



中国科学院高能物理研究所  
Institute of High Energy Physics  
Chinese Academy of Sciences



# GECAM

## A network of all-sky monitors

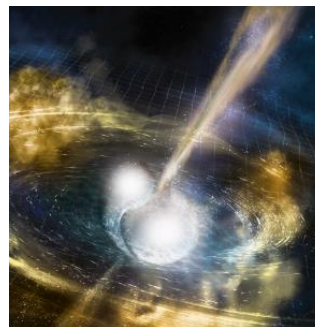
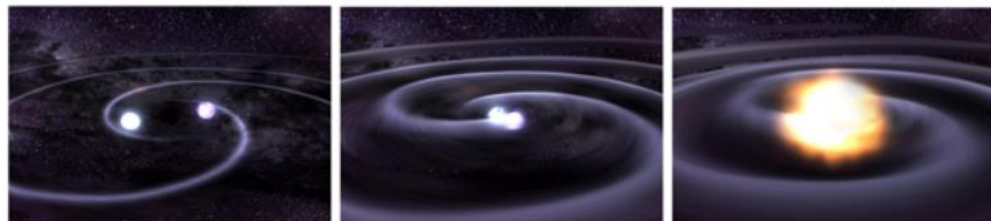
Shaolin XIONG  
(On behalf of GECAM team)

Institute of High Energy Physics (IHEP)  
Chinese Academy of Sciences (CAS)

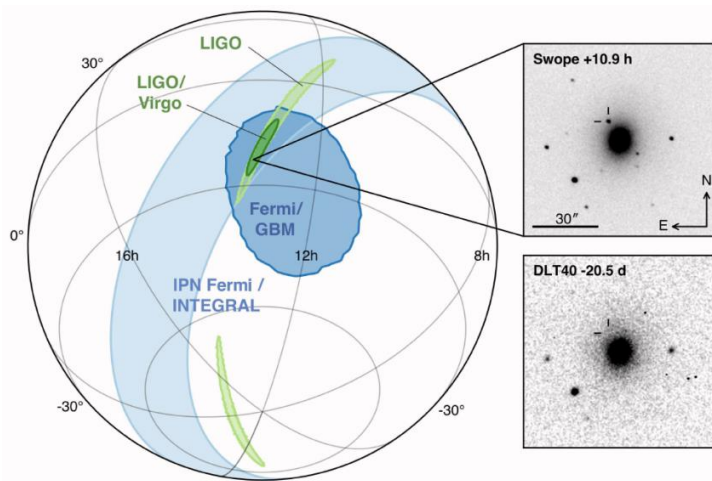
2022-09-07



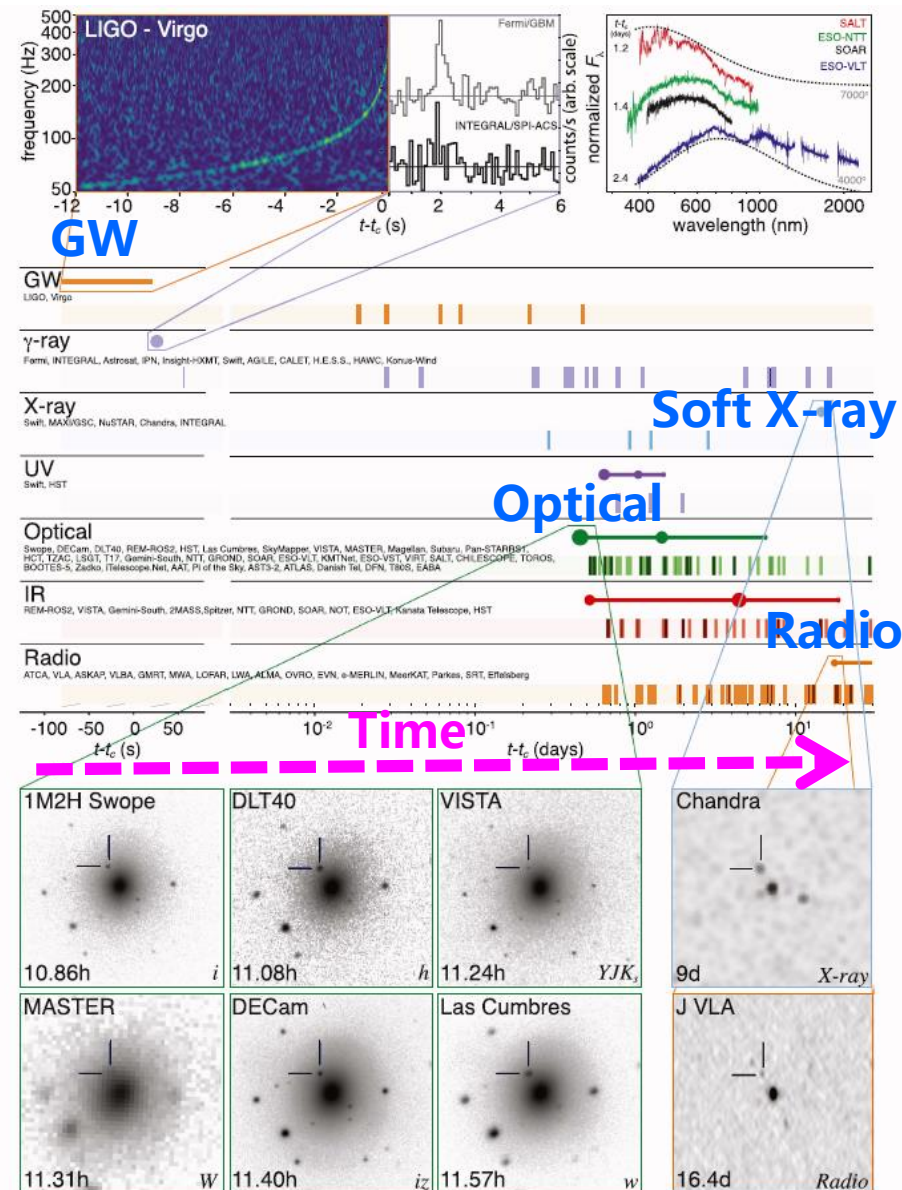
# GW High-Energy Electromagnetic Counterpart: GWGRB



**GW170817 / GRB170817A**



**Localization is crucial for follow-up observations**



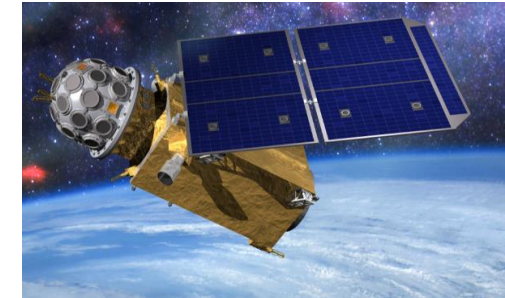
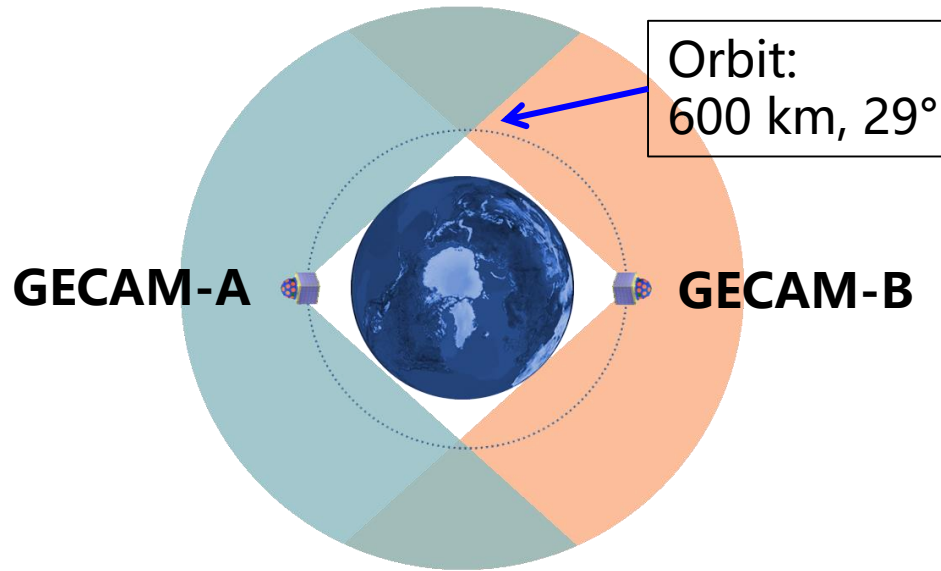
# GECAM Science: Gamma-ray Transients

- **X-ray/Gamma-ray Transients**
  - associated with Gravitational Wave, High energy Neutrino, Fast Radio Burst...
- **Gamma-ray Burst (GRB)**
  - ultra-long and ultra-soft, near-by, high-z...
- **Soft Gamma-ray Repeater (SGR)**
- **X-Ray Binaries (XRB)**
- **Tidal Disruption Event (TDE) with jet**
- **Solar flares (SFL)**
- **Terrestrial Gamma-ray Flashes (TGF) and Terrestrial Electron Beams (TEB)**
- ...



# GECAM

Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor



The design of GECAM constellation

## ● Characteristics of GECAM

- **FOV:** 100% all-sky
- **Energy band:** 6 keV – 5 MeV
- **Sensitivity:**  $< 2 \times 10^{-8}$  erg/cm<sup>2</sup>/s
- **Localization:**  $< 1$  deg (1- $\sigma$  stat.,  $1 \times 10^{-5}$  erg/cm<sup>2</sup>)

## ● Real-time alerts

- **Time Latency:** ~ 1 minute
- **Trigger information:** Trigger time, localization, duration, spectrum, etc.
- Transmitted by the **BeiDou Navigation Satellite System (BDS)** short message communication

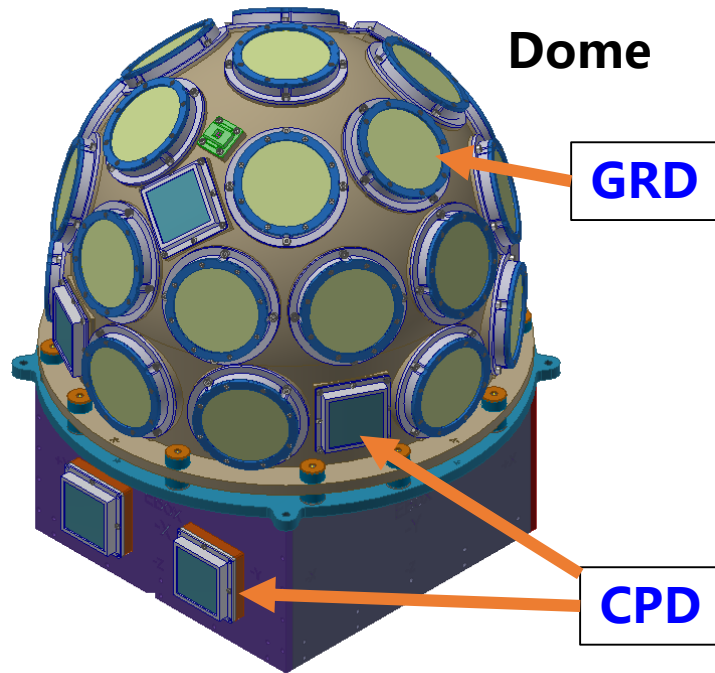
## BeiDou Navigation Satellite System (BDS)



<http://en.beidou.gov.cn/>



# GECAM Payload



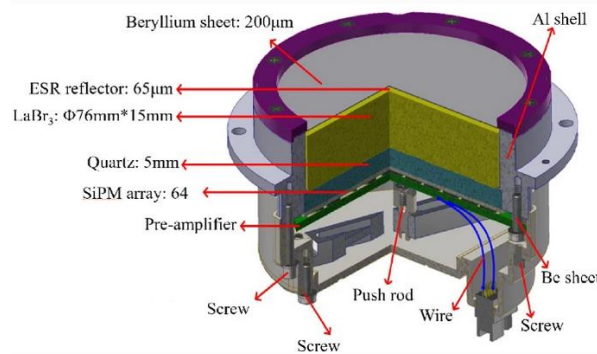
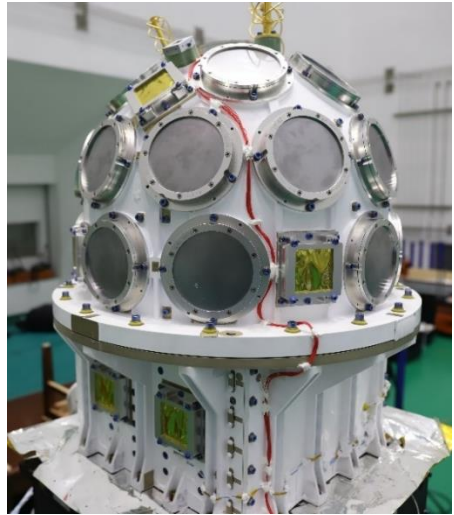
## Advantages

- Low energy threshold
- Wide energy range
- Light weight
- Without high voltage
- Insensitive to magnetic field
- Low power consumption

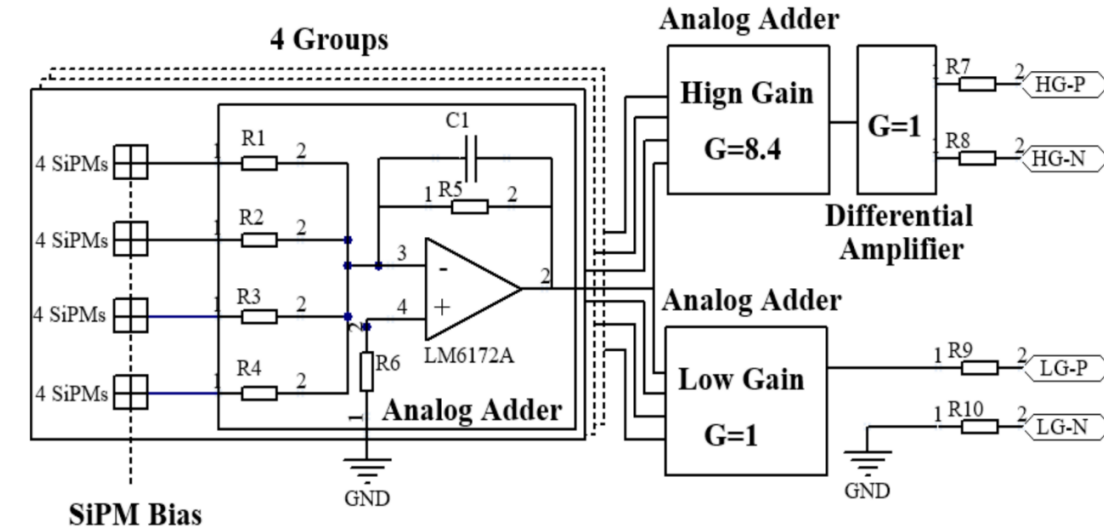
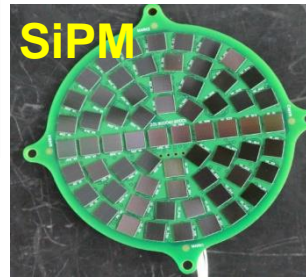
## Detectors of each GECAM satellite

