

# Off-Axis Orphan GRB Afterglow Searches with SUBARU/Hyper-Suprime-Cam

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(Credit: HSC Collaboration / Kavli IPMU)

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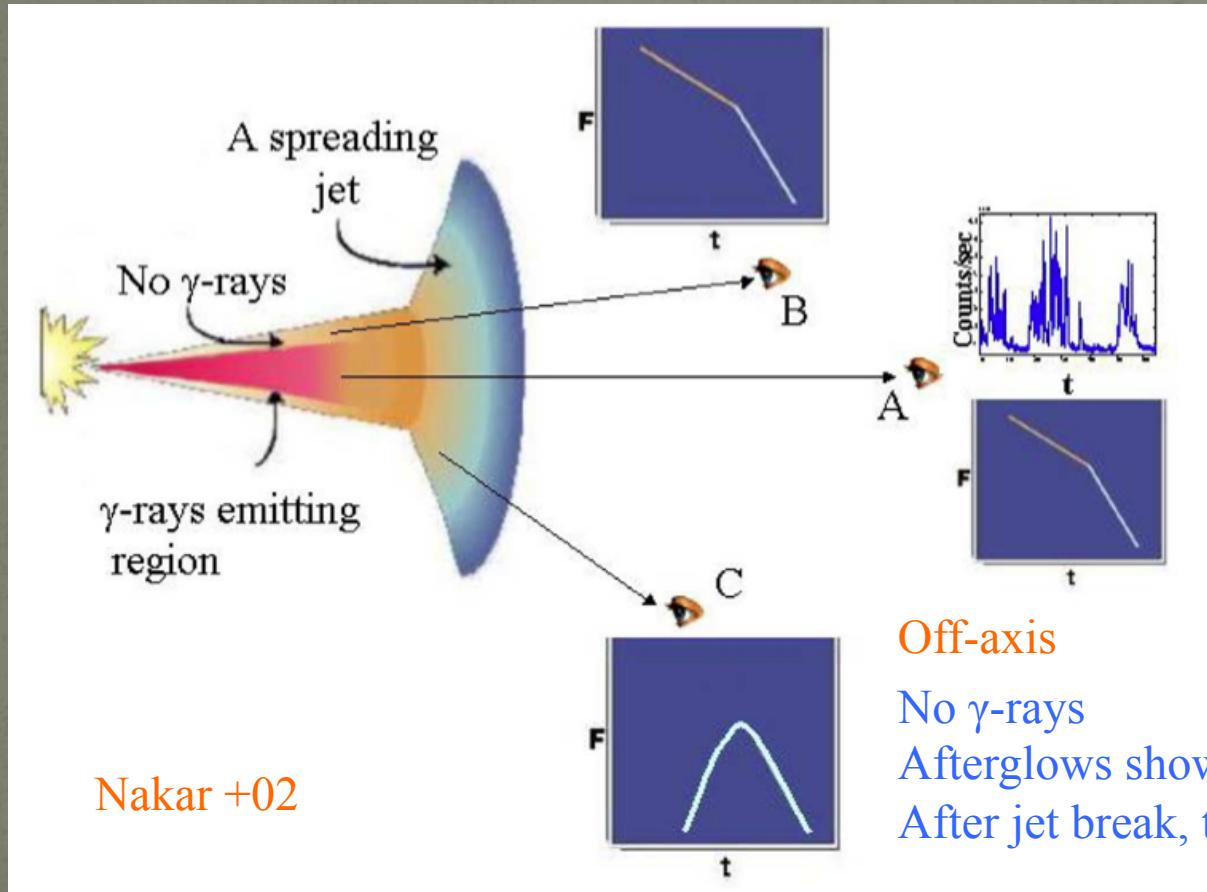
# 1. Orphan GRB afterglow

The jet collimation of GRBs is required to explain the radiation mechanism from compact sources.

Energetics  $E_{\text{iso}} \sim 10^{53-54} \rightarrow \text{Jet corrected} \sim 10^{51}$

Indirect evidences:

Achromatic temporal break in afterglow light curves



(but Chromatic breaks,  
no jet breaks....)

On-axis Orphan  
(Nakar+02)  
Failed GRBs  
(low Lorentz Factor)  
(Huang+02)  
Short GRBs

(PTF11agg as candidates  
Cenko et al 2013)

Off-axis  
No  $\gamma$ -rays  
Afterglows show rise and fall  
After jet break, the properties are similar

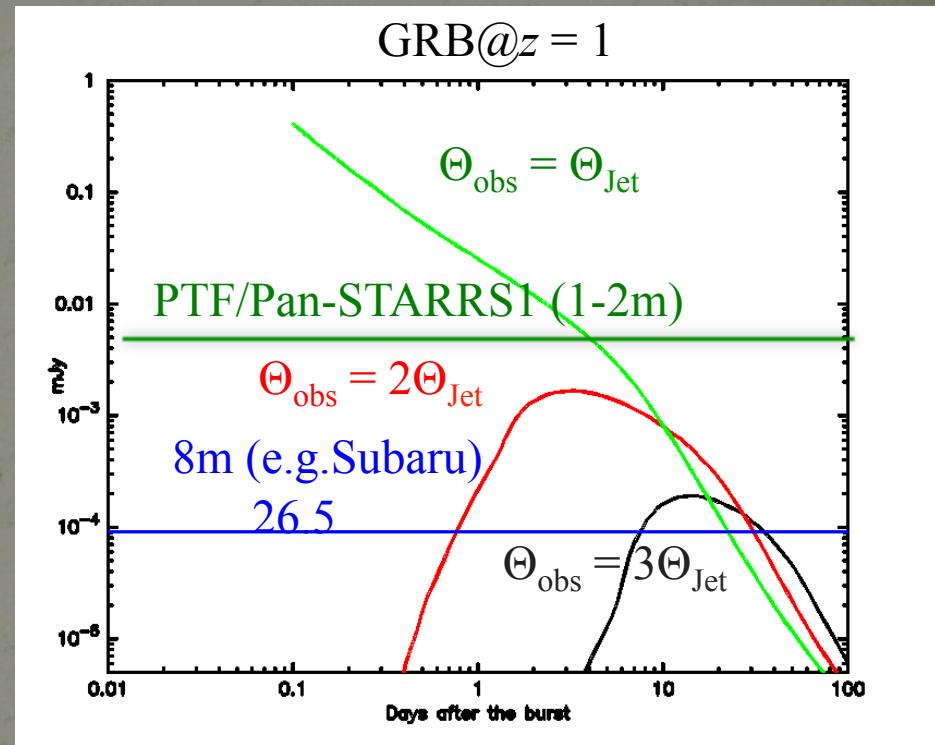
Off-axis orphan GRB afterglow = direct evidence of jet collimation

# Orphan afterglow survey

- Wider survey fields in optical
  - Swift/BAT 120 x 90 deg :
  - Life time of prompt emission is shorter..
- Deep imaging ( $r \sim 26.5$  mag)
  - 8 m class telescopes
- Cadence of the survey (days scale)
- Long-term monitoring with multi-color (monthly~ year)



Subaru, (LSST)



