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Short-GRBs and Kilonovae: Electromagnetic signatures of compact binary mergers

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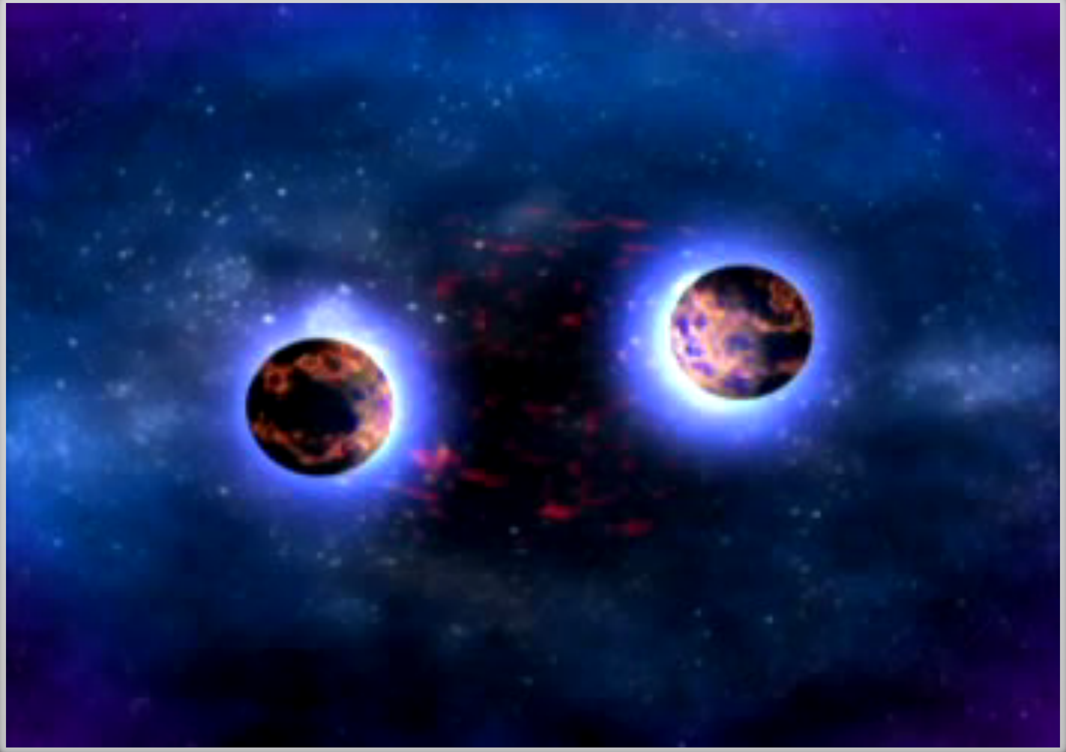
Compact binary mergers

Neutron-star/neutron-star
Neutron-star/black-hole
Black-hole/black-hole



Expected to be strong gravitational wave sources and (if NS component) likely sites of *r*-process nucleosynthesis.

Long been a candidate for production of cosmological GRBs (plausible time-scales, energetics and rates).
Eichler et al. 1989
Lipunov et al. 1995

Short-hard GRBs~ another population

CATALOG OF COSMIC GAMMA-RAY BURSTS: I AND II

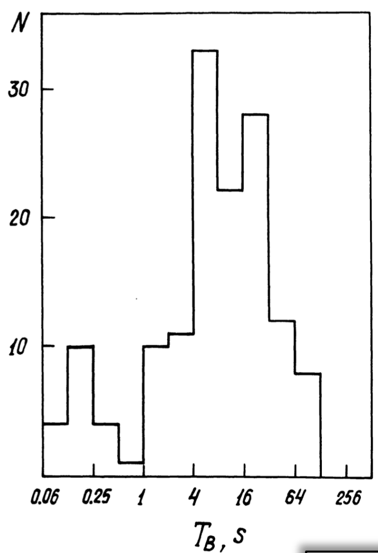


Fig. 164

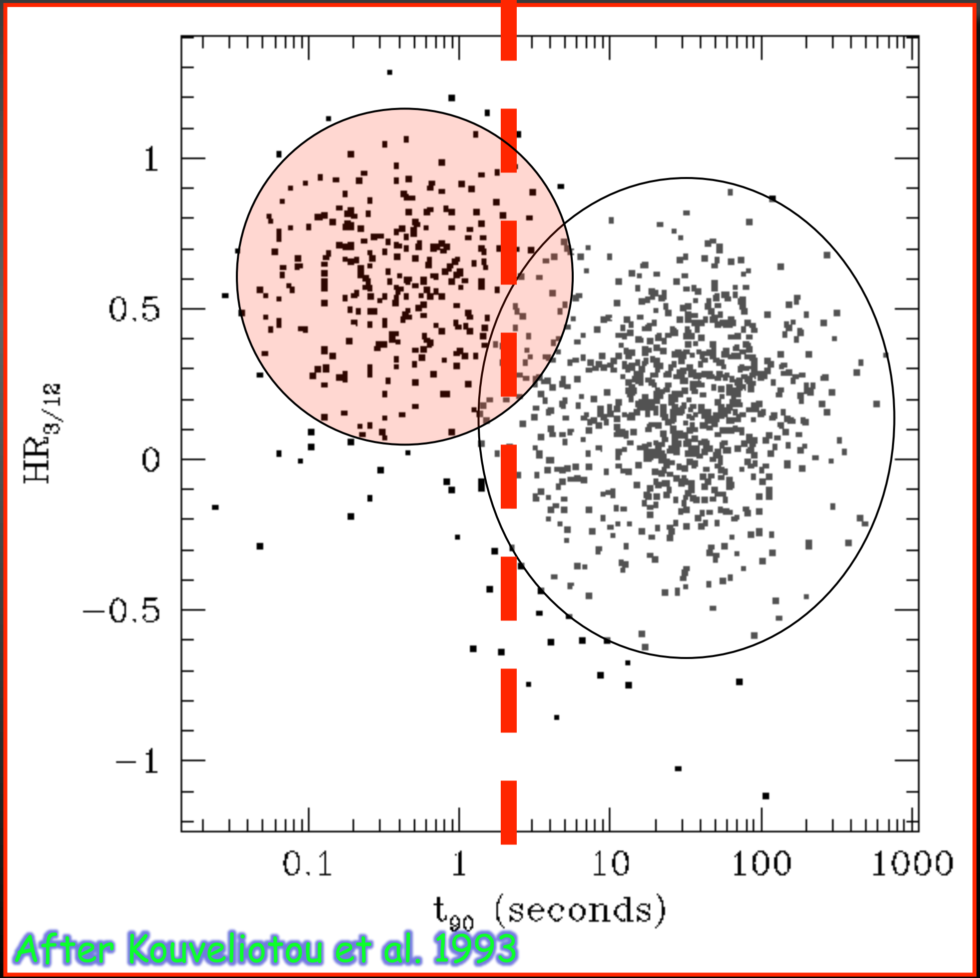
Identified as a distinct population in 1981 by Mazets et al. in a series of papers on the KONUS experiment on Venera 11 & 12.

A. THE DISTRIBUTION OF BURSTS IN DURATION

The essential differences in the gamma-burst time structure are reflected in the distribution of the observed events in duration T_b. Figure 164 shows an experimental distribution drawn for 143 events. It displays the number of bursts per equal logarithmic interval of T_b. Since some of the bursts may have long tails, the duration of the event in this case is taken to be the interval of time within which fall 80–90% of the measured burst intensity S. The distribution differs substantially from the uniform one. The main peak in the distribution is connected primarily with single and multipulse bursts. The right-hand wing is composed of double and long structureless bursts. Narrow peak in the beginning of the graph indicates the existence of a separate class of short bursts.

