Swift+HETE 時代の
ガンマ線バースト研究

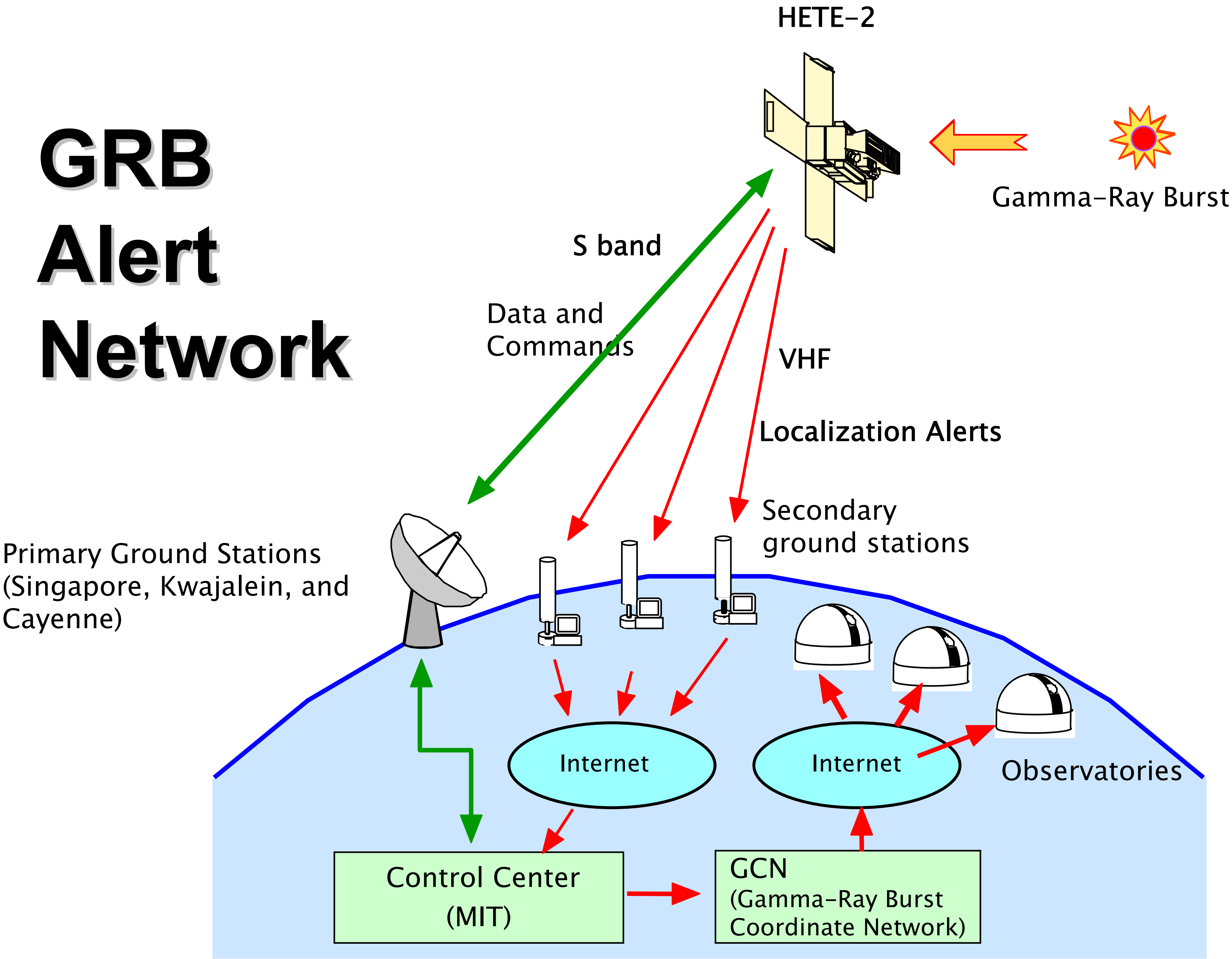
河合 誠之（東工大理）

- Long GRB ~超新星/Collapsar
- 標準光源: 宇宙論パラメータ
- 最初の3時間
- 短いGRB (magnetar flare or NS merger?)
- 高赤方偏移GRB

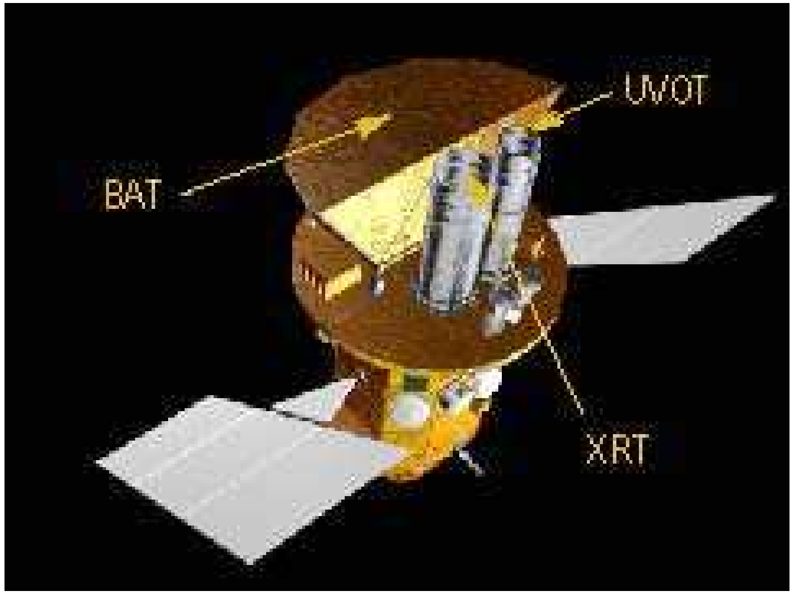
2005: Exciting Year

- 2004/12/27 Giant Flare of SGR 1806-20
  - Geotail, NMA (野辺山ミリ波干渉計)
- Short GRB: 050509B, 050709, 050724
  - Swift, HETE-2, Subaru, HST, etc.
- Most distant GRB 050904 at z=6.3
  - Swift, Subaru

GRB Alert Network



Swift

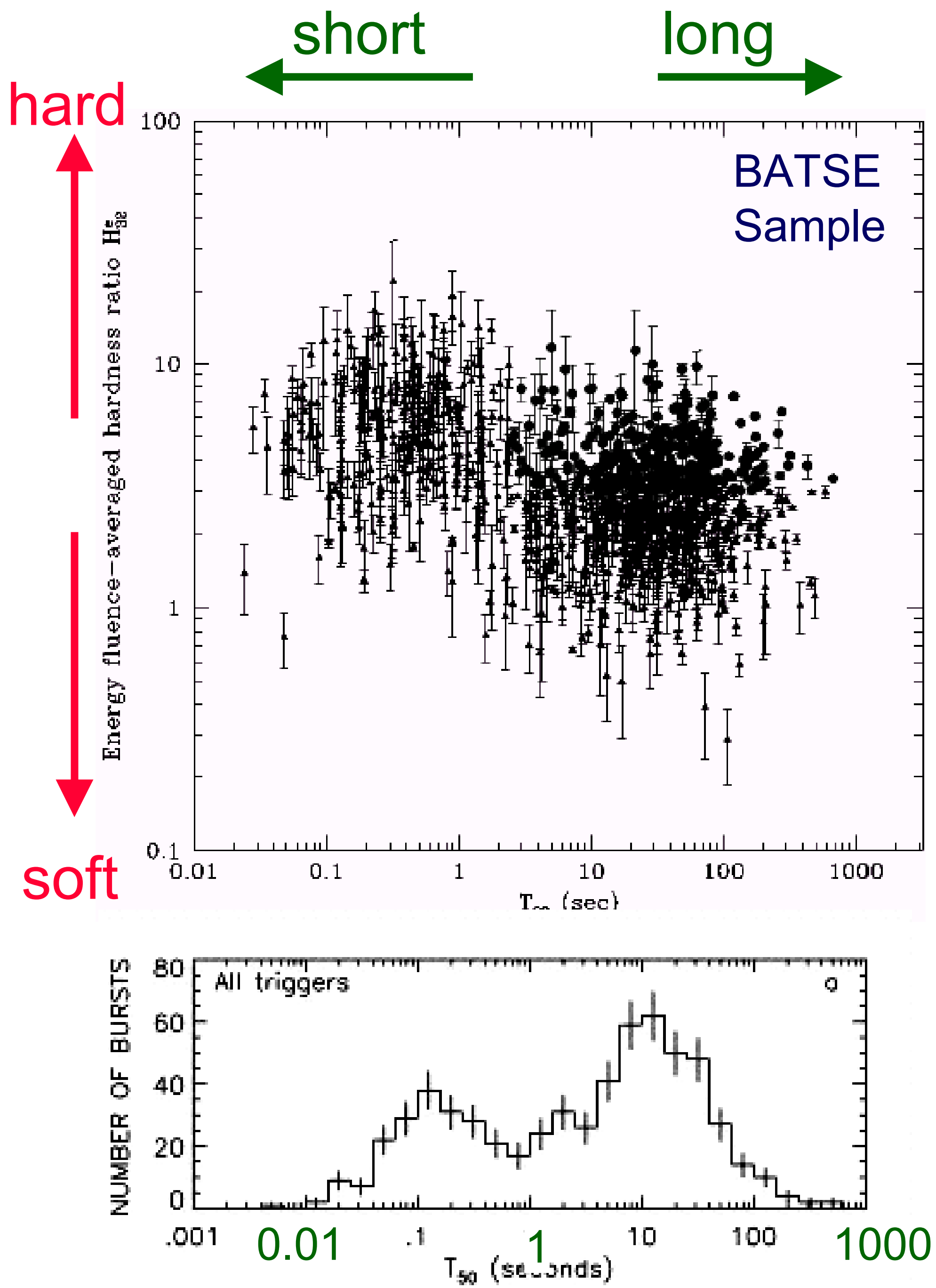


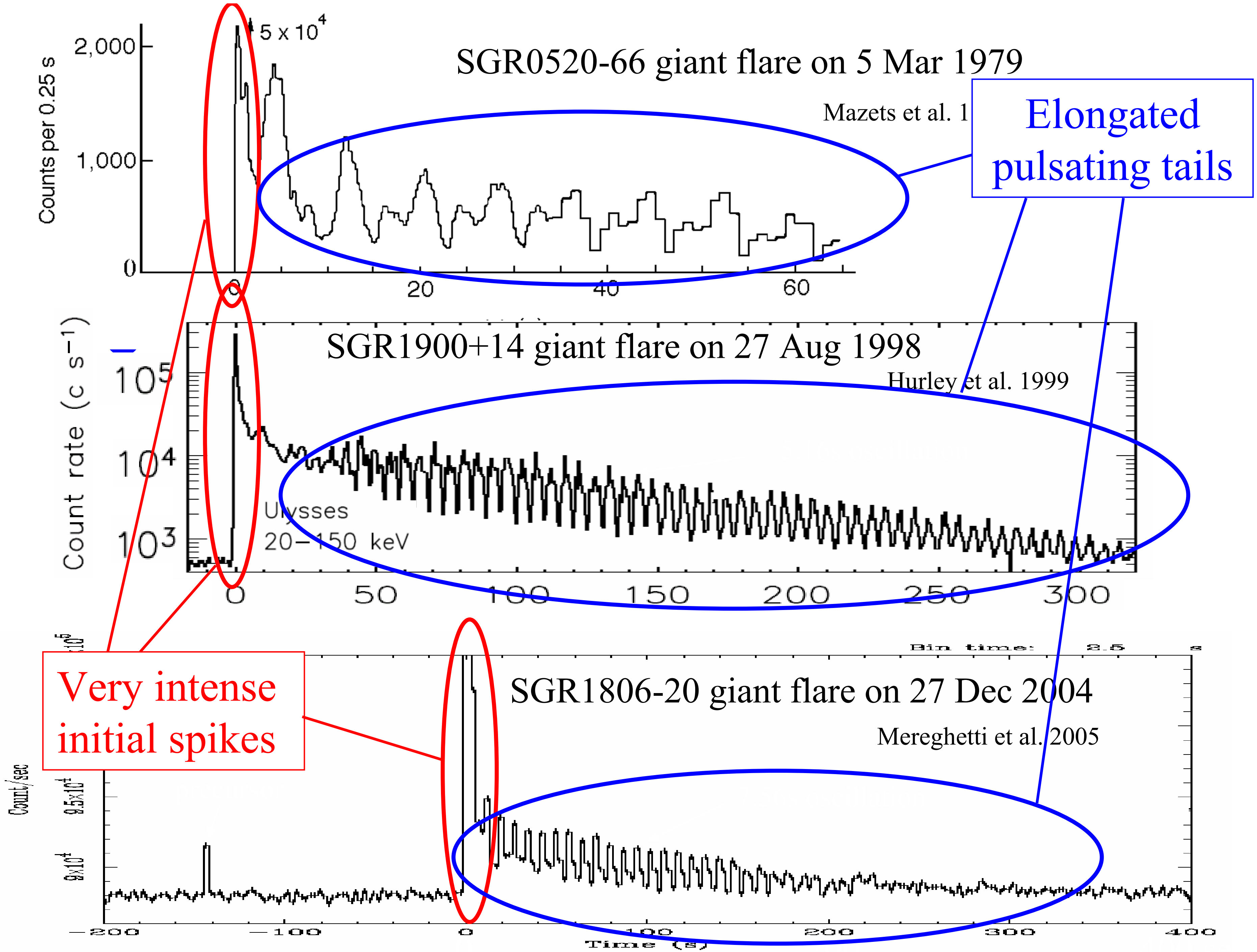
- 史上最強のγ線バーストミッション
- 2004年11月打上〜 (+3 years)
- 〜100 GRB observations/year
- バースト検出＋X線･光学追跡
- ほとんどのGRBにX線残光 → 追跡観測
- 弱点 : 狭いバンド幅 (15-150 keV): E_{peak}決定が難しい
  - Cf. HETE-2 : 2-400 keV

Short Hard GRB
--- Merger???

Short-hard GRBs

- No optical counterpart
- Origin
  - Neutron star merger?
  - Magnetar flare?
  - Supernova?

