The IPN Supplement to the Fermi GBM Catalog

An AO-2 & 3 Guest Investigator Project

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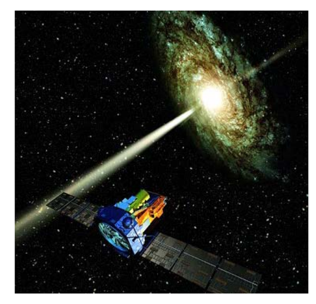
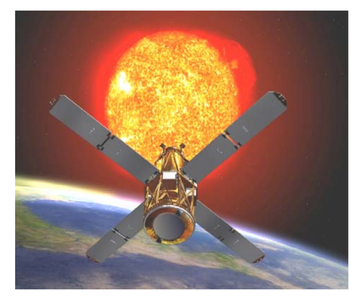
Mars Odyssey

Suzaku



INTEGRAL



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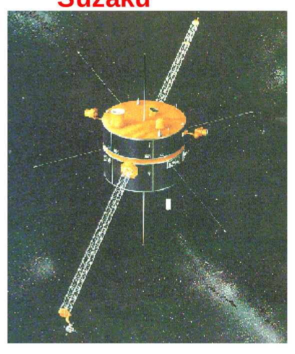

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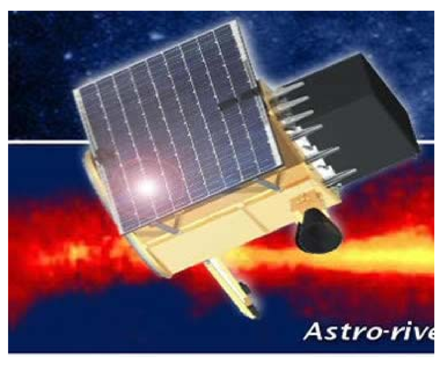

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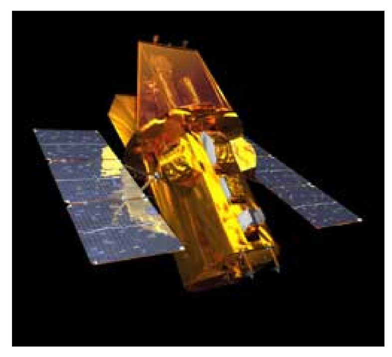
Fermi



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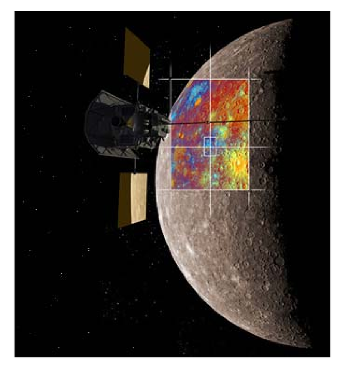

MESSENGER

SUMMARY: In the first two years of operation of the Fermi GBM, the 9-spacecraft Interplanetary Network (IPN) detected 158 GBM bursts with one or two distant spacecraft, and triangulated them to annuli or error boxes. Combining the IPN and GBM localizations leads to error boxes which are up to 4 orders of magnitude smaller than those of the GBM alone. They support a wide range of scientific investigations.

The IPN presently comprises AGILE, *Fermi*, RHESSI, *Suzaku*, and *Swift*, in low Earth orbit; INTEGRAL, in eccentric Earth orbit with apogee 0.5 light-seconds; *Wind*, up to 7 light-seconds from Earth; MESSENGER, in orbit around Mercury, up to ~700 light-seconds from Earth, and *Mars Odyssey*, in orbit around Mars, up to ~1200 light-seconds from Earth. It operates as a full-time, all-sky monitor for transients down to a threshold of about $6x10^{-7}$ erg cm^{-2}, or 1 photon cm^{-2} s^{-1}, and detects about 325 cosmic gamma-ray bursts per year. These bursts are generally not the same ones detected by more sensitive imaging instruments such as Swift BAT, INTEGRAL IBIS, SuperAGILE, and MAXI. The IPN localization accuracy is in the several arcminute and above range. The current burst detection rate of ~325/year does not include magnetar bursts, to which the IPN is also sensitive.

We have now completed a preliminary analysis of the first two years of *Fermi* GBM data (July 14 2008 – July 14 2010). In this period, the GBM reported approximately 500 GRBs. Of them, 158, or about 32%, could be triangulated using IPN data from one or more distant spacecraft, often in conjunction with Konus-Wind, to provide either a narrow error annulus or an error box. A few examples are shown in figure 1. 10 of the 158 were observed by the LAT; the IPN annuli have widths which are comparable to or less than the LAT error circle diameters. 30 of the 158 were independently localized by the *Swift* BAT or by Super-AGILE; these events are useful as end-to-end calibrations of the IPN.

