Gamma-Ray Bursts

Daisuke Yonetoku (Kanazawa Univ.)

Self Introduction

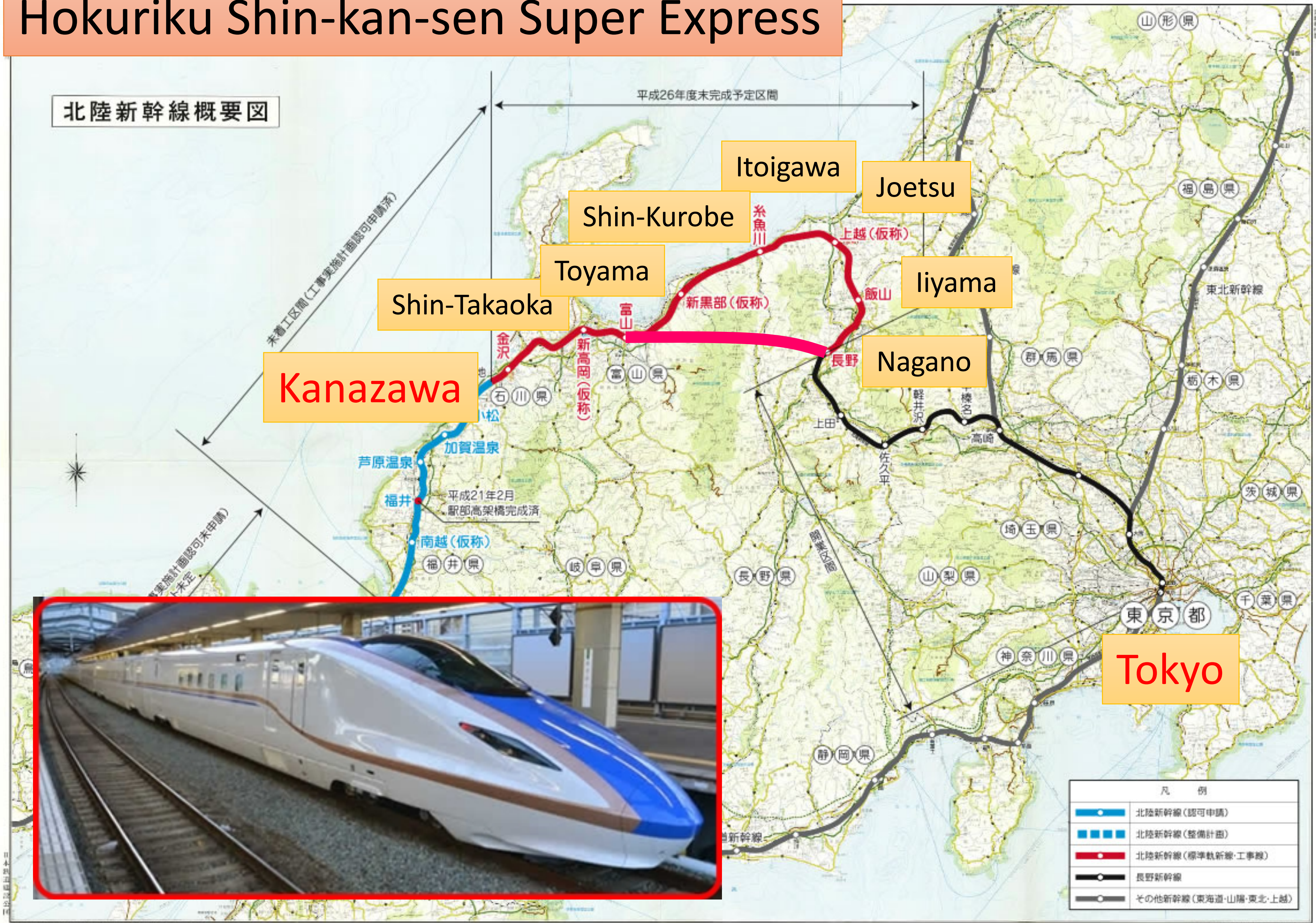
1st topic :
Introduction of Gamma-Ray Bursts

2nd topic :
Emission mechanism of long GRB probed by gamma-ray polarization

3rd topic :
Short gamma-ray bursts and gravitational wave astronomy

Future mission: HiZ-GUNDAM

Hokuriku Shin-kan-sen Super Express







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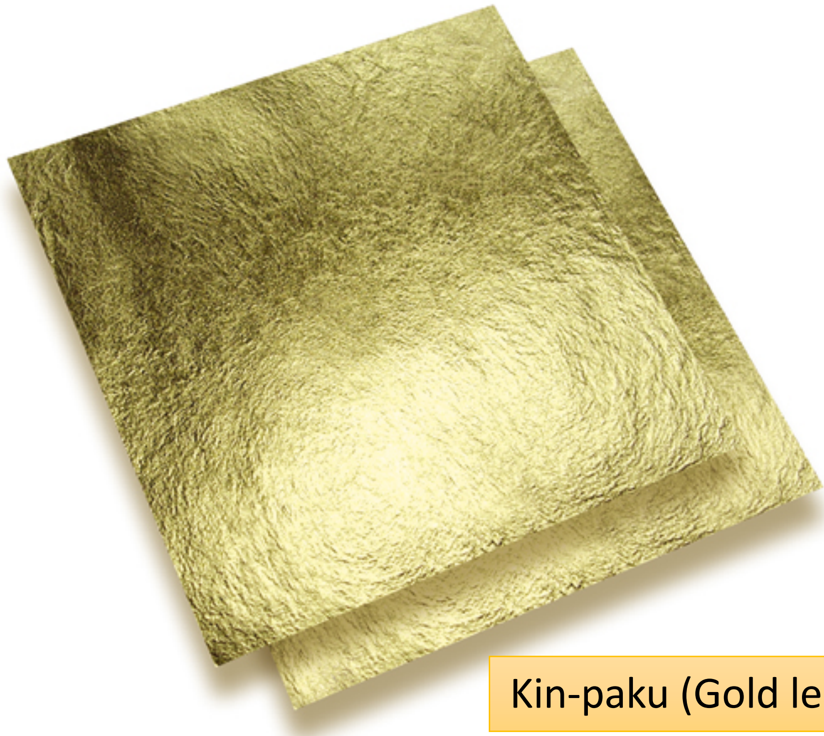
1バイ
200円
1バイ
1.500円
1バイ
1.400円



Kaga Yuzen Kimono


Wajima Nuri (Wajima ware)

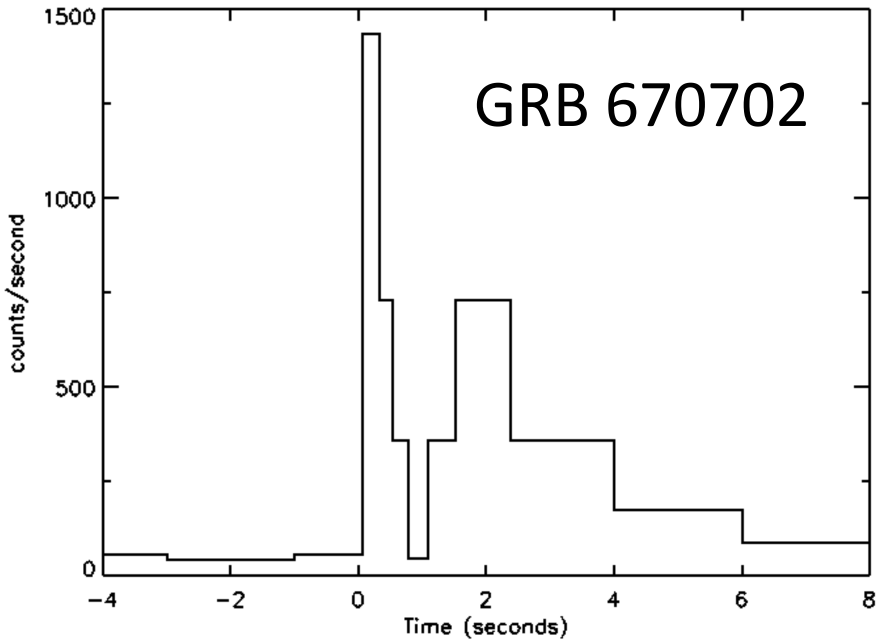

Kutani-yaki (Kutani-ware)

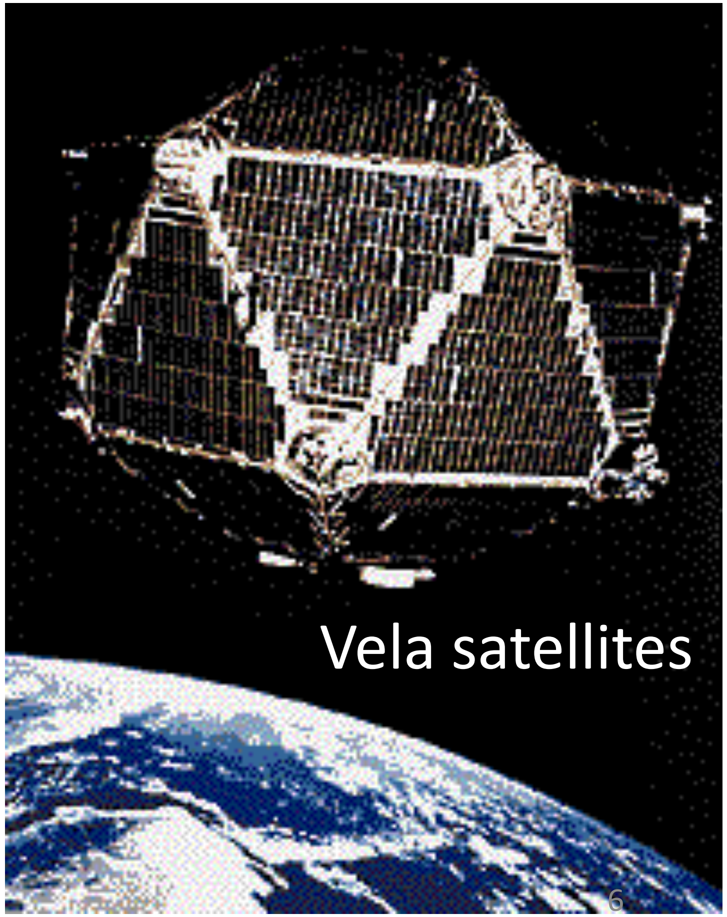

Kin-paku (Gold leaf)

1st topic :
Introduction of Gamma-Ray Bursts

Gamma-Ray Bursts (GRBs)

In 1967, human being found an unidentified gamma-ray transient.
However it had not been published during 6 years
because of military secrets…
(during the cold war, Partial Test Ban Treaty)





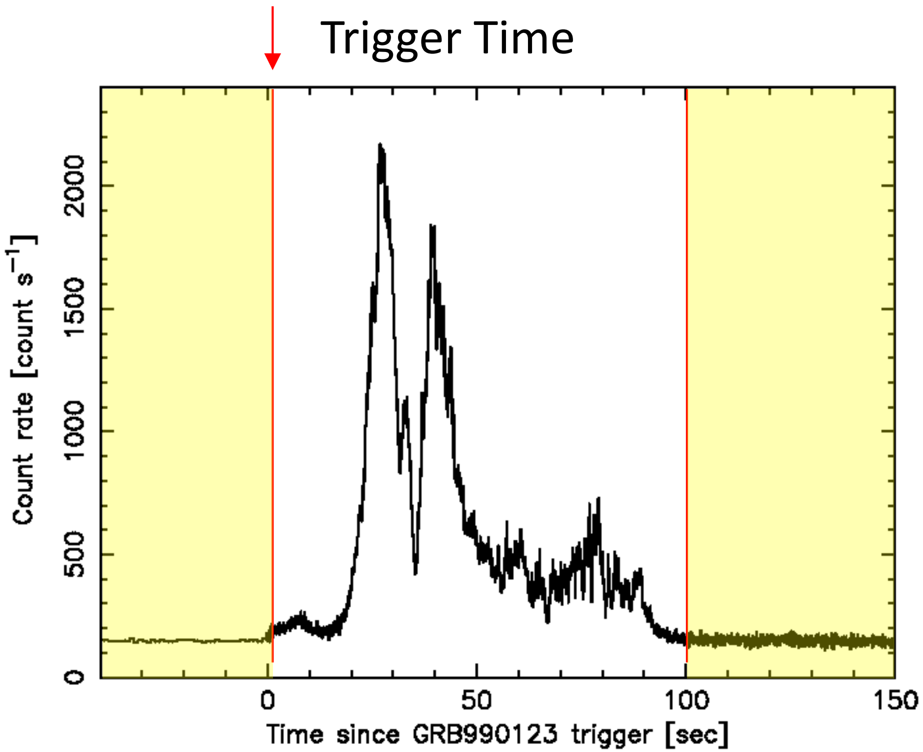
“Gamma-Ray Burst” was reported
as an astronomical phenomena in 1973.

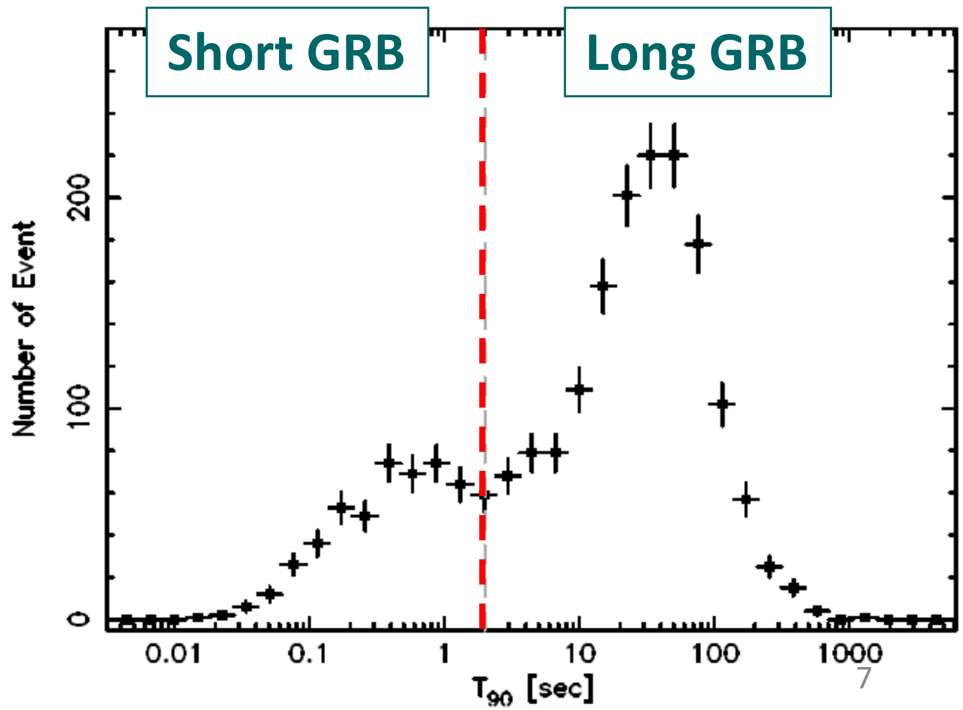
Klebesadel, Strong & Olson, ApJ (1973), 182, L85

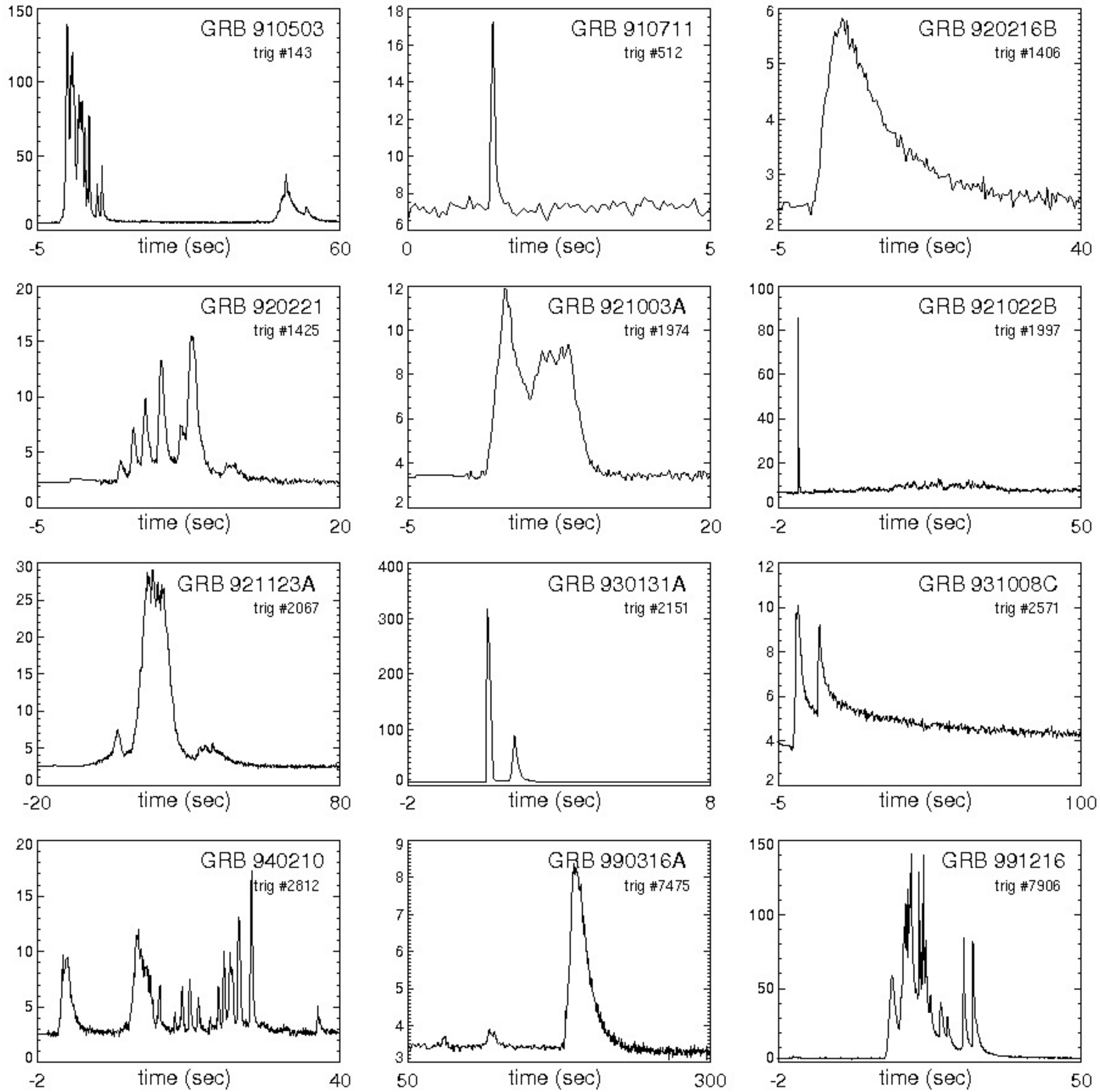
Prompt Emission of GRBs

The Most Energetic Explosion in the Universe

- Total radiation energy is 10^{52-54} erg (~ x1000 of SNe)
- The radiation energy is released around 100 keV = gamma-ray.
- Rapid variability shorter than 1 msec. (compact object ?)
- 2 classes : Long GRBs > 2 sec, and Short GRBs < 2 sec.






GRB 910503
trig #143
GRB 910711
trig #512
GRB 920216B
trig #1406
GRB 920221
trig #1425
GRB 921003A
trig #1974
GRB 921022B
trig #1997
GRB 921123A
trig #2067
GRB 930131A
trig #2151
GRB 931008C
trig #2571
GRB 940210
trig #2812
GRB 990316A
trig #7475
GRB 991216
trig #7906
time (sec)

Gamma-ray spectrum of prompt emission

Band function

Band et al. 1993

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

α : low-energy index

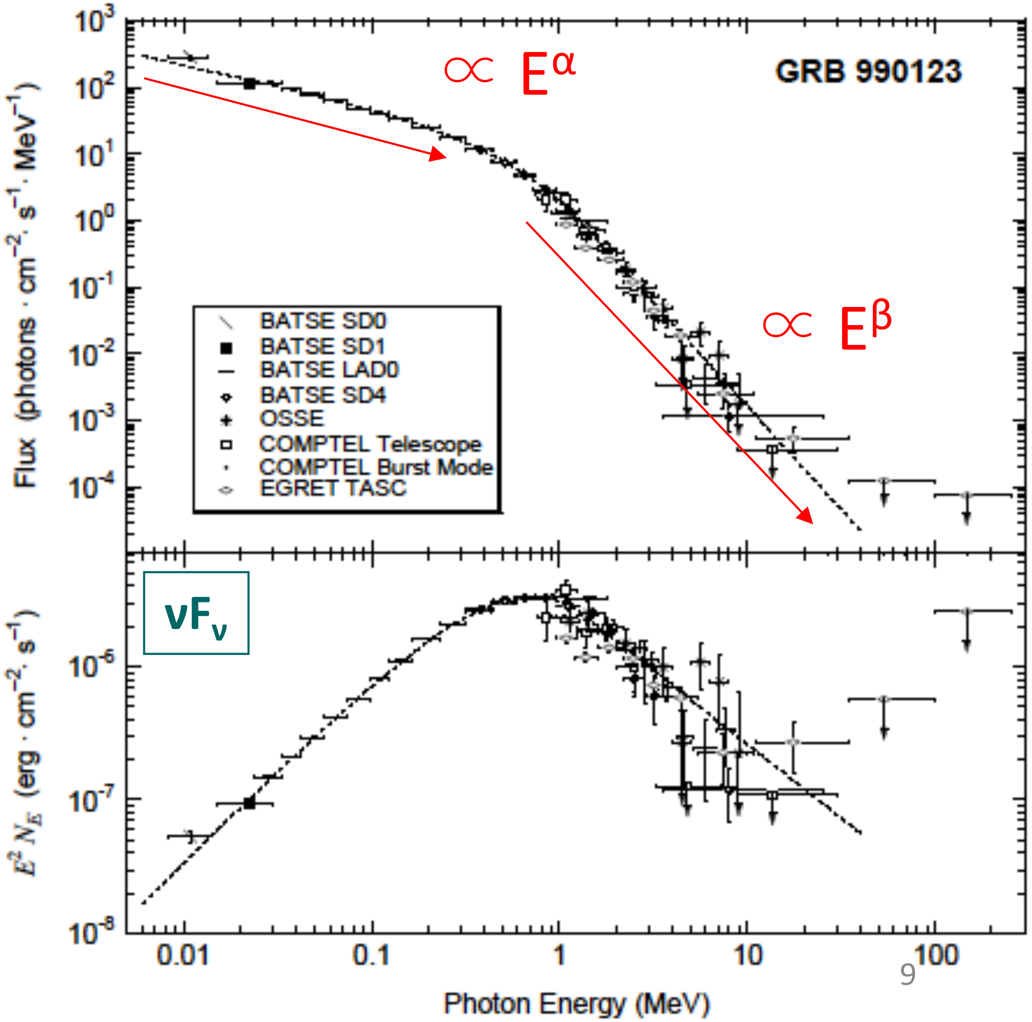
β : high-energy index

E_0 : break energy

Non-thermal radiation

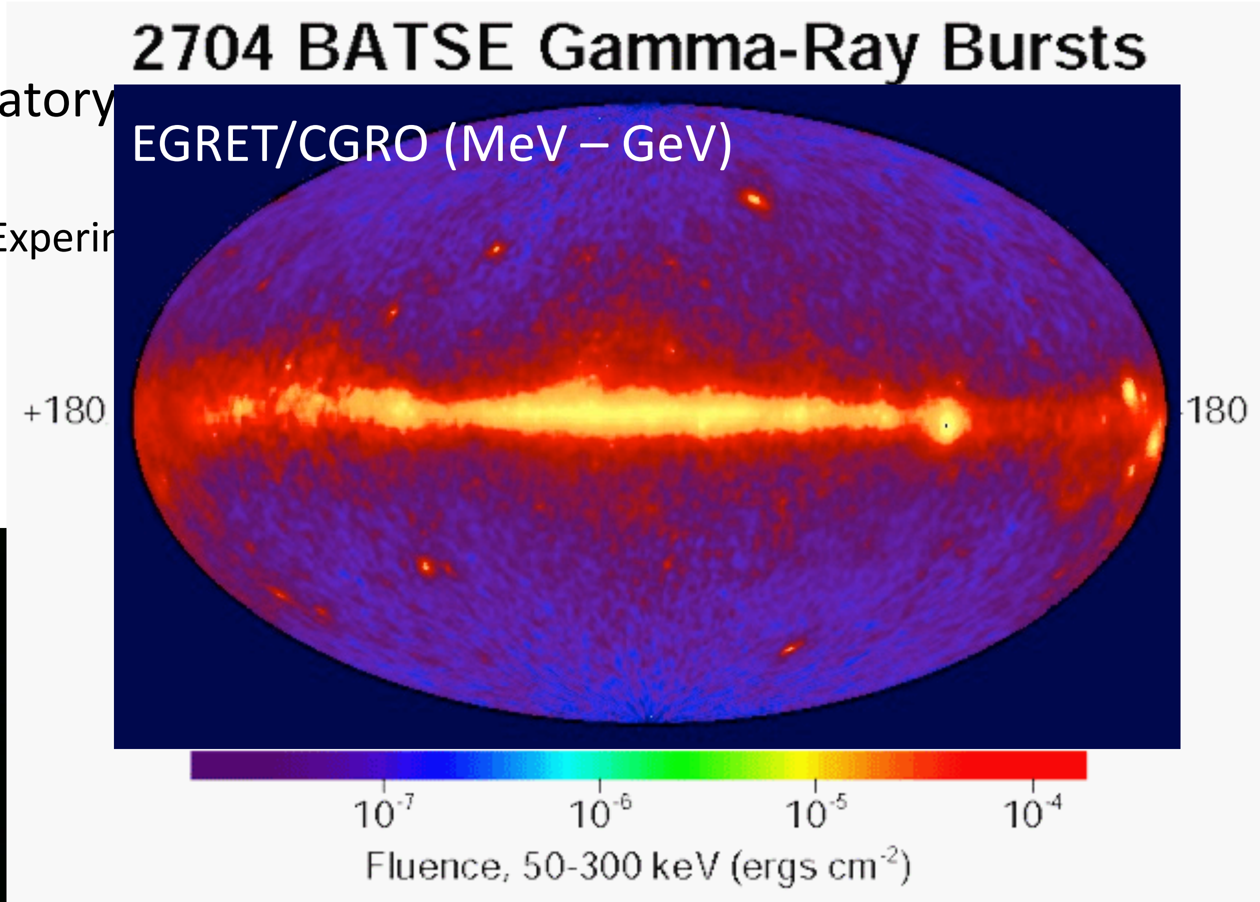
Synchrotron radiation from accelerated electrons… maybe

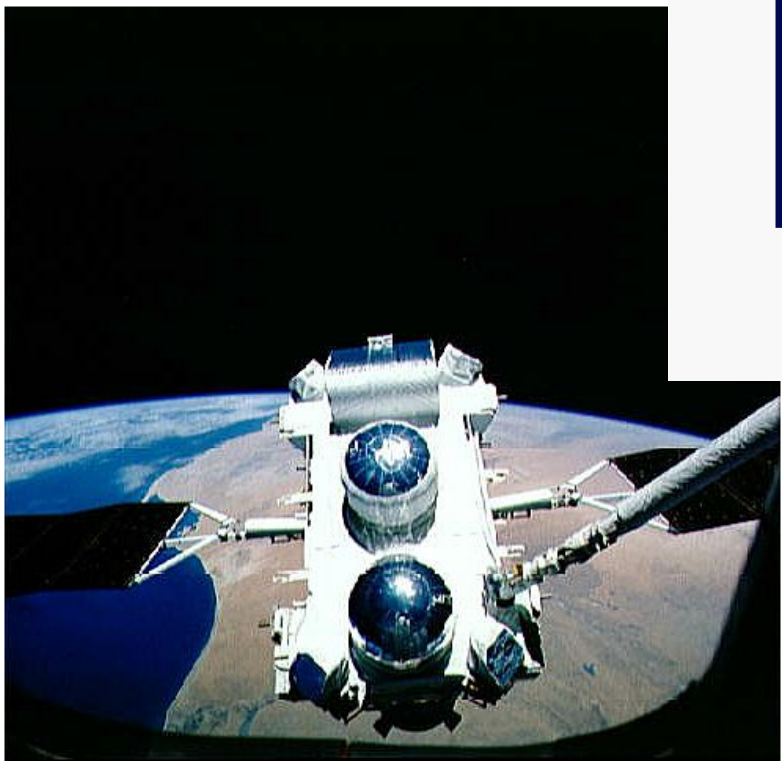
In the case of α>−2, we can determine a peak energy "Epeak = (2+α) E_0" in the νF_ν spectrum.



Spatial distribution of GRBs

Compton Gamma-Ray Observatory
launched in 1991.
BATSE (Burst And Transient Source Experir
detected 2704 GRBs





Isotropic spatial distribution
・no concentration to the galactic plane
・brightness distribution is also isotropic

Extra-galactic origin

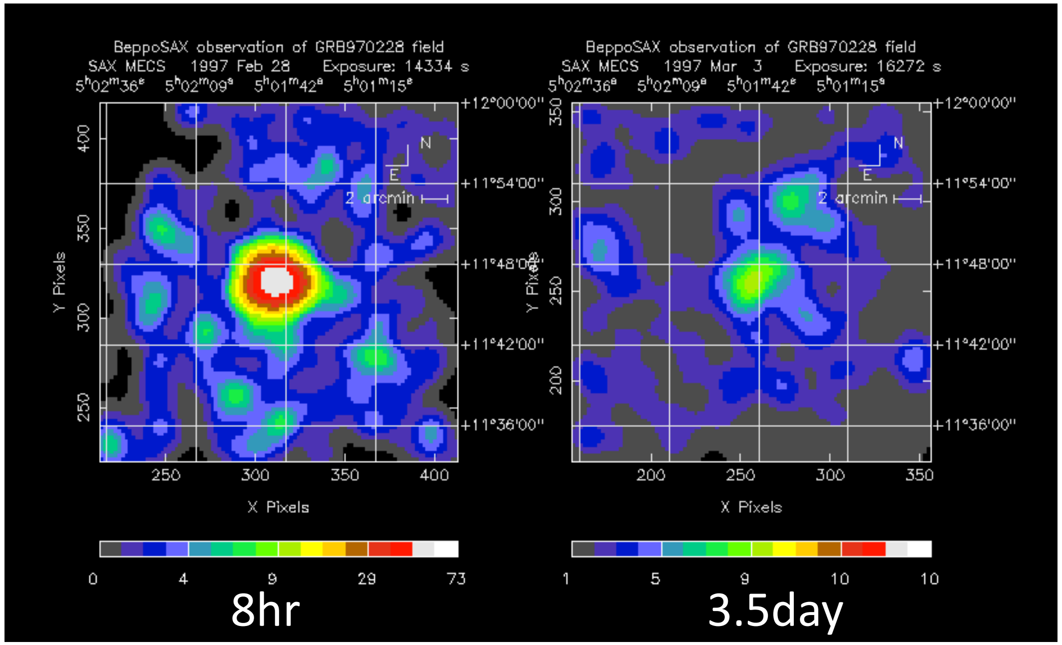
Discovery of X-ray afterglow (GRB 970228)

Long lasting X-ray transient was discovered by BeppoSAX

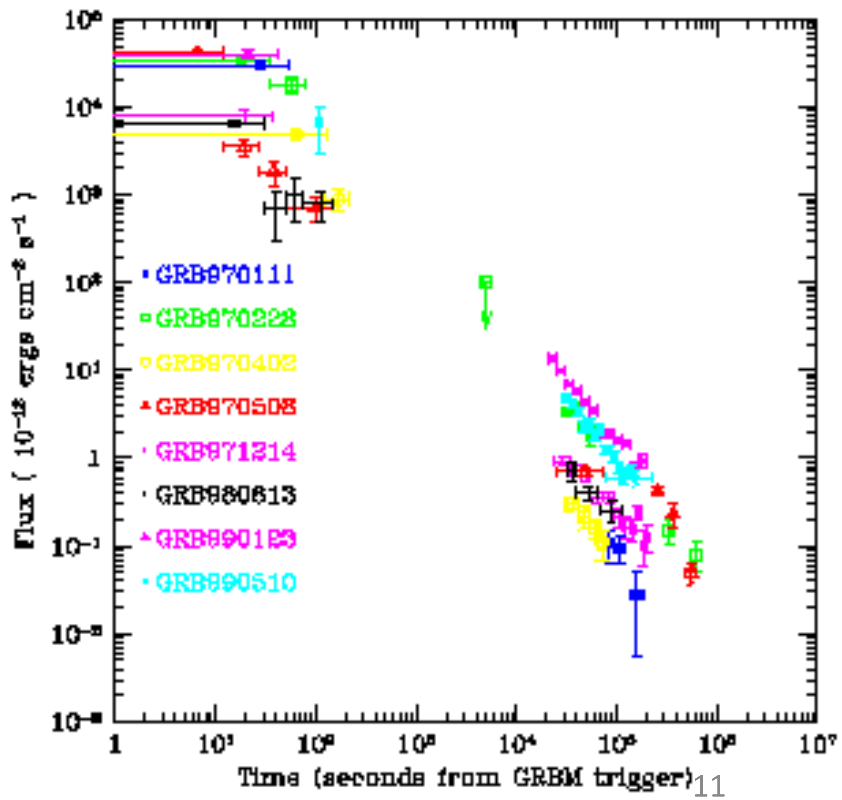
Basically Power-law decline in time.

◆ Thanks to the detail localization by X-ray telescope, multi-wavelength observations can be performed by ground-based telescopes

GRB970228

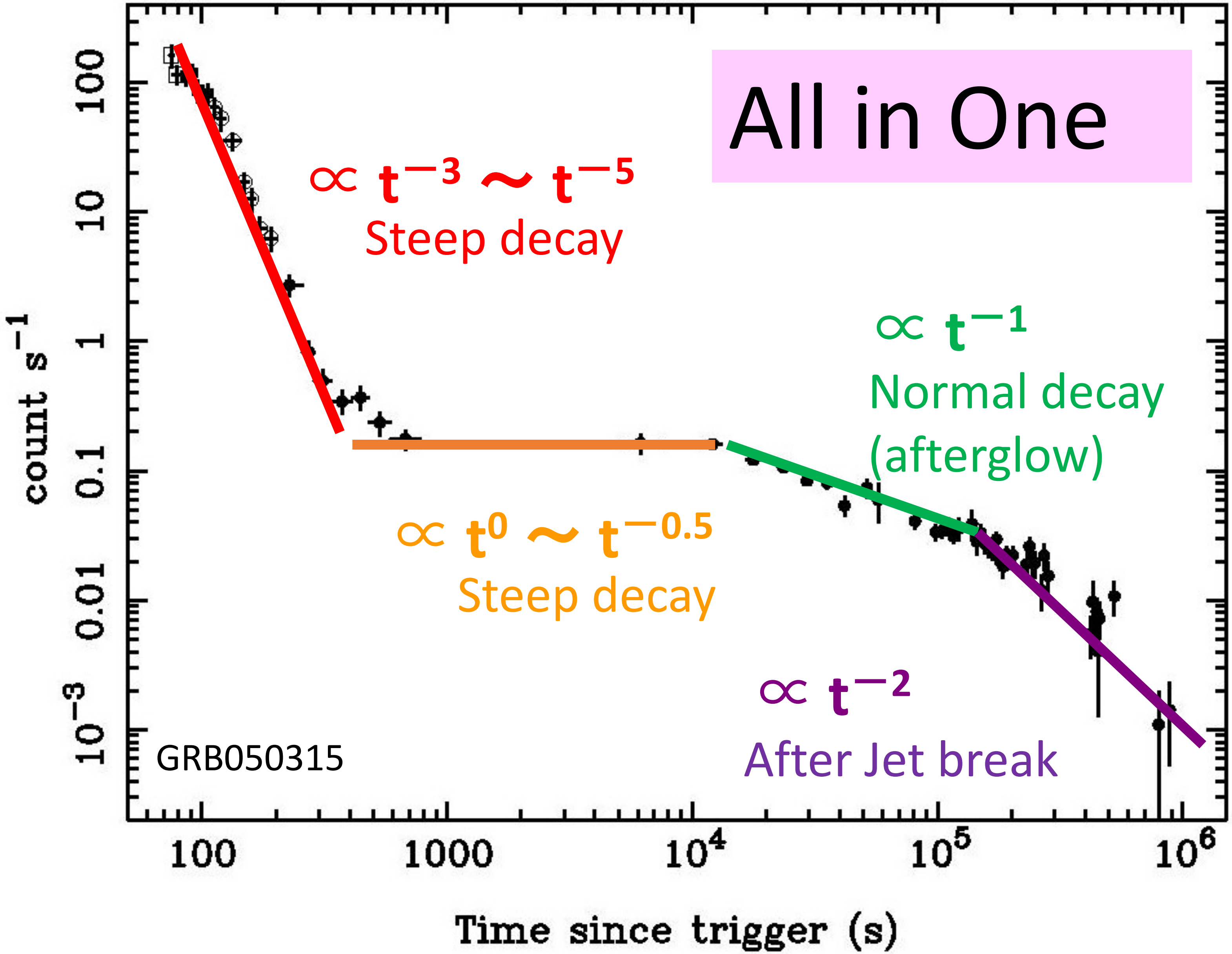


Costa et al. 1997



Typical Lightcurve of X-ray Afterglow

Vaughn et al. 2005



A lot of physical phenomena follow the exponential functions.

- Decay of radio isotope $\frac{dN(t)}{dt} = -\frac{1}{\tau}N(t)$
- Transmittance of radiation $\frac{dN(x)}{dx} = -\mu N(x)$
- Release of charge in Capacitance and Resistance system $R\frac{dQ(t)}{dt} + \frac{Q(t)}{C} = 0$
- Thermal conduction $K\frac{dT(t)}{dt} = \alpha(T(t) - T_{cool})$
- Damped oscillation $m\frac{d^2x(t)}{dt^2} + \beta\frac{dx(t)}{dt} + kx(t) = 0$
- Frothy foam on top of beer (ig Nobel Prize 2002)

Power-law function is rather rare case.