Expected number with HSC-SSP (300 nights from 2014~):  
1- 44 events

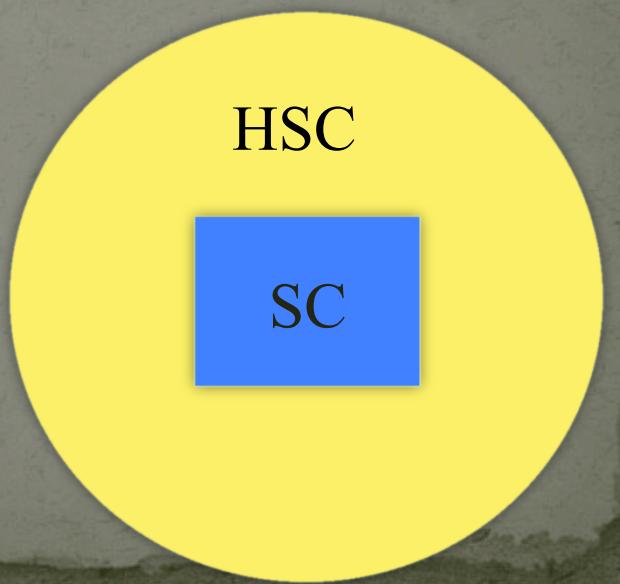
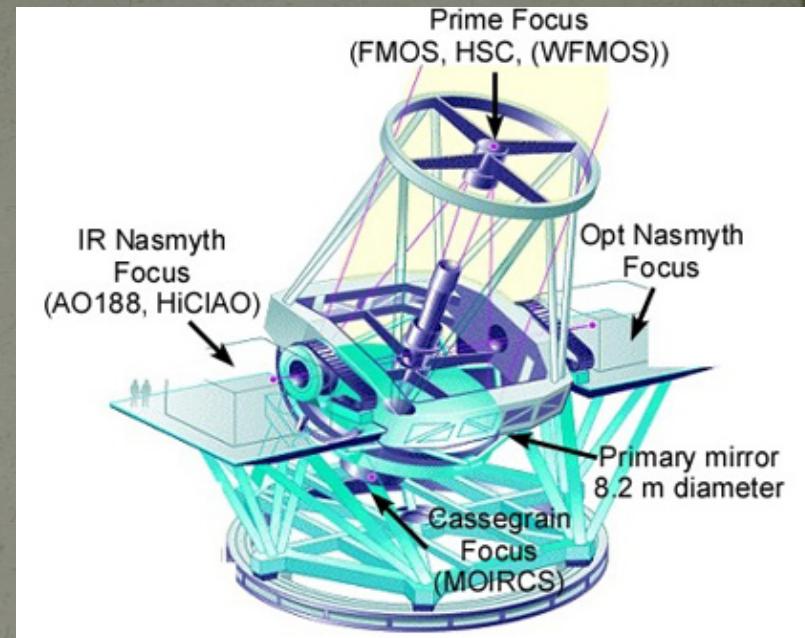
## 2. Subaru & Hyper-Suprime-Cam

- Subaru : one of largest aperture telescope 8.2 m at MaunaKea
- Prime focus : Wide field observations (imaging and spectroscopy)
- Current instruments @Prime Focus

Suprime-Cam (SC) FOV 34' x 27'

FOV of HSC 1.5 deg in diameter

HSC : Upgrading of SC about 10 times!



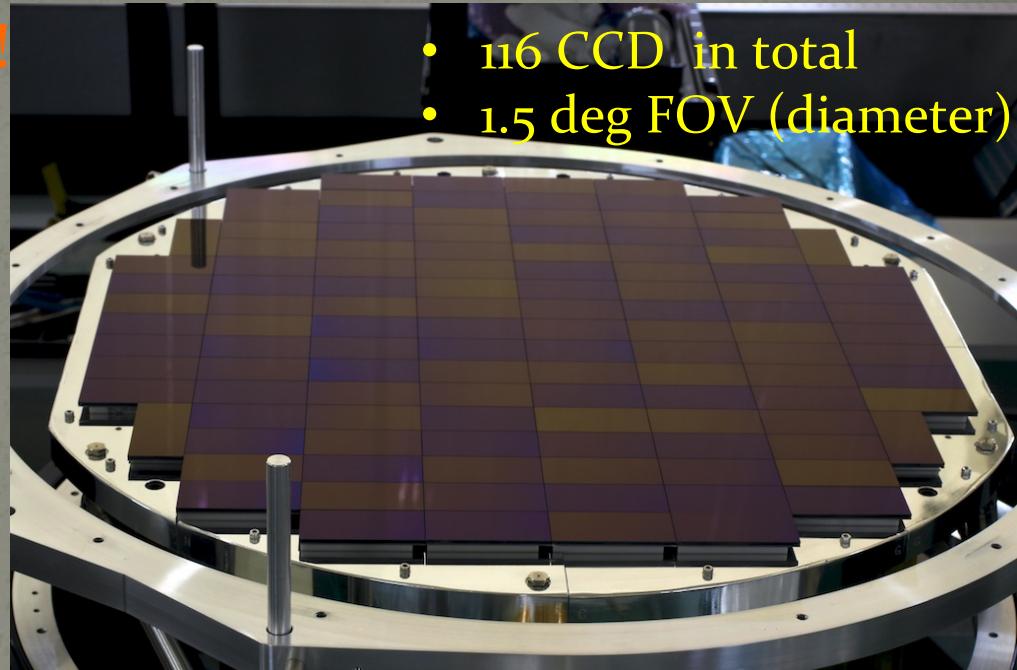
# 2. HSC is ready !

The 1<sup>st</sup> scientific observation is just started!

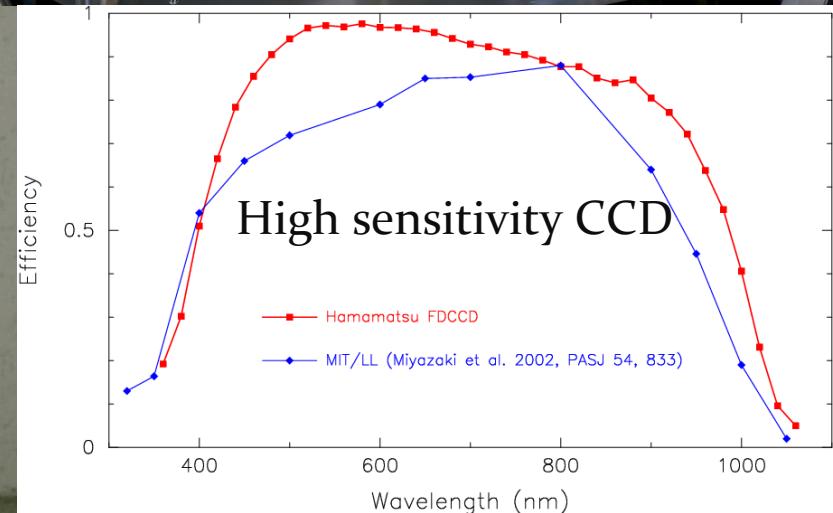
Significantly earlier than LSST!

