Observations of kilonovae

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Stockholm, 7 September 2023

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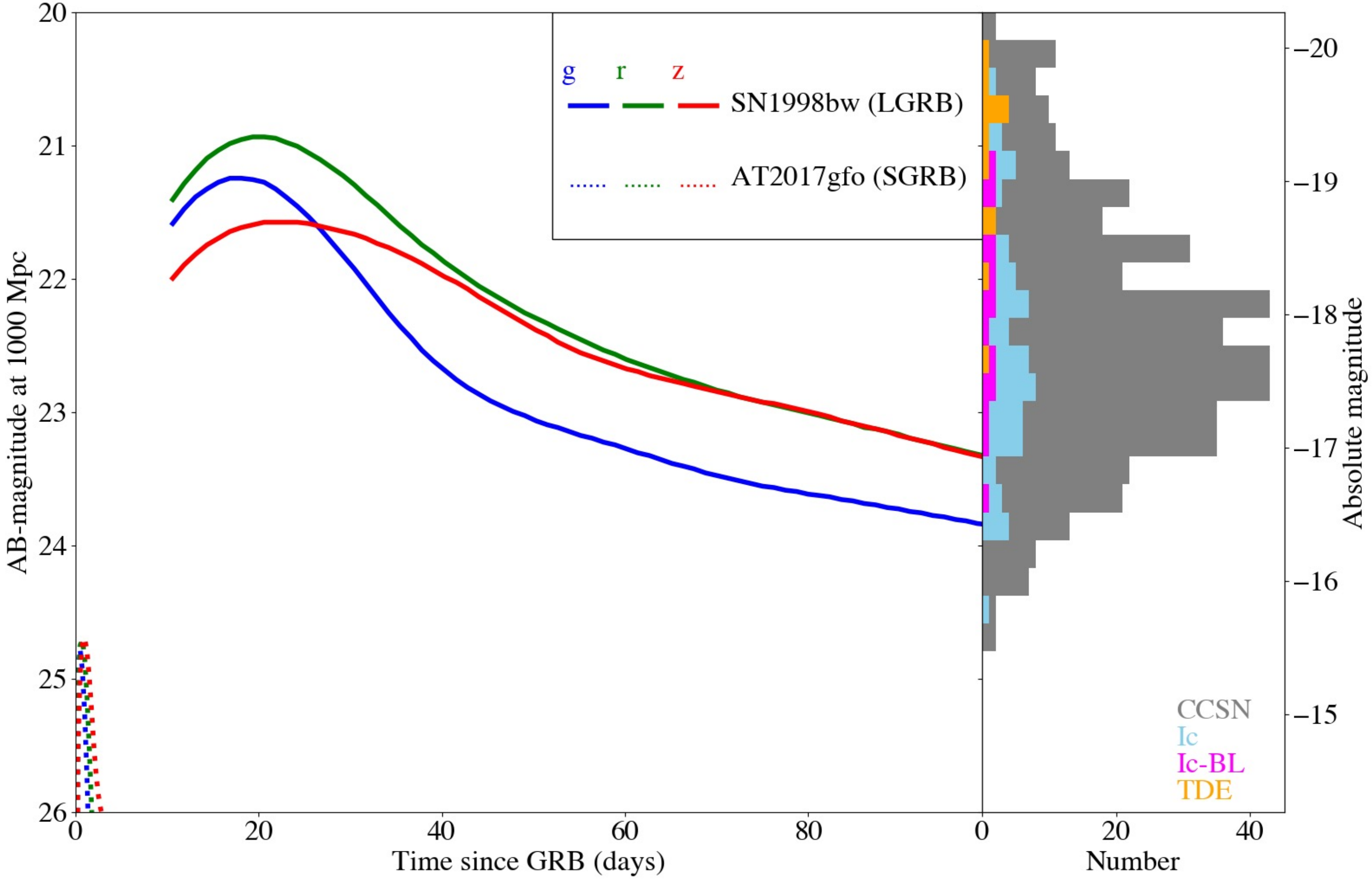
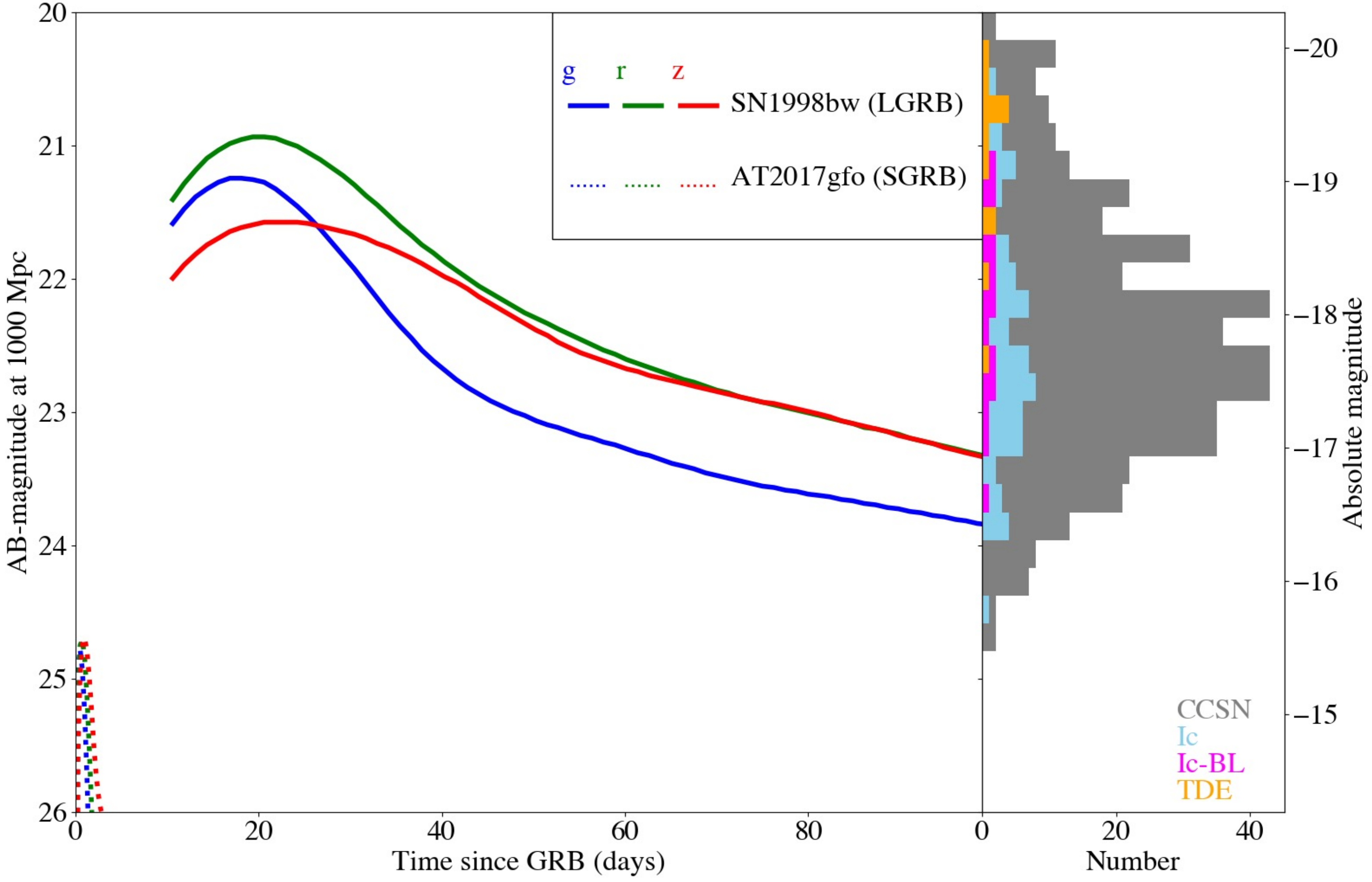
Observations of kilonovae are hard



Updated from Levan et al. 2023

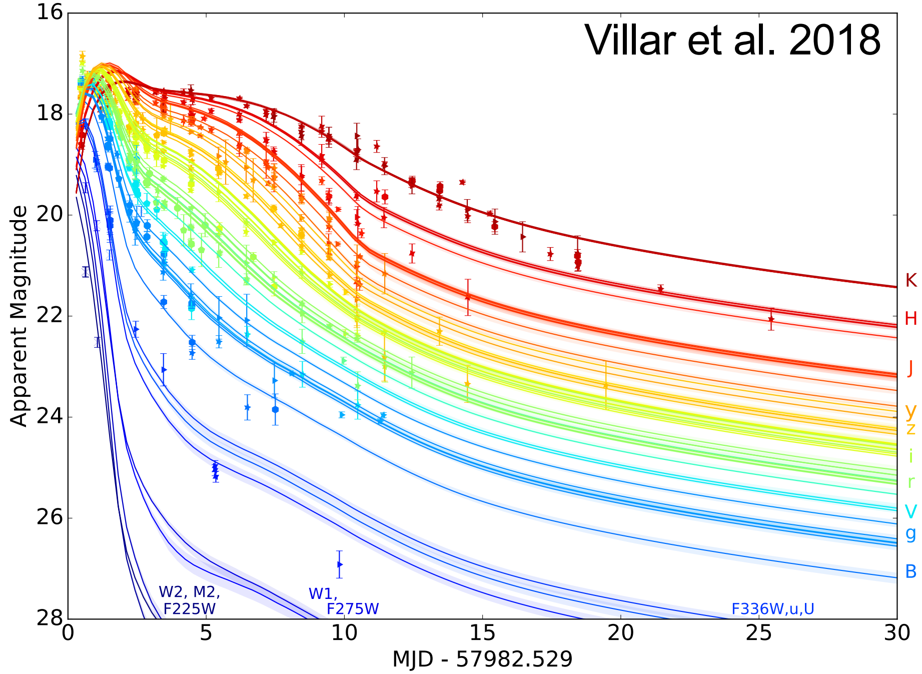
Observations of kilonovae need to know where to look

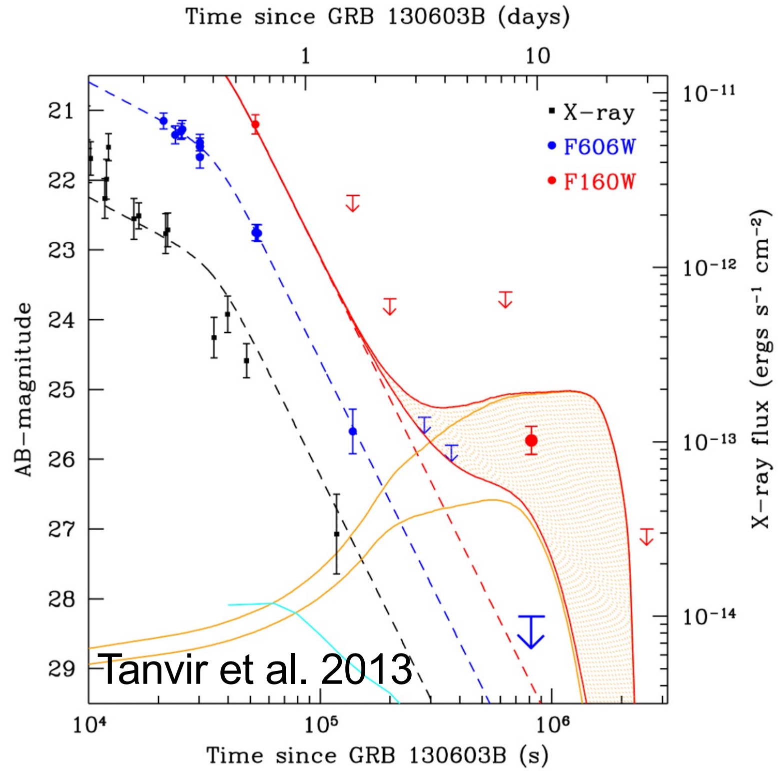


Updated from Levan et al. 2023

So far the only KNe discovered identified when sky-region and time are constrained by GW or GRB detection.

Observations of kilonova are unlikely to be much better soon

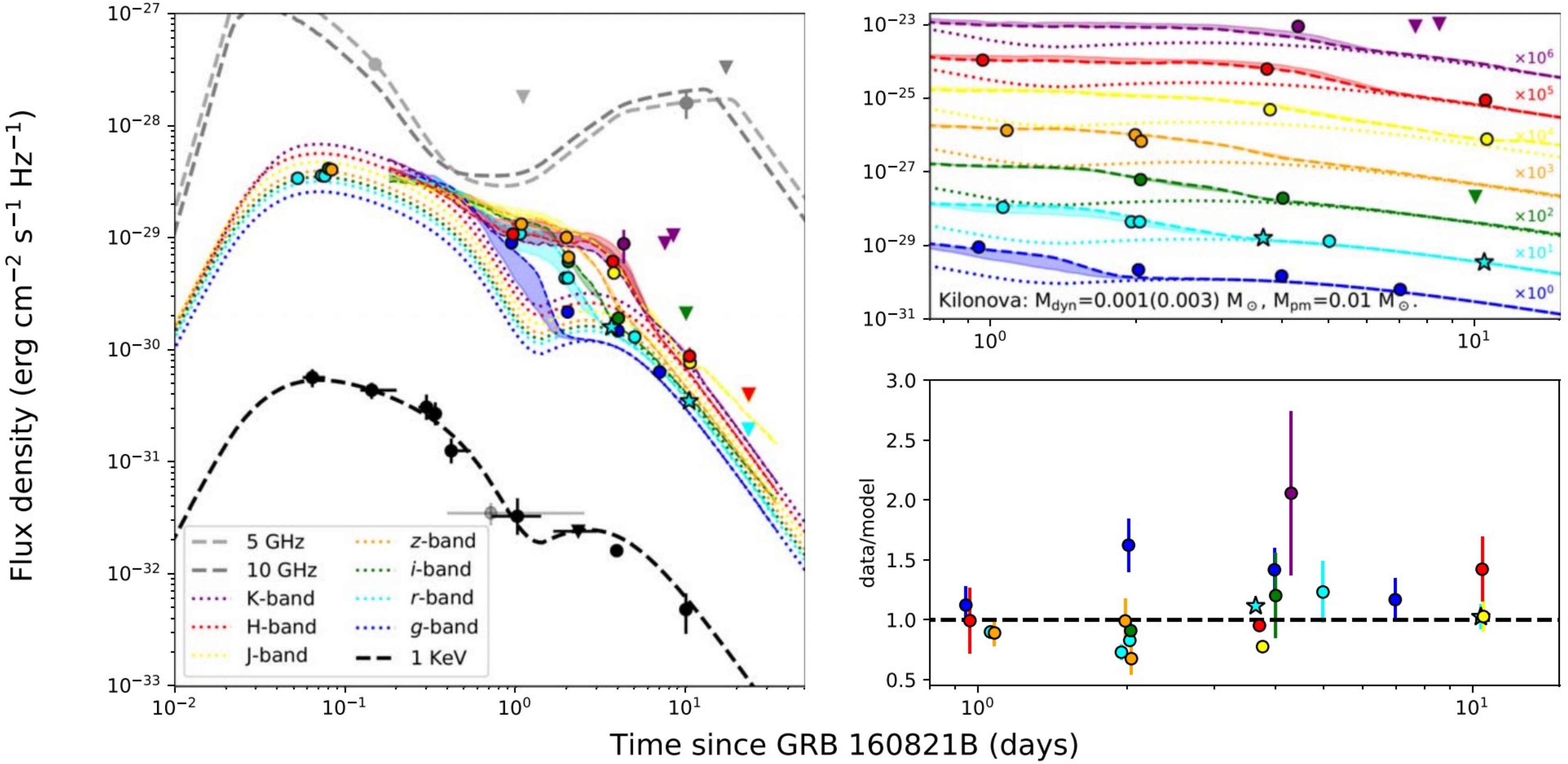




AT2017gfo:
Number of photometric points: ~750
Number of spectra:~50

Others (KN dominating):
Number of photometric points: ~50
Number of spectra: 2

Observations of kilonovae in GRBs require potentially complex decomposition

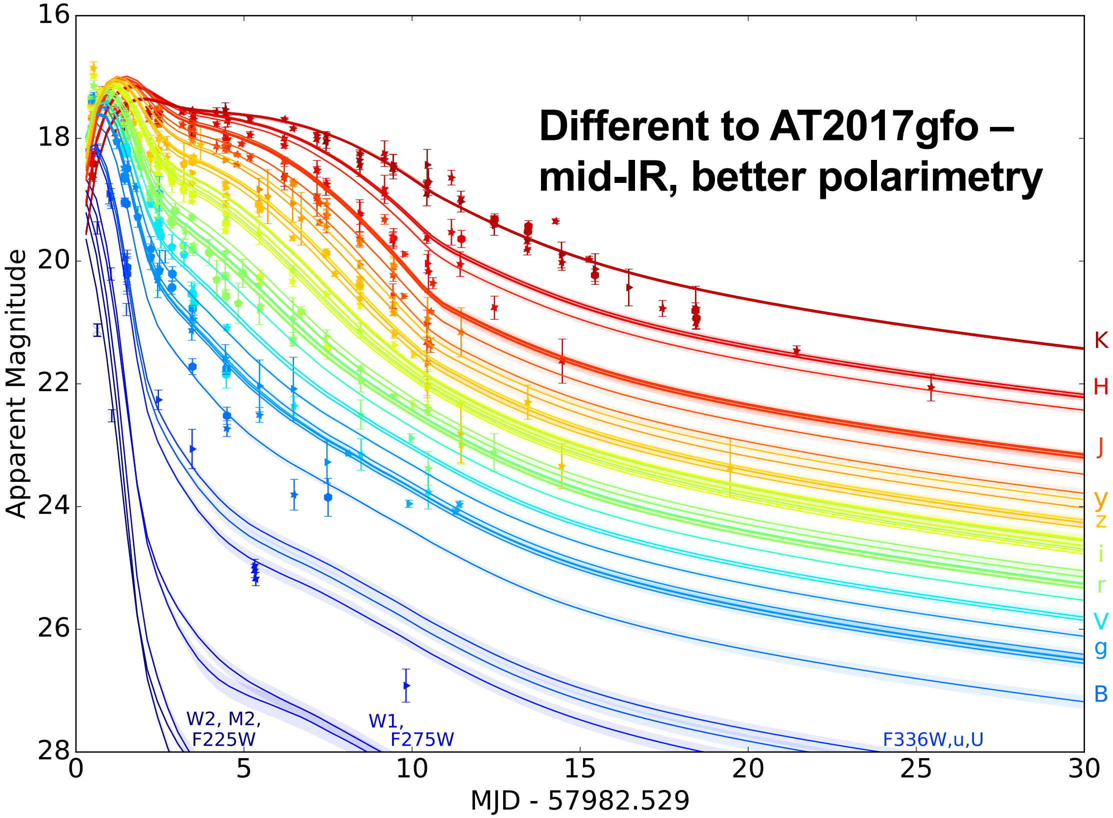


Lamb et al. 2019, Troja et al. 2019

Also Nikhil Sarin talk

Observations of kilonova can still deliver new science, even if they aren't as good as AT2017gfo