Short-hard GRBs~ another population

$T_{90}=2$ s

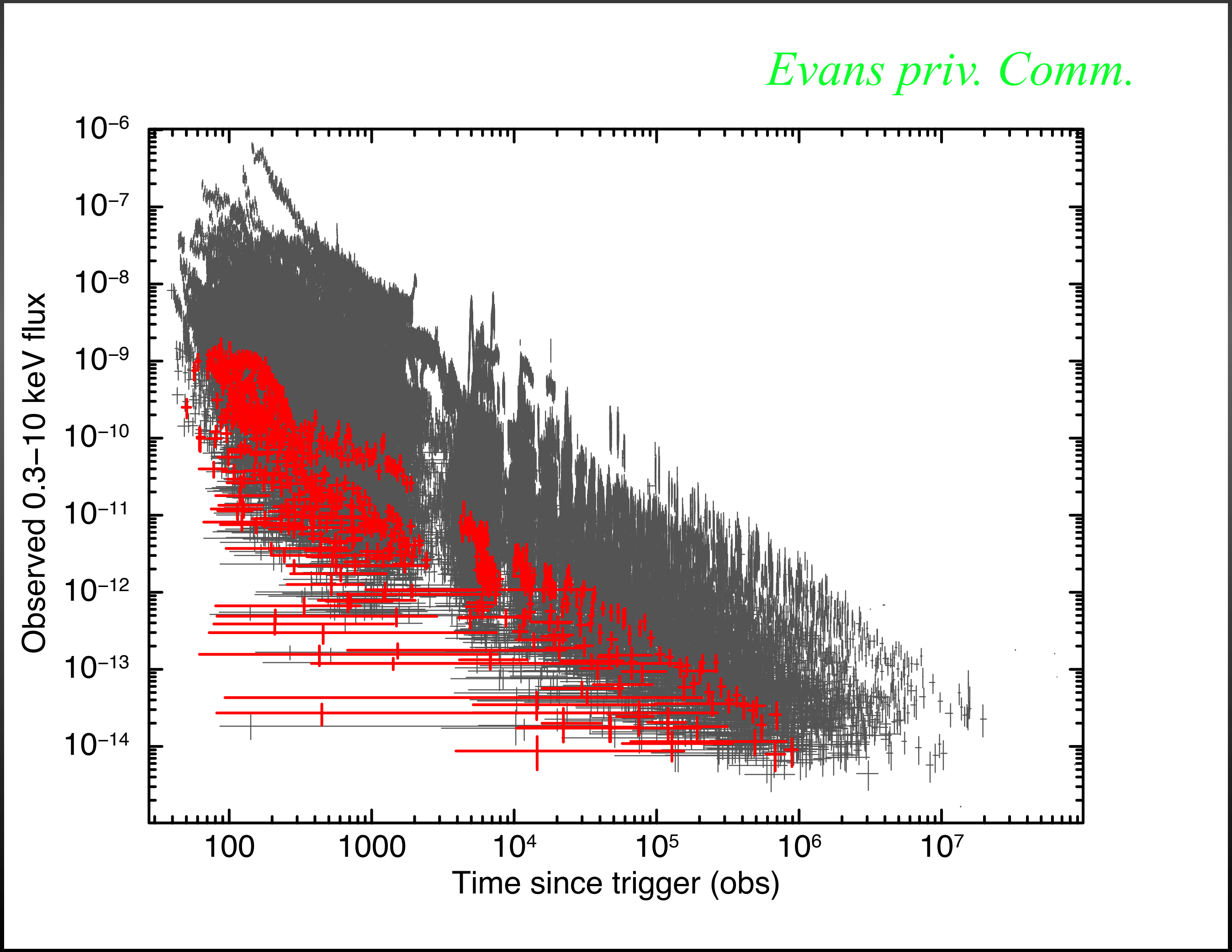


Around 25% of BATSE GRBs were “short”, but:

- 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

X-ray afterglows fainter than for LGRBs (several cases have no detection despite prompt slew).



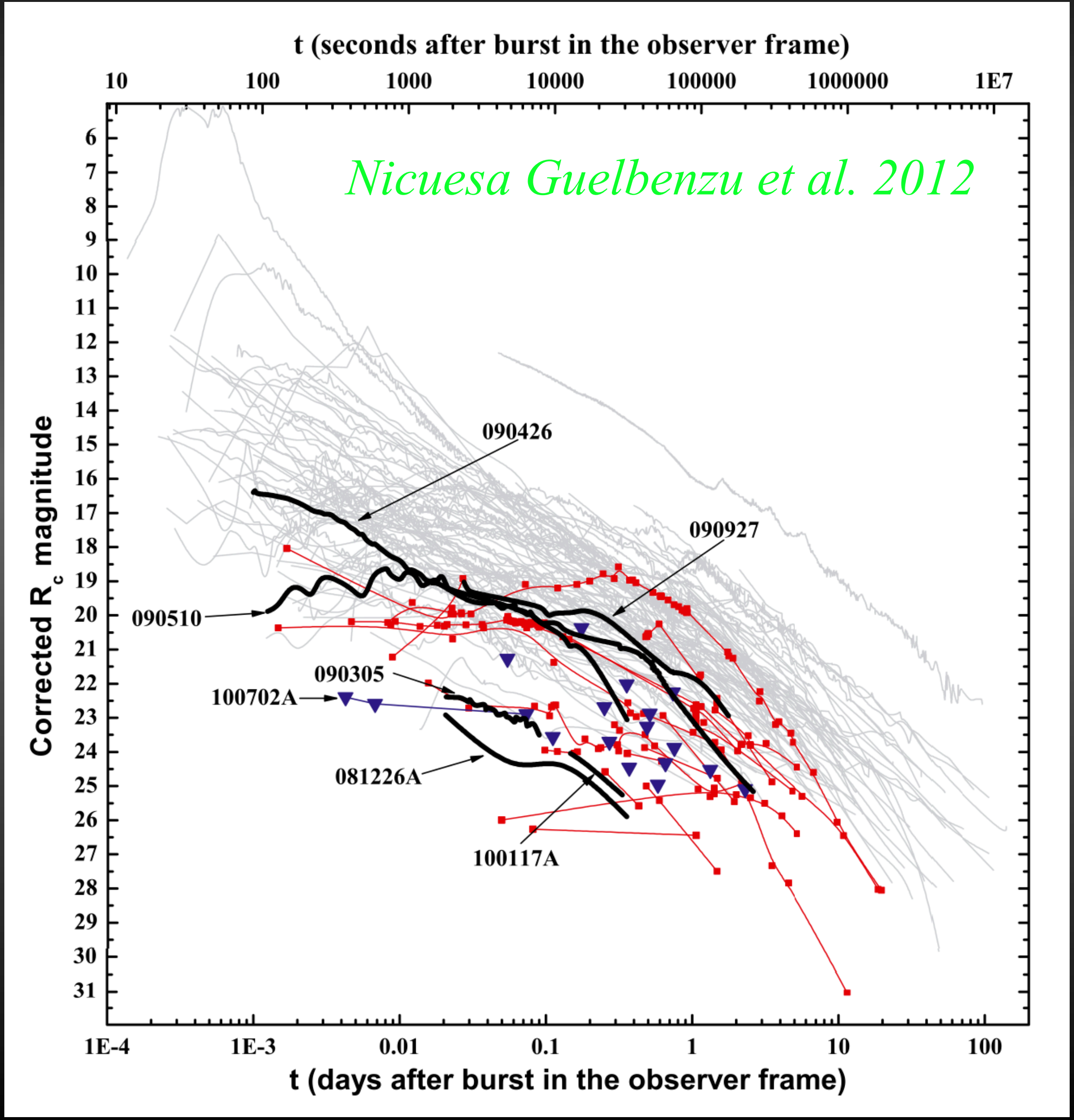
Short-duration bursts

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".

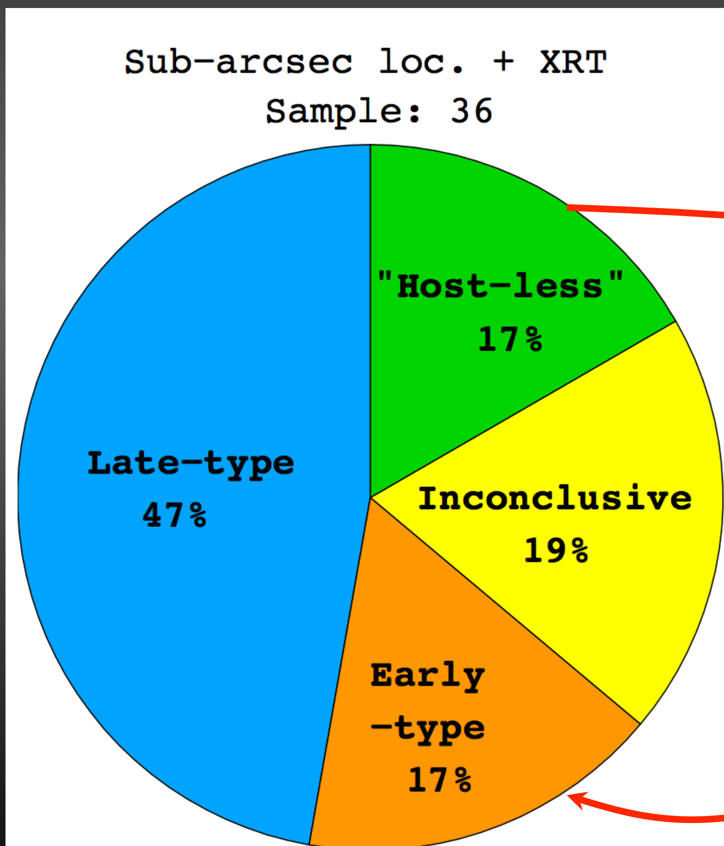
Optical afterglows usually also very faint with weak spectral features – hard to find and hard to obtain redshifts (in practice, nearly always rely on host redshift).



