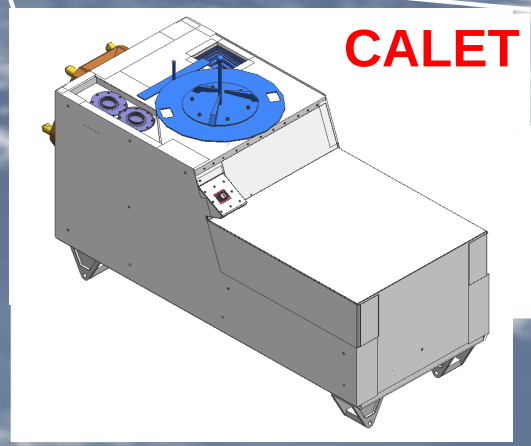
CALET Gamma-ray Burst Monitor: in-flight performance and preliminary results



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for the CALET collaboration

TeV Particle Astrophysics 2016

CERN, 12 September 2016

Summary

- The CALET mission and CGBM instrument.
- CALET GRB performances.
- CGBM in-flight operation.
- Some preliminary results on observed GRB's.
- Contribution to LIGO-Virgo gravitational wave follow-up campaign.
- Conclusions.

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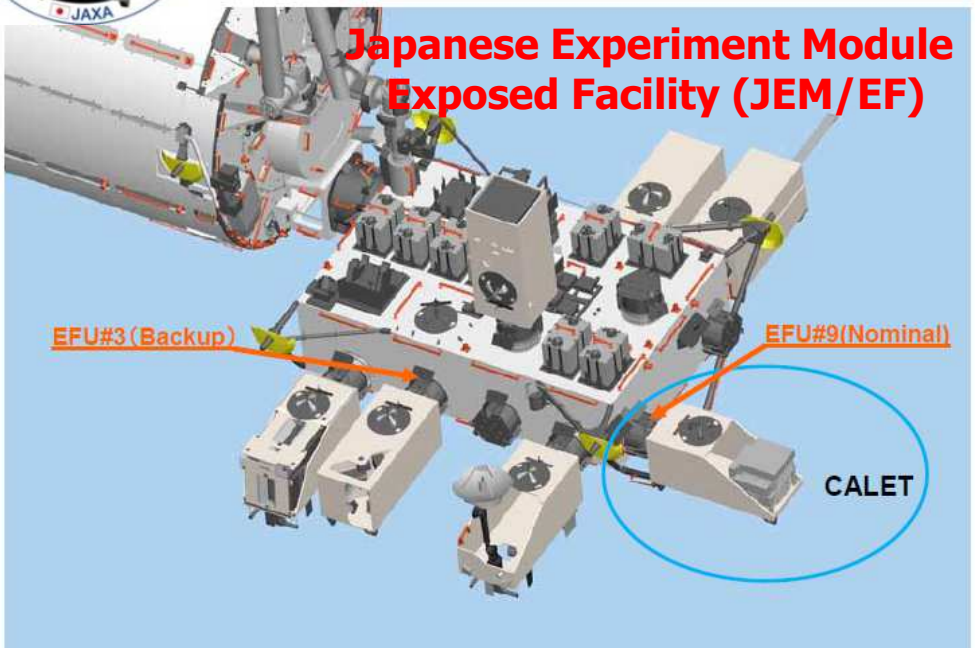
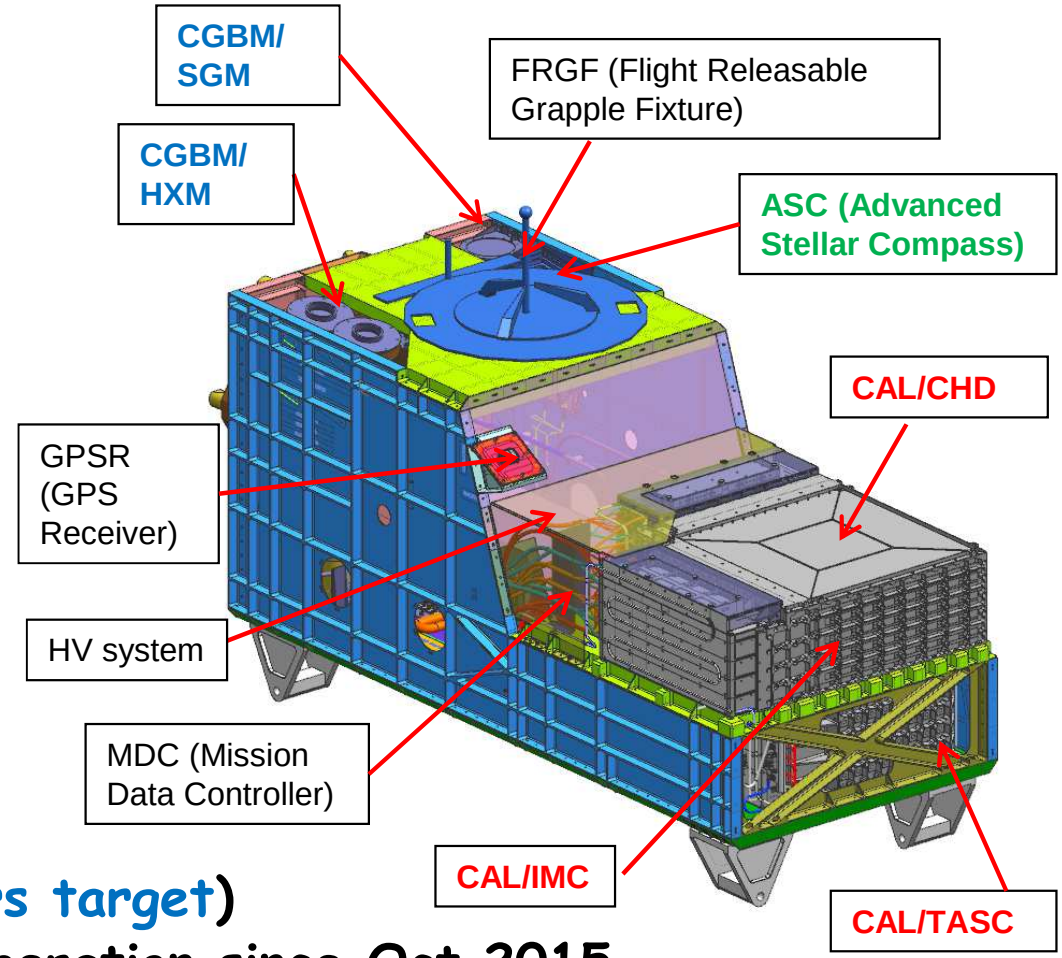
CALET payload on ISS



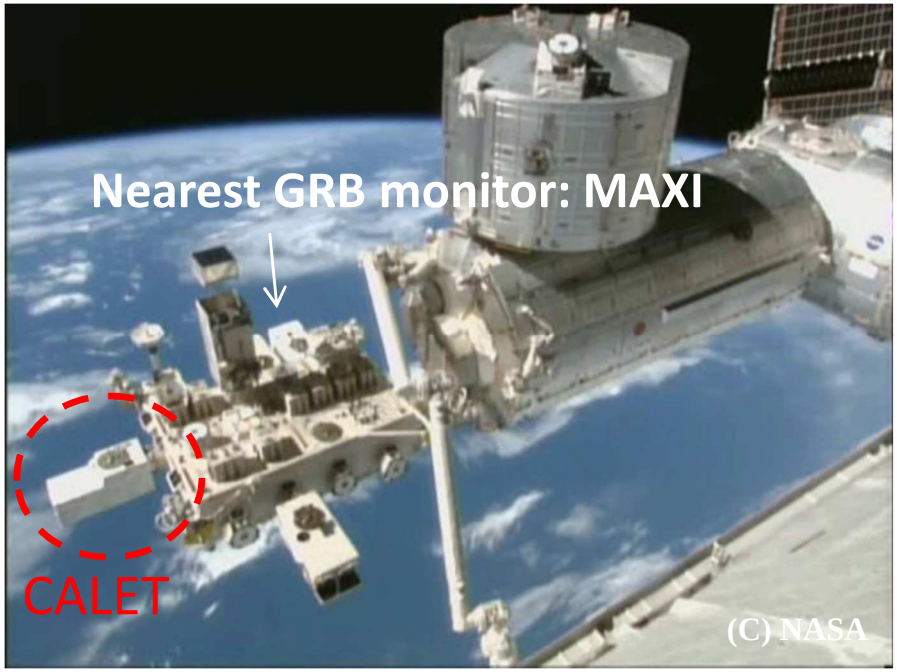


- Launch carrier: HTV-5
- Location: JEM Port 9
- Mission duration: **> 2 years (5 years target)**
- Current status: **regular scientific operation since Oct 2015**

