Observational Studies on Transient Objects with Hiroshima 1.5-m Opt-NIR Telescope and Others

Koji S. Kawabata (Hiroshima Univ.)

on behalf of Kanata team

Kanata

広島大学 極限宇宙研究拠点
CORE-U
Core of Research for the Energetic Universe
HIROSHIMA UNIVERSITY

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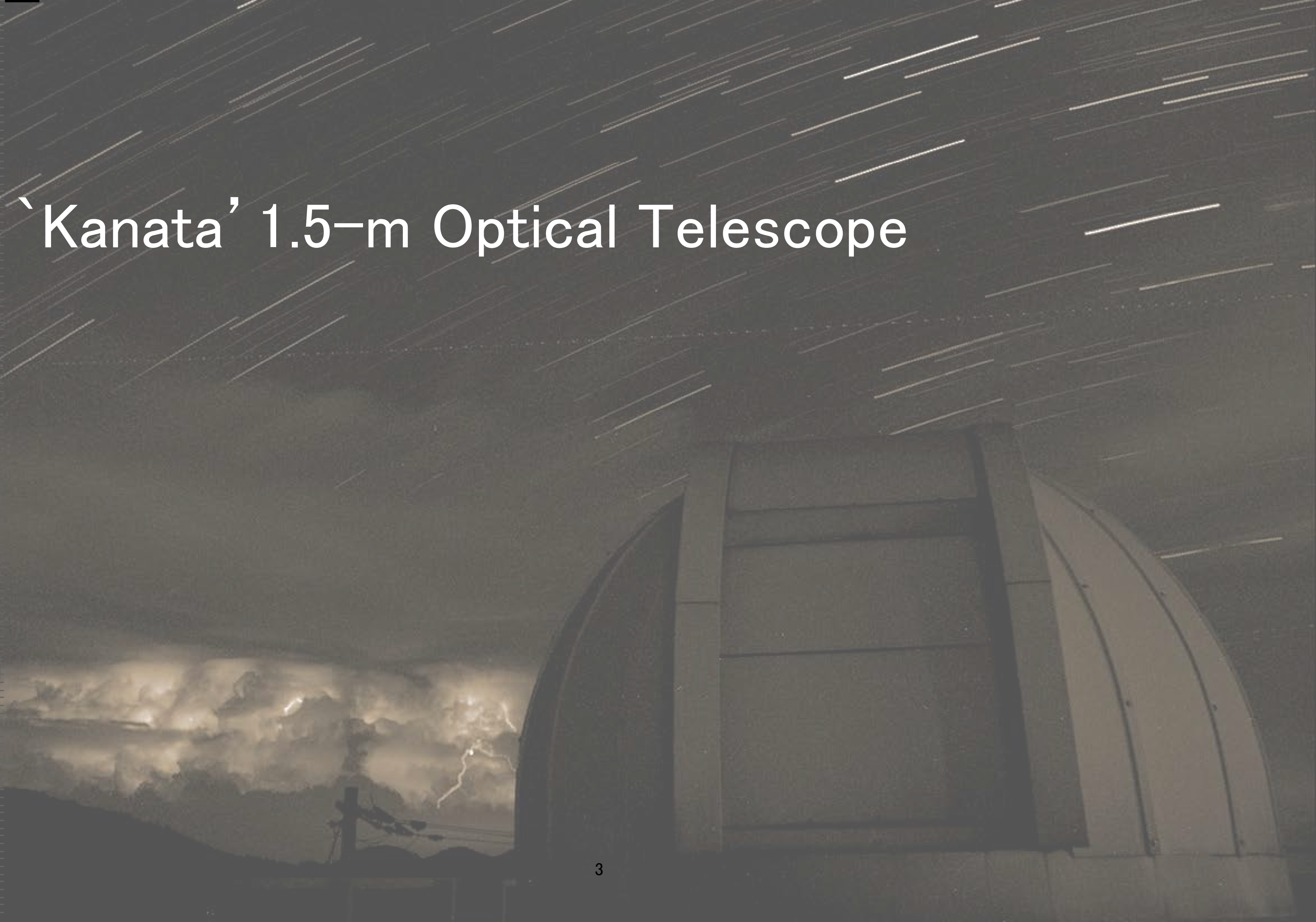
`Kanata' 1.5-m Optical Telescope



Higashi-Hiroshima Observatory

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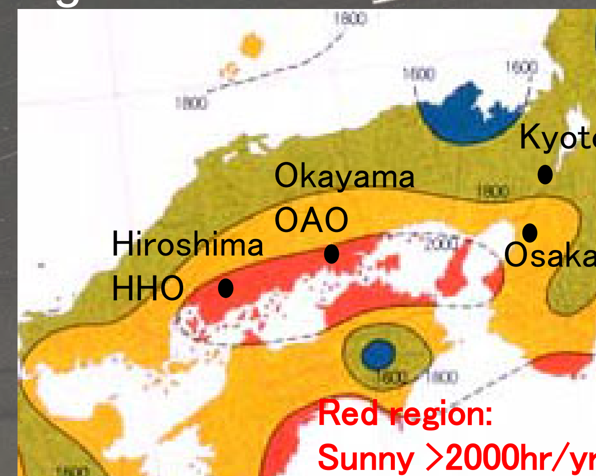
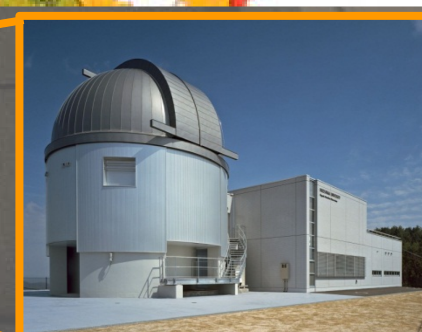
- Found in 2006; operated by Hiroshima University
- Only 25 min by car from campus (503m above sea level)
- ~40% observable nights
- Better seeing condition (median FWHM ~1.2 arcsec)
- Sky brightness R=19-20 mag/arcsec^2 in dark nights





Higashi-Hiroshima Observatory: Aim

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Multi-wavelength and/or Multi-band study for variable, transient objects

Gamma-ray, X-ray and
Optical/NIR Observations

GRB, XRB, AGN, etc

1.5m Optical/NIR telescope, Kanata (2006-)
Gamma-ray satellite (Fermi 2008-)
X-ray satellite (Suzaku 2005-, Astro-H 2016-)

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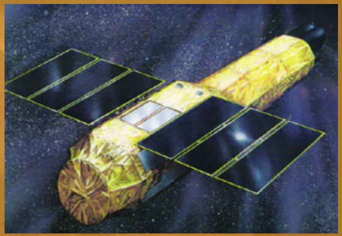

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HE & Opt/NIR Obs. Astronomy group

HE (X-ray and gamma-ray) Astronomy Group

- Fukazawa, Yasushi (Prof)
- Mizuno, Tsunefumi (Assoc. Prof)
- Takahashi, Hiroshitsu (Assist. Prof)
- Ohno, Masatoshi (Assist. Prof)
- Tanaka, Yasuyuki (S.-A. Assist. Prof)
- Kitaguchi, Takao (S.-A. Assist. Prof)

Optical and Near-Infrared Astronomy Group, 2004-

- Yoshida, Michitoshi (Prof)
- Kawabata, Koji (Assoc. Prof)
- Uemura, Makoto (Assoc. Prof)
- Akitaya, Hiroshi (S.-A. Assist. Prof)
- Utsumi, Yousuke (S.-A. Assist. Prof)

Specially Appointed Professor in the group

- Miyama Shoken (S.-A. Prof)
- Ohsugi, Takashi (S.-A. Prof)

(Theoretical Astronomy group)

- Kojima, Yamamoto, Okabe

広島大学
高エネルギー宇宙・
可視赤外線天文学研究室

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Telescope and Instruments

Nasmyth focus#2

High Speed-readout spectrograph
FoV: 2.3’×2.3′
Wavelength res.: R = λ/Δλ =
9-70（400-800nm）、
150（430-690nm）
~30 frames/sec

Nasmyth focus#1

HOWPol 2009-
Opt Imaging：FoV 15′Φ
Opt ImagPol：One-shot type
Spec：R~400(400-1050nm)
We-Do-Wo type Wollaston
`One-shot polarimetry’ is available --- Unique potential for quickly-variable object like GRB afterglows

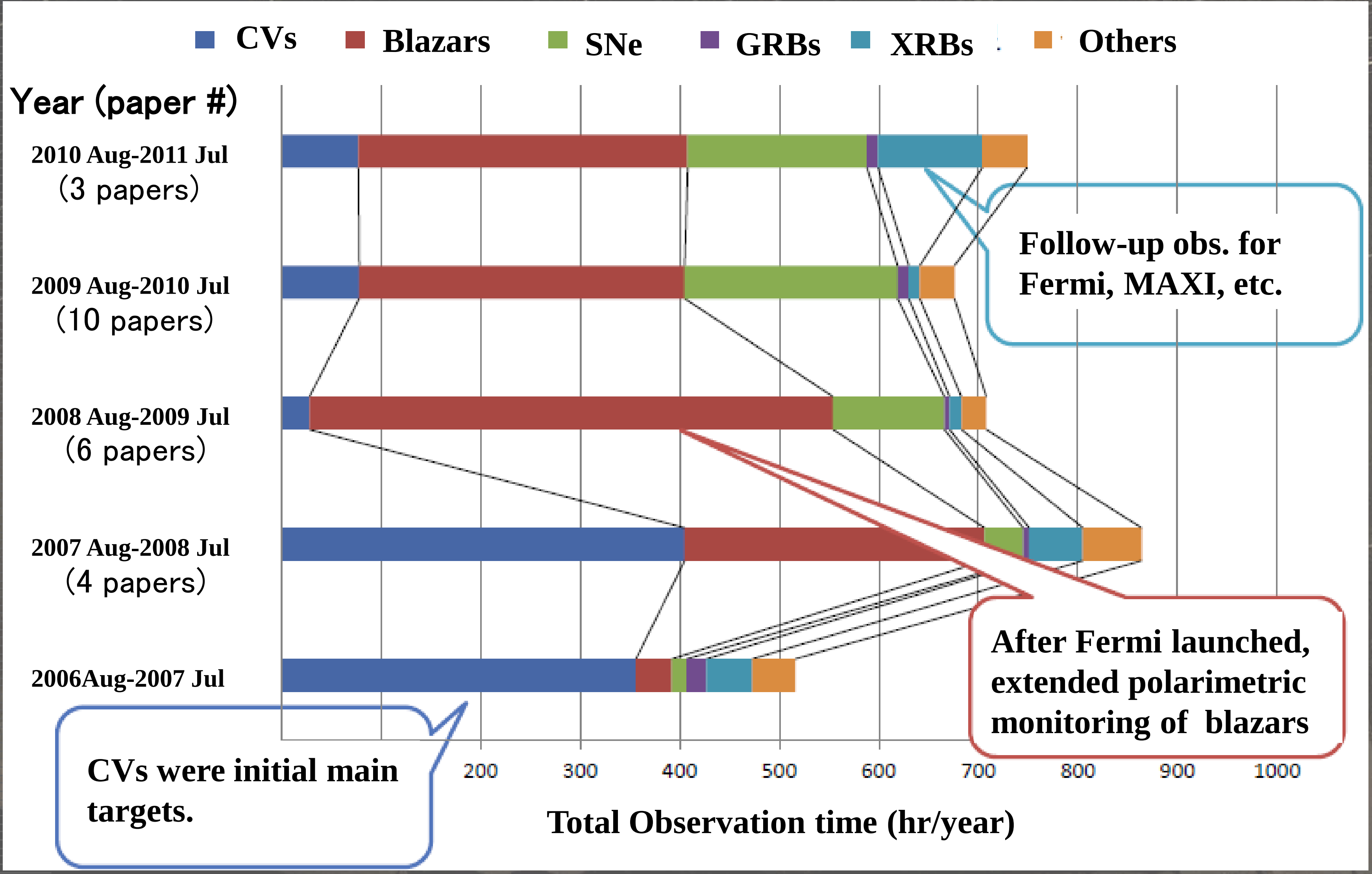
Cassegrain focus

`Kanata’ Telescope

- Successor of IR simulator of Subaru telescope
- 1.5mΦ main mirror
- Azimuth rotation speed : 5° /sec, 2-4 times faster than normal 1-m size telescopes. (merit in high-response observation (e.g. GRBs)

HONIR： 2012-
1 Optical band + 1（future 2) NIR band (simultaneous)
Opt+NIR Imaging：FoV 10′×10′
Opt+NIR Spec：R~400-500
Opt+NIR ImagPol/SpecPol
Maximizing information by single observation

