VLT Observations of the Asymmetric Etched Hourglass Nebula, MyCn 18

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Abstract: The Etched Hourglass Nebula is a typical tight-waisted, asymmetric, bipolar Planetary Nebula (PN). Here we consider near infra-red imagery, infra-red and long-slit narrowband spectroscopy and morpho-kinematic modelling with the view of understanding the structure of the nebula in terms of its ionisation along different directions, the origins of the extreme bipolar shaping and the effect of the off-centre central star. A series of infra-red images of MyCn 18, obtained using NACO (Naos-Conica) on ESO's VLT (UT4) telescope, shows the full extent of the main hourglass shell and the finely detailed features of the nebula. Two-micron ISAAC spectra from a slit position intersecting the narrow waist of the nebula demonstrate that the ionised gas resides closer to the centre of the nebula than the molecular emission. The nebula is clearly ionisation-bounded in this central direction, in contrast to the open ends of the hourglass structure. The shape and structure of MyCn 18 was reconstructed using a morpho-kinematic code to better describe the nebula's morphology. The putative central star, the much smaller 'inner hourglass', and the main nebulosity are somewhat offset from the geometric centre of the nebula, indicating the possibility of a binary companion. The role of exoplanets is also considered in the breaking of spherical symmetry of MyCn 18.

(1) Infra-red Imagery

VLT NACO images, taken on the 27th of May 2003, using Ks (top) and narrowband H_2 2.122 µm (centre) are shown, together with the WFPC2 HST [NII] (bottom) optical image from Sahai et al.(1999) in Figure 1. The left hand images show the full extent of the main hourglass shell. The right hand images show the central region, at higher contrast. The H_2 image shows finely detailed features, similar to those seen in the [NII] optical image, whereas the continuum Ks band is dominated by emission from a compact, central region. Sahai et al.(1999) showed that the optical continuum emission is similarly concentrated and is due to nebular continuum rather than scattered starlight.

