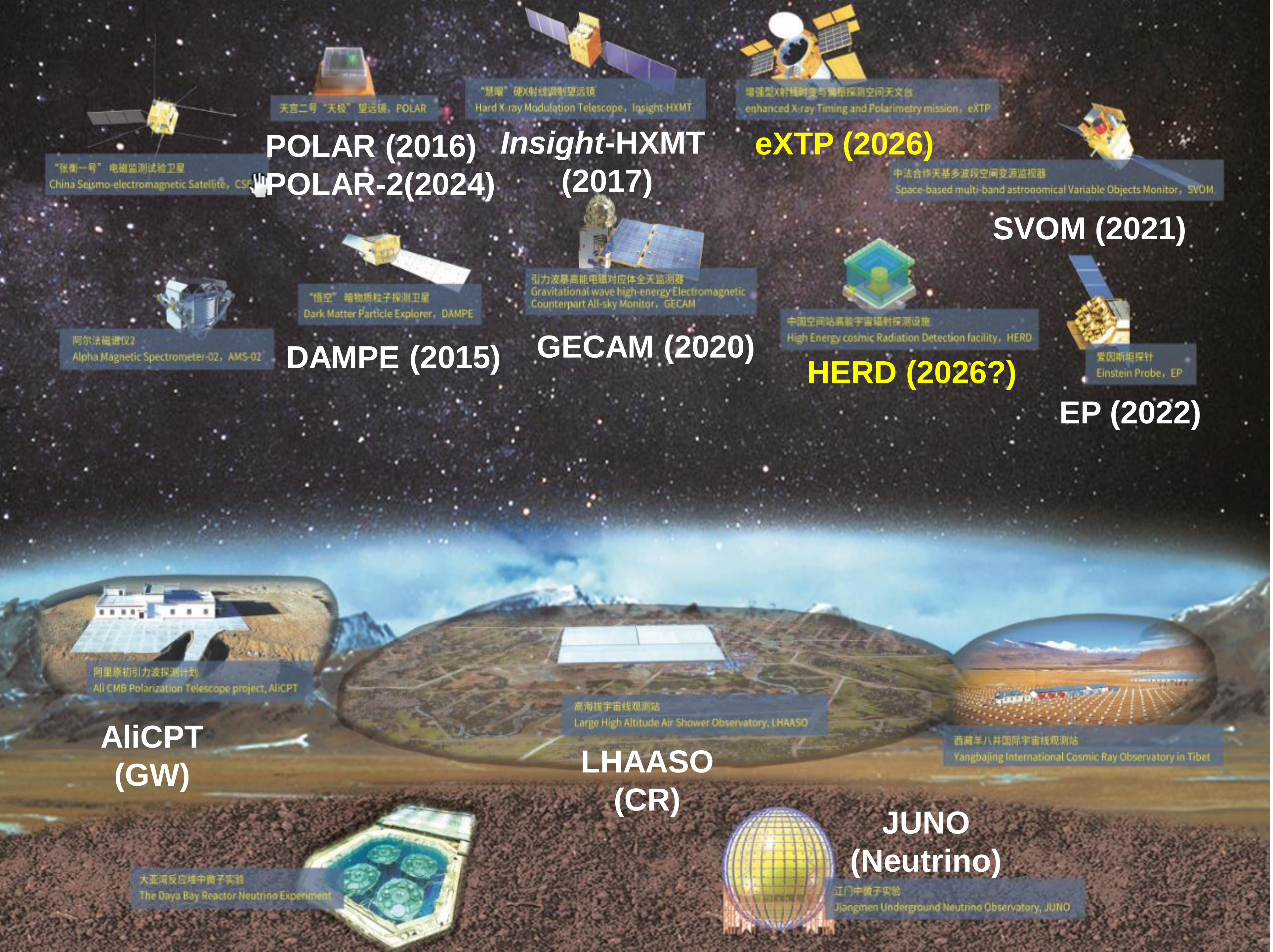
GECAM：An all-time all-sky X/γ monitor in multi-messenger/wavelength era

Shaolin XIONG

xiongsl@ihep.ac.cn

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

2019-09-12 KW25 St. Petersburg



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Adopted by CAS in July 2018

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1

Two satellites, launching in 2020, will watch for gamma rays from the violent birth of gravitational waves.
INSTITUTE OF HIGH ENERGY PHYSICS, CAS

New China space missions will watch for colliding black holes, solar blasts

By Dennis Normile | Jul. 11, 2018 , 12:45 PM

GWGRB is a special component of GWEM

Pros

- **BNS merger: Short GRB, well known for decades**
  - X/gamma-ray, E_{peak}~keV to MeV
  - Possible with the Extended Emission component
- **Provide early alerts for follow-up obs. in other EM bands**
  - Soft X-ray (Swift/XRT), Optical, IR, UV, Radio, etc.
- **Short time delay with respect to the GW**
  - Easier to associate with GW than long delay EM components
  - Fundamental physics, e.g. constrain the speed of GW
- **Could be (very) bright**
  - Easy to detect with wide-FoV gamma-ray monitor (easy and cheap)

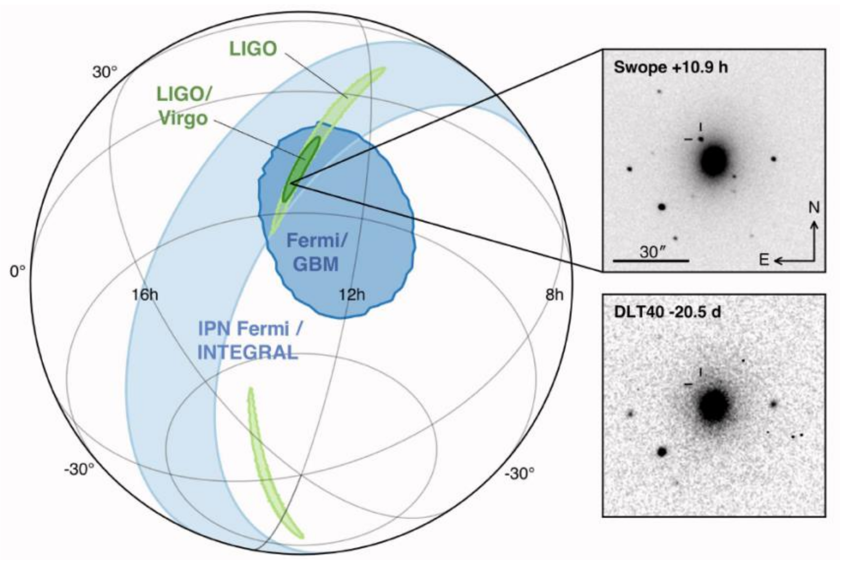
Cons

- **Short duration**
  - Hard to detect with narrow-FoV telescopes, no time for slew!
- **Likely dim and soft**
  - require monitor with high sensitivity in soft energy band

GW170817

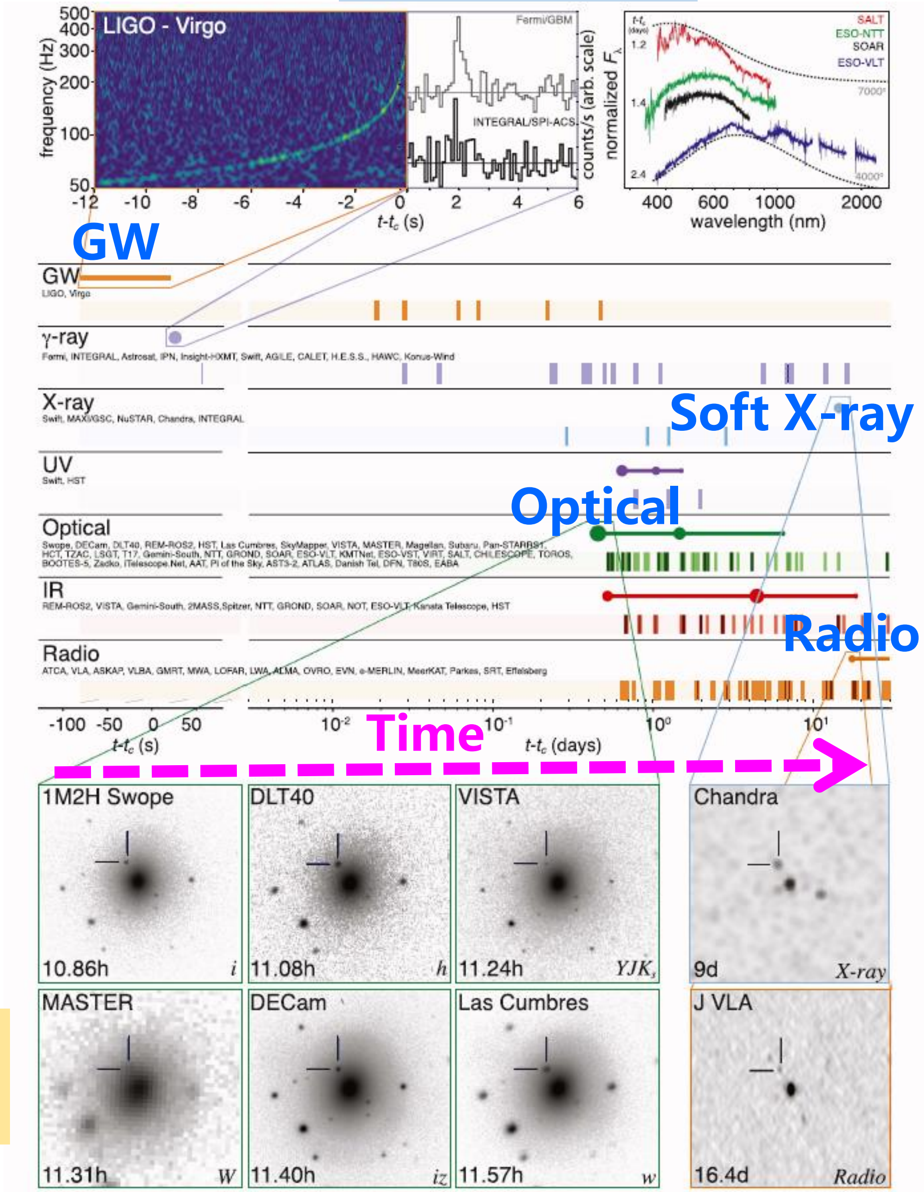
GWGRB played a critical role in the synergy observation

- **Early alert, even earlier than GW**
- Independent confirmation
- Reduced localization area facilitating follow-up observations
- Provide important astrophysics context



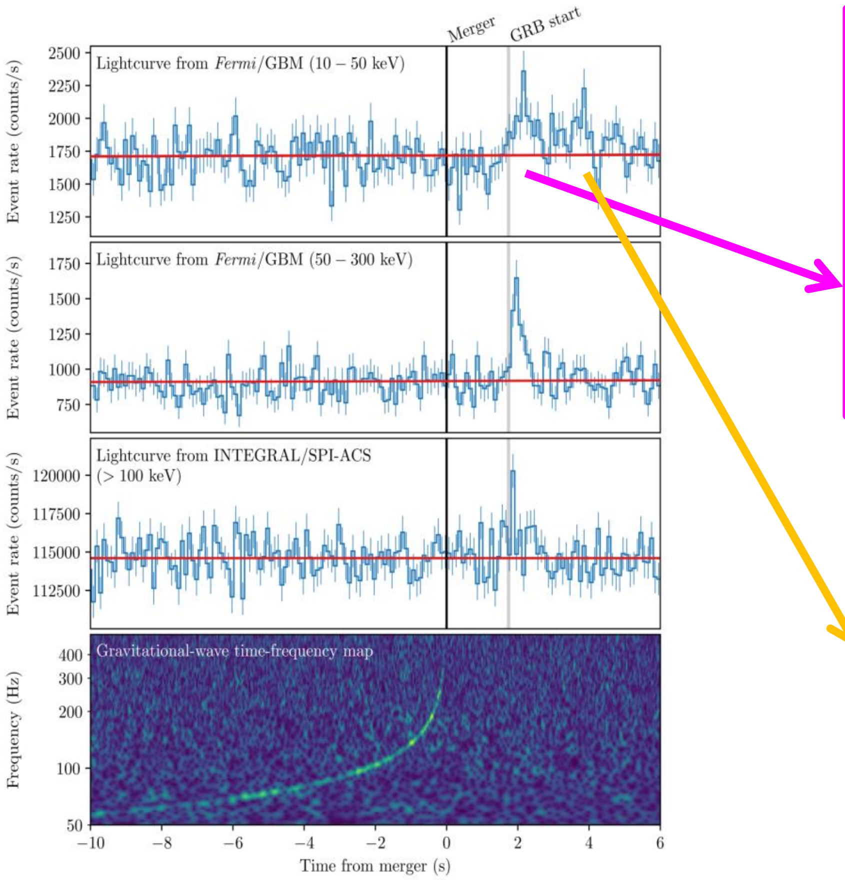
GWGRB trigger and localization are crucial for GW verification and EM follow-up

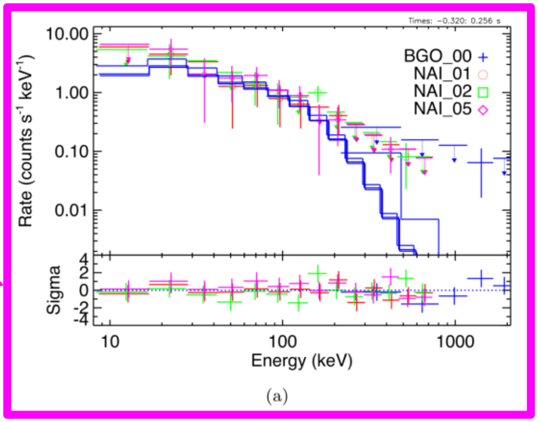
GRB170817A



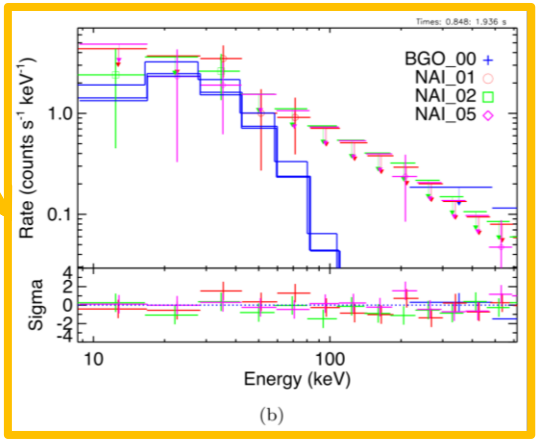
GWGRB rich physics

- Delayed ~1.7 s after the GW
- Intrinsic weak, 3-4 order of magnitude weak than previously known GRBs
- hard component followed by a soft one (likely Black Body component)



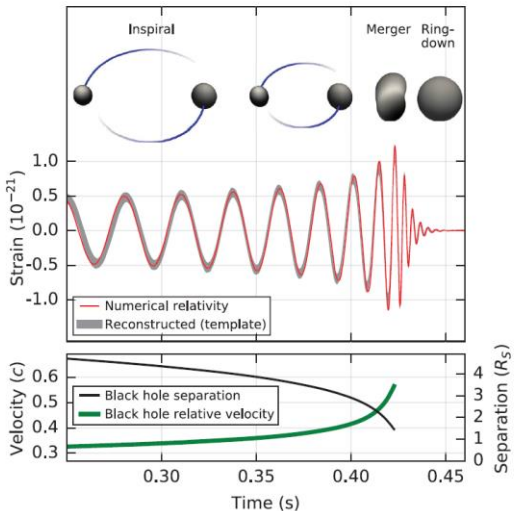


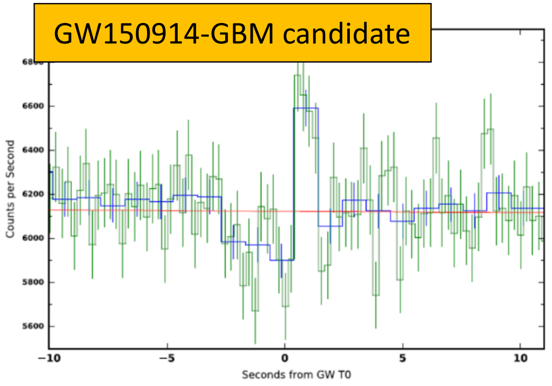
First Component

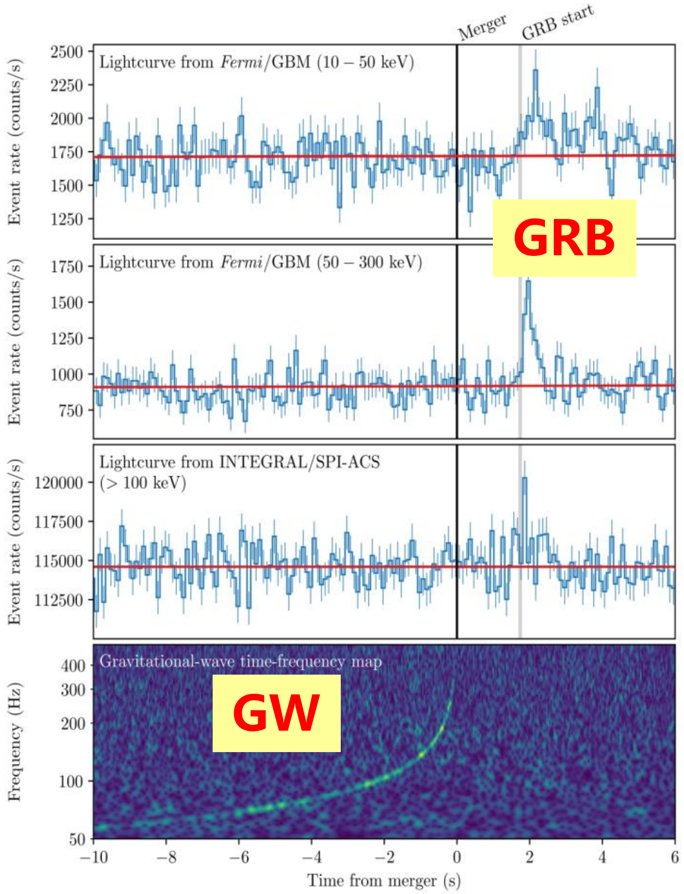


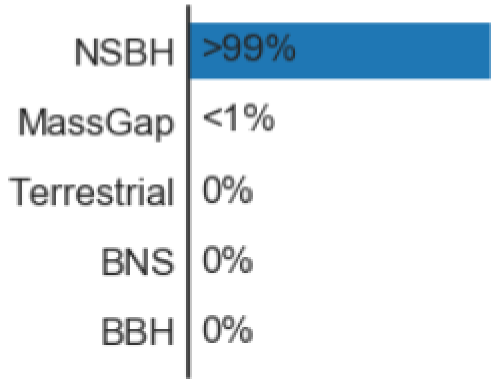
Second Component

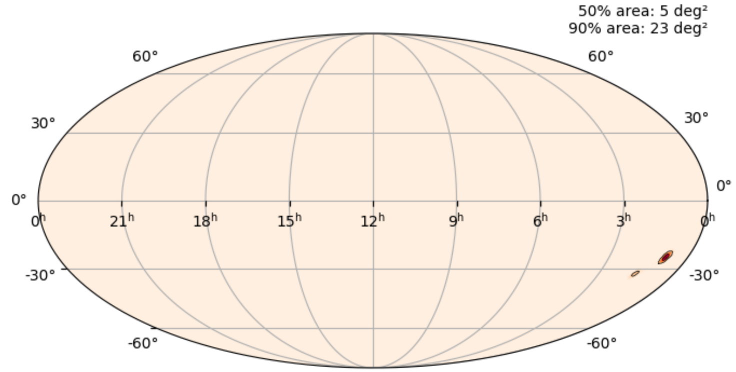
Can all kinds of GW produce GRB?











