The kinematics and binary-induced shaping of PN HaTr 4

Abstract

Here, we present a spatio-kinematical analysis of the planetary nebula HaTr 4, one of few known to contain a post-common envelope binary central star system. By combining high spatial/spectral resolution spectroscopy of the [OIII] λ 5007.64 Å nebular emission line with deep, narrow-band imagery, a spatio-kinematical model was developed in order to accurately determine its 3D morphology and orientation. The modeling has provided strong evidence that shaping and evolution of HaTr 4 has indeed been influenced by its central binary system – making it one of only 5 PNe to have had this observationally proven.

1. HaTr 4

HaTr 4 (PN G335.2 -03.8, α = 16h45m00.2s, 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 to contain a non-PN HaTr 4 (PN G335.2-03.8), matching the two velocity components seen in the spectra (see figure 3a) when 1–5 are taken at a P.A. of 7° and 6–10 were taken at a P.A. of 59° in order to give full nebular coverage in both a North-South and East-West direction. The pixel scale of the data was 0.1666'.

The seeing was between 0.8” and 1.0” for all observations. The data were acquired using grating #3 on the visual South and East slit position 8. West is up and East is down, velocity axis is heliocentric velocity, νhel. The data were acquired using grating #3 on the visual South and East slit position 8. West is up and East is down, velocity axis is heliocentric velocity, νhel.

2. Data and Reconstruction

The modelling has revealed an age of order 8200 years at a distance of 3 kpc (Steffen, 2011), a common envelope binary central star system. The inclination of the nebular symmetry axis is found to be 75° ± 5°, making it one of only five PNe to have had this link observationally shown.

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 Ha = [OIII] 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 opened oval nebular shell warped by a thick equatorial ring, as shown in figure 2 — a feature believed to be typical of central star binarity. The waist of the best-fit model has a radius of 7.5 ± 0.3 kpc and the symmetry axis lies at a position angle of 77° — 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 across section zero.

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 an inclination effect associated with the nebula as a whole. The inclination of the nebular symmetry axis is found to be 75° ± 5°, consistent with the imagery presented by Hillwig et al. (in press). The inclination effect associated with the enhanced nebular waist, rather than an inclination effect associated with the central binary plane falls within a similar range to that of the nebula as predicted by binary-induced PN shaping theories (Northaus, 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 observationally shown.

References


Figure 1 - Deep image of PN HaTr4

Figure 2 - (a) Diagram showing all 10 VLT slit positions across the nebula. S1–S5 are at a PA of 7°, S6–S10 are at a PA of 59°. (b) PV array showing reduced spectrum in [OIII] λ 5007.64 Å from S1 central slit position 5. North is up and South is down, velocity axis is heliocentric velocity, νhel. (c) PV array showing reduced spectrum in [OIII] λ 5007.64 Å from S1–S10 central slit position 8. West is up and East is down, velocity axis is heliocentric velocity, νhel.

Figure 3 - SHAPE models of the nebula of HaTr 4 along with the resultant model spectra as taken from central vertical slit position 3, at varying inclinations relative to the line of sight: (a) 75°, (b) 70°, (c) 65°.