- Sedov-Taylor Solution (Supernova, nuclear bomb)

$$R = \xi_0\left(\frac{E_0}{\rho_0}\right)^{1/5} t^{2/5} \qquad D = \frac{2}{5}\xi_0\left(\frac{E_0}{\rho_0}\right)^{1/5} t^{-3/5}$$

- Fermi acceleration of cosmic ray

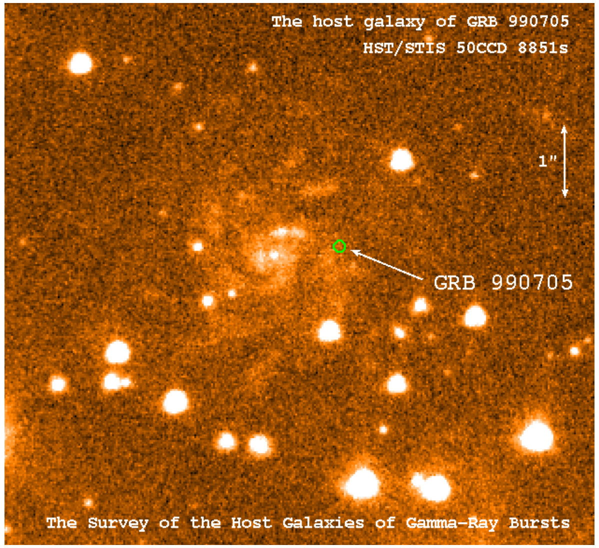
$$\frac{dN}{dE} \propto E^{-\alpha}$$

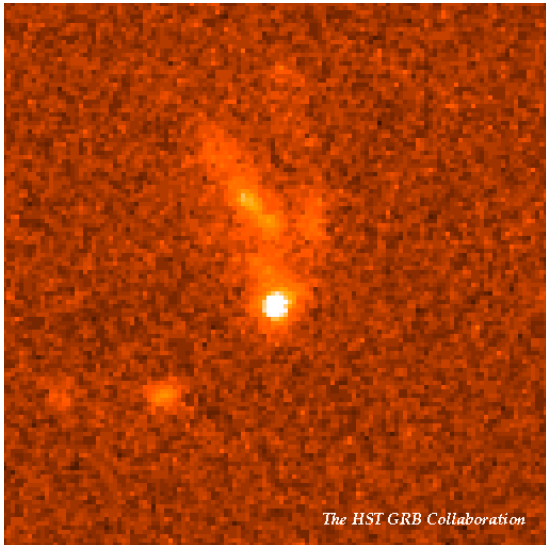
- Gravity
- Electromagnetism

follow the r^{-2} law.

First redshift measurement (GRB 970508 @ z = 0.835)

- Absorption features in bright afterglow spectrum
- Emission and absorption lines of host galaxies
- Lyα break feature in afterglow spectrum





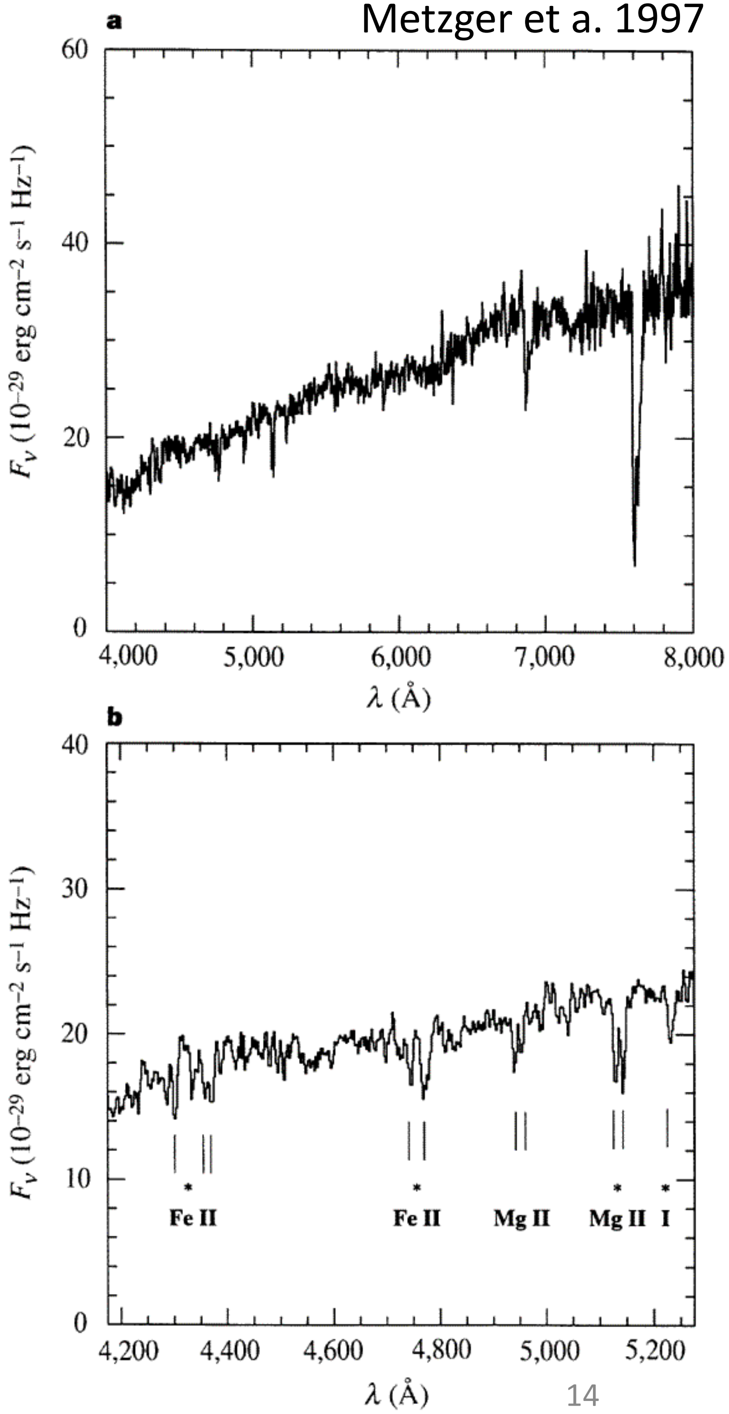
Redshifts are measured for ~ 400 GRBs (2015.6)

Fluence: $S = 10^{-5}$ erg/cm^2 (gamma-ray)

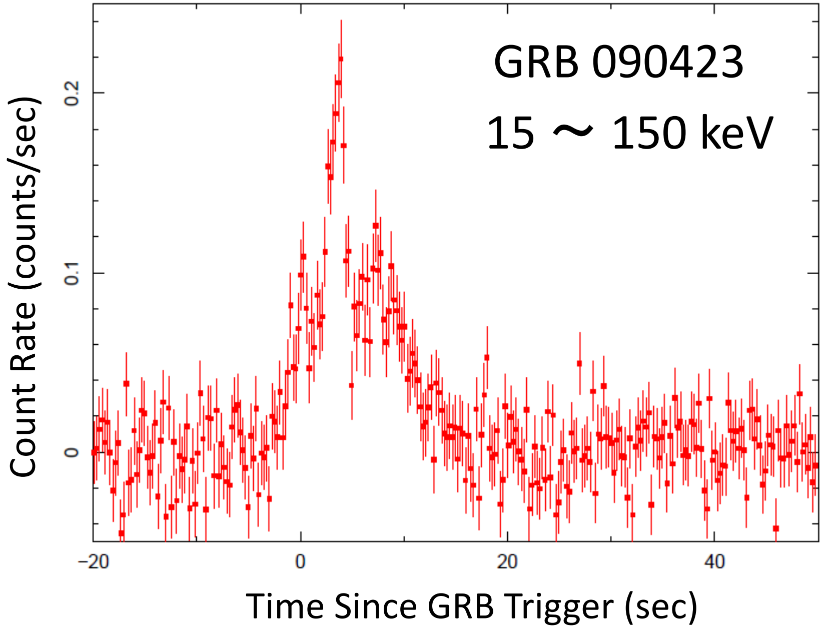
Distance : $d = 2 \times 10^{28}$ cm (z=1)

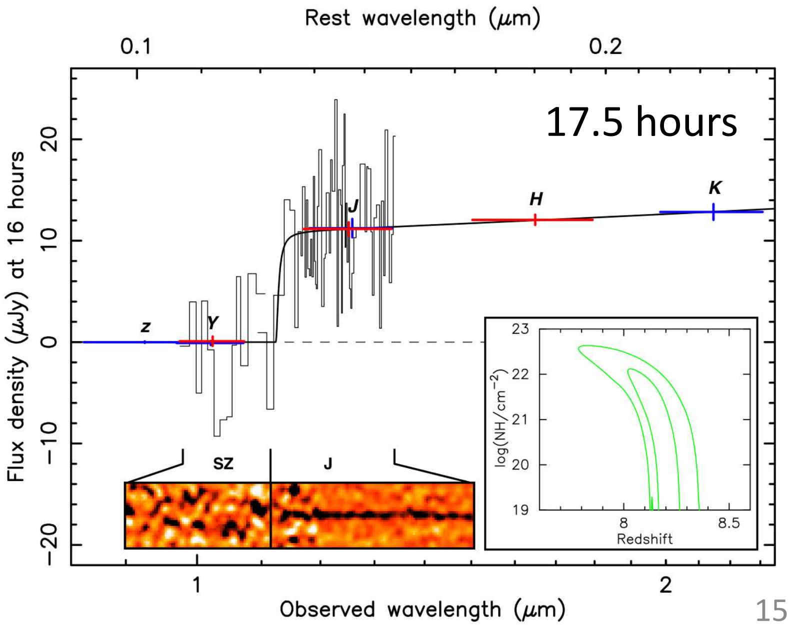
$$E_{total} = \frac{4\pi d^2 S}{(1+z)} = 2.5\times10^{52} \text{ (erg)}$$

Metzger et a. 1997

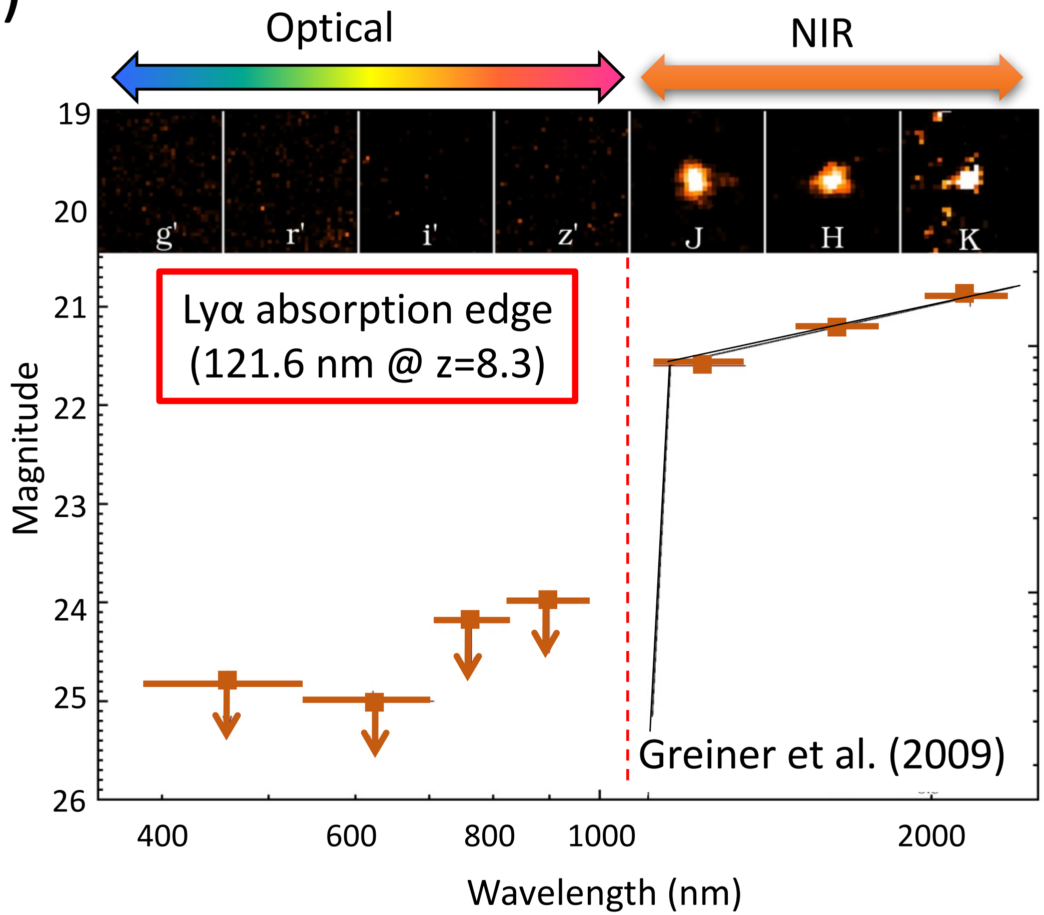


High-z GRB 090423 (z=8.26)





Photometric Redshift by GROND



We could determine the redshift of z=8.26 with spectroscopic observation,
BUT, we could NOT obtain any physical information about the early universe.

Quick obs. with large telescope is required

Compactness Problem

$$E_{total} = \frac{4\pi d^2 S}{(1+z)} = 2.5\times10^{52}\ (\mathrm{erg})$$

- Large amount of energy = 10^{52} erg
- Rapid time variability = 1 msec

$$R < c\,\Delta t = (3\times10^{10})\times(10^{-3}) = 3\times10^{7}(\mathrm{cm})$$
$$= 300\ (\mathrm{km})$$

Tokyo – Kanazawa
In straight line

Number density of gamma-rays becomes high

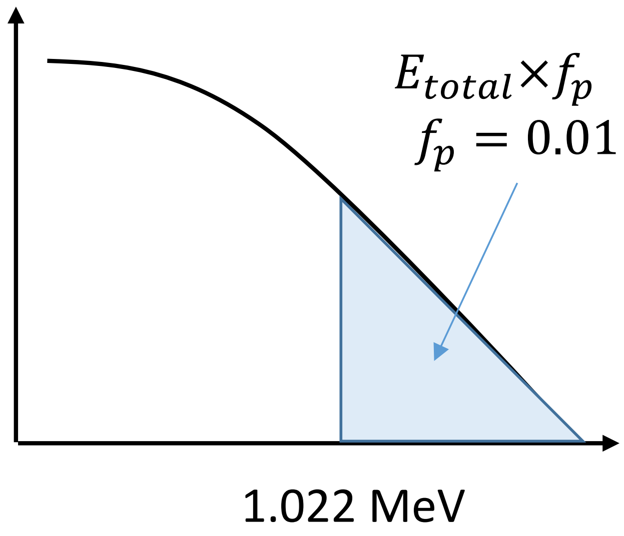
$$\gamma + \gamma \rightarrow e^{+} + e^{-}$$ (pair creation)

Optical depth of gamma-ray scattering

$$\tau_{\gamma\gamma} = \sigma_T \times n \times R$$
$$= \sigma_T \times \frac{E_{total} f_p}{\frac{4\pi}{3} R^3 m_e c^2} \times R$$
$$\sim 5\times10^{16} \gg 1$$

Thomson cross section

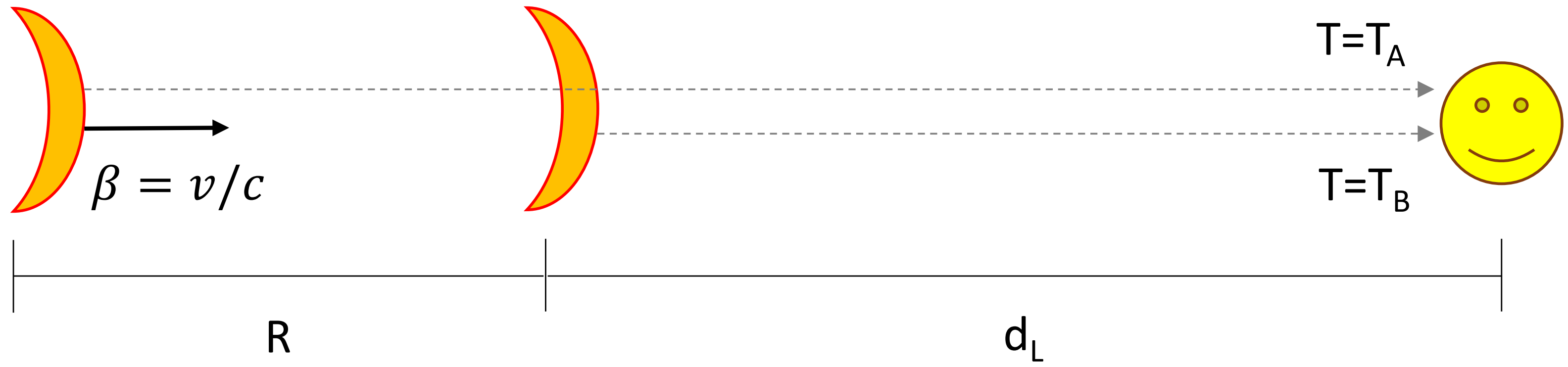
$$\sigma_T = 6.65\times10^{-25}\ (\mathrm{cm}^2)$$



In theoretically, gamma-rays can not escape from the region.
But GRBs are really observed …

Compactness Problem

Compactness Problem – solution –



$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$

① Time

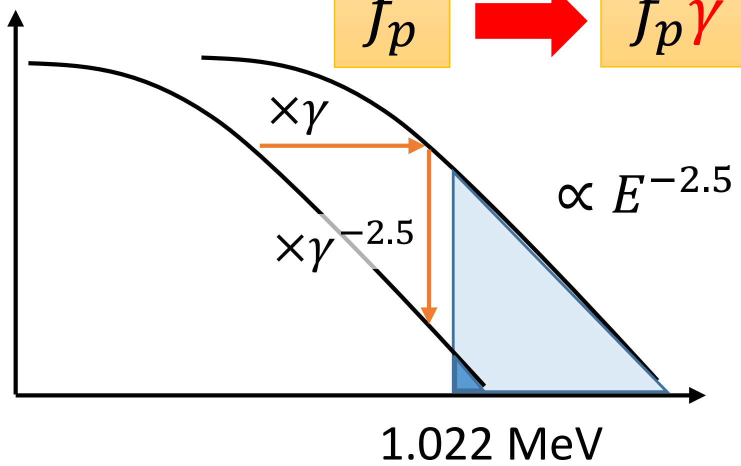
$$\Delta T_{obs} = T_B - T_A = \left(\frac{R}{\beta c} + \frac{d_L}{c}\right) - \left(\frac{R}{c} + \frac{d_L}{c}\right)$$

$$= \frac{R}{\beta c}(1-\beta) \cong \frac{R}{2c\gamma^2}$$

$R \sim c\,\Delta t$ → $R \sim 2c\gamma^2\,\Delta t$

② Blueshift

f_p → $f_p\gamma^{-2.5}$



$$\tau'_{\gamma\gamma} = \sigma_T \times n \times R$$

$$= \sigma_T \times \frac{E_{total} f_p \gamma^{-2.5}}{\frac{4\pi}{3}(R\gamma^2)^3 m_e c^2} \times (R\gamma^2)$$

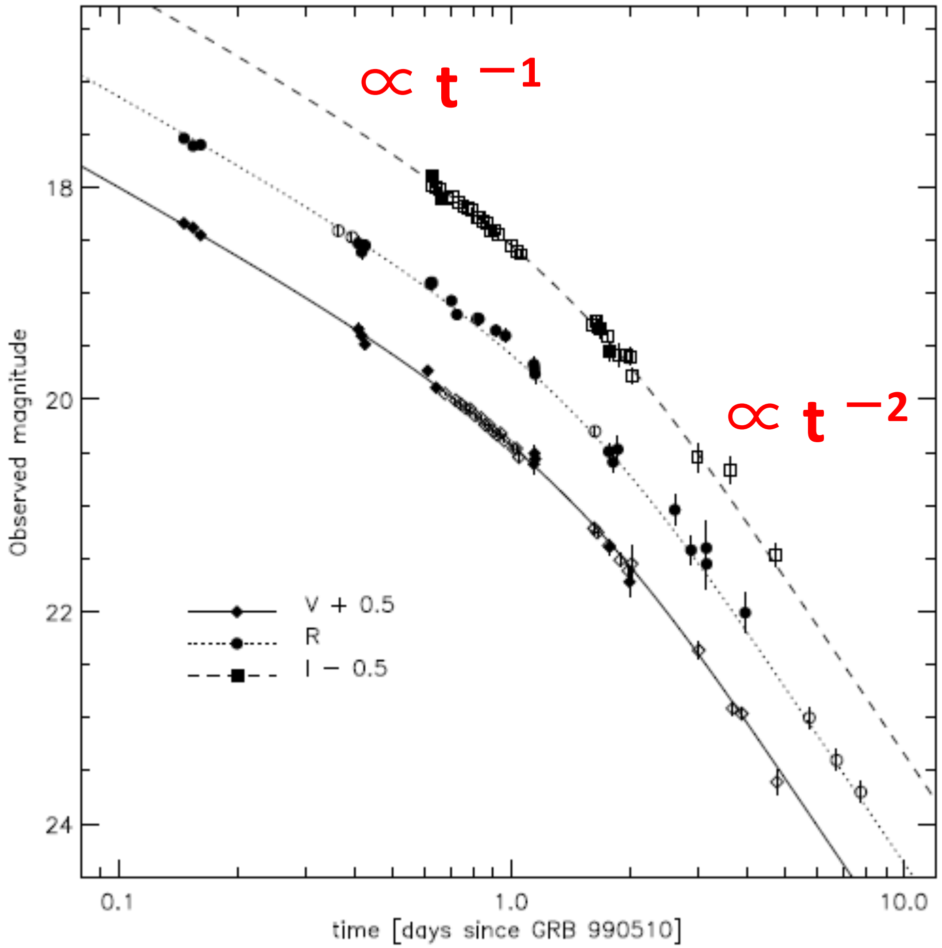
$$\sim 5\times10^{16}\gamma^{-6.5}$$

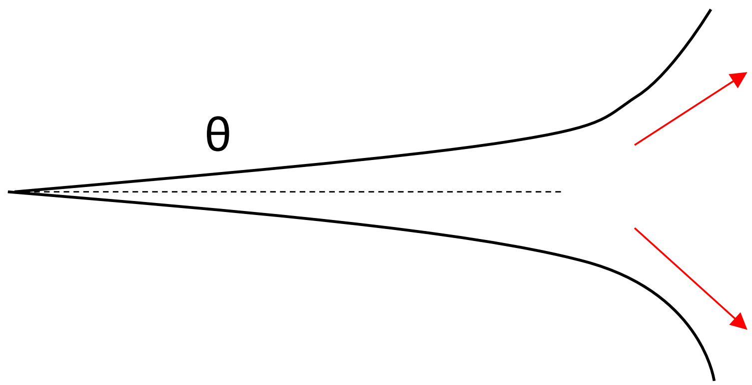
$\tau'_{\gamma\gamma} < 1$ then $\gamma > 370$

Relativistic speed is required

Evidence of relativistic jet (jet break)

Spherical afterglow shows a power-law decline in time.
But many cases show the achromatic break from -1 to -2.



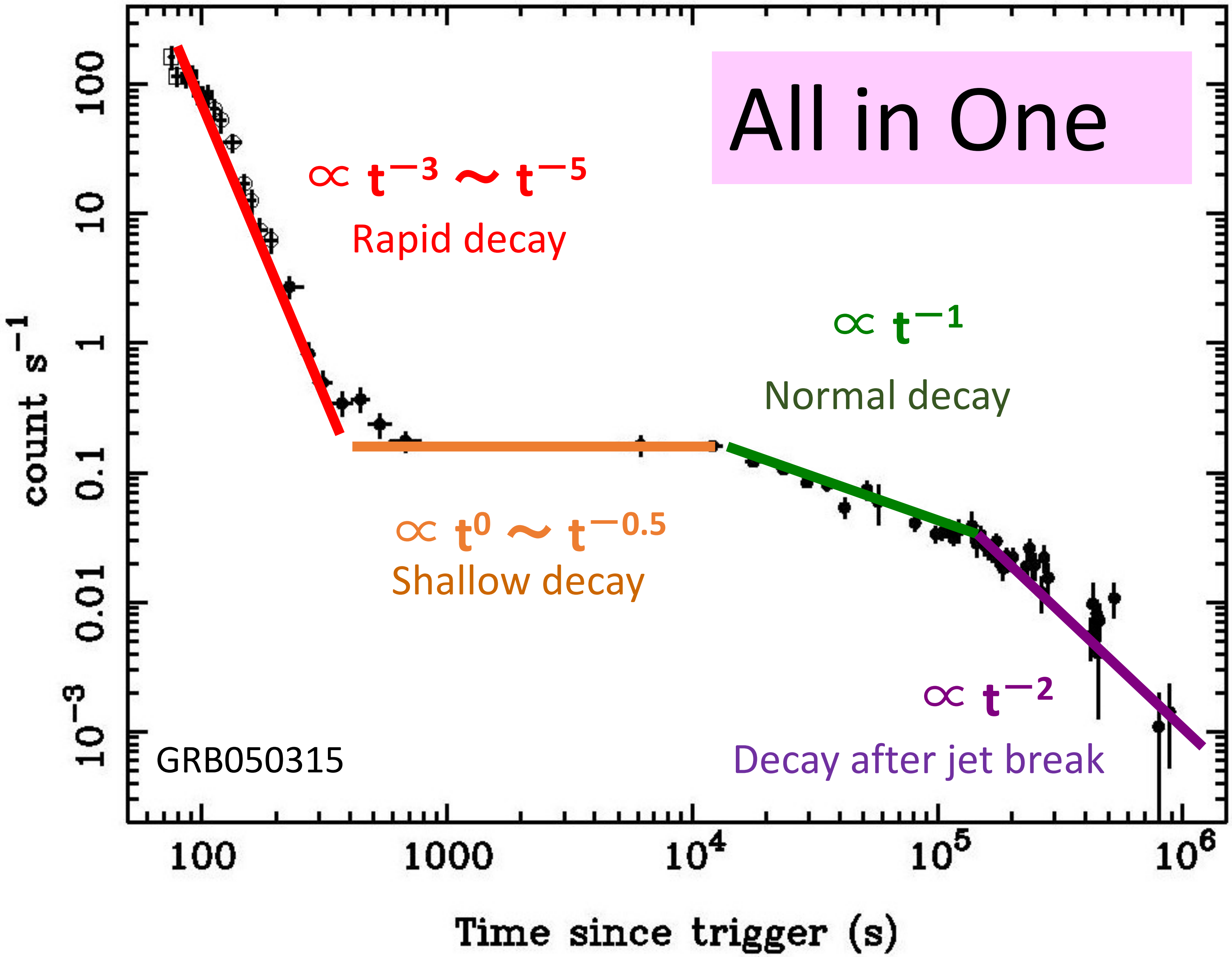


$$\theta \sim 1/\gamma$$

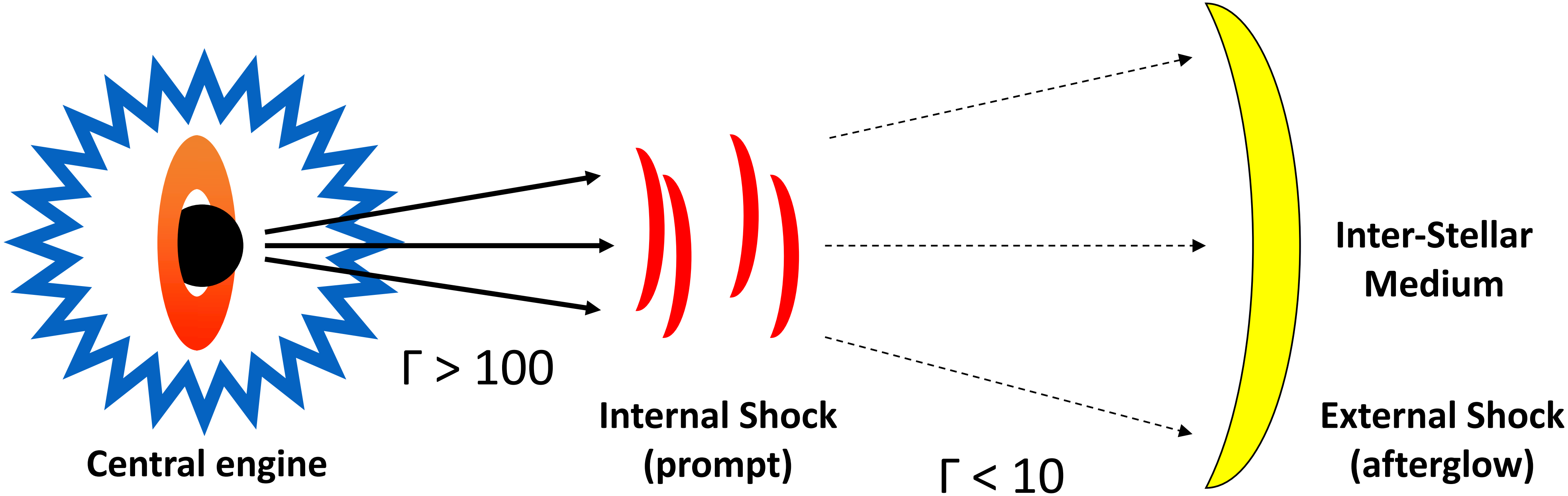
Sideway expansion
with sound velocity

X-ray lightcurve

Vaughn et al. 2005



GRB Theoretical Model (Fireball Model)

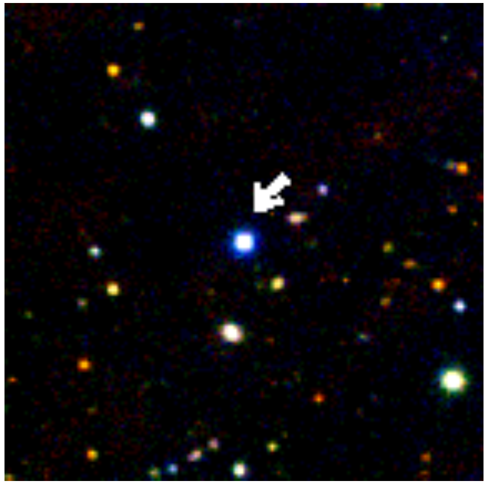


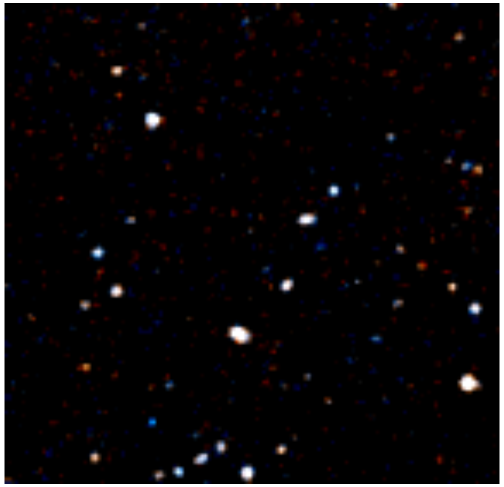
Rees & Meszaros 1992
Piran review 1997

- "Rotation energy of BH" or "Gravitational energy of accretion disc"
- relativistic outflow
- Internal shock → electron acceleration → synchrotron radiation
- external shock → the same

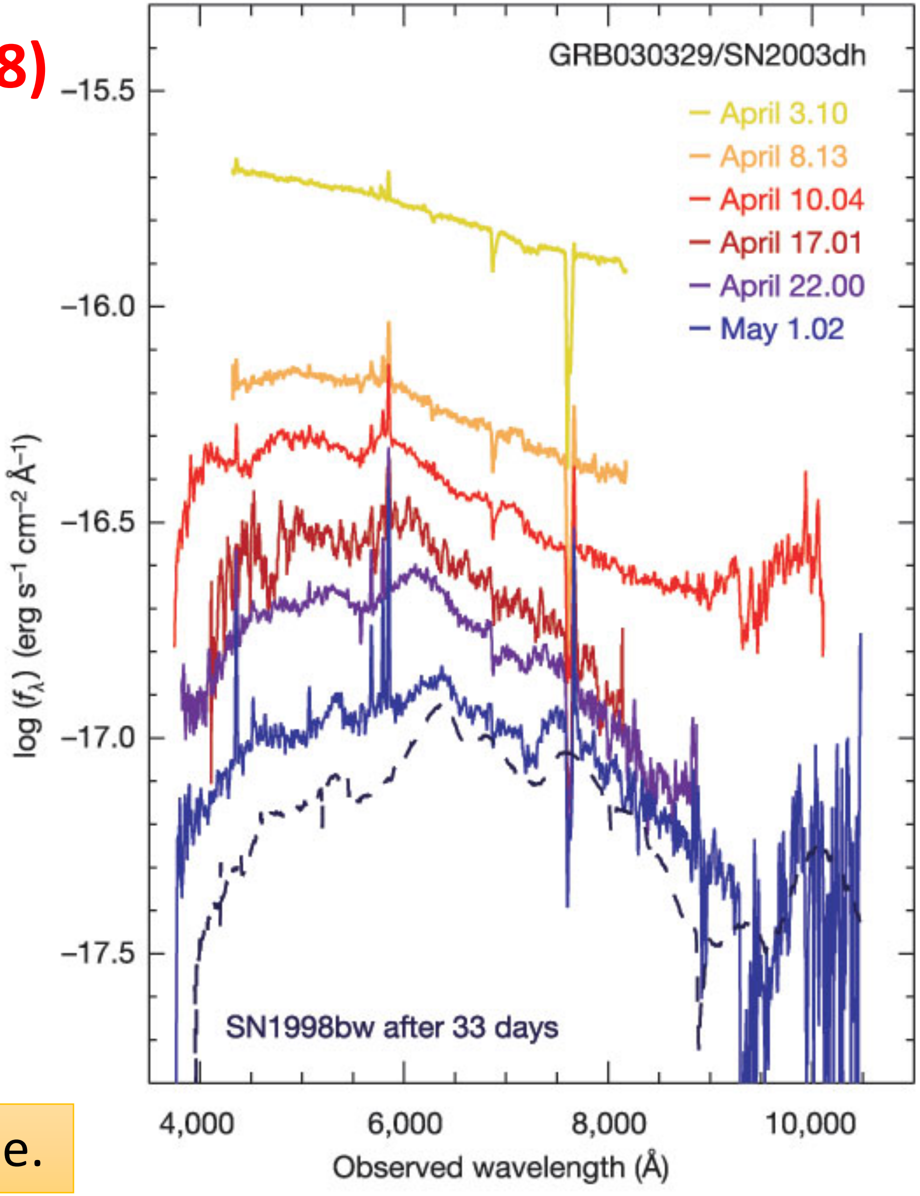
GRB 030329/SN 2003dh

One of the brightest Event
at low redshift (z=0.168)





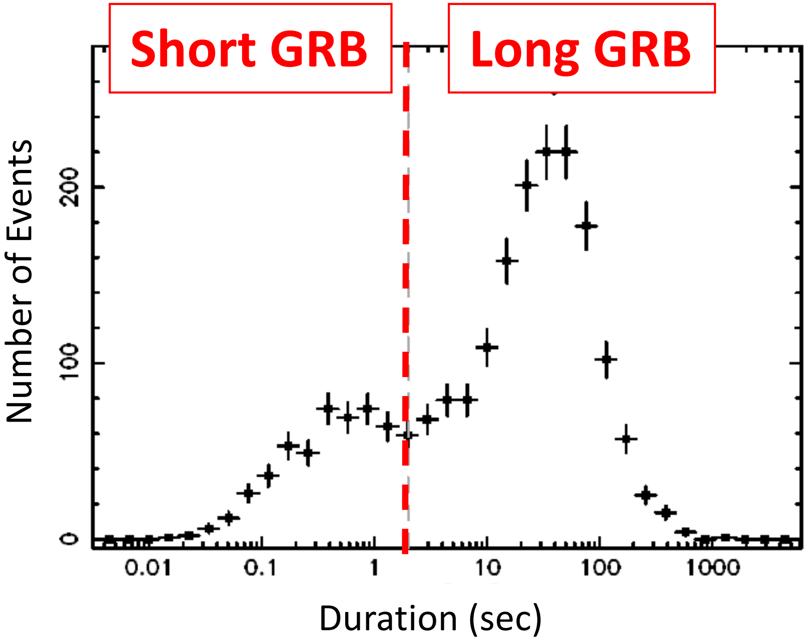
Hjorth et al. 2003

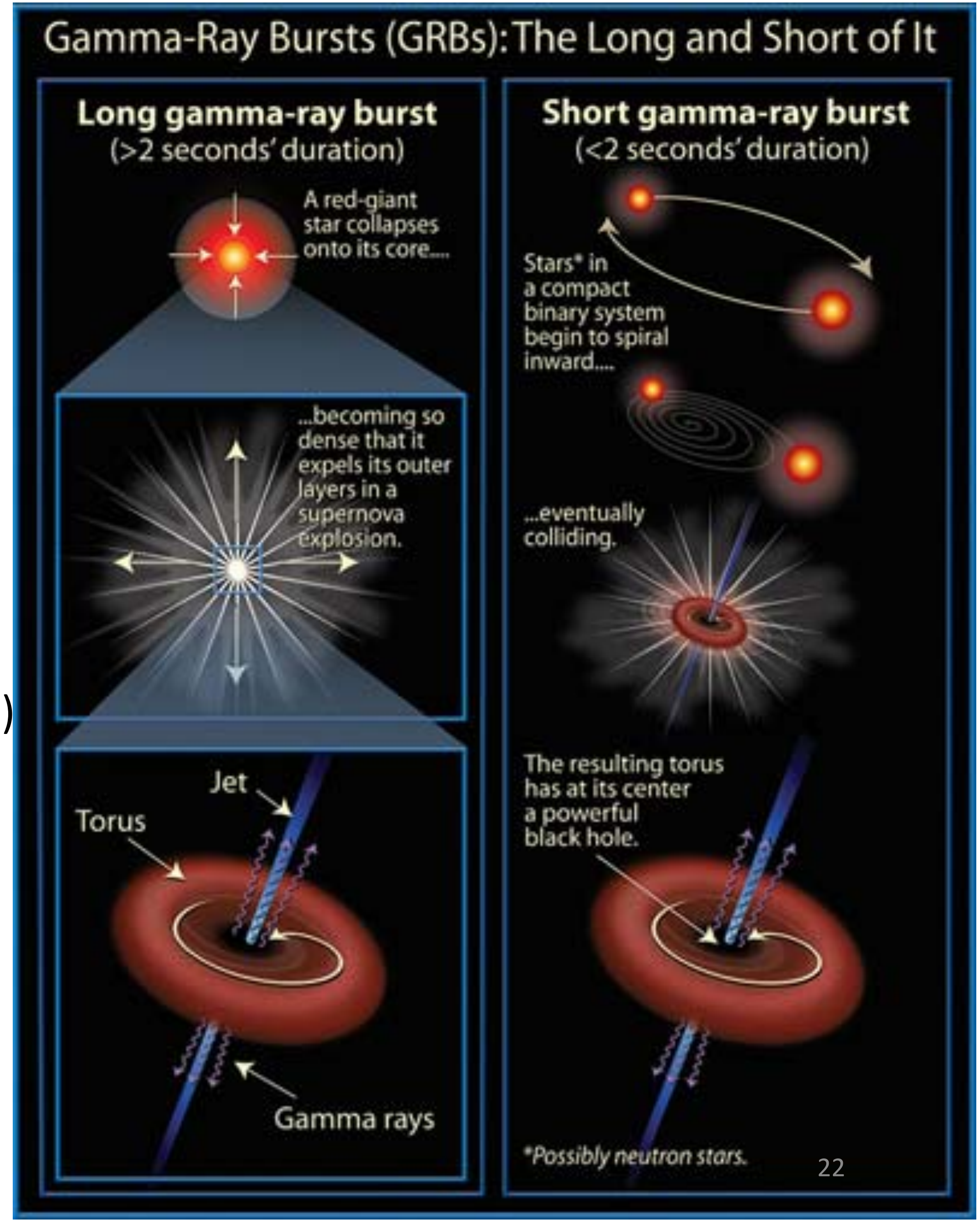


- Supernova-like spectrum was observed in the optical afterglow of GRB 030329 found by HETE-2.
- The explosion energy of SN 2003dh is estimated as 4 x 10^{52} erg.
- Energetic “Hypernova”.

