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CENTER FOR ADVANCED STUDIES INFN

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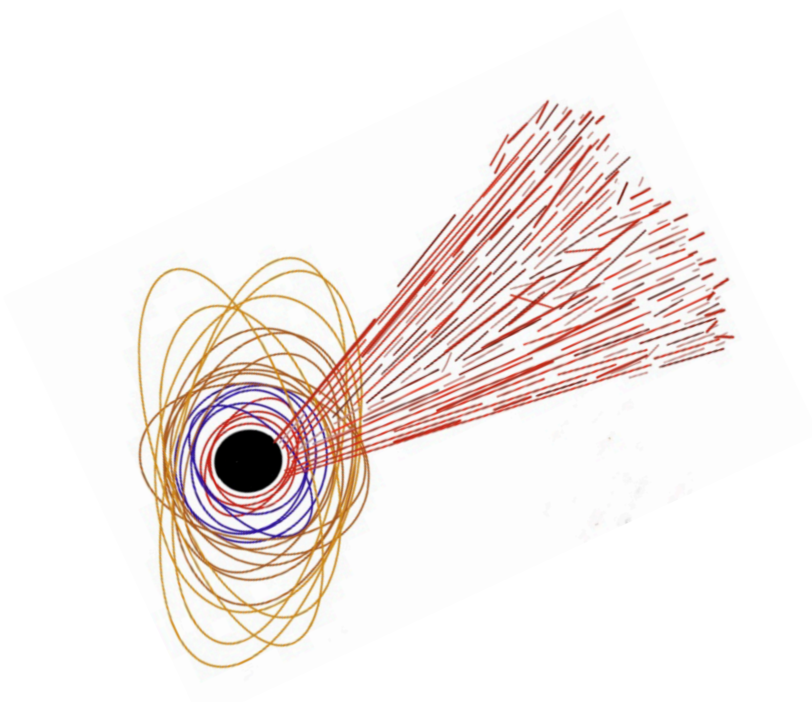
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

GW group

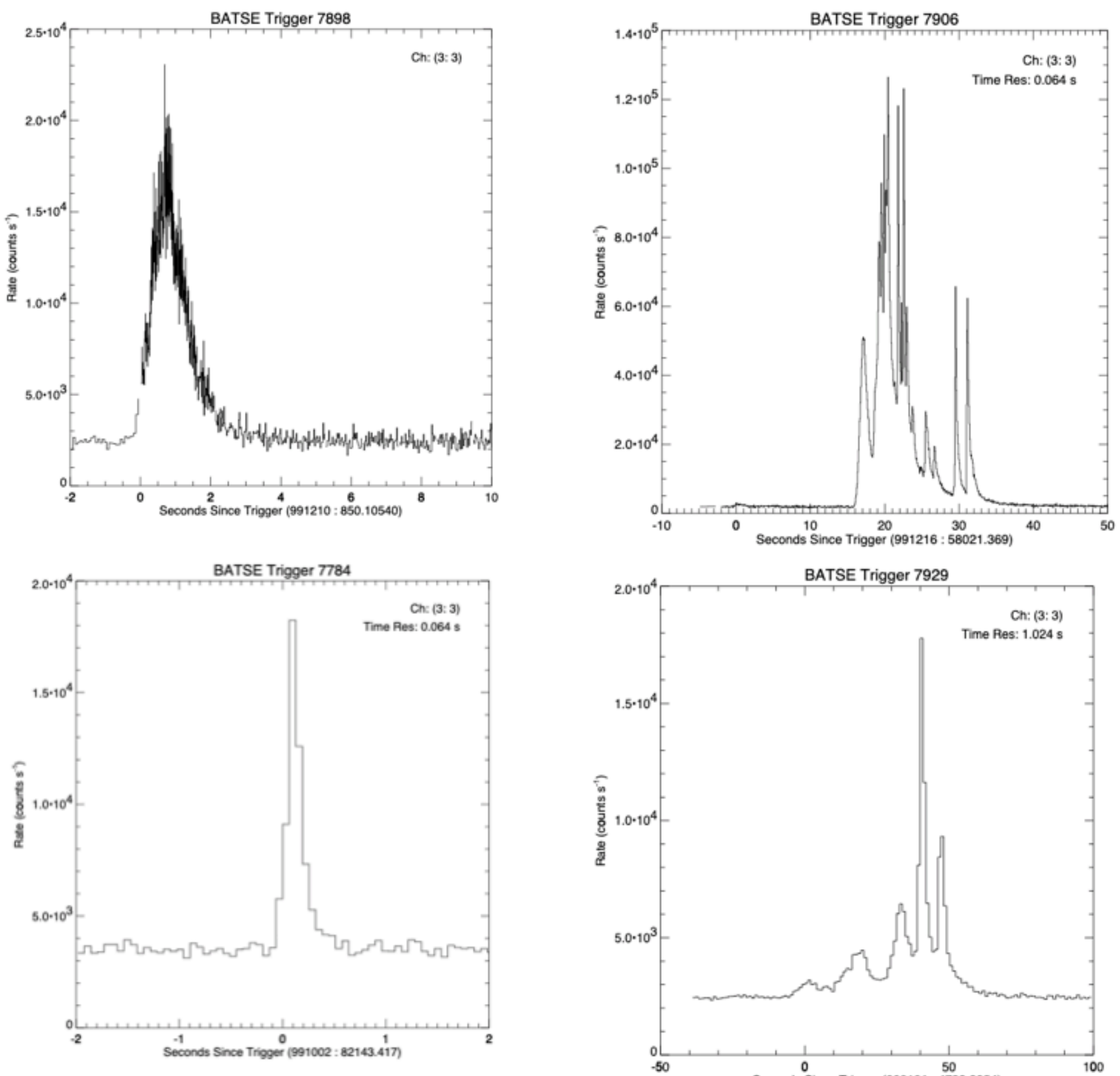
GRB precursors. Catch me if you can.

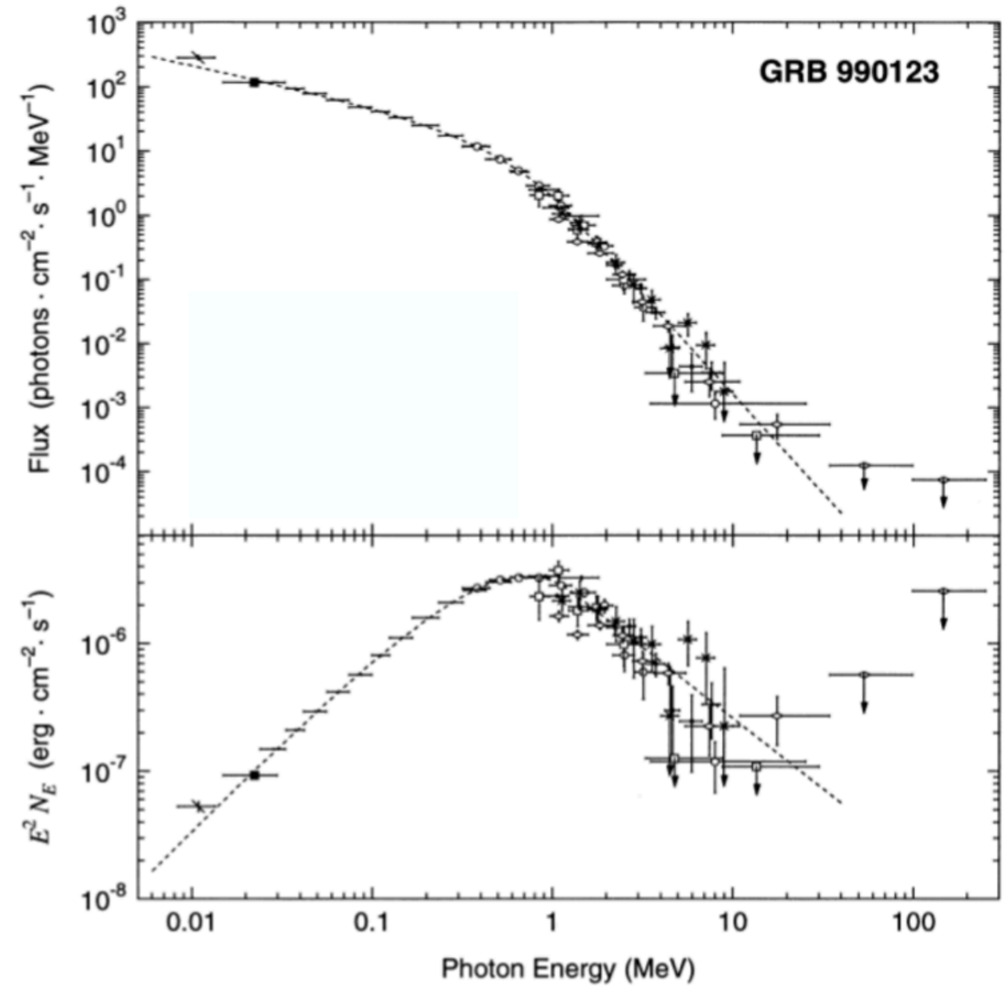


Gor Oganesyan

14 December 2023

prompt emission



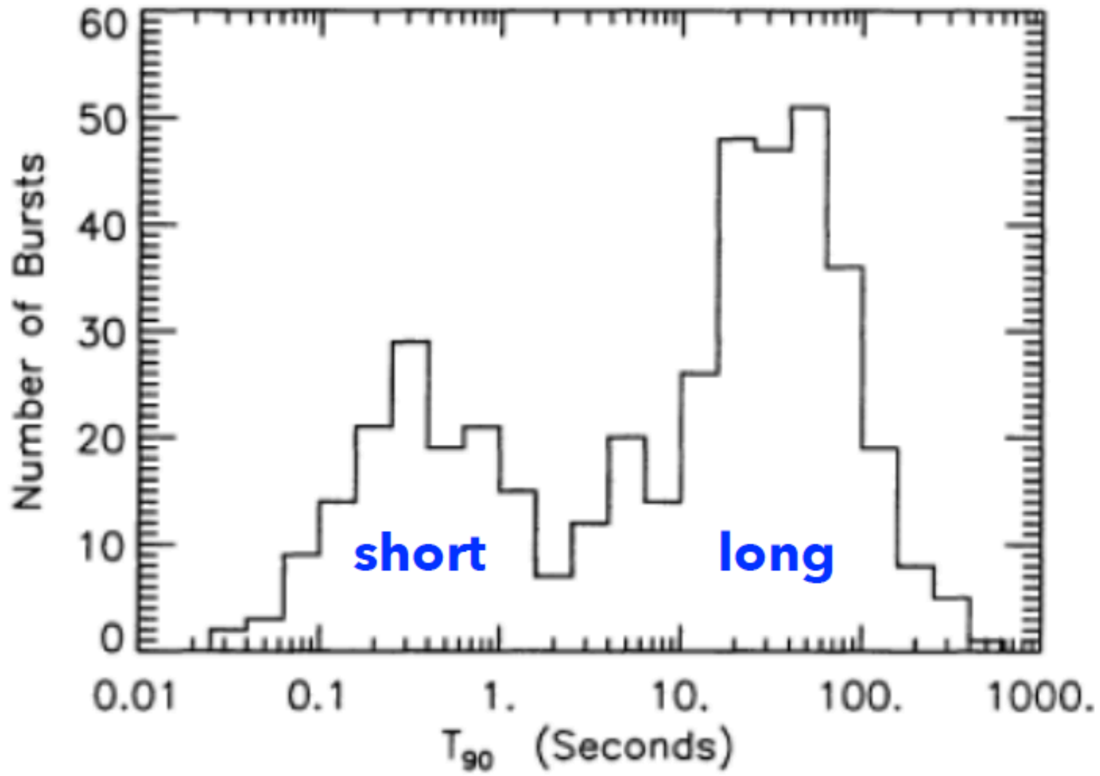


Briggs et al. 1999

[random BATSE GRBs]

band 10 keV - 10 MeV
total duration 0.1 s - 1000s
variability 0.01-1 s
total energy 1E51-1E54 erg

GRBs



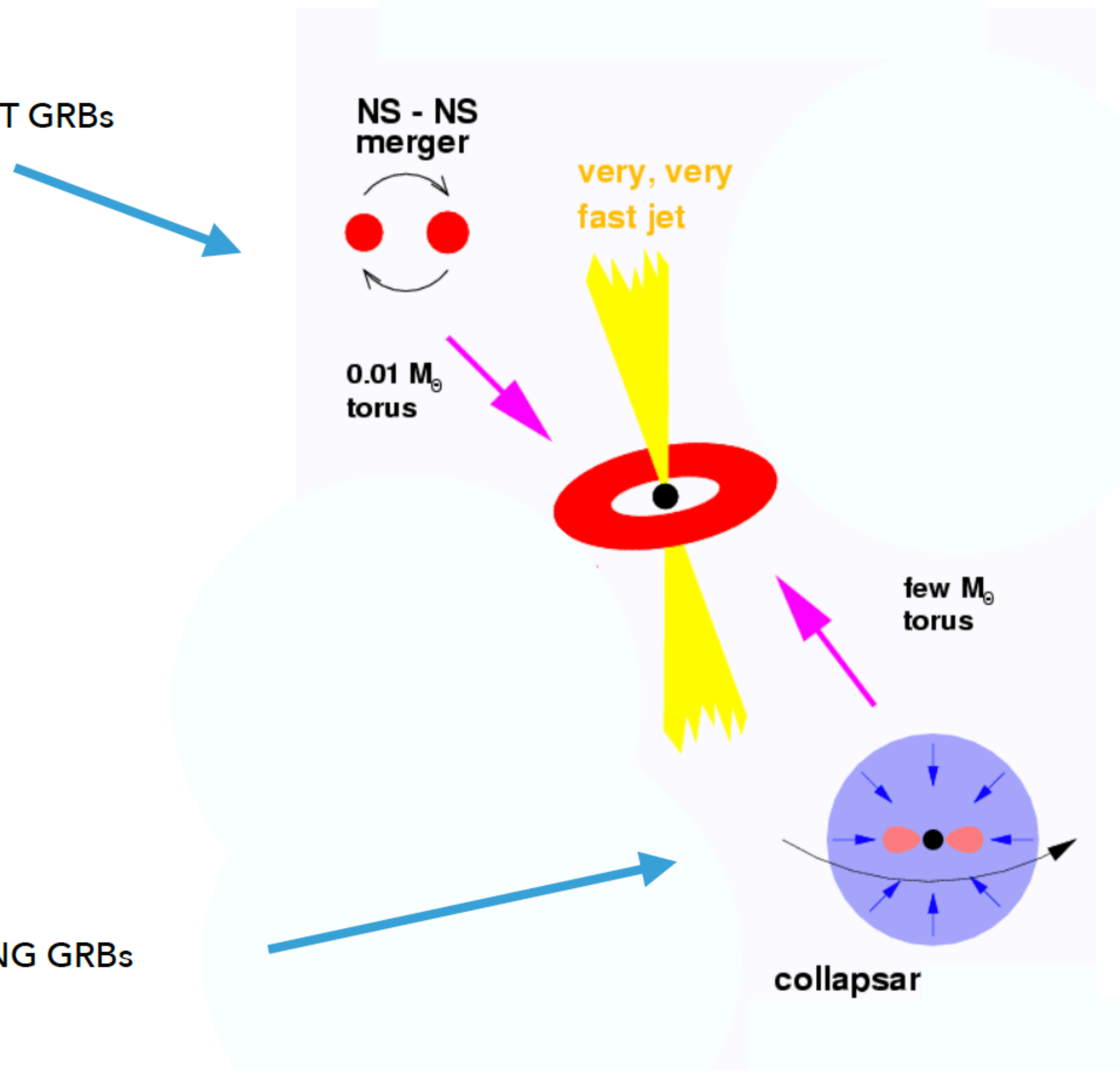
short (<2 s) and long (>2 s)

C. Kouveliotou et al. 1993, Meegan et al 1996, Sakamoto et al. 2011, Paciesas et al 2012

short-hard vs long-soft GRBs

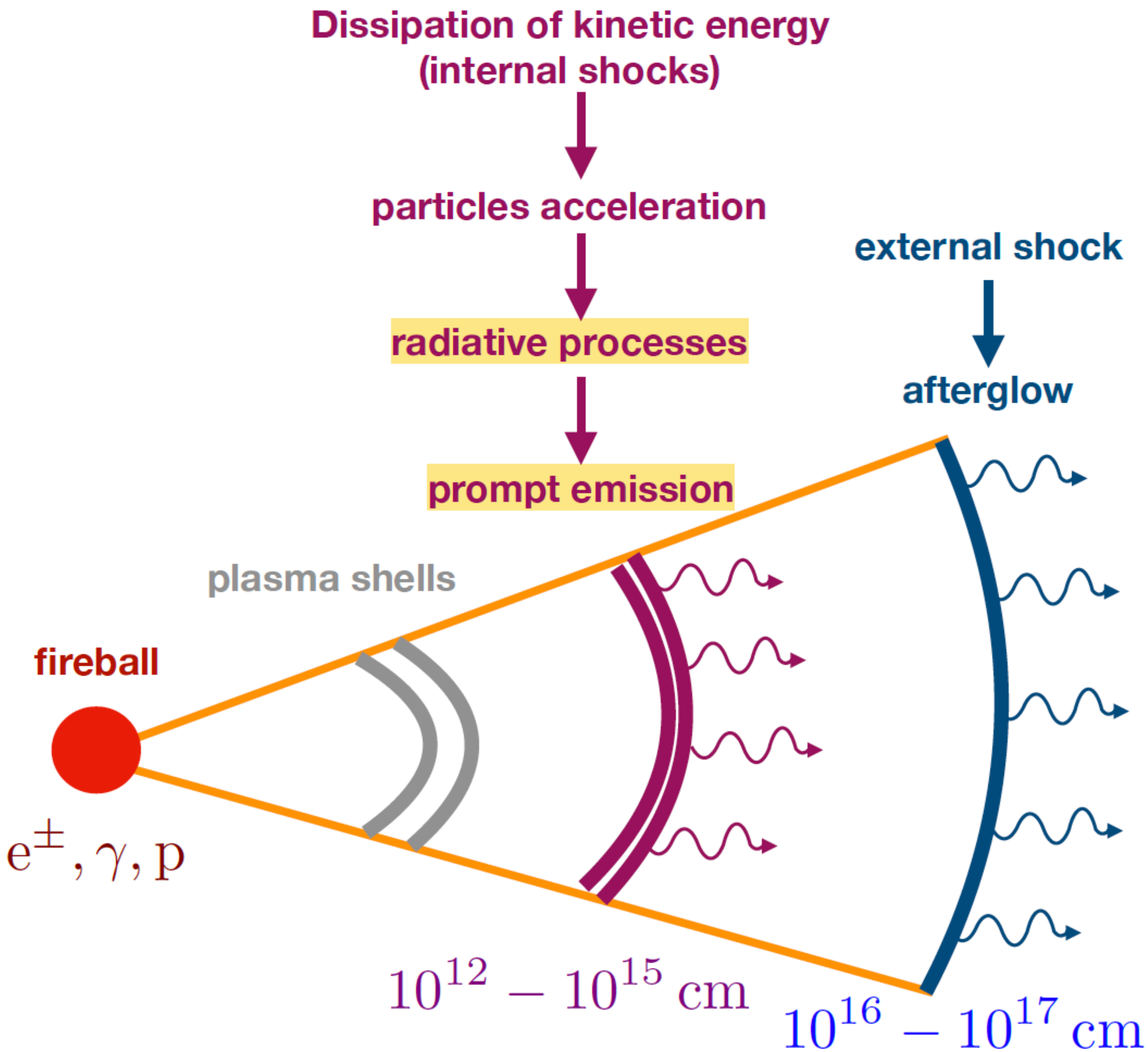
GRBs

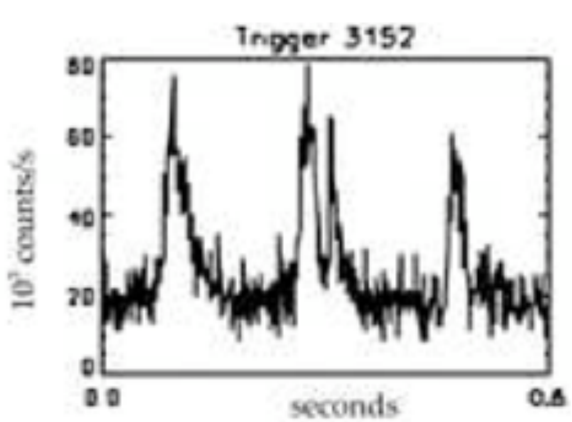
SHORT GRBs



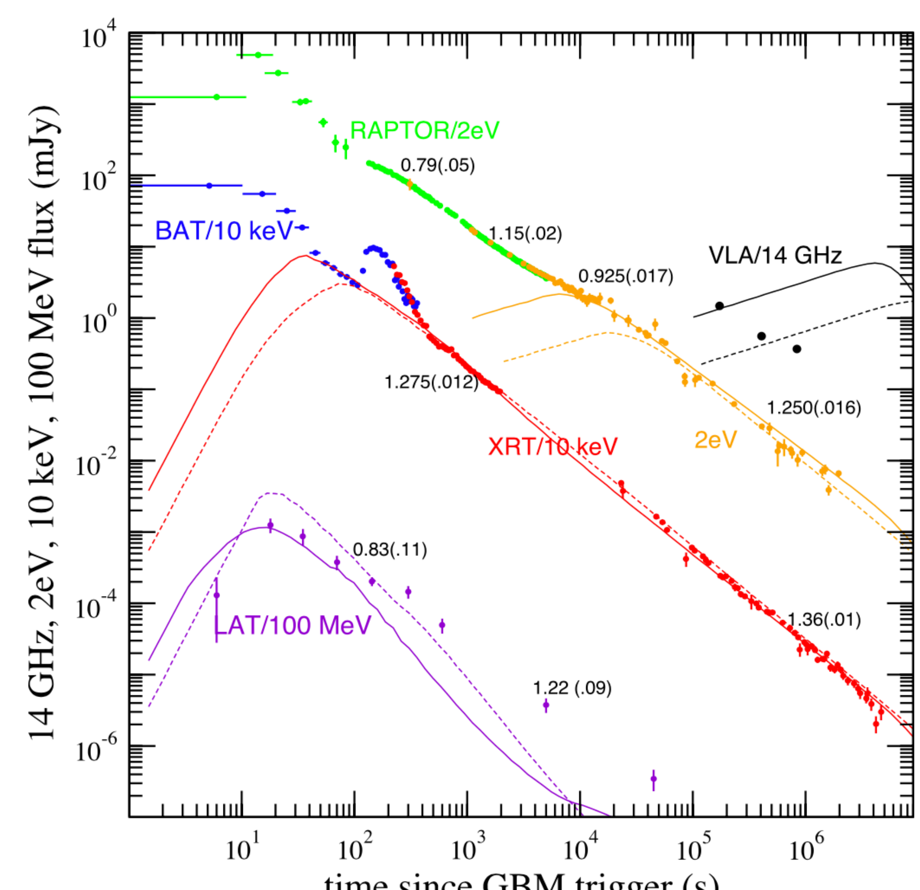
LONG GRBs

"standard model"





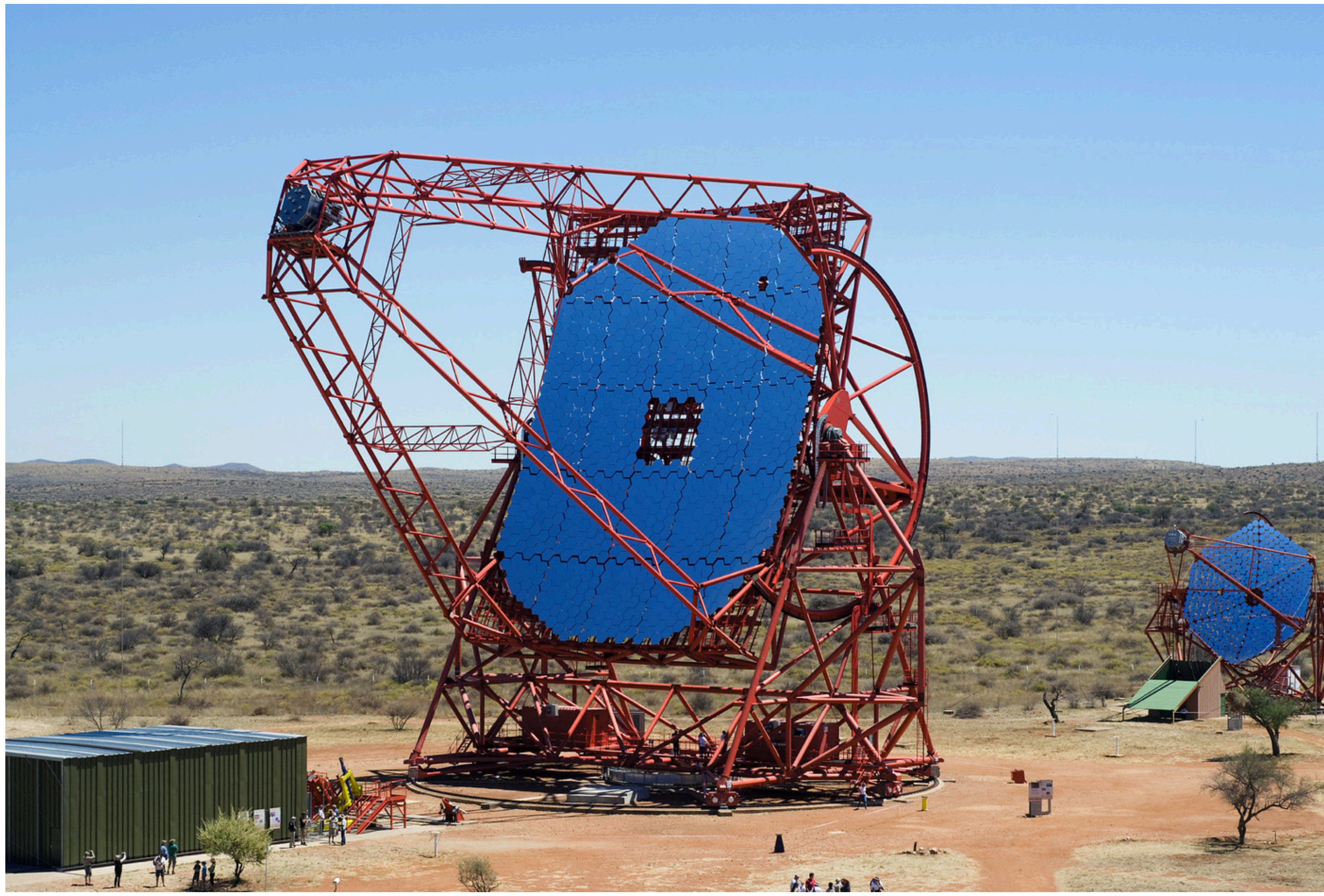
Panaitescu et al. 2013



GRBs at Very High Energies - the discoveries of 2019

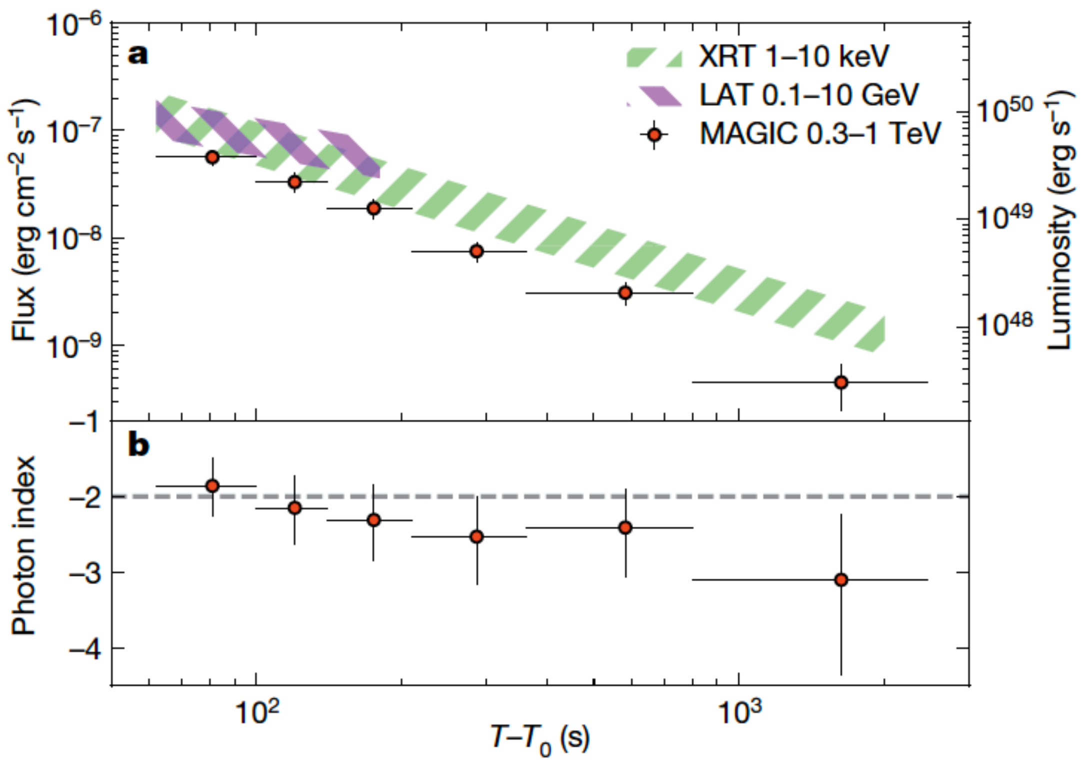
MAGIC and H.E.S.S.

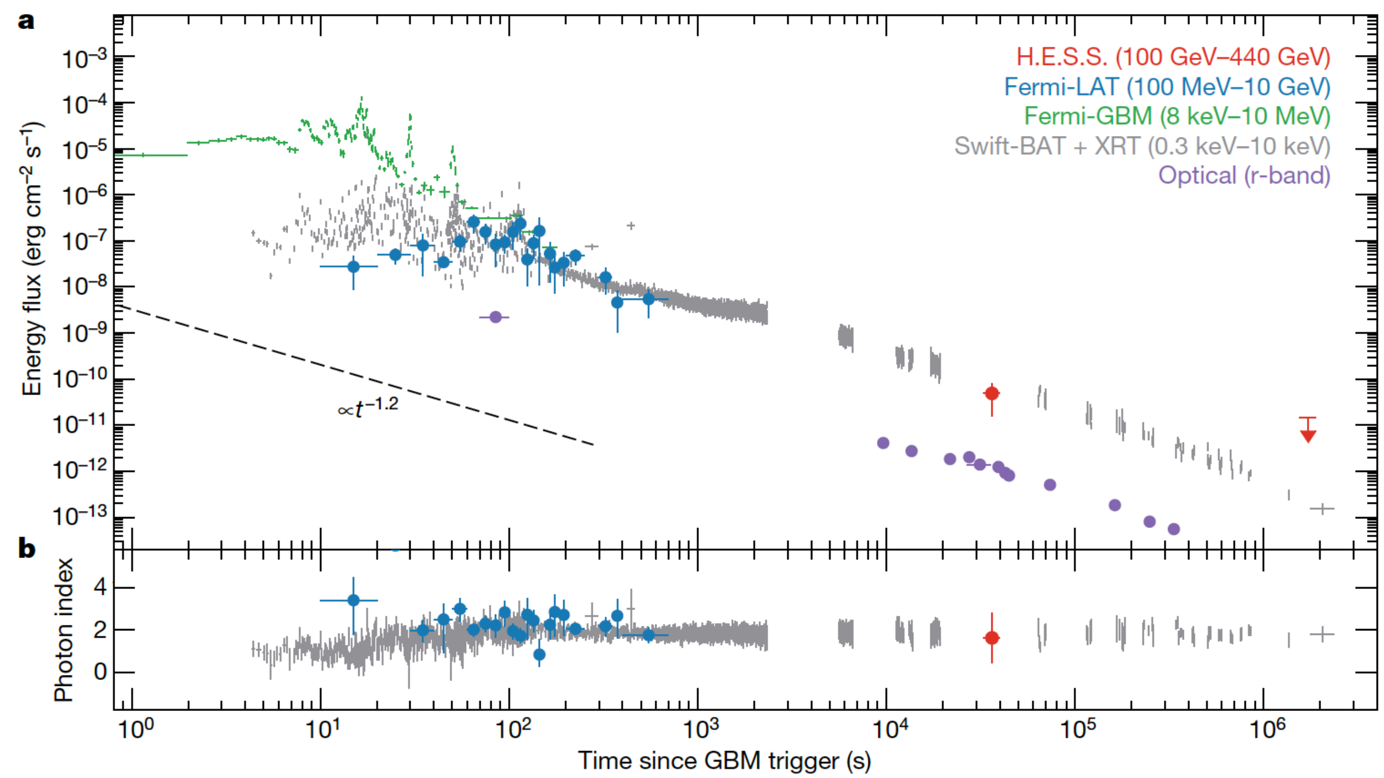
Towards TeVs!



