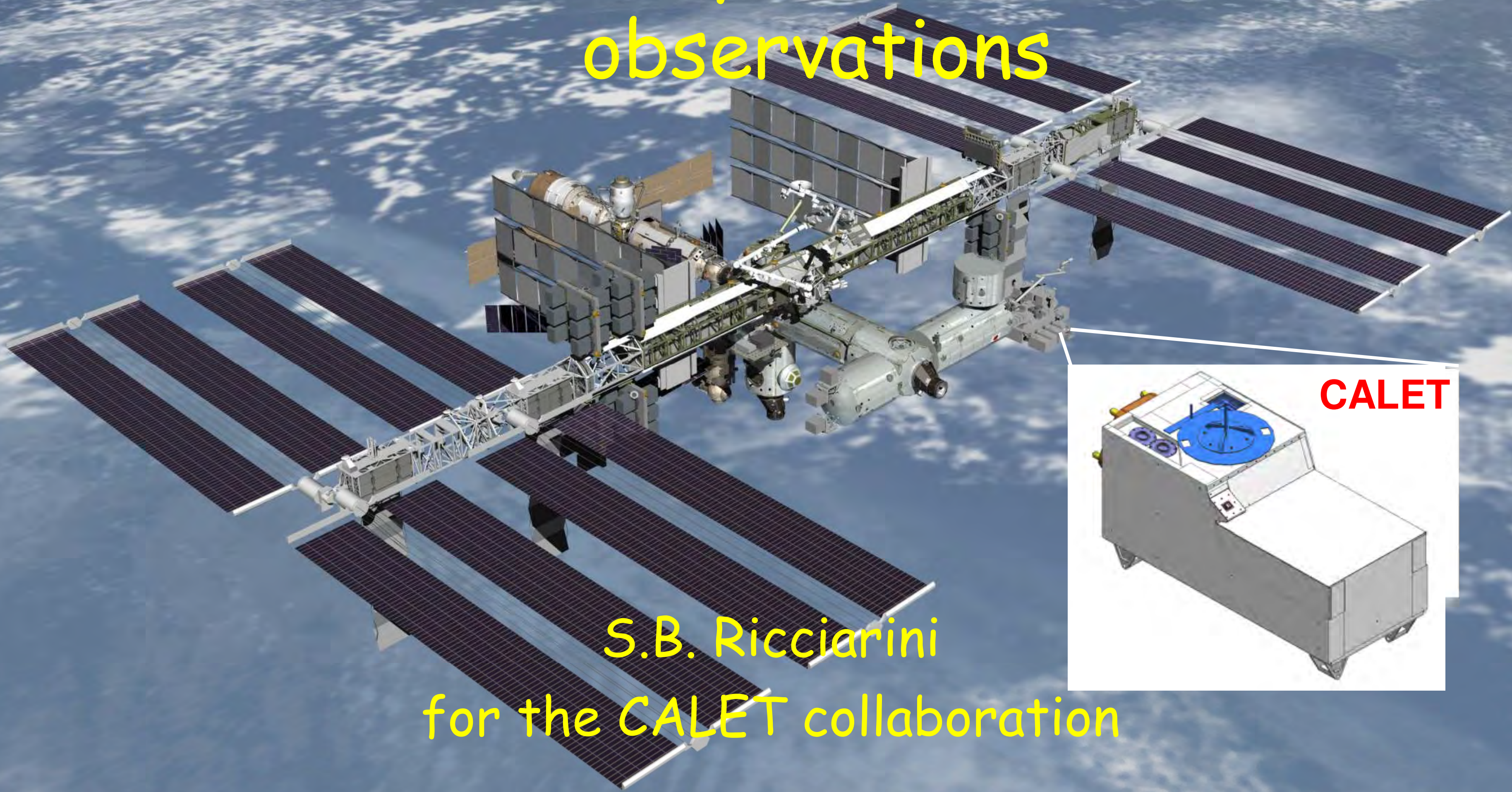
CALET Gamma-ray Burst Monitor observations



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for the CALET collaboration

COSPAR 2018

Pasadena, 17 July 2018

Summary

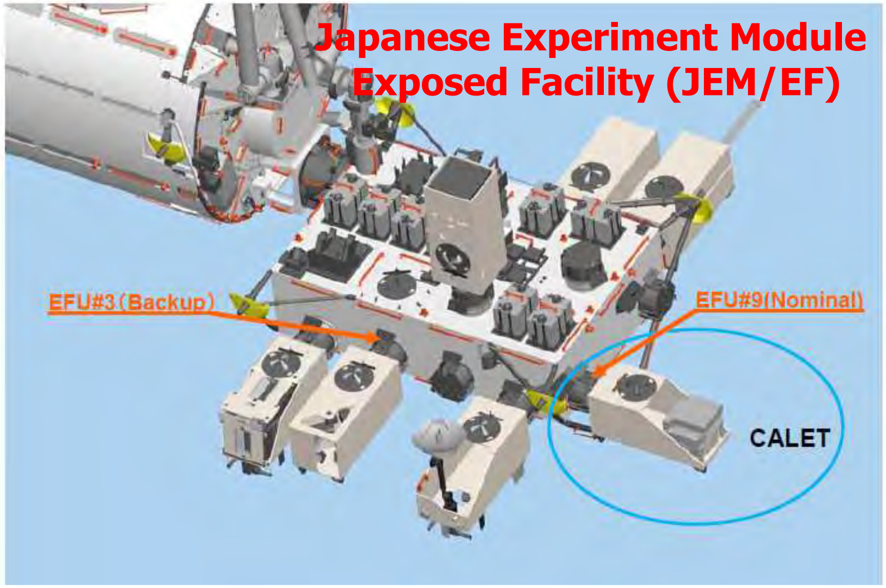
- The CALET mission and CGBM instrument.
- CGBM performances and in-orbit operation.
- Observation examples:
    - study of GRB 160107A;
    - GW follow-up.
- Conclusions.

CALET payload on ISS

- **Overall scientific goals.**
  - High-energy electrons and nuclei spectra.
  - All sky gamma-ray survey (E > 10 GeV).
  - Monitoring of **X/gamma-ray transients** in a **broad energy range (few keV - GeV/TeV)**, thus including long- and short-duration GRB's, X-ray flashes, GeV GRB's.