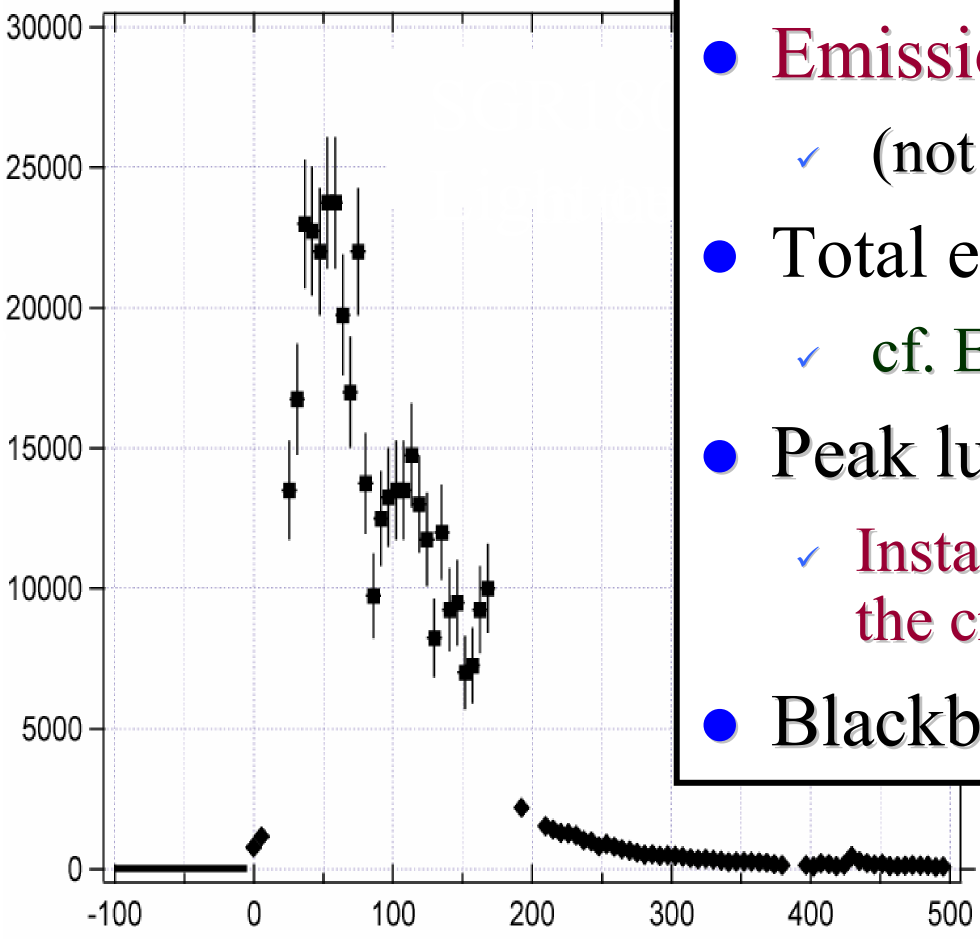




SGR0520-66 giant flare on 5 Mar 1979
Mazets et al. 1
Counts per 0.25 s
2,000
1,000
0
5 x 10^4
0
20
40
60
Elongated pulsating tails
SGR1900+14 giant flare on 27 Aug 1998
Hurley et al. 1999
Count rate (c s−1)
10^5
10^4
10^3
Ulysses
20−150 keV
0
50
100
150
200
250
300
SGR1806-20 giant flare on 27 Dec 2004
Mereghetti et al. 2005
Bin time: 2.5 s
Count/sec
9.5x10^4
9x10^4
−200
−100
0
100
200
300
400
Time (s)
Very intense initial spikes

Giant flare of SGR1806-20 on Dec 27, 2004

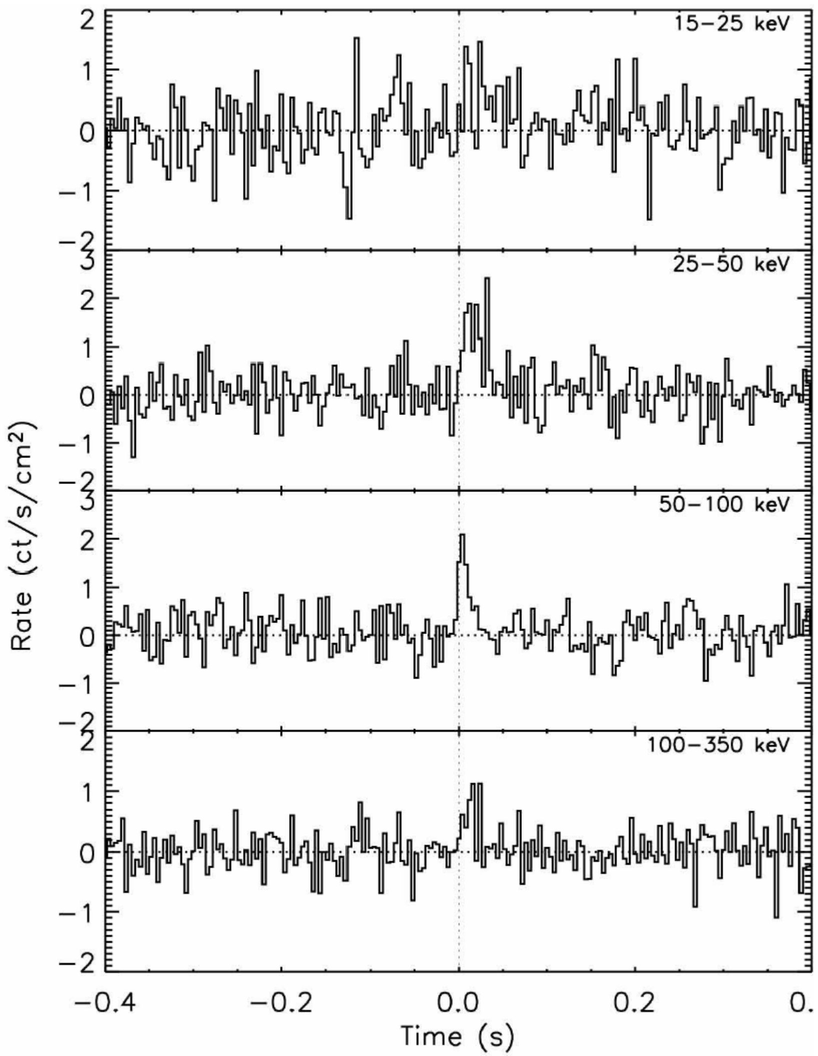
Geotail LEP



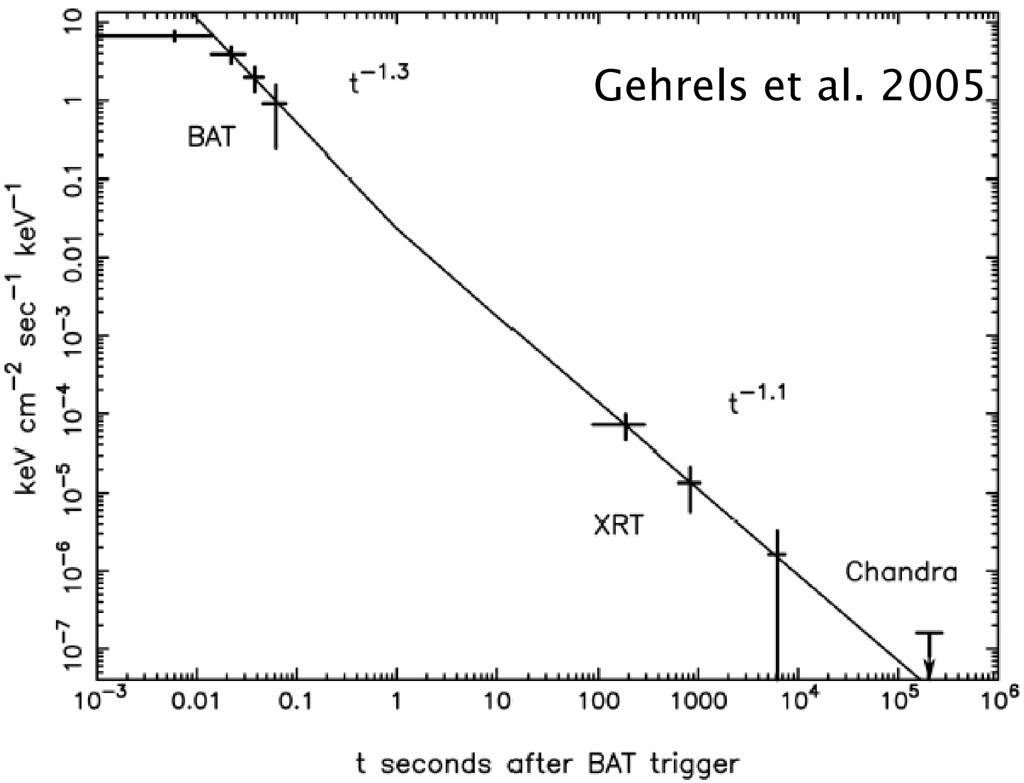
msec after the onset

- Oscillatory tail: $E_{tail} \sim 10^{44}$ erg
  - ✓ Similar for three giant flares
- Emission almost isotropic
  - ✓ (not collimated unlike GRBs)
- Total energy: 3×10^{46} erg
  - ✓ cf. $E_{mag} = 1.7 \times 10^{47} B_{15}^{2} R_{6}^{3}$ erg
- Peak luminosity: 3×10^{47} erg/s
  - ✓ Instant release of magnetic twist in the crust (???)
- Blackbody, kT=175 keV

GRB 050509B detected by Swift

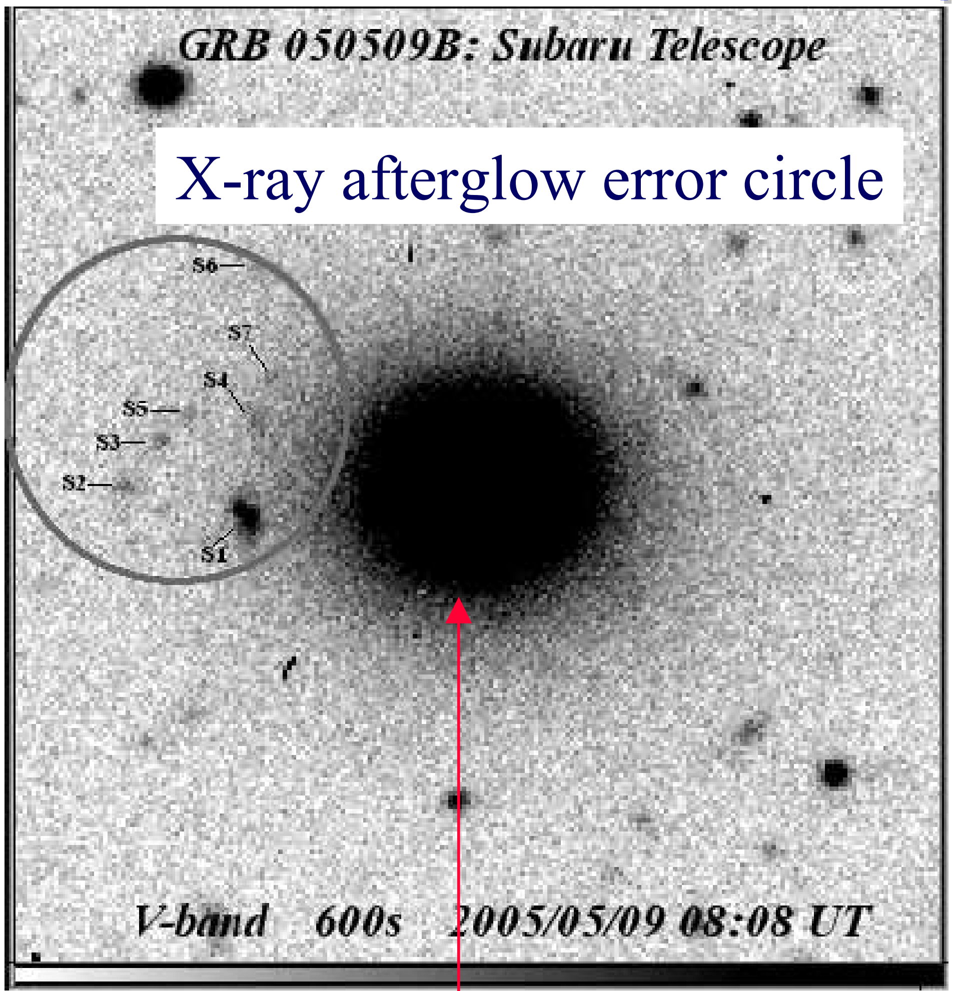


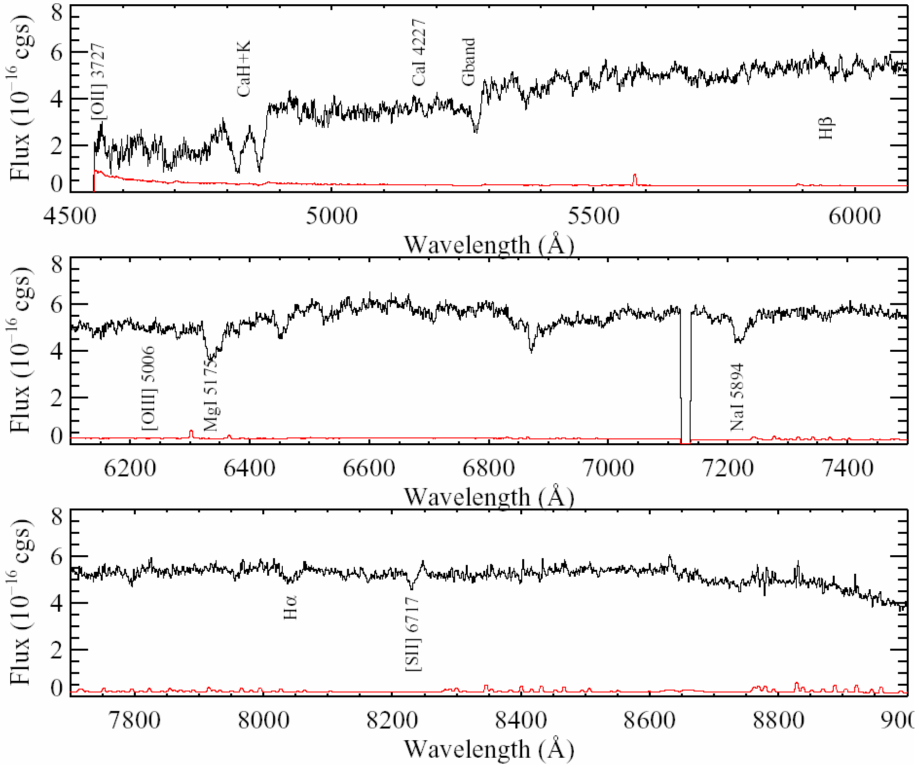
Gehrels et al. 2005



First detection of X-ray afterglow from short GRB

Association with an elliptical galaxy at z=0.225: possible, but not definite





z=0.225 $L_{H\alpha} < 1.2 \times 10^{40}$ erg s^{-1}

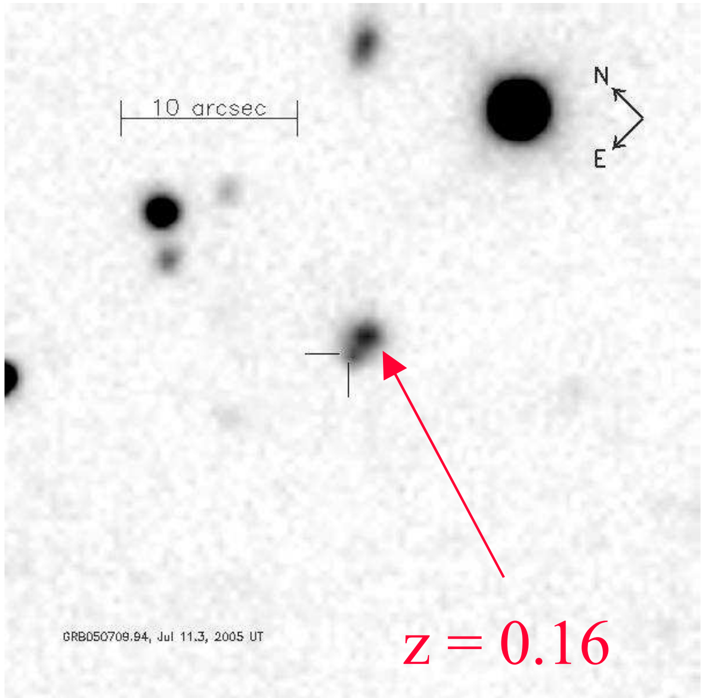
Ellipical galaxy

SFR < 0.1 M_{sun}/yr

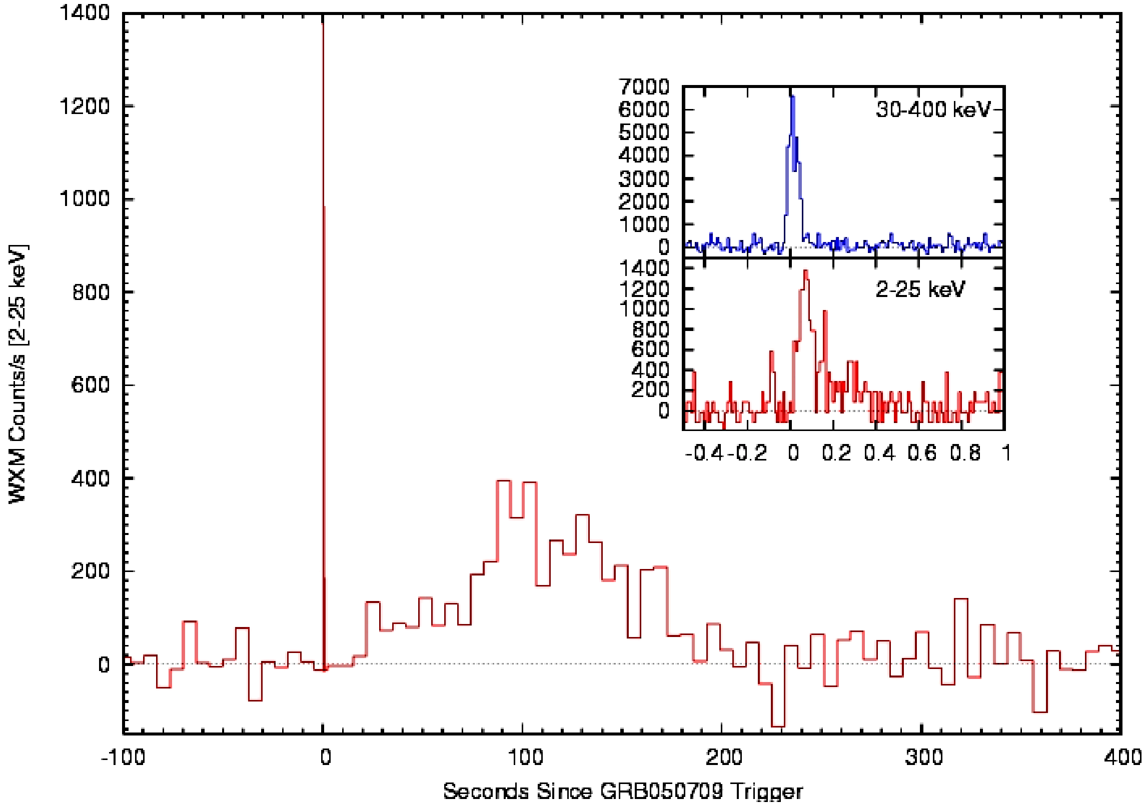
S-Cam (Kosugi, Takada, Furusawa, Kawai)

