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Gamma-Ray Bursts: Progress & Problems

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Zhang & Meszaros (2004) list of problems

Fireball content: kinetic energy or magnetically dominated?

GRB location: internal or external?

GRB emission mechanism: synchrotron and/or other?

GRB jet: uniform or quasi-universal?

Long burst progenitor: collapsar or supranova?

Central engine: what is behind?

Environment: what is in front?

Shock parameters: universal or unpredictable?

GAMMA-RAY BURSTERS AT COSMOLOGICAL DISTANCES

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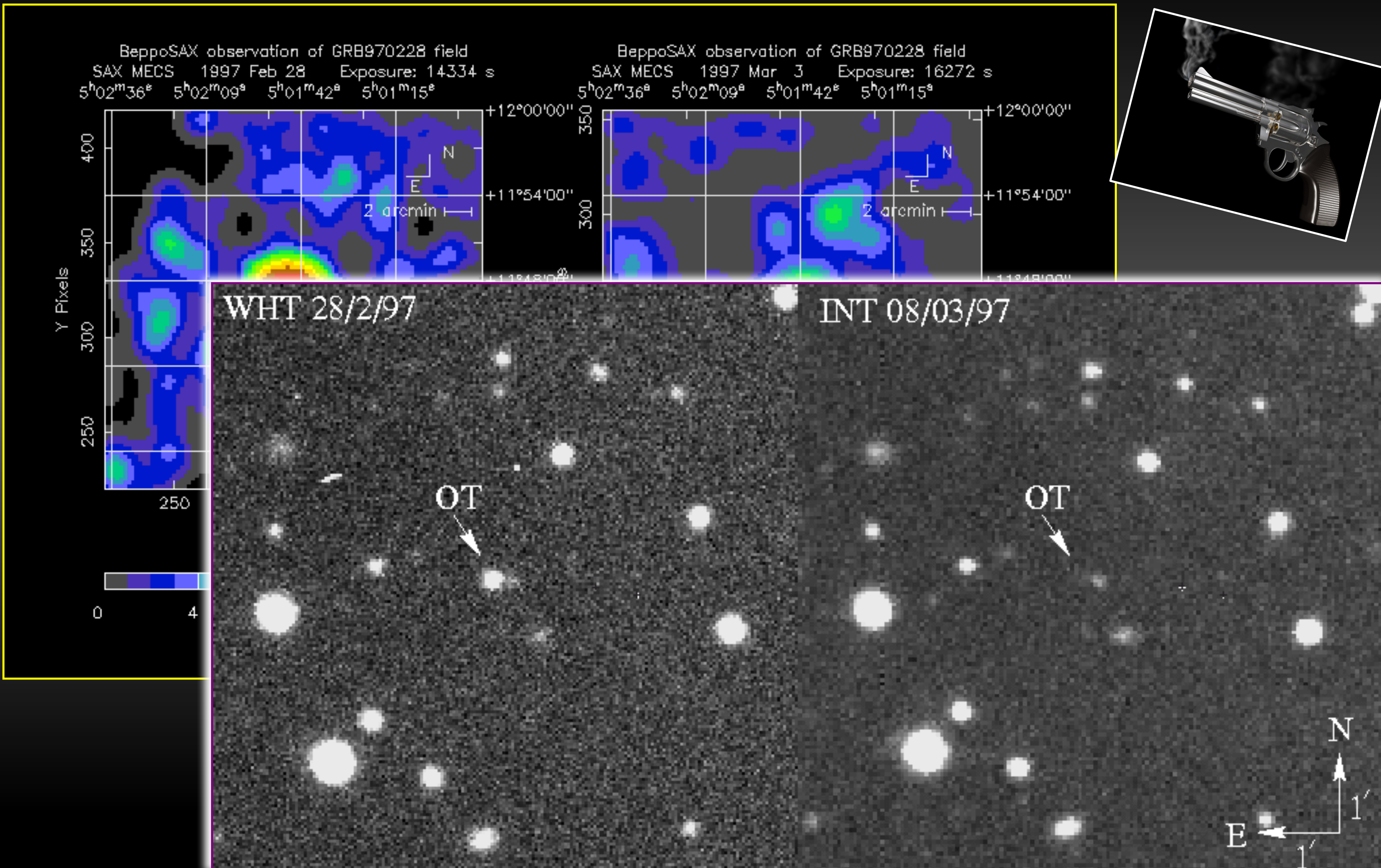
ABSTRACT

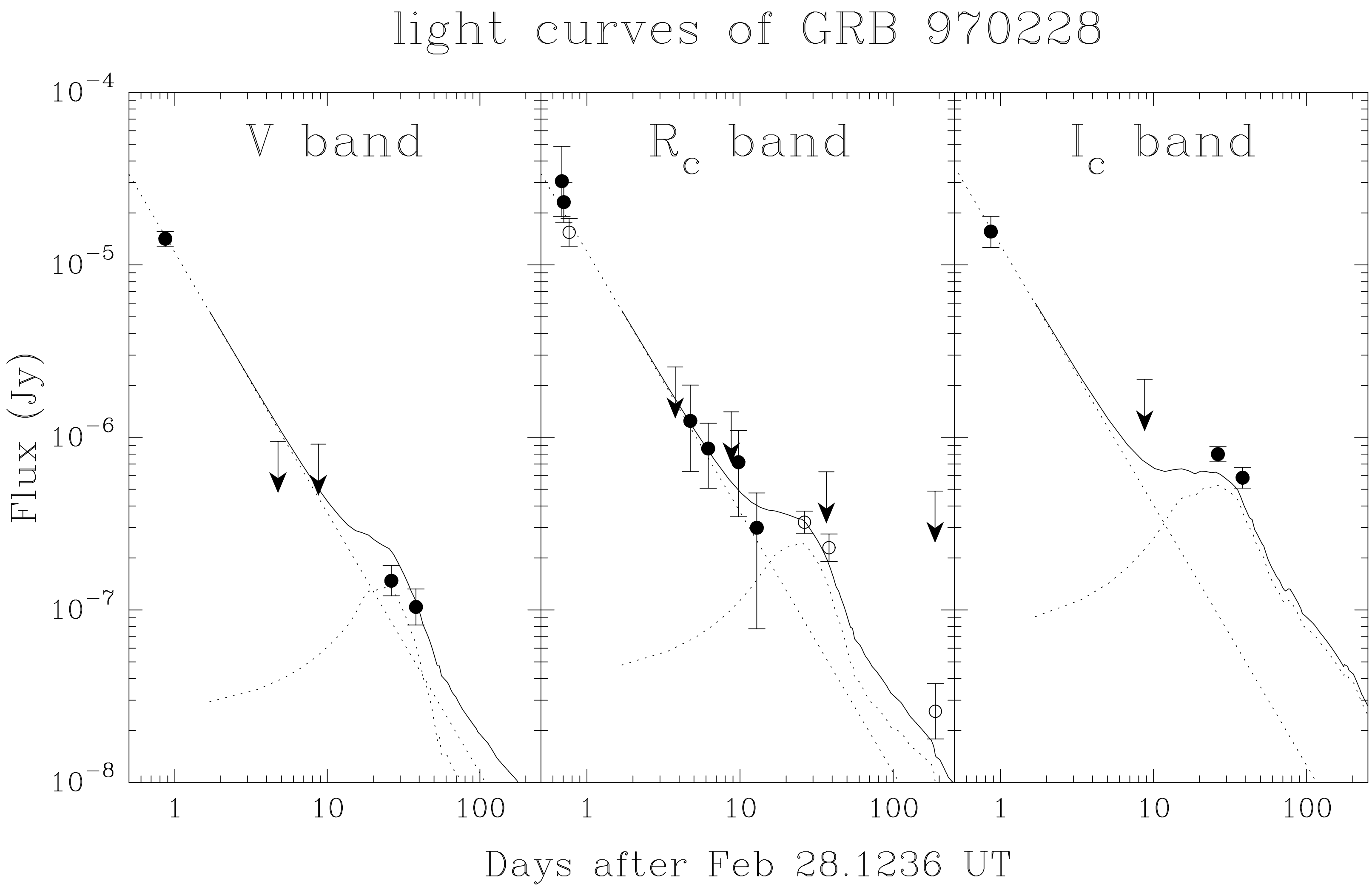
We propose that some, perhaps most, gamma-ray bursters are at cosmological distances, like quasars, with a redshift $z \approx 1$ or $z \approx 2$. This proposition requires a release of supernova-like energy of about 10^{51} ergs within less than 1 s, making gamma-ray bursters the brightest objects known in the universe, many orders of magnitude brighter than any quasars. This power must drive a highly relativistic outflow of electron-positron plasma and radiation from the source. The emerging spectrum should be roughly a black body with no annihilation line, and a temperature $T \approx (E/4\pi r_0^2 \sigma)^{1/4}$. As an example the spectrum would peak at about 8 MeV for the energy injection rate of $\dot{E} = 10^{51}$ ergs s^{-1} and for the injection radius $r_0 = 10$ km.

Paczynski (1986) – he was (mostly) right!

GRB 970228

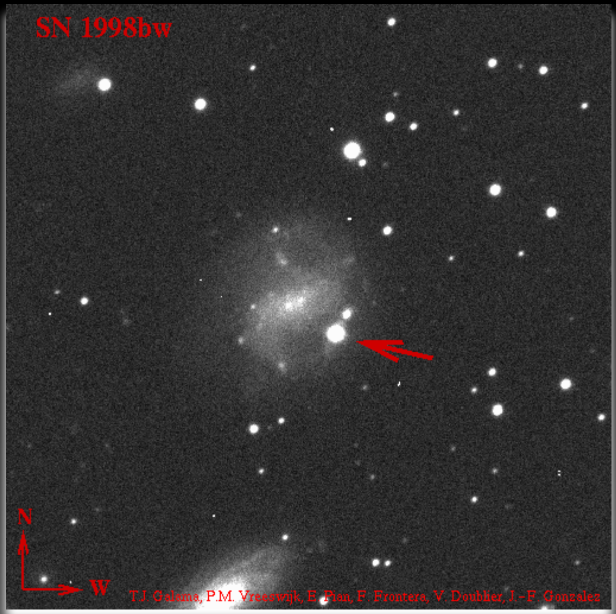
van Paradijs et al. 1997; Costa et al. 1997





