Long GRBs Observing Plan

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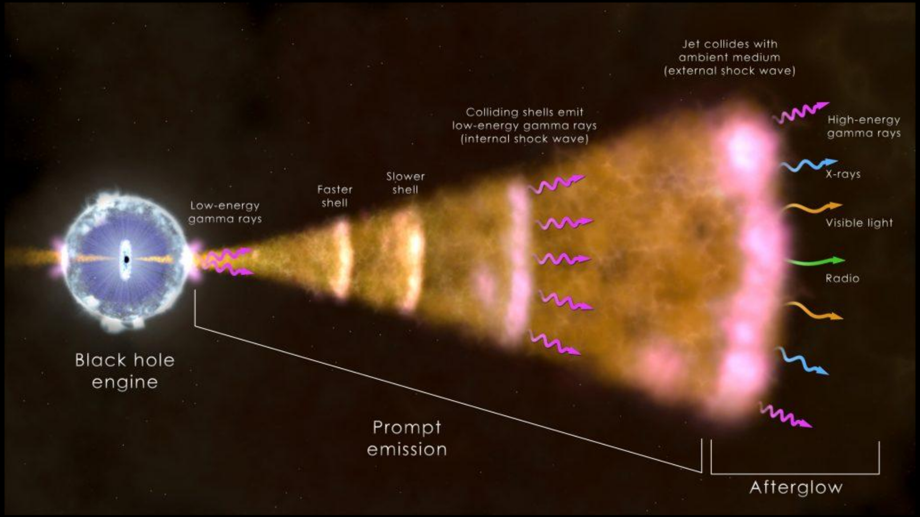
2025 Oct 27 @ NASA 4th TDAMM workshop

Long GRBs: what we have learned



- Progenitors:
  - collapsars (in most cases?)
  - associated with SN IcBL
- Jets:
  - Highly relativistic ($\Gamma \gtrsim 100$)
  - Strongly collimated (~ a few degrees)
  - Angular structure (e.g. GRB 170817A)
- Prompt emission
  - Energy dissipation
  - High variability (tied to central engine activity)
  - High radiative efficiency
- Afterglow emission
  - Forward shock interacting with CSM
  - Synchrotron emission
  - Reasonably well described by models

Open Problems (a top 5 list!)

(1) How are GRB jets launched?

BZ vs. neutrino

(2) What is the jet composition and magnetization?

Poynting-flux dominated vs baryonic

(3) Prompt emission mechanism:

Where is it produced (photosphere or above)

Dissipation mechanism (IS/reconnection/photospheric/shock breakout)

(4) What is the structure of GRB jets?

Power-law or Gaussian or multi-component

How the structure depends on progenitor

(5) What is the origin of the different GRB classes?

Long, ultra-long, llGRBs, X-ray flashes, etc

Selecting the best GRB class?

Which class allows us to improve our physical understanding the most?

Source classes

(1) Multimessenger GRBs (progenitor, central engine, jet physics)

(2) Central-engine and GRB diversity:

- (a) Ultra-long GRBs (central engine lifetime, progenitors)
- (b) Long duration mergers (GRB classification, progenitors)
- (c) Low-luminosity GRBs/XRFs/XRRs (cocoon dominated vs baryon loaded, GRB diversity)
- (d) Orphan afterglows (GRB diversity + jet structure)

(3) Jet physics

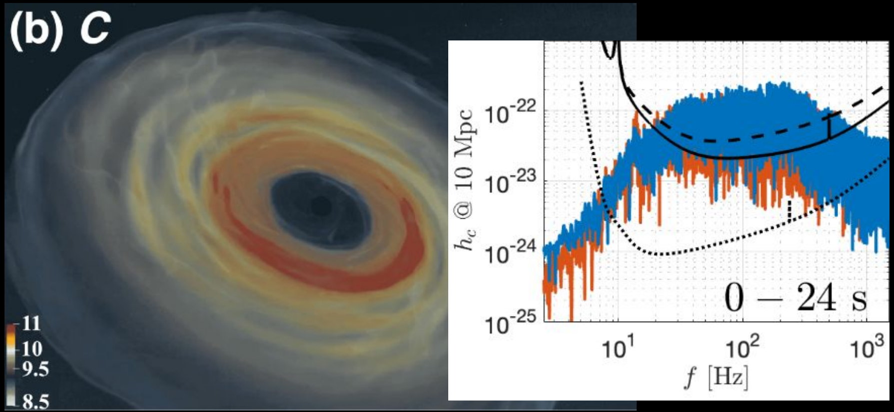
- (a) GRBs with VHE (hadronic vs. leptonic emission)
- (b) Very bright GRBs (classical prompt + afterglows microphysics)

(4) Cosmic evolution

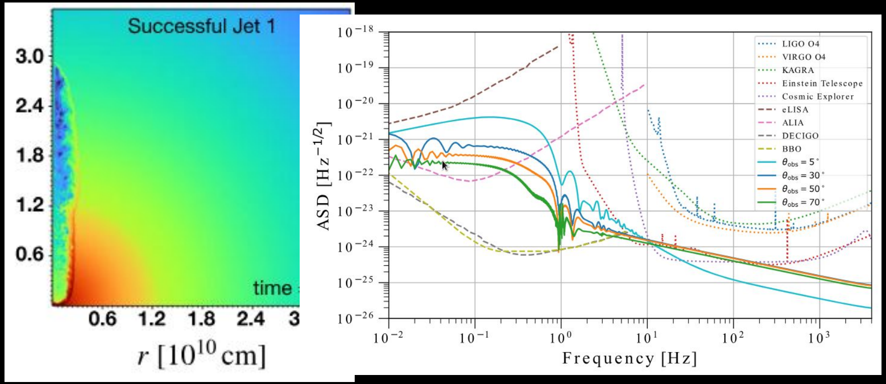
- (a) High-z GRBs (pop III, early cosmic star formation)

Multimessenger GRBs

Multimessenger GRBs: GWs



Gottlieb+24, see also Fryer+01, Cerda-Duran+10, Ott+11, Wei+19, Kotake+12, Fernandez+25, …