Bloom et al. 2005

GRB050709 localized by HETE-2



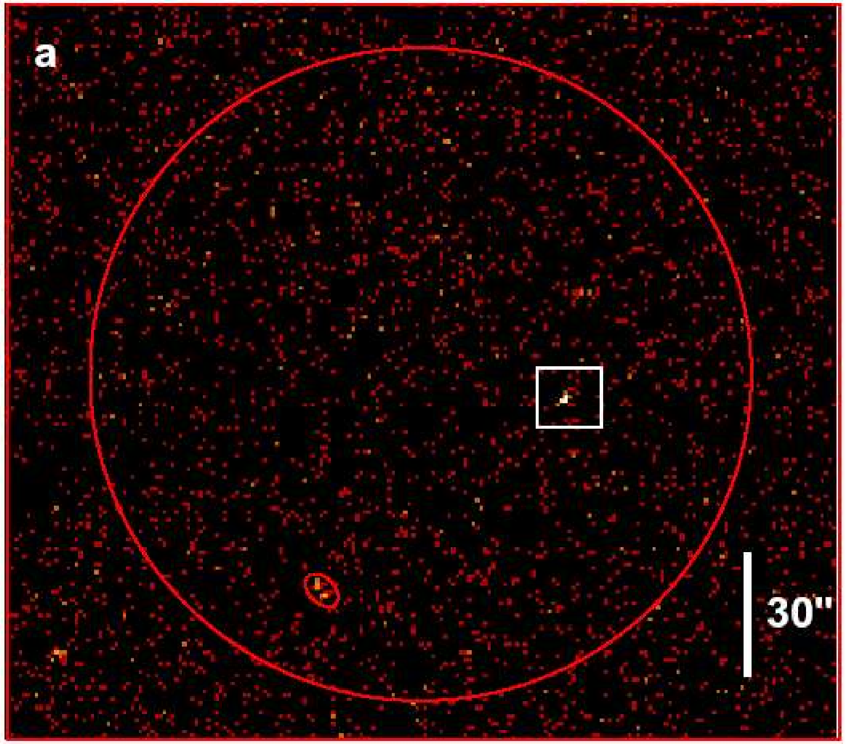
X-ray afterglow candidate



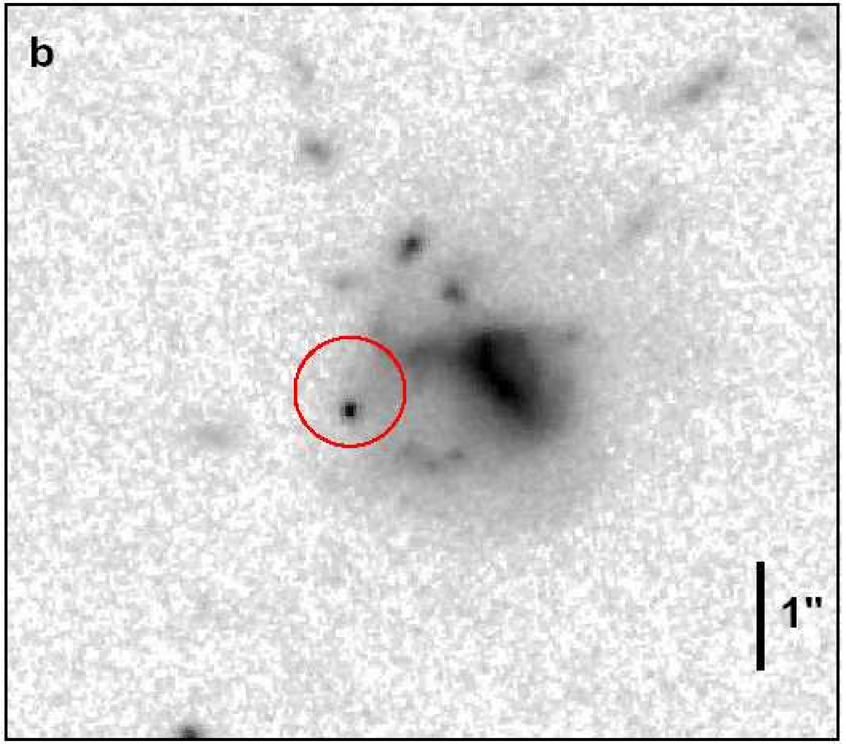
CISCO (Kosugi, Aoki, Kawai, …)

GRB 050709: 位置決定、X線残光と可視光残光

Fox et al. 2005



Chandra

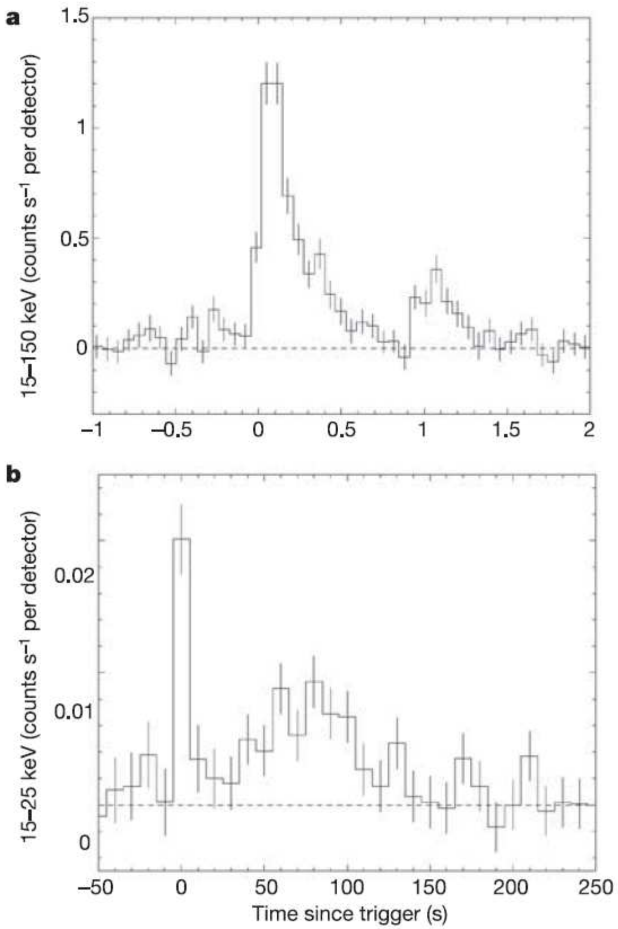


HST

z=0.160
Dwarf irregular galaxy
SFR = 0.2 M_{sun}/yr

GRB050724 localized by Swift

Barthelmy et al. 2005



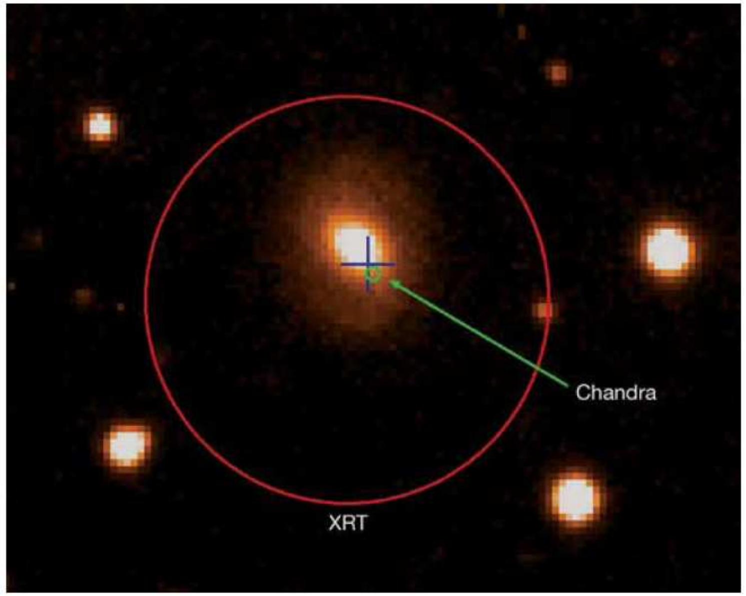
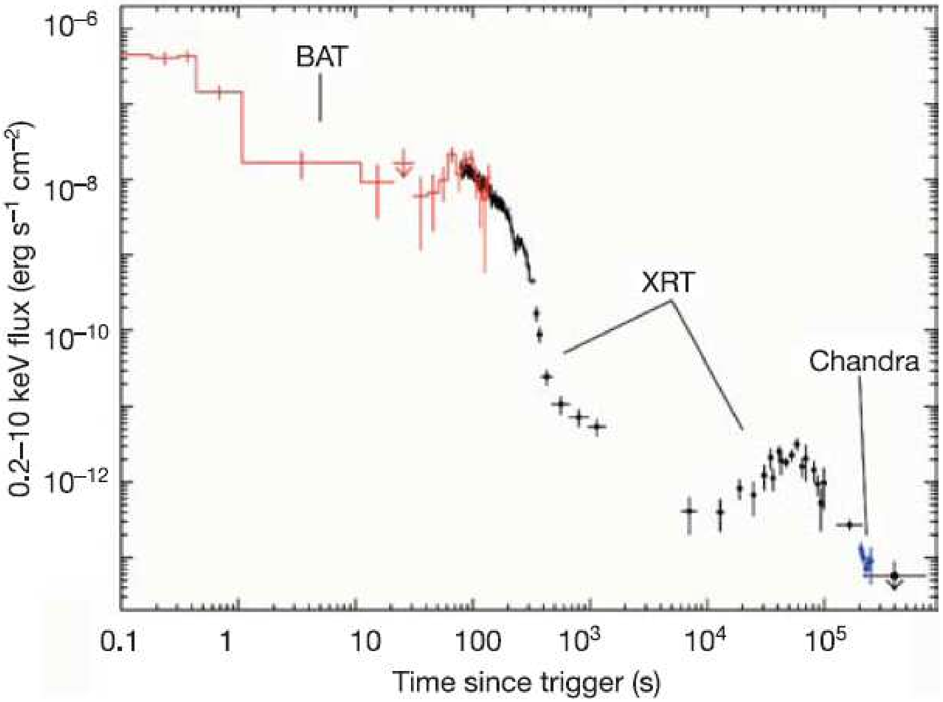


Figure 2 | VLT optical image[17] showing the association of GRB 050724 with the galaxy. The blue cross is the position of the optical transient[16,17] The XRT (red circle) and Chandra (green circle) burst positions are superimposed on a bright red galaxy at redshift $z = 0.258$ (ref. 5), implying low-redshift elliptical galaxy as the host. The XRT position has been furthe revised from the position of ref. 15 by astrometric comparison with object in the field. The projected offset from the centre of the galaxy corresponds t $\sim$4 kpc assuming the standard cosmology with $H_0 = 71\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ an $(\Omega_M, \Omega_\Lambda) = (0.27, 0.73)$.

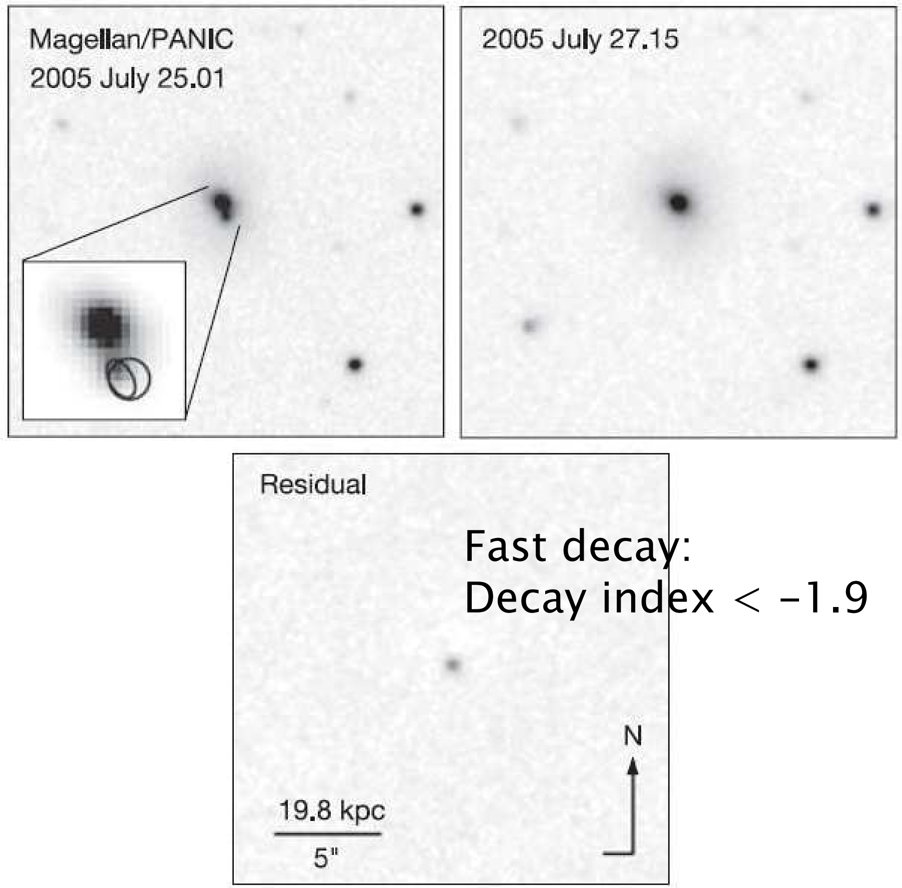
GRB 050724 afterglow

z=0.257
Ellipical galaxy
SFR < 0.02 M_{sun}/yr

Berger et al. 2005



Barthelmy et al. 2005



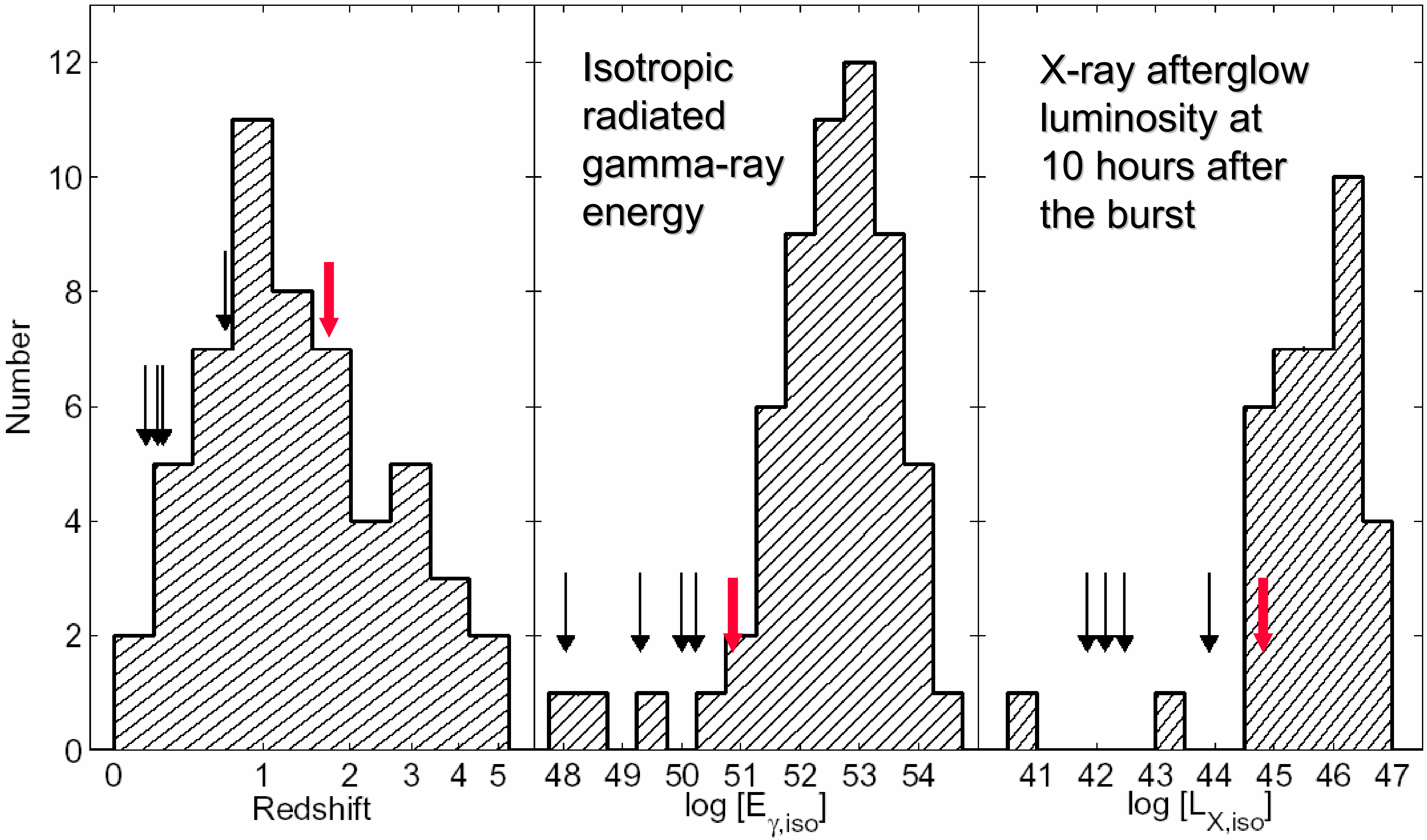
Fast decay:
Decay index < -1.9

ıre 1 | Near-infrared *K*-band images of the afterglow and host galaxy

距離が既知のγ線バーストの赤方偏移と放射エネルギーの分布

（矢印：短いバースト）

Fox et al. 2005



ガンマ線バーストの起源
モデルとの比較

	仕組み	年齢	発生場所	継続時間
コラプサー	大質量星の最期の重力崩壊による大爆発	若い星（数百万年以下）	星形成領域	>10秒
マグネターのフレア	超強磁場中性子星の星全体規模の巨大地震	若い星（数千万年以下）	星形成領域付近	<1秒
高密度星の合体	古い中性子星またはブラックホールの連星の軌道縮小による衝突	古い星（数千万年～数十億年以上）	星形成と無関係:銀河の重力圏内どこでも	<1秒

