すばるHSCで探る銀河系外可視光突発天体

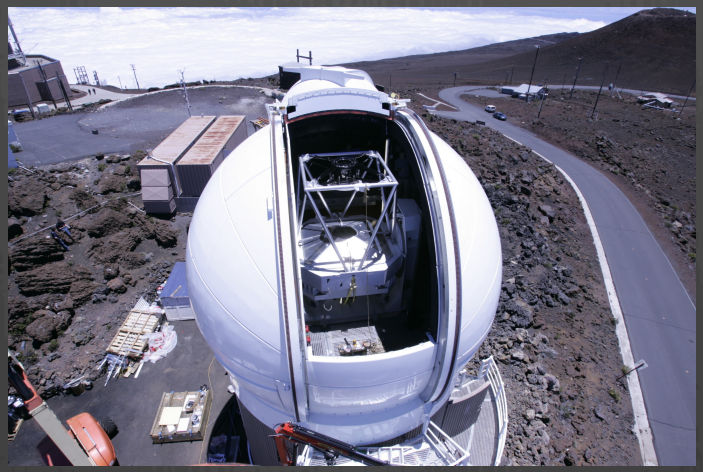
浦田裕次
（台湾国立中央大学）

CTAに関連することがほとんどないです。

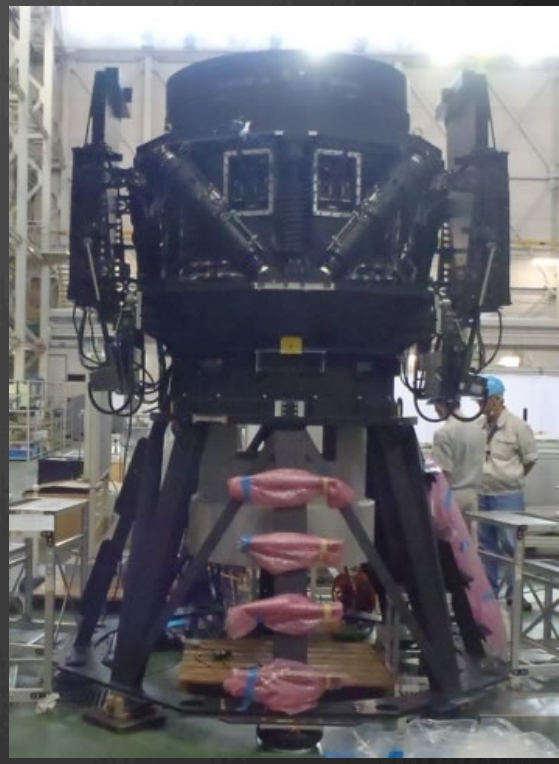
時間領域の天文学 in 台湾

Lulin Observatory in TW

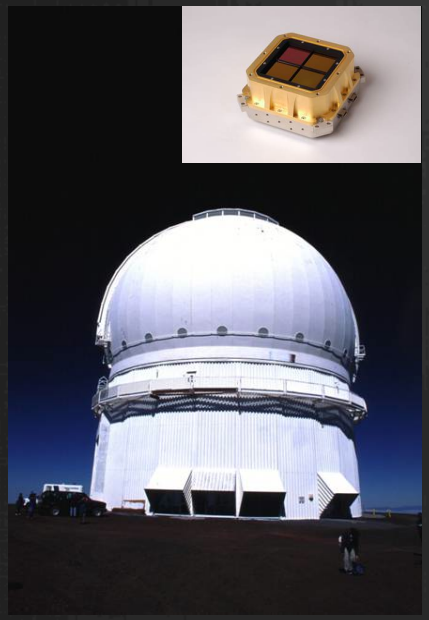
Pan-STARRS1



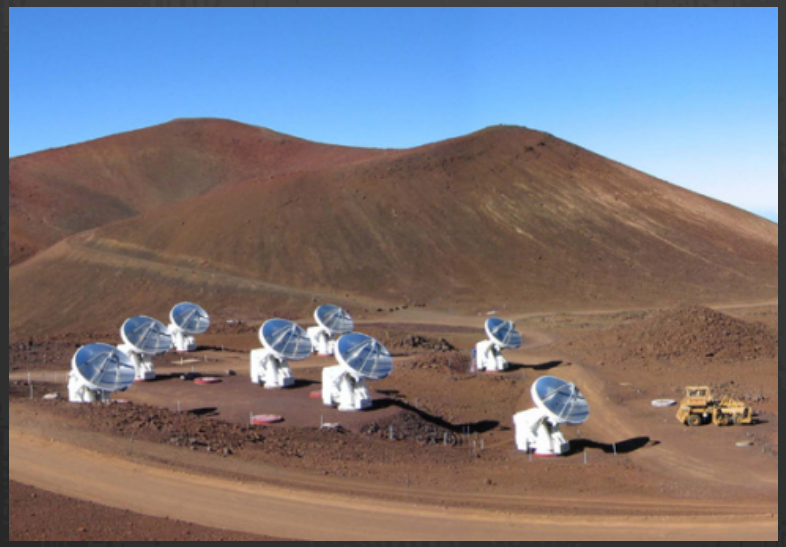
Subaru/HSC



CFHT/WIRCam

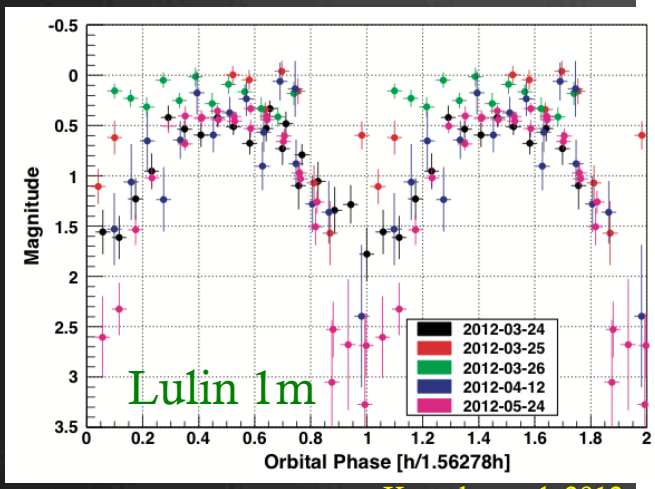


SMA



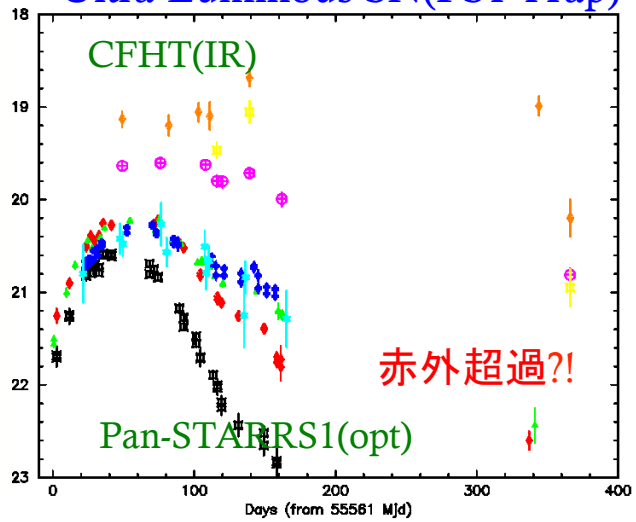
時間領域の天文学 in 台湾

Fermi unID sources

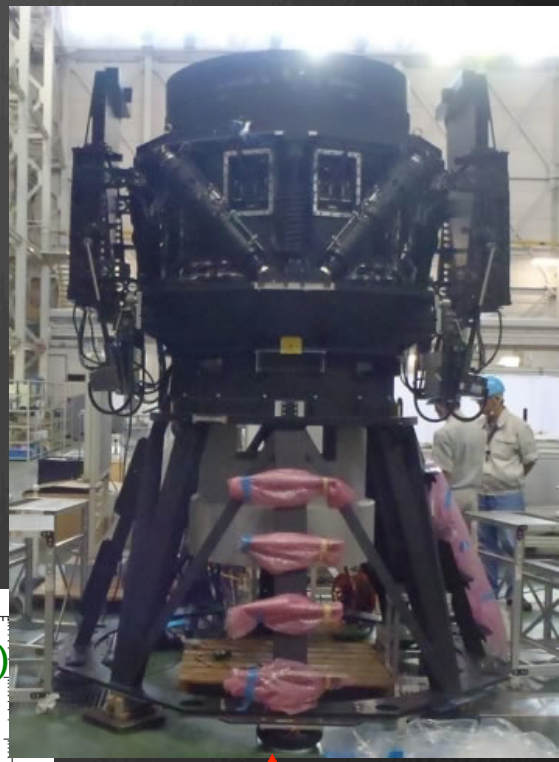


Kataoka et al. 2012

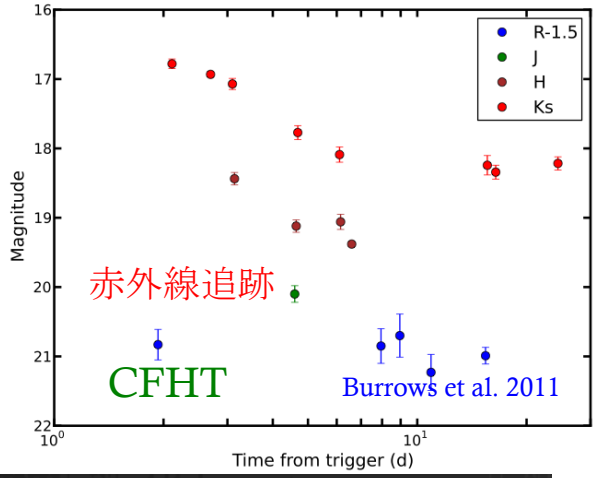
Ultra-Luminous SN(PS1-11ap)



Subaru/HSC



Tidal Disruption Flare
Sw J1644+55



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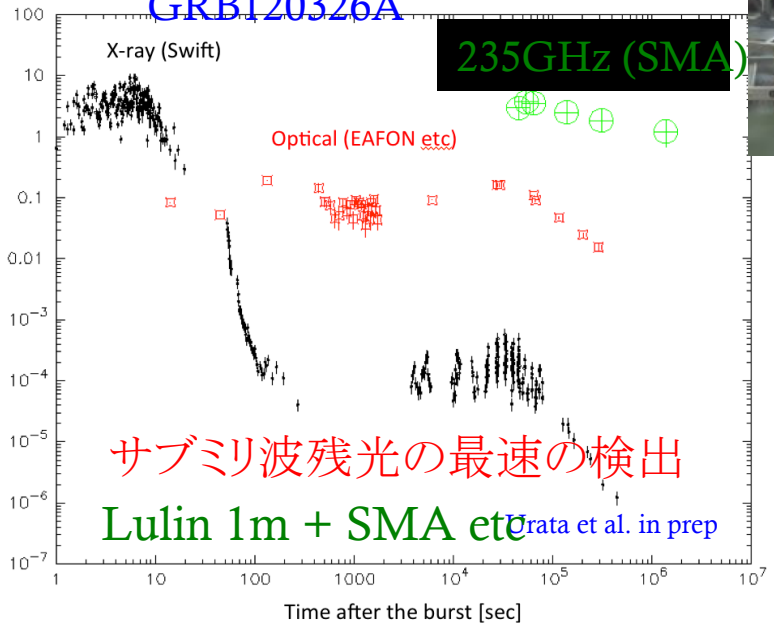


今日の話

HSC/SSP Transient team

- Taiwan : Y. Urata, M.F. Tsai, P. Tsai, Tang (NCU),
  K.Y. Huang (ASIAA), A. Kong(NTHU)
- Japan : N. Yasuda, R. Quimby, M. Moriya, N. Yoshida(IPMU),
  T. Morokuma (Tokyo U), M. Tanaka(NAOJ),
  N. Tominaga(Kounan-U), J. Okumura (Kounan-U)
- Princeton : P. Price

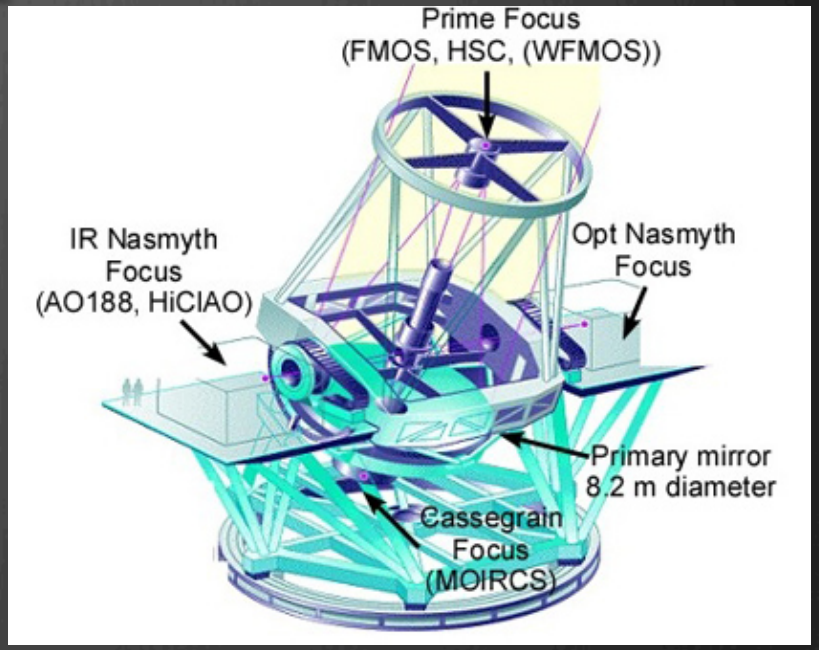
目次

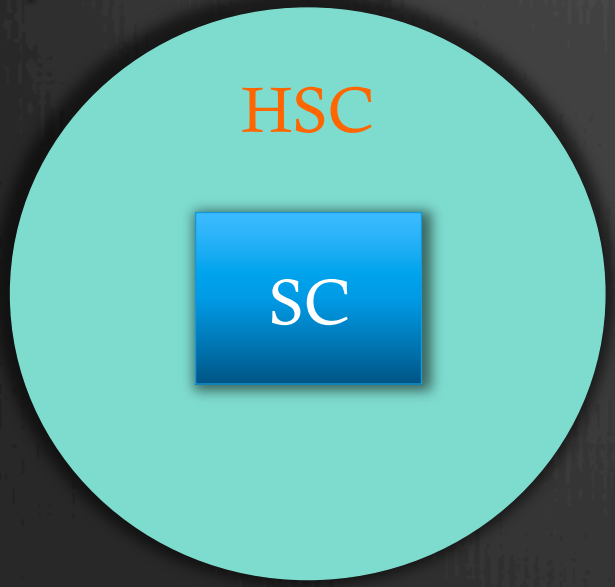
- すばる Hyper-Suprime-Cam
- 計画中のサーベイと突発天体
- 可視光突発天体を見つける方法
- Pre-sciences

すばる 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!

