Optical and NIR observations of GRB afterglow

~ Mainly with Hiroshima's activity ~

Koji S. Kawabata Hiroshima University

Collaborators

K. Takaki (Hiroshima Univ), K. Toma (Tohoku Univ),

R. Itoh, T. Uehara, M. Uemura, T. Ohsugi, M. Yoshida, H. Akitaya, M. Ohno, T. Mizuno (Hiroshima Univ), R. Yamazaki (Aoyama-Gakuin Univ)

広島大学

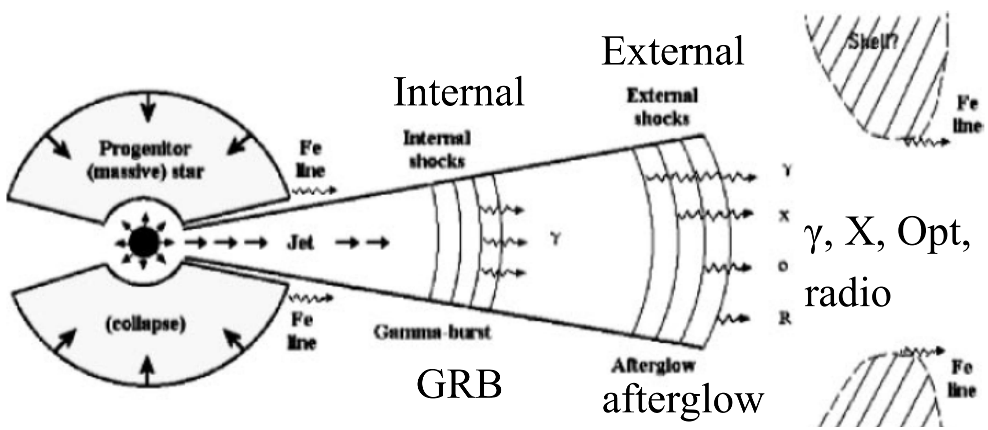
INDEX

- Optical Afterglow
  - Physical parameters
- Linear Polarimetry of Early Optical Afterglow
  - Magnetic field in the shock region
  - Prompt polarimetry with Hiroshima 1.5-m telescope
  - Results and Discussion
  - Future development

Afterglow of GRBs

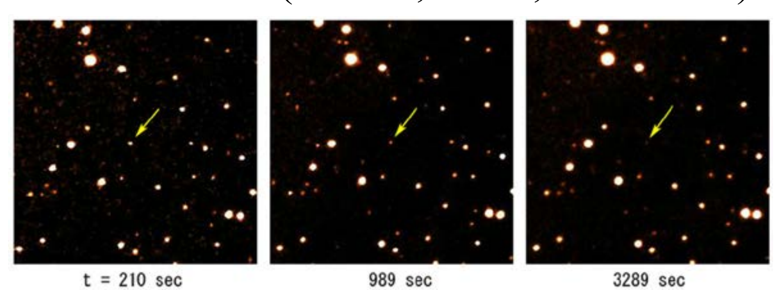
A considerable fraction of GRBs (~30% in Swift GRBs) show afterglows in optical wavelengths.

They are explained by synchrotron radiation originated in an external shock region where the relativistic jet interacts with circumstellar matter (CSM).

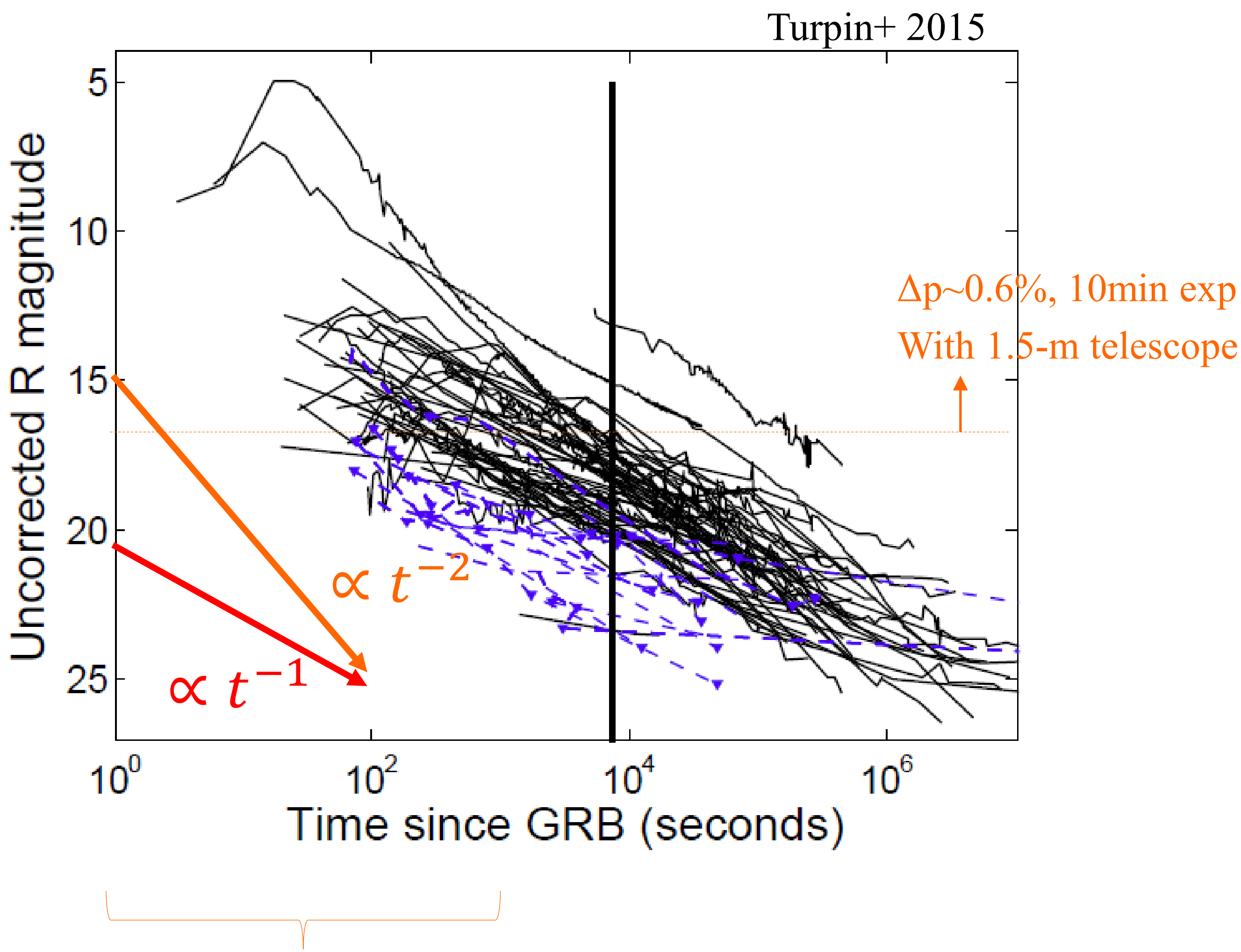


Meszaros (2002)

GRB 080506 (Uehara, Toma, KK+ 2012)



LCs of afterglows of 85 GRBs

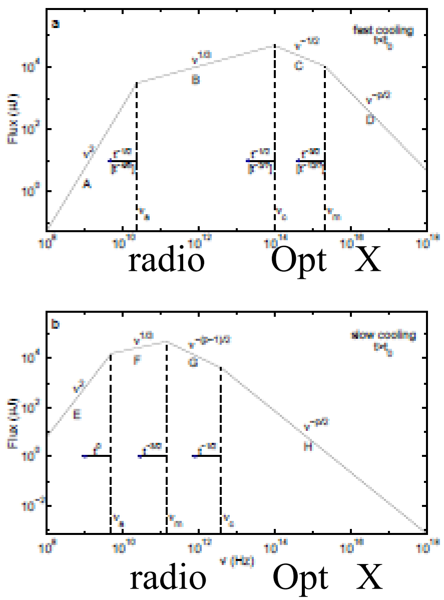


In <10^3 sec, polarimetry (and precise photometry) is available for brighter afterglows.