GRBs at Very High Energies - the discoveries of 2019

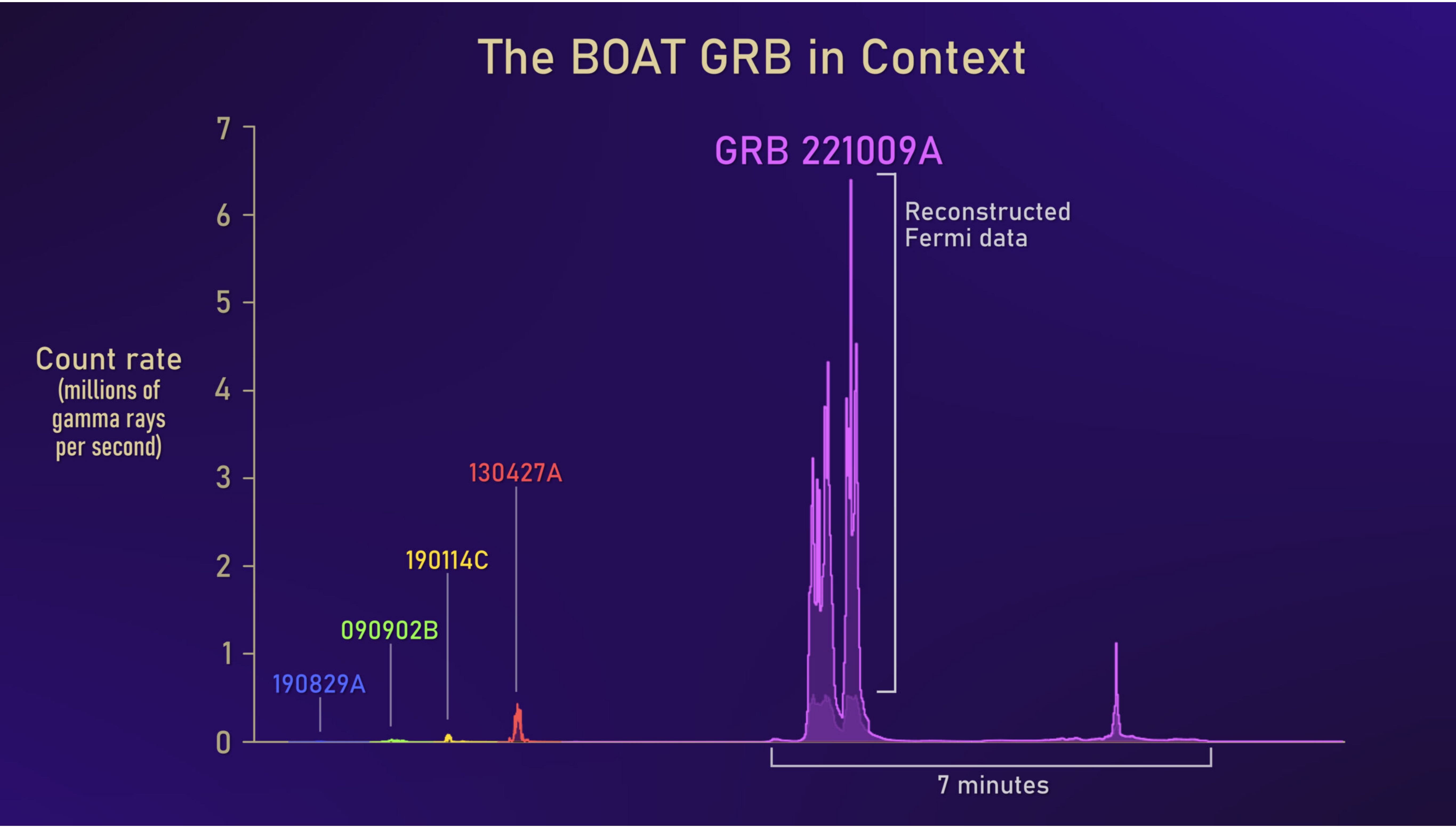
MAGIC and H.E.S.S.
collaborations



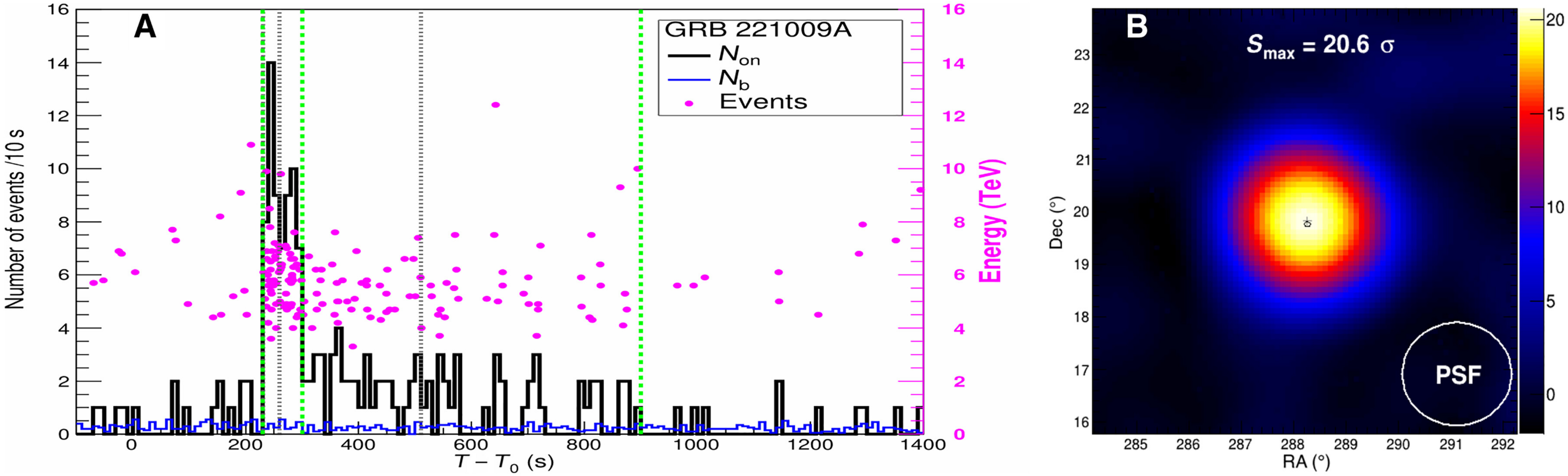


Acciari et al. 2019, Abdalla et al. 2019 & 2021; Acciari et al. 2021

The BOAT

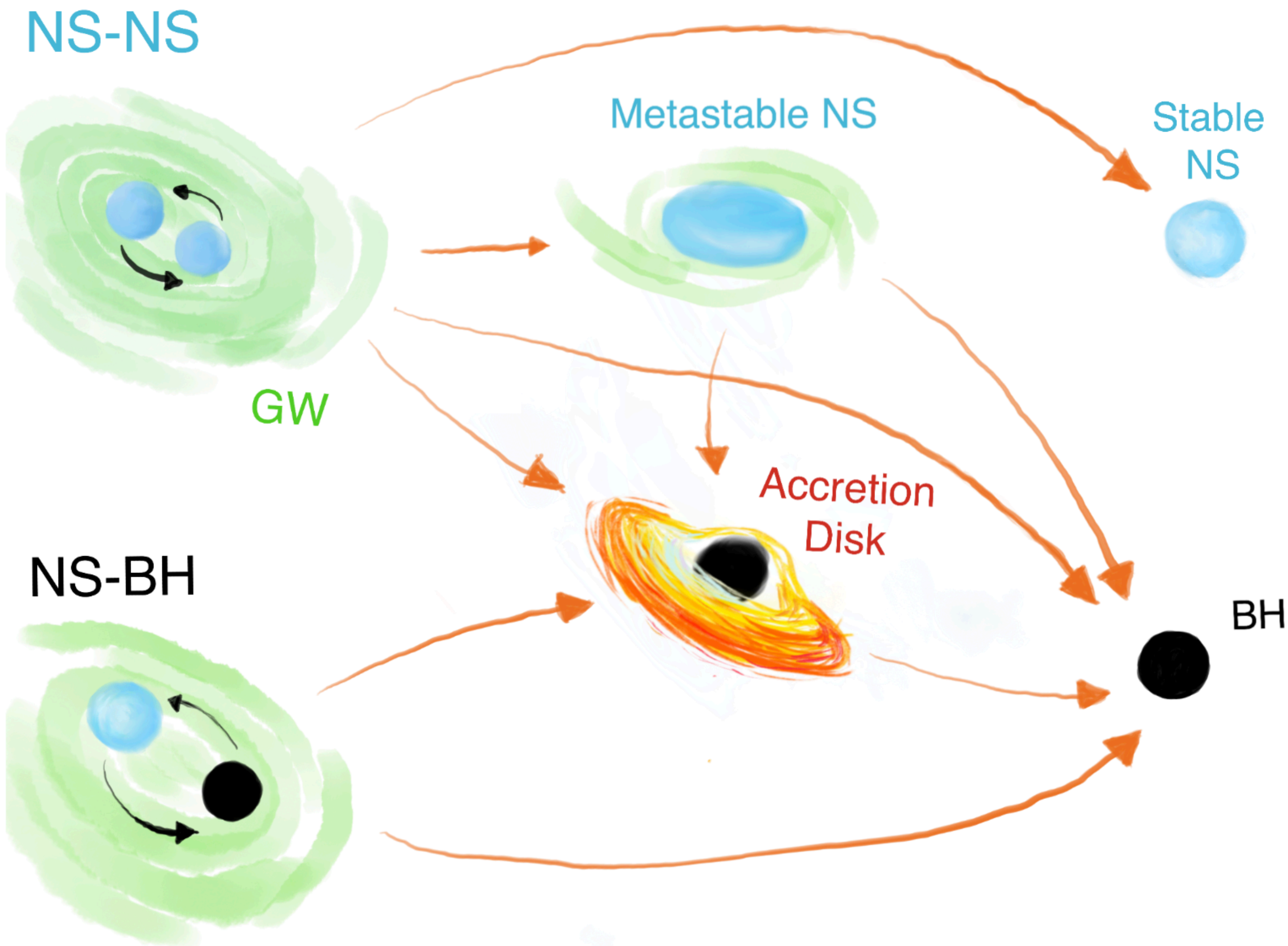


The BOAT GRB in Context
Count rate
(millions of
gamma rays
per second)
7
6
5
4
3
2
1
0
GRB 221009A
Reconstructed
Fermi data
130427A
190114C
090902B
190829A
7 minutes

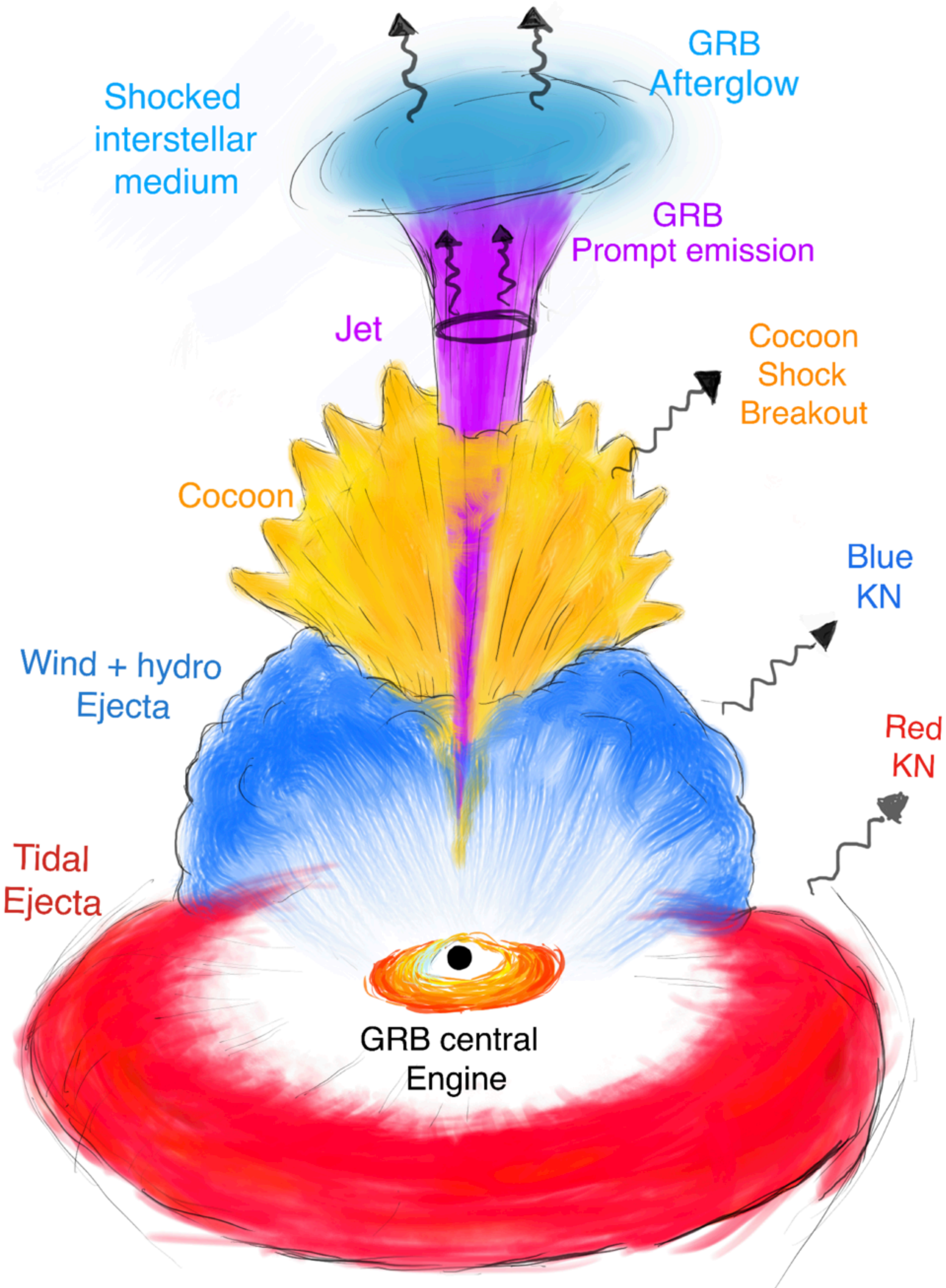


THE LHAASO COLLABORATION, 2023

SGRBs



Credit: Stefano Ascenzi



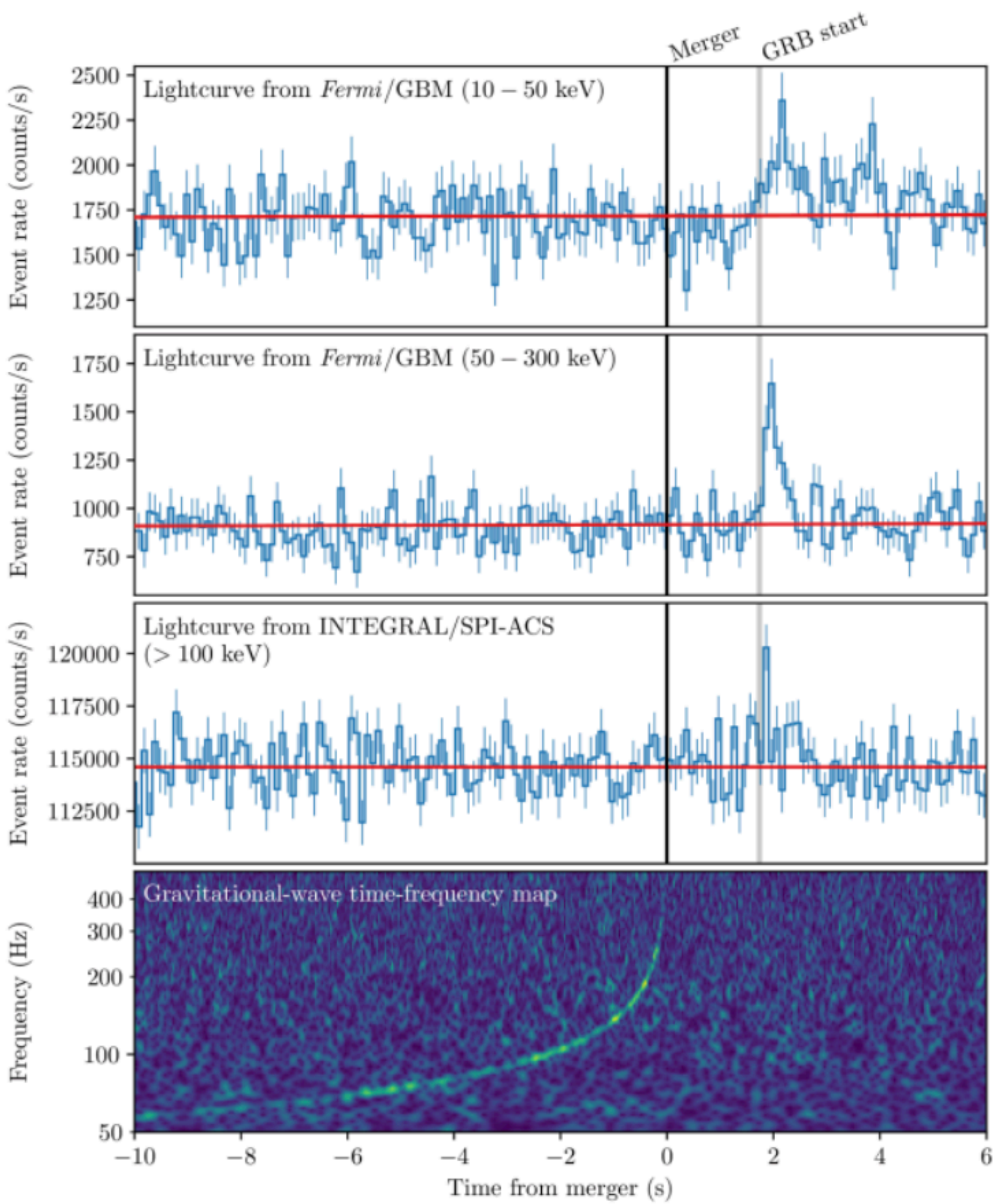
Credit: Stefano Ascenzi

BNS merger and a GRB

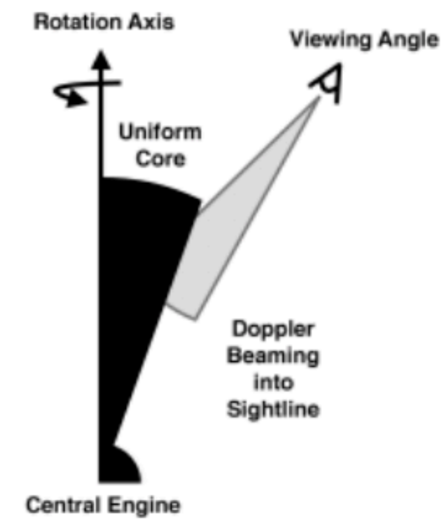
Lipunov et al. 2001; Dai & Gou 2001; Rossi et al. 2002; Zhang & Meszaros 2002

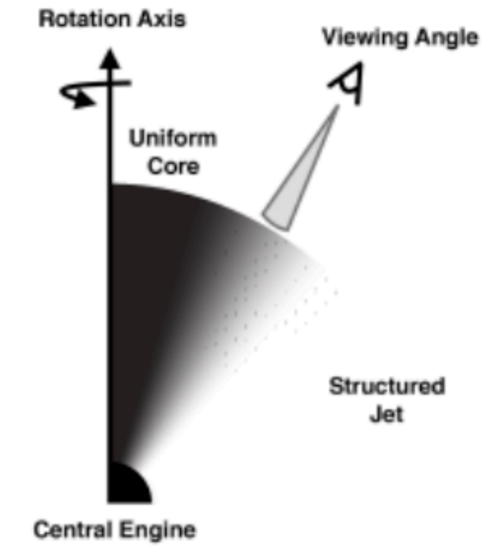
What is it?

GRB 170817/GW 170817



Abbott et al. 2017



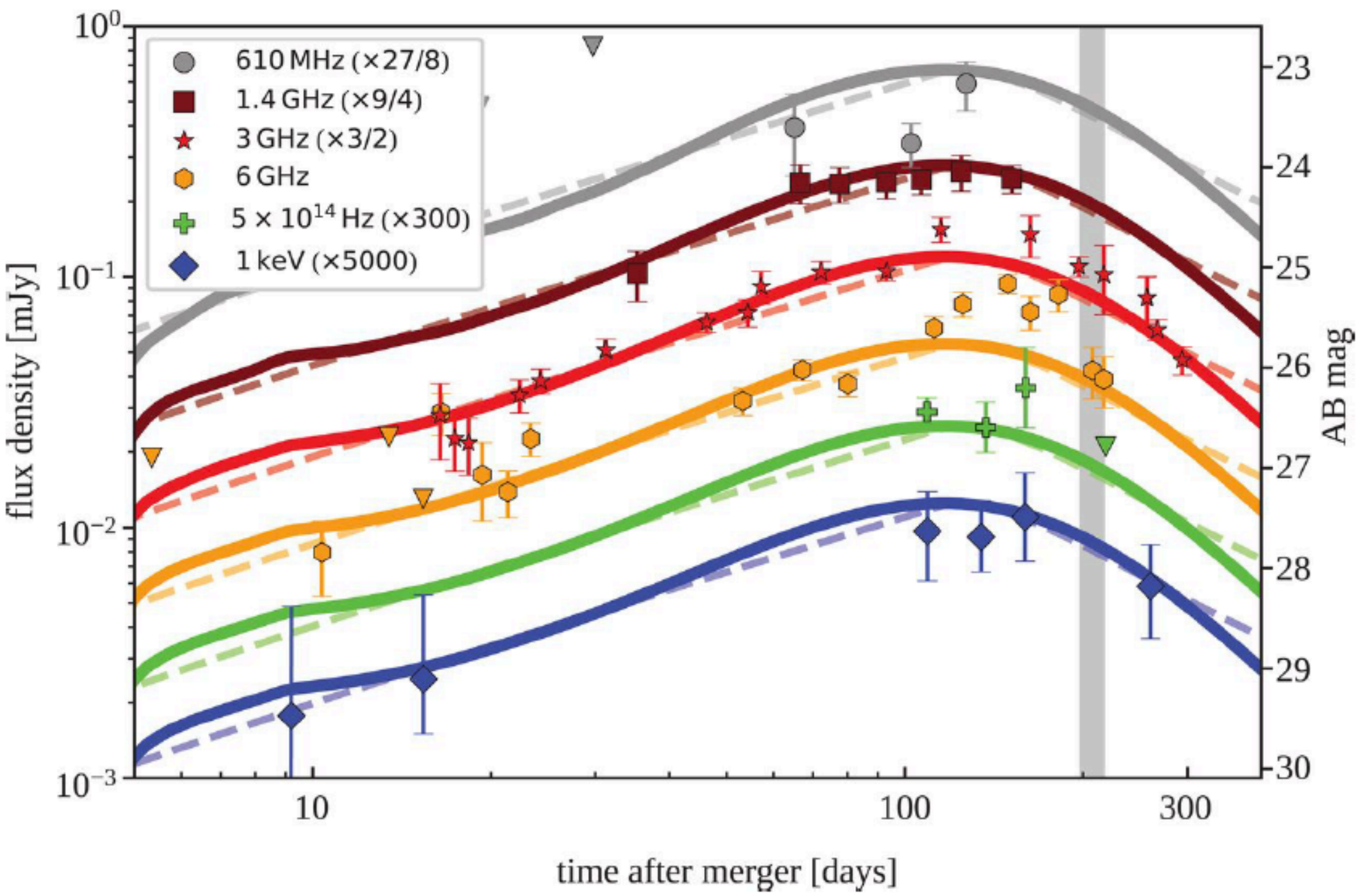


Kasliwal et al. 2017
Ioka&Nakamura 2018
Salafia et al. 2018
Lazzati 2018
Bromberg et al. 2018
Matsumoto et al 2018
....

Off-axis afterglow

GRB 170817/GW 170817

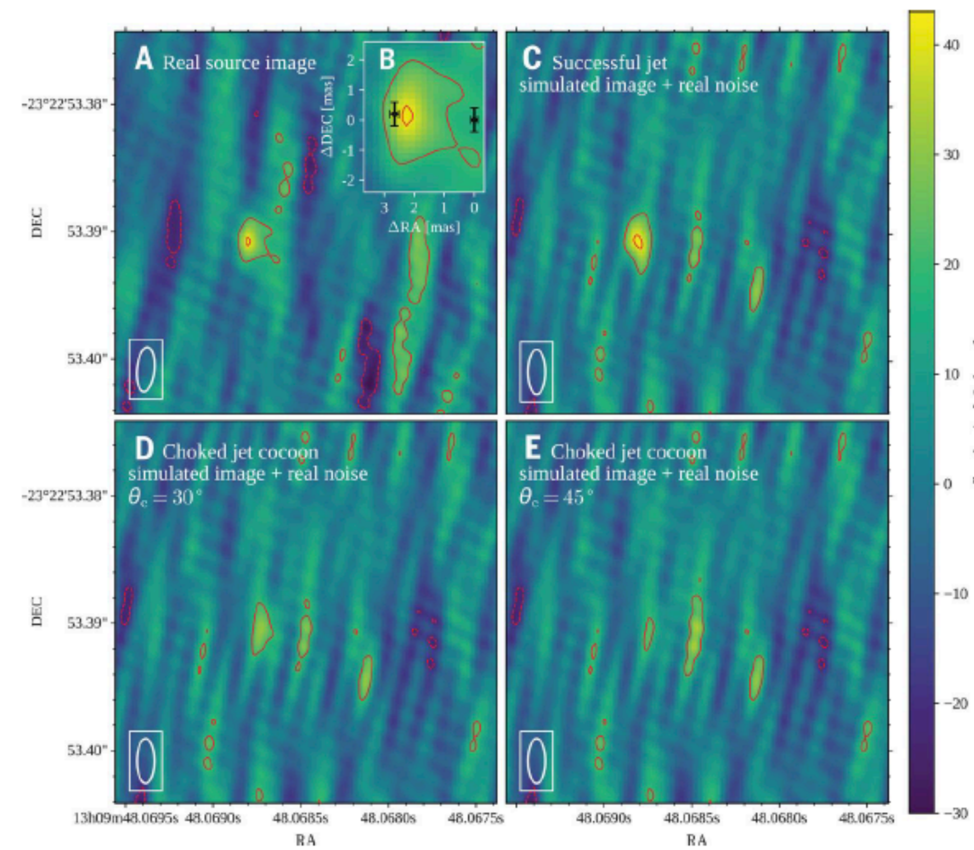
multi-wavelength LCs of the afterglow



D'Avanzo et al. 2018
Dobie et al. 2018
Alexander et al. 2018
Troja et al. 2018
.....

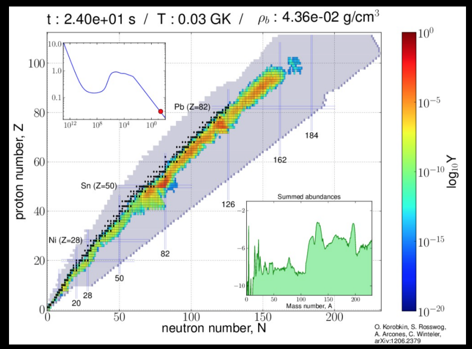
Ghirlanda et al. 2019

apparent size is 2.5 milli–arc seconds at > 200 days

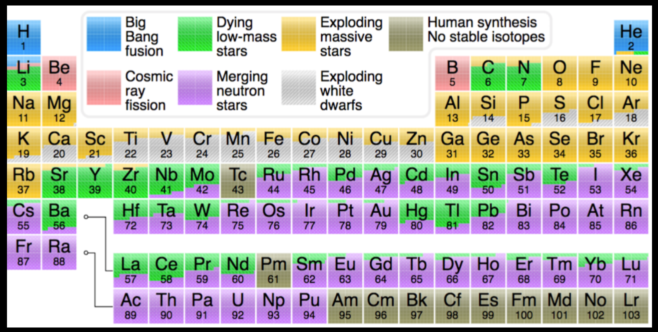


see also **Mooley et al. 2018**

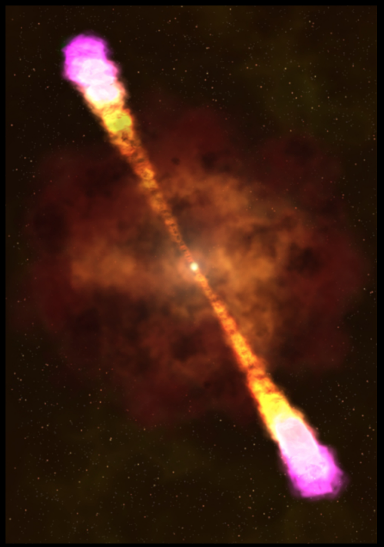
GW170817

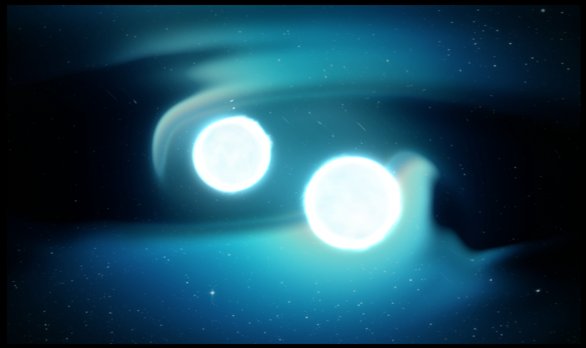


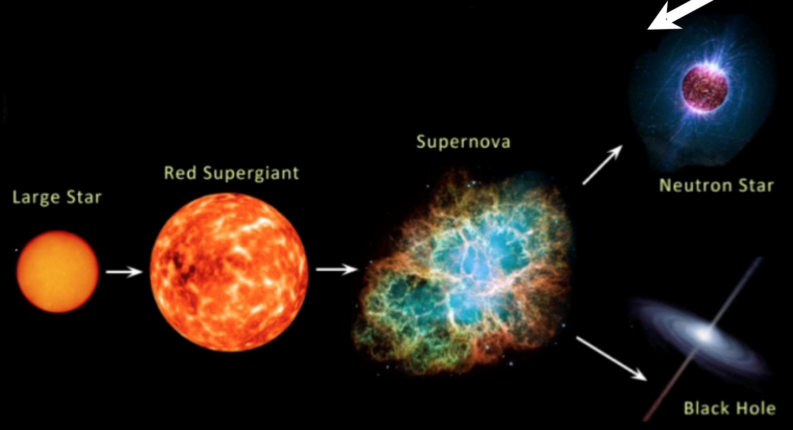
t : 2.40e+01 s / T : 0.03 GK / ρb : 4.36e-02 g/cm³
proton number, Z
neutron number, N
Pb (Z=82)
Sn (Z=50)
Ni (Z=28)
Summed abundances
Mass number, A



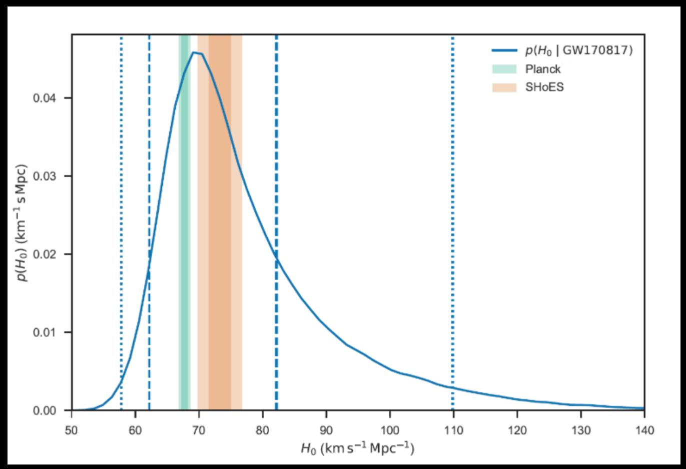
Big Bang fusion
Dying low-mass stars
Exploding massive stars
Human synthesis No stable isotopes
Cosmic ray fission
Merging neutron stars
Exploding white dwarfs



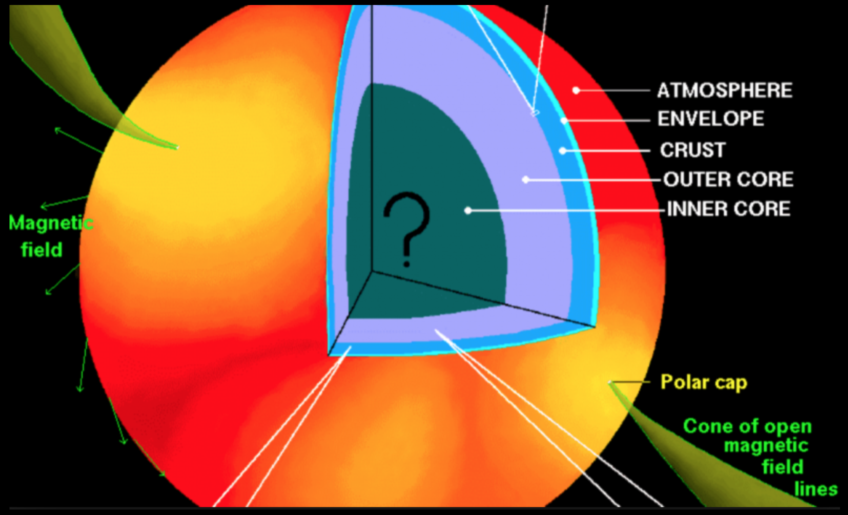




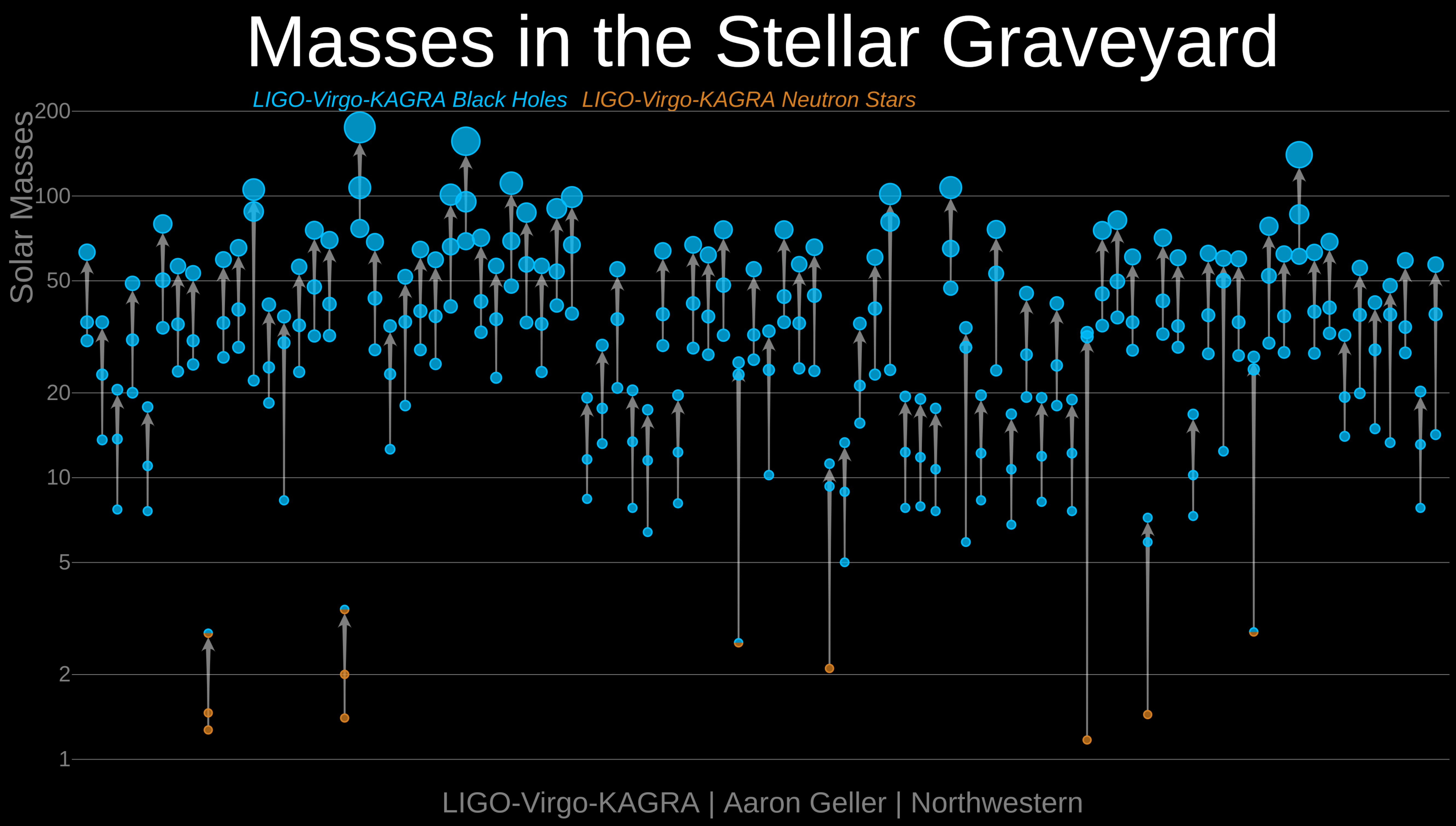
Large Star
Red Supergiant
Supernova
Neutron Star
Black Hole



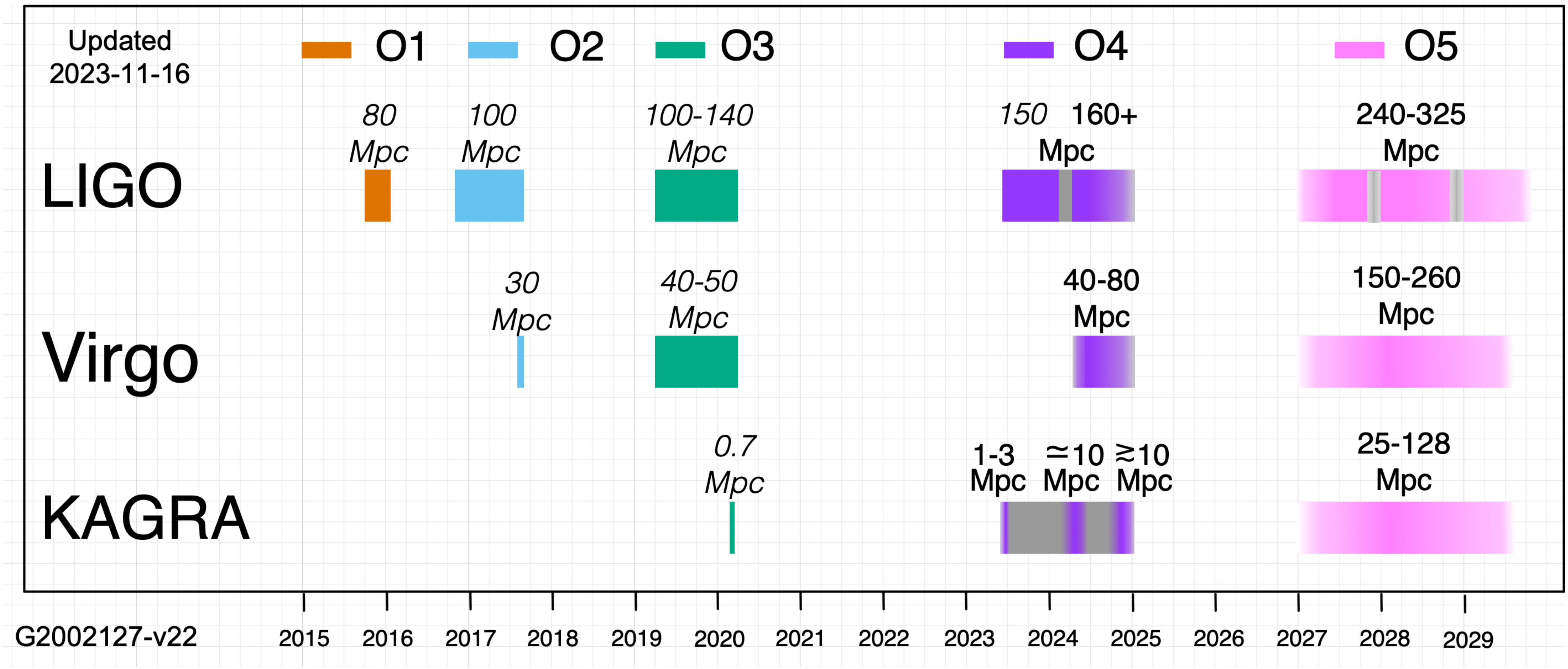
p(H0 | GW170817)
Planck
SHoES
p(H0) (km⁻¹ s Mpc)
H0 (km s⁻¹ Mpc⁻¹)

