INVERSE COMPTON SIGNATURES OF GAMMA-RAY BURSTS USING FERMI-LAT DATA

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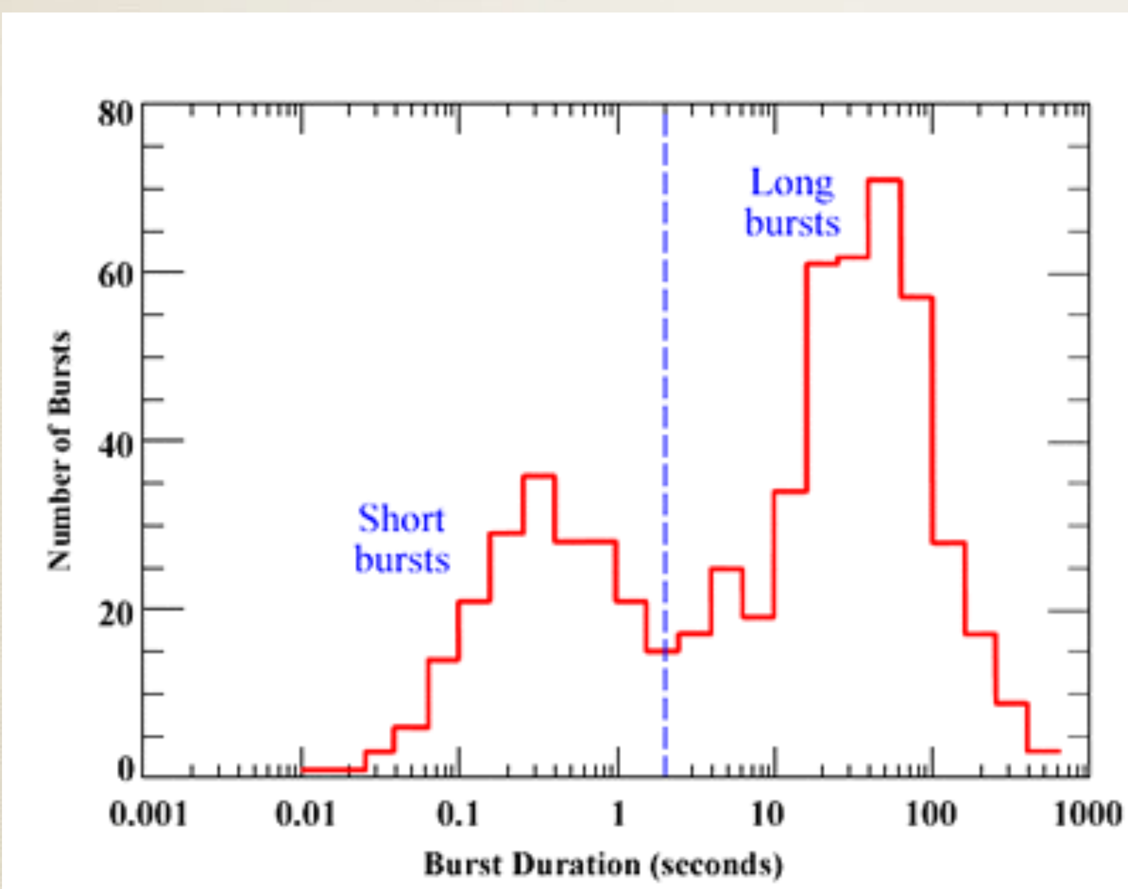
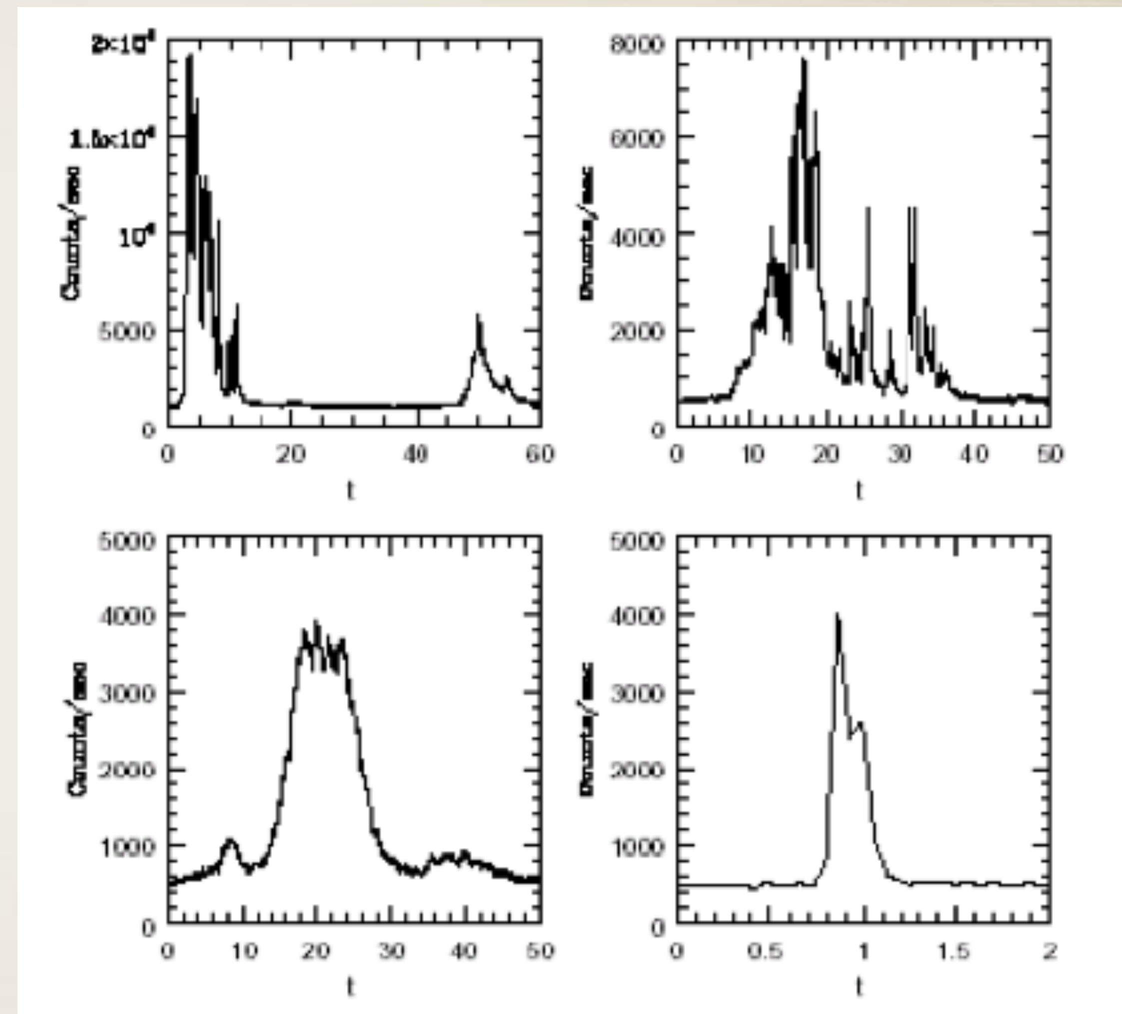
2020.1.9

Gamma-ray bursts

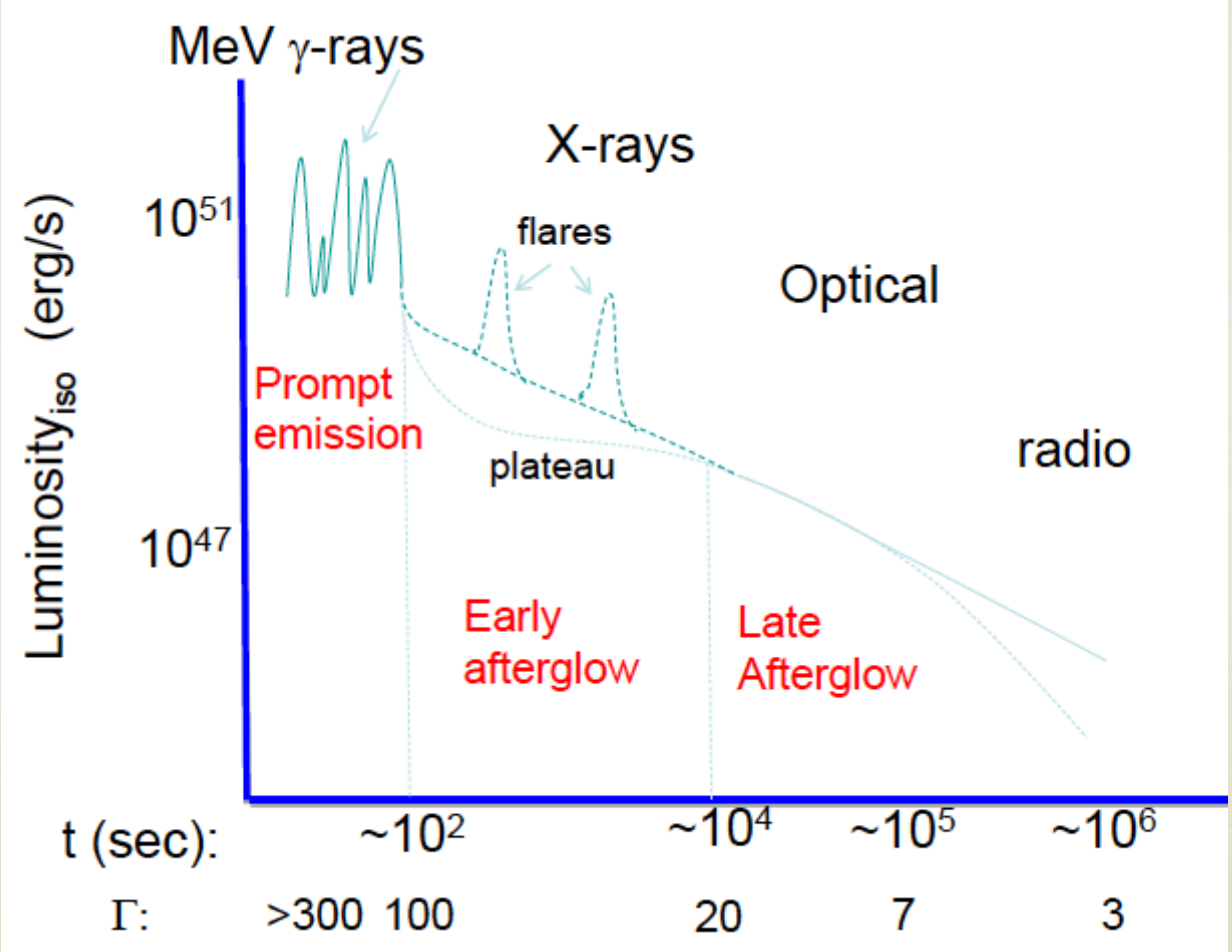
- Intense bursts of gamma-rays
- Duration: ~10ms - hundreds of seconds
- happen at a random position on the sky
  never repeat