SC → HSC

	Suprime-Cam (SC)	Hyper-Suprime-Cam (HSC)
CCD Type	MIT/LL(2000-2008) Hamamatsu (2008~)	Hamamatsu (Fully-Depleted)
Number of chip	10	116 (4 guiding, 8 focusing)
Pixel size	15um (~0.”20)	15um (~ 0.”17)
FOV	34’ x 27’	90’ (Diameter)
Gain	2.5-3.7 e/ADU	3.0 e/ADU
Readout noise	10e	TBD
Readout time	18s	20s
Number of filter	10	6
Filter exchanging time	300s	600s (900s)
AΩ (Survey Power)	13.2	95

HSC (Hardware)

Consist of three part
- Prime Focus Unit (PFU)
- Camera
- Wide Field Corrector (WFC)

PFU Mechanics

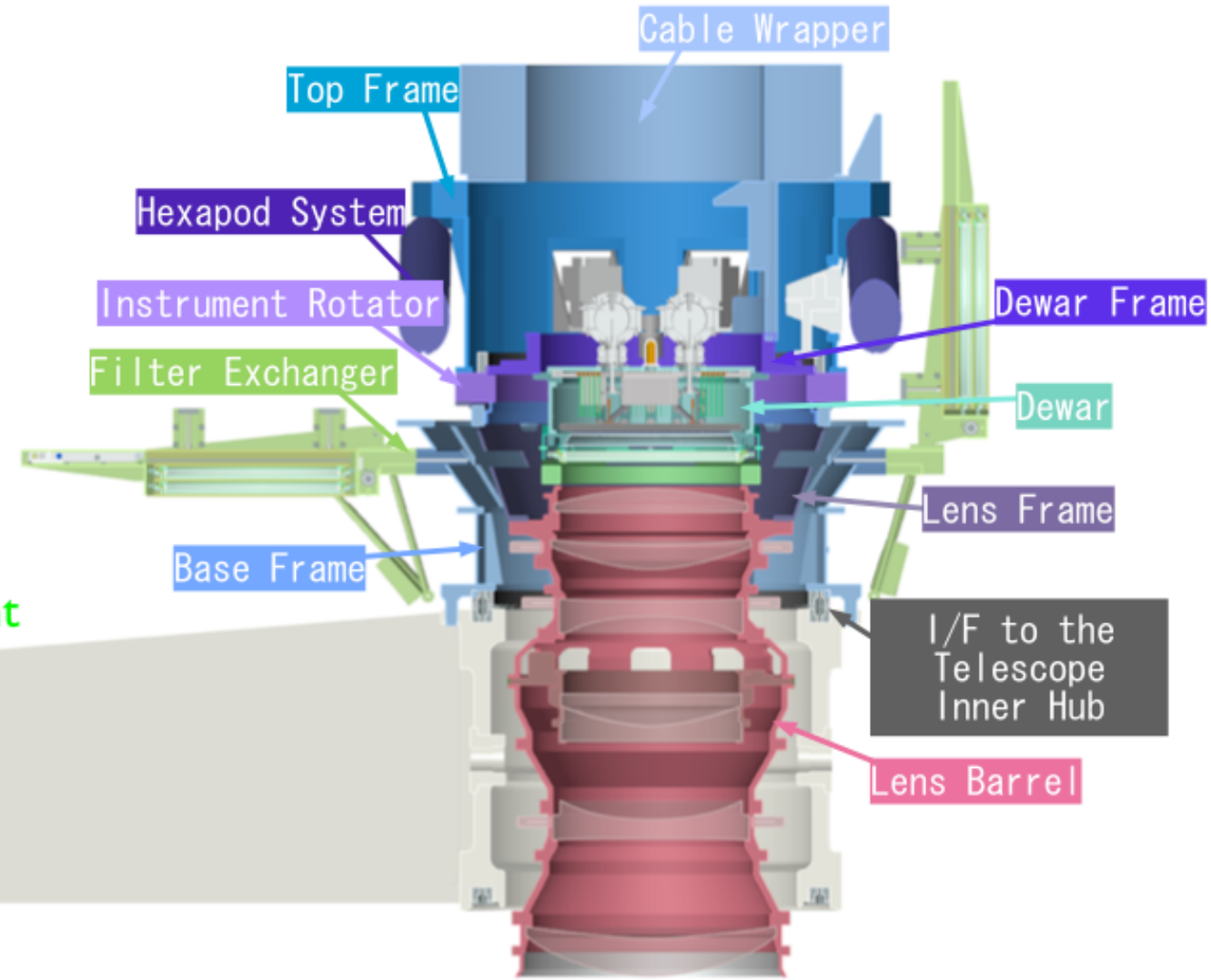
WFC

HSC Mechanics

Sensor

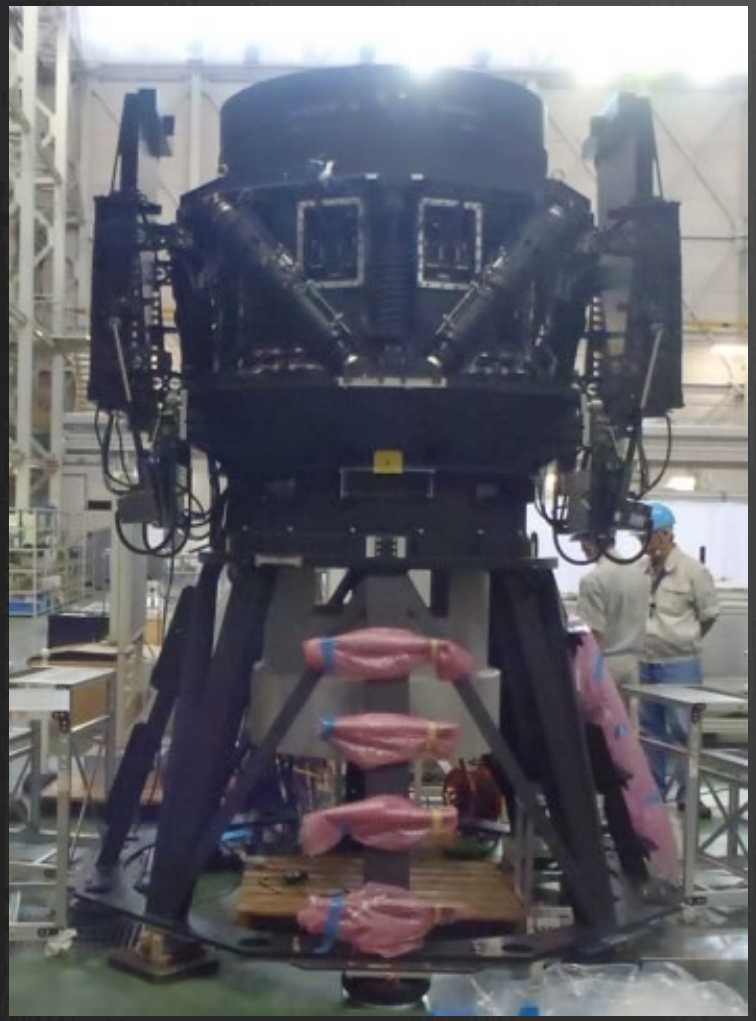
Filter

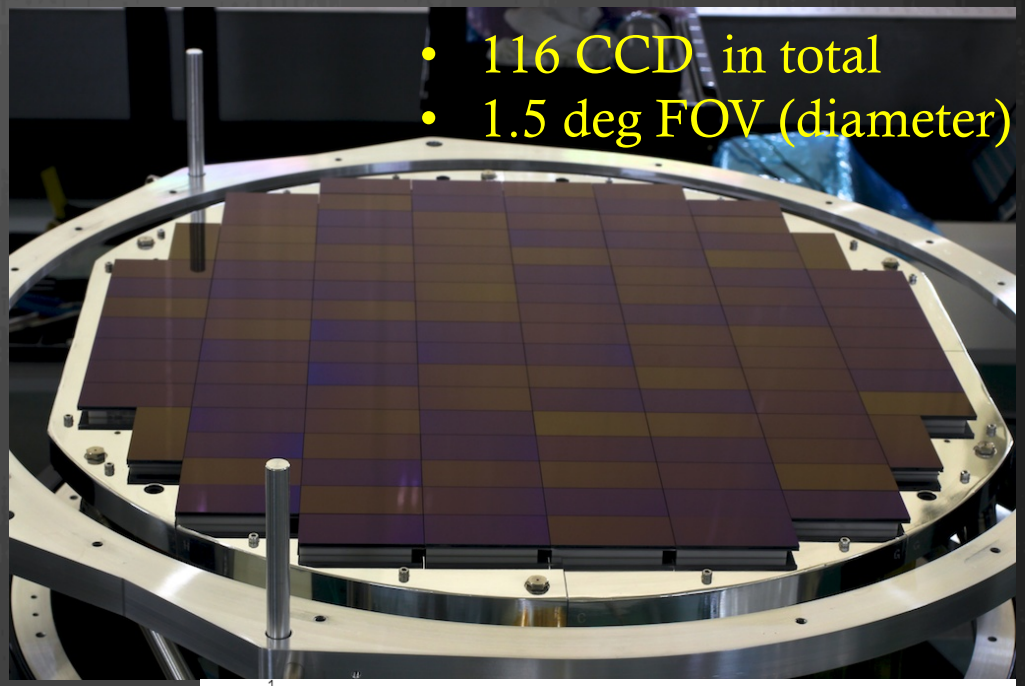
Data Management

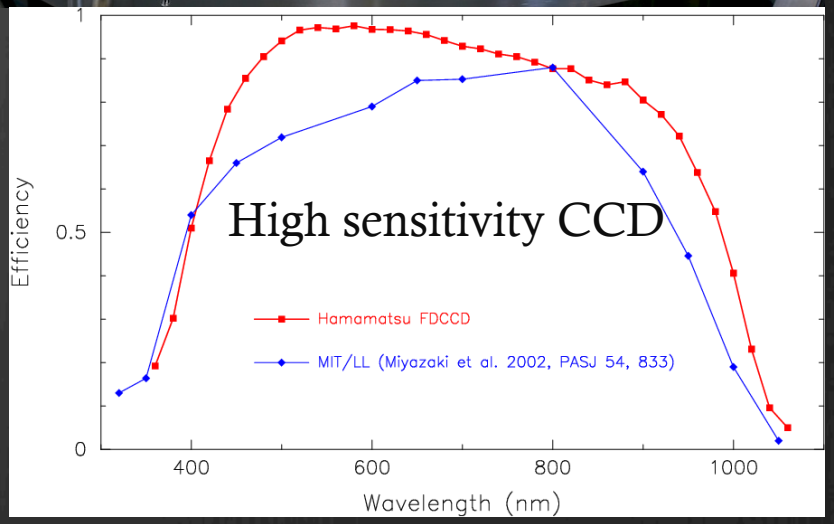


HSC will be ready soon !

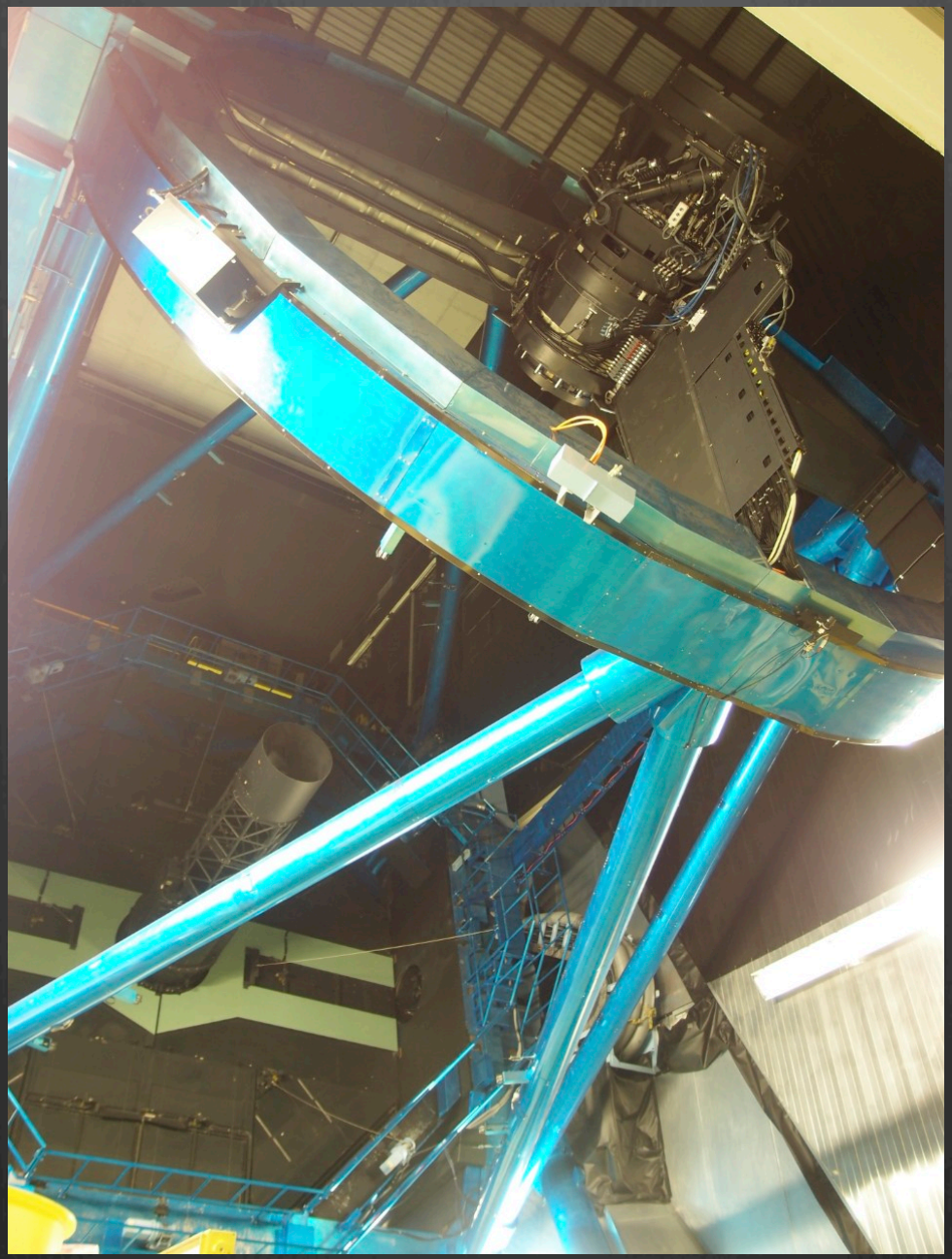
Significantly earlier than LSST!







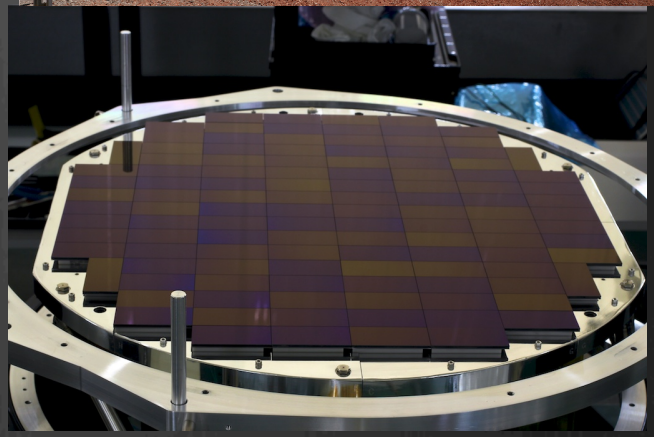
http://anela.mtk.nao.ac.jp/hscblog/builder/

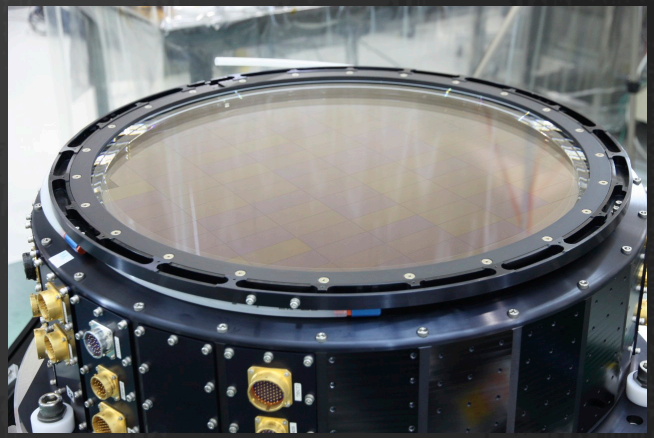


http://anela.mtk.nao.ac.jp/hscblog/builder/

Schedule

- 2011/08 Ship WFC unit to Hawaii
- 2011/12 Camera completed
- 2012/08 Engineering First light!
- 2012/10 Science First light
- 2012/10 Submission of the SSP proposal
- 2013 Expected HSC SSP survey start
- 2018 Expected HSC SSP survey end





The survey will be significantly earlier than LSST

Subaru Strategic Program(SSP)

- Subaru is the open use telescope
- HSC will be one of the open use instruments
- Subaru proposal system:
  - Normal Program up to 5 nights
  - Intensive Program (IP) up to 20 nights / several semester (Max 10 nights / semester)
  - Subaru Strategic Program (SSP) New!
    100-300 nights / 3-5 years (max 60 nights / year)
    For newly developed instrument, we can submit a proposal for this category.

