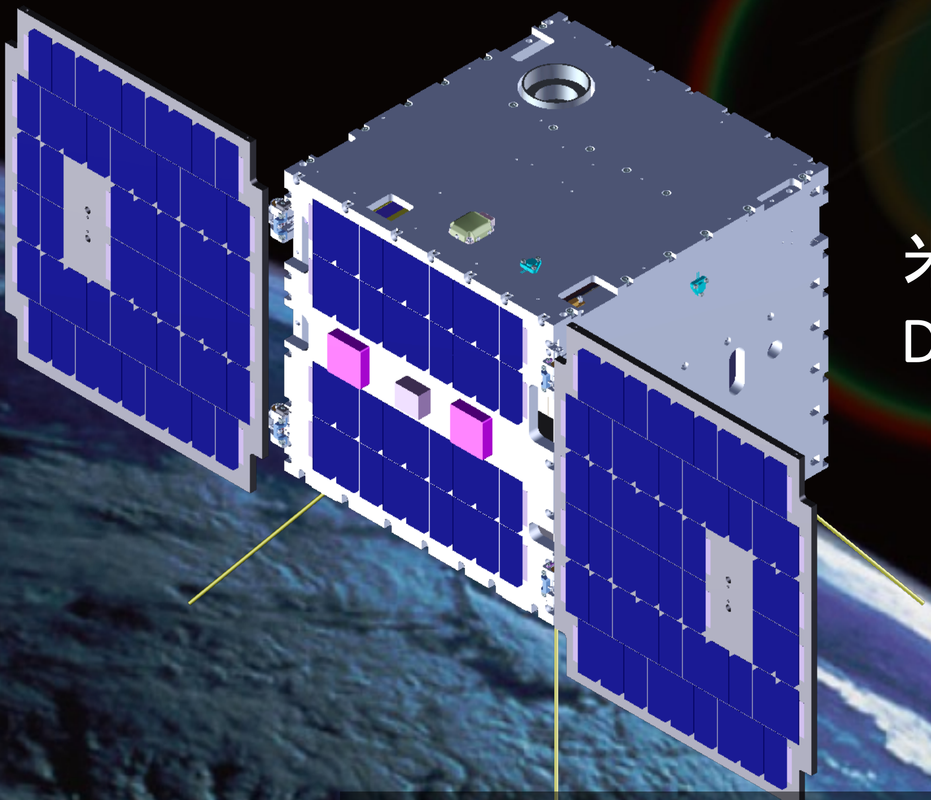
# 高密度連星系の合体と 短時間ガンマ線バースト
# Coalescence of Compact Star Binary Objects and Short Gamma-Ray Bursts



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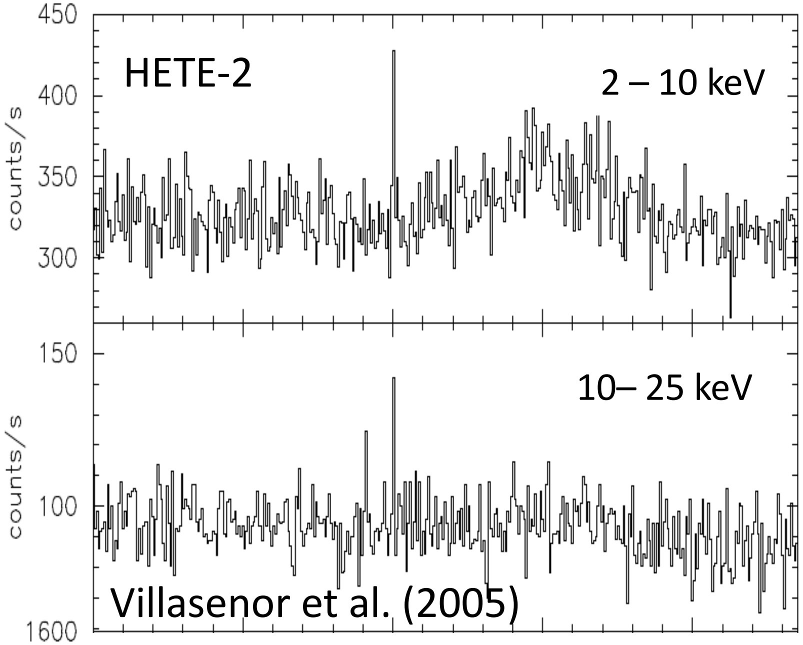
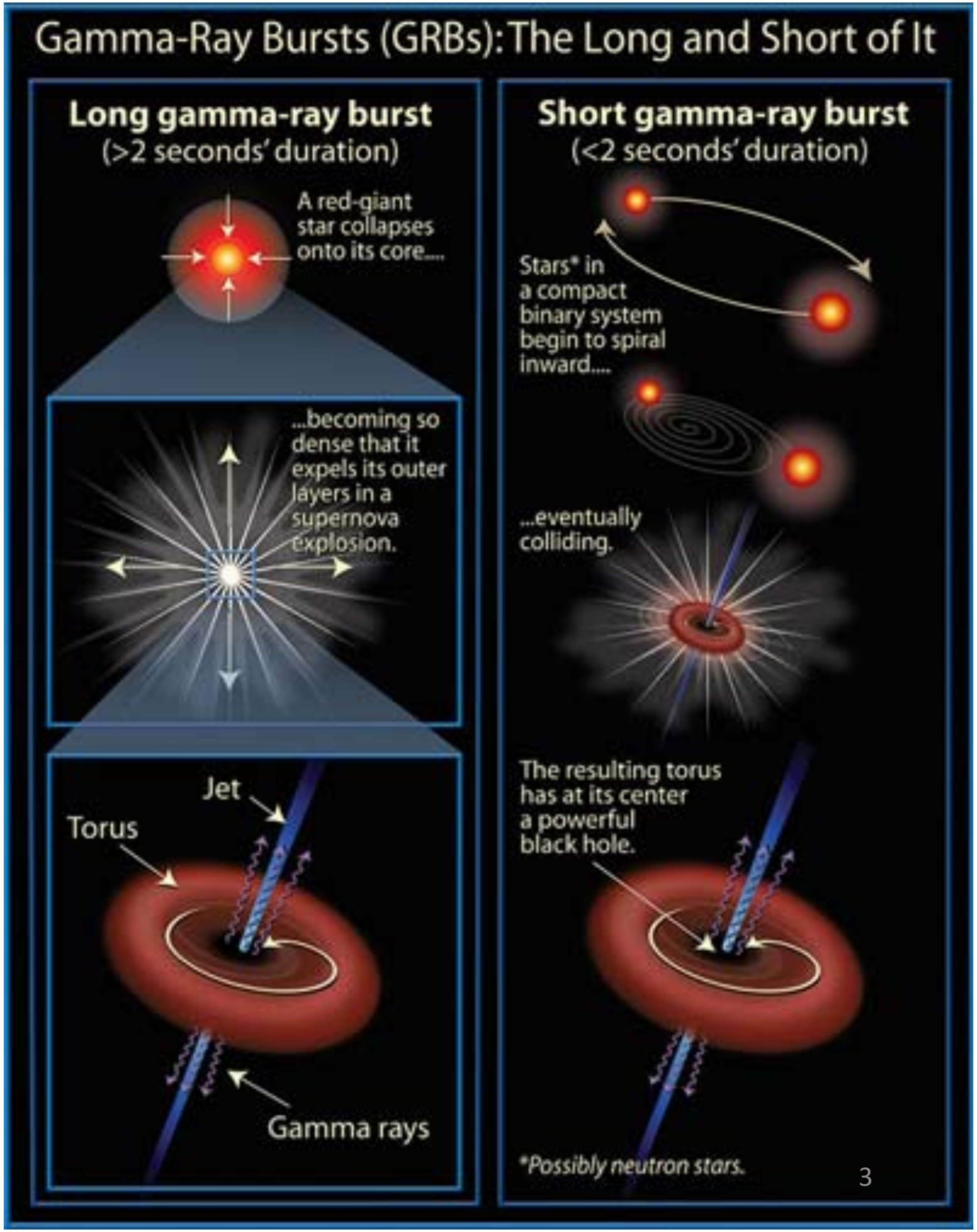
日本物理学会 2016 秋季年会 @ 宮崎大学 (2016/09/23)

# Outline

- Short Gamma-Ray Bursts & Their Characteristics
- X-ray/gamma-ray Observations for 3 GW detections
- Event Rate of GW detection from SGRB observation
- Future Mission (micro-satellite Kanazawa-SAT$^3$)

# Long & Short GRBs




LGRBs (T > 2 sec)

- Massive star explosion ($M>40M_{sun}$)
- Associated with Supernovae
  (energetic Hypernovae)
- Black Hole & relativistic jet

SGRBs (T < 2 sec)

- Coalescence of NS-NS/NS-BH (?)
- Strong GW is radiated.
- Black Hole & relativistic jet (?)

# Prompt Gamma-Ray Spectrum

Band et al. 1993

$$N(E) = \begin{cases} A\left(\frac{E}{100\ \mathrm{keV}}\right)^{\alpha} \exp\left(-\frac{E}{E_0}\right) & \text{for } E \le (\alpha-\beta)E_0, \\ A\left(\frac{E}{100\ \mathrm{keV}}\right)^{\beta} \left(\frac{(\alpha-\beta)E_0}{100\ \mathrm{keV}}\right)^{\alpha-\beta} \exp(\beta-\alpha) & \text{for } E \ge (\alpha-\beta)E_0. \end{cases}$$

$\alpha$ : low-energy spectral index

$\beta$ : high-energy spectral index

$E_0$ : break energy

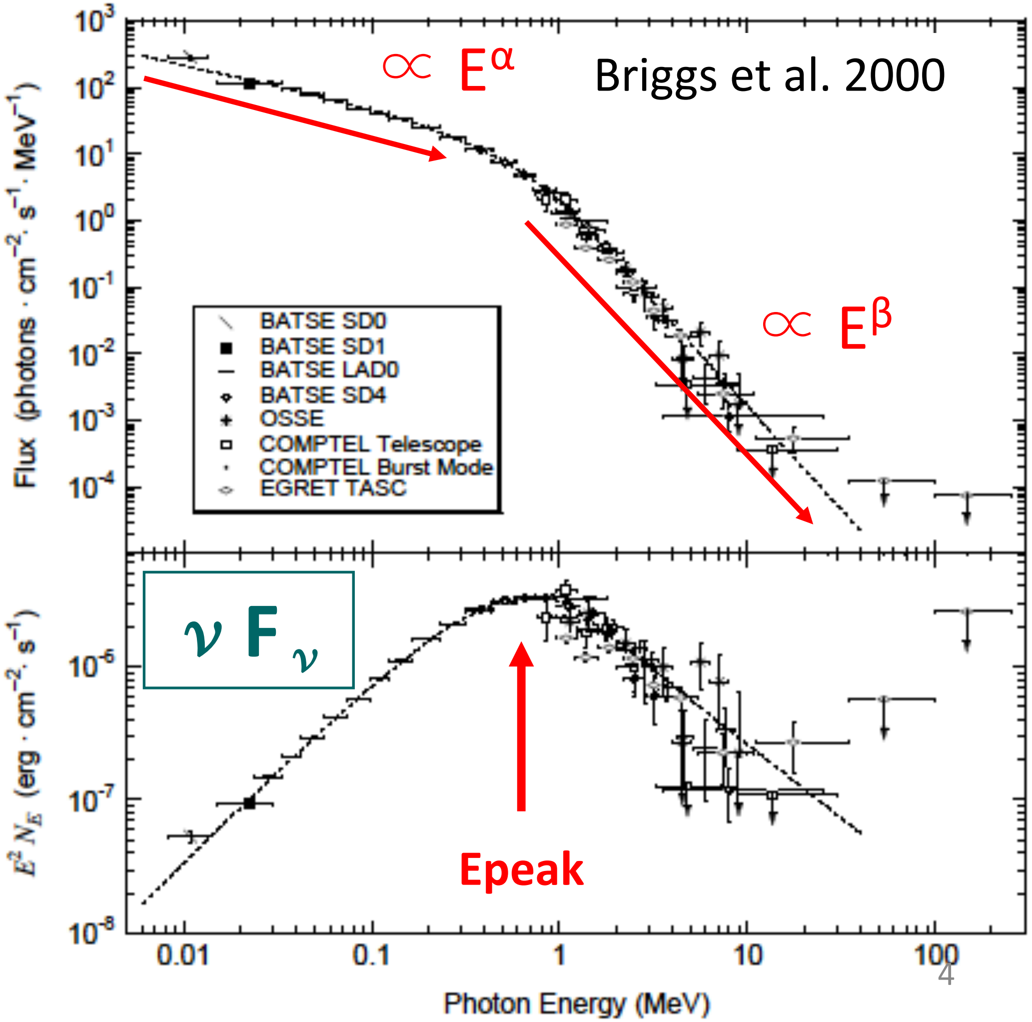
## Non-thermal spectrum

Synchrotron radiation from accelerated electrons by the relativistic shock.

