Nial Tanvir – University of Leicester

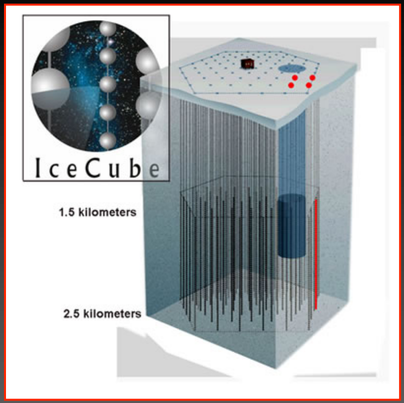
Transient astrophysics with HARMONI

Oxford - 2015

SVOM / Swift?

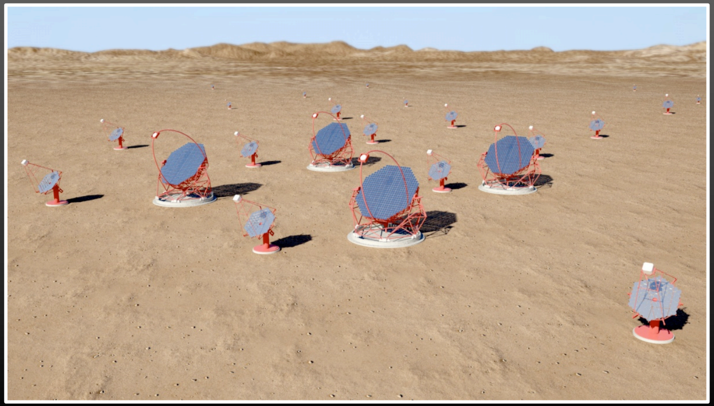
IceCube

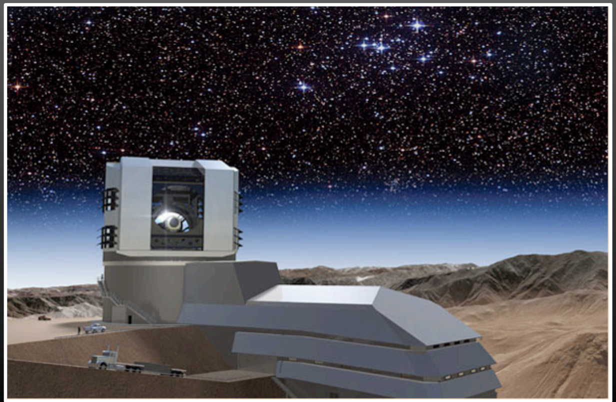
AdLIGO



2020s

Discovery





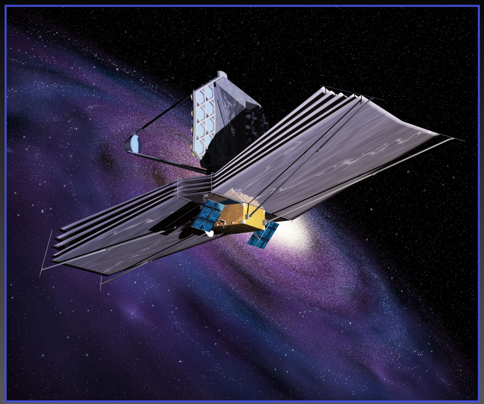
CTA

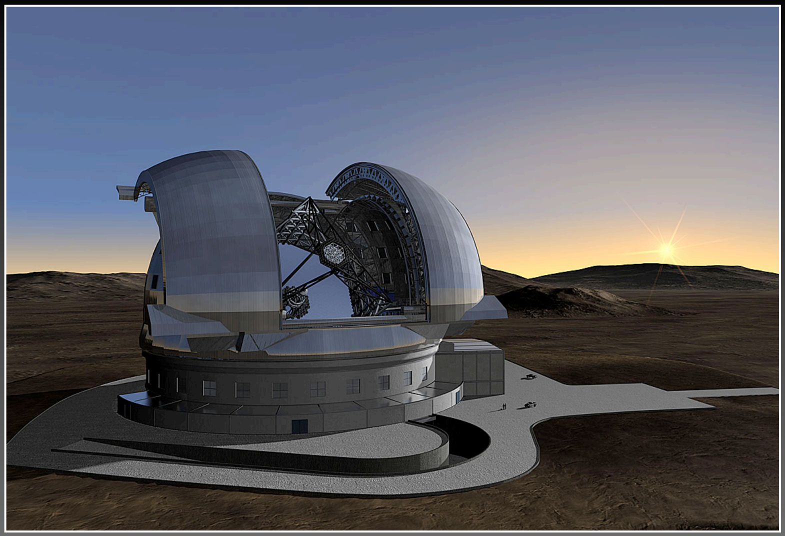
LSST

ALMA

JWST

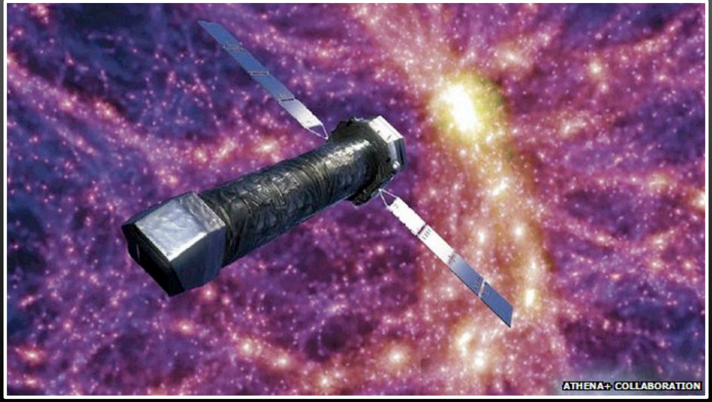
ELT+TMT/GMT





2020s

Coordinated follow-up



SKA

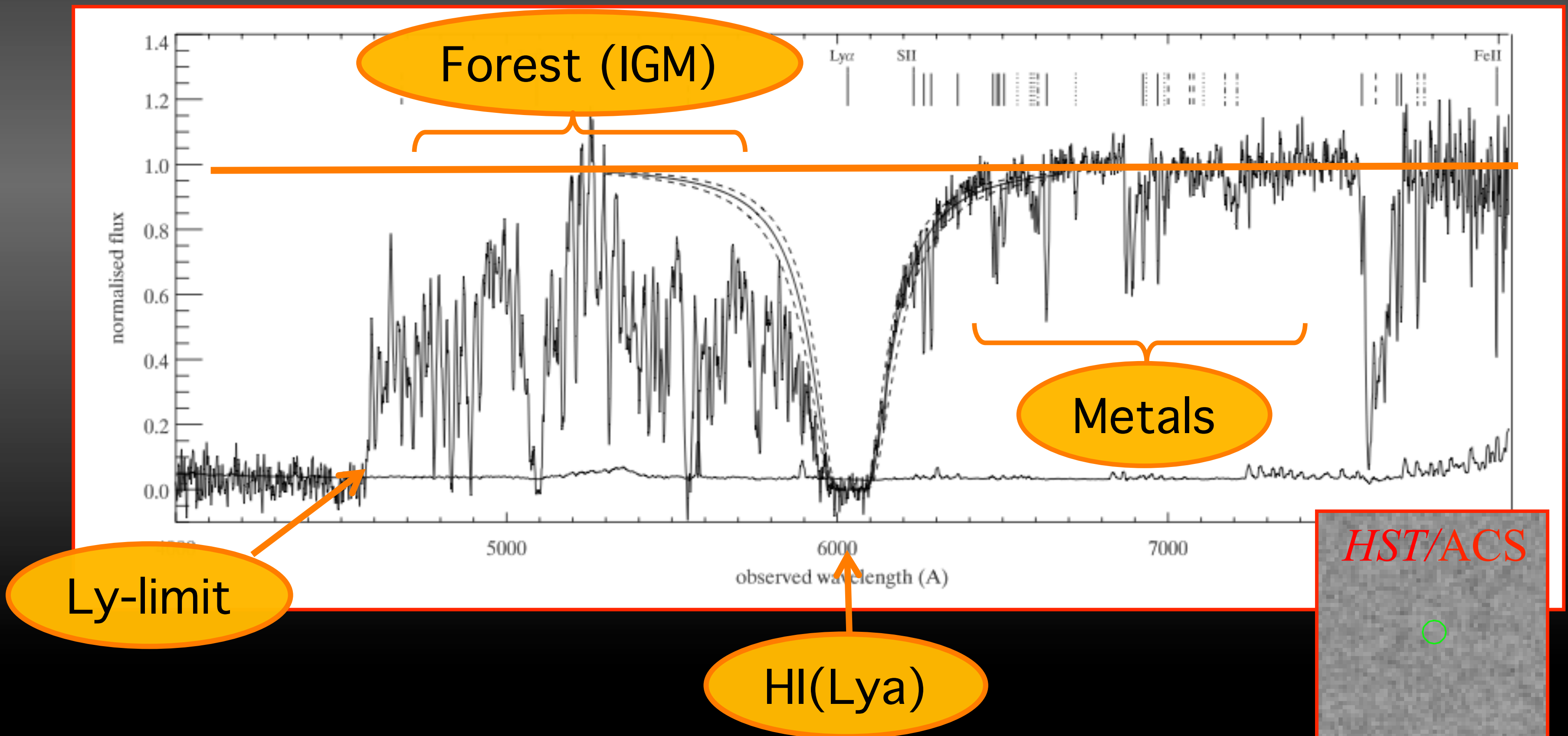
ATHENA

Long-duration gamma-ray bursts

GRB is produced from jets with velocities very close to the speed of light (bulk Lorentz factors of few hundred) – afterglow from shocked ambient medium. Most luminous sources known.

Bright back-lights to probe gas in normal star-forming galaxies over wide range in redshift, in addition to intervening absorption.

Abundances, HI, dust, dynamics etc. even for very faint hosts.
E.g. GRB 050730: faint host (R>28.5), but z=3.97, [Fe/H]=~2 and low dust, from afterglow spectrum (Chen et al. 2005; Starling et al. 2005).

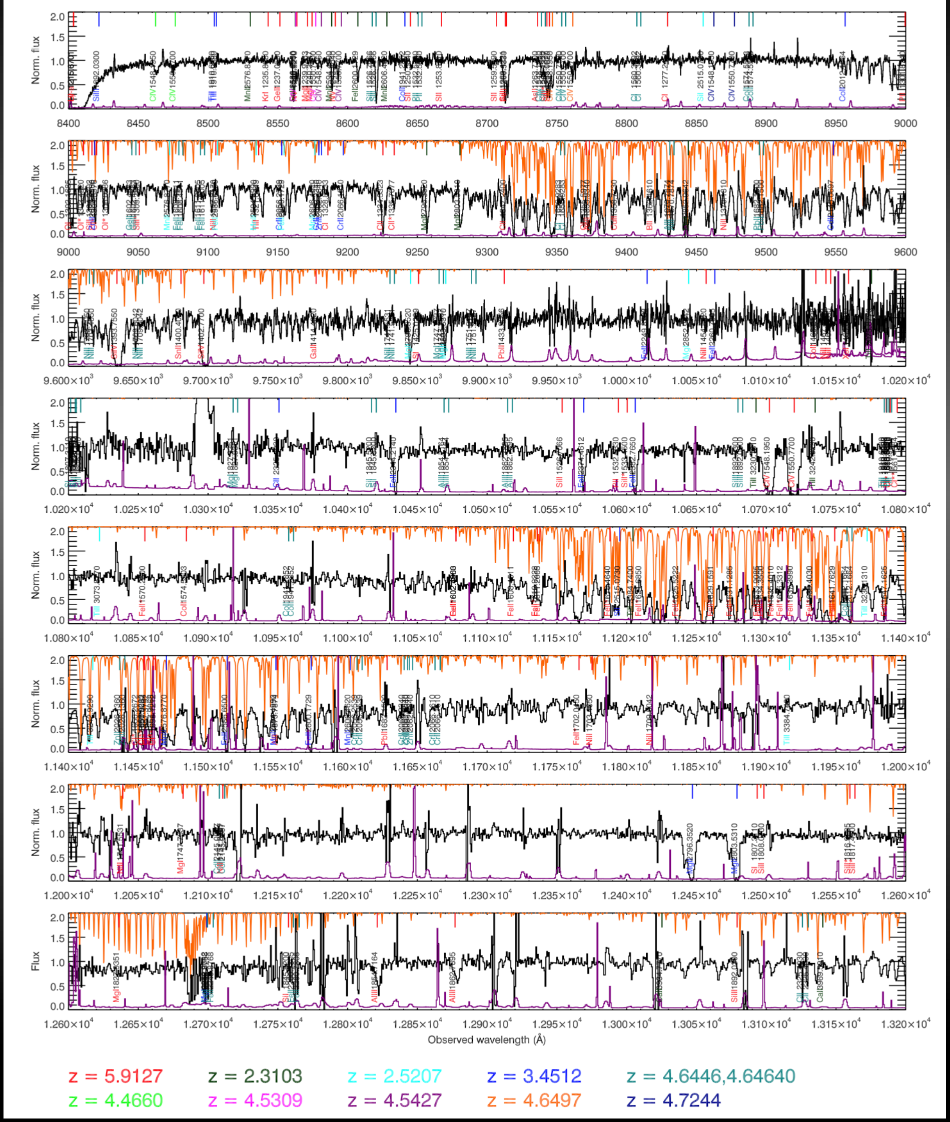


GRB 130606A at z=5.91

Bright afterglow, providing high-S/N spectra from VLT/X-shooter (also Gemini/GMOS, GTC/OSIRIS, Subaru/FOCAS).