    HiCIAO : "SEED" (Exoplanet, 5years - 120 nights)

    FMOS : " FastSound" (BAO, 2 years - 40 nights)

Only one or less program will be selected for SSP.

HSC SSP

- Establish HSC/SSP consortium (Japan, Taiwan, Princeton)
- The science driver is cosmology (Dark Energy)!
- Planning three layer (wide, deep ultra-deep) survey with grizy and narrow band filters
- Aiming 300 nights survey over 5 years

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

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

Time domain survey

- Variable stars
- Proper motion stars
- AGN (Wide, Deep, & Ultra-deep) Key science
- SNIa cosmology (z>1) (Deep & Ultra-deep) Key science
- Supernova rate (z<1) (Deep & Ultra-deep)
- Ultra-Luminous Supernova (z up to 4~6) (Deep & Ultra-deep)
- Bright SNIIn (z up to ~6) (Ultra-deep)
- Orphan GRB (Deep & Ultra-deep)
- Tidal Disruption Flare (Deep & Ultra-deep)
- SNe Shock break out (z>0.5) (Wide, Deep & Ultra-deep)
- Unknown objects…..

Time domain survey

- Variable stars
- Proper motion stars
- AGN (Wide, Deep, & Ultra-deep) Key science
- SNIa cosmology (z>1) (Deep & Ultra-deep) Key science
- Supernova rate (z<1) (Deep & Ultra-deep)

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- Bright SNIIn (z up to ~6) (Ultra-deep)
- Orphan GRB (Deep & Ultra-deep)
- Tidal Disruption Flare (Deep & Ultra-deep)
- SNe Shock break out (z>0.5) (Wide, Deep & Ultra-deep)
- Unknown objects…..

Advantages of HSC

- Large Aperture
  - Other SN surveys except for LSST use 4m telescopes
  - SNIa samples are limited to z<0.9
    → Extend to z~1.2
- Wide Field
  - 2 FoV of HSC is comparable to the survey area of SNLS
- Higher sensitivity in red bands (z, y-bands)
  - Most energy of SNIa@z=1 fall in i, z, and y-band
  - Ultra-Luminous SNe at z~6
  - Bright SNIIn at z~6
- High spatial resolution
  - SNe are point sources
- Coordinated SSP survey only enables multi-band and multi-epoch time domain survey

時間変動天体サーベイ

1. 大口径望遠鏡・宇宙望遠鏡でのdeep サーベイのデータ分割
- Hubble Space Telescope (HST, 2.4m) / WFPC2, ACS, WFC3
- Subaru (8.2m)/Suprime-Cam (SDF, SXDS), Hyper Suprime-Cam
- CFHT (3.6m)/MegaCam: Supernova Legacy Survey (SNLS)
- JWST (6.5m)/NIRCam
- WISH (1.5m), Euclid (1.2m), WFIRST (1.1-2.4m)

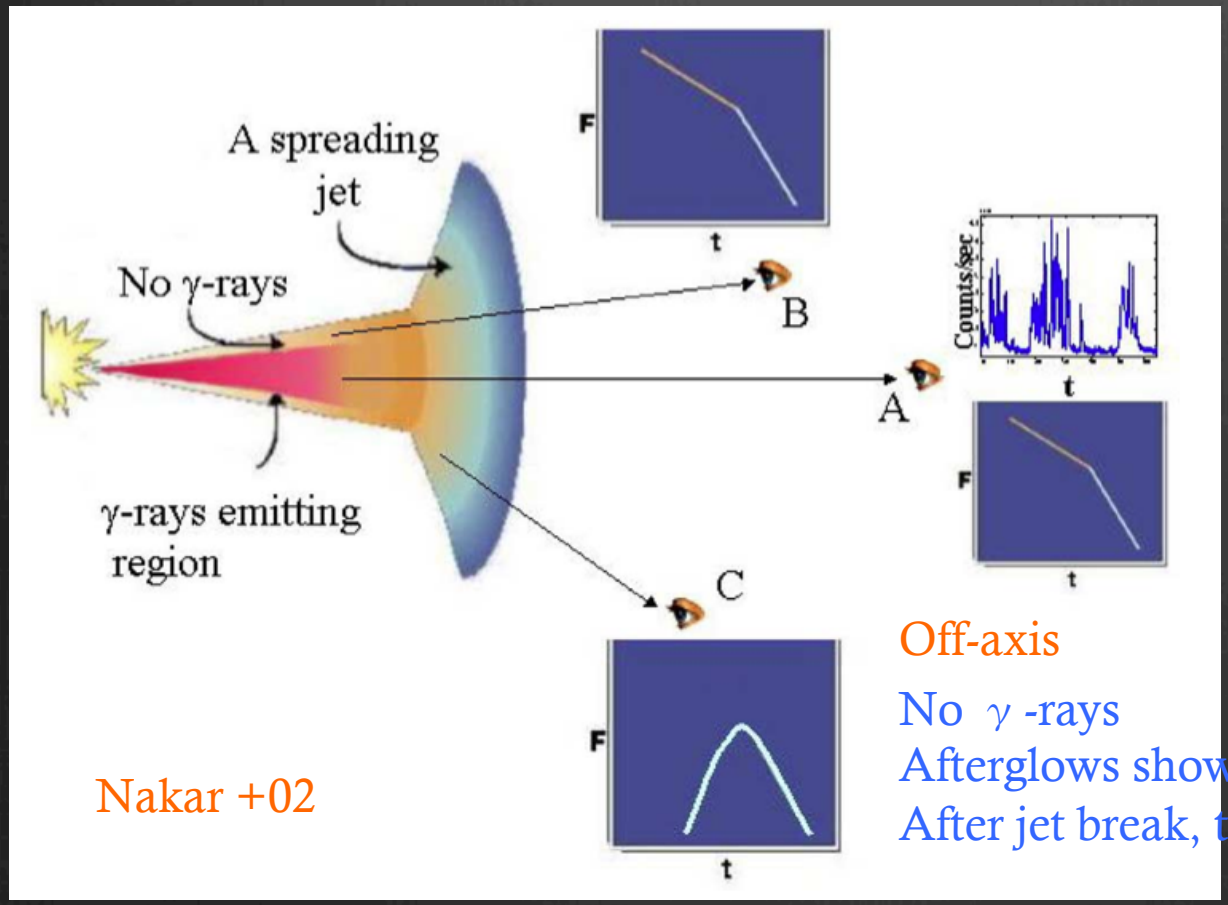
2. (中小口径)望遠鏡をほぼ占有
- ROTSE(0.45m)
- Kiso (1.05m)/KWFC: Kiso Supernova Survey (KISS), KWFC Intensive Survey Of the Galactic Plane (KISOGP)
- Palomar 48-inch Oschin (1.2m)/CFH12k: Palomar Transient Factory (PTF)
- Pan-STARRS (PS, 1.8m)
- SkyMapper (1.35m)
- SDSS (2.5m): SDSS-II Supernova Survey
- Microlensing Observations in Astrophysics (MOA, 1.8m)
- CTIO Blanco (4m)/Dark Energy Camera (DECam): Dark Energy Survey (DES)
- Large Synoptic Survey Telescope (LSST, 8.4m)

Orphan GRB afterglow

GRB collimated Jet

Energetics $E_{iso} \sim 10^{53\text{-}54} \rightarrow$ Jet corrected $\sim 10^{51}$
Achromatic temporal break in afterglow light curves

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



Nakar +02

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

Off-axis

No γ -rays
Afterglows show rise and fall
After jet break, the properties are similar

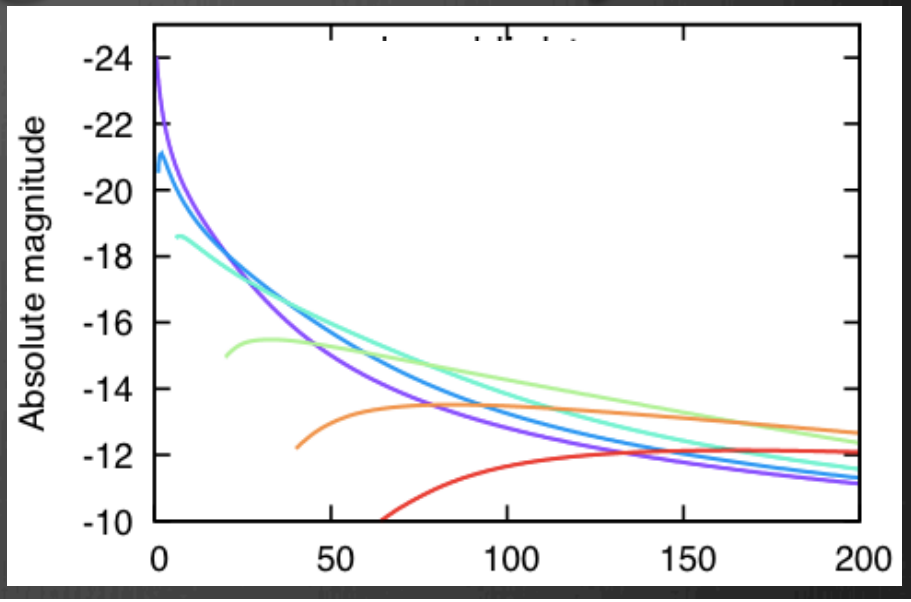
Off-axis orphan GRB afterglow = direct evidence of jet collimation

Orphan afterglow survey

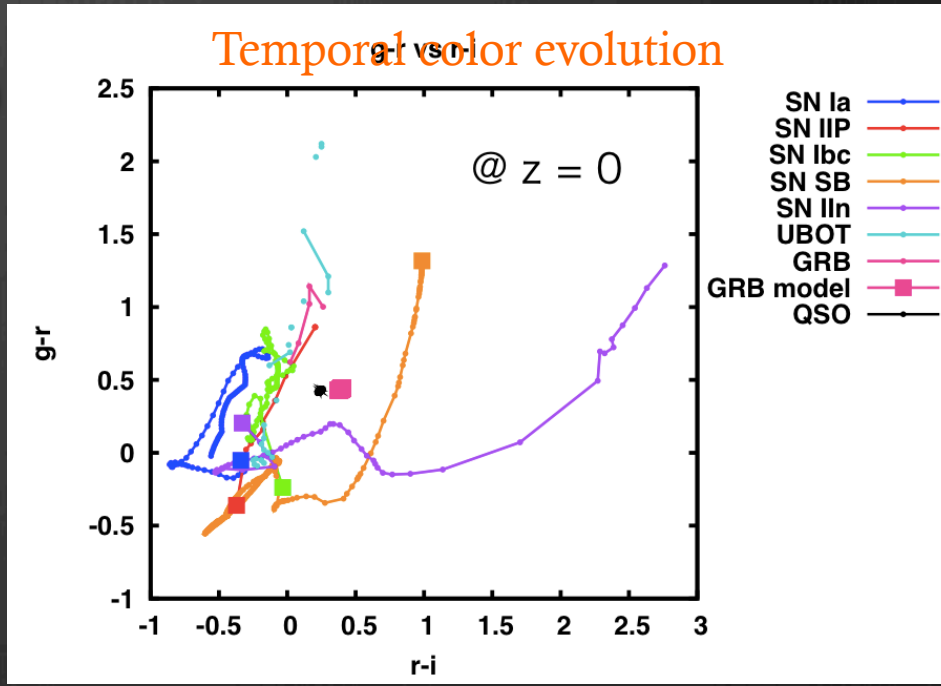
- Wider survey fields in optical
  - Swift/BAT 120 x 90 deg :
  - Typical opt imager several 10 arc min)
- Deep imaging (r ~ 26.5 mag)

  → 8 m class telescopes
- Cadence of the survey (days scale)
- Long-term monitoring (monthly~ year)

