Gamma Ray Bursts & Associated Supernovae

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Stellar Explosions

End stages of massive stars - catastrophic stellar explosions - Gamma Ray Bursts (GRBs) & Supernovae

Supernovae: progenitor mass greater than 8 M_sun

GRBs: massive stars with rotation and low metallicity

A distinct class of GRBs and Supernovae which are not born from stellar collapse (merger)

GRBs: What we know

From BATSE, BeppoSAX, HETE:

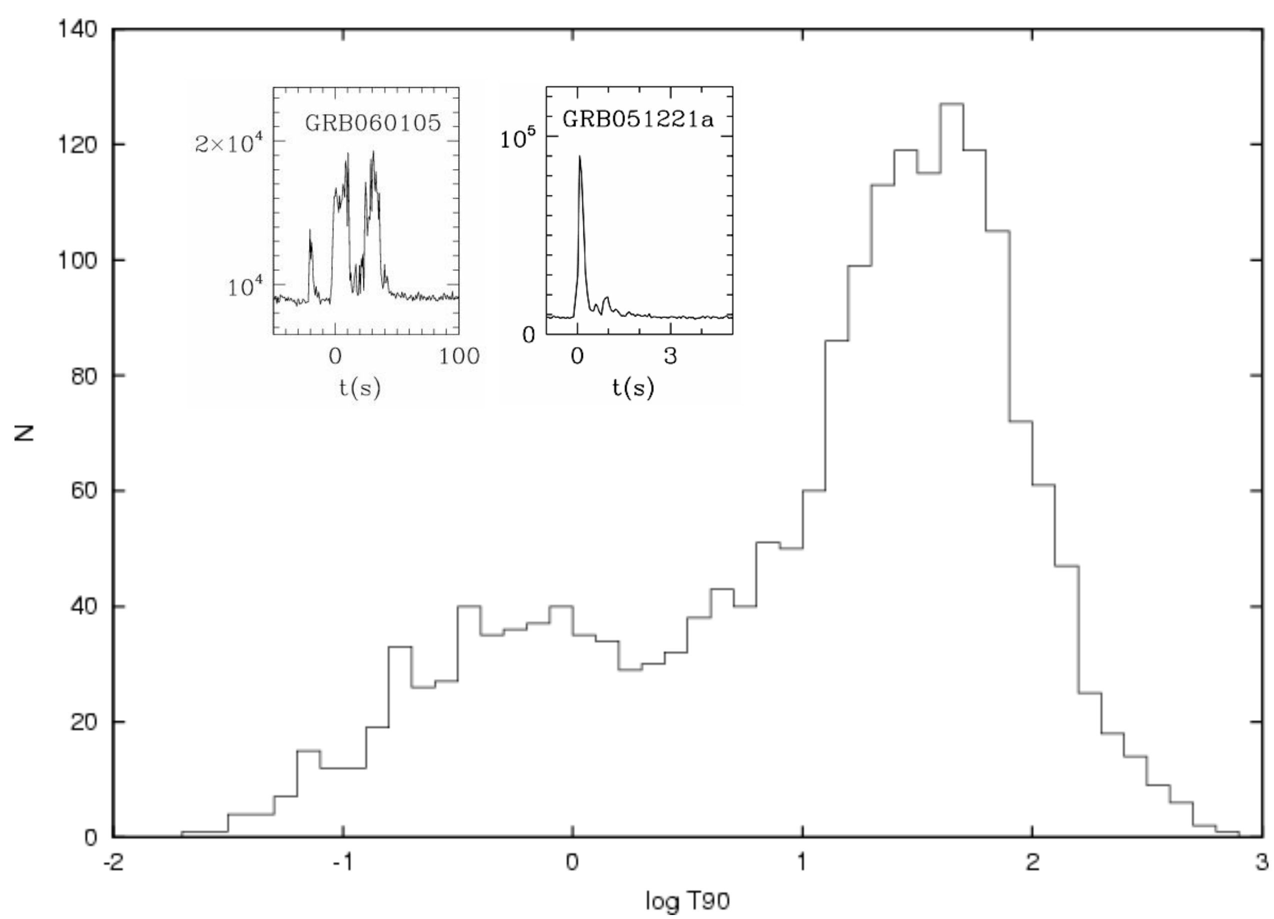
- Short intense pulses of gamma rays lasting for a few seconds

- Bimodal distribution

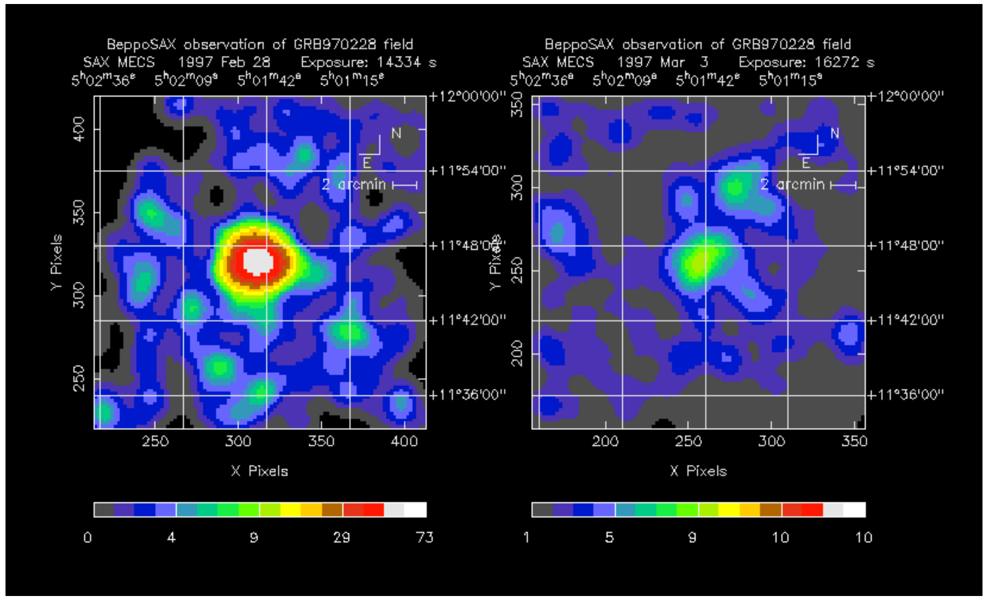
- Isotropically distributed: cosmological distances ($0.008 < z < 9.4$) & hence huge energy output (10^{51}erg)

- Two phase: Burst (prompt emission) & Afterglow (longer lasting longer wavelength counterparts; non-thermal synchrotron radiation; time varying flux)

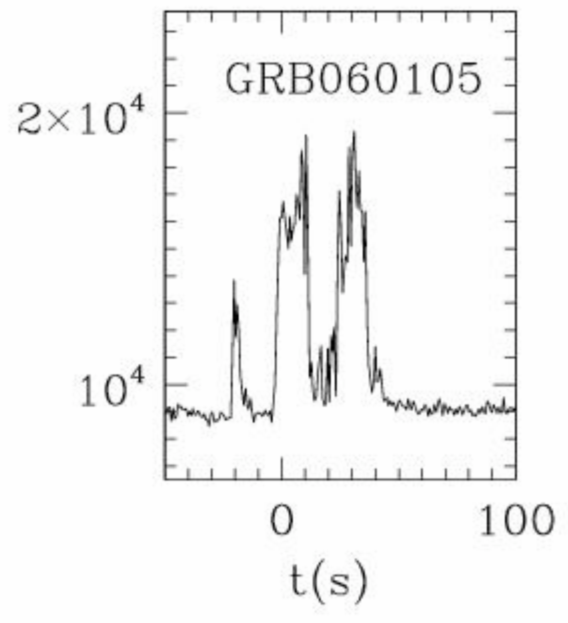
- X-ray locations allowed redshift determination and confirmed that GRBs are of cosmological origin

