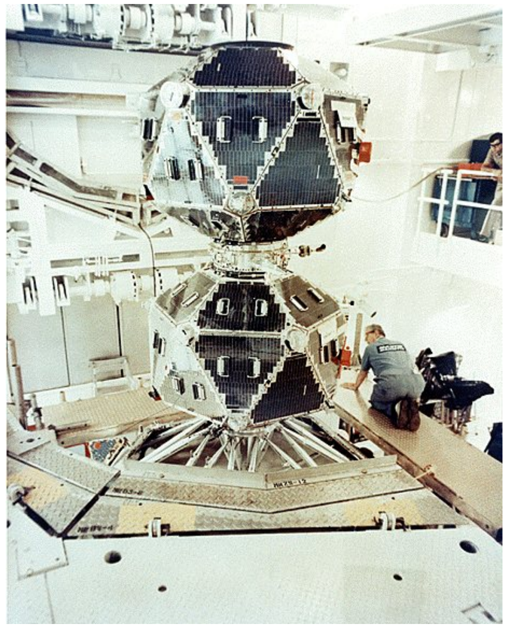
How much do we really know about γ-ray bursts?

Gor Oganesyan

19 February 2024 - IFPU

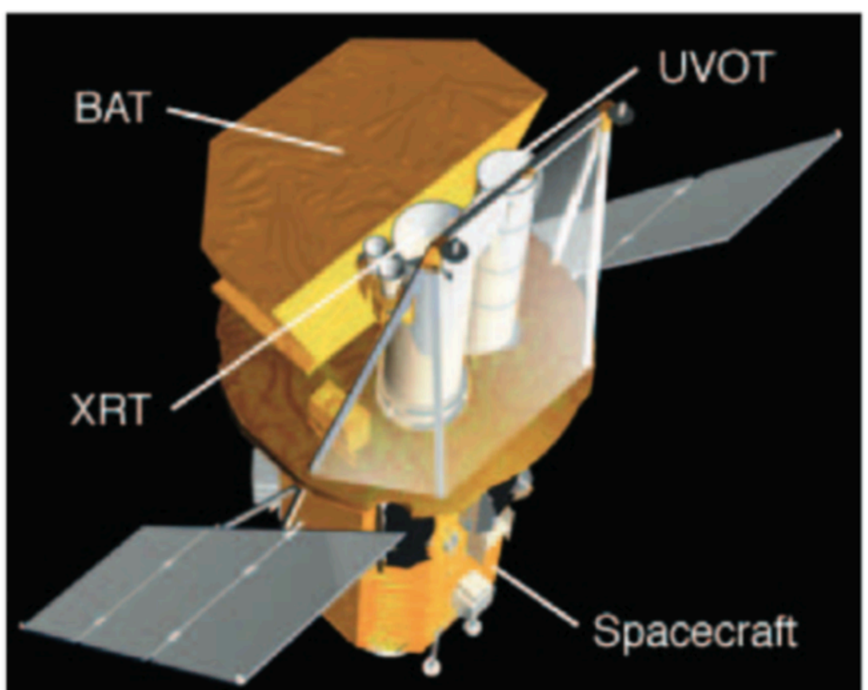
