

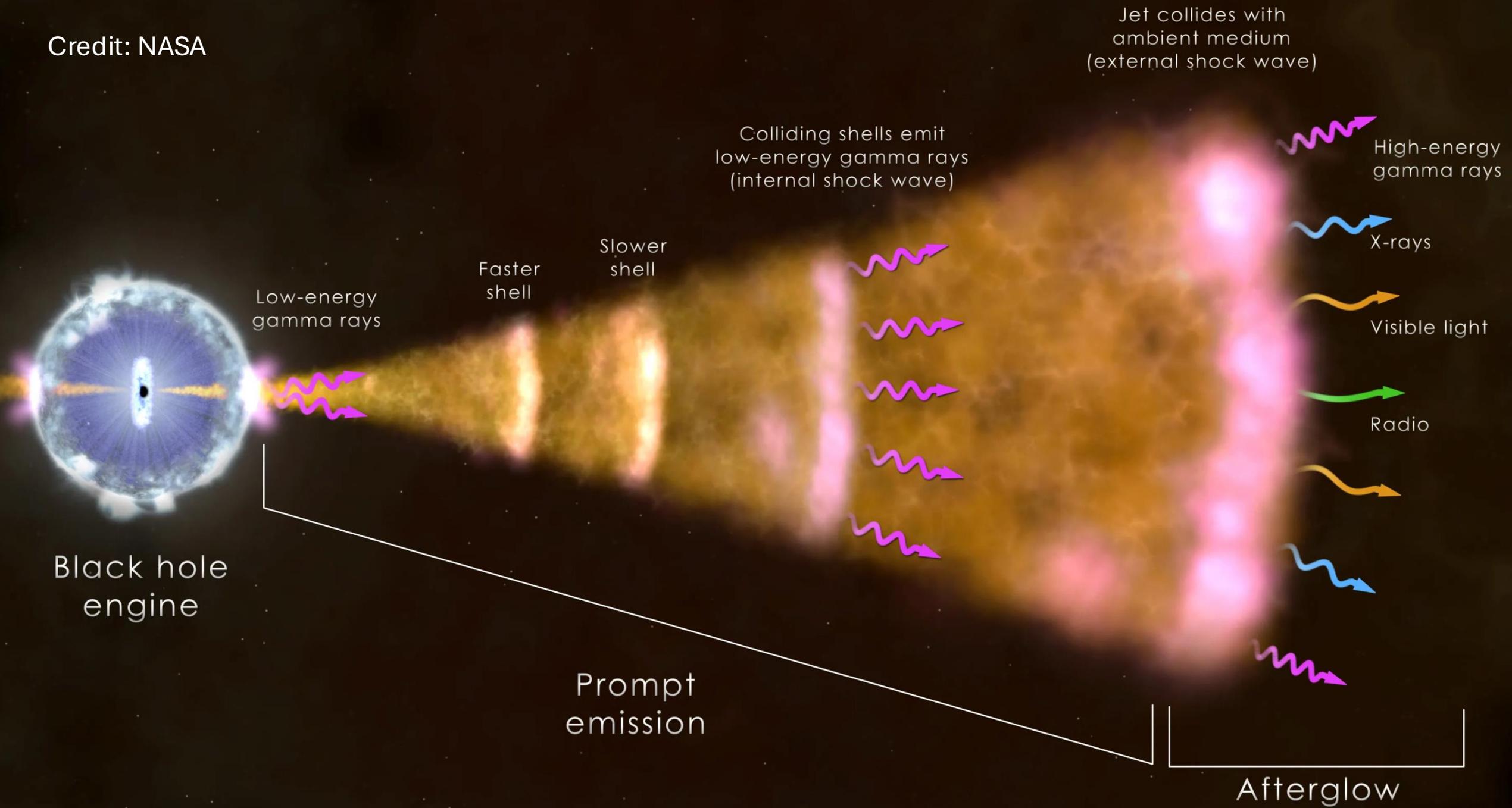
The Current State of Gamma-ray Burst Astronomy

Brendan O'Connor

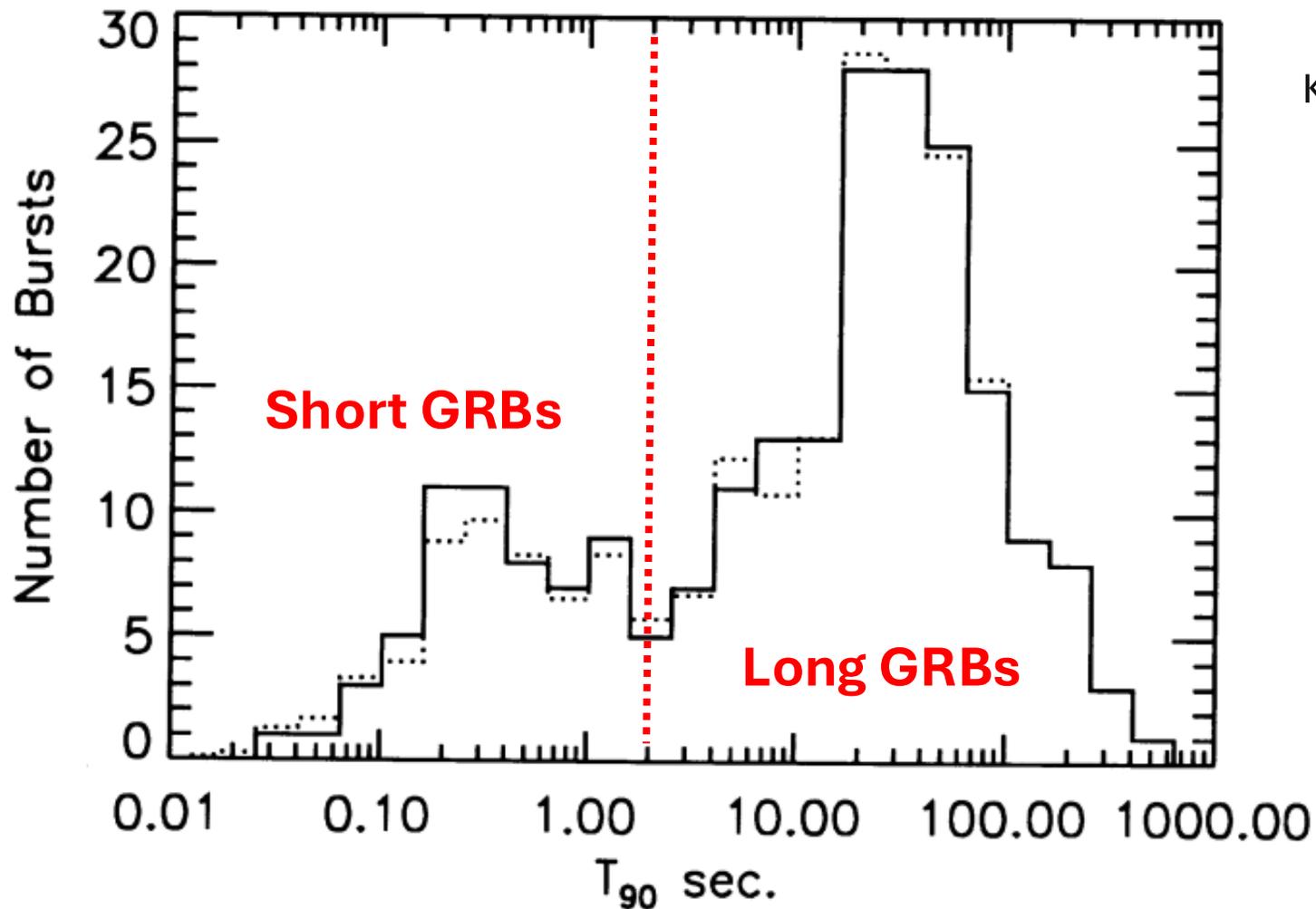
McWilliams Center for Cosmology and Astrophysics

Carnegie Mellon University

Credit: NASA



Classification: Short GRBs versus Long GRBs



Kouveliotou et al. 1993

- “short” vs “long” separation at 2 seconds
- But depends on instrument and observed bandpass (e.g., Bromberg et al. 2013)

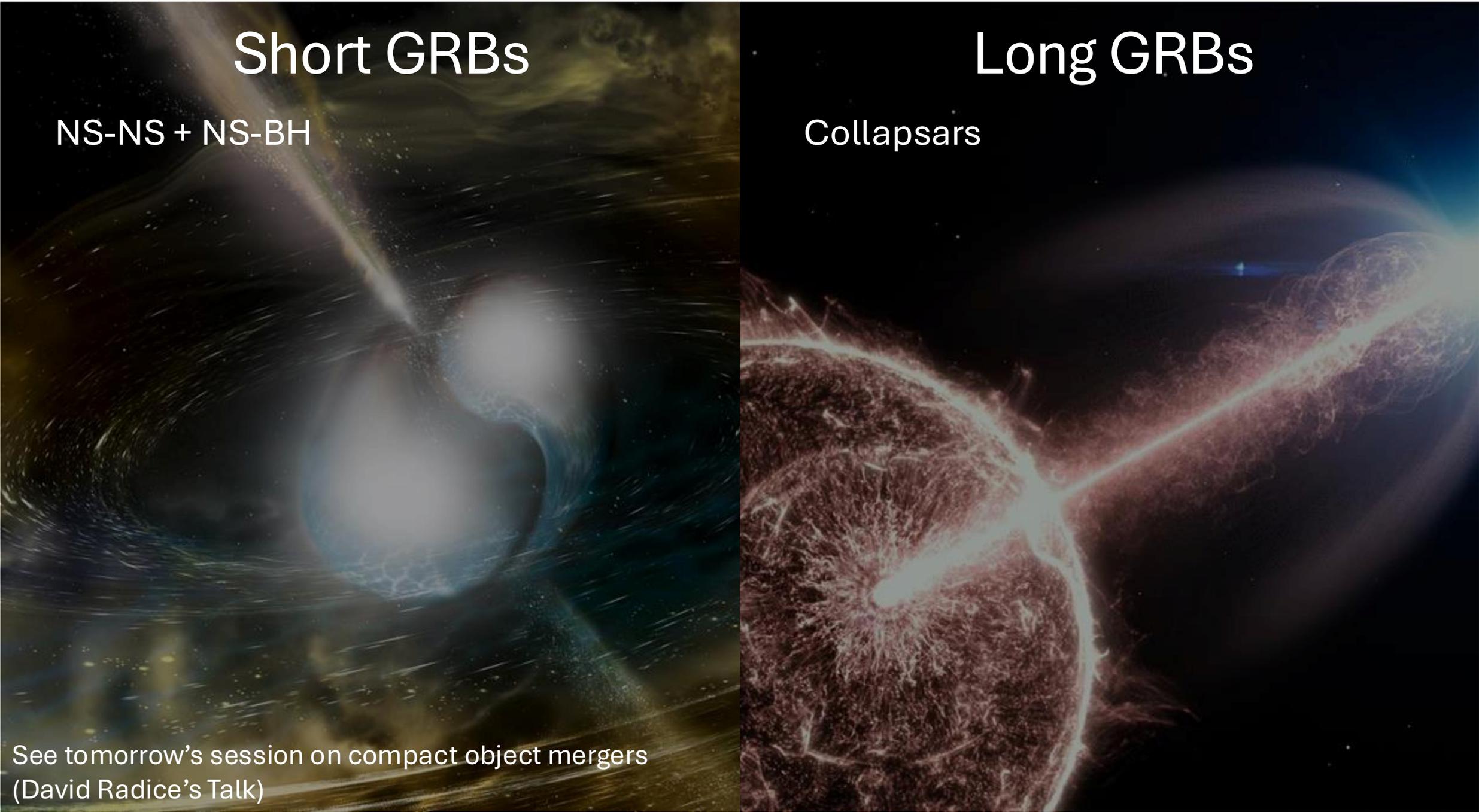
Short GRBs

NS-NS + NS-BH

Long GRBs

Collapsars

See tomorrow's session on compact object mergers
(David Radice's Talk)



Short GRBs

NS-NS + NS-BH + Collapsars +
Magnetars + ???

Long GRBs

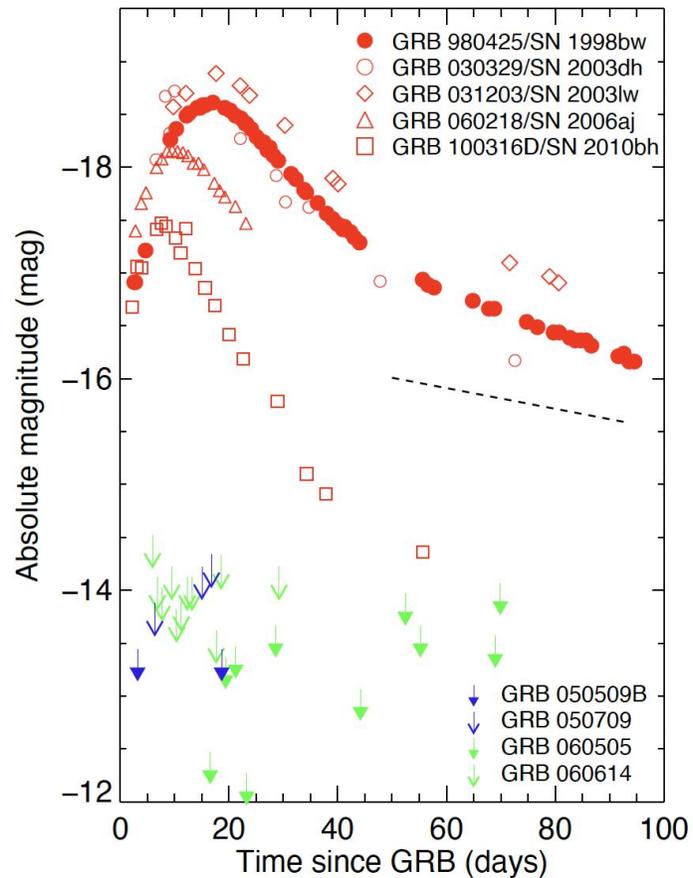
Collapsars + NS-BH + NS-NS + NS-WD +
WD-WD + WD-BH + IMBH-WD + HeC-BH
+ AIC WD + ???

**The true picture is much more complex!
The single duration divide is not robust.**

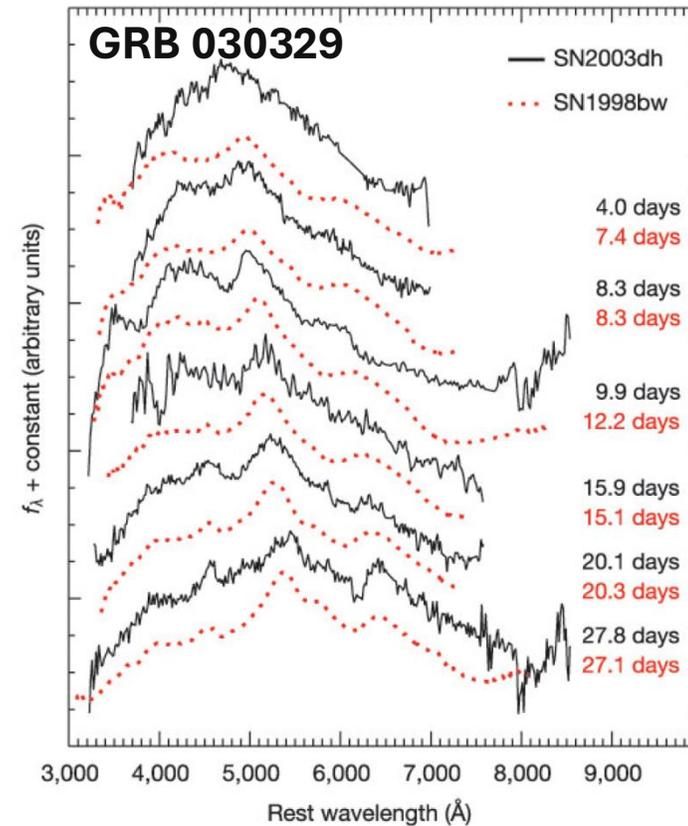
See tomorrow's session on compact object mergers
(David Radice's Talk)

Long GRB Supernova Connection

- Type Ic-BL – e.g, SN1998bw (Galama et al. 1998)
- No correlation with gamma-ray energy over 7 orders of magnitude



