SCIENCE

A Galactic Jet-Blown Nebula Observed with the Isaac Newton Telescope

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Galactic black holes release an unknown fraction of their accreting matter and energy in the form of collimated outflows (or jets) that travel into the surrounding medium. Black Hole X-ray Binaries (BHXBs) are the essential laboratories for understanding the overall physics of the accretion process in these systems, and have provided us with a wealth of understanding of, for example, the properties of the accretion disc. In comparison, the energy and matter content of the jets produced by BHXBs are not well constrained because they are radiatively inefficient (Fender, 2001). Measuring as accurately as possible the total power content of the jets (which are produced by BHXBs throughout the majority of their lifetimes; Fender, Belloni & Gallo, 2004), and hence their importance with respect to the accretion process in terms of energetics, is a primary aim of high-energy astrophysics.

Attempts at measuring the jet power from radio luminosities are riddled with assumptions about its spectrum and radiative efficiency. However, the jet power can also be constrained by analysing its interaction with the surrounding ISM. Synchrotron radio lobes associated with jets from AGN are commonly used as accurate calorimeters of the [power×lifetime] product of the jets (Burbidge, 1959), a method only very recently applied to jets from stellar mass BHs. In 2004, very deep low radio frequency observations of the field of Cyg X–1 resulted in the discovery of a shell-like structure which is aligned with the resolved radio jet of this BHXB (Gallo et al., 2005). This radio shell has been interpreted as the result of a strong shock that develops at the location where the collimated jet impacts on the ambient ISM. Models of jet-ISM interactions predict a shell of shocked compressed ISM visible via bremsstrahlung emission, containing a bubble of relativistic synchrotron-emitting plasma (Kaiser et al., 2004). The spectrum of the shocked shell should be approximately flat from radio to much higher frequencies and possess spectral lines in emission. To test this, the Cyg X–1 'jet-blown nebula' was consequently observed at optical wavelengths with the INT WFC.

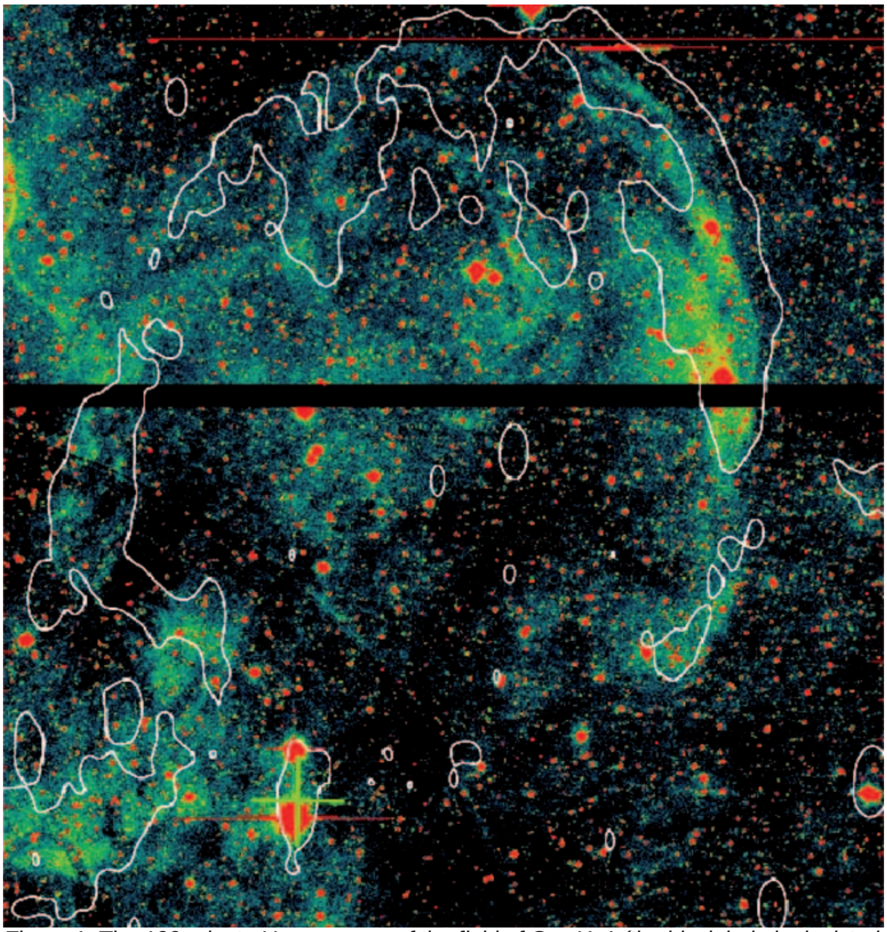

Figure 1. The 100-minute Hα exposure of the field of Cyg X–1 (the black hole is depicted by the cross on the bottom-left) and the ~5.5 arcmin jet-blown nebula. 3σ radio contours are overplotted in white.