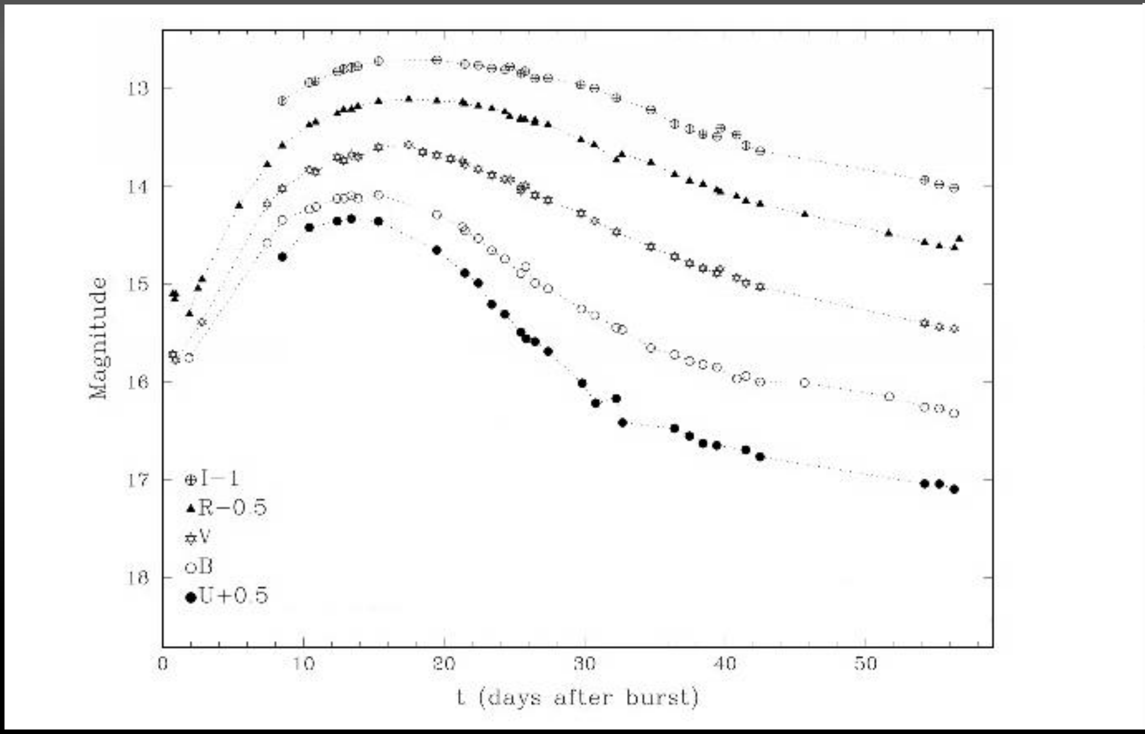
Galama et al. 2000

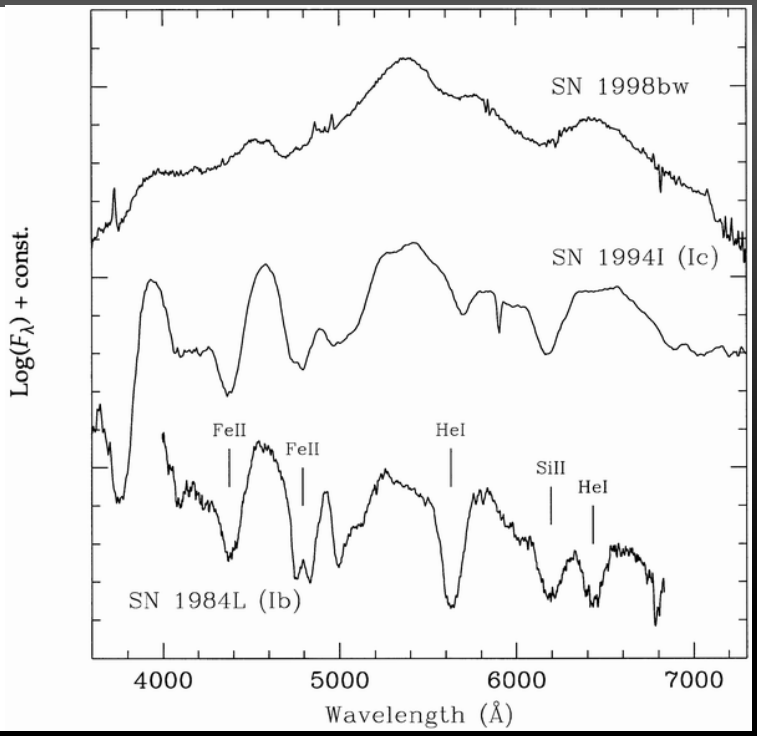
GRB 980425/SN98bw



Galama et al. 1998

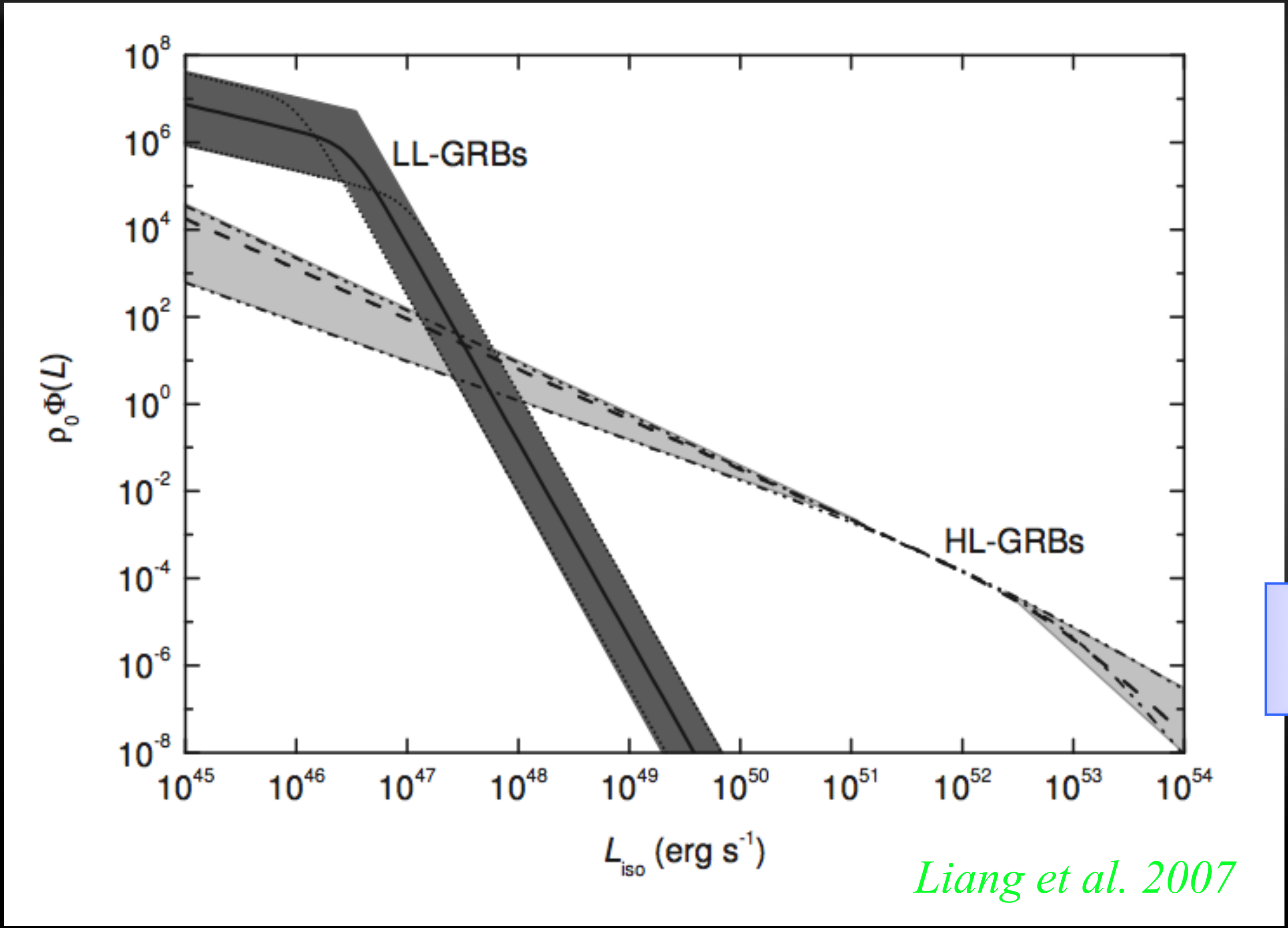
Type Ic with broad lines indicative of expansion velocities >~20000 km/s





Low-luminosity bursts

Suggestion of a distinct population from luminosity function.

