Neutron Stars in Supernova Remnants
ASP Conference Series, Vol. 271, 2002
P. O. Slane and B. M. Gaensler, eds.

Radio and X-ray imaging of two EGRET sources near $l = 312°$

Simon Johnston, Michelle Doherty, Anne Green

School of Physics, University of Sydney, Australia

Mallory Roberts

McGill University, Canada and *MIT, USA*

Roger Romani

Stanford University, USA

Bryan Gaensler

Harvard-Smithsonian Center for Astrophysics, USA

Froney Crawford

Lockheed Martin Corporation, USA

Abstract. We have carried out radio imaging of two EGRET error boxes in the southern Galactic plane. The region within the error box of GeV J1417–6100 contains a hard X-ray source embedded in what appears to be a pulsar wind nebula (PWN) and also contains the young, highly energetic radio and X-ray pulsar PSR J1420–6048. As the γ-ray source is variable, it seems likely that its origin is a mixture of emission from PSR J1420–6048 and the PWN. 3EG J1410–6147 appears to be associated with the SNR G312.4–0.4, which harbours two young pulsars within its shell. The relationship between these objects is unclear, although an H I determined distance should help clarify this. PSR J1413–6141 may be the origin of the γ-rays if it is closer than its dispersion measure derived distance suggests.

1. Introduction

The nature of the unidentified Galactic plane γ-ray sources remains an outstanding astrophysical problem. Finding low energy counterparts is complicated by the large γ-ray error boxes and the high absorption in the regions of star formation where these objects are found. For these reasons, radio and hard X-ray observations are optimum for follow-up work. Here we describe multi-wavelength observations of two unidentified EGRET sources within a few degrees of each other near $l = 312°$. A Molonglo Synthesis Telescope (MOST) image of this part of the Galactic plane is shown in Figure 1.