BH-BH merger (GW150914)

GRB Candidate

NS-NS merger (GW170817)

GRB confirmed

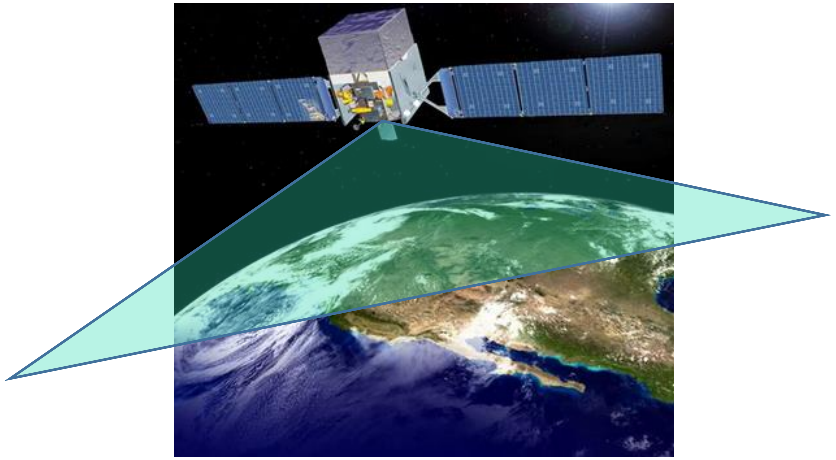
BH-NS merger (GW190814)

No GRB candidate yet

GWGRB very rare, challenging to current GRB monitors

- Fermi/GBM+LVC @2020
  - 2018-2019： 0.1-1.4/year
  - **2020： 0.3-1.7/year**

LVC, Fermi GBM, INTEGRAL, 2017, ApJL, 848, L13



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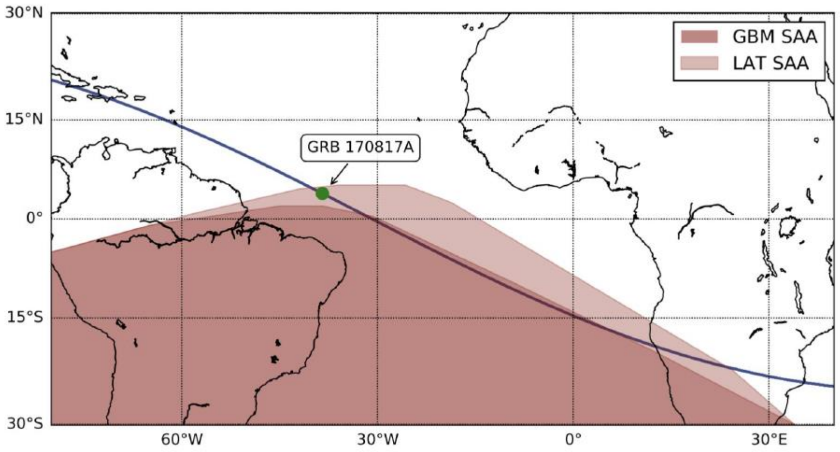
TITLE:    GCN CIRCULAR
NUMBER:   24185
SUBJECT:  LIGO/Virgo S190425z: Fermi GBM Observations
DATE:     19/04/25 15:35:23 GMT
FROM:     Cori Fletcher at USRA/NASA  <corinne.l.fletcher@nasa.gov>

C. Fletcher (USRA) reports on behalf of the Fermi-GBM Team and the
GBM-LIGO/Virgo group:

For S190425z and using the initial BAYESTAR skymap, Fermi-GBM was
observing 55.6% of the probability region at event time.
```

Current GRB monitors:

- Field Of View (FOV)
- Duty cycle
- Sensitivity and localization




```
TITLE:   GCN CIRCULAR
NUMBER:  24065
SUBJECT: LIGO/Virgo S190408an: Fermi GBM Observation
DATE:    19/04/08 21:00:15 GMT
FROM:    C. Michelle Hui at MSFC/Fermi-GBM  <c.m.hui@nasa.gov>

C. M. Hui (NASA/MSFC)

reports on behalf of the Fermi-GBM Team and the GBM+LIGO/Virgo Working Group:


At the time of S190408an, Fermi was passing through

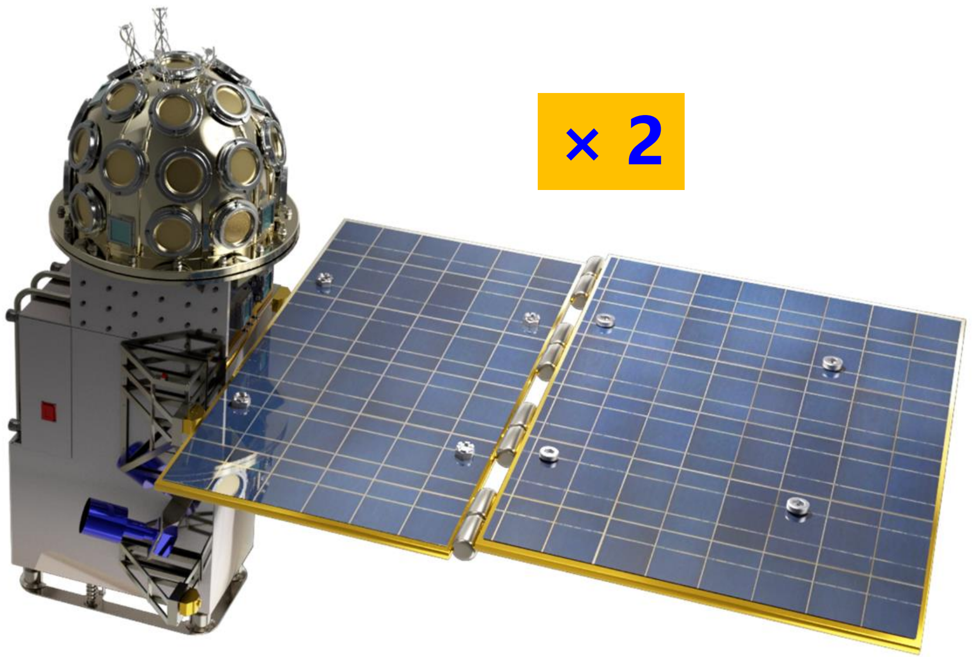
the South Atlantic Anomaly from 14 minutes prior to 15 minutes after

