Image Credit: Aaron Geller

"CROSSOVER" GRBS

JILLIAN RASTINEJAD

Fong Group Northwestern

Northwestern | CIERA
CENTER FOR INTERDISCIPLINARY EXPLORATION AND RESEARCH IN ASTROPHYSICS

Credit: Aaron Geller, Northwestern

Outline

I. [Brief] Introduction

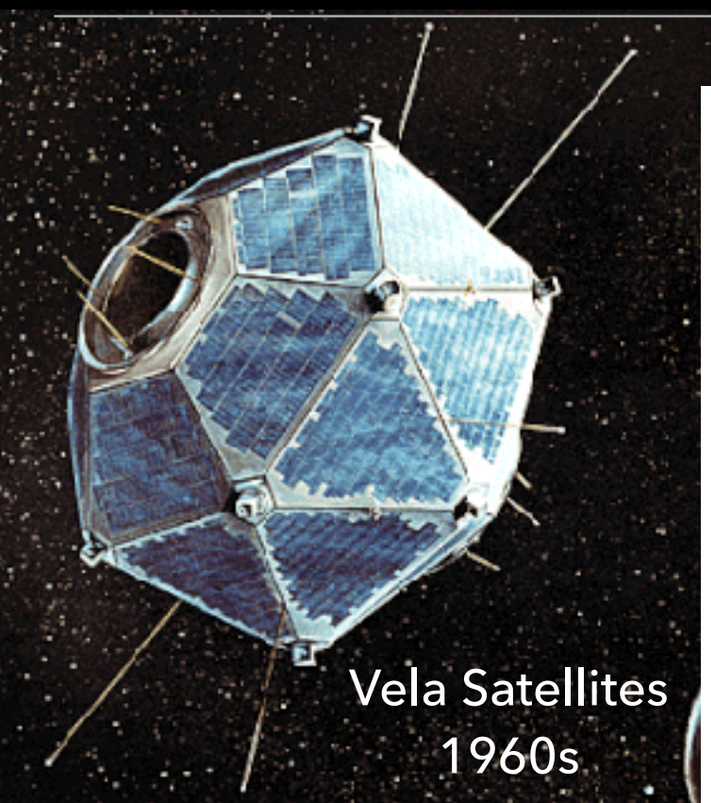
II. Observations of short GRBs from massive star collapses

III. Observations of long GRBs from merger events

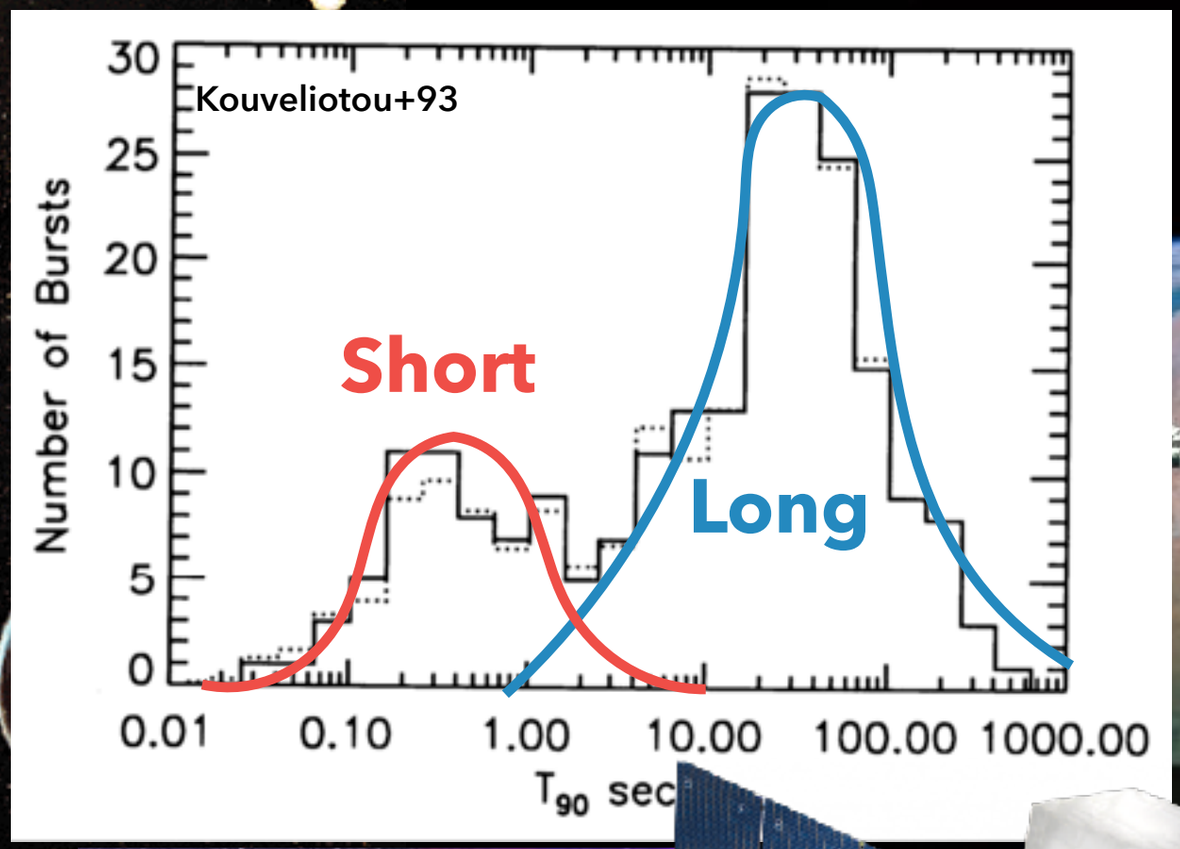
IV. Theories on the formation of long GRBs from merger events

V. Observing strategies and outlook

The GRB Paradigm

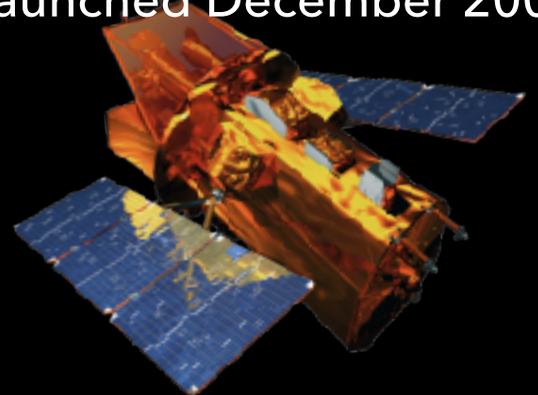


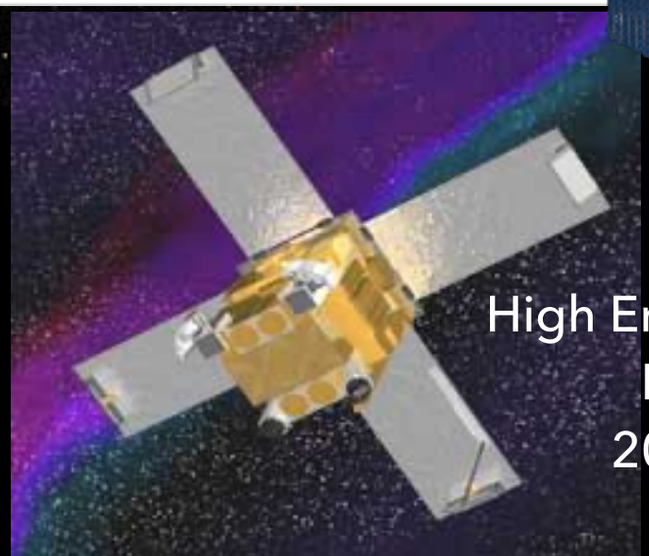
Vela Satellites
1960s



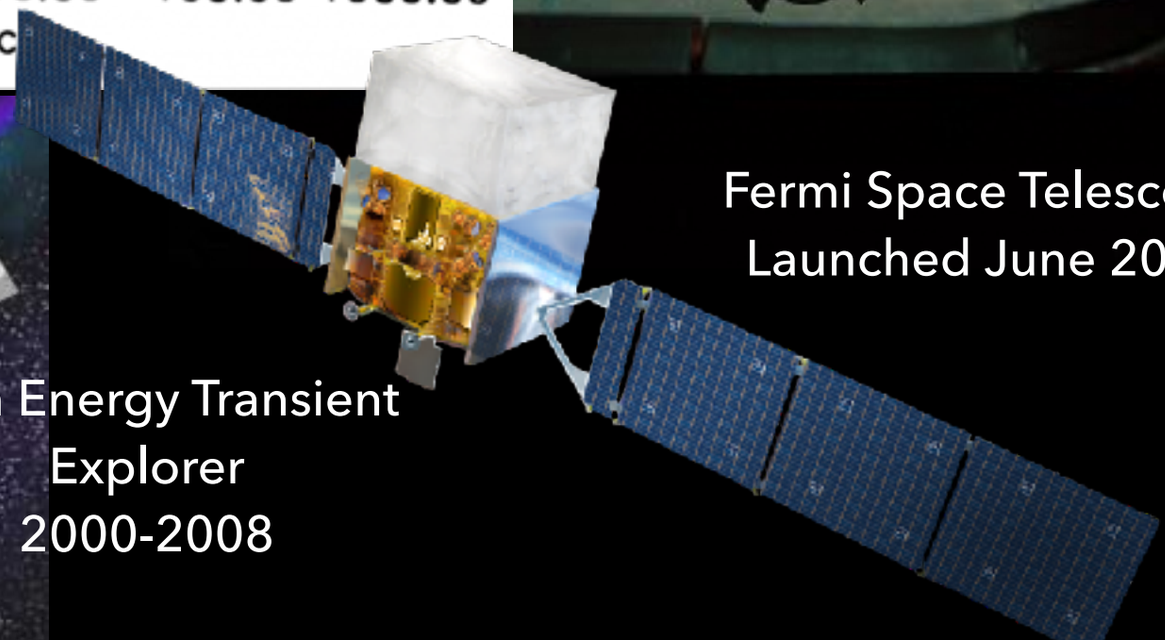
Compton Observatory
1991 - 2000

Neil Gehrels Swift
Observatory,
Launched December 2004





High Energy Transient
Explorer
2000-2008

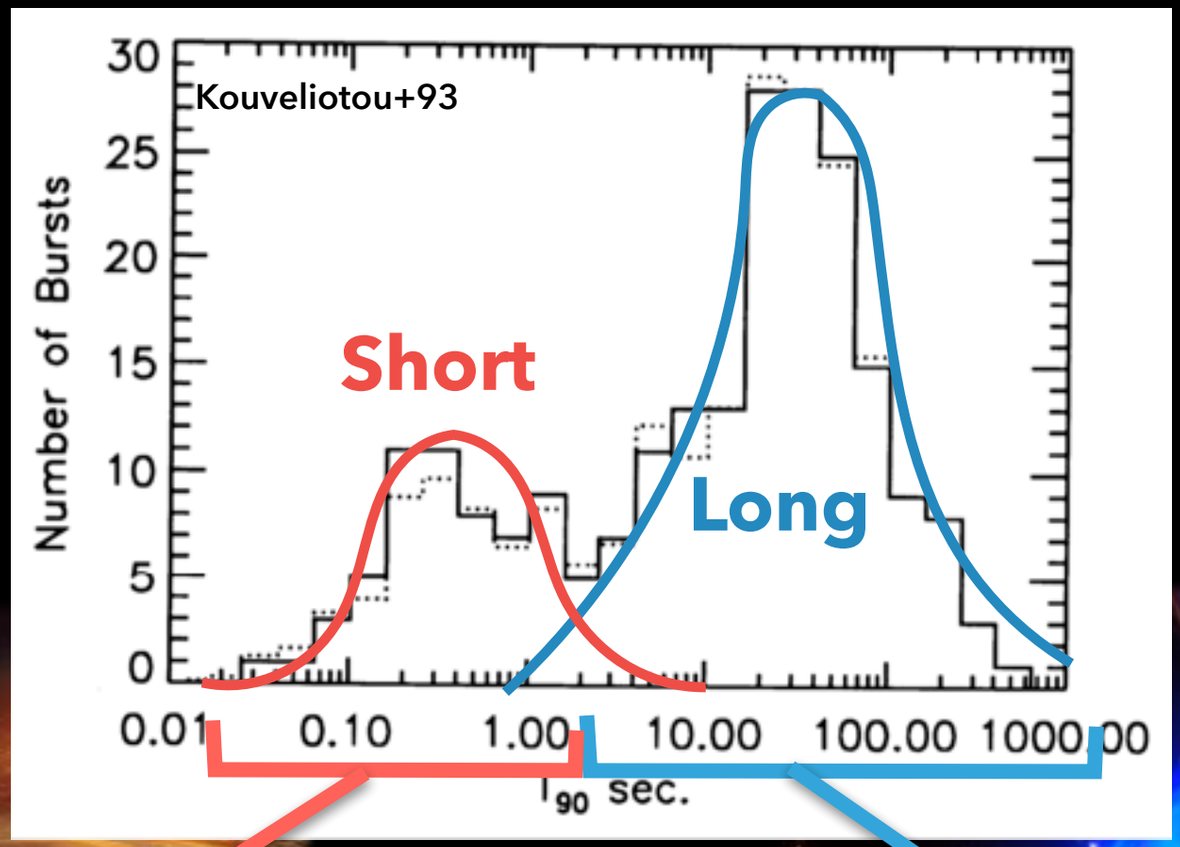


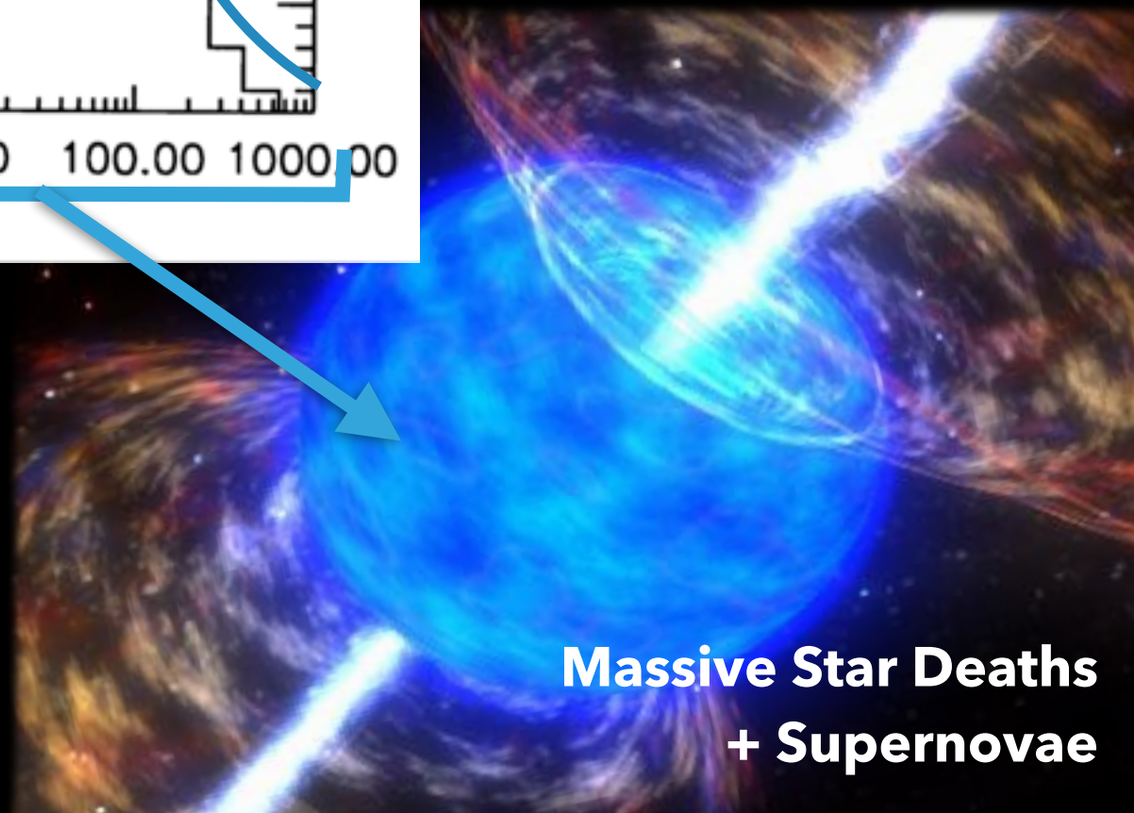
Fermi Space Telescop
Launched June 2008

The GRB Paradigm *+ semantics!*

Merger-driven

Massive star - driven



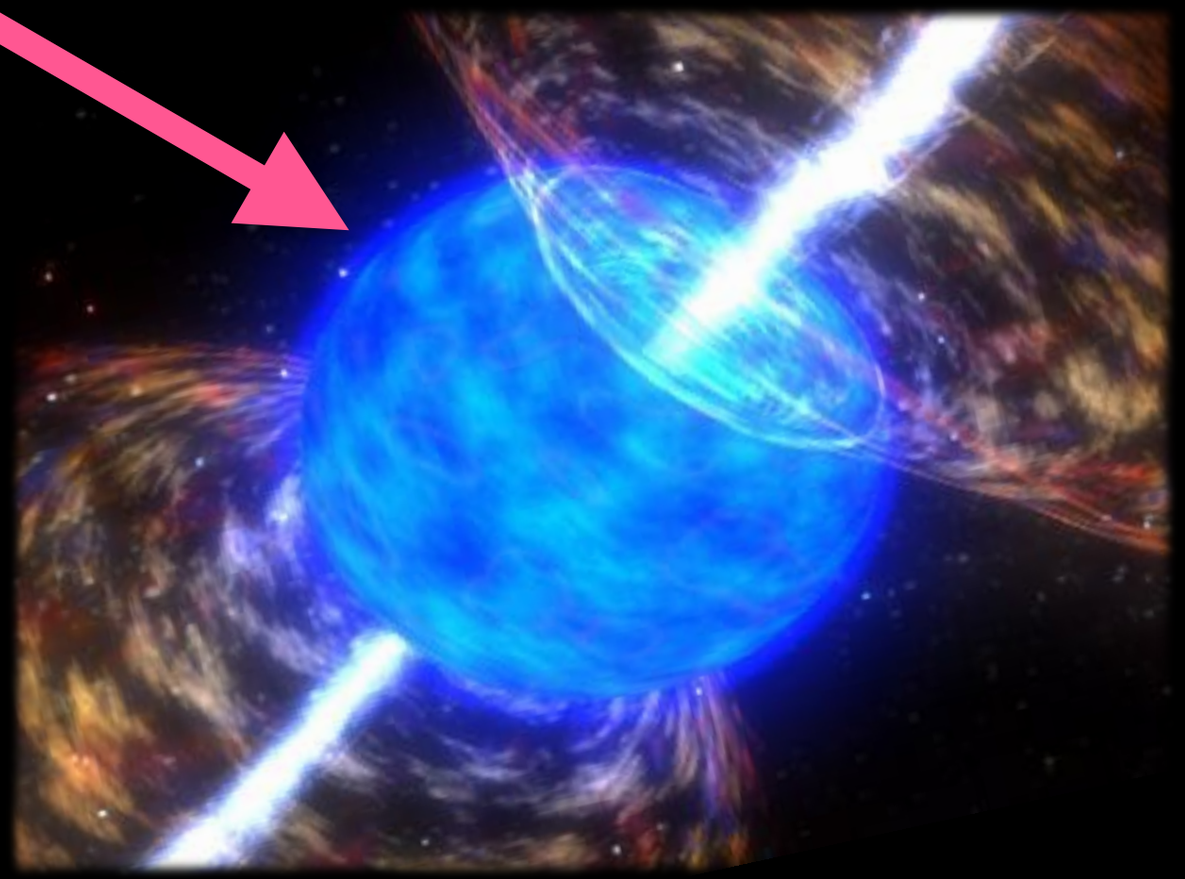


New Crossover Events Emerging!

