Potential candidates for the astrophysical neutrino signal measured by IceCube experiment and the role of GRBs

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11th Workshop on Science with the New generation of High Energy Gamma-ray Experiments
(SciNeGHE) October 18th – 21th, 2016, Pisa – Italy

Outline

High-energy neutrinos
(IceCube observations and correlations with known sources)

Gamma-ray bursts
(Some generalities and descriptions of the most powerful GRBs)

Hidden GRB jets inside progenitor stars
(Possible scenario for high-energy neutrino production)

Conclusions

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IceCube Experiment

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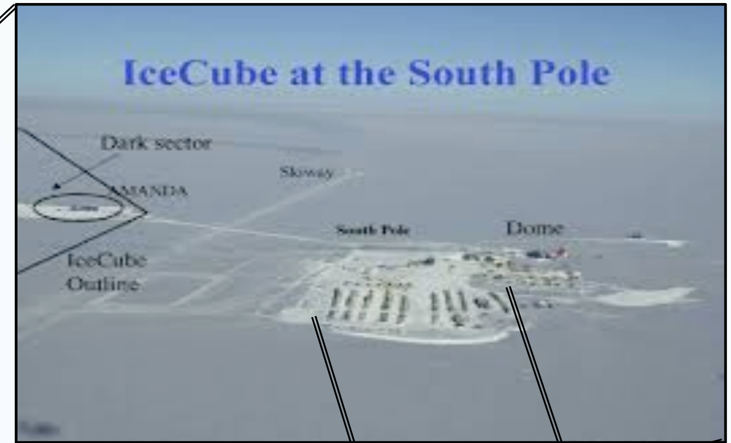
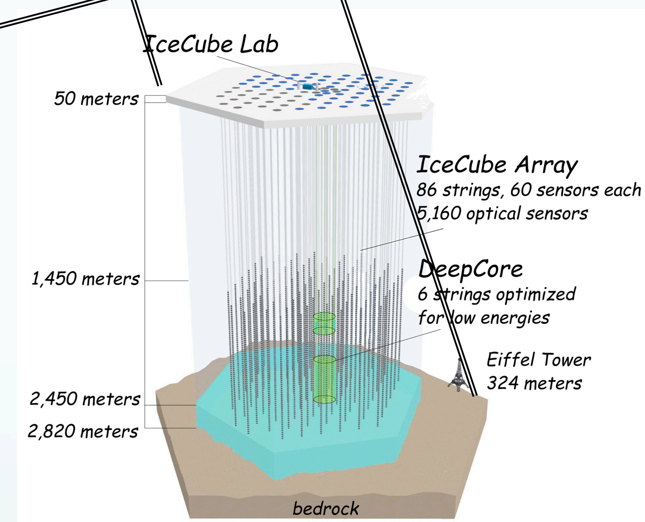
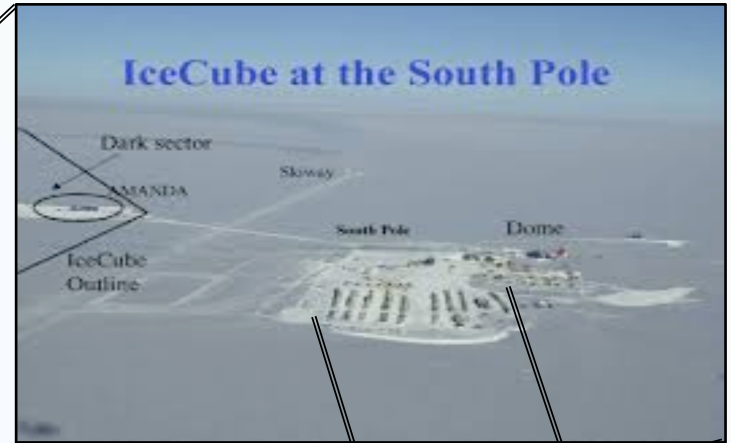
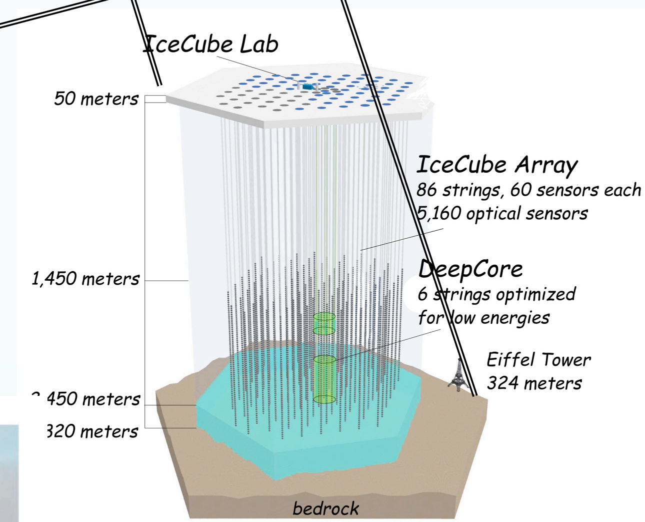




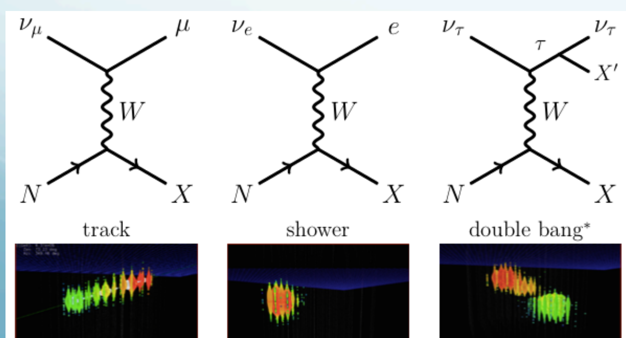
IceCube Experiment

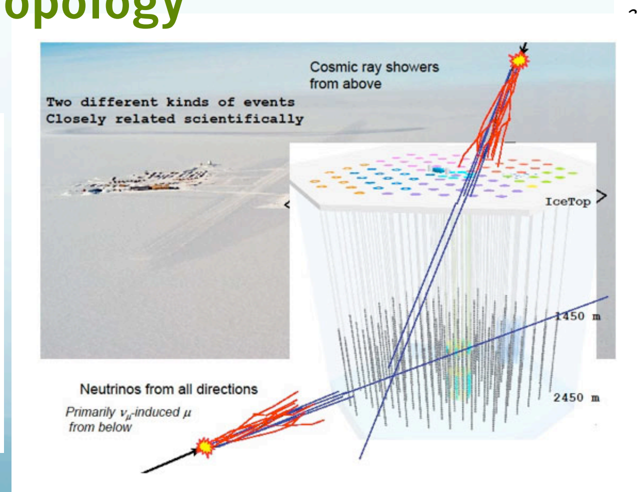




IceCube Collaboration (09)
IceCube Collaboration (13)

Event Topology

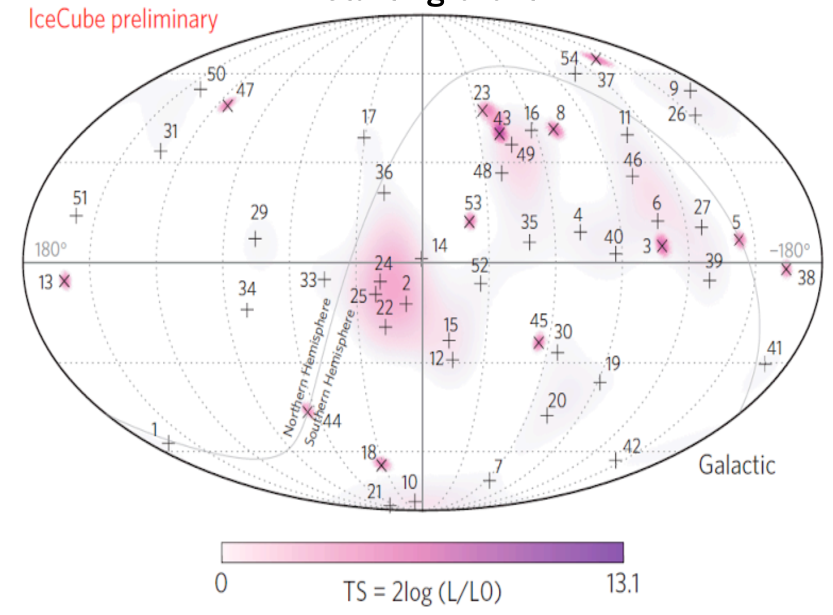




Shower-like neutrino events
Track-like neutrino events

Astrophysical neutrinos observed by IceCube experiment

Arrival directions of neutrinos in the four-year starting event



IceCube Collaboration (13)
IceCube Collaboration (14)
Francis (16)

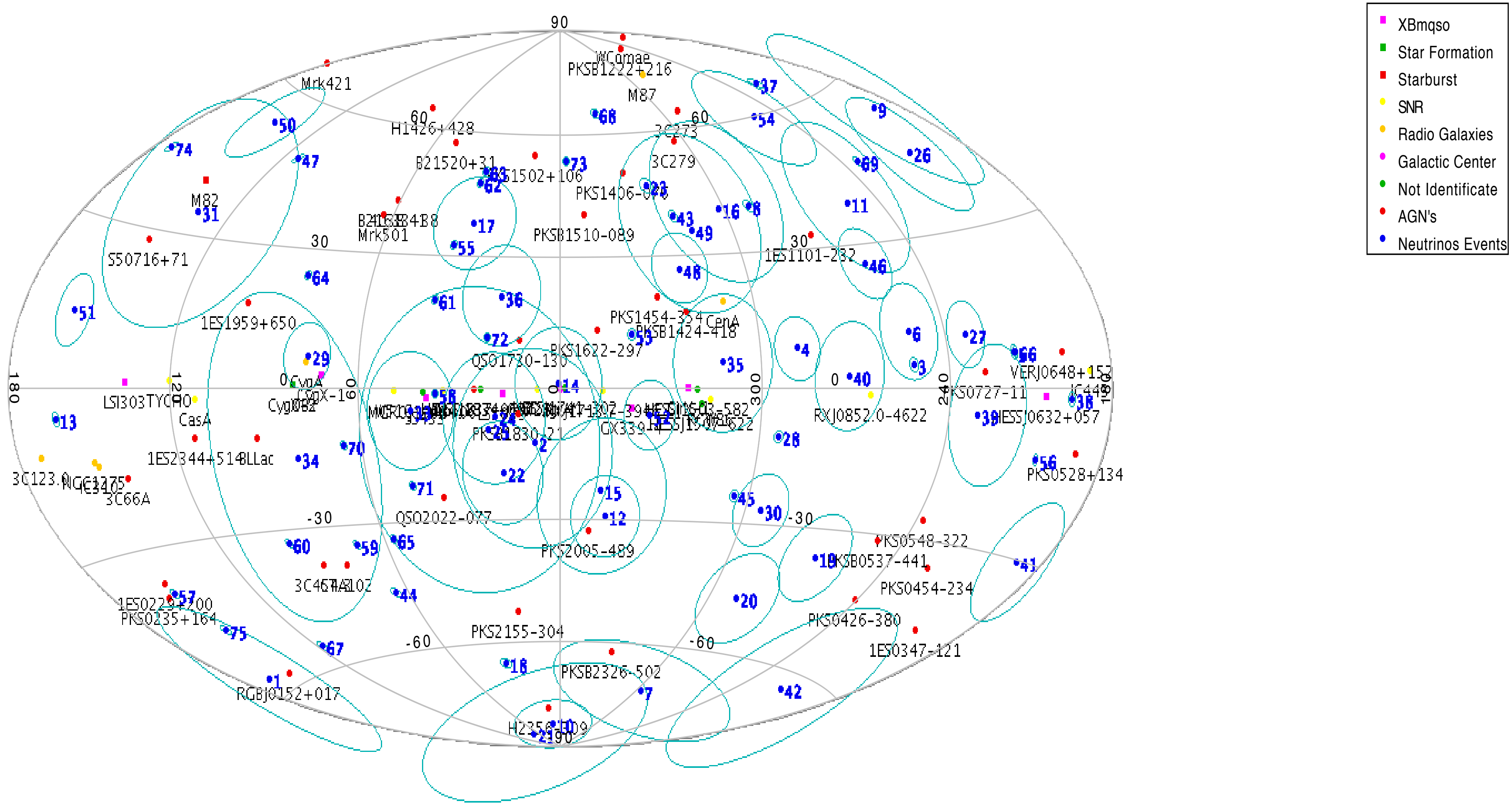
Recently added:

High-Energy Starting Events (HESE) catalog
+ 54 neutrino events (TeV – PeV energy range)

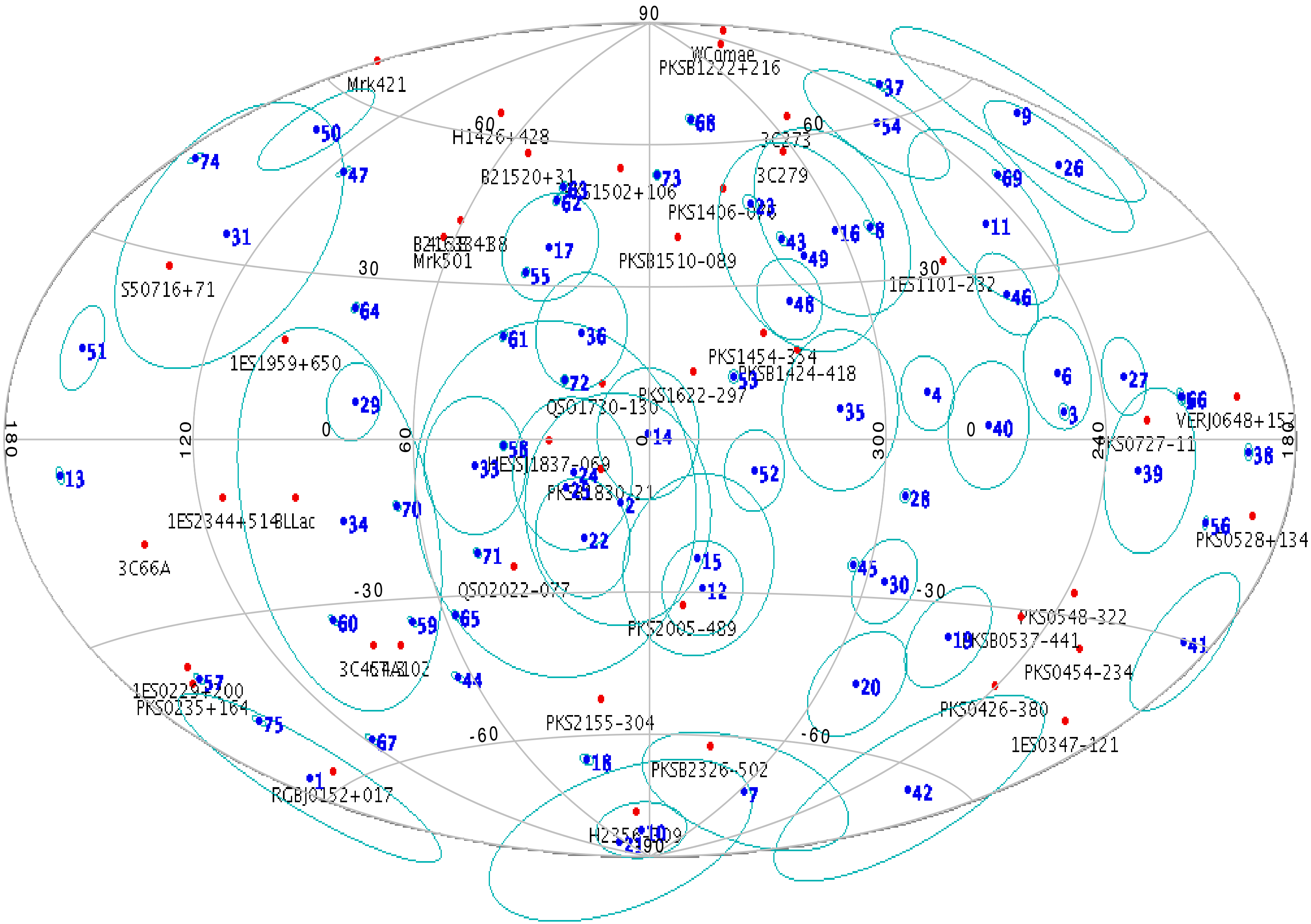
ID	Dep. Energy (TeV)	Observation Time (MJD)	Decl. (deg.)	R.A. (deg.)	Med. Angular Error (deg.)	Event Topology
1	$47.6^{+6.5}_{-5.4}$	55351.3222143	−1.8	35.2	16.3	Shower
2	117^{+15}_{-15}	55351.4659661	−28.0	282.6	25.4	Shower
3	$78.7^{+10.8}_{-8.7}$	55451.0707482	−31.2	127.9	$\lesssim 1.4$	Track
4	165^{+20}_{-15}	55477.3930984	−51.2	169.5	7.1	Shower
5	$71.4^{+9.0}_{-9.0}$	55512.5516311	−0.4	110.6	$\lesssim 1.2$	Track
6	$28.4^{+2.7}_{-2.5}$	55567.6388127	−27.2	133.9	9.8	Shower
7	$34.3^{+3.5}_{-4.3}$	55571.2585362	−45.1	15.6	24.1	Shower
8	$32.6^{+10.3}_{-11.1}$	55608.8201315	−21.2	182.4	$\lesssim 1.3$	Track
9	$63.2^{+7.1}_{-8.0}$	55685.6629713	33.6	151.3	16.5	Shower
10	$97.2^{+10.4}_{-12.4}$	55695.2730461	−29.4	5.0	8.1	Shower
11	$88.4^{+12.5}_{-10.7}$	55714.5909345	−8.9	155.3	16.7	Shower
12	104^{+13}_{-13}	55739.4411232	−52.8	296.1	9.8	Shower
13	253^{+26}_{-22}	55756.1129844	40.3	67.9	$\lesssim 1.2$	Track
14	1041^{+132}_{-144}	55782.5161911	−27.9	265.6	13.2	Shower
15	$57.5^{+8.3}_{-7.8}$	55783.1854223	−49.7	287.3	19.7	Shower
16	$30.6^{+3.6}_{-3.5}$	55798.6271285	−22.6	192.1	19.4	Shower
17	200^{+27}_{-27}	55800.3755483	14.5	247.4	11.6	Shower
18	$31.5^{+4.6}_{-3.3}$	55923.5318204	−24.8	345.6	$\lesssim 1.3$	Track
19	$71.5^{+7.0}_{-7.2}$	55925.7958619	−59.7	76.9	9.7	Shower
20	1141^{+143}_{-133}	55929.3986279	−67.2	38.3	10.7	Shower
21	$30.2^{+3.5}_{-3.3}$	55936.5416484	−24.0	9.0	20.9	Shower
22	220^{+21}_{-24}	55941.9757813	−22.1	293.7	12.1	Shower
23	$82.2^{+8.6}_{-8.4}$	55949.5693228	−13.2	208.7	$\lesssim 1.9$	Track
24	$30.5^{+3.2}_{-2.6}$	55950.8474912	−15.1	282.2	15.5	Shower
25	$33.5^{+4.9}_{-5.0}$	55966.7422488	−14.5	286.0	46.3	Shower
26	210^{+29}_{-26}	55979.2551750	22.7	143.4	11.8	Shower
27	$60.2^{+5.6}_{-5.6}$	56008.6845644	−12.6	121.7	6.6	Shower
28	$46.1^{+5.7}_{-4.4}$	56048.5704209	−71.5	164.8	$\lesssim 1.3$	Track
29	$32.7^{+3.2}_{-2.9}$	56108.2572046	41.0	298.1	7.4	Shower
30	129^{+14}_{-12}	56115.7283574	−82.7	103.2	8.0	Shower
31	$42.5^{+5.4}_{-5.7}$	56176.3914143	78.3	146.1	26.0	Shower
32	—	56211.7401231	—	—	—	Coincident
33	385^{+46}_{-49}	56221.3424023	7.8	292.5	13.5	Shower
34	$42.1^{+6.5}_{-6.3}$	56228.6055226	31.3	323.4	42.7	Shower
35	2004^{+236}_{-262}	56265.1338677	−55.8	208.4	15.9	Shower
36	$28.9^{+3.0}_{-2.6}$	56308.1642740	−3.0	257.7	11.7	Shower
37	$30.8^{+3.3}_{-3.5}$	56390.1887627	20.7	167.3	$\lesssim 1.2$	Track
...	.....	....	....	.....	.....	.....

http://icecube.wisc.edu/science/data/HE-nu-2010-2014

All known sources



Blazars



90
Mrk421
WComae
PKSB1222+216
H1426+428
3C273
3C279
B21520+31
PKS1406-076
PKSB1510-089
Mrk501
S50716+71
1ES1101-232
1ES1959+650
PKS1454-354
PKSB1424-418
PKS1622-297
QSO1730-130
VERJ0648+152
HESSJ1837-069
PKS1830-211
1ES2344+514
BLLac
3C66A
PKS0528+134
QSO2022-077
PKS0548-322
PKS2005-489
PKSB0537-441
PKS0454-234
1ES0229+200
PKS0235+164
PKS0426-380
PKS2155-304
1ES0347-121
PKSB2326-502
RGBJ0152+017
60
30
0
-30
-60
180
120
300
240

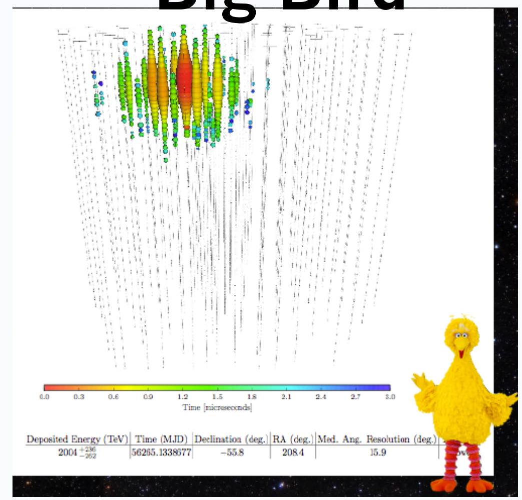
PKS B1424-418

(This quasar presented a strong flare)

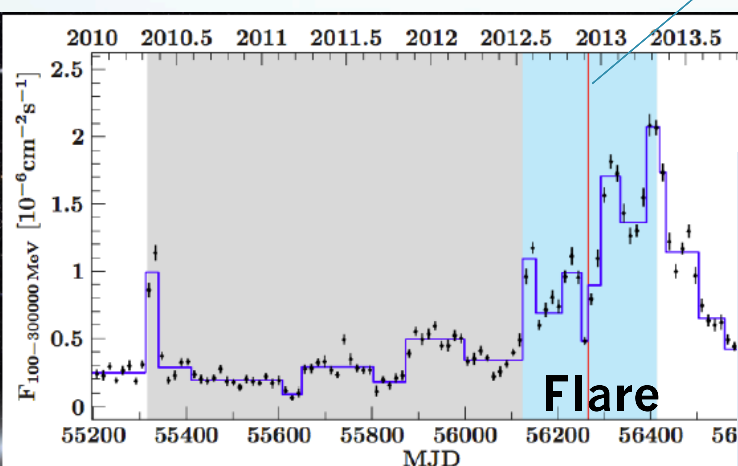
- 2PeV event on Dec 4, 201
  (Aartsen et al. 2014)
- RA = 208.4°, Dec = −55.8°
  (J2000)
- Median pos. uncertainty: 15.9deg

⇒ 17 gamma blazars (2LAC)

Big Bird



temporal coincidence



Kadler et al. (16)

The brighest sources in the south hemisphere

Name	RA (°)	Dec (°)	F_γ (10^{-10} erg cm^{-2} s^{-1})	$N^{max}_{\nu,PeV}$	$N^{pred}_{\nu,PeV}$	$N^{pos}_{\nu,PeV}$
PKS B1830-211	+278.4	−21.1	(14.34±0.27)	8.3	0.21	1
PKS B1510-089	+228.2	−9.1	(13.31±0.13)	7.7	0.19	0
3C 454.3	+343.5	+16.2	(37.50±01.3)	7.6	0.19	0
PKS B1424-418	+217.0	−42.1	(7.82±0.16)	5.7	0.14	1
PKS B2326-502	+352.3	−49.9	(4.69±0.10)	2.7	0.07	0
PKS B0537-441	+84.7	−44.1	(3.84±0.08)	2.2	0.06	0
PKS B1222+216	+186.2	+21.4	(7.94±0.12)	1.6	0.04	0
CTA 102	+338.2	+11.7	(6.42±0.12)	1.3	0.03	0
B2 1633+38	+248.8	+38.1	(6.28±0.09)	1.3	0.03	0
B2 1520+31	+230.5	+31.7	(4.75±0.25)	1.3	0.02	0

MRK421

(Flaring activity 2012)

