
Morphological and spectroscopic analysis of the planetary nebula K 3-35

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Summary. We present preliminary results of an analysis of the planetary nebula K 3-35 based on optical narrow- and broad-band HST images and ground-based near-IR broad and narrow band images, and long-slit optical spectroscopy. The HST images show the presence of two bow-shock-like structures along the major nebular axis, two bipolar lobes with noticeably different morphology, two bright point-symmetric knots and a round/elliptical halo. The near-IR images are similar to ground-based optical images of the nebula and show the bright knots embedded in faint emission. Particularly strong H₂ emission seems to be associated to the bright knots. The spectrum reveals a low-excitation nebula except at the position of the bright knots where both low-excitation emissions (e.g., [OI], [SII]) and high-excitation ones (e.g., [FeVII], HeII, [ArV]) are detected. These results, combined with the detection of water maser emission at the position of the bright knots, strongly suggest that these knots represent the sites where precessing bipolar jets impact against the bipolar lobes of K 3-35. As a whole, the available data indicate that the formation of K 3-35 appears dominated by precessing collimated outflows.

Key words: planetary nebulae: individual (K 3-35) – ISM: jets and outflows

1 Introduction

K 3-35 is a very young planetary nebula (PN) that contains a compact core from which an incipient hourglass-shaped structure emanates, a precessing bipolar jet embedded in two bipolar lobes and a dark lane that separates the lobes (Aaquist & Kwok 1989, Miranda et al. 1998, 2000). In ground-based images, two bright knots presumably trace the sites where the bipolar jets impact against the envelope of K 3-35. This PN is the first one in which water maser emission was detected (Miranda et al. 2001). The water masers trace an equatorial ring and are also found in the bright knots. Considerable amounts of neutral material are inferred from the detection of HCO⁺ from K 3-35 (Tafuya et al. 2007).

In order to increase our knowledge of this remarkable PN, we have carried out an analysis of archived HST images, near-IR images obtained with both broad and

emission line filters, and long-slit optical spectroscopy. Here we present preliminary results of this analysis. A more detailed work will be published elsewhere (Miranda et al. *in preparation*).

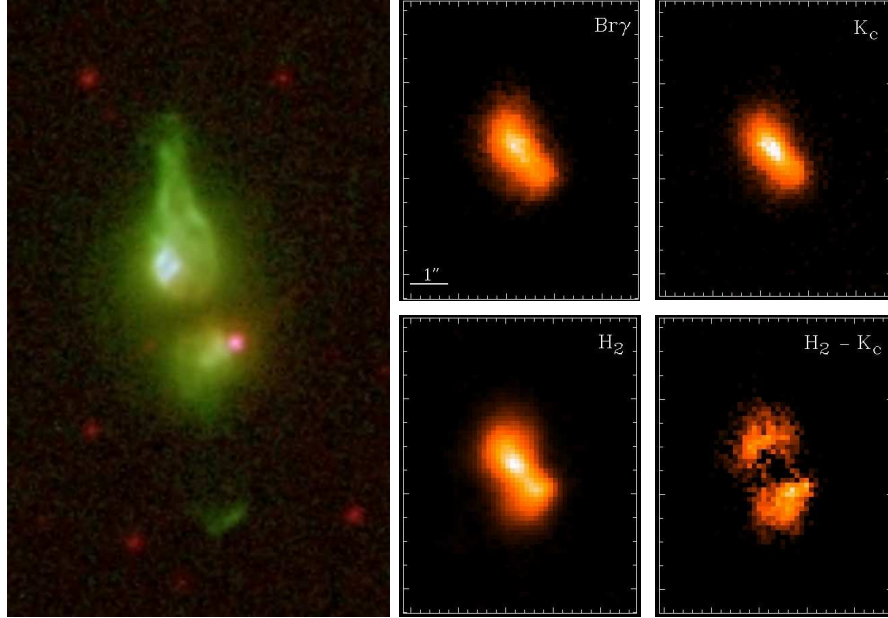


Fig. 1. (left) Composite colour picture of K 3-35 combining the R (red), [NII] (green) and I (blue) HST images. The size of the field shown is $6.25'' \times 10.12''$. (right) Near-IR images in the narrow-band filters (indicated in the upper right corner). The spatial scale is shown in the $\text{Br}\gamma$ frame. Also shown is the H_2 image after continuum subtraction. North is up and east is to the left in all images.