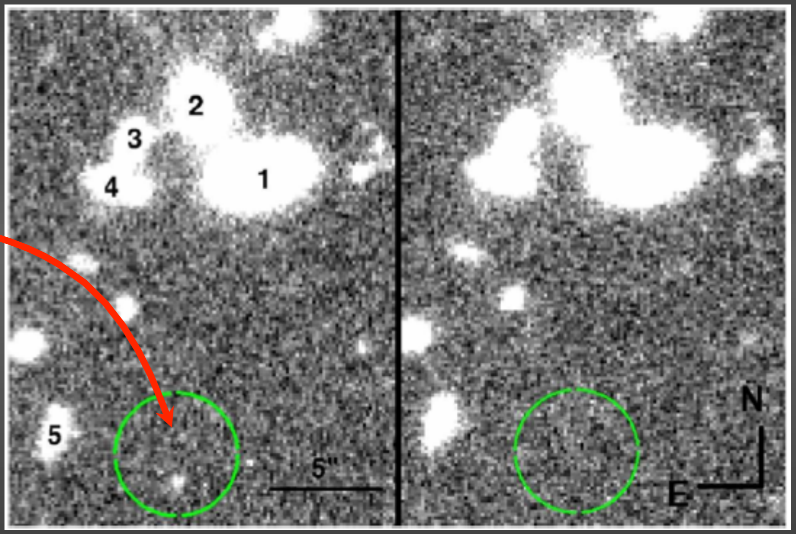
Short-hard GRBs - compact binary mergers?

- 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.



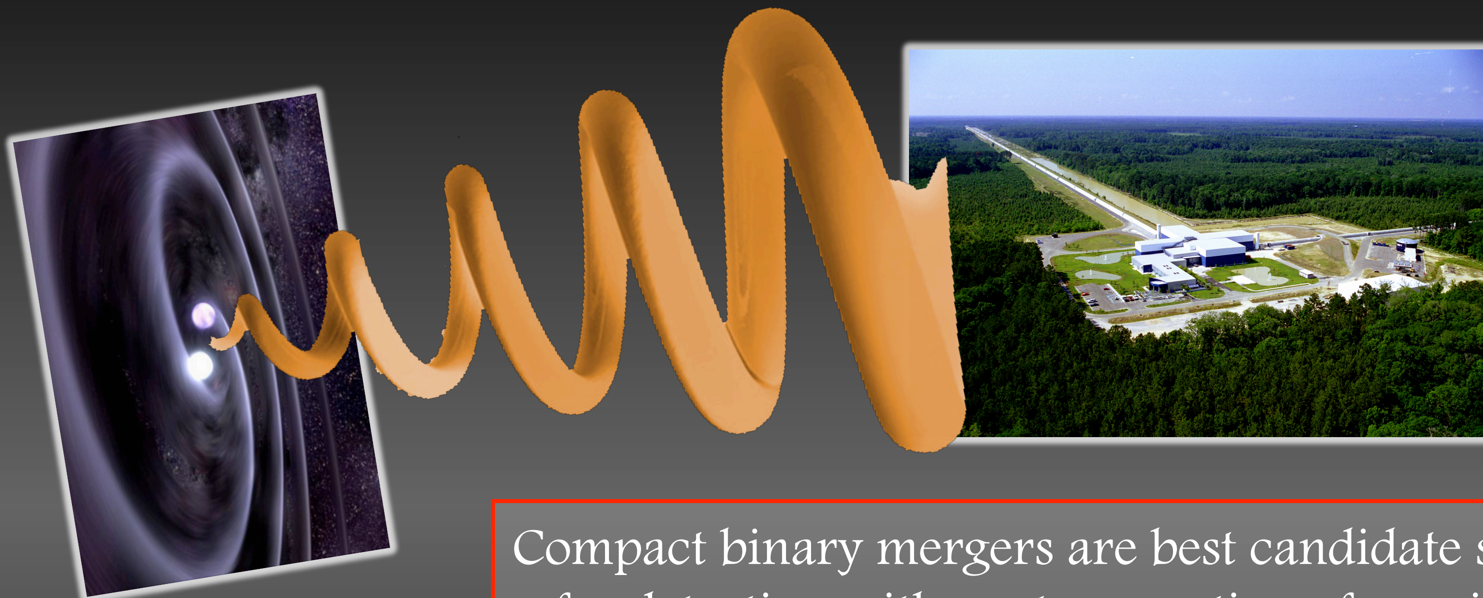
Fong et al. 2013



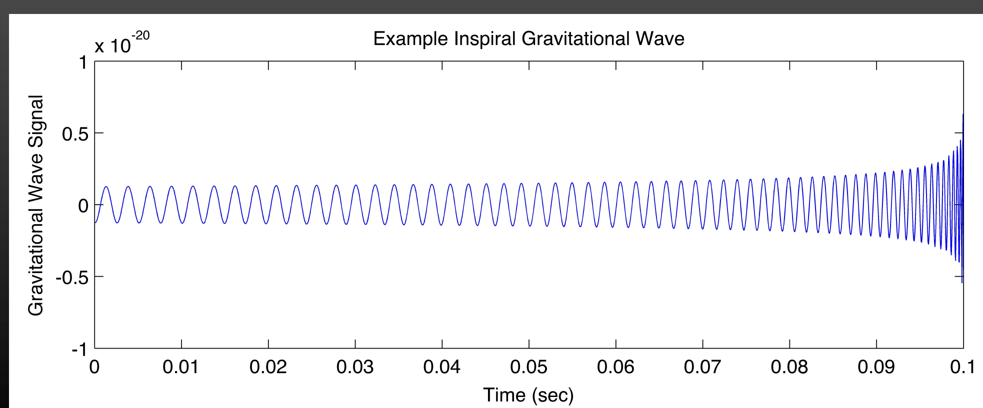
Rowlinson et al. 2010

Note, the number associated with ancient stellar populations is not high, suggesting inspiral times ~100s Myr are most common.