Short Gamma-ray Bursts

Neutron Star Mergers + Kilonovae

Long Gamma-ray Bursts



Massive Star Deaths –> Supernovae

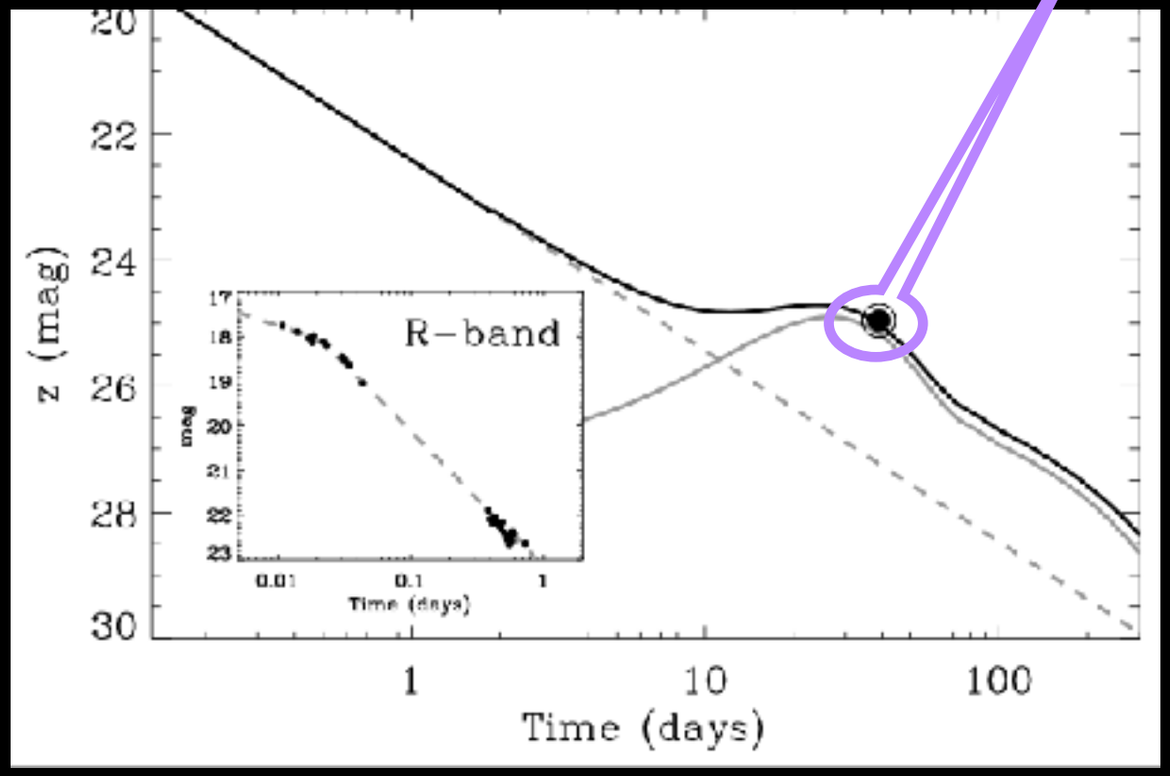
"Short" GRBs from Collapsars

GRB 040924

Soderberg+06, Wiersma+08

T90 ~ 1.29 s

SN bump!

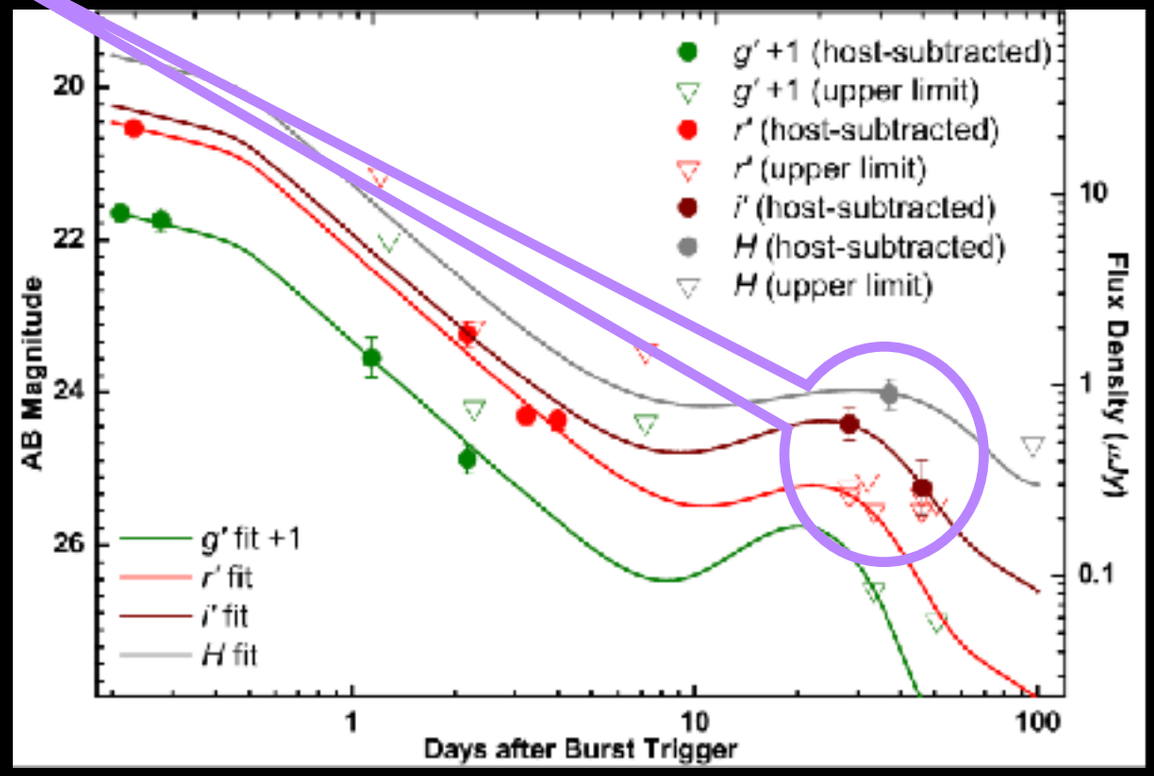


Soderberg+06

GRB 200826A

Ahumada+21, Rossi+21, Zhang+21

T90 ~ 1.14 s



Rossi+21

"Short" GRBs from Collapsars

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Soderberg+06, Wiersma+08

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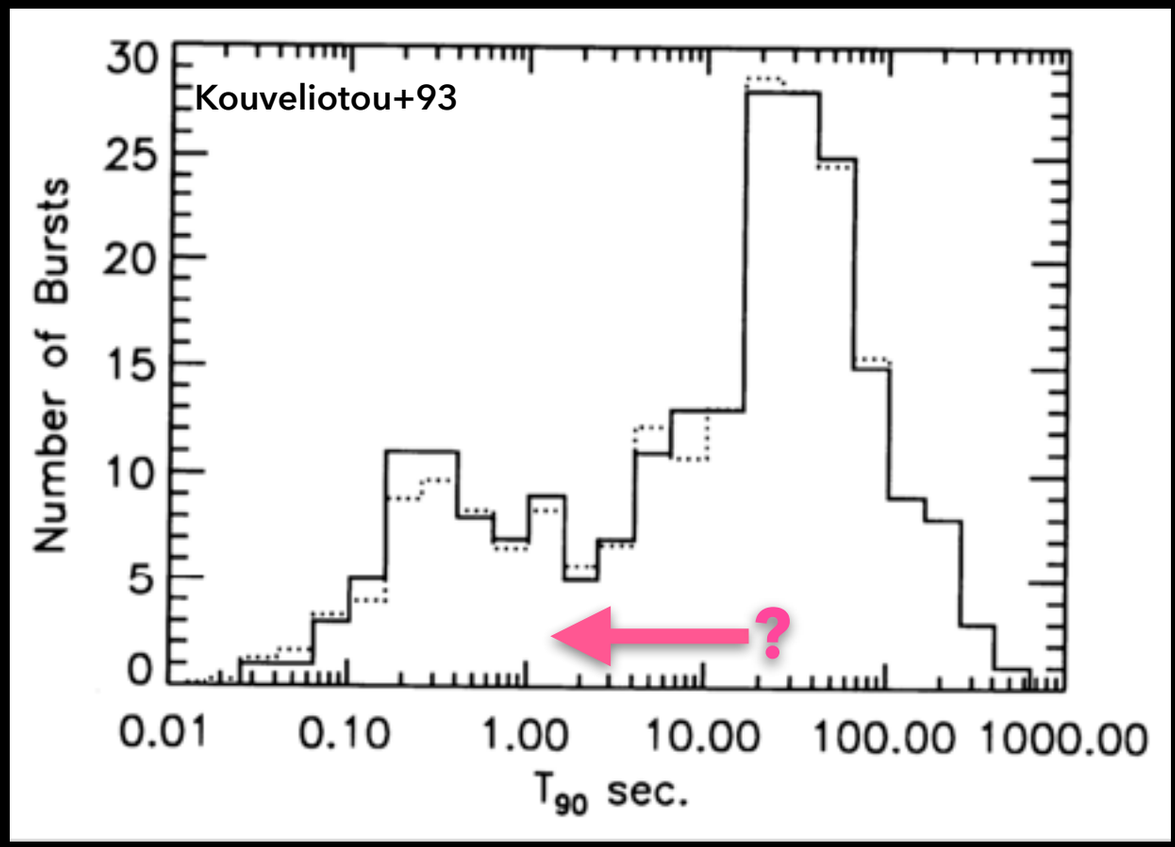
GRB 200826A

Ahumada+21, Rossi+21, Zhang+21

T90 ~ 1.14 s

Are we just seeing the tail of the long GRB distribution?

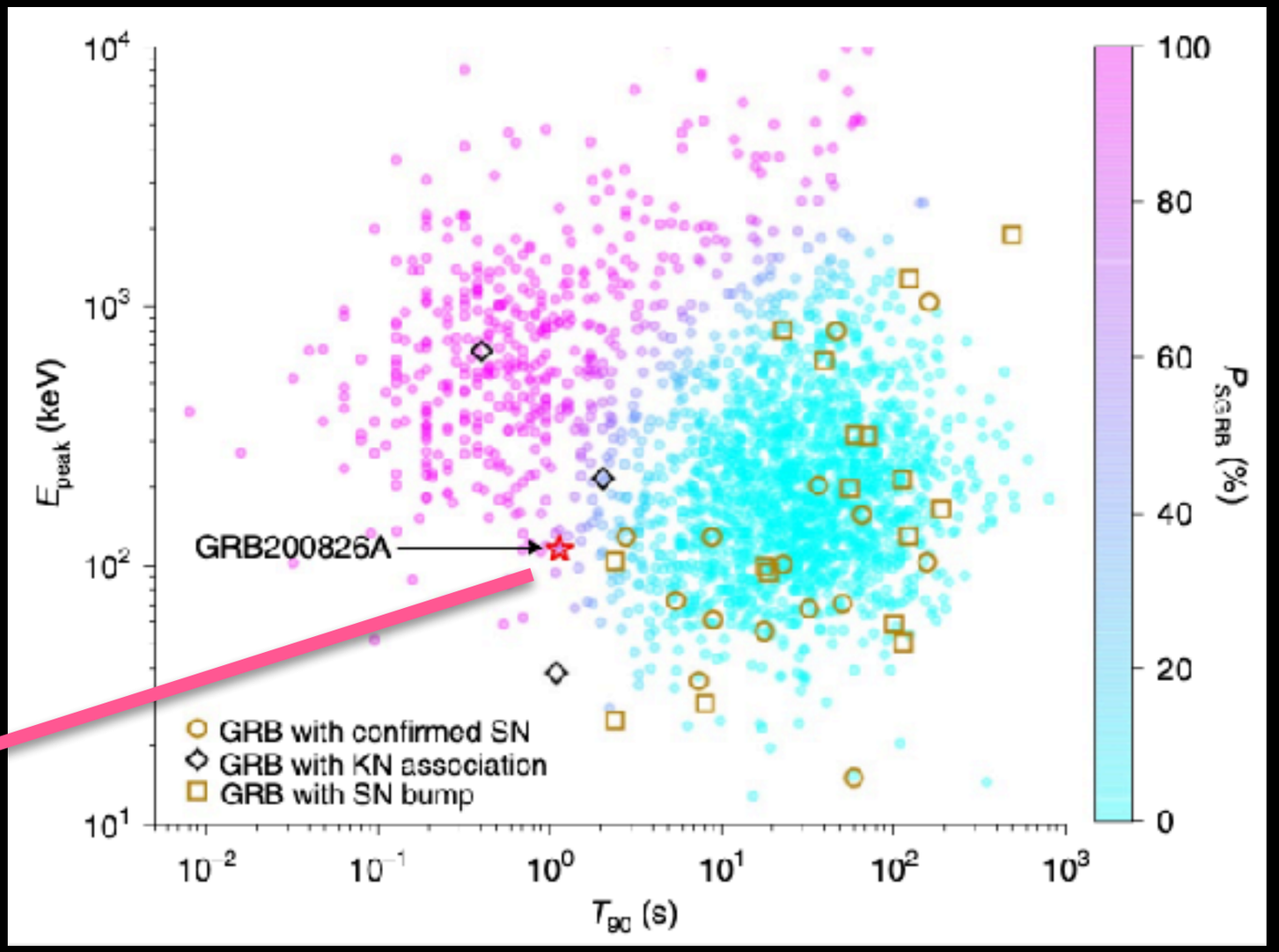


"Short" GRBs from Collapsars

Are we just seeing the tail of the long GRB distribution?

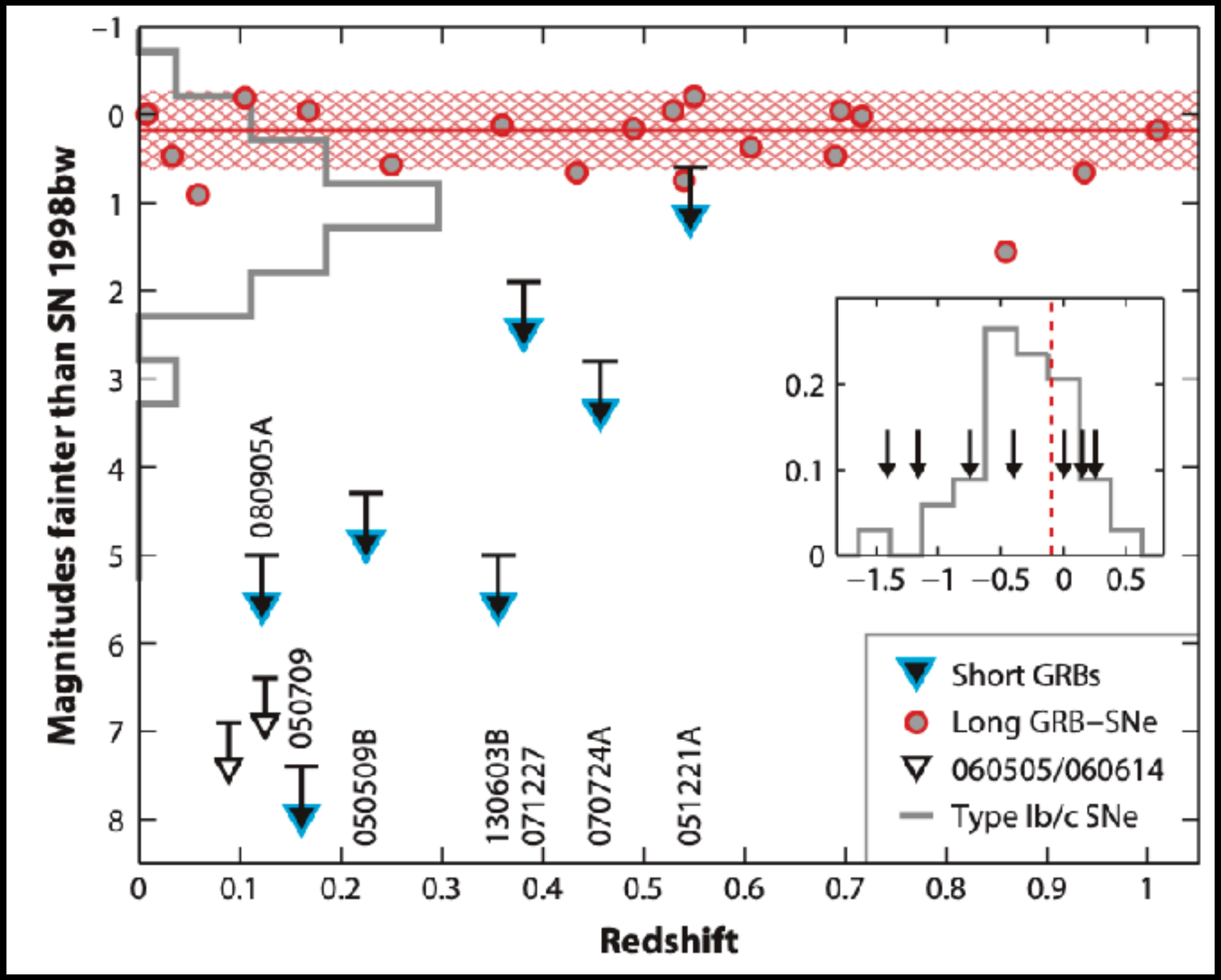
Likely

P_{SGRB} ~ 65%



Ahumada+21

Are these short GRB "interlopers" common?