Urrutia, FDC+22, see also Gottlieb+22, Segalis+01; Sun+12, Akiba+13, Du+18, Yu20; Leiderschneider+21, Sago+24, …

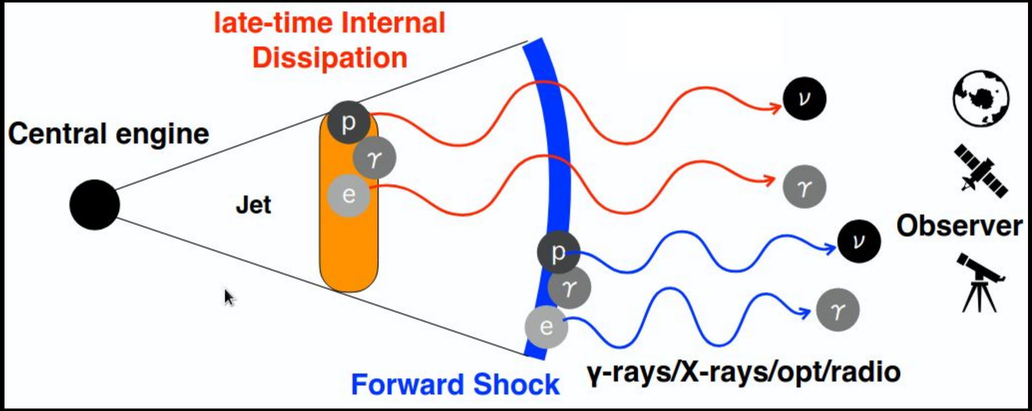
Rate:

Uncertain but possibly very low (<< 1 yr^{-1})

Triggering criteria:

LGRBs localized inside the error box of the GW and nearly coincident in time (~seconds to minutes)

Multimessenger GRBs: neutrinos



Kimura+22

Can be emitted mainly during prompt, afterglows, or llGRBs, Cocoon, baryon rich jets (see *Kimura+22* for a review)

Best case: a Fermi GRB with 10% random association (*Abbasi+24*)

Jet composition, particle acceleration process, emitting region, presence of relativistic jets (for choked jets)

Rate:

Uncertain but possibly very low (<< 1 yr^{-1})

Triggering criterium:

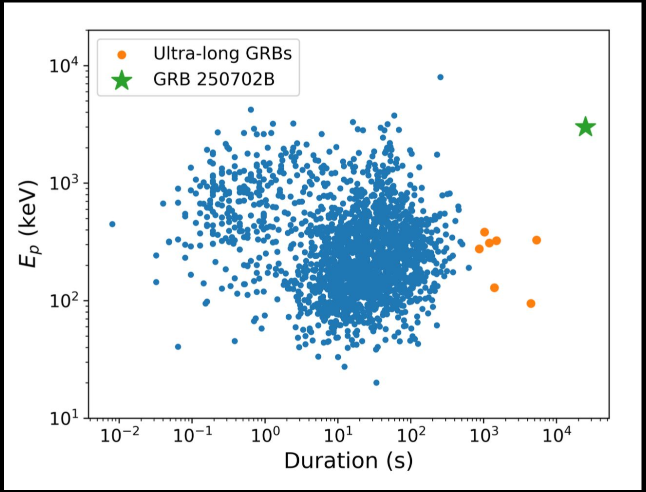
LGRBs localized inside the error box of the Icecube neutrinos

Central Engine and progenitor diversity

Ultra-long GRBs

Burst	Redshift	Observed Duration	Rest-frame Duration
GRB 220627A	3.084	3700	900
GRB 101225A	0.847	1377	800
GRB 121027A	1.773	5700	2000
GRB 091024A	1.0924	1200	600
GRB 141121A	1.469	∼1500	∼620
GRB 170714A	0.793	∼1030	∼570
GRB 111209A	0.677	10000	6000
GRB 130925A	0.347	4500	3300
GRB 090417B	0.345	2130	1600

Fryer+25



Neights+25

Rate: ~0.6 yr^{-1}

Triggering criteria:

Length of observed prompt gamma-ray duration > 1000s (*Levan+14*), including widely-spaced emission episodes

Ultra-long GRBs

Main open question:

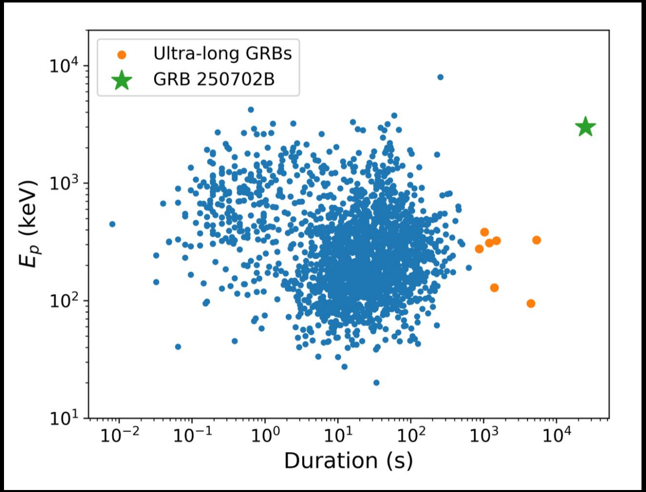
What is the progenitor?!?

Existing models:

Collapse of a supergiant, GRB powered by magnetars, (micro)TDEs, Collapsar with fallback, Jet breakout from extended envelope, Jets during common envelope phases, etc

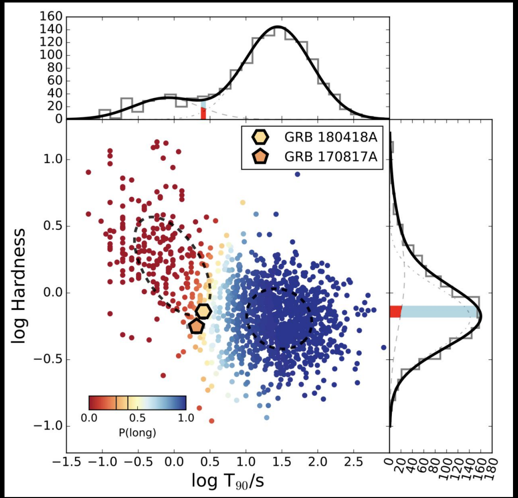
(*Metzger10, Quataert&Kasen12, Nakauchi+13, Moreno-mendez+17, Perna+18, Gendre19, Hutchinson-Smith+24, Beniamini25, …*)

Key observables: prompt emission properties, host environment, associated SNe.