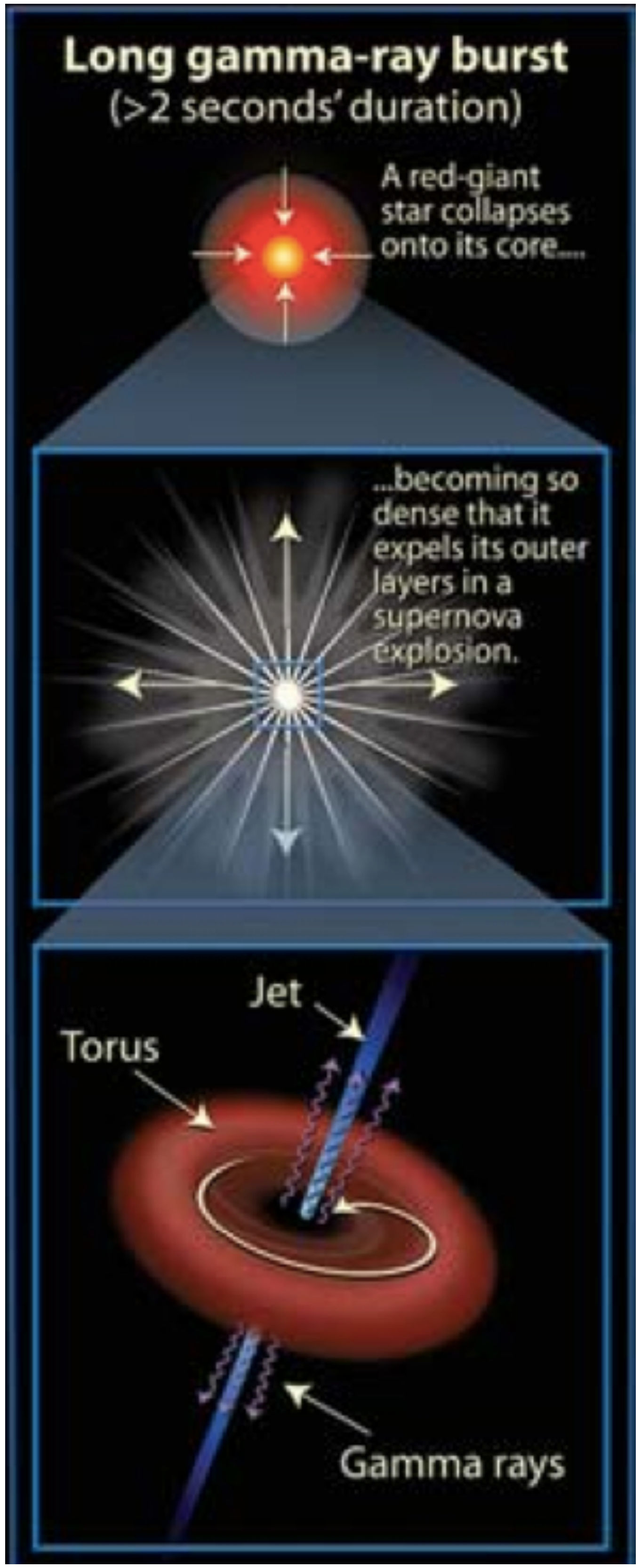


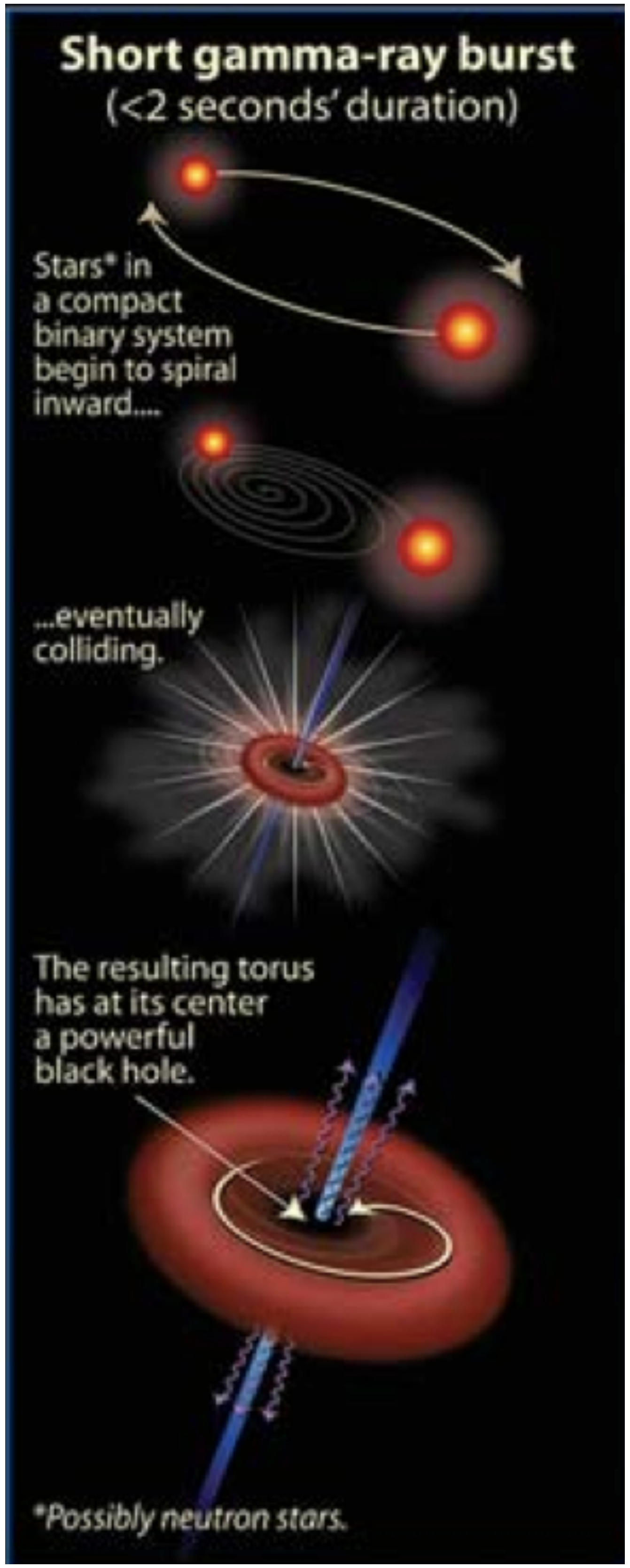
GRB 970228

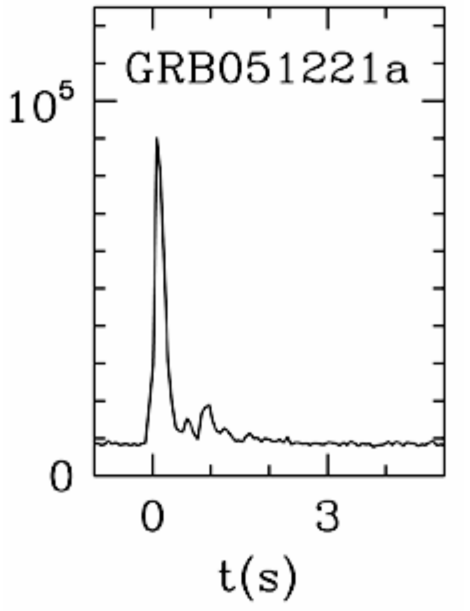


Long vs Short

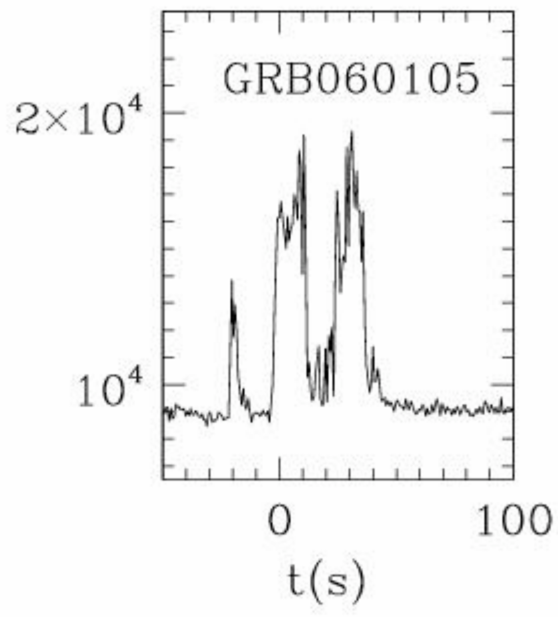


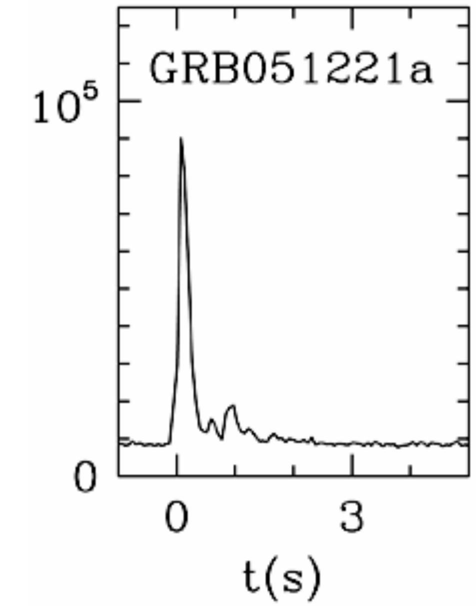






Long vs Short

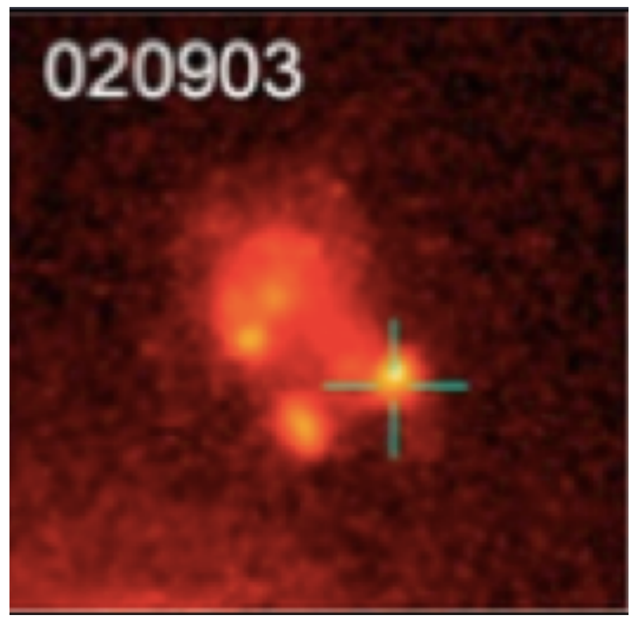