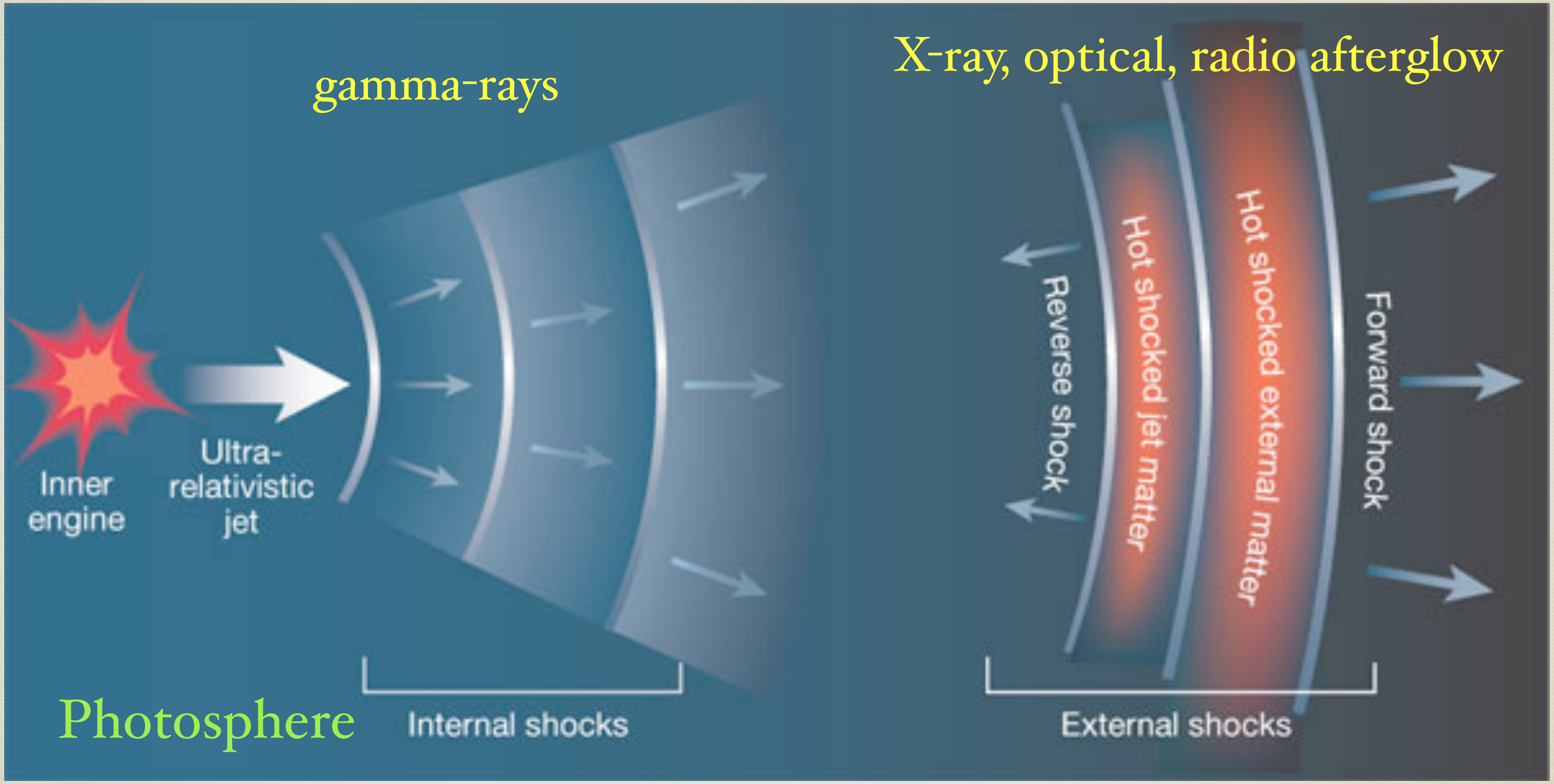


Known to be cosmological
isotropically distributed

"Schematic" multi-wavelength AFTERGLOW light curve



The Fireball Model



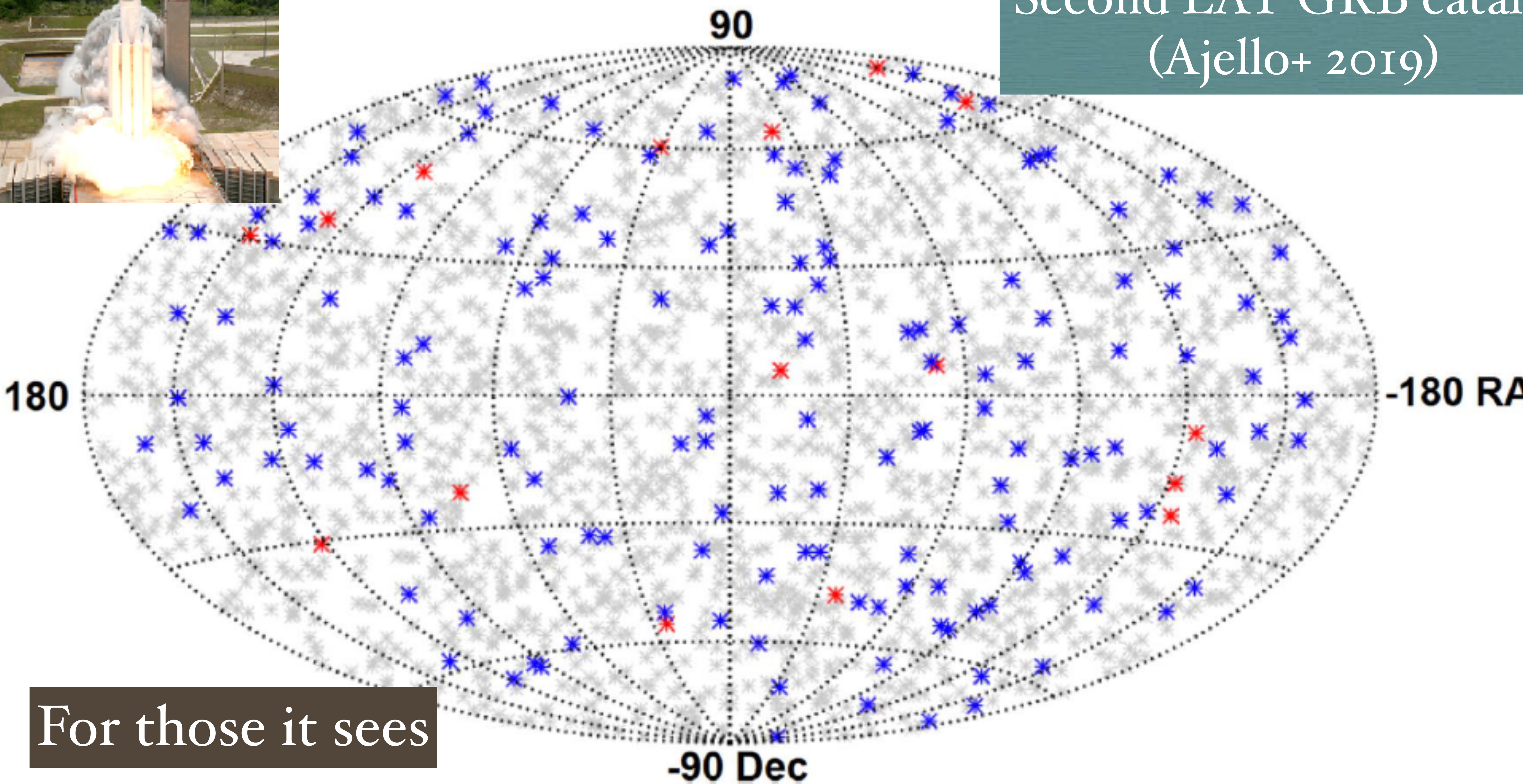
Prompt emission (short-lived, seconds)

Afterglow emission (long-lasting, up to days to weeks)

c.f. Piran (2004)

What does Fermi see?

Second LAT-GRB catalog
(Ajello+ 2019)



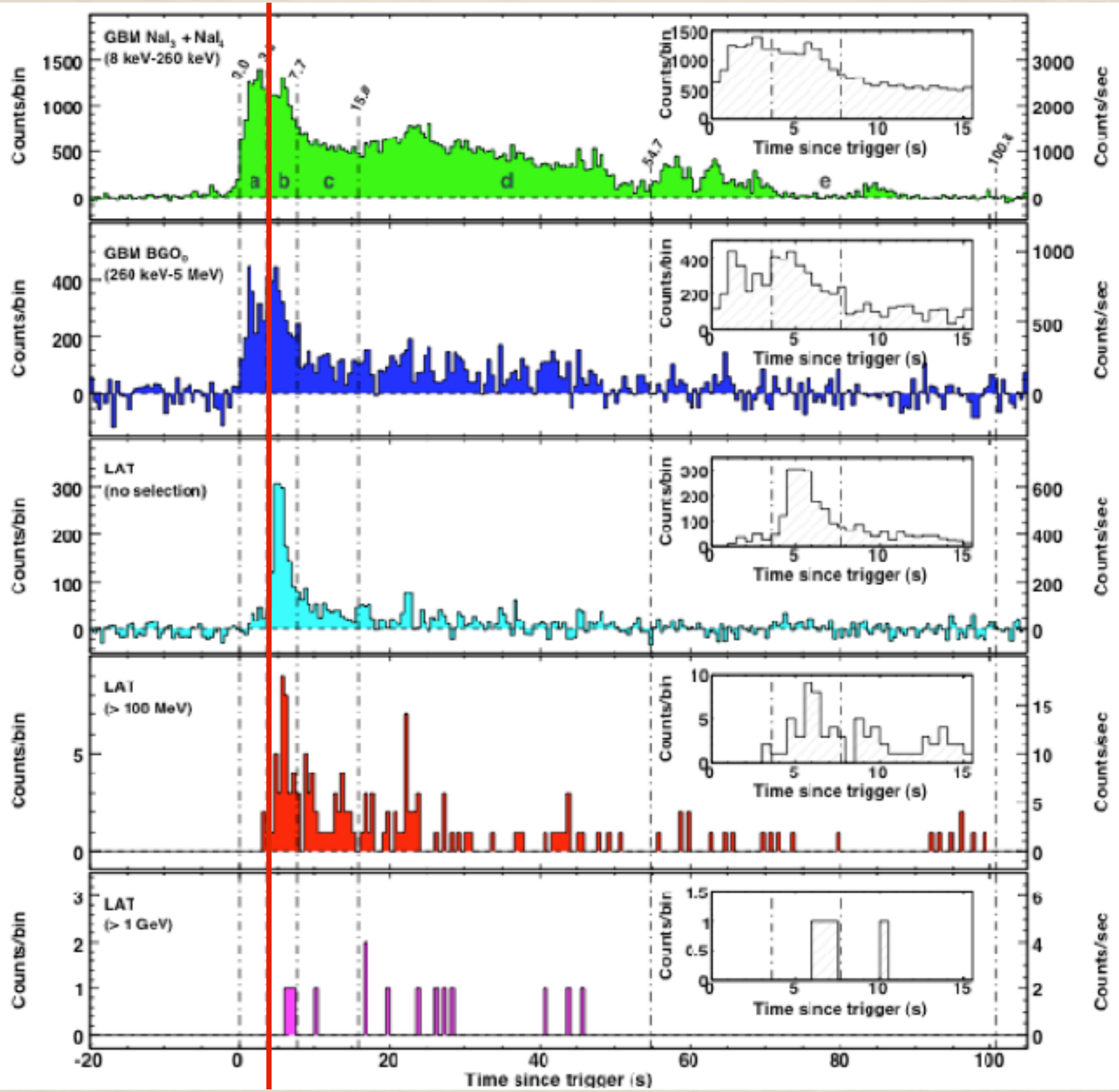
For those it sees

(1) prompt GeV
(2) afterglow GeV

Fermi-LAT only detects 5-10% GRBs at GeV energies (see, e.g., Ackermann et al., 2012)