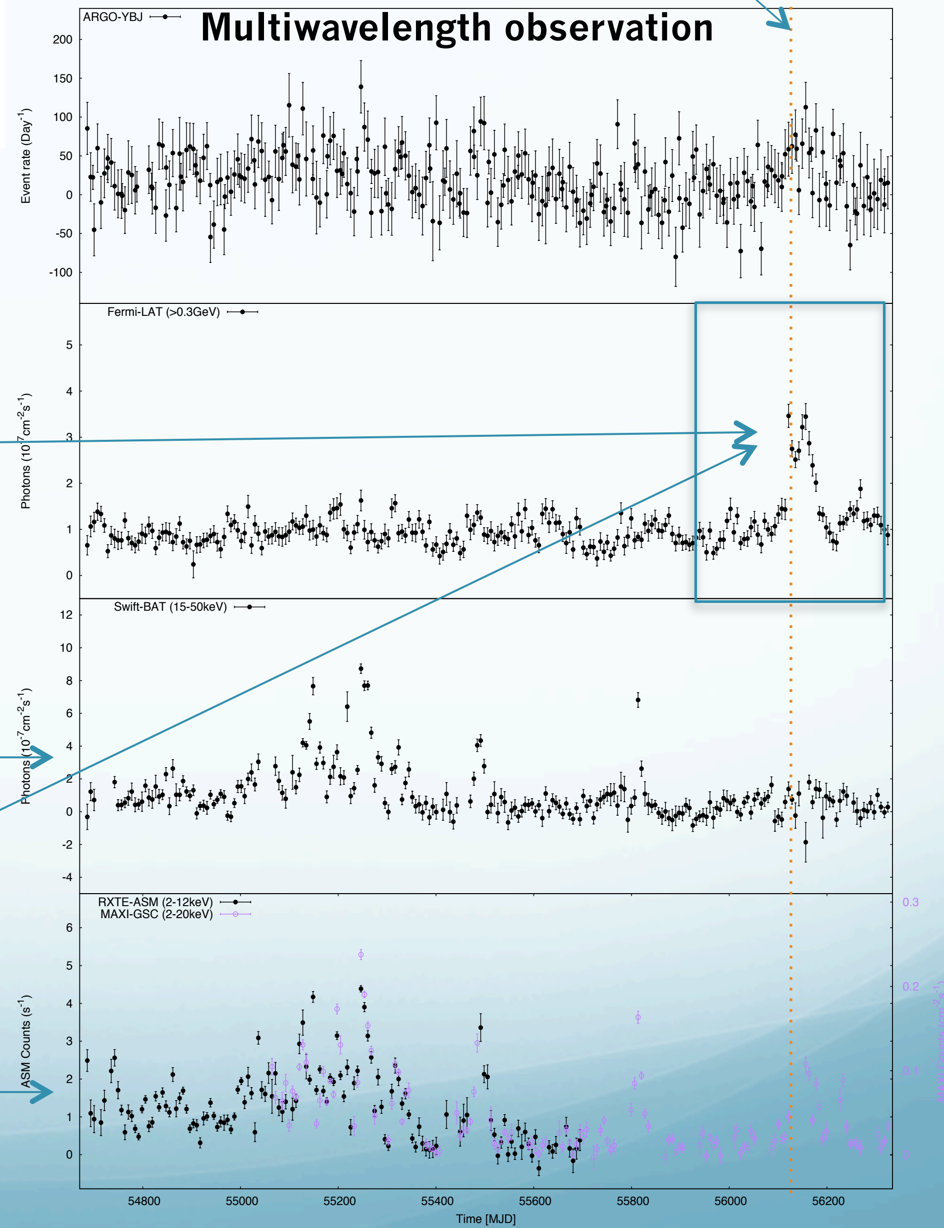
temporal coincidence

Table 2. Neutrino event detected in temporal coincidence with the 2012 flaring activity

ID	Deposited Energy (TeV)	Time (MJD)	Declination (deg)	RA (deg)	Med. Ang. Resolution	Topology
31	$42.5^{+5.4}_{-5.7}$	56176.3914143	78.3	146.1	26.0	Shower

Table 1. Integrated flux around the flaring activity of 2012.

T (days)	F_γ ($\mathrm{GeV^{-1}\ cm^{-2}\ s^{-1}}$)
20	9.9×10^{-8}
60	8.5×10^{-8}
100	6.5×10^{-8}



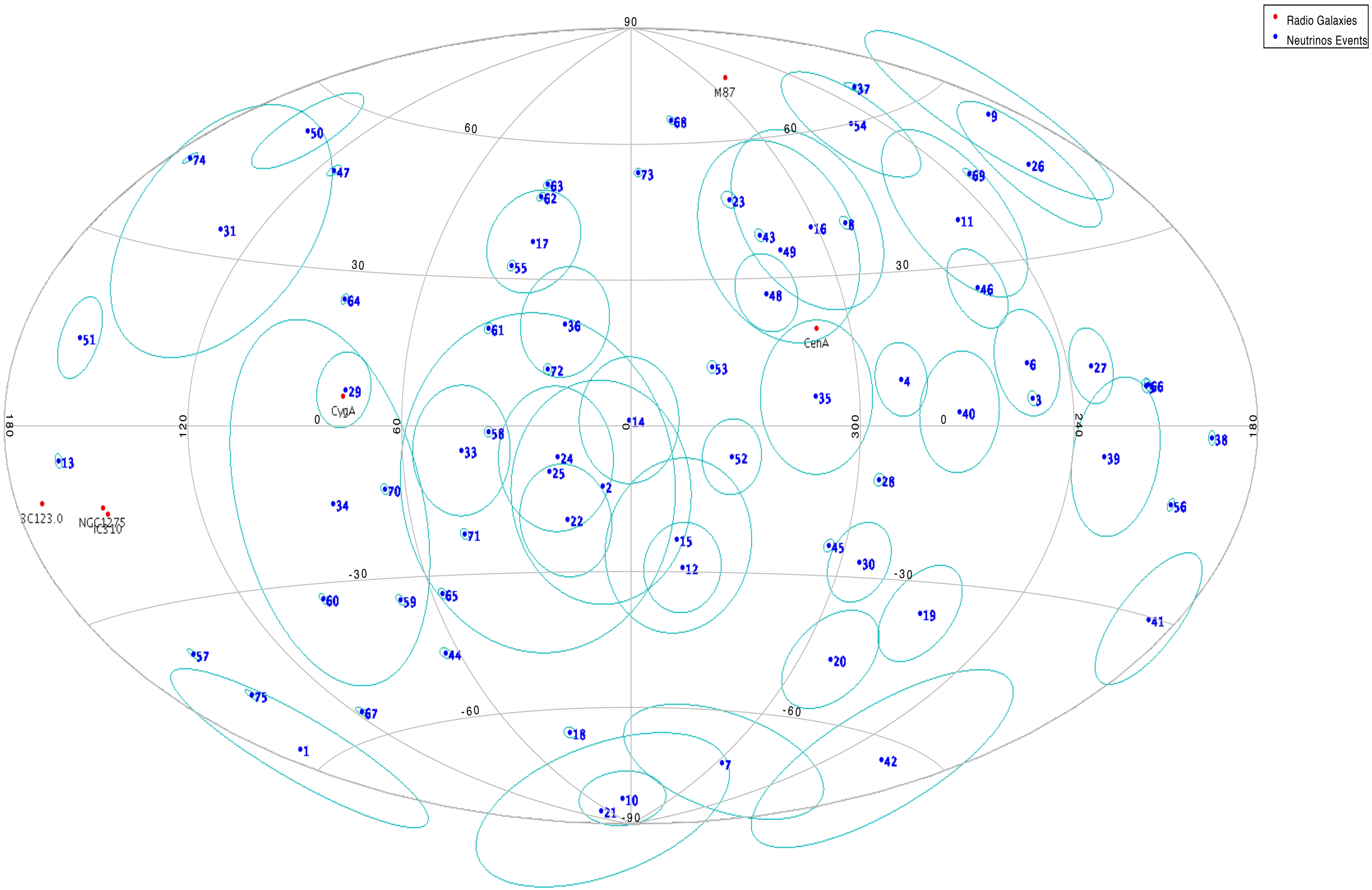
Fraija et al. (16)

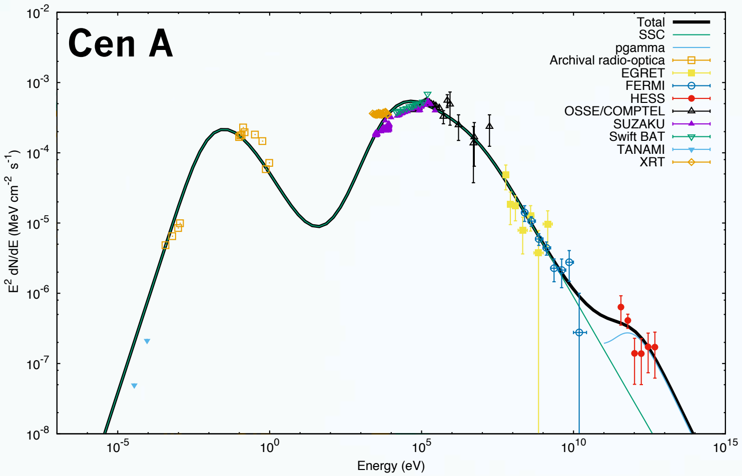
Possible orphan flare

Comparison between the expected signal and neutrino background

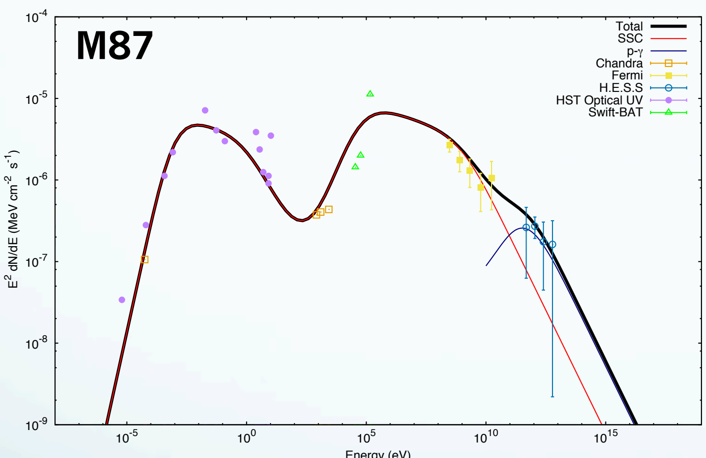
T (days)	E_{th} (TeV)	N_{ev}	N_{ev}^{atm}
20	> 25	0.34	0.10
60	> 25	0.85	0.31
100	> 25	1.08	0.51

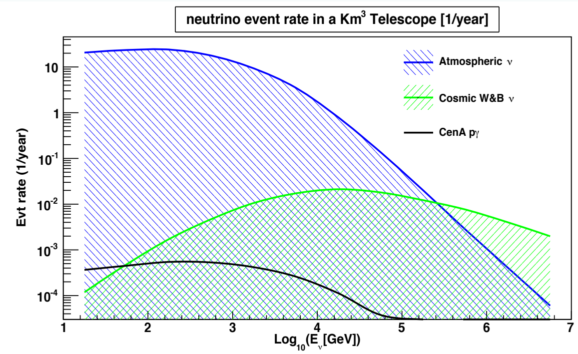
Radio Galaxies

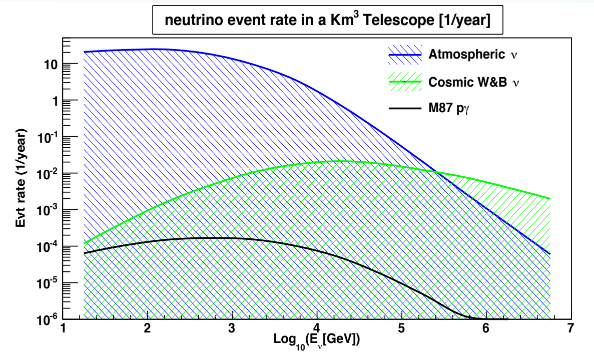


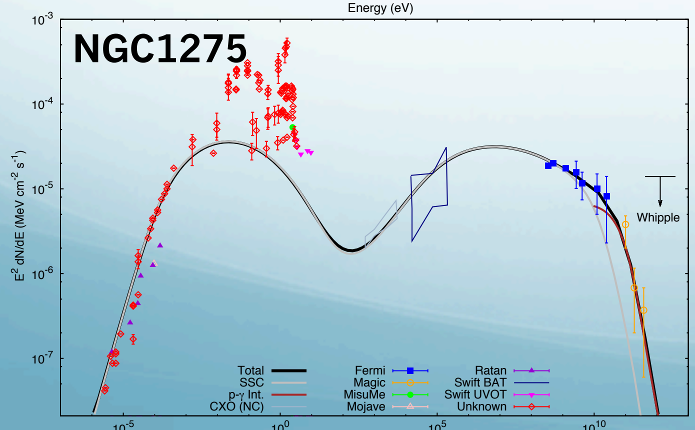


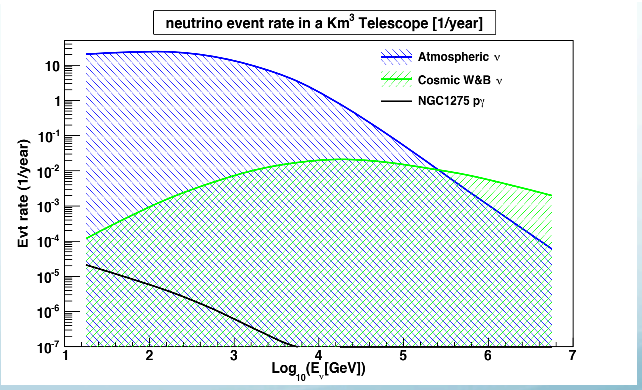
Neutrinos the closest radio galaxies





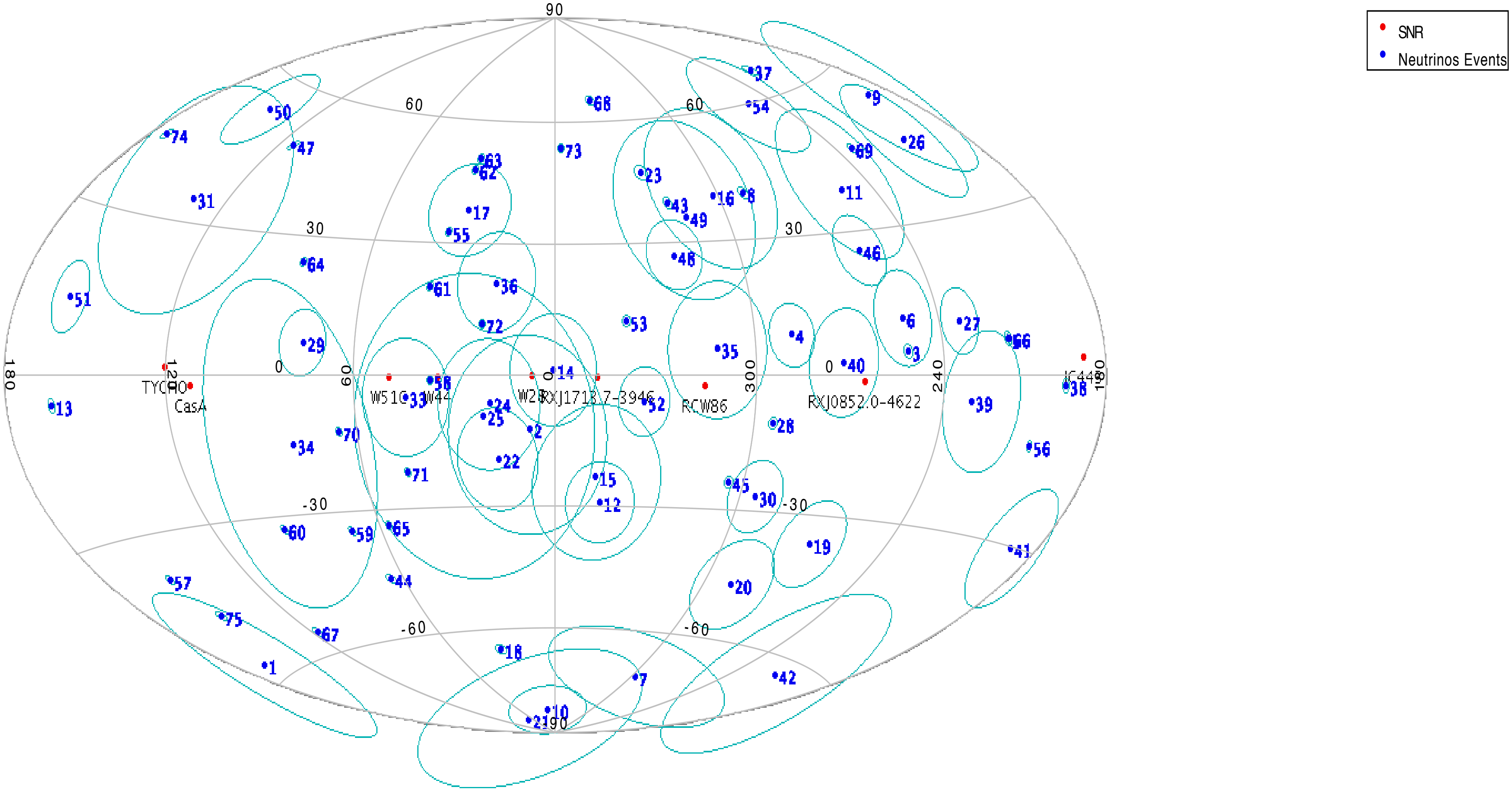






Fraija and Marinelli (16)

Supernova Remnant

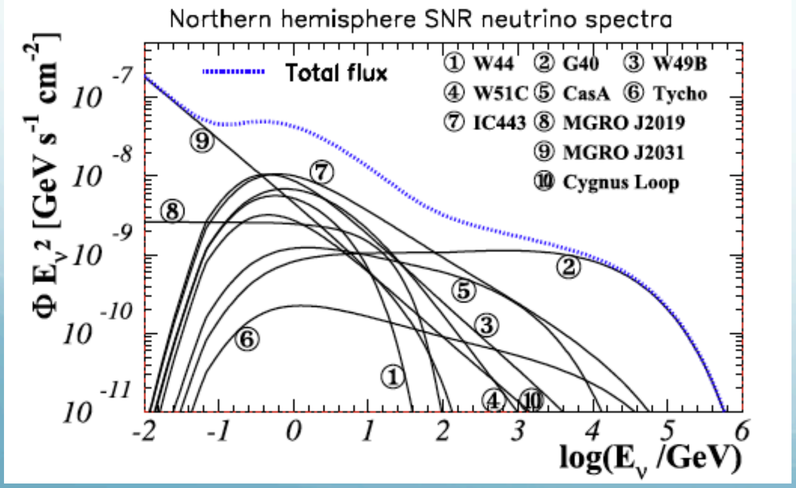


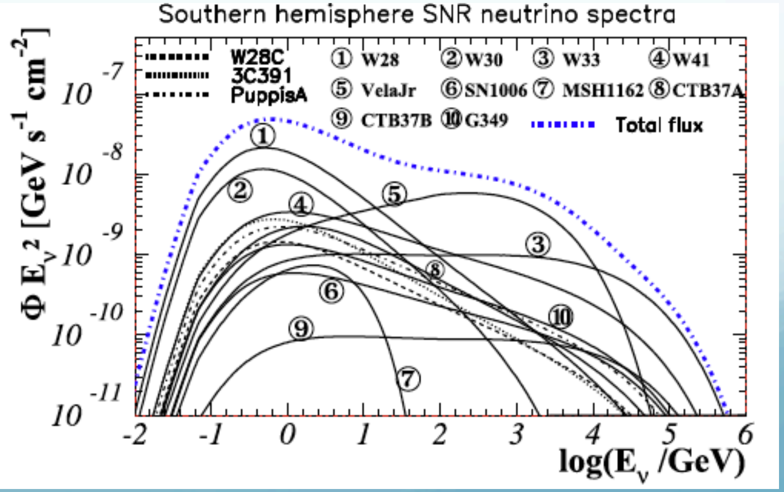
Supernova Remnants
(GeV – TeV energy range)

All Supernova Remnants with emission in GeV – TeV energies

SNR	d [kpc]	t_{SNR} [kyr]	n_H [cm^{-3}]	R_{SNR} [pc]	RA	Dec
3C391	7.2	4.0	15.0	5.2	18 h 49 m 25 s	−00° 55′ 00″
W41	4.2	100.0	6.0	20.2	18 h 34 m 45 s	−08° 48′ 00″
W33	4.0	1.2	6.0	1.6	18 h 13 m 37 s	−17° 49′ 00″
W30	4.0	25.0	100.0	26.2	18 h 05 m 30 s	−21° 26′ 00″
W28	1.9	33.0	140.0	13.3	18 h 00 m 30 s	−23° 26′ 00″
W28C	1.9	0.0	100.0	2.9	17 h 58 m 56 s	−24° 03′ 49″
G359.1-0.5	7.6	5.5	1000.0	26.5	17 h 45 m 30 s	−29° 57′ 00″
G349.7+0.2	18.3	10.0	65.0	10.7	17 h 17 m 59 s	−37° 26′ 00″
CTB 37B	13.2	1.8	1.6	32.7	17 h 13 m 55 s	−38° 11′ 00″
CTB 37A	7.9	16.0	100.0	20.0	17 h 14 m 06 s	−38° 32′ 00″
RX J1713.7-3946	3.5	1.6	0.7	30.6	17 h 13 m 50 s	−39° 45′ 00″
SN 1006	2.2	1.0	1.0	9.2	15 h 02 m 50 s	−41° 56′ 00″
Puppis A	2.0	4.6	20.0	16.0	08 h 22 m 10 s	−43° 00′ 00″
Vela Jr	1.3	4.8	1.6	23.8	08 h 52 m 00 s	−46° 20′ 00″
MSH 11-62	6.2	1.3	7.0	11.7	11 h 11 m 54 s	−60° 38′ 00″
RCW 86	2.3	1.8	2.0	14.1	14 h 43 m 00 s	−62° 30′ 00″
W44	3.0	10.0	6.0	12.9	18 h 56 m 00 s	01° 22′ 00′
G40.5-0.5	3.4	30.0	60.0	10.9	19 h 07 m 10 s	06° 31′ 00′
W49B	10.0	1.0	1000.0	4.9	19 h 11 m 08 s	09° 06′ 00′
W51C	6.0	26.0	10.0	26.2	19 h 23 m 50 s	14° 06′ 00′
IC443	1.5	3.0	200.0	14.2	06 h 17 m 00 s	22° 34′ 00′
Cygnus Loop	0.6	15.0	5.0	25.0	20 h 51 m 00 s	30° 40′ 00′
Cas A	3.5	0.3	1.9	2.0	23 h 23 m 26 s	58° 48′ 00′
Tycho	3.5	0.4	0.7	4.1	00 h 25 m 18 s	64° 09′ 00′

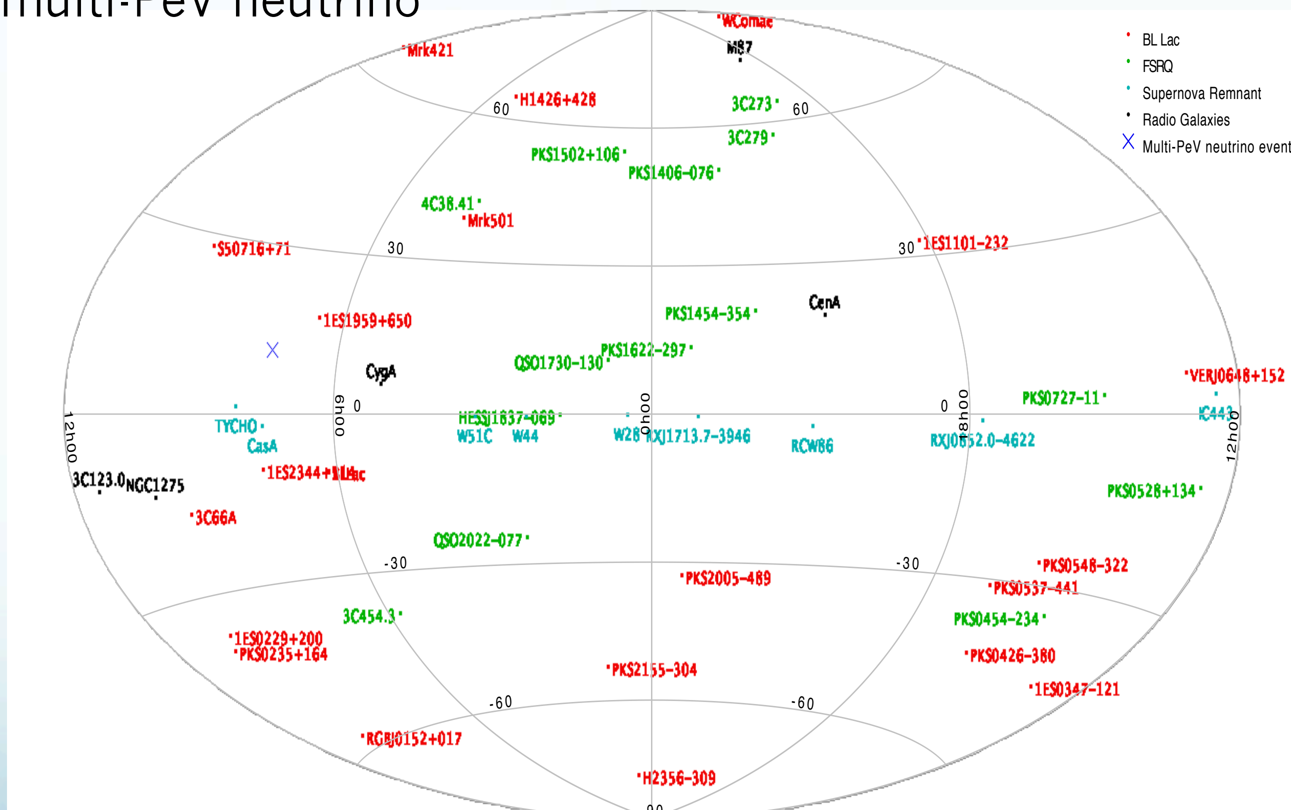
Mandelartz and Becker et al. (13)





Recently,.......

