HST NICMOS Observation of Proto-Planetary Nebulae

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Abstract.
We report NICMOS wide-band and polarimetric observations of four proto-planetary nebulae. Molecular hydrogen emission is detected near the ends of the bipolar lobes of IRAS 17150-3224, which is evidence for the interaction of a fast, collimated outflow with the remnant of the asymptotic giant branch wind.

1. Introduction
Although the circumstellar envelopes of asymptotic giant branch (AGB) stars are mostly spherical, many planetary nebulae (PN) have bipolar or butterfly morphologies. When and how this morphological transformation occurs are two of the major unsolved problems in PN research today. Recent imaging observations of PPN have found that several PPN have already developed reflection nebulosities of bipolar shape, suggesting that shaping occurs soon after the end of the AGB phase (Kwok et al. 1996, Kwok et al. 1998, Su et al. 1998, Hrivnak et al. 1999). In this paper, we present HST NICMOS observations of four of these bipolar PPN.

2. Observations & Data Reduction
The NICMOS observations (ID No. 7840; S. Kwok, PI) were obtained in 1998 with the NICMOS camera 2 (NIC2), which has the highest resolution (0\".076 pixel\(^{-1}\)) and a 19\"×19\" field of view. The observations were taken with one broad-band (F160W) and one medium-band (F222M) filters, three polarizers POL0, POL120, POL240, and the narrow-band filter F212N (H\(_2\)) and F215N (continuum). Each target was imaged three times using a predefined spiral dither pattern, which allowed us to compensate for bad pixel/columns and the area blocked by the coronographic mask.
Figure 1. The HST V-, H-, and K-band images (in log scale) of the Cotton Candy Nebula are shown in panels (a), (b), and (c) respectively. The intensity profile of arcs seen in the Cotton Candy Nebula is shown in (d). The $\text{H}_2$ continuum-subtracted image and contours are shown in (e). Panels (f), (g) and (h) are the HST V-, H- and K-band images (in log scale) of the Silkworm Nebula.

Figure 2. The HST V-, H- and K-band images (in log scale) of the Walnut Nebula (left) and the Water Lily Nebula (right).

3. **H & K Wide-band Images**

The reduced images of IRAS 17150-3224 (the Cotton Candy Nebula) are shown in Fig. 1. The two bipolar reflection lobes are found to have similar sizes in the V, H, and K bands. Superimposed on the two lobes and the surrounding halo is a series of concentric, circular arcs or rings. There are a total 8 rings (A to H, Fig. 1d) in the V-band image (Kwok et al. 1998), 6 of which are also detected in the H-band. The average separation of the 6 arcs in H is $0.51''$, which agrees with the results measured in the V-band.

While the two lobes are separated by a dark lane in the V image, the central star can be seen in the H and K images. The position of the central star agrees well with the position of the crossing point of the searchlight beams in the V-band image. A linear plot (from $10 \sigma_{\text{sky}}$ to $100 \sigma_{\text{sky}}$) of the continuum-subtracted $\text{H}_2$ image is shown in Fig. 1 (e). The clumpy $\text{H}_2$ emission regions at the end of the lobes could be the result of shock excitation as a fast, collimated outflow runs into the remnant AGB envelope.

The V, H, and K images of IRAS 17441-2441 (the Silkworm Nebula) are shown in Fig. 1 (f), (g) and (h) respectively. The arcs in the V-band image can also be seen in the H-band. The S-shaped morphology is more prominent in the K-band. A bright central star is resolved in the K-band image at the sky position which agrees with the center of the circular arcs as determined from the V-band image.

Figure 2 shows the results of IRAS 17245-3951 (the Walnut Nebula) and IRAS 16594-4656 (the Water Lily Nebula). The central star in the Walnut Nebula is obscured by a dark lane in the V-band image but is visible in the H- and K-band images. For the Water Lily Nebula, very little nebulosity is detected in the K-band image. However, the nebulosity in the H-band image bears some resemblance to that seen in V-band image.

Figure 3. Results of the NICMOS 2 $\mu$m polarimetric observations for the 4 PPN. The total intensities through the three polarizers are plotted in contours and the polarimetric vectors are plotted as vectors.
4. 2 \mu m Polarized Images

We used the algorithm developed by Hines et al. (1997) to derive the Stokes images \((I, Q, U)\), the percentages of polarization, and the position angles in the NICMOS polarization images. In order to minimize the noise contributions to the calculation, a threshold value of 10 \(\sigma_{sky}\) was used for each pixel. The data were binned by 2\times2 pixels before calculating polarization percentage and position angle.

All of the polarized vector maps (Fig. 3) show centrosymmetric patterns, similar to those observed in the equatorial regions of bipolar reflection nebulae (Kastner et al. 1995) and the Egg Nebula (Sahai et al. 1998). The presence of such patterns provides strong, independent evidence for the presence of a circumstellar disk in these PPN. The higher polarization regions are found at the edges of two reflection lobes far from the central stars, suggesting that the reflection nebulae are the result of single scattering processes. The polarization is low in the equatorial regions, implying that the light is either unpolarized or the result of multiple scattering. The centroids of the polarimetric vectors of all four PPN coincide with the positions of the central stars in the K-band images, confirming that the central stars are the source of the scattered light.

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