High-energy emission from GRBs

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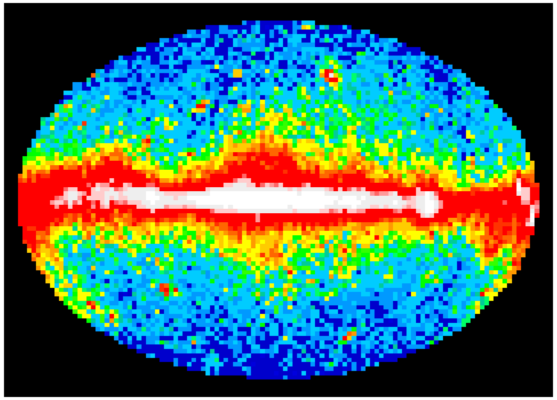
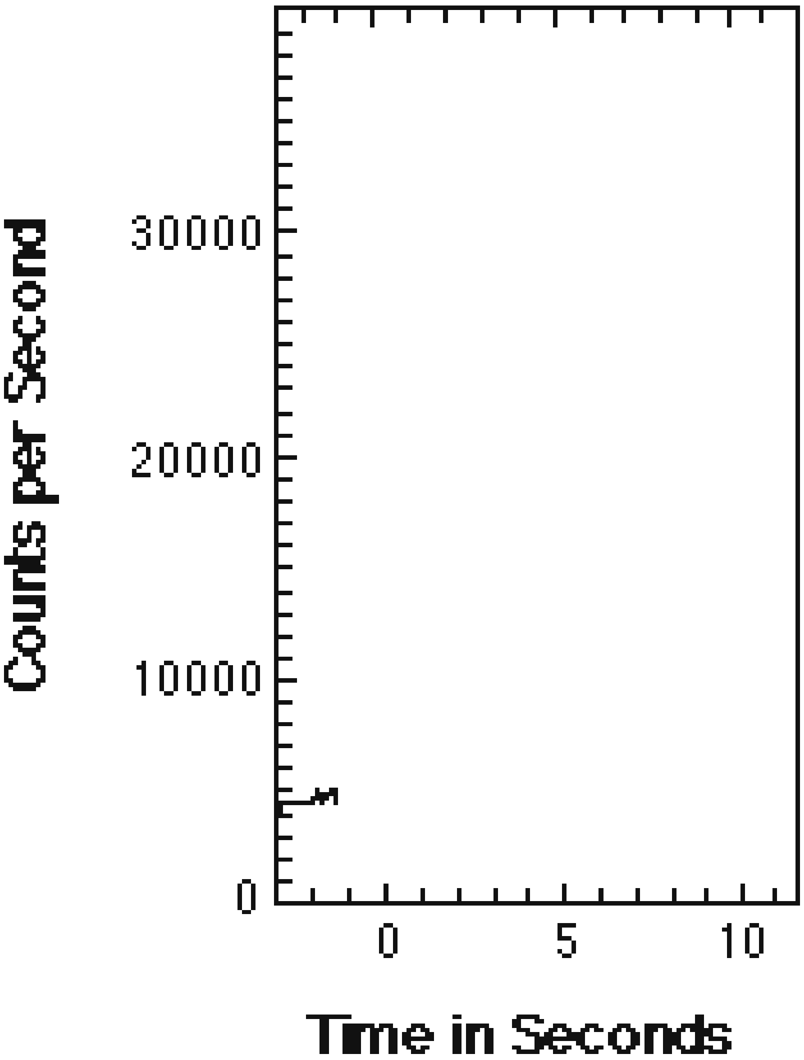
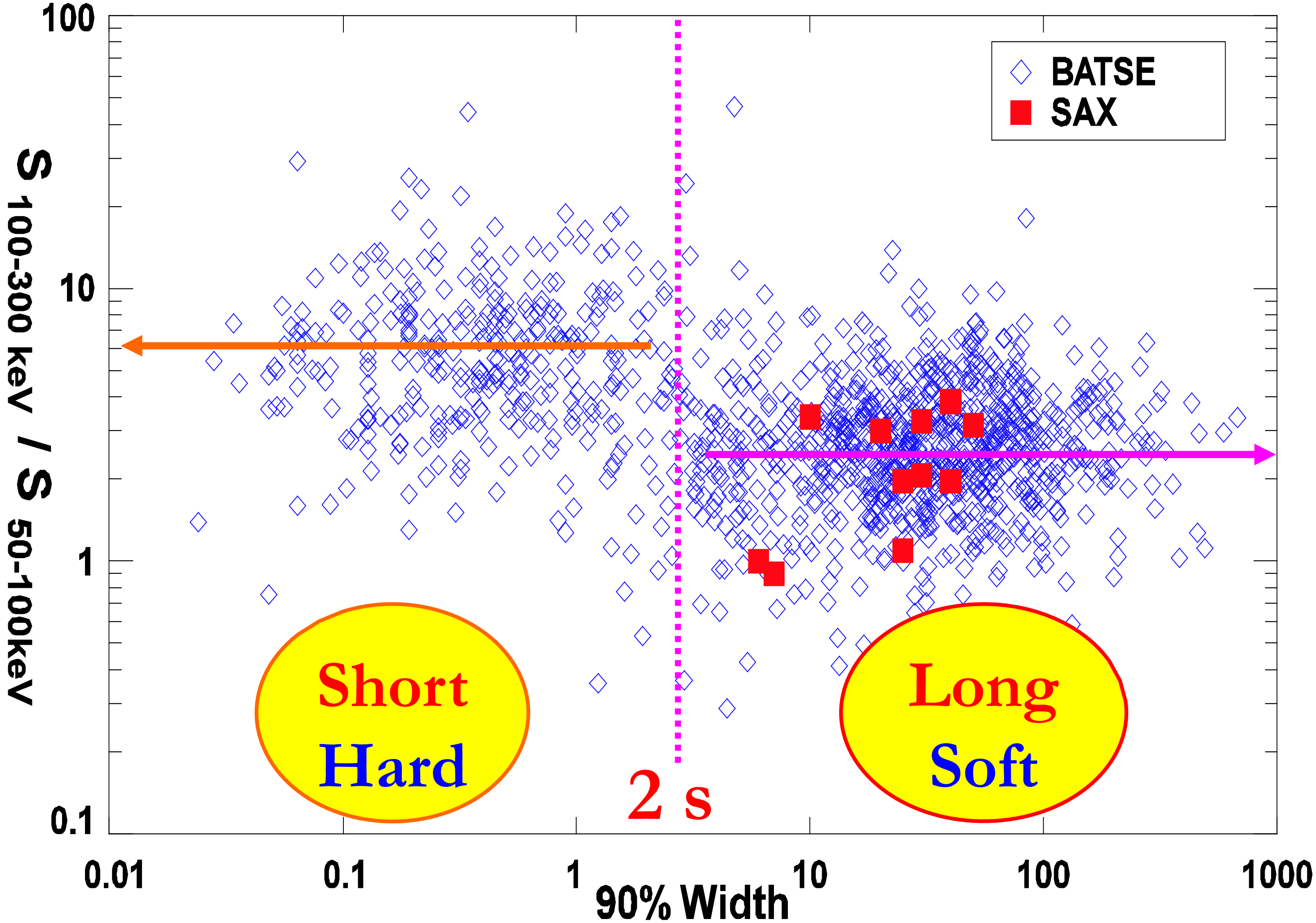
Thomas Tam, Martin Lemoine

Gamma-ray bursts are short-duration flashes of gamma-rays occurring at cosmological distances!