Earlier than AT2017gfo (probably GW triggered)

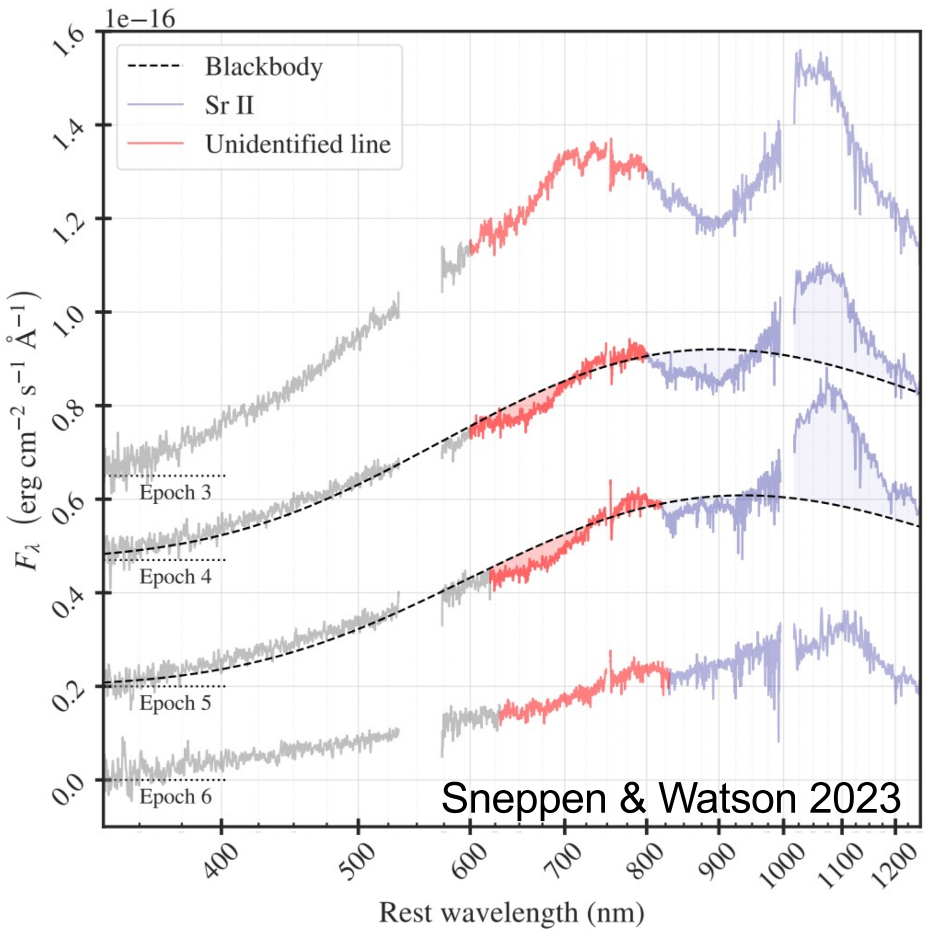


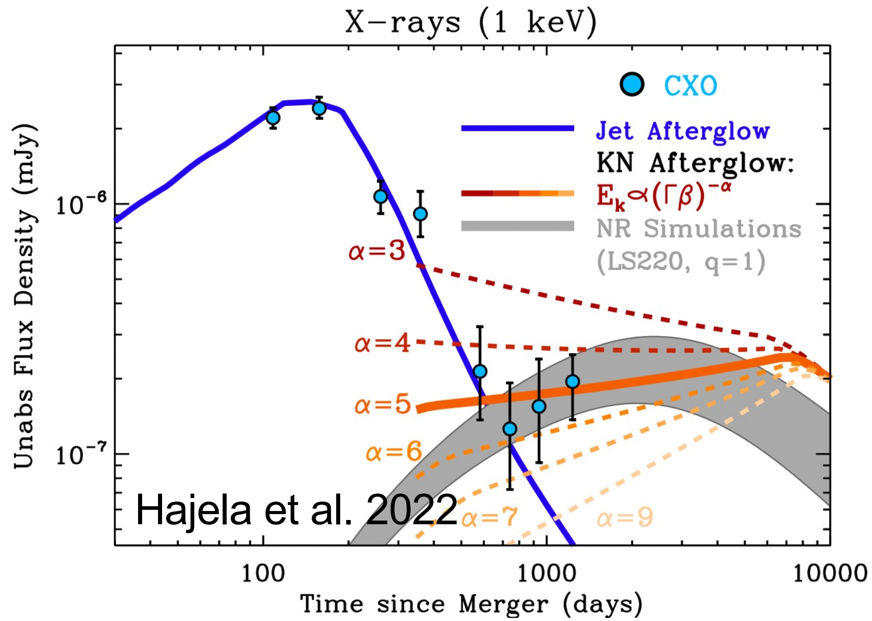
Later than AT2017gfo (e.g. GRB 230307A)

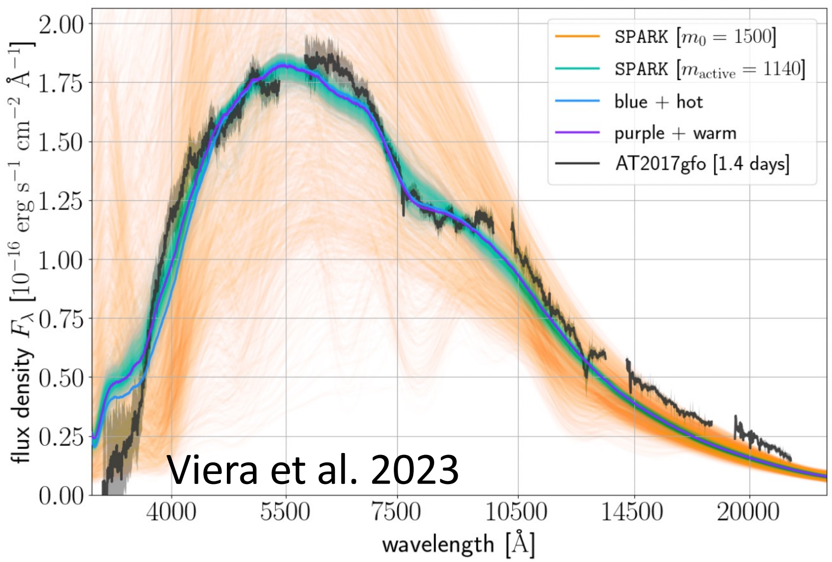
Villar et al. 2018

+ Kilonovae should have diversity depending on component masses, viewing angles etc

AT2017gfo – still providing new results

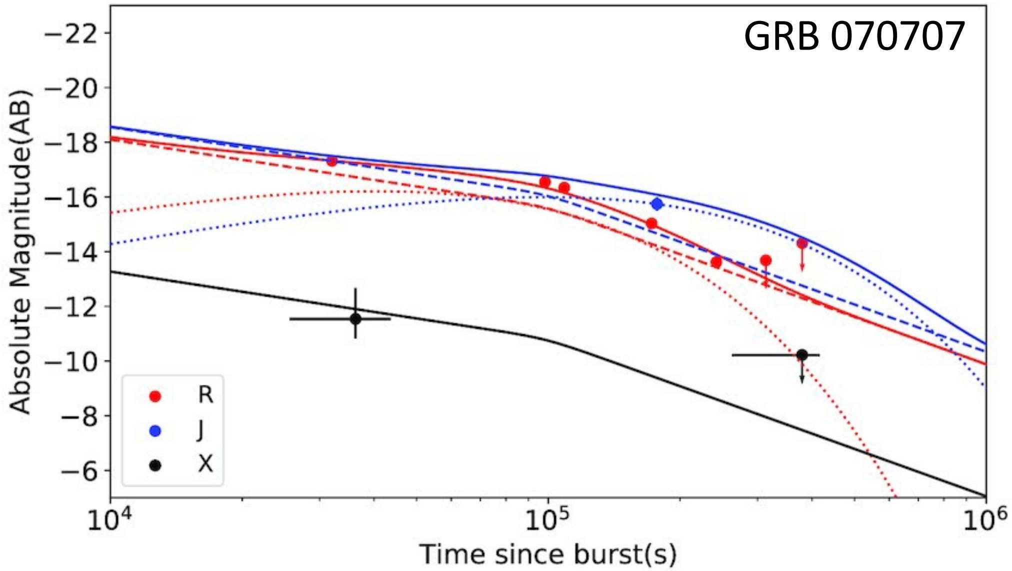




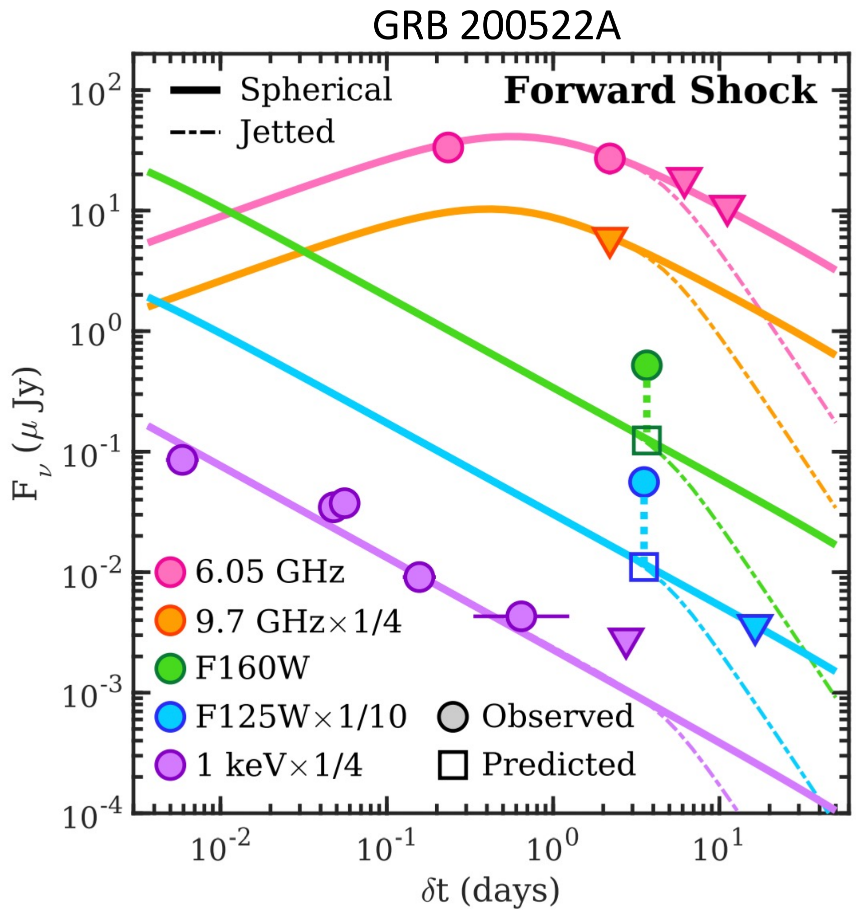


Still delivering new insight, but I won't talk much about it here.

