GAMMA-RAY BURSTS

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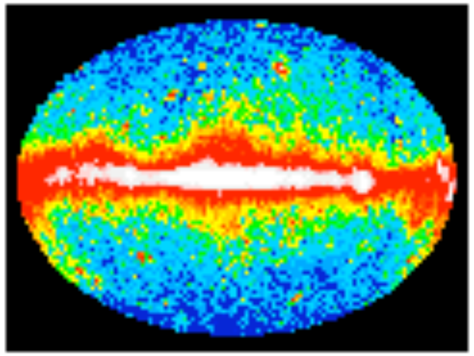
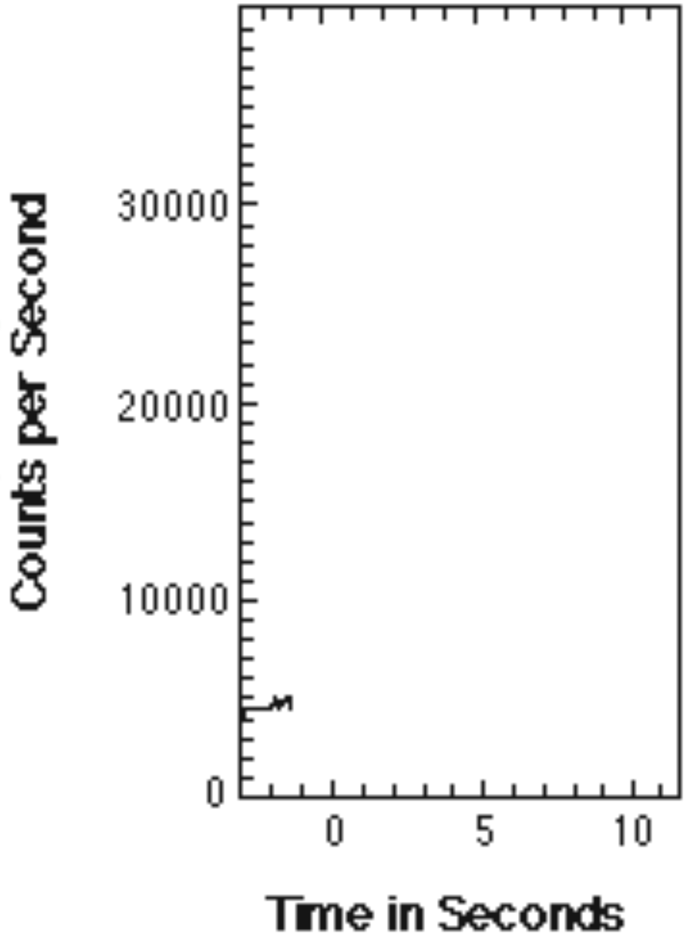
Outline

- Progenitors
  - Long GRBs
  - Short GRBs
  - Ultra-long GRBs and gamma-ray transients
- Probes
  - Late stellar evolution
  - Distant galaxies
  - First generation stars
  - Gravitational waves
  - BHs in galactic nuclei

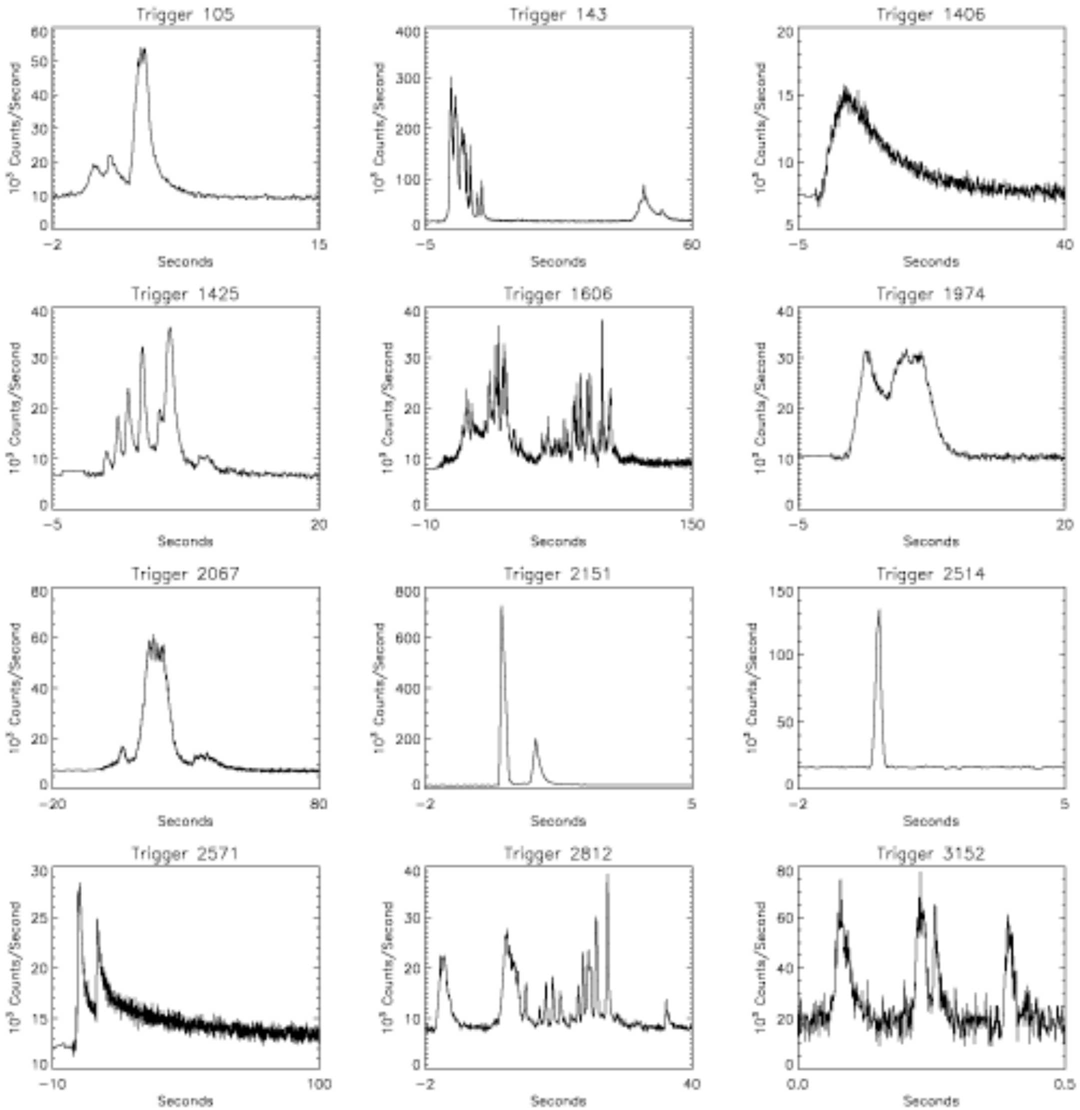
Discovery

Rate (~3 /day/Universe) c.f. Supernovae (5/s/Universe)

