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Abell 41: nebular shaping by a binary central star?

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Abstract. We present the first detailed spatio-kinematical analysis and modelling of the planetary nebula Abell 41, which is known to contain the well-studied close-binary system MT Ser. This object represents an important test case in the study of the evolution of planetary nebulae with binary central stars as current evolutionary theories predict that the binary plane should be aligned perpendicular to the symmetry axis of the nebula.

Longslit observations of the [Nii]6584 Å emission from Abell 41 were obtained using the Manchester Echelle Spectrometer on the 2.1-m San Pedro Mártir Telescope. These spectra, combined with deep, narrowband imagery acquired using ACAM on the William Herschel Telescope, were used to develop a spatio-kinematical model of [Nii]6584 Å emission from Abell 41. The best fitting model reveals Abell 41 to have a waisted, bipolar structure with an expansion velocity of ~40 km s^{-1} at the waist. The symmetry axis of the model nebula is within 5° of perpendicular to the orbital plane of the central binary system. This provides strong evidence that the close-binary system, MT Ser, has directly affected the shaping of its host nebula, Abell 41.

1. Introduction

Abell 41 (PN G009.6+10.5, $\alpha = 17^h29^m02.03^s$, $\delta = -15°13'04.4''$ J2000), discovered by Abell & Goldreich (1966), was classified by Bond & Livio (1990) as elliptical under the classification scheme of Balick (1987). However, deeper Hα+[Nii]6584 Å imagery reveals "that the nebular morphology exhibits an 'H' shape with the addition of fainter material forming a continuous loop" (Pollacco & Bell 1997).

Photometric analysis of the central star of the planetary nebula (CSPN), MT Ser, revealed it to be a close binary, showing minima at regular intervals of 2^h43^m (Grauer

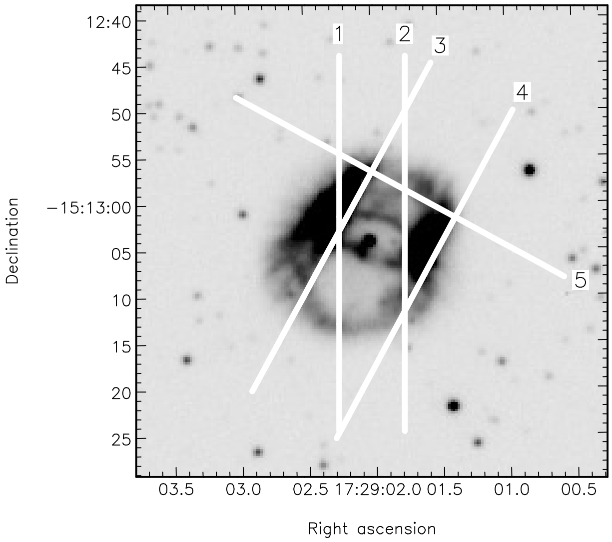

Figure 1. A deep ACAM-WHT image of A 41 in the light of [Nii]6584 Å showing the positions of the 5 MES-SPM longslits.

& Bond 1983). Bruch et al. (2001) confirmed the binary nature of MT Ser but were unable to accurately determine its orbital parameters because they found two different models which fit the observed data. (a) The binary consists of a hot sub-dwarf and a less evolved secondary, in which case the period is 2^h43^m and the variations are due to a reflection effect (inclination, $i = 42.52° \pm 1.73°$). (b) The binary consists of two evolved, hot sub-dwarfs with a period of 5^h26^m where the variability results from partial eclipses and ellipsoidal variations ($i = 65.7° \pm 0.9°$). They determined the optimum parameters for each model, but concluded that only radial velocity observations would be able to distinguish between the two. Subsequent observation and modelling by Shimanskii et al. (2008) confirmed the presence of two sub-dwarf components, but gave no independent confirmation of the orbital inclination. Only the second model of Bruch et al. (2001, $i = 65.7° \pm 0.9°$) is consistent with photometric observations and the detection of two hot sub-dwarf central stars, indicating that this is the most reliable model of the CSPN.

In these proceedings we present a spatio-kinematic model, derived from longslit spectroscopy and narrowband imaging, with the aim of understanding the relationship between the nebula and MT Ser. A more complete discussion of this work can be found in (Jones et al. 2010b).