- **25 GRDs (LaBr<sub>3</sub>+SiPM)**
  - Monitor x/gamma-ray from all-sky
  - Temporal, spectral, localization measurement for GRB
- **8 CPDs (Plastic scintillator + SiPM)**
  - Monitor charged particles (e, p)
  - Identify the bursts in GRD produced by charged particles in the Earth orbit (i.e. distinguish GRB and particle burst)

# GECAM main detector: $\text{LaBr}_3 + \text{SiPM}$

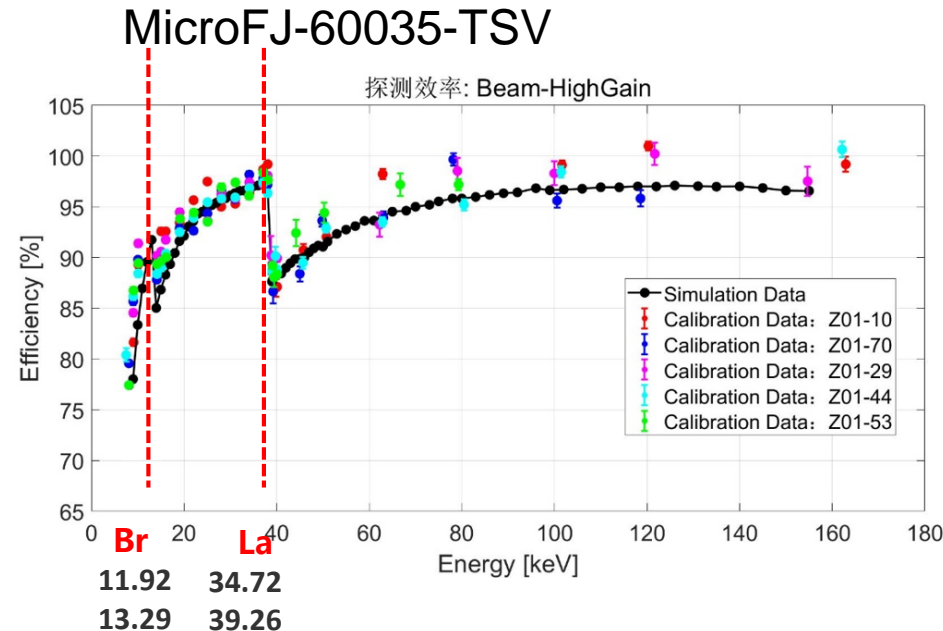
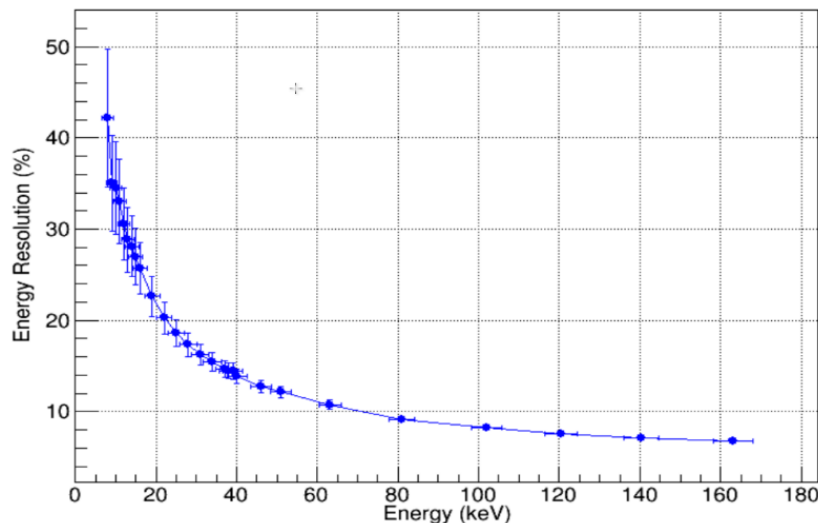


**GRD design**

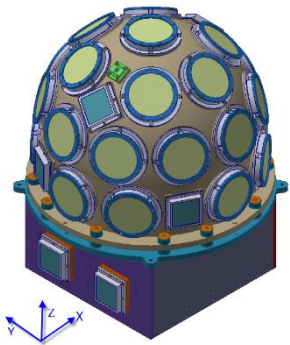


**High gain: 5 -250 keV**

**Low gain: 80 keV-5 MeV**

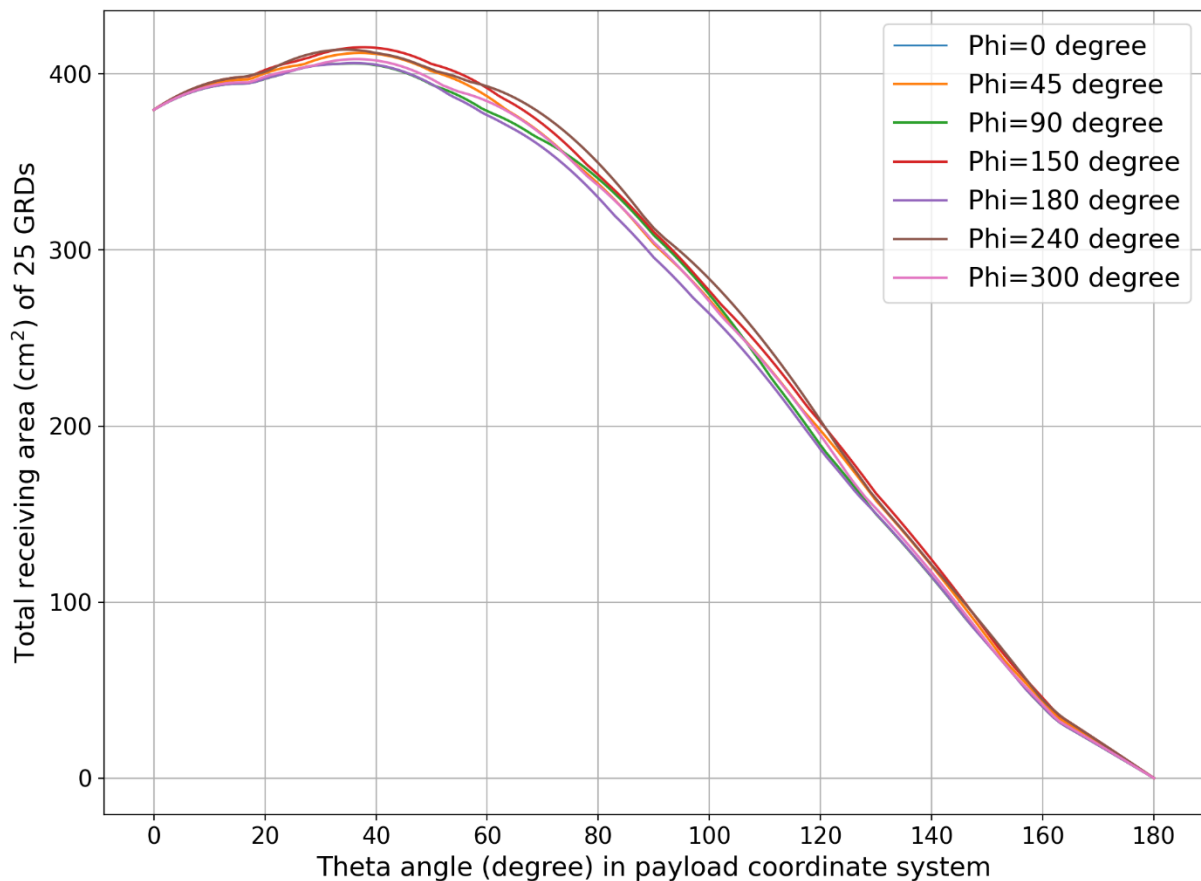


Li et al., RDTM, 6, 12-25, 2022  
 An et al., RDTM, 6, 43-52, 2022  
 Liu et al, RDTM, 6, 70-77, 2022  
 D.L.Zhang et al, NIMA, 1027, 2022  
 ...

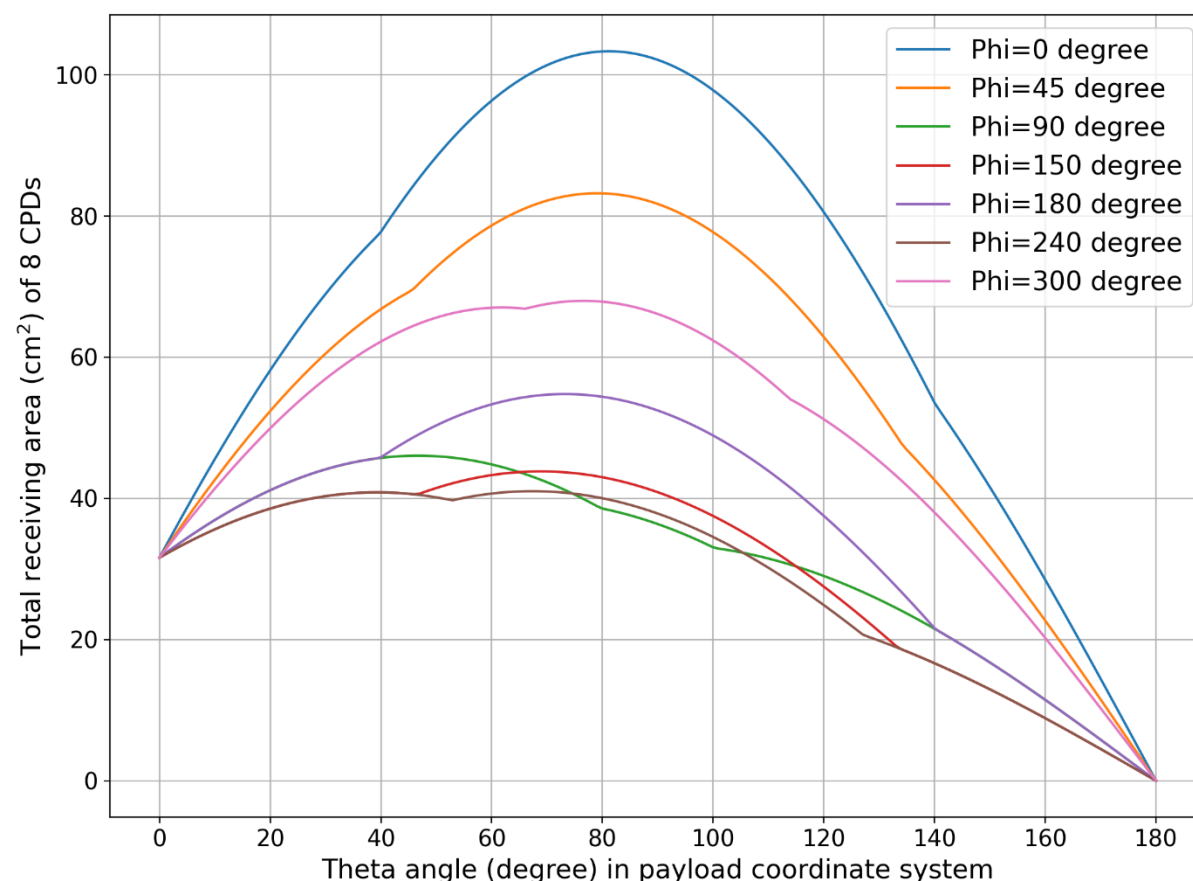


# Total geometric area of GRDs and CPDs

## 25 GRDs



## 8 CPDs



# GECAM (named as Huairou-1)

Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor

## ● In-flight Status

- GECAM-A unable to turn on instrument due to the power supply issues
- GECAM-B could observe **~11 hours/day since Jan. 14, 2021**  
& **~20 hours/day since May 30, 2022**

## ● GECAM-B monitored many gamma-ray transients

- GRBs, especially associated with GW, FRB, HEN, etc.
- Magnetars, XRBs, Pulsars,
- Solar Flares, Terrestrial Gamma-ray Flashes