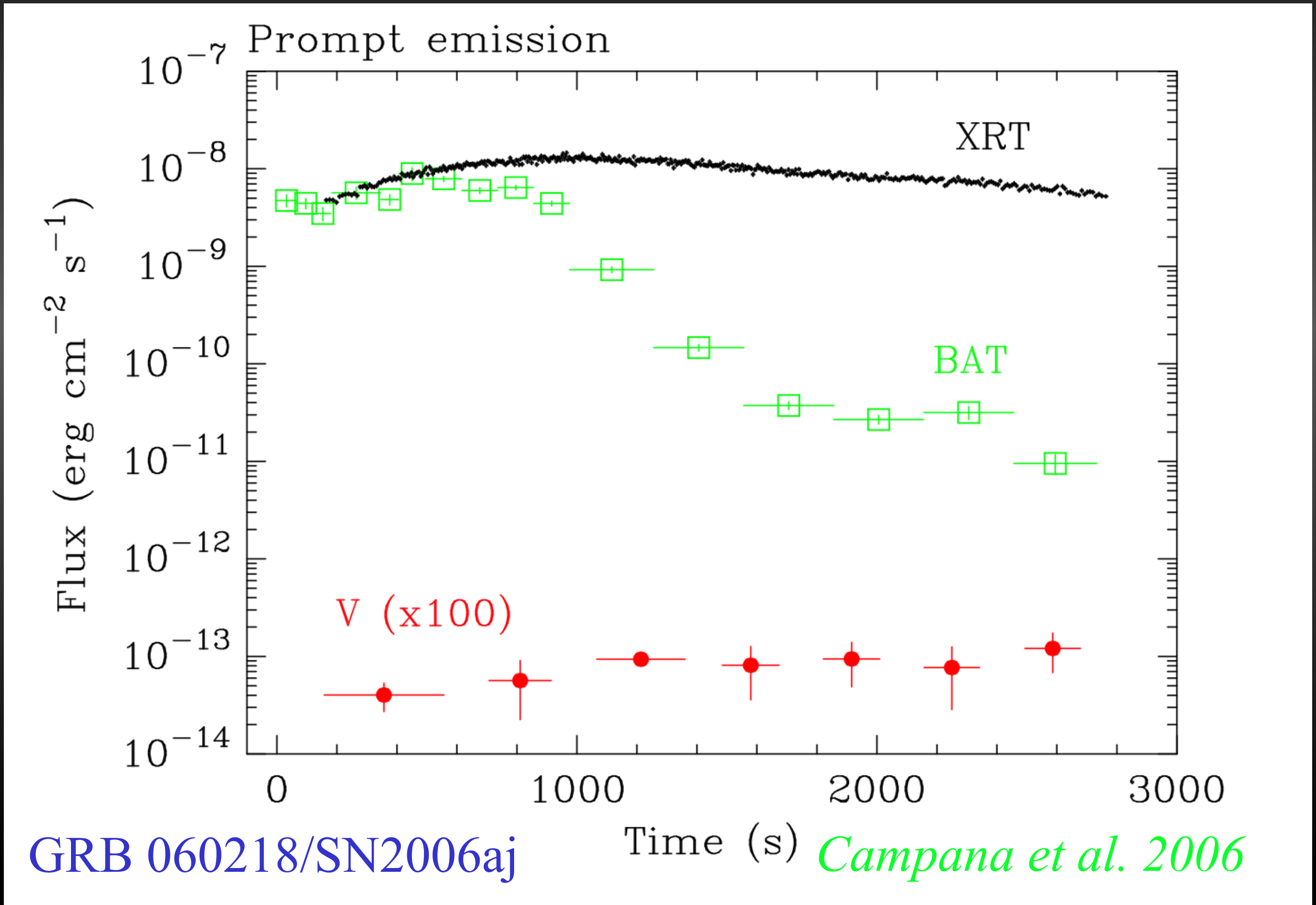


Liang et al. 2007

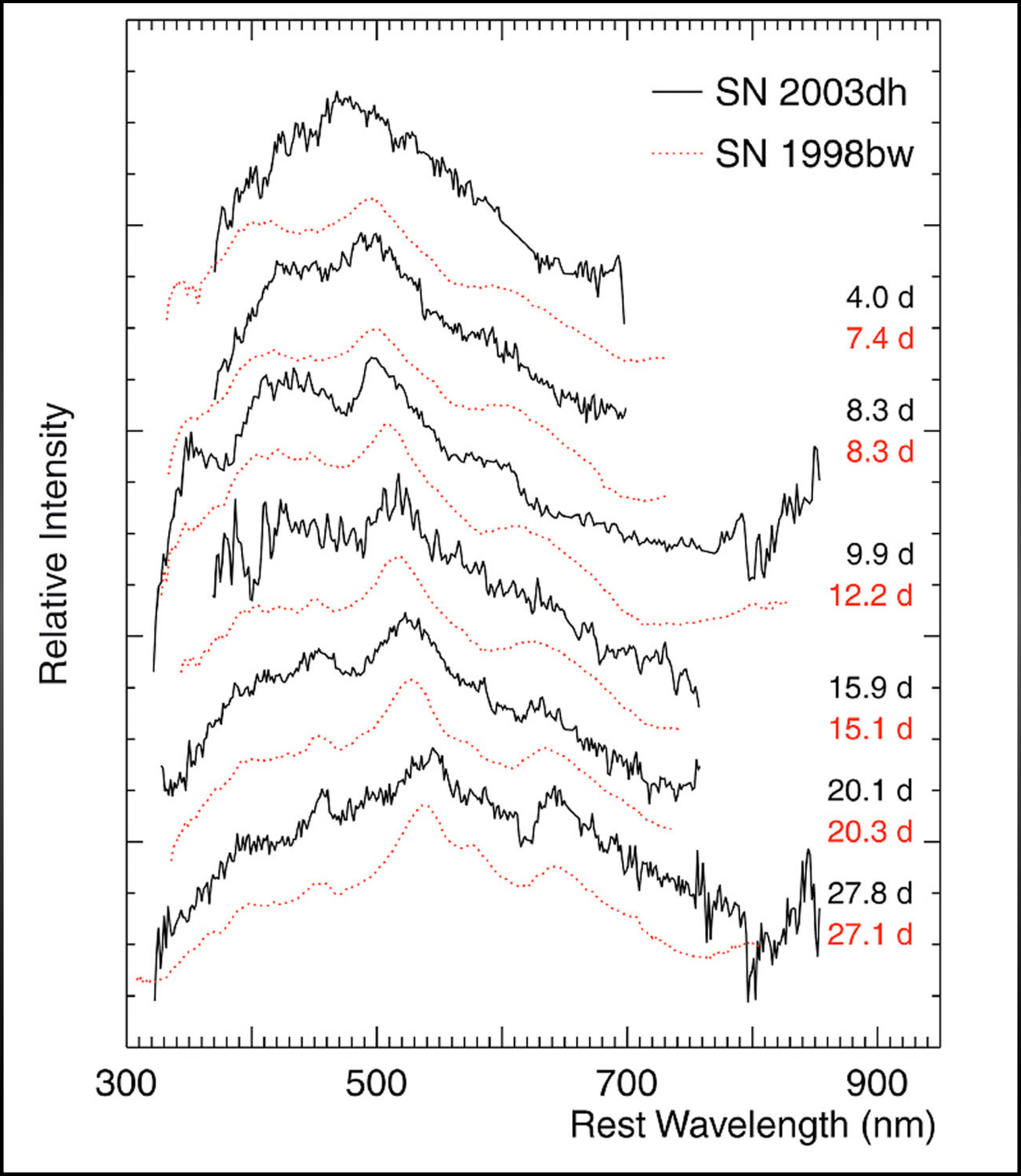
Are low-lum bursts same?

Low-luminosity bursts

In some cases, unusual soft and long-lived "prompt" emission – shock breakout rather than internal shocks? (Campana et al. 2006; Bromberg et al. 2011; Nakar 2015)

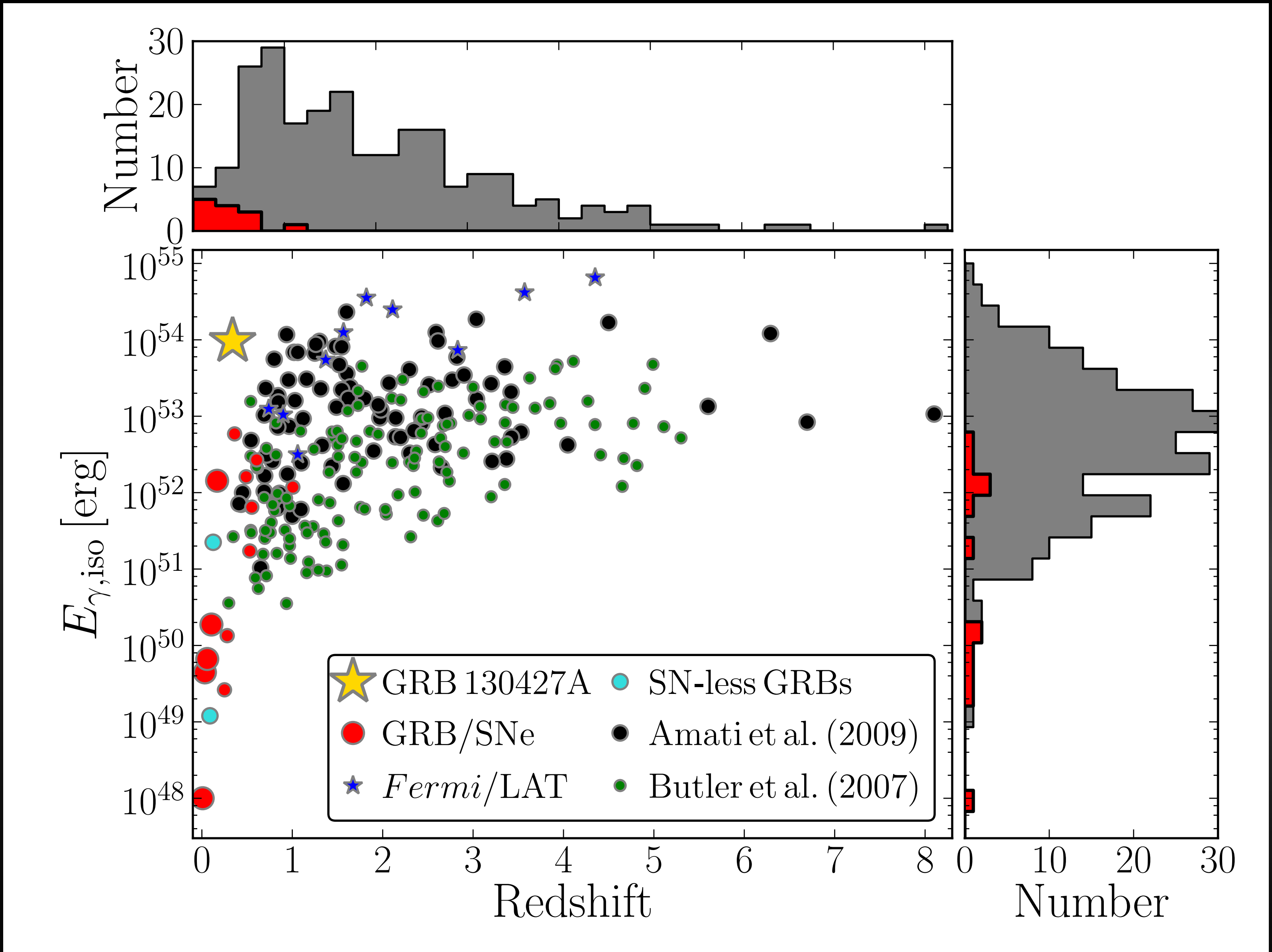


GRB 030329/ SN2003dh



First SN associated with "high luminosity" GRB.

Hjorth et al. 2003

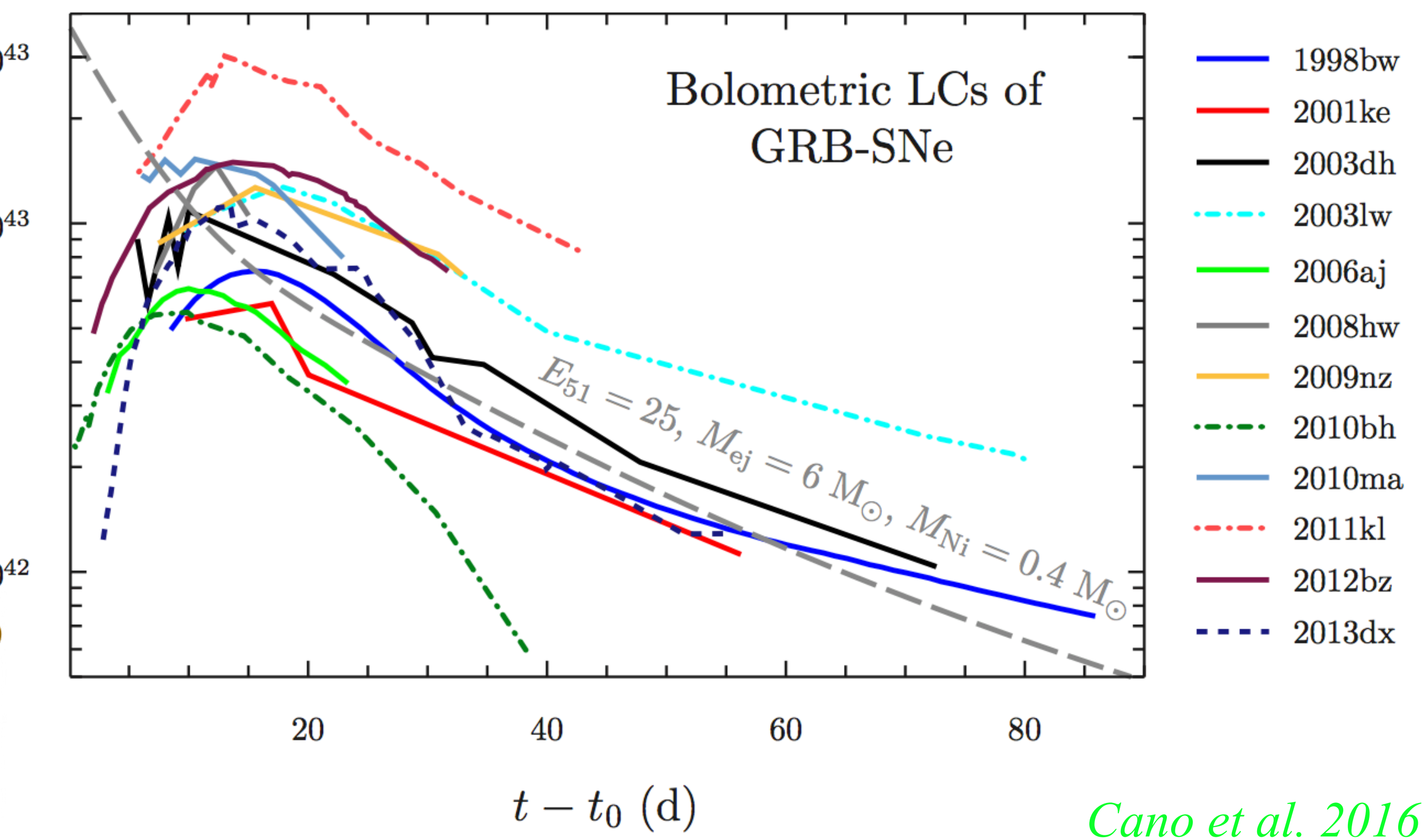


Xu et al. 2013

GRB 130427A/SN2013dq

Similarity of GRB-SN

Despite the ~6 order of mag difference in GRB luminosity, the accompanying SNe look rather similar, including possible peak-mag decline-rate relationship.