- Data rate to ground:
  - Medium data rate: 600 kbps
  - Low data rate: 50 kbps

- Mass: **613 kg**
- Size: JEM/EF Standard Payload **(1.85 m · 0.8 m · 1 m)**
- Power: **507 W** in nominal condition

CALET overview

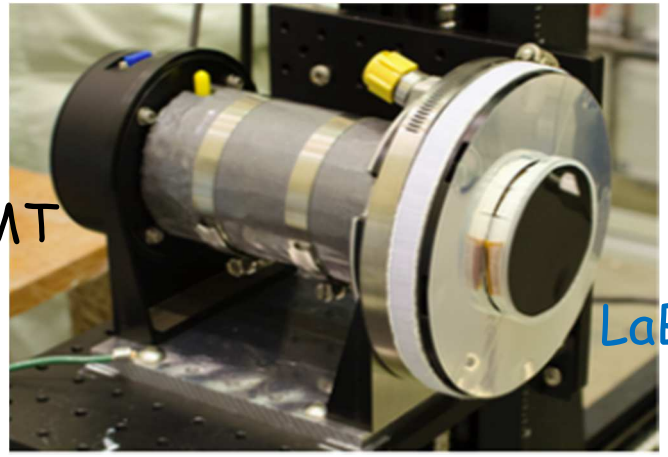


- **Overall scientific goals.**
  - High energy electrons and nuclei spectra.
  - All sky gamma-ray survey (E > 10 GeV).
  - Monitoring **X/gamma-ray transients** (GRB's, SGR's, ...) in a **broad energy range: few keV X-rays to GeV/TeV**, thus including long- and short-duration GRB's, X-ray flashes, GeV GRB's.
- **Main instrument: Calorimeter (CAL).**
  - Optimized for electrons: 1 GeV – 20 TeV.
  - **Gamma-rays: few GeV – 10 TeV.**
  - Protons and heavy ions: tens of GeV – 1 PeV.
- **Secondary instrument: CALET Gamma-ray Burst Monitor (CGBM).**
  - Hard X-ray Monitor (HXM): **7 keV – 1 MeV.**
  - Soft Gamma-ray Monitor (SGM): **100 keV – 20 MeV.**
  - **Sensitivity:** ~10^{-8} erg cm^{-2} s^{-1} (1 keV - MeV) for 50 s long bursts.
  - With **GRB trigger** from CGBM:
    - CAL trigger thresholds are lowered to also observe gamma-rays of few GeV (normally kept higher to reduce background from charged particles).
    - Advanced Stellar Compass (ASC) is activated to catch possible prompt optical GRB emission.

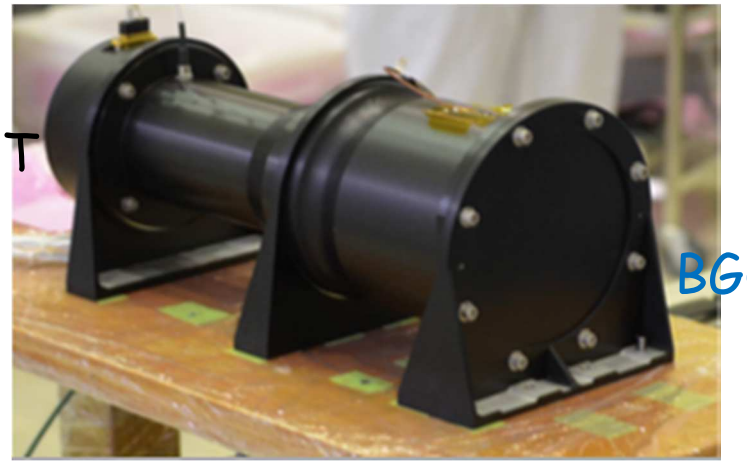
CGBM: CALET gamma-ray burst monitor

Hard X-ray Monitor (HXM)

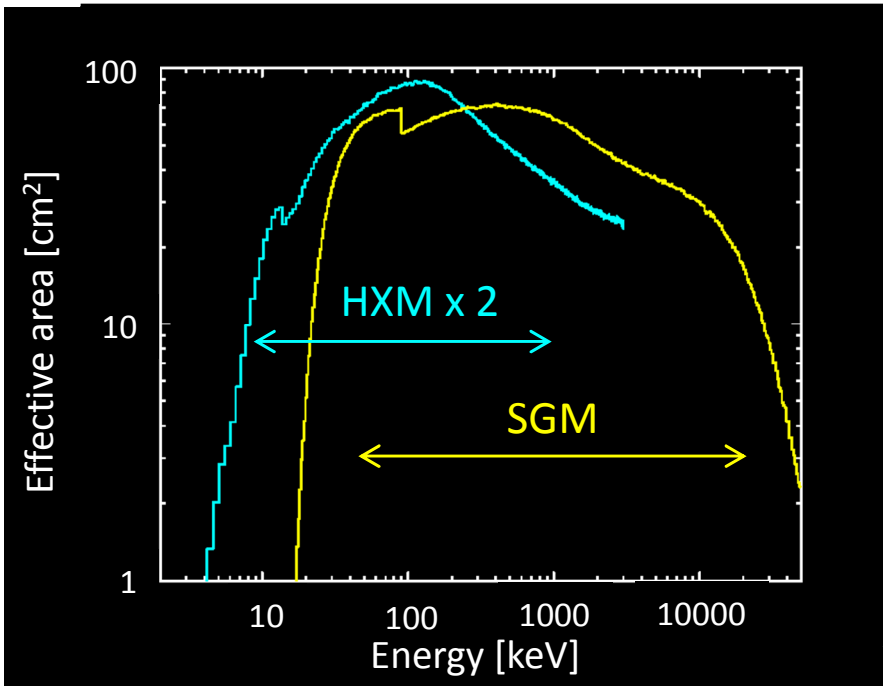
2 units



Soft Gamma-ray Monitor (SGM)

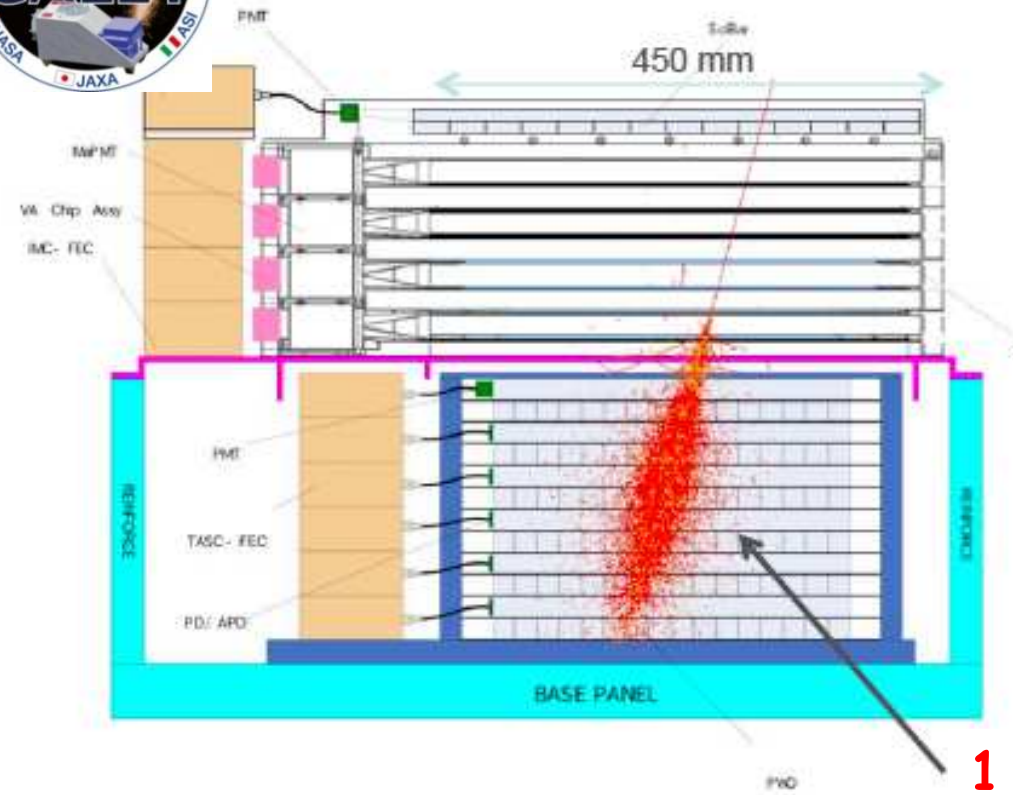


$LaBr_3(Ce)$ used for the first time in GRB observations.