Vela satellites
1963 - 1970

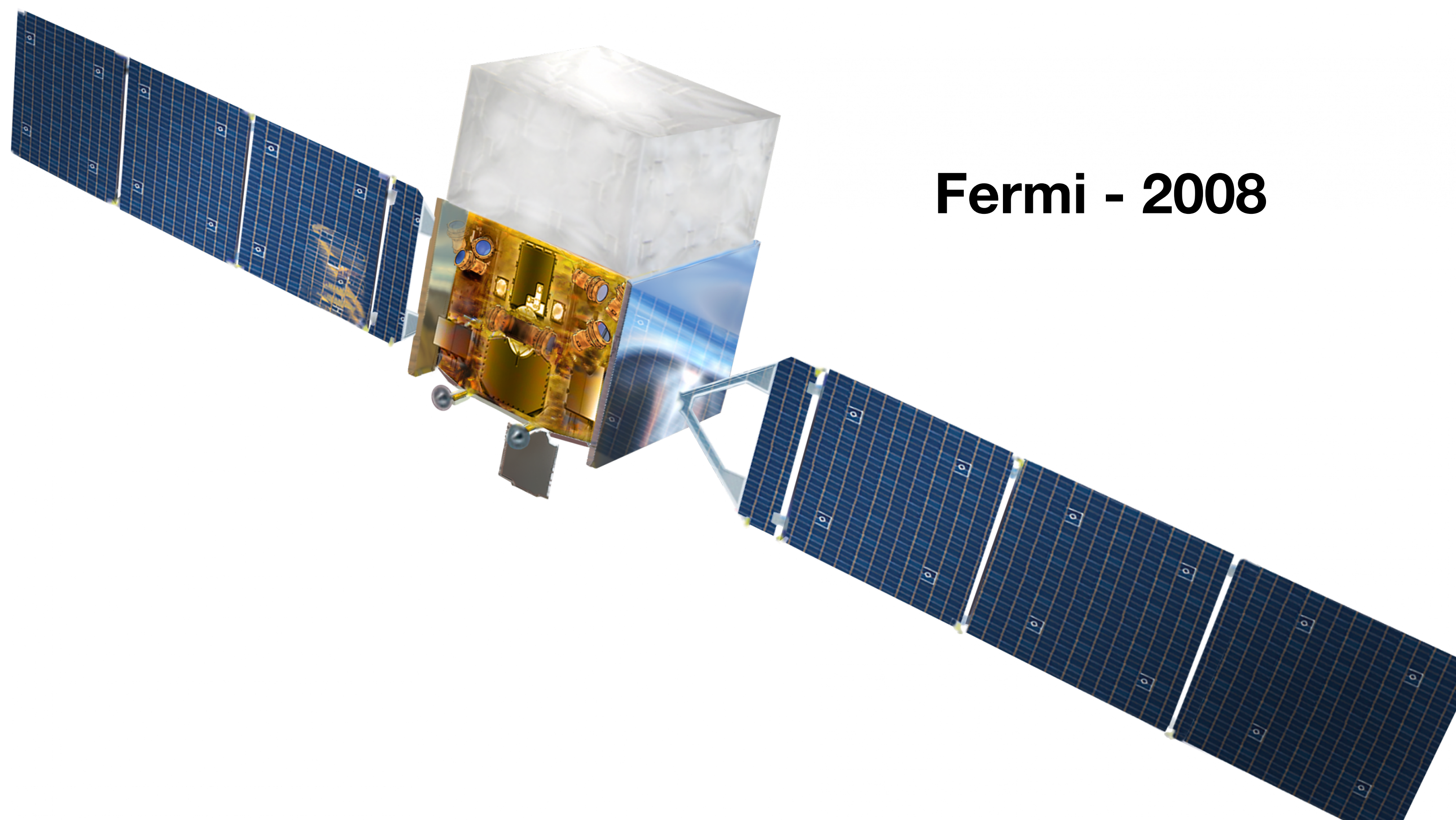


BATSE - 1991
20 keV - 2 MeV

BeppoSAX - 1992

Swift - 2004

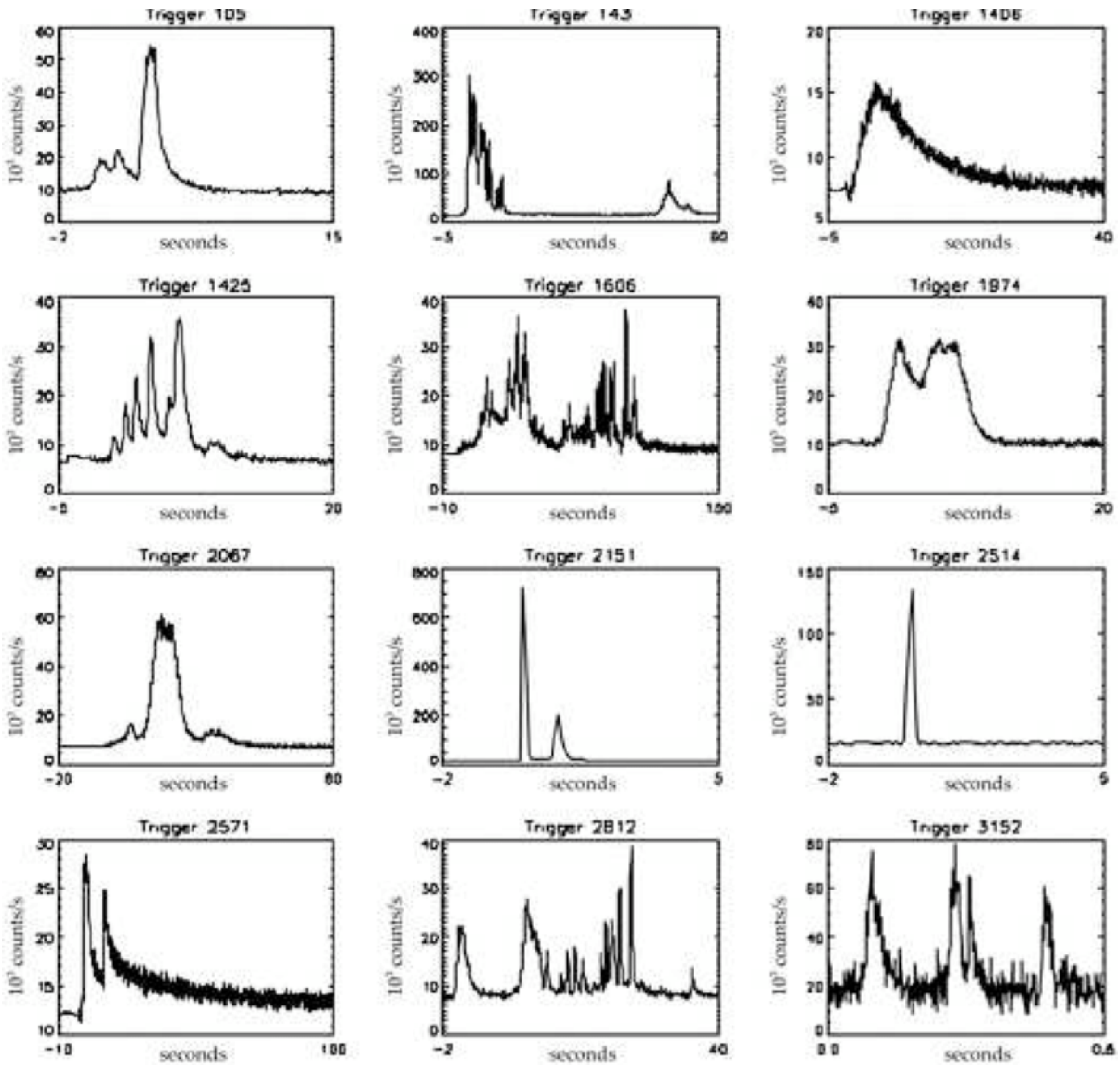




