Chandra Observations of Fermi-LAT and Radio Pulsar Fields

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219th AAS Meeting, Austin, Texas, January 2012

ABSTRACT: We continue our campaign of multi-wavelength observations of Fermi-LAT gamma-ray sources utilizing the Chandra ACIS-S instrument. These observations are to search for and determine properties of significant X-ray point sources that might be associated with the recently discovered rotation-powered pulsars J1514-4946, J1658-5324, J1302-32, J2017+06, and J1103-5403. All of these pulsars were originally discovered in radio searches of Fermi-LAT unassociated gamma-ray sources. Chandra can localize X-ray point sources with arc second positional accuracy and characterize their X-ray spectral properties. We report on the X-ray fluxes and spectral properties of the associated X-ray sources found in our observations and compare these properties with those of other rotation-powered X-ray and gamma-ray pulsars. We also discuss other interesting sources uncovered by our observations in the fields of our target pulsars.

Support for this work was provided by NASA through Chandra Award Number 12400936 and performed at the Naval Research Laboratory under sponsorship by NASA award DPR S-15633-Y.

Fermi-LAT Unidentified Source Observations

Fermi-LAT is a pair production telescope launched in June 2008 that is continually scanning the sky at energies from ~20 MeV to >300 GeV with ~8000 cm^2 of effective area, good background rejection, a 2.4 steradians field of view, and 0.6 degrees angular resolution for front-side events at 1 GeV. In its first month of operations *Fermi*-LAT achieved a sensitivity greater than EGRET on *CGRO*. The "*Fermi*-LAT Second Source Catalog" (2FGL; Abdo et al. 2011) lists 1746 sources detected by the *Fermi*-LAT during the first two years of survey operations. Many 2FGL sources are associated with known objects in other wavelength bands such as pulsars and active galactic nuclei (AGN). 576 2FGL sources, however, were listed as unassociated with any known (at the time of publication) source in any other wavelength band (see Abdo et al. 2011).

As a part of the *Fermi*-LAT collaboration effort to identify these sources we have obtained time on the *numerous* X-ray satellites, including the Chandra satellite, to observe the fields of five (Table 1) *Fermi*-LAT initially unidentified γ-ray sources subsequently detected as radio pulsars to look for possible X-ray counter parts. We report our initial analysis of the Chandra observations for three of these pulsars here.

Chandra Observations

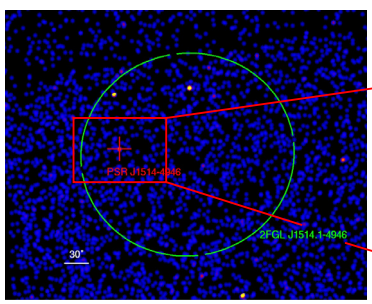
For each target γ-ray/radio source we observe the field for 10 ks in order to detect significant X-ray sources that might be within or near the γ-ray error region. Once any new X-ray sources within these fields are identified we can follow up with both the radio and Fermi/LAT data doing more detailed searches for the best pulsar position solution.

The *Chandra* Observatory (Weisskopf et al. 2002) is a set of two X-ray imaging instruments (ACIS and HRC). We utilize the ACIS-S in faint source mode with no grating. For ACIS-S observations utilizing the back-illuminated S3 chip the sensitivity limit for point sources is near ~4x10^{-15} ergs cm^{-2} s^{-1} in a 10 ks observations in the energy range 0.4-6.0 keV. The instrument has good spectral energy resolution (better than 1% at 1 keV), and spatial resolution better than 1 arc second for sources in the center of the field. The field size for the ACIS-S is roughly 8.3 arcmin for each CCD chip and thus a good match to the error regions for *Fermi*-LAT and radio positional uncertainty at the time of each observation. The ACIS-S spectral resolution allows us to gain a good initial impression of the X-ray spectral characteristics of any sources found in the fields that posses sufficient X-ray flux to be analyzed.

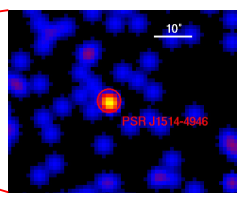
Table 1: *Fermi*-LAT/*Chandra* Sources

Pulsar Name	Initial Gamma-Ray Association	Galactic Longitude	Galactic Latitude
J1103-5403	2FGL J1103.9-5356	287.42°	+5.53°
J1302-32	2FGL J1302.4-3257	305.58°	+29.86°
J1514-4946	2FGL J1514.1-4946	325.25°	+6.81°
J1658-5324	2FGL J1658.4-5322	334.87°	-6.63°
J2017+0603	2FGL J2017.3+0603	48.62°	-16.03°

Note: PSR J1103-5403 was detected at radio wavelengths by searching in the field of 2FGL J1103.9-5356 for radio pulsations. This 2FGL source is now believed to be associated with the AGN PKS J1103-5356.