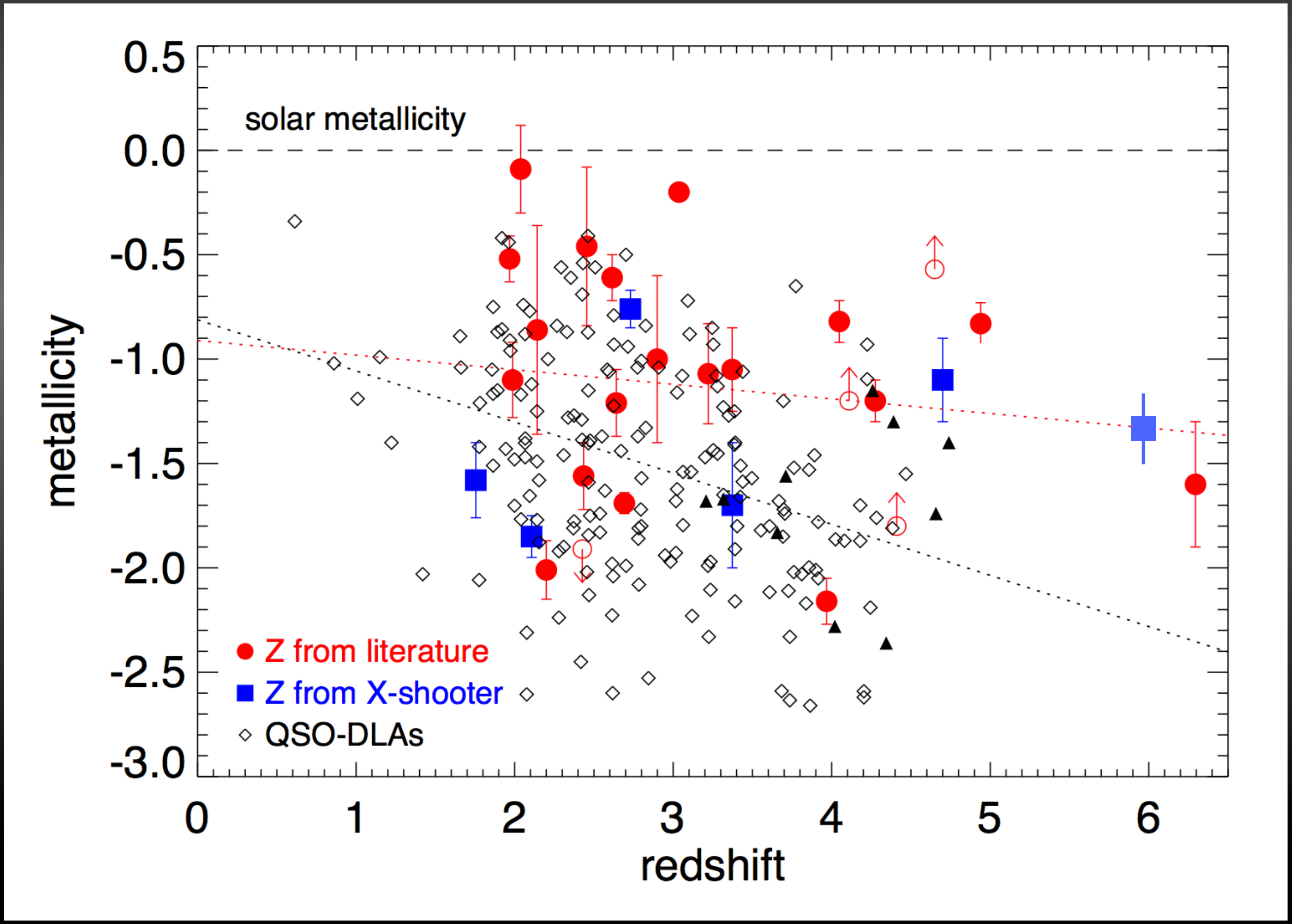
Detailed study of host and intervening absorbers (both discrete and diffuse).

Hartoog et al. arXiv:1409.4804.
(See also Chornock et al. 2013; Castro-Tirado et al. 2014; Totani et al. 2014)



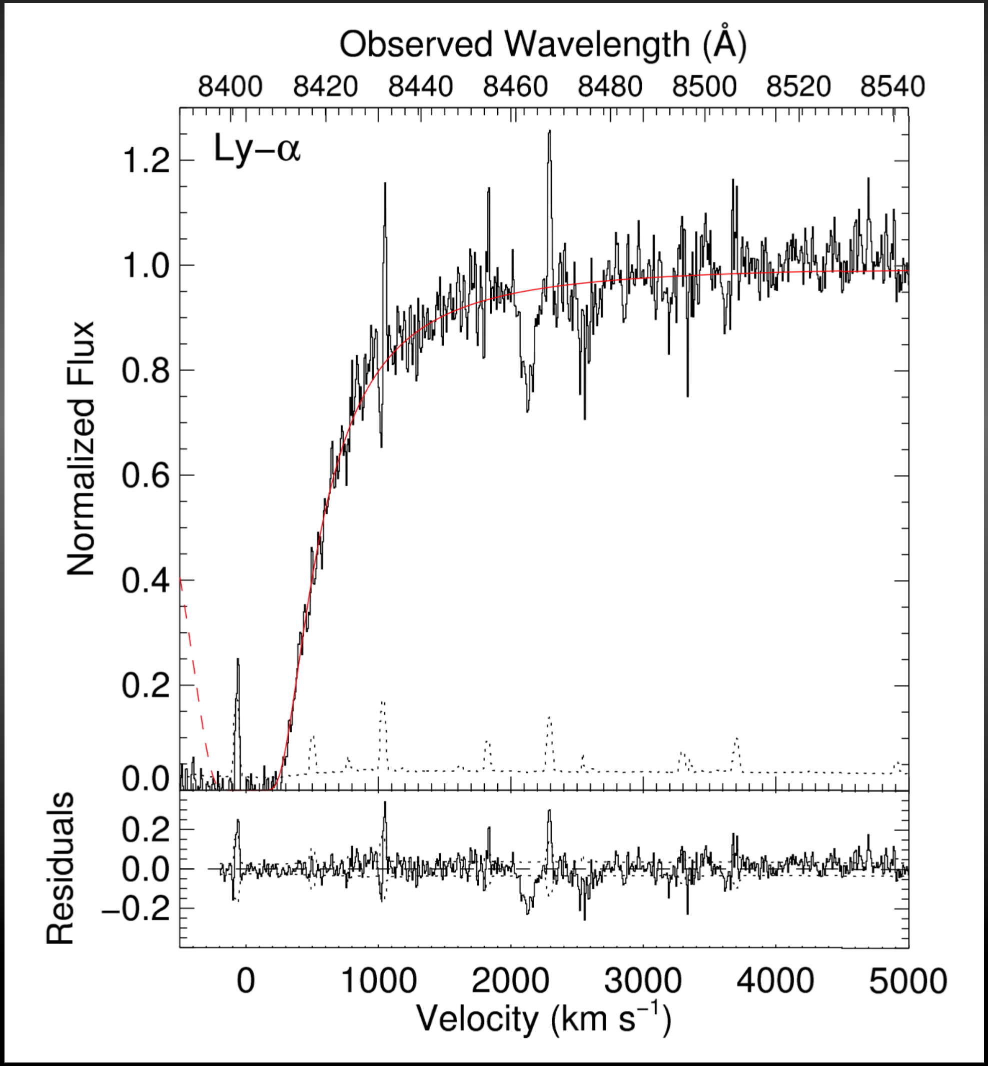
GRB 130606A at z=5.91

Numerous absorption lines (high and low ionization species) enabling detailed abundance studies ($Z \sim 0.05\ Z_{\odot}$).



GRB 130606A at z=5.91

Decomposition of Ly-alpha red-wing into IGM and ISM components.

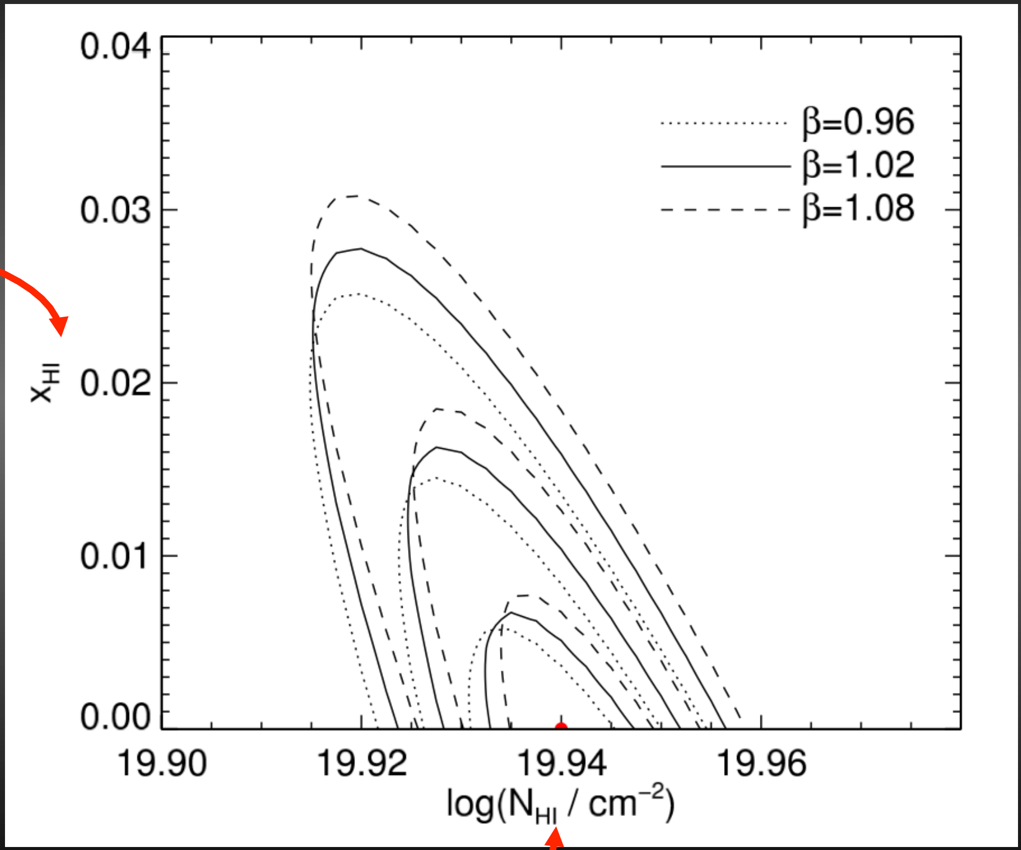


Hartoog et al. 2014

GRB 130606A at z=5.91

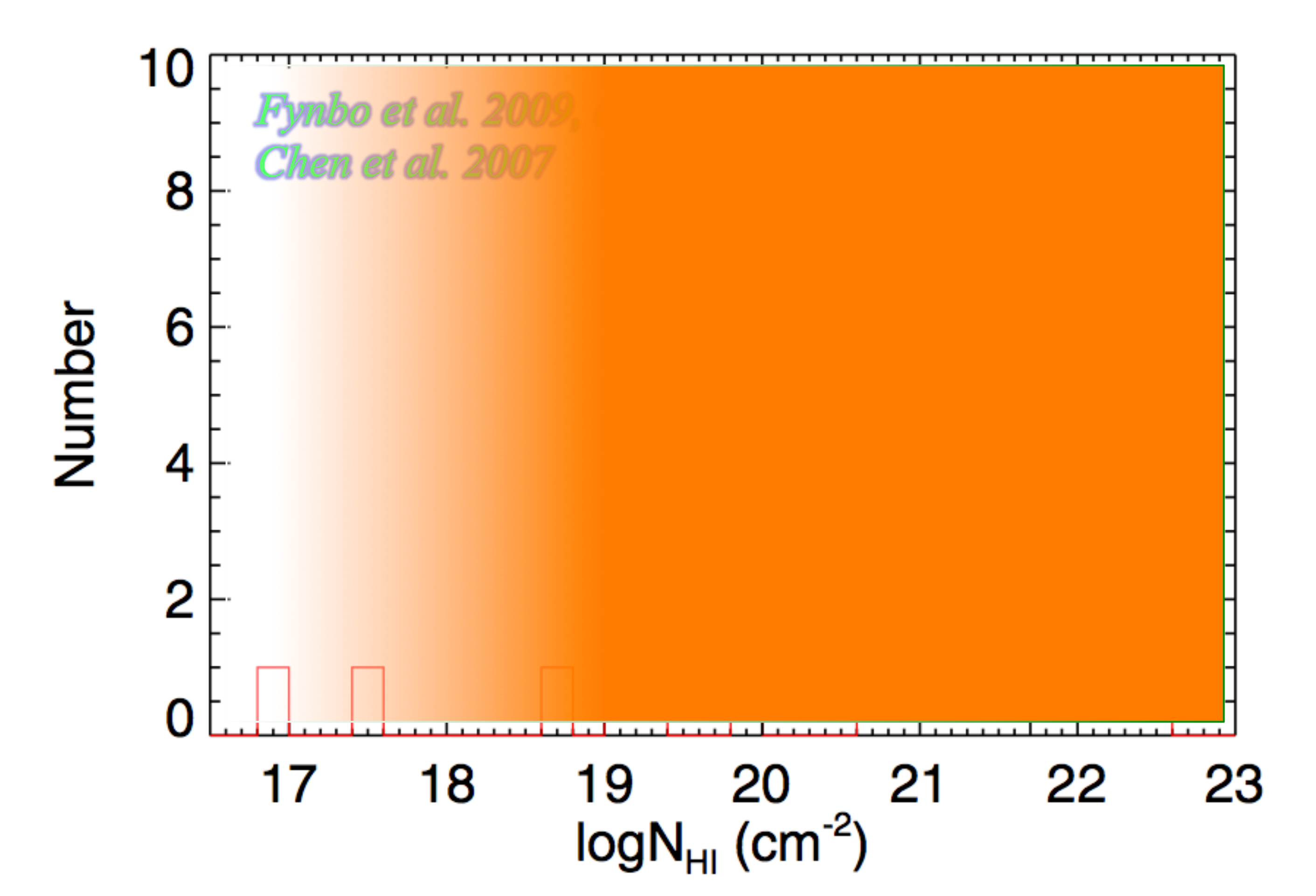
Decomposition of Ly-alpha red-wing into IGM and ISM components.