- Launch carrier: HTV-5
- ISS location: JEM Port 9

- Current status: **regular scientific operation since Oct. 2015**
- Mission target duration: **5 years**
- Mass: **613 kg**
- Size: JEM/EF Standard Payload (**1.85 m · 0.8 m · 1 m**)
- Power: **507 W** in nominal condition
- Data rate to ground:
  - Medium data rate: 600 kbps
  - Low data rate: 50 kbps

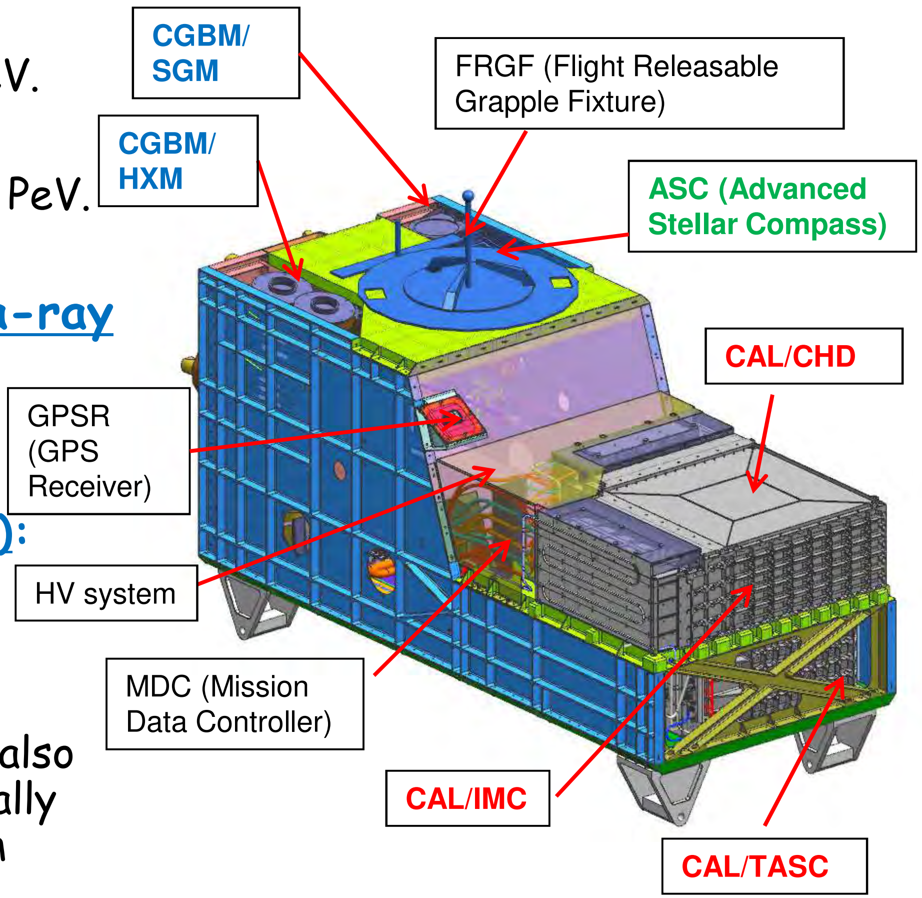


CALET overview

- **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.

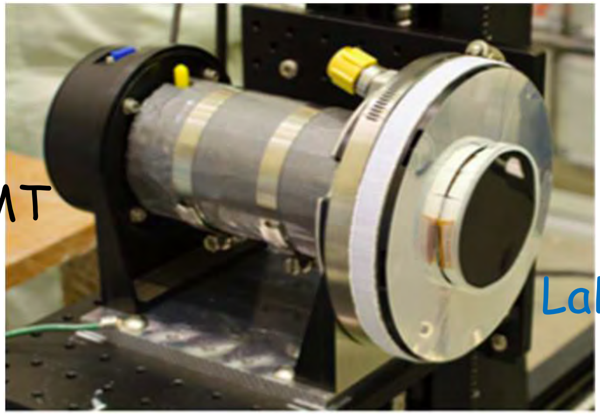
- **Secondary instrument: CALET Gamma-ray Burst Monitor (CGBM).**
  - (2 x) Hard X-ray Monitors (HXM): **7 keV – 1 MeV.**
  - (1 x) Soft Gamma-ray Monitor (SGM): **100 keV – 20 MeV.**

- With **CGBM trigger**:
  - 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.

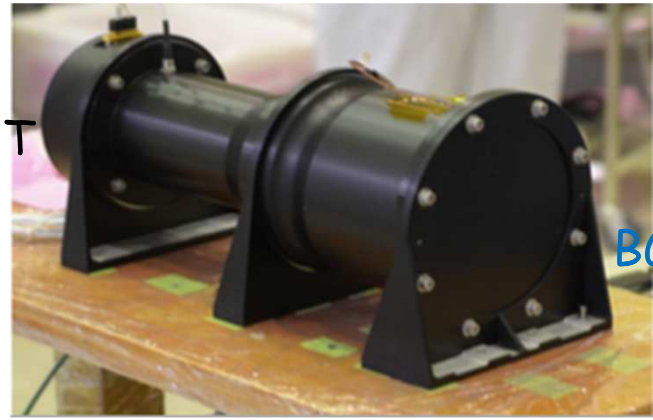


CGBM: CALET gamma-ray burst monitor

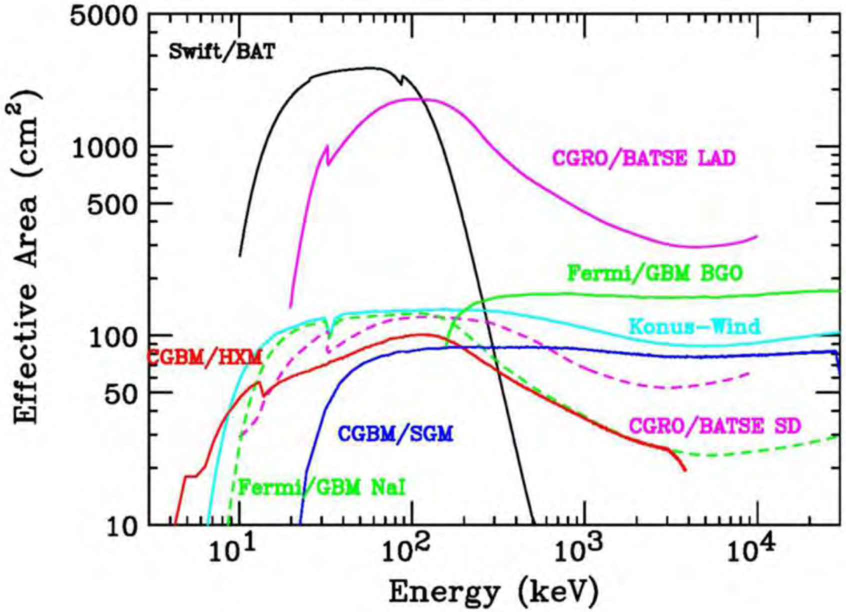
Hard X-ray Monitor (HXM)



Soft Gamma-ray Monitor (SGM)



- Independent HXM and SGM detectors covering **broad energy range** (7 keV - 20 MeV).
- $LaBr_3(Ce)$ used for the first time in GRB observations.
- **Continuous monitoring** (low-resolution data).
- **GRB trigger system** (high-resolution data).