the trigger time; therefore the GBM detectors were disabled.
```

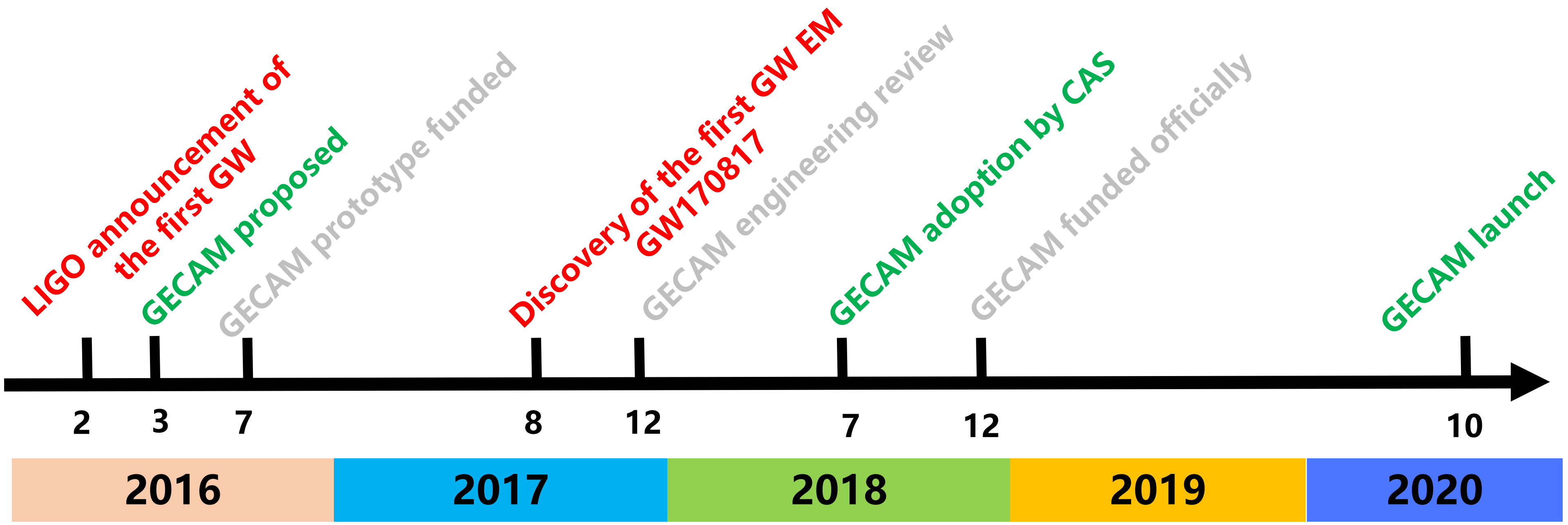
Gravitational wave high energy Electromagnetic Counterpart All sky Monitor

GECAM

引力波暴高能电磁对应体全天监测器



GECAM Timeline

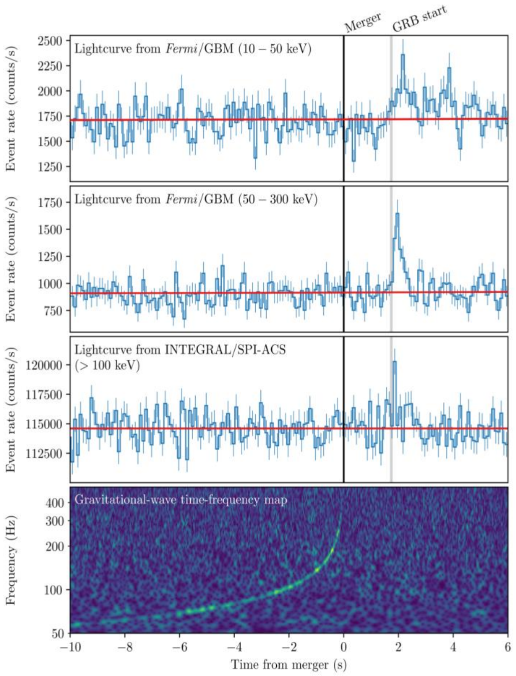


The first *Mission of Opportunity (MoO)*
in the Strategic Priority Program on Space Science (SPPSS-II),
Chinese Academy of Sciences (CAS)

GECAM Requirements for GWGRB

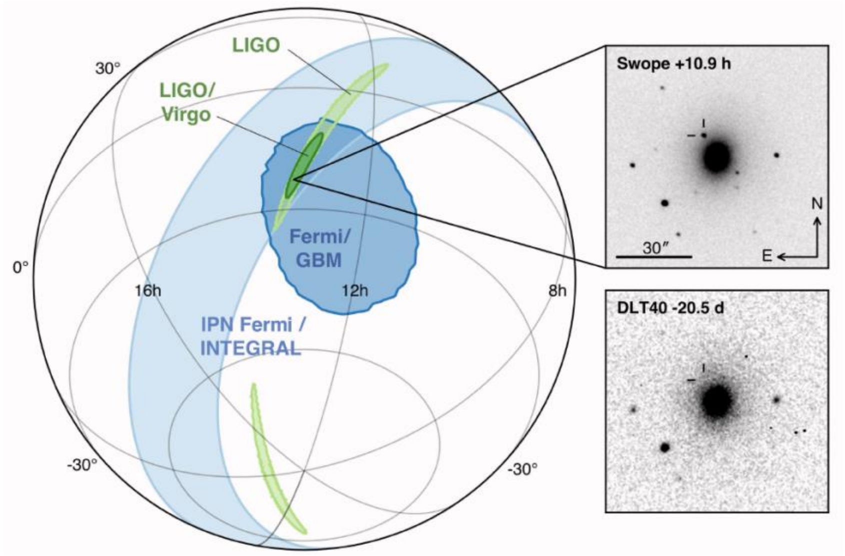
• FOV	100% all-sky, like LIGO/Virgo
• Energy coverage	lower energy
• Sensitivity	more sensitive
• Localization	more accurate

Demonstrated by the GRB170817A obs.



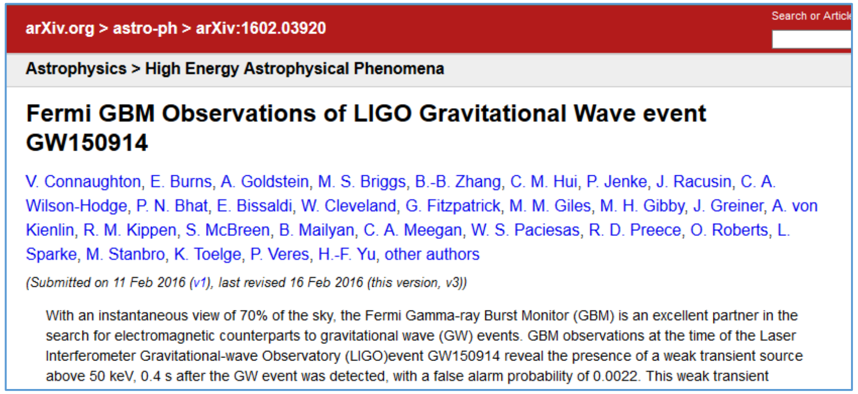
GBM

SPI-ACS



Extra requirements for GECAM

- **Reject non-GRB trigger caused by charged particles**


arXiv.org > astro-ph > arXiv:1602.03920

Search or Article

Astrophysics > High Energy Astrophysical Phenomena

Fermi GBM Observations of LIGO Gravitational Wave event GW150914

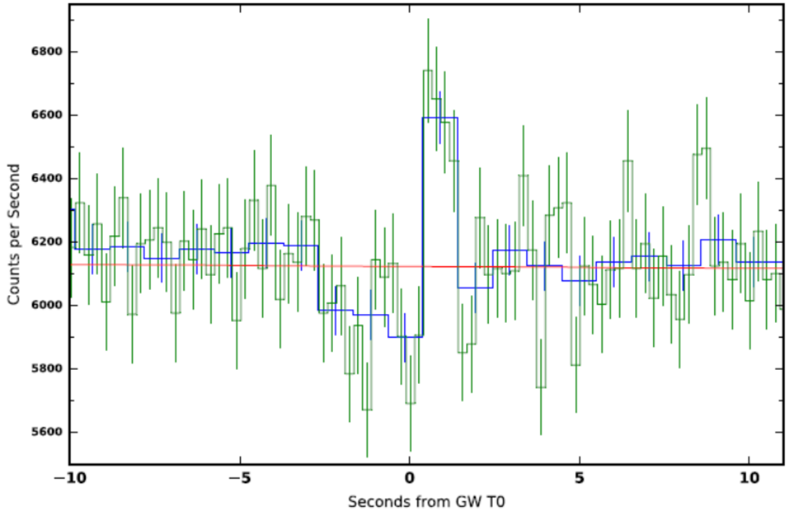
V. Connaughton, E. Burns, A. Goldstein, M. S. Briggs, B.-B. Zhang, C. M. Hui, P. Jenke, J. Racusin, C. A. Wilson-Hodge, P. N. Bhat, E. Bissaldi, W. Cleveland, G. Fitzpatrick, M. M. Giles, M. H. Gibby, J. Greiner, A. von Kienlin, R. M. Kippen, S. McBreen, B. Mailyan, C. A. Meegan, W. S. Paciesas, R. D. Preece, O. Roberts, L. Sparke, M. Stanbro, K. Toelge, P. Veres, H.-F. Yu, other authors

(Submitted on 11 Feb 2016 (v1), last revised 16 Feb 2016 (this version, v3))

With an instantaneous view of 70% of the sky, the Fermi Gamma-ray Burst Monitor (GBM) is an excellent partner in the search for electromagnetic counterparts to gravitational wave (GW) events. GBM observations at the time of the Laser Interferometer Gravitational-wave Observatory (LIGO)event GW150914 reveal the presence of a weak transient source above 50 keV, 0.4 s after the GW event was detected, with a false alarm probability of 0.0022. This weak transient

- **Launch by 2020 for joint observation with LIGO with design sensitivity**
  - Tight constraints on the budget and technology readiness both for spacecraft and payload
  - As cheaper/simple as possible with improved capability than existing GRB monitors

GW150914-GBM candidate



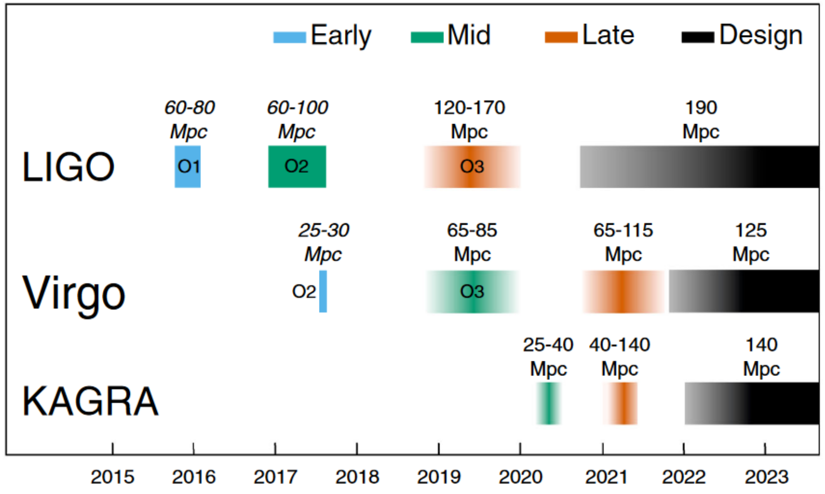


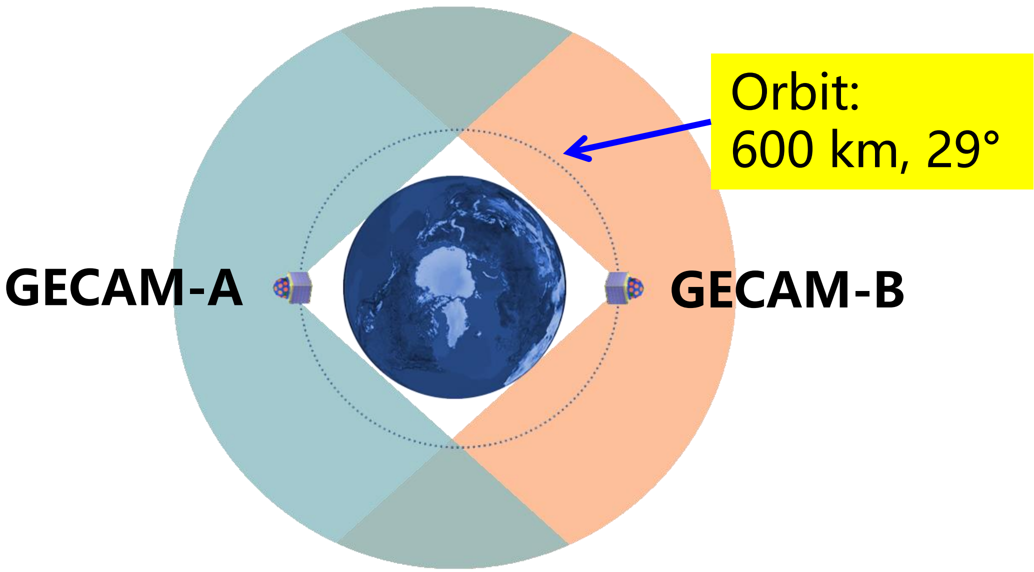
