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The kinematics and morphology of the bipolar PN HaTr 4

Abstract

HaTr 4 is a compact planetary nebula known to contain a close binary central star. Using high spectral and spatial resolution position-velocity arrays in the emission lines of [OIII] λ-5006.84 Å, we present constraints on nebular kinematics and morphology and show that binary-induced shaping of the nebula is likely.

1. HaTr 4

PN HaTr 4 (PN G335.2 –03.6, α = $16^h45^m00.2^s$, δ= -51°12´22´´), is known to contain a non-eclipsing photometric binary central star with a period of 1.71 days (Bond, 1990). On first inspection of the original imagery presented by H. Hartl and S. Tritton (1985), HaTr 4 has the appearance of a classical bipolar nebula lying in the plane of the sky with twin lobes emanating in an East-West direction. However, deeper imagery acquired by D. Pollacco is indicative of a faint extension in a North-South direction that points to the possibility that the bipolarity in fact lies perpendicular to that shown in the 1985 image.

Long-slit spectroscopy was carried out and deep narrow-band imagery acquired, from which a spatio-kinematical model was derived in order to investigate the relationship between HaTr 4 and its central binary star.

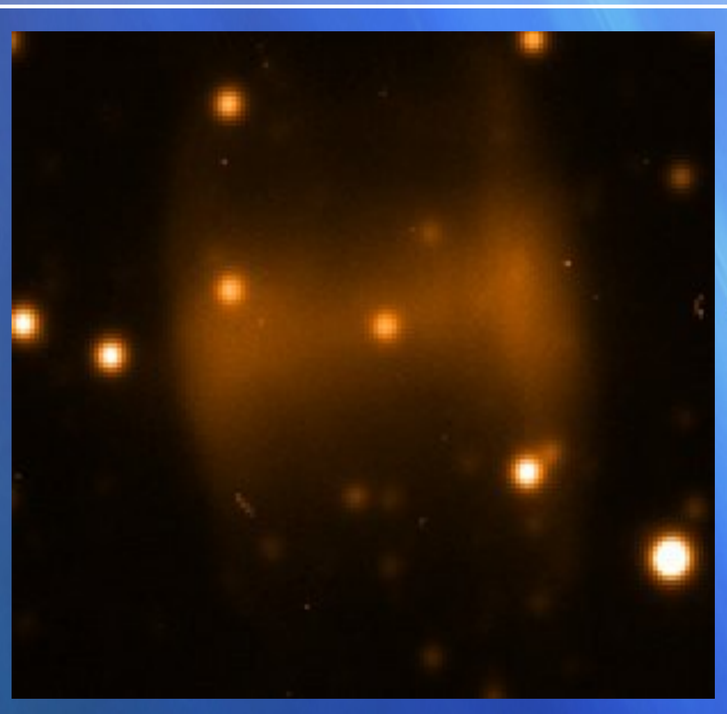
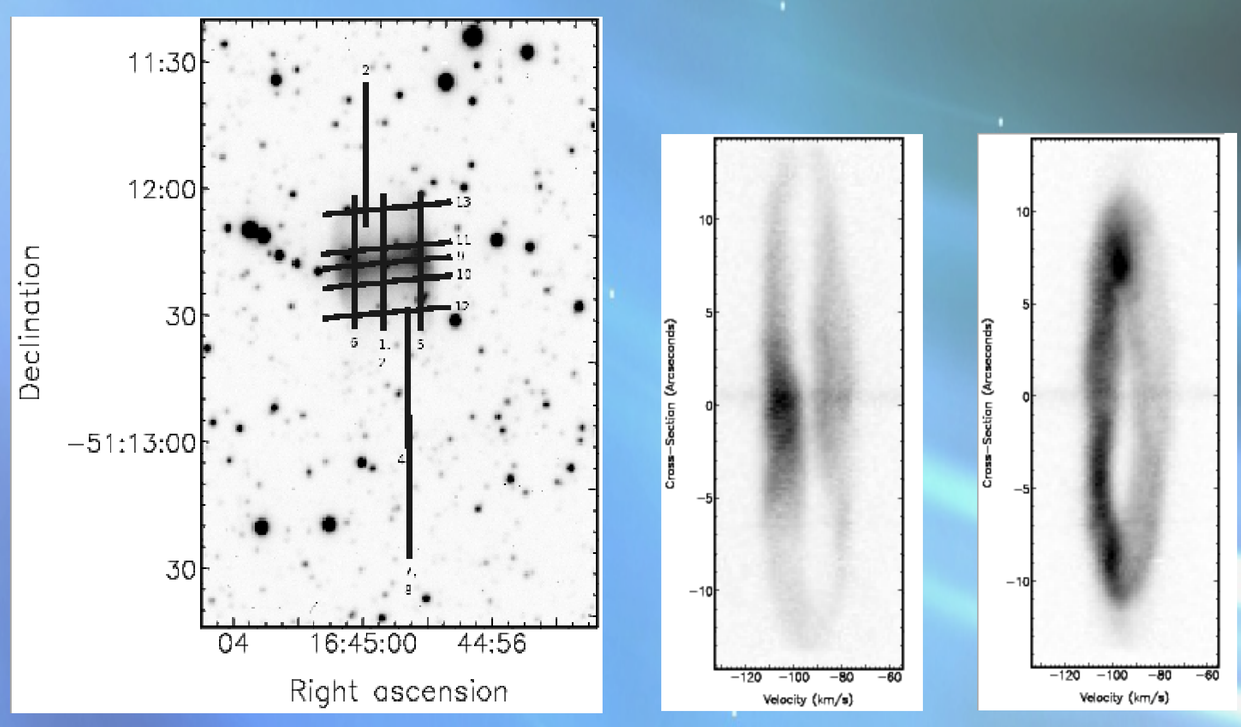