Subaru, LSST

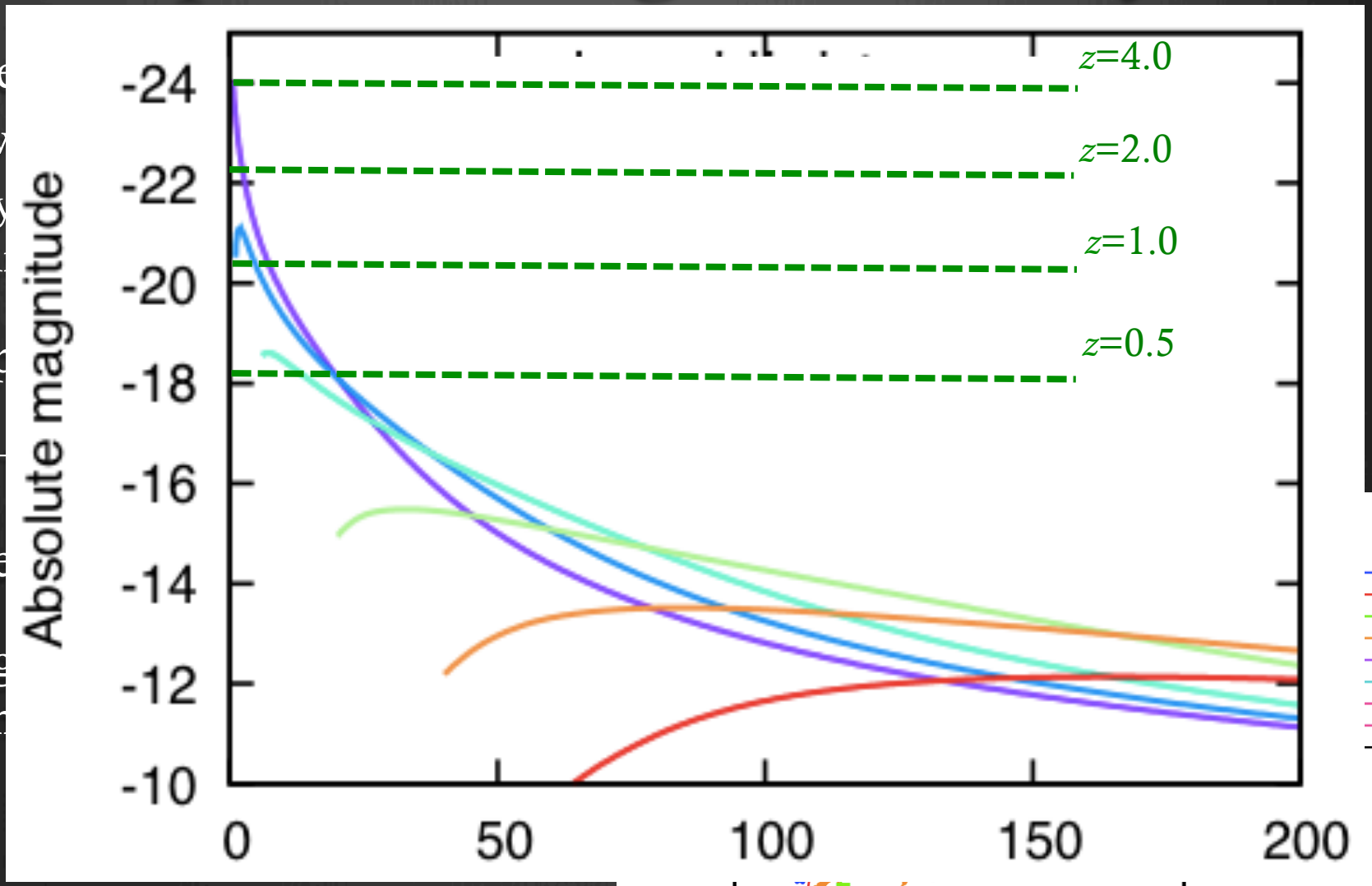


Temporal color evolution

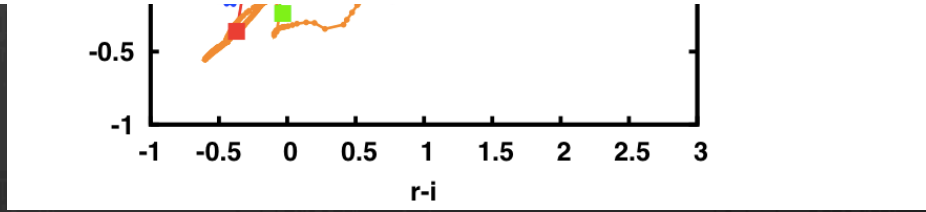


Orphan afterglow survey

- Wide
  - Sv
  - Ty
    m
- Deep
- Cade
- Long
  (mor



Subaru, LSST



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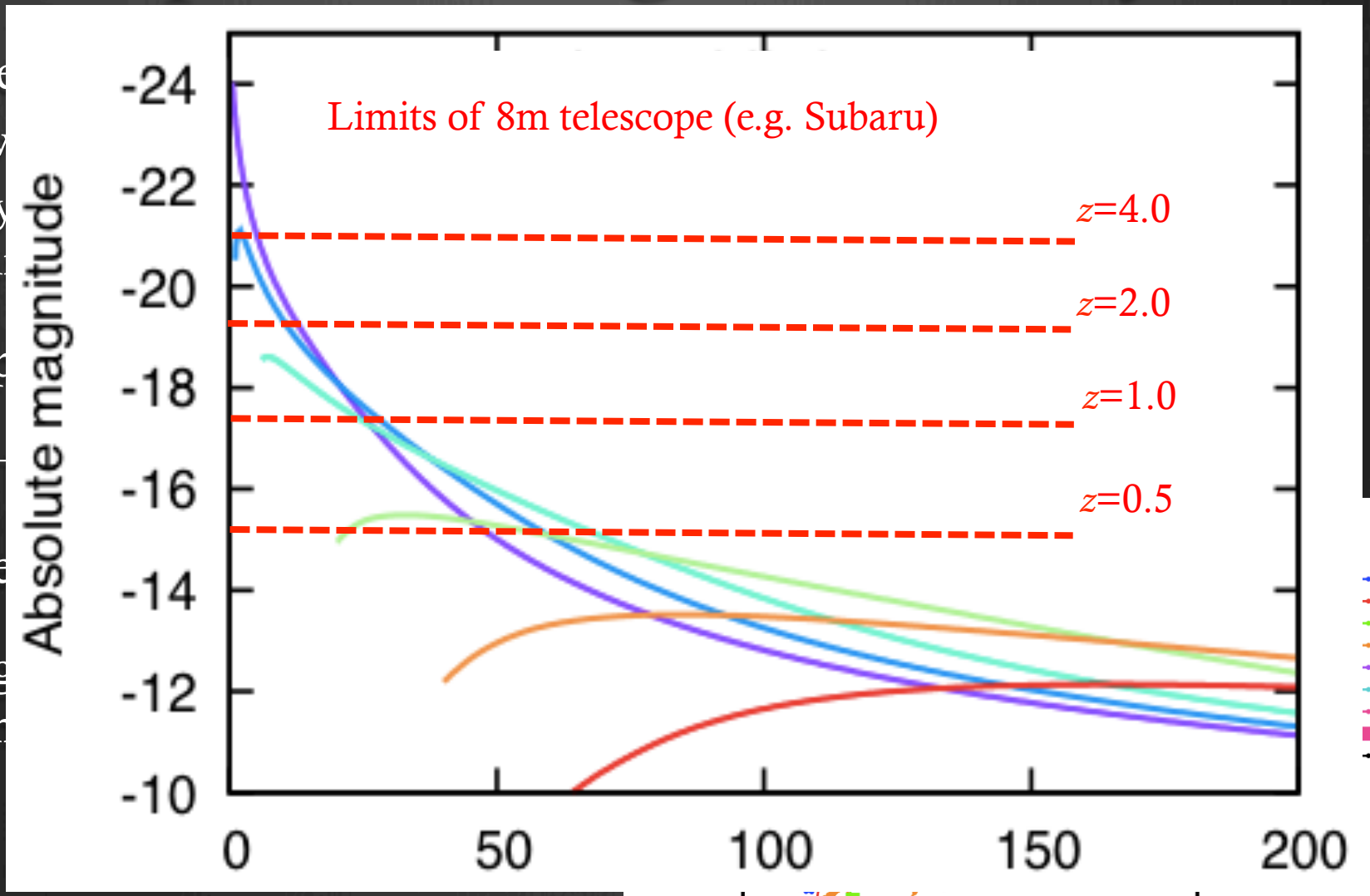
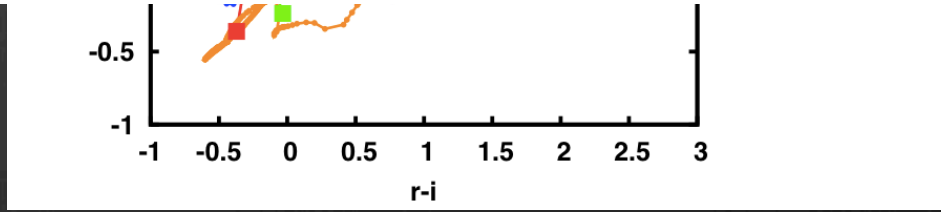


Subaru, LSST

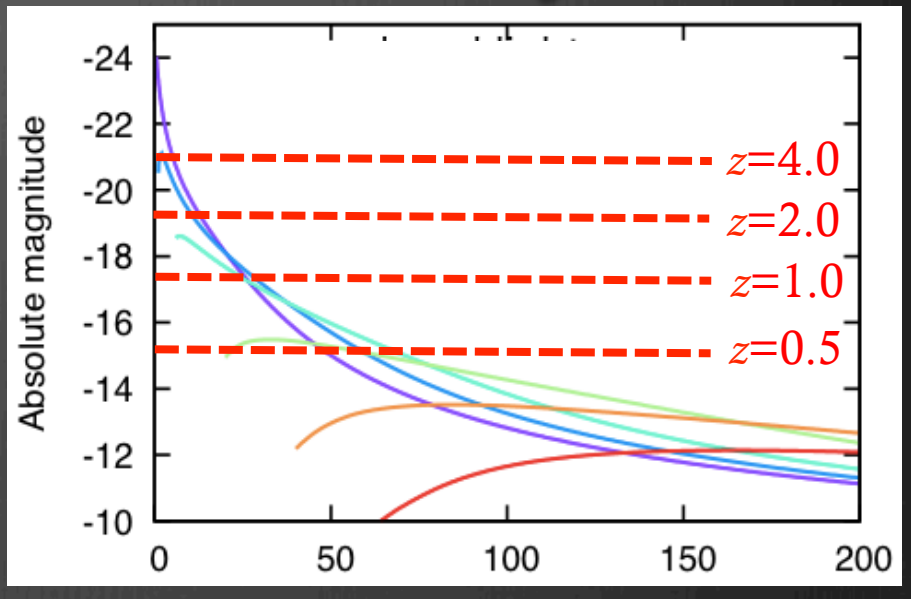


Orphan afterglow survey

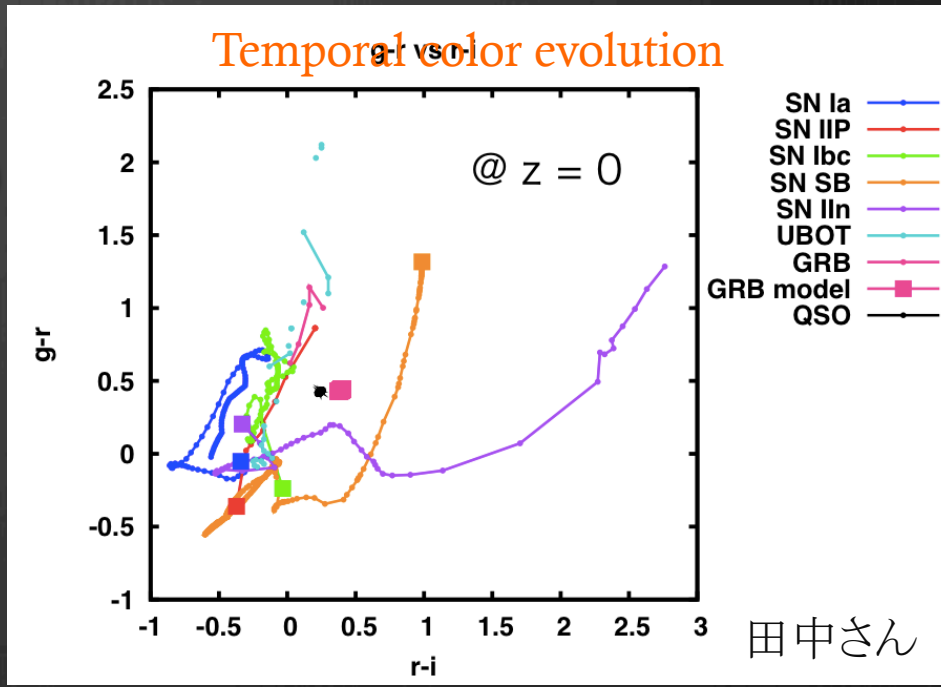
- Wider survey fields in optical
  - Swift/BAT 120 x 90 deg :
  - Typical opt imager several 10 arc min)
- Deep imaging (r ~ 26.5 mag)
  - Median redshift of GRB z~2

  → 8 m class telescopes
- Cadence of the survey (days scale)
- Multi-color monitoring (monthly~ year)

Subaru, LSST



Temporal color evolution



田中さん

Planned Cadence

- Example for Deep & Ultra deep
- Optimize to SNIa hunting
  - 1st year : Making reference images for image subtraction
  - 2nd year : SNe Ia. Orphan GRB etc hunting
  - 3rd year : Long term monitoring for Luminous SNe, SNIIn, AGN
  - 4th year : SNe Ia. Orphan GRB etc hunting
  - 5th year : Long term monitoring for Luminous SNe, SNIIn, AGN

		XMM-LSS Deep									Ultra Deep										
		u	g	r	i	z	y	3	8	9	g	r	i	z	y	3	5	7	8	9	1
S12B	Aug																				
	Sep	10	30	30	30	20	20						30	61	61						
	Oct							40	40	80						324			234	288	
	Nov										30	30	60	81	81						
	Dec																270	180			450
	Jan																				
S13A	Feb																				
	Mar																				
	Apr																				
	May																				
	Jun																				
	Jul																				
S13B	Aug																				
	Sep	10	30	30	30	20	20						30	61	61						
	Oct										30	30	120	162	162						
	Nov										30	30	120	162	162						
	Dec										30	30	120	162	162						
	Jan																				
S14A	Feb																				
	Mar																				
	Apr																				
	May																				
	Jun																				
	Jul																				
S14B	Aug																				
	Sep							40	40	80						432			312	384	
	Oct	10	30	30	30	20	20														
	Nov	10	30	30	30	20	20				180	180	60	122	122						
	Dec																360	240			600
	Jan																				
S15A	Feb																				
	Mar																				
	Apr																				
	May																				
	Jun																				
	Jul																				
S15B	Aug																				
	Sep	10	30	30	30	20	20						30	61	61						
	Oct										30	30	120	162	162						
	Nov										30	30	120	162	162						
	Dec										30	30	120	162	162						
	Jan																				
S16A	Feb																				
	Mar																				
	Apr																				
	May																				
	Jun																				
	Jul																				
S16B	Aug																				
	Sep	10	30	30	30	20	20						30	61	61						
	Oct										30	30	60	81	81						
	Nov							40	40	80						324			234	288	
	Dec																270	180			450
	Jan																				
S17A	Feb																				
	Mar																				
	Apr																				
	May																				
	Jun																				
	Jul																				
Total	min	60	180	180	180	120	120	120	120	240	420	420	1020	1500	1500	1080	900	600	780	960	1500
	hr	1	3	3	3	2	2	2	2	4	7	7	17	25	25	18	15	10	13	16	25

	Deep						Ultra Deep				
Day	u	g	r	i	z	y	g	r	i	z	y
−6											
−5											
−4					72	72				81	81
−3											
−2		48		72			30		60		
−1											
0		48	48				30	30			
1											
2			48			72		30			81
3											
4				72	72				60	81	
5											
6											
	0	96	96	144	144	144	60	60	120	162	162

Filter	Limit (5 σ)
g	26.9
r	26.6
i	26.6
z	25.7

Planned Survey

- Three layer (wide, deep ultra-deep) survey with grizy
- Aiming 300 nights survey over 5 years (2013 – 2018)

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

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

Time Domain Survey

Limit for 1 visit

Filter	Limit (5 σ)
g	26.9
r	26.6
i	26.6
z	25.7

350 SNIa (180@z>1)

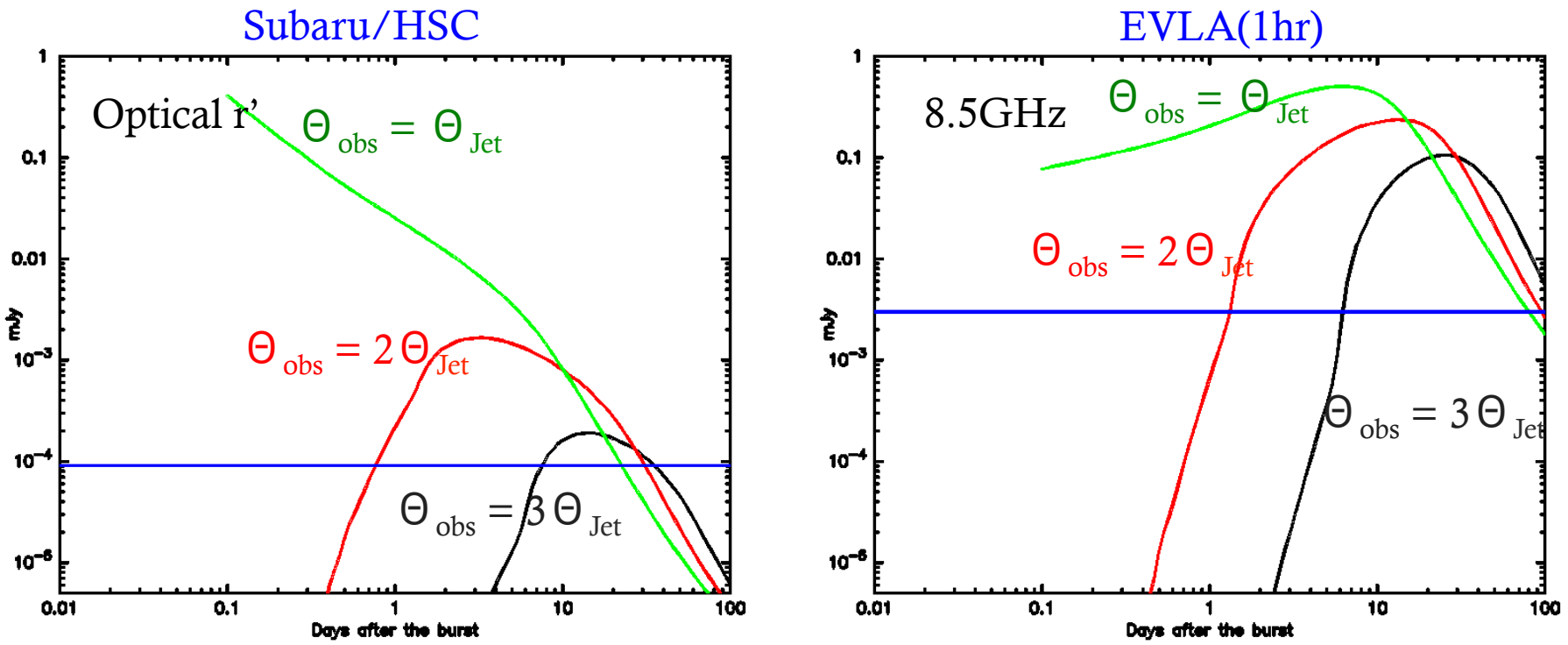
	HSC Deep	HSC Ultra-Deep
FOV (sq. deg)	30	4
Epoch (each filter)	12	28
Totani and Panaitescu(2002)	35	9
Nakar&Piran (2002)	5	2
Rossi+08	1	0.14