IGM predominantly ionized by z~6



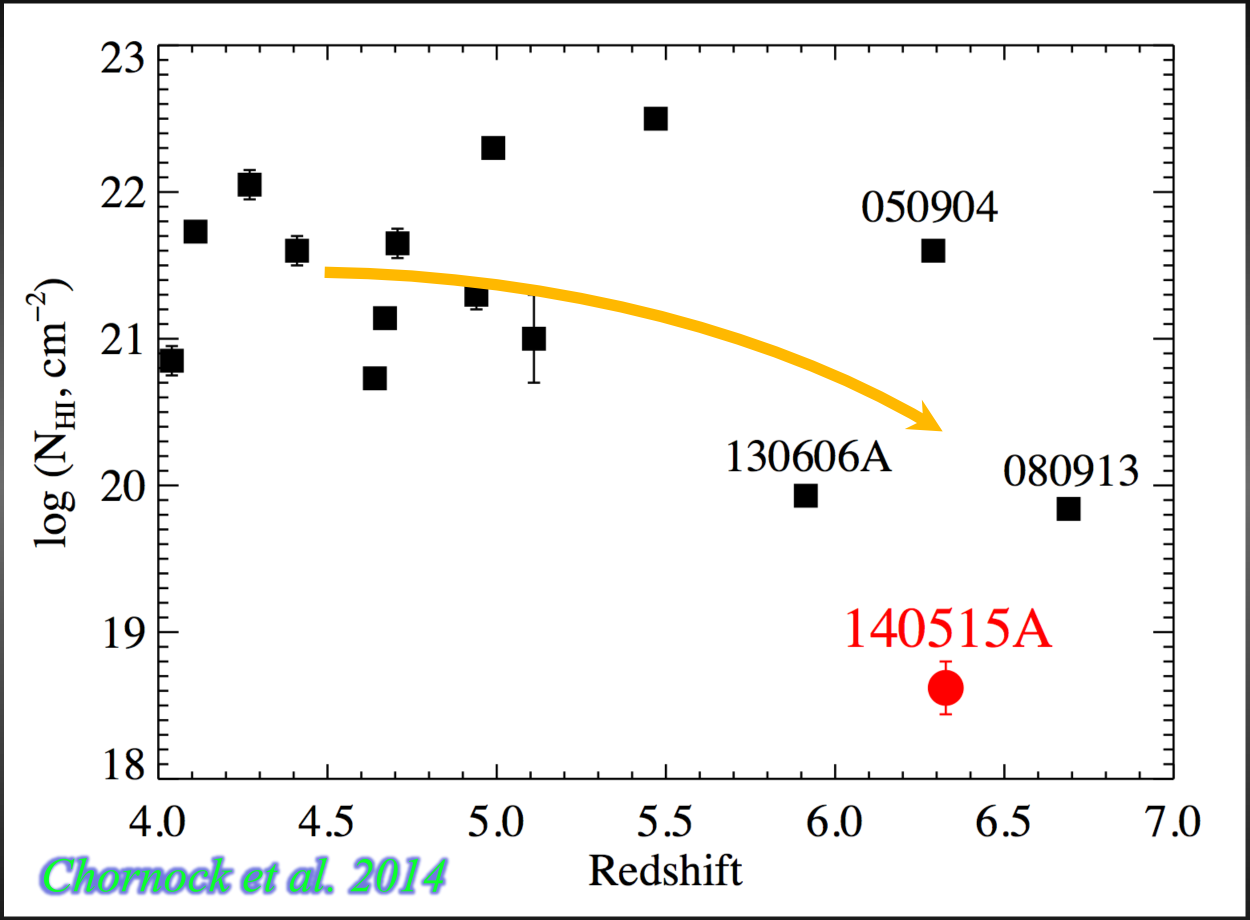
Host NH relatively low, but still opaque to ionizing photons.

Escape fraction at high-z from GRBs



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

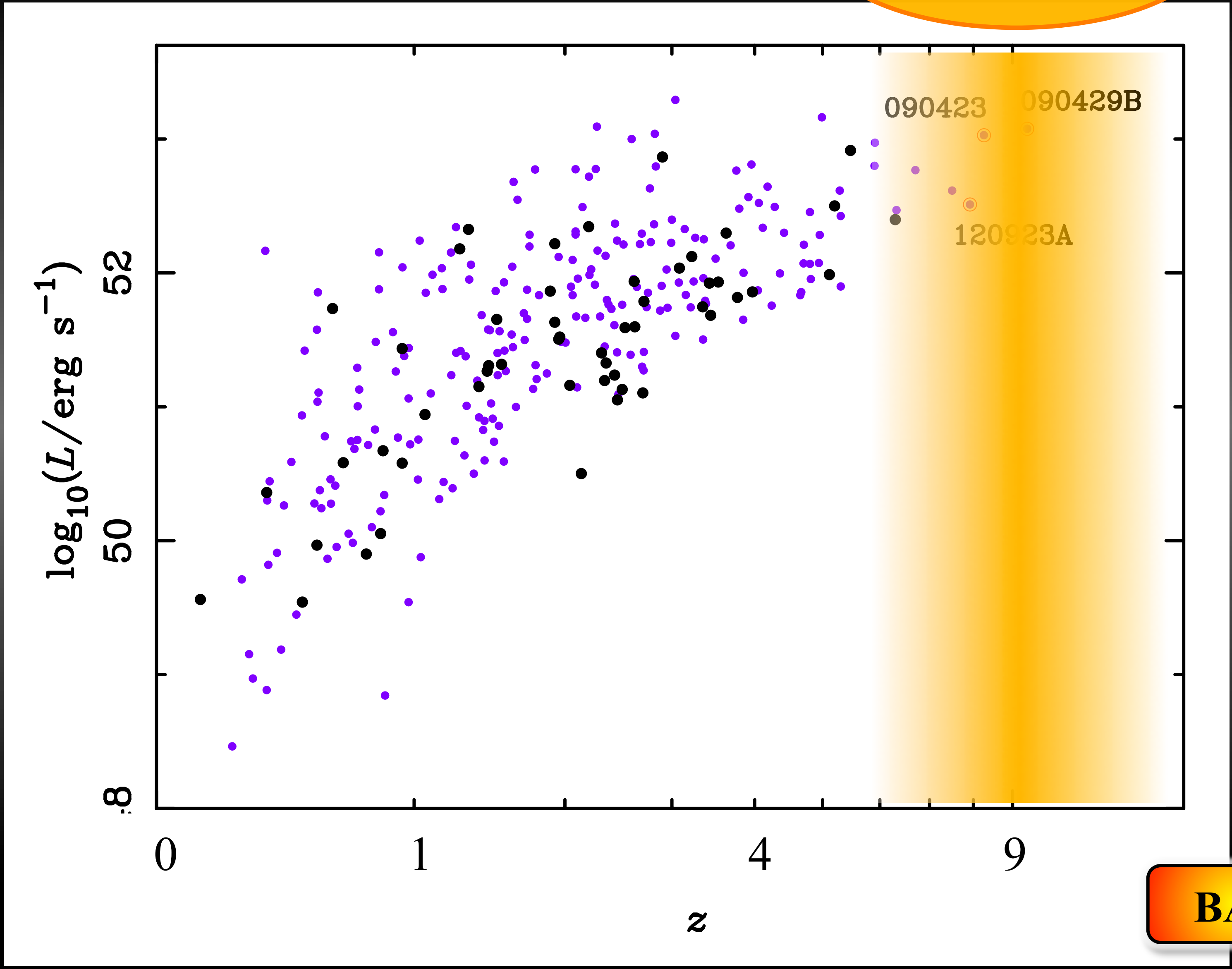
Escape fraction at high-z from GRBs



Marginal evidence for reducing opacity at high redshift, but from four GRBs at 6<z<7, inferred escape fraction remains zero ! (2-sigma limit is ~50%)

