Hubble Space Telescope Imaging of the Young Planetary Nebula GL 618

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Abstract. We present narrow-band Hubble Space Telescope images of the young planetary nebula GL 618. These images have allowed us to study the detailed morphology of shock-excited emission present in the bipolar lobes of this object. These images reveal the presence of three highly collimated outflows emanating from the central regions of GL 618. We discuss the significance of the detection of these outflows and the possible origins of these features.

1. Introduction

GL 618 is a young, bipolar planetary nebula (PN). Ground-based optical and near-IR imaging of this object reveal two lobes of emission (each about 3′′ in extent) separated by a dark lane. The central regions of the nebula are hidden from direct view at optical wavelengths by the lane of obscuring material. The spectrum of GL 618 is composed of a faint continuum and a variety of low-excitation emission lines. Trammell, Dinerstein, & Goodrich (1993) used spectropolarimetry to study GL 618 and found that the continuum and part of the permitted line emission are reflected from deep in the nebula. The low-excitation, forbidden line flux and remainder of the permitted line emission are produced in the bipolar lobes. The emission produced in the bipolar lobes is indicative of shock heating ($V_s = 50–100 \text{ kms}^{-1}$). Long-slit optical spectroscopy of GL 618 confirms that the shock emission is associated with out-flowing gas (Carsenty & Solf 1982) and near-IR spectroscopy of GL 618 has revealed the presence of thermally excited H$_2$ emission (Thronson 1981; Latter et al. 1992). GL 618 exhibits [Fe II] emission also thought to be associated with the shock-heated gas (Kelly, Latter, & Rieke 1992) and more recent observations establish that this emission is associated with an outflow (Kelly, Hora, & Latter 1999). Shock-excited emission dominates the spectra of the lobes of GL 618. We present WFPC2 images of this object that demonstrate that the source of this shock-excited emission is a set of highly collimated outflows originating in the central regions of the object.

2. Observations

We have obtained WFPC2 images of GL 618 as part of a HST Cycle 6 program. GL 618 was centered in the Planetary Camera which has a $36'' \times 36''$ field of
view and a plate scale of 0.0455" per pixel$^{-1}$. Images were obtained through four filters: F631N (isolating [O I]$\lambda6300$ line emission), F656N (isolating H$\alpha$ line emission), F673N (isolating [S II] $\lambda\lambda6717,31$ line emission), and F547M (a continuum band). These filters were chosen so that we could study the morphology of the shock-excited emission in the lobes of GL 618. The images were processed through the HST data reduction pipeline procedures and cosmic rays were removed by combining several exposures of each object. The images of GL 618 were obtained on 23 October 1998 and exposure times ranged from 15 to 45 minutes.

3. Results

The overall morphologies seen in the [S II] and [O I] images are similar (Figure 1, panels (a) and (b)). These images trace the morphology of the shock-excited forbidden line emission in GL 618. Three highly collimated outflows, or jets, are seen in both images. The brightest emission occurs near the tip of each of the outflows and there is no forbidden line emission seen in the central regions of GL 618. Ripple-like morphology is seen in the outflows in both the [S II] and [O I] images. These ripples might be the result of instabilities in the flow and/or an interaction with the surrounding nebular material.

The morphology observed in the H$\alpha$ image (Figure 1, panel (c)) differs slightly from the forbidden line morphology. H$\alpha$ emission is seen associated with the outflows, but in addition, a significant amount of H$\alpha$ emission is seen towards the central regions of GL 618. Spectropolarimetric observations indicate that part of the H$\alpha$ emission is reflected and part of this emission is produced by shocks in the lobes (Trammell et al. 1993). We have spatially separated these components in the HST images. The H$\alpha$ emission associated with the central regions of the object is probably reflected emission from an H II region buried deep in the nebula. A high density H II region has been observed at the center of GL 618 at radio wavelengths (e.g. Kwok & Feldman 1981) and in the reflected optical spectrum (Trammell et al. 1993). The H$\alpha$ emission coincident with the outflows is the shock-excited component of the permitted line emission.

The [O I] to [S II] line ratios in the bullet-like structures at the tips of the outflows are approximately 3.0–3.5. By comparing these observed line ratios with the predictions of planar shock models (Hartigan, Raymond, & Hartmann 1987), we estimate the shock velocity in these regions to be approximately 80 km$^{-1}$. This is consistent with the range in shock velocities estimated from previous spectropolarimetric observations (Trammell et al. 1993).

Careful examination of the bullet-like structures at the tip of the outflow in the upper lobe in Figure 1 reveals an excitation gradient across this region. H$\alpha$ is brightest on the side of the spot facing away from the central regions of GL 618. [S II] and [O I] are brighter on the side closest to the central source. This type of gradient is expected for a jet flowing away from the central source and impinging on the surrounding nebular material. The bright spots near the tops of the outflows are not clumps of material being overrun by a wind or outflow.
4. Discussion

HST observations (e.g. Trammell & Goodrich 1996; Sahai & Trauger 1998) and ground-based imaging surveys (e.g. Balick 1987; Schwarz, Corradi, & Melnick 1992) have revealed the presence of collimated outflows, FLIERs, and a myriad of other small-scale structures in PN. The origins of these structures and their role in the overall development of PN remain puzzling. The debate concerning the origin of these small-scale structures, and also the formation of aspherical PN in general, centers on whether binary or single stars are responsible for producing aspherical mass loss. Both models of binary star interaction (e.g. Soker & Livio 1994) and magnetic confinement (e.g. Garcia-Sergura 1997), while providing a scheme for producing the overall aspherical structure in PN, may also provide mechanisms to produce the highly collimated outflows. The complex, multipolar outflow geometry seen in GL 618 may be difficult for either of these types of models to explain.

Our observations demonstrate that jets can be present during the early phases of PN development and may play an important role in the early shaping of these objects. Further, these collimated outflows may set the stage for the development of other small scale structures seen in more evolved objects.

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Figure 1. Narrow-band WFPC2 images of GL 618. Three collimated outflows are clearly evident in all three images. (a) The F631N image which traces the [O I] emission (b) The F673N filter image which traces the [S II] emission. (c) The F656N filter image which traces the Hα emission.