However, all GRBs do not have Hypernovae.

Long & Short GRBs





LGRBs (T > 2 sec)

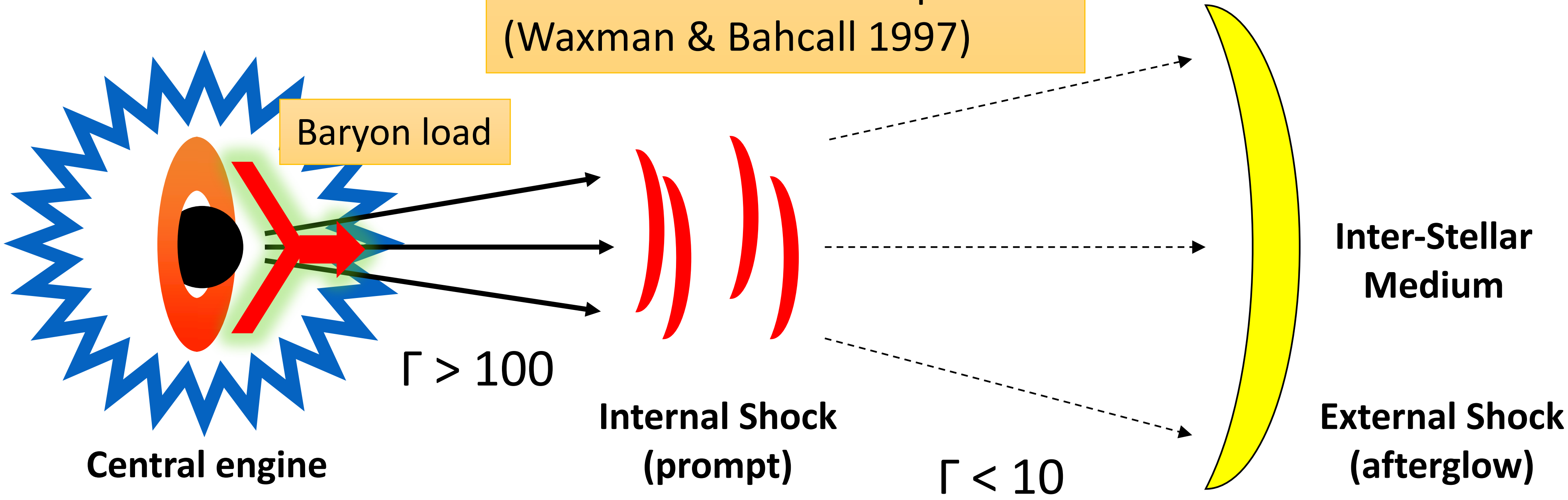
- Massive star explosion ($M>40M_{sun}$)
- Associated with Supernovae (energetic Hypernovae)
- $E = 10^{50} – 10^{54}$ ergs
- Black Hole & relativistic jet

SGRBs (T < 2 sec)

- Merging Neutron Star Binaries (?)
- $E = 10^{48} – 10^{51}$ ergs
- Black Hole & relativistic jet (?)

Neutrino emission from Fireball Model

$p + \gamma \rightarrow p + \pi^+ + \pi^-$
~20% of proton energy
~10^{14} eV neutrino is expected
(Waxman & Bahcall 1997)

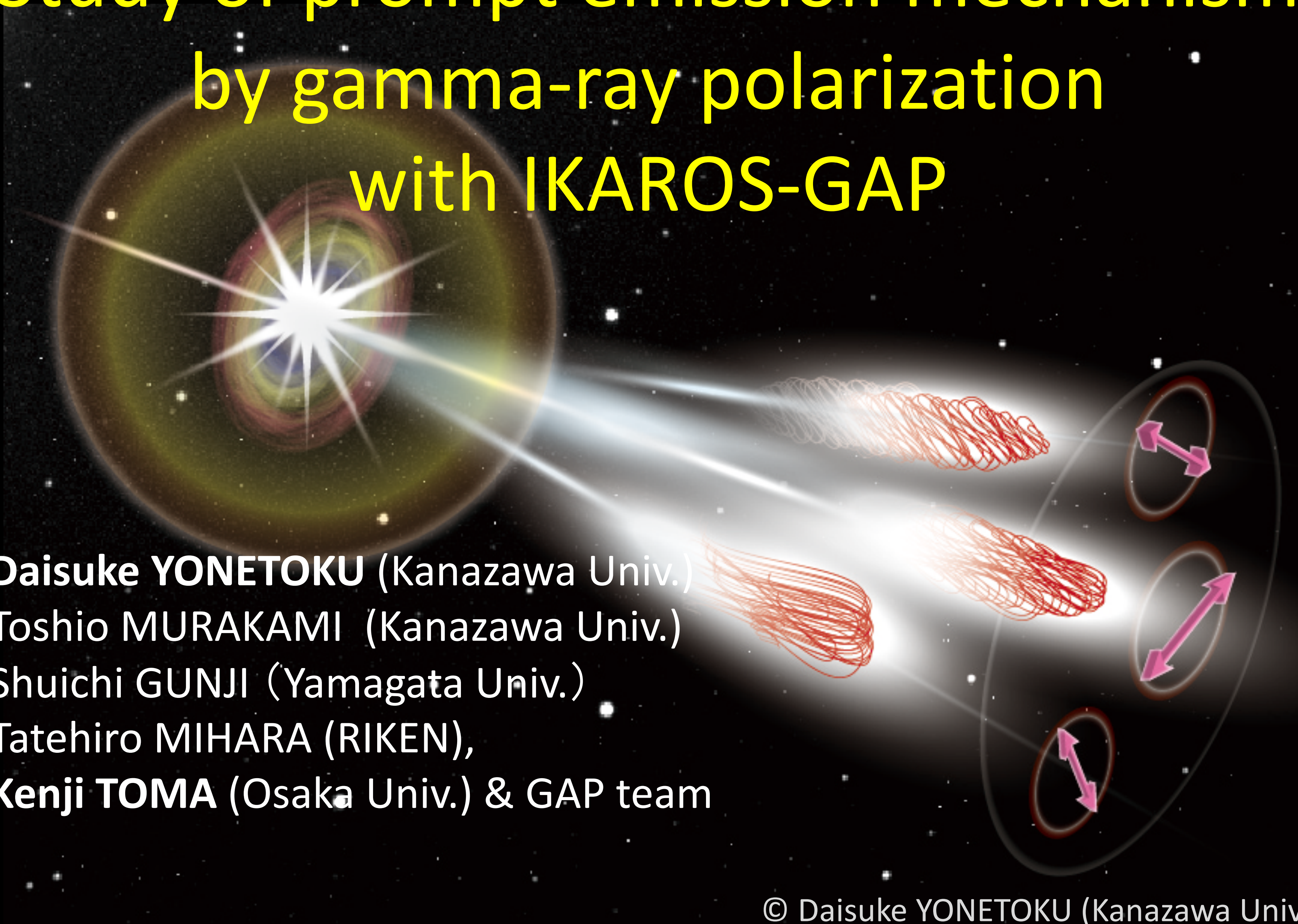


Stellar collapse
Supernova neutrino MeV - GeV
10^{53-54} erg
Jet driving force?

If relativistic jet contains neutron,
Additional nucleon scattering
may generate $10^9 - 10^{12}$ eV neutrino

2nd topic :
Emission mechanism of long GRB
Probed by gamma-ray polarization

Study of prompt emission mechanism by gamma-ray polarization with IKAROS-GAP



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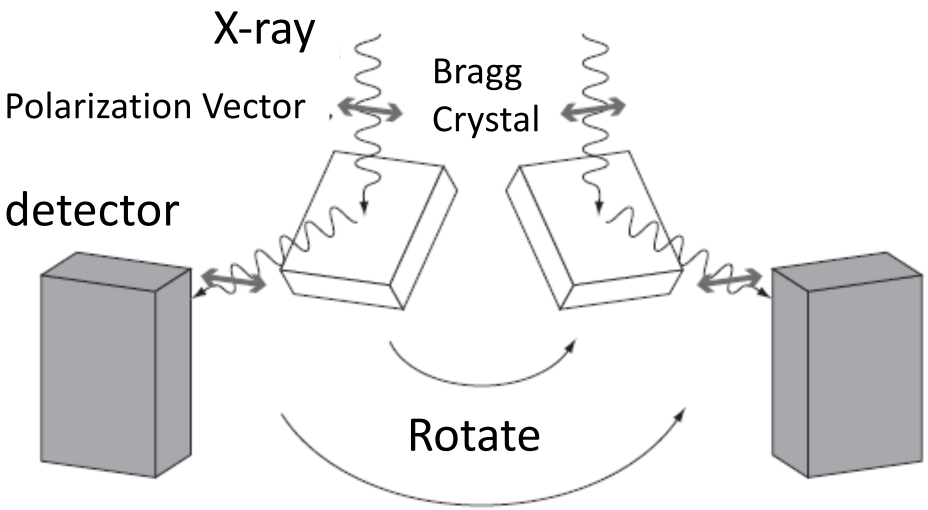
Tatehiro MIHARA (RIKEN),
Kenji TOMA (Osaka Univ.) & GAP team

Bragg Reflection (~ a few keV :)

(OSO-8 : Crab Nebula, Weisskopf et al. (1978)



Compton Scattering (~ 100 keV)

(e.g. **GAP**, PoGO Lite, PHENEX)

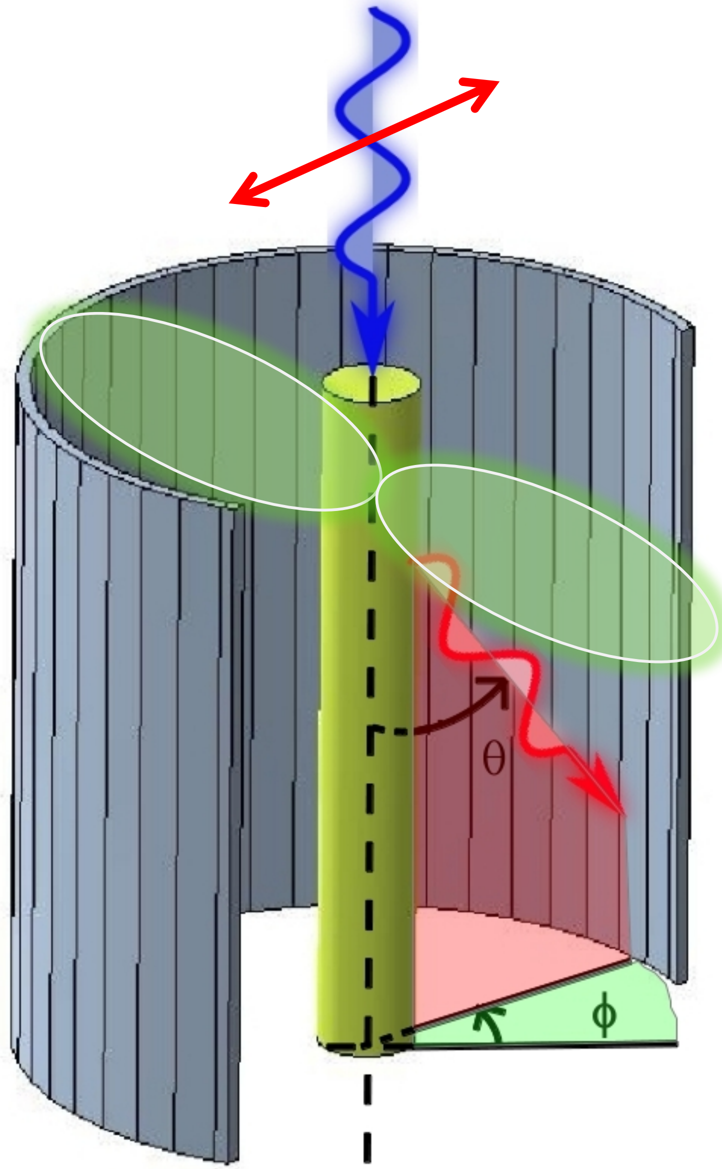
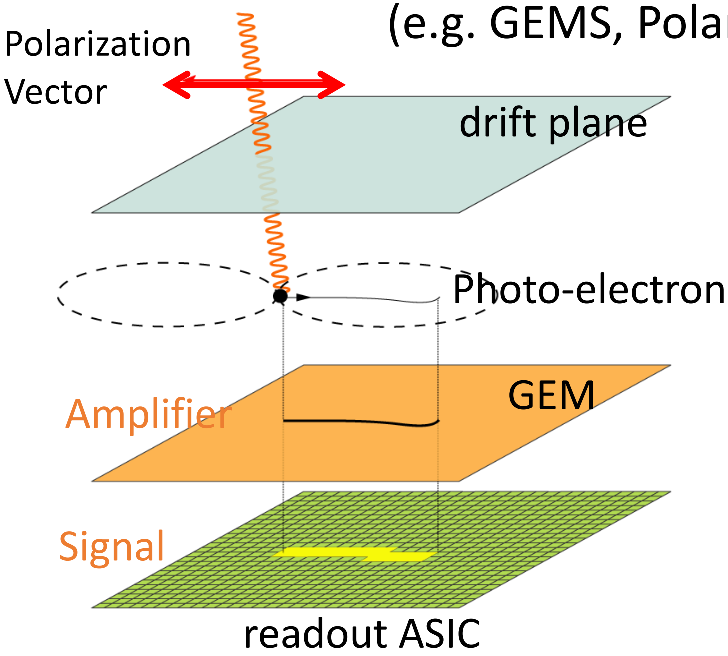


Photo-Electric Absorption (~ 10 keV)

(e.g. GEMS, PolariS)



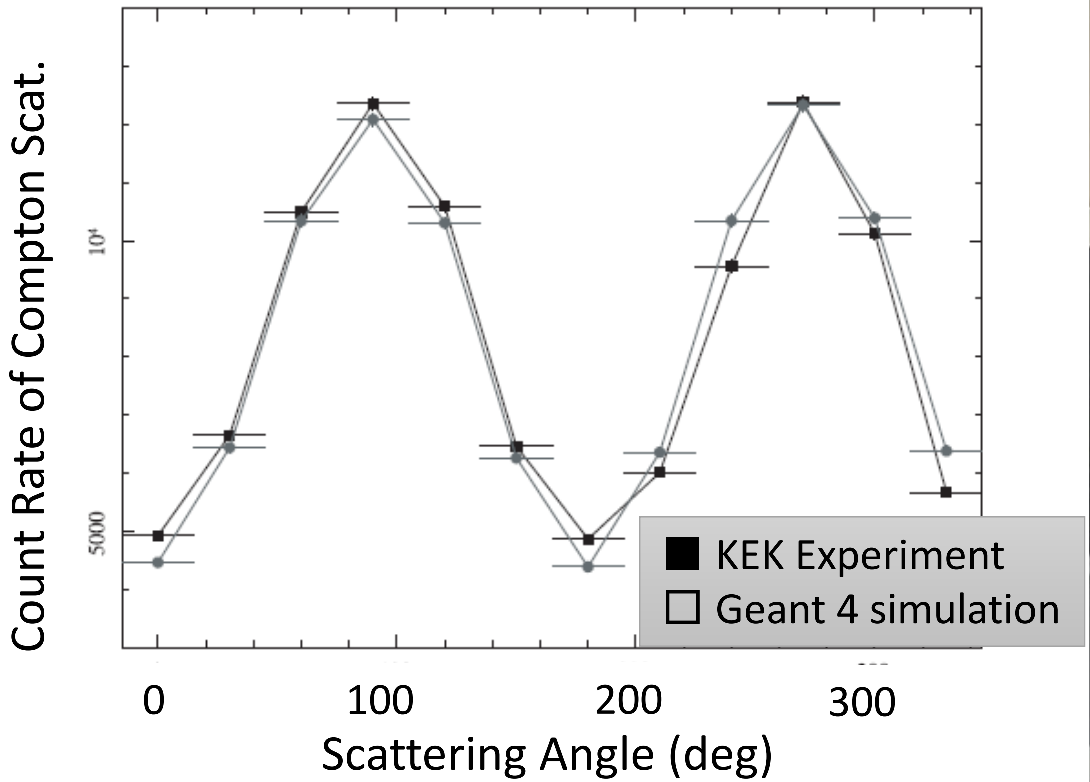
GAmma-ray burst Polarimeter

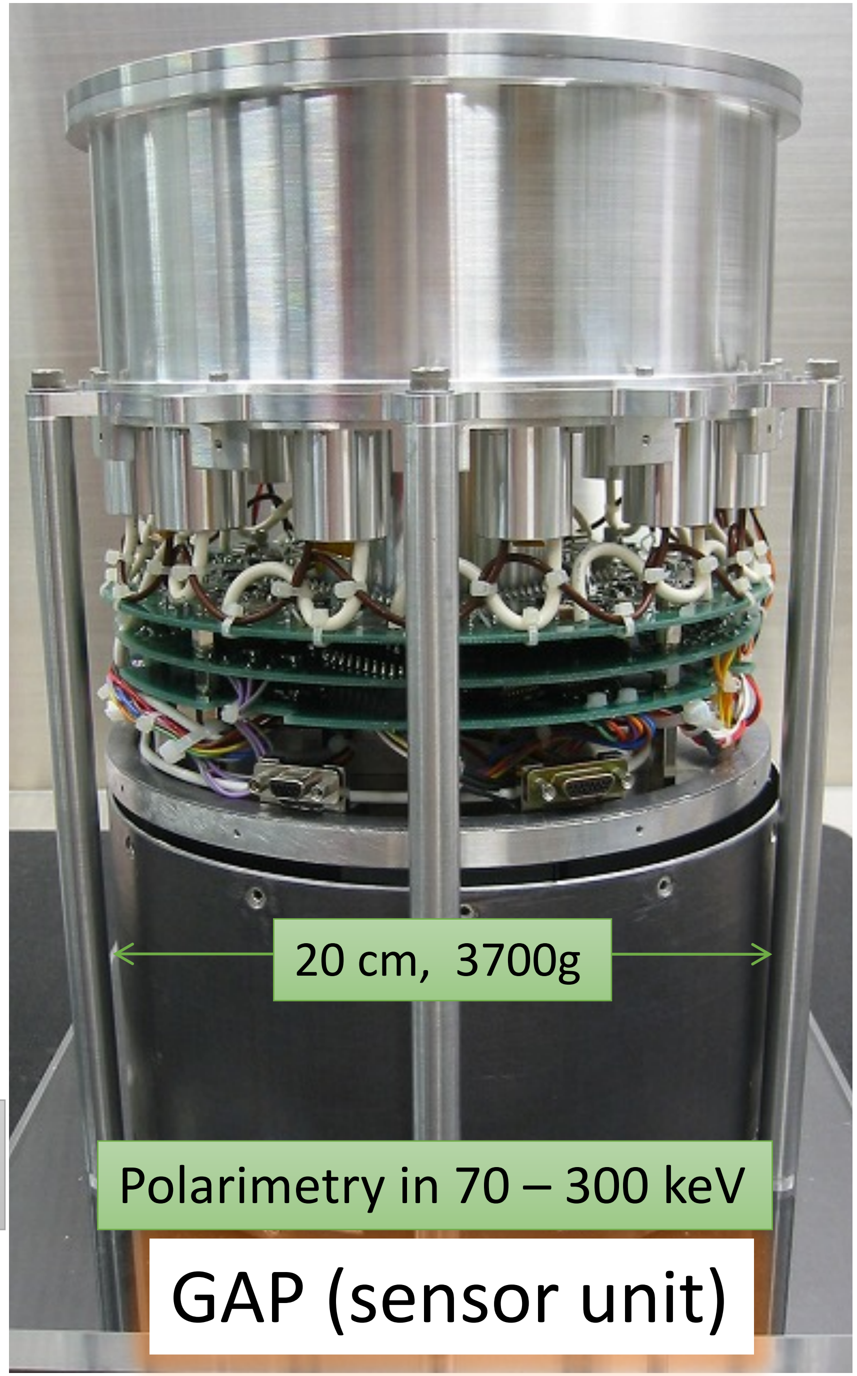
Yonetoku et al. (2006, 2011)

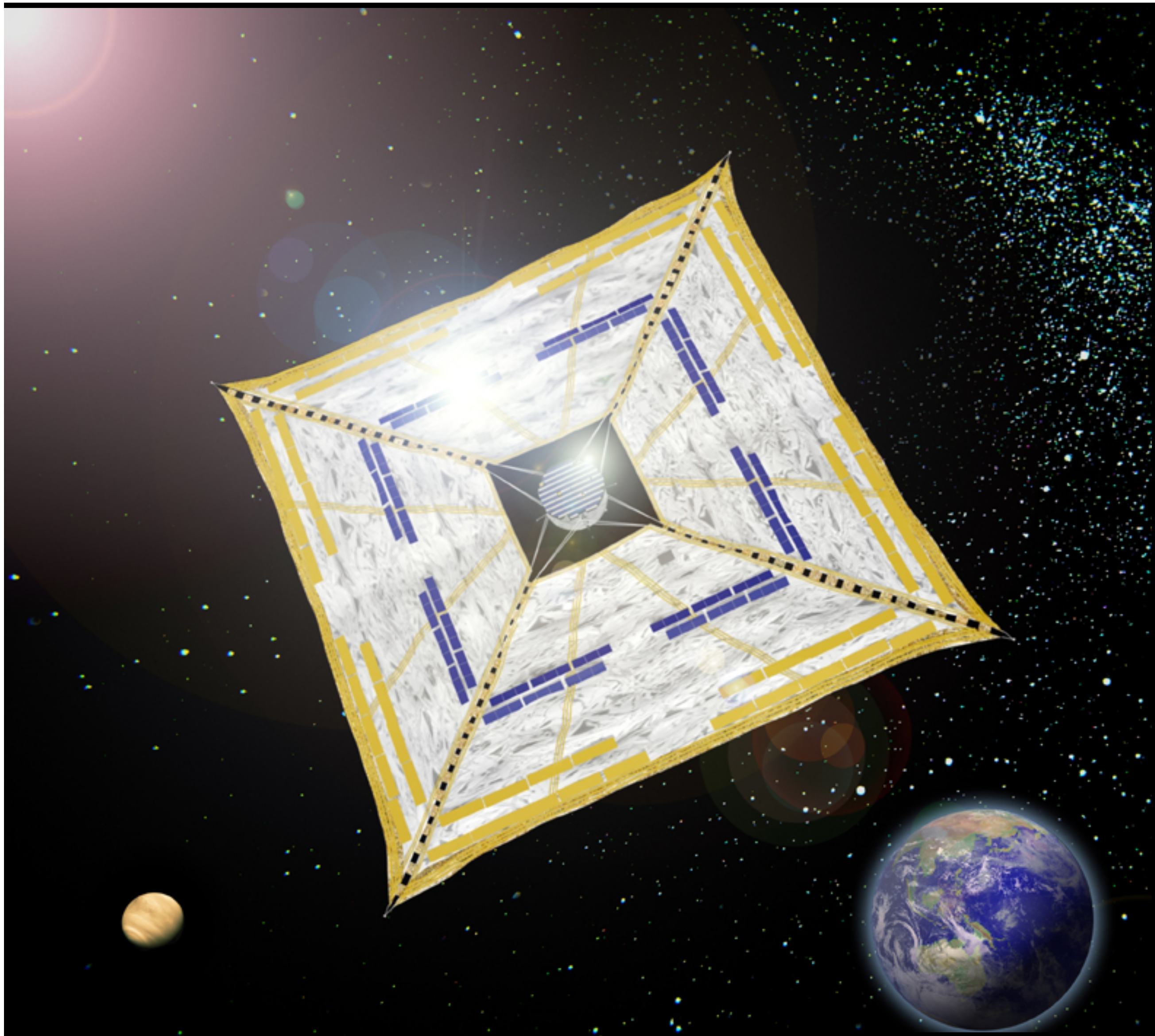
- Angular distribution of Compton Scat.
- Geometrical symmetry

$$\frac{d\sigma}{d\Omega} = \frac{r_0^2}{2}\frac{E^2}{E_0^2}\left(\frac{E_0}{E} + \frac{E}{E_0} - 2\sin^2\theta\cos^2\phi\right)$$

r_0 : classical electron radius
E_0 : energy of incident photon
E : energy of scattered photon







IKAROS

Launched
May 21, 2010

Interplanetary Kite-craft Accelerated by Radiation Of the Sun

Data Samples

Konus, Fermi, Swift, WAM, Integral, Mess.

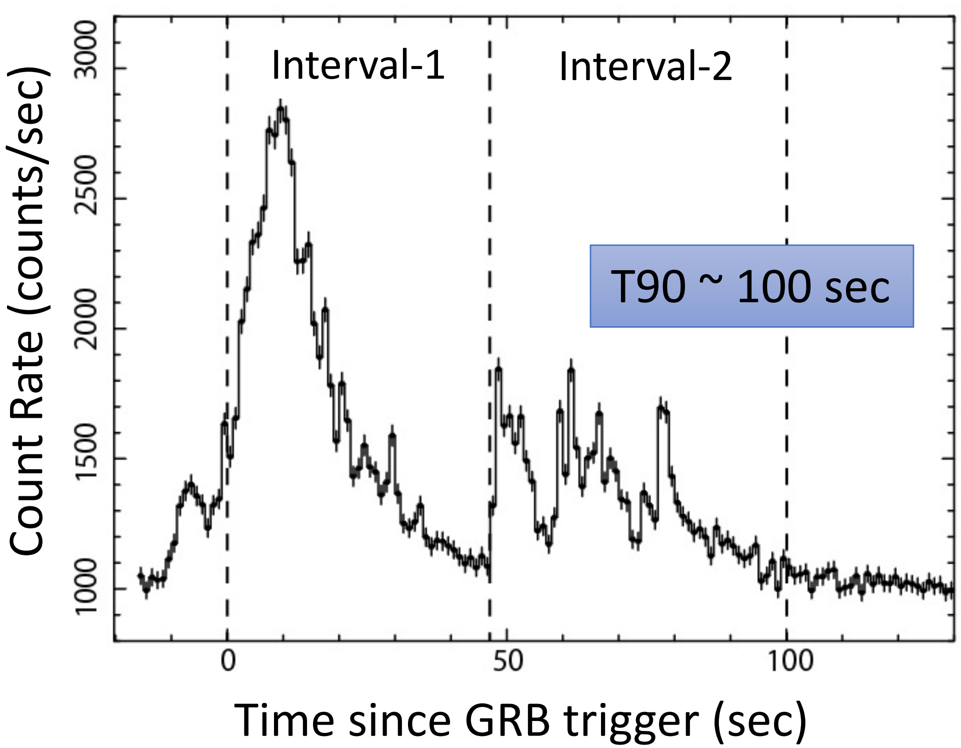
a : 10-1000 keV c : 20-5000 keV
b : 20-10000 keV d : 20-200 keV

No.	GRB	Fluence (erg/cm²)	incident angle	Other Obs.	No.	GRB	Fluence (erg/cm²)	incident angle	Other Obs.
1	100707A	[a] 8.8×10^{-5}	93	K,F,W,M	16	110124A		-	K,W
2	100715A		19	K,I,W,M	17	110301A	[a] 3.7×10^{-5}	48	K,F,W
3	100719B		145	K,F	18	110406A	[b] 4.8×10^{-5}	133	K,W,I,Sw
4	100722A		34	K,F	19	110423A		-	K
5	100804A		63	K,F	20	110428A	[a] 2.3×10^{-5}	109	K,F,W,Sw
6	100809A		-	K	21	110505?		-	?
7	100820A		34	K,F	22	110510?		-	?
8	100826A	[b] 3.0×10^{-4}	20	K,F,W,M	23	110514		-	K
9	101014A	[a] 2.0×10^{-4}	54	K,F	24	110604A	[c] 3.1×10^{-5}	43	K,W,Sw
10	101021A		41	K,F	25	110625A	[b] 6.1×10^{-5}	41	K,F,Sw
11	101113A		26	K,F	26	110708A	[d] 2×10^{-6}	67	K,F,Sw
12	101123A	[a] 1.3×10^{-4}	74	K,F,I,Sw	27	110715A	[b] 2.3×10^{-5}	88	K,W,Sw
13	101126A		62	K,F	28	110717B		25	F,K
14	101219A	[b] 3.0×10^{-6}	52	K,Sw	29	110721A	[a] 3.5×10^{-5}	30	K,F,I,M
15	101231A		63	F	30	110825A	[a] 5.4×10^{-5}	29	

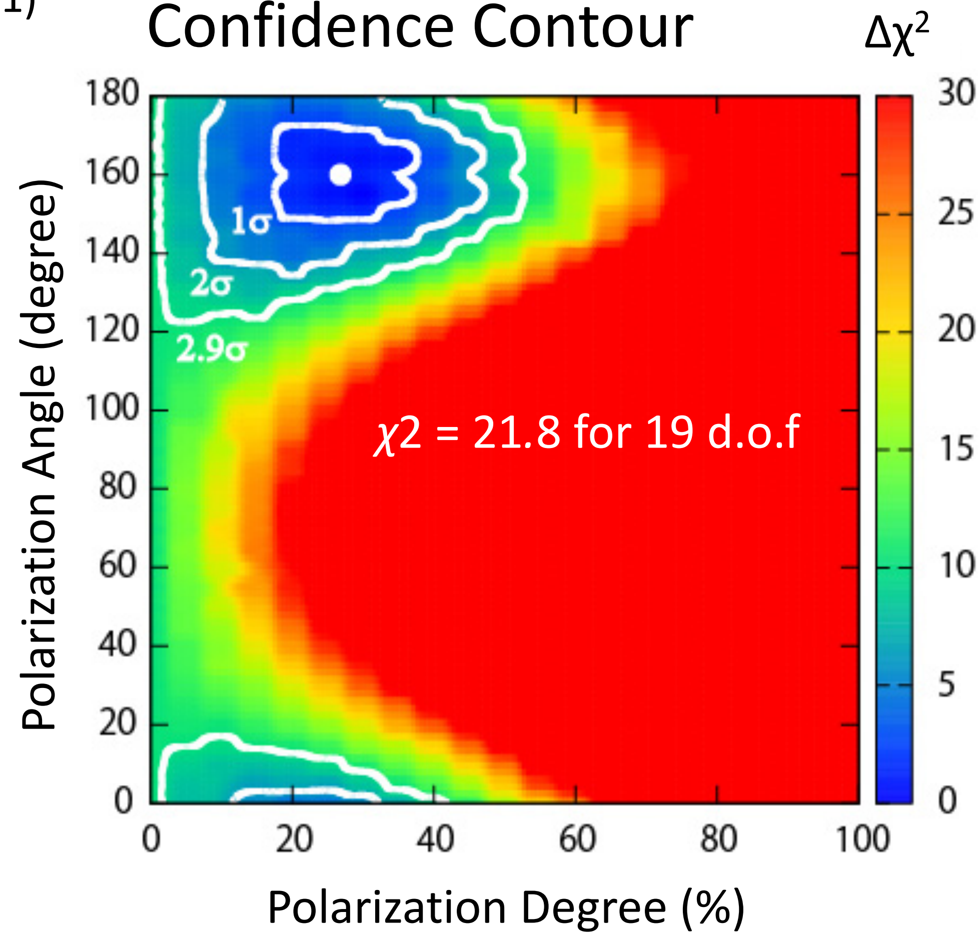
GRB100826A

Yonetoku et al. (2011)

Very bright events with F = 3.0×10^{-4} erg/cm2



Confidence Contour



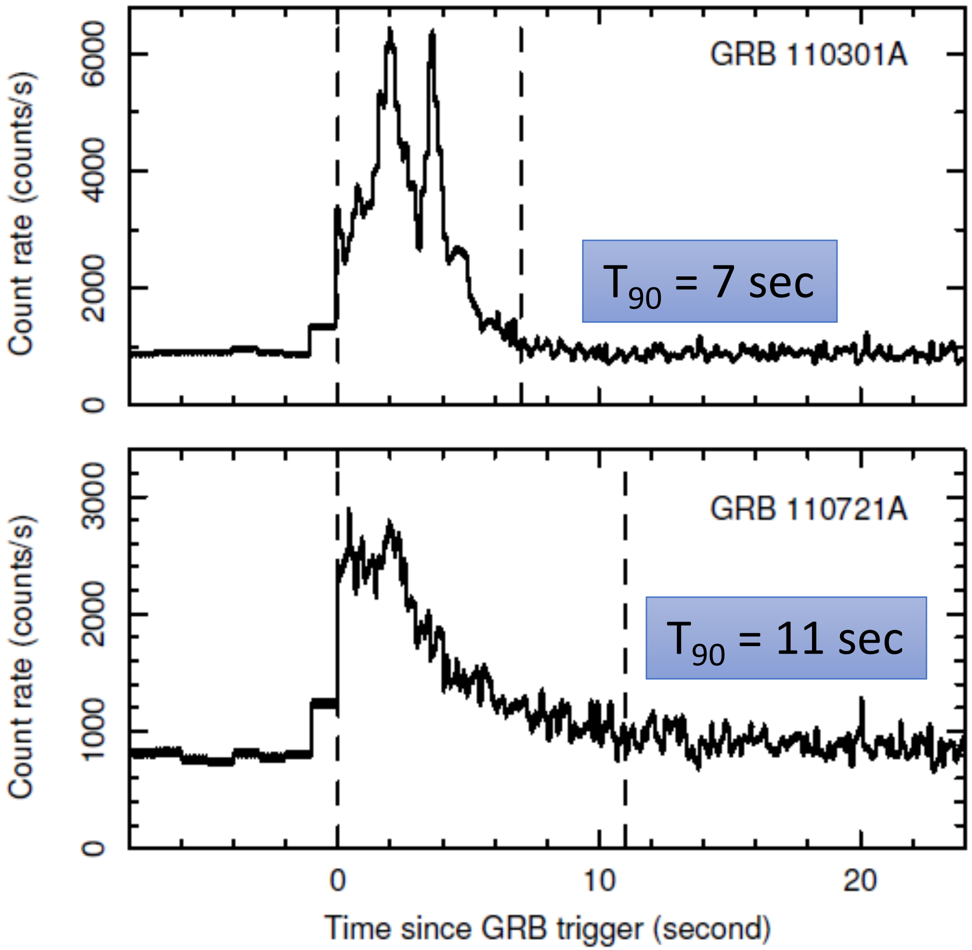
	Polarization Degree (including sys. uncertainty)	**Polarization Angle**
Interval-1	P = 25±15% (95.4% C.L.)	PA = 159±18 deg
Interval-2	P = 31±21% (89.0% C.L.)	PA = 75±20 deg
Combined Fit	P = 27±11% (99.4% C.L.)	

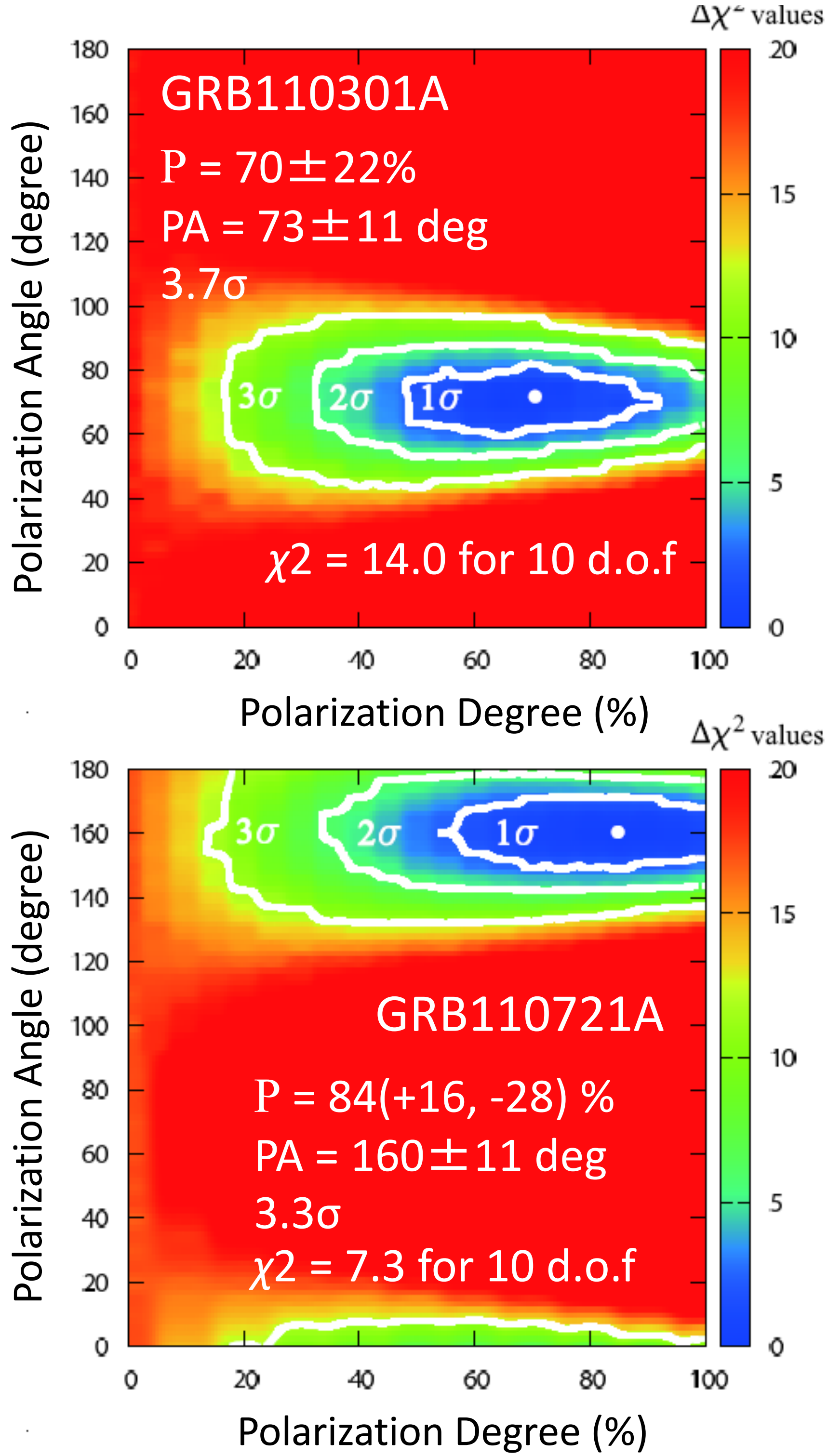
3.5σ Confidence Level

GRB110301A & GRB110721A

We detected the polarization from two bright GRBs with high significance.

The polarization angles did not change during the prompt GRBs.