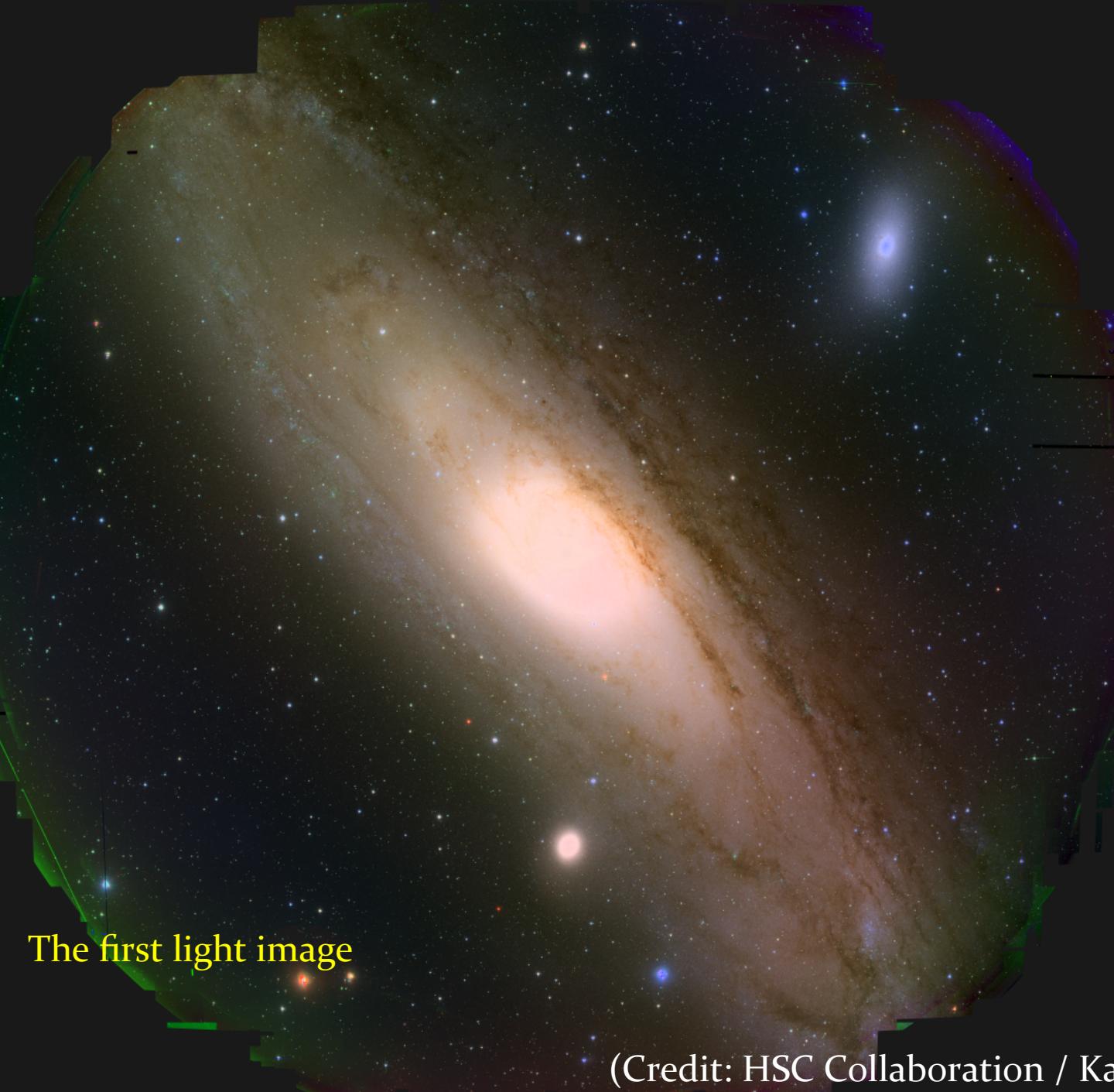


3m height  
3tons weight  
870 million pixel



- 116 CCD in total
- 1.5 deg FOV (diameter)





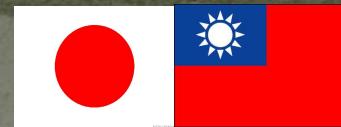
The first light image

(Credit: HSC Collaboration / Kavli IPMU)

For a stellar field, we found that the image quality is about 0.5" FWHM across the focal plane, as designed!



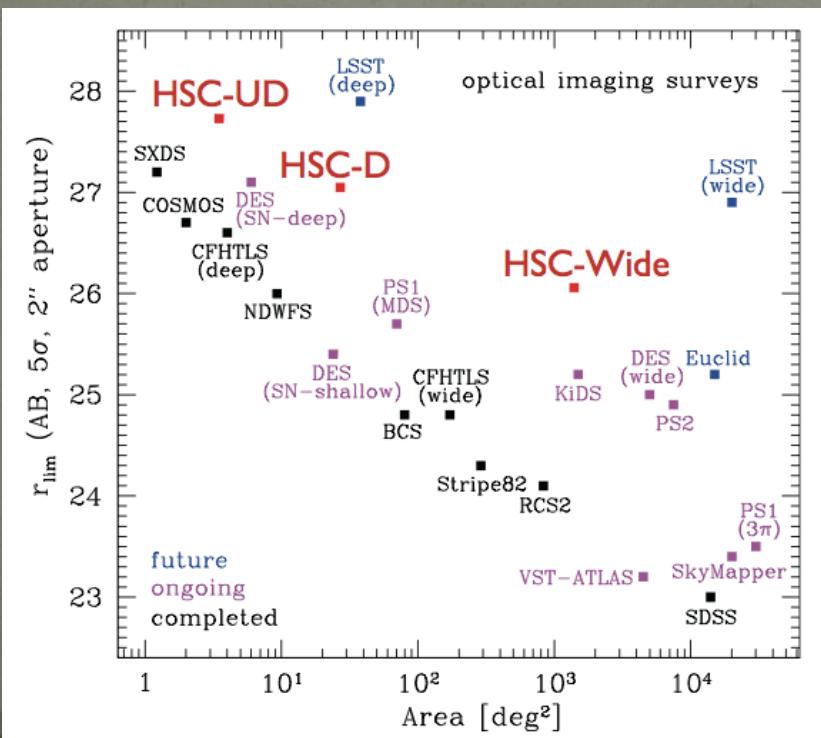
# 3. Planned Survey



- Three layer (wide, deep ultra-deep) survey with grizy
- Awarded 300 nights survey over 5 years (2014 - 2018)

Table 3.1: A quick summary of HSC-wide, deep and ultra-deep surveys

Survey	Area [sq. deg.]	Depth [AB, 5 $\sigma$ , 2'']	Key Sciences
Wide	1500-2000	<i>grizy</i> ( $i \sim 25.8$ )	Cosmology, Clusters, QSOs
Deep	~30	<i>grizy+NBs</i> ( $i \simeq 27.2$ )	Galaxies, QSO/AGN, Clusters, SNe
Ultra-Deep	~2 HSC FoVs	<i>grizy+NBs</i> ( $i \simeq 28$ )	high- $z$ galaxies (LAEs, LBGs), SNe



Filter	Limit (5 $\sigma$ )	
g	26.9	
r	26.6	
i	26.6	
z	25.7	

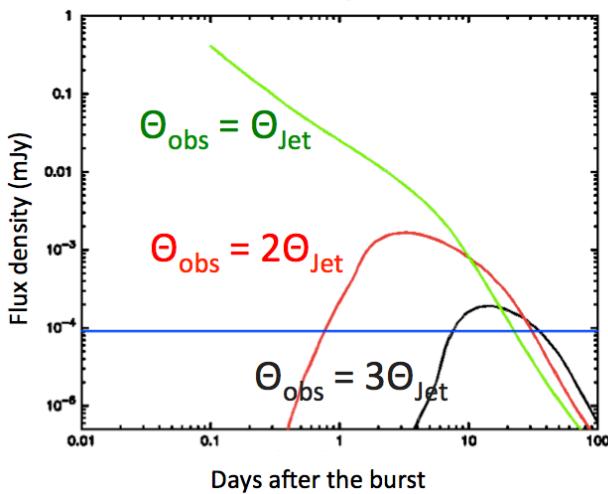
1- 44 events (Total)	HSC Deep	HSC Ultra-Deep
FOV (sq. deg)	30	4
Epoch (each filter)	12	28
Totani and Panaiteescu(2002)	35	9
Nakar&Piran (2002)	5	2
Rossi et al (2008)	1	0.14

# Radio Follow-ups

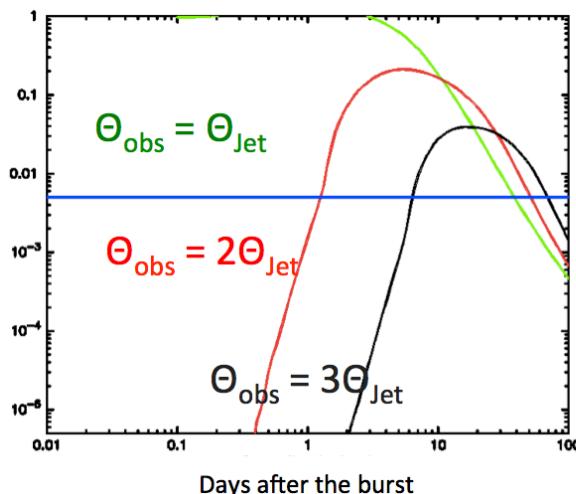
- Radio follow-up is powerful to make confirmation
- HSC surveys are also timely with ALMA and JVLA!