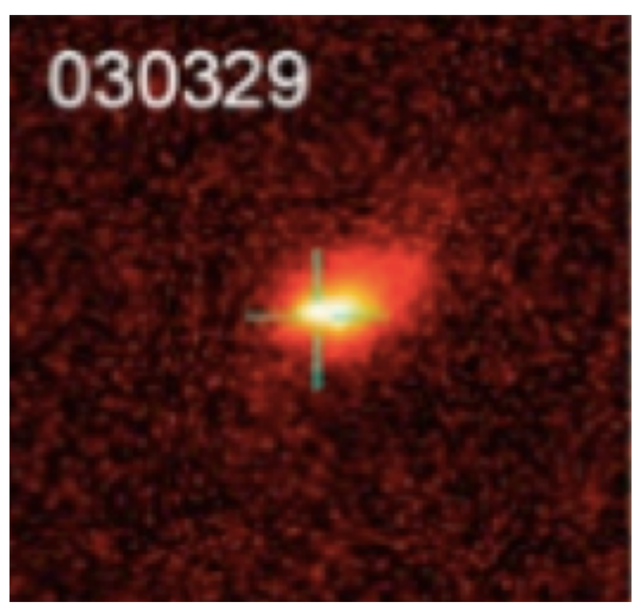


SF Irregulars

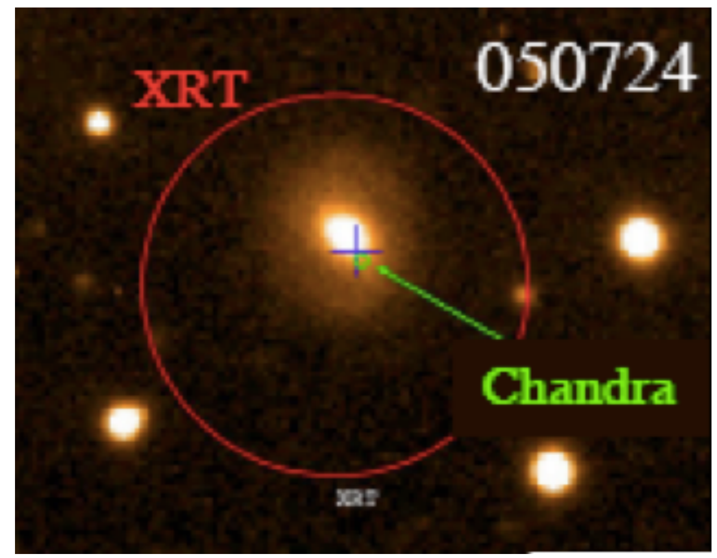
Accompanied by SNe

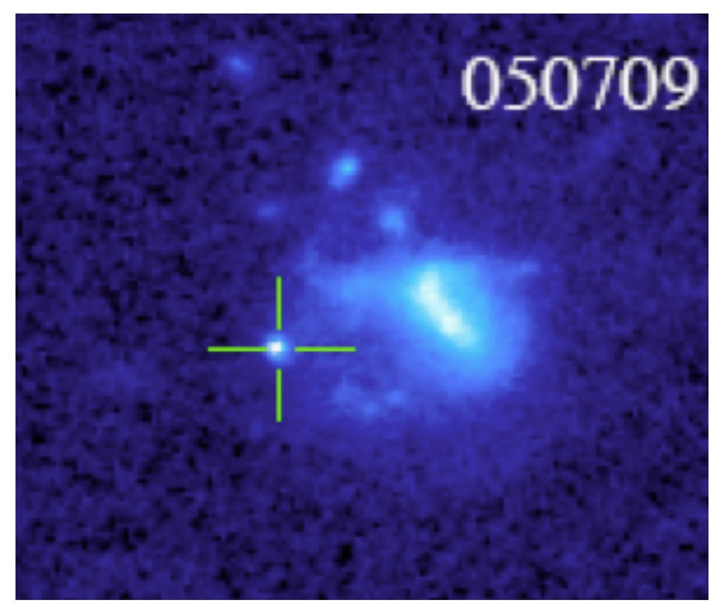
Collapsar model





Fruchter et al. 2006





Barthelmy et al. 2005
Fox et al. 2005

Ellipticals, SF galaxy with an offset

No SNe detected?