Fig. 2 The planned sensitivity evolution and observing runs of the aLIGO, AdV and KAGRA detectors over the coming years. The colored bars show the observing runs, with the expected sensitivities given by the data in Fig. 1 for future runs, and the achieved sensitivities in O1 and in O2. There is significant uncertainty in the start and end times of planned the observing runs, especially for those further in the future, and these could move forward or backwards relative to what is shown above. The plan is summarised in Sect. 2.2

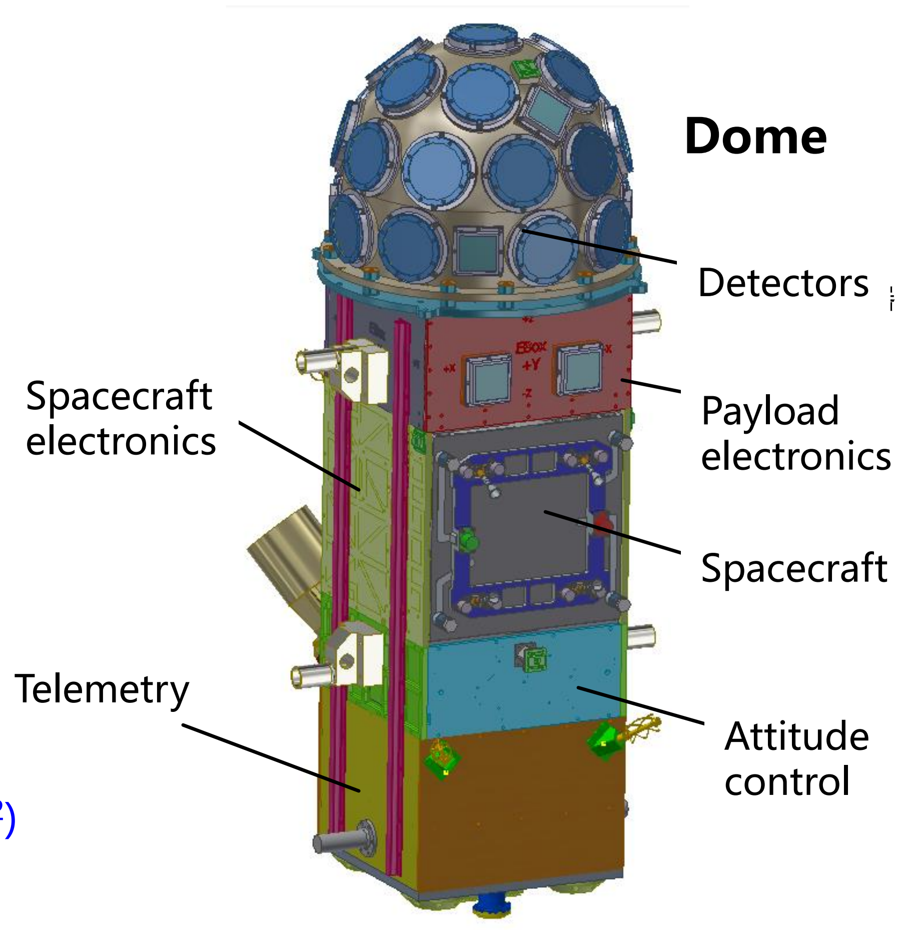
Abbott+2018, Living Rev Relativ.

GECAM

Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor

truly ALL-TIME ALL-SKY Monitor

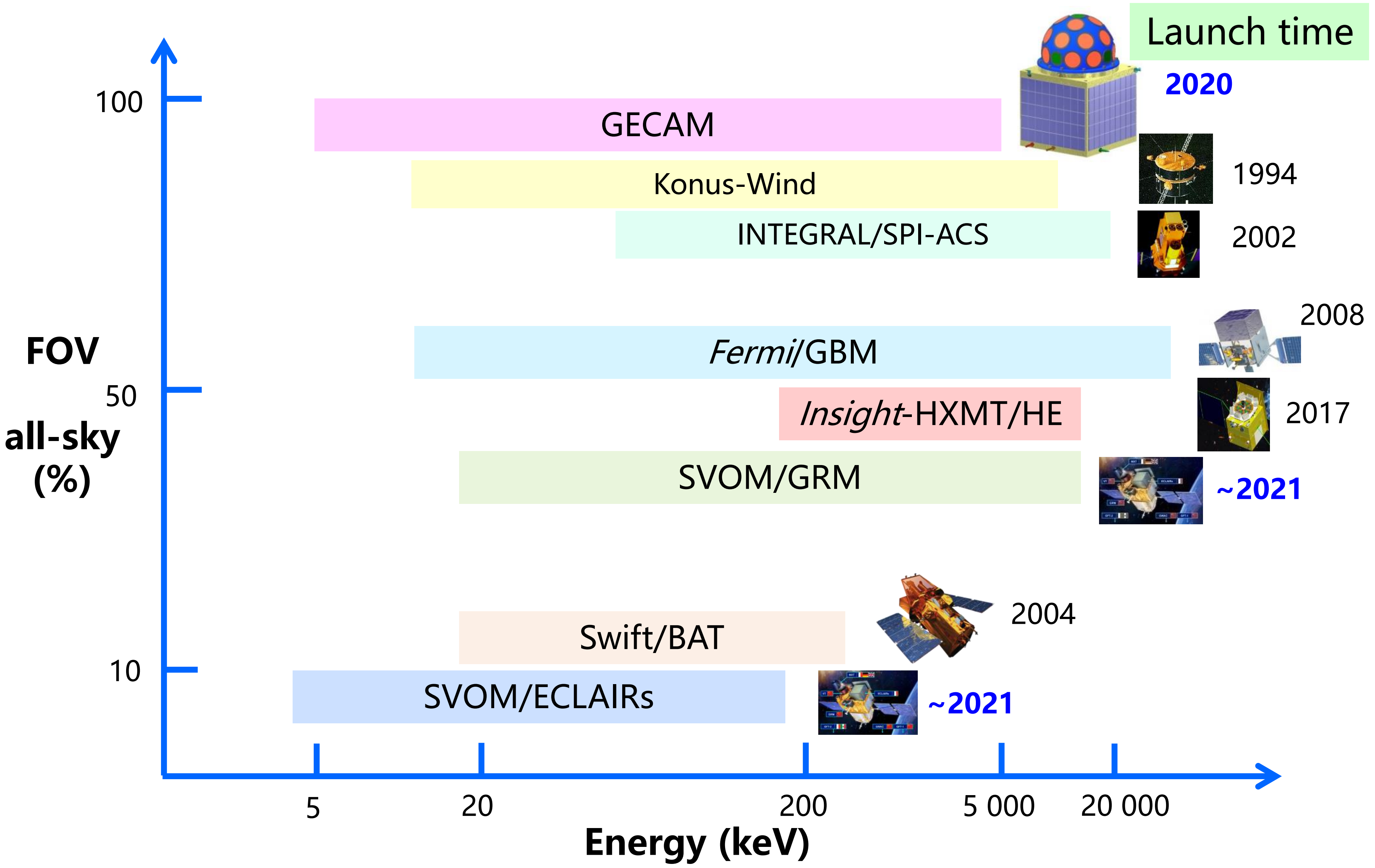


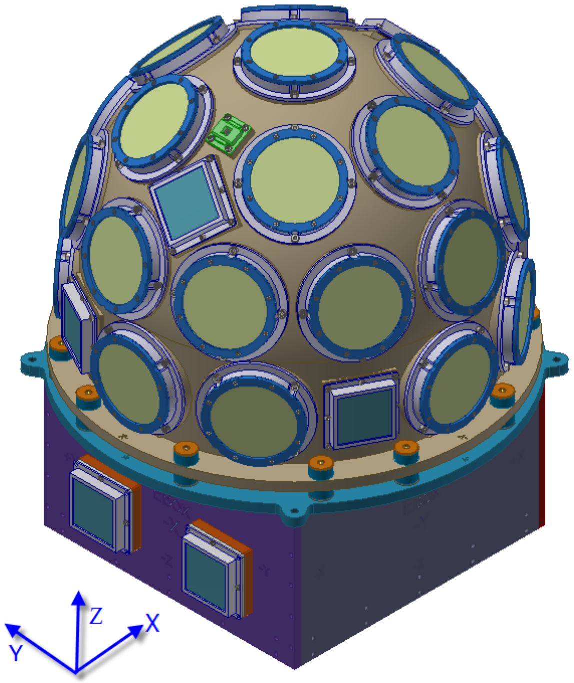


GECAM satellite (150 kg)

- **Characteristics**
  - **FOV:** 100% all-sky
  - **Energy band:** 6 keV – 5 MeV
  - **Sensitivity:** <2E-8 erg/cm^2/s
  - **Localization:** <1 deg (1-σ stat., 1E-5 erg/cm^2)
- **Real-time alerts**
  - Trigger time, localization, duration, spectrum, etc
  - Latency: 2-10 minutes

Current and future gamma-ray monitors





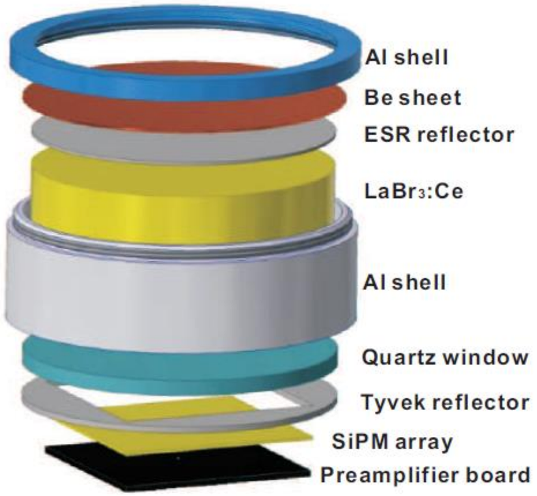
Detector configuration

For each GECAM satellite

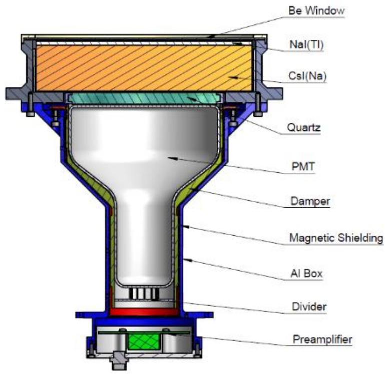
- **25 Gamma-ray detectors (GRD, circle)**
- **8 Charged particle detectors (CPD, square)**

- **GRD (LaBr$_3$+SiPM)**
  - Monitor x/gamma-ray from all-sky
  - Temporal, spectral, localization measurement for GRB
- **CPD (Plastic scintillator + SiPM)**
  - Monitor charged particles (e, p)
  - Identify the GRD bursts produced by charged particles in the Earth orbit (i.e. distinguish GRB and fake-GRB)

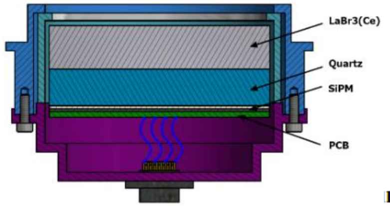
GRD: $LaBr_3$+SiPM



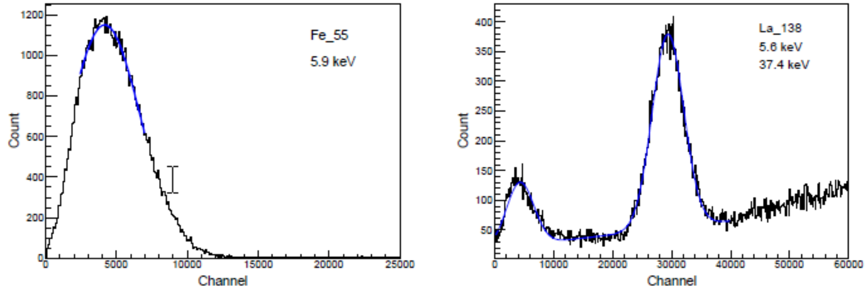
- **Novel technology**
  - $LaBr_3$ very bright, insensitive to Temp.
  - SiPM very compact, robust, HV-free
  - Low energy threshold & Wide energy
  - Could stay on during SAA passage
  - Gain stabilization by SiPM temp-voltage bias feedback



Traditional design
Based on PMT



New design
Based on SiPM



re 5. The spectra of ^{55}Fe and ^{138}La radioactive sources. The energy resolutions are 95.6% at 5.9 keV, 126.6% at 5.6 keV and 24.1% at 37.4 keV.

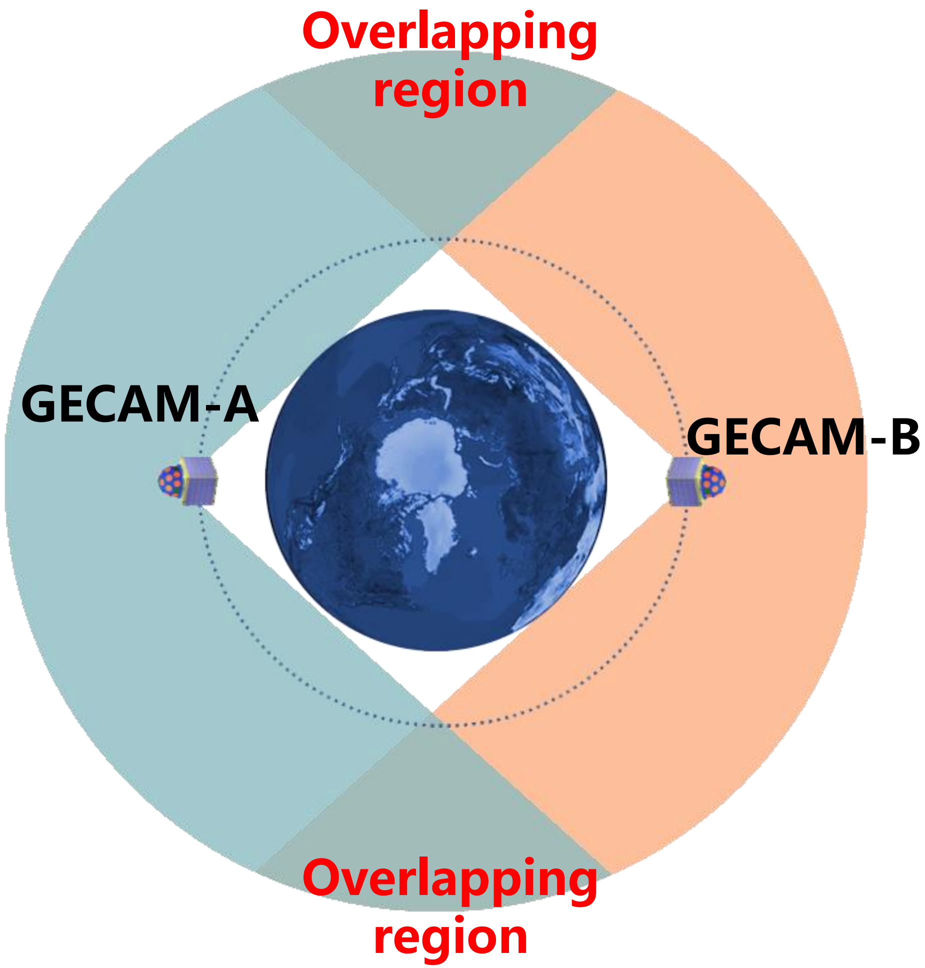
Journal of Instrumentation

A low-energy sensitive compact gamma-ray detector based on $LaBr_3$ and SiPM for GECAM

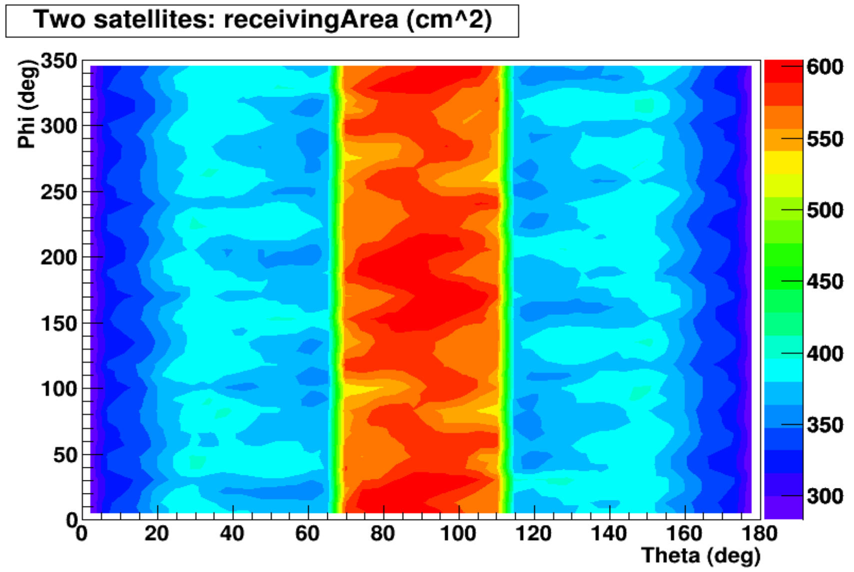
P. Lv[a,b,c], S.L. Xiong[a], X.L. Sun[a,b], J.G. Lv[a,b] and Y.G. Li[a]