## ● Characteristics of **GECAM-B**

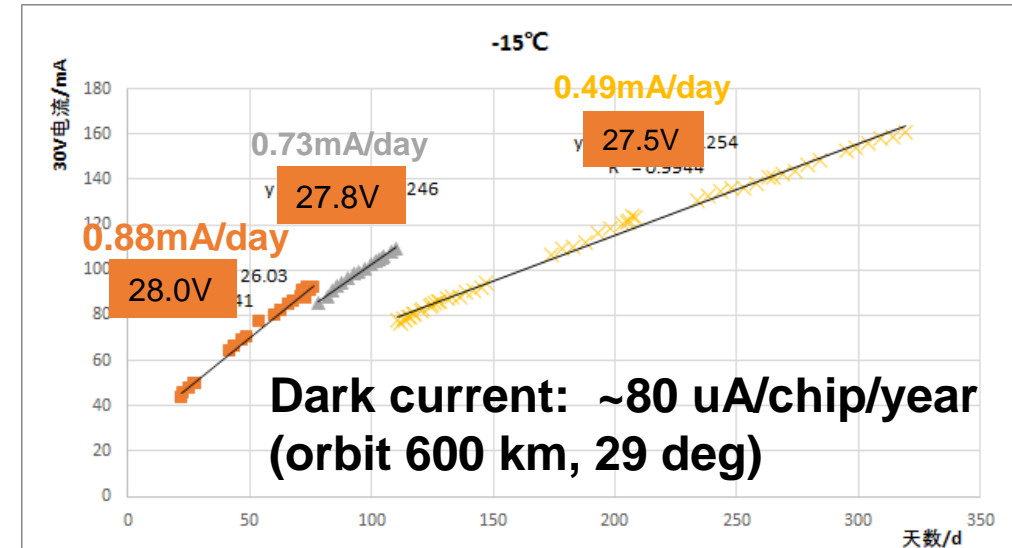
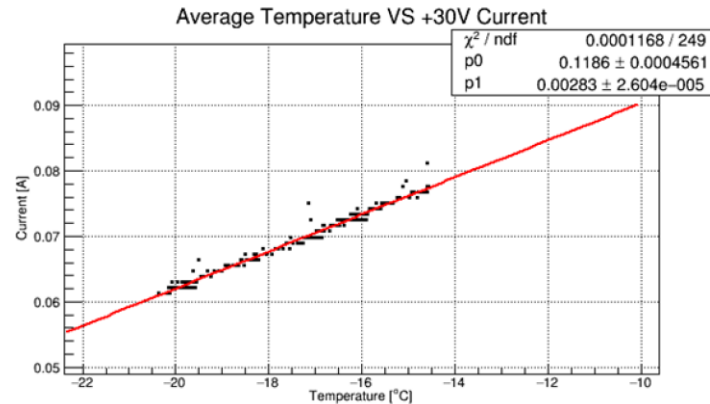
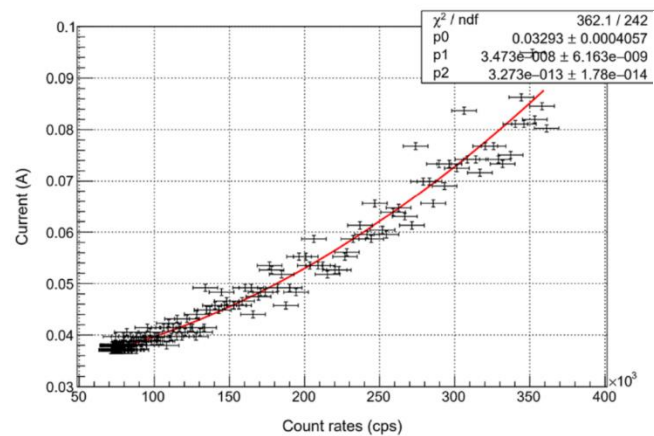
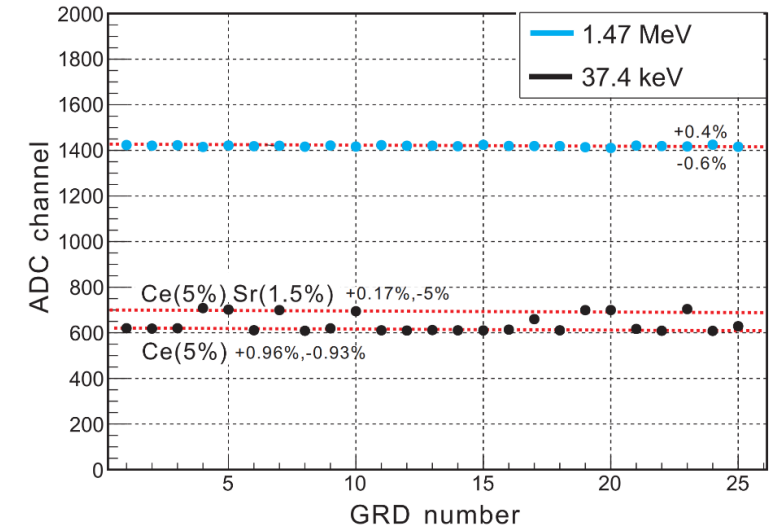
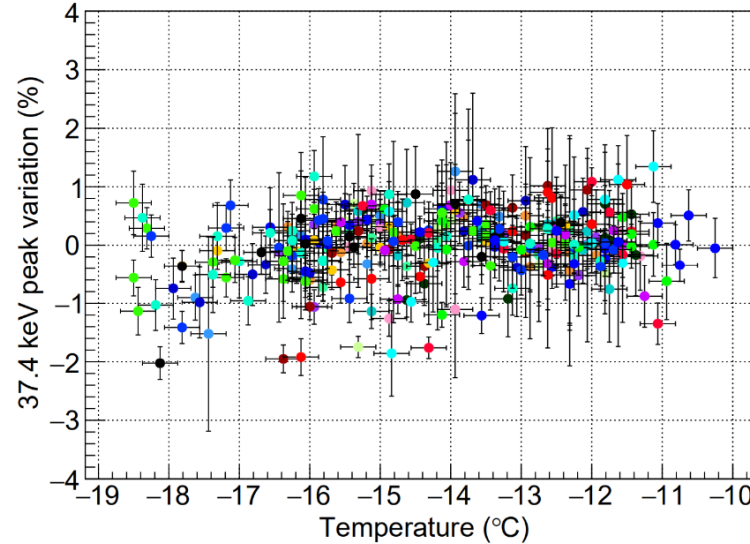
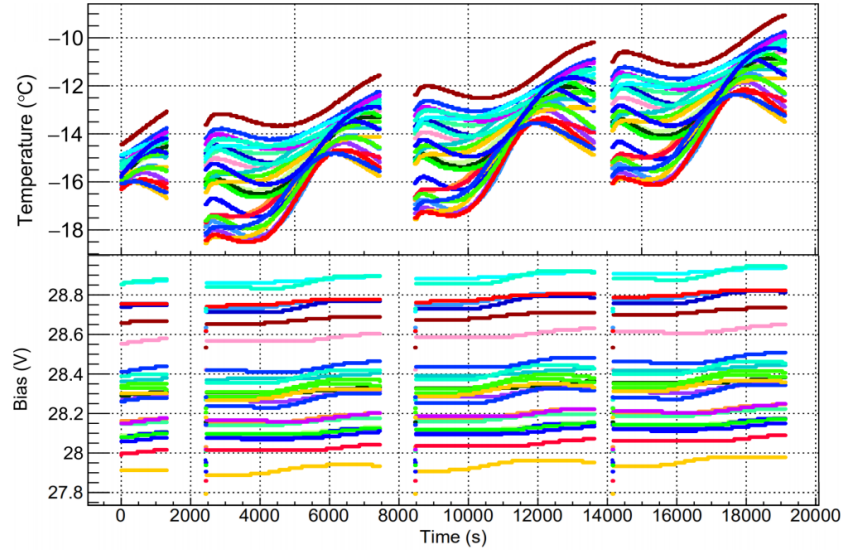
- **FOV:** ~60% all-sky
- **Energy band:** 15 keV – 5 MeV
- **Sensitivity:** ~1E-8 erg/cm<sup>2</sup>/s
- **Localization:** ~2 deg (1- $\sigma$  stat., 1E-5 erg/cm<sup>2</sup>)  
~2.5 deg (syst. error)



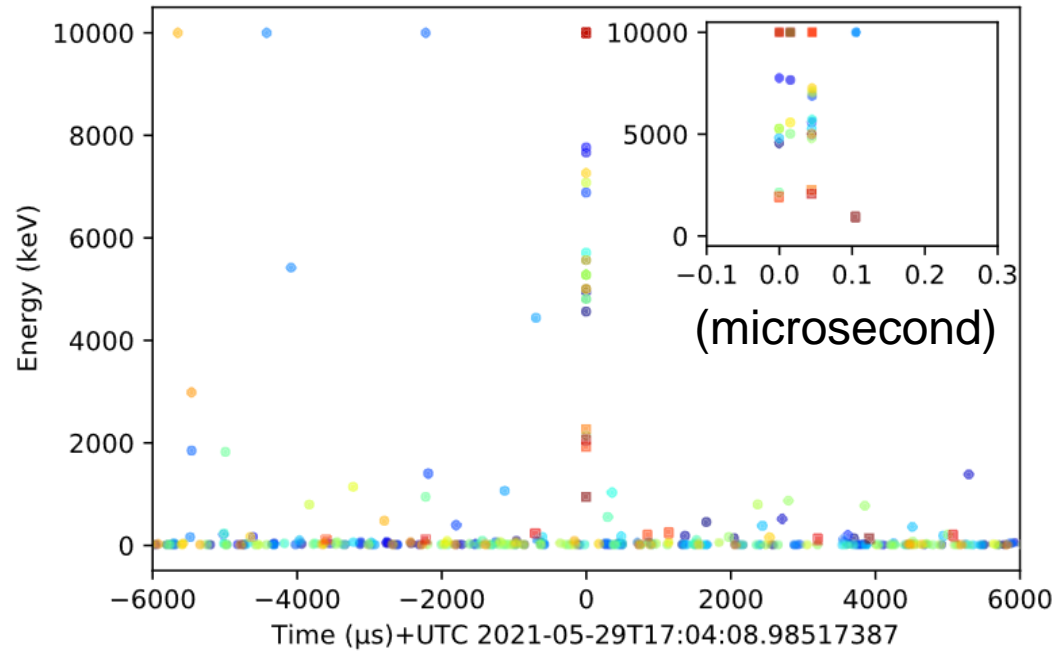
GECAM was launched on Dec 9, 2020  
at Xichang Satellite Launch Center (XSLC)



# SiPM in-flight performance



# In-flight calibration: timing, energy gain, response



**Figure 5.** A cosmic-ray shower event simultaneously observed by 25 GRDs and 8 CPDs on board GECAM-B. The dots and squares are events recorded by GRD and CPD respectively, and the different colours represent different GRD and CPD detectors.

Xiao et al, MNRAS, 511, 964 (2022)

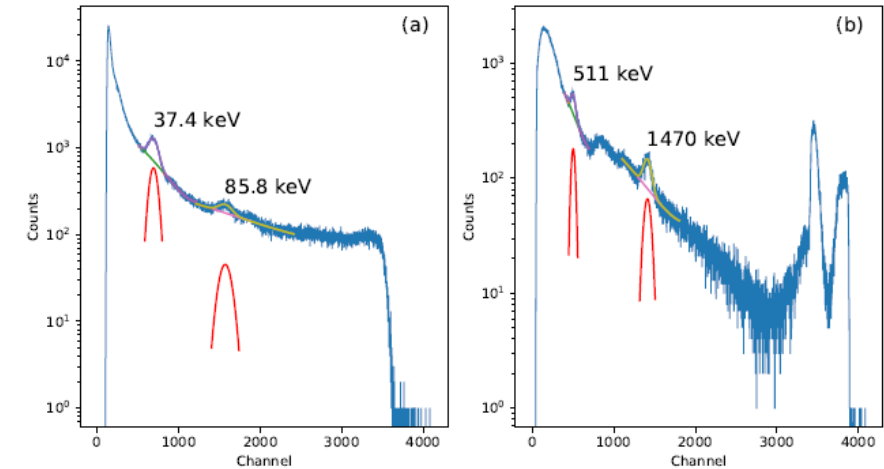


Fig. 1: The in-flight spectra of the high-gain (a) and the low-gain (b) channels.

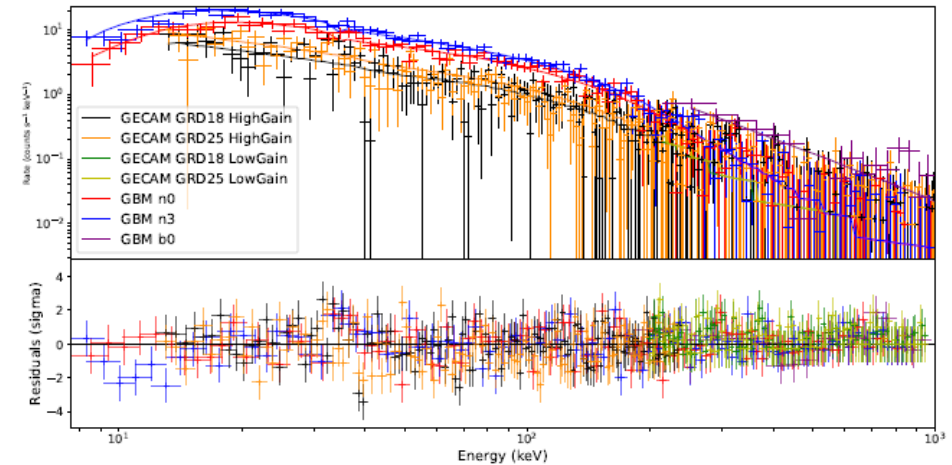


Fig. 10: Joint spectral fit results with GRD and *Fermi* GBM using the GRB 210511B.