Figure 1 - Deep image of PN HaTr4

2. Data and Reconstruction

The data were acquired using grating #3 on the visual-to-red arm of the UVES cross-dispersion echelle spectrograph on VLT-UT2 at the Paranal Observatory, Chile (Dekker et al. 2000). The spectral resolution of UVES in this mode is R = 70,000. Observations were taken in [OIII] λ-5006.84 Å using 13 different slit positions — slits 1-8 were taken at a position angle of 7° and 9-13 at a position angle of 97° in order to give full nebular coverage in both the NS and EW directions. The slit corresponds to an area of 30" x 0.6" on the sky, and long spectral exposures of 1200s were acquired for each slit position. The pixel scale of the data was 0.1665", and seeing was between 0.8" and 1.0".

Reduction of the data was carried out using standard routines within the STARLINK software package. The reduced spectra from the N-S and E-W central slits are shown below in *figures 2 (a)* and *(b)* respectively, as position-velocity arrays.



(a) (b) (c)

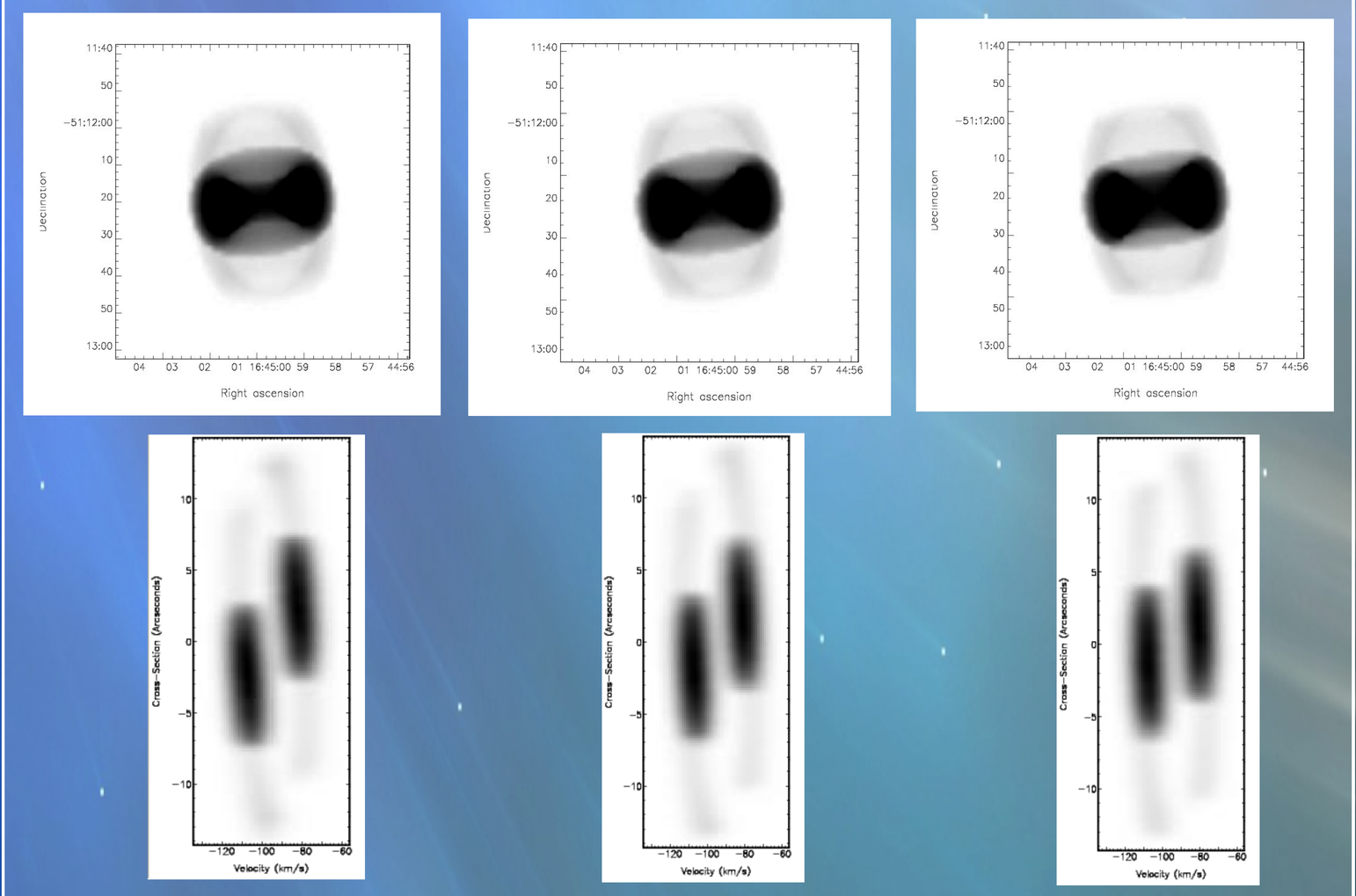
Figure 2 - (a) Diagram showing all 13 slit positions across the nebula. Slits 1-8 are at a PA of 7°, slits 9-13 are at a PA of 97°. (b) PV array from vertical central slit position #1. (c) PV array from horizontal central slit position #9.