Simulated light curves ( $E_{\text{total}}=10^{53}$  erg,  $z=1$ ,  $\theta_{\text{jet}}=0.1$  rad)

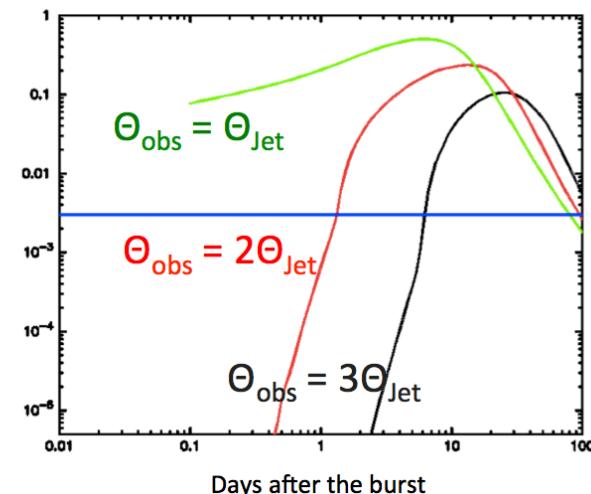
Subaru/HSC optical r' (1hr)



ALMA Band3 (1hr)



JVLA 8.5 GHz(1hr)



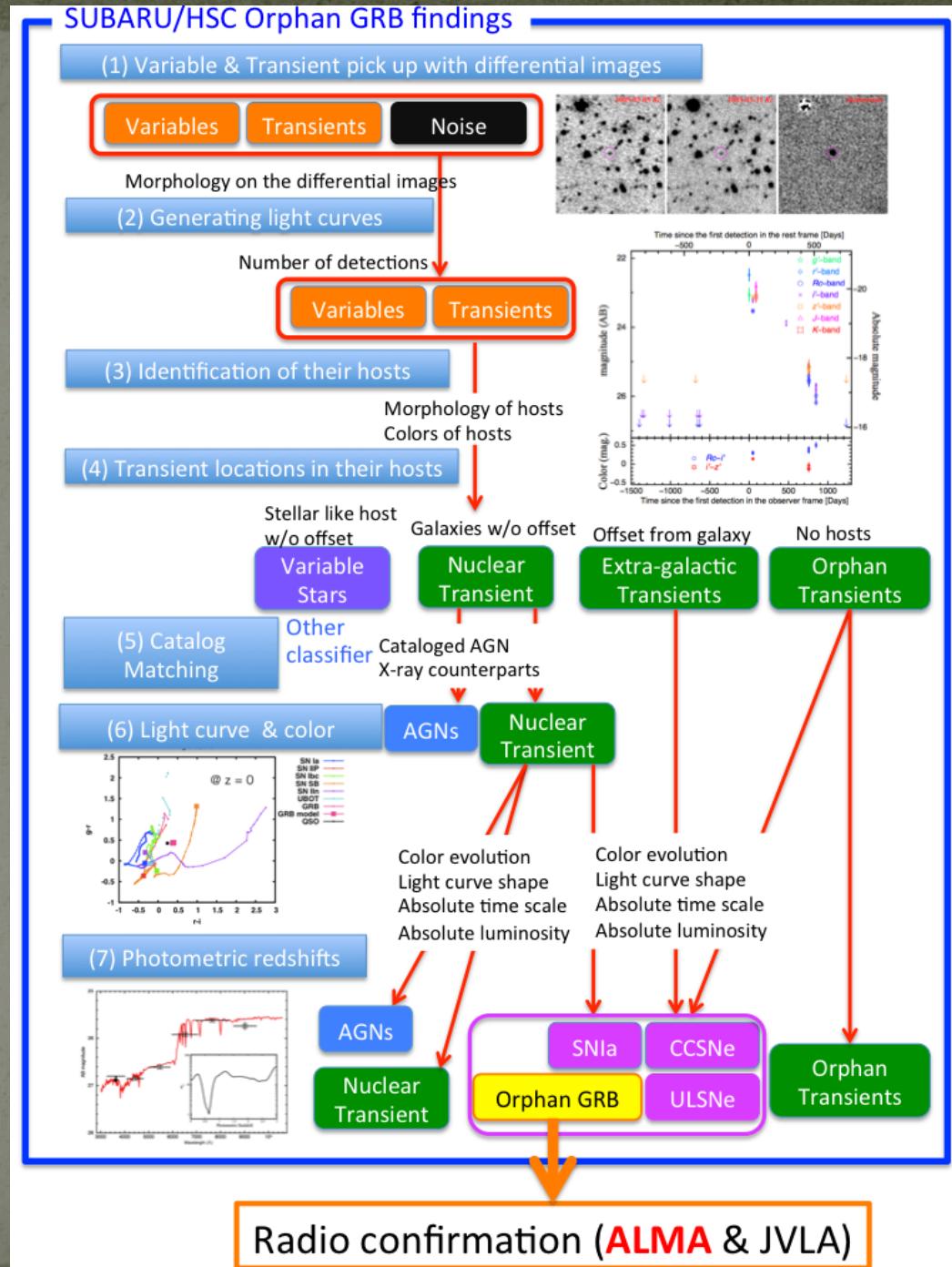
Simulated light curves ( $E_{\text{total}}=10^{53}$  erg,  $z=1$ ,  $\theta_{\text{jet}}=0.1$  rad)

ALMA & JVLA can constrain some of parameters accurately

# Transient Classification

- Basic reduction will be made with official pipe line (including LSST package)
- PSF matched image subtraction in the HSC official pipeline
- Transient Database@NCU
- Collection of external catalogs for each fields
- Making known source catalogs with PS1MDS (e.g. AGN, VS)
- Light curve classifier
- Photometric redshift
- Preparation/coordination of Radio follow-ups

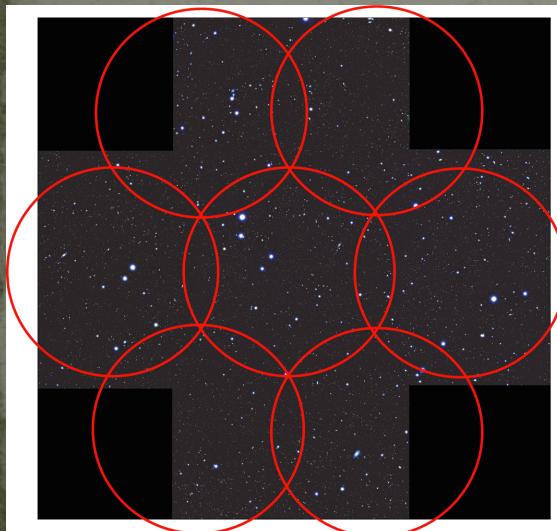
Tested with two deep surveys made by Suprime-Cam



# 4. Pre-searches with SC

- Two deep fields were already made using SC!

	<u>Subaru Deep Field (SDF)</u>	<u>Subaru-XMM Deep Survey (SXDS)</u>
Observations	2001-2007	2002-2005, 2008-2010
FOV (deg <sup>2</sup> )	0.25 ( = 0.14 HSC)	1.3 (5FOV of SC = 0.73 HSC)
Cadence	20 epochs / 6 yrs	8-10 epochs/ 4yrs
Filters	BVRiz + Narrow Bands	BVRiz +Narrow bands
Others	UV, NIR, MIR	X, UV, NIR, MIR, FIR, sub-mm, radio



