Searching for neutrino and ultra-high-energy gamma ray counterparts of gamma-ray bursts and neutrinos on the GCN/TAN

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The Gamma-ray Coordinates Network (GCN) — a system that distributes information about gamma-ray bursts, transients.

*It is not yet possible to give a definitive start date for O4*

https://www.ligo.org/scientists/GWEMalerts.php (04.06.21)
Types of Alerts

• GCN Notices (machine-readable) — short text messages with information about the event, distributed through socket. They can be formed both in real time and by people.
• GCN Circulars (human-readable) — messages formed by people. Distributed through email.

Alert contents

• Socket packets contain 40 fields
• Necessary information:
  1) Packet type (which setup/spacecraft is the origin)
  2) Date TJD
  3) Time UTC, SOD
  4) Coordinates RA, Dec, Error
## General information

<table>
<thead>
<tr>
<th>Type of alert</th>
<th>№ of packet</th>
<th>Epoch</th>
<th>Time delay</th>
<th>Location accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWIFT_BAT_GRB_POSITION</td>
<td>61</td>
<td>J2000</td>
<td>13-30 sec</td>
<td>1-3 arcmin</td>
</tr>
<tr>
<td>INTEGRAL_WAKEUP</td>
<td>53</td>
<td>Current</td>
<td>~1 min</td>
<td>&lt;4 arcmin</td>
</tr>
<tr>
<td>INTEGRAL_REFINED</td>
<td>54</td>
<td>Current</td>
<td>1-2 min</td>
<td>&lt;4 arcmin</td>
</tr>
<tr>
<td>INTEGRAL_OFFLINE</td>
<td>55</td>
<td>Current</td>
<td>1-3 hr</td>
<td>&lt;4 arcmin</td>
</tr>
<tr>
<td>FERMI_GBM_FLT_POS</td>
<td>111</td>
<td>J2000</td>
<td>~10 sec</td>
<td>~20 deg</td>
</tr>
<tr>
<td>FERMI_GBM_GND_POS</td>
<td>112</td>
<td>J2000</td>
<td>20-300 sec</td>
<td>1-10 deg</td>
</tr>
<tr>
<td>FERMI_GBM_FIN_POS</td>
<td>115</td>
<td>J2000</td>
<td>~2 hr</td>
<td>1-3 deg</td>
</tr>
<tr>
<td>FERMI_LAT_GRB_POS_UPD</td>
<td>121</td>
<td>J2000</td>
<td>2-32 sec</td>
<td>60-120 arcmin</td>
</tr>
<tr>
<td>FERMI_LAT_GND</td>
<td>127</td>
<td>J2000</td>
<td>4-8 hr</td>
<td>10-60 arcmin</td>
</tr>
<tr>
<td>FERMI_LAT_OFFLINE</td>
<td>128</td>
<td>J2000</td>
<td>4-8 hr</td>
<td>10-60 arcmin</td>
</tr>
<tr>
<td>HAWC_BURST_MONITOR</td>
<td>171</td>
<td>J2000</td>
<td>0.5-1 min</td>
<td>0.4-0.8 deg</td>
</tr>
<tr>
<td>ICECUBE_ASTROTRACK_GOLD</td>
<td>173</td>
<td>J2000</td>
<td>0.5-1 min</td>
<td>0.2-0.75 deg</td>
</tr>
<tr>
<td>ICECUBE_ASTROTRACK_BRONZE</td>
<td>174</td>
<td>J2000</td>
<td>0.5-1 min</td>
<td>0.2-0.75 deg</td>
</tr>
</tbody>
</table>
SWIFT_BAT_GRB_POSITION

BAT_Position alerts are issued once per burst. This notice type does also contain detections of hard x-ray transients. There is both flight- and ground-software in place to correctly identify bursts from transients. If, after ground-processing with humans-in-the-loop, the initial "burst" identification is determined to be incorrect, then a Retraction notice will be issued. The combination of the flight s/w identification code and the ground-processing identification code is 98% accurate (i.e. only 2% false positives: said it was a real GRB when it was not).

Energy range 15-150 keV
INTEGRAL_WAKEUP/REFINED/OFFLINE

- WAKEUP packets are issued only once per burst, but may not be present for all bursts. This type of Notice comes first in the sequence of Notices on the burst. Since it is based on the least amount of data in the processing, it has the lowest significant in the localization and lowest confidence in the burst-vs-nonburst identification. These WAKEUP Notices come from automated ground processing.
- REFINED packets are issued only if there is more data with an increased significance that improves the detection and localization of the burst. There can be 0 to N of these Notice for each burst. These REFINED Notices come from automated ground processing.
- OFFLINE packets are generated manually by ground personnel. The OFFLINE Notice represents the final confirmation (or rejection) of a GRB and contains the most accurate GRB properties.

Energy range 15 keV-10 MeV

INTEGRAL spacecraft, www.cosmos.esa.int/web/integral/mission-overview
GBM_Flight_Position - positions are calculated by the on-board Flight software in real time. They are issued 1 to 5 times per burst. It contains detections of both GRBs and hard x-ray transients. There is both flight- and ground-software in place to correctly identify bursts from transients.

GBM_Ground_Position - positions are calculated by automated ground software as soon as they are received on the ground in real time. More sophisticated algorithms can be applied to the data to improve the location accuracy. There can be 0, 1, or more instances of this Notice Type per trigger.

