Population Studies: Prospects for AGILE and GLAST

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ABSTRACT. We present a number of preliminary studies that demonstrate the capabilities of AGILE in the study of gamma-ray source populations, and a comparison to the capabilities of GLAST.

1. Introduction

The 3rd EGRET Catalog (Hartman et al. 1999) revealed 271 gamma-ray point sources above 100 MeV. Of these, seven were identified as pulsars, 68 as external galaxies, and the rest, a majority, remain unidentified. The degree-scale angular resolution of EGRET means that in a typical EGRET error box there are dozens of possible radio, optical and X-ray counterparts. Positional coincidence alone is insufficient to yield a direct identification. Additional characteristics must be used both to make firm identifications and to provide clues about the nature of the unidentified sources.

1.1. Variability

With the exception of the Large Magellanic Cloud, all the identifications of EGRET sources have relied on time variability of the source. EGRET pulsars were identified using radio or X-ray ephemerides, and AGN by their flaring behavior at multiple wavelengths. All the identified pulsars are consistent with persistent (i.e. non-variable) flux over long time scales.

1.2. Angular and Flux Distribution

The identified gamma-ray pulsars are confined to low latitudes, as are most of the persistent pulsar-like unidentified sources. The AGN are consistent with an isotropic source distribution, although the actual distribution of the catalog sources is dependent on the highly non-uniform exposure of EGRET. The spatial distribution of the unidentified sources indicate that they contain by a galactic component, and various studies have shown an association with SN/OB associations.

Population studies (Gehrels et al. 2000) indicate the possibility of multiple Galactic components, including a component related to the Gould belt.

1.3. Spectra

Spectra are another characteristic that can distinguish between source classes. All the identified EGRET pulsars exhibit spectral breaks at high energy when fit by a power law, while nearly all blazars are well fit by a single power law.

1.4. AGILE

AGILE, an ASI Small Scientific Mission, is designed to detect and image photons in the 30 MeV–50 GeV and 10–40 keV energy bands. The AGILE **Gamma-Ray Imaging Detector (GRID)** is characterized by the smallest ever obtained deadtime for gamma-ray detection ($\leq$200 μs) and by a trigger based exclusively on silicon plane detectors. The GRID is designed to achieve an optimal angular resolution (source location accuracy $\sim 5' - 20'$ for intense sources), an unprecedently large field-of-view ($\sim$ 3 sr), and a sensitivity comparable to that of EGRET for on-axis (and substantially better for off-axis) point sources. Long term monitoring with uniform exposure over a wide field of view will vastly improve the measurement of variability of source classes and individual sources. Improved angular resolution and exposure will aid in the identification of unidentified and new sources. Here we present some preliminary studies that quantify the contributions AGILE will make to the study of these sources.

2. Variability studies

Many attempts have been made to characterize the variability of EGRET sources, but the low photon count and lack of clear theoretical predictions create a degree of ambiguity. One family of statistics attempts to measure the consistency of each source with the assumption of a constant flux i.e. zero intrinsic variability (McLaughlin et al. 1996). Others seek to measure the most probable ratio between the standard deviation and mean real (as opposed to measured) flux of a source, assuming some parent distribution (Torres et al. 2001, Nolan et al. 2003). The sensitivity of EGRET limits the number of photons detected from a given source per viewing period, placing a fundamental statistical limit on any measure of variability. An additional, serious constraint is that the effective area falls off steeply as a function of off-axis angle, meaning that exposure and therefore statistical significance varies between viewing periods. Most sources have observations with flux upper limits higher than detected fluxes in other viewing periods. The result is that even different statistics that nominally measure the same intrinsic parameter are weakly or not at all correlated, and the Nolan statistic, the only one with estimated confidence intervals, shows very broad intervals for individual sources.

We simultaed the ability of AGILE to measure source variability by generating two ensembles of simulated source observations, 10 each for AGILE and EGRET. In the case of EGRET we used the detected counts of each source in each viewing period in the 3rd EGRET catalog as the mean number of counts in the Poisson distribution from which we drew the simulated detected number of counts in the each viewing period with the same exposure. In the case of AGILE we used the same number of viewing periods for each source, with the number of mean counts set equal to the product of the flux of the source in each viewing period and the maximum exposure of that source. This rough estimate simulates the roughly equal sensitivity of AGILE and EGRET as well as the much larger and more uniform field of view of AGILE.

Once the 10 ensembles were generated for each instrument, we calculated the Torres statistic I for each source in each ensemble. The results are shown in Figure 1. In each case we confirm that the I distributions cluster about the observed value on average. To compare directly the two ensembles we calculated the fractional spread $\delta I/I$ for each source and plotted a histogram of the ratio of the fractional spread between the two instruments. It appears that the fractional spread in I is, on average, roughly 1/10 of the spread found for EGRET, implying that the calculated statistics for AGILE sources will be more reliable than those calculated for EGRET.

