Search for GeV-TeV emission from GRB 080319B using the Milagro Observatory

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Summary

One of the brightest gamma-ray bursts every recorded, the “naked-eye” GRB 080319B was fortuitously located within the field of view of the Milagro observatory. No emission was seen by Milagro and upper limits on the prompt emission, that strongly constrain the popular single-zone synchrotron self-Compton model of gamma-ray bursts, are presented here.

Abstract

On March 19, 2008 NASA’s Swift satellite observed one of the brightest gamma-ray bursts ever recorded. With a peak visual magnitude of 5.3, GRB 080319B was dubbed the “naked-eye” burst. Due to the proximity in both time and space to GRB080319A, prompt emission from GRB 080319B was detected in both the optical and γ-ray bands by several wide-field instruments. Follow-up observations spanned 11.5 orders of magnitude in wavelength, making GRB 080319B one of the most well-studied gamma-ray bursts to date. A search for GeV-TeV emission from GRB 080319B is presented here. No evidence for emission is found. The fluence upper limits derived from the Milagro observations are incompatible with the standard synchrotron self-Compton model of gamma-ray bursts, which predicts a strong second order inverse-Compton peak at tens of GeV in the spectrum of GRB 080319B.

The Milagro Observatory

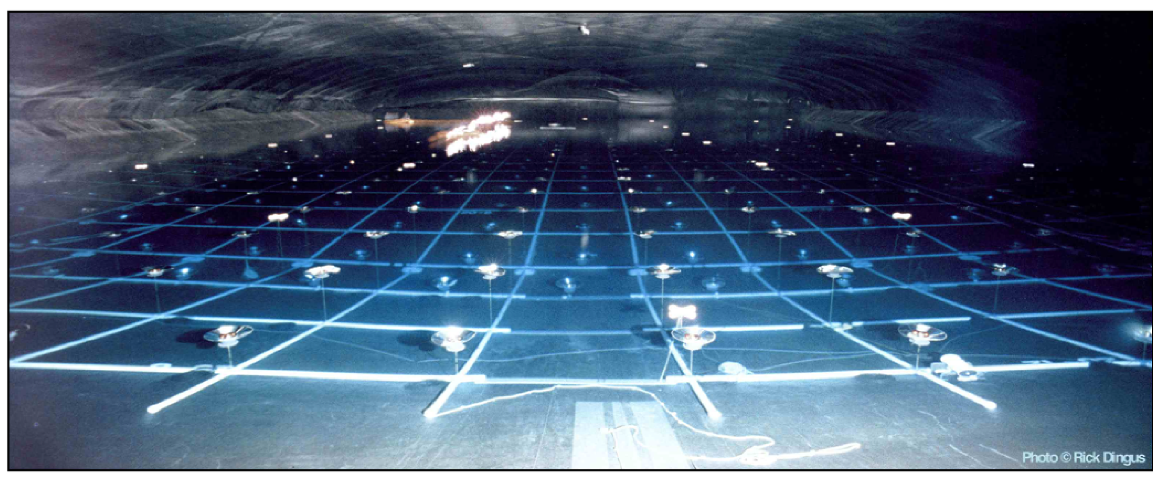

Figure 1: Inside the Milagro pond, with cover inflated

- Extensive Air Shower Array
- Central Pond
  - 450 PMTs submerged 1.5 m
  - 273 PMTs submerged 6 m
- Array of Outriggers - Single PMT in a small tank
- 2630 m a.s.l
- 2 sr FOV, >90% duty cycle
- 5000 m^2 pond, 40000 m^2 outrigger array
- Operated nearly continuously Jan. 2000 - May, 2008

Figure 2: (left) The Milagro observatory. (right) A cut-away outrigger.