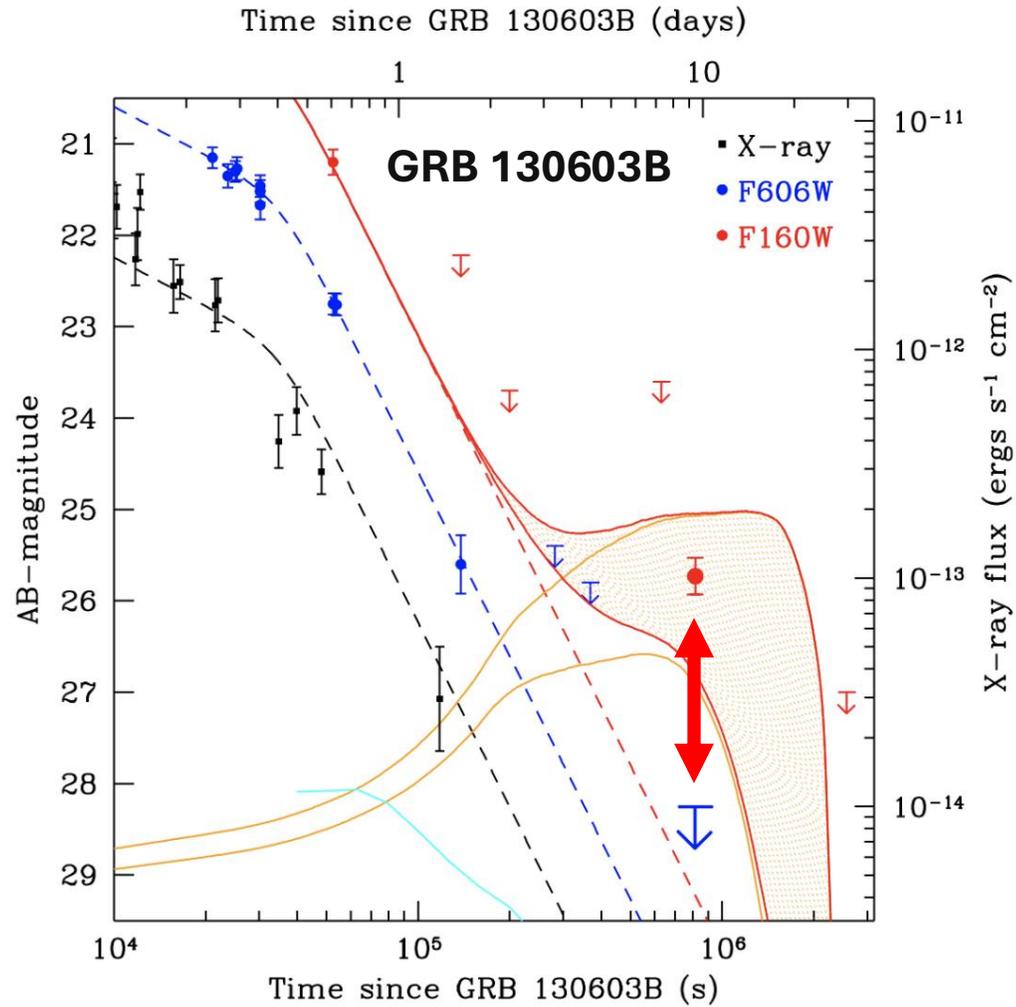
Hjorth & Bloom 2012



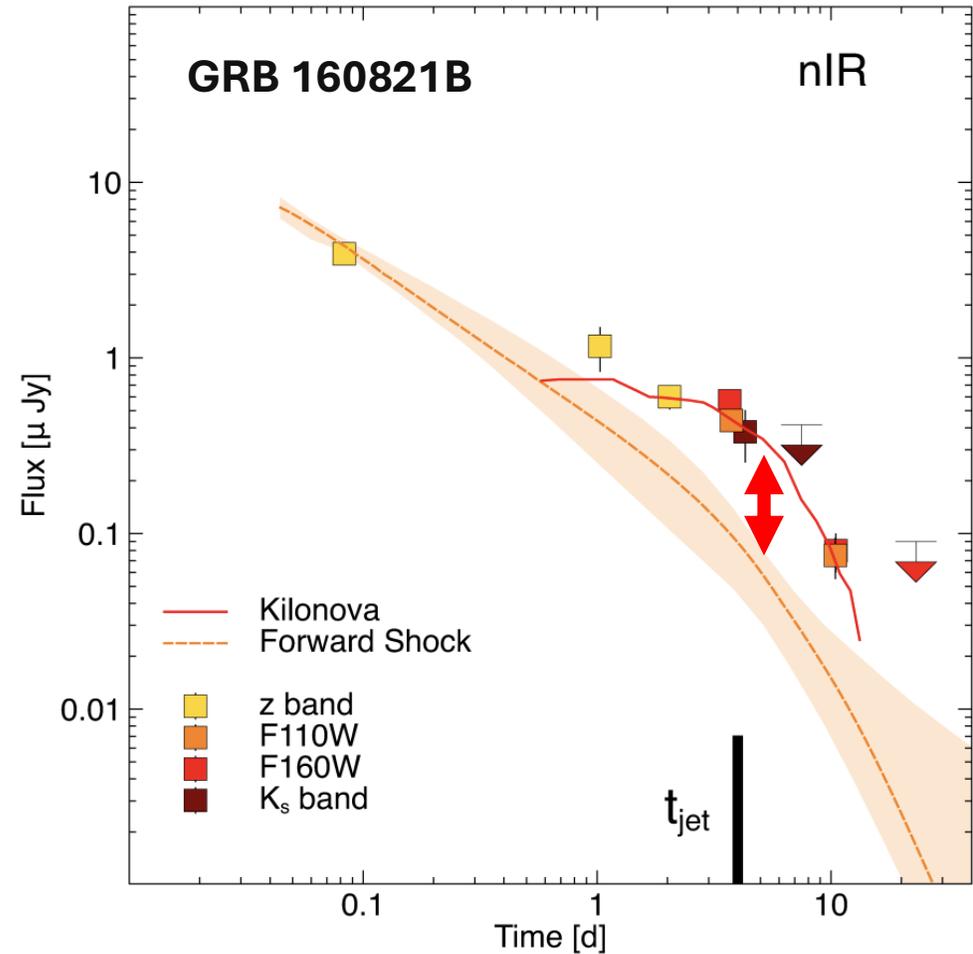
Hjorth et al. 2003

Short GRB Kilonova Connection

See also David Radice's talk



Tanvir et al. 2013
Berger et al. 2013

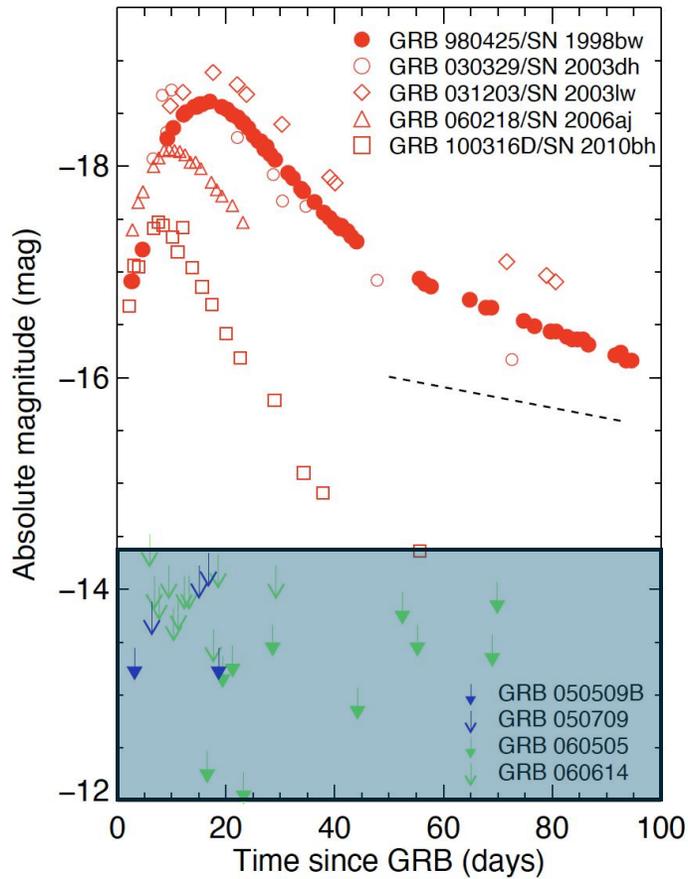


Troja et al. 2019
Kasliwal et al. 2017; Lamb et al. 2019

Long GRB Kilonova Connection

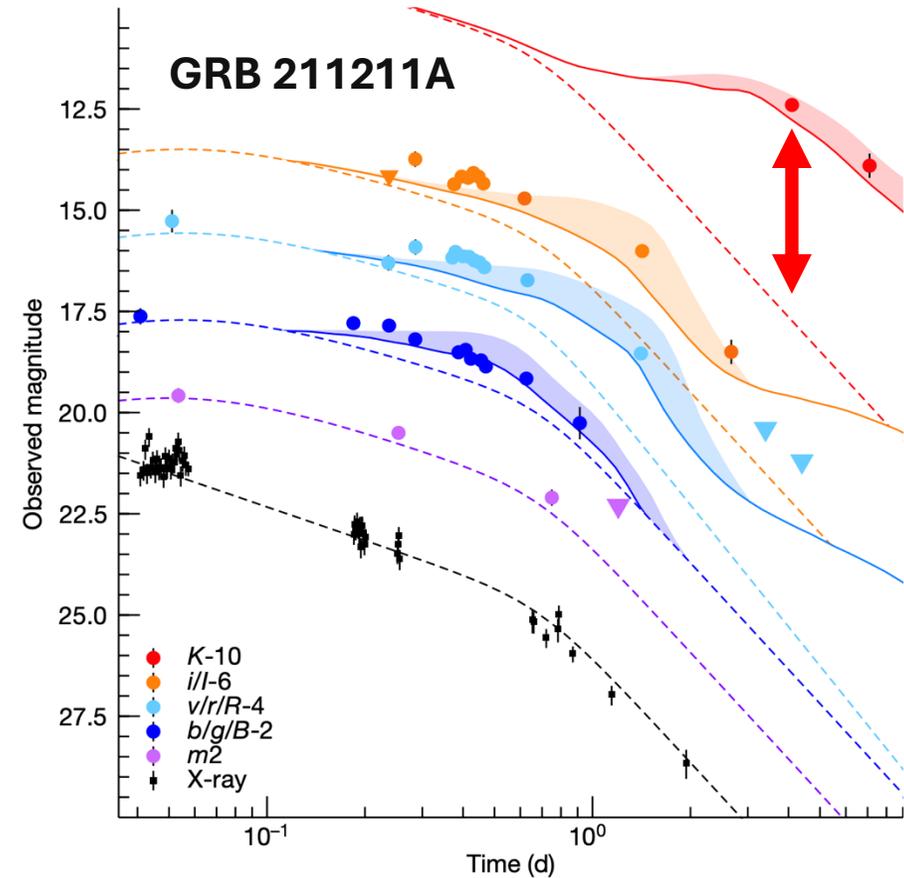
See also David Radice's talk

Long & Short GRBs with no SN



Hjorth & Bloom 2012

Long GRBs with KN



Troja, Fryer, O'Connor et al. 2022 – GRB 211211A

Yang, Troja, O'Connor et al. 2024 – GRB 230307A

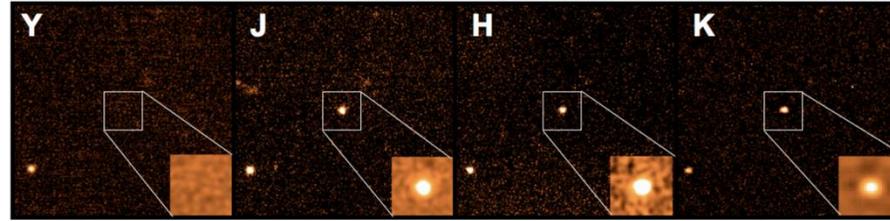
(see also Rastinejad et al. 2022; Levan et al. 2023)

High Redshift GRBs

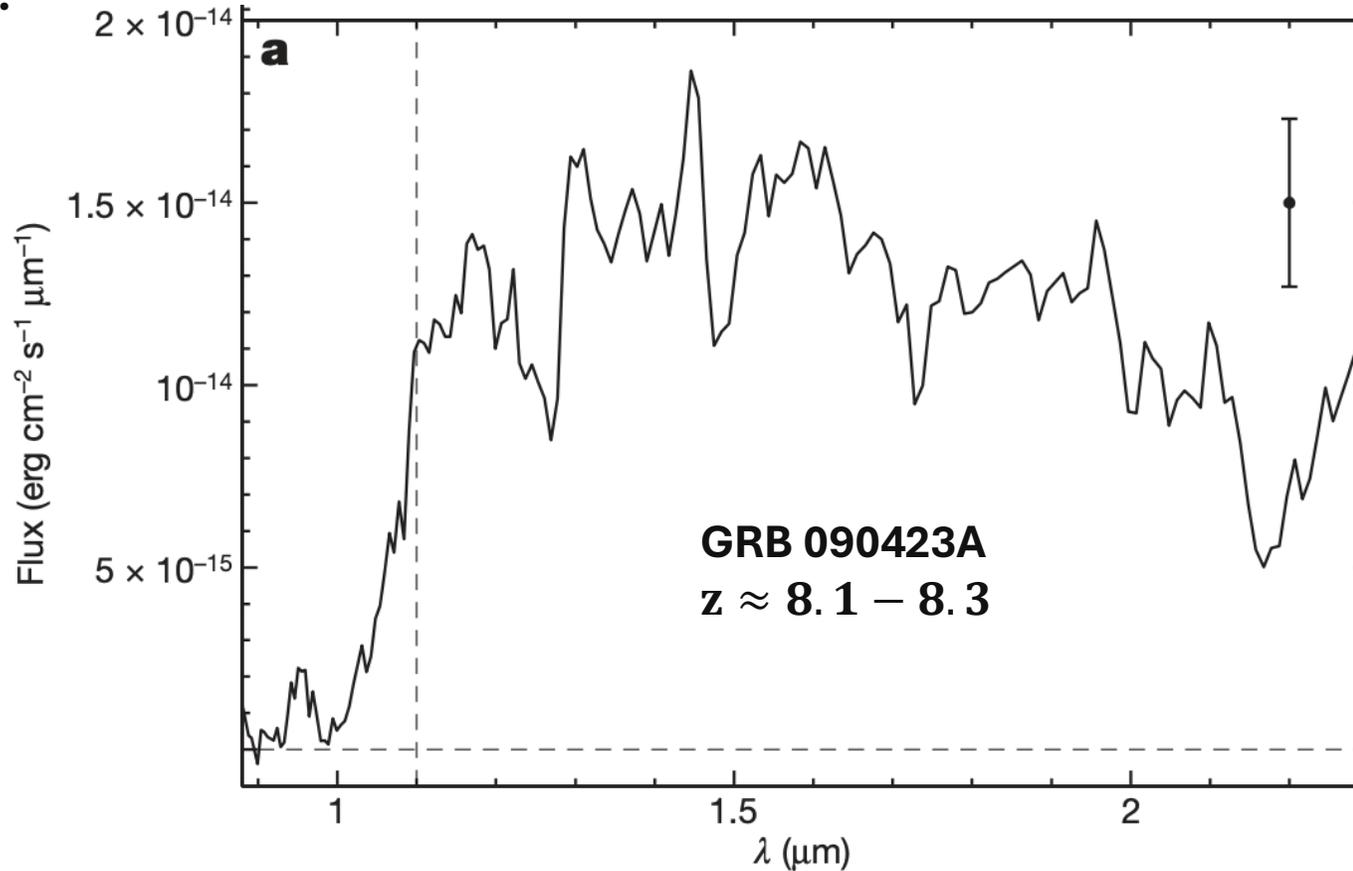
Less than 1 Gyr after Big Bang!

Detected during the Epoch of Reionization

Neutral hydrogen fraction, UV
escape fraction, metallicity of
ISM/IGM, Pop III stars?



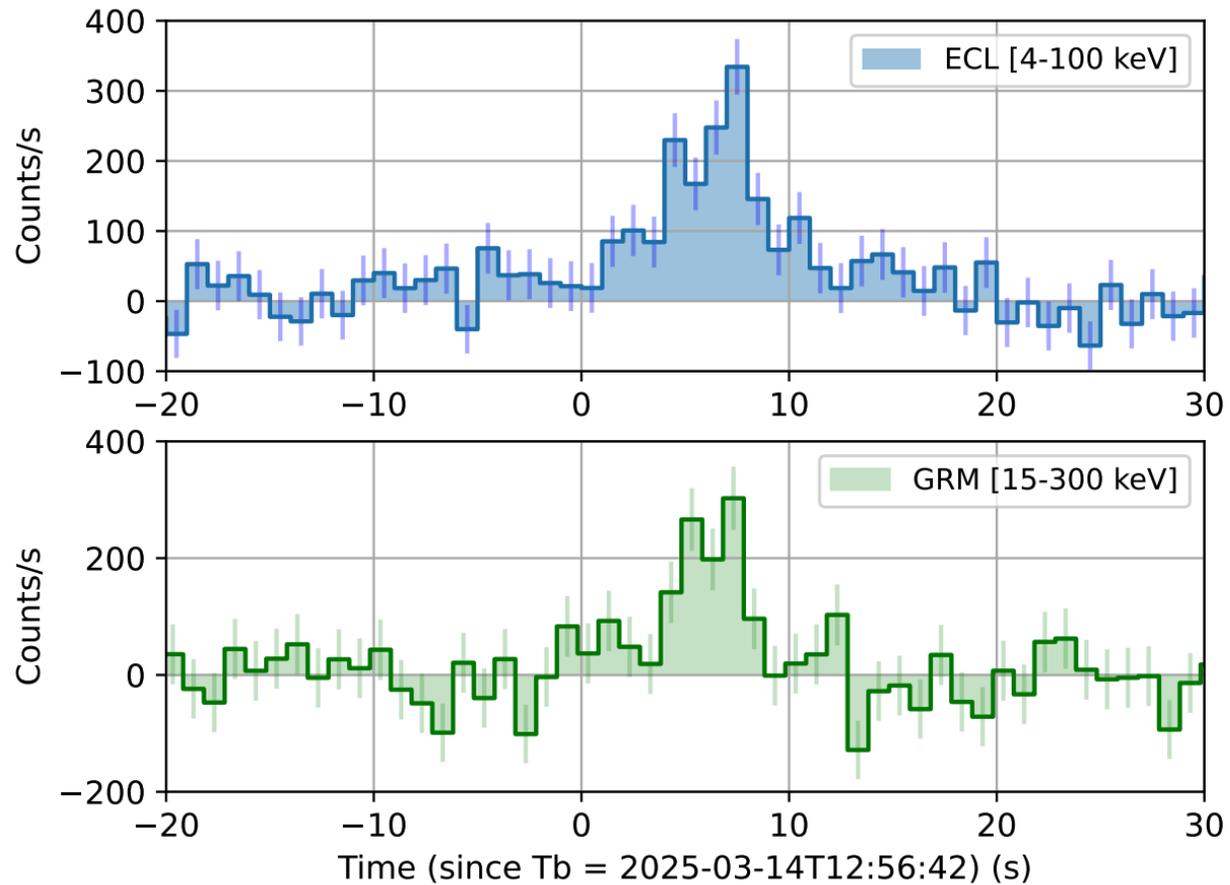
Salvaterra et al. 2009
Tanvir et al. 2009



12 GRBs have been uncovered at $z > 6$ in the last 20 years
SVOM/EP may increase this rate!
(and in the future, THESEUS)

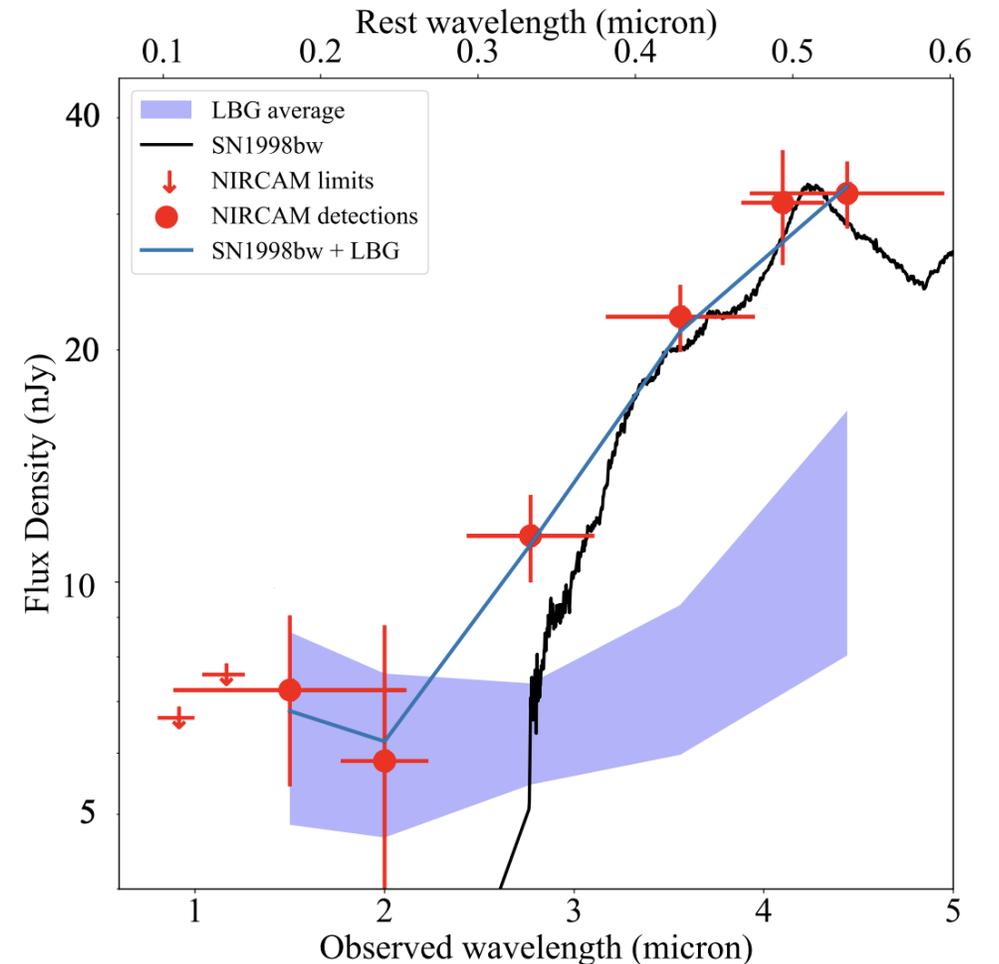
SVOM GRB 250314A at $z \approx 7.3$

Rapid near-infrared imaging and spectra are required to find these GRBs!



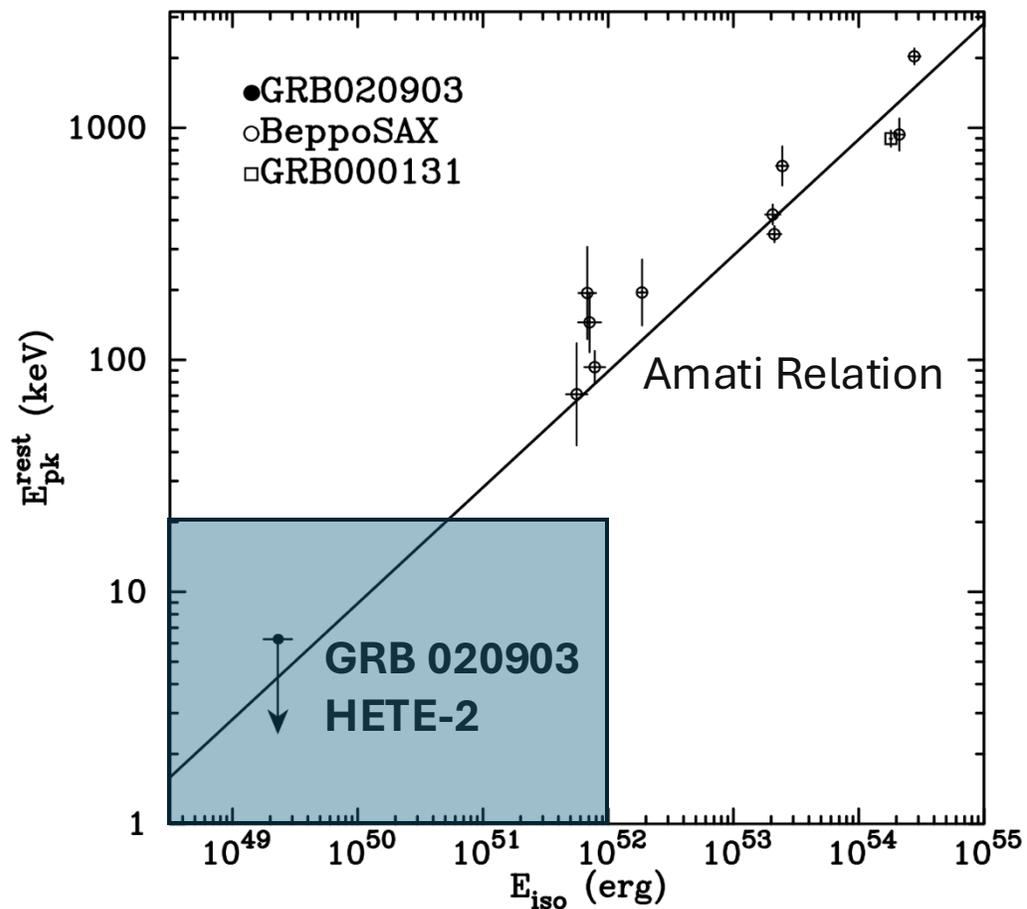
Cordier et al. 2025

The highest redshift supernova?