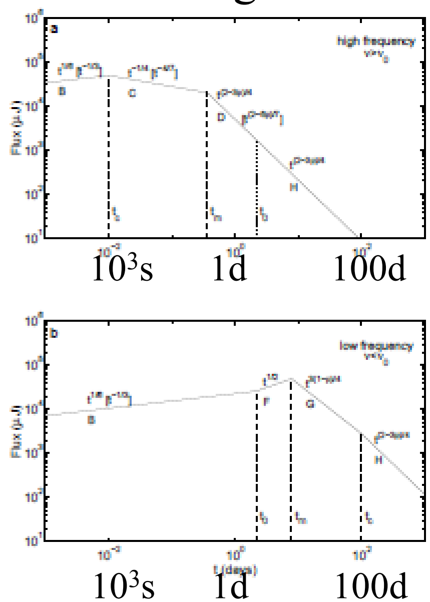
広島大学

Mode of afterglow emission

Model SED

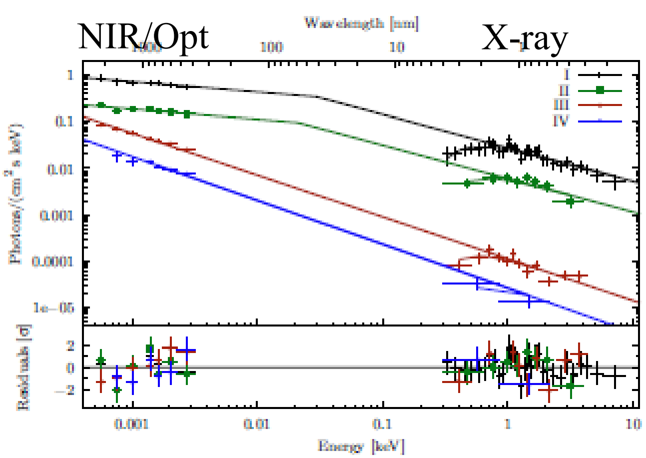


Model light curve

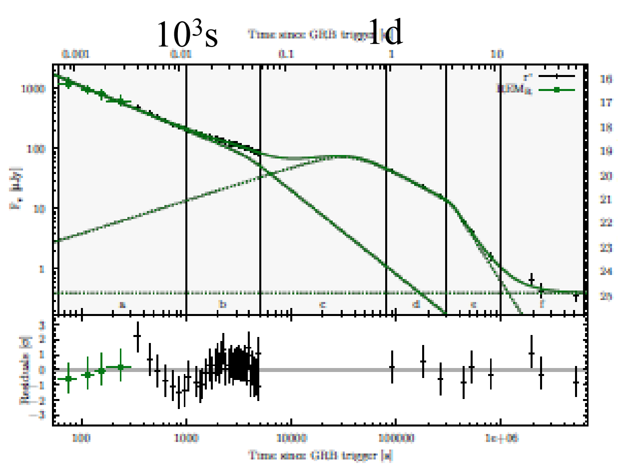


The afterglow emission (SED and temporal variation) has been well explained by the external shock model (standard model).

Sari+ 98; Zhang & Meszaros 04; Kumar & Zhang 15



Observation and Two component model



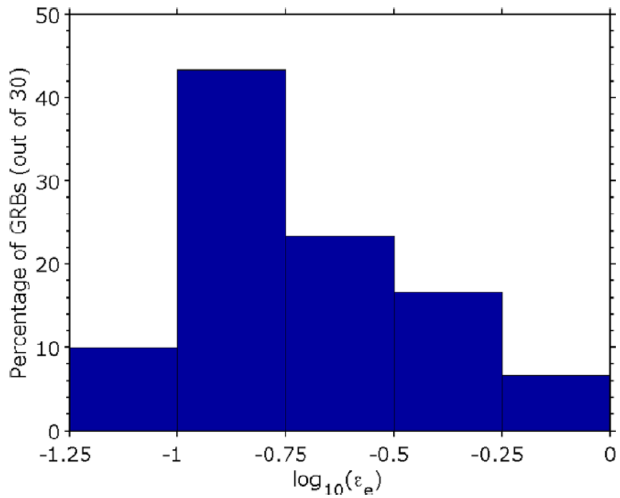
080413B

Filgas+ 2011

Microphysics parameters estimated from afterglow

Fractional energy of electrons

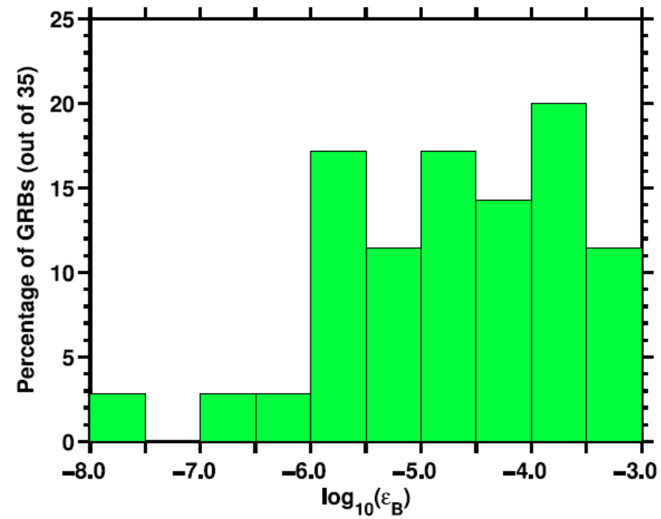
ϵ_e



$\simeq$ 0.1 - 0.3

Fractional energy of magnetic field

ϵ_B



$\simeq$ 0.000001 - 0.001

(assuming $\epsilon_e = 0.2$ and $n = 1/\mathrm{cm}^3$)

Distribution of ϵ_e is relatively narrow.

Distribution of ϵ_B is very wide.

No dependence on Γ (Kumar & Zhang 2015; Sironi 2011)

Suggesting "magnetic fields is unlikely to be determined by micro-physics of relativistic collisionless shock alone."

Kumer & Zhang 2014

Origin of magnetic field in afterglow emitting region

広島大学

It is widely accepted that synchrotron radiation in the shocked plasma is the essential mechanism of the afterglow emission.

However, the origin of the magnetic field is still unclear.

- **Interstellar magnetic field amplified by GRB external shock**
  Amplification factor: $\sim 10 - 100$
- **Magneto-hydrodynamic instability in CSM region**
- **Weibel instability in the shock region**
  ϵ_B reaches ~ 0.1 near the shock front
- **Shear across GRB-jet**

For magnetic field, polarimetry can be a unique probe since the synchrotron radiation is intrinsically highly polarized.

Because polarimetric instruments are relatively rare, polarimetry of early afterglows ($< \sim 10^3$sec) became available in recent years (>2006).