References

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Acknowledgments

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GRB 080319B

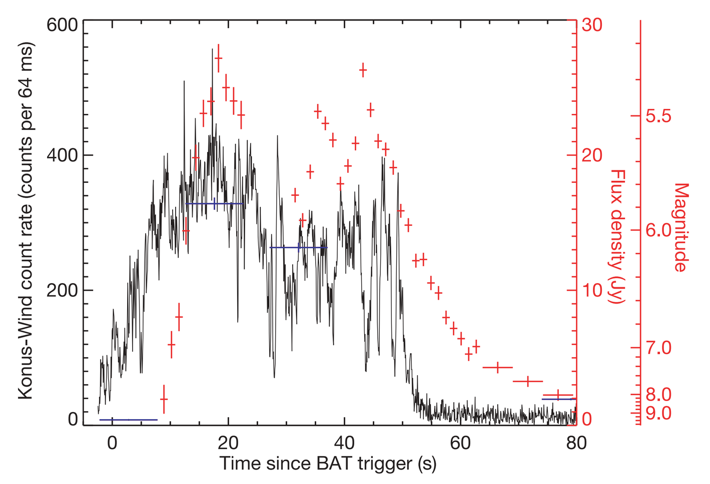

Figure 3: Prompt lightcurve of GRB 080319B from [4]. Black: Konus-WIND, Red: TORTORA, Blue: Pi of the Sky. The temporal coincidence of the onset and cessation in both the optical and gamma-ray emission indicate that both may originate at the same site.

- The most complete broadband coverage - due in large part to GRB 080319A
- Extremely bright - peak optical magnitude of 5.3
- Detected in γ-rays by Swift and Konus/WIND
- T_{90} = 60 s (50 - 150 keV)
- z = 0.937
- In the FOV of Milagro ($\sim 50^\circ$ elevation)

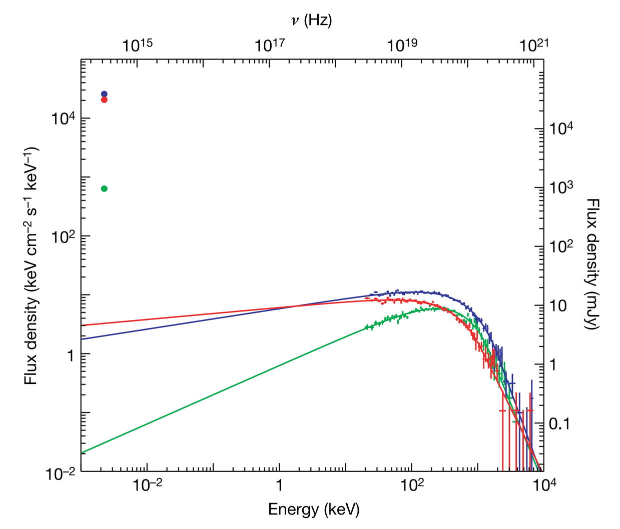

Figure 4: SED of the prompt emission, also from [4]. High energy points are Konus/WIND, with best fit Band functions for thre different time intervals (R,G,B). Low energy points are from “Pi of the Sky”. The four order of magnitude difference between the gamma-ray extrapolation and the optical suggests different radiation mechanisms.

A GRB model which explains the optical/MeV observations is the synchrotron self-Compton (SSC) model.

Milagro Observations

Two methods of Milagro data analysis:

- Standard event-by-event shower reconstruction
- “Scaler” or single-particle technique [5, 1]

Scaler Analysis:

- No shower reconstruction/angular resolution
- Sum counts from each PMT each second
- Search for rates above background coincident with GRBs
- Improved low-energy (<100 GeV) sensitivity

Flux limits on GRB 080319B:

- Testing the hypothesis of a synchrotron+SSC emission spectrum
- Second inverse Compton (IC) peak located at $\sim$GeV energies
- Second IC peak parameterized as a Band function [2] with α, β from well-measured first IC peak
- Intrinsic burst spectrum attenuated by EBL at high energies (Gilmore ’09)[3]