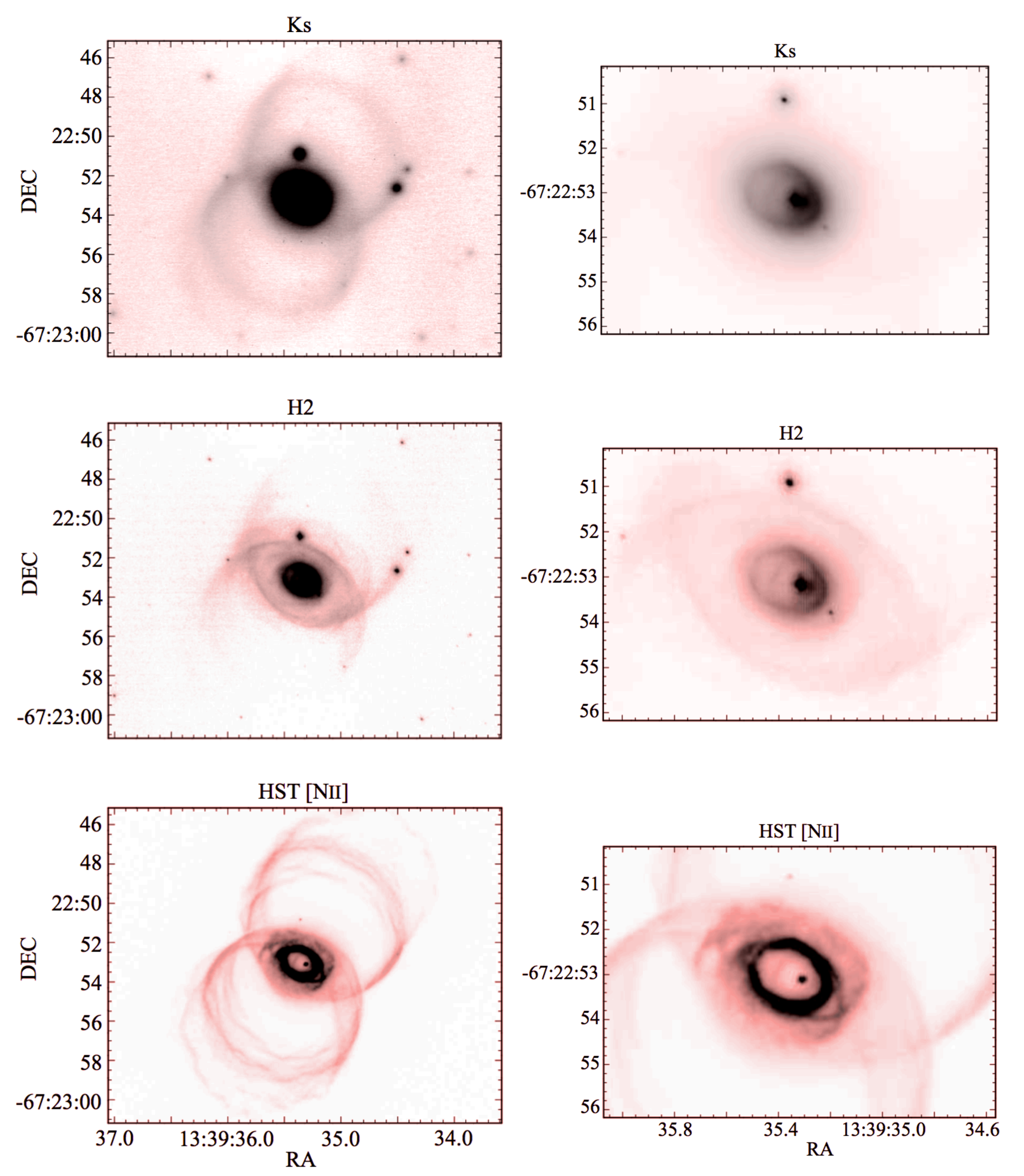

Figure 1: Left–infra-red images taken in the Ks and H_2 bands, together with an HST [NII] optical image for comparison, and right–focused central regions of the same images at higher contrast.

(2) Infra-red Spectroscopy

The two boxes across the ISAAC long slit, as shown in Figure 2 (left), represent the regions of the centre and outflow spectrum, obtained on the 24th of April 2004. The approximate slit location is shown, and the orientations of the slit are from north-east to south-west. The image on the right of this figure shows the relative contributions of the different emission components: Brackett gamma - green, H2 1-0 S(1) - red, continuum - black, from spatial cuts through 0.01 µm wide sections of the ISSAC spectrum. It is clear that the Br γ and He emission lines originate in the compact, ionised zone around the star. Bumps at ± 3 arcsec in the H_2 profile indicate H_2 emission from the lobes. The central region of the H_2 profile is almost identical to the continuum profile, indicating that there is no significant H_2 from the inner region of the nebula.