Possible merger model

The GRB-Supernova Association

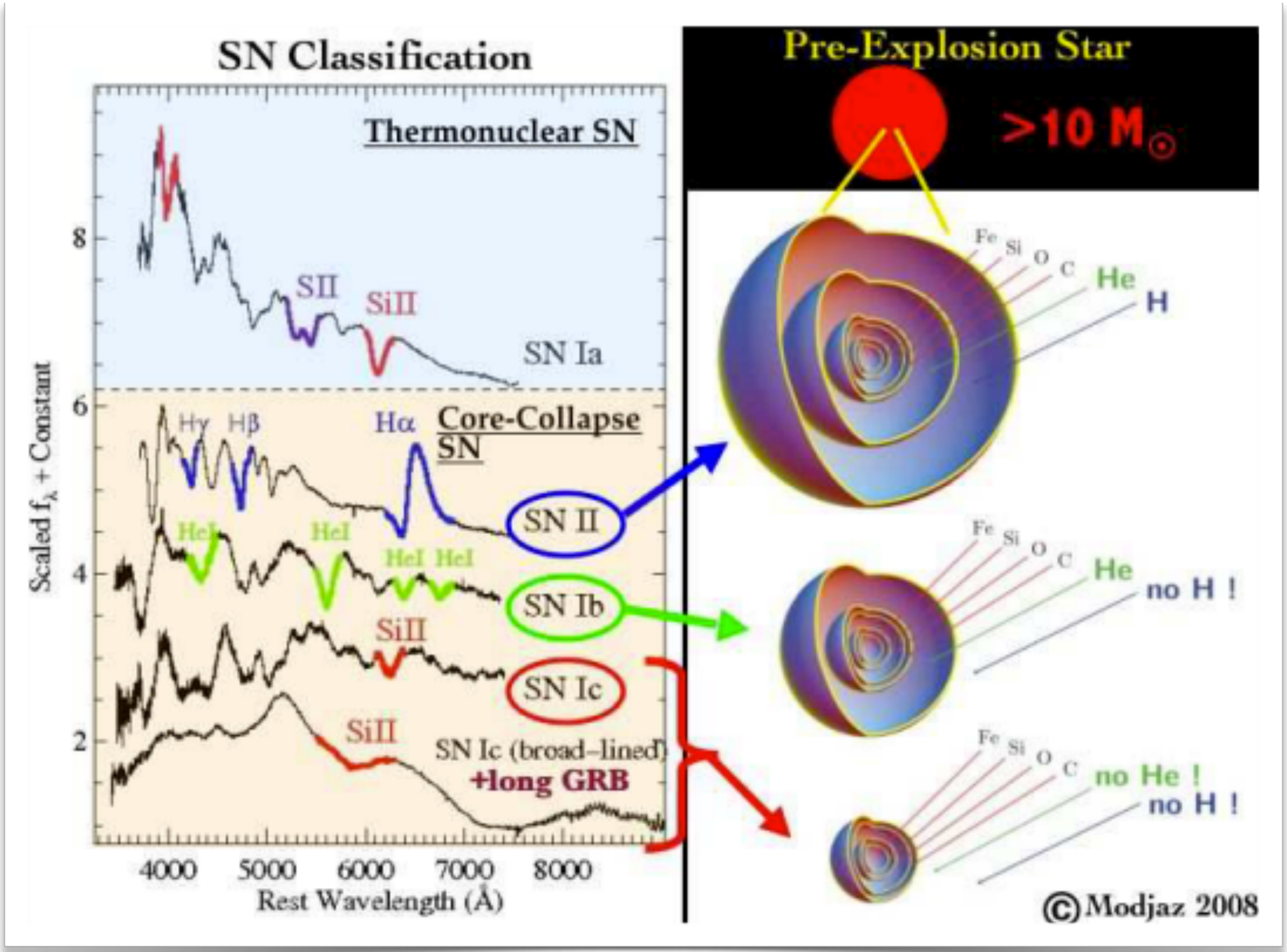
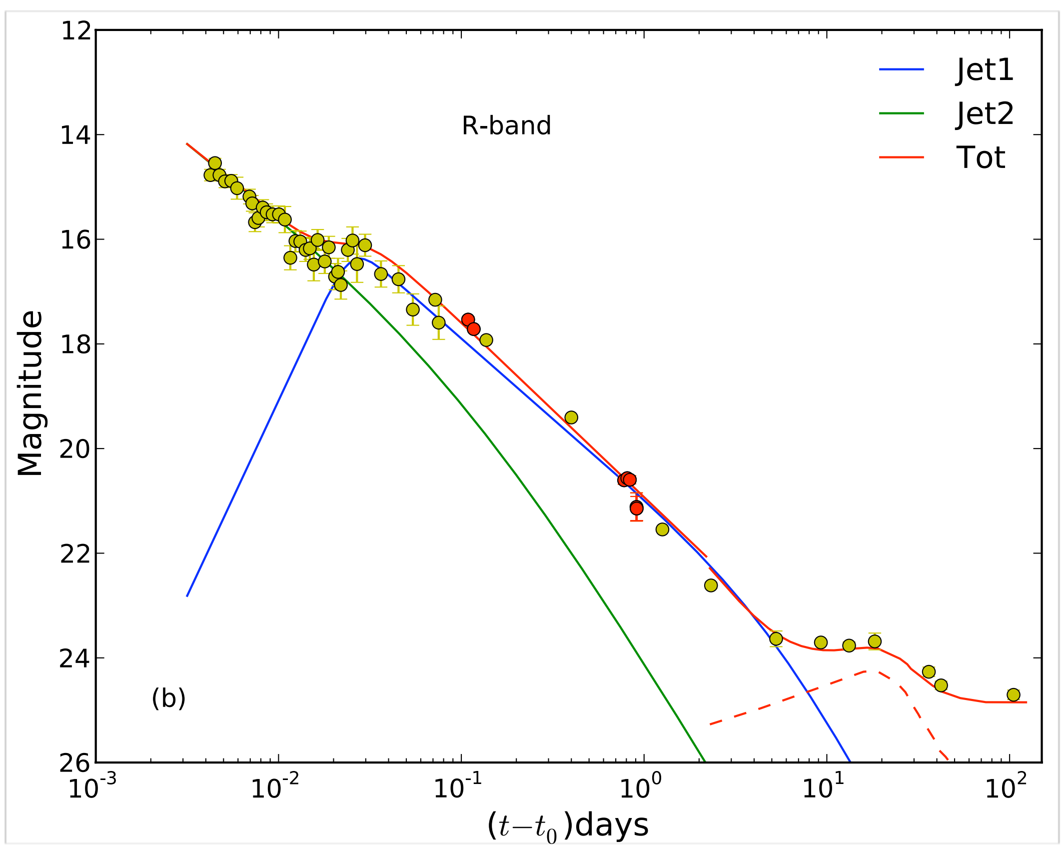


