Pair Attenuation Signatures in Evolving Gamma-Ray Burst Spectra

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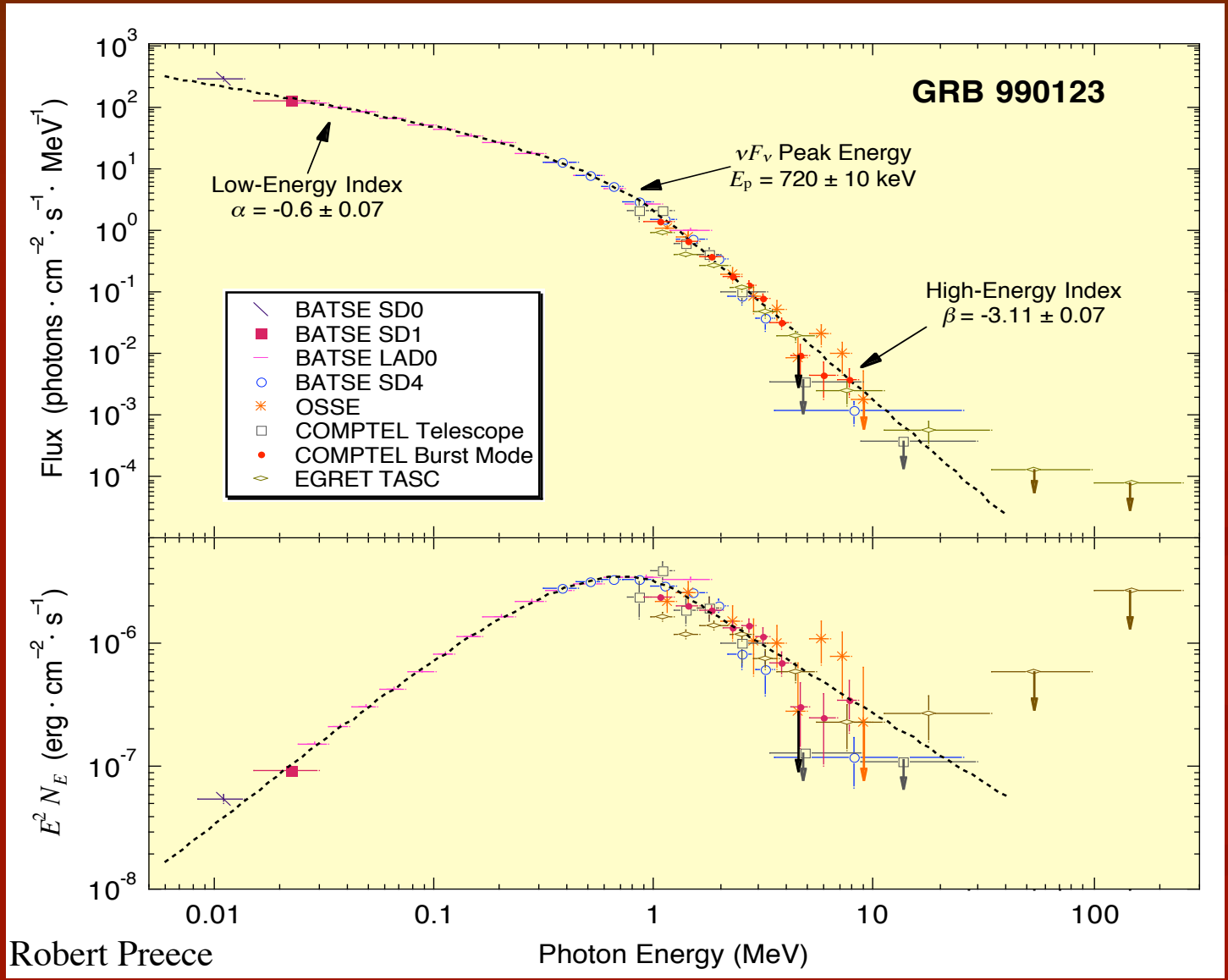
Internal Pair Creation Context

- Relativistic bulk motions with Gamma > 100 have been invoked for EGRET bursts to explain the absence of attenuation of their spectra above 100 MeV;
- This talk builds on extensive work by Baring & Harding in 1990s to tailor them for diagnostics in GLAST era;
- Baring (2006) explored time-dependent expectations for burst spectra in GLAST band, identifying distinctive trends for internal pair creation turnovers;
- Here we develop this work by delving into the interesting case of GRB 941017. This EGRET-TASC burst has exhibited (Gonzalez et al. 2003) strong evidence of a second component that peaks above 100 MeV; potential turnovers at higher energies are explored.