ガンマ線バーストの起源
モデルとの比較　長いバースト

	仕組み	年齢	発生場所	継続時間
コラプサー	大質量星の最期の重力崩壊による大爆発	若い星（数百万年以下）	星形成領域	>10秒
マグネターのフレア	超強磁場中性子星の星全体規模の巨大地震	若い星（数千万年以下）	星形成領域付近	<1秒
高密度星の合体	古い中性子星またはブラックホールの連星の軌道縮小による衝突	古い星（数千万年～数十億年以上）	星形成と無関係：銀河の重力圏内どこでも	<1秒

ガンマ線バーストの起源
モデルとの比較　短いバースト

	仕組み	年齢	発生場所	継続時間
~~コラプサー~~	大質量星の最期の重力崩壊による大爆発	~~若い星（数百万年以下）~~	~~星形成領域~~	~~>10秒~~
~~マグネターのフレア~~	超強磁場中性子星の星全体規模の巨大地震	~~若い星（数千万年以下）~~	~~星形成領域付近~~	<1秒
高密度星の合体	古い中性子星またはブラックホールの連星の軌道縮小による衝突	古い星（数千万年～数十億年以上）	星形成と無関係:銀河の重力圏内どこでも	<1秒

Localized short GRB in 2005

GRB	T90 (s)	log Flu.	X AG	Opt	Redshift	Host
050509B	0.04	-7.9	**Yes**		0.225 (?)	elliptical?
050709 (HETE)	0.07	-6.4	**Yes**	**Yes**	0.16	SF irr.
050724	3	-5.9	**Yes**	**Yes**	0.257	elliptical
050813	0.6	-7.4	n/a		1.8/0.72?	
050815	2.8	-7.0	**Yes**			
050906	0.13	-8.1	<8e-14		130Mpc ?	IC328?
050925	0.07	-7.1	<3e-14			
051105A	0.28	-7.7	?			
051103 (IPN)	0.17	-4.6	n/a		4Mpc (?)	M81?
051114	2.2	-6.9	<2e-14			
051210	1.4	-7.1	**Yes**			
051221A	1.4	-5.9	n/a	**Yes**	0.547	SFG

Correlation of short GRBs with nearby galaxies

Tanvir et al. 2005

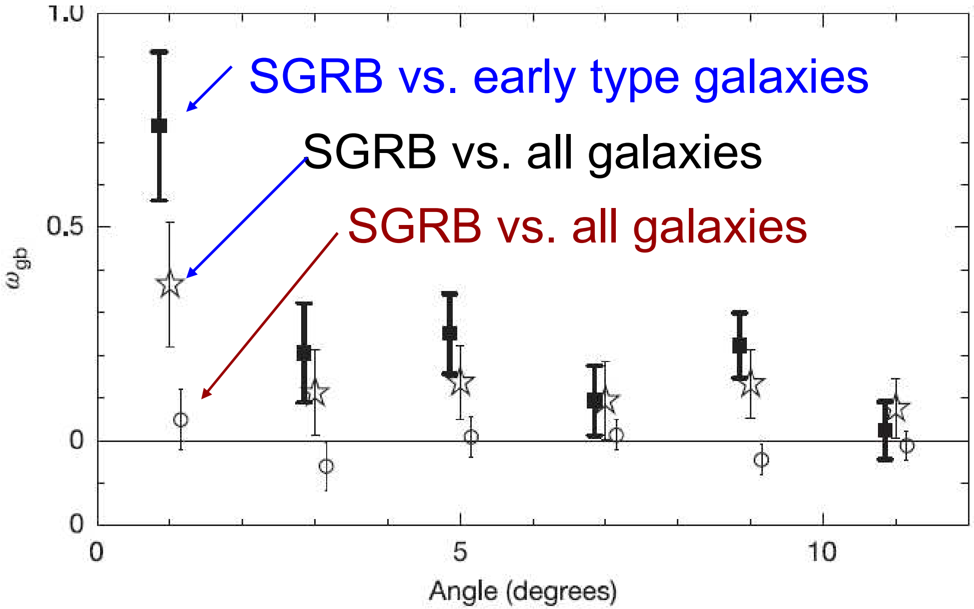
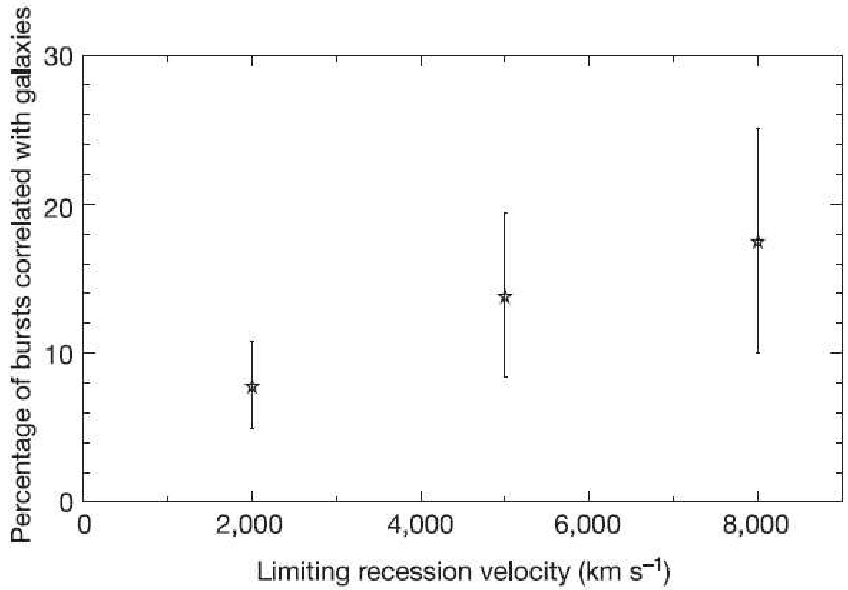


Figure 1 | Angular cross-correlation functions for BATSE short bursts with nearby galaxies from the PSCz catalogue. Two-point angular correlation functions, ω_{gb} (in two-degree bins), are shown for 400 BATSE short bursts ($T_{90} < 2$ s and statistical position uncertainty $\leq$10 degrees) with nearby galaxies from the PSCz catalogue (recession velocities $v \leq 2{,}000$ km s^{-1} $\approx$ 28 Mpc distant). Filled circles show the correlation with



igure 3 | The percentage of correlated bursts with increasing edshift. This figure shows the results of repeating the analysis of Fig. 2

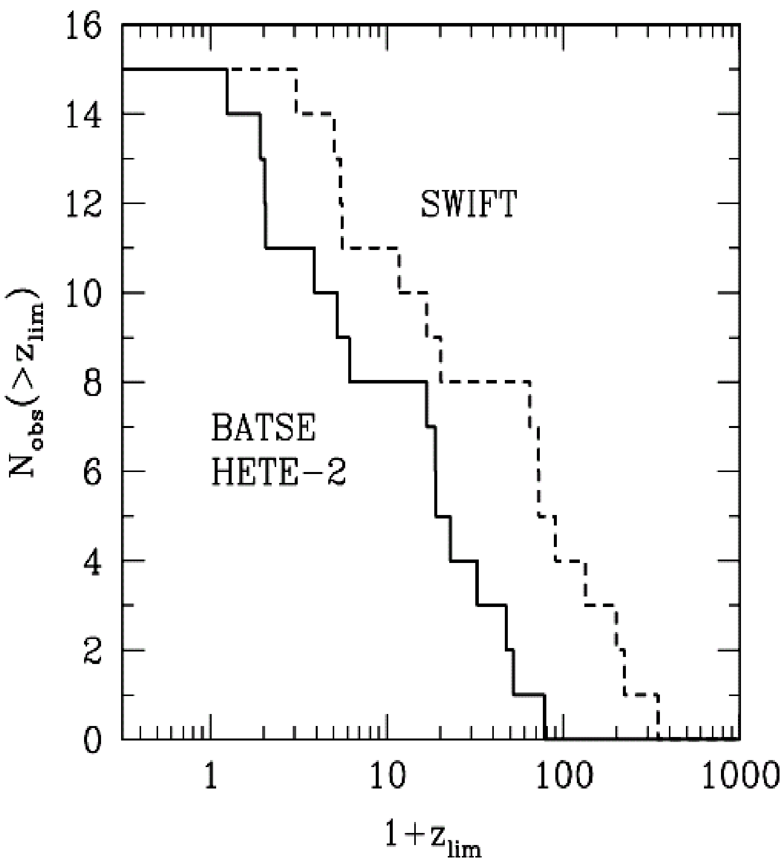
Summary of short GRB study

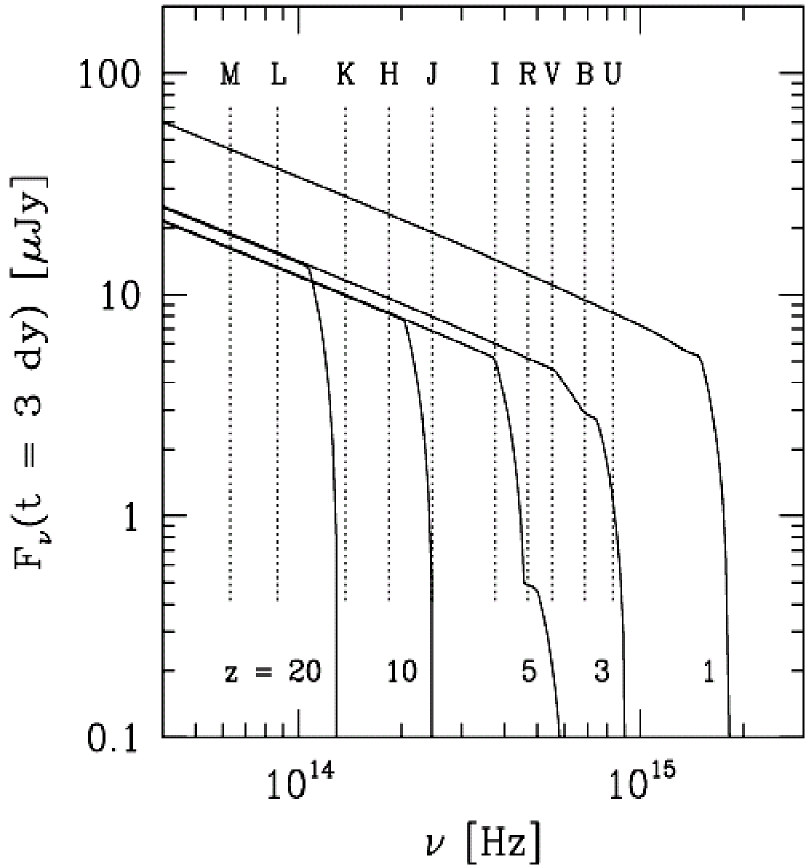
- Association with early-type galaxies and star-forming galaxies
- Energy scale smaller than long GRBs
- Distant scale smaller (but …)
- Upper limits for supernovae
- Likely a mixed bag
  - ✓ NS-NS/BH merger (gravitational wave)
  - ✓ Magnetar flare (oscillating tail)
  - ✓ Collapsar (supernova)
  - ✓ Accretion-induced collapse (?)