Short GRB kilonovae



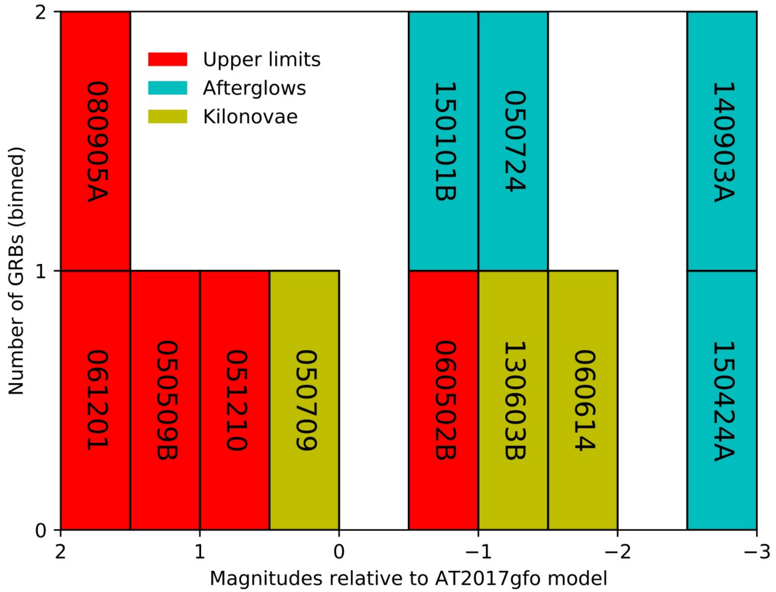
Ming-Zhu et al. 2023



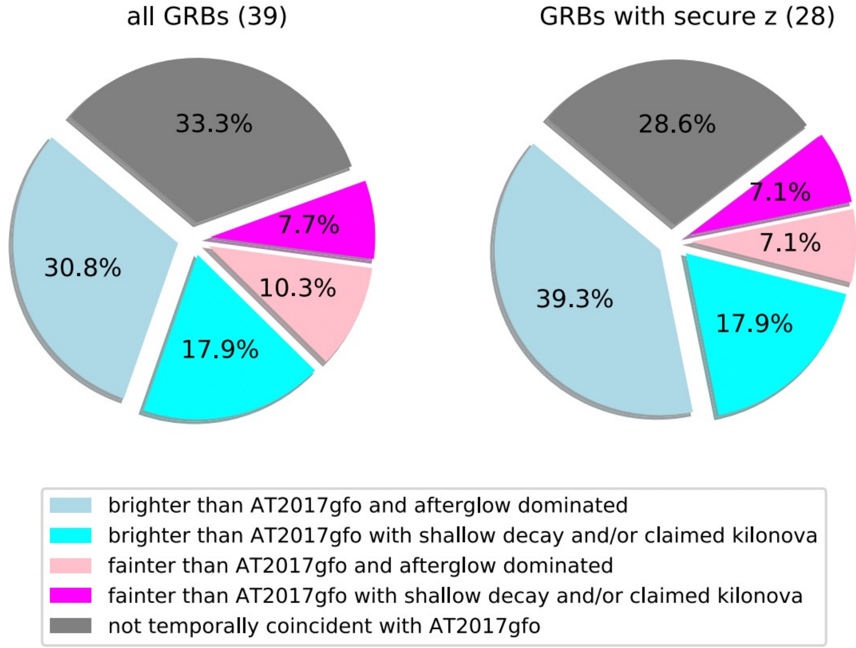
Fong et al. 2022

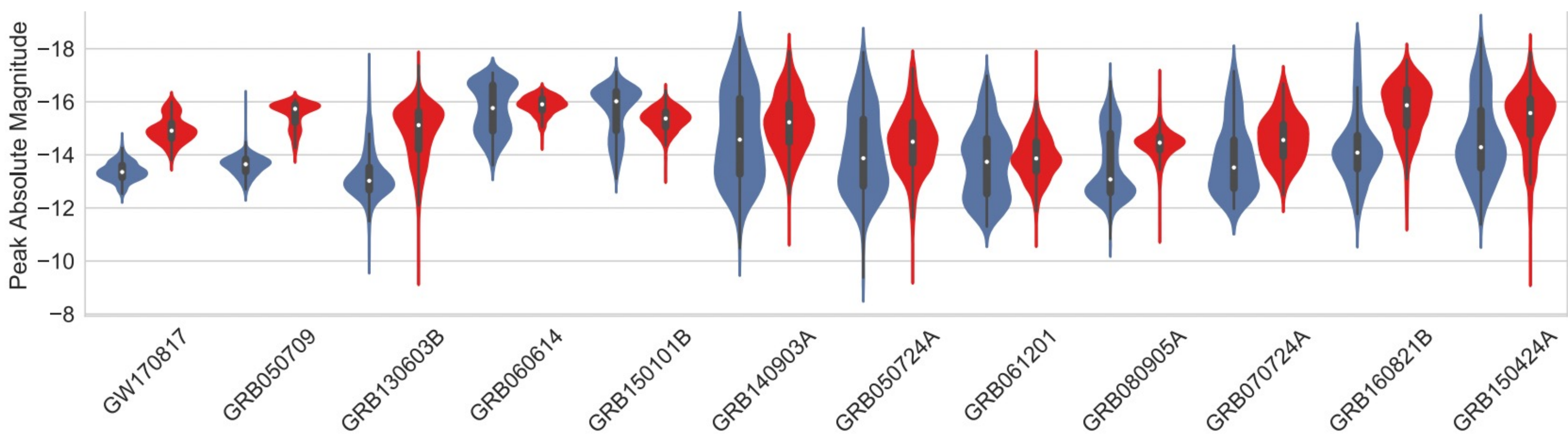
Diversity in short GRB kilonovae

Gompertz et al. 2018



Rossi et al. 2020



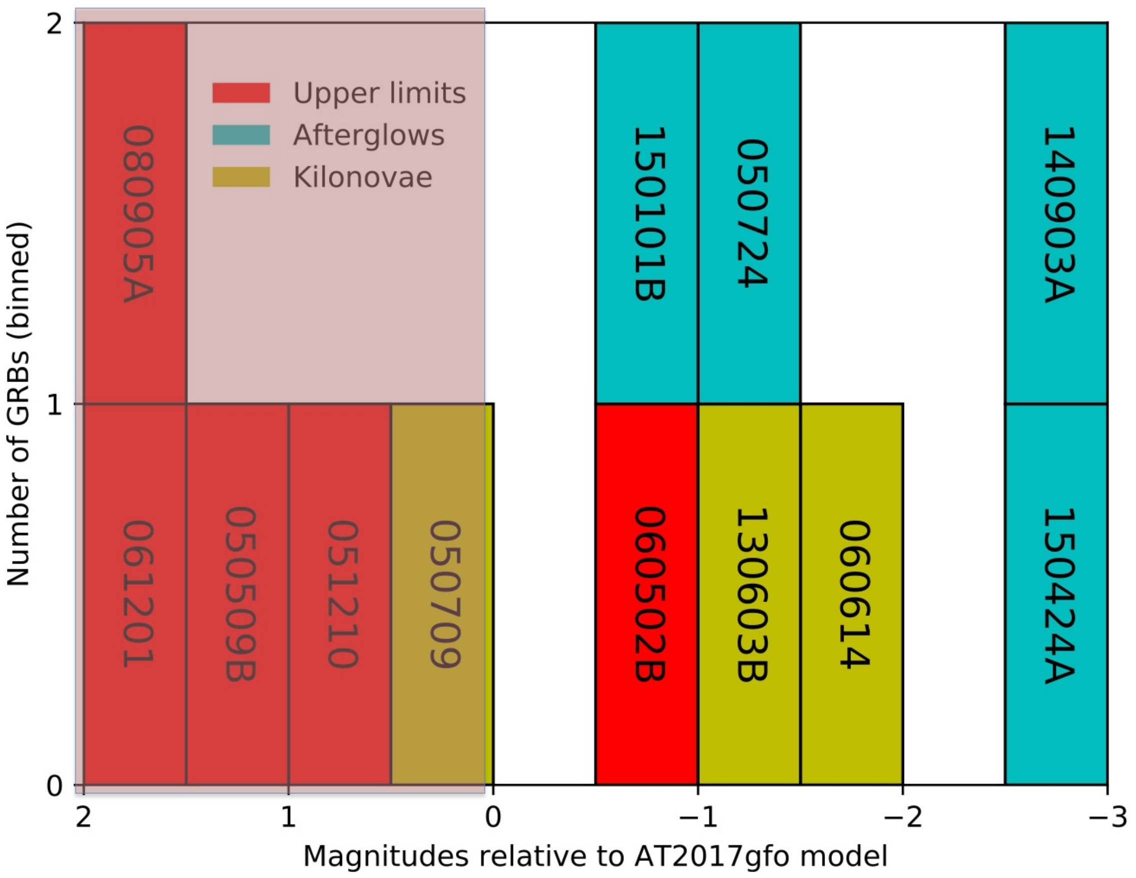


Ascenzi et al. 2019

Radboud Universiteit

Diversity in short GRB kilonovae

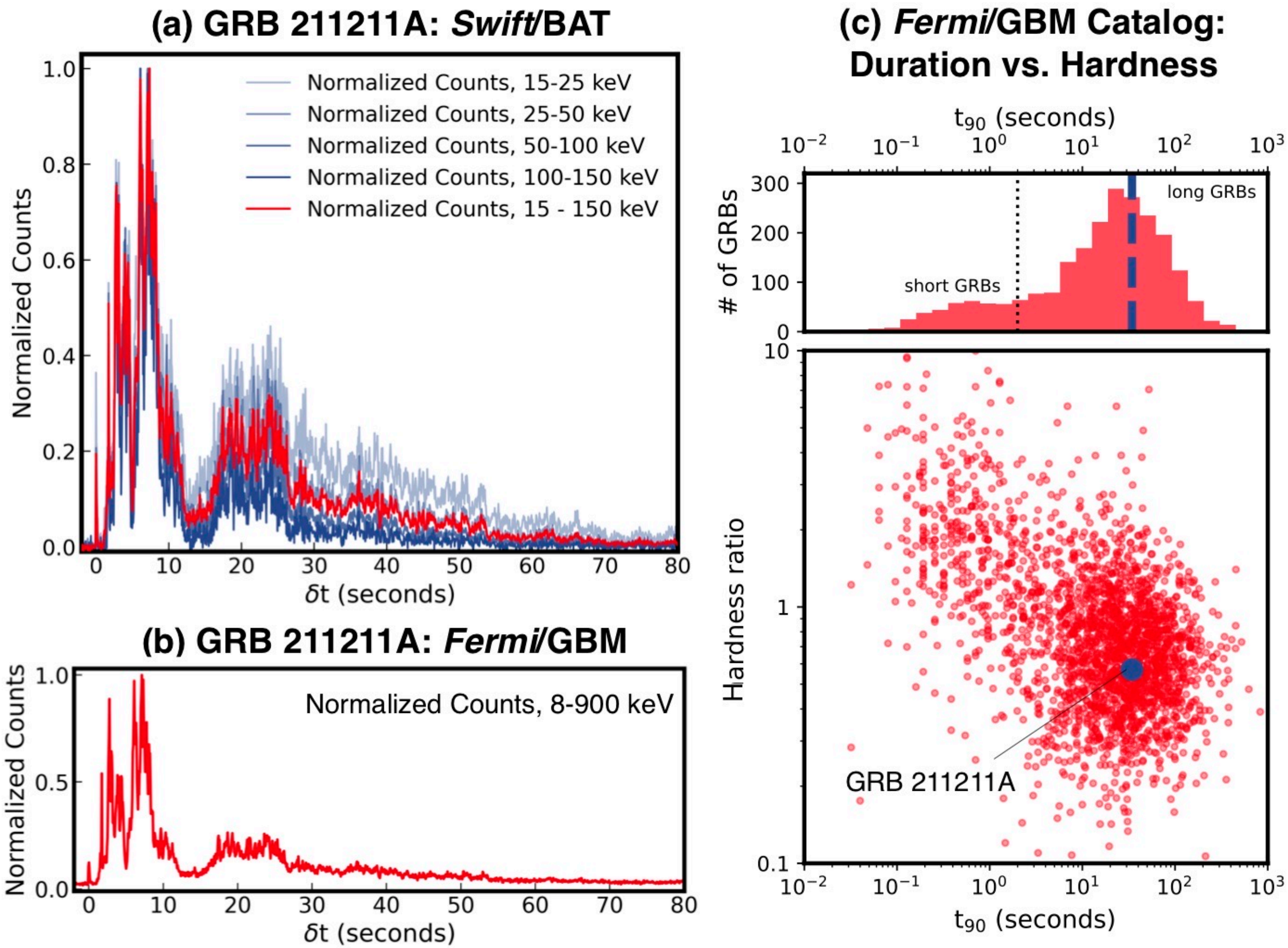
Gompertz et al. 2018



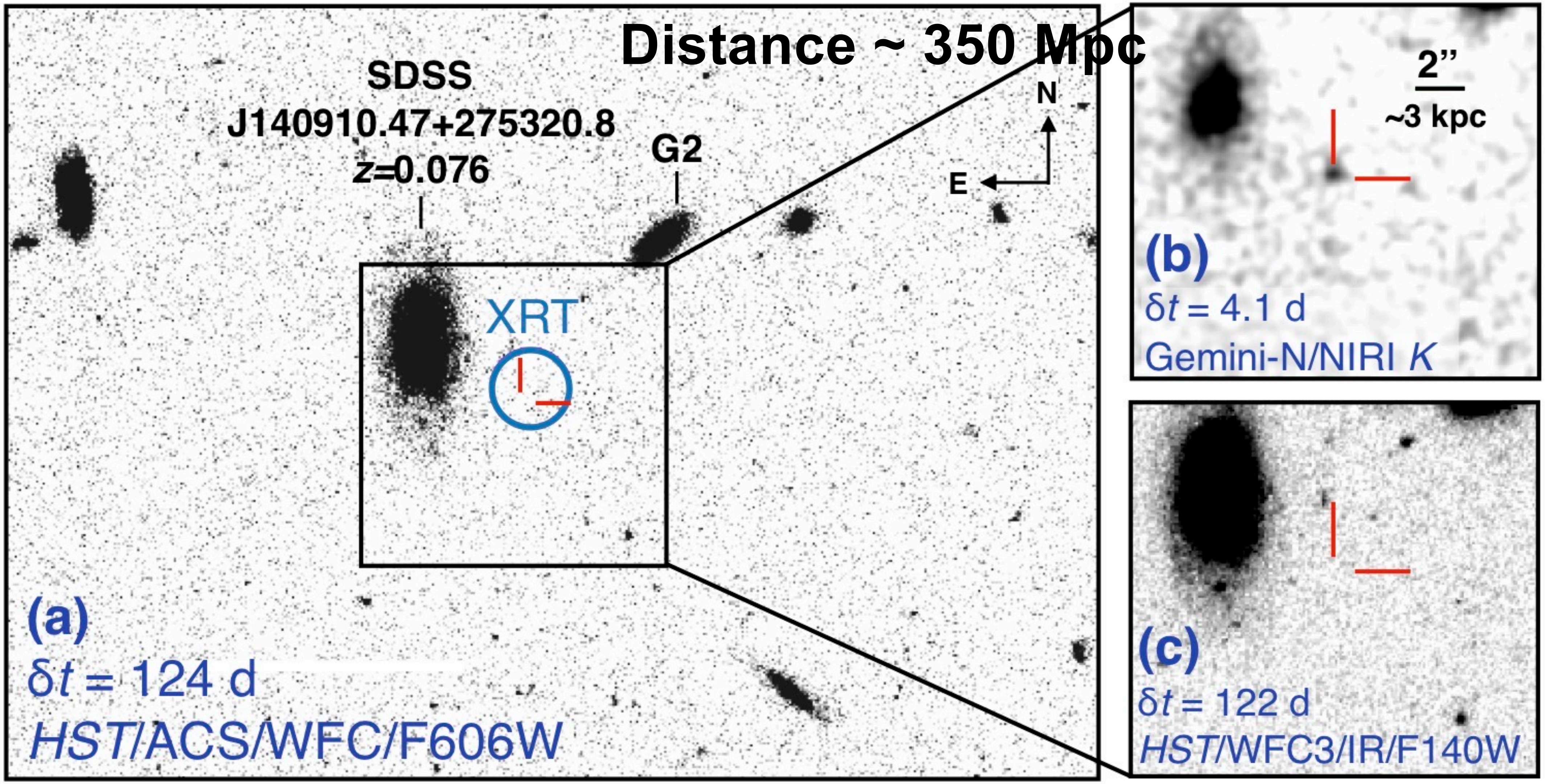
Lack of arcsecond positions

Of faint bursts only GRB 080905A has an optical afterglow

Uncertainty in host association/redshift



Rastinejad,et al. 2022, Troja et al. 2022, Yang et al. 2022, Gompertz et al. 2023



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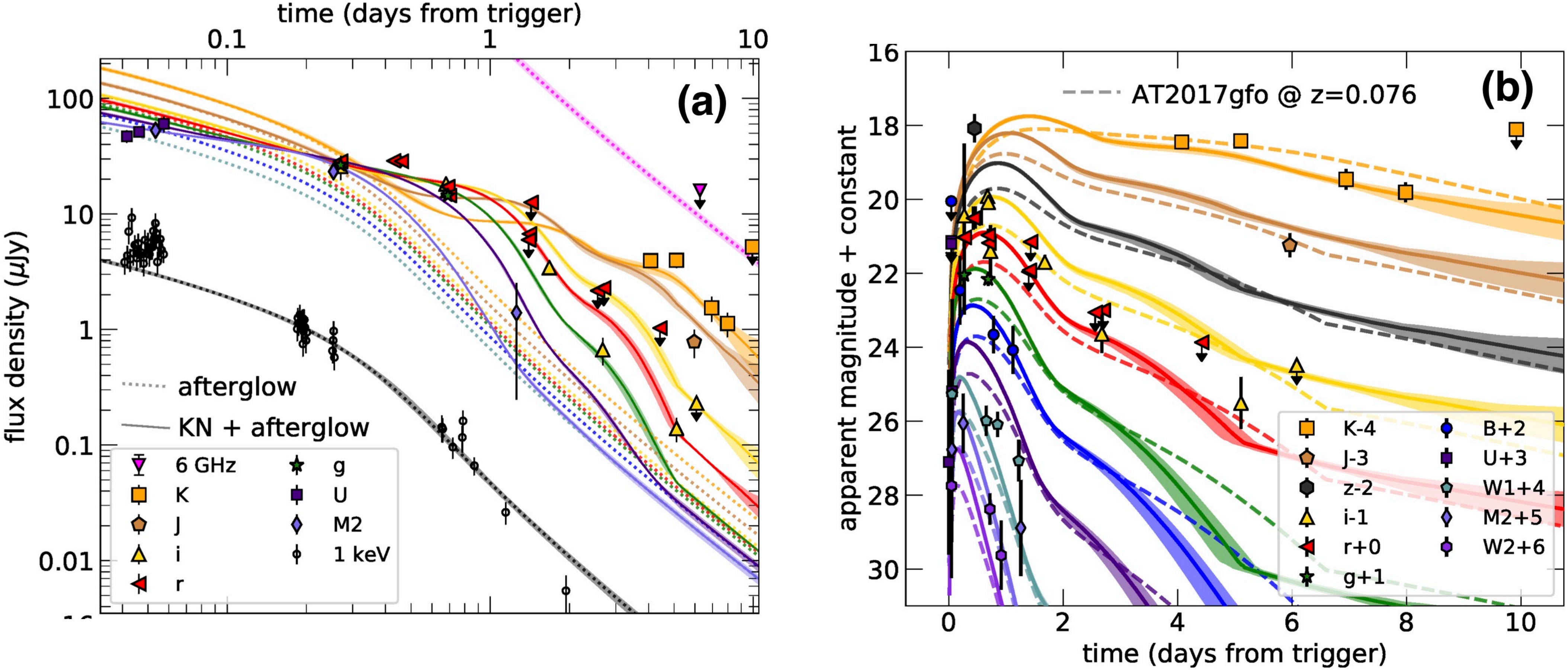

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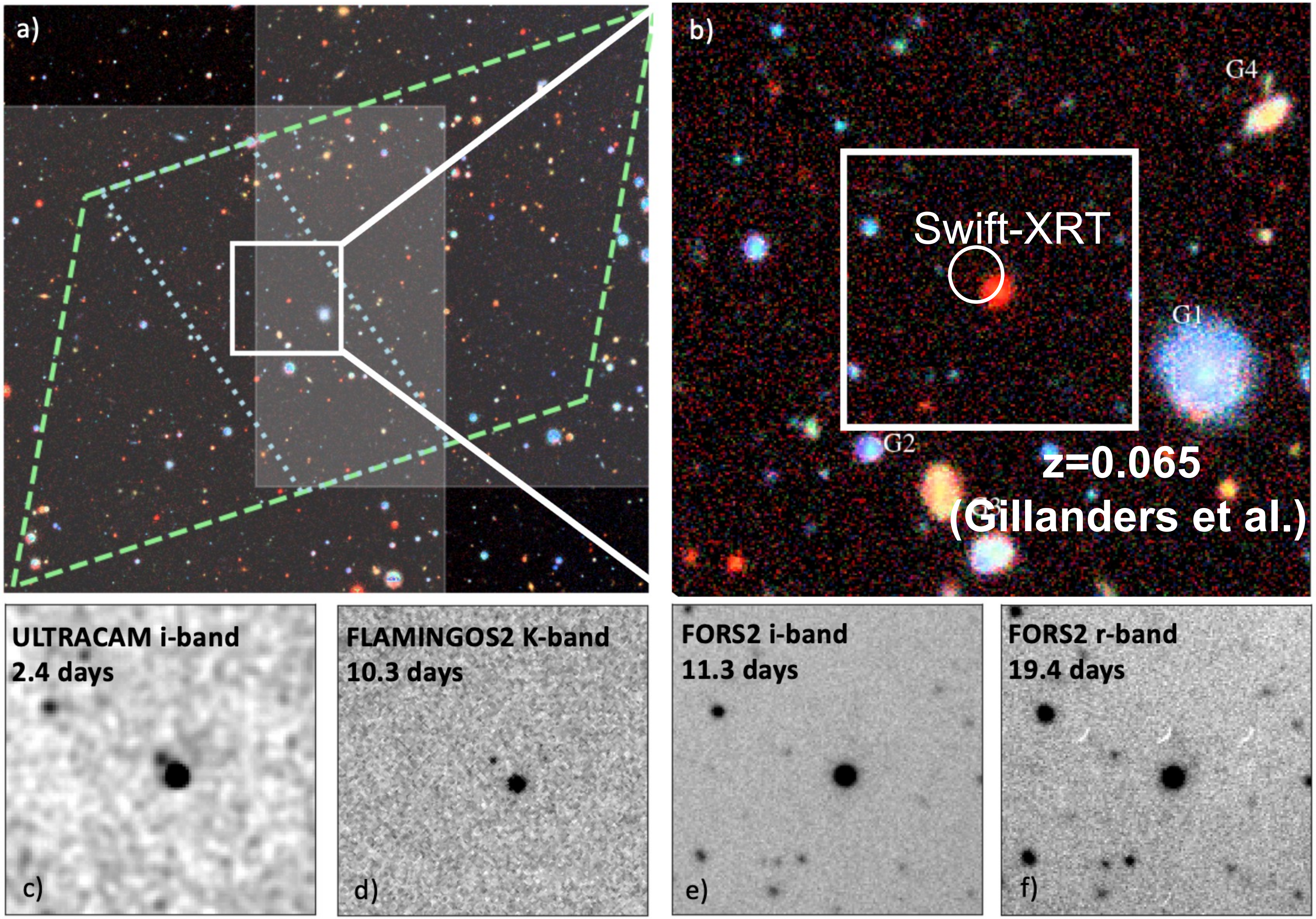


Timeline:

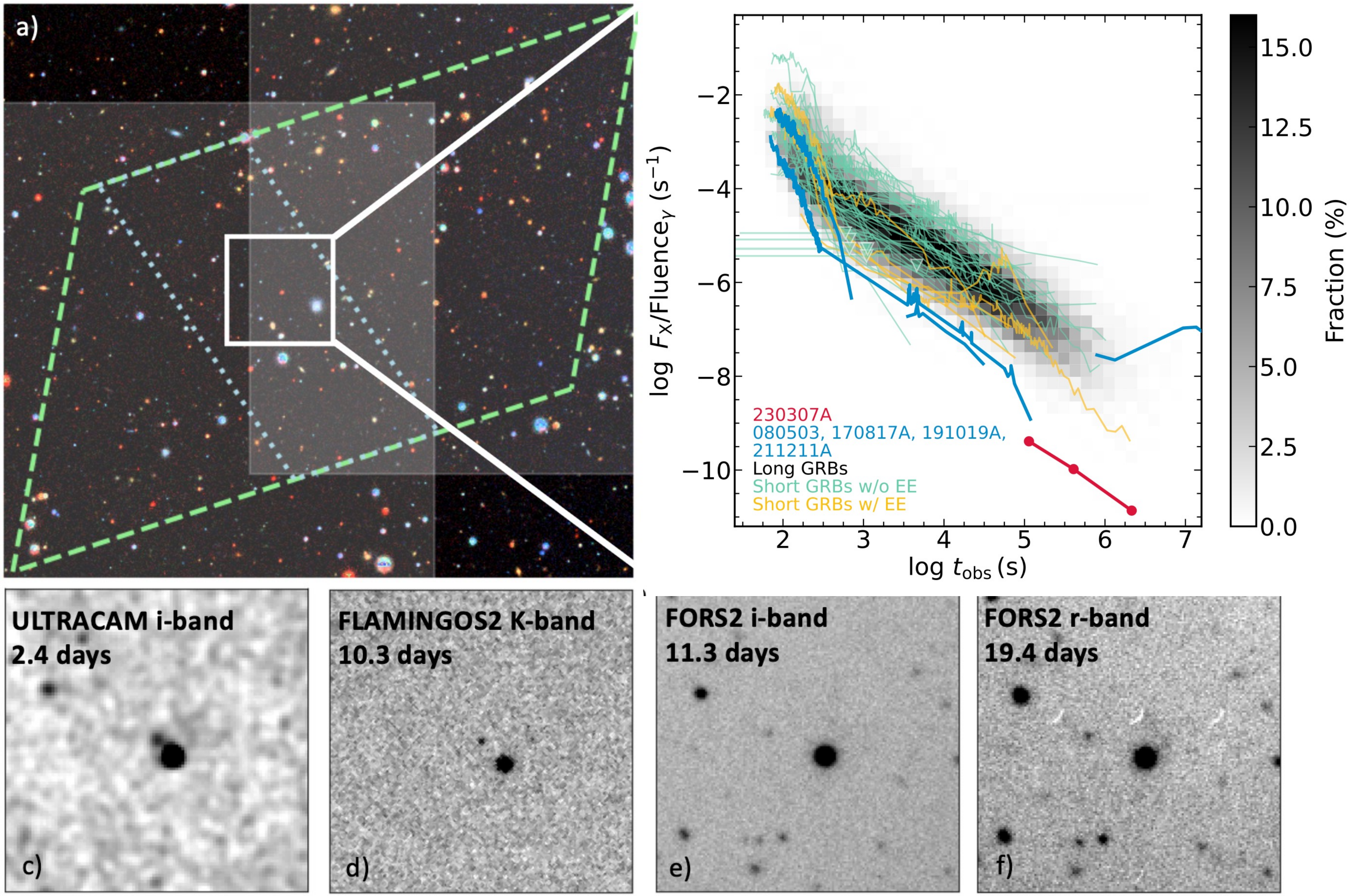
+8 hours
First IPN (2 sq. degrees)

+20 hours
Swift tiling begins

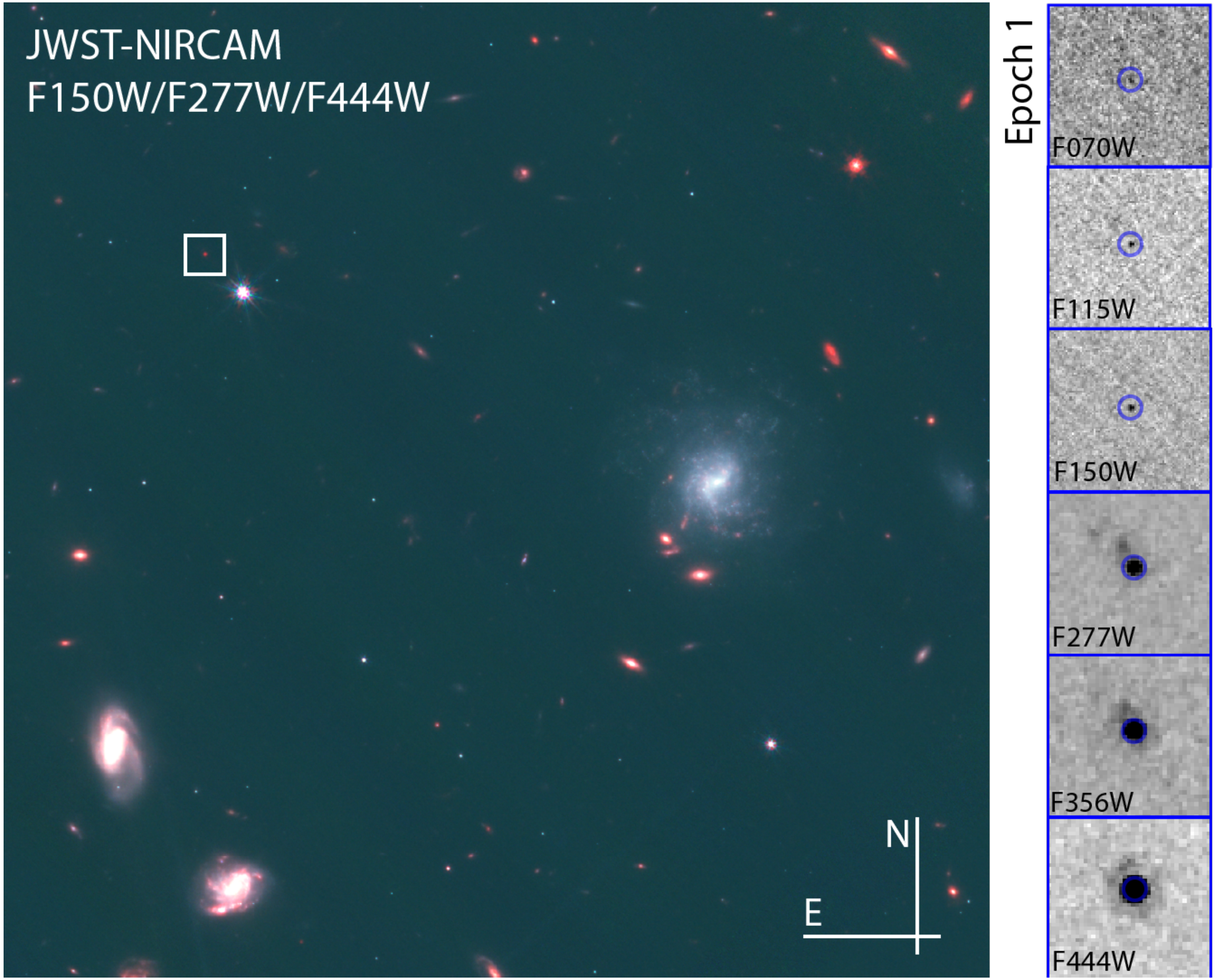
+29 hours
improved IPN (30 sq. arcmin)

+31 hours
Swift reports, 1 faint source, plausible afterglow but not clear if it is new and/or transient

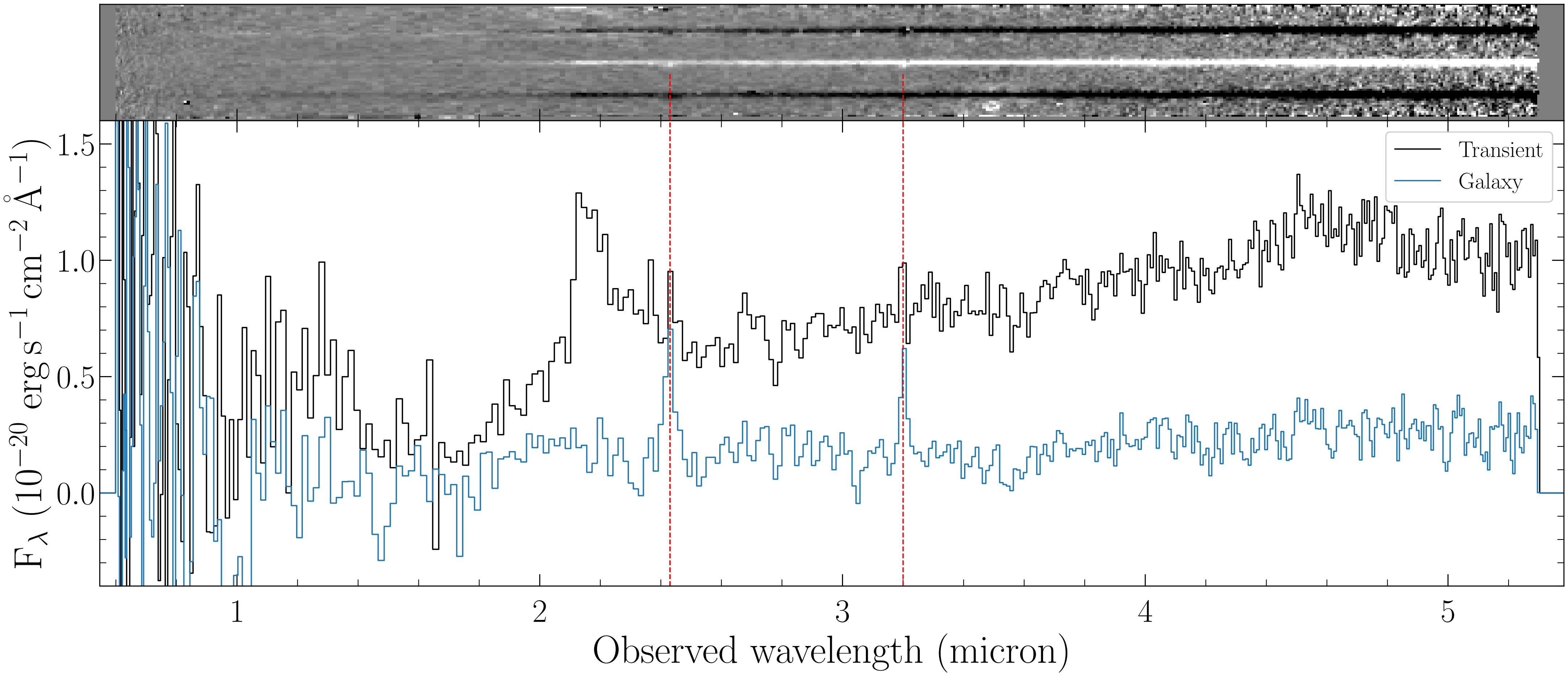
+33 hours
ULTRACAM – new source vs legacy survey, confirm optical afterglow.



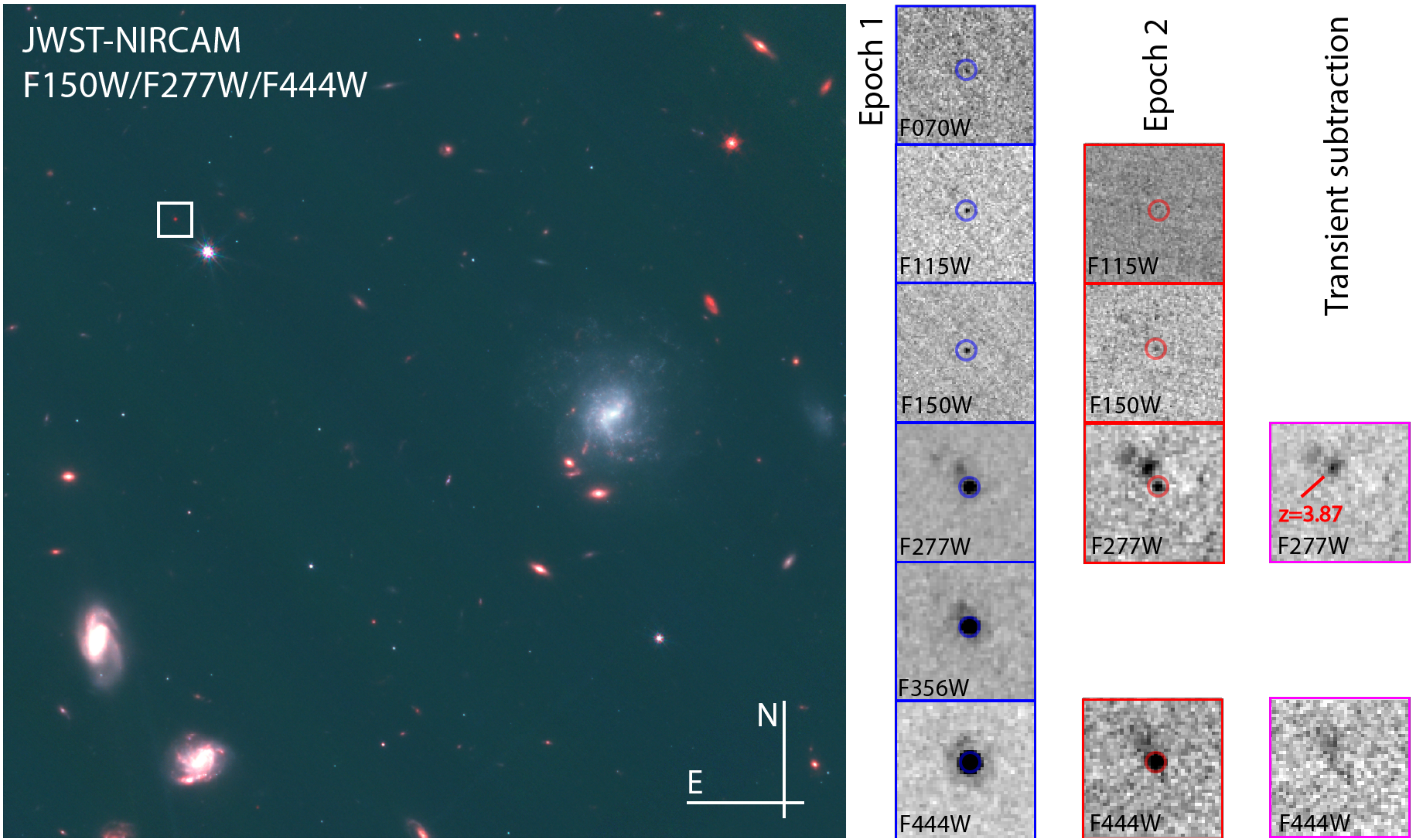
a)
log F_X/Fluence$_\gamma$ (s^{-1})
log t_{obs} (s)
230307A
080503, 170817A, 191019A, 211211A
Long GRBs
Short GRBs w/o EE
Short GRBs w/ EE
Fraction (%)
ULTRACAM i-band
2.4 days
c)
FLAMINGOS2 K-band
10.3 days
d)
FORS2 i-band
11.3 days
e)
FORS2 r-band
19.4 days
f)



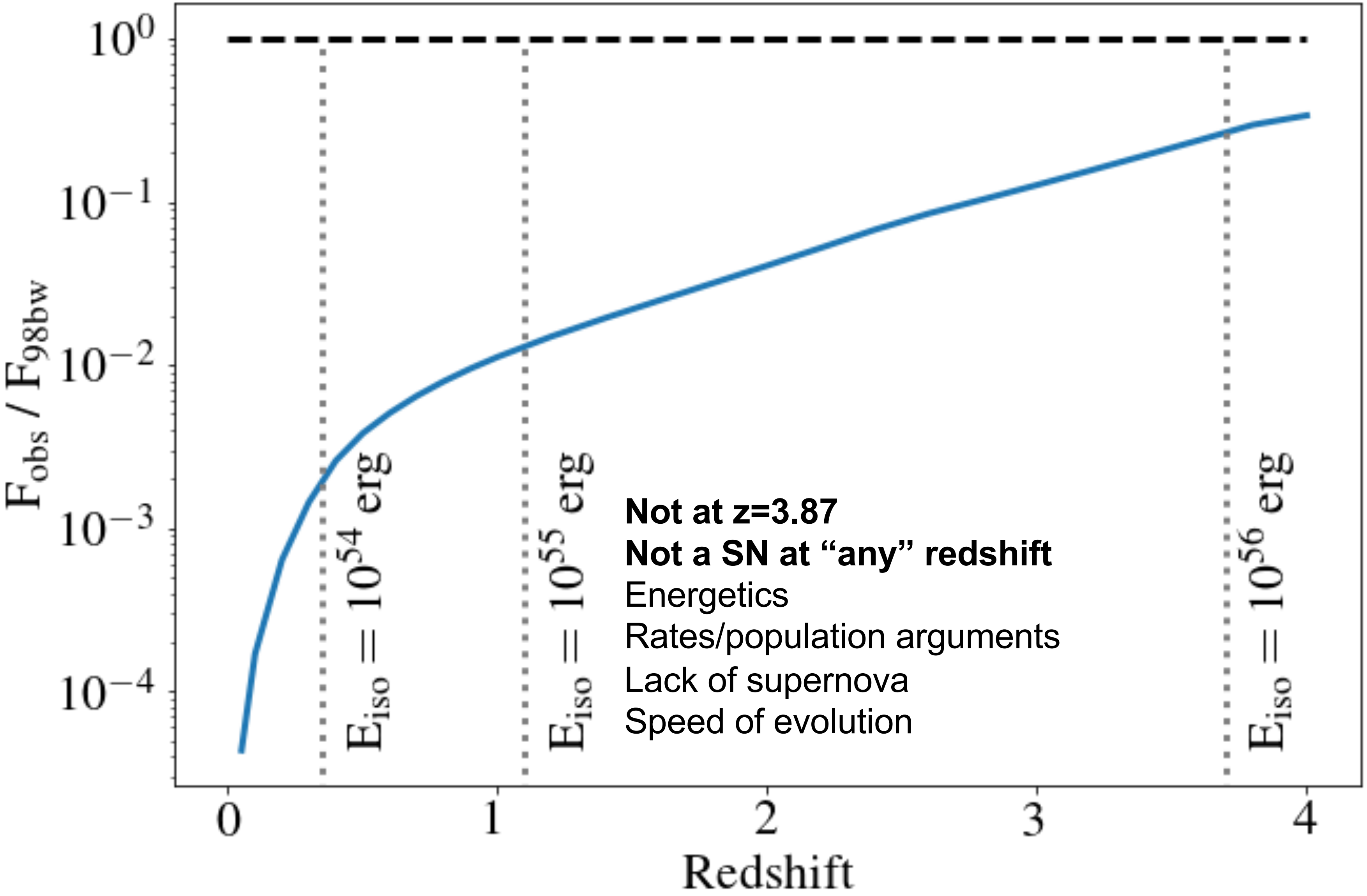
JWST-NIRCAM
F150W/F277W/F444W
N
E
Epoch 1
F070W
F115W
F150W
F277W
F356W
F444W



