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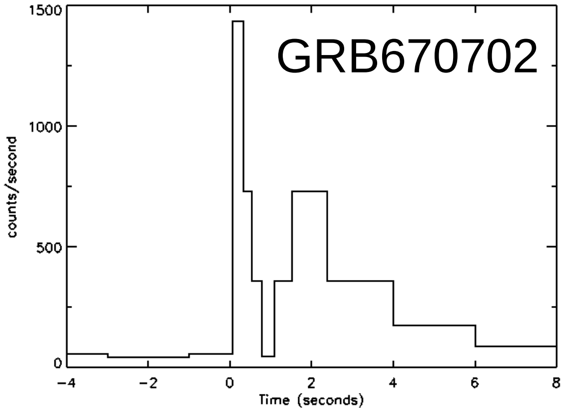
GW counterparts with Fermi and Integral: the case of GRB170817A

DFA
25/10/2017

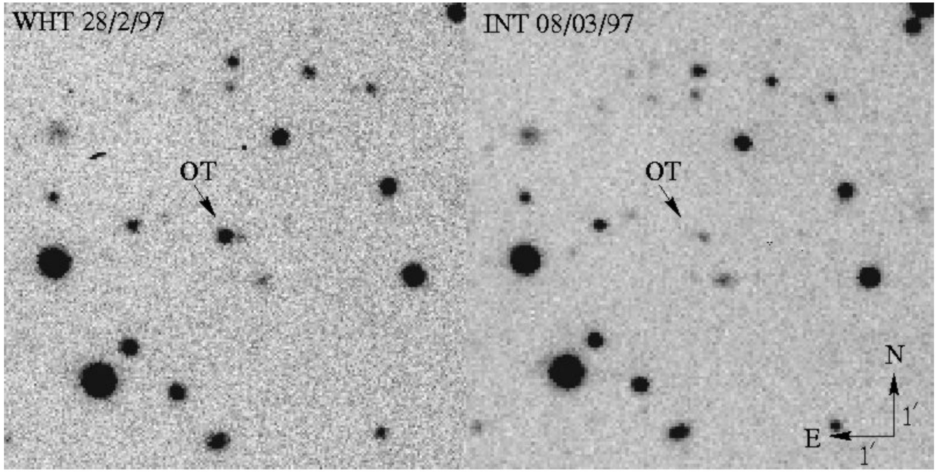
CREDITS!
Most of what I am showing for GRB170817A:
E. Burns (Fermi-GBM),
N. Omodei (Fermi-LAT),
V. Savchenko (INTEGRAL)
@ 2017 Fermi Symposium last week

Introduction to GRBs

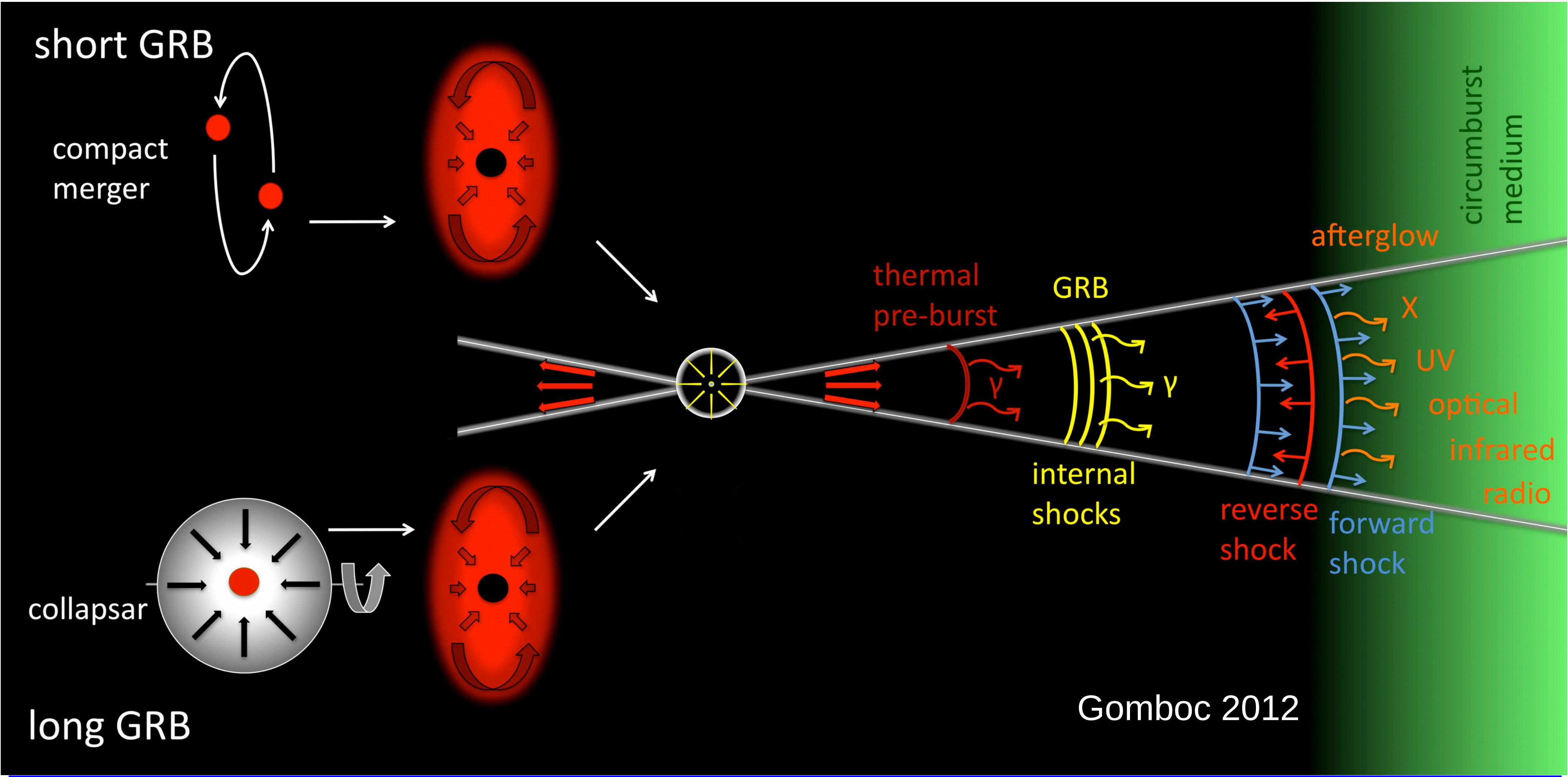
- Gamma ray flashes from space
- Observed since the 60's
- Isotropic distribution: extragalactic
- Exceedingly energetic: beamed emission
- High energy: optically thin
- Long-duration afterglow, from X to radio
- Studied in detail in the 90's (BATSE on CGRO, Beppo-SAX)
  - ➔ long & short



GRB970228
z=0.695



GRB: the standard model



GRB:

- 12 NaI scintillators (8 keV – 1 MeV)
- 2 BGO scintillators (200 keV – 30 MeV)
- Cover all non-occulted sky