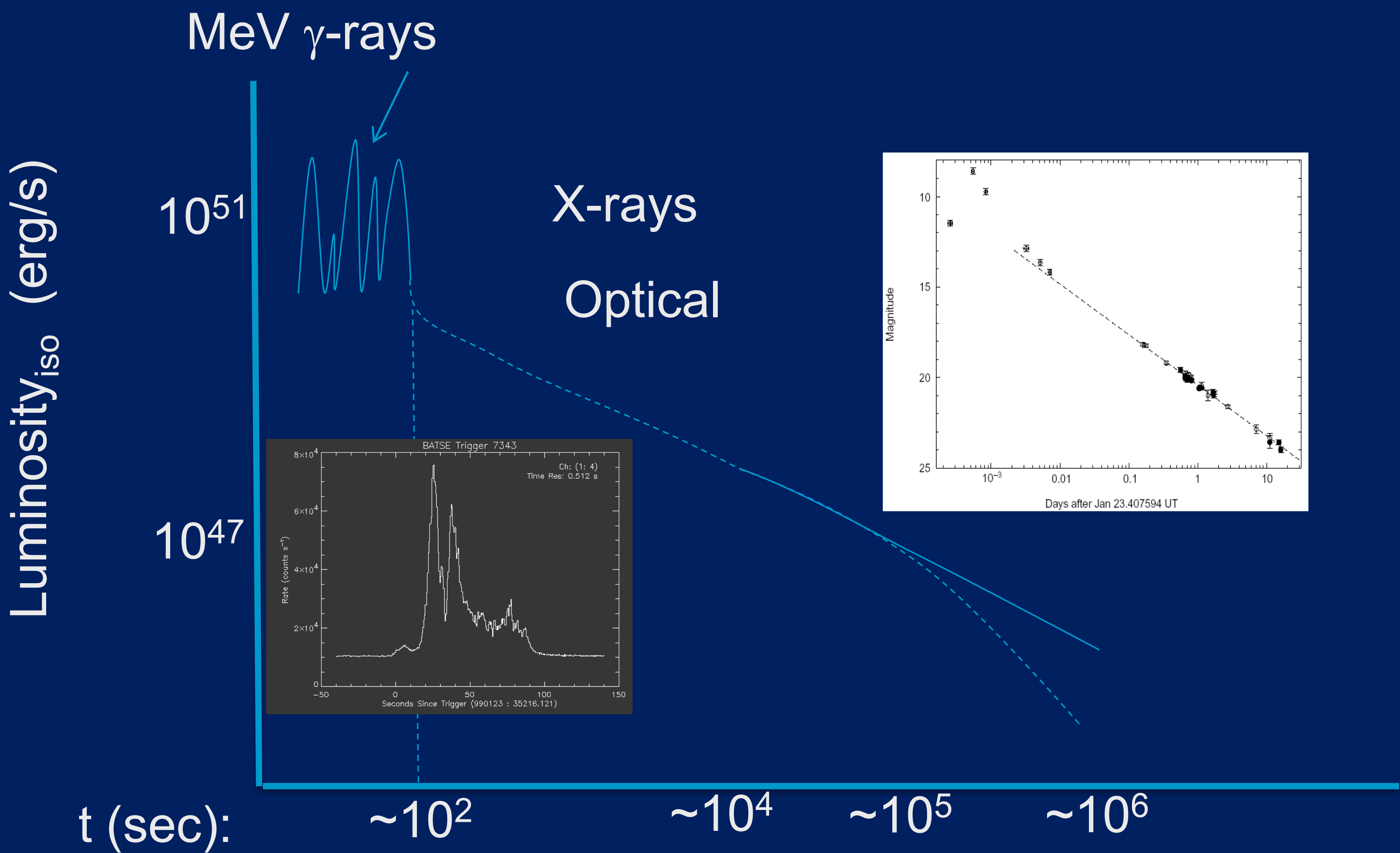




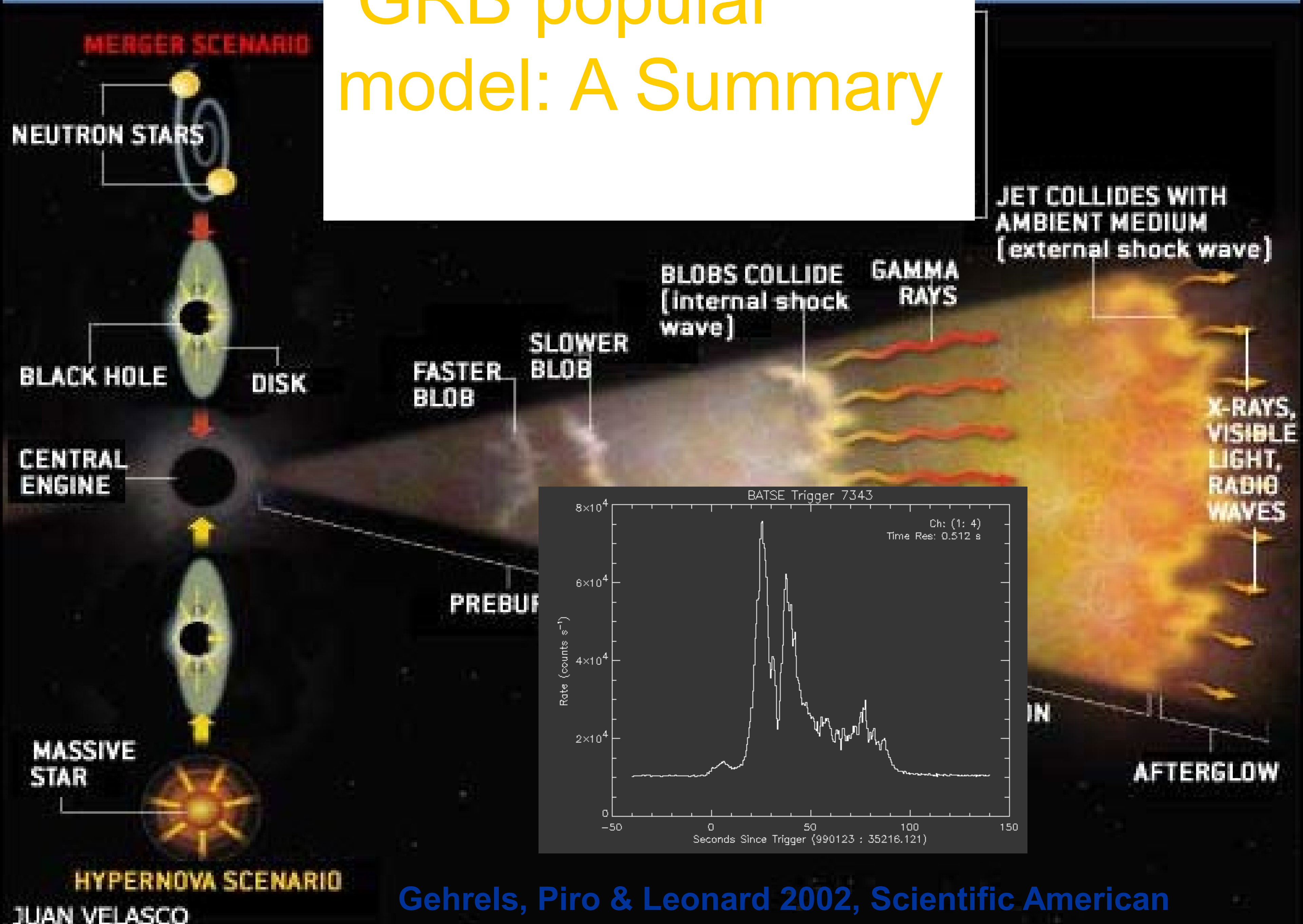
Bimodal distribution of durations



Typical GRB light curves

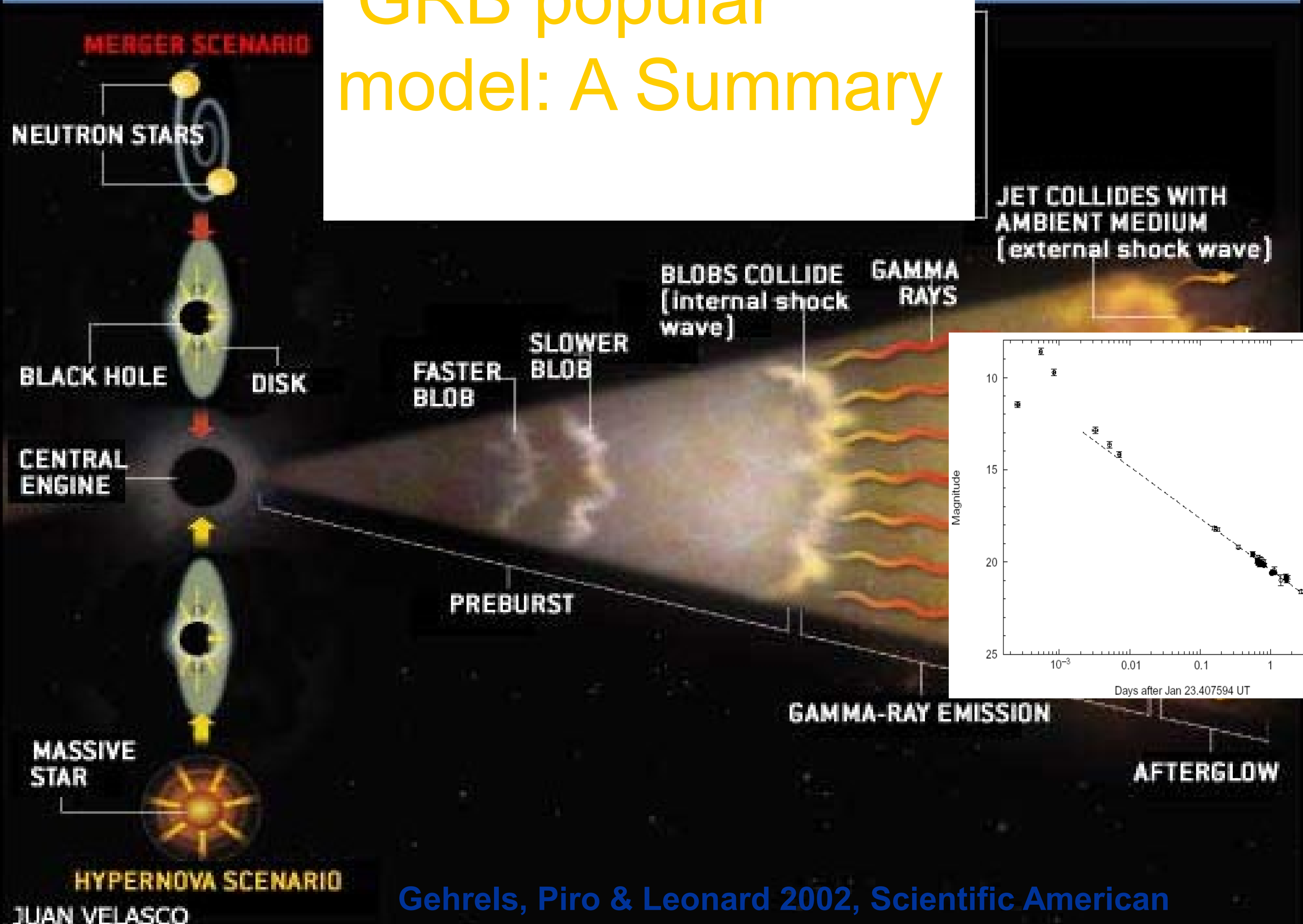


GRB popular model: A Summary



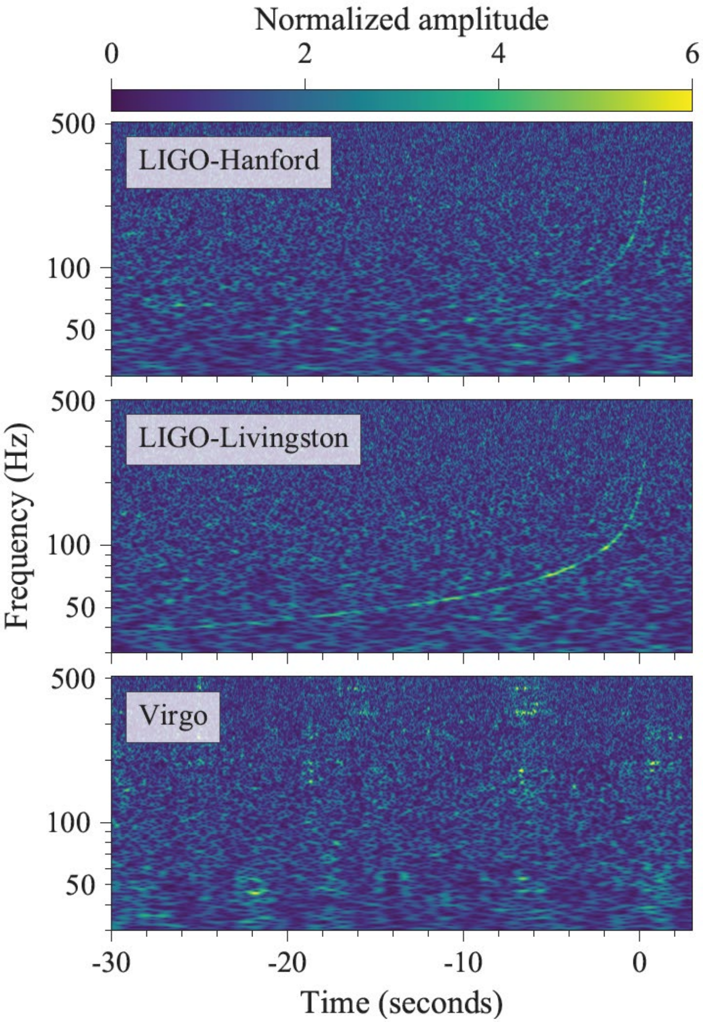
Gehrels, Piro & Leonard 2002, Scientific American