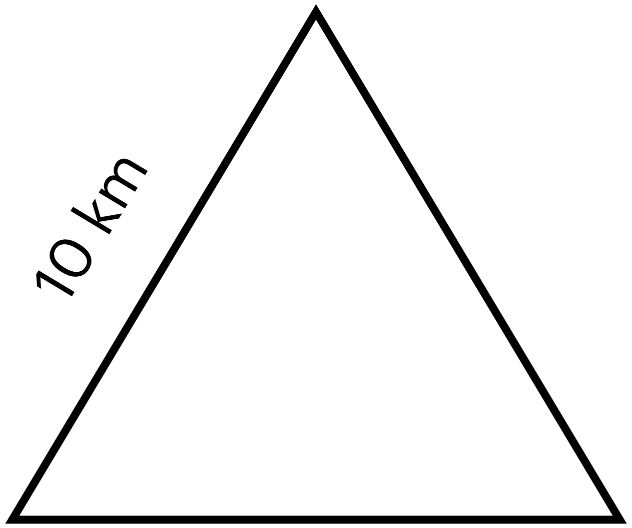


ATMOSPHERE
ENVELOPE
CRUST
OUTER CORE
INNER CORE
?
Magnetic field
Polar cap
Cone of open magnetic field lines

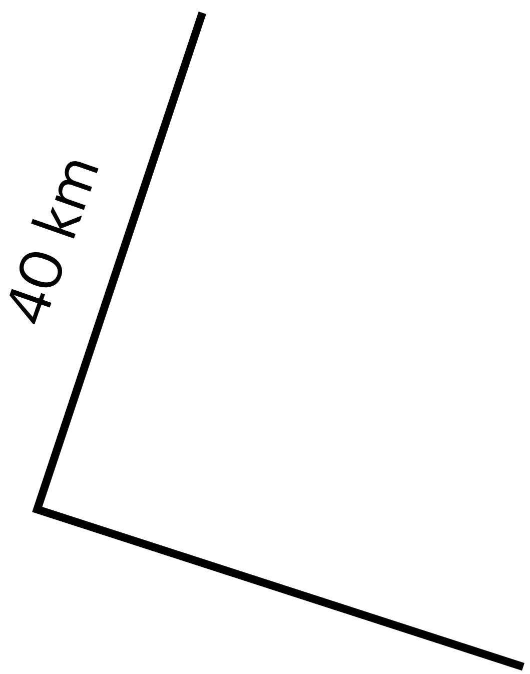

Masses in the Stellar Graveyard
LIGO-Virgo-KAGRA Black Holes
LIGO-Virgo-KAGRA Neutron Stars
Solar Masses
200
100
50
20
10
5
2
1
LIGO-Virgo-KAGRA | Aaron Geller | Northwestern

Current status of LVK

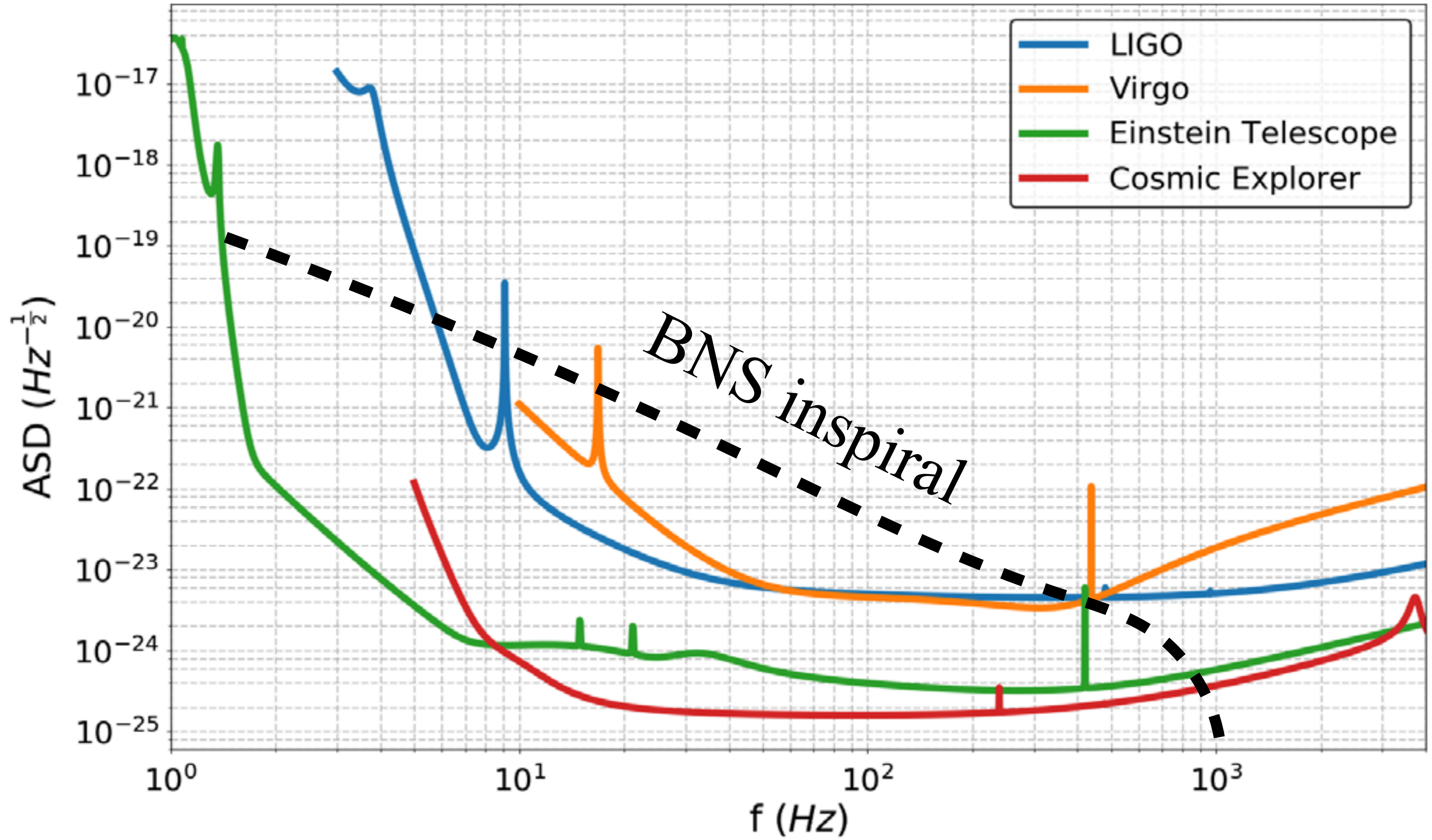




Einstein Telescope
(ET)

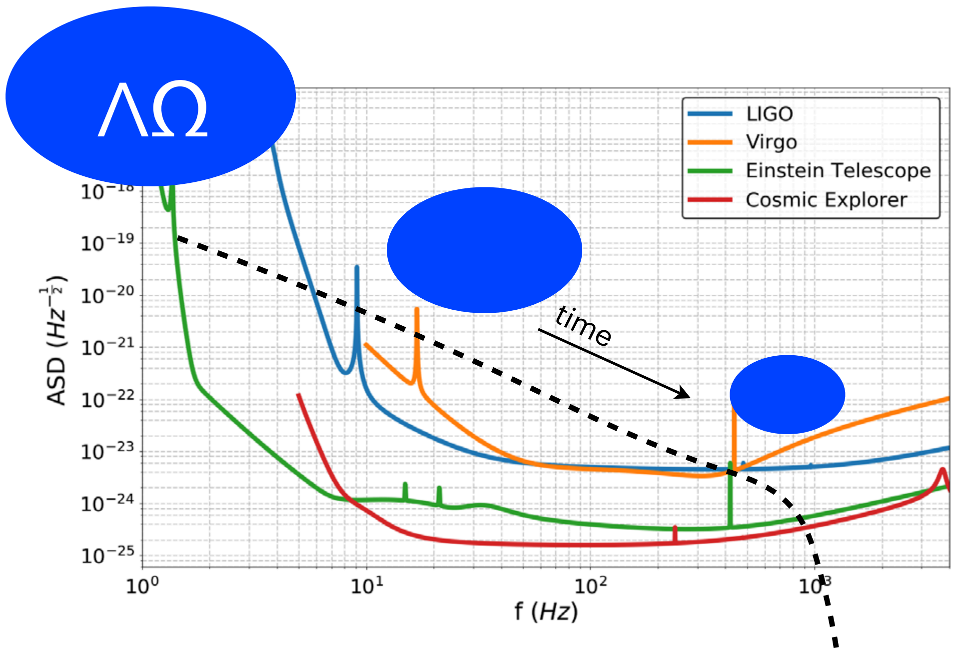


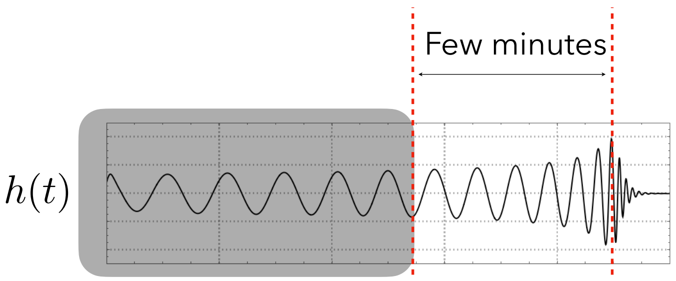
Cosmic Explorer
(CE)

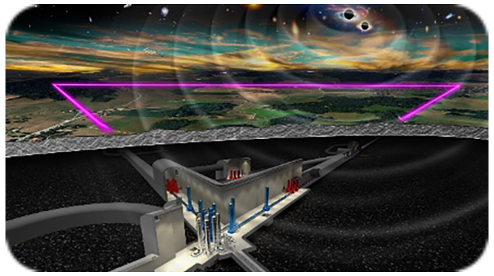


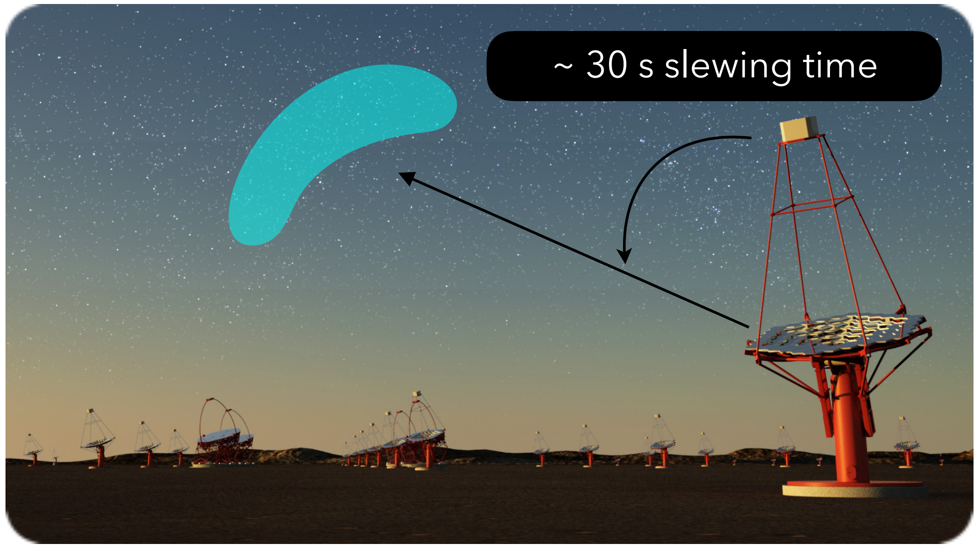
From Chan et al. 2018

Pre-merger sky localisation





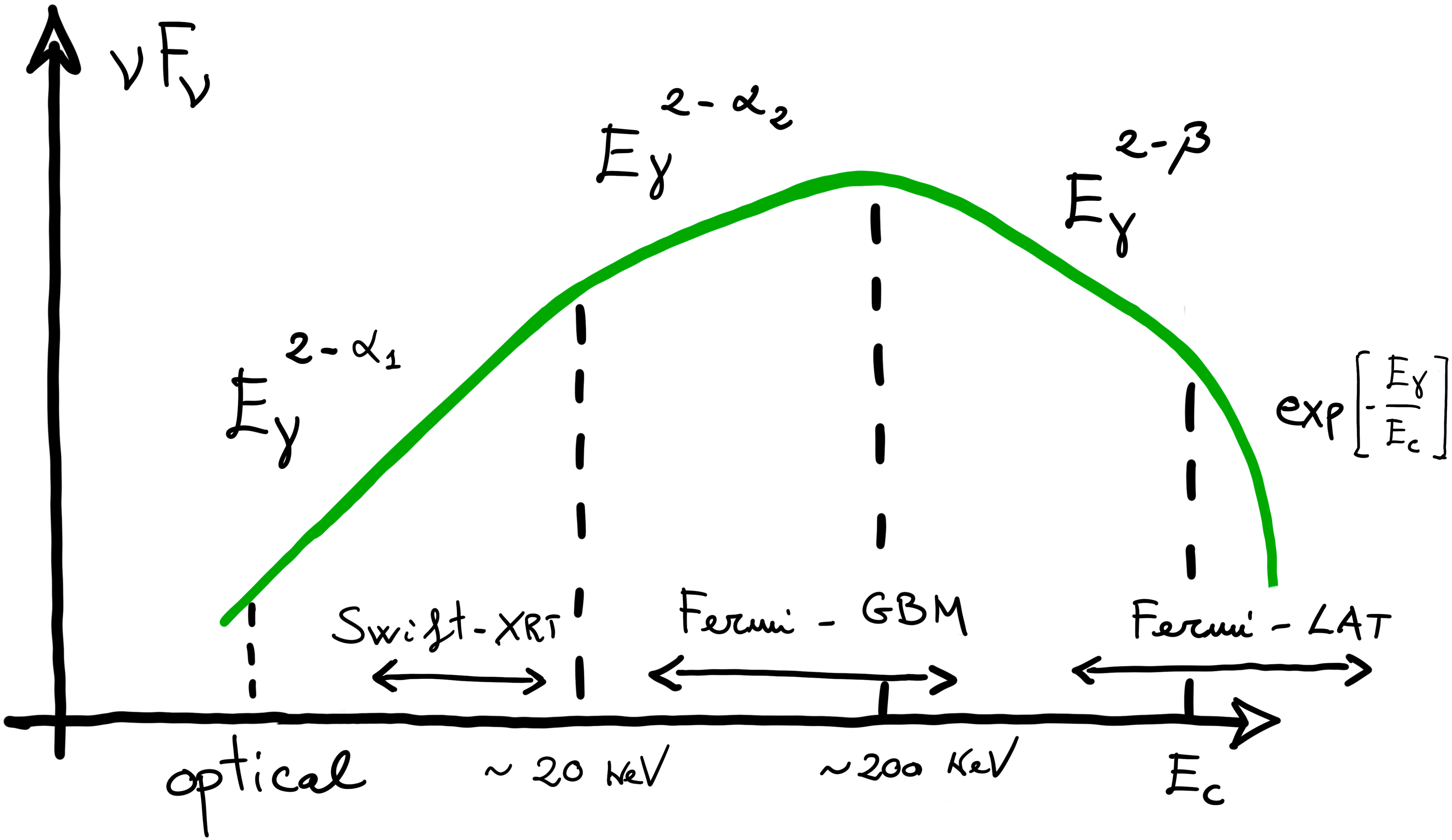




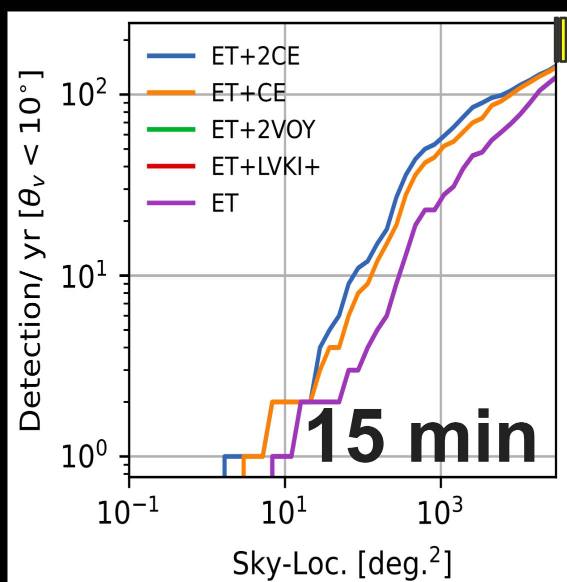
where and when the GRB will occur in the sky!

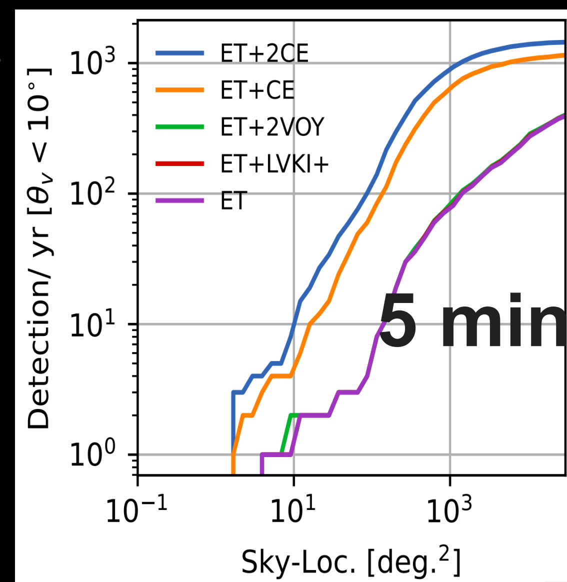
Banerjee et al. 2023

GRB prompt emission spectrum

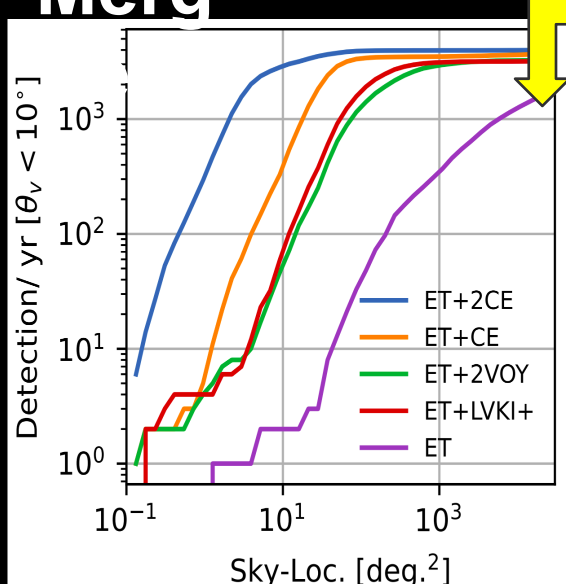


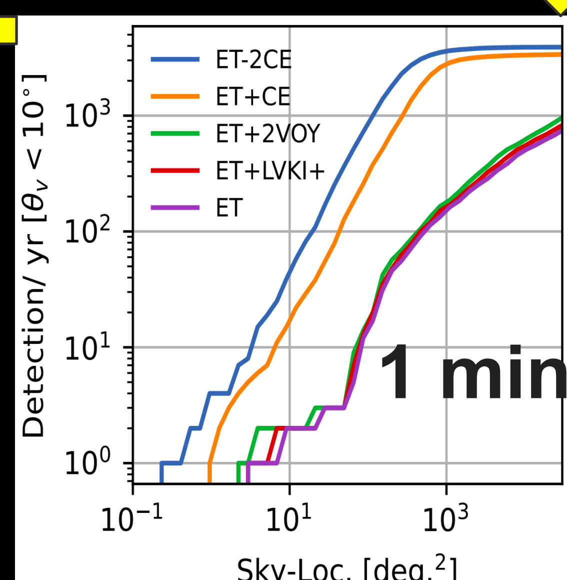
Sky-localization capability:





Merg

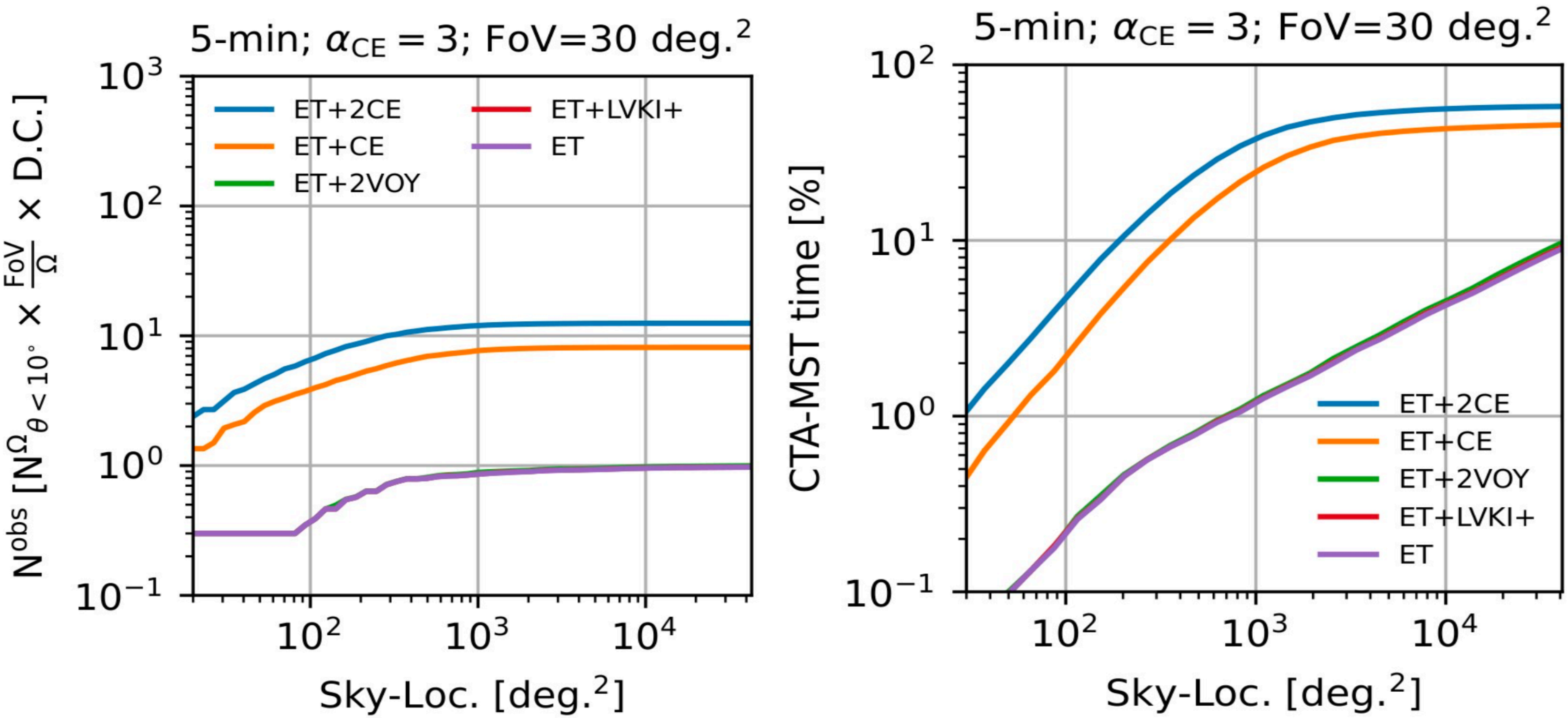




Detector	Ω [deg^2]	All orientations			
		15 min	5 min	1 min	0 min
ET + CE	**100**	**442**	**1325**	**5075**	**123303**
ET	**100**	**90**	**130**	**208**	**436**

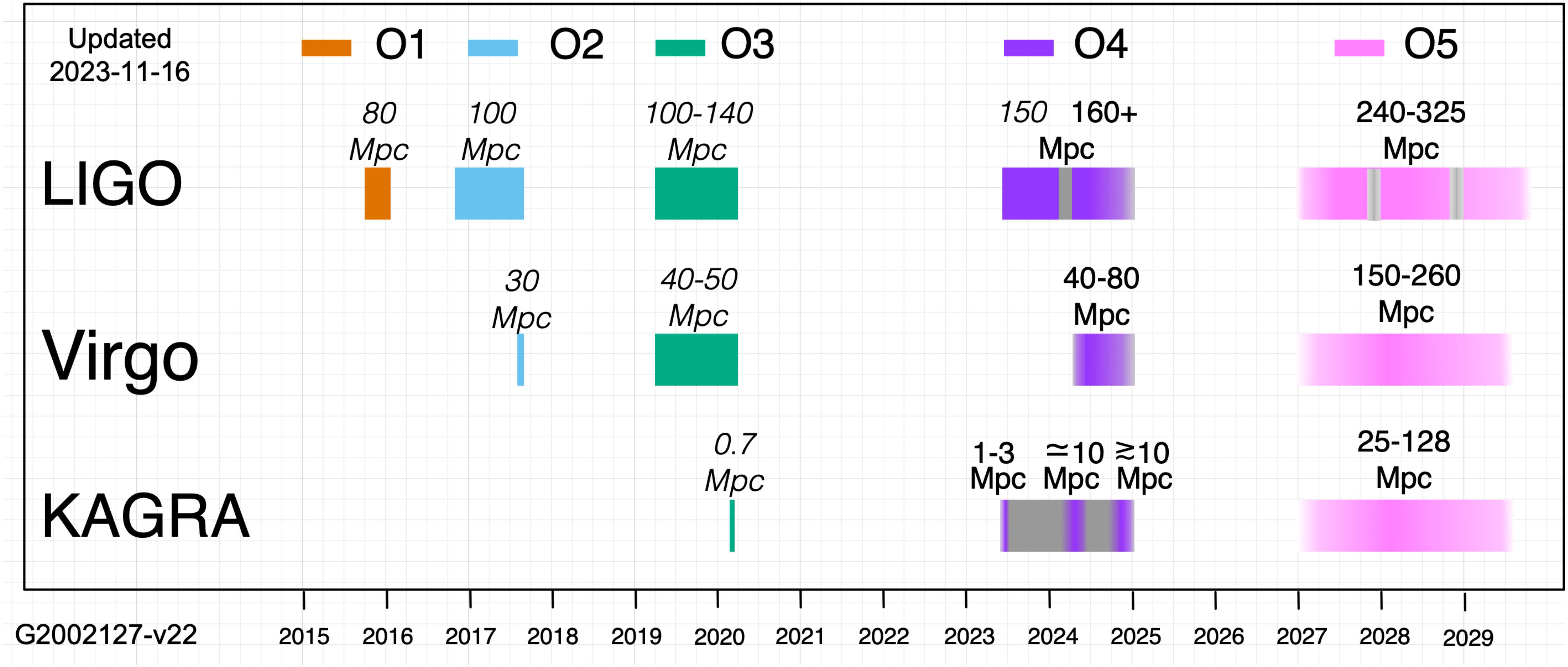
Detector	Ω [deg^2]	Viewing angle (<10^0)			
		15 min	5 min	1 min	0 min
ET + CE	**100**	**21**	**71**	**314**	**3376**
ET	**100**	**3**	**6**	**13**	**40**

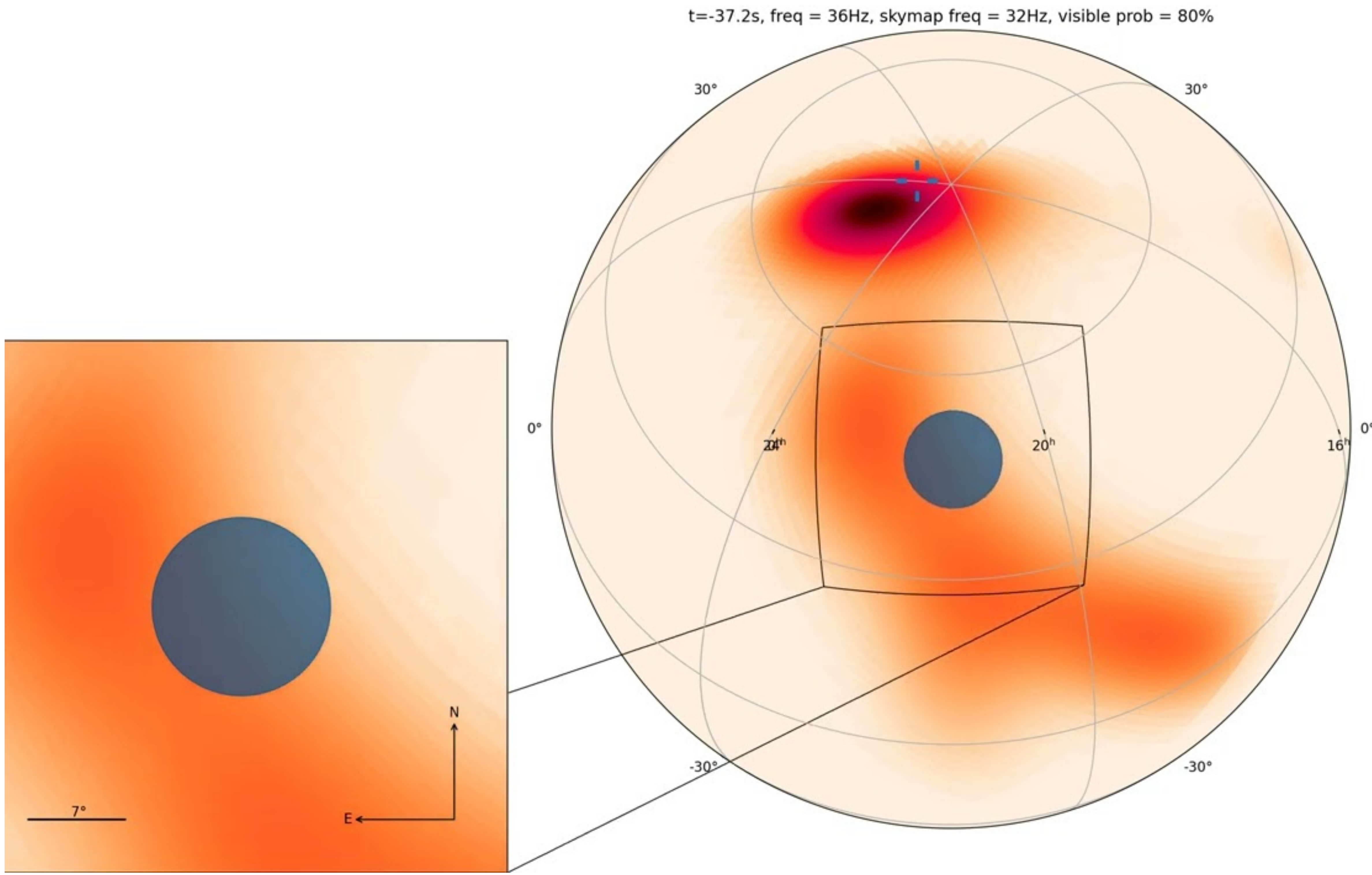
Very High Energy Emission



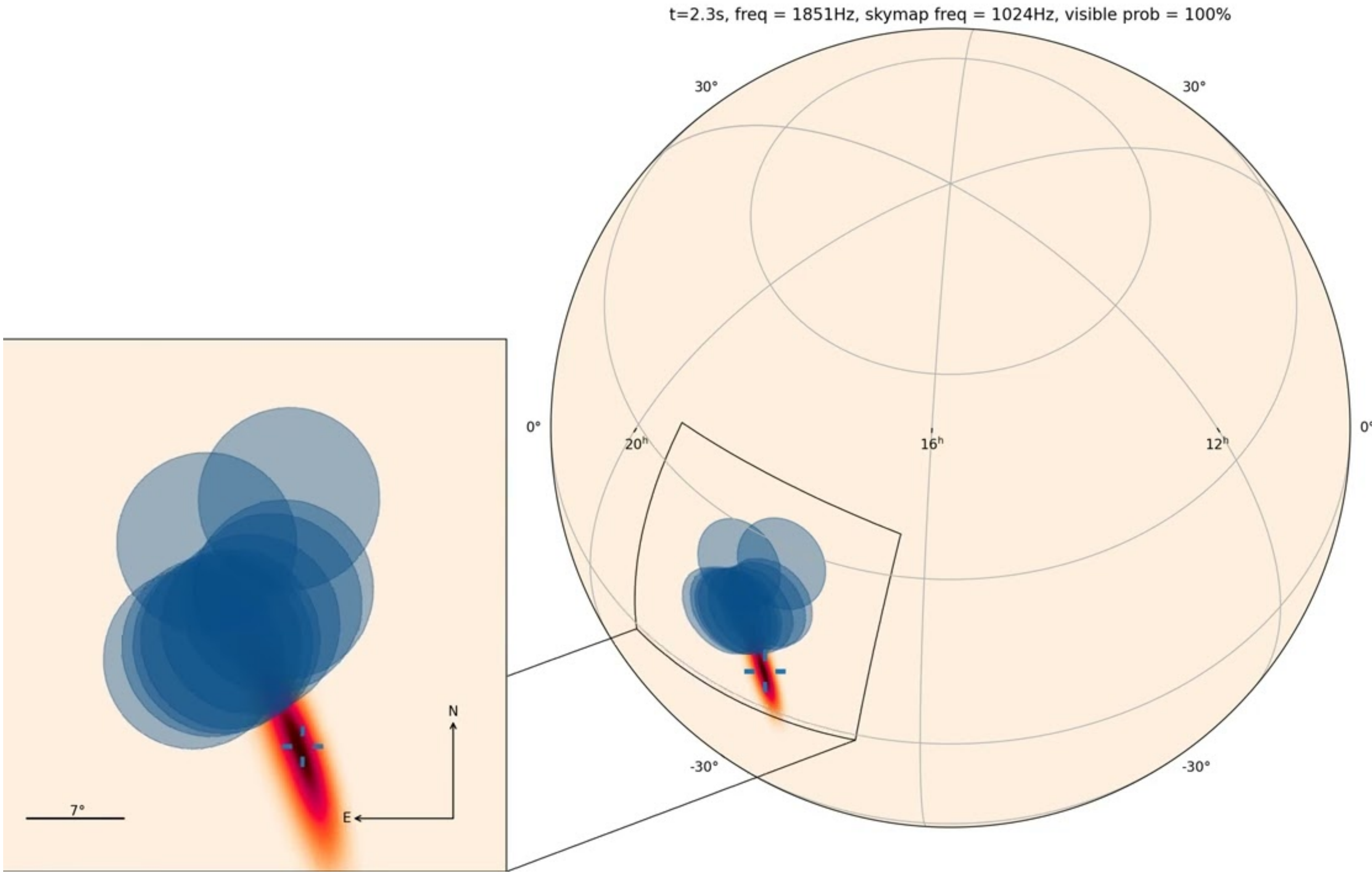
Banerjee et al. 2023

Current status of LVK





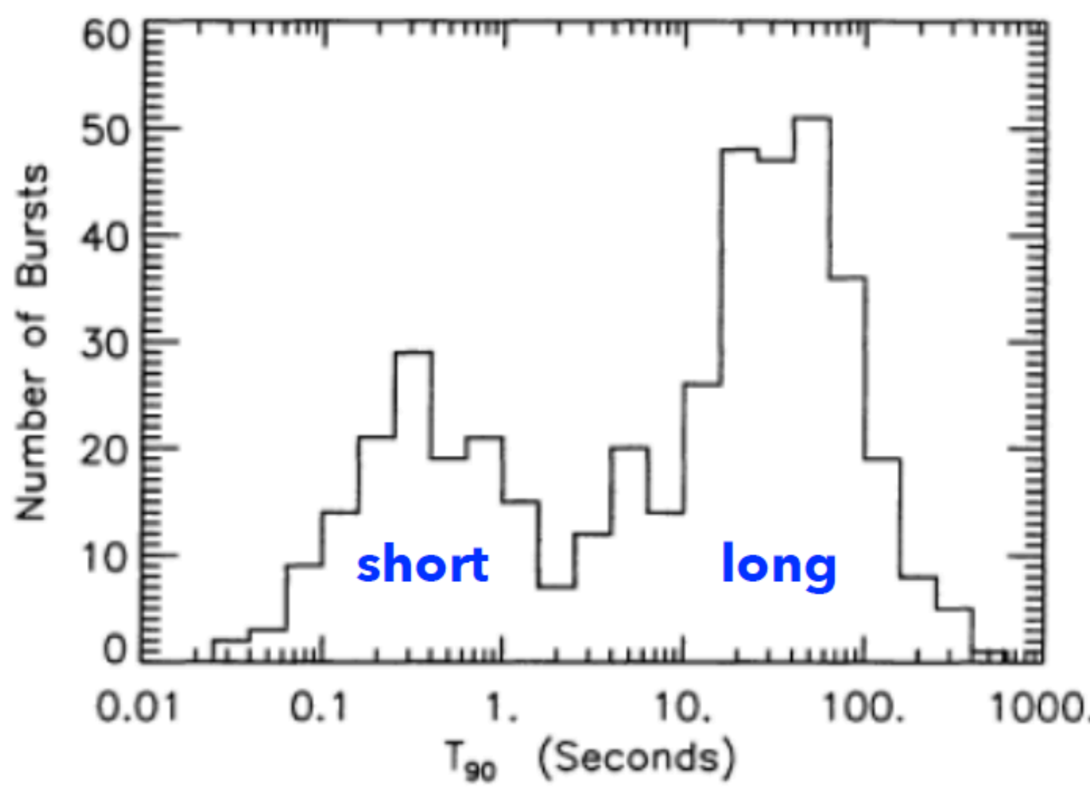
t=-37.2s, freq = 36Hz, skymap freq = 32Hz, visible prob = 80%
30°
30°
0°
0°
20h
16h
-30°
-30°
N
E
7°



t=2.3s, freq = 1851Hz, skymap freq = 1024Hz, visible prob = 100%
30°
30°
0°
20h
16h
12h
0°
-30°
-30°
N
E
7°