Expected geometry of magnetism and polarization

1. **Totally random orientation of magnetism.**

   → Null polarization

2. **Combination of coherent patches (scale length ~ *cτ*). Within each patch, the magnetic field is ordered. Normal jet may have ~50 patches.**

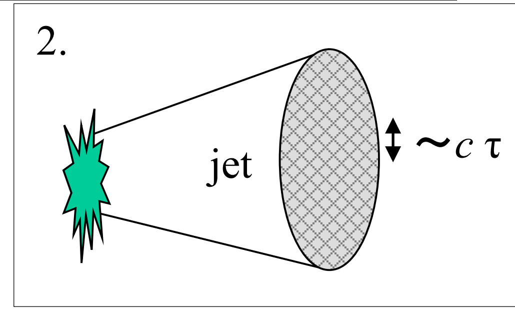
   → Constant polarization of ~10% (=70%/√N) (e.g., Gruzinov & Waxman 1999)

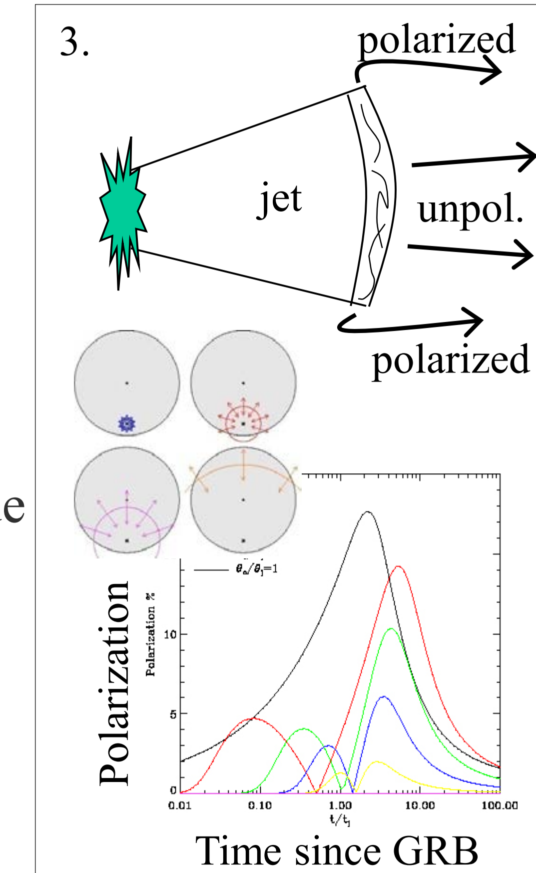
3. **Axi-symmetric polarization pattern due to compressed, tangled magnetic field, coupled with relativistic `beaming' and `occultation' of emitting region.**

   → Variable polarization of p=0-15% from oblique line of sight (e.g, Sari+ 1999; Rossi+ 2004)

4. **Large scale ordered-magnetic field, originated in jet or CSM** (e.g, Lyutikov+ 2003; Inoue+ 2011)

   → Large polarization (10-50%)

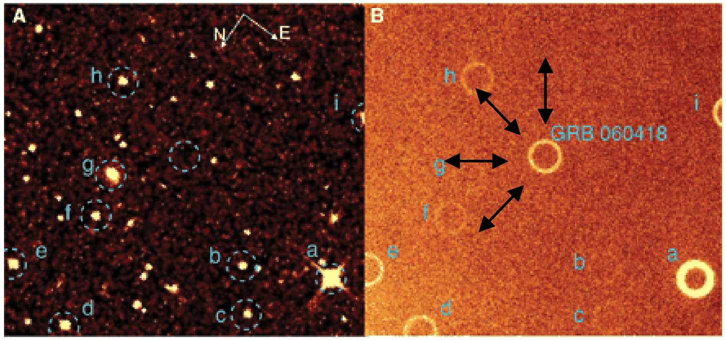




Rossi+ 04

広島大学

Polarimeters dedicated for earliest GRB afterglows



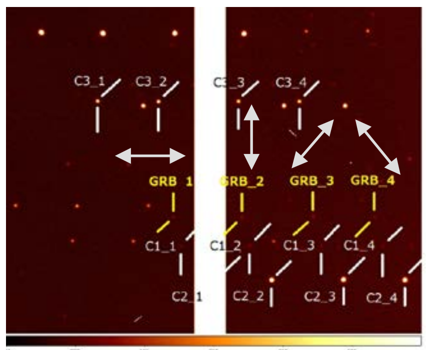
RINGO/RINGO2/RINGO3

Liverpool 2-m

(Steel+ 2006; Mundell+ 07)

Since 2006

Rotating polaroid
+ wedged plate



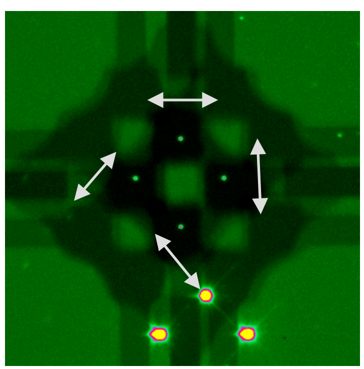
HOWPol

Hiroshima, Kanata 1.5-m

(KK+ 2008; Uehara+ 2012)

Since 2009

Wedged double
Wollaston prism



RoboPol

Skinakas 1.3-m

(Angelakis+ 2014)

Since 2013

Wedged double
Wollaston prism

Telescope/Instruments

Kanata 1.5-m telescope and its enclosure can quickly move (with 5 degs/sec in azimuthal speed), which enables us to finish pointing within ~1 minute in most cases.

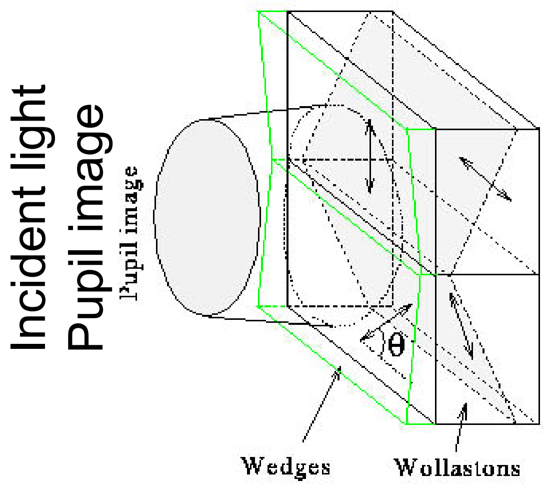
We developed HOWPol (Hiroshima One-shot wide-field polarimeter); its field of view is 15′ in diameter.

HOWPol started observation in 2009.

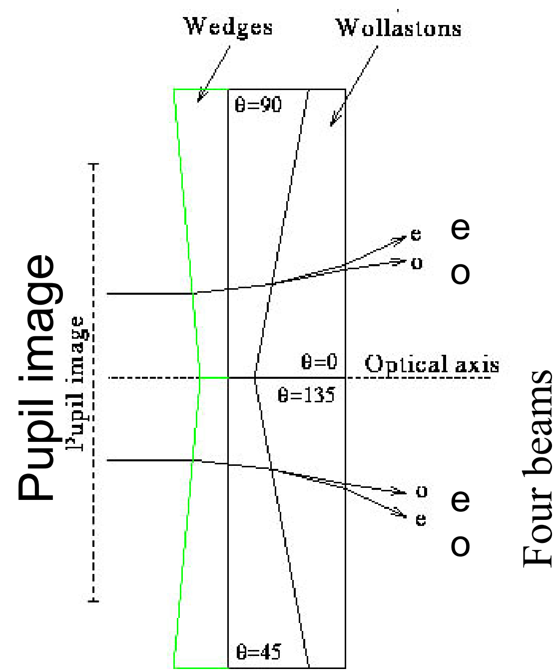
HOWPol has two types of wedged double Wollaston prism (Oliva 1997) and enables us to derive the Stokes parameters, Q/I and U/I, from only a single exposure. It ensures simultaneous monitoring of Q and U even for highly variable objects.

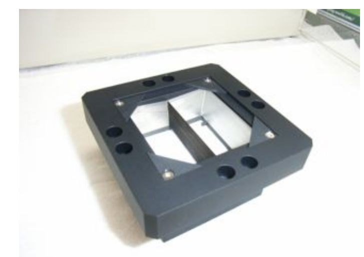
Wedged Double Wollaston (WeDoWo)

Two Wollaston prisms, of which the optical axes differ by 45 degrees each other, are cemented toghether. The first prism piece in each Wollaston are wedged and then produces four linearly polarized beam at PA=0, 90, 45 and 135 degs. HOWPol places it at (well-achromatized) pupil position in the optical train.