Spectral Character: GRB990123



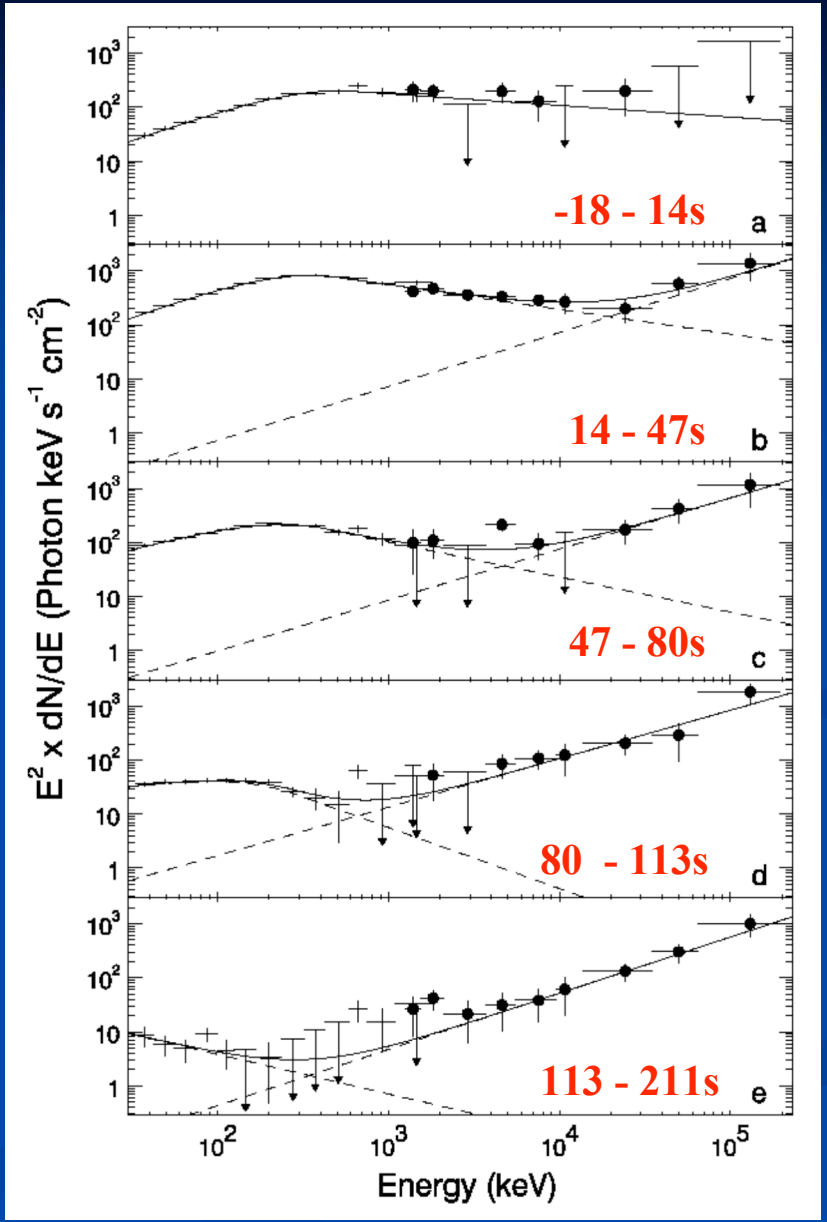
Credit: Robert Preece

See Band et al. poster P16.2 for projected GBM-LAT capability.