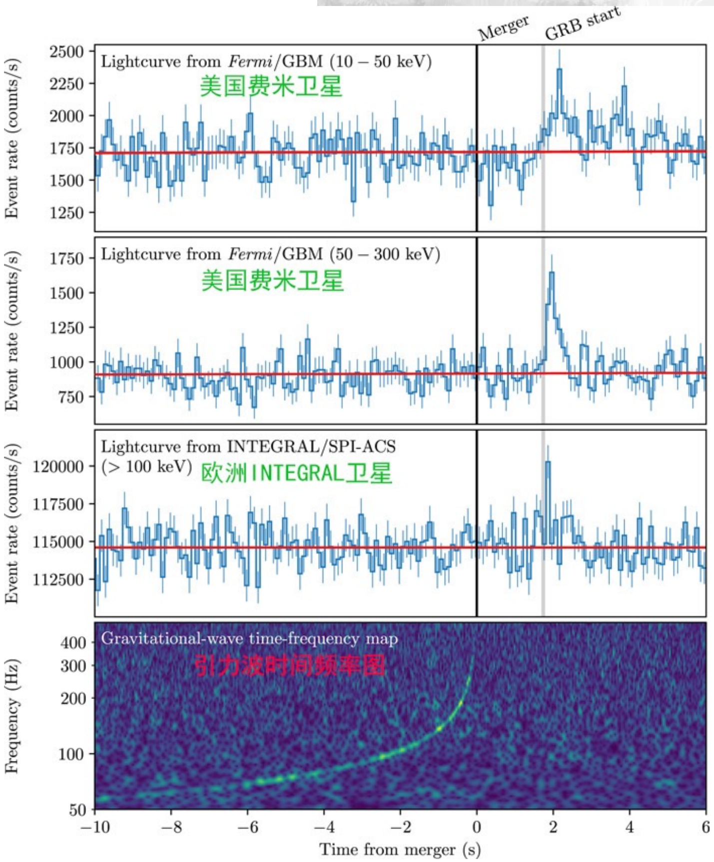
GRB popular model: A Summary



Gehrels, Piro & Leonard 2002, Scientific American

Gravitation wave detection from GW170817/GRB170817A

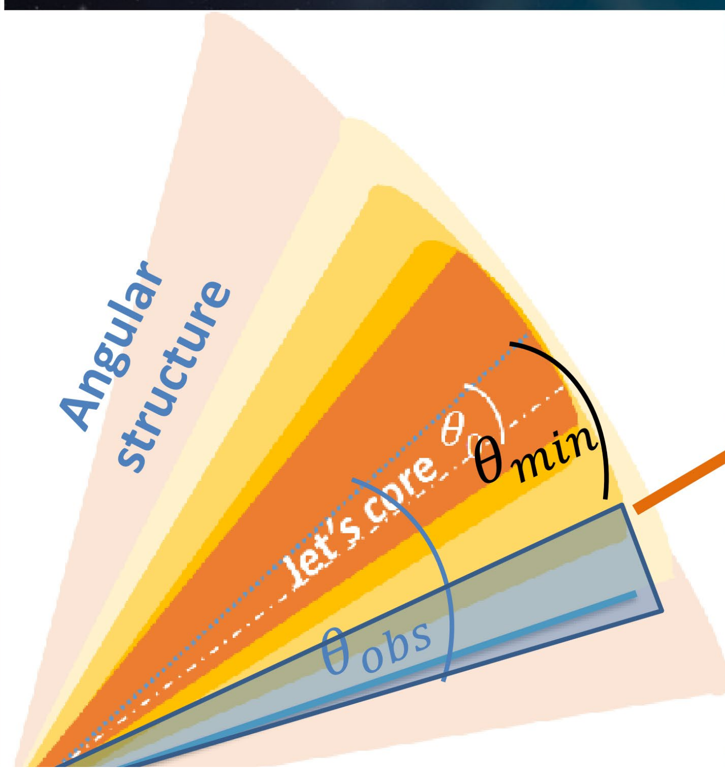


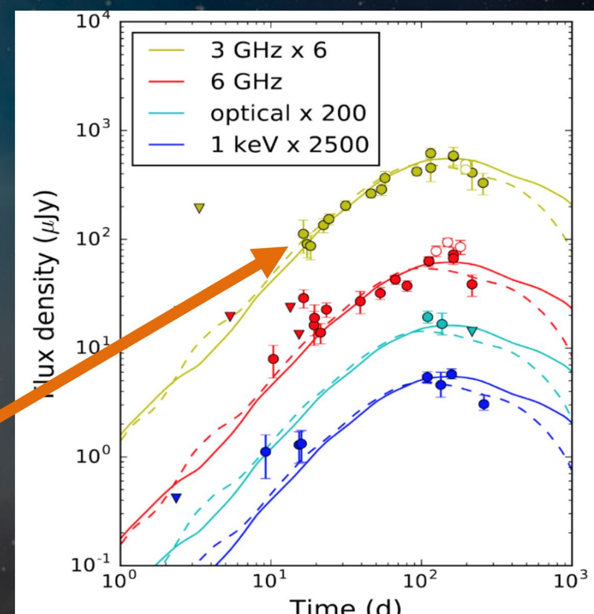


A short GRB

Multiwavelength observations of GW170817

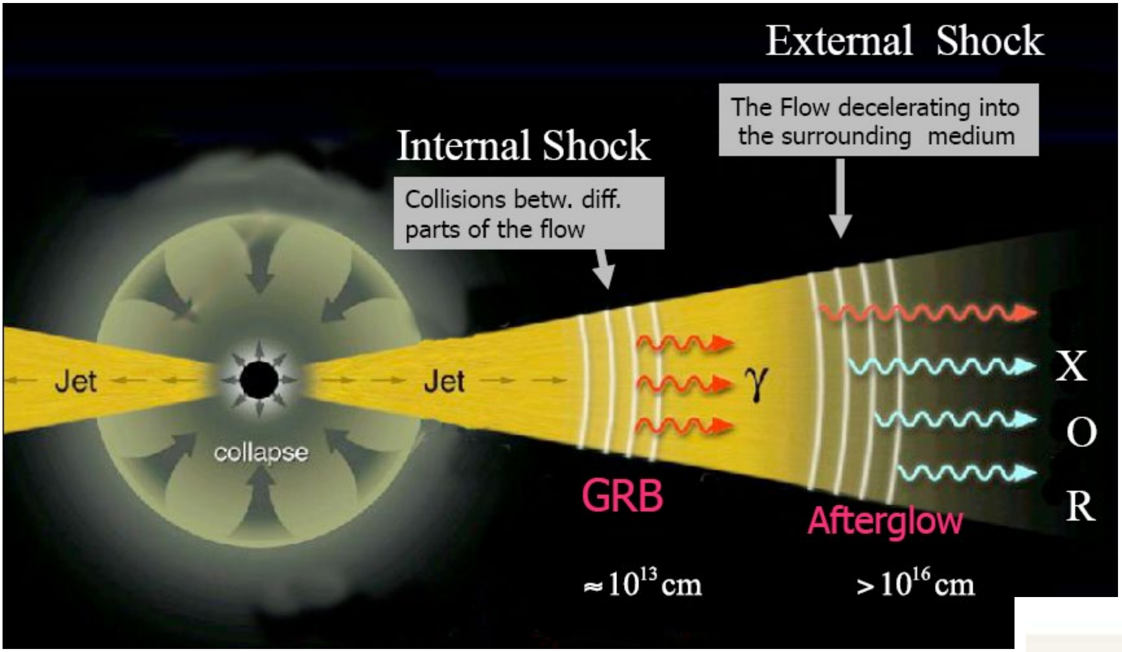
- Afterglow dominated by angular profile of E and Γ
- Initial view off-axis. With time inner material with more energy becomes visible.

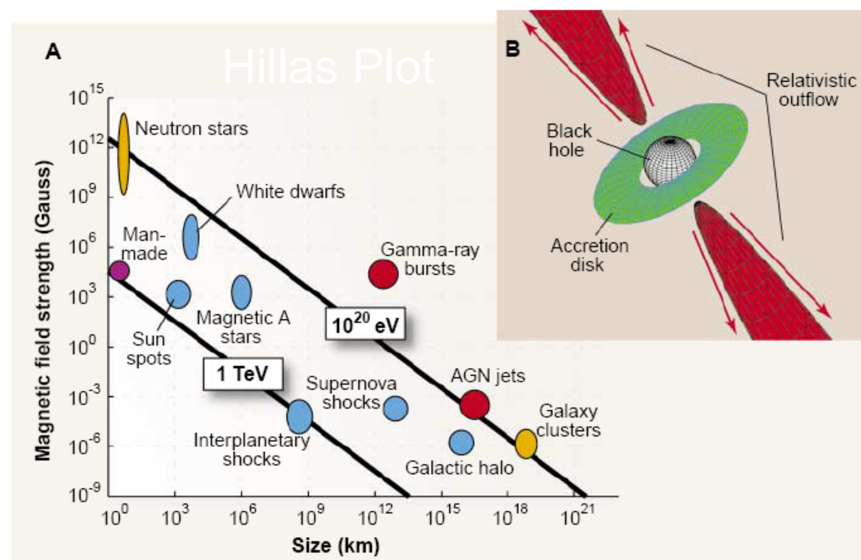




Light-curve increases as more energetic material contributes

CR acceleration in GRBs

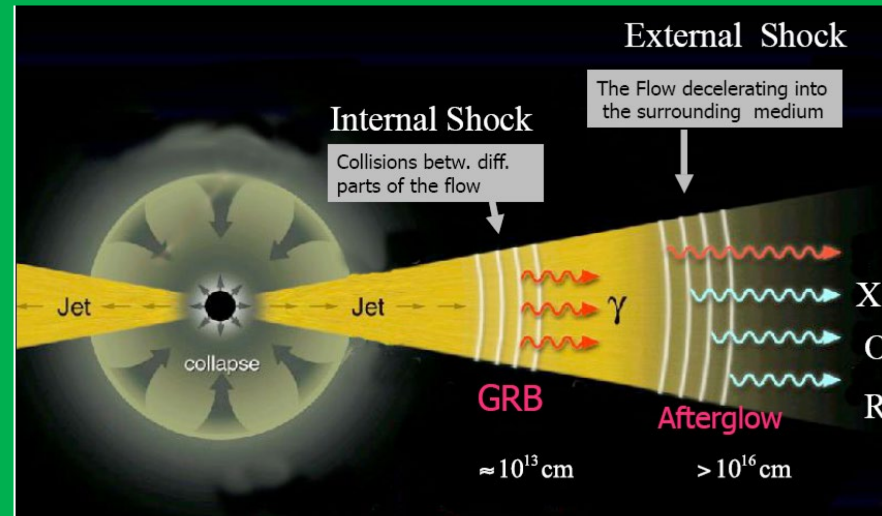


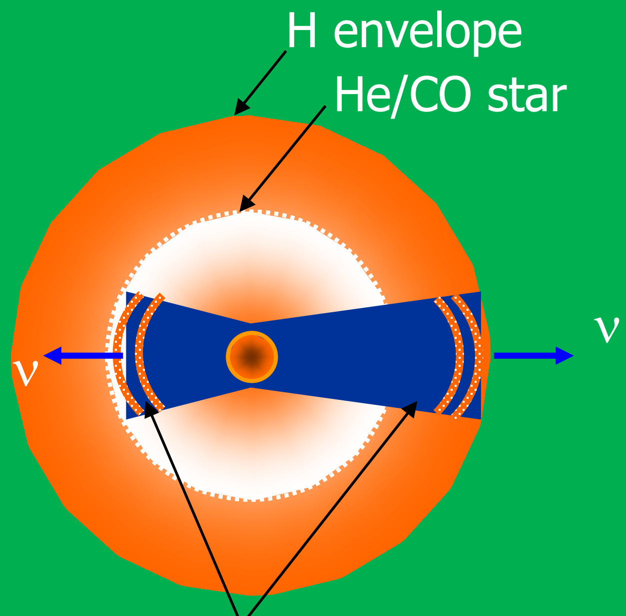


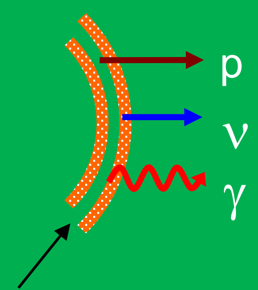
- Internal shocks (Waxamn 9
- External shocks (Vietri 95)

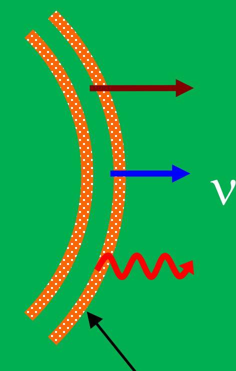
GRB Neutrino prediction

$$\varepsilon_p \varepsilon_\gamma \geq 0.3\ \mathrm{GeV}^2 \Gamma^2$$









Buried shocks
No γ-ray emission
Precursor ν's

Razzaque, Meszaros & Waxman '03
Murase et al. 2013, 2017

TeV

Internal shocks
Prompt γ-ray (GRB)
Burst ν's

Waxman & Bahcall '97
Murase & Nagataki 07
Wang & Dai 09

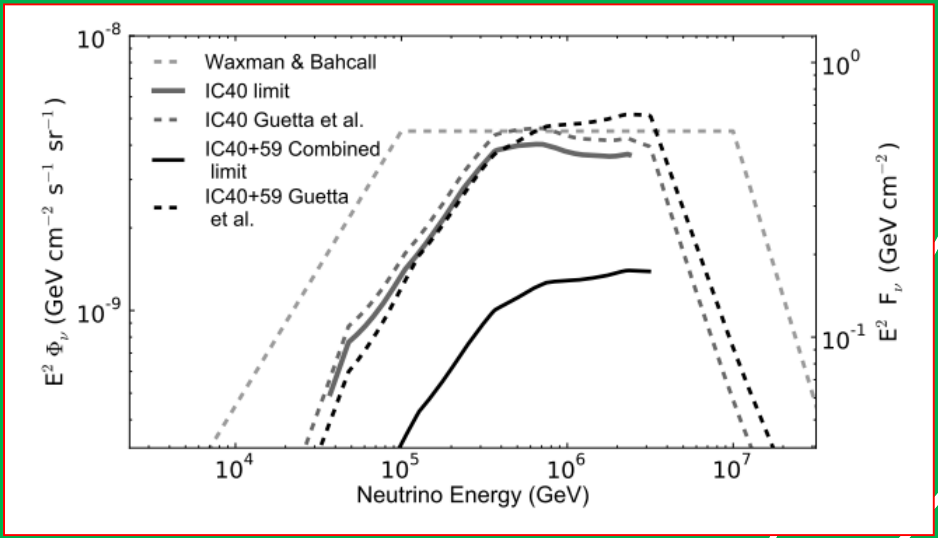
PeV

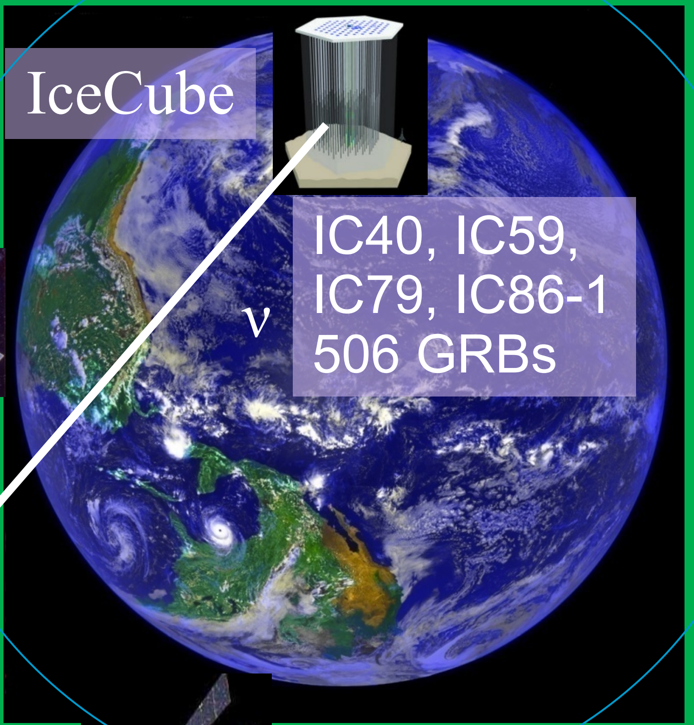
External shocks
Afterglow X,UV,O
Afterglow ν's