Figure taken from Modjaz et al. 2011

Hypernovae signature in long bursts

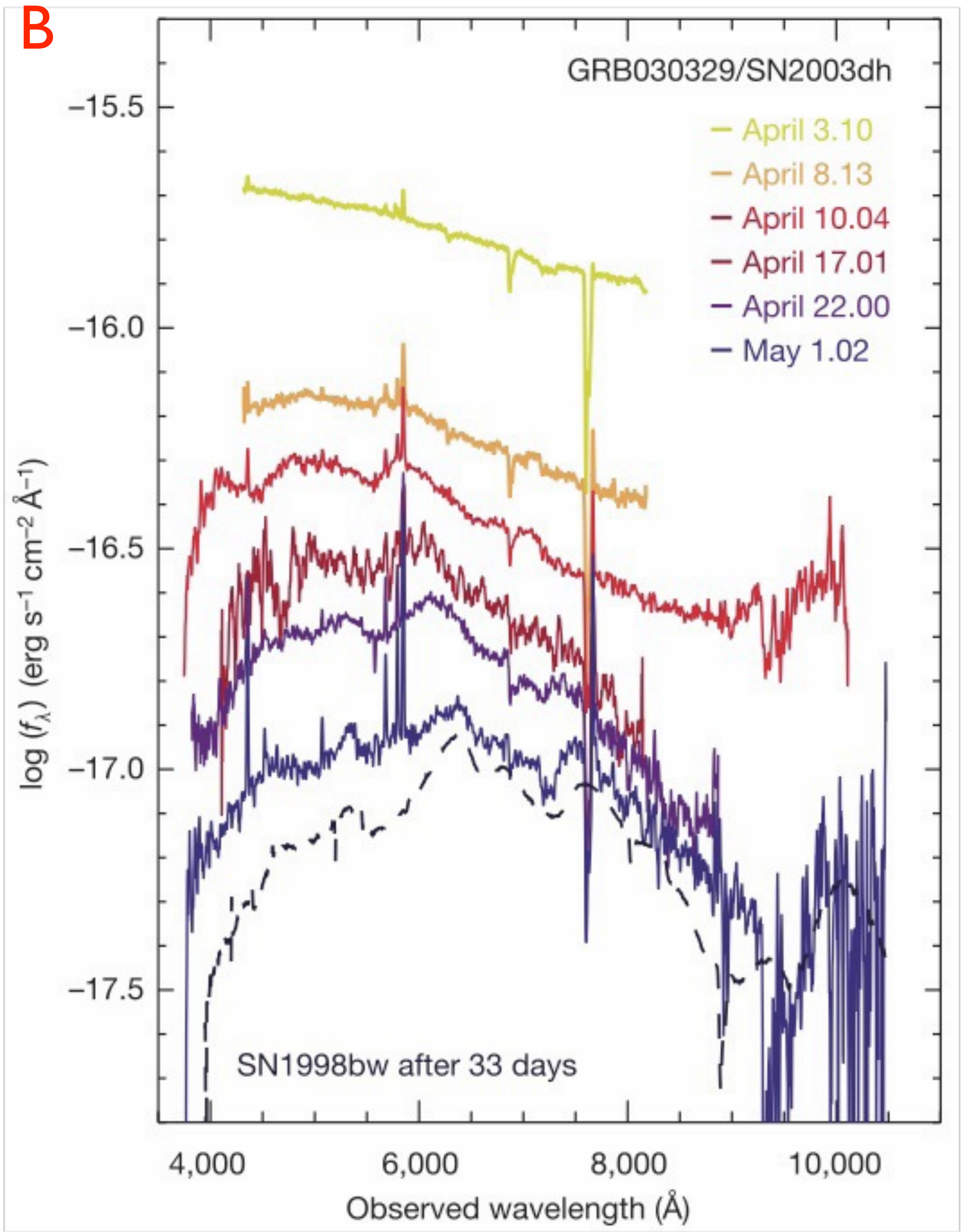
GRB 050525A

A



Resmi, Misra et al. 2012

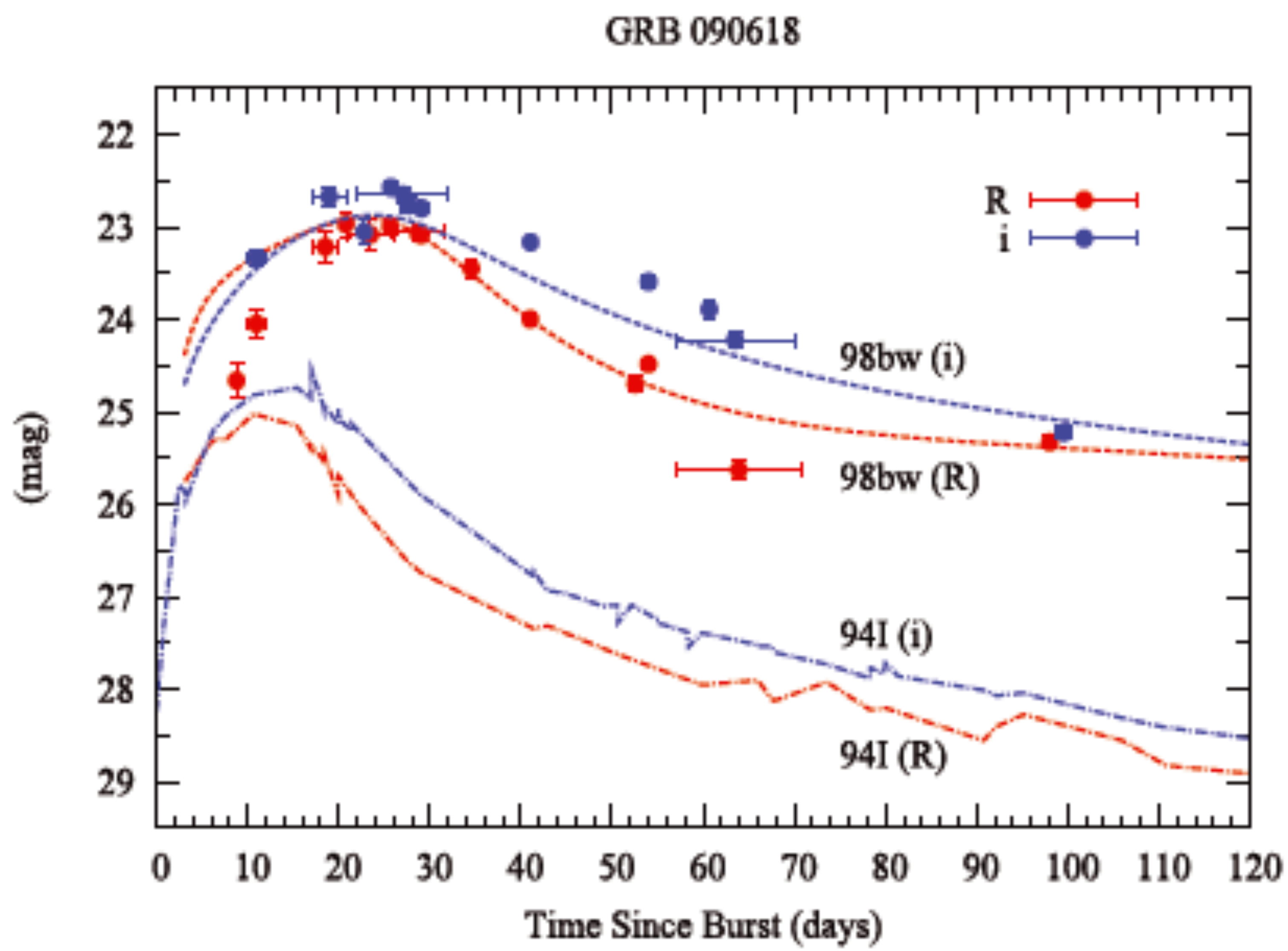
B



Matheson et al. 2003

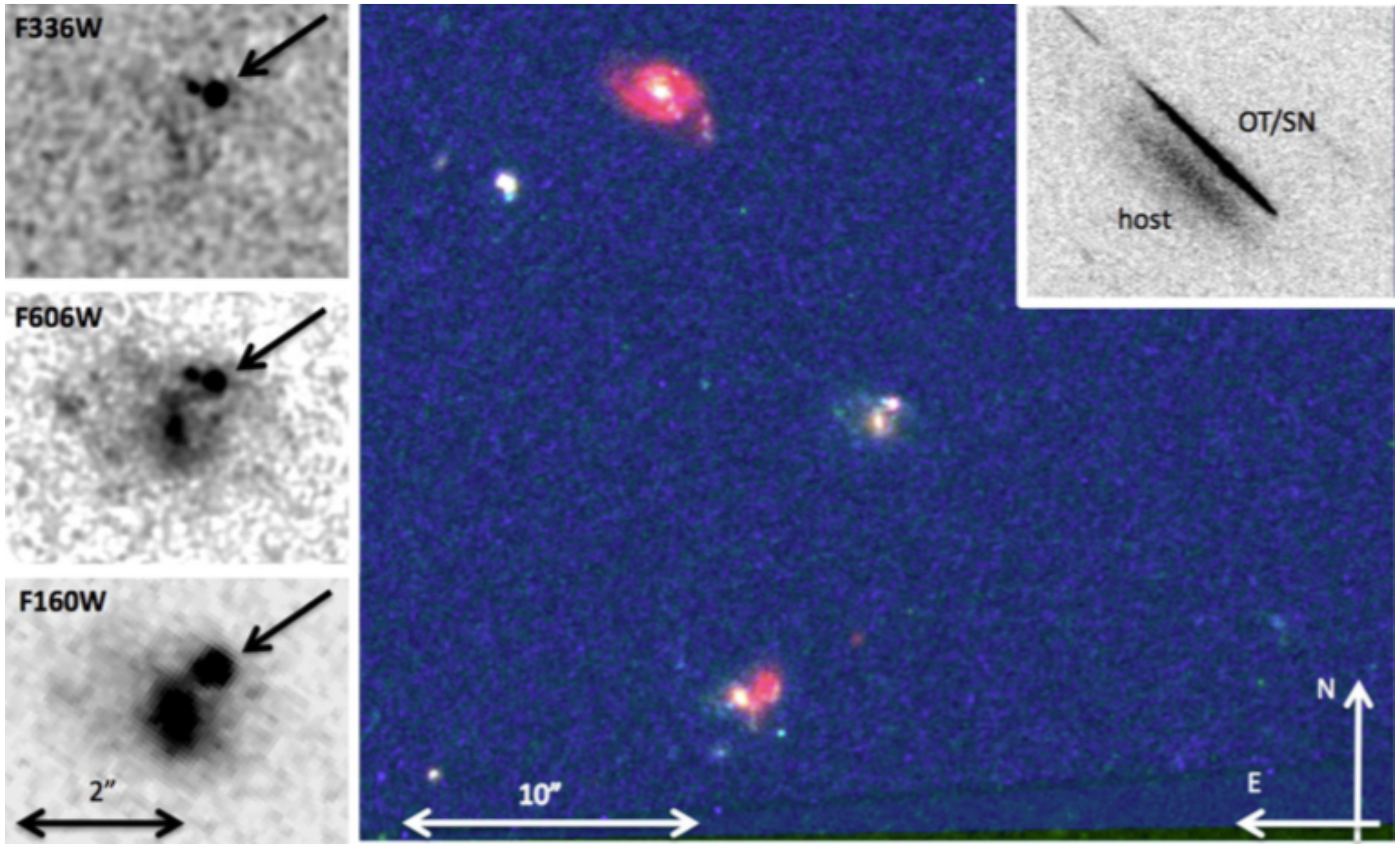
Isolating and Characterizing the SN

- Total Flux = Afterglow + SN + Host
- Afterglow: Powerlaw
- SN: 1998bw as template
  --Account for the effect of redshift in the shape of light curve and bandpass (k correction)
  --Apply a stretch factor in time and a shift in brightness
- Host: Constant



