GRB010921 in Milagro

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1 Introduction

This is the first HETE burst with a measured afterglow. It has a redshift of z=0.45. The WXM camera on HETE detected a burst which lasted for 12 seconds with a fluence of 1e-6 erg in the 8-85 keV band. The FREGATE detector on HETE also saw this burst: this instrument is sensitive at higher energies than the WXM. It saw a burst with duration 23.3 seconds. They measured a fluence in the 8-400 keV band of 1.5e-5 erg/cm^2 and in the 30-400 keV band of 1.1e-5 erg/cm^2.

This was the first HETE burst with an optical afterglow. Spectroscopy of the host galaxy indicates that this burst was at a redshift of z=0.45. Hubble observations of the optical afterglow, show that it lies on the outer edge of the galaxy. From our point of view, the burst position is sufficiently well known, that we can look just at one position.

2 Our Results

The burst was at a zenith angle of 10.3 degrees at Milagro. I looked at this burst with an analysis with nfit>20 and with and without an X2 cut. I used a 1.2 degree circular bin at the GRB location.

2.1 Simulations

I used our gamma3.0 simulations thrown on a E-2.4 spectrum. The effective areas I am quoting here are:

$$A_{eff} = (N_{cut}/N_{tot})A_{throw} \tag{1}$$

Where N_{cut} are the number of events which trigger (55 air shower tubes) and pass all analysis cuts (nfit >20, delangle <1.2 etc) and A_{throw} is the area over which the simulations were thrown (10^6m^2). I divided the MC into 3 zenith angle ranges 0-15, 15-30 and 30-45 degrees. Since the burst was at a zenith angle of 10 degrees, I will consider only the 0-15 degree range.

Our integrated (over energy) effective area from 100 GeV to 100 TeV at a zenith angle of 0-15 degrees is:

$525 \pm 17m^2$ without an X2 cut
$320 \pm 13m^2$ with an X2 cut

Since this is at a redshift of 0.45 we can crudely approximate the effect of the cutoff due to the IR background as a sharp cutoff at 150 GeV. I calculated our integrated (over energy) effective area from 100 GeV to 150 GeV. I chose 150 GeV based on the plot by

James Bullock (who was in Joel Primacks group) which shows for a variety of cosmological models, energy versus redshift lines where the opacity to pair production is one. i.e. I could find z=0.45 and obtain the energy where the opacity to pair production was one. For a zenith angle of 0-15 degrees our effective areas are:

$8 \pm 2m^2$ without an X2 cut and
$4 \pm 1m^2$ with an X2 cut

I looked at zenith angles from 0-15 degrees because for the simulations below 150 GeV I did not have enough triggers to bin things more finely in zenith angle. To get a feel for how large this effect might be, I looked at the effective area for no cutoff or X2 cut from zenith angles between 9–15 degrees. It was 510 m^2, which is consistent with the value of 525 m^2 measured for 0–15 degrees.

I also looked at simulations thrown from 10 to 100 GeV. The effective area from 10-100 GeV with and without the X2 cut was less than $1m^2$.

2.2 Data Analysis

2.2.1 12 second duration

Without X2 cut:
we see 18 signal events and 17.8 background. The 99% upper limit is 11.07 cnts. Our effective area integrated from 100 GeV to 150 GeV is 8+-2 m^2. Thus our 99% fluence upper limit is 1.35e-4 ph/cm^2. Assuming that these photons are at 150 GeV we can convert to an energy fluence of 3.3e-5 erg/cm^2. If we do not apply a cutoff at 150 GeV then our 99% upper limit is 1e-7 erg/cm^2 above 4 TeV.
With an X2 Cut:
We saw 3 signal events and 2.52 background events. The 99% upper limit is 7.97 cnts. The effective area integrated from 100 GeV to 150 GeV is 4+-1 m^2. Our 99% upper limit with the X2 cut is 4.8e-5 erg/cm^2. If we do not apply a cutoff at 150 GeV, then our 99% limit is 1.2e-7 erg/cm^2 above 4 TeV.

2.2.2 23.3 second duration

Without X2 cut:
There were 33 signal events and 34.7 background events. The 99% upper limit is 13.62 counts. Thus our 99% fluence upper limit for a spectrum truncated at 150 GeV is 4.1e-5 erg/cm^2 and for an untrucated spectrum is 1.2e-7 erg/cm^2 above 4 TeV
With X2 cut:
There were 8 signal events and 4.8 background events. The 99% upper limit is 13.37 counts. Thus our 99% fluence upper limit for a spectrum truncated at 150 GeV is 8.1e-5 erg/cm^2 and for an untrucated spectrum is 2.0 erg/cm^2 above 4 TeV.

3 How does this compare to HETE?

The HETE team in CESR sent us some spectral fits for this burst as measured by the FREGATE instrument. They fit a power-law spectrum to their data, i.e. $dN/dE = AE^{-\alpha}$, where α is the differential photon spectral index and A is the normalization. Objects which have $\alpha < 2$ emit more power at higher energies (i.e. the spectrum is rising if plotted on a spectral energy distribution plot). They measure of $\alpha = 1.7 \pm 0.23$, this implies that we would expect a higher fluence at GeV/TeV energies than at keV energies. We do not observe this.

They were also able to fit a broken power-law spectrum. The spectrum at below 165 keV was 1.4+/- 0.8, and the spectrum above 165 keV was 2.27 +/- 0.35. This spectrum was fit with around the same statistical significance as the straight power law fit.

4 GCN Circular

I think that it would be useful to send out a GCN circular reporting our result. This burst is particularly interesting because the TeV observations cannot simply be discounted by assuming that the photons are absorbed by the IR background. It is important to remind people that we are up and running and making interesting observations at teV energies. This will hopefully encourage people to extend their models up to our energies. GCN circulars are designed to be brief communications of results you can read then at http://gcn.gsfc.nasa.gov/gcn/gcn3_archive.html. I have written some words (below) that I think we should submit as a GCN circular

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SUBJECT: GRB 0100921 - Milagro GeV/TeV Observations

Someone on behalf of the Milagro collaboration reports:

Milagro observed GRB010921 at GeV/TeV energies during the burst
duration reported by the HETE WXM (GCN 1096). No evidence for GeV/TeV
emission was found. A preliminary analysis gives an upper limit on the
fluence at the 99% confidence level of:

J(E > 4 TeV) < 1 * 10^(-7) erg cm^(-2)

The spectrum of the host galaxy of the proposed afterglow of GRB010921
implies a redhift of 0.45 (GCN 1108). We expect that TeV photons will
be attenuated by pair production with infrared photons in
intergalactic space so we also calculated an upper limit on the fluence,
assuming a spectrum truncated at 150 GeV. in this case we
find a upper limit on the fluence at the 99% confidence level of:

J(100-150 GeV) < 3.3 * 10^(-5) erg cm^(-2)

These upper limits are preliminary and will be refined with further
analysis.
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