ImBaSE 2017 – ESO Garching

Binary interactions and gamma-ray bursts

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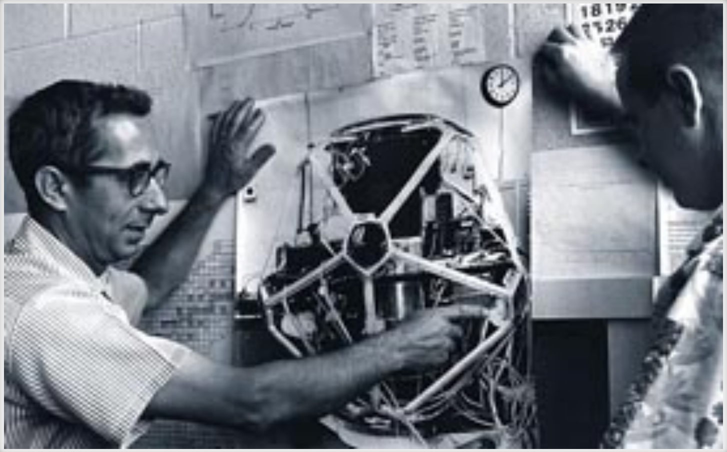
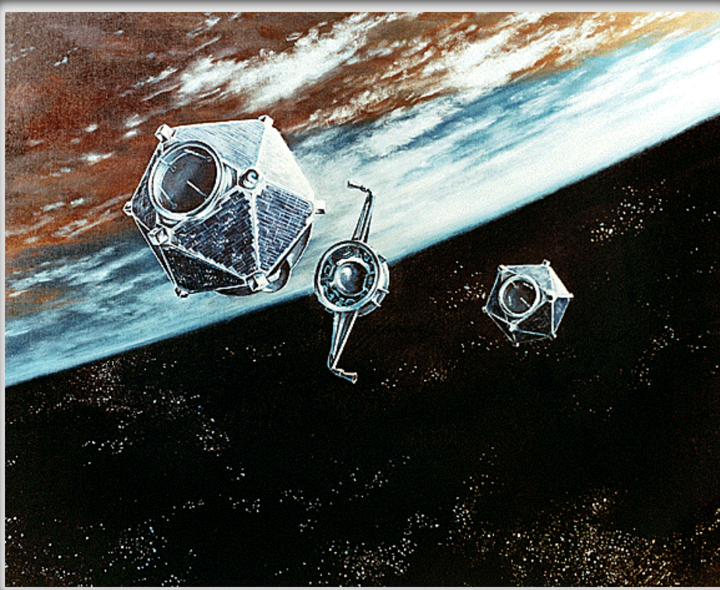
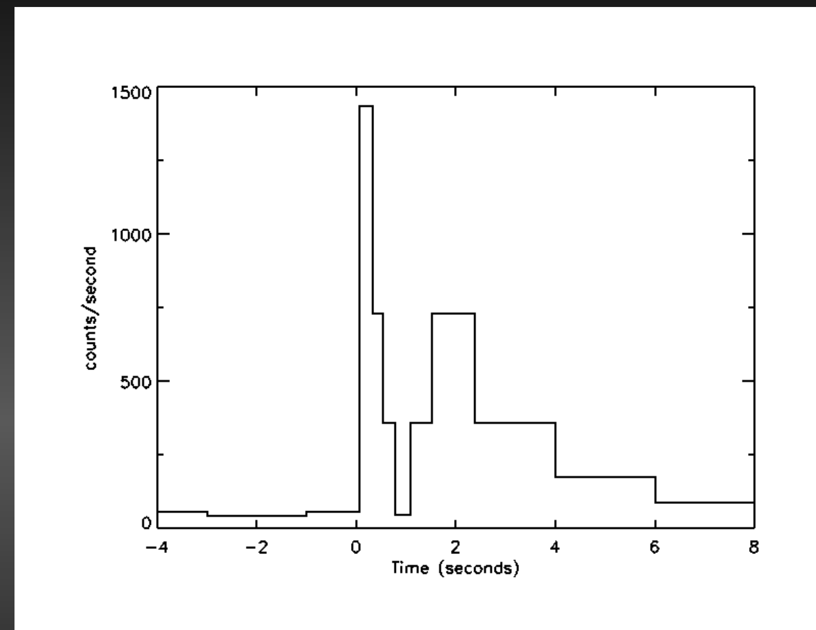
Golden anniversary

Golden anniversary

First known GRB detected 2nd July 1967 by US Vela 4 satellites. *Strong & Klebesadel 1993*



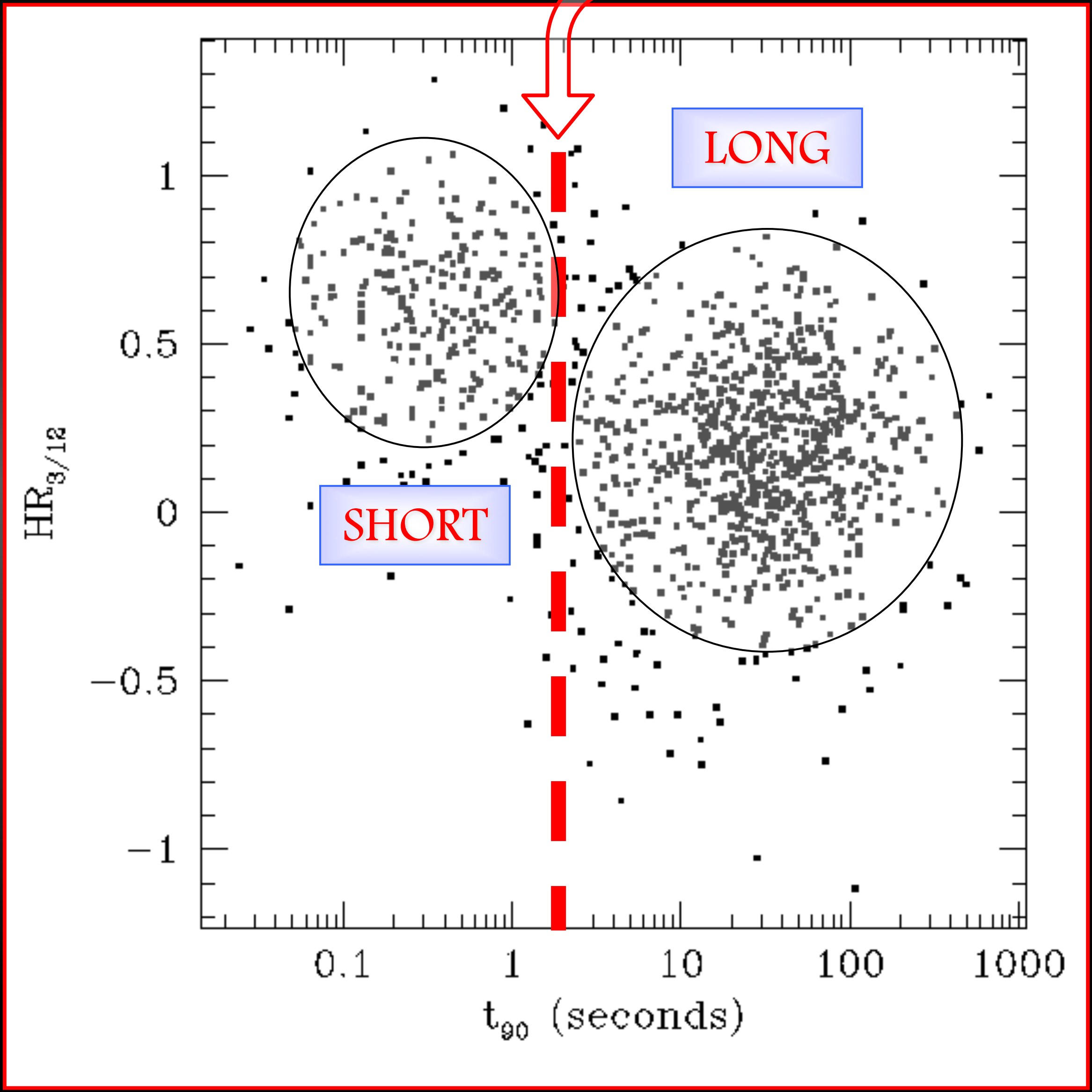




- Rapid variability of prompt emission (in some bursts) suggests compact progenitor.
- Compactness and non-thermal spectrum resolved if emission produced through dissipation after ultra-relativistic expansion.
- Requires low baryon pollution.

Two populations

T_{90}=2 s



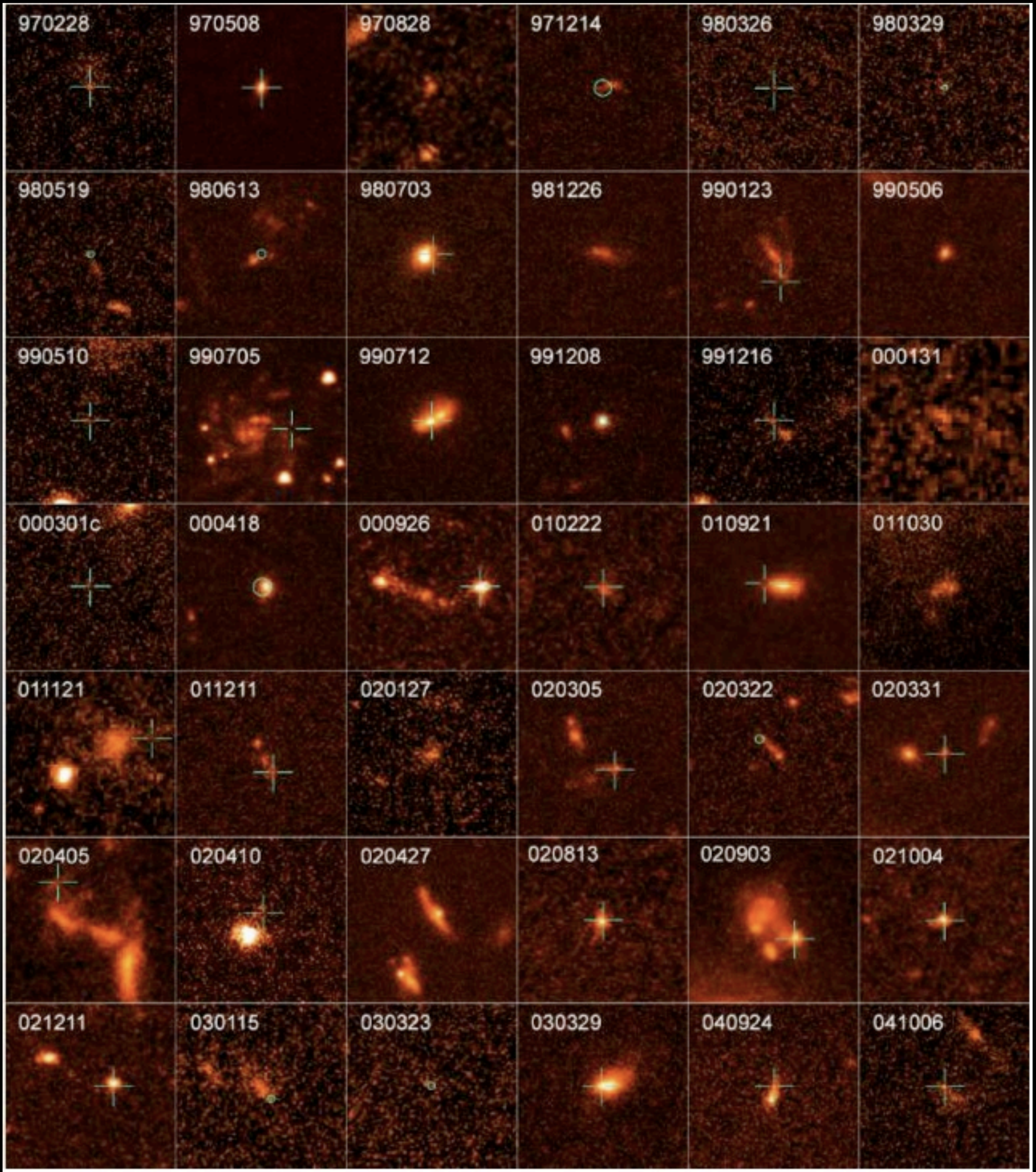
- Obviously overlap
- Detector dependent
- Redshift dependent (in complicated ways)

Kouveliotou et al. 1993
Mazets et al. 1982

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.