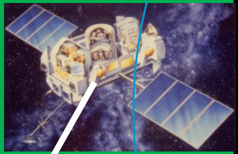
Waxman & Bahcall '00

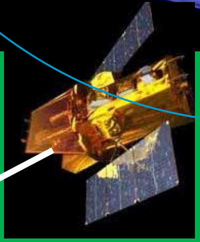
EeV

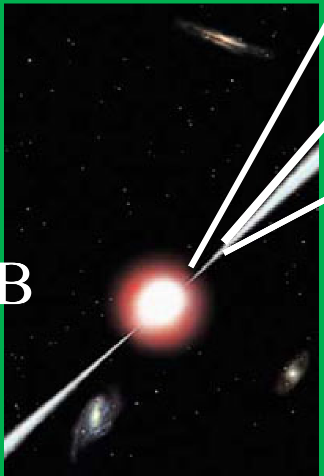
Neutrinos in coincidence with gamma-ray bursts?





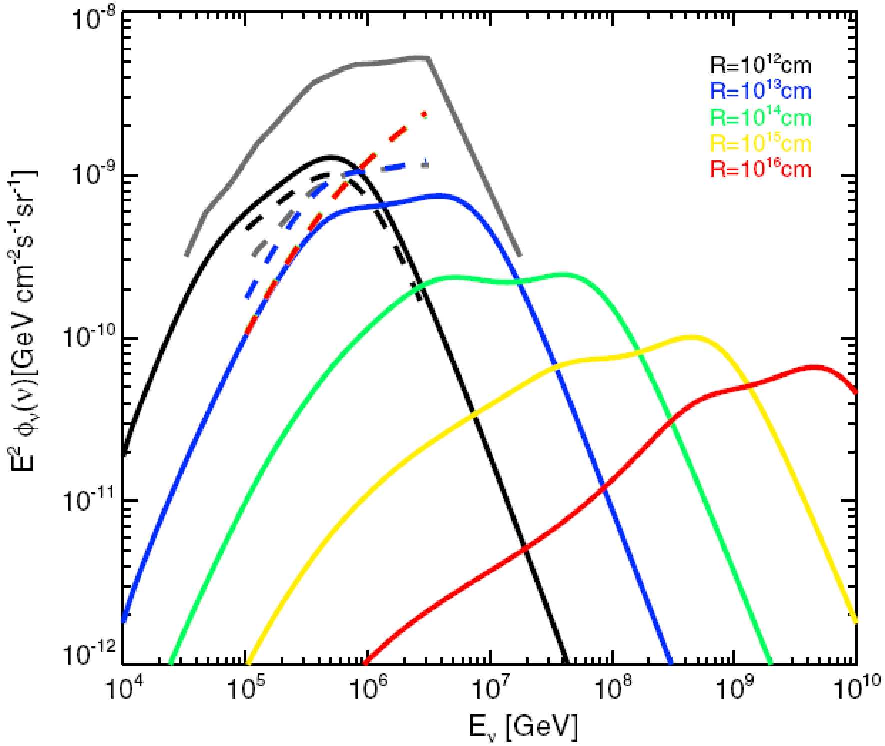






- **Normal-luminosity GRBs contribute to <1% neutrinos !**
- **But, no constraints on low-luminosity GRBs and choked jets !**

GRB neutrino flux is model-dependent



He, et al. 2012

R >4 × 10^12 cm

- **Small dissipation radius scenario**

-- Challenged

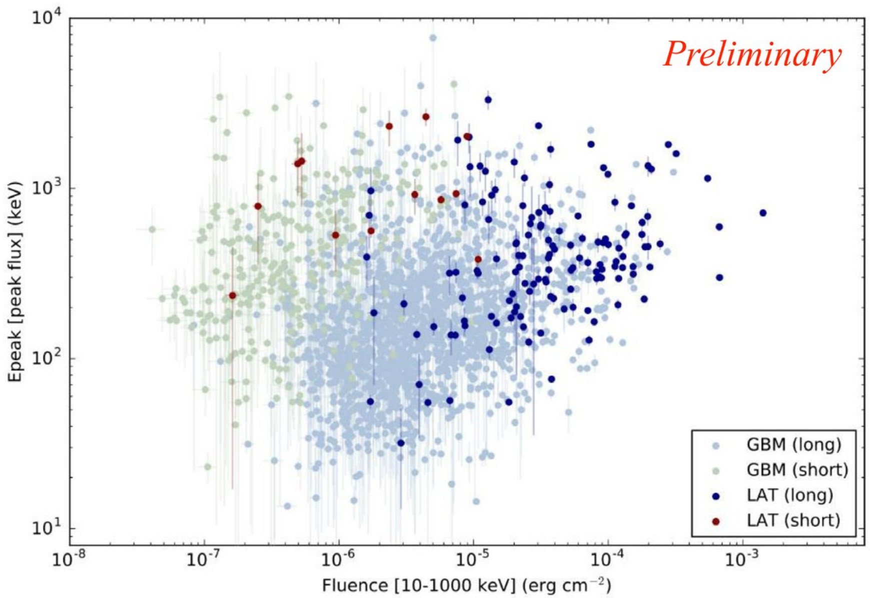
- **Large dissipation radius scenario**

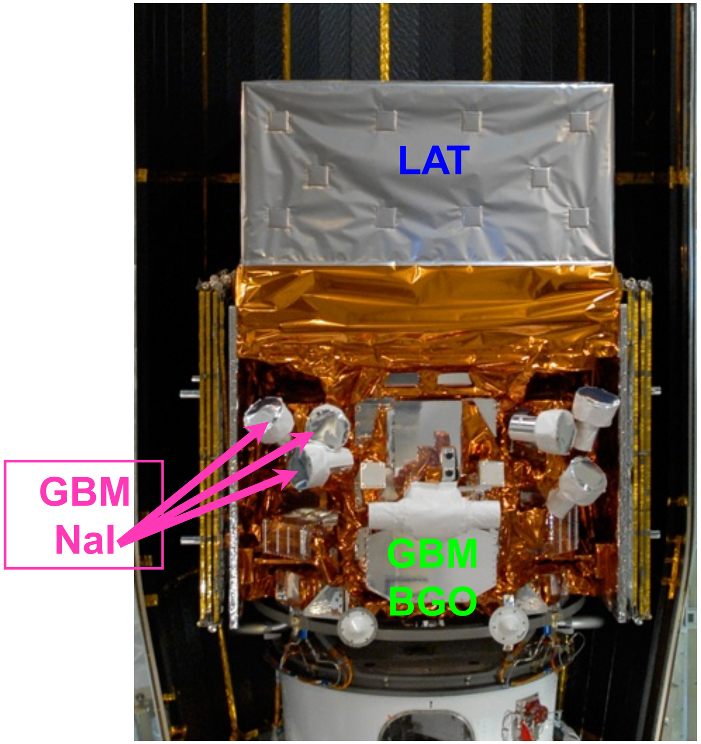
-- OK

But, do not rule out UHECR origin

Fermi satellite

- Fermi LAT covers energy band (100 MeV to > 300 GeV)
- 180 GRBs detected in 10yr
- 34 LAT GRBs with known redshift

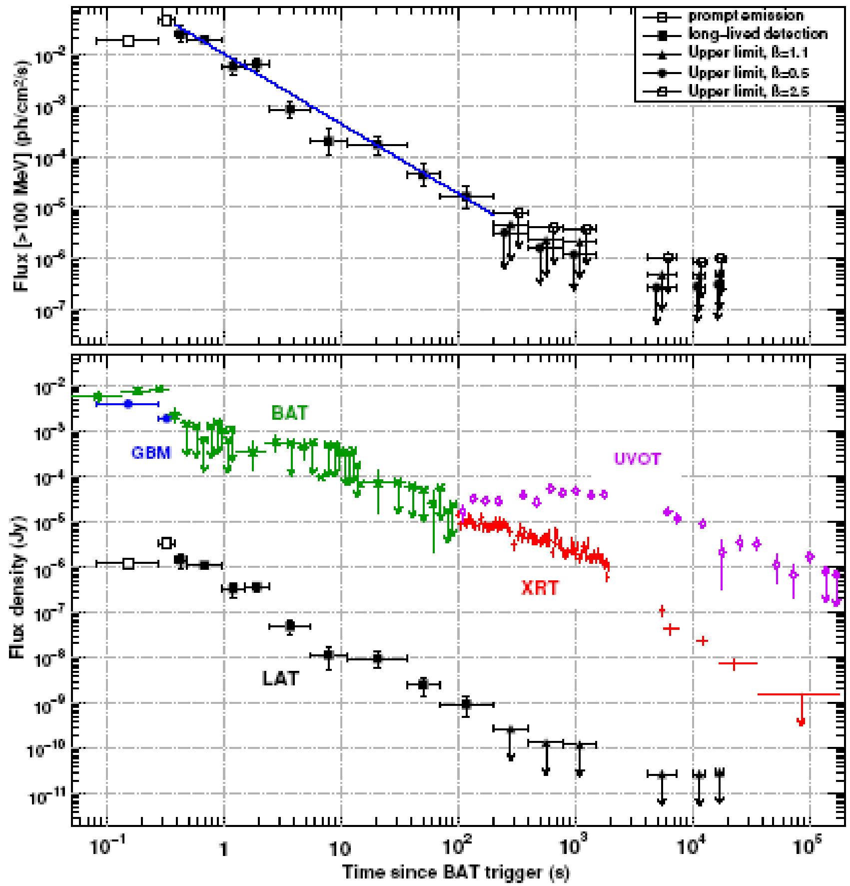




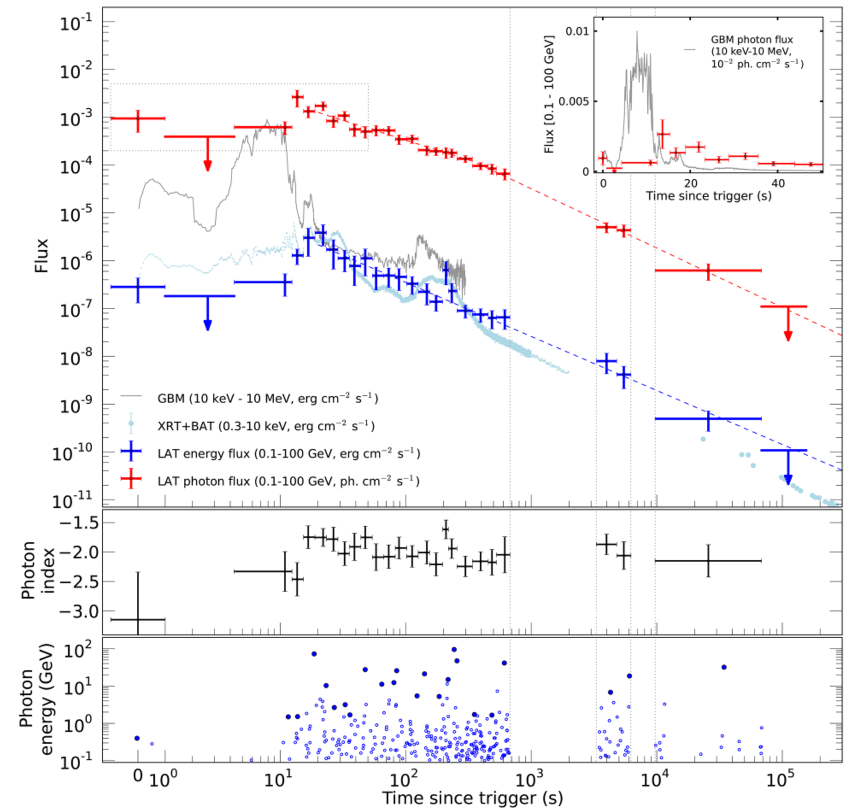
NaI: 8 keV - 1 MeV
BGO: 200 keV - 40 MeV