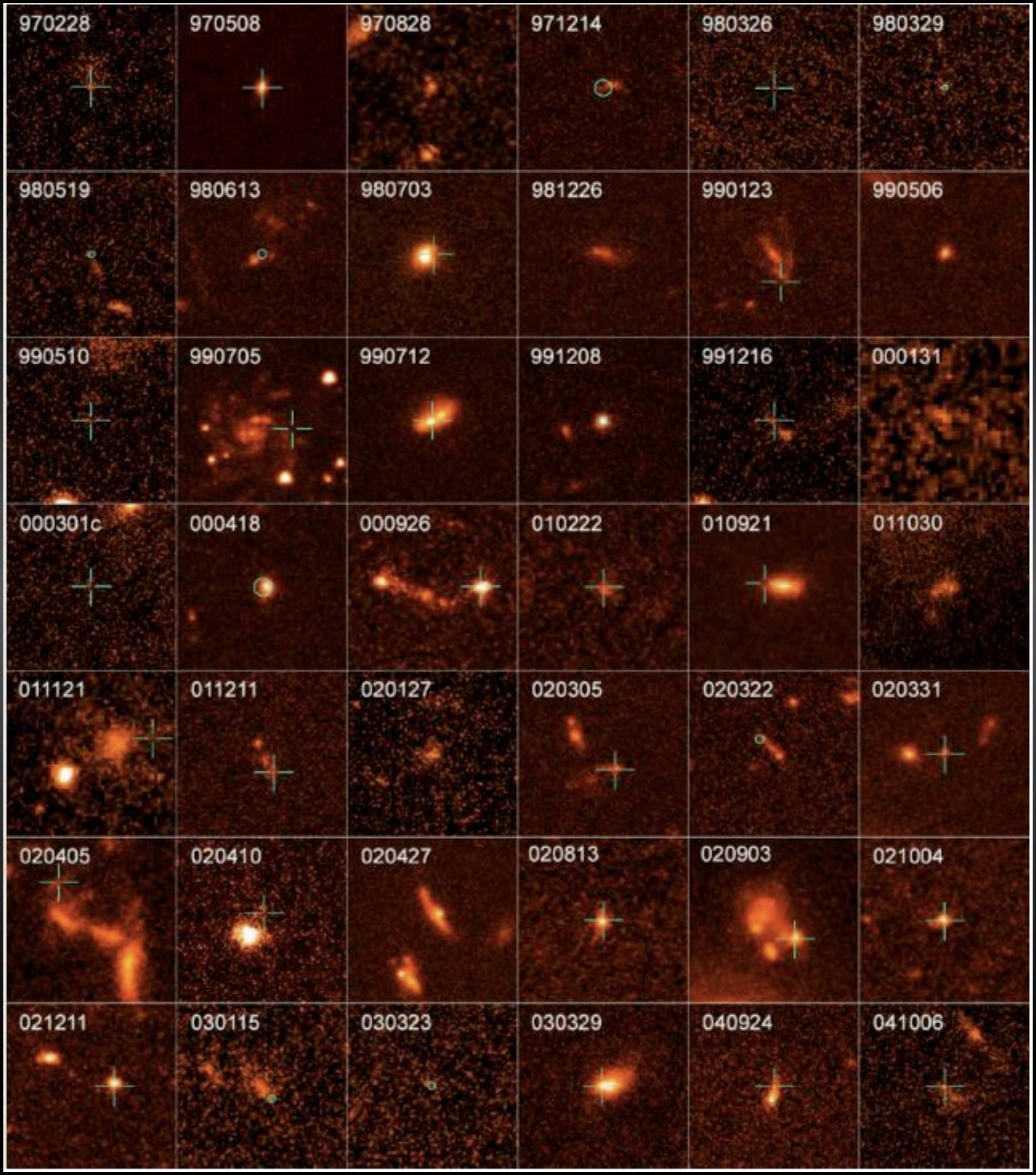


Cano et al. 2016

Hosts

Actively star forming, typically low luminosity, irregular, low(ish) metallicity.

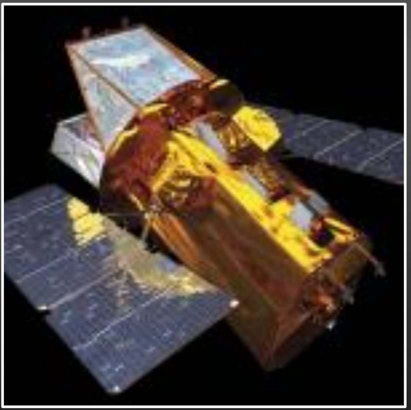
Generally trace brightest regions of star formation, suggestive of short-lived (<~10 Myr) massive star progenitor.

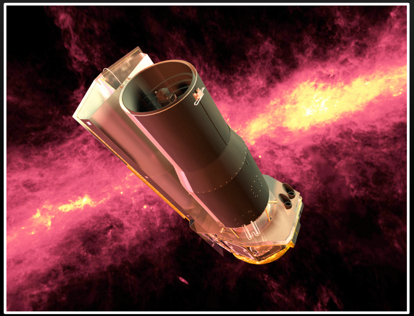


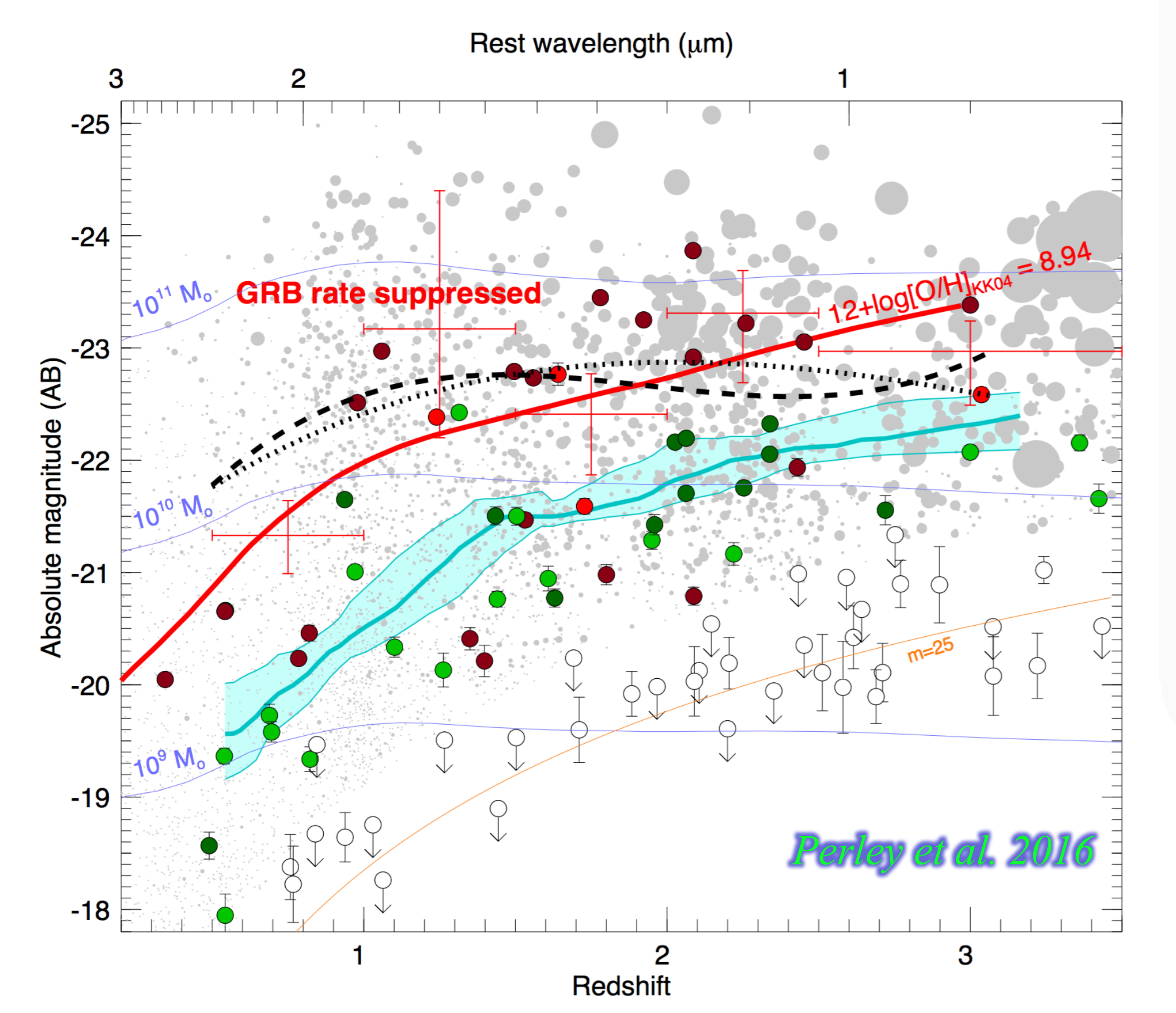
Fruchter et al. 2006

GRBs seem to roughly follow sub-solar metallicity SF

10-20% of GRBs occurring in relatively massive and dusty hosts, but still not unbiased tracer of all star formation.

