Limits on Intrinsic VHE Emission from Gamma-Ray Bursts with the Milagro Observatory

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GRB Redshift Distribution

Number of GRBs vs Redshift (z)
Inverse Compton TeV Emission
EBL Absorption

Observed Photon Energy (eV) vs Optical Depth $\tau$
GRB Search
Implementation of the Weighted Analysis Technique

- Real time search.
- On the fly data selection.
- Search nine logarithmically spaced time intervals from 40 s to 3 hours duration.
- Rapid notification of any observed transients.
Results

Milagro data taken between May 2\textsuperscript{nd}, 2001 and May 22\textsuperscript{nd}, 2002 was analyzed for TeV transients of 40 s to 3 hours duration.

No evidence for TeV transient emission was observed.
History of the Online Search

Oct. 17th  online analysis starts in engineering mode.

Nov. 30th  online analysis becomes active at all times.

Dec. 12th  e-mail reporting and saving of GRBs starts.

Jan. 11th  data mode starts, stability much improved after tracking down a Linux kernel bug and a standard library bug.

Jan. 30th  version 1.0 of the search installed online incorporating several small improvements.

April 1st  analysis updated to track total exposure.

April 4th  last bug fix.
Probability Distributions for April 2\textsuperscript{nd} - May 22\textsuperscript{nd}, 2002
Removal of Poor Data from Offline Data Set

Example Distribution

-\log_{10}(\text{Raw Probability})

<table>
<thead>
<tr>
<th>File Set Removed</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002_04_07_10.11.IDL</td>
<td>2560 s and longer time scales had poor distributions</td>
</tr>
<tr>
<td>2002_04_09_05.22.IDL</td>
<td>640 s and longer time scales had poor distributions</td>
</tr>
<tr>
<td>2002_04_09_07.04.IDL</td>
<td>1280 s and longer time scales had poor distributions</td>
</tr>
<tr>
<td>2002_04_21_23.19.IDL</td>
<td>160 s to 2560 s scales had poor distributions</td>
</tr>
<tr>
<td>2002_04_23_06.00.IDL</td>
<td>160 s to 640 s scales had poor distributions</td>
</tr>
<tr>
<td>2002_04_24_06.00.IDL</td>
<td>all time scales had very poor distributions</td>
</tr>
<tr>
<td>2002_04_26_09.27.IDL</td>
<td>640 s to 2560 s scales had poor distributions</td>
</tr>
<tr>
<td>2002_05_02_06.00.IDL</td>
<td>4 long alerts from different locations during this day</td>
</tr>
<tr>
<td>2002_05_02_22.21.IDL</td>
<td>4 long alerts from different locations during this day</td>
</tr>
</tbody>
</table>
Probability Distributions for May 2\textsuperscript{nd}, 2001 – March 1\textsuperscript{st}, 2002
Total Probability Distributions
## Total Exposure Time

<table>
<thead>
<tr>
<th>Search Duration (s)</th>
<th>Total Exposure (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 s</td>
<td>290.2</td>
</tr>
<tr>
<td>80 s</td>
<td>290.2</td>
</tr>
<tr>
<td>160 s</td>
<td>290.0</td>
</tr>
<tr>
<td>320 s</td>
<td>289.7</td>
</tr>
<tr>
<td>640 s</td>
<td>289.2</td>
</tr>
<tr>
<td>1280 s</td>
<td>288.1</td>
</tr>
<tr>
<td>2560 s</td>
<td>286.1</td>
</tr>
<tr>
<td>5124 s</td>
<td>282.2</td>
</tr>
<tr>
<td>10240 s</td>
<td>275.7</td>
</tr>
</tbody>
</table>
Determining Limits with the Weighted Analysis Technique

The response of the detector and analysis chain is determined by the photon probability densities $p_i$ added to the sky map. The response is represented by the three dimensional histogram:

$$g(p_i, \theta_j, E_k)$$

The response to a single event can be determined by choosing a probability density according to:

$$P_s(E_k)g(p_i, \theta_s, E_k)$$

The response of the detector to a signal is then given by:

$$\omega_s = \sum_{i=0}^{N_s} p_i$$
Observer Frame Limits

The signal strength $J$ at which Milagro will detect 90% of the events

$$\frac{dN}{dE} = J \left( \frac{E}{E_0} \right)^{-\alpha}$$

where $J$ is in units of photons/s/cm$^2$/TeV.
Observer Frame Limits

-2.0 Spectrum

Total Error +44%/-27%
Intrinsic Limits

The frequency of TeV emitting GRBs at a given intrinsic luminosity at which Milagro has a 90% chance of seeing at least one burst. Because of the distance and energy dependence of the EBL absorption, this is highly model dependent. For this example the model parameters are:

- EBL absorption given by James Bullock, based on a flat ΛCDM cosmology with $\Omega_M = 0.3$ with collisional star formation and Kinnicut IMF. (New numbers are imminent)
- GRBs trace the SFR. (SFR changes significantly)
- Flat ΛCDM cosmology for determining comoving volume and the luminosity distance. These are used to determine the number of GRBs as a function of redshift and the apparent luminosity.
- -2.0 emitted spectrum at TeV energies.
EBL Absorption

Observed Photon Energy (eV) vs. Optical Depth $\tau$

- Optical Depth values: 0.01, 0.02, 0.04, 0.08, 0.16, 0.32, 0.64, 1.28

- Energy range: $10^{10}$ to $10^{14}$ eV
Intrinsic Limits vs. GRB Duration

Intrinsic Upper Limit

GRBs per year per Mpc$^3$

$10^{-7}$

$10^{-8}$

$10^{-9}$

$10^{-10}$

$10^{-11}$

$10^{-12}$

$10^{-13}$

Log$_{10}$ GRB Duration in Seconds

$10^1$

$10^2$

$10^3$

$10^4$

$10^5$

GRBs per Solar Mass of Star Formation

$10^{50}$ ergs/s

$10^{51}$ ergs/s

$10^{52}$ ergs/s
Intrinsic Limits vs. Isotropic Luminosity

Log_{10} Isotropic TeV Luminosity ergs/s

GRBs per Solar Mass of Star Formation

- 160 s
- 80 s
- 640 s
- 40 s
- 5120 s
- 1280 s
- 320 s
Conclusion

• This search for 40 s – 3 hour VHE transient emission observed by Milagro between May 2\textsuperscript{nd}, 2001 and May 22\textsuperscript{nd}, 2002 represents the most sensitive search for moderate duration unidentified VHE transients yet performed.

• Due to uncertain model parameters and EBL absorption, no model independent limits can be set. Limits for local emission and a model where GRBs trace the SFR are presented.

• First intrinsic limits on VHE GRB emission.
Publishing

How do we want to publish this?