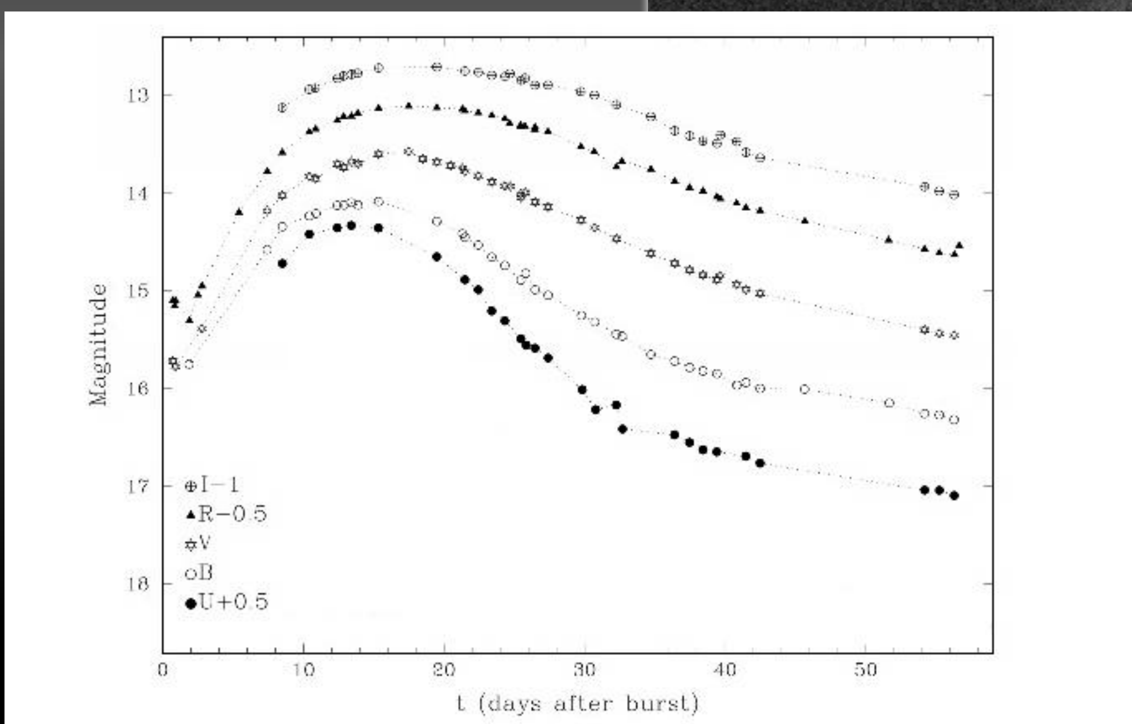


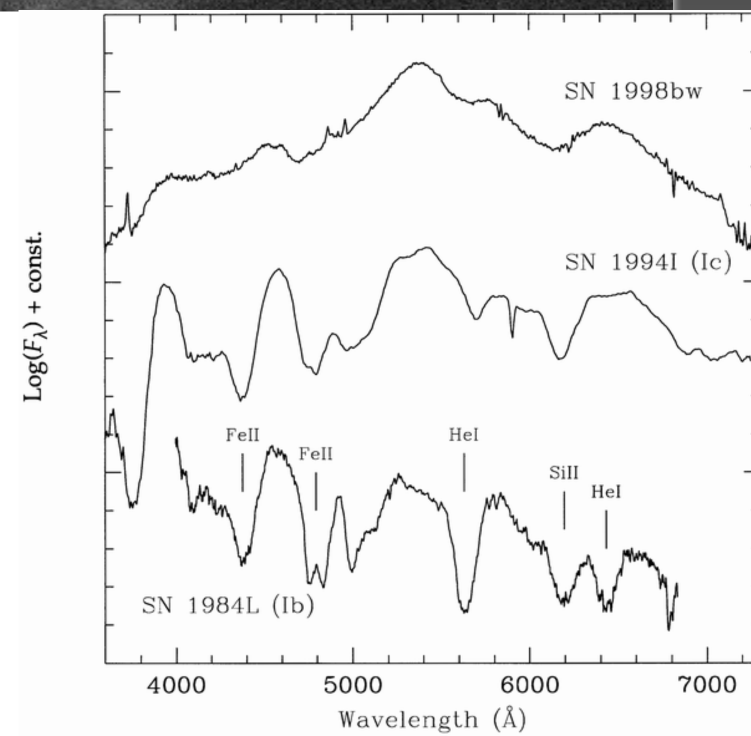
Fruchter et al. 2006

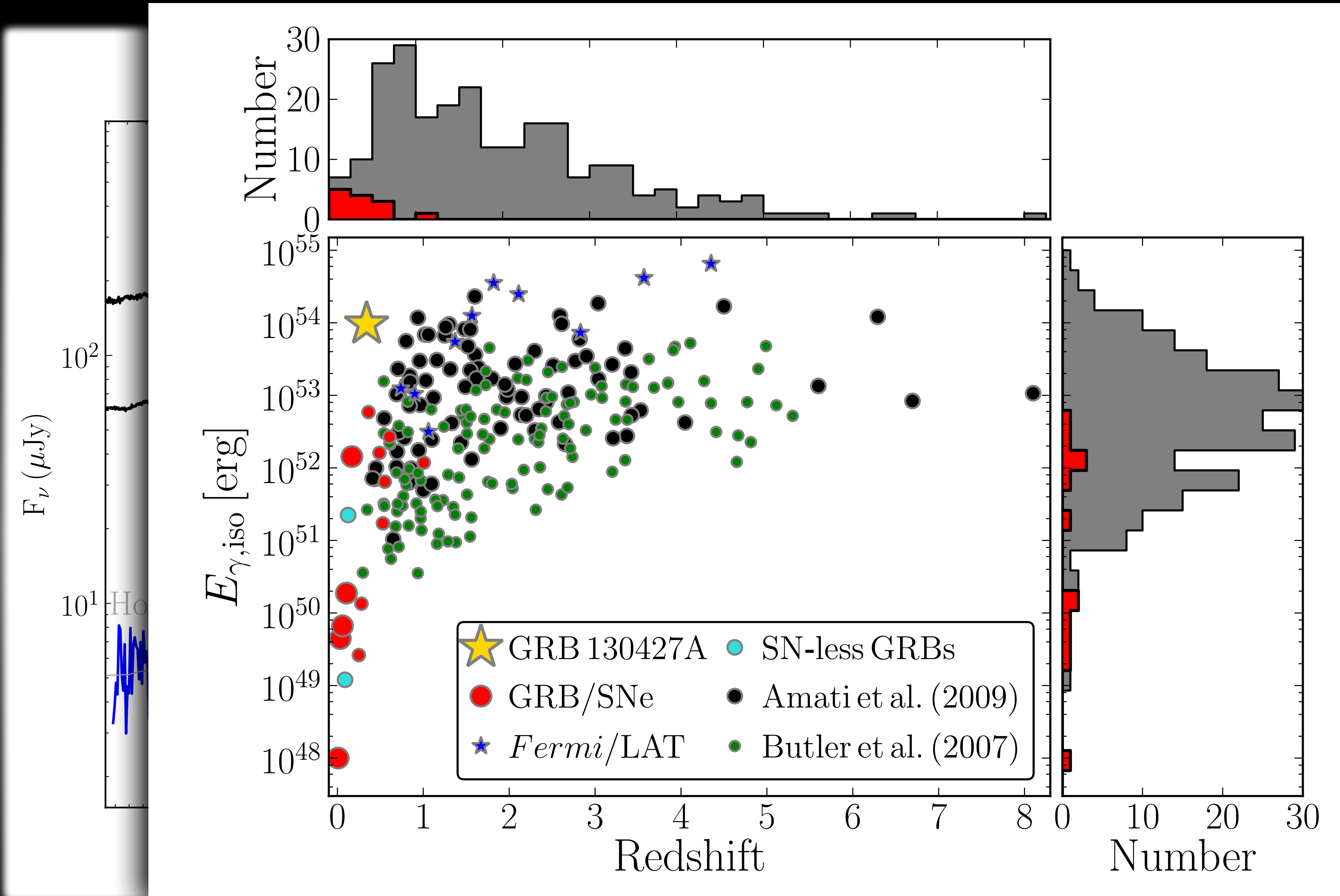
GRB 980425/SN98bw

Galama et al. 1998

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





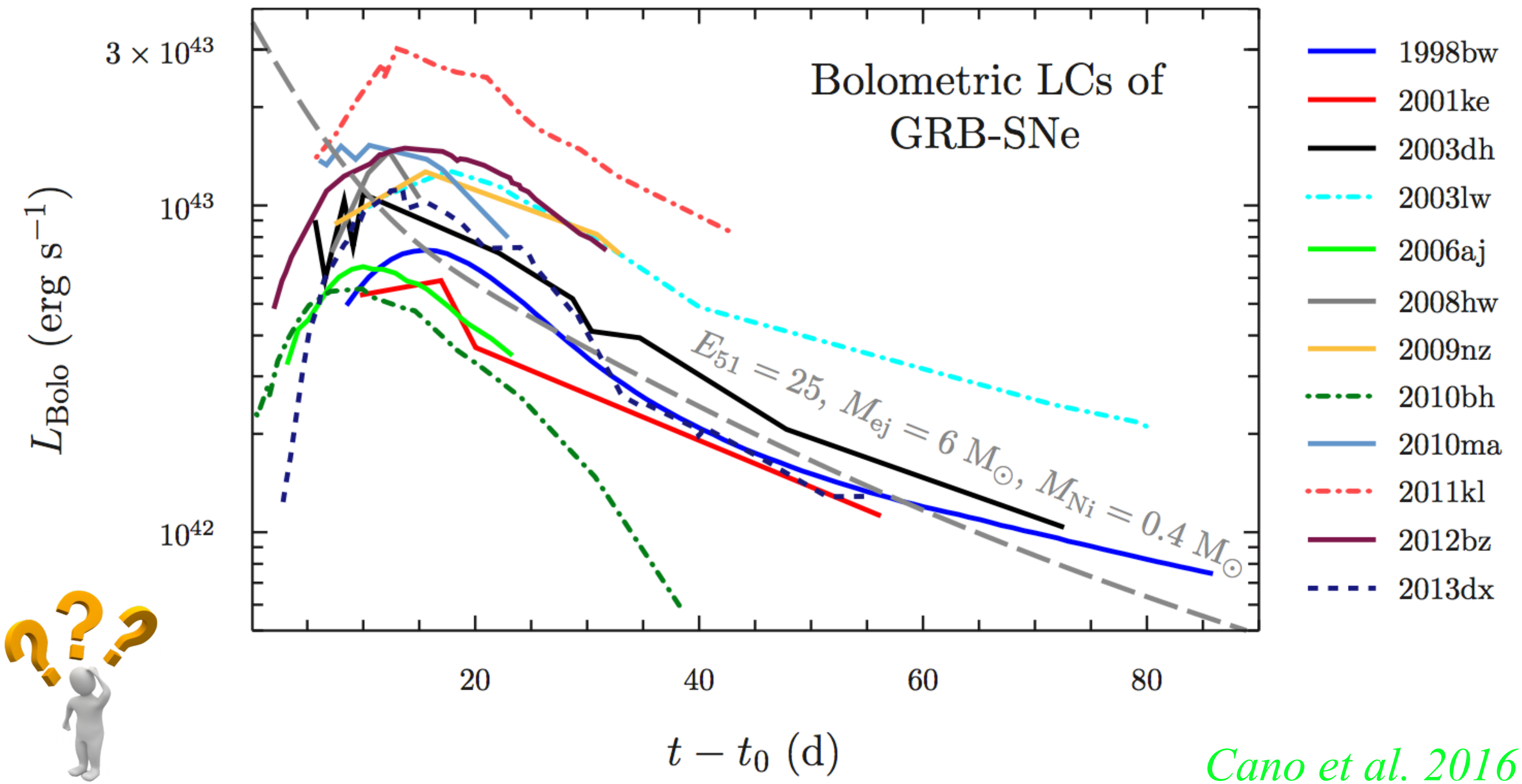


Xu et al. 2013

GRB 130427A/SN2013dq

Similarity of GRB-SN

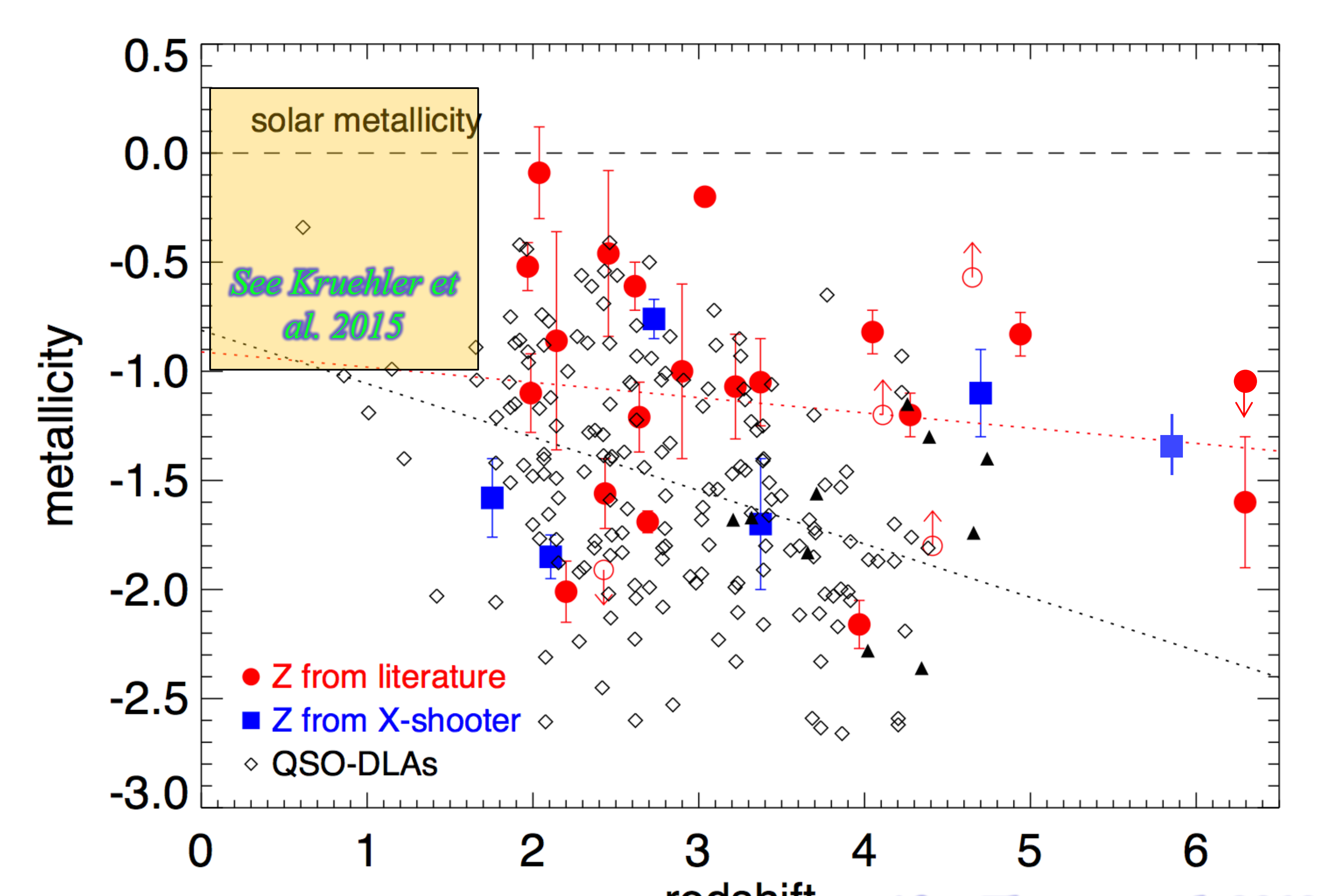
Despite the ~6 order of mag difference in GRB luminosity, the accompanying SNe look rather similar, including possible "peak-mag decline-rate" relationship.