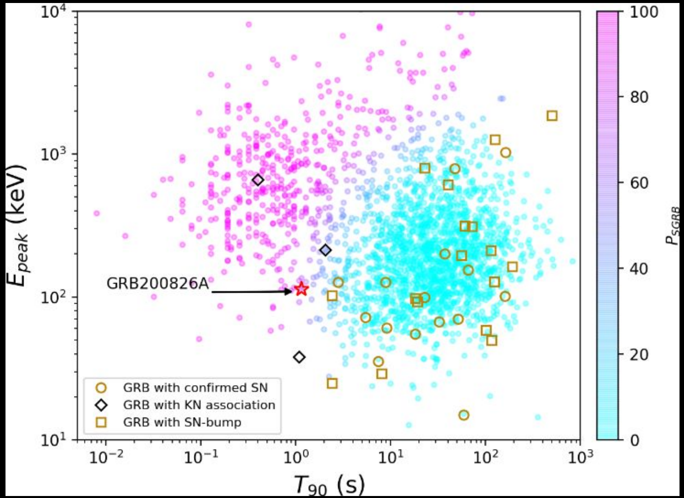


Neights+25

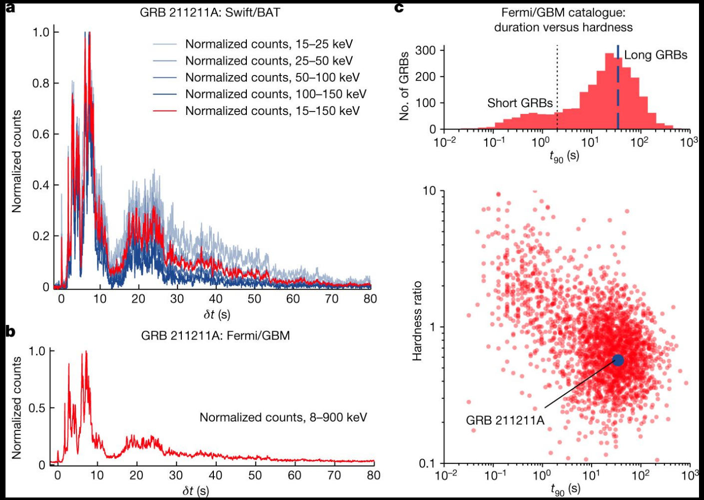
Long duration mergers



Ruoco-Escorial+21



Ahumada+21



Rastinejad+22, see also Troja+22, Yang+24, …

- Significantly offset from the host galaxy, or in very old quiescent galaxies.
- Lack of evidence of a supernova and evidence of a kilonova

Long duration mergers

Main open question: accretion and prompt emission in mergers, constraints KN properties and r-process

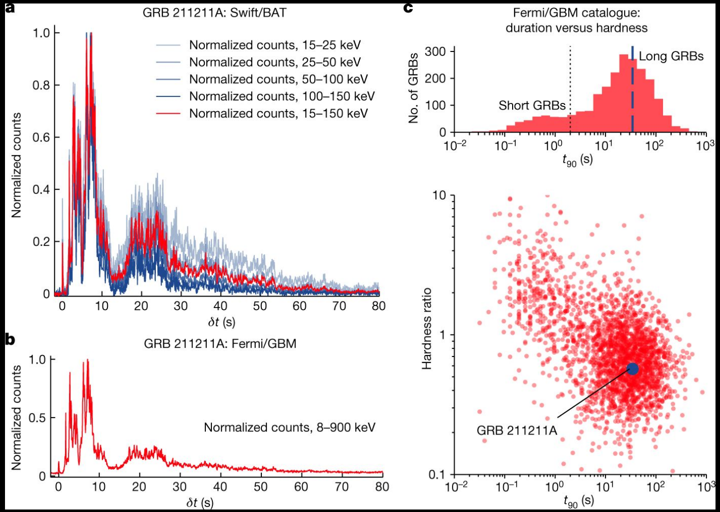
Rate:

~1/few years

Triggering criteria:

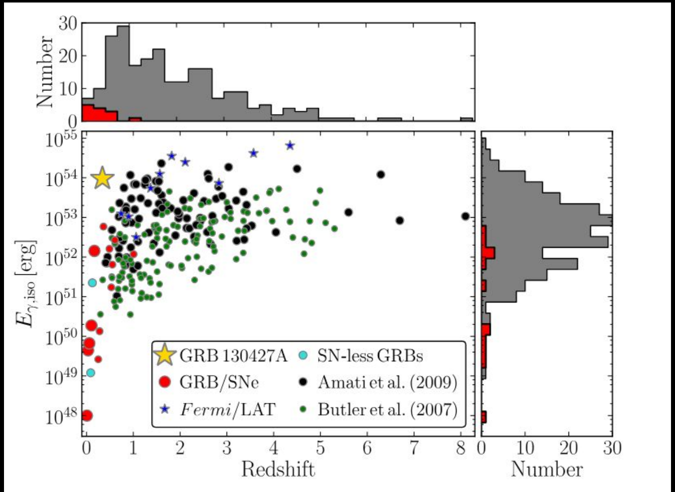
LGRBs lacking SN and evidence of a KN,

Significantly offset from the host galaxy, or in very old quiescent galaxies.

