GRB Science with Next Generation VHE Gamma Ray Instrument

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and GRB White Paper group:

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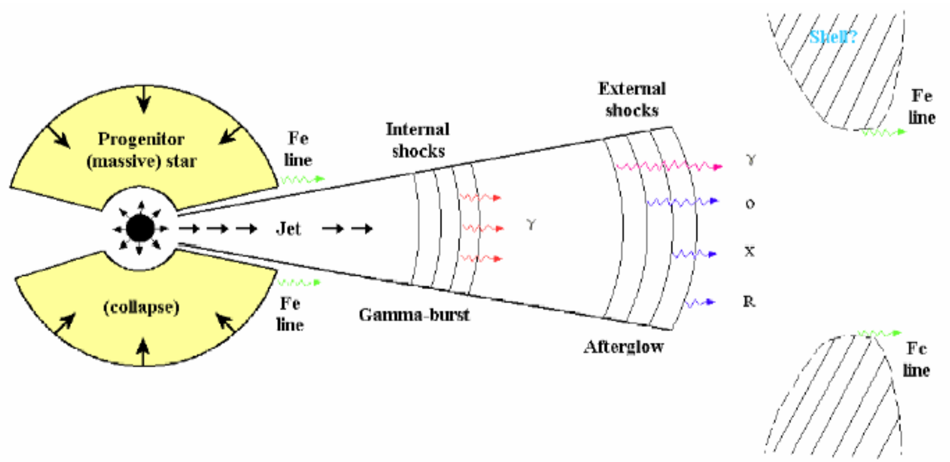
Dominant GRB Models



Long Gamma-Ray Bursts:

- Explosion of a massive star

- Extreme Supernova (e.g. Woosley et al. 1993, ...)

 (*collapsar or supranova*)

- Formation of a black hole
  (possibly following neutron star phase)

- Afterglows from external shock in jet predicted (e.g. Meszaros and Reese, ...)

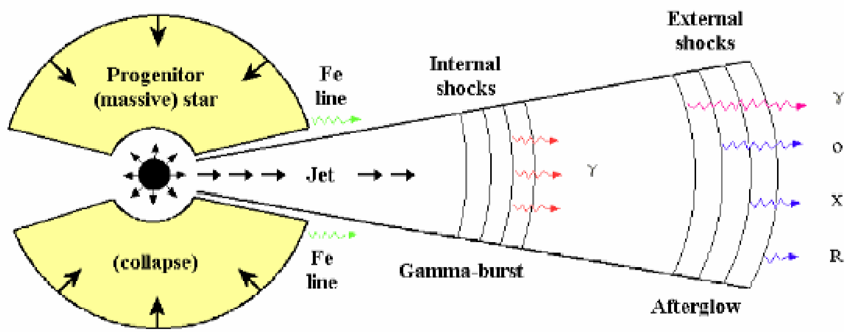
Short Gamma-Ray Bursts:

-Merging of Neutron star with

  Neutron star or Black hole

- Formation of central black hole, beamed jets, and shocks in jets

Why Study GRBs at Very High Energy?



- Need to understand acceleration mechanisms in jets, energetics, and therefore constrain the progenitor and jet feeding mechanism
- Understanding progenitor then leads to an understanding of cosmology/evolution required to support progenitor population
- Constrain local environment characteristics: Doppler factor, seed populations, photon density, B field, acceleration and cooling timescales, …
- Potential sources of ultra high energy cosmic ray acceleration
- Neutrinos and TeV gammas offer the only possibility to unambiguously distinguish between hadronic and leptonic acceleration in GRBs and blazars

Direct GRB Studies

- 3 basic categories
  - <10 s (bulk of nominal prompt emission)
  - 10-1000 s (extended prompt & injection phase & early afterglow & flares)
  - >1000 s (afterglow & flares)