2 Observations and Results

Optical images in the [NII], R and I filters were retrieved from the HST archive. Near-IR images were obtained using NICS at the Telescopio Nazionale Galileo (Observatorio del Roque de los Muchachos, ORM, La Palma) on 2003 September 19. Broad J, H and K filters as well as narrow $\text{Br}\gamma$, H_2 and continuum (K_c) filters were used. Exposure time was 720 s for the broad band filters and between 1200–1800 s for $\text{Br}\gamma$, H_2 and K_c . The seeing was $\simeq 0.5''$. Optical spectroscopy was obtained on 2002 May 18 using ALFOSC at the Nordic Optical Telescope (ORM). The slit was centered on the object and oriented at position angle (PA) = 25° ; the exposure time was 600 s. The seeing was $\simeq 1''$.

The [NII] HST image shows many details of the nebula (Fig. 1). Two bow-shock-like structures are detected at $3.3''$ from the center along the major nebular axis

at PA 10° . The northern lobe presents a spindle-like structure that extends from the northern bow-shock-like structure down to the dark band. The southern lobe appears roundish and is not connected to the southern bow-shock-like structure. The bright knots in the lobes are resolved in the HST images. The NE knot presents two branches that emanate from a common point, a fact also observed in the 3.6 cm radio continuum images (Miranda et al. 2001). The SW knot appears composed of two sub-knots. Finally, a faint circular/elliptical halo surrounds the brightest parts of the lobes.

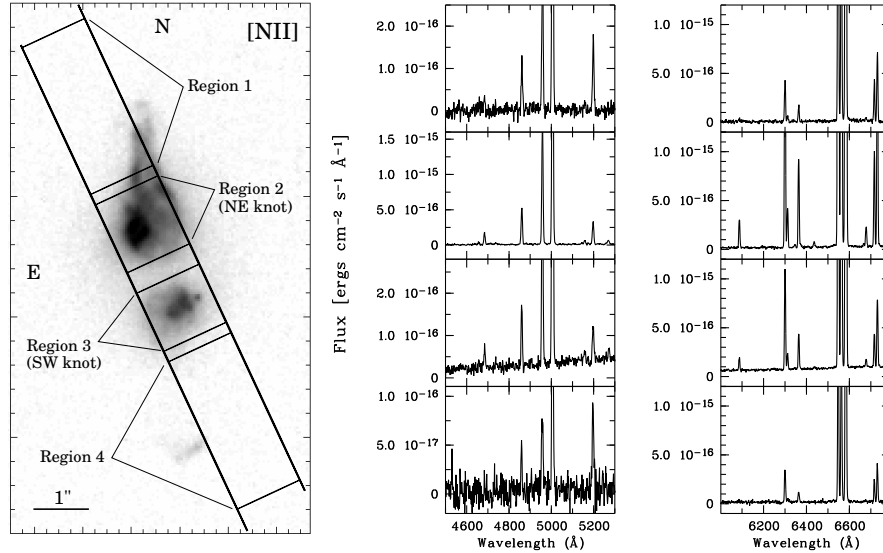


Fig. 2. (left) The slit used for spectroscopy overlaid on a grey scale representation of the [NII] HST image of K 3-35. The four analyzed regions are indicated. (right) Selected portions of the spectra of the four regions, arranged according to their relative spatial position (Region 1 at the top, Region 4 at the bottom).

The narrow-band near-IR images (Fig. 1, the J, H and K images are not shown here) show a structure similar to that observed in ground-based [NII] and $H\alpha$ images. In addition to faint emission, two bright knots can be recognized in each filter. In some filters (J, H, H_2) the observed knots appear close to the position of the optical knots, while in other filters (K, $Br\gamma$, K_c) the observed knots are located closer to the center than the optical ones. In addition, the H_2 - K_c image (Fig. 1) shows that particularly strong H_2 emission is associated to the bright knots, suggesting shock excitation.