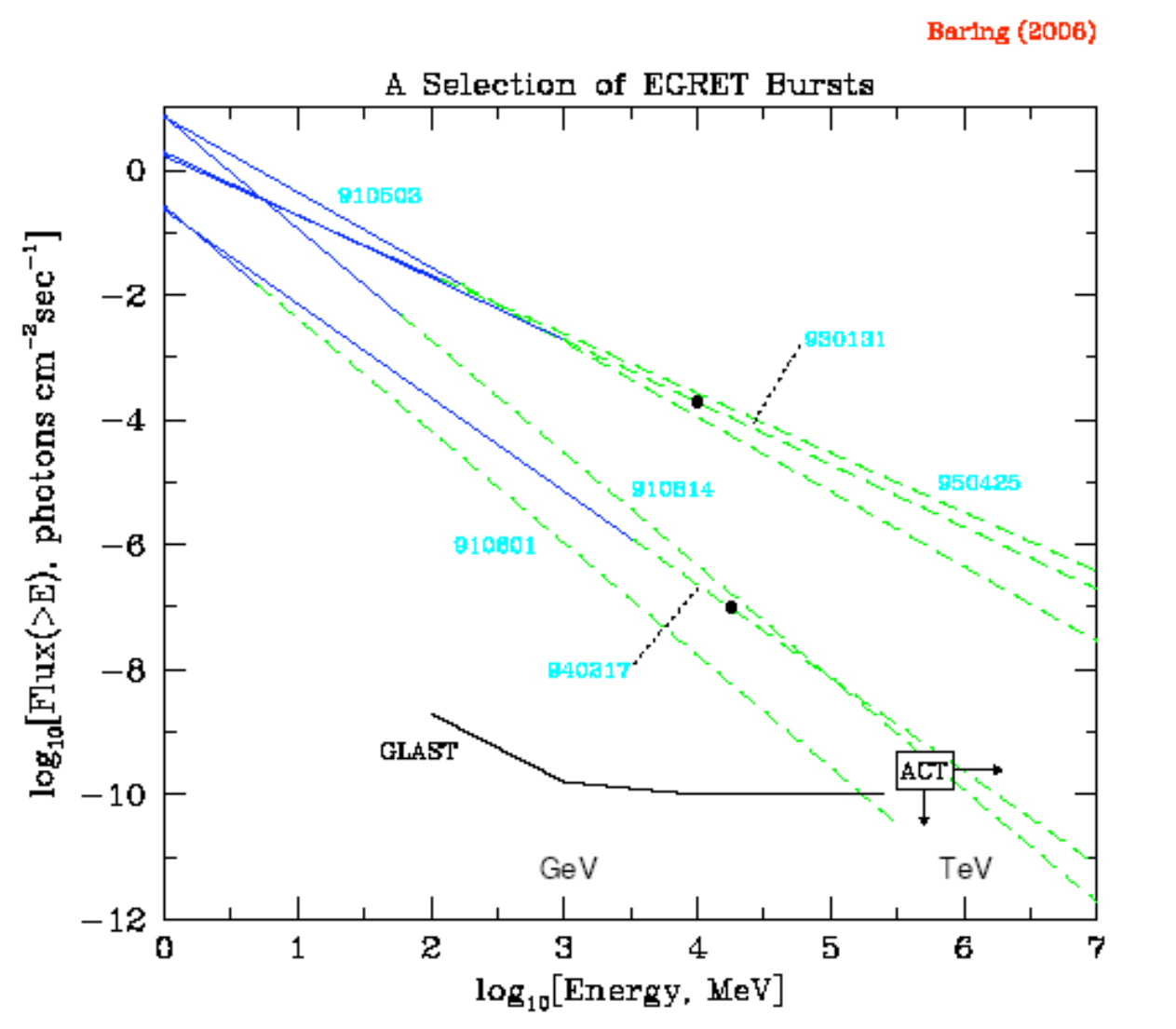
GRB 941017

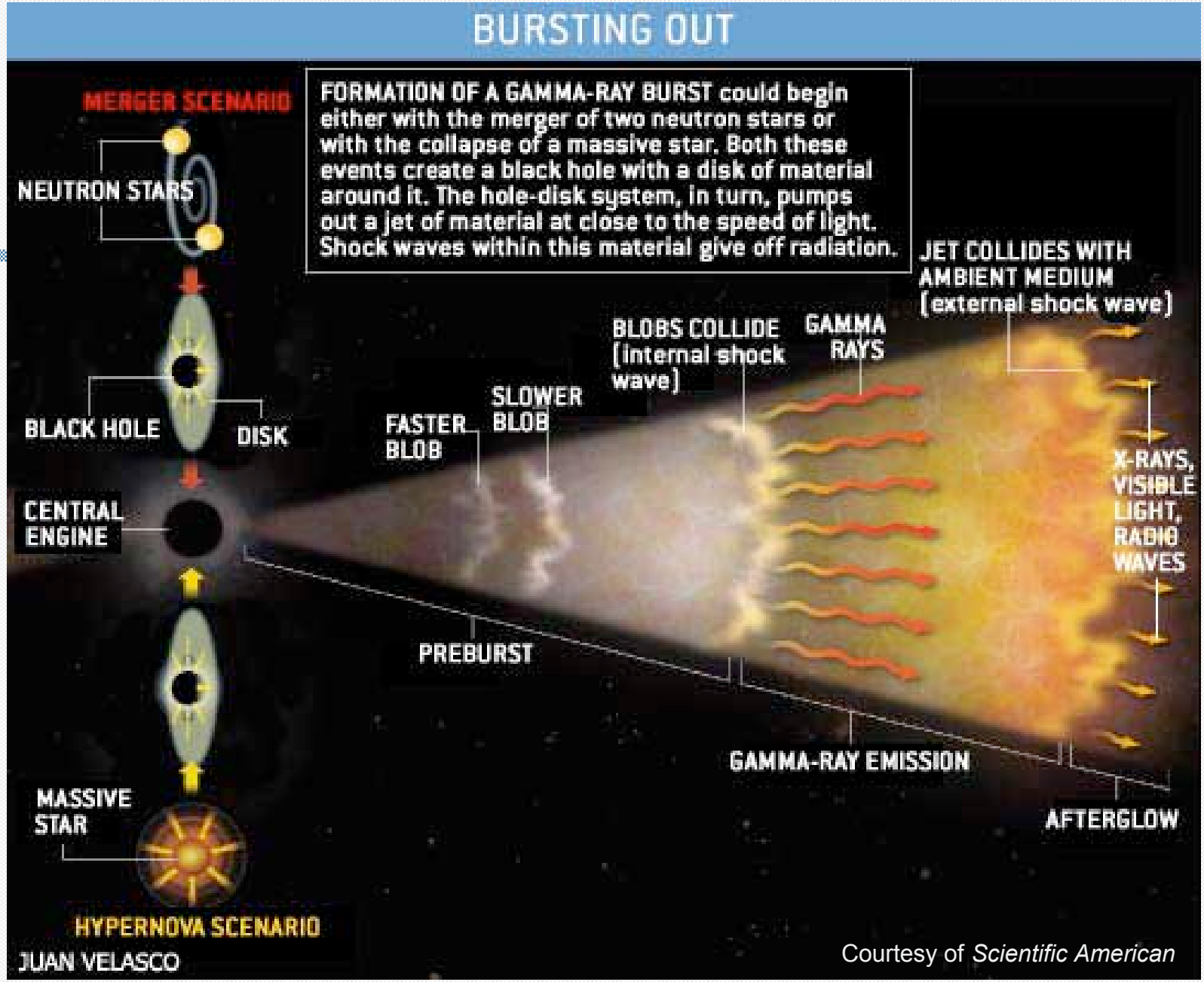
A new spectral component (Gonzalez et al. 2003)

- Duration ~150 seconds
- Photon spectral index ~ -1.
- Peak flux at > 200 MeV
- Fluence > 3*Fluence$_{<1\ MeV}$
- Temporal evolution different from the lower energy (synchrotron?) component;
- Explanation: inverse Compton models, or maybe reverse shock or hadrons.



High Energy Emission in EGRET Bursts





$$\text{Pair threshold: } 2(m_e c^2)^2 = E_1 E_2 (1-\cos\theta) \sim E_1 E_2 / 2\Gamma^2$$

Bulk Lorentz Factors from Internal Pair Creation Transparency Constraints

- Observation of GRB emission above 511 keV *implies transparency in the source to* $\gamma\gamma \rightarrow e^- e^+$.
  - Schmidt (1978) used this to argue for a distance scale $\lesssim 2\,\mathrm{kpc}$, assuming source isotropy, and no relativistic beaming.
- Cosmological association for GRBs led several groups (Krolik & Pier 1991; Fenimore et al. 1992; Baring 1993; Baring & Harding 1994, etc.) to argue for **relativistic bulk motion** with $\Gamma \gg 1$:

$$\tau_{\gamma\gamma} \propto n_\gamma \sigma_{\rm T} R \, \frac{\varepsilon_\gamma^{\alpha-1}}{\Gamma^{2\alpha}} \quad , \quad n_\gamma \propto \frac{\mathcal{F}(1\mathrm{MeV})}{R^2} \quad ,$$