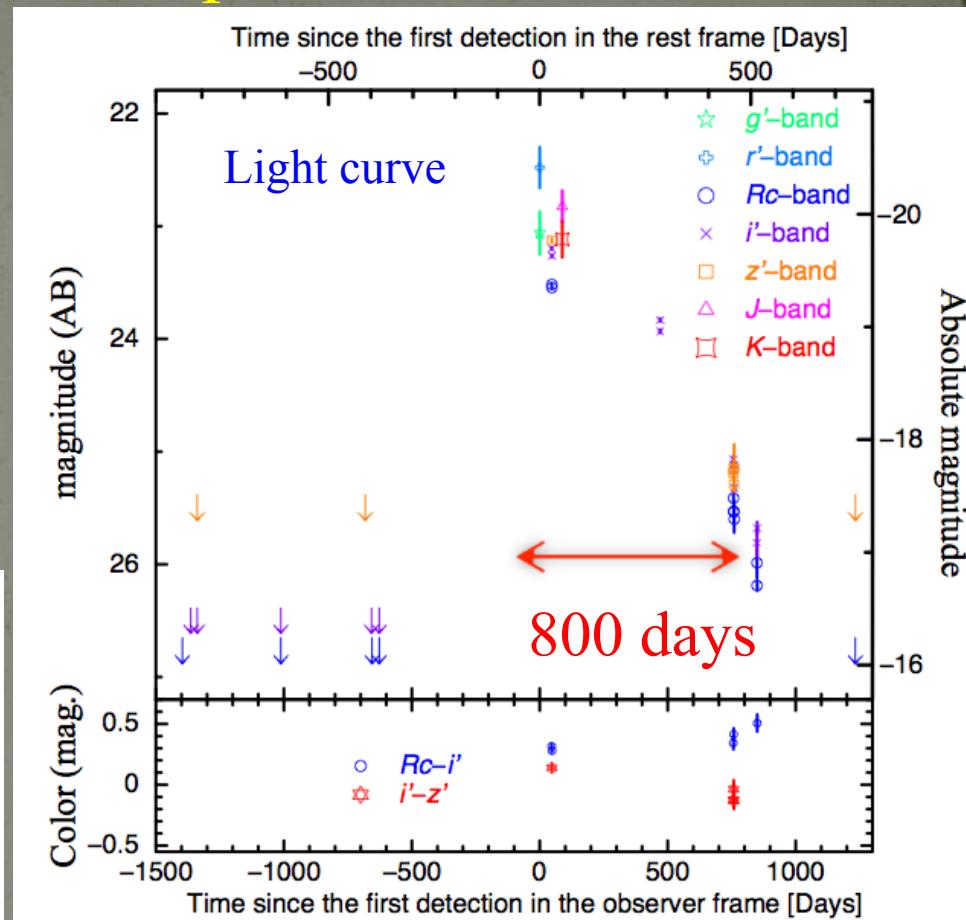
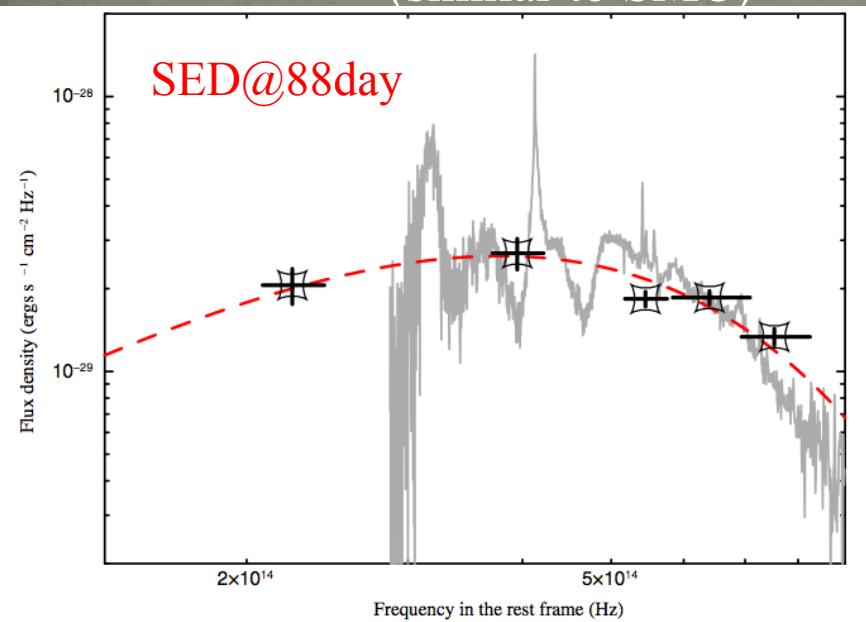
	SDF	SXDS	HSC Deep	HSC Ultra-Deep
FOV (sq. deg)	0.25	1.3	30	4
Epoch	20	8	12	28
Totani+02	0.47	0.75	35	9
Nakar+02	0.07	0.11	5	2
Rossi+08	0.01	0.02	1	0.14

# New type SDF-05M05

Urata et al. 2012 ApJL

## Unusual Long and Luminous Optical Transient

- Duration > 500 days in the rest  
> 800 days in the obs
- $z_{\text{phot}} \sim 0.65$  (+0.02 -0.03)
- Offset from the host galaxy
- Maximum absolute mag -20 mag
- Total radiated energy  
 $> \sim 1 \times 10^{51} \text{ erg } (\sim \text{GRB})$
- Faint Host  $M_V = -16.3$  mag  
(similar to SMC)

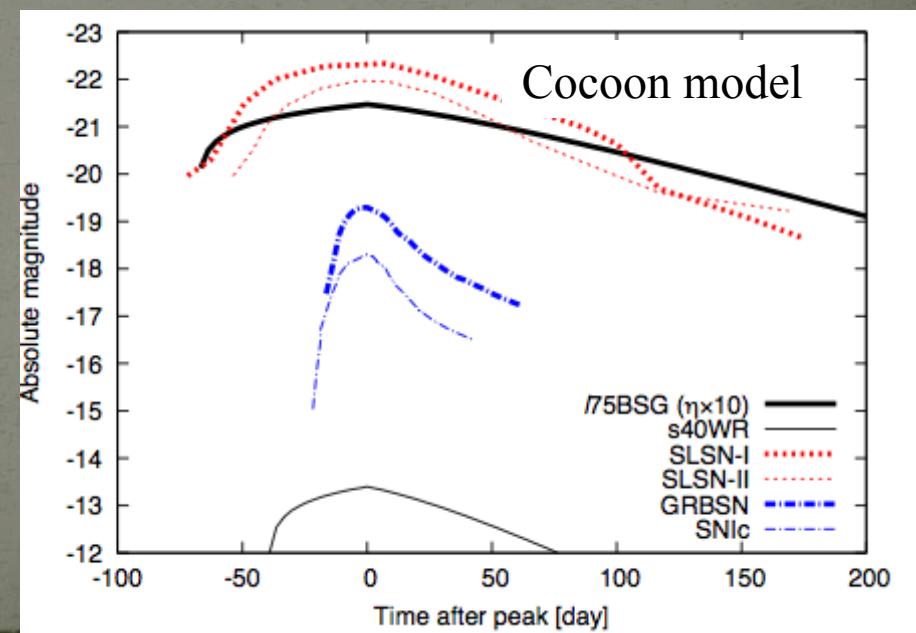
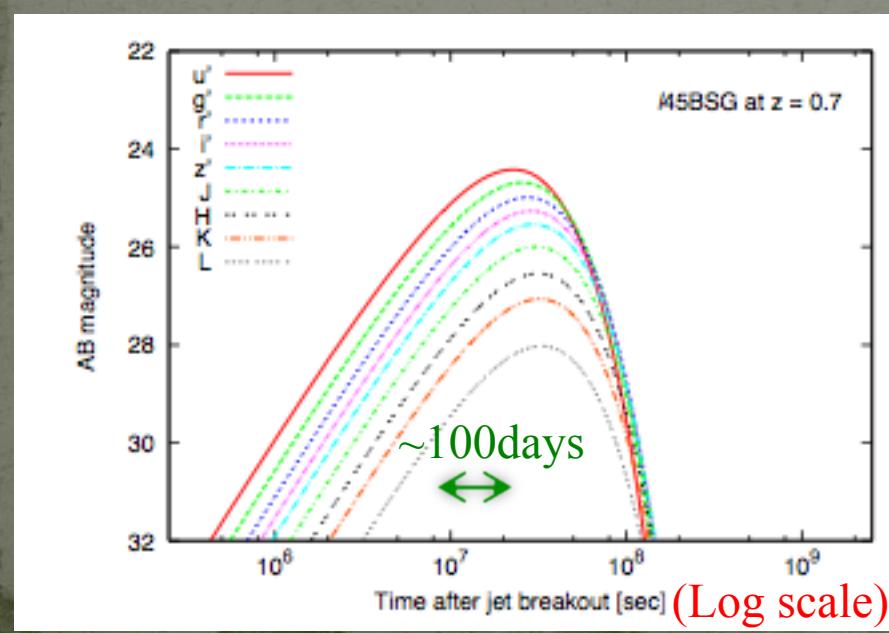
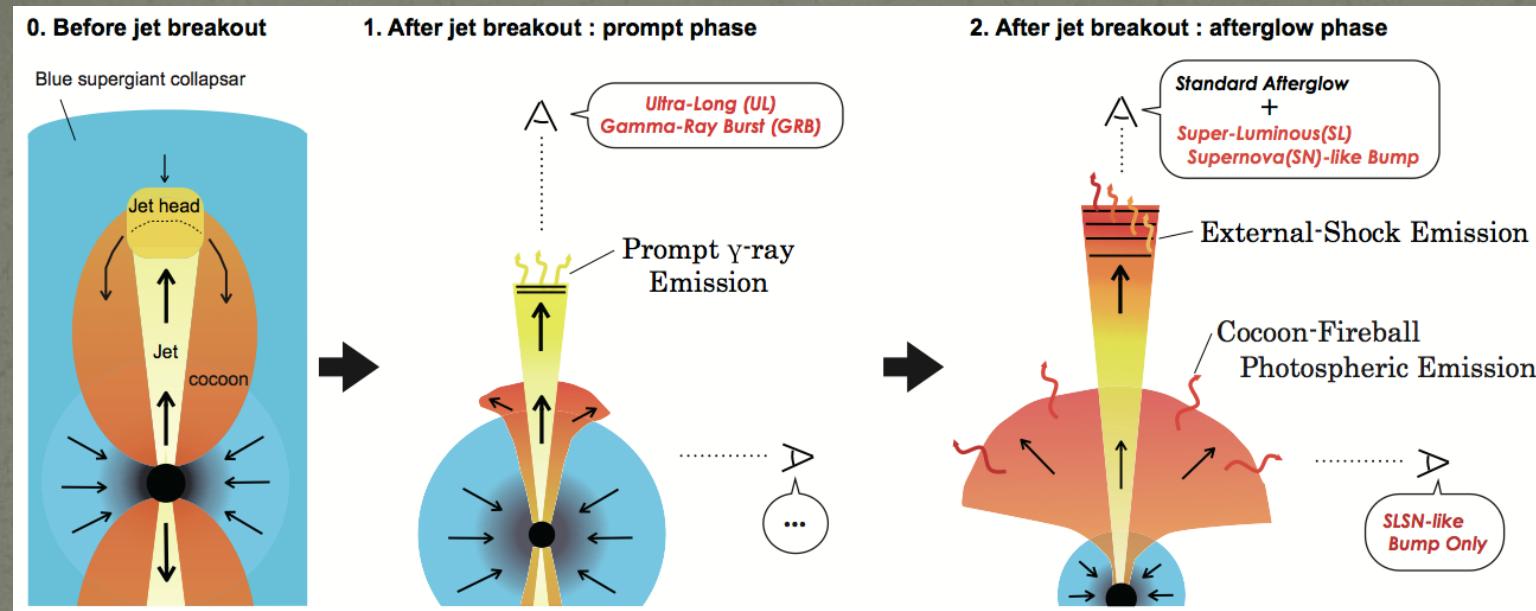