CGBM features

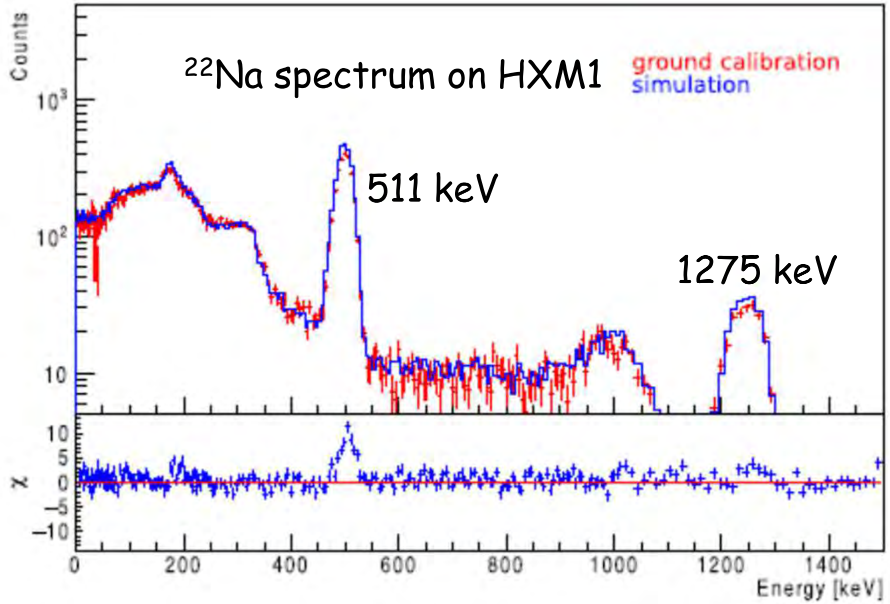
	HXM (2 units)	SGM
Detector	$LaBr_3(Ce)$	BGO
Read-out	PMT (Ham. R6232-05) + CSA	PMT (Ham. R6233-20) + CSA
Diameter (mm)	61	102
Thickness (mm)	12.7 (0.4 mm Be window)	76
Tilt from zenith	10°	0°
On-axis effective area (cm^2)	68 (2 units)	82
Field of view	~120° (**~3 sr)**	~180° (**~2π sr)**
Angular meas.	no	no
Energy range	high gain: 7 keV - 100 keV low gain: 60 keV - 1 MeV	high gain: 100 keV - 1 MeV low gain: 500 keV - 20 MeV
Energy resolution	~18% (32 keV)	~12% (662 keV)
Time resolution	**GRB trigger data**: 45 μs with 4096 energy channels **Monitor data (continuous)**: 125 ms with 8 en. ch.; 4 s with 512 en. ch.	

CGBM trigger operation

- **CGBM trigger system with adjustable settings,** as best compromise between **high GRB trigger efficiency** and **low number of spurious triggers** (radiation belt particles, solar flares, etc.).
  - Several independent and simultaneously active trigger channels (different detectors and energy bands).
  - Trigger condition: number of signal pulses during signal integration time exceed expected background N_{exp_bgd} by $n \cdot \sqrt{N_{exp\_bgd}}$.
  - Configurable energy band, signal integration time, decision level (n), background integration time, duration of trigger data taking.
- GRB trigger data are taken with **high time/energy resolution.**
- Automatic data processing after downlink to ground.
  - Generation of **public real-time alert through GCN *notice*** (possible for ~70% triggers, when ISS bandwidth for immediate downlink is available).
- Independently from GRB trigger, **monitor data taking** (pulse count) is performed continuously with low time/energy resolution.
  - These data allow for investigation of not-triggering GRB's.

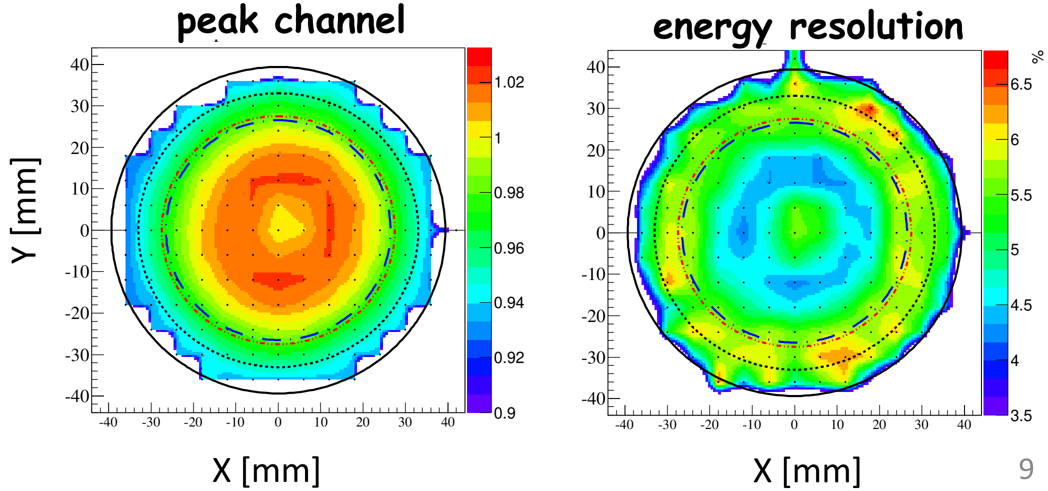
Energy response calibration

- Ground tests performed with **radioactive and soft X-ray sources** for tuning the Geant4 "response function" simulator :
  - 2D mapping of peak channel and energy resolution;
  - response linearity, dependence of resolution on energy, dependence on photon incidence angle.