Fermi - 2008

γ-ray bursts

Time



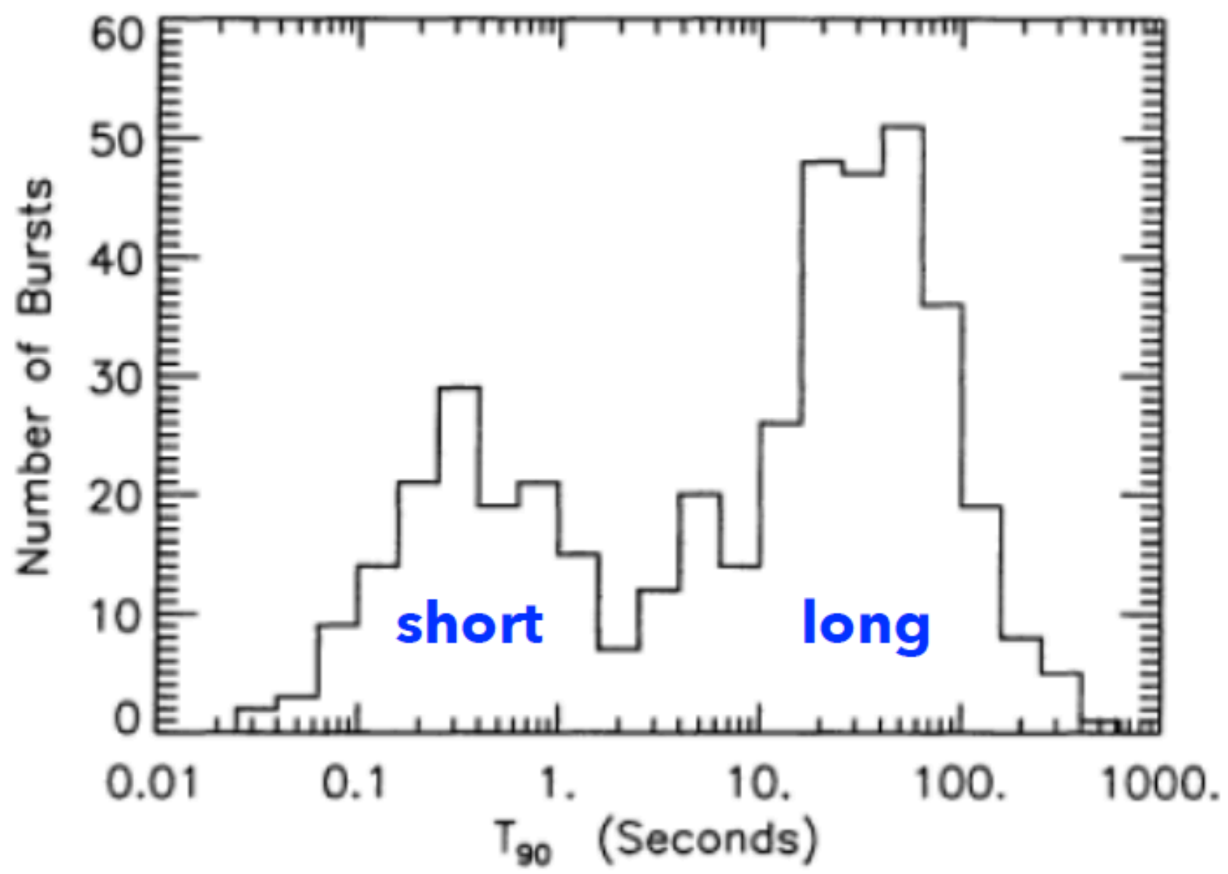
observed at keV - MeV

variability $\sim 10^{-2}$ s

duration $10^{-3} - 10^{3}$ s

