How SVOM could have observed GW170817 in the Gamma-Ray band

Third SVOM workshop
Les Houches, 2018/05/14

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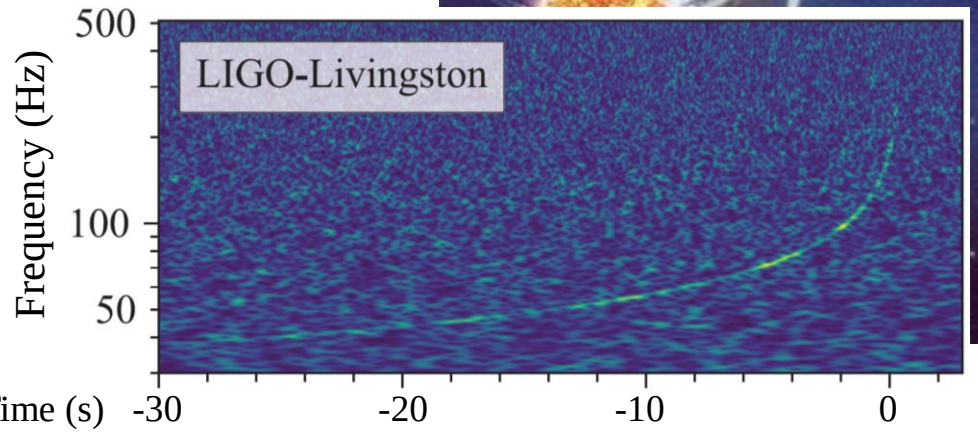
The golden event of 17 august 2017

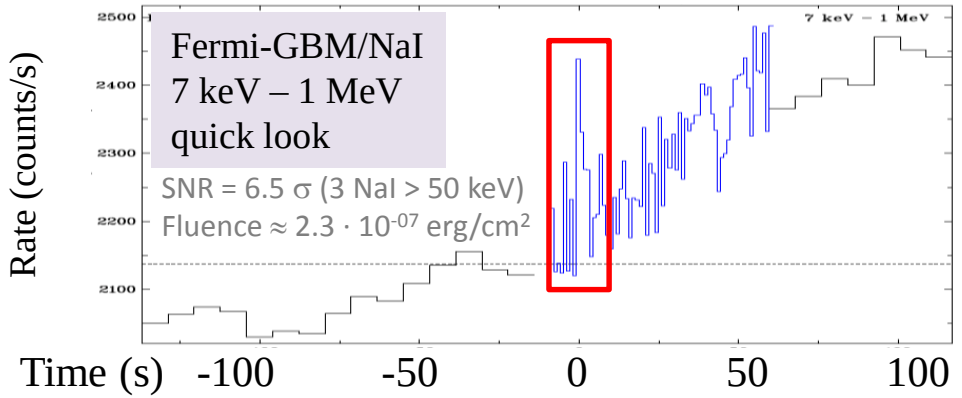
Gravitational wave detection from coalescence of 2 neutron stars

- $T0^{GW}$ = 12:41:04 TU (trigger at T^{GW} +6mn)
- M_1, M_2 = 1.17 – 1.60 Msol
- Sky region ≈ 28 deg^2 (LIGO & Virgo)
- Distance ≈ 40 Mpc



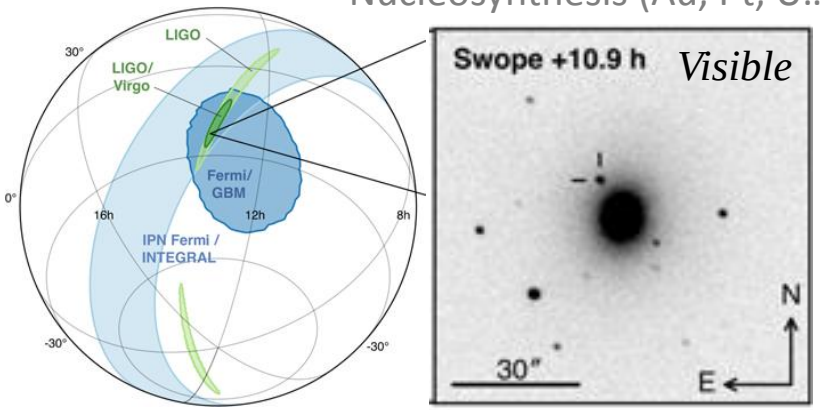
Short GRB 170817A

- $T0^{GRB}$ = 12:41:06.47 TU (≈ $T0^{GW}$+2s)
- Fermi-GBM Trigger (at $T0^{GRB}$ +14 s)
  Duration ≈ 2.5 s (main peak ≈ 0.5 s)
  Sky region ≈ 1800 deg^2
- Integral-SPI/ACS (trigger at $T0^{GRB}$ +76mn)

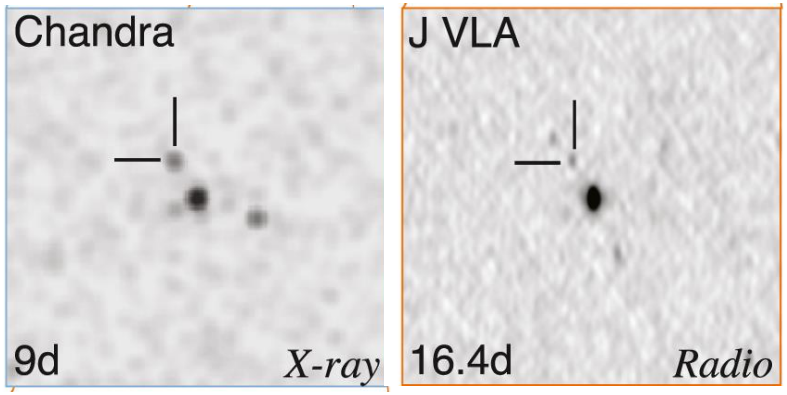


Kilonova

- Inside galaxy NGC4993
- Nucleosynthesis (Au, Pt, U…)

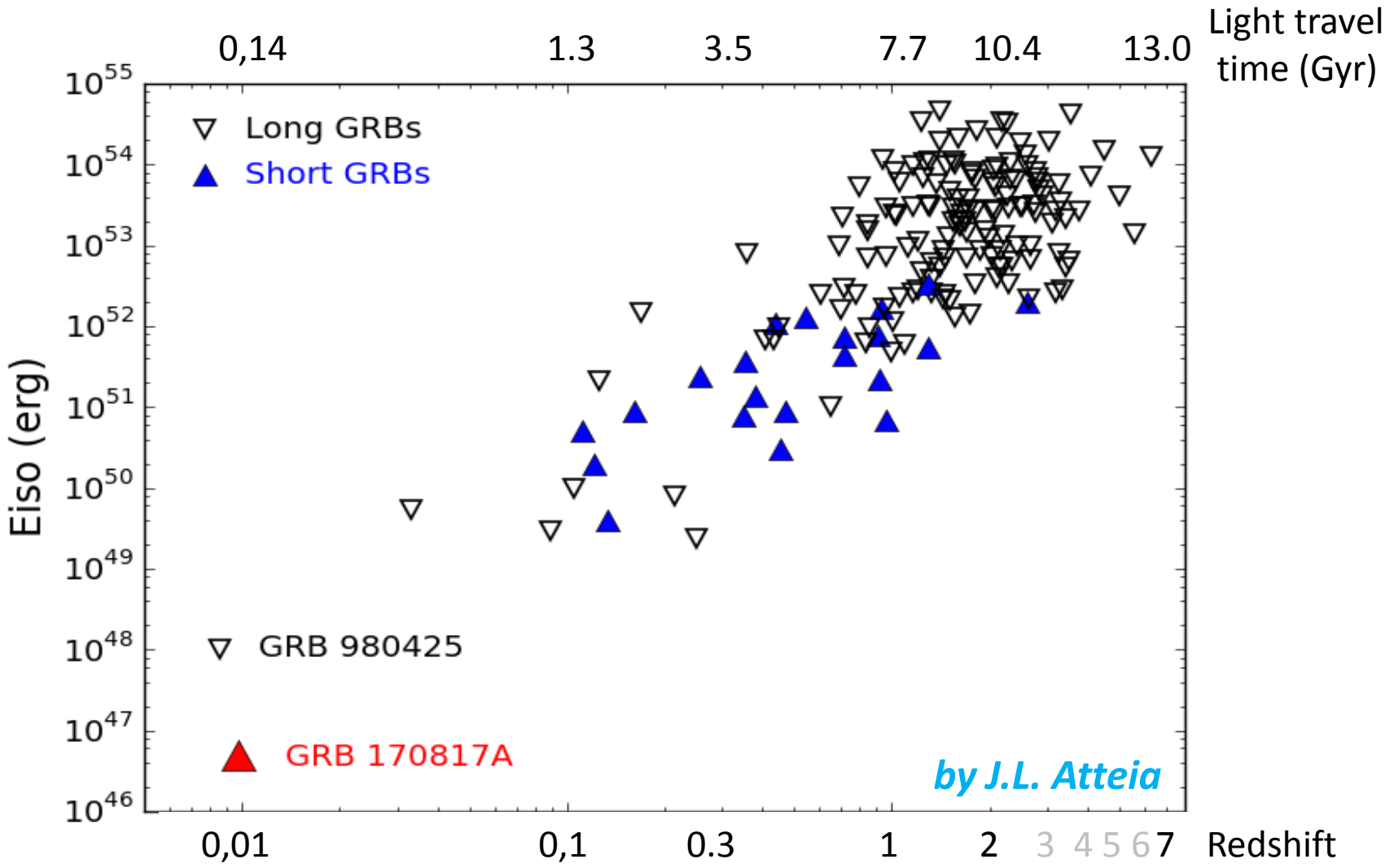


Afterglow



GRB170817A, a peculiar GRB

- Short GRB
- Associated to a NS-NS merger in galaxy NGC 4993 at 40 Mpc (z = 0.009727)
- Sub-energetic GRB: $E_{iso} \approx 5\ 10^{46}$ erg, $L_{iso} = 2.8\ 10^{46}$ erg/s

