

## Imaging and Spectroscopy of the Planetary Nebula NGC 6778

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**Abstract.** We present narrow-band images and long-slit echelle spectra of the planetary nebula (PN) NGC 6778. The data show this PN as bipolar, with a very prominent low-excitation equatorial toroid, high-excitation lobes and two pairs of collimated outflows. Morphologically, the pairs of outflows are different from each other; one is linear and oriented along the bipolar axis, the other presents an S-shape with changing orientations. Besides the different morphology, both pairs of collimated outflows present radial velocities increasing with distance from the central star and share a common origin in bright knots at the tips of the shell.

### 1. Introduction

NGC 6778 is a planetary nebula (PN) of excitation class 5 whose central star has Zanstra temperatures between  $4.5 \times 10^4$  K (H) and  $7.5 \times 10^4$  K (He) (Preite-Martinez & Pottasch 1983). No molecular material (CO or H<sub>2</sub>) has been detected in the nebula (Huggins et al. 1996; Kastner et al. 1996). Electron density and electron temperature are  $\simeq 1700$  cm<sup>-3</sup> and  $\simeq 10500$  K, respectively (Preite-Martinez & Pottasch 1983). Its distance is uncertain, ranging from 1.0 to 3.7 kpc (see Acker et al., 1992), with an averaged value of  $\simeq 3$  kpc. Classified as a bipolar, filamentary PN by Peimbert & Torres-Peimbert (1983), the H $\alpha$ + [N II] and [O III] images by Schwarz, Corradi & Melnick (1992) show an elliptical nebula with hints of point-symmetric filaments.

We have obtained narrow-band images and high resolution long-slit spectra of NGC 6778 in order to analyze in detail its structure and kinematics. In this paper, we present the preliminary results of our investigation.

### 2. Observations

Narrow-band images of NGC 6778 were obtained on 2002 June 24 with the 1.5m telescope at Observatorio de Sierra Nevada (Granada, Spain). The nebula was

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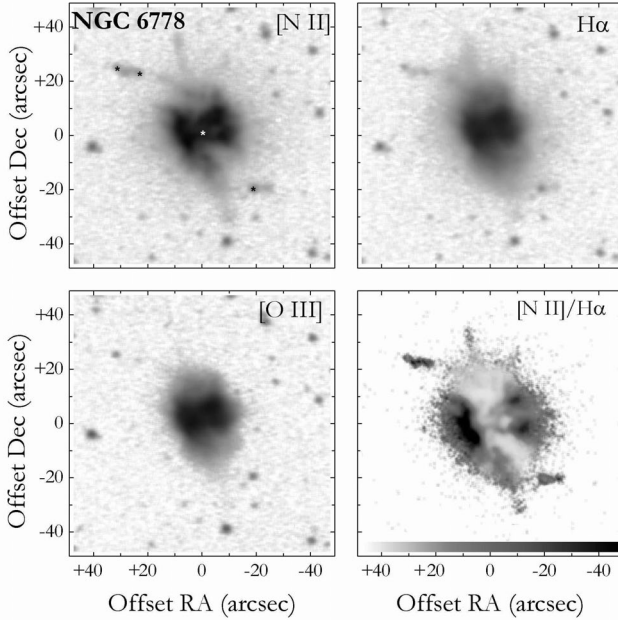


Figure 1. Grey-scale [N II], H $\alpha$  and [O III] images and [N II]/H $\alpha$  intensity ratio map of NGC 6778. Black dots in the [N II] image indicate field stars, the white dot marks the position of the central star, as deduced from the continuum image (not shown here).

observed through narrow-band filters centered in the H $\alpha$ , [N II]  $\lambda$ 6583 and [O III]  $\lambda$ 5007 emission lines and in the continuum at  $\lambda$ 6652 Å. The detector was a Wright CCD with  $820 \times 1152$  pixels and an image scale of  $0''.38 \text{ pixel}^{-1}$ . Exposure time ranged between 600 s and 1800 s. Seeing was  $\simeq 1''.8$ .

Long-slit echelle observations of NGC 6778 were obtained on 2002 June 23 and 24 using the echelle spectrograph on the 4m telescope at the Cerro Tololo Inter-American Observatory (CTIO). The spectrograph was used in the single-order, long-slit mode covering only the H $\alpha$  and [N II]  $\lambda\lambda$ 6548,6583 lines with a slit length of  $\sim 3'$ . The data were recorded with the SITE 2K #6 CCD, resulting in a spatial scale of  $0''.26 \text{ pixel}^{-1}$ . The instrumental FWHM was  $\sim 8 \text{ km s}^{-1}$ . The slit was oriented at position angles (PAs)  $15^\circ$ ,  $24^\circ$ ,  $47^\circ$ , and  $100^\circ$  to cover the different morphological features of NGC 6778. Integration times were 1200 s at each slit position.