Unlikely

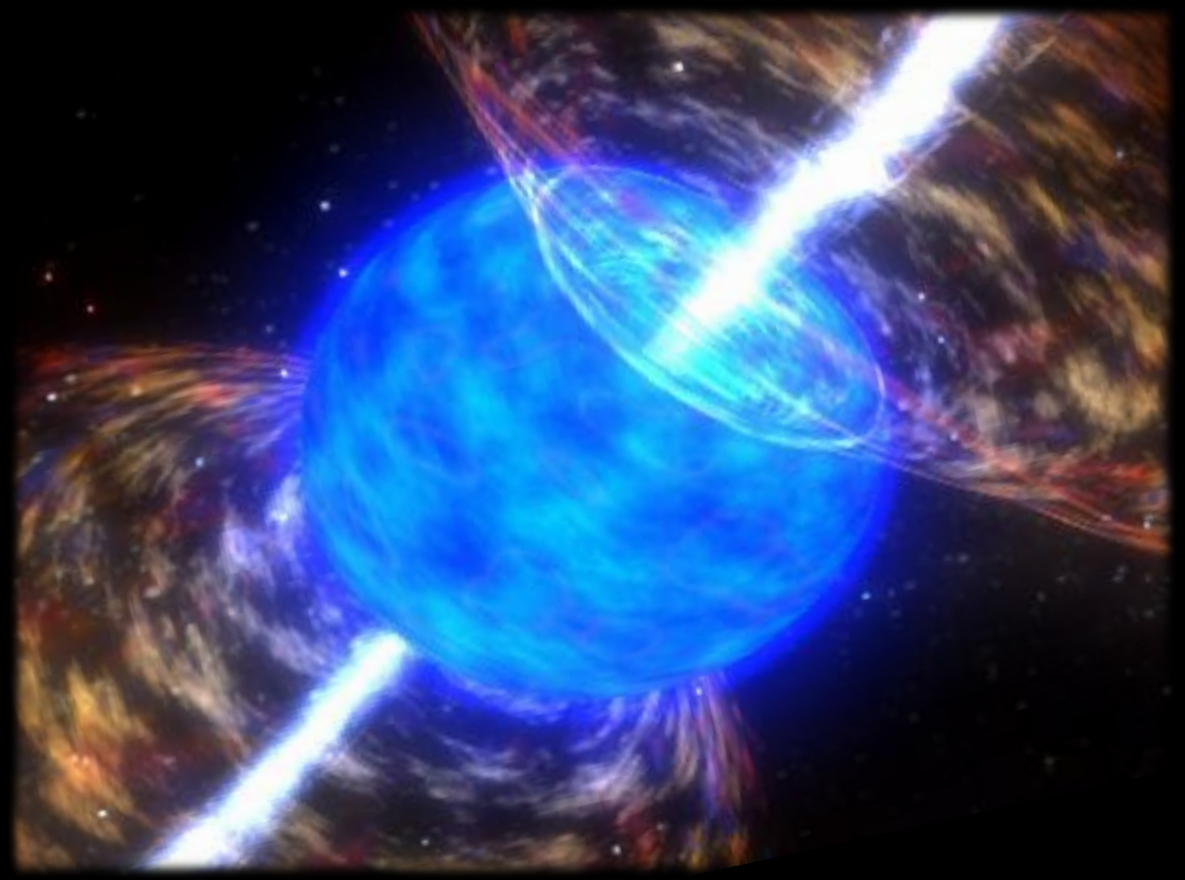
Berger+14

The GRB Paradigm

Short Gamma-ray Bursts

Neutron Star Mergers + Kilonovae

Long Gamma-ray Bursts

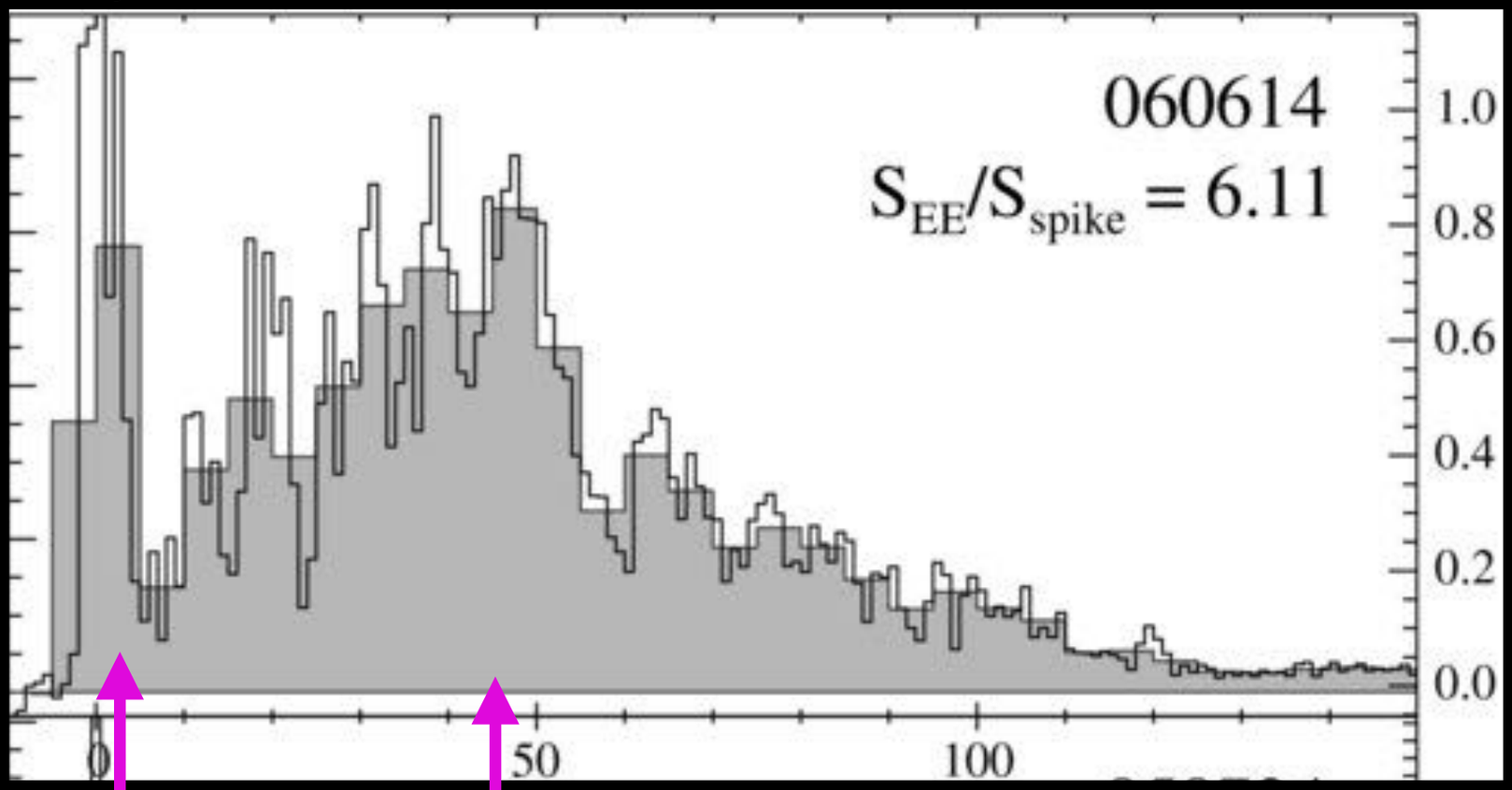


Massive Star Deaths –> Supernovae

SN-less LGRB 060614

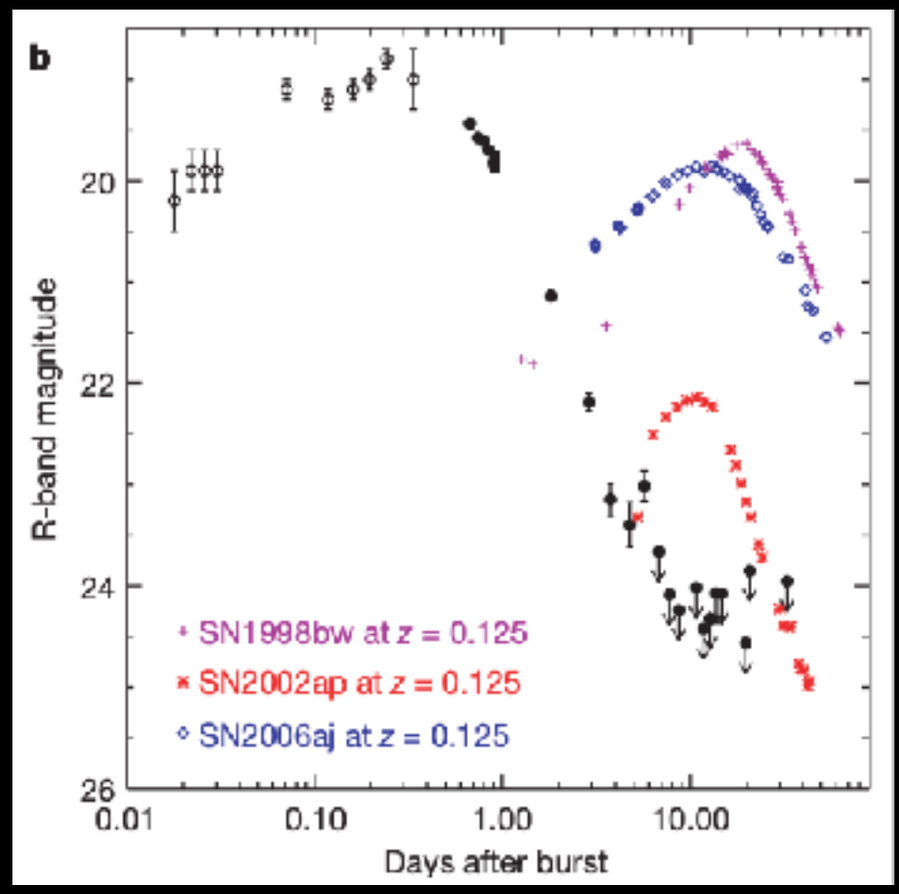
z=0.125, Duration ~102 s

Perley+09



Spectrally-hard pulse complex lasting ~6s

Tail of softer extended emission (seen for ~25% of SGRBs; ***Norris+10***)



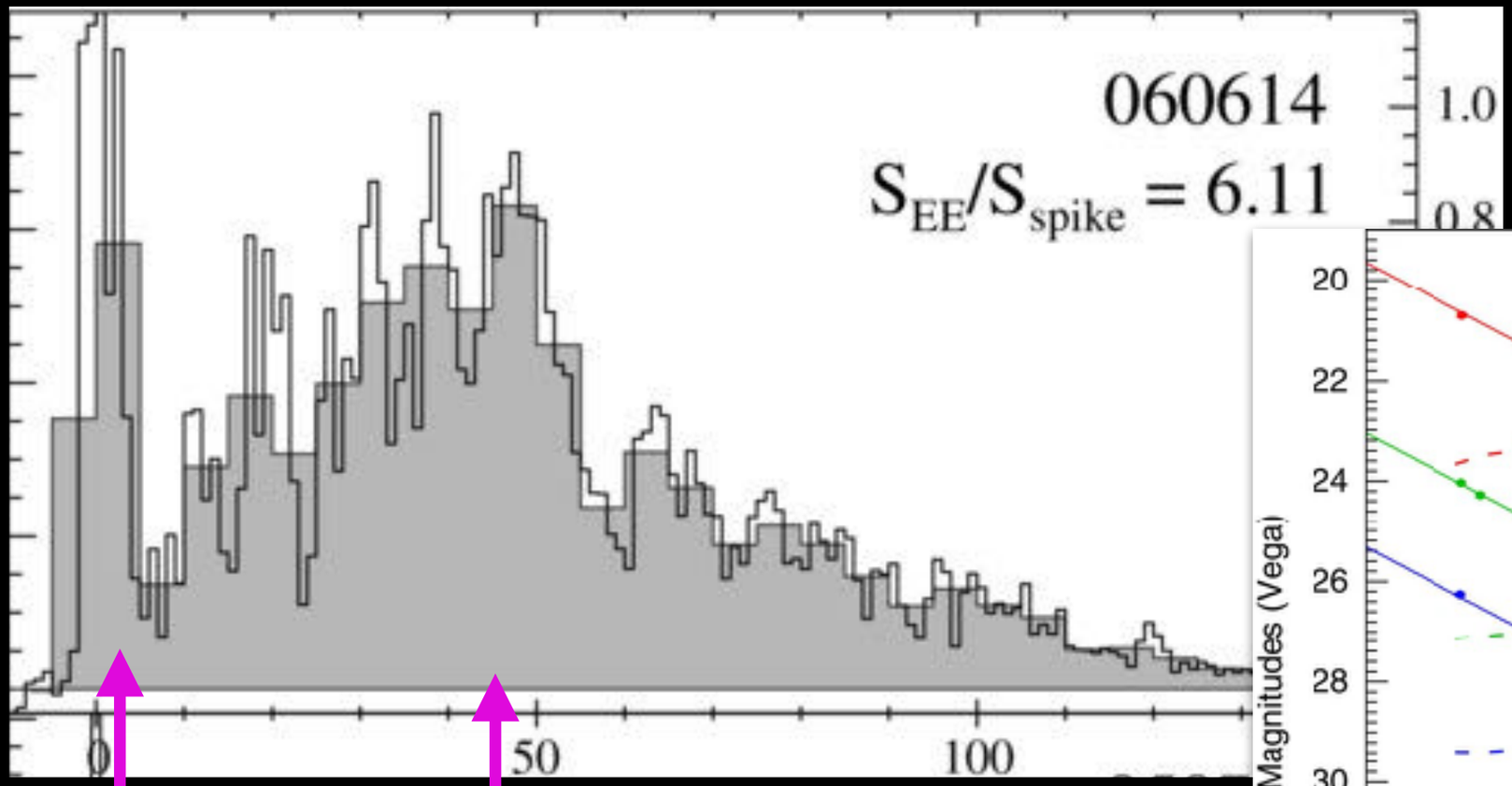
In star-forming region

High dust extinction ruled out (Fynbo+06, Della Valle+06, Gal-Yam+06, Gehrels+06)

EE-SGRBs and **GRB 060614**

Duration ~102 s

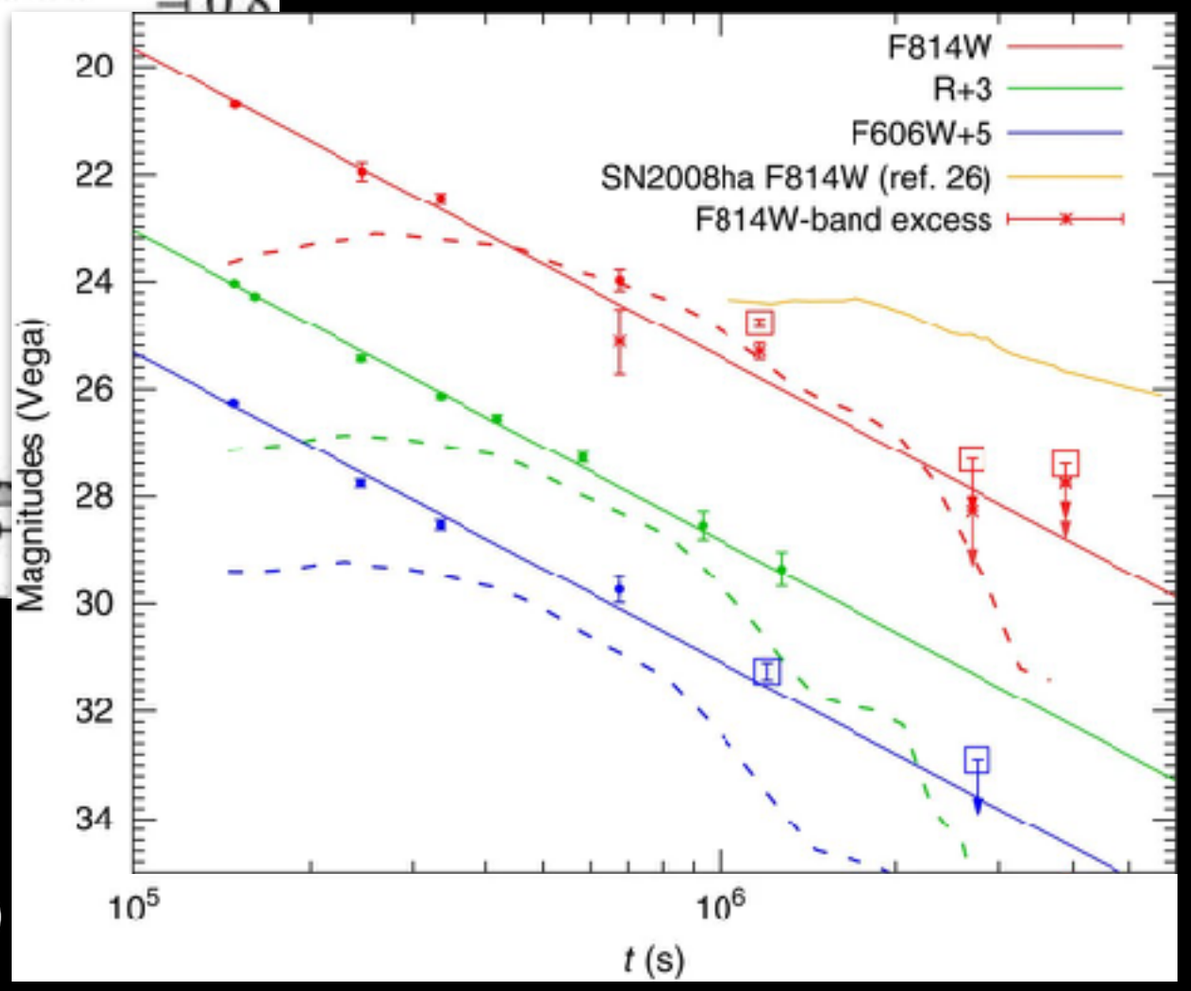
Perley+09



Spectrally-hard pulse complex lasting ~6s

Tail of softer extended emission (seen for ~25% of SGRBs; ***Norris+10***)