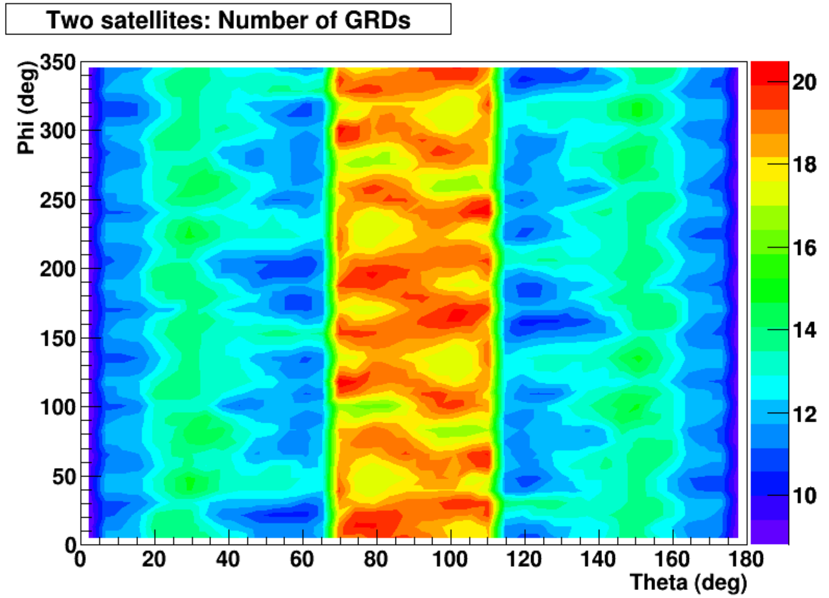
Published 16 August 2018 • © 2018 IOP Publishing Ltd and Sissa Medialab
Journal of Instrumentation, Volume 13, August 2018

Field of View (FOV)



100% all-sky monitoring with
~40% GRBs detected by both satellites

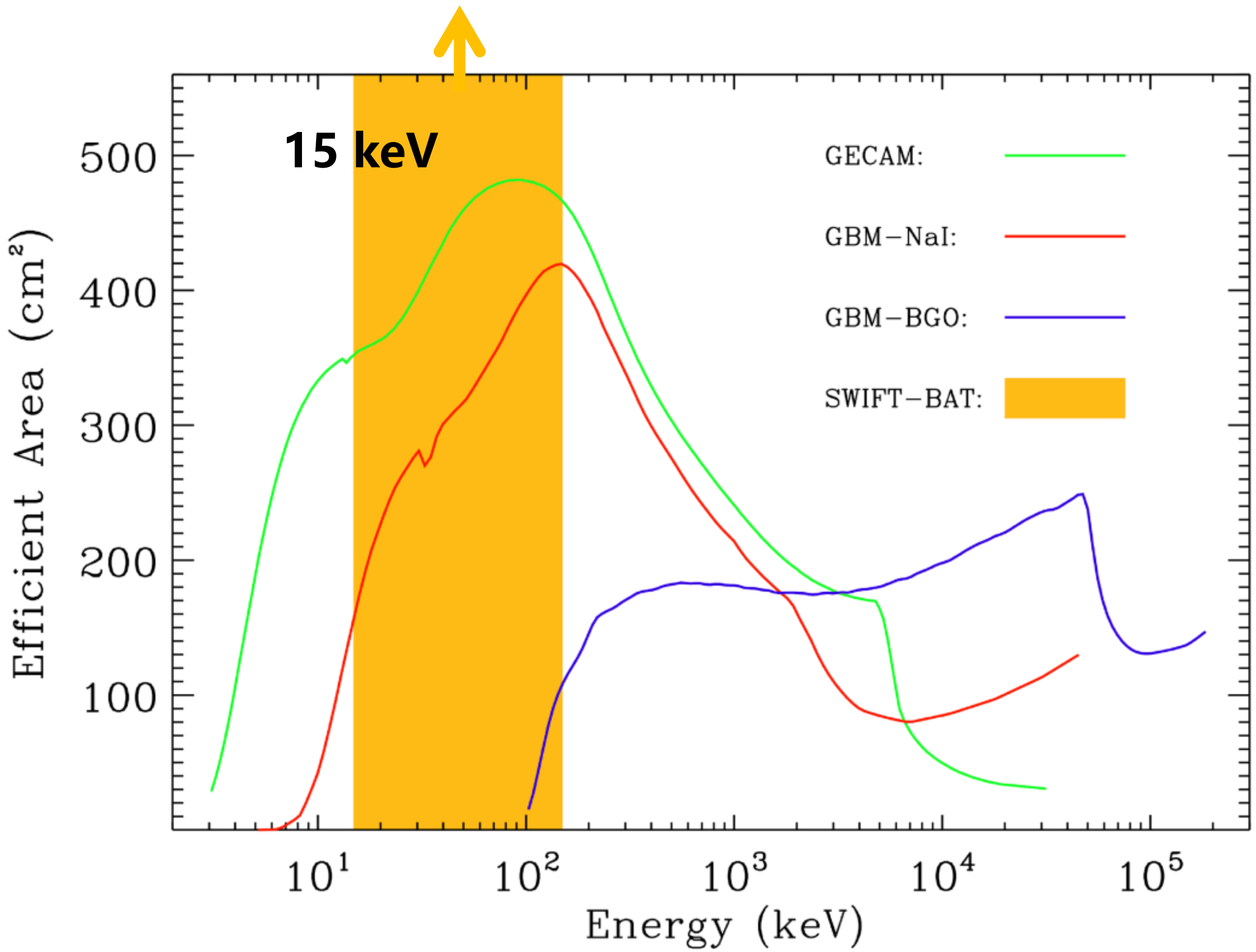




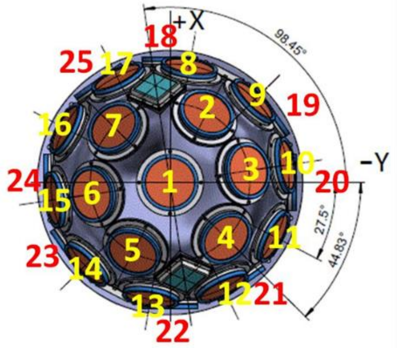
Energy range and Effective Area

- **Lower energy coverage down to ~6 keV**

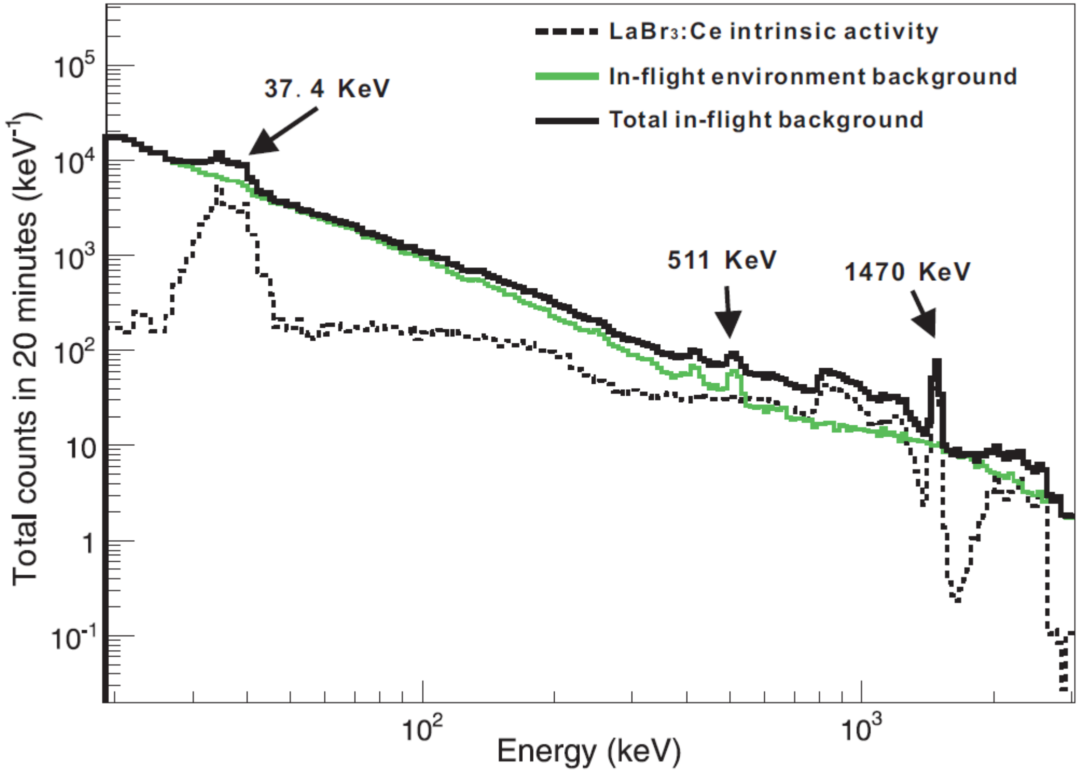
  → Very suitable for detecting GRB170817A-like GWGRB



In-flight Background



Background spectrum



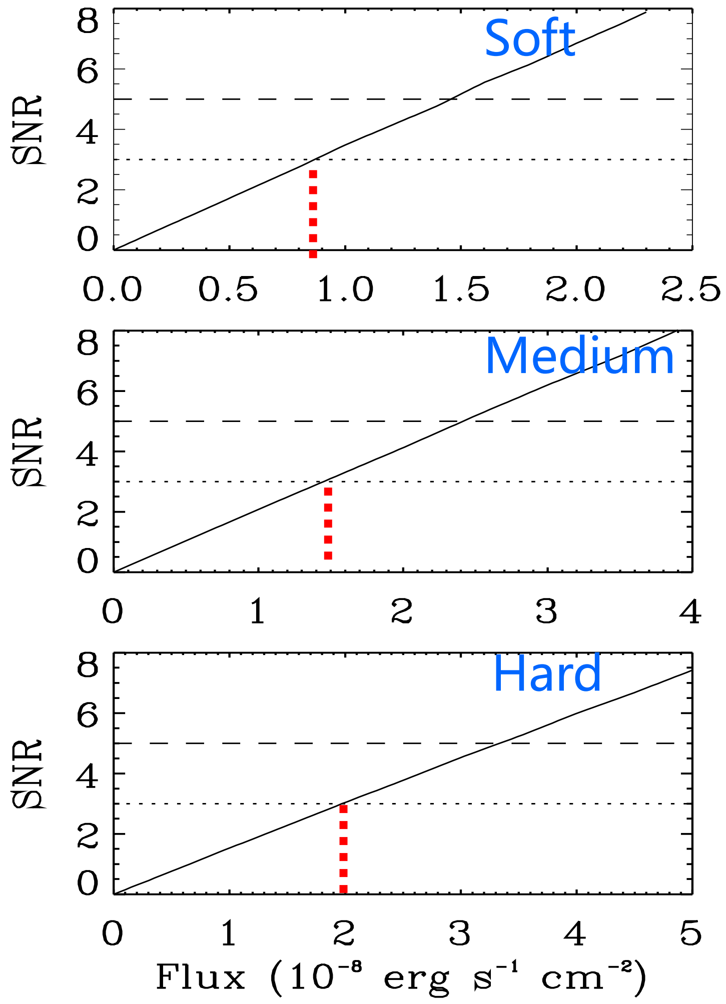
Characteristic lines for in-flight gain calibration

Background light curve

Background increase during and after SAA passages

orbital modulation

Sensitivity

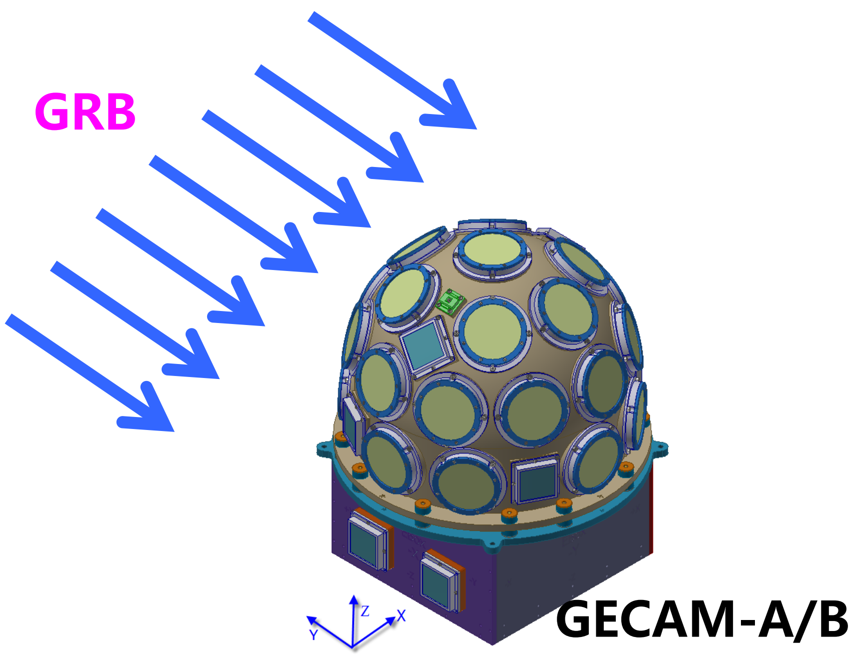


- Sensitivity: ~10^{-8} erg/cm^2/s
- Horizon for GRB 170817A: ~100 Mpc
  - Depends on:
    - Offset viewing angle
    - Spectral shape of the GWGRB
    - Incident angle to GECAM constellation
  - Working on further improvements

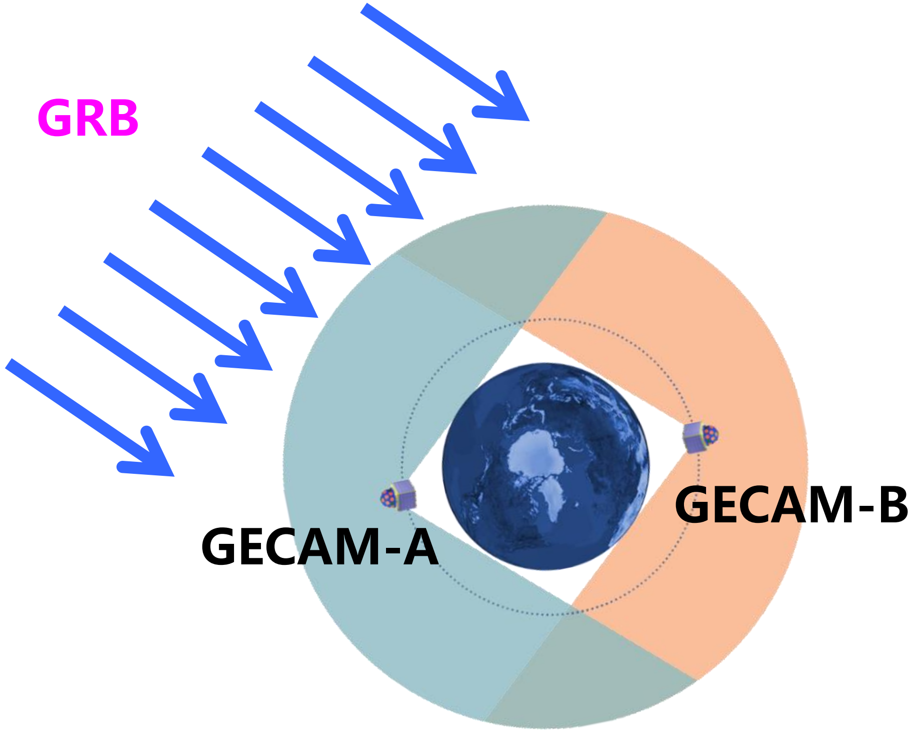
Band	α	β	Epeak (keV)
Soft	-1.9	-3.7	70
Medium	-1.0	-2.3	230
Hard	0.0	-1.5	1000

Localization

- Using the flux distribution of detectors (e.g. Fermi/GBM)
- Using the time lag between two satellites (e.g. IPN location)

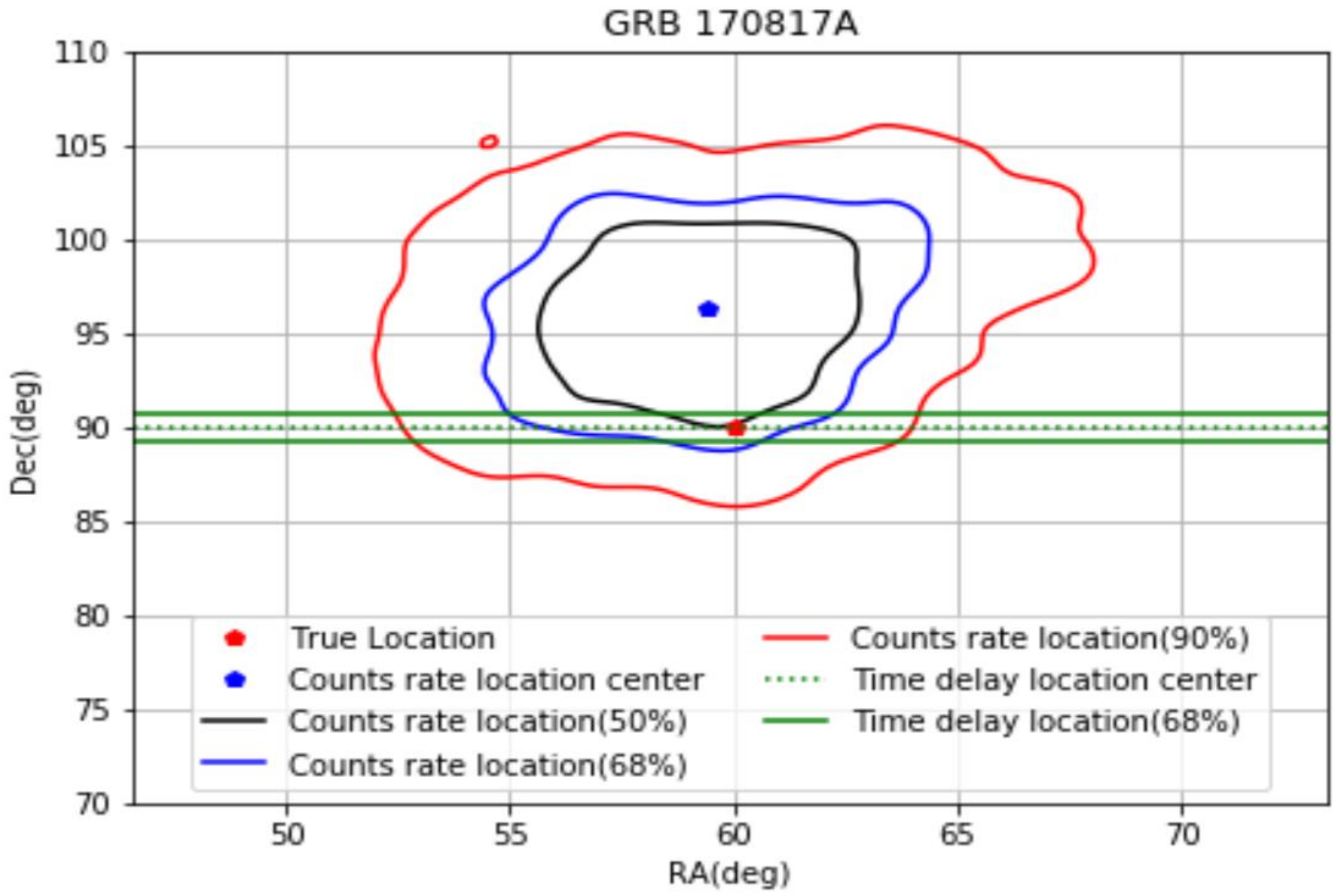


Flux distribution method



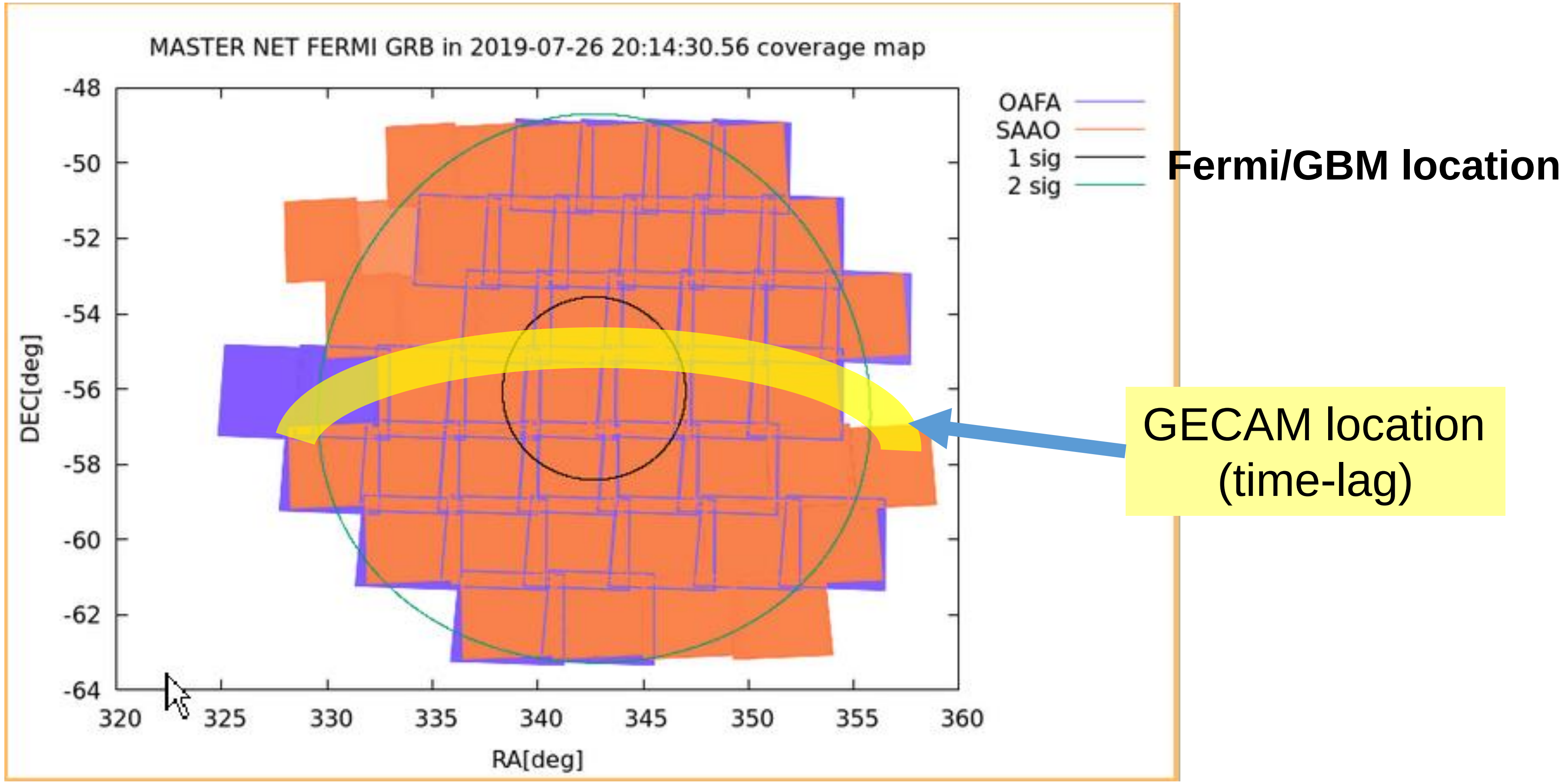
Time lag method

Simulated GECAM localization for GRB170817A



Location region: several deg^2 (1-sigma)

smaller location error, better follow-up



https://master.sai.msu.ru/site/master2/observ.php?id=1087257

Short GRB detection rate

- ***Fermi*/GBM detection rate of sGRB**
  - Triggered: 40/yr
  - Untriggered: ~20/yr (rough estimation)
    - *Insight*-HXMT confirmed ~15 GBM untriggered sGRB in two years

- **GECAM detection rate of sGRB**
  - FOV + duty cycle improvement over Fermi/GBM: x 2
  - Sensitivity improvement over Fermi/GBM: x a few

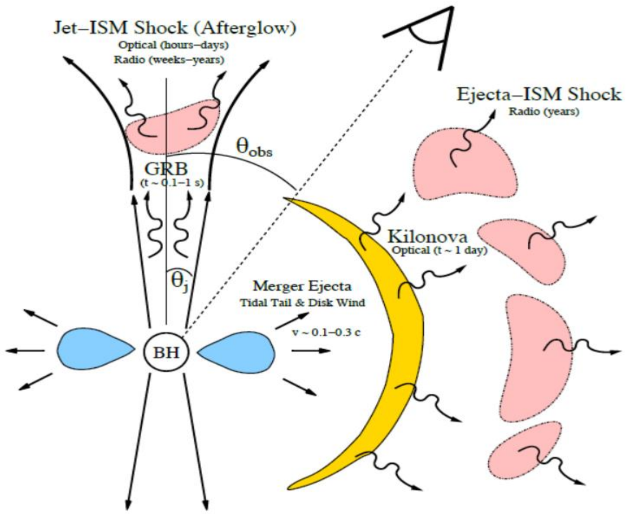
→ Minimum: (40+20) x 2 ~ **120 sGRB/yr**

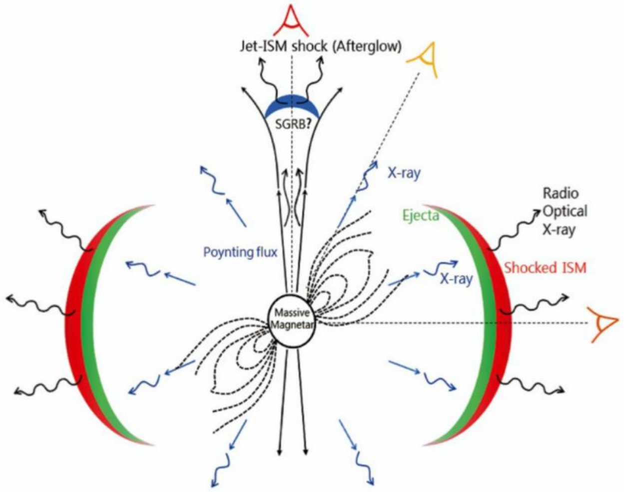
- ~50 sGRB/yr (40%) will have time-lag localization (~ several deg^2)

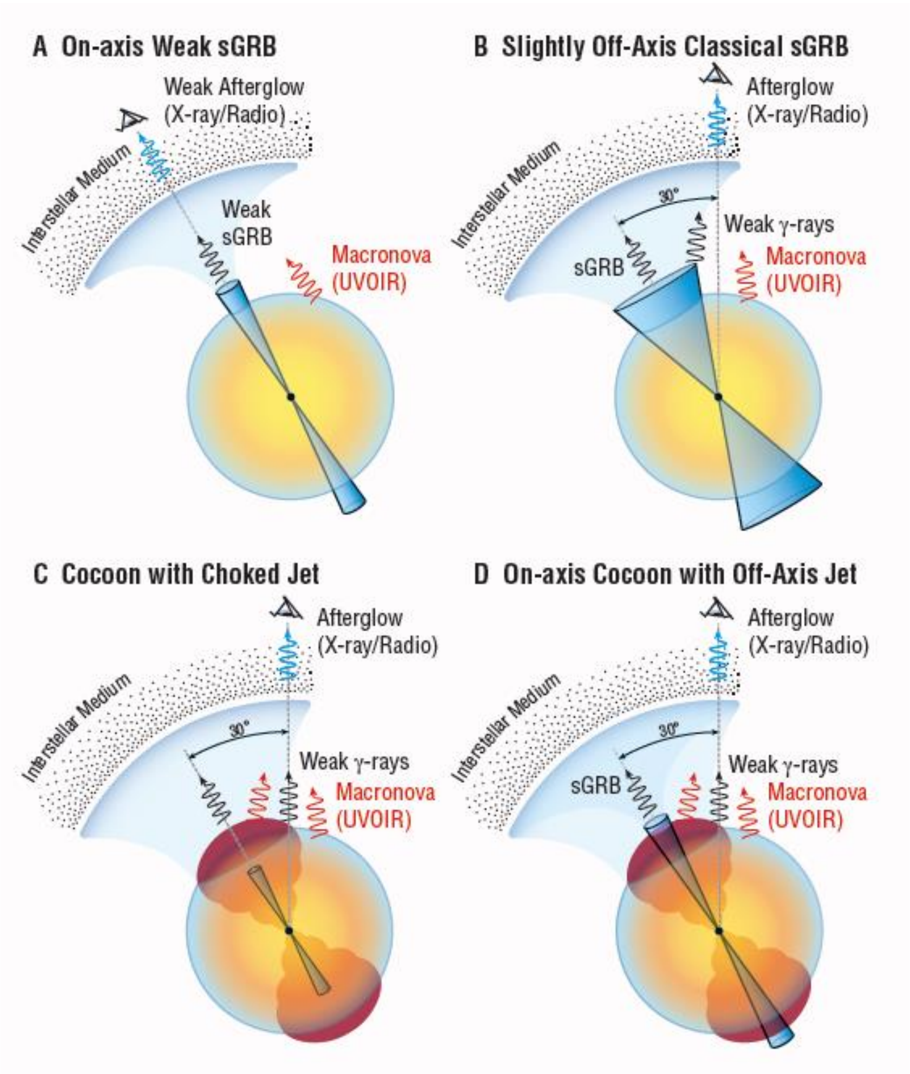
GECAM sciences

- **Gamma-ray emission of GW sources**
- **Gamma-ray emission of High Energy Neutrino (HEN)**
- **Gamma-ray emission of FRB**
- **GRBs, especially ultra-long and ultra-soft ones**