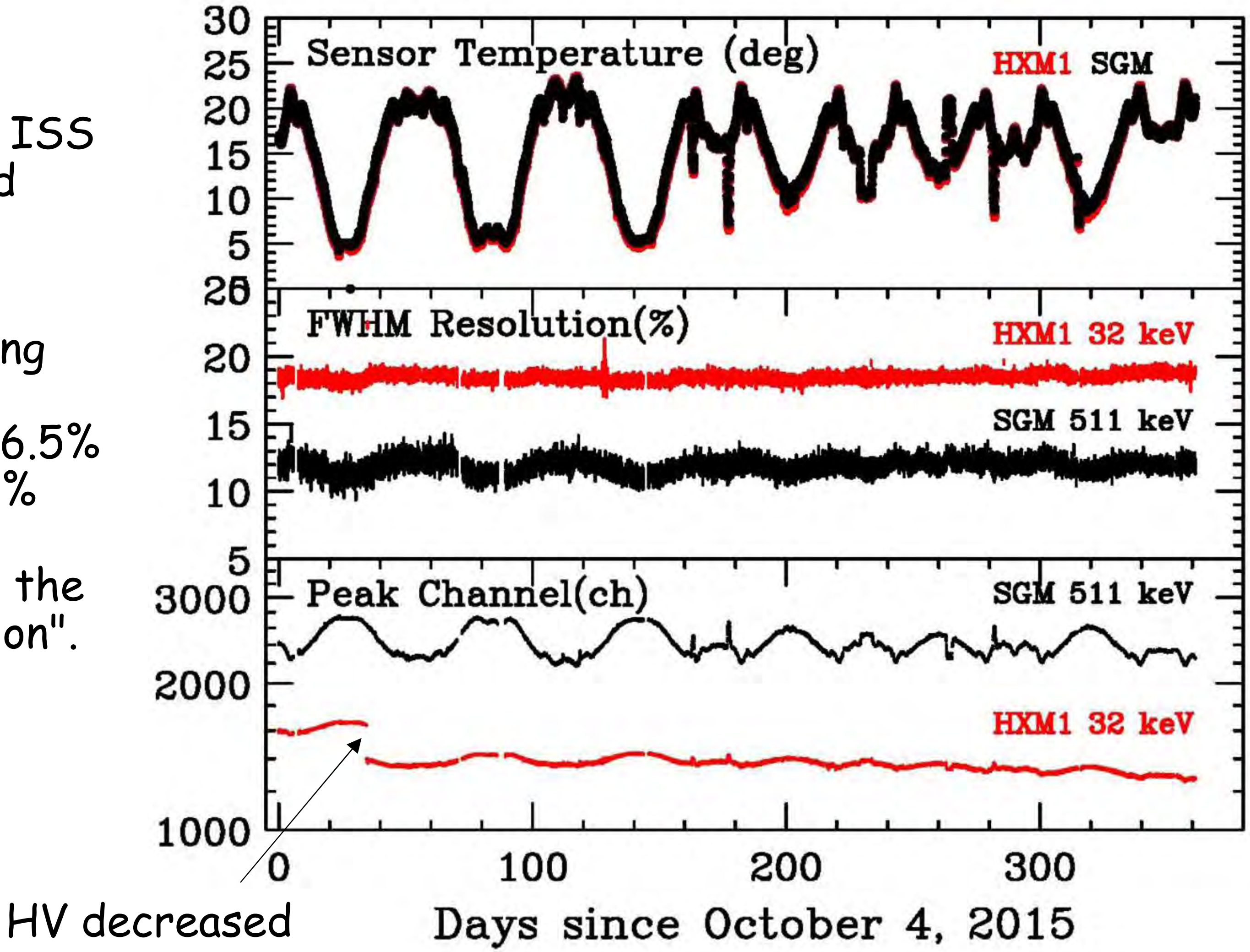
- **In-flight cross-checks** with radioactive background lines.
- **In-flight cross-calibration with other instruments** for check of measurement accuracy.

Ground HXM 2D mapping with collimated 511 keV (^{22}Na)



In-flight temperature variation

- **Long-term temperature variation** due to ISS sun exposure and CGBM passive thermal control.
- The corresponding **detector gain variation** (up to 6.5% for HXM and 26% for SGM) is accounted for in the "response function".



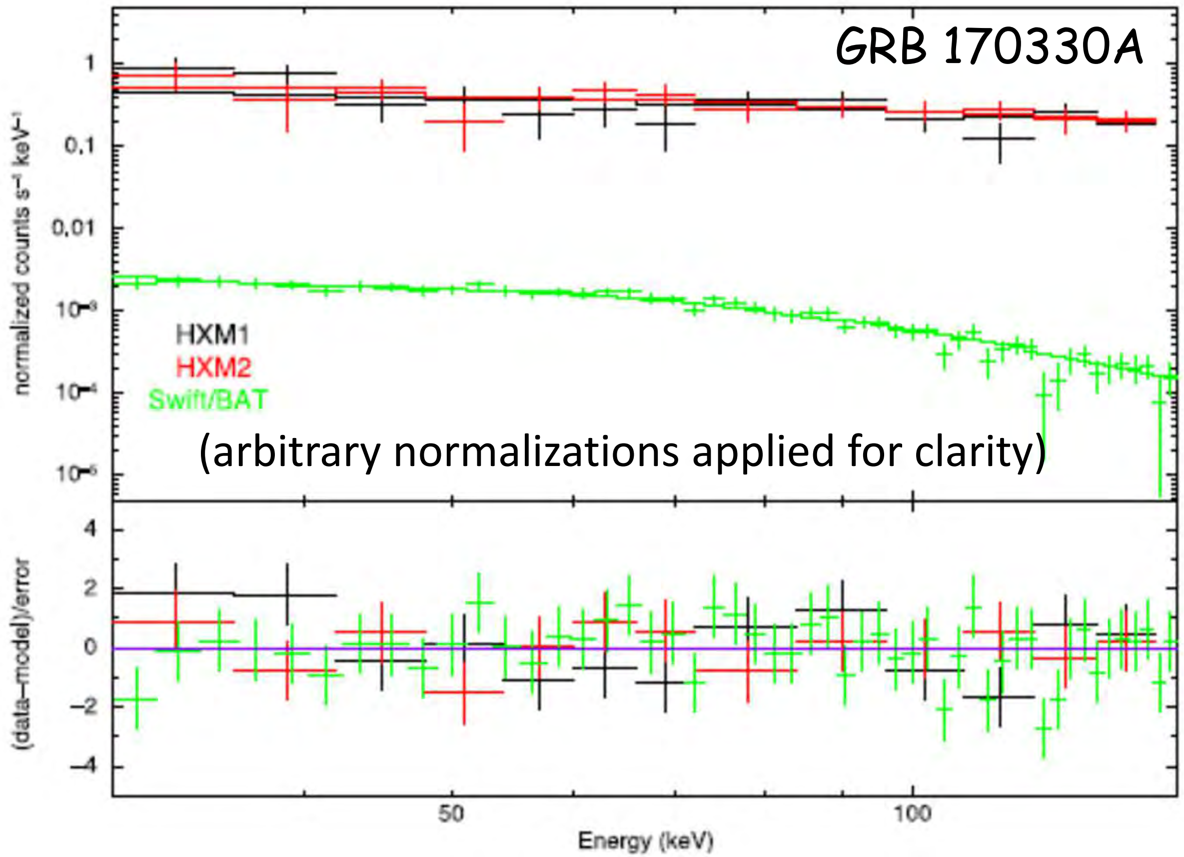
In-flight cross calibration

- Example of **spectral cross-calibration of HXM with Swift/BAT data** for simultaneously observed GRB 170330A.
- In the 30 - 150 keV region, data are consistently described by power-law $E^{-\alpha}$:

$\alpha_{CGBM} = 1.17 \pm 0.09$

$\alpha_{Swift} = 1.22 \pm 0.25$

- *CGBM energy accuracy is 10 - 20 % in this energy range.*

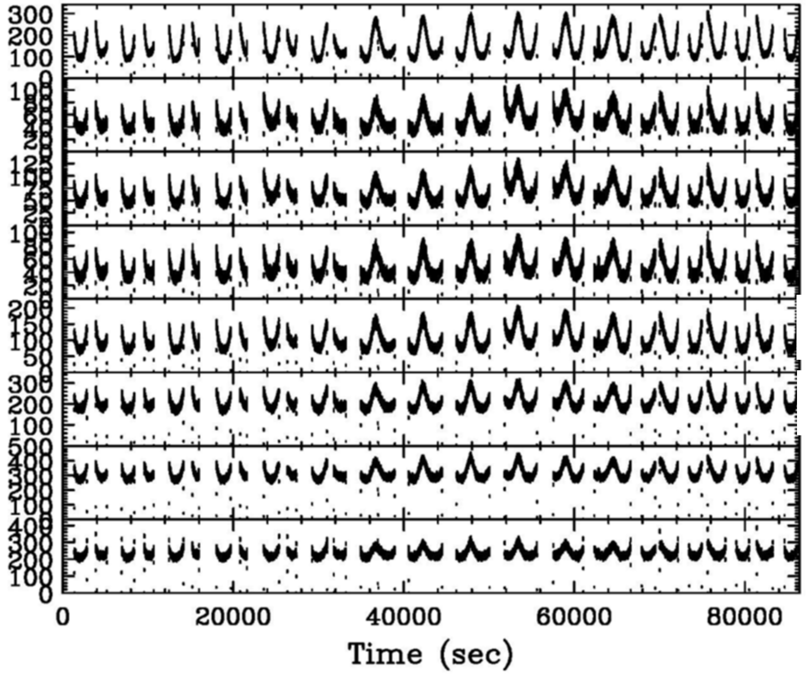


In-flight background

- **Variation of background rates** in CGBM continuous monitor data.

Variation with <u>single orbits</u>
(radiation-belt charged particles)

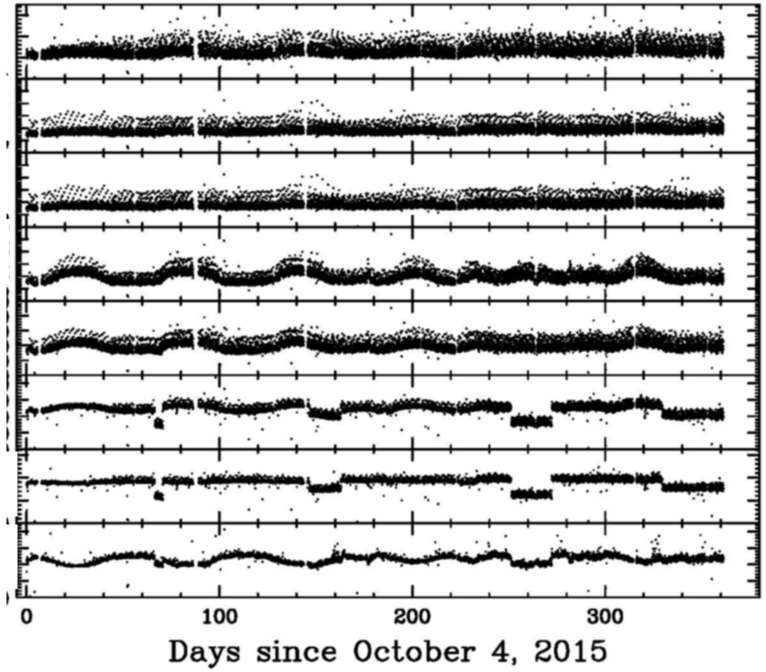
count/s



SGM

2.5 - 26 MeV
1.4 - 2.5 MeV
0.8 - 1.4 MeV
0.5 - 0.8 MeV
430 - 860 keV
210 - 430 keV
88 - 210 keV
33 - 88 keV

<u>Long-term</u> variation
(temperature effect, sporadic solar activity, Soyuz (un)docking on ISS)



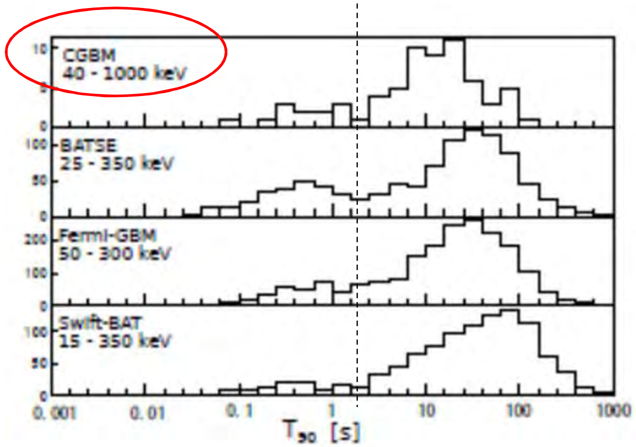
1 day

PMT high-voltage automatically set off in high-radiation areas (high-latitude, SAA).

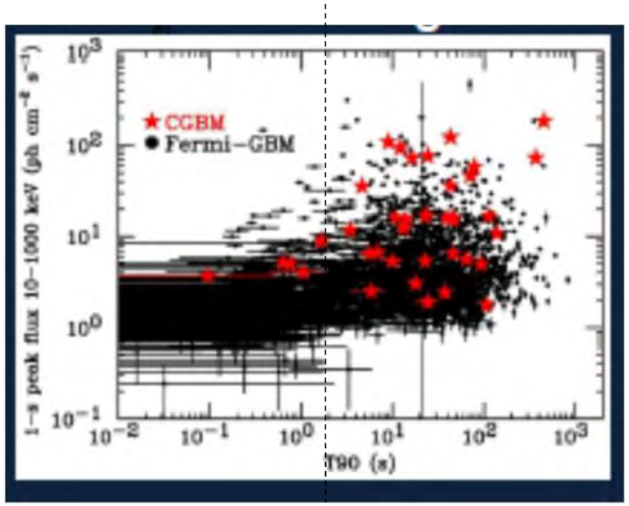
1 year

GRB observations

- Observed **~35 confirmed GRB's/yr** (since Oct. 2015), issued GCN circulars with light curves.
  - Observation efficiency ~58% because of HV-off periods.
- Mostly long GRB's (~20% are short GRB's).