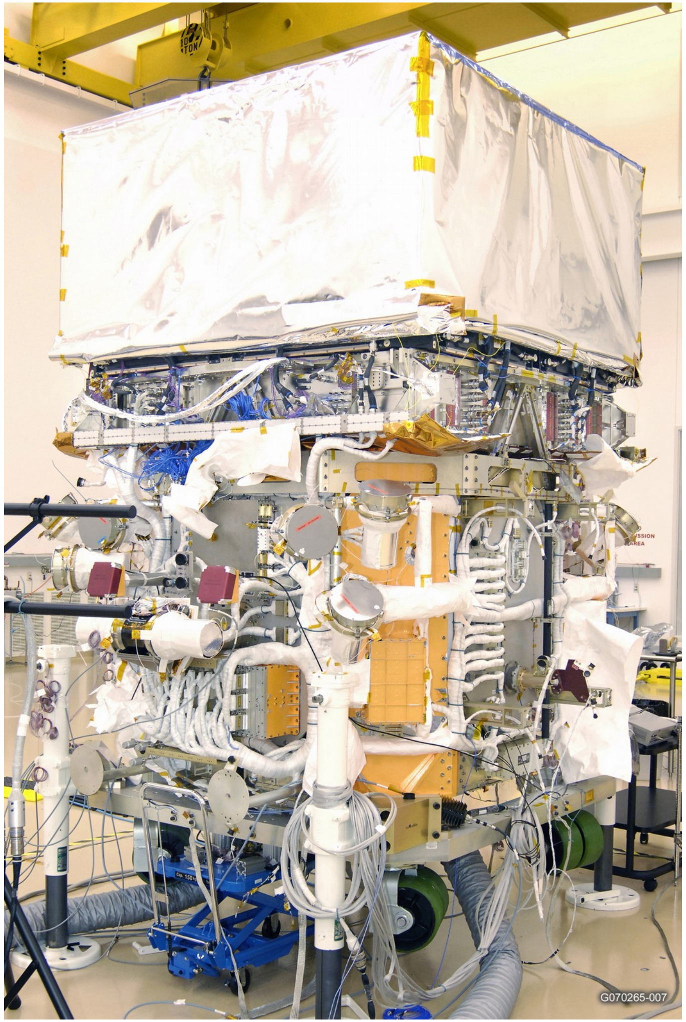
LAT

- Pair-conversion tracker + CsI calorimeter
- >40 MeV – ~2 TeV
- ~ 2.5 sr FOV

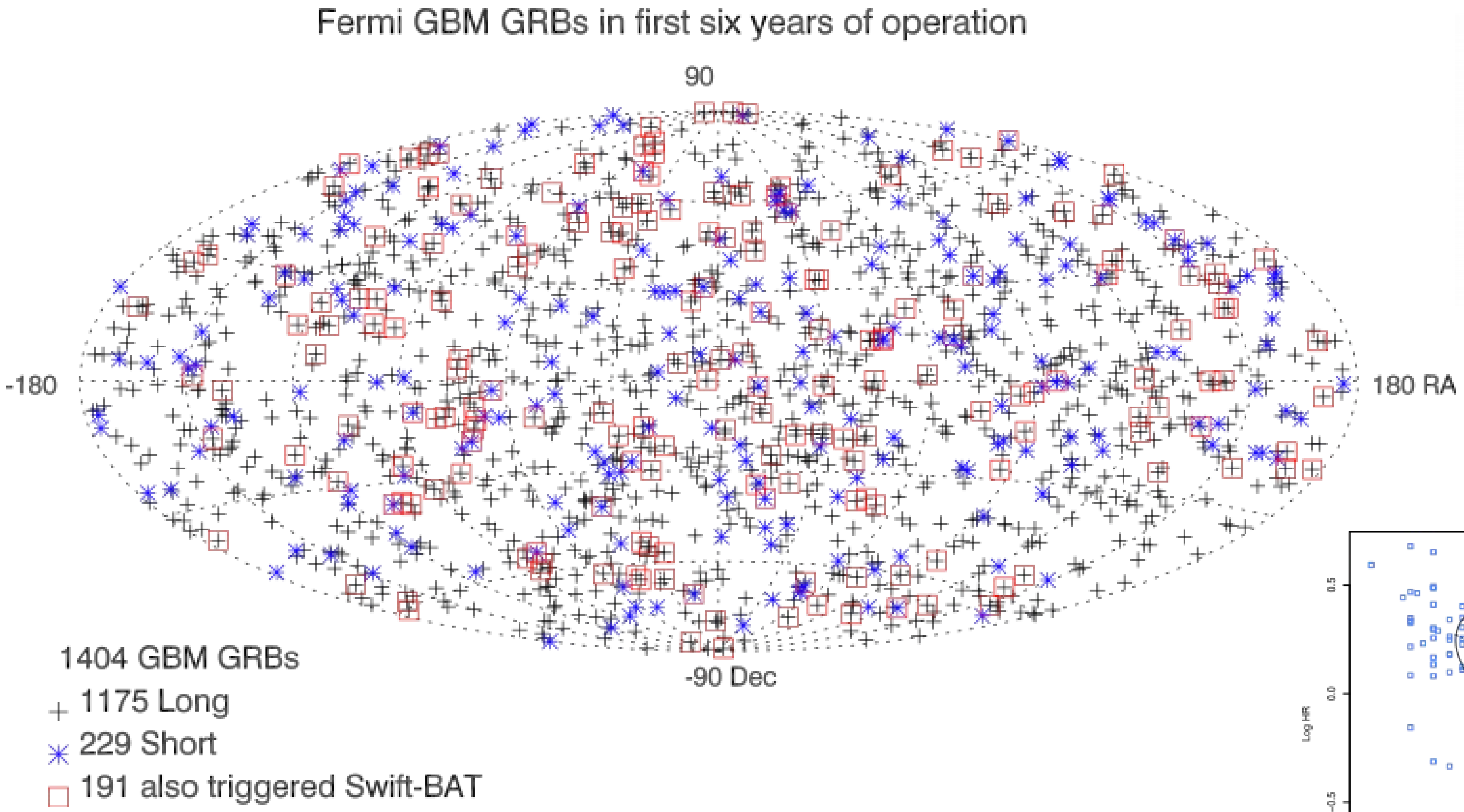
Almost overlapping energy range

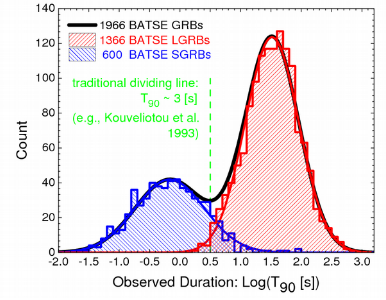
Transients:

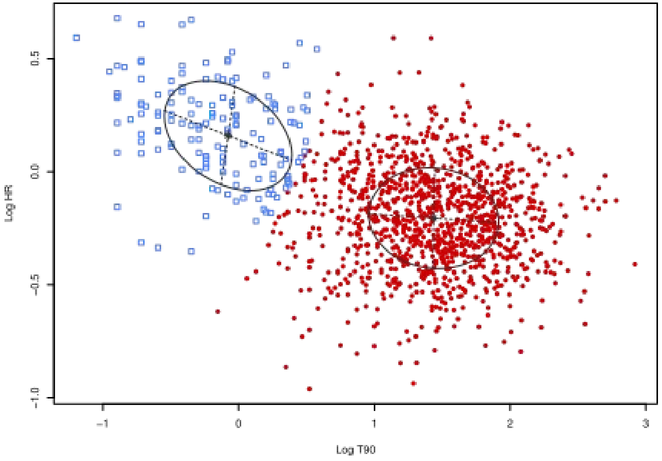
- GBM can issue notices and request re-points
- >120 re-points to observe transients with LAT