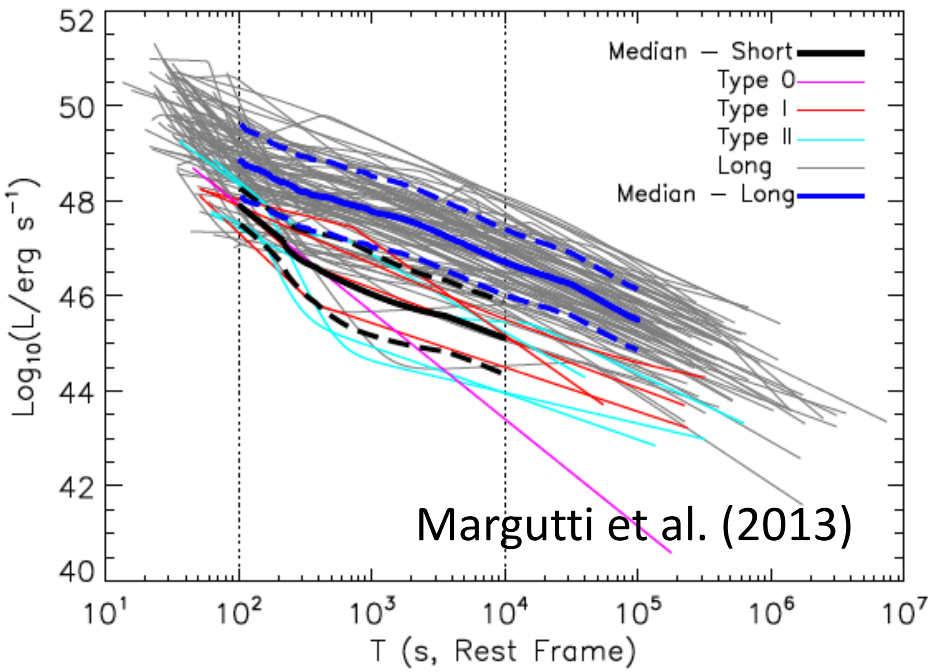
Maybe …

Maximum of $\nu F_\nu$ spectrum

**Peak energy ($E_{peak}$)**



# X-ray Afterglow




X-ray afterglow of SGRB is generally dimmer than one of LGRB

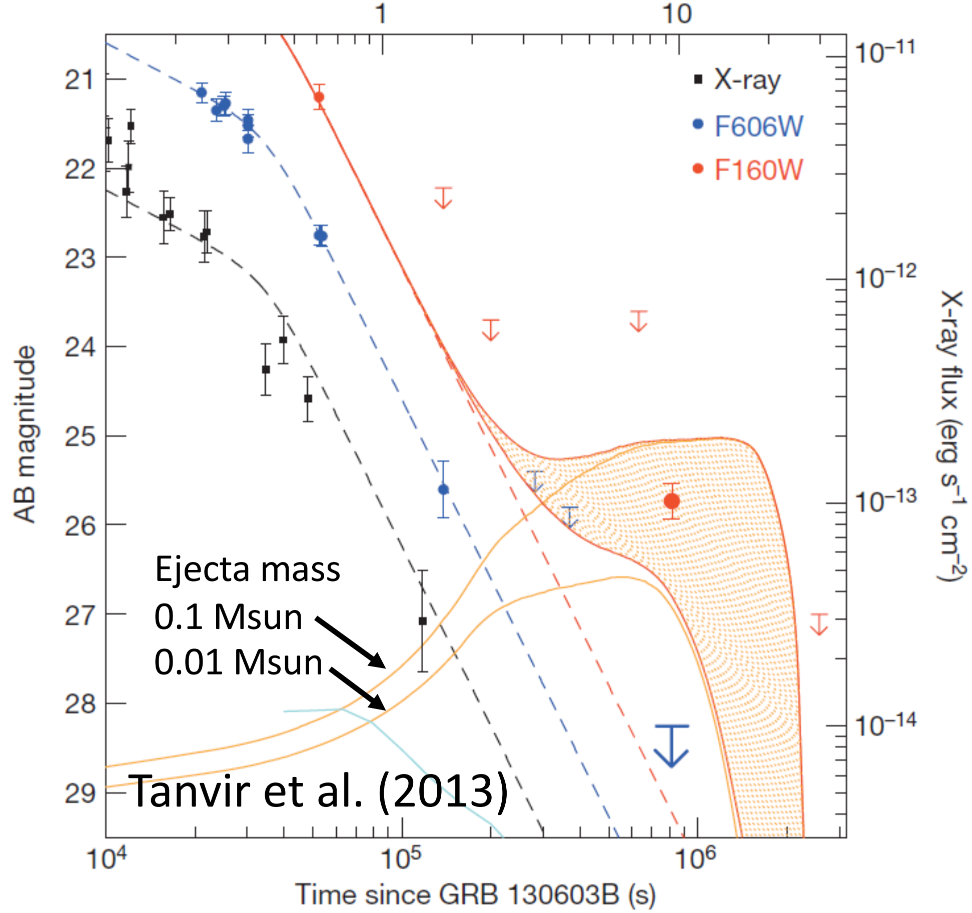
e.g. Decay part of the extended emission (exponential decay τ ~ 50 sec)

Kagawa, DY + (2015)

Extended emission
- 7% (CGRO-BATSE: Bostanci et al. 2013)
- 25% (Swift-BAT: Norris et al. 2010)
- 40% (Swift-BAT+XRT: Kagawa, DY+ 2016)

# Optical/NIR Afterglow & kilonova/macronova

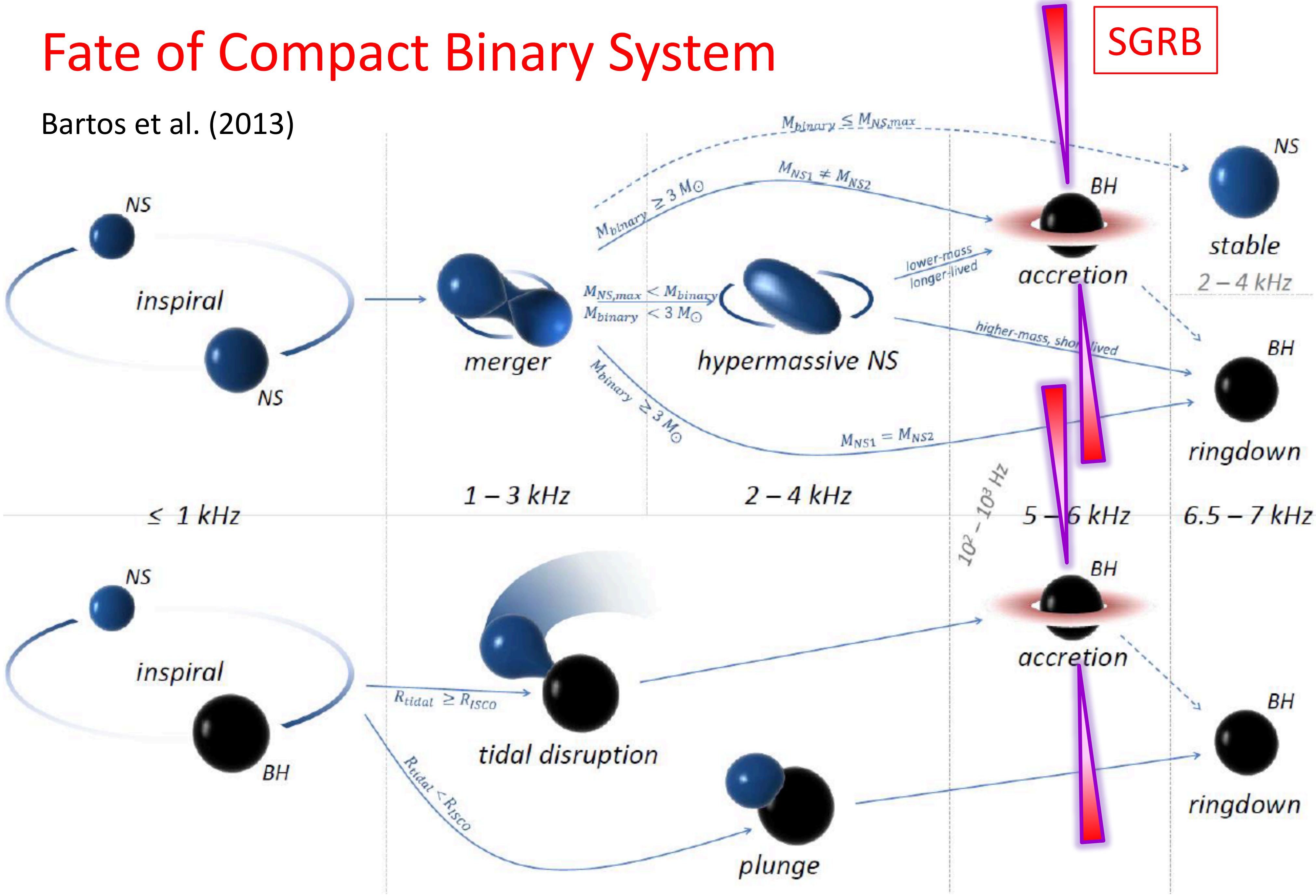
GRB 130603B @ z = 0.356




- Heating by nuclear beta decay of r-process (neutron rich) elements
- Benchmark of future optical/NIR obs.

# Fate of Compact Binary System

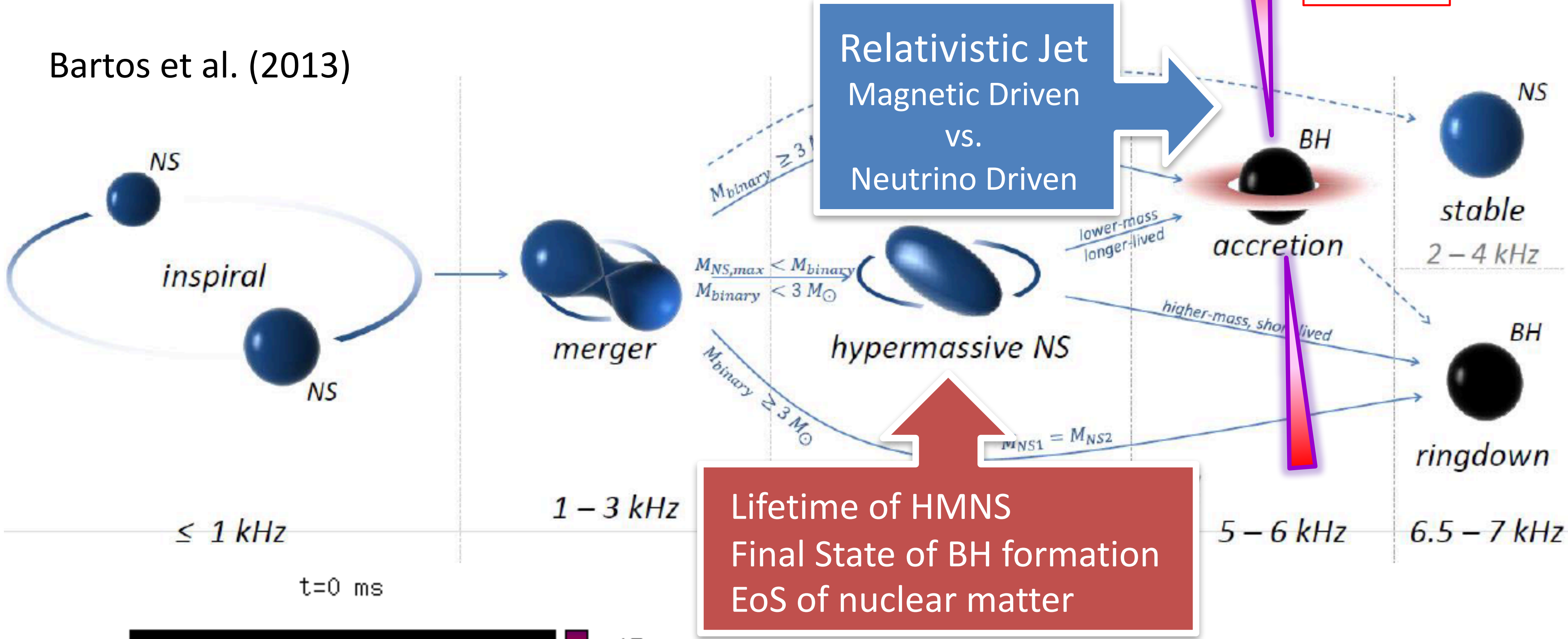
Bartos et al. (2013)