Oliva 1997, A&AS, 123, 589





Narrow-field type
MgF2+SiO2
Wide-field type
Rutile

GRBs polarimetry with HOWPol

広島大学

	GRB trigger t1	GCN receive t2	Expos. start t3	t3−t1 (s)	t3−t2 (s)	
GRB 091208B	9:49:58	9:50:24	9:52:27	149	123	R=16.8@150s
GRB 111228A	15:44:43	15:45:33	15:47:25	162	112	z=0.72
GRB 120212A	9:11:22	9:11:44	9:12:36	74	52	Data unavailable before T_0~1000 s due to twilight
GRB 121011A	11:15:30	11:16:09	11:17:02	92	53	R=16.8@388s MITSuME
GRB 130427A	7:47:57	7:49:15	11:40:26	14027	13949	R=15.5@14000s
GRB 130505A	8:22:28	8:22:51	10:46:08	8643	8620	R=18.3@8700s
GRB 130511A	11:30:47	11:31:06	11:32:32	105	86	R=20.0@2571s
GRB 131128A	15:06:24	15:11:31	15:12:24	360	53	R=17.5@375s
GRB 140629A	14:17:30	14:17:46	14:18:43	73	57	R~13.4@2.5min
GRB 140907A	16:07:08	16:15:47	16:17:30	622	103	R=17.2@20min

Start exposure time since GRB trigger

Response time of telescope and instrument

GRB 091208B (z=1.063)

広島大学

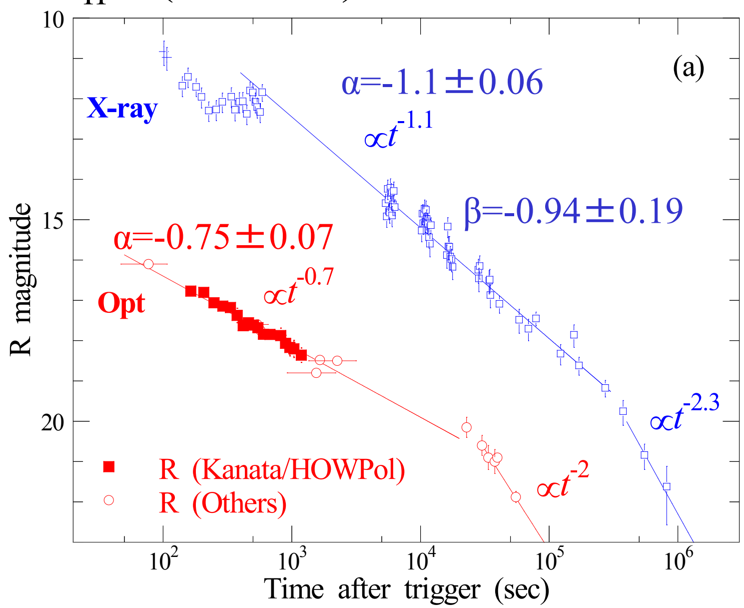
T_{90} (15-350keV) = 14.9±3.7sec (GCN Rep. 266.1)

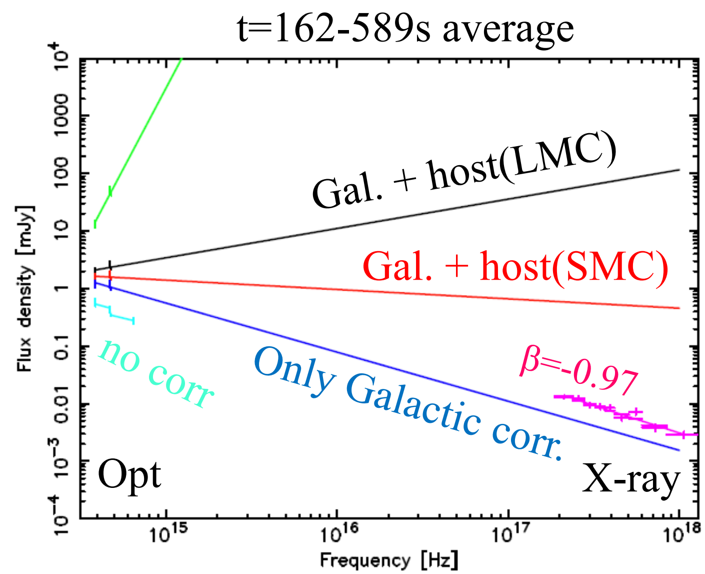
$E_{\gamma,iso} > 2\times10^{52}$ erg

In X-ray LC, possible jet break at $T_0+3.1\times10^5$sec

α=1.1 (α=2.3) before (after) break

$N_H = (2.9\pm0.5)\times10^{21}\text{cm}^{-2}$ from best-fit spectrum



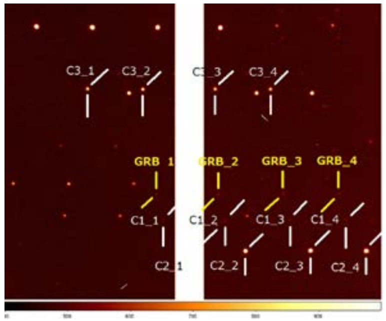


Uehara, Toma, KK+ (2012)

Optical/X-ray emission is consistent with emission from external (forward) shock region model.

広島大学

GRB 091208B: Polarimetric results



Polarimetry began at $T_0 + 149$ s

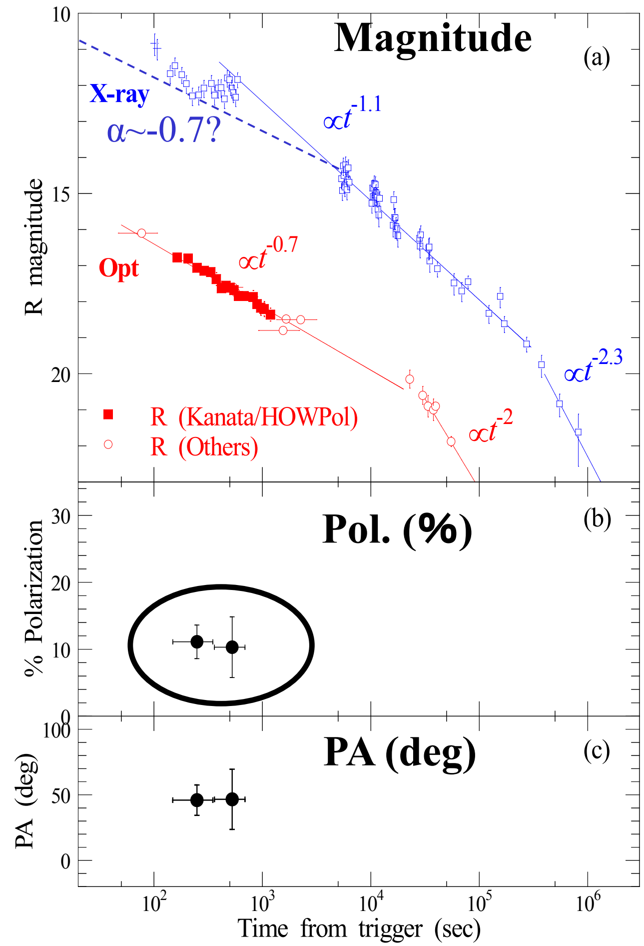
The record of earliest polarimetry before 2010!

$p\ =\ 10.4 \pm 2.5$ % at T_0+149 s to 676 s

$p = 11 \pm 2\%$ at T_0+149 s to 334 s

$p = 9 \pm 4\%$ at T_0+404 s to 676 s

PA was nearly constant.