GBM_Final_Position Notice - humans are involved in the analysis. They will be issued for the 10-20% brightest of the GRBs.

Energy range
10 keV-25 MeV

Placement of the GBM on Fermi.
https://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/Cicerone_Introduction/GBM_overview.html
LAT_Position_Update - positions come from the LAT flight software in real time.

LAT_Position_Ground - (delayed) positions come from the LAT ground processing where more sophisticated algorithms and data are used. This automated processing refines the position for on-board triggered events, and scans the total stream of LAT events applying trigger criteria looking for bursts that did not trigger on-board.

LAT_Position_Offline - (delayed) positions come from the LAT ground-processing software plus human inspection/refinement of the results. They are issued only once (rarely twice) per ground-detected burst.

Placement of the GBM on Fermi.
https://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/Cicerone_Introduction/LAT_overview.html

Energy range 20 MeV-300 GeV
HAWC_BURST_MONITOR contains alerts from short time-scale searches looking for GRBs. The search is done using fixed-width sliding time windows in all points in the sky within 50 degrees from HAWC’s zenith angle.

Energy range 300 GeV-100 TeV

HAWC observatory, www.hawc-observatory.org
ICECUBE_ASTROTRACK_GOLD/BRONZE contain a single high-energy IceCube track neutrino event directions.

For the ICECUBE_ASTROTRACK GOLD notice type; the occurrence rate is about 12/yr; >50% are astrophysical.

For the ICECUBE_ASTROTRACK BRONZE notice type; the occurrence rate is about 16/yr; >30% are astrophysical.

Energy range 100 GeV-10^9 GeV
Real-time data analysis

GCN alert

Search for neutrino events/GRB within ± 500s from the moment of the "alert" event

- No event
- There is an event

Check if "alert" event is in the field of view of BUST/Carpet

- No overlap
- There is overlap

There is overlap

- Fluence limit

No overlap

Neutrino from the lower hemisphere / gamma-ray burst

Search for "alert" events within ± 500s from the moment of the neutrino/GRB event

- There is an event
- No event

Comparison of the position of the source from the alert with the coordinates of the neutrino/GRB event on the BUST/Carpet

- No counterpart
- There is counterpart

There is counterpart

Sending alert with the neutrino/GRB source position
Alert processing

Fluence limit

\[ I_{\text{lim}} = \frac{n_{90}}{\int_{E_{\text{min}}}^{E_{\text{max}}} I(E_\nu) \cdot S_{\text{eff}}(E_\nu) \, dE_\nu} \]

\[ F_{\text{lim}} = \frac{n_{90}\int_{E_{\text{min}}}^{E_{\text{max}}} I(E_\nu) \cdot E_\nu \, dE_\nu}{\int_{E_{\text{min}}}^{E_{\text{max}}} I(E_\nu) \cdot S_{\text{eff}}(E_\nu) \, dE_\nu} \]

Telescope area in different zenith, azimuth angles (muon crosses 3 or more planes)

\[ S_{\text{eff}}(E_\nu, \theta, \phi) = \sigma_{\nu N}(E_\nu) \cdot N_N \]

\[ I(E_\nu, \theta, \phi) = \frac{n_{90}}{\epsilon \cdot S_{\text{eff}}(E_\nu, \theta, \phi)} \]

\[ n_{90} = 2.3, \ \epsilon = 0.84 \]

\[ S_{T_{\text{min}}} = 72 \text{ m}^2 \]

\[ S_{T_{\text{max}}} = 217 \text{ m}^2 \]
Alert processing

**Fermi-GBM** 21/06/06, 03:56:02 UT, $I_{\nu\mu} = 57 \text{ cm}^{-2}, I_{\nu\bar{\mu}} = 112.2 \text{ cm}^{-2}$

**Fermi-LAT** 21/05/20, 19:07:02 UT, $I_{\nu\mu} = 62.1 \text{ cm}^{-2}, I_{\nu\bar{\mu}} = 122.2 \text{ cm}^{-2}$

**Swift-BAT** 21/06/03, 09:45:46 UT, $I_{\nu\mu} = 53.1 \text{ cm}^{-2}, I_{\nu\bar{\mu}} = 104.5 \text{ cm}^{-2}$

**IceCube** 21/03/22, 02:34:09 UT, $I_{\nu\mu} = 56 \text{ cm}^{-2}, I_{\nu\bar{\mu}} = 110.2 \text{ cm}^{-2}$

**HAWC** 21/05/07, 10:38:22 UT, $I_{\nu\mu} = 63.7 \text{ cm}^{-2}, I_{\nu\bar{\mu}} = 125.5 \text{ cm}^{-2}$

**INTEGRAL** No events in the field of view
Carpet-2 includes a 200 m$^2$ continuous central scintillator detector (Carpet); five outer detector stations with 9 m$^2$ of scintillator in each of them; and a 175 m$^2$ shielded muon detector. The muon detector is used to select candidate gamma-ray showers which are muon-poor [1,2,3]. Carpet's field of view is within zenith angle $<$40°.

In the near future Carpet will be connected to the GCN. GRB candidate events will be shared and used for counterpart search. Thus real time alert analysis will be fully operating.

Thanks for your attention!