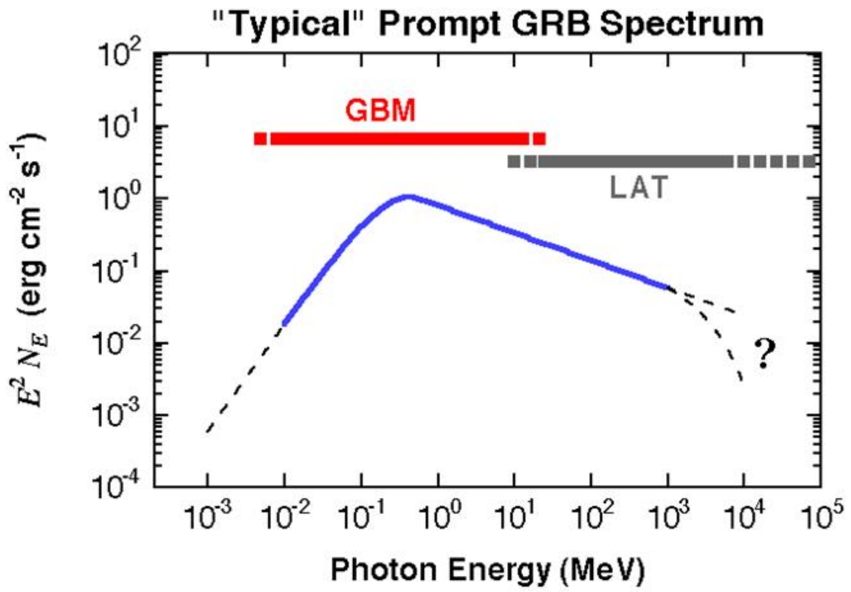


GRBs: FERMI GBM

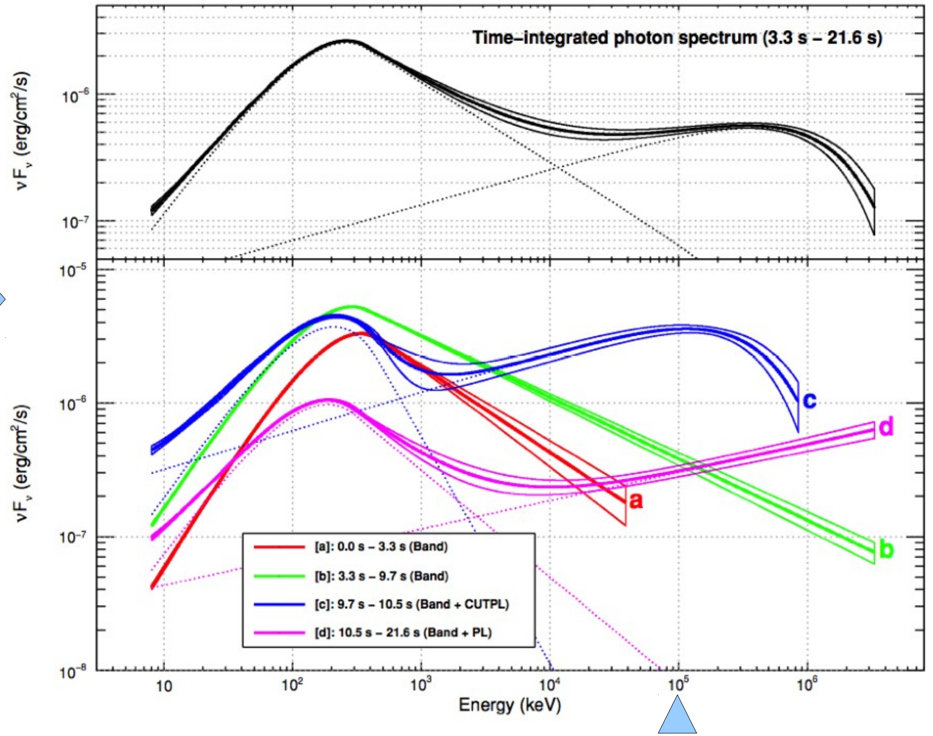




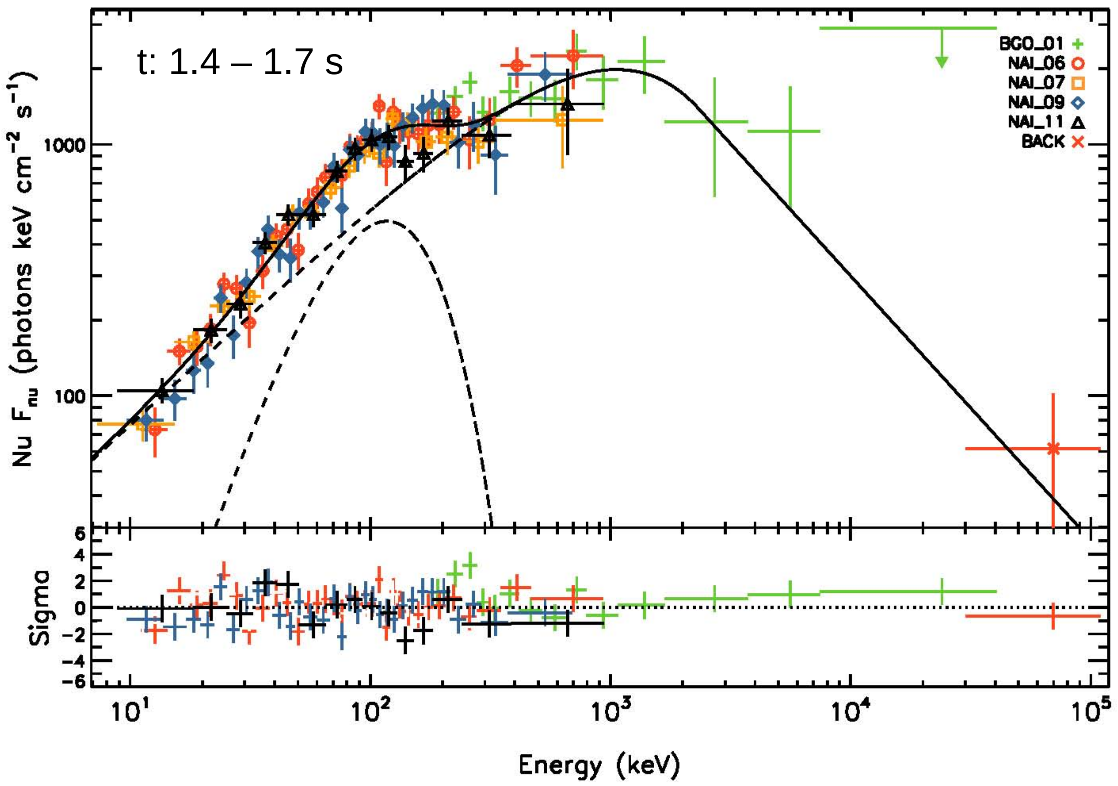




Before FERMI: Band spectrum
2 smoothly joined power-laws
Uncertainty above 100 MeV: cutoff?



GRB090926A: additional spectral components
Significant spectral evolution in time



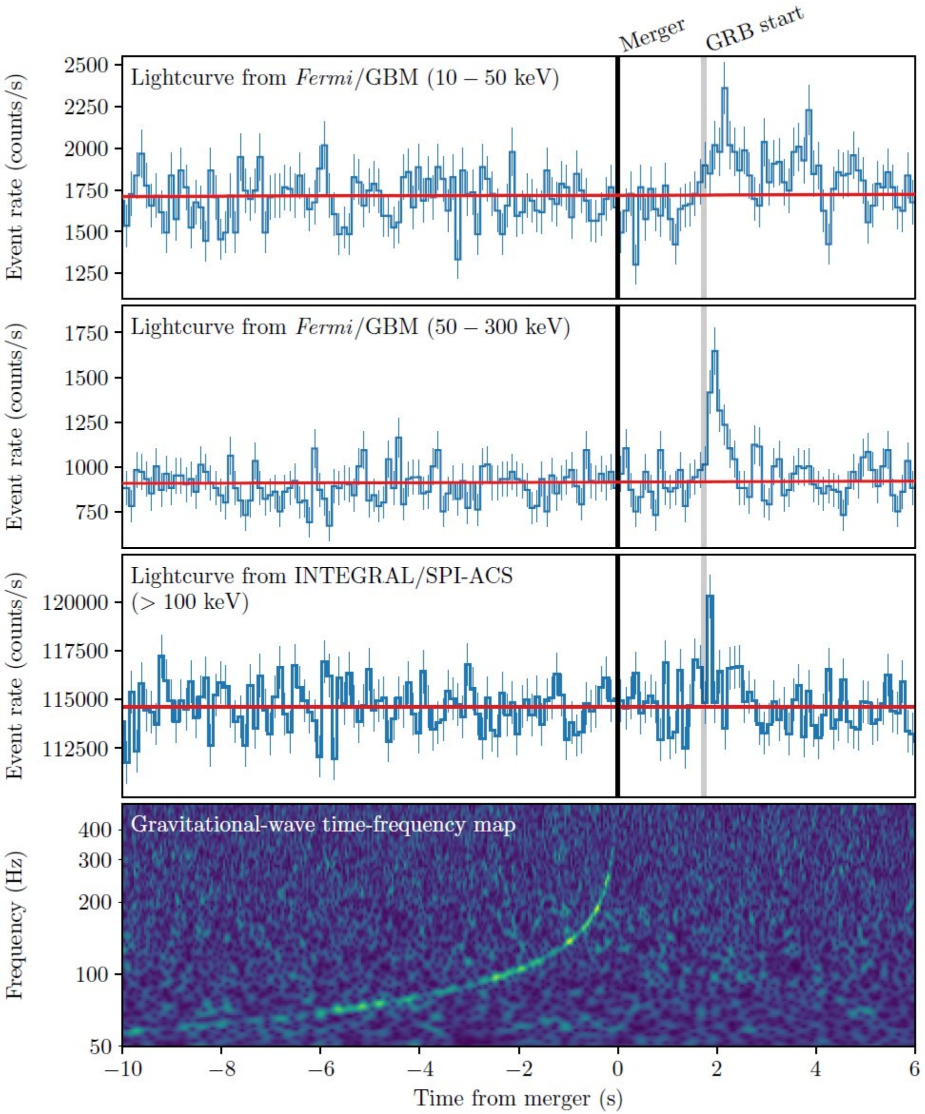
GRB110721A (Axelsson et al.):
Extreme initial peak energy: 15 MeV
Additional thermal component
Signature of the photosphere?

See also :
GRB100724B
(Guriec et al.)

GRB090820
(Burgess et al.)