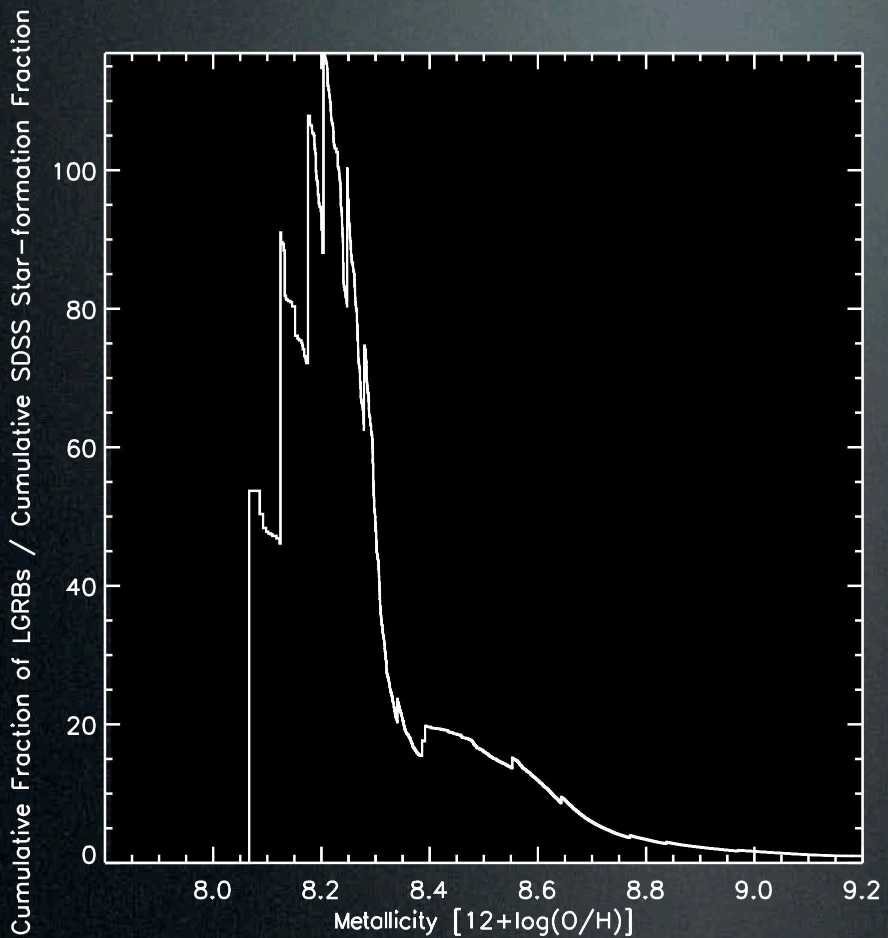






GRBs seem to roughly follow sub-solar metallicity SF

Rate vs. Metallicity



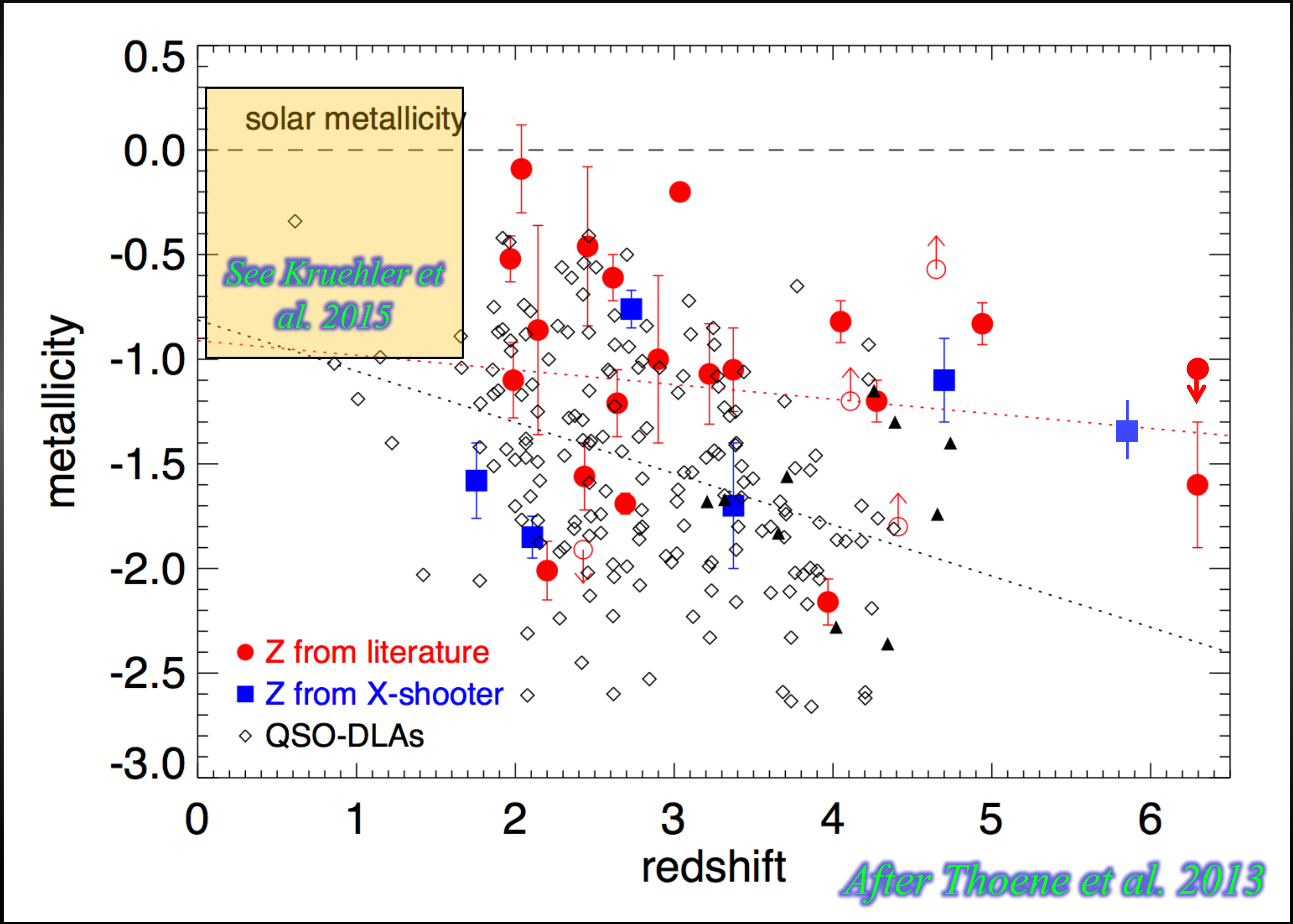
LGRBs have a strong intrinsic preference for low metallicity environments.

Somewhat lower *Z* cut-off from the lower redshift events (but includes several “low-luminosity” GRBs).

Graham & Fruchter 2016

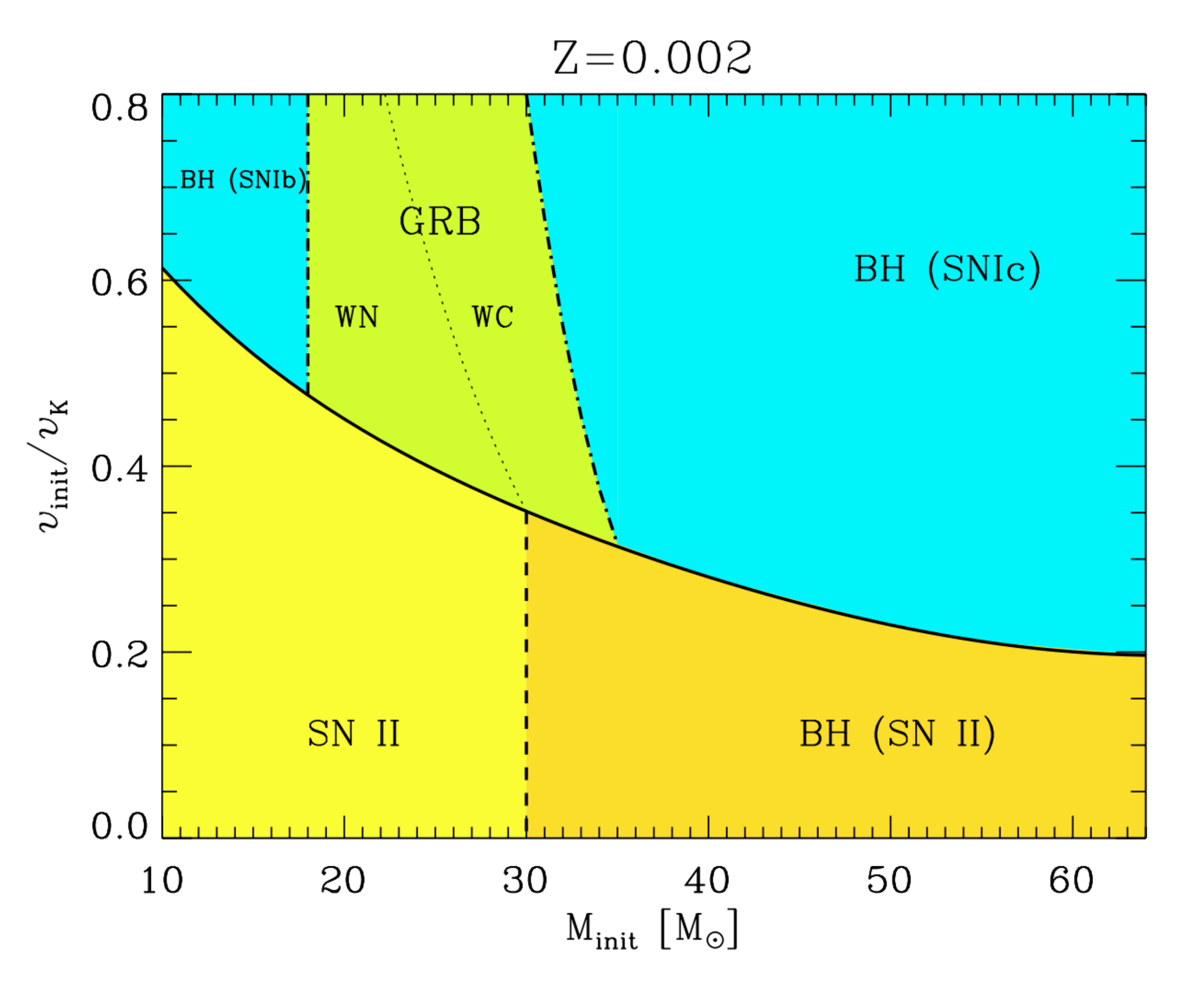
The environments

From hosts and afterglow spectroscopy, mostly low (at least ~sub-solar) metallicity.



Single and/or binary channel?

Require rapid rotation, envelope stripped, massive core.

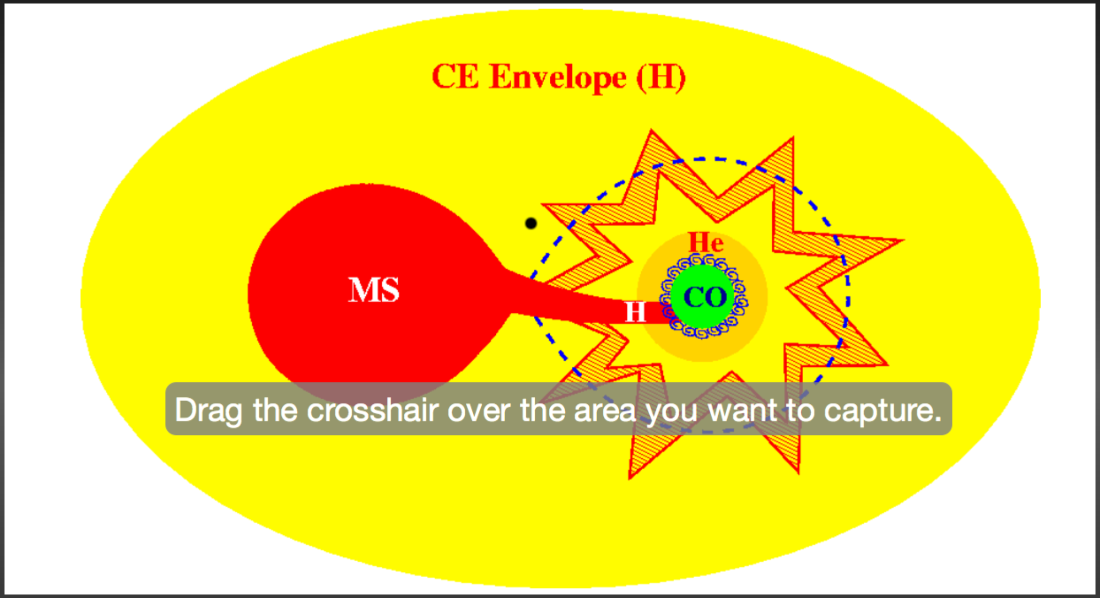


Rapidly rotating single star models ☞ chemically homogeneous evolution ☞ require $Z <\sim 0.1\ Z_\odot$ to give sufficient final angular momentum to make GRBs

Yoon et al. 2006

Single and/or binary channel?

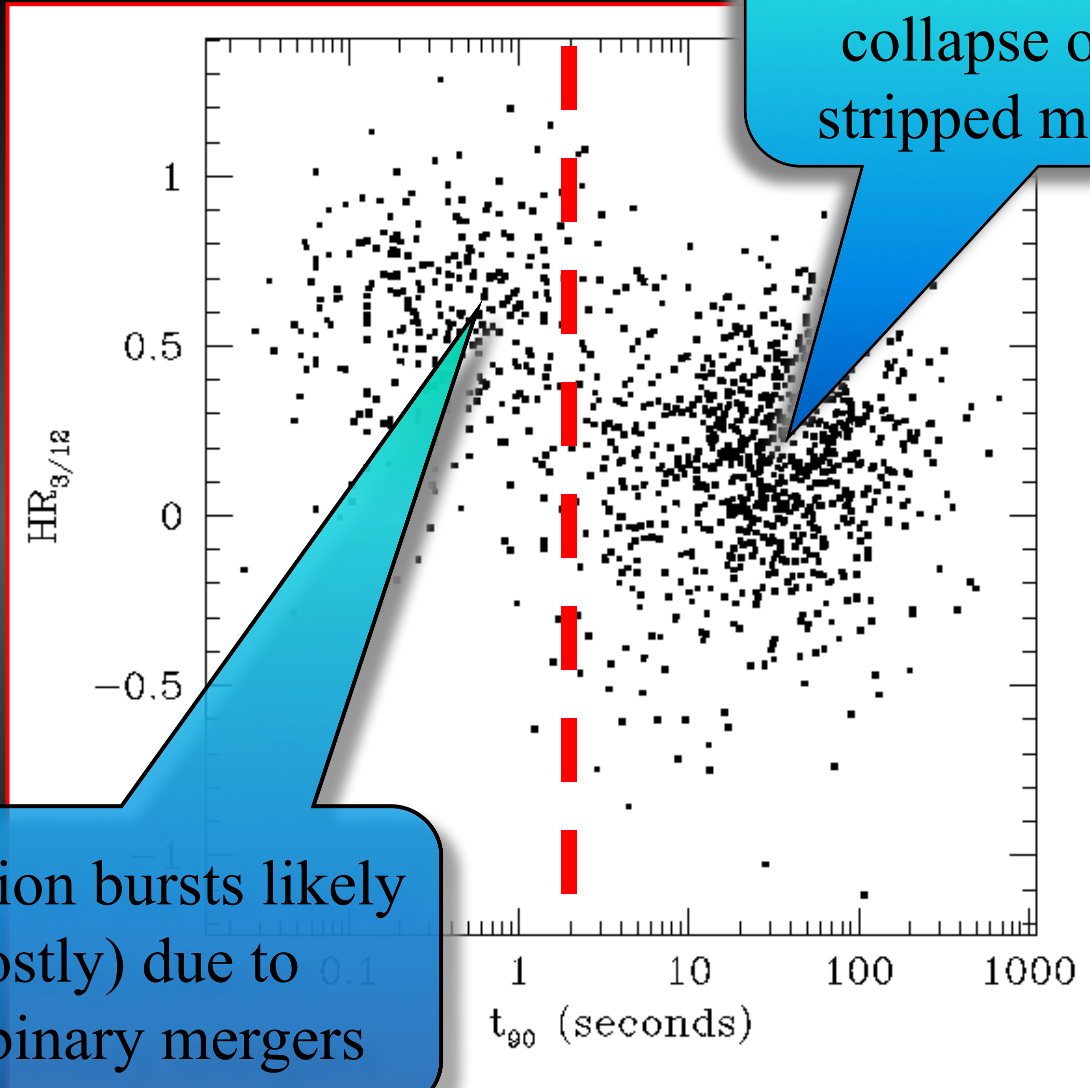
Require rapid rotation, envelope stripped, massive core.