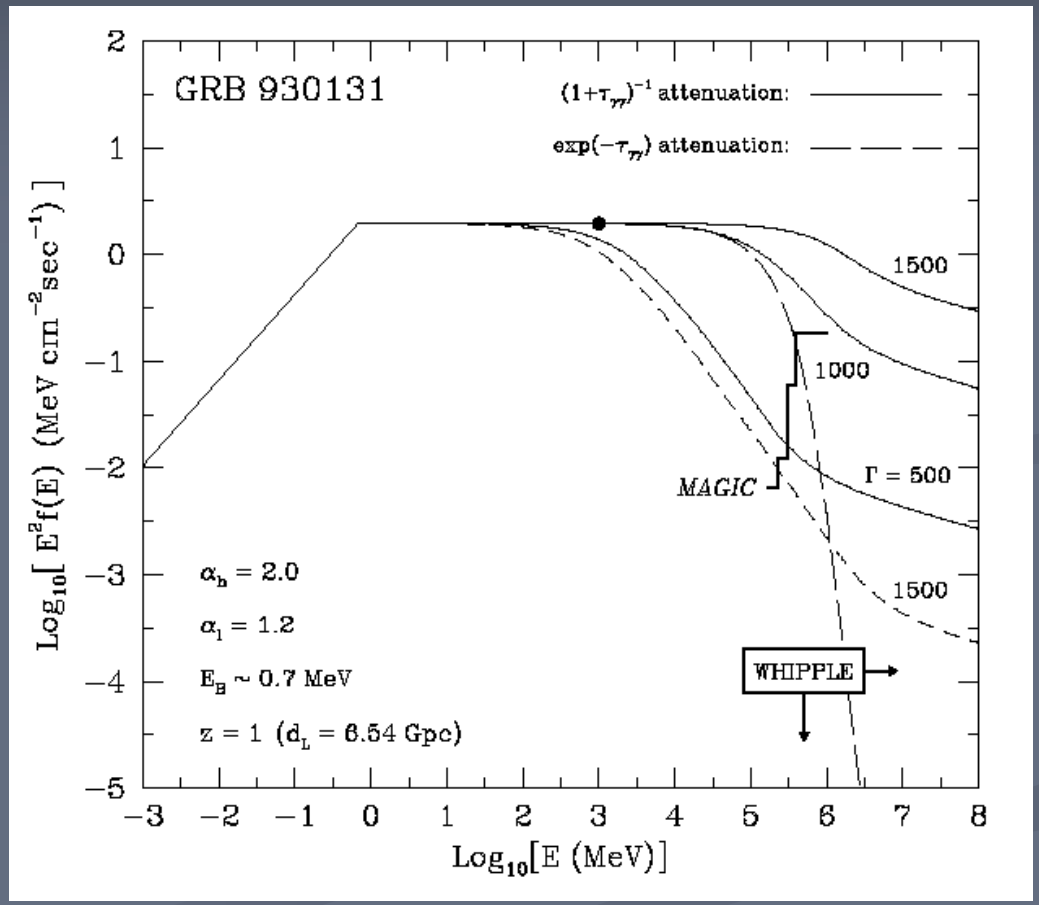
  for an $\varepsilon_\gamma^{-\alpha}$ differential source distribution.
- For $d = 1\,\mathrm{Gpc}$, $\tau_{\gamma\gamma} \sim 10^{12}$ for isotropic, $\Gamma \sim 1$ emission regions; $\Gamma \gtrsim 300 - 10^3$ generates source transparency to $e^- e^+ \rightarrow \gamma\gamma$.
  - Γ blueshifts pair threshold above observational window.

For AGN contexts: see Padovani & Celotti talks