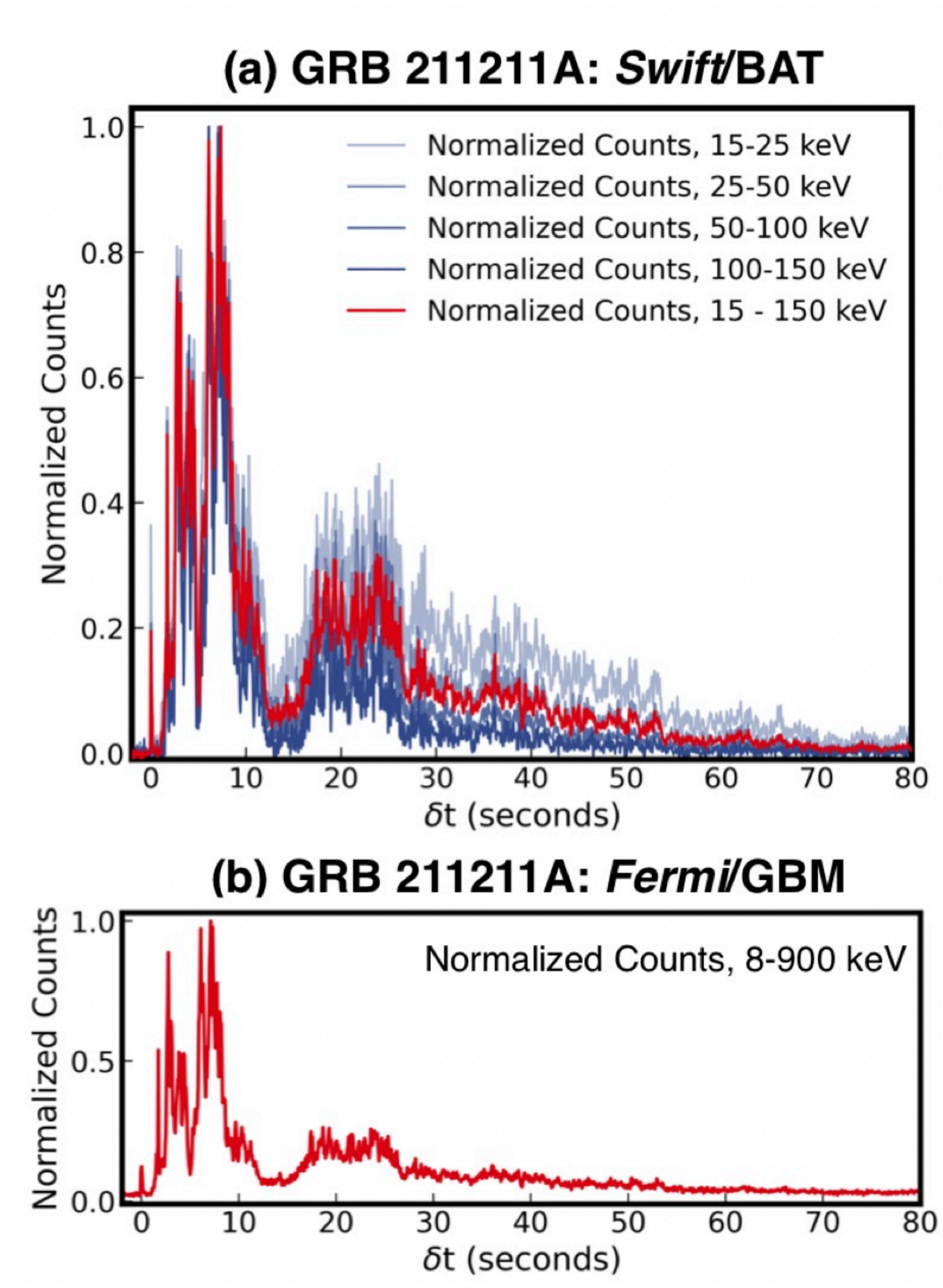
One MM event (GW170817) and bright future

Anything between?



short (<2 s) and long (>2 s)

December 2021



GRB 211211A

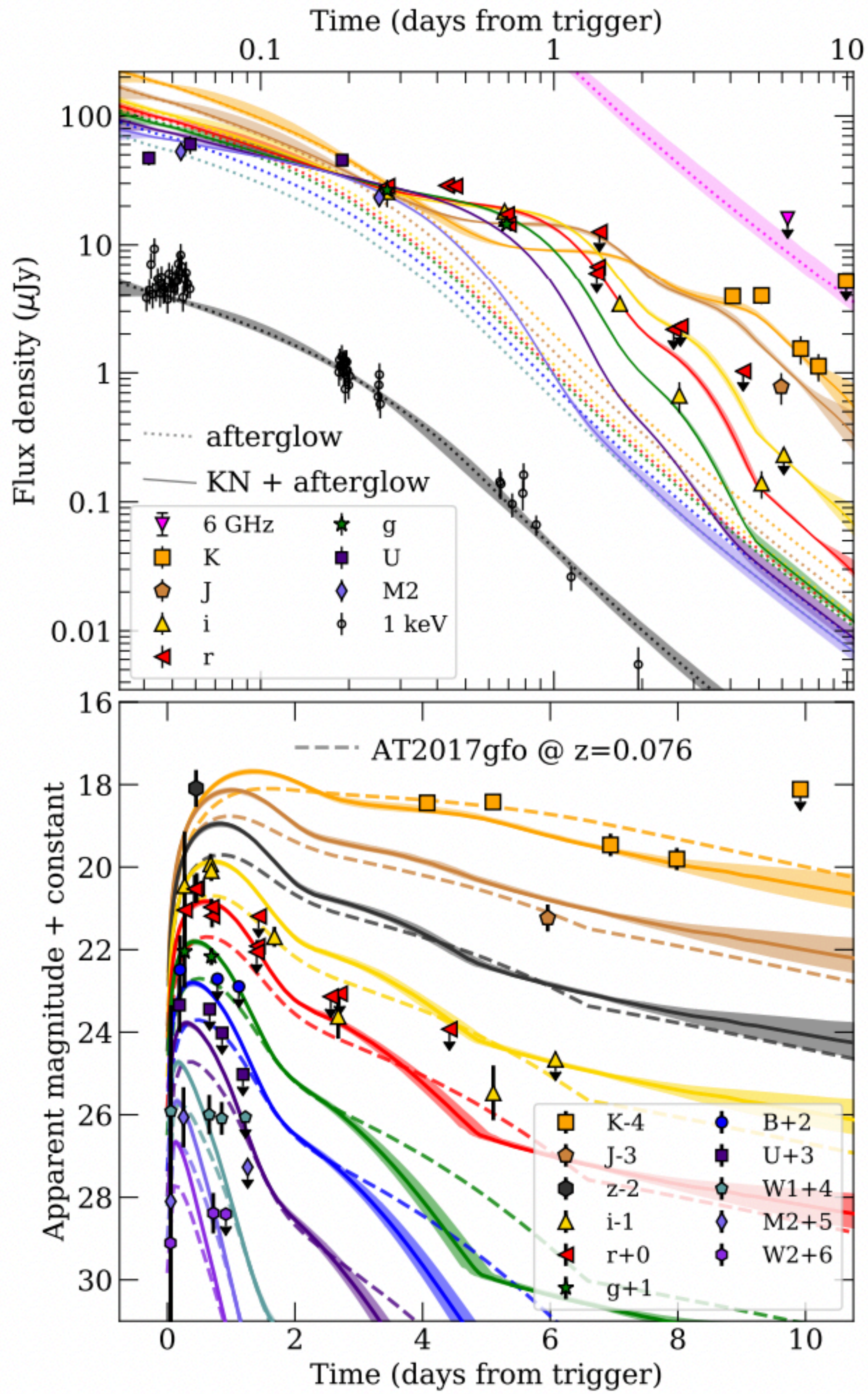
T90 ~ 34 s

z = 0.076
350 Mpc

Rastinejad et al. 2022, Nature

GRB 211211A

350 Mpc



Three-component kilonova fit

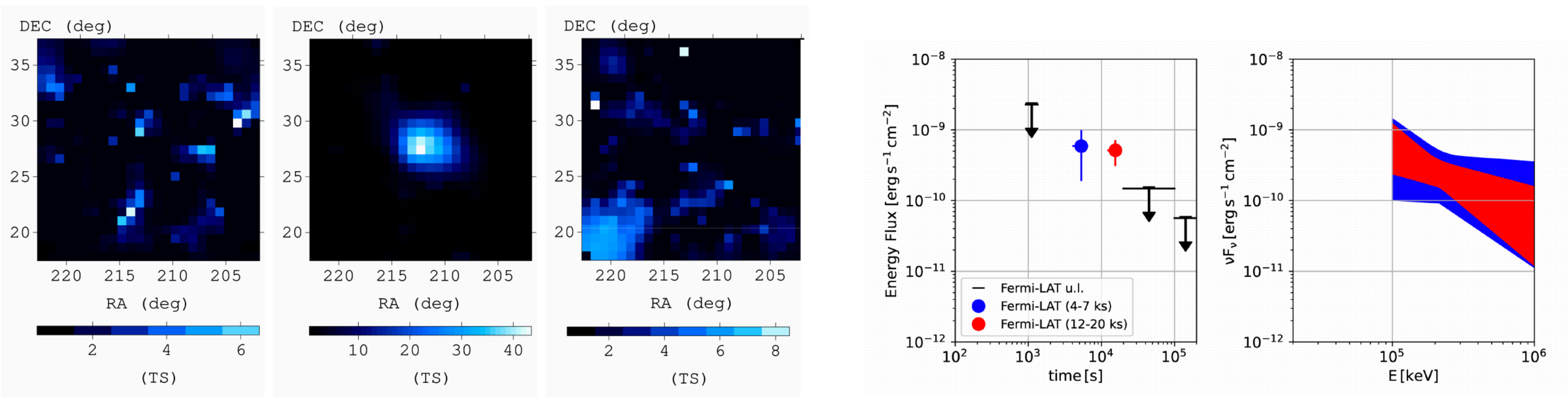
- $M_{ej} = 0.04 \pm 0.02\ M_{\odot}$, almost all lanthanide-rich, in reasonable agreement with at2017gfo.
- $v_{ej} \simeq 0.25 - 0.3\ c$
- Associated to compact object merger in a binary system, likely BNS

Rastinejad et al. 2022, Nature

(see also Troja et al. 2022, Nature)

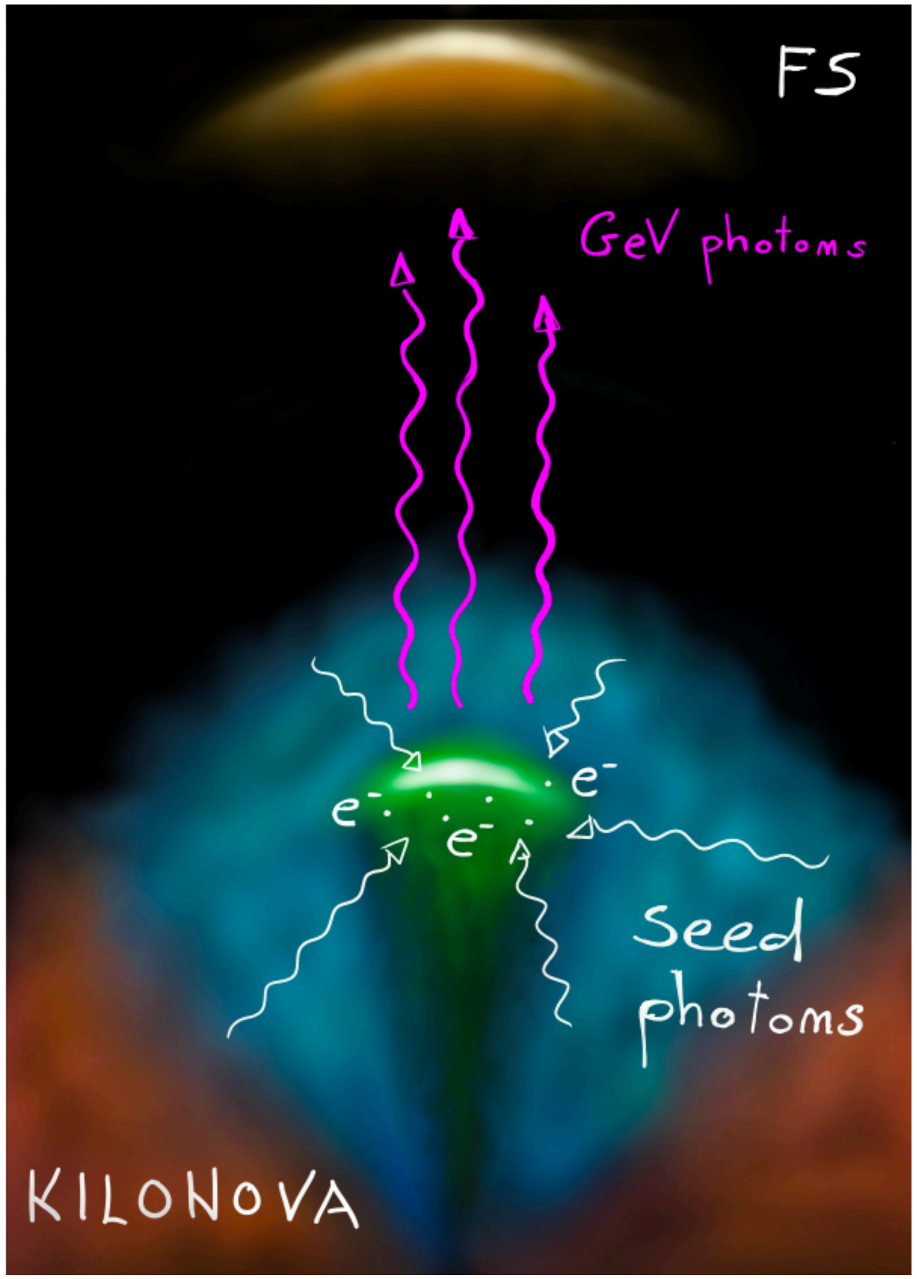
GRB 211211A

GeV emission

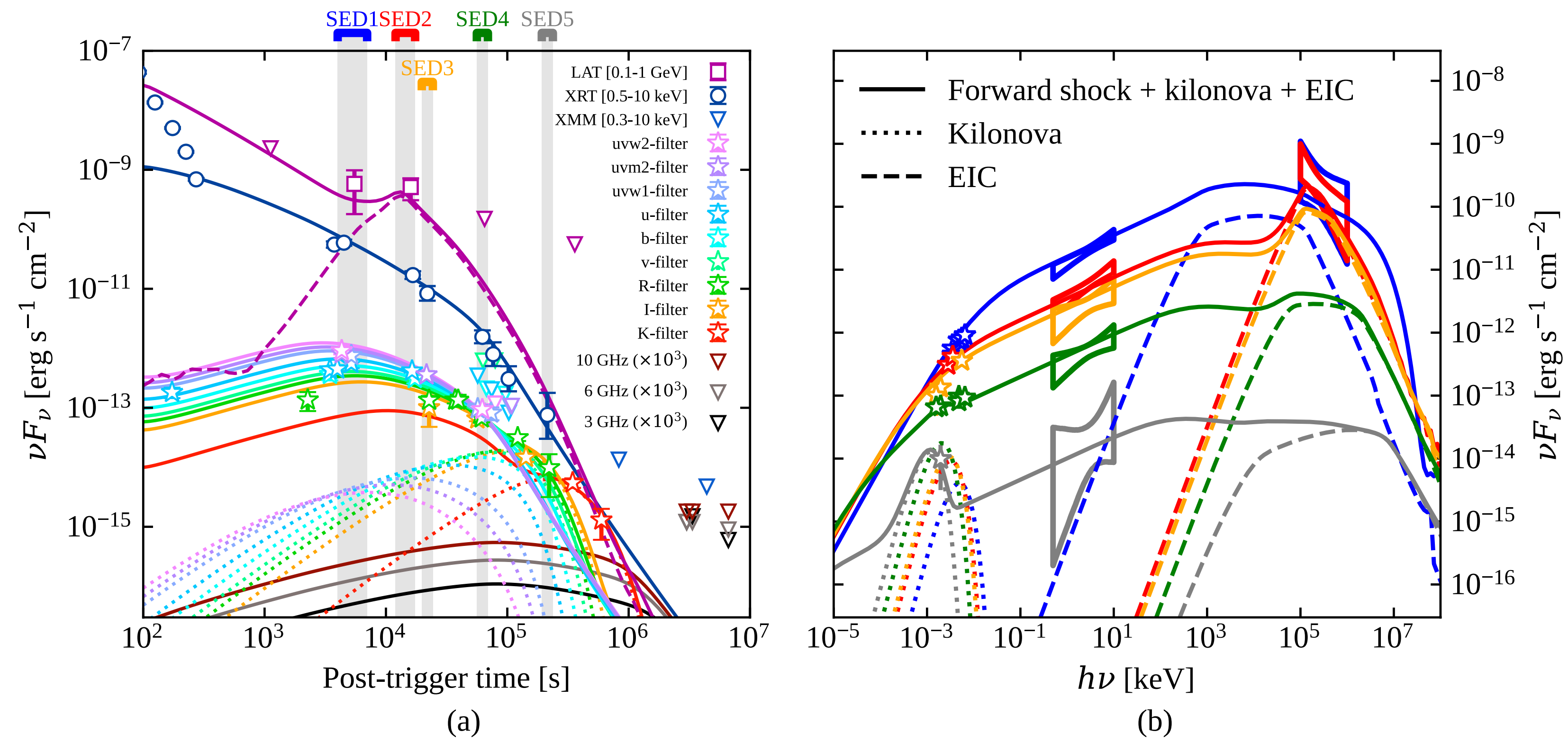


(a) t_0-1 d to t_0 (b) t_0 to t_0+20 ks (c) t_0+1 d to t_0+2 d (d) t_0 to t_0+2 d

Mei et al. 2022, Nature



GeV emission from a BNS merger

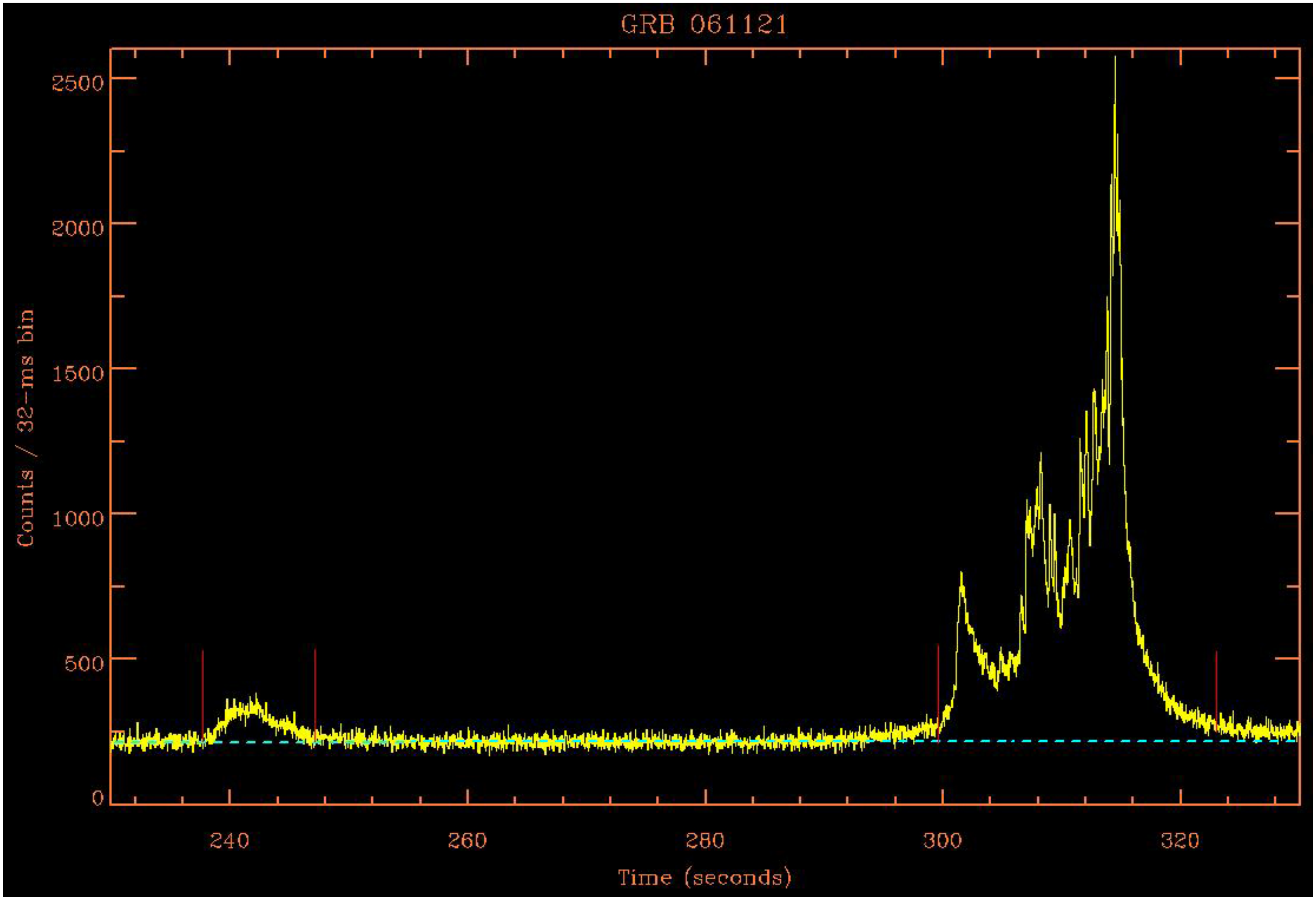


- **not present in GW/GRB 170817**
- **new component from KN-jet interaction**

Mei et al. 2022, Nature

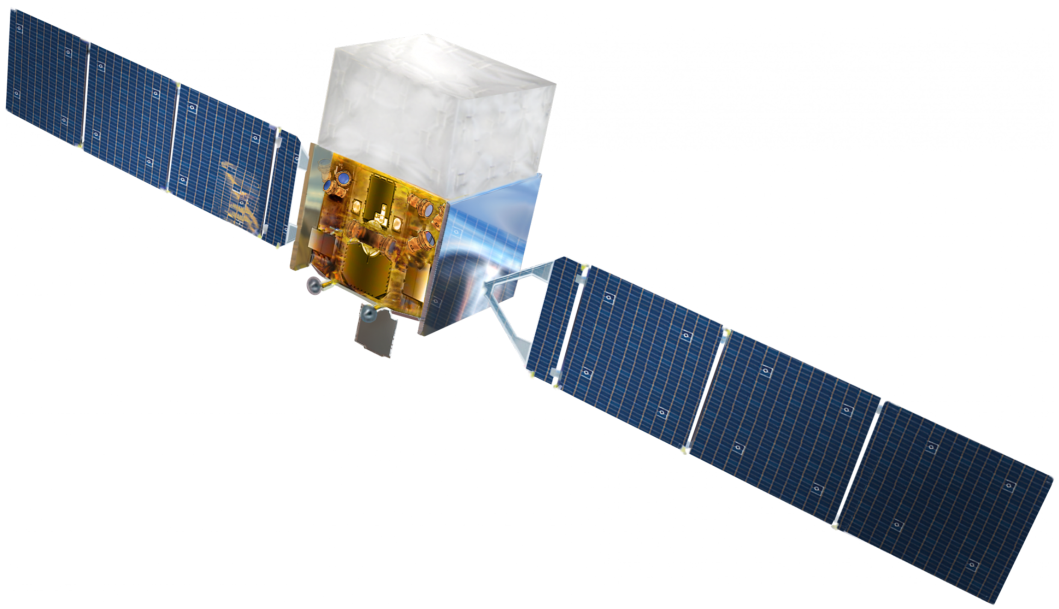
LGRBs

GRB precursors

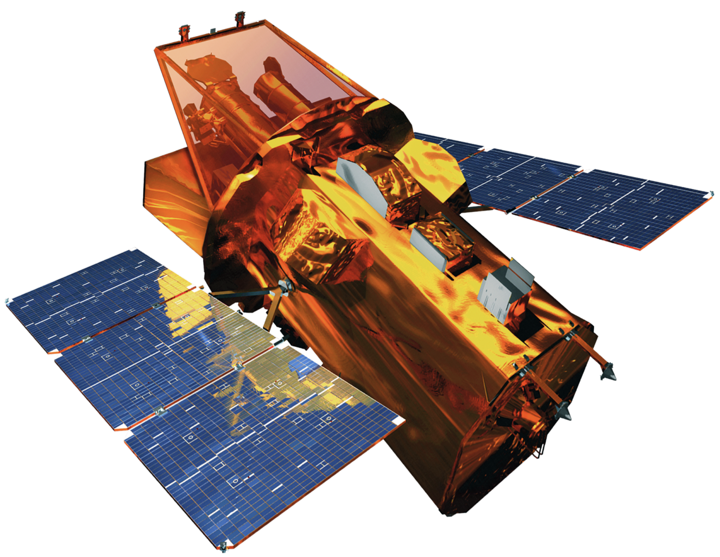


LGRBs VHE emission

Fermi-GBM



Swift



Fermi-GBM

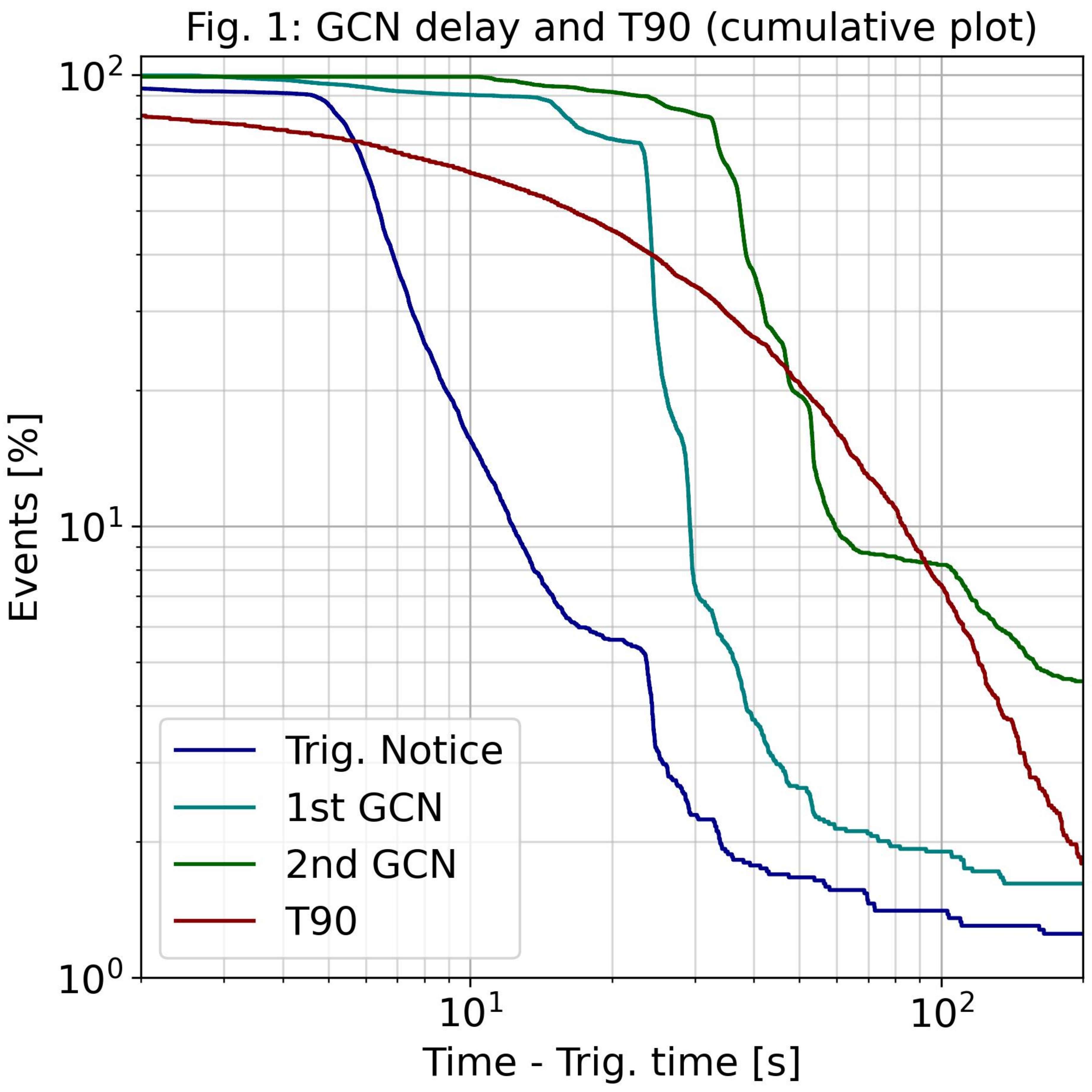


Fig. 1: GCN delay and T90 (cumulative plot)
Events [%]
Time - Trig. time [s]
Trig. Notice
1st GCN
2nd GCN
T90

Fermi-GBM

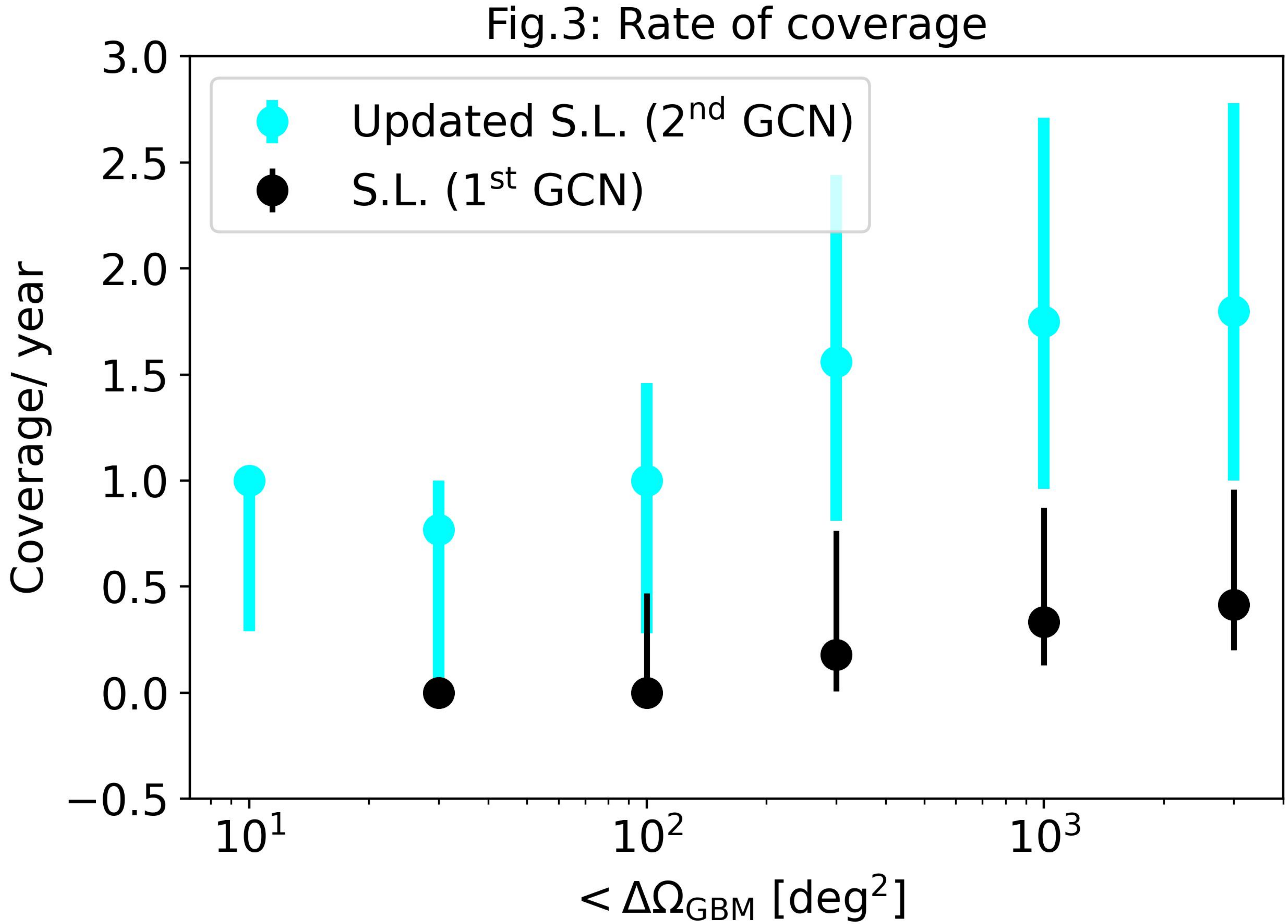


Fig.3: Rate of coverage
Updated S.L. (2nd GCN)
S.L. (1st GCN)
Coverage/ year
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
10^1
10^2
10^3
< ΔΩ_GBM [deg^2]

LGRBs optical emission

Swift

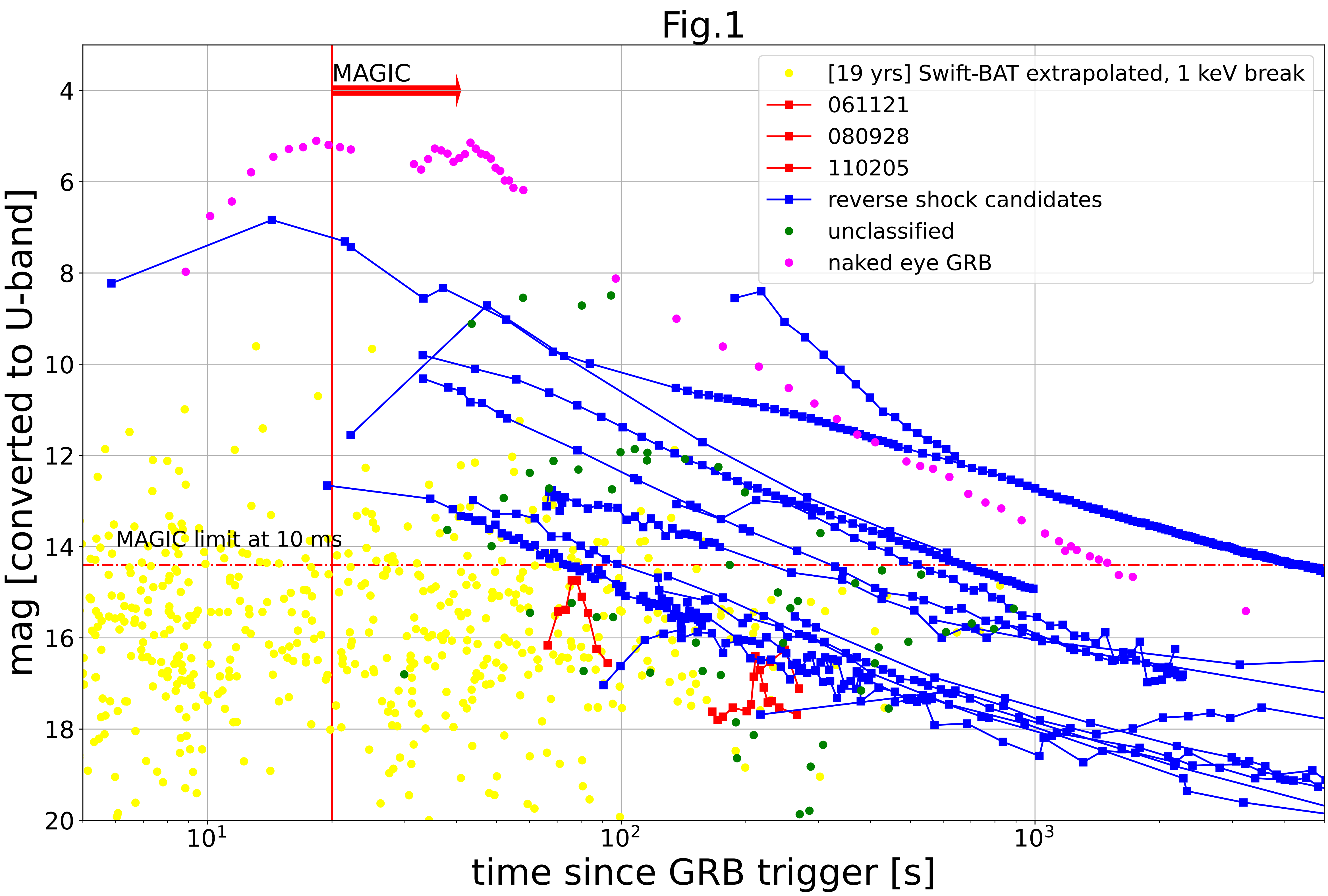
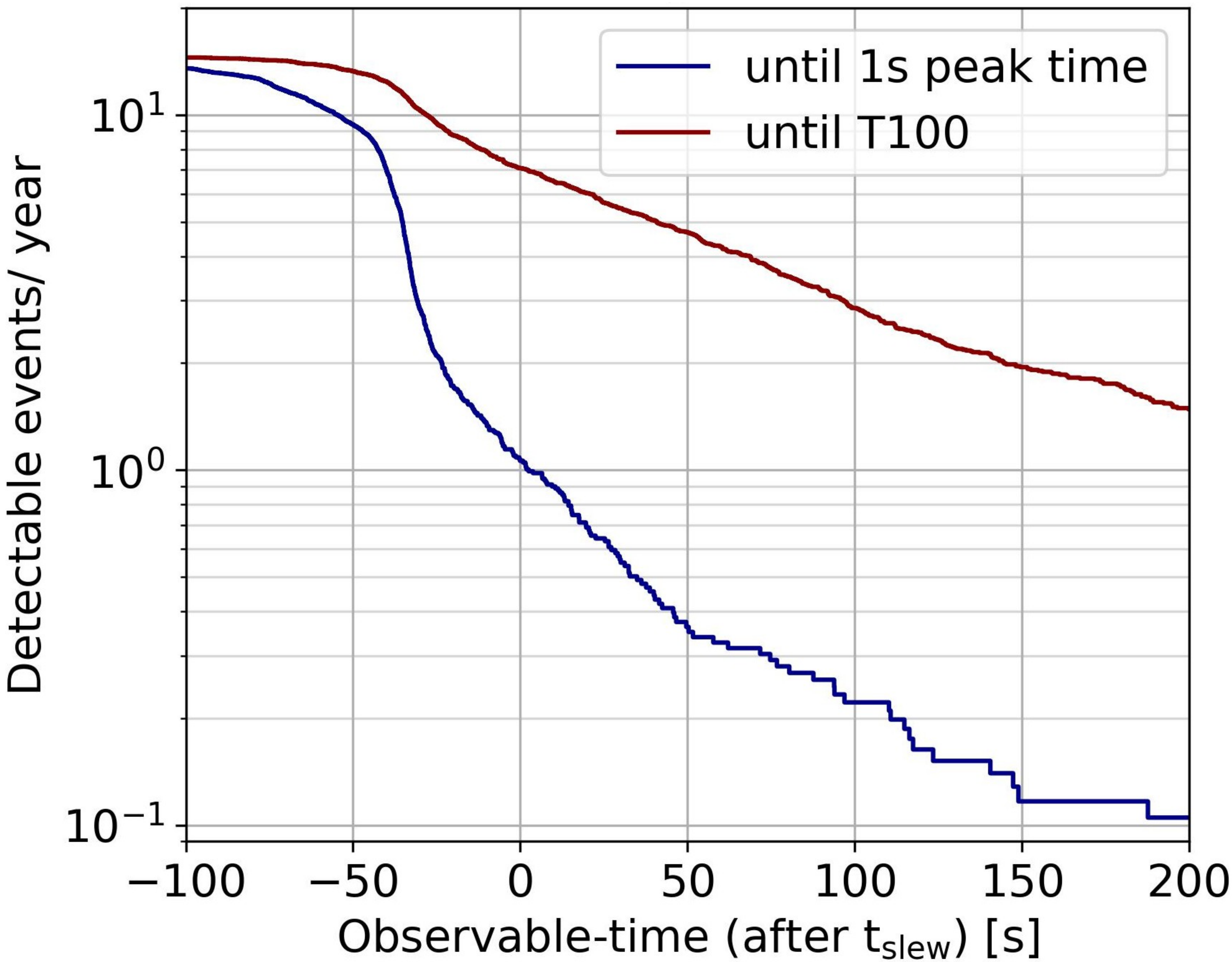