Other Studies

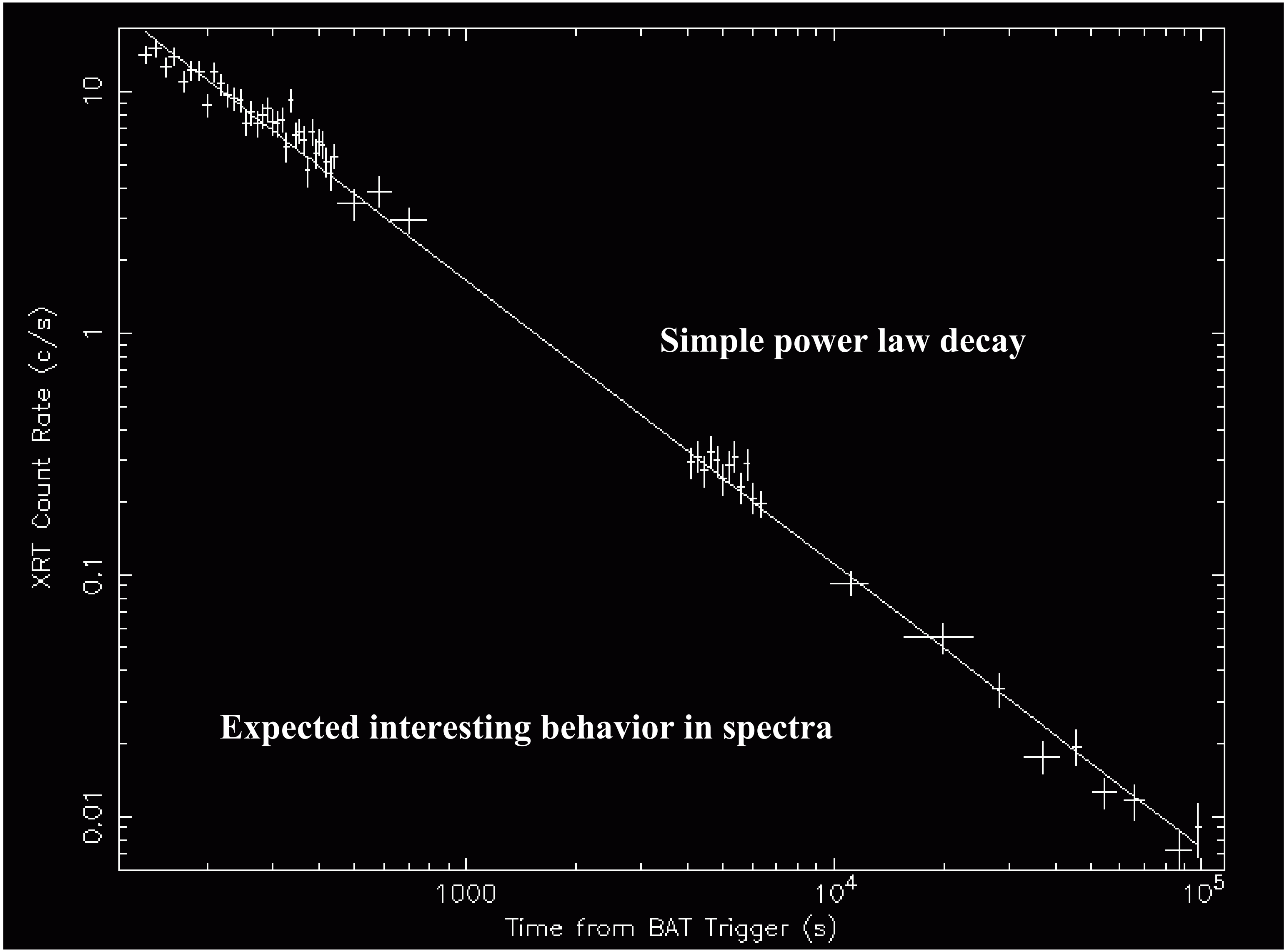
- Lorentz invariance violation
- GRB remnants
- Cosmic Ray acceleration