Results of Polarization Analyses

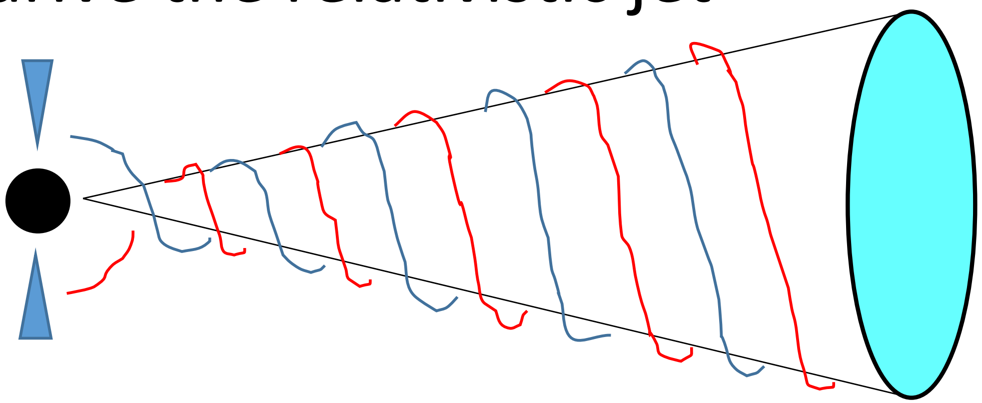
GRB	Polarization Degree (%)	Duration T90 (sec)	Incident Angle (deg)	E_p (keV)	fluence (erg cm^{-2})	flux (photon cm^{-2} s^{-1})
100826	27 ± 11	100	20	606^{+134}_{-109}	2.94×10^{-4}	9.03
110721	84^{+16}_{-28}	11	30	$375.5^{+26.5}_{-23.6}$	3.43×10^{-5}	6.71
110301	70 ± 22	7	48	$106.80^{+1.85}_{-1.75}$	3.35×10^{-5}	75.59
110825	< 47	12	29	$233.6^{+21.9}_{-19.9}$	5.06×10^{-5}	6.16
110625	< 56	27	41	190^{+17}_{-14}	6.09×10^{-5}	8.21
100715	< 83	30	19	-	-	-
101014	< 71	30	54	$181.40^{+5.66}_{-5.44}$	1.88×10^{-4}	3.74

90% upper-limit

- Significant Polarization was detected from bright 3 GRBs.
- GRB100826A : Polarization angle changed (3.5σ confidence level.)
- GRB110721A & GRB110301A : Polarization angle was stable.

We need the emission model to explain both cases of change and no-change of polarization angle.

Helical Magnetic Fields to drive the relativistic jet

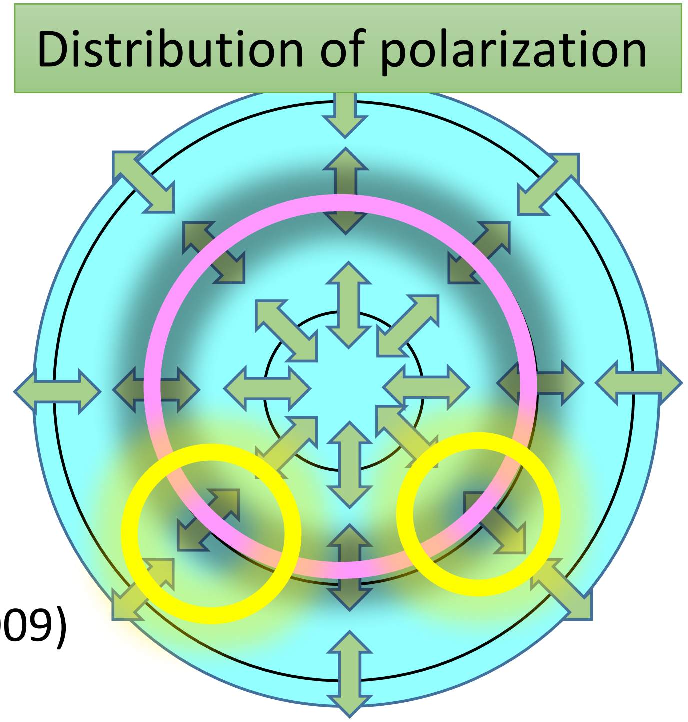


Jet opening angle : θj

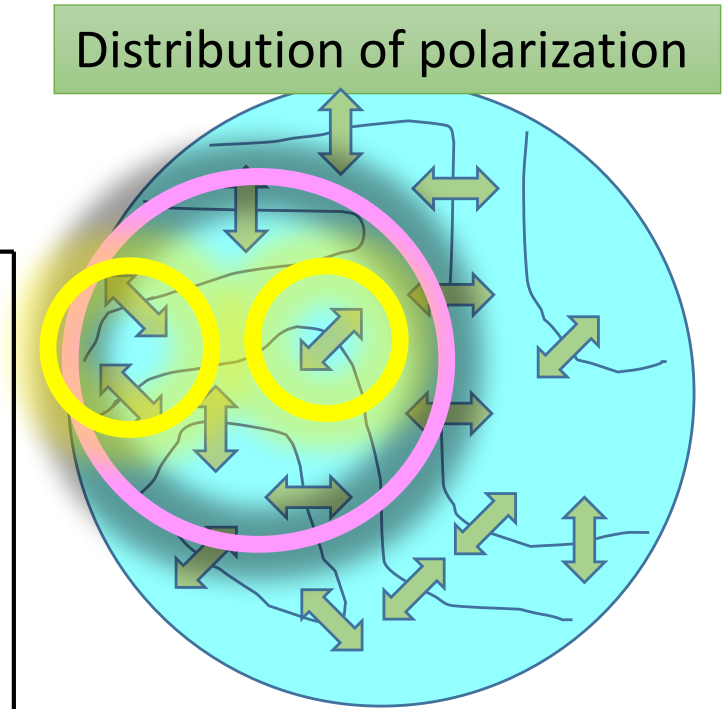
Relativistic beaming effect : $1/\Gamma$

Lazzati et al. (2003–2009)

Toma et al. (2009)



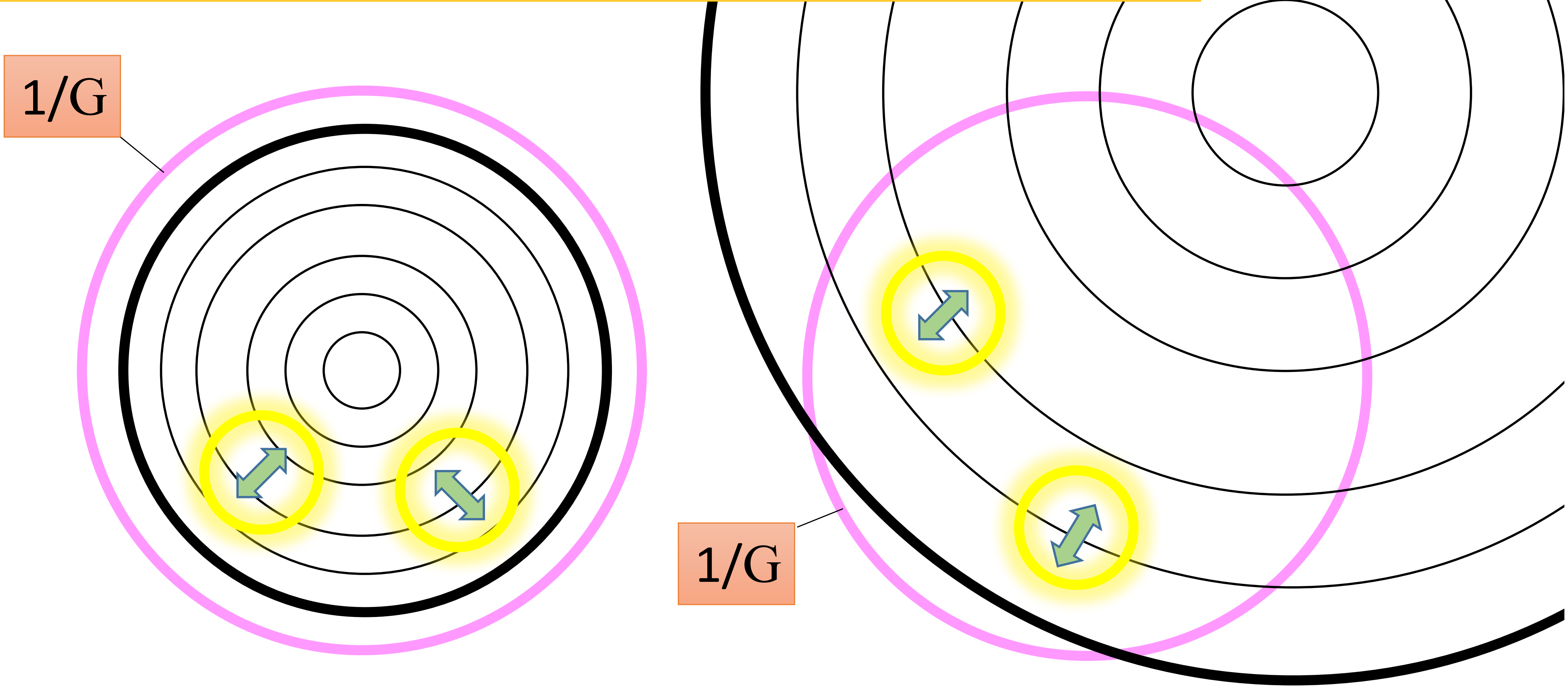
Globally Random Magnetic Fields, But Locally Coherent



The change of polarization angle can be explained with patchy structures of smaller than $1/\Gamma$.

Inner Structures may exist in the Jet.

Jet Opening Angle
Change/No-Change of Polarization Angle

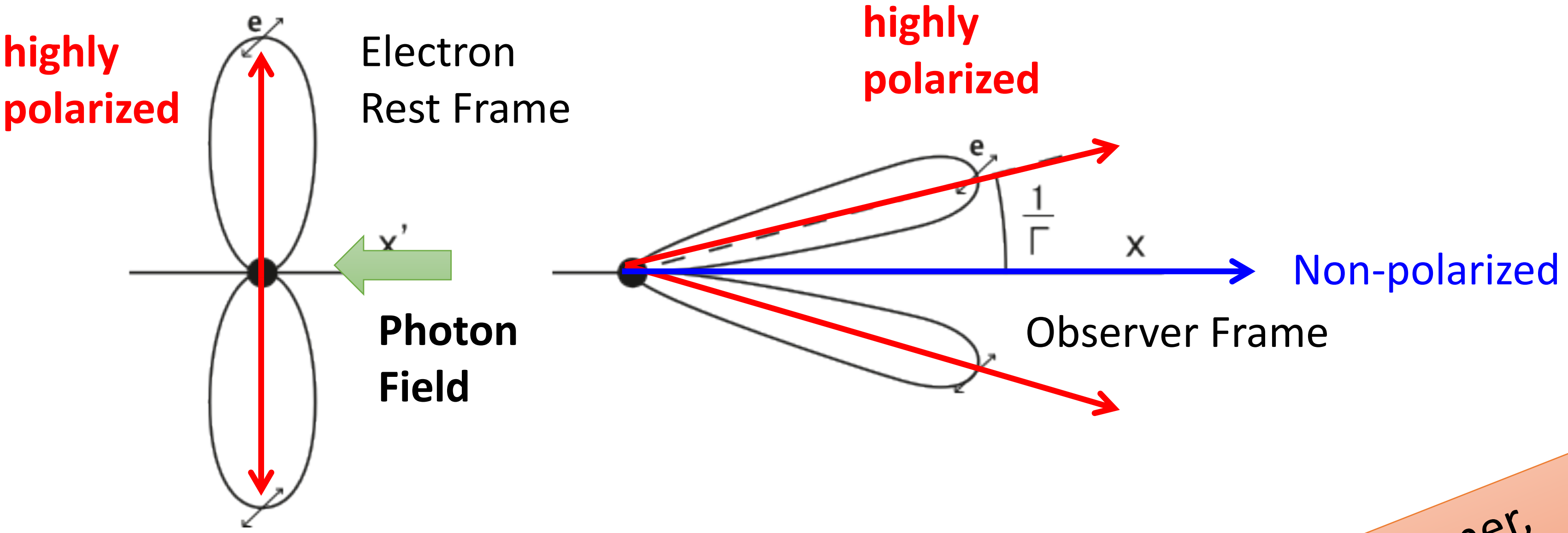


Narrow: $\theta_j < 1/\Gamma \sim 0.01$ rad

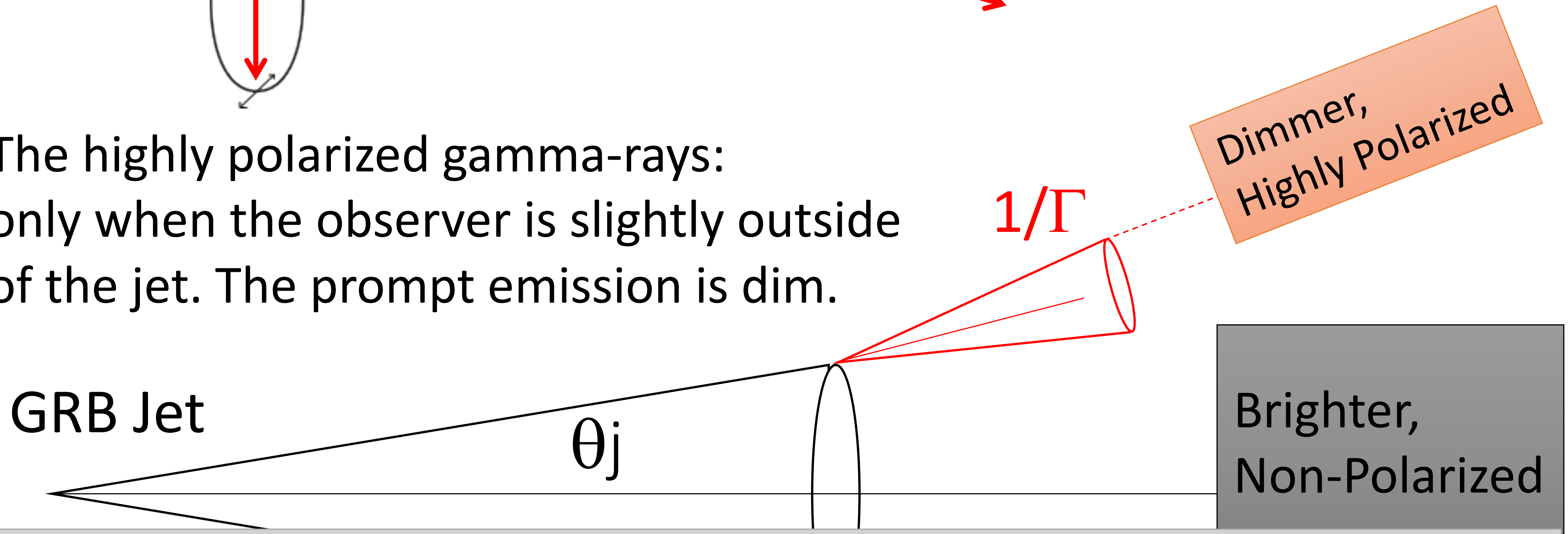
Broad: $\theta_j > 1/\Gamma \sim 0.01$ rad

We can explain both cases of change/no-change of pol. angle with the relation between θ_j and $1/\Gamma$, and also the patches.

Compton Drag Lazzati et al. (2005) & Photospheric Emission

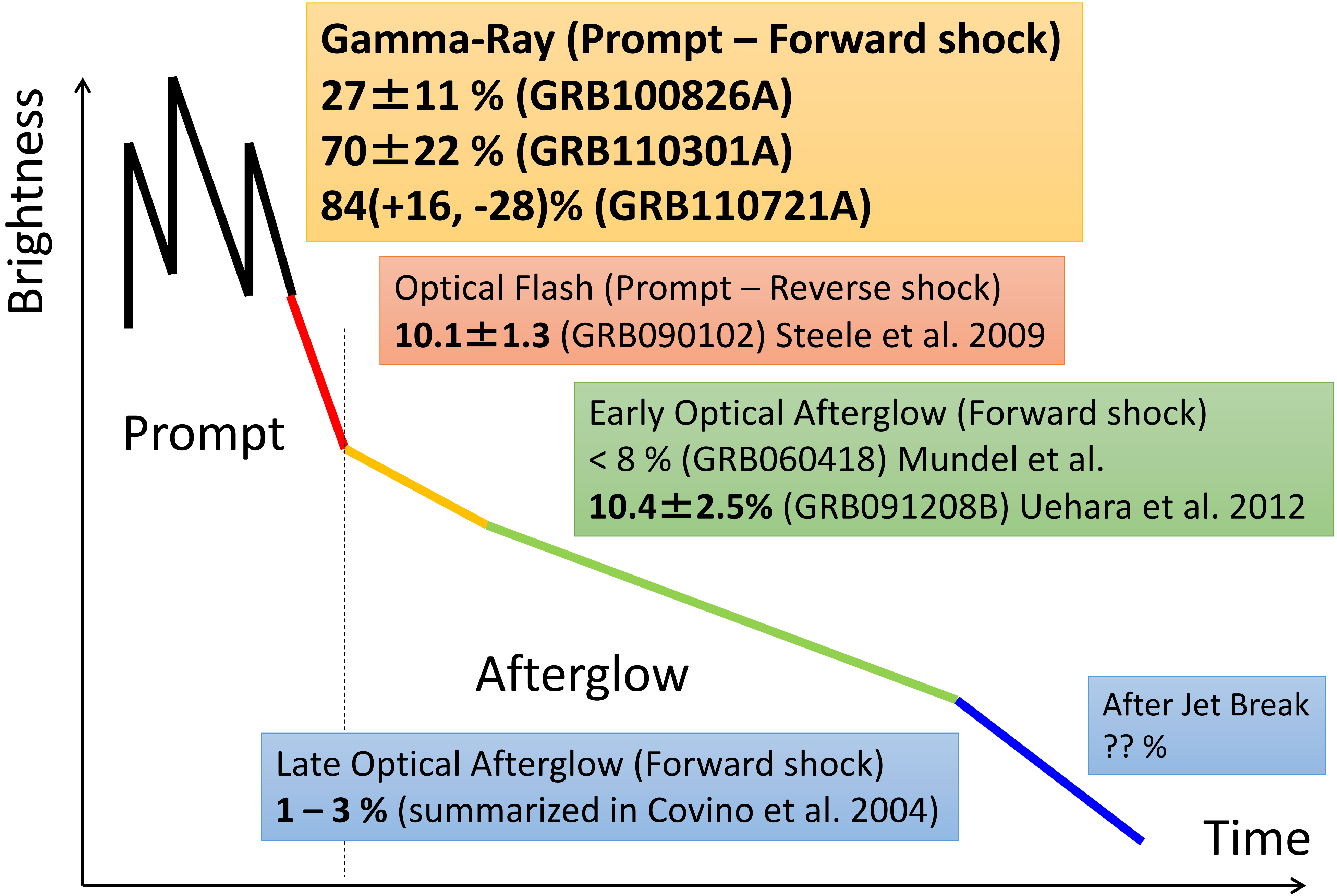


The highly polarized gamma-rays:
only when the observer is slightly outside of the jet. The prompt emission is dim.



It is difficult to explain the existence of **bright & highly polarized GRBs** in the frame work of Compton drag and Photospheric emission mode.

Evolution of polarization



- We detected the γ-ray polarization from **3 bright GRBs**, and set U.L. for 4 GRBs with GRB polarimeter "GAP".

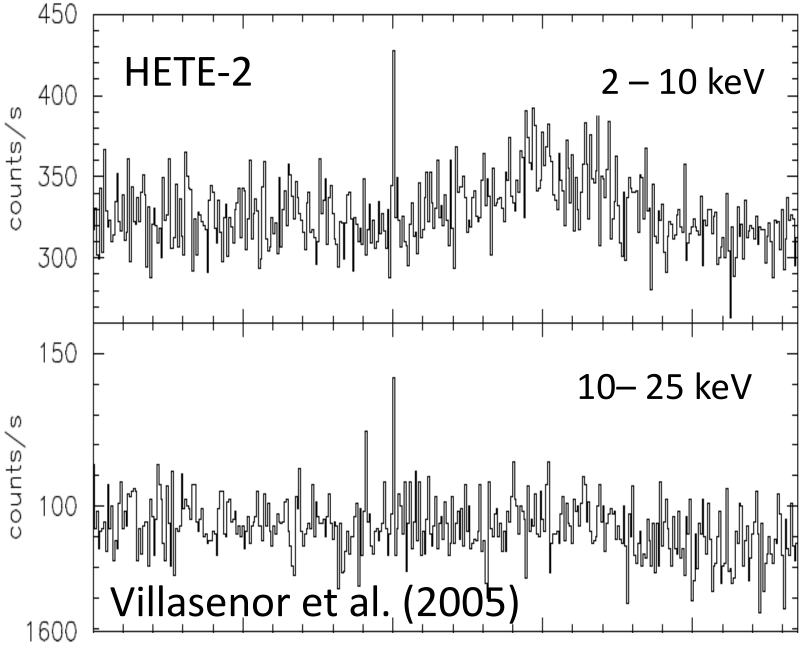
- The emission mechanism of prompt GRBs are probably the synchrotron radiation in the coherent magnetic fields.

  (Our results favor theICMART model (Zhang's group).
  We cannot exclude the photospheric and comptonized emission model)

- Since the polarization angle rapidly changed, the multiple emission regions and/or the patchy structures with the scale of $< 1/\Gamma$ may exist in the relativistic jet.

3rd topic :
Short Gamma-Ray Bursts and Gravitational Wave Astronomy

Long & Short GRBs

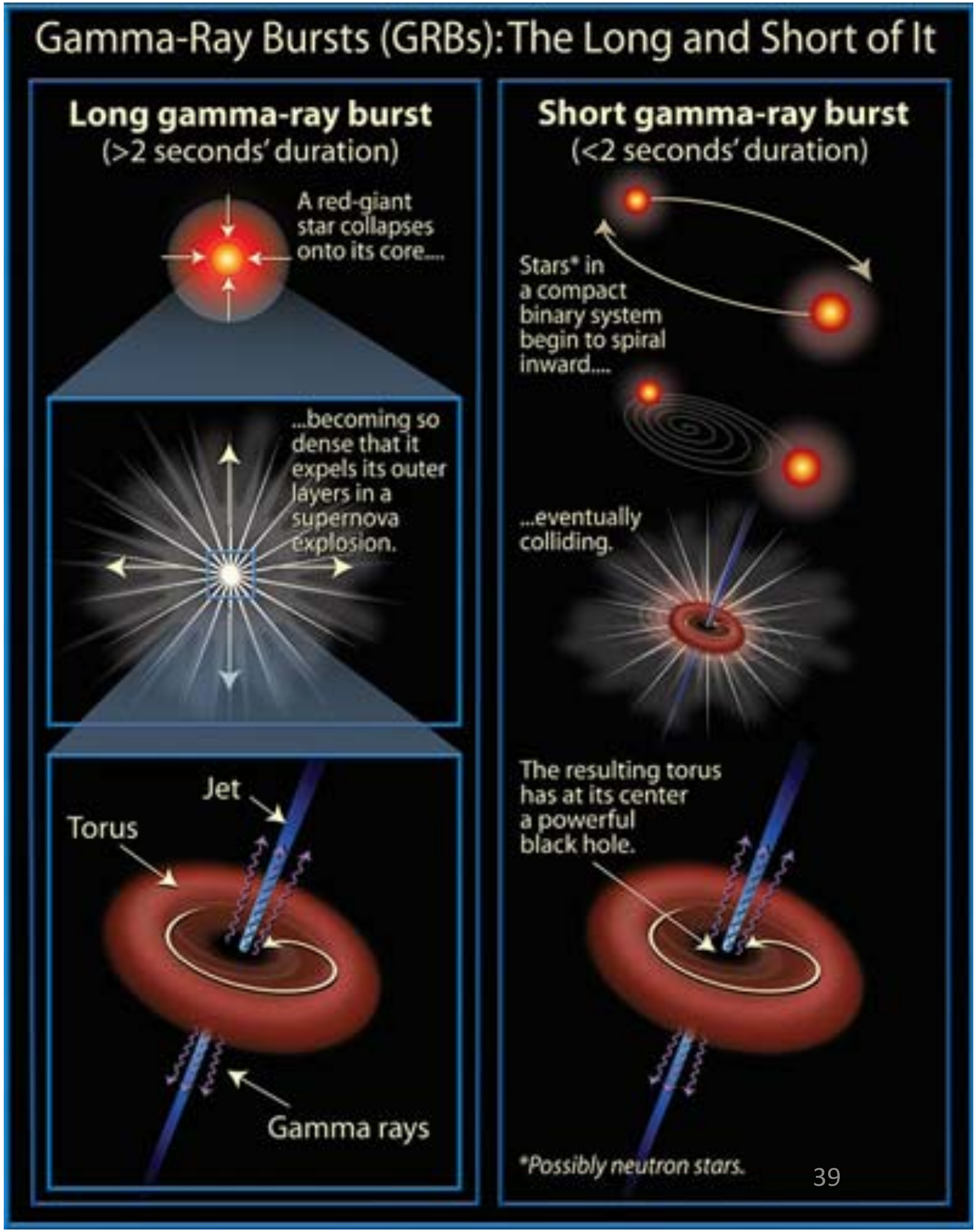


LGRBs (T > 2 sec)

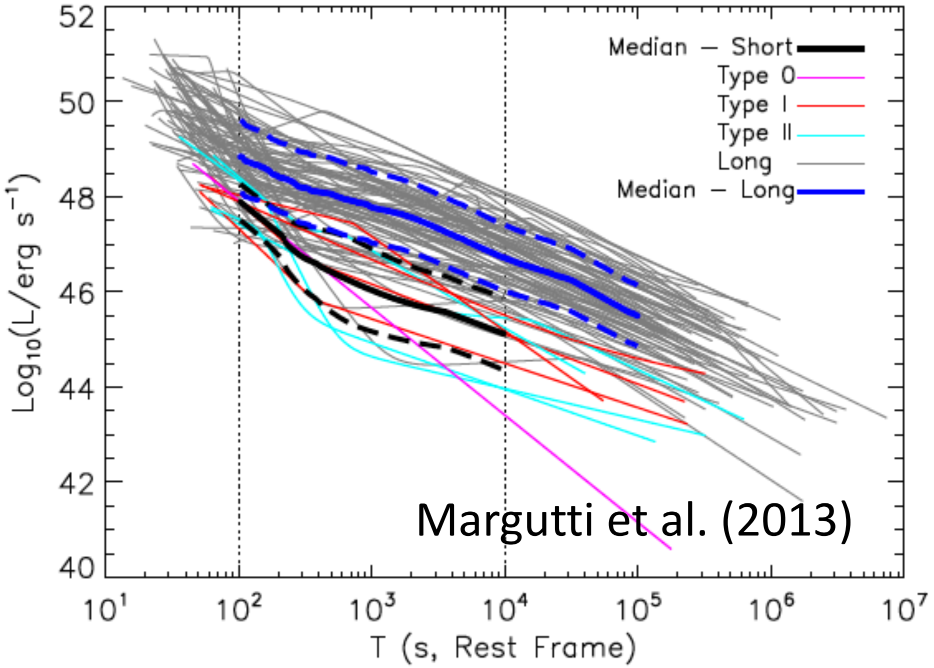
- Massive star explosion (M>40M_{sun})
- Associated with Supernovae (energetic Hypernovae)
- Black Hole & relativistic jet

SGRBs (T < 2 sec)

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



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)

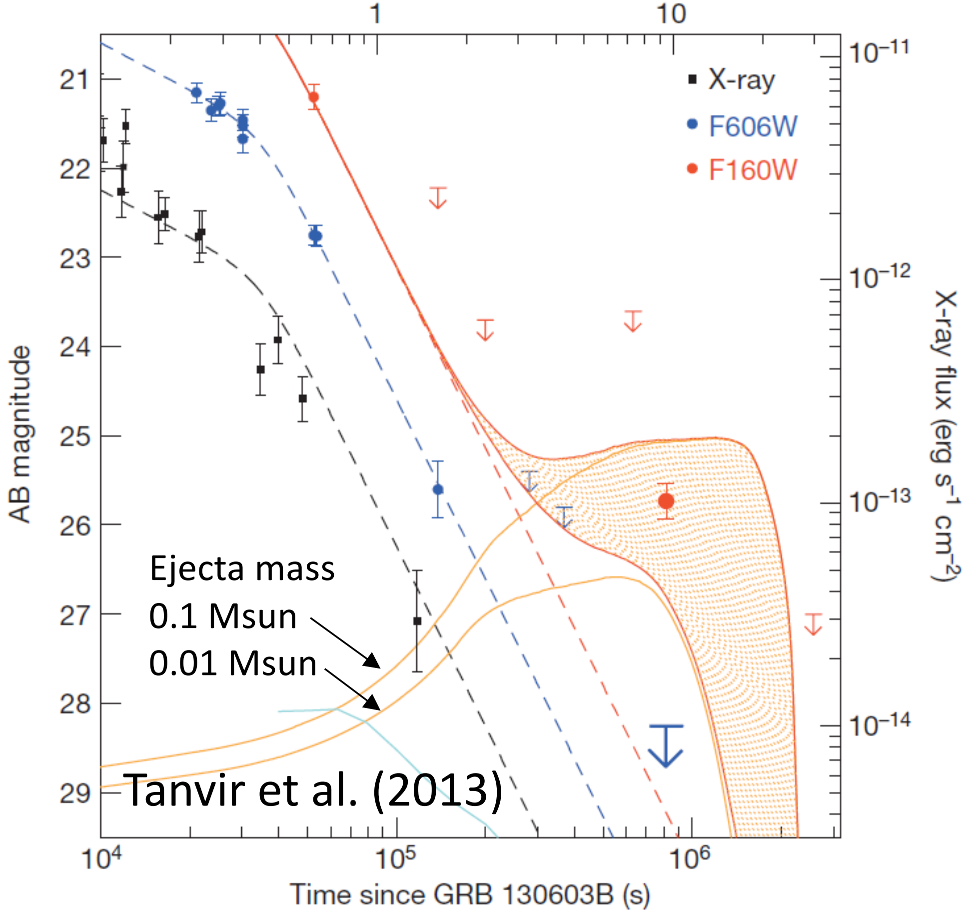
Kagawa, DY + (2015)

Extended emission

- 7% (CGRO-BATSE: Bostanci et al. 2013)
- 25% (Swift-BAT: Norris et al. 2010)
- 40% (Swift-BAT+XRT: Kagawa, DY+ 2016)
- ~100% (Swift-XRT: Kisaka+, 2016)

Optical/NIR Afterglow & kilonova/macronova

GRB 130603B @ z = 0.356

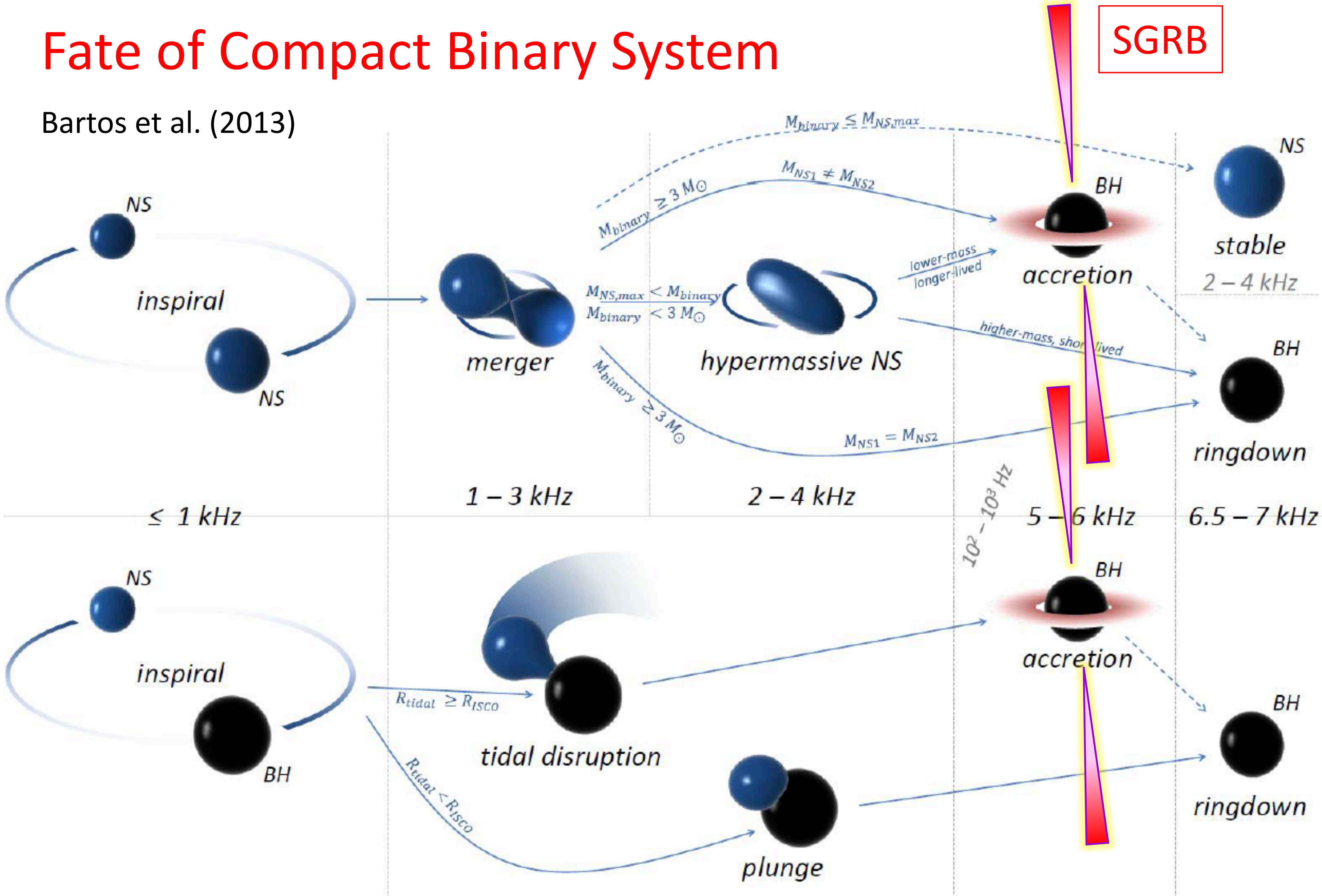


- Heating by nuclear beta decay of r-process (neutron rich) elements
- Benchmark of future optical/NIR obs.