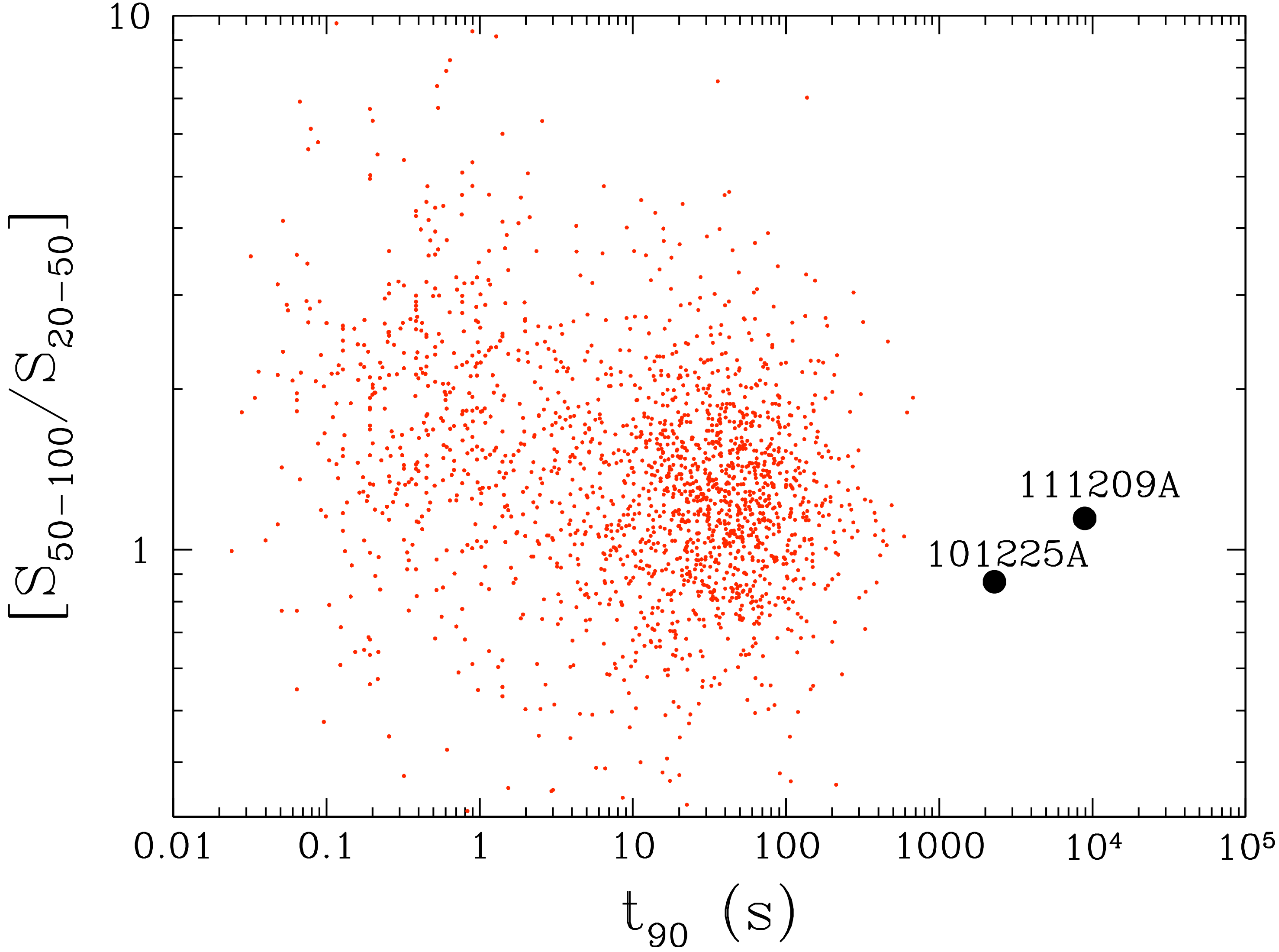


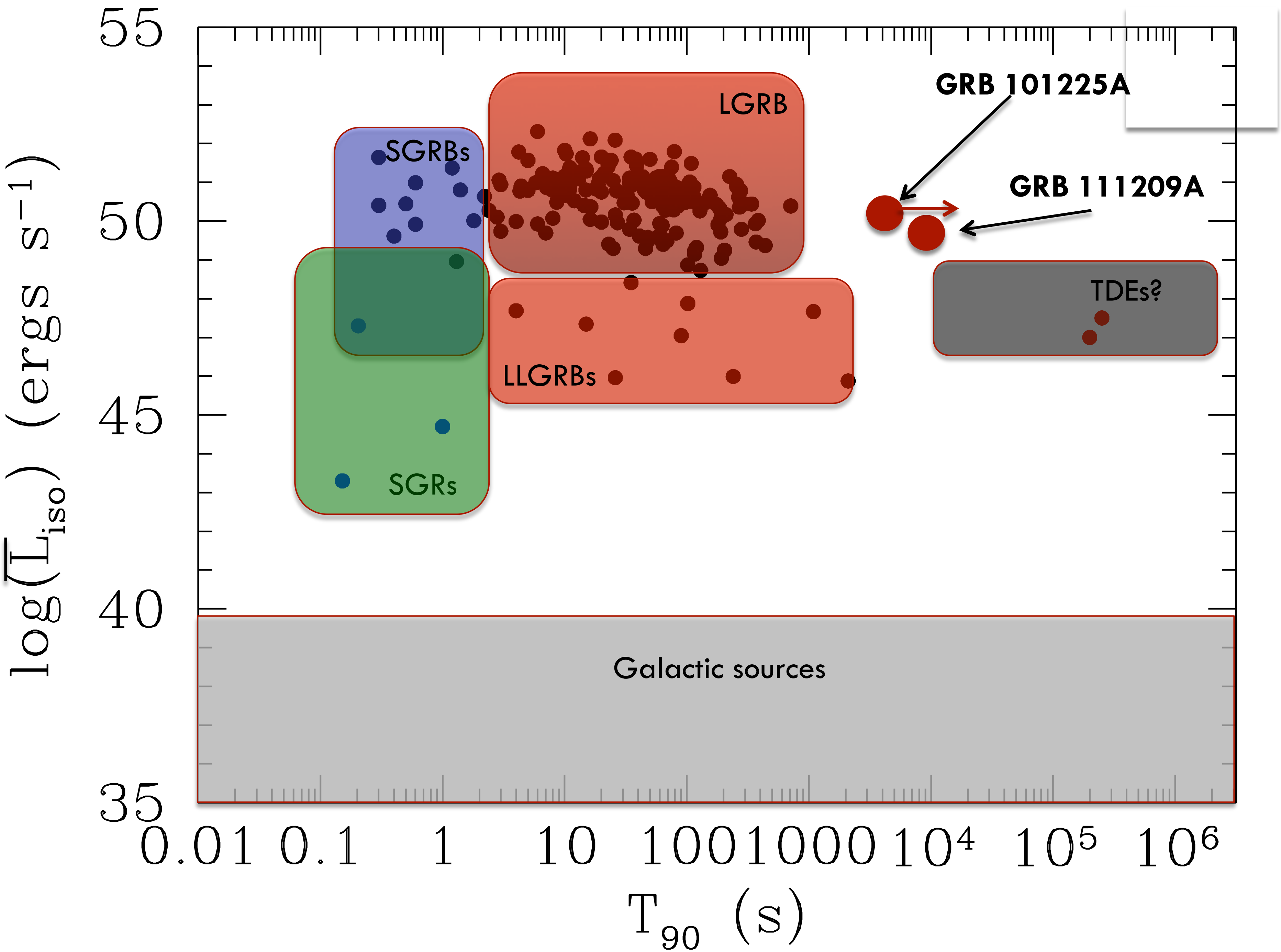


Light curves



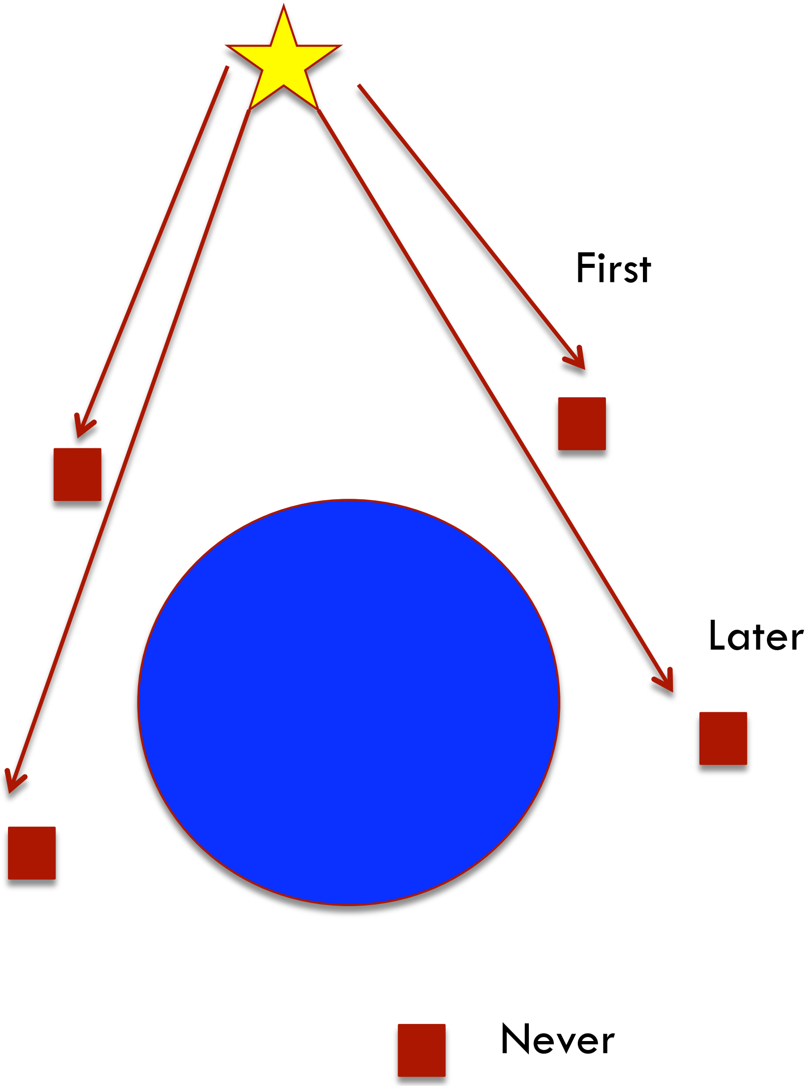
Classification - I

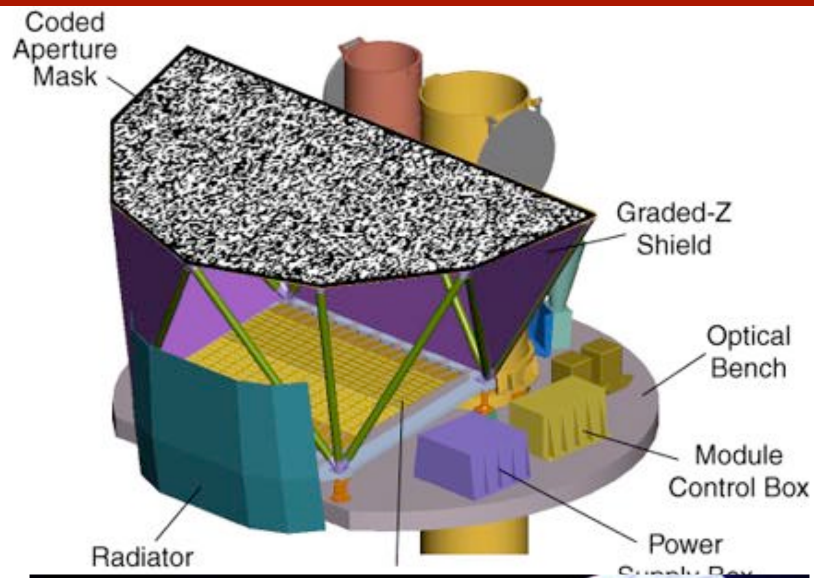


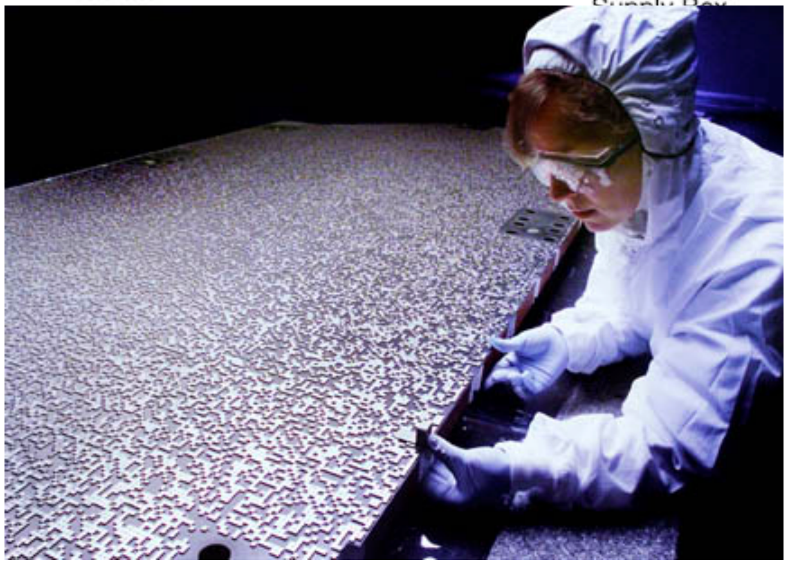

55
50
45
40
35
$\log(\overline{L}_{iso})$ (ergs s^{-1})
0.01
0.1
1
10
100
1000
10^4
10^5
10^6
T_{90} (s)
SGRBs
LGRB
GRB 101225A
GRB 111209A
SGRs
LLGRBs
TDEs?
Galactic sources