Nominal prompt emission

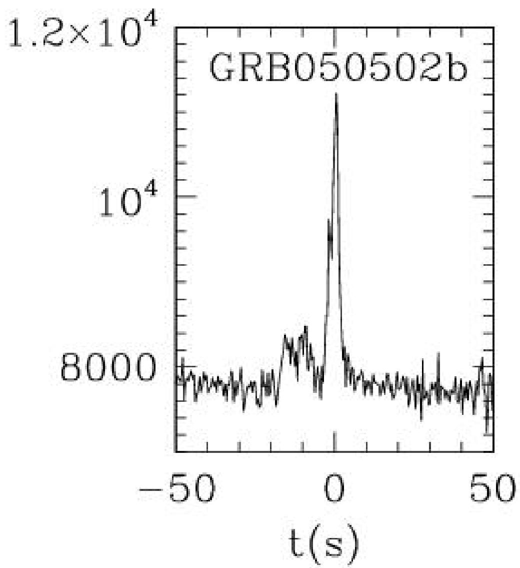
- Initial prompt emission is generally thought to be from internal shocks
- IC of MeV-keV emission should create GeV/TeV emission, and hadron acceleration should lead to pion decay
- Can measure VHE cutoff energy and bulk Lorentz factor
- GLAST will do this at lower GeV range (~1 burst/year); Current ACTs << 1/year
- Wide range of Lorentz factors expected (~100-1500)
- Short GRBs could provide more likely detections due to proximity (i.e. less IR absorption)
- Ground-based needed for GRBs with very high (>500) Lorentz factor
- All sky ***or*** VERY fast slewing needed, AND probably need sensitivity >10x VERITAS (with low threshold to **overcome opacity**) to observe many

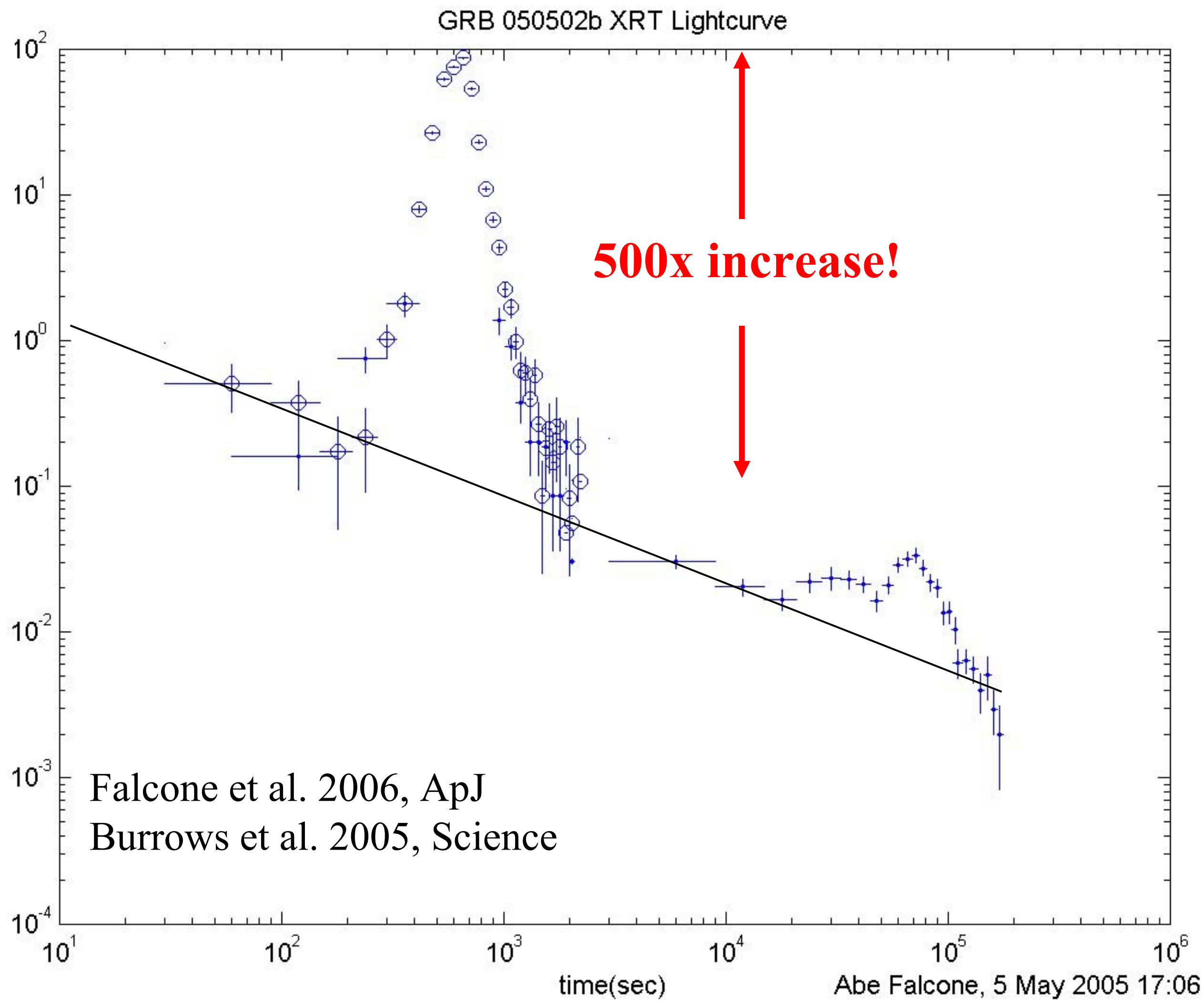
How about Later times (>10 s)?