Binaries also hard to to prevent loss of J. One possibility is explosive common envelope ejection during case C mass transfer ☞ should work up to solar metallicity.

Podsiadlowski et al. 2010

GRB populations



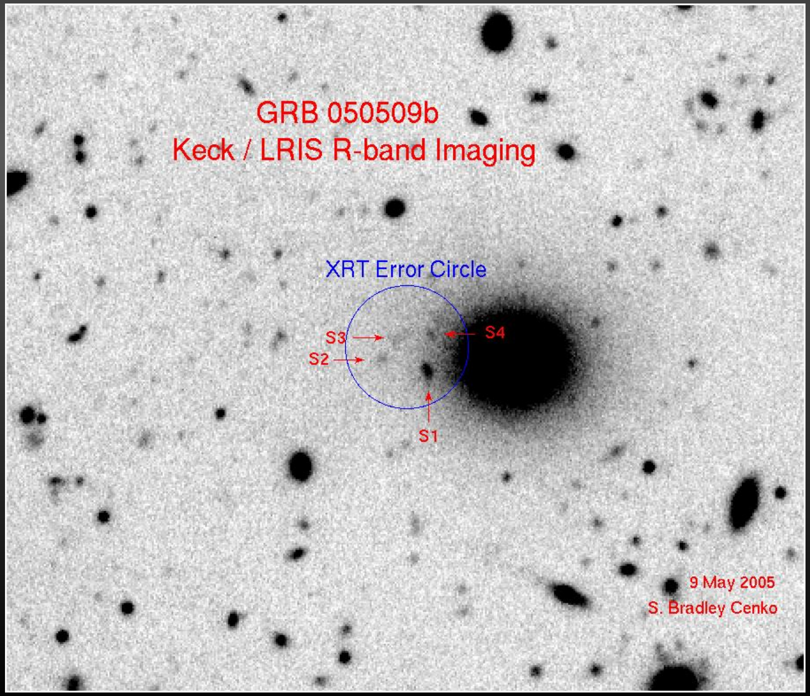
Classical long bursts are associated with core collapse of some H-stripped massive stars

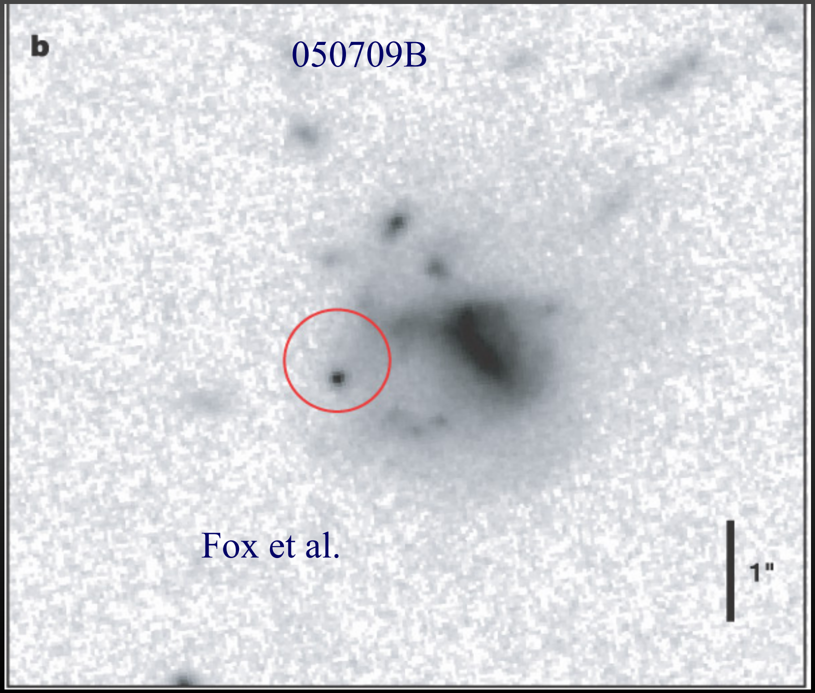
Short duration bursts likely are (mostly) due to compact binary mergers

Kouveliotou et al. 1993

Short-duration bursts

Thanks largely to *Swift*, many tens of short GRBs have now been rapidly localised to few arcsec accuracy, allowing identification of likely hosts, and hence redshifts in some cases.



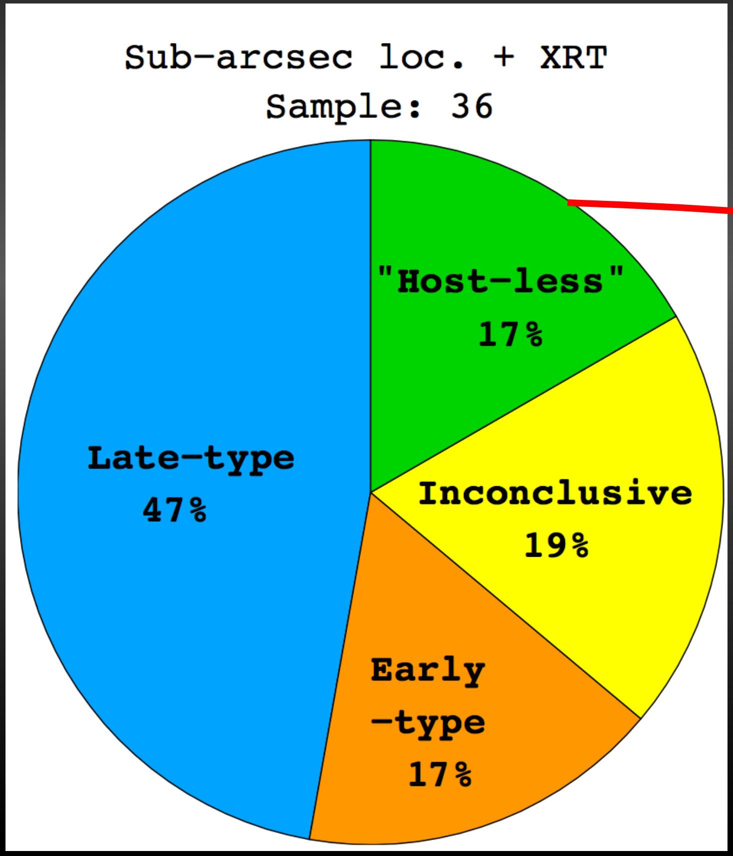


Short-hard GRBs - compact binary mergers?

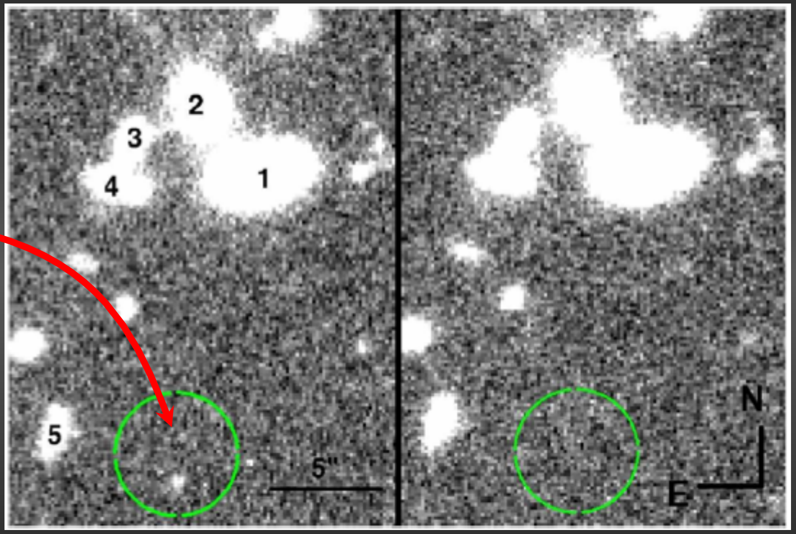
Associated with a range of host stellar populations.

Sometimes apparently far from their host.

e.g. GRB090515 afterglow R~26.5 at 2 hours post burst. No obvious host.



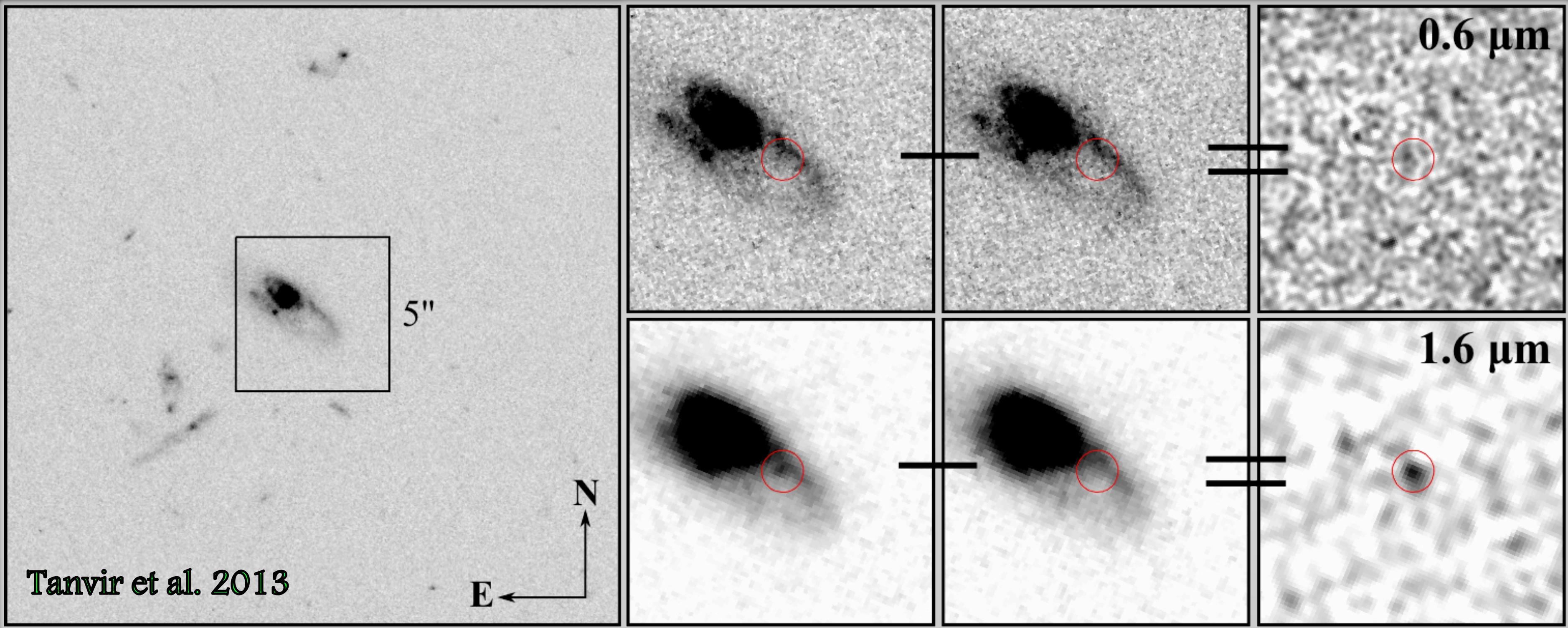
Fong et al. 2013



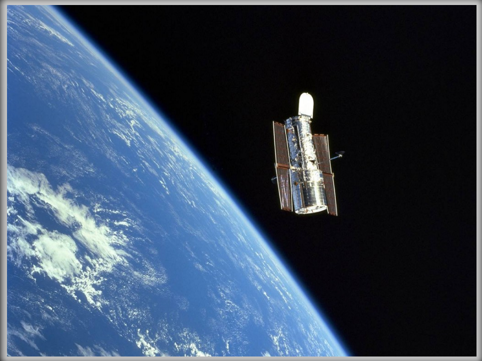
Rowlinson et al. 2010

Evidence generally consistent with compact binary merger origin.