Expected

1- 44 events (Total)

HSC & Radio Follow-ups

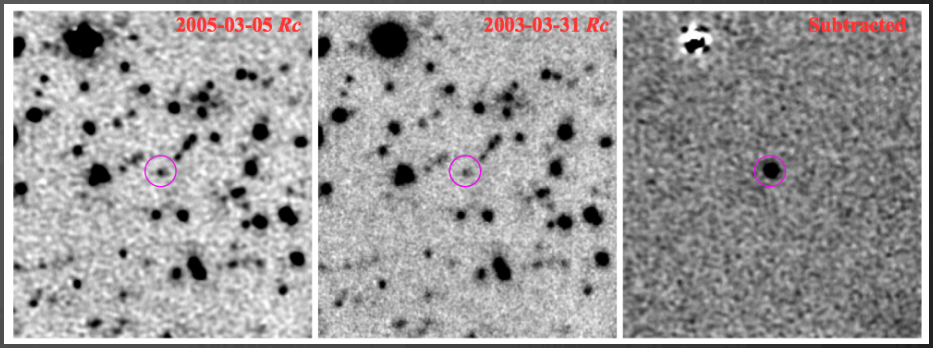
Simulated light curves ($E_{total}=10^{53}$ erg, z=1, $\theta_{jet}=0.1$ rad)

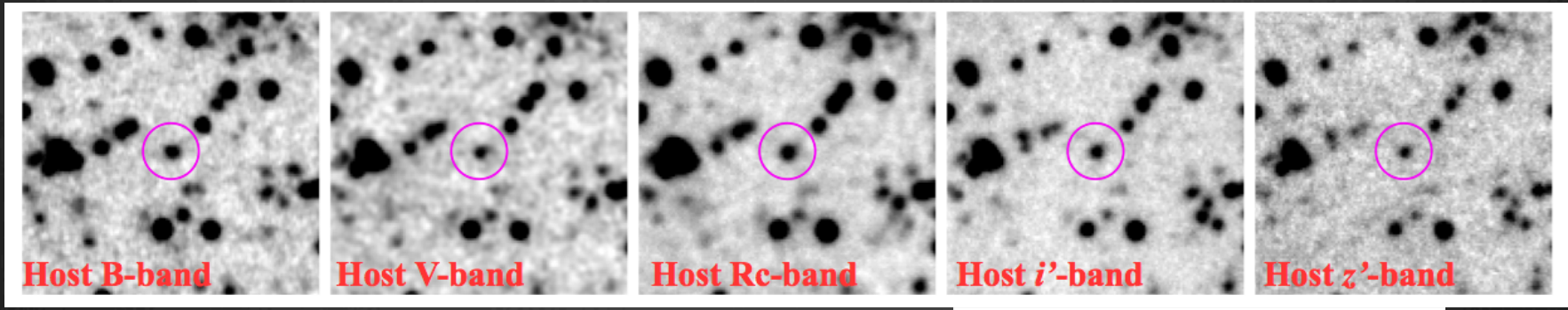


EVLA を使うと off axis 角などが精度よく求まる

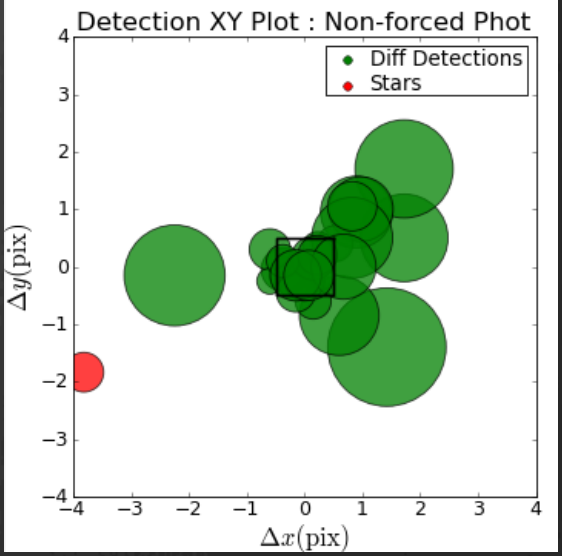
探査方法

- PSF合わせた画像引き算
- 光度曲線の生成
- 母銀河の同定

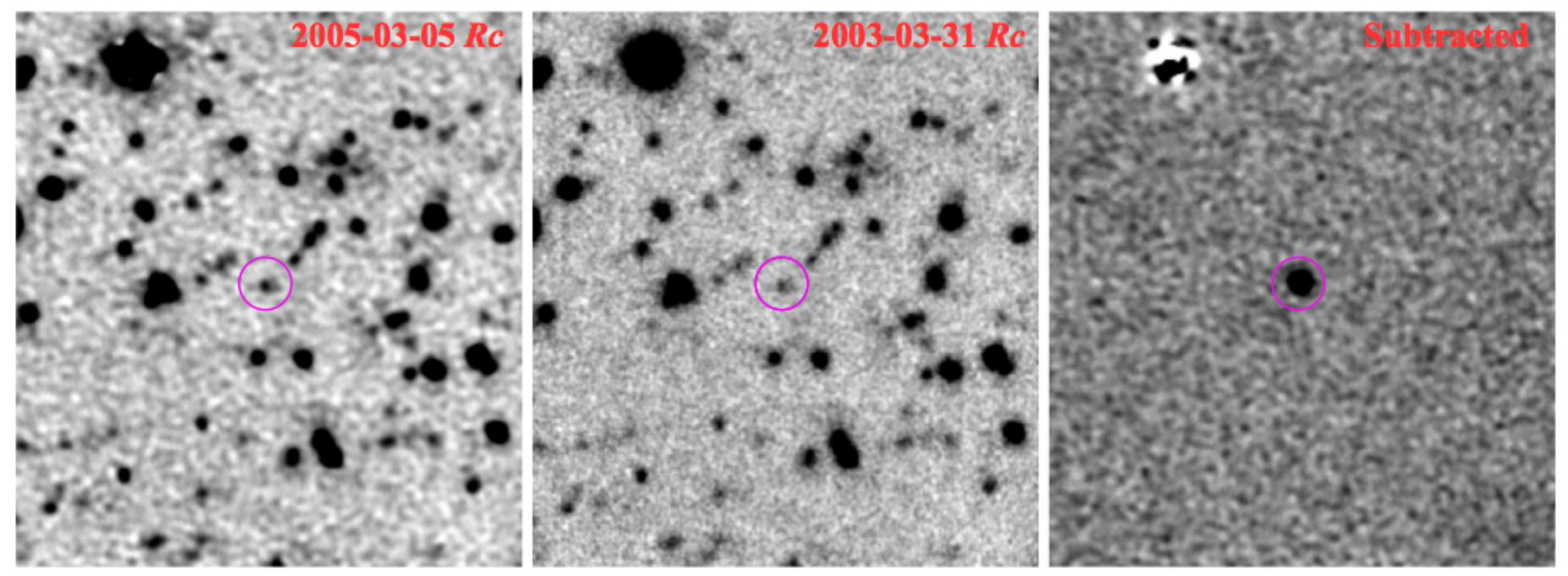




- 母銀河内での位置の測定
- 赤方偏移の測定
  - (Phot-z, Spec-z)
- 絶対等級の測定
- 突発天体/変動天体の分類

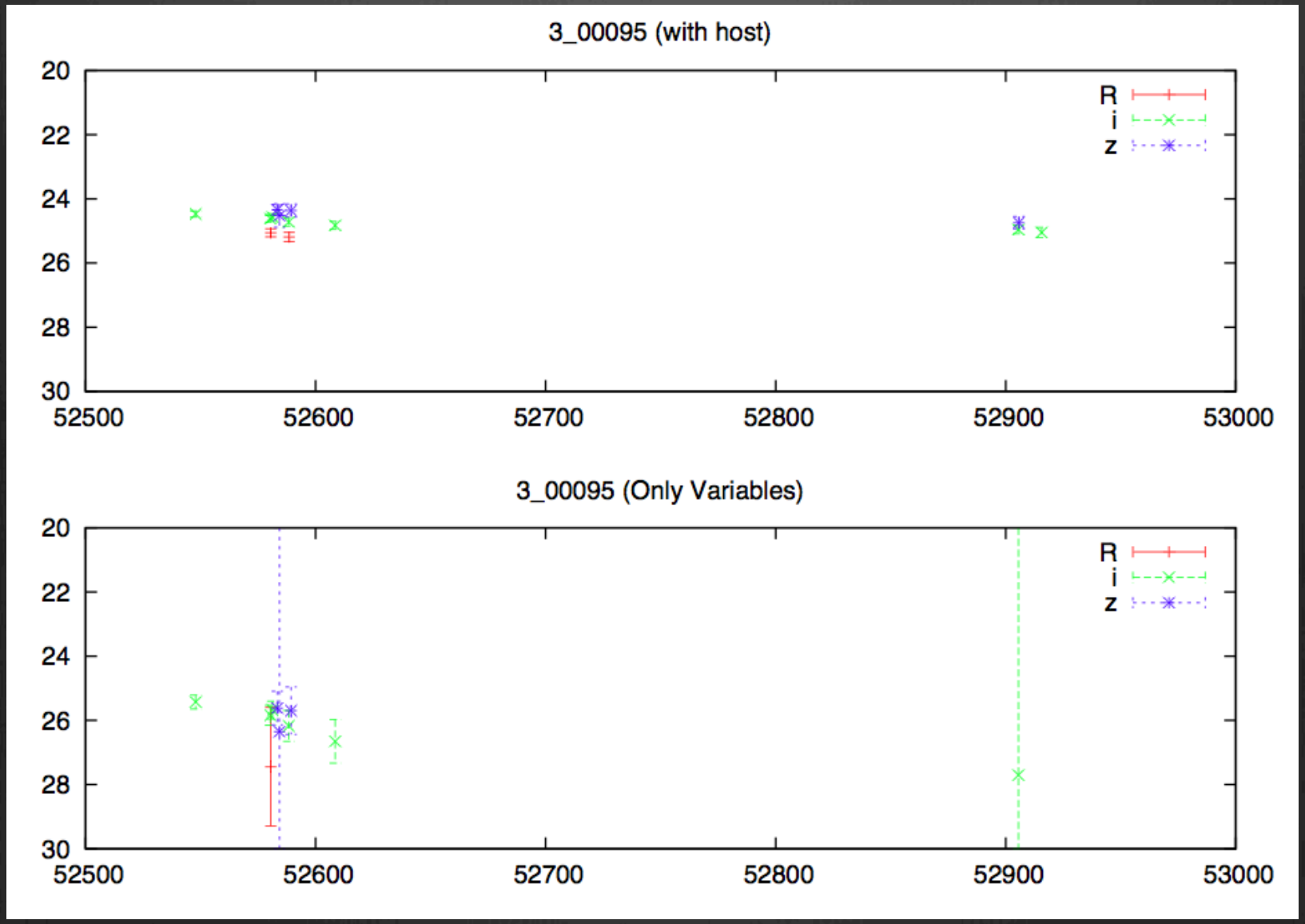


PSF matched image subtraction

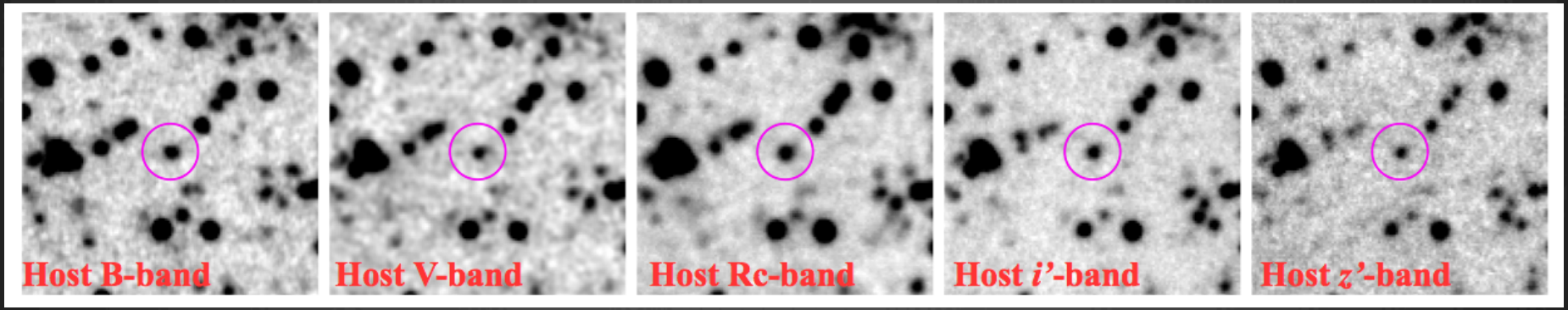


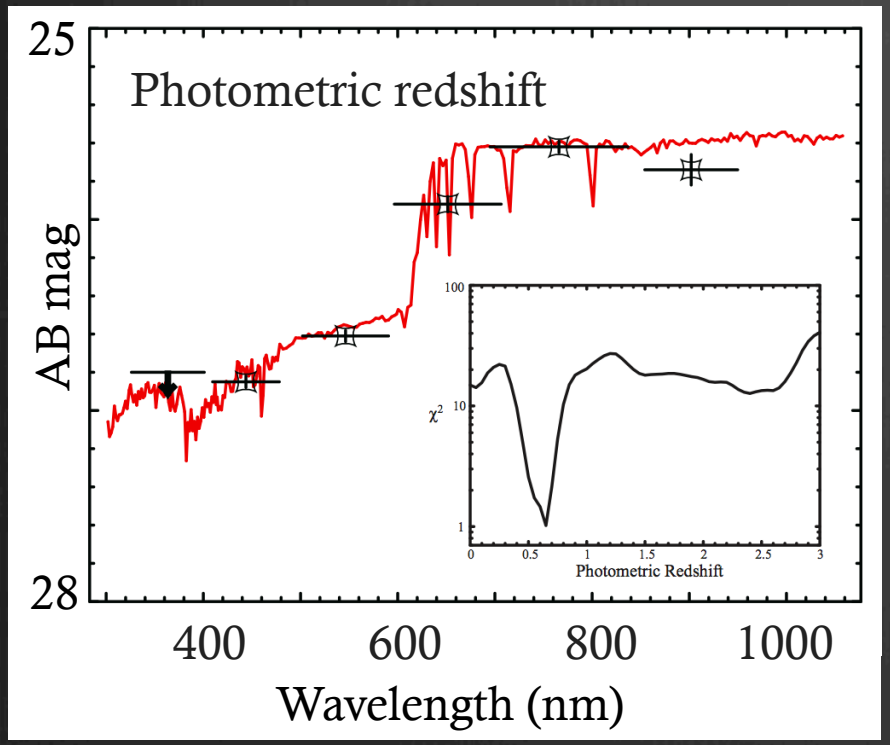
PSF matched image subtraction は、HSC analysis pipelineの一部に組み込まれる