- Keeping -19 mag about 500 days
- SED@~88 day BB T~6400K

Probably massive star explosion!

# Possible unified progenitor

Kashiyama et al. 2013,  
Nakauchi et al. 2013

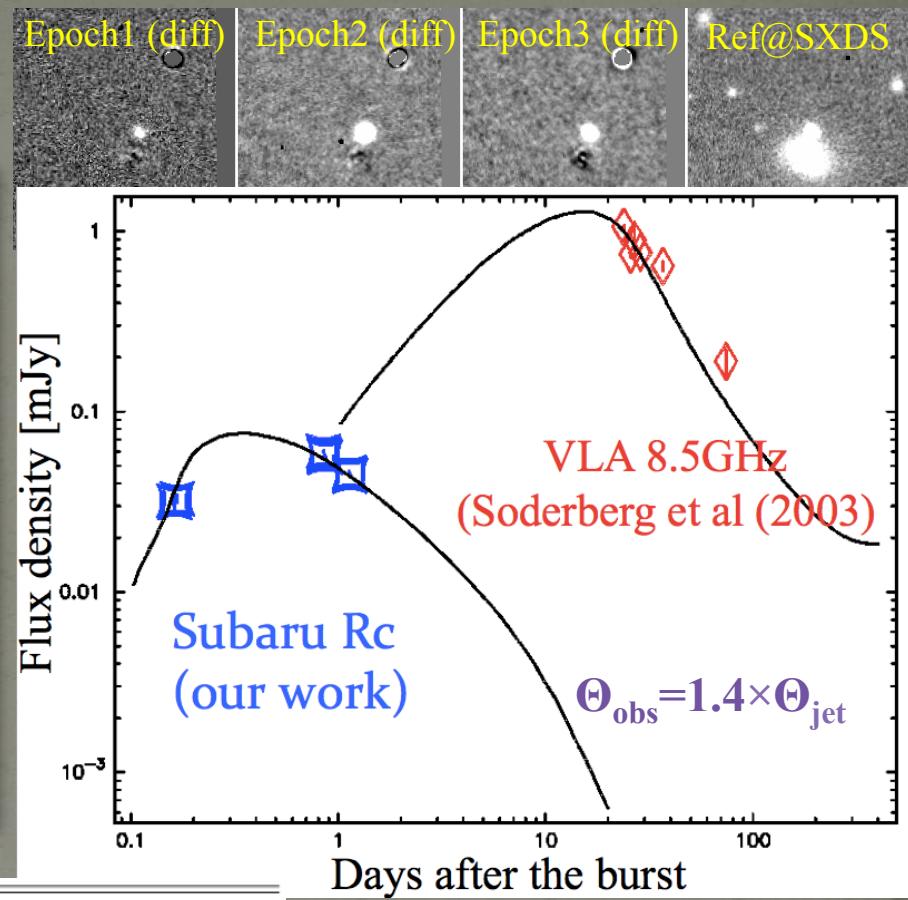
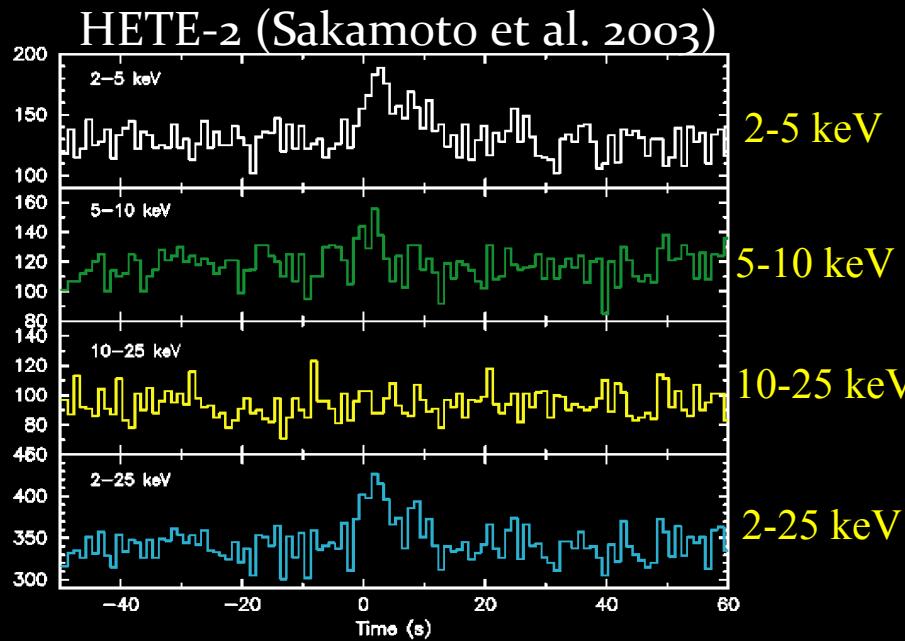


# 4. Revisit of lowest E<sub>peak</sub> event (XRF)

XRF020903 (HETE-2 event)

E<sub>peak</sub> < 5 keV (~3 keV)

(2 orders lower than classical GRB)



Parameters	GRB990510	GRB120326A	GRB131030A	PTF11agg	XRF020903
$\theta_{\text{jet}}$ (rad)	0.075	0.14	0.15	0.20	0.18
$E_{\text{iso}}$ (erg)	$1.8 \times 10^{53}$	$3.9 \times 10^{52}$	$3.4 \times 10^{52}$	$9 \times 10^{52}$	$5.8 \times 10^{52}$
$n$ (cm <sup>-3</sup> )	0.03	1.0	0.57	0.001	27.3
$\theta_{\text{obs}}$ (rad)	0 (fixed)	0 (fixed)	0 (fixed)	0.19	0.26
$p$	2.28	2.5 (fixed)	2.1 (fixed)	3.0	2.01 (fixed)
$\epsilon_B$	$4.6 \times 10^{-3}$	$1.0 \times 10^{-3}$	$1.0 \times 10^{-1}$	$4 \times 10^{-2}$	$3.0 \times 10^{-2}$
$\epsilon_e$	$3.7 \times 10^{-1}$	$6.9 \times 10^{-1}$	$1.5 \times 10^{-1}$	$2 \times 10^{-1}$	$2.1 \times 10^{-1}$
Data	X,Opt,Radio	Opt	Opt, NIR, Submm(ALMA)	Opt, Radio	Opt, Radio
Ref.	van Eerten+12	Urata+14a	Urata+14b	Cenko+13	This work