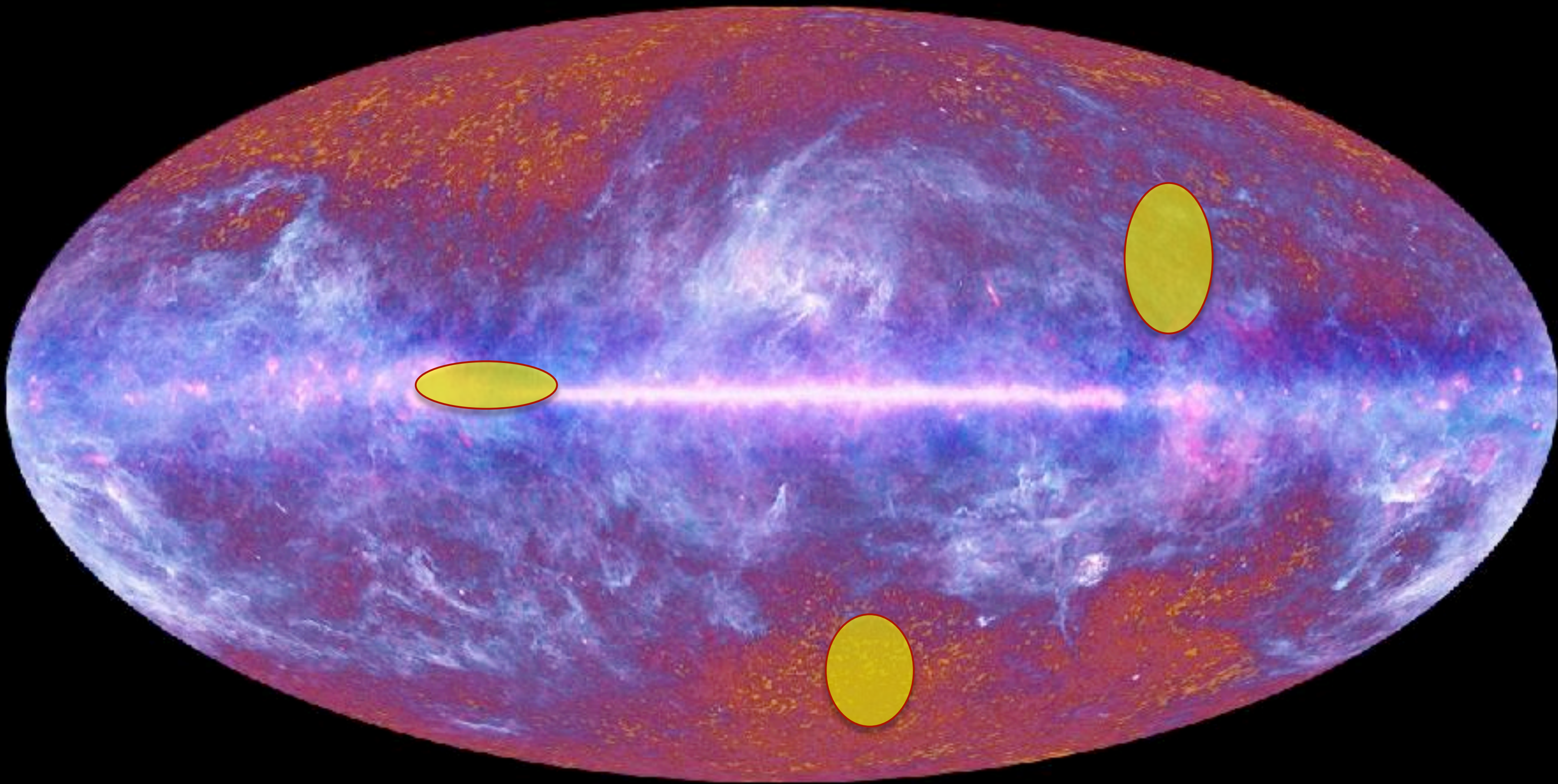
Gamma-ray localisation

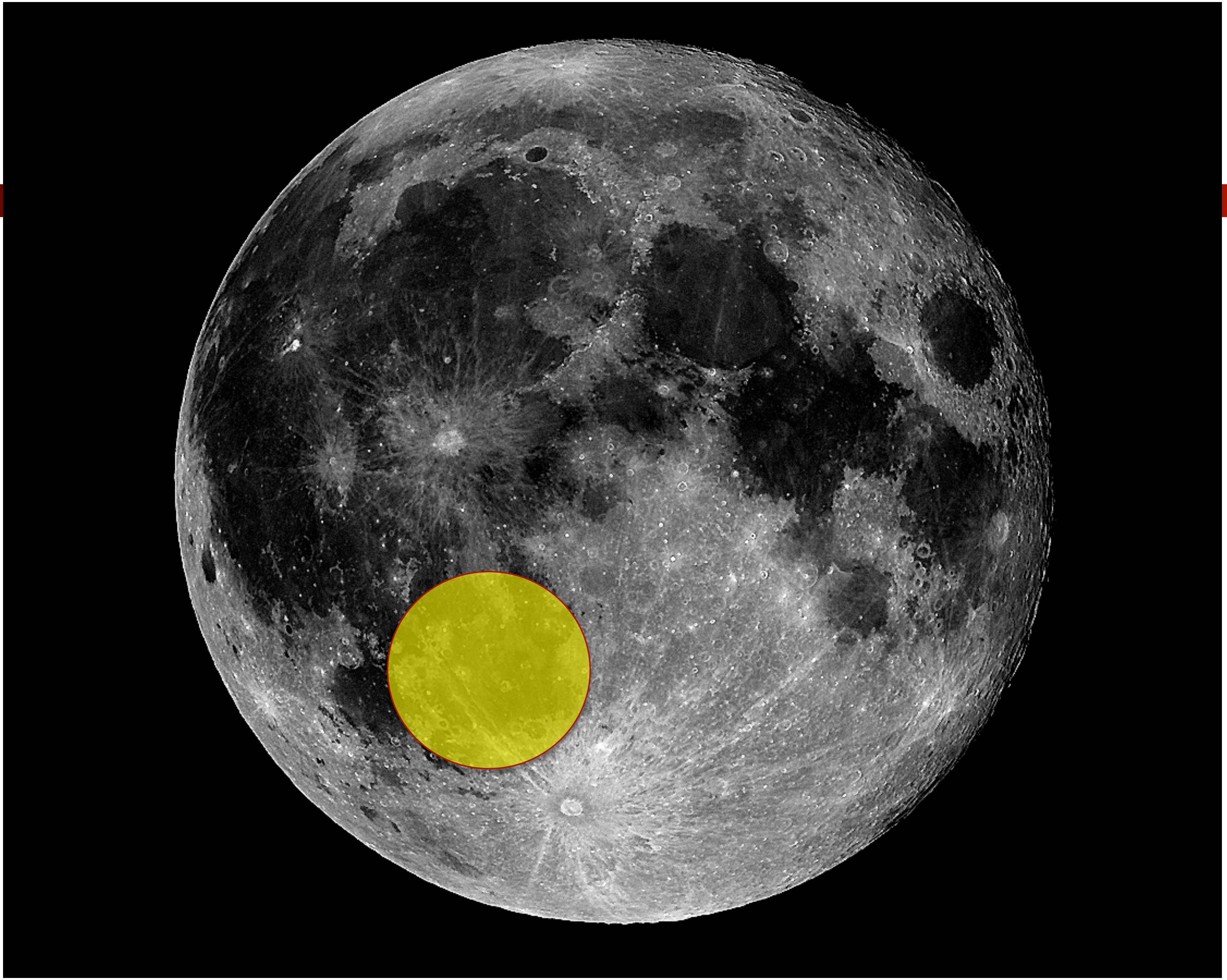
Of old | **Today**

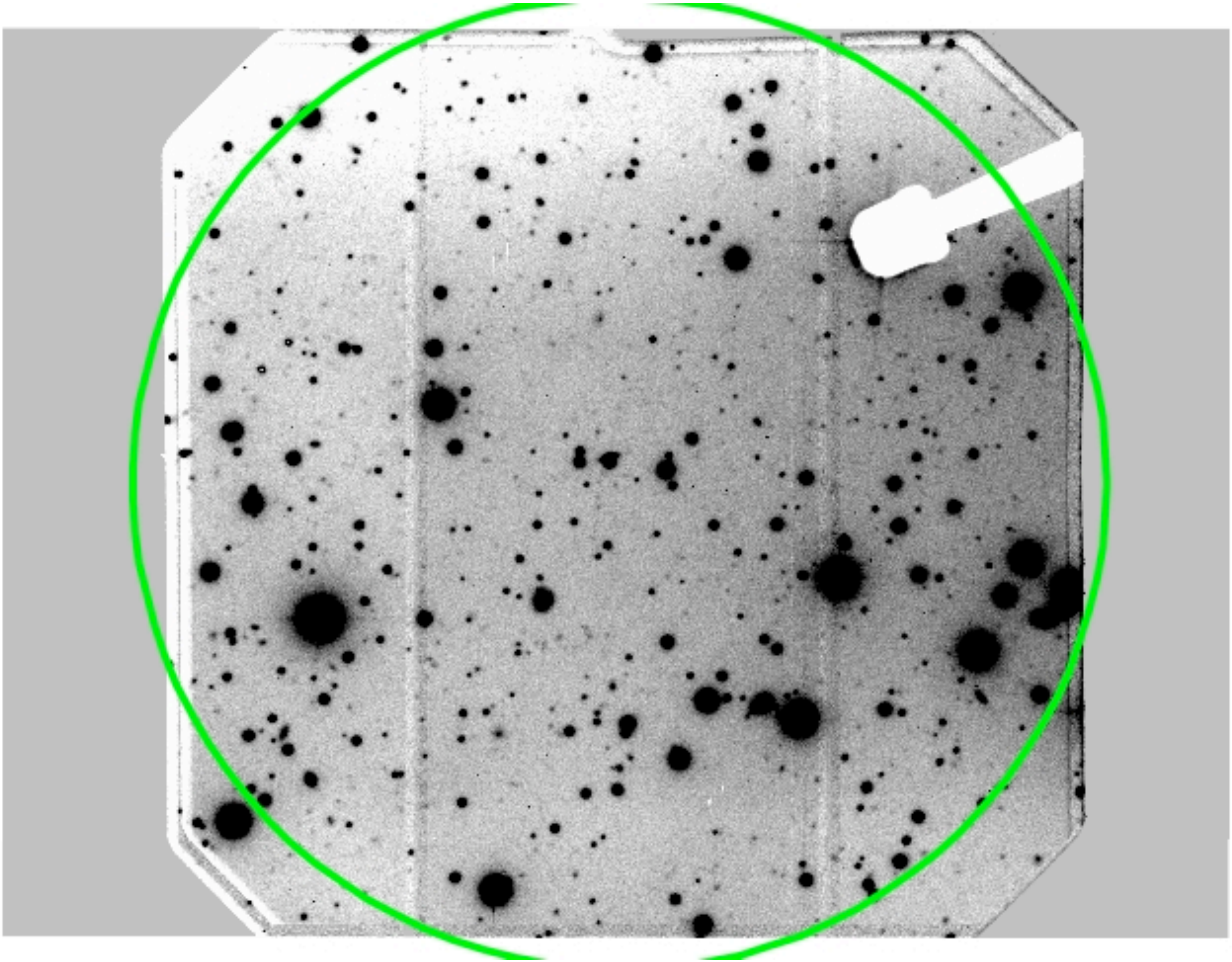










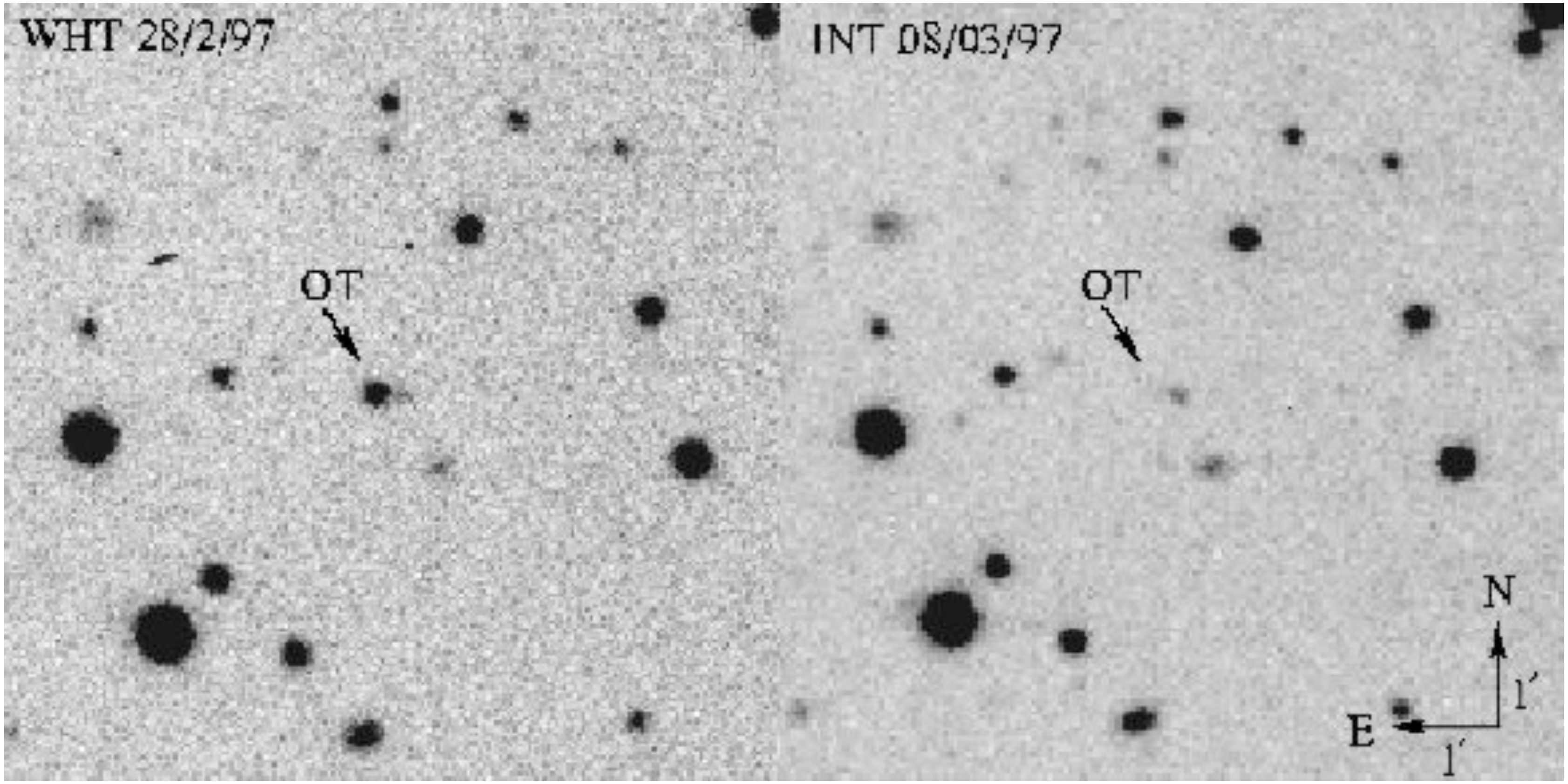


Afterglows

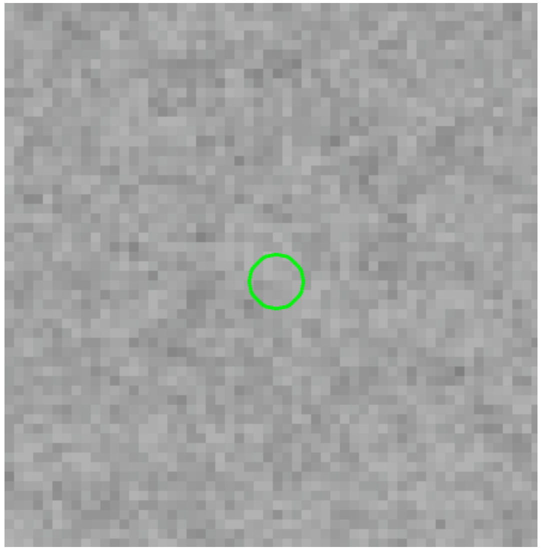
- Rapid variability (millisecond) – compact emitting region
- Extragalactic origin (high energy)
- Photons above apparent pair production threshold