If the triangulation is coarse (several degrees) it can be used in conjunction with the GBM localization to produce a joint error box whose area is smaller than that of either one by itself. When it is more accurate, it can also be used to refine the GBM systematic errors. Since the IPN detects and localizes the stronger bursts, for which the GBM systematic uncertainties tend to dominate the statistical ones, IPN events are particularly useful for understanding these effects. This is analogous to the role which the IPN played in the BATSE era.

IPN GRBs are being used to study polarization, to search for neutrinos, gravitational radiation, and VHE gamma-ray emission, to search for associations with supernovae, and to determine whether high-B radio pulsars emit SGR-like bursts, among other projects. Studies such as these do not require rapid localizations, or the identification of optical or X-ray counterparts, and constitute an alternative approach to the use of GRBs as astrophysical tools. They benefit from using the large IPN database, which contains localizations of bursts which in general are more intense than those observed by imaging instruments, and therefore, on the average, closer (the average redshift of an IPN burst is 1.8±1.2).

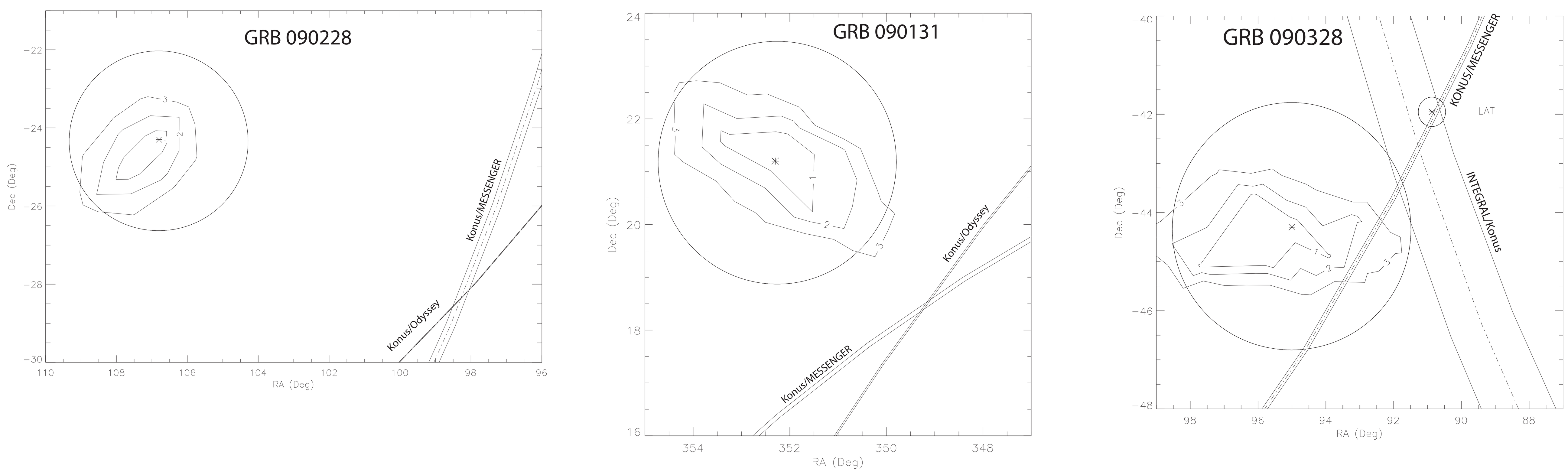

Figure 1. Three examples of bursts from the IPN Supplement to the GBM 2-year catalog. The figures show the 1, 2, and 3 σ GBM contours. The circles are approximations to the 1 σ contours, with a 2° systematic uncertainty added. Asterisks indicate the most likely positions. The annuli represent the IPN 3 σ confidence regions; the spacecraft used to derive them are labelled. In some cases, the IPN and GBM error regions do not intersect. These cases are being investigated for possible GBM systematic uncertainties. The LAT error circle is also indicated for GRB090328.