3. Galactic Center Simulation

In order to produce preliminary quantitative estimates for the capacity of AGILE to detect Galactic point sources, we simulated a ten week AGILE observation of the Galactic center region. The details of the simulation are given in these proceedings (Vercellone et al.). All of the 3rd EGRET catalog sources were included with constant fluxes equal to the average flux from the catalog. No additional sources below the EGRET detection threshold were added. The counts and exposure maps were then analyzed using

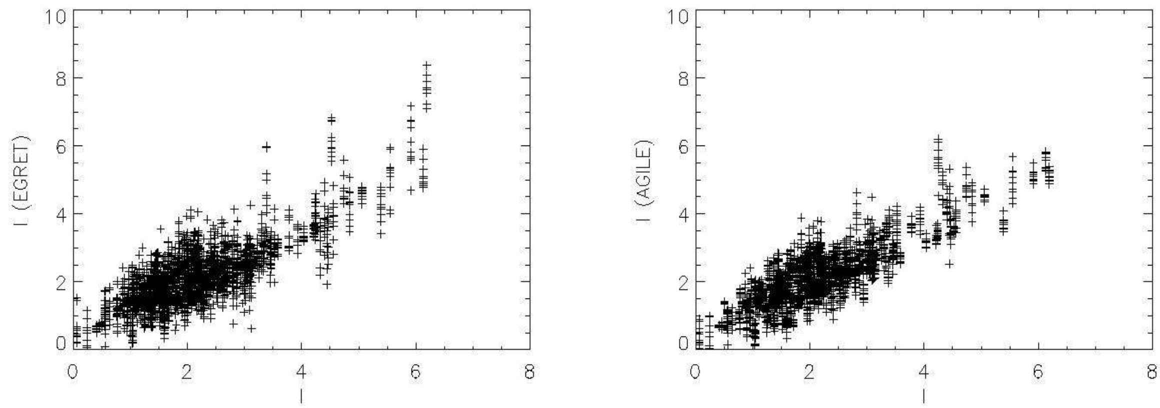

Fig. 1. Torres statistic calculated from simulated source catalogs of EGRET and AGILE compared to actual value.

an iterative maximum likelihood procedure, with point source location left as a free parameter for each source, but with initial locations provided by the EGRET source catalog positions rather than a blind search for the maximum test statistic. The region of interest was confined to a 40° radius around the galactic center and a single power law with index −2.1 was assumed for all point sources, in order to simplify the analysis by assuming a uniform point spread function. The sources were detected and added to the point source list in descending order of flux. After each detection the point source list was re-iterated until convergence. The process ended when the newest detected source failed to reach the detection threshold for point source location. The resulting counts map with detected sources is shown in Figure 2. Out of 90 sources within the region of interest, 70 were detected. In a more detailed simulation with added sources below the threshold we would expect the total number of detected sources to be roughly comparable to that of EGRET.

For each source we measured the detection significance, flux, and source location radius and compared the results to the 3rd EGRET catalog. In most respects the AGILE performance for the 10-week observation is comparable to the performance of EGRET for the 4-year period of the 3rd EGRET catalog. As shown in Figure 3, the source location radii are markedly improved at high latitudes.

4. Population Studies

Many studies have appeared on the populations of gamma-ray sources. Following the work of Gehrels et al. we examine the contribution of AGILE to source population analysis, estimating the number of new sources AGILE may detect from each population. Gehrels et al. show that the EGRET sources comprise at least three distinct populations: a low latitude Galactic disk population, a high latitude population possibly associated with the Gould belt, and an isotropic, presumably extragalactic population.

We produced intrinsic (l, b, F) distributions for each of the three components such that, when convolved with the flux threshold map from the 3rd EGRET catalog the observed (l, b, F) distributions were consistent with those of the three Gehrels et al. components, with the identified sources added back in. We then convolved those source distributions with the sensitivity map for an AGILE one-year all-sky survey. The results are shown in Table 1. We find that we expect almost no new low latitude sources, but

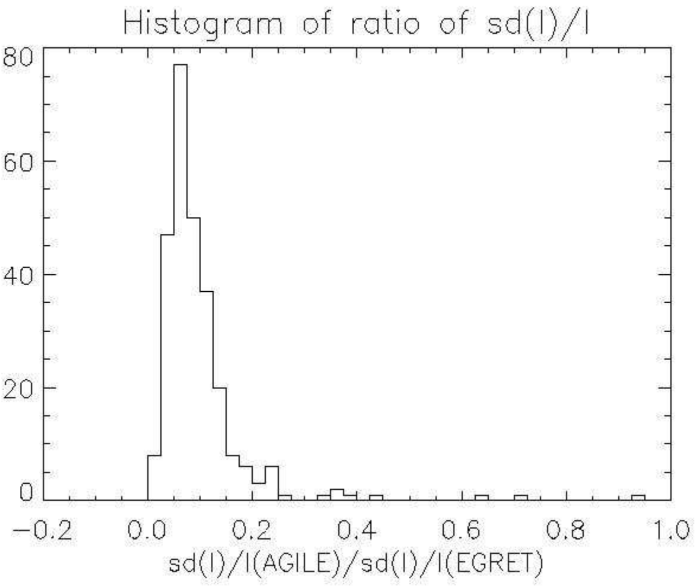

Fig. 2. Histogram of the ratio between the fractional spread in the Torres et al. statistic between simulated AGILE and EGRET catalog sources.