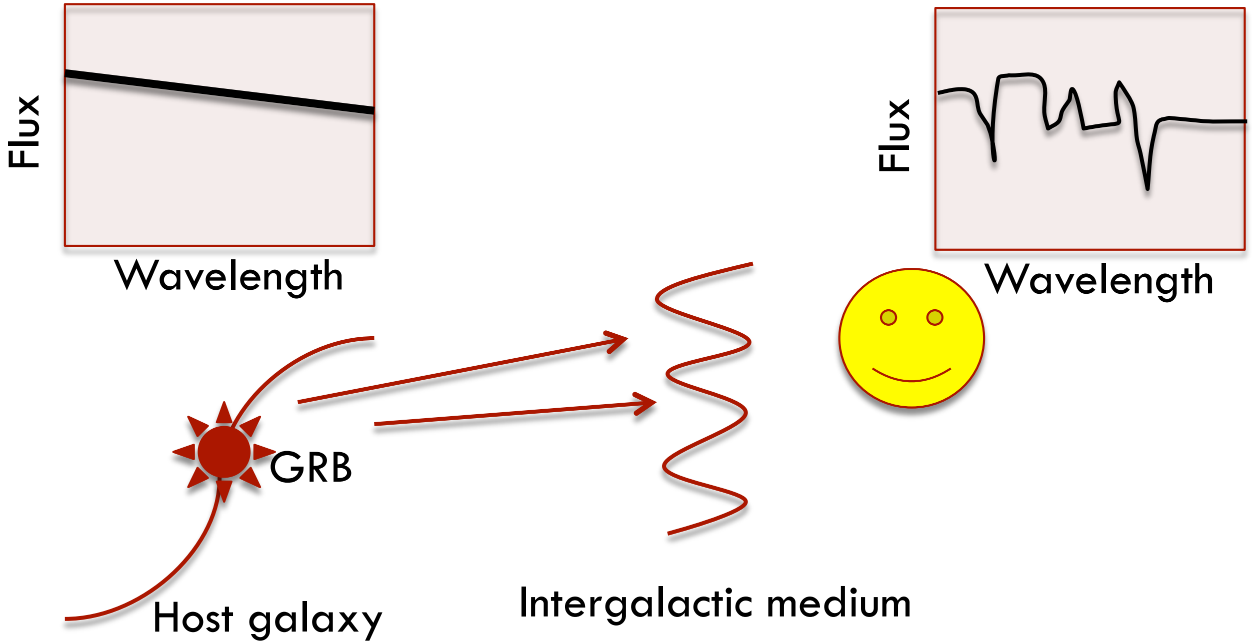
- Solution: Highly energetic, relativistic outflow – a **fireball**
- Interaction with interstellar medium should provide a detectable multiwavelength **afterglow**.

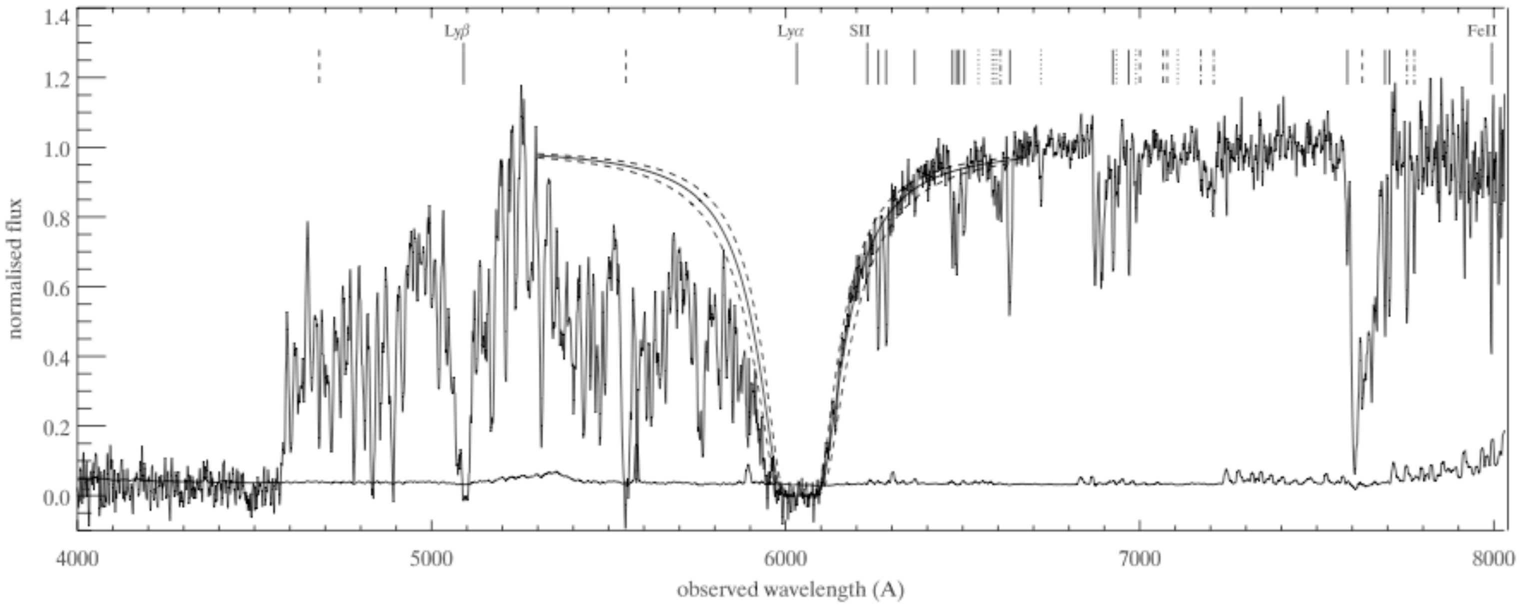
Long duration GRBs ($2 < t_{90} < 1000$)s



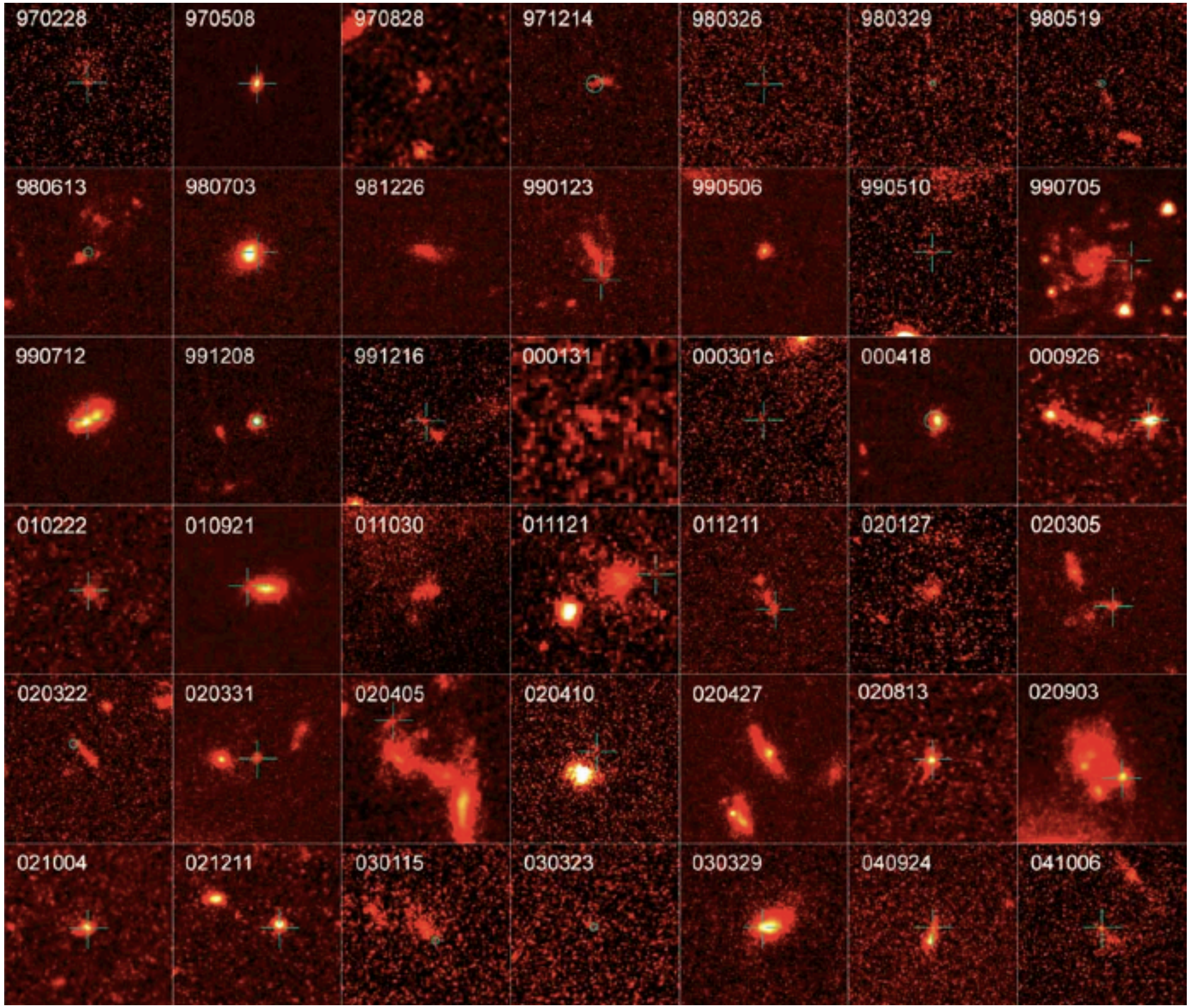
Redshifts



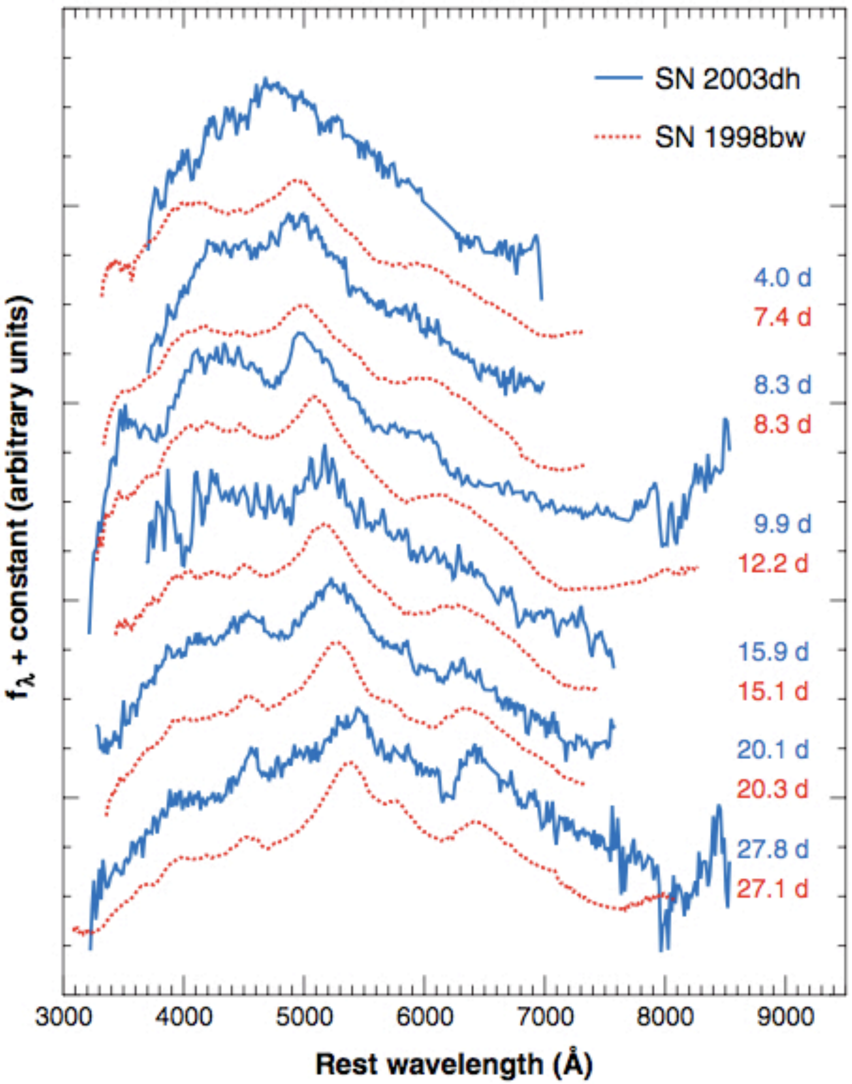

Flux
Wavelength
Flux
Wavelength
GRB
Host galaxy
Intergalactic medium


Lyβ
Lyα
SII
FeII
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
normalised flux
4000
5000
6000
7000
8000
observed wavelength (A)