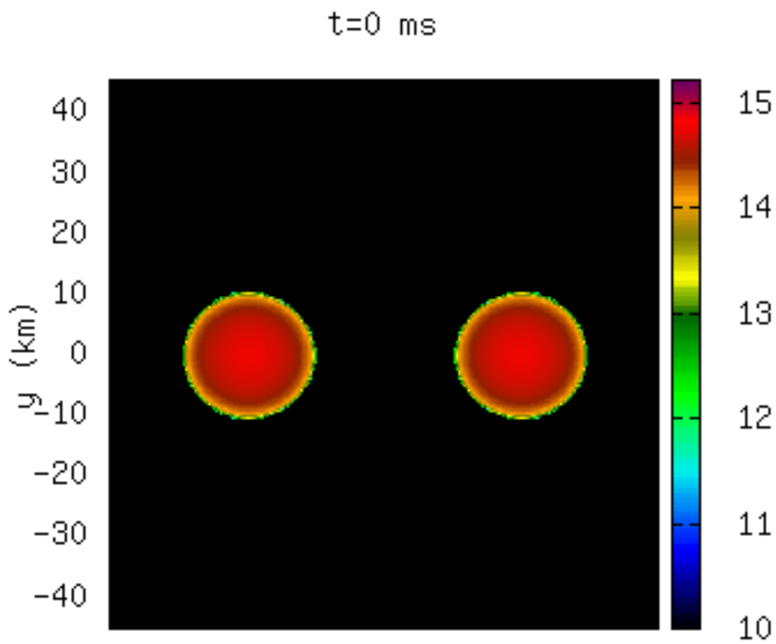


# Fate of Compact Binary System

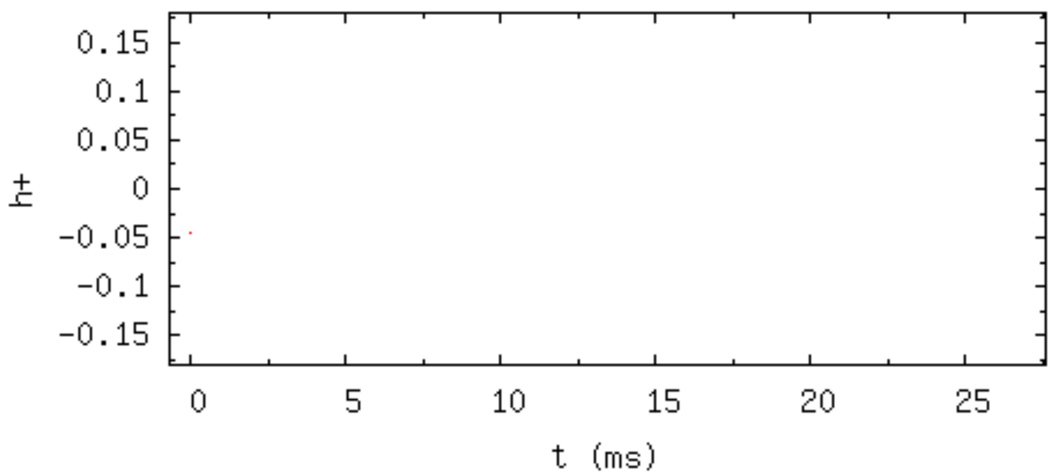
SGRB

Bartos et al. (2013)




Hotokezaka et al. (2011)



# Electro-Magnetic (X- & gamma-ray) counterpart

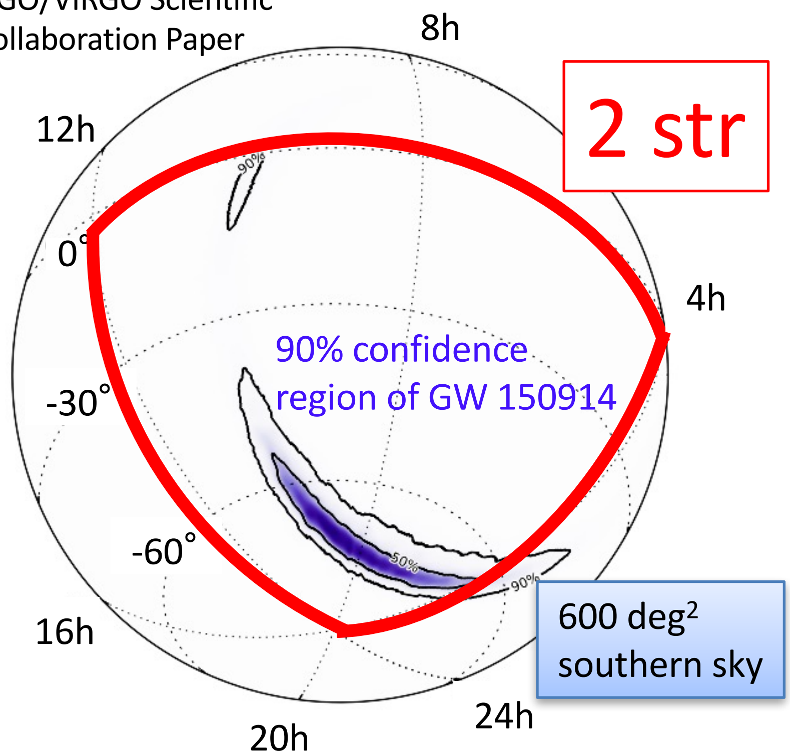
## ➢ Localization

- Multi-wavelength follow-up observations
- Deep understanding of astrophysical object and strong gravitational field
- Luminosity distance from both GW and EM

## ➢ Timing

- To improve S/N ratio of GW detection
  … Event rate of GW sources
- Black hole formation and jet launch
- Velocity of GW (graviton mass scale)

LIGO/VIRGO Scientific Collaboration Paper




◆ Black Hole Formation Mechanism

Coalescence of NS-NS/NS-BH → Direct Formation of Black Hole / Hyper-massive NS → Black Hole

10 – 100 msec difference between GW and EM

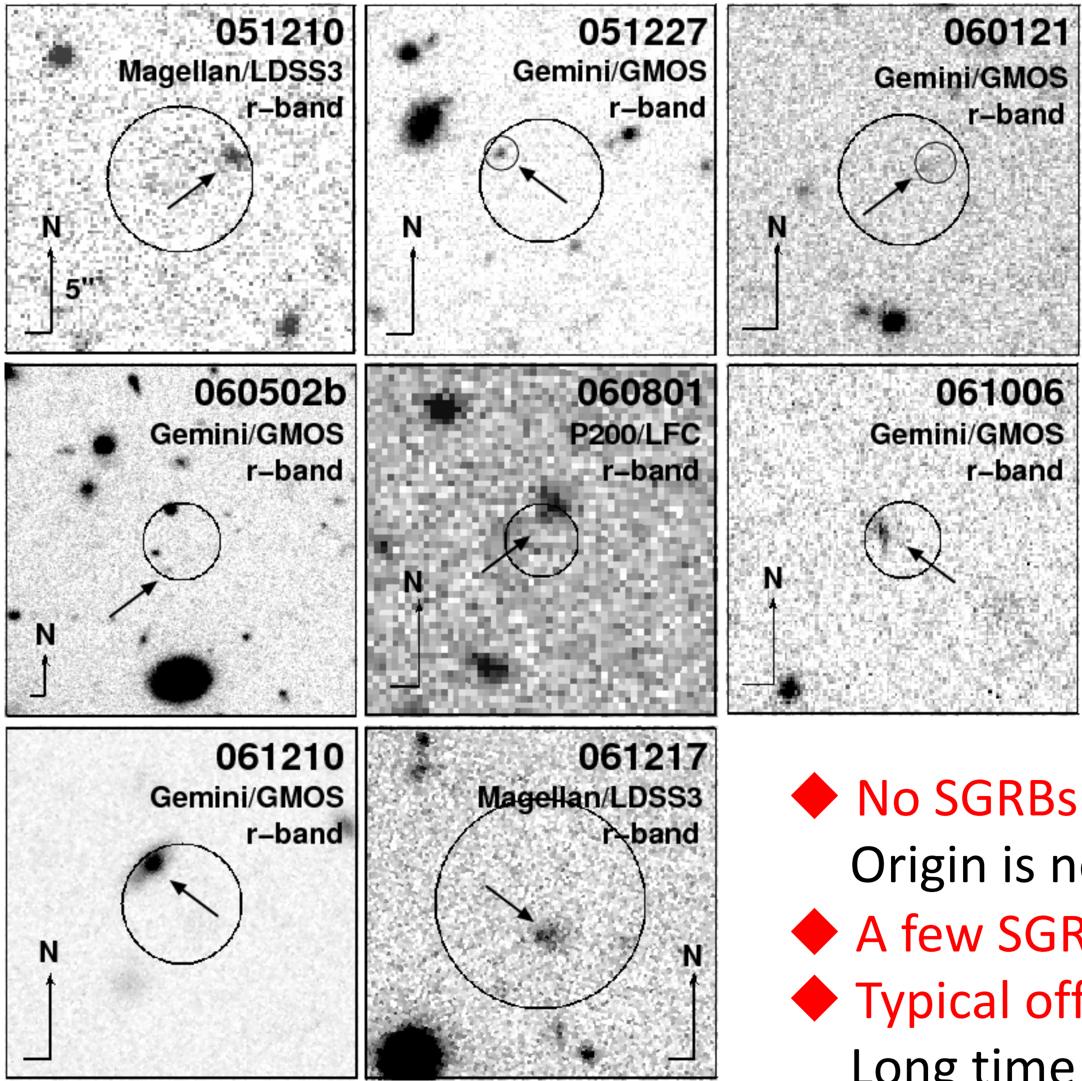
◆ Energy Source of Relativistic Jet

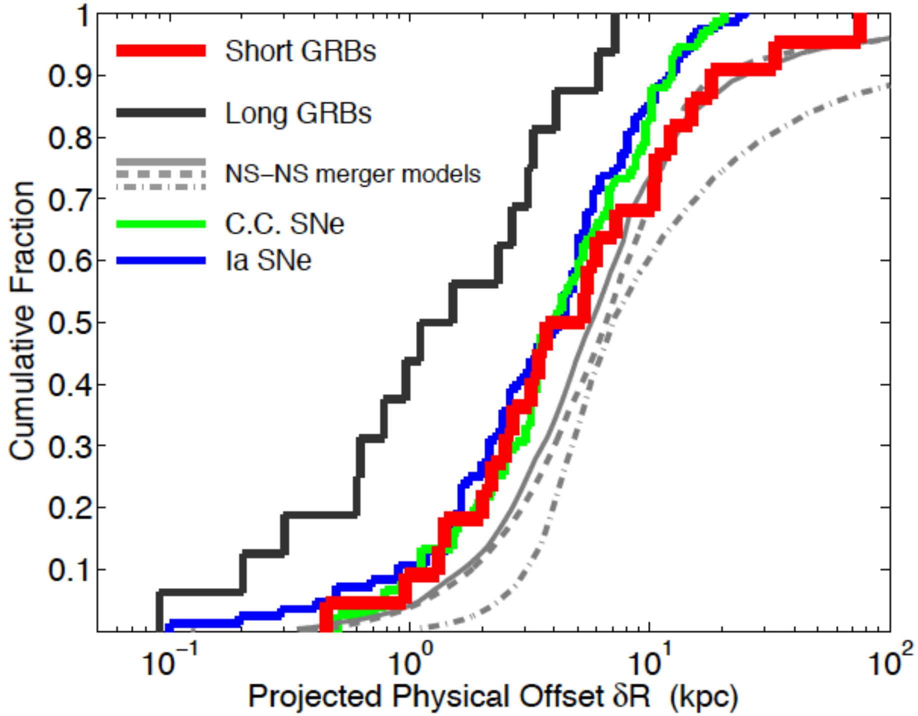
Black Hole Formation → Neutrino Driven / Magnetic Field Driven