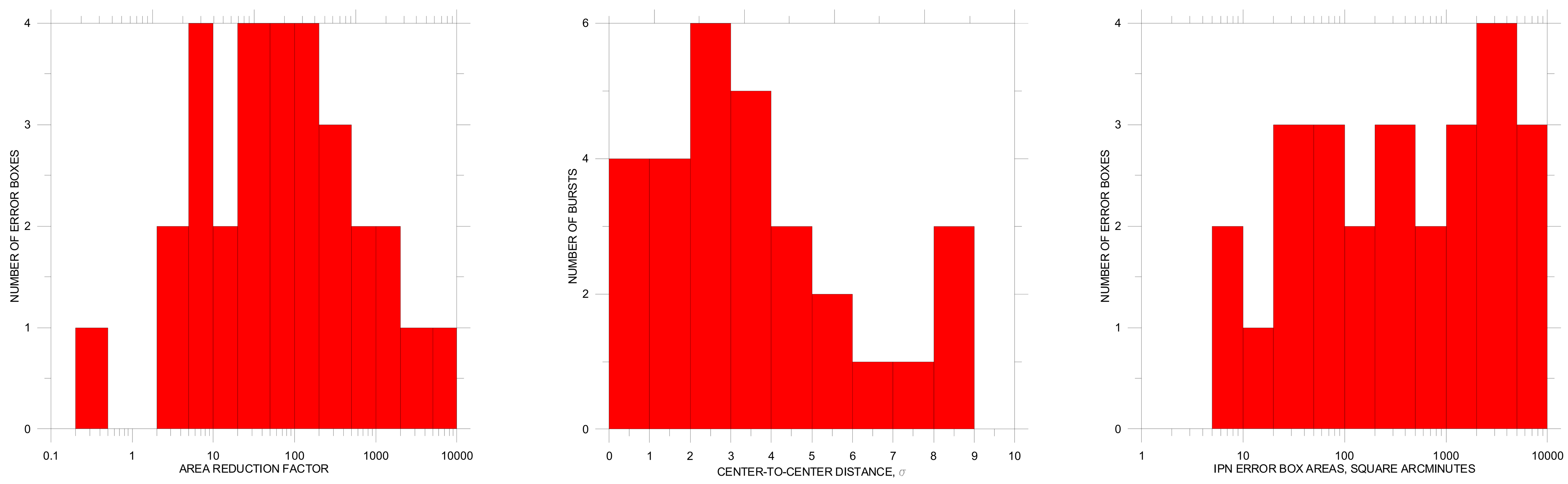

Figure 2. The statistics of 30 IPN-enhanced GBM localizations. Left hand panel: the area reduction factor, defined as the ratio of the 1σ statistical-only GBM error circle area to the 3σ IPN error box area. Note that reductions of up to 4 orders of magnitude are possible. Middle panel: the distance between the most likely GBM position and the center of the IPN error box, measured in units of the GBM 1σ (statistical only) error radius. This illustrates the need for a systematic error component in some of the GBM localizations. Right hand panel. The IPN 3σ error box areas.

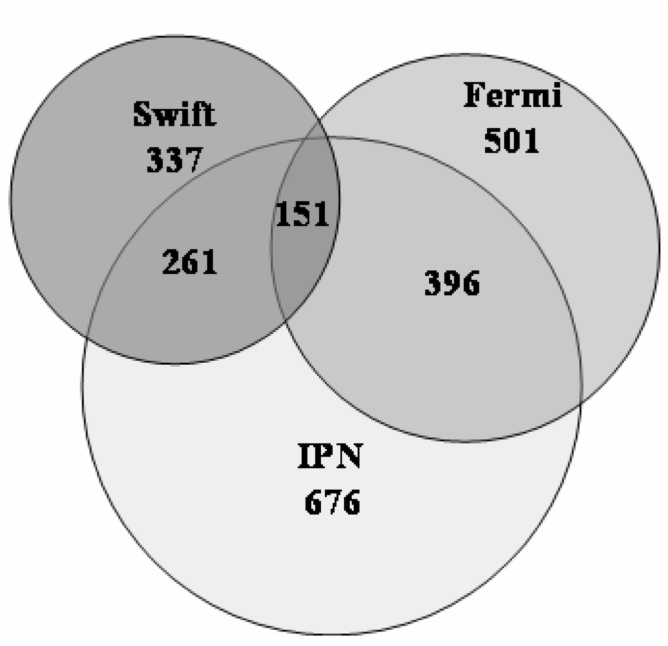

Figure 3. Venn diagram (not to scale) showing the numbers of *Swift*, IPN, and *Fermi* bursts during the first two years of operation and their relation. The *Swift* bursts are those both inside and outside of the BAT coded FoV. IPN instruments observed 396 of the *Fermi* bursts, of which 158 involved one or more distant spacecraft (Odyssey or MESSENGER).