	HXM	SGM
Detector	$LaBr_3(Ce)$	BGO
Read-out	PMT+CSA	PMT+CSA
Diameter (cm)	6.6 (front) 7.9 (rear)	10.2
Thickness (cm)	1.3	7.6
Number of units	2	1

CALET/CAL structure



- **CHarge Detector (CHD)**
  (Charge Measurement in Z=1-40)
- **Imaging Calorimeter (IMC)**
  (Particle ID, Direction)
  Total Thickness of Tungsten (W): $3X_0$, $0.11\ \lambda_I$
  Layer Number of Scifi Belts: 8 Layers × 2(X,Y)
- **Total Absorption Calorimeter (TASC)**
  (Energy Measurement, Particle ID)
  PWO 20mm x 20mm x 320mm
  Total Depth of PWO: $27\ X_0$ (24 cm) , $1.35\ \lambda_I$

1 TeV electron shower

	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Function	Charge Measurement (Z=1-40)	Arrival Direction, Particle ID	Energy Measurement, Particle ID
Sensor (+ Absorber)	Plastic Scintillator : 2 layers Unit Size: 32mm x 10mm x 450mm	SciFi : 16 layers Unit size: 1mm² x 448 mm Total thickness of Tungsten: 3 X_0	PWO log: 12 layers Unit size: 19mm x 20mm x 326mm Total Thickness of PWO: 27 X_0
Readout	PMT+CSA	64 -anode PMT+ ASIC	APD/PD+CSA PMT+CSA (for Trigger)

Overall CALET performances for GRB's

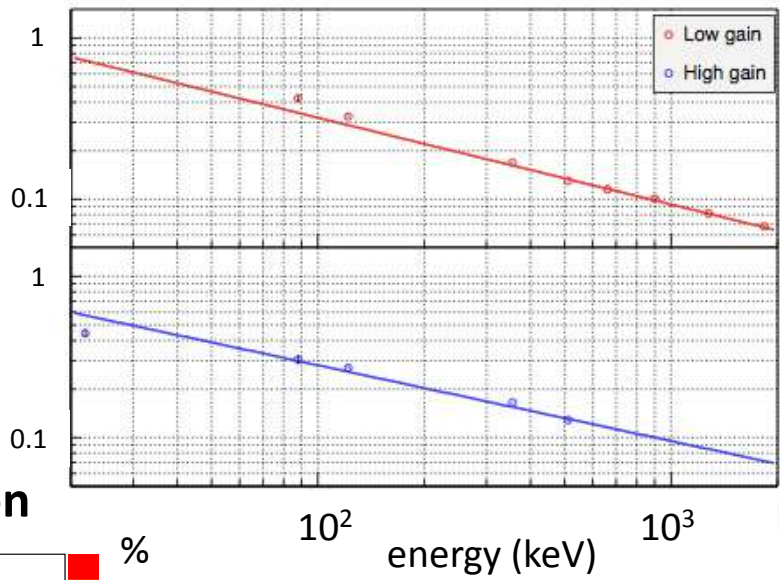
	CALET/CAL	CGBM	ASC
Energy range	After GRB trigger: **1 GeV - 10 TeV** Regular: **10 GeV - 10 TeV**	**HXM:** **high gain ch. 7 keV - 100 keV** **low gain ch. 60 keV - 1 MeV** **SGM:** **high gain ch. 100 keV - 1 MeV** **low gain ch. 0.5 MeV - 20 MeV**	Wavelength 3000 - 8000 Å
Energy resolution	**3%** (at 10 GeV)	HXM: ~ 5% (at 662 keV) SGM: ~ 15% (at 662 keV)	
On-axis effective area	~ 600 cm^2 (at 10 GeV)	HXM: ~ 80 cm^2 (2 units) SGM: ~ 70 cm^2	
Field of view	~ 45° (~ 2 sr)	**HXM: ~ 3 sr** **SGM: ~ 2π sr**	18.4° · 13.4°
Angular resolution	2.5° (at 1 GeV) 0.35° (at 10 GeV)	-	~ 1"
Time resolution	62.5 μs	**GRB trigger data:** 45 μs with 4096 energy channels **Regular data:** 125 ms with 8 en. ch.; 4 s with 512 en. ch.	0.5 s (2 images per GRB trigger)

CGBM ground calibration

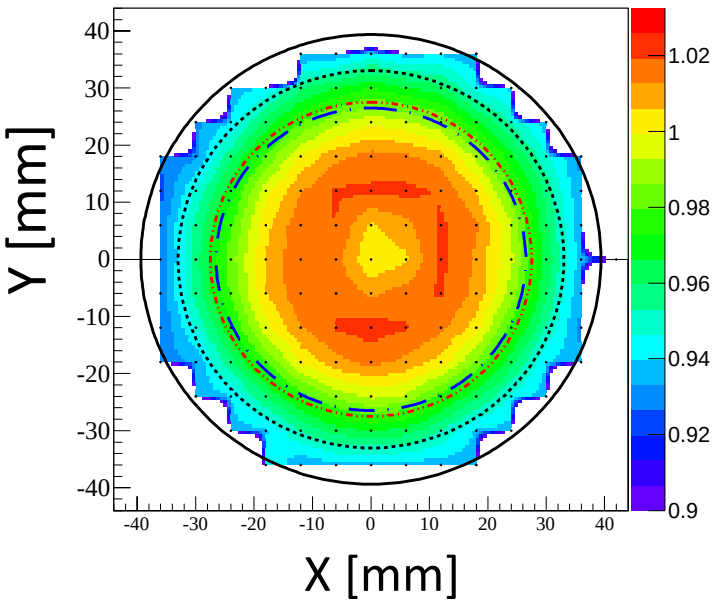
- Ground tests performed:
  - 2D mapping of peak channel and energy resolution;
  - response linearity;
  - dependence of resolution on energy;
  - response dependence on photon incidence angle.

- HXM 2D mapping with 511 keV gamma-ray from ^{22}Na collimated to ~ 10 mm at crystal surface.

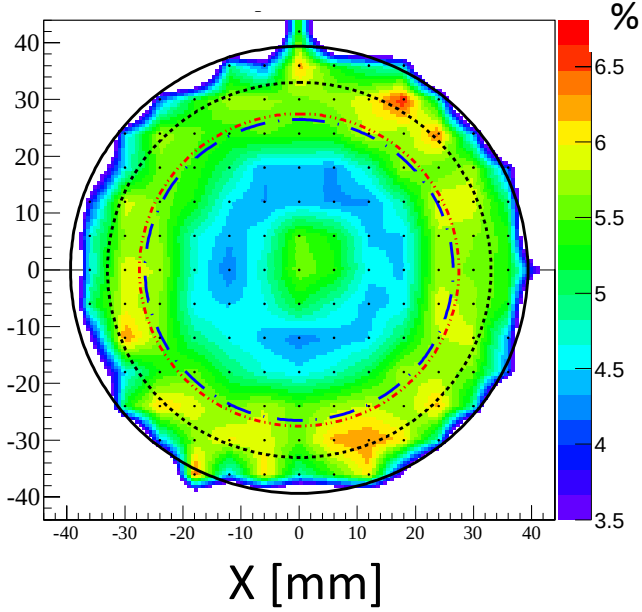
- SGM energy resolution.



peak channel (normalized at centre)