Fermi GRB light curves- extended emission

GRB090510



GRB130427A

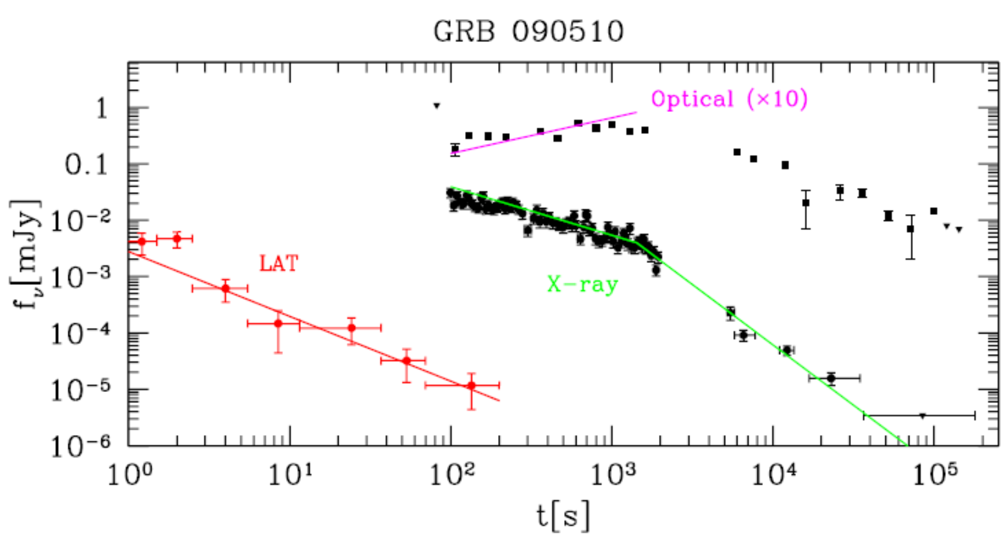


◆ **>100 MeV: much more extended**

Synchrotron afterglow scenario ?

(Kumar & Barniol Duran 09, Ghisellini et al. 09, Wang et al. 10)

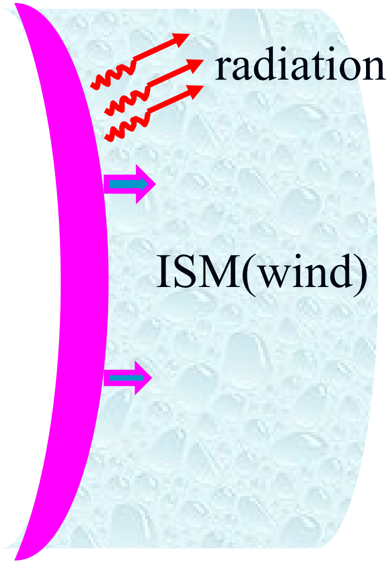
- afterglow synchrotron emission to account for all the LAT emission:
  - Simple PL decay: similar to X-ray/optical afterglows
  - Synchrotron flux could match the observed level



(Kumar & Barniol Duran 09)

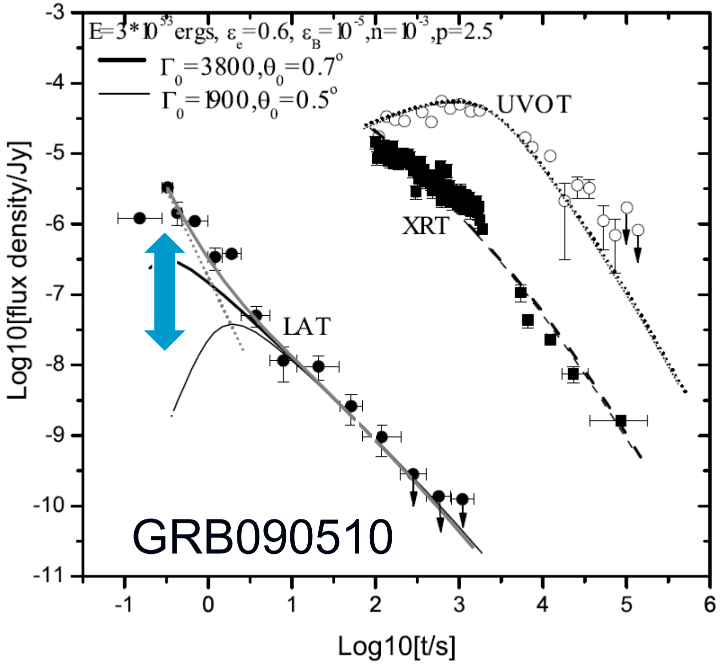
Broadband modeling

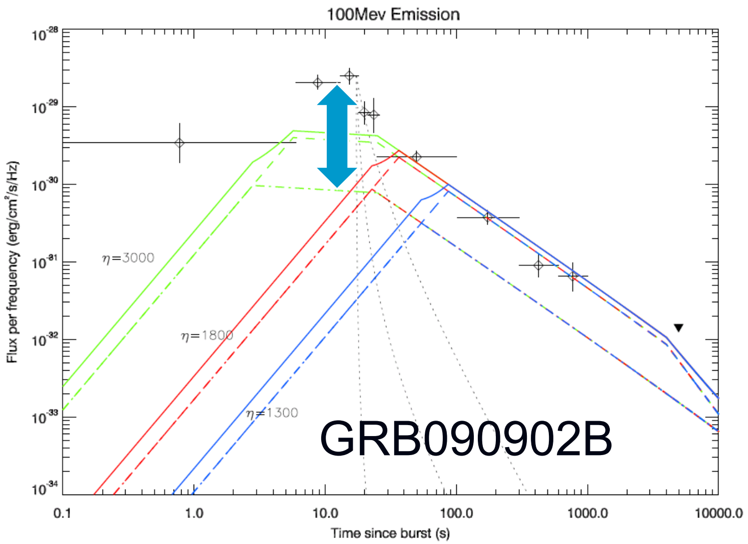
- Dynamics:
  Relativistic blast wave
- Radiation:
  Synchrotron, IC
- Input parameters:
  E, θ, Γ, n, p, ε_e, ε_B



Detailed broadband modeling…

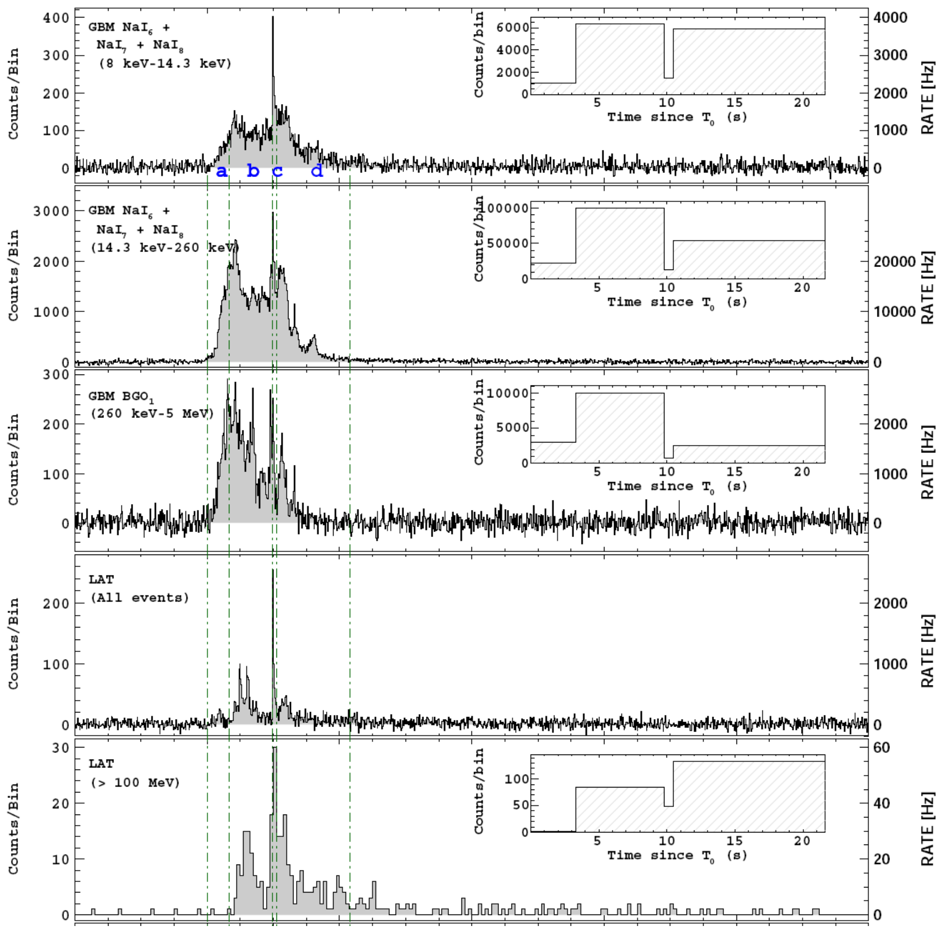
(He, Toma, Wu, Wang & Meszaros 2011; Liu & Wang 2011)





□ At early time, afterglow synchrotron emission model falls below the observed flux -> Internal origin

Correlated spikes seen by Fermi

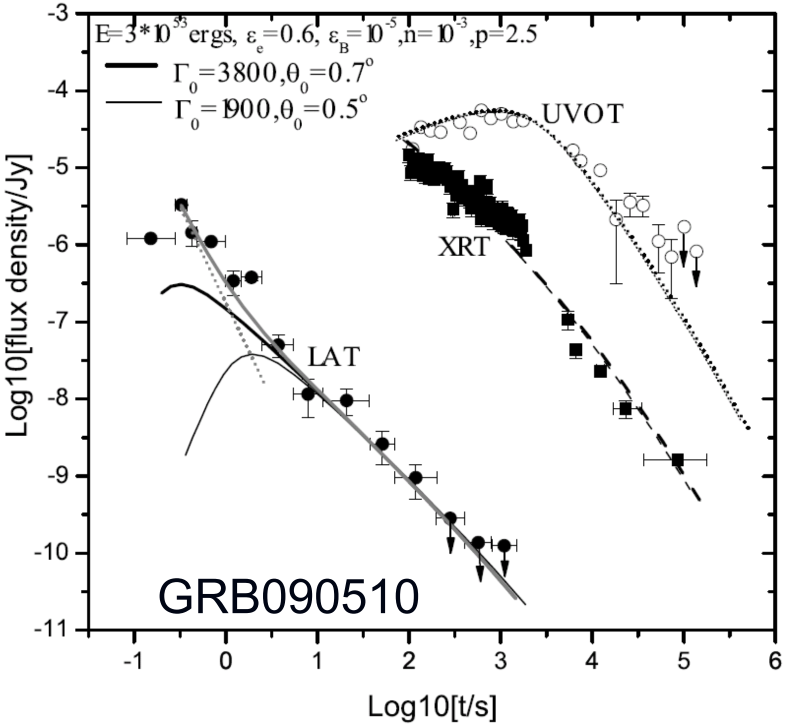


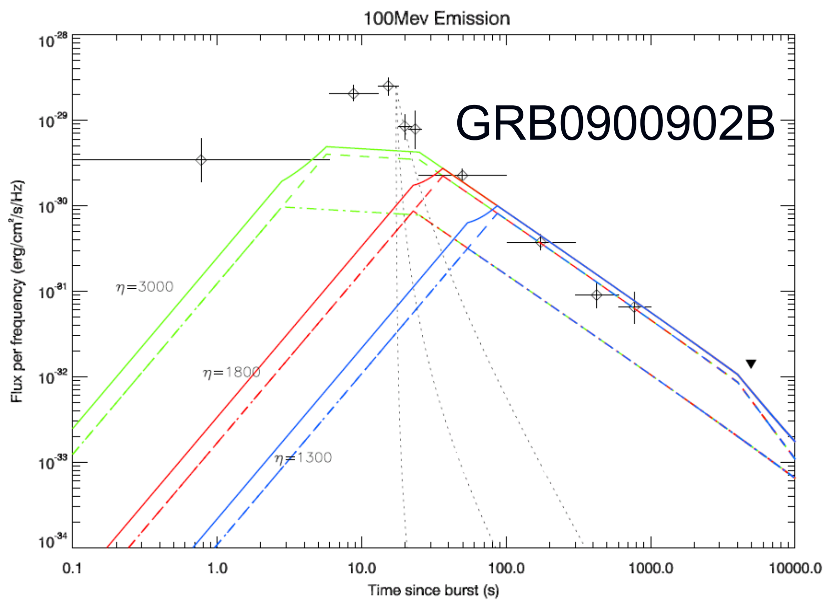
Abdo et al. 2011

- Support internal origin for the early prompt LAT emission

Detailed broadband modeling…

(He, Toma, Wu, Wang & Meszaros 2011; Liu & Wang 2011)