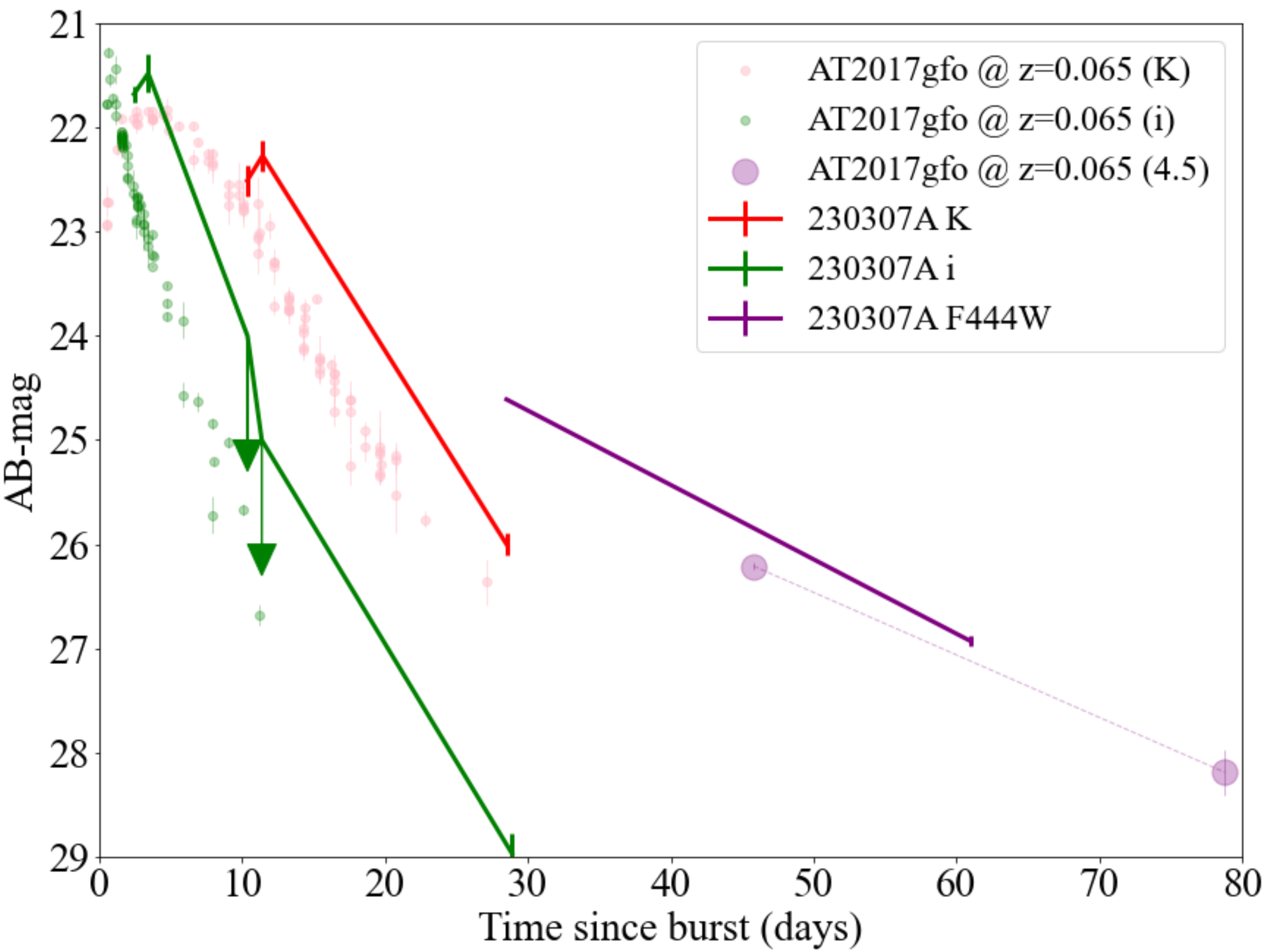
Transient
Galaxy
F_λ (10^{-20} erg s^{-1} cm^{-2} Å^{-1})
Observed wavelength (micron)



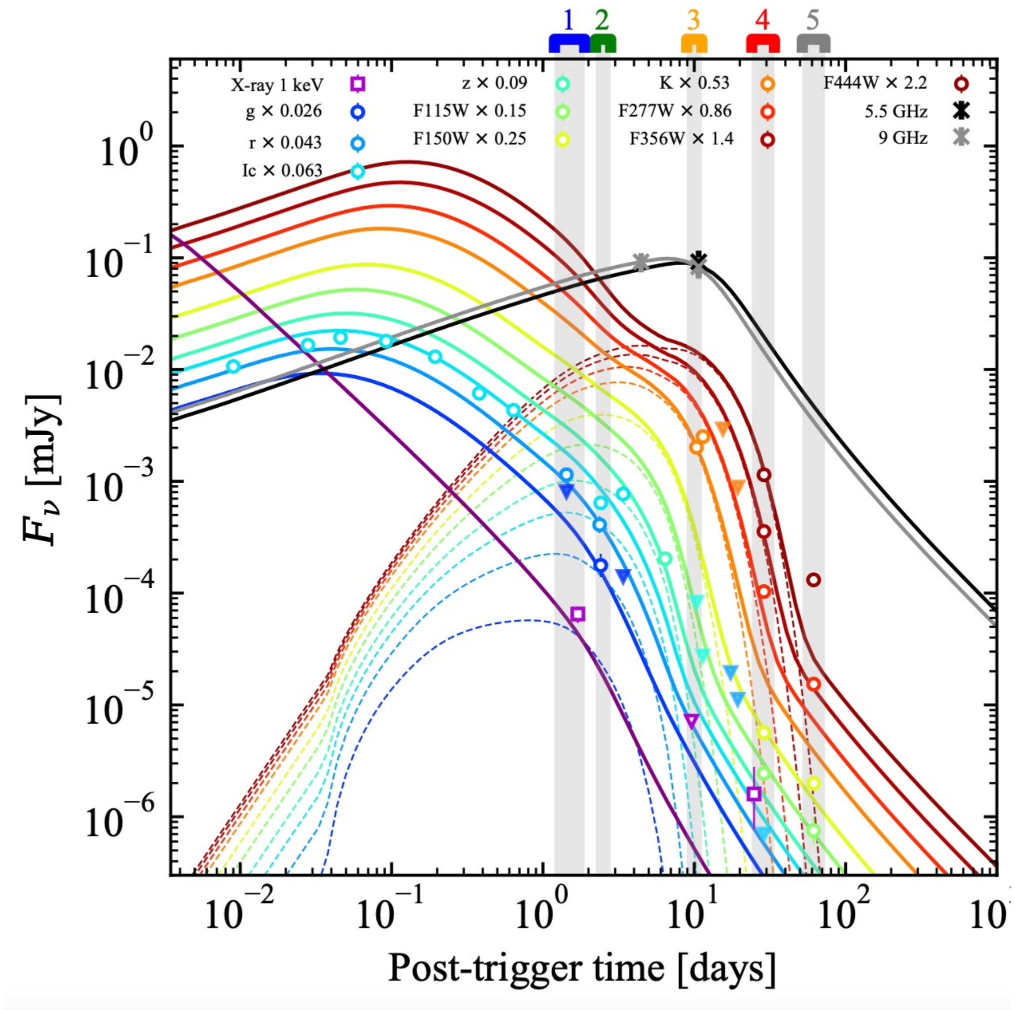
JWST-NIRCAM
F150W/F277W/F444W
N
E
Epoch 1
Epoch 2
Transient subtraction
F070W
F115W
F115W
F150W
F150W
F277W
F277W
z=3.87
F277W
F356W
F444W
F444W
F444W



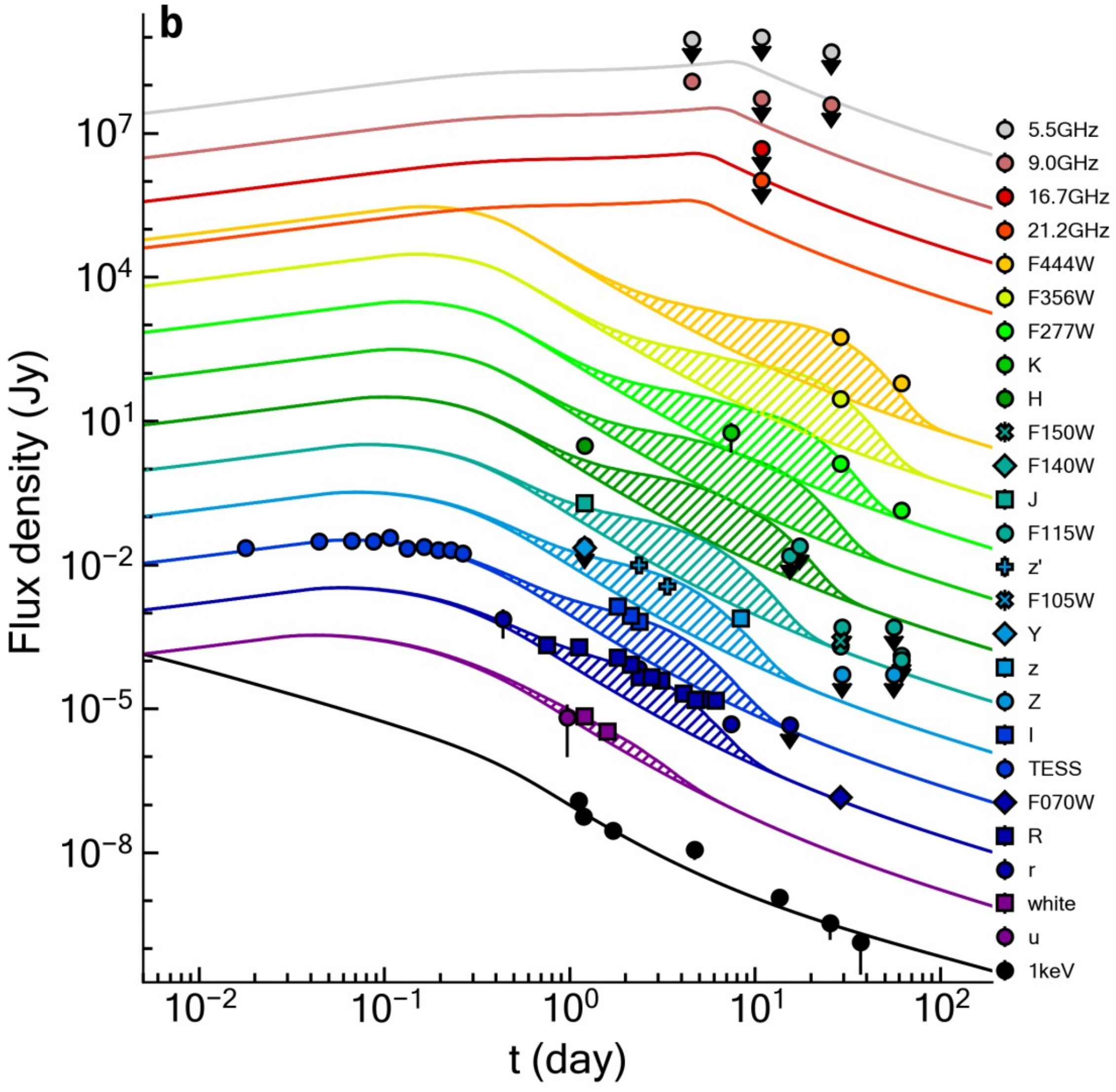
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
F_{obs} / F_{98bw}
0
1
2
3
4
Redshift
$E_{iso} = 10^{54}$ erg
$E_{iso} = 10^{55}$ erg
$E_{iso} = 10^{56}$ erg
Not at z=3.87
Not a SN at “any” redshift
Energetics
Rates/population arguments
Lack of supernova
Speed of evolution



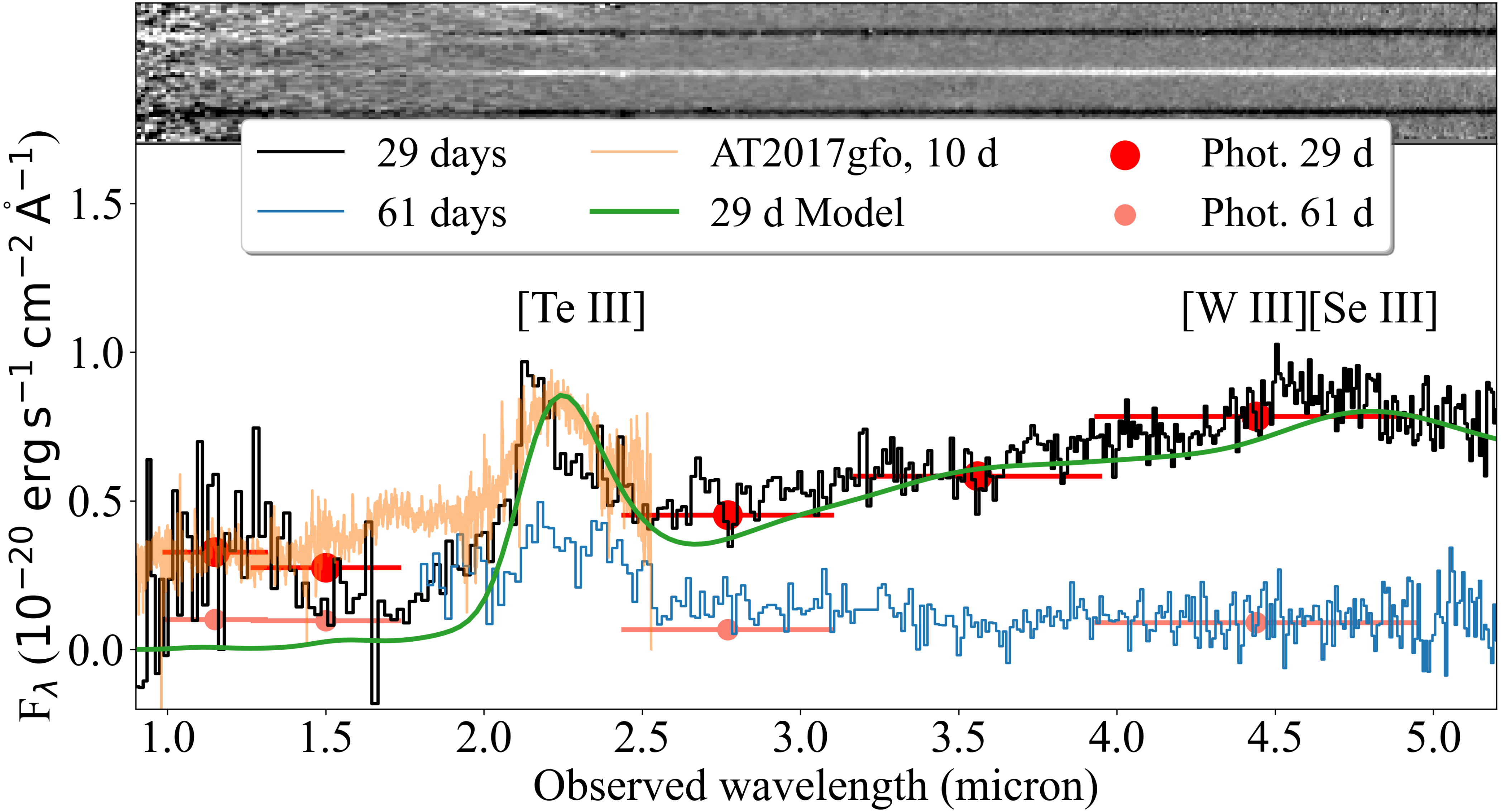
Levan et al. 2023
See also Yang et al. 2023