GRB 130603B

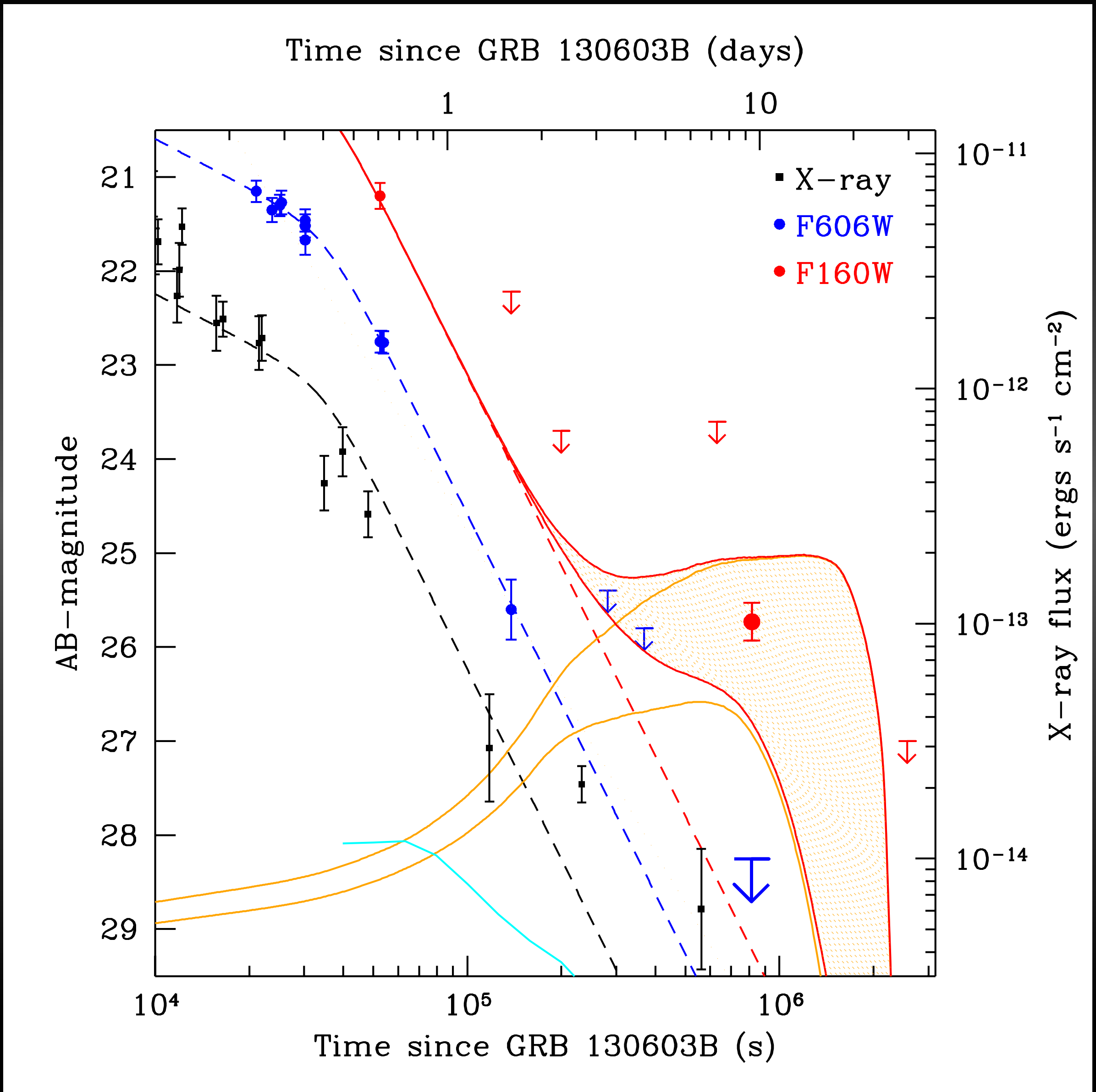


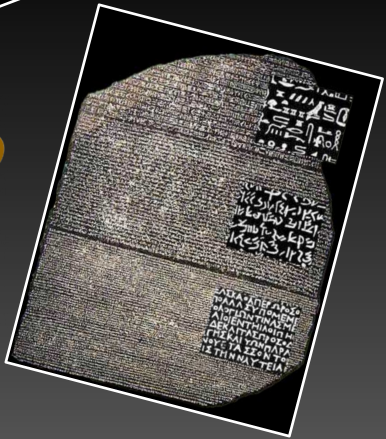
Transient emission seen in near-infrared in *HST* imaging at 9 days post-burst.



Consistent with high opacity due to synthesised r-process elements ☞ line-blanketing of optical light.

GRB 130603B



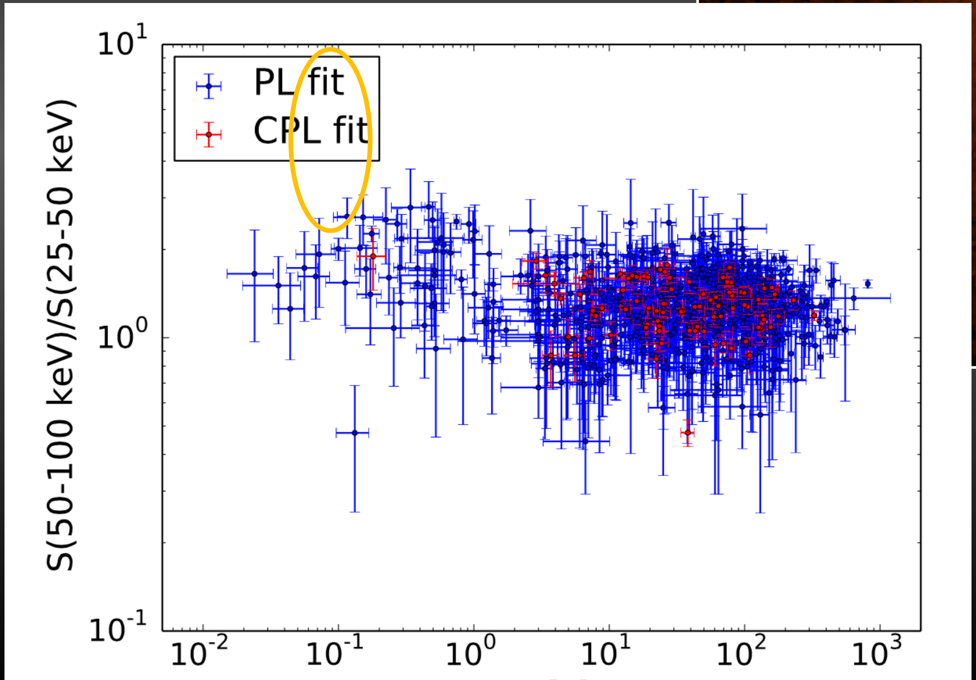


Comparison to Barnes & Kasen (2013) models suggests ejected mass ~0.05 $M_\odot$

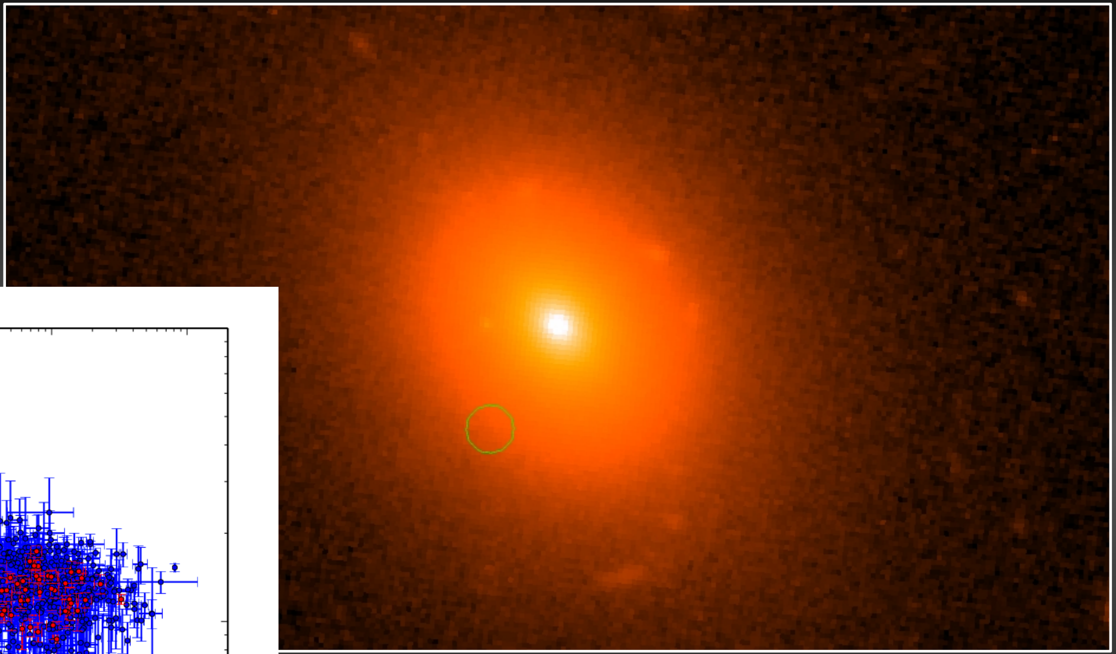
NT et al. 2013
Berger et al. 2013
Fong et al. 2014