Fate of Compact Binary System

SGRB

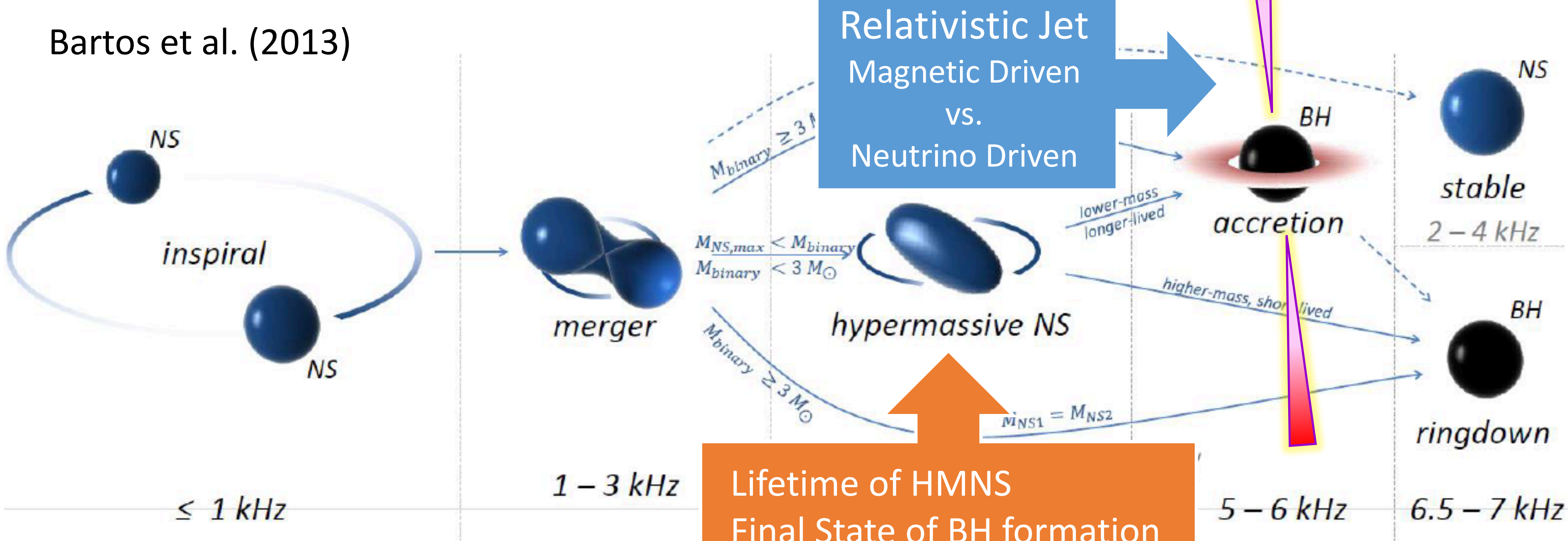
Bartos et al. (2013)



Fate of Compact Binary System

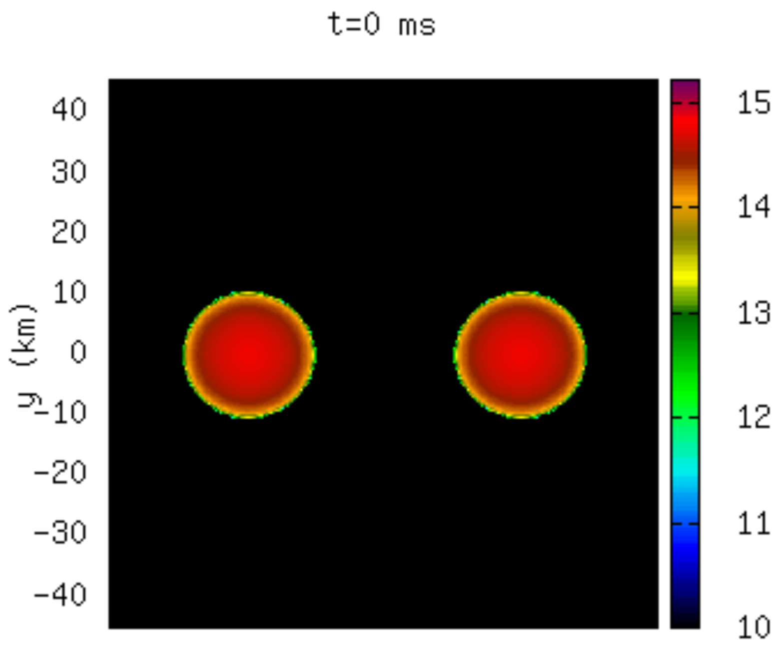
SGRB

Bartos et al. (2013)

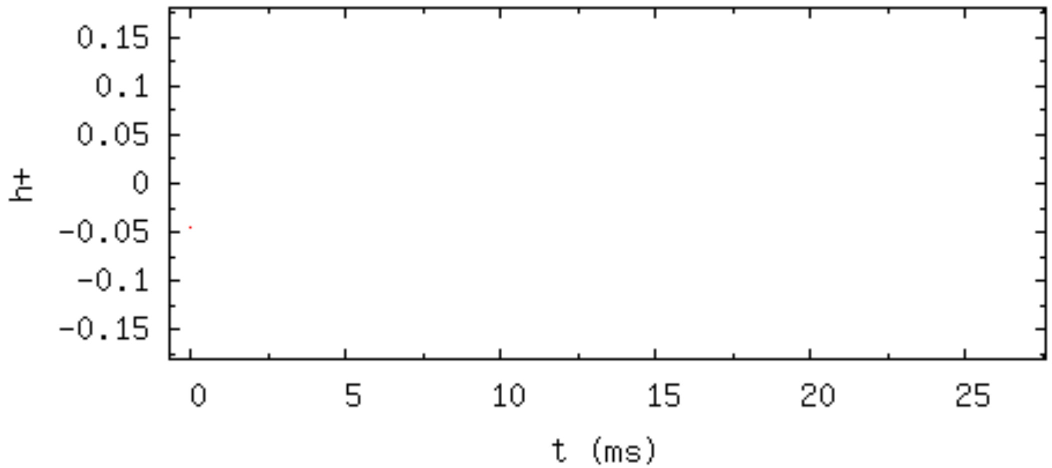


Relativistic Jet
Magnetic Driven
vs.
Neutrino Driven

Lifetime of HMNS
Final State of BH formation
EoS of nuclear matter

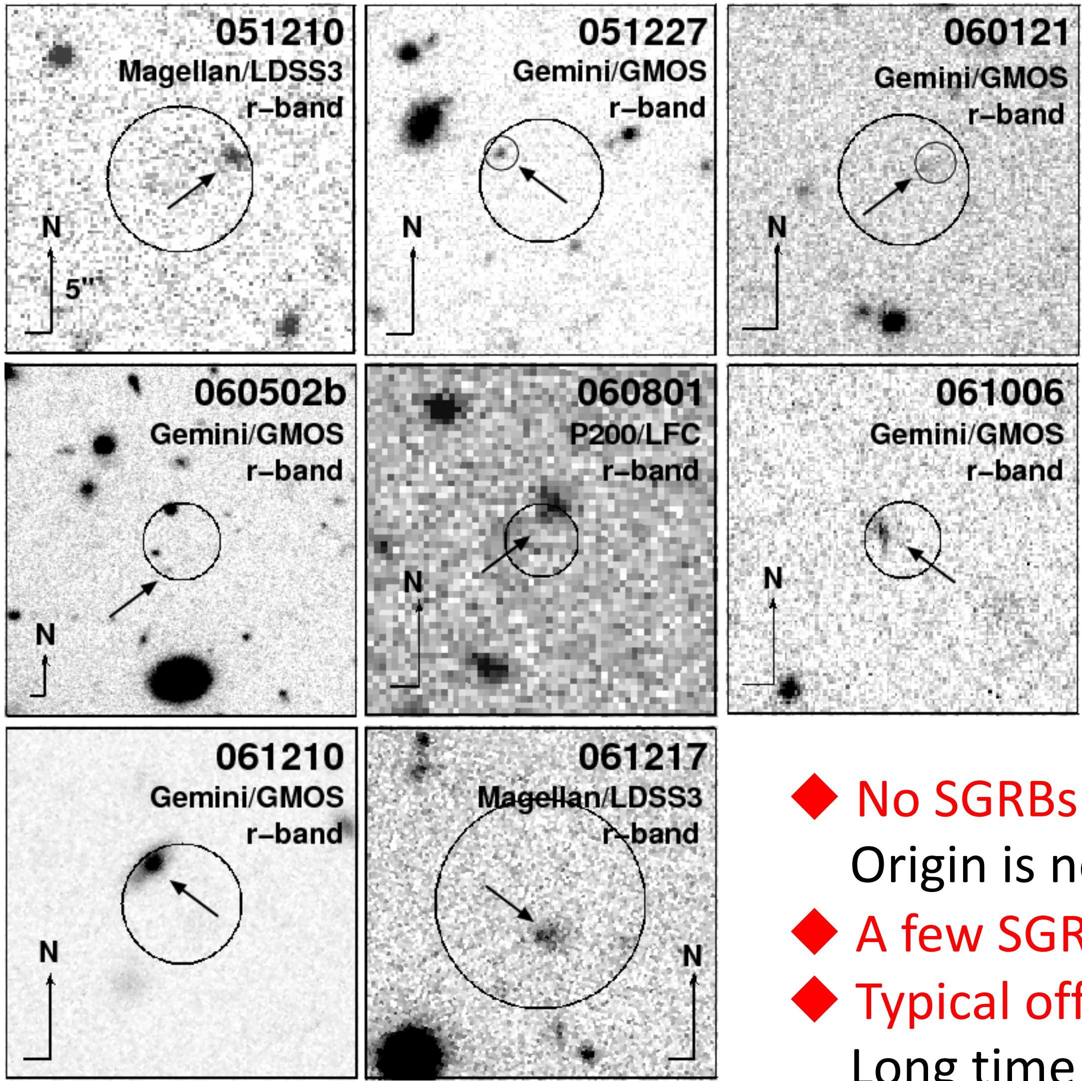


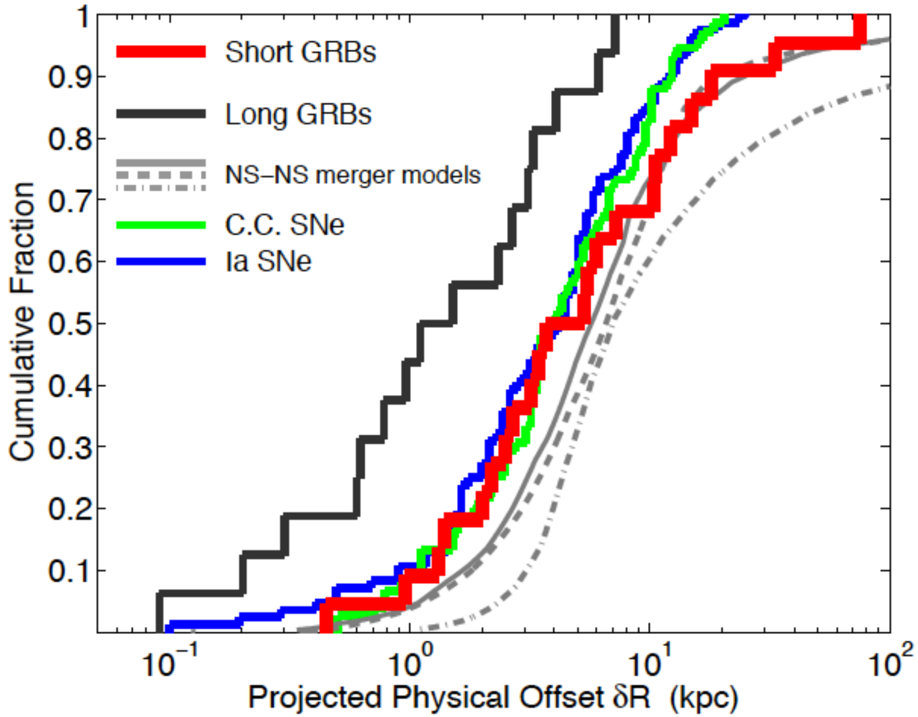
Hotokezaka et al. (2011)



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

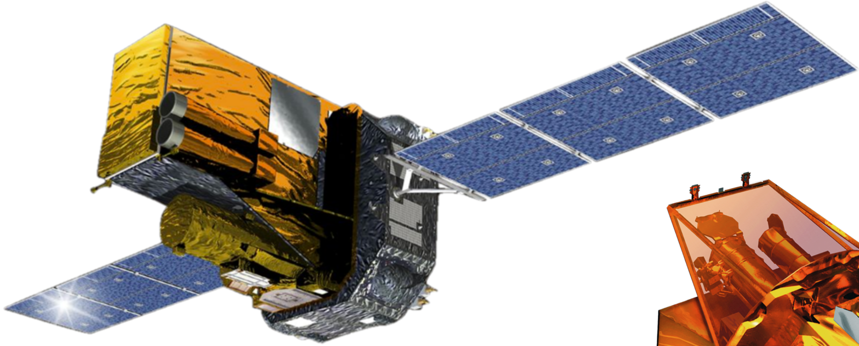
  Long time scale

  kick velocity ~ 100 km/s → ~ 0.1 Gyrs

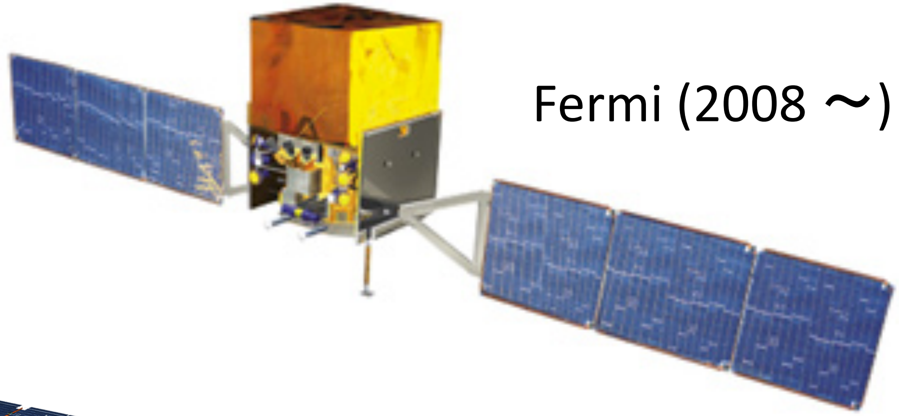
Coalescence of NS-NS/NS-BH is an acceptable scenario

X-ray/ γ -ray Observations for 3 BH-BH (GW 150914, LVT 151012, GW 151226)

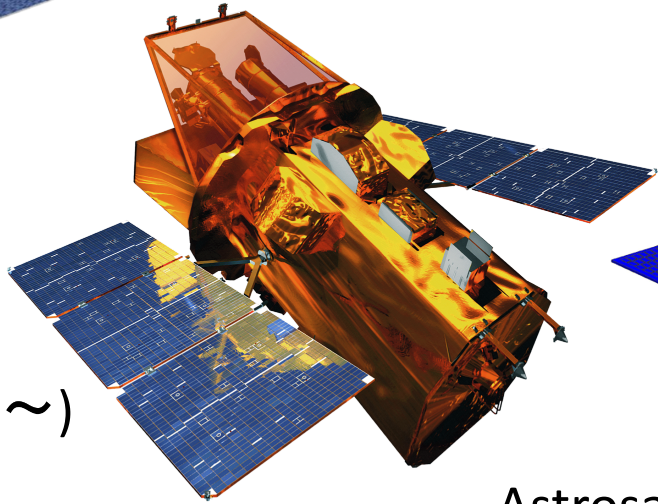
Current GRB Mission



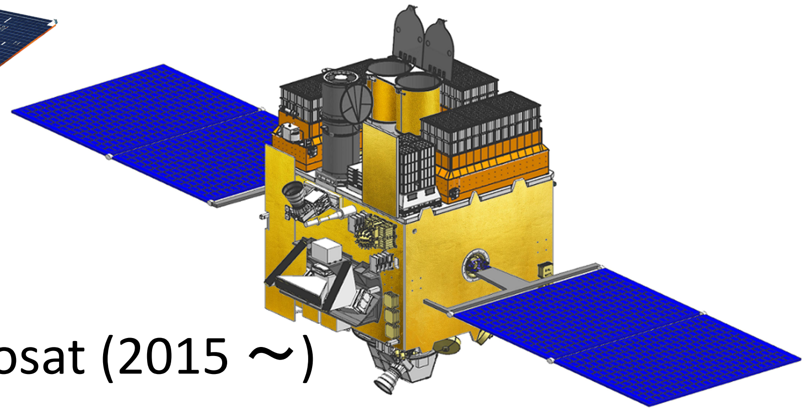
INTEGRAL (2002～)



Fermi (2008 ～)

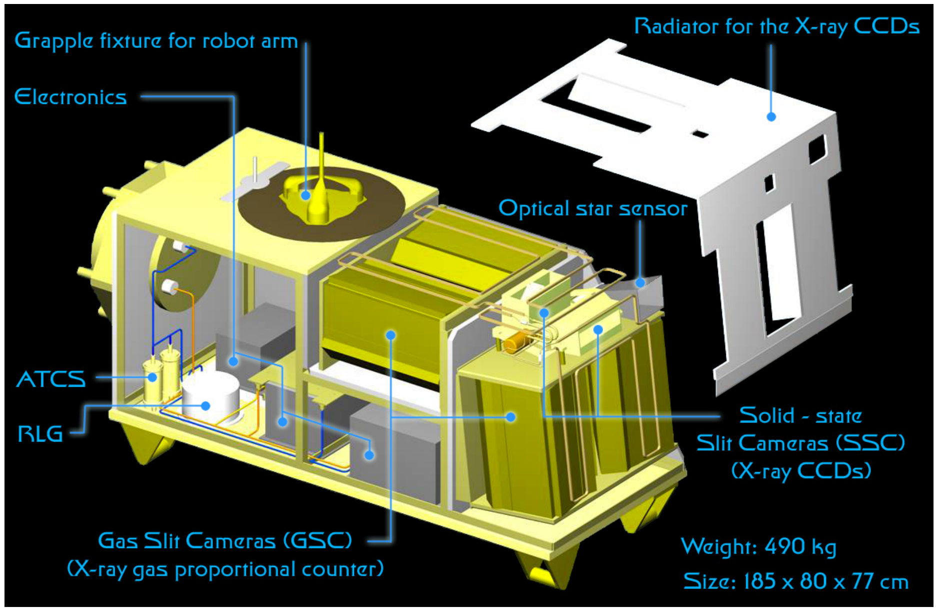


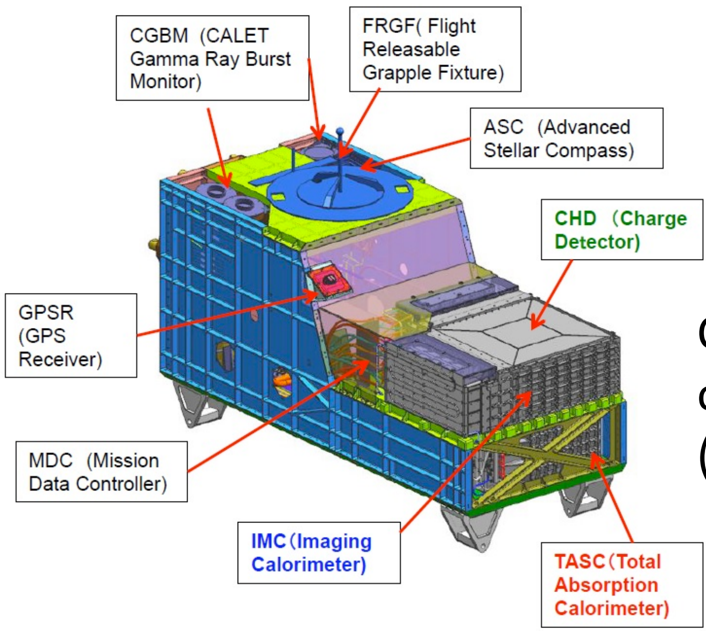
Swift (2004～)



Astrosat (2015 ～)

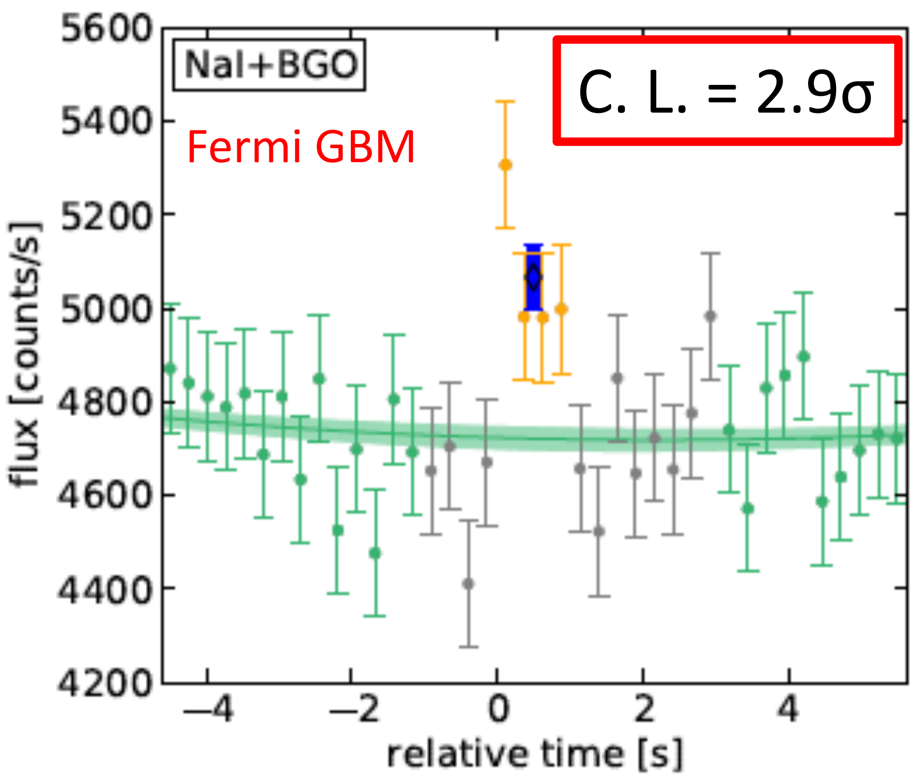
MAXI onboard ISS (2009 ～)





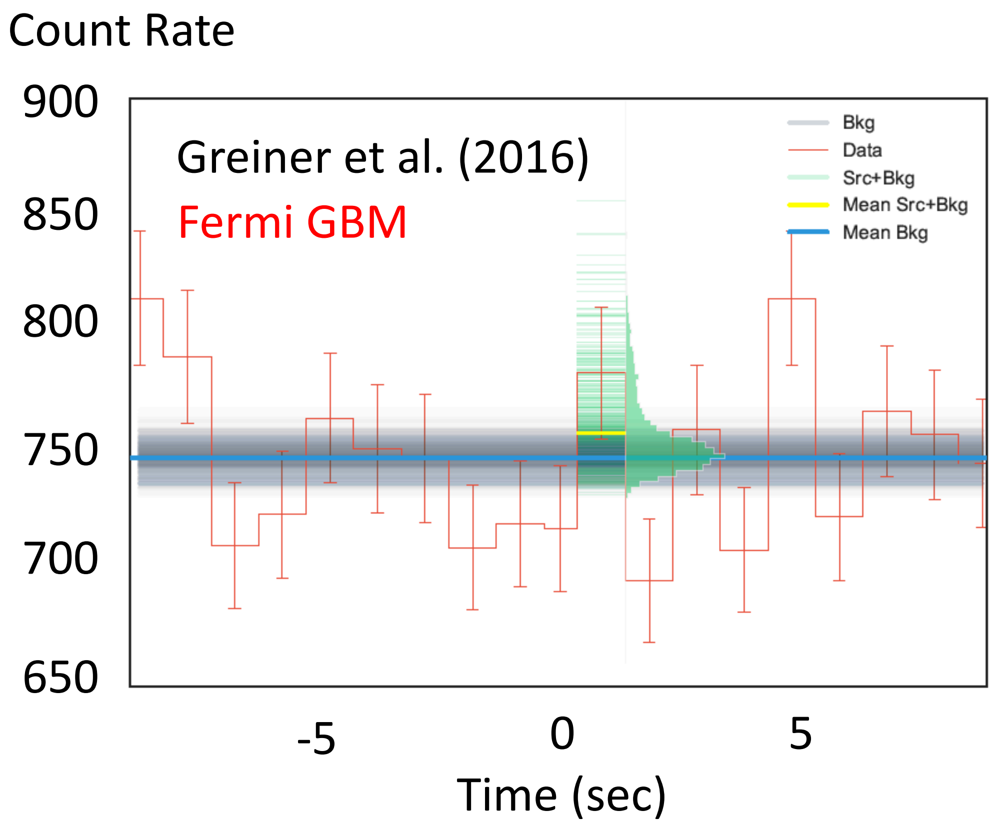
CALET onboard ISS (2015 ～)

X-ray/ γ -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 INTEGRAL

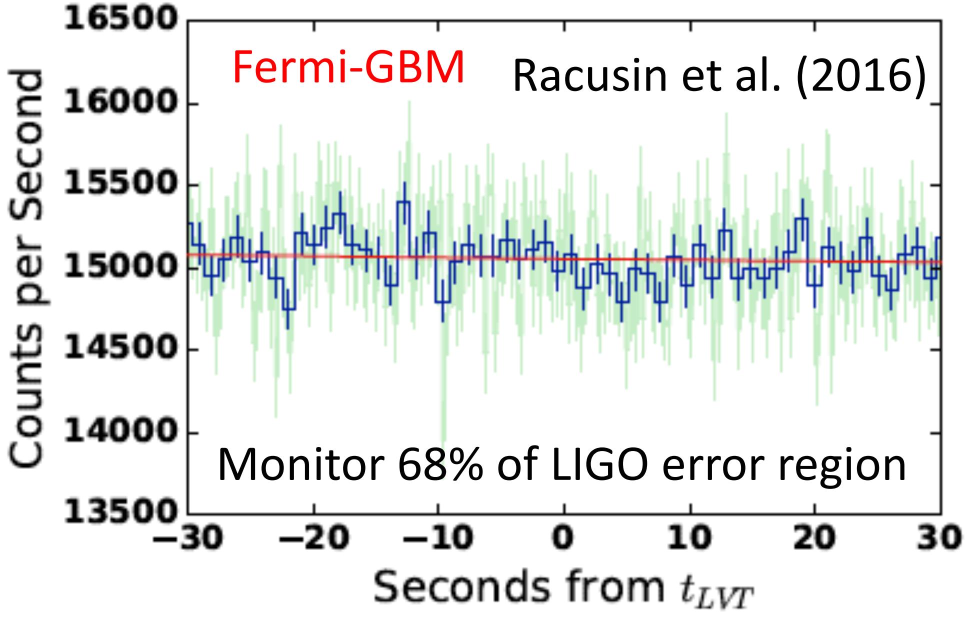
$$E_\gamma < 2 \times 10^{48} \mathrm{erg} \left(\frac{F_\gamma}{10^{-7} \mathrm{erg\ cm^{-2}}}\right) \left(\frac{D}{410\,\mathrm{Mpc}}\right)^2 .$$

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

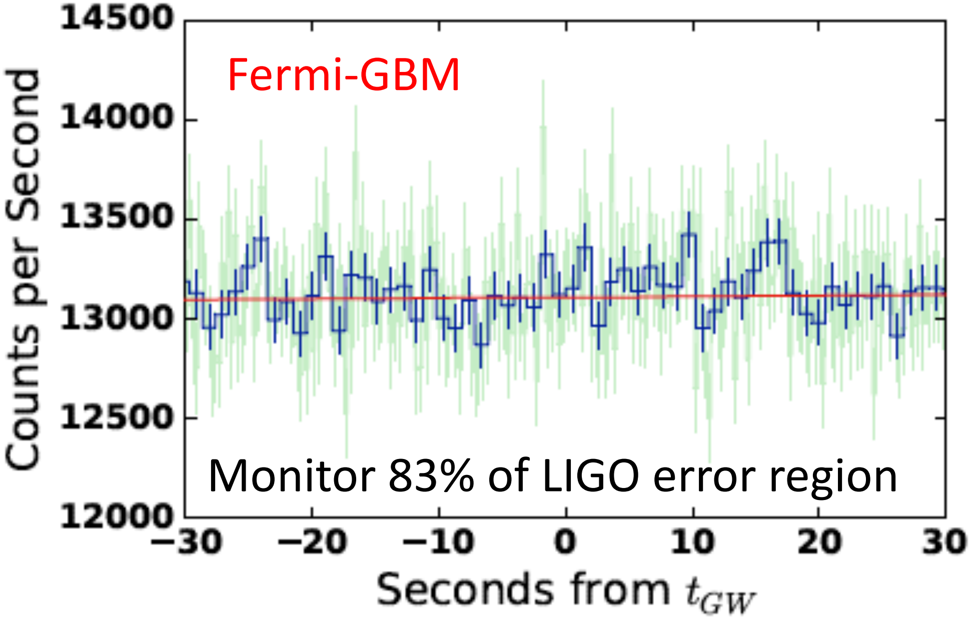
Non detection from the same data

Fermi-GBM event must be Background Fluctuation

LVT 151012

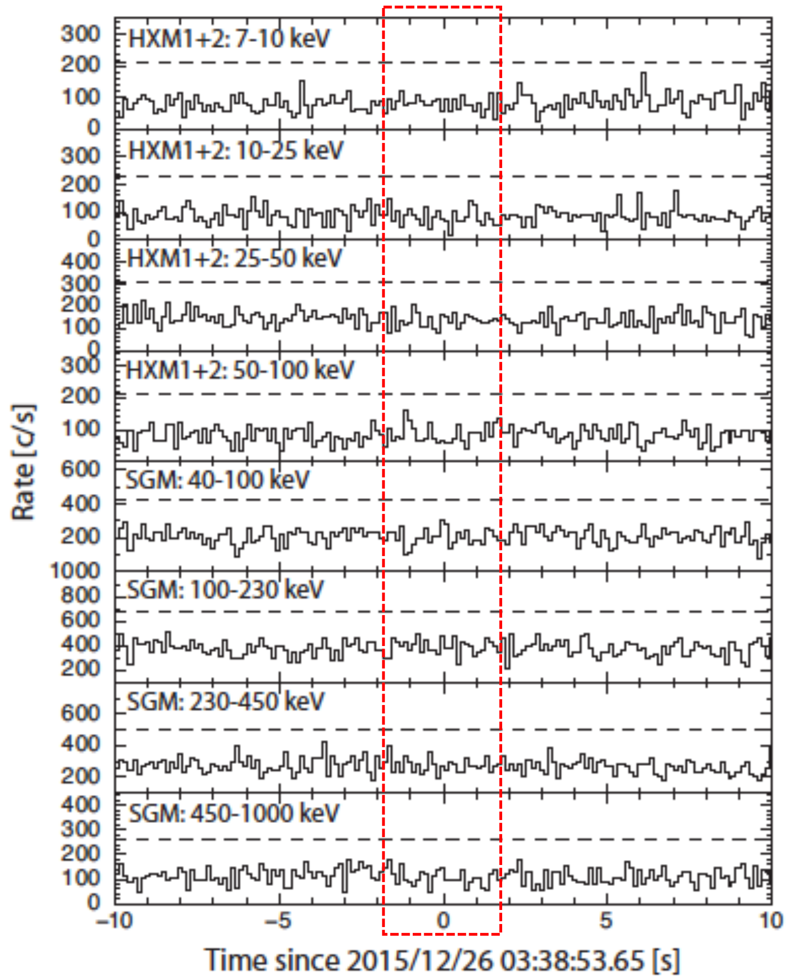


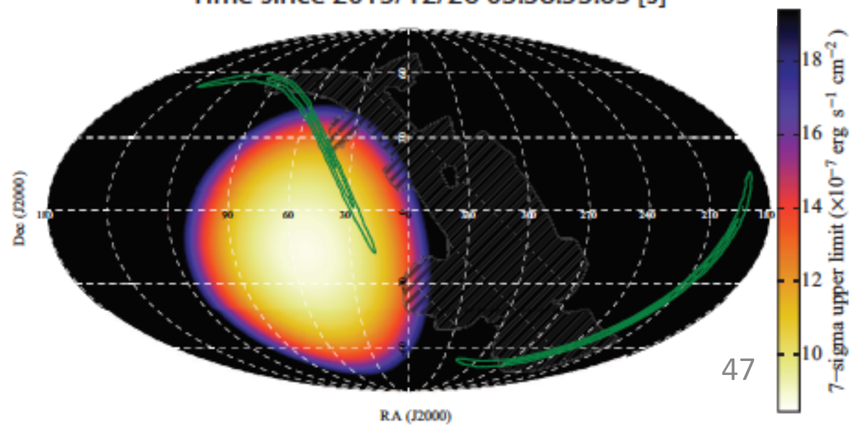
GW 151226



GW 151226

CALET-GBM

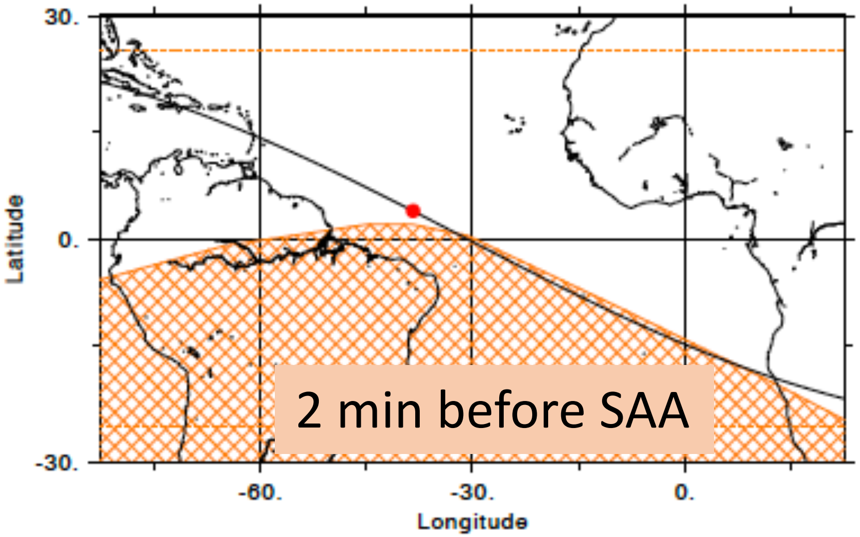




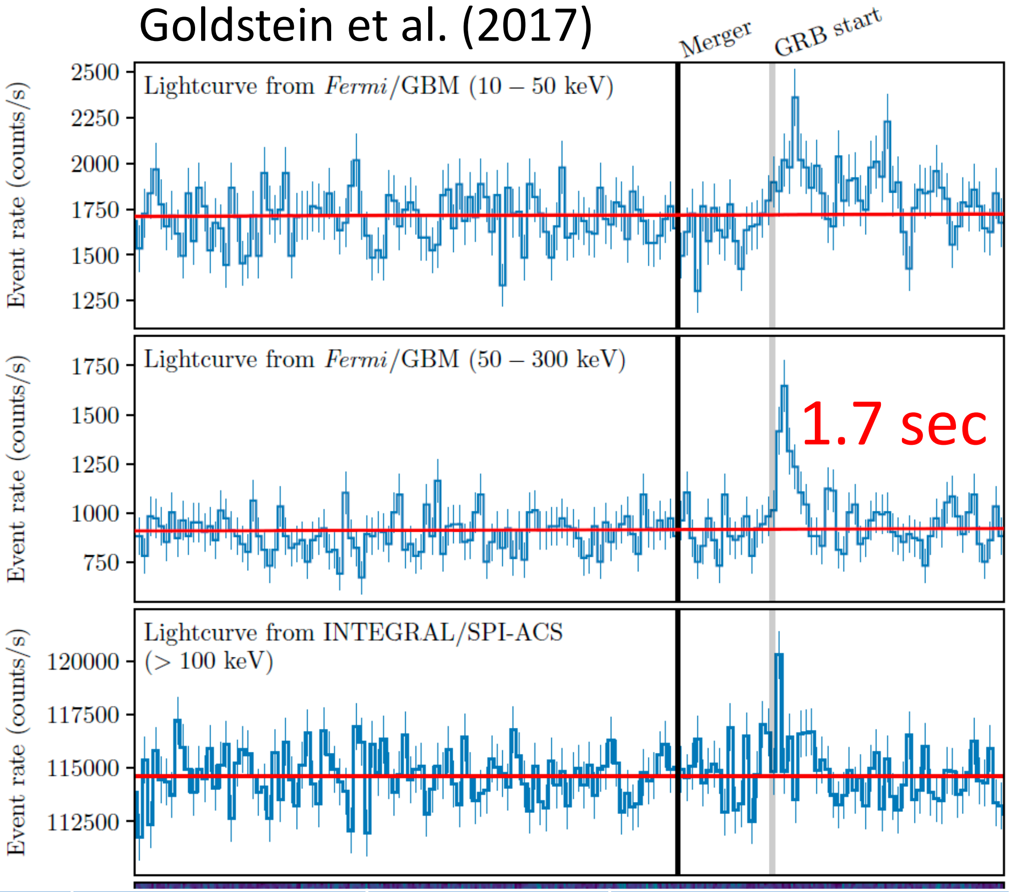
EM counterparts for NS-NS (GW 170817/GRB 170817A)

GW 170817/GRB 170817A

First detection of gamma-ray emission from NS-NS associated with GW.

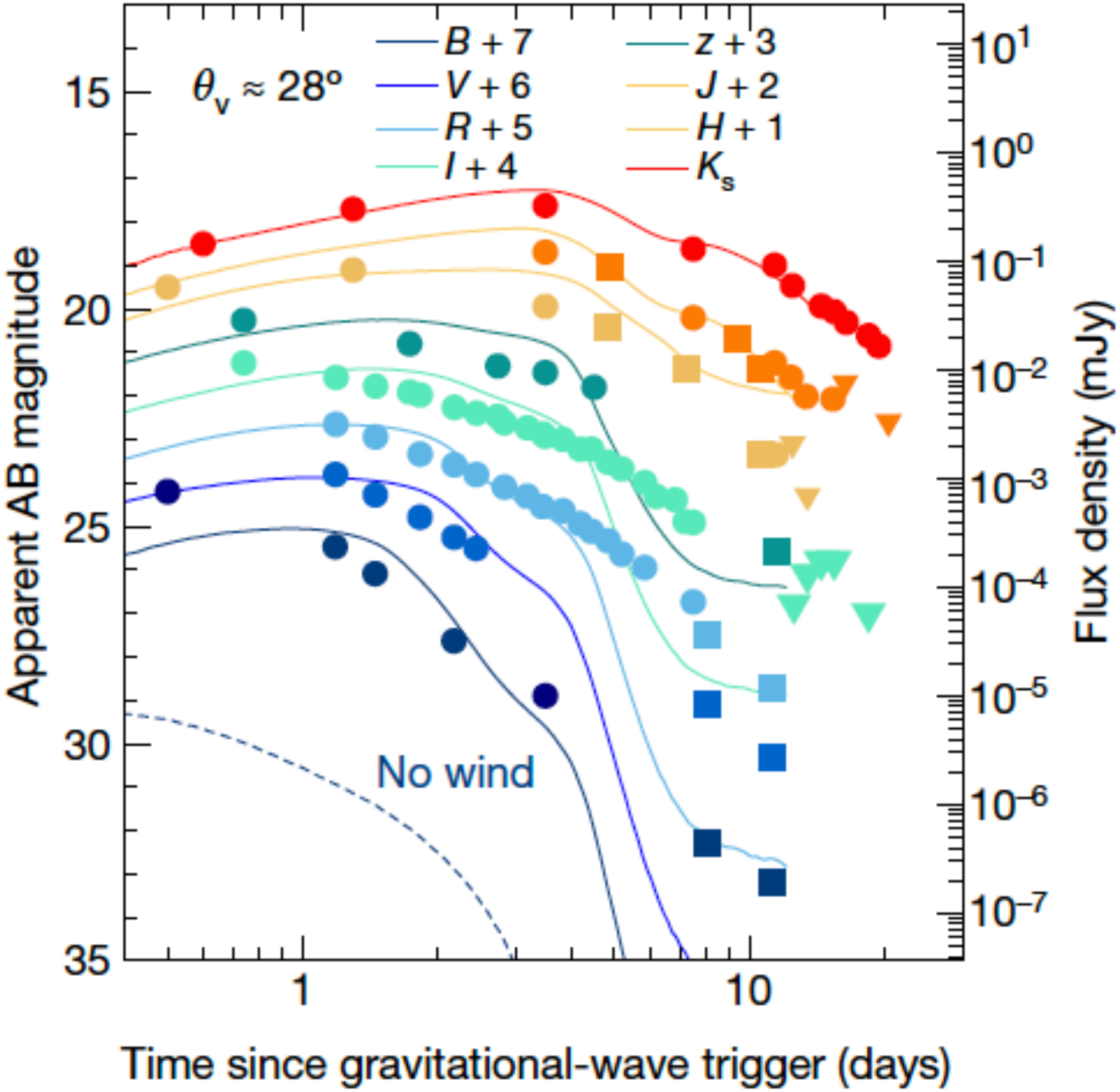


Goldstein et al. (2017)



	Duration (sec)	Spectral Index	Energy (keV)	Flux ($erg/cm^2/s$)	Fluence (erg/cm^2)	Reference
Main peak	~ 0.5	-0.62+/- 0.40	E_{peak} = 185 +/- 62	3.1E-7	1.8E-7	Goldstein et al. (2017)
Soft tail	~ a few	–	kT = 10.3+/-1.5	5.3E-8	6.1E-8	Goldstein et al. (2017)
Main peak	~ 0.5	-1 +/- 0.2	E_{peak} = 240 (+130, -70)	4.8E-7		Begue et al. (2017)

Macronova/kilonova



Blue macronova

With rapid decline in time

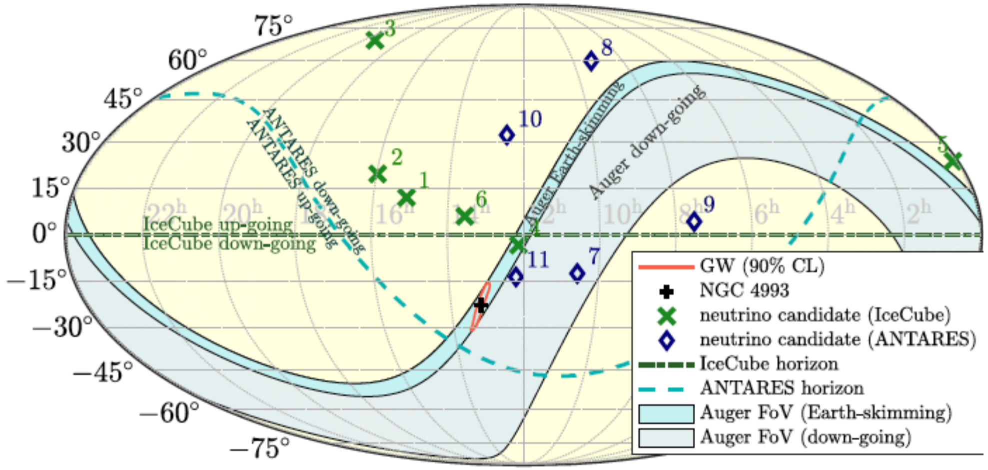
- jet direction
- light r-process
- ejecta/cocoon/wind ?