Cano et al. 2016

The environments

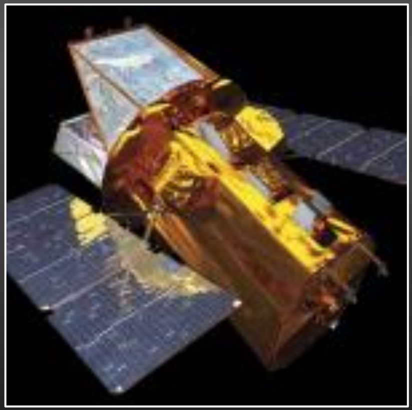
From hosts and afterglow spectroscopy, mostly low (at least ~sub-solar) metallicity.

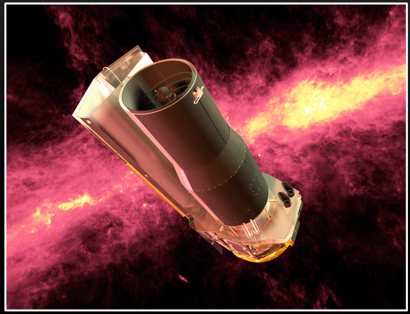


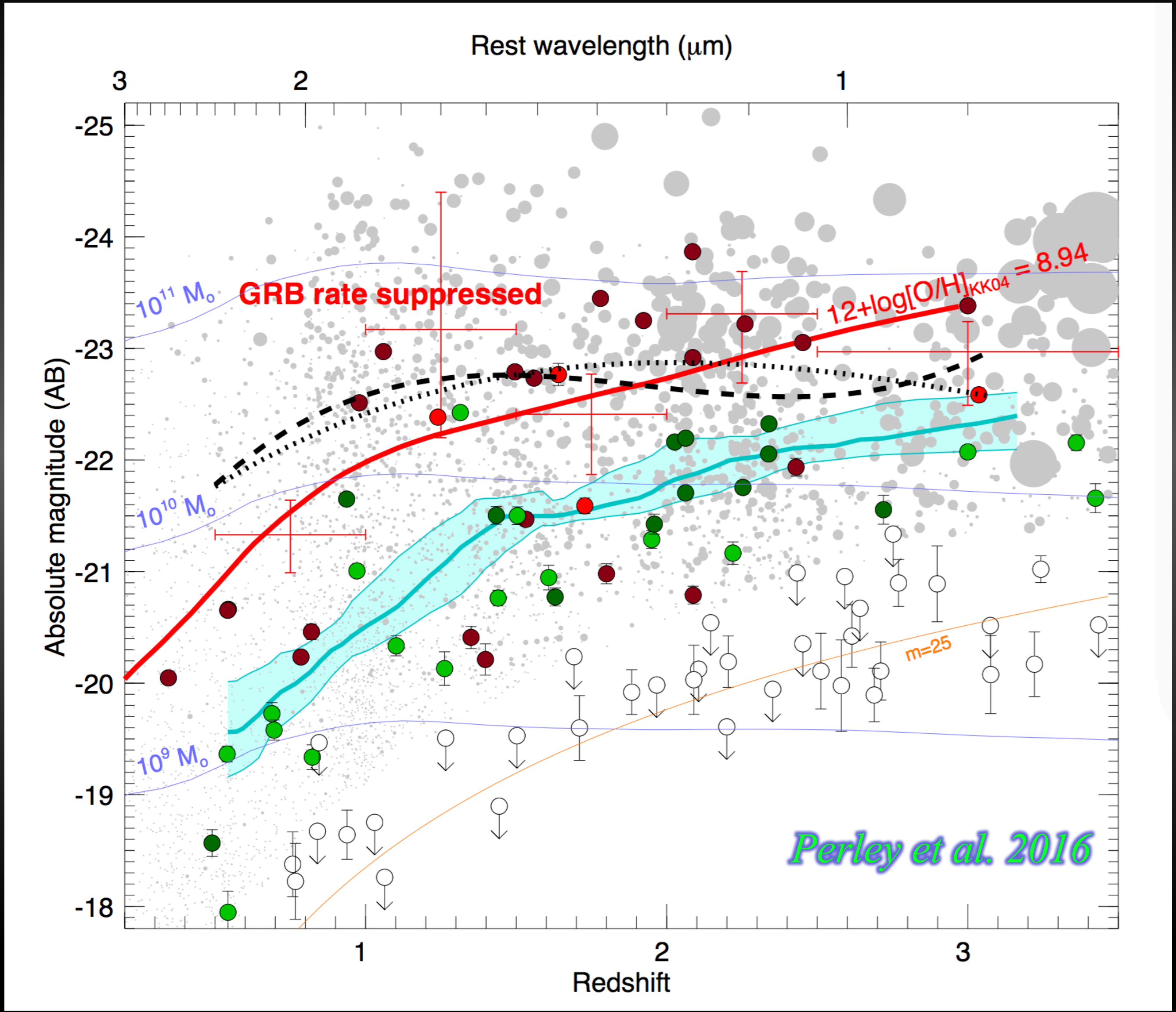
After Thoene et al. 2013

GRBs seem to roughly follow sub-solar metallicity SF

10-20% of GRBs occurring in relatively massive and dusty hosts, but still favour $Z<Z_{sol}$ star formation.

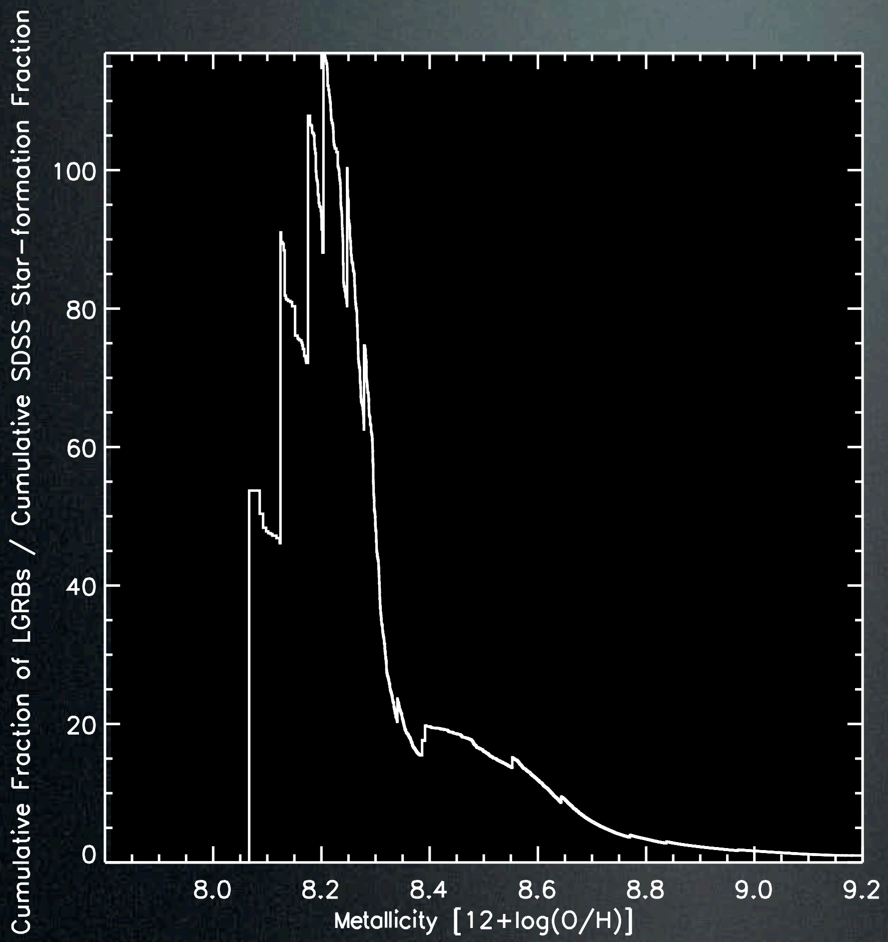






GRBs seem to roughly follow sub-solar metallicity SF

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

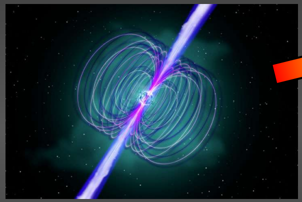
Relativistic fireball

"Standard picture" ultra-relativistic jet ($\Gamma \sim 300$) produces prompt emission via internal shocks from shell collisions within jet, and afterglow emission via shocking of ambient medium.

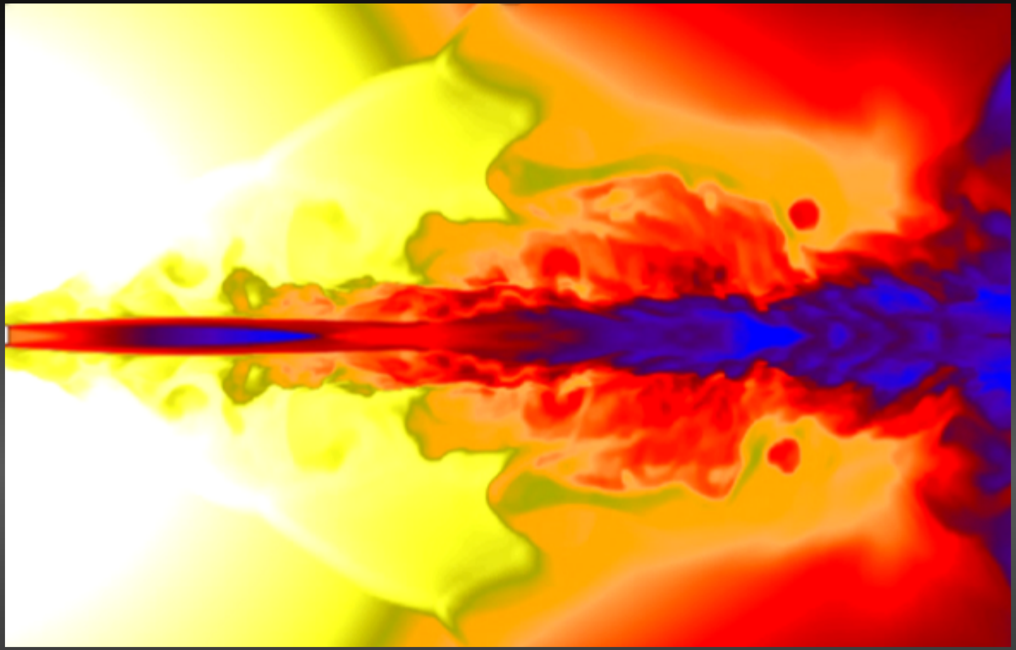
Zhang et al. 2004

Requirements for engine and star

Accretion on BH



Magnetar



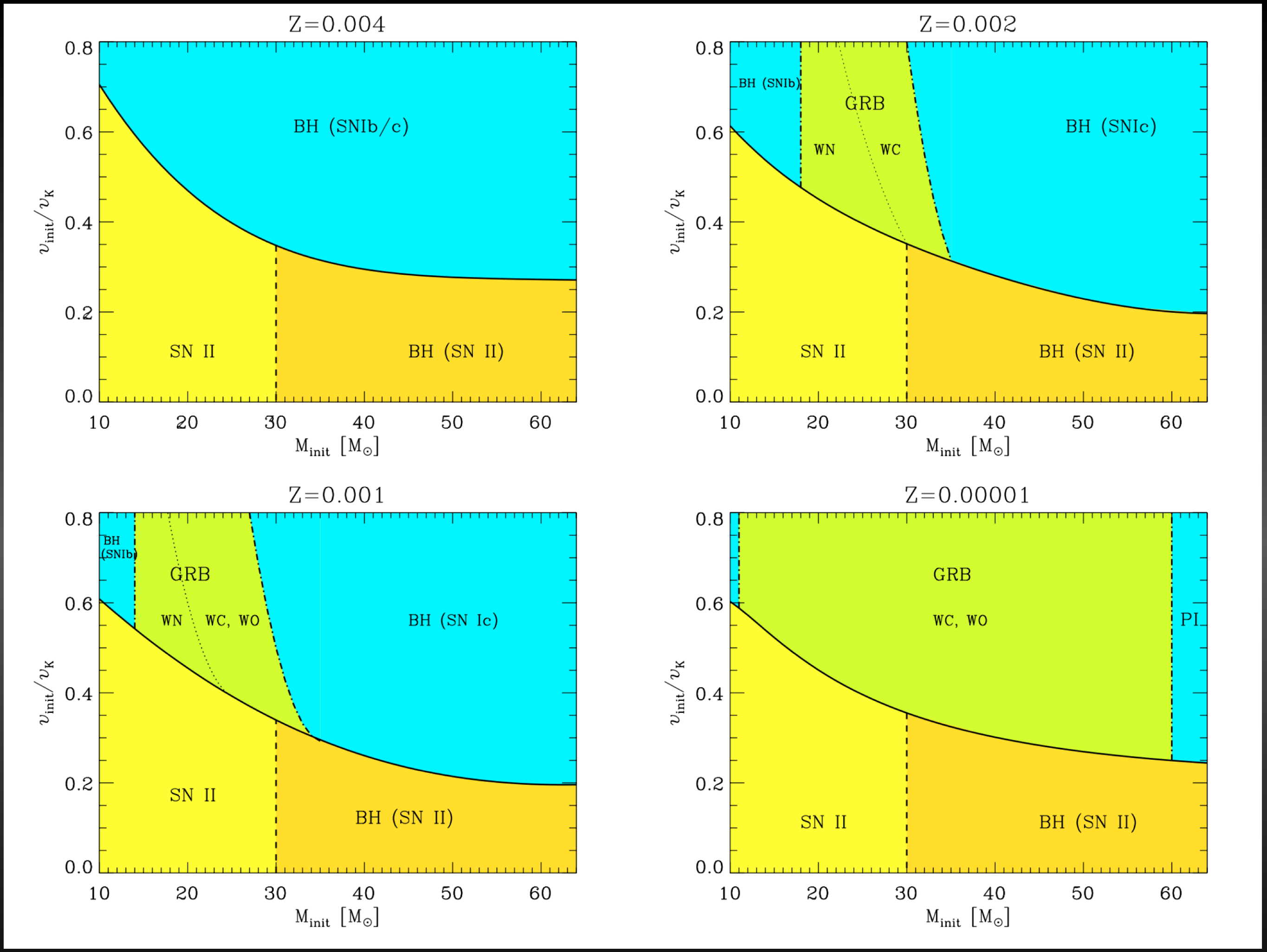
Rapid rotation $j > 10^{16}\ \mathrm{cm^2\ s^{-1}}$

Envelope stripped

Massive core

Single and/or binary channel?