TITLE: The Astronomer´s Telegram
NUMBER: 7856
SUBJECT: Detection of a multi-PeV neutrino
DATE: 07/15



Recently,.......

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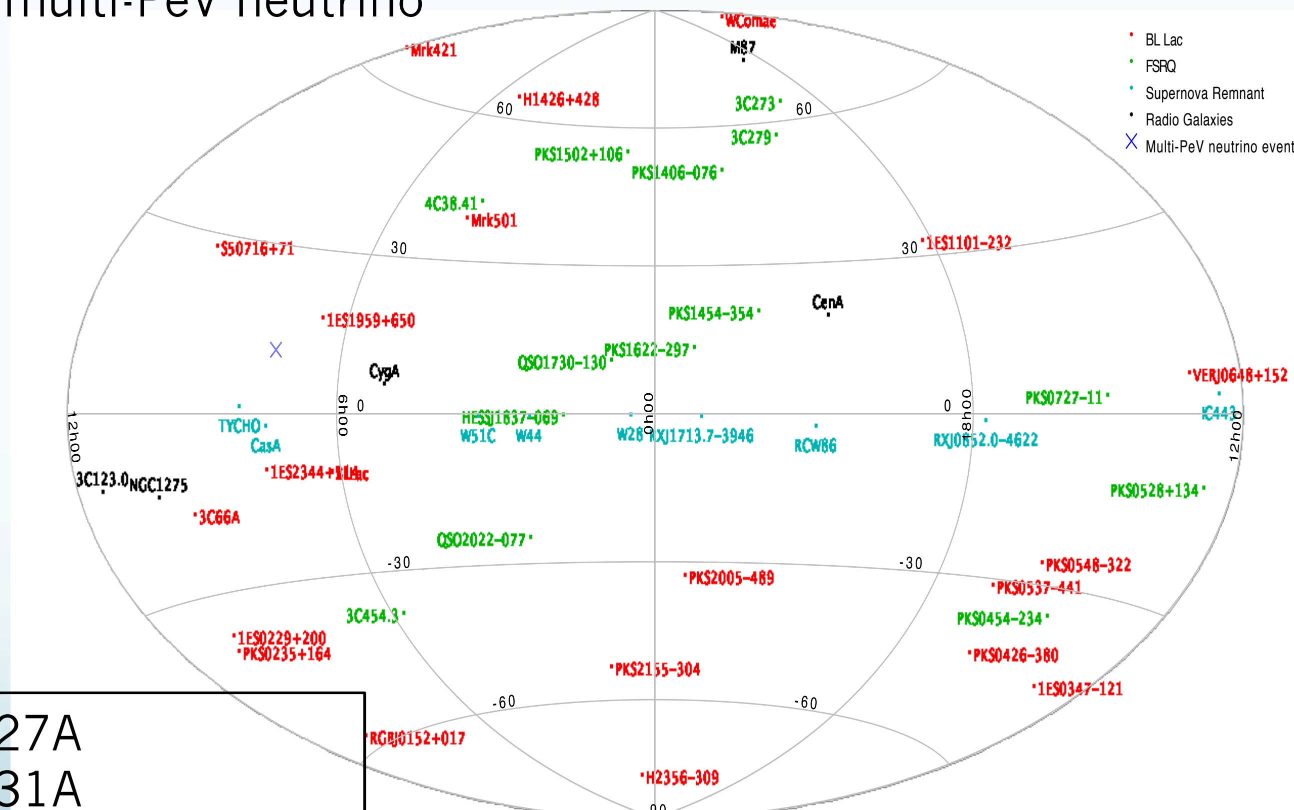
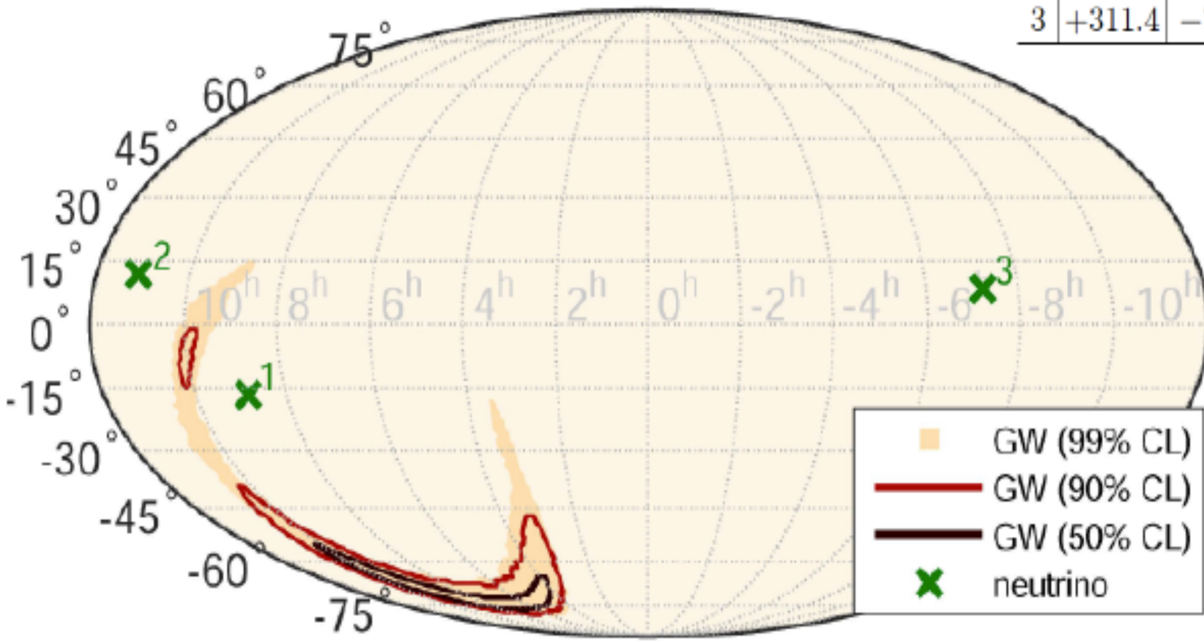


IceCube-160427A
IceCube-160731A
IceCube-160814A
(many ATels, but no direct association)

Searching for IceCuve neutrino signal associated to GW150914

ANTARES, ICECUBE, LIGO/VIRGO coll arXiv:1602.05411

#	ΔT [s]	RA [h]	Dec [°]	σ_μ^{rec} [°]	E_μ^{rec} [TeV]	fraction
1	+37.2	8.84	−16.6	0.35	175	12.5%
2	+163.2	11.13	12.0	1.95	1.22	26.5%
3	+311.4	−7.23	8.4	0.47	0.33	98.4%



In the time windows of ~ 500 s from the GW150914, no neutrinos were spacial correlation

Others ……

Galactic sources

- supernova remnants [Mandelartz & Tjus'14]
- pulsars [Padovani & Resconi'14]
- microquasars [Anchordoqui, Goldberg, Paul, da Silva & Vlcek'14]
- Sagittarius A* [Bai, Barger, Barger, Lu, Peterson & Salvado'14; Fujita, Kimura & Murase'15]
- Fermi Bubbles [MA & Murase'13; Razzaque'13]
[Lunardini, Razzaque, Theodoseau & Yang'13; Lunardini, Razzaque & Yang'15]
- Galactic Halo [Taylor, Gabici & Aharonian'14]
- heavy dark matter decay [Feldstein, Kusenko, Matsumoto & Yanagida'13]
[Esmaili & Serpico '13; Bai, Lu & Salvado'13; Cherry, Friedland & Shoemaker'14]

Extragalactic sources

- Extragalactic:
- Association with sources of UHE CRs [Kistler, Stanev & Yuksel'13]
[Katz, Waxman, Thompson & Loeb'13; Fang, Fujii, Linden & Olinto'14]
- Association with diffuse gamma-ray background [Murase, MA & Lacki'13]
[Chang & Wang'14; Ando, Tamborra & Zandanel'15]
- Active galactic nuclei (AGN) [Stecker'13;Kalashev, Kusenko & Essey'13, Fraija& Marinelli 15]
[Murase, Inoue & Dermer'14; Kimura, Murase & Toma'14; Kalashev, Semikoz & Tkachev'14]
[Padovani & Resconi'14; Petropoulou, Dimitrakoudis, Padovani, Mastichiadis & Resconi'15]
- Gamma-ray bursts (GRB) [Murase & Ioka'13; Dado & Dar'14; Tamborra & Ando'15, Fraija 16, Fraija 15]
- Galaxies with intense star-formation
[He, Wang, Fan, Liu & Wei'13; Yoast-Hull, Gallagher, Zweibel & Everett'13]
[Murase, MA & Lacki'13; Anchordoqui, Paul, da Silva, Torres& Vlcek'14]
[Tamborra, Ando & Murase'14; Chang & Wang'14; Liu, Wang, Inoue, Crocker& Aharonian'14]
[Senno, Meszaros, Murase, Baerwald & Rees'15; Chakraborty & Izaguirre'15]
- Galaxy clusters/groups [Murase, MA & Lacki'13; Zandanel, Tamborra, Gabici & Ando'14]
- . . .

Gamma-Ray Bursts???

Outline

High-energy neutrinos
(IceCube Observations and correlations with known sources)

Gamma-ray bursts
(Some generalities and modeling the most powerful GRBs)

Hidden GRB jets inside progenitor stars
(Possible scenario for high-energy neutrino production)

Conclusions

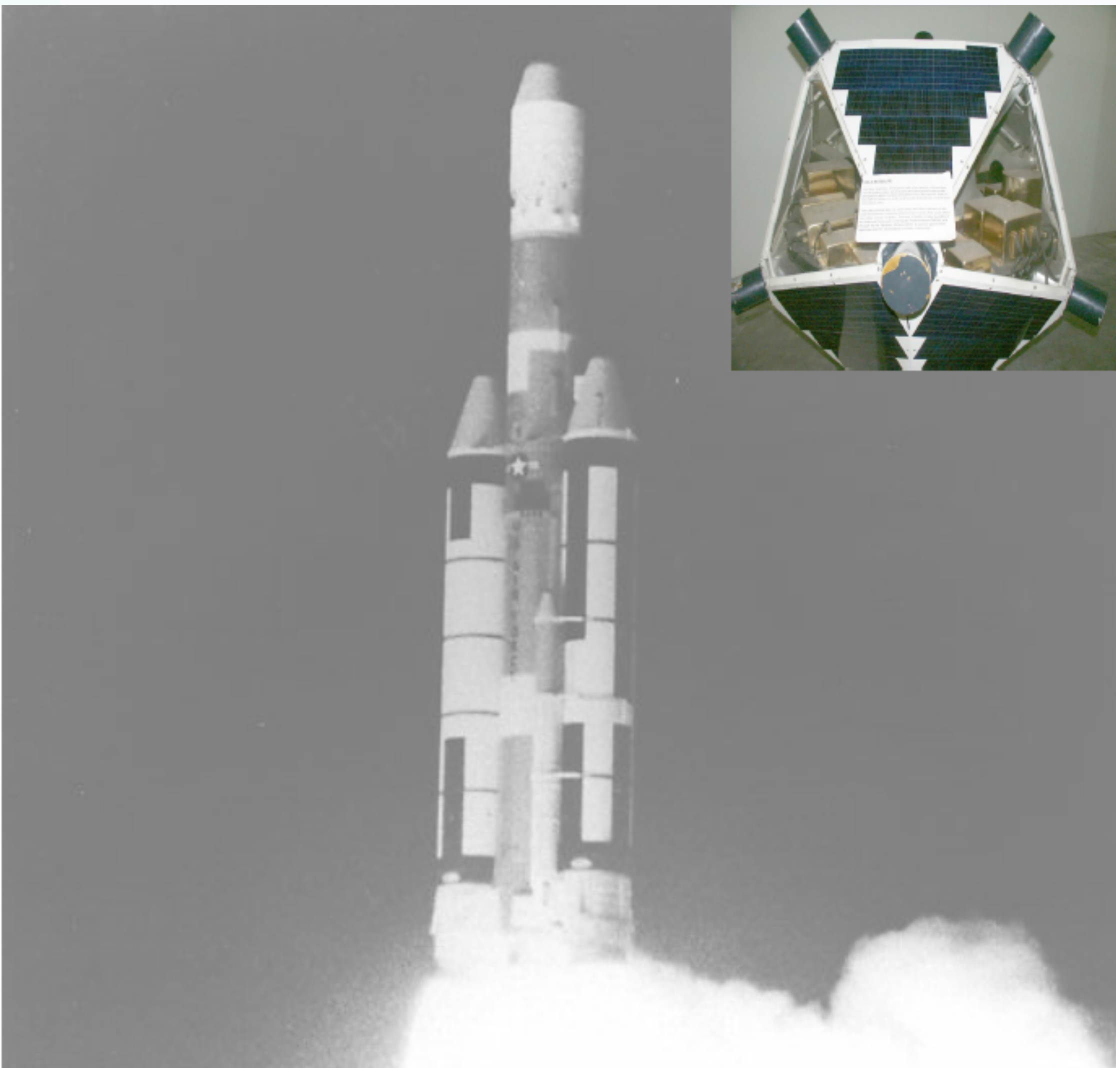
History

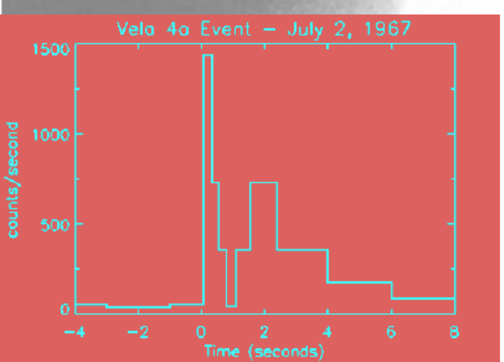
Gamma-ray Bursts (GRBs)

were discovered (accidentally [8]) by Vela satellites in 1967.

For about 20 years the distance to GRBs was completely uncertain.

[8] Colgate (1968) anticipated GRBs -- associated with breakout of relativistic shocks from the surfaces of SNe.





The Astrophysical Journal, 182:L85–L88, 1973 June 1

OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

Ray W. Klebesadel, Ian B. Strong, and Roy A. Olson

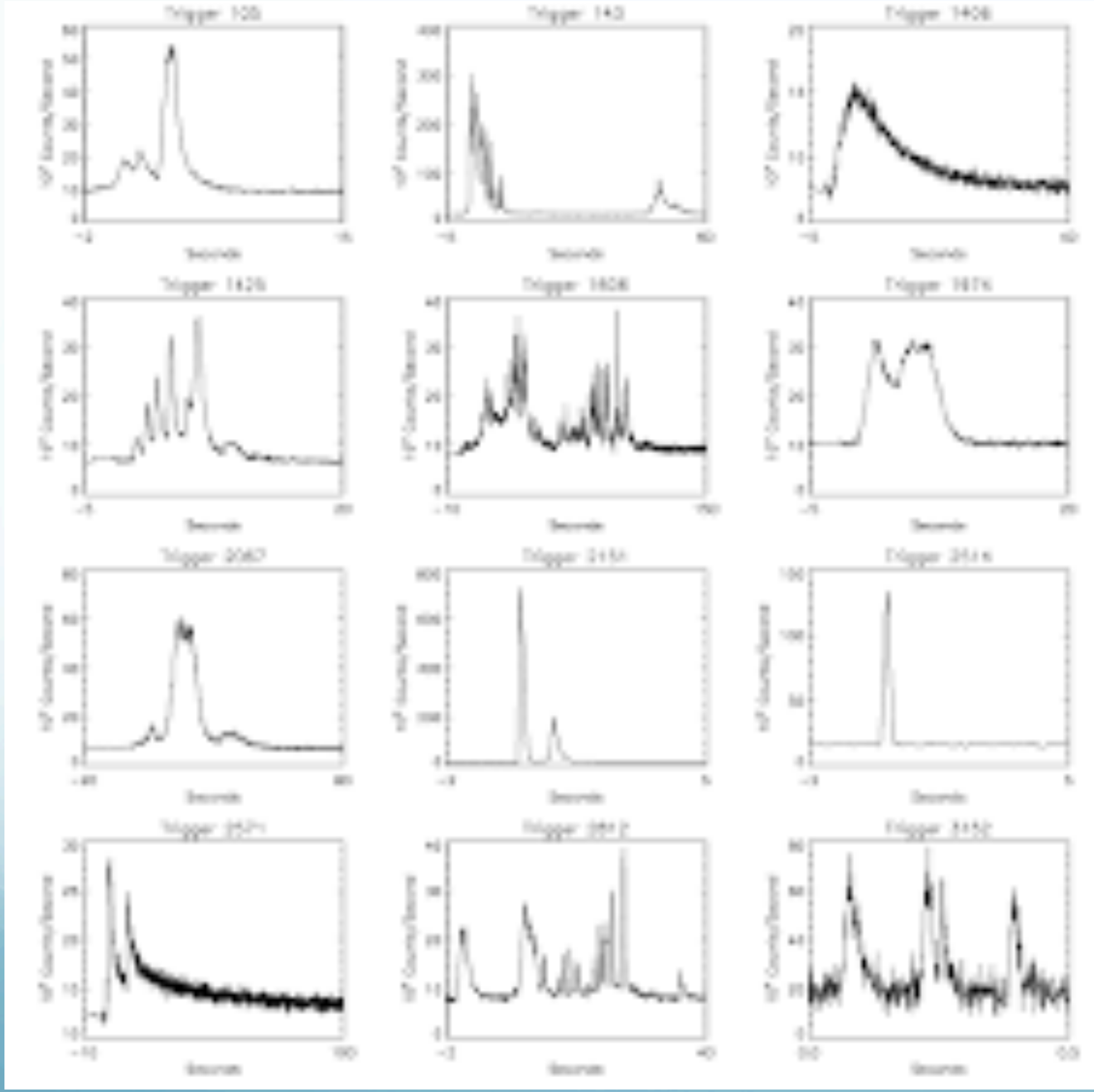
University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
Received 1973 March 16; revised 1973 April 2

ABSTRACT

Sixteen short bursts of photons in the energy range 0.2–1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than 0.1 s to ~30 s, and time-integrated flux densities from $\sim 10^{-5}$ ergs cm^{-2} to $\sim 2 \times 10^{-4}$ ergs cm^{-2} in the energy range given. Significant time structure within bursts was observed. Directional information eliminates the Earth and Sun as sources.

Subject headings: gamma rays — X-rays — variable stars

Diverse temporal properties



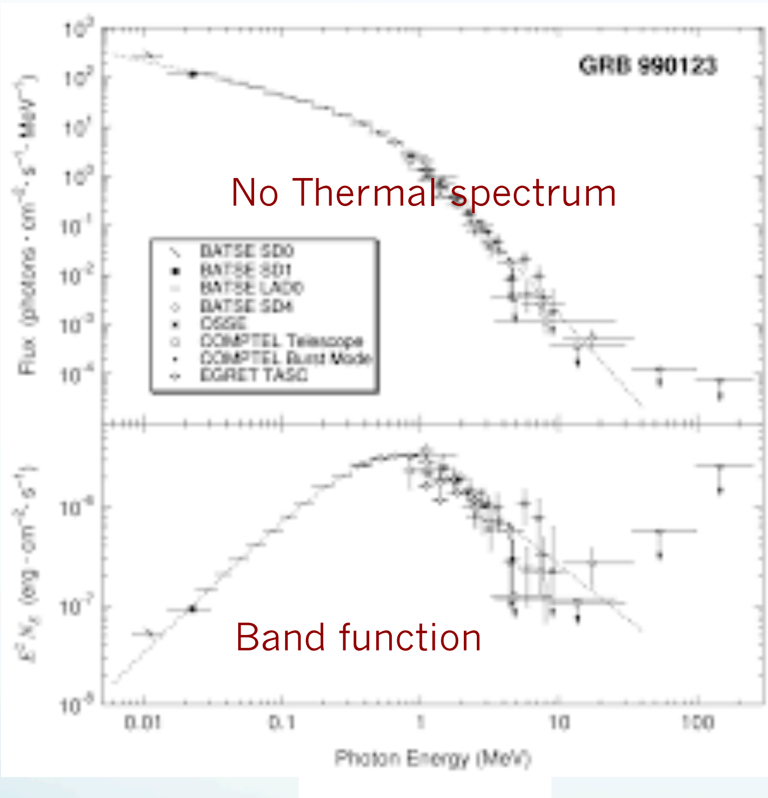
- Fast variability
- No variability
- Many peaks or episodes

BATSE team

http://heasarc.gsfc.nasa.gov/docs/cgro/images/epo/gallery/grbs/

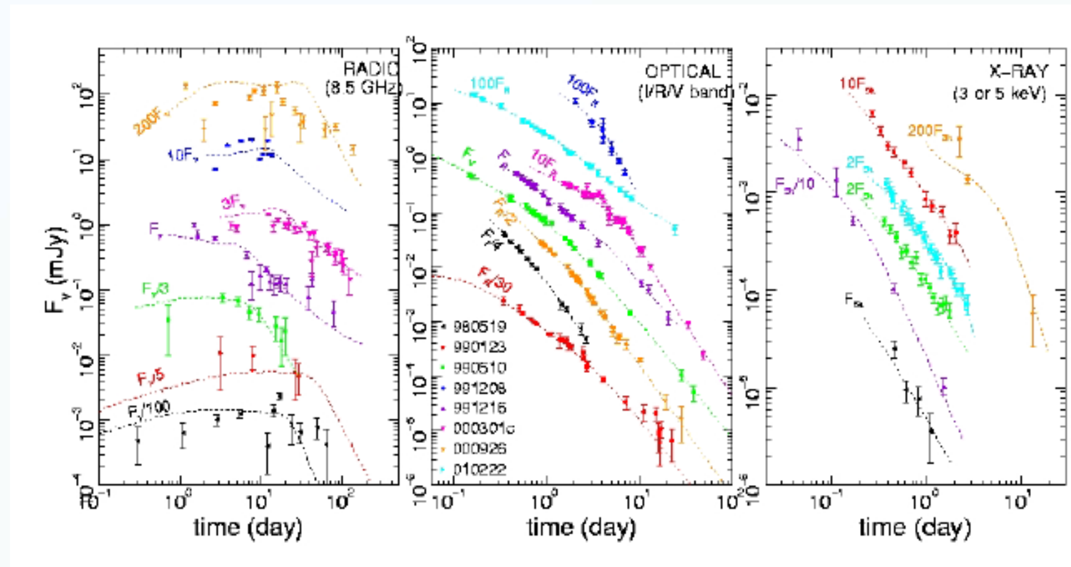
Spectrum (Prompt)

Spectrum (Afterglow)