### 3. Results

Figure 1 presents the [N II], H $\alpha$ , [O III] images and [N II]/H $\alpha$  intensity ratio map of NGC 6778. The H $\alpha$  and [O III] images show a bipolar PN of  $20'' \times 40''$  in size

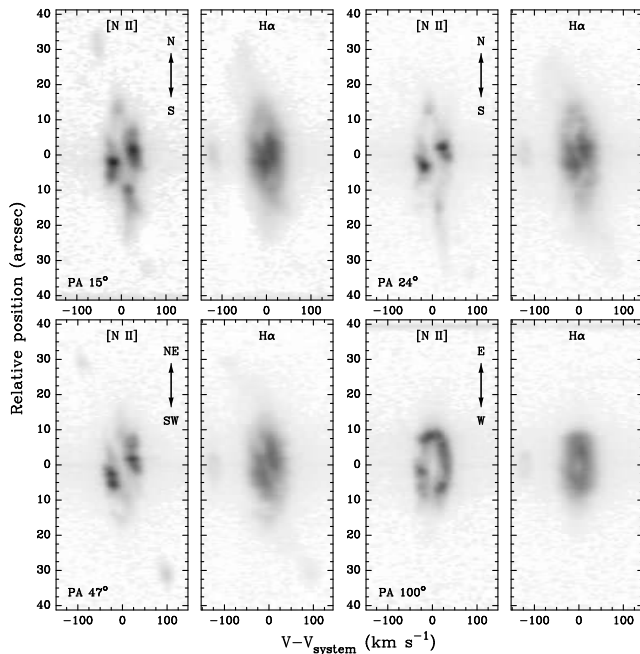


Figure 2. Grey-scale position-velocity maps of the  $[\text{N II}]$  and  $\text{H}\alpha$  emission lines from NGC 6778 observed at four different PAs, shown at the bottom-left corner of the  $[\text{N II}]$  pictures. The origin of the vertical scale corresponds to the location of the central star, as implied from the position of the stellar continuum peak.

with its major axis oriented at  $\text{PA} \sim 15^\circ$ , embedded in a faint elliptical structure detected in  $\text{H}\alpha$  with a size of  $\sim 50'' \times 60''$ .

The nebular emission is dominated by a bright and knotty equatorial region of  $\sim 16'' \times 10''$  in size. In the light of  $[\text{N II}]$ , the emission is mostly confined to this equatorial region. Very interestingly, two pairs of jet-like features are detected in this low-excitation line. One pair has linear morphology oriented along the main axis of the bipolar structure at  $\text{PA} \sim 15^\circ$  and can be traced up to  $\simeq 35''$  from the central star. The other pair presents an S-shape morphology between  $\text{PA} \sim 15^\circ$  and  $\sim 50^\circ$  and can be traced up to  $\simeq 35''$  from the central star.

The  $[\text{N II}]/\text{H}\alpha$  intensity ratio map (Fig. 1) shows that low-ionization material is concentrated around the equatorial region and in the jet-like features, while high-ionization material dominates the bipolar lobes.

Figure 2 shows position-velocity maps of the four echellograms in the light of  $[\text{N II}]$  and  $\text{H}\alpha$ . The shapes of the emission lines in the position-velocity maps are compatible with a bipolar shell. The bright toroid observed in the direct images can be identified with the brightest knots detected in the spectra. If we assume circular cross-section for the toroid, its axis is tilted by  $\sim 15^\circ$  with respect to the plane of the sky, as determined from its relative size along the major and minor axes of the nebula observed in the spectra.

The jet-like features detected in the images are associated with high velocity features in the long-slit spectra (Fig. 2), confirming that they are collimated outflows. The radial velocity of the outflow at PA  $15^\circ$  increases linearly with the distance to the central star from  $\simeq 20 \text{ km s}^{-1}$  up to  $\simeq 60 \text{ km s}^{-1}$  with respect to the systemic velocity of NGC 6778. Assuming that this outflow shares the inclination of the bipolar shell, its (maximum) deprojected velocity is  $\simeq 230 \text{ km s}^{-1}$ . Similarly, the radial velocity of the S-shaped outflow increases with the distance to the central star, with a maximum observed radial velocity of  $100 \text{ km s}^{-1}$ .

It is interesting to note that the collimated outflows seem to originate from bright knots at the tips of the bipolar shell, as it has already been observed in NGC 6891 (Guerrero et al. 2000). The likely connection between the collimated outflows and nebular features suggests either that the shell has contributed to the collimation of the outflows or that the outflows have interacted and shocked material in the nebular shell.

#### 4. Conclusions

Narrow-band images and long-slit echelle spectra indicate that NGC 6778 is a bipolar PN with a very bright equatorial region. Two pairs of collimated outflows have been detected in the object; one is linear and oriented along the bipolar axis and the other one presents an S-shape morphology. The radial velocity in these outflows increases with the distance to the central star, reaching values up to  $100 \text{ km s}^{-1}$ . The outflows seem to arise from bright knots at the tips of the bipolar shell suggesting that the shell has been involved in the collimation or that the outflows have interacted with the nebular shell.

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