高赤方偏移のGRBは~~見える~~

見えた

Detectability of High-z GRB





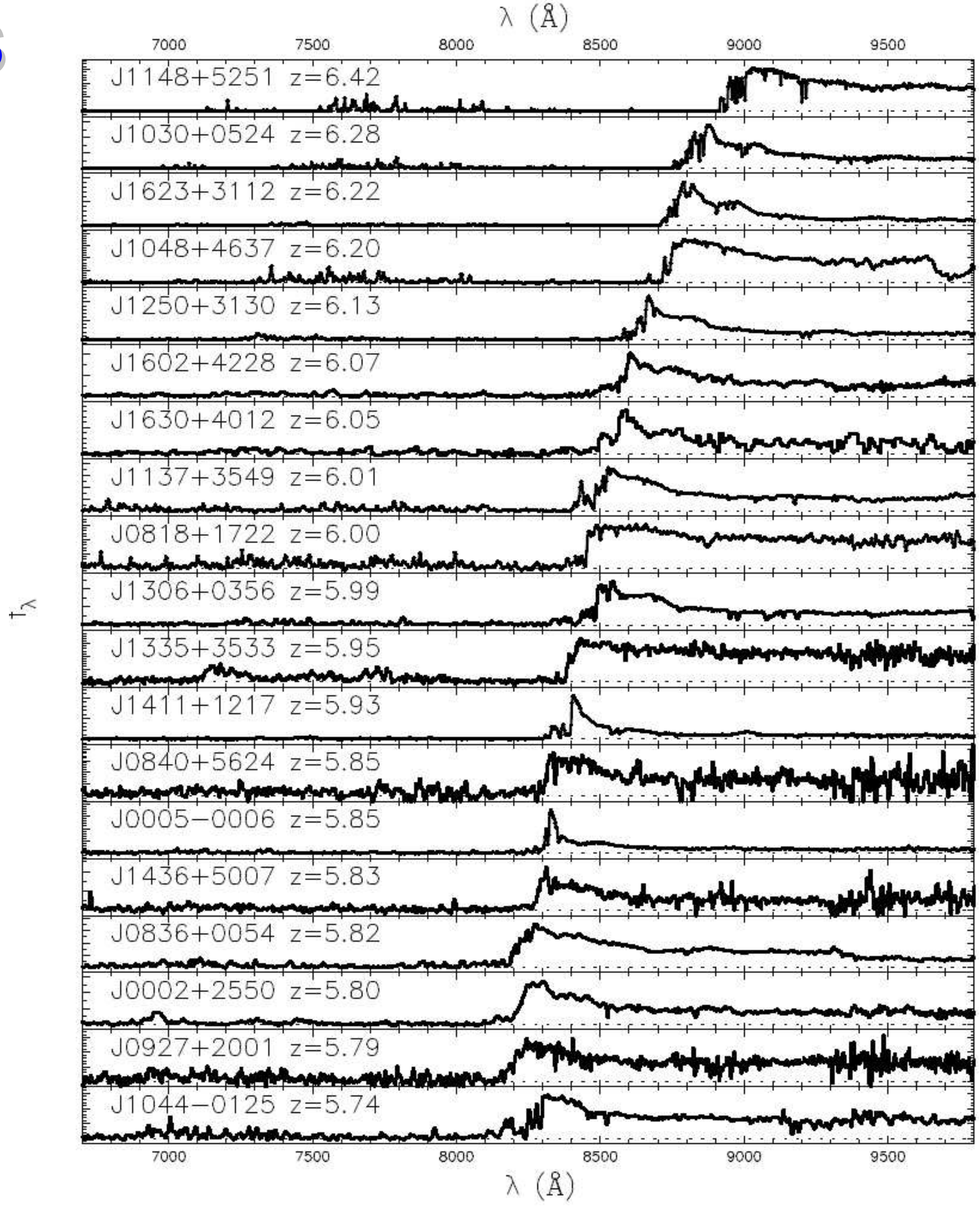
15 GRBs with well-determined redshifts

early afterglow of GRB 000131,

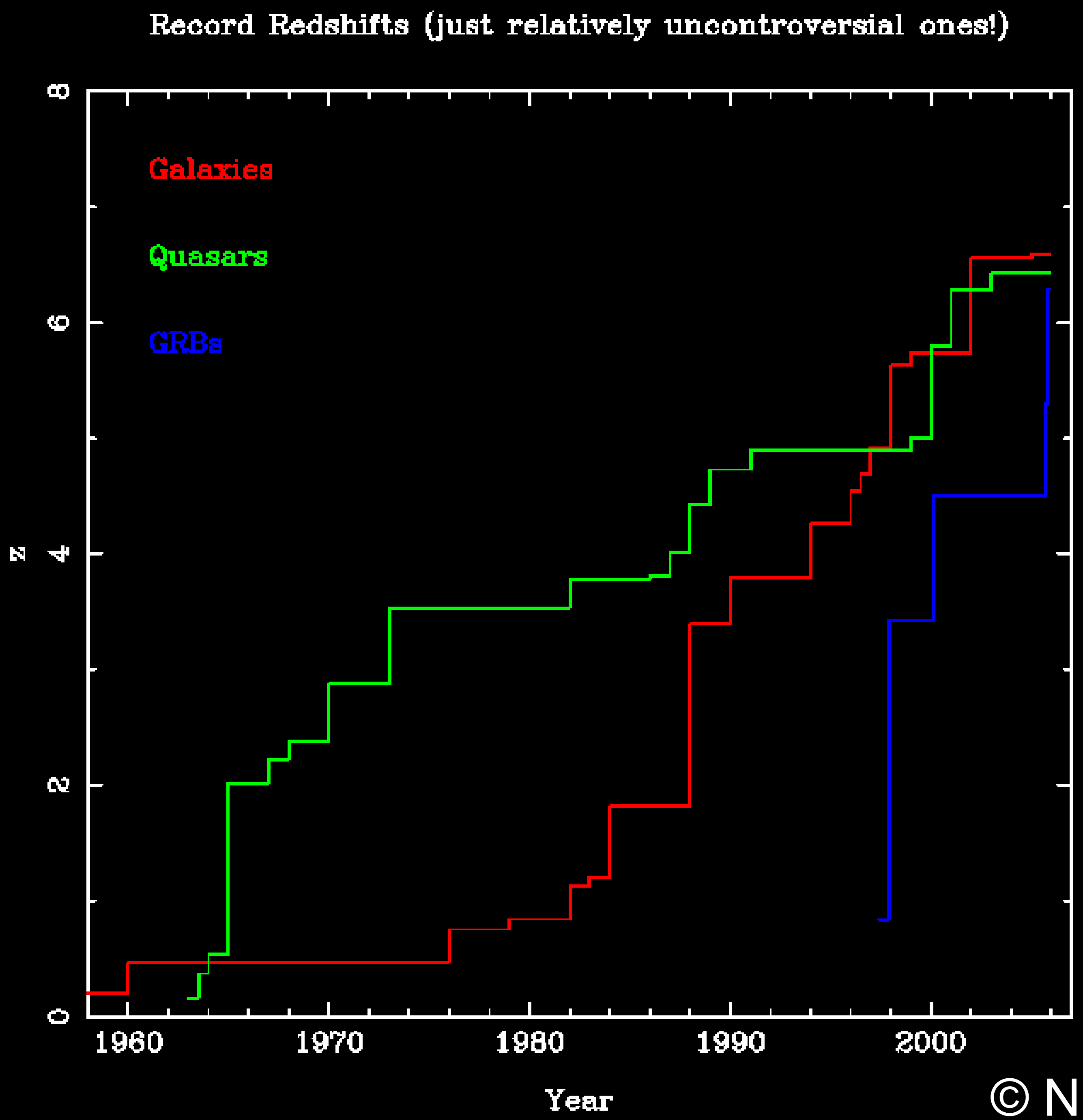
as observed one day after the burst

Lamb and Reichart 2001

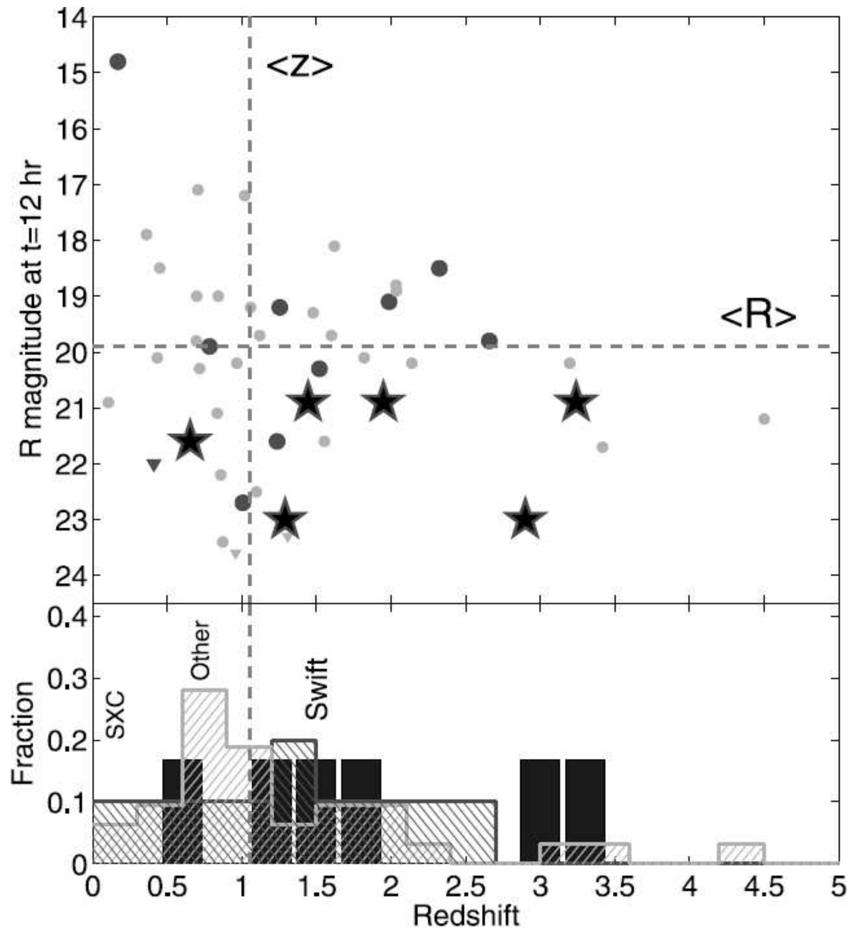
High-z quasars are difficult to find: 19 SDSS quasars with z>5.7



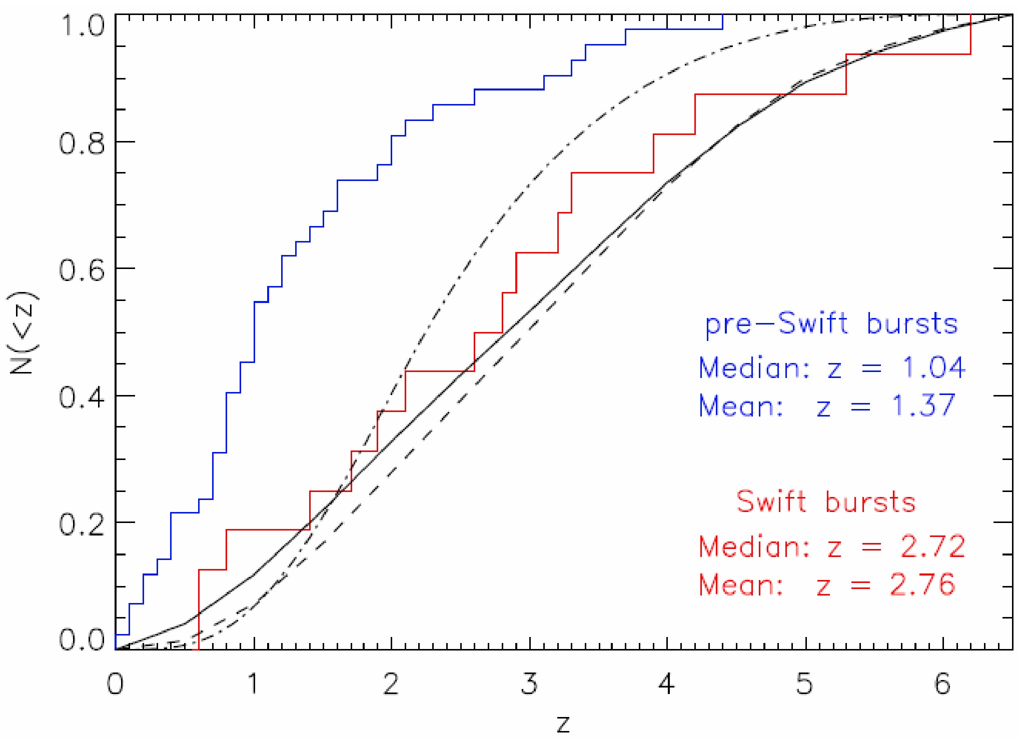
Fan et al. 2005


Record Redshifts (just relatively uncontroversial ones!)
Galaxies
Quasars
GRBs
z
0
2
4
6
8
1960
1970
1980
1990
2000
Year

Swift GRBs: fainter and more distant



Berger et al. 2005



Jacobsson et al. 2005

Subaru spectroscopy of the afterglow of GRB050904

GRB000131 previous record: z=4.50

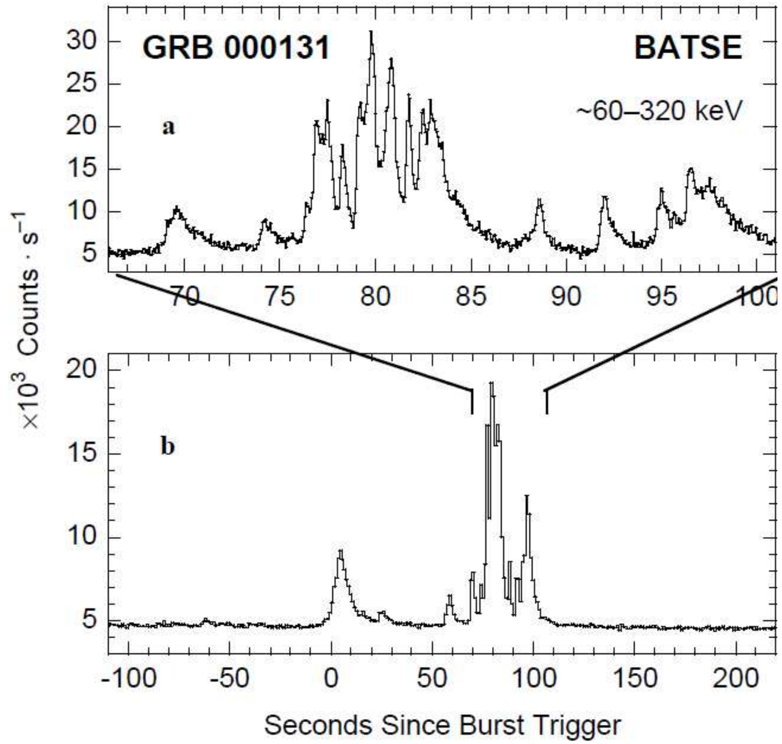


Table 1. Spectral data from BATSE

Peak Flux: 7.89 ± 0.08 ph cm^{-2} s^{-1} (46–313 keV; 1.024 s)

Fluence: $(3.51 \pm 0.08)\ 10^{-5}$ erg cm^{-2} (26–1800 keV; 137 s)

Duration: T90 = 96.3 s (error 1 s)

T50 = 30.7 s (error 1 s)

Time-averaged Epeak = 163 ± 13 keV

spectral Low-energy index = -1.2 ± 0.1

parameters: High-energy index = -2.4 ± 0.1

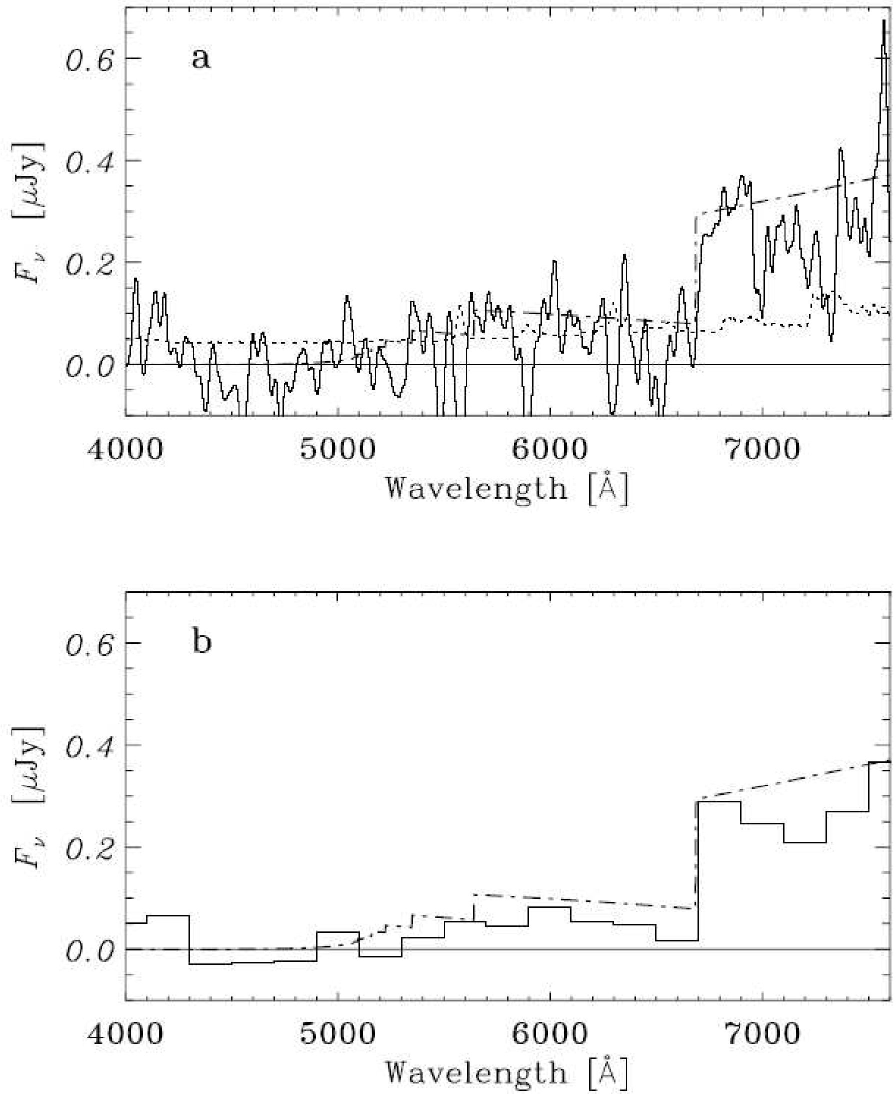


Fig. 6a and b. The spectrum of the GRB 000131 afterglow: **a** smoothe to a resolution of 30 Å, **b** rebinned to a resolution of 200 Å. The dotte curve shows the noise per bin, while the dot-dashed line is the mod spectrum shown in Fig. 5.