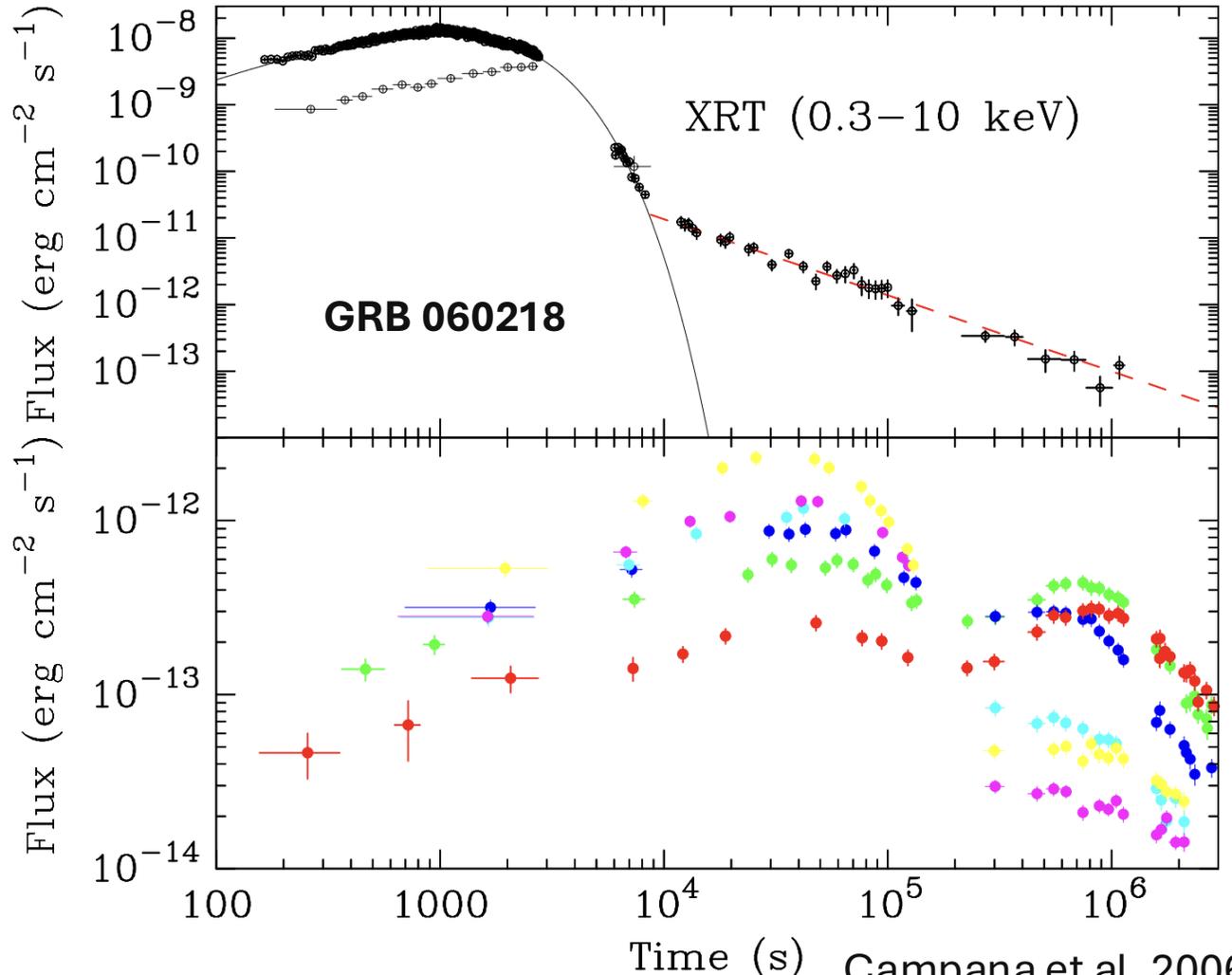
Levan et al. 2025

X-ray Flashes (XRFs)



Sakamoto et al. 2004
 Amati et al. 2002

**Low luminosity GRBs and XRFs
 dominate the volumetric rate of events**



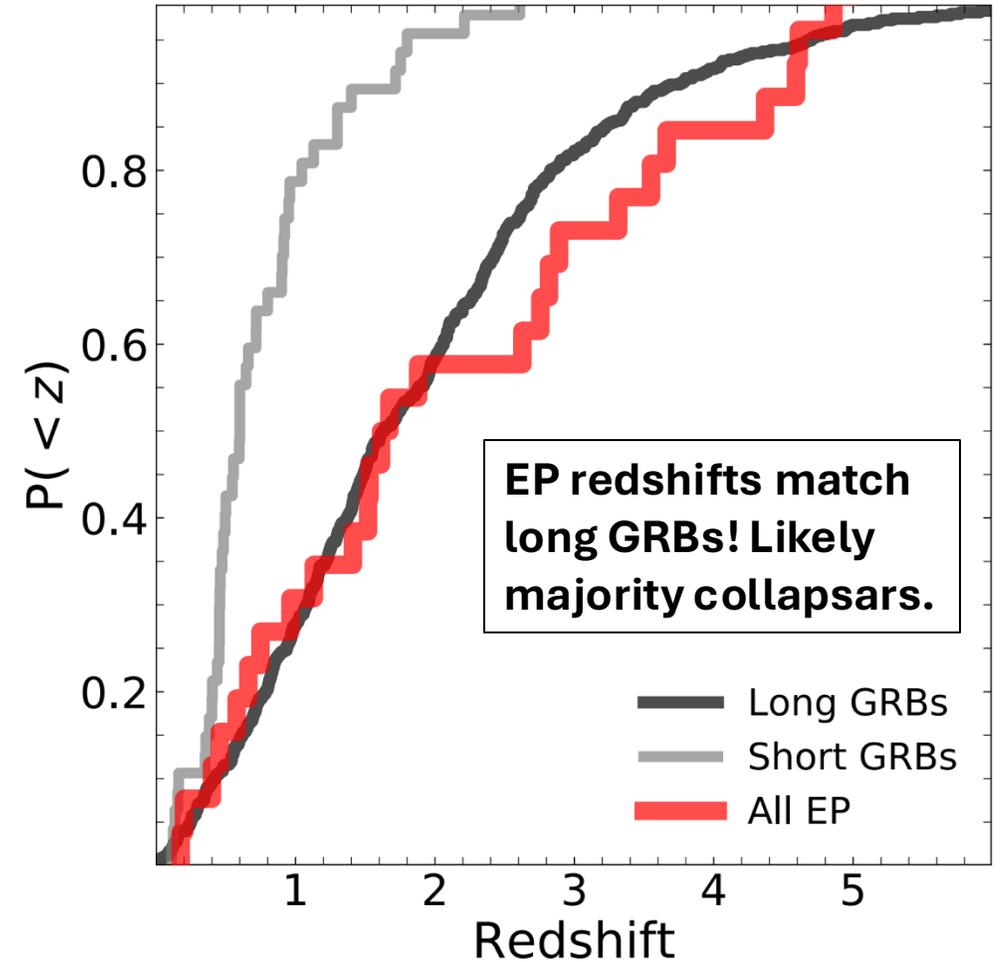
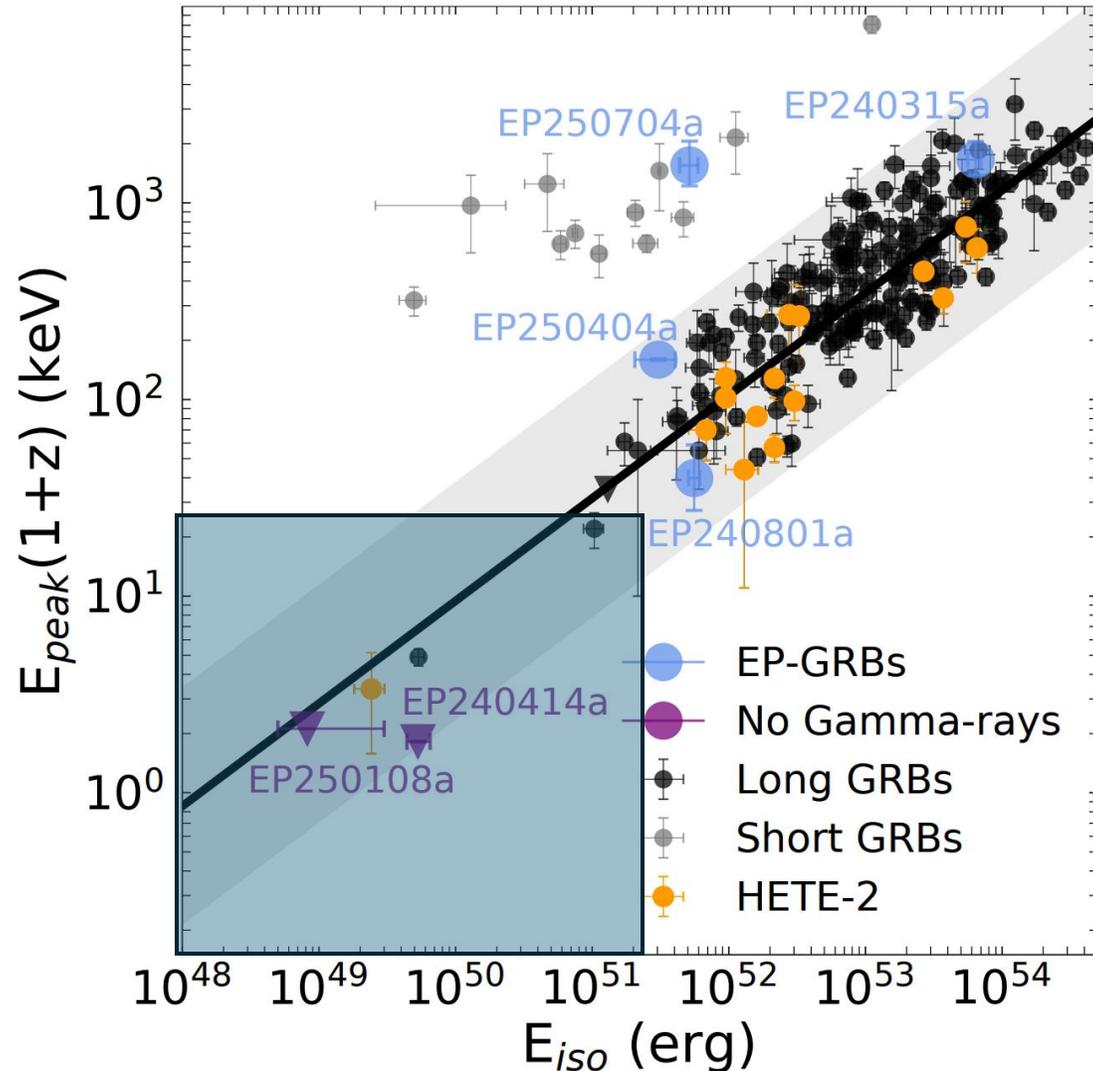
Campana et al. 2006
 Soderberg et al. 2006
 Pian et al. 2006

Einstein Probe Comes on the Scene...

Yuan et al. 2022, 2024, 2025

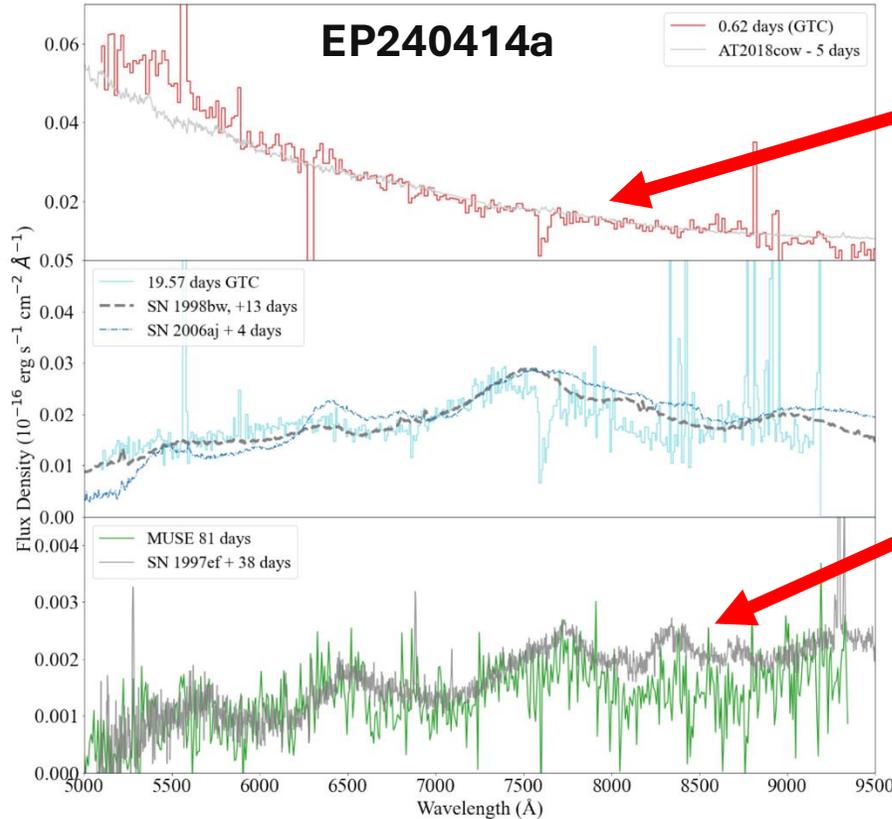


Most EP Fast X-ray Transients (FXTs) have no gamma-rays



FXTs/XRFs with Supernovae

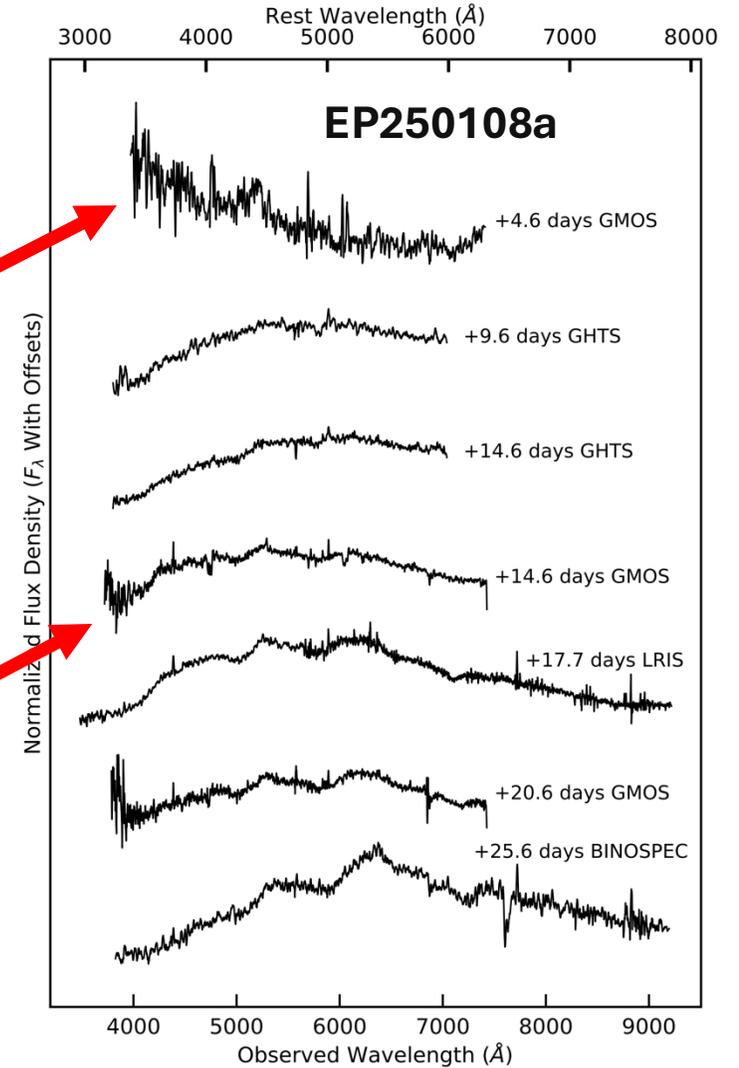
**Nature of early optical decay:
Cocoons? Different progenitors?
Extended stellar envelopes?**



Early blue
excess

Typical
supernova

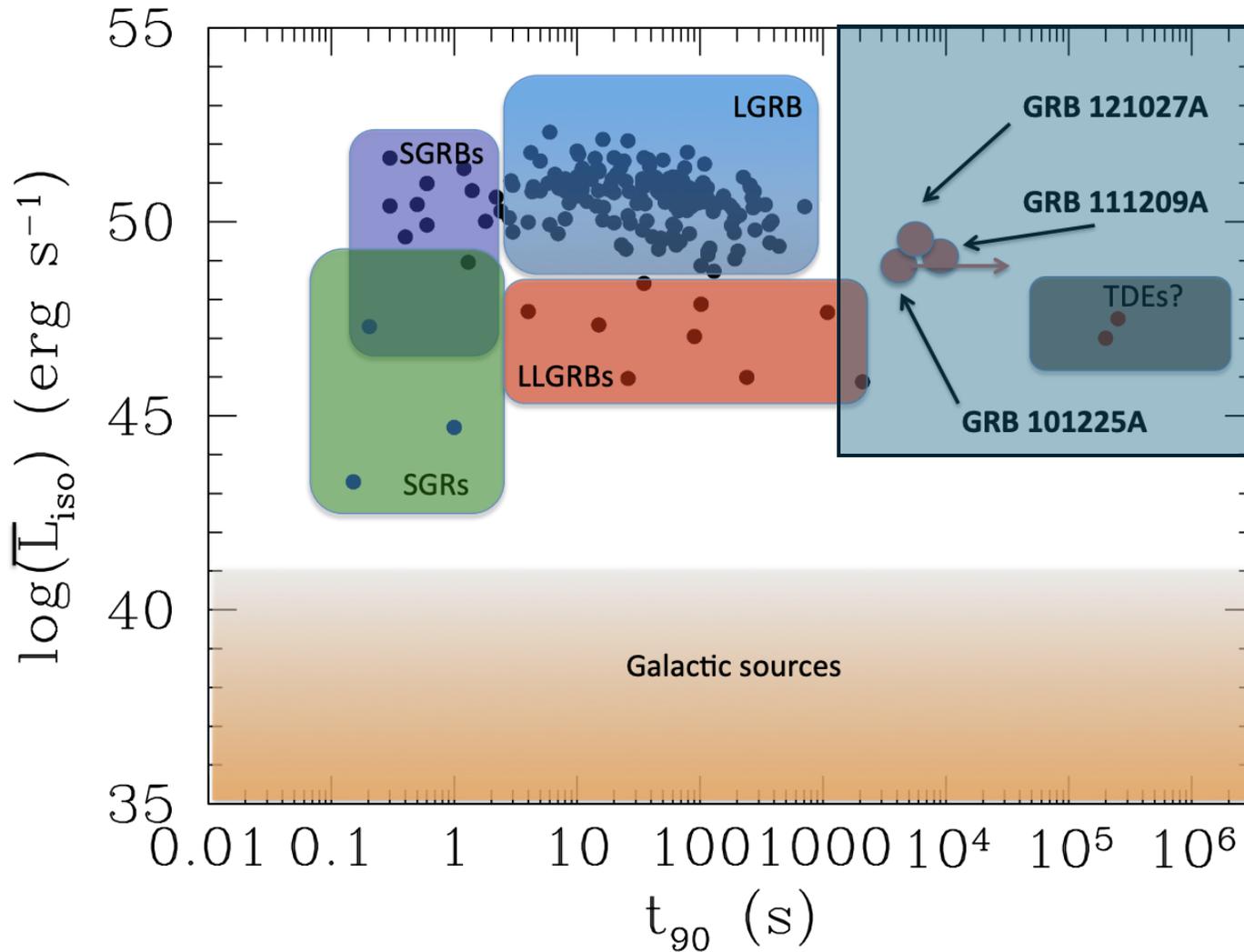
No Gamma-rays Detected



Van Dalen et al. 2024
Srivastav et al. 2024
Sun et al. 2025

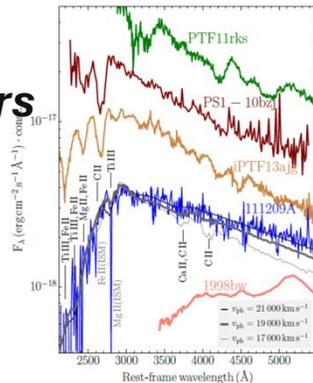
Srinivasaragavan et al. 2025
Rastinejad et al. 2025
Eyles-Ferris et al. 2025
Li et al. 2025

What is the Nature of Ultra-long GRBs?



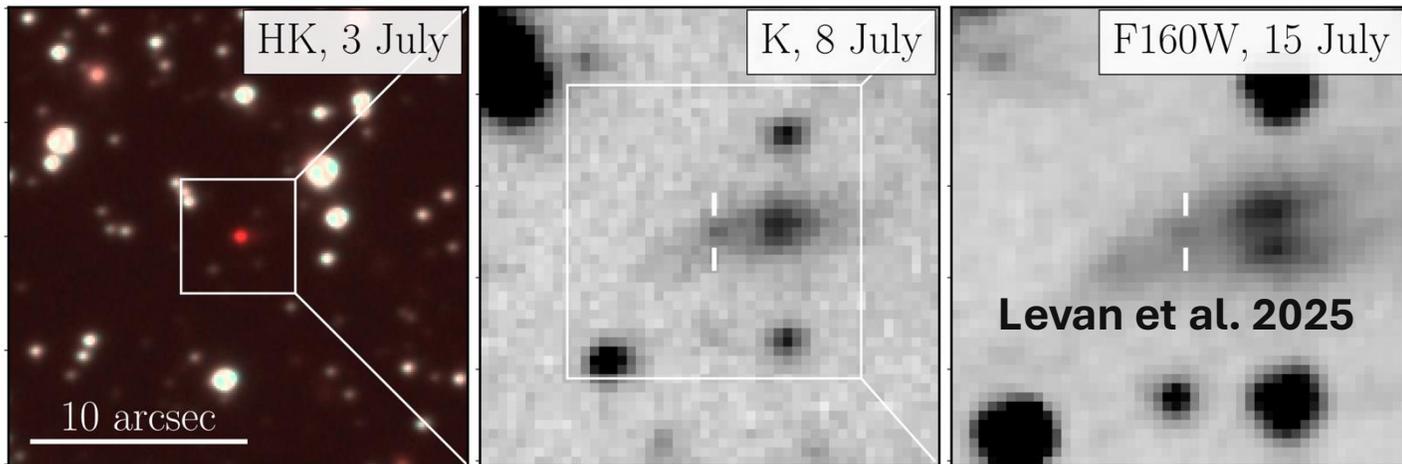
Levan et al. 2014

- Selection effects?
 - Gamma-ray telescopes are not designed to detect these ultra-long events
 - Requires interconnection, e.g., IPN
- How do their progenitors differ?
 - *Blue supergiant collapsars?*
 - *Extended stellar envelopes/CSM?*
 - *Magnetars?*
 - *Helium core (HeC) – BH mergers?*
 - *Micro-TDEs?*
 - *IMBH-WD TDEs?*
 - *Etc?*
- **At least some are collapsars (Greiner et al. 2015)**



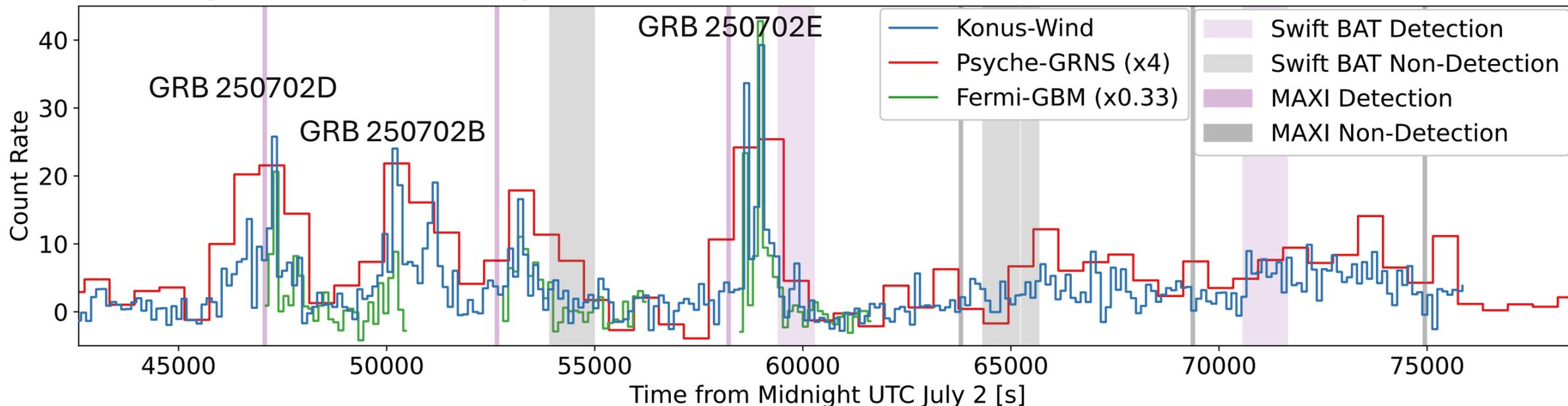
GRB 250702B ($z \approx 1.036$)

The Longest of All Time! (*LOAT?*)