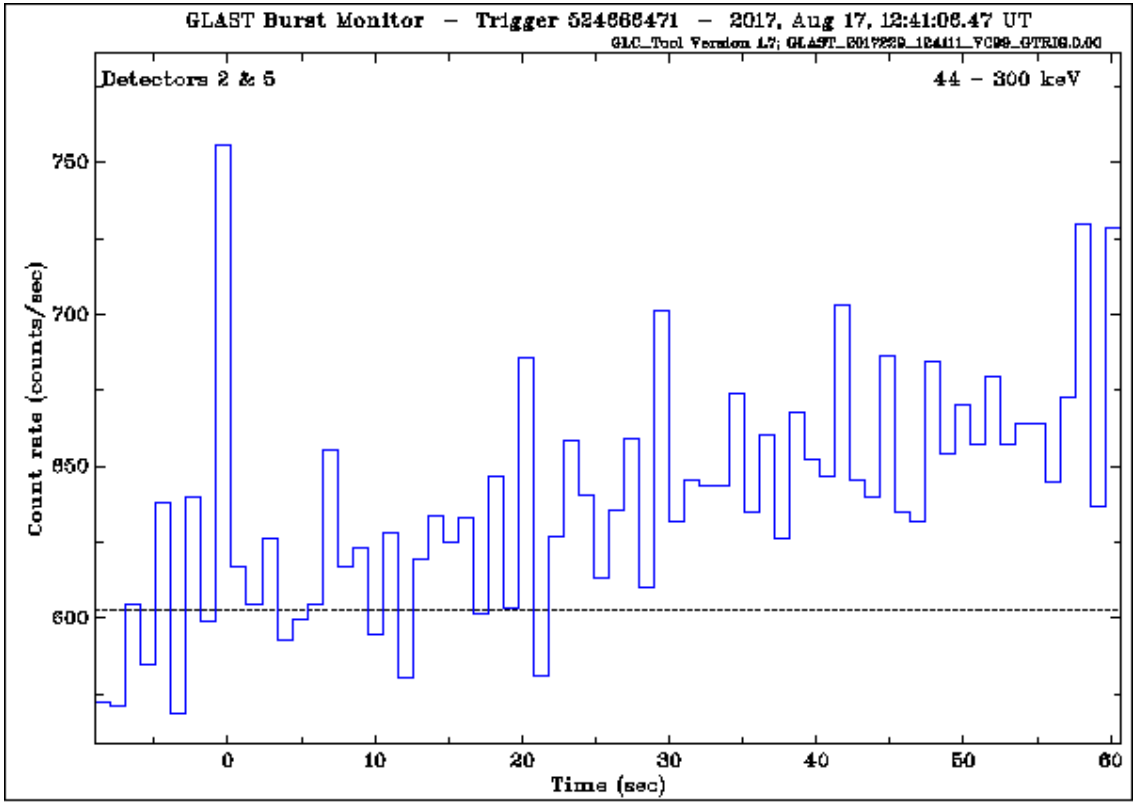


GRB170817A: **Fermi/GBM data**

Quick Look data of Fermi-GBM,
NaI detectors 2 & 5,
High energy band 44 to 300 keV

- **GRB seen in 1 bin of 1 s**
  with
  total: 750 c/bin
  bkg: 600 c/bin

→ SNRc = 150 / sqrt(600) ~ 6.1



Low significance burst,
at trigger detection limit!

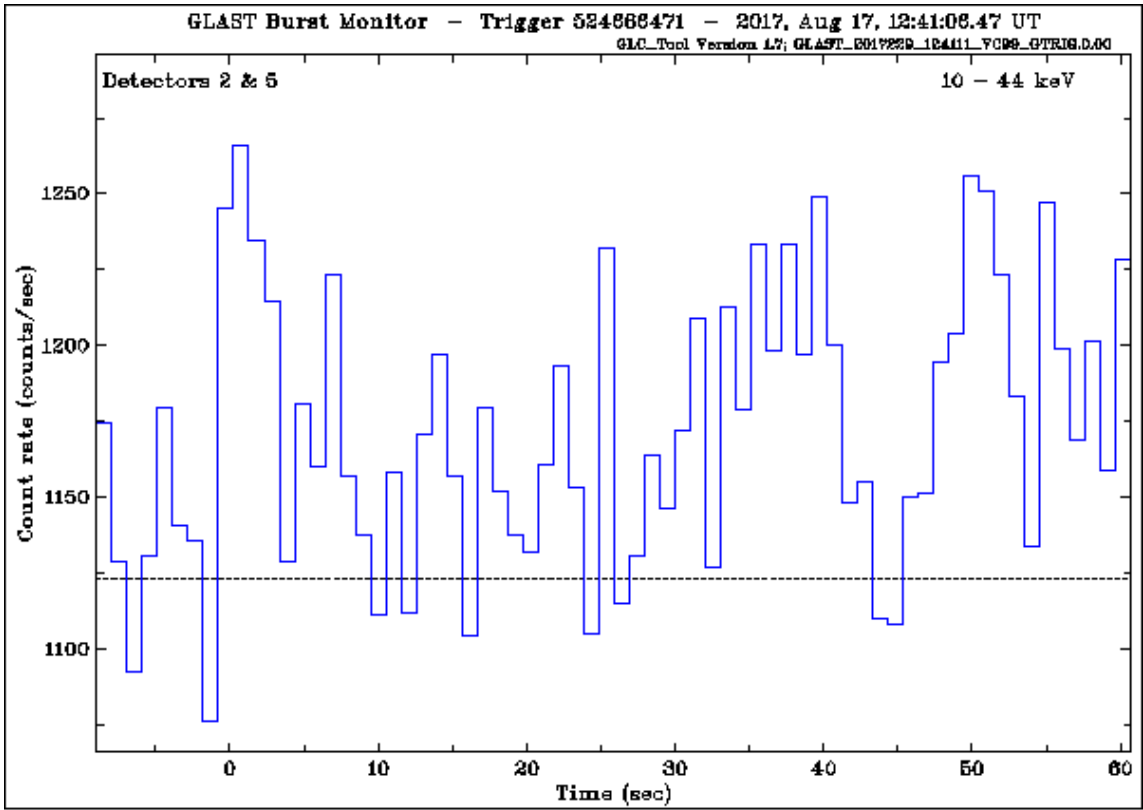
Would not have gained attention
hadn't there been the GW event!

GRB170817A: **Fermi/GBM data**

Quick Look data of Fermi-GBM,
NaI detectors 2 & 5,
Low energy band 10 to 44 keV

- **GRB seen in 4 bins of 1 s**
  with
  total : (1240+1270
  +1230+1210) c/4bins
  bkg: ~1120 c/bin

→ SNRc = 470 / sqrt(4480) ~ 7.1



GRB170817A: **Fermi/GBM first public GCN circular**

TITLE: GCN CIRCULAR
NUMBER: 21520
SUBJECT: GRB 170817A: Fermi GBM detection
DATE: 17/08/17 20:00:07 GMT
FROM: A. von Kienlin (MPE), C. Meegan (UAH) and A. Goldstein (USRA) on behalf of the Fermi GBM Team.

At **12:41:06.47 UT on 17 August 2017**, the Fermi Gamma-Ray Burst Monitor triggered and located **GRB 170817A** (trigger 524666471 / 170817529).

The **on-ground calculated location** … RA = 176.8, DEC = -39.8 (J2000 degrees,
… with an **uncertainty of 11.6 degrees** … additionally a systematic error … **3.7 deg error …**
The angle from the Fermi LAT boresight at the GBM trigger time is 91 degrees.

The **GRB light curve shows a weak short pulse** with a duration (T90) of about 2 s (50-300 keV).
The time-averaged **spectrum from T0-0.512 s to 2.048 s** is well fit by a power law function with an exponential high-energy cutoff.
The **power law index is -0.89 +/- 0.5 and the cutoff energy, parameterized as Epeak, is 82 +/- 21 keV**
The **event fluence (10-1000 keV) in this time interval is (2.3 +/- 0.4)E-07 erg/cm^2**.

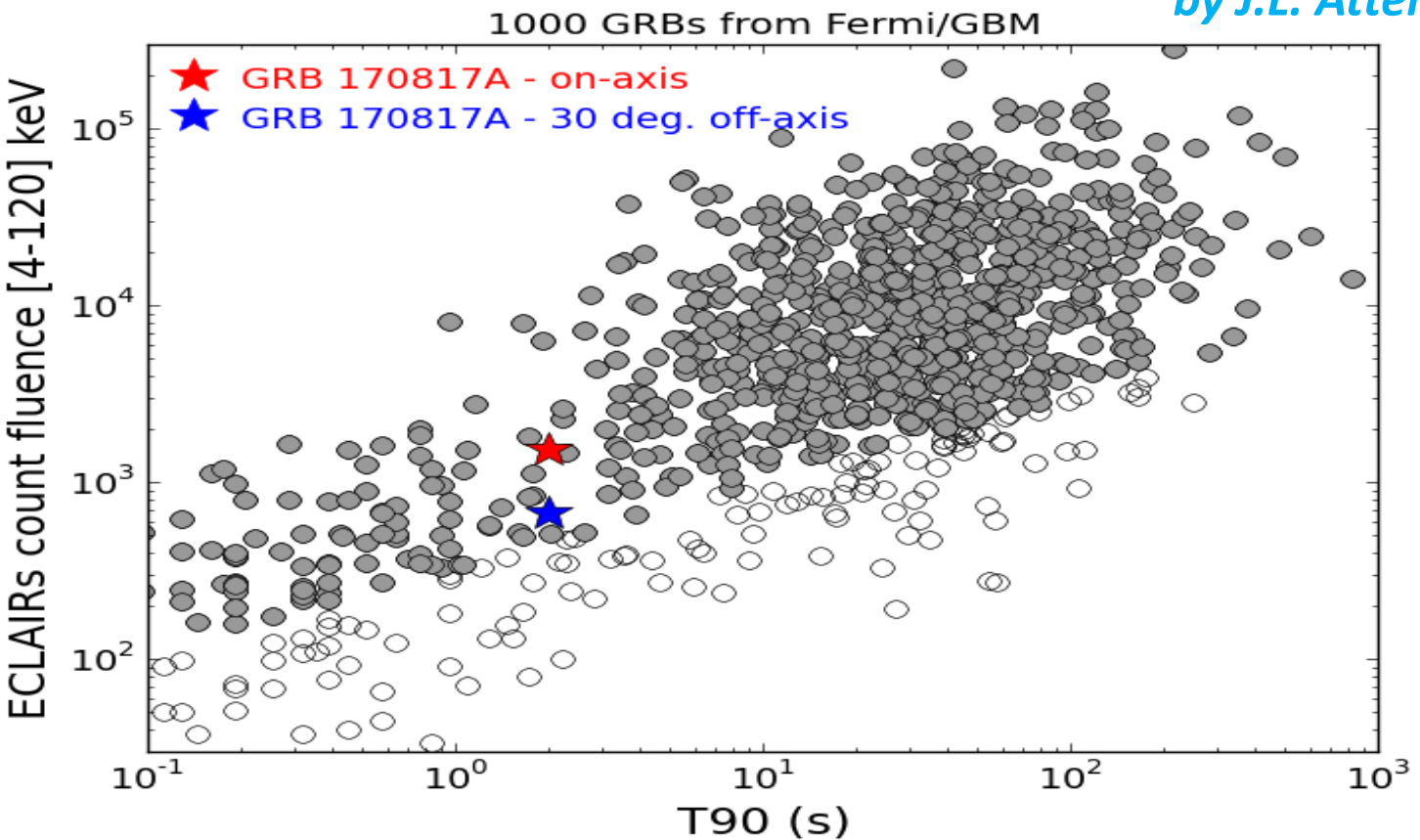
The **1.024-sec peak photon flux measured starting from T0-0.32 s is 1.9 +/- 0.2 ph/s/cm^2**.