GRB 080916C

(1) prompt GeV

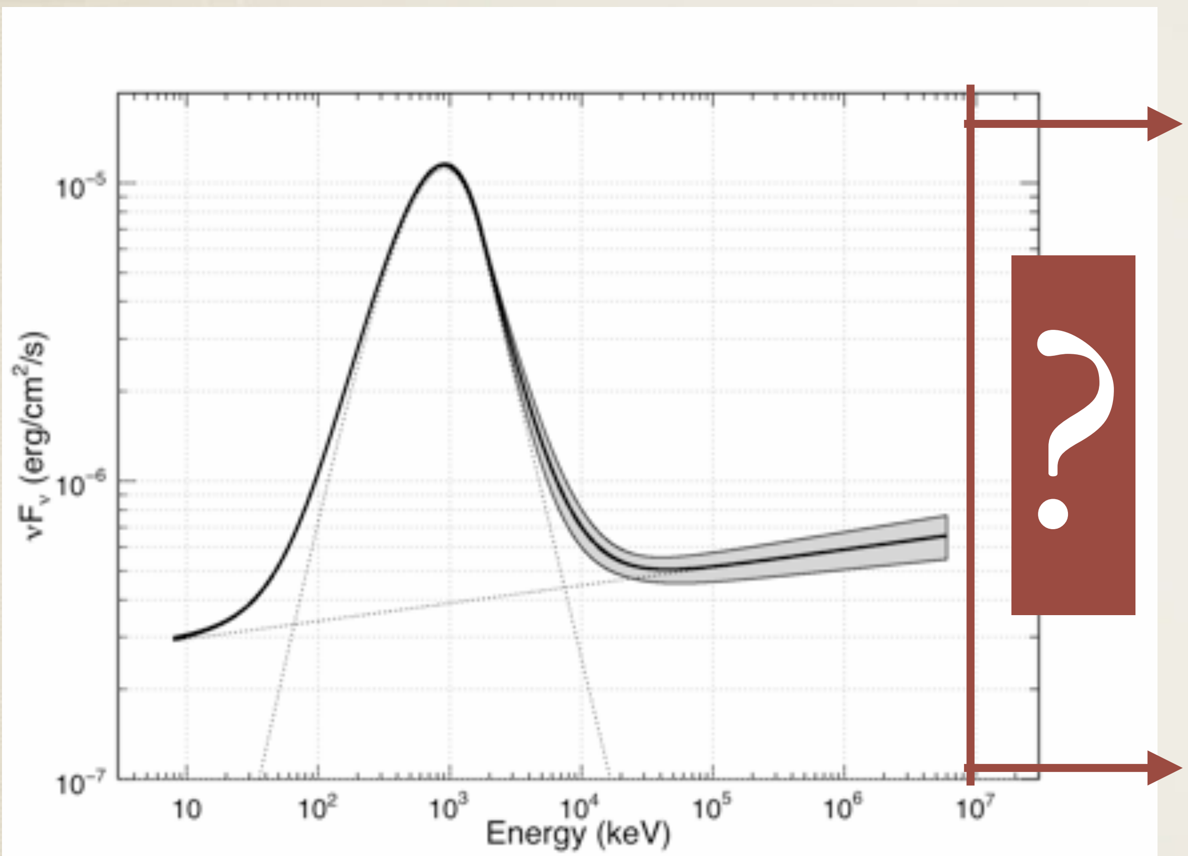


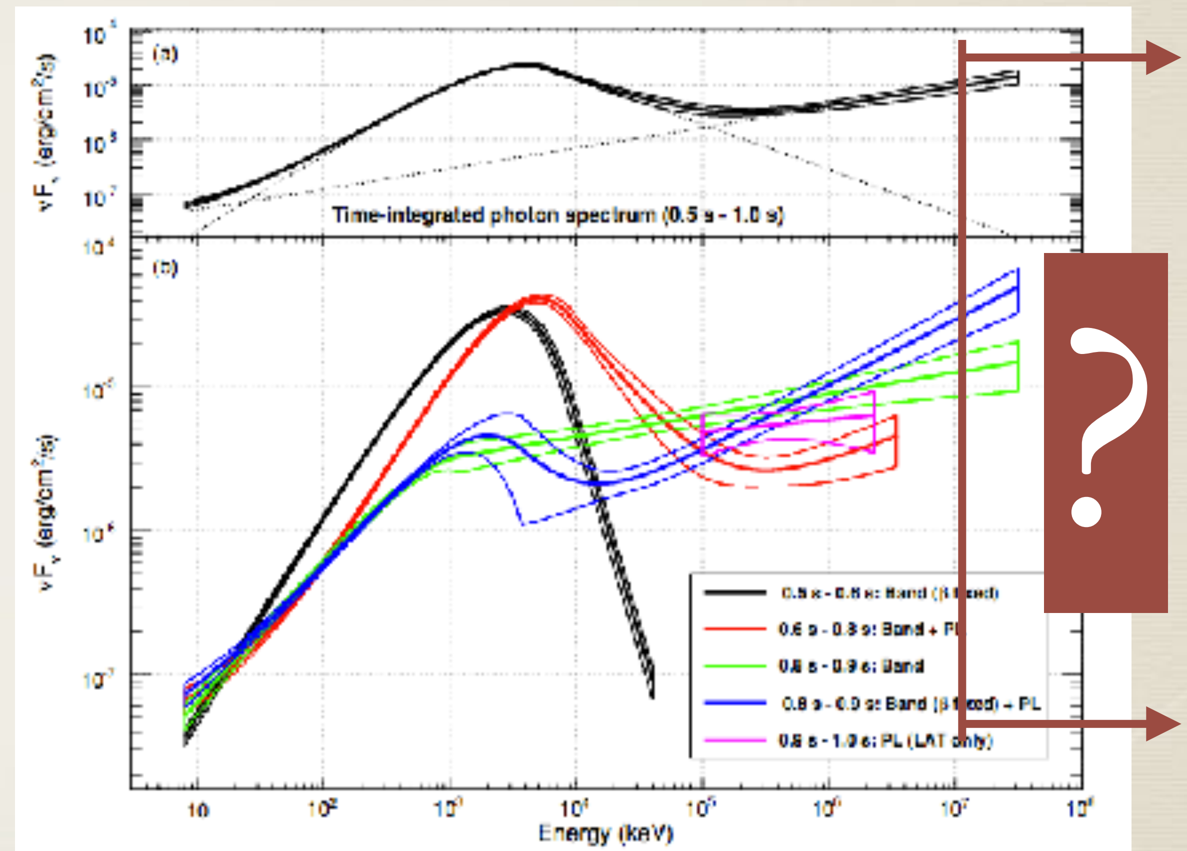
(1) prompt GeV

Second component during PROMPT PHASE

GRB 090902B

GRB 090510





10 GeV

10 GeV

Abdo et al. (2009)