The spectrum of K 3-35 (Fig. 2) reveals the existence of two distinct regions in the nebula: the outer regions (Regions 1 and 4) and the inner regions (Regions 2 and 3) that correspond to the NE and SW knots, respectively. The outer regions present lower excitation than the inner ones. In the inner regions, both low excitation (e.g., [OI], [SII]) and high excitation emission lines are detected. In particular, HeII 4686, [ArV] and [FeVII]5720,6087 emissions are detected from Regions 2 and 3 but not

from Regions 1 and 4. Figure 3 presents the spatial distribution of different emission lines along the slit. Surprisingly, all emission lines (except [NI]) in the spectra of Regions 2 and 3 peak at the same position (the bright knots) indicating that possible stratification effects have not been resolved and/or that the size of the region where all emissions arise is very small.

Extinction in the nebula $c(H\beta)$ presents a systematic variation, being 2.55 in Region 1, 2.67 in Region 2, 3.22 in Region 3, and 2.74 in Region 4. This result is compatible with the orientation of the nebula (the northern lobe pointing towards the observer) previously reported (Miranda et al. 1998, 2000). It is reasonable to conclude that the large extinction towards Region 3 is due to material in a tilted dense disk associated to the dark band observed in the optical images.

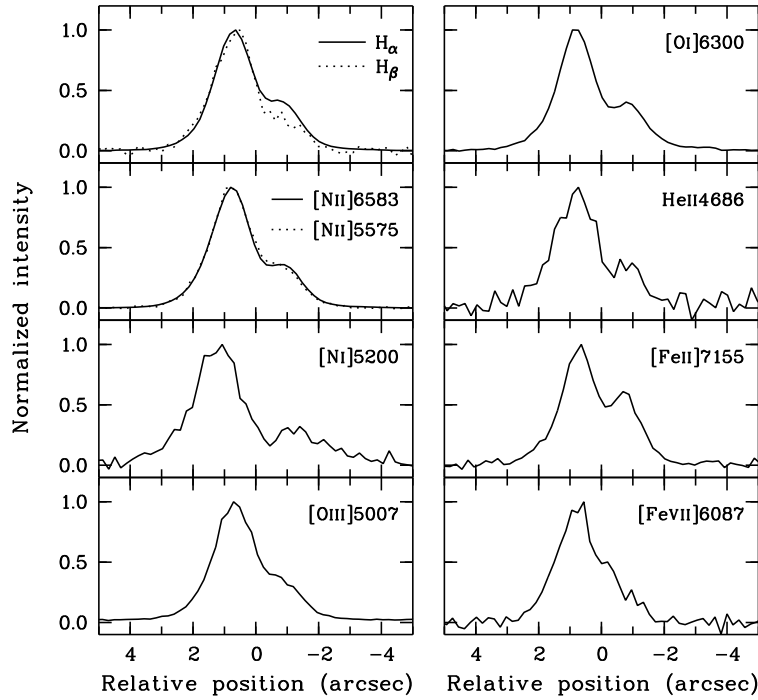


Fig. 3. (left) Spatial distribution of different emission lines along the slit shown in Fig. 2. The origin (0) corresponds to the middle point the two emission maxima (NE and SW knots). NE is to the left.

$N_e([SII])$ is 6000 cm^{-3} in Regions 1 and 4 and at the high density limit ($> 10^4 \text{ cm}^{-3}$) in Regions 2 and 3. Electronic temperature derived from the [NII] emission lines is unrealistic (up to 30000 K), while the [OIII]4363 emission line cannot be used for temperature estimate due to possible contamination by other emission lines.

3 Discussion and final remarks

Photoionization models are able to reproduce many of the observed line ratios assuming a $T_{\text{eff}} \simeq 150000$ K for the central star. However, the presence of shocks at the position of the bright knots cannot be ruled out given the association of these knots with a large range of excitation, water maser emission and possible H_2 emission.

Our data suggest that the formation of K 3-35 may have begun with a collimated ejection along the present major nebular axis, which corresponds to the bow-shock-like structures observed in the HST image. Wobbling or precession of the jet may have originated the spindle-like shape of the northern lobe and the formation of the wider bipolar lobes. The bright knots may trace the sites where the jet impacts against the bipolar lobes. Differences between the northern and southern halves of the nebula may be attributed to different physical conditions in the AGB envelope of the progenitor, to asymmetries in the precessing jet and/or to internal extinction.

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