Qiao et al., In prep; Zhang et al., In prep.<sup>10</sup>

# Main Characteristics of GECAM-B

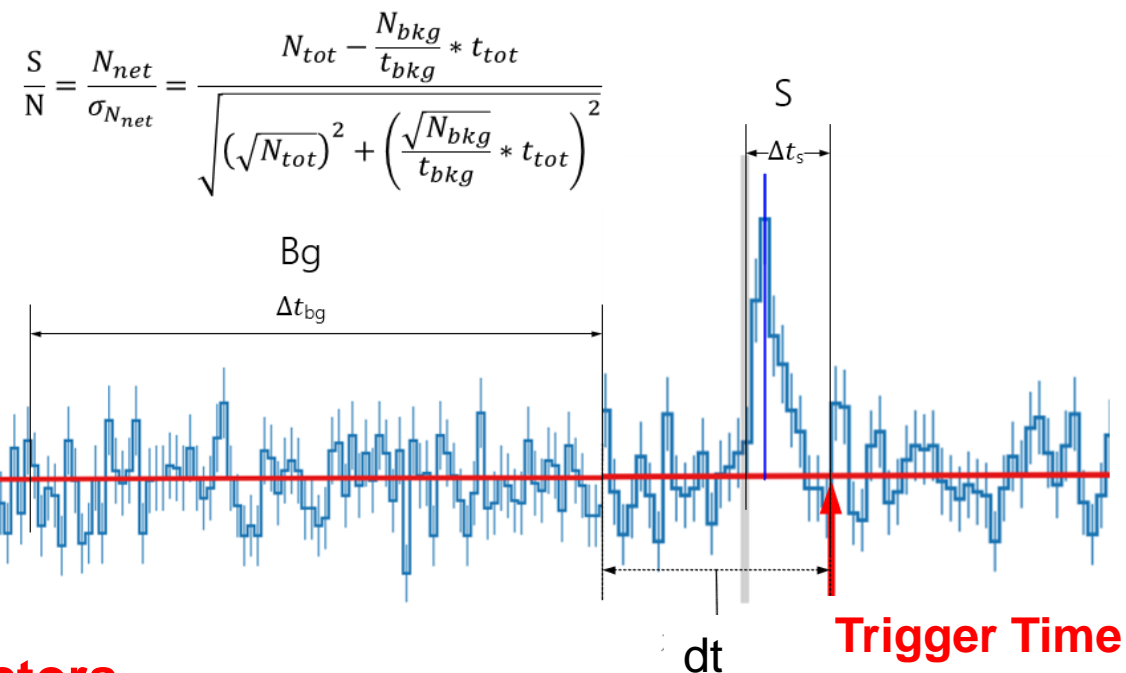
Items	Value	Comments
Launch and lifetime	Dec 9, 2020 & 3yrs	5 yrs (goal)
Orbit	600 km, 29 deg	-
Gamma-ray energy range	<b>15 keV – 5 MeV</b>	GRD
FOV	<b>~60% all-sky</b>	GECAM-B
Burst sensitivity	~ 1E-8 erg/cm <sup>2</sup> /s (20 s, 10-1000 keV)	Band medium spectrum
Burst location error	<b>~ 2 deg (1-<math>\sigma</math> stat. error)</b> <b>~2.5 deg (syst. error)</b>	1E-6 erg/cm <sup>2</sup> /s, 10s
Electron energy range	300 keV - 5 MeV	CPD
Dead time	4 $\mu$ s and 4.8 $\mu$ s (normal event)	For GRD and CPD respectively
Absolute time accuracy	~ 3 $\pm$ 6 $\mu$ s (1 $\sigma$ )	GNSS system
Relative time accuracy	<b>~ 0.1 <math>\mu</math>s</b>	GRD and CPD detectors
In-flight alert time latency	<b>~1 minute (BeiDou Navigation System)</b>	In-flight performance



# GECAM In-Flight trigger and localization software

time scale (s)	Energy range(keV)
0.05	15~400
	50~400
	15~50
	8~25
0.1, 0.2, 0.5, 1, 2, 4	15~400
	50~400
	25~200
	15~50
	8~25

- 3 detectors
- 4 sigma



- Localization: location template (Band-soft, norm, hard, 3072 direction)
- Classification: solar flare, Earth occultation, particle event, **GRB**, ...

**Type I** (GRB-like trigger, BDS alerts) or **Type II** (no BDS alerts)

# GECAM alert data: BDS messages

No.	Trigger type	BDM index	Format code	Main information
1	long trigger(L)	1-2	1	Trigger, location, classification, spectrum of the highest 3 GRDs(best loc. Time scale)
2	long trigger(L)	3	2	Light curve of the highest 3 GRDs
3	long trigger(L)	4	3	Light curve of the lowest 3 GRDs
4	long trigger(L)	5	4	Light curve of CPD
5	long trigger(L)	6~30	5	Light curve of GRD
6	long trigger(L)	31	0	Attitude information
7	short trigger(S)	1-2	1	Trigger, location, classification, spectrum of the highest 3 GRDs(short trigger best loc. Time scale)
8	short trigger(S)	3~4	6	Compress scheme、start time of light curve, Hight resolution light curve
9	short trigger(S)	5~≤31	7	Hight resolution light curve

## ◆ Long-duration trigger:

**Light curve (-50 to 200 s) of each GRD**

## ◆ Short-duration trigger:

**Total light curve of 25 GRDs**

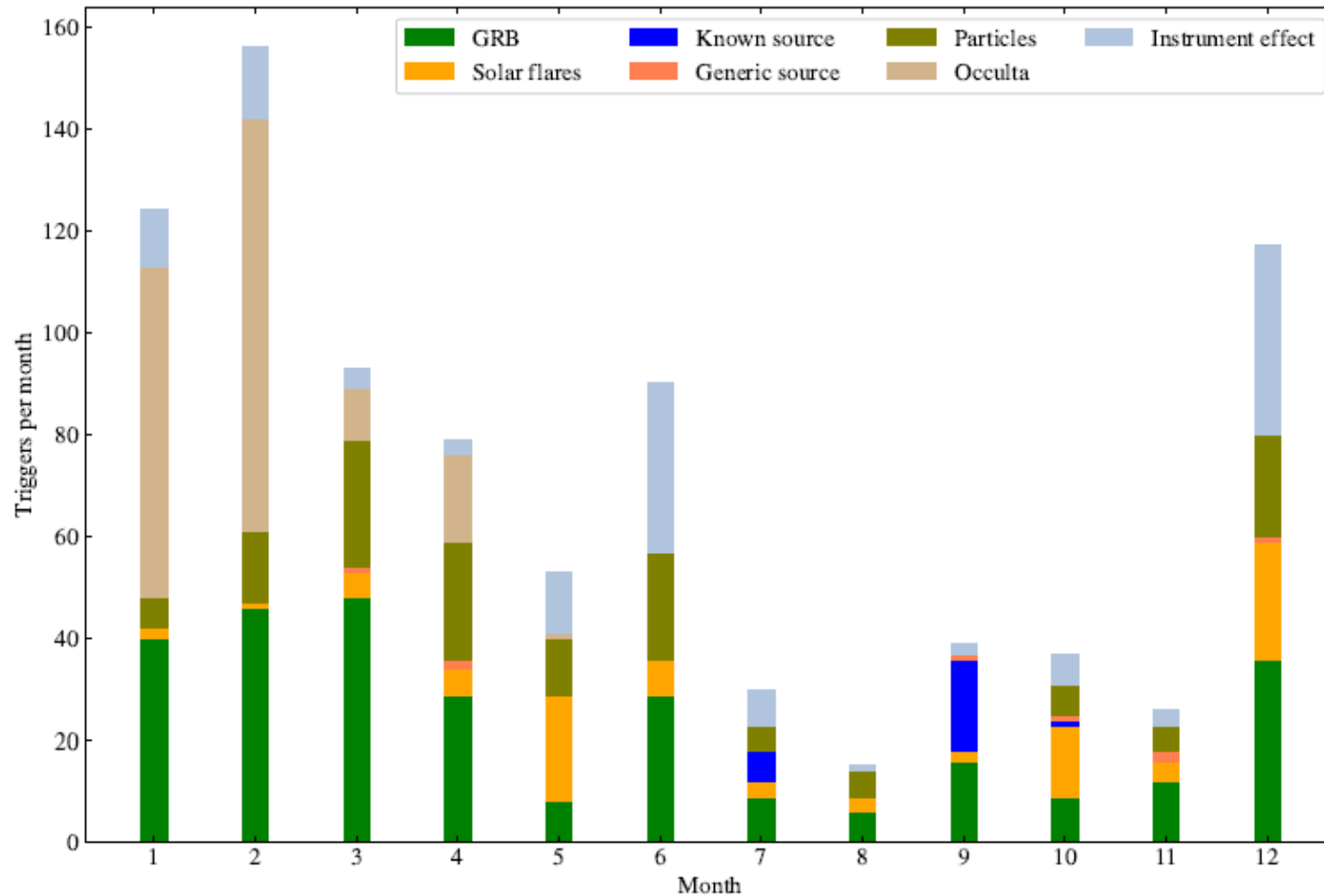
**High resolution (1 ms)**

**Beidou short message: 560 bit**

- Send ~3 messages per minute.
- All messages ( $\leq 31$ ) for a trigger will be downlinked within ~10 min.

# GECAM triggers in 2021

**Automatic classification:** GRB、Solar Flare、Particle events、Known Source、Occultation、Instrumental effect





# GECAM alerts for follow-up observations

- **In-flight alerts**

- Content: Trigger time, location, duration, spectrum, etc
- Latency: **~1 minutes**

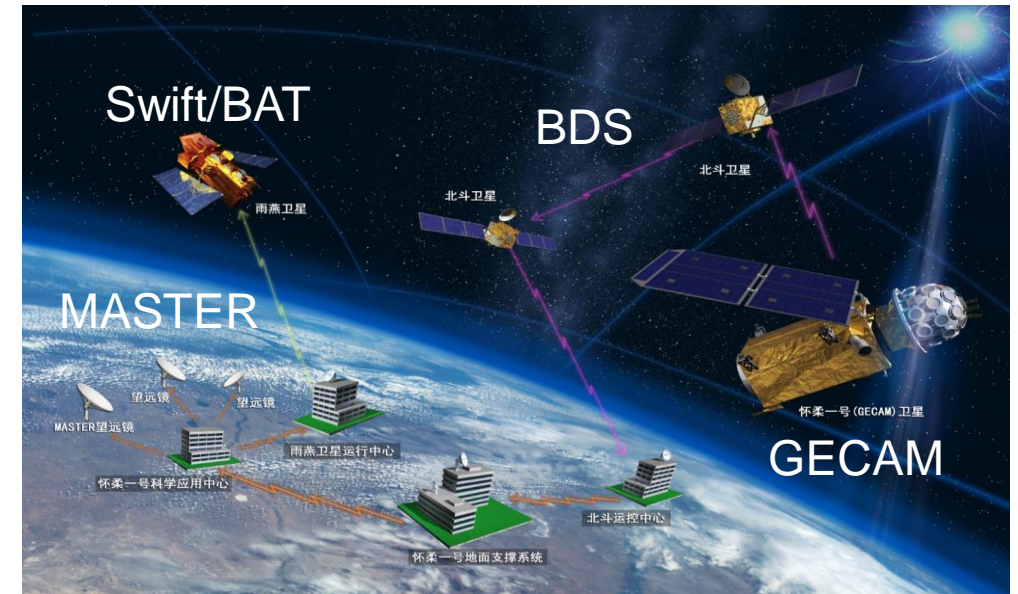
- **Ground automatic alerts**

- Content: refined location, duration, refined trigger classification, etc.
- Latency: **~10 minutes**

- **Final alerts**

- Content: final results of GECAM
- Latency: **~hours**

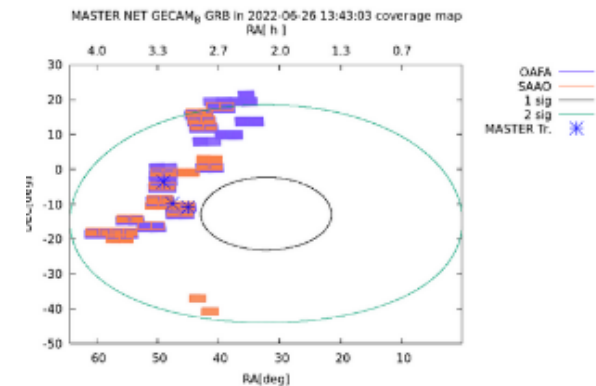
**GECAM alerts have been sent to collaborators by email**  
**Working on the connection to GCN website...**



GECAM alerts initiate follow-up observations

Swift/BAT did not trigger on GRB 211105A (T0: 2021-11-05T04:35:20.2 UTC, **GECAM-B** GCN #31046).  
The **GECAM** notice, distributed in near real-time, triggered the Swift Mission Operations Center operated Gamma-ray Urgent Archiver for Novel Opportunities (GUANO; Tohuvavohu et al. 2020, ApJ, 900, 1).

Swift/BAT GUANO



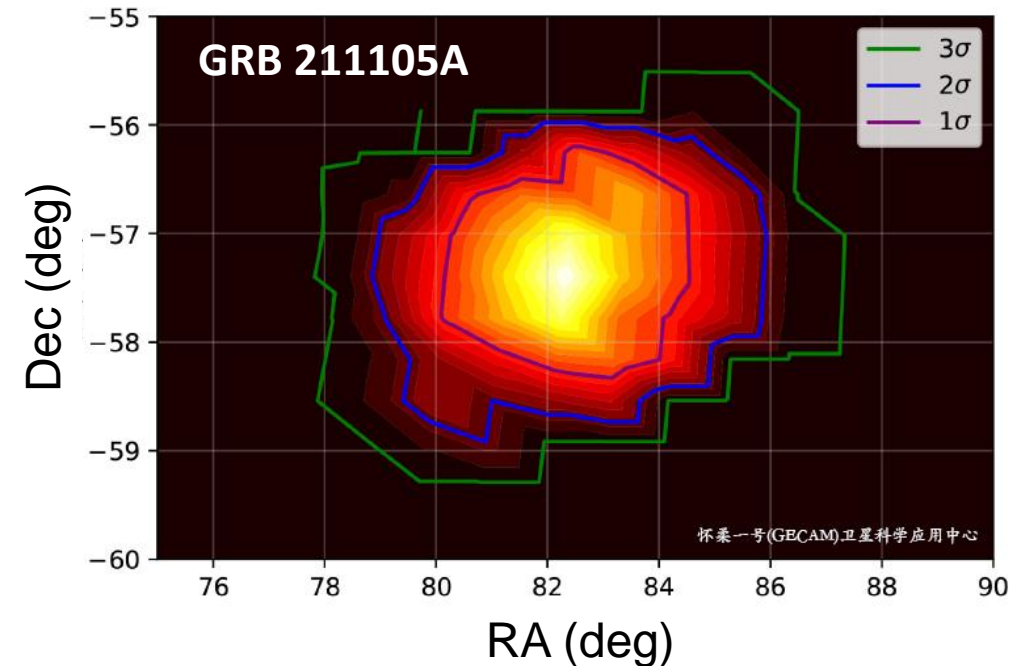
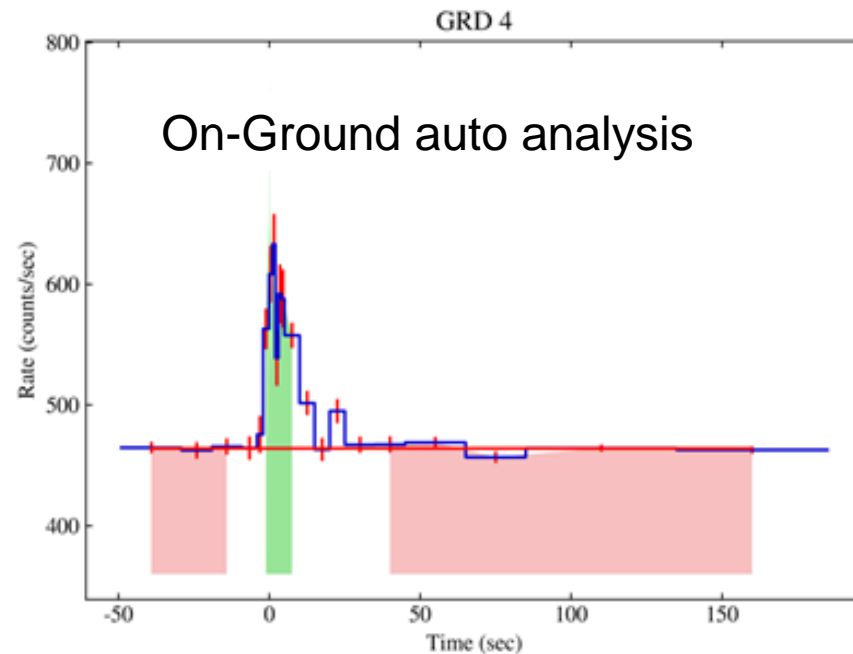
MASTER optical network

