Introduction – Globular Clusters

Local globular clusters have the following characteristics:

- They are old (~10^9 years), dust-free satellites of the Milky Way galaxy, characterised by dense cores of 100 to 1000 stars per cubic parsec and consequently high stellar encounter rates.
- Some GCs are noted for hosting populations of millisecond pulsars (MSPs) which arise from binary interactions. GCs may also contain central intermediate mass black holes or reside within dark matter halos.
- MSPs are strong gamma sources emitting gamma rays through curvature radiation and electron / positron pair production cascades in their magnetospheres.

25 GCs are significant gamma ray sources and a re-survey with the most up to date pass 8 Fermi-LAT data is likely to refine spectra further due to 1 - 7 years of further photon statistics since the last publications.

In addition the latest Pass 8 data release and tools of the Fermi-LAT now allow spectral analysis in the 60- 100 MeV range, for which no further due to 1 - 7 years of further photon statistics since the last publications.

**Globular Cluster Selection**

We select 30 local GC for analysis (Table 1) based on the following criteria:

- All GCs to have a well defined absolute visual magnitude, central surface brightness and a known mass.
- Heliocentric distance for 25 of these GC are < 12.5 Kpc and <19.3 Kpc for the rest.
- |b| > 15° to mitigate Galactic disc background uncertainties.

**Analysis Method**

Our standard analysis uses 8.5 years of Fermi Pass 8 data from 4th Aug 2008 to 28th Dec 2016 with source class photons and valid front and back converting events. A zenith angle 90° cut excludes photons from the Earth limb.

For reasons of processing speed, an initial cut down analysis method is used to determine significant gamma ray emitters using the Fermipy package with energy selection 100 MeV to 300 GeV and a 15° radius of Interest (ROI). Two iterations of the Fermipy GTAnalysis 'find sources' method is used to identify new power law sources with significances of at least 3σ. The 'optimize' method of the GTAnalysis object is then run. This loops over all model sources in the ROI and fits their normalization and spectral shape parameters and computes the test statistic (TS) of all sources in the ROI. Gamma ray sources within the tidal radius of the cluster are then analysed further to produce a spectral energy distribution.

Detected globular clusters are re-analysed between 60 MeV to 300 GeV with a 25° Radius of Interest (ROI) and 40° source region with the following steps and methods of the Fermipy GTAnalysis object:

**Analysis Results**

We detect 6 globular clusters (Table 2) and show the best fit SED for 4 of them. (Fig 1 - 4). NGC 6254 is a new detection.
Selected Results – Spectral Energy Distributions and Spectral Models

We show SEDs for 4 GCs along with their spectral model parameters (Fig 1 – 4). These GCs are binned at 4 bins per decade of energy within a restricted energy range so that only significant points are fitted.

The flux bin upper limits for the SEDs in Fig 1 – 4 (shown as points with a downward pointing arrow) are determined at a confidence level of 5σ.

The range of TS values for the individual flux bins of each GC SED are listed (Table 3):

<table>
<thead>
<tr>
<th>GC</th>
<th>Lowest TS</th>
<th>Highest TS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 6218</td>
<td>4.5</td>
<td>19.3</td>
</tr>
<tr>
<td>NGC 6093</td>
<td>6.6</td>
<td>30.1</td>
</tr>
<tr>
<td>NGC 6254</td>
<td>10.7</td>
<td>23.3</td>
</tr>
<tr>
<td>NGC 6752</td>
<td>24.6</td>
<td>76.2</td>
</tr>
</tbody>
</table>

Table 3: TS value range for binned flux points in each GC SED.

The luminosity for each GC in the energy range 60 MeV to 300 GeV is also calculated (Table 4):

<table>
<thead>
<tr>
<th>GC</th>
<th>$L_{\gamma\text{60 MeV - 300 GeV}}$ (erg / s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 6218</td>
<td>$(1.09 \pm 0.21) \times 10^{34}$</td>
</tr>
<tr>
<td>NGC 6093</td>
<td>$(8.50 \pm 1.14) \times 10^{34}$</td>
</tr>
<tr>
<td>NGC 6254</td>
<td>$(0.89 \pm 0.18) \times 10^{34}$</td>
</tr>
<tr>
<td>NGC 6752</td>
<td>$(1.10 \pm 0.19) \times 10^{34}$</td>
</tr>
</tbody>
</table>

Table 4: Luminosities of each GC plotted as a SED.
NGC 6093 and 6218 exhibit flat, hard spectra (Fig 1 - 2) in the range 1 - 10 GeV. This is unlike typical MSP spectra whose binned flux tends to fall markedly between 1 - 10 GeV [4] and have spectral models fit by a power law with super exponential cut off or a power law [3]. These GCs have no known MSPs (Fig 5) and a corresponding low mass encounter rate product (Fig 6) which can be taken as a proxy for the prevalence of binary system creation and MSP recycling. This suggests a predominantly non MSP origin for the gamma ray emission in these clusters.

NGC 6254 (Fig 3) is a new detection with an angular offset within the ROI of 0.18° from the GC co-ordinates (RA=254.28°, DEC=-4.10°), placing this source inside the GC tidal radius of 0.29°. Like NGC 6093 and NGC 6218, this GC has no known MSP and a low mass encounter rate product. However the upper limit at above 5 GeV means that a high energy spectral cut-off, characteristic of MSPs, cannot be discounted.

NGC 6752 has a hard, flat spectrum when binned in the range 300 MeV - 4 GeV (Fig 4). The source of the sub 100 MeV emission is not known but work is ongoing to characterise the SED of objects in the ROI within the point spread function of the LAT to see if they are contributors in this low energy regime.

Discussion

References


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