3. SHAPE Modelling

Using the astrophysical modelling program SHAPE (Steffen, 2011), a spatio-kinematical model was developed in order to reconstruct the nebular morphology of HaTr 4 based on both the high-resolution Hα + [NII] imagery shown in *figure 1* and the high-resolution, spatially resolved [OIII] spectra shown in *figure 2*.

The nebular expansion velocity was assumed to be a Hubble-type flow. The best fitting basic model was an open-ended ovoid nebular shell waisted by a thick equatorial ring, as shown in *figure 3*. The waist of the best-fit model has a radius of 7.5 ± 0.5" and the symmetry axis lies at a position angle of 7°, consistent with the imagery presented.

The model accurately reproduces the two velocity components seen in the spectra (see *figures 2(b)* and *(c)*) corresponding to the front (blue-shifted) and back (red-shifted) walls of the main nebular shell, as well as the bright emission associated with the nebular waist that appears around cross-section zero.



(a) (b) (c)

Figure 3 - SHAPE models of the nebulosity of HaTr 4 along with the resultant model spectra as taken from vertical central slit position at inclinations relative to the line of sight of : (a) 70° (b) 75° (c) 80°

4. Discussion

HaTr 4 possesses an elongated, axisymmetric morphology with an equatorial enhancement consistent with a nebular ring. The `bow-tie' appearance of the central region is shown to result from a line-of-sight inclination effect associated with the enhanced nebular waist, rather than a bipolar structure (see the model nebulae and spectra in *figure 3*).

The modelling has revealed an age of order 8200 years at a distance of 3 kpc (Frew, 2008), and an expansion velocity of 26 ± 4 kms^{-1} — fairly typical for PNe. No evidence is found for extended emission or jet-like outflows associated with the PN, such as those found in ETHOS~1(Miszalski, 2011) and The Necklace (Corradi, 2011).

The inclination of the nebular symmetry axis is found to be 75° ± 5°, consistent with the non-eclipsing nature of the binary central star. Further investigation into the central star system performed by Hillwig et al. (in preparation) and Bodman et al. (in press), indicates that the inclination of the central binary plane falls within a similar range to that of the nebula as predicted by binary-induced PN shaping theories (Nordhaus, 2006). This alignment between the nebular symmetry axis and binary plane provides strong evidence that HaTr 4 has been shaped by its central binary star, making it one of only five PNe to have had this link observationally shown.

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