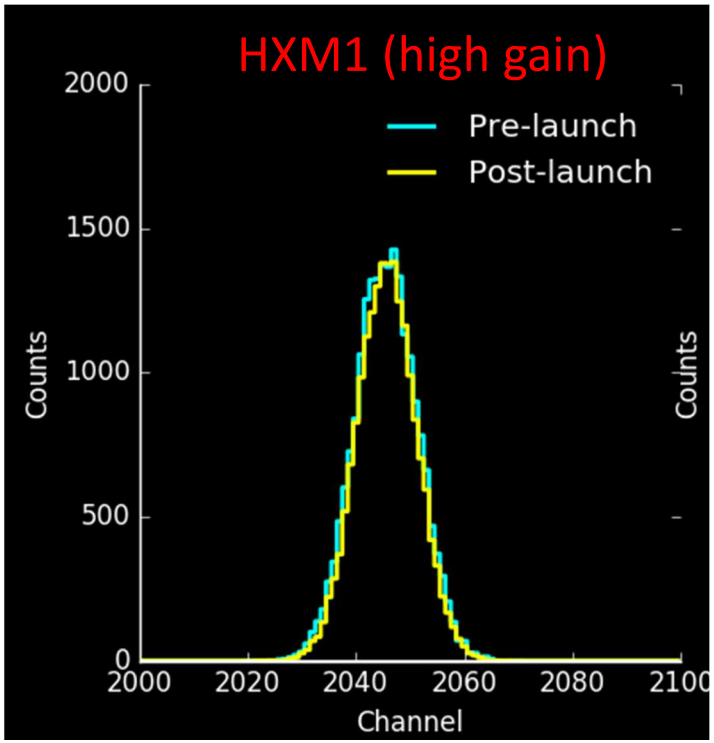
energy resolution



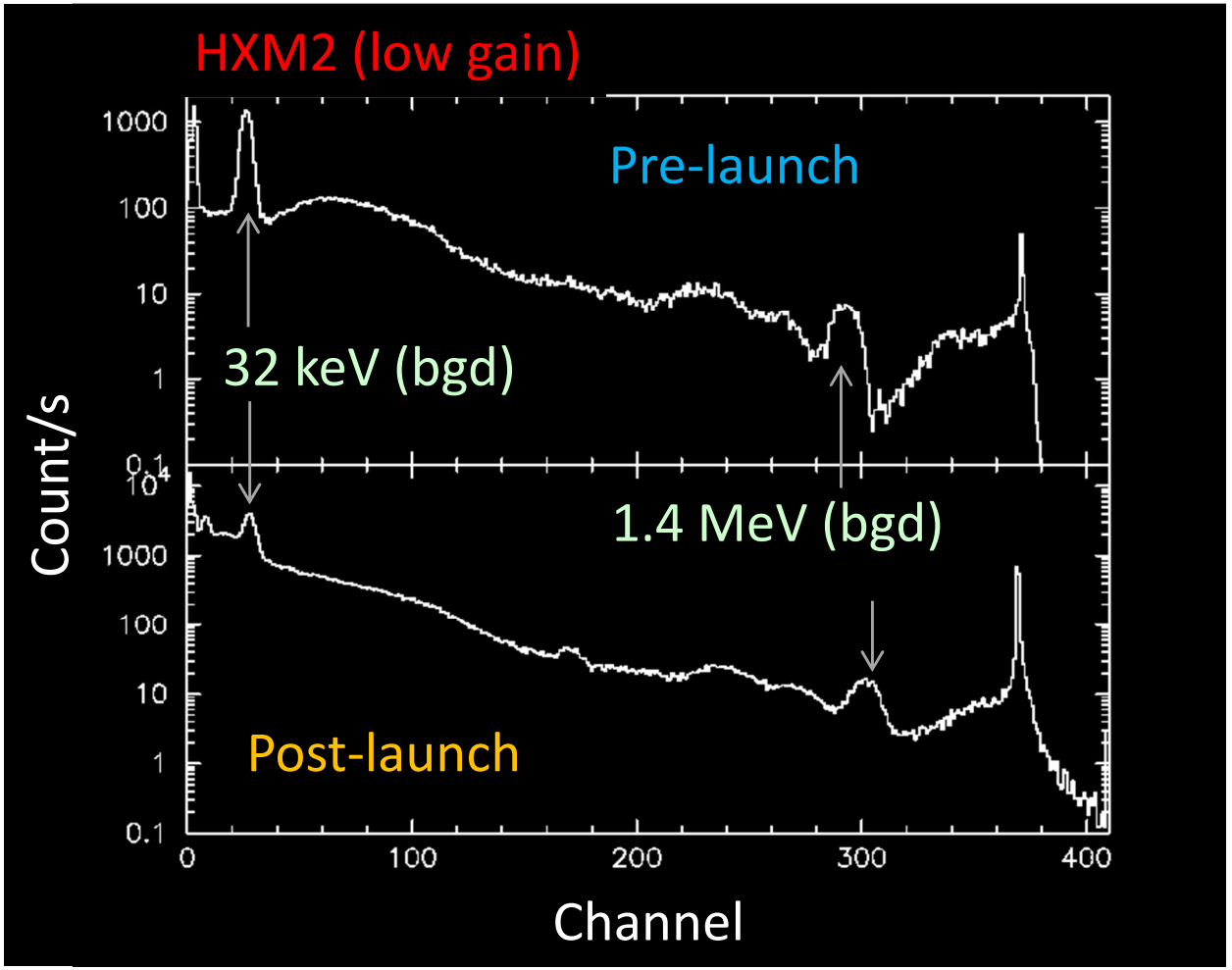
CGBM in-flight performance check

- **Good consistency found between pre-launch and post-launch data** for all read-out channels (no degradation in performance between ground and flight data).

- Peak channel and width of pedestal data.

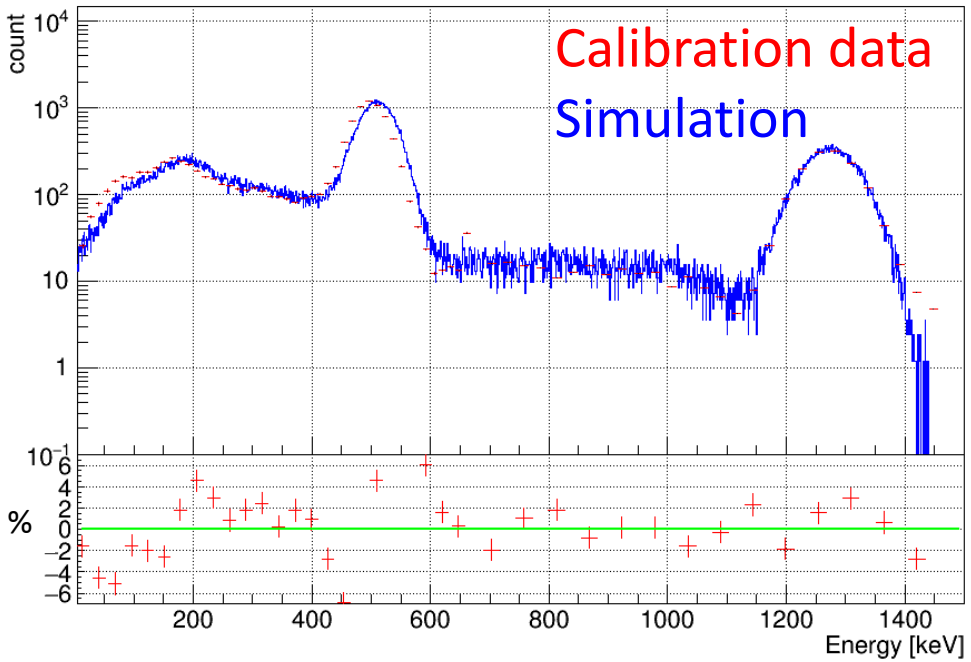


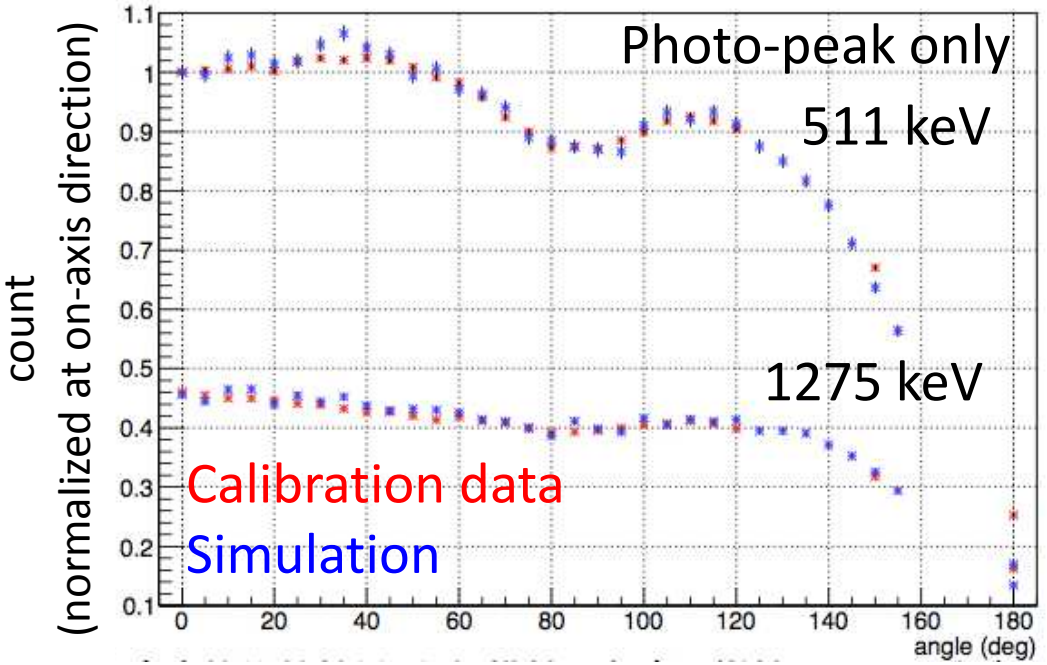
- Energy resolution of internal background lines.