Host galaxies



Supernovae

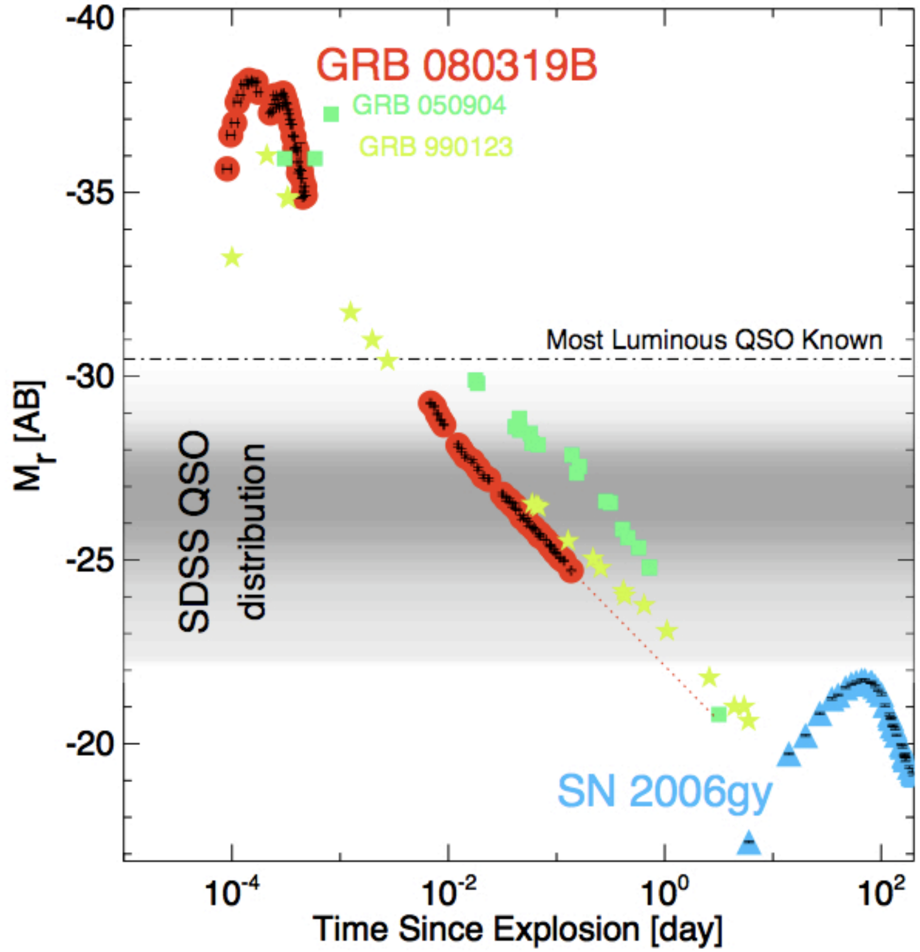


Unusual type Ic supernovae

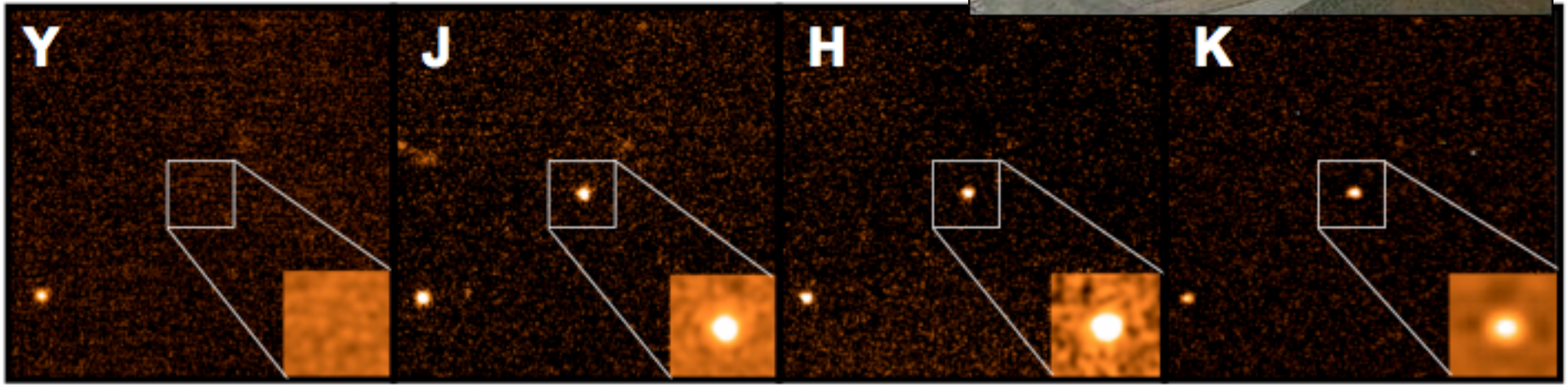
Driven by an “engine” (BH + accretion disc)

GRBs as probes : LGRBs

- Origin in core collapse supernovae
- GRB rate ⇔ star formation rate
- Luminosity: Large horizon distances
- Possible tracers of first generation (pop III) stars
- Afterglows probe composition of ISM (metallicity, dynamics etc) and IGM (in particular ionization state)

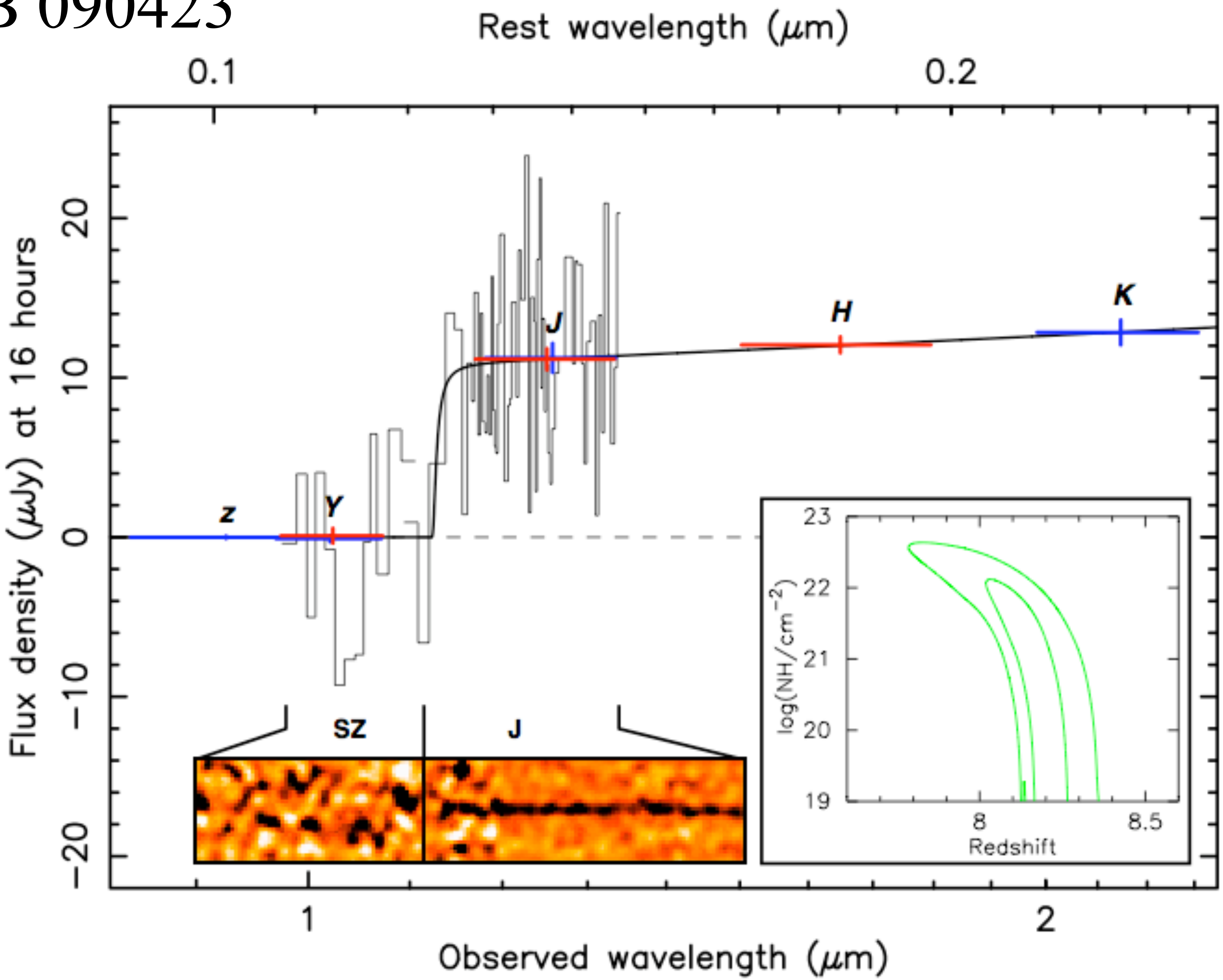


090423



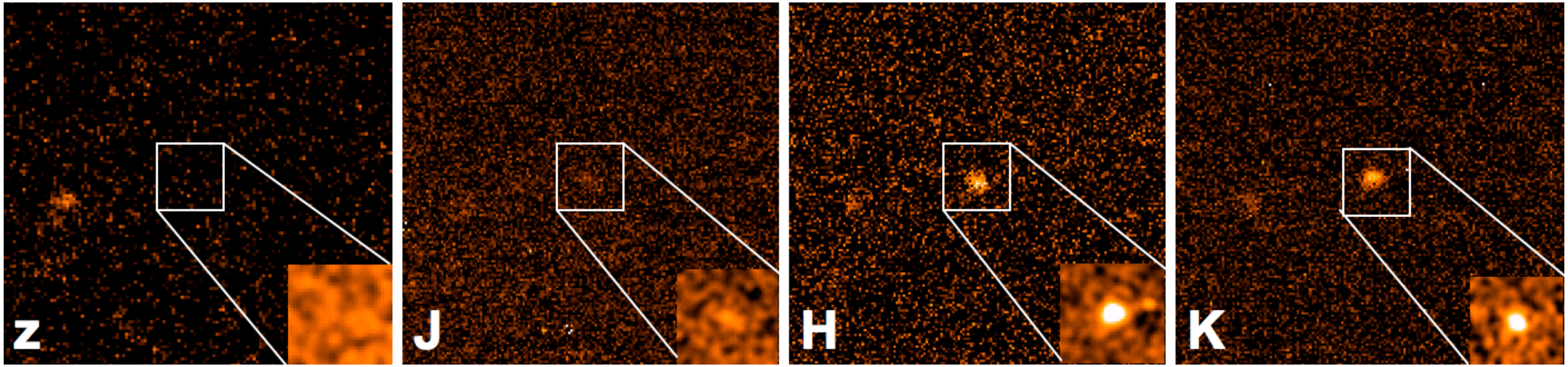
090423

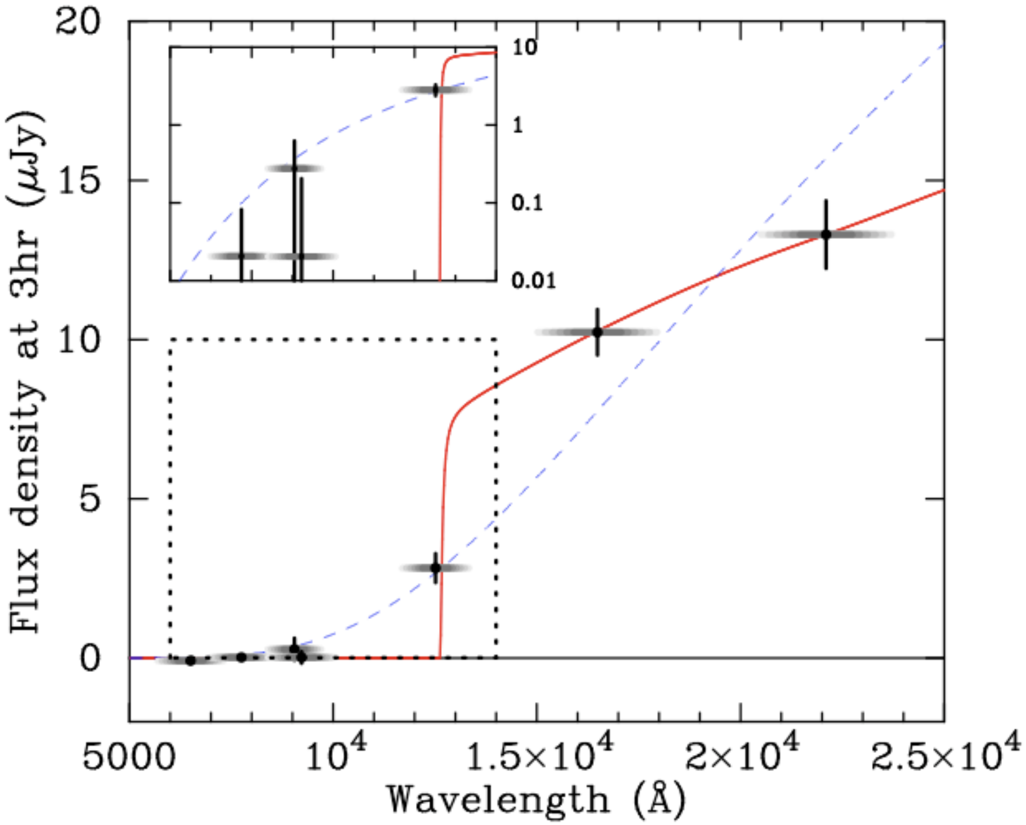
GRB 090423



Rest wavelength (μm)
0.1
0.2
Flux density (μJy) at 16 hours
20
10
0
−10
−20
z
Y
J
H
K
SZ
J
1
2
Observed wavelength (μm)
23
22
21
20
19
log(NH/cm^−2)
8
8.5
Redshift

