Surveying the Galactic X-Ray Binaries with *Fermi*-LAT

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Introduction

X-ray binaries (XRBs) are systems where a compact object (a black hole or neutron star) accretes matter from a companion star. Approximately 300 X-ray binaries are known in the Milky Way. Around 100 of these are High Mass X-Ray binaries (HMXBs) [1], where the companion's stellar wind feeds the compact object, and 200 Low Mass X-Ray binaries (LMXBs) [2], where accretion occurs through Roche lobe overflow.

In the most recent Fermi-LAT point source catalogue, 8 HMXBs and 4 LMXBs are listed as γ-ray emitters. Additionally, although uncatalogued, the microquasar SS 433 is a known γ-ray source [3]. The majority of these systems are γ-ray binaries, which produce γ-ray emission through shocks between the stellar environment and a pulsar wind. There are also several microquasars, which produce γ-ray emission through particle acceleration in the jet.

Given the low number of X-ray binaries known to emit observable γ-rays, much is still unknown about the nature of these systems, their morphologies and emission mechanisms. We present the methodology and initial results of our survey of the X-ray binary population, using 12.5 years of Fermi-LAT data. The goal of this survey is to detect any previously undetected persistent or transient emission from these elusive systems.

LAT Observations

We use approximately 12.5 years of Fermi-LAT γ-ray data to construct a model around the position of each XRB. We use the standard SOURCE photon classes and associated instrument response and isotropic background together with the latest point source catalogue, the 4FGL-DR2 and the 8 year Galactic diffuse background. Given that the vast majority of the XRB population lie on the Galactic plane, accurately modelling this region is difficult, given the extremely luminous diffuse emission (as shown in Figure 1).

As a result, we employ a binned likelihood analysis [4] around the position of each XRB using the Fermitools and Fermipy, populate the model with previously undetected sources, and fit a power law source to the spatial position of each XRB. We then execute a likelihood fit to generate a test statistic (TS) for the significance of any γ-ray emission, which equates to a value of χ^2.

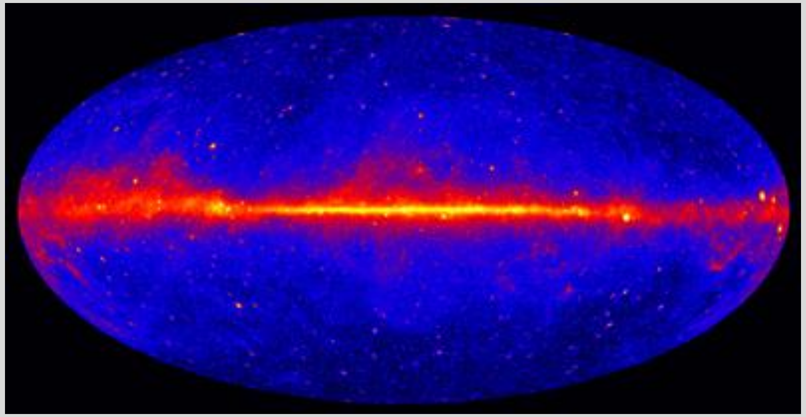

Figure 1: The Galactic plane diffuse emission after 5 years of LAT observations, at energies greater than 1 GeV. (Image Credit: NASA/Fermi-LAT Collaboration)

We consider any γ-ray excess with a significance above 5σ to be a full detection, and anything in the range 3σ to 5σ to be a sub threshold excess. In order to test for transient γ-ray emission, we generate 6 month light-curves at the position of each XRB, and test these for significant transient γ-ray emission. For any XRBs where we find a spatially coincident γ-ray excess, we examine nearby sources to test for source confusion, and look at Swift-BAT data to attempt to establish correlated multi-wavelength variability, and run further source localisation tests on the excess.

Preliminary Results

Several XRBs included in the 4FGL are included in our survey, and our analysis of the HMXBs reveals we detect all of these more significantly than detected in the 4FGL-DR2. This data is shown in Table 1. The increased significances of these systems with respect to the catalogue is encouraging, as generally doubling observation time leads to a $\sqrt{2}$ factor increase in significance for a steady source and for most of these systems our increase in significance is higher than this factor, likely a result of a more accurate analysis.

HMXB	Detection z-score	4FGL z-score
LS 5039	130 σ	62 σ
Cyg X-1	9.4 σ	8.6 σ
Cyg X-3	29 σ	11 σ
LS I +61 303	410 σ	250 σ

Table 1: The 4 HMXBs included in our sample which are also included in the 4FGL, together with their detection significances from our survey and the reference detection values from the 4FGL-DR2.

Currently, we have fully analysed the entire HMXB population, and performed a preliminary analysis on the LMXB population. In the HMXB population, we identify 21 XRBs where there is either a transient or persistent γ-ray excess coincident with the position of the XRB. We believe that in many of these cases, source confusion with nearby objects is causing a false positive and therefore these excesses are very unlikely to represent γ-ray emission from the XRB. Nonetheless, there is tentative evidence for independent γ-ray emission coincident with the positions of several HMXBs, all of which are likely to be γ-ray binaries, although analysis regarding these systems is still ongoing. Our preliminary analysis of the LMXB systems reveals a greater proportion of these systems having coincident γ-ray emission, however also a greater number of false positives, for example many of these systems are within globular clusters, which are themselves γ-ray sources. Nonetheless, the prospect of identifying new γ-ray emitting XRBs through detailed surveying remains promising.

References

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