Constraints on Very High Energy Emission from GRB 130427A

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tl;dr

- GRB130427A was really bright and should be detectable at VHE (>100 GeV) under favorable conditions.
- VERITAS looked at it about 1 day after the burst went off.
- No VHE emission was seen:
  - this disfavors additional components and
  - there’s probably a cut off.

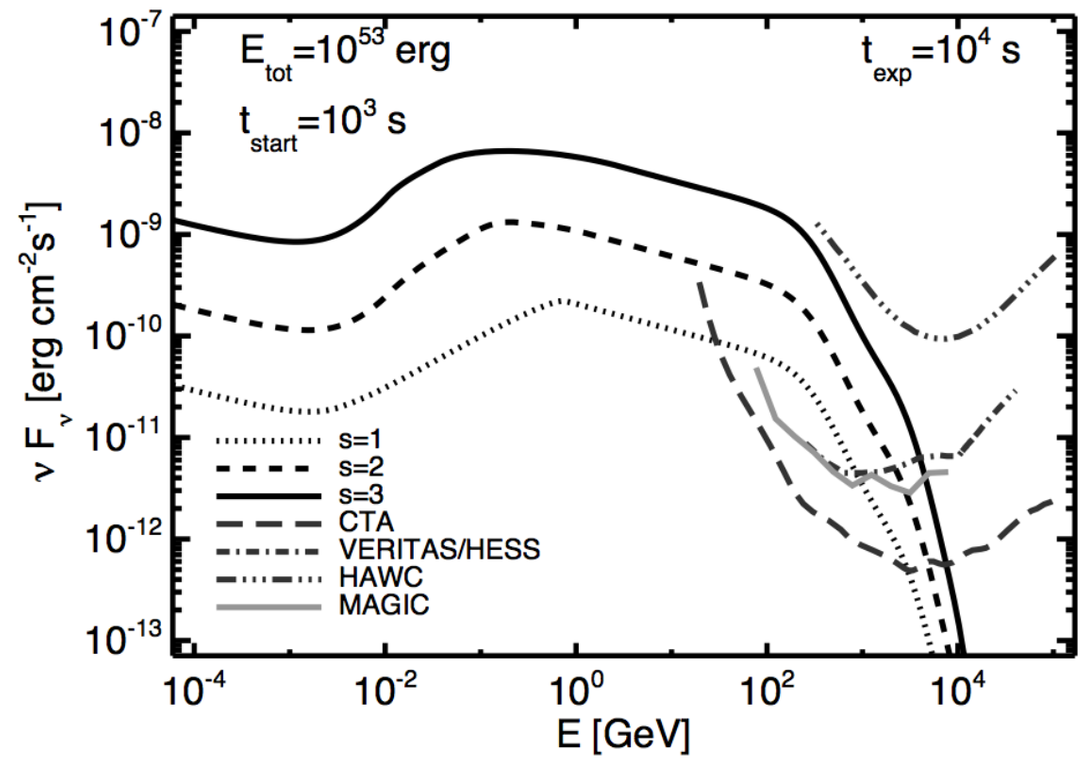
What's VERITAS and why do we look for GRBs?

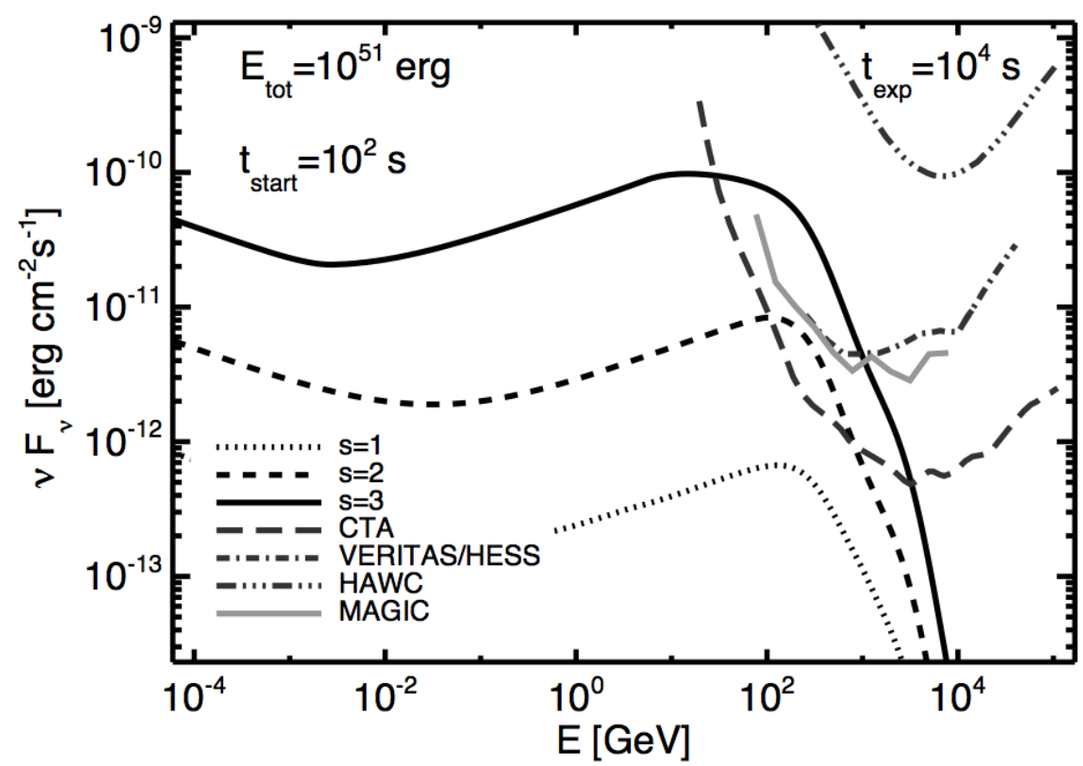
- An IACT array located in Southern AZ, recently upgraded:
  - Energy Range: **100 GeV** to > 30 TeV
  - Point-source Sensitivity: 1% Crab in < 30 hr, **10% Crab in < 30 min**,
  - FoV: **3.5 degrees**
  - Peak effective area: **~10^5 m^2**
- Active VERITAS GRB program calls for collecting data on all observable GRBs less than 1 hour old unless they are 'exceptional bursts' then exceptions are made (Median unconstrained GRB observing delay for 2012/2013: 159 s)

Veres & Mézáros, ApJ 787, 168 (2014)

GRBs at VHE?