Pre-Swift Anticipated X-ray Afterglow Behavior (GRB 050922C, XRT)



Giant X-ray Flare: GRB 050502B

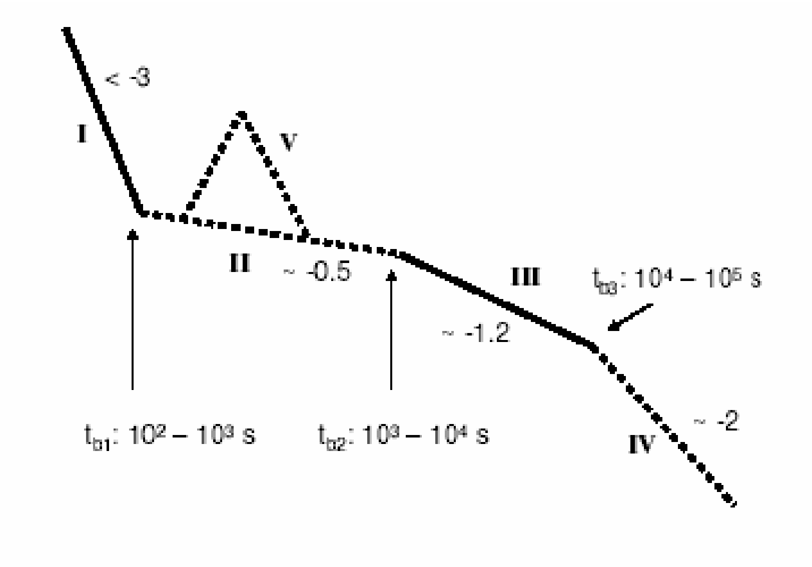




GRB Fluence:
8E-7 ergs/cm²

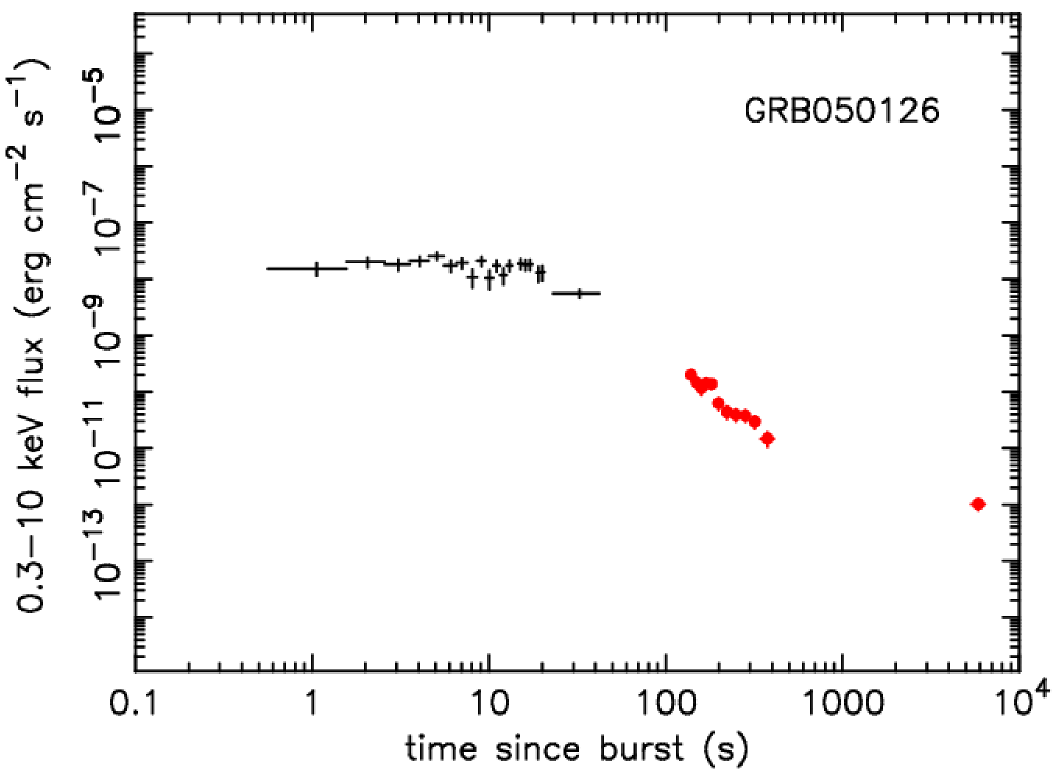
Flare Fluence:
9E-7 ergs/cm²

The Overall Lightcurve



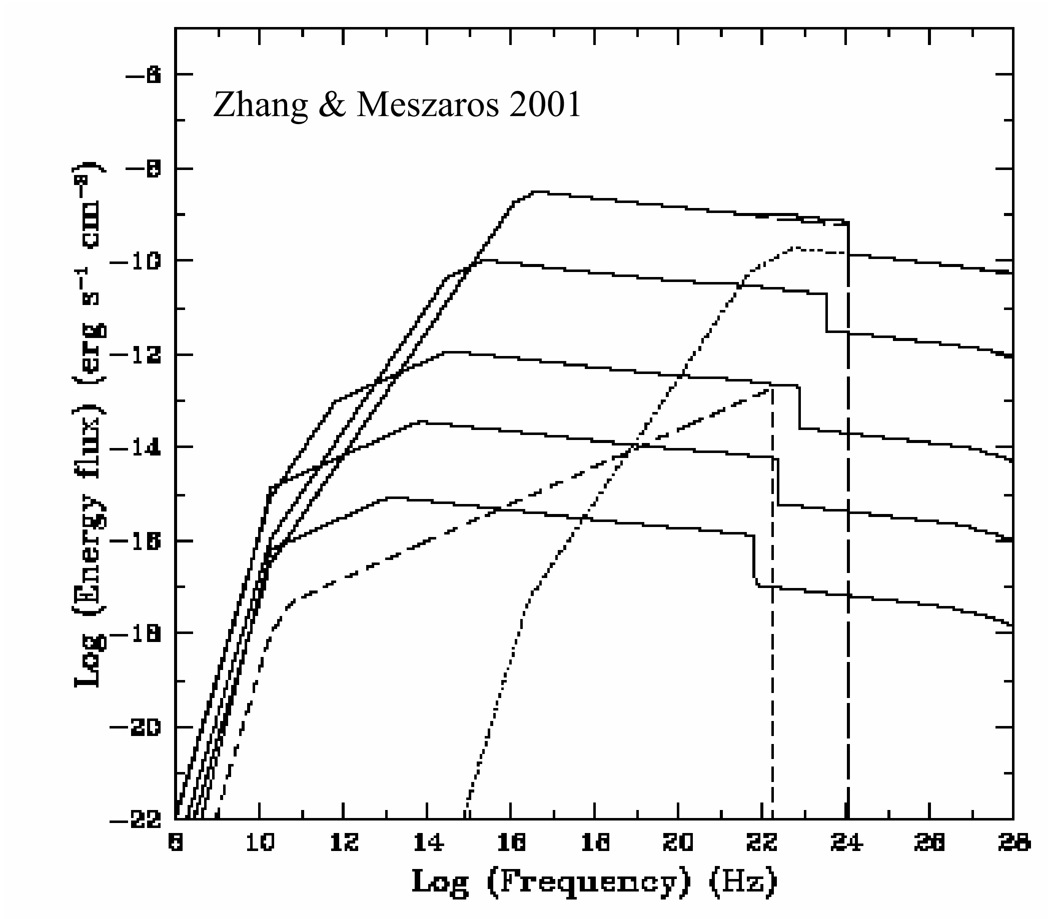
Zhang et al. 2005

The Movie



>10 sec

- ~4 Mechanisms:
  - More prompt emission; thought to be from internal shocks
  - external shock blast wave (i.e. nominal afterglow)
  - prolonged energy injection
  - Flares
- Again: IC of MeV-keV emission should create GeV/TeV emission; can measure VHE cutoff energy and bulk Lorentz factor
- Can map out jet/shock parameters --> refute/confirm current model
- Nominal afterglow: NEED sens. >10x VERITAS to have a hope of seeing many bursts and to get a lightcurve