Ackermann, et al. 2010

Lack of photon statistics from Fermi-LAT

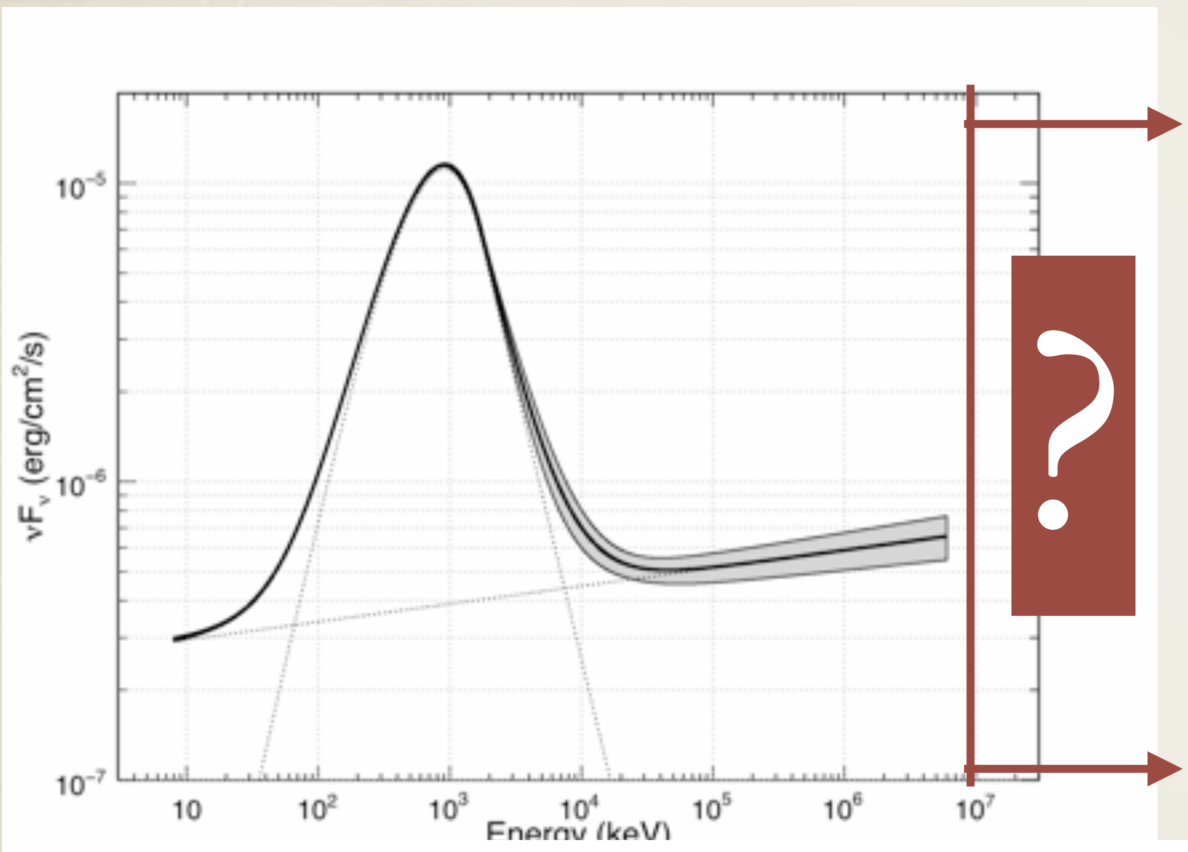
~10 sec after trigger

~1 sec after trigger

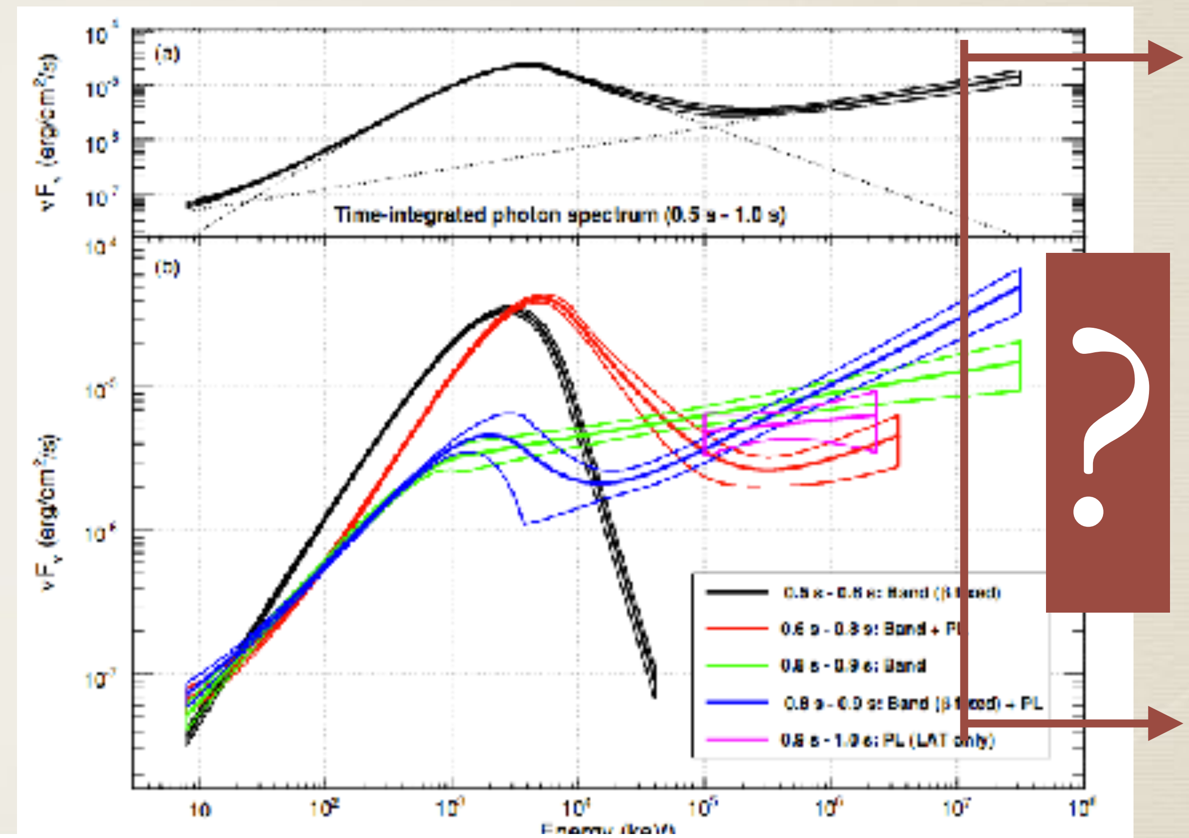
(1) prompt GeV

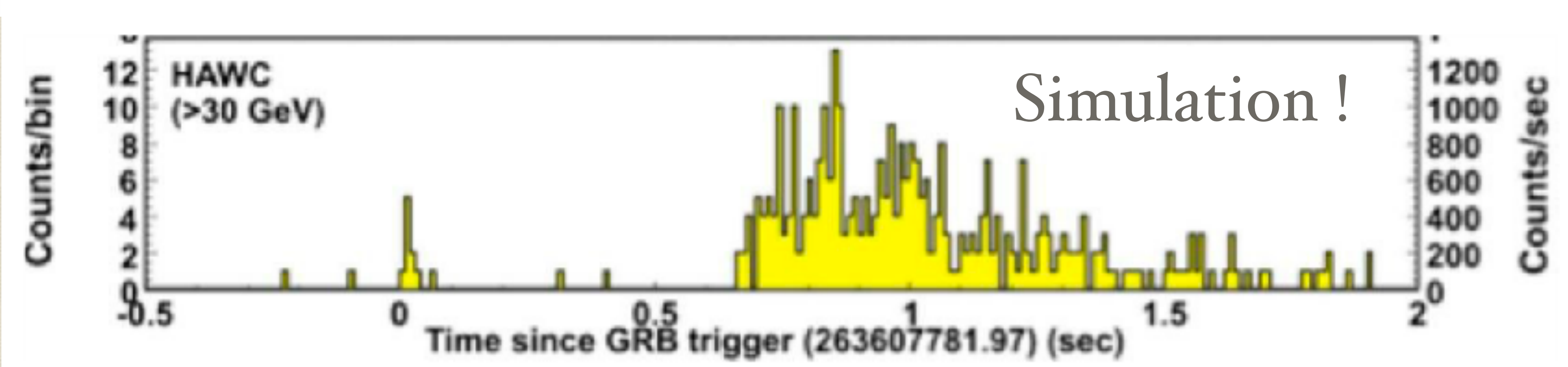
Second component during PROMPT PHASE

GRB 090902B



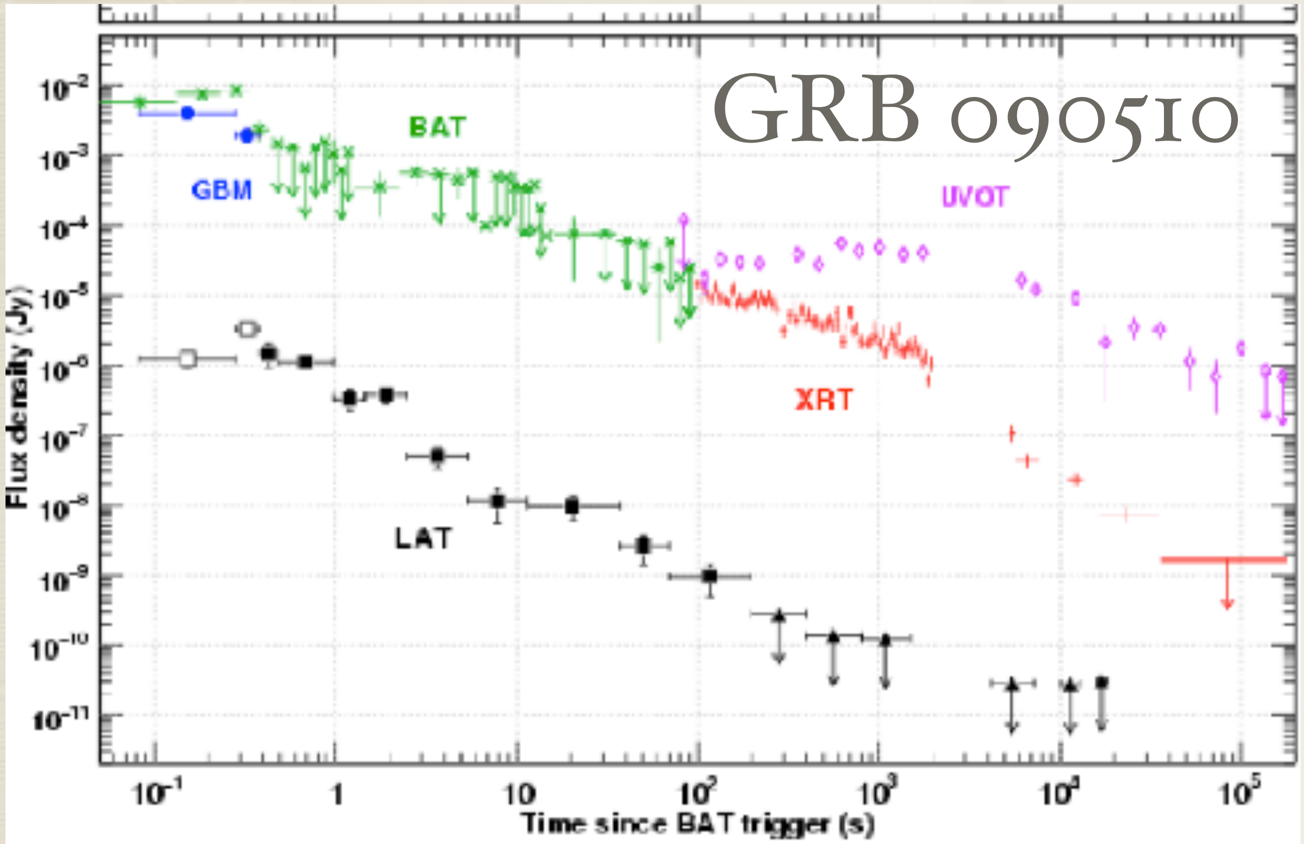
GRB 090510



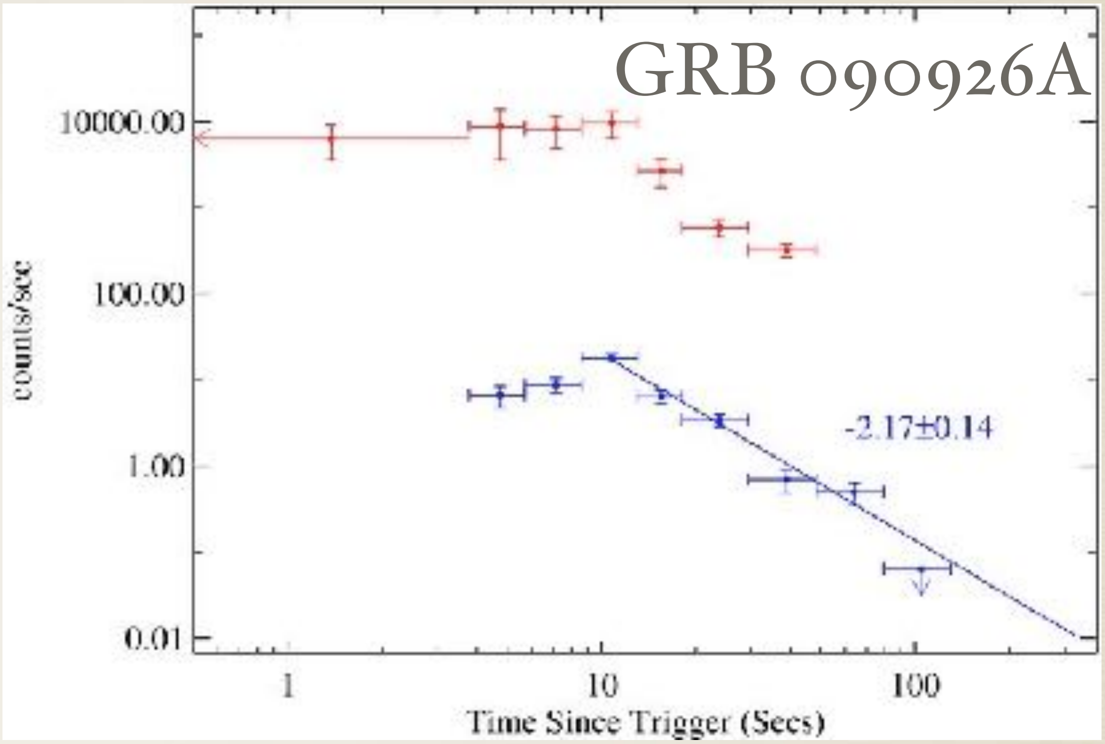


Power-law decayed GeV emission during afterglow

(2) afterglow GeV



Abdo et al. (2010)



Swenson et al. (2010)

- Well established synchrotron radio-opt-X emission from external shock electrons
- GeV afterglow naturally comes from synchrotron as well

Synchrotron or not synchrotron?

- Synchrotron emission from external shock electrons (e.g., Kumar & Barniol 2009, Ghisellini et al. 2010) becomes the 'standard' radiation mechanism in the Fermi era
- but there exists a maximum synchrotron energy, typically <<10 GeV
- Inverse Compton emission was suggested back in ~2000

