Searching for Gamma-Ray Binaries using the Fermi Second Source Catalog

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Introduction

The Large Area Telescope (LAT) is an imaging high-energy gamma-ray telescope on the Fermi Gamma Ray Space Telescope spacecraft. The Fermi LAT Second Source Catalog contains 1873 gamma-ray sources. A large fraction of these sources remain unidentified, or have been statistically associated to AGN.

Recently, a new class of gamma-ray source has emerged, the so-called "gamma-ray binaries", composed of a compact object and a massive star, distinguished by their relatively high gamma-ray luminosity in the 0.1-100 GeV range. However, only 5 gamma-ray systems have been identified thus far.

Here we present an attempt to discover new gamma-ray binaries by studying unidentified, or weakly associated, Fermi LAT sources.

Background and Theory

The 5 previously discovered gamma-ray binaries all share some common characteristics. All systems contain a massive companion star of early spectral type (O and Be). They are galactic systems located at a distance of several kpc. In four of the five systems (exception due to high extinction) the companion star has an optical magnitude of between 10 and 13. All of the systems are radio sources. When attempting to discover new gamma-ray binary systems we look within the Fermi error ellipses for objects that match these characteristics, in particular, an optically bright star that is also a radio source.

The source of the non-thermal emission is still not entirely clear. There are two main models of gamma-ray binaries: accretion-powered microquasars and rotation-powered pulsars. The mechanisms responsible for the generation of the gamma-rays are somewhat generic to both models. While neither model is completely successful in characterising the systems and both have their merits, the pulsar model is currently favoured. The prevailing idea is that their non-thermal emission is due to particles accelerated at the shock between the wind of the massive star and the wind of the pulsar.

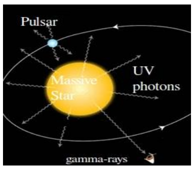


Figure 1: Rotation powered pulsar model [image: Gamma-Ray Binaries Revealed Science 13 January 2012 (edited)]

Hence gamma-ray emission is ultimately powered by the spindown of a rotating neutron star with a strong magnetic field, 10^{11} - 10^{13} G[4]. Most models of the high-energy spectrum invoke synchrotron emission and inverse Compton scattering from electrons or electron-positron pairs, with the dominant seed photon field assumed to be the light from the very luminous companion star.

Methodology

We want to search within the error ellipses of the Fermi sources for objects which match the characteristics of gamma-ray binaries.

- First we identify radio sources from the NRAO/VLA Sky Survey which are positionally coincident with a Fermi source
- The radio error circles are then searched for optical counterparts consistent with those of a gamma-ray binary (via optical/IR colors and spectroscopy).
- Here we present our attempts to identify 3 such systems - 2FGLJ0359.1+6003, 2FGLJ1748.6-2913 and 2FGLJ0747.5-3305.

2FGL J0359.1+6003

Location: 03 59 06.0 +60 03 19
Error margin: 0.11 (deg)

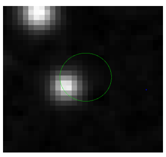


Figure 2: NVSS radio error margin with optical counterpart

There are 15 NVSS radio sources within the error circle of this Fermi source. Most of these radio sources do not have optical counterparts and were hence excluded from further consideration. However one NVSS source is of particular interest: NVSS 03 59 01.01 +60 10 54.5. There is a possible optical counterpart within the NVSS error circle (see Fig 2), whose photometric properties may be consistent with a gamma-ray binary. The field of the counterpart has a neutral atomic hydrogen density of $N_H \sim 4.4\times10^{21}$ cm^{-2}. Archival NOMAD optical magnitudes, when combined with the interstellar reddening from the N_H measurement[3] indicate a de-reddened B magnitude of ~14.5. Unfortunately large error margins on the NOMAD magnitudes prevent an accurate determination of temperature via the stars colours. This is an interesting candidate that warrants additional photometric and spectroscopic follow-up.