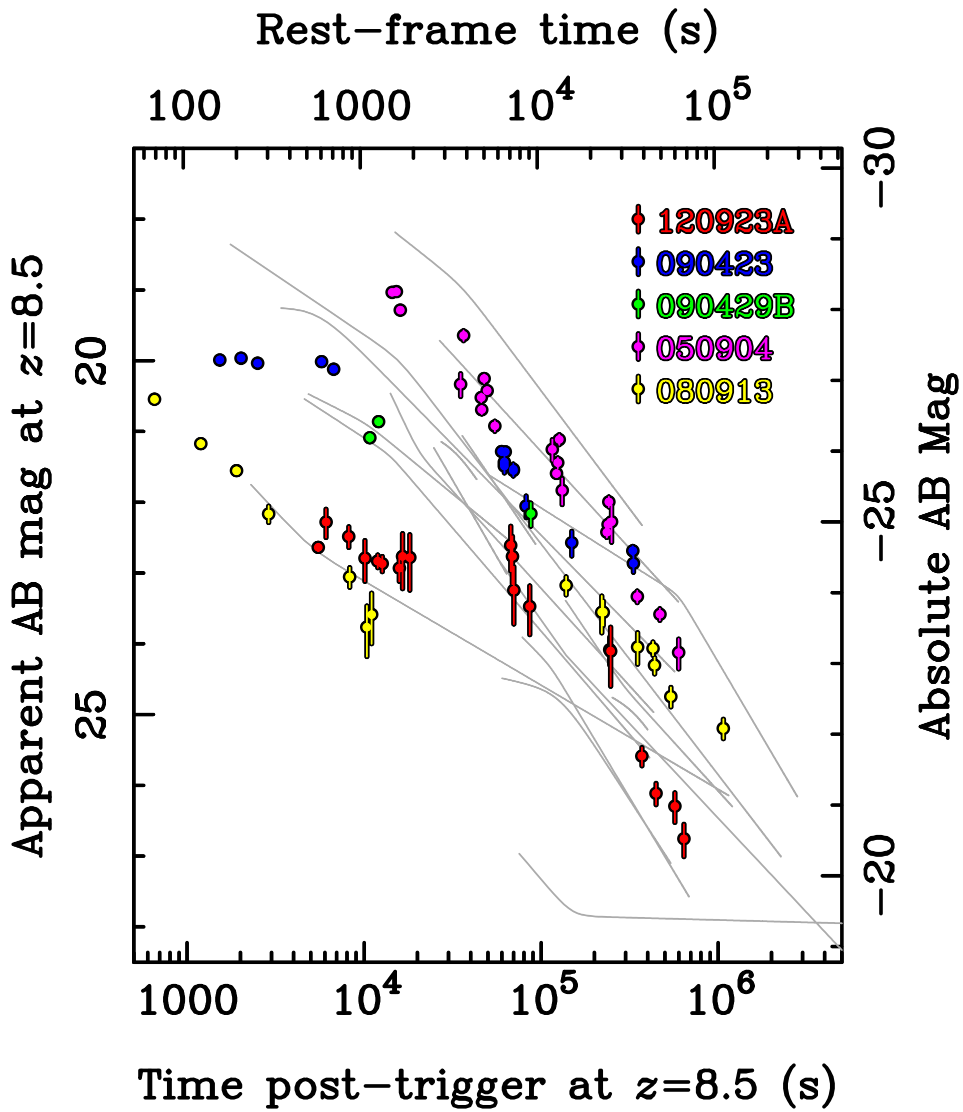
The high redshift burst population

Planck reionization



BAT

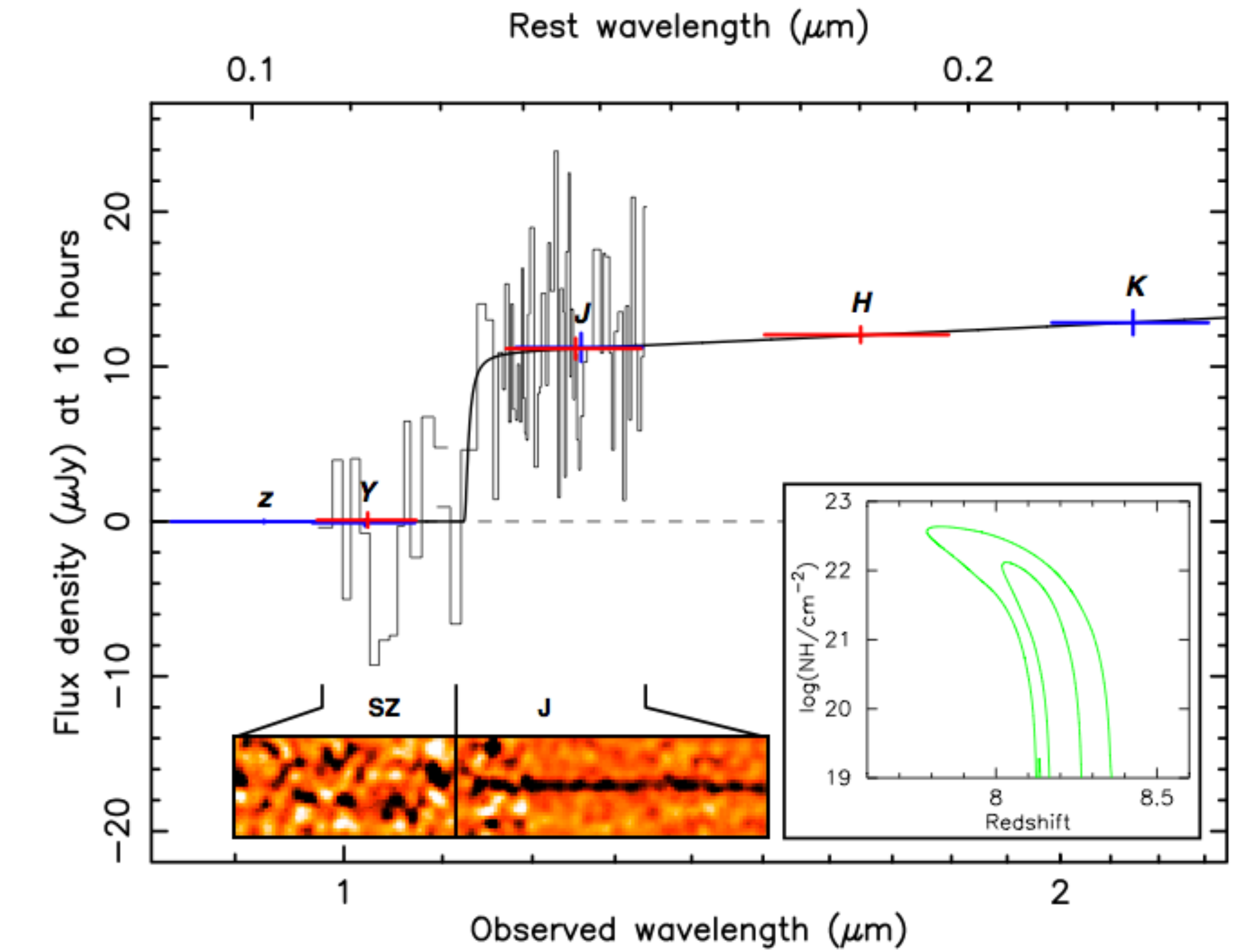
The high redshift burst population



Ground

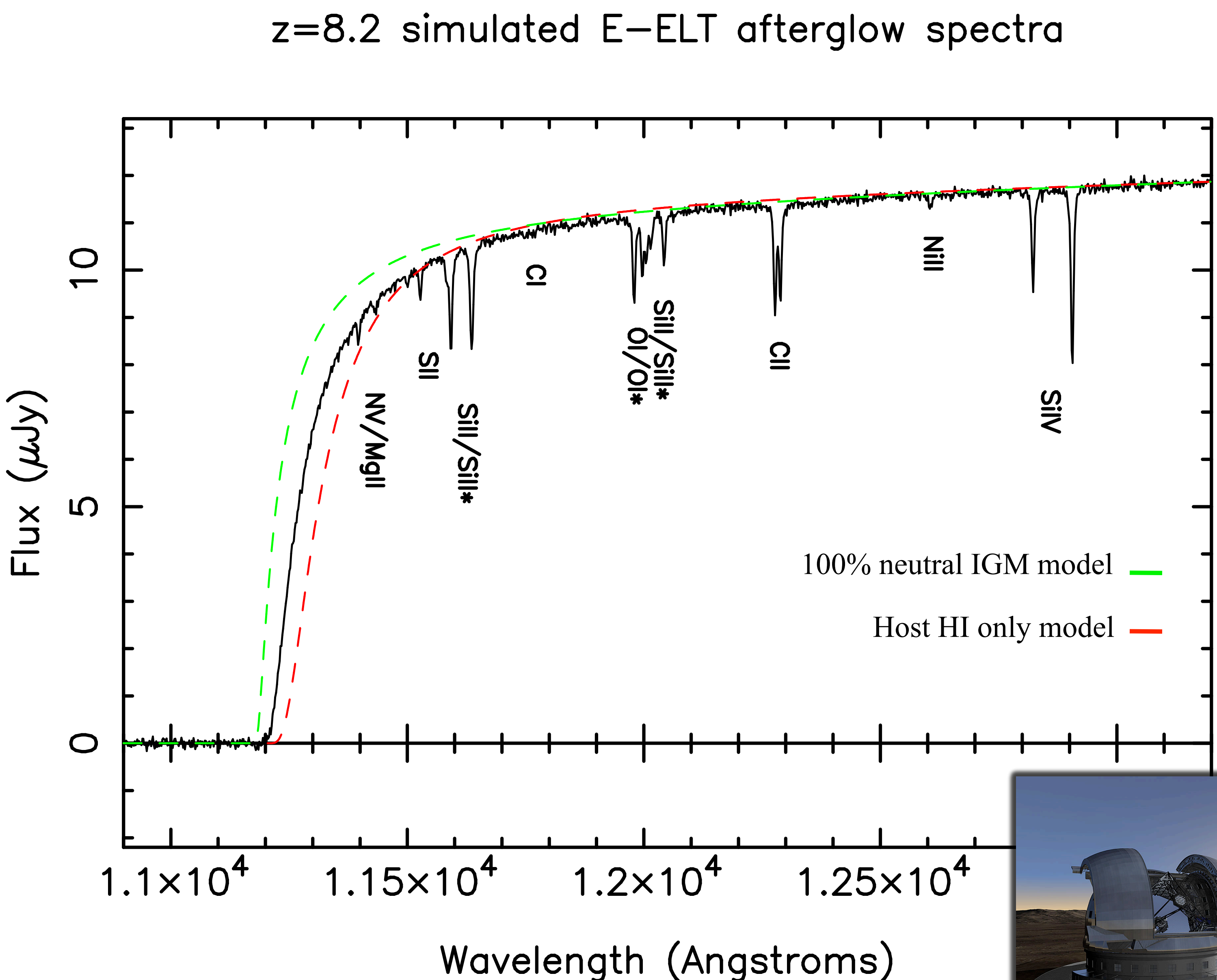
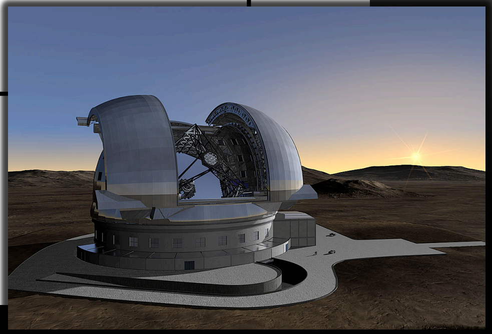
GRB 090423

$z = 8.23 \pm 0.08$



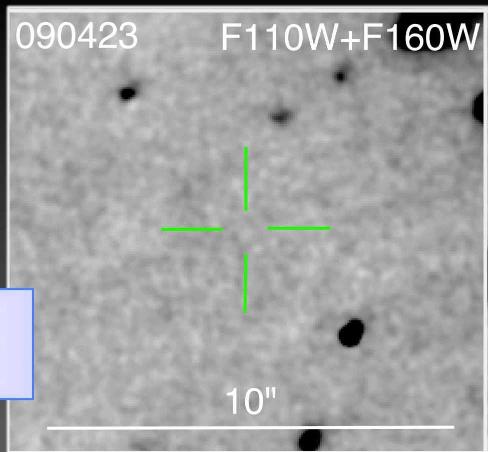
VLT

Tanvir et al. 2009

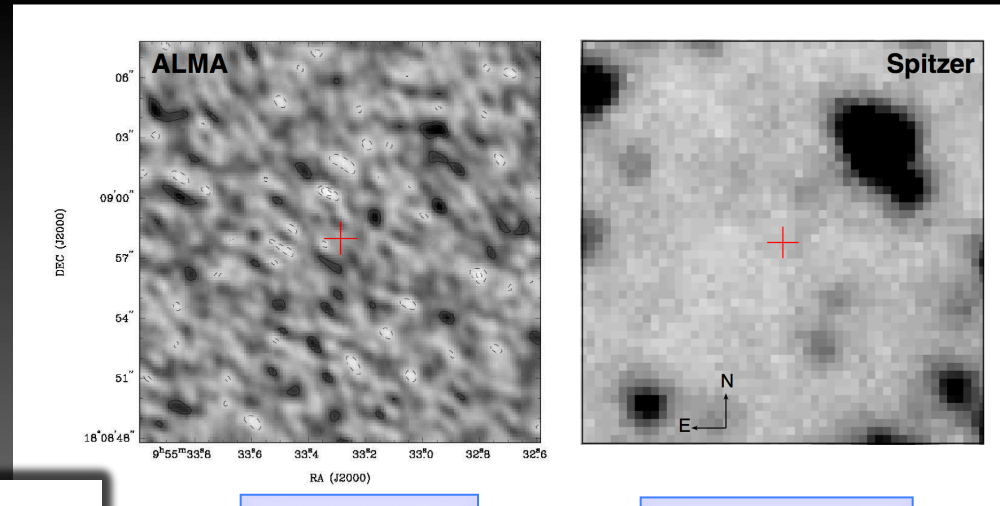

z=8.2 simulated E-ELT afterglow spectra
Flux (μJy)
0
5
10
Wavelength (Angstroms)
1.1×10^4
1.15×10^4
1.2×10^4
1.25×10^4
NV/MgII
SII
SiII/SiII*
CI
OI/OI*
SiII/SiII*
CII
NiII
SiIV
100% neutral IGM model
Host HI only model


Detecting undetectable galaxies

GRB090423 @ z=8.2

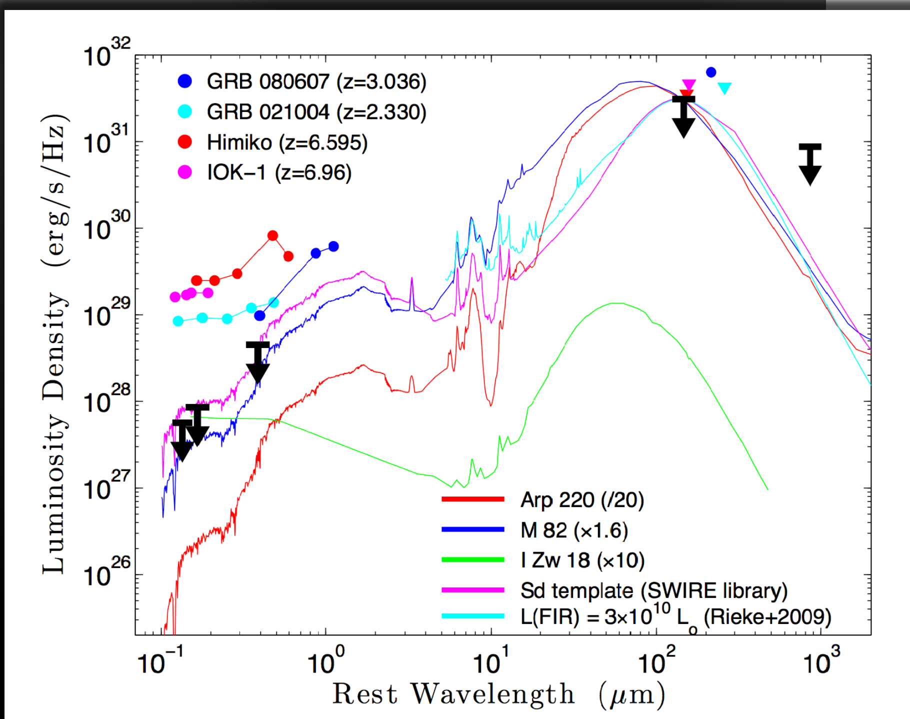


HST



ALMA

Spitzer

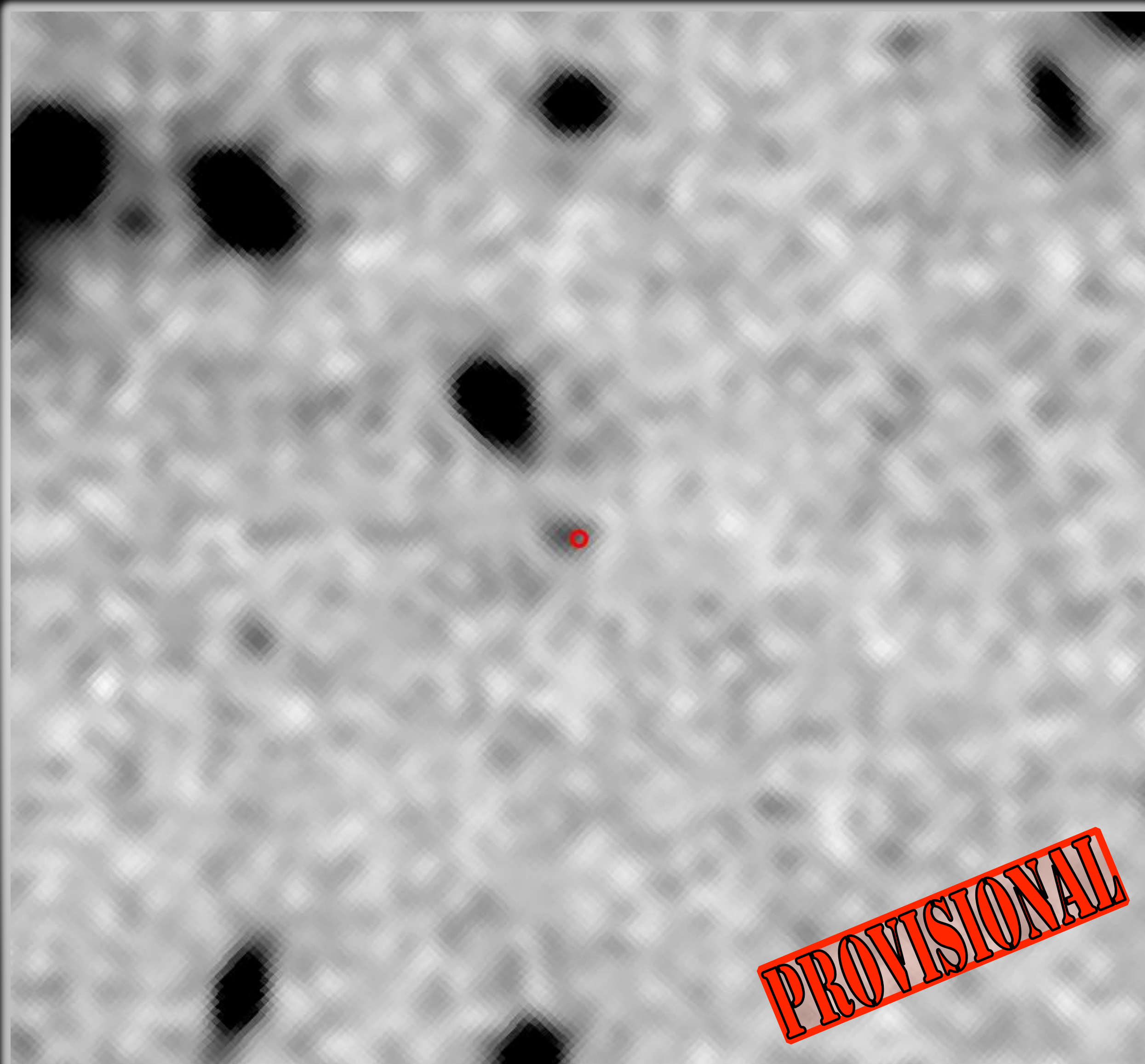


3hr Band 6 – 3σ limit $F_\nu < 33\mu$Jy,
$L_{IR} < 3\times10^{10}\ L_\odot$

$SFR_{IR} < 4\ M_\odot/yr$, $SFR_{UV} < 1.2\ M_\odot/yr$

Tanvir et al. 2012; Berger et al. 2014

Beyond the tip of the iceberg...