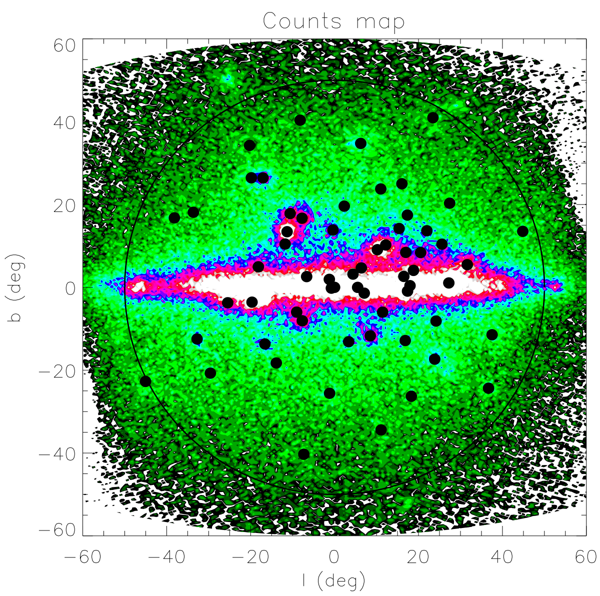

Fig. 3. Counts map for simulated 10 week AGILE observation of the Galactic center region. The AGILE field of view is indicated by the large circle; small filled circles are EGRET sources detected by AGILE.

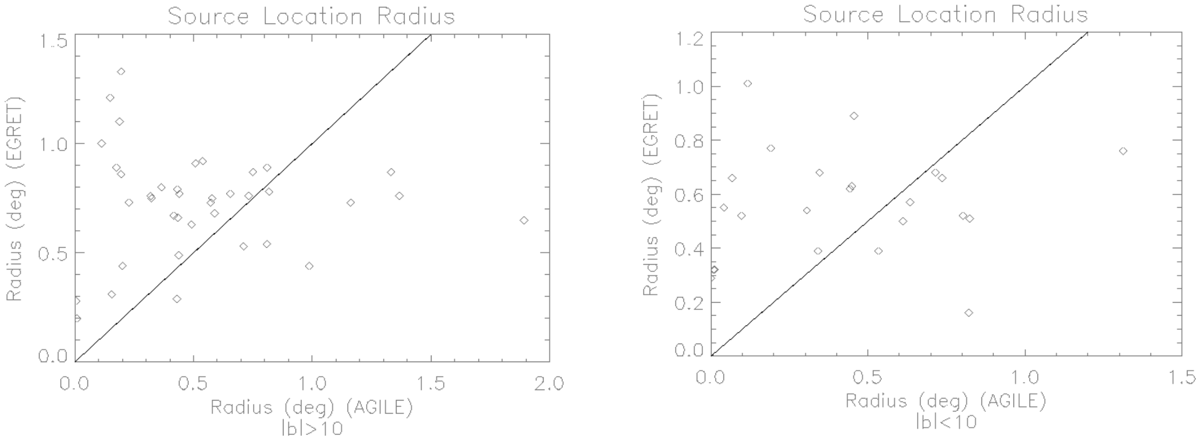

Fig. 4. Comparison of source location radii for EGRET and AGILE sources.

substantial increases in the high latitude and isotropic components. This effect is largely due to the wider field of view and more uniform exposure of the AGILE survey, since the peak sensitivity of the two instruments is comparable.

TABLE I
Population study: Results

Component	lN/lS	No. EGRET	min EGRET flux	No. AGILE	min AGILE flux
Isotropic	-1.43	151	4.0×10^{-8}	196	5.0×10^{-8}
High latitude	-2.9	83	5.0×10^{-8}	114	4.7×10^{-8}
Low latitude	rolloff	371	2.4×10^{-7}	38	2.1×10^{-7}

5. Prospects for GLAST

The GLAST mission, set to launch in 2007, is a large area telescope with superior response at high (> 10 GeV) energies. With its increased effective area and angular resolution it will detect thousands of new point sources, at flux levels at least an order of magnitude lower than EGRET and GLAST. The same characteristics will yield new point source identifications, especially in confused regions and regions containing extended emission. For example, many supernova remnants may contain both a point source such as a pulsar and extended emission arising from shock-accelerated cosmic rays interacting with interstellar gas; also, Population I regions associated with both potential source concentrations and bright interstellar emission. With the ability to detect faint sources, GLAST also has the potential to find entirely new classes of gamma ray sources.

6. Conclusions

With AGILE it will be possible for the first time to measure the variability of individual sources reliably. In addition to quantifying the variability of different source classes, we can begin to characterize the duty cycles and constrain emission models. Improved source location and higher detection significance for some sources will constrain and in some cases define new source identifications, as well as confirming EGRET sources and detecting new ones. These identifications and detections will help to constrain models of Galactic source populations.

GLAST will produce many new sources and new identifications, especially at high energies. Dense population I regions will be resolved, and new source classes will open up the possibility of new physics.

Acknowledgements

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