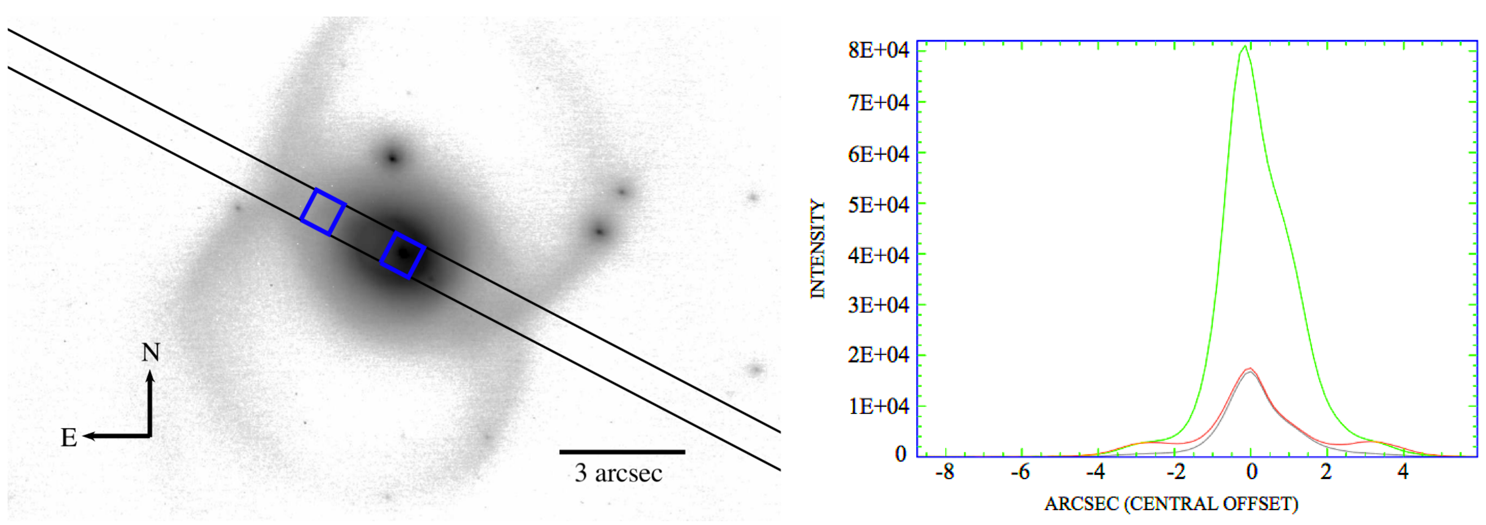

Figure 2: Left; approximate ISAAC slit position displayed on NACO Ks-image. Two boxes show the places whose spectra are displayed in Figure 3. The plot on the right shows the intensity of the emission components with respect to the nebular centre

Spatially resolved ISAAC spectra, taken across the minor axis of the main hourglass nebula, are shown in Figure 3, with the most prominent atomic and molecular emission lines indicated. A K-band spectrum extracted from the central region is compared to a spectrum extracted from the nebular outflow region. In the central region, continuum is dominant, and both the central star and free-free and bound-free contribute to this continuum, as found in the images. In contrast, in the outflow spectrum, a forest of H_2 lines are found, in addition to the hydrogen and helium recombination lines.