Yoon et al. 2006

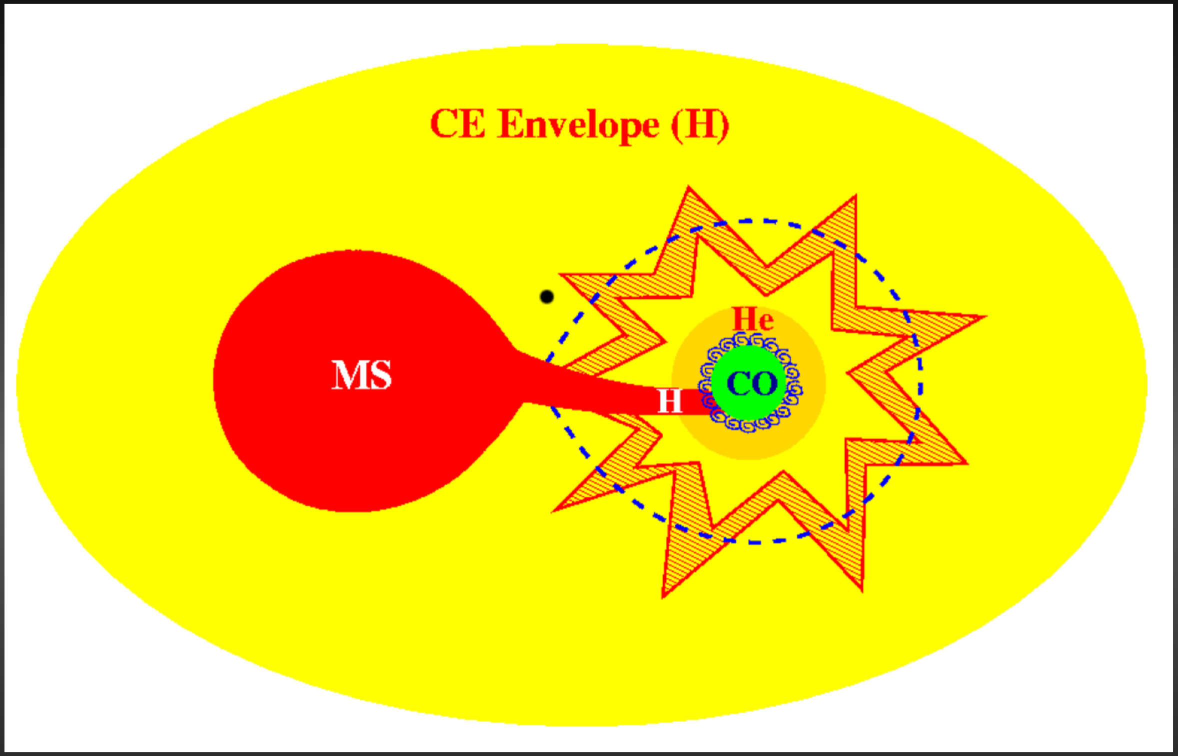


Rapidly rotating single star models

☞ chemically homogeneous evolution

☞ require $Z <\sim 0.1\ Z_\odot$ to retain sufficient final angular momentum to make GRBs

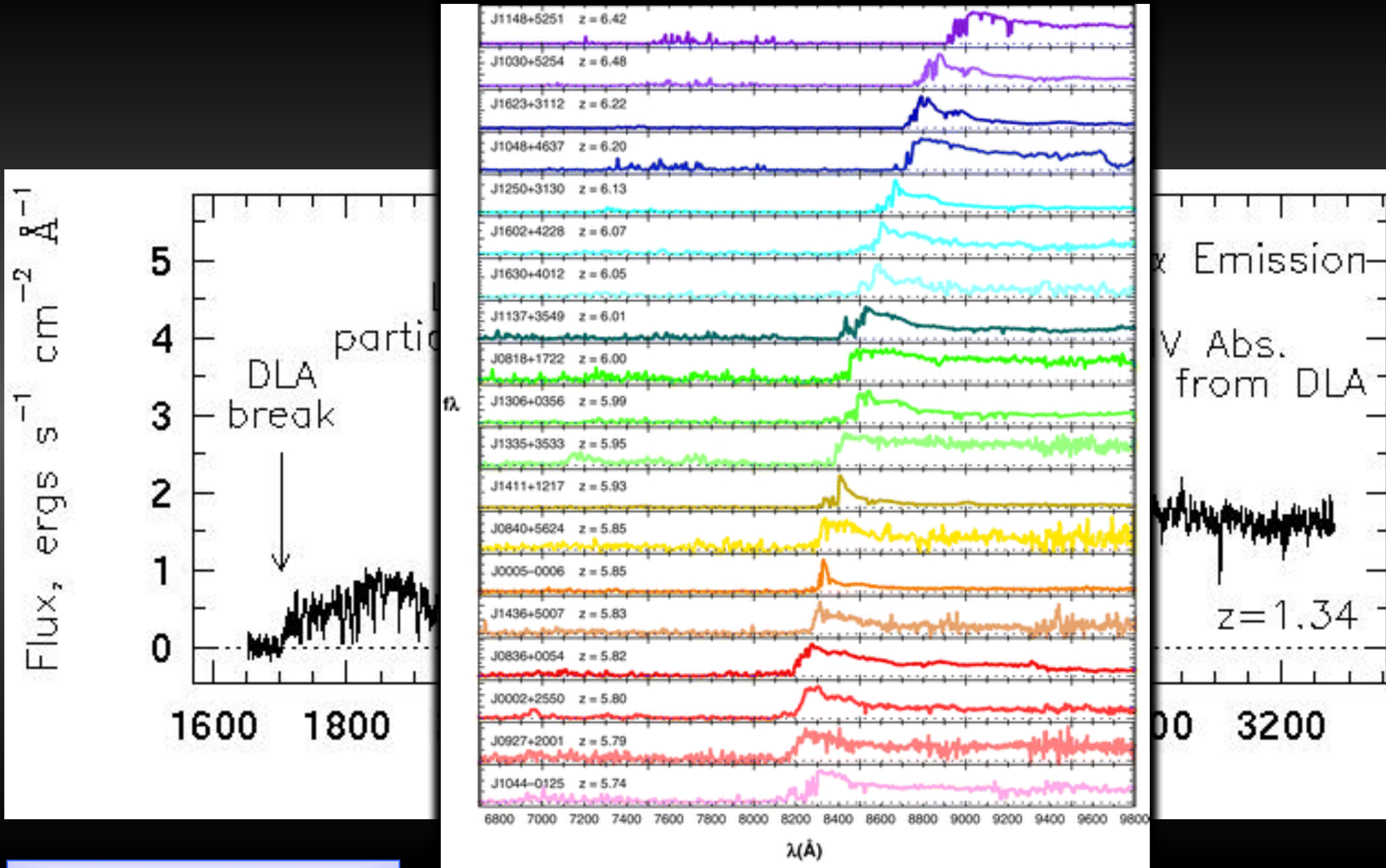
Single and/or binary channel?



Podsiadlowski et al. 2010

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.

Reionization of the intergalactic medium



Fan X, et al. 2006.
Annu. Rev. Astron. Astrophys. 44:415–62

IGM largely ionized

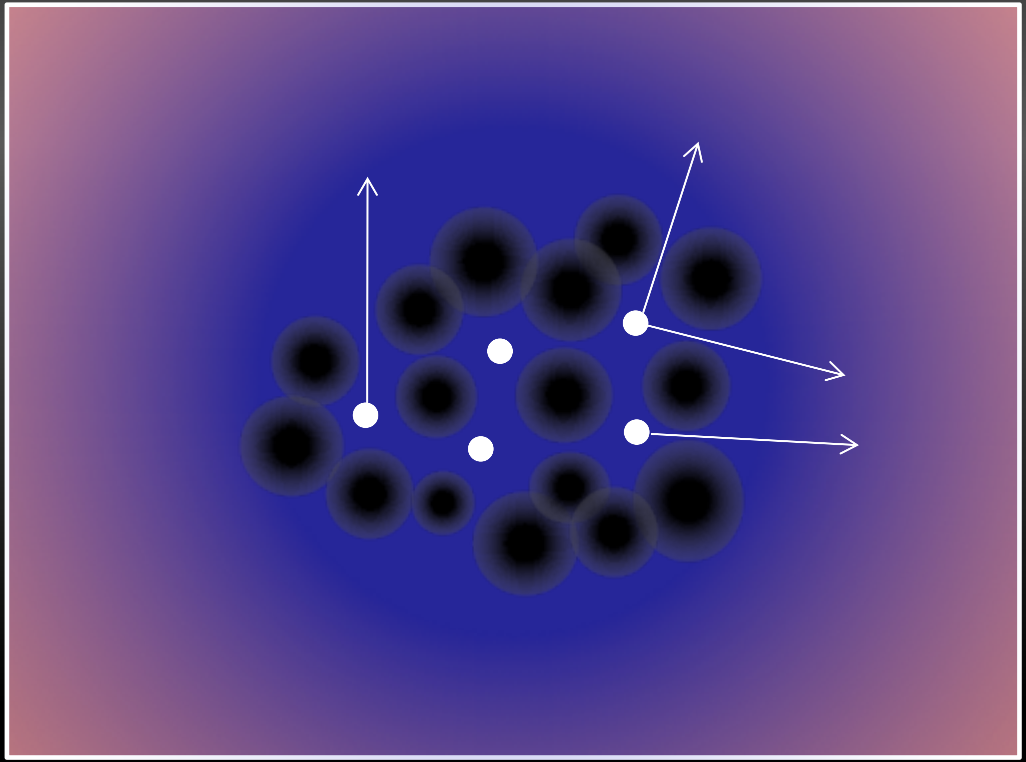
Reionization of the intergalactic medium

The intergalactic medium went from being completely neutral to completely ionized, in the era between z=10 and z=7 (strongest constraints from CMB)

Ionizing escape fraction

Generally assumed some fraction of ionizing radiation from stars escapes their host galaxies.

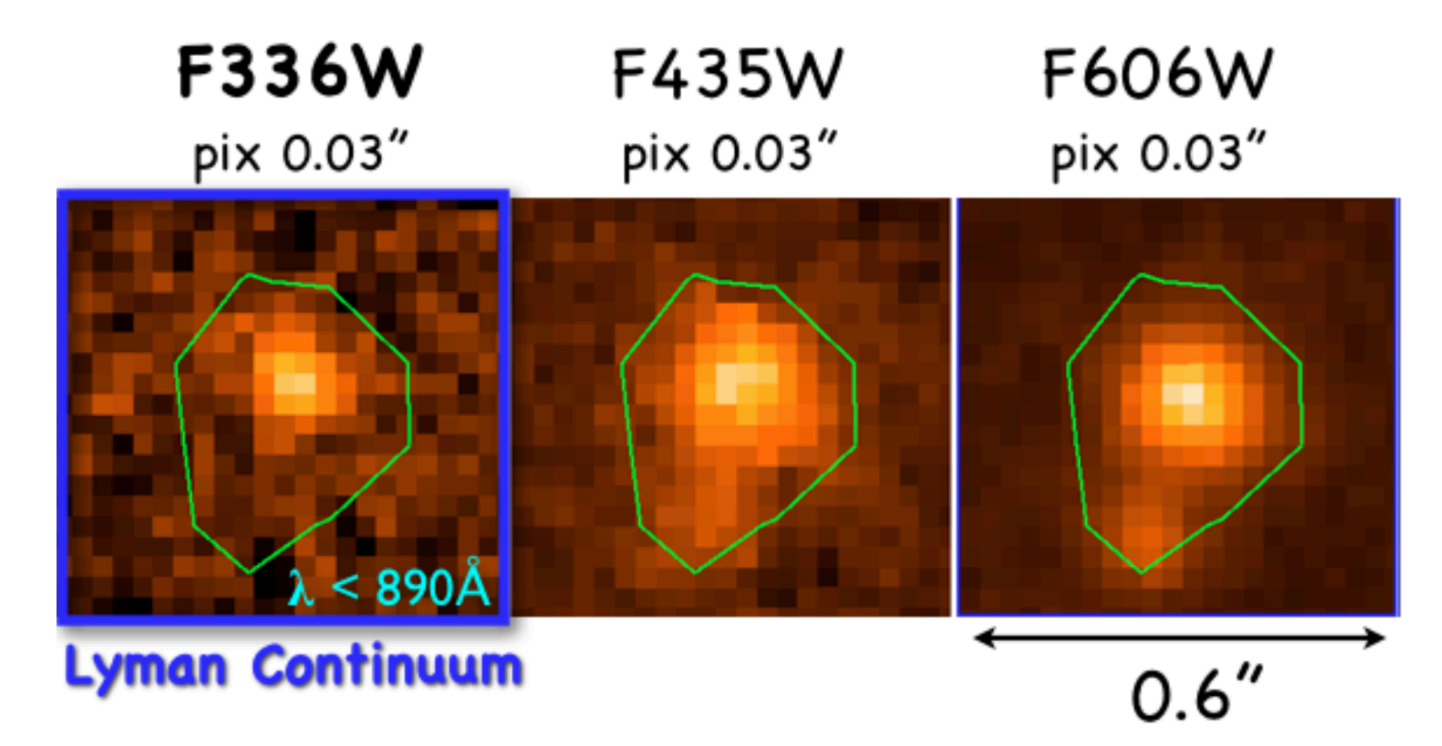
If this is not reasonably high (>10%) at z>6 then becomes hard to envisage reionization being driven primarily by stars.