Fig.1
MAGIC
MAGIC limit at 10 ms
[19 yrs] Swift-BAT extrapolated, 1 keV break
061121
080928
110205
reverse shock candidates
unclassified
naked eye GRB
mag [converted to U-band]
time since GRB trigger [s]
4
6
8
10
12
14
16
18
20
10^1
10^2
10^3

Swift

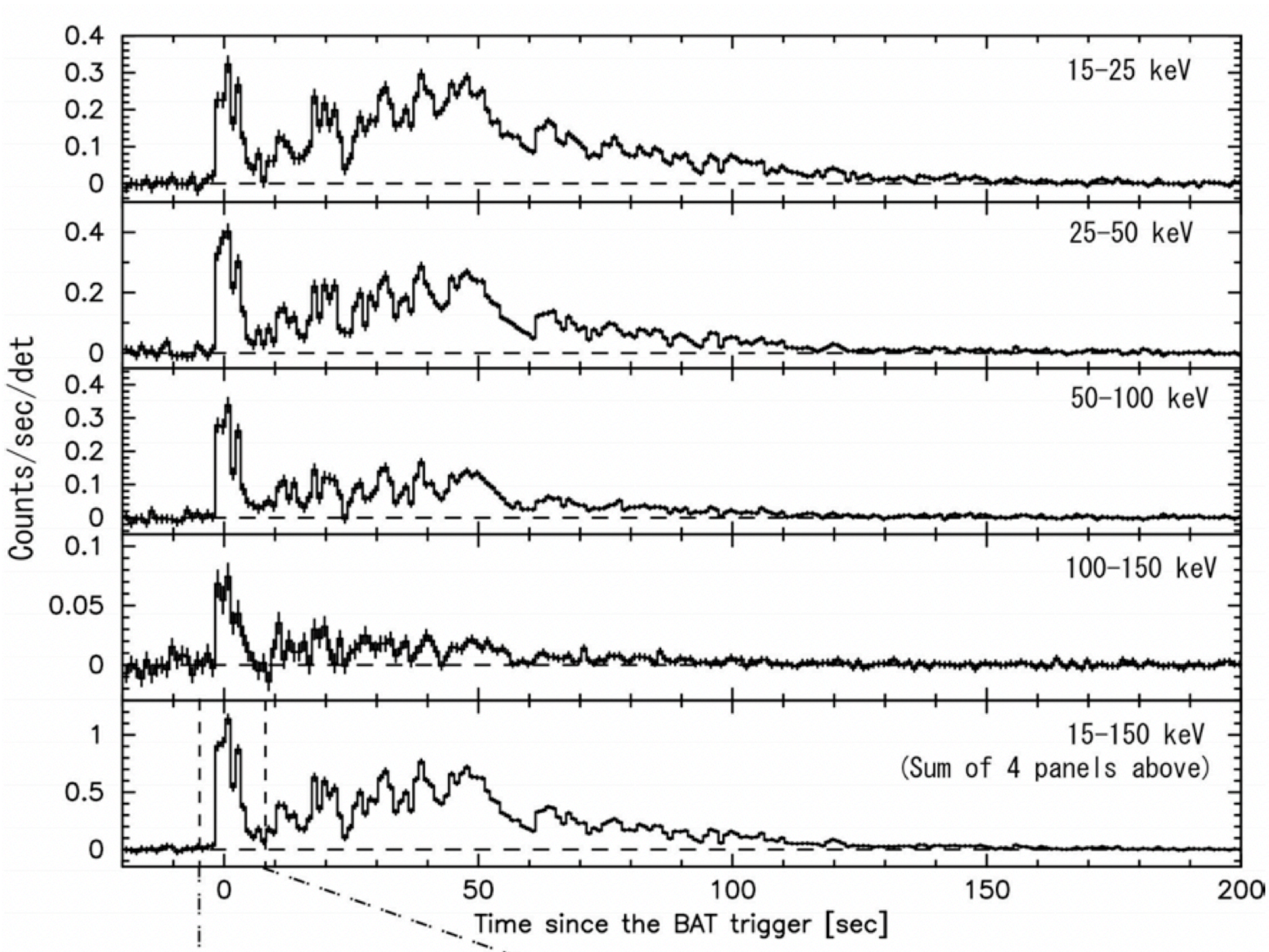


until 1s peak time
until T100
Detectable events/ year
10^1
10^0
10^{-1}
−100
−50
0
50
100
150
200
Observable-time (after t_{slew}) [s]

Thank you!

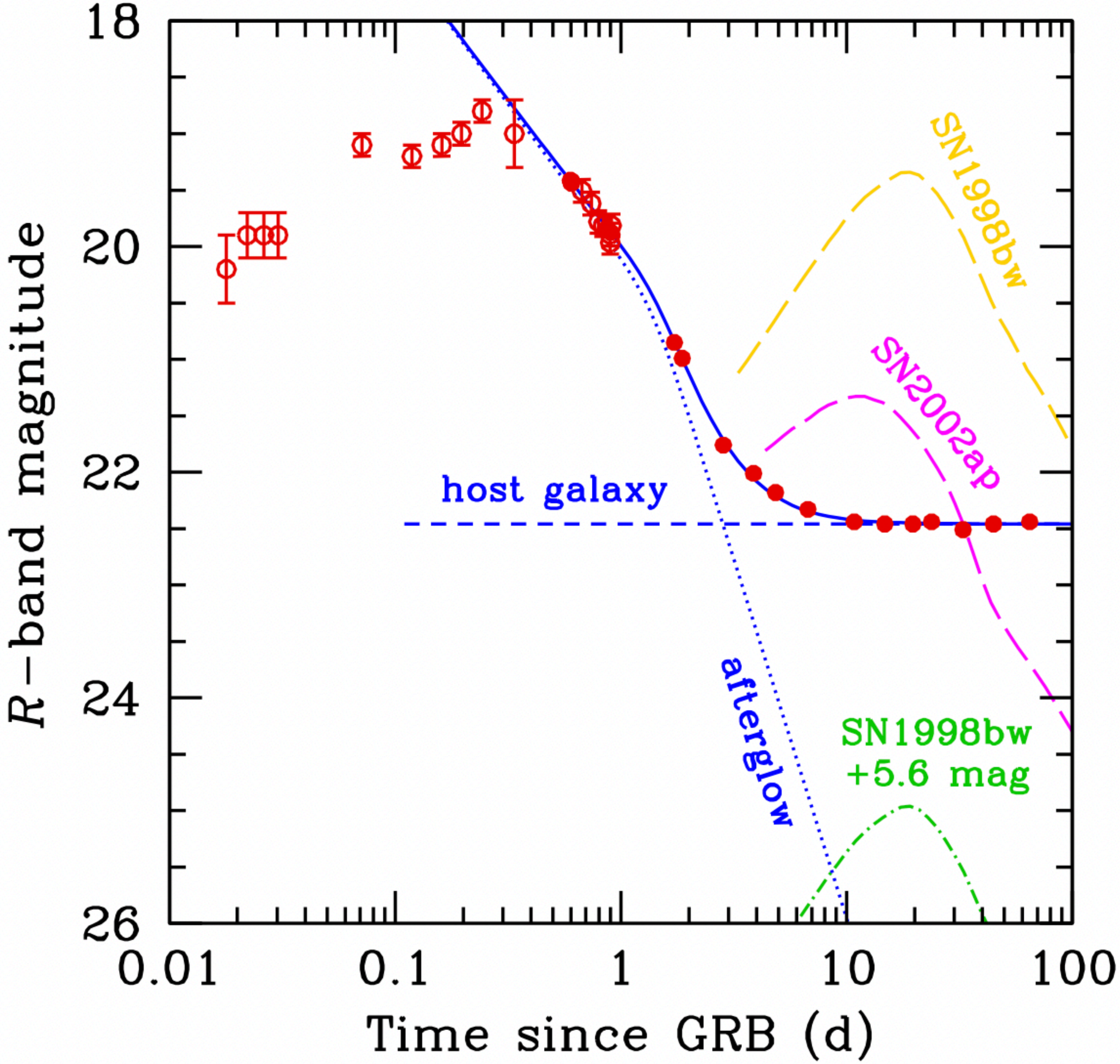
Anything similar from the past?

Historical example #1 GRB 060614



Gehrels et al. 2006, Nature

Historical example #1 GRB 060614



any SN should be x100 fainter

Della Valle et al. 2006, Nature

Gal-Yam et al. 2006, Nature

Example #2

GRB 060505

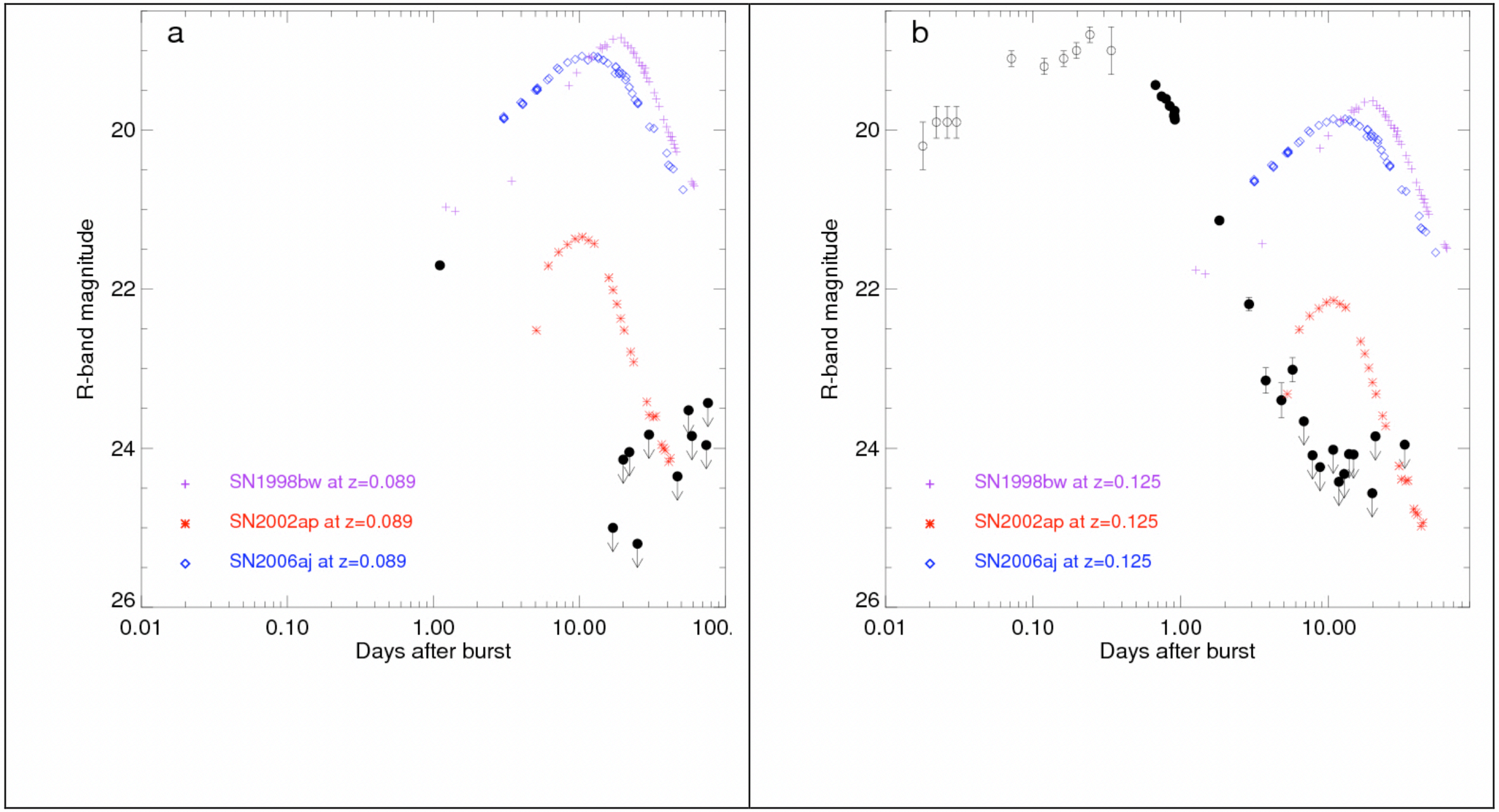
T90 ~ 4 s

z=0.089

GRB 060614

T90 ~ 100 s

z=0.125



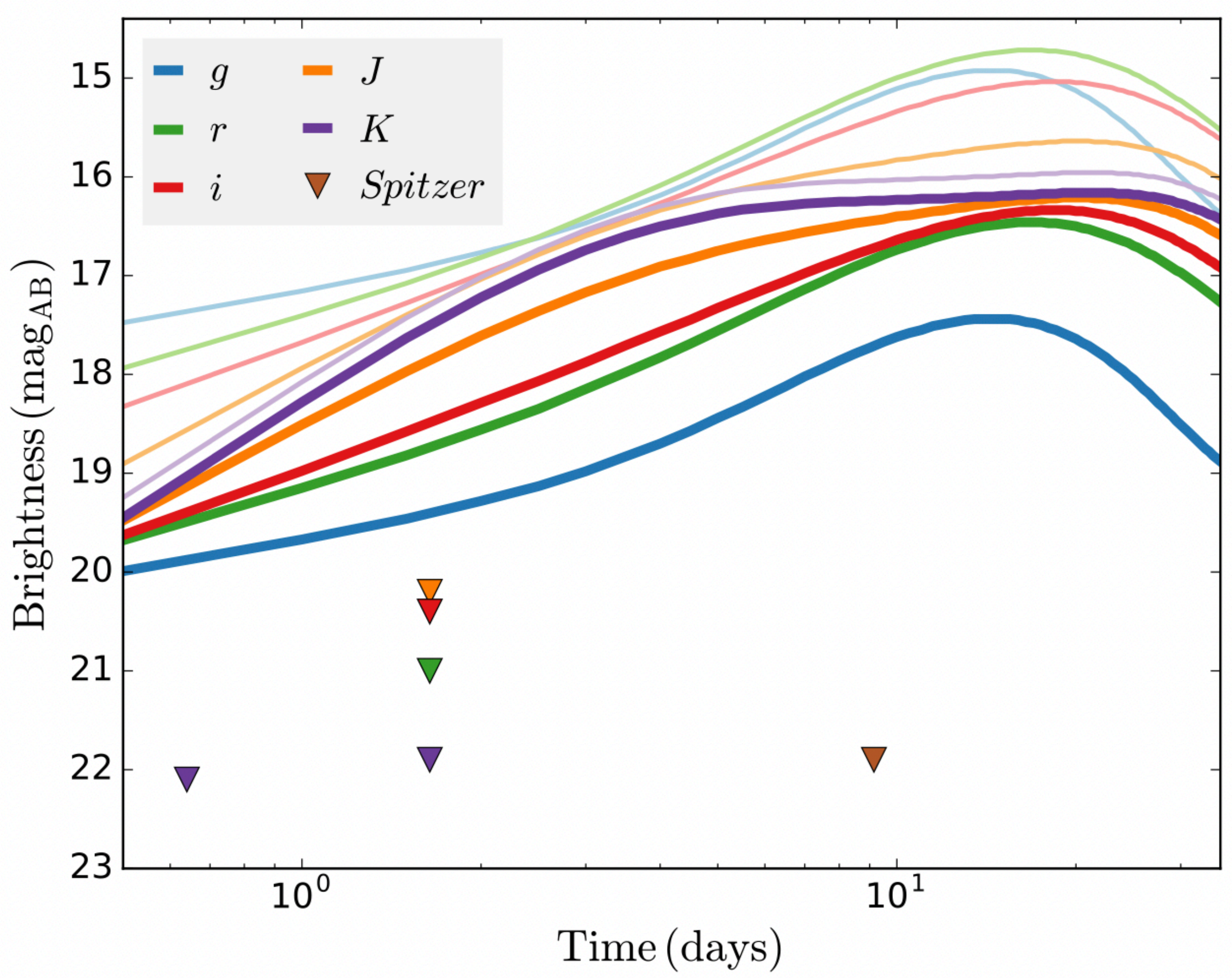
Fynbo et al. 2006, Nature 2006

Example #3

GRB 111005A

T90 ~ 26 s

z=0.013



Tanga et al. 2018, A&A

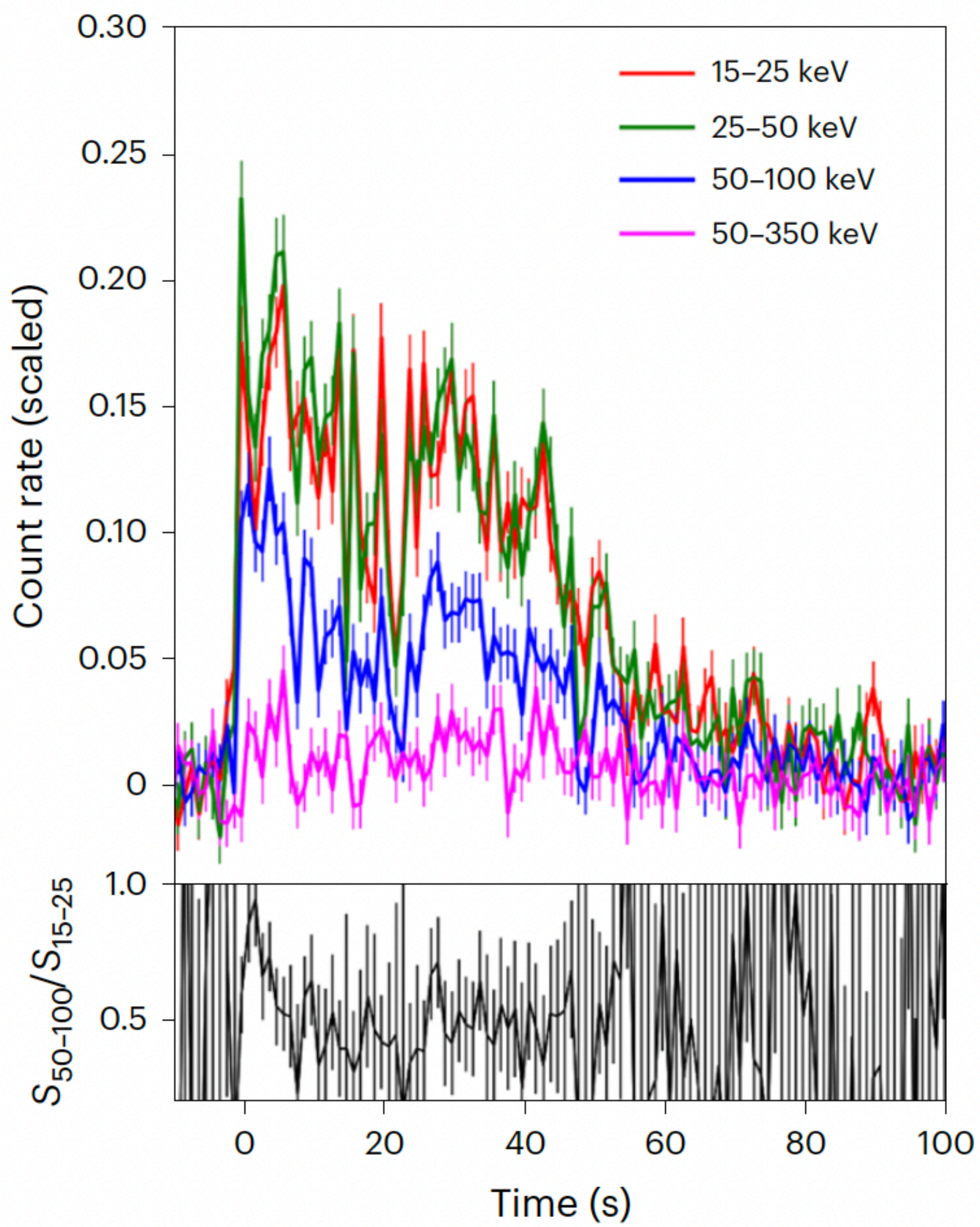
Michałowskl et al. 2018, A&A

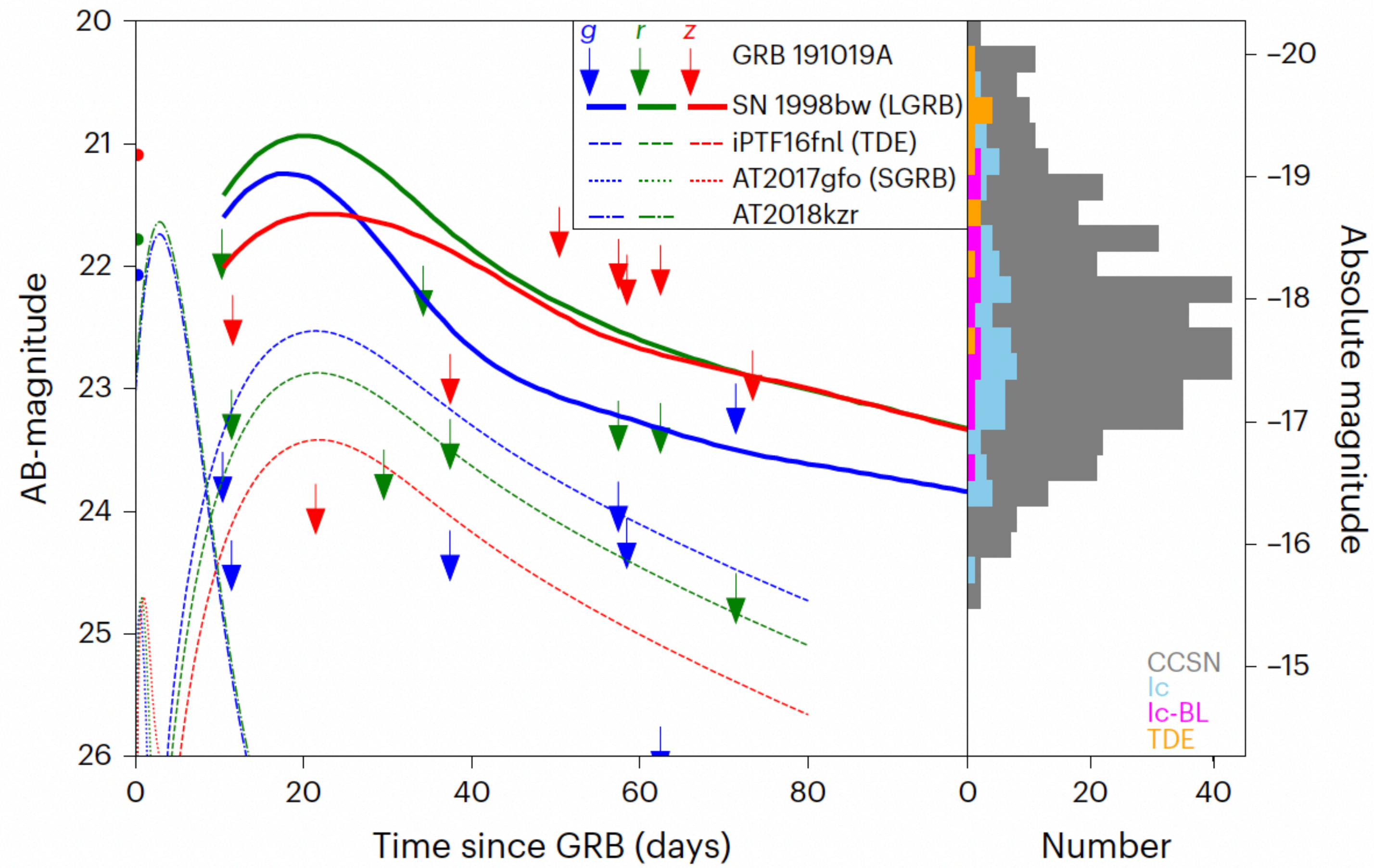
Example #4

GRB 191019A

T90 ~ 64 s

z = 0.248





Levan et al. 2023, Nature Astronomy

GRB	band	$T_{90}(s)$	$T_{50}(s)$	$D_L(Mpc)$	kilonova
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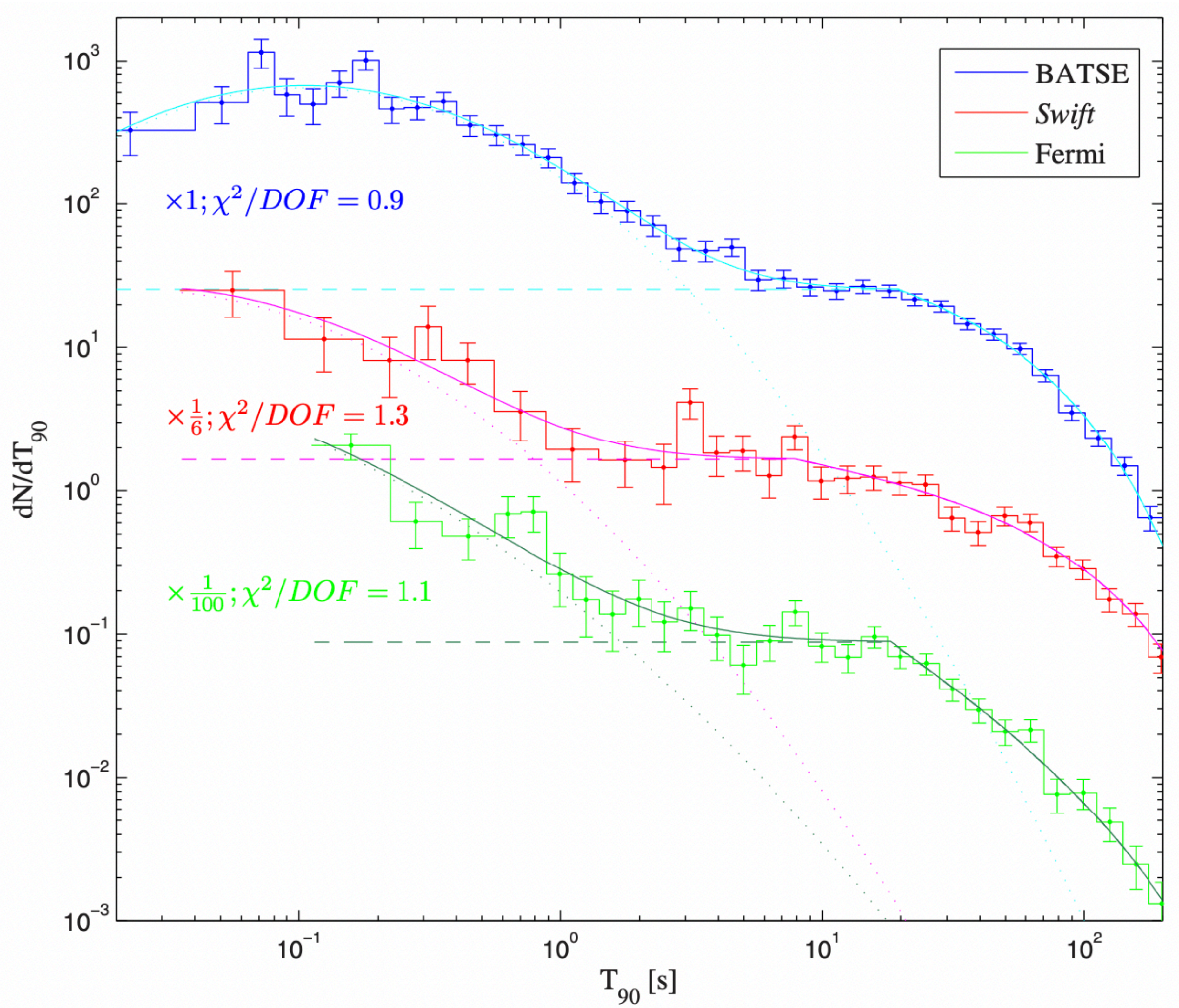
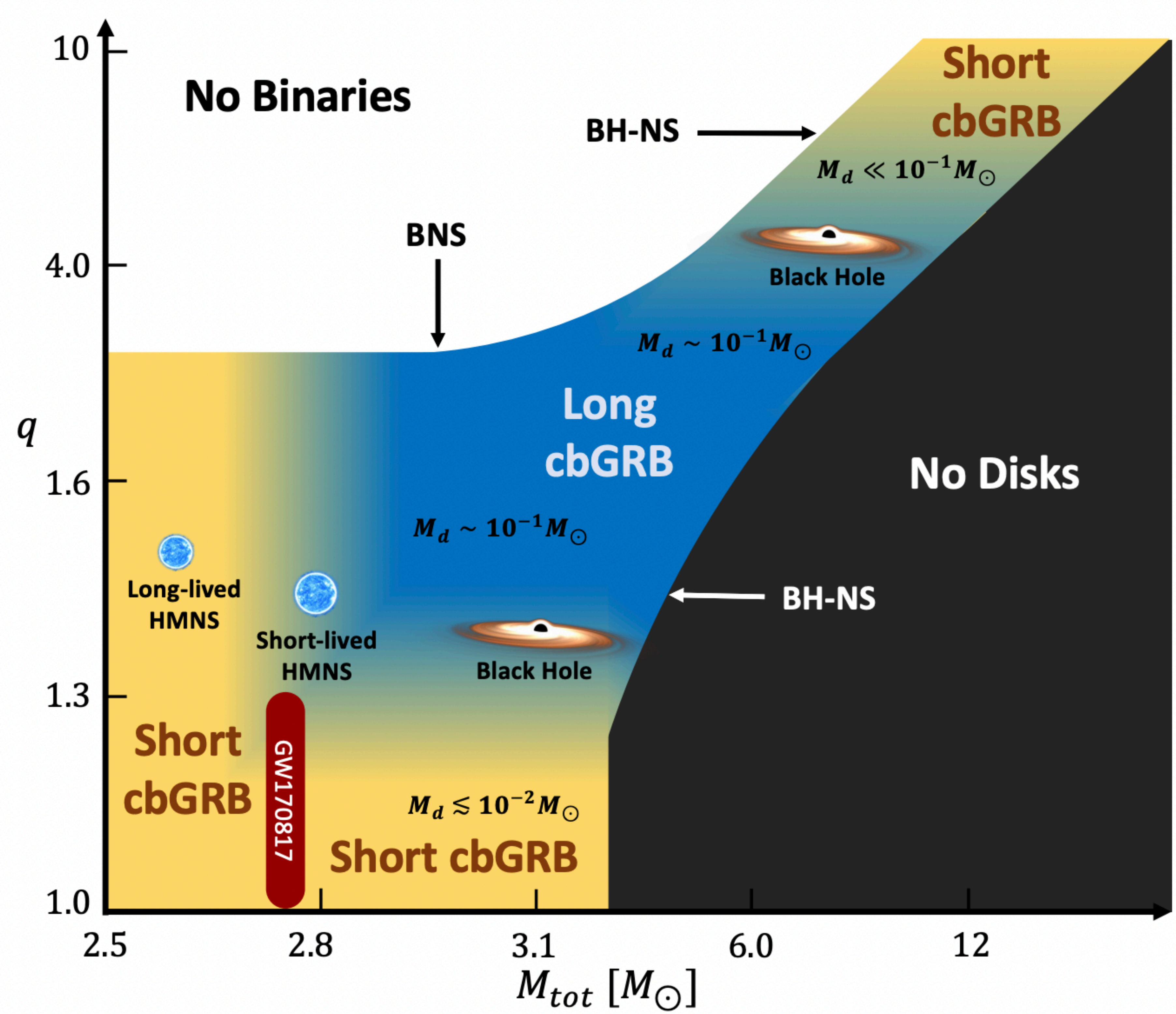
Collapsar vs Non-Collapsar classification



Bromberg et al. 2013 (see also Moharana & Piran 2017)

Possible progenitors



Gottlieb et al. 2023, arXiv

Summary

GW 170817 / GRB 170817A

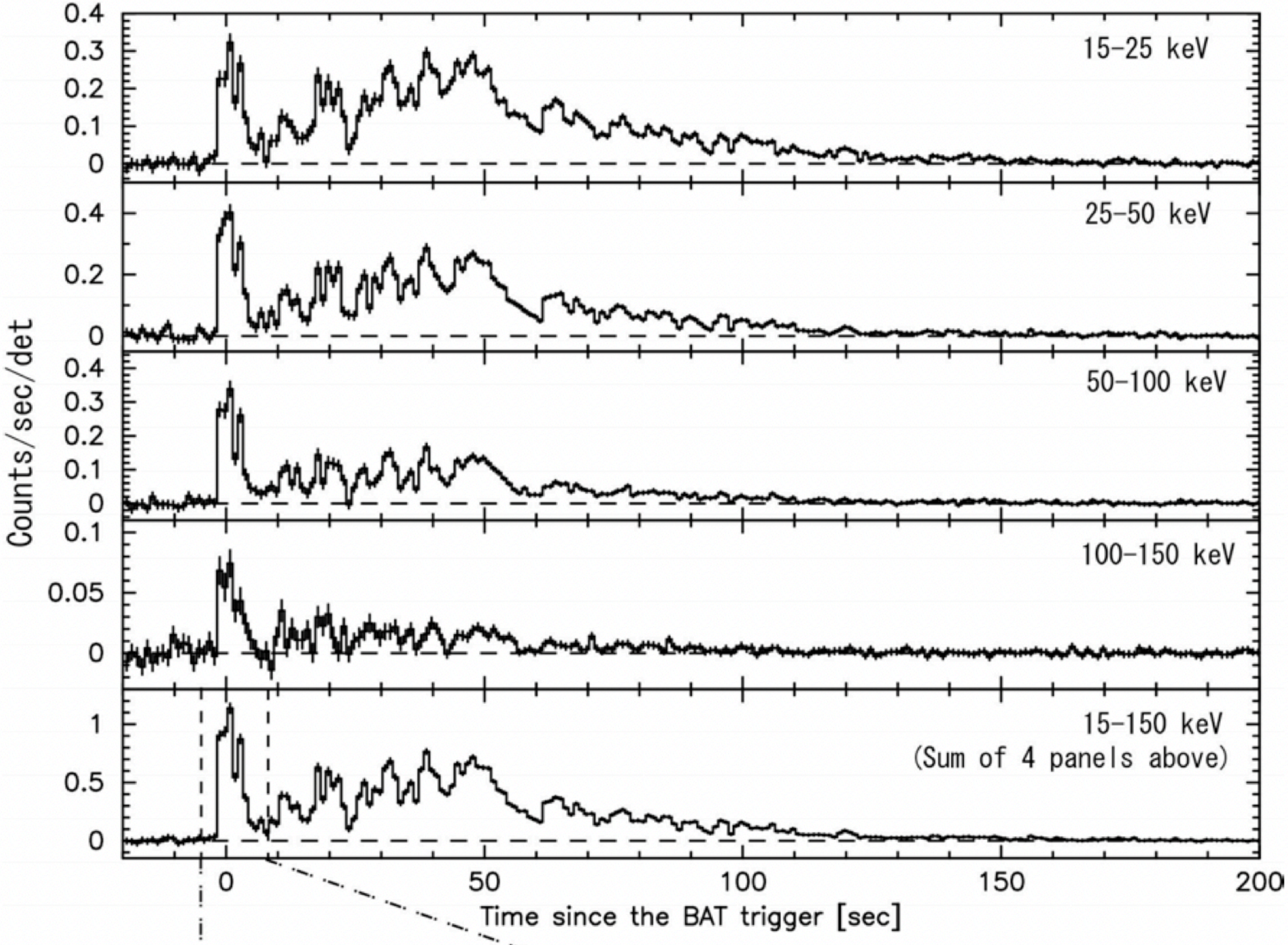
Emerging class of long-duration merger-driven GRBs