Observational Targets with Kanata telescope 1



Observational Targets with Kanata telescope 2

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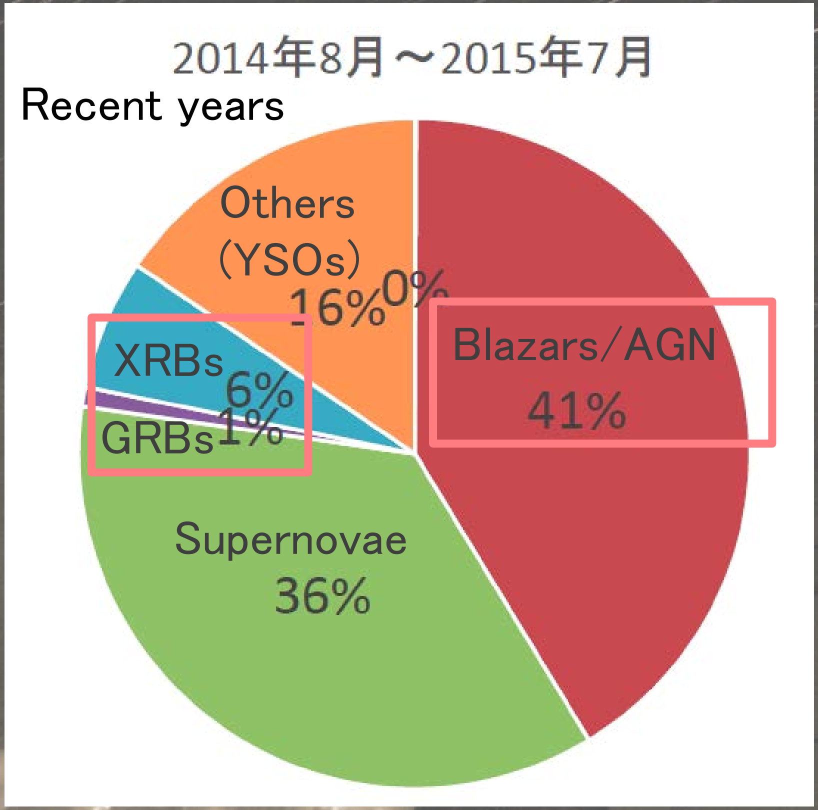

Multi-wavelength study
with HE photons (+radio)

Number of Refereed Papers using Kanata Telescope

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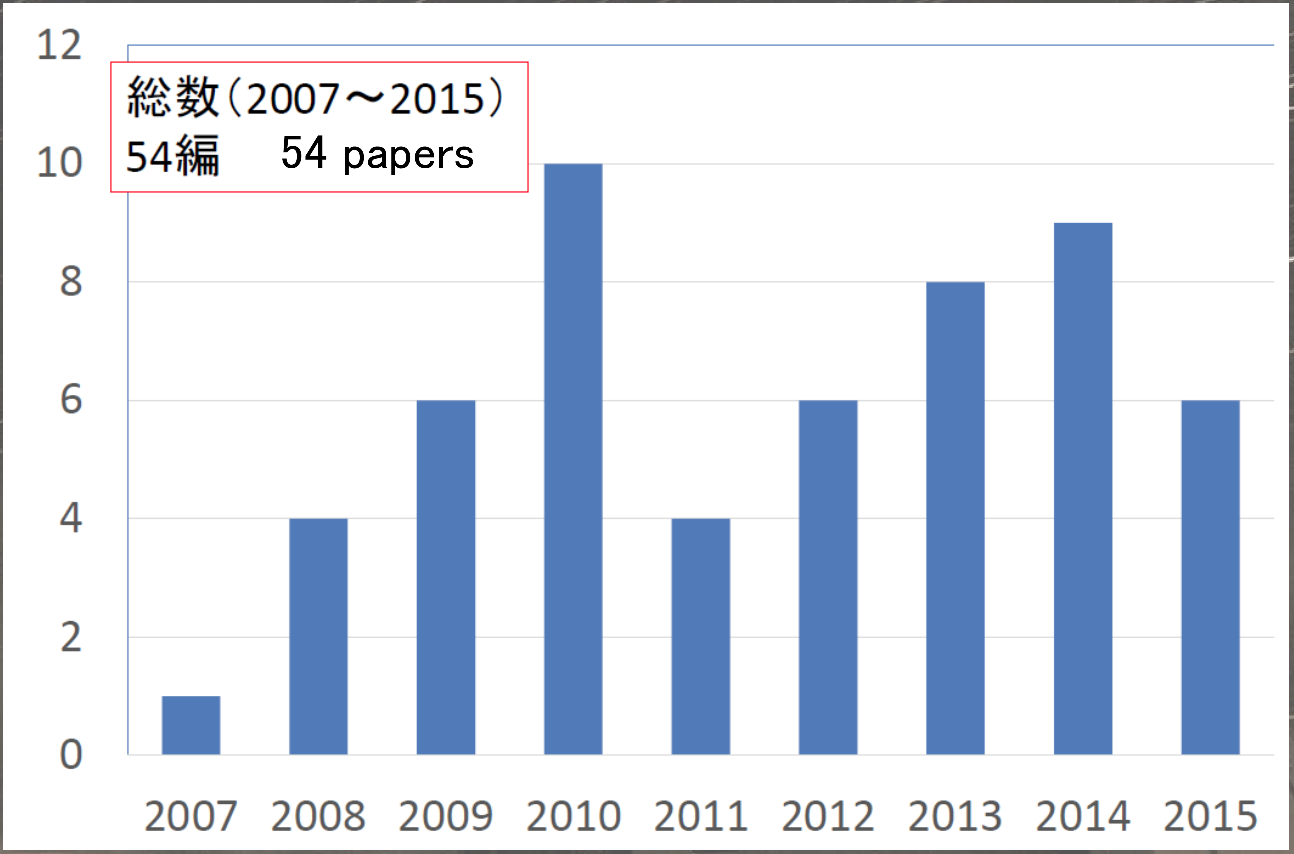

A member of Opt/NIR Inter-University Cooperation Network: OISTER（2011-）

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(Japan)	(Chile)	(South Africa)
16 tels.	1 tel.	1 tel.
0.5-2m	1m	1.4m

A few Campaign Observation in a year

Strategy of Kanata Telescope

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Discrimination from other telescopes

- Transient phenomena
  - Requiring high response system and/or extended observations (being hard for large telescopes)
- Multi-wavelength
  - Coordinated with X/Gamma-ray observations supported by high-energy (and theoretical) people.
- Multi-mode
  - Simultaneous Opt/NIR observation including polarimetry and spectroscopy, maximizing information gaining from a single observation.

Comment for multi-wavelength observation

- There are large differences in observing technique and conditions between Opt/NIR and X/Gamma-ray regimes.
- Special skill is required for planning an effective multi-wavelength collaborative study.
- For long-lasting collaborative study, daily cooperation (, mutual understanding, and interdependence, …) will be necessary.
- Our group may luckily satisfy it, because it has established supposing daily education and collaboration in a single unit.

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Comment for multi-mode observation

- Polarimetry has been focused in our instrumentation and observation.
- Generally, `polarization of light' is minor subject in astronomy (although I disagree with it) and optical instruments having capability of polarimetry is still rare.
- It is quite rare that a polarimeter is always attached to telescope (that is, polarimetry is capable every night at the telescope), even among worldwide 1-2-m class small telescopes.

Instruments

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Kanata tel. is quite unique facility

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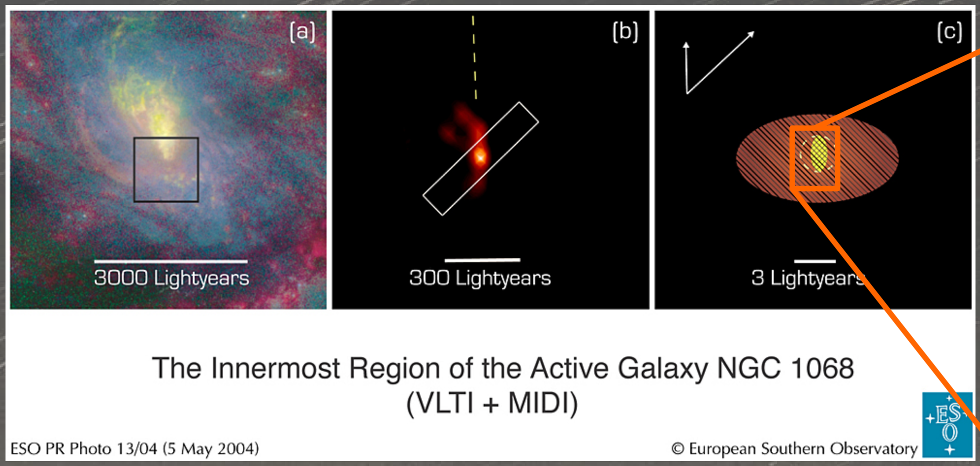
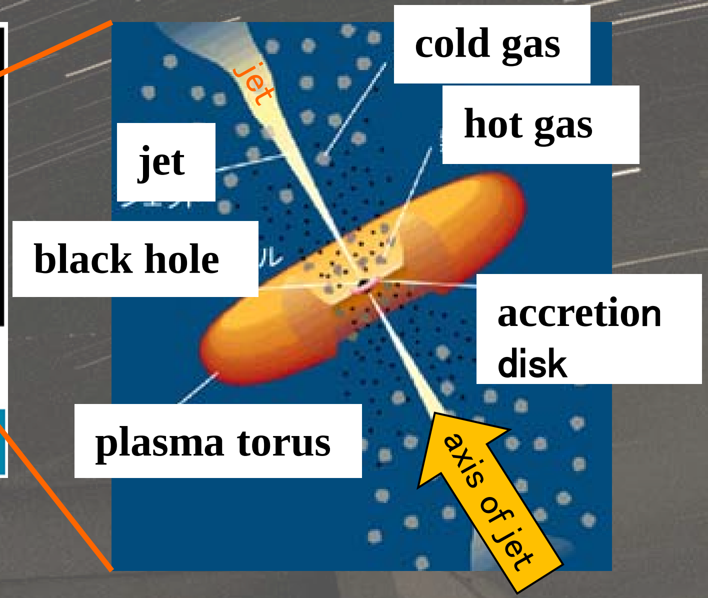
Opt+NIR ImagPol/SpecPol
Maximizing information by single observation