Cano et al. 2011

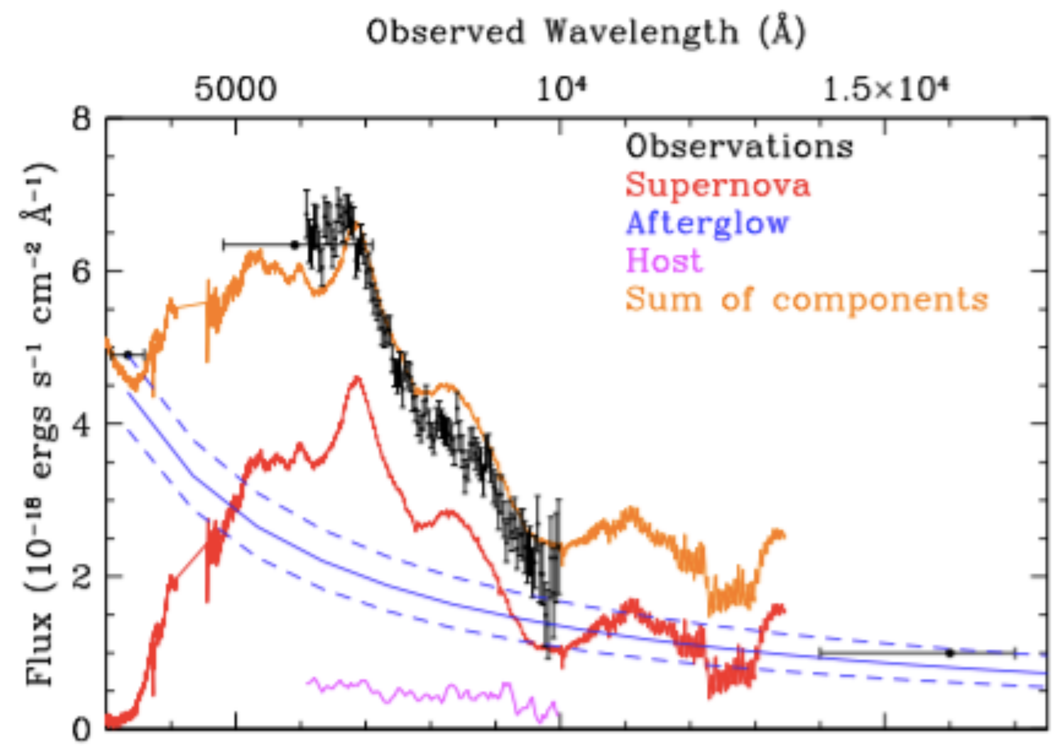
GRB 130427A ($E_{iso} \sim 10^{54}$ erg)



★GRB 130427A, at a redshift of 0.34, provides a unique opportunity to study the *associated SN with an intrinsically extremely luminous burst*, much more luminous than any previously studied GRB-SN

★Image quality and UV capability of *HST* was used to *separate the afterglow, SN and host* suggesting that the burst originated ~4 kpc from the nucleus of a moderately star forming galaxy, possibly an interacting disc galaxy

★Similarity of SNe from both the *most luminous* and *least luminous* GRBs suggests broadly similar progenitor stars can create GRBs across *six orders of magnitude in E_{iso}*



Levan et al. 2014

Sub-classes of GRB-SNe based on $L_{\gamma,iso}$

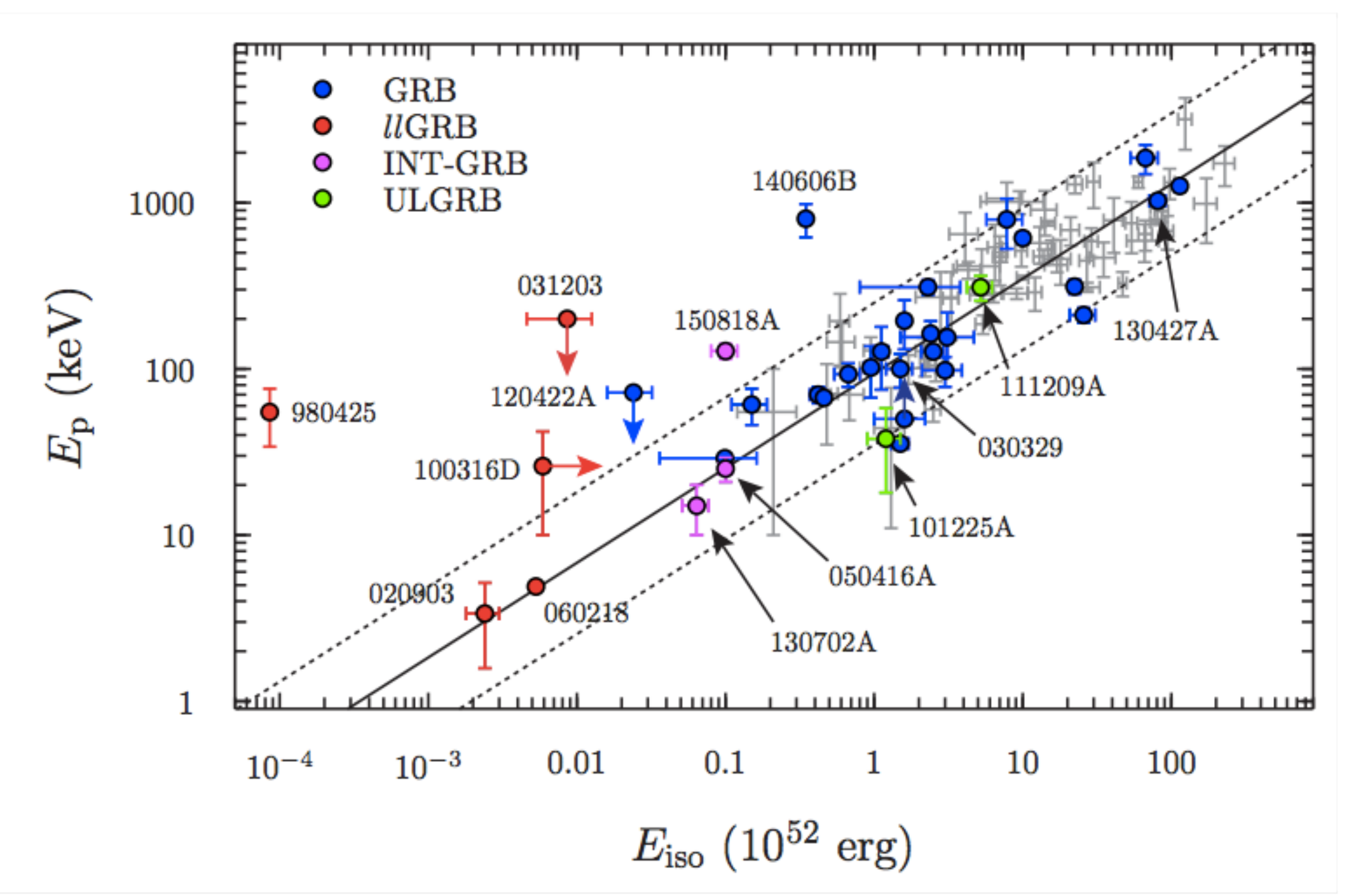
★ *ll*GRB-SNe: GRB-SNe associated with low luminosity GRBs ($L_{\gamma,iso} < 10^{48.5}$ erg/s)

★ INT-GRB-SNe: GRB-SNe associated with intermediate luminosity GRBs ($10^{48.5}$ erg/s < $L_{\gamma,iso} < 10^{49.5}$ erg/s)

★ GRB-SNe: GRB-SNe associated with high luminosity GRBs ($L_{\gamma,iso} > 10^{49.5}$ erg/s)

★ ULGRB-SNe: ultra-long duration GRB-SNe (exceptionally long duration of their γ-ray emission ~ 10^4 sec rather than their γ-ray luminosities)

Cano et al. 2016



*ll*GRB-SNe

★ Typically low redshift
GRBs 980425 (z=0.0085); 031203 (z=0.105); 060218 (z=0.033); 100316D (z=0.059)

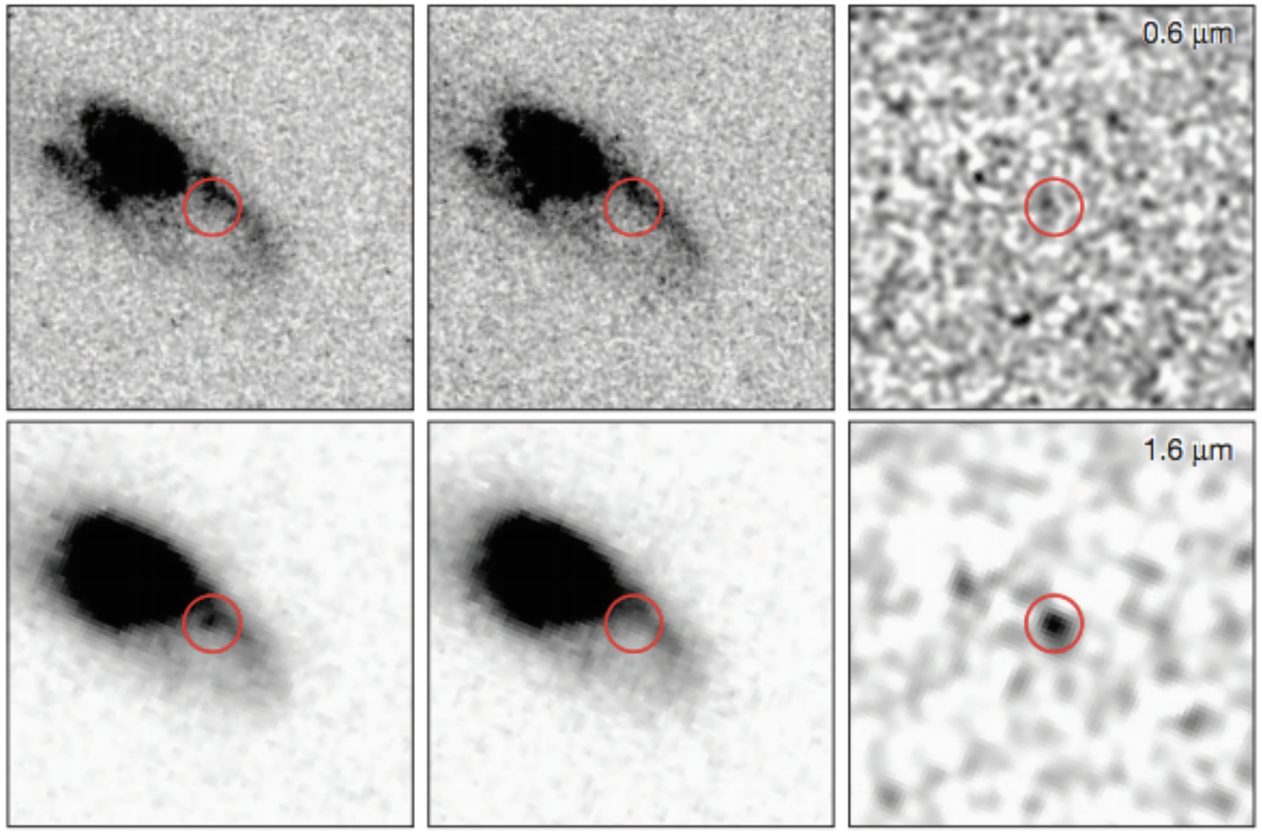
★ Follow E_{peak} - E_{iso} correlation; occasionally divergent