Red (IR) macronova

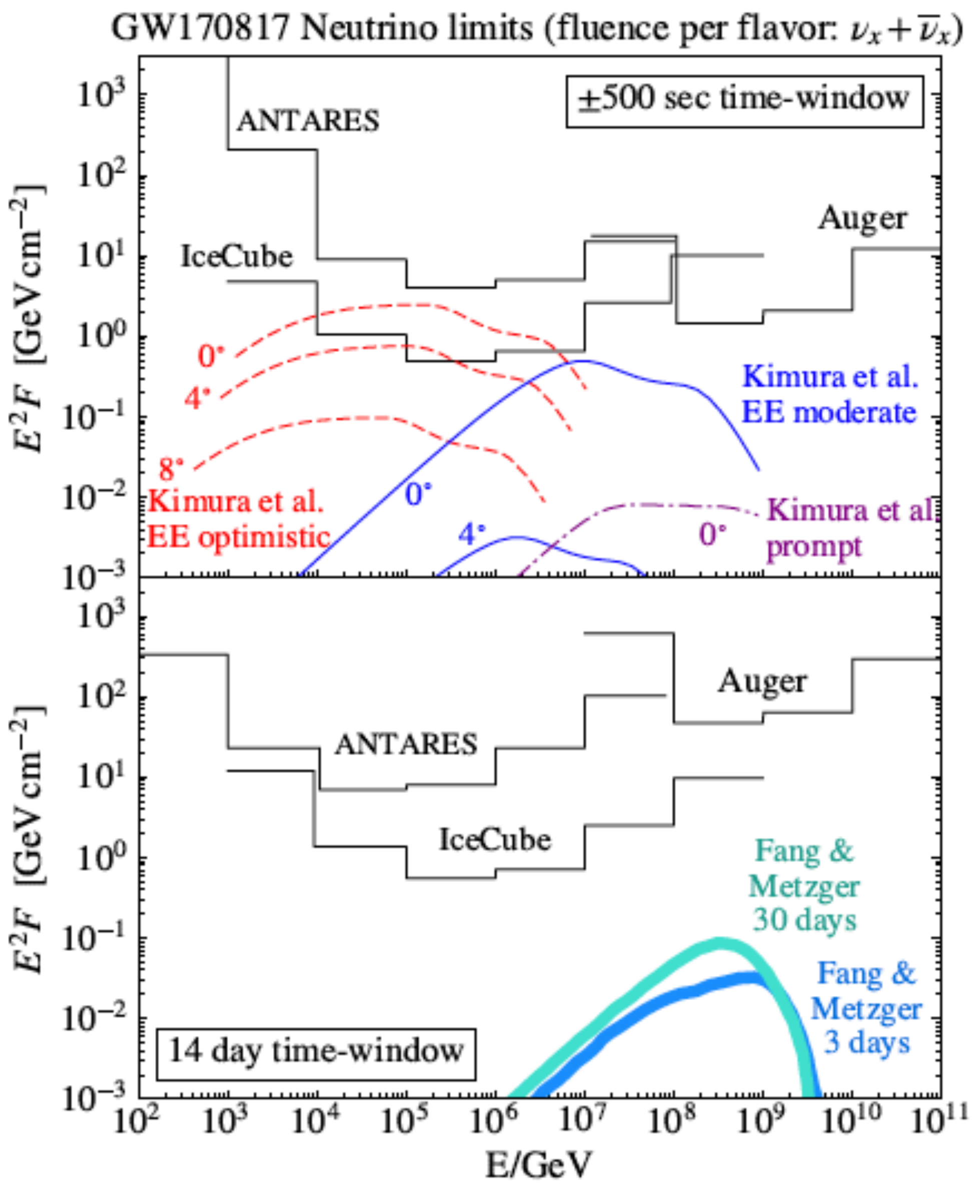
With rapid decline in time

- equatorial direction
- heavy r-process
- ejecta

Neutrino observations for GW 170817



Albert et al. 2017



ANTARES, IceCUBE, Pierre Auger

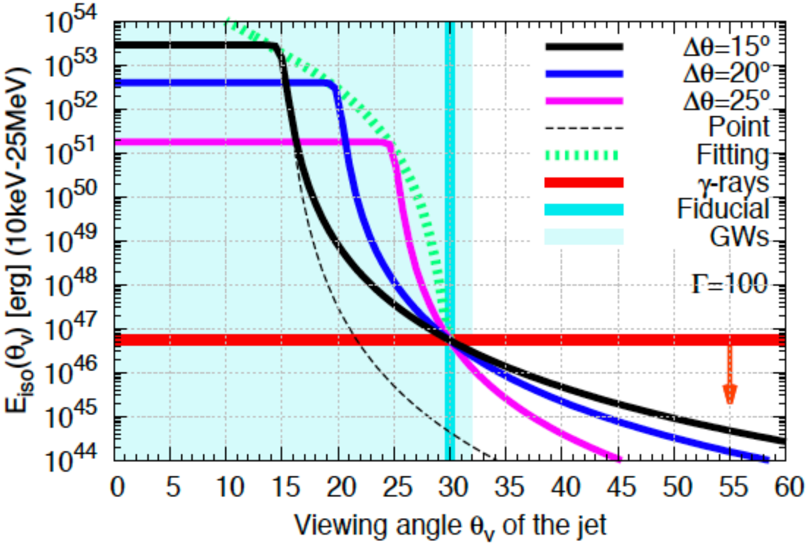
$10^{11} – 10^{20}$ eV energy range

+/- 500 sec window: No detection

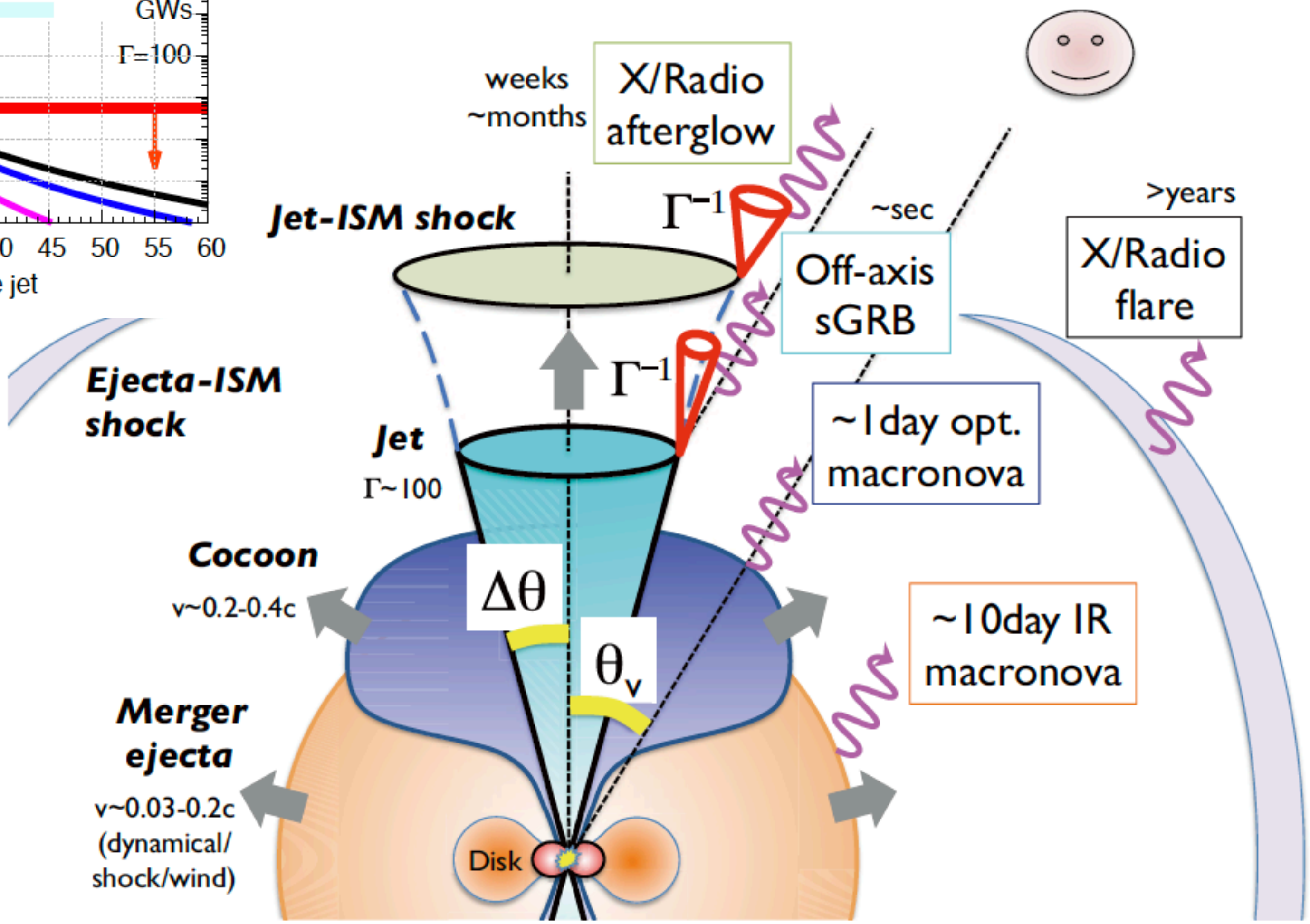
14 days window: No detection

Optimistic model was constrained

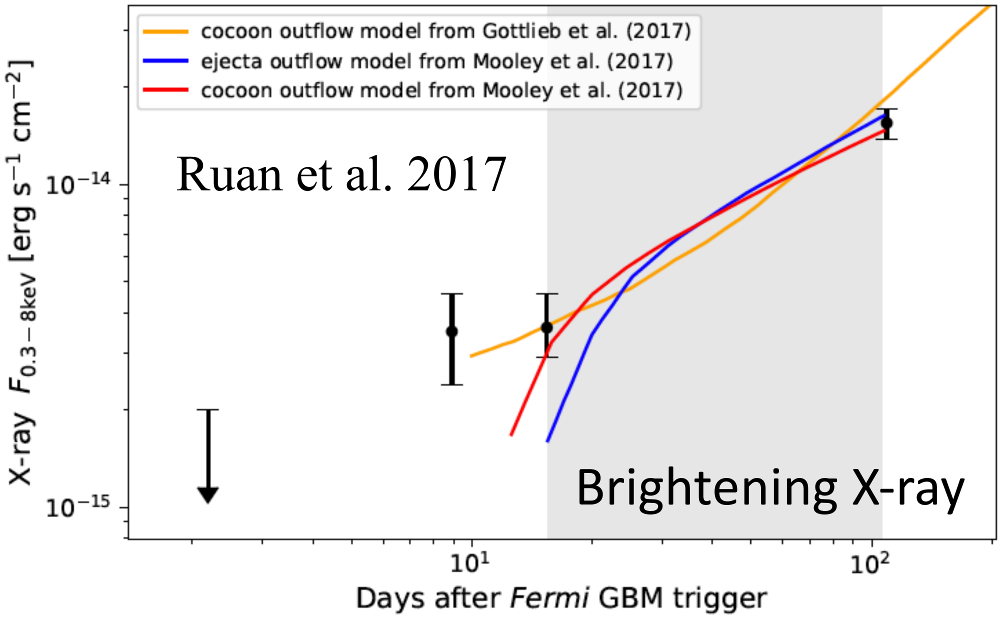
Unified Picture of GW 170817/GRB 170817A

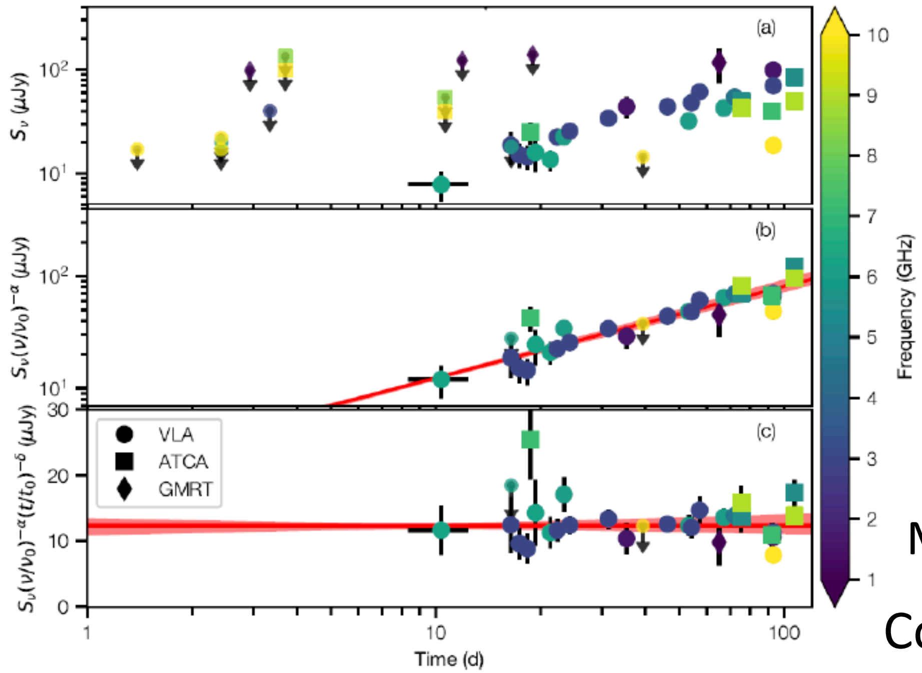


Ioka & Nakamura (2017)

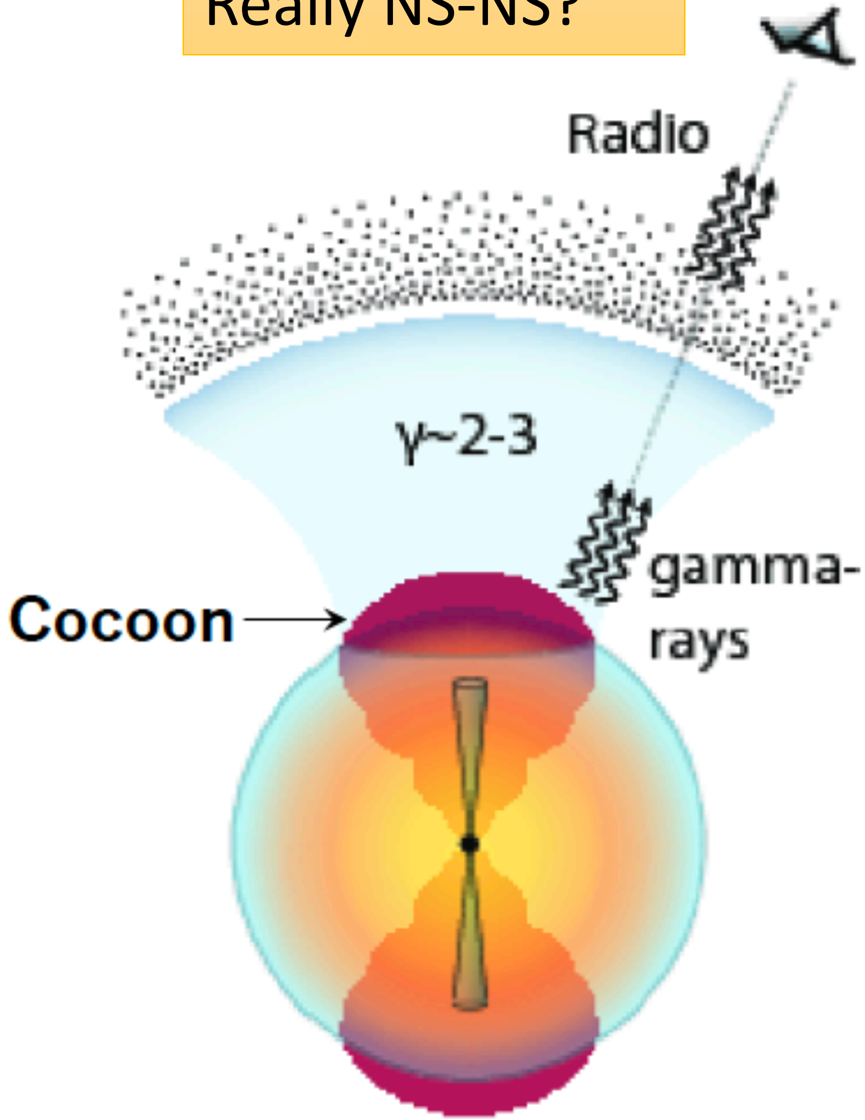


Late time EM emission





Origin of SGRB is Really NS-NS?

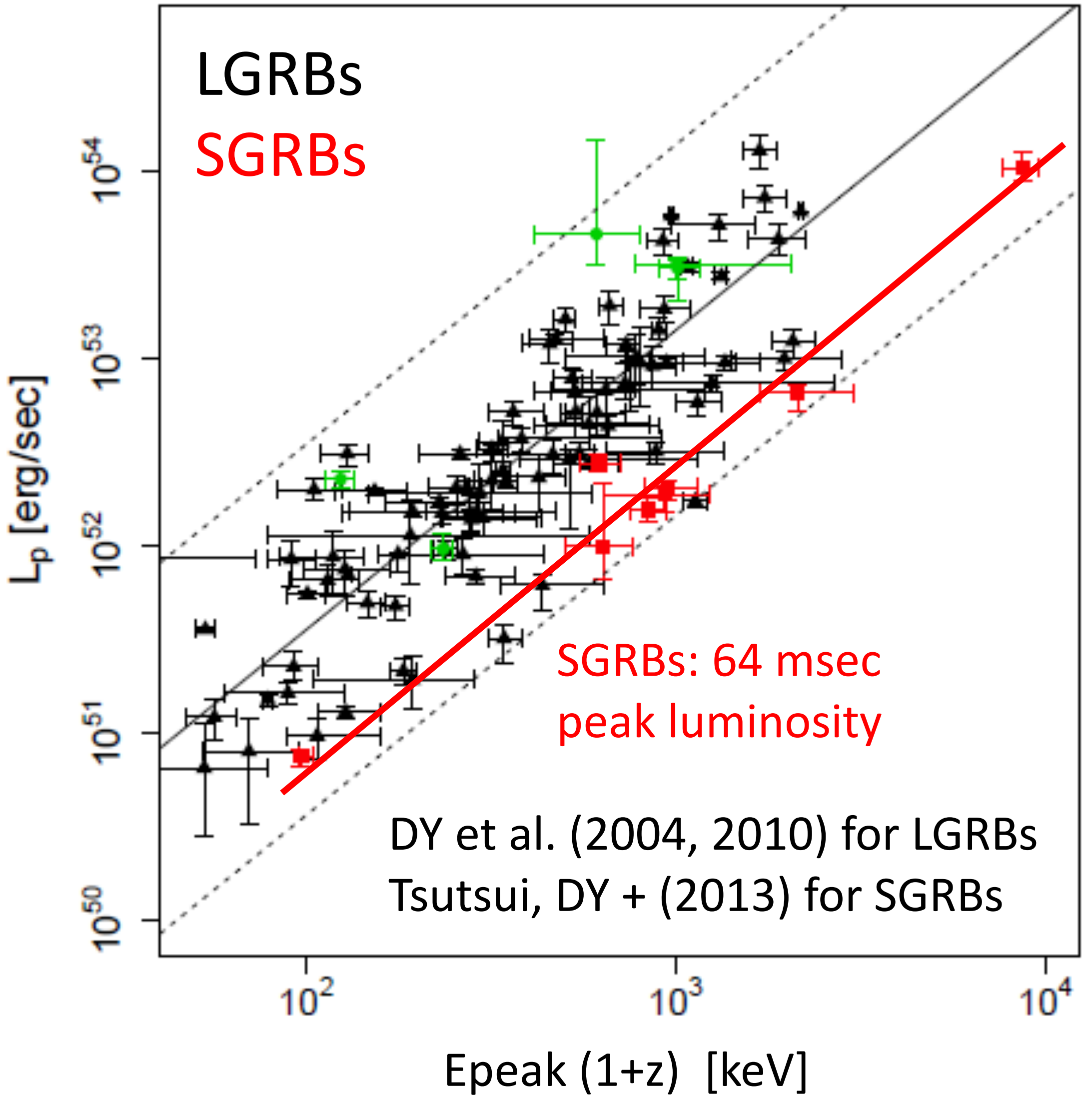


Mooley et al. (2017)

Continuously rising radio

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

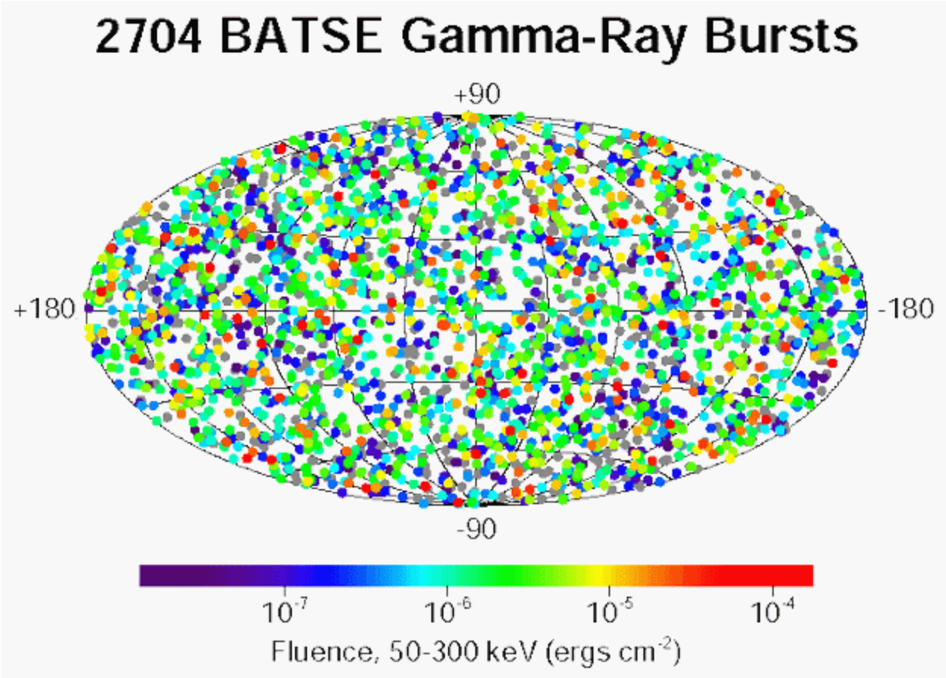
CGRO/BATSE current burst catalog

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

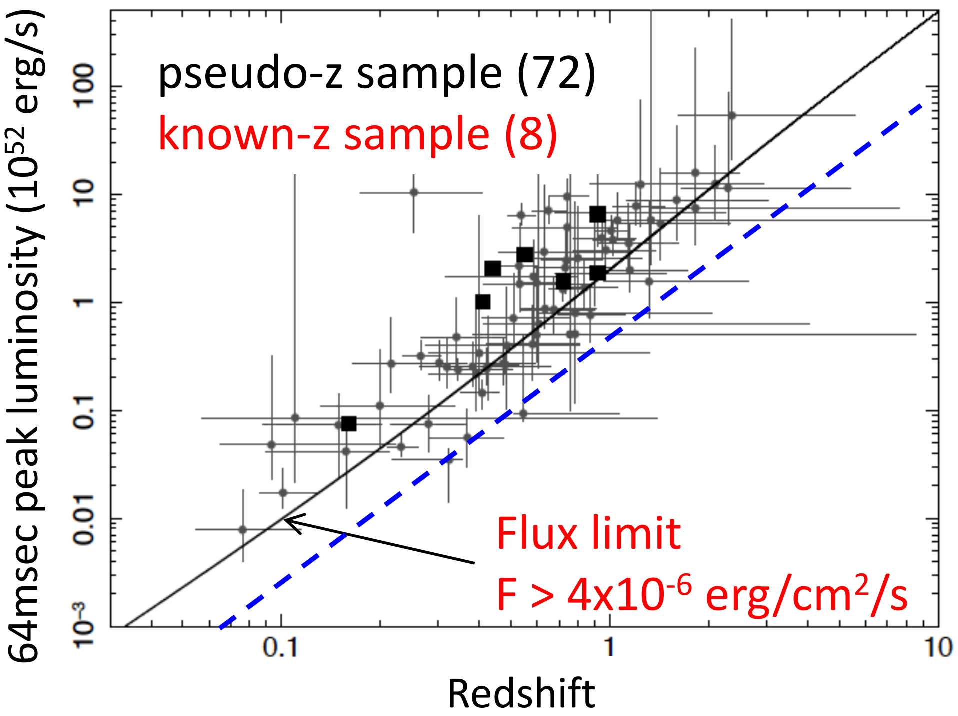
(2) Spectral parameters are obtained
for 72 SGRBs.
(for remaining 28, poor statistics
and variable BGD condition)

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

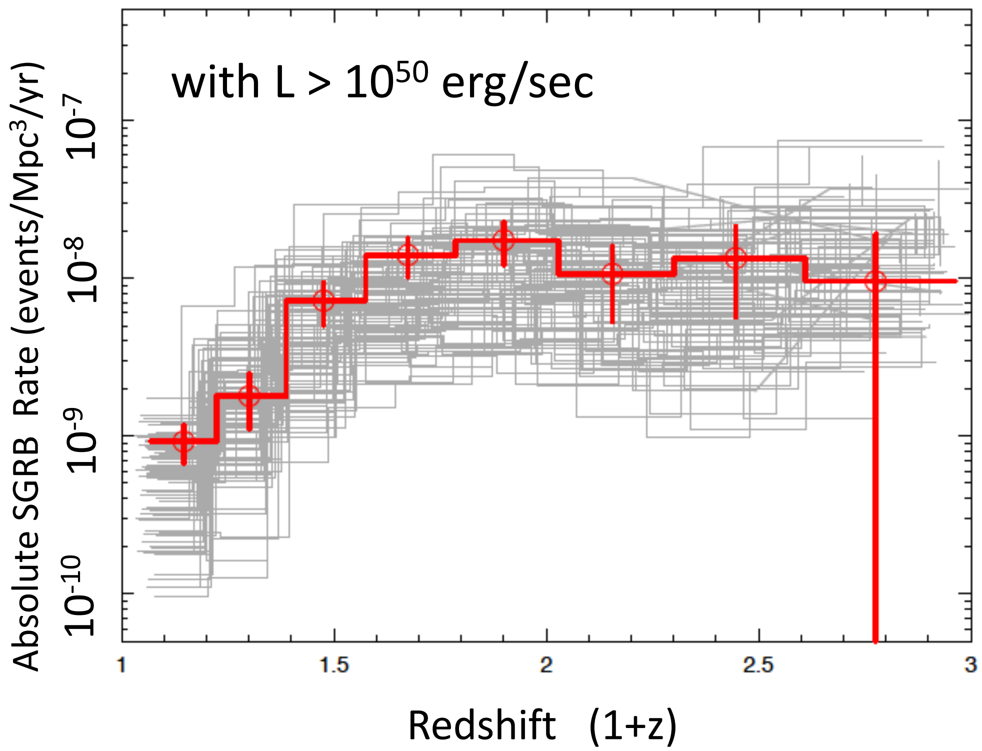
BATSE life time = 9.2 years
Fraction of sky coverage = 0.483
Trigger efficiency > 99.988 % for F = 1 ph/cm^2/s
Effective life time = 4.4 years

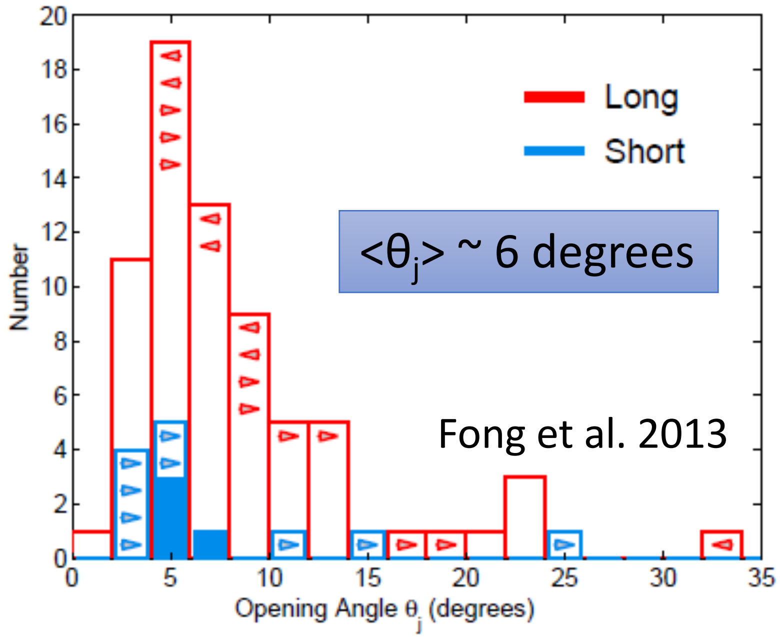


Redshift Distribution



SGRB Formation Rate





We used a non-parametric method.

(Lynden-Bell 1971, Petrosian 1993, etc.)

Local Rate including geometrical factor

> 1.2×10^{-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 $(200\ Mpc)^3$

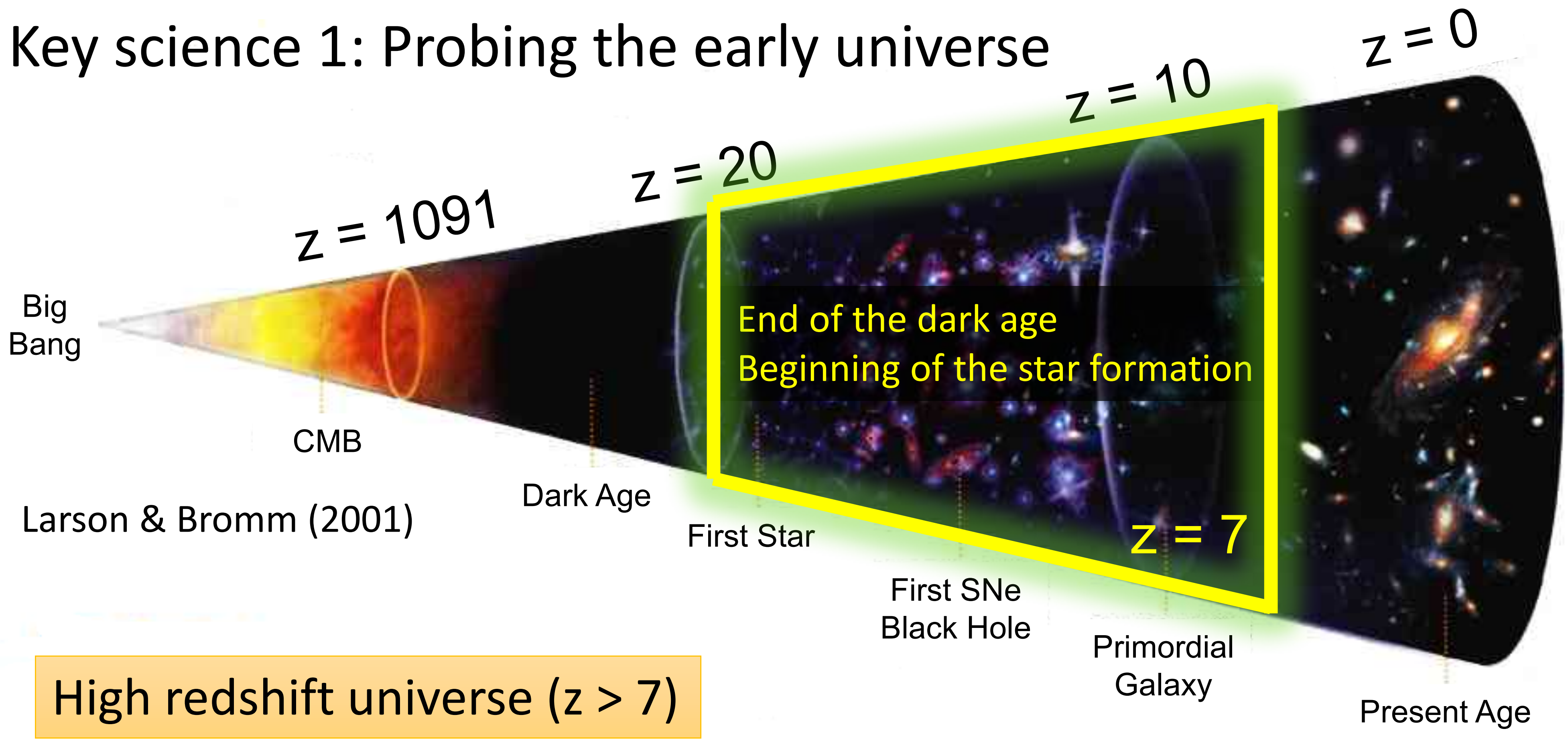
600 events/year : NS-BH in $(670\ Mpc)^3$

HiZ-GUNDAM

High-z Gamma-ray bursts for Unraveling the Dark Ages Mission

Daisuke YONETOKU (Kanazawa University)
HiZ-GUNDAM working group

Key science 1: Probing the early universe



High redshift universe (z > 7)

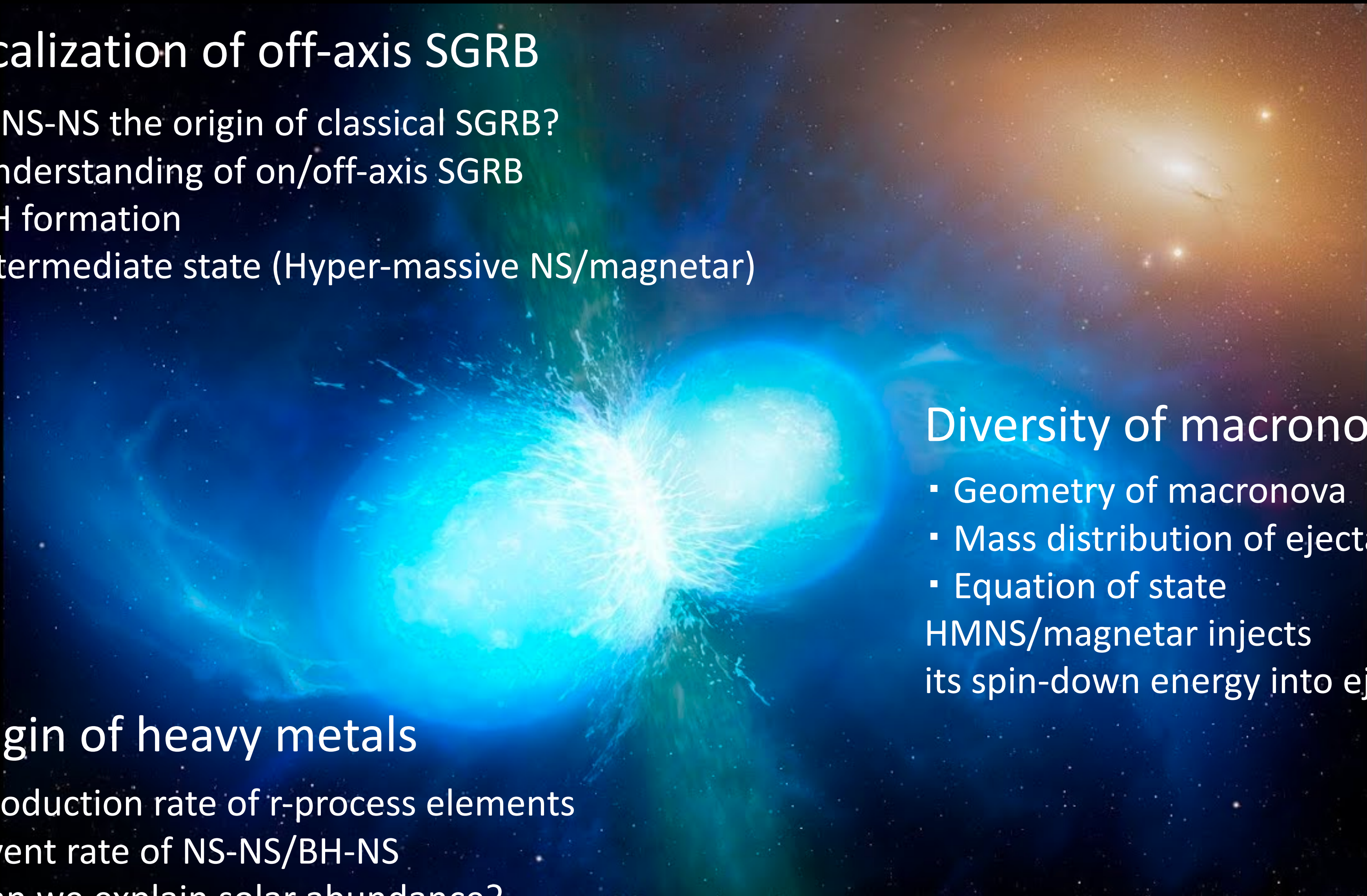
- Formation of first stars (Pop-III stars) → Massive stars → GRBs
- Cosmic reionization ← UV radiation (Massive stars)
- First metal production ← Nucleosynthesis (Massive stars)
- First black hole formation ← explosion (GRBs)

↓

Evolution to super massive BH?

GRBs as a cosmological probing tool.