CGBM energy response matrix

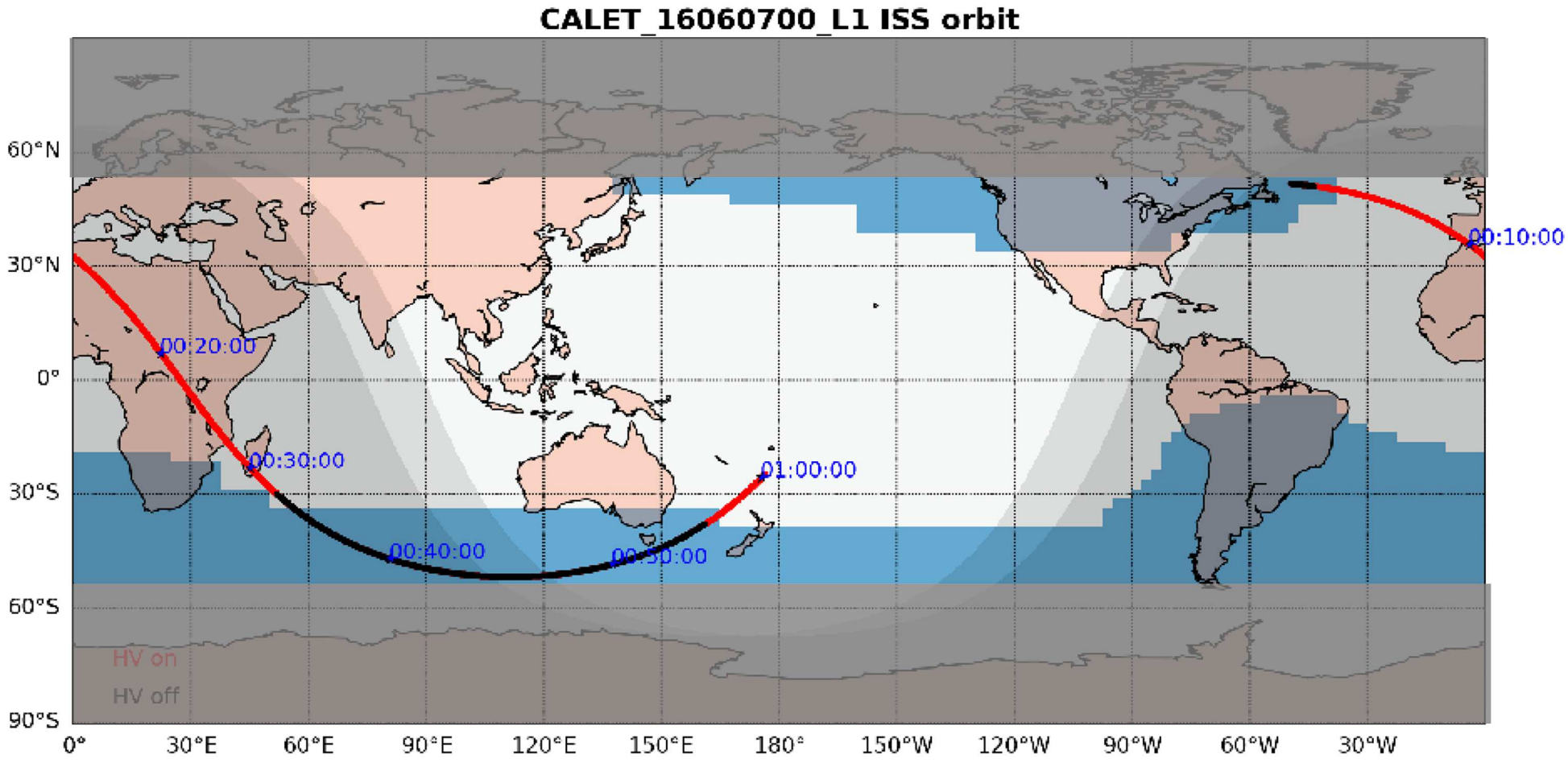
- Detector response matrix is obtained with Geant 4 simulator tuned with experimental data, collected during ground calibration tests and cross-checked with flight data where possible.
- Also foreseen cross-calibrations by using simultaneous GRB observations of CGBM and other GRB instruments (Swift/BAT, Fermi/GBM, etc.).
  - SGM simulation vs. ground calibration data with ^{22}Na source.





CGBM in-flight operation

- PMT high-voltage on/off is automatically done to avoid high-radiation areas.
- HV-on time fraction ~ 60 %.



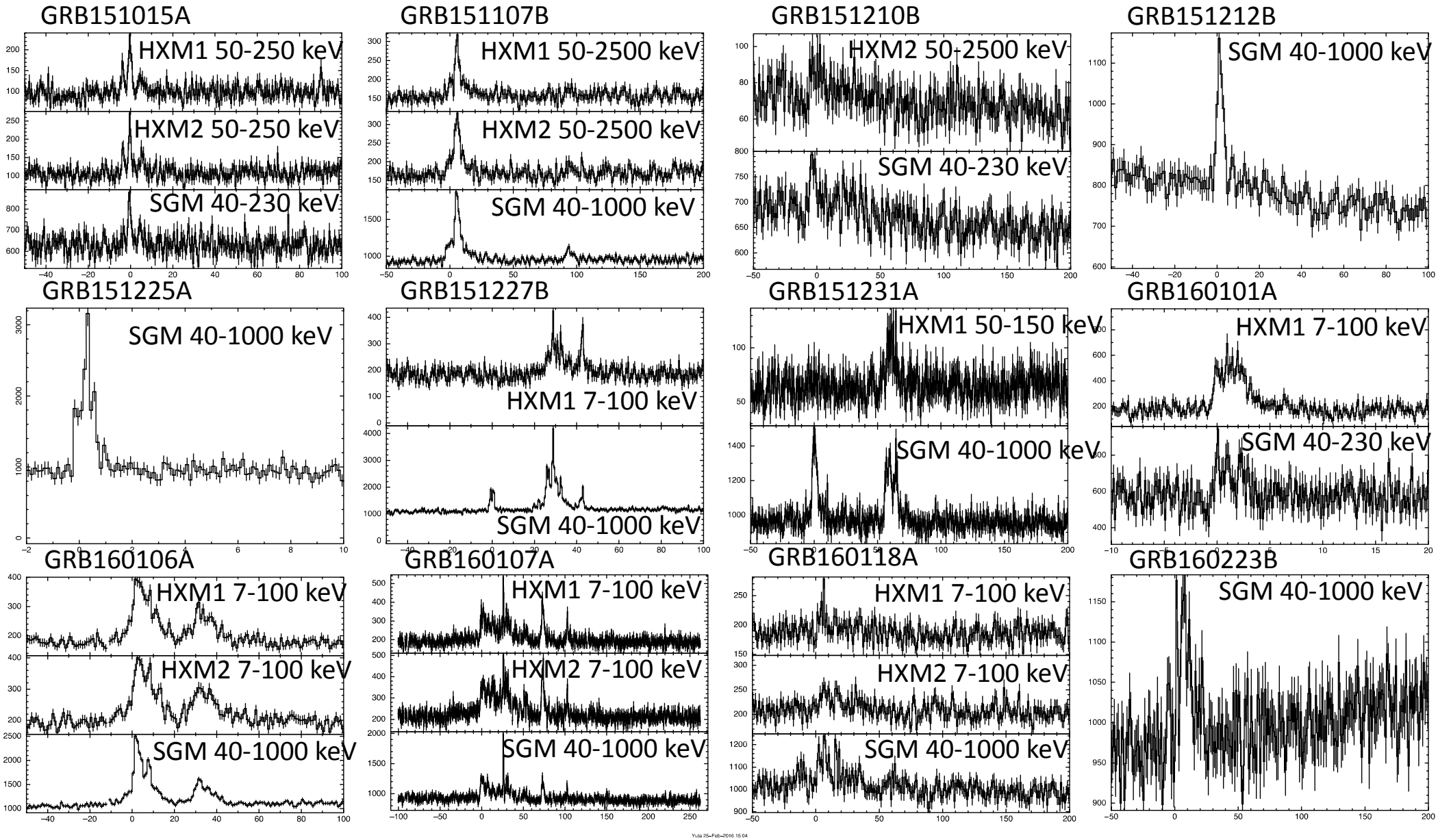
HV off region

Typical GRB trigger operation

- **Flexible CGBM trigger system with adjustable settings** for best compromise between **high GRB trigger efficiency** and **low number of spurious triggers** (radiation belt particles, solar flares, etc.).
  - Trigger condition: number of signal pulses during signal integration time exceed expected background N_{exp_bgd} by $n \cdot \sqrt{N_{exp\_bgd}}$
  - Signal pulses only considered in a configurable energy band, typically:
    HXM: 25 - 100 keV **SGM: 50 - 300 keV**
  - Several trigger channels with different signal integration times (from 0.25 s to 4 s) independently activated for each detector.
  - Decision levels (*n*) independently configured from 4 to 13, typically:
    HXM: n = 8.5 **SGM: n = 7**
  - Background integration time can be varied from 8 s to 64 s.
- After GRB trigger, ***high-time-resolution event data*** saved for a configurable time interval (typically: 8 s) around trigger.
  - Automatic data processing after downlink to ground.
  - Generation of **public real-time alert through GCN notice** (possible for ~ 70% triggers, when bandwidth for immediate downlink available).