GRB050904
@ z=6.29

H_{AB}=27.6
M_{abs}= -19.2

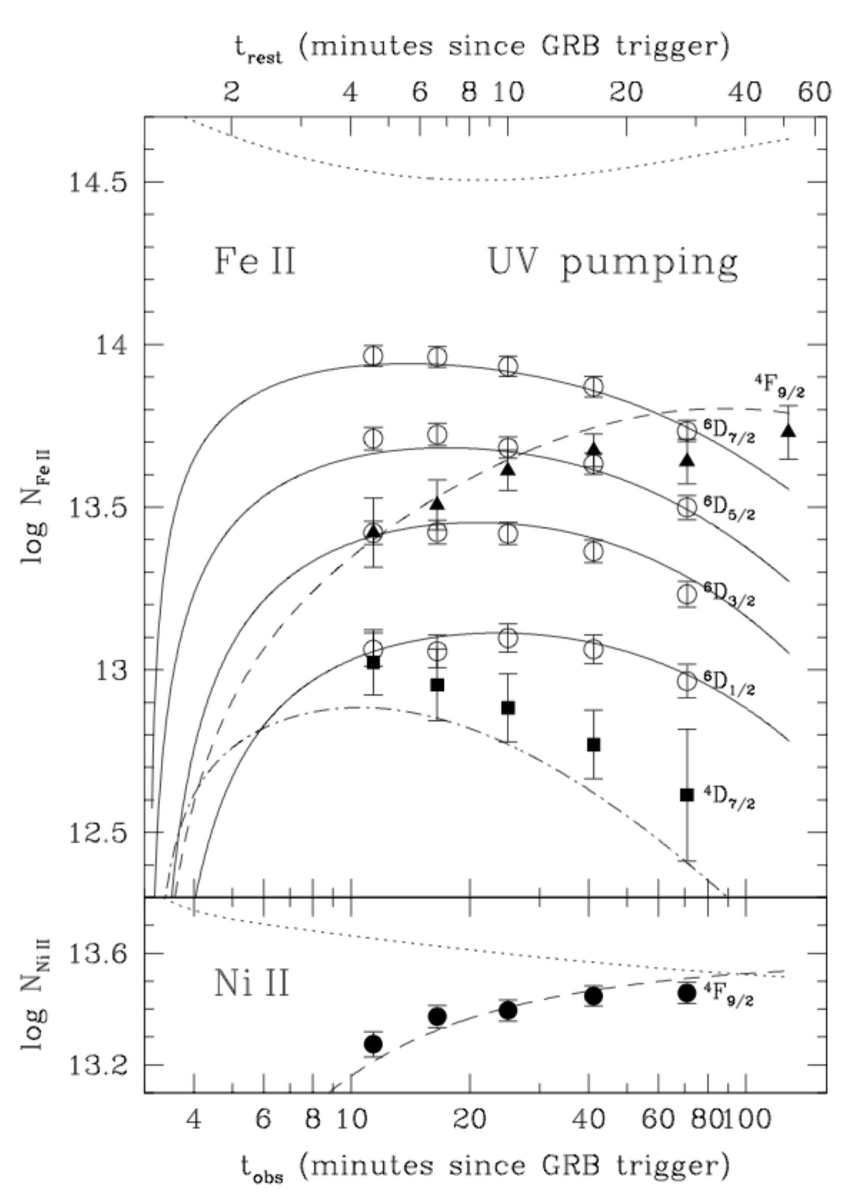
L ~ L*/2

SFR_{UV} ~ 3 $M_{\odot}$/yr

Time variable absorption.

Vreeswijk et al. 2007

Due to either absorber size or effects of prompt UV/X flash/ afterglow (ionization and dust destruction, recombination, de-excitation etc.).



e.g. several GRBs have shown evidence of time-variable fine structure lines, which are well fitted by absorption from distant absorbers, initially excited by UV from the GRB itself.

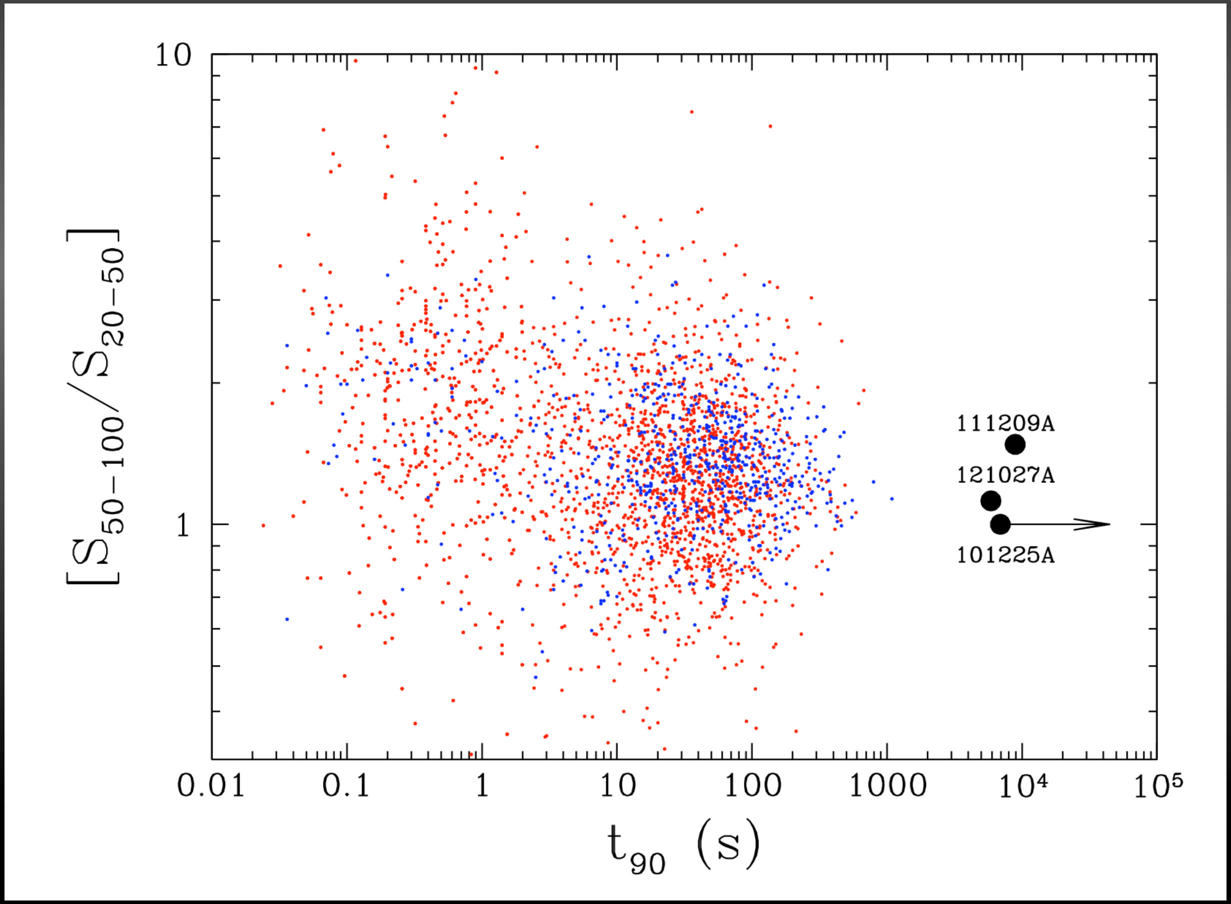
Long-duration GRBs

What we may hope to learn:

- Gas properties in many individual galaxies
- Global star formation history
- Global metallicity evolution
- Global dust evolution
- Escape fraction evolution
- Molecules
- IGM neutral fraction
- Star-forming galaxy luminosity function

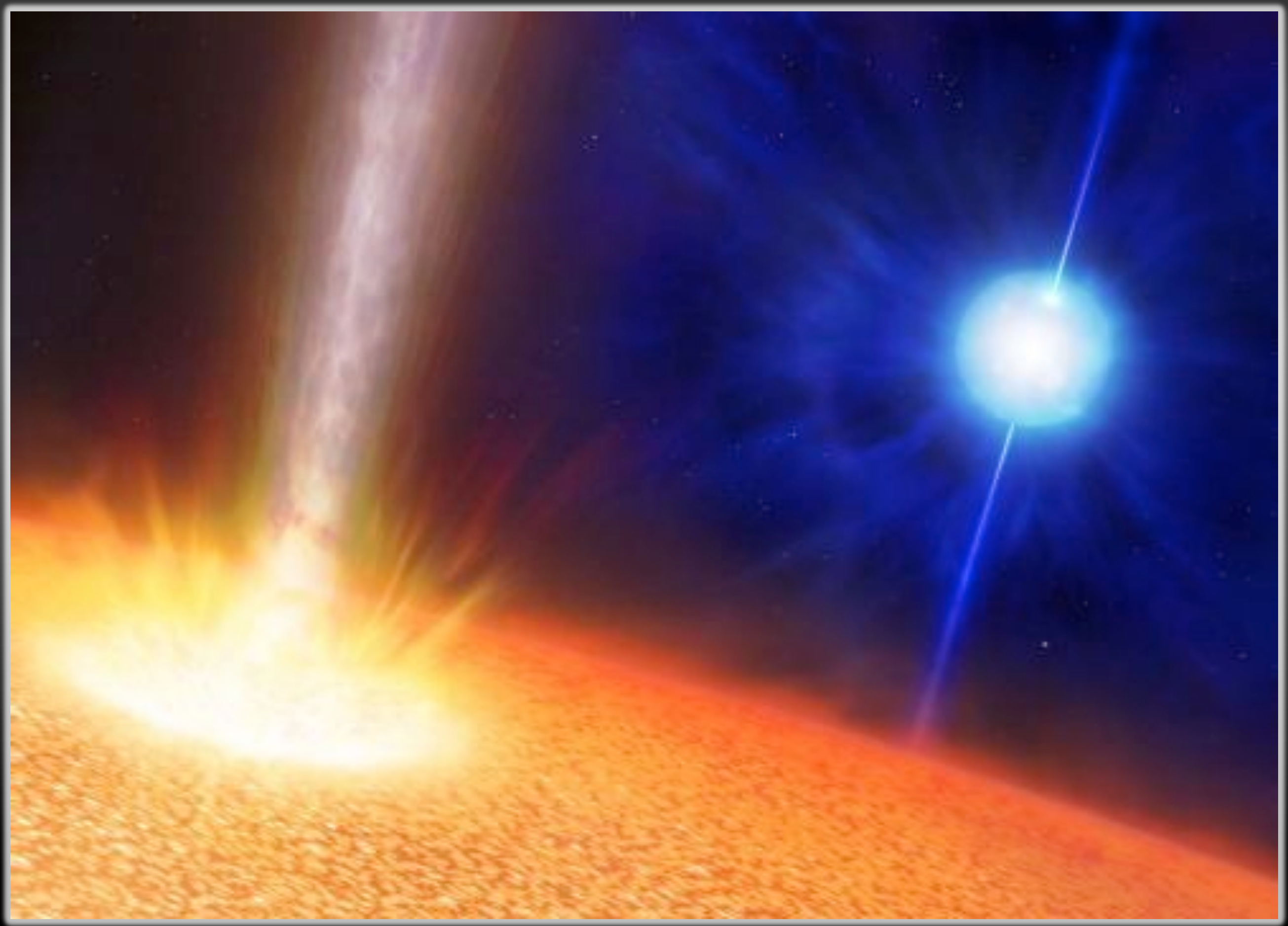
Ultra-long GRBs

Apparently new class(es) of very long-lived GRB-like events uncovered in recent years. Afterglows (and hosts) typically faint and difficult to obtain absorption redshifts.



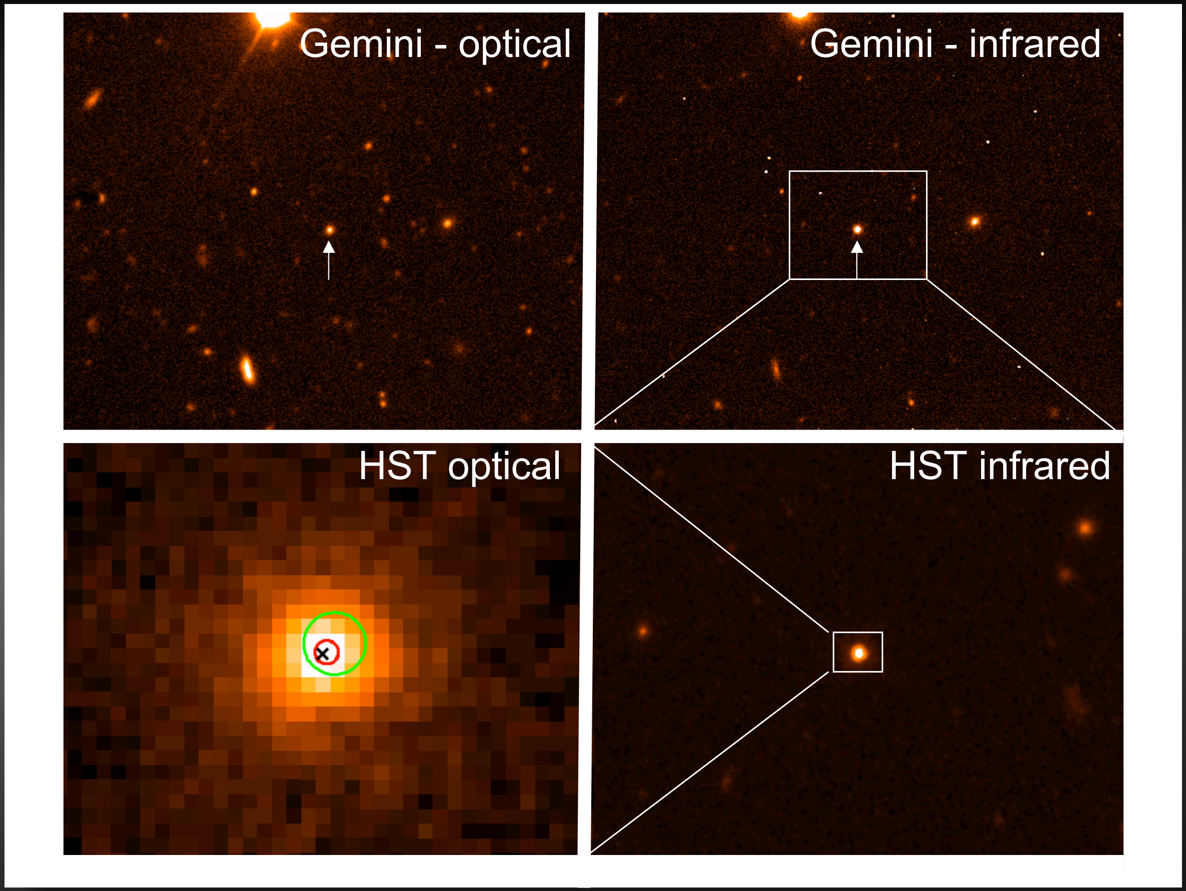
Ultra-long GRBs

Cosmological distances, but origin still unclear – plausibly relativistic jets in red supergiant stars.