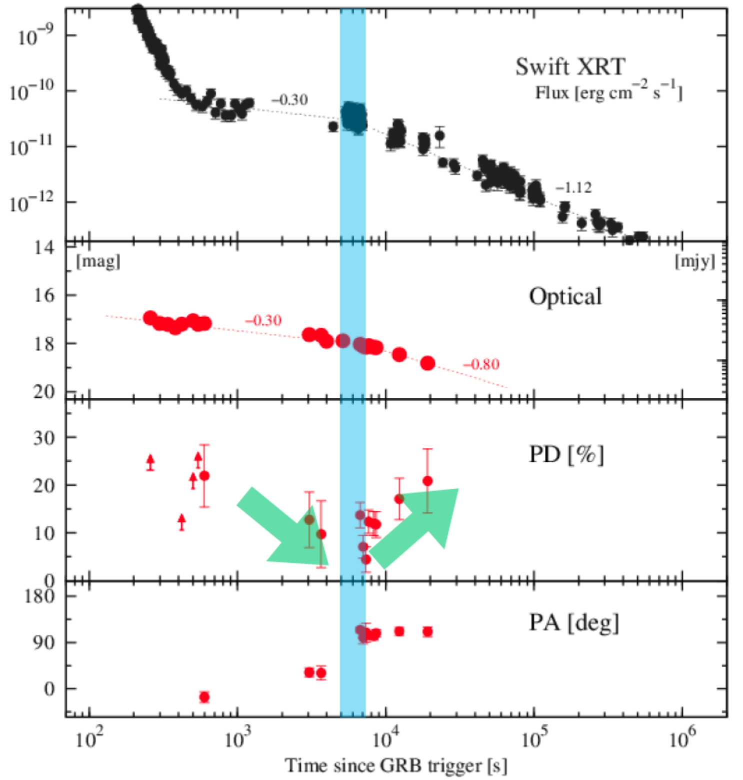


Uehara, Toma, KK+ (2012)

GRB 091208B: Strongly polarized

GRB 111228A (z=0.714)

広島大学



Takaki, Toma, KK+, submitted

This afterglow shows significant temporal polarization change.

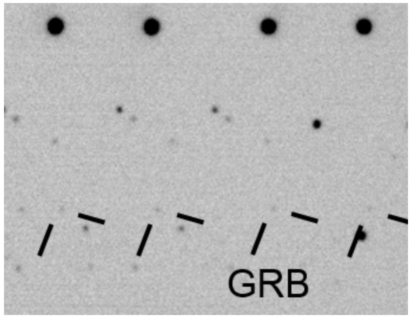
<u>GRB 111228A: Strongly polarized</u>

Katsutoshi Takaki will give a talk on the study of this GRB afterglow on third day of this GRB conference.

GRB 121011A (z unknown)

広島大学

T_{90} (15-350keV) = 75.6±12.7sec (GCN 13852)
$N_H = (2.3 \pm 0.5) \times 10^{20} cm^{-2}$
Galactic $A_V = 0.08$; upper-limit $p_{MW} \sim 0.24\%$



Polarimetry began at $T_0 + 92$ s

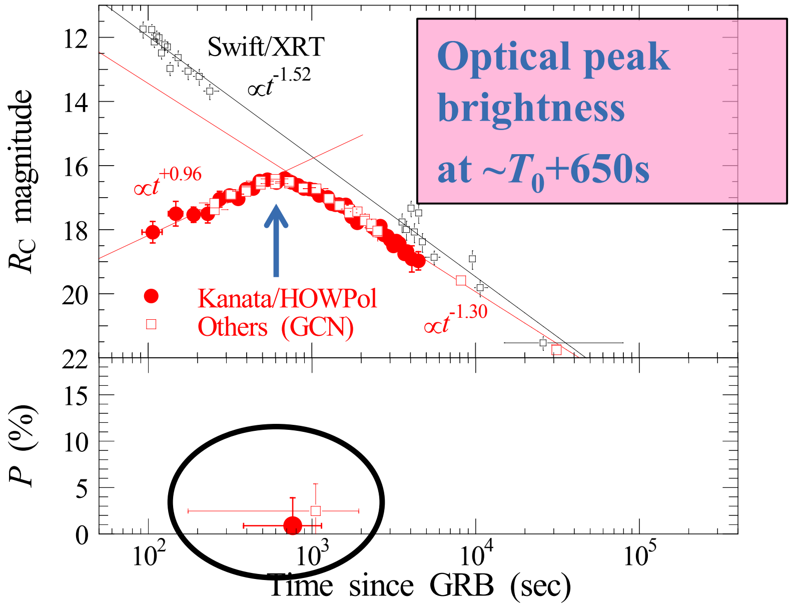
The record of earliest polarimetry before 2014!

$p = 0.8 \pm 2.9$ % at T_0+382 s to 1113 s

$p = 2.5 \pm 2.9$ % at T_0+175 s to 1900 s

$p = 7.1 \pm 8.4$ % at T_0+175 s to 610 s

$p = 7.5 \pm 2.8$ % at T_0+652 s to 1900 s



Takaki+, in prep.

<u>**GRB 121011A: Unpolarized (or only weakly polarized)**</u>

GRB 130427A (z=0.34)

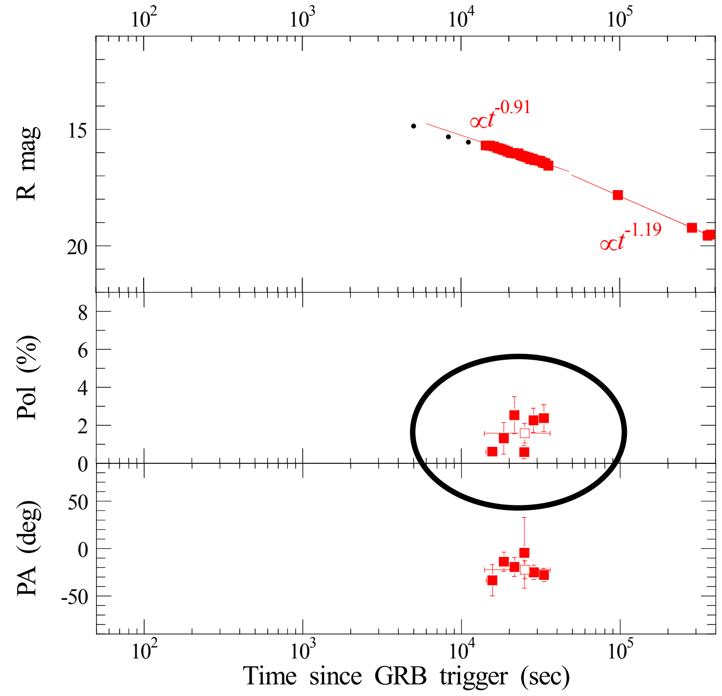
T_{90} (15-350keV) = 162.8±1.4sec

Galactic $A_V = 0.055$; upper-limit p_{MW}~0.17%

Polarimetry began at $T_0 + 3.9$ hr

$p = 1.6 \pm 0.5$ % at T_0+3.9 hr to 10.0 hr

GRB 130427A: Unpolarized (or only weakly polarized)



Takaki+, in prep.