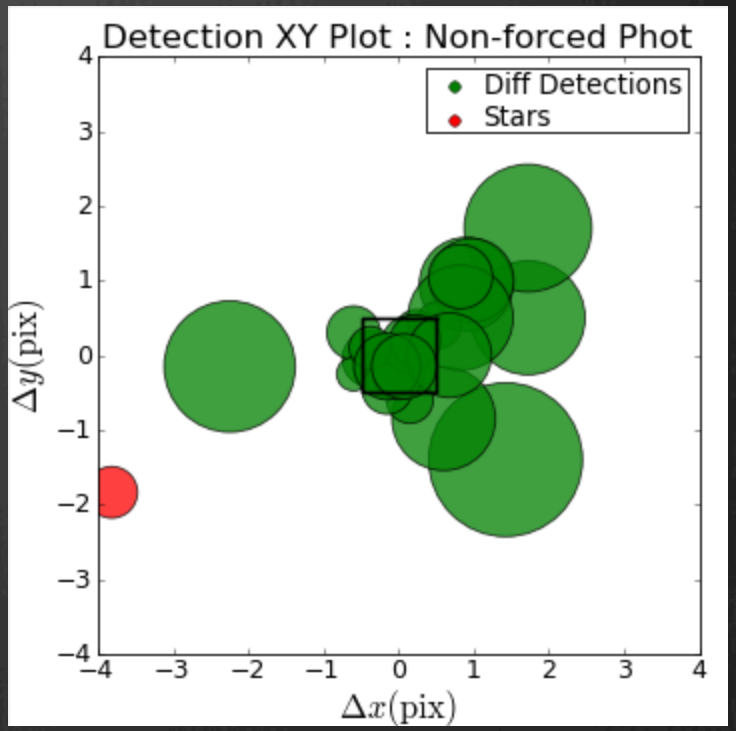
光度曲線の作成


3_00095 (with host)
20
22
24
26
28
30
52500
52600
52700
52800
52900
53000
R
i
z
3_00095 (Only Variables)
20
22
24
26
28
30
52500
52600
52700
52800
52900
53000
R
i
z

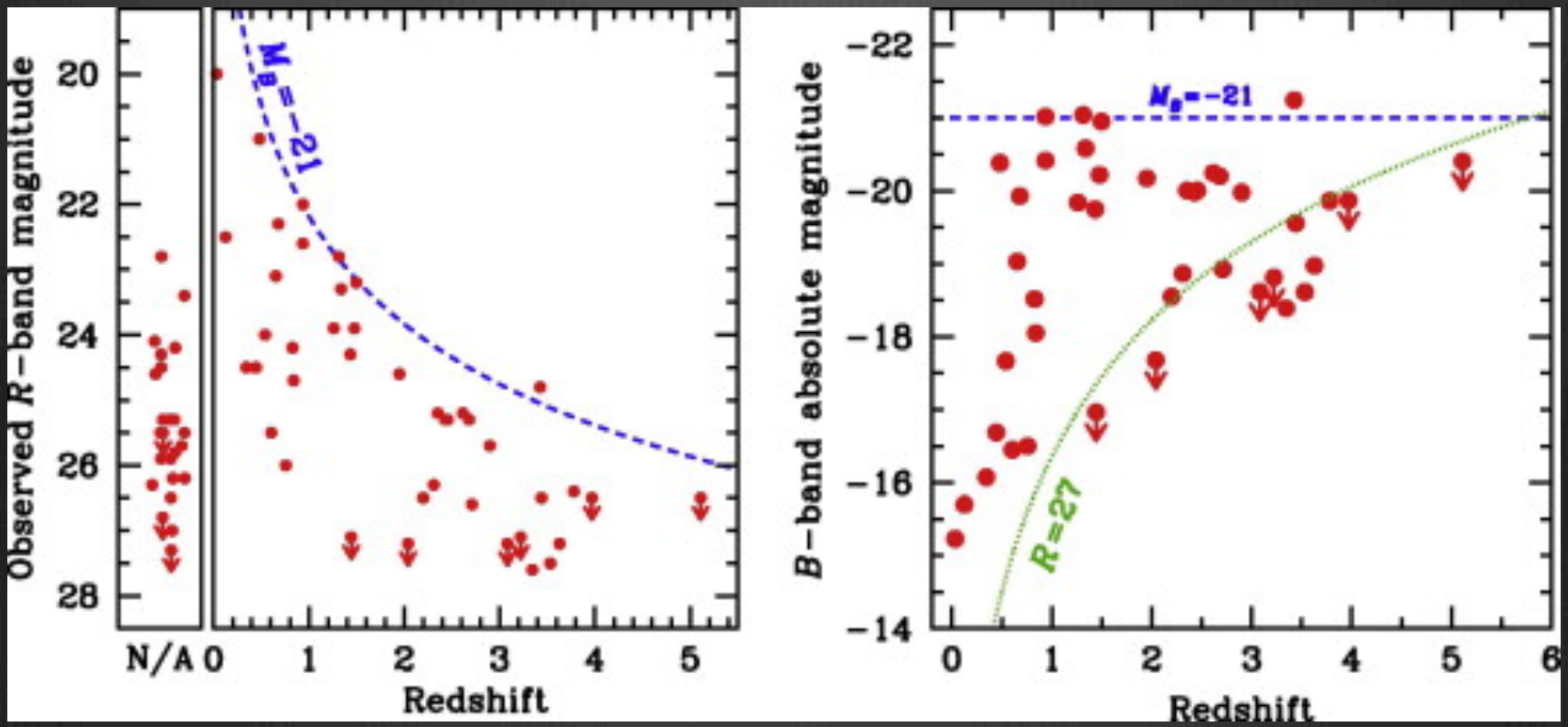
母銀河の同定


Host B-band
Host V-band
Host Rc-band
Host i'-band
Host z'-band


Photometric redshift
AB mag
25
28
400
600
800
1000
Wavelength (nm)
χ²
Photometric Redshift


Detection XY Plot : Non-forced Phot
Diff Detections
Stars
Δy(pix)
Δx(pix)

GRB母銀河

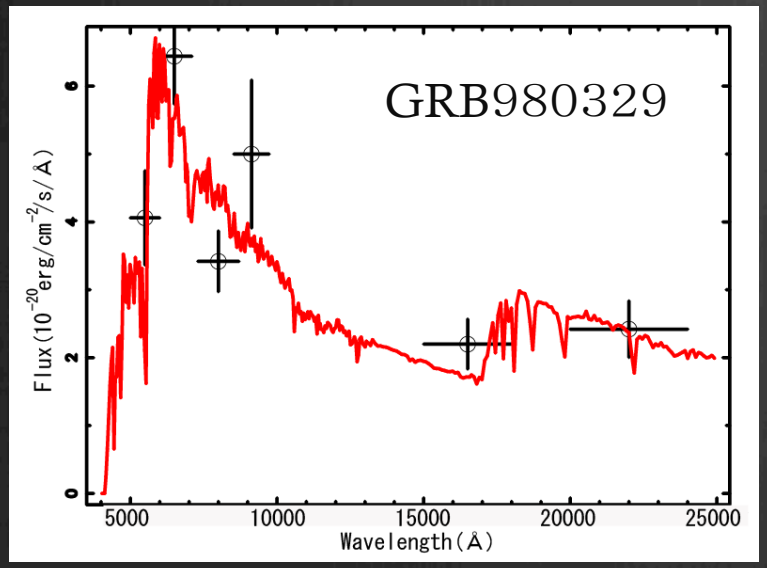


Jakobsson et al. 2011

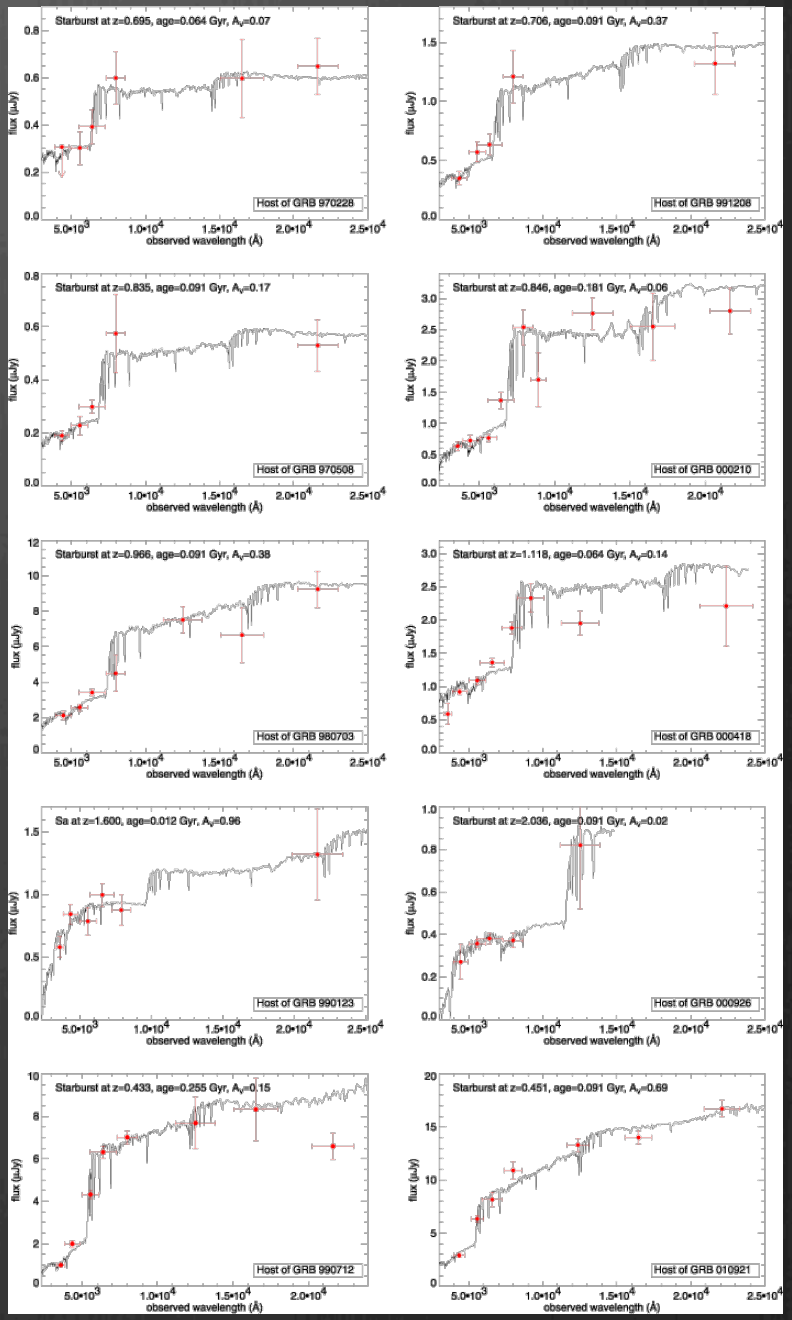
HSCで見つかる Orphan GRBは、 z ~2 くらいまで

HSCのpre/late-imagingで母銀河は、ほぼ同定されるはず！

GRB母銀河のPhot-Z



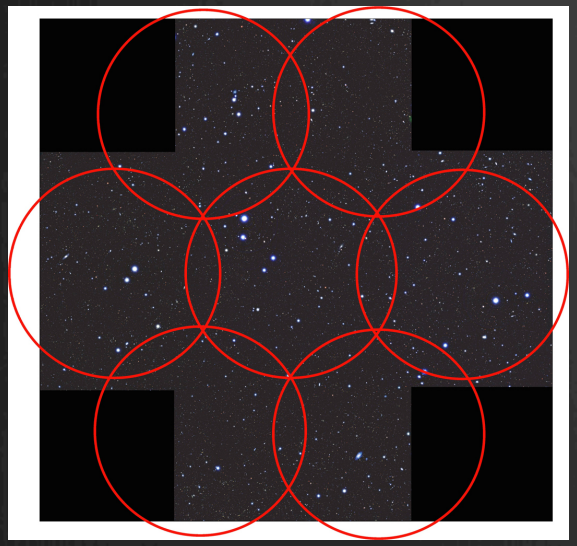
Urata et al. 2004



Christensen et al. 2004

Pre-searches with SC

	Subaru Deep Field (SDF)	Subaru-XMM Deep Survey (SXDS)
Observations	2001-2007	2002-2005, 2008-2010
FOV (deg^2)	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



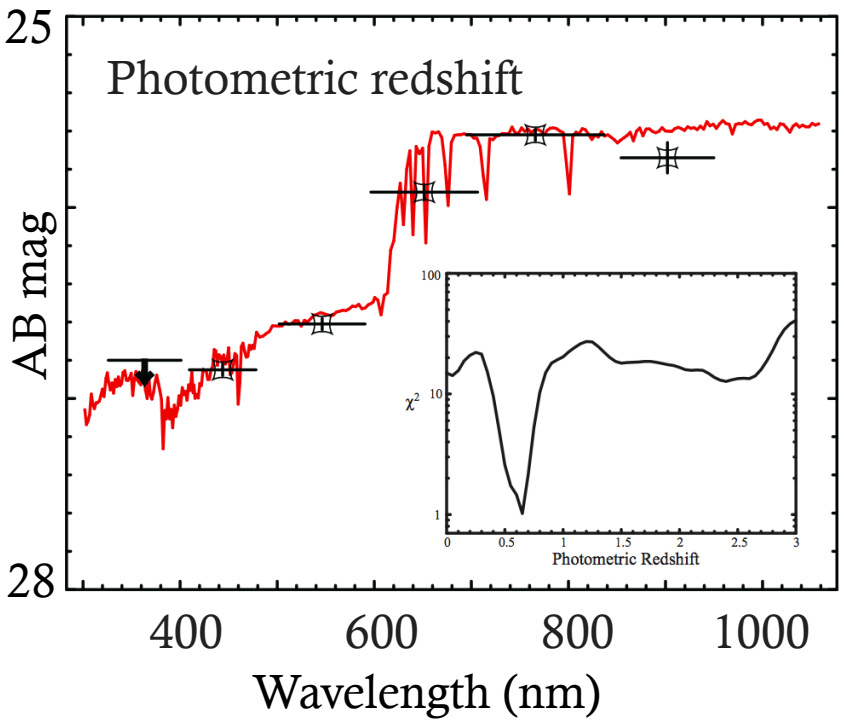
	SDF	SXDS	HSC Deep	HSC Ultra-Deep
FOV (sq. deg)	0.25	1.3	30	4
Epoch	20	8	12	28
Totani+02	0.47	0.75	35	9
Nakar+02	0.07	0.11	5	2
Rossi+08	0.01	0.02	1	0.14