# On-Ground automatic refined analysis

- **Refined analysis with the BDS messages**

- Background estimation
- Spectrum analysis
- Localization
- Classification

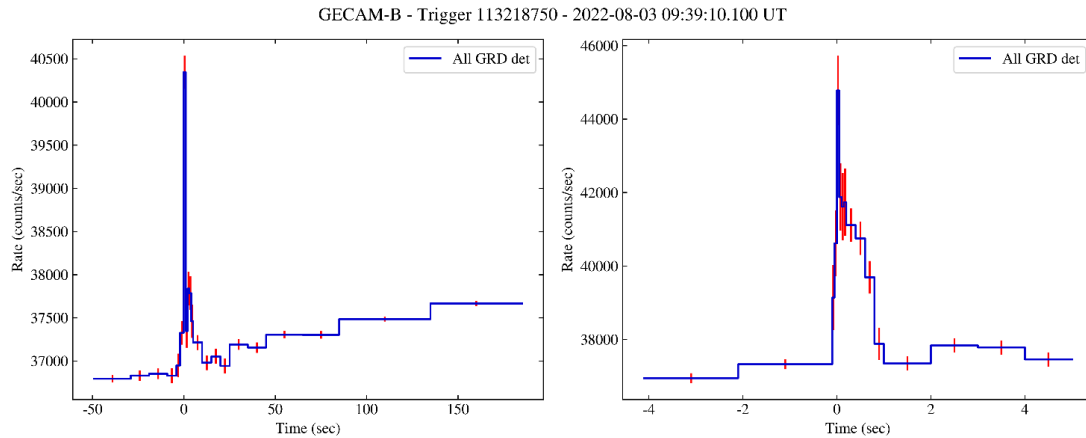
ID	[CALSS]	Note
1	OCCULTA	e.g. Sco X-1
2	SFLARE	
3	DISTPAR	
4	MOON	
5	Known Source	e.g. SGR J1935
6	Galactic Source	
7	GRB	e.g. GRB 210511



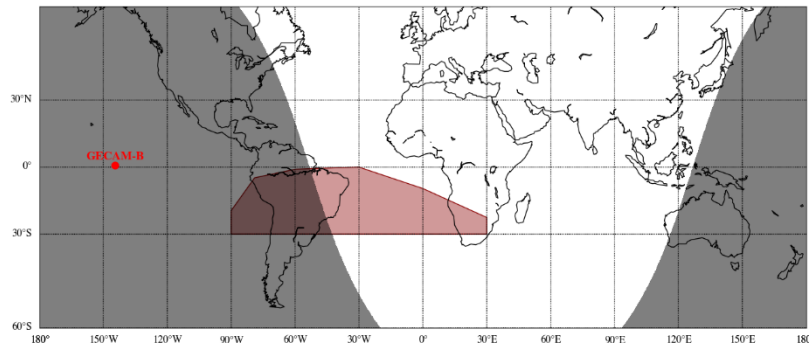
# GECAM GRB with real-time alert data

- **GECAM real-time data by the BeiDou Navigation System (BDS)**

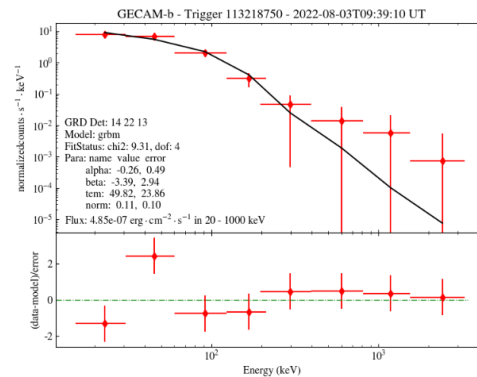
- In-flight trigger information: Time latency of  $\sim 60$  seconds
- Light curves, spectra etc.: Time latency of  $\sim 10$  minutes



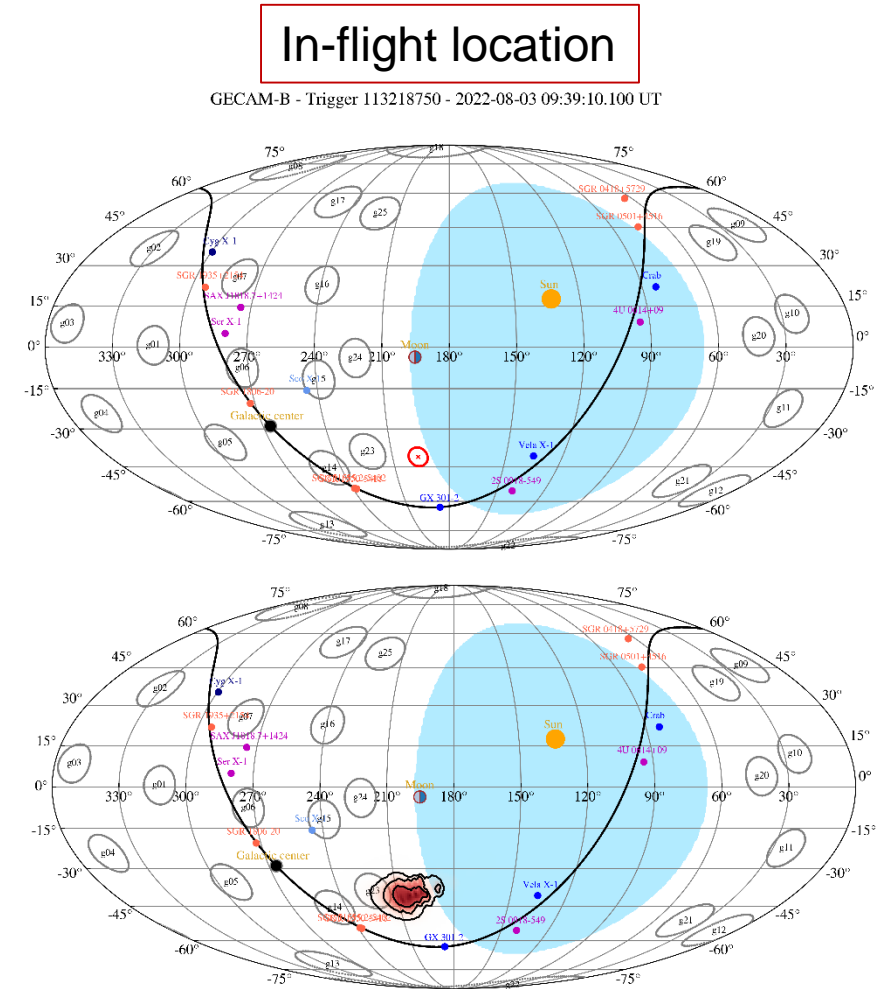
GECAM real-time alert data: Light curves



GECAM position



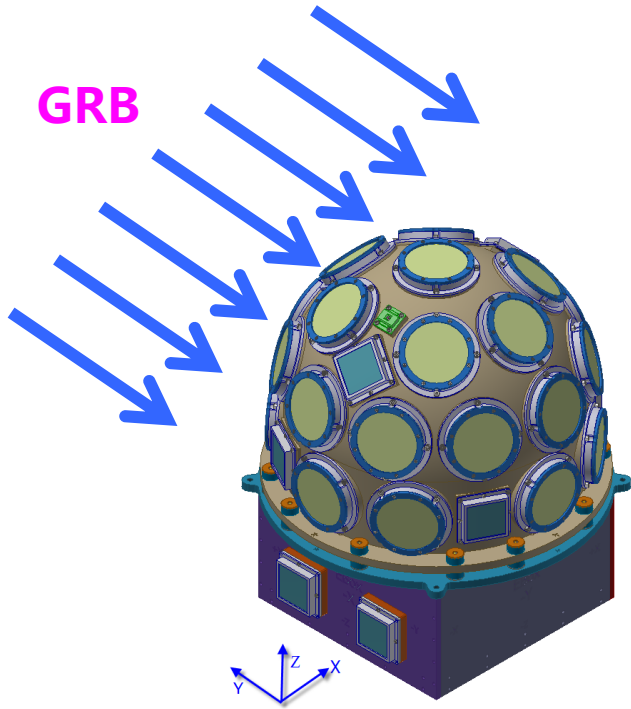
Ground spectrum with the alert data



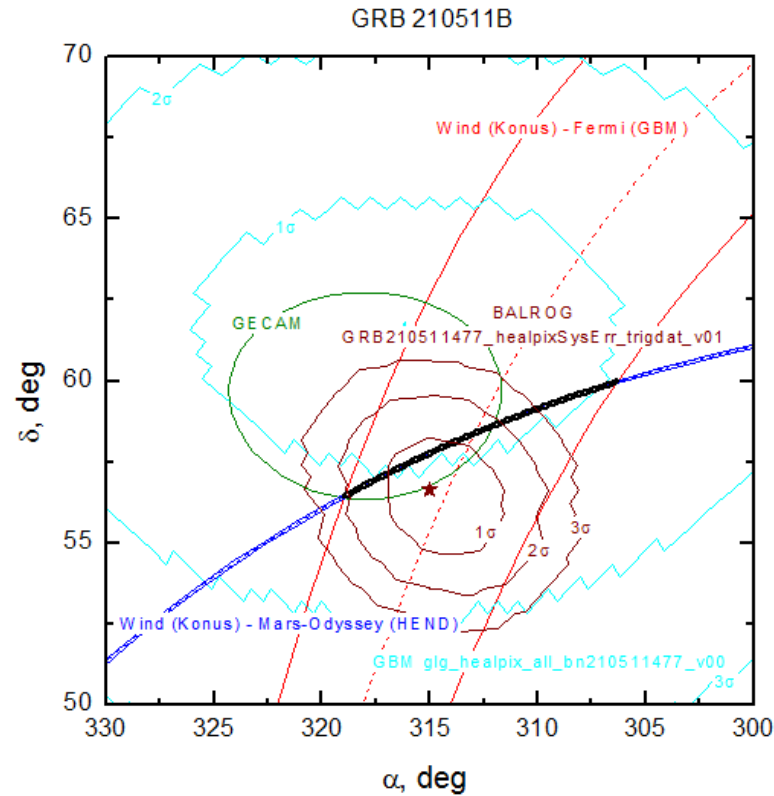
Ground location with the alert data



# GECAM-alone localization of bursts

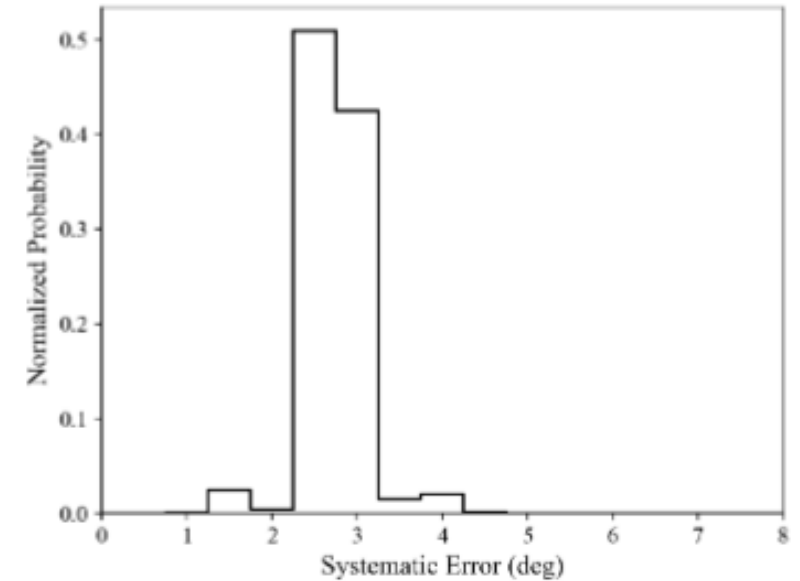


GECAM can localize bursts using counts distribution on detectors, just like BATSE, Fermi/GBM, POLAR



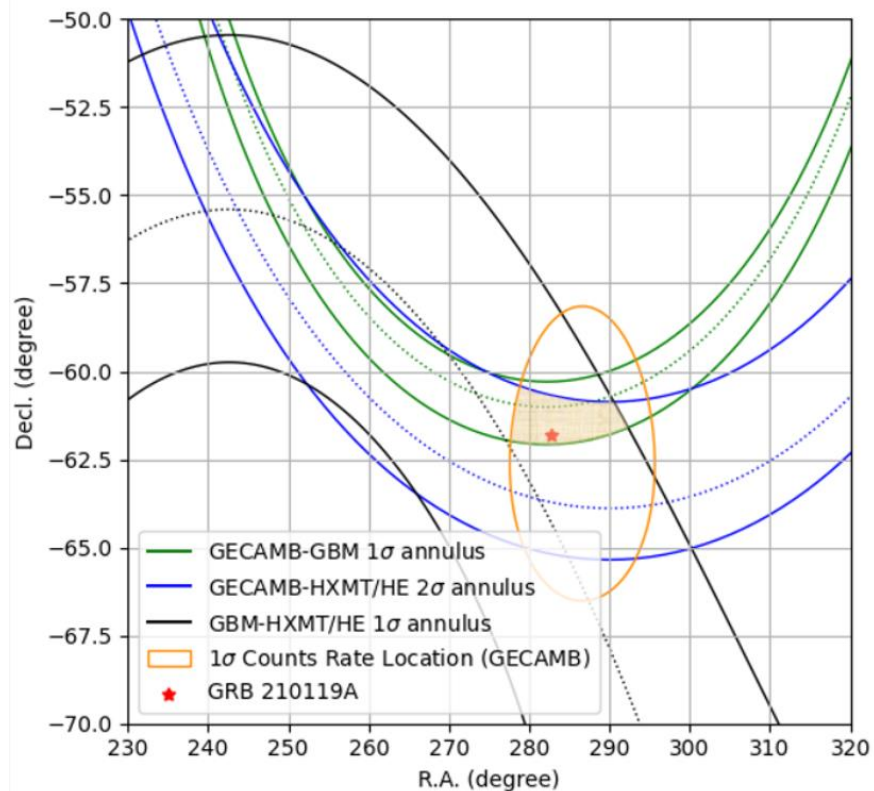
GECAM localization (green circle)  
with IPN locations for GRB 210511B