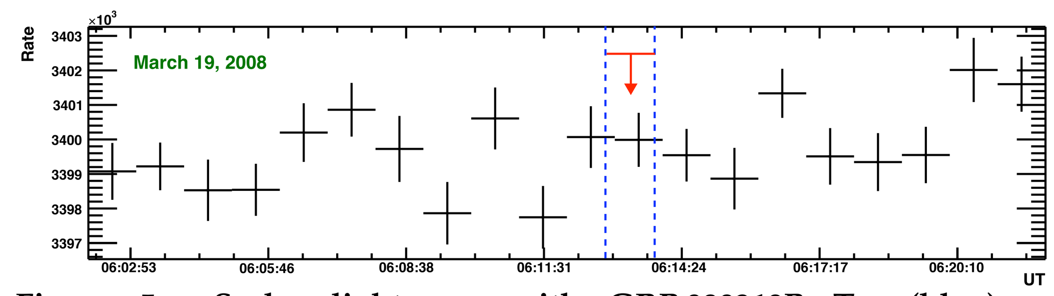

Figure 5: Scaler lightcurve with GRB 080319B T_{90} (blue) and the 99% confidence upper limit on the number of counts (red).

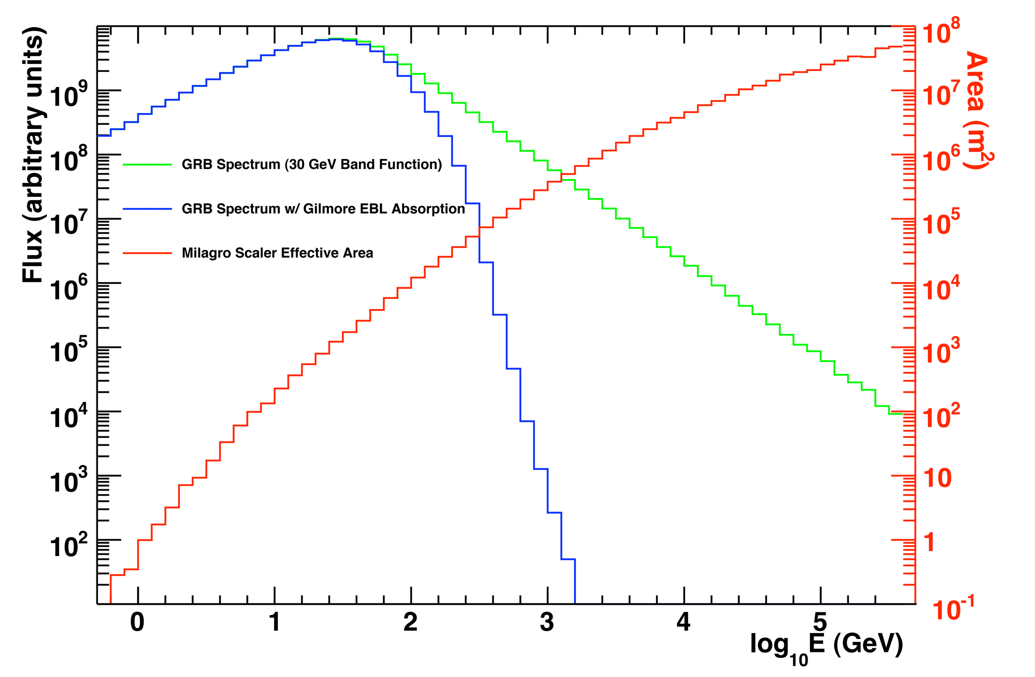

Figure 6: Milagro scaler effective area vs. energy (red), theoretical second-IC peak of GRB 080319B (E_{peak} = 30 GeV) (green), and the latter after factoring in absorption of VHE photons by the EBL model of Gilmore *et al.*[3].

Results

E_{peak} (GeV)	$E^2\,dN/dE$ (erg cm^{-2} s^{-1})	Y_2
3	$< 3.1\times10^{-4}$	26
10	$< 2.7\times10^{-5}$	7
30	$< 1.2\times10^{-5}$	3
100	$< 9.7\times10^{-6}$	2
300	$< 1.6\times10^{-5}$	4
1000	$< 4.6\times10^{-5}$	12

Table 1: Milagro scaler upper limits on the flux and corresponding Compton Y_2 parameter for several assumed values of the second IC E_{peak}.