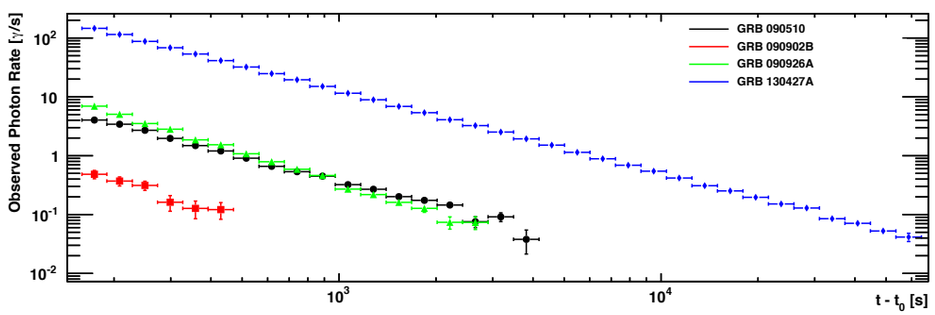
- Lots of predictions that GRBs could emit gamma rays at energies above 100 GeV but none have ever been seen (Connaugton et al. ’97, Aharonian et al. ’09, Albert et al. ’07, Acciari et al. ’11)
- Fireball IC scattering (Beleborodov 2005, Wang et al. 2006) or SSC (Zhang & Mészáros 2001; Wang et al. 2001)
- External Shocks (Pe’er & Waxman 2005, Mezaros & Rees 1994; Dermer et al. 2000; Fan et al. 2008)
- IC from X-ray flares (Fan et al. 2008; Galli & Piro 2008)
- Short GRB afterglows (Veres & Mézáros 2014)?

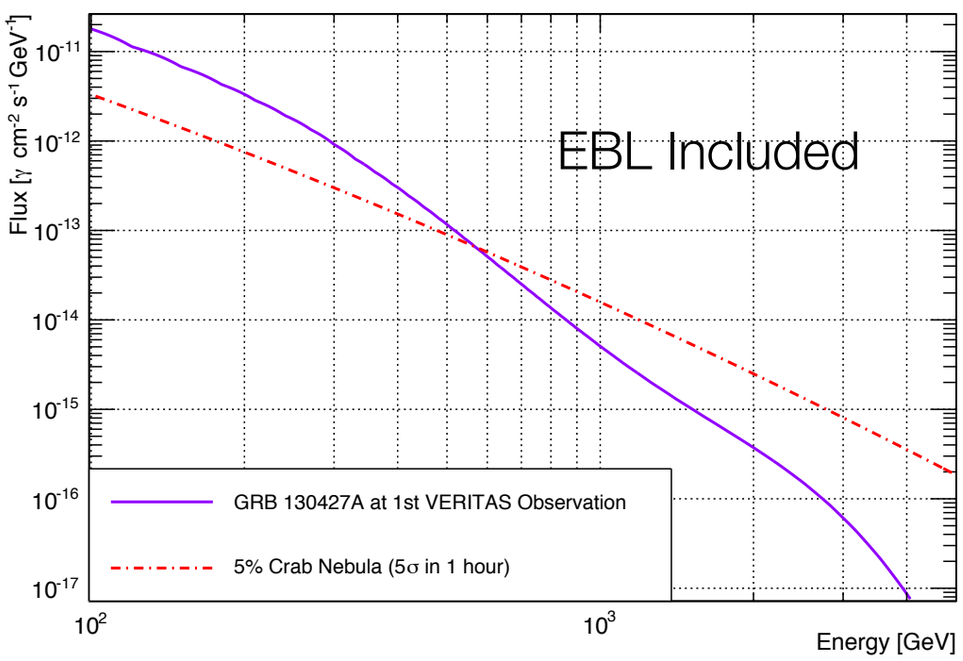




GRBs at VHE?

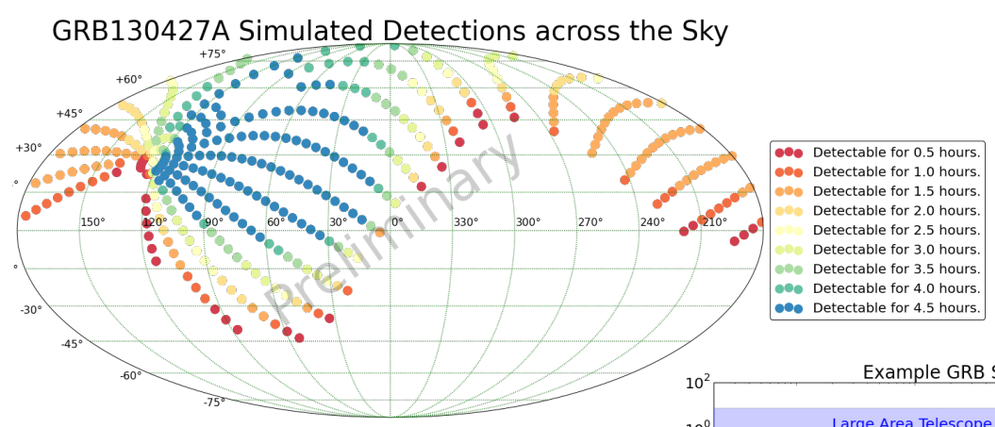
The current generation of VHE instruments are sensitive enough to detect a burst like 130427A up to ~1 day after T0:

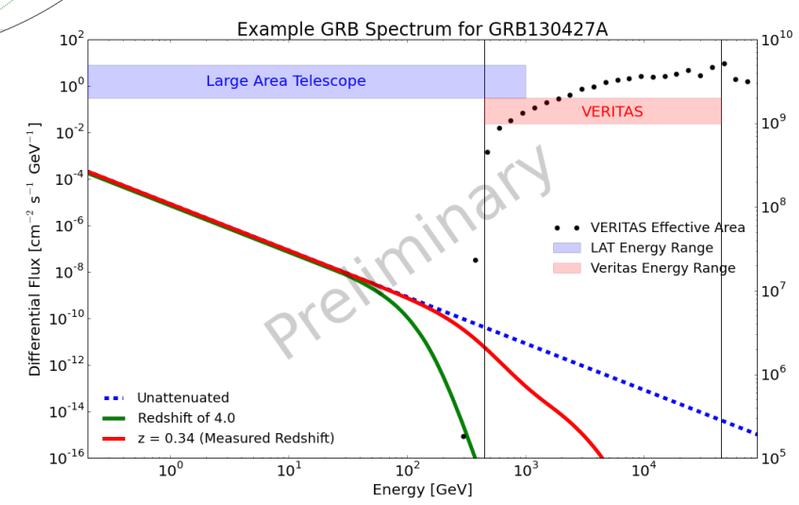




It's Hard

- GRBs are **transient**, most VHE instruments have **small FoVs** (3 - 5 degrees, but not HAWC) and **low duty cycles** (but not HAWC).
- GRBs are usually at cosmological distances and the **EBL is a factor**.
- There are probably **intrinsic cutoffs** at play as well.





Ian Morgan, Saint Mary's College of Maryland

The ‘Extraordinary’ GRB130427A

- **Coverage:** Emission independently detected at ~07:47 UTC by several orbiting telescopes and RAPTOR ground-based optical monitors
- **Nearby:** Associated with Type IC SN 2013cq in a galaxy at z = 0.34
- **Observationally bright:** Highest prompt GRB fluence ever recorded by Konus-WIND and *Fermi*-GBM
- **Long-lived high-energy:**
  - *Fermi*-LAT detected GeV emission for ~20 hours after trigger
  - Highest observed energy photon detected from a GRB: 95 GeV

Proximity is what makes this GRB special

The ‘Extraordinary’ GRB130427A

- **CV: Extremely Bright, Delayed HE Emission, Really Close (z = 0.34), Observed 95 GeV Photon**

- First VTS observations from 71 to 75ks, GRB in LAT FoV from 72.1 to 73.4 ks and 73.5 to 74.9 ks.

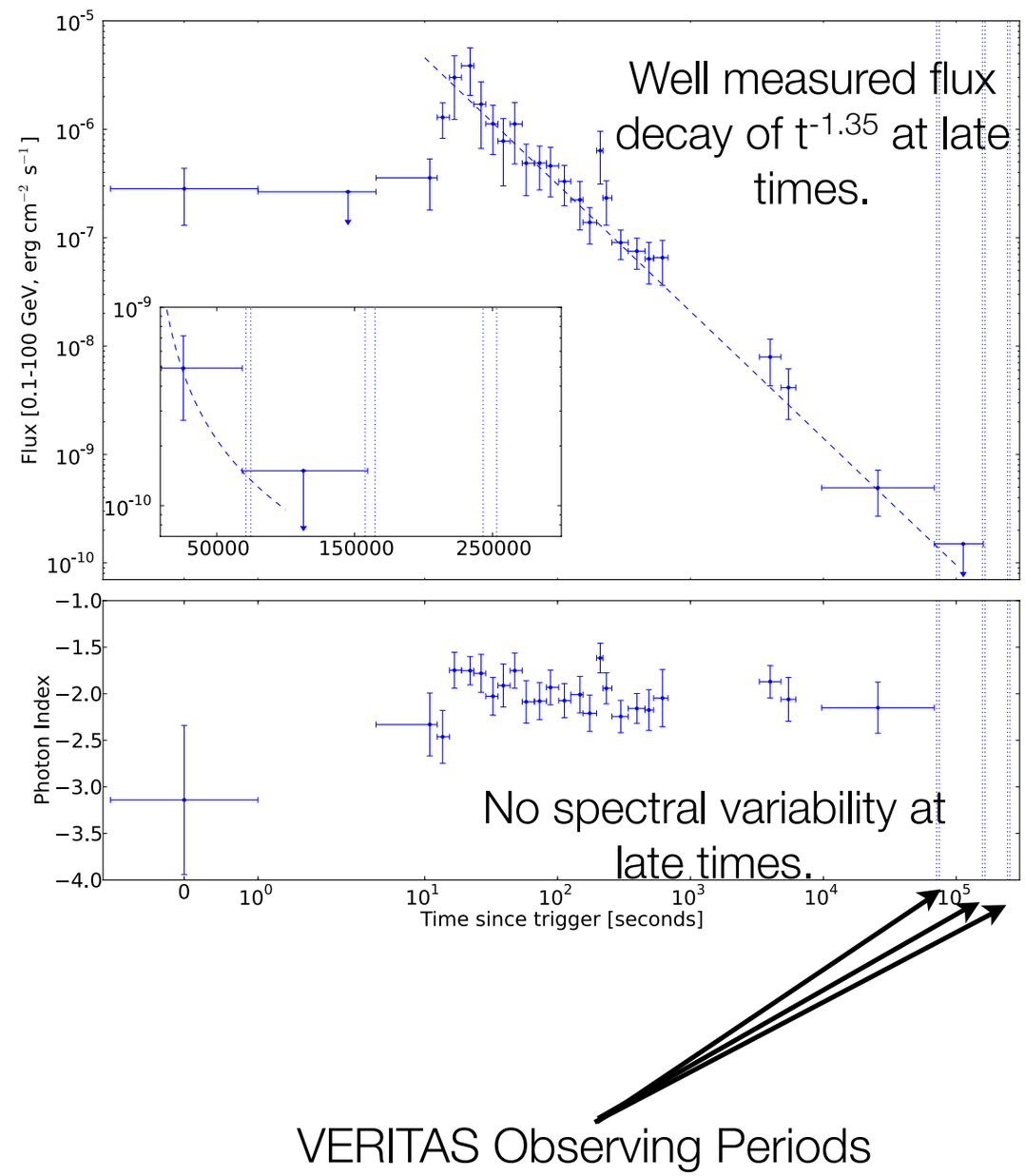
    - Last GeV photon detected at 68.4 ks, Well-measured flux decay, no late-time spectral variability.