Multi-wavelength Observation Sample 1: Blazars and related objects

Blazars



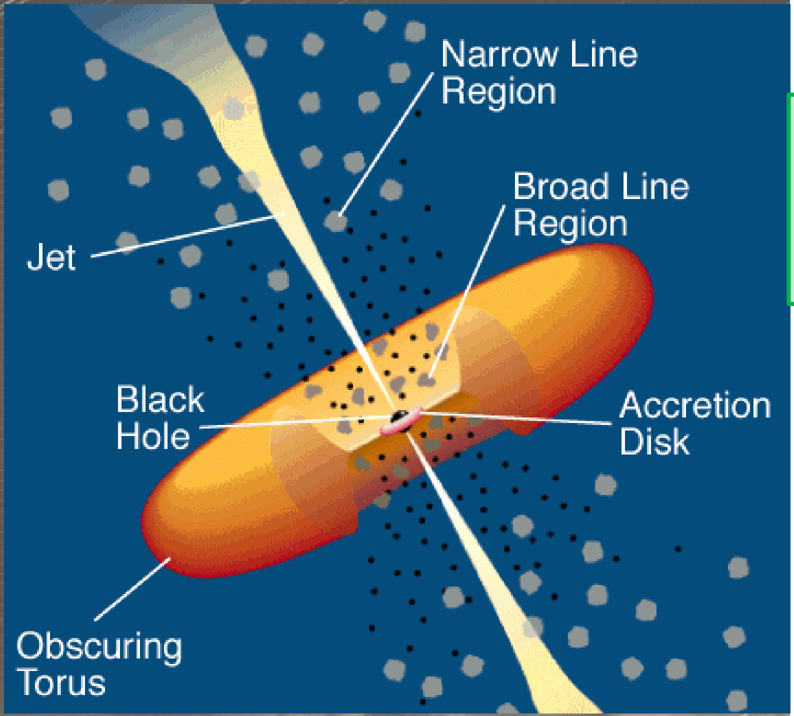


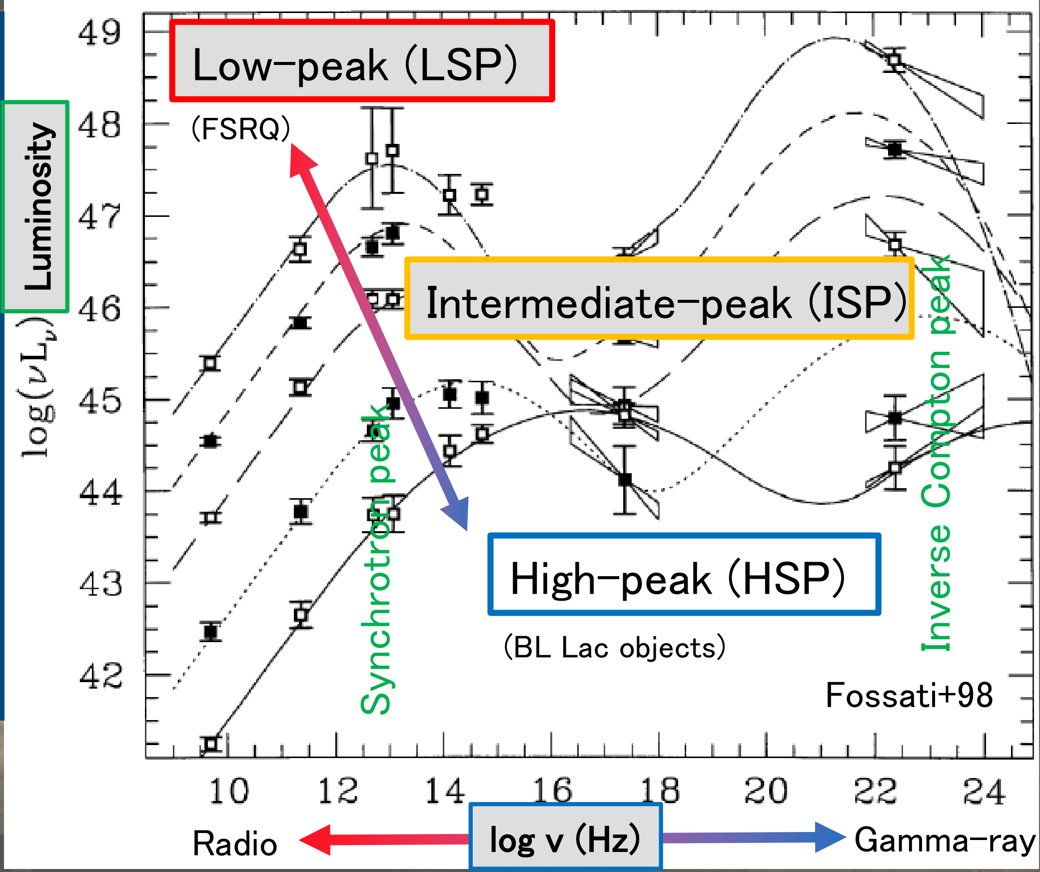
Blazars are believed to be AGN seen along the jet axis.
→ Synchrotron radiation would dominate the flux at IR/optical wavelengths

SED of Blazars

Relativistic beaming;
brightened by δ^4 ~
10,000 times

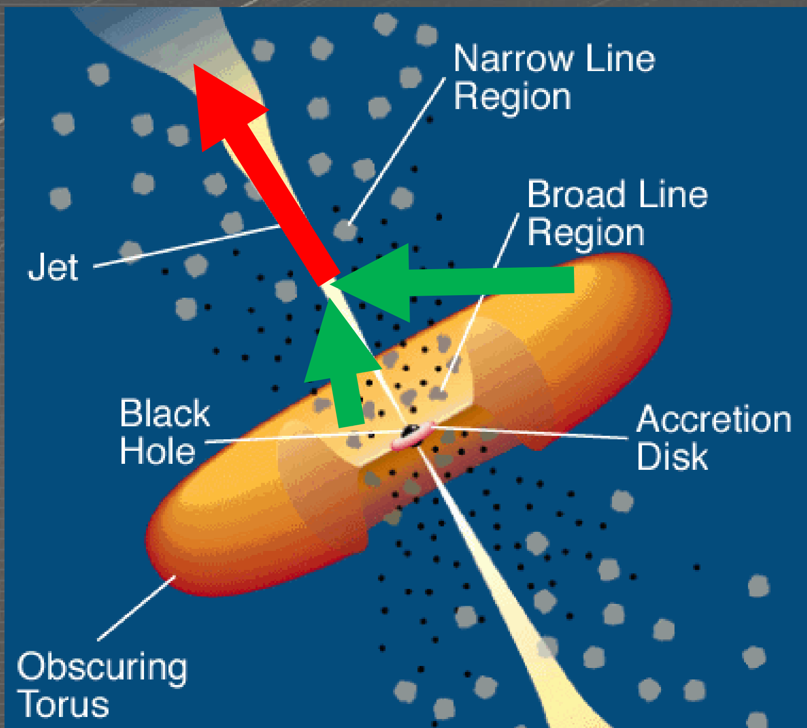
Emission from the jet dominates from radio through gamma-ray; rapid and large amplitude variability and strongly polarized light

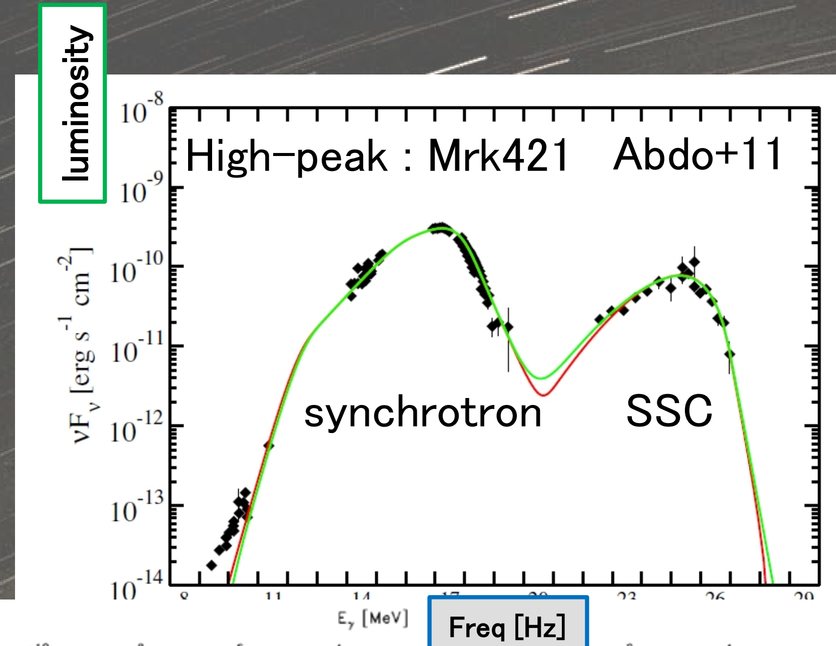


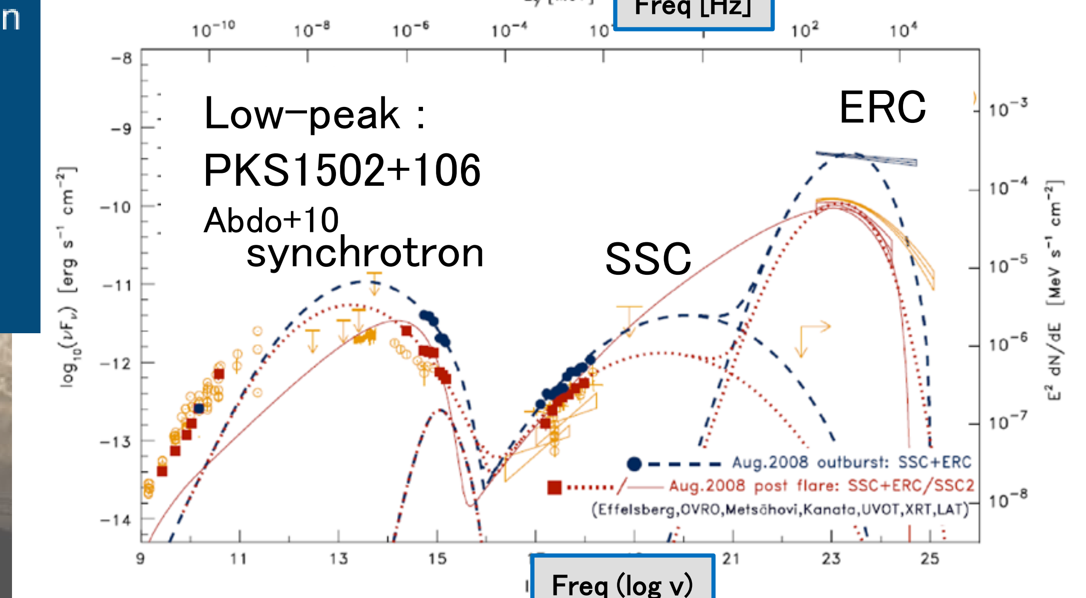


Emission model of high energy part

Synchrotron –Self Compton (SSC)
External Radiation Compton (ERC)







Emission at GeV regime
High–peak : SSC
Low–peak : ERC

Kanata Blazar Photo-Polarimetry Campaign

We performed polarimetric campaign with Kanata telescope and a simultaneous optical and NIR instrument, as a joint observation with *Fermi* Gamma-ray satellite
in 2008-2010.
42 blazars (13 FSRQs, 8 LSPs, 9 ISPs, and 12 HSPs; the classification based on Abdo et al. 2010) are monitored in V, J, and Ks-band.
Most comprehensive polarimetric data set obtained.

Ikejiri et al. 2011

Target Blazars						
PKS 0048	QSO 0324	PKS 0754	Mrk 421	3C279	H1722+119	BL Lac
S2 0109	1ES 0323	1ES 0806	RGB 1136	OQ 530	PKS 1749	1ES 2344
MisV1436	PKS 0422	OJ 49	ON 325	PKS 1502	S5 1803	3C454.3
PKS 0215	QSO 0454	OJ 287	ON 231	PKS 1510	3C371	
3C66A	1ES 0647	S4 0954	3C 273	PG 1553	1ES 1959	
AO 0235	S5 0716	3EG 1052	QSO1239	Mrk 501	PKS 2155	

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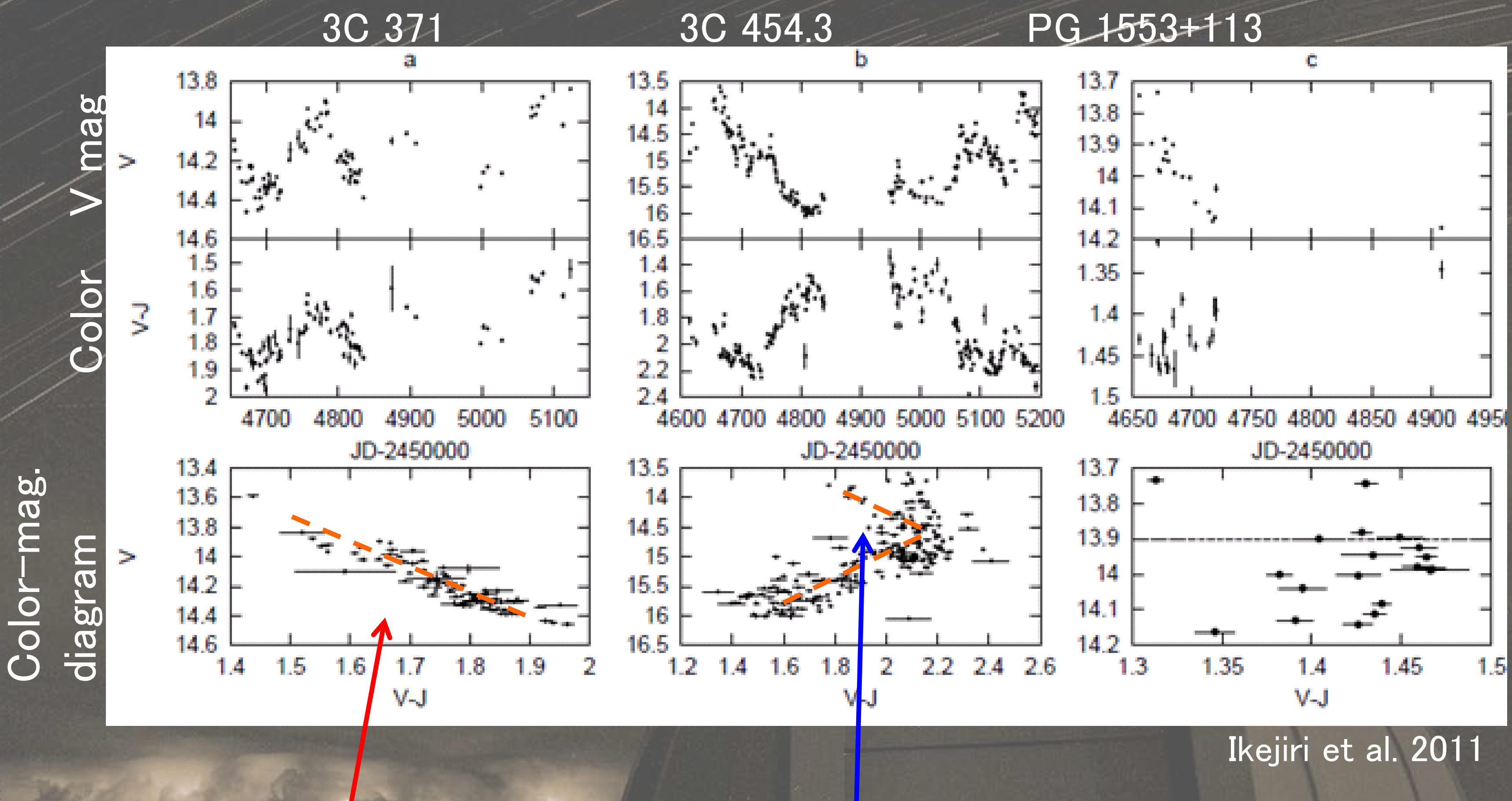
Flux-color correlation