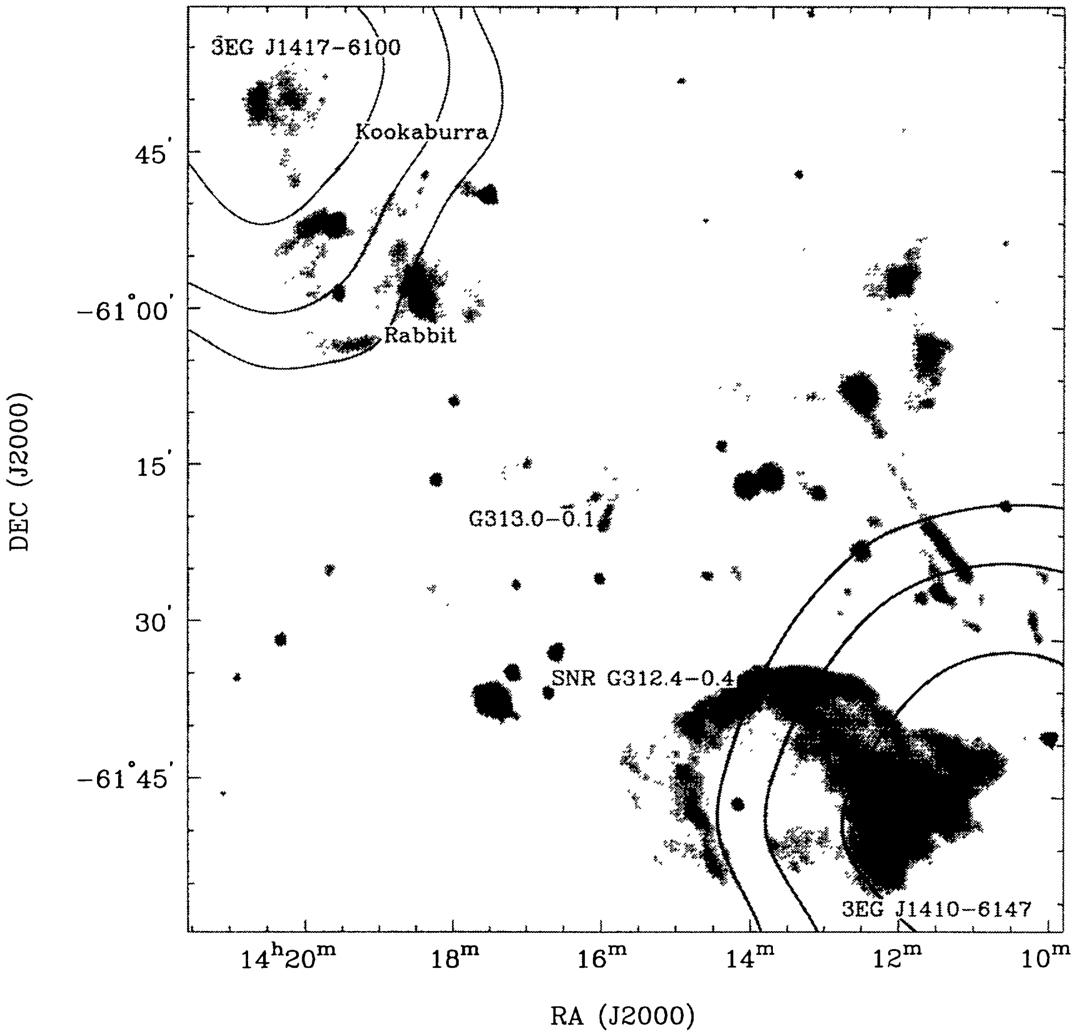

Figure 1. Radio continuum image of the Galactic plane near $l = 312°$. The grey-scale runs from 0 mJy (white) to 40 mJy (black). The contours denote the 68%, 95% and 99% confidence ellipses of the two γ-ray sources. Features described in the text are marked.

2. GeV J1417–6100

Radio imaging of the region contained within the error box of GeV J1417–6100 with the MOST (Whiteoak, Cram, & Large 1994; Green et al. 1999) and the Australia Telescope Compact Array (ATCA) have revealed a complex of compact and extended radio sources (Roberts et al. 1999). This complex, dubbed the Kookaburra, consists of a shell with two 'wings' stretching to the northeast and southwest.

Although the shell appears to be mostly thermal, a structure within the shell (the 'Rabbit') is highly polarized in the radio and has a low infrared to radio flux ratio indicating a non-thermal origin. Within the Rabbit there is a hard X-ray point source, presumably a pulsar. We therefore surmise that the Rabbit is a pulsar wind nebula, powered by the X-ray pulsar (Roberts et al.

1999). A deep survey for radio pulsations using the Parkes telescope proved unsuccessful, and this is therefore a likely further example of a young X-ray pulsar whose radio beams do not intersect Earth (Brazier & Johnston 1999).

A second X-ray source, AX J1420.1–6049, is coincident with a slight enhancement in the northeast wing (Roberts & Romani 1998; Roberts, Romani, & Kawai 2001). It is also coincident with the 68.2 ms pulsar PSR J1420–6048 recently discovered in the Parkes multibeam survey (D'Amico et al. 2001). This pulsar has the extremely high spin-down energy, $\dot{E}$, of 1.0×10^{37} erg s^{-1}, higher than all known γ-ray pulsars except for the Crab. Re-analysis of *ASCA* data showed X-ray pulsations at a high significance level (Roberts, Romani, & Johnston 2001). The precise nature of the 'wing' is unclear - is it an SNR in its own right, a PWN powered by PSR J1420–6048, or merely thermal?

Given the rarity of such high $\dot{E}$ pulsars, it is natural to assume a connection between GeV J1417–6100 and PSR J1420–6048. However, the γ-ray source is variable perhaps pointing to an origin in the pulsar wind nebula associated with the Rabbit. It is likely therefore that the γ-ray emission arises from a combination of both. *Chandra X-ray Observatory* and *XMM-Newton* observations of this region are planned in the near future. H I data have been taken with the ATCA to derive kinematic distances to objects in the field. Data analysis is proving difficult however, because of the low surface brightness of the relevant features.