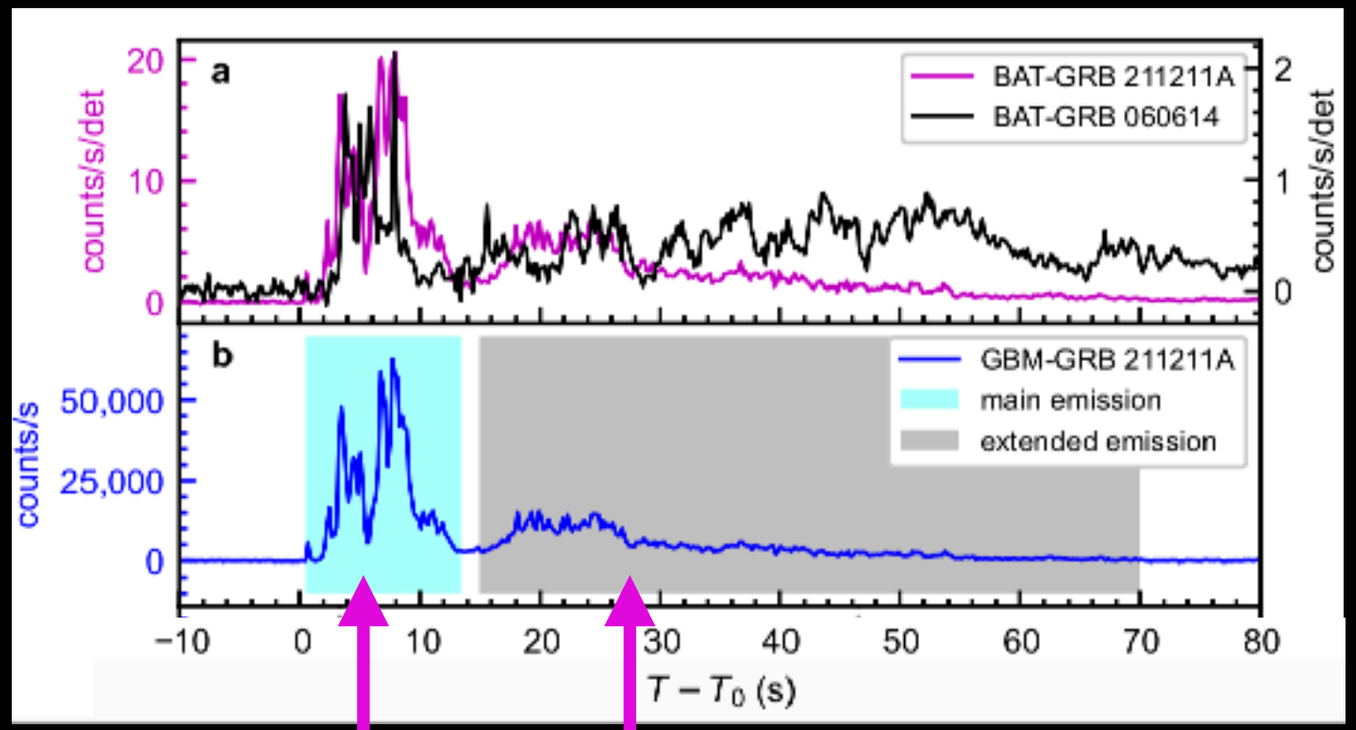
Yang+15;
KN claim without IR



GRB 211211A: Exciting Ingredients

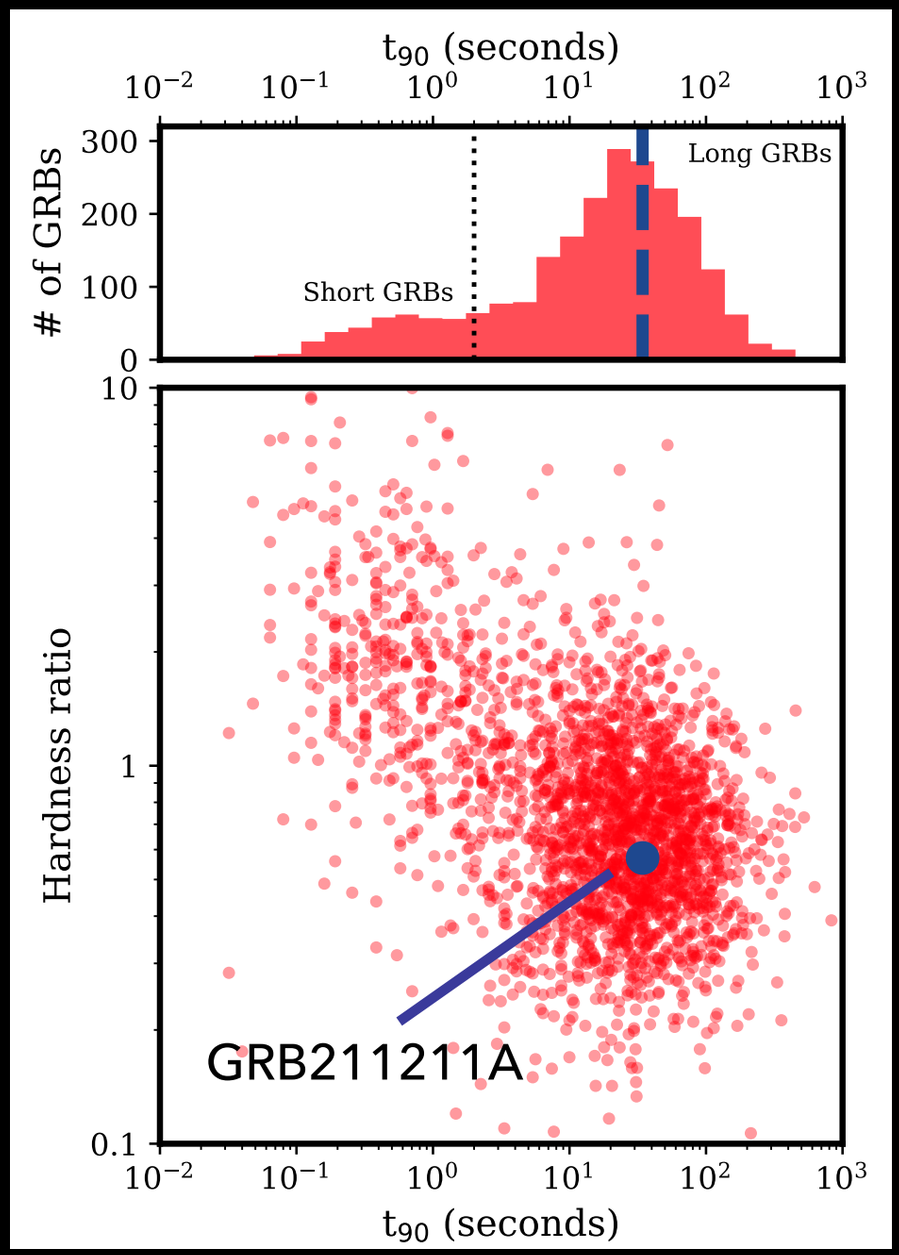
An ambiguous gamma-ray light curve

Yang+22



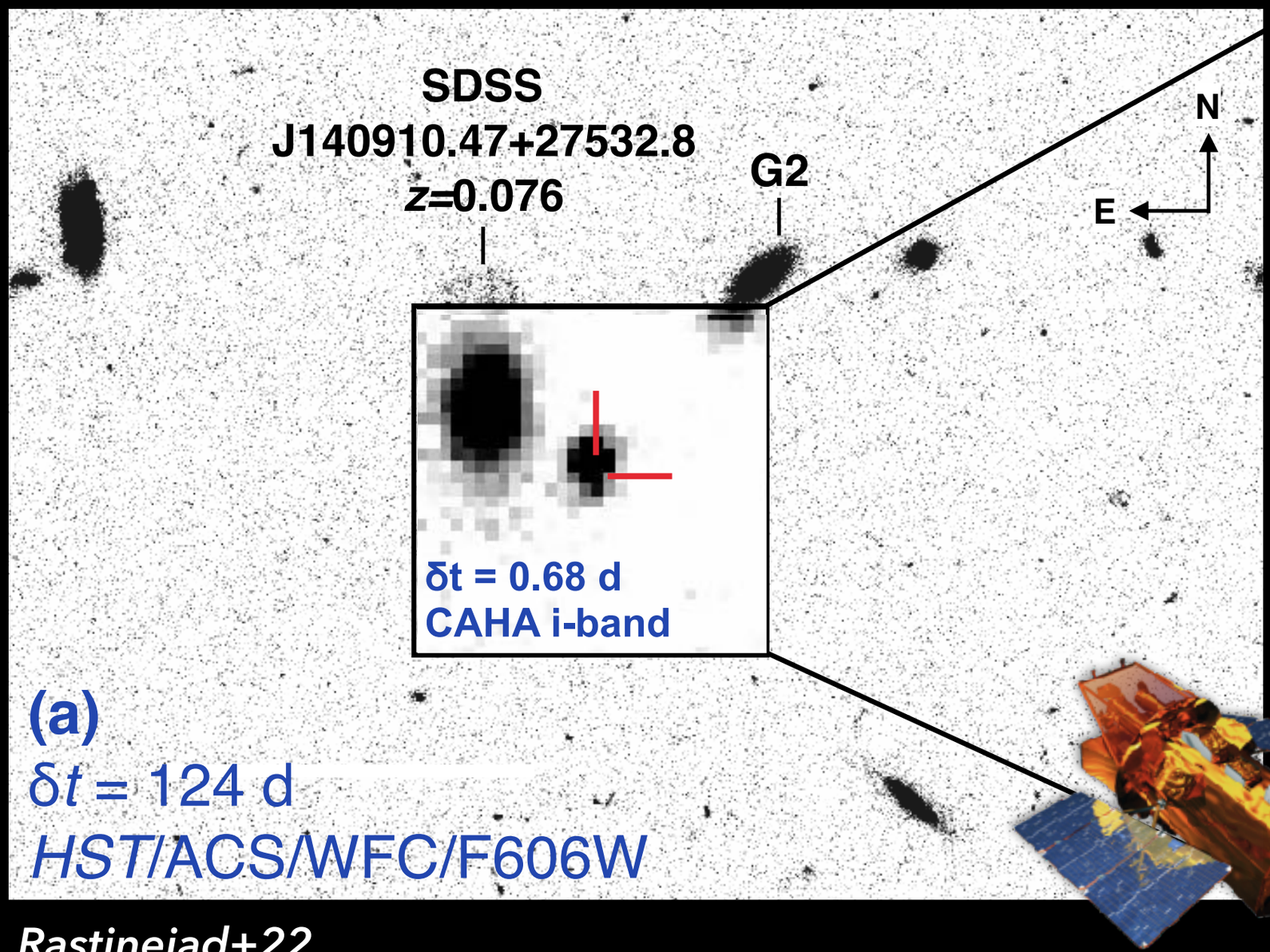
Spectrally-hard pulse complex lasting ~12s

Tail of softer extended emission (seen for ~25% of SGRBs; ***Norris+10***)

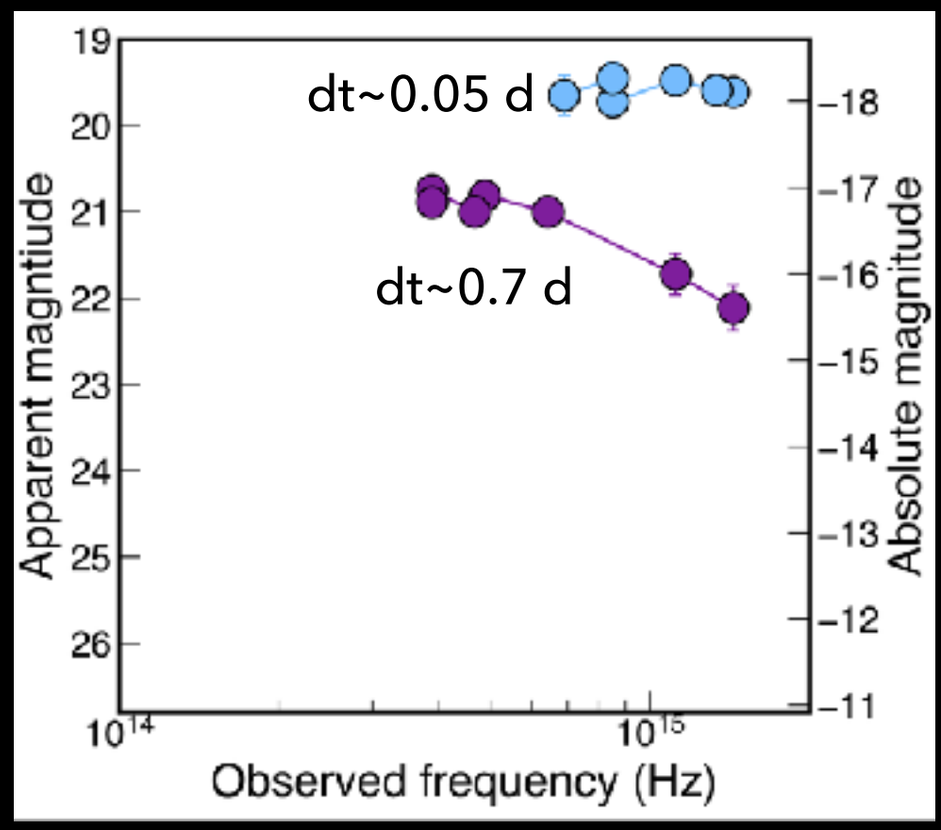


Rastinejad+22

Observing a red excess following the **50-s duration GRB 211211A at 350 Mpc**



Rastinejad+22

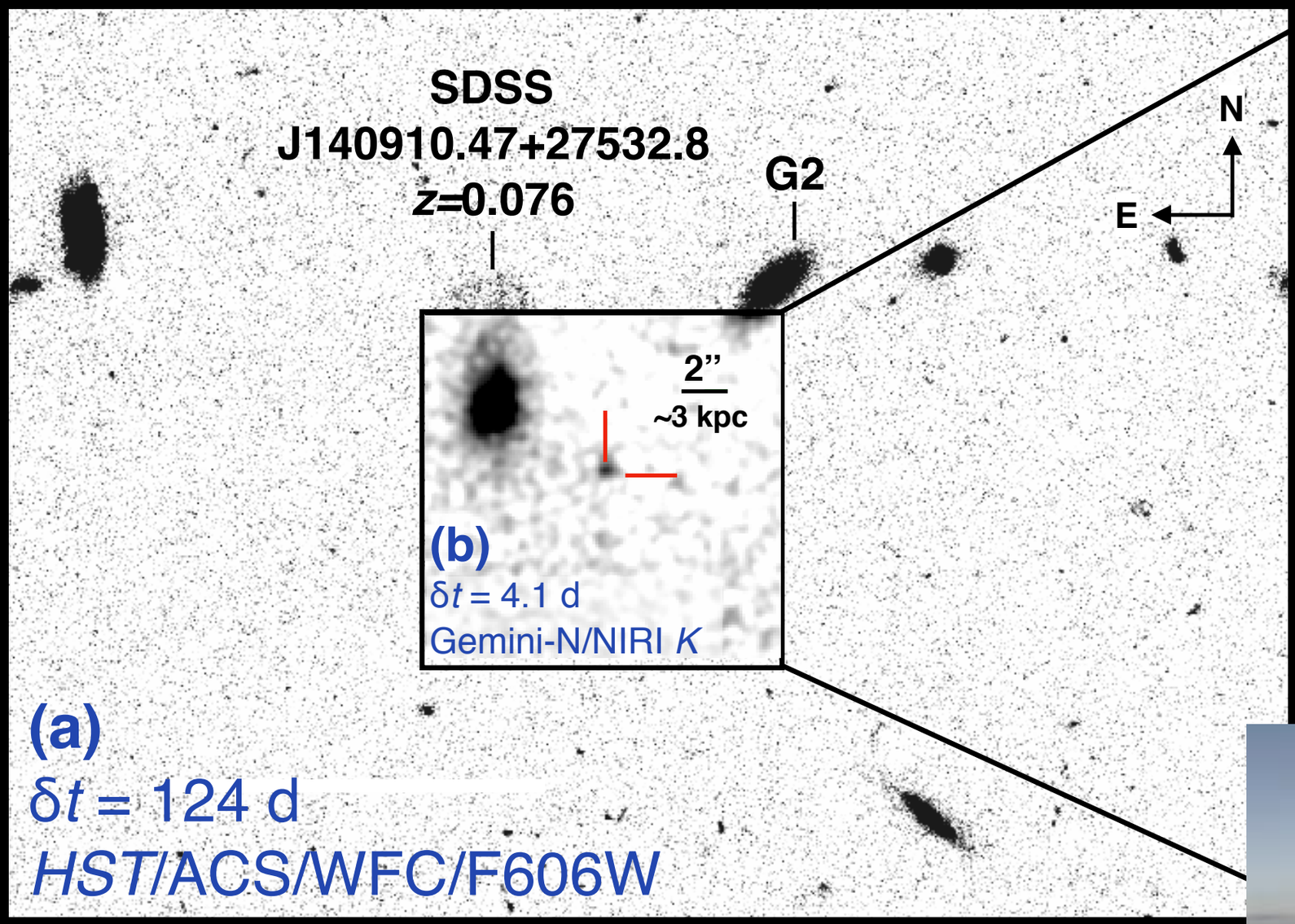


Swift/XRT, UVOT

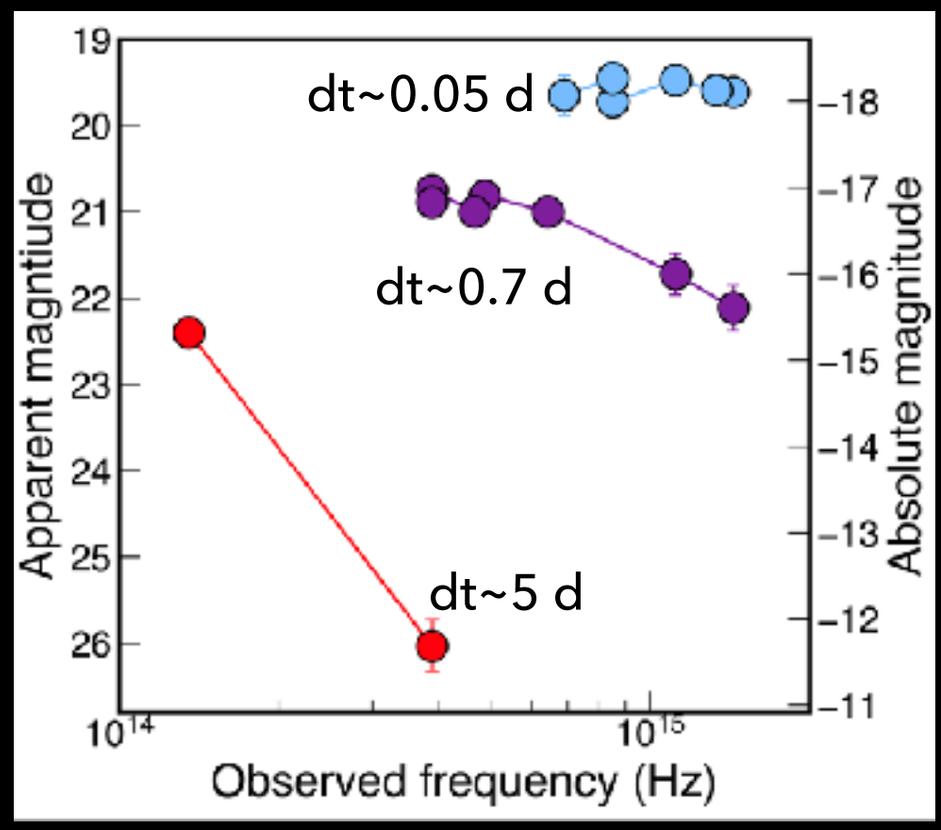
CAHA

NOT

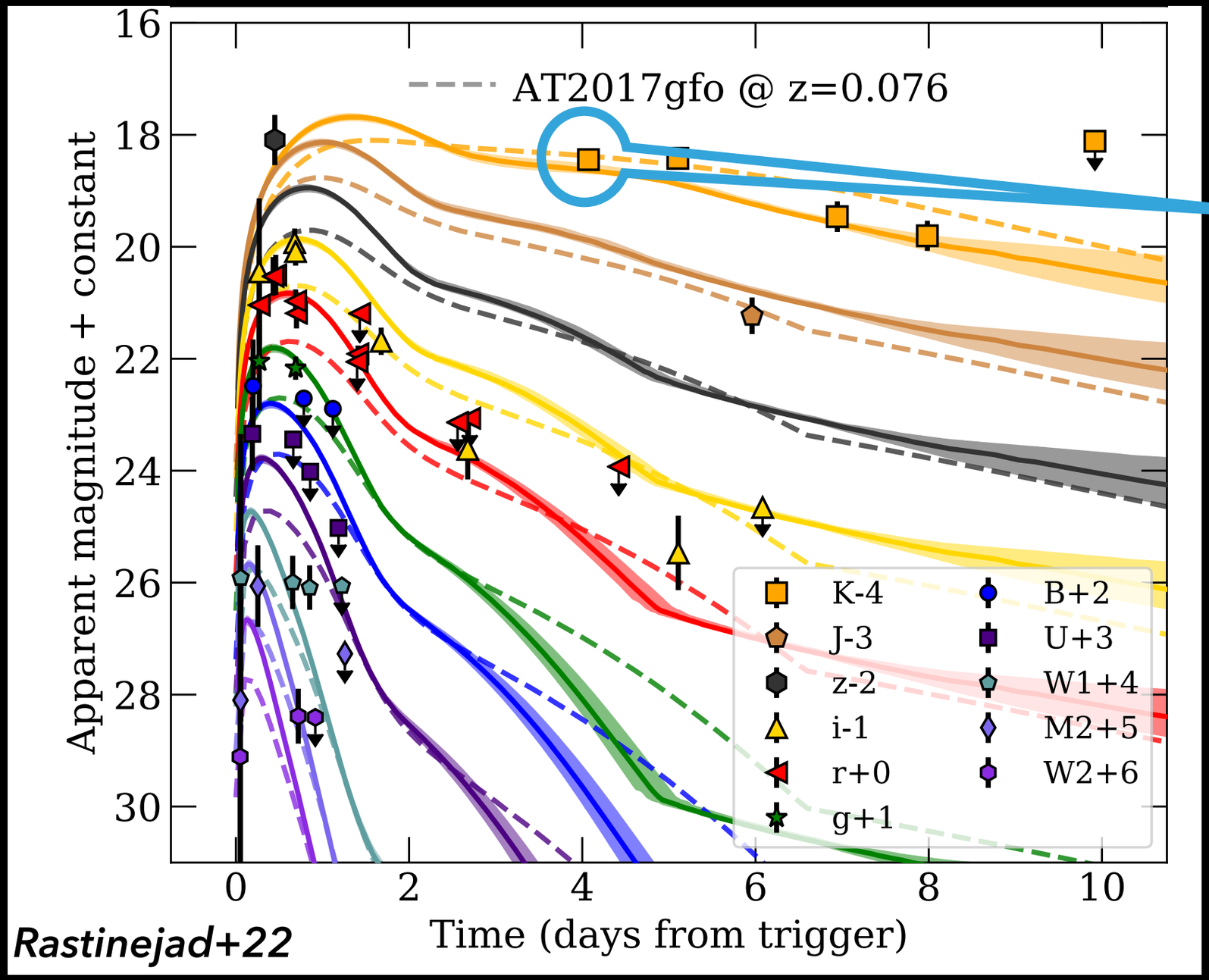
Observing a red excess following the **50-s duration GRB 211211A at 350 Mpc**