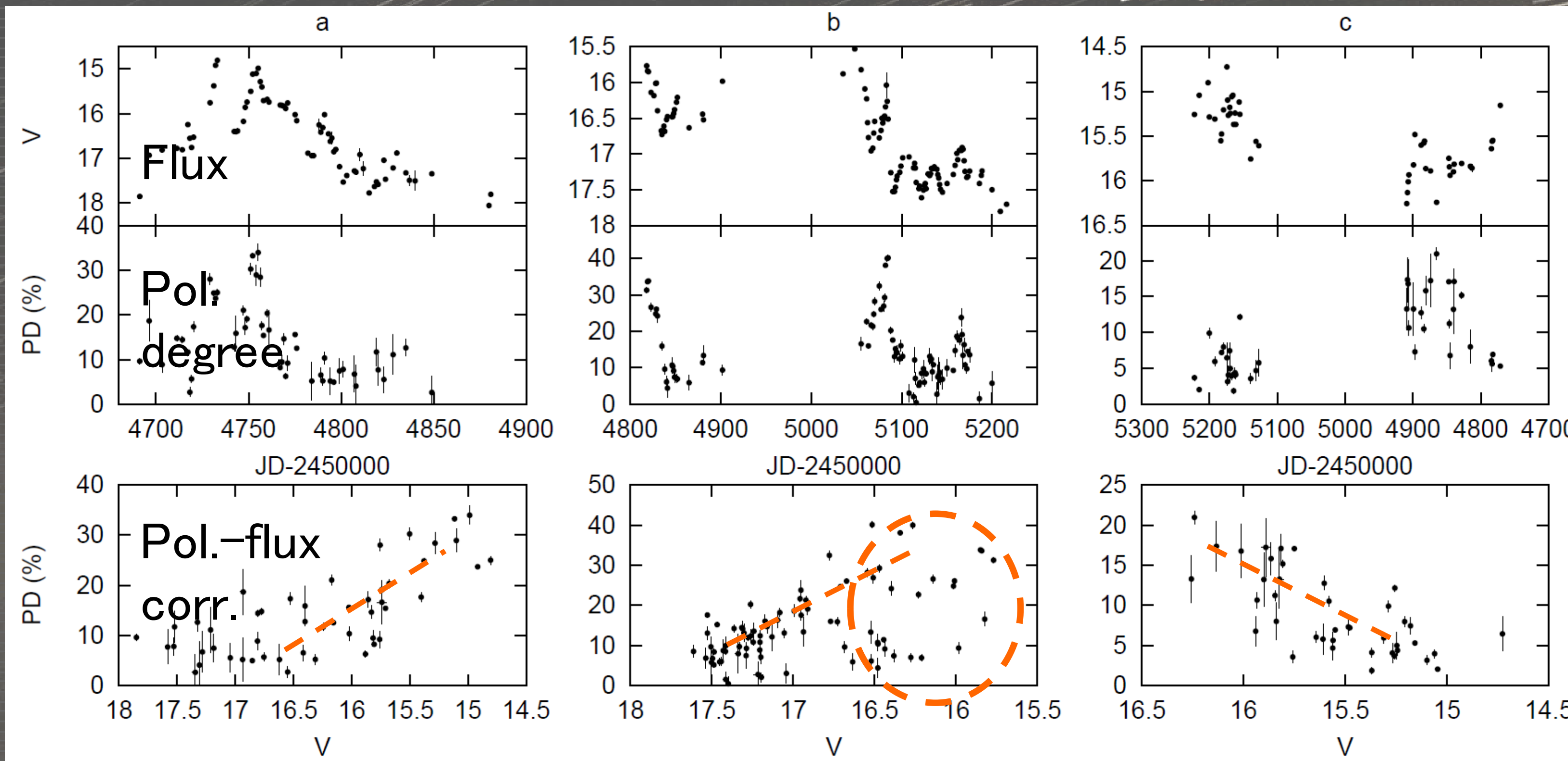
Ikejiri et al. 2011

\`Bluer when brighter' trend in the whole data (72%)

\`Bluer when brighter' in brighter phase (16%)
(In faint phase, hot disk component is dominant)

Flux-polarization correlation

AO 0235+164 MisV1436 OJ 49



positive corr. positive corr. + other negative corr.

45%

Ikejiri et al. 2011

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Rotation of Linear Polarization Angle

PKS 1510−089

3C 66A

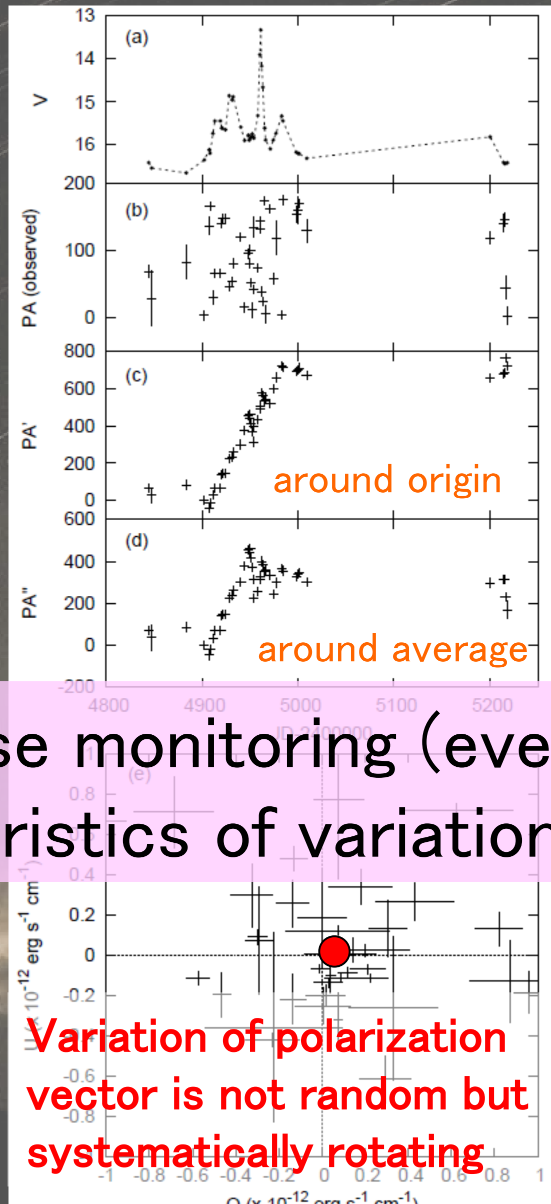
V mag

PAobs

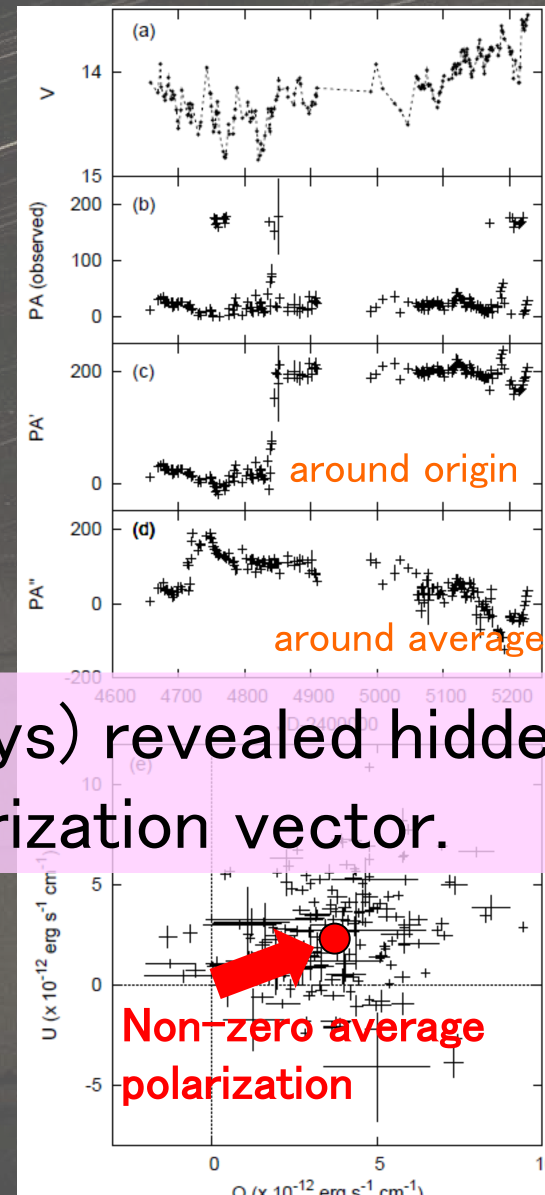
PA180

PAshift

QU−diagram



Typically, 10−20° /day

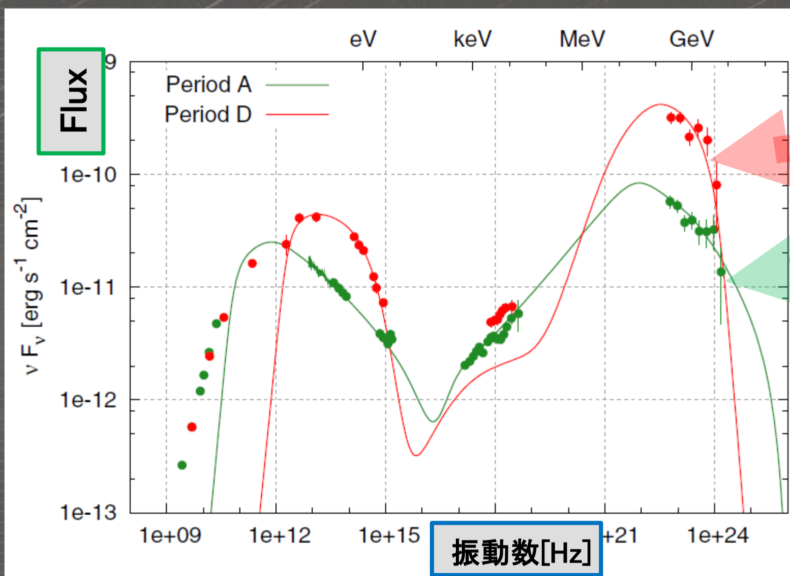


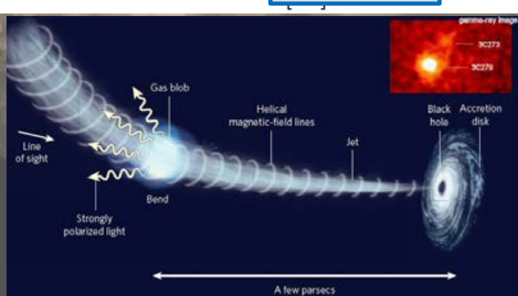
Our dense monitoring (every ~3 days) revealed hidden characteristics of variation of polarization vector.