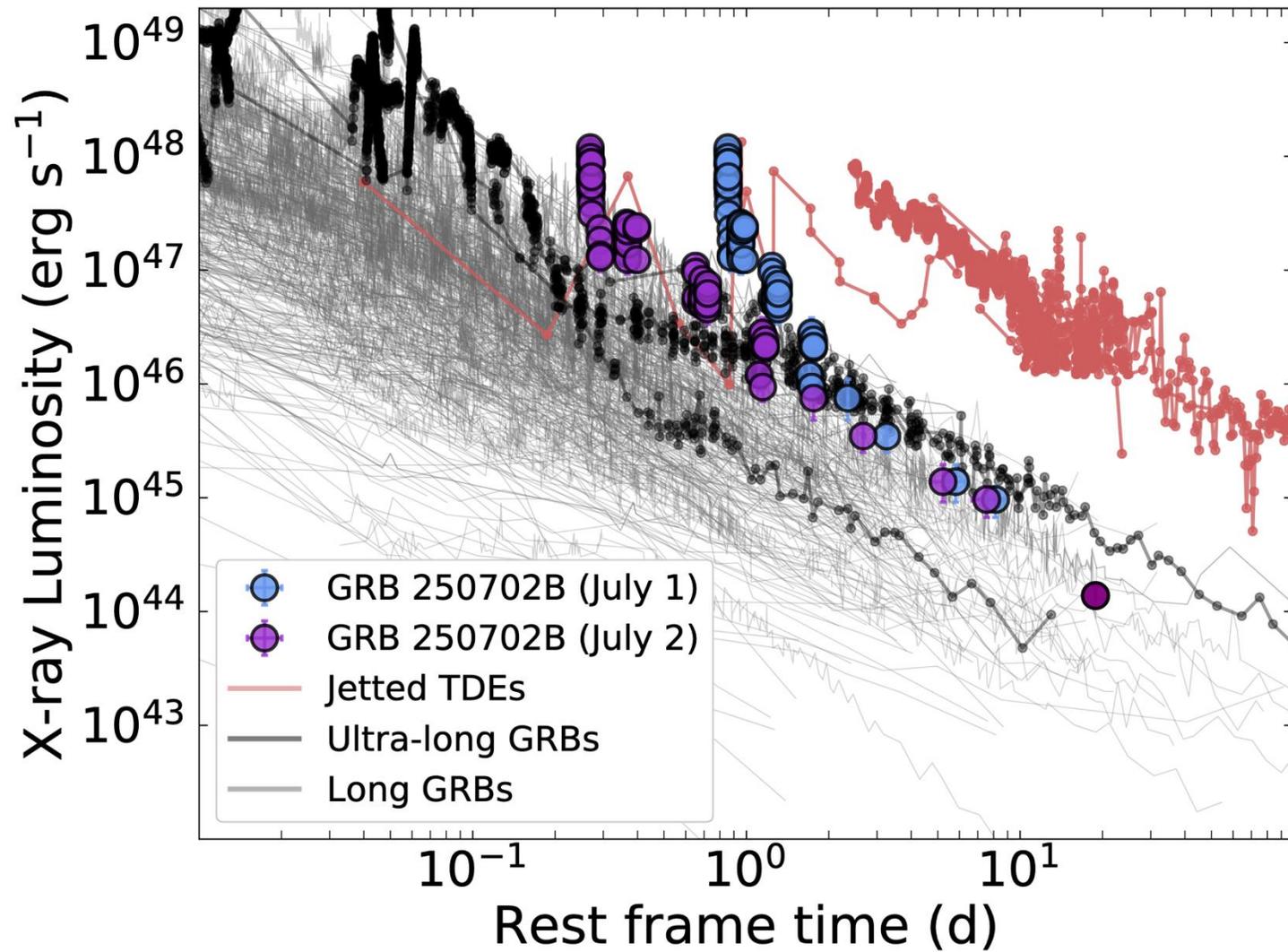


- **Multiple gamma-ray triggers**
- **25 ks gamma-ray emission (Neights et al. 2025)**
- **Short ~ 1 s minimum variability timescale**
- **Early EP X-ray detection ~ 1 day before the first GRB trigger (Li et al. 2025)**

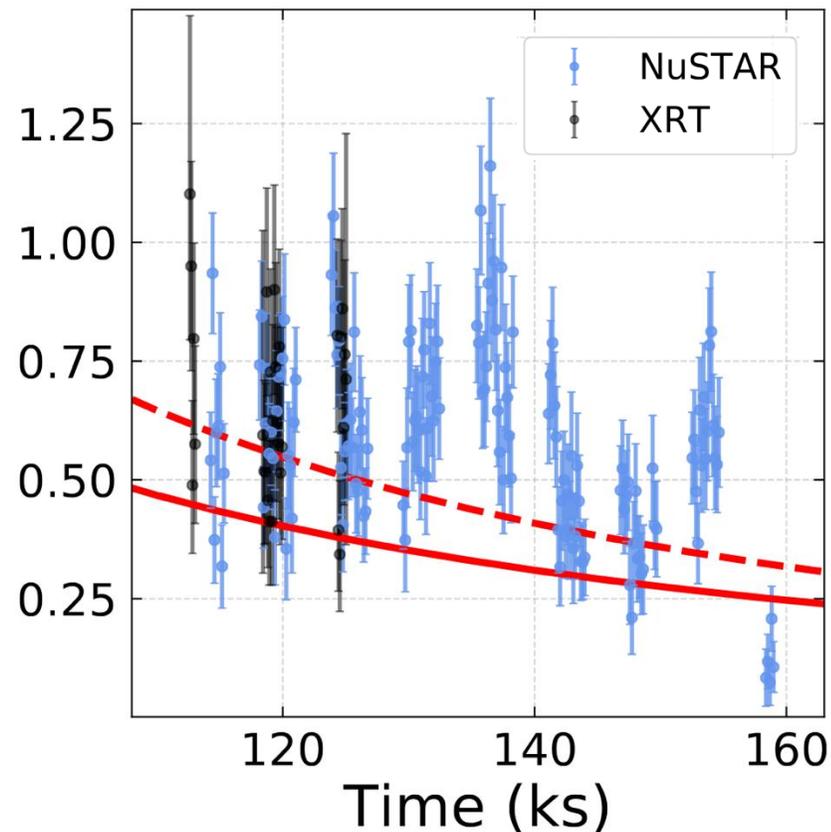
See also Gompertz et al. 2025; Carney et al. 2025



GRB 250702B X-ray Properties



Short timescale flaring requires an internal dissipation process and prolonged central engine activity



A New GRB Progenitor?

HeC-BH merger? (Neights et al. 2025)

Micro-TDE? (Beniamini et al. 2025)

IMBH TDE? (Li et al. 2025; Levan et al. 2025)

Additional Topics

VHE/TeV GRBs

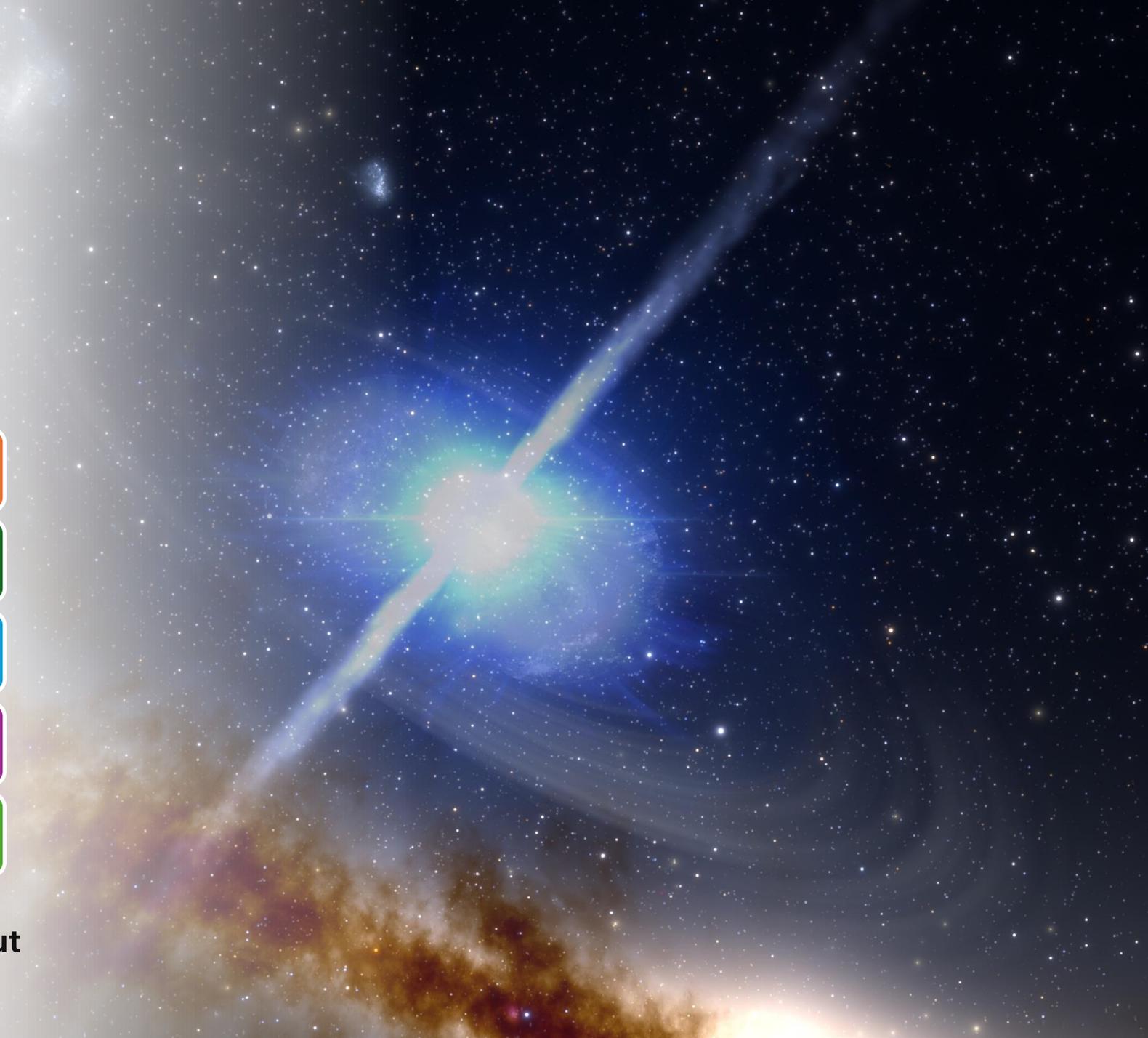
Orphan afterglows

Dirty Fireballs

Off-axis jets and jet structure

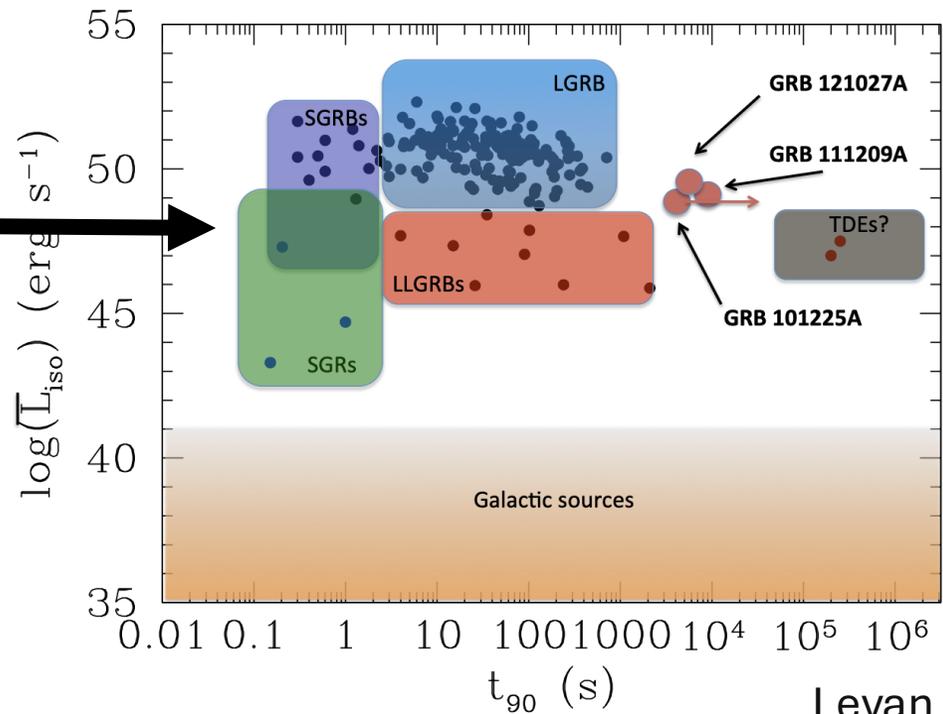
R-process Supernovae

Likely more is missing so please point it out during the discussion...

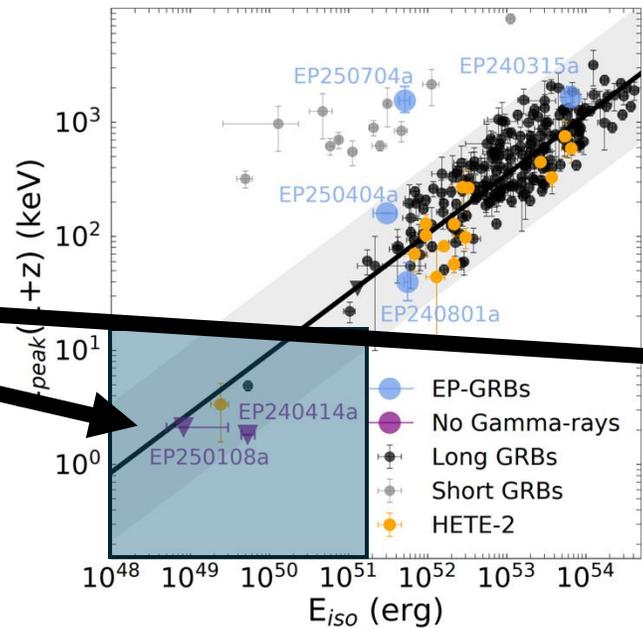


Major Open Questions

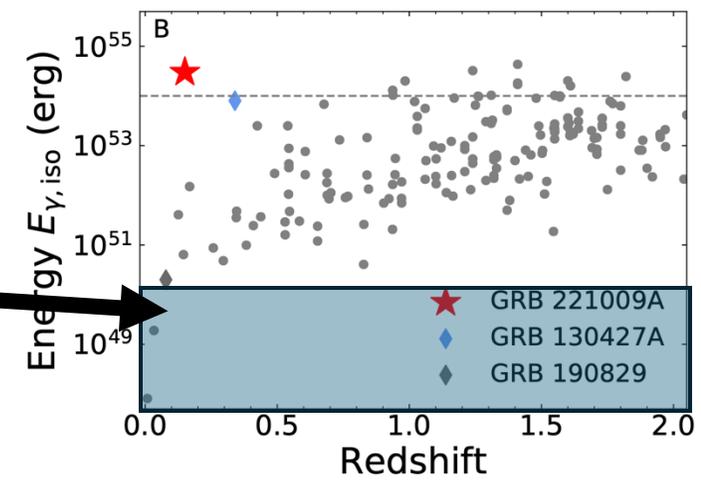
- Diversity of Progenitors?
- Improved GRB classification?
 - Long vs Short is overly simplified...
- Central engine: BH or Magnetar?
- Earliest GRB progenitors (Pop III?) at $z > 5$
 - Are their supernovae different?
- Where are the orphan afterglows, dirty fireballs, and failed jets? (EP/Rubin?)
- Connection between EP FXTs and “classical” (XMM/Chandra) FXTs?



Levan et al. 2014



O'Connor et al. 2025a



O'Connor et al. 2023

A cosmic scene featuring a bright blue light source on the right, emitting a powerful beam of light that illuminates two glowing, orange, fibrous structures on the left. The background is a dark, starry space. The text "Thank you!" is centered in the image.

Thank you!

The background of the slide is a deep space scene. It features a dense field of stars of various colors, including white, yellow, and blue. A prominent blue nebula with a bright central core is visible in the upper right quadrant. In the lower left, there is a large, diffuse cloud of brownish dust and gas, likely a protoplanetary disk or a similar interstellar structure. The overall color palette is dominated by dark blues, blacks, and the warm tones of the dust cloud.