- Re-analyzed the LAT data during late times (10 - 70 ks) to determine the spectral shape and flux:

    - Last time period when the GRB was LAT detectable.

    - No evidence for curvature.

    - Generated an SED from 100 MeV to 100 GeV and extrapolate it in time (using the decay rate) to the first VERITAS observing period.



VERITAS Observations of GRB130427A

- The GRB went off at a great location in the sky but the Moon was really bright (97% full).
- Follow-up observations were performed the next night, at high elevation, about 71ks after the burst.
- Continued follow-up for 2 and 2.5 hours on the 29th and 30th.
- Energy threshold of ~100 GeV.
- Upper limits are derived for each night assuming a power-law spectrum along with absorption on the EBL.

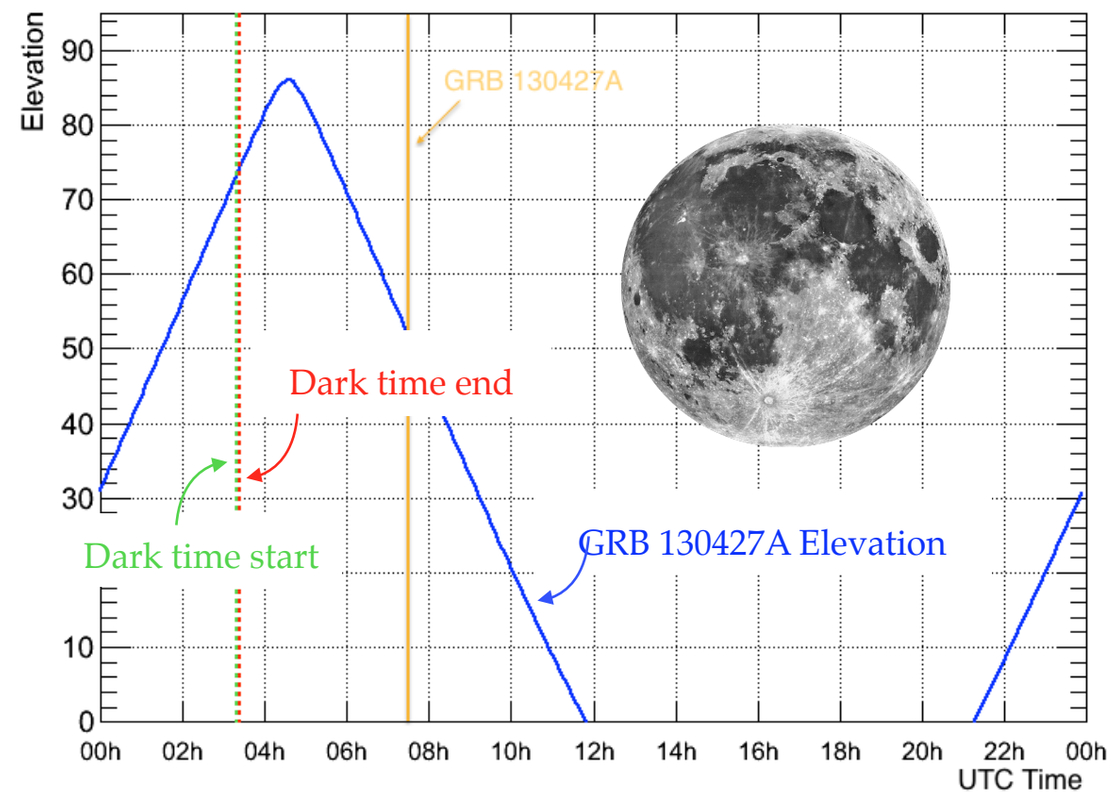
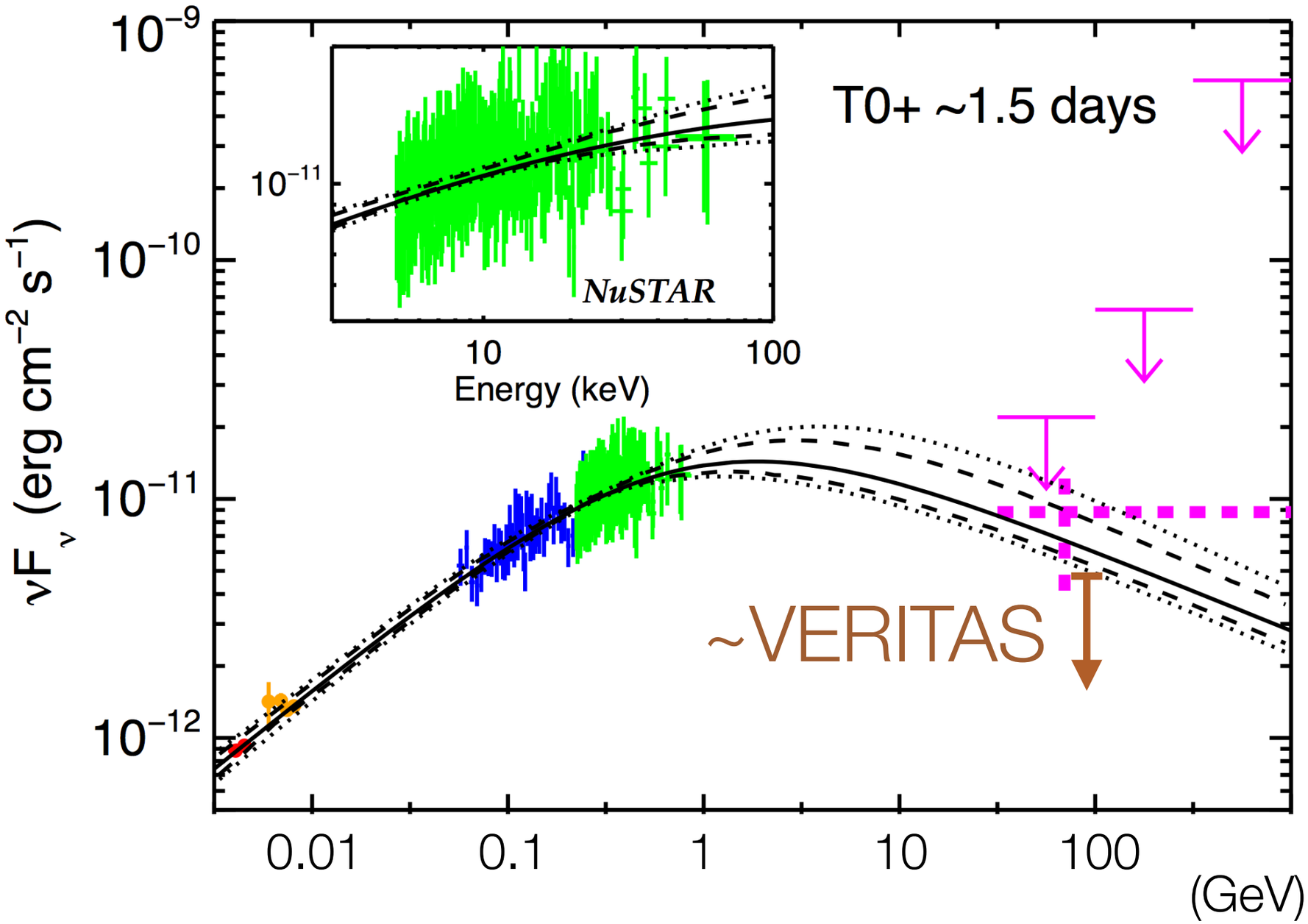