2FGL J0747.5-3305

Location: 07 47 33.3 -33 05 30
Error margin: 0.24 (deg)

2FGL J0747.5-3305 has a relatively large error margin in which lies 16 NVSS radio sources. Most of these radio sources do not have optical counterparts, which is not consistent with the characteristics of a gamma-ray binary, and were hence discarded. However there was one very promising object. NVSS 07 48 23.67 -33 12 08.9 has a possible optical counterpart of magnitude 17.18 in the B band, in a field with a column density $N_H \sim 6.68\times10^{21}$ cm^{-2}.

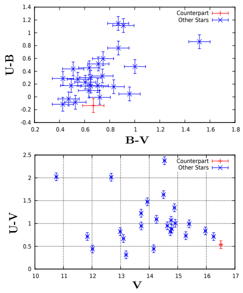
Using the Faulkes South Telescope photometry was performed on this counterpart, in an attempt to constrain the spectral type and effective temperature.

In both the colour-colour and colour-magntiude diagrams (see Figs 3 and 4), the NVSS counterpart is one of the bluest in the field.

As an additional check, a code was written which progressively reddens 5 colours of the star and compares them to the colours of stars of known spectral type. Shown is a χ^2 contour plot of temperature against absolute extinction in the V band. At the 95% confidence level we can say that this star is a relatively hot star (above 10,000 K) at about 4 magnitudes of extinction in the V band.

The statistical odds of randomly finding a main sequence star of spectral type O or B within this error circle is 0.02%.

This is clearly a promising candidates for further spectroscopic observations



Figures 3 and 4: Colour-Colour and Colour-Magnitude diagrams of NVSS optical counterpart field

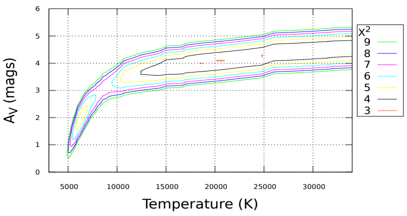


Figure 5: χ^2 contour plot of Temperature against A_V for counterpart

Filter	Magnitude	Error
U	11.64	0.23
B	12.51	0.20
V	12.98	0.14
R	12.29	0.44
I	12.68	0.30
J	13.39	0.06
H	13.31	0.06
K_s	12.98	0.06

Table of de-Reddened magnitudes for the optical counterpart assuming A_V = 3.5

2FGL J1748.6-2913

Location: 17 48 39.2 -29 13 53
Error margin: 0.07 (deg)

This Fermi Source has no published association, and it has only 3 NVSS radio sources located within its error margin. One of the radio sources has a possible bright optical counterpart: NVSS 17 48 30.06 -29 16 08.7 (see Fig 6). This optical counterpart appears in several optical catalogs (without error margins). The column density of this field is approximately $N_H \sim 9\times10^{21}$ cm^{-2}, which gives an interstellar reddening of $A_V \sim 5$ mags. However this reddening calculation is distance dependent, and 5 magnitudes is considered to be too high based on the de-reddened colours it would produce. A reddening of just $A_V = 2$ would give a de-reddened B-V colour corresponding to an effective temperature of about 25000 K. This level of reddening would be plausible for an object at a distance of several kpc.
We have recently acquired a spectrum of this counterpart, which displays a relatively featureless continuum with no strong Hα emission (although the data reduction is still preliminary). Additional observations are planned.

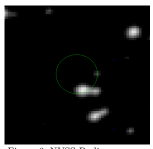


Figure 6: NVSS Radio error margin with optical counterpart

Filter	Magnitude
B	14.760
V	14.53 , 14.16
R	13.97 , 14.47
J	13.135
H	11.502
K_s	10.689

Table of Observed Magnitudes obtained from Optical Catalogs.

Conclusions

- Several potential gamma-ray binary optical counterparts have been identified: spectroscopic observations are required in the next step of this identification process. The five previously discovered gamma-ray binaries all contain an early spectral type companion star. Be class stars occur in three of the systems, so Hα emission would confirm the presence of a disk structure.
- Additional X-ray and radio observations would also help constrain the nature of these counterparts.

References

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