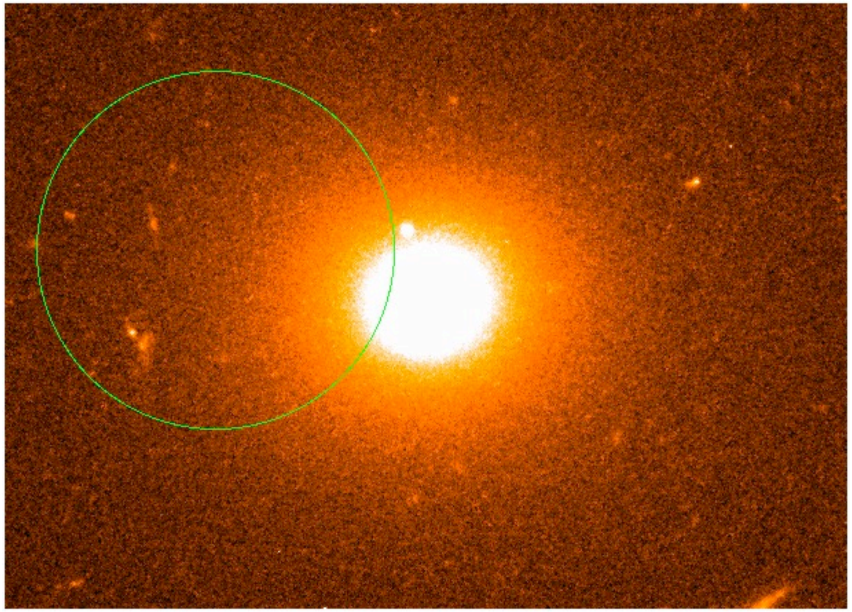
090429B

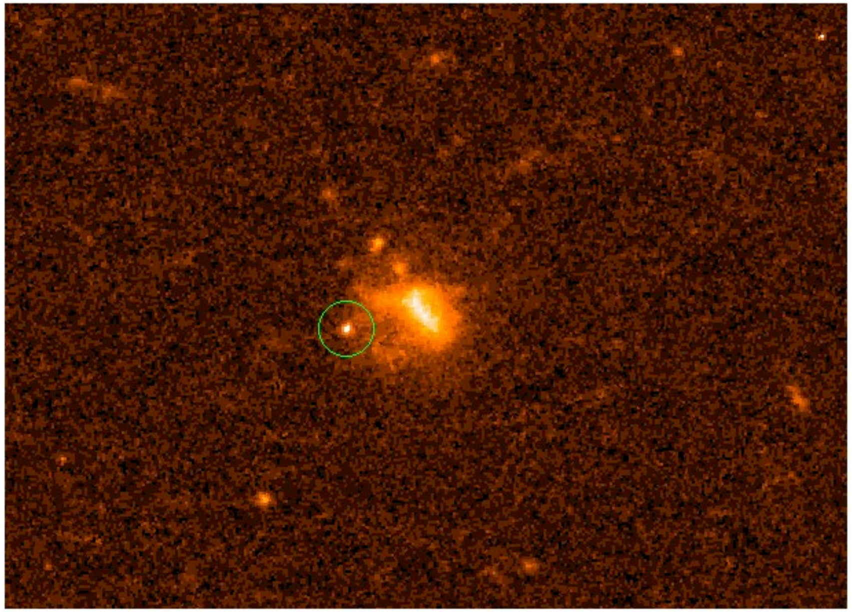




Cucchiaria et al. 2011

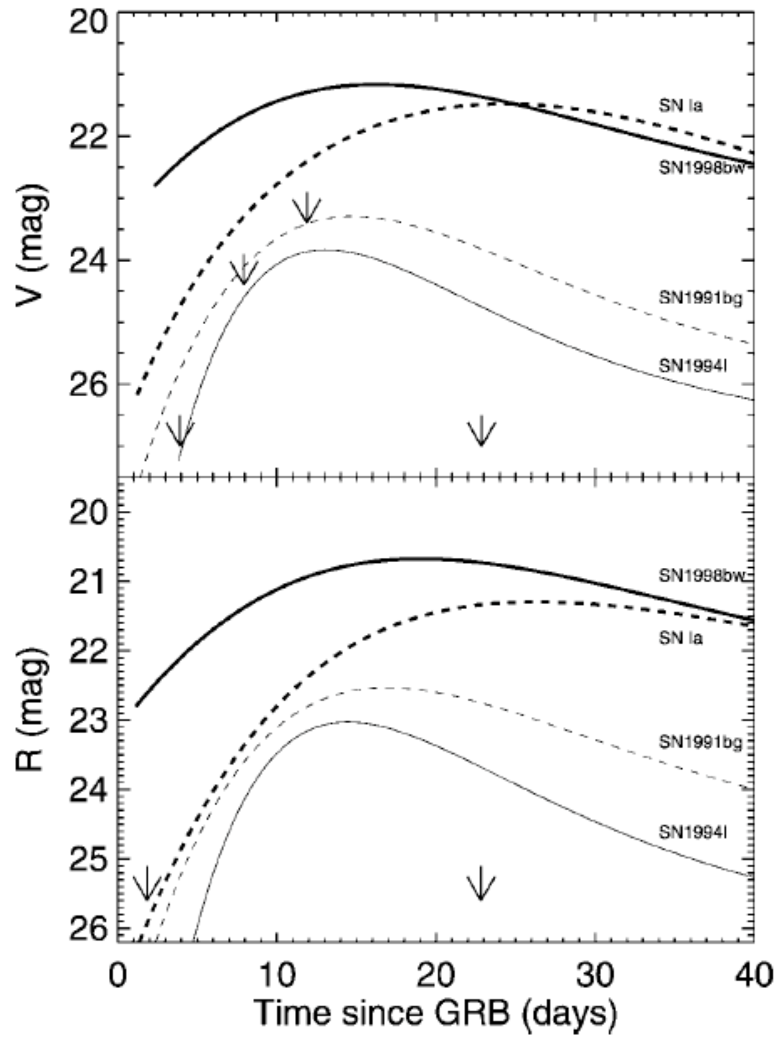
Short duration GRBs ($t_{90} < 2s$)





- Short GRBs also have afterglows, but they are typically a factor of 10-100 **fainter** than those of long bursts

No - supernovae



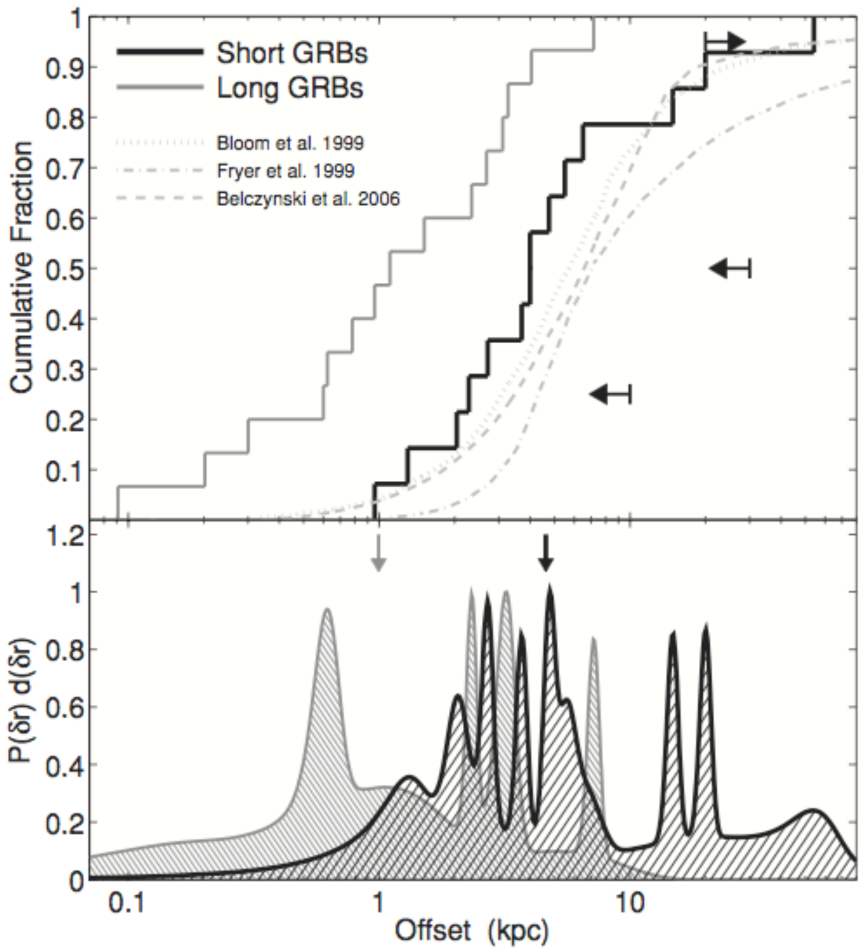
Hjorth et al. 2005

Double compact object binaries

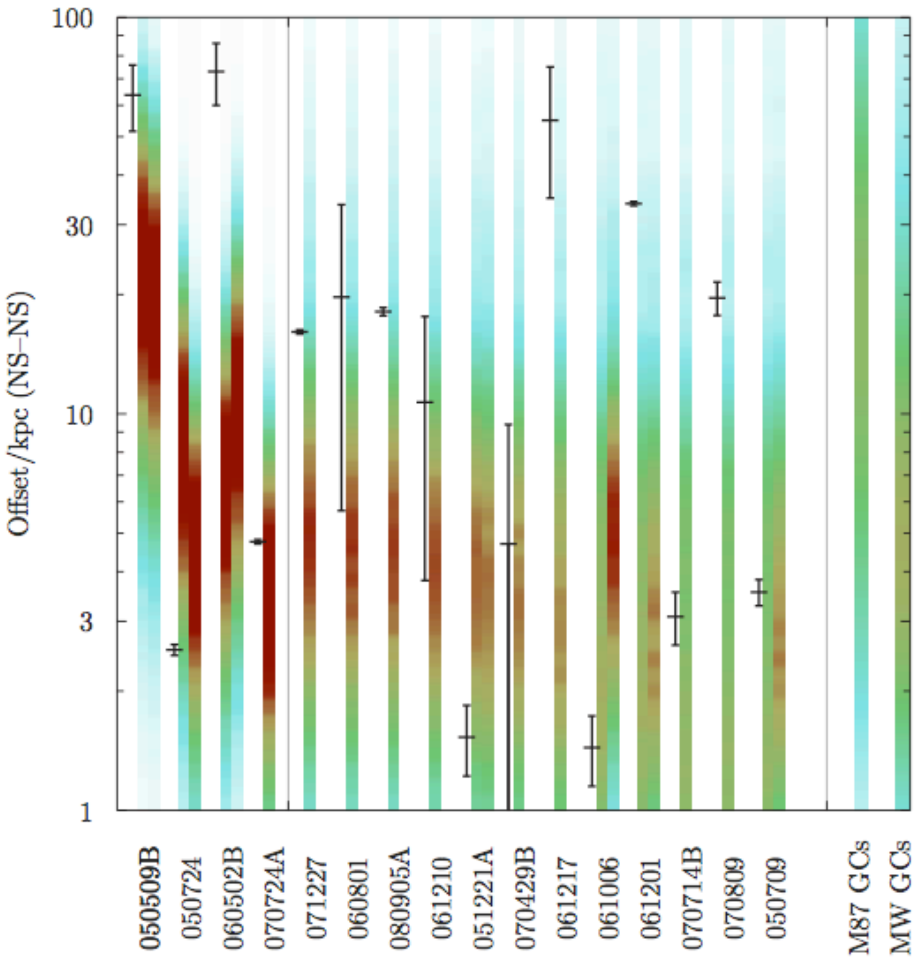
- Formed from two massive stars via two SN.
- Merge in 10-1000 Myr (old systems) via gravitational radiation
- Merger creates conditions to form a GRB (BH + torus)
- Good candidate from short GRBs
- Each SN creates a "kick" to the NS binary.