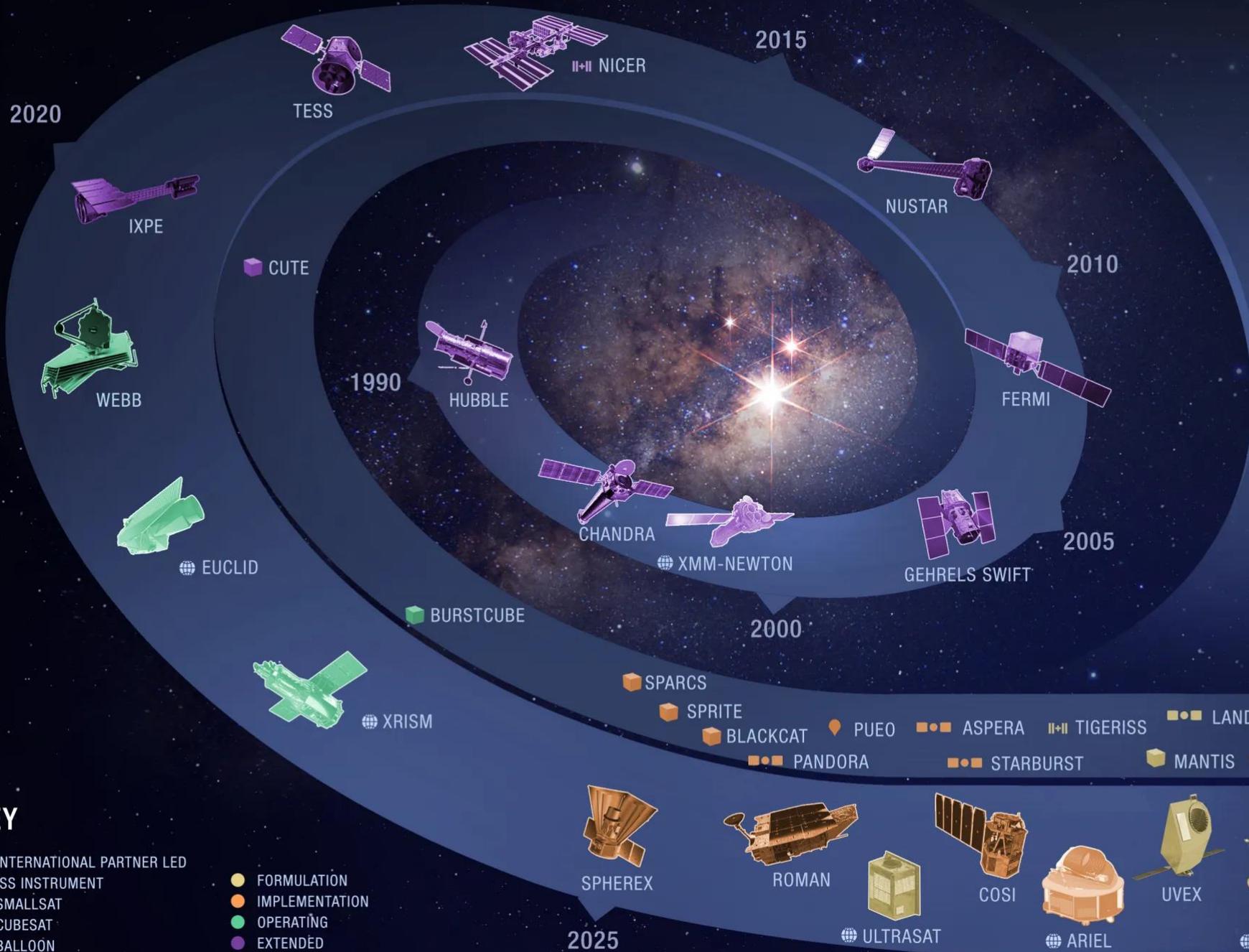
Backup Slides



ASTROPHYSICS FLEET

PRE-FORMULATION

PROBE ~2030
ATHENA EARLY 2030s



KEY

- INTERNATIONAL PARTNER LED
- ISS INSTRUMENT
- SMALLSAT
- CUBESAT
- BALLOON

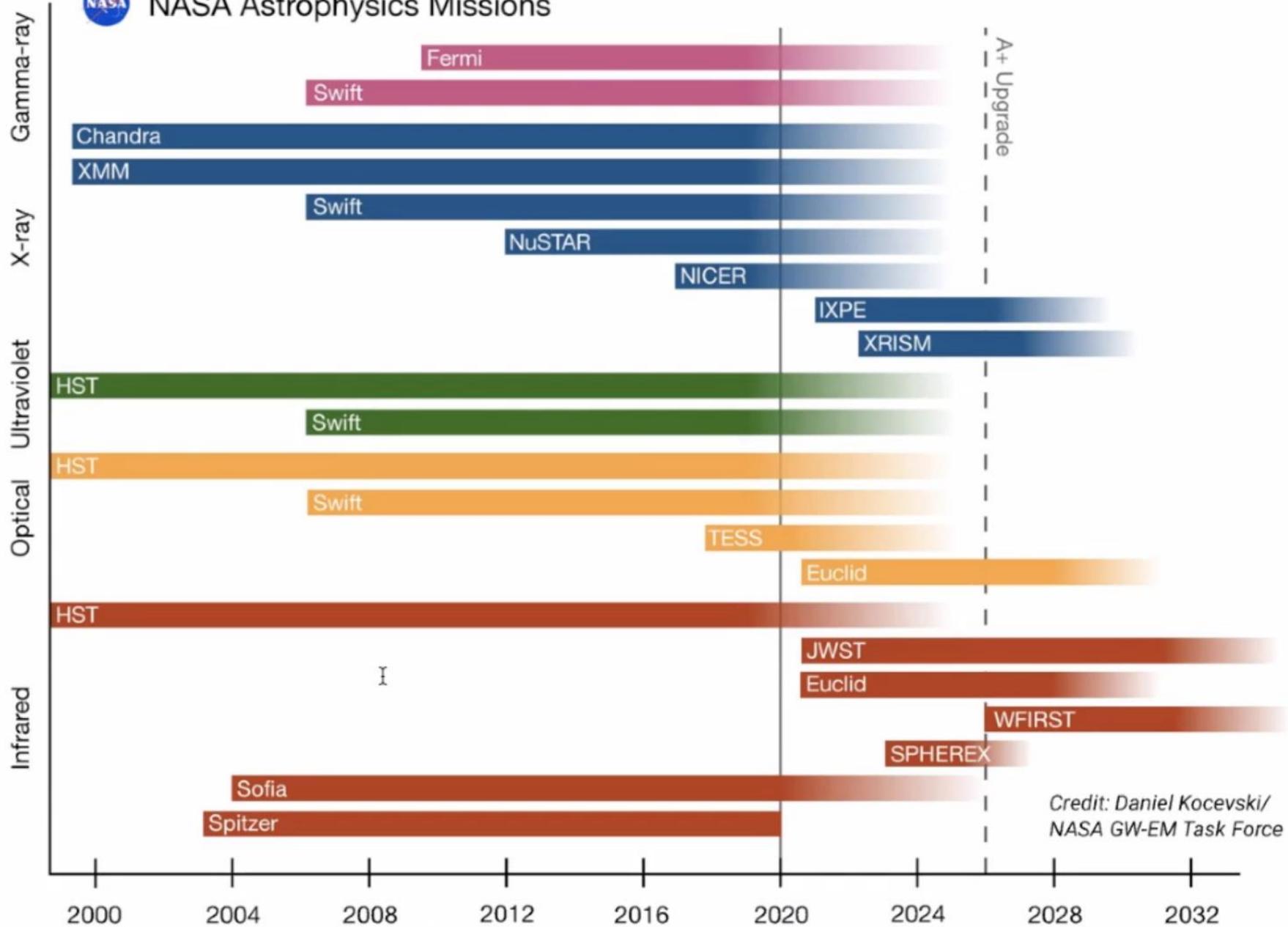
- FORMULATION
- IMPLEMENTATION
- OPERATING
- EXTENDED

- SPARCS
- SPRITE
- BLACKCAT
- PANDORA
- PUEO
- ASPERA
- TIGERISS
- LANDOLT
- STARBURST
- MANTIS
- POEMM





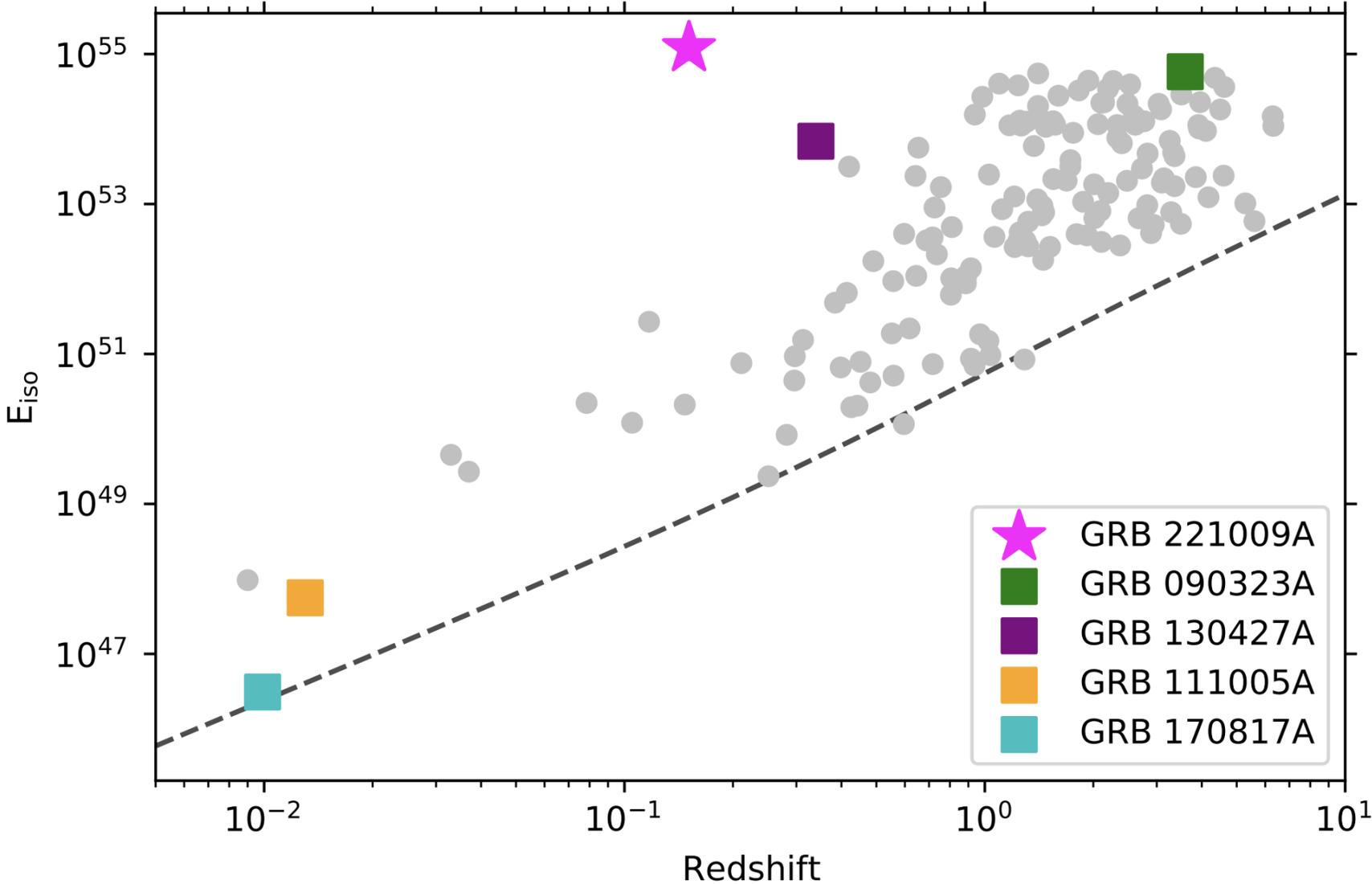
NASA Astrophysics Missions



Credit: Daniel Kocevski/
NASA GW-EM Task Force

GRBs are detectable over extreme distances!

GRBs are detectable out to $z \approx 9$ and potentially higher!

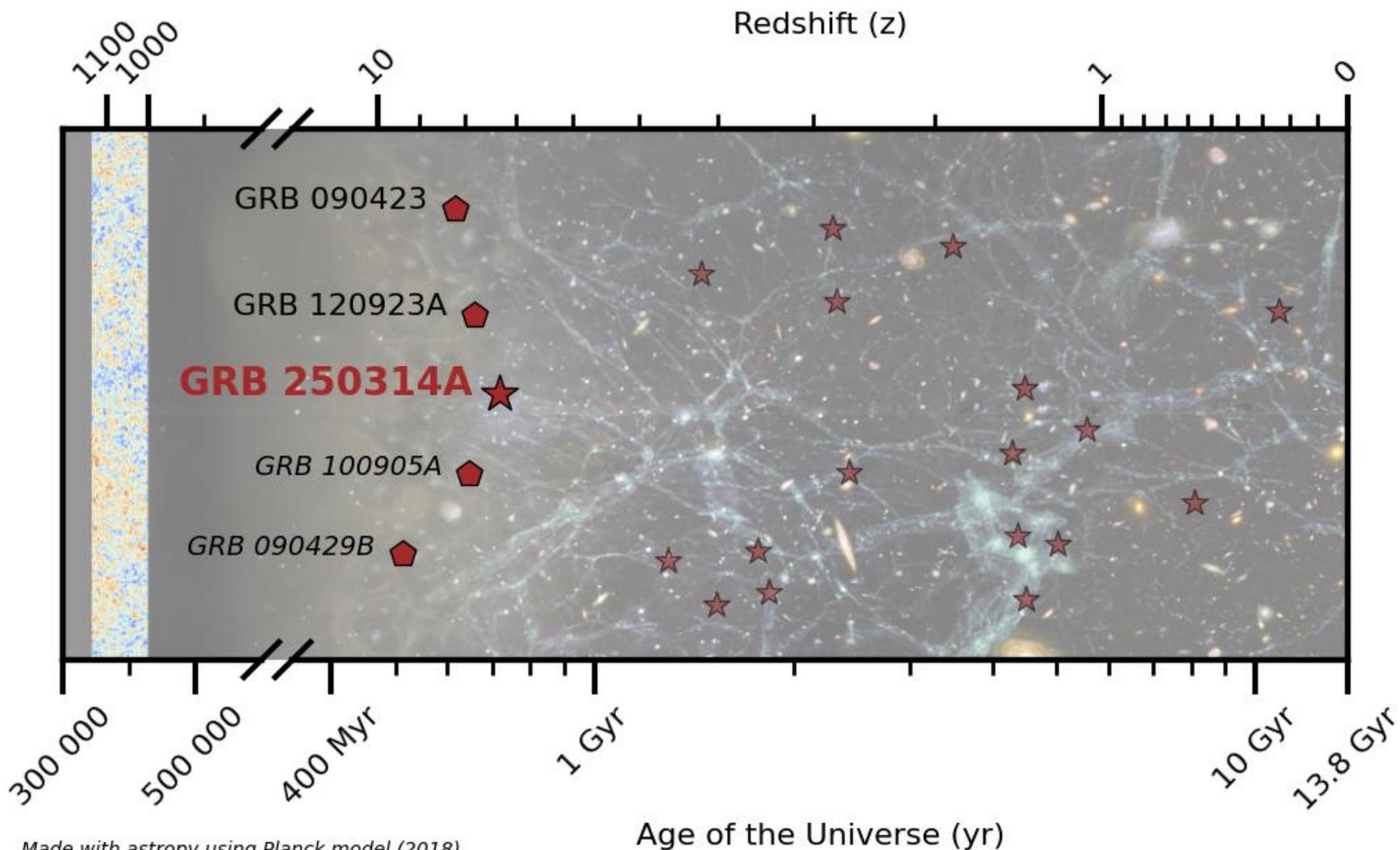


Burns et al. 2023

Exquisite Probes of Reionization

Less than 1 Gyr after Big Bang!

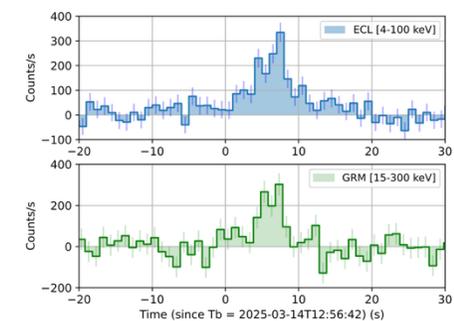
Neutral hydrogen fraction, UV escape fraction, metallicity of ISM/IGM, measure of cosmic SFR at faint end of galaxy luminosity function, Pop III stars?



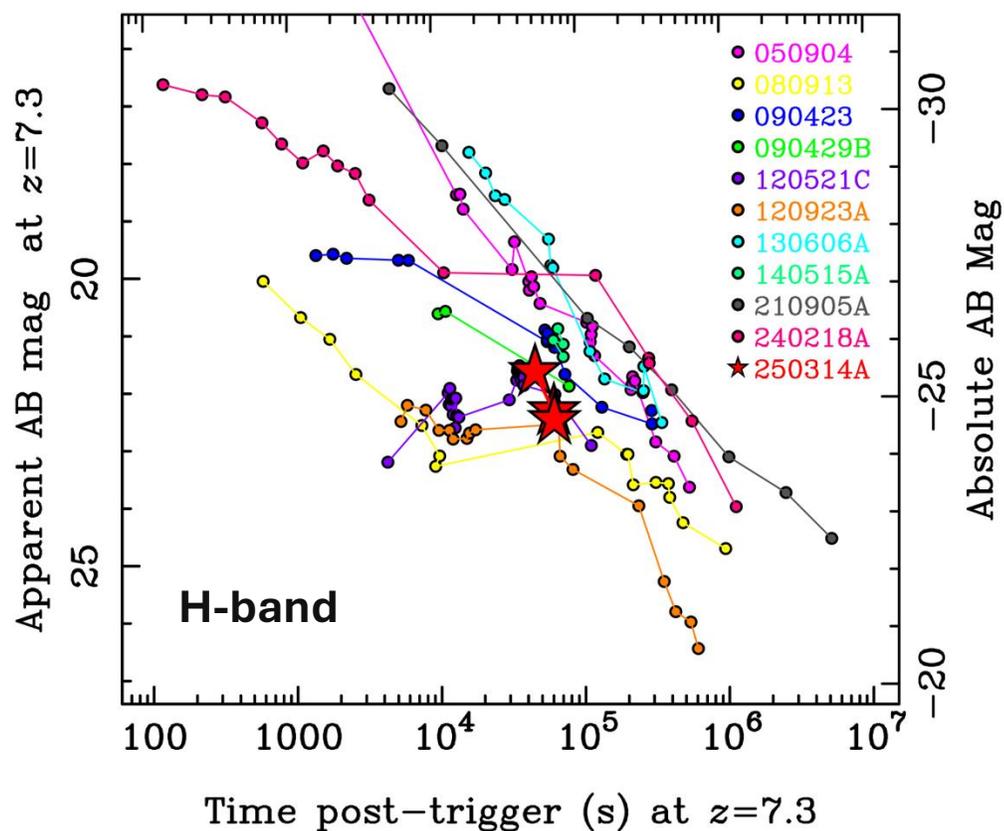
Made with astropy using Planck model (2018).
Background adapted from: ©ESA, ©Planck Collaboration.

SVOM GRB 250314A at $z \approx 7.3$

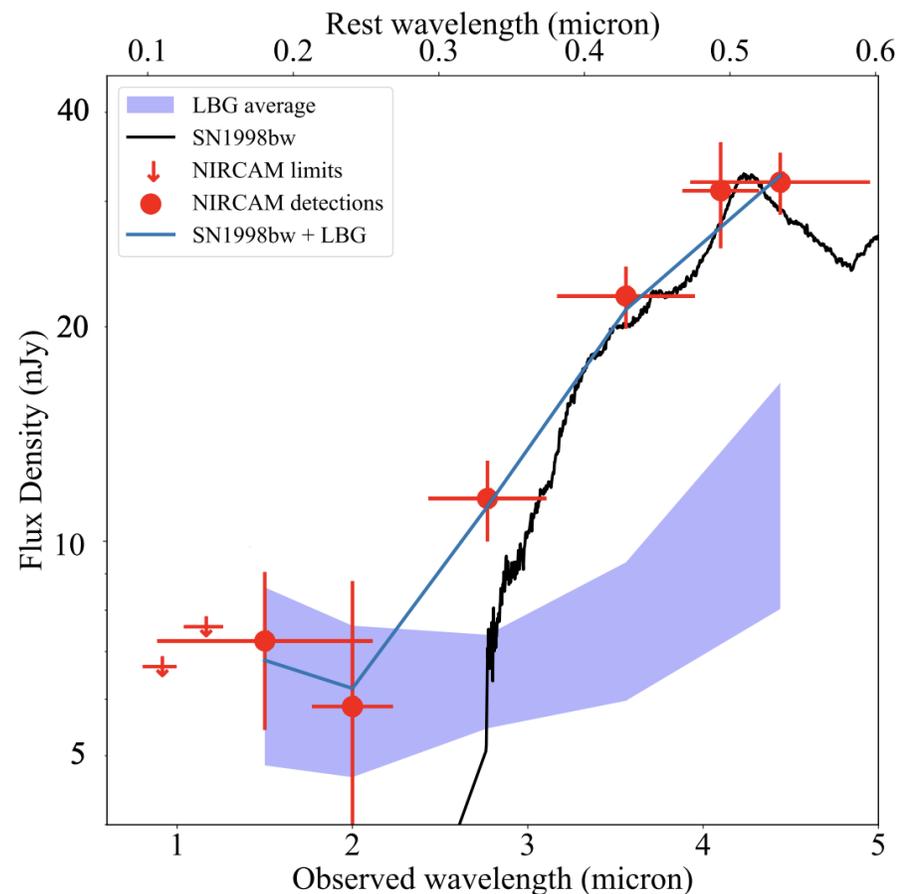
Cordier et al. 2025



Rapid near-infrared imaging and spectra can detect high redshift GRBs!



The highest redshift supernova?

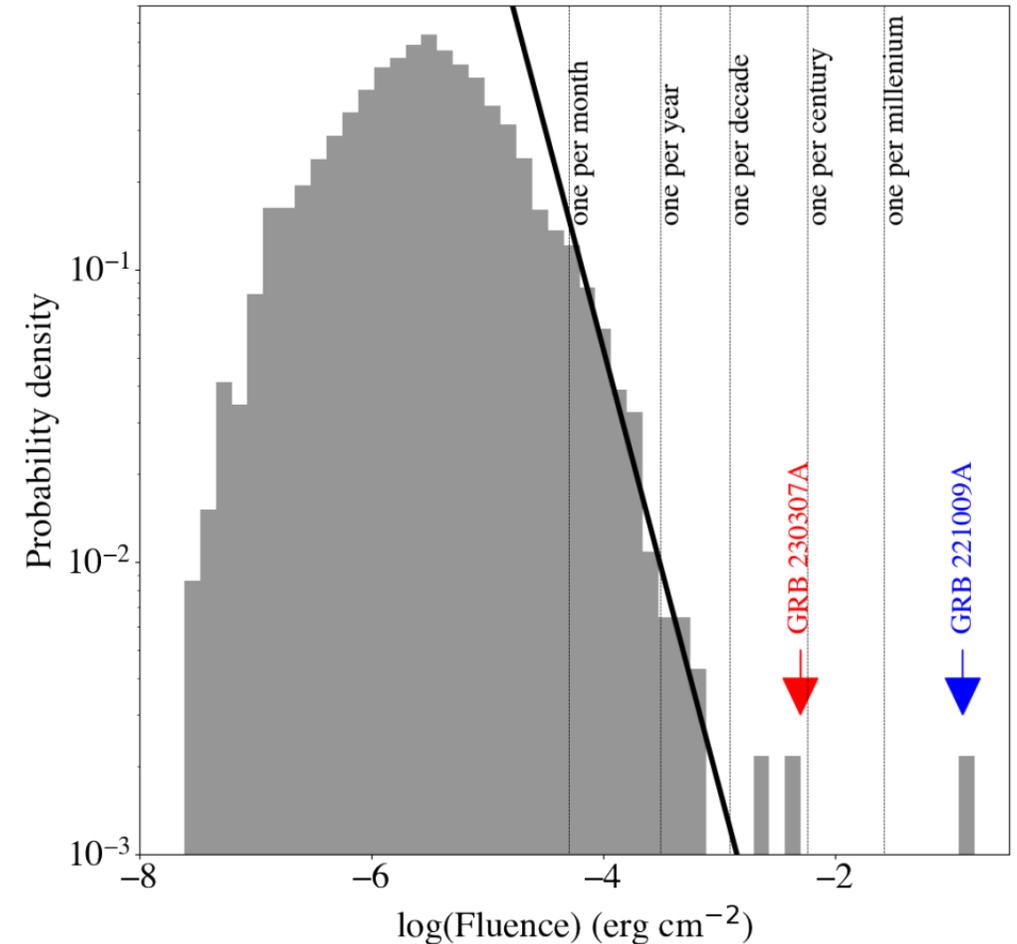
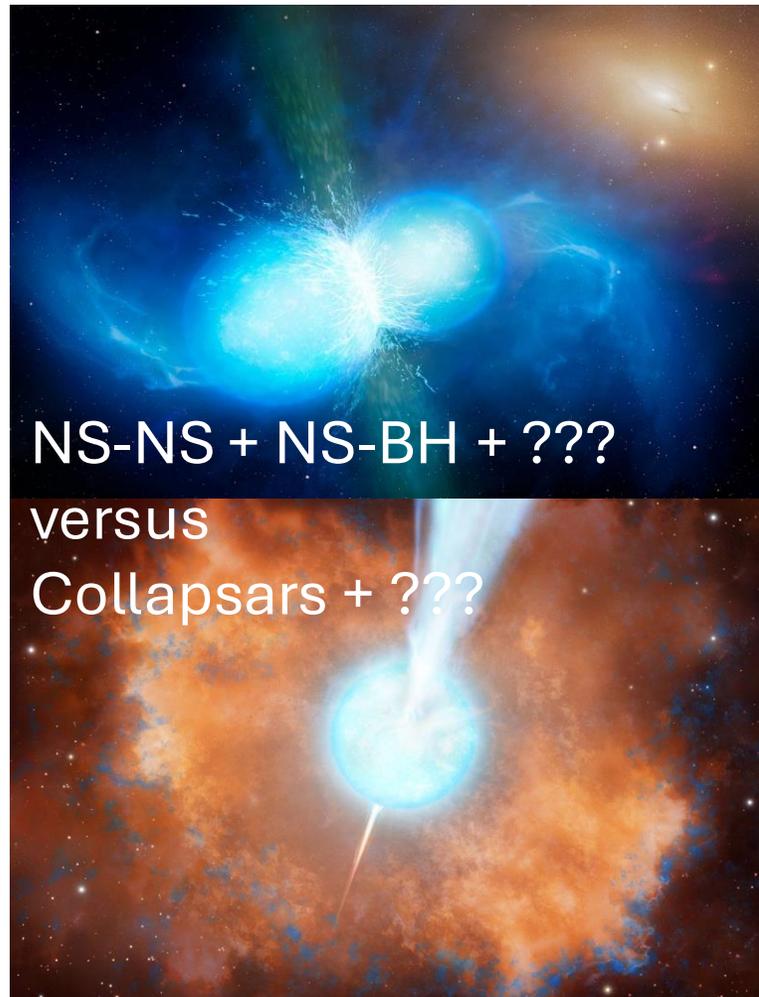


Cordier et al. 2025

Levan et al. 2025

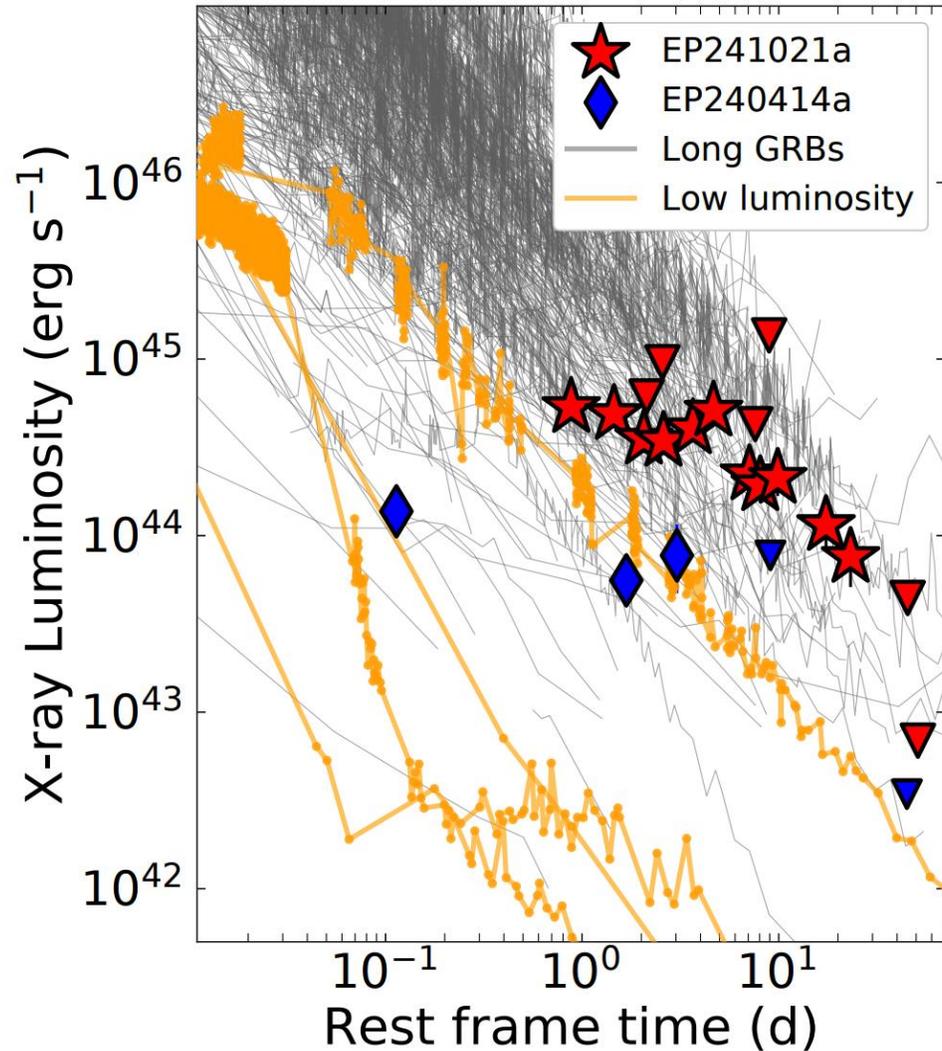
Long GRB KN are Notably Rare!

