub>2</sub> emission can be seen in the equatorial torus regions as well as in the bipolar lobes of IC 4406 and NGC 2346 (Fig. 1). A bright elliptical ring can clearly be seen in the waist of IC 4406. Molecular hydrogen emissions from the bipolar lobes are particularly prominent in comparison to the optical images of this nebula taken with the *HST* (O'Dell *et al.* 2002). The bright rims in the lobes sharply define the edges of the lobes, suggesting that the lobes are confined by an external medium and that the H<sub>2</sub> emission trace regions of wind interaction. The H<sub>2</sub> emissions at the caps of the lobes probably represent the regions where the fast wind is breaking through the remnant AGB circumstellar envelope. Most interestingly, radial jets can be seen along the equatorial plane of IC 4406. These features resemble the high-speed “skirts” seen around the waist of NGC 6302 (Meaburn *et al.* 2005), or the “chakram” of Mz-3 (Santander-Garcia *et al.* 2004). Similar structures



**Figure 1.** Continuum-subtracted H<sub>2</sub> image of IC 4406 (left) and NGC 2346 (right).



**Figure 2.** Continuum-subtracted H<sub>2</sub> images of K3-72 (left) and NGC 2440 (right).

of equatorial torus, bipolar lobes, and radial equatorial jets can also be seen in K3-72 (Fig. 2). NGC 2440, a well-known multi-polar nebula, shows an extended spherical molecular halo of 73'' in diameter (Fig. 2). A bright rim of the halo probably traces the shock interaction between the halo and the ISM. It is interesting to note that the nebula is not located at the center of the spherical halo.

These results indicate that ground-based, deep-H<sub>2</sub> imaging is useful in tracing extended structures as well as wind-interaction regions. These images can be compared to the *Spitzer* IRAC images (Hora *et al.*, these proceedings) and the *Gemini* 10 and 20 μm images (Volk *et al.*, these proceedings) that trace the dust distributions in PNe.

## References

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