[http://www.ioffe.ru/LEA/GRBs/GRB210511\\_T41201/IPN/](http://www.ioffe.ru/LEA/GRBs/GRB210511_T41201/IPN/)

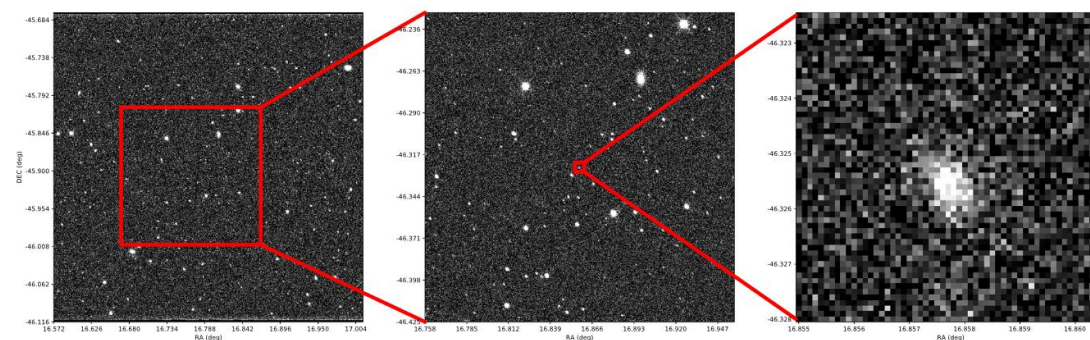
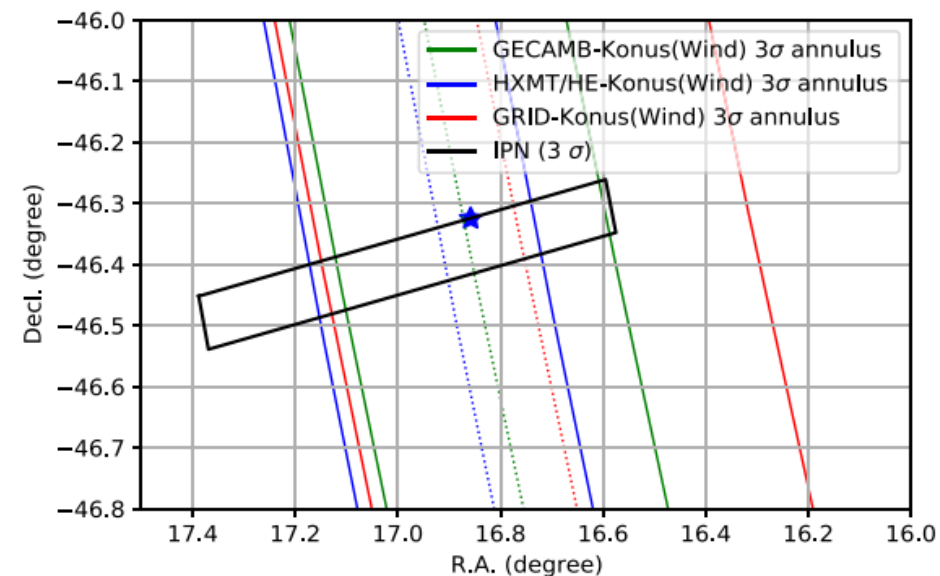


New method to estimate  
systematic error of localization  
(Zhao et al. In prep)

# GECAM joint localization with other GRB monitors



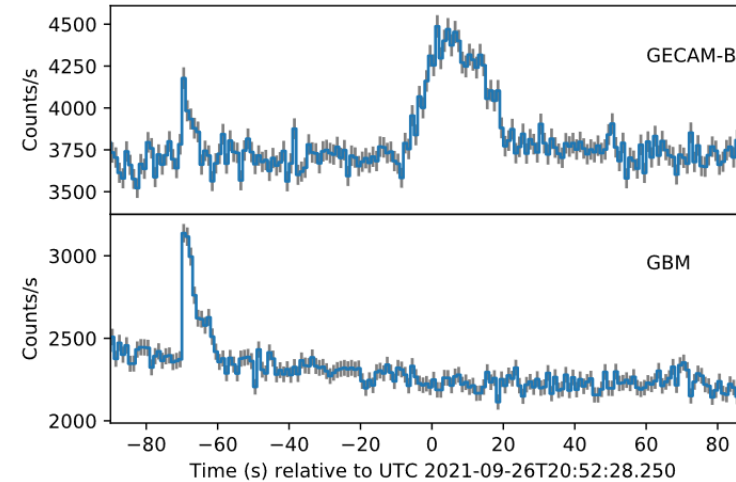
Joint localization for **GRB 210119A**



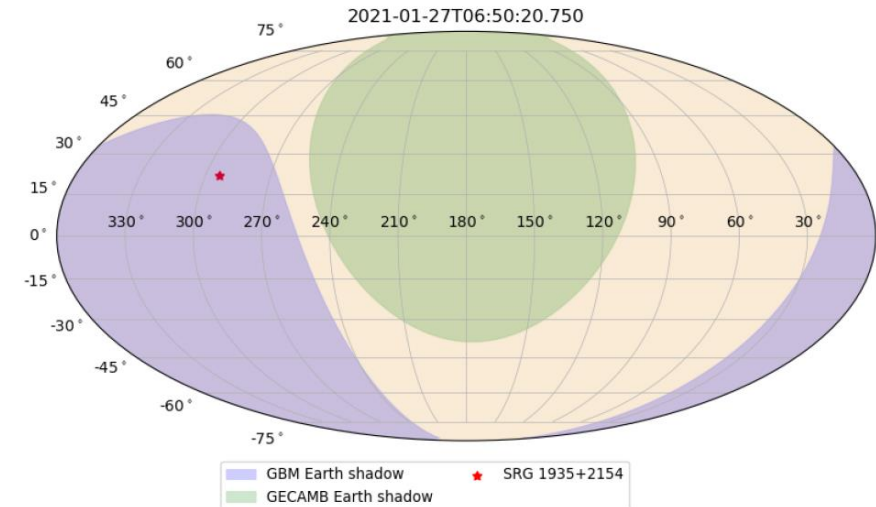
**GRB 210121A**, host galaxy candidate  
(Wang et al. ApJ, 922, 237, 2021)

# GECAM detection of GRBs

GECAM GRB	Fermi/GBM detection?
GRB 210120A	Yes
GRB 210121A	Yes
GRB 210126A	Yes
GRB 210131A	No
GRB 210204A	Yes
GRB 210207B	No
GRB 210228A	Yes
GRB 210307A	No
GRB 210307B	No
GRB 210317A	Yes
GRB 210328A	Yes
GRB 210330A	No
GRB 210401A	Yes
GRB 210409A	No
GRB 210413A	No
GRB 210421B	Yes
GRB 210421A	No
GRB 210425A	No



**Figure 1.** Light curves of GRB 210926A observed by GECAM-B (top) and Fermi/GBM (bottom), respectively. GBM only detected the first pulse because the second pulse was blocked by the Earth.

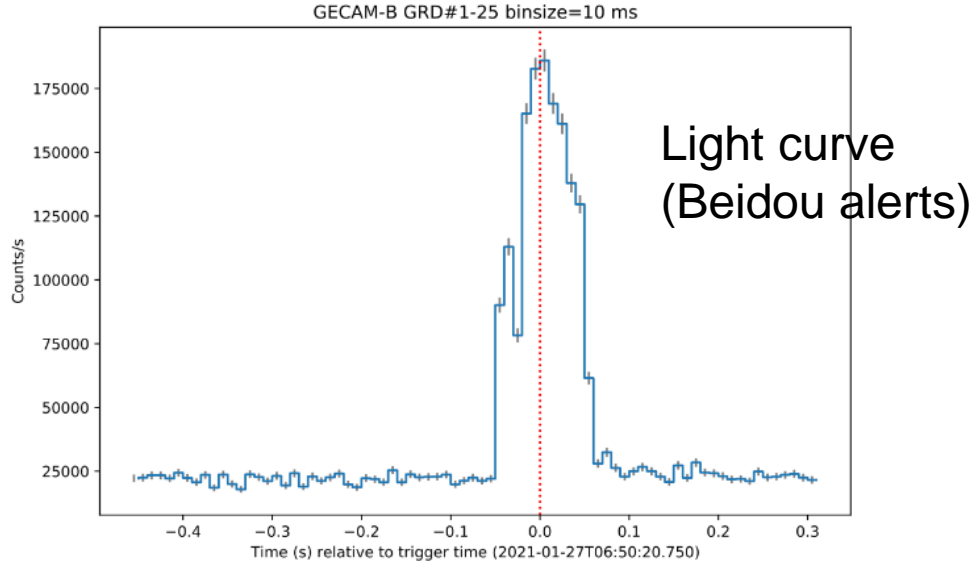


GECAM and Fermi/GBM  
Observations of GRB 210926A  
(Xiao et al., MNRAS, 514, 2397, 2022)

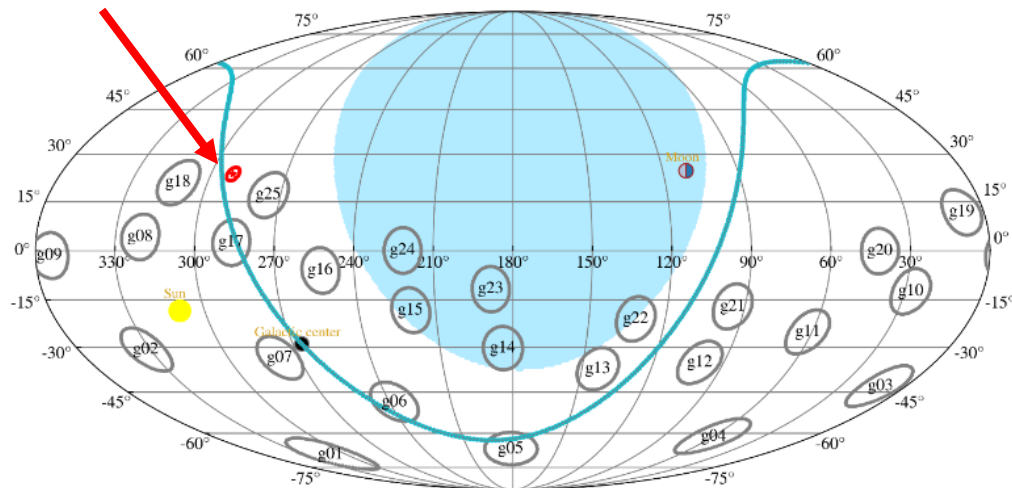
Field of view (FOV)  
of GECAM and Fermi/GBM

- **GECAM detection rate: 150-200 GRBs/year**
- **GECAM and Fermi/GBM complementary to each other**

# GECAM detection of SGR J1935+2134



## In-flight Location



Xie et al., MNRAS, submitted

The bright, short-duration, soft burst (GECAM detection: Huang et al., GCN Circ. 29363) was detected by GECAM, Konus-Wind, and Swift (BAT) at about 24617 s UT (06:50:17) on January 27. The burst was outside the coded field of view of the BAT.

We have triangulated it to a Konus-BAT annulus centered at RA(2000)=315.213 deg (21h 00m 51s) Dec(2000)=-14.116 deg (-14d 06' 56"), whose radius is 41.658 +/- 0.174 deg (3 sigma).

The position of SGR 1935+2154 lies inside the annulus at 3.5 arcmin from its center line.

Given the positional coincidence (initially suggested in GCN 29363) of this burst with SGR 1935+2154, its time history, and softness of its spectrum (as observed by Konus-Wind), we conclude this burst is likely originated from SGR 1935+2154.

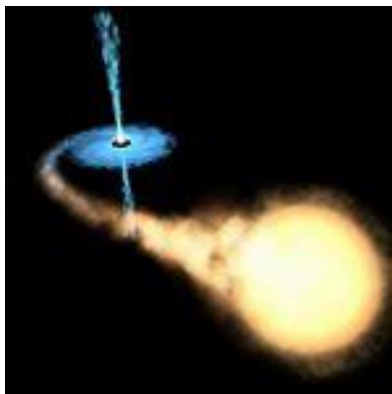
A triangulation map is posted at [http://www.ioffe.ru/LEA/SGRs/210127\\_T24616/IPN/](http://www.ioffe.ru/LEA/SGRs/210127_T24616/IPN/)



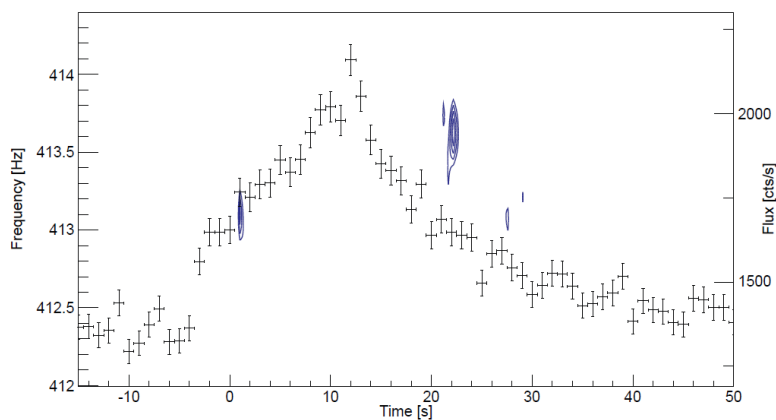
Co-ordinate observations with FAST etc.