- **SGR/AXP**
- **TDE**
- **X-Ray Bursts**
- **X-Ray Binaries (long-term)**
- **X-ray Pulsars**
- **Solar flare**
- **Terrestrial Gamma-ray Flashes**
- **Terrestrial Electron Beams**
- **etc.**

Monitor GWGRB from BNS merger







GECAM detection rate of BNS GWGRB

(Abbott+2018, Living Rev Relativ)

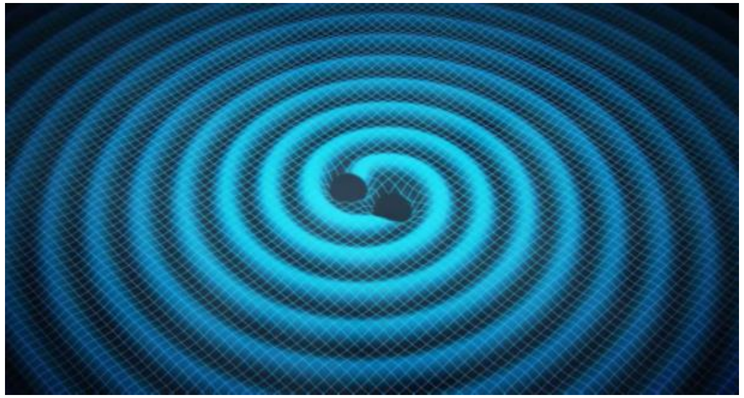
Epoch			2015 – 2016	2016 – 2017	2018 – 2019	2020+	2024+
Planned run duration			4 months	9 months	12 months	(per year)	(per year)
Expected burst range/Mpc		LIGO	40 – 60	60 – 75	75 – 90	105	105
		Virgo	—	20 – 40	40 – 50	40 – 70	80
		KAGRA	—	—	—	—	100
Expected BNS range/Mpc		LIGO	40 – 80	80 – 120	120 – 170	190	190
		Virgo	—	20 – 65	65 – 85	65 – 115	125
		KAGRA	—	—	—	—	140
Achieved BNS range/Mpc		LIGO	60 – 80	60 – 100	—	—	—
		Virgo	—	25 – 30	—	—	—
		KAGRA	—	—	—	—	—
Estimated BNS detections			0.05 – 1	0.2 – 4.5	1 – 50	4 – 80	11 – 180
Actual BNS detections			0	1	—	—	—
90% CR	% within	5 deg^2	< 1	1 – 5	1 – 4	3 – 7	23 – 30
		20 deg^2	< 1	7 – 14	12 – 21	14 – 22	65 – 73
	median/deg^2		460 – 530	230 – 320	120 – 180	110 – 180	9 – 12
Searched area	% within	5 deg^2	4 – 6	15 – 21	20 – 26	23 – 29	62 – 67
		20 deg^2	14 – 17	33 – 41	42 – 50	44 – 52	87 – 90

Expected GWGRB rate from BNS in 2020

- **Fermi/GBM: 0.3-1.7/year**
- **GECAM: 2-10/year**

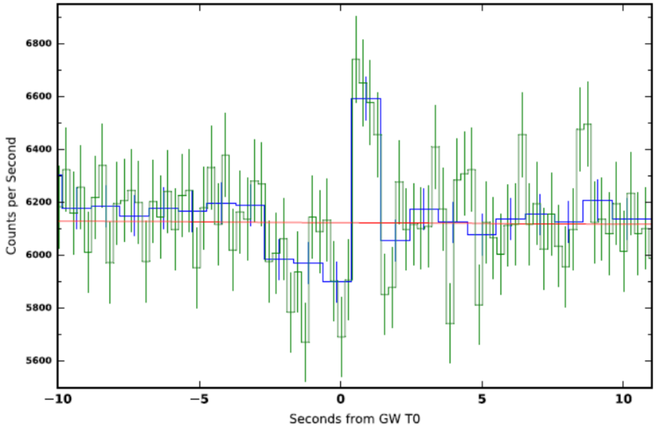
GECAM improvements over Fermi/GBM:
(1) FoV & duty cycle: x 2
(2) Sensitivity: x ~3 (volume)

GWGRB from NS-BH, BH-BH merger?

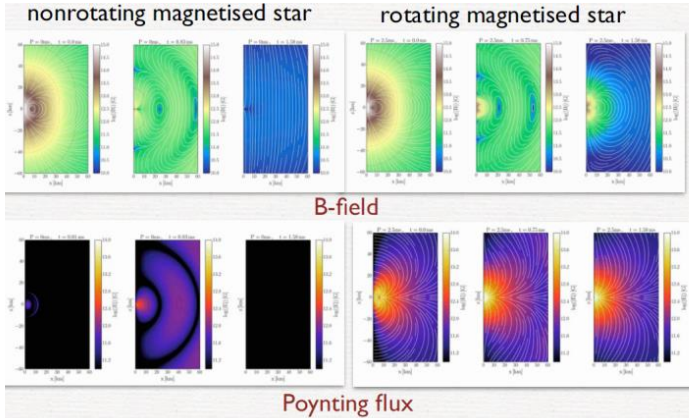


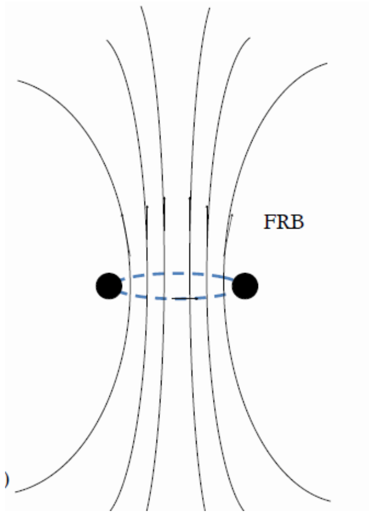
Binary BH merger

- Suggested by theory models
  - BBH from one star, Loeb 2016
  - Activated accretion disk, Perna+2016
  - Charged BH, Zhang 2016
  - …



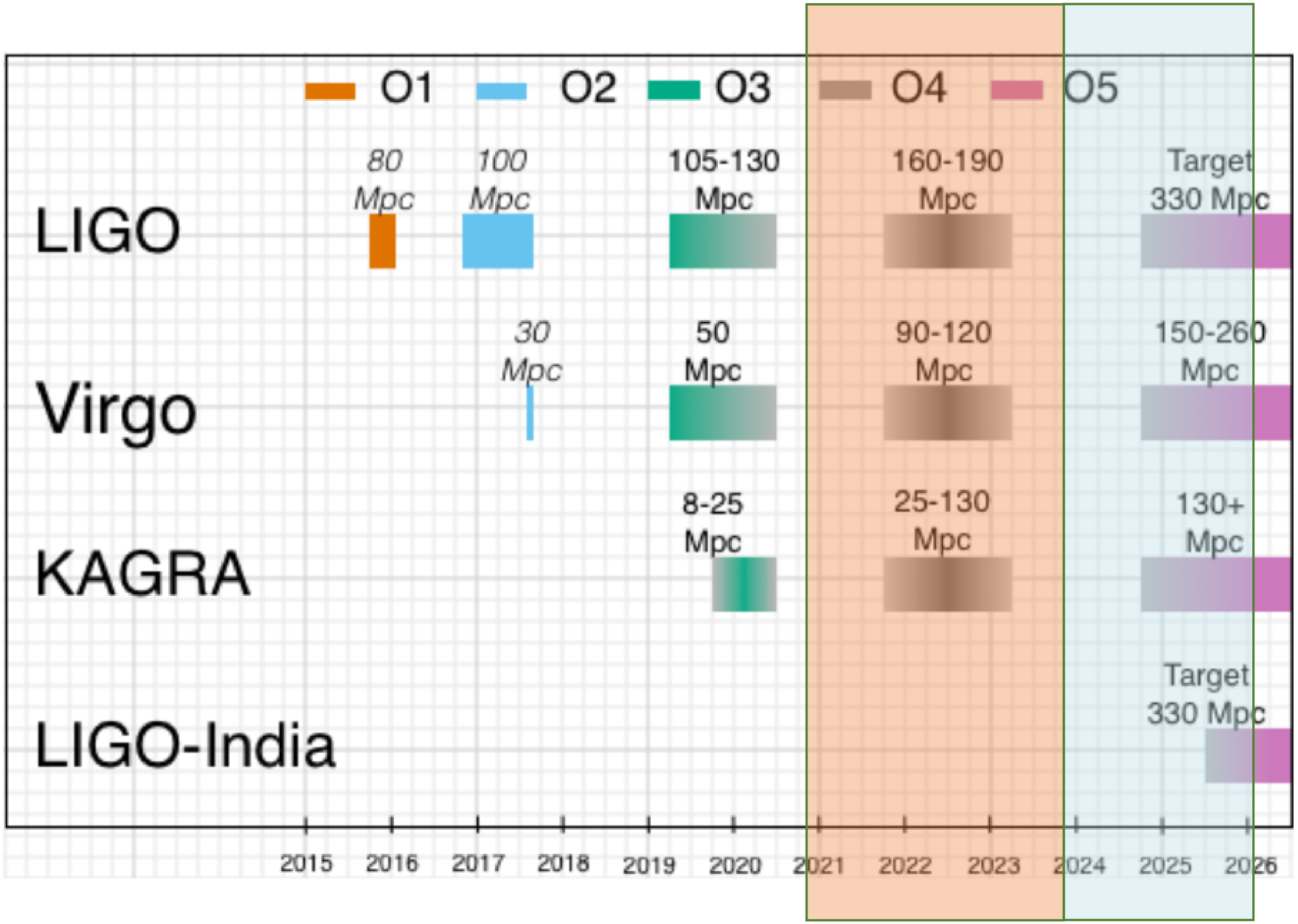
GW150914-GBM candidate





Left: charged BH (Nathanail, Most & Rezzolla, 2017)
Right: BBH merger EM emission (Liebling&Palenzuela 2016)

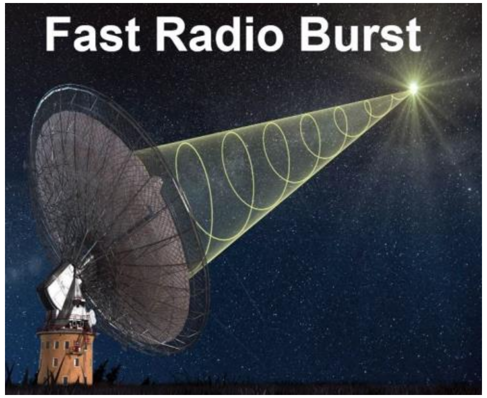
Synergy observations with GW detectors

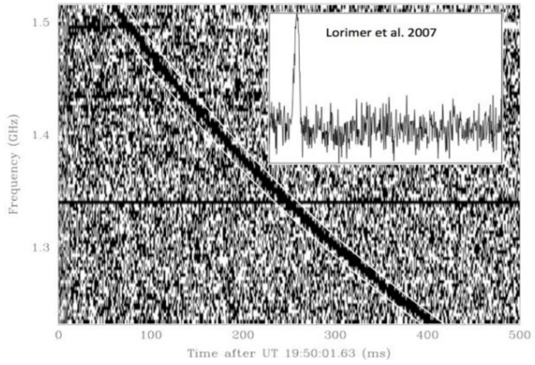


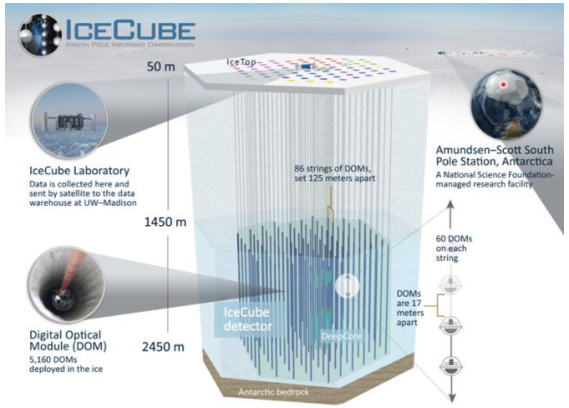
GECAM lifetime: min. 3 yrs goal 5 yrs

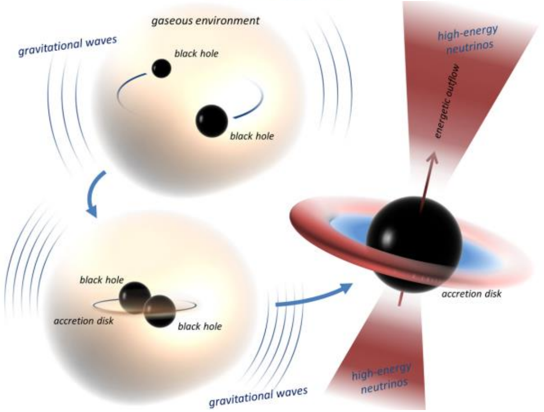
Gamma-ray from HEN and FRB

- **Multi-messenger and Multi-wavelength**
  - High Energy Neutrinos (HEN): EM counterpart
  - Fast Radio Bursts (FRB): potential high-energy counterpart



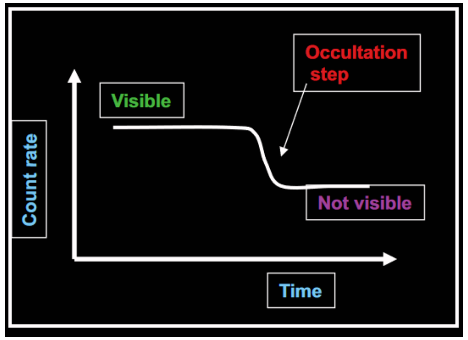




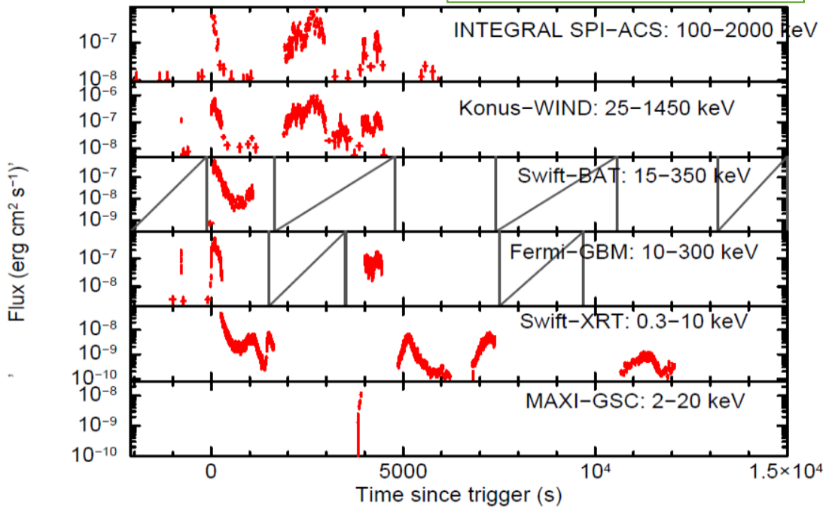