No Thermal spectrum

Band function



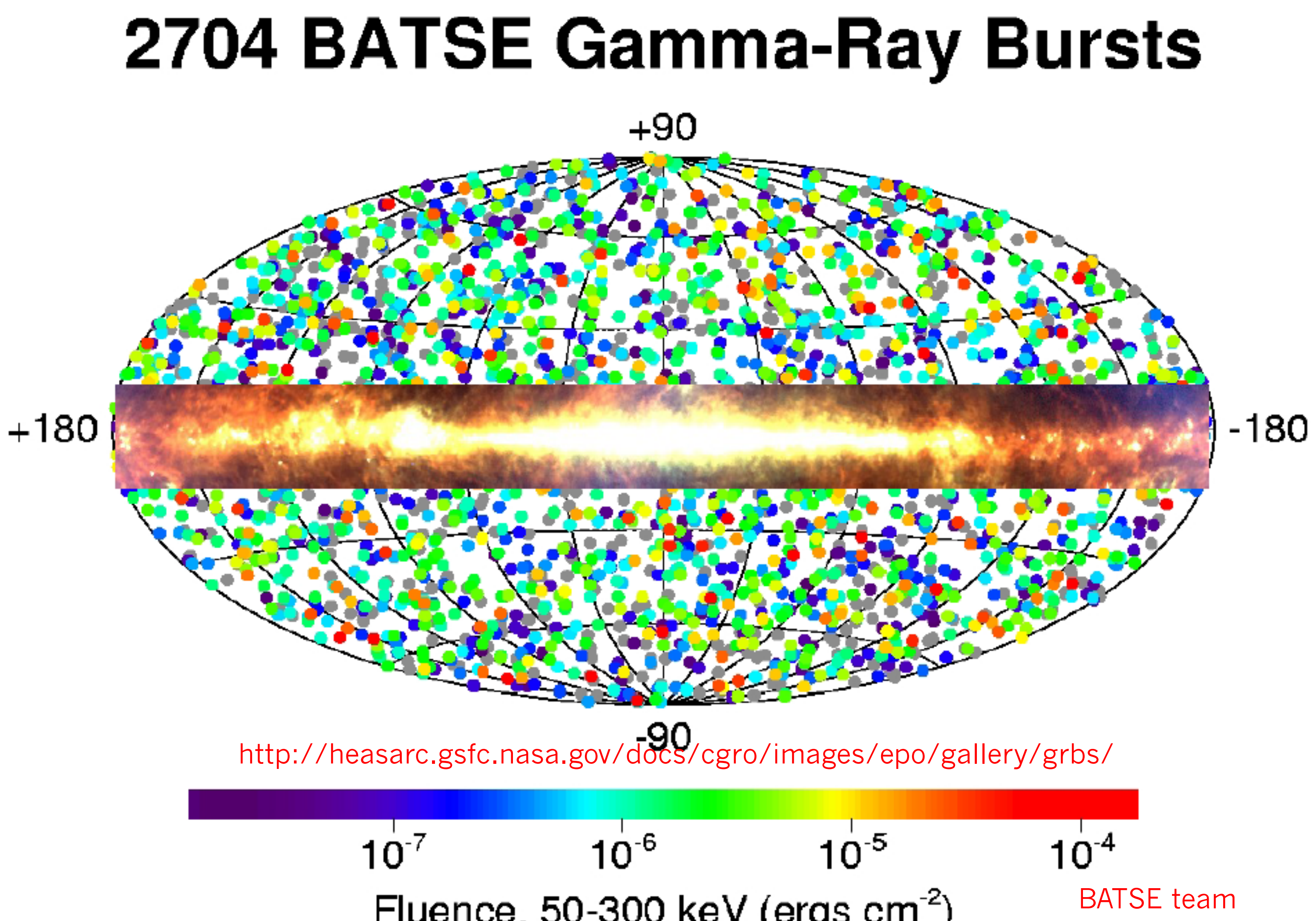
Synchrotron radiation

Band et al. (93)

Piran (93)
sari et al. (98)

$$N(\epsilon)=\begin{cases} A\left(\dfrac{\epsilon}{100\,\mathrm{keV}}\right)^{\alpha}\exp\left[-\dfrac{\epsilon(2+\alpha)}{\epsilon_p}\right] & \epsilon<\epsilon_c \\ A\left[\dfrac{(\alpha-\beta)\epsilon_p}{(2+\alpha)100\,\mathrm{keV}}\right]^{(\alpha-\beta)}\exp(\beta-\alpha)\left(\dfrac{\epsilon}{100\,\mathrm{keV}}\right)^{\beta} & \epsilon>\epsilon_c \end{cases}, \quad (5)$$

ISOTROPY



http://heasarc.gsfc.nasa.gov/docs/cgro/images/epo/gallery/grbs/

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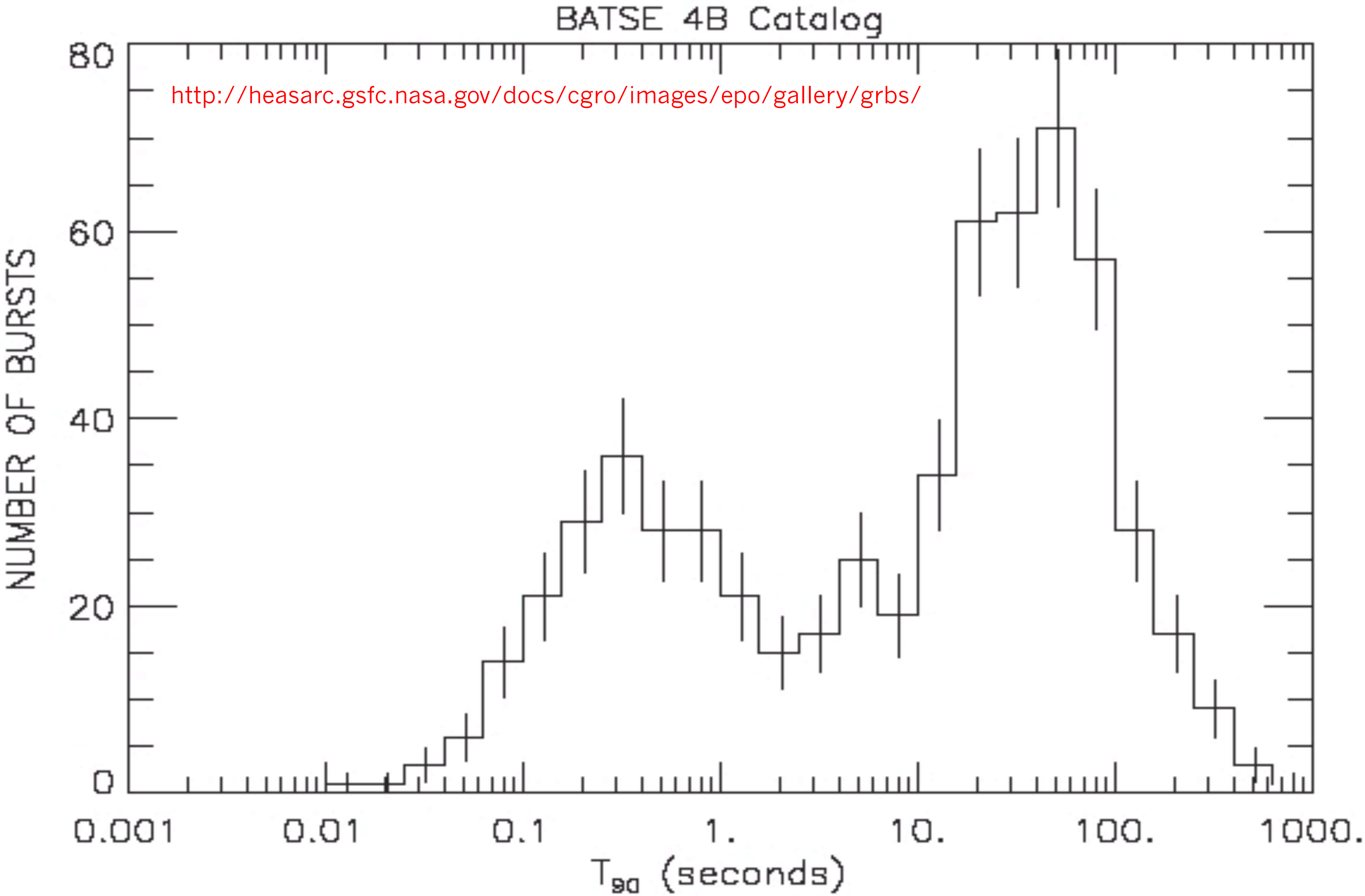
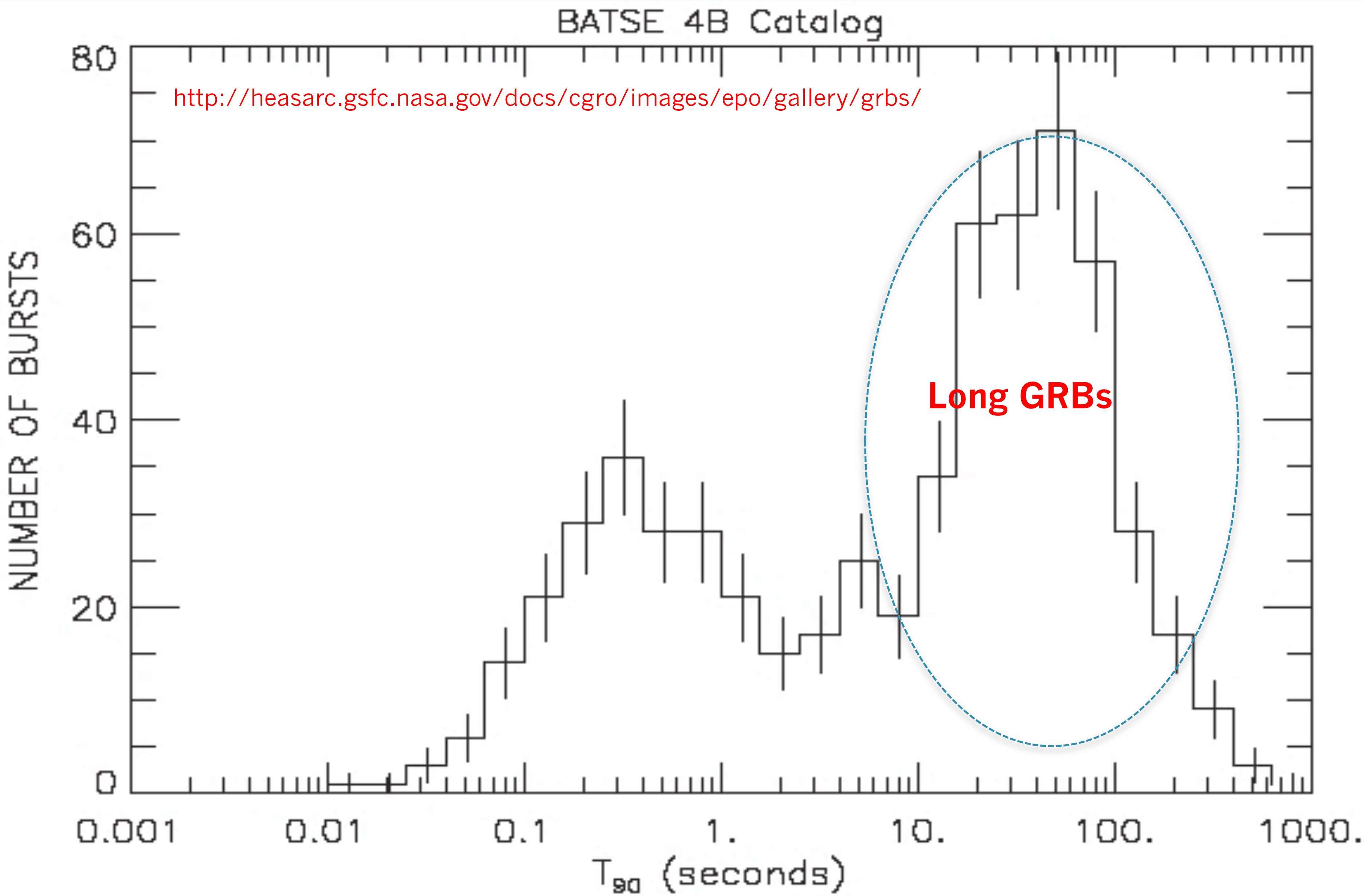
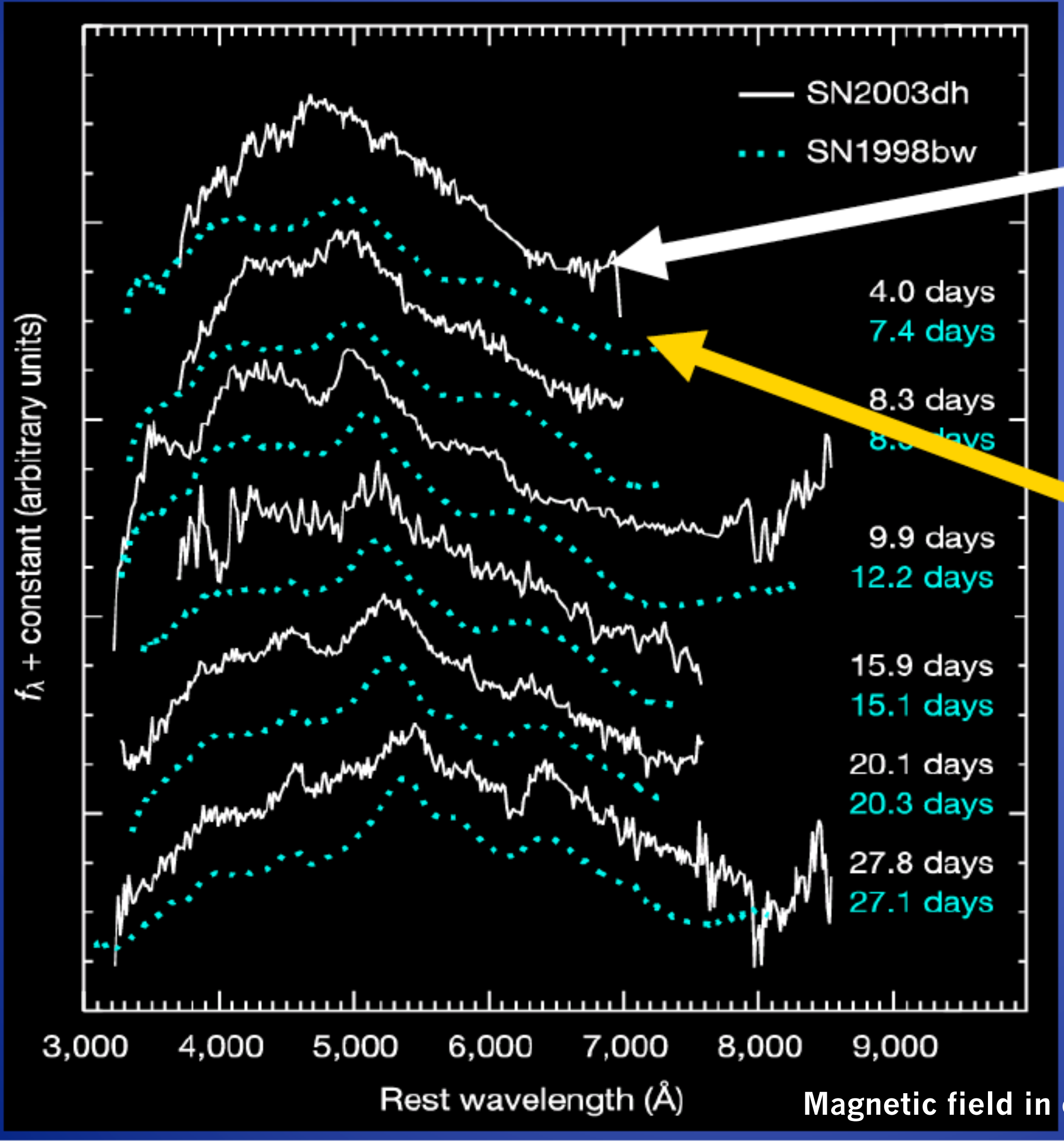
GRB Duration



GRB Duration



Long-GRB – collapse of a massive star (Woosley and Paczynski)



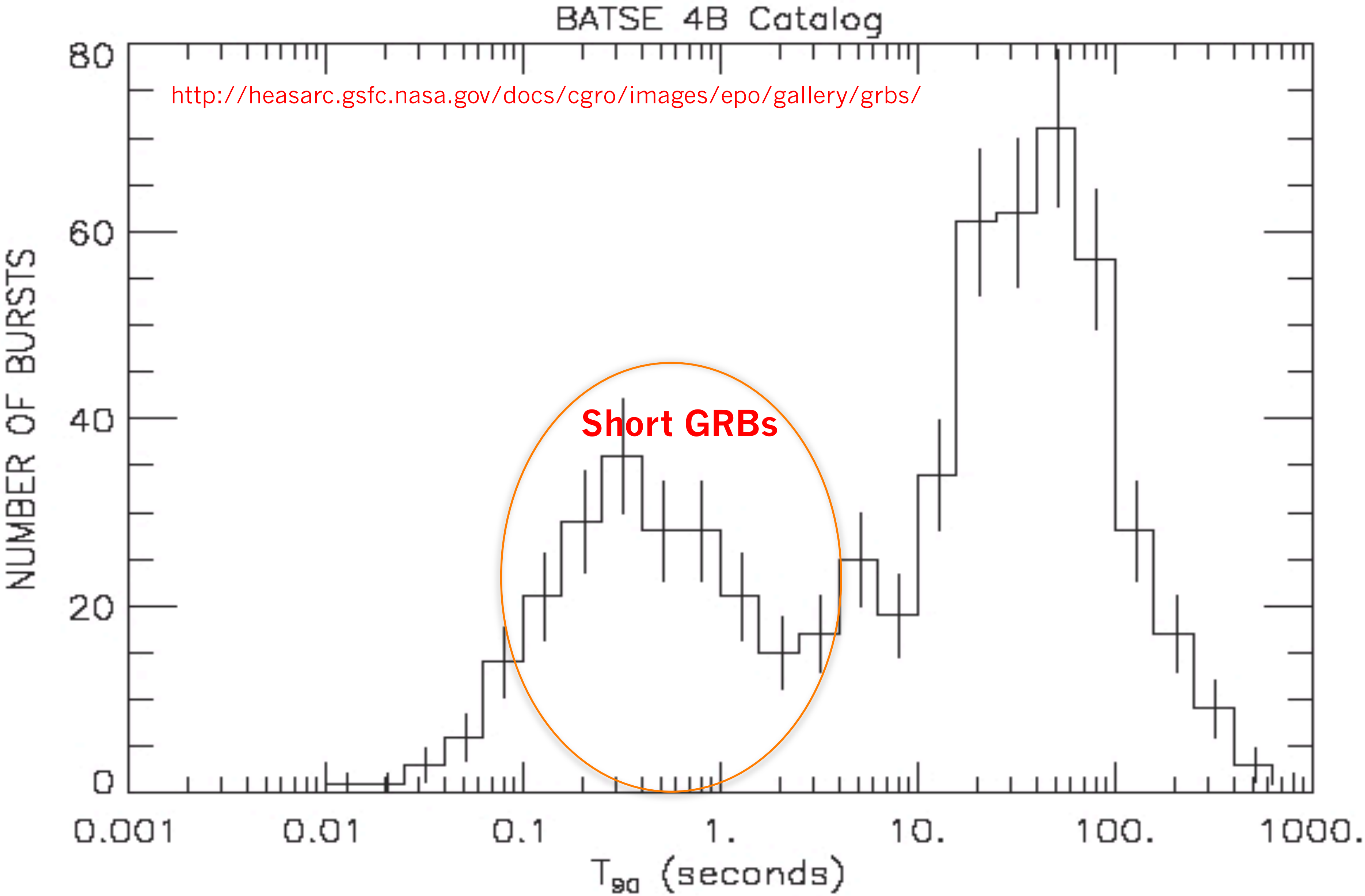
GRB 030329: z=0.17
(afterglow-subtracted)

SN 1998bw:
local, energetic, core-collapsed Type Ic

Stanek et al.,
Chornock et al.
Eracleous et al.,
Hjorth et al.,
Kawabata et al.

Magnetic field in central engine

GRB Duration



Neutron star merger

Berger (12)

- The most popular progenitor associated with sGRBs is the merger of compact object binaries
  NS-NS or NS – BH

Neutron star merger

- Magnetic field amplification during the merger NS - NS

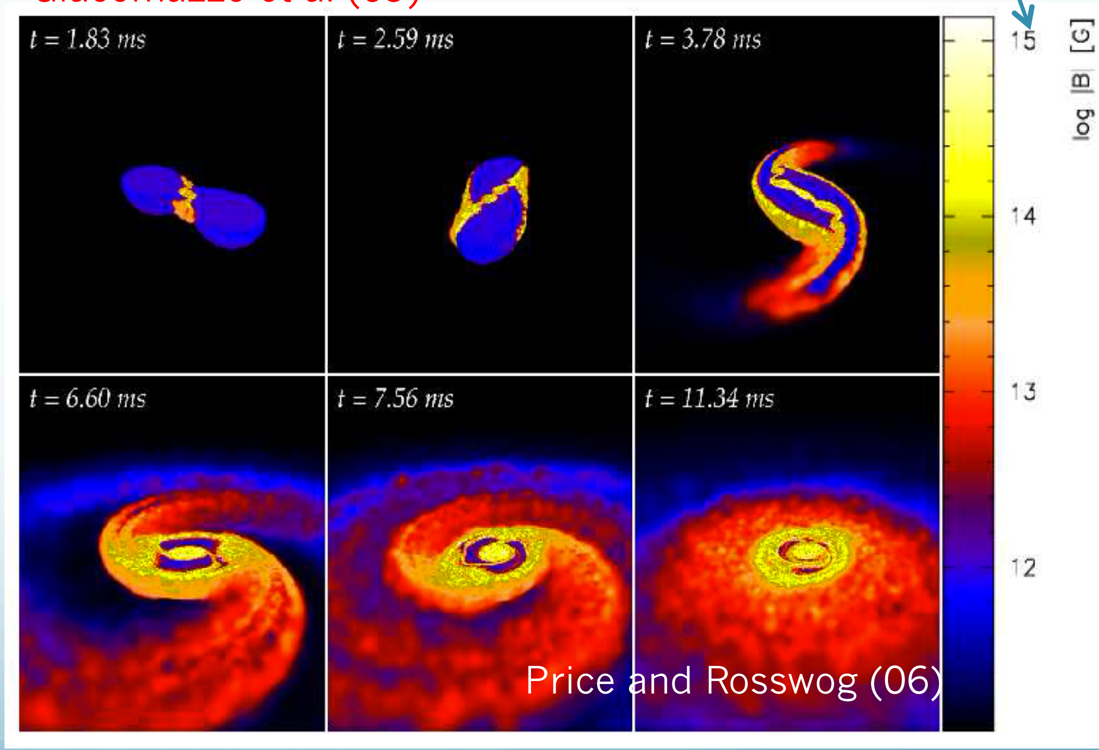
- The growth related to KH instabilities and turbulent amplification

Berger (12)

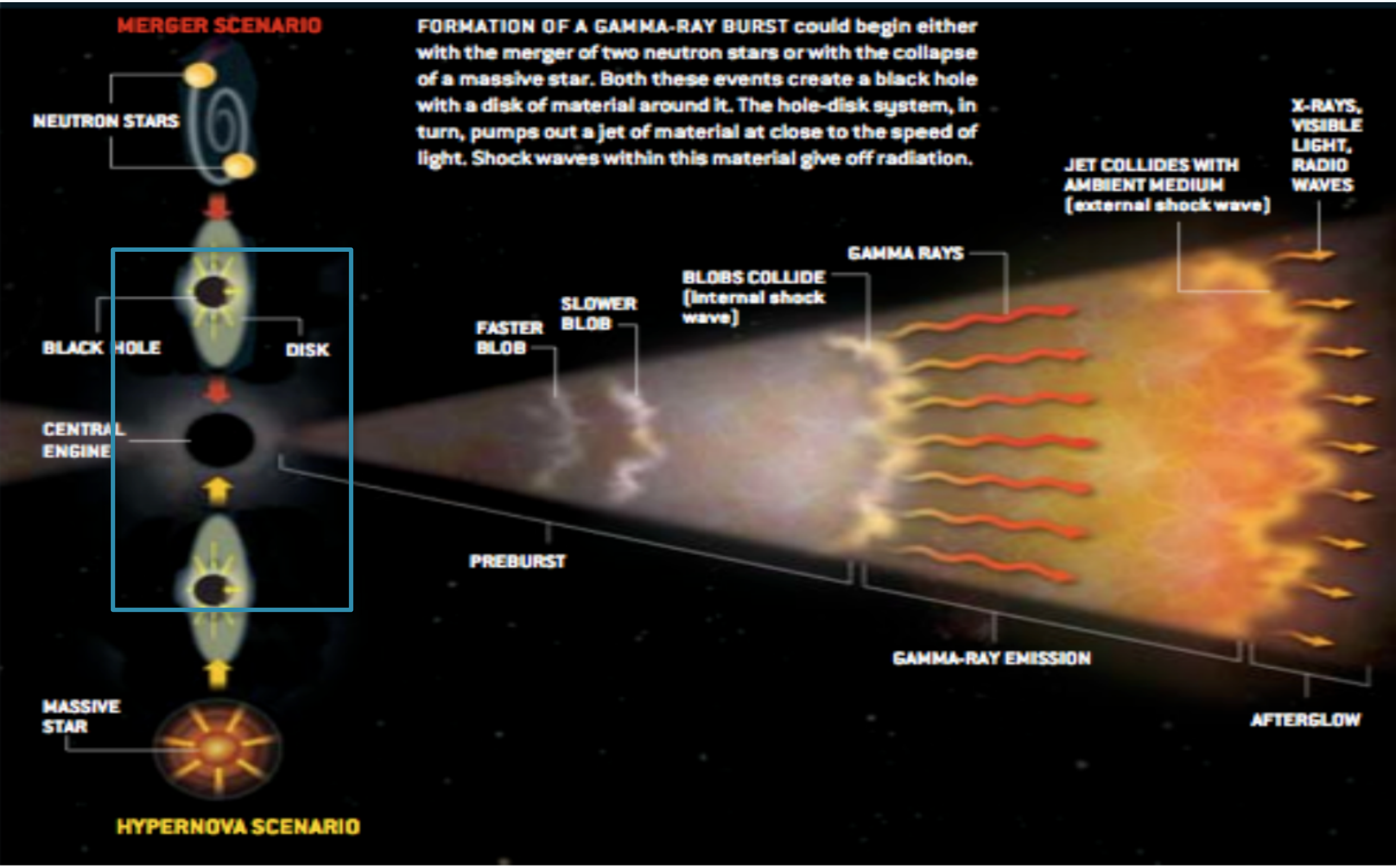
- The most popular progenitor associated with sGRBs is the merger of compact object binaries
  NS-NS or NS – BH