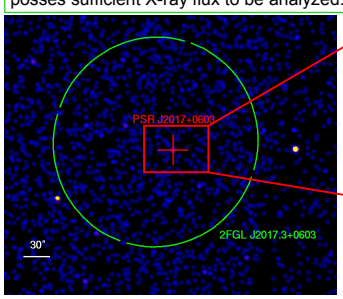


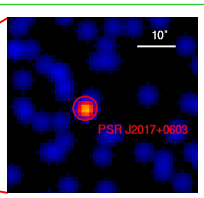
PSRJ1514-4946



Pulsar position is a red cross in the larger view and a 3" radius circle centered on the radio position in the close-up view. Green is the 2FGL error ellipse. Other X-ray sources in the field are in yellow.

On February 2, 2011 Chandra observed for 10 ks the field of 2FGL J1514.1-4946 (Abdo et al. 2011) from which pulsations with period 3.589 ms had recently been detected in the radio (Camilo et al. 2012). At that time the position of the pulsar was not well known and the then-best position was centered on the back-illuminated S3 chip in order to increase the ACIS-S sensitivity to point sources. We detected a faint X-ray point source at the now-known radio position of the pulsar as shown in the close-up image. The S/N of the point source is ~2.1 and a net count rate of 9.1x10^{-4} c/s making this a marginal detection of a point source. If this source is real we estimate its 0.5-7.0 keV flux at ~6.1x10^{-15} ergs cm^{-2} s^{-1}, very close to the Chandra ACIS-S point source sensitivity limit.





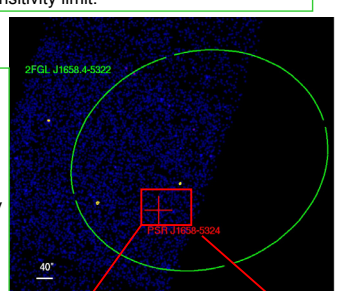
Pulsar position is a red cross in the larger view and a 3" radius circle centered on the radio position in the close-up view. Green is the 2FGL error ellipse. Other X-ray sources in the field are in yellow.

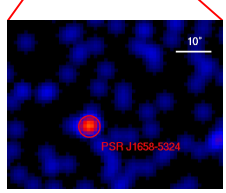
PSRJ2017+0603

On July 30, 2011 the Chandra observatory observed the field of this γ-ray and radio pulsar for 10 ks in ACIS-S faint source mode. The associated γ-ray source is 2FGL J2017.3+0603 (Abdo et al. 2011). Pulsations have already been identified (Cognard et al. 2011) at a period P = 2.896 ms with spin-down luminosity ~1.35x10^{34} ergs s^{-1} and a surface magnetic field strength of ~1.6x10^8 gauss. Chandra ACIS-S detects an X-ray source with S/N = 3.4 at the nominal radio pulsar position with 19±5.5 counts giving a count rate of 0.0019 c/s. Assuming a power law spectral model yields a source flux ~1.2x10^{-14} ergs cm^{-2} s^{-1}.

PSRJ1658-5324

On January 25, 2011 Chandra ACIS-S observed for 10 ks the field of 2FGL J1658.4-5322. This is a P = 2.439 ms γ-ray and radio pulsar with a spin-down luminosity of ~3.2x10^{34} ergs s^{-1} and a surface magnetic field of 1.7x10^8 gauss. Chandra ACIS-S detects an X-ray source at the position of the radio pulsar at S/N = 3.6. The X-ray flux in the 0.3-7.0 keV band is ~1.6x10^{-14} ergs cm^{-2} s^{-1}. The figures at right are a larger view of the field around PSRJ1658-5324 and a close-up view of the faint X-ray source at the pulsar position. This pulsar is discussed further in Camilo et al. (2012).





Pulsar position is a red cross in the larger view and a 3" radius circle centered on the radio position in the close-up view. Green is the 2FGL error ellipse. Other X-ray sources in the field are in yellow.

Conclusions

Using the ACIS-S instrument on the *Chandra* observatory we have observed the fields of five *Fermi*-LAT γ-ray sources that were initially unidentified in any other energy range. Subsequent analysis of data obtained for all of these γ-ray sources has shown them to be either pulsars in the radio and *Fermi*-LAT energy ranges, or in the case of 2FGL J1103.9-5356 observations revealed the source to be an AGN. These Chandra observations have identified faint X-ray sources in the case of 3 of our 5 targets, namely, J1514-4946, J1658-5324, and J2017+0603. For the γ-ray pulsar J1302-32 we have yet to determine a solution for the exact radio/γ-ray pulsar position and so no X-ray source has been identified for this pulsar. In the case of PSRJ1103-5403, the original gamma-ray source (2FGL J1103.9-5356) is now believed to be associated with the AGN PKS J1103-5356. We have found no X-ray source at the position of the radio pulsar PSRJ1103-5403 (see Keith et al. 2011).

References:

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Weisskopf et al. 2002, PASP, 114, 1