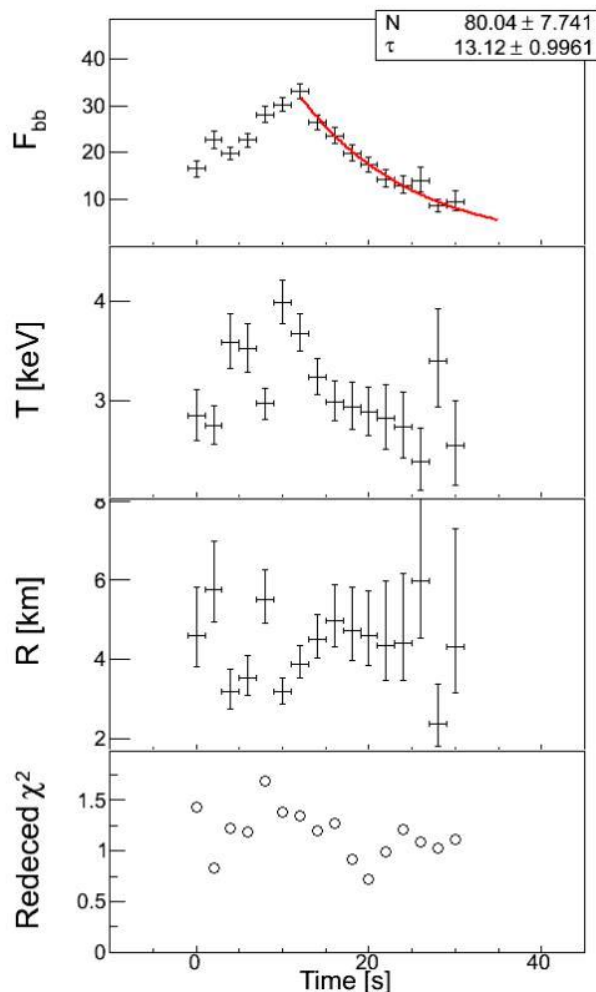
# GECAM detection of bursts from X-ray Binaries



**4U 0614+091**  
(Neutron Star XRB)



burst oscillation at 413 Hz



Time-resolved spectrum

## GECAM detection of a bright thermonuclear burst from 4U 0614+091

ATel #14363; [Y. P. Chen \(IHEP\)](#), [J. Li \(USTC\)](#), [S. L. Xiong \(IHEP\)](#), [L. Ji \(SYSU\)](#), [S. Zhang \(IHEP\)](#), [W. X. Peng \(IHEP\)](#), [R. Qiao, X. Y. Zhao, Y. Huang, F. J. Lu, S. N. Zhang, L. M. Song, S. Xiao, C. Cai, B. X. Zhang, Z. H. An, C. Chen, G. Chen, W. Chen, M. Cao, K. Gong, D. Y. Guo, J. J. He, B. Li, C. Li, C. Y. Li, J. H. Li, Q. X. Li, X. B. Li, X. Q. Li, Y. G. Li, X. H. Liang, J. Y. Liao, J. C. Liu, X. J. Liu, Y. Q. Liu, Q. Luo, X. Ma, G. Ou, D. L. Shi, J. Y. Shi, X. Y. Song, G. X. Sun, X. L. Sun, Y. L. Tuo, C. W. Wang, J. Z. Wang, P. Wang, X. Y. Wen, Y. B. Xu, Y. P. Xu, W. C. Xue, S. Yang, M. Yao, Q. B. Yi, C. Y. Zhang, D. L. Zhang, Fan Zhang, Fei Zhang, H. M. Zhang, K. Zhang, P. Zhang, Y. Q. Zhang, Z. Zhang, S. Y. Zhao, Y. Zhao, C. Zheng, S. J. Zheng, X. Zhou \(IHEP\), report on behalf of GECAM team:  
on 1 Feb 2021; 05:06 UT](#)

Credential Certification: Yu-Peng Chen ([chenyp@ihep.ac.cn](mailto:chenyp@ihep.ac.cn))

Subjects: X-ray, Binary, Neutron Star

**Tweet**

During the commissioning phase, GECAM-B detected a very bright X-ray burst at 2021-01-24T11:50:03.600 UTC (denoted as T<sub>0</sub>, GCN 29350) from a direction centered on Ra: 94.9 degree, Dec: 6.6 degree with an error circle 2.7 degree (1-sigma, statistical only). The burst has a fast rise of 10 s, an exponential fashion decay and a duration of ~60 s. With 4 detectors out of 25, the peaks flux is ~700 cts/s above the pre-burst emission.

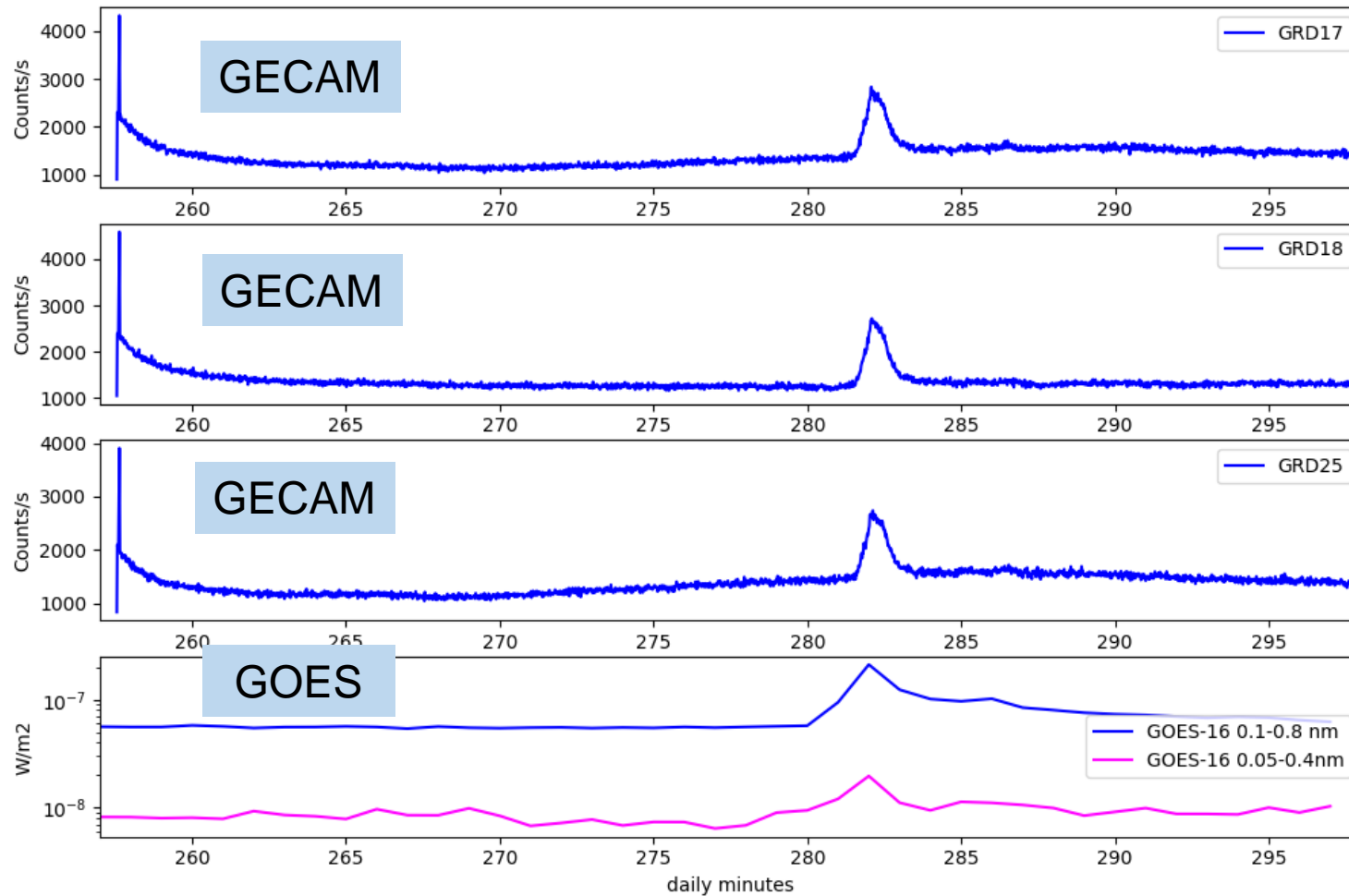
A pulsation at 413 Hz is detected with ~4 sigma. The 2-second time bin burst spectra are well represented by a blackbody, with a temperature peaking at 4.0±0.2 keV and a peak flux (3.3±0.2) × 10<sup>-7</sup> erg/cm<sup>2</sup>/s. The spectrum softens with the temperatures from ~4 keV to ~2 keV during the decay. Assuming the source at a distance 3 kpc, the unabsorbed bolometric peak luminosity is (3.6±0.2) × 10<sup>38</sup> erg/s, which is well consistent with the Eddington limit with a stellar mass of 1.4 solar mass for hydrogen-poor matter.

This analysis shows convincingly the burst is a genuine thermonuclear X-ray burst from 4U 0614+09, a faint and persistently accreting neutron star X-ray binary lying within the location error, from which the 415 Hz burst oscillation was first reported with data from Swift/BAT (Strohmayer et al. 2008). Since 4U 0614+091 has a burst recurrence time ~12 day (Linares et al. 2012), thanks to the very wide field of view (more than a half sky) of GECAM-B, more bursts should be detected during future observations of GECAM-B.

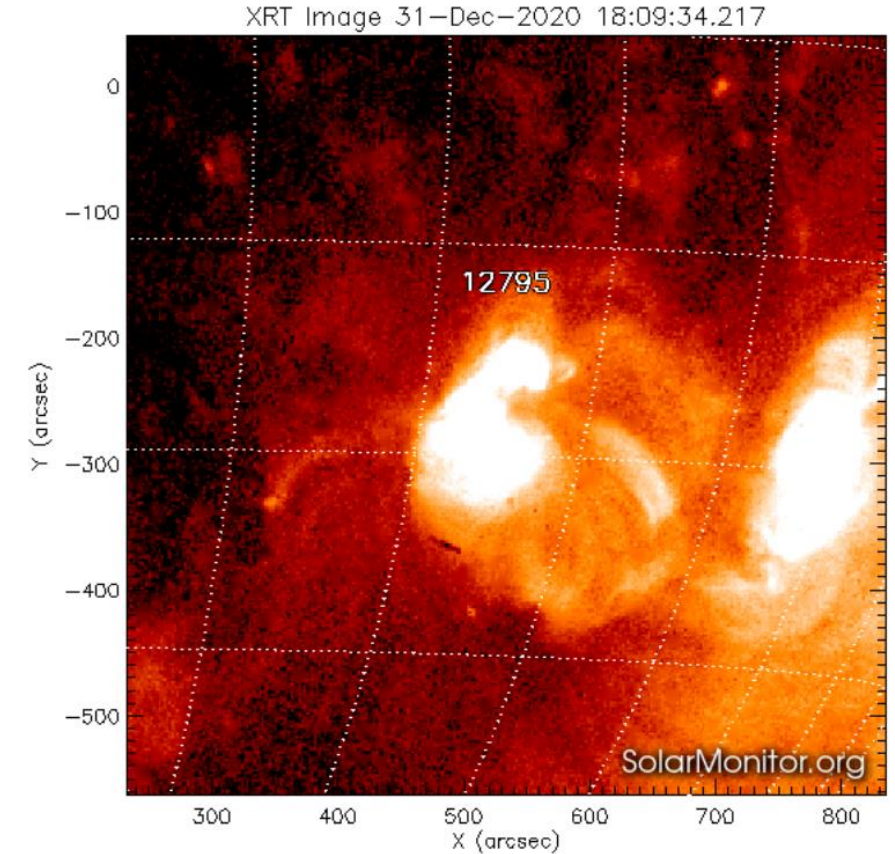
Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor (GECAM) mission consists of two small satellites (GECAM-A and GECAM-B) in Low Earth Orbit (600 km, 29 deg), launched on Dec 10, 2020 (Beijing Time), which was funded by the Chinese Academy of Sciences (CAS).