Afterglow inverse-Compton Spectra

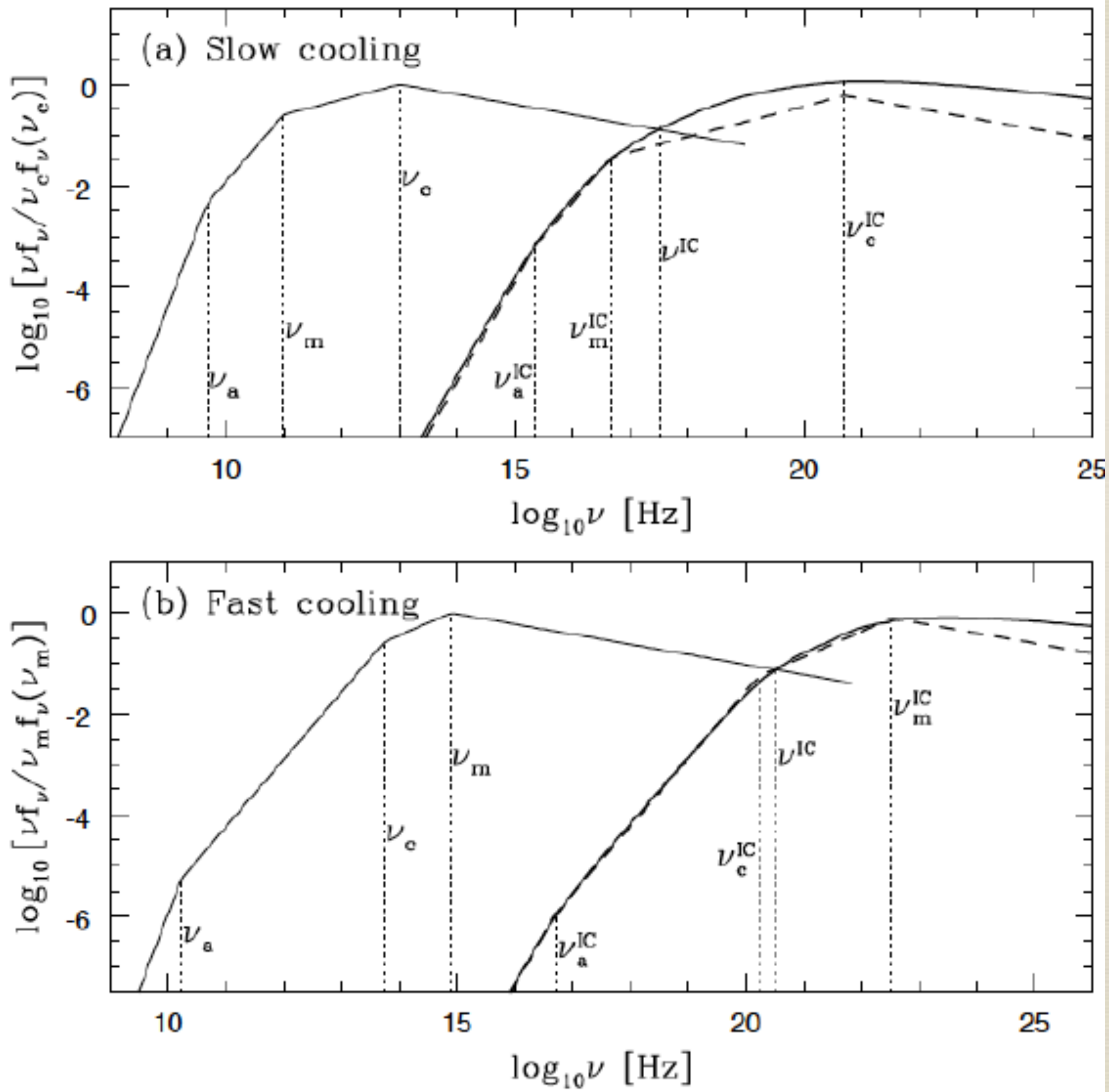
- Synchrotron-self-Compton emission from the same electrons
- Simple scaling in the Thomson regime

$$\nu^{IC} = 2\gamma^2 \nu$$

Chiang & Dermer 1999
Sari & Esin 2001
Zhang & Meszaros 2001

We are likely observing now in the VHE regime

c.f. talks in this section

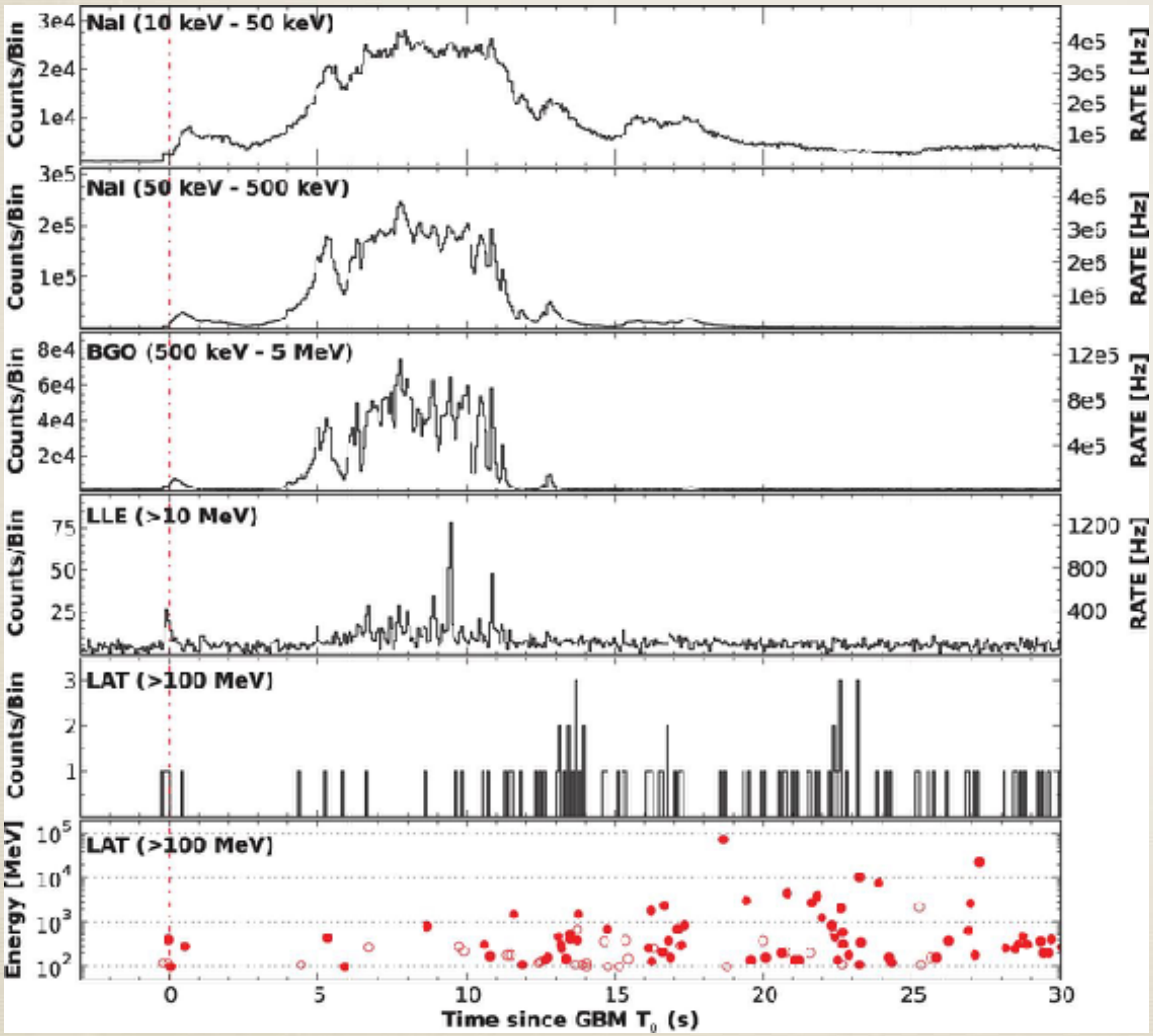


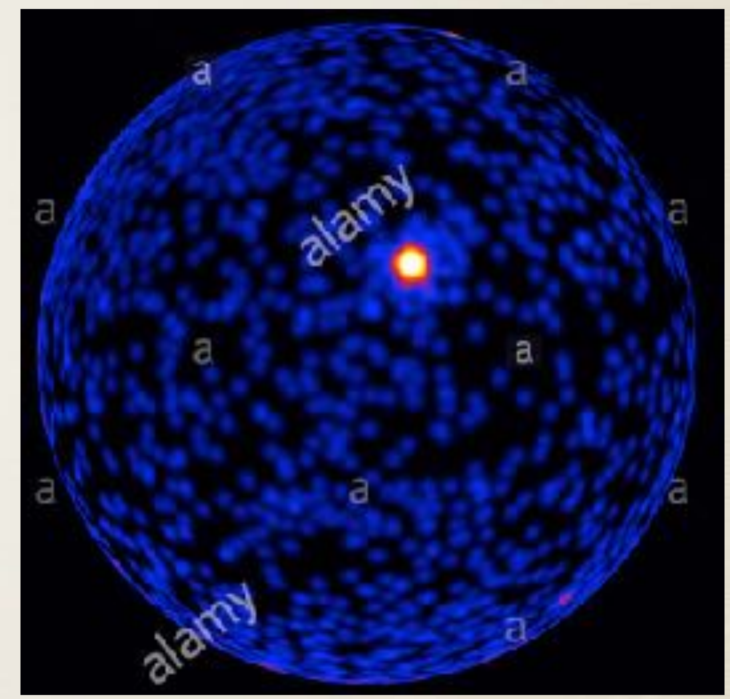
Sari & Esin (2001)

WHAT DO WE SEE ABOVE A FEW GEV ?

Very bright GRB 130427A

A good case to look deep into the issue

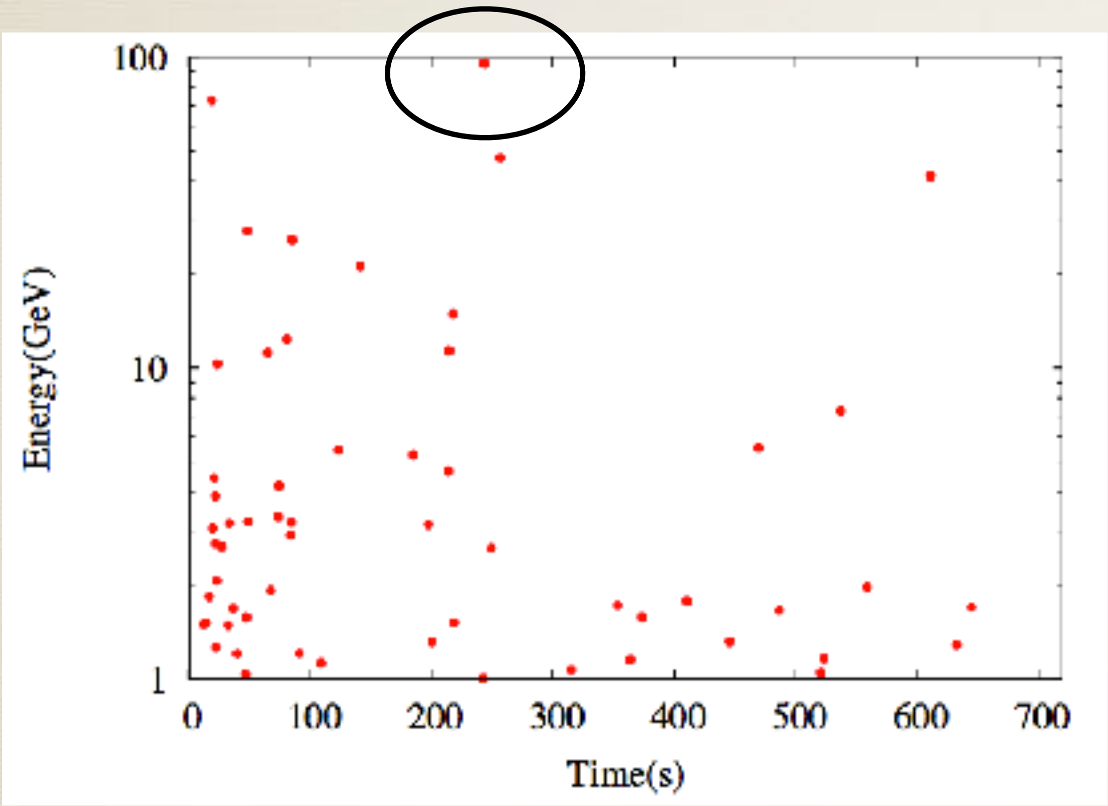




Very bright GRB 130427A

A good case to look deep into the issue

95 GeV

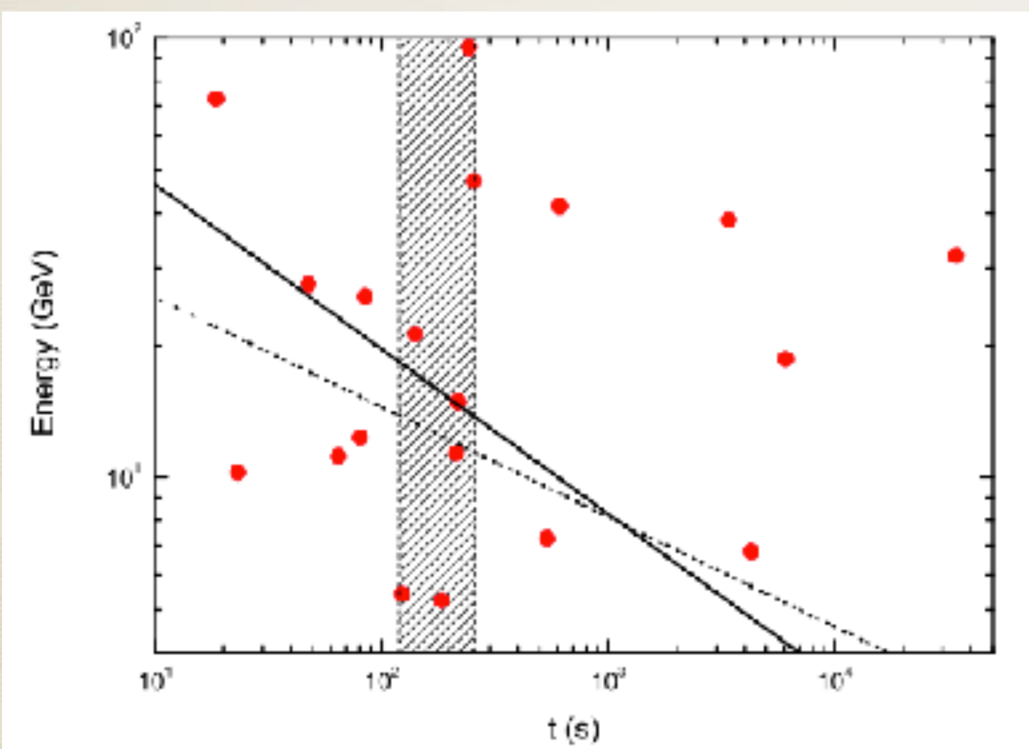


Fan, Tam, et al. (2013)