Ionizing escape fraction

Studies at z~2-3 generally find low values of <~few %, although some exceptional systems.

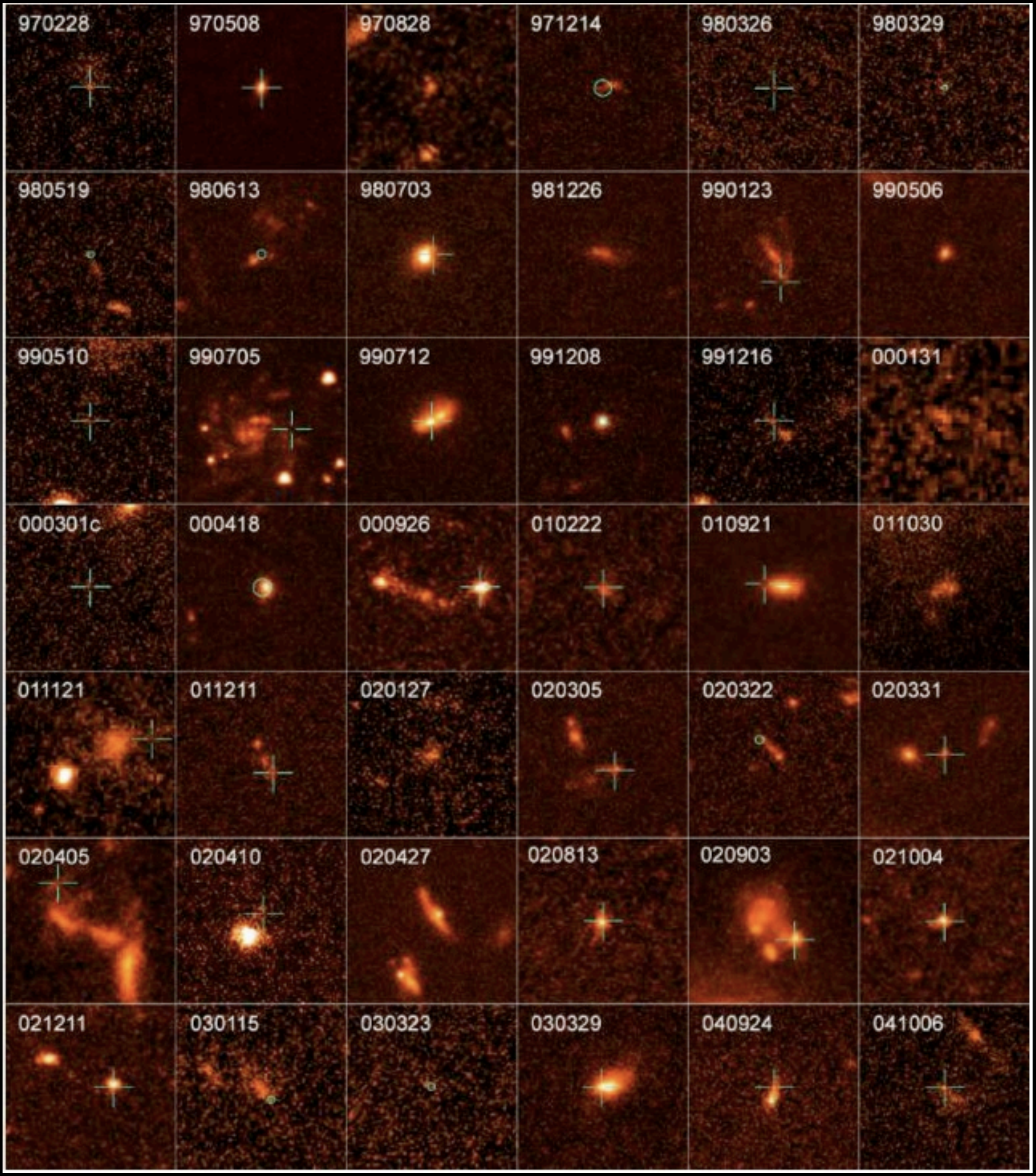
Weak constraints for (dominant population) of faint galaxies.



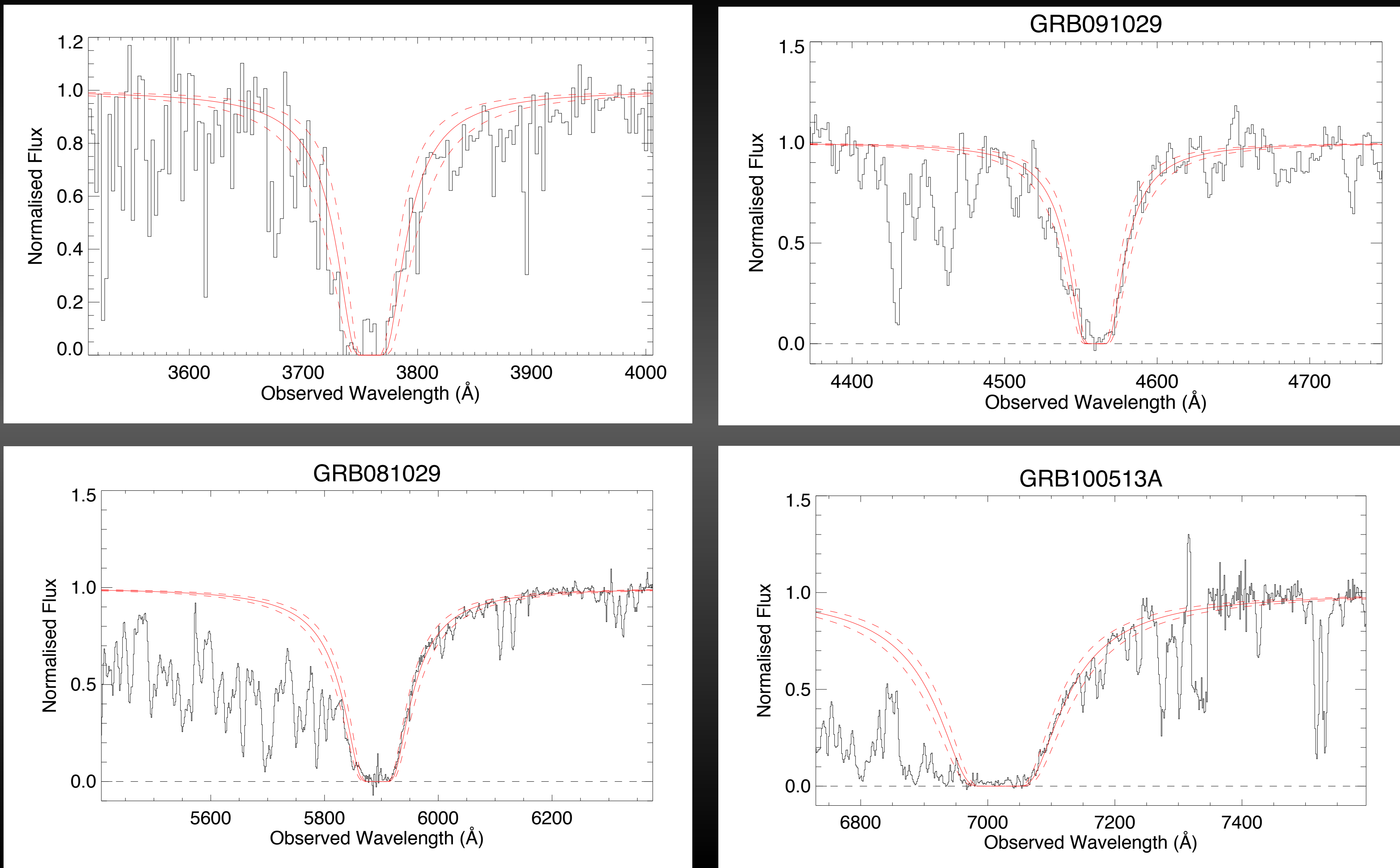
Vanzella et al. 2016 – z=3.2 galaxy, fesc>0.5

Long-GRBs

Correlation with UV light suggests sight-lines to GRBs should be representative of sight-lines to ionizing stellar populations.