Rastinejad+22

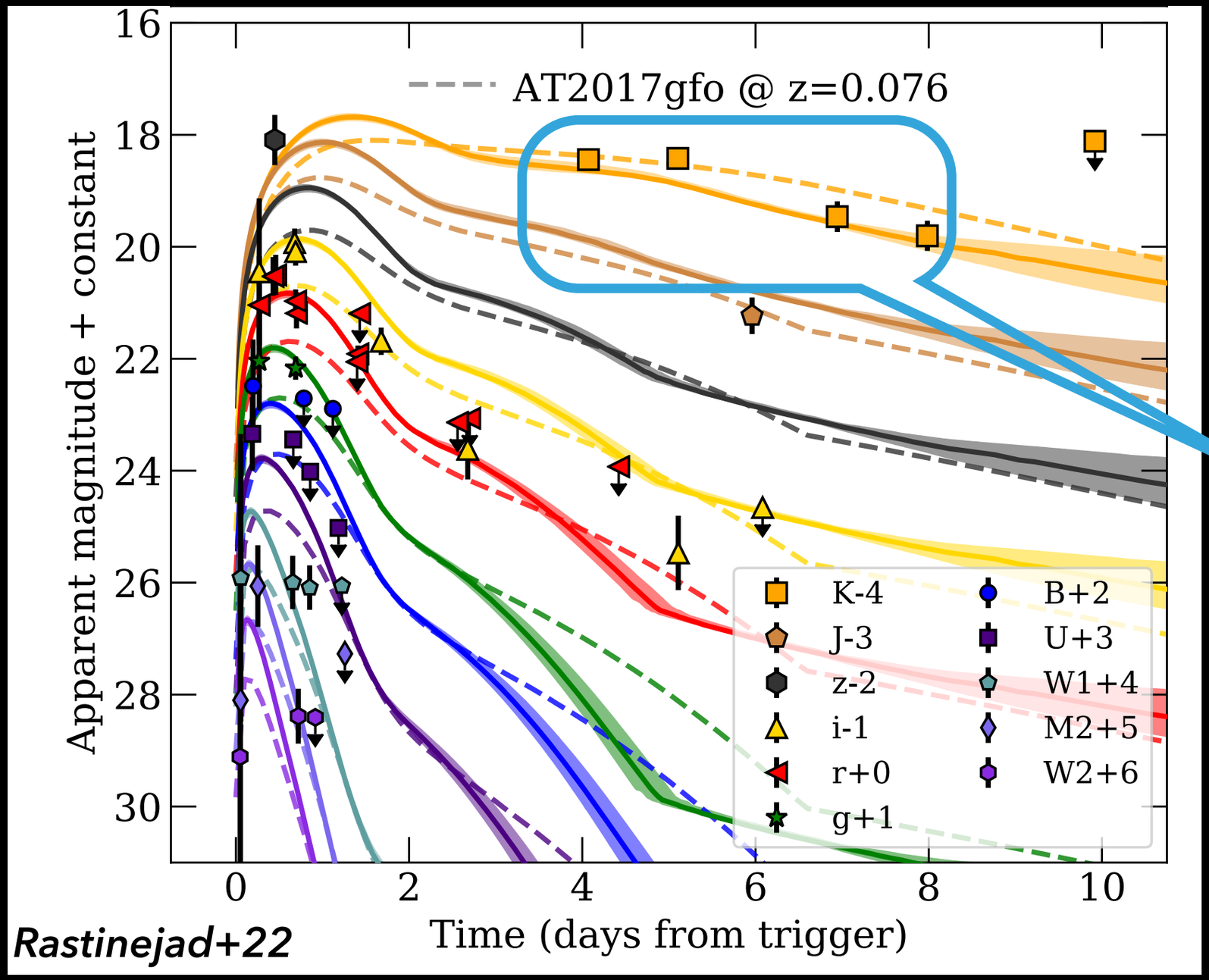


A Kilonova followng the **50-s duration GRB 211211A**



Nearly the same K-band luminosity as AT2017gfo

A Kilonova followng the **50-s duration GRB 211211A**



Nearly the same K-band luminosity as AT2017gfo

K-band fades on similar timescales to AT 2017gfo

Good fit to kilonova model of M_{ej}~0.04 $M_\odot$

Alternate explanations to a kilonova

What about a supernova?

Upper limit at 18 days rules out SN > 200 times fainter than 1998bw + any known GRB SN at z<0.5

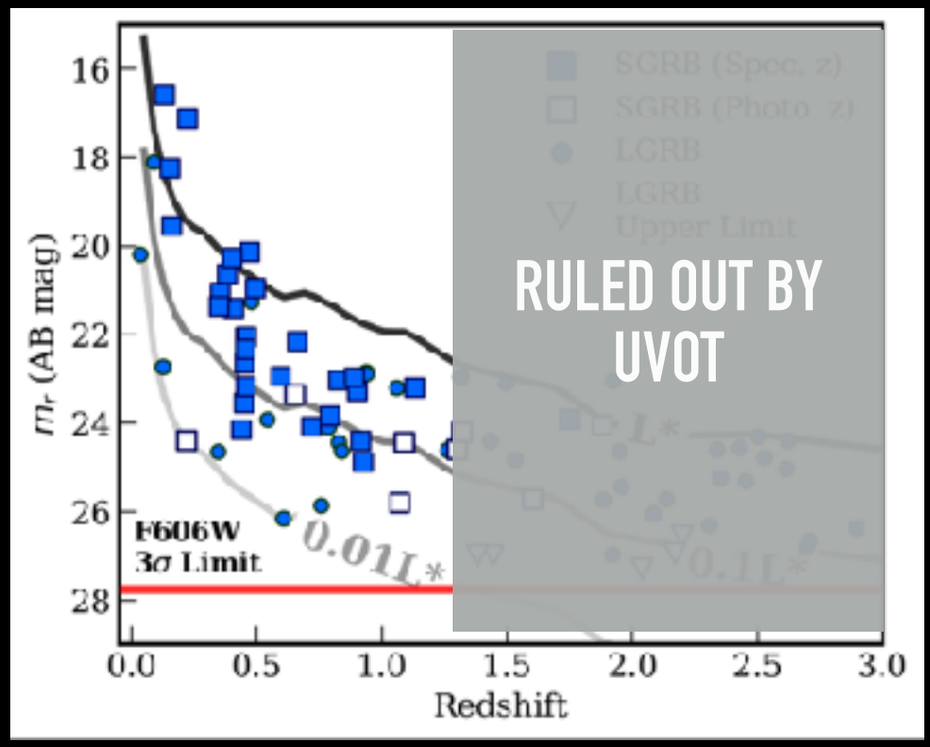
Light curve poorly fit with Ni56 model

What about host association?

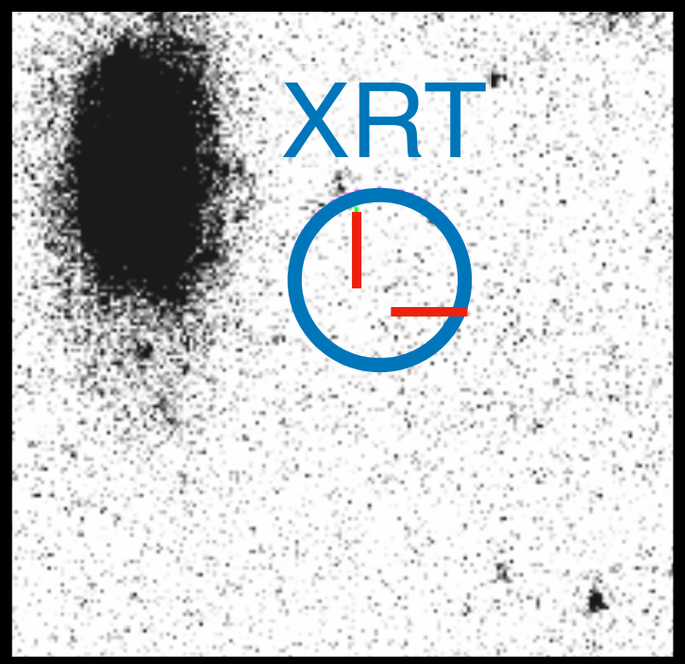
Higher-z scenarios limited by HST observations + UVOT detection

What about dust heating (e.g., Waxman+22)**?**

No signs of star formation at the location, X-ray+UV spectra shows no signs of dust