1 – 10 msec difference between GW and EM

# Location of short GRBs

Berger et al. 2013



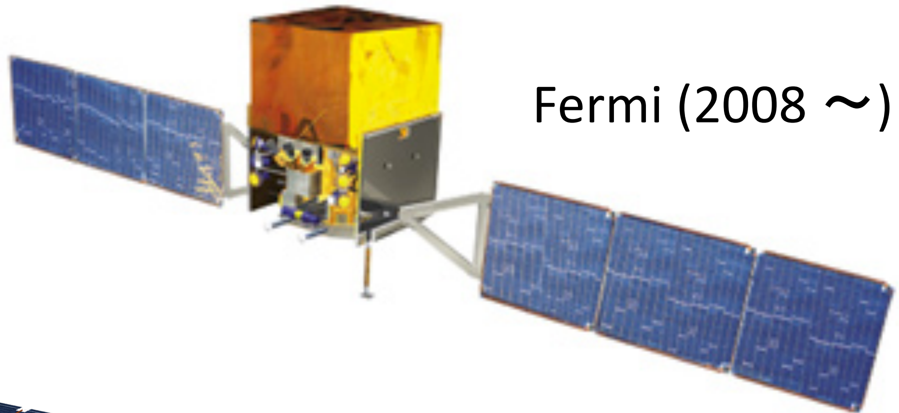

Berger et al. 2009

- No SGRBs in star forming region
  Origin is not massive star (No SN association)
- A few SGRBs occur in elliptical galaxy
- Typical offset from host galaxy : ~ 10 kpc
  Long time scale
  kick velocity ~ 100 km/s → ~ 0.1 Gyrs

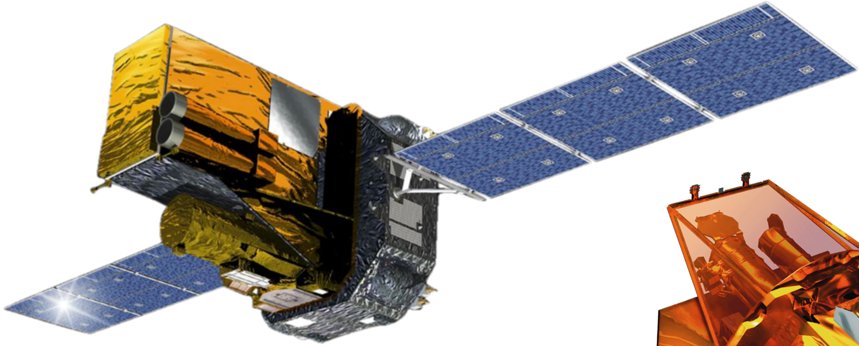
Coalescence of NS-NS/NS-BH is an acceptable scenario

# X-ray/ $\gamma$ -ray Observations for 3 GW sources (GW 150914, LVT 151012, GW 151226)

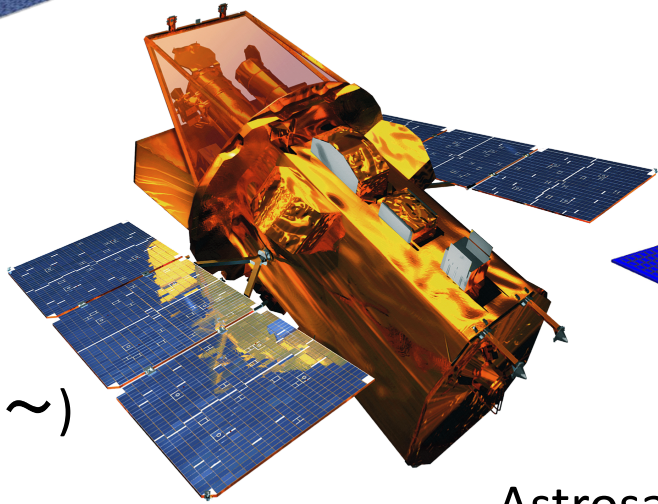
# Current GRB Mission



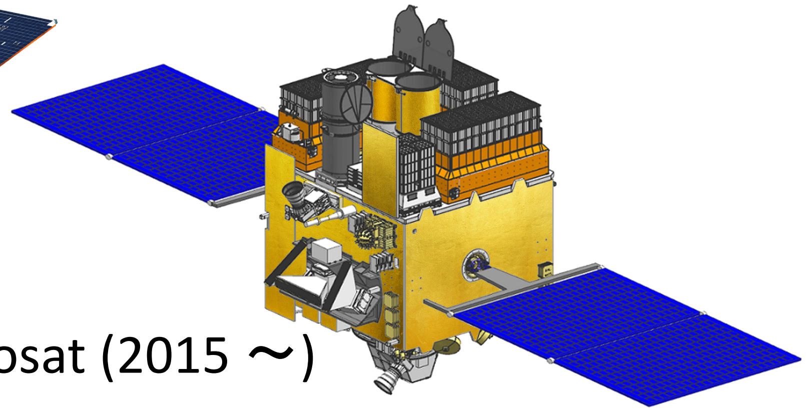
Fermi (2008 ～)



INTEGRAL (2002～)

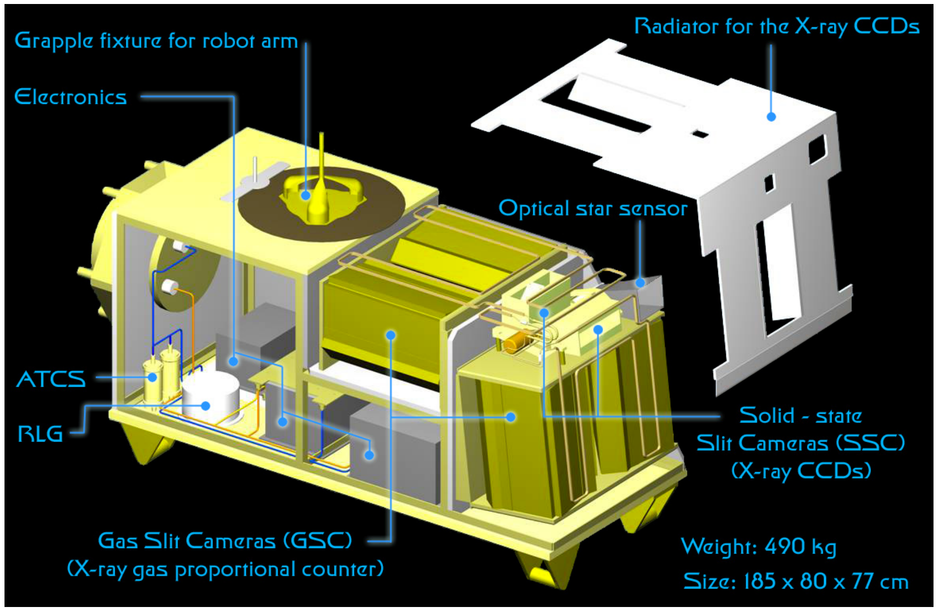


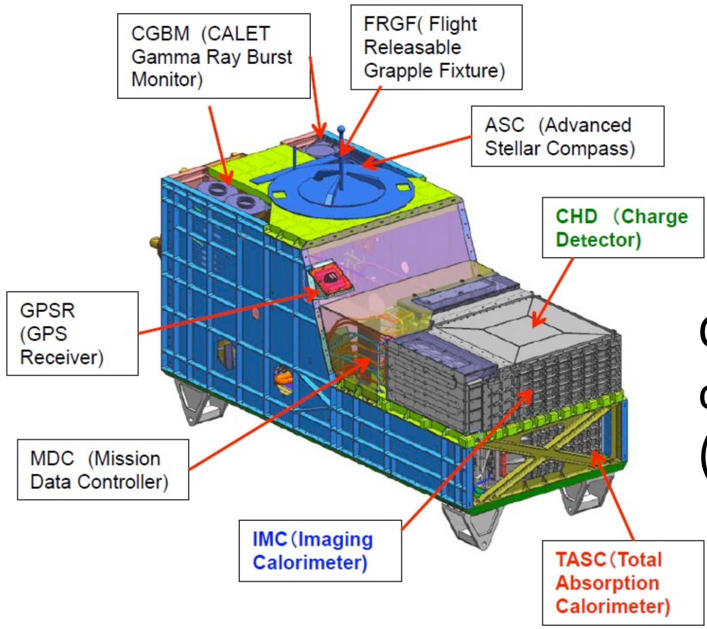
Swift (2004～)



Astrosat (2015 ～)

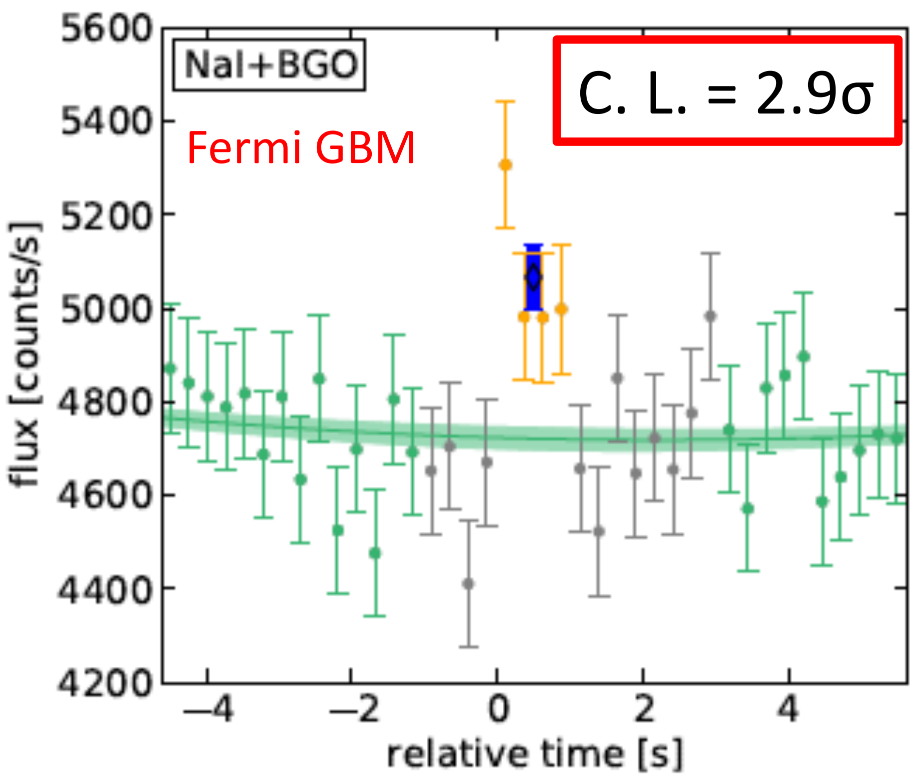
MAXI onboard ISS (2009 ～)