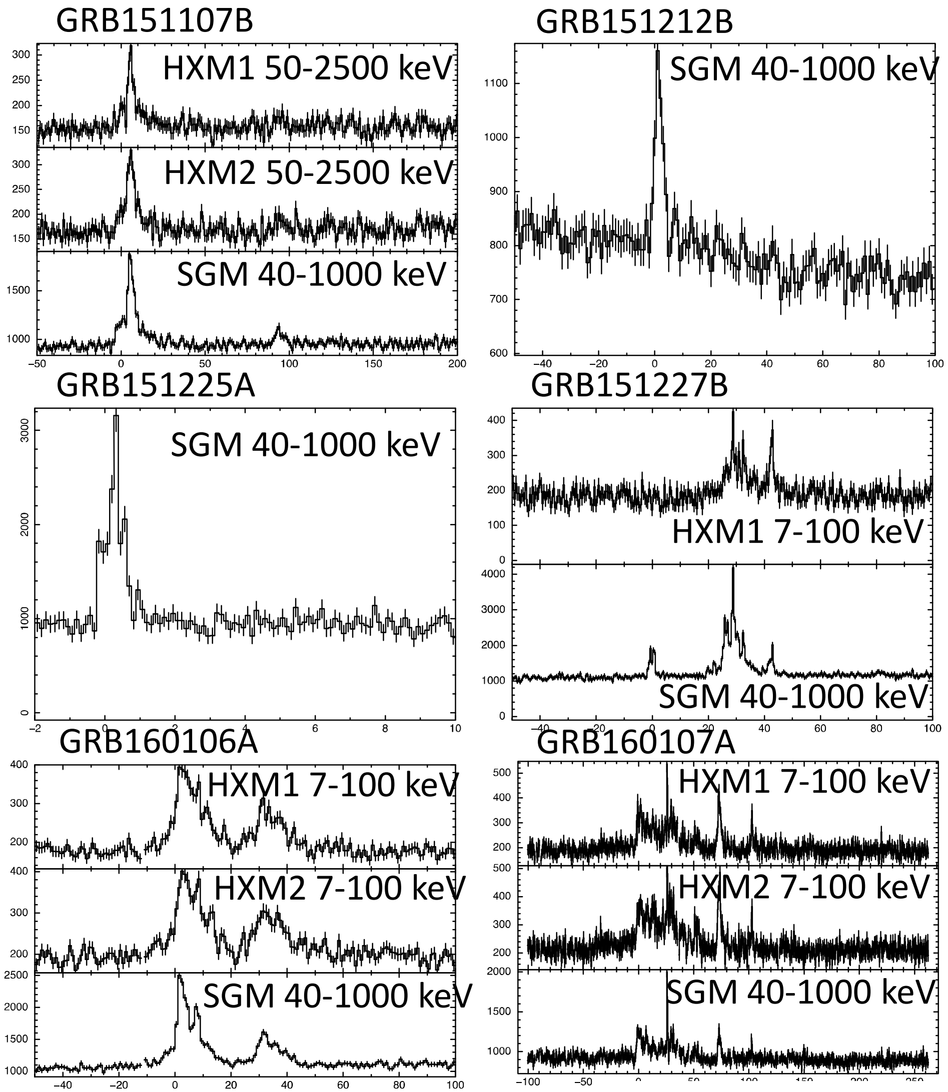
- Given the relatively small effective area, CGBM can observe bright GRB's.
  - **Sensitivity:** ~10^{-8} erg cm^{-2} s^{-1} (1 keV - 1 MeV) for 50 s long bursts.



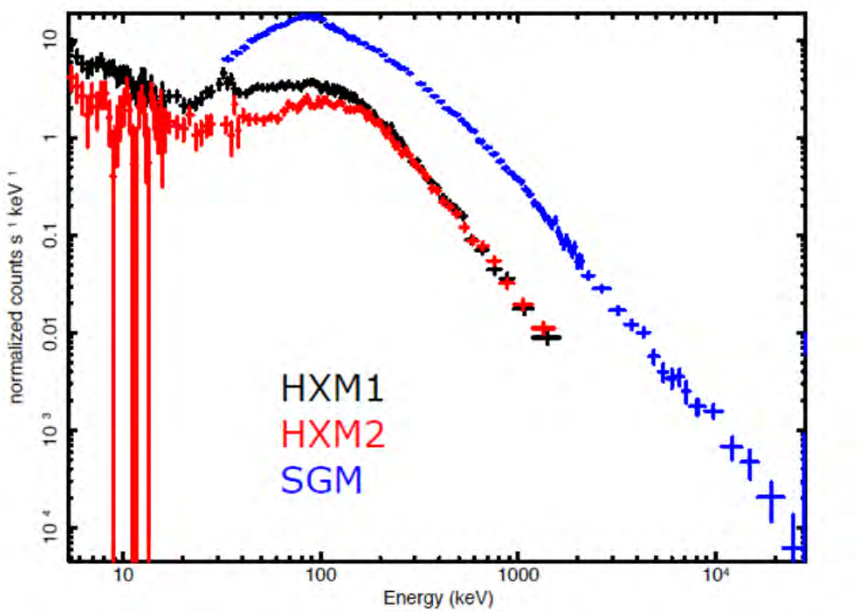
- **4 GRB's simultaneously observed by nearby experiment MAXI on ISS**, in 1 year of overlapping operation.

Examples of observed GRB's

CGBM light curves (count rates vs. time) in different detectors and energy bands.