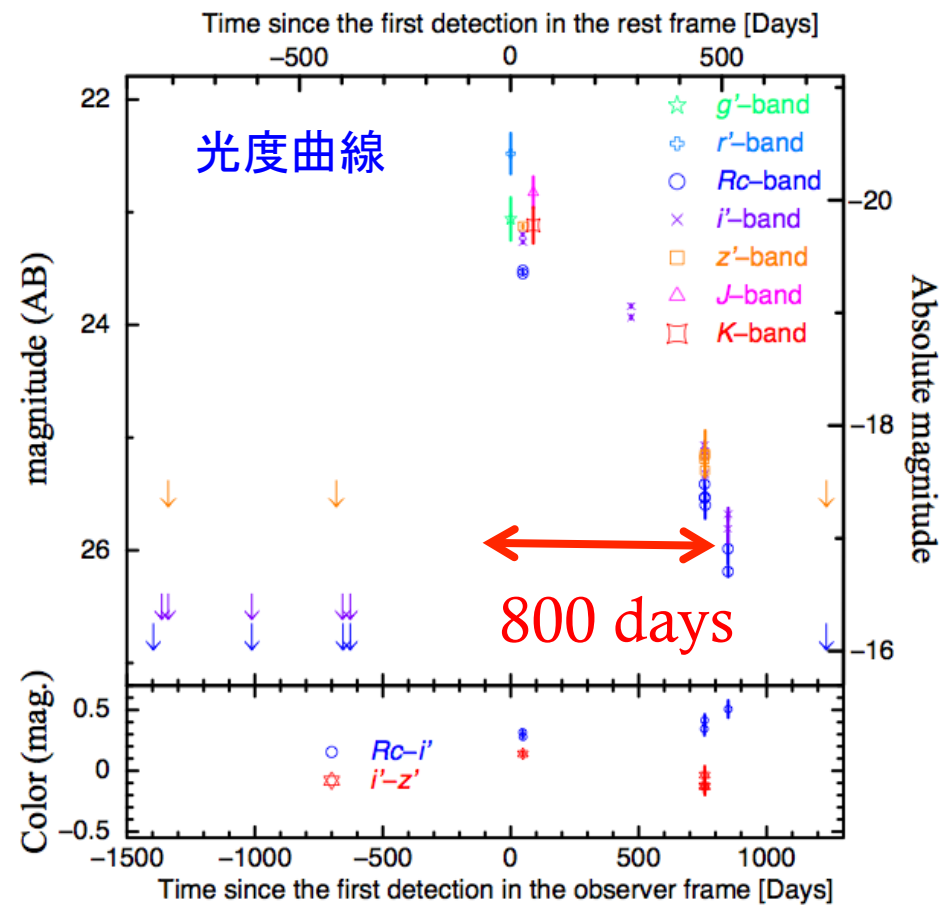
SDF-05M05

Urata et al. 2012ApJL submitted

Unusual Long and Luminous Optical Transient

- 検出 2005年3月5日
- SDSSもたまたま検出 (2005年1月18日
- 継続時間 > 800 days in the obs frame
- 母銀河からのoffset
  ΔRA=+0.”15, Δdec=-0.”24
- 母銀河 Rc ~ 26 mag
- z_{phot} ~ 0.65 (+0.02 -0.03)





- 最大光度 -20 mag (-19等以上が~500日)
- 放射エネルギー~ 1 x 10^{51} erg
- 暗い母銀河 M_V = -16.3 mag
  (SMCと同じくらい暗い)
- SED@~88日 黒体放射 T~6400K

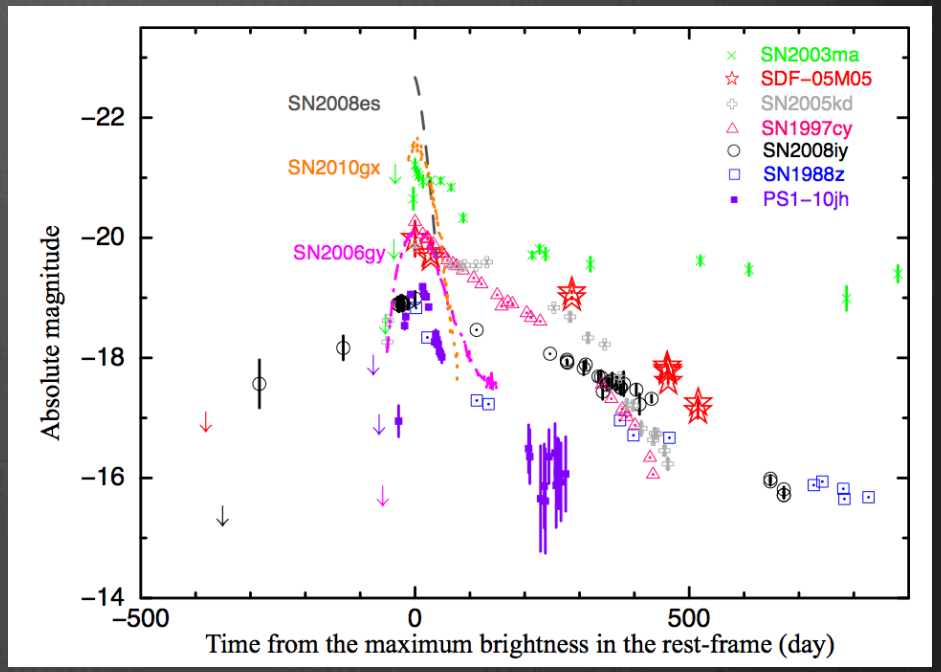
SDF05-M05の起源

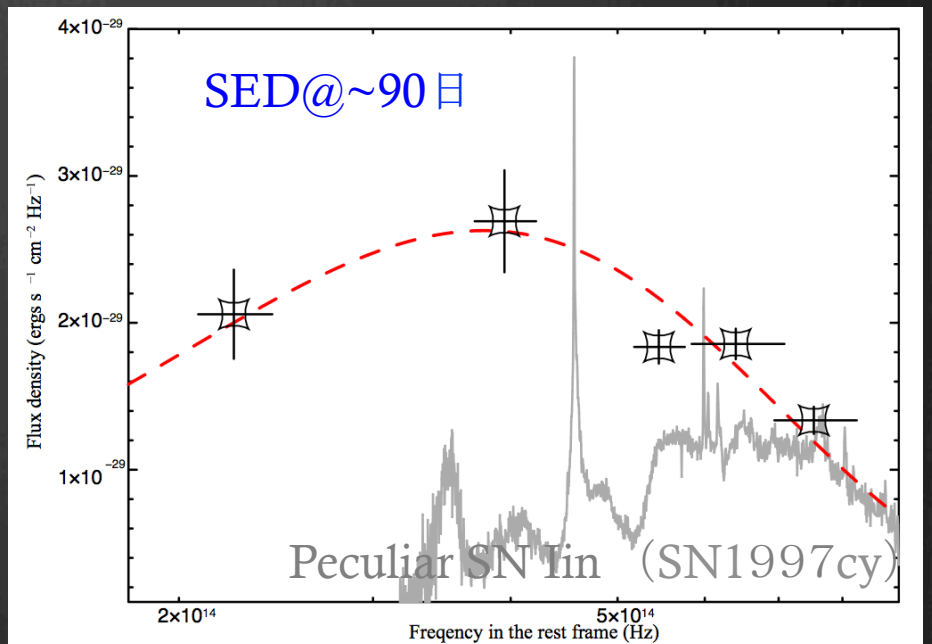
- 母銀河からのoffset
  AGN / TDF を棄却

- Ultra-Luminous SNe
  暗い母銀河は、共通
  光度、時間発展は異なる

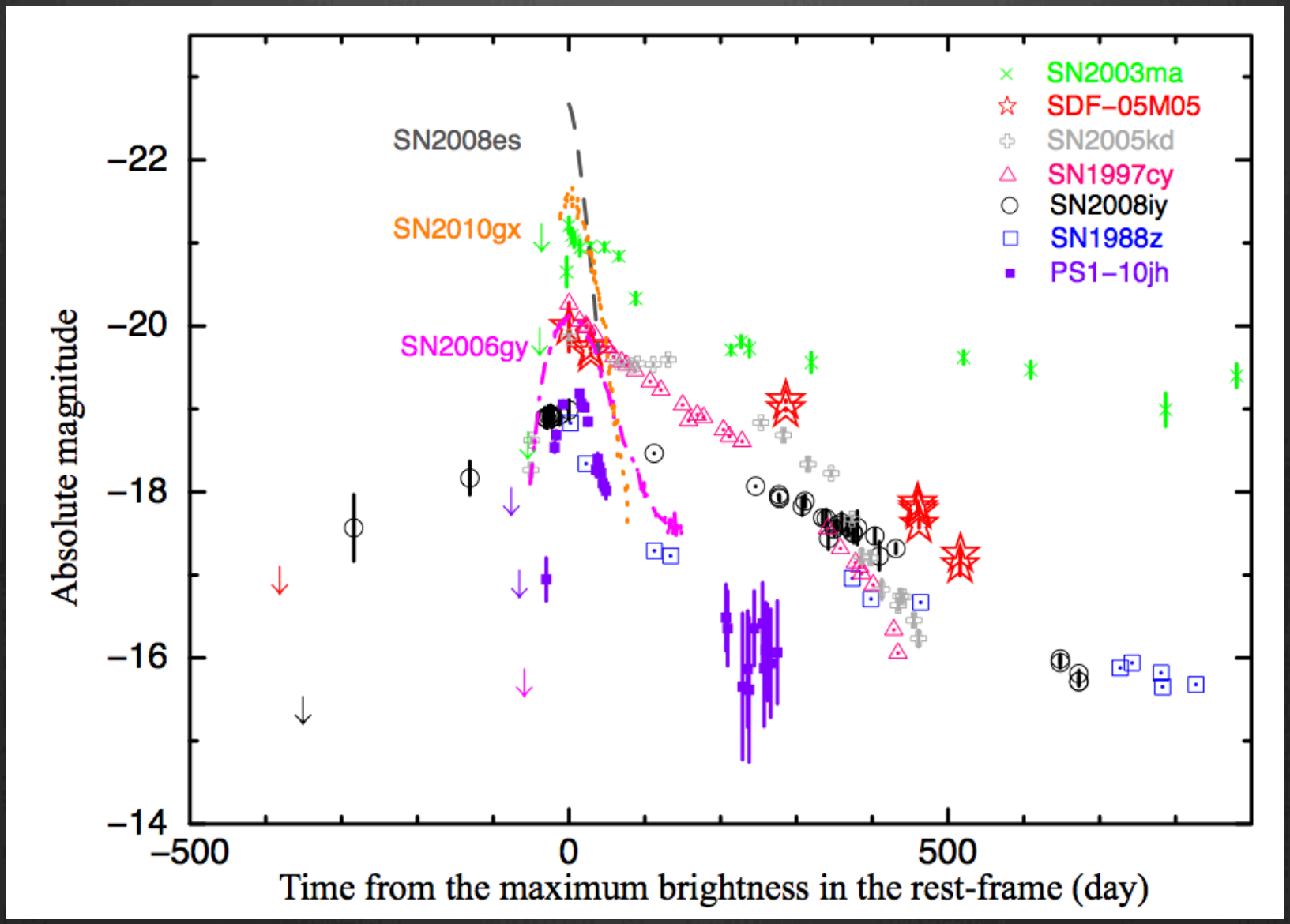
- 特異なSN IIn
  暗い母銀河を持つ傾向
  光度、時間発展はまちまち
  (共通の特徴はない)
  SED 黒体放射　半々
  BB温度 ~ 20,000K
  (SDF-05M05 T~6400K)