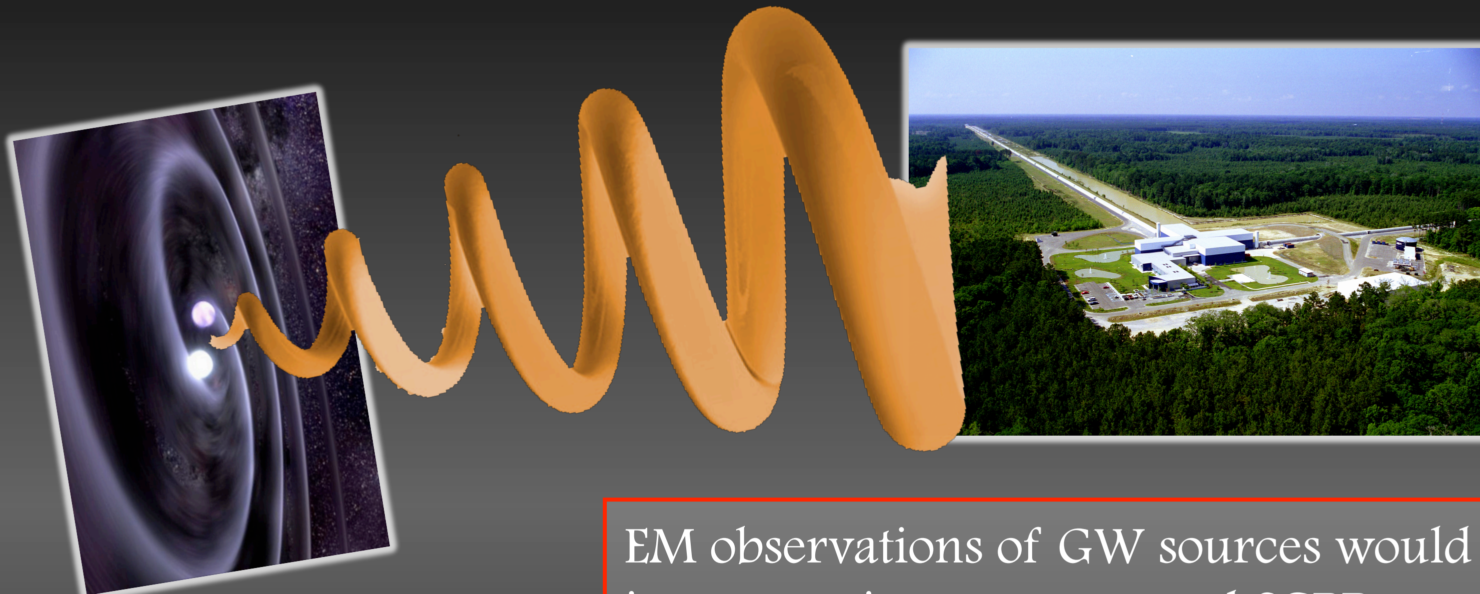
Short-hard GRBs- prospects for GW



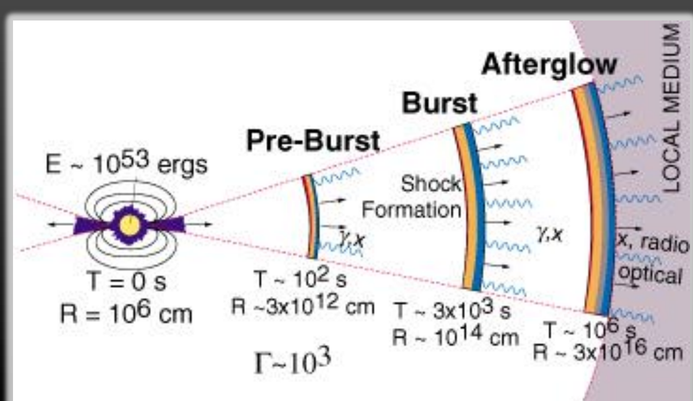
Compact binary mergers are best candidate systems for detection with next generation of gravitational wave detectors e.g. A-LIGO, from ~2015.

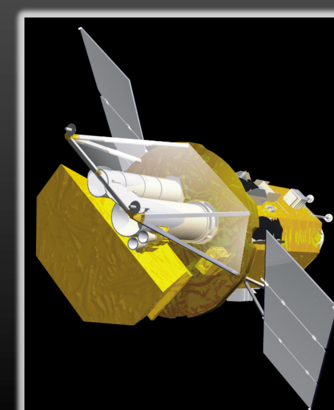


Short-hard GRBs- prospects for GW



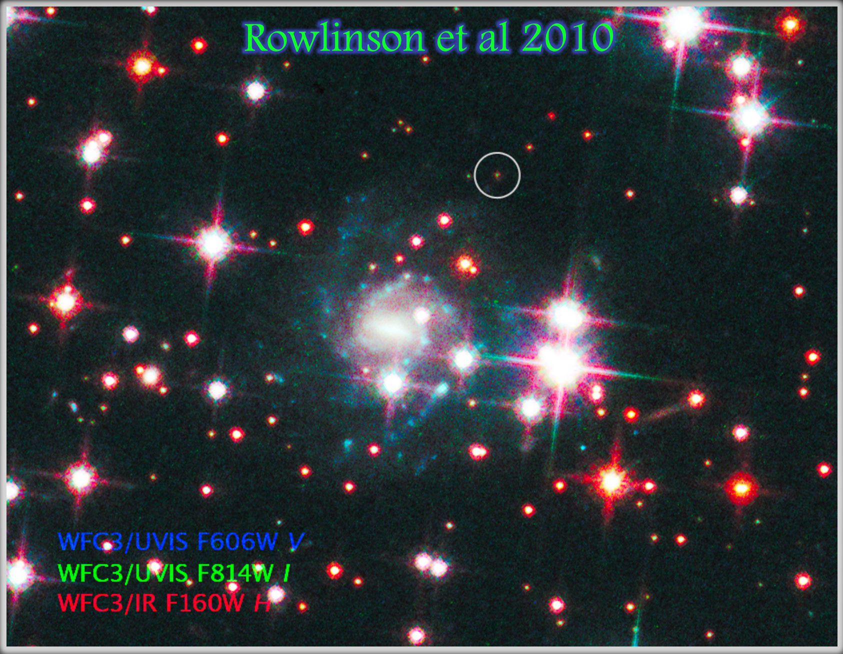
EM observations of GW sources would greatly increase science return, and SGRBs could be the signatures of compact binary mergers, but…

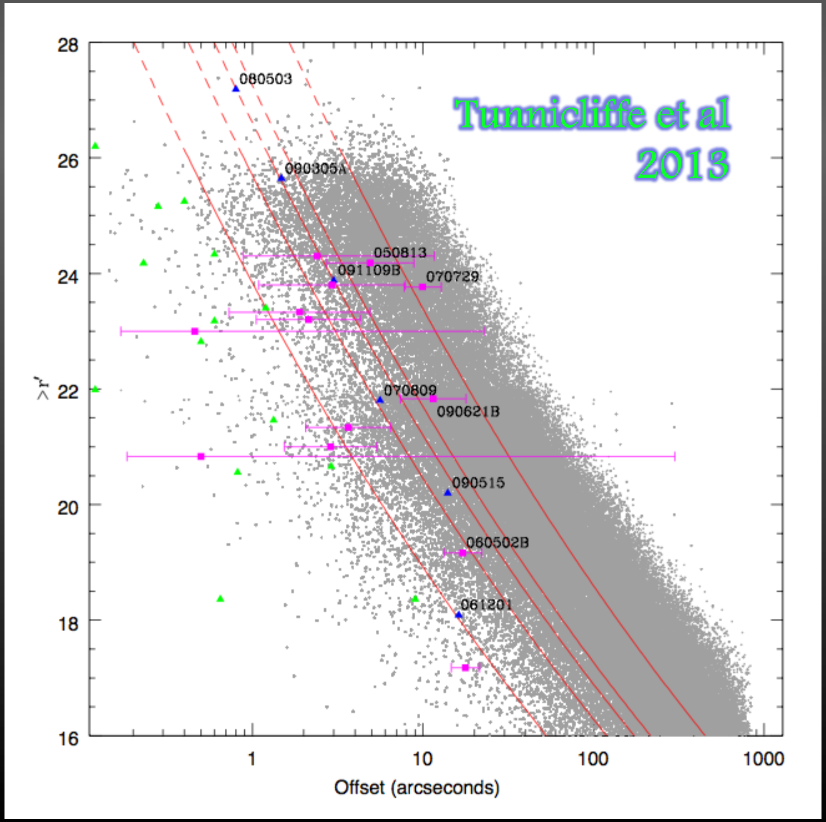




Short-hard GRBs~ rates

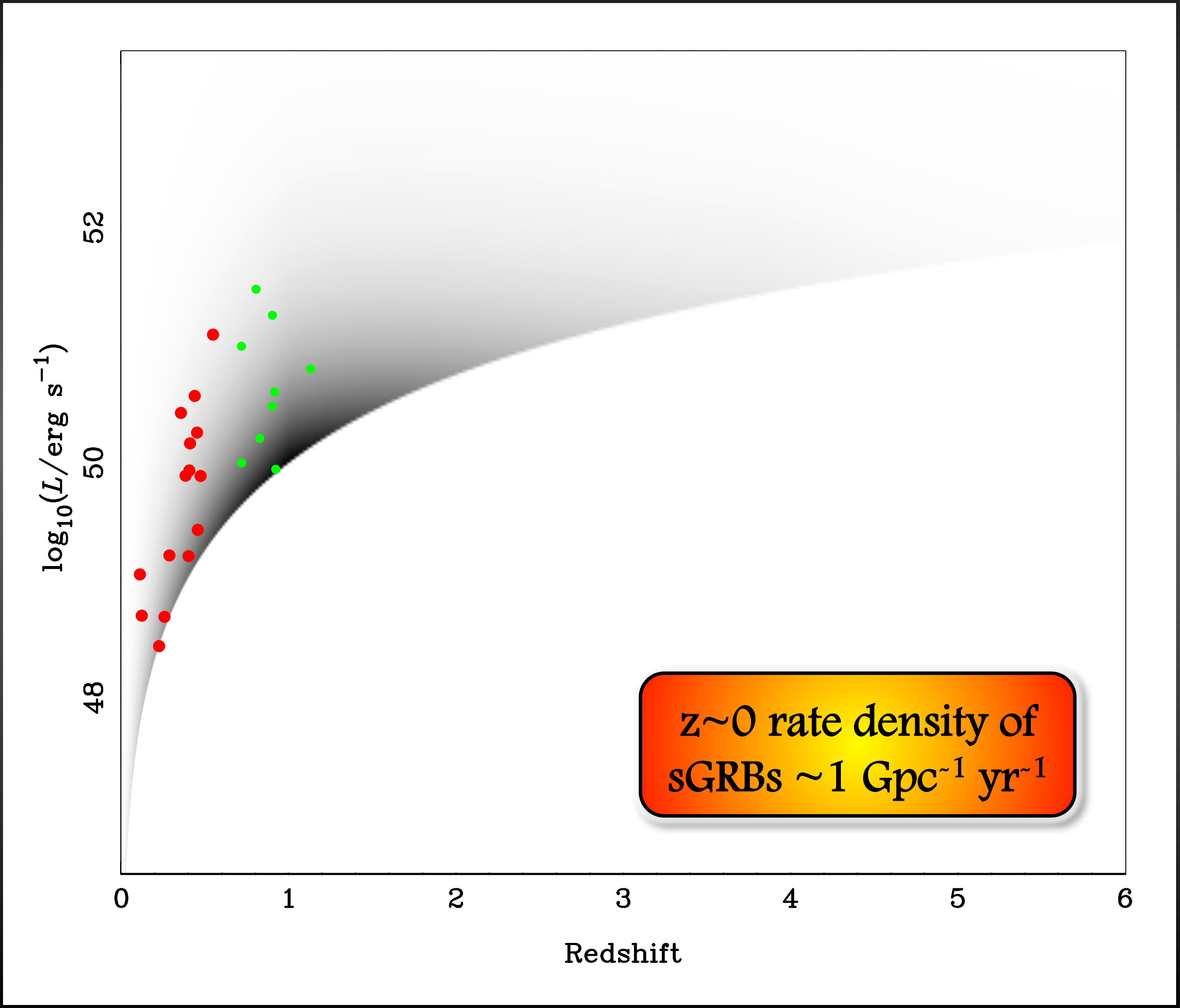
In 9.5 years, nearest SGRB so far found by *Swift* is GRB 080905A at $z = 0.12$ (~500 Mpc)