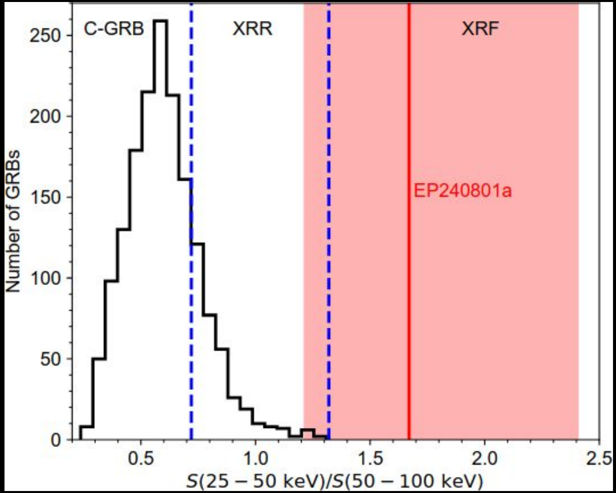


Rastinejad+22

llGRBs/X-ray flashes/X-ray rich



Levan16



Jiang+25

Represent the largest fraction of existing GRBs (200 Gpc^{-3} yr^{-1}; ~100 times more frequent than regular GRBs)

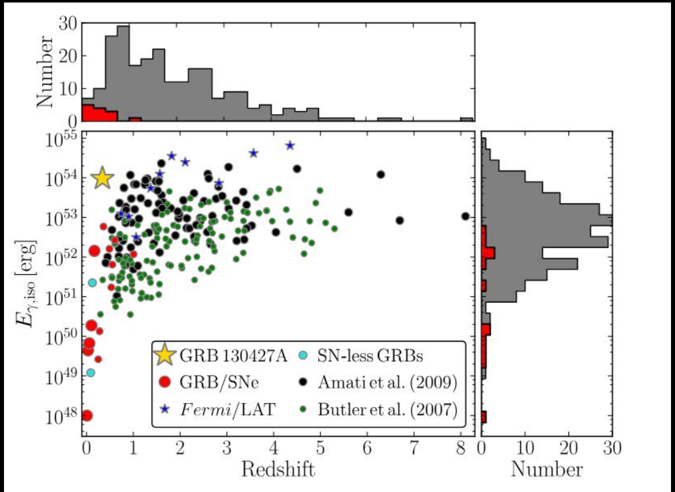
Rate:

1 every ~ few yrs

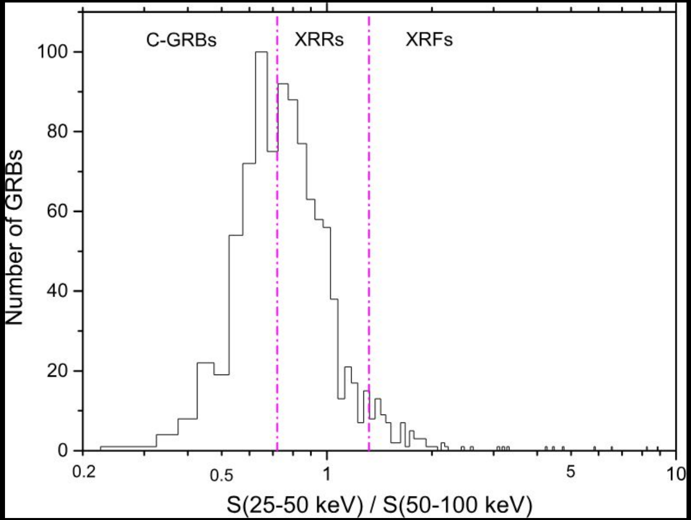
Detectability criteria:

Low redshift	z < 0.1 (d < 500 Mpc)
Eiso	< 10^{49} erg (*Liang+07*)
Soft spectrum	E_p ~ a few to 10s of keV

llGRBs/X-ray flashes/X-ray rich (+FXTs)



Levan16



Bi+18

Represent the largest fraction of existing GRBs (200 Gpc^{-3} yr^{-1}; 100 times more frequent than regular GRBs)

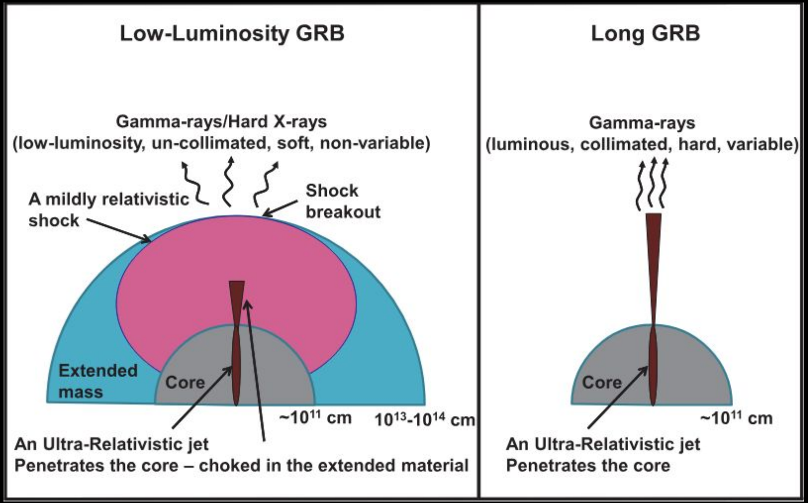
Rate:

1 every ~ few yrs

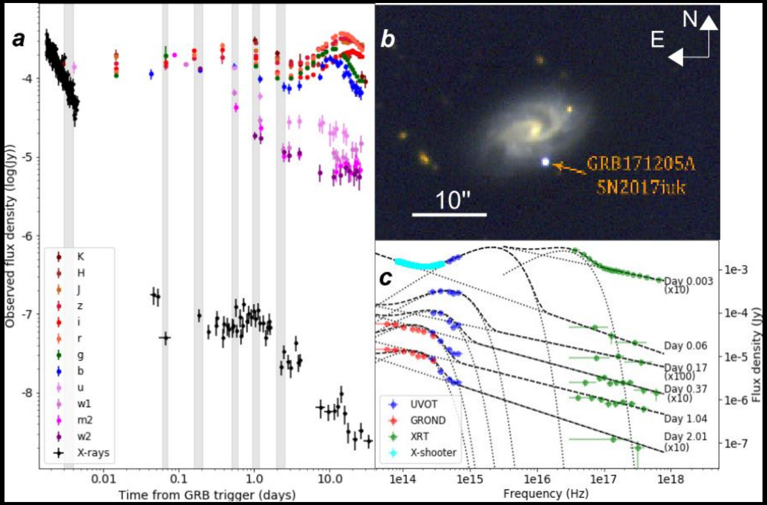
Detectability criteria:

Low redshift	$z < 0.1$ ($d < 500$ Mpc)
Eiso	$< 10^{49}$ erg (*Liang+07*)
Soft spectrum	E_p ~ a few to 10s of keV

llGRBs/X-ray flashes/X-ray rich (+FXTs)



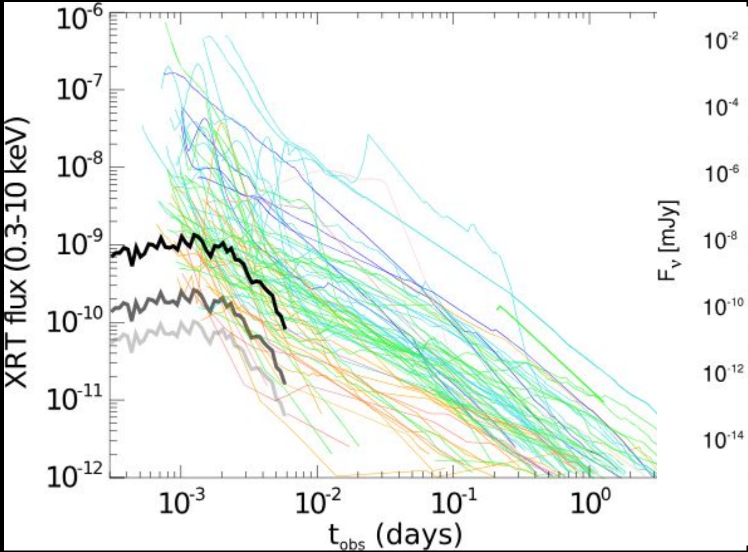
Nakar 2015

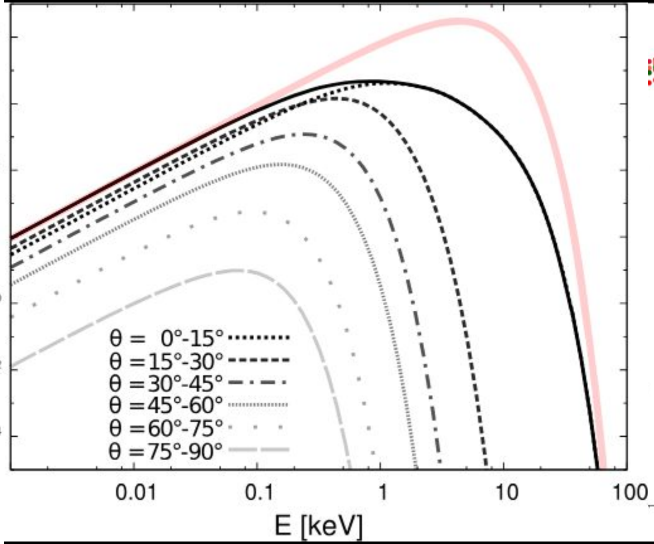


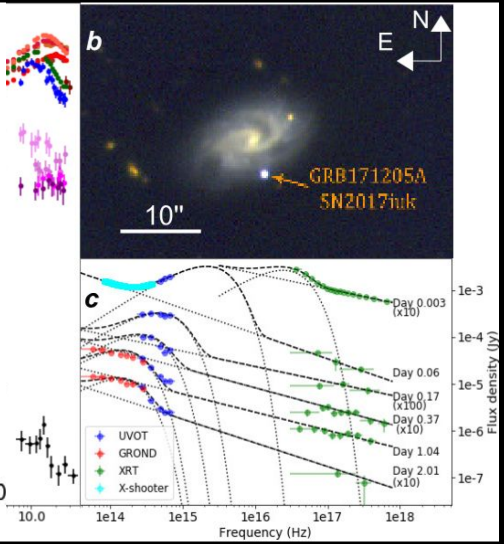
Izzo+19

Origin:
Intrinsically low-luminous vs Failed jets

llGRBs/X-ray flashes/XRR



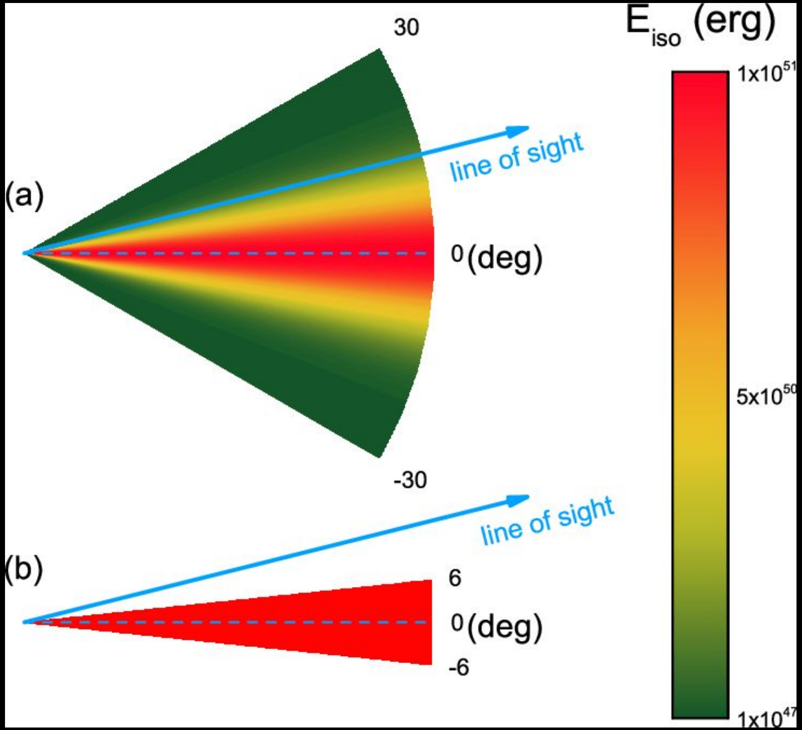




De Colle+18

Izzo+19

Orphan afterglows



Jin+18

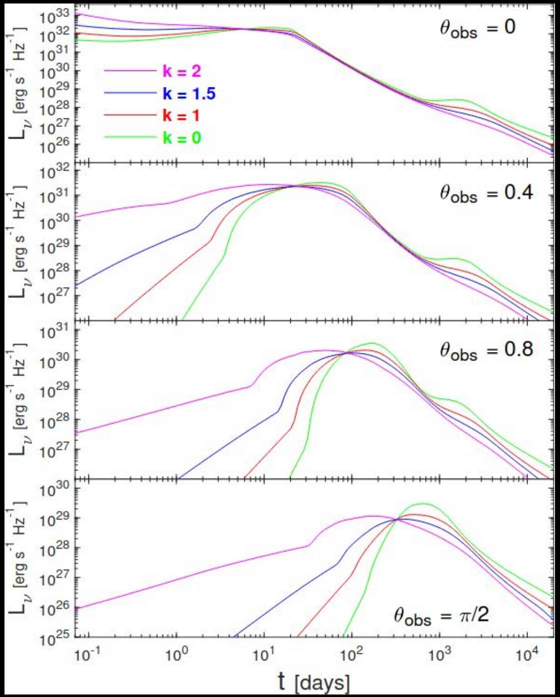
X-ray/optical/radio afterglows detected without an associated gamma-ray emission

The jet is outside of the line of view (Classical LGRBs viewed off-axis)

The jet is weaker