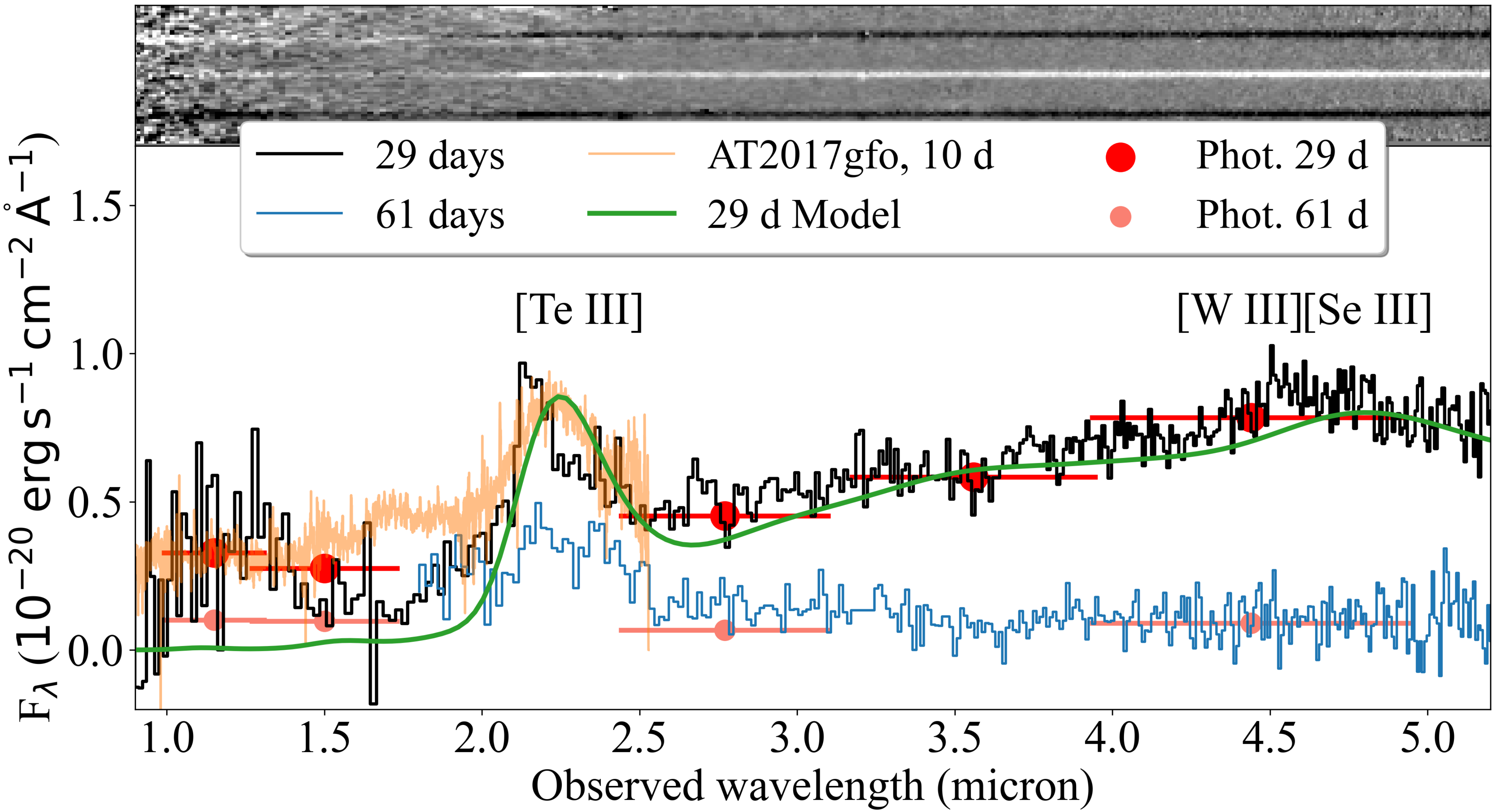
Levan et al. 2023



Yang et al. 2023



Levan et al. 2023, see also Gillanders et al. 2023



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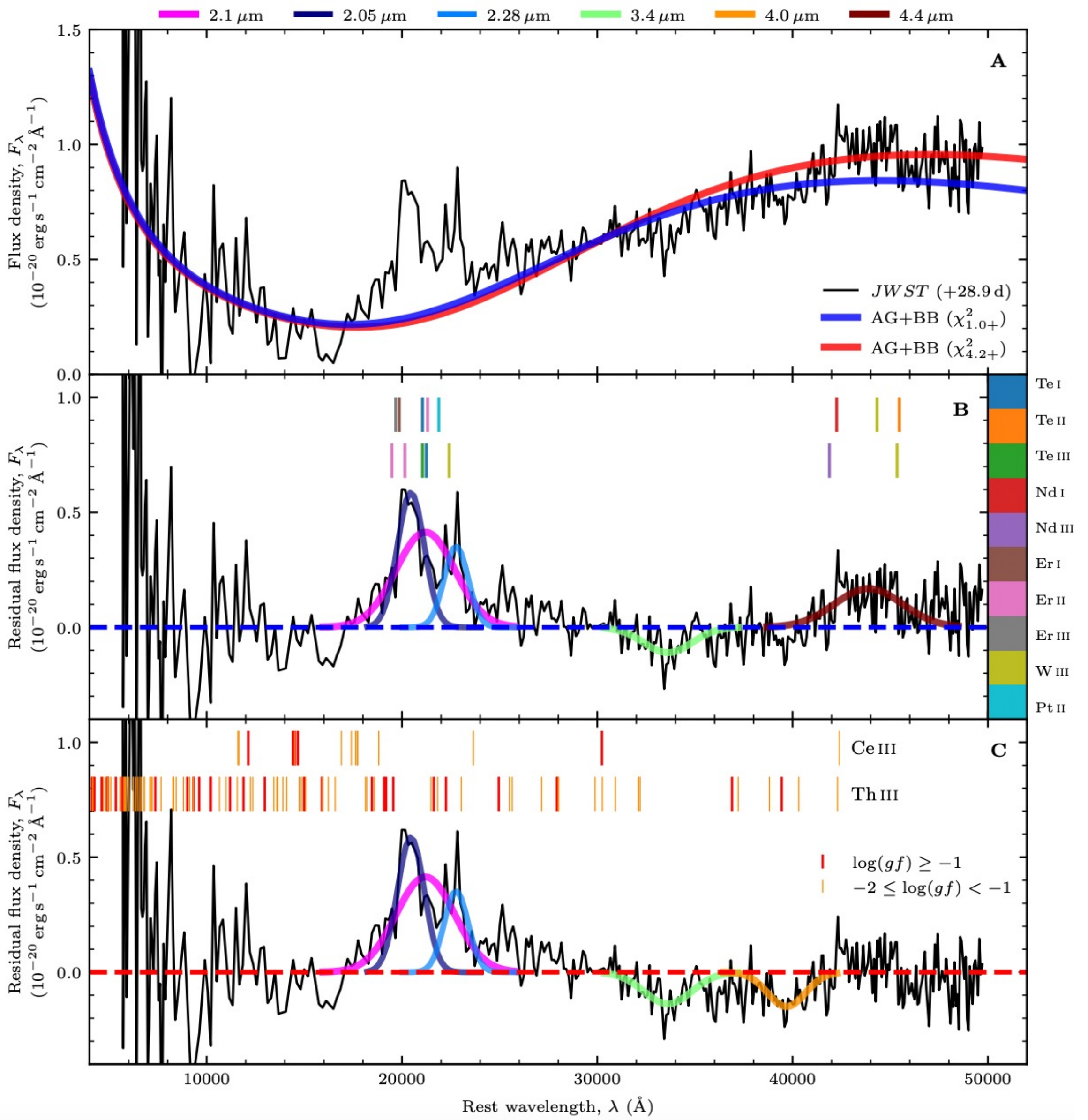
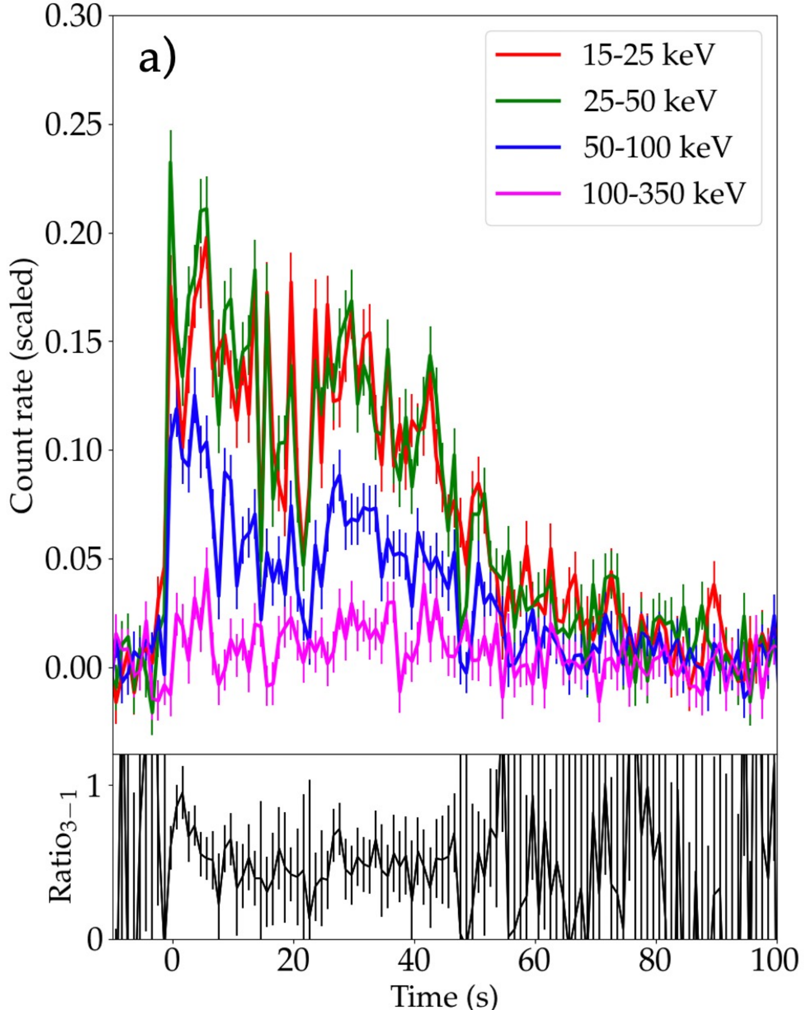
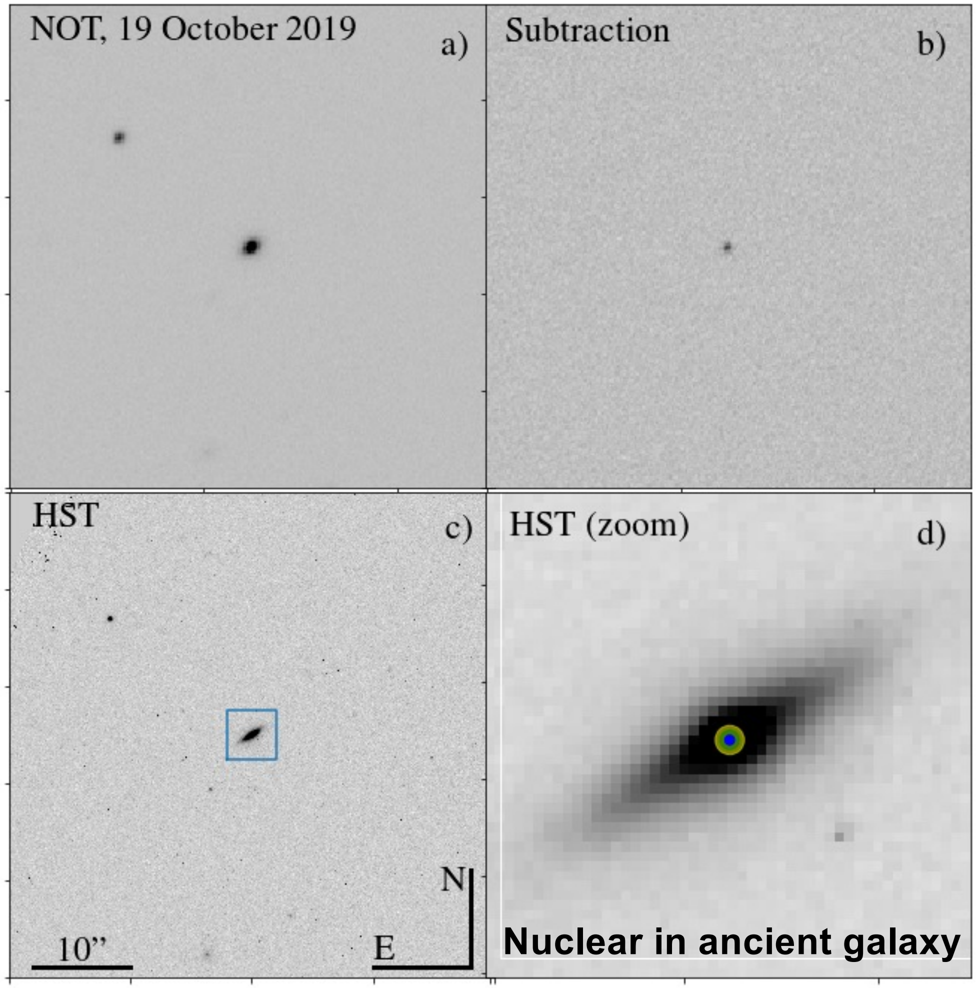


Gillanders et al. 2023

Other “long GRBs” from mergers – GRB 191019A, dynamical?





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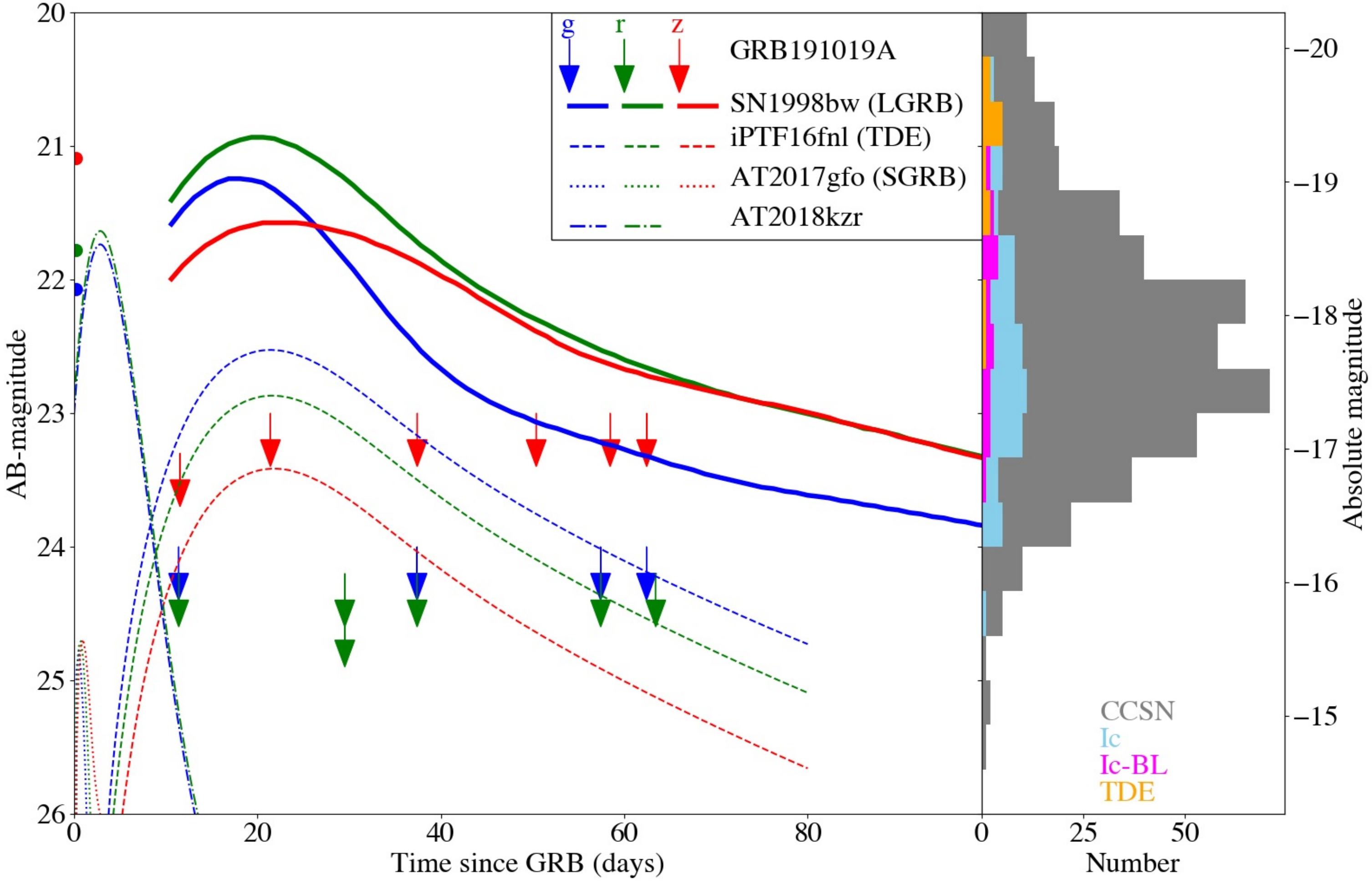