Hostless shorts also do not appear to be at lower redshifts, since most probable hosts are typically also faint galaxies.

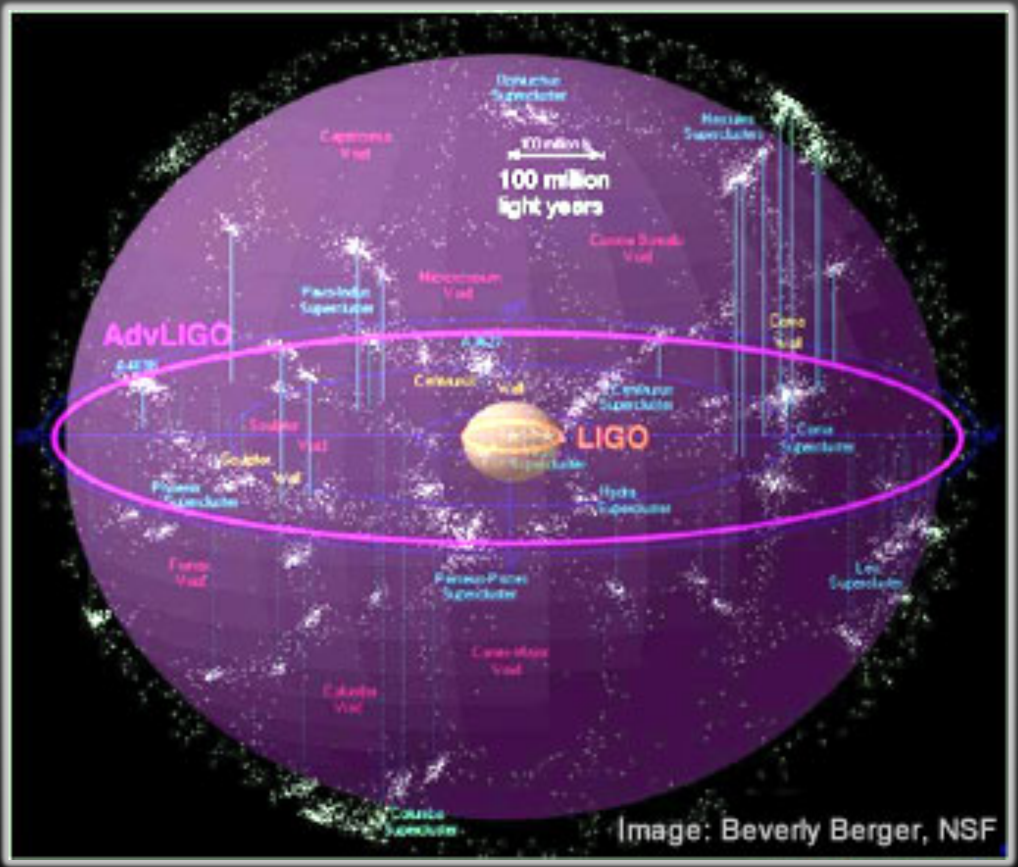
Short-hard GRBs~ rates



Most sGRBs without redshifts are probably 0.7<z<2 with a tail to higher redshifts

Short-hard GRBs– horizons

For NS-NS nominal horizon of Advanced detectors is ~200 Mpc (larger for NS-BH).



Suggests prompt detections with *Swift* or other satellites will be rare (~1 per decade) – helped somewhat if timing coincidence produces sub-threshold detection (either EM or GW).

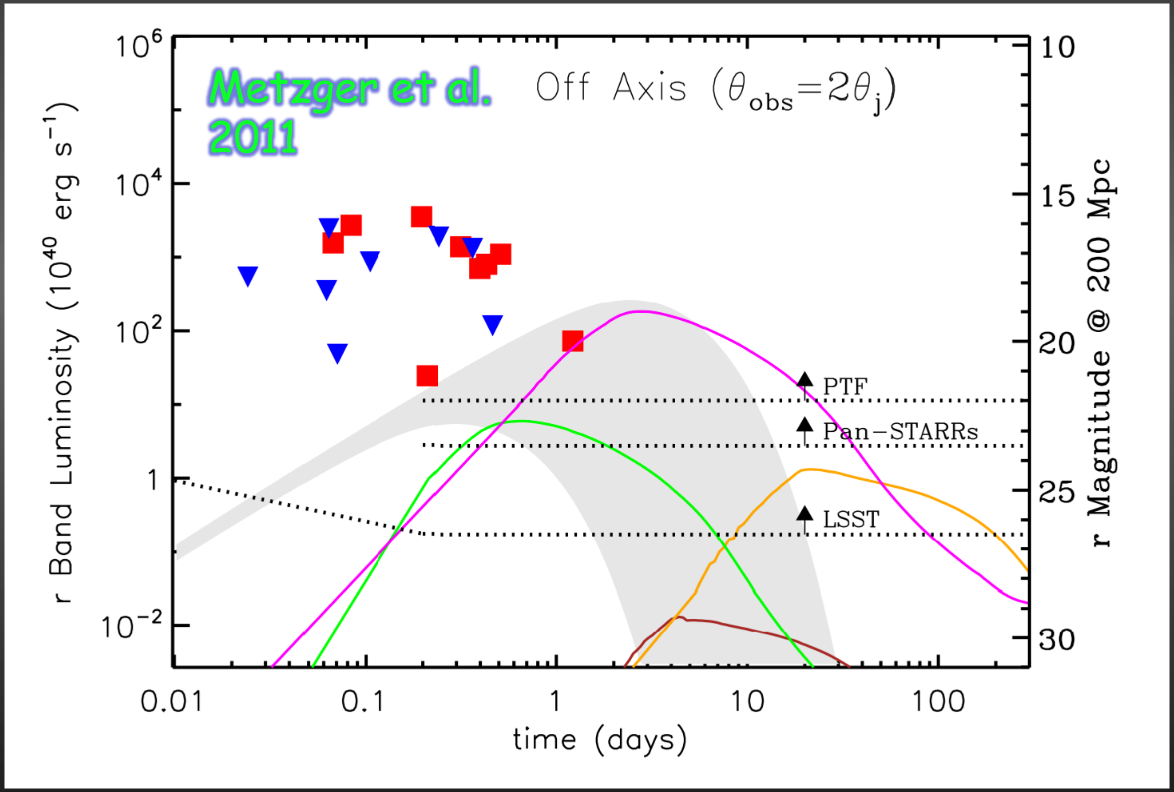
Why such low rate density? May be beaming of SGRBs - poorly constrained, but $f_b > 100$ is plausible.

Short-hard GRBs- faint afterglows

What about afterglow emission if not prompt? On-axis events similarly rare. Off-axis implies faint, late optical afterglows which may be hard to identify.