Zrake and MacFadyen (13)
Giacomazzo et al (09)

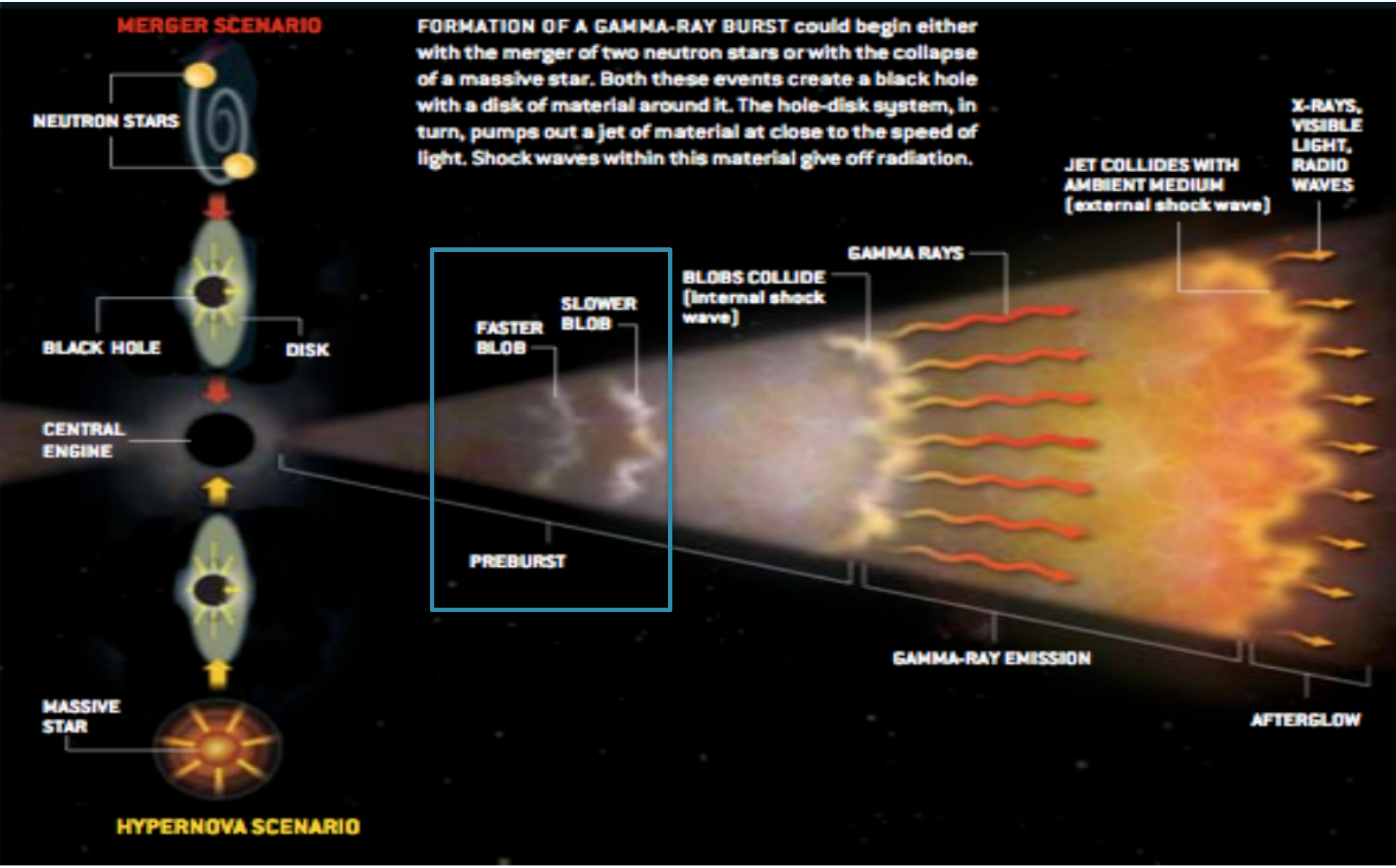
Magnetic field can increase up to 10^{15} G or more



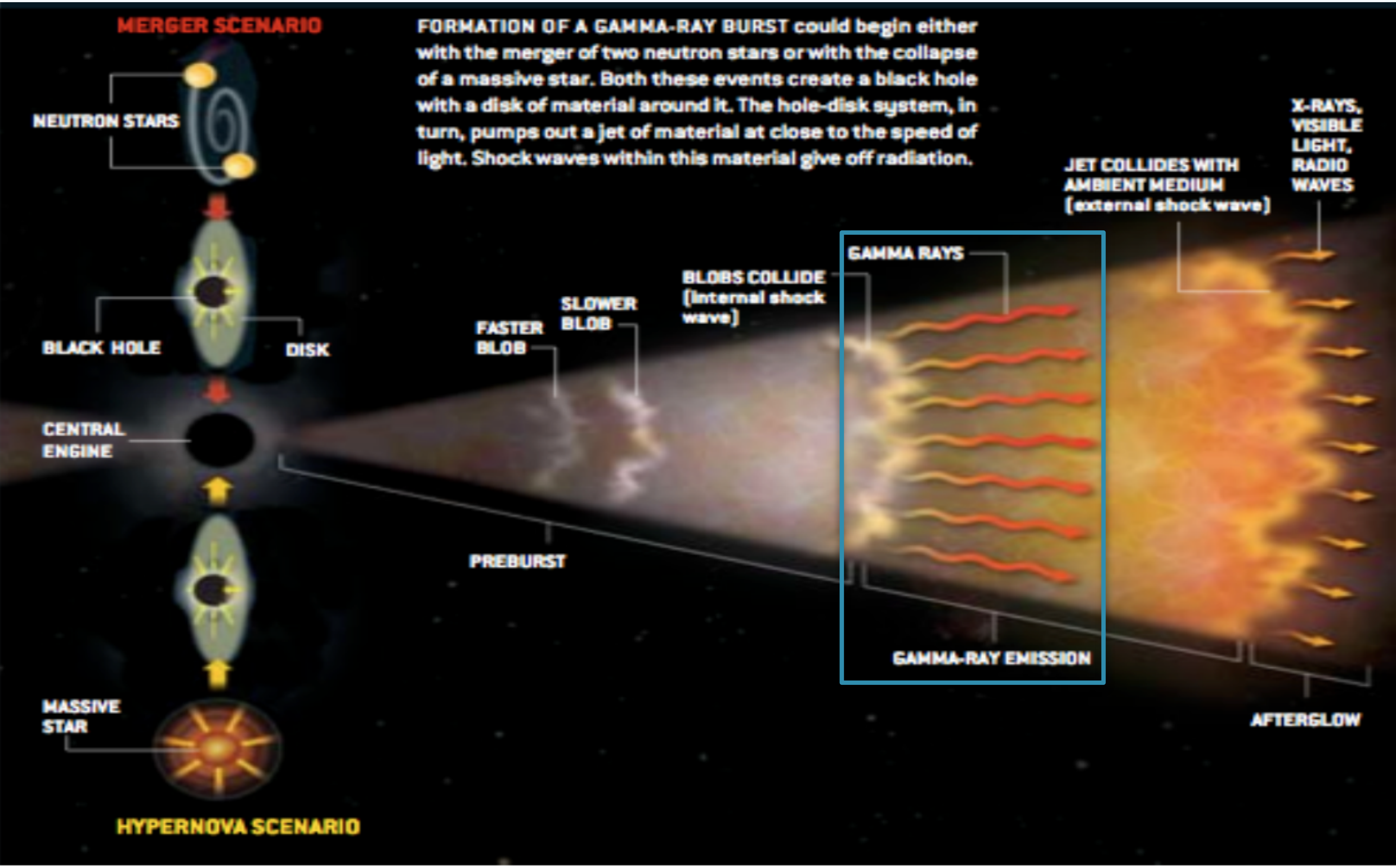
Fireball model



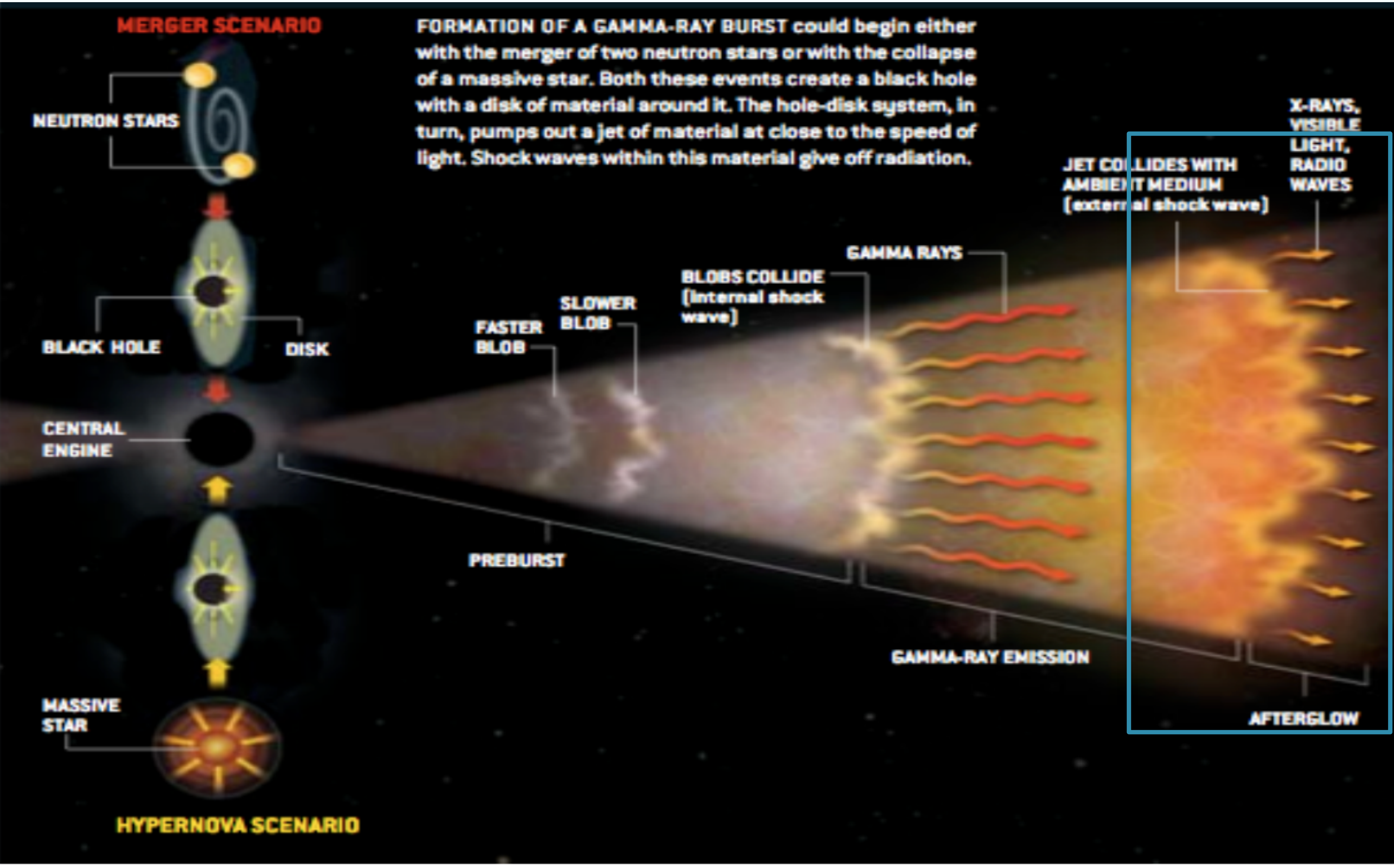
Fireball model



Fireball model



Fireball model



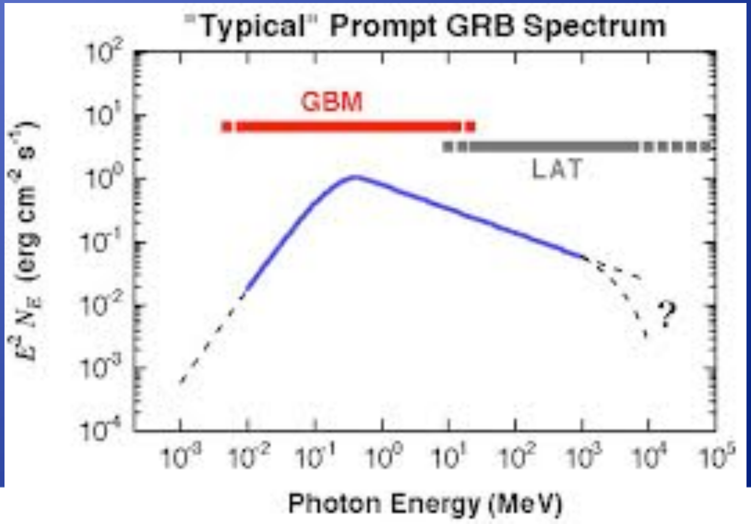
Fermi

8 KeV to 300 GeV

6/11/2008

How are γ-rays generated?

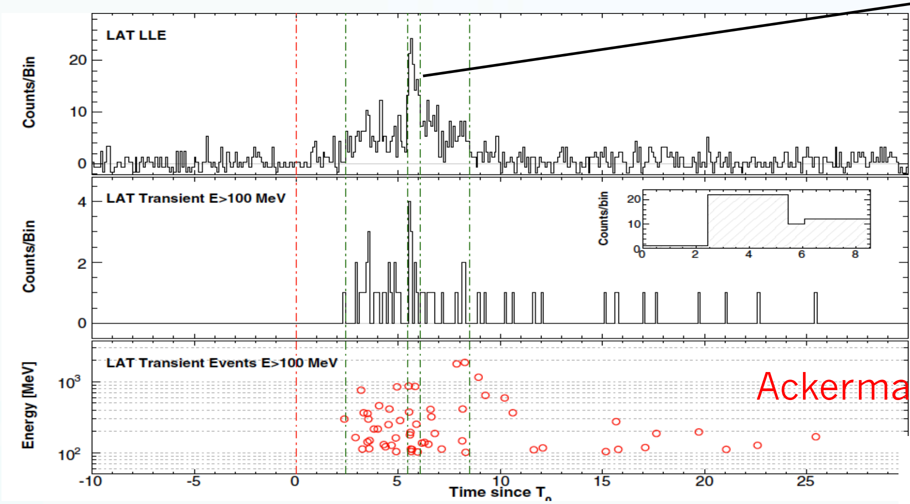
One of the goals for Fermi is to understand γ-ray burst prompt radiation mechanism by observing high energy photons from GRBs.



BATSE team

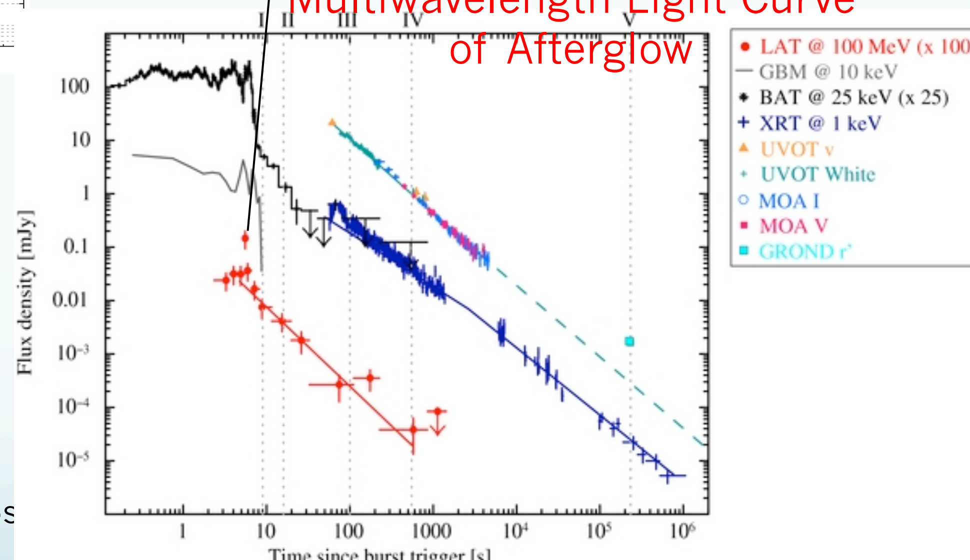
GRB110731A

The brightest peak
at ~ 5.5 s



Ackermann et al. (13)

Multiwavelength Light Curve
of Afterglow



Three important features:

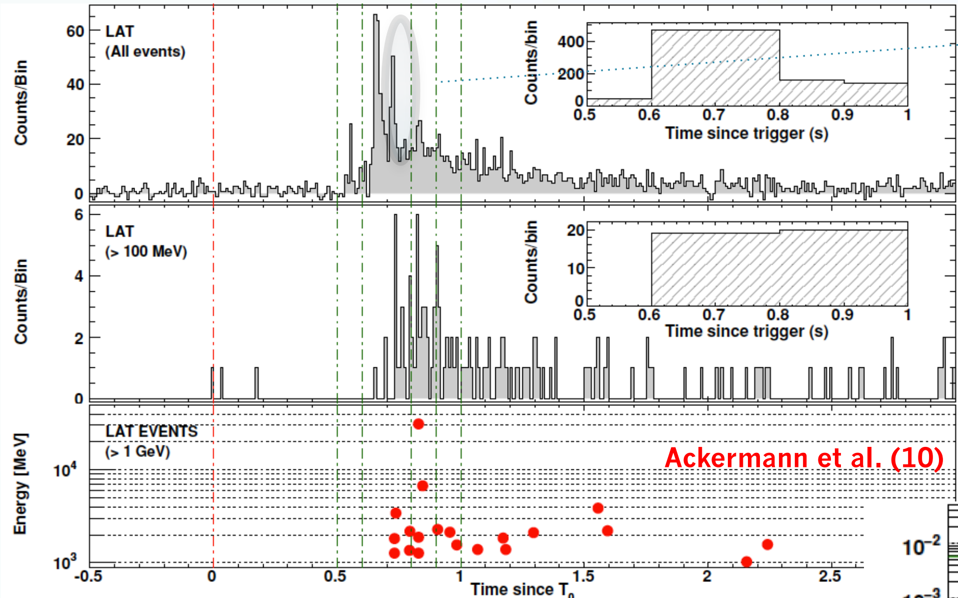
1. The LAT emission at > 10 MeV is slightly delayed (~2.5s
   with respect to the GBM light curves.

2. An outstanding peak with high count rate was presented
   at 5.5s in the LAT data.

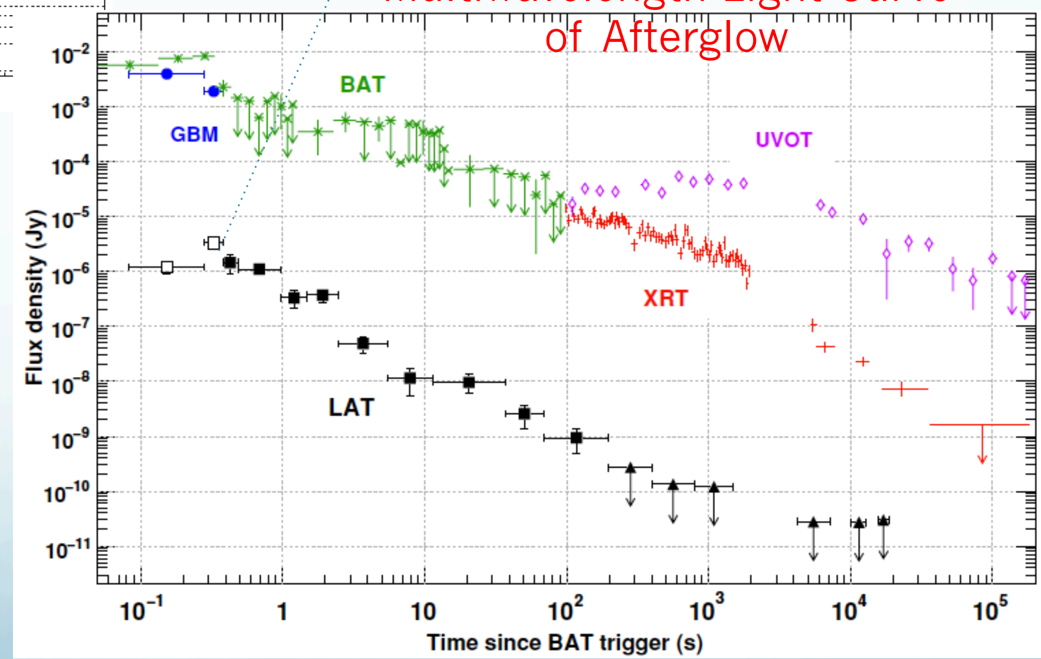
3. A temporally extended emission lasting hundreds of seconds.

GRB090510

The brightest peak before 1s



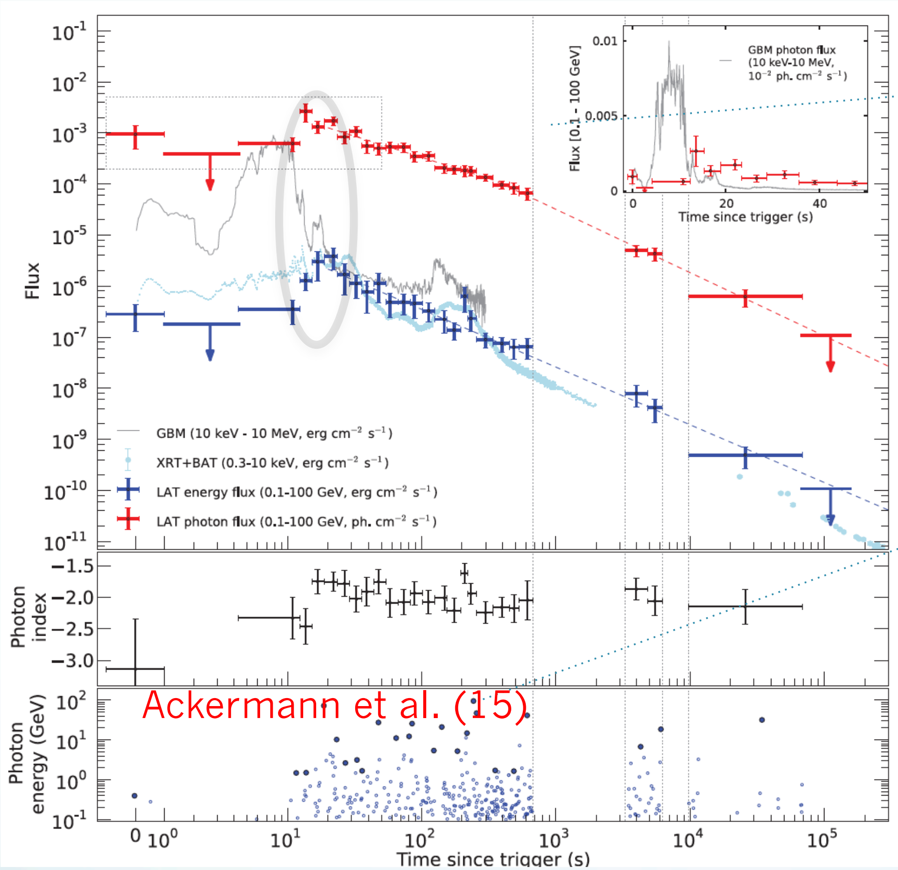
Multiwavelength Light Curve of Afterglow



Three important features:

1. The LAT emission is delayed with respect to the GBM light curves.
2. An outstanding peak with high count rate was presented before 1s in the LAT data.
3. A temporally extended emission lasting hundreds of seconds.