Ikejiri+ 2011

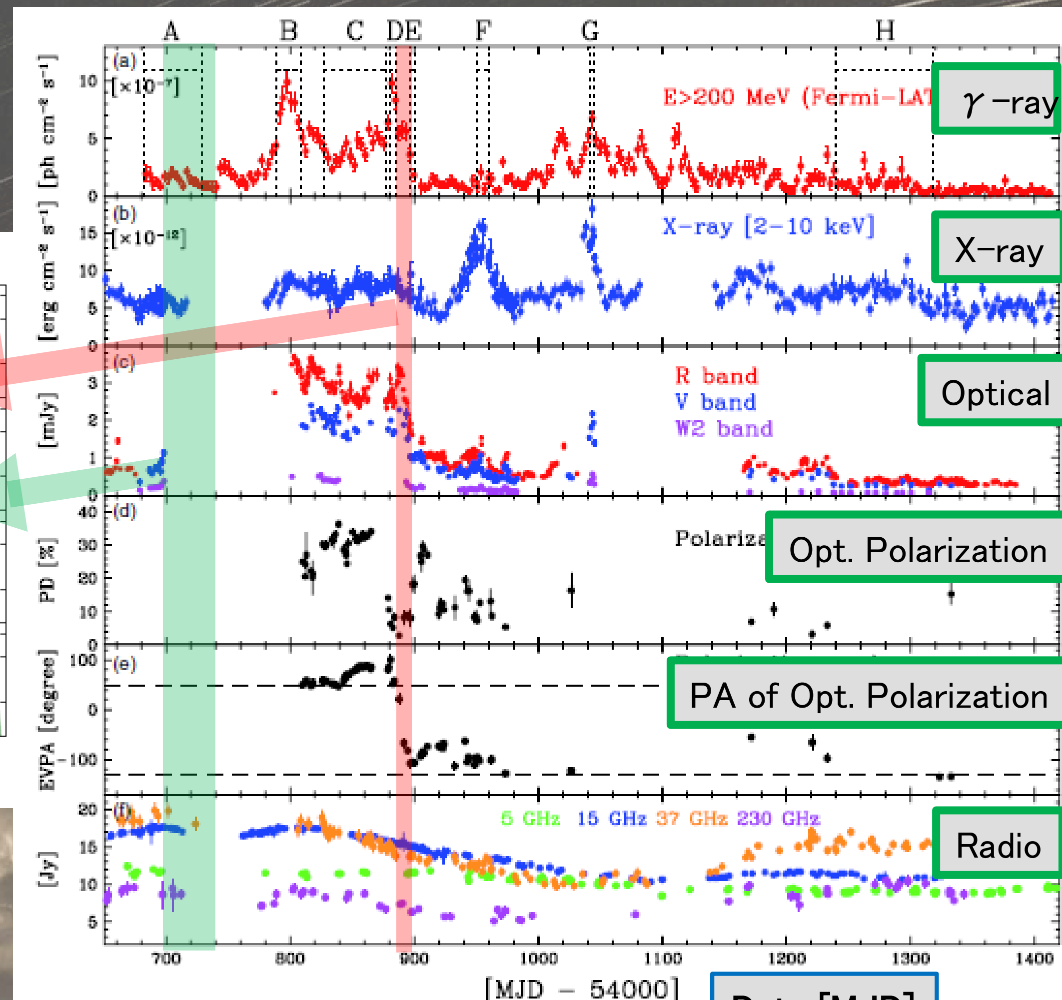
Multi-wavelength study in 3C 279

SED





MW Light Curve and Opt. Polarization



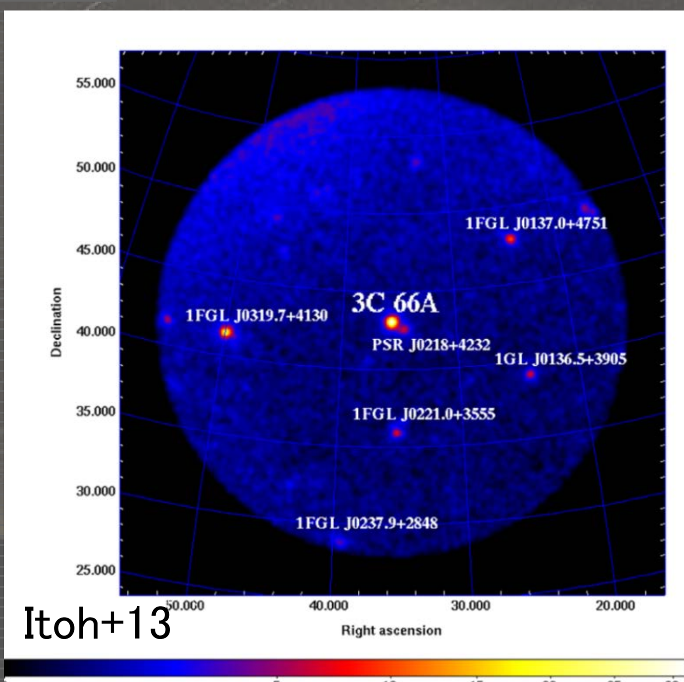
Abdo+10, Hayashida+12; Itoh private comm.

Multi-wavelength study in 3C 66A

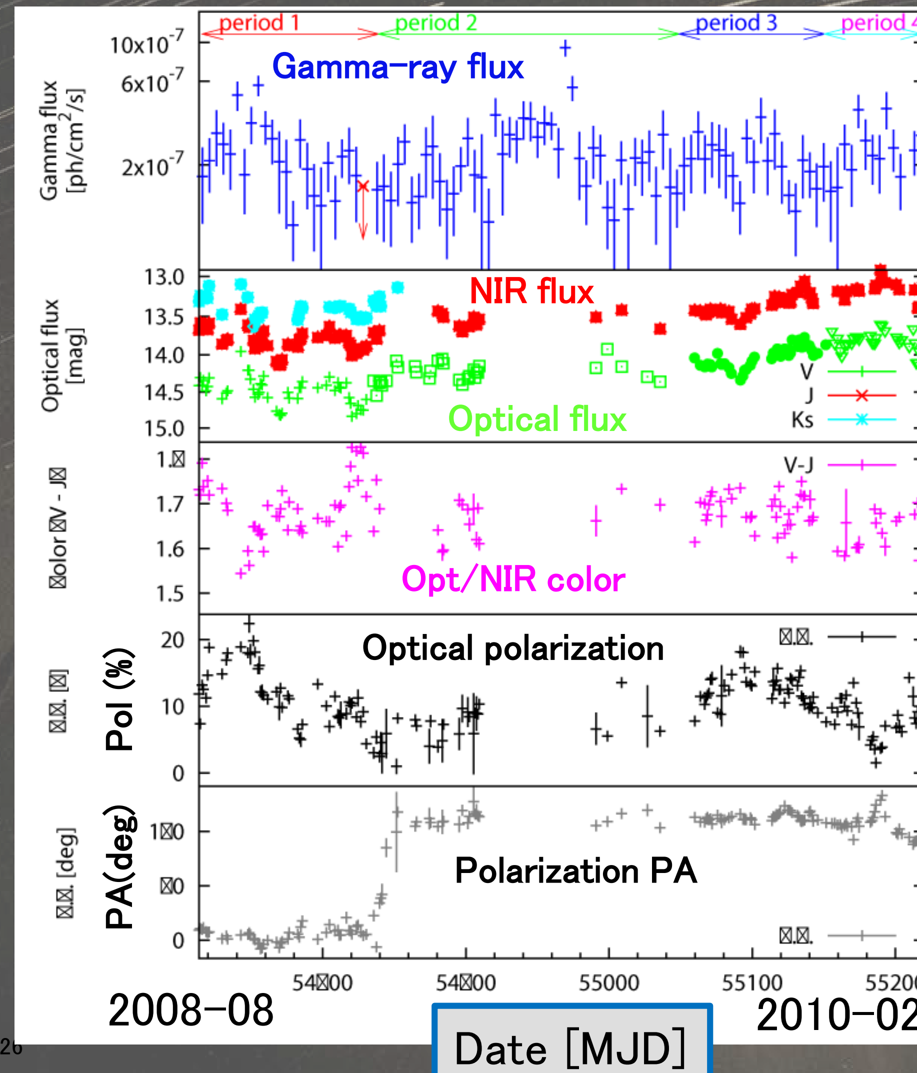
Itoh+13

ISP (z = 0.444)
Flare in 2008 Sep
Extended monitoring with Fermi/LAT & Kanata tel.

3C 66A Gamma-ray image



Itoh+13



Inverse Compton Scattering: External radiation source

Period 1 → Period 4.

Optical flux: Increased by 2 times

Gamma-ray: No variation

Variation of ERC radiation

$$\frac{L_{\mathrm{ERC}}}{L_{\mathrm{sync}}} \sim \Gamma^2 \frac{u_{\mathrm{ext}}}{u_{\mathrm{B}}} \longrightarrow u_{\mathrm{ext}} \sim \frac{B^2}{8\pi\Gamma^2} \frac{L_{\mathrm{ERC}}}{L_{\mathrm{sync}}}$$

Shikora et al. 2007

(B = 0.23 [G], Γ =50, R = 1.5×10^{16} cm are assumed by spectral fitting; Abdo+10)

Epoch	Uext [10^{-7} $erg\ cm^{-3}$]
Period 1	9.04
Period 4	4.54

Suggesting different environment/location for radiation soueces for Period 1 (more ER) and 4 (less ER)

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Active phase monitoring in CTA 102

FSRQ (z = 1.037)

Flare observed on

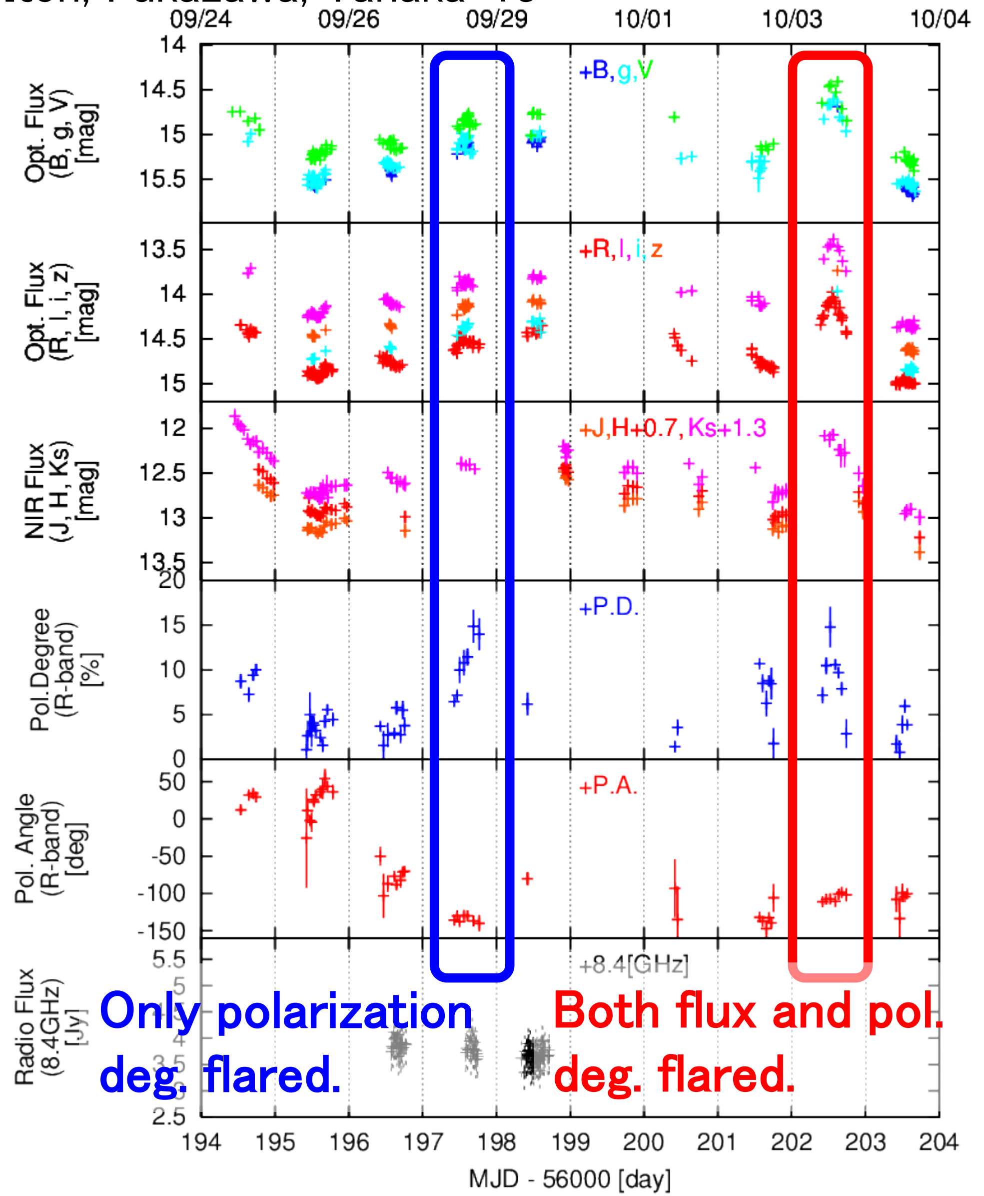
19 Sep 2012 Optical report (ATel #4397)

21 Sep 2012 GeV report (ATel #4409)

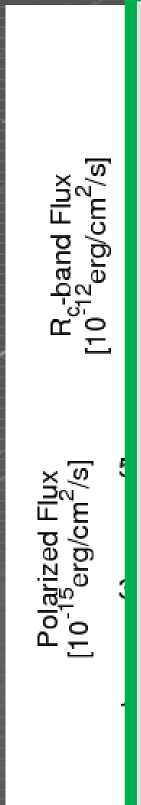
Started dense monitoring with Kanata + OISTER