The intrinsically brightest, the least far off axis and the nearest may be visible to modest telescopes.

e.g. at 100 Mpc, GRB 130603B would have peaked M_{AB}~15.

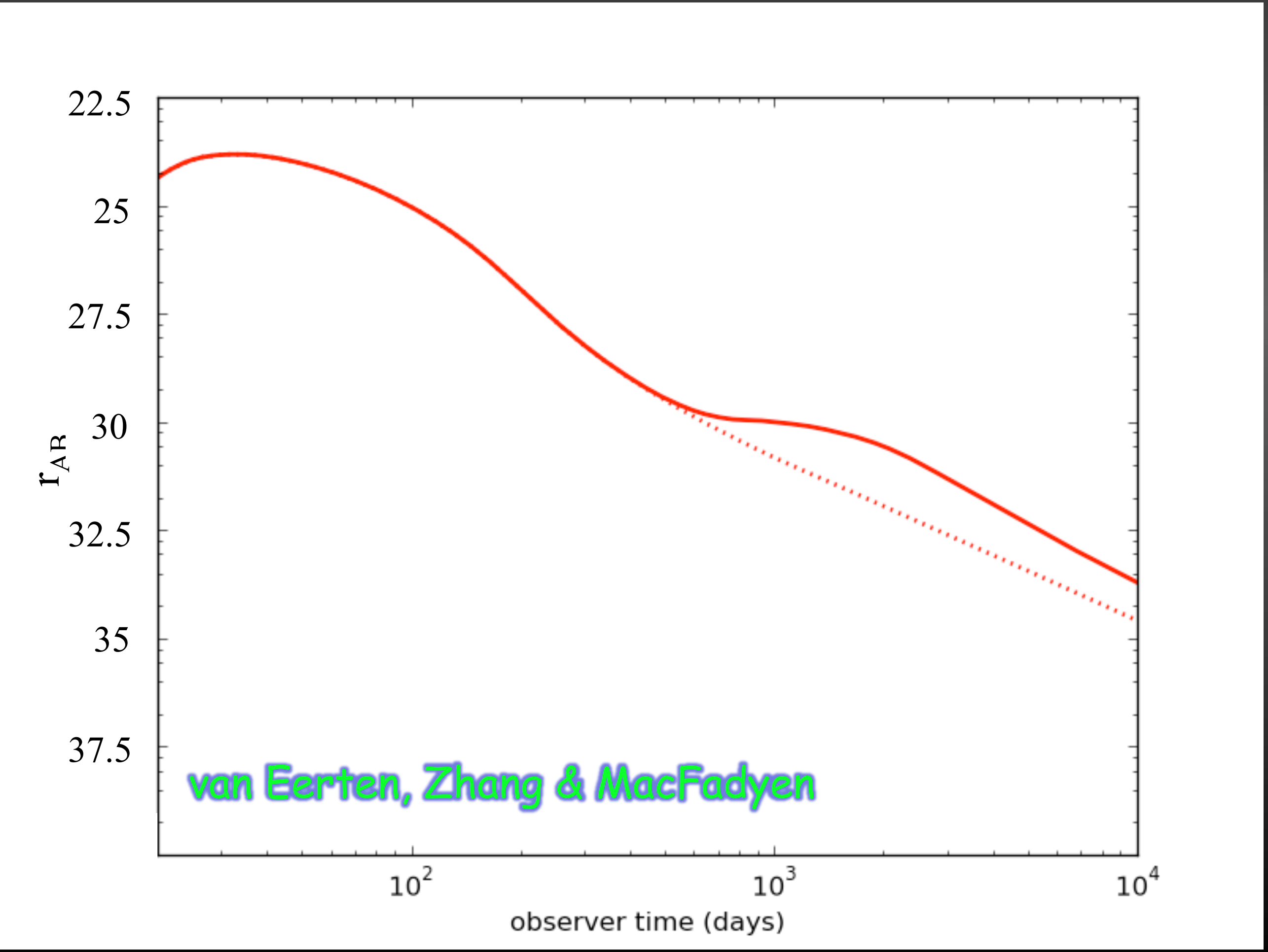


Short-hard GRBs- faint afterglows

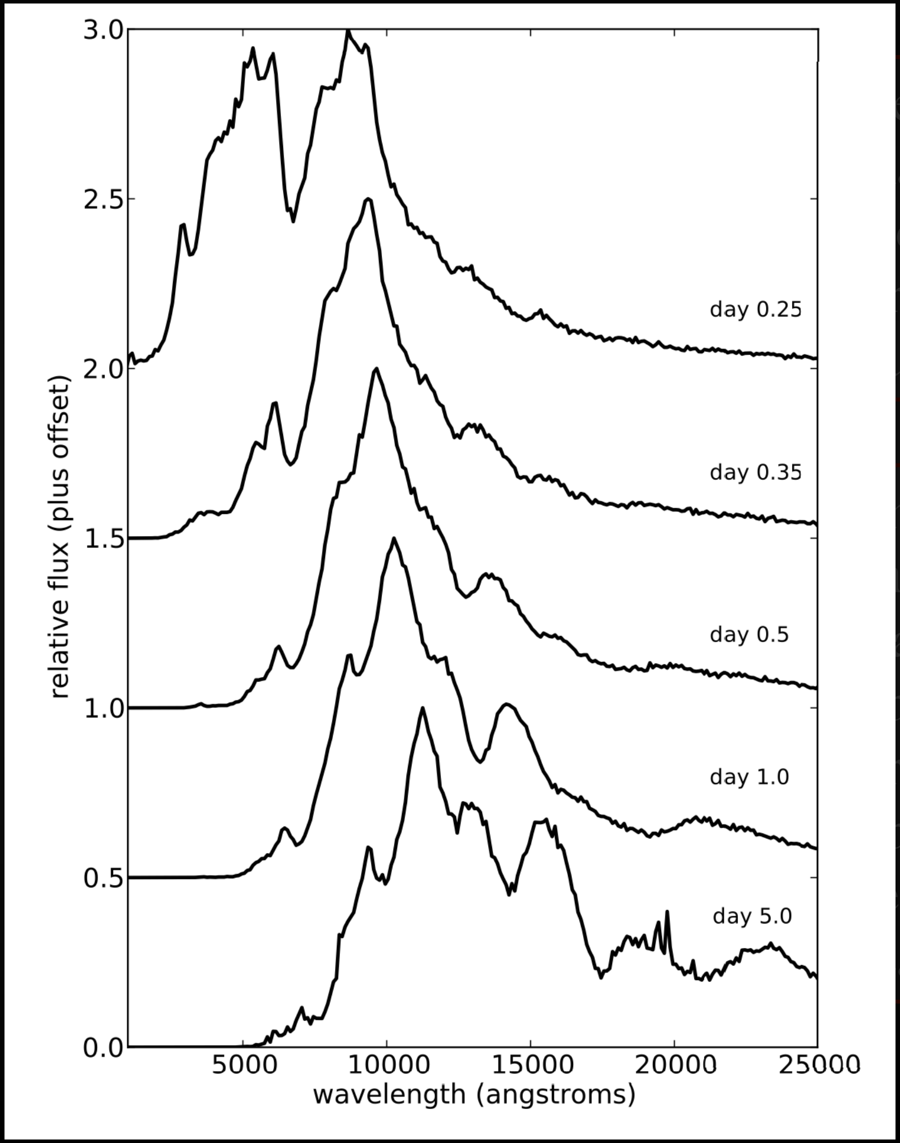
More typically will require large aperture, large camera telescopes (e.g. LSST) to give good prospects for significantly off-axis emission.

Same example, and assuming a 10° jet opening angle and observing and 35° to line of sight (n =1 cm^{-3}).

Viable, but hard even in optimistic case (and rate only increased by ~10x).



r-process kilonovae



ecompressed aterial thrown/ own out in merger oduces neutron rich dioactive isotopes.

eir decay powers a ort-lived radioactive ansient. High acity expected to eatly attenuate tical, hence quiring infrared arch.