- At early time, afterglow synchrotron emission model falls below the observed flux -> Internal origin
- For late GeV emission, the afterglow synchrotron scenario fits the data well

One issue for the synchrotron scenario of late GeV emission

- **Expected:** maximum synchrotron energy:
- ~50 MeV in the shock rest frame (Bohm acceleration approximation)
- Observer frame： 50MeVxΓ, Γ<100 at 1-10ks

$$\Gamma = 200 E_{54}^{1/8} n_{-2}^{-1/8} (t_2/(1+z))^{-3/8}$$

- **Observed:** E_max~5GeV at 1-10ks

- **>10 GeV photons challenge the synchrotron scenario** (e.g. Piran & Nakar 10; see, however, Kumar 2014)

Even worse …

(Lemoine 2012)

- Bohm approximation breaks down for microturblence magnetic field

$$\lambda = 10 - 30(c/\omega_{pi})$$

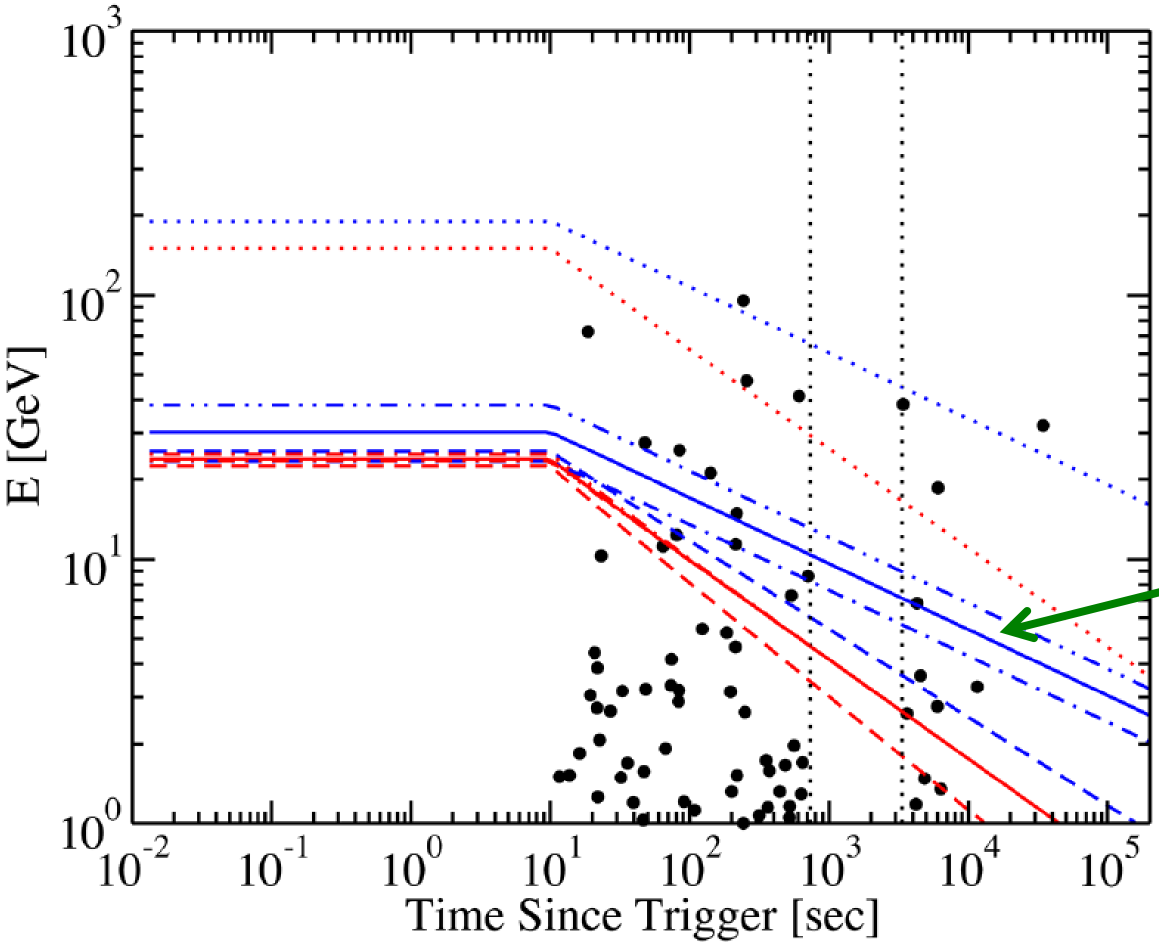
$$\frac{R_L(\gamma_{e,max})}{\lambda} = 25\lambda_1^{-2/3} n_{-2}^{-1/24} \epsilon_{B+,-2}^{-1/2} E_{54}^{-1/8} t_2^{3/8} \gg 1$$

- Lead to an even lower maximum synchrotron energy…

GRB130427A

Fermi collaboration 2013

- the brightest GRB so far



Maximum synchrotron energy limit

Origin of >10 GeV photons ?

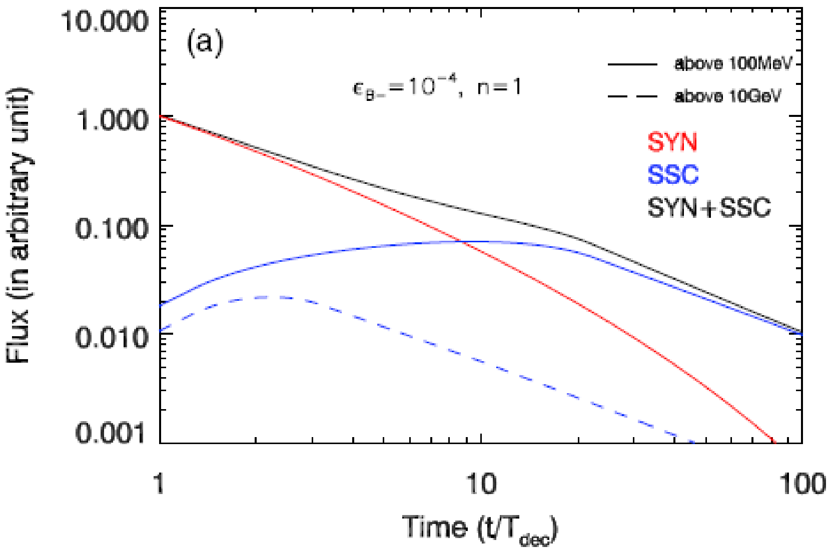
A natural way out :

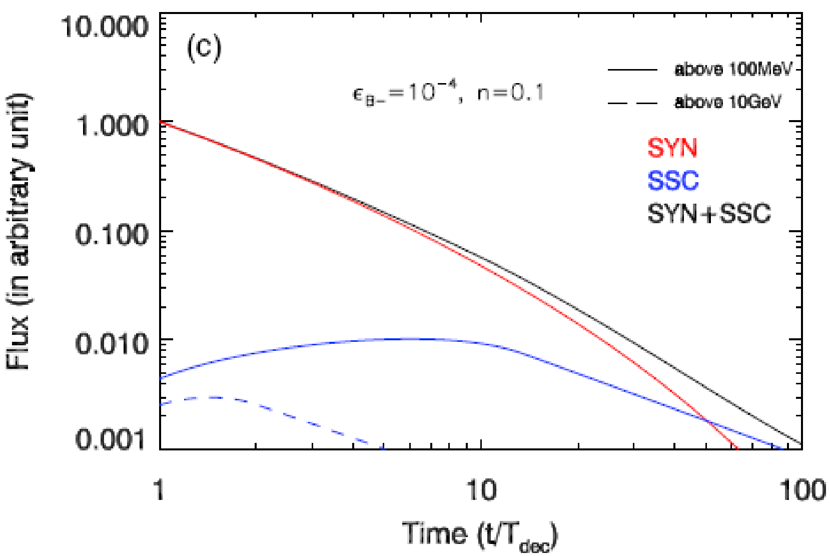
- Electron inverse Compton (IC) processes:
  - Afterglow synchrotron self-Compton (SSC) emission

    (Zhang & Meszaros 2001; Wang, Liu & Lemoine 2103;…)

Synchrotron + SSC components

(Wang, Liu & Lemoine 2103)



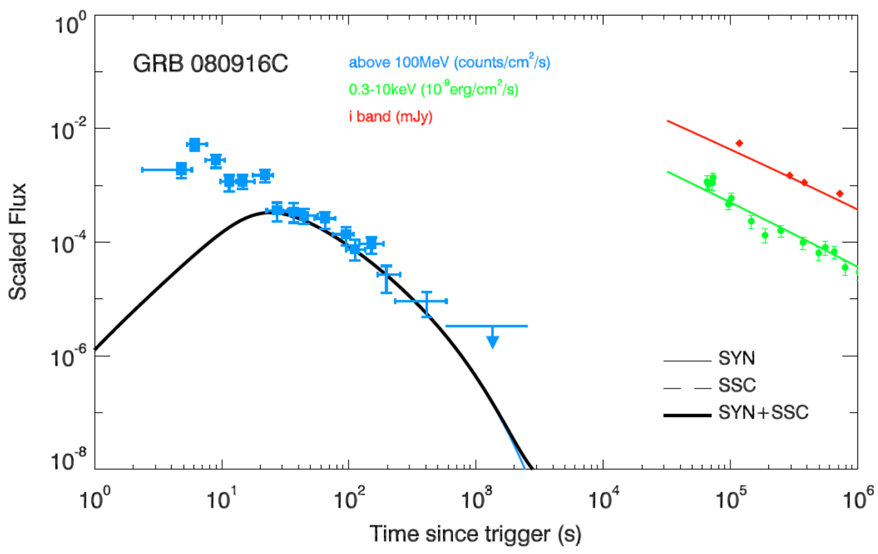


- The SSC intensity is sensitive to the circumburst density
- No obvious flattening seen at the transition