GRB130427A

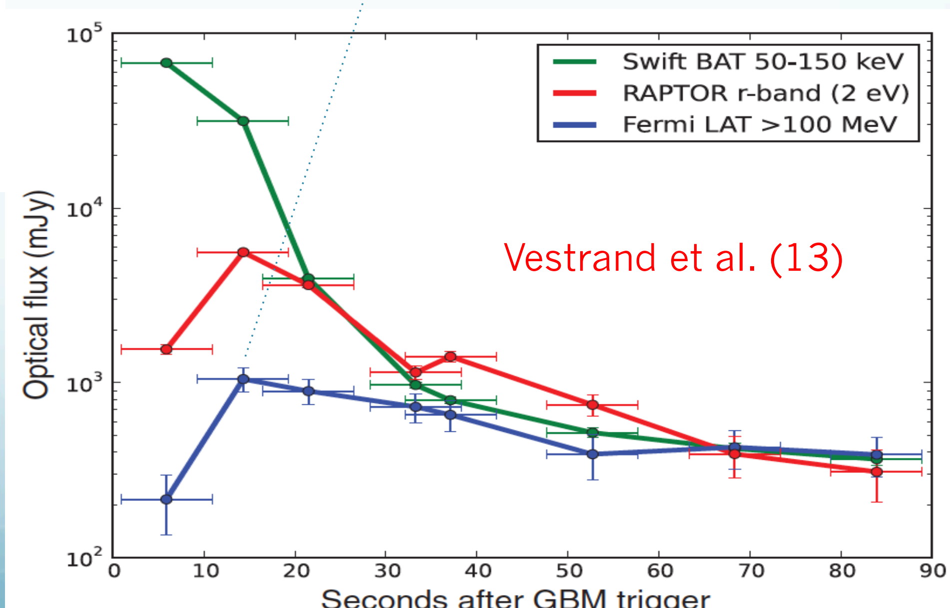


The brightest peak at 15s

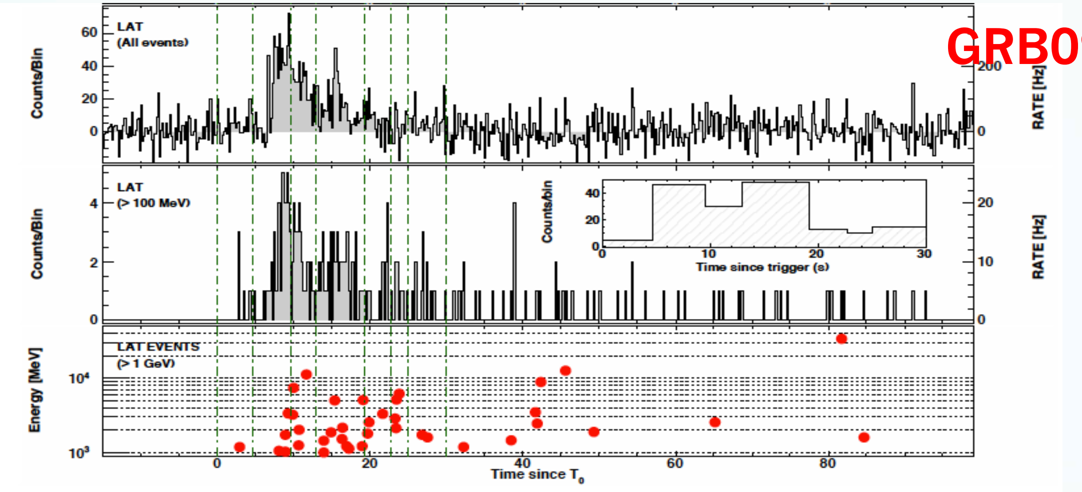
LAT observed the highest-energy photon ever recorded of 95 GeV

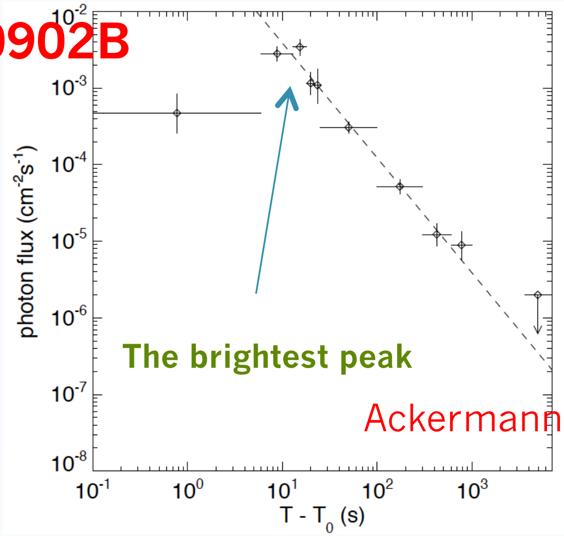
Three important features:

1. The LAT emission is delayed with respect to the GBM light curves.
2. An outstanding peak was presented at 15s in the LAT and optical data.
3. A temporally extended emission lasting more than thousand of seconds.



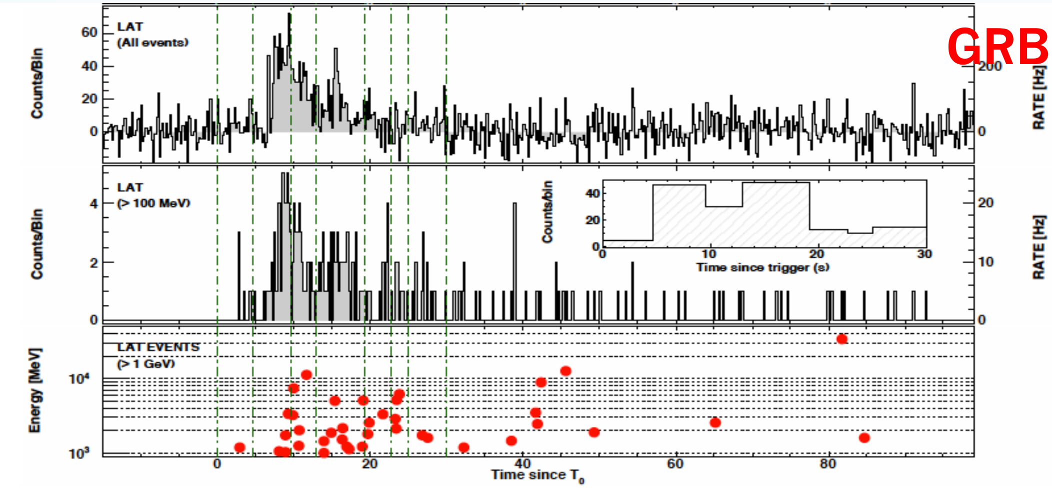
GRB090902B

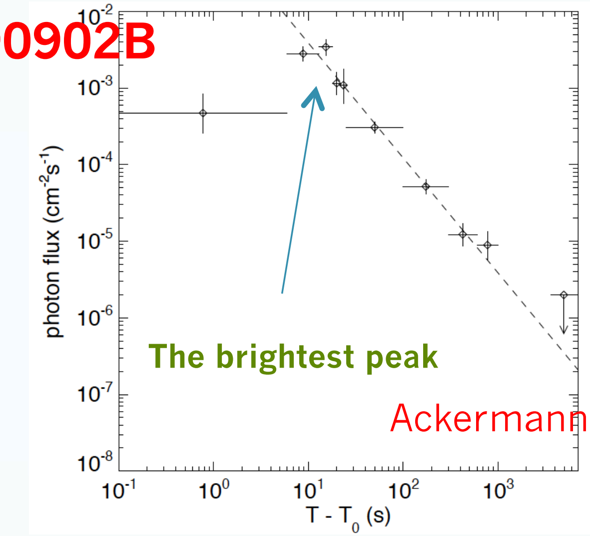




Ackermann et al. (10)

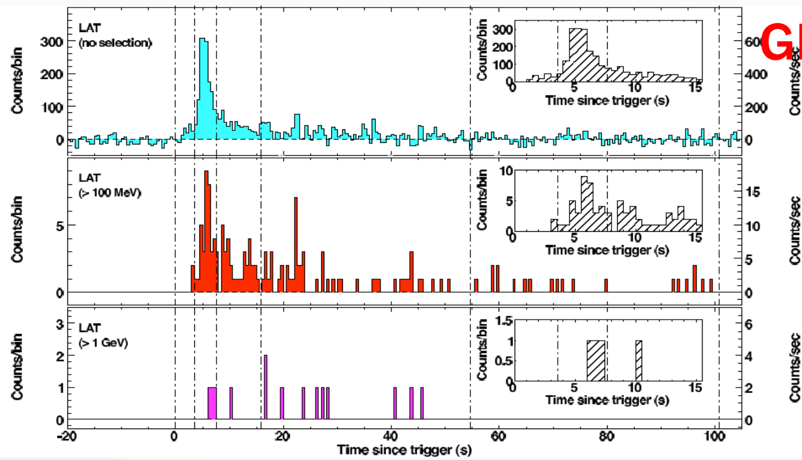
GRB090902B

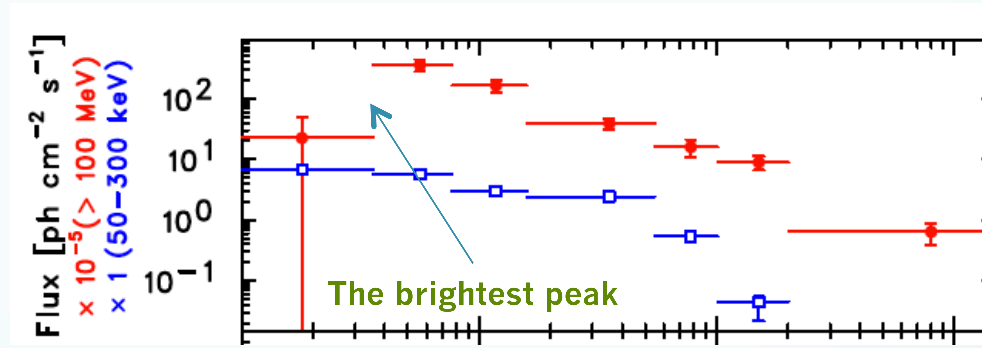




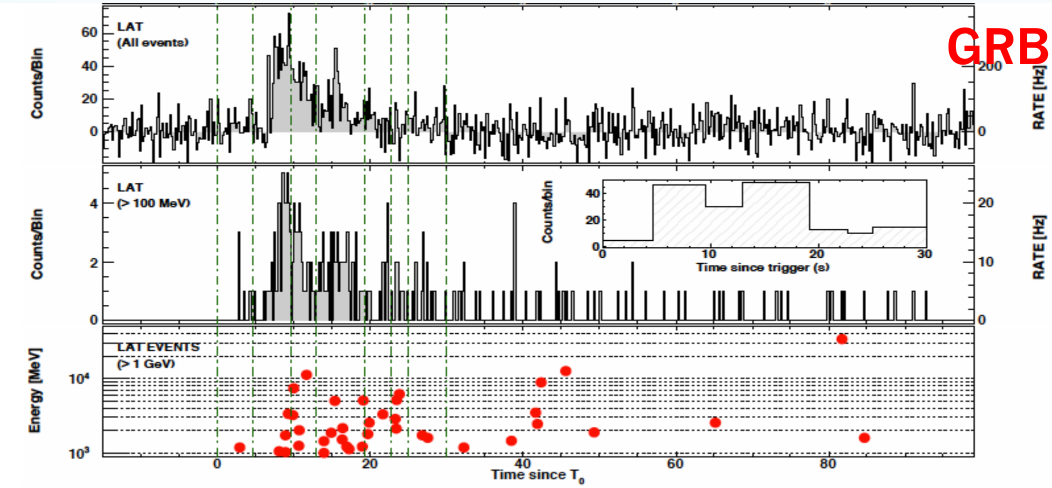
Ackermann et al. (10)

GRB080916C

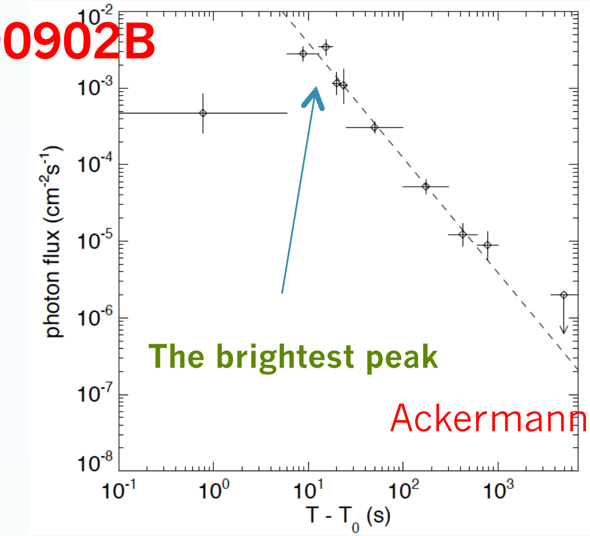




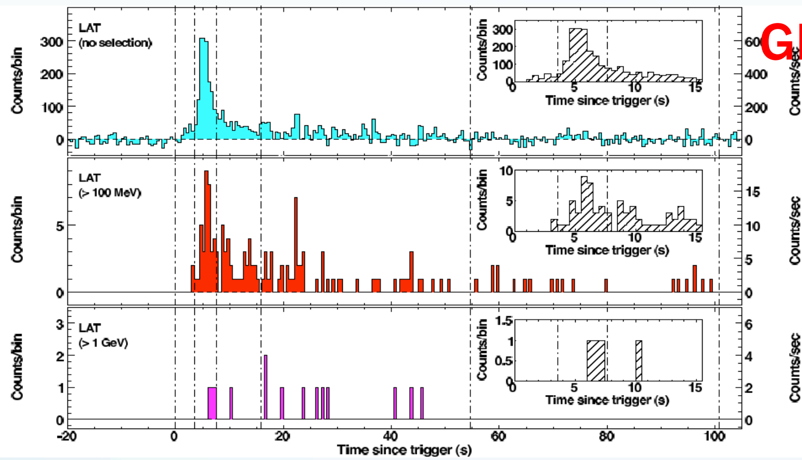
Ackermann et al. (09)



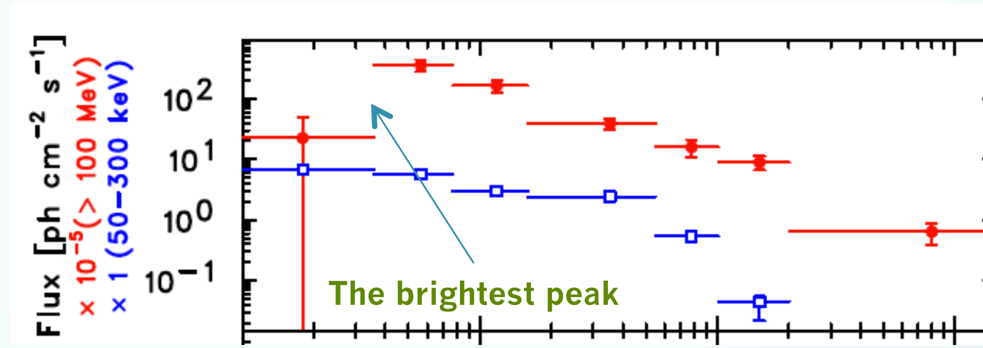
GRB090902B



Ackermann et al. (10)

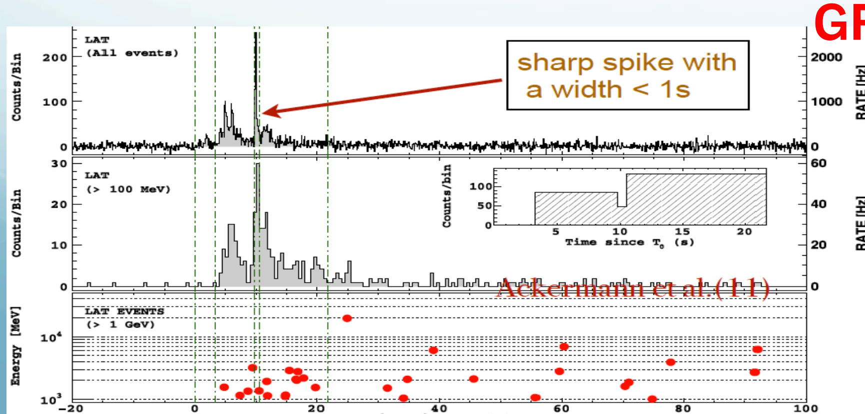


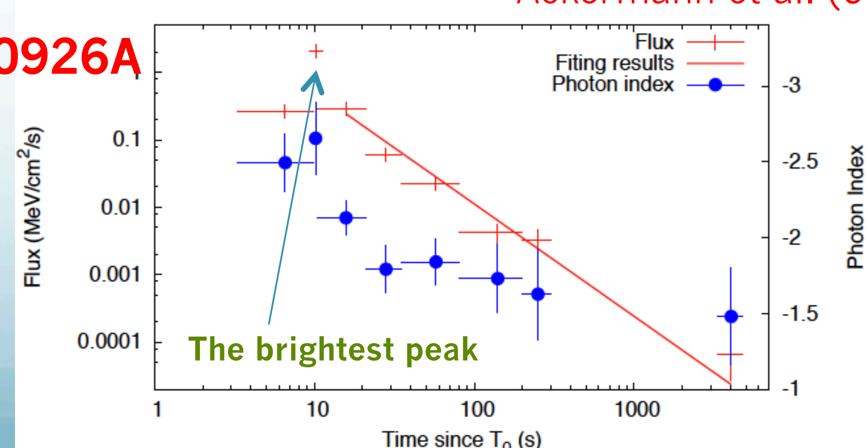
GRB080916C



Ackermann et al. (09)

GRB090926A





Leptonic model based on external shocks

Zhang et al. (03)
Kobayashi et al. (05)
Fraija et al. (12)

GRB Values

GRB110731A GRB090510 GRB130427A GRB090926A GRB090902B GRB080916C

$\Gamma \simeq 520$ $\Gamma \simeq 3000$ $\Gamma \simeq 550$ $\Gamma \simeq 520$ $\Gamma \simeq 550$ $\Gamma \simeq 520$

$A = 5 \times 10^{10}$ gram/cm $n = 0.1$ cm^{-3} $A \simeq (10^9 - 10^{11})$ gram/cm $A \simeq (10^9 - 10^{11})$ gram/cm $A \simeq (10^9 - 10^{11})$ gram/cm

$E \simeq 10^{54}$ erg $E \simeq 10^{53}$ erg $E \simeq 10^{54}$ erg $E \simeq 10^{54}$ erg $E \simeq 10^{54}$ erg $E \simeq 10^{54}$ erg

Ackermann et al. (10)

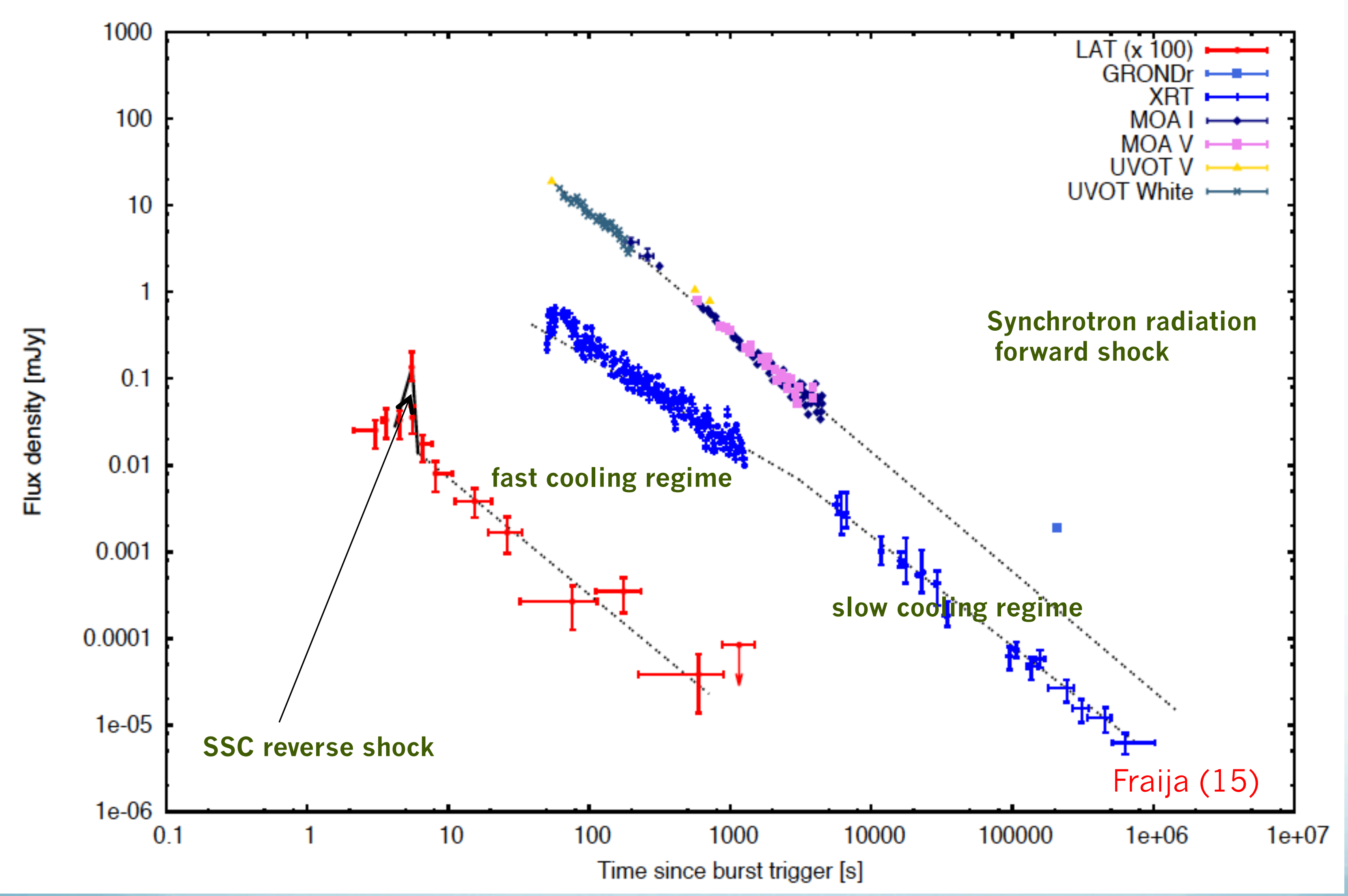
De Pasquale et al. (10)
Lu et al. (10)

Ackermann et al. (15)
Vestrand et al. (15)
Vestran et al. (14)

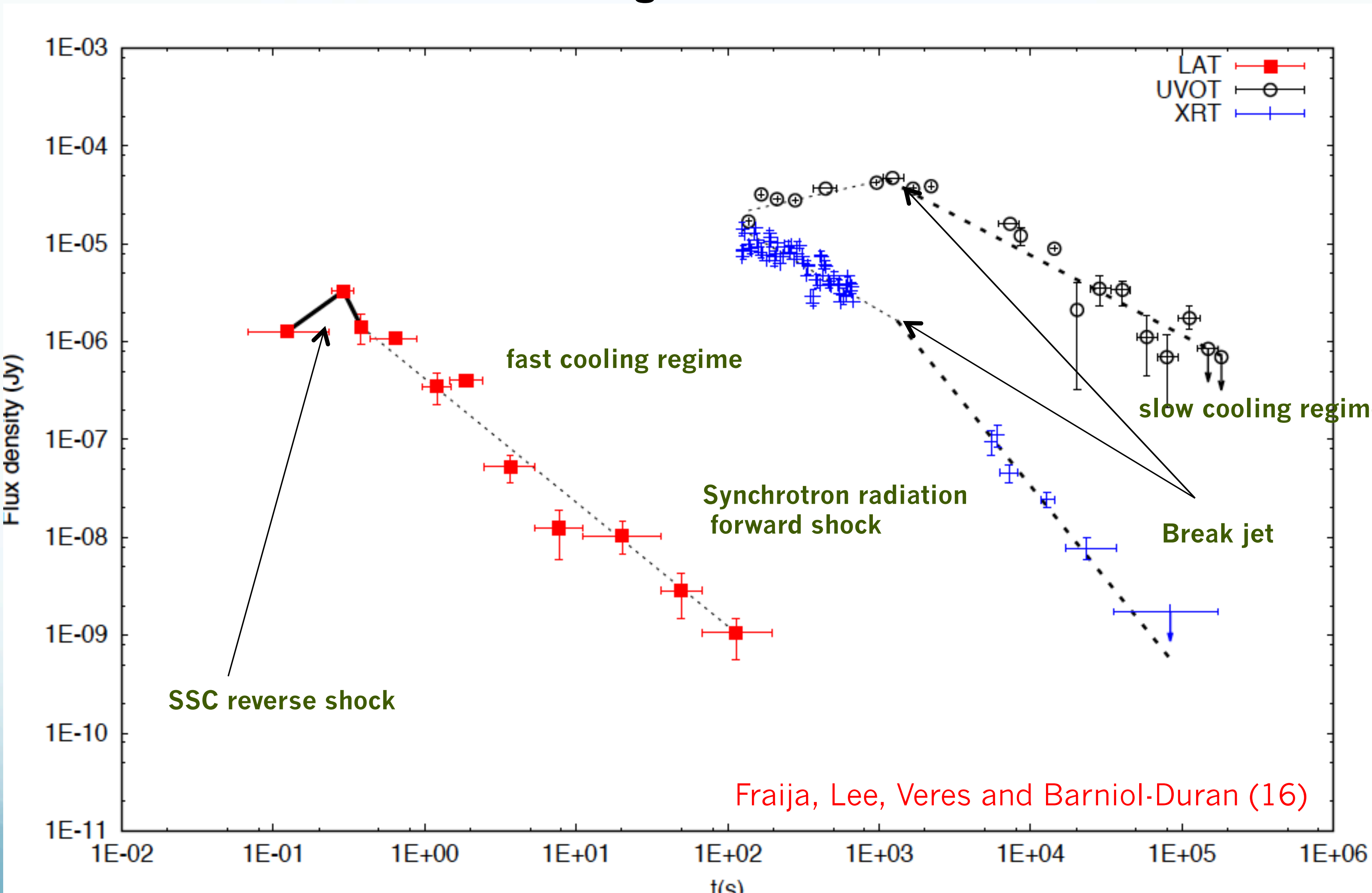
??????