2. Spatio-kinematic modelling

Spatially-resolved, high spectral-resolution echelle spectroscopy of the [Nii]6584 Å line acquired using the Manchester Echelle Spectrograph on the 2.1-m San Pedro Mártir telescope (MES-SPM), in combination with deep narrowband imagery obtained using ACAM on the 4.2-m William Herschel Telescope (WHT-ACAM), have been used to develop a spatio-kinematic model of A 41. The modelling was performed using SHAPE

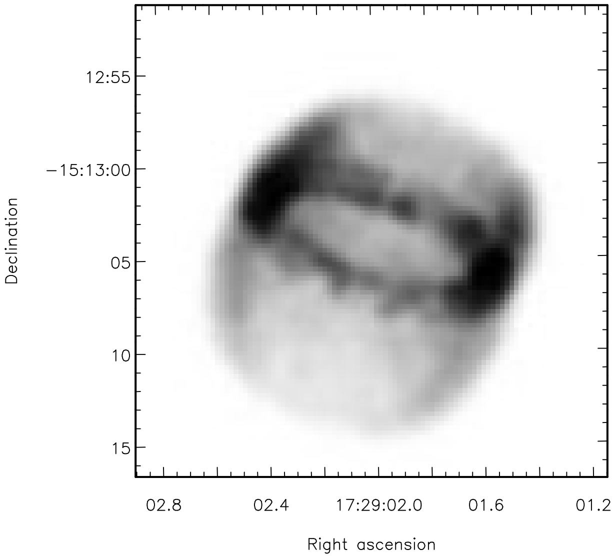

Figure 2. The synthetic SHAPE model for the [NII]6584 Å emission from A 41.

(Steffen & Lopez 2006). Further details of the observations and modelling process are found in Jones et al. (2010b).

This best fit model comprises a bipolar shell waisted by an equatorial ring with an expansion velocity of ~40 km s^{-1}. The model nebula is slightly asymmetric in that the northern lobe is shortened by 15%, has a narrower opening angle and has a slight shear with respect to its southern counterpart. No symmetric model could be found which reproduced the observed PV arrays. The nebular inclination angle, as defined by the un-sheared southern lobe, is determined to be 66° ± 5°, in excellent agreement with the inclination of the CSPN (see section 1). The model nebula is shown at the observed orientation in Figure 2. The synthetic position-velocity arrays can be found, along with their observed counterparts, in Jones et al. (2010b).

2.1. Systemic velocity and kinematical age

Comparison of synthetic model spectra to their observed counterparts provides an unambiguous measure of the nebular systemic heliocentric radial velocity (V_{sys}), unaffected, for example, by brightness variations or nebular asymmetry (Jones et al. 2010a). Using our best-fit model, V_{sys} is determined to be 30 ± 5 km s^{-1} in good agreement with the value of 30 km s^{-1} determined by Beaulieu et al. (1999).

The nebular expansion velocity, determined by the kinematical modelling, can be used to calculate a kinematical age for the nebula. This, however, requires the distance to the nebula to be known. The distance to A 41 is a matter of some debate with values in the literature ranging from ~1 kpc (Grauer & Bond 1983) up to 9.0 ± 0.4 kpc (Shimanskii et al. 2008), this probably results from the notorious variation in results from different methods of distance determination (see e.g., Gurzadyan 1997). Therefore, rather than favour one particular distance estimate over another we quote a kinematical age per kiloparsec of ~ 800 years kpc^{-1}.

3. Conclusions

Using high-resolution longslit spectroscopy and deep imaging, a spatio-kinematical model of A 41 has been developed which clearly shows that the nebula is aligned with the binary central system exactly as predicted by current theories of PN shaping by binary CSPN. This is only the second nebula to have this link observationally constrained (after A 63, Mitchell et al. 2007). The kinematical data confirm A 41 exhibits a waisted, bipolar structure, with some small deviations from perfect axisymmetry. The presence of an equatorial ring is also confirmed, adding further weight to the link between ring structures and central binary stars as commented on by Miszalski et al. (2009, 2010) and López et al. (2010).

Further kinematical investigations, such as this and others presented in these proceedings (e.g. Huckvale et al. 2010, Tyndall et al. 2010), coupled with in-depth studies of the CSPN of other PNe with confirmed close-binary CSPN, are necessary to investigate the full extent of the influence of central star binarity on PN nebular shaping. Only once a significant statistical sample has been acquired can generalisations be made about the role of CSPN binarity in PN evolution.

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