Final Report for XMM Grant NAG5-13203: "A Search For The Young and Energetic Pulsar in G328.4+0.2"

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The pulsar-powered nebula G328.4+0.2 is one of the largest and most luminous such sources known. The nature of G328.4+0.2 (shown in Fig. 1) has been a source of controversy — the object's flat radio spectral index has been used to argue that this object is a young pulsar wind nebula (PWN), while others have used radial protrusions in the magnetic field orientation along the source's outer edge to argue that it is an old supernova remnant (SNR). In the first interpretation, the X-ray nebula inside this radio source would be located inside the central "bar" detected in the radio. In the second interpretation, the expectation is that the X-ray PWN would be located at either end of this central "bar". The goals of our *XMM* observation were to try and detect the pulsar, and to use its location and other properties to distinguish between the above two possibilities.

Observations were carried out successfully in Mar 2003. To our surprise, we found that neither of the possibilities outlined above appears to be viable. Figure 1 shows that the X-ray nebula in this source is significantly displaced from the center, but is not coincident with the central bar. The *XMM* observation also demonstrated that the X-ray emission from this source has a rather complicated morphology, composed of a bright, compact source at one end of an elongated diffuse region of enhanced X-ray emission. The PWN's elongation could indicate that it is traveling supersonically through a surrounding SNR, or that it is in the process of interacting with a SNR reverse shock. The known X-ray and radio properties of this remnant make this object a powerful test of the numerous analytical and numerical models of the evolution of composite SNRs that have recently been developed. We are currently completing a comparison of these model predictions to the observed properties of this SNR, which will allow us to both better understand this peculiar remnant as well as evaluate the accuracy of the theoretical models.

We have completed our spectroscopic analysis of this source. The X-ray spectrum is a highly absorbed power law, with absorbing column $N_H = 9.5^{+2.1}_{-1.2} \times 10^{22}$ cm^{-2}, photon index $\Gamma = 1.9^{+0.4}_{-0.2}$ and unabsorbed flux (0.5–10 keV) $f_x \approx 2.0 \times 10^{-12}$ ergs cm^{-2} s^{-1}. This corresponds to an X-ray luminosity $L_x \approx 7 \times 10^{34}$ ergs s^{-1} at the presumed distance of 17 kpc, consistent with this nebula being powered by a very energetic pulsar as we had previously argued.

We have also carried out a timing analysis, using the EPIC PN "small window" mode to search for the pulsed signal coming from the neutron star. At the time of writing we have not detected any pulsed signal; we are currently refining this analysis so that we can quantify the upper limit on the pulsed fraction.

Our analysis and interpretation on all these issues is largely complete. We are correspondingly preparing a paper for publication, to be submitted to *The Astrophysical Journal* in July 2005.

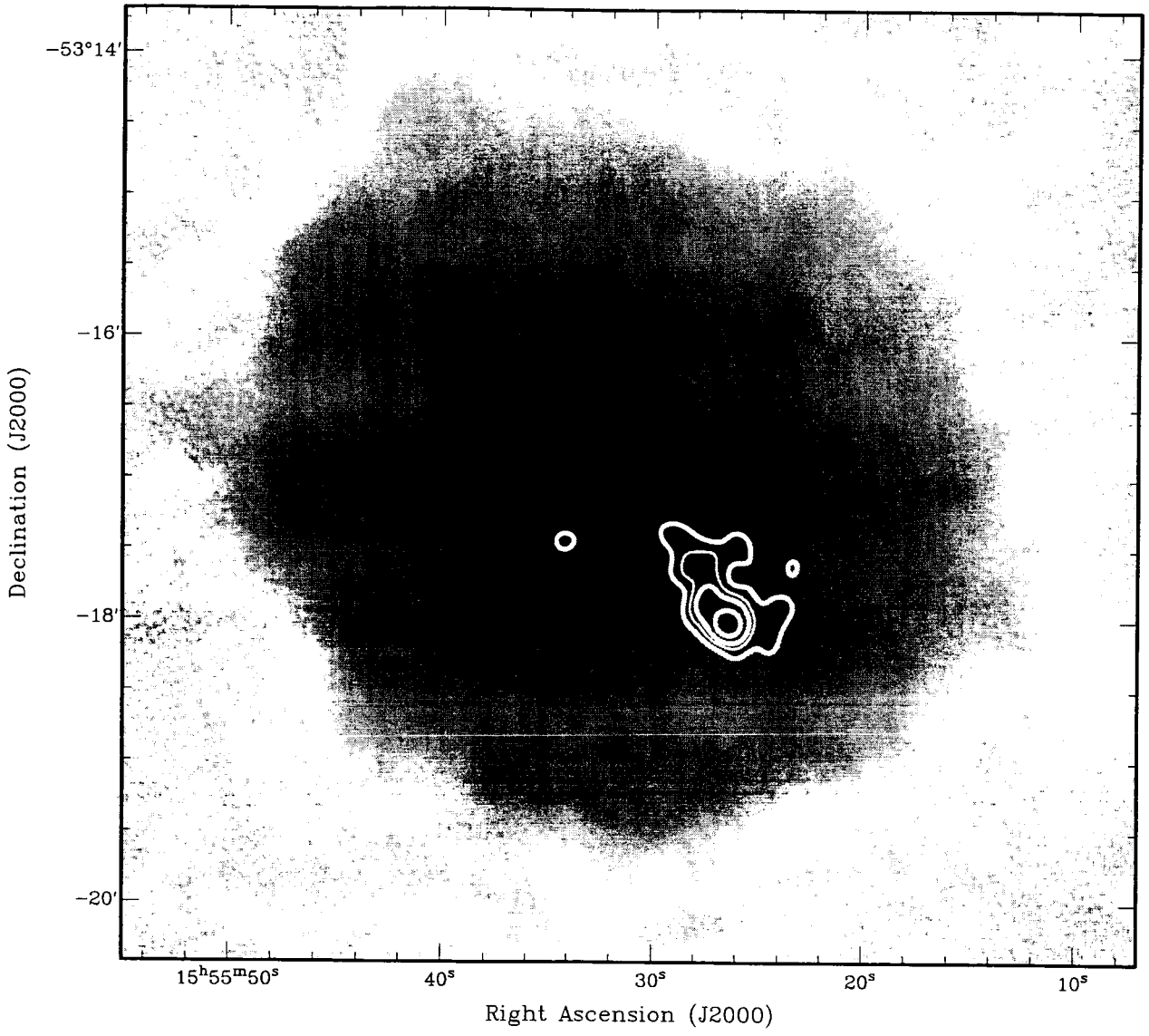

Figure 1: Radio and X-ray images of G328.4+0.2. The greyscale shows a previous 5 GHz radio image of the source, overlaid with contours corresponding to our *XMM* detection. The X-rays shown are from the MOS1 and MOS2 detectors, smoothed with a 10″ gaussian.