- Requirements on FOV and slew speed are somewhat relaxed, but bigger/faster gives more detections


Zhang & Meszaros 2001
Log (Energy flux) (erg s^{-1} cm^{-2})
Log (Frequency) (Hz)
−6
−8
−10
−12
−14
−16
−18
−20
−22
8
10
12
14
16
18
20
22
24
26
28

Cosmic Ray Source

- While most GeV/TeV emission is expected to be IC, there is some component from p^+ synchrotron, p+γ initiated cascades, and inelastic n+p initiated cascades. The latter is thought to be dominant.
- If there is significant UHECR acceleration, then we could detect these
- BUT, like blazars, it will be difficult to break degeneracy between IC and hadronic
  - Have the advantage of better constraints on Lorentz factor and smaller timescales/regions
- May still need neutrinos, ... but simultaneous X-ray, GLAST, and TeV measurements of prompt and afterglow emission could solve problem (see Zhang et al. 2007)

Lorentz Invariance Violation

- Energy dependent delays of simultaneously emitted photons can limit (or measure) Lorentz invariance
- Lower limits to-date from GRBs at keV/MeV energies;
  - $0.0066E_{pl} \sim 0.66\times10^{17}$ GeV
- Our major disadvantage: we can't see the distant GRBs due to IR absorption
- Our major advantage: High and broad energy range, especially if we measure a delay between GLAST - TeV
- Everyone's disadvantage: Inherent energy dependent delays
- With a detection of ~1 TeV photons by a >10x V/H/M sensitivity instrument and a detection by GLAST, the limit could be increased by ~100x (to $\sim E_{pl}$), asumming a GRB like 050502B at z=0.5 !!!