Some GRB's observed by CGBM

- Light curves in different detectors and energy bands are shown.



Summary of observed GRB's

- **37 confirmed GRB's observed in 315 days** (~ 43 GRB's/yr).
- Mostly long GRB's (~ 10% are short GRB's).
- ~ 30% of GRB's only seen by SGM.
- 4 GRB's also simultaneously observed by nearby experiment MAXI.
  - GRB's observed during August 2016.

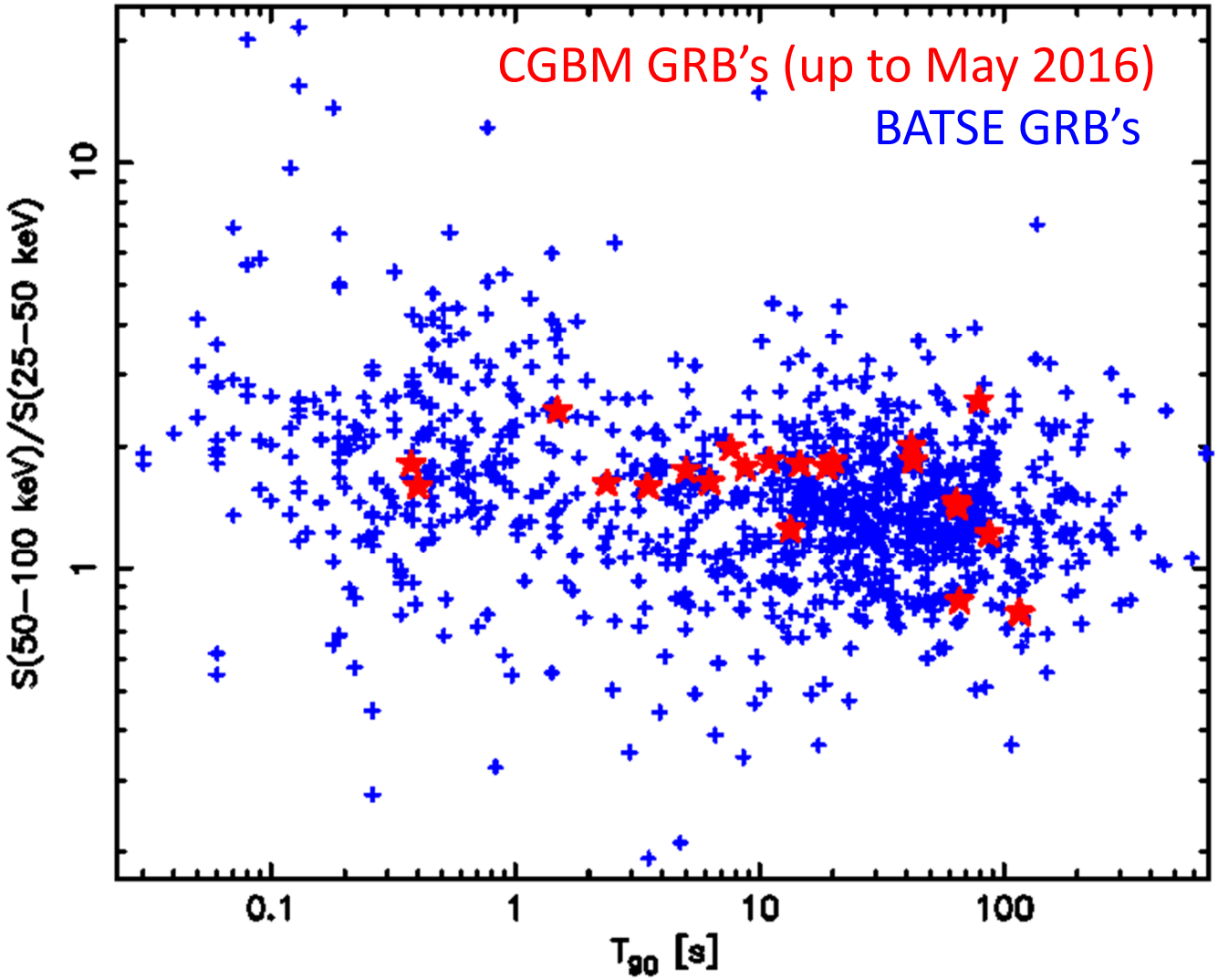
GRB name	HXM1	HXM2	SGM	T_{90} [s] (SGM data)	Other experiments
GRB 160802A	✔	✔	✔	16.1 ±0.1	F, K, L
GRB 160804B	-	-	✔	0.41 ±0.04	F
GRB 160814A	✔	✔	✔	10 ±1	K, M
GRB 160815A	-	-	✔	3.6 ±0.6	F, S
GRB 160821A	✔	✔	✔	35.1 ± 0.8	F, I, S
GRB 160824B	✔	✔	✔	2.7 ± 0.1	F, I

F:Fermi/GBM I:INTEGRAL/ACS K:KONUS L: Lomonosov/BDRG M:MAXI/GSC S:Swift/BAT

- Complete list of observed GRB's can be retrieved via GCN circulars.

Observed GRB's

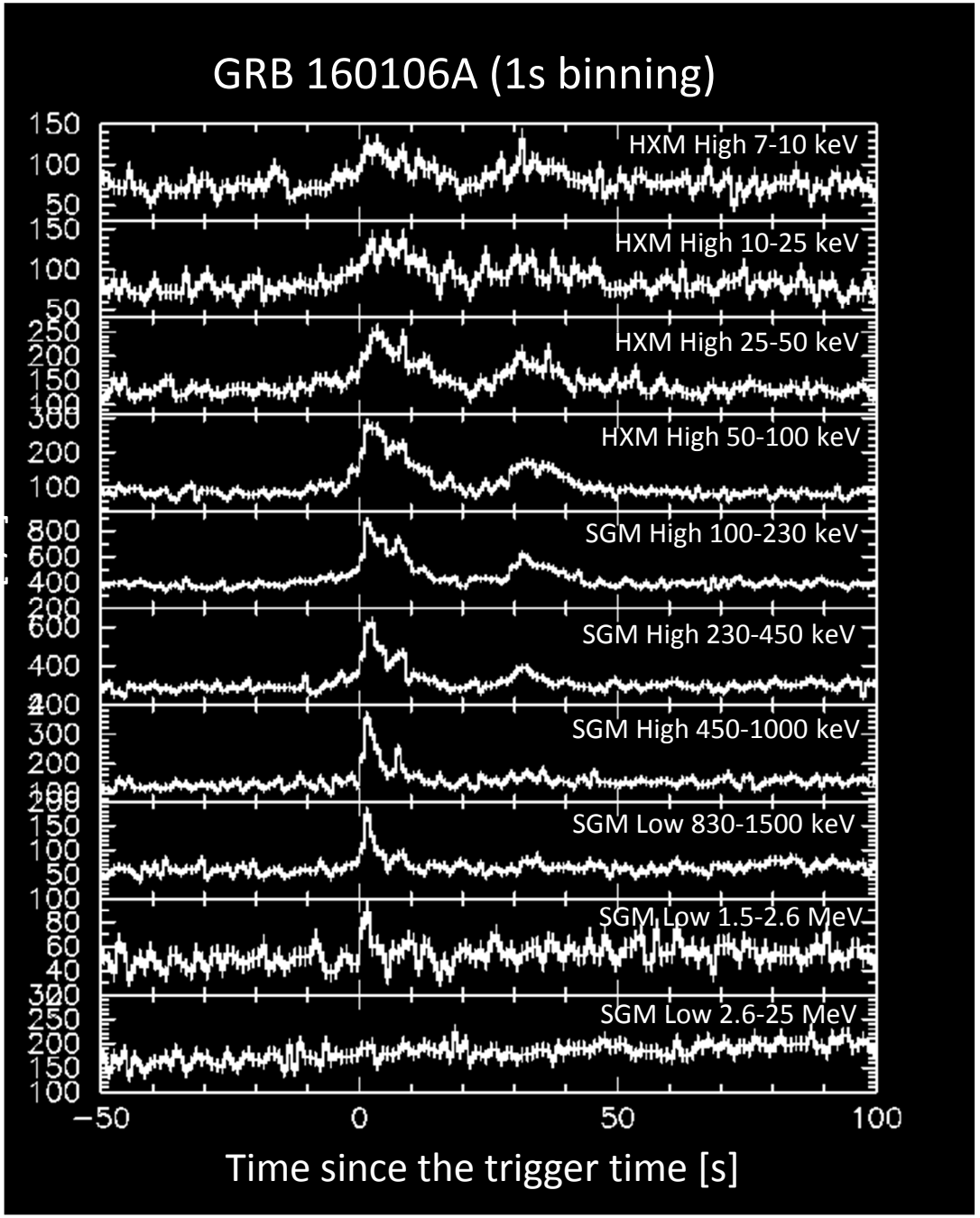
Hardness vs. T_{90}



- T_{90} : time over which the central 90% counts have been accumulated.

