Discovery of a Bow-Shock Nebula Around the Pulsar B0740-28

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Bow-shock nebulae around high-velocity pulsars provide our primary insight into the interaction between a pulsar and its surrounding environment. Specifically, optical observations of such nebulae allow us to derive full three-dimensional pulsar velocities which are extremely important for the birth rates and evolution of pulsars. They can also provide important information on the density, temperature and composition of the surrounding ambient medium. Unfortunately, only a few bow-shock nebulae have been discovered, despite there being nearly a thousand pulsars known from radio surveys. We have therefore commenced a search for pulsar bow-shocks, using the results to characterise the properties of the associated pulsars, pulsar winds and ambient environments.

During the first two nights of this programme (January 4 and 5, 2001), we discovered an optical bow-shock nebula around the radio pulsar B0740-28 using SUSI2 at the NTT. Prior to this, only four pulsars were known to power optical bow-shock nebulae (see Cordes 1996 and references therein), and only one of these at southerly declinations (J0437-4715; Mann, Romani & Fruchter 1999).

Figure 1 shows Hα images of a newly-discovered nebula associated with PSR B0740-28 (Fig. 1a, top), and of the (previously known) bow-shock associated with PSR J0437-4715 (Fig. 1b, bottom). Each was taken through the 656/7 filter of SUSI2 and is 1 arcmin on a side with north to the top and east to left. The B0740-28 image is the result of nearly 2 hours of integration while that for J0437-4715 was obtained in a little more than 30 minutes. The faint star directly behind the shock front of J0437-4715 is a white dwarf companion to the pulsar (which is not seen in the optical). Both images were treated using standard techniques for bias and flat-field signature removal, image registration and then co-addition. CCD defects and cosmic rays were removed using cross-pixel interpolation on the final frame rather than filtering through the stack, in order to preserve as much of the faint nebula signal as possible. A residual background was subtracted separately from the B0740-28 image, presumably arising from scattered moonlight on one of the nights. Finally, the nebula counts were top-hat filtered out and smoothed before being recombined with the original, to increase the contrast of the object against the sky background. The continuum component was not separately observed and so has not been subtracted in either case.

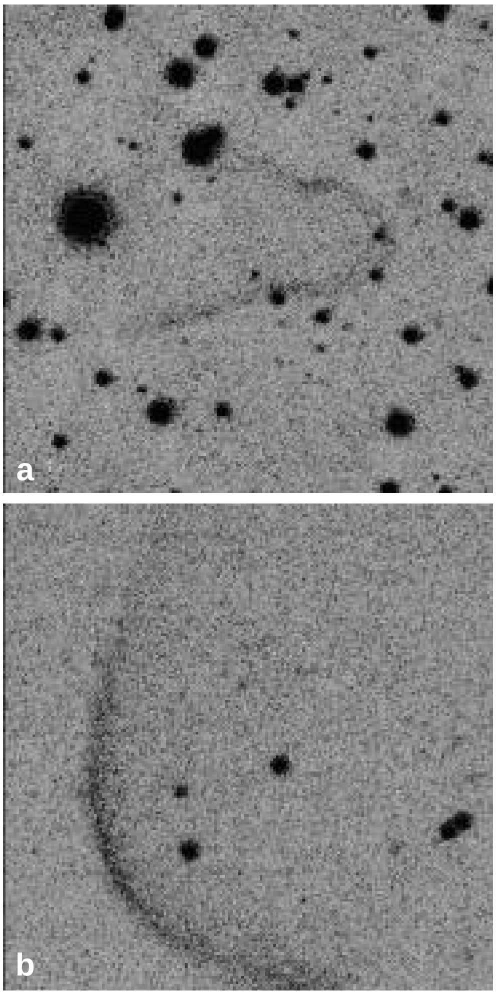

Figure 1: Two pulsar-powered bow-shock nebulae imaged in Hα on 4–5 January 2001 at the NTT. (a) The newly-discovered nebula associated with PSR B0740-28 (the pulsar is located about 1 arcsec to the left of the head of the bow shock) and (b) the bow-shock associated with PSR J0437-4715. The star directly behind the shock front is a companion to the pulsar which itself is not detected in the optical. Images are 1 arcmin on a side with north up, east left.

The images in Figure 1 show the nebula associated with PSR B0740-28 to have a closed cometary morphology, more like the nebula around PSR B2224+65 (the "Guitar" nebula; Cordes, Romani & Lundgren 1993) than the open bow-shock of PSR J0437-4715. Like the bow-shock associated with PSR B2224+65, the B0740-28 nebula has a distinct key-hole shape, with the spherical head of the shock-front protruding from the fanned tail. The position of the pulsar (about 1 arcsec to the left of the head of the bow-shock), and the measured proper motion for the pulsar of 29 mas/yr westwards (Bailes et al. 1990), confirm the bow-shock interpretation for the nebula.

All of the pulsars with known bow-shock nebulae in the optical have high energy loss due to spin-down and/or high velocities (including the recent addition of PSR B0740-28). However, at the same time, they exhibit a diverse range of spin periods, ages and magnetic field strengths, highlighting the variety of pulsar winds which can be probed by these sources. The recently-discovered nebula associated with a so-called "radio-quiet" neutron star further exemplifies the variety of neutron star forms known to power nebulae (van Kerkwijk 2000, ESO press release 19/00).

Detailed studies of nebular emission, such as that carried out on B1957+20 by Aldcroft et al. (1992), enable a determination of not only the nature of the shock and the properties of the ambient ISM, but also of the kinematic distance to the pulsar. Such a distance determination is essential of course in improving our understanding of the individual system, but also allows an independent test of the pulsar distance scale as determined by its dispersion measure. We are currently in the process of doing this for B0740-28, and in doing so, solve another small piece of the puzzle.

However, the first step towards a general understanding of these fascinating objects is to build a sample of them sufficiently large that it canvasses the full range of conditions encountered. This is the main aim of our continuing survey.

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