GRB 230307A is the **second brightest** GRB behind GRB 221009A and GRB 211211A was the **second brightest *Swift*** GRB behind GRB 130427A



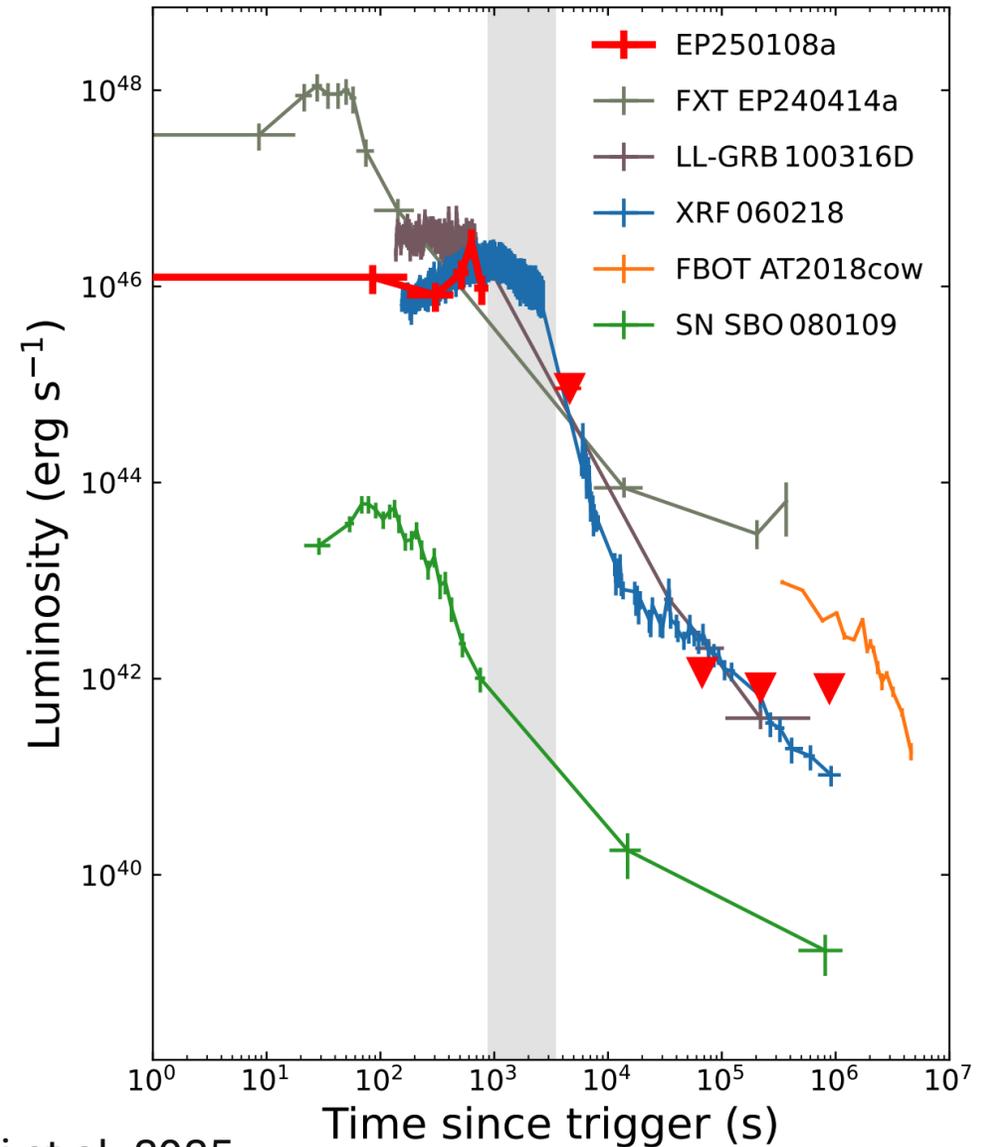
Dalessi et al. 2025
Burns et al. 2023

X-ray Lightcurves of XRFs and Low Luminosity GRBs



Busmann, O'Connor, et al. 2025

See Shu et al. 2025 and Gianfagna et al. 2025

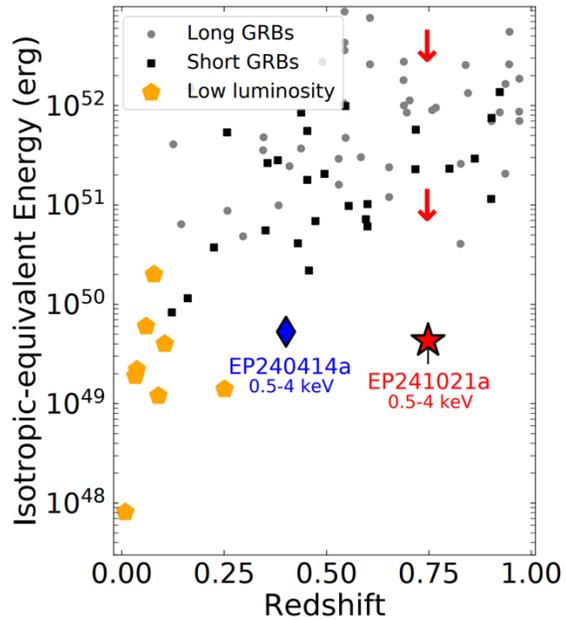


Li et al. 2025

More Peculiar Fast X-ray Transients: Relation to Orphans/Dirty Fireballs?

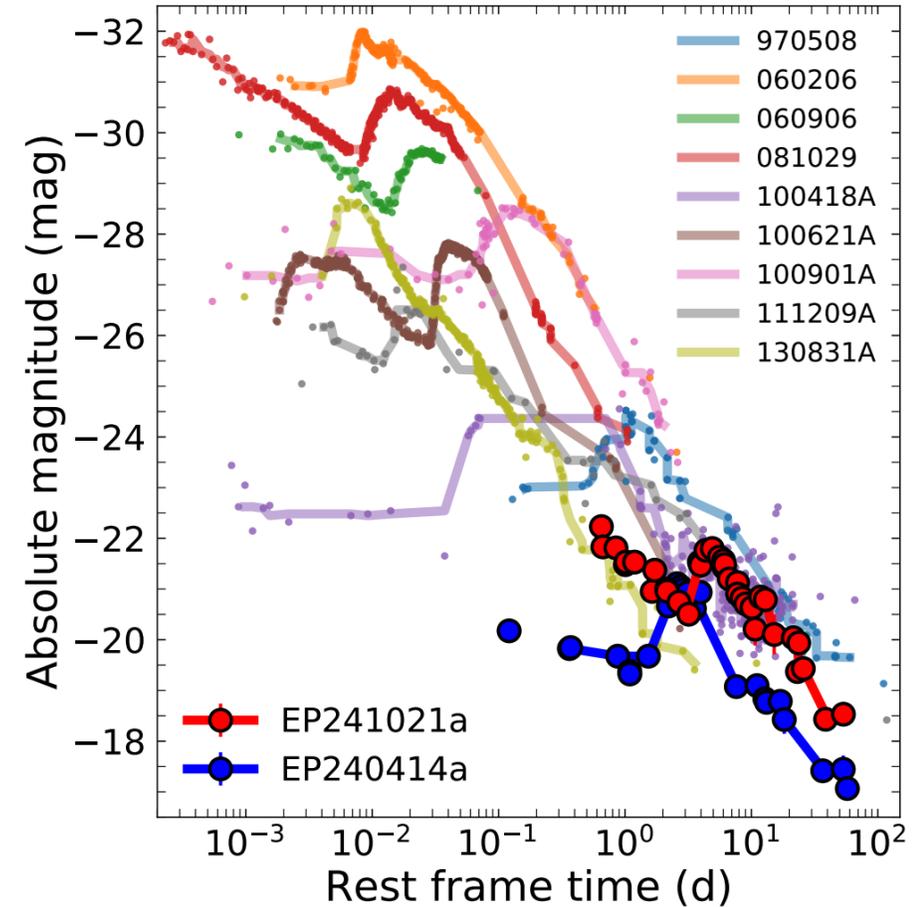


- Are EP FXTs related to dirty fireballs? Lower Lorentz factor outflows without prompt gamma-rays? (e.g., Rhoads et al. 1997, 2003)
- What is the nature of the early steep decay and late steep rebrightening? Cocoon? Refreshed shocks? Different collapsar progenitors (e.g., extended stellar envelope)?
- Will Rubin allow us to identify others? (e.g., Ho et al. 2022)



This is a very active area of research!

Shu et al. 2025; Gianfagna et al. 2025; Yadav et al. 2025; Wu et al. 2025; Sun et al. 2025; Van Dalen et al. 2025; Srivastav et al. 2025; Hamidani et al. 2025; Zheng et al. 2025; Bright et al. 2025; Levan et al. 2025; Ricci et al. 2025; Gillanders et al. 2024; and many others on recent EP sources.

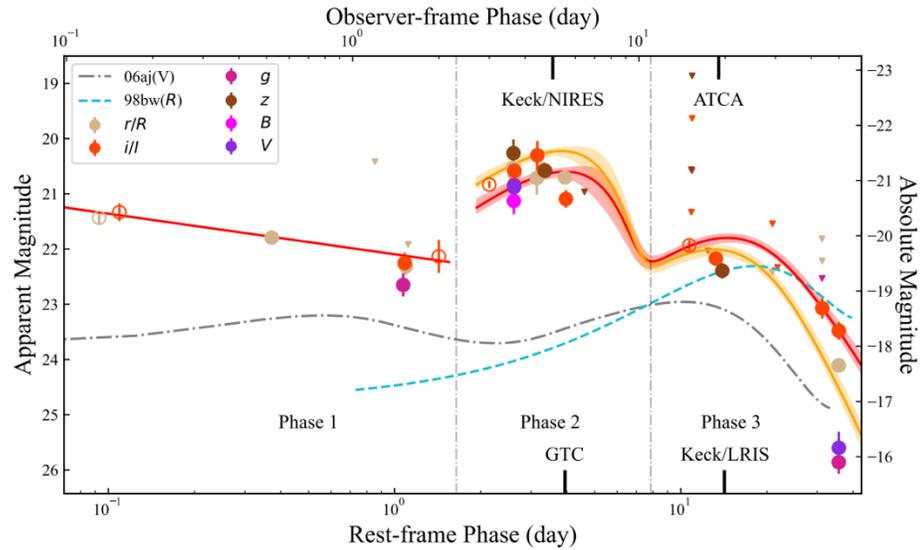


Busmann, O'Connor, et al. 2025

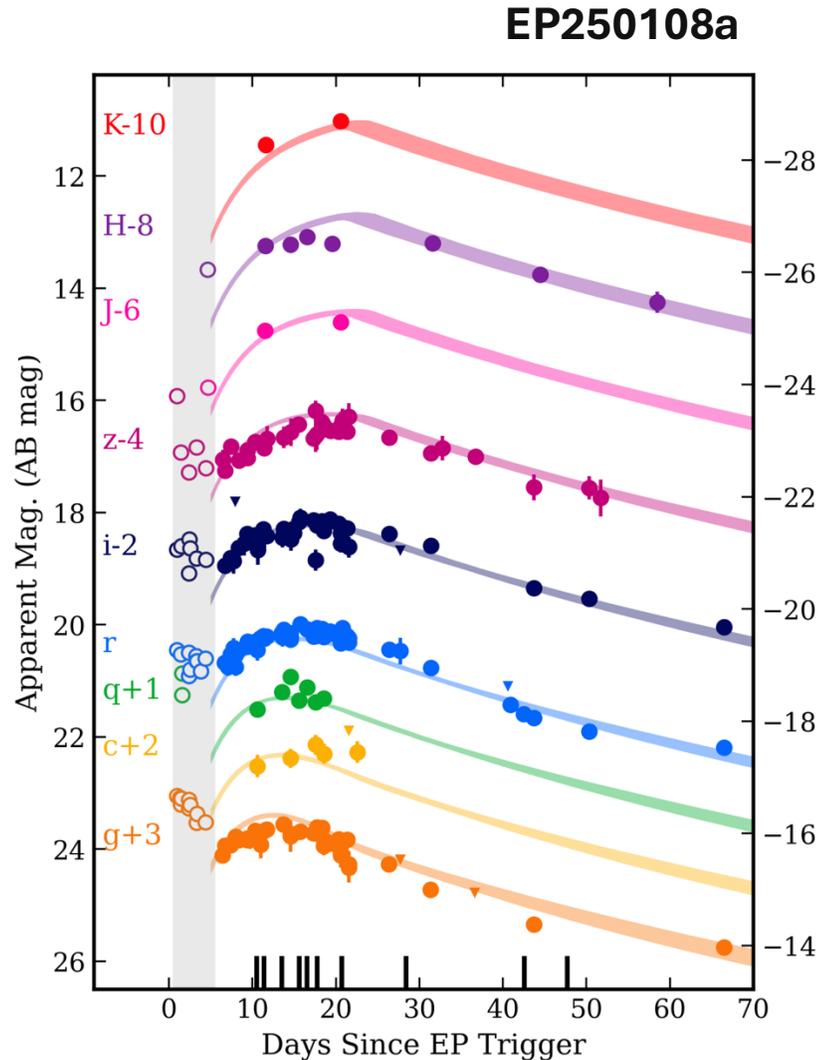
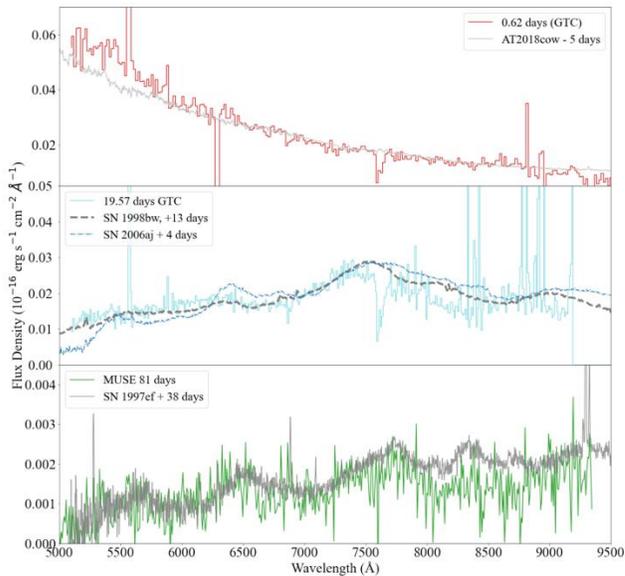
FXTs/XRFs with Supernovae

Nature of early steep optical decay: Cocoons? Different progenitors? Extended stellar envelopes?

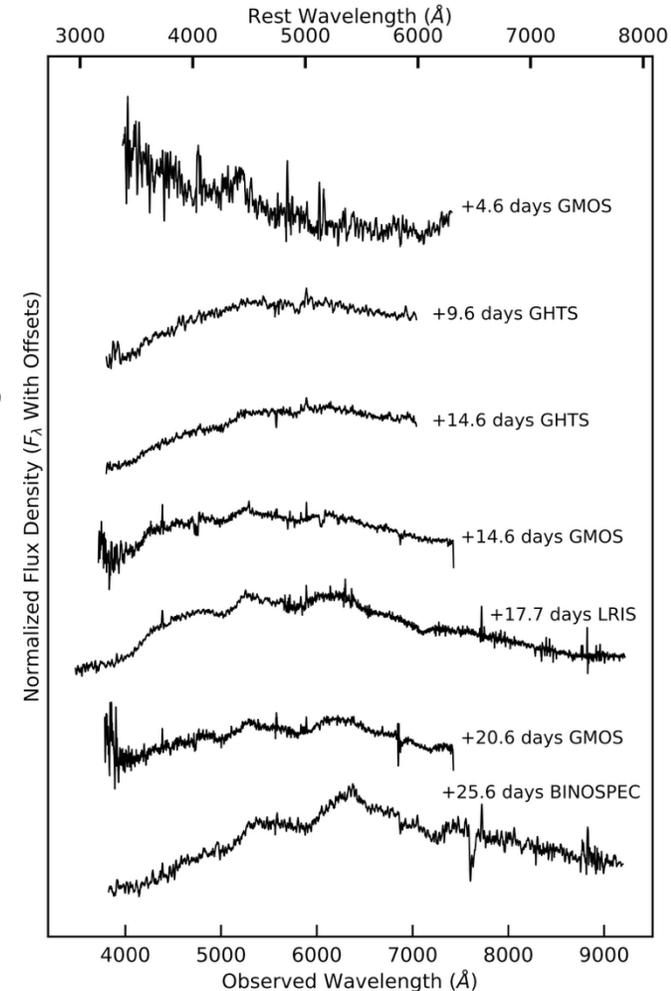
See also Eyles-Ferris et al. 2025; Li et al. 2025