Data from Hjorth+12, Fong+22

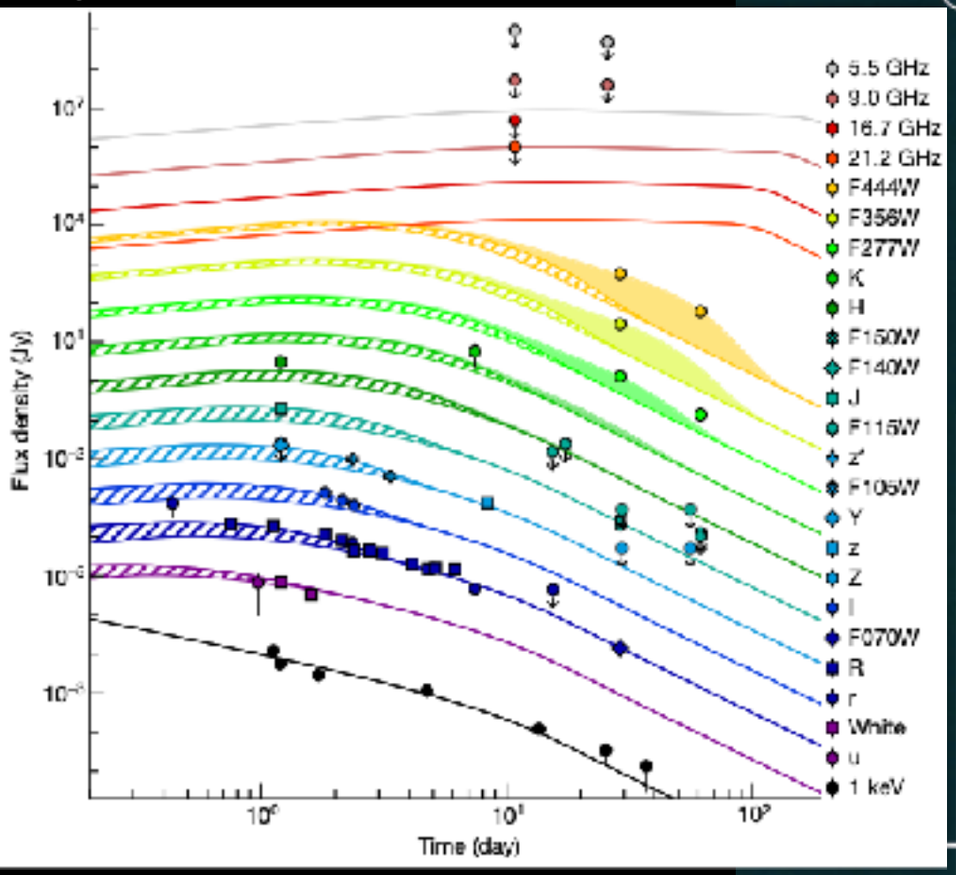


Rastinejad+22

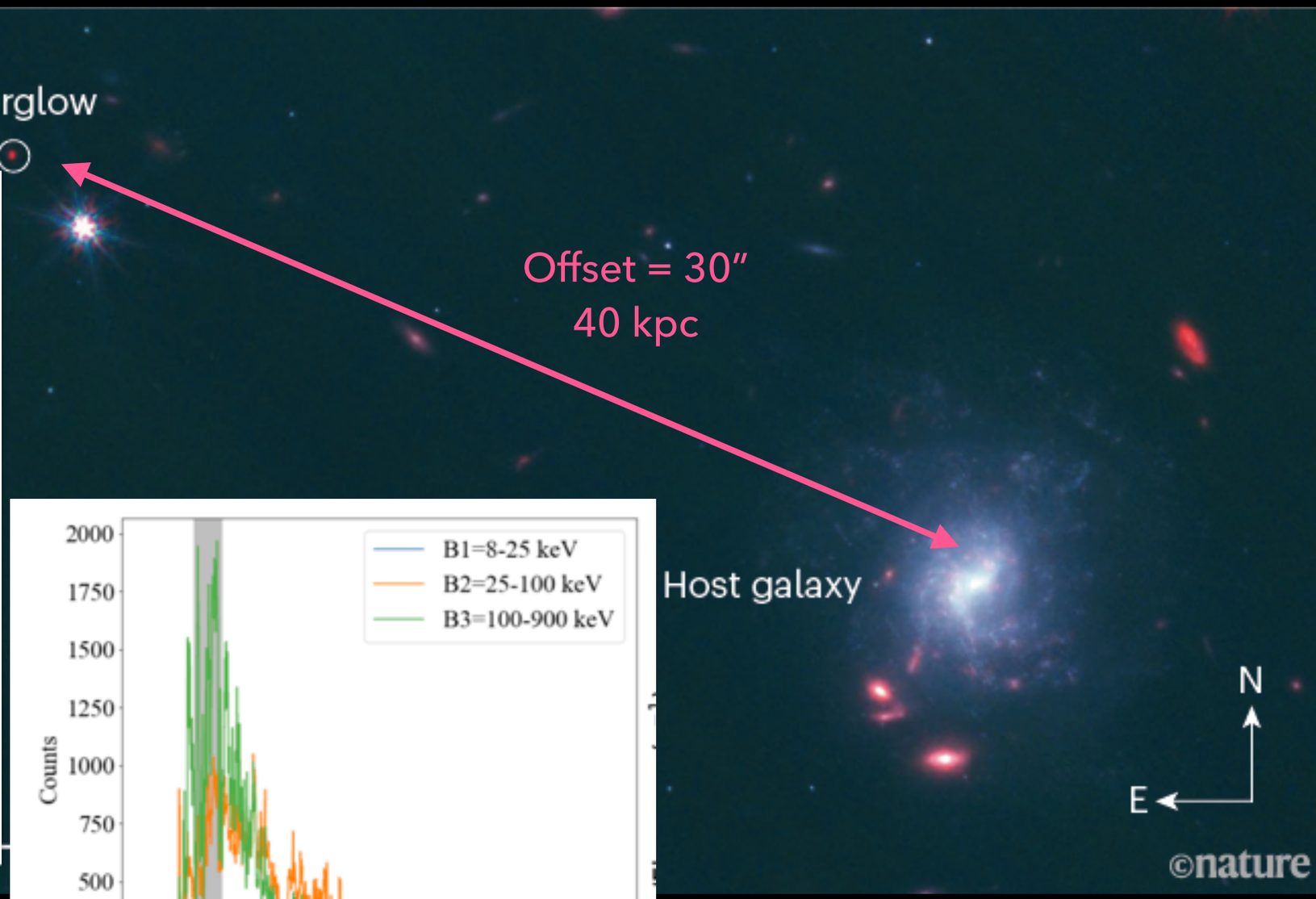
A second very nearby LGRB KN

GRB 230307A at 300 Mpc

Yang+24



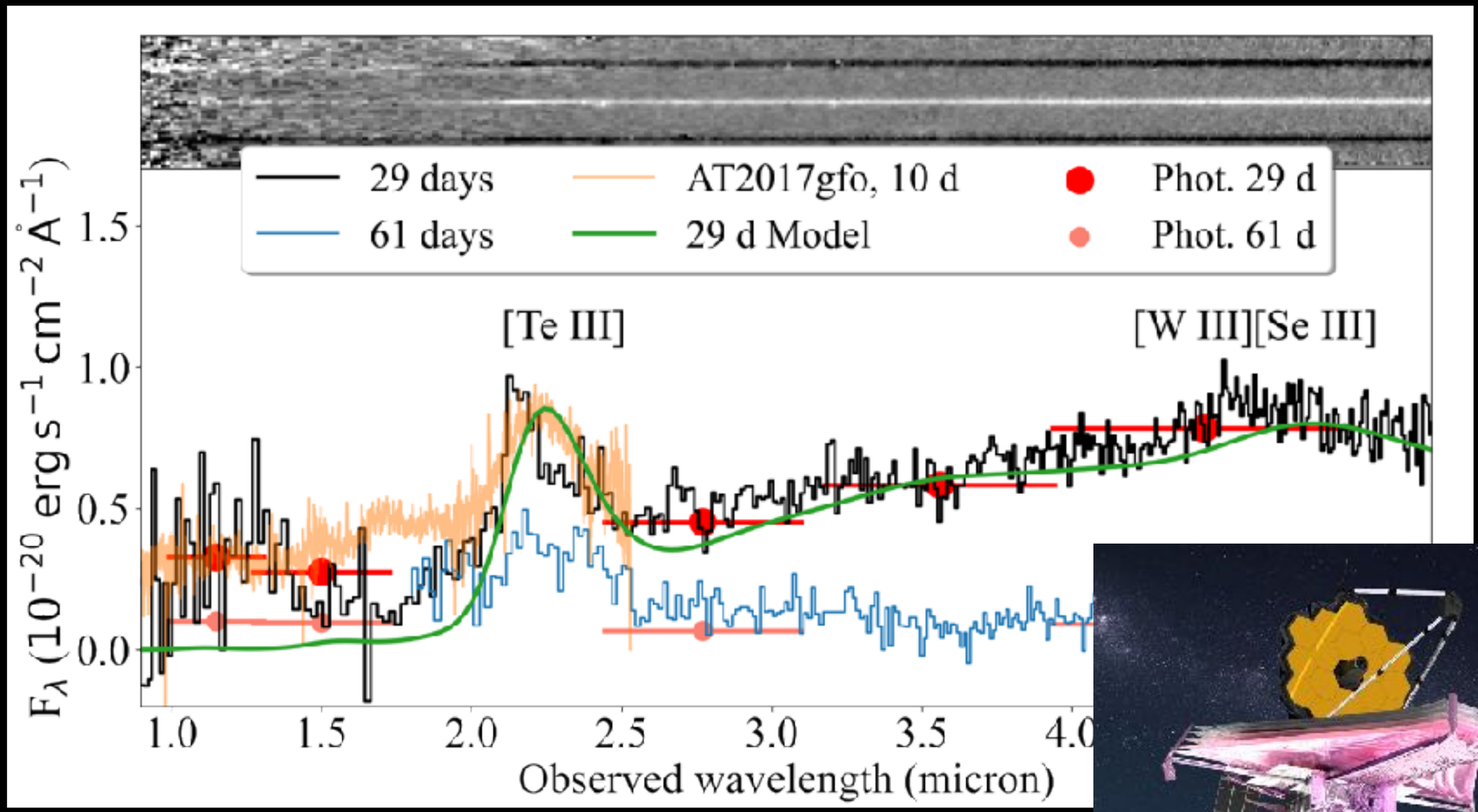
T90 ~ 35 s



Levan+24

A second very nearby LGRB KN

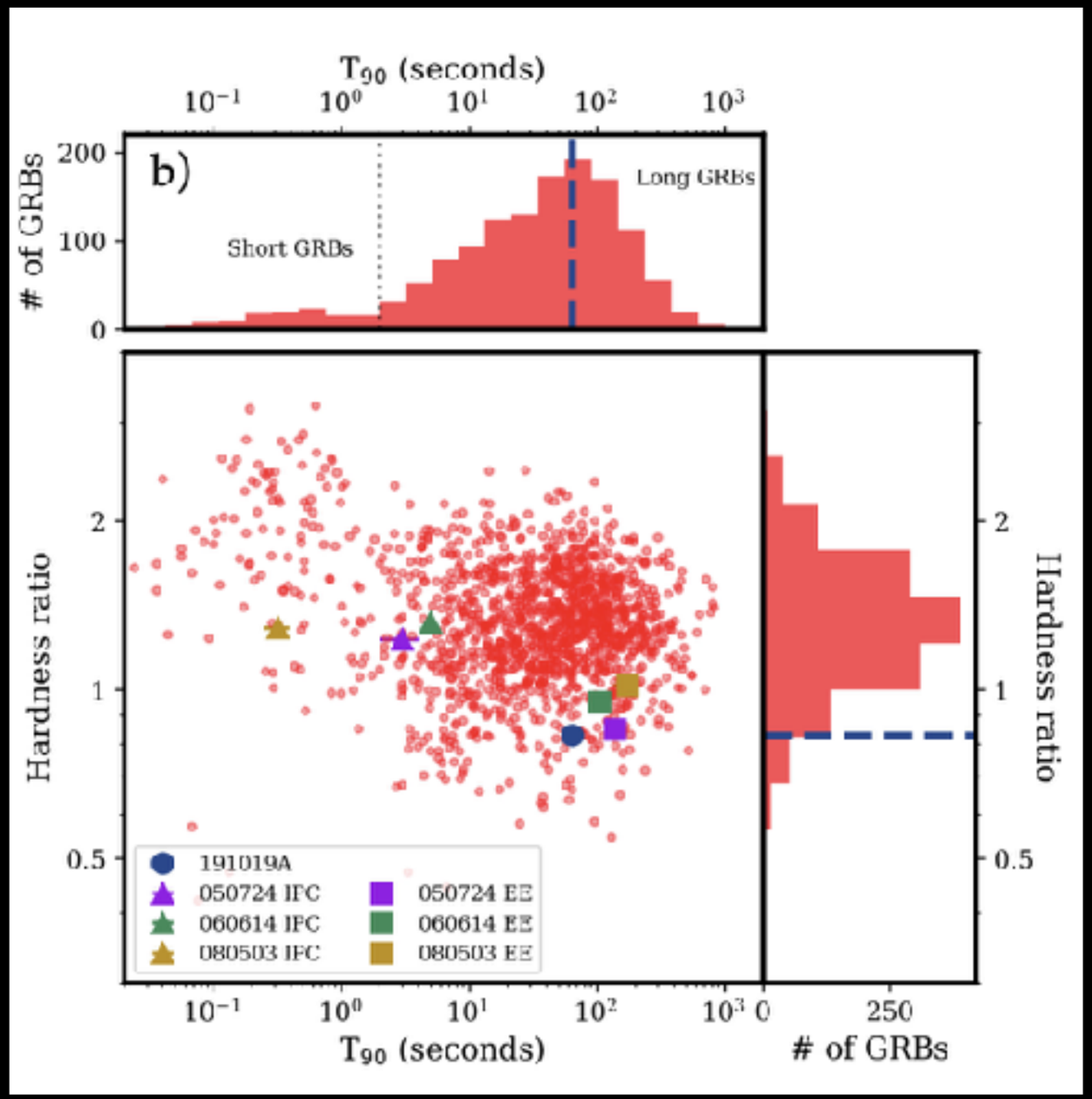
GRB 230307A at 300 Mpc



Levan+24; see also Gillanders+23

A SN-less LGRB in an atypical location

GRB 191019A at z=0.248

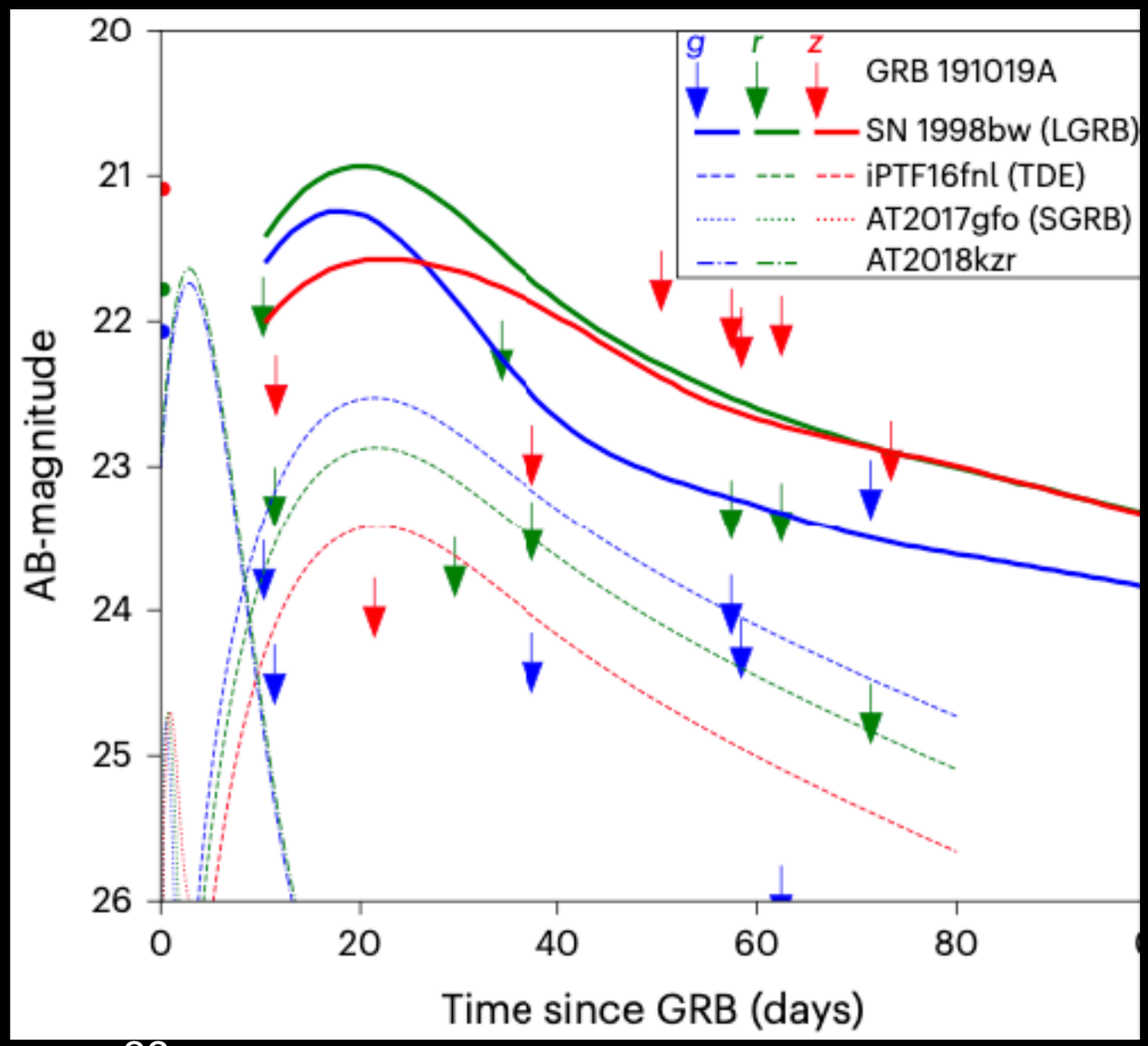


Levan+23

A SN-less LGRB in an atypical location

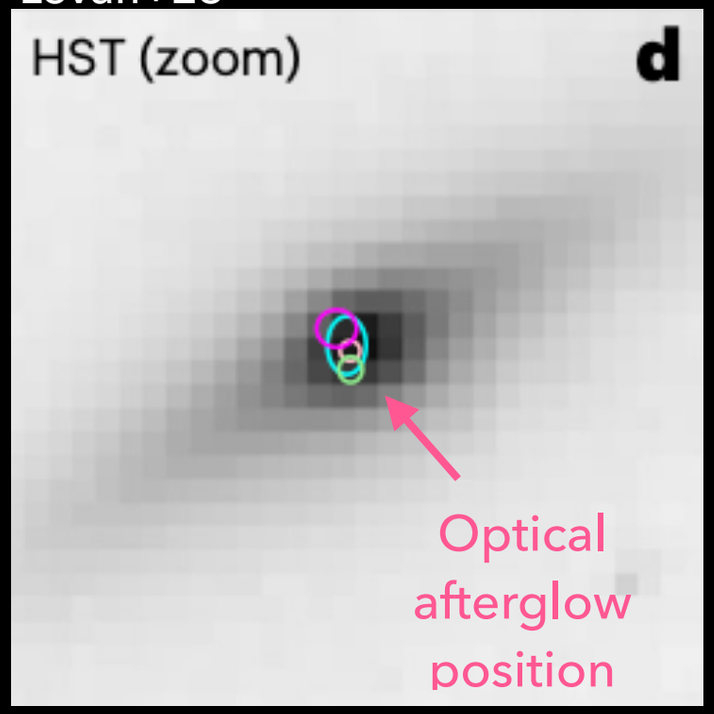
GRB 191019A at z=0.248

Optical AG detected but deep limits on a SN



Levan+23

Levan+23



Nuclear

Galaxy spectrum + fitting favor little ongoing SF

↓

Dynamical formation of merger?