★ Faint undetected optical afterglows

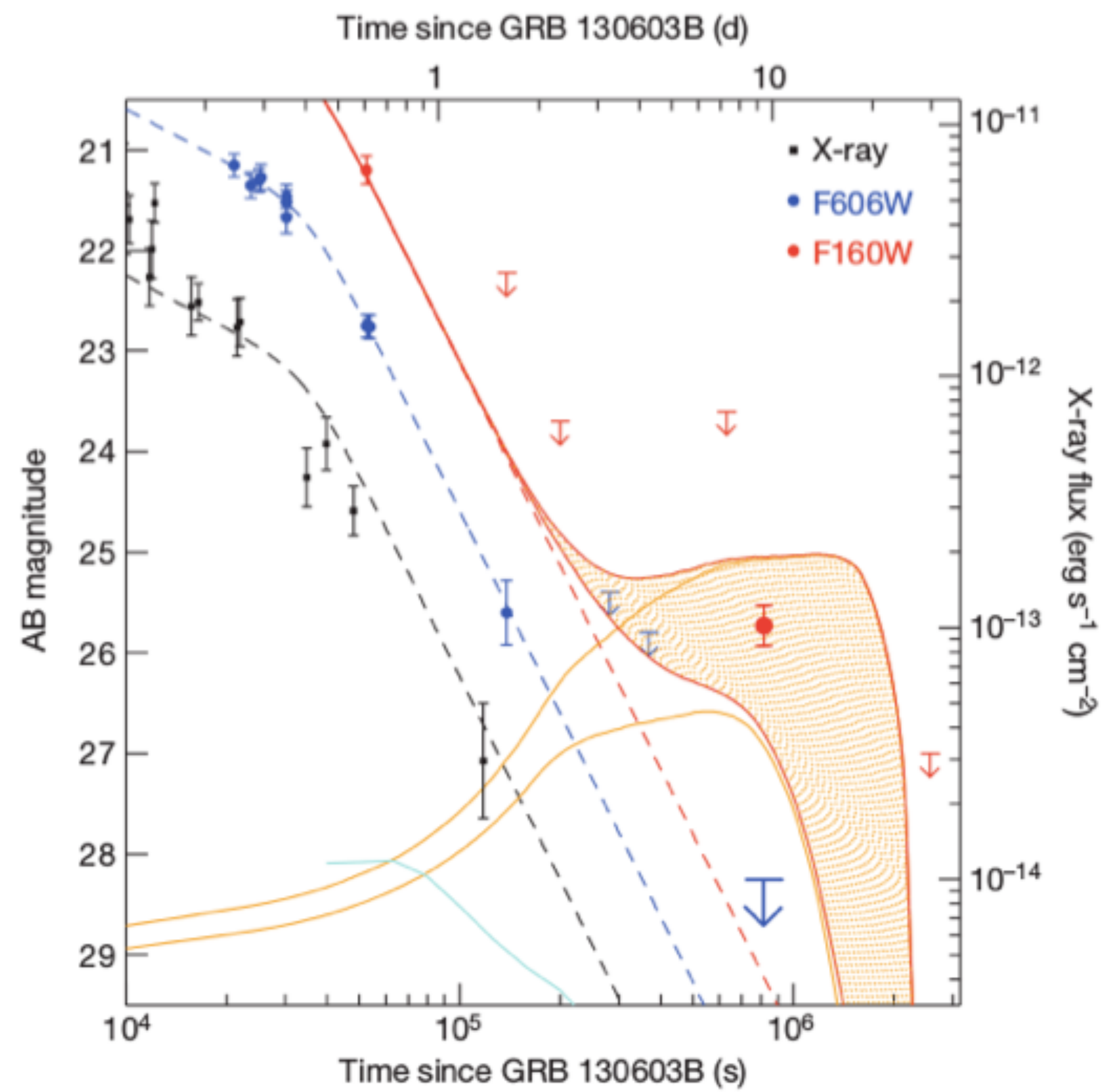
- Do these represent a different population?
- Are all lGRBs associated with SNe?