EP240414a



Rastinejad et al. 2025

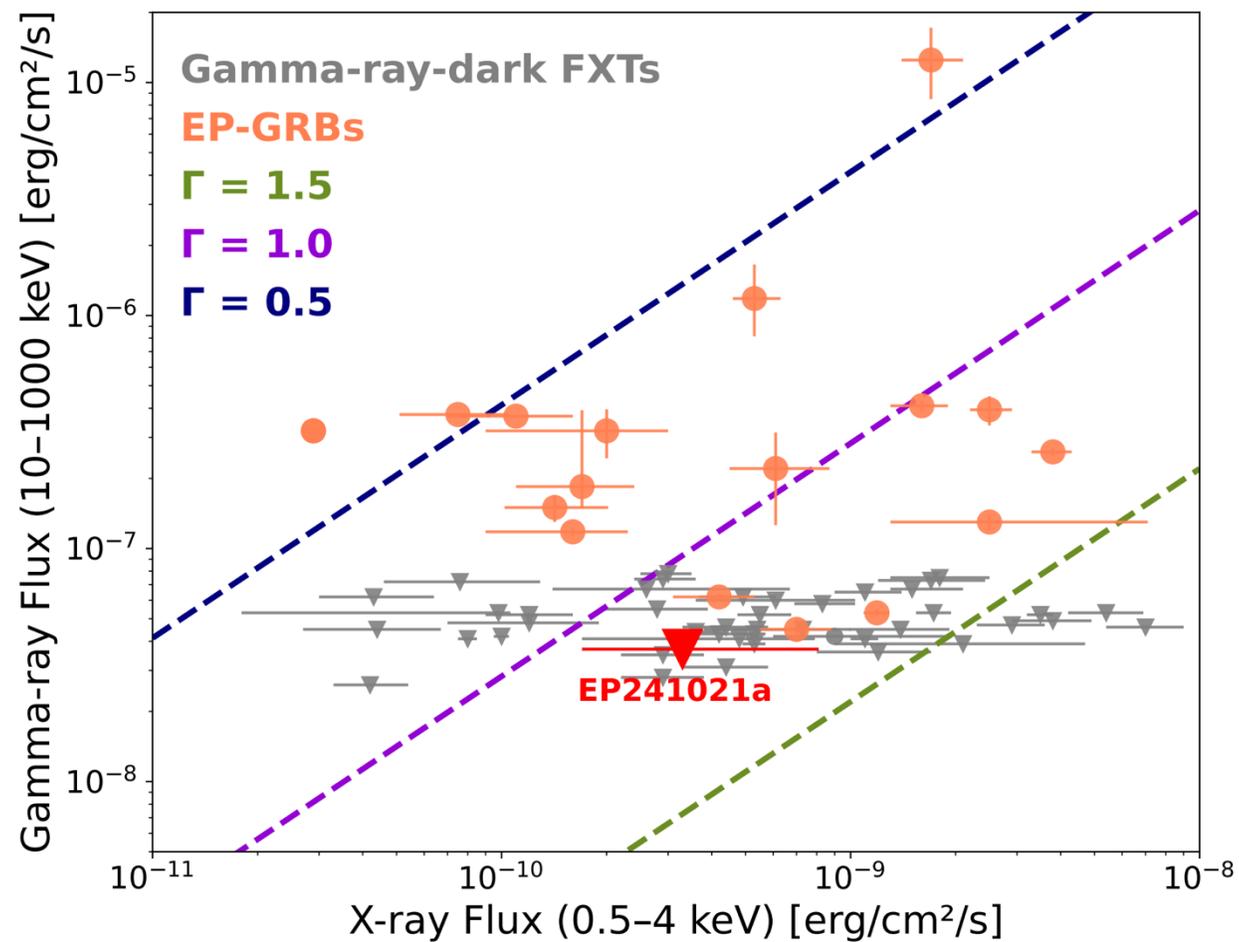


Srinivasaragavan et al. 2025

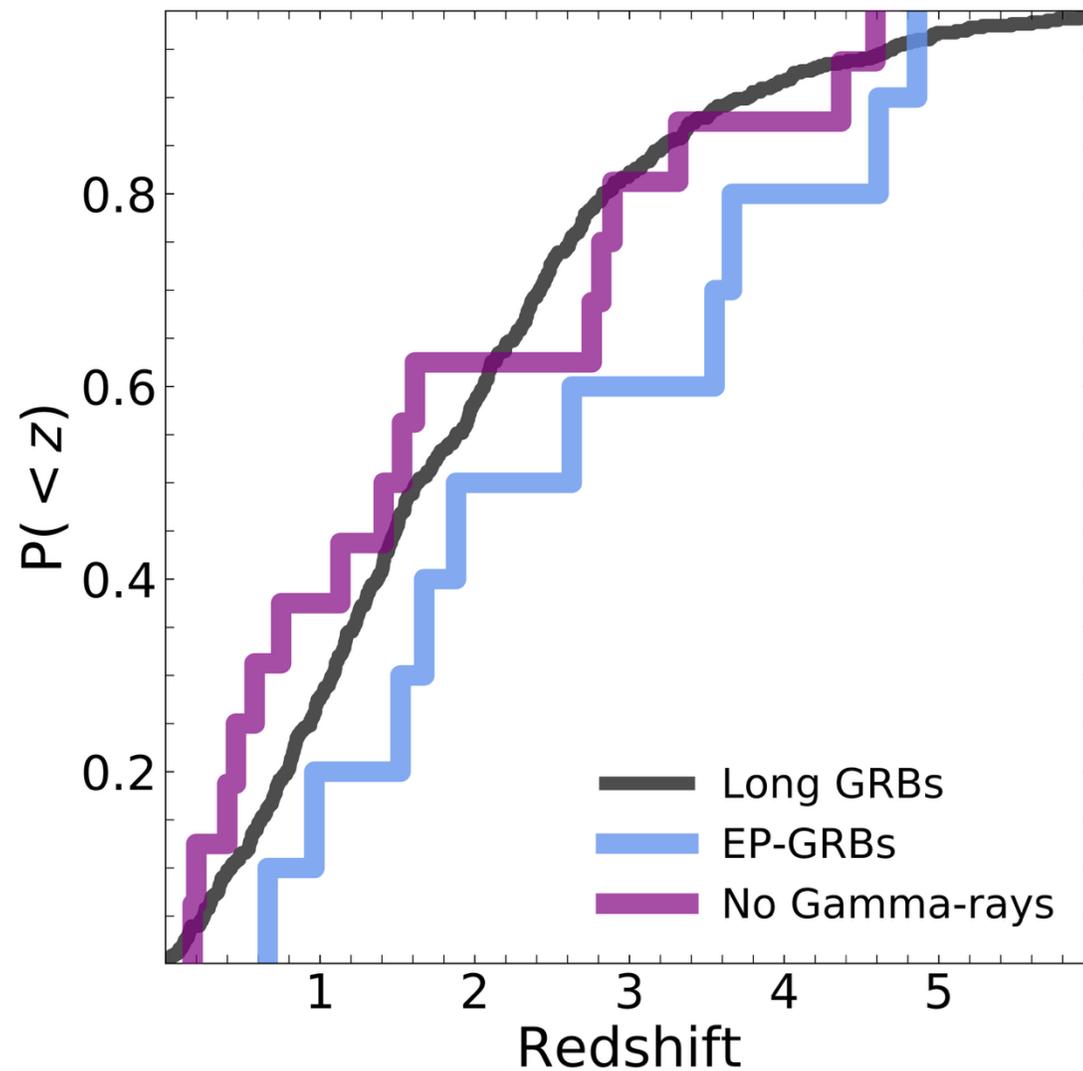
Van Dalen et al. 2024

See also Srivastav et al. 2024 and Sun et al. 2025

EP/FXTs without Gamma-rays



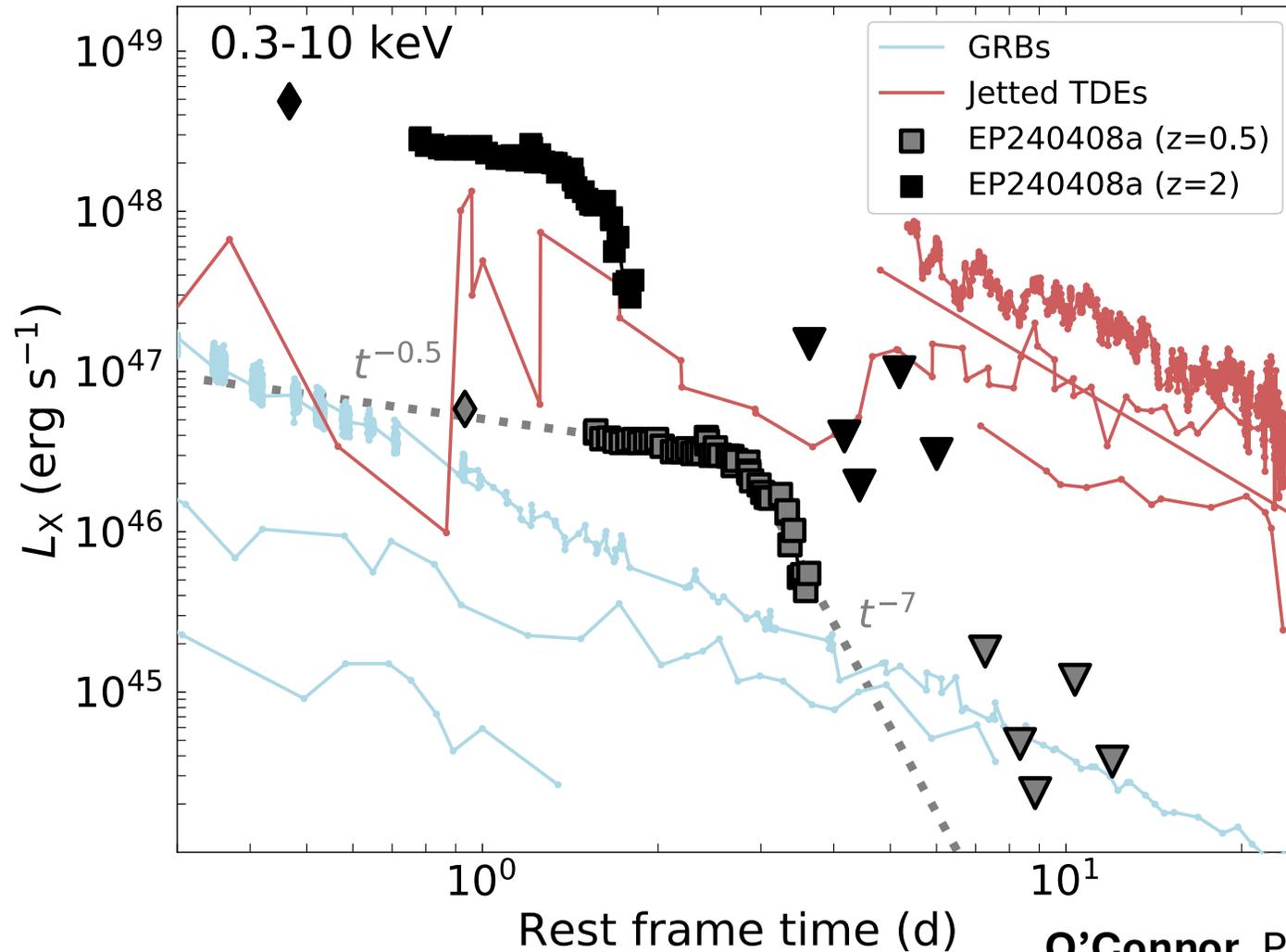
Yadav et al. 2025



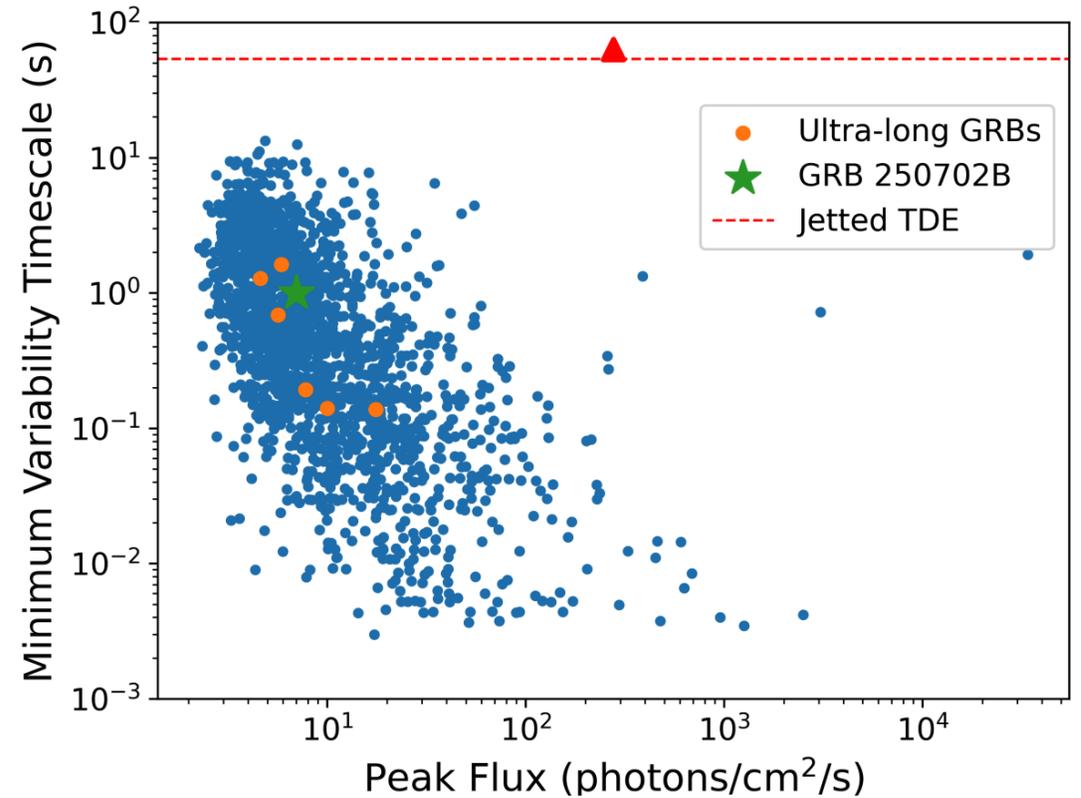
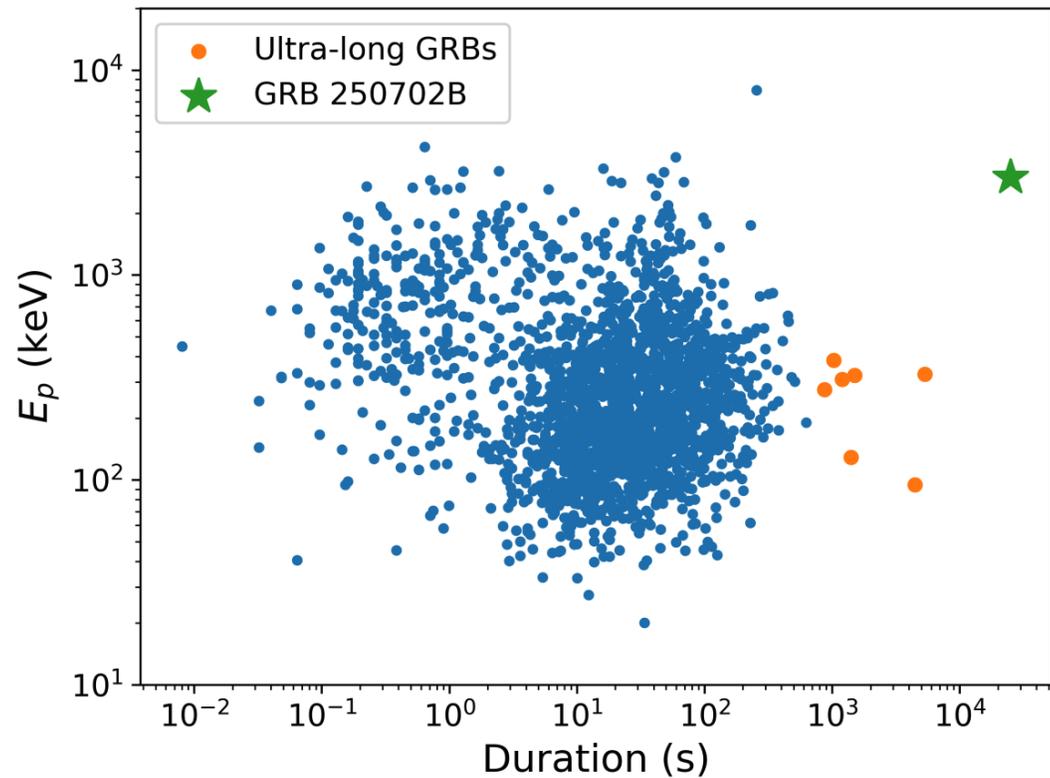
O'Connor et al. 2025a

EP240408a: Exotic GRB or Abnormal jetted TDE?

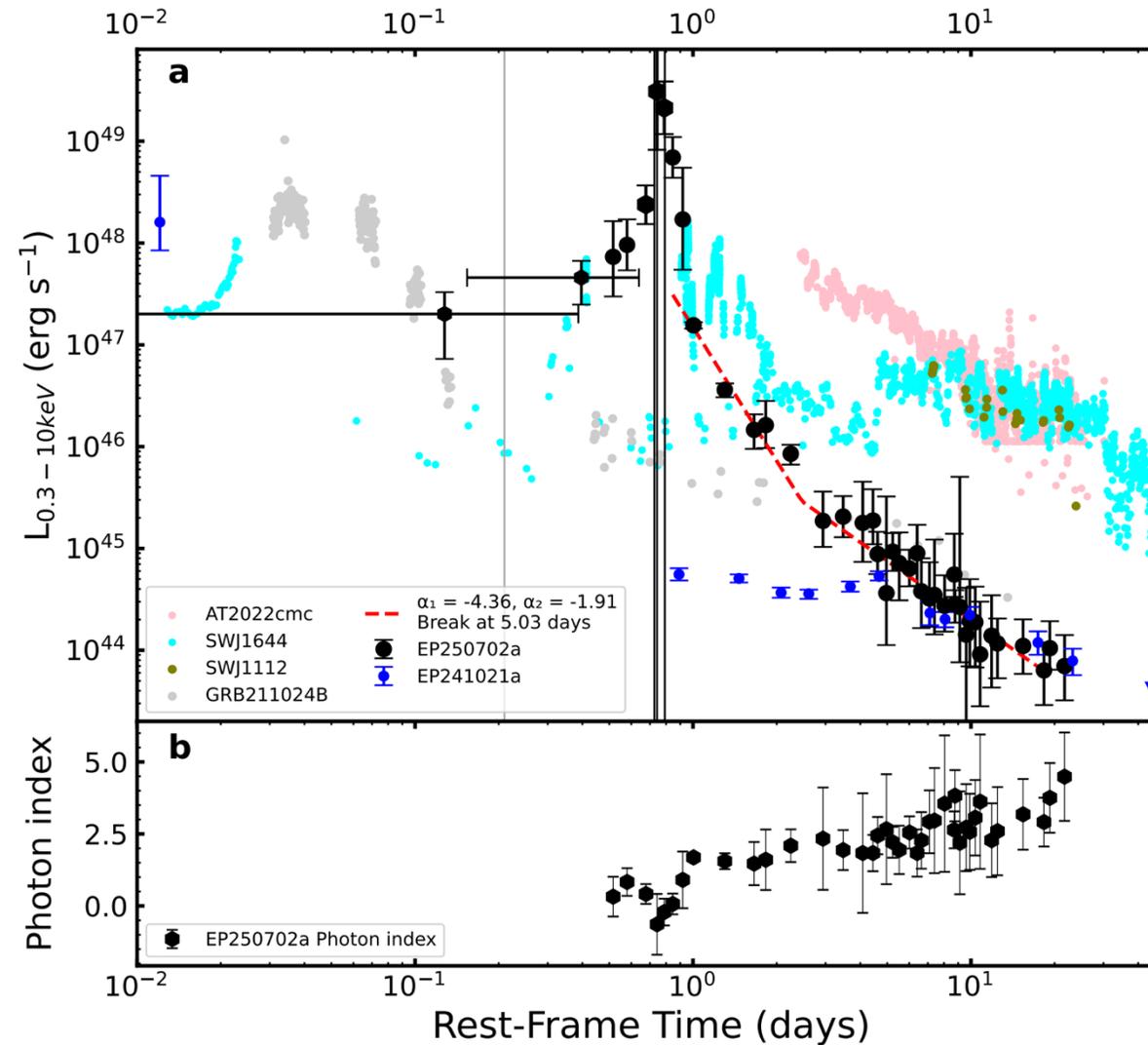
- **Swift provided localization. NICER monitoring revealed long-lived transient.**
- *X-ray lightcurve unlike other high energy transients (e.g., GRBs, TDEs).*



GRB 250702B Gamma-ray Properties

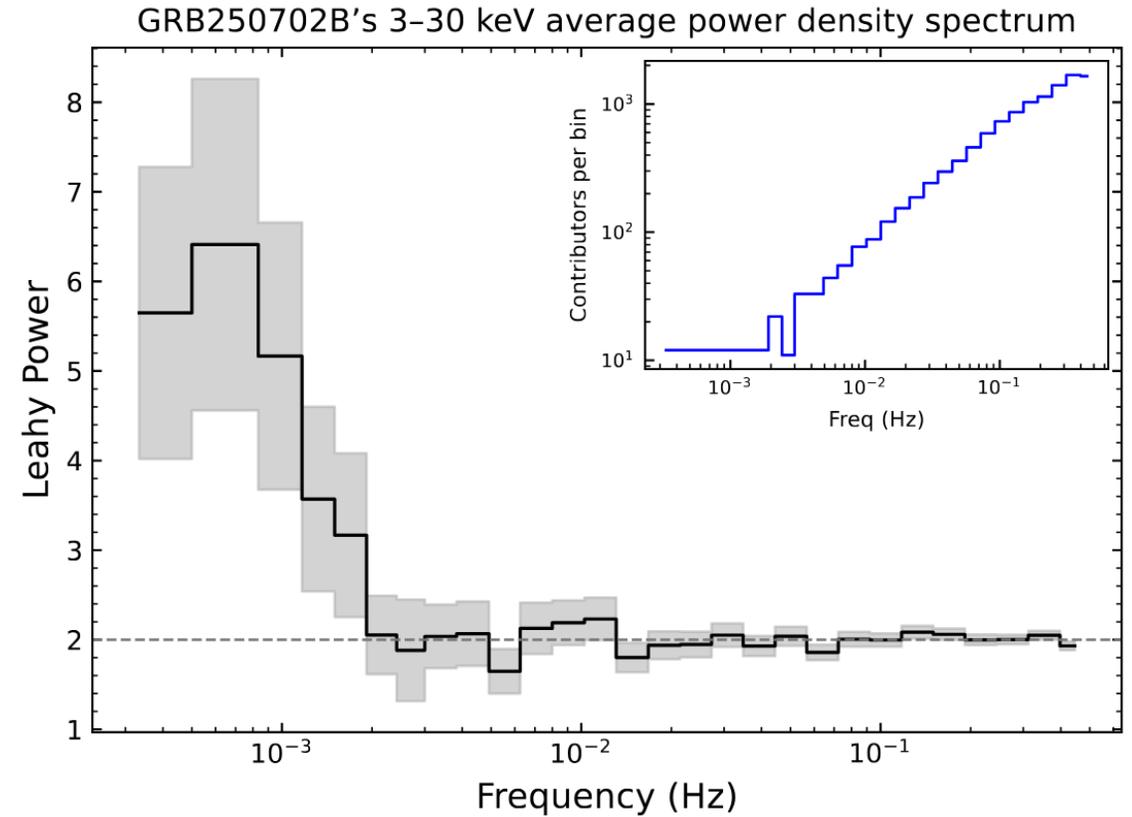
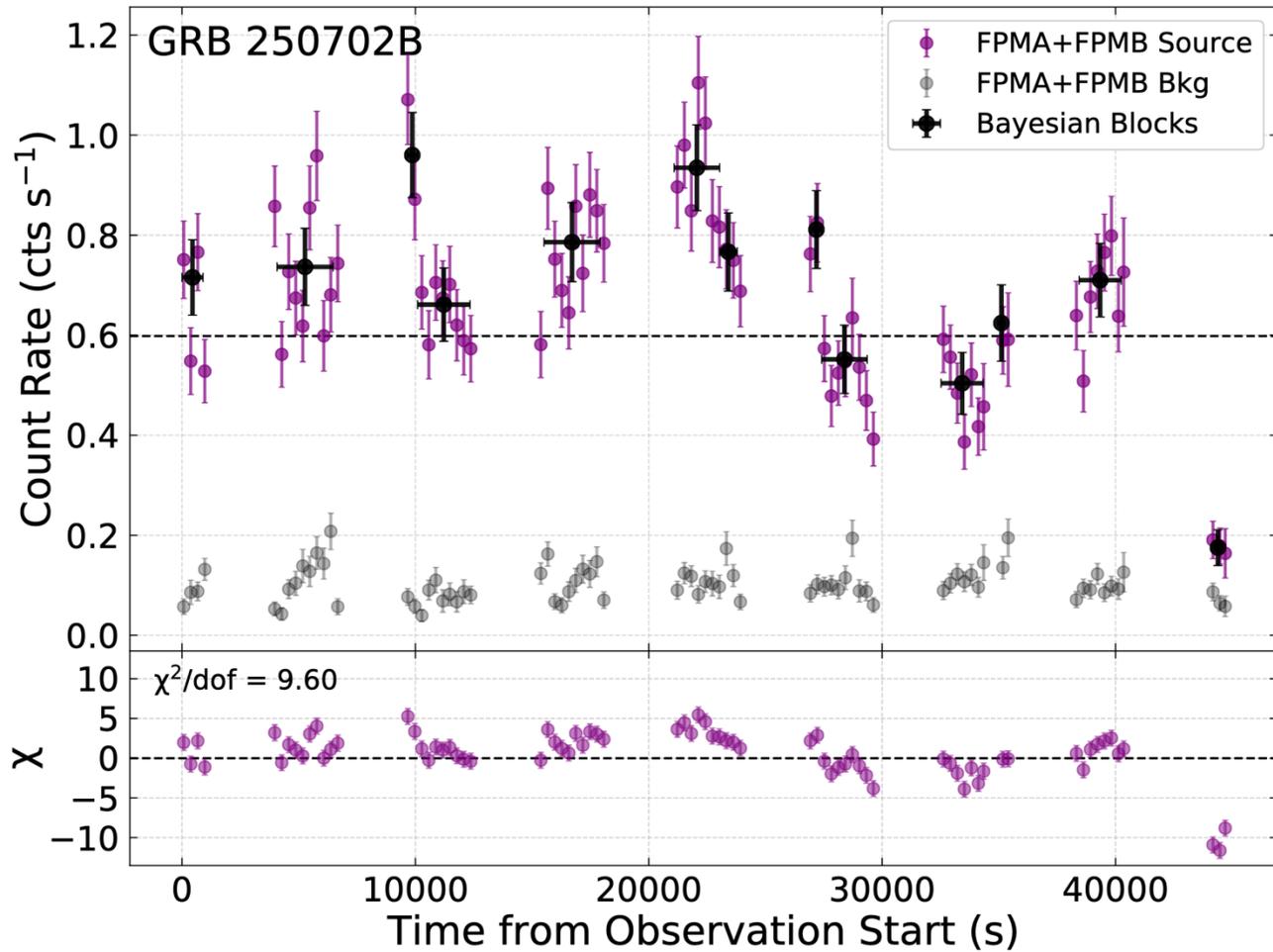