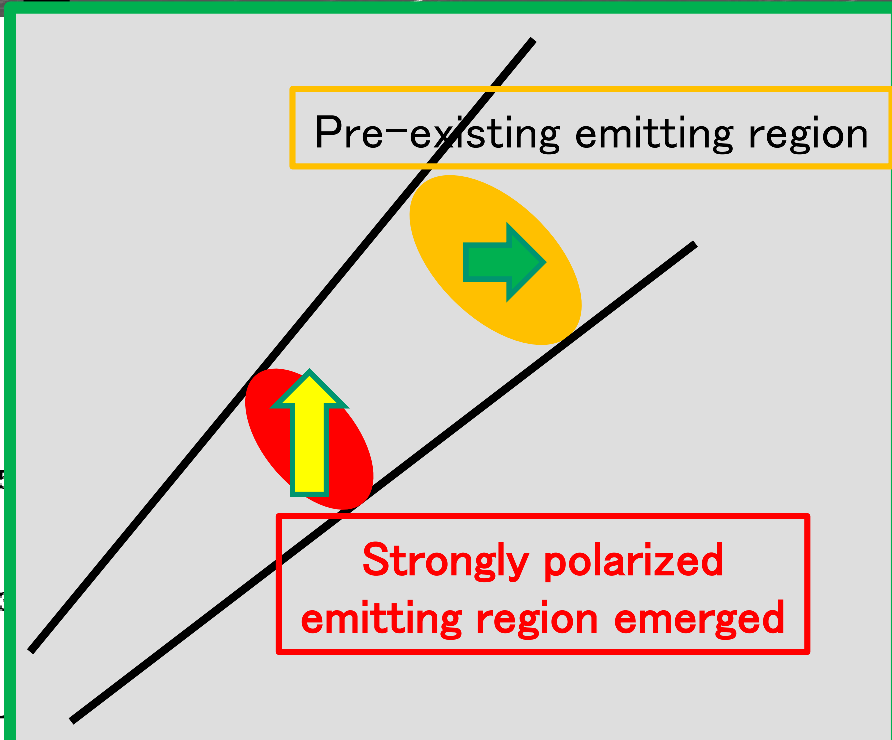
Two types of violent variation in optical polarization observed.

Itoh, Fukazawa, Tanaka+13



Flare with polarization (MJD 56202)





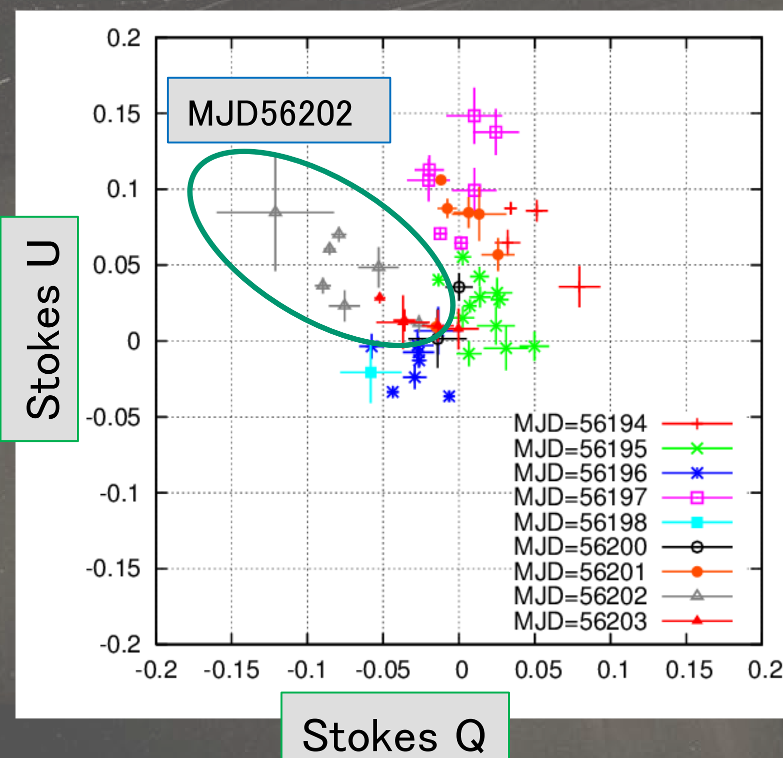
Emergence of new emission region?

polarization vector

Itoh, Fukazawa, Tanaka+ 13

First detection of simultaneous flaring in both luminosity and polarization within <1 day.

Polarization variation in Stokes QU



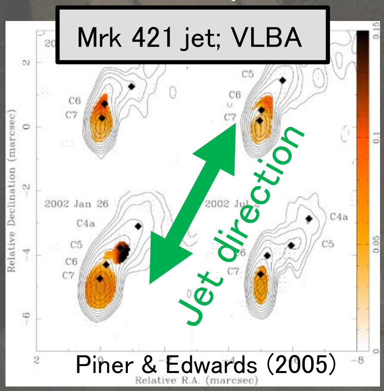
Summary of our blazar monitoring across flaring

Itoh et al., private comm.

Object	Class	Correlation of opt and gamma fluxes	Corr. of opt flux and opt polarization	Multi site for emitting region	Alignment of jet and polarization
3C 66A	ISP	△	○	○	‖
Mrk 421	HSP	×	×	×	‖
CTA 102	FSRQ	○	△	○	⊥
AO 0235+164	LSP	○	○	×	‖
GB6 1310	FSRQ	○	○	×	--

LSP: Low-peaked, ISP; Intermediate, HSP; High-peaked FSRQ(LSP); Flat spectrum radio quasar

Condition differs object to object…



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Ongoing study (Itoh+ in prep.)

More comprehensive study with Fermi and Kanata

(*); Number of optical observations
Red; GeV bright source

FSRQ	LSP	ISP	HSP	RL-NLSy1
3C 454.3 (498)	**BL Lac** (539)	**S5 0716+714** (628)	**Mrk 501** (244)	1H 0323+342
3C 273 (332)	OJ 287 (413)	**3C 66A** (487)	**PG 1553+113** (225)	PMN J0948+0022
3C 279 (177)	AO 0235+164 (93)	**1ES 1959+650** (202)	**PKS 2155−304** (161)	
PKS 1749+096 (163)	OJ 49 (70)	S2 0109+22 (102)	**Mrk 421** (74)	
3C 371 (124)	S4 0954+658 (5)	PKS 0048−097 (63)	**ON 325** (56)	
RX J1542.8+612 (113)	1ES 1218+304 (3)	ON 231 (48)	1ES 0806+524 (54)	
PKS 1510−089 (110)		OQ 530 (19)	H 1722+119 (66)	
Mis V1436 (106)			PKS 0422+004 (42)	
CTA 102 (92)			1ES 2344+514 (33)	
PKS 1502+106 (76)			1ES 0647+250 (24)	
QSO 0454−234 (28)			1ES 0323+022 (21)	
S5 1803+784 (35)				
PKS 0754+100 (28)				
PKS 0215+015 (5)				
GB6 J1239+0443 (5)				

Coming soon!

- Bright in GeV gamma-ray
- Observable with Kanata telescope
- Flares have been observed

Multi-wavelength Observation Sample 2:
X-ray binary; Micro quasars

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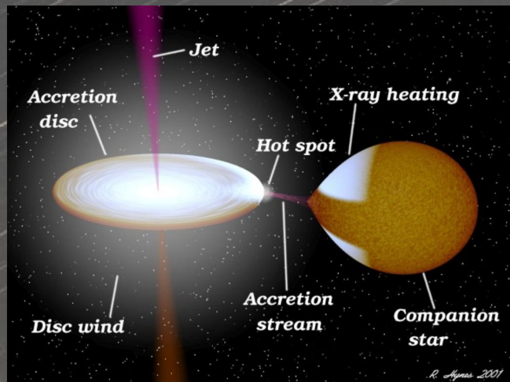
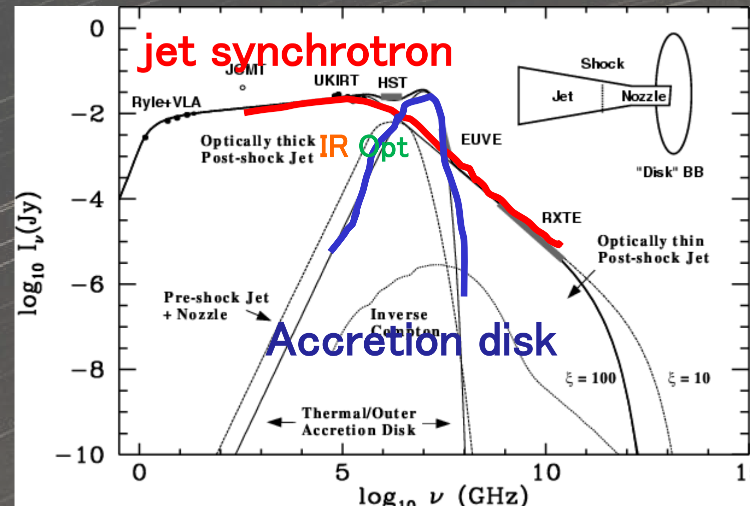
X-ray binary



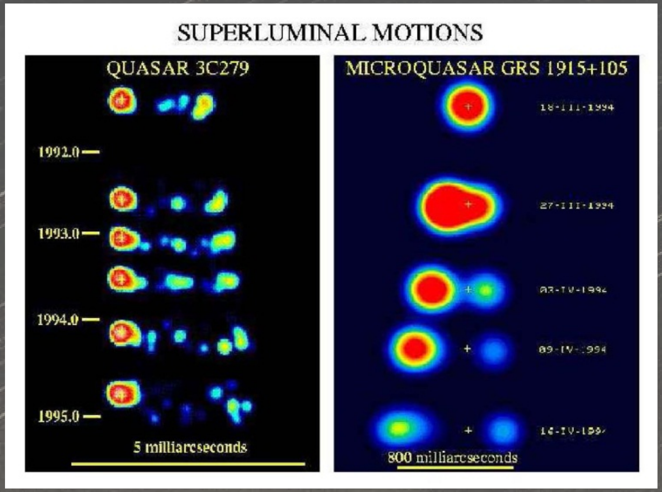
Binary including BH or NS

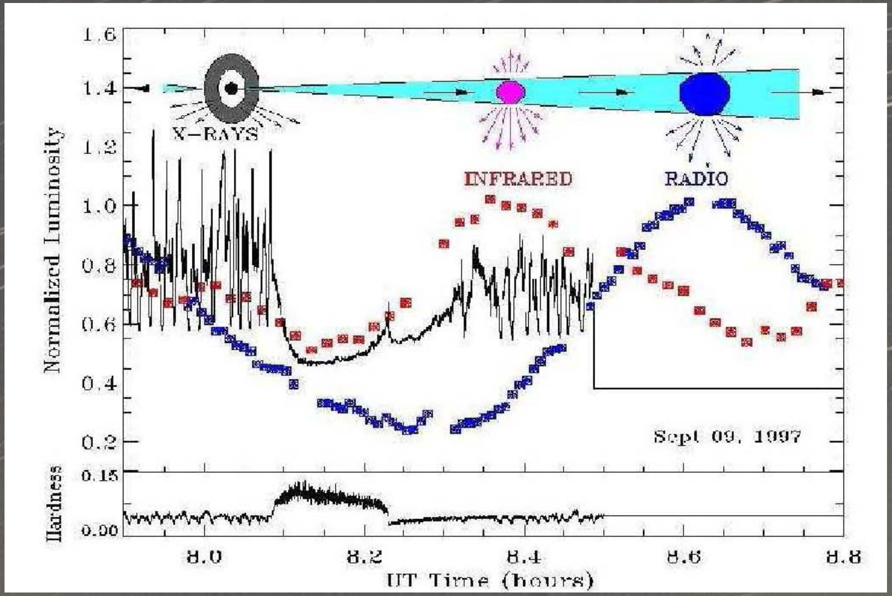


XTE J1118+480; Markoff et al (2001)

- It has been claimed that NIR light is produced by jet. (Most X-ray binaries locate near the milky way, and the optical light is heavily absorbed, but NIR light is much less absorbed.)
- Thus, jet can be probed by NIR observation (as well as X-ray and radio observations)