Dirty fireballs - jets that couple more matter to the ejecta and have a lower Lorentz factor; Γ~10)

The jet is absent
(jet choked in a stellar envelope or dense CSM - relativistic SNe?)

Orphan afterglows



Granot+18

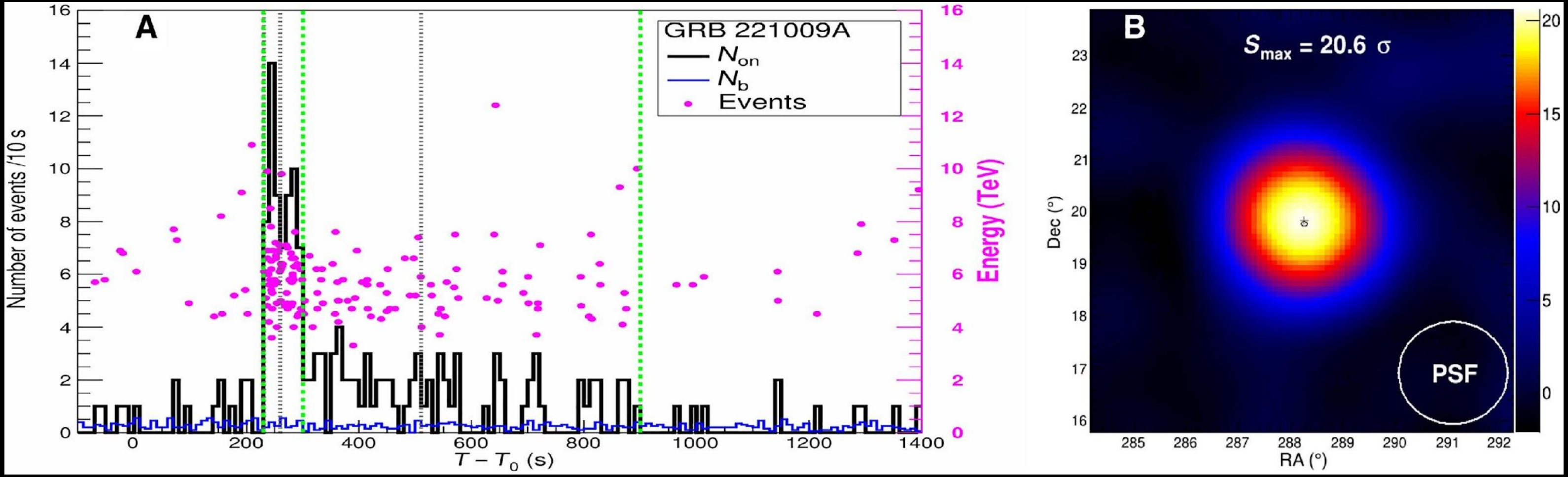
Science goals:
- understand the jet structure;
- constrain the GRB rate;
- understand jet propagation and mixing with baryons inside the star and CSM
- Origin of FXT associated with SNe? E.g. *Sun+25*

Triggering criteria:
- Afterglow detected in X-ray/optical/radio
- $L_{iso, gamma} < 10^{49}$ erg/s;
- peak of high-energy emission < 4keV.

Event rates:
Uncertain, specially for off-axis GRBs

Jet Physics

GRBs with VHE



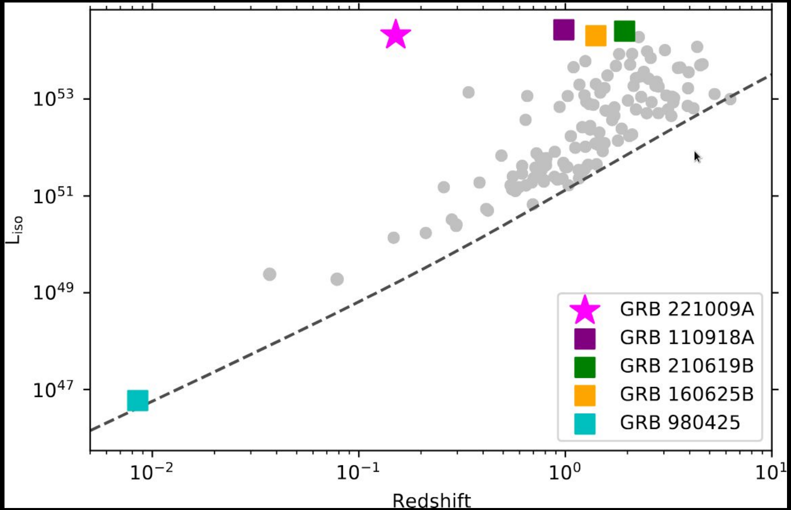
LLHASO coll. (2023)