Additional GRB-SN examples required

Kilonovae associated with Short GRBs

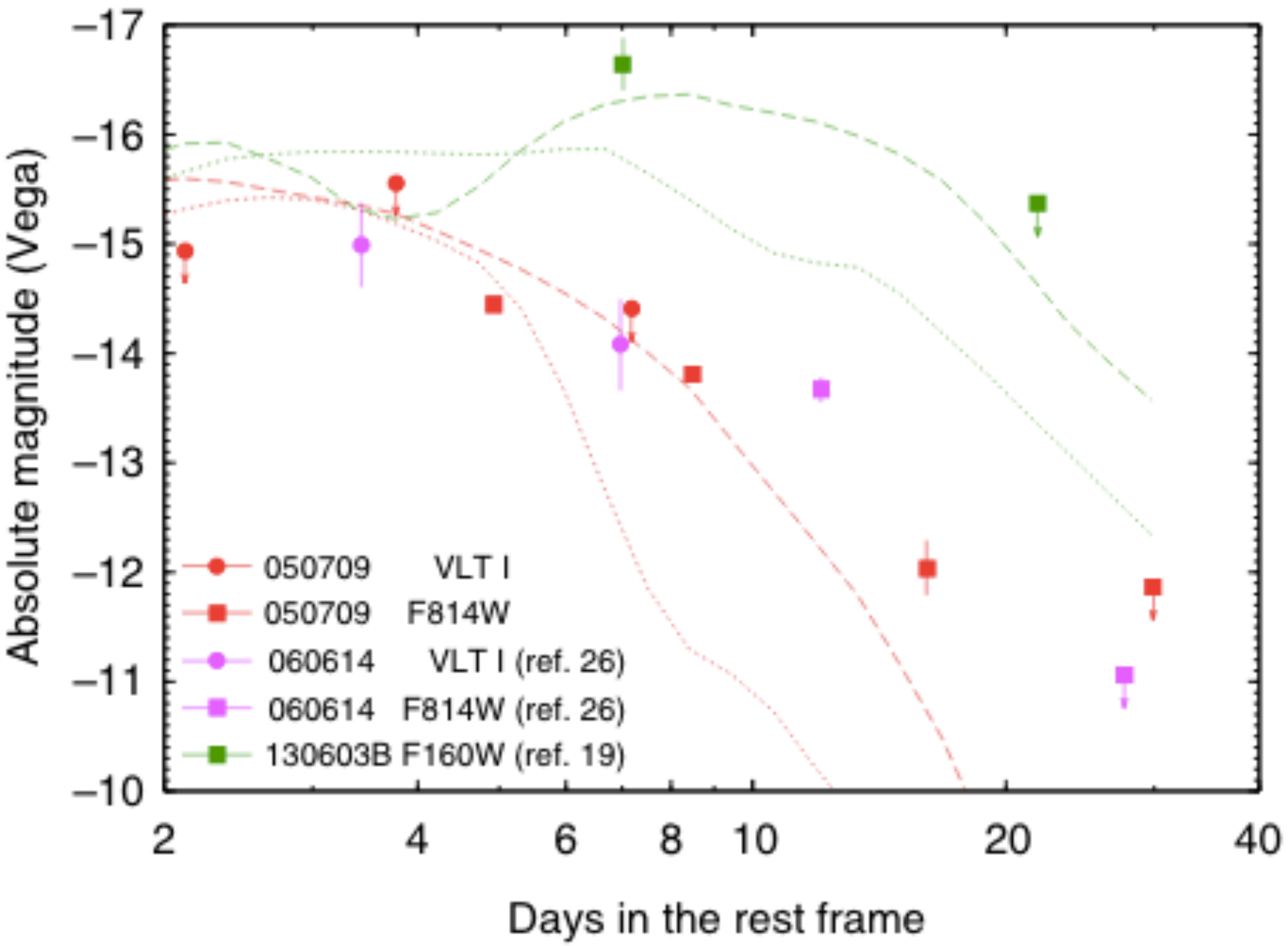


Tanvir et al. 2013



Tanvir et al. 2013

Comparison of the lightcurves of Kilonova/ Macronova candidates



Zhi-Ping et al. 2016

Table 1 | Physical properties of GRBs/macronovae/afterglows with known redshifts.

	GRB 050709*	GRB 060614†	GRB 130603B‡
$E_{\gamma,\mathrm{iso}}$ (10^{51} erg)	0.069	2.5	2.1
z	0.16	0.125	0.356
Duration§ (s)	0.5 (+130)	5 (+97)	0.18
Classification	sGRB + extended X-rays	hGRB	sGRB
Identifying macronova	in I/F814W	in I/F814W	in F160W
Macronova peak luminosity	$\sim 10^{41}$ erg s^{-1} (I)	$\sim 10^{41}$ erg s^{-1} (I)	$\sim 10^{41}$ erg s^{-1} (F160W)
M_{ej}‖	$\sim 0.05\,M_\odot$	$\sim 0.1\,M_\odot$	$\sim 0.03\,M_\odot$
$R_{MN/X}$¶	~1	~0.1	~0.4

*Villasenor *et al.*[29] and this work.
†Gehrels *et al.*[21], Yang *et al.*[25] and Jin *et al.*[26].
‡Tanvir *et al.*[19], Berger[20] and Hotokezaka *et al.*[64].
§The durations include that of the hard spike and the 'extended emission' (in the bracket).
‖The M_{ej} is estimated from the dynamical ejecta model and the value can change by a factor of a few due to uncertainties in the opacity, nuclear heating, and ejecta morphology.
¶$R_{MN/X}$ denotes the ratio between the macronova 'peak' luminosity and the simultaneous X-ray luminosity.

Zhi-Ping et al. 2016

Search for short GRB merger ejecta

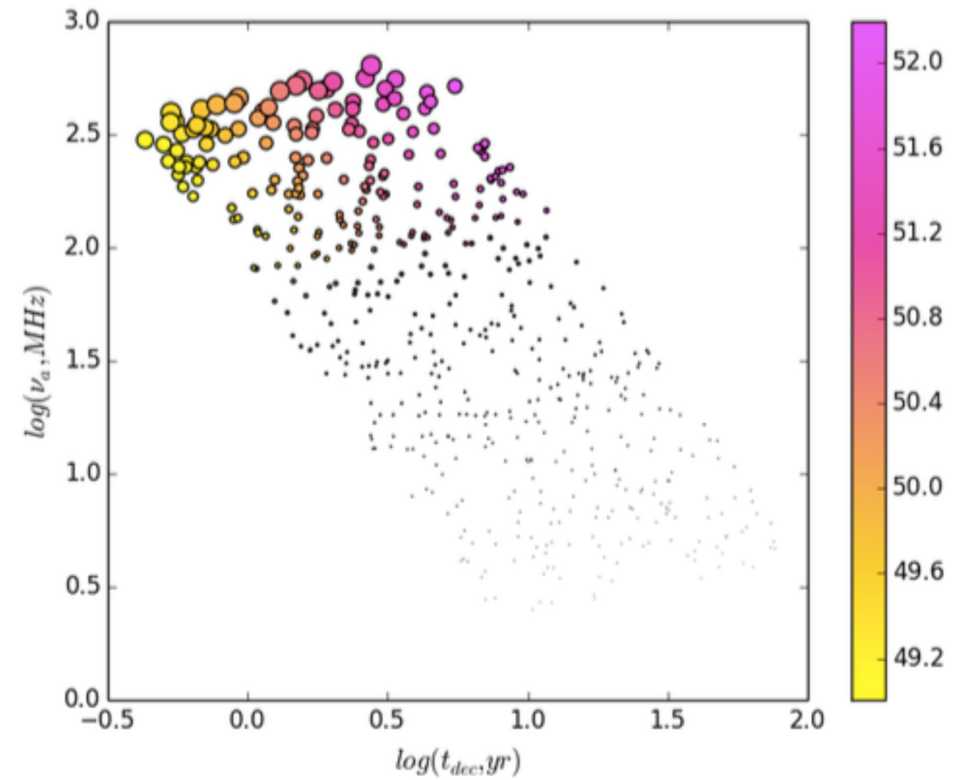
- ★Short GRBs thought to be coming from the merger of binary compact objects - NS-NS or a NS-BH; In case of DNS merger, the remnant could be a magnetar (long or short lived)

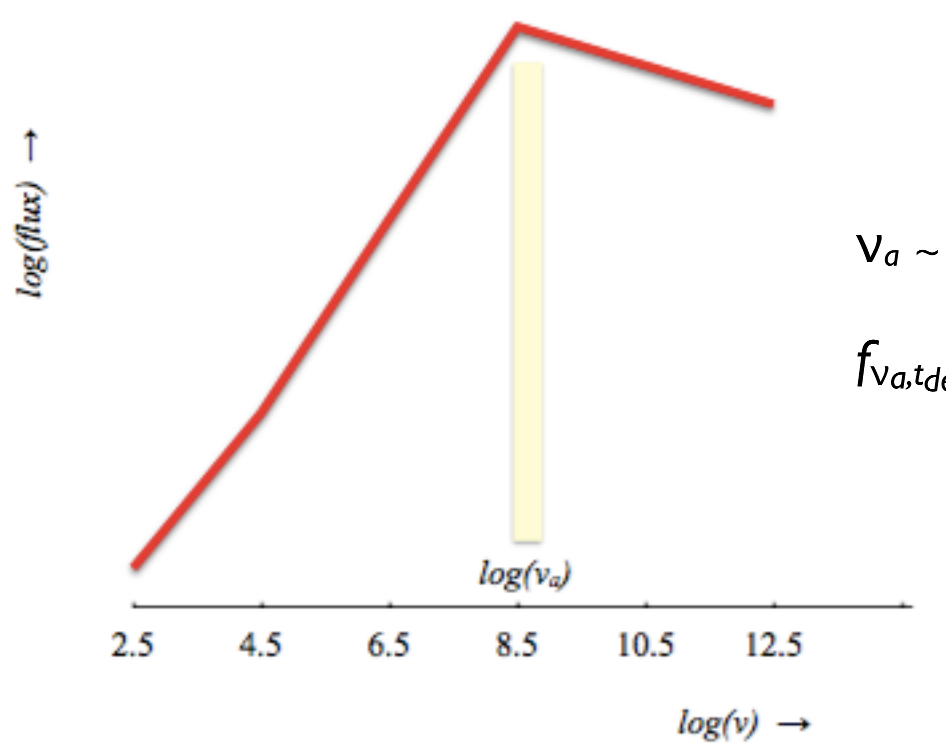
- ★Excess emission in X-ray afterglows of short GRBs due to an additional component - most likely a magnetar; In such cases the wind from the magnetar can further boost the kinetic energy of the ejecta in the merger and increase the radio flux

- ★The radio flux is expected to peak around the time of deceleration of the shock (~5-10 yrs since the burst)

- ★*GMRT* observations aimed at searching the ***signature of merger ejecta powered by a magnetar*** (GRBs 050709 and 061210) at 610 and 325 MHz. 16 hours.

- ★If detected it will be the first ever detection of tidal ejecta in radio confirming the merger origin of short GRBs. Previous studies done at high frequencies with VLA resulted in upper limits





$\nu_a \sim 1GHz E_{49}^{0.1} n_0^{0.6} \beta_0$

$f_{\nu a, t_{dec}} \sim 0.5 mJy E_{49} n_0^{1/2} \beta_0 / d_{27}^2$