Andersen et al. 2001

GRB 050904

- a long burst (T_{90} = 225 s) detected by Swift on 4 September 2005, 01:51:44 UT6. [Cummings et al., GCN 3910]

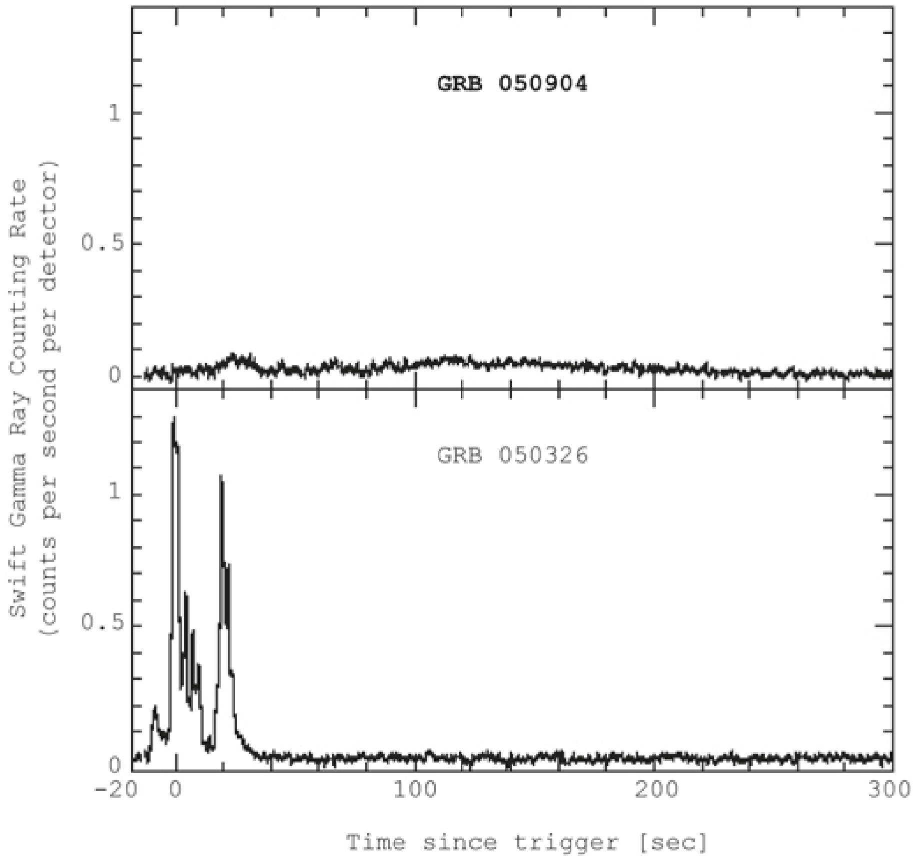
- High Redshift?
  - ✓ No detection in the optical band
  - ✓ relatively bright afterglow in the near infrared

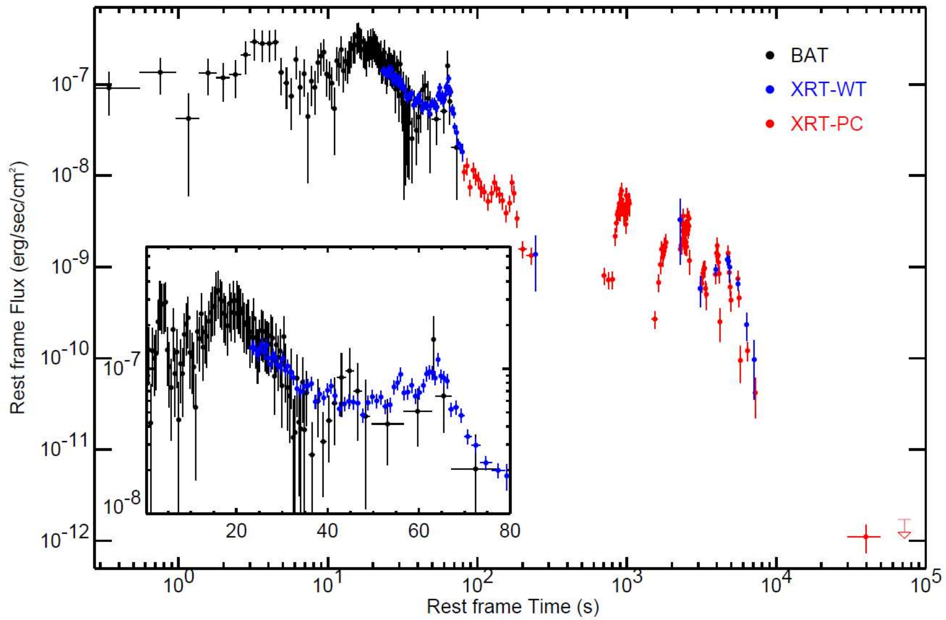
- Palomar 60” (t_0 + 3.5 hours):
  R>20.8 mag, I>19.7 mag [Fox and Cenko, GCN3912]
- SOAR (t_0 + 3 hours) J≈17.5 mag [Haislip et al GCN 3913.]
  → $5.3<z<9.0$ [Haislip et al. GCN 3914]
- ESO VLT (J,H,K,I)
  → $5.98<z<6.47$ [Antonelli et al. GCN 3924]

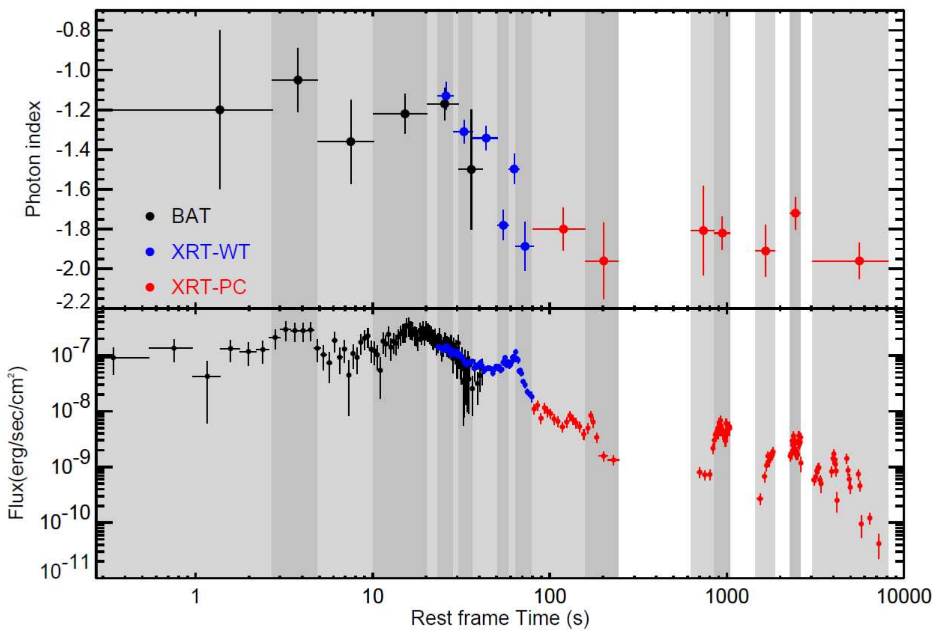
cf. previous record: $z=4.50$ [Andersen et al., (2000)]

Swift detection

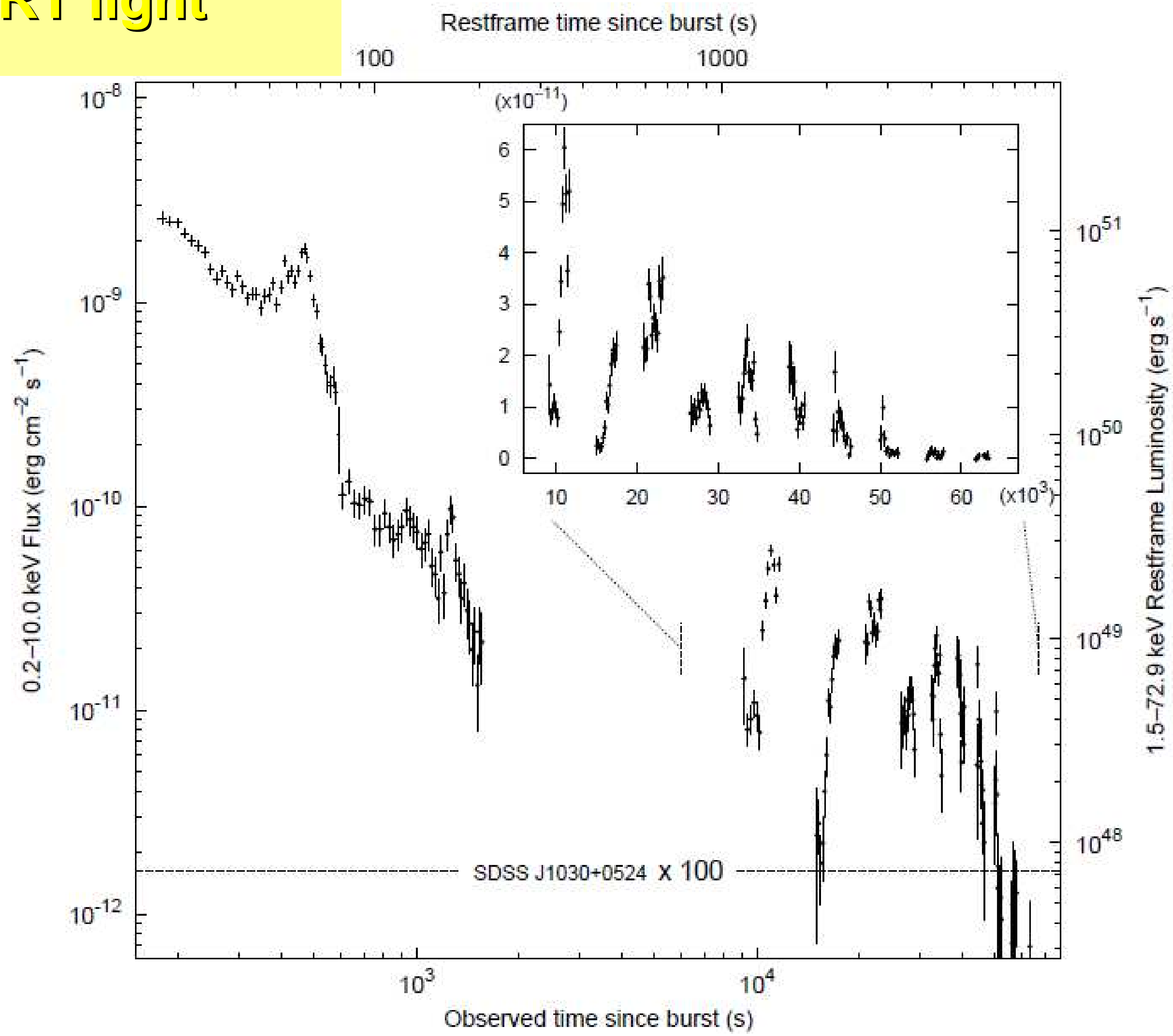
GRB 050904 GRB 050904 was a long burst (duration T90 = 225 s) detected by the Swift gamma-ray burst satellite on 4 September 2005, 01:51:44 UT6,







Swift XRT light curve



SOAR etc.: Haislip et al.astro-ph/0509660

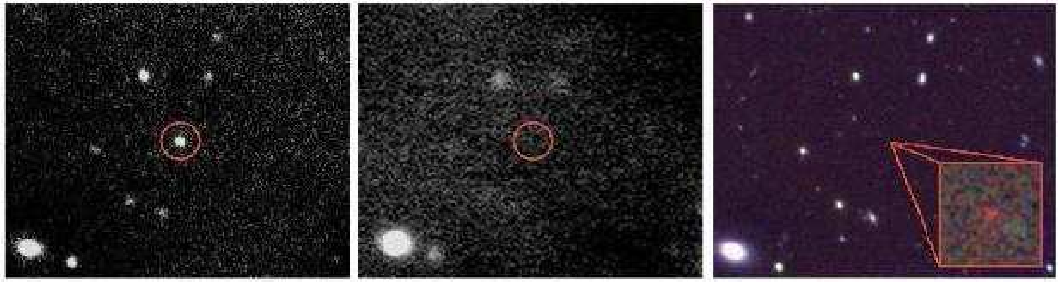


Figure 1. *Left panel:* NIR discovery image of the bright (J = 17.36 ± 0.04 mag) afterglow of GRB 050904 from 4.1-m SOAR atop Cerro Pachon, Chile. *Middle panel:* Near-simultaneous non-detection of the afterglow at visible wavelengths (unfiltered, calibrated to $R_c > 20.1$ mag) from one of the six 0.41-m PROMPT telescopes that we ar building atop Cerro Tololo, which is only 10 km away from Cerro Pachon. *Right pane* Color composite (riz) image of the afterglow 3.2 days after the burst from 8.1-m Gemi South, which is also atop Cerro Pachon.

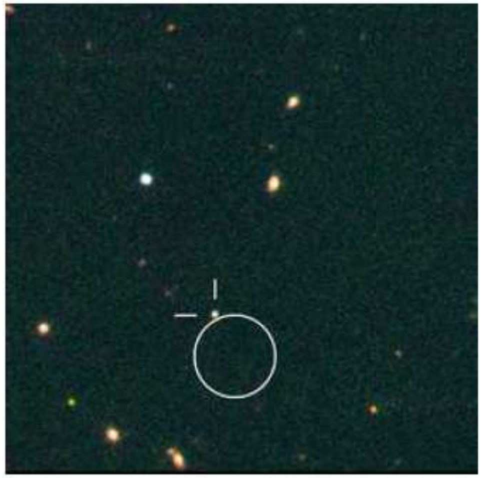
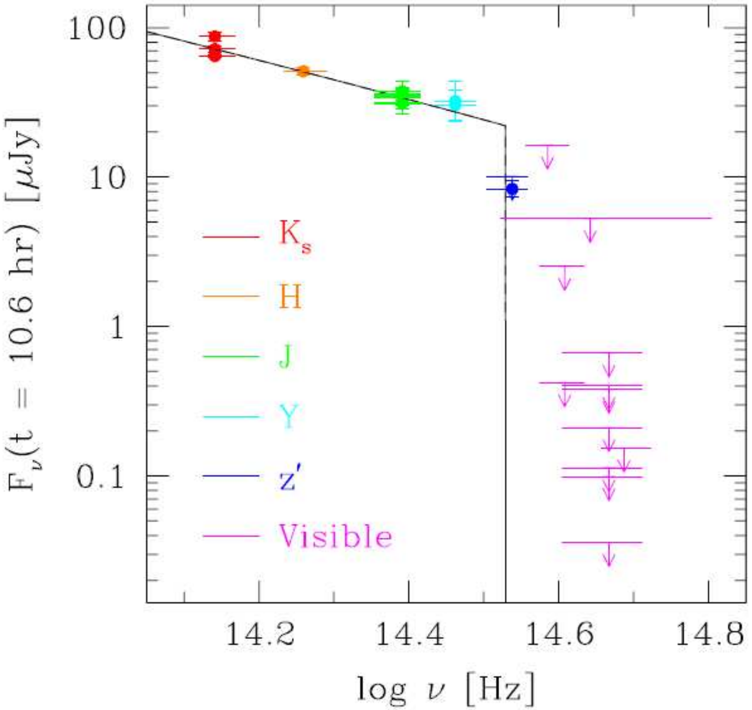
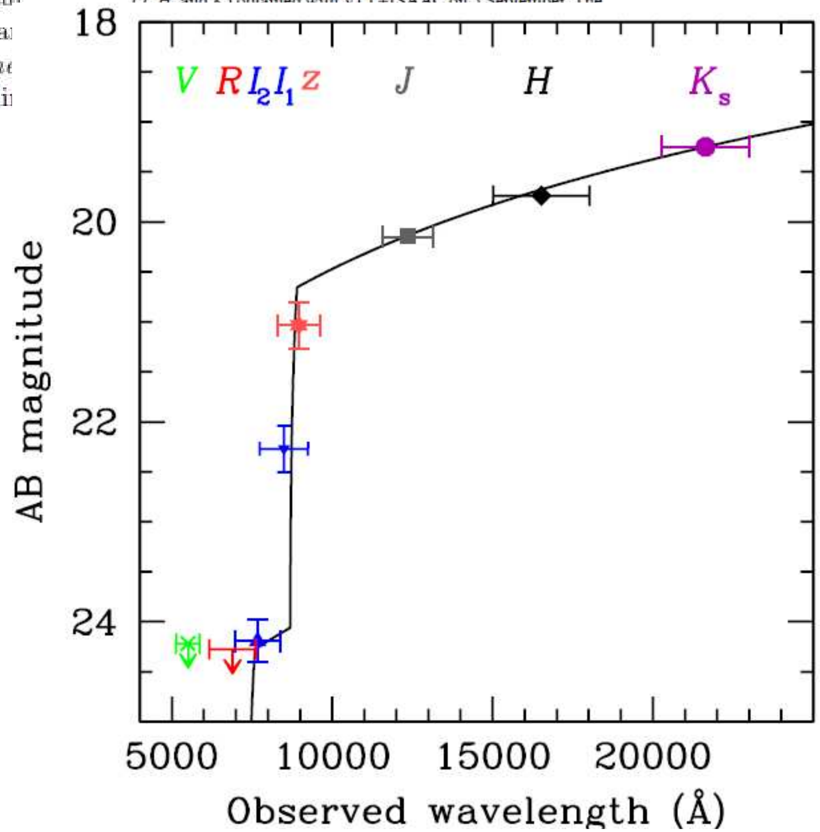