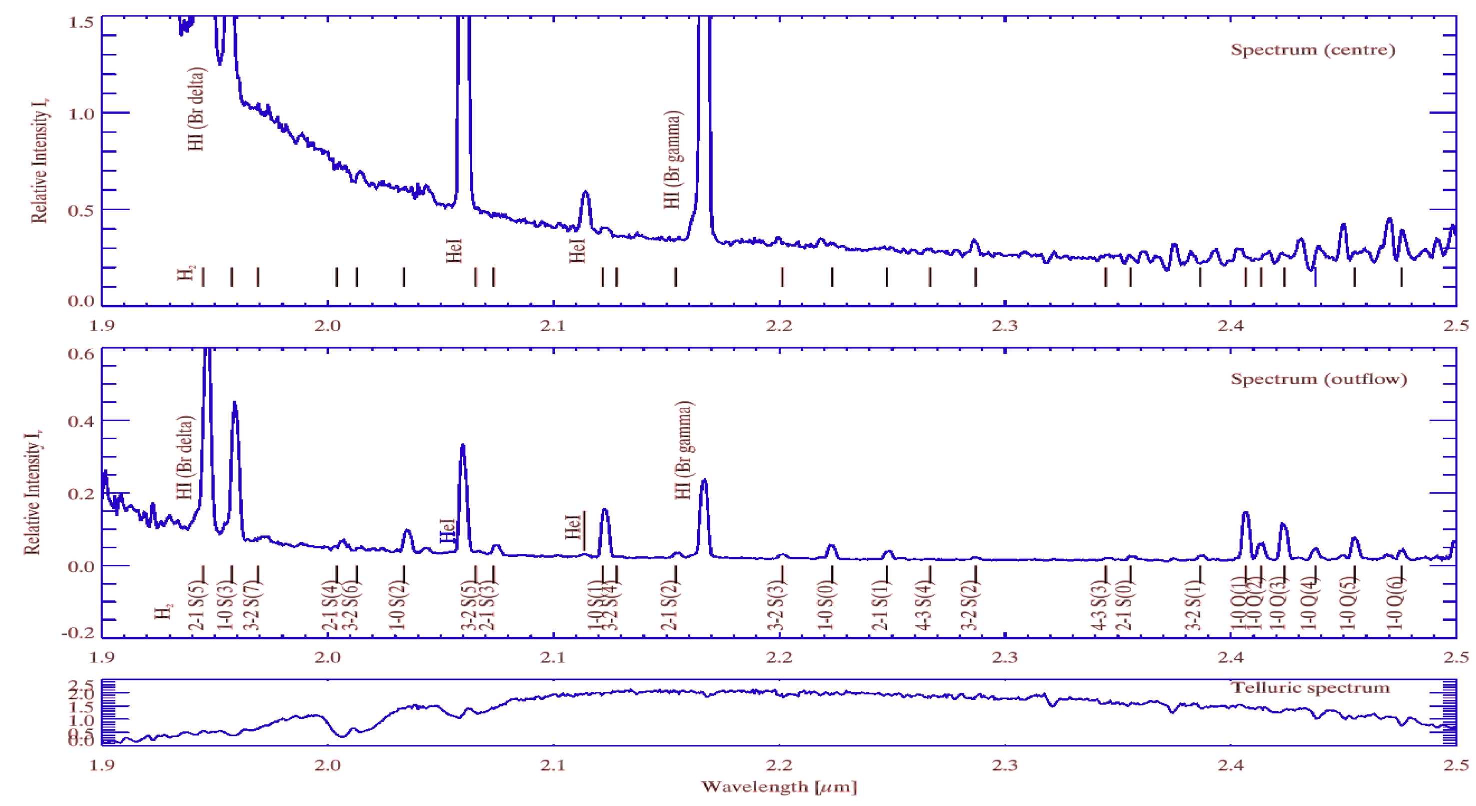

Figure 3: Two-micron spectra of MyCn 18 from the central 0.75 arcsec region (top) and 2.25 arcsec away from the central region to north-east (middle). Major H I and He II lines are indicated, and the expected positions of H_2 lines are marked. Displayed on the bottom panel is a telluric spectrum showing the atmospheric features.

(3) Morpho-kinematic Modelling

A morpho-kinematic model of MyCn 18 was developed to allow for the reconstruction of its nebular morphology, using a 3-D astrophysical modelling program called SHAPE (Steffen & Lopez 2006; Steffen et al. 2011). This involved the modelling of optical kinematic data to help describe the morpho-kinematics of MyCn 18 that were characterised by Bryce et al. (1997); O'Connor et al. (2000); Sahai et al.(1999). See Figure 5 for observed and synthetic position-velocity (PV) arrays.

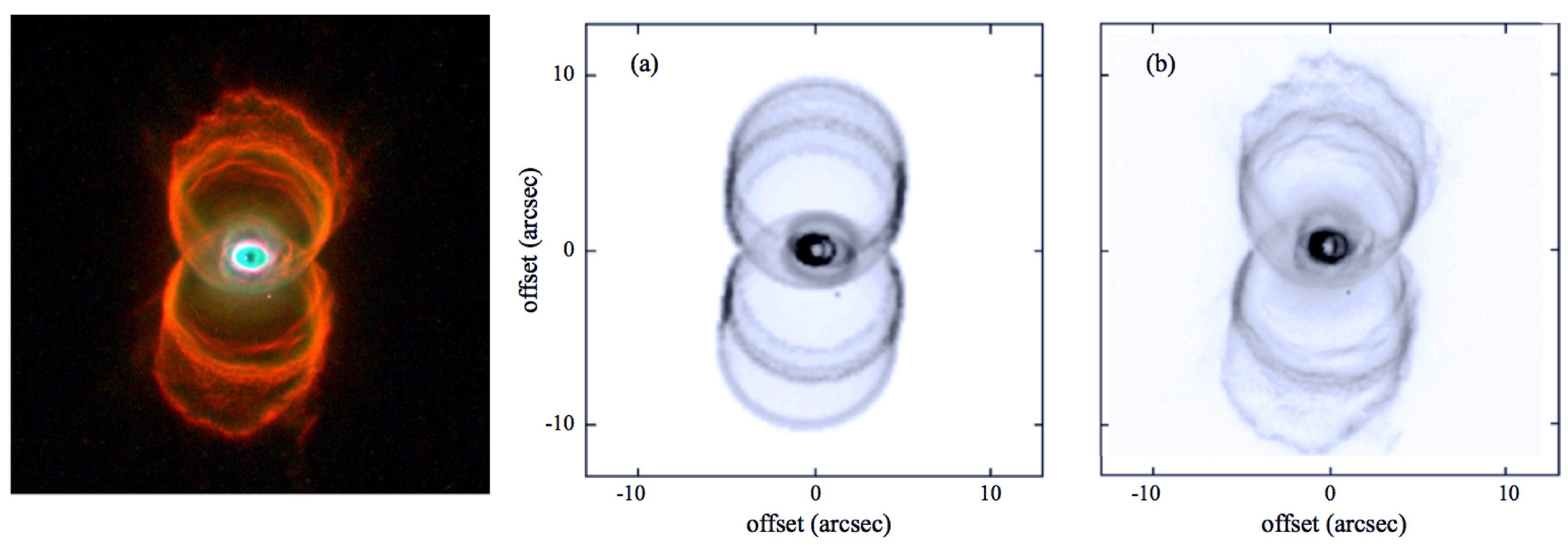

Figure 4: Shown on the left is an optical HST image of MyCn 18 revealing its nebular features and emission components. a) The final reconstructed SHAPE model of MyCn 18's nebular morphology, and b) an HST image scaled for comparison.