↓

Promising future

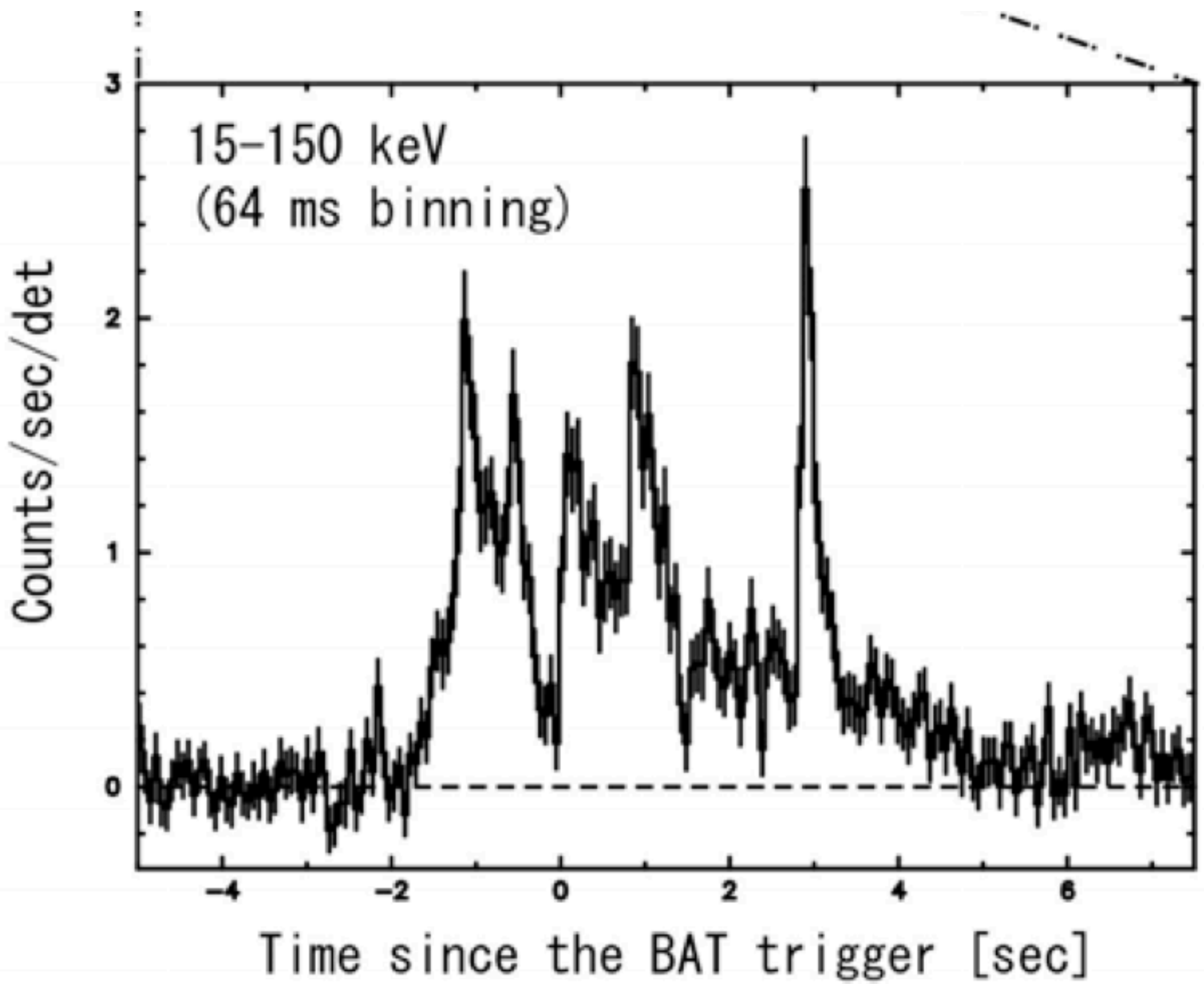
Long but supernovaless

Historical example #1 GRB 060614



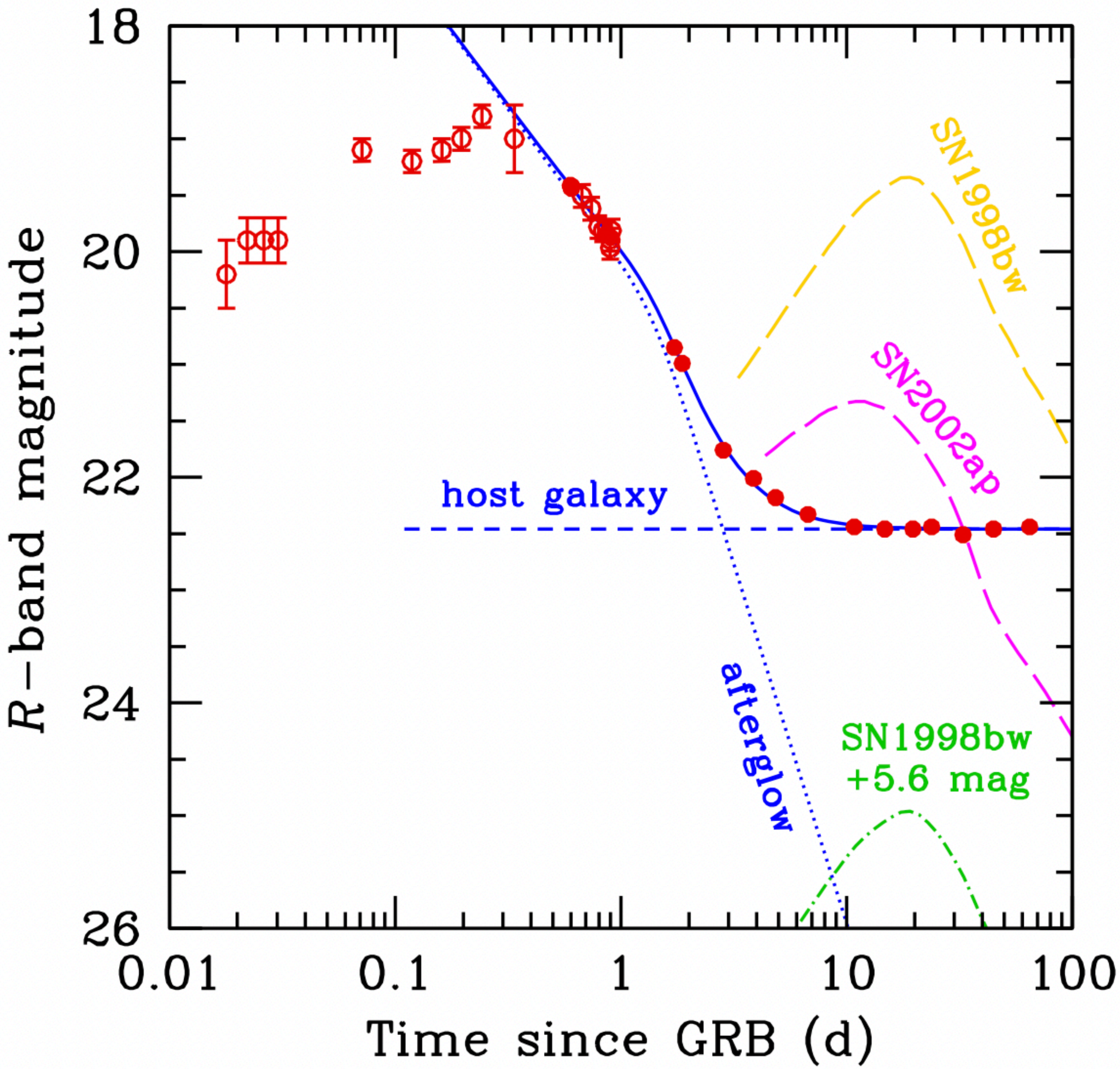
Gehrels et al. 2006, Nature

Historical example #1 GRB 060614



Gehrels et al. 2006, Nature

Historical example #1 GRB 060614



any SN should be x100 fainter

Della Valle et al. 2006, Nature

Gal-Yam et al. 2006, Nature

Example #2

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z=0.089

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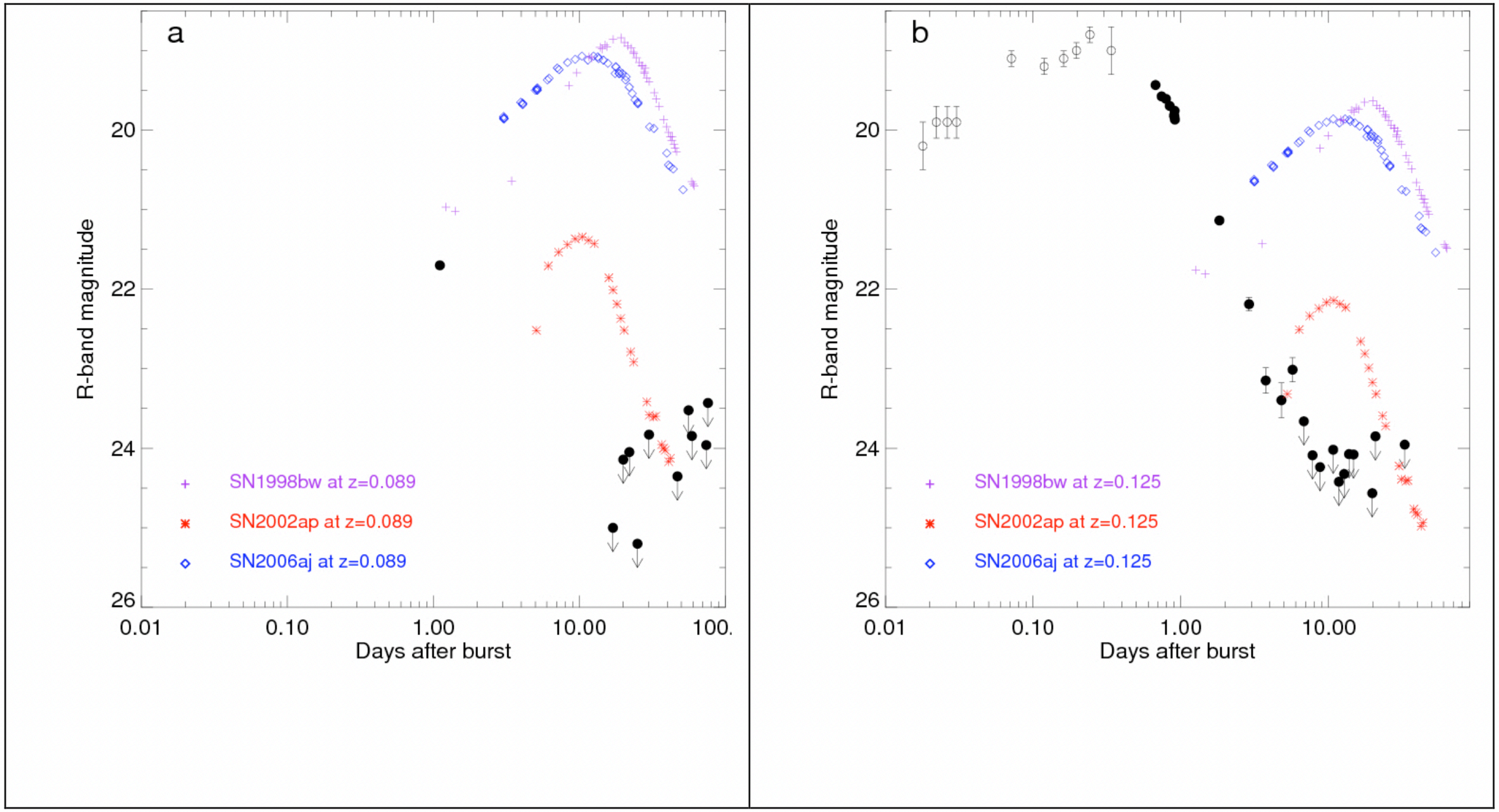
T90 ~ 100 s

z=0.125



Fynbo et al. 2006, Nature 2006

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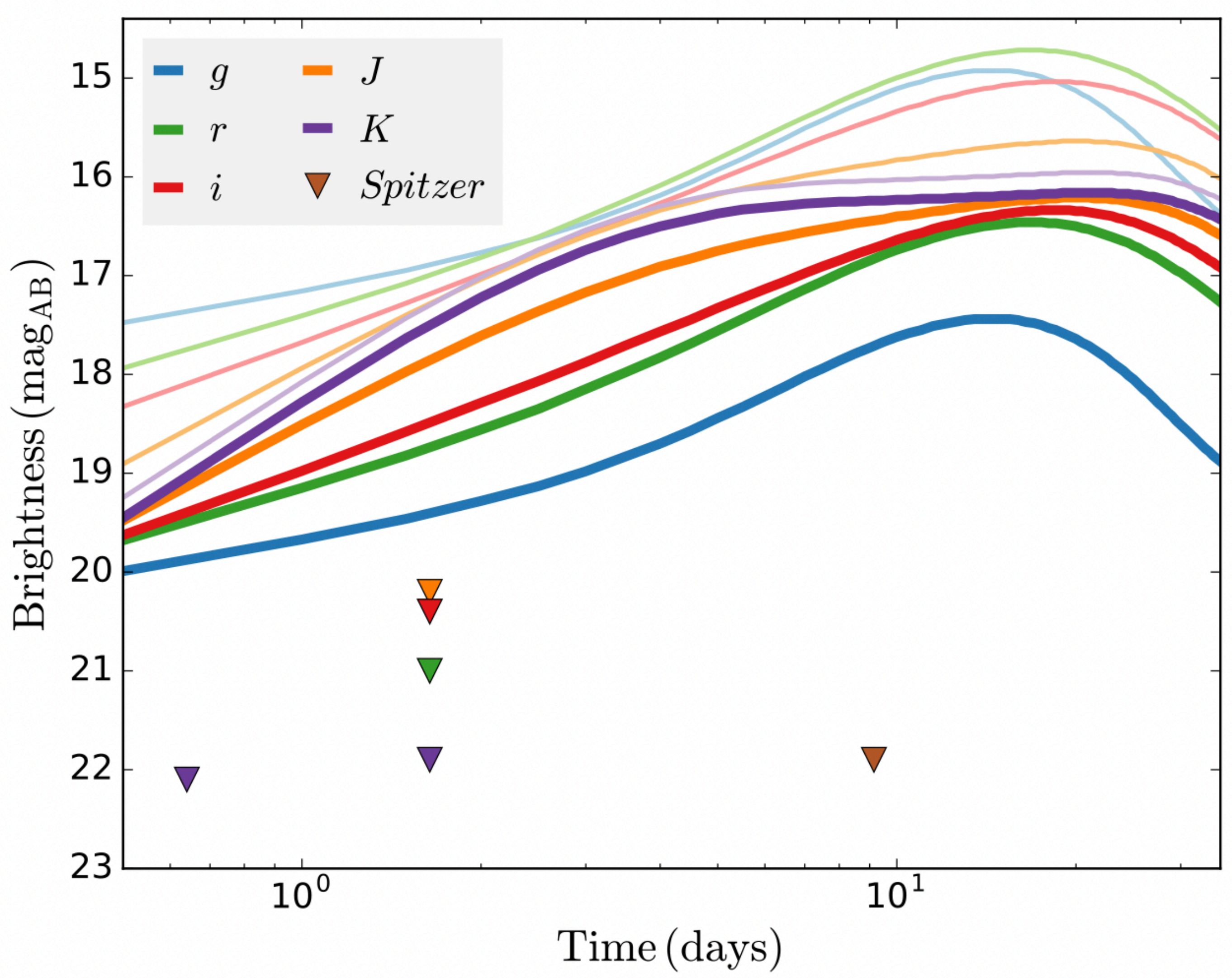
GRB 111005A

T90 ~ 26 s

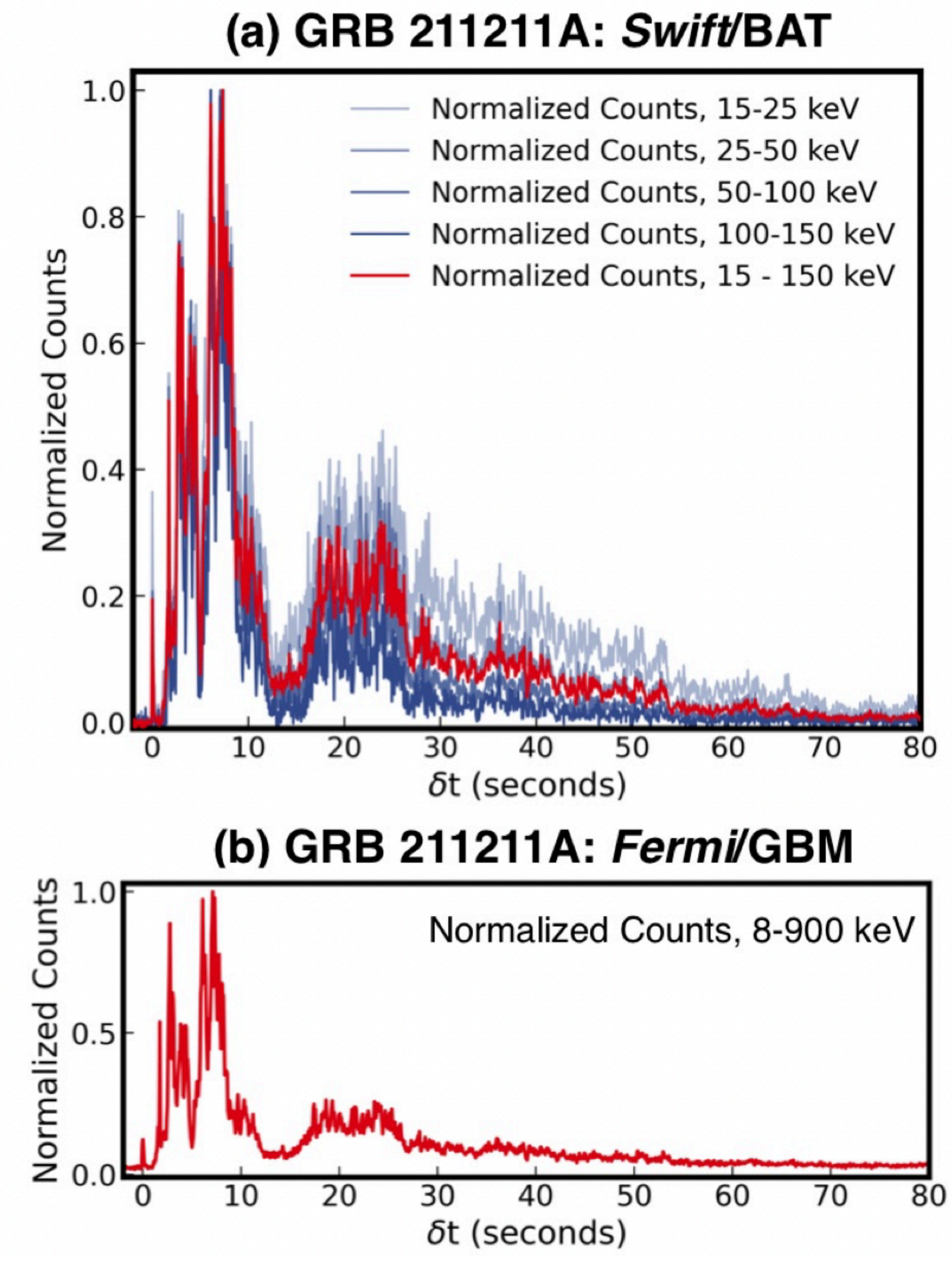
z=0.013



Tanga et al. 2018, A&A

Michałowskl et al. 2018, A&A

Example #4



GRB 211211A

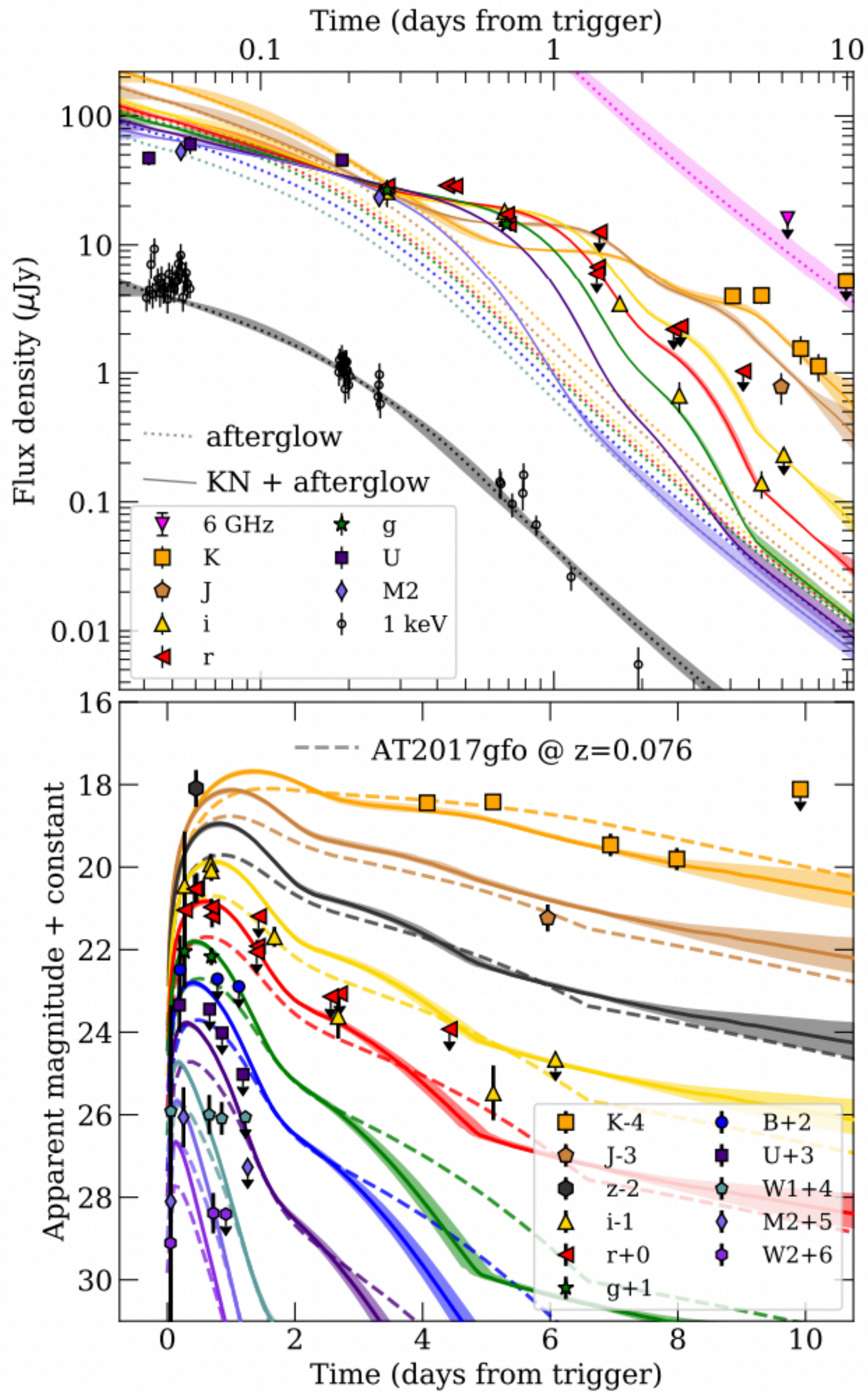
T90 ~ 34 s

z = 0.076
350 Mpc

Rastinejad et al. 2022, Nature

GRB 211211A

350 Mpc



Three-component kilonova fit

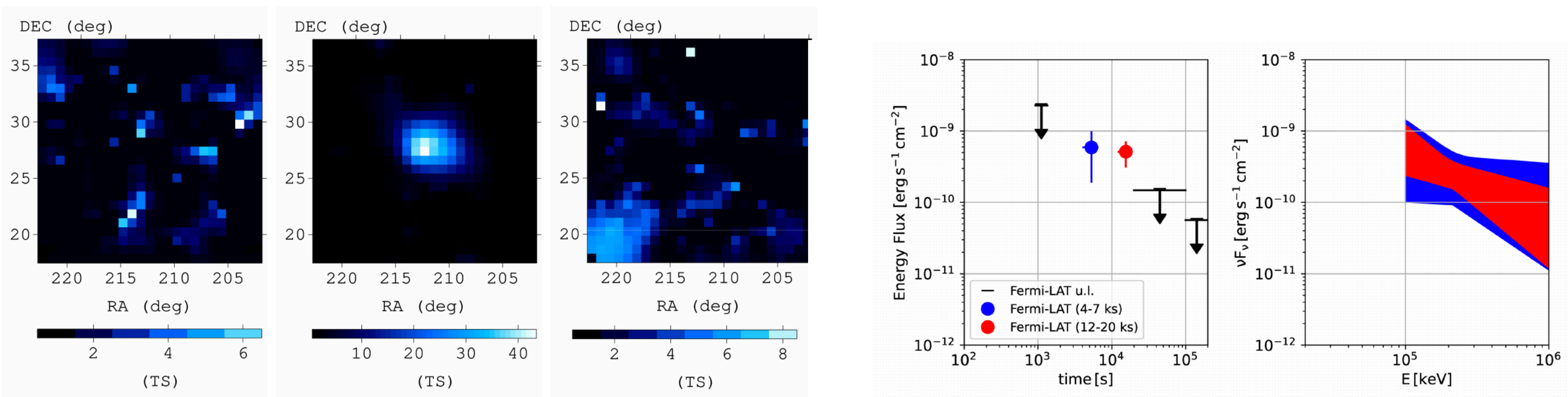
- $M_{ej} = 0.04 \pm 0.02\ M_{\odot}$, almost all lanthanide-rich, in reasonable agreement with at2017gfo.
- $v_{ej} \simeq 0.25 - 0.3$ c
- Associated to compact object merger in a binary system, likely BNS

Rastinejad et al. 2022, Nature

(see also **Troja et al. 2022, Nature**)

GRB 211211A

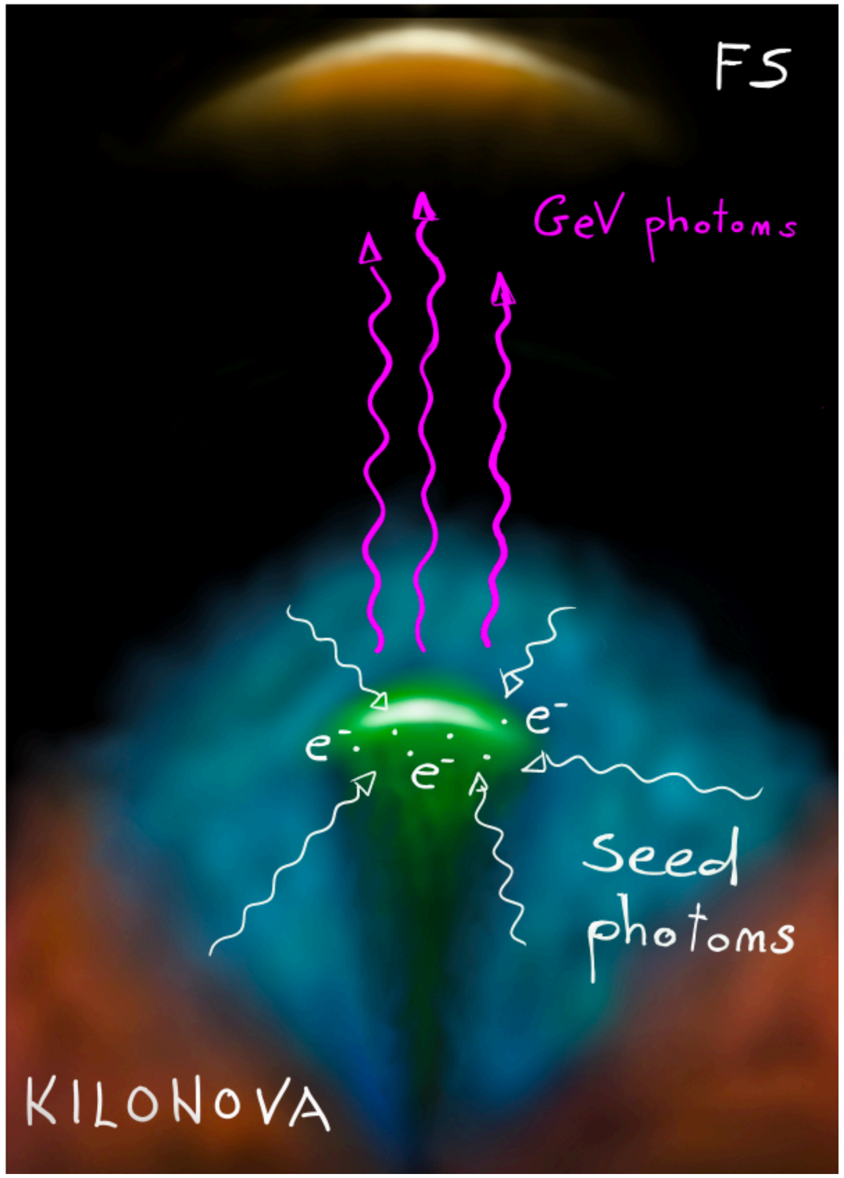
GeV emission



(a) t_0-1 d to t_0 (b) t_0 to t_0+20 ks (c) t_0+1 d to t_0+2 d (d) t_0 to t_0+2 d