Levan, et al. 2023

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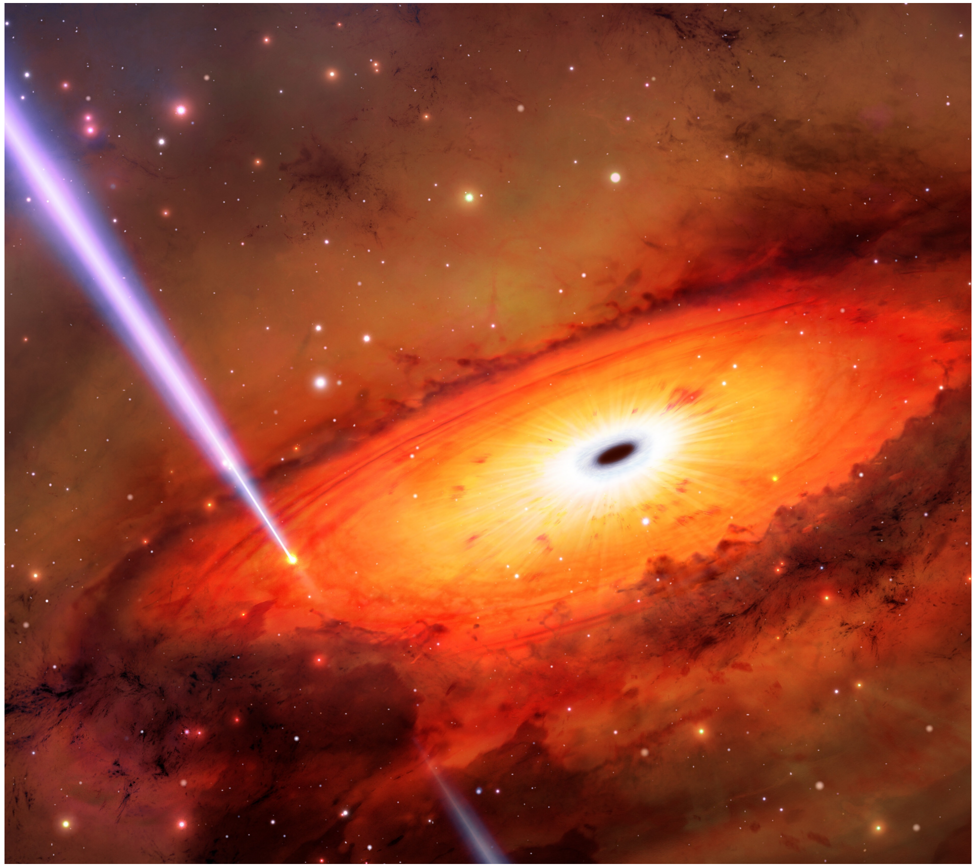
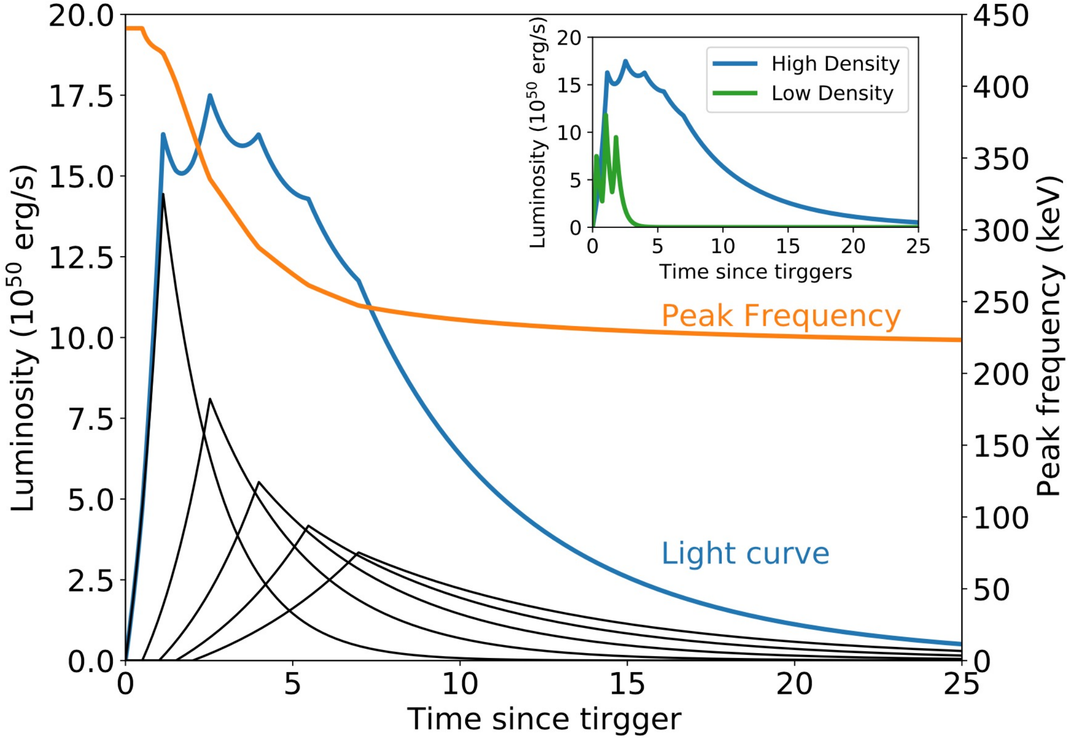


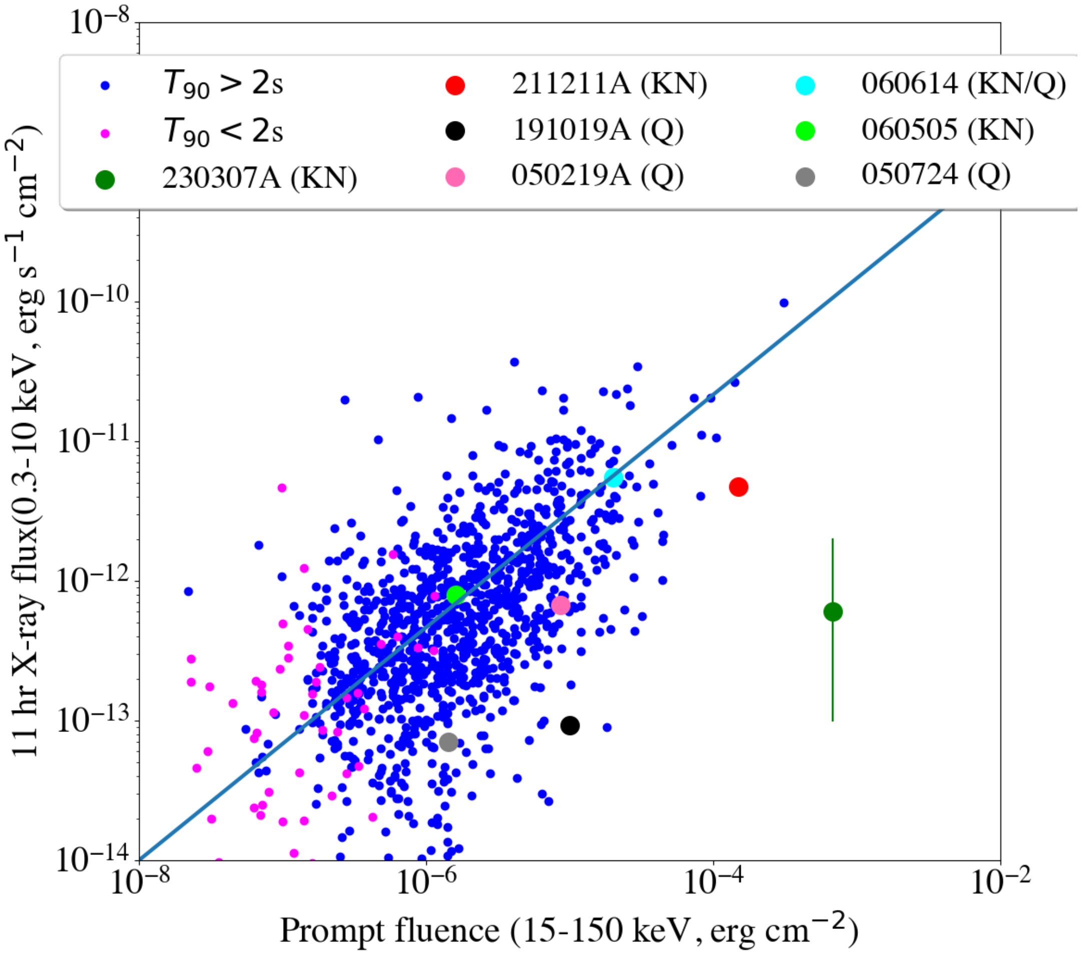


Lazzati et al. 2023

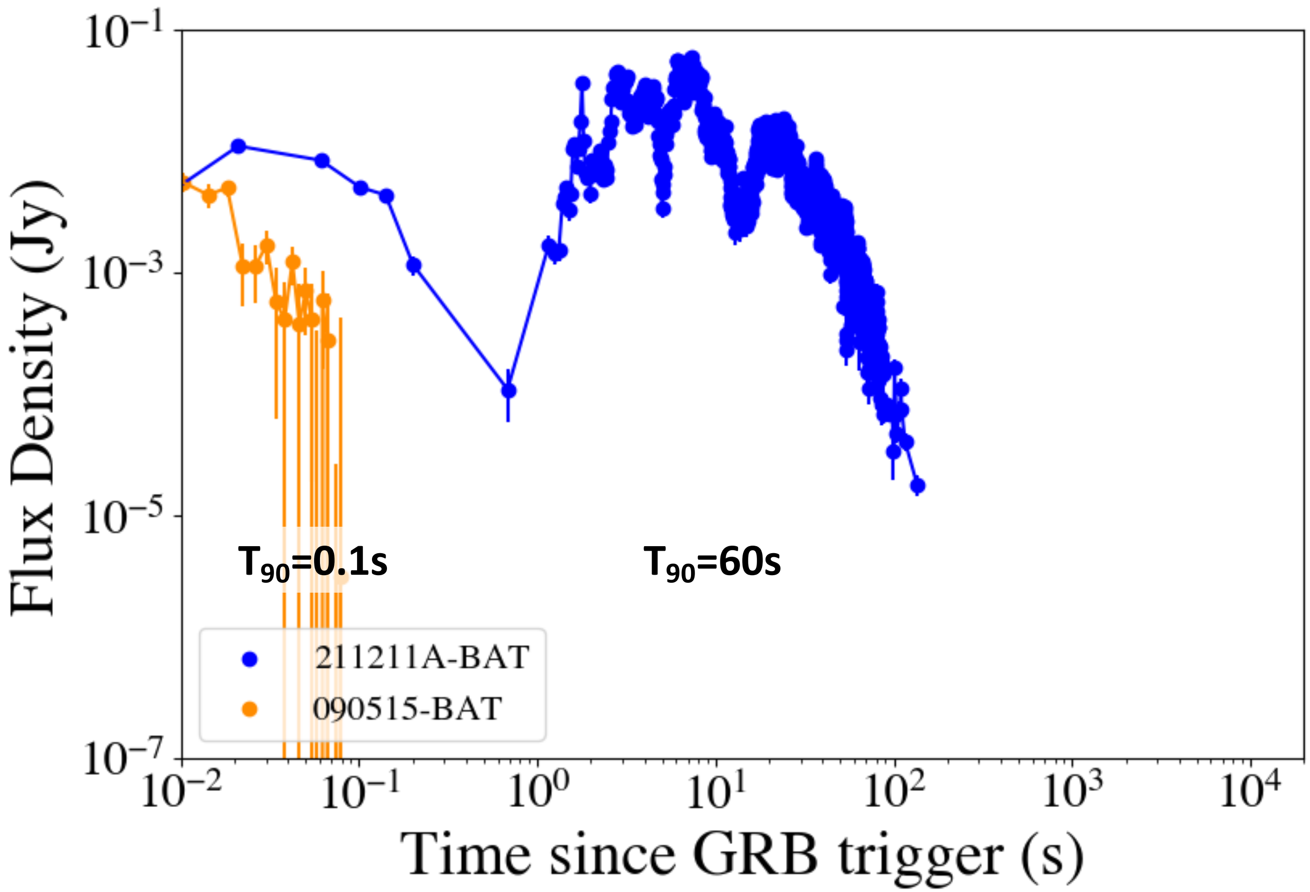
The sample of long GRBs from mergers

- At z<0.3 there are 24 bursts detected by Swift
  - 5 are short (T90 < 2s)
  - 19 are long (T90 > 2s)
  - 7 are long but with no supernova emission or in ancient galaxies (**050219A**, **050724**, *060505*, *060614*, 111005A, **191019A**, *211211A*).
  - Selection effects (mostly faint afterglows) mean merger GRBs more likely to be missed than collapsar GRBs.

- Long GRBs from mergers may be as common as short GRBs (for Swift).
- JWST can do KN spectroscopy (at peak) out to z~0.3 ➔ likely 1 opportunity per 18 months.
- JWST can do KN imaging to z=1 ➔ many opportunities per year (but which bursts…..)



Long lived central engines are common



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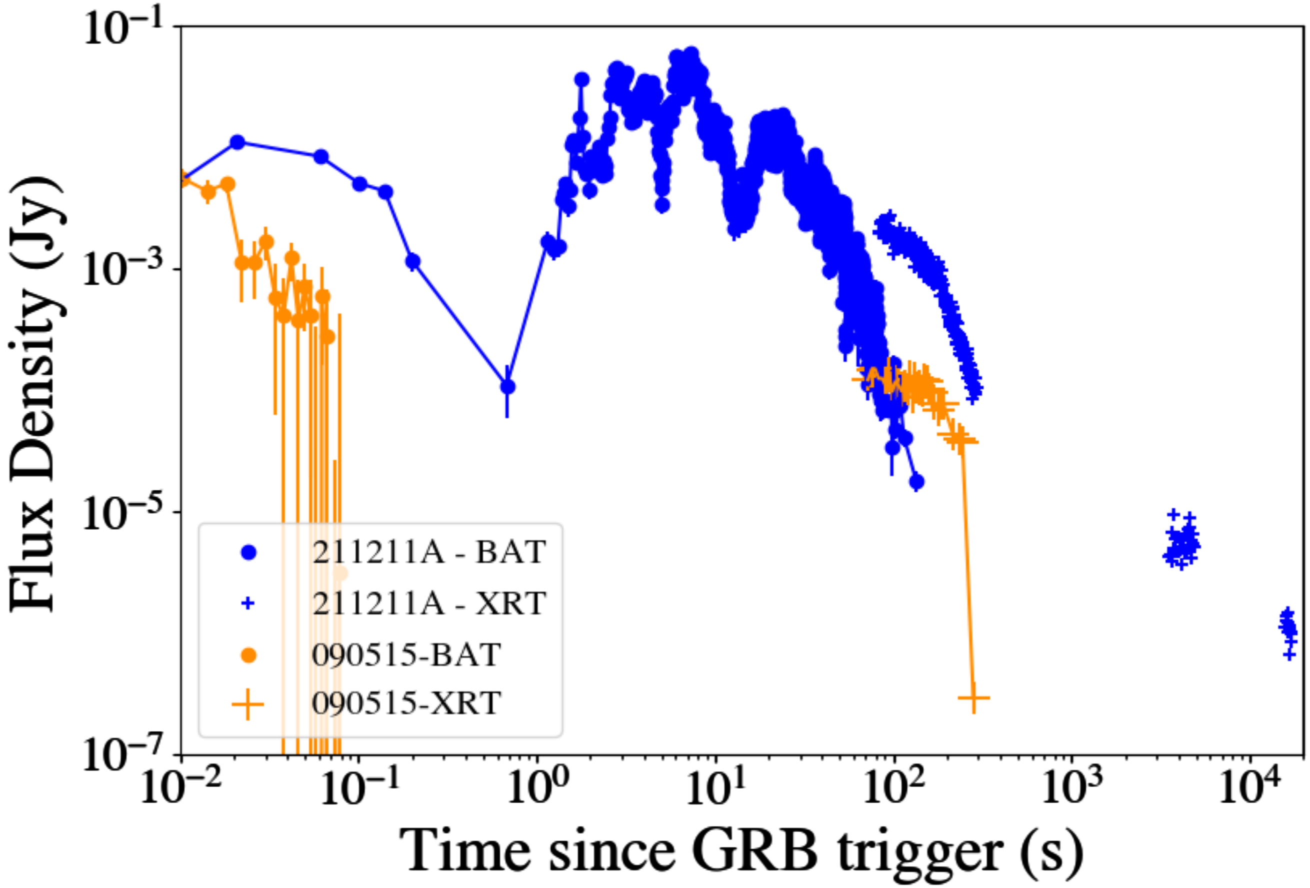
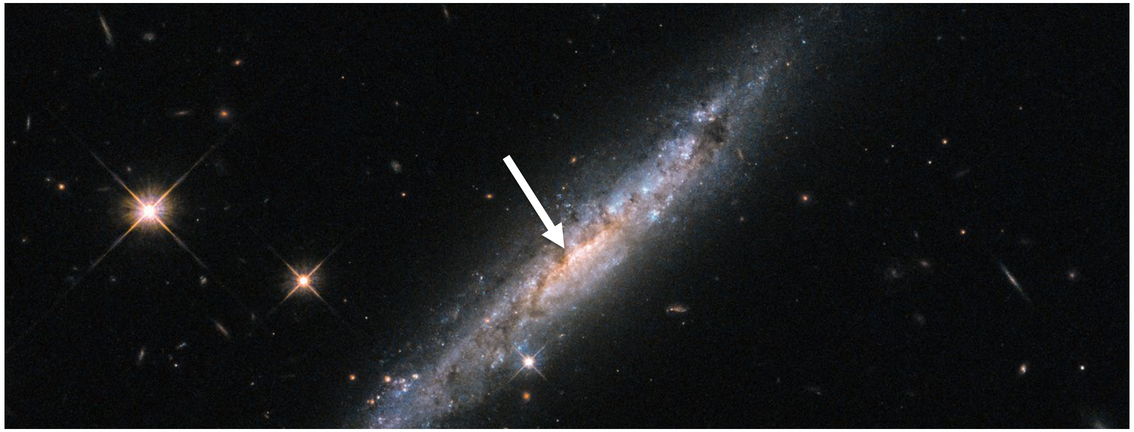


Even genuine "short" GRBs can have long lived central engine activity.

Outliers

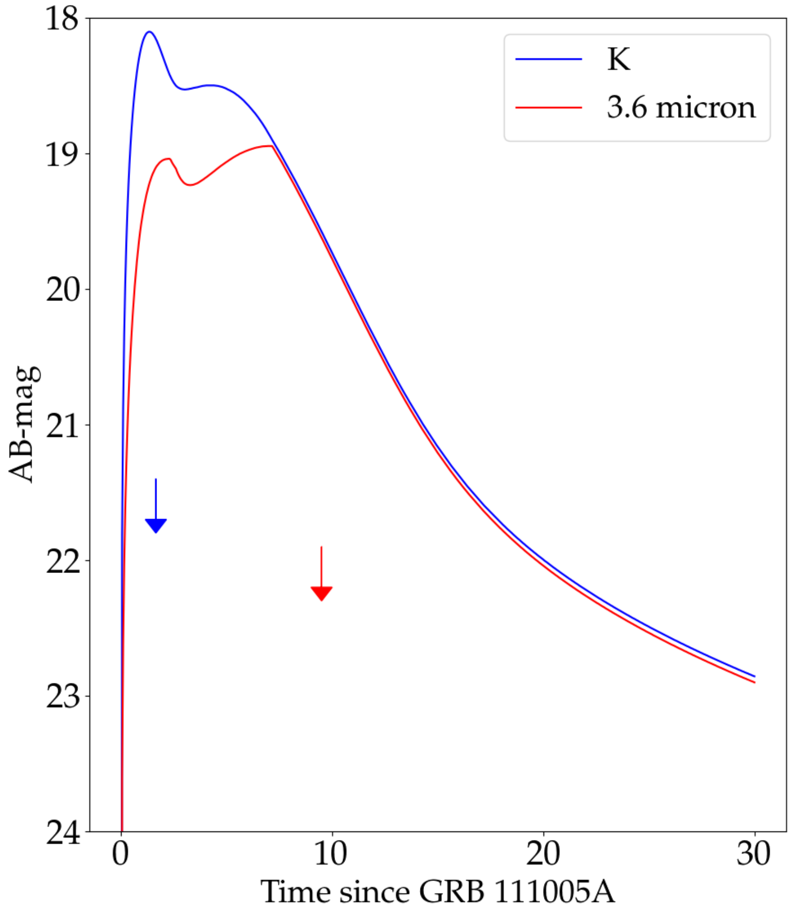
But beware false dichotomies

It's a long GRB without a supernova → it must be a merger



GRB 111005A

Suggested as merger by e.g. Michalowski et al., very nearby (55 Mpc), $E_{iso} = 2 \times 10^{47}$ erg.