Pair Attenuation Spectra for Bursts

- Pair creation turnovers are most sensitive to bulk Lorentz factor Γ;
- Atmospheric Cherenkov telescopes are sensitive to low-z bursts;
- MAGIC obtained prompt emission bounds to GRB 050713a; (Albert et al. 2006);
- MILAGRO had similar bounds for GRB 010921 (Atkins et al. 2005);
- GLAST may be sensitive enough to offer diagnostics for the brightest, hardest GRBs.

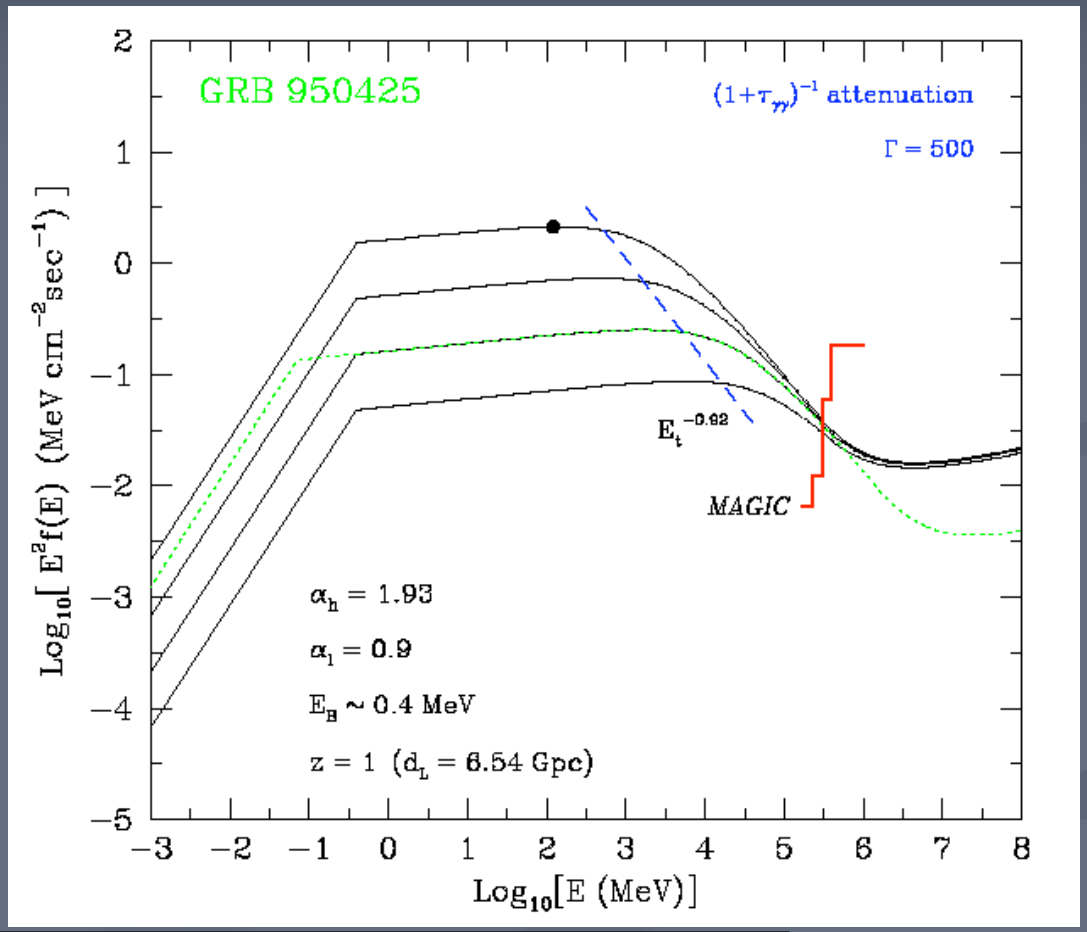
Baring (2006)