Alessio Mei et al. 2022, Nature

GeV emission from a BNS merger



- not present in GW/GRB 170817
- new component from KN-jet interaction

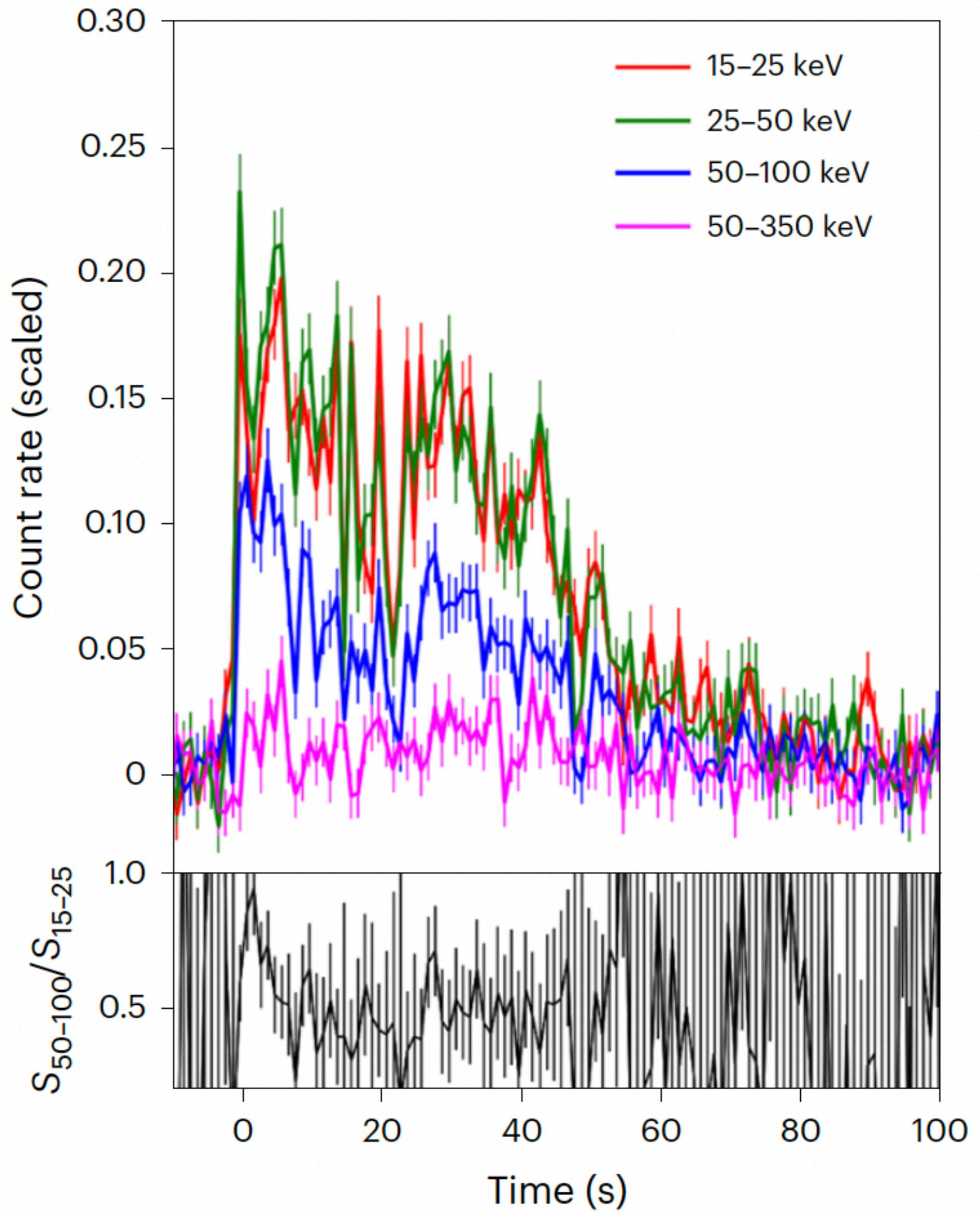
Mei et al. 2022, Nature

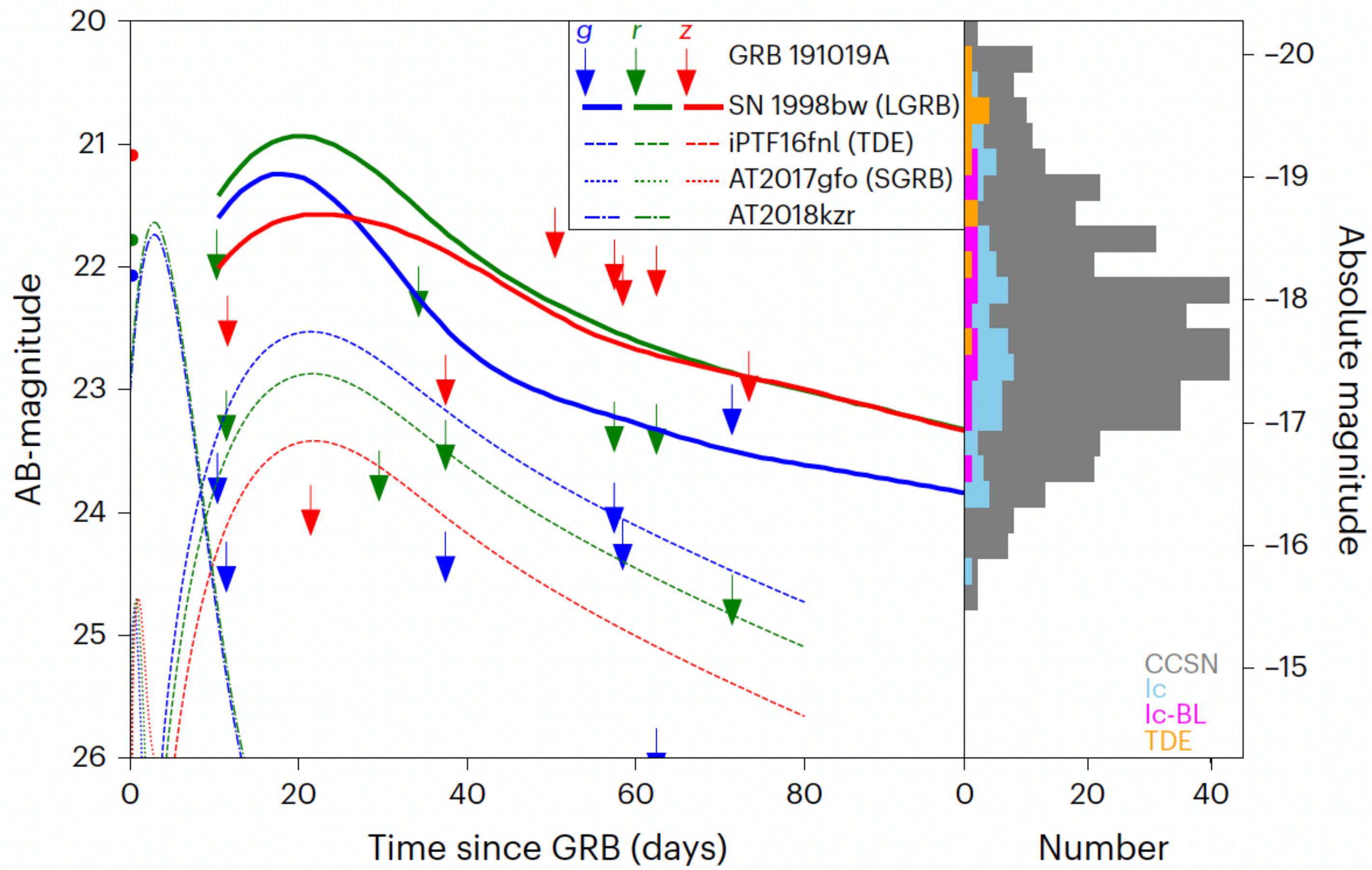
Example #5

GRB 191019A

T90 ~ 64 s

z = 0.248





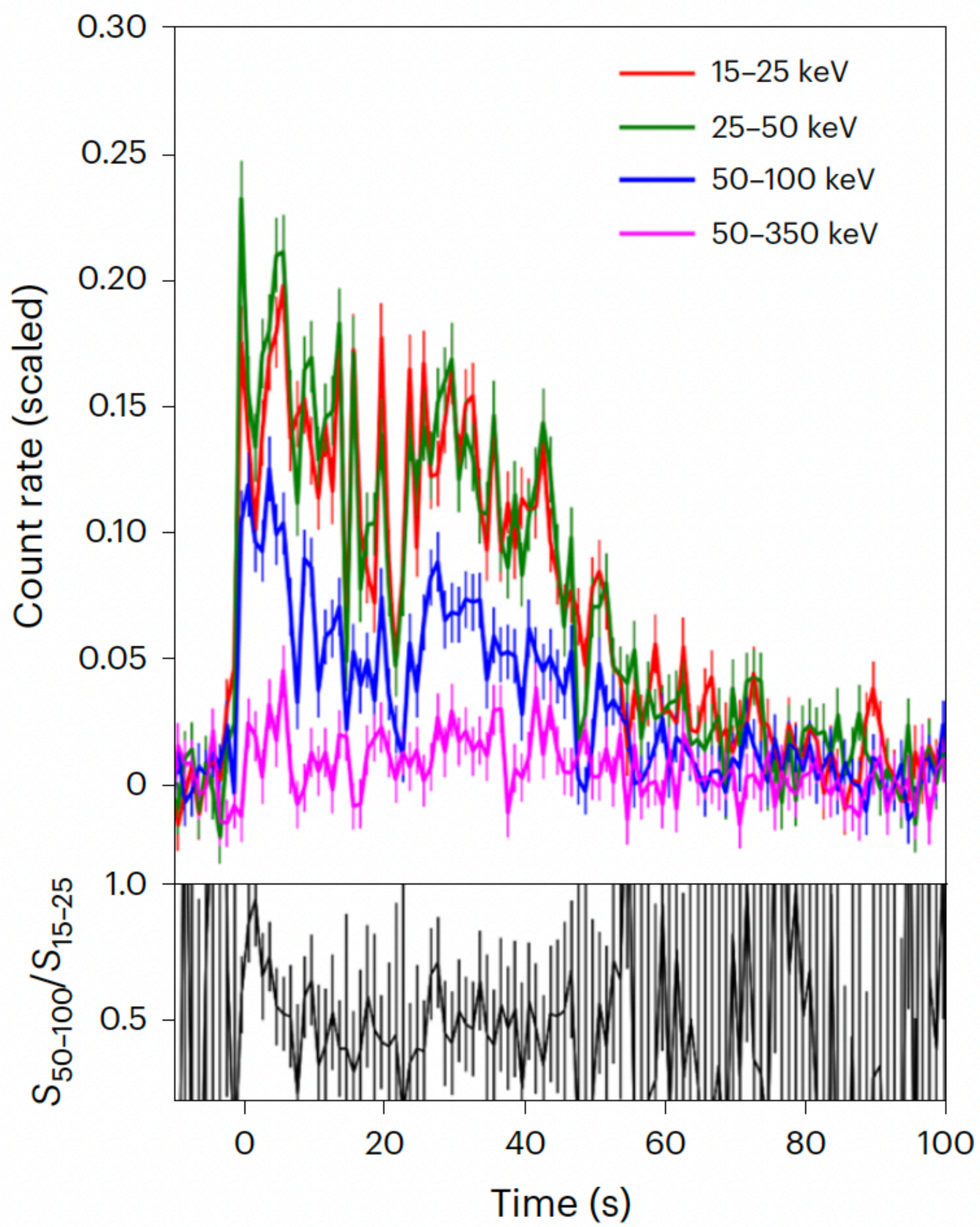
Levan et al. 2023, Nature Astronomy

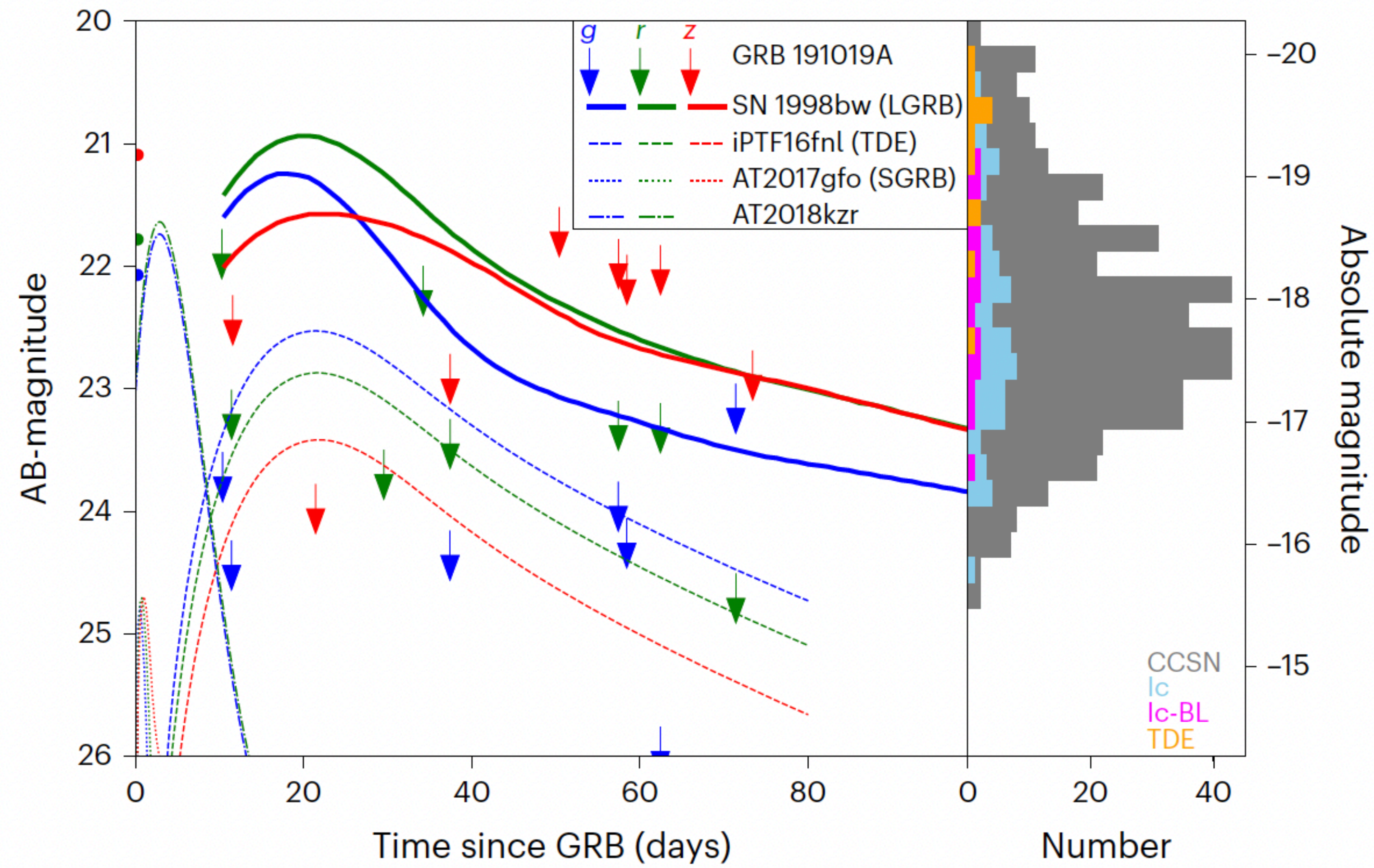
Example #5

GRB 191019A

T90 ~ 64 s

z = 0.248





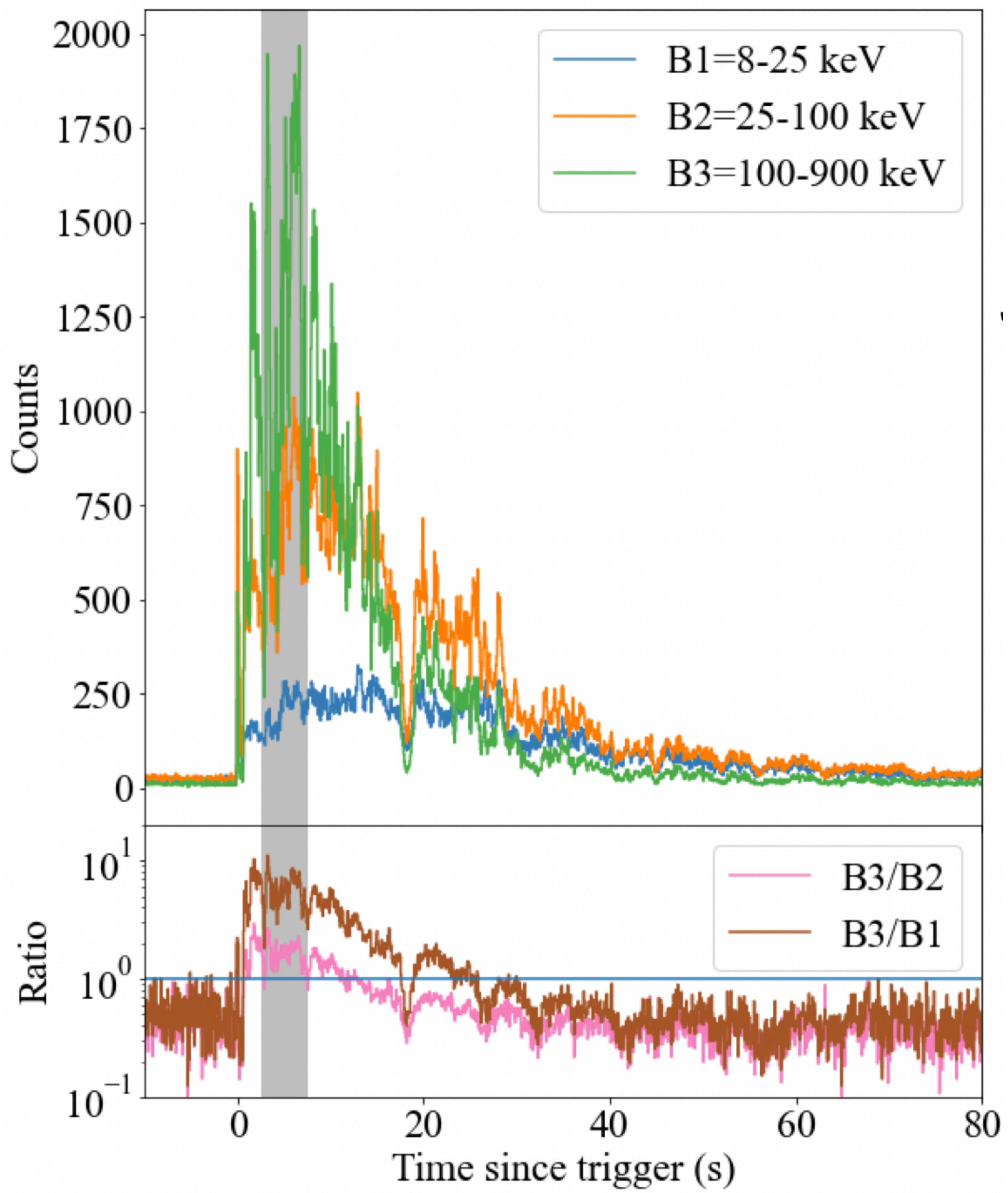
Levan et al. 2023, Nature Astronomy

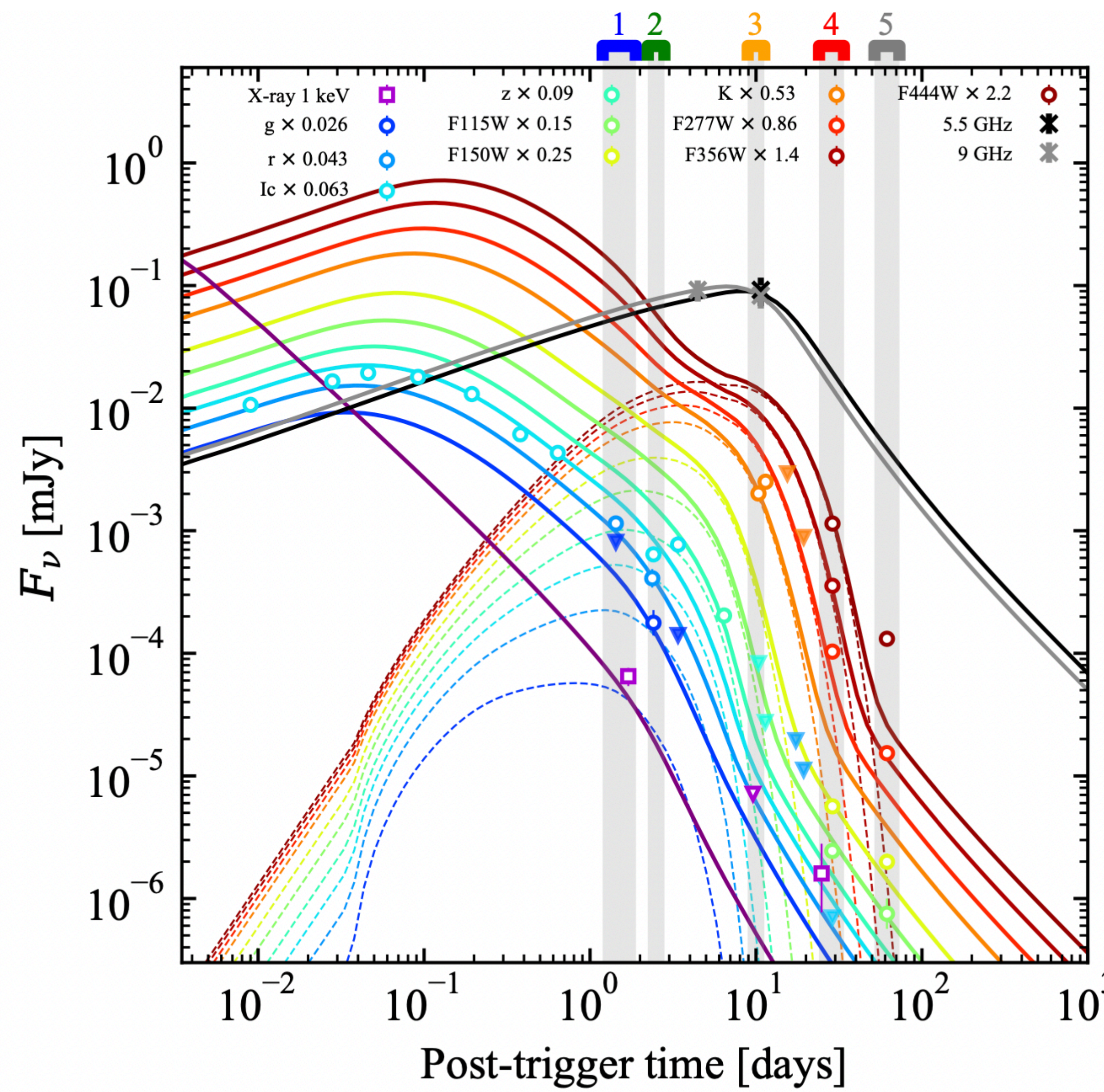
Example #6

GRB 230307A

T90 ~ 30 s

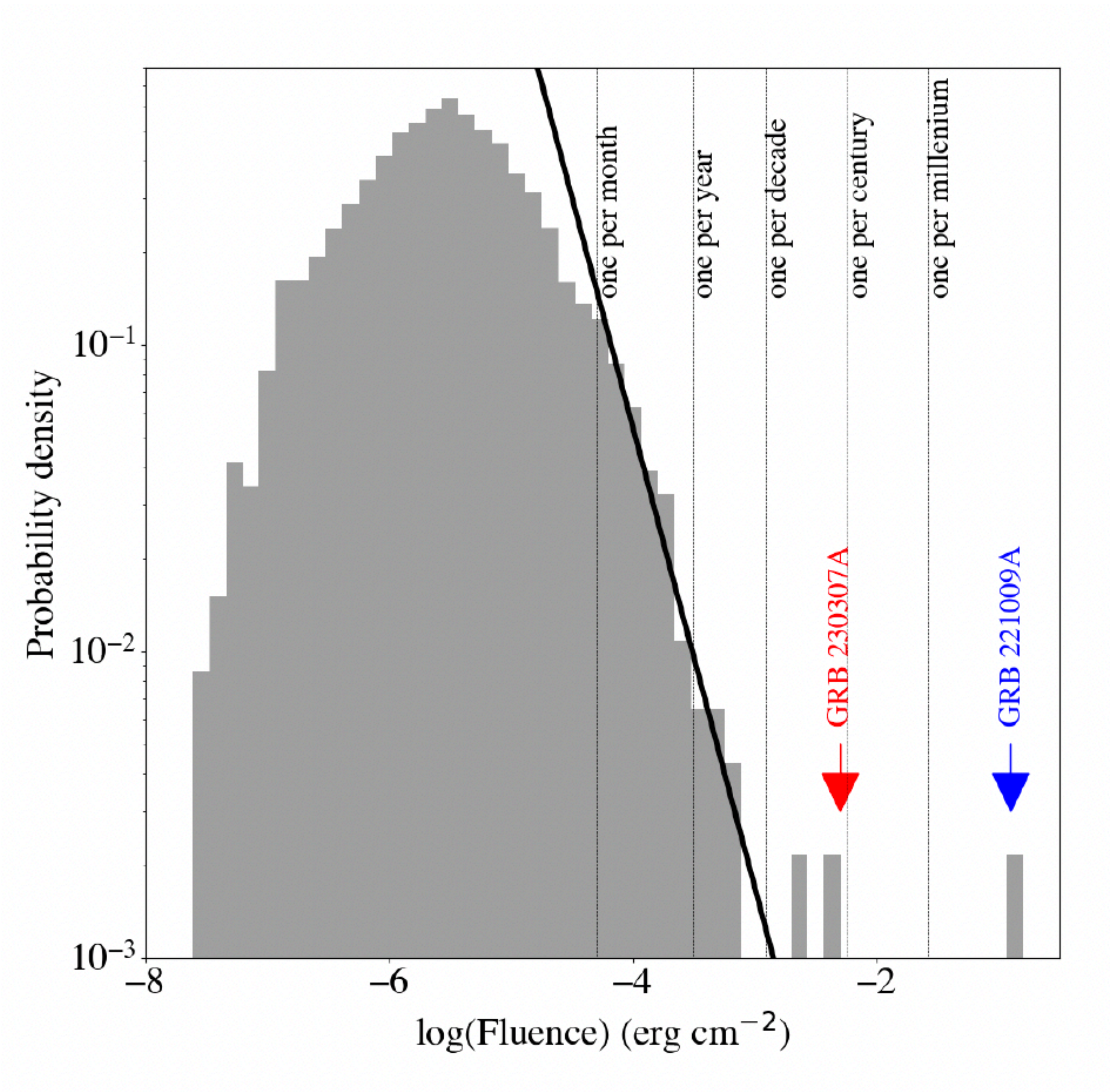
z = 0.065





Levan et al. 2023, arXiv

Example #6



Levan et al. 2023, arXiv

GRB 230307A

T90 ~ 35 s

z = 0.065

Summary

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060614	15-350 keV	106	43	590	hint (Yang et al. 2015)
060505	15-350 keV	4		409	hint? (Jin et al. 2021, arXiv)
111005A	15-350 keV	26	11	57	-
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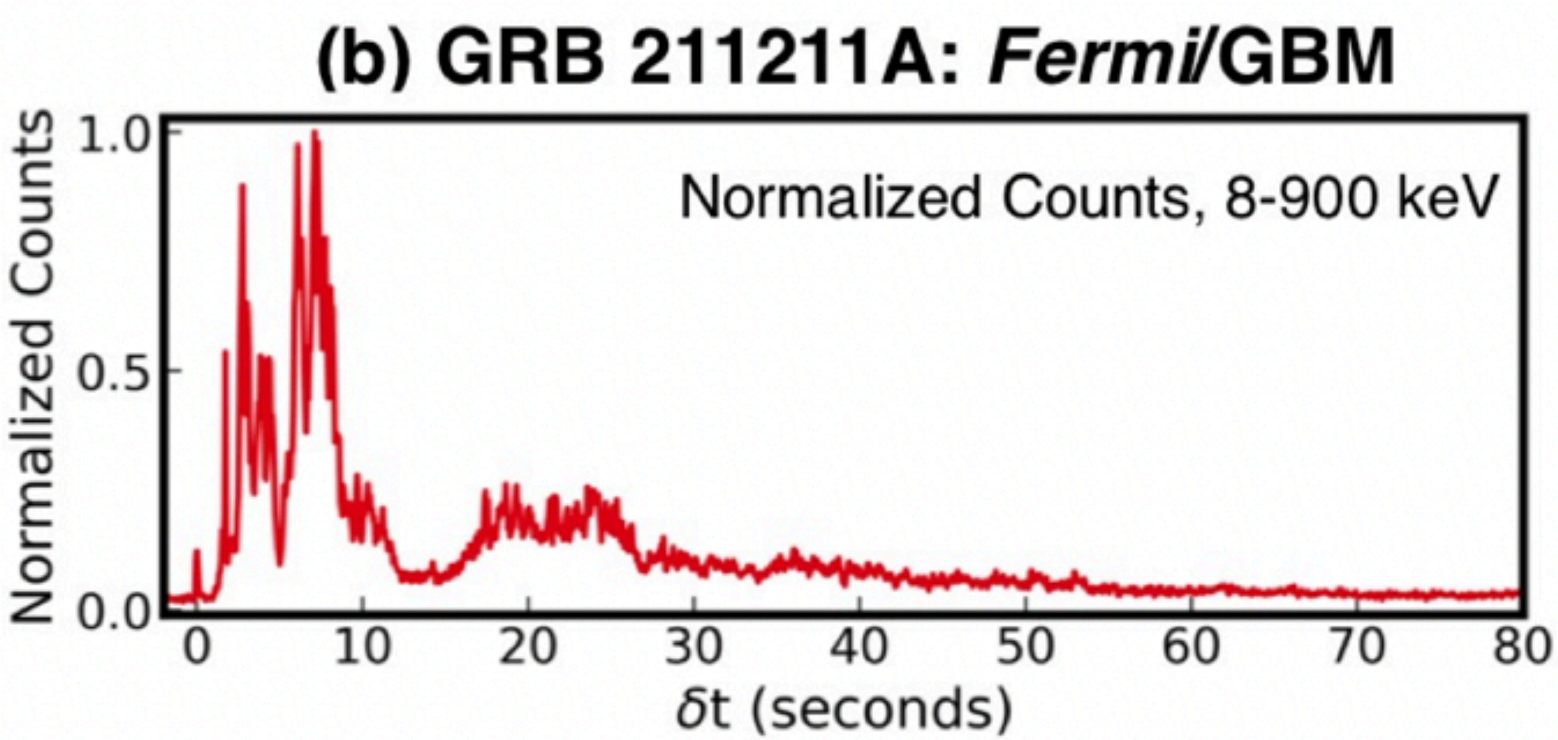
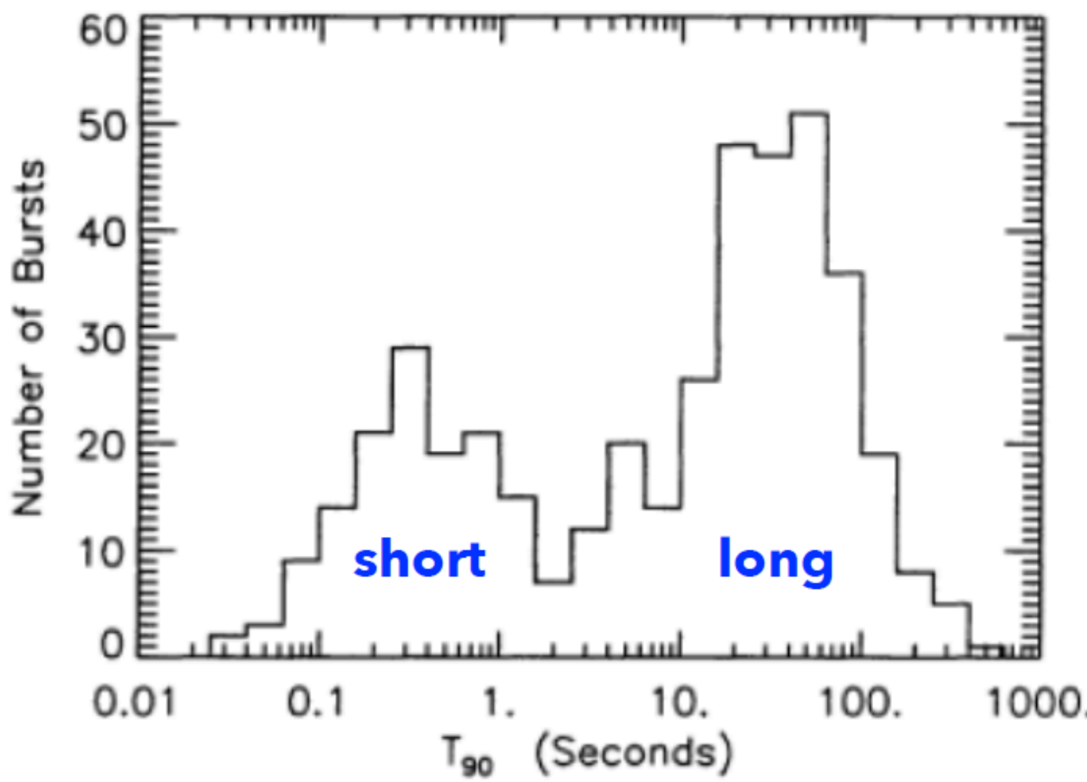


Rastinejad et al. 2022, Nature

What is going on?

Standard classification

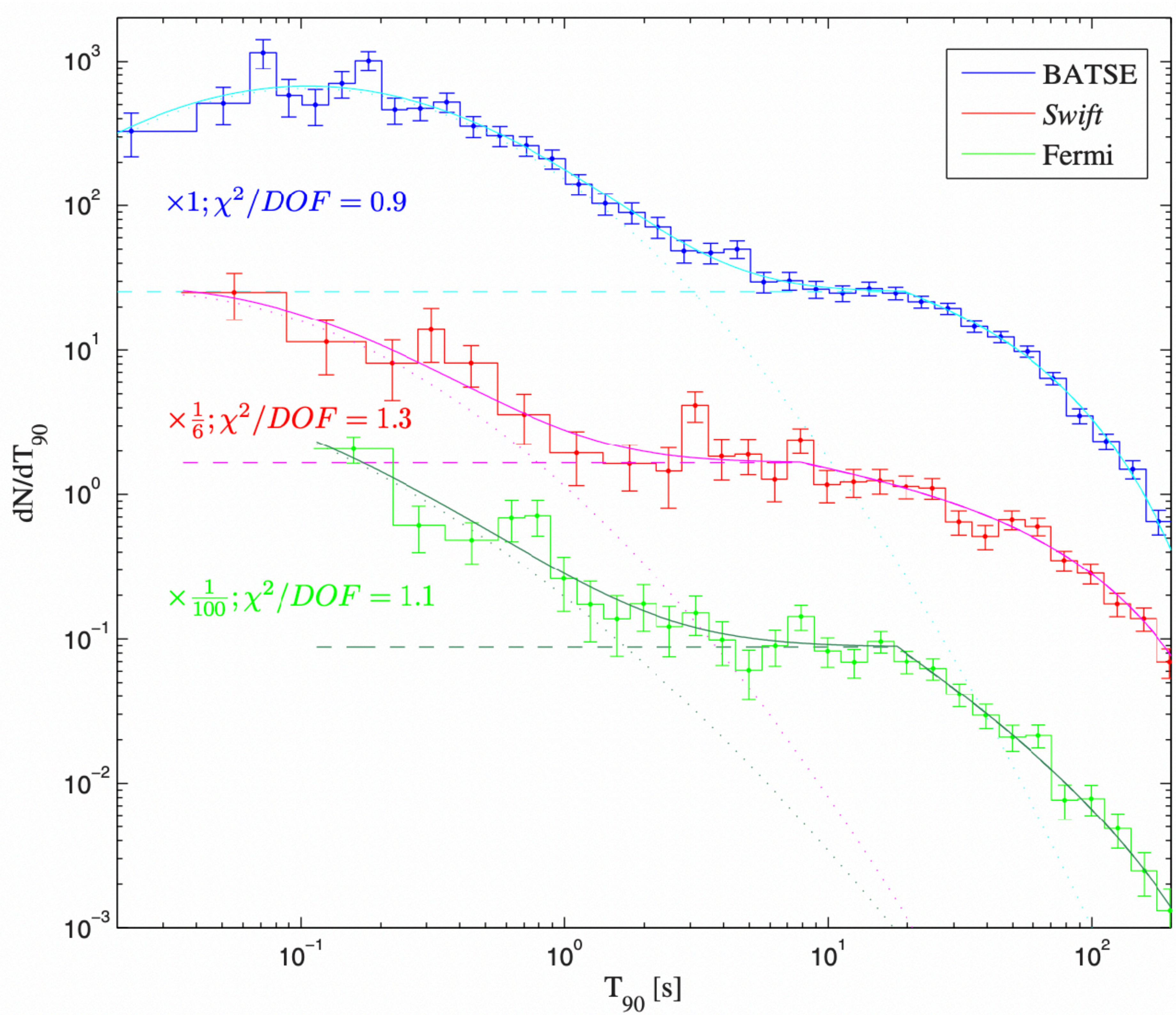


short (<2 s) and long (>2 s)

C. Kouveliotou et al. 1993, Meegan et al 1996, Sakamoto et al. 2011, Paciesas et al 2012

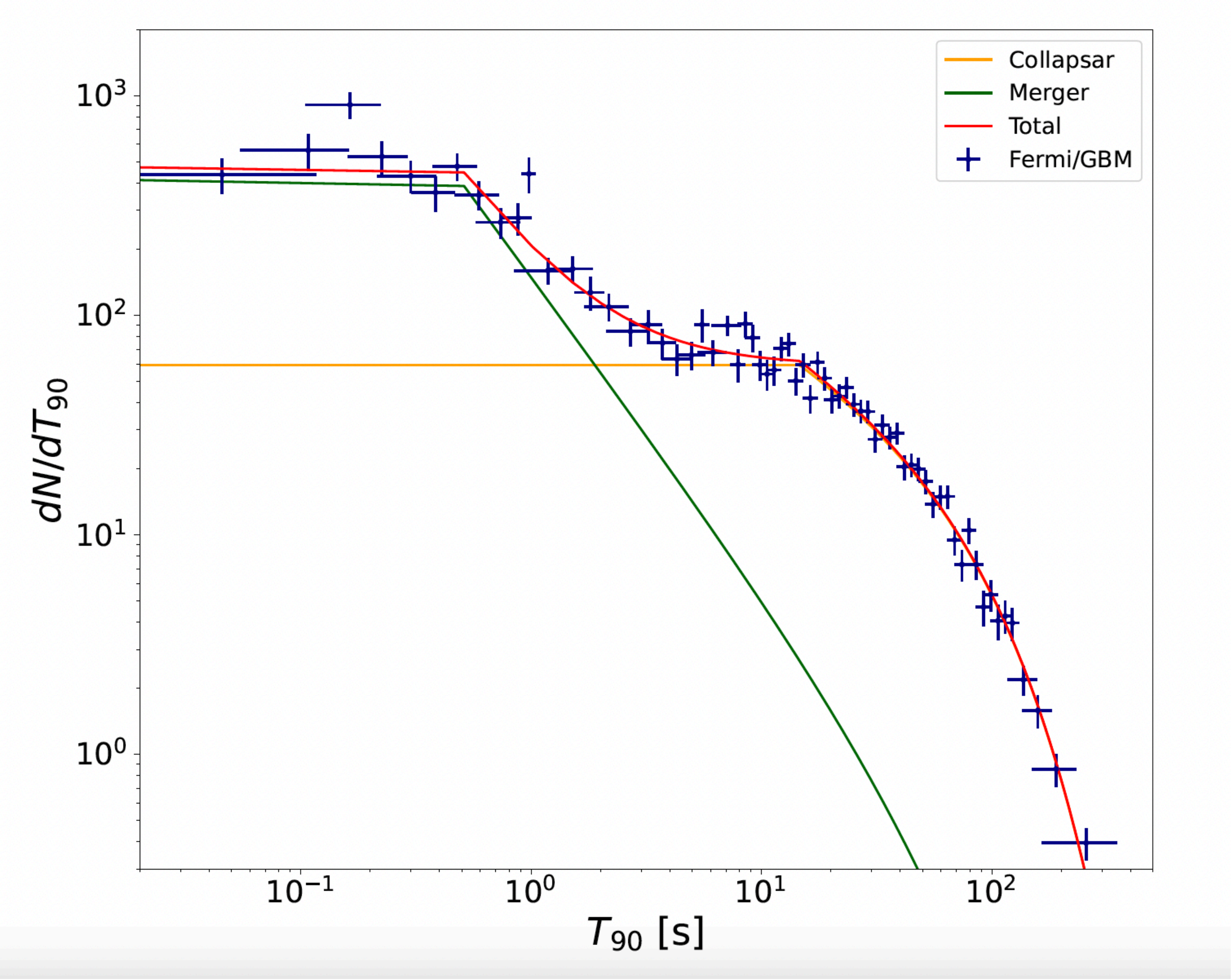
short-hard vs long-soft GRBs

Collapsar vs Non-Collapsar classification



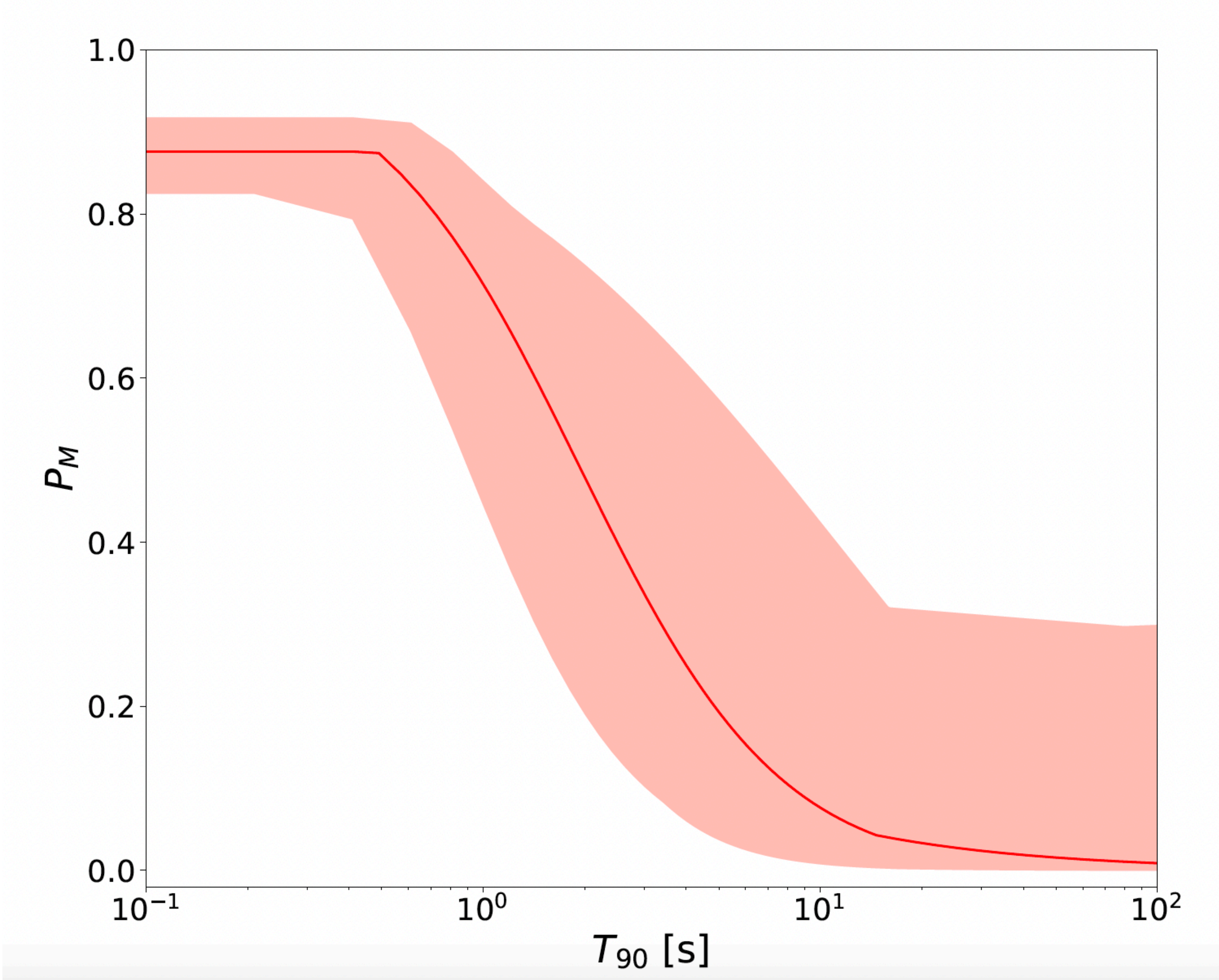
Bromberg et al. 2013 (see also Moharana & Piran 2017)