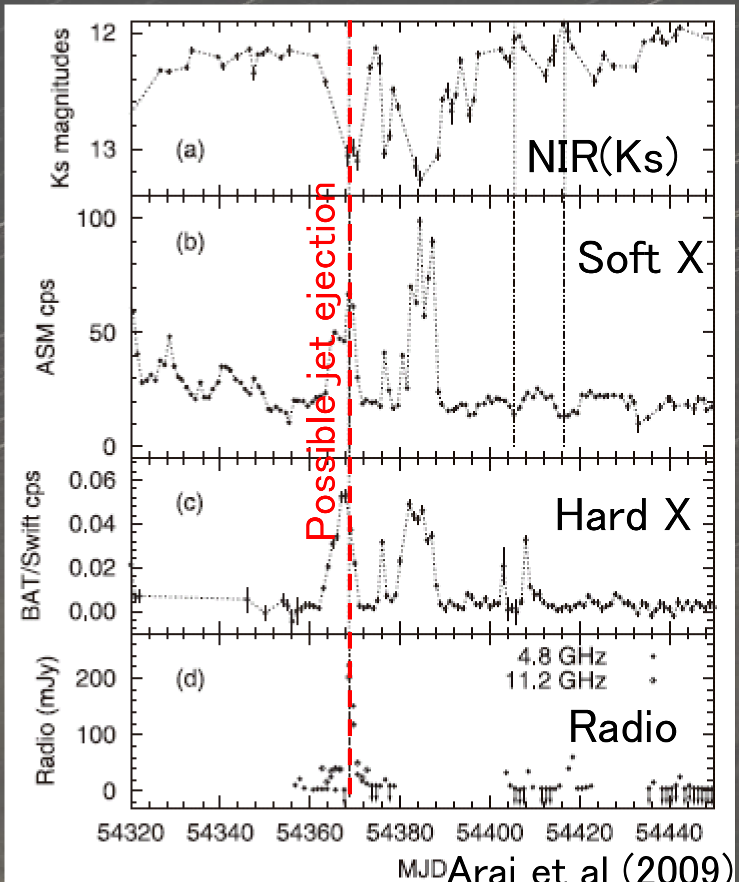
GRS 1915+015 as `microquasar'





- Superluminal motion in radio (VLBI)
  → High-velocity jet → Called as microquasar
- BH mass 14±4 $M_{\odot}$ from NIR spectroscopic period (Greiner et al. 2001)
- A time-sequential flare among X-ray, NIR and radio wavelengths is found, explained by disk-jet model (Mirabel et al. 1998)
- But, the observational material for accretion and jet physics is still poor.

Anti-correlation in X-ray and NIR

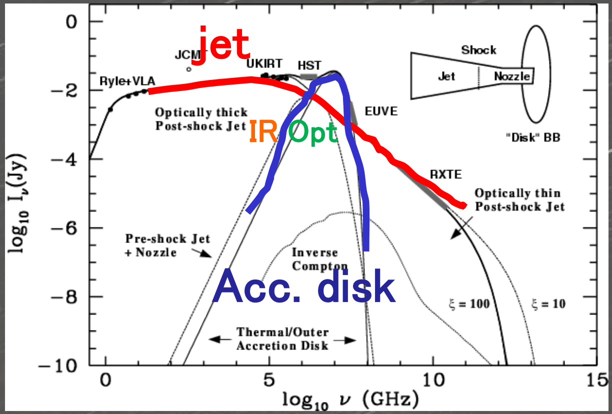


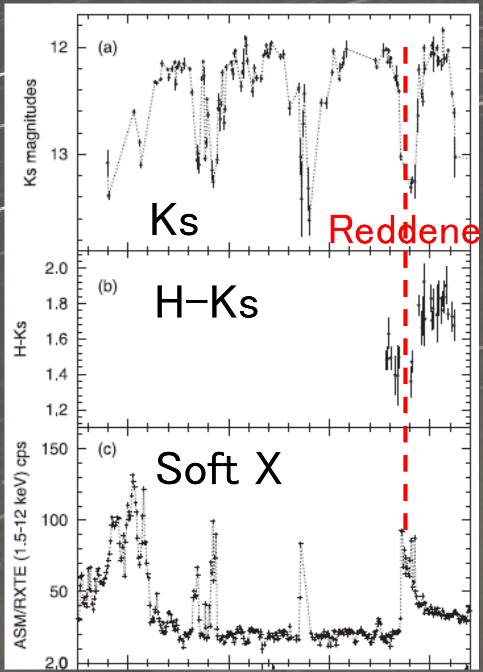
Arai et al (2009)

NIR photometric monitoring.
X-ray hardness ratio suggests this binary is in soft state at MJD 54320-54570.
Around MJD 54370, X-ray and radio flare appeared
→ jet ejection
In contrast, NIR flux decreased.
(Time lag < 1d)

This NIR - X/radio anti-correlation continued during its soft state (~250 d).

What does the anti-correlation indicate?





Arai et al (2009)

- NIR flux becomes redder at flare.

  This suggests that the jet synchrotron component is significant at flare, but thermal emission from hot accretion disk dominates NIR flux normally.

- Why does NIR flux decrease at jet ejection?

  Accretion disk disappeared temporally?

  Coronal disk wind hides the disk in NIR?

  Future NIR spectroscopy and/or polarimetry will give another insight.

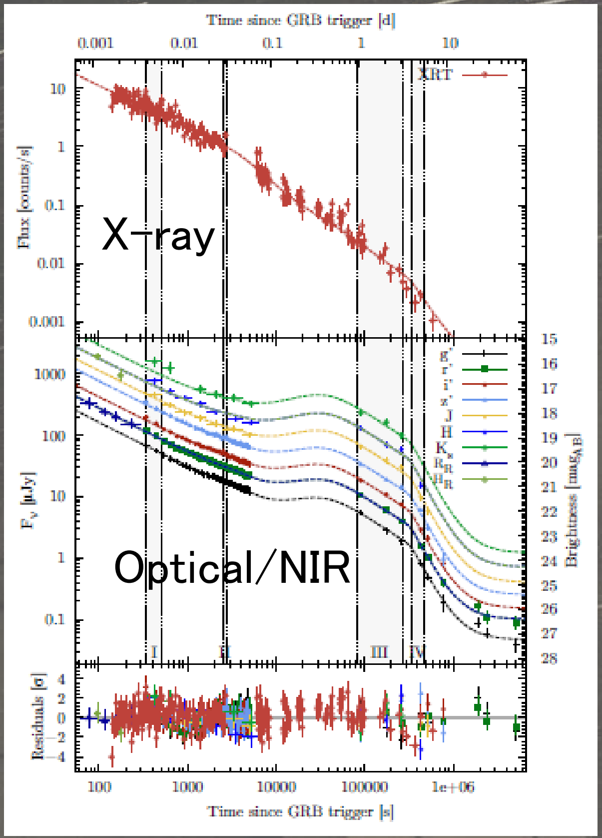
Multi-wavelength Observation Sample 3: Gamma-ray bursts and their afterglows

Afterglow of GRBs

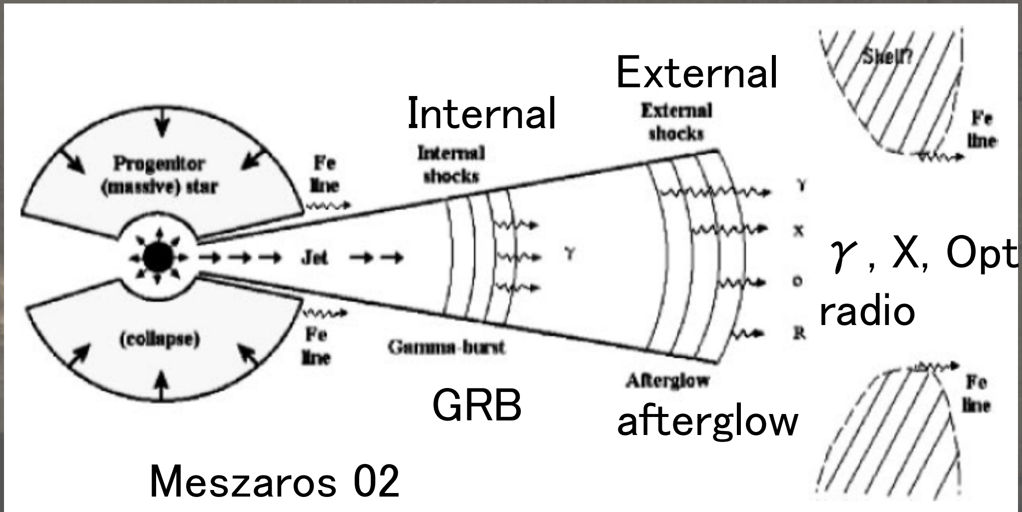
A considerable fraction of GRBs (~30%) show afterglows in optical wavelengths.

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

080413B Filgas+ 2011



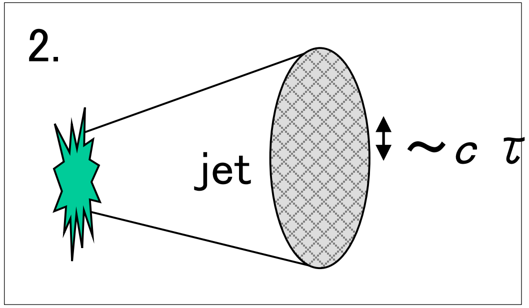
Time since (sec)

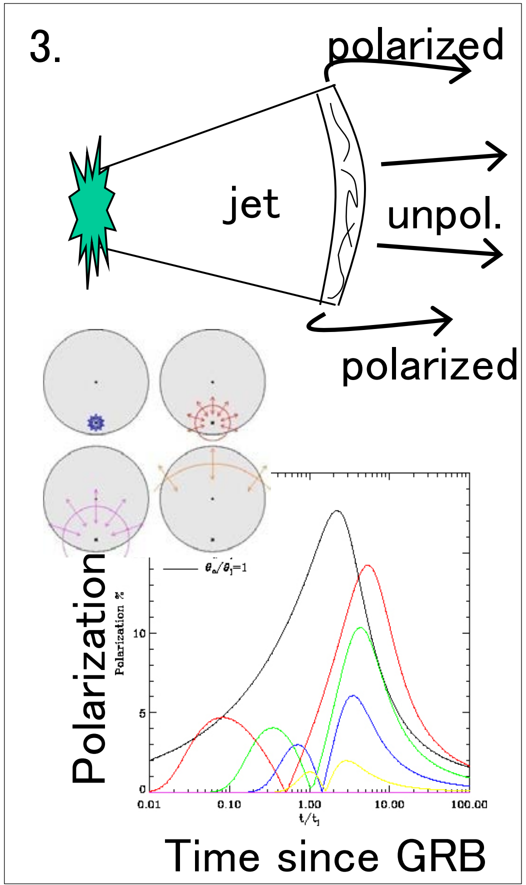


Meszaros 02

Expected geometry of magnetism and polarization

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=0–10% from oblique line of sight (e.g, Sari+ 1999; Rossi+ 2004)
4. **Large scale ordered-magnetic field in (not hydrodynamic jet, but) Poynting-flux dominated jet** (e.g, Lyutikov+ 2003)
   → Large polarization (up to ~50%)





Rossi+ 04

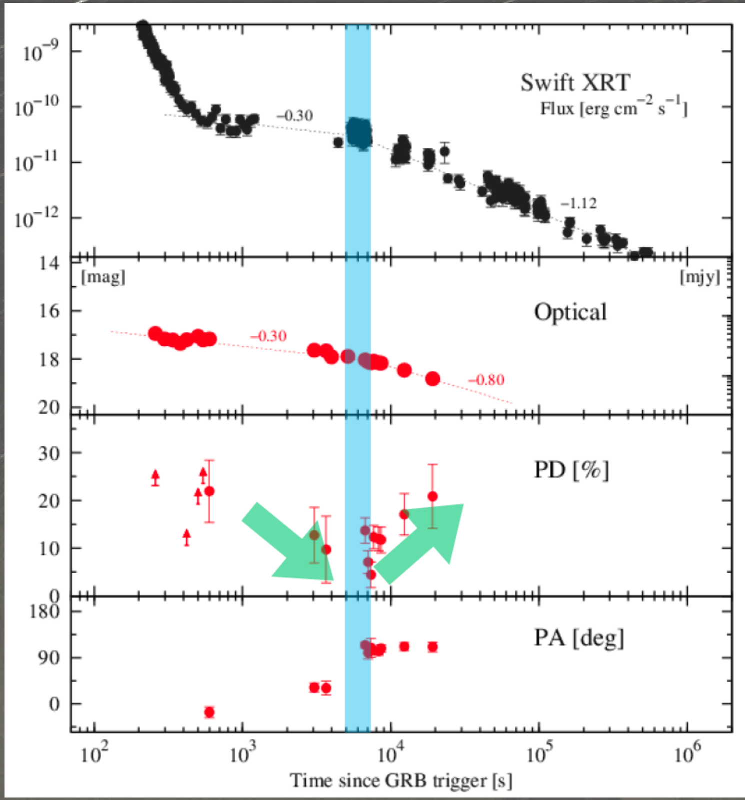
List of Kanata optical polarimetry for GRBs

HIROSHIMA UNIVERSITY

	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

We have the record of earliest observation ($\lesssim$100s after gamma-ray trigger) for GRB afterglow in polarimetry (091208B, 121011A, 140629A).