Levan et al. 2014

GRB 110328/*Swift* J1644+57



Levan et al. 2011

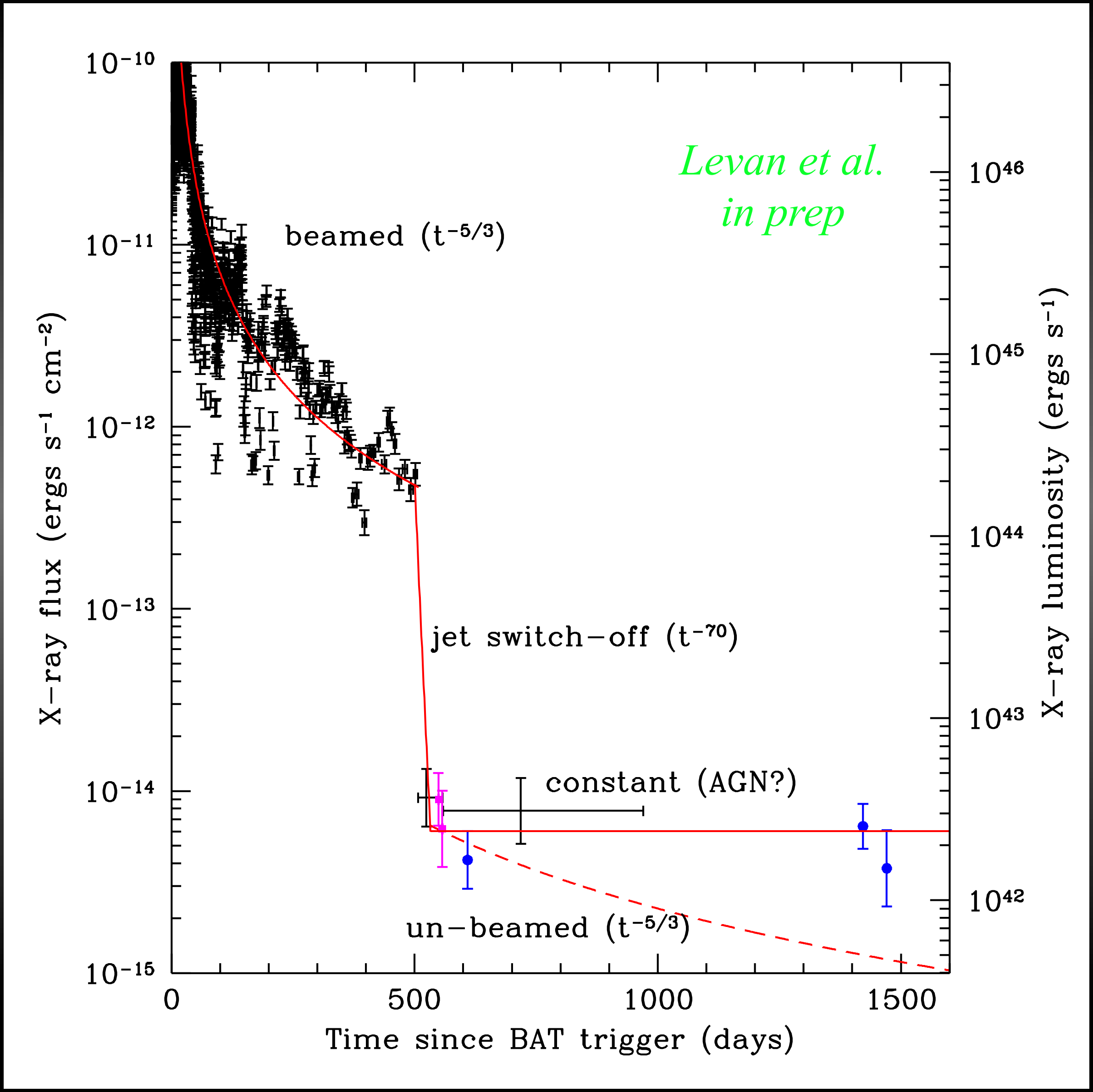
Even longer-lived GRB-like event, from nucleus of galaxy at z=0.34

(High extinction in this case – good HARMONI target!)

GRB 110328/*Swift* J1644+57

Relativistic jet produced by disruption of star by supermassive BH

GRB 110328/*Swift* J1644+57



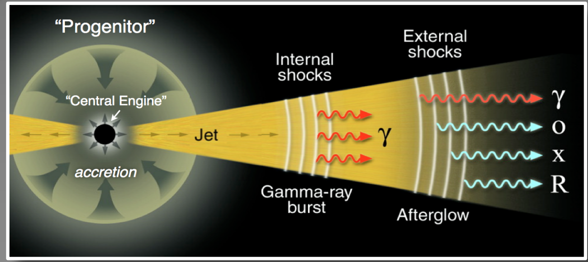
Jet seen to abruptly "turn off" after ~500 days.

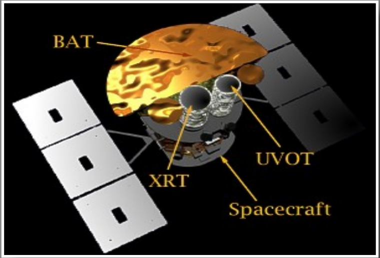
Tidal disruption events & UL-GRBs

What we may hope to learn:

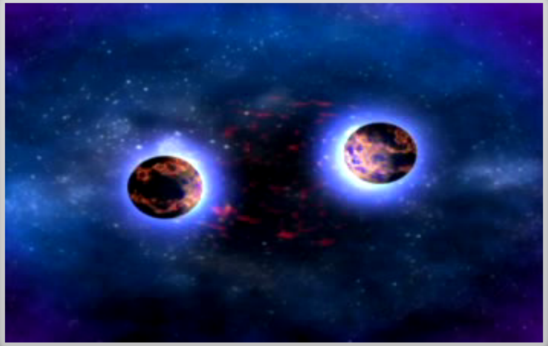
- Rare classes of relativistic explosions
- Demographics of black holes
- Requirements of relativistic jet launching

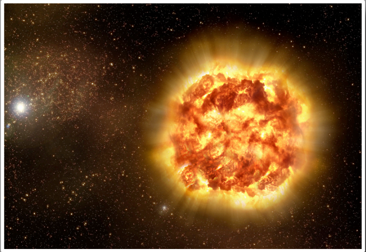
Compact binary mergers

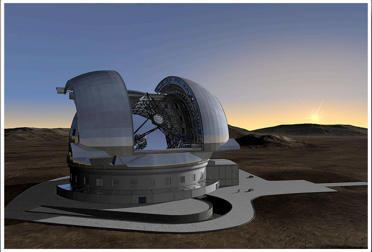




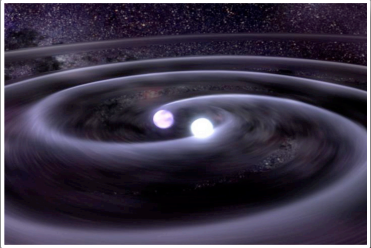
Short GRBs







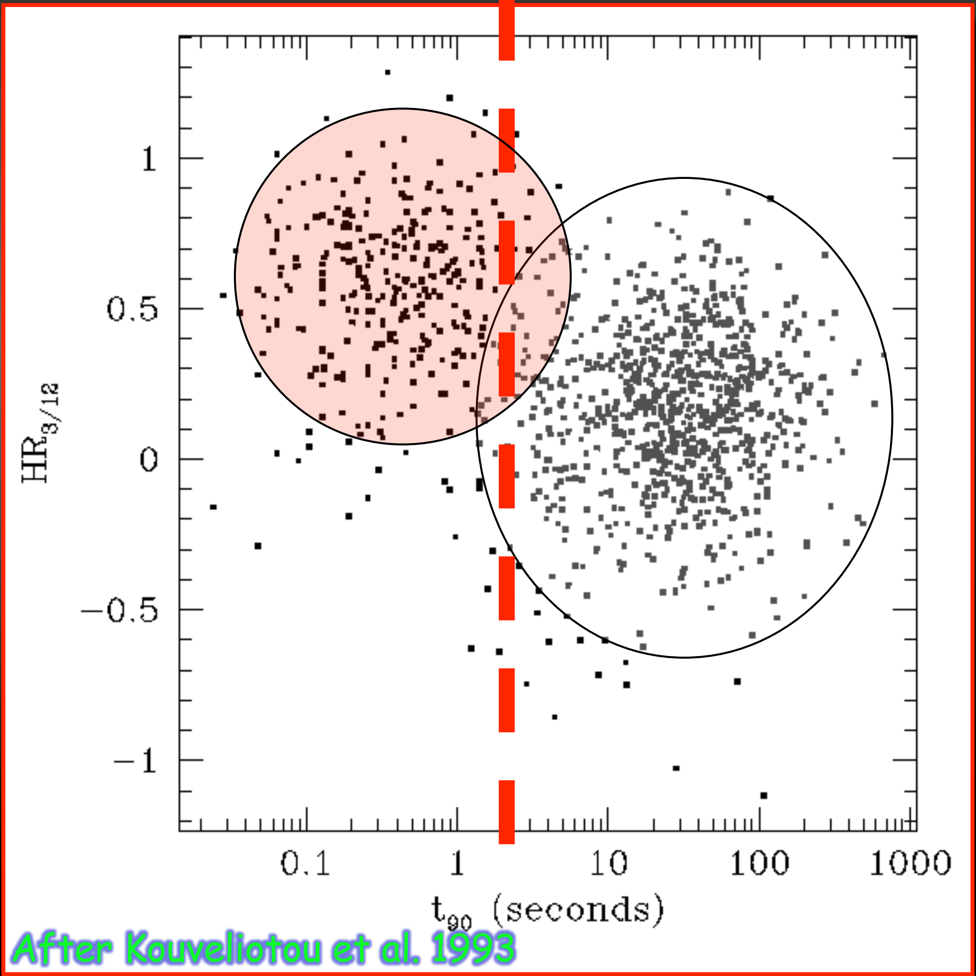
R-process kilonovae



Gravitational wave events

Short-hard GRBs

T_{90}=2 s



Around 25% of BATSE GRBs were "short", but:

- Populations obviously overlap
- Detector dependent (e.g. *Swift* sees fewer sGRBs, with "borderline" probably rather shorter).
- Both axes redshift dependent (in complicated ways)

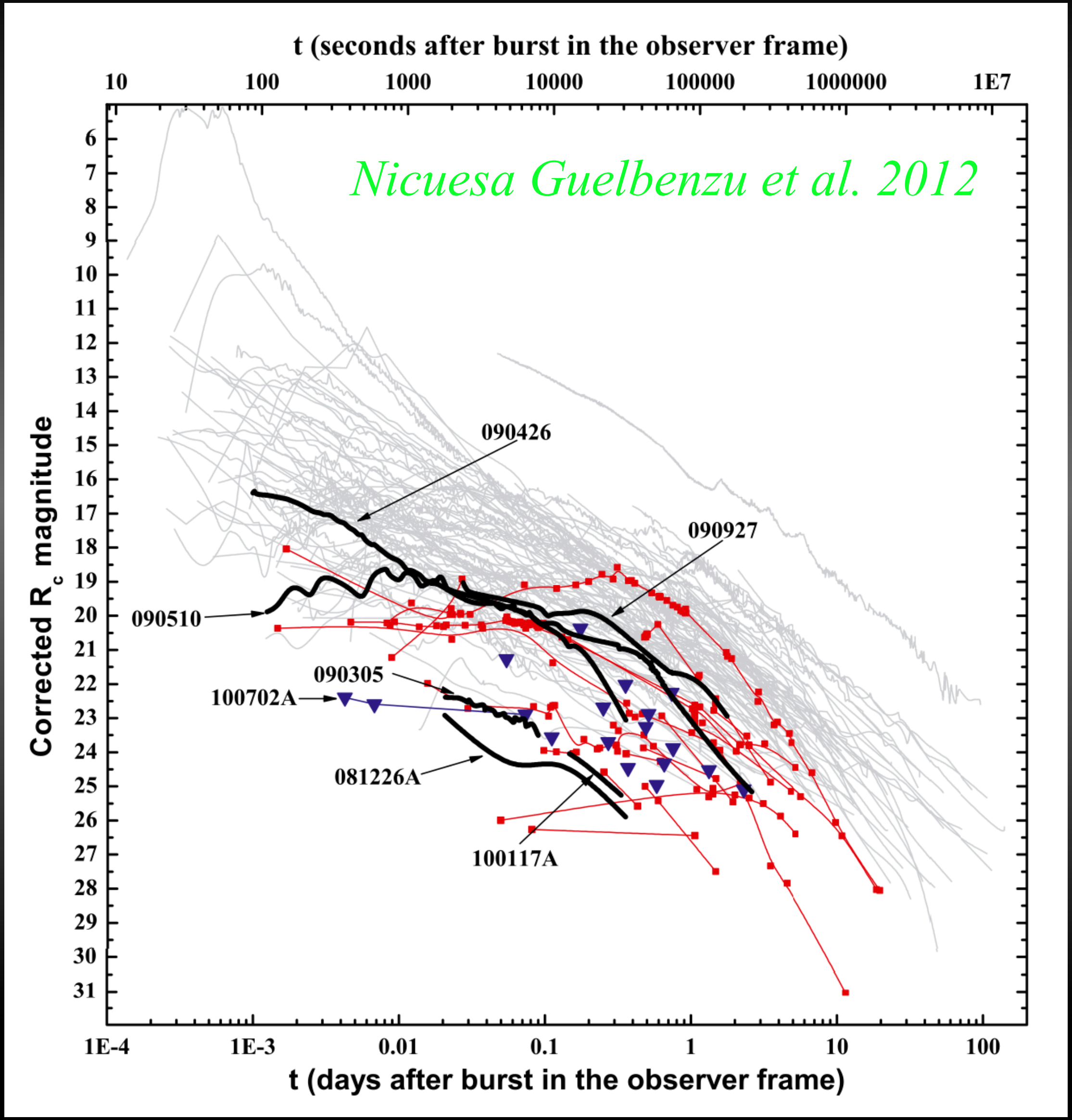
Short-duration bursts

Generally lower luminosity (hence lower <z>~0.5)