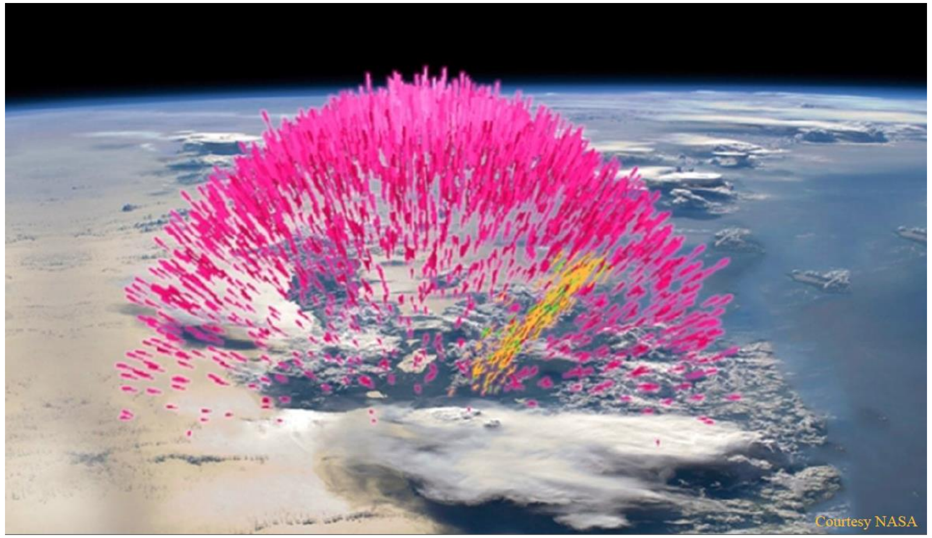
X-ray/Gamma-ray Sources

- Ultra-long GRBs
- X-ray Flashes
- Magnetars
- TDE
- XRB (Earth occultation)
- Pulsars
- Solar flares (SFL)
- Terrestrial Gamma-ray Flash (TGF/TEB)

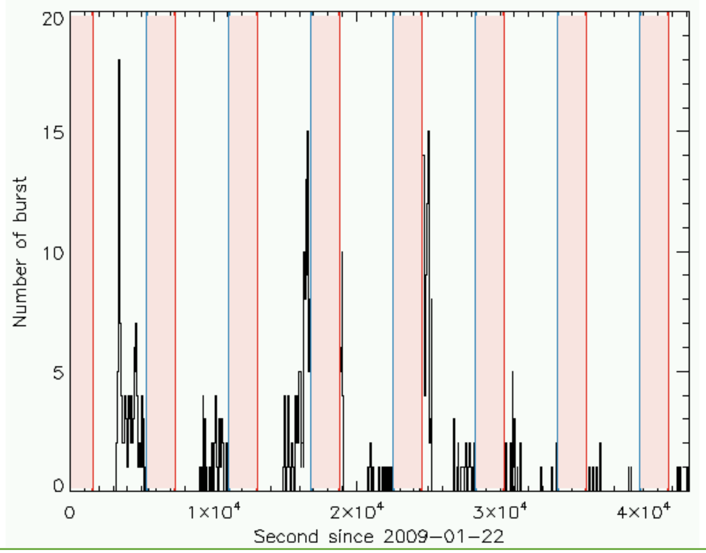


GRB 130925A



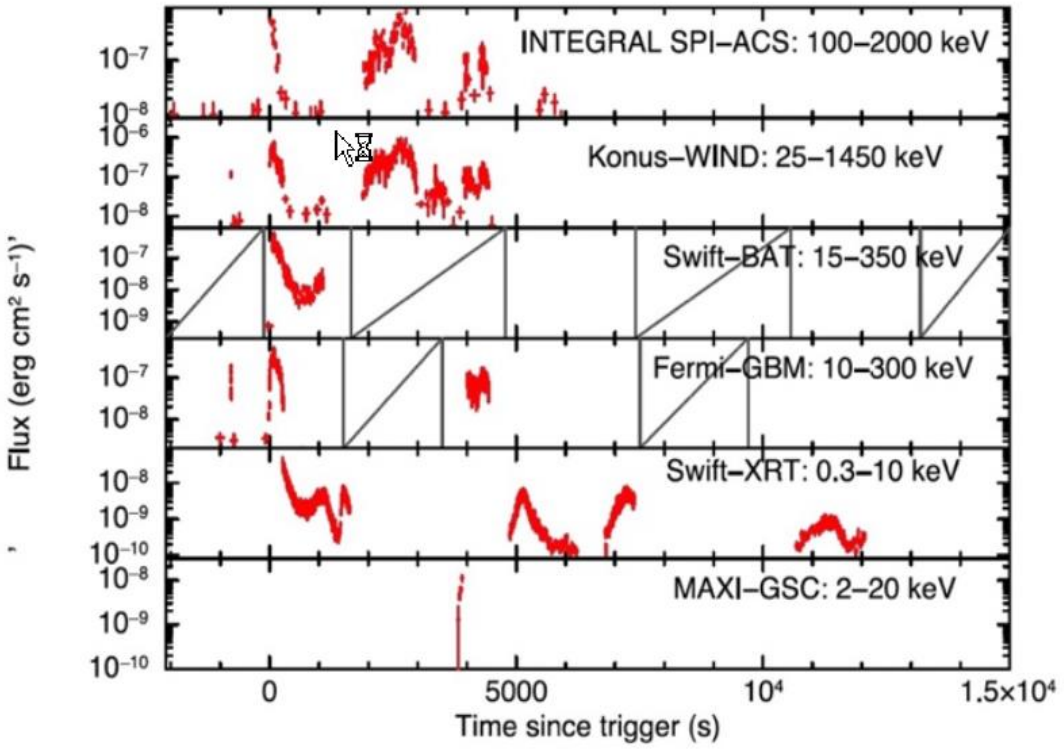


TGF and TEB

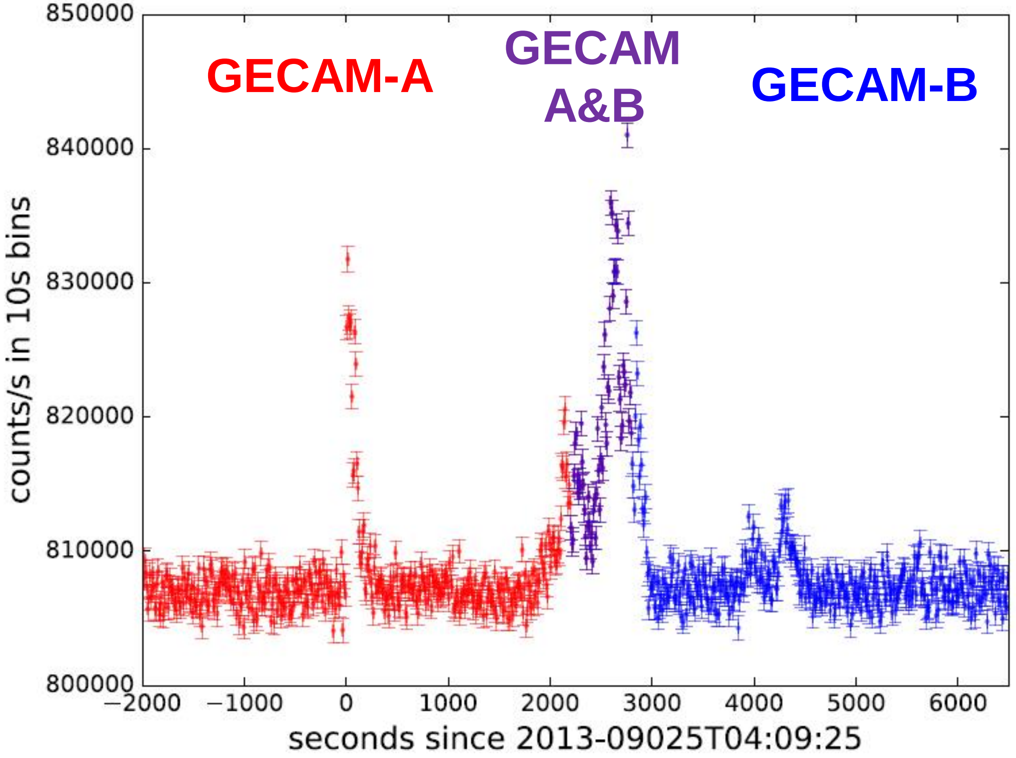


Magnetar burst seen by Fermi/GBM

Ultra-long GRB

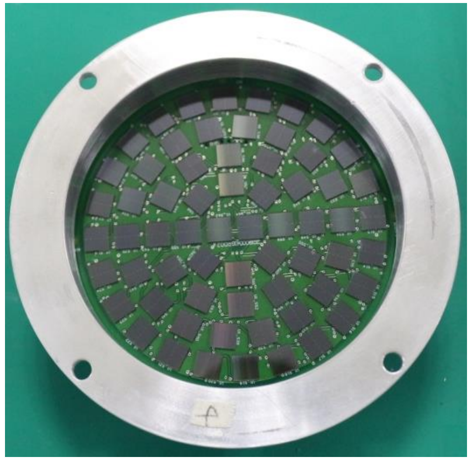


Evans et al. 2014

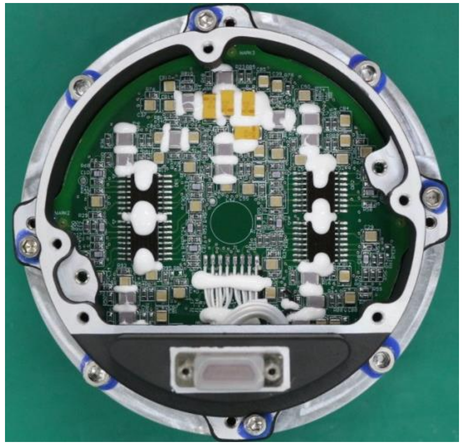


GRB 130925A

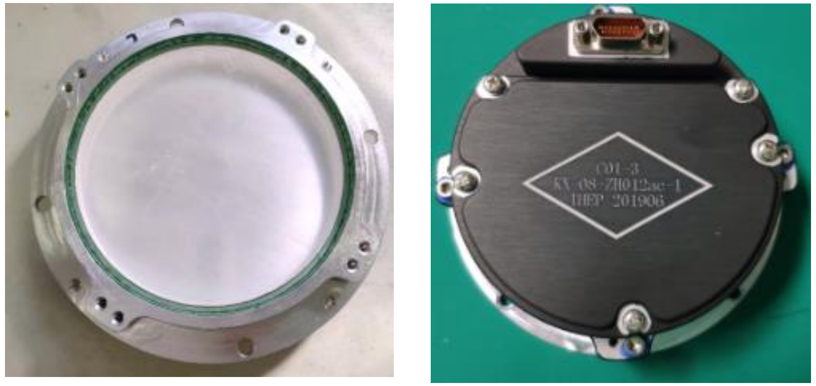
GECAM Qualification and Engineering Model (QEM)



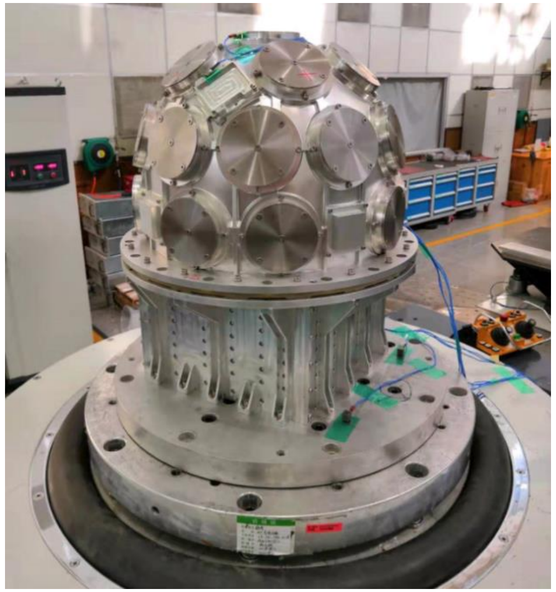
GRD SiPM (64)



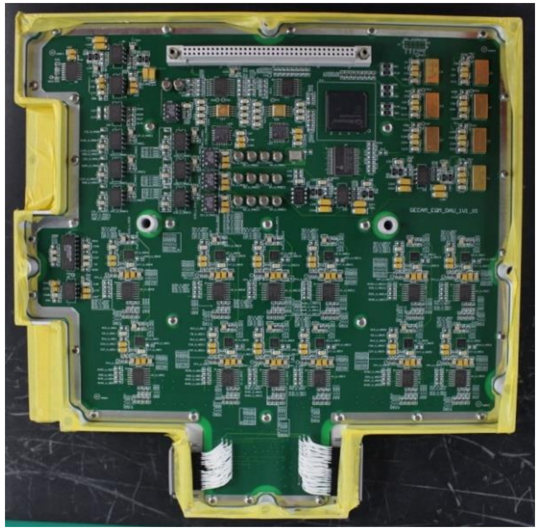
GRD Pre-amplifier



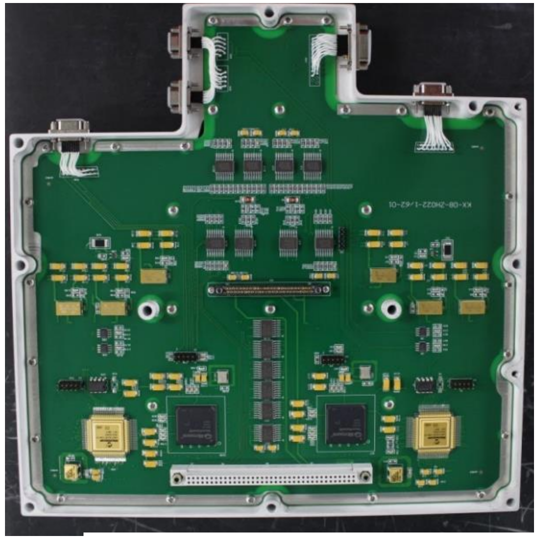
GRD detector



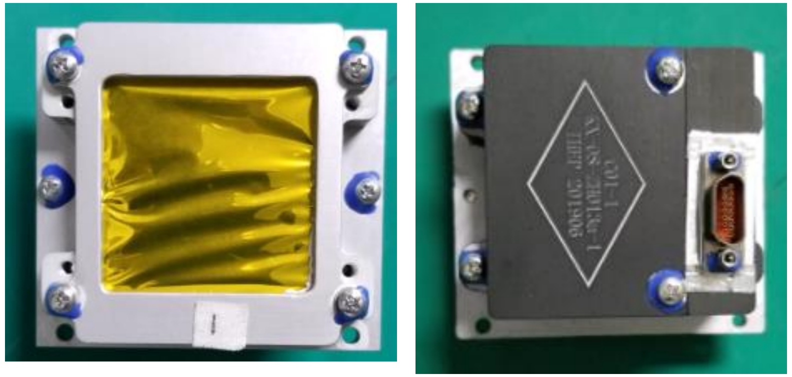
Vibration Test



Data Acquisition Board

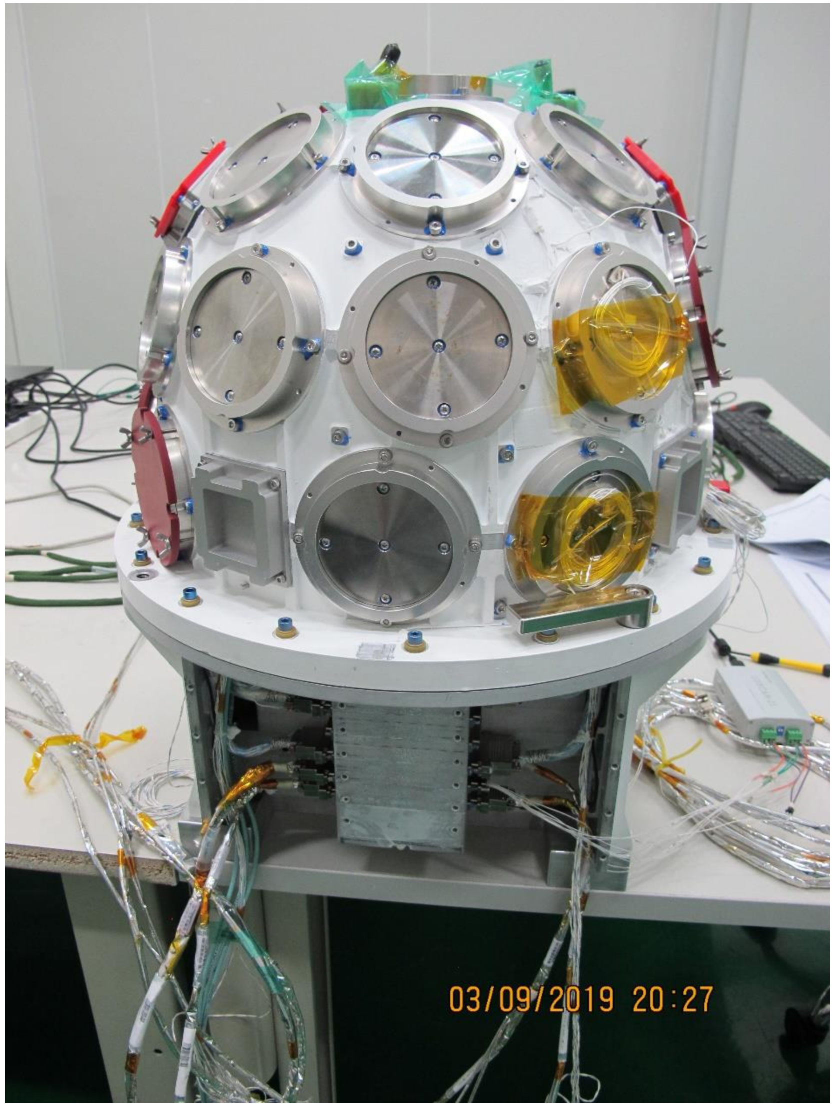


Data Management Board



CPD Detector

2019/9/6: QEM Test Finished



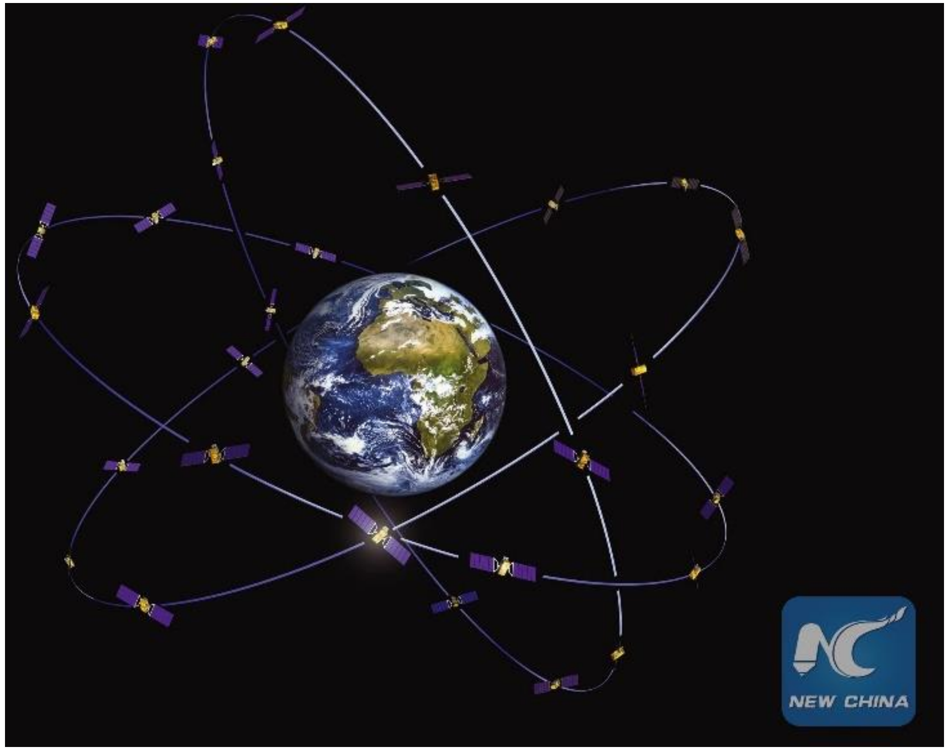
Summary

- **GECAM as ALL-SKY ALL-TIME X/γ monitor**
  - 100% all-sky, 6 keV - 5 MeV, localization (~ degs), very sensitive
  - Real-time trigger alerts (~ several minutes)
  - Provide detection or constraints for every transients/sources
- **Science cases in the multi-messenger/wavelength era**
  - Monitor all GW events, including BNS, NS-BH and BH-BH mergers
  - FRB/HEN counterpart, Ultra-long/soft GRBs, Magnetars, XRB, Pulsars, SFL, TGF/TEB, etc.
- **Plan to launch by the end of 2020**

Collaboration is OPEN. Data will be OPEN.

Backup

Real-time alerts

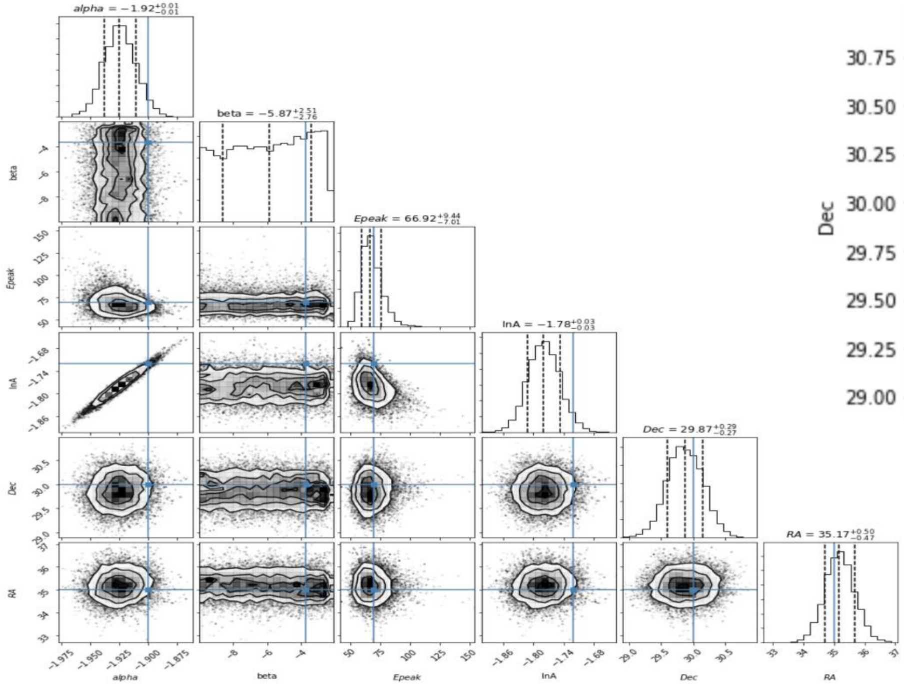


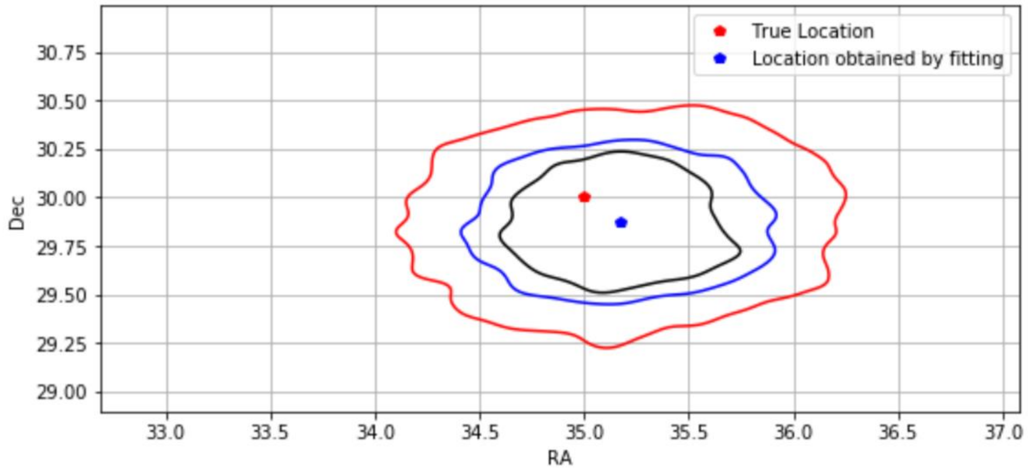
Localization + spectrum

prior $$P(\mathrm{RA}, \mathrm{Dec}, \mathrm{alpha}, \mathrm{Epeak}, \mathrm{InA}) = \frac{K}{4\pi}$$

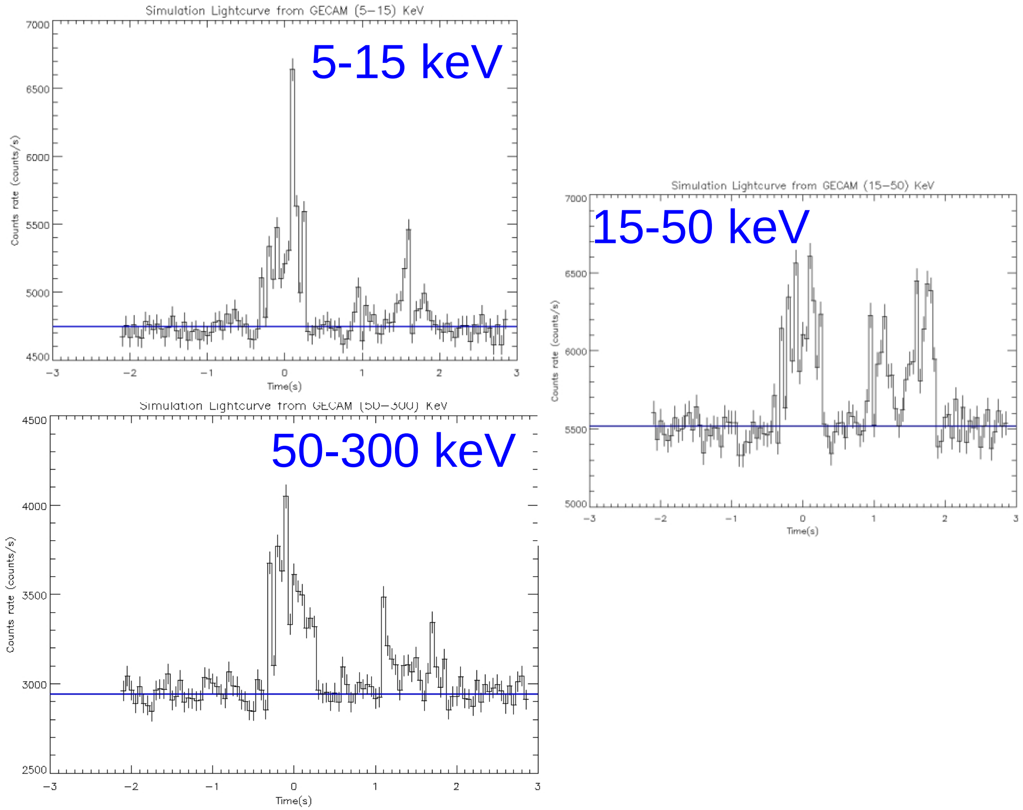
likelihood $$P(N\_obj\_dj|\mathrm{alpha}, \mathrm{A}, \mathrm{Epeak}, \mathrm{RA}, \mathrm{Dec}) = \prod_{d=1}^{Nd} \prod_{j=1}^{Nj} P(N\_obj\_dj|N\_mod\_dj)$$

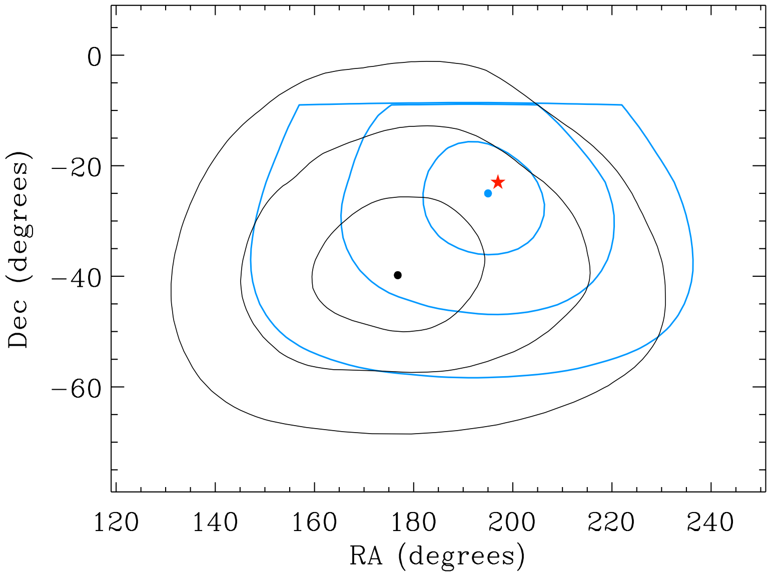
posterior $$P(\mathrm{alpha}, \mathrm{A}, \mathrm{Epeak}, \mathrm{RA}, \mathrm{Dec}|N\_obj\_dj) \propto P(\mathrm{RA}, \mathrm{Dec}, \mathrm{alpha}, \mathrm{Epeak}, \mathrm{InA}) * P(N\_obj\_dj|\mathrm{alpha}, \mathrm{A}, \mathrm{Epeak}, \mathrm{RA}, \mathrm{Dec})$$





Simulation of GRB170817A





Localization map