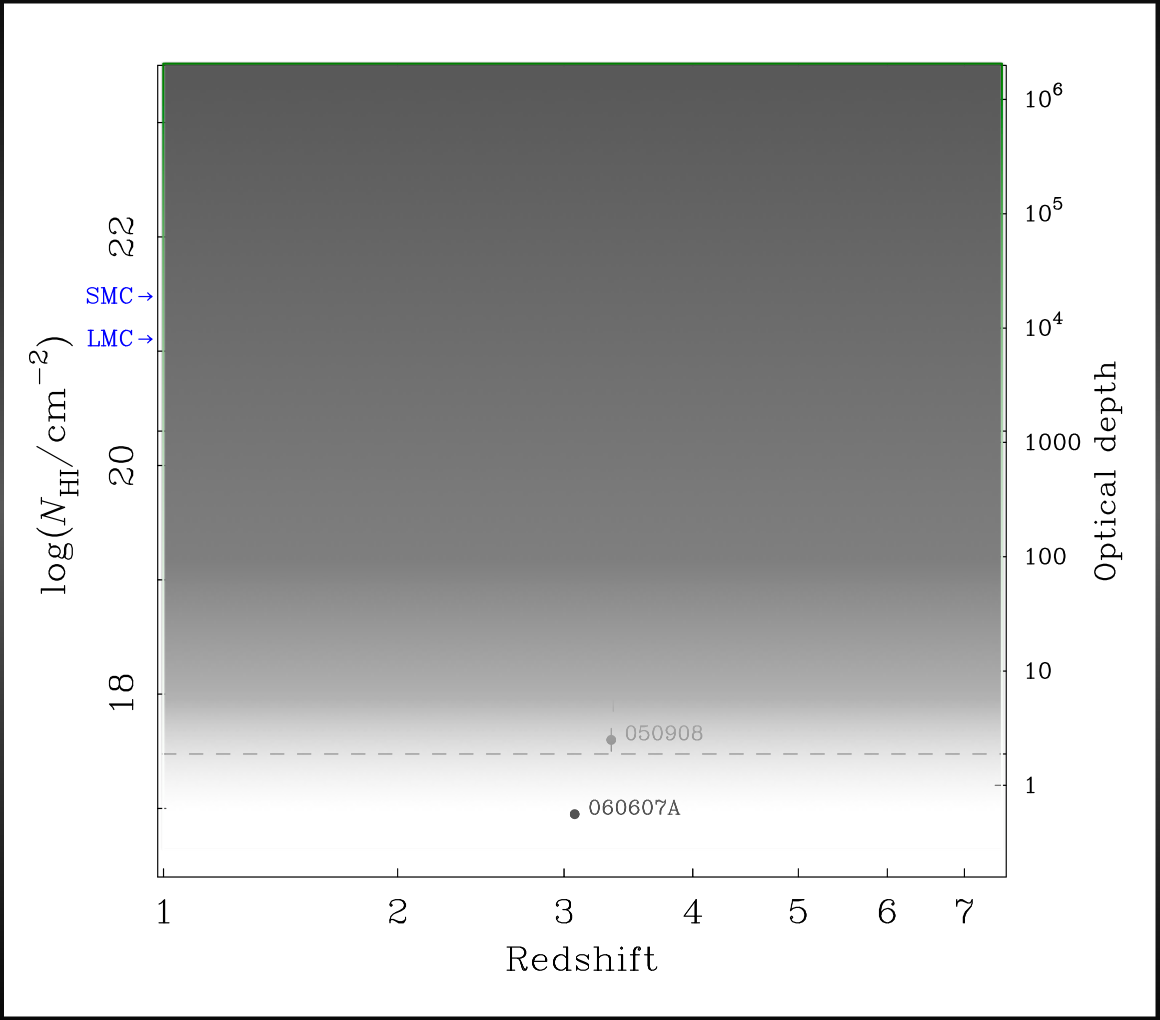


HI column density from Ly-a absorption in afterglow spectra



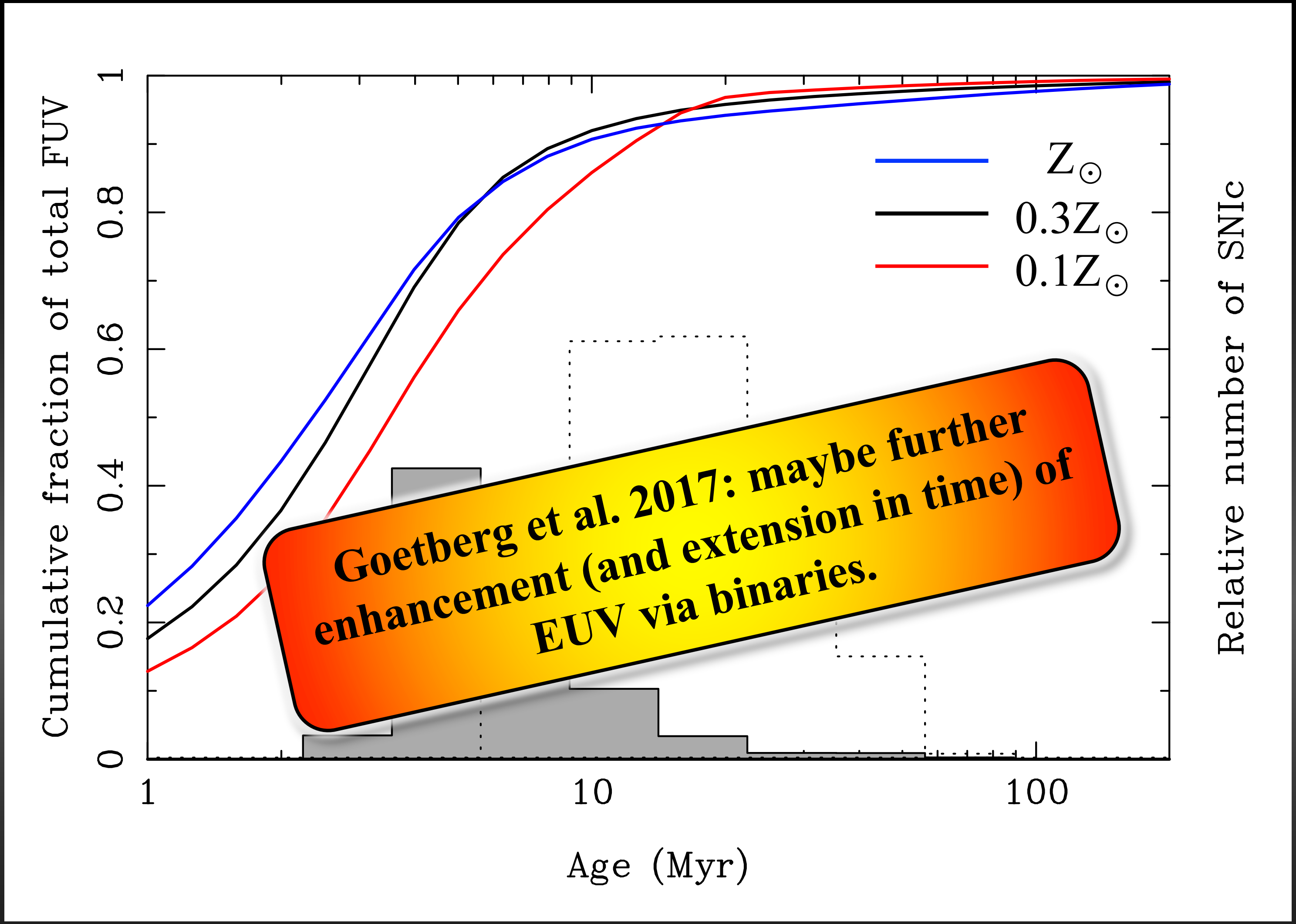
Provides direct upper limit on escape fraction on each line of sight.

HI column density evolution



High column densities seen in optical spectra of most 2<z<4 GRBs suggest escape fractions for these stellar pops of <~1 %.

NT et al. (subm. soon)



Single burst stellar population synthesis, based on binary evolution BPASS-2 models (Stanway & Eldridge 2016) – most production is t <10 Myr, consistent with typical GRB progenitor lifetimes (and SNIc).

Factors making this upper limit stronger

1. There is a bias against locating and measuring redshifts for the high NH (dusty) systems (especially at higher redshifts). Also the low NH systems may also have dust absorption.

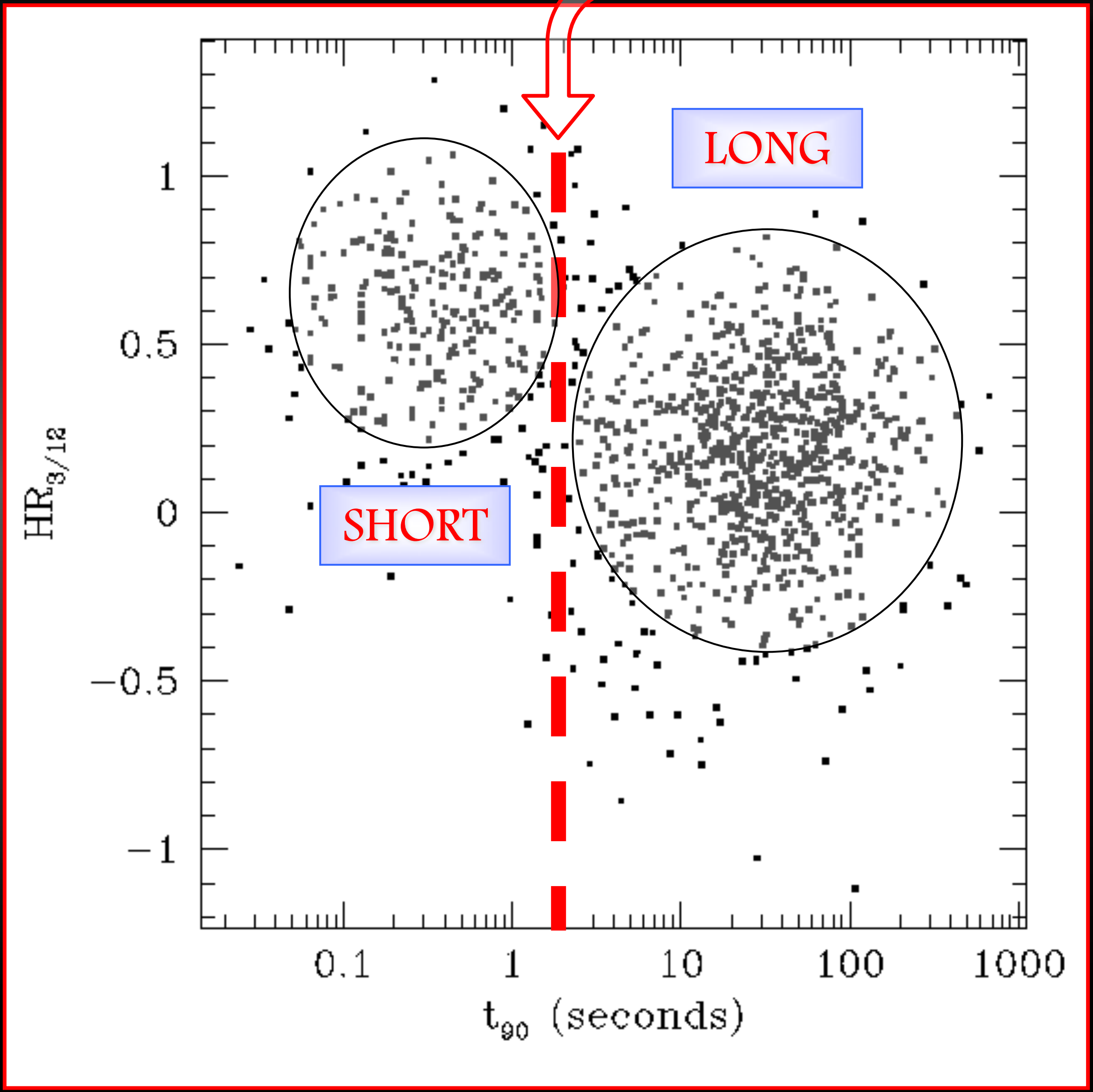
2. Neutral gas proximate to the progenitor is likely to be ionized by the GRB and early afterglow, so we may underestimate the the column in some cases.

Also note:

- No clear trend with host UV magnitude (proxy for star formation rate), or stellar mass.
- Only marginal reduction in NH at $z>5$ (but statistics poor)

Two populations

T_{90}=2 s

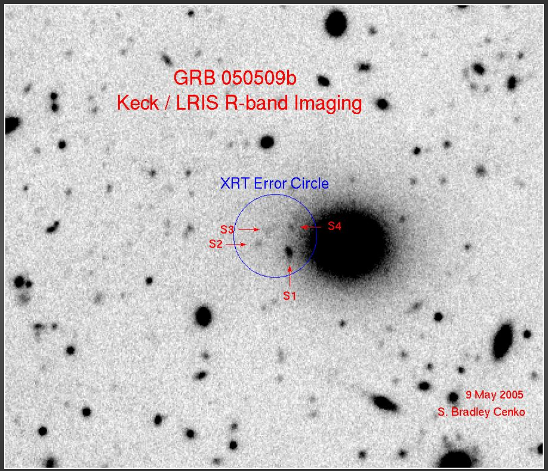


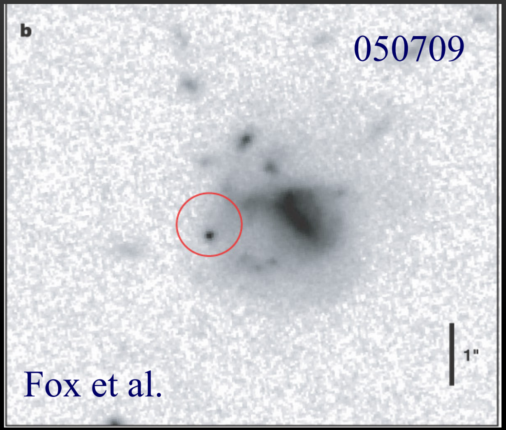
What about the short-duration events?

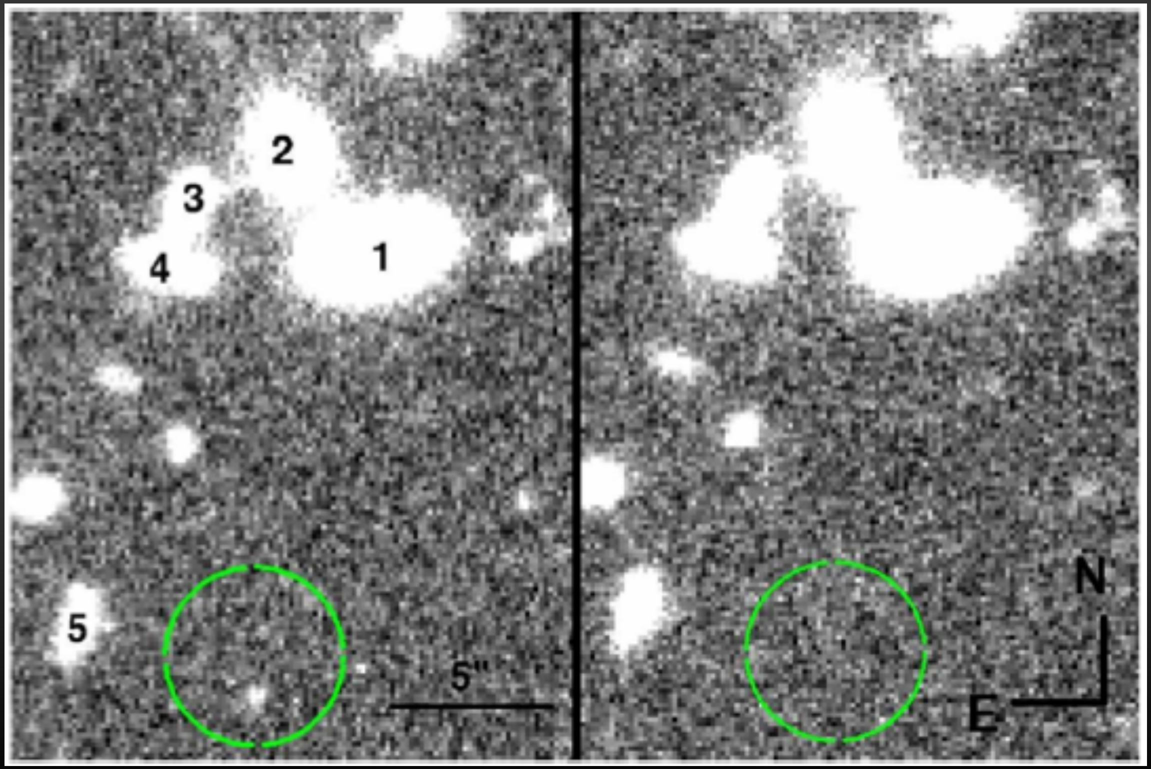
Kouveliotou et al. 1993
Mazets et al. 1982

Short-duration bursts

Long thought to be likely NS-NS or NS-BH mergers, due to timescales, energies and lack of compelling alternatives. Association with variety of stellar populations and some "hostless" supports this hypothesis.