  (caveat: assuming no energy dependent delay uncertainties)
- Need a very sensitive (>10x VERITAS) instrument to create light curves; energy resolution may drive instrument requirements

Preliminary Conclusions

- Most agree that we need more than just a single GRB detection to make a big science impact; a reasonable goal is ~10 GRBs/year
- Nearly all science goals require >10x VERITAS sensitivity AND low thresh.
- Nominal impulsive emission can only be captured with all sky (such as HAWC-like) or with a very fast (5-10^{o}/s) slewing Air Cherenkov Telescopes (internal opacity effects could hinder this)
- There are many possible sources of IC emission after the nominal prompt emission; not just the afterglow
- Detection after the first 10 sec is best served by a very sensitive (>10 x VERITAS) low threshold instrument, such as km^2 Air Cherenkov
- CR acceleration can be addressed by the future, but firm conclusions may be complicated by IC/hadronic ambiguity
- Lorentz Invariance violation may be addressed at ~E_{pl} by catching time variable emission with a >10x VERITAS sensitive instrument

Final Remark

- We are attempting to identify the best path of improvement in the FoV, slewing speed, sensitivity, duty-cycle, energy threshold phase space, and any additional input is welcome:

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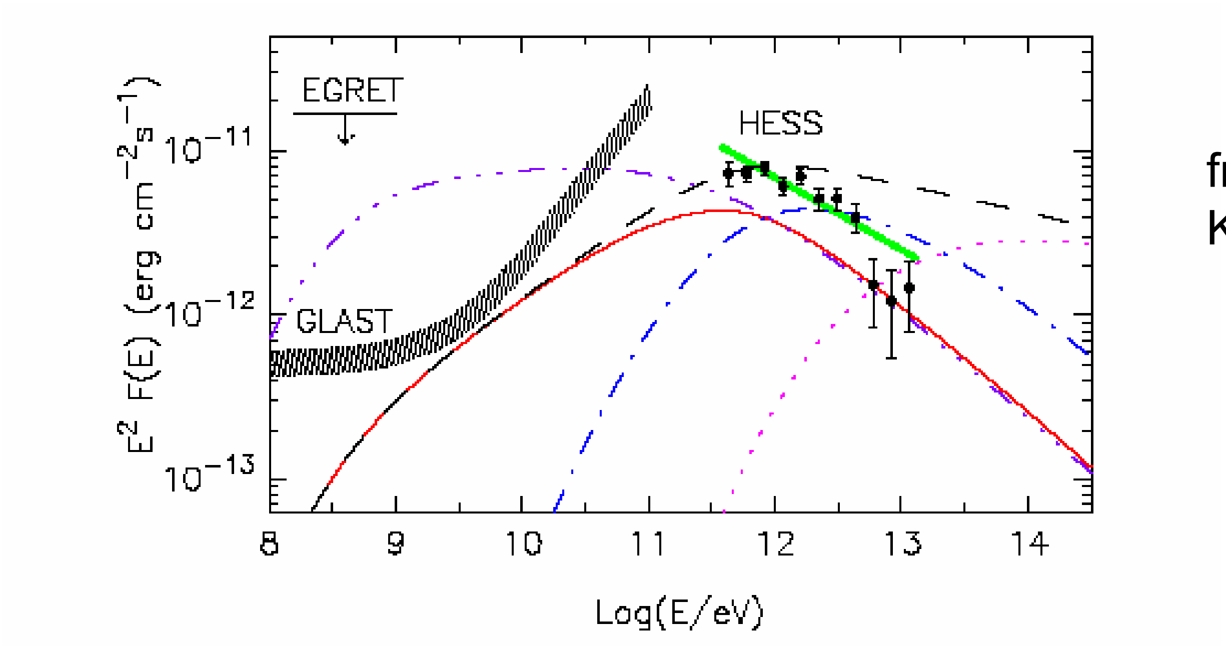
GRB remnants



from Atoyan, Buckley, Krawczynski 2005

- Could be unique science to ground-based gamma ray
- VERITAS will answer some of these questions first
- **Problem**: Not many of these are expected to be local (only 1-2)
- However, increased spatial and energy resolution could provide new science