- GRB 130427A emits many GeV gamma-rays during the prompt & afterglow period
- a 95 GeV photon arrived at T_0 + 243s, corresponding to an intrinsic photon energy 128 GeV at z=0.34

Origin of the afterglow GeV

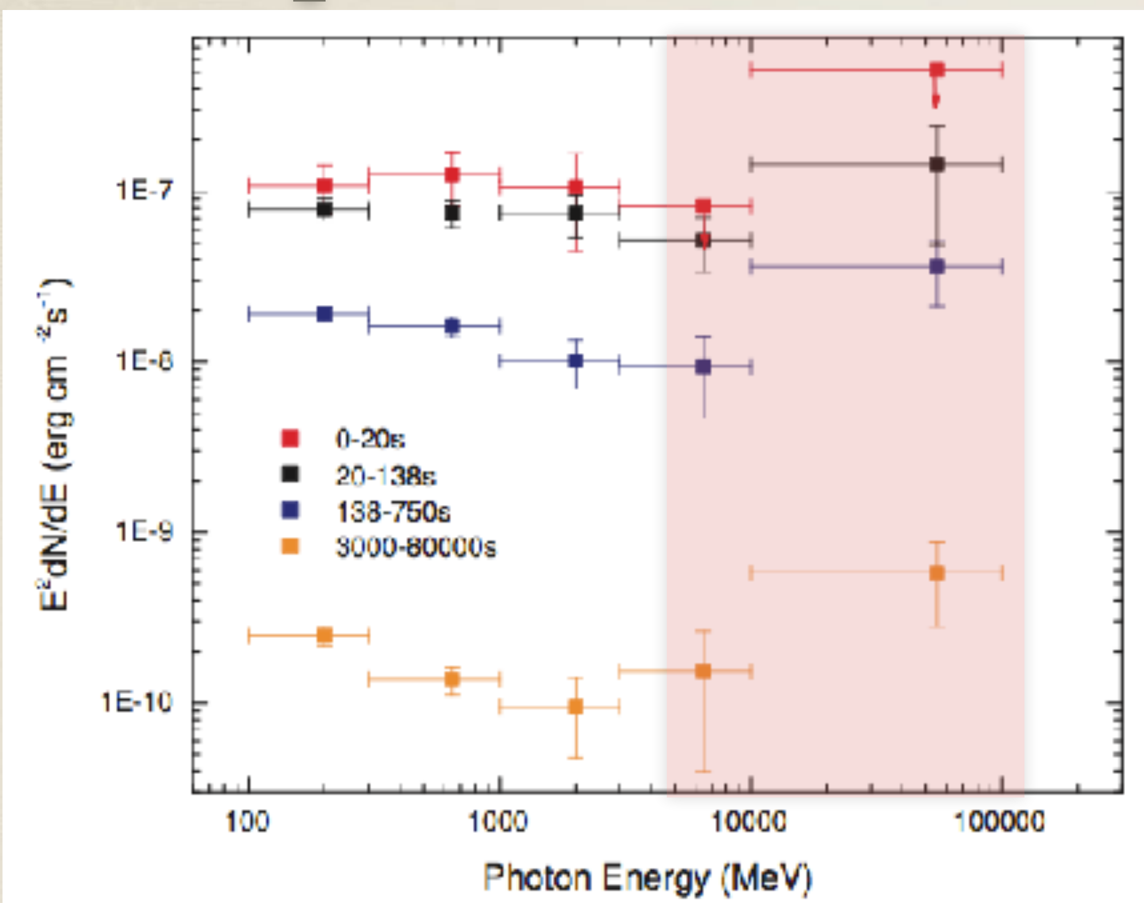
* Synchrotron emission (e.g., Kumar & Barniol 2009, Ghisellini et al. 2010) can explain <a few GeV emission
* but there exists a maximum synchrotron energy, it is hard to explain the >10 GeV photons

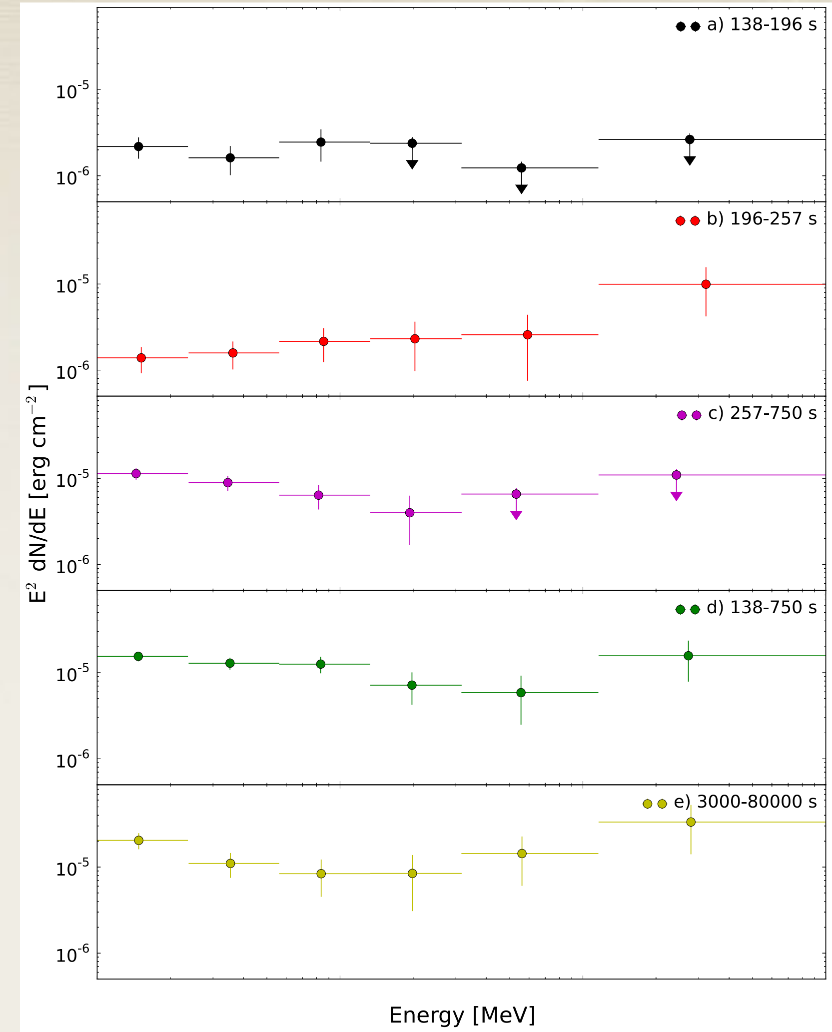


$$\epsilon_{\rm syn,M} \sim 100\ {\rm MeV}\ \Gamma(1+z)^{-1} \sim \begin{cases} 20\ {\rm GeV}\ E_{\rm k,54}^{1/8} n_{-2}^{-1/8} t_2^{-3/8} \left(\frac{1+z}{1.34}\right)^{-5/8}, & {\rm ISM;} \\ 15\ {\rm GeV}\ E_{\rm k,54}^{1/4} A_{*,-2}^{-1/4} t_2^{-1/4} \left(\frac{1+z}{1.34}\right)^{1/4}, & {\rm wind;} \end{cases}$$

Fan, Tam, et al. (2013)
also see Ackermann et al. (2013)

A new >2.5 GeV component identified





Ackermann et al. (2014)

$t - T_0$ (sec)	Power Law (PL) Γ	Broken Power Law (BPL) Γ_1 ($E < E_b$)	Γ_2 ($E > E_b$)	E_b (GeV)	Improvement of BPL over PL[a] (σ)
0–20	−2.0±0.2		...		...
20–138	−1.9±0.1		...		...
138–750	−2.1±0.1	−2.2±0.1	−1.4±0.2	4.3±2.0	2.5
3000–80,000	−2.1±0.1	−2.6±0.7	−1.4±0.2	1.1±0.9	2.9
138–80,000	−2.1±0.1	−2.3±0.2	−1.4±0.1	2.5±1.1	3.5

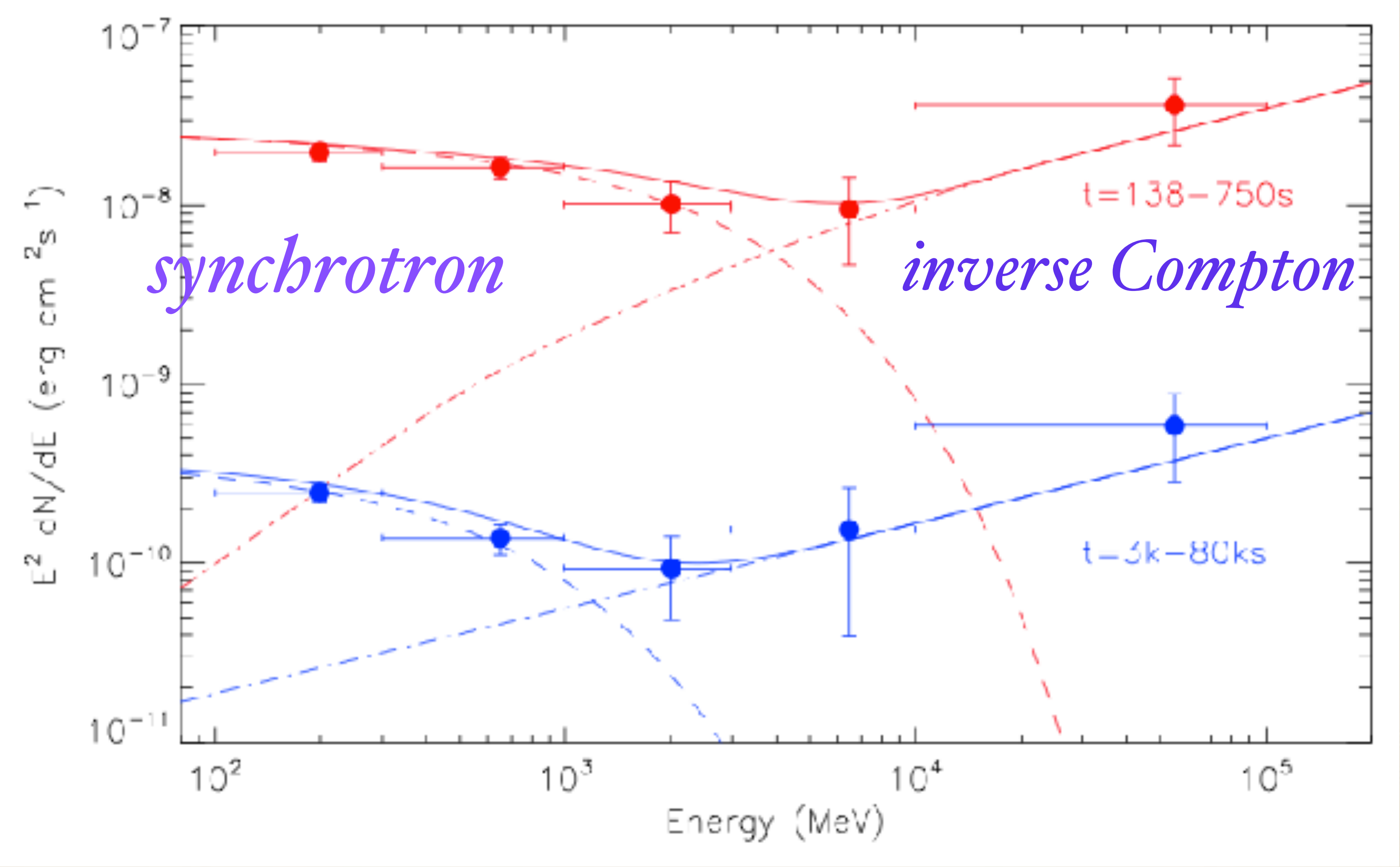
[a] calculated as $\sqrt{2} \times [\log(\mathcal{L}_{BPL}) - \log(\mathcal{L}_{PL})]$

Power law index doesn't change!