- 新種の突発天体の可能性も



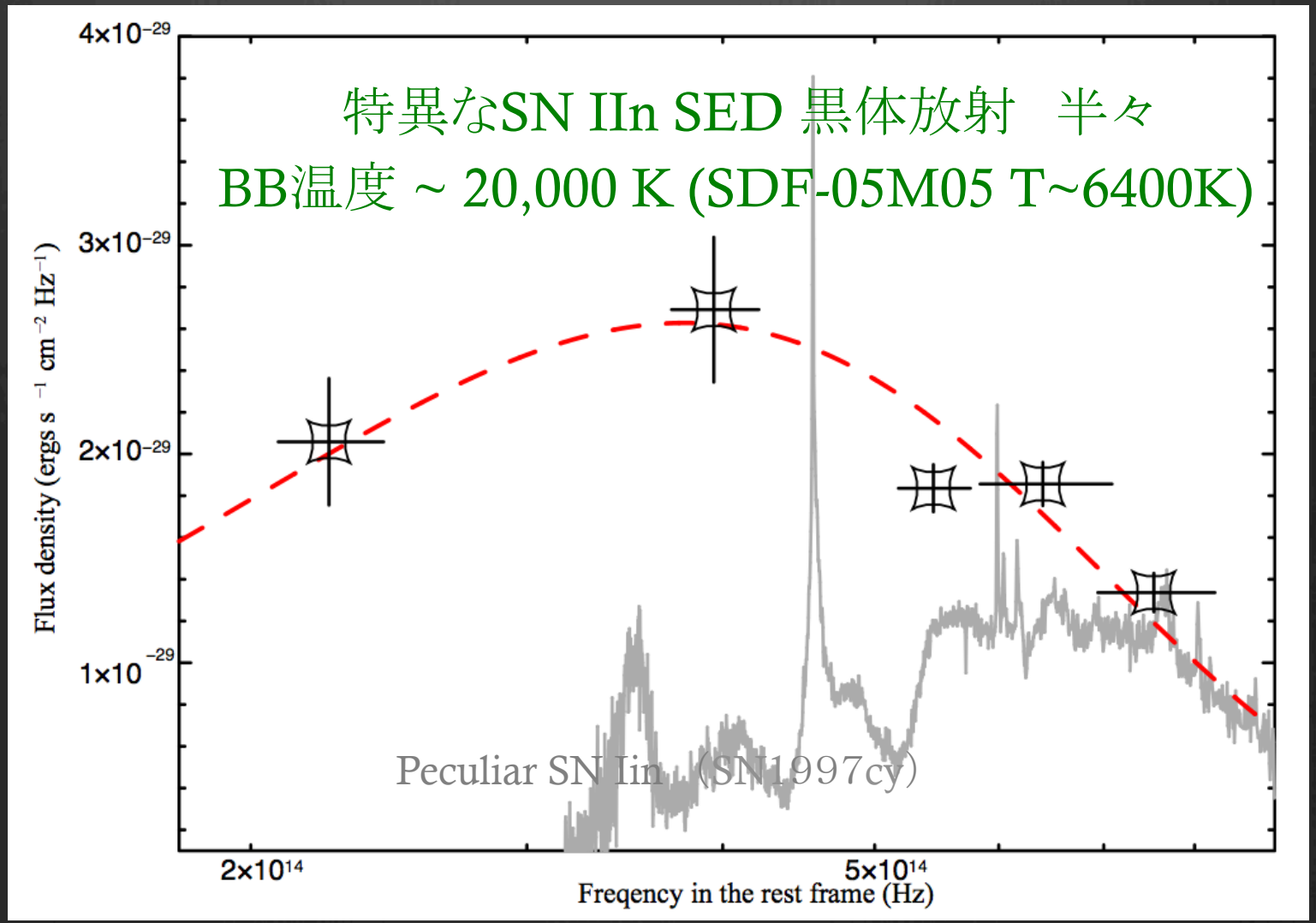


SDF05-M05の起源



SDF05-M05の起源

- 特異なSN IIn　との比較
  暗い母銀河を持つ傾向
  光度、時間発展はまちまち（共通の特徴はない）

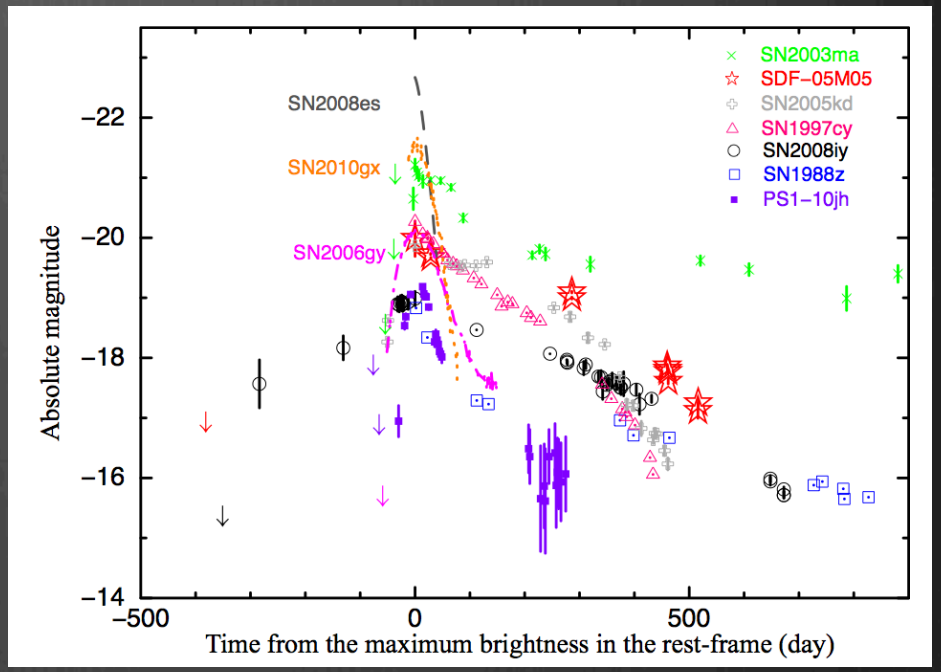


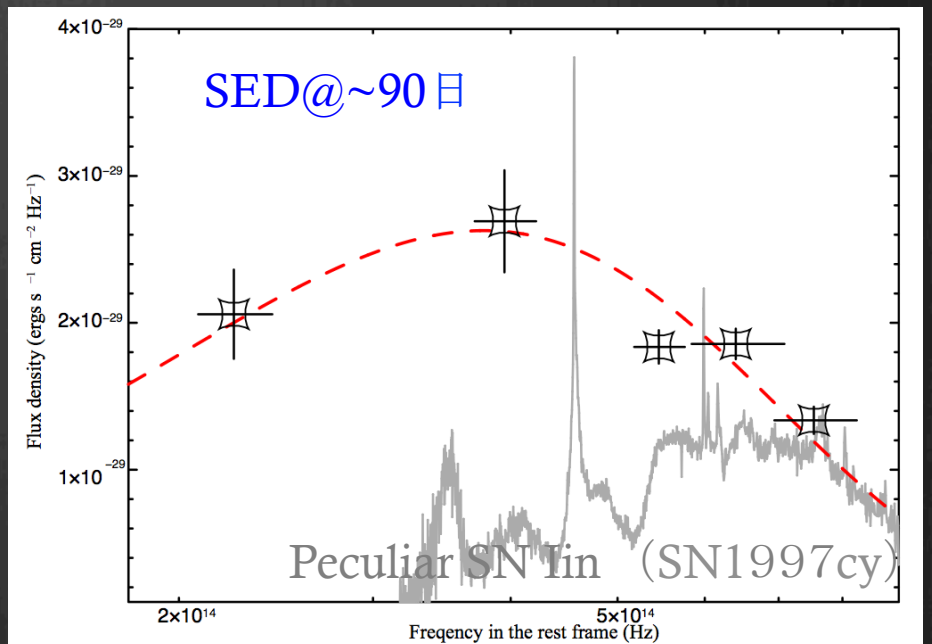
SDF05-M05の起源

- ~~AGN/TDF~~
  母銀河からのoffset
  AGN / TDF を棄却
- ~~Ultra-Luminous SNe~~
  暗い母銀河は、共通
  光度、時間発展は異なる

- 特異なSN IIn ▲
  暗い母銀河を持つ傾向
  光度、時間発展はまちまち
  (共通の特徴はない)
  SED 黒体放射　半々
  BB温度 ~ 20,000K
  (SDF-05M05 T~6400K)

- 新種の突発天体の可能性●?





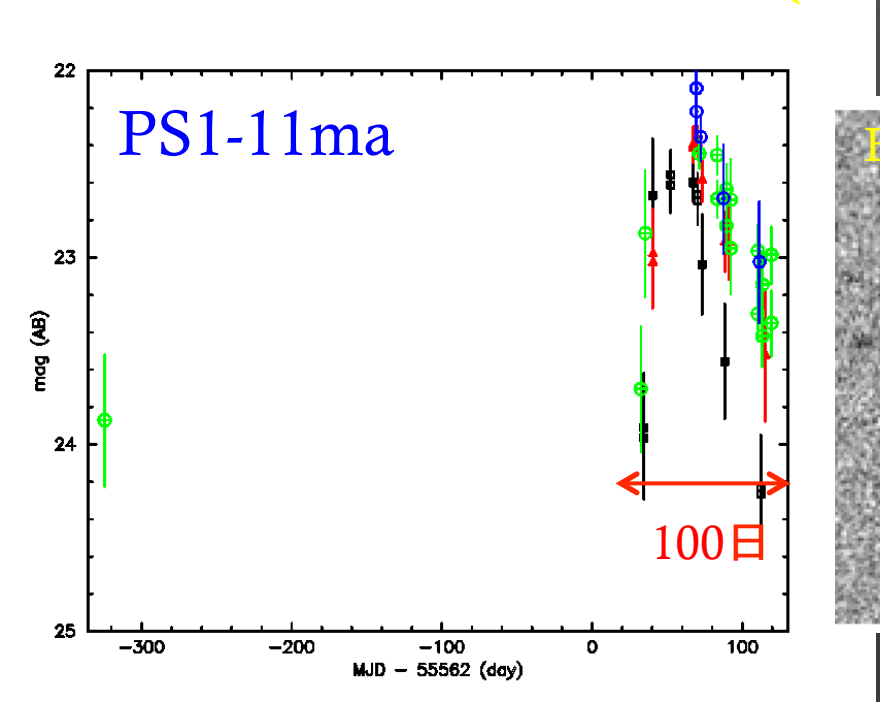
Pan-STARRS1 未同定突発天体の母銀河探査

- Pan-STARRS 100-150 突発天体/月 (分光ID~10%)

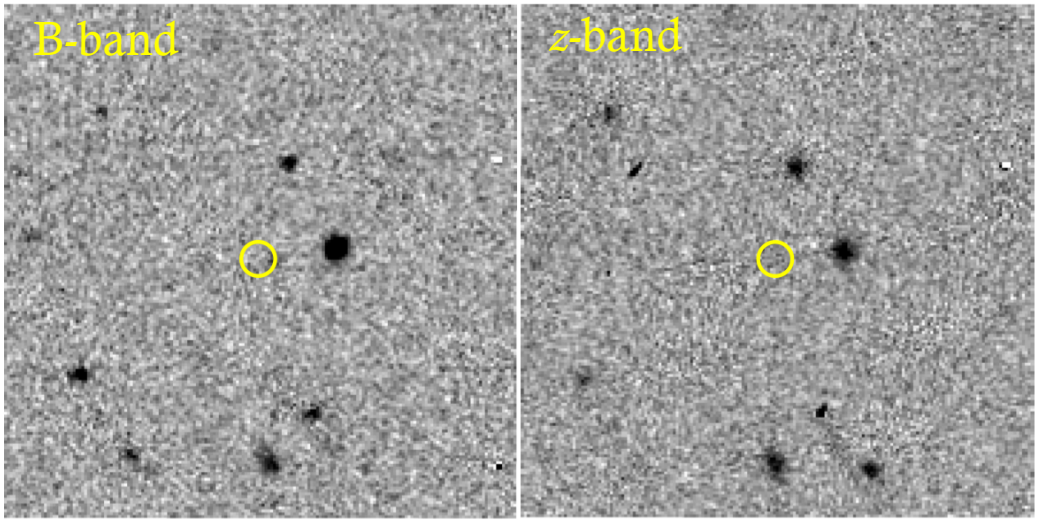
- Pan-STARRS1 MDS は、すばるのDeep pre-imagingが豊富

結構似たような天体がたくさん?! 暗い(>24 mag) 母銀河 、ゆっくりな時間発展）

PS1-MD04(= COSMOS) 33 天体（2.5年）



すばる Suprime-Cam Deep imaging



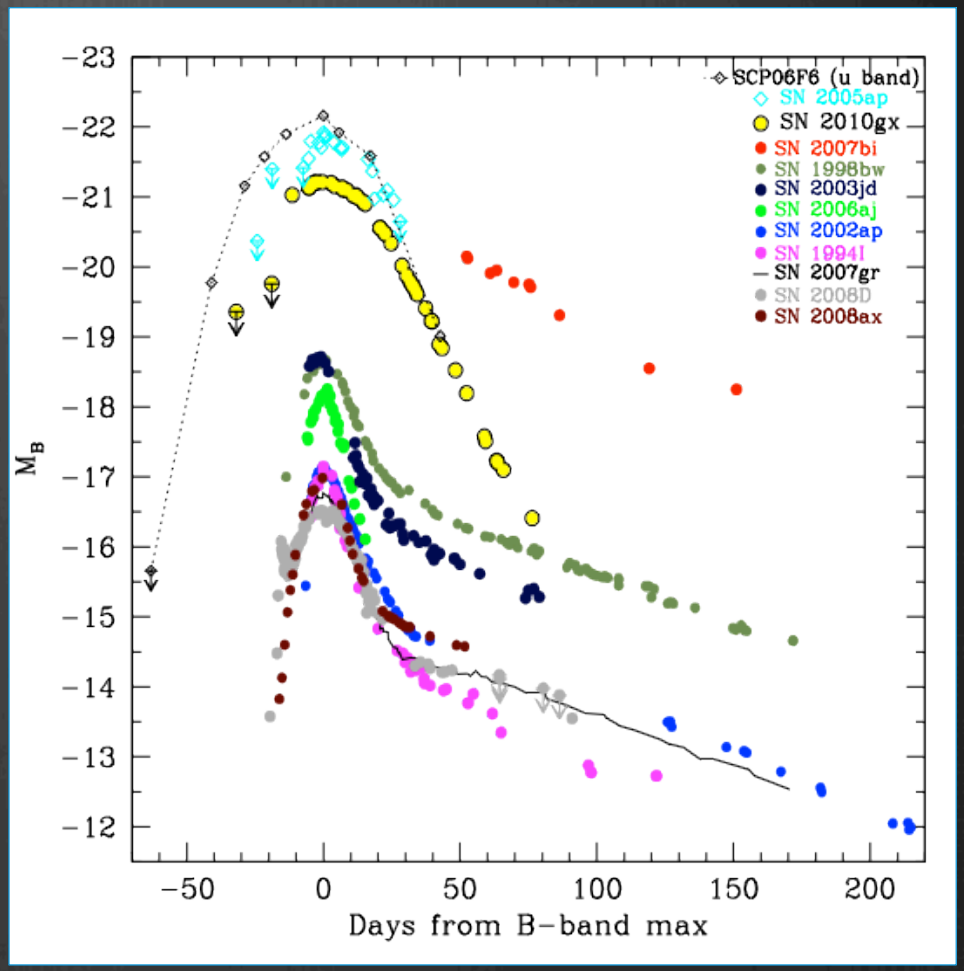
突発天体の可視光の分光観測があると良いが。。。

- 4つのPS1 MDS fields と HSCのDeep/UD fieldは、同じ。

9年(Pan-STAARS1 4 年 + すばる 5 年)のモニター観測

Ultra-Luminous Supernova

- New category of transient discovered in 2006 (SCP06F6)
- Peak absolute magnitude nearly -22 mag!
- Slow light curve evolution
- Brighter than -21 mag for ~100 days
- Host less/faint (probably metal poor host)
- Some are related with some kind of supernova
- Recent optical surveys (e.g. PanSTARRS, PTF) are finding many!



Pastorello et al. 2010 ApJL 724, 16

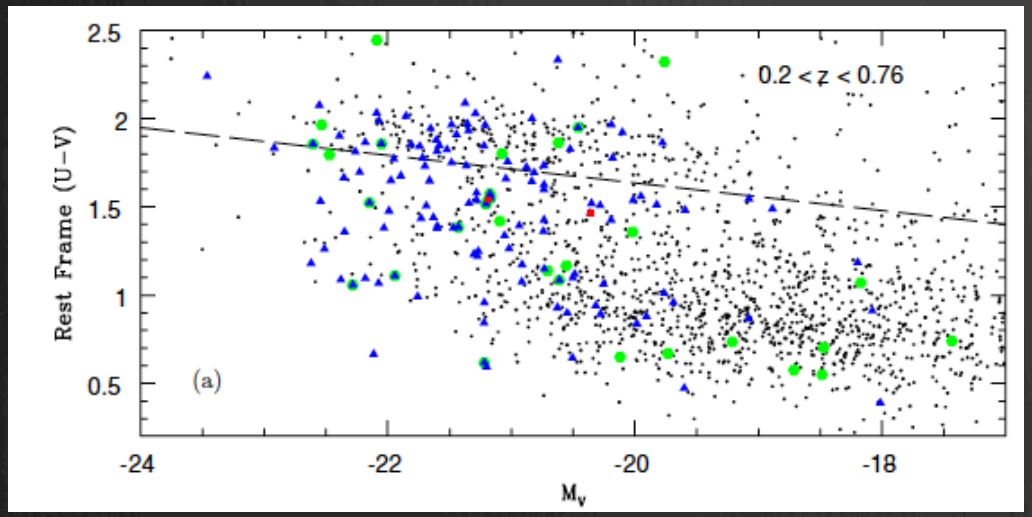
諸隈さんのPPT

Variable AGNの可能性

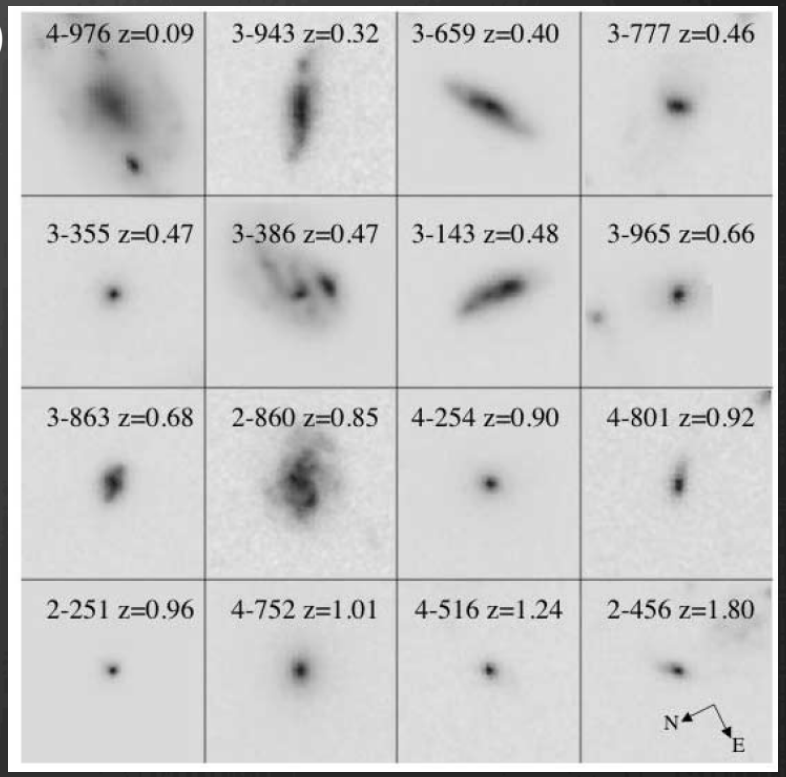
- HST studies @ CDF-South (Sarajedini+2003,2006,2010, Cohen+2006, [Trevese +2008], [Villforth+2010,2012])
- Subaru study @ SXDS (TM+2008b, Morimoto+2012 in prep.)

- 1% of galaxy cores show variability (months to years)
- several tens % are undetected in X-ray (XMM, Chandra)
- variability-selected AGN exist everywhere in CM diagram
- low-L AGN in bright galaxies
- no clear environmental dependence (Villforth+2012)

Villforth+2012



Sarajedini+2003



variability-selected AGN / X-ray sources

まとめ

- すばる Hyper-Suprime-Cam を用いた突発天体探査を準備中
- Orphan GRB afterglowをはじめて発見できる可能性大
- 既にあるすばるのdeep observationsからいくつかの新種の突発天体を発見
  - Unusual Long & Luminous event SDF-05M05を発見
  - 特異なSNIInと相違 (新種の突発天体の可能性も)
  - High-z ULSN candidates
- Pan-STARRS1 と すばる(SC/HSC)で新たな発見の可能性
- 日本を中心にLSSTよりもはるかに先に、突発天体の探査を行える！
- 将来的には、すばる/HSC + 30m telescopesの連携