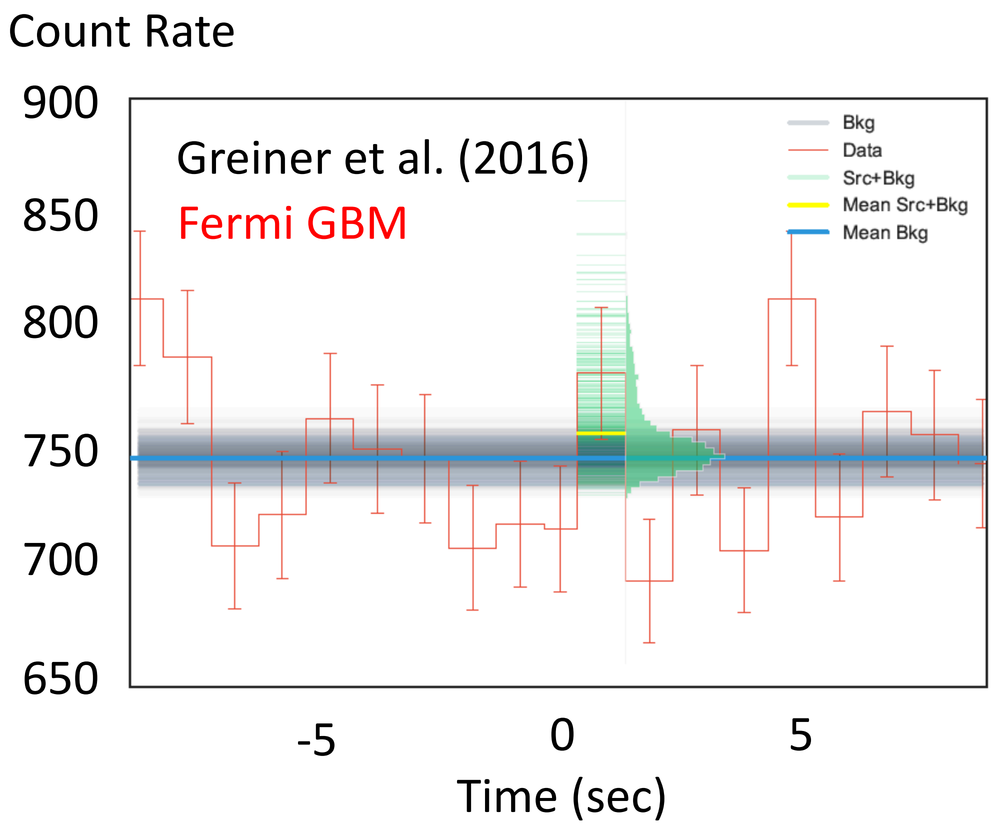




CALET onboard ISS (2015 ～)

# X-ray/ $\gamma$ -ray Counterpart (?) of GW 150914




Connaughton et al., ApJ, 826, L6 (2016)




$1.8^{+1.5}_{-1.0} \times 10^{49}$ erg s$^{-1}$ ~ Normal SGRB

No coincidence with known astrophysical, solar, terrestrial, or magnetospheric activities.

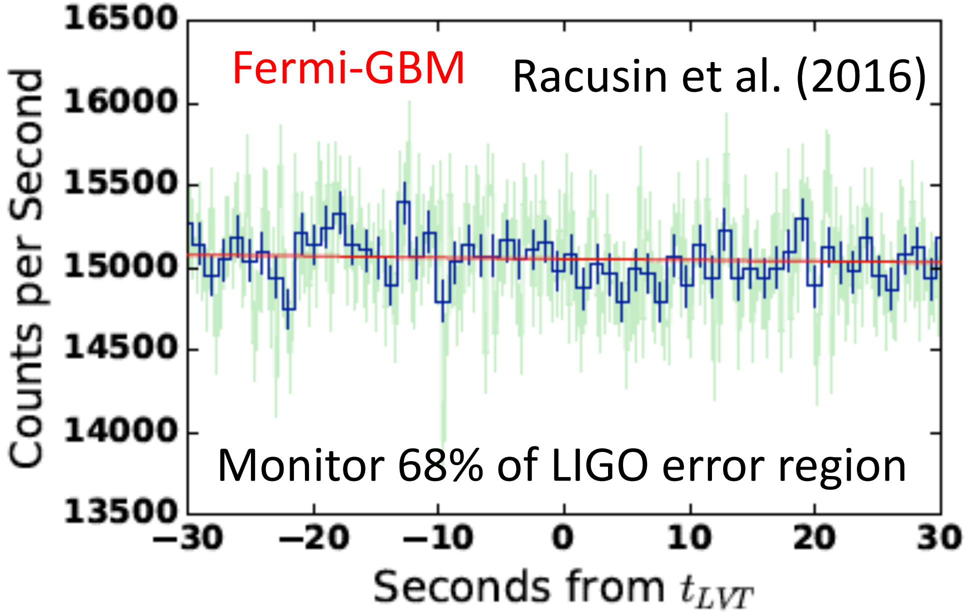
No coincidence with INTEGRAL

$$E_\gamma < 2 \times 10^{48} \mathrm{erg} \left(\frac{F_\gamma}{10^{-7} \mathrm{erg\ cm^{-2}}}\right) \left(\frac{D}{410\,\mathrm{Mpc}}\right)^2.$$