Summary of the Observed Events

GRB 060614

Della Valle+06, Gal-Yam+06, Gehrels+06, Yang+15

GRB 211211A

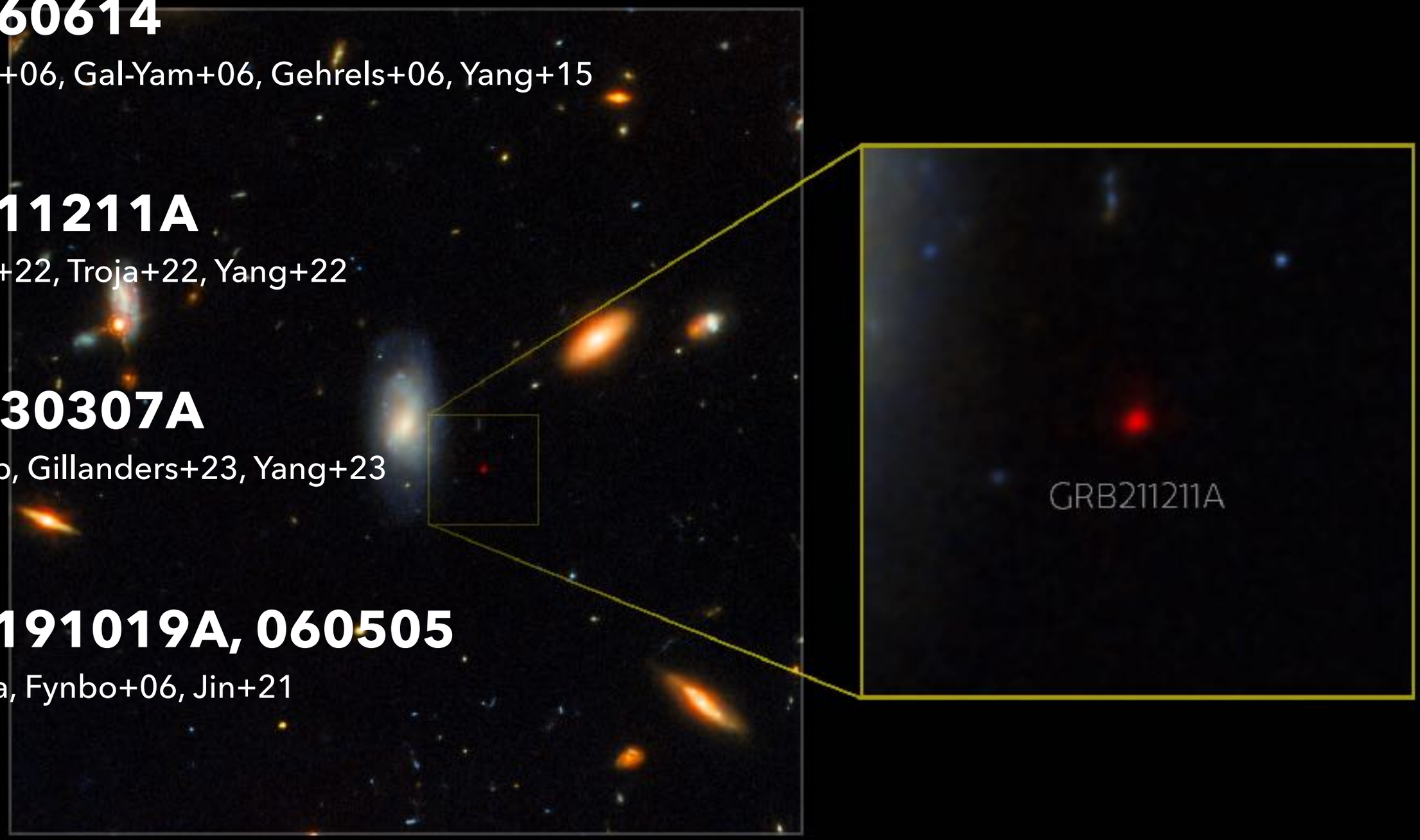
Rastinejad+22, Troja+22, Yang+22

GRB 230307A

Levan+23b, Gillanders+23, Yang+23

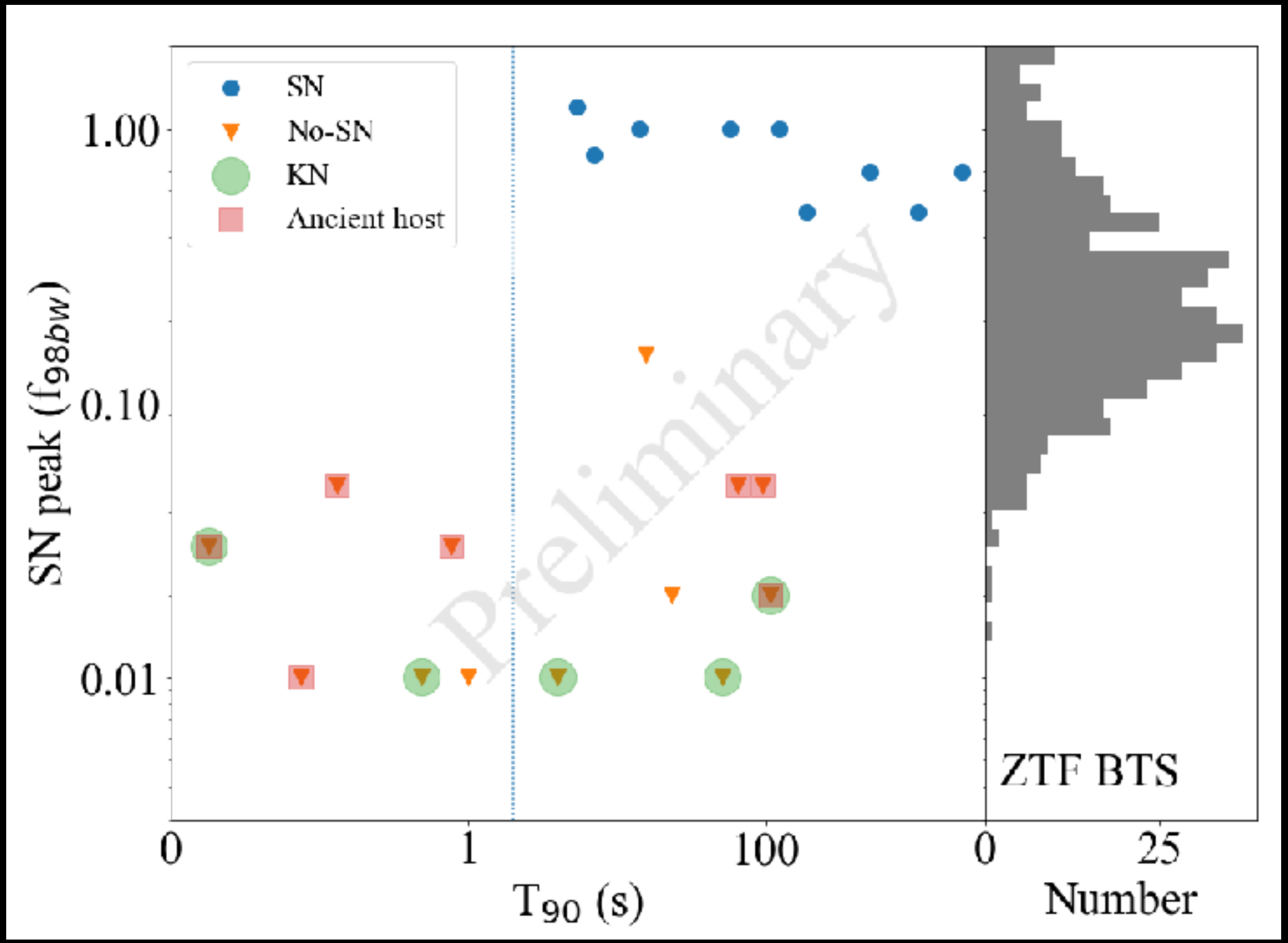
GRBs 191019A, 060505

Levan+23a, Fynbo+06, Jin+21



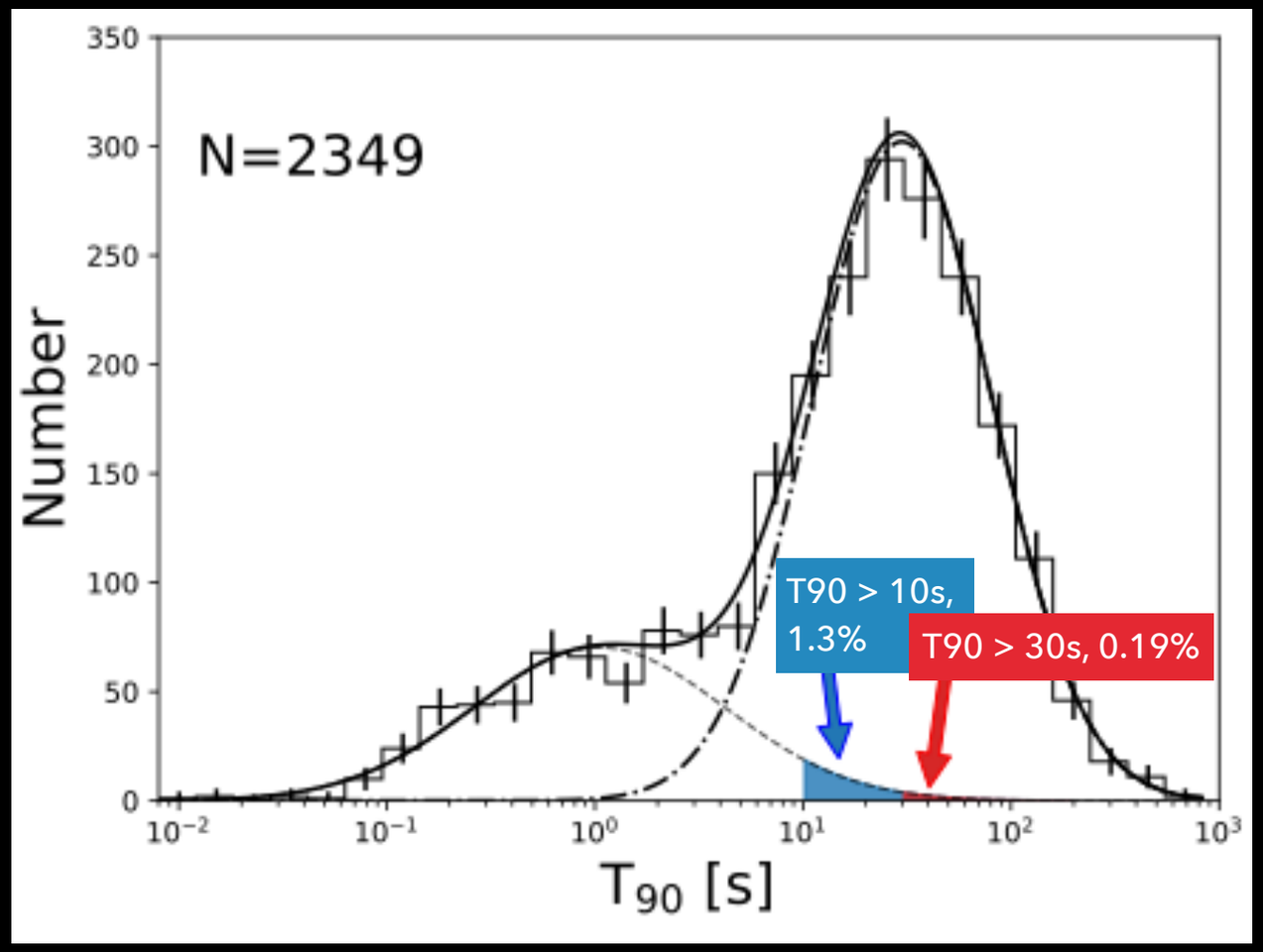
International Gemini Observatory/NOIRLab/NSF/AURA/M. Zamani; NASA/ESA

Alternate explanations to a kilonova



Levan+, in prep

Are we just seeing the tail end of the sGRB distribution?



Fermi GRBs, Veres+23

Seems unlikely

Since Swift's Launch of GRBs found at z<0.3...

~5 LGRB KNe

8 LGRB SNe *(Dainotti+22)*

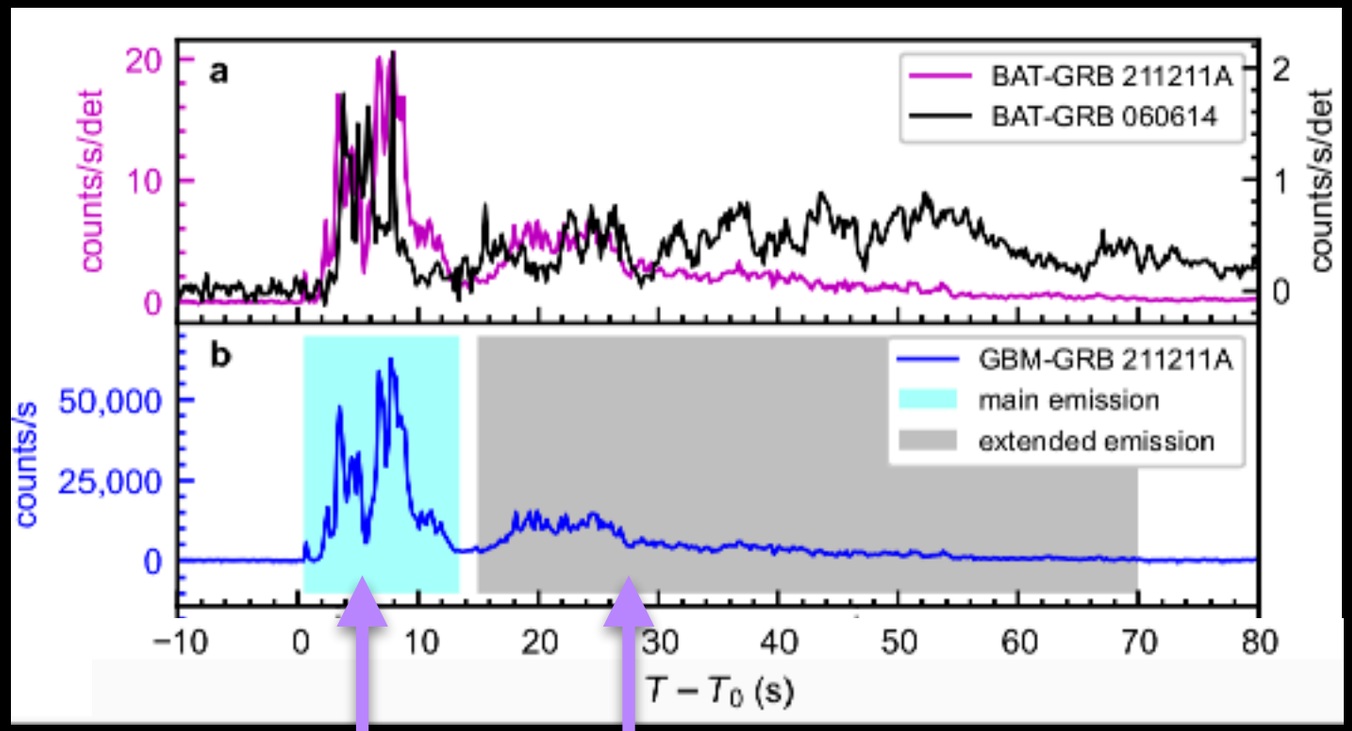
Significant fraction of nearby LGRBs

~9SGRBs detected *(Fong+22)*

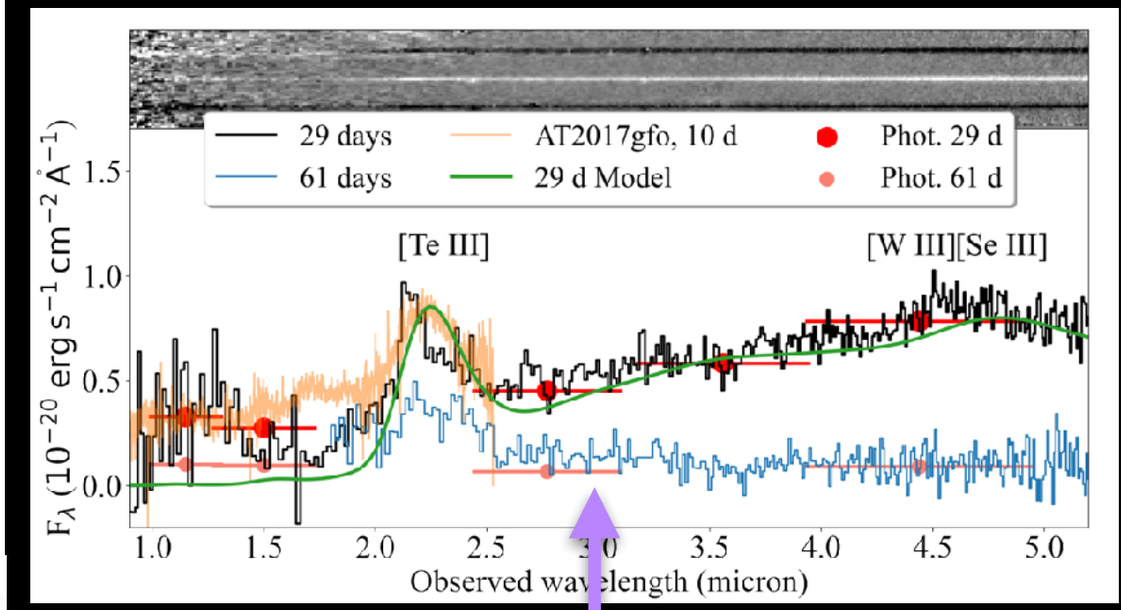
~1/3 of mergers from LGRBs

What source(s) can explain merger-driven LGRBs?

Yang+22



Levan+24



Spectrally-hard pulse complex lasting ~12s

Tail of softer extended emission (seen for ~25% of SGRBs; ***Norris+10***)

Lanthanide-rich kilonova

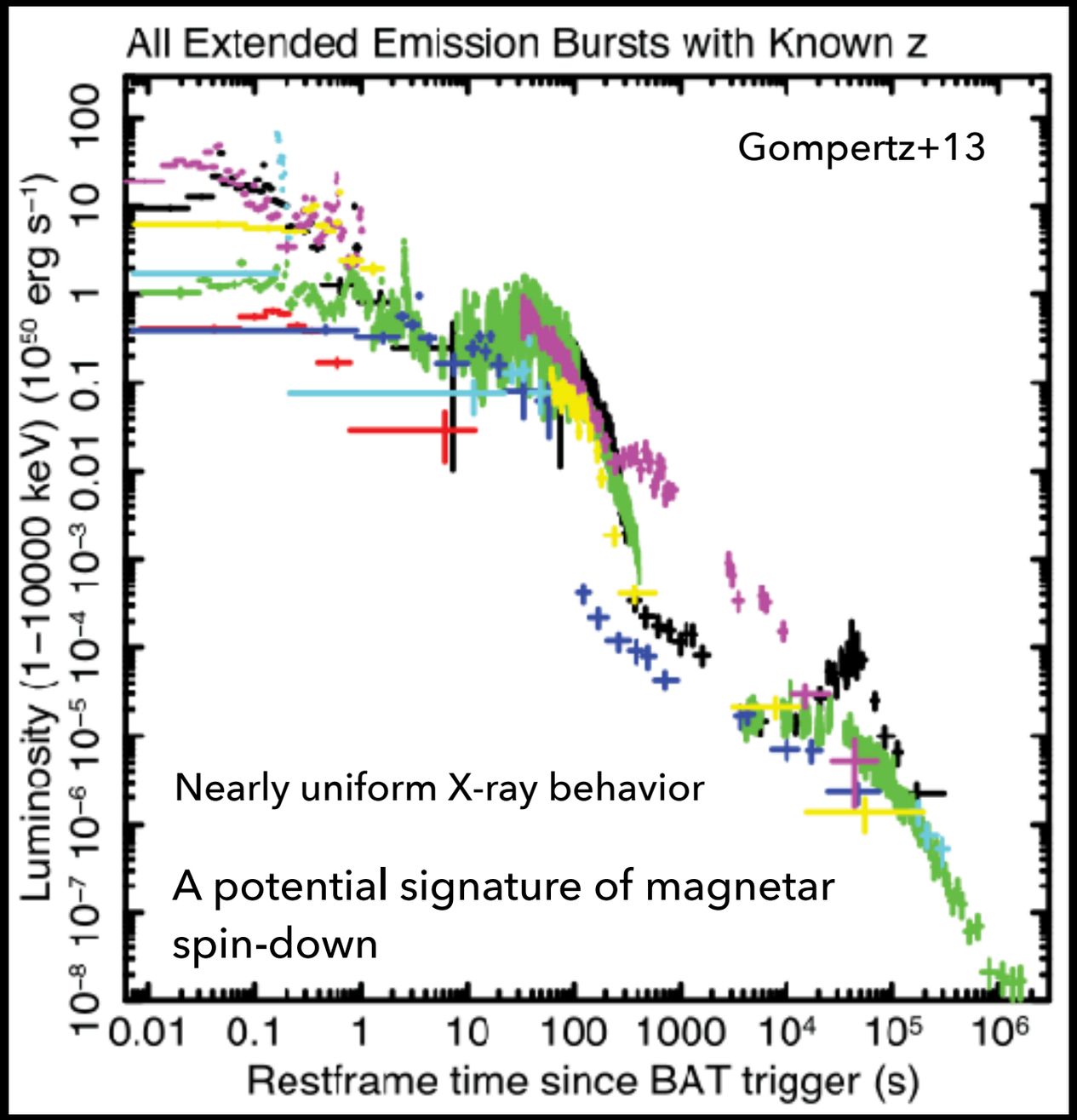
Must explain all components!

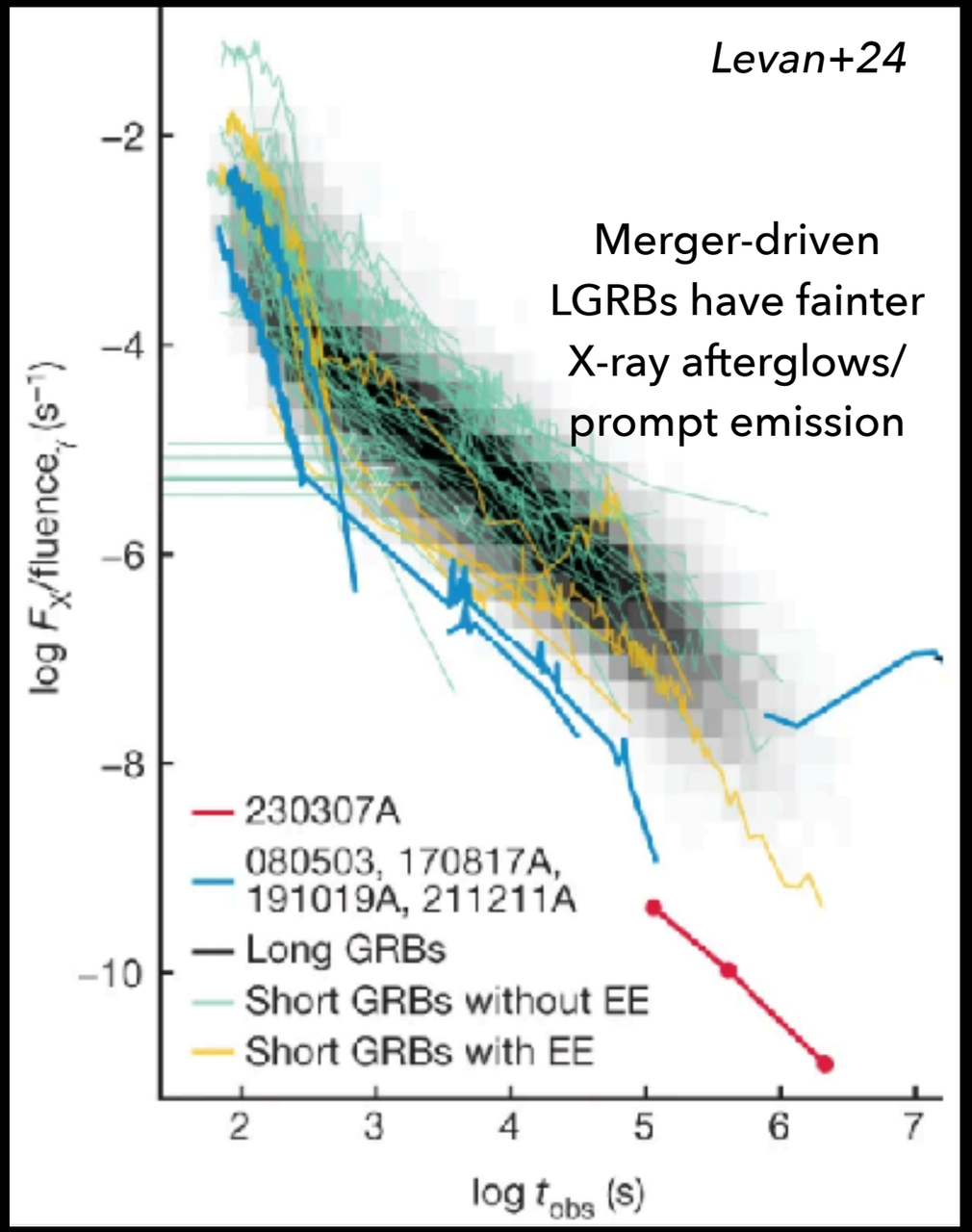
What source(s) can explain merger-driven LGRBs?