How *ECLAIRs* could have seen GRB170817A

GRB170817A: **ECLAIRs first estimate for 2.56 s (T90) and comparison to GRBs**

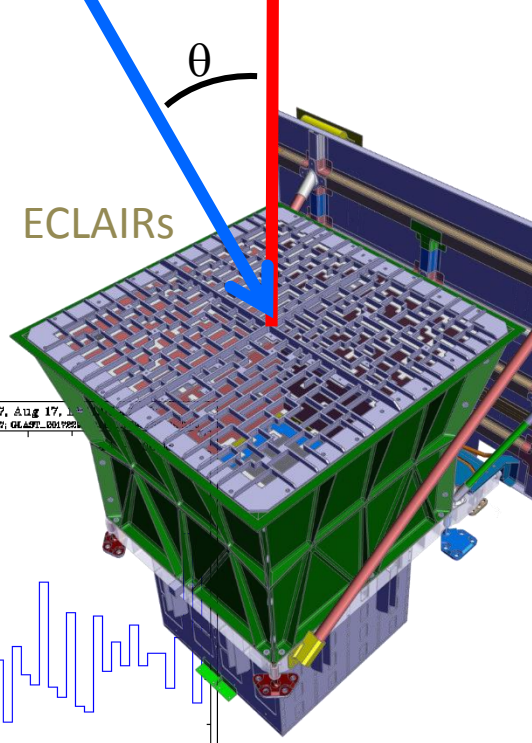
- GRB170817A spectral parameters from Fermi-GBM (first public GCN)
- 1000 GBM GRBs randomly in a 40° cone, through ECLAIRs response → count fluence
- Undetected (open circles) if SNRc <6 or <150 counts

by J.L. Atteia



GRB170817A: **ECLAIRs estimate for peak 1 s**

by S. Sch.

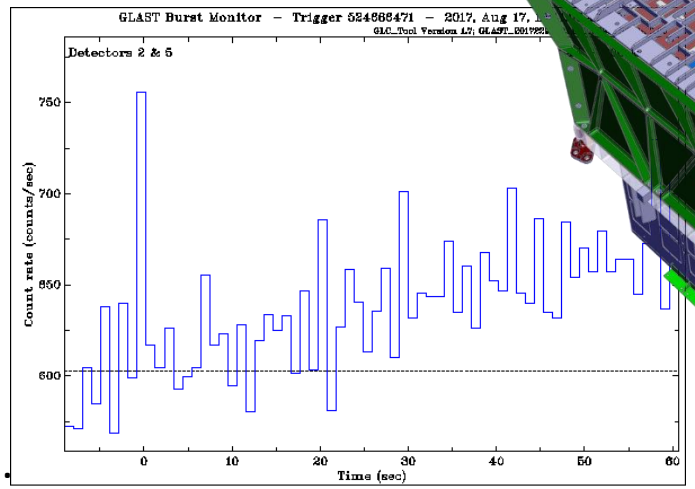


Taking the spectrum from the Fermi/GBM public GCN:

- equivalent Band function Alpha=-0.89, Epeak=82 keV, Beta<-7
- Normalization for duration 1.024 s

→ N(10-1000keV) = 1.9 ph/cm^2/s
i.e. NE(10-1000) = 1.36E-7 erg/cm^2/s

→ N(4-120keV) = 2.64 ph/cm^2/s

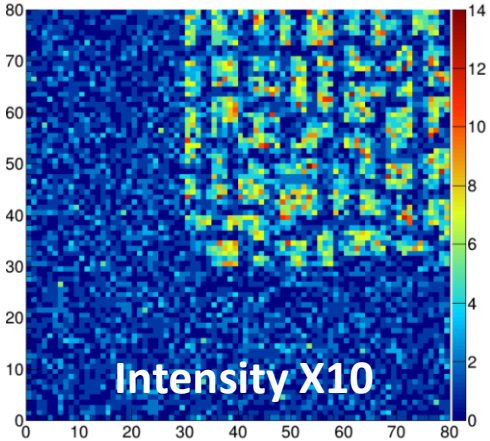


Simulation with CxgSim
(raytracing with MC calibrated response)
4-120 keV, energy redistribution,
new mask with cross, new deconvolution.
std bkg (CXB Zombek: 2080 c/s + instrumental: 365 c/s),

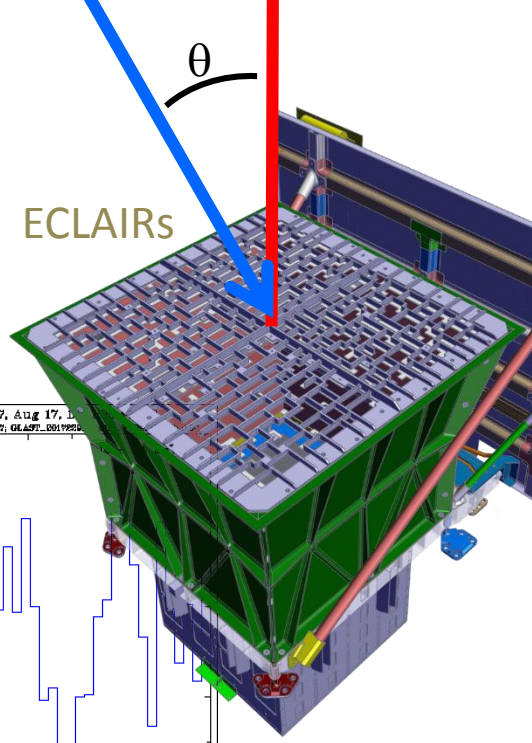
- on axis, pixel (0,0) (0°) : SNRc = 802 / sqrt(2443) = 16.2
  SNRi = 15.3
- off axis, pixel (60,0) (30°) : SNRi = 8.7
- off axis, pixel (70,0) (34°) : SNRi = 7.6
- off axis, pixel (80,0) (38°) : SNRi = 4.5

➔ Detection up to ~32° off axis

Detector plane image



GRB170817A: **ECLAIRs estimate for 2.56 s (T90)** *by S. Sch.*

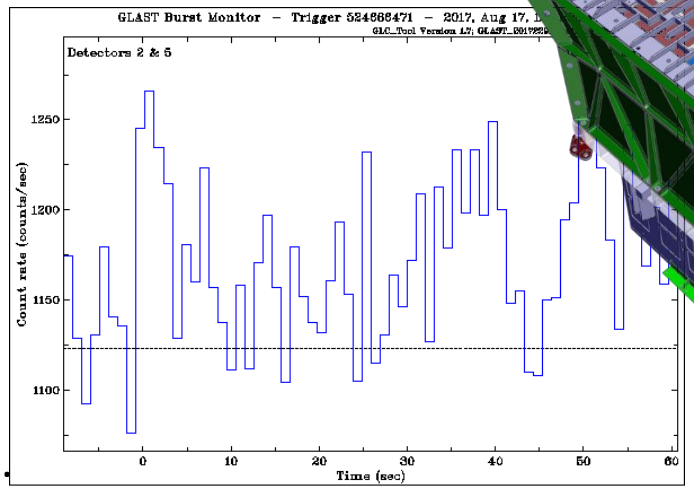


Taking the spectrum from the Fermi/GBM public GCN:

- equivalent Band function Alpha=-0.89, Epeak=82 keV, Beta<-7
- Normalization for duration T90~2.56 s : fluence NE(10-1000keV)= 2.3 E-7 erg/cm^2

→ N(10-1000keV) = 3.20 ph/cm^2

→ N(4-120keV) = 4.45 ph/cm^2

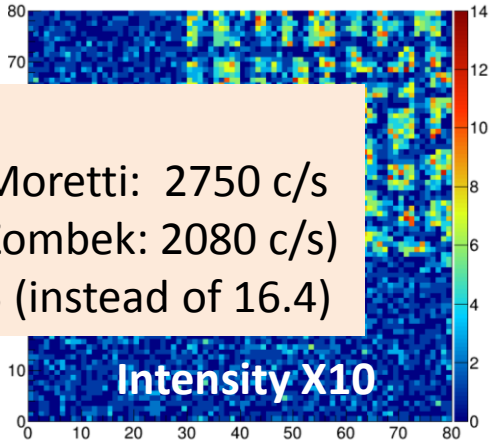


Simulation with CxgSim
(raytracing with MC calibrated response)
4-120 keV, energy redistribution,
new mask with cross, new deconvolution.
std bkg (CXB Zombek: 2080 c/s + instrumental: 365 c/s),

- on axis, pixel (0,0) (0°) : SNRc = 1377 / sqrt(6240) = 17.4
  SNRi = 16.4
- off axis, pixel (60,0) (30°) : SNRi = 9.7
- off axis, pixel (70,0) (34°) : SNRi = 8.9
- off axis, pixel (80,0) (38°) : SNRi = 6.5

→ Detection up to ~36° off axis

Detector plane image



Rem: bkg
using CXB Moretti: 2750 c/s
(instead CXB Zombek: 2080 c/s)
→ SNRi ~ 14.5 (instead of 16.4)

GRB170817A: **ECLAIRs estimate for 2.56 s on-axis**

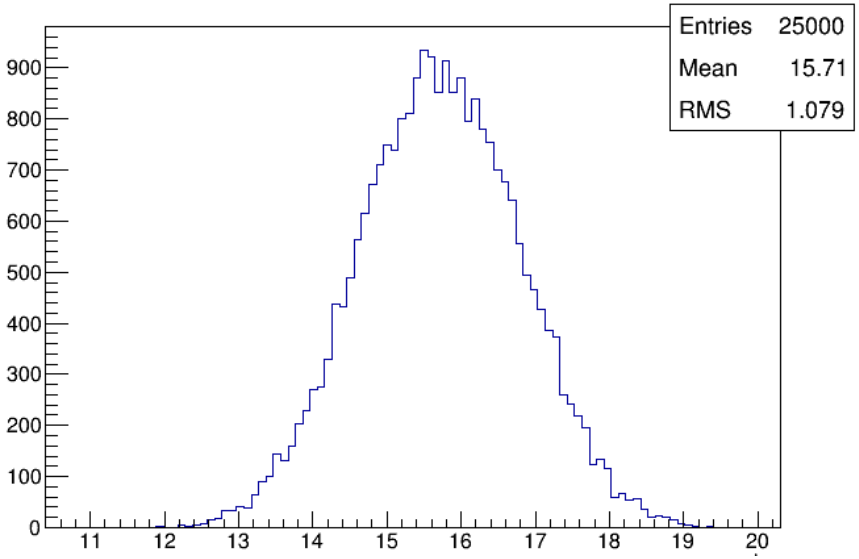
Simulation of 25000 sources, on axis within [-2, 2] central pixels , *fixed GRB parameters*:

Band function Alpha=-0.89, Epeak=82 keV, Beta=-7

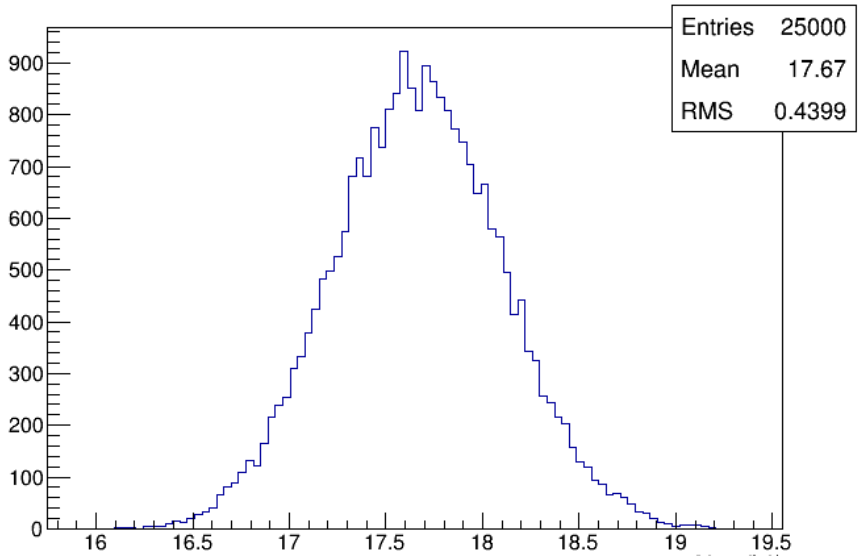
Fluence NE(10-1000keV)= 2.3E-7 erg/cm2

➔ **Distribution of SNRi (signal to noise in image) and SNRc (in count rates)**

SNRi ~ 14 to 18 sigma



SNRi



SNRc

GRB170817A: **ECLAIRs estimate for 2.56 s on-axis**

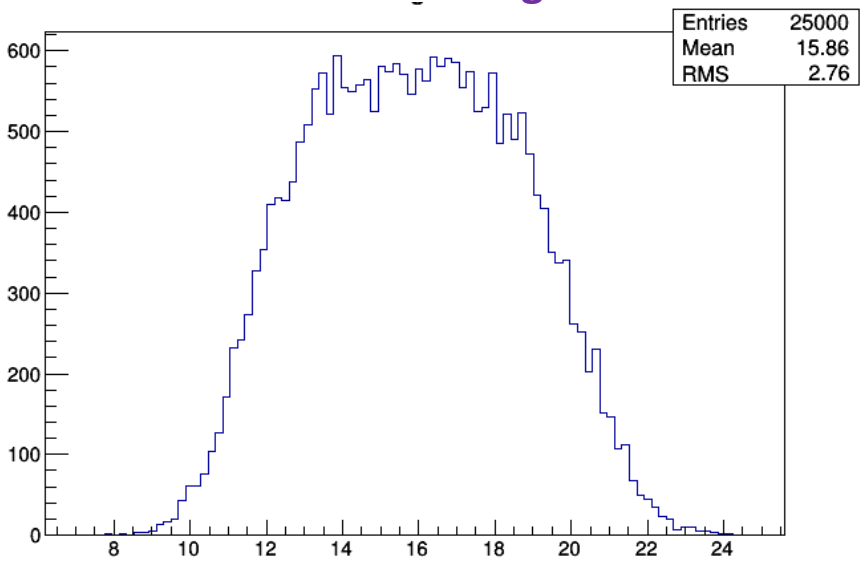
Simulation of 25000 sources, on axis within [-2, 2] central pixels, *varying GRB parameters*:

Band function Alpha=-0.89±0.5, Epeak=82±21 keV, Beta=-7

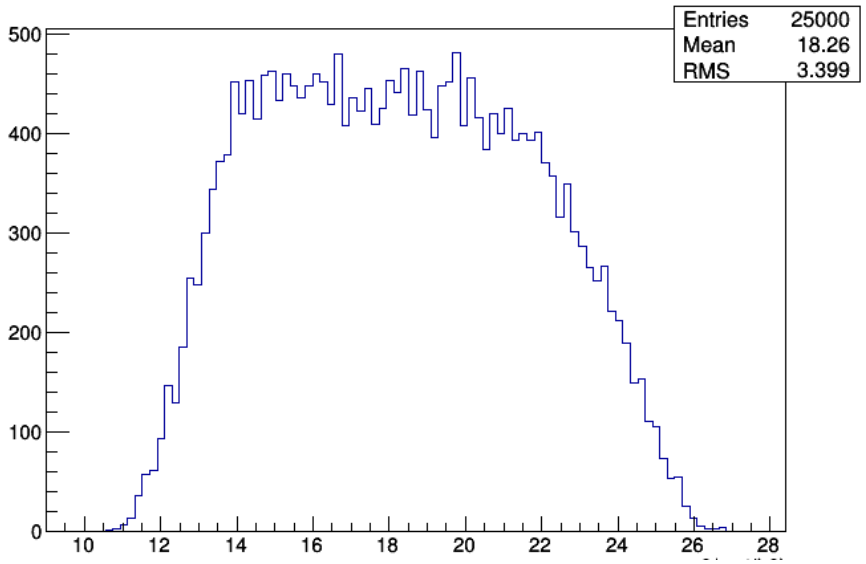
Fluence NE(10-1000keV)= (2.3±0.4)E-7 erg/cm^2

➔ **Distribution of SNRi (signal to noise in image) and SNRc (in count rates)**

SNRi ~ 10 to 22 sigma



SNRi

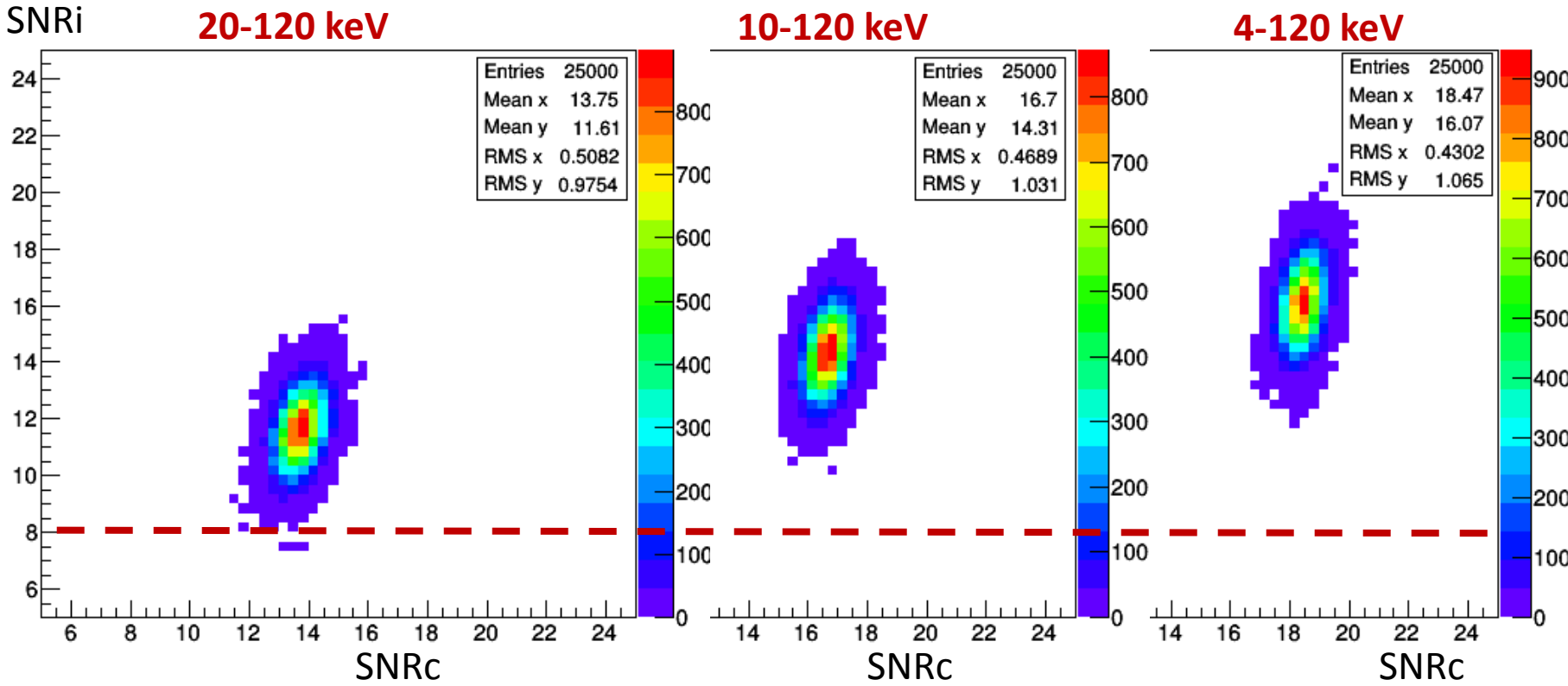


SNRc

GRB170817A: **ECLAIRs estimate for 2.56 s on-axis**

Simulation of 25000 sources, on axis within [-2, 2] central pixels, *fixed GRB parameters*