Modeling with BOXFIT  
(van Eerten et al. 2012)

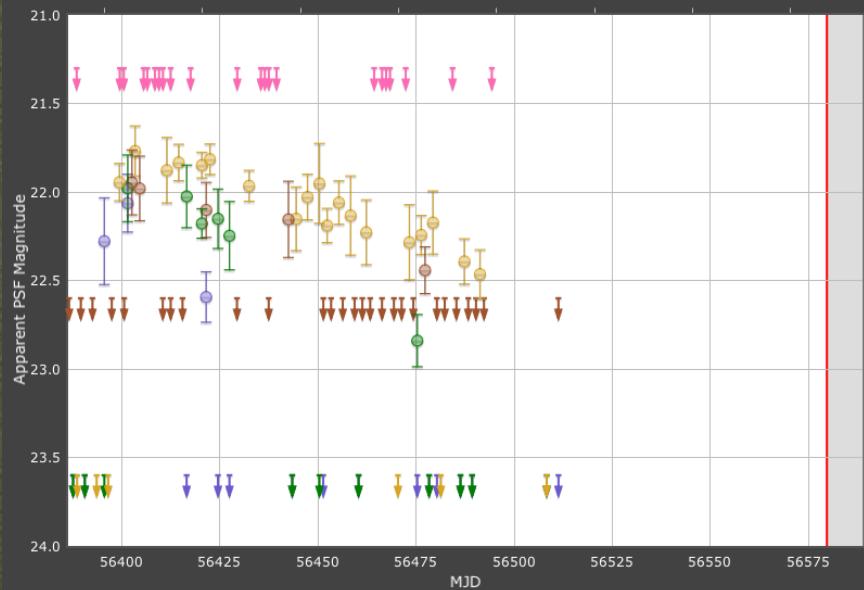
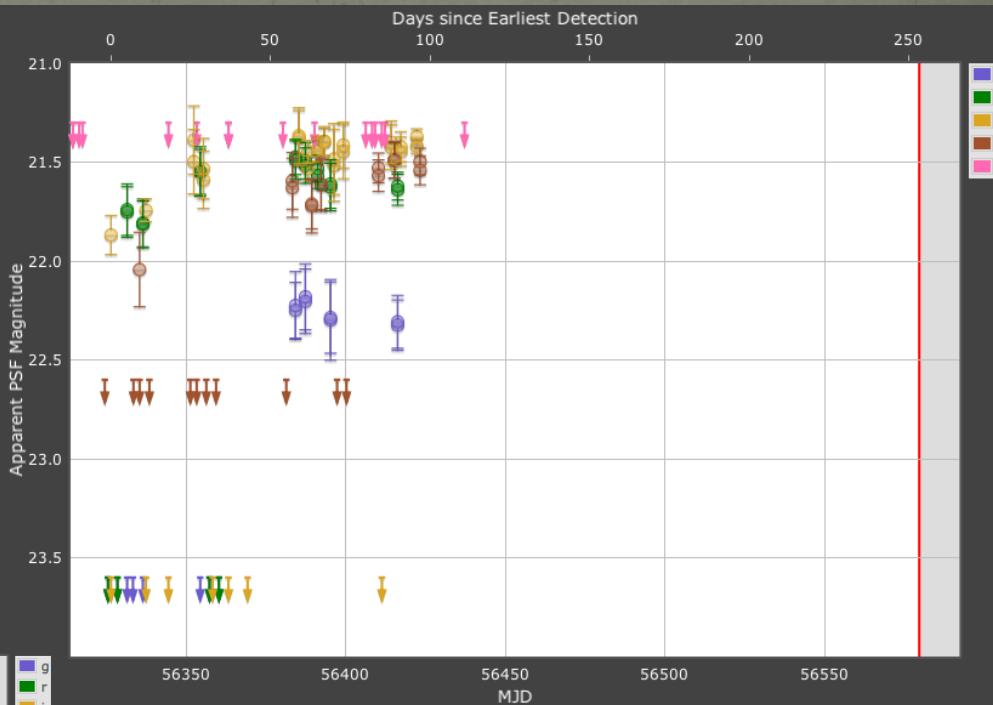
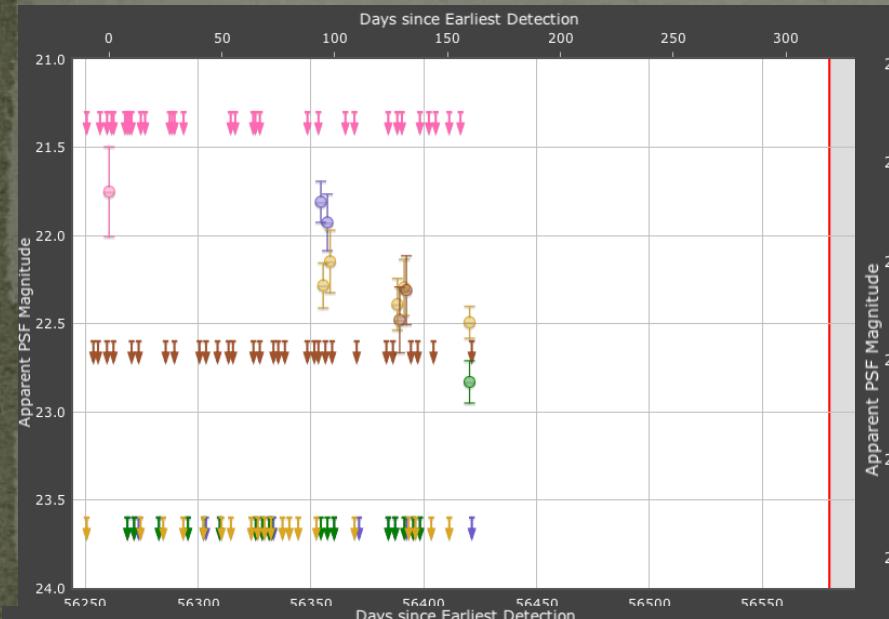
GRB120326A: Also see poster

# 5. Summary

- Prepared and started the new Orphan GRB afterglow survey with new wide field image Hyper-Suprime-Cam
- The expected number of detections : 1 – 44 events
- Some candidates were found with previous Subaru deep surveys
- The new time-domain survey with 8m telescope is just started!

Further collaborations are welcome !

# Similar events from PanSTARRS1

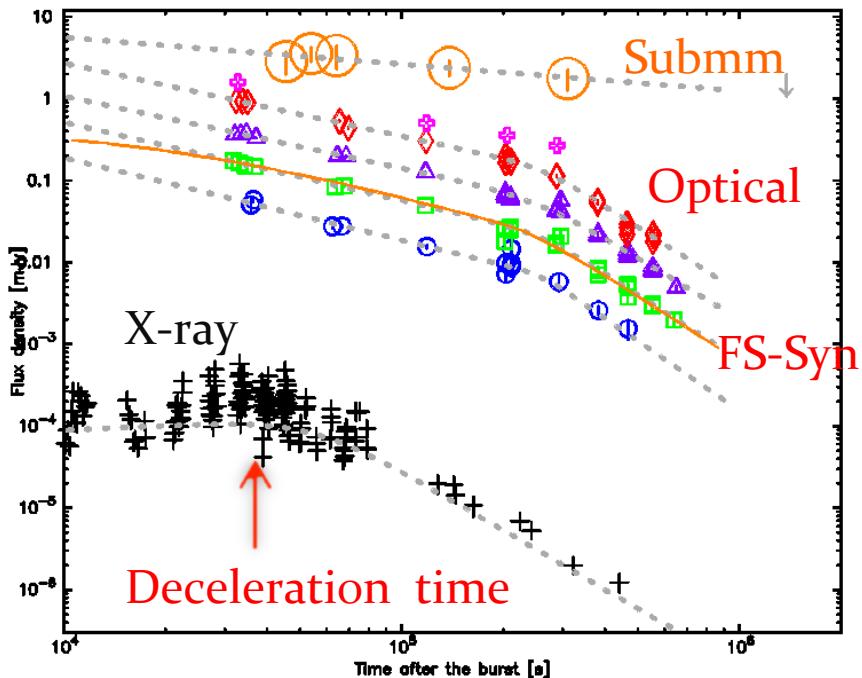


Many similar events!