GRB 130505A (z=2.27)

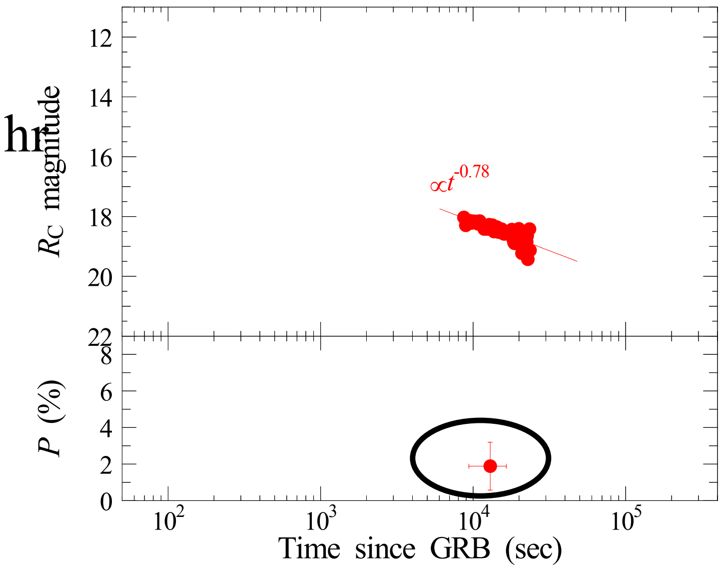
T_{90} (15-350keV) = 88±10sec

Galactic $A_V = 0.13$; upper-limit $p_{MW} \sim 0.39\%$

Polarimetry began at $T_0 + 2.6$ hr

$p = 1.9 \pm 1.3$ % at T_0+2.6 hr to 4.6 hr (0.8 hr to 1.4 hr in rest frame)

GRB 130505A: Unpolarized (or only weakly polarized)



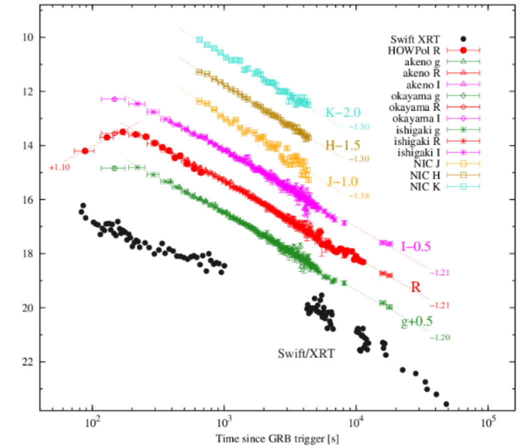
Takaki+, in prep.

広島大学

GRB 140629A (z=2.3)

T_{90} (15-350keV) = 75.6±12.7sec

Galactic $A_V = 0.022$; upper-limit $p_{MW} \sim 0.07\%$



Polarimetry began at $T_0 + 73$ s

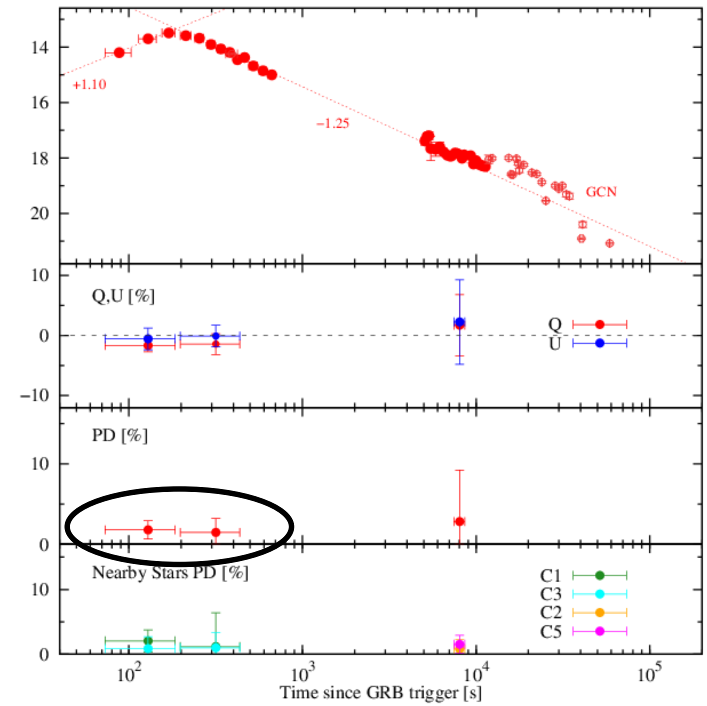
(22 s in rest frame)

The record of earliest polarimetry ever!

$p = 1.8 \pm 1.1$ % at T_0+73 s to 185 s

$p = 1.5 \pm 1.8$ % at T_0+198 s to 436 s

$p = 2.8 \pm 6.4$ % at T_0+7456 s to 8618 s



Takaki+, in prep.

<u>GRB 140629A: Unpolarized (or only weakly polarized)</u>

GRB 140907A (z=1.21)