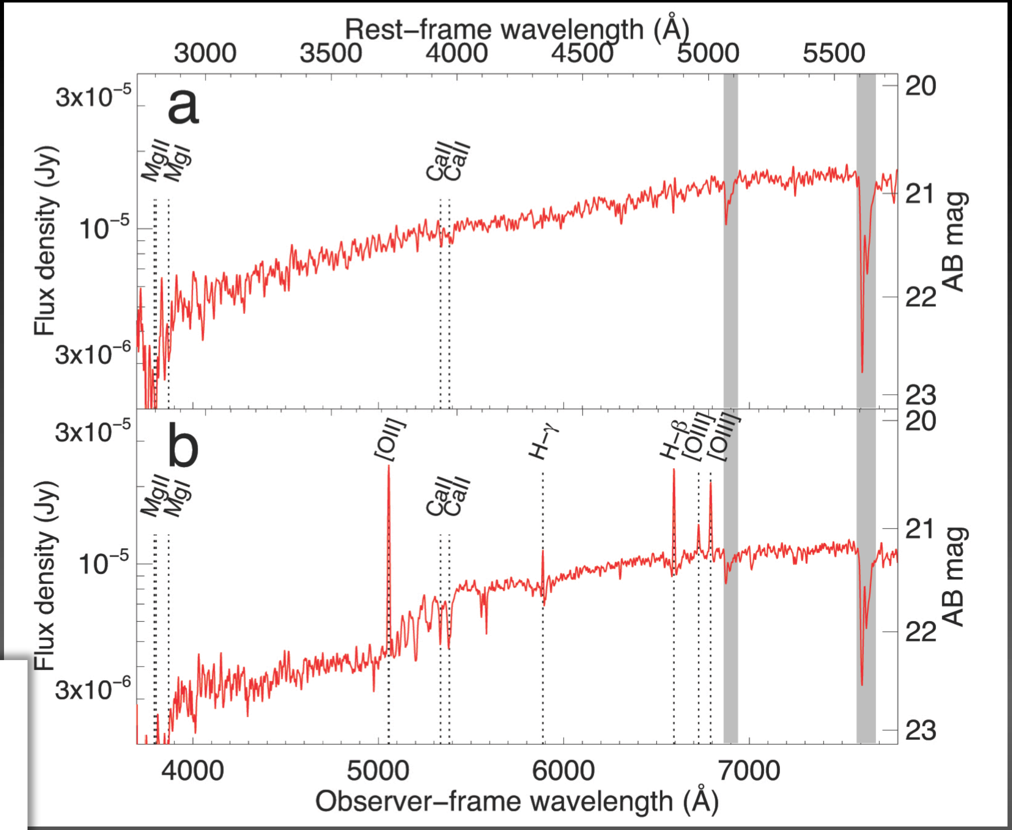
Movie removed

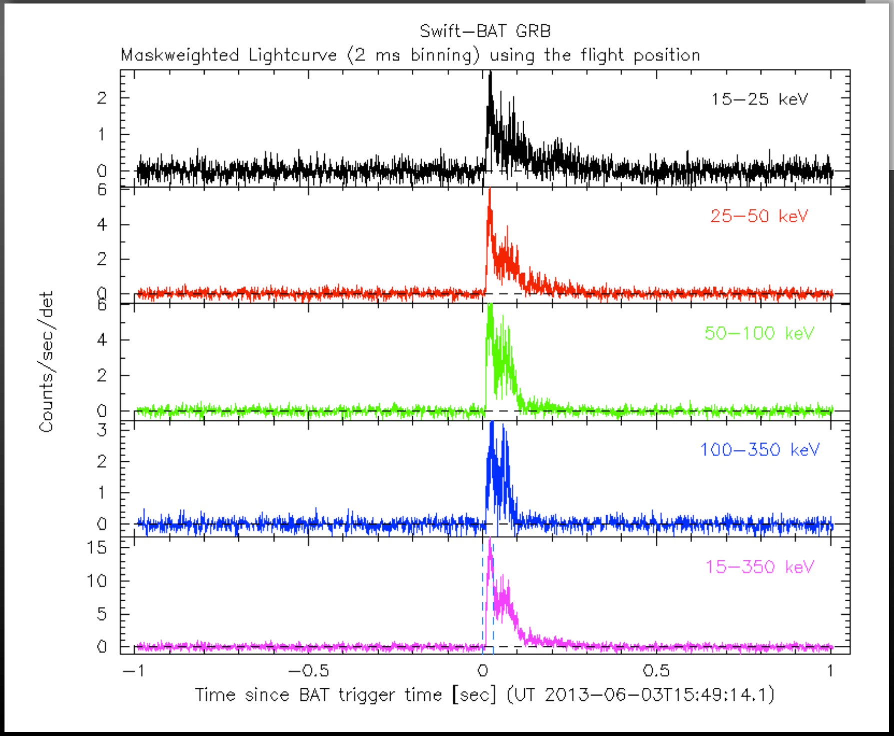
Rosswog et al. 2012

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

GRB 130603B

Bright burst and unambiguously short duration.