Modeling light curves with different ISM densities

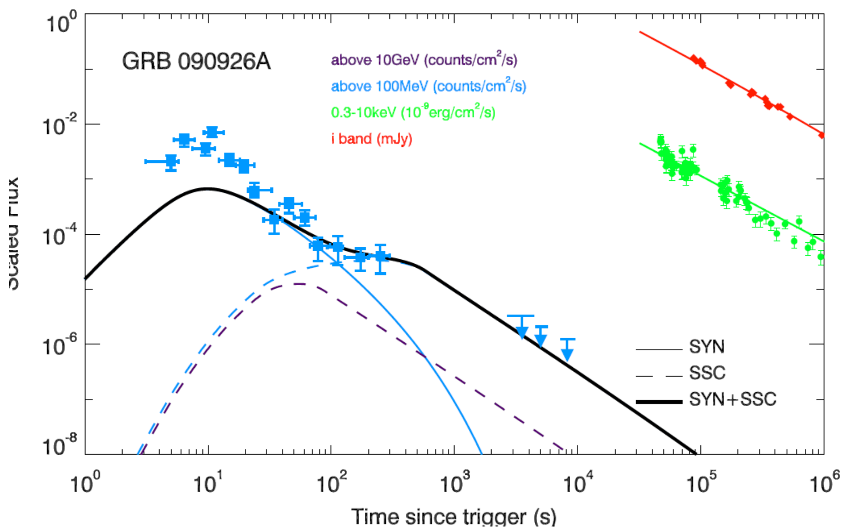
(Wang, Liu & Lemoine 2103)

n = 0.003 cm^−3



Rapid decay due to limited maximum synchrotron energy

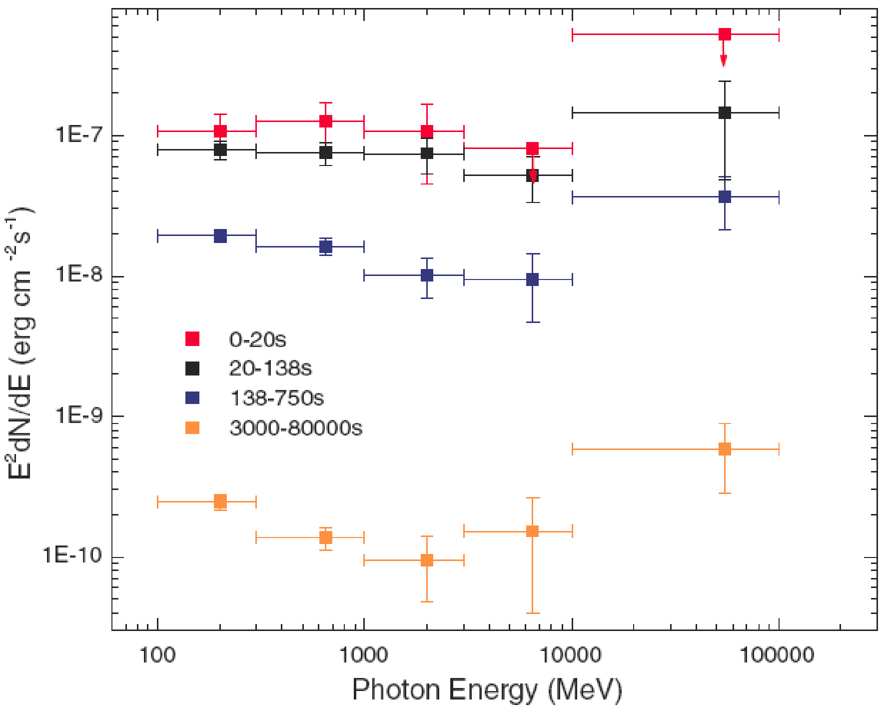
n = 1.2 cm^−3



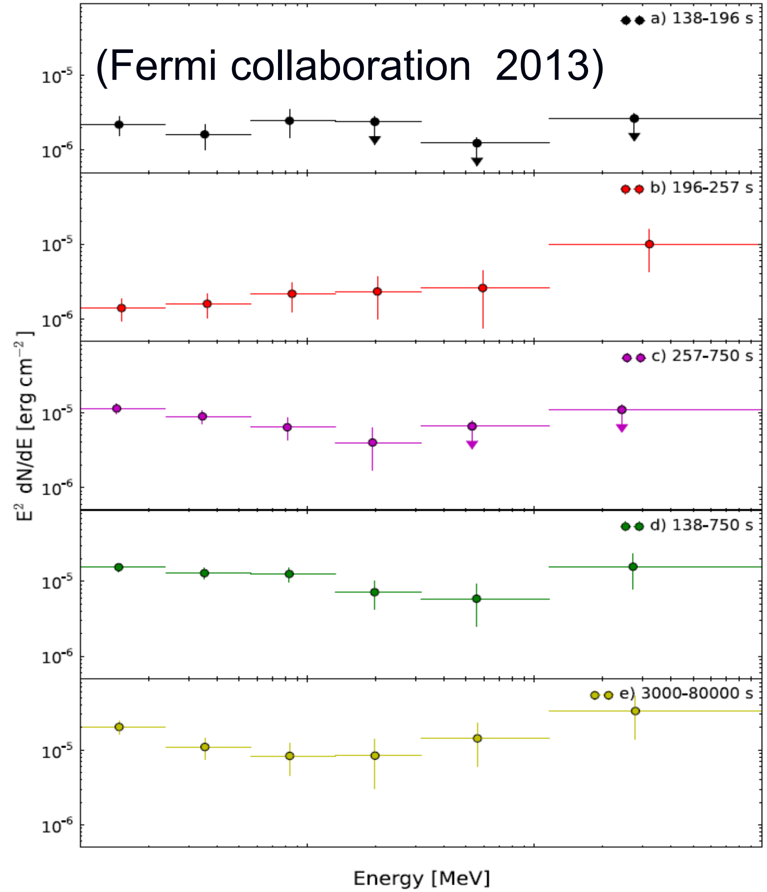
90 GeV photon at 80 s comes from SSC

LAT data of 130427A

(Tam, Tang, Hou, Liu & Wang 2013)



(Fermi collaboration 2013)

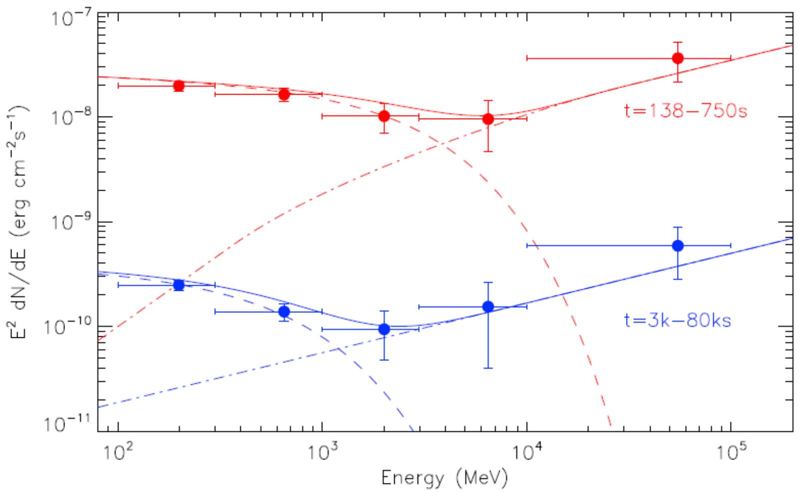


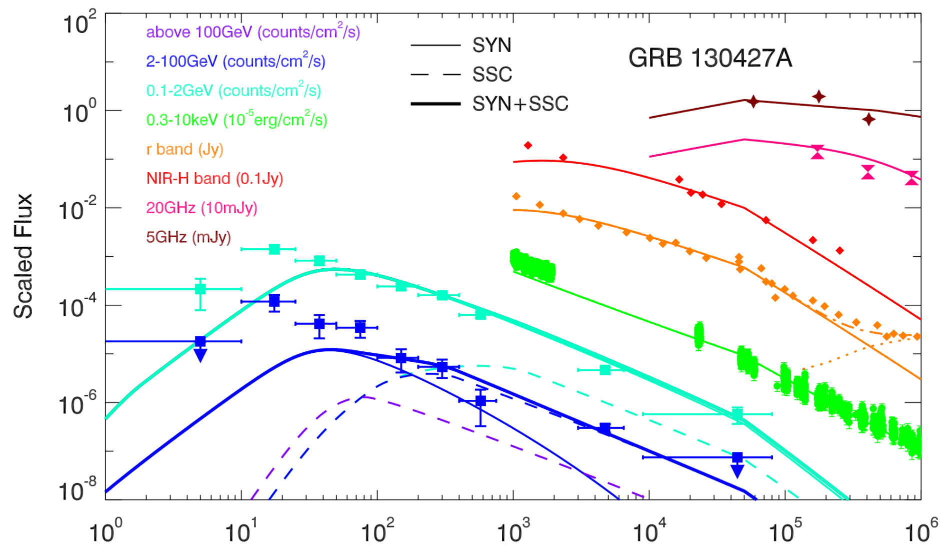
◆Possible signature of spectral hardening at ~10 GeV (~2.9 σ for 3-80 ks)

◆Interpreted as spectral hardening

Broad-band modeling: Synchrotron + IC components

(Liu et al. 2103)

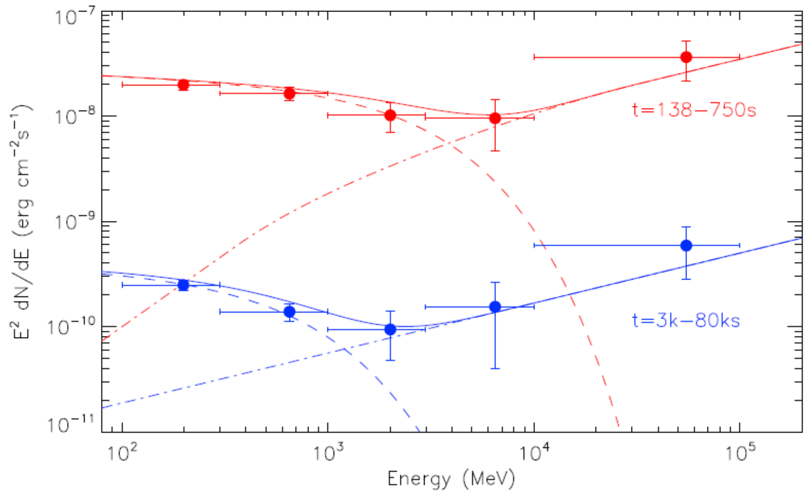




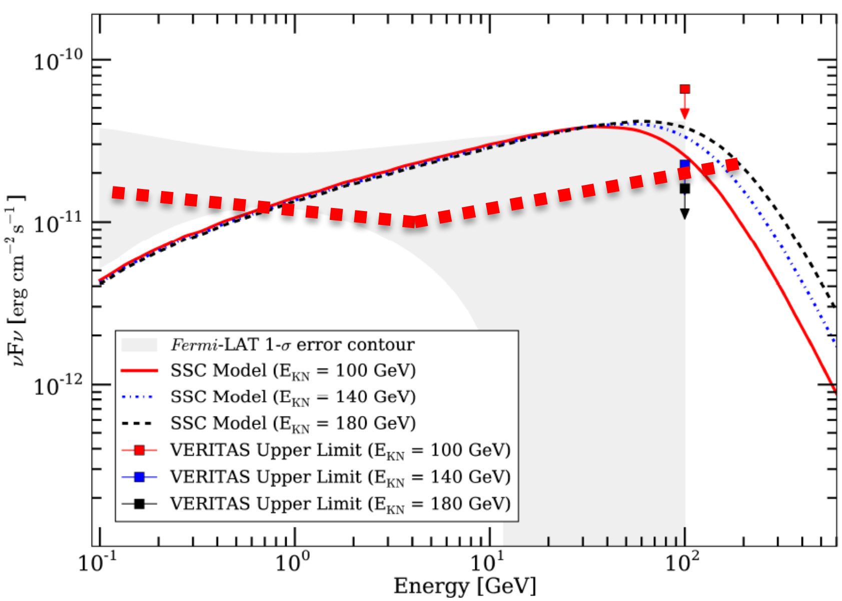
GRB 130427A

100 GeV flux

Liu et al. 2013



Aliu et al. 2014



◆ Below ~3GeV, synchrotron flux is still the dominant component

◆VERITAS data at 70ks inconsistent with SSC ?