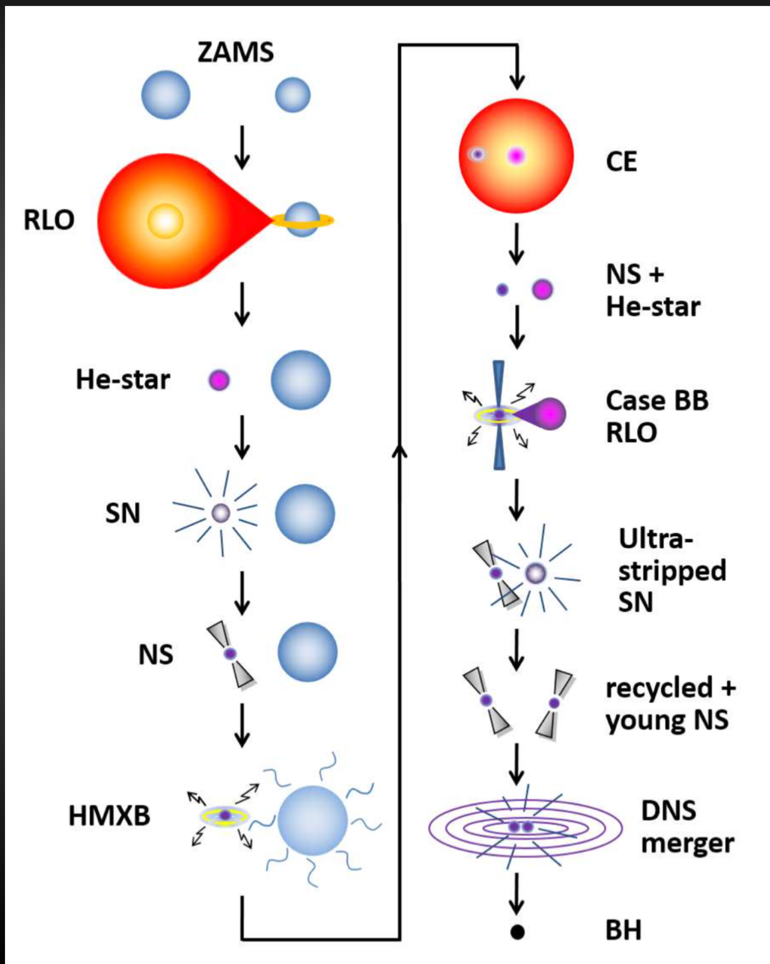






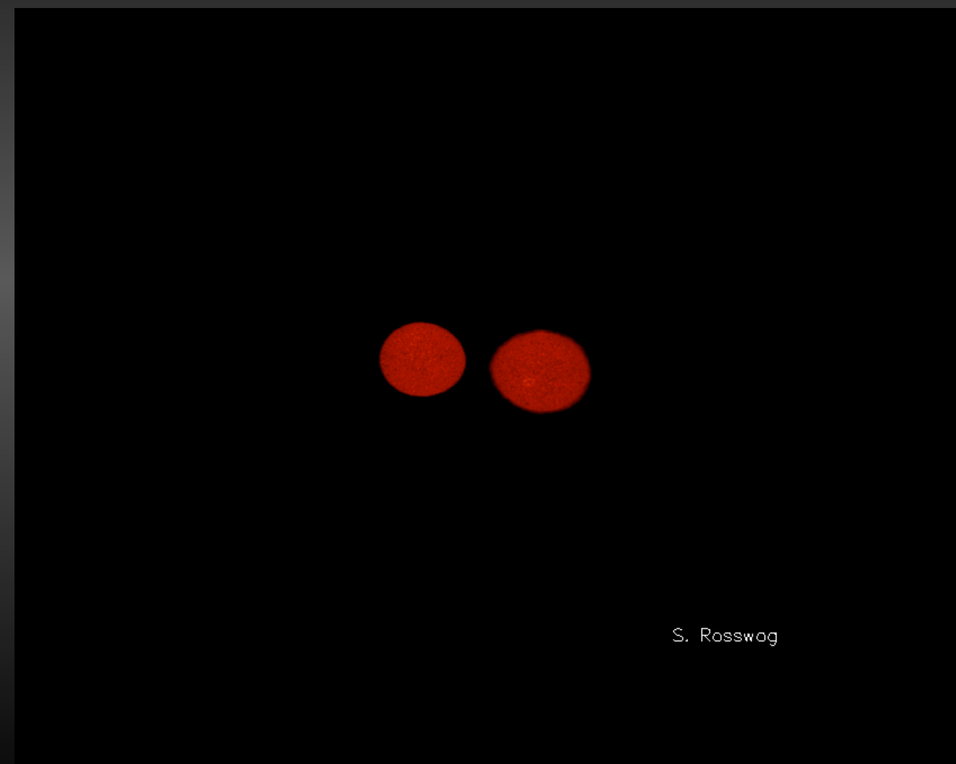
GRB090515 - Rowlinson et al. 2010

Various possible evolutionary pathways to creation.



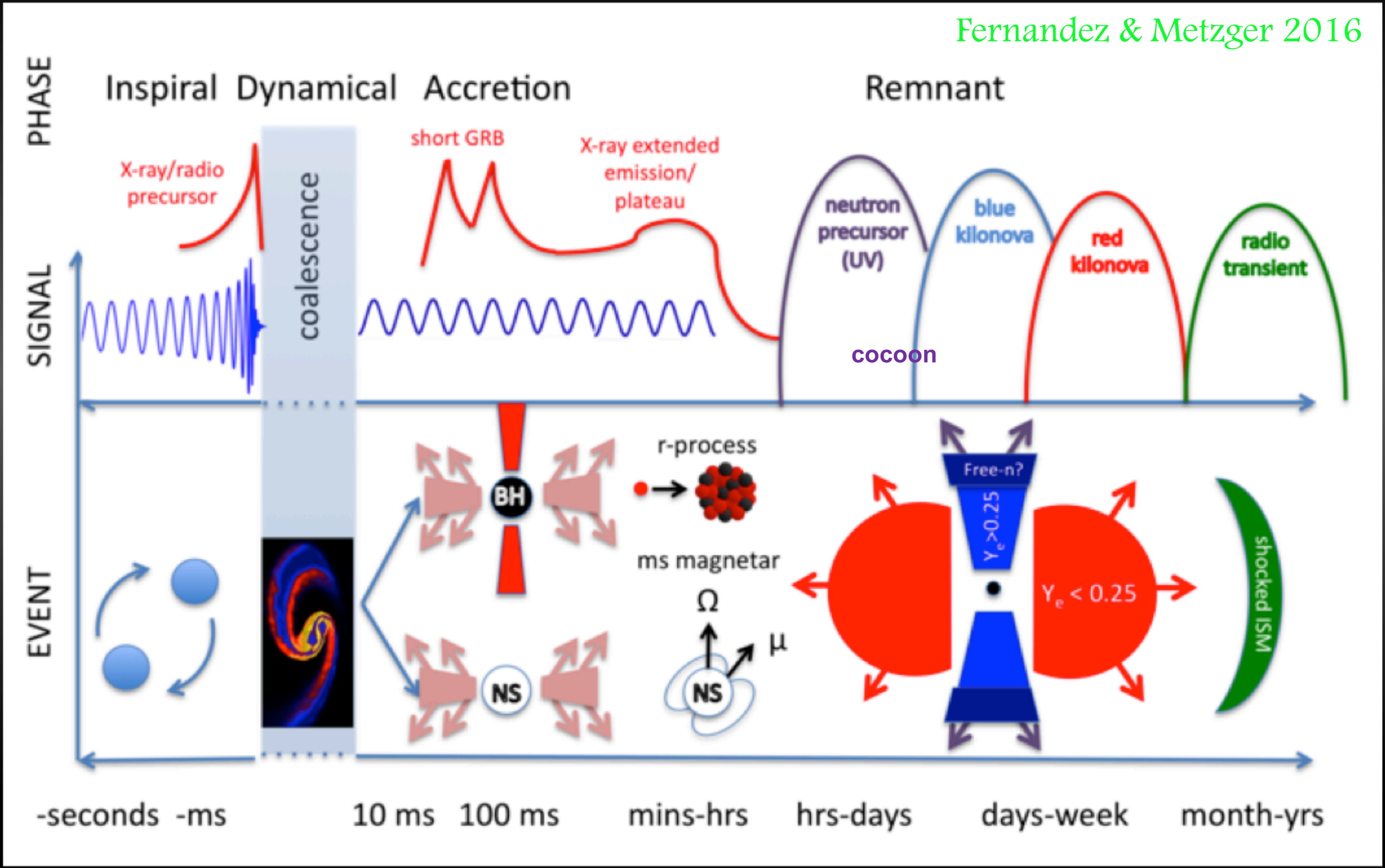
Tauris et al. 2017

During merger, some material is ejected (tidally, through collisional debris and disk winds).

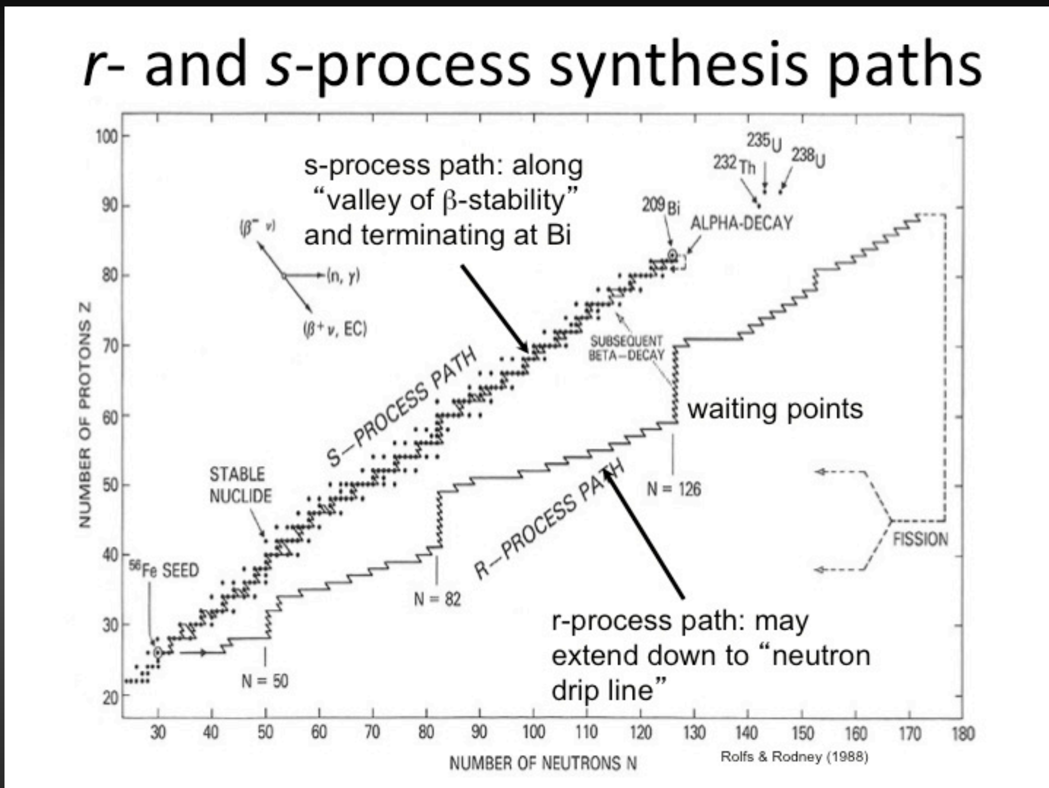


Compact binary mergers

Potentially rich variety of astrophysical phenomena!



Other EM signatures



Radioactive decay powers (isotropic) transient, but high opacity may lead to emission in nIR after ~days.

Macro-
Kilo-
Merger-
Bling-
Minisuper-
} nova

~~Luminous red nova~~

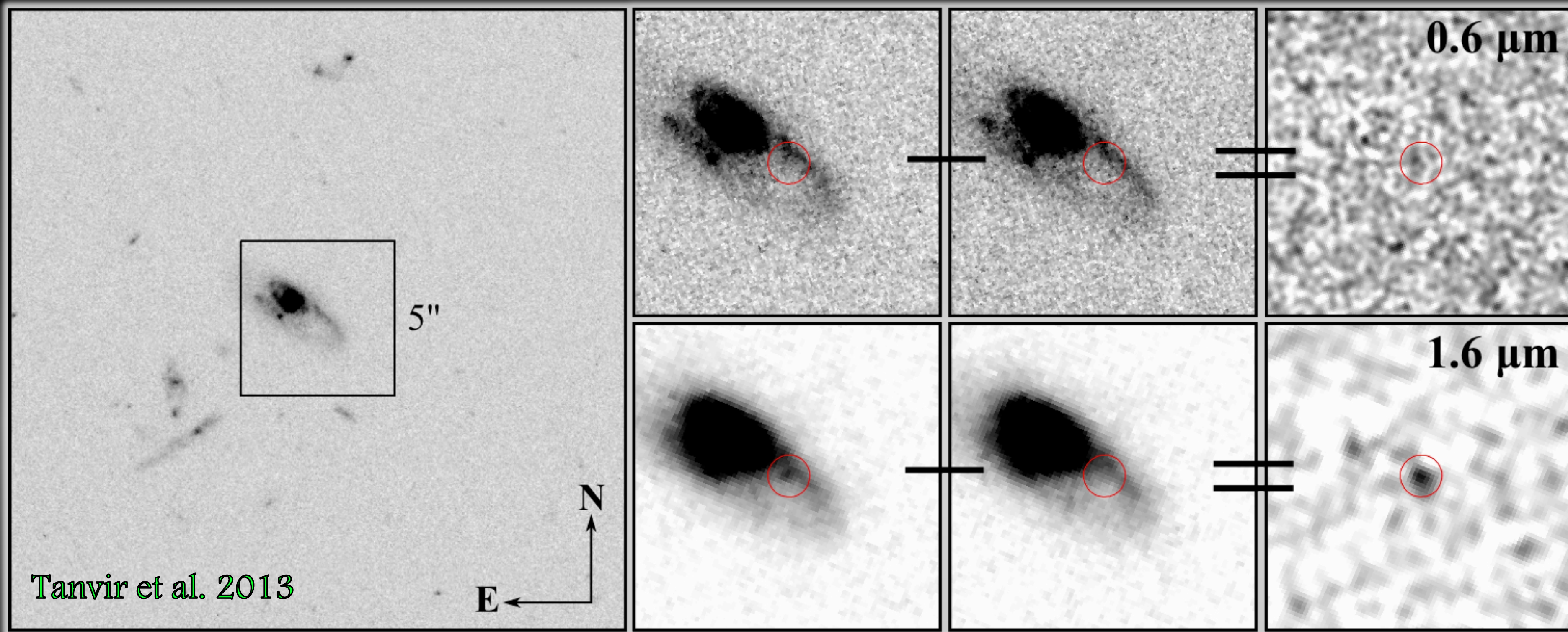
Predictions of behaviour require highly complex physics.