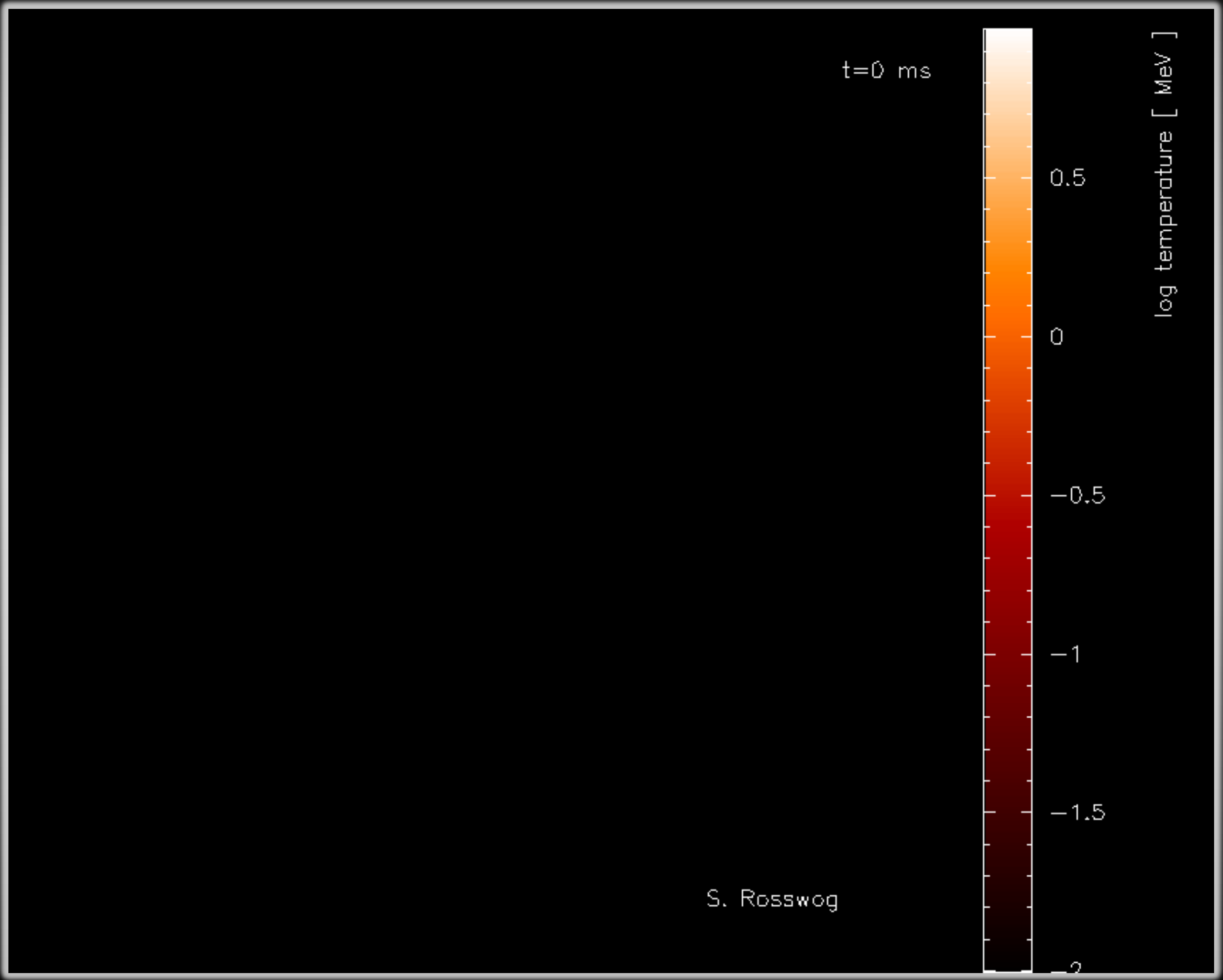
Never associated with supernovae.

May break into sub-classes e.g. a proportion have "extended soft emission".

Optical afterglows usually also very faint with weak spectral features – hard to find and hard to obtain redshifts (in practice, nearly always rely on host redshift).



r-process kilonovae



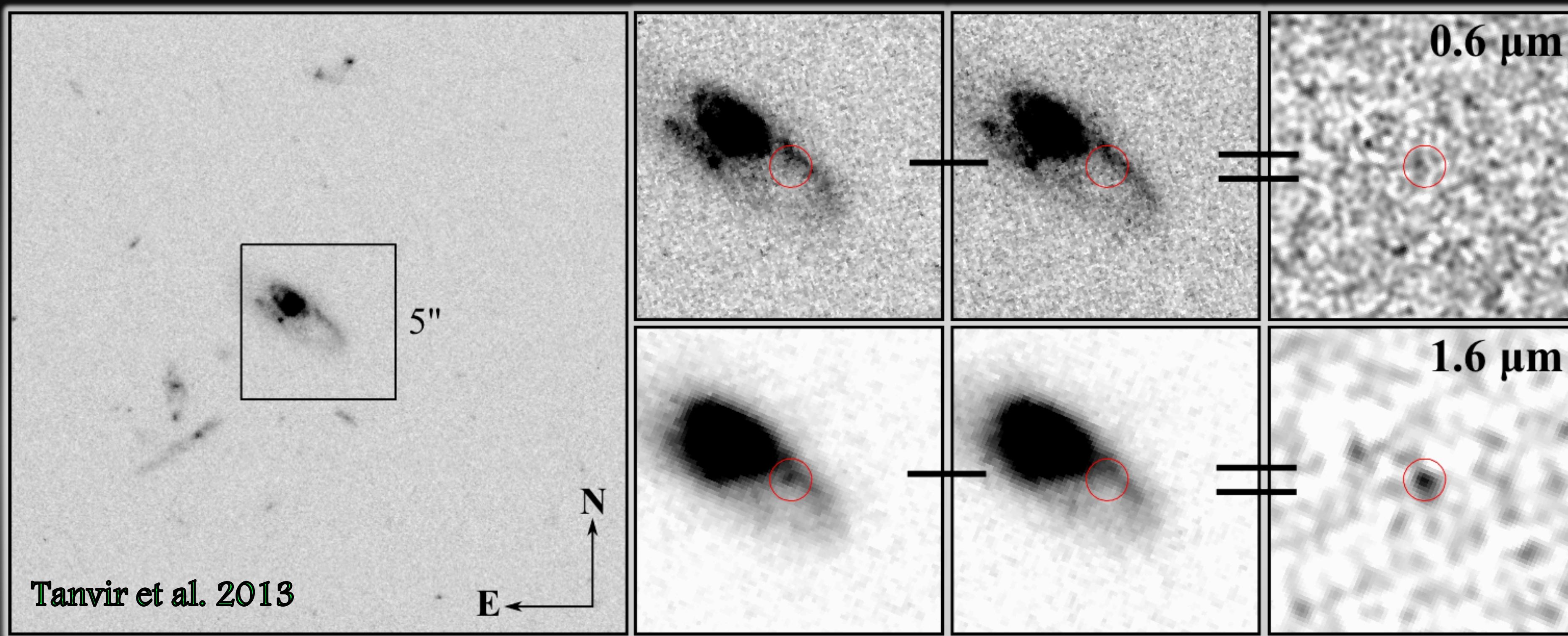
Rosswog et al. 2012

Decompressed material thrown/ blown out in merger produces neutron rich radioactive isotopes.

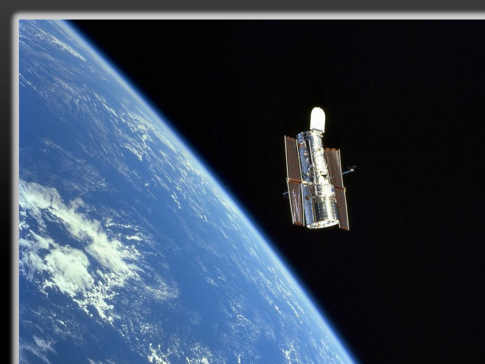
Their decay powers a short-lived radioactive transient. High opacity expected to greatly attenuate optical, hence requiring infrared search.

Rosswog et al. 2013
Piran et al. 2013
Kasen et al. 2013

GRB 130603B

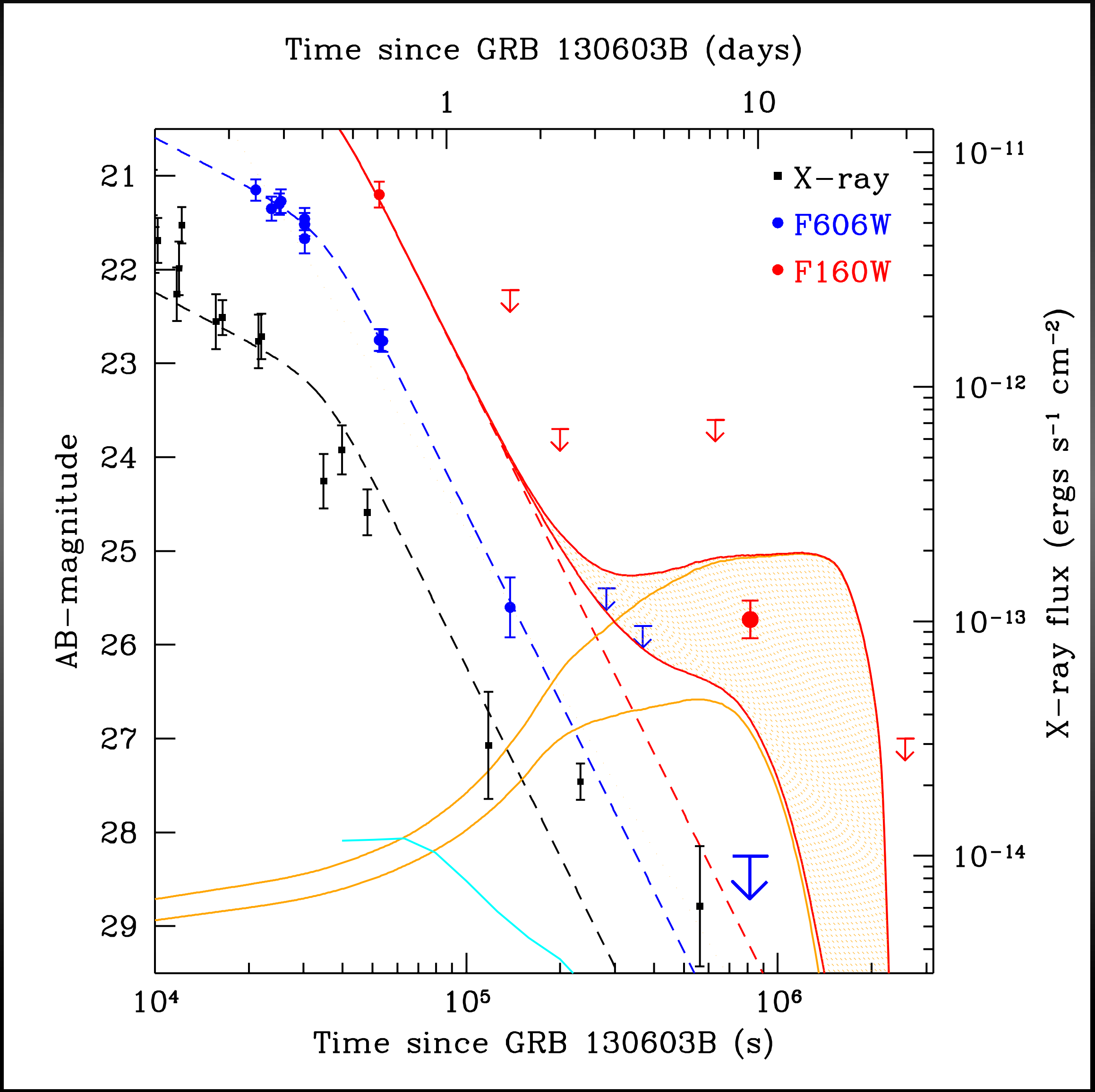


Transient emission seen in near-infrared in *HST* imaging at 9 days post-burst.



Consistent with high opacity line-blanketing of optical light.

GRB 130603B



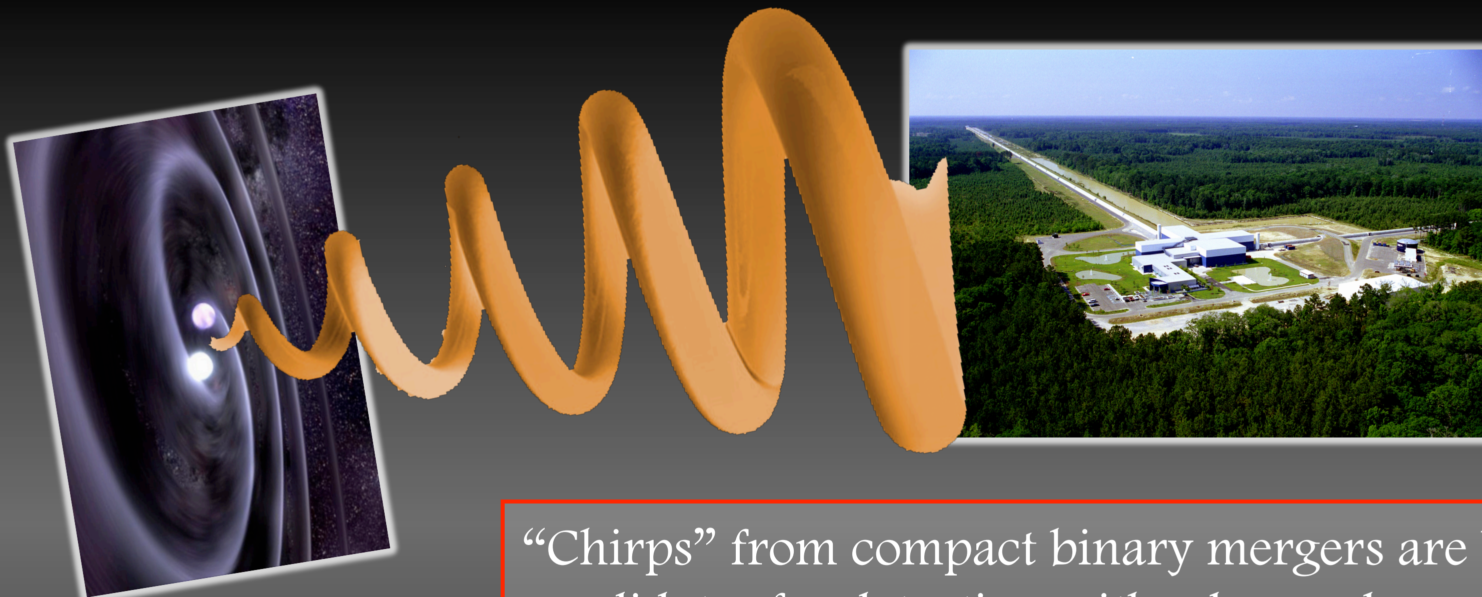
Comparison to Barnes & Kasen (2013) models suggests ejected mass ~0.05 $M_{\odot}$

Compact binary mergers ~ likely site of significant (possibly dominant) production of r-process elements in universe.