[selected] **Models**	**Explanation**	**Challenges**
NSBH Merger:; *e.g. Rosswog+07, Desai+19*	Late-time fall-back accretion from tidally-disrupted material could explain longer light curve	Kilonova is not redder than 170817's
NSM with Magnetar Remnant: e.g. Metzger+08, Gompertz+14, Gompertz+22	Can explain consistent EE/X-ray timescales (~100s when system becomes optically-thin neutrinos)	Bimodality of GRB distribution
NSWD Merger *e.g. Fryer+99, Gillanders+23, Sun+23*	Less compact merger could explain longer light curve	How to produce lanthanides ?
NSM with Large Disk *e.g. Gottlieb+23*	Outcome of standard picture of NSM GRBs	Bimodality of GRB distribution

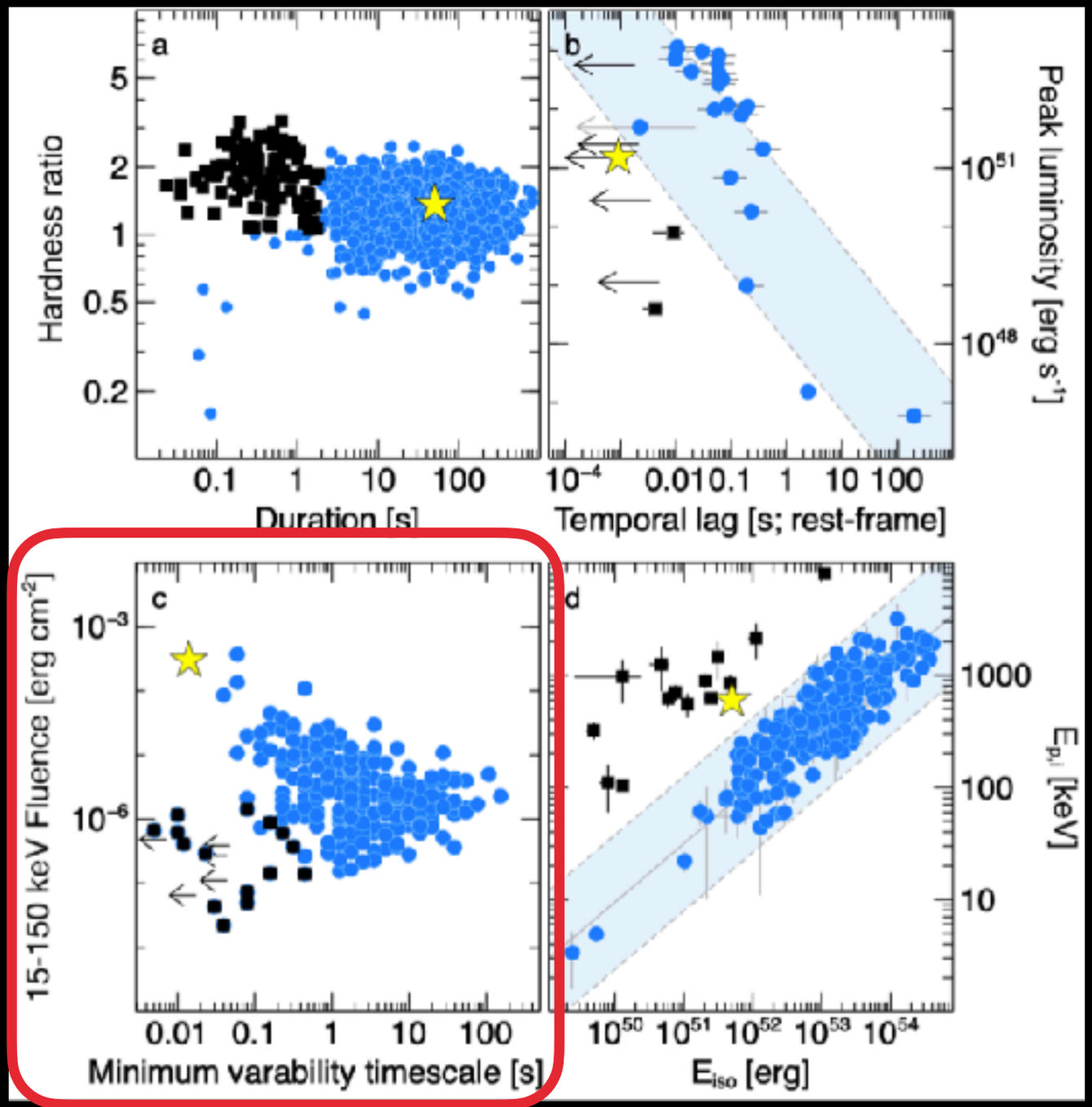
+ your favorite model!

Identifying Future Events: prompt X-ray Afterglow

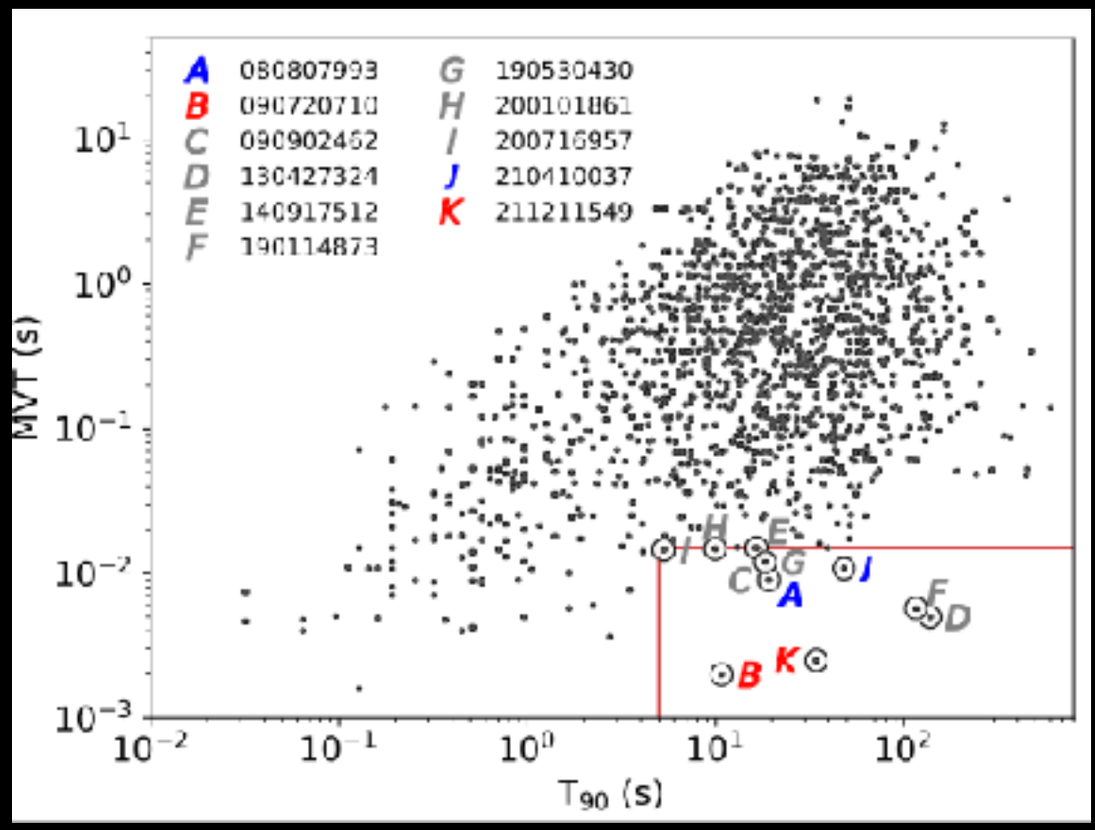




Identifying Future Events: Minimum Variability Timescale



Troja+22



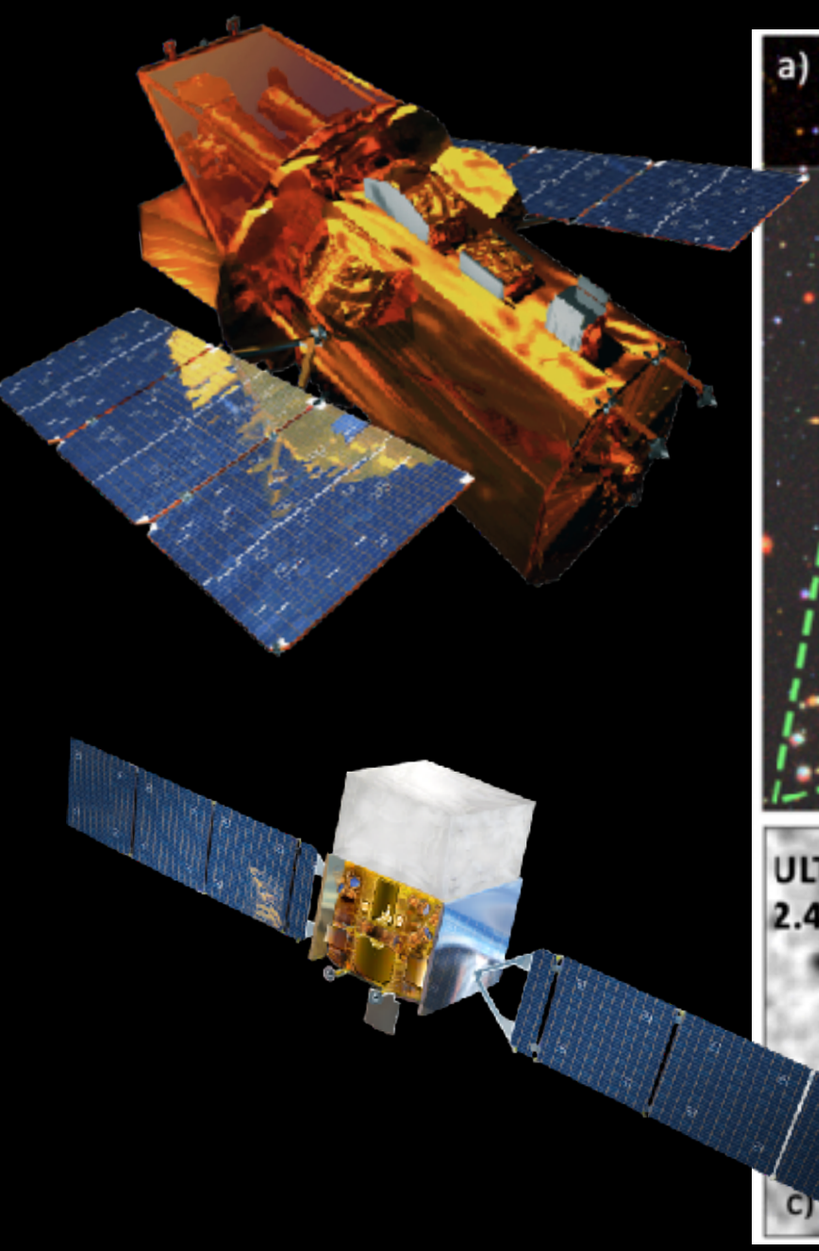
Veres+23

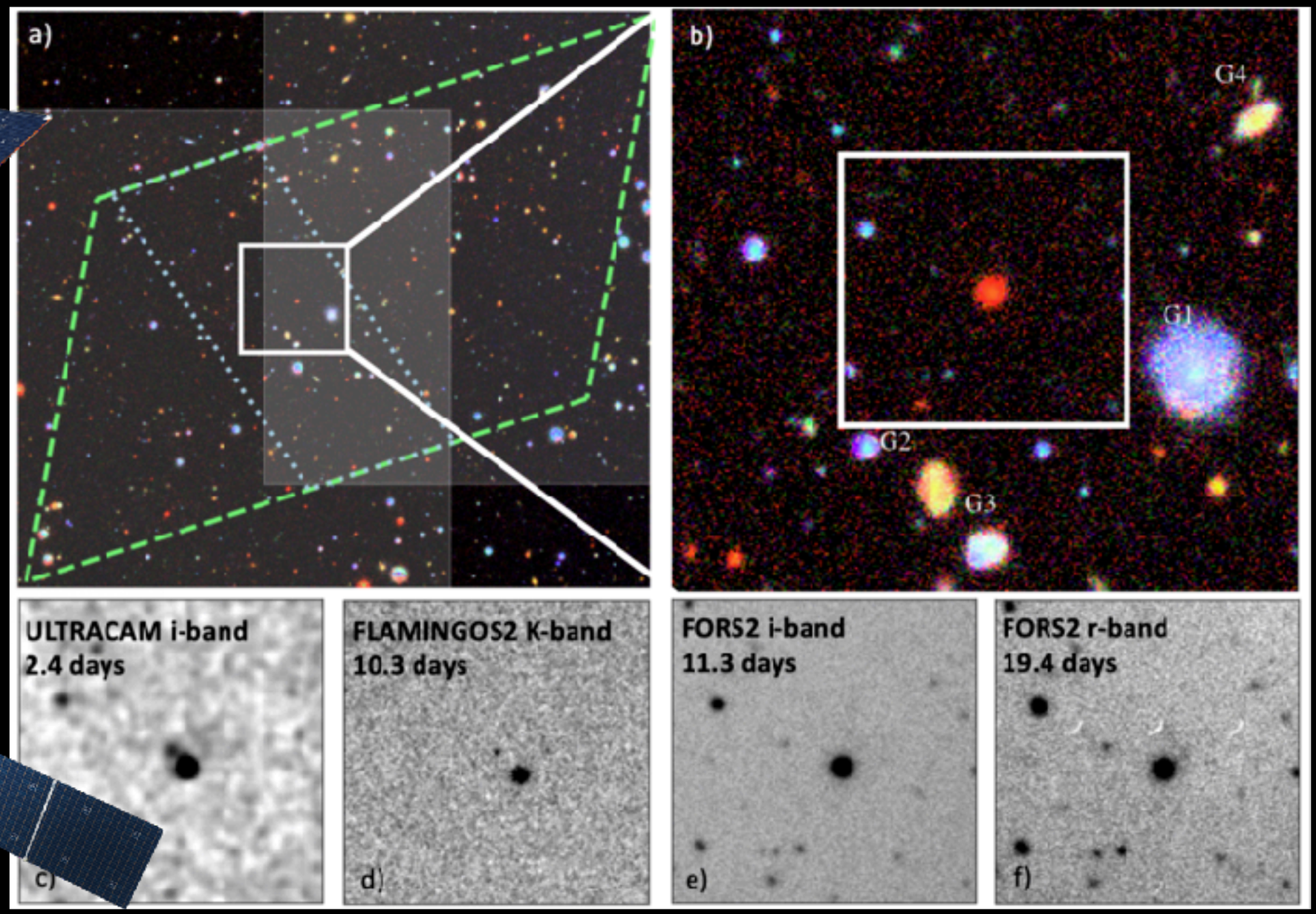
A path to distinguishing future merger-driven LGRBs?

Must be available in real-time

Well-localized GRB missions or mission coordination (e.g., the IPN) & wide-field afterglow searches are critical to localizing events

Levan+24





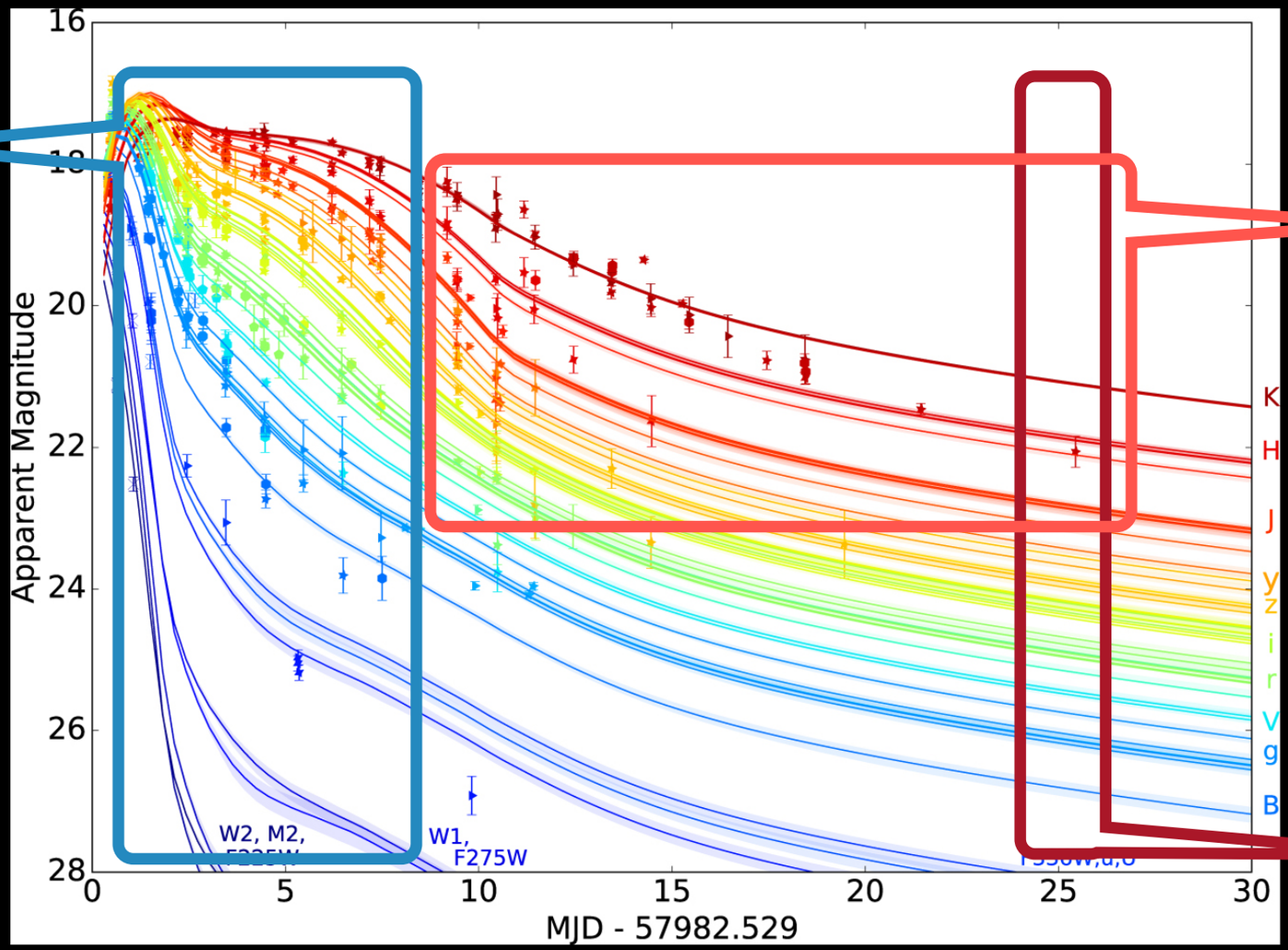
Rapid TOO programs are necessary to identify host distances, and find afterglows and kilonovae

Ground facilities

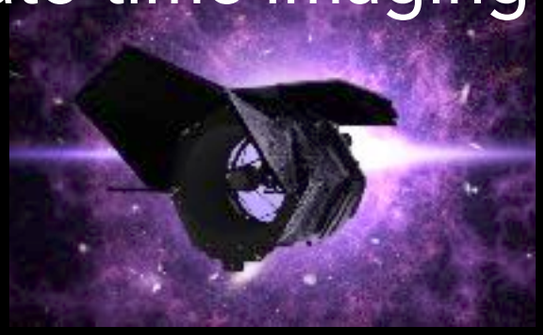
Gemini-S

GROND, RATIR

GW170817's kilonova AT2017gfo



Hubble/Roman late-time imaging



JWST late-time imaging + spectra

Villar+17 w/ data compiled from Andreoni+17; Arcavi+17; Coulter+17; Cowperthwaite+17; Diaz+17; Drout+17; Evans+17; Hu+17; Kasliwal+17; Lipunov+17; Pian+17; Pozanenko+17; Shappee+17; Smartt+17; Tanvir+17; Troja+17; Utsumi+17; Valenti+17

Credit: Aaron Geller, Northwestern

Takeaway Points

I. sGRBs from massive star collapses do not require a novel formation channel and likely do not compromise a significant fraction of detected sGRBs

II. We have now found several candidate LGRBs from merger events. These events represent a new way to study compact object mergers and kilonovae.

III. No leading theory can explain all observations of LGRBs from merger events. Further observations, including GWs, may elucidate the matter.

IV. Rapid TOO programs and well-localized GRB missions are critical to expanding this sample of crossover events.

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