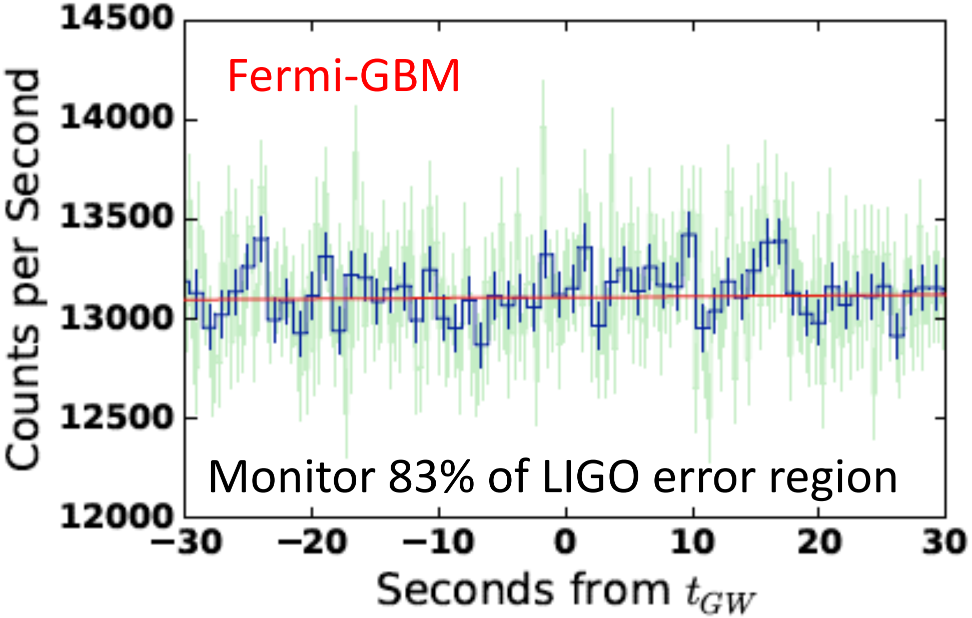
Non detection from the same data

**Fermi-GBM event must be Background Fluctuation**

## LVT 151012

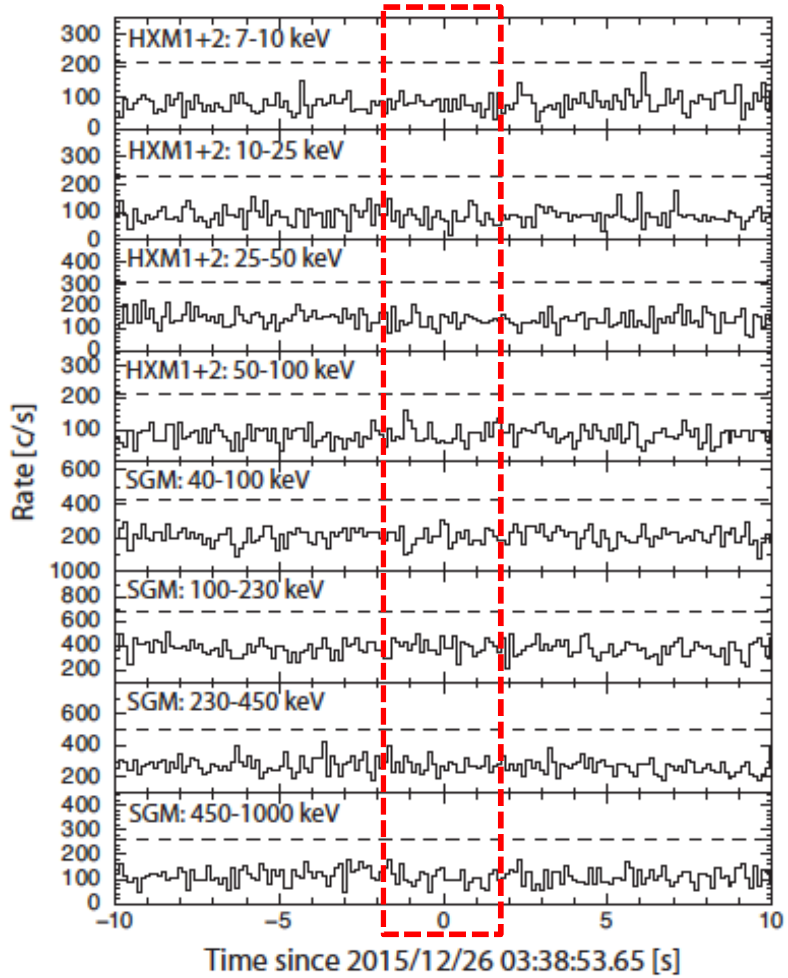


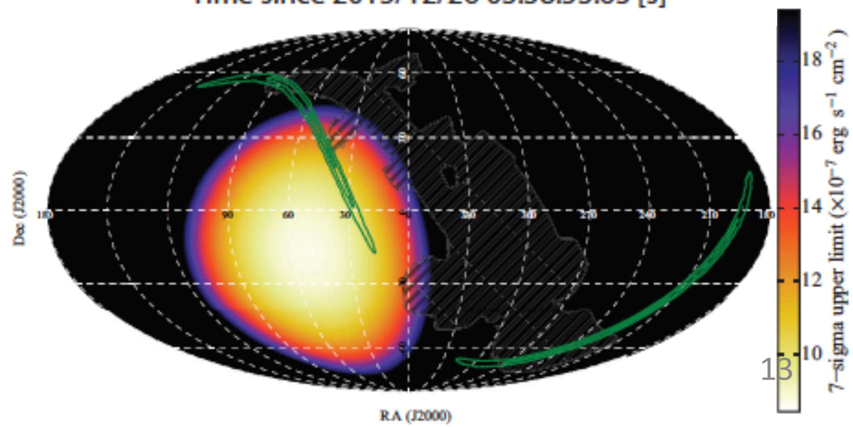

## GW 151226




## GW 151226

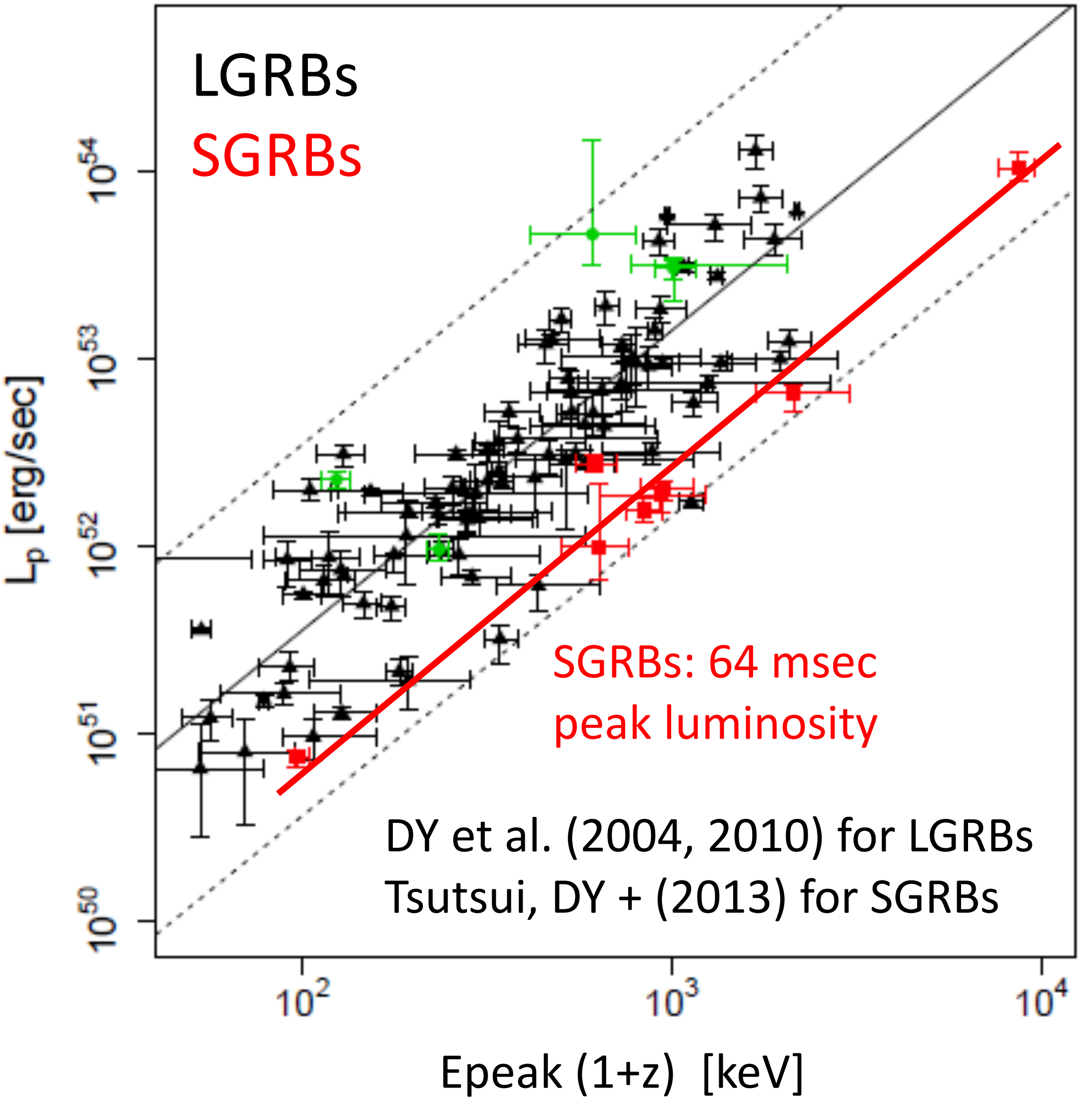
CALET-GBM



# Event Rate of GW detection from SGRB observation

# $E_{peak}$ – Luminosity Correlation of LGRBs/SGRBs




LGRB (DY et al. 2004, 2010)

$$L_p = 4\pi d_L^2 F_p = A[E_p(1+z)]^{1.6}$$

$$\Rightarrow \frac{d_L^2}{(1+z)^{1.6}} = \frac{A}{4\pi F_p}\left(E_{peak}\right)^{1.6}$$

SGRB (Tsutsui et al. 2013)

$$L_p = 4\pi d_L^2 F_p = B[E_p(1+z)]^{1.6}$$

$$\Rightarrow \frac{d_L^2}{(1+z)^{1.6}} = \frac{B}{4\pi F_p}\left(E_{peak}\right)^{1.6}$$

We can use the correlation as the Luminosity/Distance indicator.

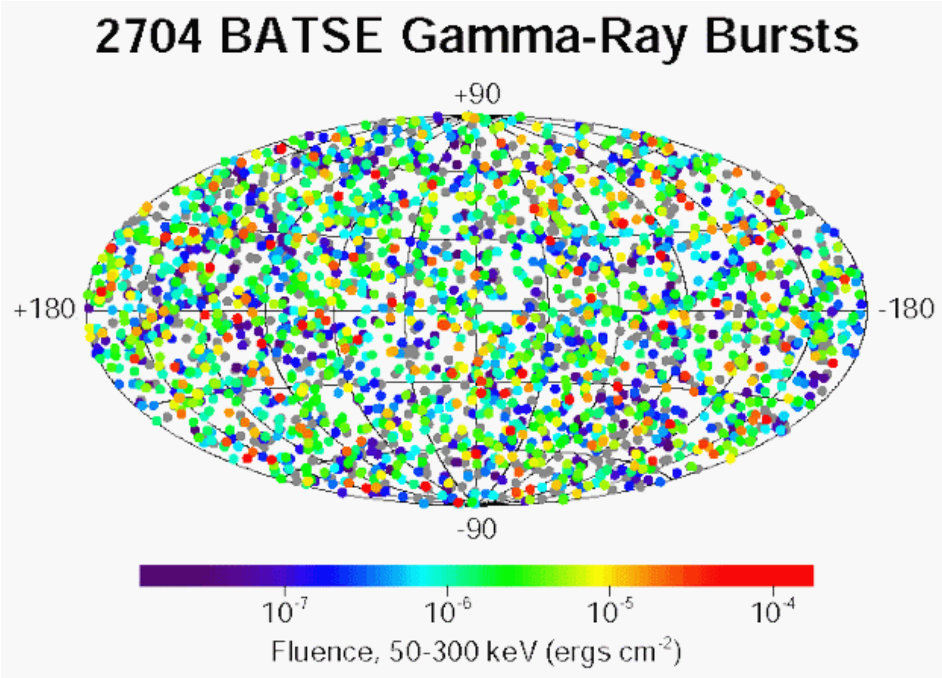
# Event selection

CGRO/BATSE current burst catalog

(1) 100 brightest SGRBs with $T_{90}$ < 2 sec

(2) Spectral parameters are obtained
for 72 SGRBs.
(for remaining 28, poor statistics
and variable BGD condition)

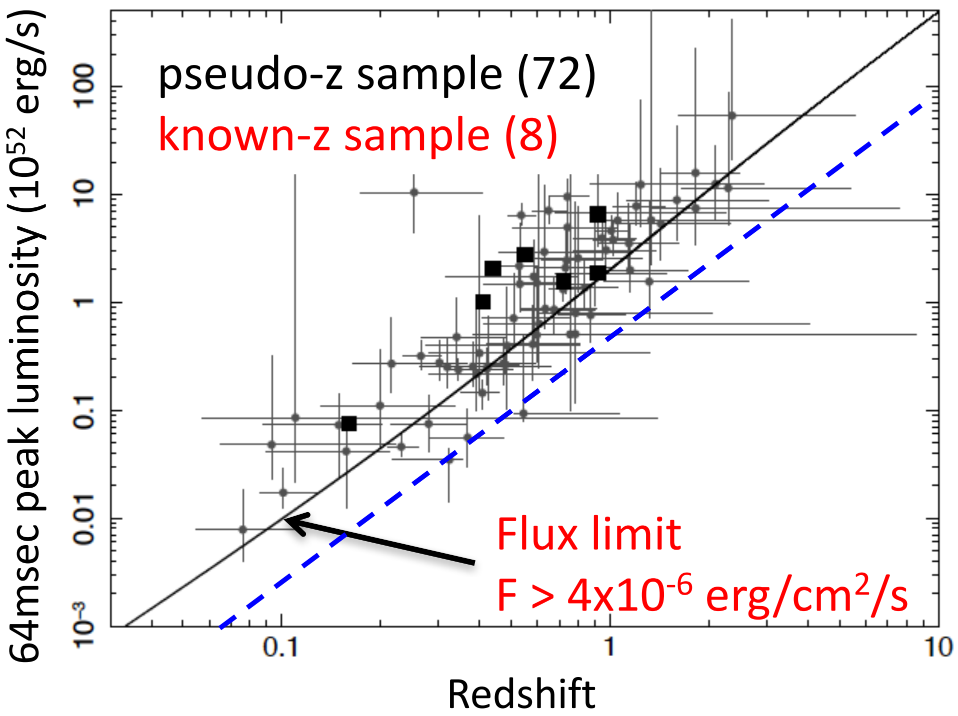
(3) We succeeded in calculating the pseudo-z
for all 72 SGRBs.



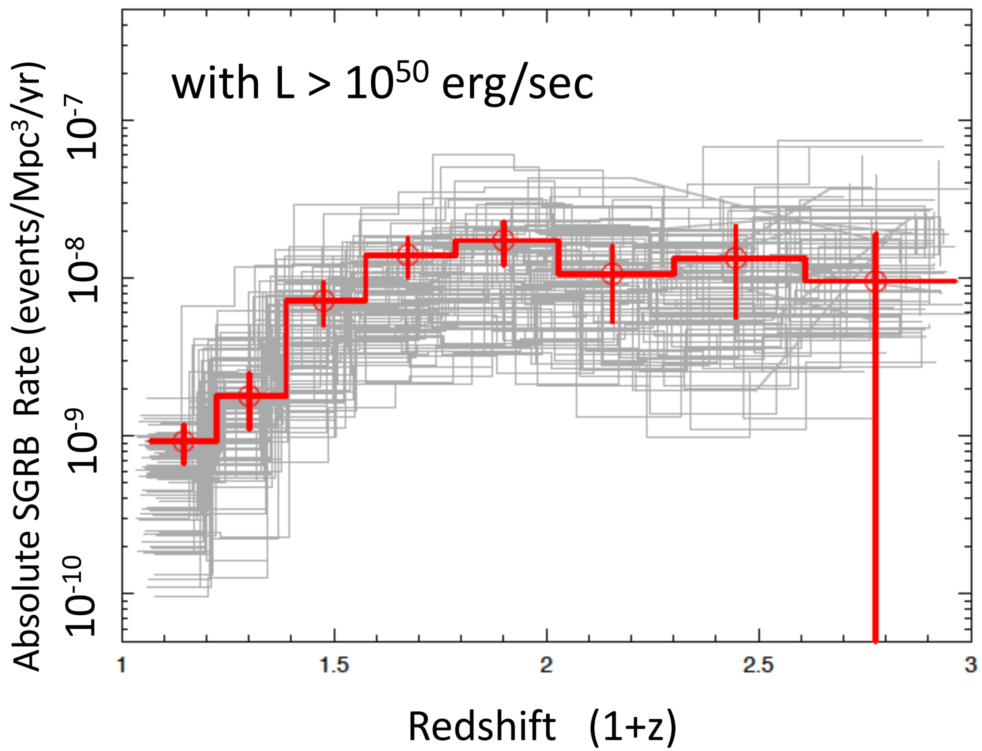


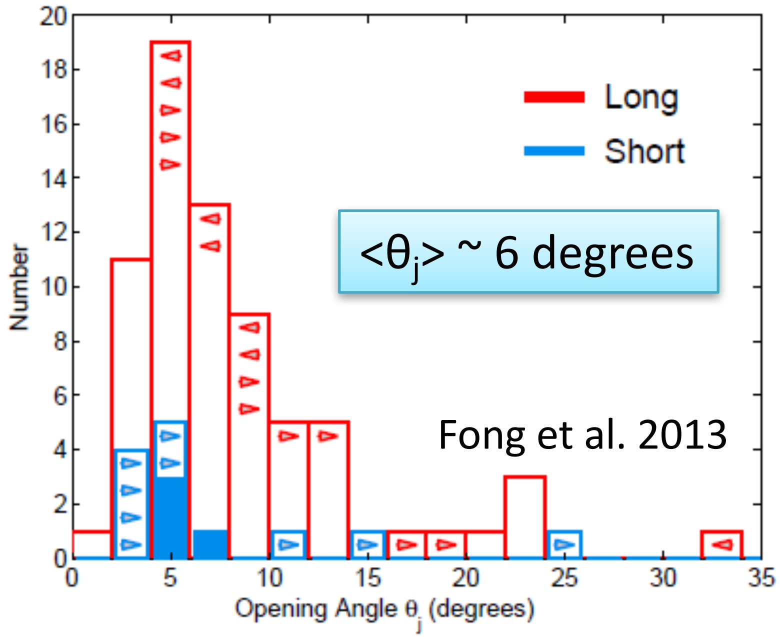
BATSE life time = 9.2 years
Fraction of sky coverage = 0.483
Trigger efficiency > 99.988 % for F = 1 ph/cm$^2$/s
Effective life time = 4.4 years

## Redshift Distribution




## SGRB Formation Rate




We used a non-parametric method.
(Lynden-Bell 1971, Petrosian 1993, etc.)