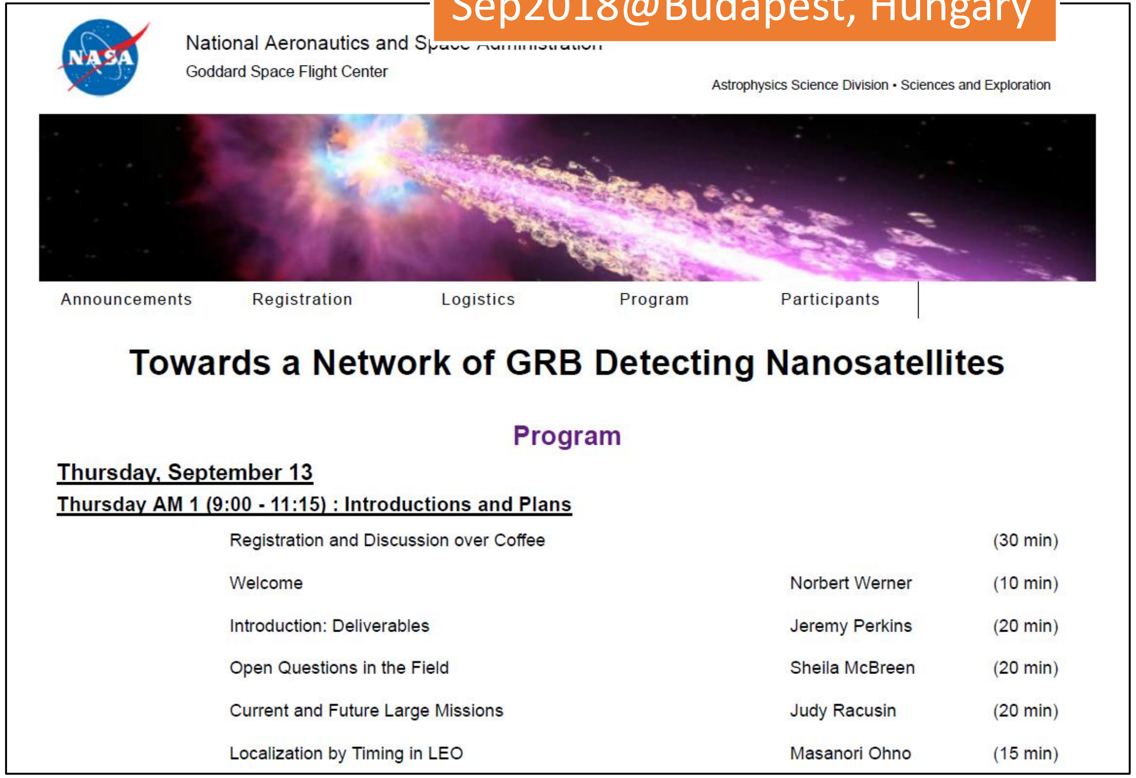
True value, GECAM, GBM

Item	Input Value	GBM error	GECAM error
SNR	-	~6 sigma	~12 sigma
Loc. Error	-	17°	11°
Epeak (keV)	128	33.3	23.3
Spec. index	-0.88	0.44	0.23
Fluence (1E-7 erg/s/cm^2)	2.2	0.5	0.27

Proposals for GWEM mission

- **~20 proposals**
  - BlackCAT
  - BurstCube
  - Moonbeam
  - Nano-Gam
  - Solar Neutrons
  - GRID
  - Camelot
  - Gifts/Eirsat
  - HERMES
  - MERGER/Glowbug
  - Sphinx
  - SPHiNX
  - PICSAT
  - RadCube
  - Skyhopper
  - UVI BurstCube
  - MeVCube
  - Hibari
  - SiriusSat1,2

Sep2018@Budapest, Hungary


National Aeronautics and Space Administration
Goddard Space Flight Center

Astrophysics Science Division • Sciences and Exploration

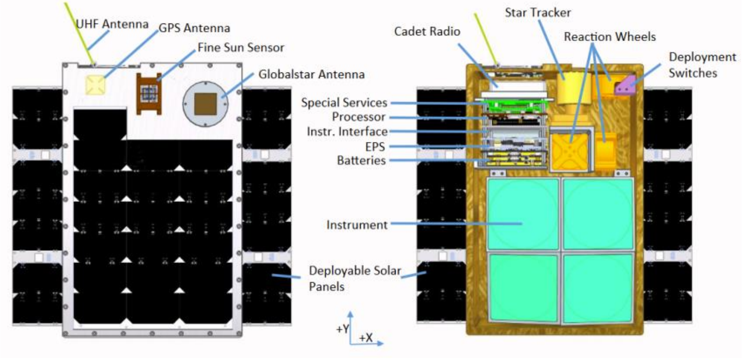
Announcements Registration Logistics Program Participants

Towards a Network of GRB Detecting Nanosatellites

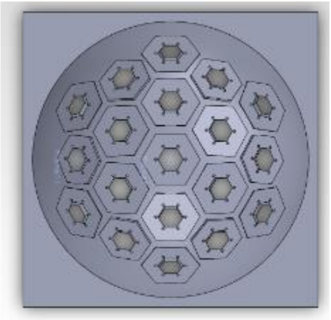
Program

Thursday, September 13
Thursday AM 1 (9:00 - 11:15) : Introductions and Plans

Registration and Discussion over Coffee		(30 min)
Welcome	Norbert Werner	(10 min)
Introduction: Deliverables	Jeremy Perkins	(20 min)
Open Questions in the Field	Sheila McBreen	(20 min)
Current and Future Large Missions	Judy Racusin	(20 min)
Localization by Timing in LEO	Masanori Ohno	(15 min)



BurstCube



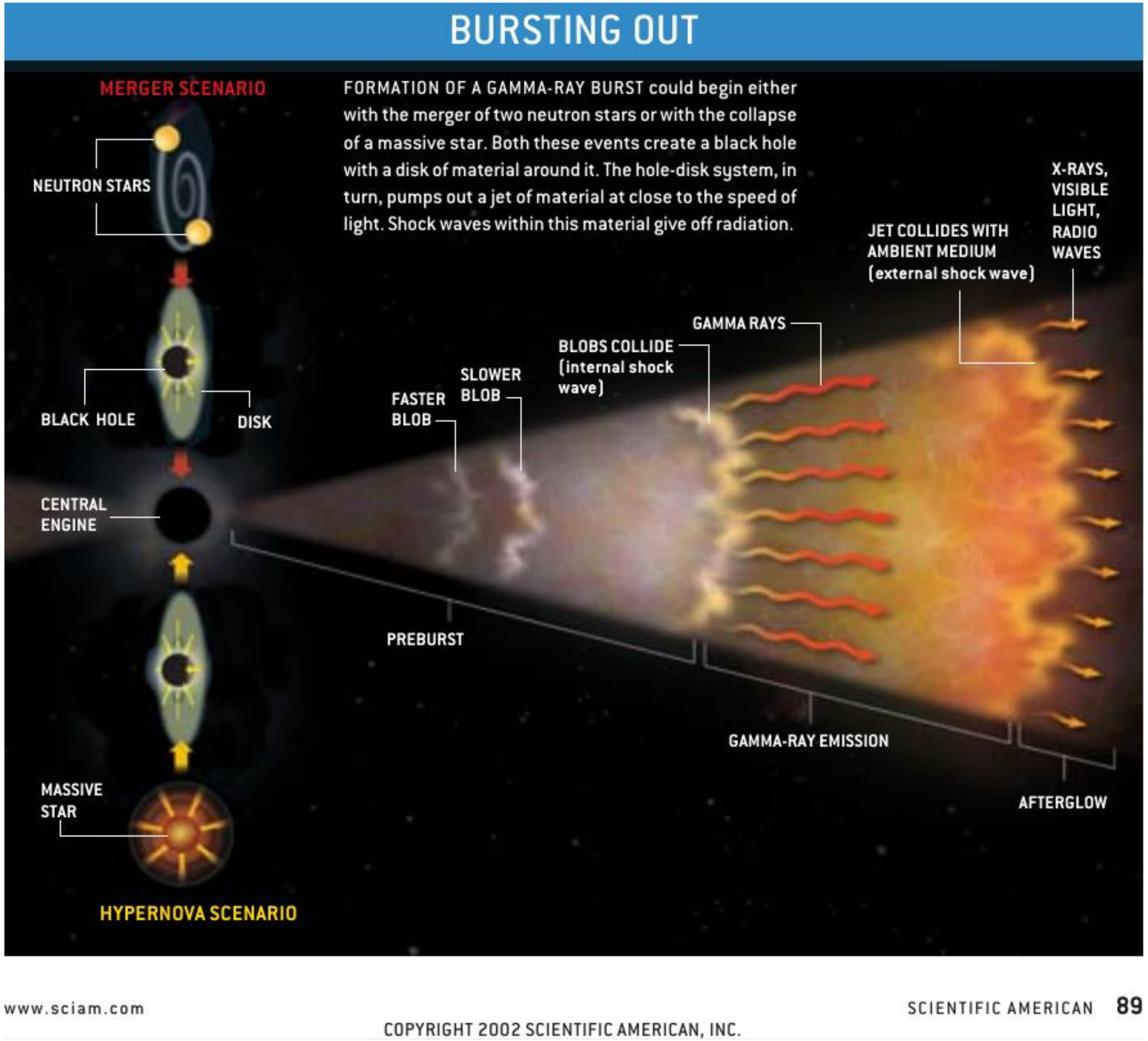
MERGER/Glowbug

Science cases

- **Monitor for Galactic SN**
- **Axions?**
- **Dark matter?**

backup

Gamma-Ray Burst (GRB)

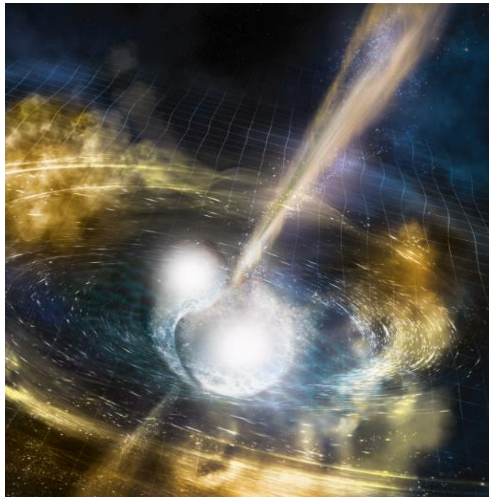


- **Discovered** in late 1960s
- **Related Sciences**
  - star, galaxy, universe
- **Observations**
  - Prompt emission: short/long
  - Afterglow: rich features
  - Multi-messenger: GW, …
- **Open questions**
  - Progenitor
  - Central engine
  - Jet launch
  - Jet composition
  - Radiation mechanism
  - Standard candle?
  - …

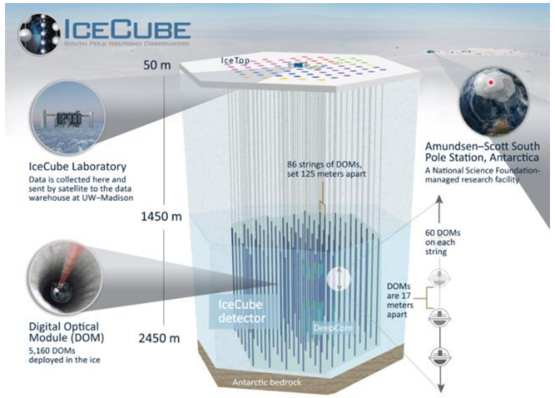
GRB in Multi-Messenger Astronomy Era

- **Gravitational Wave event (GW)**

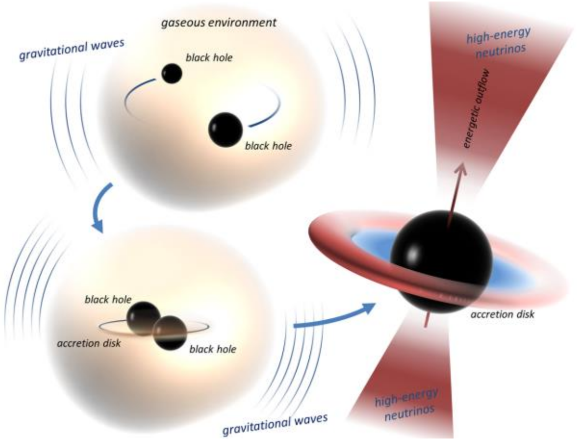
LIGO
Virgo
KAGRA



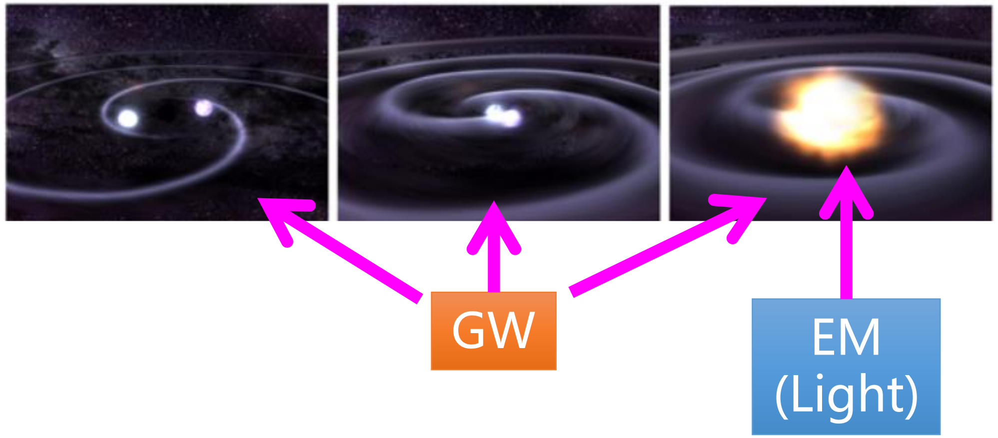
- **High Energy Neutrino (HEN)**

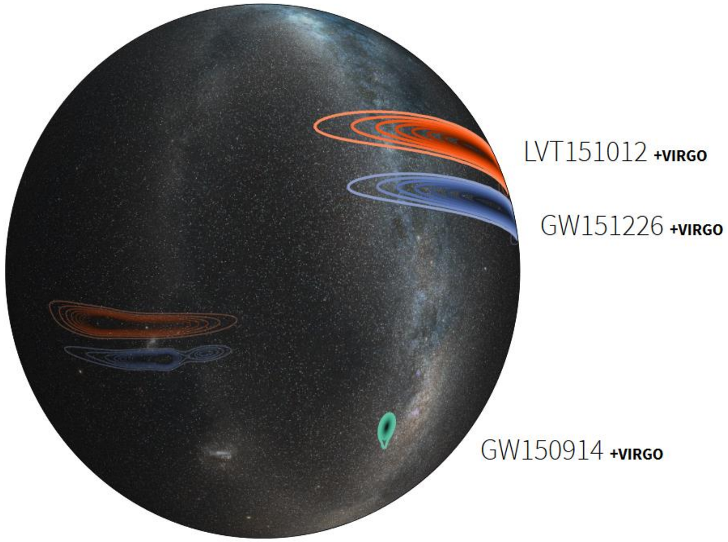


IceCube



GW Electromagnetic counterpart (GWEM)





Credit: LIGO/Leo Singer
(Milky Way image: Axel Mellinger)

- Independent confirmation of GW event
- Accurate localization, host galaxy, redshift
- Astrophysical content of the GW source
- GW+EM, Cosmology, fundamental physics