Finally:
GRB170817A

(1.74 ± 0.05) s delay

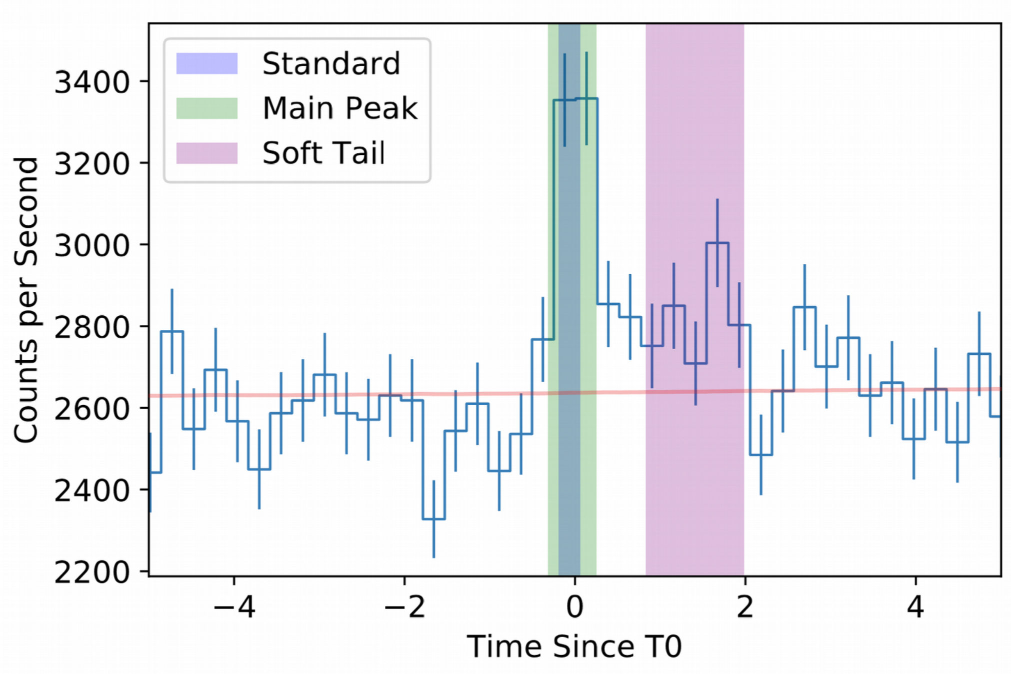


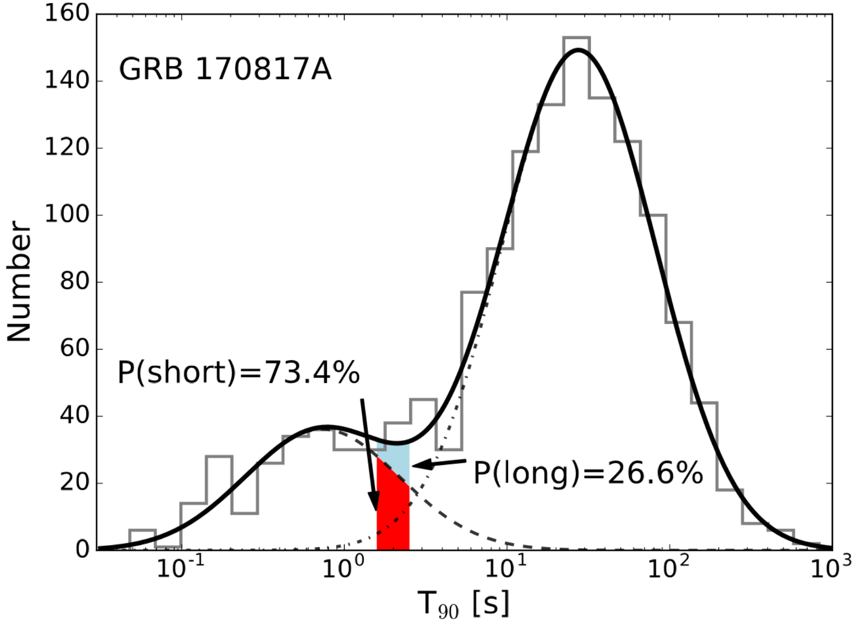
GRB17017A

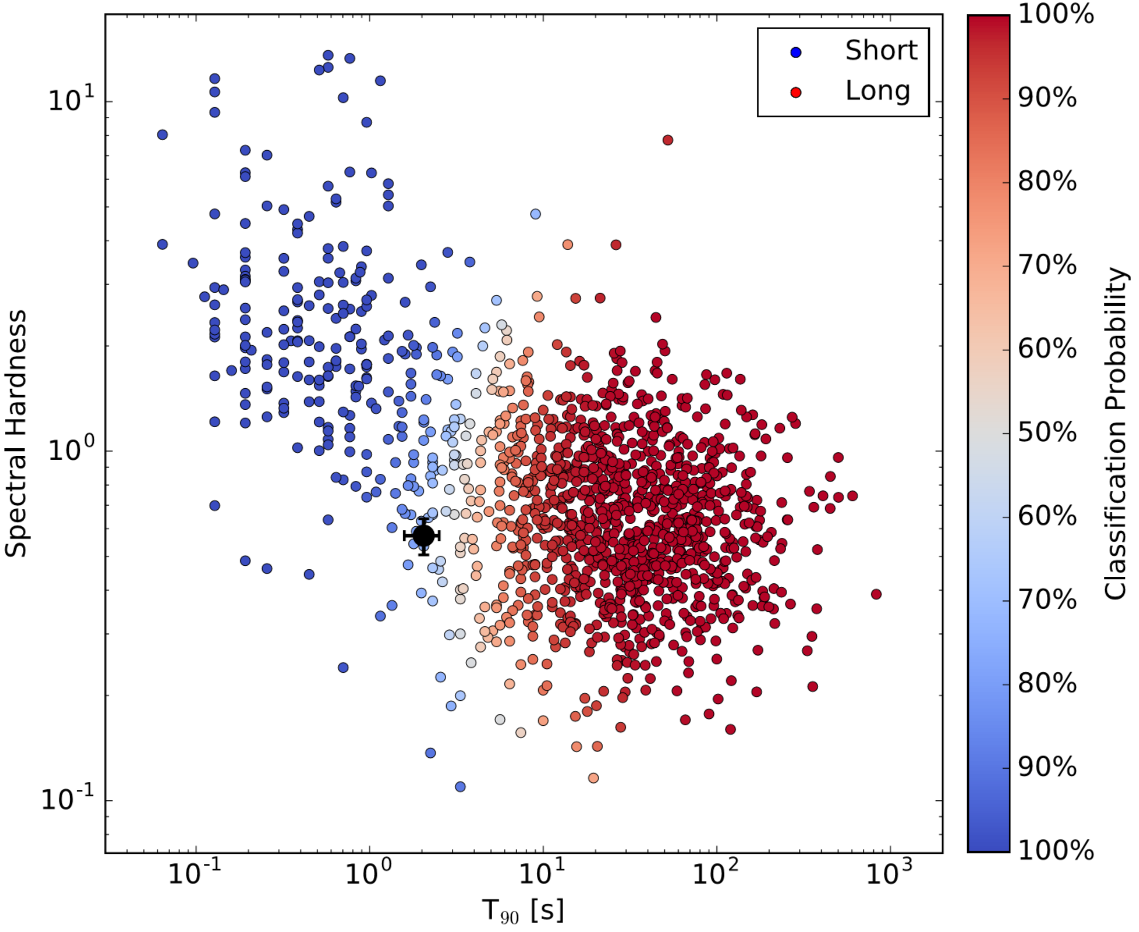
Triggered the GBM in <1 s
Alert issued: 14 s
Auto localization and classification ~25 s
Estimated significance > 8sigma
Public circular: ~ a few hours

- Main Peak (~0.5 s)
  - E_{peak} = (185 ± 62) keV
  - (3.1±0.7)x10^{-7} erg s^{-1} cm^{-2}
  - (1.8±0.4)x10^{-7} erg cm^{-2}

- Soft Tail (~ s)
  - k_BT = (10.3±1.5) keV
  - $(0.5±0.1)^{-7}$ erg s^{-1} cm^{-2}
  - $(0.6±0.1)^{-7}$ erg s^{-1}