Tam et al. (2013)

Significance of broken power law over power law

Inverse Compton emission can explain the hard component



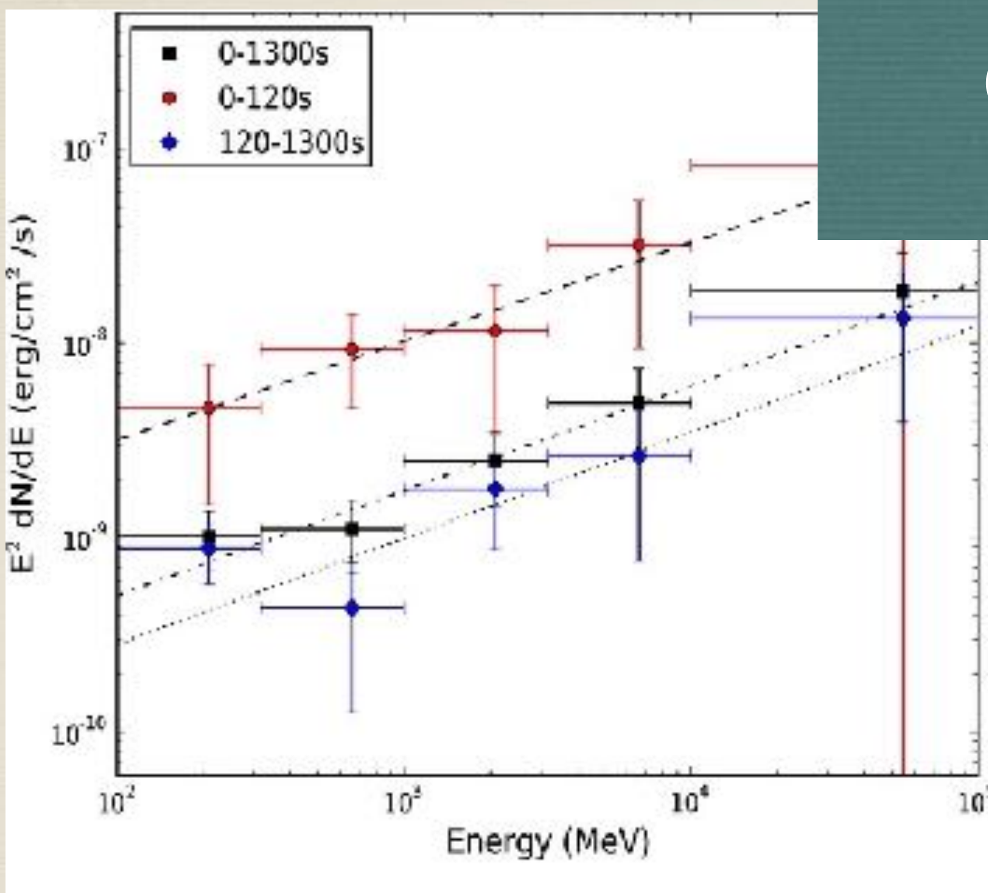
Liu et al. (2013)

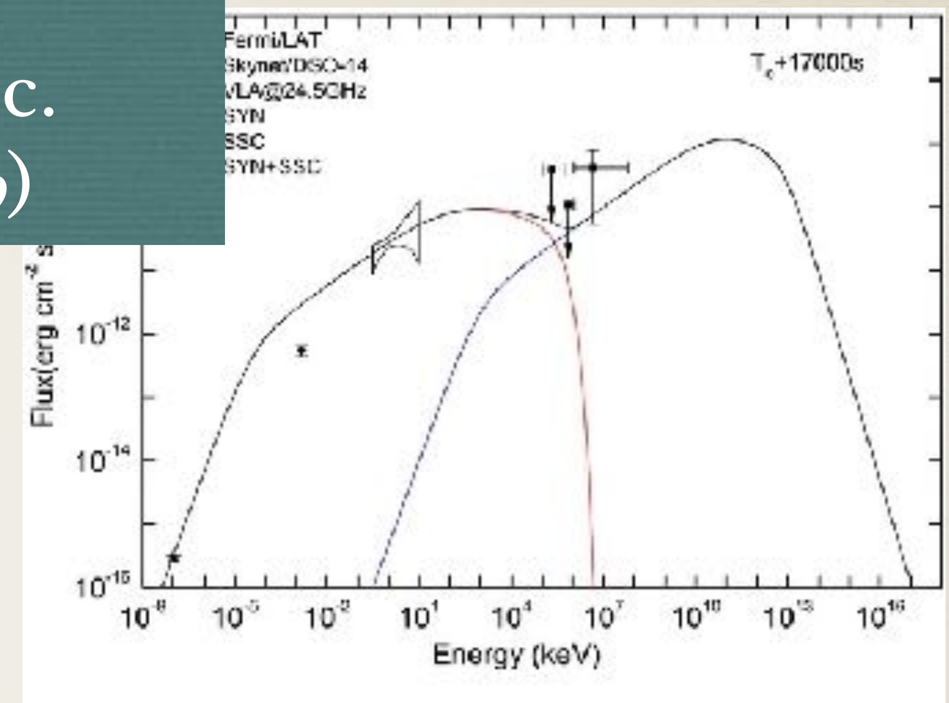
Note that VERITAS did not see this GRB starting T_0+20 hours (Aliu et al. 2014)

GRB 131231A

Mysterious 173 GeV photon from GRB 131231A
(57 ks, assoc. prob=97%)