Key science 2: GW astronomy
From discovery to understanding



Localization of off-axis SGRB

- Is NS-NS the origin of classical SGRB?
- Understanding of on/off-axis SGRB
- BH formation
  intermediate state (Hyper-massive NS/magnetar)

Diversity of macronova

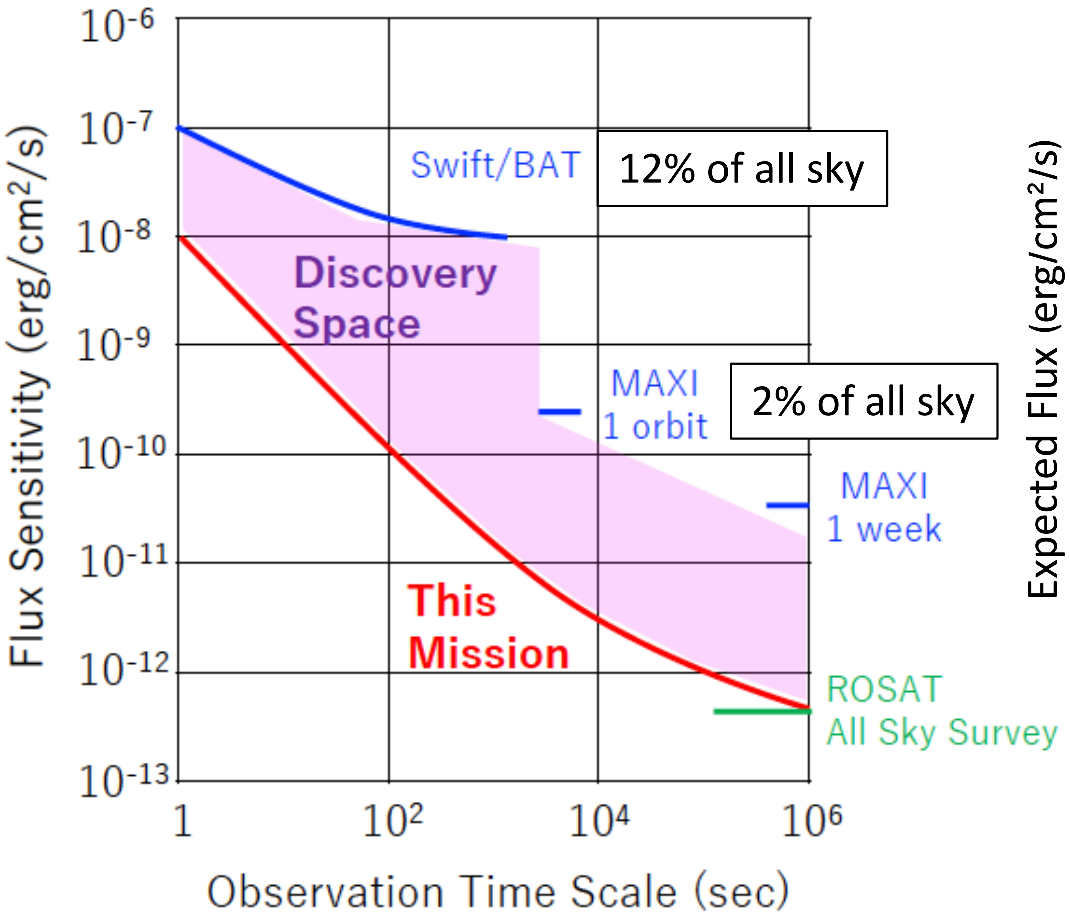
- Geometry of macronova
- Mass distribution of ejecta
- Equation of state

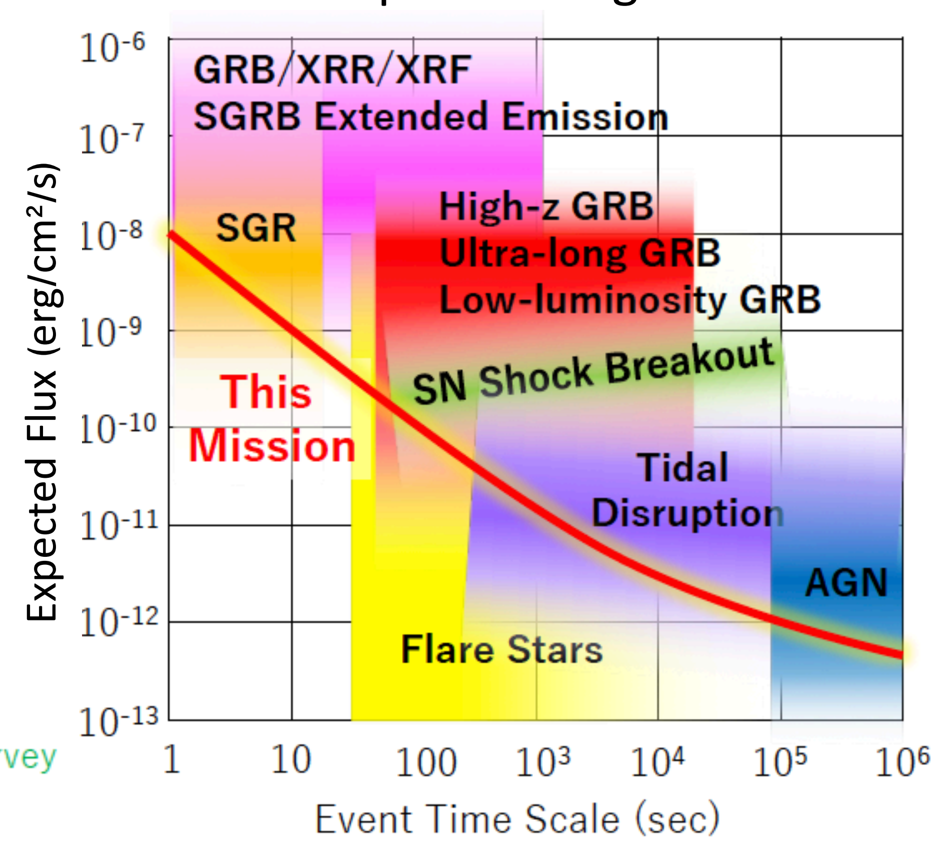
HMNS/magnetar injects
its spin-down energy into ejecta

Origin of heavy metals

- production rate of r-process elements
- event rate of NS-NS/BH-NS
- Can we explain solar abundance?

Discovery Space of Time Domain Astronomy

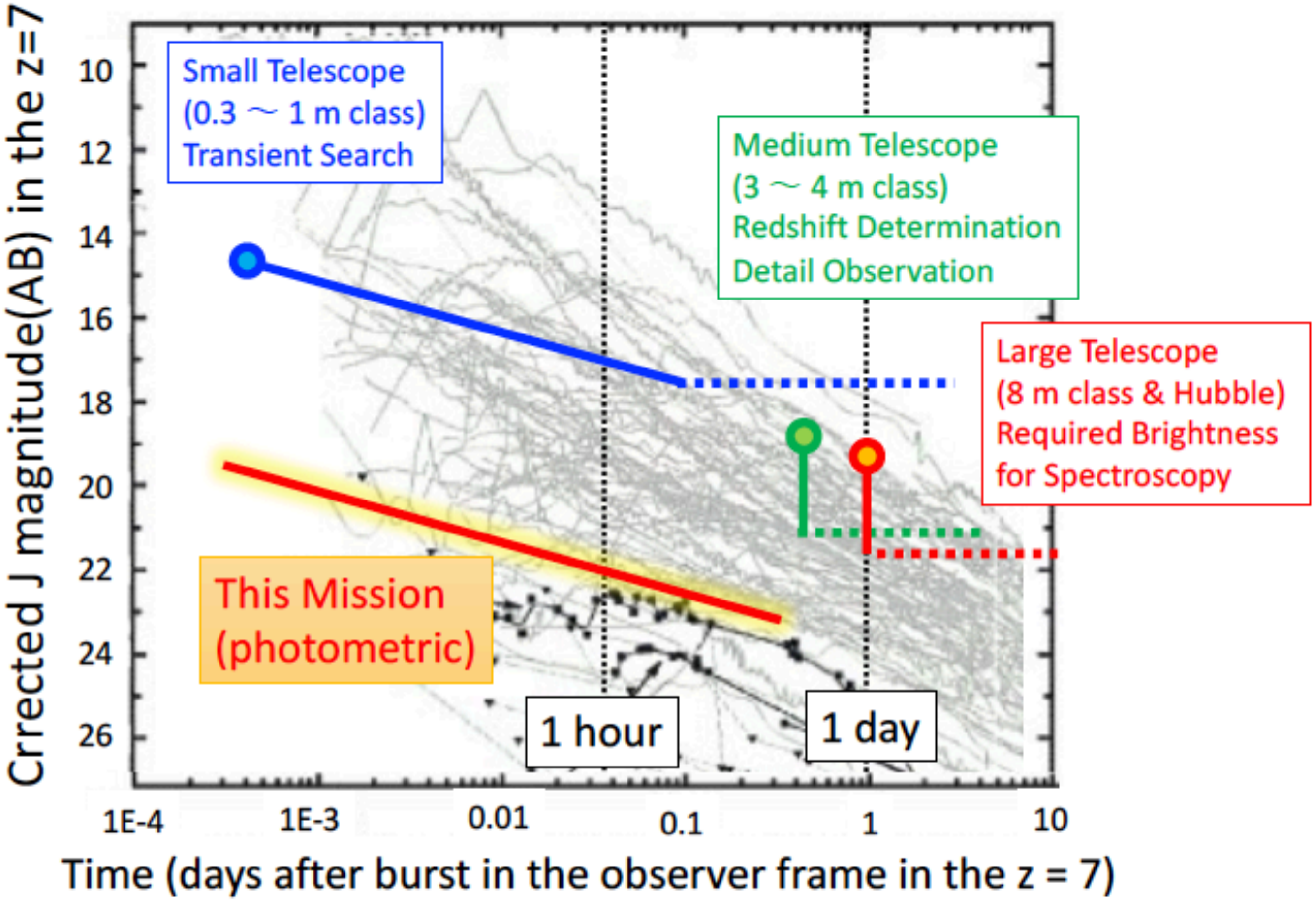




You may enable to perform “timing correlation analysis” for XRF, Low-luminosity GRB, SN shock breakout, and so on.

Time scale of general GRB observation

(1) Discovery of GRB: in space
(2) ~ a few hours later: Afterglow search with the small telescope (0.3 ~ 2 m)
(3) Half a day to 1 day: redshift measurement and physical property
Spectroscopic/photometric observation with the medium telescope (3 ~ 4 m)
(4) After 1 day ~: high dispersion spectroscopy
Observation with a large telescope only if the event is interesting

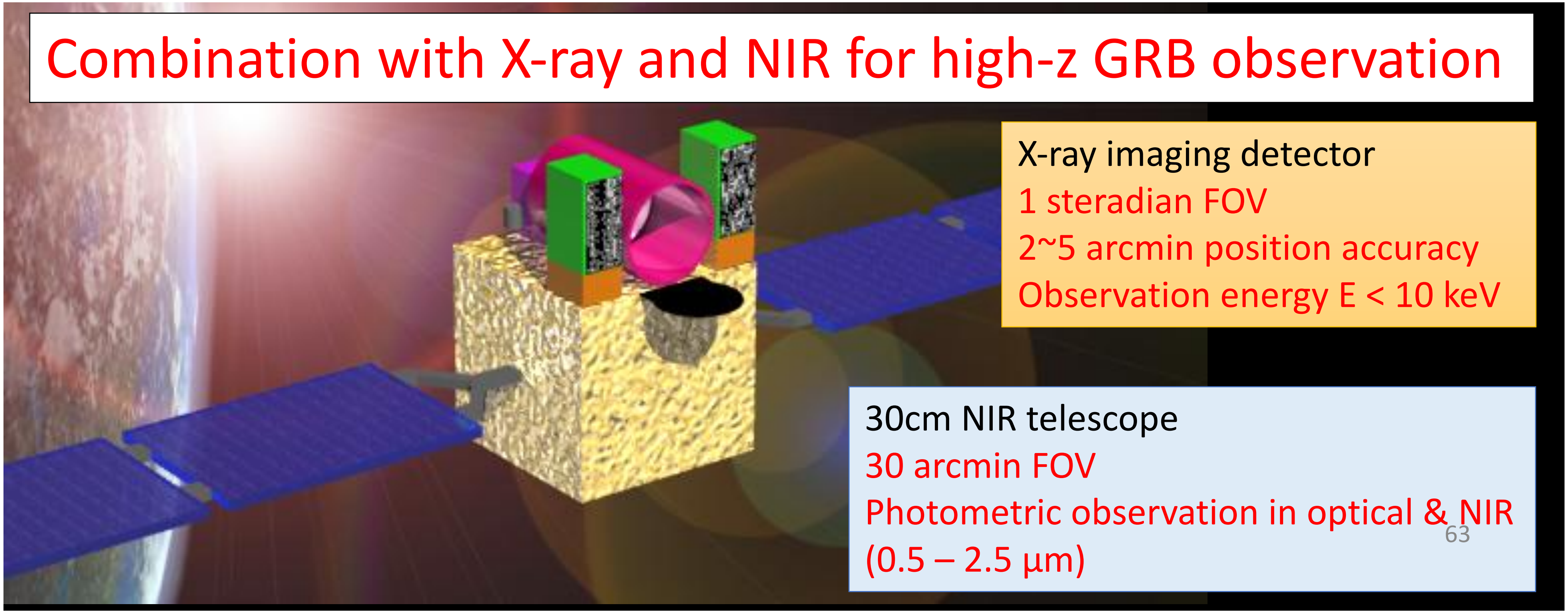


HiZ-GUNDAM observation strategy

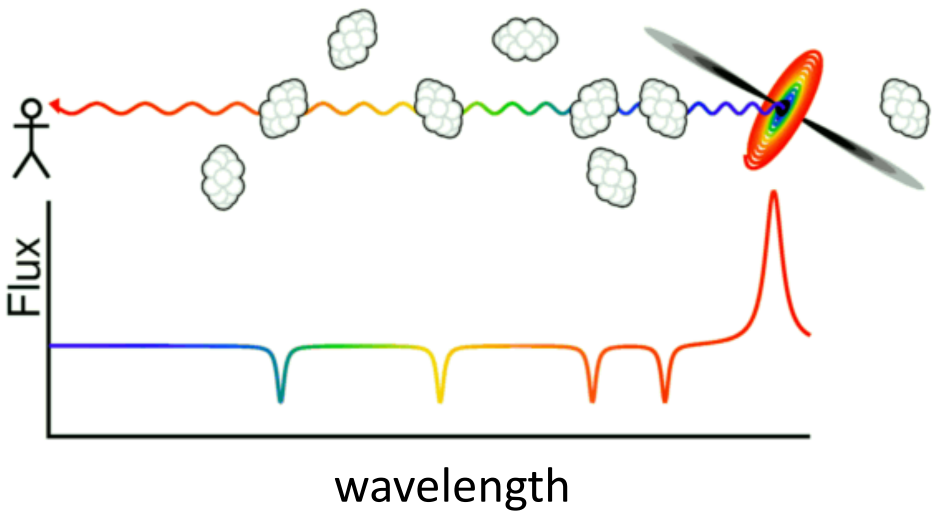
(1) GRB discovery in X-ray band, and send 1st alert of the localization.
(2) Automatically start follow-up obs. with near infrared telescope.
(3) 2nd alert of fine localization (~ 1”) and rough redshift (z>5 or z>7).

after that,

(4) Spectroscopic observation with large area telescopes.



Probing the Reionization History



Lyα (n=1 → n=2) absorption feature of neutral hydrogen (1216 Å)

Column density : $\Sigma < 10^{13}$ cm^{-2} → Lyα forest

The Gunn-Peterson Trough

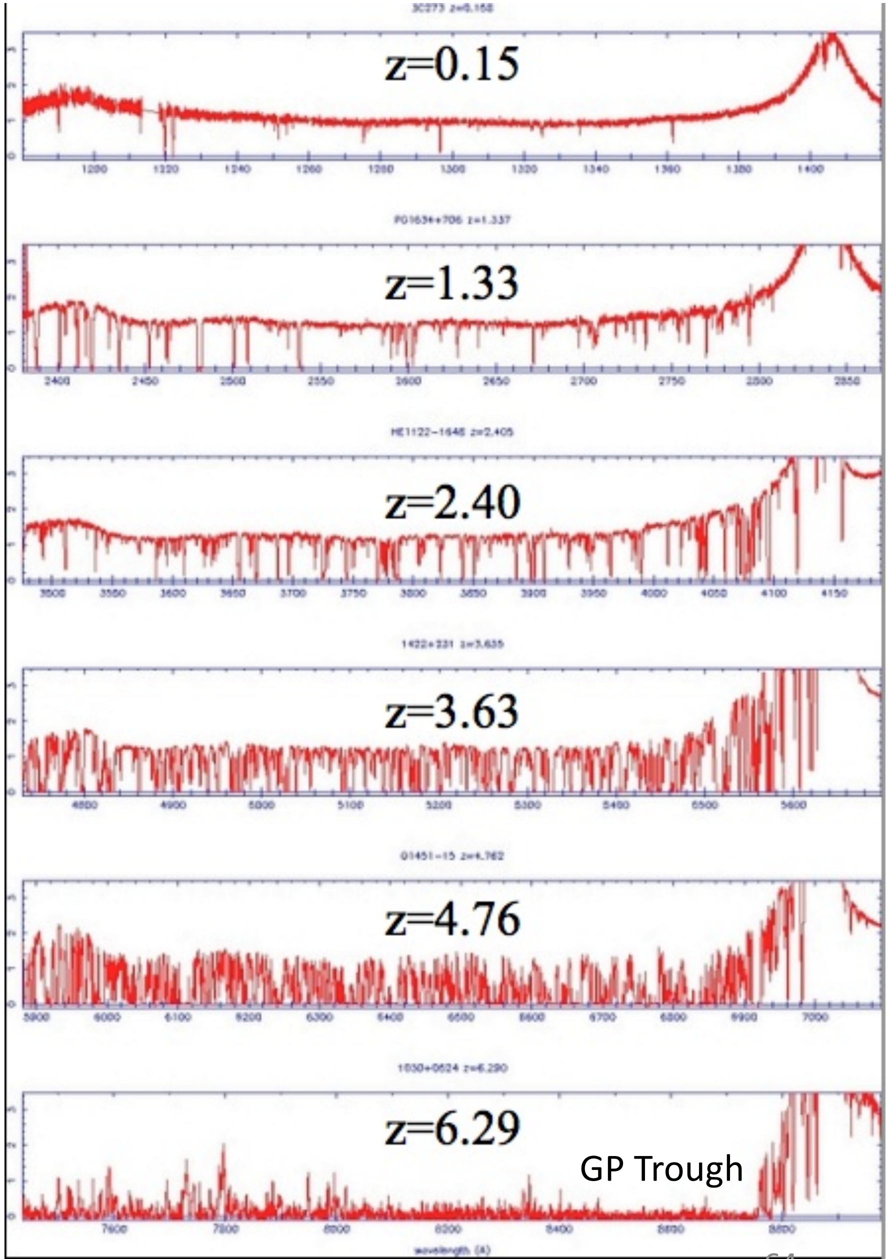
= IGM is still neutral ??

= End of reionization ??

- Complete absorption for QSOs at z > 6
- Neutral fraction of H_I is $x_{HI} > 10^{-3}$

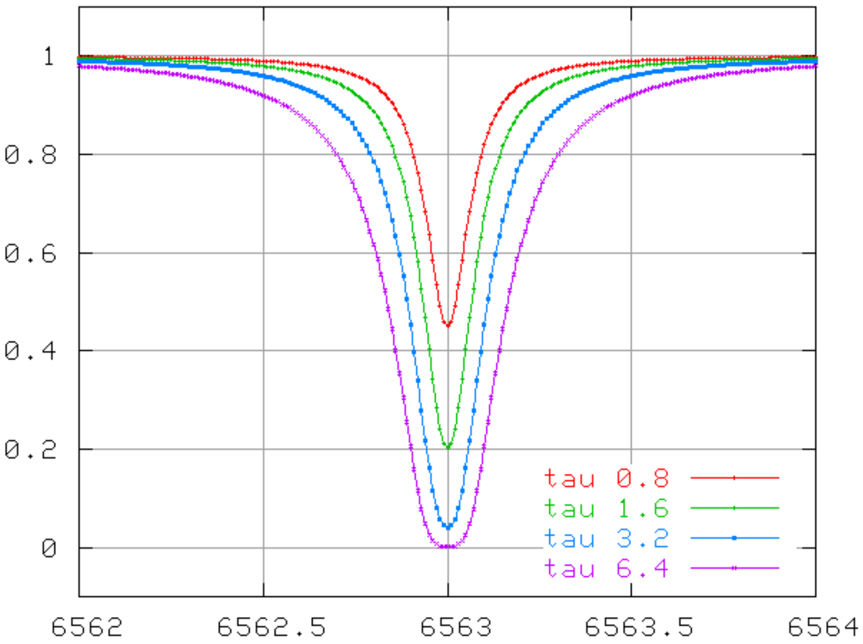
it may be difficult to measure the higher neutral fraction degree with Gunn-Peterson Trough. We may need an alternative method.

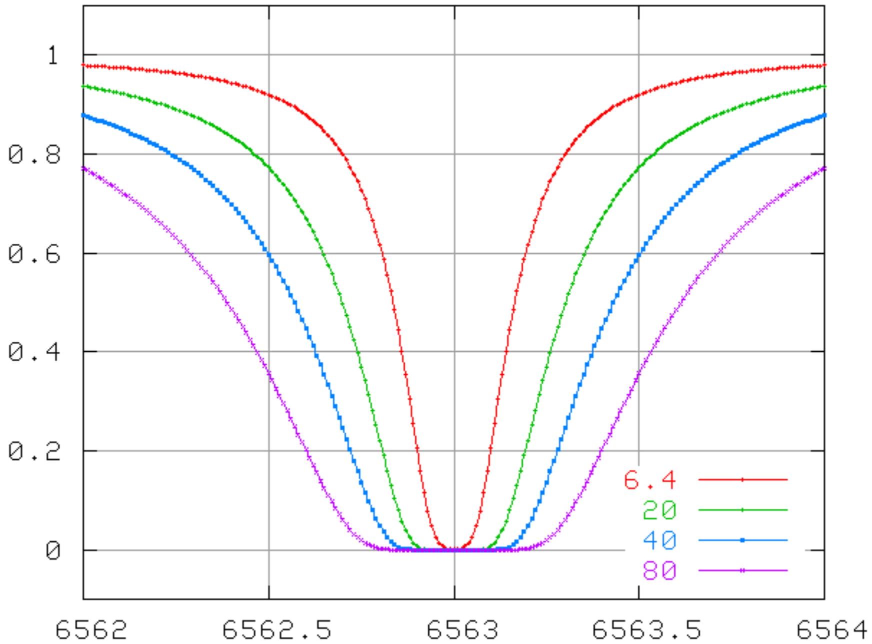
Lyman-a Forest & Gunn-Peterson Trough



Probing the Reionization History – 2

◆ Absorption feature = Lorentzian distribution





Lyα absorption cross-section : Peebles (1993), section 23

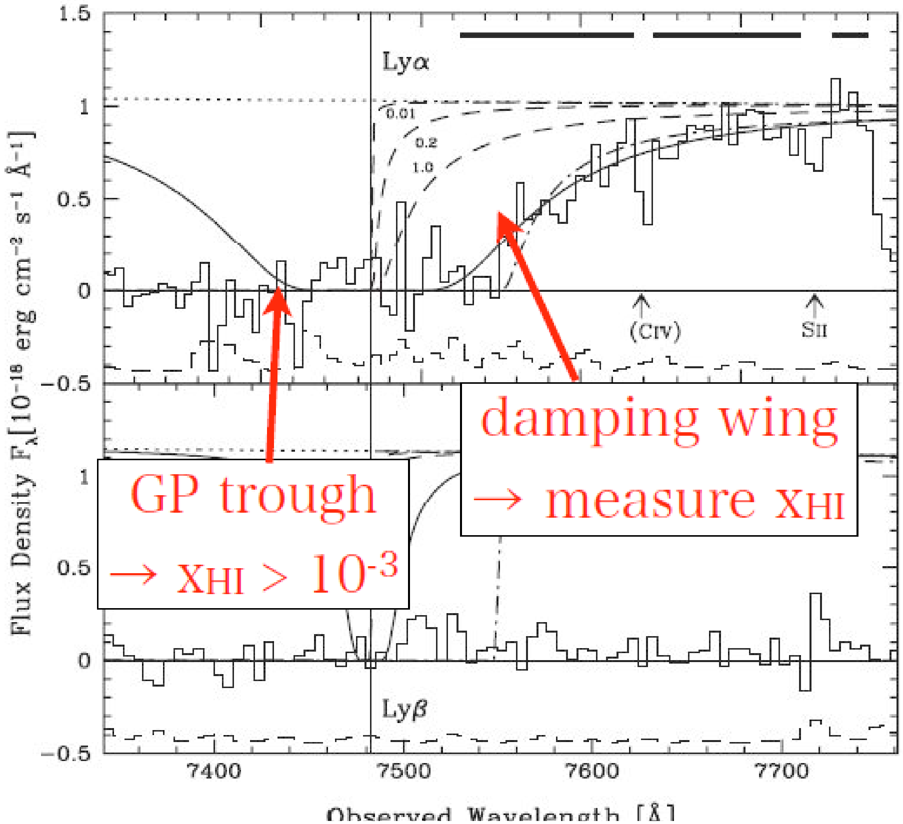
$$\sigma(\omega) = \frac{3\lambda_\alpha \Lambda^2}{8\pi} \frac{(\omega/\omega_\alpha)^4}{(\omega - \omega_\alpha)^2 + \Lambda^2 (\omega/\omega_\alpha)^6/4}$$

In the case of high column density of $\Sigma \sim 10^{20}$ cm^{-2},
Damping wing structure can be observed. Miralda-Escude (1998)

Cosmic Reionization

GRB 050904 @ z = 6.295

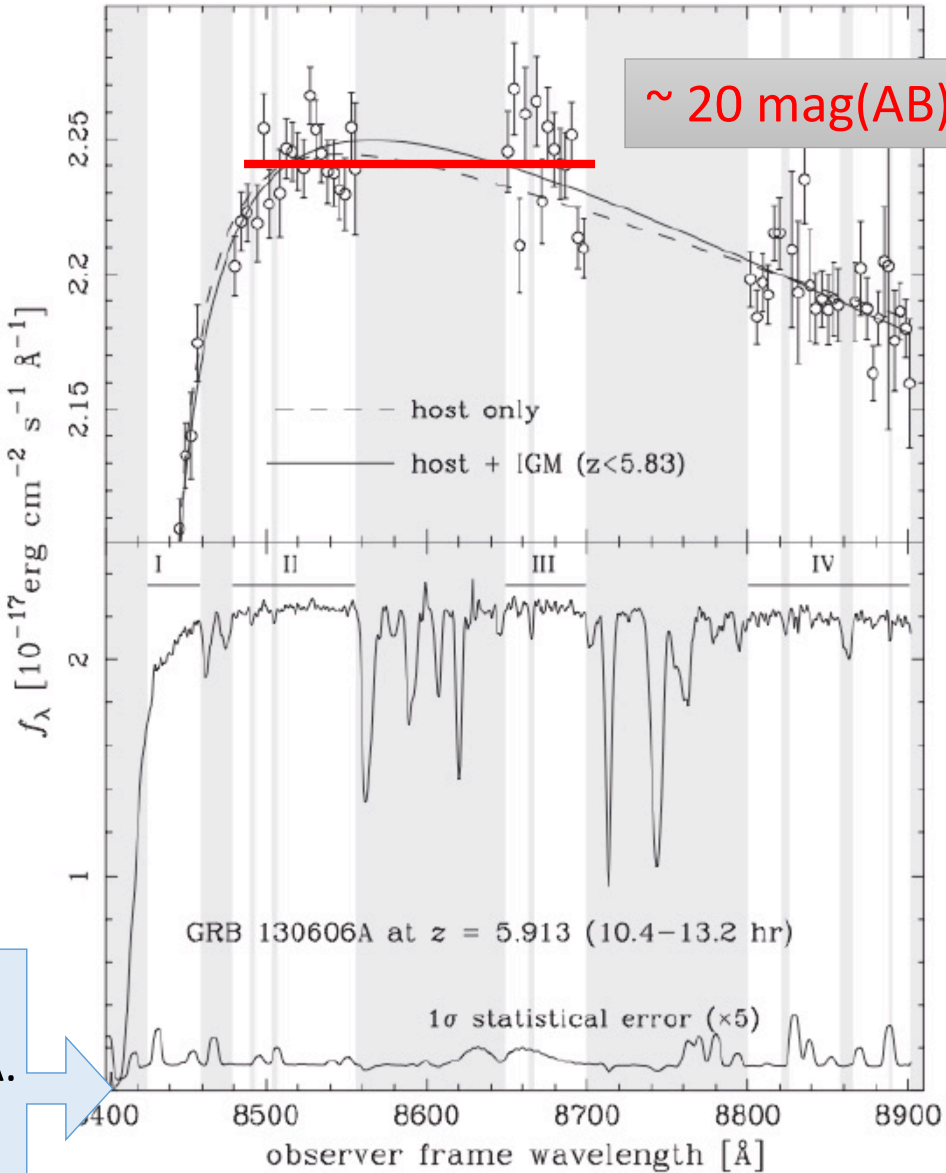
Kawai et al. (2006)
Totani et al. (2006)



x_{HI} < 0 .17 and 0.60 at 68 and 95%

The existence of neutral hydrogen was found more than 3 σ statistical level for GRB130606A. The neutral fraction of IGM is measured as x_{HI} = 0.1 – 0.5.

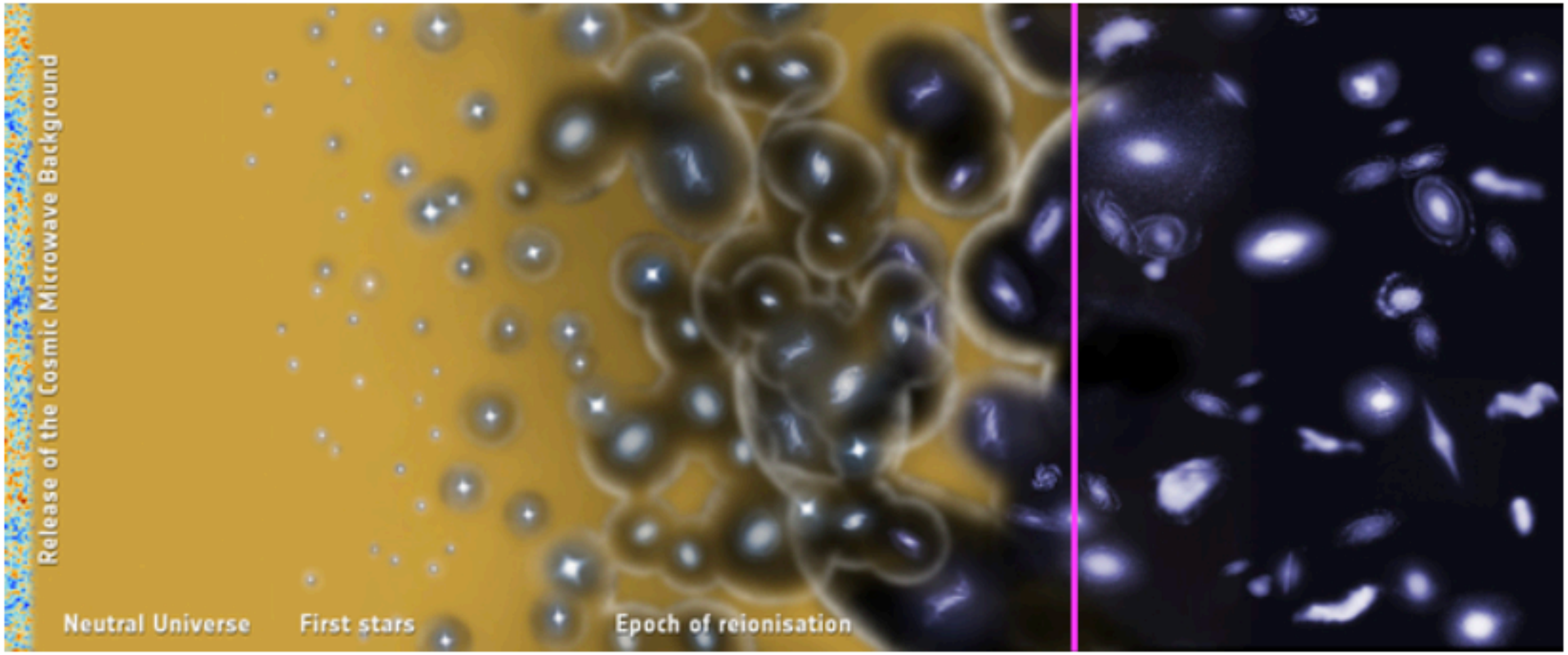
GRB 130606A @ z = 5.913



Totani et al. (2014)

Reionization History of the Universe

Big Bang



z ~ 1000 | First Star Formation | End of Reionization z = 8.8 (+1.7, -1.4) | z = 0

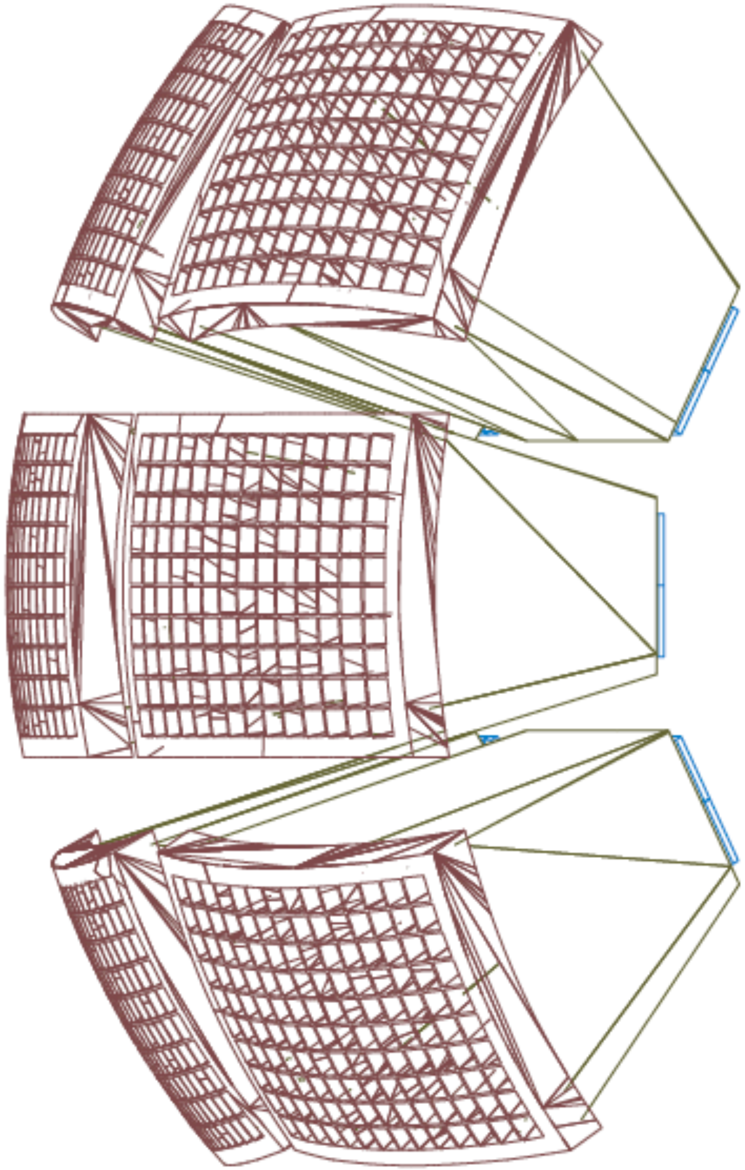
Merit

- GRB is transient phenomena → IGM is not affected by the progenitors
- Optical spectrum is simple power-law → Easy to measure the damping wing structure
- The host galaxy is dwarf gal. → Less biased observation

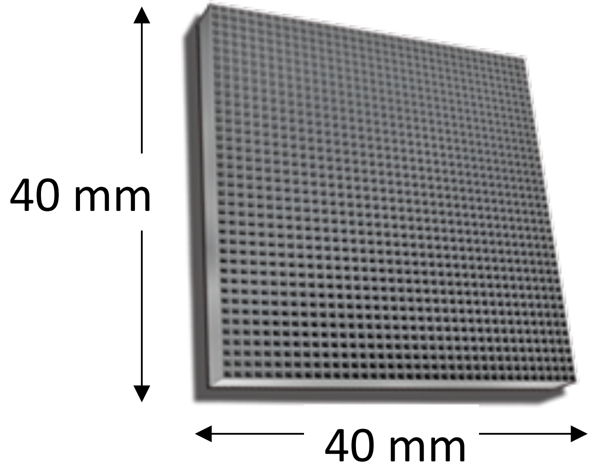
Demerit

- GRB is transient phenomena → Rapid follow-up observations are required

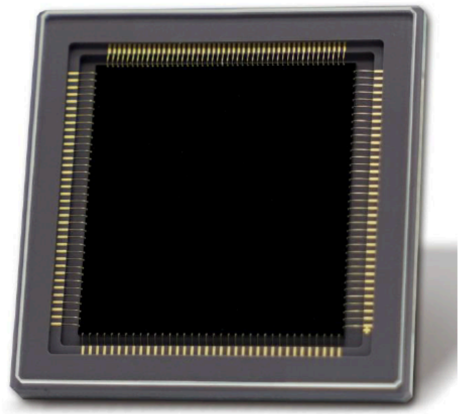
Wide Field X-ray Imaging Detector



Micro Pore Optics (Lobster Eye Optics)

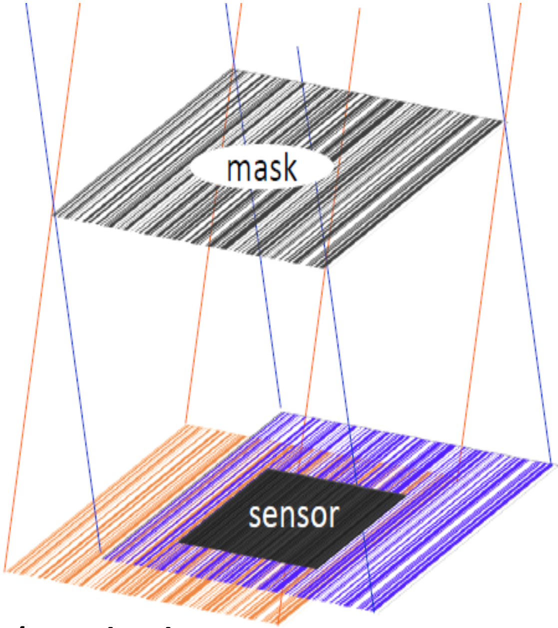


Backside Illuminated CMOS



	Wide field X-ray
Energy Band	0.5 ~ 4 keV
Field of View	> 1 str (full coded)
Position Accuracy	2 arcmin
Sensitivity	10^{-10} erg/cm^2/s (for 100 sec)

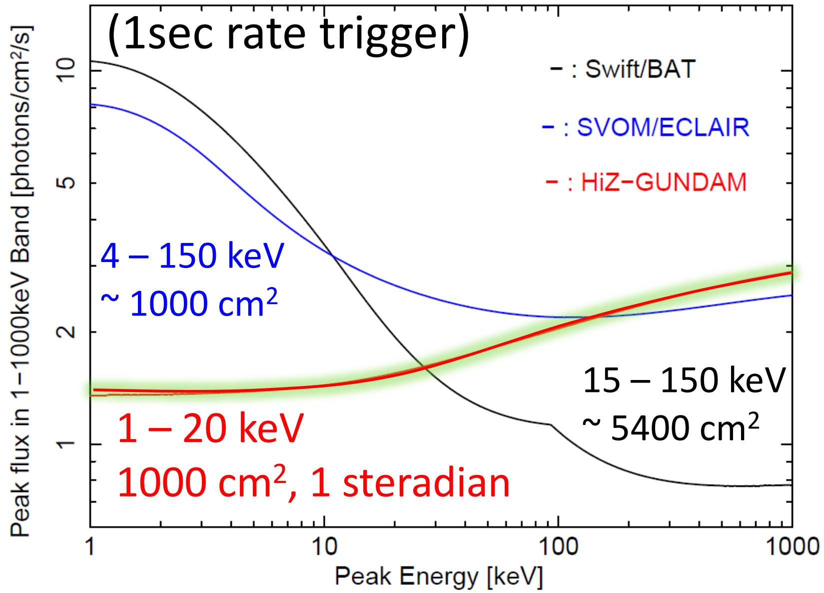
Alternative Wide Field X-ray Imaging Detector