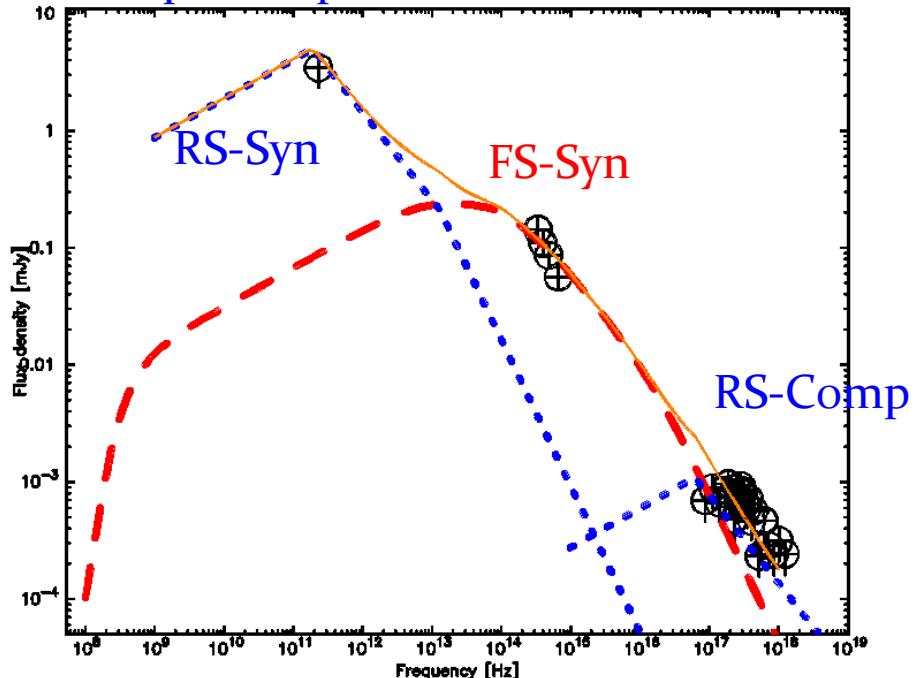
Spectrum confirmations are ongoing  
with Gemini/GMOS ToO.  
(SUBARU time exchange, PI Y.Urata)

# GRB120326A : RS SSC + FS Syn

## Light curves



## Snapshot Spectrum



Spectrum excesses from FS-Syn in submm and X-ray

→ Reverse shock synchrotron and self-Compton

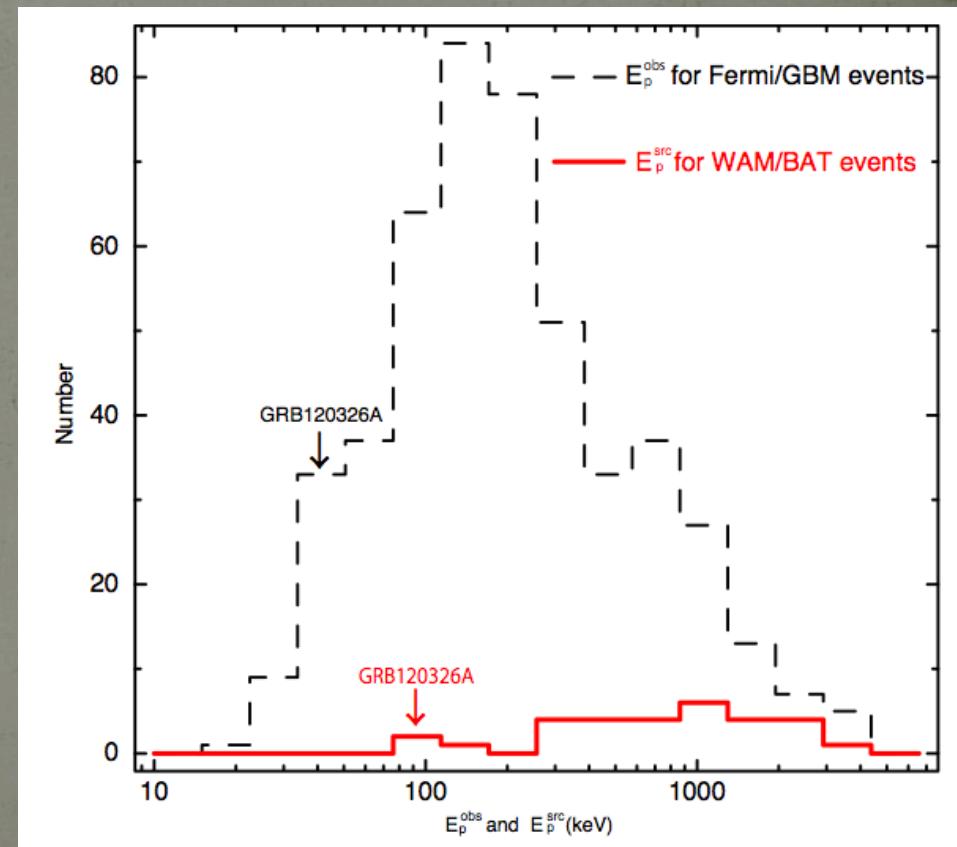
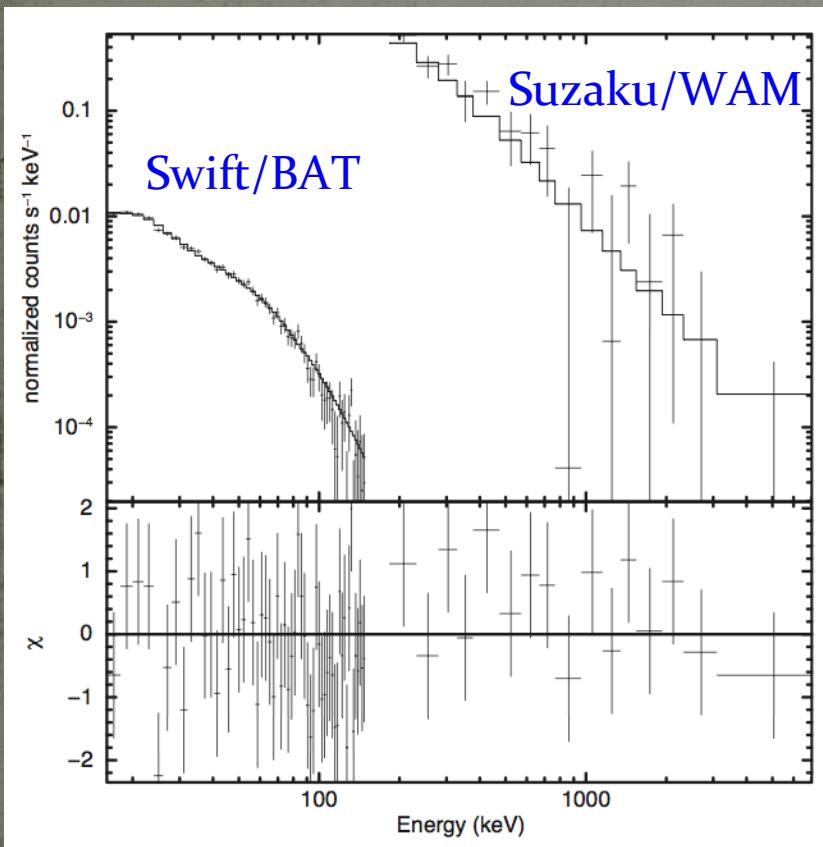
$$\Gamma_0 = 18$$

$$\nu_{m,RS}^{Sync} \sim 1.9 \times 10^{11} \text{ Hz}, \nu_{c,RS}^{Sync} \sim 1.3 \times 10^{13} \text{ Hz}, \nu_{m,RS}^{IC} \sim 6.2 \times 10^{16} \text{ Hz}, \nu_{c,RS}^{IC} \sim 1.8 \times 10^{20} \text{ Hz}$$

This is the first observational confirmation of RS SSC  
(Follow-ups with multi-wave including submm and RHD are powerful)

# Smaller initial Lorentz factor

## Prompt emission properties of GRB120326A



Smaller Lorentz factor is also reasonable to explain prompt properties!