GRB 130907

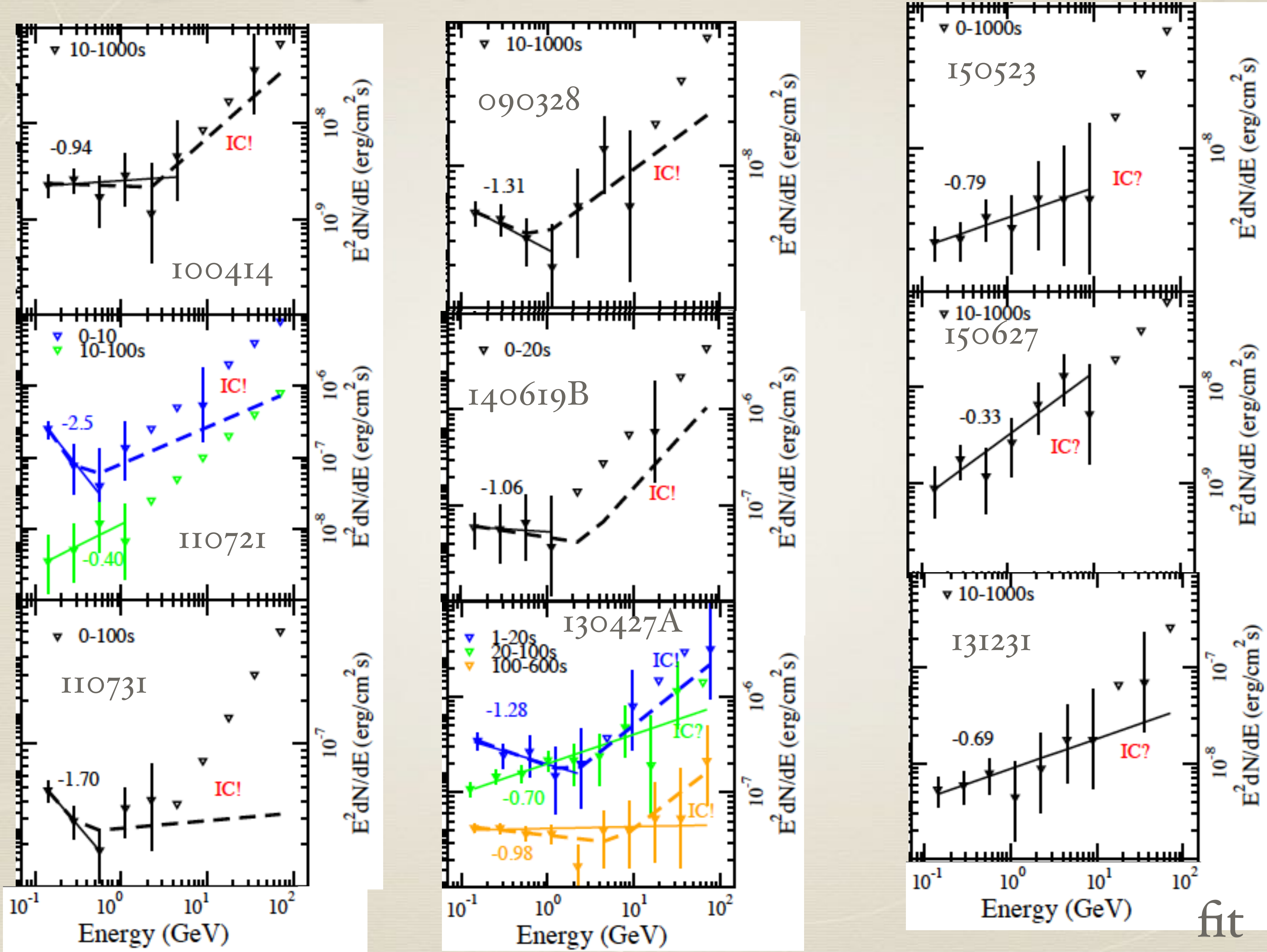




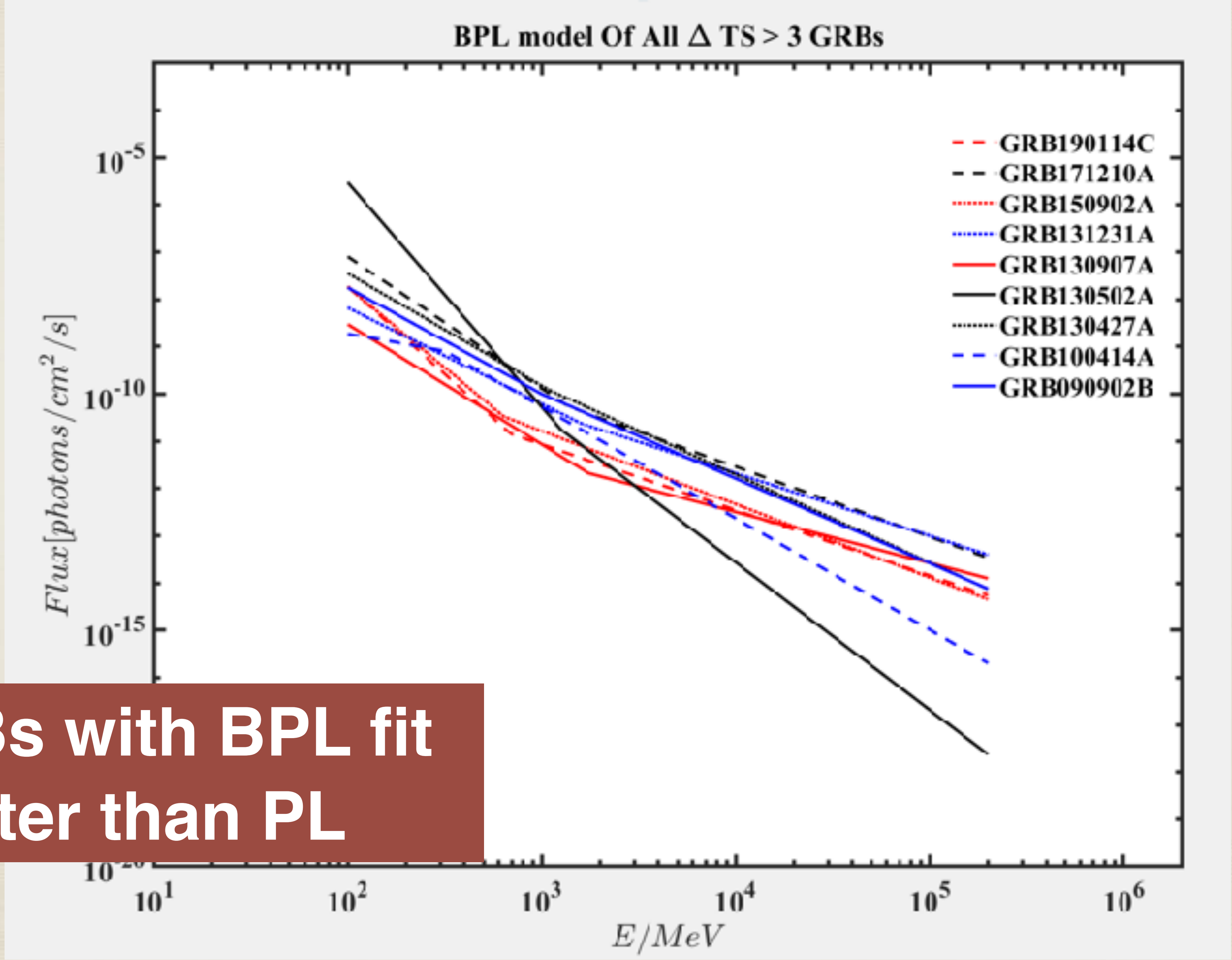
Hard photon index all the way from 100 MeV
Liu, B. et al. (2014)

The energy of the 55 GeV photon exceeds the maximum synchrotron photon energy at this time.
SSC emission of the afterglow?
(Tang, Tam & Wang, 2014)

A larger sample (Panaitescu 2017, up to ~1ks)



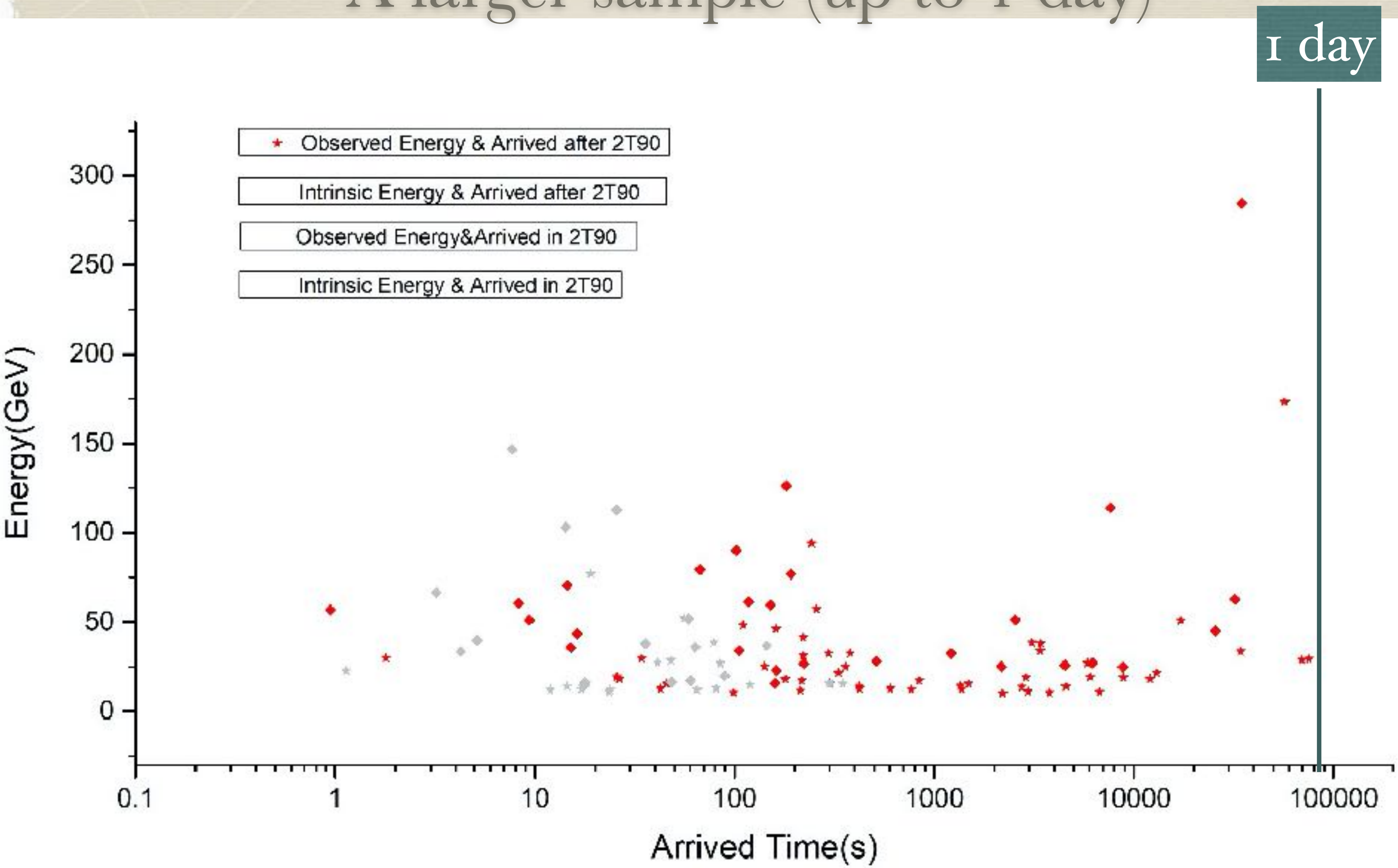
A larger sample (up to 1 day)



9 GRBs with BPL fit better than PL

He+ in preparation

A larger sample (up to 1 day)



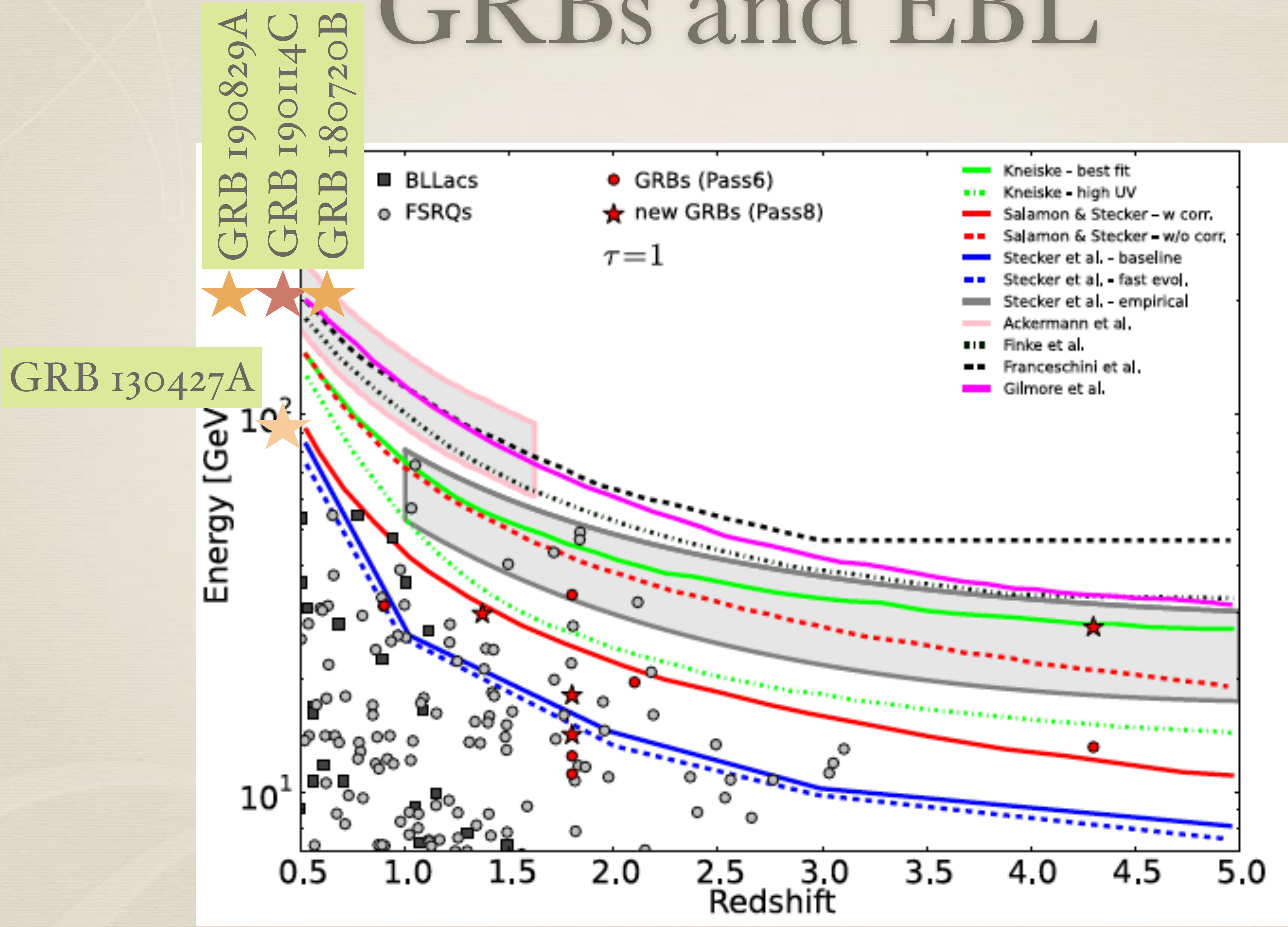
He+ in preparation

Conclusions

* Inverse Compton afterglow is rather common in LAT GRBs
* TeV emission established, also from IC
* LHAASO-WCDA will detect GRBs!

SPARE SLIDES

GRBs and EBL


GRB 190829A
GRB 190114C
GRB 180720B
GRB 130427A
BLLacs
FSRQs
GRBs (Pass6)
new GRBs (Pass8)
τ=1
Kneiske - best fit
Kneiske - high UV
Salamon & Stecker – w corr.
Salamon & Stecker – w/o corr.
Stecker et al. - baseline
Stecker et al. - fast evol.
Stecker et al. - empirical
Ackermann et al.
Finke et al.
Franceschini et al.
Gilmore et al.
Energy [GeV]
Redshift
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

Swift-XRT GRBs
energy flux distribution