Jet Sweepback in the PWN of PSR J1709-4429

Martijn de Vries¹, Roger Romani¹, Oleg Kargaltsev², George Pavlov³, Bettina Posselt³,⁴ and Patrick Slane⁵

¹Dept. of Physics and Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, Stanford, CA 94305, USA
²Department of Physics, George Washington University, Washington, DC 20052, USA
³Department of Astronomy & Astrophysics, Pennsylvania State University, University Park, PA 16802, USA,
⁴Department of Physics, University of Oxford, OX1 3PU Oxford, UK
⁵Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

Introduction

Chandra observations of PSR J1709-4429 and its associated pulsar wind nebula (PWN) reveal a distinct toroidal structure, equatorial outflow, and narrow polar jets. The jets are of particular interest, as they are swept back at scales of 2" by the pulsar motion. We present here preliminary results of new sensitive observations of J1709 totaling >650ks. With these new data we aim to

1) Constrain the jet perpendicular motion by comparing data from different epochs (10² timescales)
2) Perform a sensitive spectral analysis of the torus, equatorial outflow, jets, and bow shock, probing the interaction between the PWN and the surrounding ISM
3) Determine or constrain the proper motion of the pulsar by comparing with archival data from 2000 and 2004. This will allow us to check the relationship with the nearby supernova remnant (SNR) G343.1-2.3, seen at radio wavelengths

Thus, with this study we can address a wide range of PSR/PWN/jet physics.

Large-scale X-ray and radio emission

Radio observations of SNR G343.1-2.3 reveal a spur of emission extending towards the location of the pulsar. Our deep Chandra exposures also show faint and diffuse emission along this radio spur, suggesting a connection between the two (Figure 2). Additionally, The HESS galactic plane survey shows TeV emission extending towards the pulsar.

Closer to the pulsar, we observe an equatorial outflow at radii of up to 25", and the X-ray jets seem to have punched a hole through the radio plasma (Figure 3).

We have performed a spectral analysis of several components in the system (Table 1). The photon index increases between the torus and the outflow, as the spectrum gets softer due to synchrotron losses.

Table 1: Results of spectral fits to several components in the system. Galactic absorbing column density was fixed to 6 x 10¹⁸ cm⁻² for all fits

Pulsar and torus

Maps of the core at subpixel resolution reveal the structure of the pulsar, torus, jet and counterjet. Romani et al. (2004) have previously fit the torus model and obtained values for the positional parameters, as well as the torus radial flow velocity (β = 0.70).

Figure 1: Left: 12.5"x12.5" RGB image of the pulsar, torus and outflow at Chandra subpixel resolution (1/8th of the normal pixel size), adaptively smoothed with momoth. Red: 0.7 - 1.5 keV. Green: 1.5 - 3 keV. Blue: 3-8 keV. Right: model of the pulsar, torus, and jets (Romani et al., 2004)

The Dynamic Jets

Figure 4 compares Chandra images of the pulsar jets at different epochs. This comparison reveals jet variability on timescales of months, similar to the Vela pulsar jet (Pavlov et al., 2003). The jets appear to show curved structure, as well as blobs appearing and disappearing between epochs. We also noticed two bright spots east and west of the pulsar in the first epoch, which will be investigated at a later time.

We analyzed the intra-epoch jet variability by using a cross-correlation routine to compare counts profiles of different epochs along the jet axis (Figure 5). Unfortunately, the data are noisy and we have not yet determined the statistical significance of the correlation. The fact that we obtain significantly different velocities for the jet and counterjet is hard to explain. These plots should therefore be interpreted as suggestive rather than conclusive.

Figure 5 Top: Counts profiles of the jet (towards the left) and counterjet (towards the right) at the epochs shown in Figure 4. The cross-correlation suggests blob motion of β = 0.05 for the jet and β = 0.22 for the counterjet. Bottom: The result of the cross-correlation plot for both jets.