$\epsilon_{B,f/r}$ and $\epsilon_{e,f/r}$

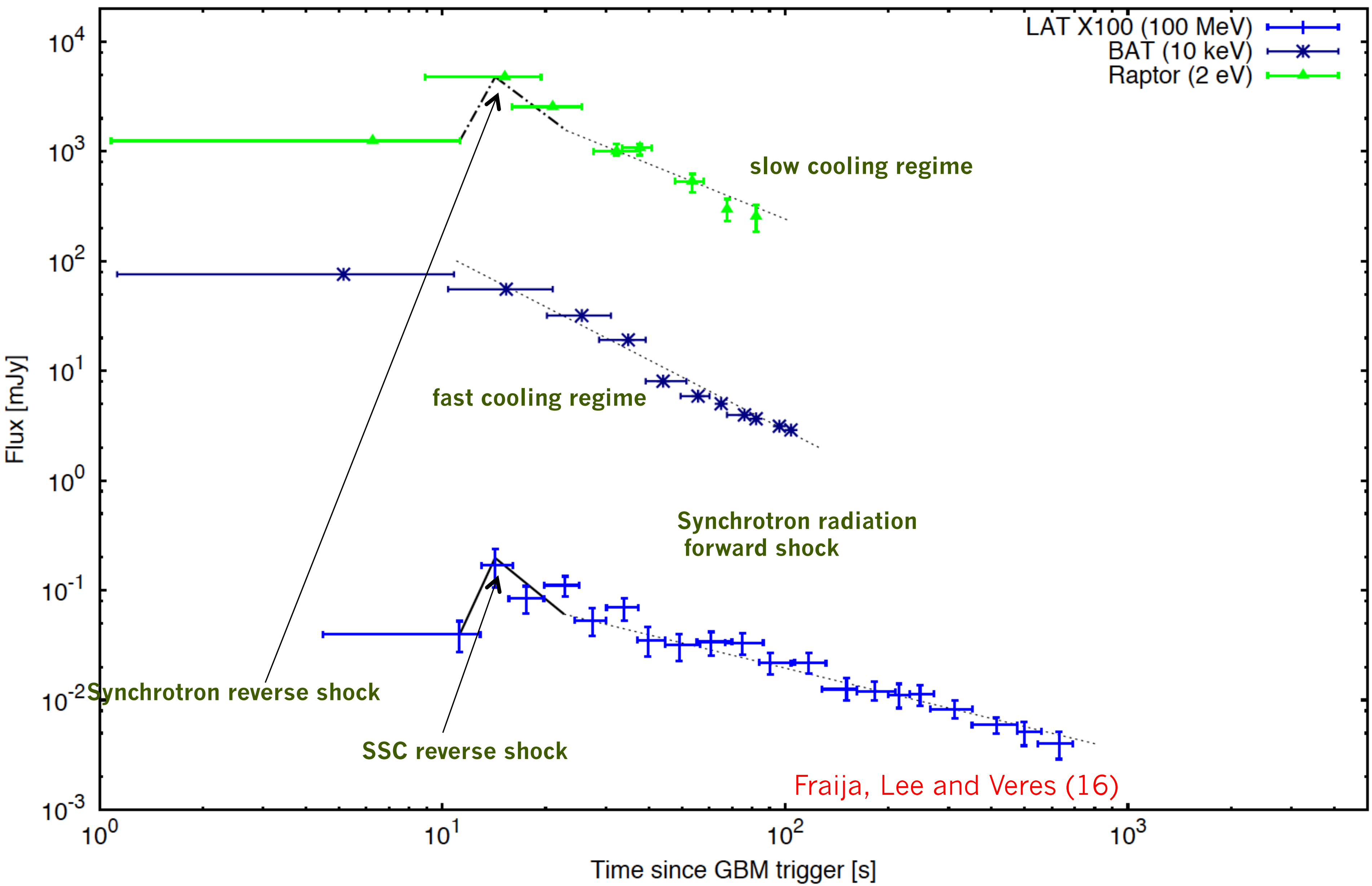
Fits of the multiwavelength LCs of GRB110731A



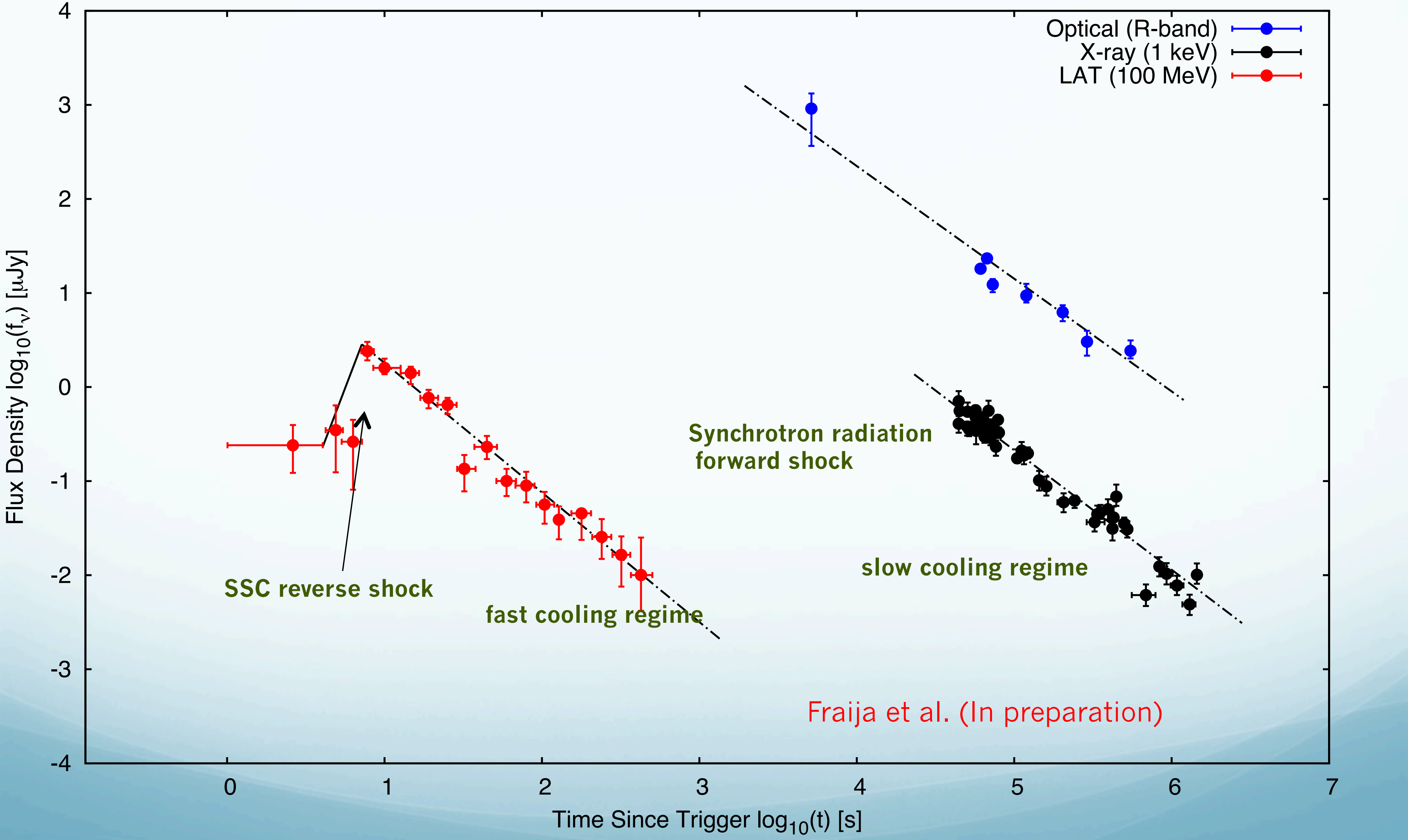
Fits of the multiwavelength LCs of GRB090510



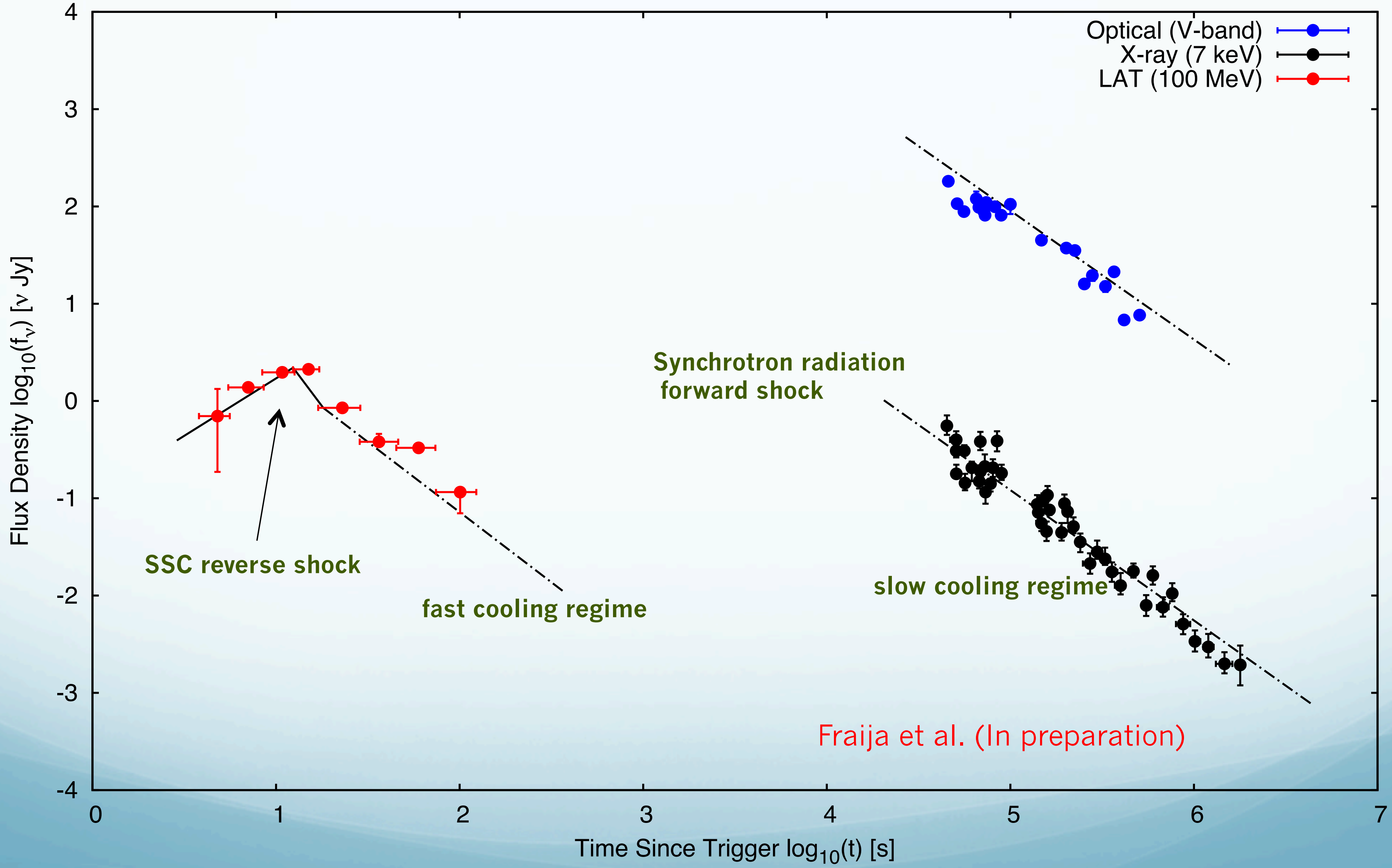
Fits of the multiwavelength LCs of GRB130427A



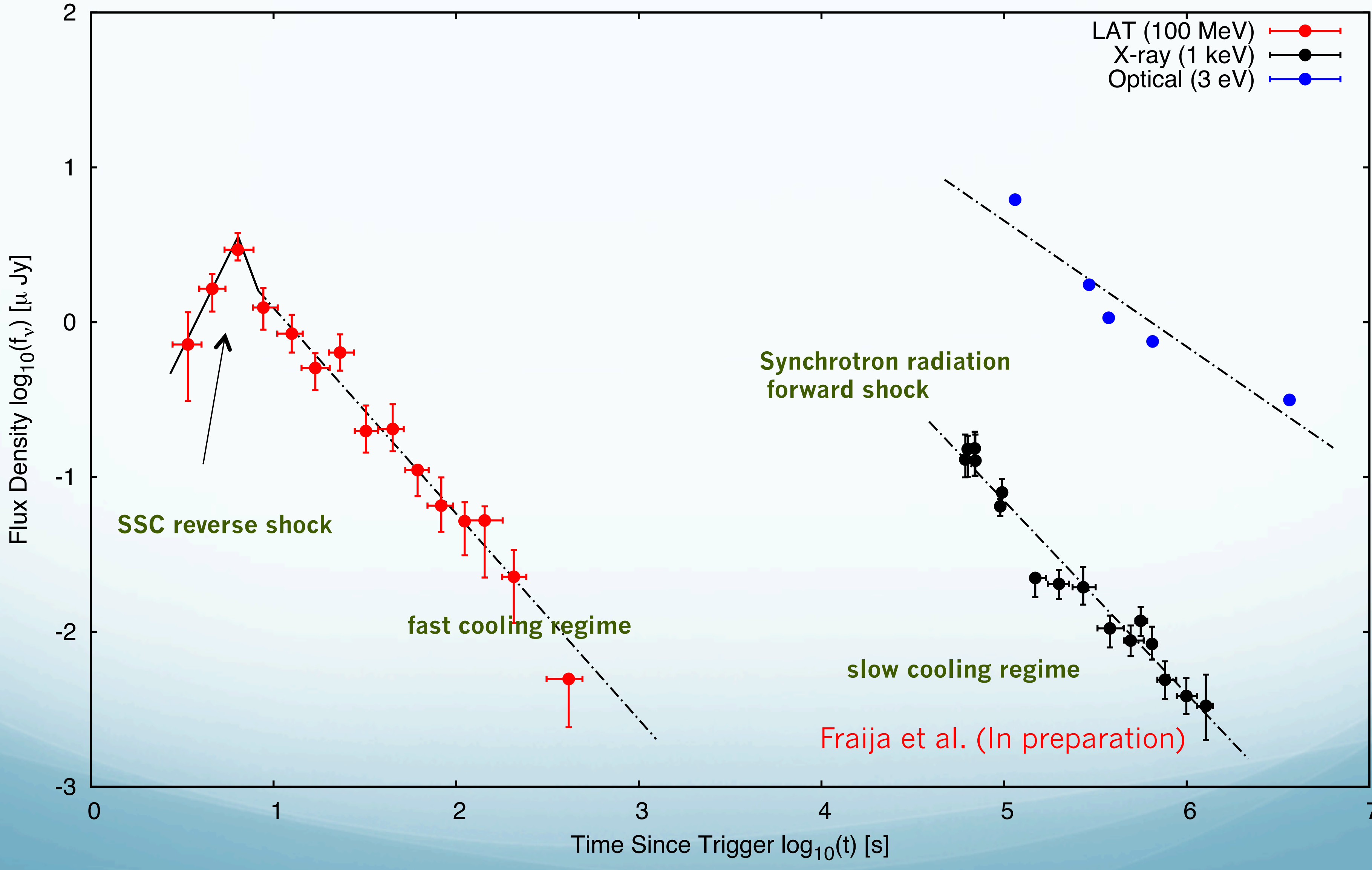
Fits of the multiwavelength LCs of GRB090902B



Fits of the multiwavelength LCs of GRB090926A



Fits of the multiwavelength LCs of GRB080916C



An Absence of Neutrinos Associated with Cosmic Ray Acceleration in Gamma-Ray Bursts

Gamma-Ray Bursts (GRBs) have been proposed as a leading candidate for acceleration of ultra high-energy cosmic rays, which would be accompanied by emission of TeV neutrinos produced in proton-photon interactions during acceleration in the GRB fireball. Two analyses using data from two years of the IceCube detector produced no evidence for this neutrino emission, placing strong constraints on models of neutrino and cosmic-ray production in these sources.

IceCube collaboration
Nature 484 (12) 351-353

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IceCube collaboration
Nature 484 (12) 351-353

TITLE: GCN CIRCULAR
NUMBER: 14520
SUBJECT: GRB 130427A: High-energy neutrino search
DATE: 13/05/01 14:09:45 GMT
FROM: Erik Blaufuss at U. Maryland/IceCube <blaufuss@icecube.umd.edu>

Search for high-energy neutrinos in coincidence with GRB 130427A

The IceCube collaboration (icecube.wisc.edu) reports:

We used the data from IceCube to perform several searches for high-energy neutrinos in spatial and temporal
coincidence with GRB 130427A (A. Maselli et al., GCN 14485). **No neutrinos were found in this search.**

The null result reported by IceCube Collaboration could be explained in the framework of magnetized outflow where neutrino flux is degraded

PRL Zhang and Kumar (13)

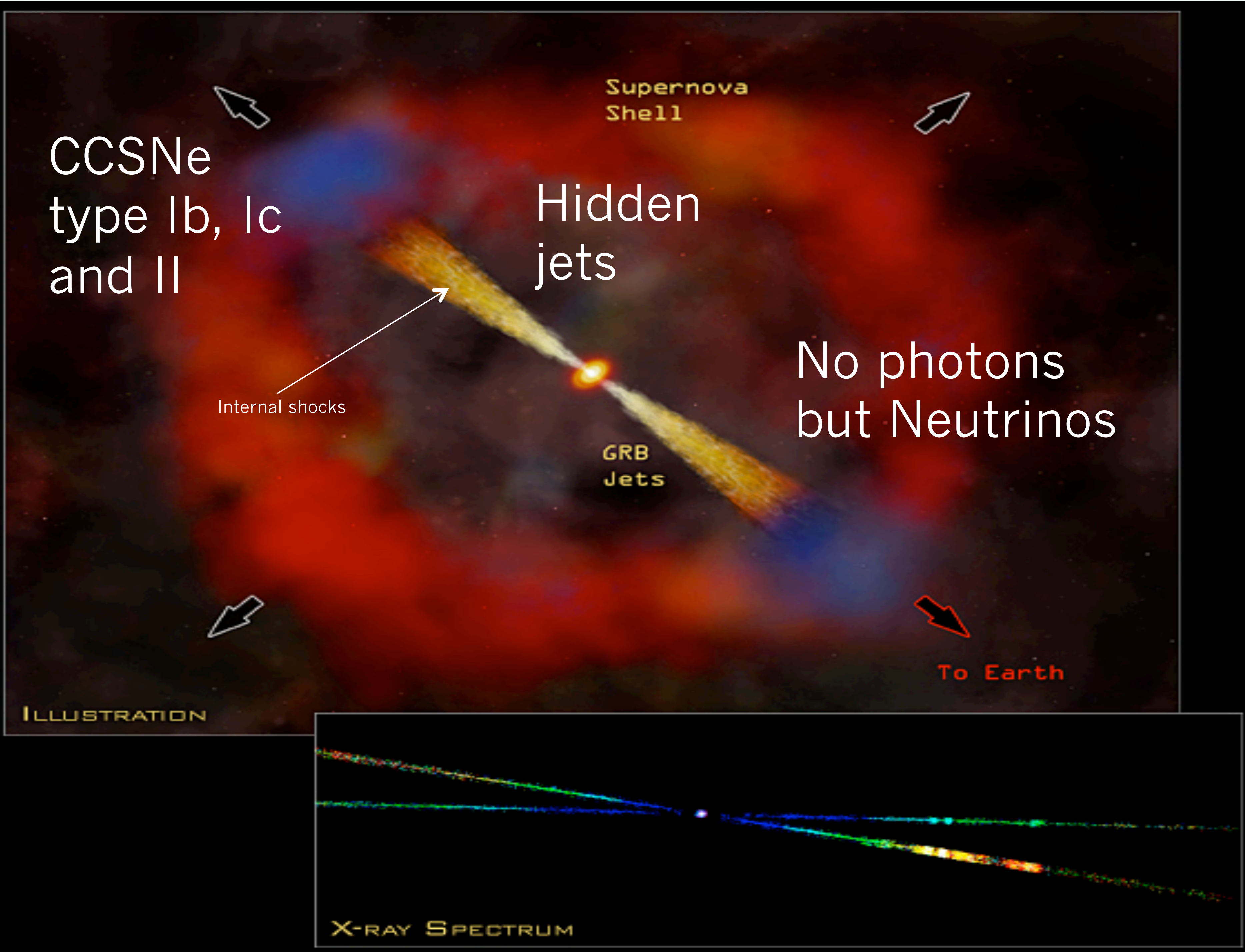
Outline

High-energy neutrinos
(IceCube Observations and correlations with known sources)

Gamma-ray bursts
(Some generalities and modeling the most powerful GRBs)

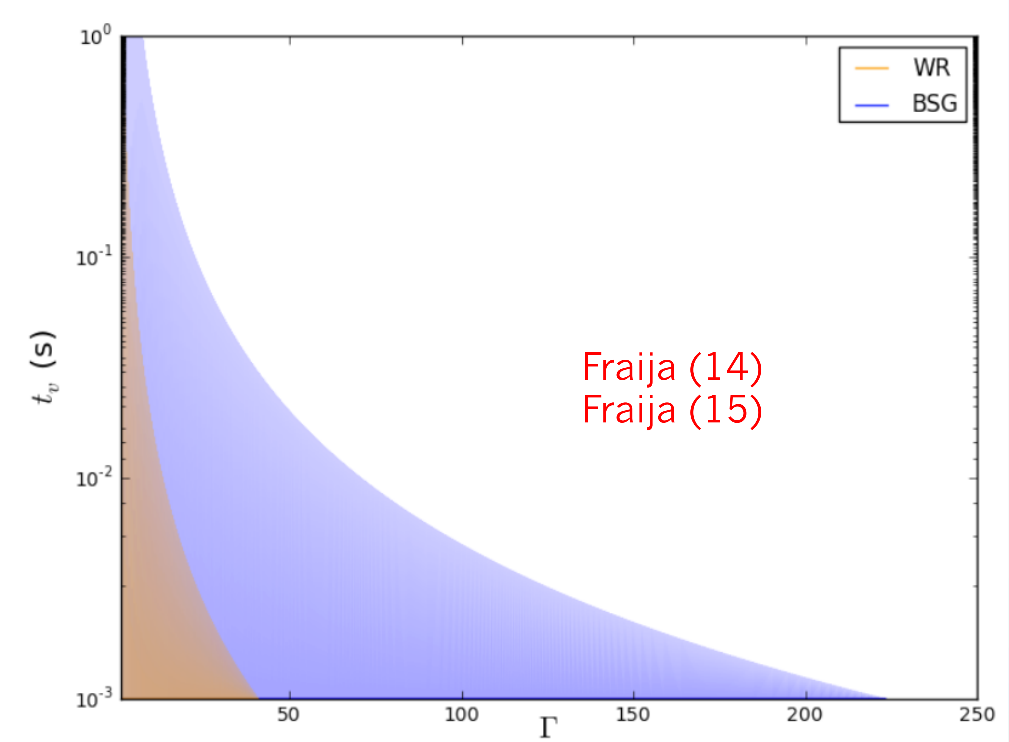
Hidden GRB jets inside progenitor stars
(Possible scenario for high-energy neutrino production)

Conclusions



CCSNe
type Ib, Ic
and II
Hidden
jets
No photons
but Neutrinos
Supernova
Shell
Internal shocks
GRB
Jets
To Earth
Illustration
X-ray Spectrum