Local Rate including geometrical factor

> $1.2 \times 10^{-7}$ events/Mpc$^3$/yr (Lower Limit)

> 4.0 event/year in (200Mpc)$^3$ (Lower Limit)

Event rate of GW detection

16 events/year : NS-NS in (200 Mpc)$^3$
600 events/year : NS-BH in (670 Mpc)$^3$

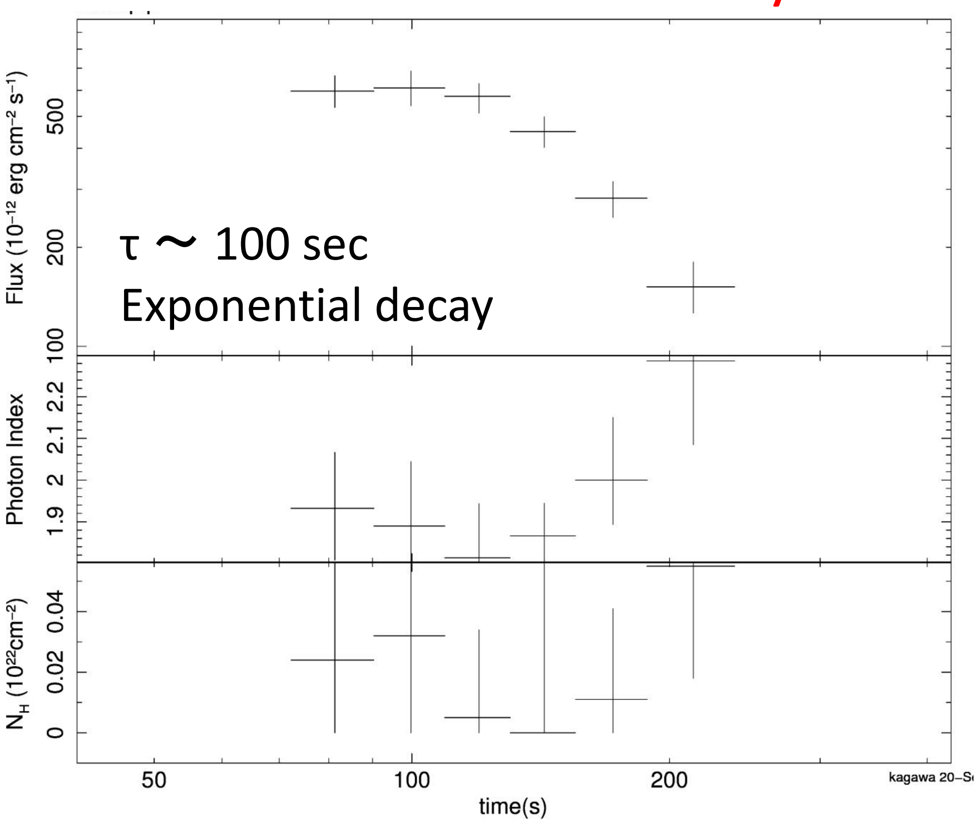
# Recent Nearby SGRB 160821B (z=0.16)

e.g. GRB 080905A (z = 0.1218)

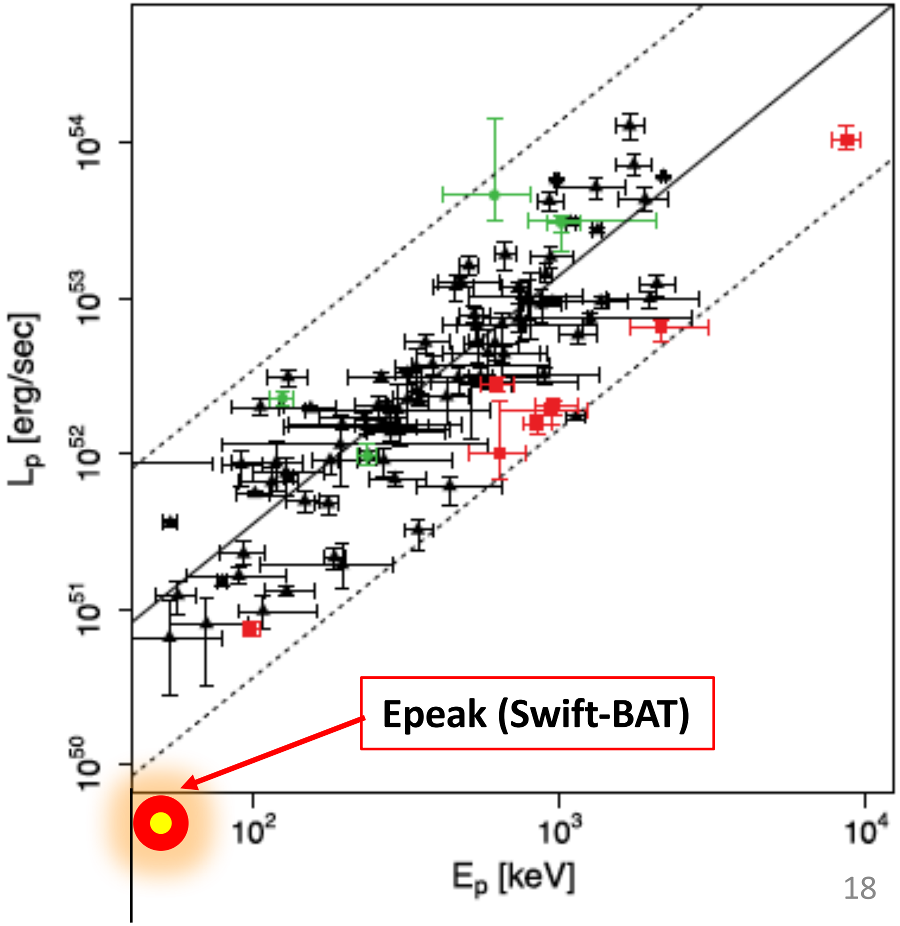
- 15 kpc offset from host galaxy
- Epeak – Lp – Eiso property is normal
- No kilonova information up to now, but some important results coming soon

**Probably Typical SGRB**

SGRB 160821B E.E. decay



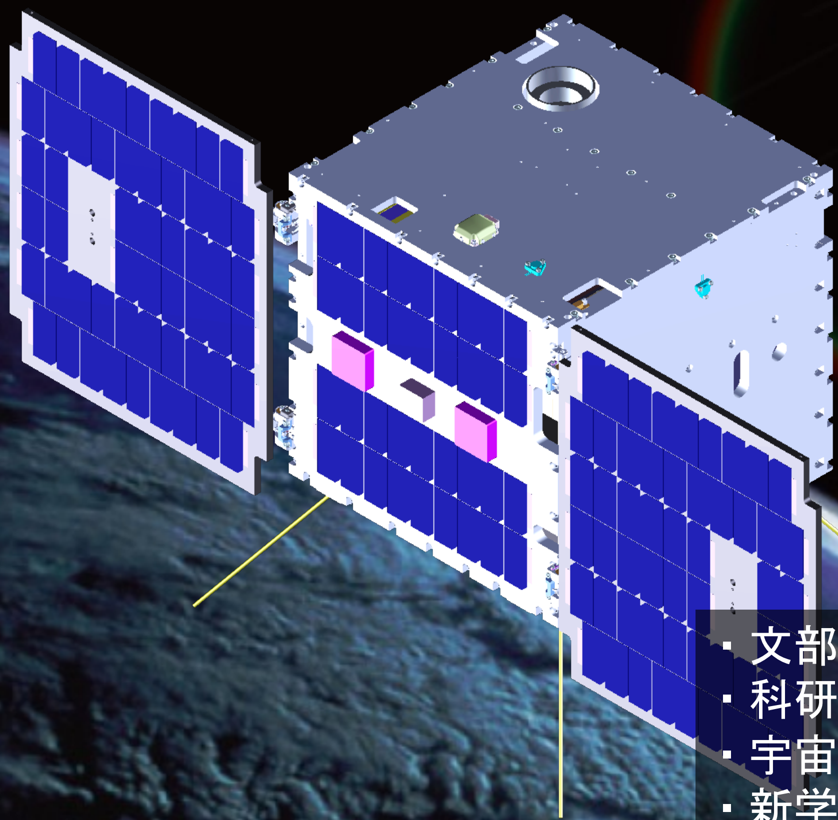

Ep –Lp



# How to find EM counterparts of GW sources

# X-ray Transient Monitor for GW Sources aboard Kanazawa-SAT$^3$

**Launch Target**
**End of FY2018**



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・科研費基盤(S) （代表：米徳大輔, H28 – H32 ）
・宇宙航空科学技術推進委託費（代表：米徳大輔, H27 – H29）
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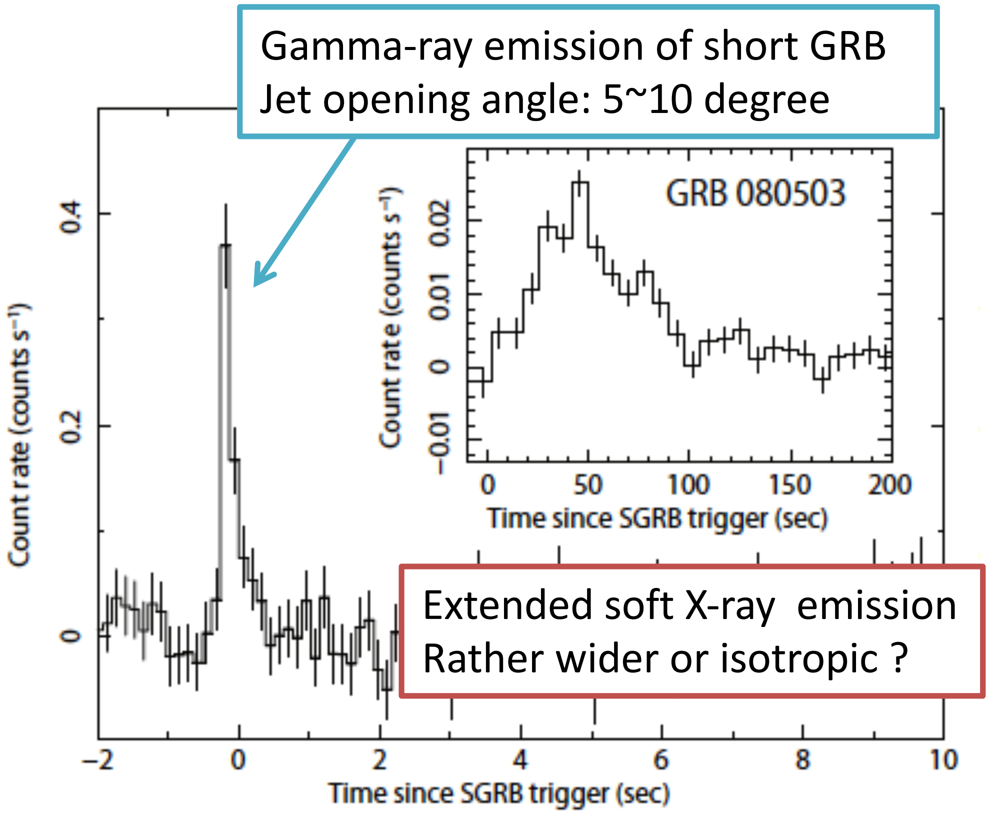
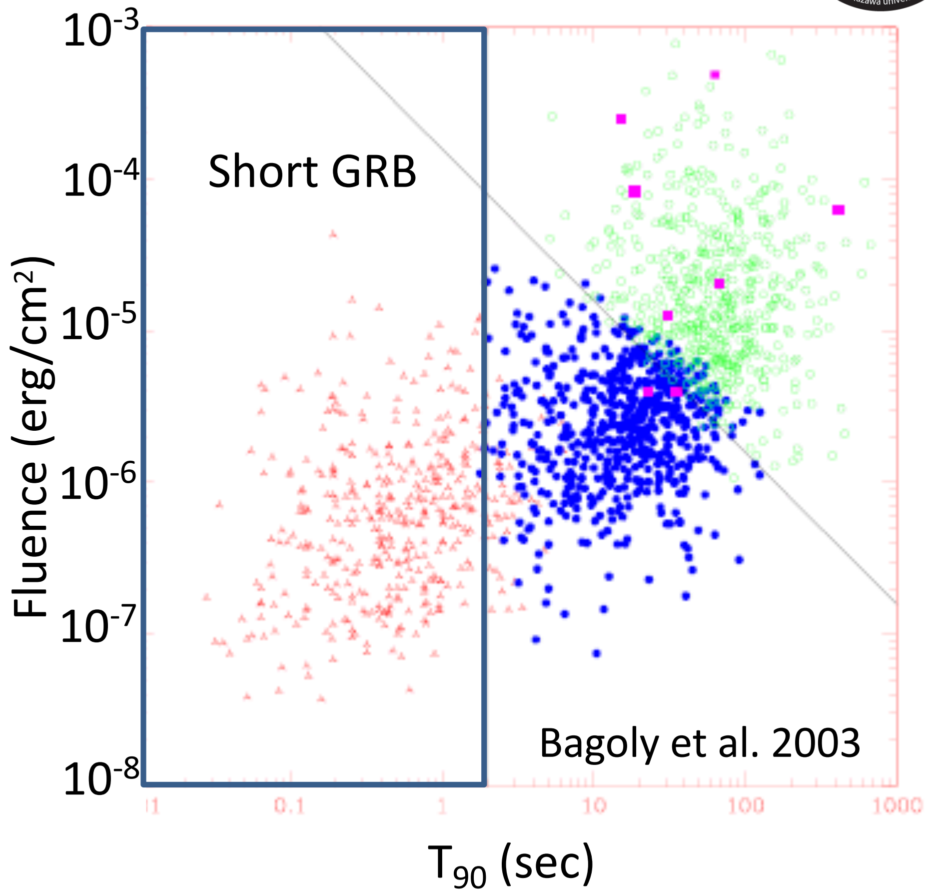
# Apparent Brightness of SGRBs