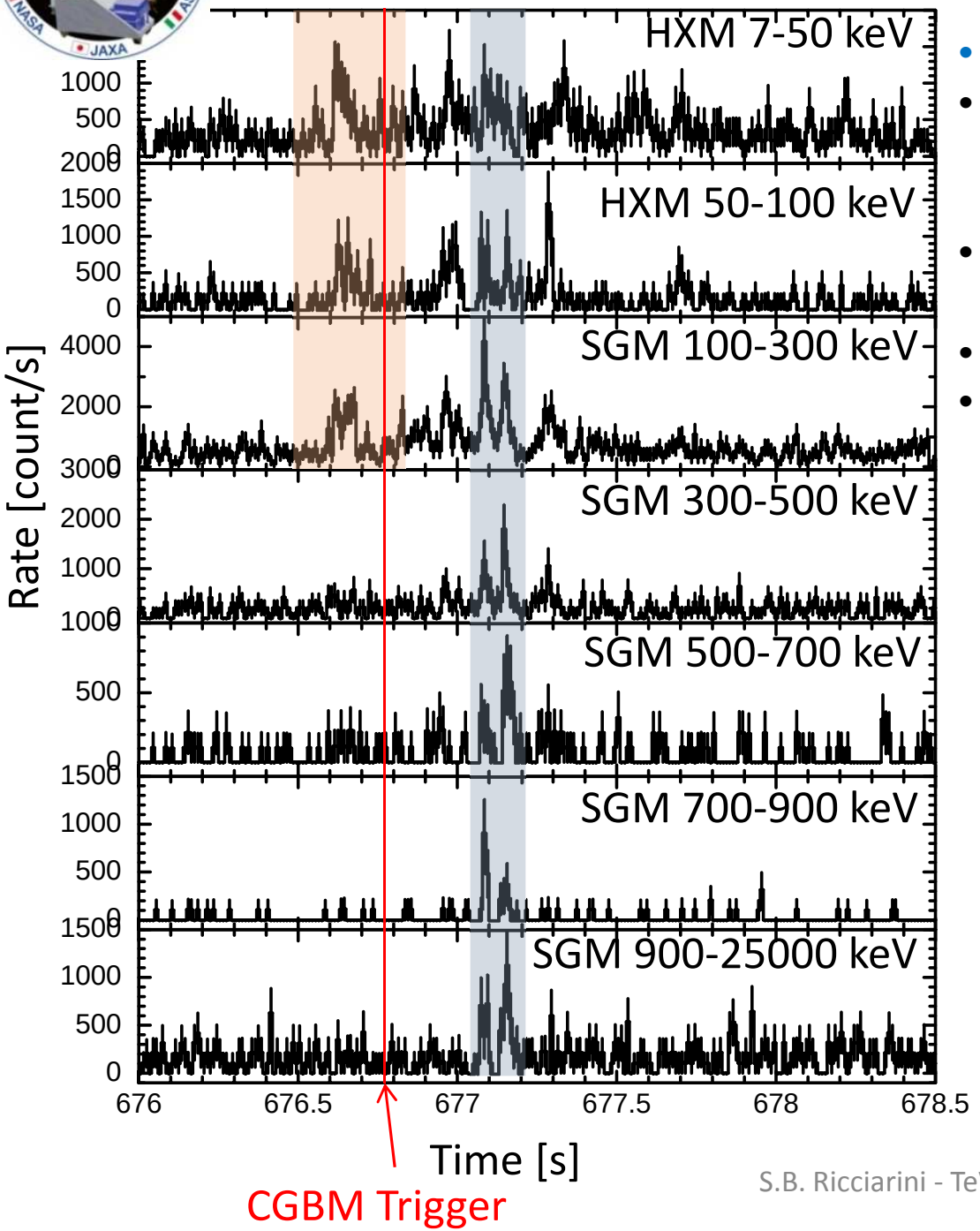
Observed GRB's

- Note the CGBM broad energy coverage (7 keV to 25 MeV), obtained with two different detectors and two gain channels each.
- Coverage will be further extended (E > 1 GeV) with CALET/CAL data (analysis underway).



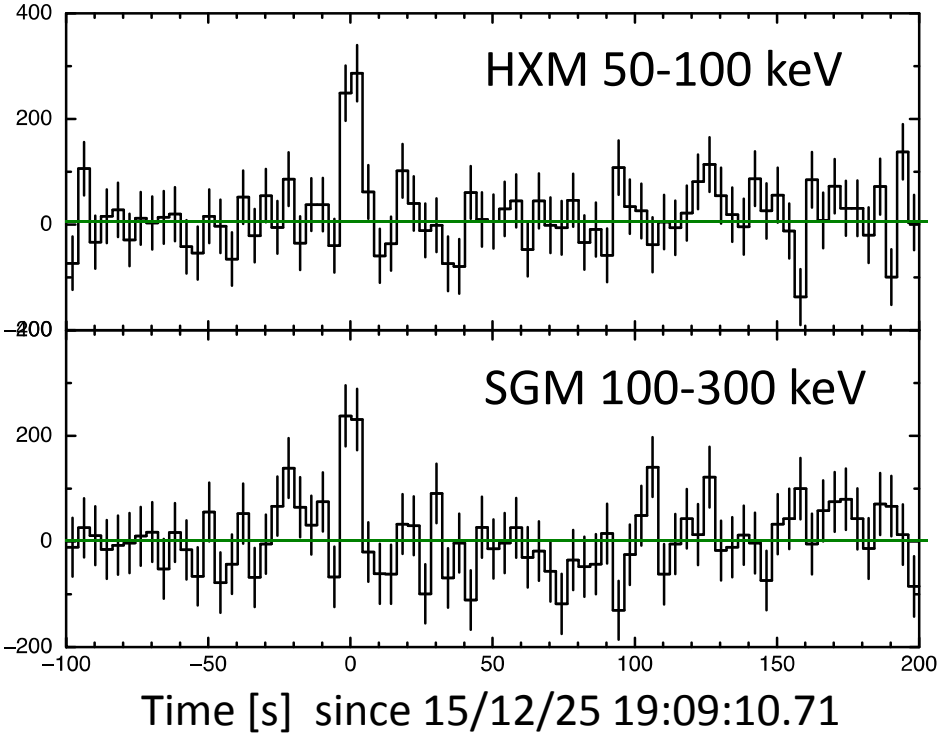
First short GRB observed: 151225A

(Kawakubo et al. in prep.)