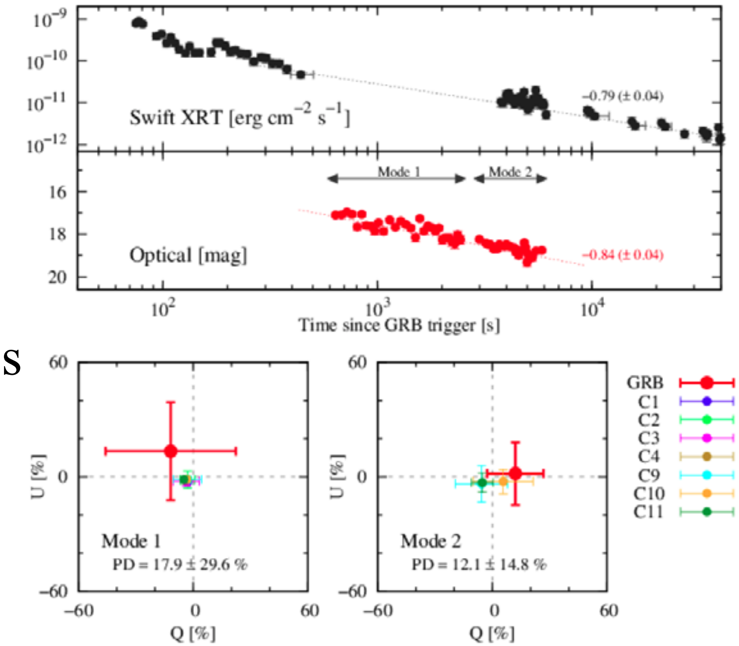
T_{90} (15-350keV) = 79±31sec

Galactic $A_V = 0.08$; upper-limit $p_{MW} \sim 0.24\%$

Polarimetry began at $T_0 + 622$ s

$p = 17.9 \pm 29.6$ % at T_0+622 s to 2467 s

$p = 12.1 \pm 14.8$ % at T_0+2955 s to 58727 s



<u>GRB 1400907A: No meaningful data in polarimetry</u>

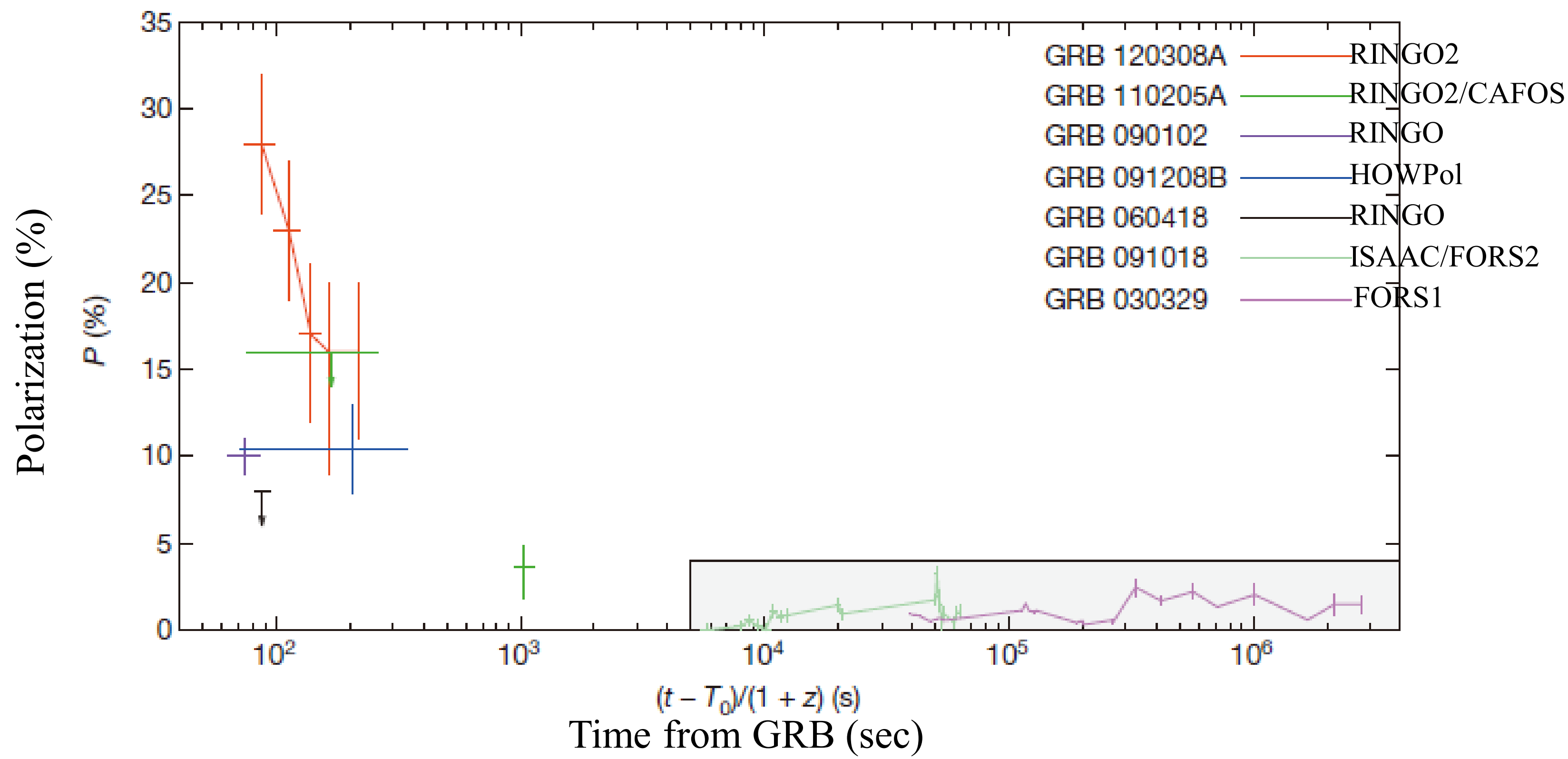
広島大学

	GRB trigger t1	GCN receive t2	Expos. start t3	t3−t1 (s)	t3−t2 (s)	Polarized?
GRB 091208B	9:49:58	9:50:24	9:52:27	149	123	Yes
GRB 111228A	15:44:43	15:45:33	15:47:25	162	112	Yes
GRB 121011A	11:15:30	11:16:09	11:17:02	92	53	No
GRB 130427A	7:47:57	7:49:15	11:40:26	14027	13949	No
GRB 130505A	8:22:28	8:22:51	10:46:08	8643	8620	No
GRB 140629A	14:17:30	14:17:46	14:18:43	73	57	No

Other early afterglow polarimetry

広島大学

Mundell+ (2013), Nature

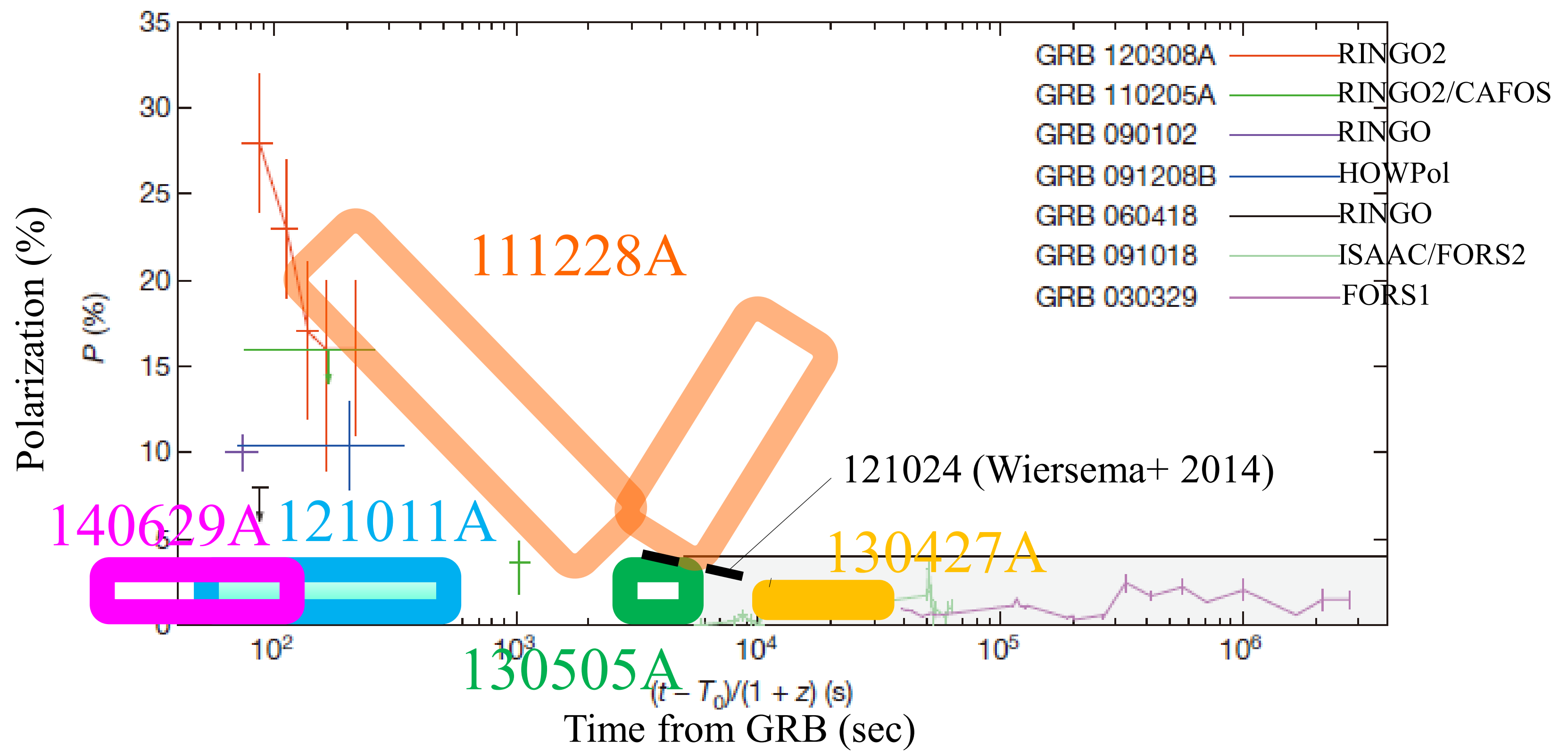


Earliest afterglow is generally strongly polarized?

Other early afterglow polarimetry w/ HOWPol data

広島大学

Mundell+ (2013), Nature



Earliest afterglow is generally strongly polarized?

— No.