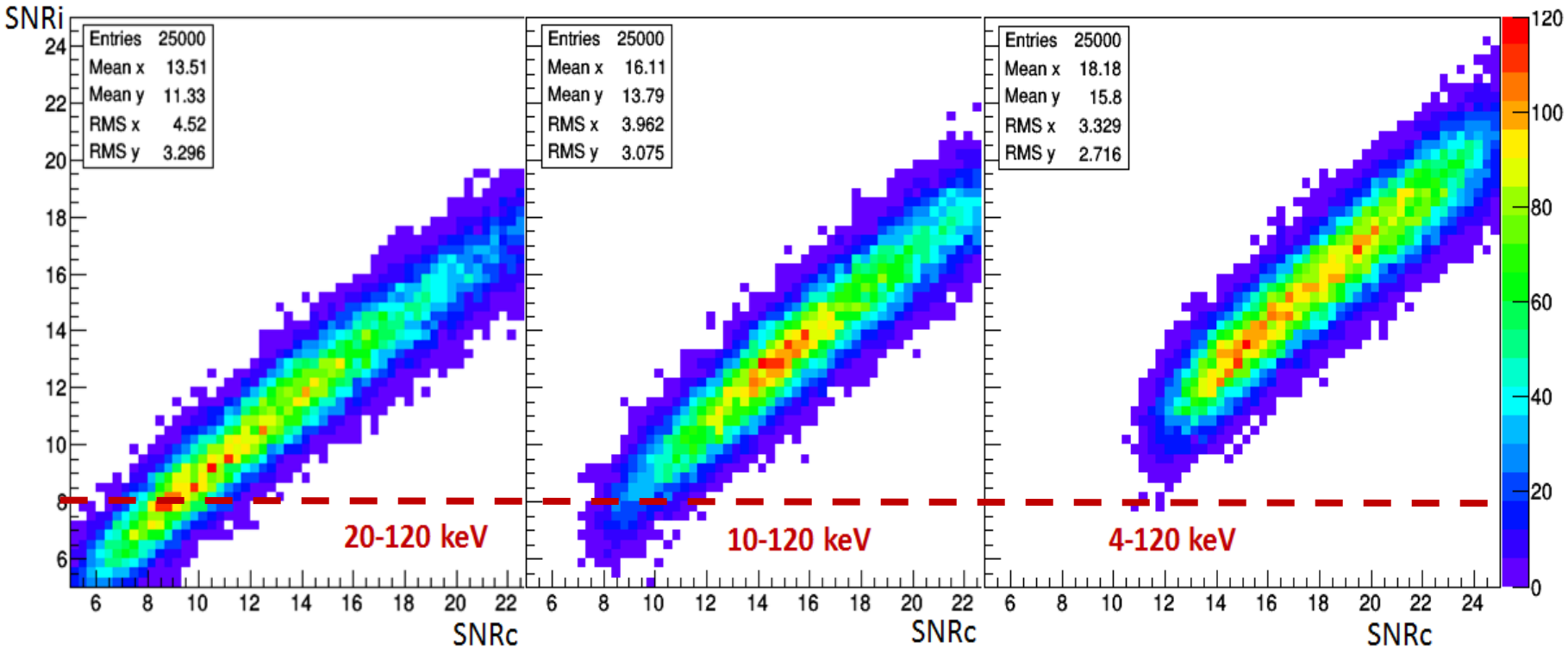
➔ **Gain in SNR thanks to low energy threshold of 4 keV compared to 10 and 20 keV**



GRB170817A: **ECLAIRs estimate for 2.56 s on-axis**

Simulation of 25000 sources, on axis within [-2, 2] central pixels, *varying GRB parameters*

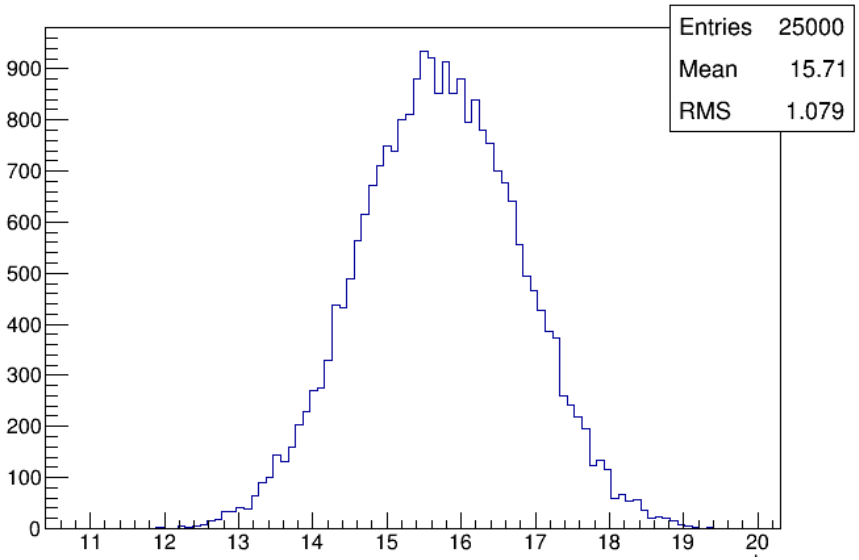
➔ **Gain in SNR thanks to low energy threshold of 4 keV compared to 10 and 20 keV**

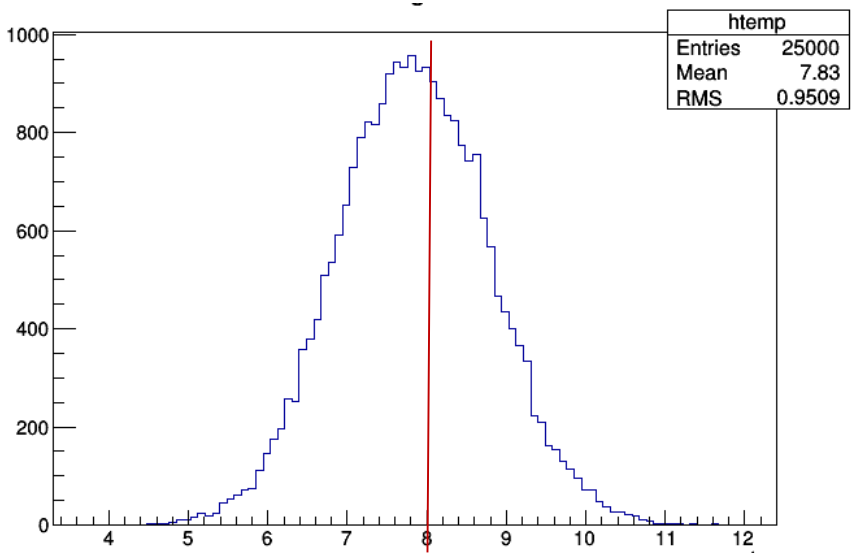


GRB170817A: **ECLAIRs estimate for 2.56 s on-axis**

Simulation of 25000 sources, on axis within [-2, 2] central pixels, fixed GRB parameters
Same spectral shape, same T90

fluence	NE(10-1000keV)= 2.3E-7 erg/cm²	→	**reduced to 1E-7 erg/cm²**
	N(4-120keV) = 4.45 ph/cm²	→	**N(4-120keV) = 2 ph/cm²**
	Distance = 40 Mpc	→	**Distance = 60 Mpc**
	mean on-axis SNRi = 15.7	→	**SNRi = 7.8**





GRB170817A: **ECLAIRs estimate for 2.56 s in FoV**

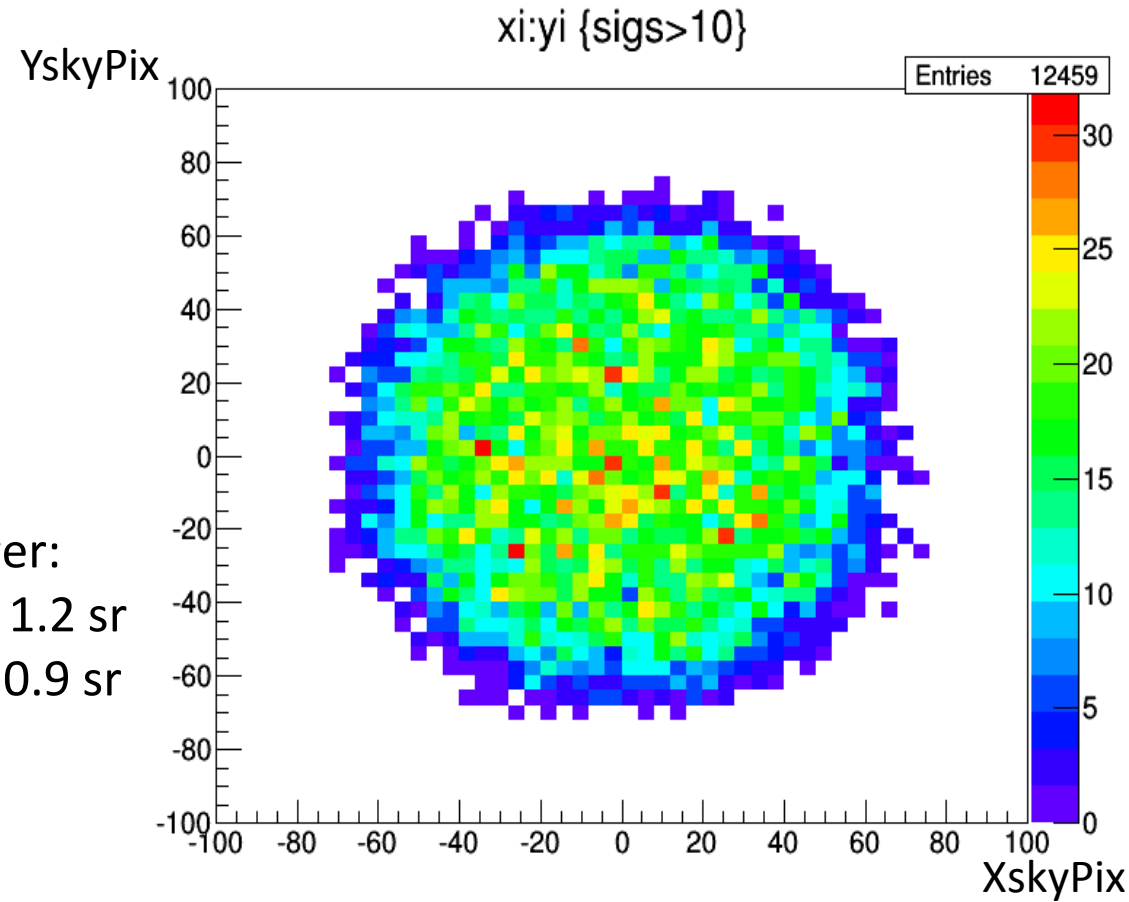
Simulation of 25000 sources, isotropic in FoV (excluding 10 pixel-border, 1.85 sr), fixed par.