● SSC flux @100GeV is 3*10^-8 erg/cm^2/s at t~200s

● F(100GeV)~t^-1.35

● At 70 ks, SSC flux @100GeV is 1.1*10^-11 erg/cm^2/s

●SSC model not ruled out…

GRB190114C: Magic sub-TeV

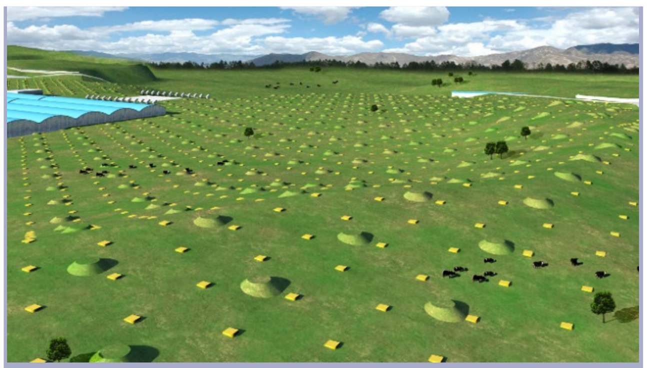
GCN 23701

MAGIC detects the GRB 190114C in the TeV energy domain

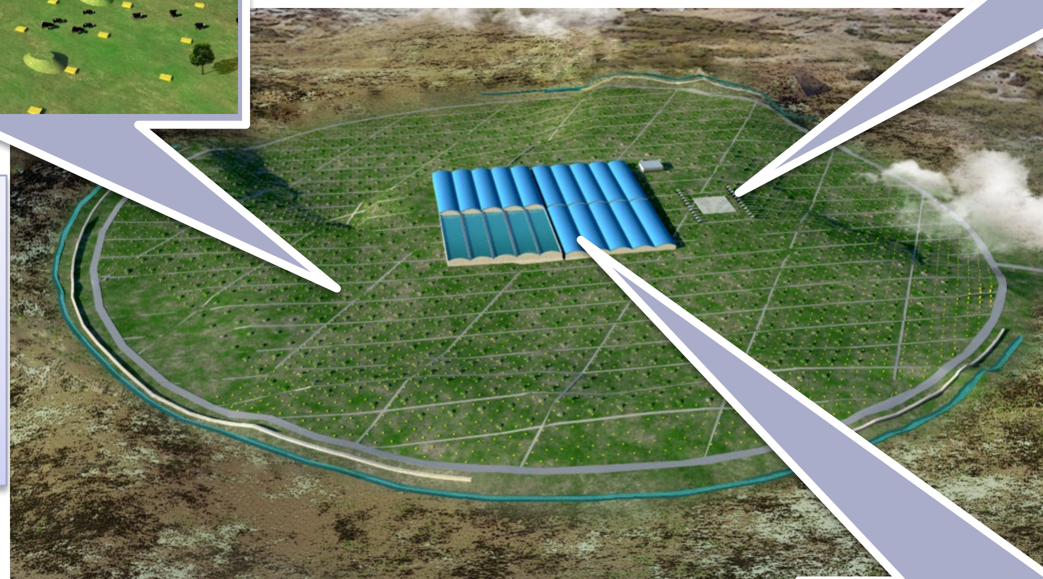
The MAGIC telescopes detected very-high-energy gamma-ray emission from GRB 190114C. The observation started about 50s after the Swift T0. The GRB data of MAGIC shows a clear excess of gamma-ray events with the significance >20 sigma in the first 20 min (starting at T0+50s) for energies >300GeV. The relatively high detection threshold is due to the large zenith angle of observations (~60 deg.) and the presence of partial moon. After the first bright flash the source is quickly fading.

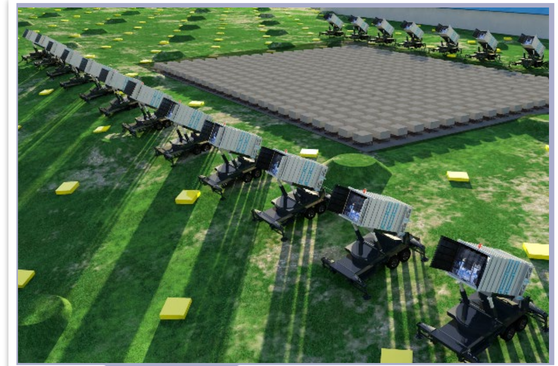
Mirzoyan + 19

LHAASO



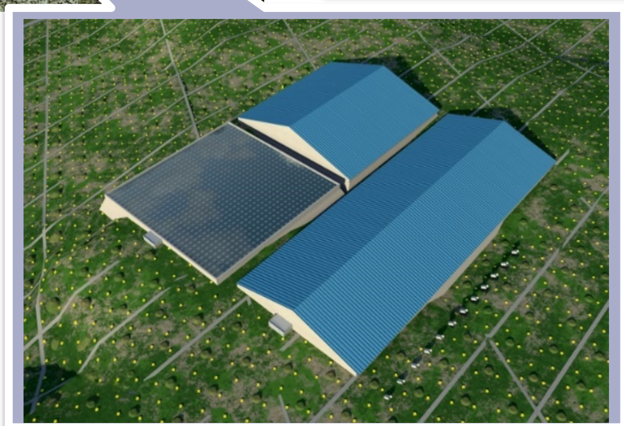
KM2A:
- 5195 Scin's: 1 m^2, 15m spacing
- 1171 MDs: 36 m^2, 30m spacing

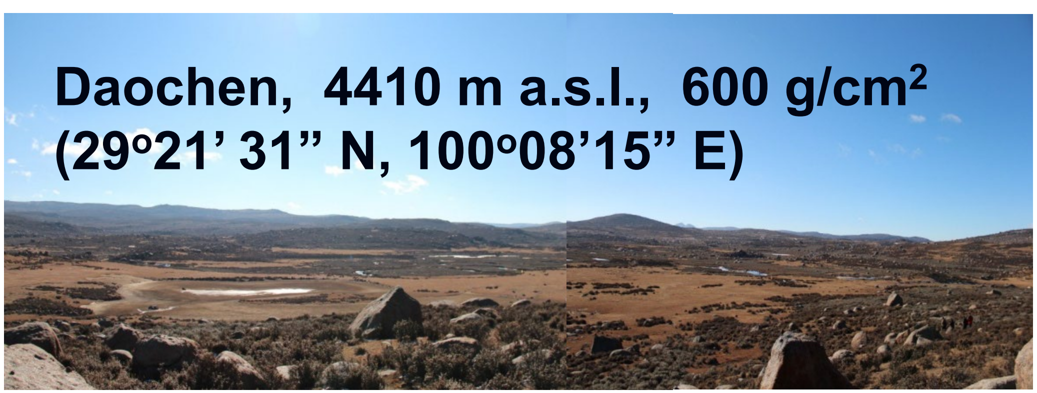




WFCTA:
18 Cherenkov telescopes (1024 pixels/telescope)

WCDA:
3120 cells ($25m^2$/cell)



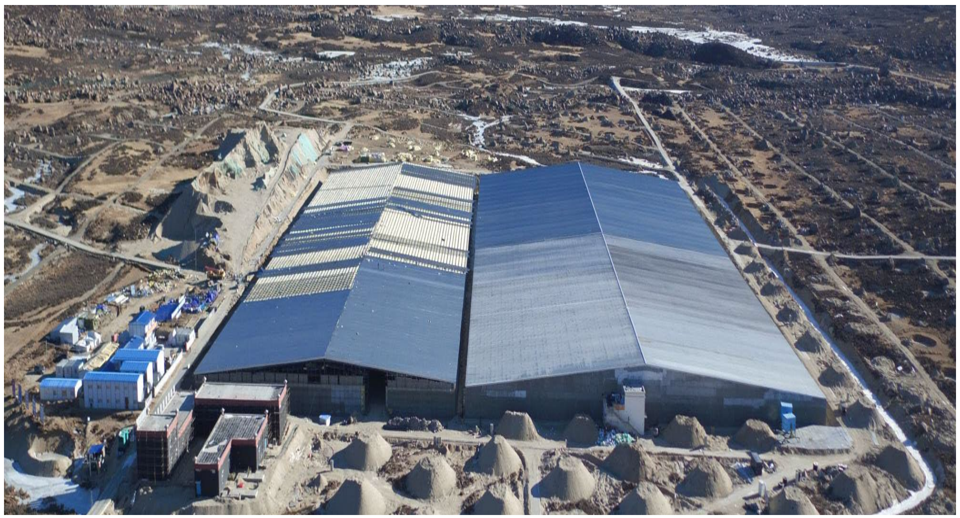


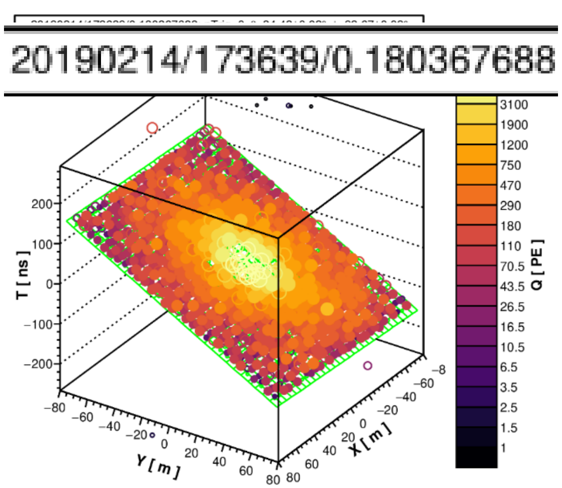
Construction status

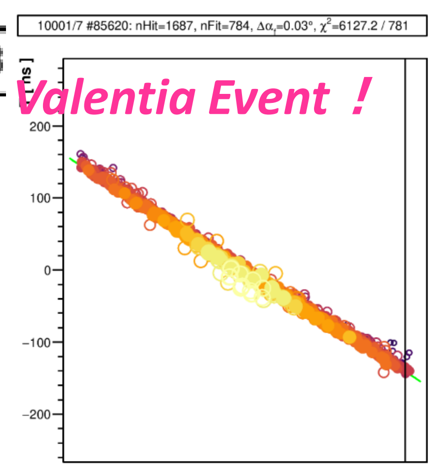
A glance from sky: 1/4 array is there !

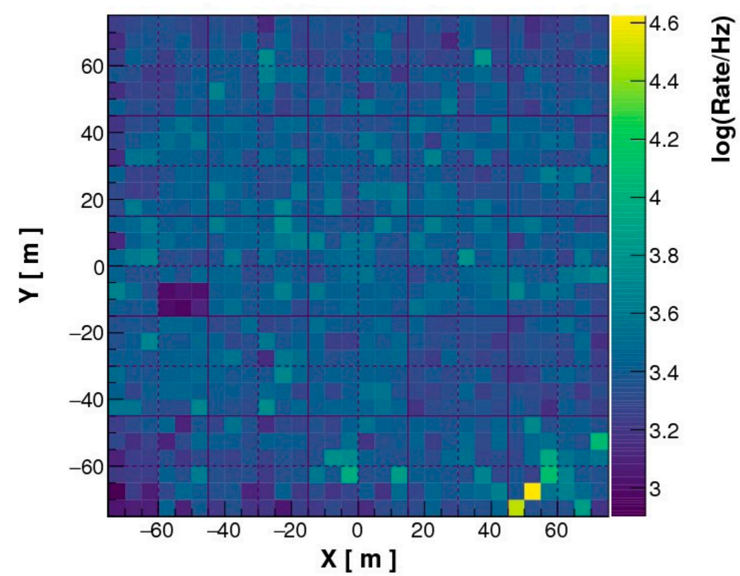
Water Cherenkov Detector Array (big ponds)

- Three ponds will be built in this year.
- The 1st has been filled up and turned on for operation



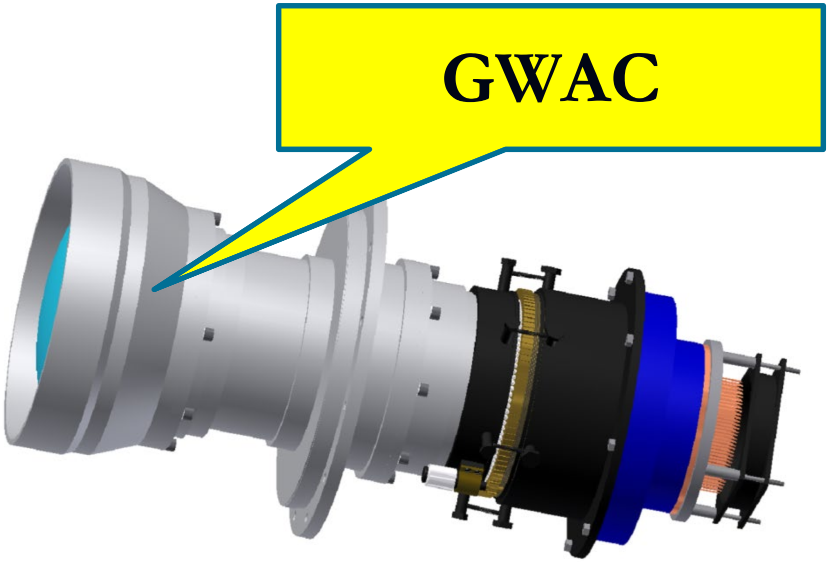






Ground Wide Angle Cameras System

SVOM



- Ground Wide Angle Cameras System (GWAC) is the follow-up telescope of SVOM, already in use
- GWAC includes 40 18-cm telescopes， partly supported by Nanjing University

Thank you!