3. 3EG J1410–6147

The spatial coincidence between the supernova remnant SNR G312.4–0.4 and 3EG J1410–6147 led Case & Bhattacharya (1999) to propose an association between the two objects. Since then the Parkes multibeam survey has discovered two young pulsars located (in projection) within the shell of the SNR. PSR J1413–6141 has a characteristic age of 13 kyr, an $\dot{E}$ of 5.6×10^{35} erg s^{-1} and a dispersion measure (DM) derived distance of 11 kpc. PSR J1412–6145 has an age of 51 kyr, an $\dot{E}$ of 1.2×10^{35} erg s^{-1} and a distance of 9 kpc. Neither pulsar is coincident with the enhancement of the radio shell to the southwest. Either could originate in the same explosion as the SNR. A lower limit of 3.8 kpc to the distance to the SNR was obtained by Caswell & Barnes (1985) on the basis of H_2CO absorption.

We observed the region near SNR G312.4–0.4 at radio wavelengths with the ATCA in both continuum at 1.4 GHz and H I mode and in the X-ray with the *Chandra X-ray Observatory.* The ATCA observations include polarization information and comparison with the MOST image allows spectral indices to be derived. We find that the northern rim of the SNR has a spectral index of –0.7, whereas the bright region to the southwest has a much flatter spectral index of –0.2 indicative of a pulsar wind nebula. However, we consider it unlikely that this region is a PWN – it is physically too large, has a flux density in excess of 10 Jy at 1.4 GHz, and neither of the pulsars is coincident with it. The H I data should allow us to determine a kinematic distance to the SNR; the pulsars are too weak to attempt this. These data are currently under analysis.

There is a lack of a radio pulsar wind nebula around PSR J1413–6141. For any reasonable parameters for the ambient density and space velocity of the pulsar, we would expect to have an unresolved bow-shock nebula at the pulsar position. Given our upper limit of 0.5 mJy for the PWN, the efficiency of converting the spin-down energy to a radio PWN is of order 10^{-6} which is two orders of magnitude lower than for other pulsars of a similar age (Gaensler et al. 2000).

Preliminary analysis of the X-ray data reveal no extended emission related to the SNR and no detection of the pulsars as point sources although there appears to be a slight enhancement of the X-ray emission near PSR J1412–6145. At a distance of 10 kpc, we would not expect to detect either non-thermal (pulsed) emission from the pulsars nor any associated PWN. This argues for a distance greater than 4 kpc based on our upper limits.

If we assume that the pulsars are at their DM derived distances, then neither are in the top 100 when ranked by $\dot{E}/d^2$. Furthermore, in order to explain the γ-ray flux of 3EG J1410–6147, their γ-ray efficiency must be close to or exceed 100% of $\dot{E}$, depending on the beaming fraction. Thus, either the pulsars are significantly closer than their DM suggests or they are not the source of the γ-rays.

These data and the conclusions as to the nature of the EGRET source will be written up for publication in the near future (Doherty et al. 2002).

References

Brazier, K. T. S., & Johnston, S. 1999, MNRAS, 305, 671

Doherty, M. et al. 2002, MNRAS – in preparation

Case, G., & Bhattacharya, D. 1999, ApJ, 521, 246

Caswell, J., & Barnes, P. 1985, MNRAS, 216, 753

D'Amico, N. et al. 2001, ApJ, 552, L45

Gaensler, B. M., Stappers, B. W., Frail, D. A., Moffett, D., Johnston, S., Chatterjee, S., 2000, MNRAS 318, 58

Green, A. J., Cram, L. E., Large, M. I., & Ye, Y. 1999, ApJS, 122, 207

Roberts, M. S. E., & Romani, R. W. 1998, ApJ, 496, 827

Roberts, M. S. E., Romani, R. W., & Johnston, S. 2001, ApJ, 561, L187

Roberts, M. S. E., Romani, R. W., Johnston, S., Green, A. J. 1999, ApJ, 515, 712

Roberts, M. S. E., Romani, R. W., & Kawai, N. 2001, ApJS, 133, 451

Whiteoak, J. B. Z., Cram, L. E., & Large, M. I. 1994, A&AS, 118, 329