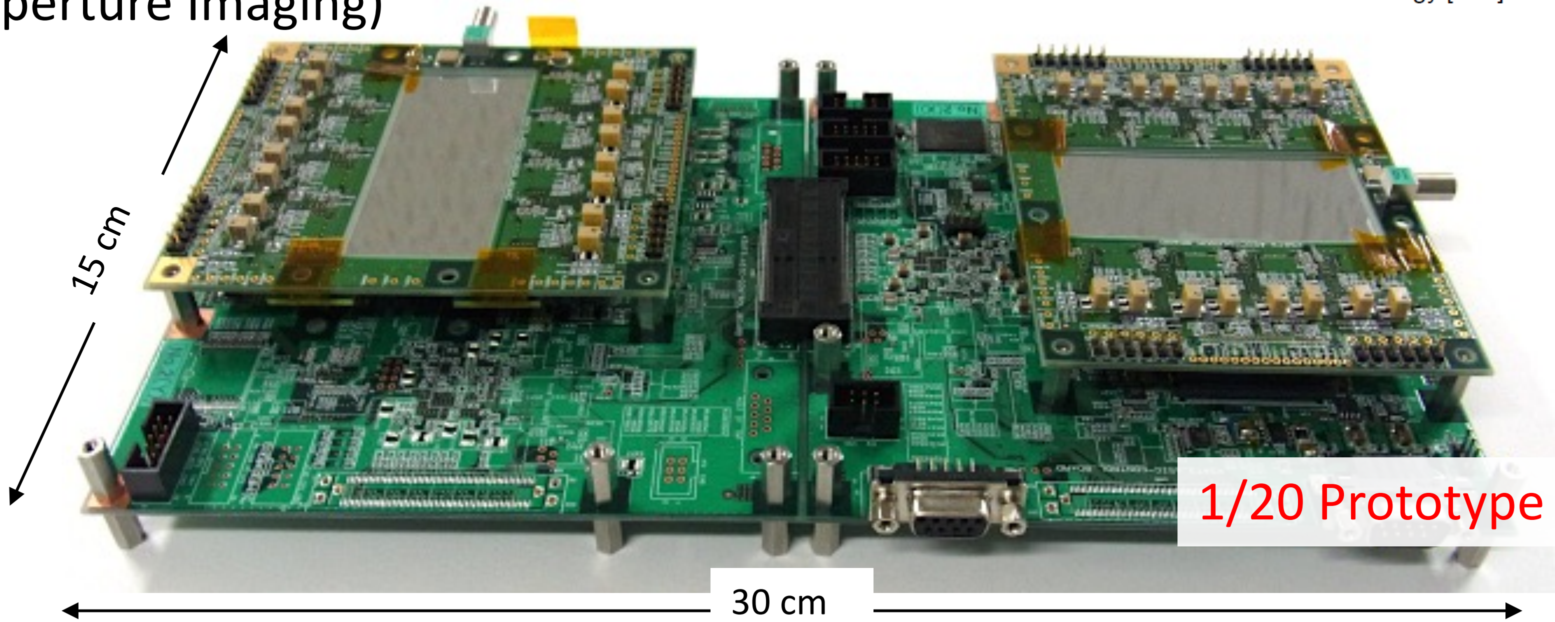


(Coded Aperture Imaging)

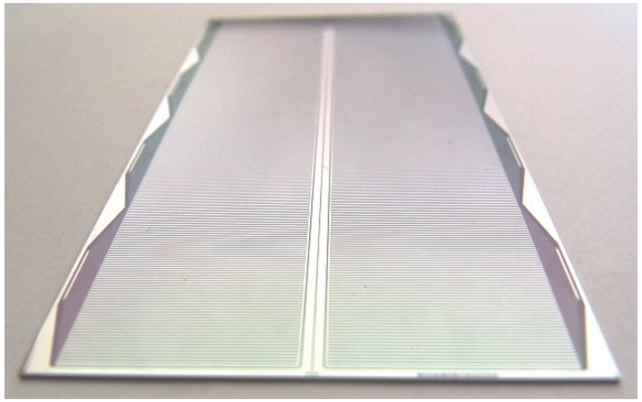
	Wide field X-ray
Energy Band	1 ~ 20 keV (goal)
Detector Area	1,000 cm^2
Field of View	> 1 str (full coded)
Position Accuracy	5 arcmin
Sensitivity	10^{-9} erg/cm^2/s (for 100 sec)

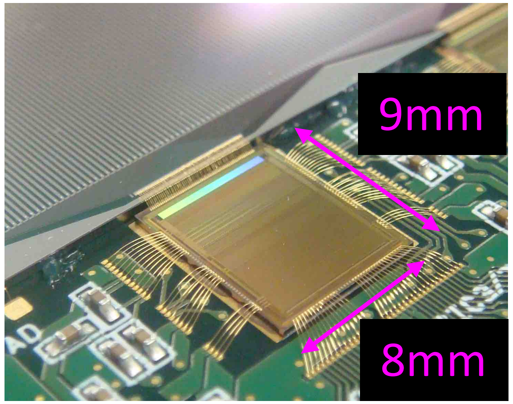
8σ detection sensitivity

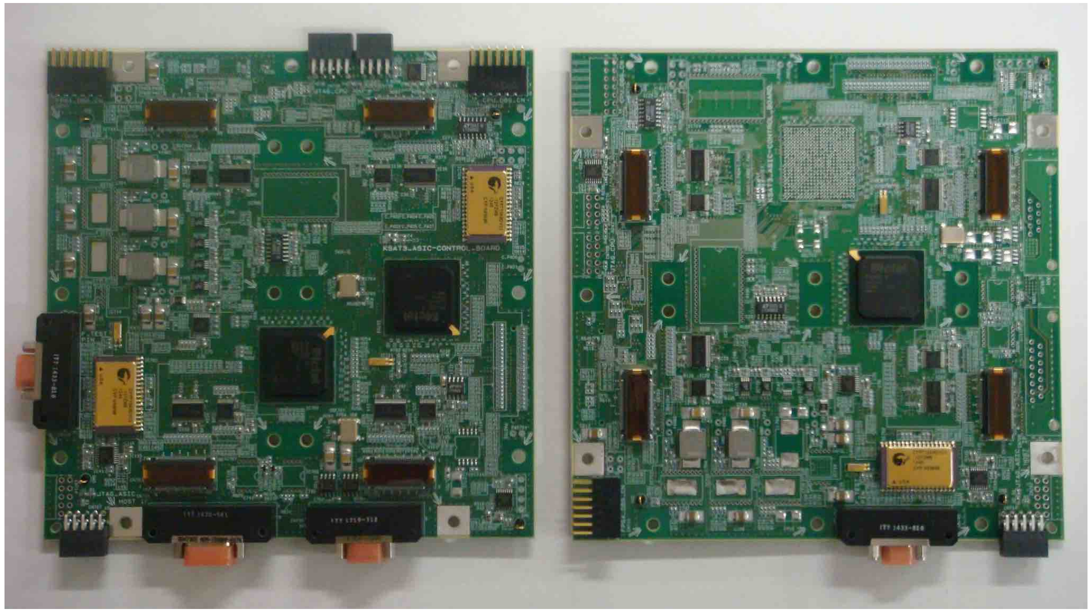


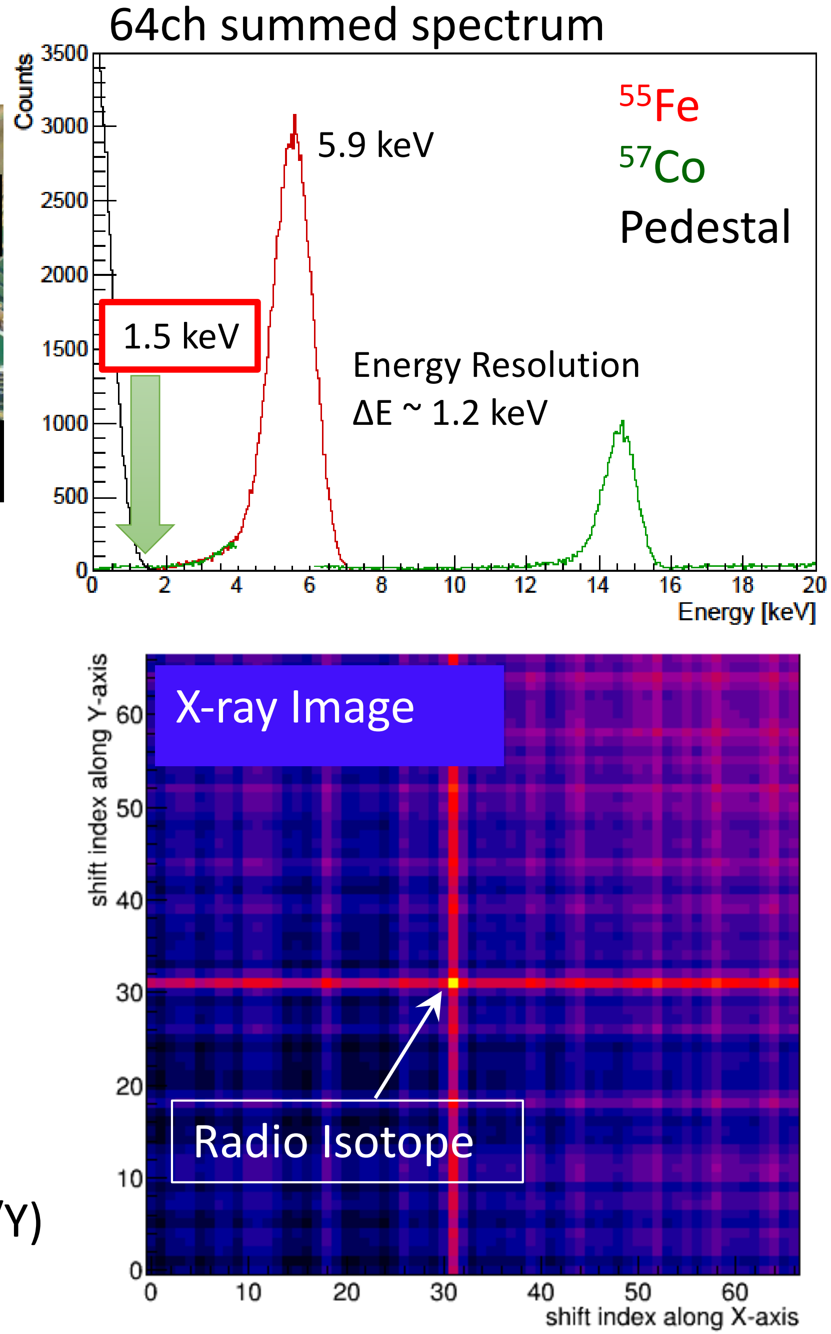


Wide Field X-ray Imaging Detector





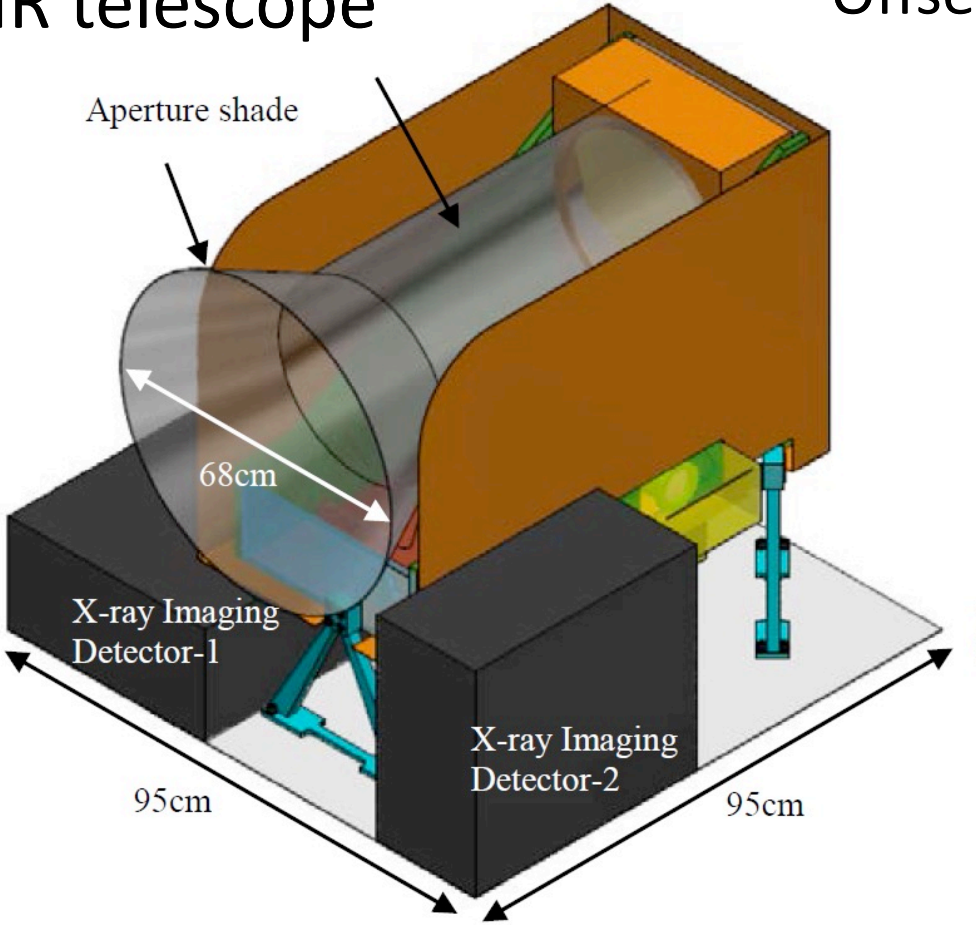




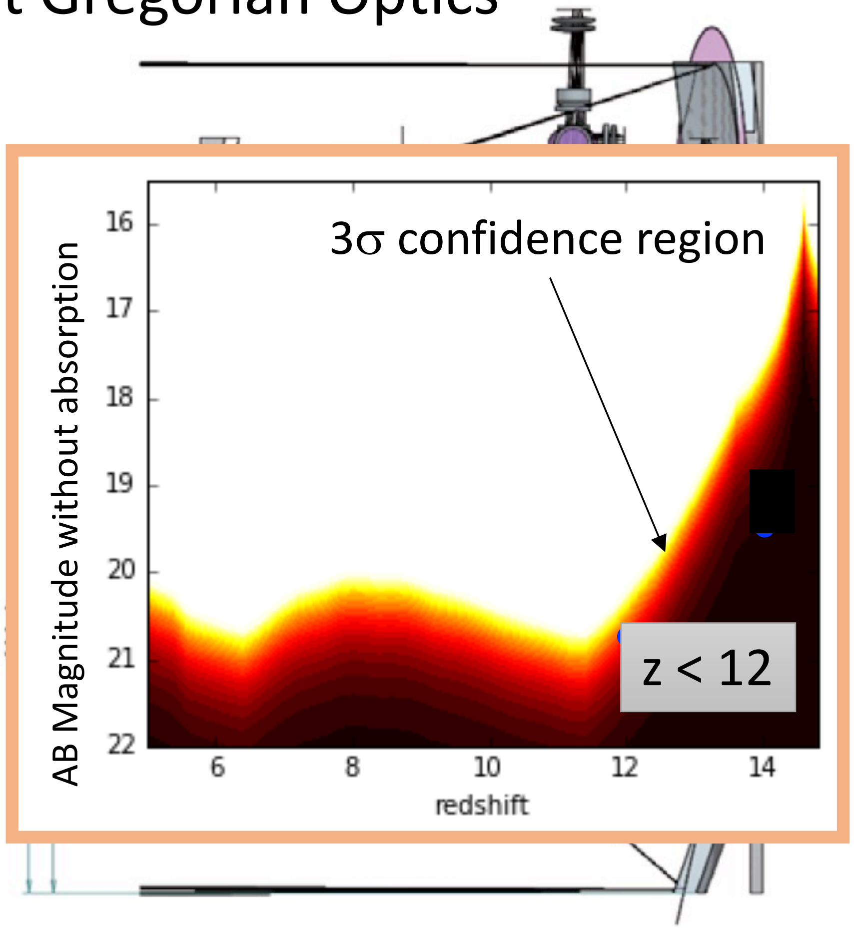
Prototype configurations (1/20 scale)

- Silicon Strip Detector (300 μm x 256 strips x 2 for X/Y)
- Ultra high-gain readout ASICs (64 ch x 16 chips)
- Digital electronics board and communication interface
- Verification test of X-ray Imaging

NIR telescope



Offset Gregorian Optics



Optics	Offset Gregorian			
Aperture Size	30 cm			
Focal Length	183.5 cm			
F	F6.1			
Field of View	34 x 34 arcmin^2			
Pixel Scale	2 arcsec (assuming 1k x 1k)			
Temperature	Telescope : < 200 K Camera Optics : <170 K Detector : <80 K			
Band	0.5–0.9 μm	0.9–1.5 μm	1.5–2.0 μm	2.0–2.5 μm
Limiting Mag.	21.4	21.3	20.9	20.7
Detectors	HyViSi	HgCdTe	HgCdTe	HgCdTe

Similar to the optics of NISS satellite by Korea/KASI (Woong-Seob Jeong's talk)

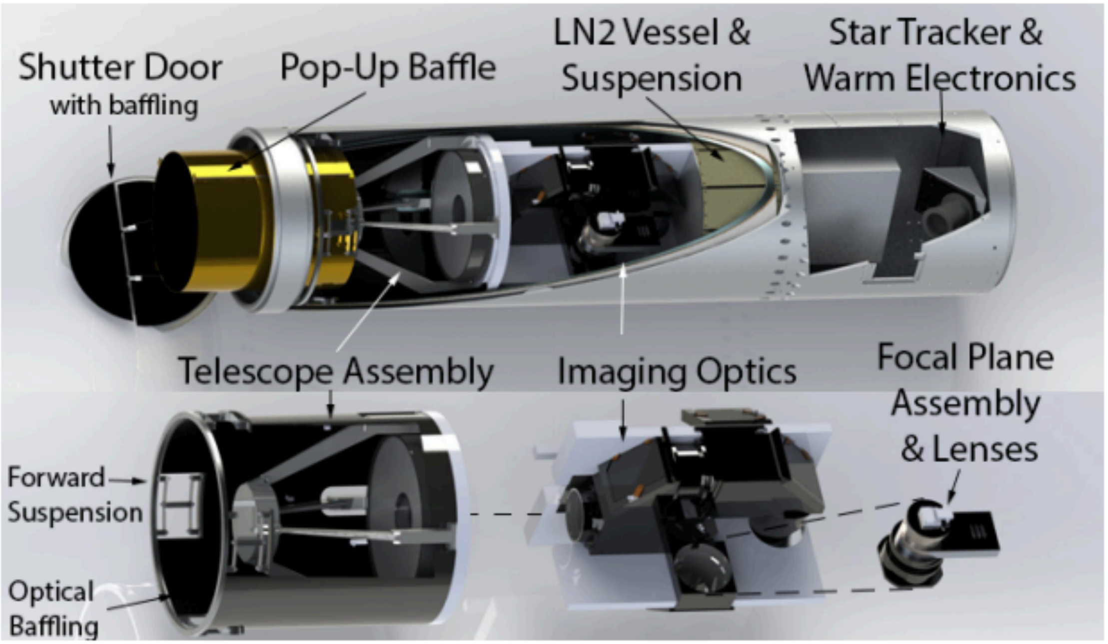
CIBER-2 Rocket Experiment

Lanz et al. (2014)

- NASA's rocket experiment for the near infrared background light
- Telescope Size : 28.5cm cooled telescope ⇒ 30 cm
- 3 band photometric observation in optical and NIR

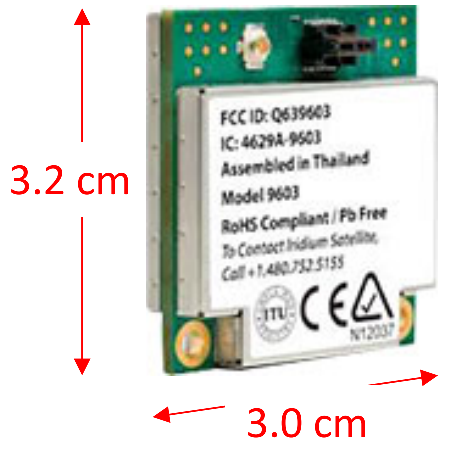
→ Verification for the NIR telescope aboard HiZ-GUNDAM

Flight Configuration



Flight Primary Mirror

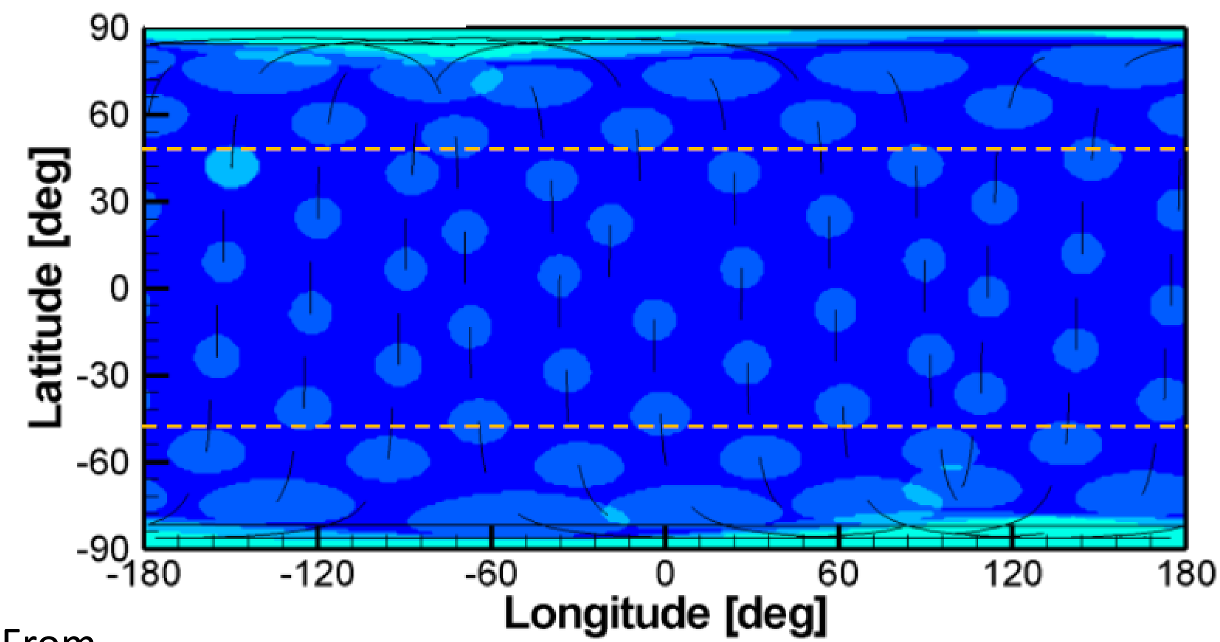
Real Time Alert



Iridium Short-Burst-Data (SBD 9603)

Packet Communication
Send： 340 byte
Receive： 270 byte
Delay： 1〜3 min

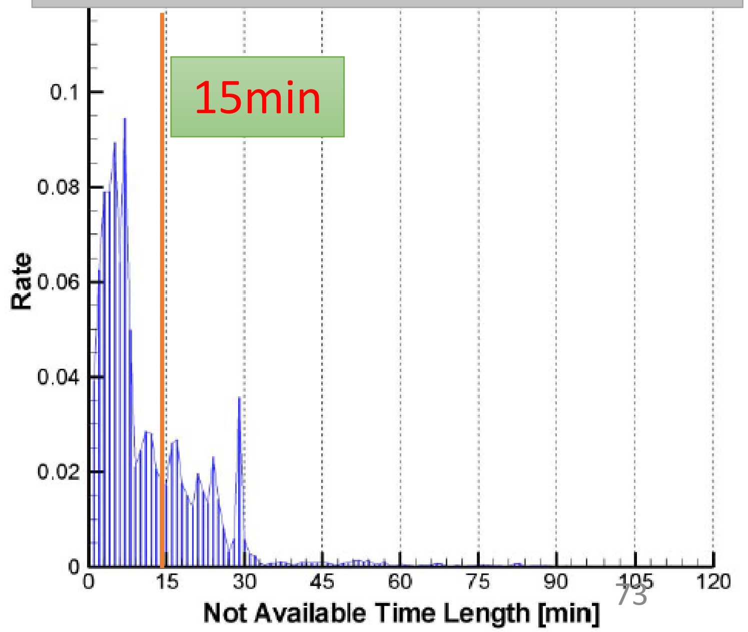
Sendable area fraction of real time alert (400 km otbit)



From
Nagata-san (Okayama U.)
Yamada-san (ISAS/JAXA)

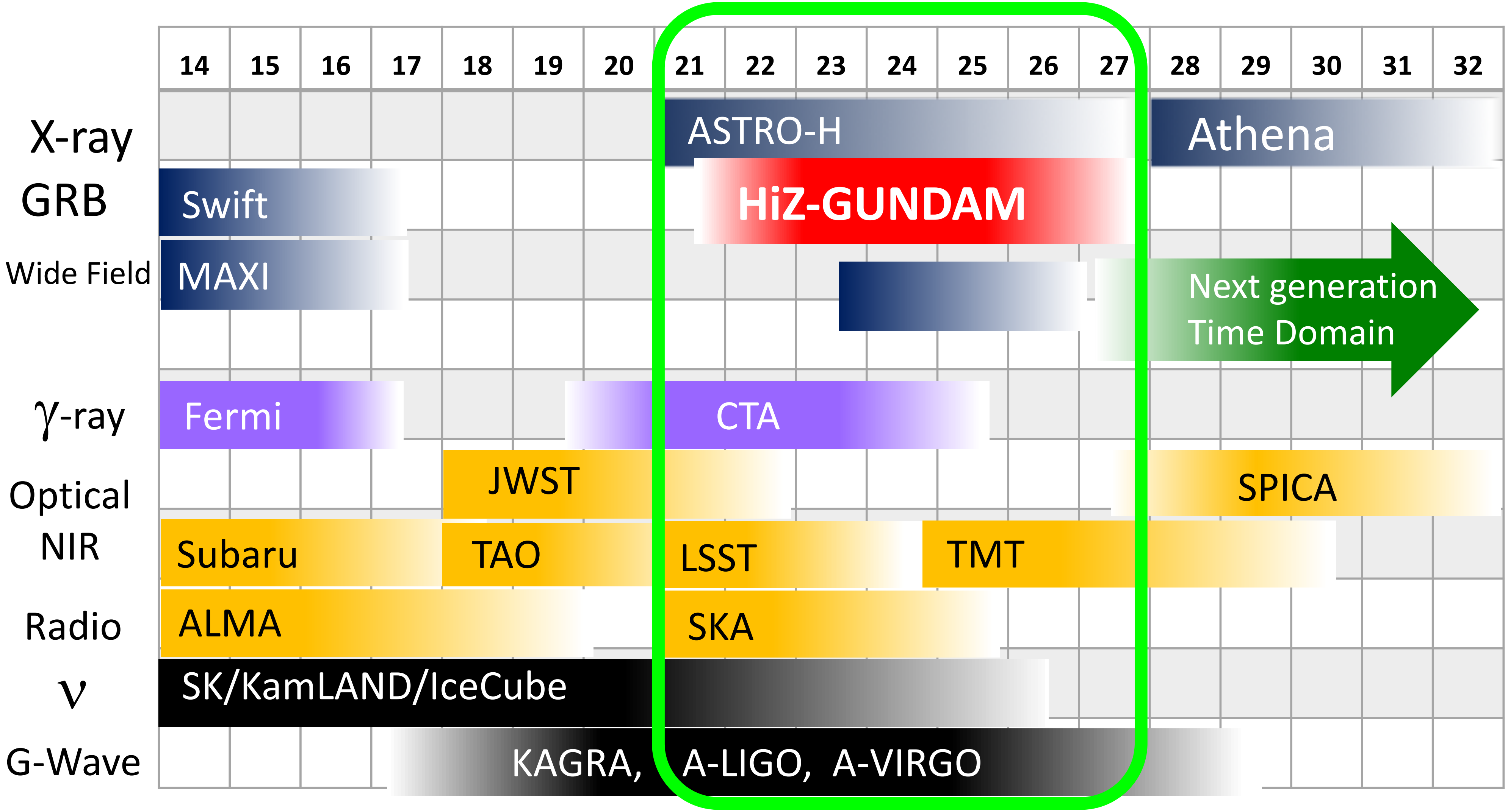
Special thanks
Yamada-san (TMU)

Distribution of non-contact time



- Duration of non-contact time is less than 15 minutes : 50 ~ 60 %, but the longest case is 5 hours
- Almost perfectly covered around Arctic/Antarctic regions.
- We need an additional UHF antenna.

Schedue



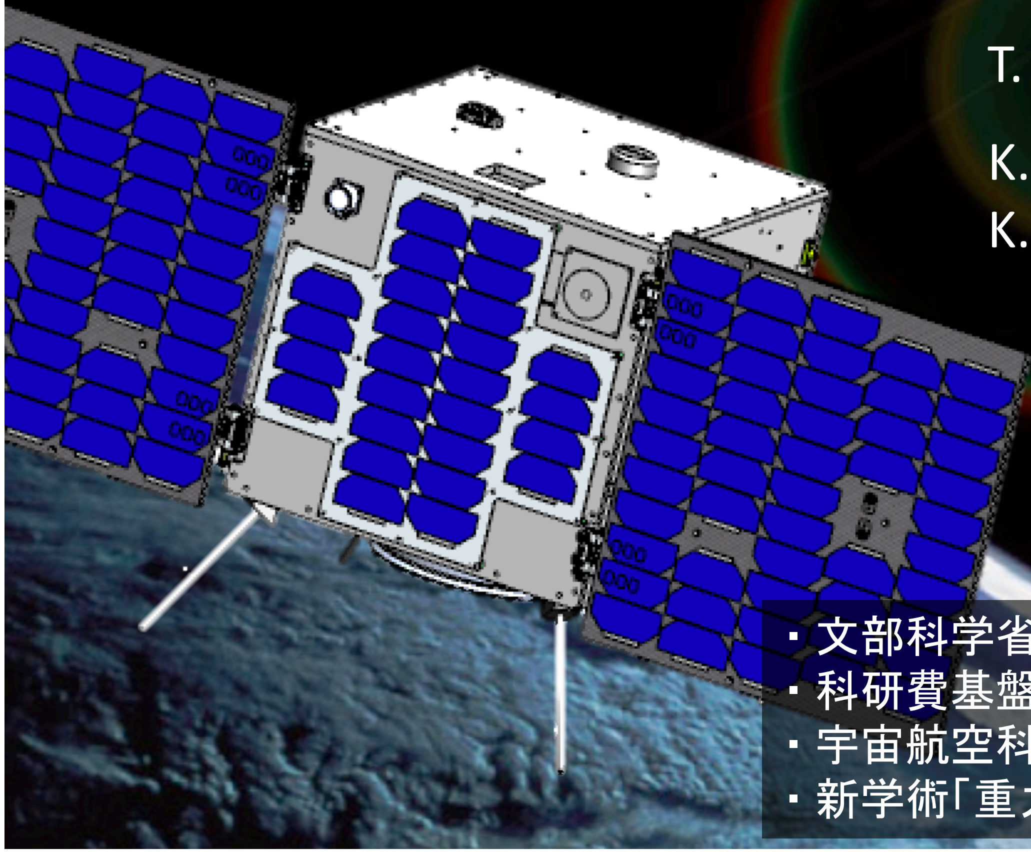
- We will propose the HiZ-GUNDAM to the next AO of competitive M-Class Mission.
- Collaboration with TAO, Subaru, Keck, VLT, JWST and TMT
- Multi-Messenger/Multi-Wavelength observatory

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

Launch Target
Early FY2019

D. Yonetoku, T. Sawano
S. Yagitani, Y. Kasahara, T. Imachi,
M. Ozaki, Y. Goto, R. Fujimoto
(Kanazawa Univ.)
T. Mihara, K. Kyutoku (RIKEN)

K. Yoshida, Y. Kagawa, K. Kawai, M. Ina,
K. Ota, Y. Minami (Kanazawa Univ.)



KANAZAWA SAT^3

・文部科学省特別経費（代表：八木谷聡, H26 – H 30）
・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）
・新学術「重力波天体」(公募研究)（代表：米徳大輔, H25 – H28）

Kanazawa-SAT^3

- 50 cm & 50 kg class of micro-satellite
  (launch in early FY2019, mission life ~ 3 years)

(1) Wide field X-ray imaging detector

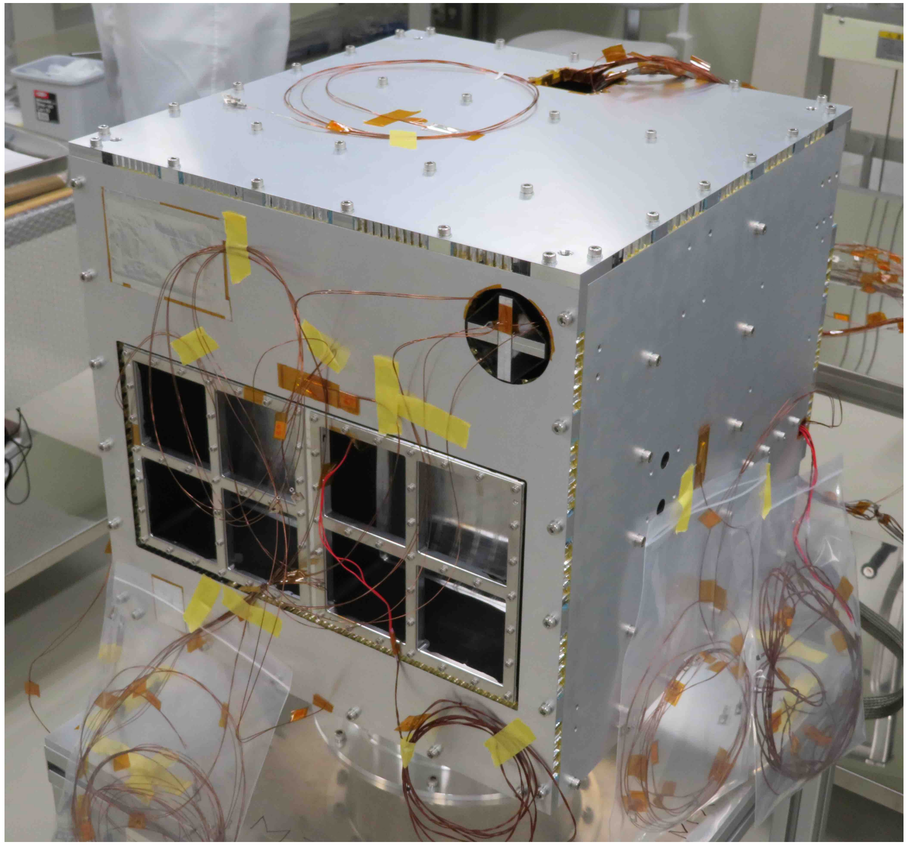
Transient **L**ocalization **EX**periment (**T-LEX**)

Energy Range	2 – 20 keV
Field of View	~ 1.5 str (half coded)
Position Accuracy	~ 15 arcmin
Detector Area	100 cm^2
Time Resolution	8 msec

(2) Gamma-ray trigger detector

Energy Range	20 – 500 keV
Field of View	~ π str
Position Accuracy	N/A
Detector Area	~ 100 cm^2
Time Resolution	8 msec

Thermal-Structure Model



Overhead View

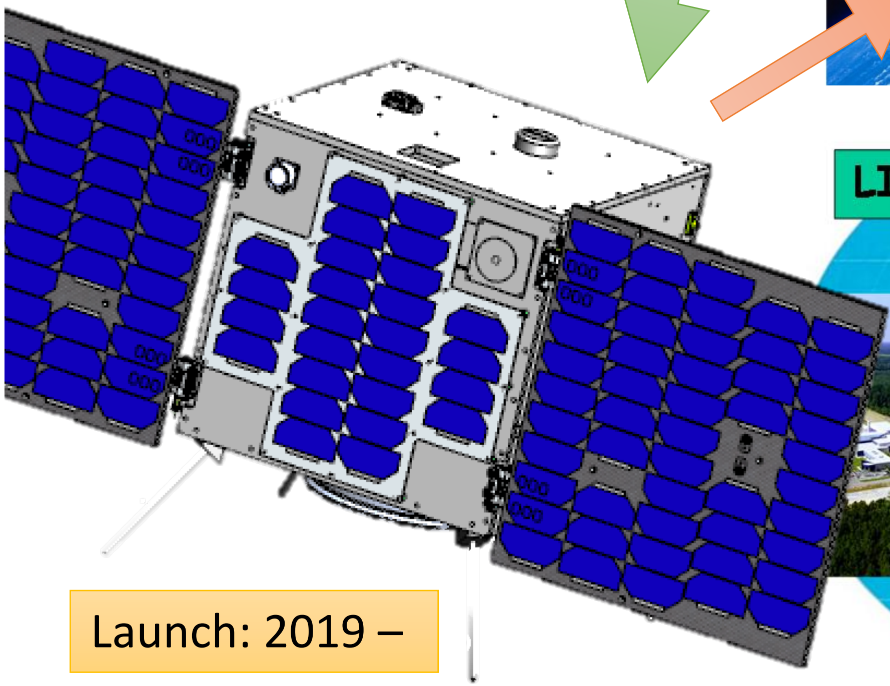
GRBs & X-ray Transients

(1) Wide Field X-ray Imaging

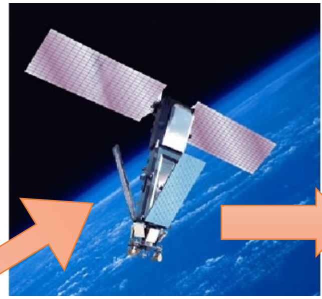
γ-ray Trigger Detector

X-ray Transients

Time and Coordinate



Launch: 2019 –

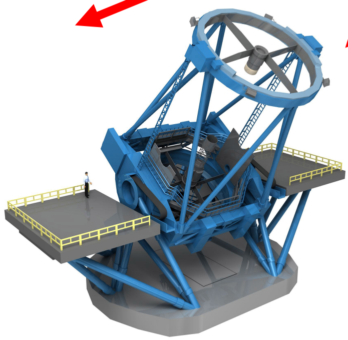


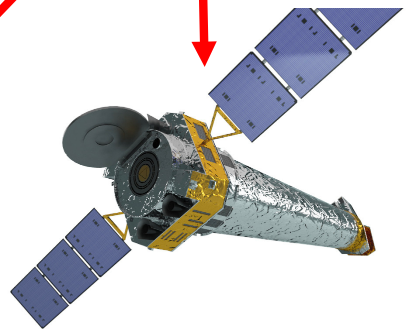
(2) Quasi real time alert

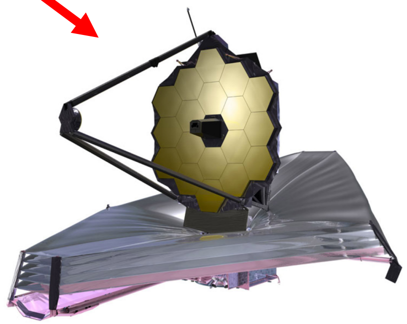
Alert by Iridium satellite network

(3) Ground network

Multi wavelength follow-up observations







Summaries

- Japanese GRB community considers the future GRB mission "HiZ-GUNDAM".
- We are developing the 1/10 proto-type model of the X-ray instrument, and the flight model of NIR telescope for CIBER-2 rocket experiment.
- We need a world wide collaboration
  especially for the NIR telescope system, satellite operation, alert system, and also the driving powers of scientific outputs.
  We strongly hope to collaborate with Space Astronomy Group at KASI.
- We will propose the HiZ-GUNDAM project to
  the next AO of "competitive medium-class mission" of ISAS/JAXA.
  (The end of 2018/01)
  We are appreciated if you become working group members before the mission proposal.
- We, Kanazawa-Univ., are developing the micro satellite "Kanazawa-SAT^3".

Thanks