GRB 250702B EP WXT+FXT Lightcurve

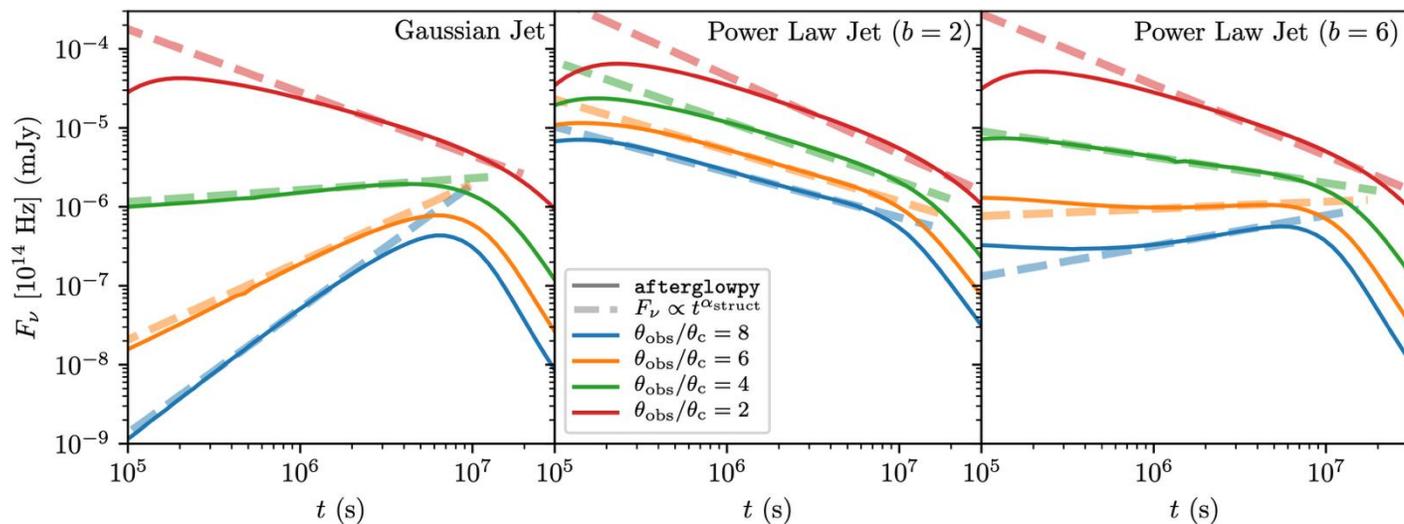
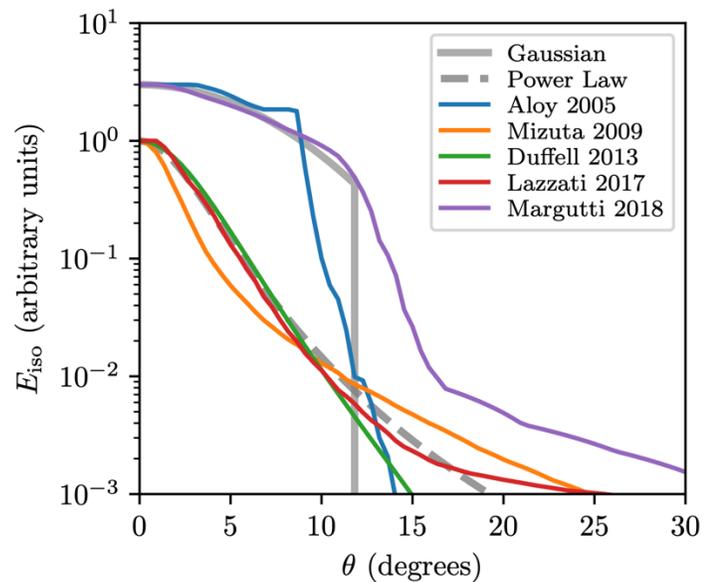
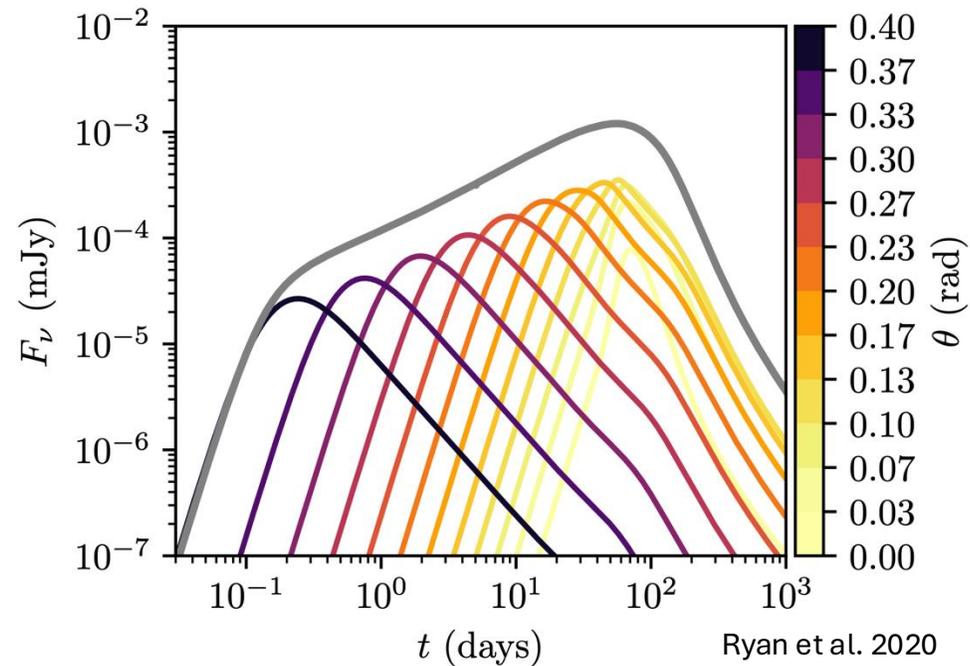
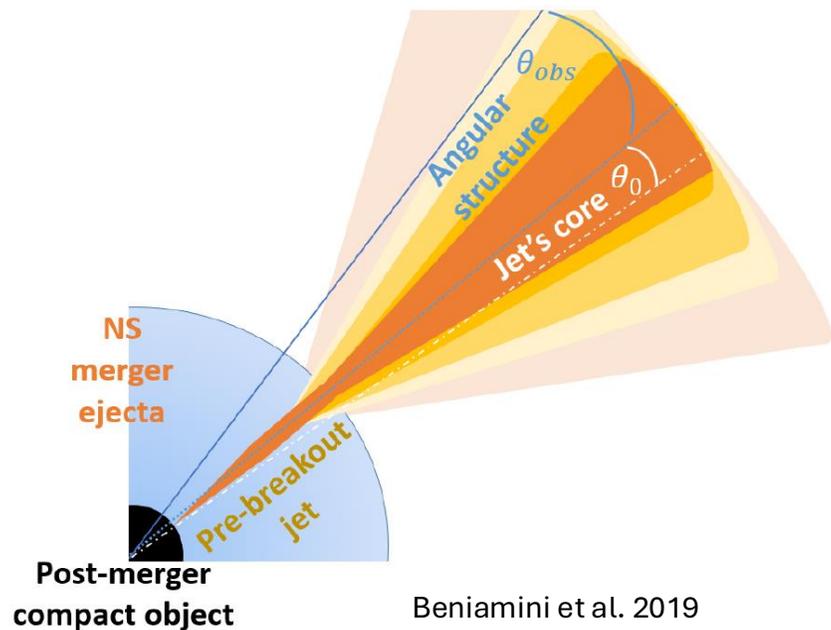


Li et al. 2025

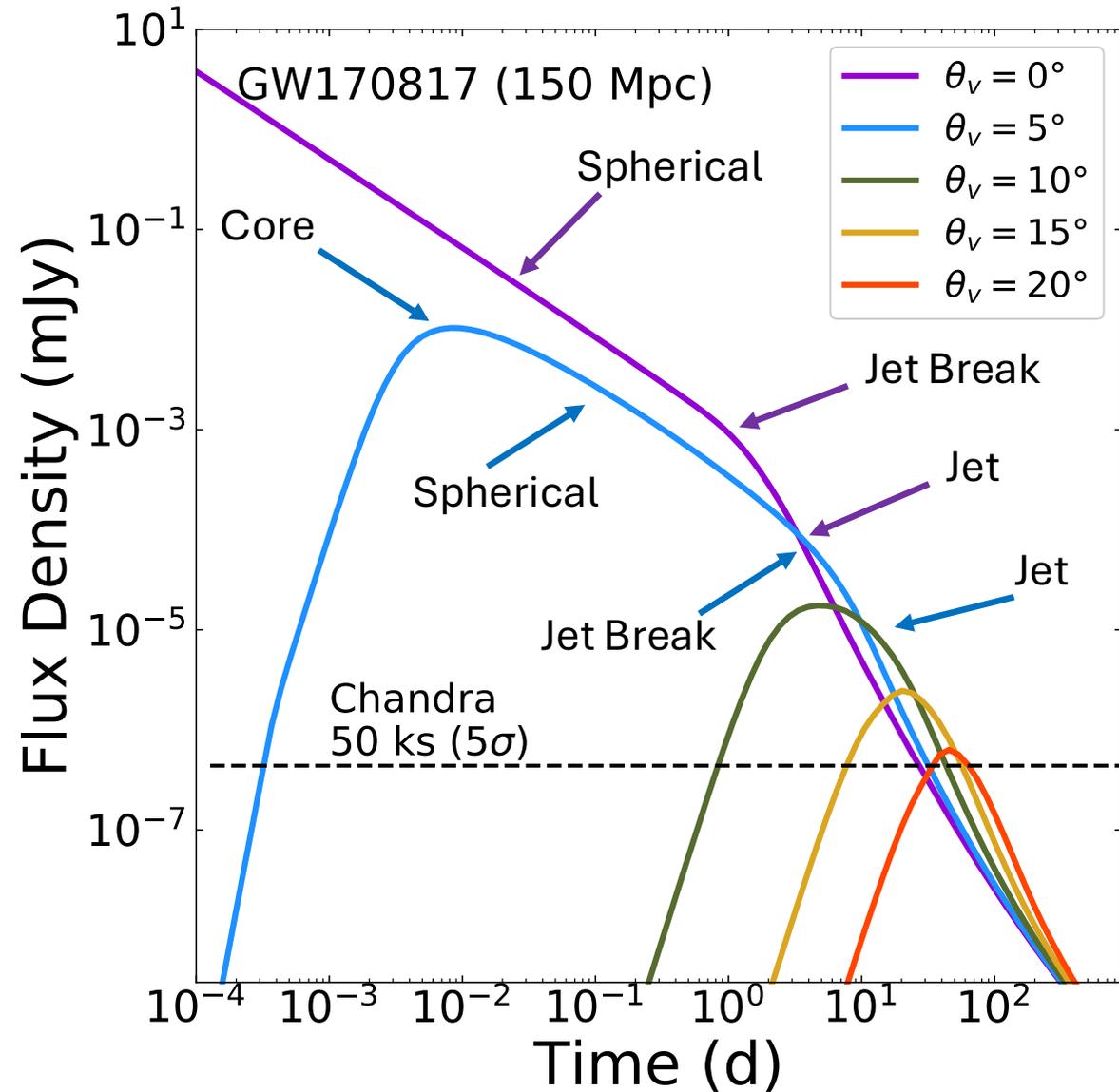
GRB 250702B X-ray Variability



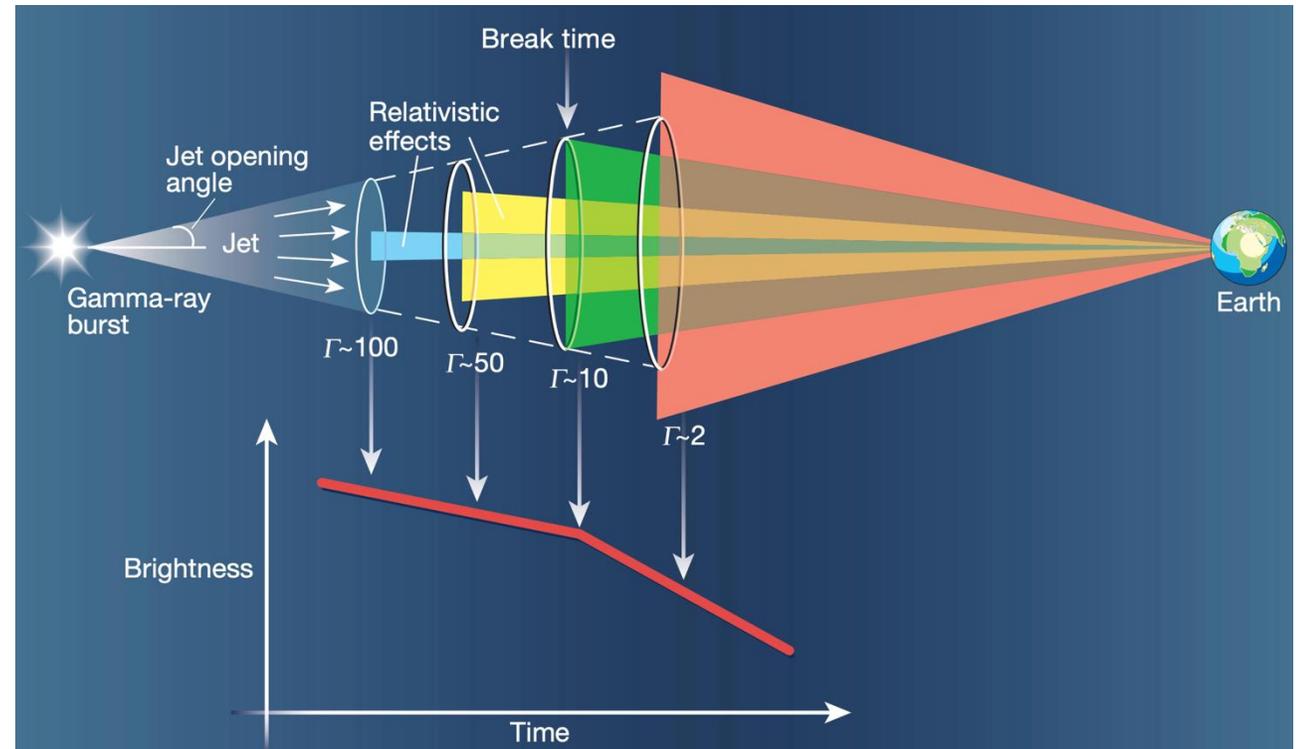
GRB Jet Structure



Off-axis jets and jet collimation



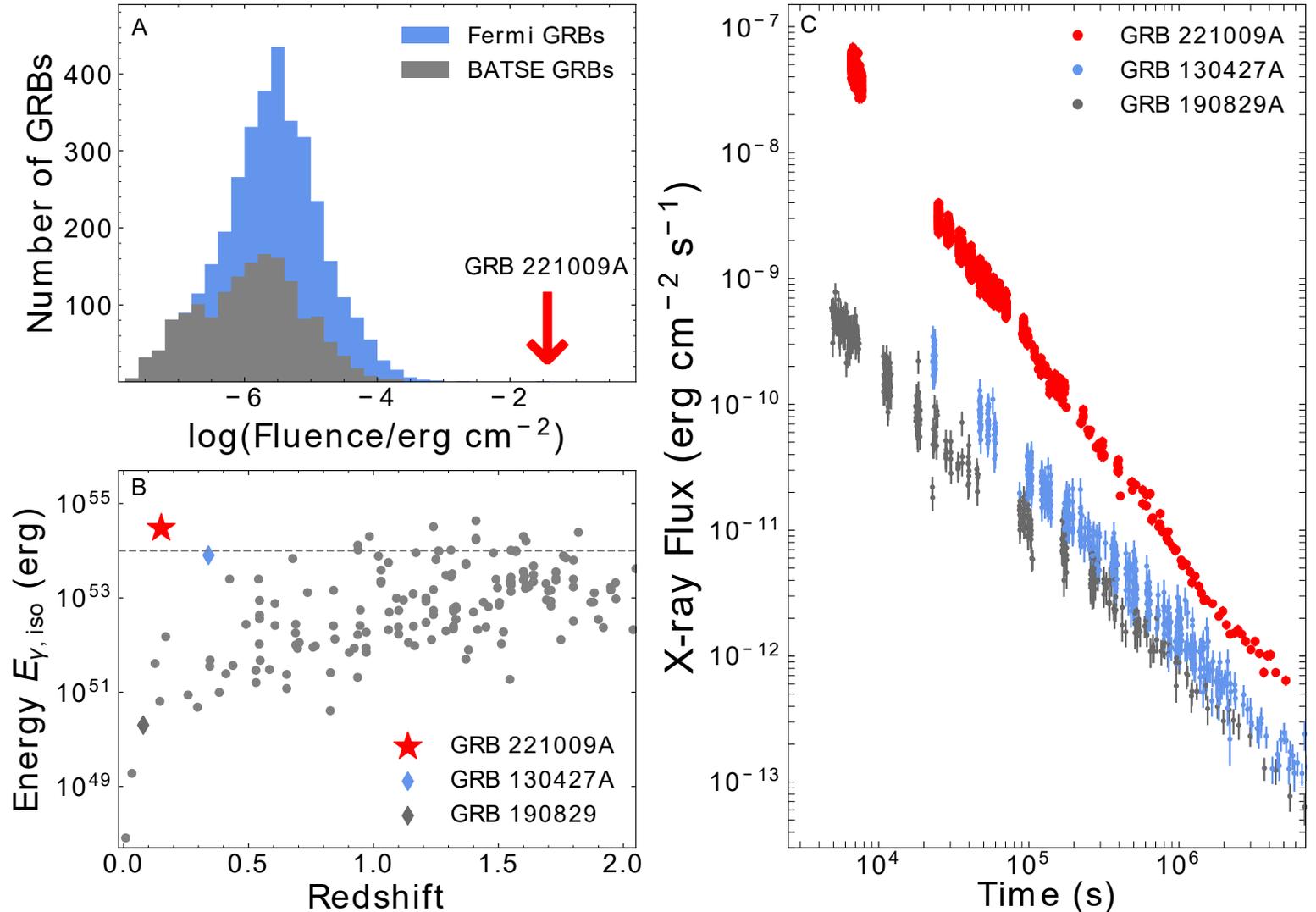
- Increasing viewing angle leads to later peak times at lower fluxes
- The jet break tells us the jet's half opening angle (the *collimation*)



Credit: Stan Woosley

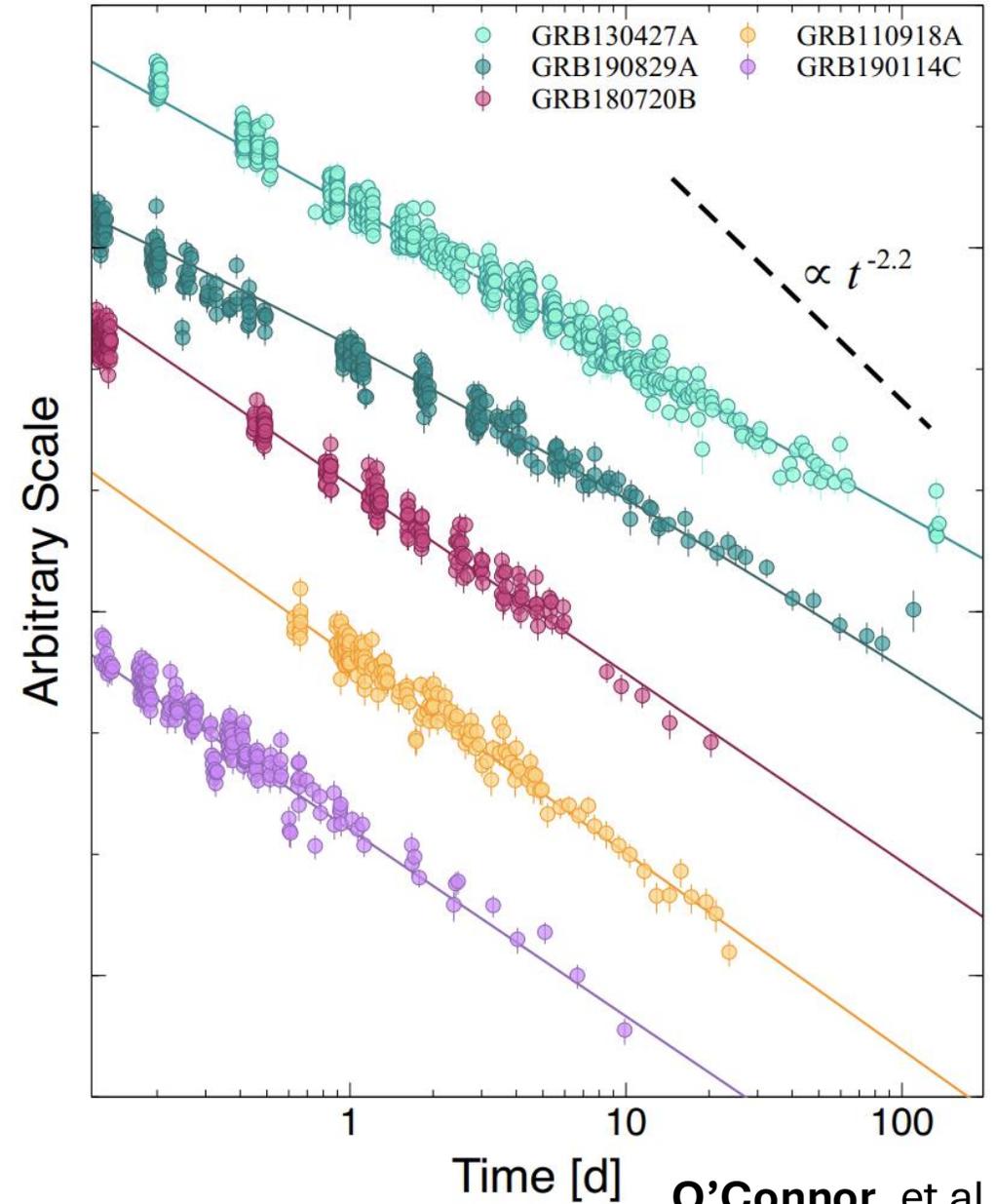
The brightest gamma-ray burst of all time

- GRB 221009A outshines all other known GRBs in gamma-rays and X-rays
- Nearby explosion at 720 Mpc ($z=0.15$)
- The extreme energy release in gamma-rays implies a rate of once a millennia



Lack of jet-breaks in bright GRBs

- The lack of a late-time steepening implies a wide jet
- Same behavior in other nearby, energetic GRBs
- Common central engine and/or structured jet for extreme events?



See also Berger et al. 2003 or de Pasquale et al. 2016

O'Connor, et al. 2023