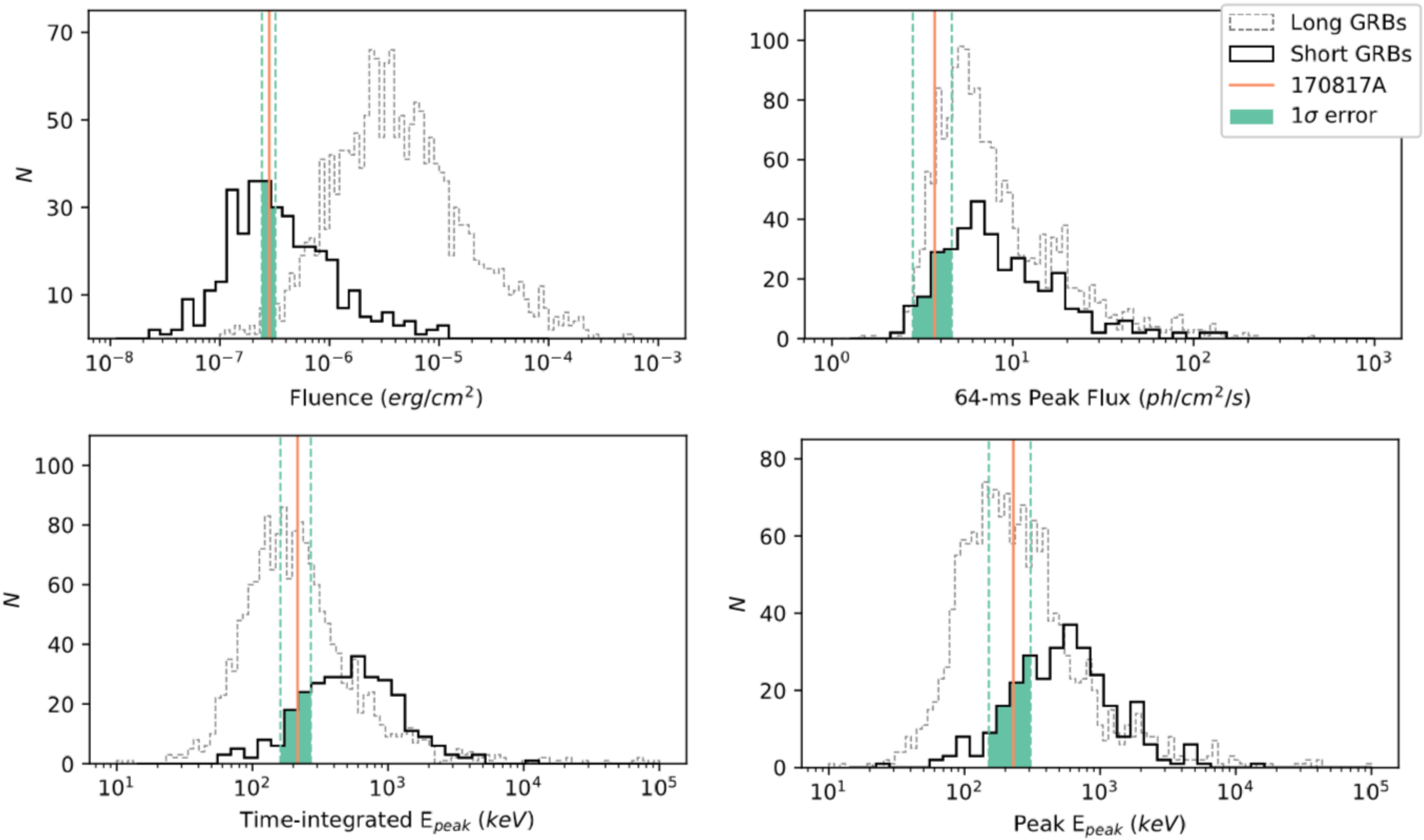




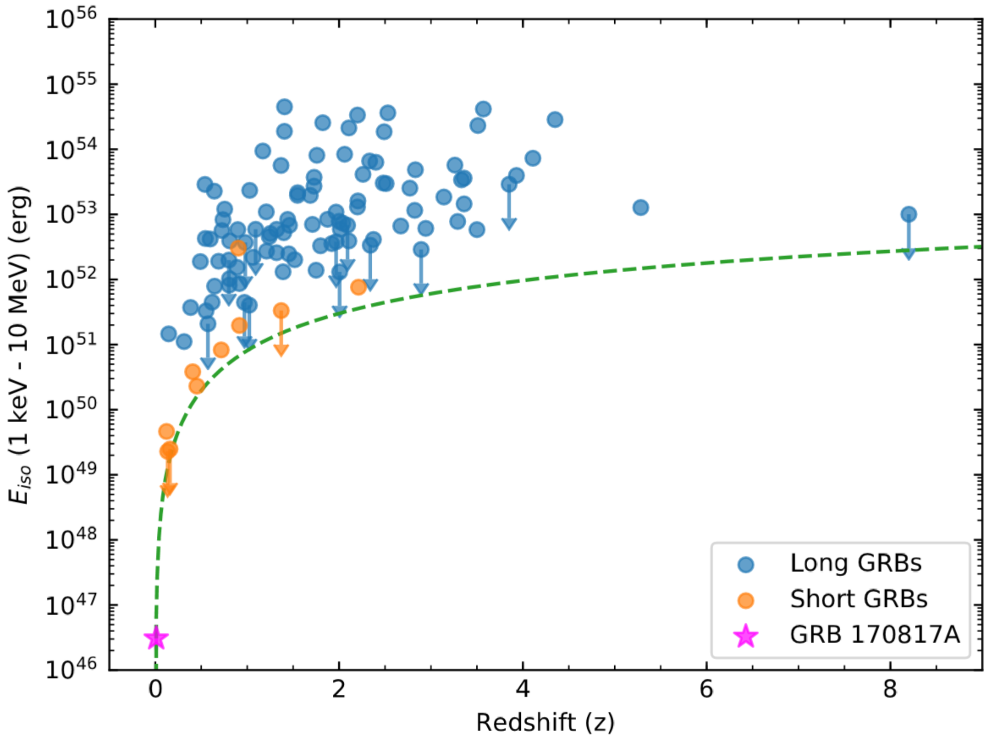


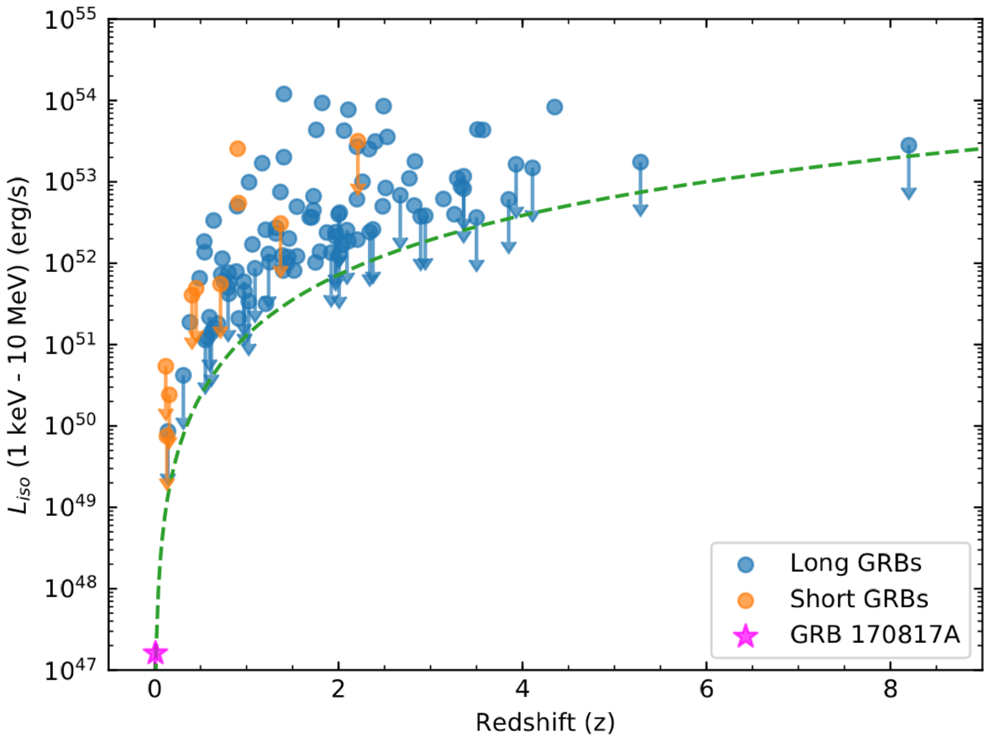
~3 times more likely to be a short GRB
(this even without excluding the soft tail!)

A fairly standard short GRB (no z info here)



Account for z: exceedingly dim





GRB170716A is 2 to 6 orders of magnitude less energetic than previously known SGRBs with firm redshifts

Why so dim?