Pair Turnover Trends: Constant Gamma

Baring (2006)

- Pair creation turnovers energies rise in energy as peak flux drops with time (Baring, 2006);
- Turnover locus depends only on high energy power-law index;
- Turnovers do not care about BATSE-band νF_ν peak energy:
  - Image of this appears in TeV band, which is heavily-absorbed by EBL if z>0.1.

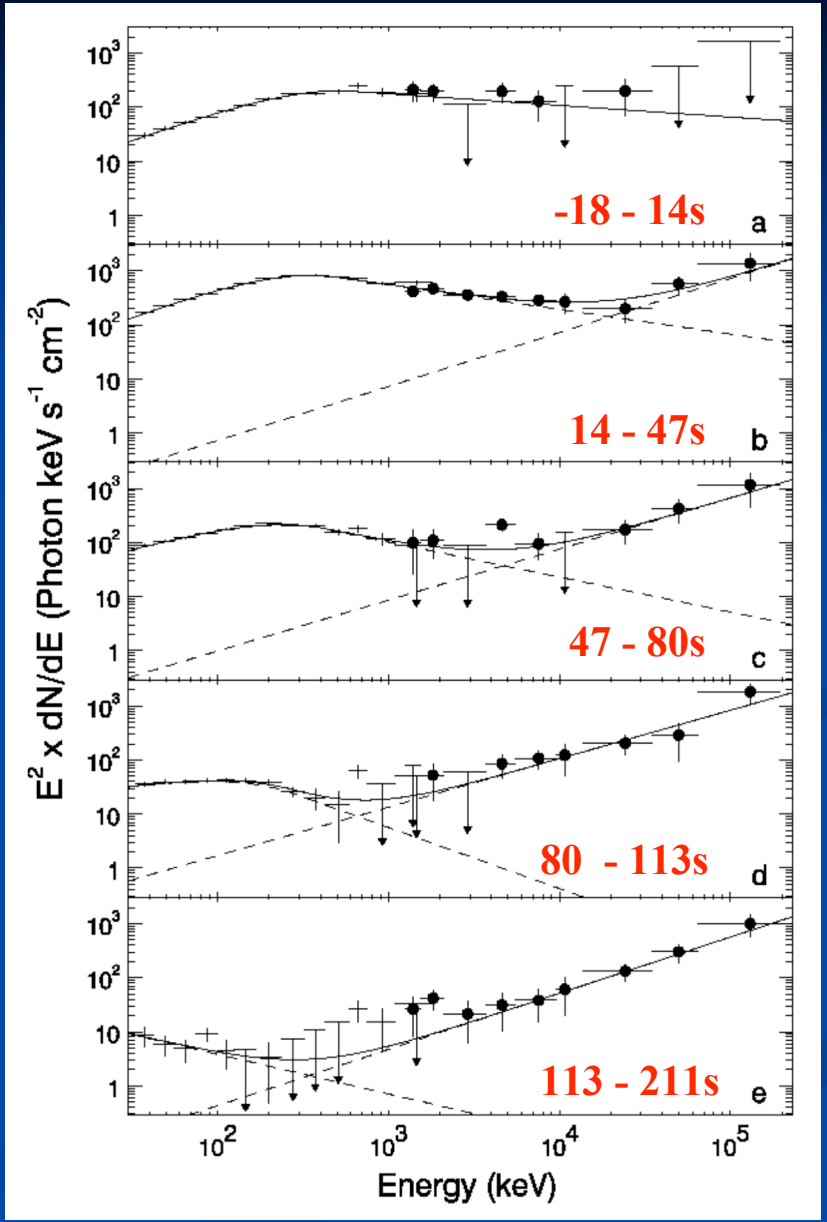


For pair attenuation off EBL: see Hartmann talk.

GRB 941017

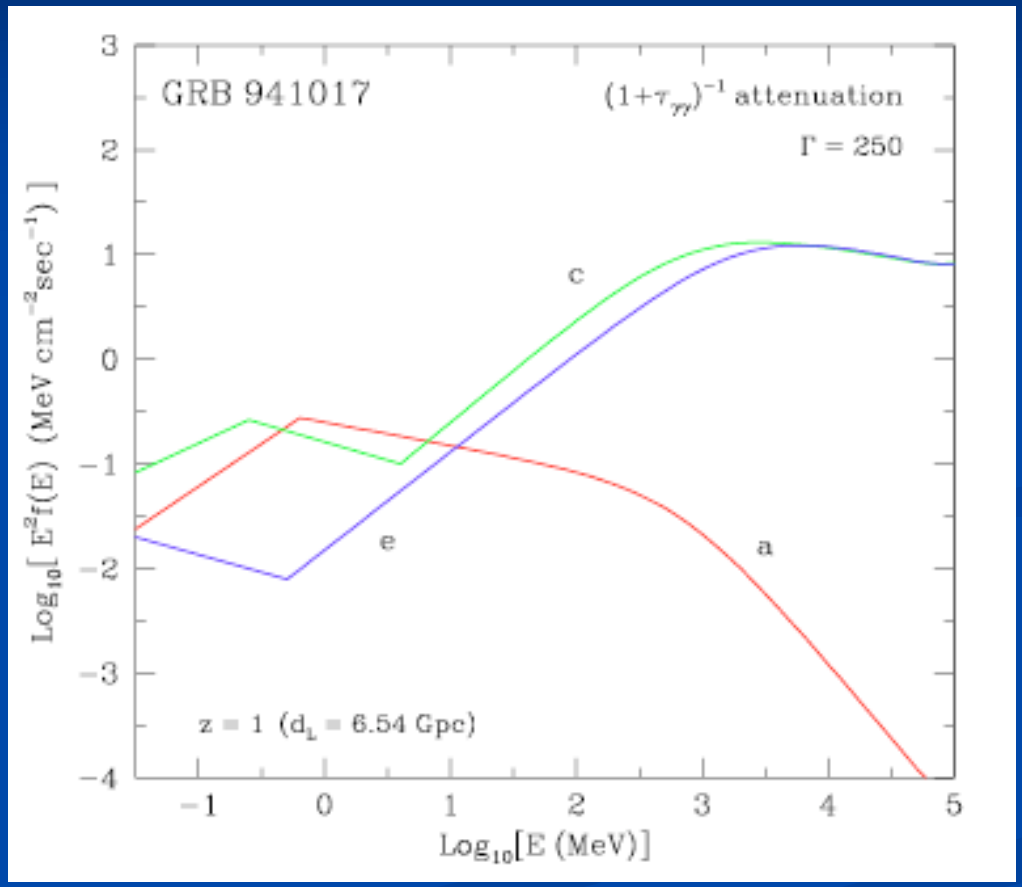
A new spectral component (Gonzalez et al. 2003)

- Duration ~150 seconds
- Photon spectral index ~ -1: persists throughout burst;
- Peak flux at > 200 MeV
- Fluence > 3*Fluence$_{<1\ MeV}$
- Temporal evolution different from the lower energy (synchrotron?) component.