Offset distribution

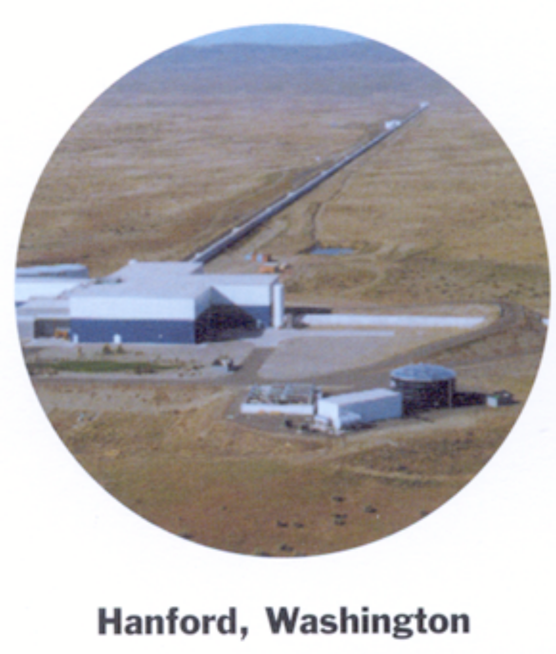
Fong et al. 2010



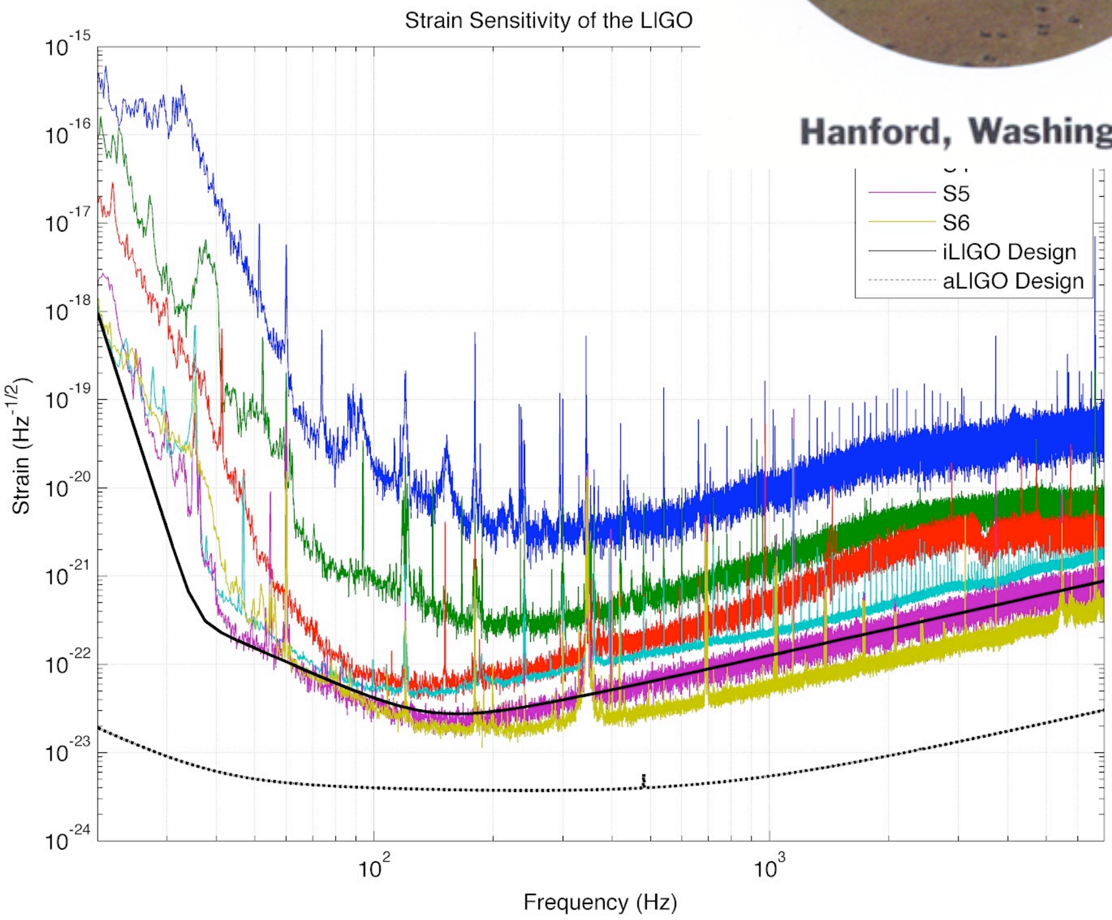
Church et al. 2011



GW – chirp

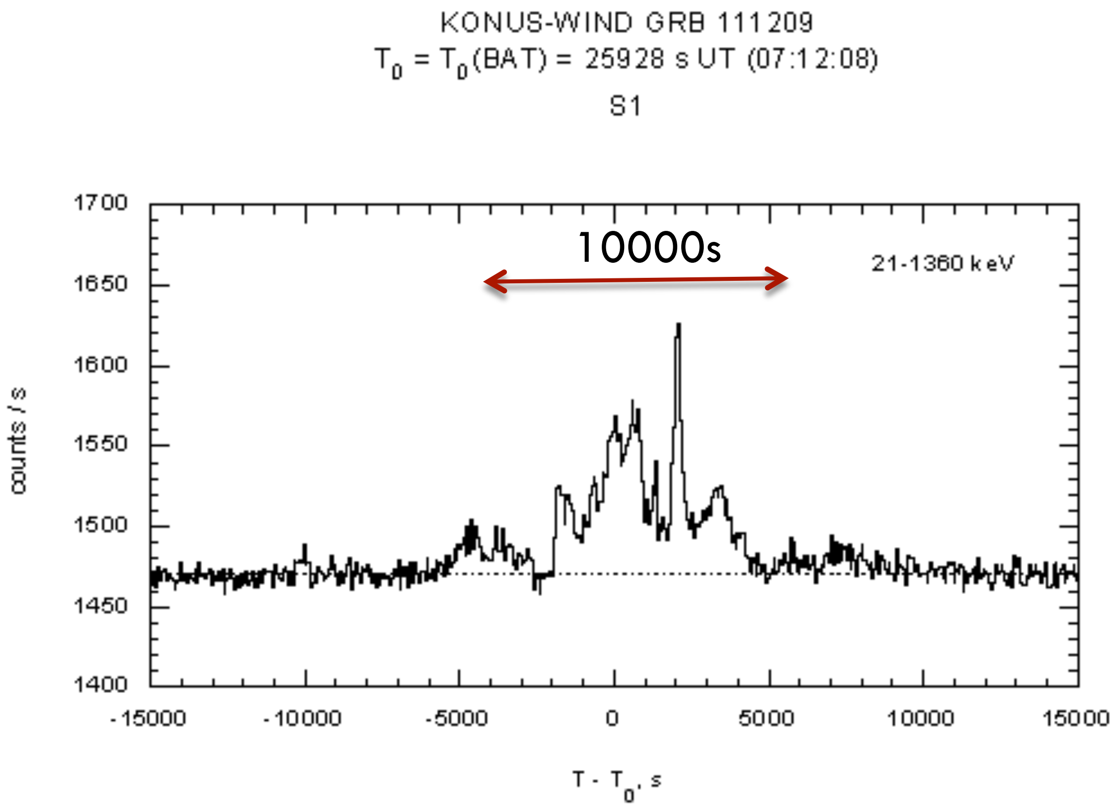

Hanford, Washington


Livingston, Louisiana

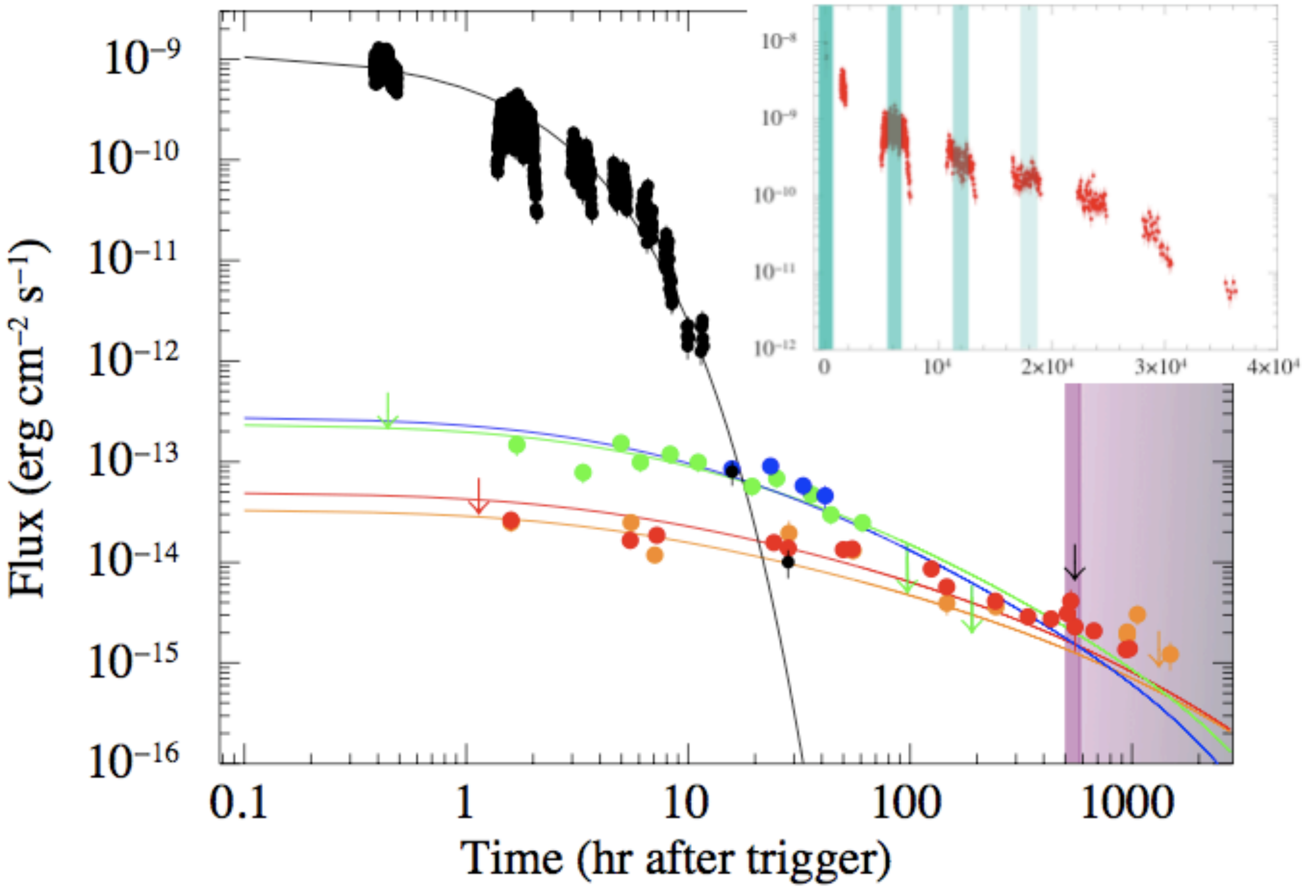

Strain Sensitivity of the LIGO
S5
S6
iLIGO Design
aLIGO Design
Strain (Hz^-1/2)
Frequency (Hz)

Ultra-long GRBs (t_{90} > 2000s)

GRB 101225A and GRB 111209A are the "prototypes"