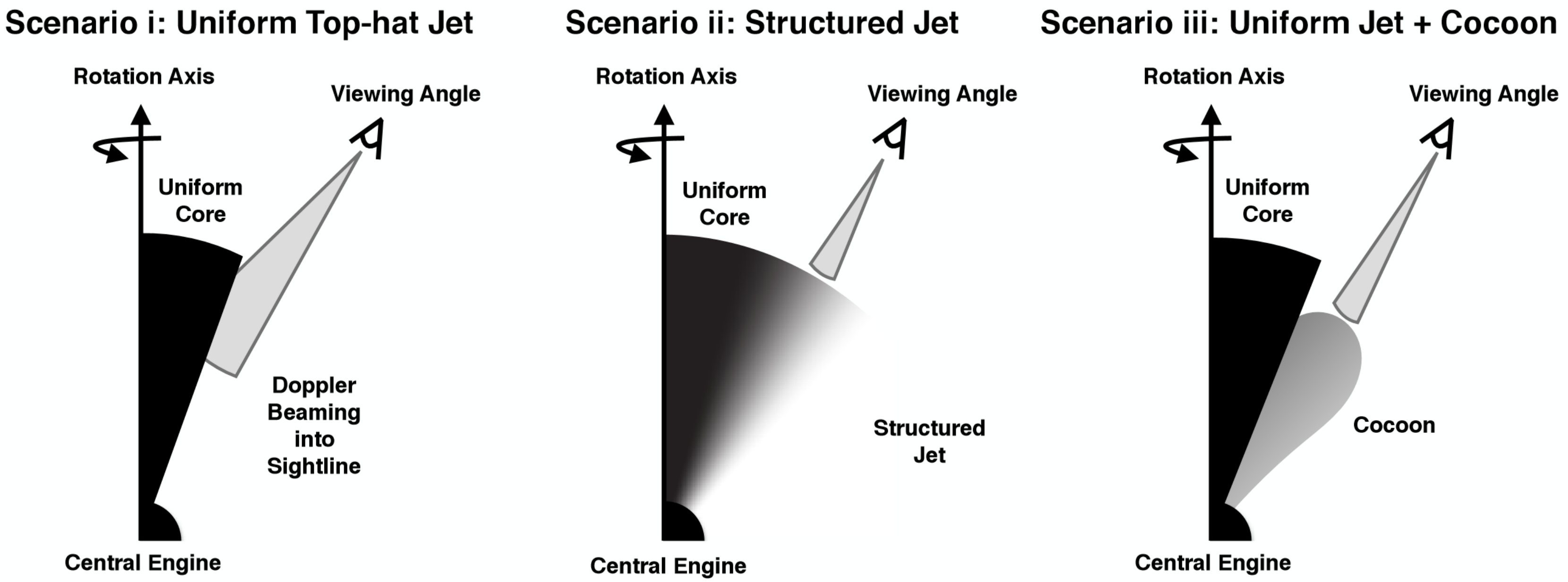


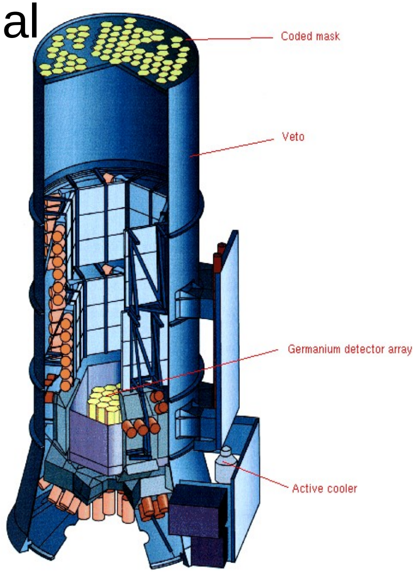
Figure 5. The three potential jet viewing geometries and jet profiles that could explain the observed properties of GRB 170817A, as described by scenarios (i)–(iii) in Section 6.2.

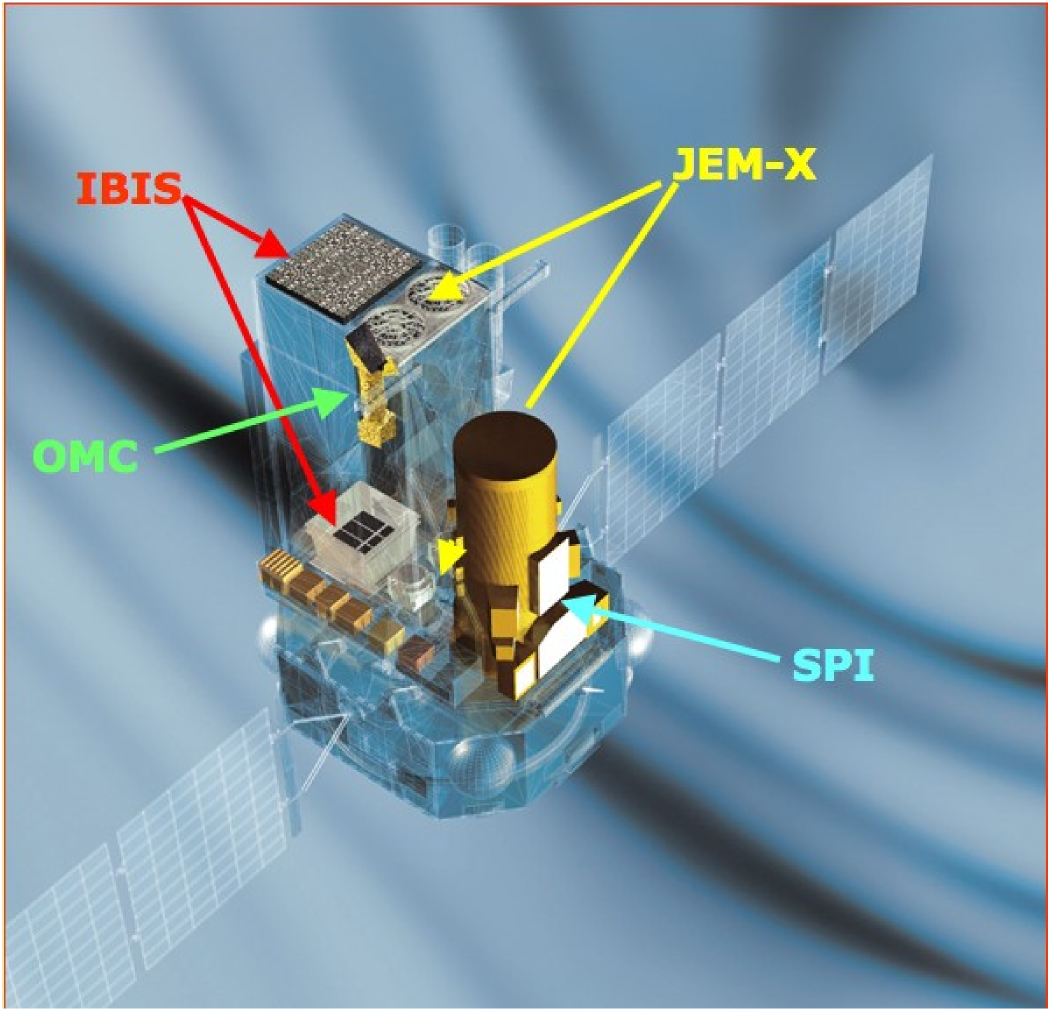
Broad-band modeling appears to suggest an off-axis observation. Also see Covino et al. 2017 suggesting a low inclination angle due to a low degree of polarization

4 instruments:

- SPI (20 keV – 8 MeV)
- IBIS (15 keV – 10 MeV)
- JEM-X (3 – 35 keV)
- OMC (optical V band)

The SPI ACS is also used as an omni-directional detector above ~75 keV

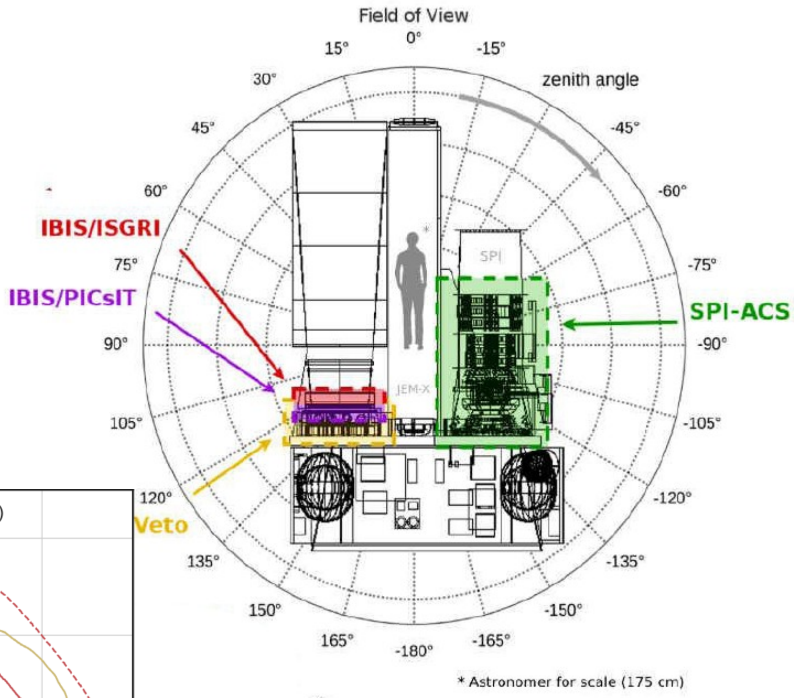


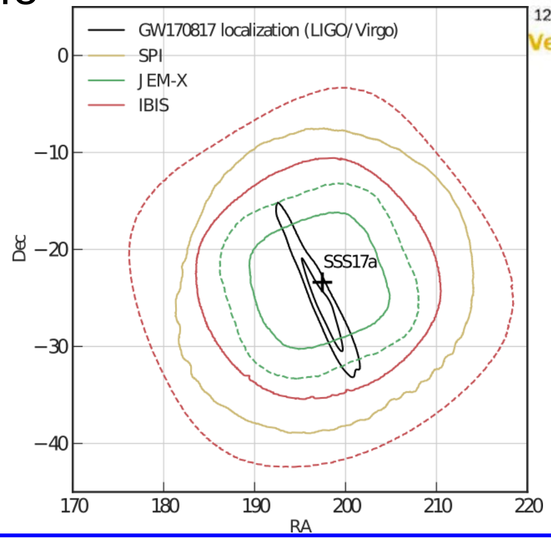


INTEGRAL: GRB170817A

IBIS: zero response at ~30° from axis
SPI: z.r. at ~30°
JEM-X: z.r. at ~13°
Event: ~32° from axis
3.9 sigma by ACS alone in one 0.1 s bin