Conditions of Internal shocks inside the star

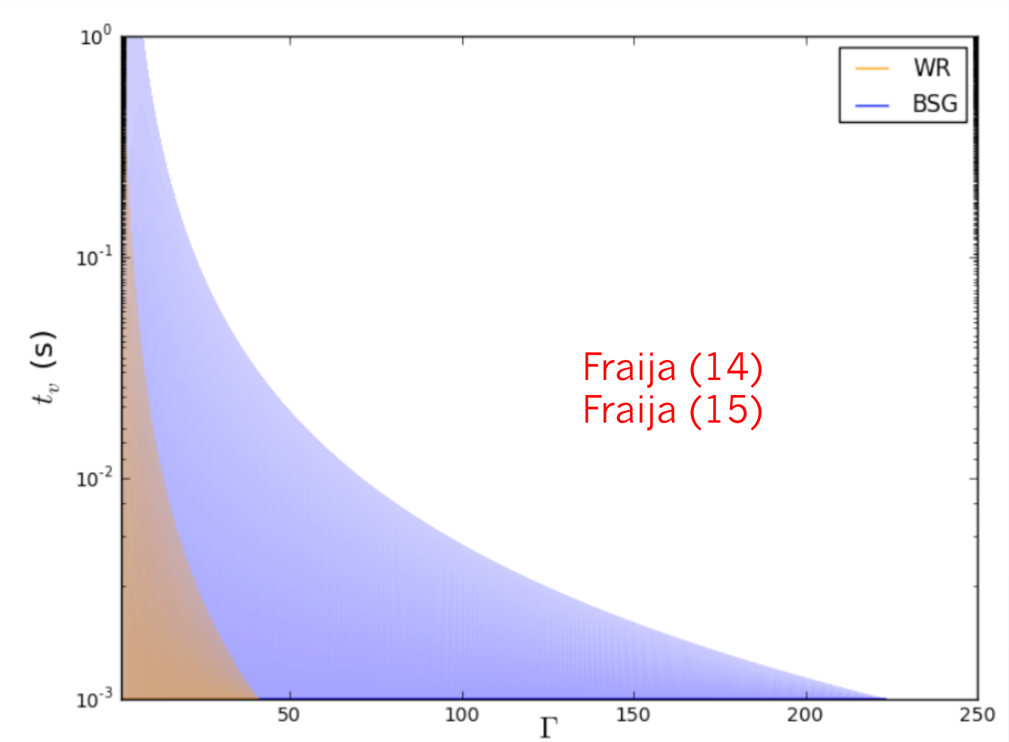


$$r_j = 2\Gamma^2 t_\nu < R_\star$$

$$R_{WR} \simeq 10^{11}\,\mathrm{cm}$$

$$R_{BSG} \simeq 3 \times 10^{12}\,\mathrm{cm}$$

Conditions of Internal shocks inside the star



$$r_j = 2\Gamma^2 t_\nu < R_\star$$

$$R_{WR} \simeq 10^{11}\,\mathrm{cm}$$
$$R_{BSG} \simeq 3 \times 10^{12}\,\mathrm{cm}$$

Radiation mediated shocks → Do not allow that CR can be accelerated up to UHE

$$\tau \sim n_p \sigma_T r \lesssim \min[\Gamma_{rel}^2, 0.1C^{-1}\Gamma_{rel}^3]$$

Murase & Ioka (13) Bromberg et al. (11)
Mizuta & Ioka (13)

CR are expected → $\tau \sim 1 - 10$

Hadronic Processes

Interaction

proton- proton

$$\mathrm{p} + \mathrm{p} \longrightarrow \mathrm{p}+\mathrm{p} + \pi^0$$
$$\mathrm{p} + \mathrm{n} \longrightarrow \mathrm{p}+\mathrm{n} + \pi^0$$

proton – photon

$$\mathrm{p} + \gamma \longrightarrow \Delta^+ \longrightarrow \pi^0 + \mathrm{p}$$

$$\pi^0 \longrightarrow \gamma + \gamma$$

$$p + p \rightarrow p + \pi^+$$
$$p + \gamma \rightarrow p + \pi^+ + \pi^-$$
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

Fraija (14,16)

Hadronic Processes

Interaction

proton- proton

proton – photon

$$p + p \longrightarrow p + p + \pi^0$$
$$p + n \longrightarrow p + n + \pi^0$$
$$p + \gamma \longrightarrow \Delta^+ \longrightarrow \pi^0 + p$$

$$\longrightarrow \quad \pi^0 \longrightarrow \gamma + \gamma$$

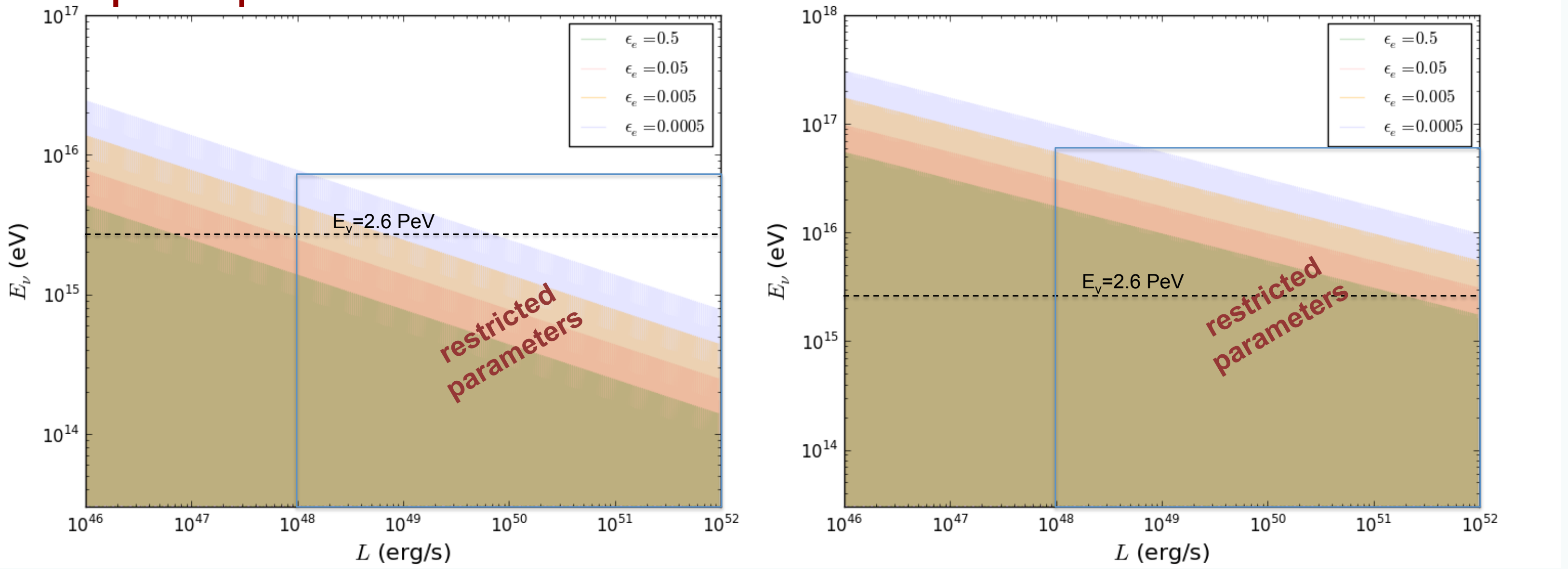
$$p + p \to p + \pi^+$$
$$p + \gamma \to p + \pi^+ + \pi^-$$
$$\pi^+ \to \mu^+ + \nu_\mu$$
$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$$

Fraija (14,16)

Quantities for the neutrino production

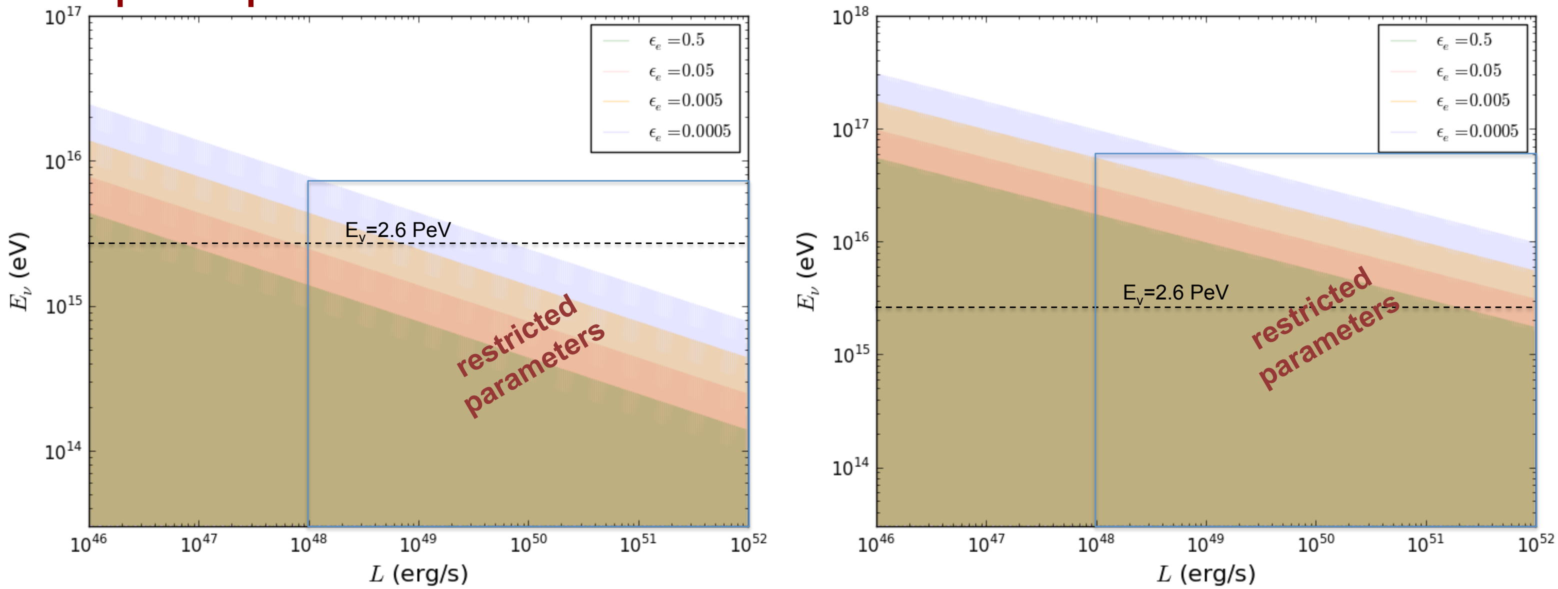
$$n_\gamma = F(\Gamma, t_v, L, \epsilon_e, \epsilon_B)$$
$$n_p = F(\Gamma, t_v, L, \epsilon_e, \epsilon_B)$$
$$E_\nu = F(\Gamma, t_v, L, \epsilon_e, \epsilon_B)$$

proton-photon interactions



Fraija (14,16)

proton-photon interactions

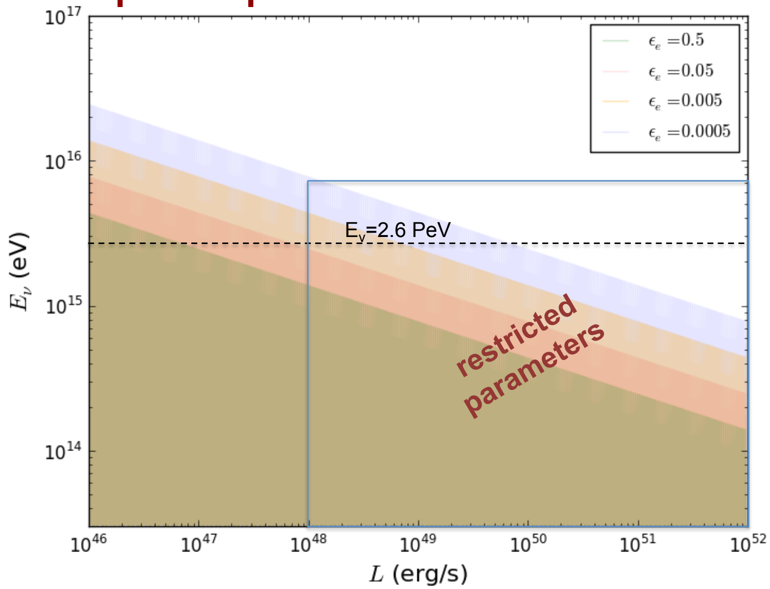


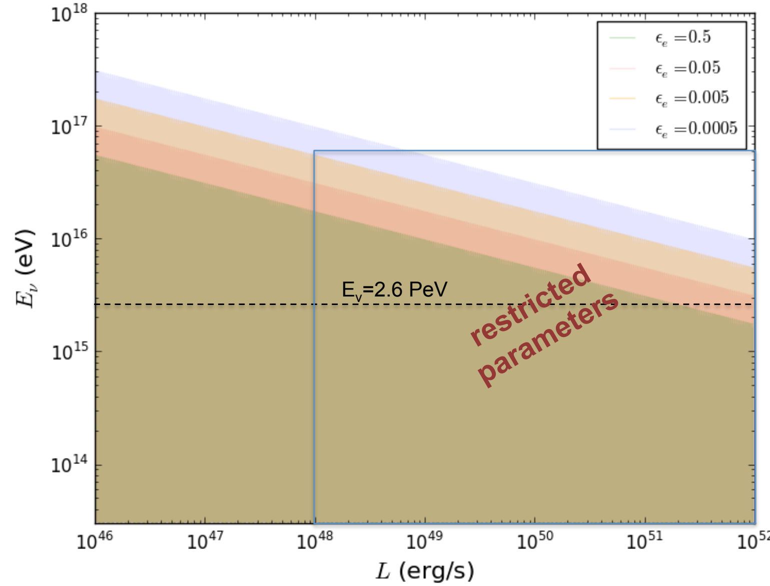
restricted parameters

$$\tau \simeq \begin{cases} 5.1 L_{j,48} r_{j,10.8}\, \Gamma_{1.21}^{-1} \text{ for WR} \\ 3.2 L_{j,48}\, r_{j,12.2}\, \Gamma_{2.32}^{-1} \text{ for BSG} \end{cases} \lesssim \min[\Gamma_{rel,1}^{2}, C^{-1}\Gamma_{rel,1}^{3}]$$

Fraija (14,16)

proton-photon interactions



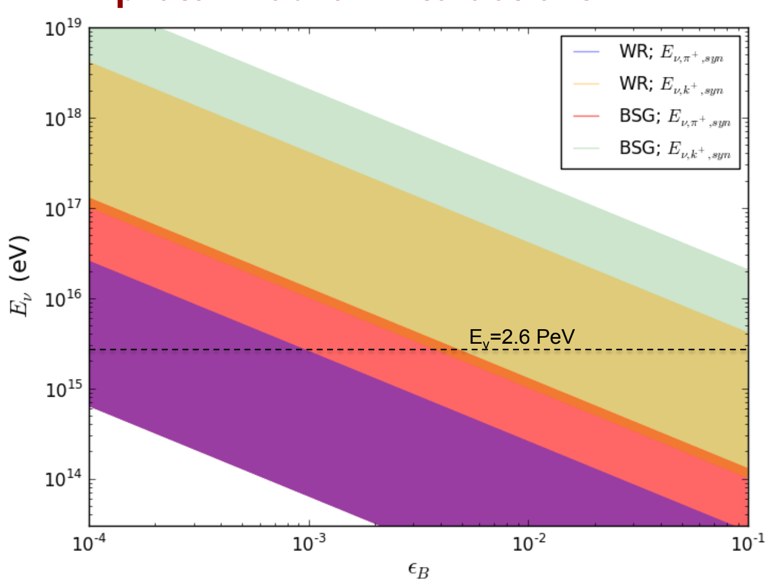


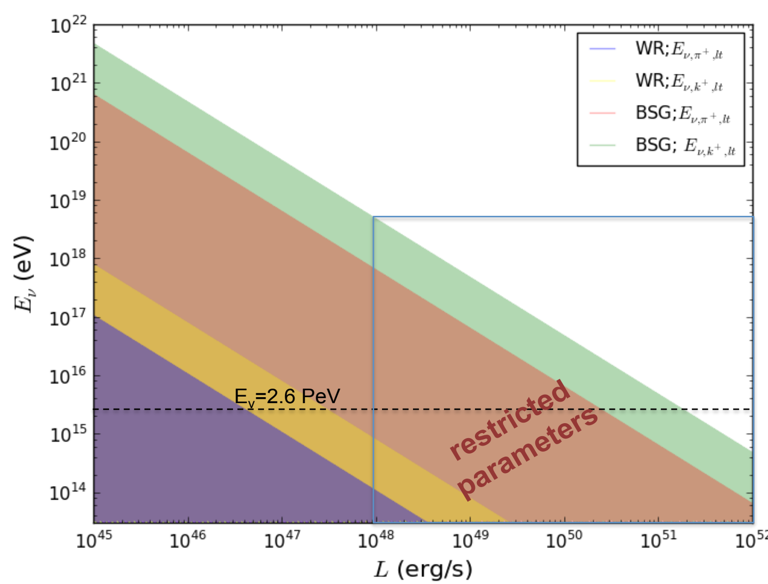
restricted parameters

$$\tau \simeq \begin{cases} 5.1 L_{j,48} r_{j,10.8}\, \Gamma^{-1}_{1.21} \text{ for WR} \\ 3.2 L_{j,48}\, r_{j,12.2}\, \Gamma^{-1}_{2.32} \text{ for BSG} \end{cases} \lesssim \min[\Gamma^2_{rel,1}\,, C^{-1}\Gamma^3_{rel,1}]$$

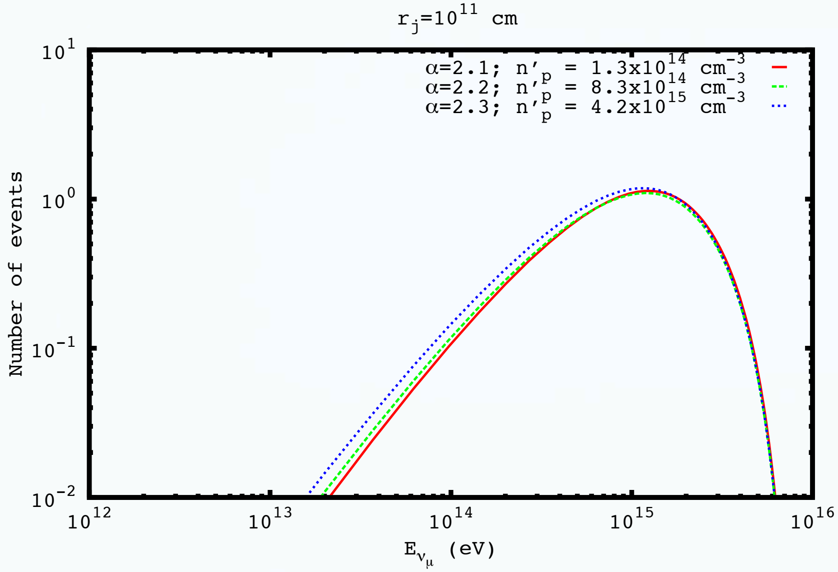
Fraija (14,16)

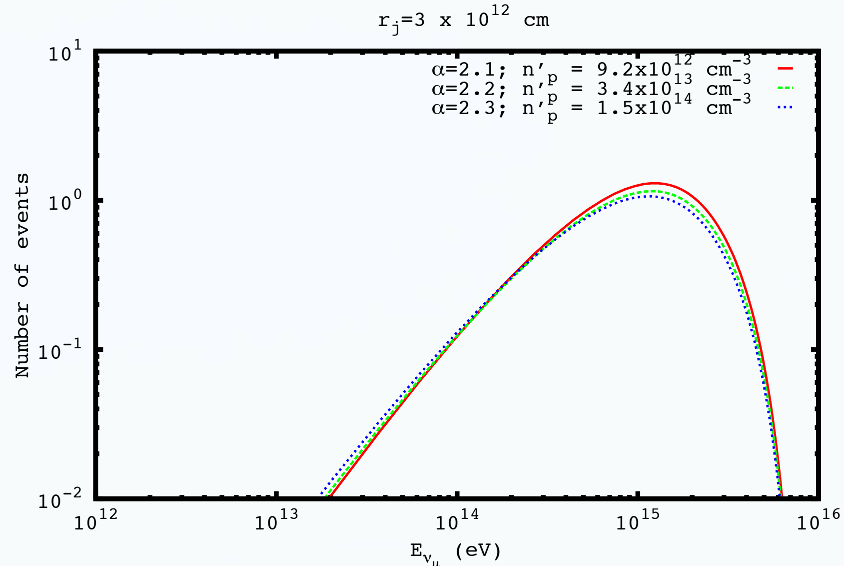
proton-hadron interactions





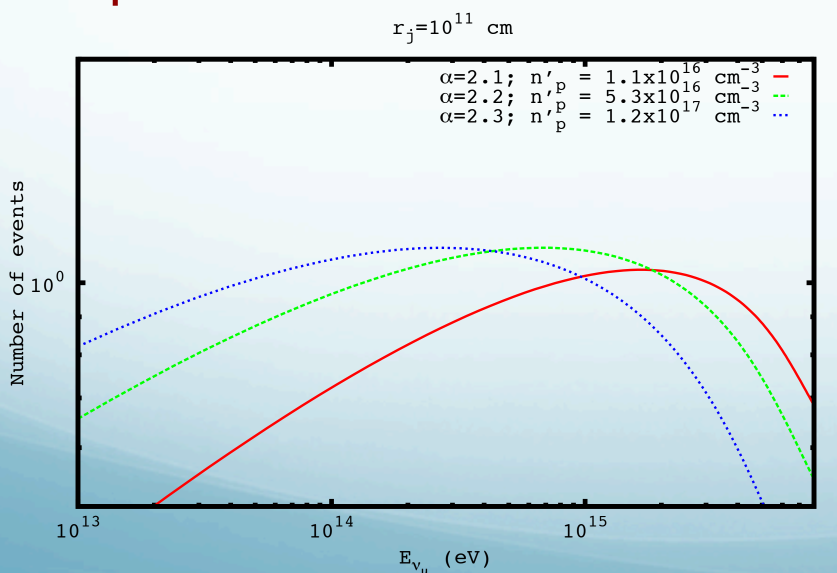
proton-photon interactions

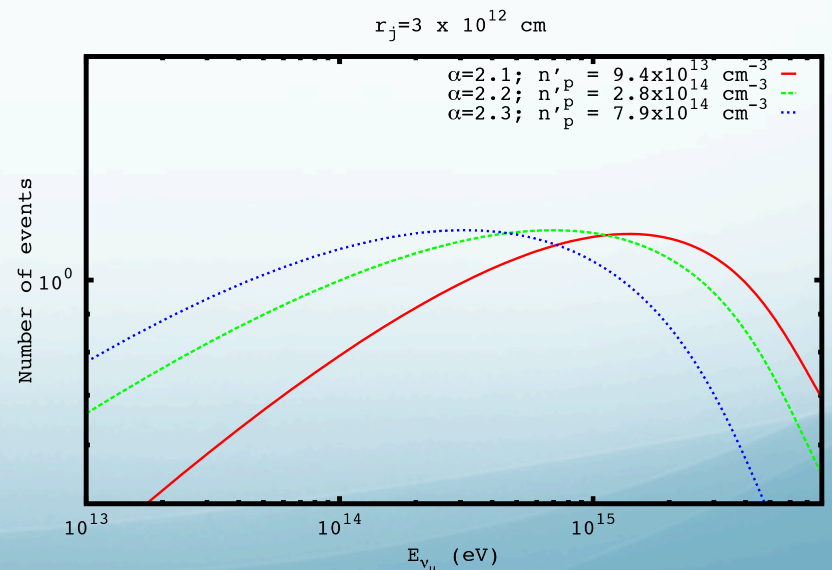




Fraija (16)

proton-hadron interactions





Outline

High-energy neutrinos
(IceCube Observations and correlations with known sources)

Gamma-ray bursts
(Some generalities and modeling the most powerful GRBs)

Hidden GRB jets inside progenitor stars
(Possible scenario for high-energy neutrino production)

Conclusions

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In the early afterglow framework, the short HE emission that falls in the MeV regimen and in coincidence with the prompt phase could be interpreted as SSC - RS and the temporally extended GeV emission can be described as synchrotron - FS. In the most powerful GRBs, the strength of the **B** in the RS is 50 – 200 times stronger than FS. The central engine is entrained with strong **B**. The stength of magnetic field is related with the decrease of neutrinos.

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The high-energy neutrino detected could be generated by proton-photon and proton-hadron interactions in internal shocks inside GRB progenitor star. lGRBs with values of luminosity $L < 10^{48}\, erg/s$ and equipartition parameters $10^{-4} < \epsilon_B < 10^{-1}$ and $\epsilon_e > 0.05$ favor the HE neutrino production in progenitors such as Wolf-Rayet and blue super giant stars