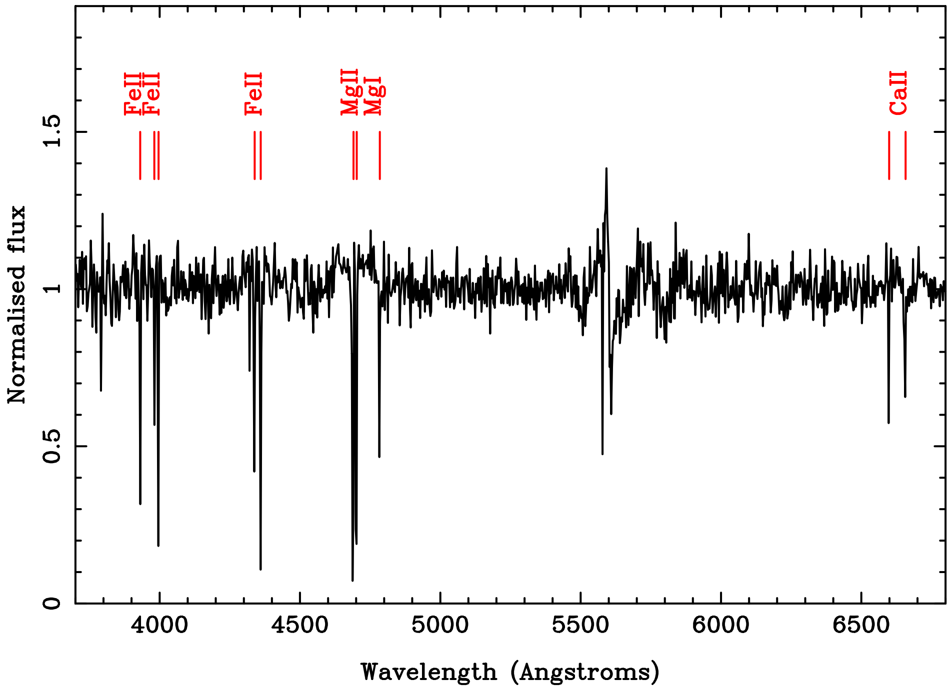


Galactic or extragalactic



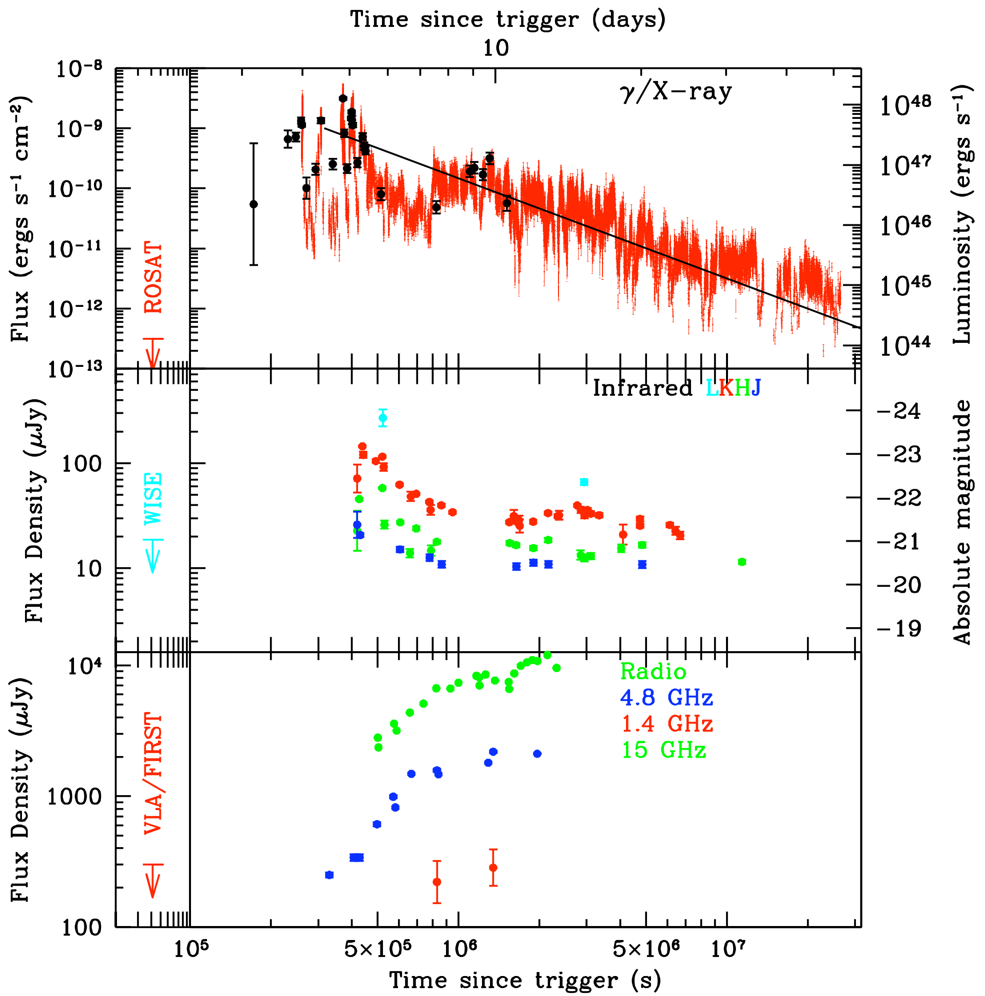
Comet + NS (Campana et al. 2011 Nature) He star + NS merger (Thoene et al. 2011 Nature)

~~Galactic or~~ extragalactic



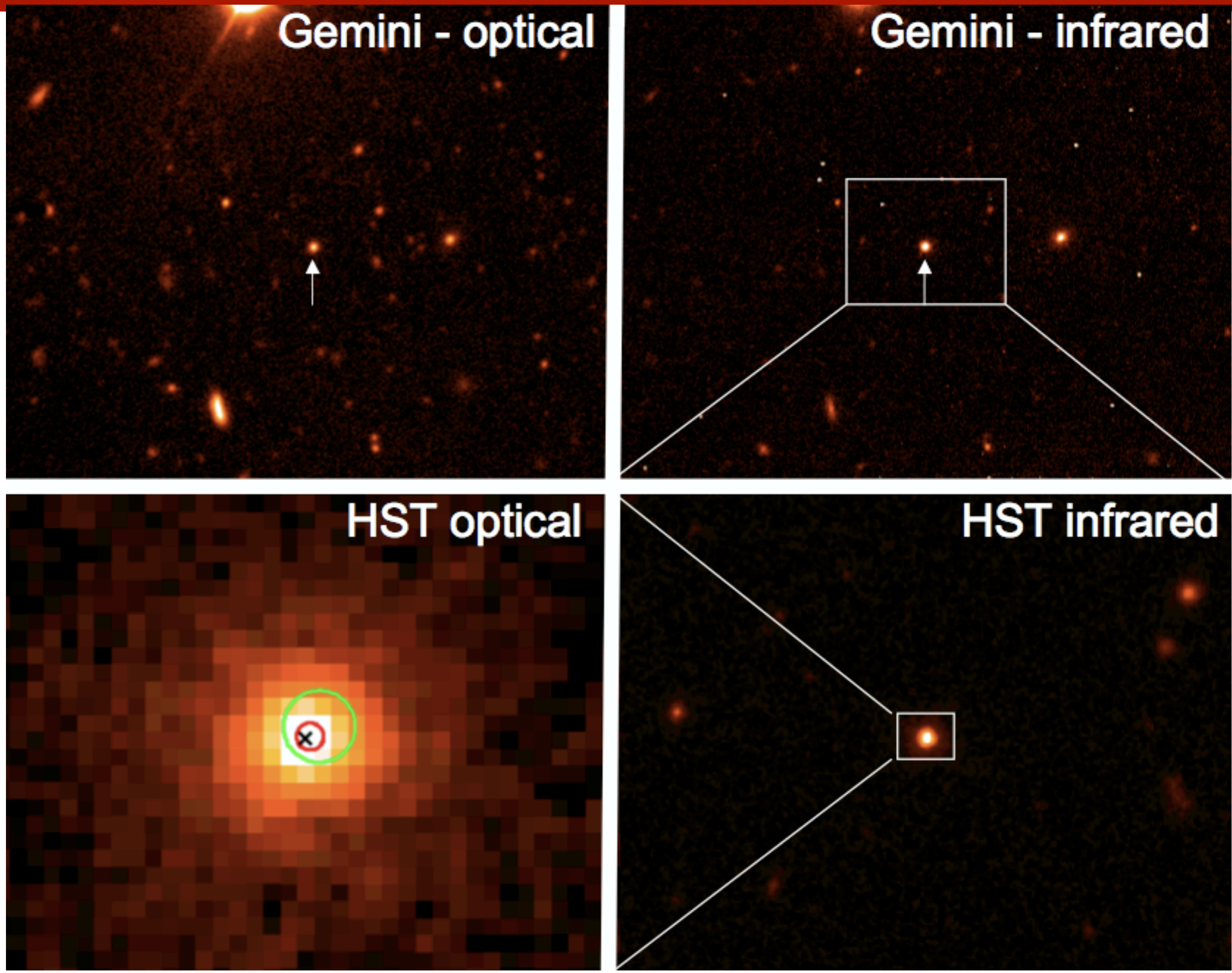
BUT: Very faint host galaxies
Supernova signatures not obvious

The longest transients ($t_{90} \sim$ days)

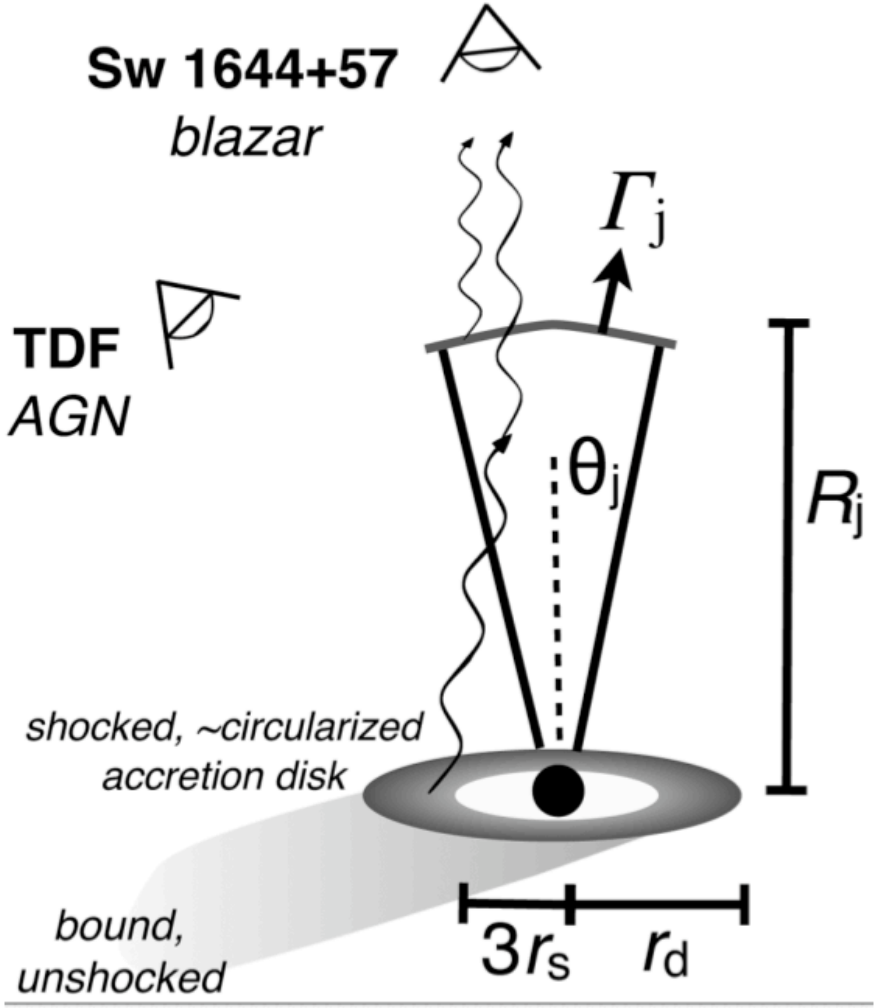


Levan et al. 2011

In galactic nuclei



Tidal disruption events (+ jet)



Levan et al. 2011, Bloom et al. 2011

Progenitors: Summary

- Two classical populations of GRBs **long** and **short**
- **Long GRBs** arise from unusual supernovae
- **Short GRBs** are likely from compact object binaries

- Populations of **even longer** GRBs are now being uncovered. These may suggest mechanisms creating GRBs in many stellar types, or from completely different physical processes.

Probes: Summary

- Long GRBs are powerful, and well used probes of **distant galaxies** and **massive stars** and show promise for tracing the **star formation rate**, and **reionization.**

- Short GRBs may provide constraints on **GW-wave origins.**
- Very long transients test the ubiquity **of black holes in Galactic nuclei.**

Any questions?