Summary: Polarization of early afterglow

広島大学

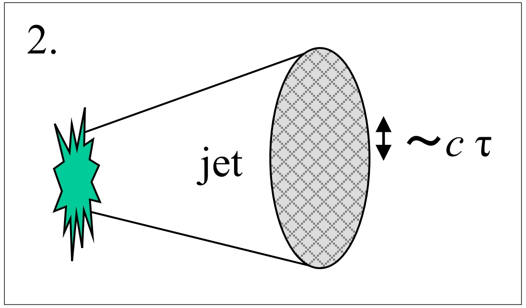
- **There is a diversity in polarization of early afterglow ($< 10^3$s): A part of GRBs show large polarization (more than 10%); while others show weak (or nearly zero) polarization.**

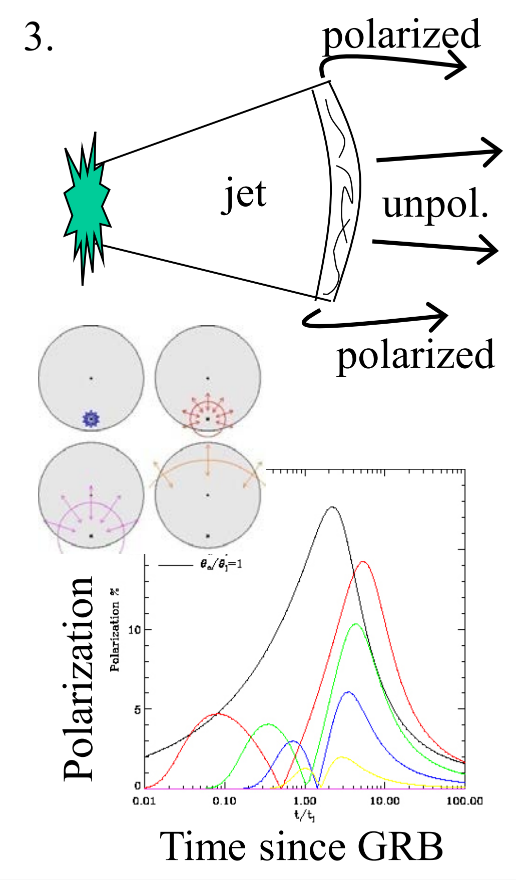
- **These suggest that, in a part of GRBs, the magnetic field in the shocked region is highly ordered.**

- **So far, no correlation is found between polarization and LC parameters (time decay index α, etc), probably because the observed sample is still small.**

Comparison with polarization model

1. **Totally random orientation of magnetism.**
   → Null polarization
2. **Combination of coherent patches (scale length ~ $c\tau$). Within each patch, the magnetic field is ordered. Normal jet may have ~50 patches.**
   → Constant polarization of ~10% (=70%/√N) (e.g., Gruzinov & Waxman 1999)
3. **Axi-symmetric polarization pattern due to compressed, tangled magnetic field, coupled with relativistic `beaming' and `occultation' of emitting region.**
   → Variable polarization of p=0-15% from oblique line of sight (e.g, Sari+ 1999; Rossi+ 2004)
4. **Large scale ordered-magnetic field, originated in jet or CSM** (e.g, Lyutikov+ 2003; Inoue+ 2011)
   → Large polarization (10-50%)



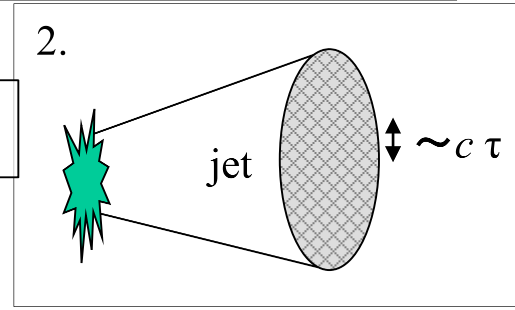


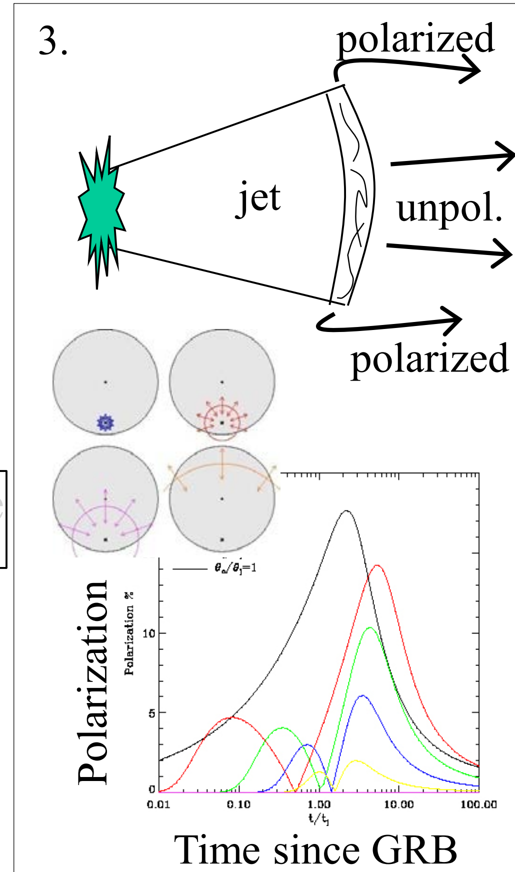
Rossi+ 04

広島大学

Comparison with polarization model

1. **Totally random orientation of magnetism.**
   → Null polarization
   140629A, 121011A, etc
2. **Combination of coherent patches (scale length ~ $c\tau$). Within each patch, the magnetic field is ordered. Normal jet may have ~50 patches.**
   → Constant polarization of ~10% (=70%/√N)
   (e.g., Gruzinov & Waxman 1999)
3. **Axi-symmetric polarization pattern due to compressed, tangled magnetic field, coupled with relativistic `beaming' and `occultation' of emitting region.**
   111228A (Takaki's talk)
   → Variable polarization of p=0-15% from oblique line of sight (e.g, Sari+ 1999; Rossi+ 2004)
   (Not ever seen at < 10^3 sec)
4. **Large scale ordered-magnetic field, originated in jet or CSM** (e.g, Lyutikov+ 2003; Inoue+ 2011)
   091208B, 120308A, etc
   → Large polarization (10-50%)





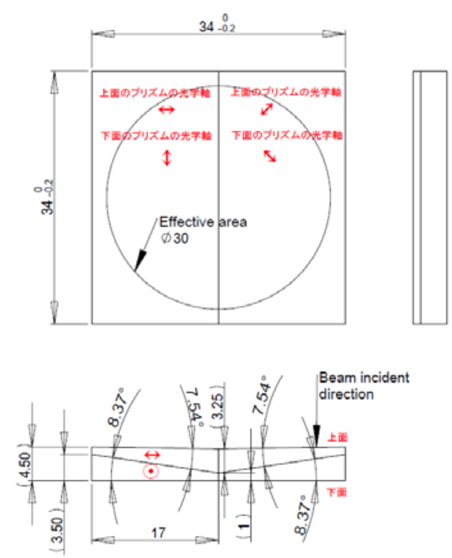
Rossi+ 04

広島大学

Ongoing development

- For simultaneous optical and NIR instrument, HONIR, at Hiroshima 1.5-m, one-shot polarimetry mode will be available in 2016 spring.

- HONIR is attached to Cassegrain focus, and thus instrumental polarization free ($p_{instr} < 0.1 - 0.2\%$). Therefore, polarimetric accuracy will be greatly increased (e.g., $p_{instr} = 3 - 4\%$ in HOWPol at Nasmyth focus).



Simultaneous 2 band (e.g., R-band~0.66μm and H-band~1.6μm) one-shot polarimetry will be available soon in Hiroshima 1.5-m telescope.

広島大学

Future perspectives

- By continuing polarimetry of early afterglow, the number of well observed samples will increase, and a clue for the problems of magnetic field would be provided. Also, we might meet brighter (i.e., precisely-observed) objects.
- Since in NIR bands the afterglow is brighter and simultaneous polarimetry in optical and NIR bands (soon available with HONIR, Hiroshima Univ) will provide robust results. It is also a merit that the interstellar polarization is much less in NIR than those in optical.
- If the target is longest-duration GRBs (> 100sec), we can perform polarimetry for prompt emission in optical wavelengths.