➔ **position (xi,yi) of the source exceeding different SNRi thresholds (6,7,8,10 sigma)**

SNRi>6	82% (1.52 sr)
SNRi>7	74% (1.37 sr)
SNRi>8	66% (1.22 sr)
SNRi>10	50% (0.92 sr)

We can expect a SVOM trigger:

- Alert ~ if event in central 1.2 sr
- Slew ~ if event in central 0.9 sr

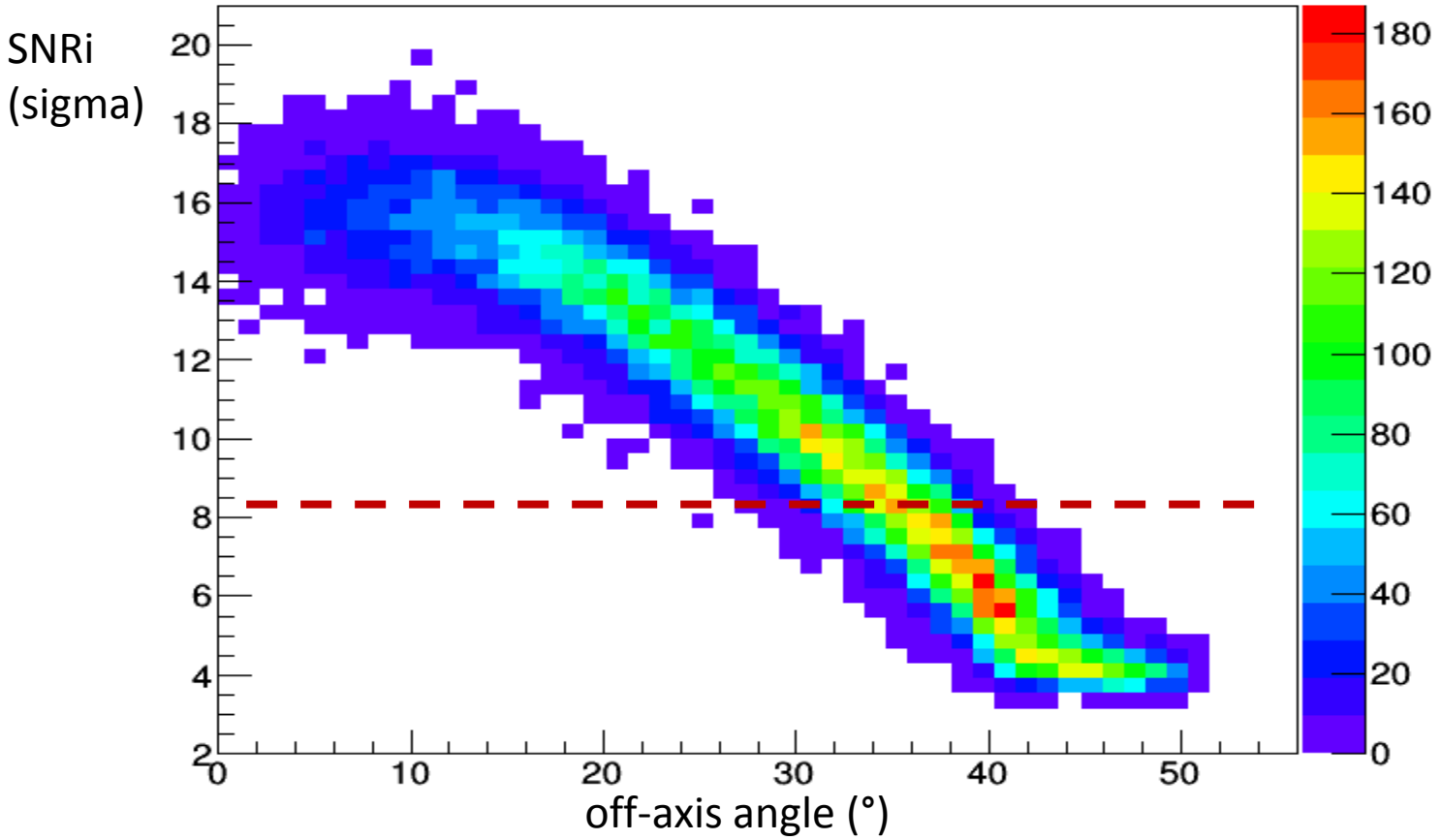


GRB170817A: **ECLAIRs estimate for 2.56 s in FoV**

Simulation of 25000 sources, isotropic in FoV (excluding 10 pixel-border, 1.85 sr), fixed par.

➔ **Distribution of sources in plane SNRi vs off-axis angle**

➔ **Most probable location in the FoV is ~36° off axis, this is also ~detection limit…**

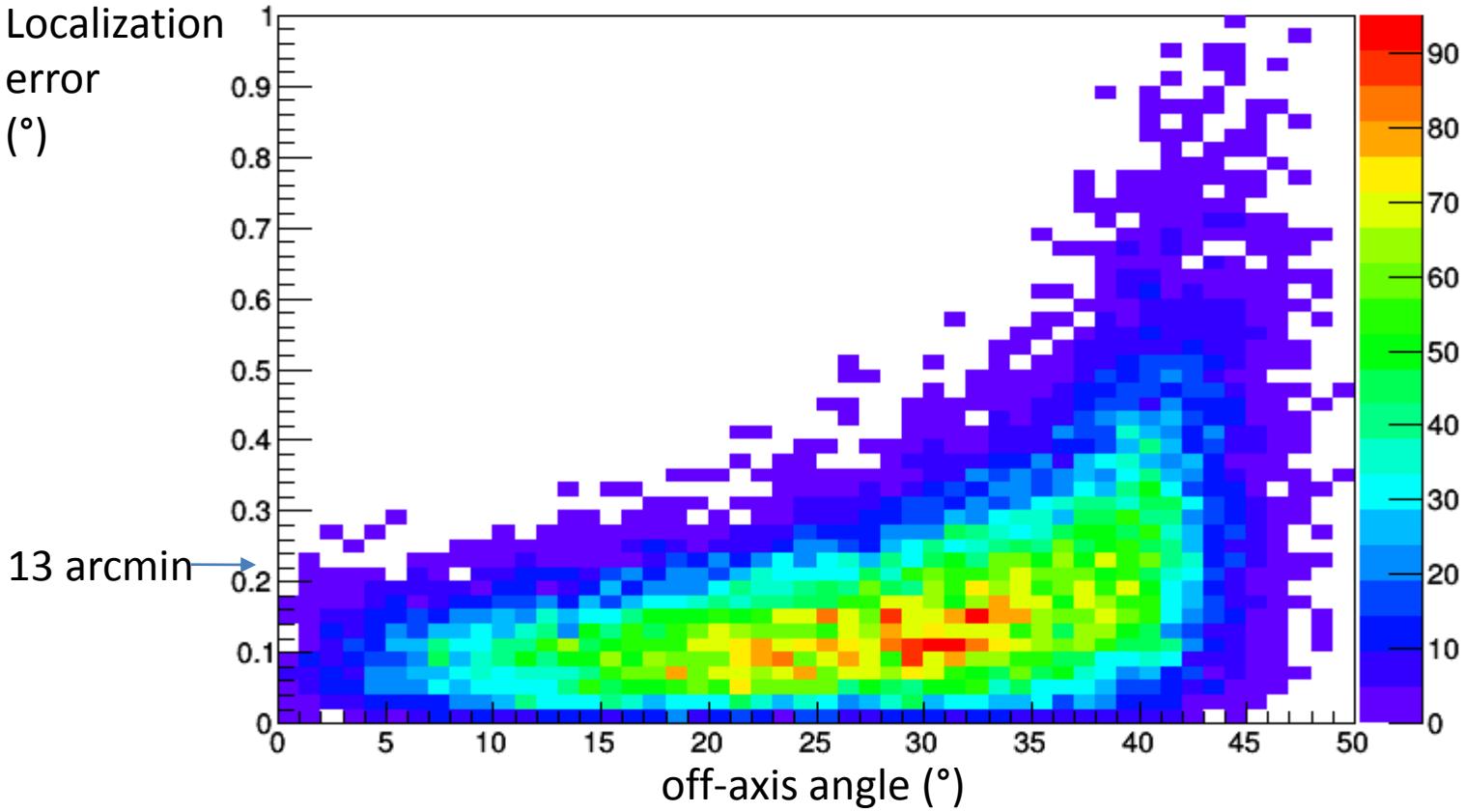


GRB170817A: **ECLAIRs estimate for 2.56 s in FoV**

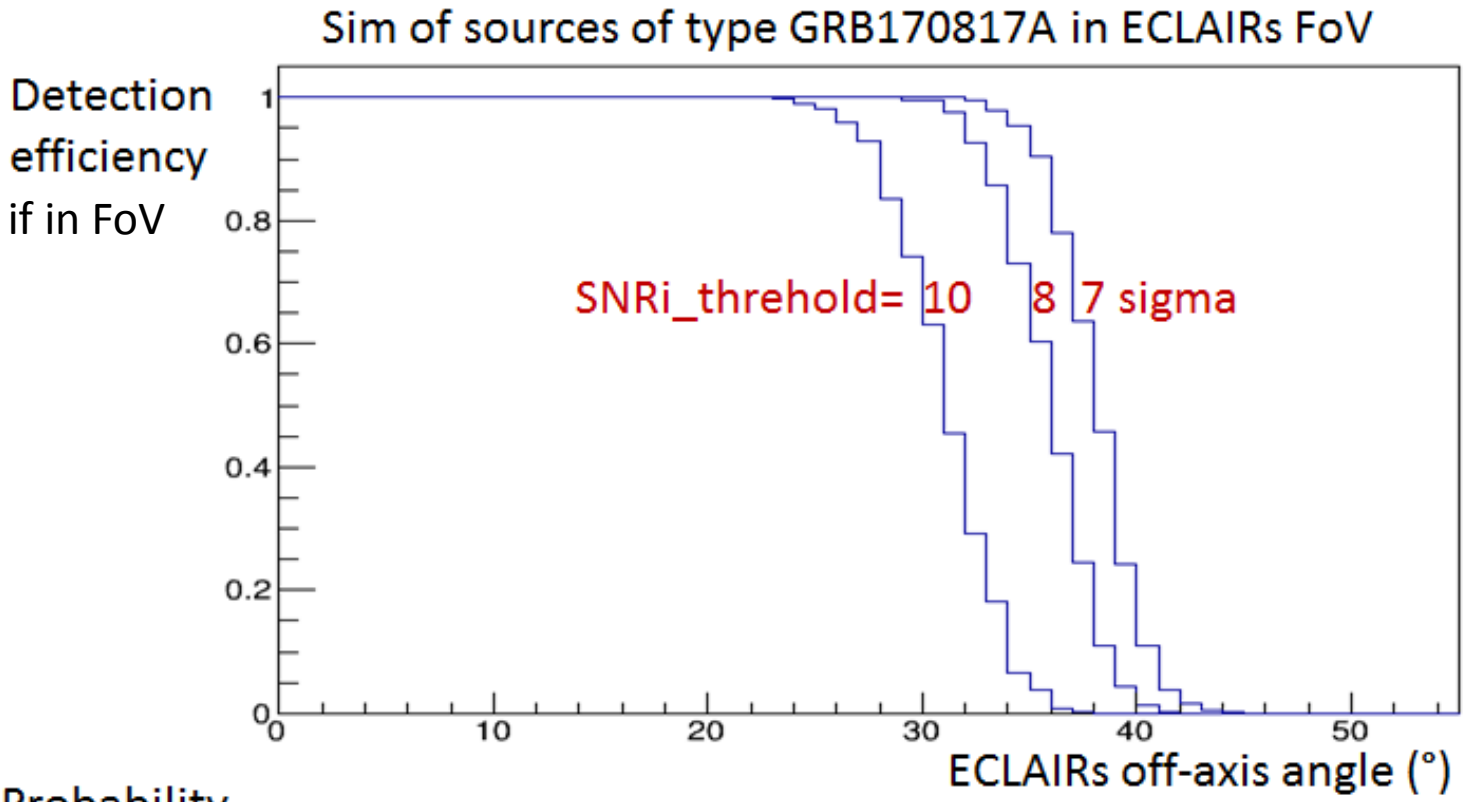
Simulation of 25000 sources, isotropic in FoV (excluding 10 pixel-border, 1.85 sr), fixed par.