Table 1: VERITAS Observations of GRB 130427A

Date	t_{start} (UTC)	t_{end} (UTC)	Exposure (s)	$n_{\gamma,excess}$	Sig. (σ)	Flux UL$^{\alpha}$
28 April 2013	03:32:35	04:31:16	2925	19.5	1.3	9.4×10^{-12}
29 April 2013	03:32:59	05:33:39	5746	19.3	1.1	6.6×10^{-12}
30 April 2013	03:22:02	06:05:40	7814	-13.2	-0.5	2.7×10^{-12}
Total			16485	28.0	0.9	3.3×10^{-12}

$^{\alpha}$ 99% confidence-level upper limit on νF_{ν} in erg cm^{-2} s^{-1}. The upper limit is calculated assuming an intrinsic GRB spectrum of $\frac{dN}{dE} \propto E^{-2}$ and deabsorbed using the EBL model of (Gilmore et al. 2009).

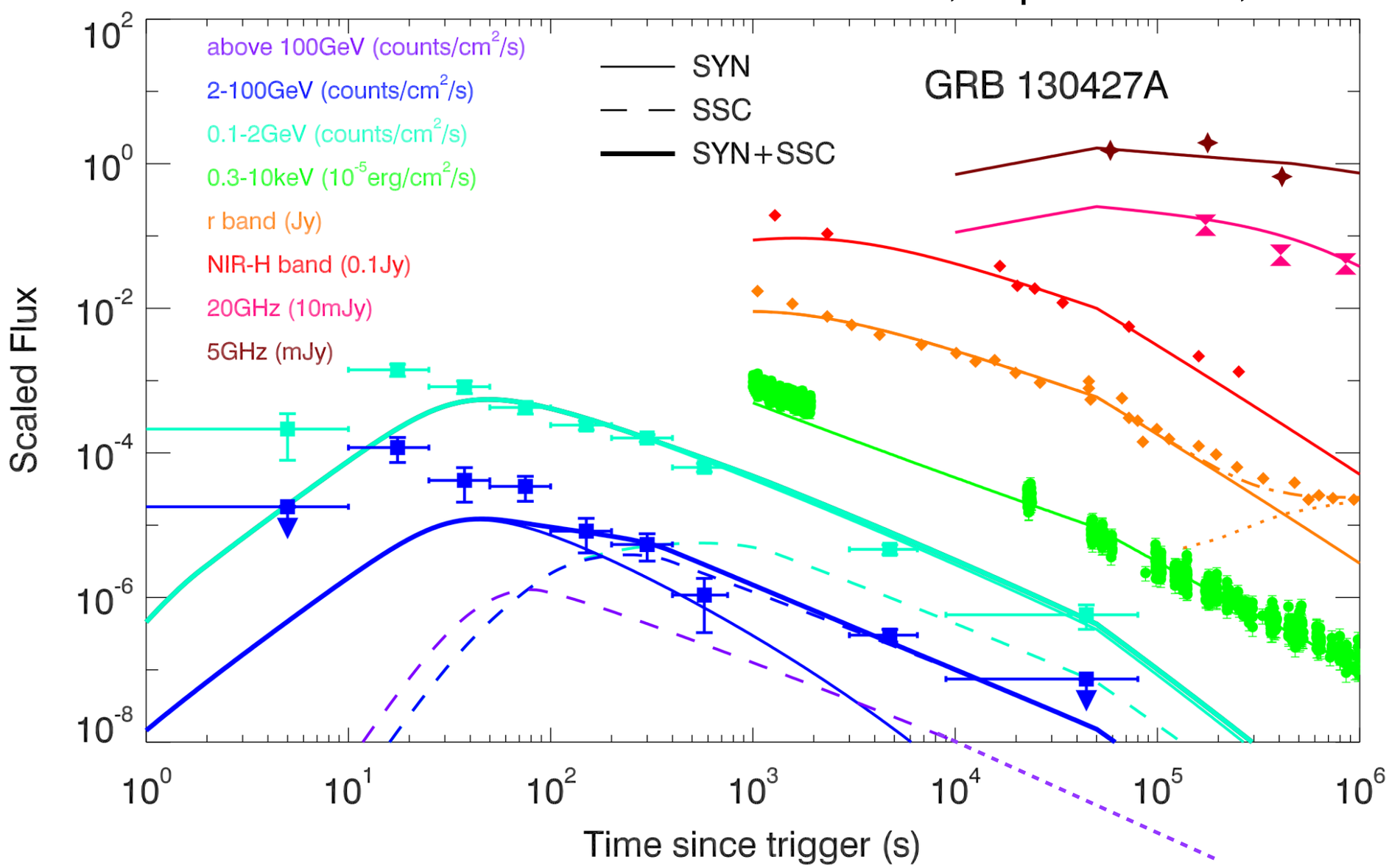
Synchrotron?



Kouveliotou et al., ApJL 779, L1 (2013).

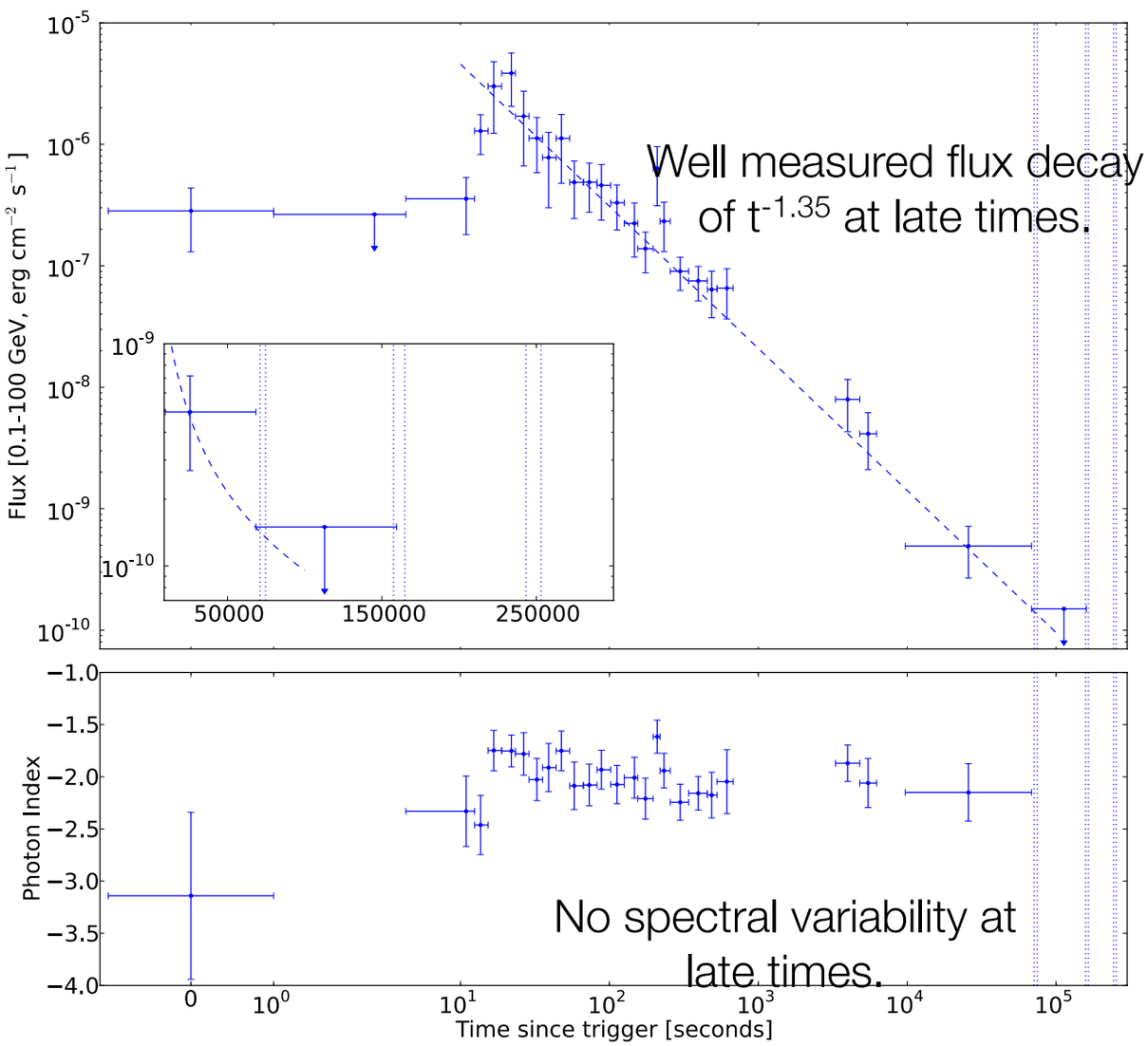
SSC?