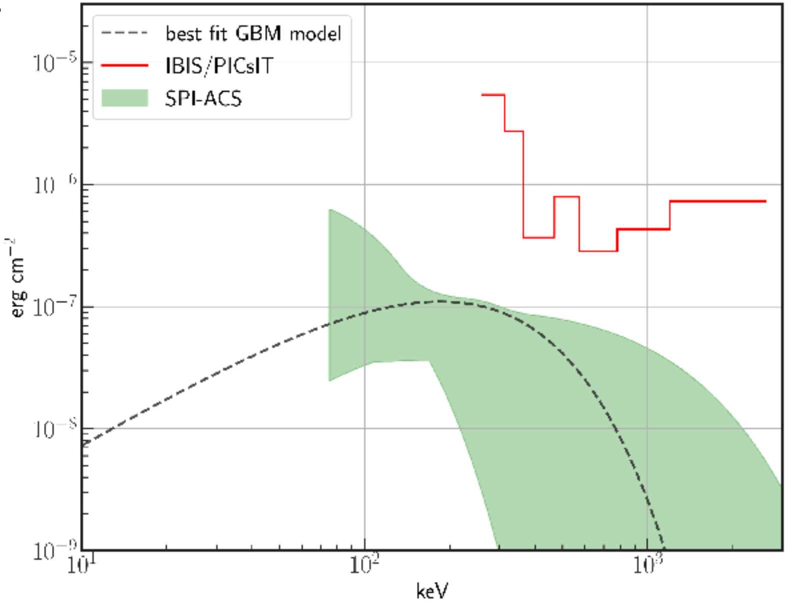
First re-point, 19.5 hrs later (70 ks) in GBM area
Location was still uncertain, not good
New re-point 24 hrs later on AT2017gfo
Upper limits on emission

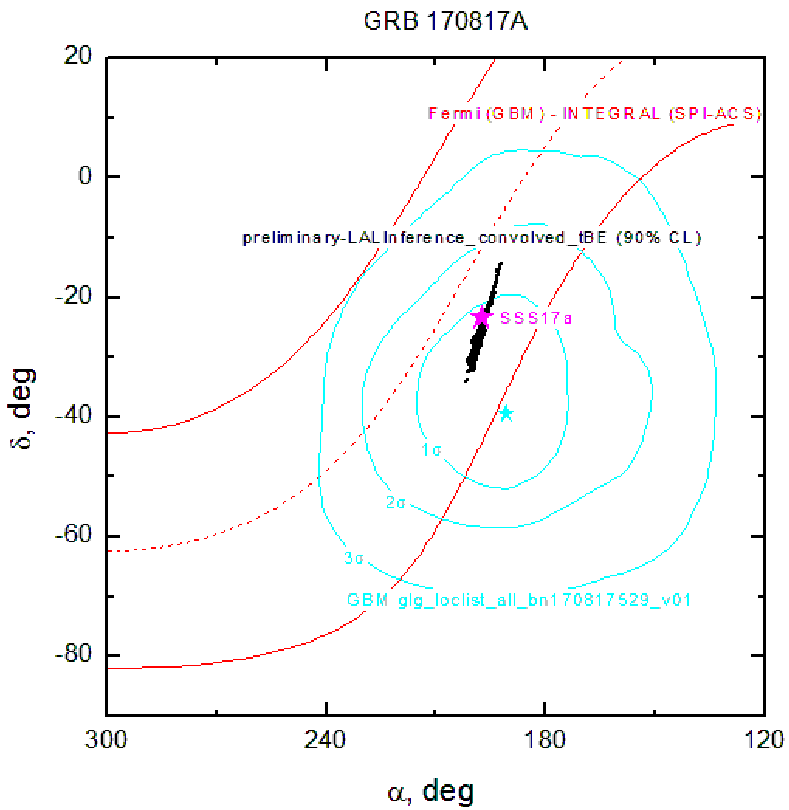




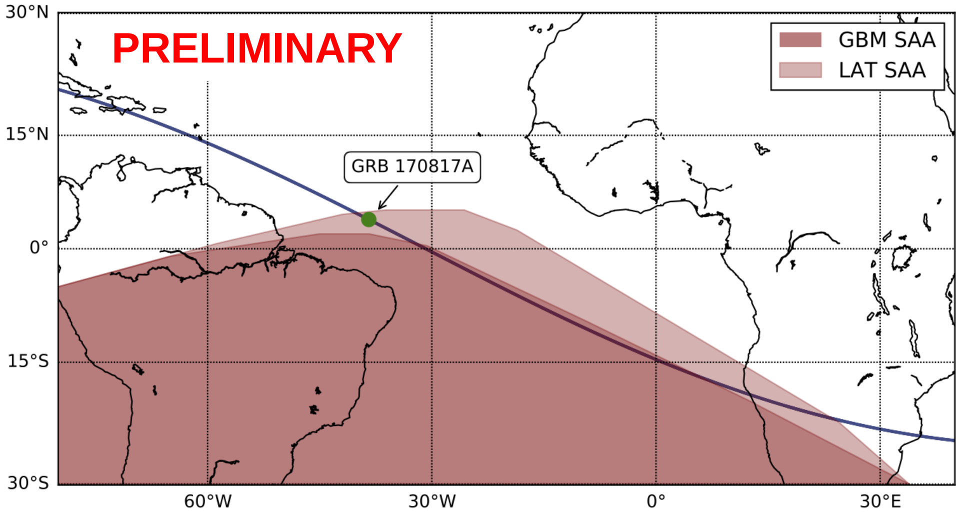
Improve localization by triangulation using relative delay between INTEGRAL-ACS and FERMI-GBM (149 ms)
GCN circular issued at t_0+6 h
Halved GBM localization window

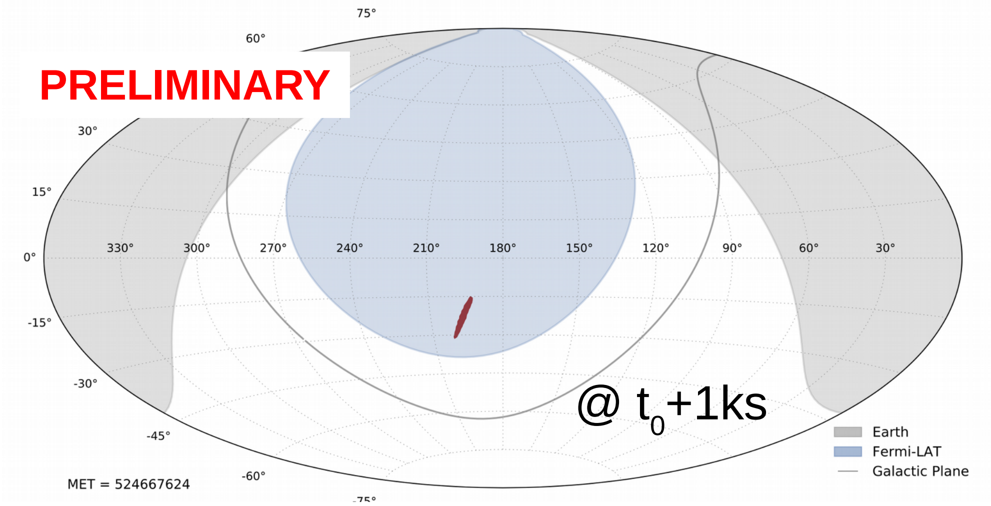
Spectrum from GBM compared with ACS response
IBIS: upper limit





FERMI LAT was "offline"