# GECAM detection of Solar Flares

GECAMB GRD Vs GOES (20210101)



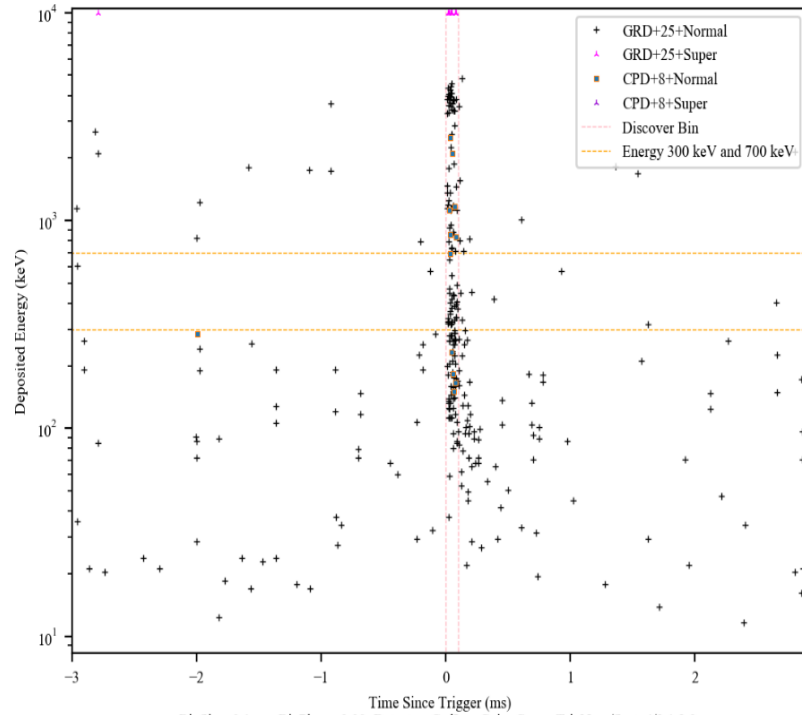
Zhao et al., In prep



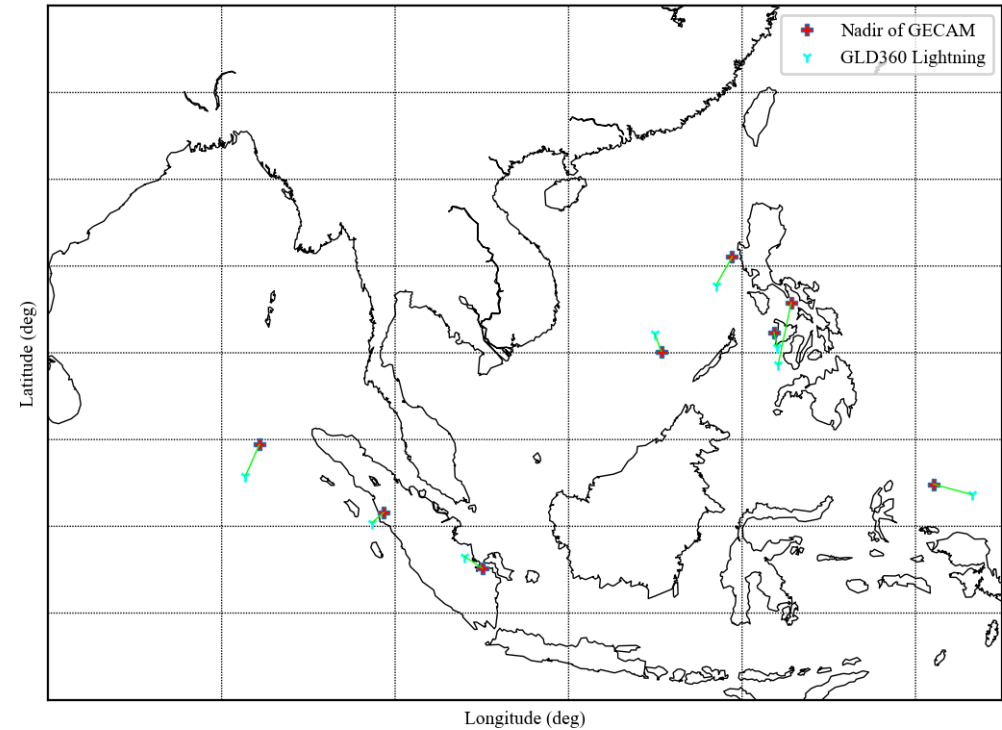
B2.1 class flare

# GECAM detection of Terrestrial Gamma-ray Flash (TGF)

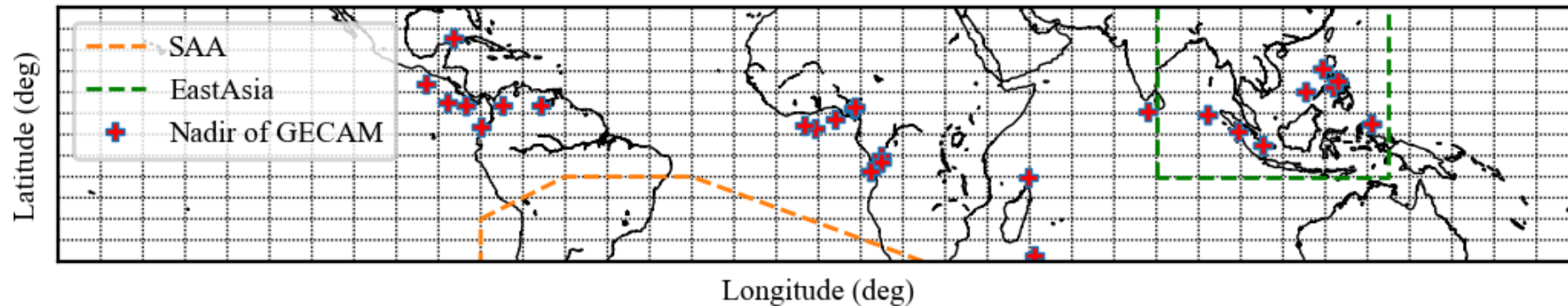
GECAM Time-Energy Scatter of TGF Candidate for Total Detector Short  
UT: 2021-03-07T19:13:49.995527



GECAM Map of TGF Candidates



GECAM Map of TGF Candidates



# GECAM observations

## • Bursts observed

- GRB (>100 bursts)
  - GRB 210126A, GRB 210121A, GRB 210120A
- SGR (>100 bursts)
  - SGR 1935+2154, SGR 1555.2, SGR 1830
- X-ray Binary
  - 4U 0614+09
- X-ray sources by Earth occultation
  - Sco X-1, Crab
- X-ray pulsars
  - Crab
- Solar Flares
  - >80 bursts

## • Joint observations

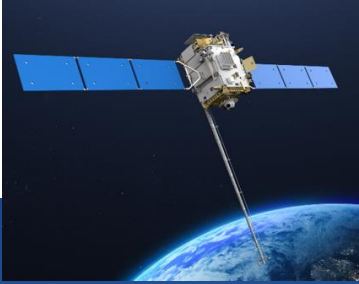
- *Swift, Fermi, Insight-HXMT, FAST, LHAASO, MASTER, GWFUNC, etc.*
- Routinely report observation results through GCNs

- [29363](#) **GECAM** detection of a short burst probably from SGR 1935+2154
- [29362](#) GRB 210127A: Fermi GBM Final Real-time Localization
- [29361](#) GRB 210120A: Fermi GBM detection
- [29360](#) Fermi trigger No 633348010: Global MASTER-Net observations report
- [29359](#) HAWC Transient event on 2021/01/25
- [29358](#) Konus-Wind detection of GRB 210121A
- [29357](#) Konus-Wind detection of GRB 210124B
- [29356](#) GRB 210126A: **GECAM** detection
- [29355](#) IPN triangulation of GRB 210124B (short)
- [29354](#) GRB 210126A: BALROG localization (Fermi Trigger / GRB 210126417)
- [29353](#) GRB 210124B: Insight-HXMT/HE detection
- [29352](#) Fermi trigger No 633257525: Global MASTER-Net observations report
- [29351](#) GRB 210123A: Fermi GBM Final Localization
- [29350](#) **GECAM** detection of a burst possibly from the X-ray burster 4U 0614+09 or GRB 210124A
- [29349](#) GRB 210123A: Insight-HXMT/HE detection
- [29348](#) IPN triangulation of GRB 210121A
- [29347](#) GRB 210121A: **GECAM** detection
- [29346](#) GRB 210121A: Insight-HXMT/HE detection
- [29345](#) GRB 210120A : 1.3m DFOT optical observations
- [29344](#) ZTF21aaeyldq: GROND and CAHA jet break confirmation
- [29343](#) ZTF20aaeyldq: VLA radio detection
- [29342](#) GRB 210116A: AstroSat CZTI detection
- [29341](#) GRB 210120A(MASTER OT J105242.66+152355.0 / AT2021axc): Mondy optical observations
- [29340](#) GRB 210116: AstroSat LAXPC detection
- [29339](#) GRB 210120A: MASTER OT (possibly) discovery
- [29338](#) **GECAM** In-Flight Trigger of GRB 210120A
- [29337](#) GRB 210104A: 3.6m DOT optical upper limit
- [29336](#) Fermi GRB 210120A: Global MASTER-Net observations report
- [29335](#) GRB 210120A: BALROG localization (Fermi Trigger 632819449 / GRB 210120299)
- [29334](#) GRB 210120A: Fermi GBM Final Real-time Localization
- [29333](#) GRB 210112A: 3.6m DOT optical detection
- [29332](#) GRB 210119A (Swift J1851.2-6148): Swift-BAT refined analysis
- [29331](#) **GECAM** detection of a short GRB 210119A or a new SGR candidate Swift J1851.2-6148

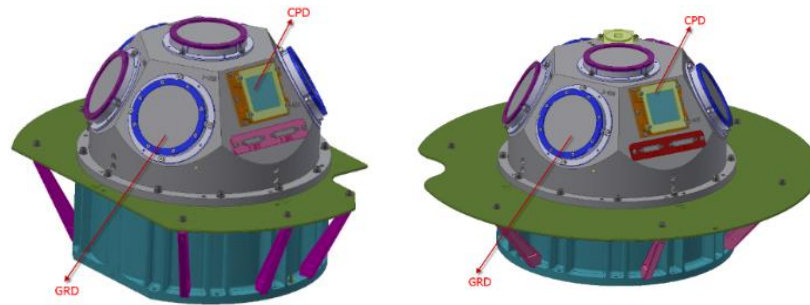
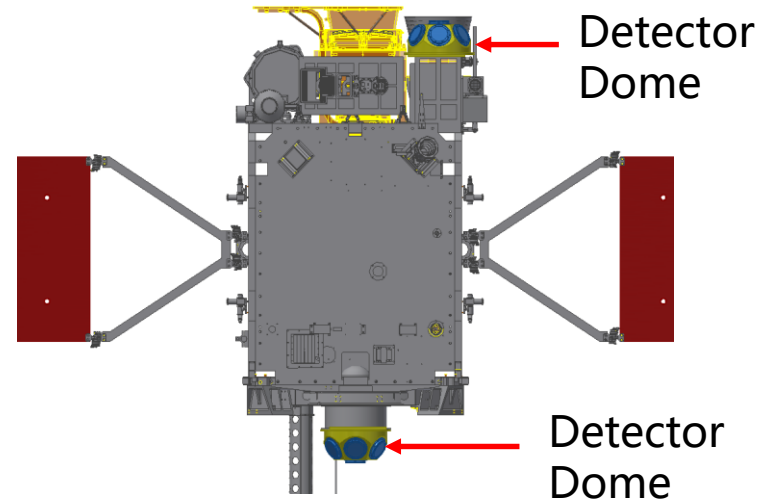
GECAM GCNs



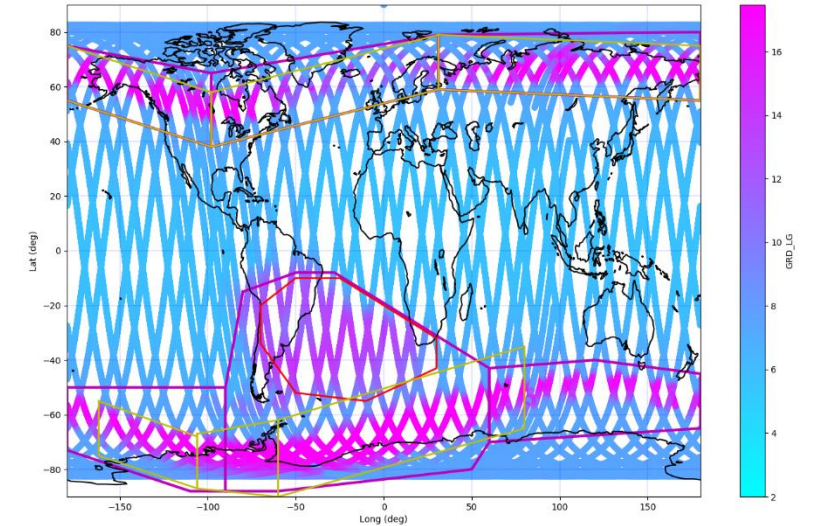
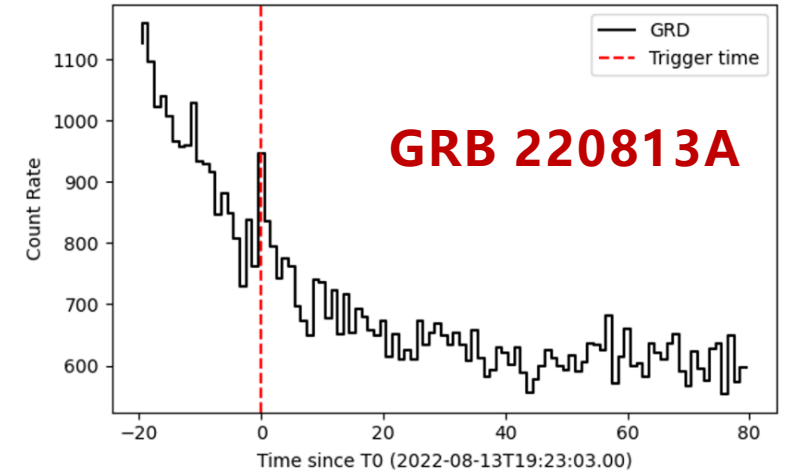
# New member in GECAM family: GECAM-C (SY01/HEBS)



**Orbit: 500 km, SSO**



**detector dome**  
**Similar design as GECAM-B**



Detector counts rate map

**GECAM-C is under commissioning**

Launched on 2022/07/27

# GRB missions in IHEP, CAS

Missions	Launch Time	Energy range	Field of View (all-sky)	Features
<i>Insight-HXMT</i>	2017-06-15	200-3000 keV	~60%	Large effective area in MeV range
<b>GECAM-B</b>	2020-12-09	15-5000 keV	~60%	Real-time alert, wide energy band
<b>GECAM-C</b>	2022-07-27	10-5000 keV	~60%	Real-time alert, wide energy band
<b>GECAM-D</b>	~2023	20-1000 keV	~90%	Deep space, all-sky and all-time coverage Near real-time alert
<b>SVOM/GRM</b>	~2023	15-5000 keV	~60%	Real-time alert. Multi-wavelength. Quick slew
<b>POLAR-2/BSD</b>	~2024	10-5000 keV	~50%	Real-time alert, polarization in 1-800 keV Chinese Space Station.

**In operation**   **Forthcoming**

# Summary

- GECAM is a gamma-ray monitor proposed in 2016 and launched in 2020
  - Two microsatellites: **GECAM-A (still off)**, **GECAM-B (20 hours/day)**
- Detectors performance good while SiPMs showed complicated behaviors
  - GRD (LaBr3 + SiPM) and CPD (PS + SiPM)
- Near real-time alert system based on BeiDou Navigation System (BDS)
  - Latency ~ 1 minute for the in-flight results and ~10 minutes for refined results
- Many detections of GRBs, SGRs, XRBs, SFLs, TGFs...
  - Data and software will be released soon
- **GECAM-C is joining us**, GECAM-D is coming in 2023

**Collaboration is very welcome!**  
**Contact: Shaolin XIONG (xiongsl@ihep.ac.cn)**