*High Energy Processes and Phenomena in Astrophysics*
*IAU Symposium, Vol. 214, 2003*
*X. D. Li, V. Trimble, and Z. R. Wang, eds.*

# *Chandra* Observations of the Guitar Nebula

Diane S. Wong[1], James M. Cordes[1], Shami Chatterjee[1], Ellen G. Zweibel[2], John P. Finley[3], Roger W. Romani[4], and Melville P. Ulmer[5]

[1]*Cornell Univ, Depts of Physics/Astronomy, Ithaca, NY 14853, USA*
[2]*Univ of Colorado, JILA, Boulder, CO 80309, USA*
[3]*Purdue Univ, Dept of Physics, West Lafayette, IN 47907, USA*
[4]*Stanford Univ, Dept of Physics, Stanford, CA 94305, USA*
[5]*Northwestern Univ, Dept of Physics & Astronomy, Evanston IL 60208, USA*

**Abstract.** As part of a multi-wavelength study, we report on a 50 ks *Chandra*/ACIS observation of the Guitar Nebula, a bow shock nebula associated with the radio pulsar B2224+65. We see a "hot spot" at the tip of the bow shock. We also notice a "jet" of X-ray emission at position angle (PA) -69°. However, the proper motion of the pulsar and the axis of optical emission is at PA 52°.1. We discuss the resulting interpretations of the relativistic pulsar wind and the surrounding ISM.

## 1. Observations

The Guitar Nebula is a bow shock nebula located 2.0 kpc away. On October 21, 2000, pointed observations (Observation ID 755) of the Guitar Nebula region were obtained with *Chandra*'s Advanced CCD Imaging Spectrometer (ACIS). 48261 s of usable data were reduced using *Chandra* Interactive Analysis of Observations (CIAO) software "threads" and CALDB version 2.10.

We might expect to see X-rays from the Guitar since a bow shock has an inner layer of shocked pulsar wind which emits synchrotron radiation. However, no excess emission is seen in the Guitar Nebula region. Instead, we see two prominent features: a "hot spot" (point source) at the position of the pulsar, and a "jet" extending outward from the pulsar position. We will discuss each of these in turn.

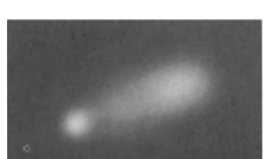

Figure 1. Adaptively-smoothed, exposure-corrected image of the jet. The pulsar position is marked by a white circle.



https://doi.org/10.1017/S0074180900194276 Published online by Cambridge University Press

Table 1. Results of the Spectral Fits for the Hot Spot and Jet

| Parameter | Hot Spot | Jet |
|---|---|---|
| $N_H(\times 10^{21}\ cm^{-2})$ | 1 | 1 |
| Γ, photon index | $1.4^{+0.6}_{-0.5}$ | ... |
| kT (keV) | ... | $0.5^{+0.1}_{-0.1}$ |
| Absorbed flux ($\times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$) | $1.6^{+0.7}_{-0.7}$ [0.4-10keV] | $2.4^{+0.6}_{-0.4}$ [0.3-10keV] |
| $\chi^2$ | 0.67 (13 bins) | 1.24 (17 bins) |

## 2. The Hot Spot

Given the spatial coincidence (within $0\farcs31$) of the hot spot ($\alpha = 22^h25^m52\fs554$, $\delta = 65°35'34\farcs58$) and the pulsar ($\alpha = 22^h25^m52\fs5801, \delta = 65°35'34\farcs842$), the most obvious source of the emission would be the pulsar itself. However, the luminosity of the hot spot is $9\times10^{30}$erg s$^{-1}$ (0.3-10 keV) which is 0.7% of $\dot{E}$; the implied efficiency is too high for direct emission from the surface or magnetosphere (e.g. Kaspi et al. 2001) only. Thus, the hot spot is likely emission from the nebula.

The CIAO tool PSEXTRACT was used to extract spectra. We then used the XSPEC spectral fitting package to fit the background-subtracted source. The best fit was obtained by a power law model. The results are summarized in Table 1. This is consistent with synchrotron radiation from the shocked nebula. Moreover, the photon index of 1.4 is similar to that obtained for other compact nebular regions in ram-pressure confined pulsar wind nebulae e.g. $\Gamma = 1.5$ for the nebula in SNR N157B (Wang et al. 2001).

## 3. The Jet

We see a jet of emission seeming to originate from the pulsar (Figure 1). Using CIAO's fitting package Sherpa, two 2-dimensional Gaussians were fitted to the jet, which appears to have two components. The second component is nearly circular whereas the first is elliptical with a PA of -69°. This is 121° out of alignment with the proper motion of the pulsar. The length of the jet is $\sim 80''$ and its width is $\sim 30''$.

A spectrum of the jet was extracted. The best fit was obtained by an absorbed blackbody (Table 1). The data are puzzling to say the least. A thermal blackbody spectrum might lead us to expect H$\alpha$ emission along the jet. However, there is no correspondence between the jet and H$\alpha$. Another possibility is that it is a random ISM filament. However, there are no known examples of this in X-rays (E. Gotthelf, personal communication).

**Acknowledgments.** D.S.W. is also supported by NSERC of Canada.

## References

Kaspi, V. M., Gotthelf, E. V., Gaensler, B. M., & Lyutikov, M. 2001, ApJ, 562, L163

Wang, Q. D., Gotthelf, E. V., Chu, Y.- H., & Dickel, J. R. 2001, ApJ, 559, 275