Collapsar vs Non-Collapsar classification



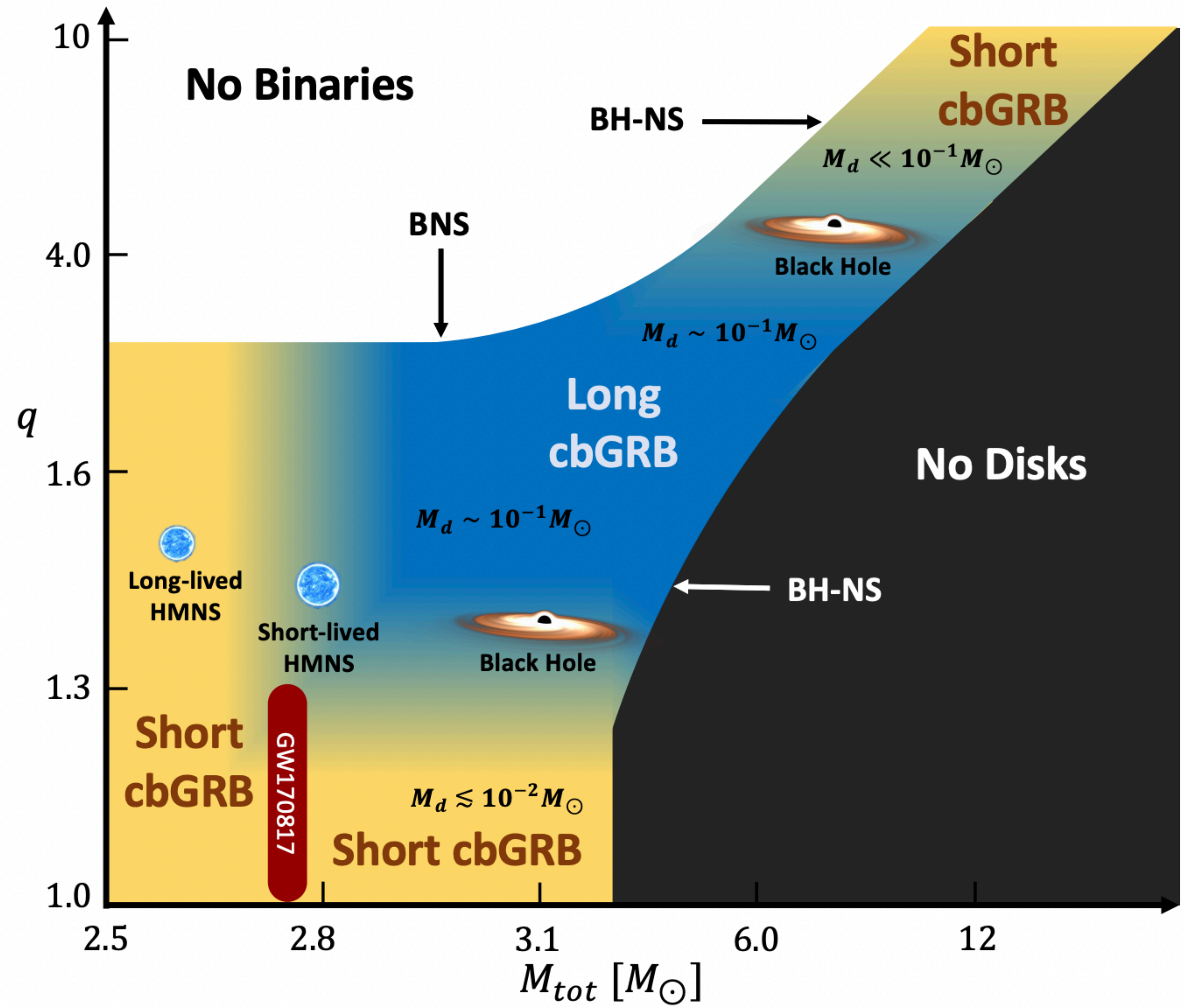
all Fermi/GBM data, Alessio Mei

Collapsar vs Non-Collapsar classification



all Fermi/GBM data, Alessio Mei

Possible progenitors



Gottlieb et al. 2023, arXiv

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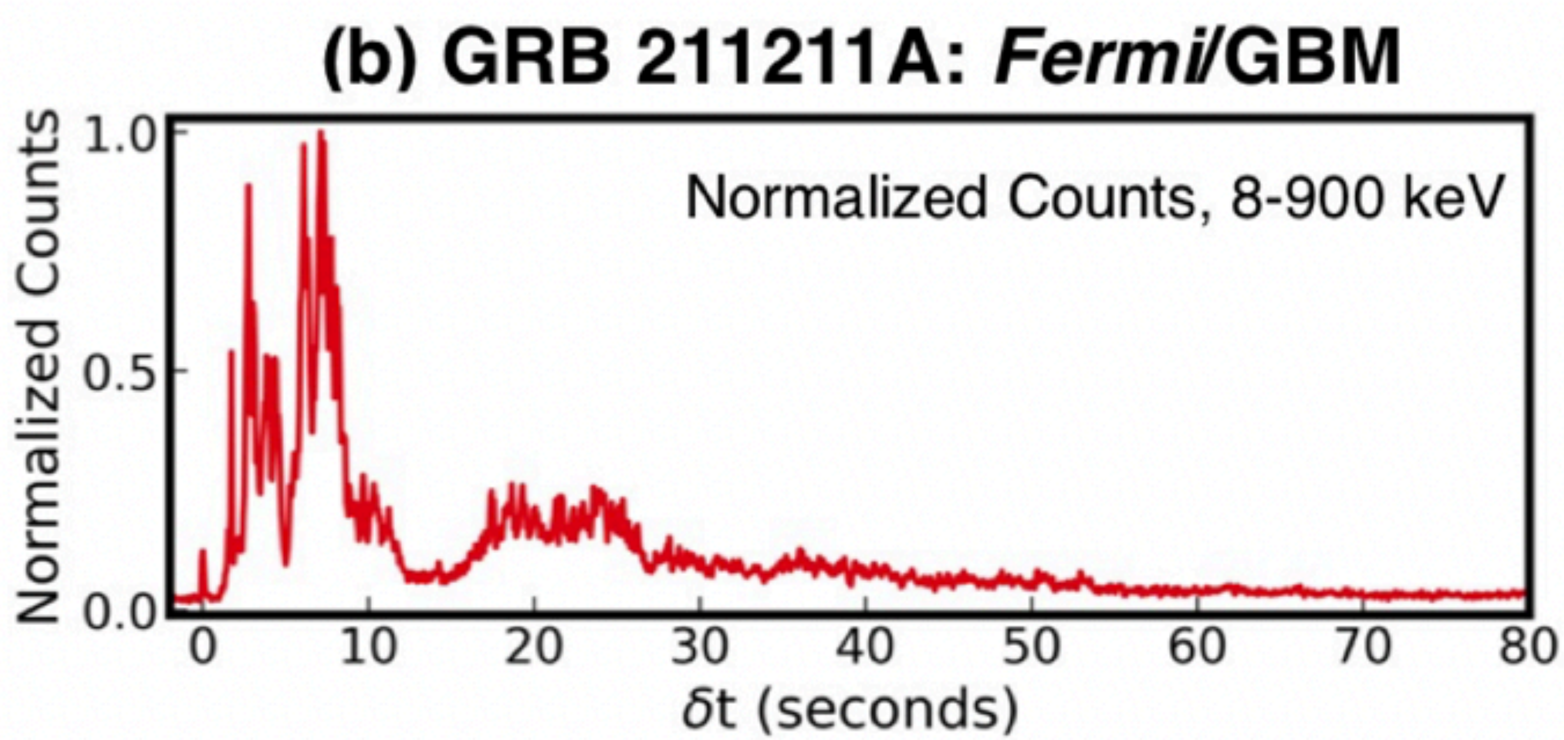


Rastinejad et al. 2022, Nature

Conclusions

- Duration vs hardness classification is not enough
- Contamination of collapsars vs mergers
- Emerging class of SNless long-duration GRBs

Possible steps for the offline analysis

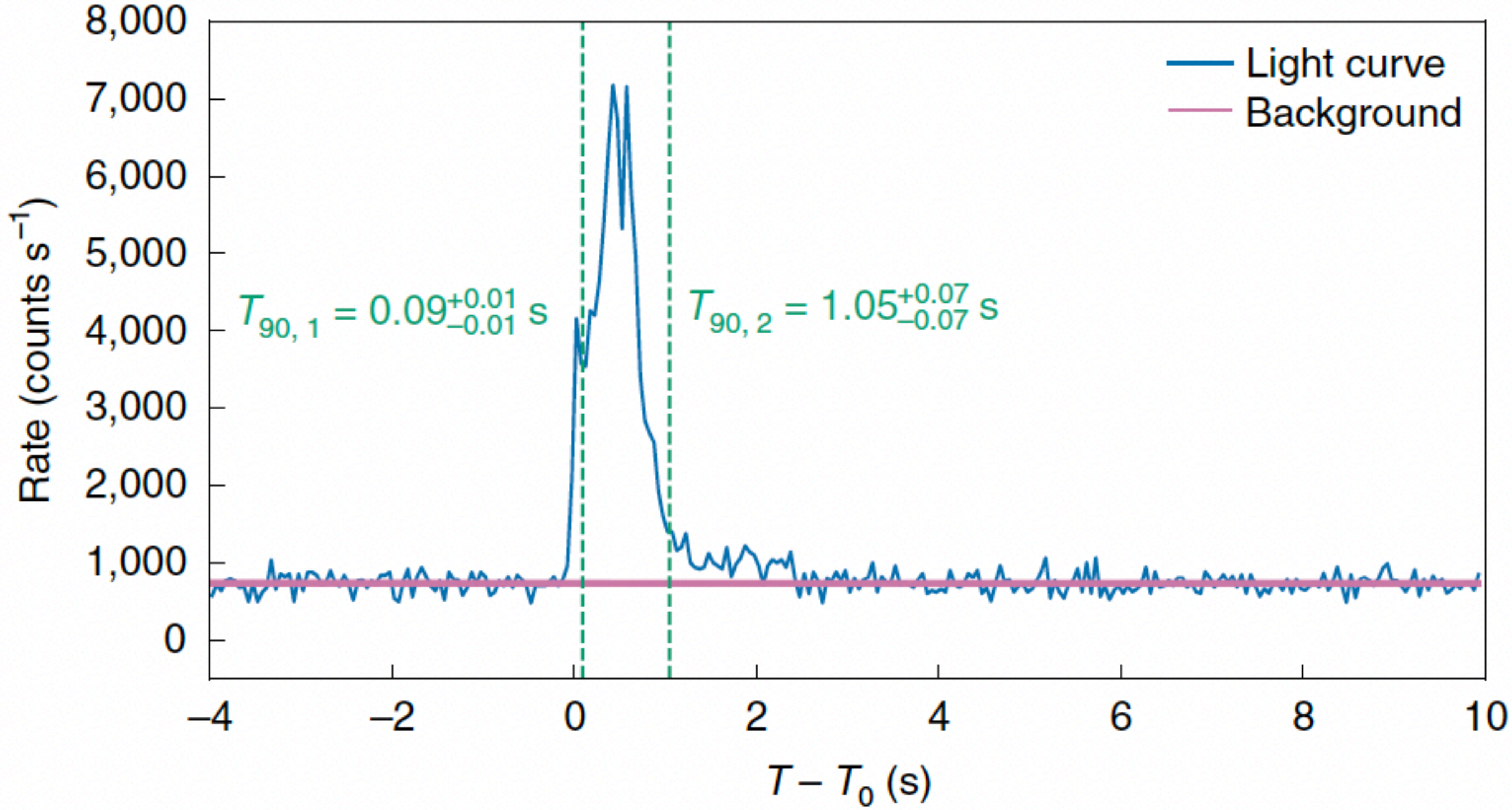
- Increase the sample of sGRBs beyond 2 s (Fermi/GBM)
- Caution on Swift/BAT GRBs
- Find an optimal duration cut (T90 vs T50)
- Fermi/LAT (100 MeV - 10 GeV) for late-time EM counterparts

Back up slides

Short but a collapsar

GRB 200826A

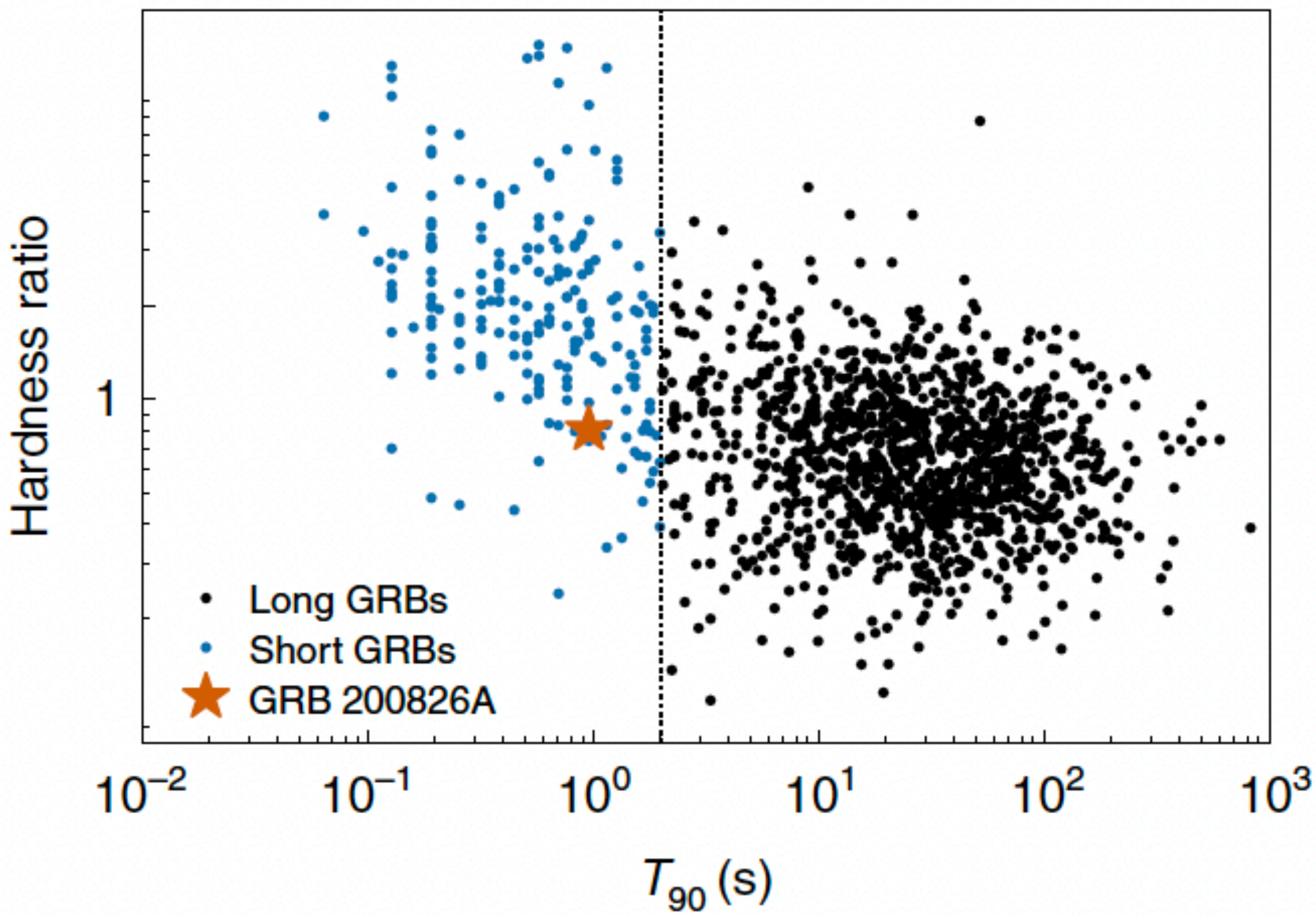
z=0.748



Zhang et al. 2021, Nature Astronomy

GRB 200826A

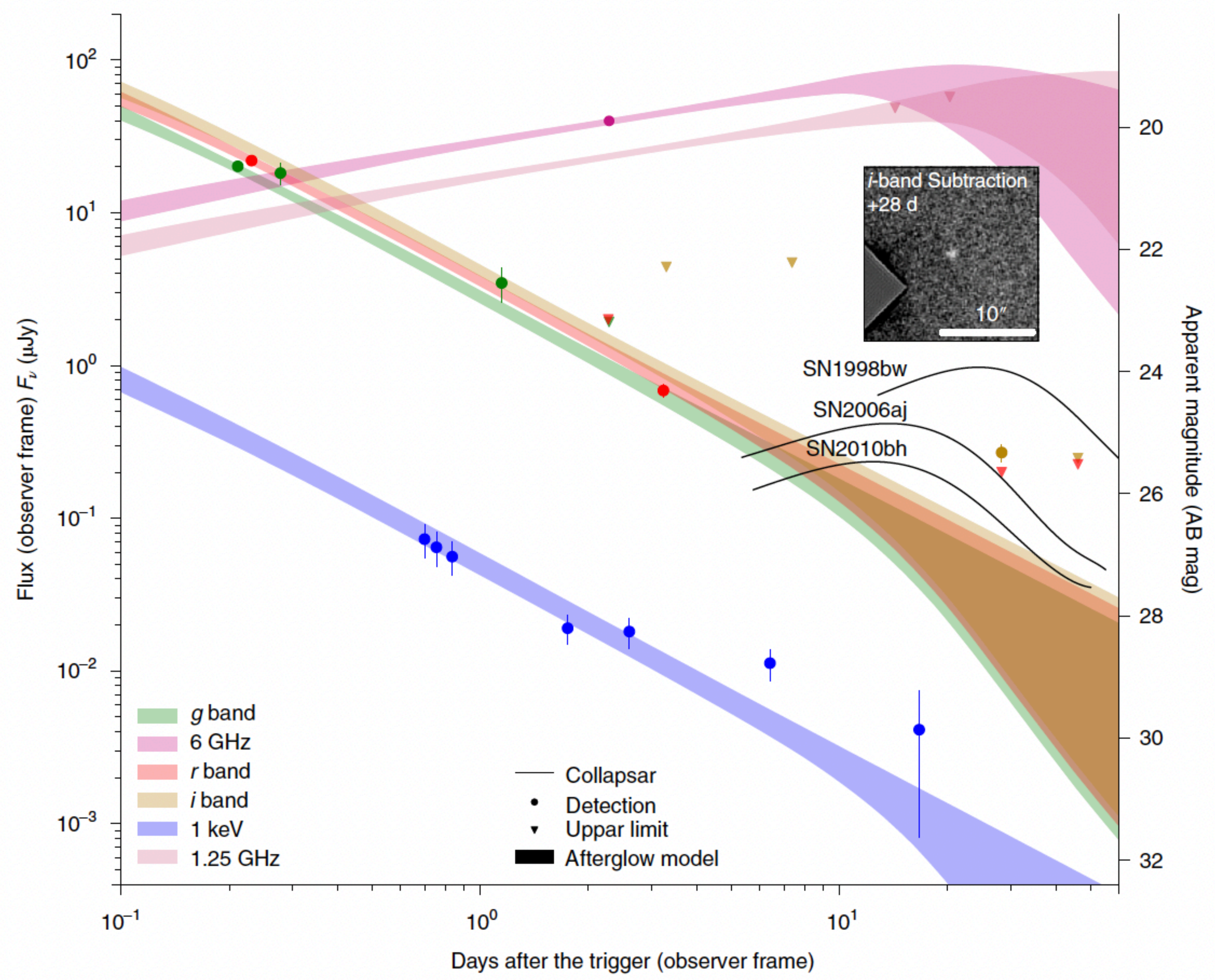
z=0.748



Zhang et al. 2021, Nature Astronomy

GRB 200826A

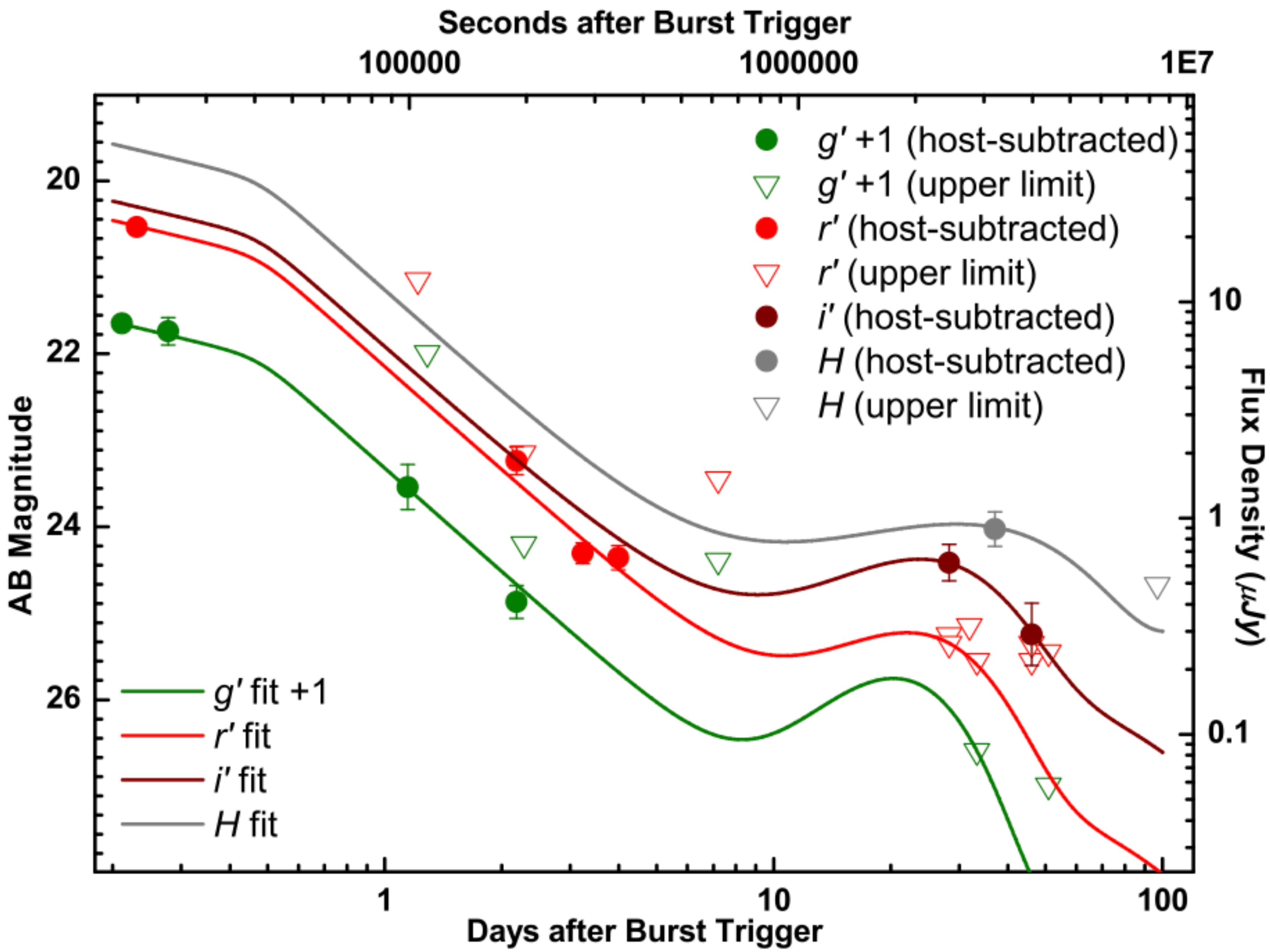
z=0.748



Ahumada et al. 2021, Nature Astronomy

GRB 200826A

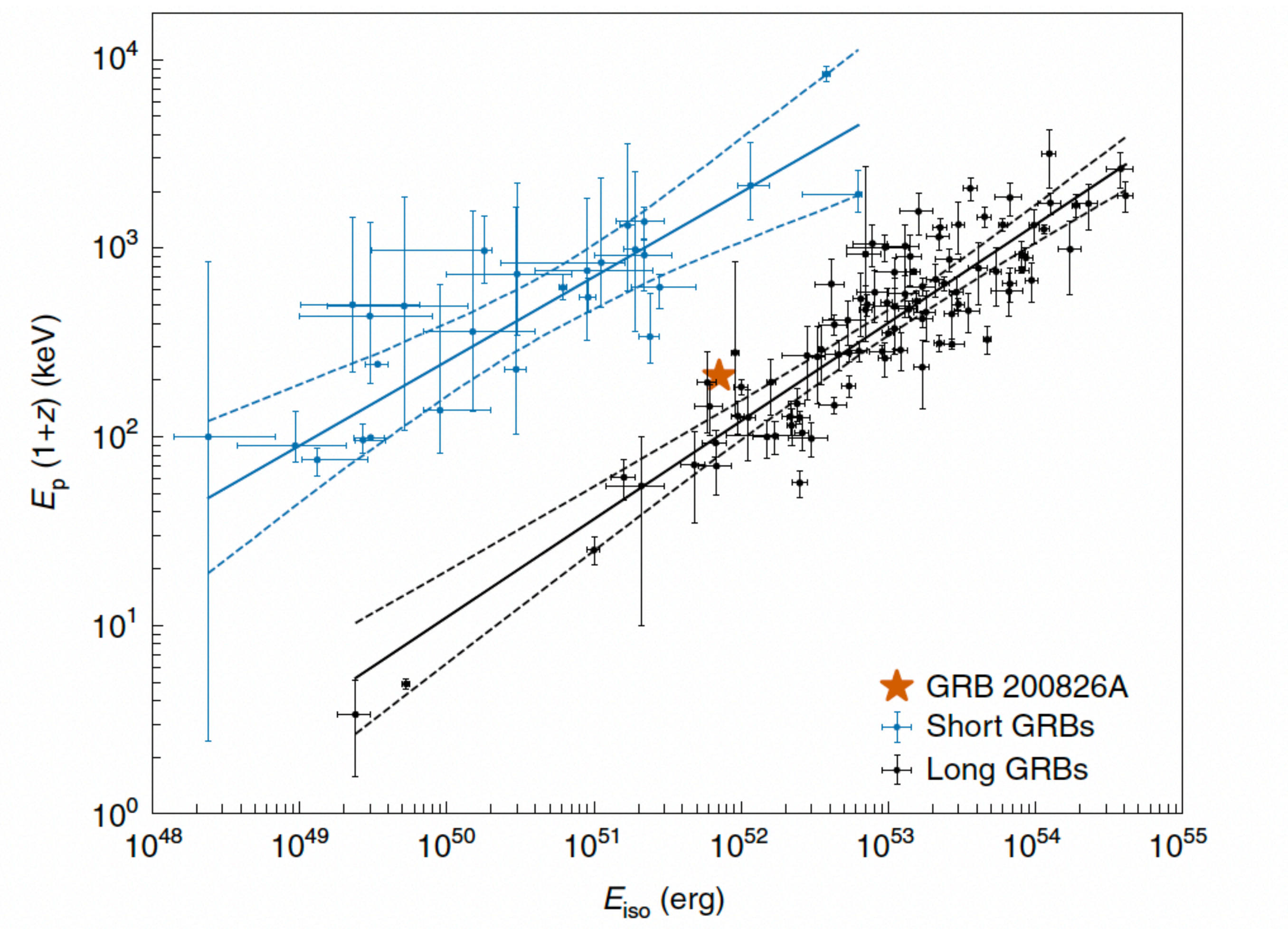
z=0.748



Rossi et al. 2022, A&A

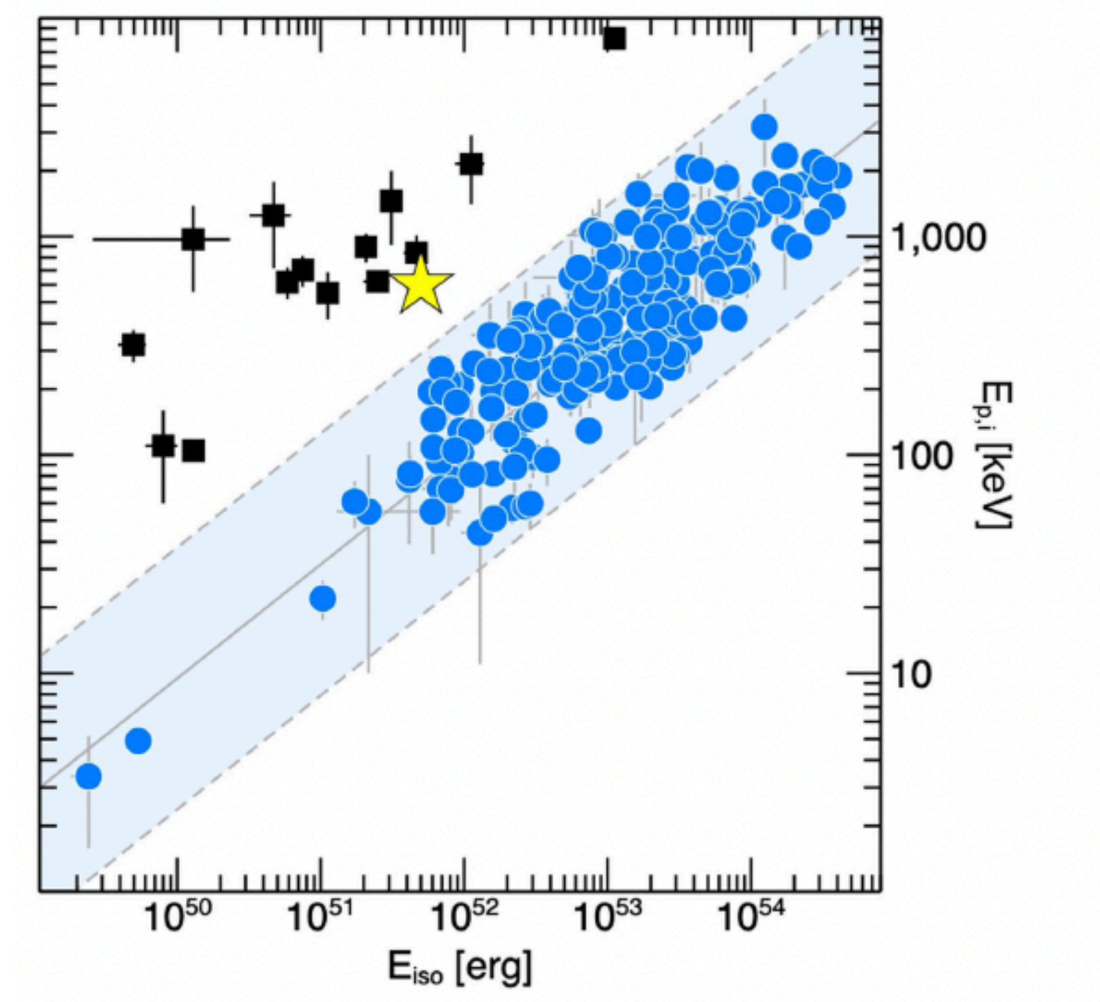
sGRBs vs lGRBs in the Amati relation

GRB 200826A



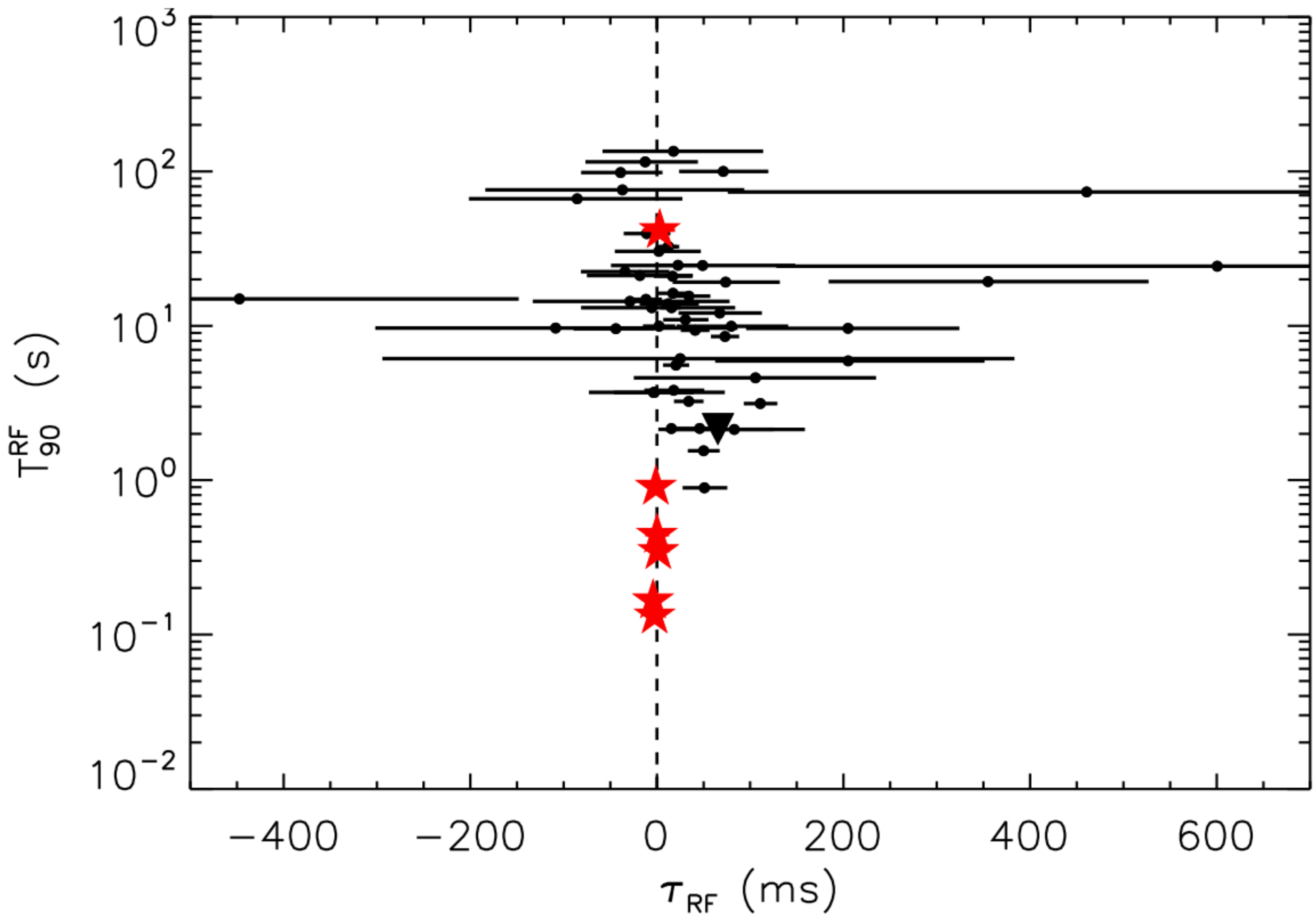
Zhang et al. 2021, Nature Astronomy

GRB 211211A



Troja et al. 2022, Nature

Spectral lags in sGRBs vs lGRBs



Bernardini et al. 2015, MNRAS