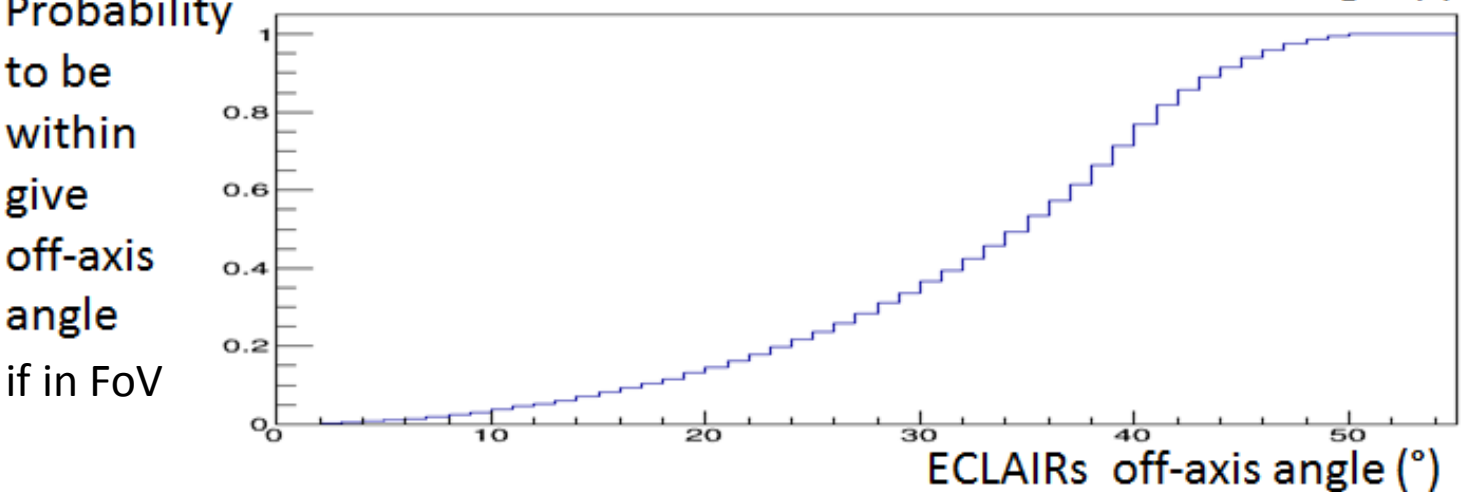
➔ **Distribution of sources in plane Localization error vs off-axis angle**

➔ **Localization < 6 arcmin if on-axis (for 90% of on-axis cases)**



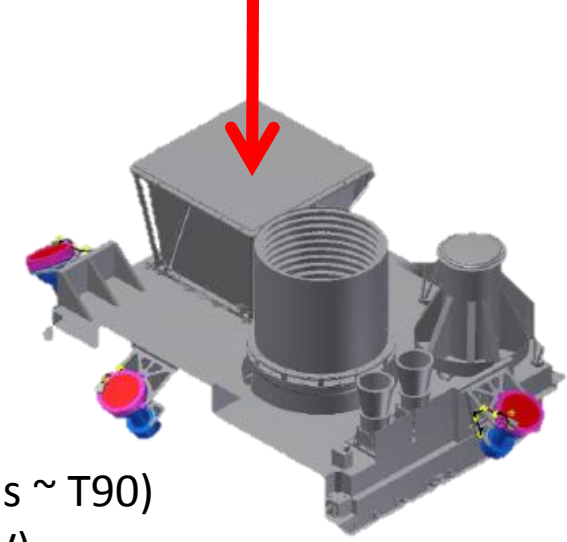
GRB170817A: **ECLAIRs estimate for 2.56 s**





How *GRM* could have seen GRB170817A

GRB170817A: **GRM estimate for 2.56 s and ECLAIRs on-axis**



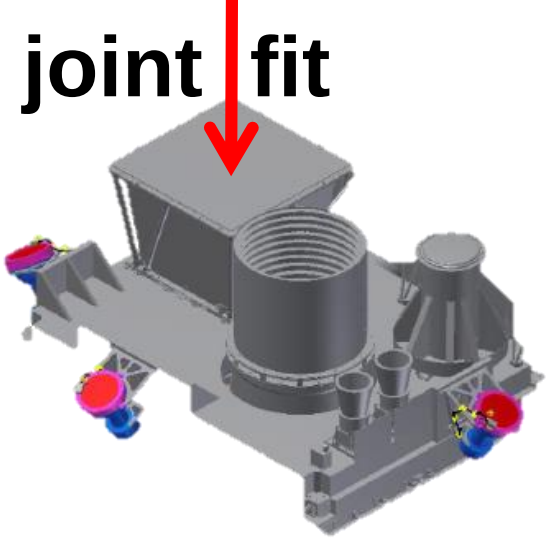
by M.-G. Bernardini

- GRB :
  - Same spectrum from Fermi/GBM public GCN (for 2.56 s ~ T90) for ECLAIRs (4-150 keV) and for each GRD (15-5500 keV)
  - assumed on-axis for ECLAIRs (30 deg off-axis for each GRD)
- Background:
  - CXB : Moretti (2009, <164 keV) and Gruber (1999, >164 keV)
  - Earth albedo: cosmic-ray induced gamma emission (Churazov 2006)
  - Reflection of CXB on Earth atmosphere (Sazonov 2007)
  - Activation in SAA (dominant at high E)
- Using the ARF and RMF of ECLAIRs and GRM (from Geant4 detailed MC) → **Xspec**

Results:

- GRM, GRD_1: grb = 393 c, bkg = 3095 c, SNR = 7.0
- GRM, GRD_2: grb = 402 c, bkg = 3052 c, SNR = 7.2
- GRM, GRD_3: grb = 407 c, bkg = 3045 c, SNR = 7.3
- GRM, 3 GRDs combined: SNR = 12.5
- ECLAIRs: grb = 1577 c, bkg=7806 c, SNRc=17.8

GRB170817A: **GRM + ECLAIRs joint fit for 2.56 s and ECLAIRs on-axis**



by M.-G. Bernardini

Simulated spectrum (central values used)

- power-law with an exponential cutoff
  alpha=-0.89 ± 0.5 and Epk=(82 ± 21) keV,
  i.e. Ecut=Epk/(2+alpha)=(74 ± 38) keV
  Fluence (10-1000 keV) = (2.3 ± 0.4)E-07 erg/cm^2 in 2.56 s

Reconstructed model : power-law with an exponential cutoff:

- **best-fit with ECLAIRs and GRM combined** (errors at 1 sigma):
  - alpha=-0.78 -0.13 +0.12
  - Ecut=(63.2 -10.9 +14.6) keV
  - C-Statistic = 4322.33 using 6622 PHA bins and 6619 degrees of freedom.

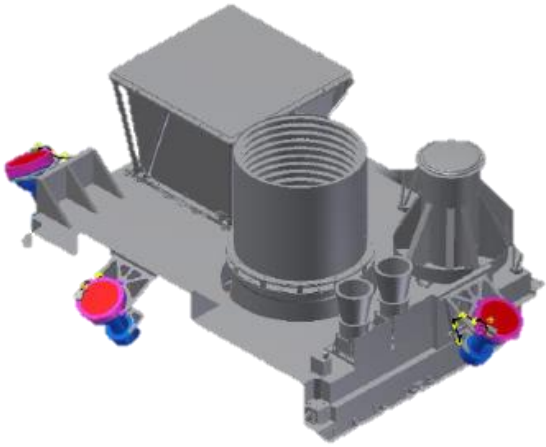
- **best-fit with GRM alone** (errors at 1 sigma):
  - alpha=-0.52 -0.61 +0.43
  - Ecut=(49.1 -15.0 +22.7) keV
  - C-Statistic = 3751.53 using 6039 PHA bins and 6036 degrees of freedom.

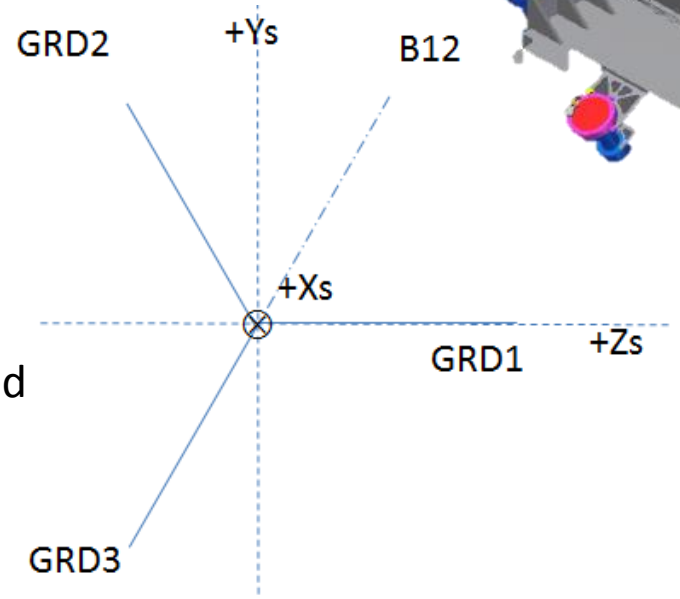
  → **much worse constrained**

  → **ECLAIRs contribution important in GRB spectral analysis**

GRB170817A: **GRM estimate for 2.56 s and off axis angles**

by S. Sch.





On axis numbers from Maria-Gracia, estimate number of counts for different GRB localizations.