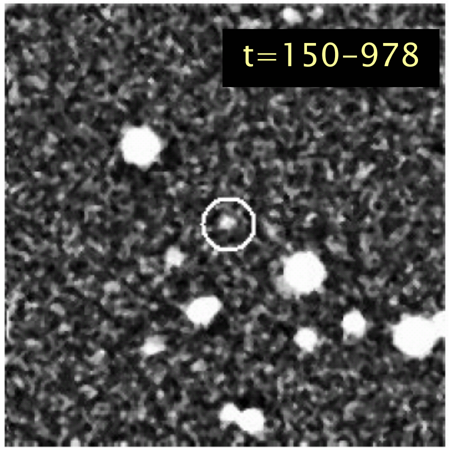
Fig. 1. Three colour-composite image based on our NIR bands



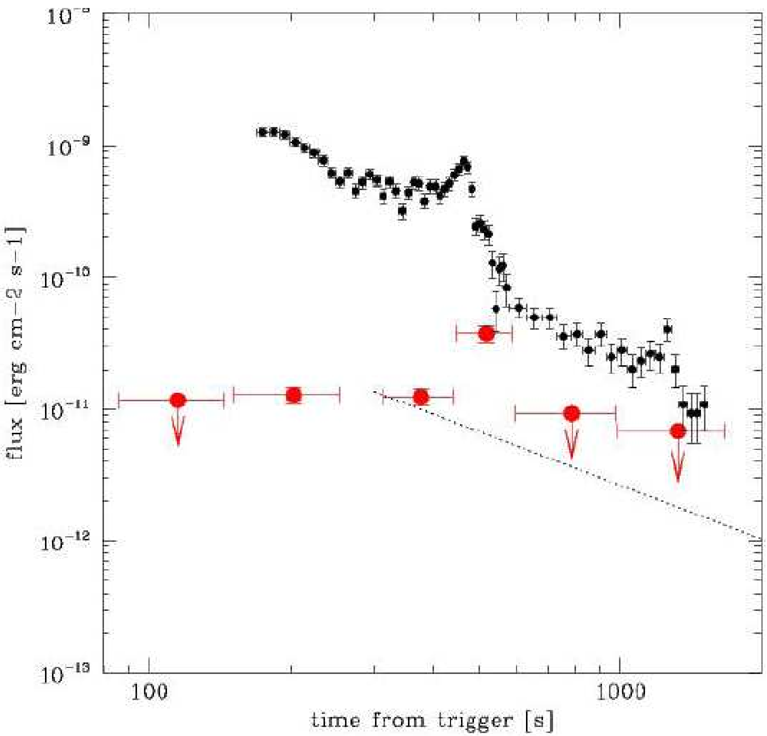


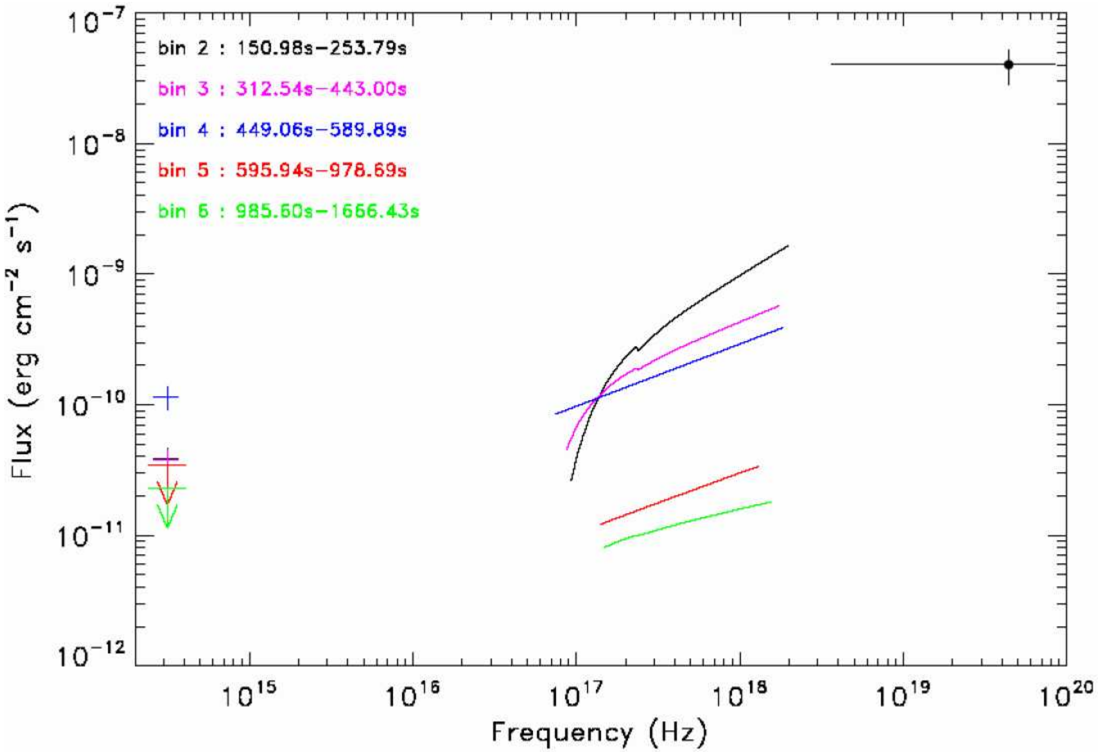
VLT:Tagliaferi et al. :astro-ph/0509766

Prompt optical flash with Tarot



Boer et al. 2005





Collaborators

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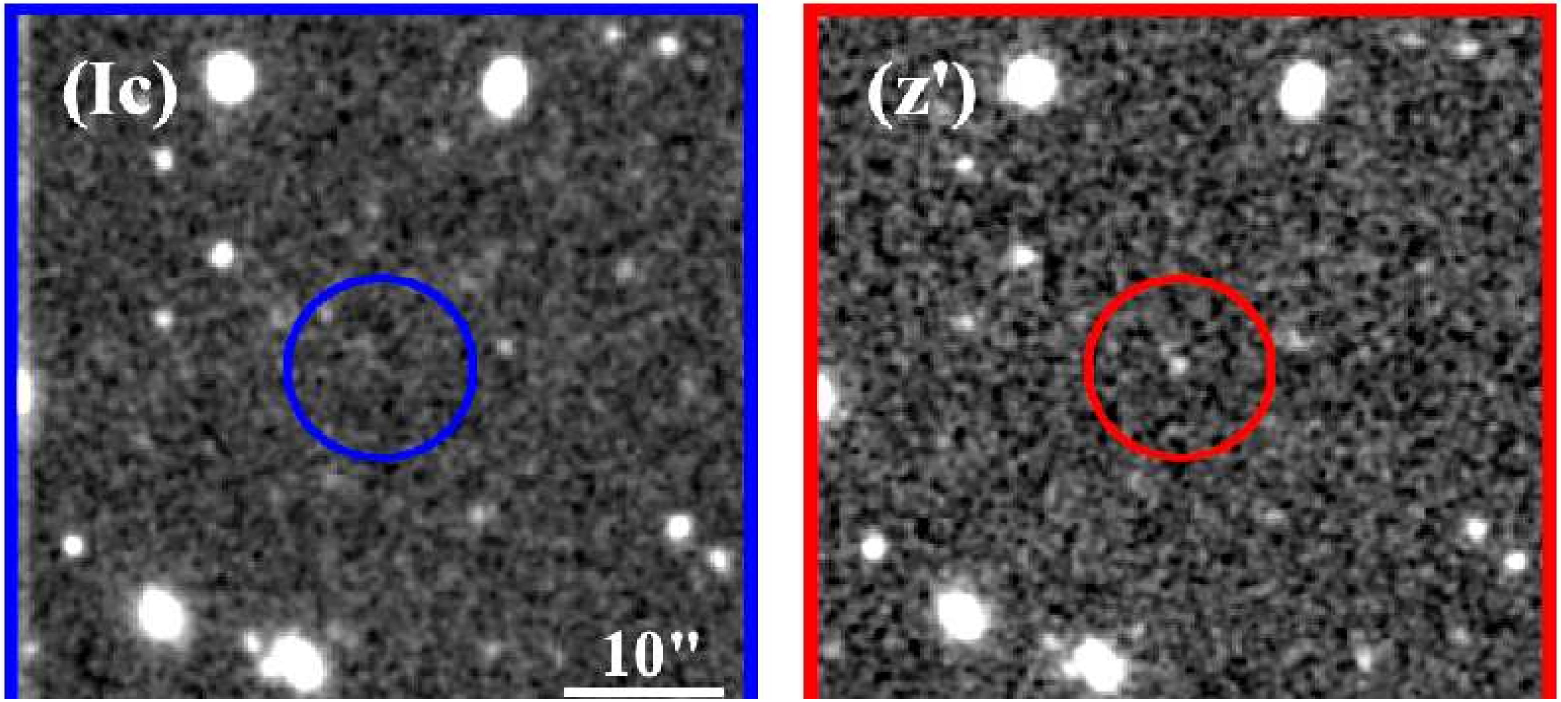
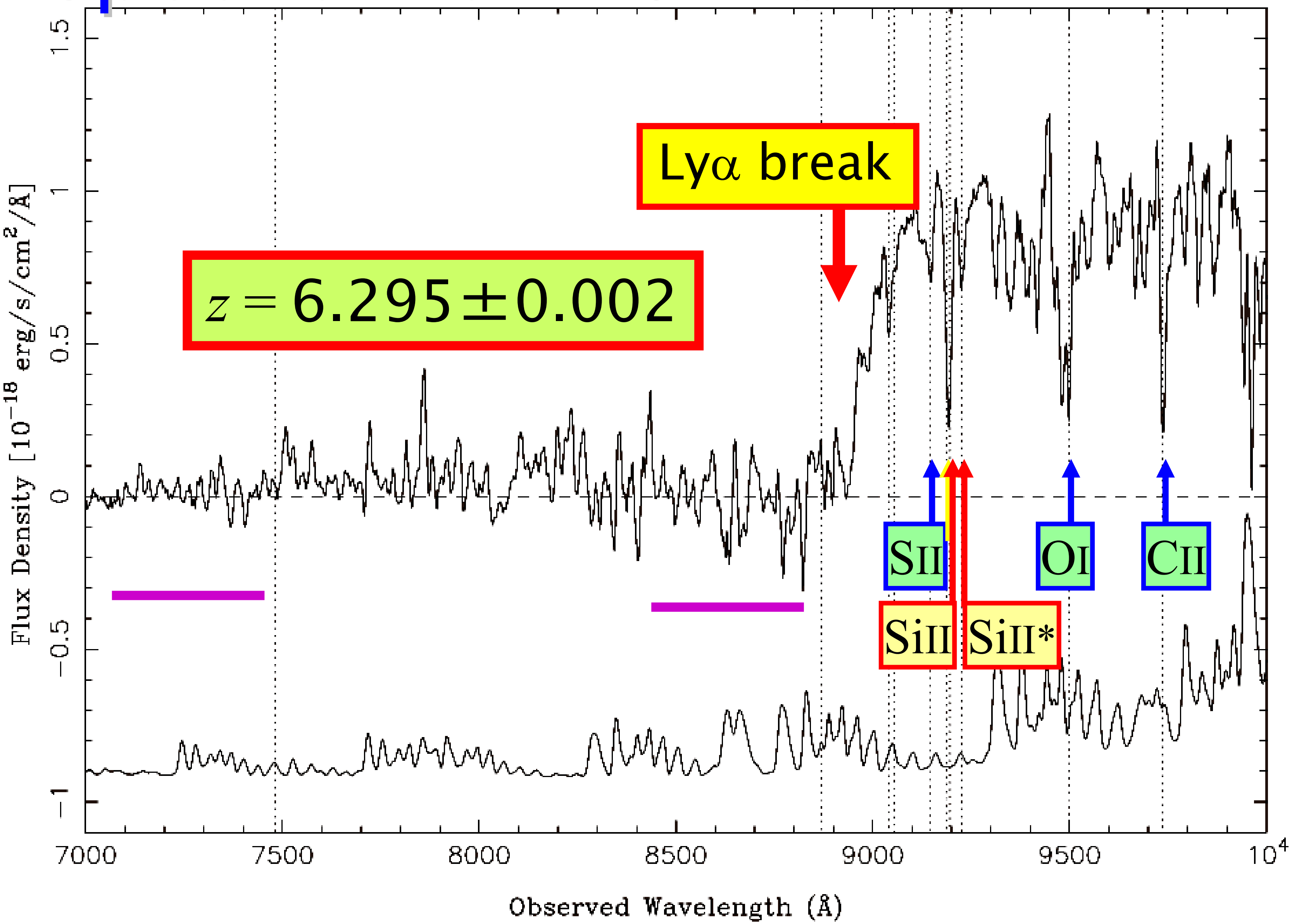
Subaru Images

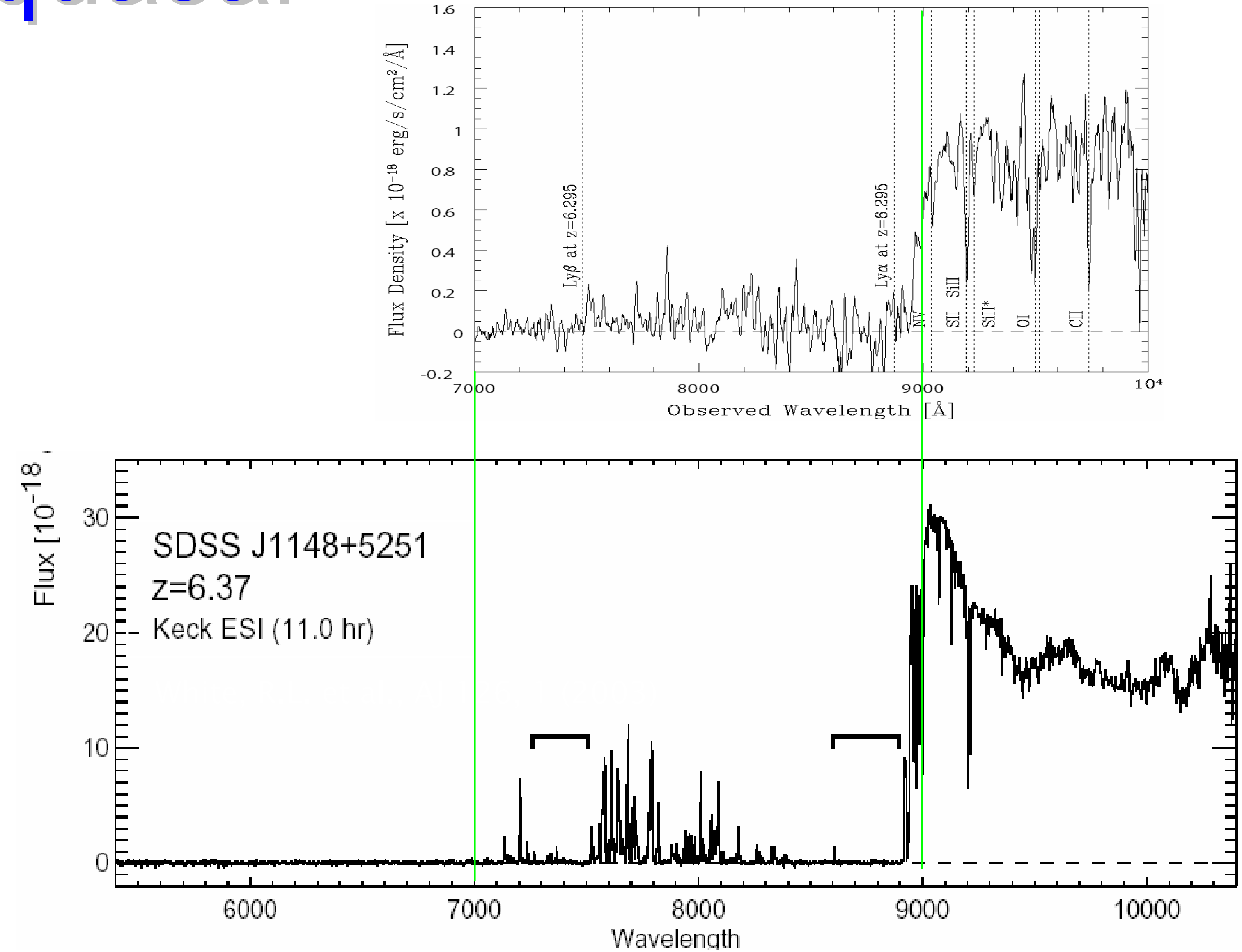


- z'(AB) = 23.71 ± 0.14 mag,
- No detection in Ic band.
- → Ly break at 8500-9000 A° .