GRB 180720B - HESS
GRB 190114C - MAGIC
GRB 190829A - HESS
GRB 201216C - MAGIC
GRB 221009A - LHAASO

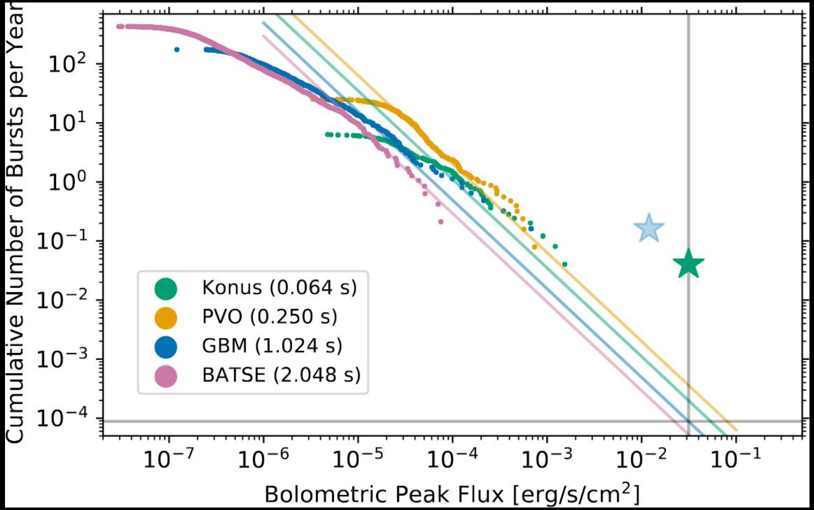
Rate ~ 1/yr
Triggering Criteria:
VHE (> 100 GeV) detection by HESS, Magic, Hawc, Lhaaso

Jet composition (hadronic vs. leptonic), particle acceleration

Very Bright GRBs



Burns+2023



Burns+2023

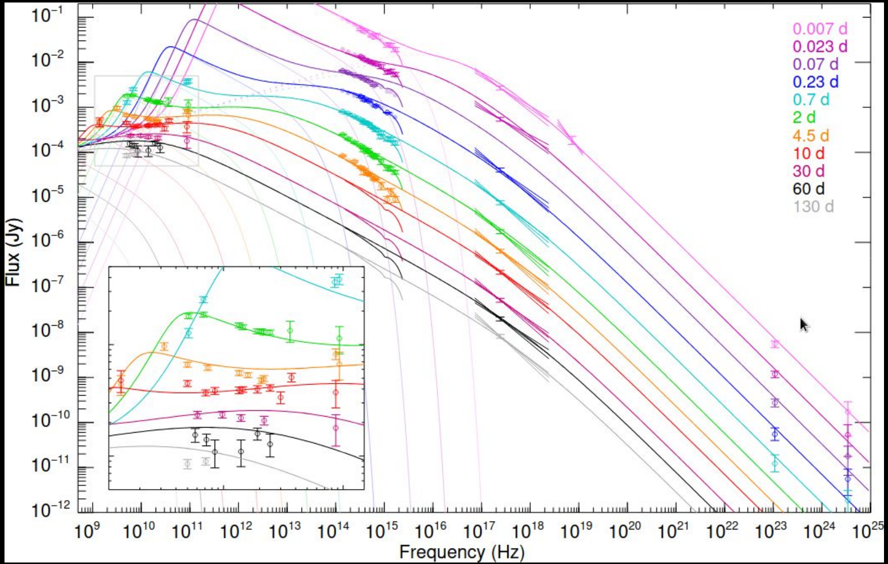
Rate:

~0.3 yr^{-1}

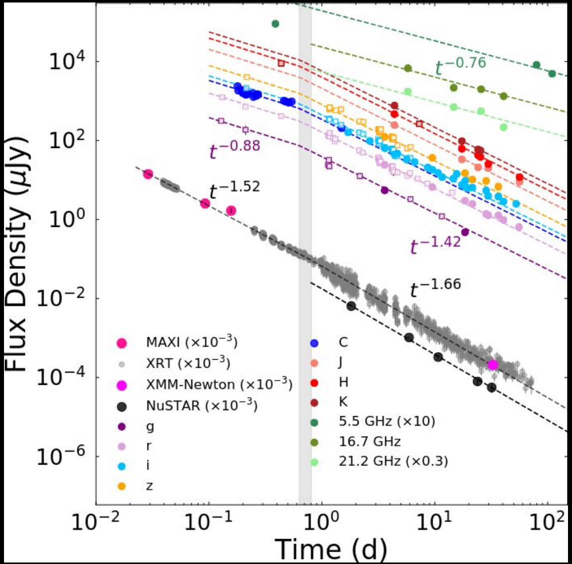
Triggering criteria:

bolometric fluence $F > 10^{-3}$ erg/cm^2

Very Bright GRBs



Perley+14



O'Connor+23, see also Gill+23 Laskar+23,...

They provide the best case to study properties of the afterglow (and prompt) emission!

Origin of the X-ray flares, shallow decay phases, plateau, lack of jet break, etc

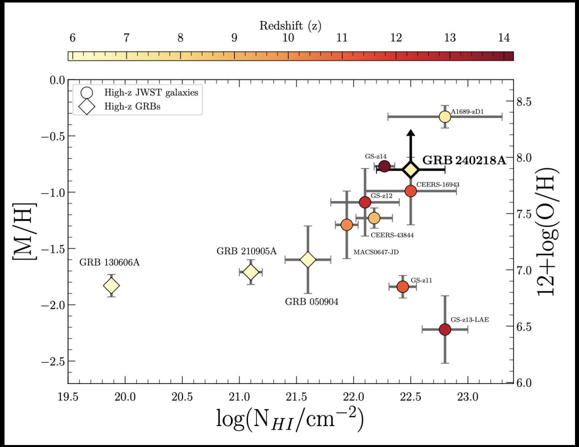
Cosmic evolution

High-redshift GRBs

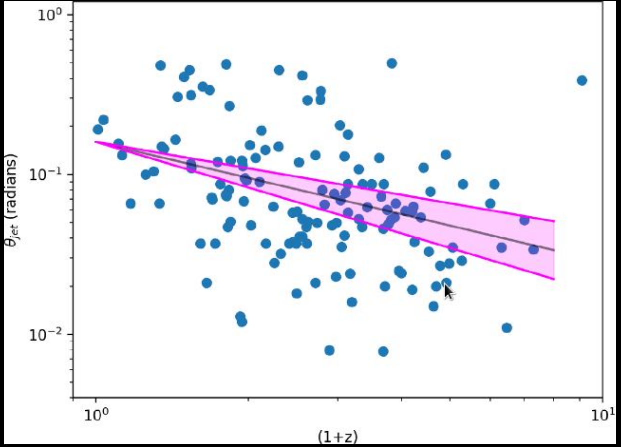
Probe the high redshift universe

- early star formation history
- Very first massive star explosions
- CSM at z > 6 → properties of the high-z star-forming galaxies