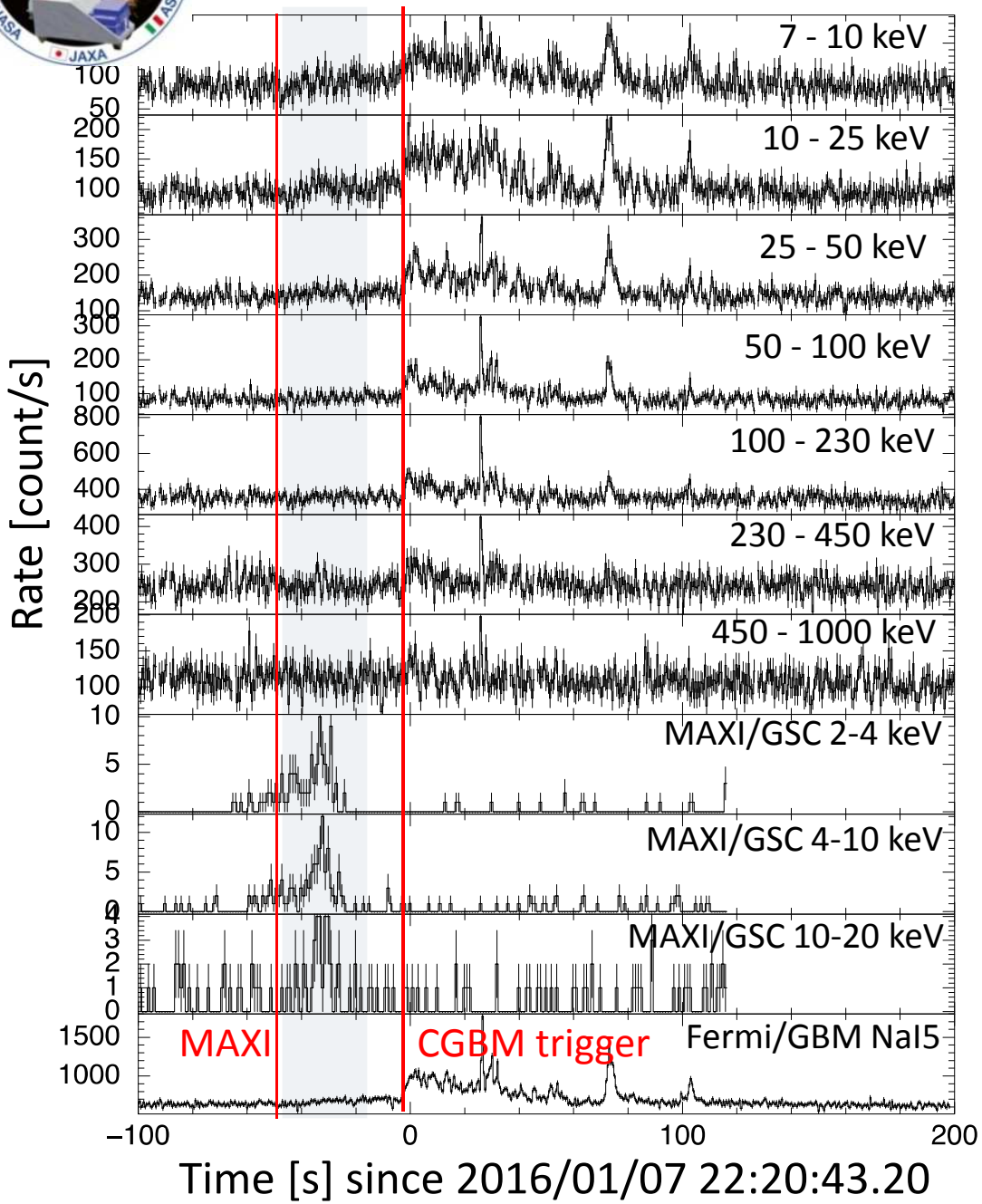


- **Double burst structure** (0.7 s separation).
- First burst not like a typical precursor of s-GRB, but emission is softer than the rest of the GRB.
- No spectral lag.

- T_{90} = 1.87 ± 0.13 s (SGM, 40 - 450 keV).
- No time-extended emission (see below).



Combined observations with other instruments



- **GRB 160107A** also observed by MAXI/GSC and Fermi/GBM instruments.
- **MAXI-CALET combined analysis paper in preparation** (Sakamoto, Serino, Kawakubo et al.).
- MAXI trigger time was ~ 40 s before CGBM and Fermi/GBM trigger time.

LIGO-Virgo gravitational wave follow-up

- CALET takes part in the **follow-up search for electromagnetic counterparts of GW events** reported by LIGO-Virgo collaboration (MoU signed).
- Starting with next LIGO-Virgo O2 run, CALET will deliver:
  - fine-time-resolution CGBM light curves (in few days);
  - CGBM spectral analysis (if source localization info available);
  - CALET/CAL preliminary light curves, spectra and localization info.

- CALET set 7σ **upper limits on possible hard X-ray and gamma-ray counterparts of GW 151226** in HXM, SGM and CAL energy bands (article accepted for publication in ApJ letters).

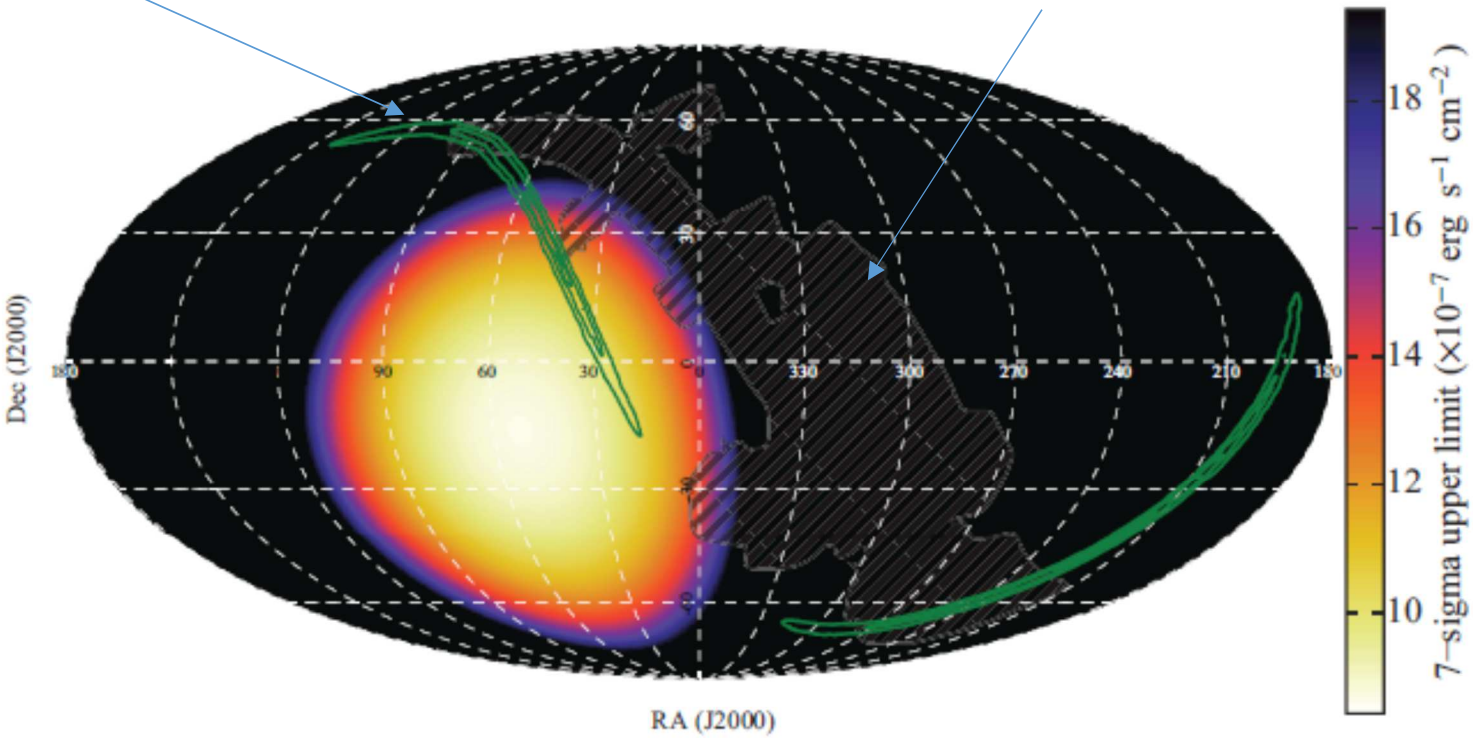
	HXM (7-500 keV; 30° off-axis)	SGM (50-1000 keV; 45° off-axis)
s-GRB	1.0×10^{-6} erg cm^{-2} s^{-1}	1.8×10^{-6} erg cm^{-2} s^{-1}
Crab-like	5.1×10^{-7} erg cm^{-2} s^{-1}	1.4×10^{-6} erg cm^{-2} s^{-1}

Upper limits on GW 151226 counterparts

- Example: sky map of the 7σ upper limit on emission intensity set by HXM (7 - 500 keV), assuming an emission spectrum of a typical BATSE s-GRB.

GW 151226 probability map by LIGO-Virgo

shadow of ISS



Conclusions

- **CGBM fully operating and detecting GRB's at a rate of ~ 43 GRB/yr.**
- Light curves of 37 confirmed GRB's reported on GCN circulars.
- CGBM energy response function is being finalized.
- CAL and ASC data analysis for CGBM detected GRB's is underway.
- **Short GRB 151225A** and **combined CGBM-MAXI observation of GRB 160107A** are analyzed in detail for publications.
- **Upper limits on EM counterpart of GW 151226** are accepted for publication in ApJ letters.