Tidal ejecta – very low Y_e – high optical opacity – slower/redder – more isotropic

Disk wind – neutrino irradiation – higher Y_e – lower opacity – faster/bluer – less isotropic

GRB 130603B

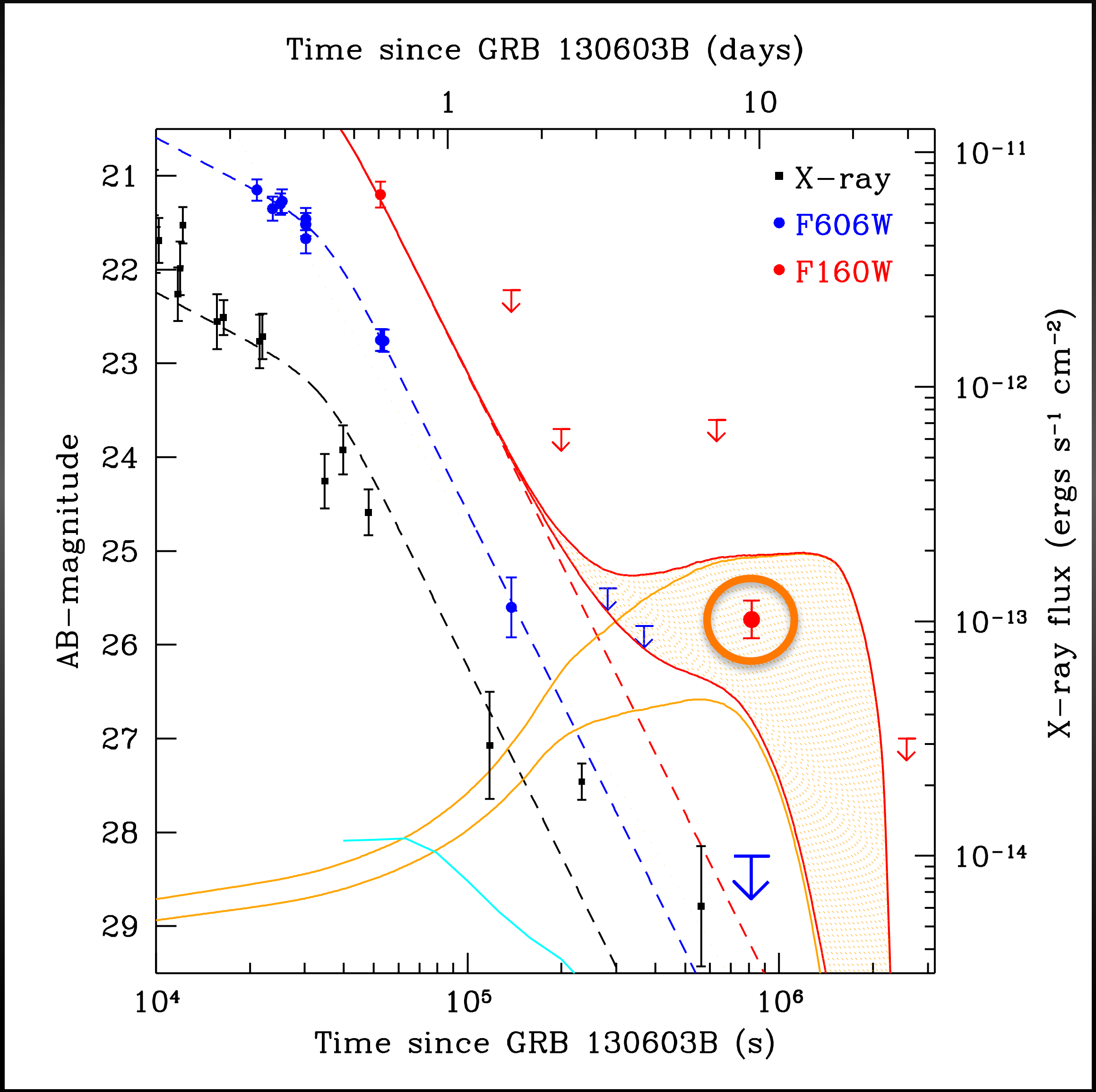
Constraining the kilonova



9 day

30 day

GRB 130603B …or, much ado about a data-point



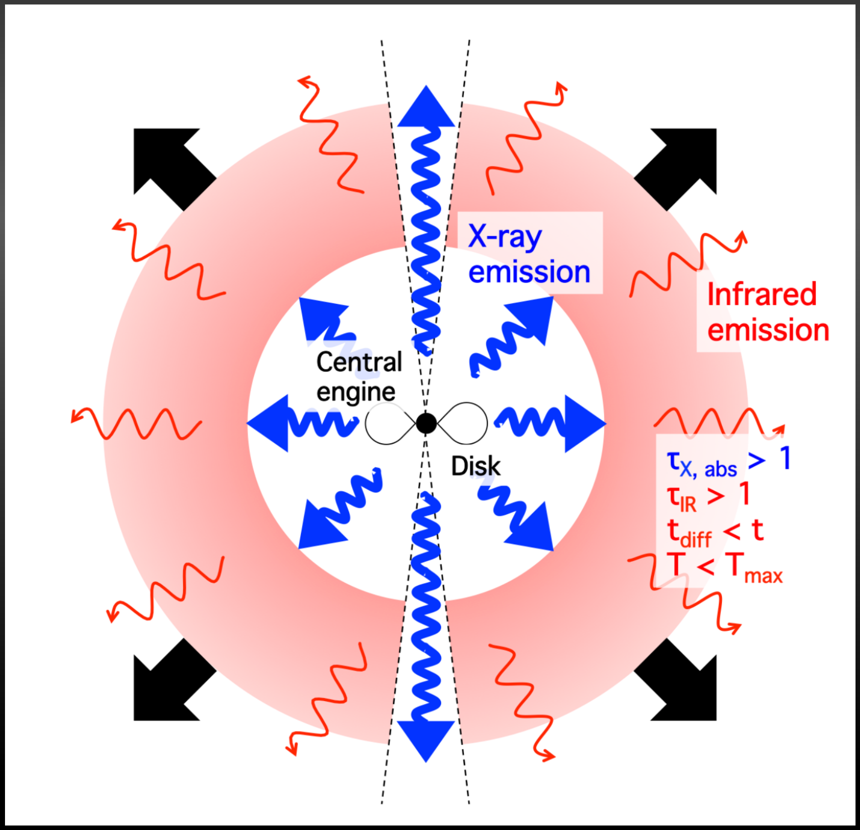
Comparison to Barnes & Kasen (2013) models suggests ejected mass ~0.05 $M_\odot$

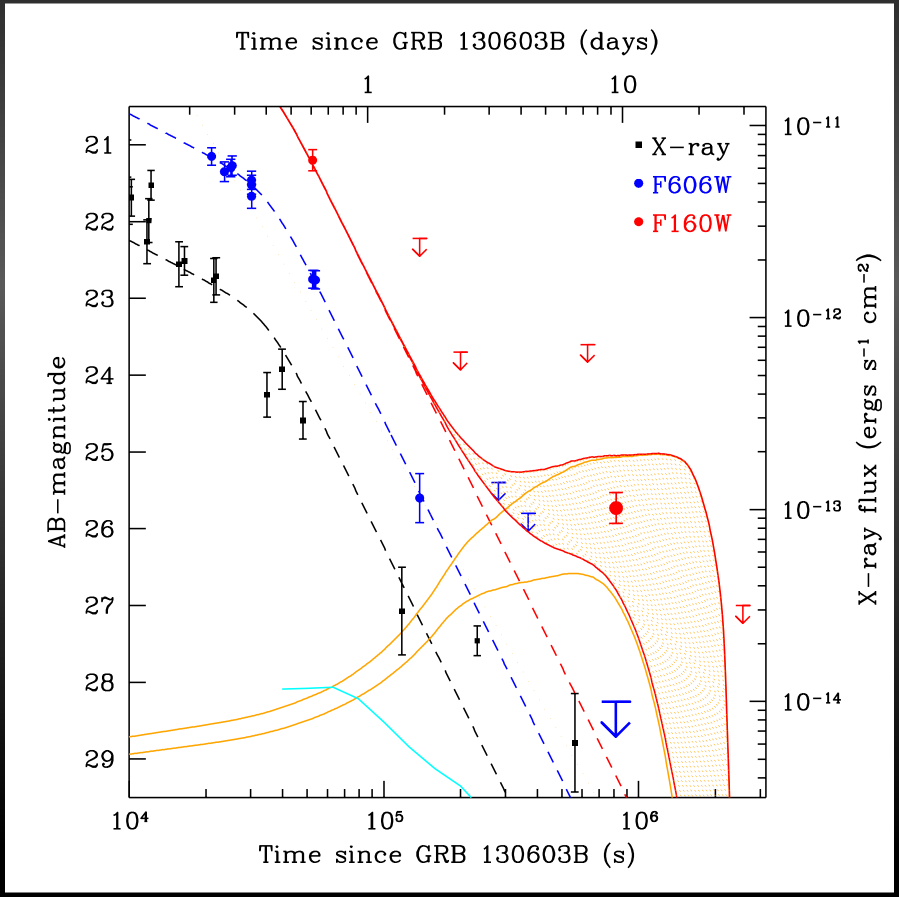
Tanvir, Levan et al. 2013
Berger et al. 2013
Fong et al. 2014

X-ray signal?

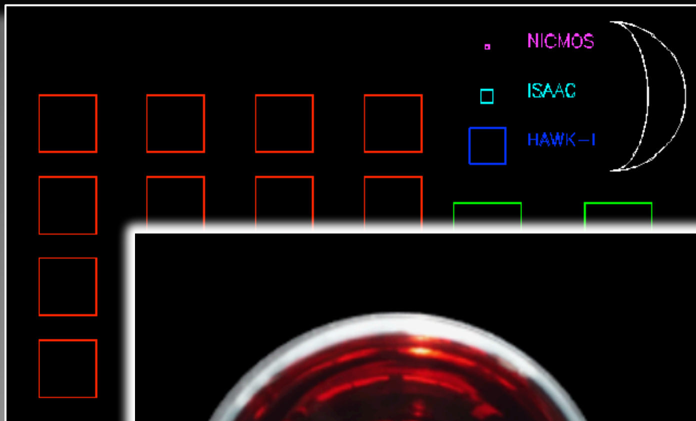
The 'kilonova' GRB 130603B, had an X-ray excess in addition to IR bump (Fong et al., 2014).

Kisaka, Ioka & Nakar (2016) suggested that the KN could be substantially powered by central engine activity via isotropic X-ray emission.

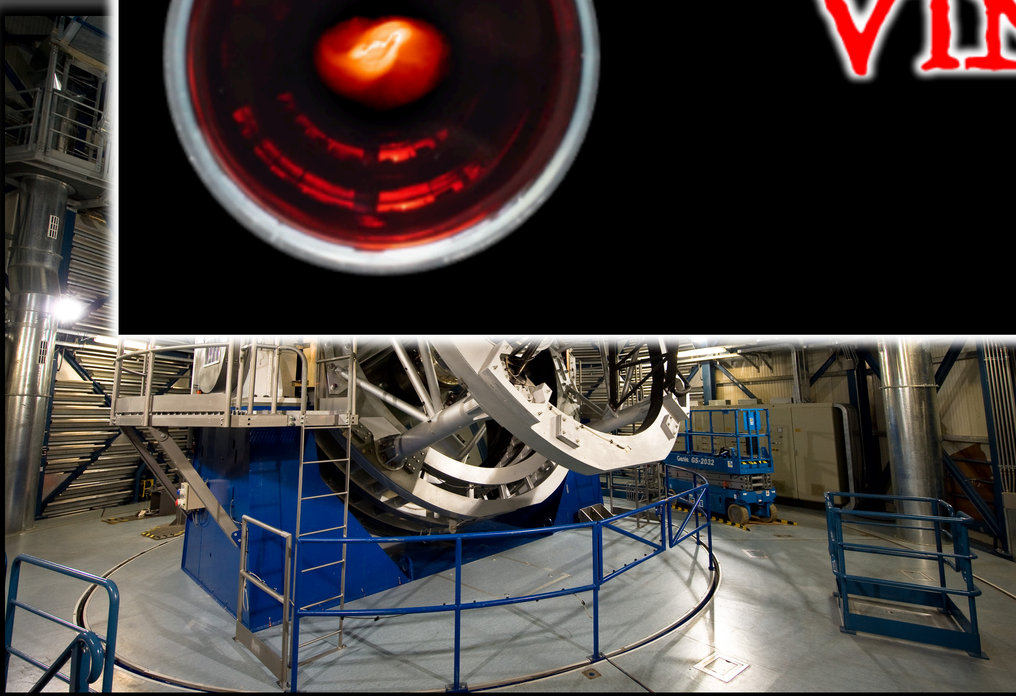




ESO/VISTA programme



Near-IR optimised
4.1 m wide field



Conclusions

- Important questions remain concerning the progenitors of long-GRBs e.g. single, binary, both?
- A particular problem is how to reconcile the observed low escape fraction of ionizing radiation from GRB locations with the requirement to reionize the intergalactic medium. Can binaries help provide other sources of EUV? Any reasons to believe GRBs are not in the right locations?
- Short-GRBs themselves may be EM signatures of GW events. They also allow us to study kilonova behaviour and hone strategies for GW follow-up.
- Please find some ways to produce reasonable numbers of NSNS or NSBH mergers!