- ECL on axis: burst probably triggered by each of the 3 GRDs separately
- GRD1 on-axis: not sure that GRD2 and GRD3 would have triggered
- On-axis B12: surely GRD3 would not have triggered

Note:

- ECLAIRs trigger enhancement uses GRM triggers with 3 GRDs only
- GRM trigger timescales: 1/8, 1 and 8 s

➔ Not sure GRM would help ECLAIRs

Cnts BKG	**3100.00**		
Source	ECL on axis	GRD1 on axis	B12 on axis
Cnts GRD1	**400.00**	461.88	404.15
Snr GRD1	7.18	8.30	7.26
Cnts GRD2	400.00	288.67	404.14
Snr GRD2	7.18	5.18	7.26
Cnts GRD3	400.00	288.67	230.94
Snr GRD3	7.18	5.18	4.15
CntsTot	1200.00	1039.23	1039.23
SnrTot	12.44	10.78	10.78

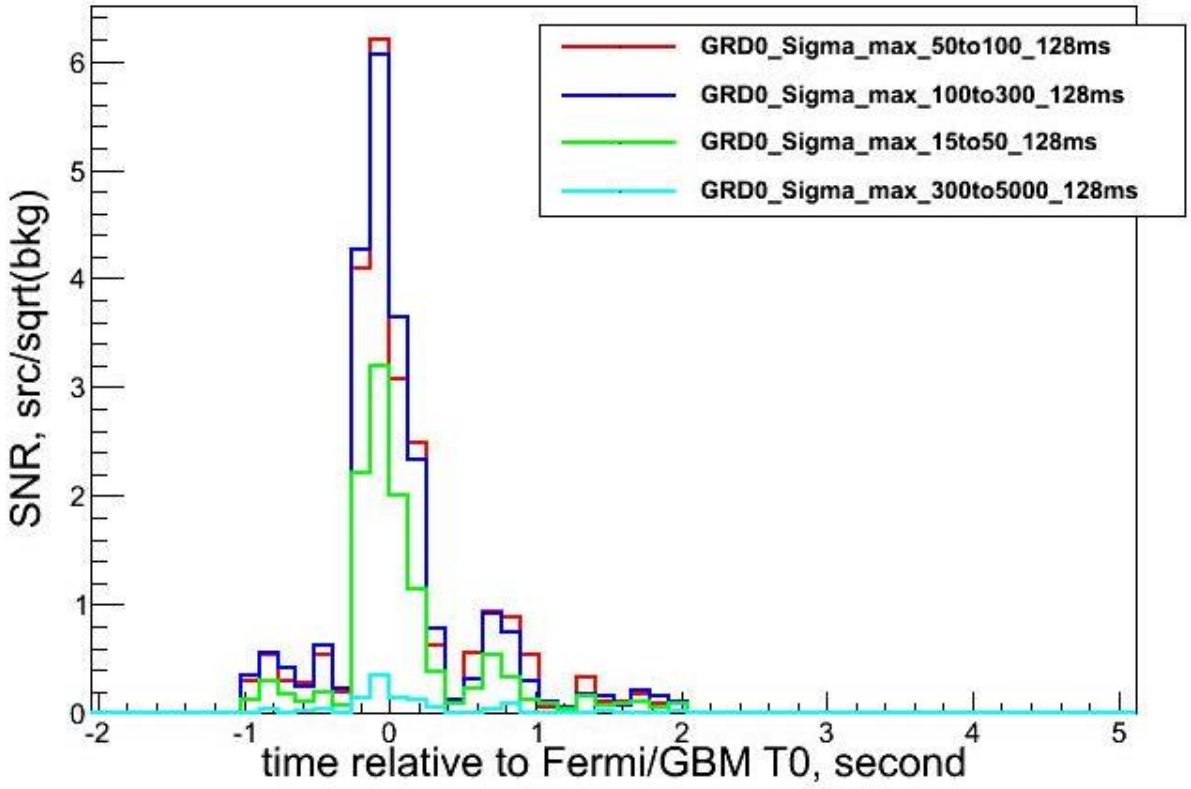
GRB170817A: **GRM estimate on 128 ms timescales on adjacent energy bands**

by S. Antier and F. Xie

- Photon by photon propagation through Geant-4 Model of GRM (by F. Xie)
- spectrum from GBM public GCN, amp=0.0092 (ph/cm^2/keV/s) alpha=-0.89 Epk=82 keV
- light-curve used: GBM (50-300 keV), containing only 1 peak
- GRB on-axis of ECLAIRs.

- Results for one GRD in adjacent energy bands:

15 – 50 keV
50 – 100 keV
100 – 300 keV
300 – 5000 keV



GRB170817A: **GRM estimate on 128 ms timescales on overlapping energy bds**

by S. Sch.

Best overlapping energy bands ?

* Numbers from Sarah and Fei's simulation on separate energy bands.

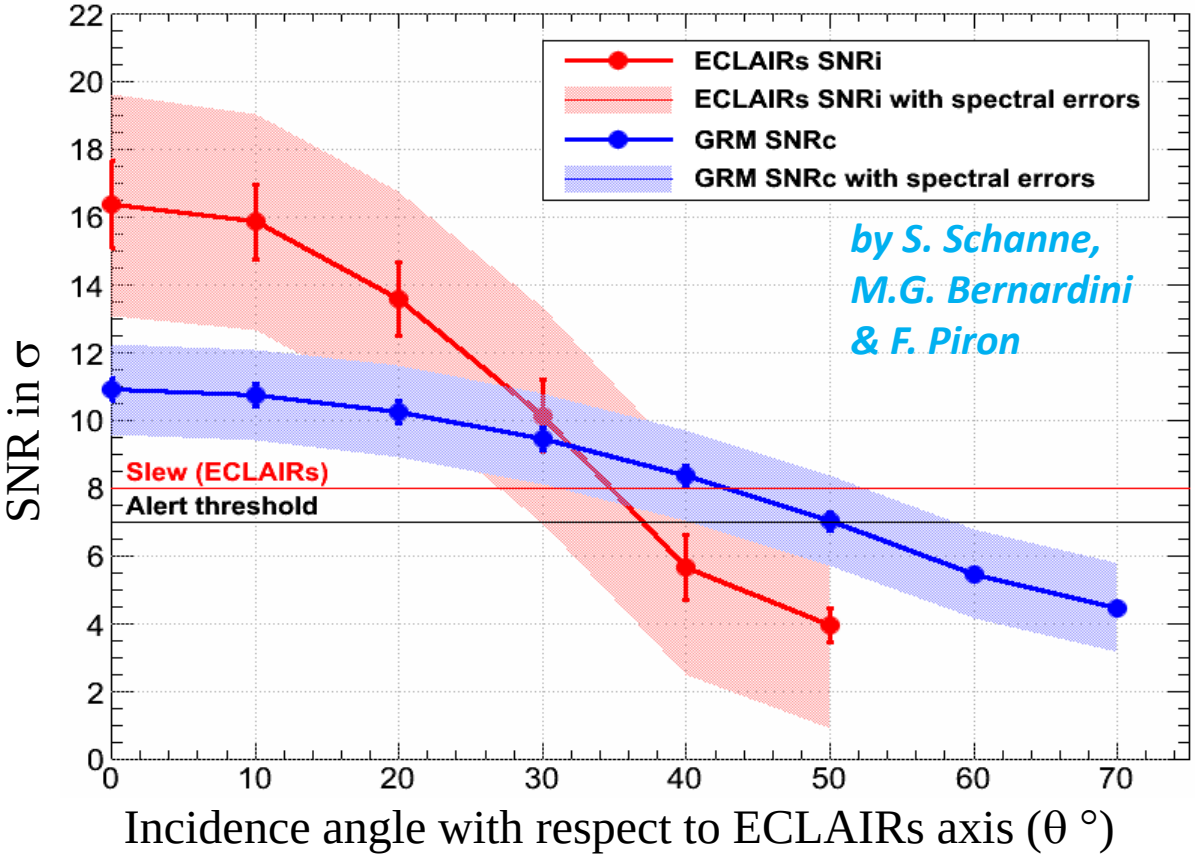
Energy Band	Bkg(cnt/s)	Bkg(cnt)	GRDi cnt	GRDi SNR	3 GRD cnt	3 GRD SNR
15-50 keV	530.00	67.84	26.63	3.23	79.89	5.60
50-100 keV	225.00	28.80	33.27	6.20	99.82	10.74
100-300keV	210.00	26.88	31.80	6.13	95.40	10.62
0.3-5 MeV	110.00	14.08	1.63	0.43	4.88	0.75
0.05-15 MeV	1075.00	137.60	93.33	7.96	279.99	13.78
15-300 keV	965.00	123.52	91.70	8.25	275.11	14.29
50-300 keV	435.00	55.68	65.07	8.72	195.21	15.10

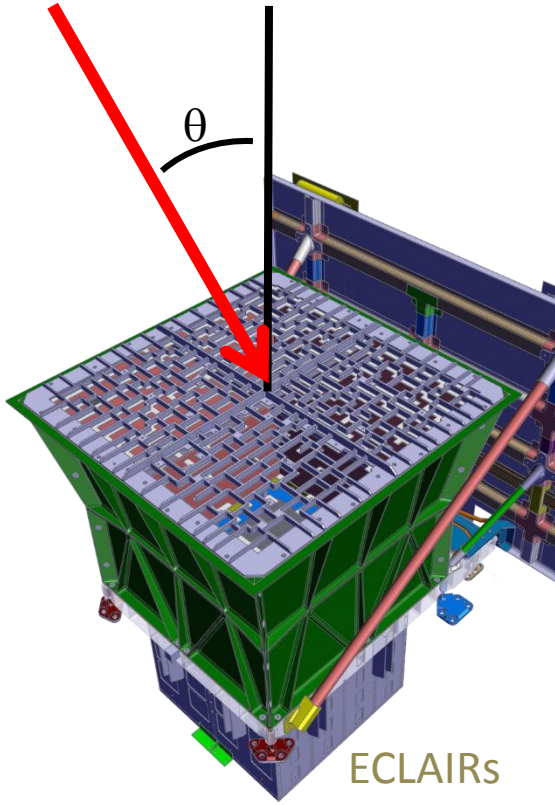
➔ Best energy band combination: **50-300 keV** > 15-300 keV > 50-5000 keV

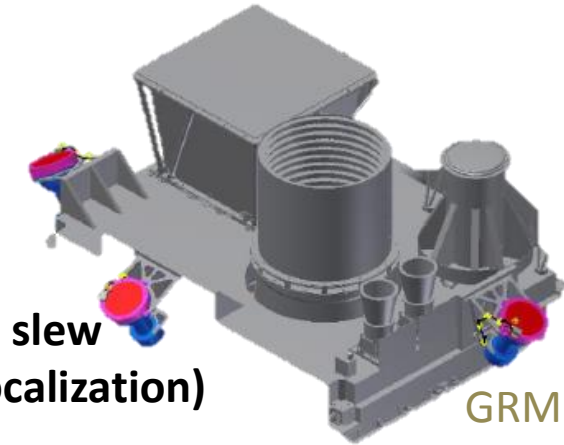
Summary on how *ECLAIRs and GRM* could have seen GRB170817A

GRB170817A: **detectability by ECLAIRs+GRM**

Assuming GRB spectral parameters and duration 2.56 s (T90)
from Fermi-GBM (first public GCN)







- **On axis: detection very likely, localization < 6 arcmin (90%)**
- **Up to 35°: ECLAIRs detection & localization probable, alert & slew**
- **Up to 50°: GRM detection probable, alert (without precise localization)**