(increase only partially our understanding of GRBs…)



Saccardi+25



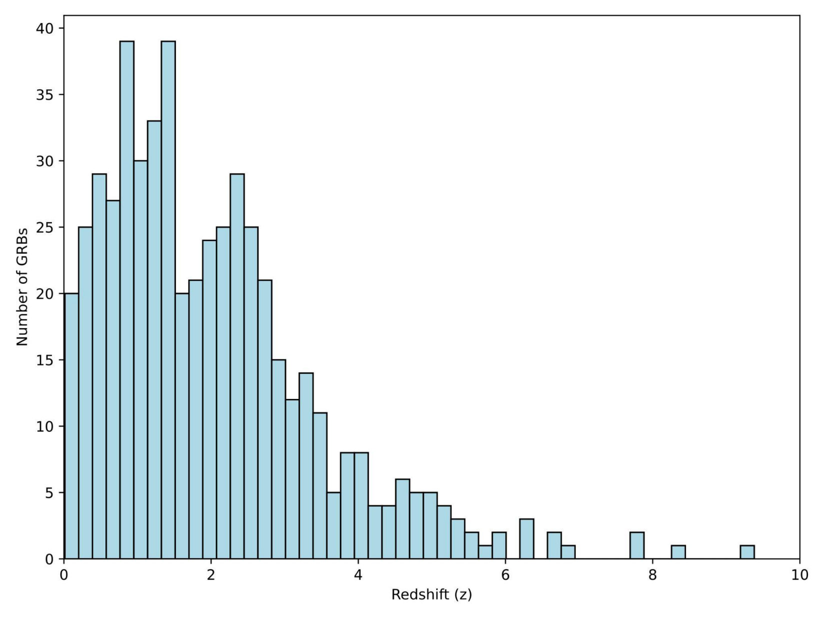
Lloyd-Rooning+19

High-z GRBs

Rates:

~ 0.5 yr^{-1} with Swift (10 in ~20 yrs)

~1 yr^{-1} for both SVOM and EP (assuming 30% of EP events have redshift determination) - e.g., *Wei & Wu (2025)* - see GRB 251403A observed by SVOM (*Cordier+25*)



Triggering criteria: spectroscopic identification of *z*>6 (~2% of the Swift LGRB population)/ *z*>7 (~1%) or secure photometric redshift (with <~10% uncertainty)

What worked well

- Plenty of observations for extraordinary events, followed by different groups independently.
- Alerts and the new and improved GCN system
- All data made public by Swift and Fermi
- Rapid ToO follow-up at many facilities (shoutout to Gemini)
- Automation of ToOs by Swift (without human intervention)

What could be improved

- Proposals for rare events (e.g., ultra-long GRB, nearby GRB-SNe) are sometimes not favored by TAC.
- A lack of ability to perform very rapid response observations, from both space (e.g., only one ultra-disruptive ToO per year for Hubble) and some ground observatories.
- A lack of existing database that stores all follow-up data (but IPN is funded by NASA and NSF to build this).
- On the NRAO side, all priority A proposals are scheduled first at the start of each semester, even for non–time-critical targets such as ~10-year-old supernovae.
- Lack of plans to develop next generation of US gamma-ray space observatories.

NASA

Key observatories that contribute to GRB science

Fermi, Swift, Konus-Wind gamma-ray detectors: GRB discovery, prompt emission studies

Swift: prompt X-ray, UV, and optical follow-up observations at early time

Chandra and XMM-Newton: X-ray localization, deep X-ray follow-up at >~ days

HST, JWST imaging: precise localization, host characterization, deep late OIR follow-up

JWST spectroscopy: IR spec of SNe, KNe, determine redshift

HST, UVEX: UV spectroscopy

ULTRASAT: UV discovery of low-luminosity GRB shock breakout

Others

Key observatories that contribute to GRB science

EP, SVOM: GRB (orphan, high-z) discovery, prompt emission studies

EP: prompt X-ray follow-up observations at early time

VLA and ALMA: radio localization, mm/radio afterglow observations at >~ days

Keck, VLT, Gemini spectroscopy: Optical/NIR spec of SNe, KNe, determine redshift

ZTF, LS4, LSST, etc: orphan afterglow discovery

LCO, LT etc: afterglow follow-up

Recommended Observing Timeline

T_0 + 0–1 hr

- Rapid-response triggers (γ-ray, X-ray)
- Continuous γ-ray/X-ray monitoring

T_0 + 1–24 hr

- Optical (including polarization) and X-ray imaging (≥2 epochs): localize afterglow, measure early decline
- UVOIR spectroscopy: determine redshift

T_0 + 1–7 days

- Multi-epoch X-ray/UV/optical/IR/radio coverage
- Cadence: 1/day

Recommended Observing Timeline

T_0 + 1 week–1 month

- SN peak expected
- Radio (including polarization), UVOIR, X-ray imaging follow-up
- If SN detected → trigger UVOIR spectroscopy to constrain SN type
- Cadence: every 4 days

T_0 + 1 month–years

- Radio follow-up (including VLBI if the source is close enough)
- Long-term X-ray/UVOIR/radio monitoring
- Cadence: $\Delta \log t \approx 0.3$ dex (until undetectable)

New facilities coming online that will improve follow-up

1) UVEX: UV spectroscopy
2) ULTRASAT: early orphan afterglow discovery
3) LSST: afterglow (discovery and) continued photometry

Discussion points

1) Prioritize which source classes?

   Those with well-defined triggering criteria. (GW GRB, ultra-long GRB, high-z GRB?)

2) What observations are needed? (energies / wavelengths / filters / bands, instrument modes, observing setup(s), types of calibrations, cadence across facilities, allowed tolerance for each of these, types of coordination needed)
3) A relevant rate
4) An associated science case