GRB 150101B

Z=0.14, but unusually short and unusual host



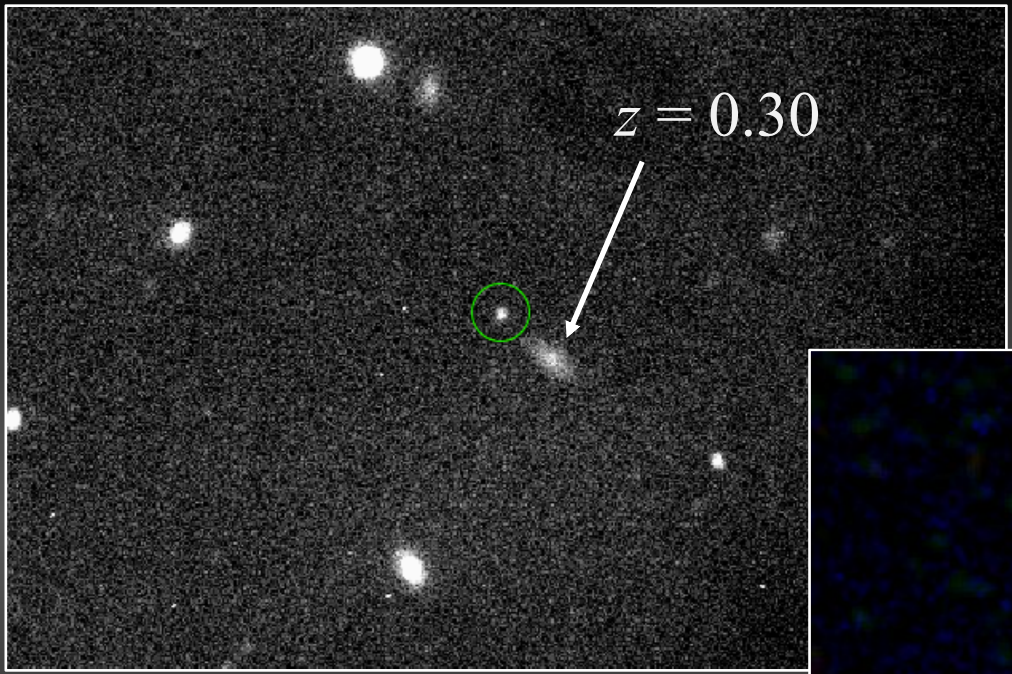
Lien et al. 2016

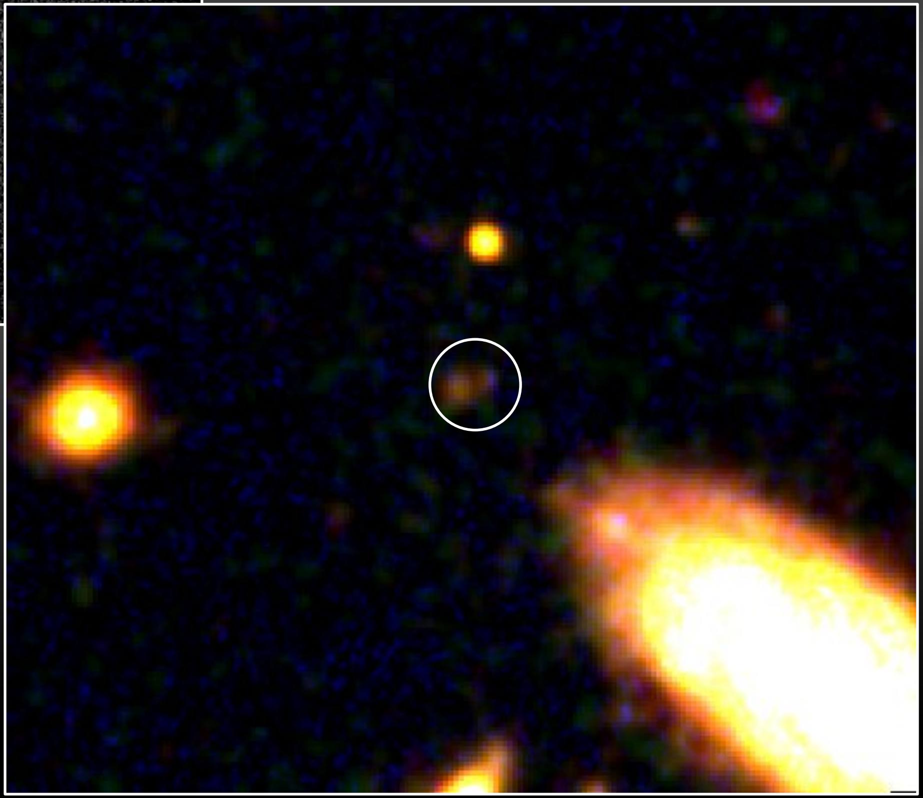


Fong et al. subm.

GRB 150424A

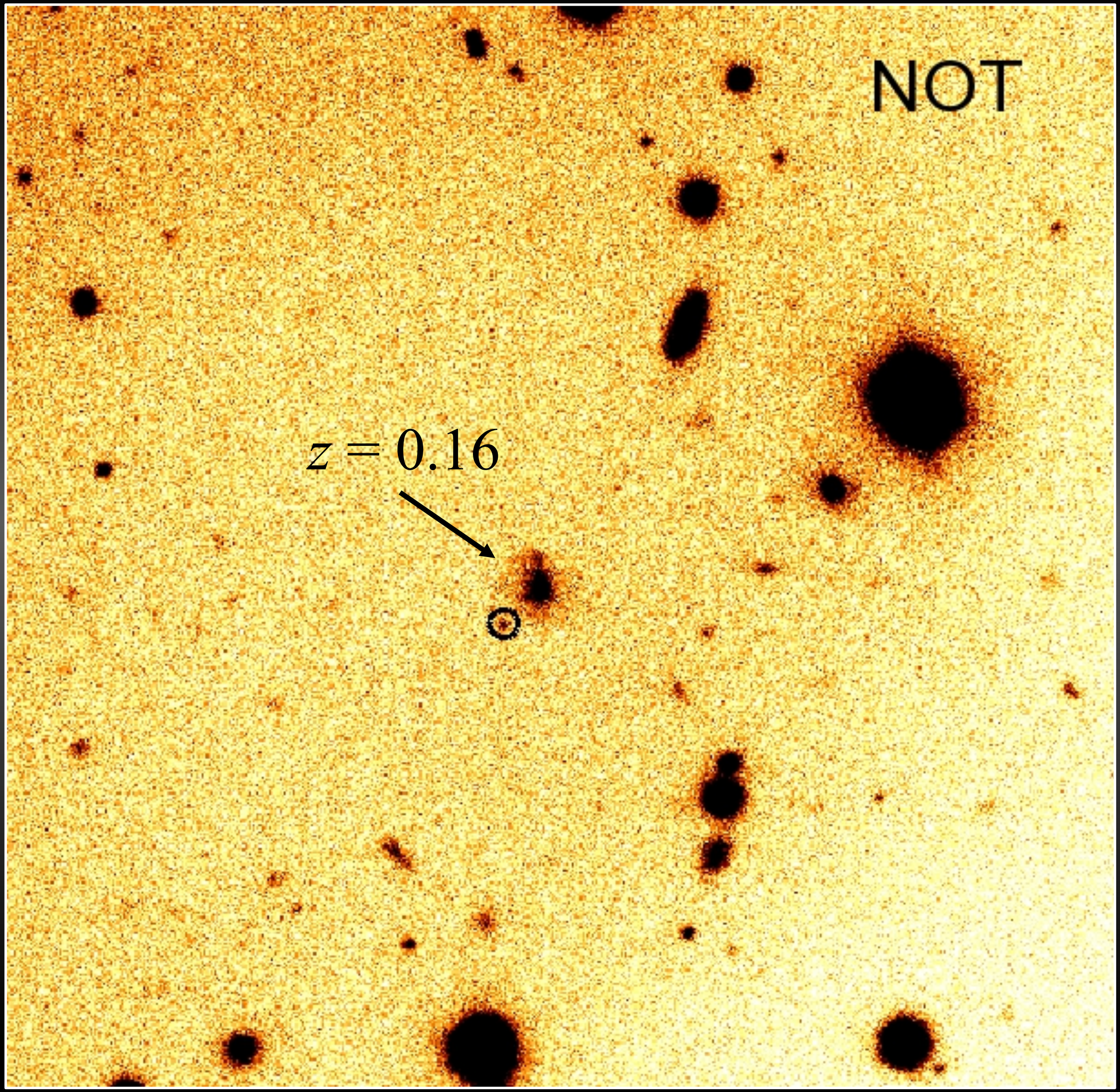
Appears to be in faint background galaxy.





NT et al. in prep.

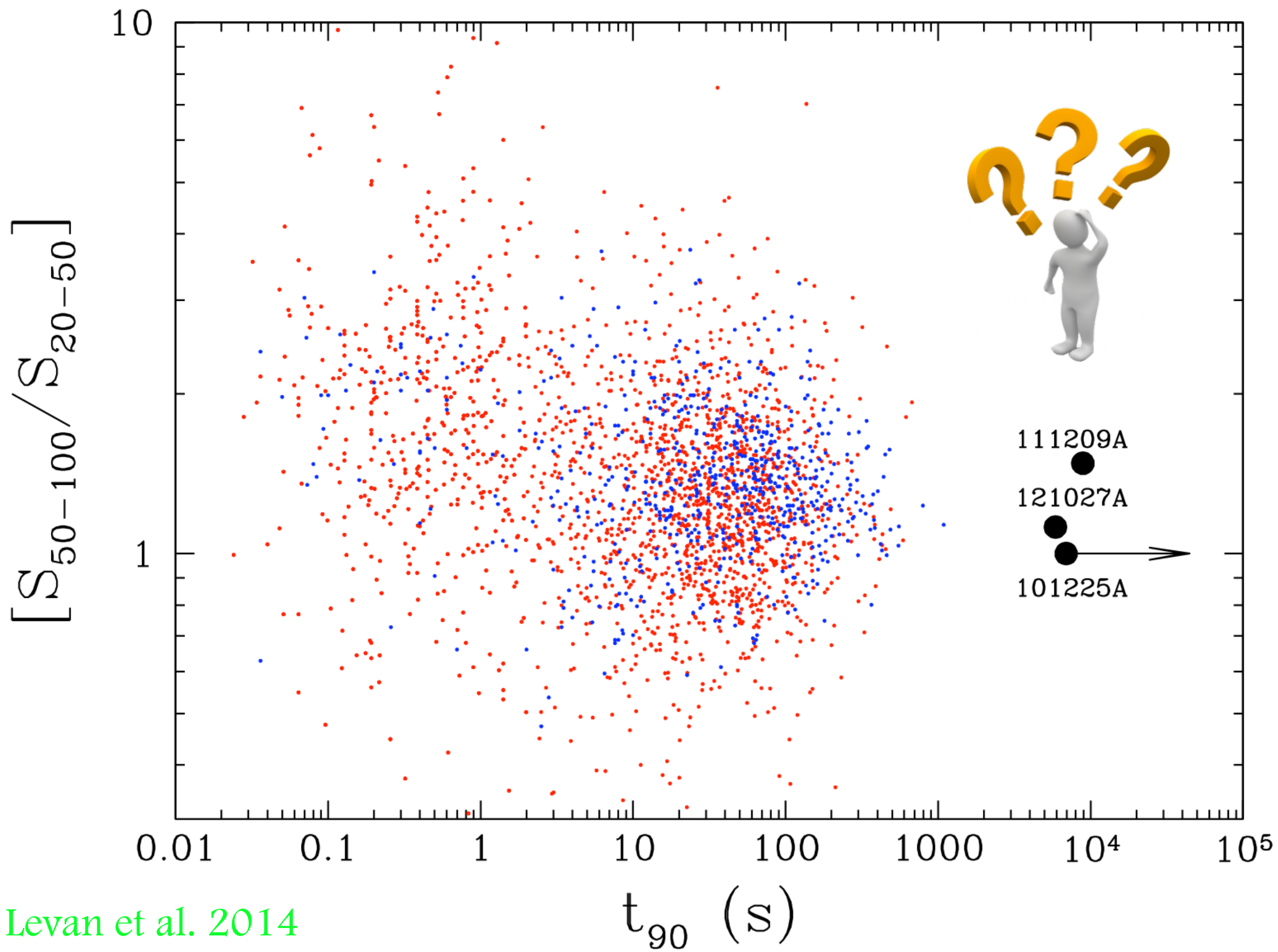
GRB 160821B



Ongoing!

Ultra-long GRBs

New class of very long-lived GRBs



Levan et al. 2014

Is the large diversity (spikiness) of prompt behaviour expected?

Why little evidence of burst properties correlating with environmental properties?

What gives rise to "precursor" episodes, when seen?

Engines – black holes or magnetars or both (or neither)?