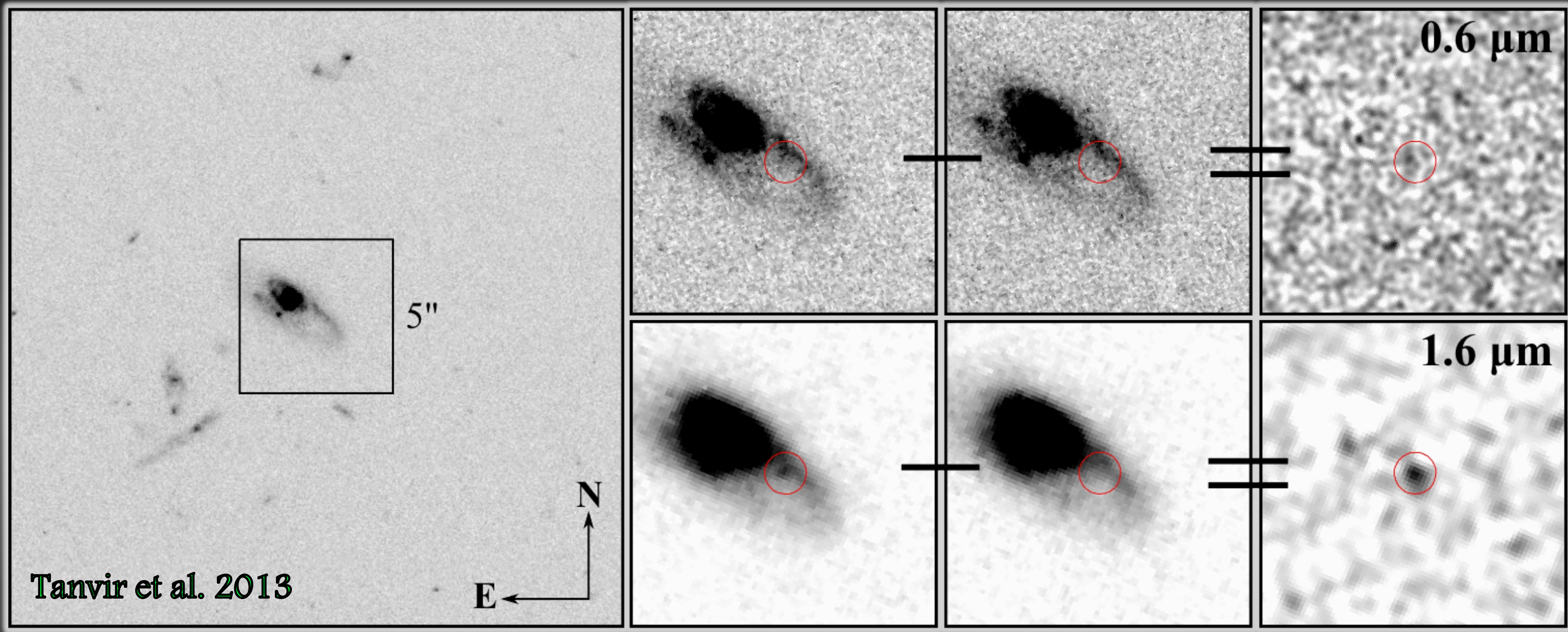




de Ugarte Postigo et al. 2013

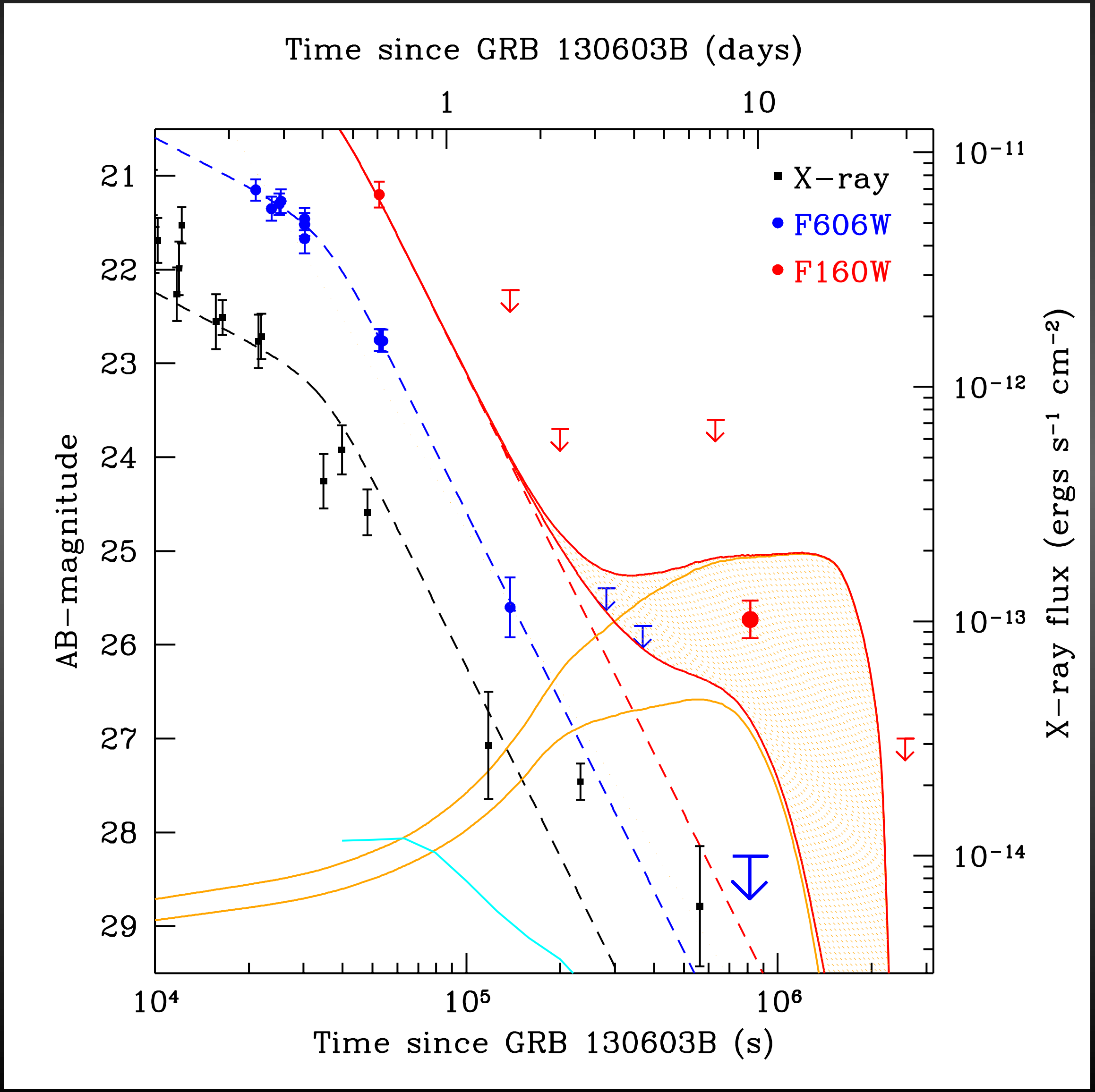
Afterglow provided afterglow redshift with GTC, $z \sim 0.36$

GRB 130603B



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

GRB 130603B



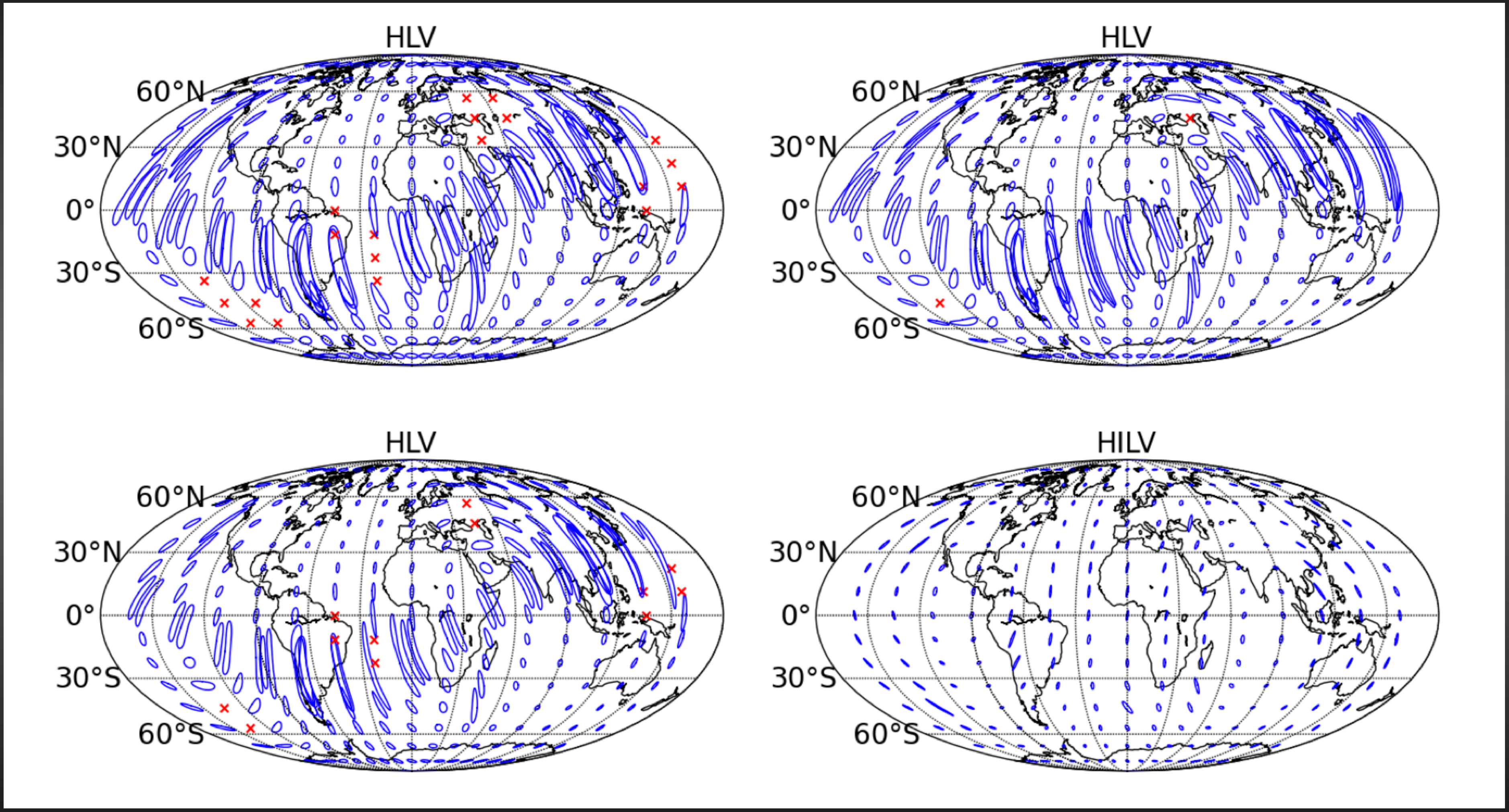
Comparison to Barnes & Kasen (2013) models suggests ejected mass ~0.05 $M_\odot$

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

Scanning for kilonova signatures



Aasi et al. 2013

Scanning for kilonova signatures

Network	BNS Horizon	Typical error region
Early A-LIGO/A-VIRGO (2016)	60-100 Mpc	100 □°
Full Advanced Network (inc. India; 2022)	130-200 Mpc	20 □°

Telescope	Time to scan 100 □°	Time to scan 20 □°
VISTA	7 hr, reaching J_{AB} = 20	21 hr, reaching J_{AB} = 21.5
LSST	3 hr, reaching z_{AB} = 24	8 hr, reaching z_{AB} = 25.5

Exposure times required to reach S/N=15 σ (assuming GRB130603B is typical). Strategies likely to require multiple filters and possibly multiple visits.

=> Viable over several nights, but demanding. Also requires further followup (spectra, light curves, host searches) to weed out false positives.

Conclusions and prospects

- Compelling evidence that compact object mergers produce both sGRBs and r-process kilonovae.
- Electromagnetic signatures therefore include prompt emission, afterglow emission and radioactive emission (also probably late-time radio emission as slow outflows produce shocks; Nakar & Piran 2011).
- Best prospects for electromagnetic detection may be near-IR searches for accompanying kilonovae, and optical searches for faint off-axis afterglow emission.
- Further KN studies required to understand range of behaviour.
- Outflows (both relativistic and not) should also produce longer-lived, late-time radio emission, which may also be detectable (e.g. Nakar and Piran 2011).
- All such searches will require significant dedicated follow-up and effort in chasing down false positive detections.