The Case of GRB 941017

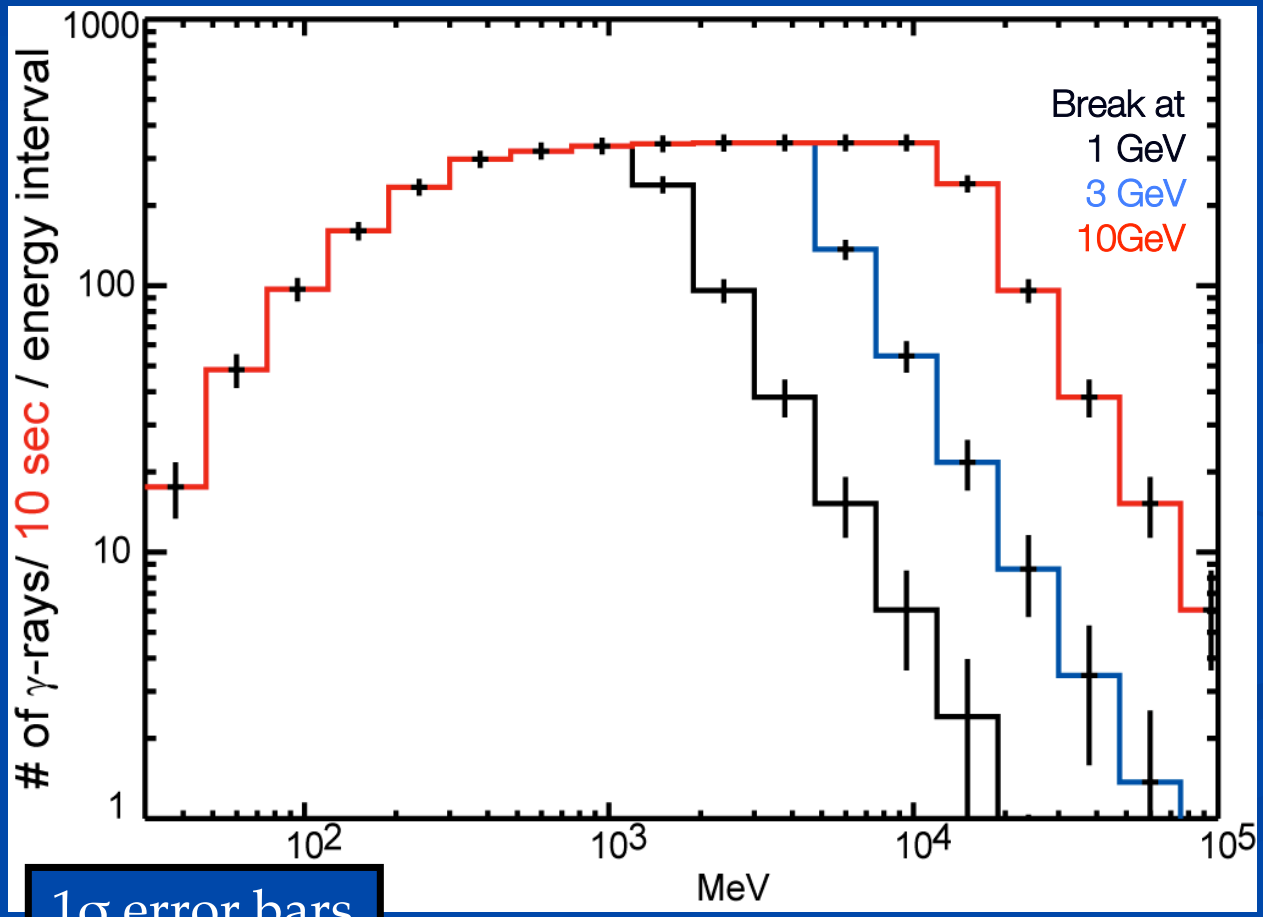
- Time evolution of broad band spectra, matching below 300 MeV the panels a,c,e (as labelled) of the Gonzalez et al. 2003 data plot;
- Spectra of high energy component is extrapolated to around 100 GeV;
- Pair attenuation signatures above 200 MeV illustrated for a *constant Lorentz factor outflow (coasting);*



Pair attenuation turnovers increase in energy as burst evolves due to depletion of target photons.

GLAST LAT response to 941017

Bright flux and hard spectrum would allow 20 observations of the temporal evolution of the break energy over this burst duration of 200 seconds



1σ error bars

- Flux @ 30 MeV = 2×10^{-4} γ/(cm² sec MeV)
- Photon spectrum $dN/dE \propto E^{-1}$
- *Assume LAT on-axis effective area*

Projected LAT Sensitivies: see Omodei et al. Poster P16.18.

Conclusion

- GLAST should perform *internal pair creation diagnostics* on a handful of hard bursts given the example of GRB 941017 in the EGRET era:
- Should be possible to **measure Lorentz factors** (as opposed to bound) in GLAST bursts;
- Probes of Lorentz factor evolution (or otherwise) may prove possible;
- ***'Worst case' scenario***: complete absence of internal pair production signatures below turnovers above 30-100 GeV due to cosmological absorption would imply very large bulk Lorentz factors - larger than in current GRB paradigms;
- => Signatures highlighted here should be seen in the GLAST era, beginning 2007!