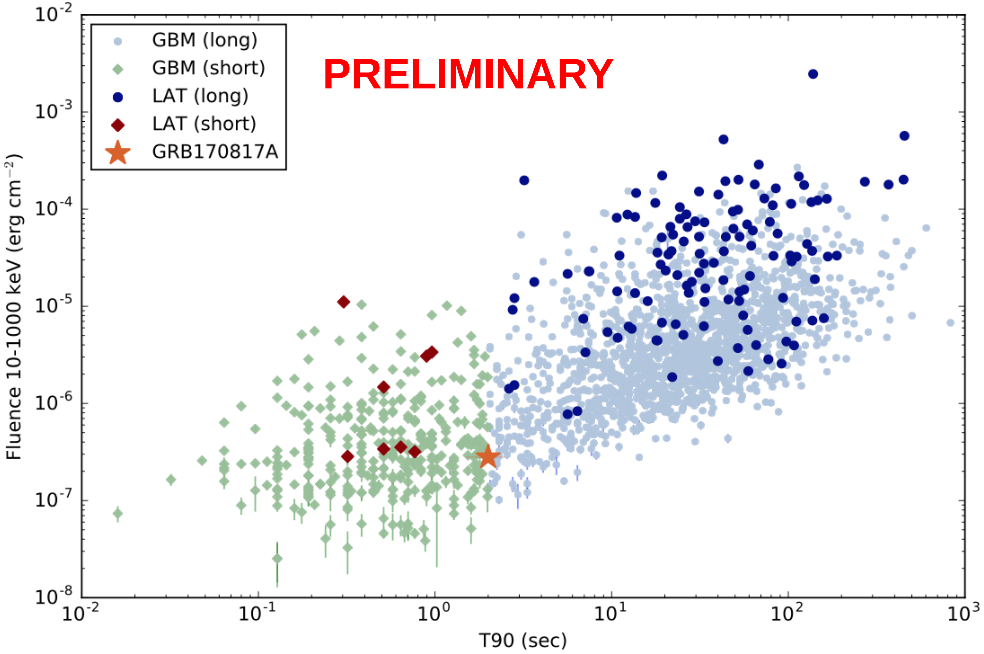
The LAT and the GBM do not collect data when in the SAA

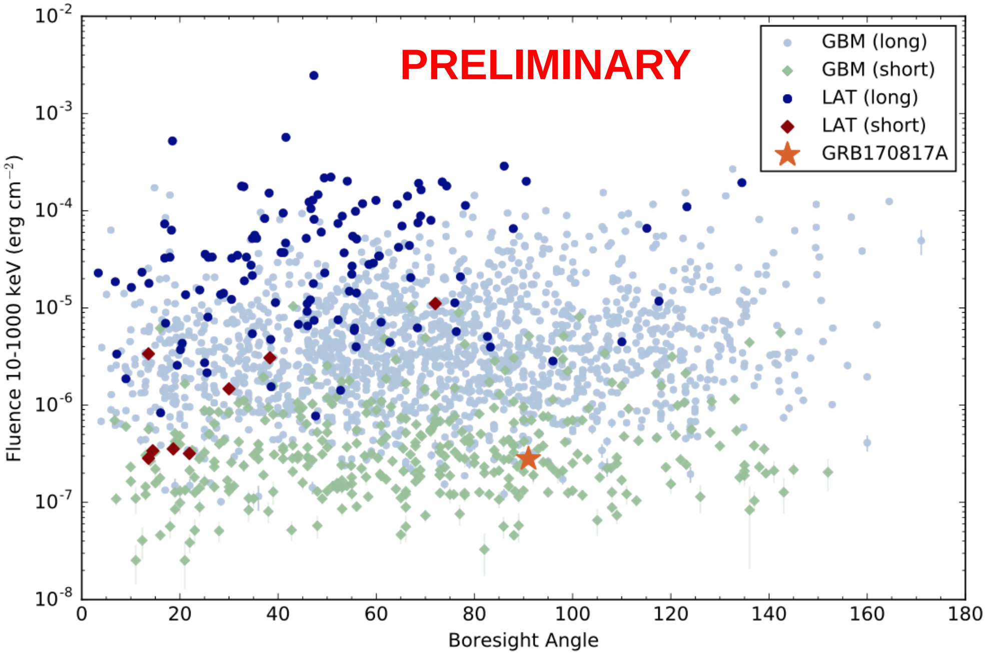
Given the different instrument requirements, the SAA definition for the LAT is slightly larger (14%) than the GBM one

At the time of the GW event (and GBM trigger), the LAT was in the SAA

We observe the entire region between t_{GW}+1153 – t_{GW}+2017
Upper bound (0.1–1 GeV):
$F < 4.5\times10^{-10}$ erg cm^{-2} s^{-1}
$L_{iso} < 9.3\times10^{43}$ erg s^{-1}

What if?





In the middle of the GBM SGRB population:

- other 4 SGRBs of similar fluence have been detected by the LAT above 100 MeV

Detectability of SGRBs depends on the off-axis angle

- LAT can repoint within few hundreds of seconds

Estimated probability of detecting a GW-related GRB with the LAT: 5-10%

Fundamental physics

(1.74 ± 0.05) s delay

$$\Delta v = v_{\mathrm{GW}} - v_{\mathrm{EM}}$$

$$\Delta v / v_{\mathrm{EM}} \approx v_{\mathrm{EM}} \Delta t / D$$

$$-3 \times 10^{-15} \leq \frac{\Delta v}{v_{\mathrm{EM}}} \leq +7 \times 10^{-16}$$

Assuming D = 26 Mpc (the lower bound on the 90% confidence interval for distance based on GW data alone, and bounding t between [-10, +1.74] s, where the -10 s is a reasonably conservative assumption.

$$\Delta v = -\sum_{\substack{\ell m \\ \ell \leq 2}} Y_{\ell m}(\hat{n}) \left(\frac{1}{2}(-1)^{1+\ell} \bar{s}^{(4)}_{\ell m} - c^{(4)}_{(I)\ell m} \right)$$

- Effective field theory
- Different group velocities in EM and GW sectors
- Non-birefringent, non-dispersive limit; mass dimension d=4; GW sector

Table 1. Constraints on the dimensionless minimal gravity sector coefficients.

ℓ	Previous Lower	This Work Lower	Coefficient	This Work Upper	Previous Upper
0	-3×10^{-14}	-2×10^{-14}	$\bar{s}^{(4)}_{00}$	5×10^{-15}	8×10^{-5}
1	-1×10^{-13}	-3×10^{-14}	$\bar{s}^{(4)}_{10}$	7×10^{-15}	7×10^{-14}
	-8×10^{-14}	-1×10^{-14}	$-\mathrm{Re}\ \bar{s}^{(4)}_{11}$	2×10^{-15}	8×10^{-14}
	-7×10^{-14}	-3×10^{-14}	$\mathrm{Im}\ \bar{s}^{(4)}_{11}$	7×10^{-15}	9×10^{-14}
2	-1×10^{-13}	-4×10^{-14}	$-\bar{s}^{(4)}_{20}$	8×10^{-15}	7×10^{-14}
	-7×10^{-14}	-1×10^{-14}	$-\mathrm{Re}\ \bar{s}^{(4)}_{21}$	2×10^{-15}	7×10^{-14}
	-5×10^{-14}	-4×10^{-14}	$\mathrm{Im}\ \bar{s}^{(4)}_{21}$	8×10^{-15}	8×10^{-14}
	-6×10^{-14}	-1×10^{-14}	$\mathrm{Re}\ \bar{s}^{(4)}_{22}$	3×10^{-15}	8×10^{-14}
	-7×10^{-14}	-2×10^{-14}	$-\mathrm{Im}\ \bar{s}^{(4)}_{22}$	4×10^{-15}	7×10^{-14}

Equivalence principle

$$\delta t_{\mathrm{S}} = -\frac{1+\gamma}{c^3}\int_{\mathbf{r}_{\mathrm{e}}}^{\mathbf{r}_{\mathrm{o}}} U(\mathbf{r}(l))dl$$

The bending and delay are proportional to γ-1, where the parameter γ is unity in general relativity but zero in the newtonian model of gravity. The quantity γ-1 measures the degree to which gravity is not a purely geometric effect and is affected by other fields.

δt_S = Shapiro delay using the same time bounds
$\mathbf{r_o}$ = observation positon, $\mathbf{r_e}$ = emission position
$U(\mathbf{r})$ = gravitational potential (here the Milky Way's)
l = wave path
γ = deviation from Einstein-Maxwell theory
(where γ_{EM} and γ_{GW} are both equal to 1)

$$-2.6\times10^{-7} \le \gamma_{\mathrm{GW}} - \gamma_{\mathrm{EM}} \le 1.2\times10^{-6}$$

The best absolute bound on γ_{EM} is $\gamma_{\mathrm{EM}}-1 = (2.1\pm2.3)\times10^{-5}$, from the measurement of the Shapiro delay (at radio wavelengths) with the Cassini spacecraft (Bertotti et al. 2003).

References:

FERMI:
- GBM: https://arxiv.org/abs/1710.05446
- LAT: https://arxiv.org/abs/1710.05450

INTEGRAL:
- https://arxiv.org/abs/1710.05449

ALL:
- https://arxiv.org/abs/1710.05834 (fundamental physics)