Off-axis long version of GRB 170817A, or something different

If this is a merger then $M_K > -12$, or $A_V > 60$ for AT2017gfo-like event

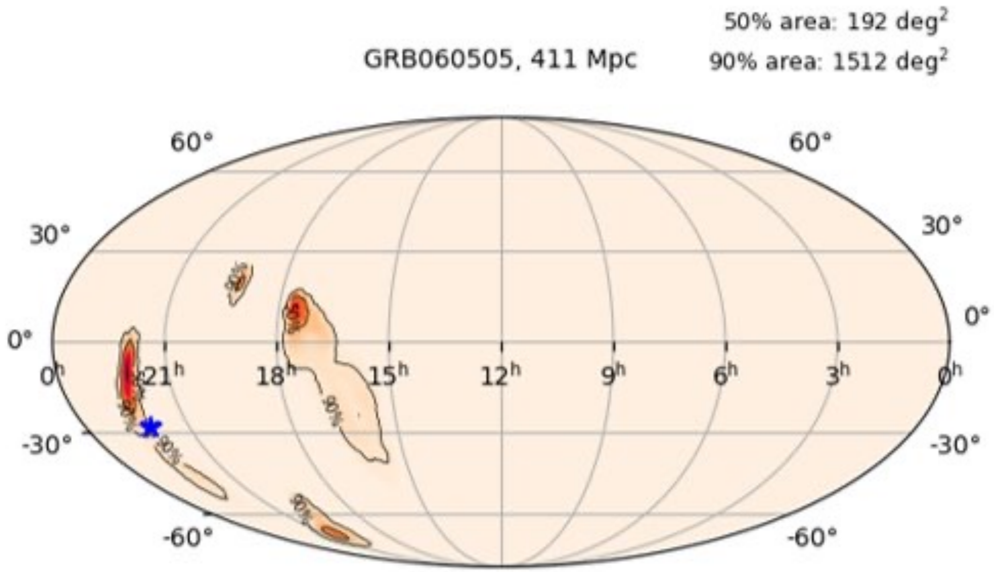
Rates

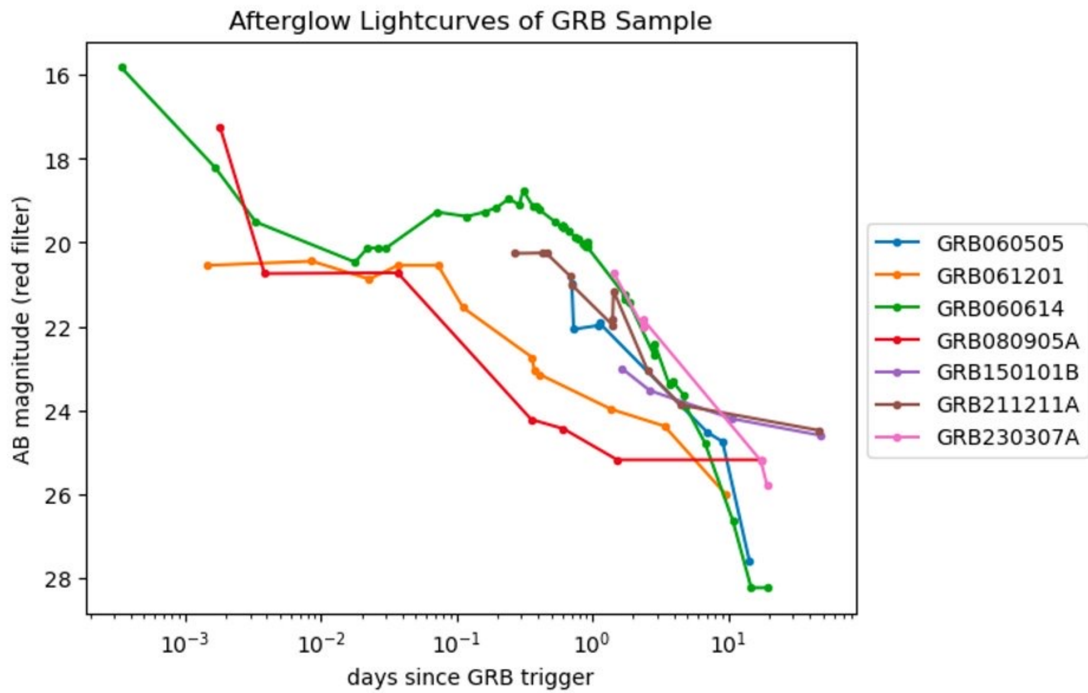
- Rates are also **extremely challenging,** V_{max} rates dominated by local, low luminosity examples (e.g. high-L $R_{211211A}$ = 0.01 $Gpc^{-3}\ yr^{-1}$, low-L $R_{111005A}$ = 1000 $Gpc^{3}\ yr^{-1}$)
- Lower limit. Swift has seen 12 mergers to z<0.3 in 18 years, 1/6th sky, 80% duty cycle.
- There have been > $f_b f_{GRB(L)}$. 3 $Gpc^{-3}\ yr^{-1}$ mergers*
  - f_b – beaming fraction ~ 20 for SGRBs
  - $f_{GRB(L)}$ – faint end of luminosity function ~10-100…..

- Rates consistent with LVK BNS merger rates

Crude calculation, as it isn't really volume limited, but OK for lower limits

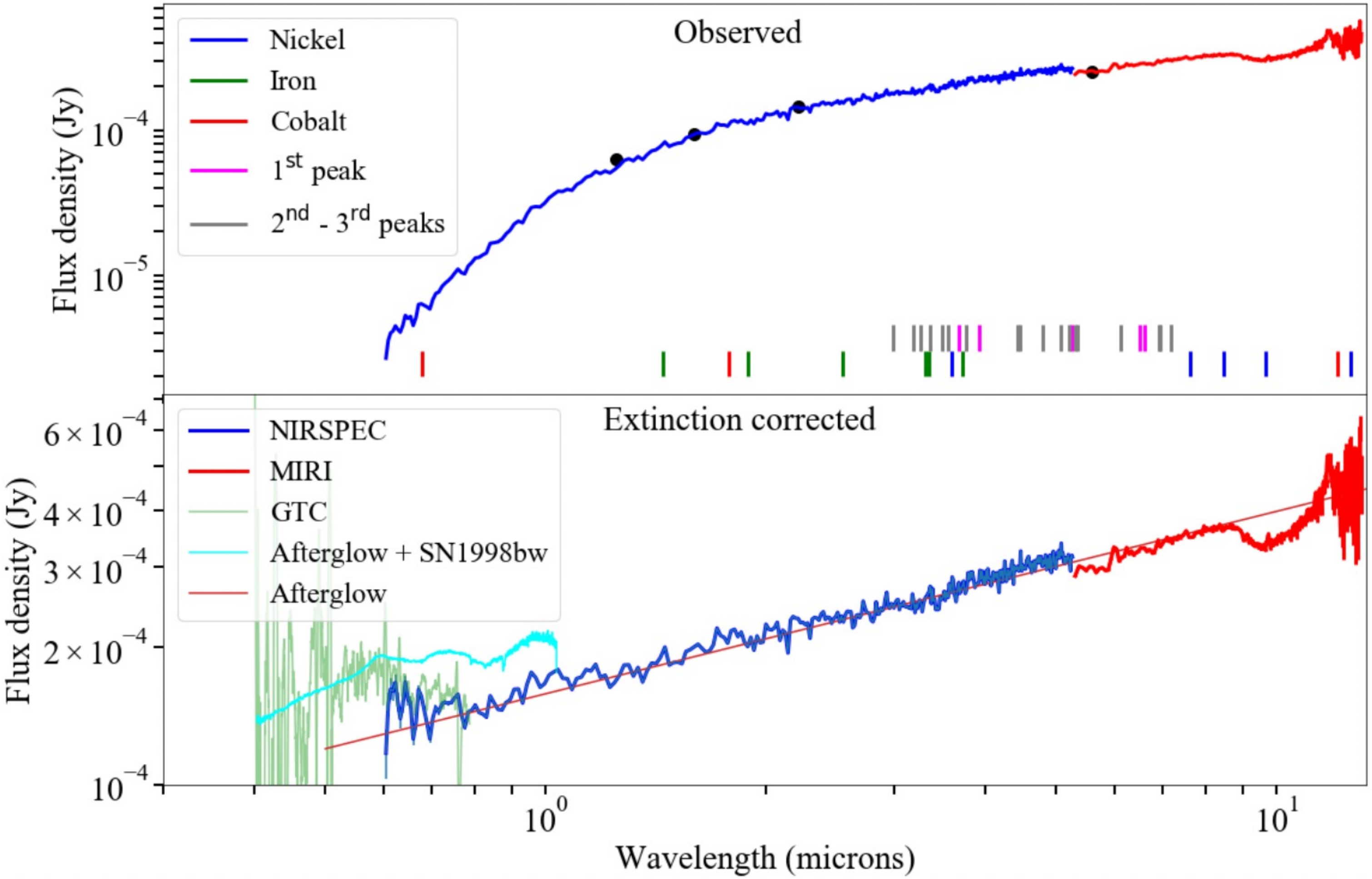
GW localisations for nearby GRBs





What about collapsars?

GRB 221009A – brightest ever long GRB



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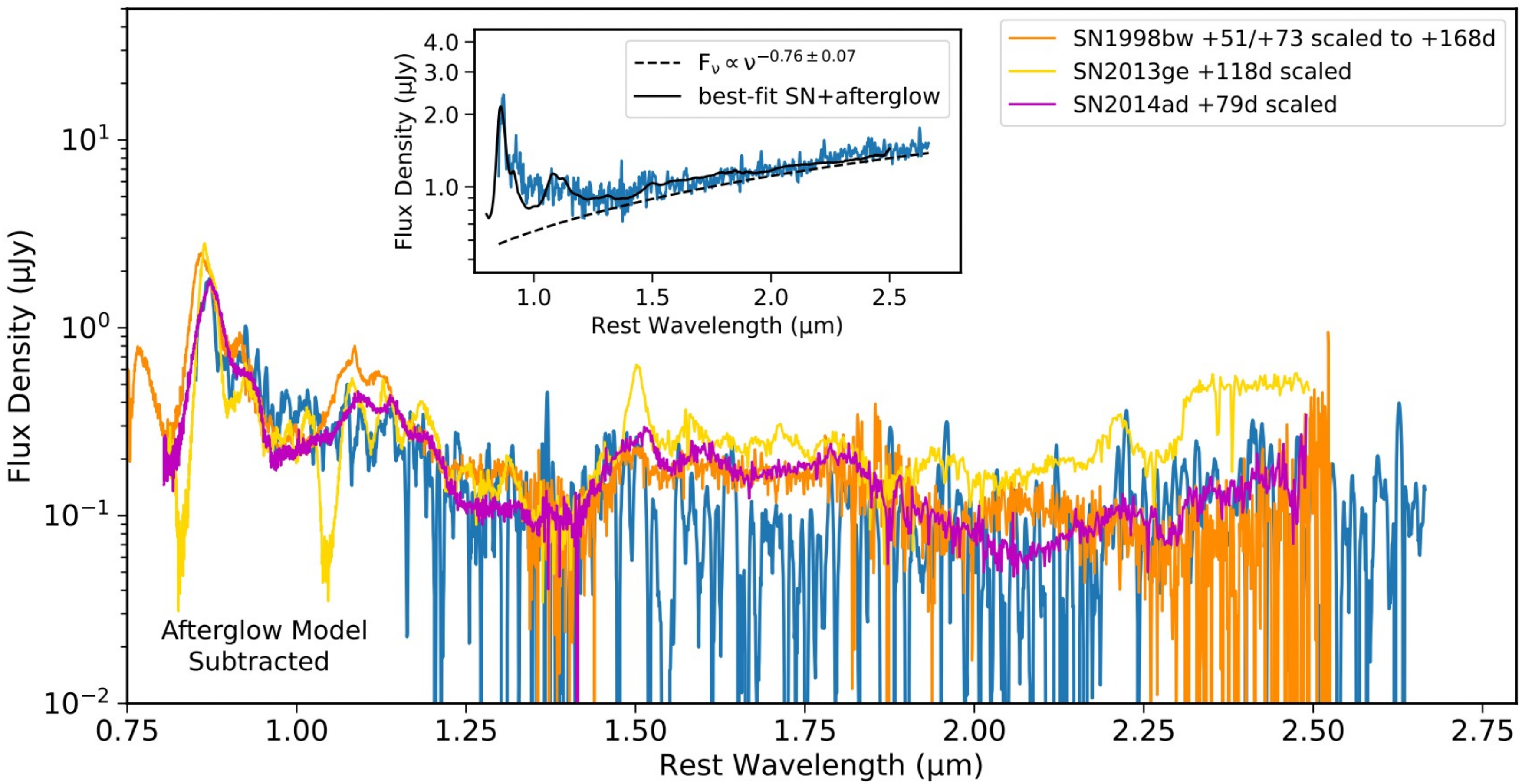
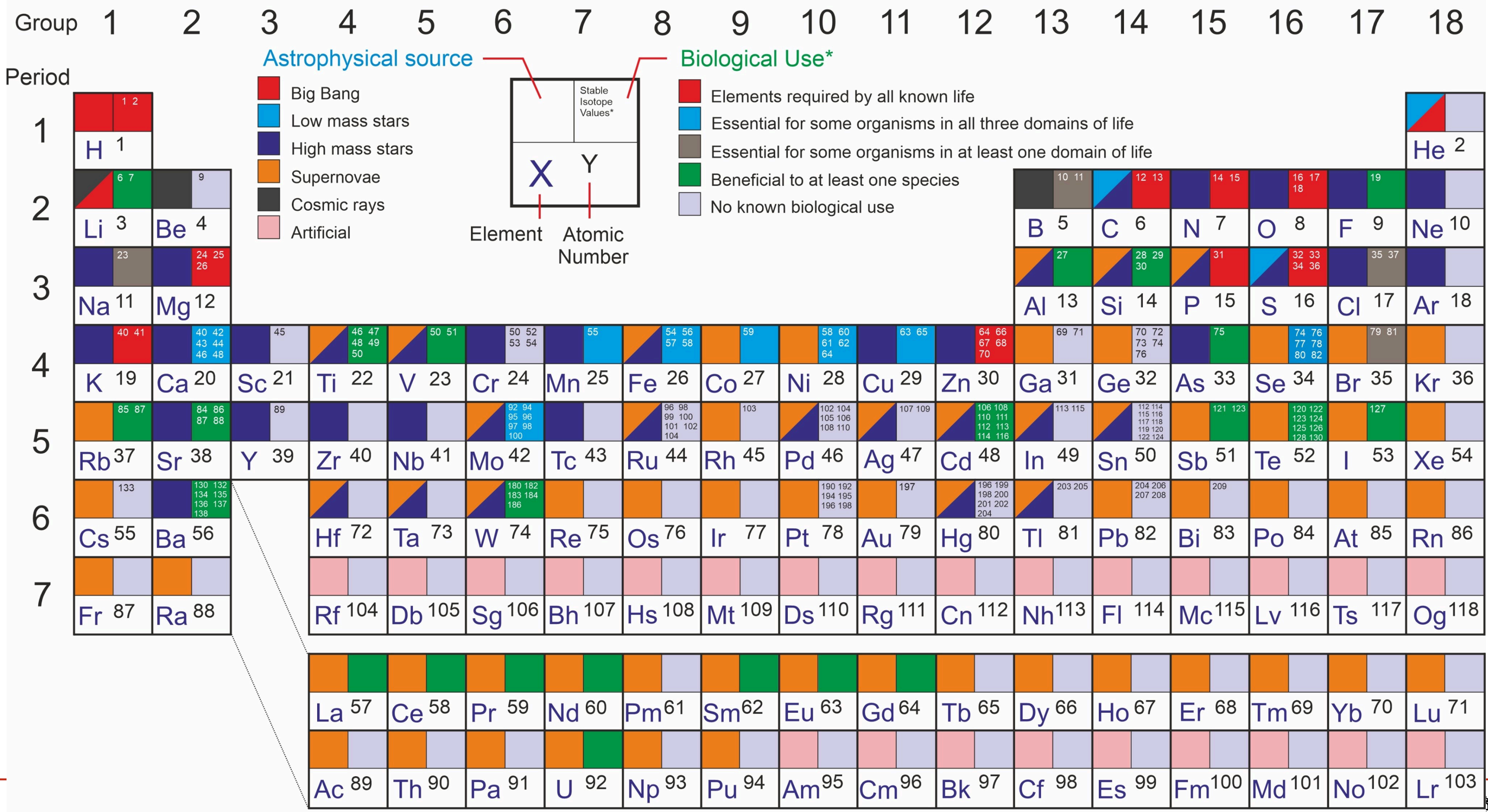


Blanchard et al. 2023

The Astrobiology Periodic Table

For comments email: c.s.cockell@ed.ac.uk



* Biological categorization taken from Remick KA and Helman JD. (2023) The elements of life: a biocentric tour of the periodic table. *Adv. Microbial Phys.*

Conclusions

- Observations of kilonovae are hard for many reasons, but there are routes to improvements
  - Future GW still likely to give the best lightcurves and spectra (distances <300 Mpc) and no afterglow contamination. But they are rare.
  - Still no wide-field survey discoveries, but things may improve (see Stephen Smartt talk).
- GRBs currently seem the most promising route to expand the KN sample.
  - Short and long GRBs may contribute to the merger rate at similar levels
  - Rate of such events with LVK volume (for face-on mergers) is ~1/yr – GRB 211211A/230307 should have been seen
  - But GRBs require afterglow subtractions and so not good for early KN properties
- **If our goal is to understand the r-process in mergers, then GRBs likely to provide more opportunities than GW in the next few years.**

Conclusions

- Open questions:
  - What new observations will really solve open problems (robust to model uncertainties)?
  - Can we separate what we can learn from small samples with good data and larger sparsely sampled data?
  - How can we (pre-)select objects that will contain kilonovae?
  - Do we need GW to determine if long GRBs with kilonovae are BNS, BH-NS or even WD-NS?