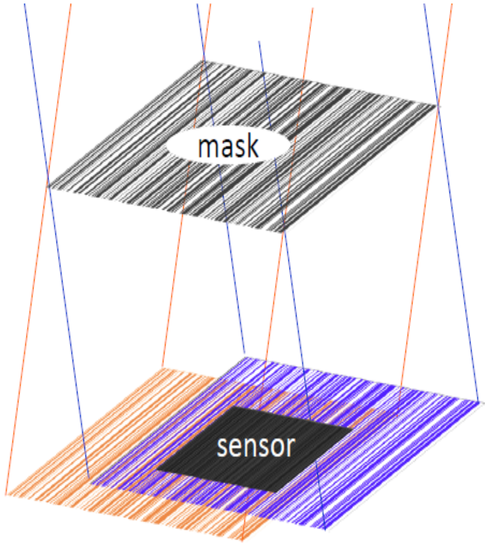



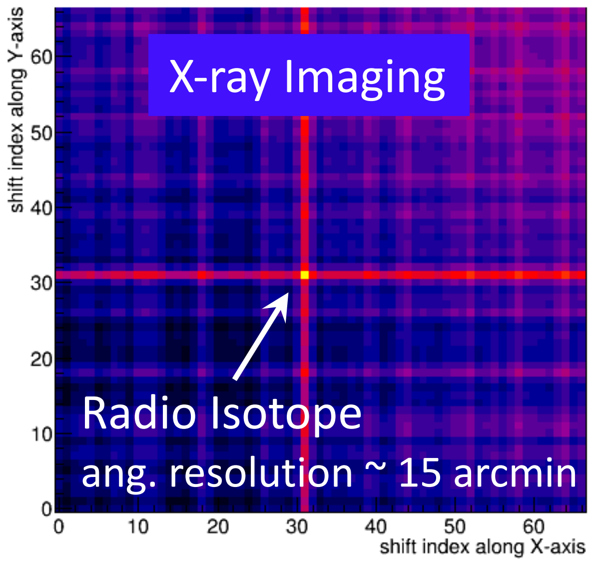

Expected photon flux : $10^{-6}$ erg/cm$^2$ ~ 300 photon/cm$^2$

Extended Emission ($\propto$ $E^{-1}$~$E^{-2}$, 1~10 keV):

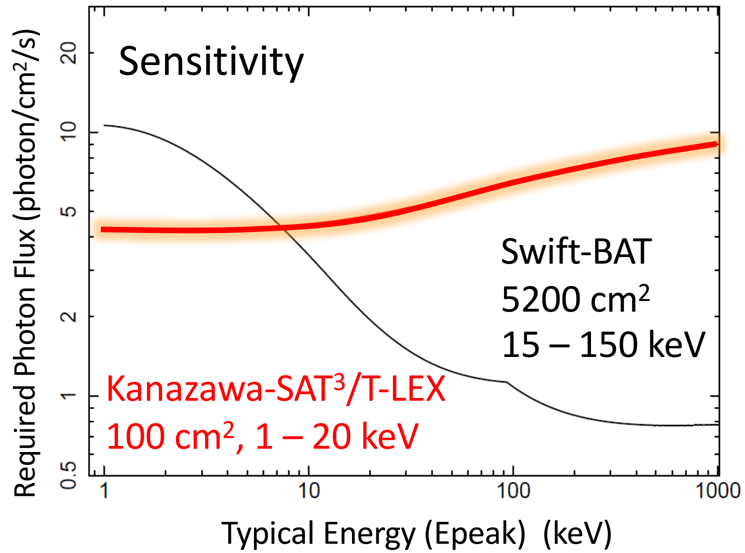
Extended emission of nearby SGRBs is enough bright.
We can observe them by small instruments with 100 cm$^2$.

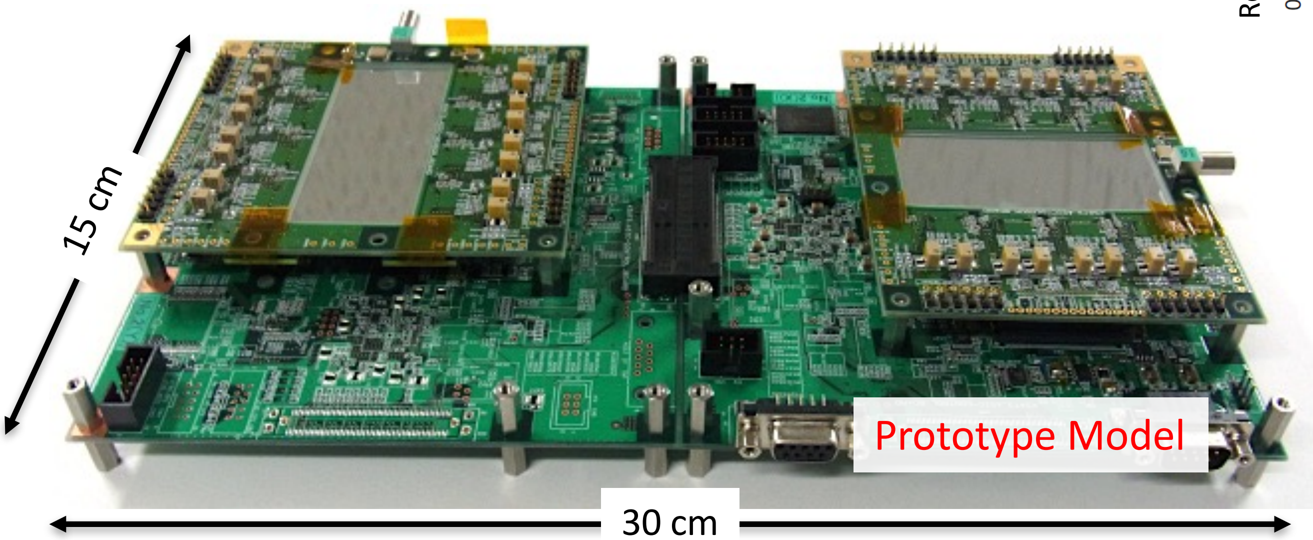
# Transient Localization Experiment (T-LEX)




Better sensitivity for Epeak < 10 keV
(Extended Emission, X-ray Flash, etc… )




We will also install
a gamma-ray trigger detector.
~ 100 $cm^2$, 20 – 1,000 keV

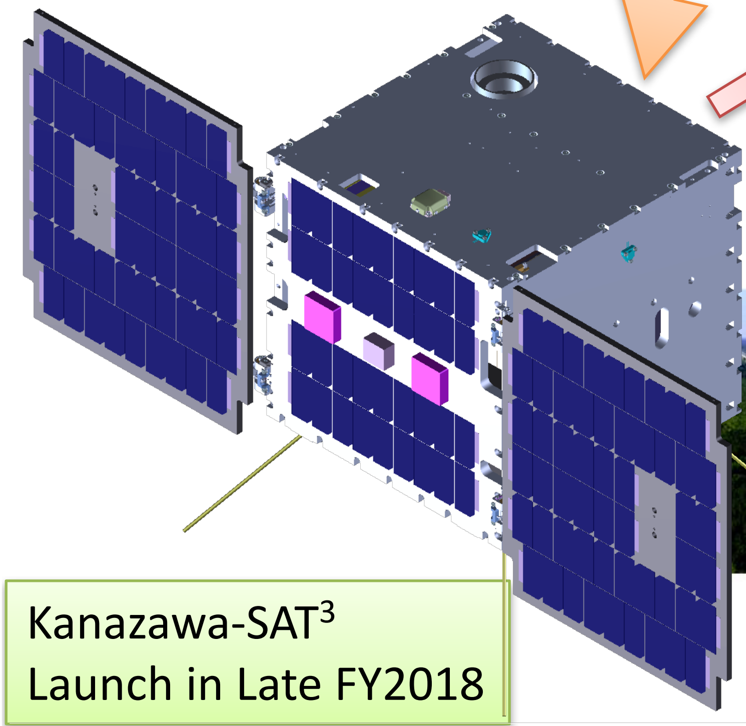
24aSR-4 澤野達哉 (T. Sawano)
24aSR-5 伊奈正雄 (M. Ina)

Flight Hardware will be completed within 6 months

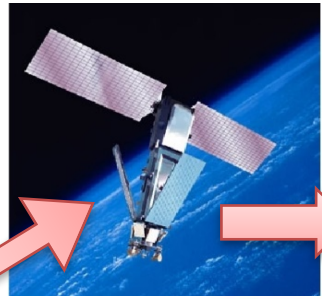
# Mission Overview

Transients

(1) Wide Field X-ray Monitor
Gamma-Ray Trigger Sys.
Localization / Timing
of X-ray transients



Kanazawa-SAT$^3$
Launch in Late FY2018

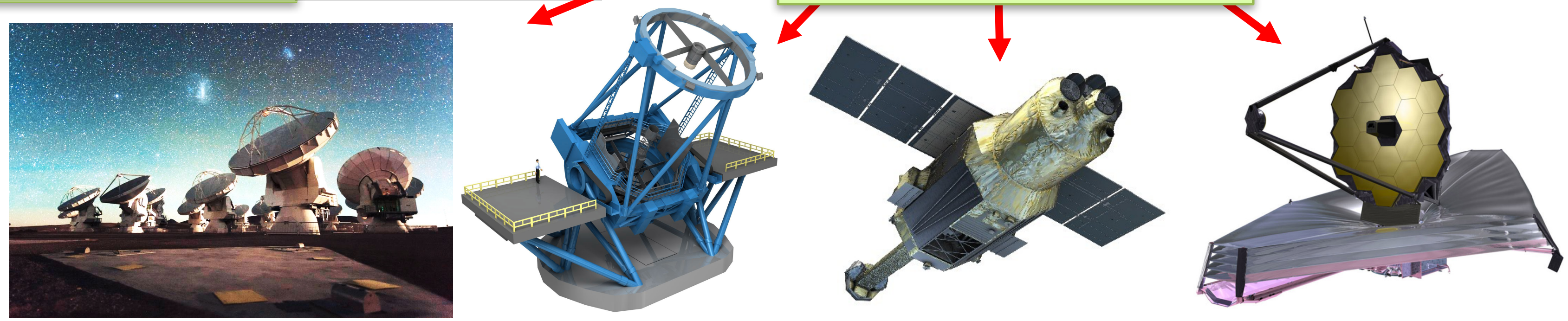


(2) (Quasi) Real Time Alert
- Packet transfer with Iridium satellite
- Downlink with UHF/VHF

(3) Information Sharing

Follow-up Observation


Multi-wavelength Obs.



# Summaries

(1) Short GRB is a probable candidate of EM counterpart of GW sources.

(2) At present, no significant X-ray/gamma-ray was detected from BH binaries. Fermi-GBM result for GW 150914 is still in debate, and will be revealed in LIGO O2 run.

(3) Event rate of GW detection is estimated from the Epeak – Lp correlation of SGRBs

16 events/year : NS-NS case in $(200\ \mathrm{Mpc})^3$

600 events/year : NS-BH case in $(670\ \mathrm{Mpc})^3$

(4) We are developing a wide field X-ray imaging detector (T-LEX) aboard a micro-satellite. Launch target is the end of FY2018.