Liu et al., ApJL 773, L20 (2013)



~VERITAS

(simple) SSC Electron Spectrum



- For the LAT energy range (0.1 - 100 GeV) the measured temporal and spectral characteristics set an election spectrum in the SSC model

$$\frac{dN}{dt} \propto t^{\alpha}, \alpha = \frac{-(9p-11)}{8} = -1.35$$

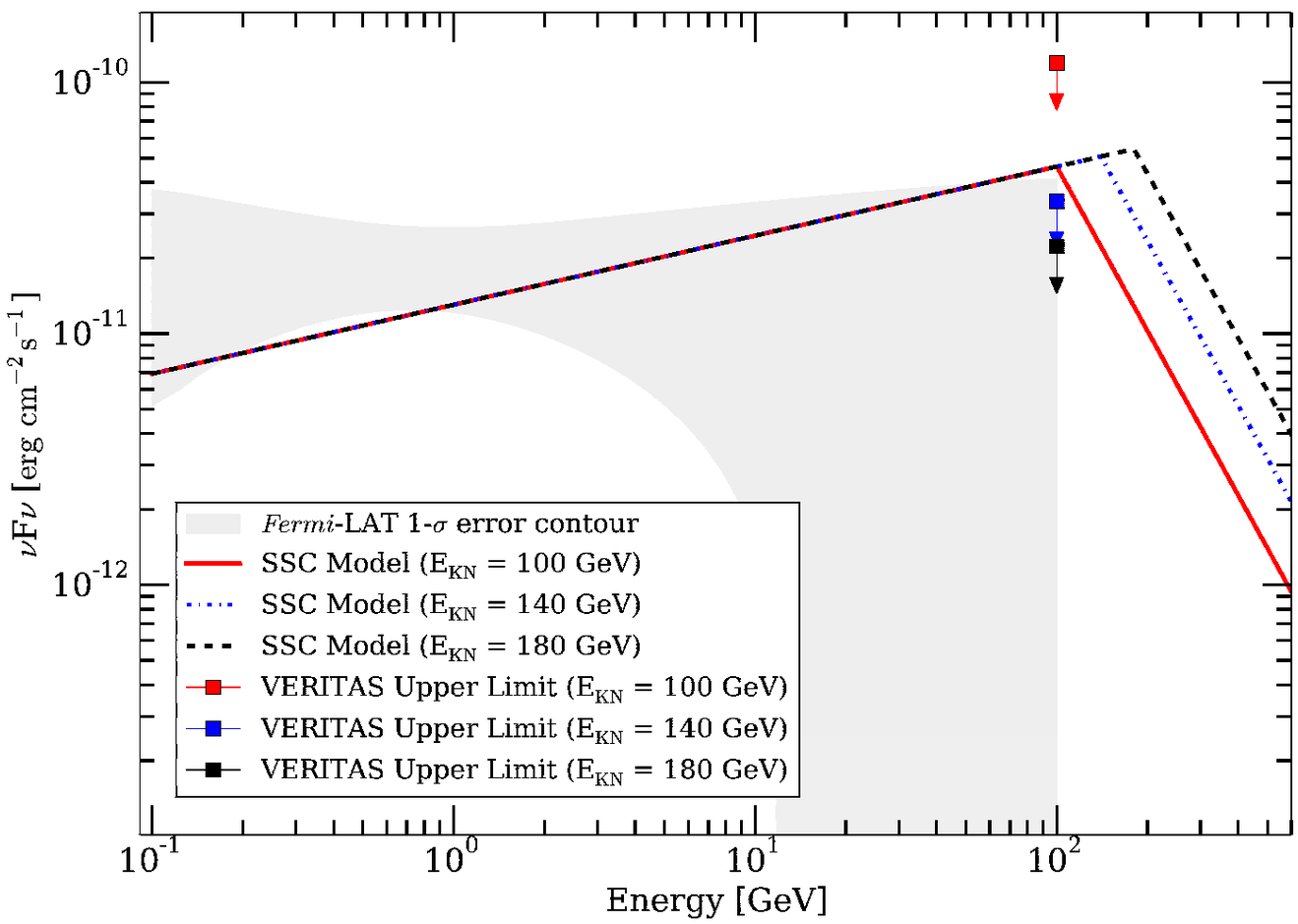
$$\frac{dN}{dE} \propto E^{\Gamma}, \Gamma = \frac{-p+1}{2} \approx -1.7$$

- Assuming the 100+ GeV flux arrises from IC, a cutoff is expected from the K-N suppression of gamma-e cross-section

$$E_{\mathrm{KN}} = \Gamma \gamma_c m_e c^2 (180\,\mathrm{GeV}) \frac{t}{t_v}^{1/4}$$