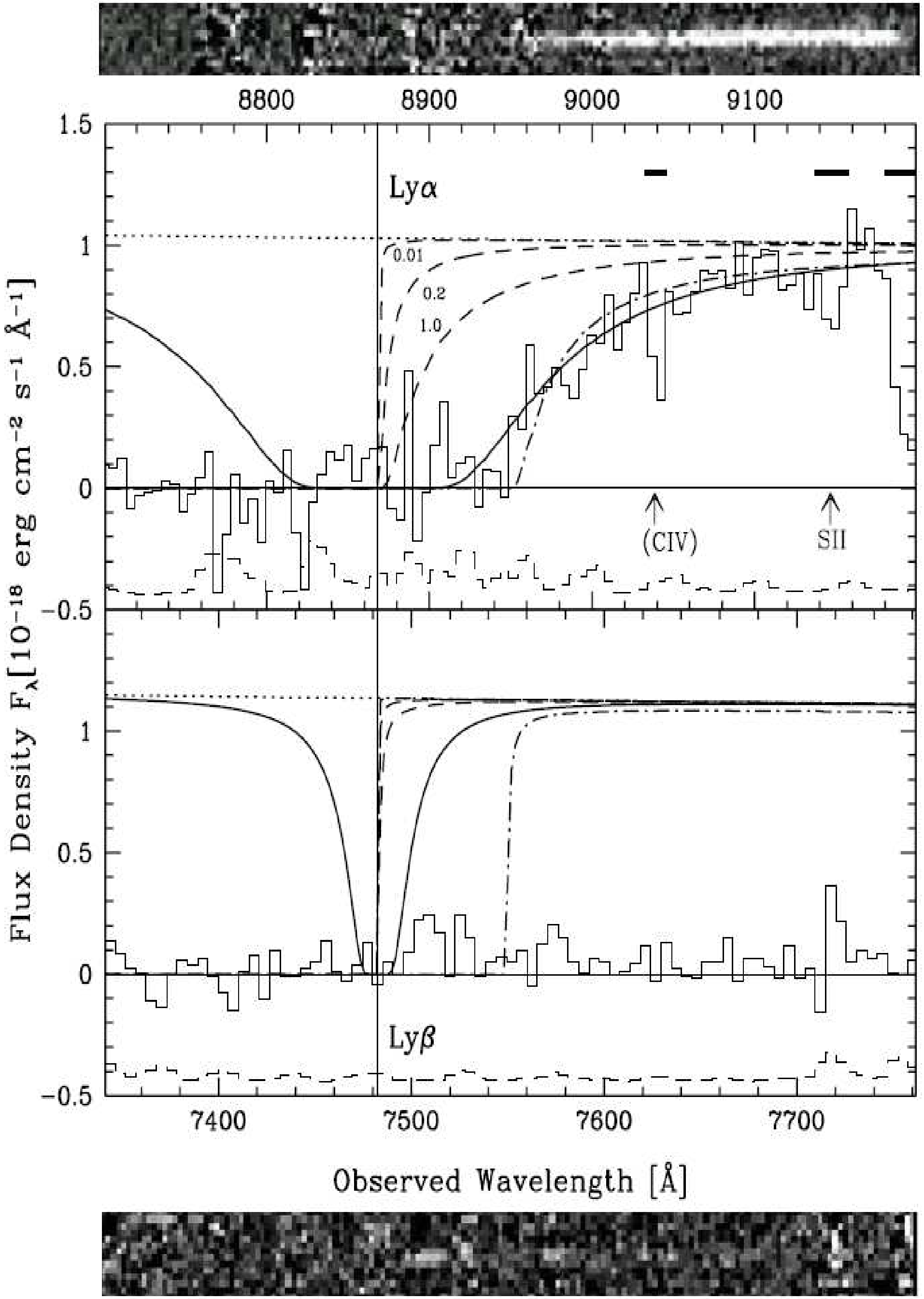
Spectrum at t=3.4 d

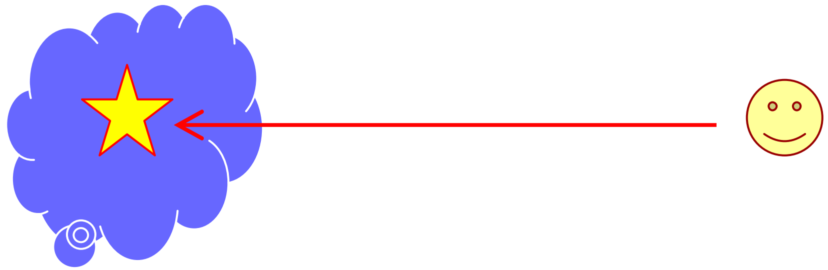


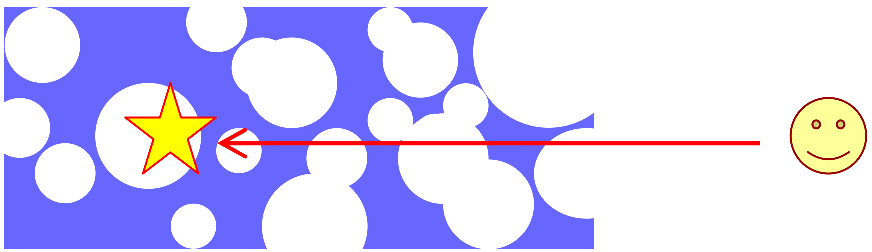
comparison with high-z quasar



Damping wing of Ly α and Ly β

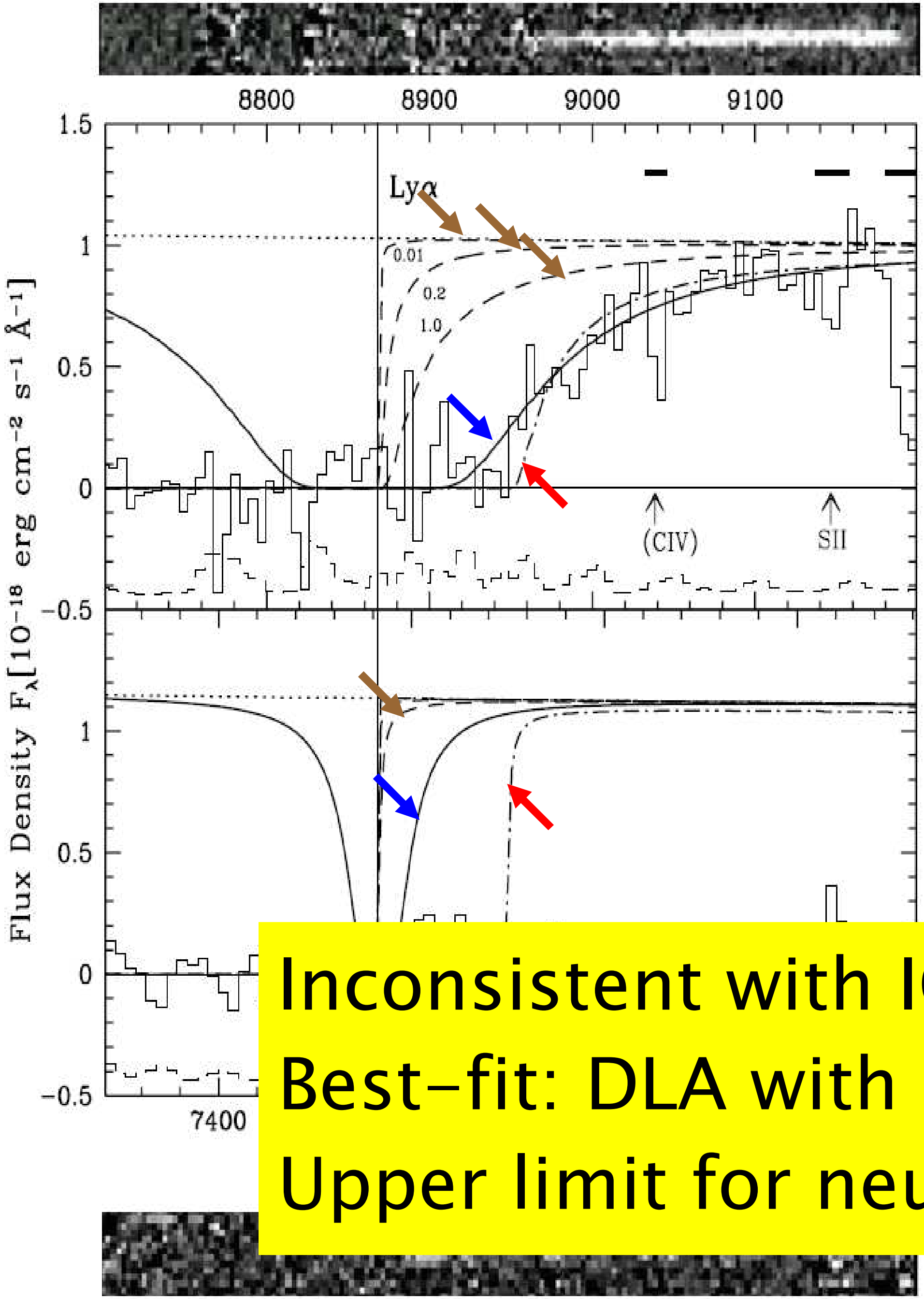






(Totani et al. astro-ph/0512154)

Damping wing of Ly α and Ly β



- solid curve: DLA model (log N_{HI}=21.6, z=6.295)
- dashed curves: IGM model ($z_{IGM,u}$ = 6.295, x_{HI} = 0.01, 0.2, 1.0)
- dot-dashed curve: IGM-dominated model ($z_{IGM,u}$ = 6.36 and x_{HI} = 1.0)

Inconsistent with IGM-dominated model

Best-fit: DLA with log N_{HI}=21.3, z=6.320

Upper limit for neutral fraction: x_{HI}<0.6

(Totani et al. astro-ph/0512154)

Identification of absorption lines

Observed Wavelength (Å)	Equivalent Width (Å)	Column Density log (cm^{-2})	Line Identification	Redshift
9041.0 ± 0.8	4.5 ± 1.0	$14.44^{+0.14}_{-0.16}$	C IV λ1548.2	4.840±0.001
		– –	(N V λ1238.8)	(6.298±0.001)
9055.9 ± 1.7	1.7 ± 1.0	$14.21^{+0.25}_{-0.46}$	C IV λ1550.[illegible]	[illegible]
		– –	(N V λ1242.8)	(6.287±0.001)
9146.4 ± 1.8	3.8 ± 1.1	$15.60^{+0.14}_{-0.17}$	S II λ1253.8	6.295[illegible]001
9188.7 ± 2.6	6.1 ± 3.7	$16.20^{+1.87}_{-0.92}$	S II λ1259.5	[illegible]
9195.9 ± 1.2	8.3 ± 2.7	$14.29^{+0.57}_{-0.39}$	Si II λ1260.4	[illegible]
[illegible]	[illegible]9 ± 1.1	$13.63^{+0.13}_{-0.16}$	Si II* λ1264.7	6.295±0.001
9499.1[illegible].9	10.3 ± 1.9	$15.85^{+0.39}_{-0.28}$	O I λ1302.2	[illegible]
[illegible]	[illegible]	[illegible]$5.41^{+0.30}_{-0.26}$	C II λ1334.5	[illegible]

Log N_{HI}=21.3

[S/H]=−1.0

[Si/H]=−2.6

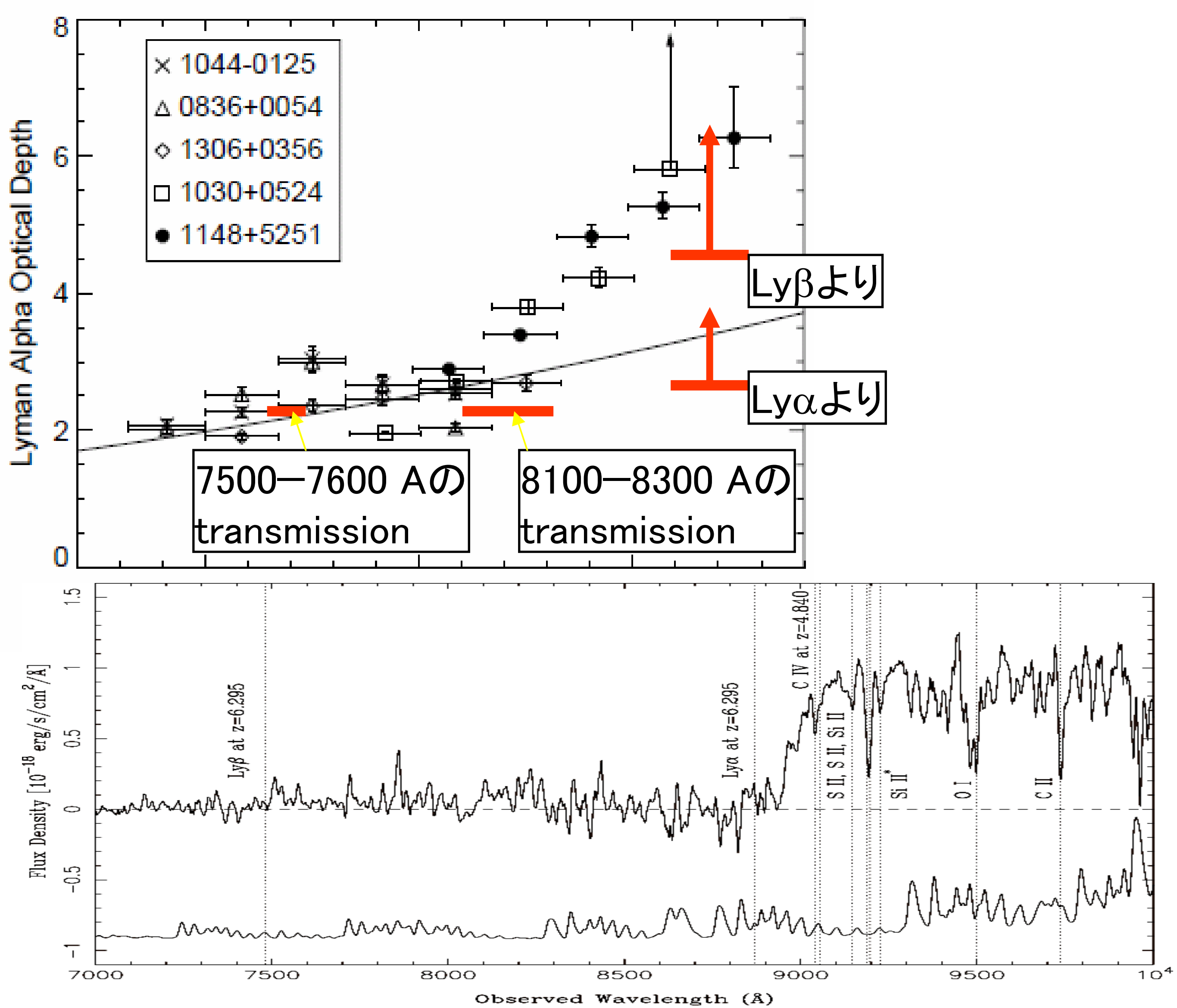
[O/H]=−2.3

[C/H]=−2.4

n_e=200 cm^{-3}

size ~ 0.4 (0.1HI/H^+) pc

Lyman α optical depth



Conclusions and implications

- Firm and precise identification of the highest known redshift of GRB $z=6.295$
- Measurement of gas content (neutral hydrogen column density, metallicity, ionization, ...) at $z>6$ galaxy
- Evidence for localized heavy elements
  - ✓ if CBM, high z GRB in low Z galaxy may be identifiable with metal absorption lines
- Confirmation that GRB is a powerful probe for cosmology: very high z GRB may be very bright
- Re-ionization of the Universe can be probed with low N_{HI} GRB at $z>6$