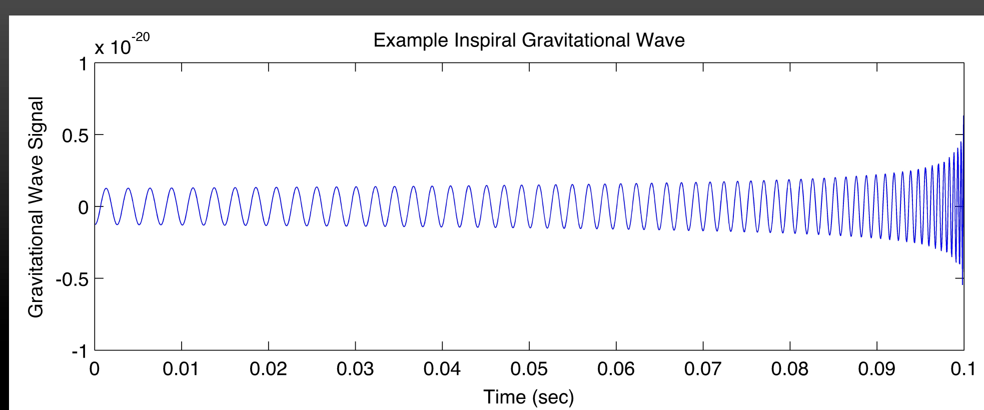
KN emission likely to be roughly isotropic and environment independent.

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

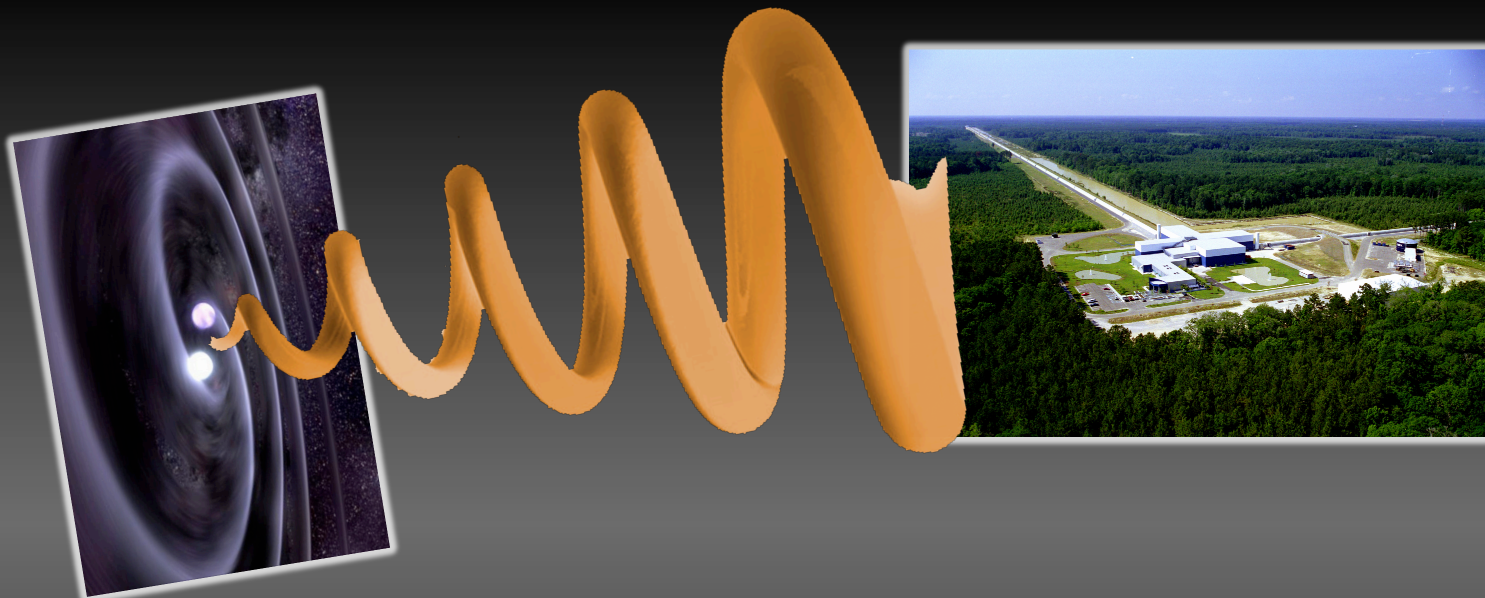
Prospects for GW



"Chirps" from compact binary mergers are best candidates for detection with advanced generation of gravitational wave detectors, from ~mid-2015.

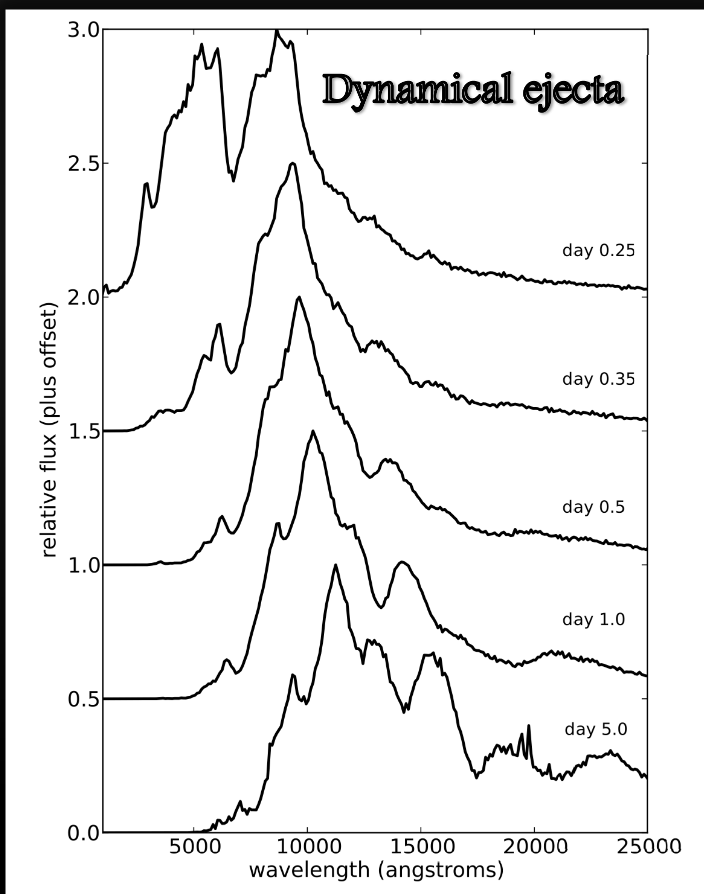


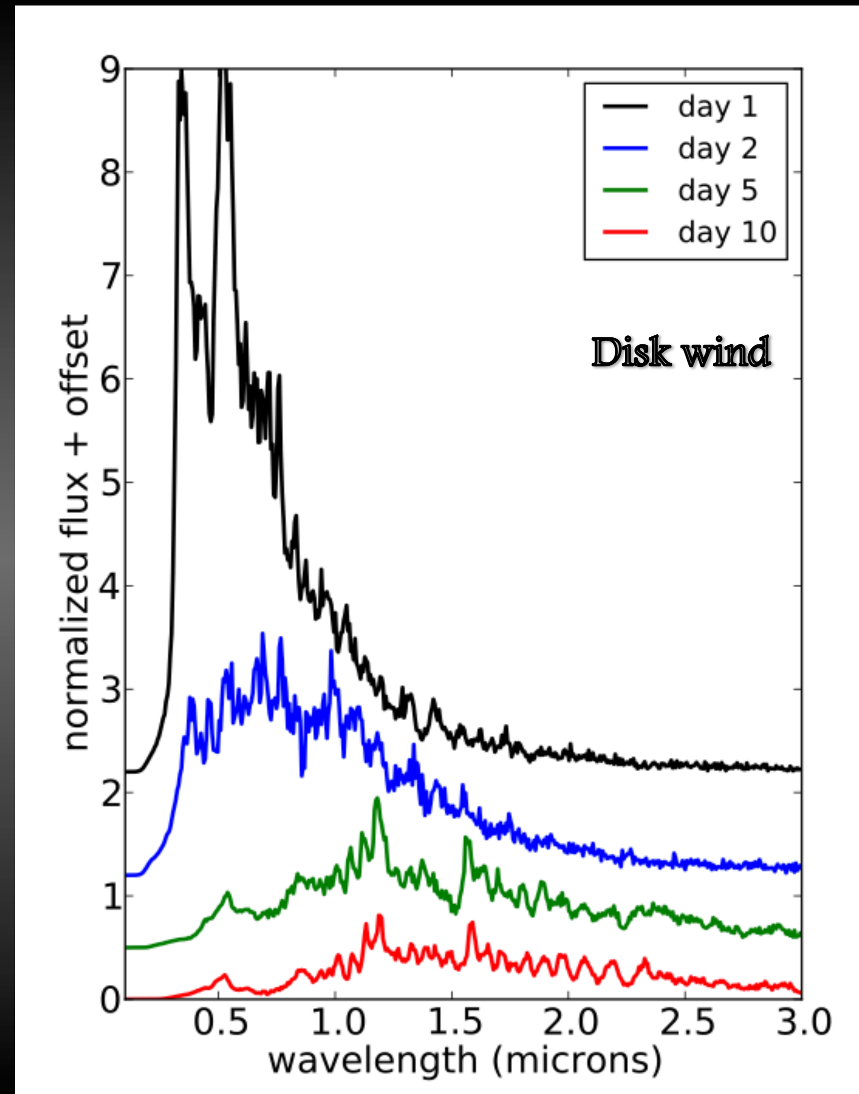
Prospects for GW+EM



Unlikely to be "on-axis", so searching for the accompanying (isotropic) kilonova emission in the LARGE error boxes is likely to be most fruitful route to electromagnetic counterparts.

Spectroscopy could provide insight into different emission components, ejecta composition and velocity, r-process yields.





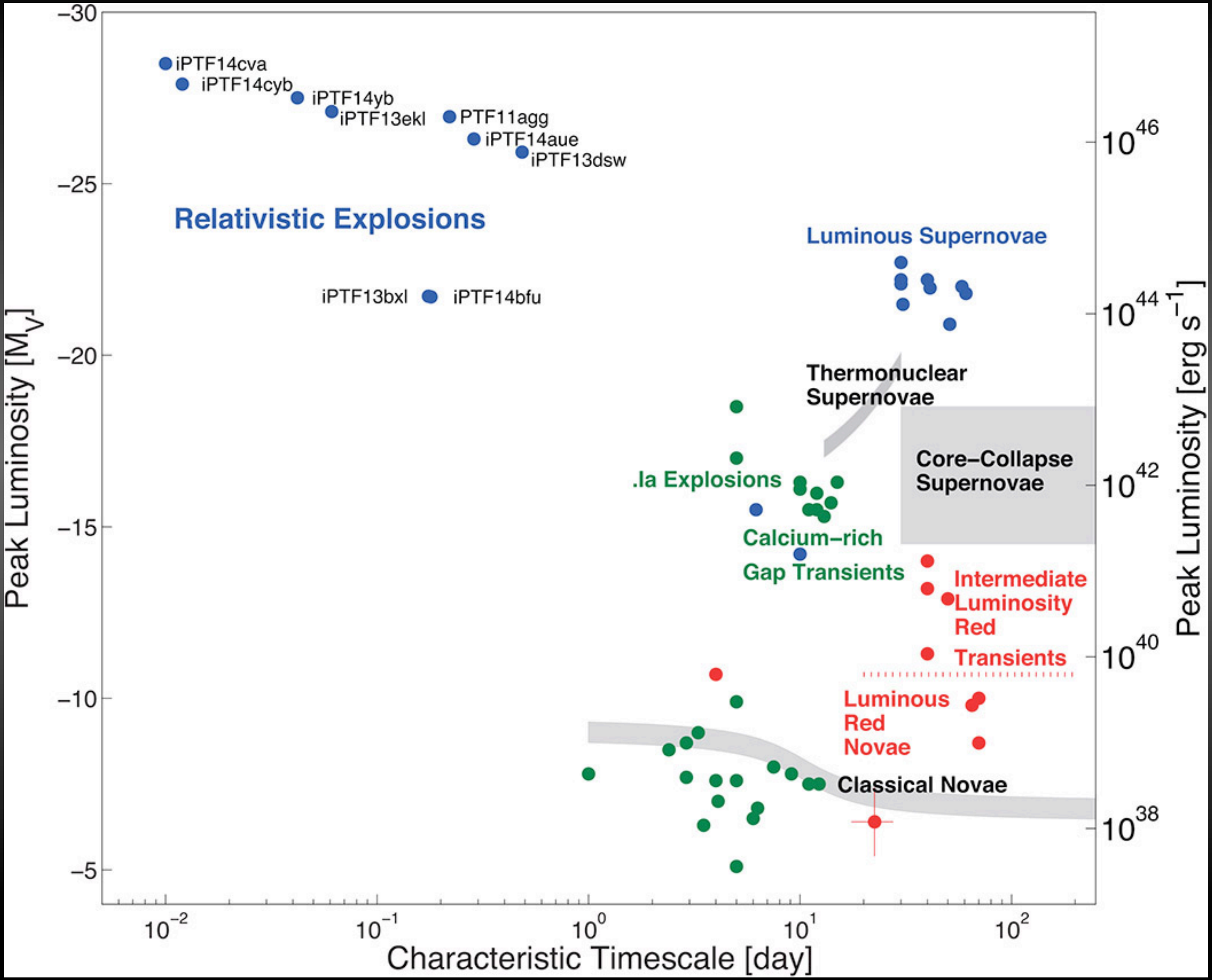
Kasen et al 2013; 2014

Short-GRBs, Kilonovae and gravitational wave counterparts

What we may hope to learn:

- R-process nucleosynthesis budget from compact binaries
- Nature of short-GRBs
- Redshifts, environments and progenitor information for GW events

Supernovae and related phenomena



Supernovae and related phenomena

What we may hope to learn:

- Numerous classes of rare SN and SN-like events uncovered thanks to existing large area transient surveys: likely to be even more in future.
- E.g. coming talks.

Conclusions and requirements

Exotic transient sources, mostly associated with compact objects or their formation, are being found in increasing diversity. Optical/nIR spectroscopy provides evidence of their nature and powerful probe of intervening matter.

For transients we want (at least):

- Good AO and wide sky coverage – possibly acquisition in largish field?
- Flexible, fast response to triggers: needs to be "easy" for observers to define observations, ideally a graceful exit from current observations, quick instrument/mode changes and reasonably rapid slewing, acquisition etc. at telescope (30 min would be "ok")
- Rapid calibration and reduction of data to "usable" standard, and means of returning products quickly to observers (20 min would be "ok").
- Possibly communication between instruments?
- Still likely need smaller telescopes to identify, filter and prioritise targets.