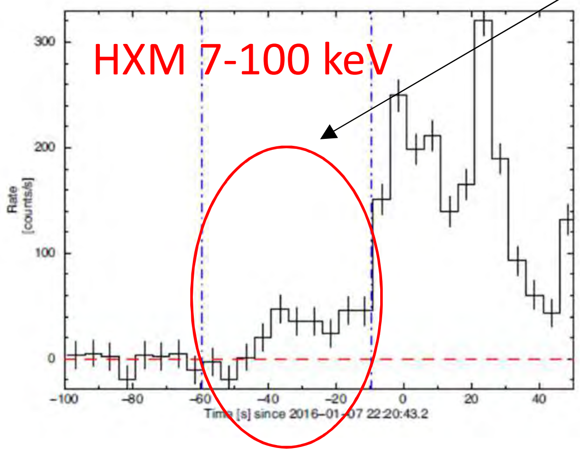
Raw count spectra of GRB 160625B

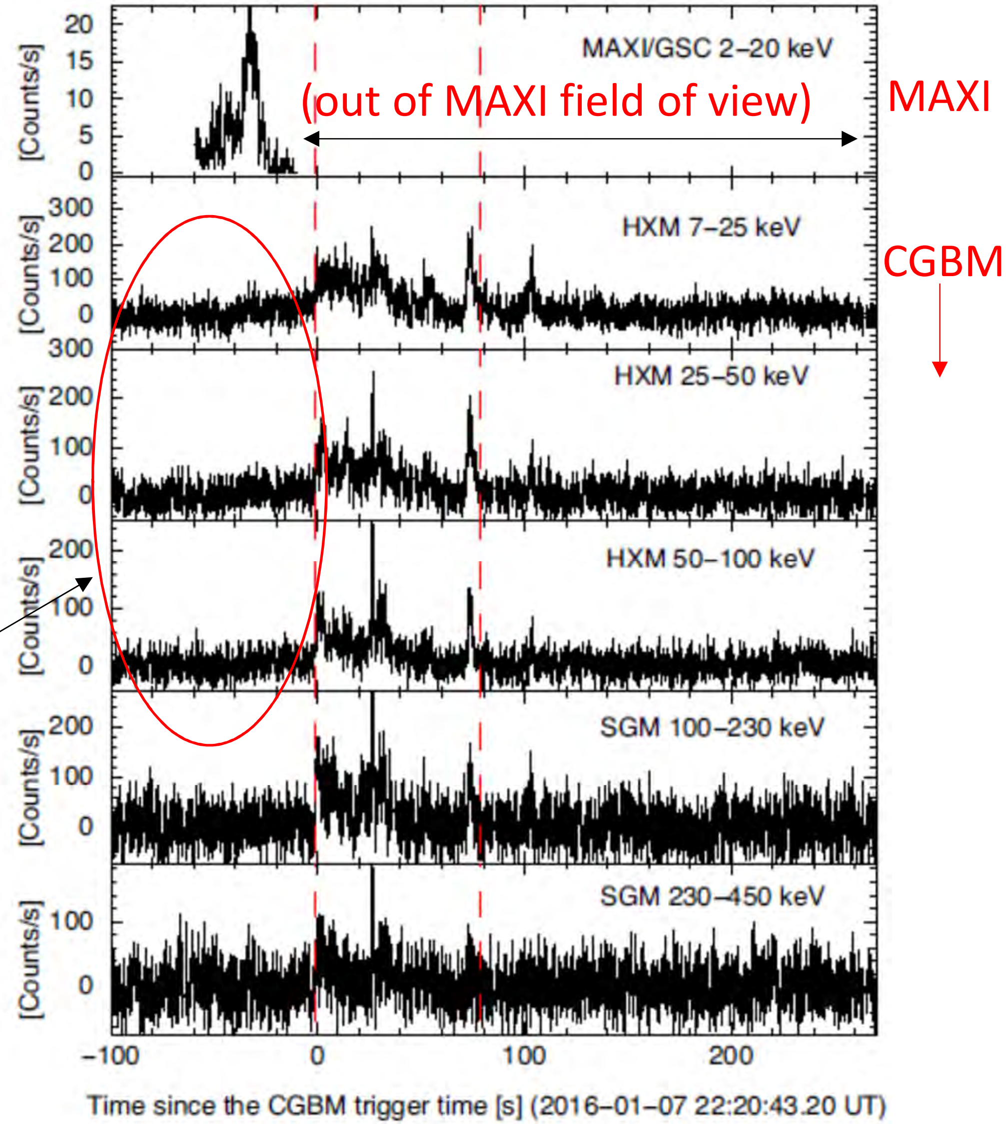


GRB 160107A

[Kawakubo et al.,
Publ. Astron. Soc. Japan (2018) 70 (1), 6 (1-10)]

- **Coordinated observation with MAXI** (nearby on ISS).
- CGBM adds **broad energy coverage** and **wide field-of-view**.
- MAXI (2-20 keV) soft X-ray burst seen **45 s before CGBM** (> 7 keV) trigger.
- **Subthreshold burst** seen also in CGBM data during MAXI-observed burst.





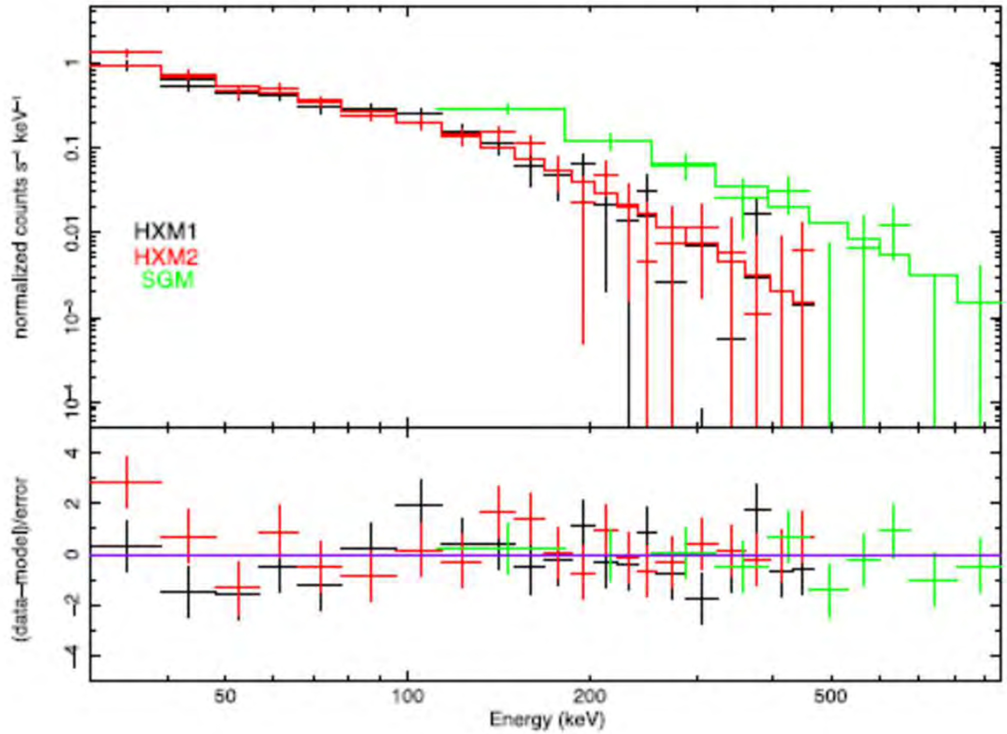
GRB 160107A: CGBM spectrum

- Background estimated with polynomial fit of monitor data taken before/after the burst.
- Burst source location given from MAXI (~1° uncertainty).
- Spectrum well fitted with single "cutoff power law": $E^{-\alpha} e^{-E/E_{peak}}$:

  $\alpha = 1.7_{-0.3}^{+0.2}$

  $E_{peak} = (102_{-40}^{+48})$ keV

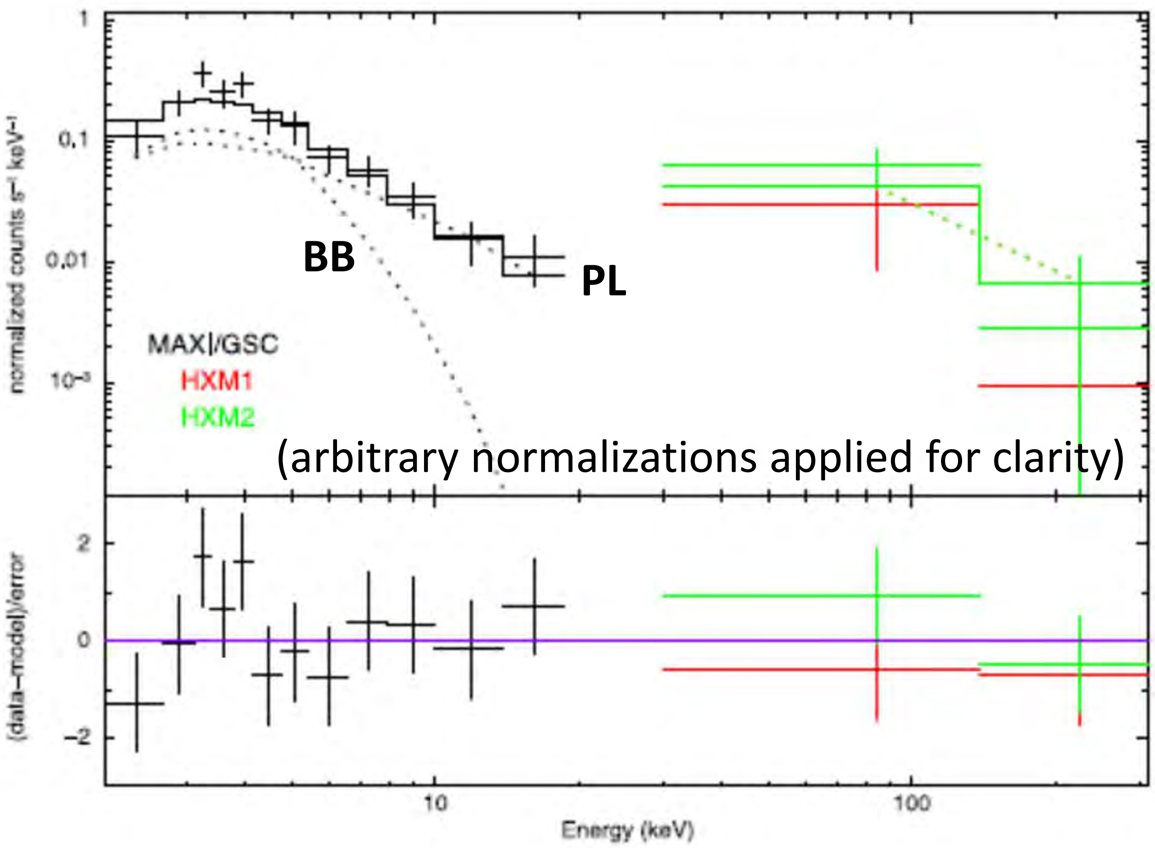
- Band function (2 smoothly connected "cutoff power laws") does not significantly improve goodness of fit.



- HXM1 and HXM2 are mutually consistent.
- SGM flux is overestimated (by a factor 1.4): we concluded that a more detailed model of structures surrounding CGBM is needed (SGM is sensitive to 4π background).

GRB 160107A: CGBM/MAXI joint analysis of prompt emission

- **Prompt emission** (45 s before CGBM trigger) is best fitted by power-law · black-body spectrum (**PL · BB**).
- **PL spectral index measured by HXM** (30 - 300 keV): $\alpha \approx 1.6$
- **BB temperature measured by MAXI** (2 - 20 keV): $kT \approx 1$ keV.
- Delay between soft-X prompt and hard-X main emission can be used to estimate ratio of source radius (but red-shift measurement by optical follow-up not available for this GRB).



Gravitational wave follow-up

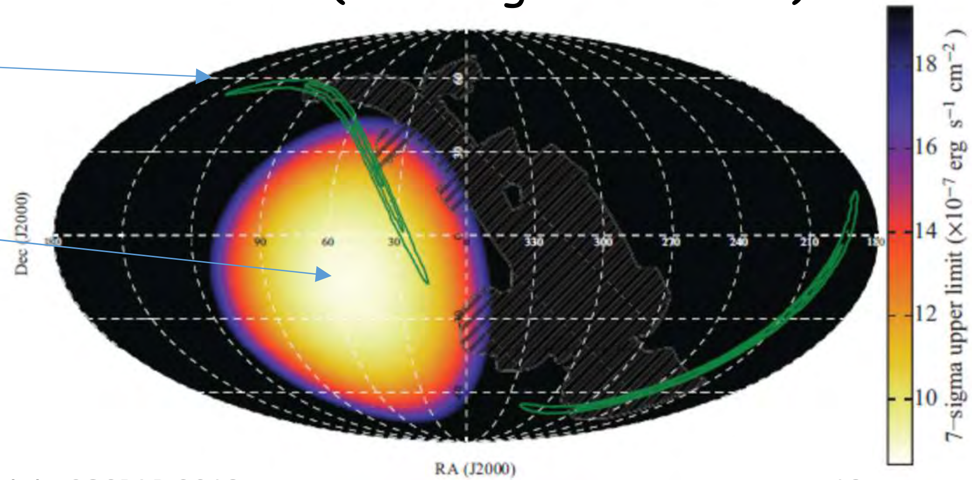
- CALET took part in the **EM follow-up of GW triggers** during LVC runs O1+O2 (4+7 months between 2015 and 2017).
  - CGBM can deliver fine-time-resolution light curves, spectral analysis possible if accurate source localization available.
- 9 (out of 14) LVC "triggers of interest" happened when CGBM active (HV on) and with probability map for GW source location overlapping significantly with CGBM field-of-view.
- In all cases, **no statistically significant background excess seen in CGBM** light curves around the GW trigger times.

GW 151226 (colliding black holes)

probability map by LVC

- HXM 7σ upper limit on emission intensity (7 - 500 keV, typical BATSE s-GRB CPL spectrum)

  ⇒ Estimated luminosity (at 440 Mpc) is **few % of typical short GRB** ($1.6 \cdot 10^{51}$ erg/s).



Upper limits on GW 170817 (GRB 170817A)

- **Multimessenger observation of binary neutron star merger**: GW 170817, GRB 170817A, optical transient SSS17a [ApJL, 848:L12, 2017].
- The source location (given from optical transient) is out of view for HXM but inside the field-of-view of SGM (though covered by ISS structure).
- **No statistically significant signal seen in SGM**, 7σ upper limit on emission intensity calculated by using Fermi/GBM best-fit parameters (cutoff power-law) and assuming no shielding by ISS structure:

  UL = $5.5 \cdot 10^{-7}$ erg cm^{-2} s^{-1} (10 - 1000 keV)

  - Shielding by ISS structure should be taken into account with detailed ISS modeling.
- This estimated upper limit is of the same order of the Fermi/GBM measured peak flux: $7.3 \cdot 10^{-7}$ erg cm^{-2} s^{-1} .

Conclusions

- **CGBM fully operating and detecting ~35 GRB/yr.**
- GRB light curves reported on GCN circulars.
- **GRB spectra and "energy response function" under refinement.**
- Combined CGBM-MAXI observation of GRB 160107A was published.
- **Upper limits set on emission intensity for several LVC triggers of interest or confirmed GW events.**
- Public archive of CGBM monitor and GRB trigger data is being finalized.
  - See e.g. http://darts.isas.jaxa.jp/astro/calet/ .