In Fig. 1, the resulting 100-minute exposure in Hα is overplotted with contours of radio flux. The shell of the nebula is clearly visible; an Hα flux lower limit of m ≤ 23.1 arcsec^{-2} from the nebula was calculated from the observations. This corresponds to an intrinsic flux density of the nebula (accounting for the optical extinction towards Cyg X–1; A_V=3.3) of ≥ 0.022 mJy arcsec^{-2}. From the measured radio flux density, we calculated the corresponding radio-optical spectral index; $a > 0.2$ (a is defined such that the monochromatic flux F_ν scales as ν^a). This implies an emission mechanism with a flat spectrum, such as bremsstrahlung, plus excess flux possibly due to line emission, as expected in the case of radiative shock. The spectrum is inconsistent with that of optically thin synchrotron radiation, where $\alpha \approx -0.7$. This, therefore, is the first discovery of a thermal shell of gas that is shocked by its interaction with a jet of a Galactic black hole (Gallo et al., 2005).

The optical-radio spectrum of the nebula acts as an effective jet calorimeter, and, also for the first time, allows an estimate of the [power × lifetime] product of the jets from radio–optical measurements, which is independent of the uncertainties associated with their spectrum and radiative efficiency. We calculated that to account for the observed broadband spectrum of the shocked gas, the power carried by the jet of Cyg X–1, averaged over its lifetime, is $\sim 9\times10^{35} \le P_{jet} \le 10^{37}$ erg s^{-1}. Taking into account the contribution of the counter jet, the total power in the jets is then $f \sim 0.06$–$1 \times$ the bolometric X-ray luminosity of the system. This significantly overshoots all previous estimates of the jet power in black hole X-ray binaries.

This profitable technique has potential for constraining the jet power associated with other BHXBs if further jet-blown nebulae are identified. With the confirmation of this jet-ISM interaction associated with Cyg X–1, it is clear not only that there may be an undiscovered population of jet-blown bremsstrahlung nebulae associated with BHXBs, but also that these nebulae may easily be found with simple wide-field red-optical imaging. To this end, we have been awarded 4 nights with the INT WFC in October 2005 and 3 nights in the southern hemisphere on the ESO/MPI 2.2 m WFI in February 2006, to search the fields of ~20 known Galactic BHXBs.

The power in the jets of persistent BHXBs such as Cyg X–1 are orders of magnitude larger than those of transients, which spend the majority of their lifetimes in quiescence. However, Cyg X–1 is short lived, and the [power × lifetime] product, and therefore the expected luminosity of shocked ISM gas, is comparable to the older quiescent sources. Essentially, the apparent magnitude of the thermal shell of a jet-blown nebula is highly dependent on the distance, the Galactic dust extinction towards the source and the local density of the ISM surrounding the BHXB. Given these constraints and the existing estimates for these variables for Galactic BHXBs (where known), nebulae associated with ≤20 BHXBs may be visible with the INT and ESO/MPI 2.2 m telescopes during the observing runs.

In addition to searching for more jet-ISM interactions, follow-up observations of the Cyg X–1 nebula, for example optical spectra using the WHT, may also confirm the presence of emission lines and their flux, will further constrain the power of the jets and the nature of the composition of the nebula. Eventually, accurate high-resolution spectroscopy will reveal the temperature and velocity distribution of the shocked shell. ¤

References:

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The Deep Impact Event as Seen from the Roque de Los Muchachos Observatory

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At 05:44:36 UT on July 4th, 2005 the Deep Impact (DI) spacecraft collided with comet Tempel 1, producing an impact of 19 GJ of kinetic energy and excavating a crater shaped by gravity. DI consisted in two spacecrafts: an impactor, weighting 364 kg; and a flyby spacecraft for observing the impact and relaying data from the impactor. The main goal of the mission was to study the interior and outer layers of a comet. Until the impact, very little was known of the internal structure and the physical evolution of the outer layers of a comet nucleus. Most of what we know relies primarily on theoretical models. The relationship between the coma's composition and the nucleus composition is also uncertain. Even if the coma is formed by material from the nucleus, there are several physical and chemical processes that rapidly affect the material ejected from the nucleus.

The DI mission was designed to have much of the mission-critical science done from Earth-based telescopes. An unprecedented worldwide coordinated campaign was organised. Many observatories around the world and in space observed the comet before, during and after the impact, to follow the effects of the event and its evolution.

The Roque de Los Muchachos Observatory (ORM) played a substantial role in this campaign. Starting in 2000, photometric observations performed during several runs by Tozzi and Licandro with the 3.6-m Italian Telescopio Nazionale Galileo (TNG) were used together with others worldwide, to understand the rotational properties of the comet. From March to June 2005 the comet activity was also tracked by our group with the TNG by means of imaging and