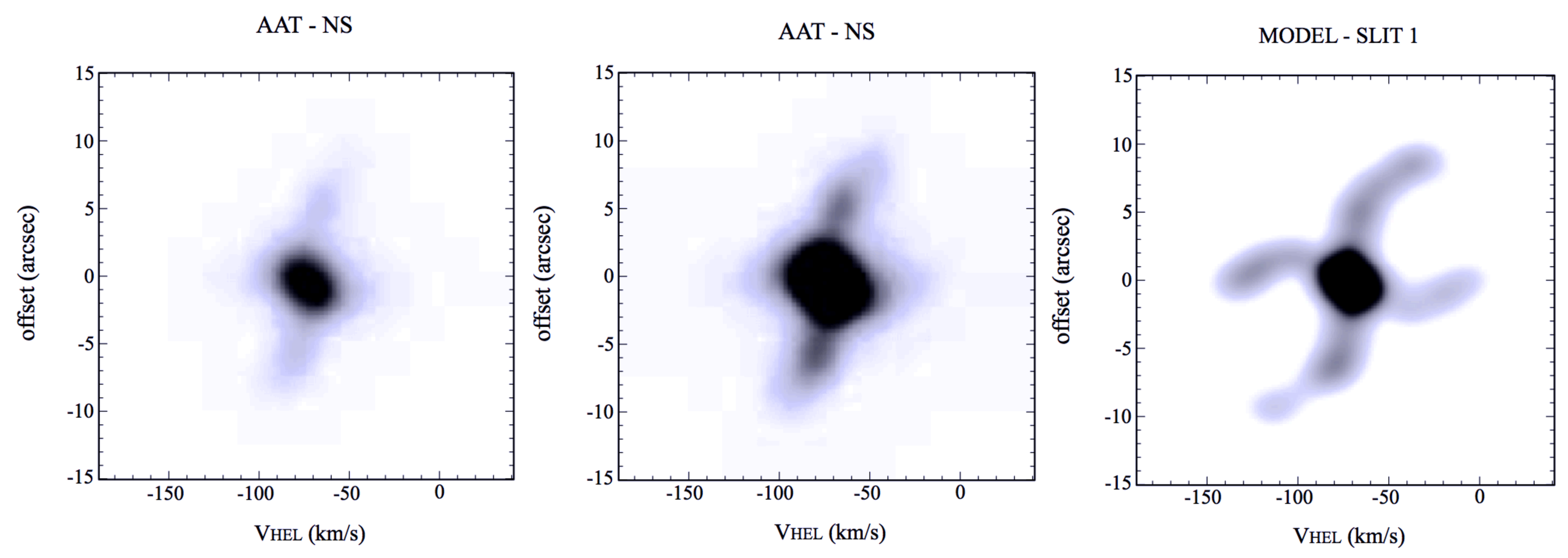

Figure 5: The image on the left is a PV-array for a long-slit placed directly down the major axis (north-to-south) of the nebula. This PV-array was obtained by O'Connor et al. (2000) from the Angelo-Australian telescope (AAT) using the Manchester Echelle Spectrometer (MES; Meaburn et al. 1984). The middle PV-array is the same array at higher contrast. The image on the right is a resultant synthetic PV-array generated from the final reconstructed 3-D model.

(4) Discussion & Conclusion

In relation to the infra-red imagery, the Ks-image shows faint, relatively smooth emission from the edges of the main hourglass shell, together with a much brighter central region. The H_2 image in contrast shows a much clearer thin, filamentary 'eye-shaped' feature surrounding the bright inner region. It's quite noticeable that the H_2 image reveals more distinct features around the central region. With regards to the infra-red spectra, the central region is dominant in continuum and ionisation-bounded, whereas, the nebular outflow region reveals a plethora of H_2 emission lines and is density-bounded. The resultant SHAPE model and synthetic PV-arrays better explain for MyCn 18's asymmetric morphology and kinematics. As for the nebula's bipolar asymmetry, a binarity scenario is still the favorable mechanism for explaining the misalignments of its features with the nebula's geometric centre.

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