GRB 111228A (z=0.714)



Takaki, Toma, KK+, submitted

Optical afterglow shows significant temporal polarization change.

GRB 111228A: Strongly polarized

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

GRB 140629A (z=2.3)

T_{90} (15–350keV) = 75.6±12.7sec
Galactic $A_V = 0.022$; upper-limit p_{MW}~0.07%

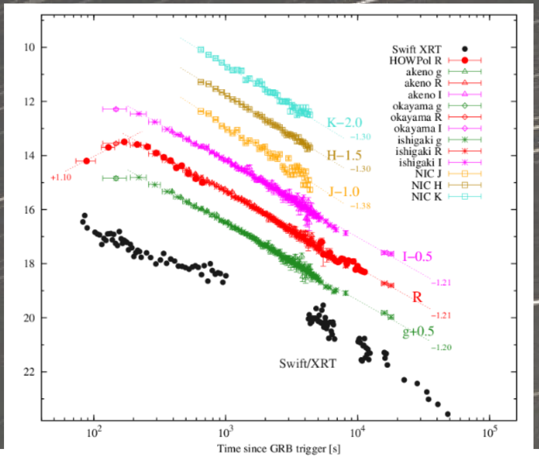
Polarimetry began at $T_0 + 73$ s

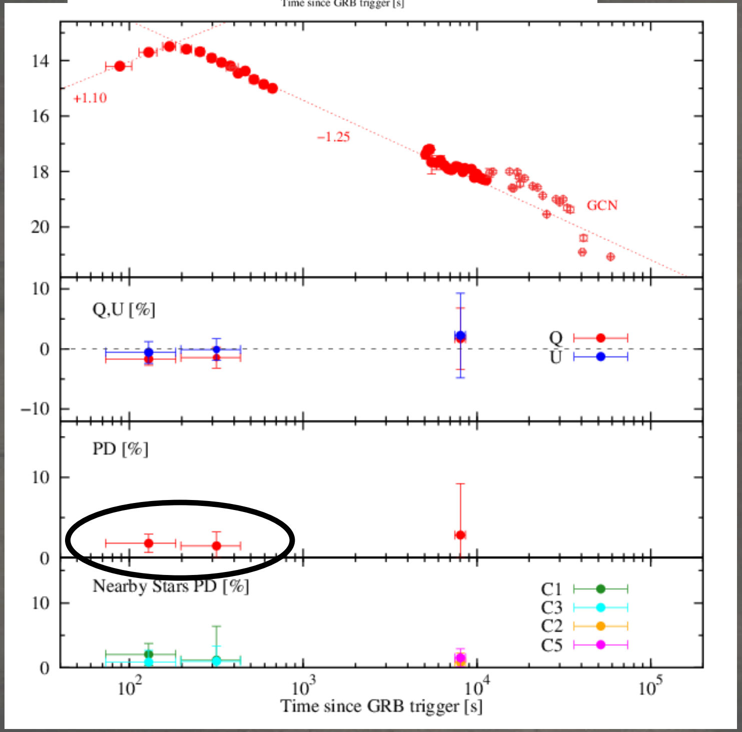
(22 s in rest frame)

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

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

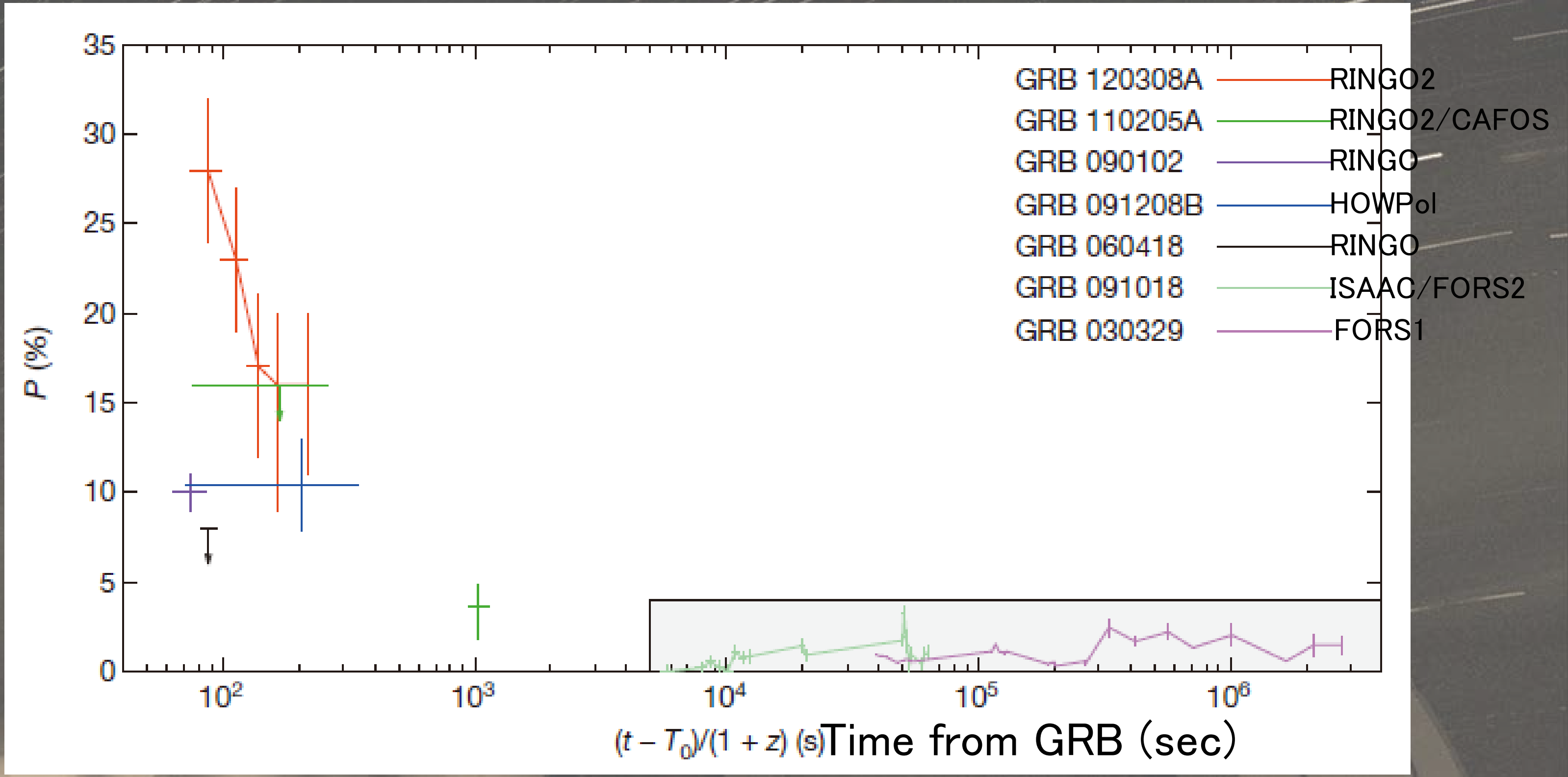




Takaki+, in prep.

Other early afterglow polarimetry

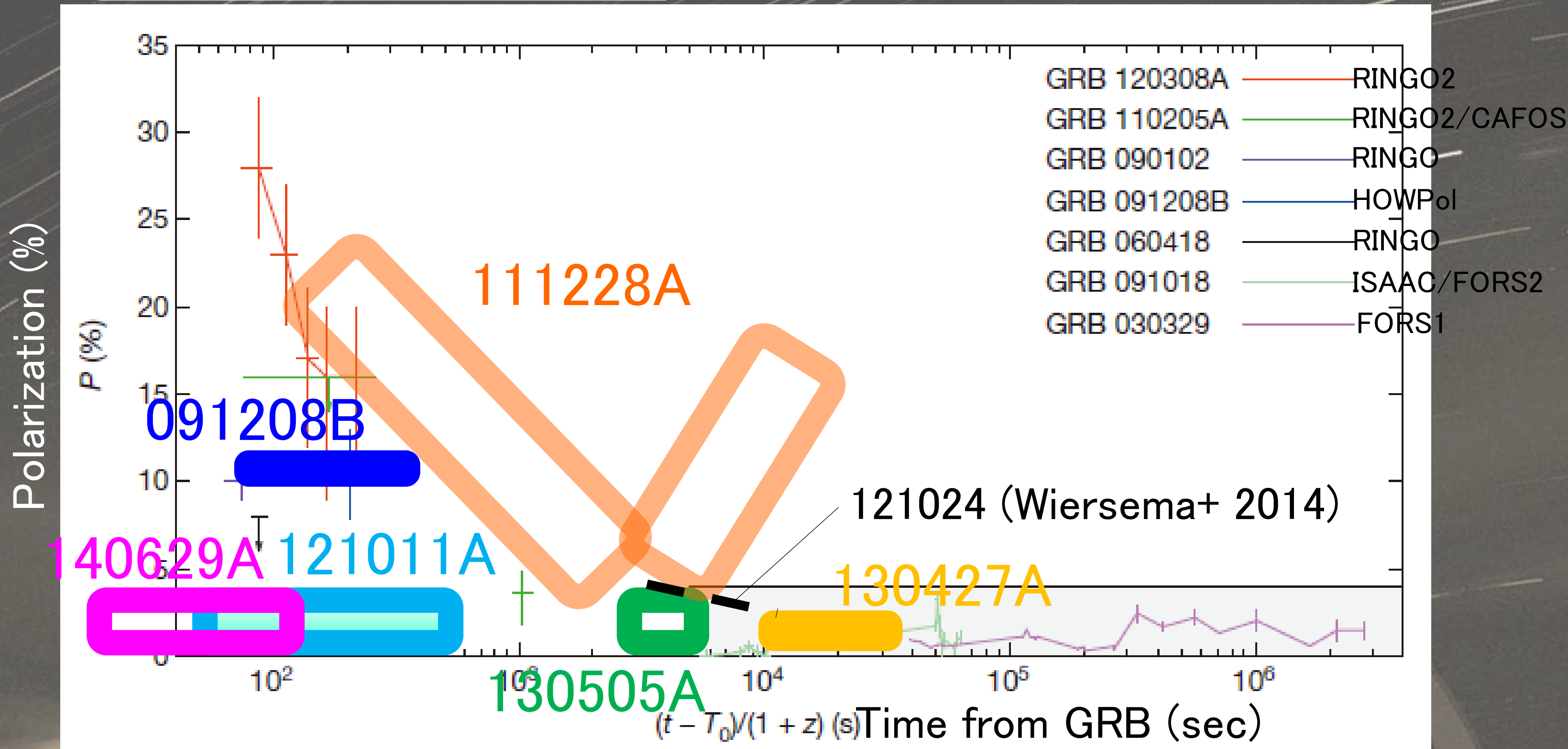
Mundell+ (2013), Nature



Earliest afterglow is generally strongly polarized?

Other early afterglow polarimetry w/ HOWPol data

Mundell+ (2013), Nature



Earliest afterglow is generally strongly polarized?

— No.

- Summary and Future Prospects

Summary of Kanata telescope

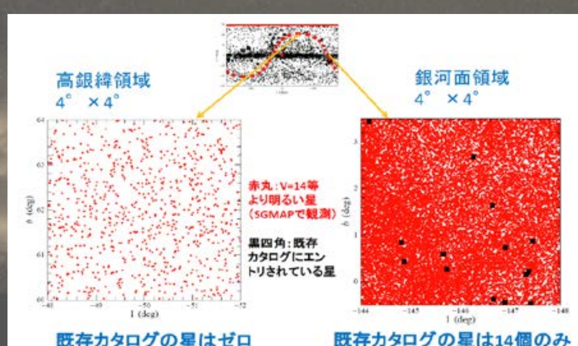
- Originally constructed for multi-wavelength observation
- Basic, multi-purpose instruments have been developed and are always stand-by for observation
- Unique results have been provided for optical/NIR photometry/polarimetry monitoring for Blazars, XBs, GRBs, supernovae, etc.

Future Prospects with Kanata telescope

- Collaborative Study with future telescopes/satellites
  (Small telescopes still can contribute featuring unique modes.)

- Search and Follow-up of Optical Counterpart of Gravitational Wave Source (a member of J-GEM)

- Promoting a future project: SGMAP
  First polarimetric survey in northern hemisphere



~10^4 stars (existing catalogue)
→ 10^6–10^7 stars
Supplementary with Gaia astrometry (including distance) catalogue (~2021)

⇨ **Seeds for future study**