- Standard SSC Model predicts:

$$E_{peak,IC2} \approx \frac{E^2_{peak,IC1}}{E_{peak,syn}} \approx 23\frac{20\,\mathrm{eV}}{E_{peak,syn}}\,\mathrm{GeV}$$

  - $E_{peak,IC2}$ is inversely related to $E_{peak,syn}$ which is not precisely determined

$$Y \sim \frac{\nu F_\nu(E_{peak,IC1})}{\nu F_\nu(E_{peak,syn})} \gtrsim 10$$

  - The amount of energy in the second IC peak should be at least 10 times that in the first IC peak
- Klein-Nishina effects important at

$$E \gtrsim 50\frac{\Gamma}{1000}\sqrt{\frac{20\,\mathrm{eV}}{E_{peak,syn}}}\,\mathrm{GeV}$$

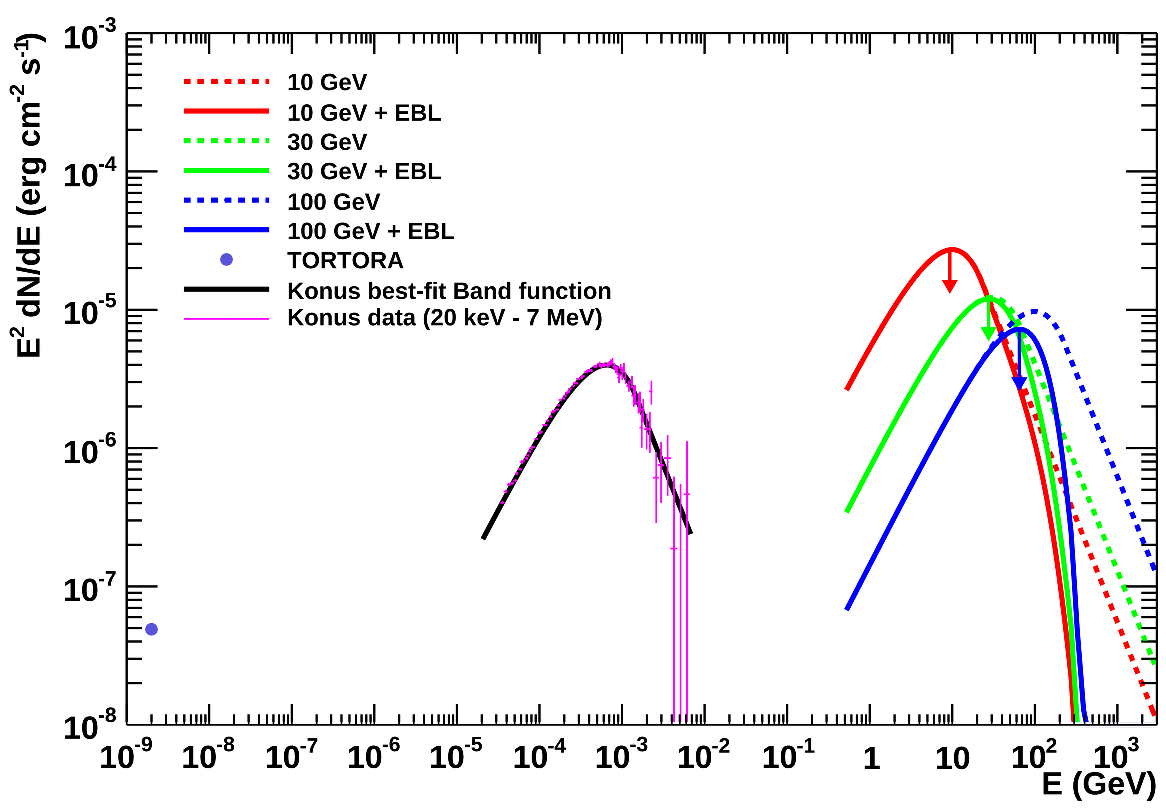

Figure 7: E^2 dN/dE plot of the prompt emission from GRB 080319B from TORTORA (optical) and Konus/WIND (MeV γ-rays). Included are the Milagro scaler upper limits on the second IC Band function peak.

- 99% confidence level U.L.s on GRB flux and Compton Y_2 parameter corresponding to E_{peak} values of the assumed Band spectrum where:

$$Y_2 = \frac{\nu F_\nu(E_{peak,IC2})}{\nu F_\nu(E_{peak,IC1})}$$

- SSC model constrained over a wide range of energies