The Joint SED

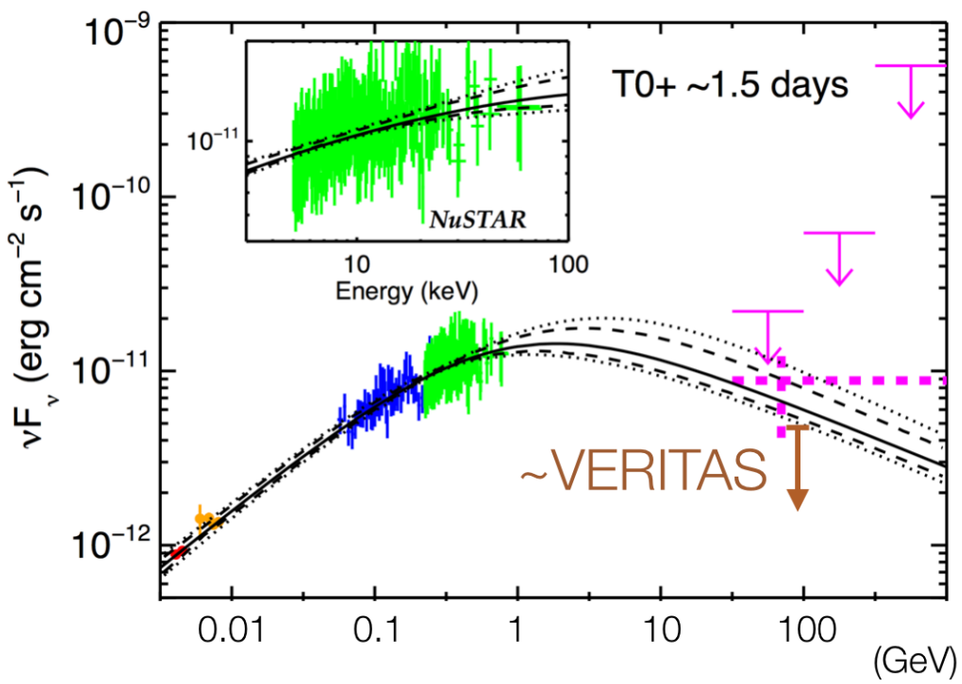
Even without a model assumption, the VERITAS upper limits disfavor additional components.



We are probably seeing the K-N cutoff below the VHE range.

- The grey band is the LAT SED for 10 - 70ks extrapolated in time into the VERITAS observing period.
- Each line shows the expected flux from a simplified SSC model with different breaks.
- Each VERITAS upper limit assumes the spectral shape in the respective model.
- The ULs are compatible with a spectral break at or below ~100 GeV.
- Note that the sharp break isn't really correct. Working on a smoothly broken model right now.

What about the Synchrotron assumption?



Kouveliotou et al., ApJL 779, L1 (2013).

- Synchrotron emission could work but you would need to assume a cutoff around 100 GeV.
- If you assume the emission is from Synchrotron, you can use the VERITAS upper limit to place constraints on the magnetic field.

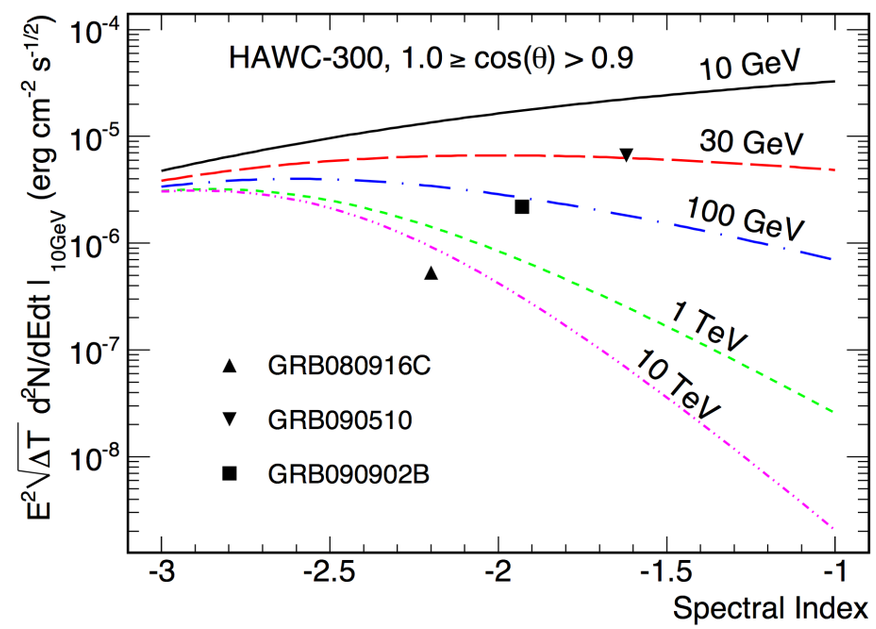
$$E_{\mathrm{cut,syn}} = 50\ \mathrm{MeV}\left[\frac{\Gamma}{1+z}\right](B_w/B_0)$$

- → $B_w/B_0 \lesssim 200$

…and what about the future?

- We could wait for 25 years for another GRB130427A to go off directly overhead (or just a normal burst to do this).
    - Already shown that we can constrain models, measure cutoffs with one, bright burst.
- …but we've got two really good chances out there right now to measure VHE emission (even before CTA is online):
    - HAWC and/or HESS2 will see a GRB at VHE (depending on your definition of VHE).
    - HAWC: 1 - 2 short bursts/year (Valerie says so)
    - However, take home message from the VERITAS observations is that there are probably intrinsic cut-offs that need to be taken into account.

HAWC Coll., Ast. Par. 35, 10, 641



Pierre Brun, these proceedings