Spatially-resolved Spectroscopy of the IC443 Pulsar Wind Nebula and Environ

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Deep Chandra ACIS observations of the region around the putative pulsar, CXOU J061705.3+222117, in the supernova remnant IC443 reveal, for the first time, a ring-like morphology surrounding the pulsar and a jet-like structure oriented roughly north-south across the ring and through the pulsar location.

The observations further confirm that (1) the spectrum and flux of the central object are consistent with a rotation-powered pulsar interpretation, (2) the non-thermal surrounding nebula is likely powered by the pulsar wind, and (3) the thermal-dominated spectrum at greater distances is consistent with emission from the supernova remnant. The cometary shape of the nebula, suggesting motion towards the southwest (or, equivalently, flow of ambient medium to the northeast), appears to be subsonic; there is no evidence for a strong bow shock, and the circular ring is not distorted by motion through the ambient medium.

The X-ray shape and spectrum of the PWN

The pulsar emission geometry, magnetic field, and energy distribution as well as the properties of the ambient medium and the relative motion of the pulsar in that medium all determine the shape and spectrum of the PWN. In our case, most of these properties are unknown, and we must use the shape and X-ray spectrum to infer what we can about the pulsar and its surroundings.

For supersonic flow, we expect (going outward from the PSR) a wind termination shock (TS), a contact discontinuity between the shocked wind and the shocked ambient medium, and a bow shock separating shocked and unshocked ambient flow.

Is the Point Source a Pulsar?

We have fit models to the X-ray spectrum of the bright point source and find it is characteristic of a young rotation-powered pulsar. As shown at right, both an absorbed blackbody+power law and an absorbed neutron star atmosphere+power law provide statistically-acceptable fits to the observed spectrum. The table below shows the best-fitting model parameter values, the derived total X-ray luminosity (in the 0.5-8.0 keV range), and estimated spin-down luminosity, \( \dot{E}_{\text{sd}} \), or rate at which the rotational energy is dissipated, relative to the Crab, assuming an efficiency of 10\(^{-4}\). The 3.2 s time resolution is long to search for a period in the data but the spectrum and the bright non-thermal nebula indicate CXOU J061705.3+222117 is indeed a pulsar with a PWN.

\begin{table}
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
Model & \(n_0\) & \(L_{\text{X}}\) (10\(^{39}\) erg s\(^{-1}\)) & \(L_{\text{sd}}\) (10\(^{37}\) erg s\(^{-1}\)) & \(\text{Crab}\) \(L_{\text{sd}}\) (10\(^{37}\) erg s\(^{-1}\)) \\
\hline
BB+PL & 0.6 & 1.6 & 1.2 & 2.0 & 2.6\times10\(^{37}\) \\
NS+PL & 0.2 & 0.9 & 1.3 & 1.1 & 1.0 & 2.0\times10\(^{37}\) \\
\hline
\end{tabular}
\end{table}

Where \(L_{\text{X}}\) is the X-ray luminosity, \(n_0\) is the number density of particles, and \(L_{\text{sd}}\) is the spin-down luminosity.

What is the nature of the ring and jet?

The interpretation of the nearly circular-ring-like feature poses some difficulty. Its circularity implies either a (limb-brightened) isotropic PSR wind or, if the wind is equatorial, then a co-alignment of the jet (and probably therelative PSR velocity) with our line of sight. The ring may define the location of the TS or, in analogy to the Crab Nebula, a torus at a distance \(\sim 4\text{~s}r\). For subsonic incompressible flow and negligible B field strength, the apex of the nebula occurs at a distance \(R=R_{\text{TS}}/(3P)^{2}\), where \(c\) is the speed of light, and \(P\) is the relative velocity of the PSR with respect to the ambient medium (e.g., Kennel & Coroniti 1984). In our case, \(R=10^{-4}\) (1-folding length upstream of the PSR) and, for a transonic \((M=1)\) flow, \(P=500\text{~km/s}\) so \(R=10^{-3}\) or less. Thus, the ring is likely similar to the Crab torus and the TS is too close to the PSR to be easily resolved.

References