γ-ray bursts

Duration

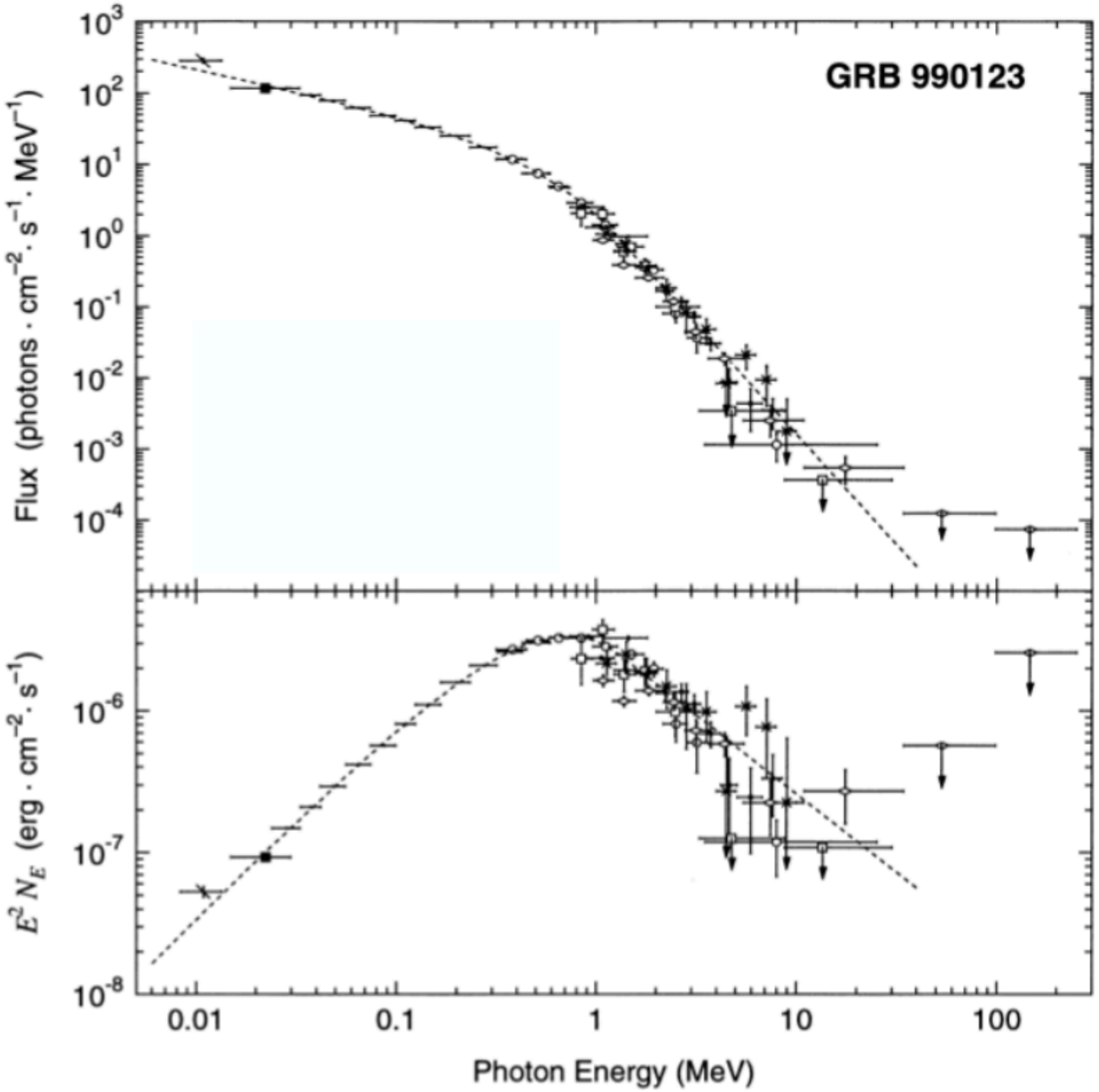


short (<2 s) and long (>2 s)

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

γ-ray bursts

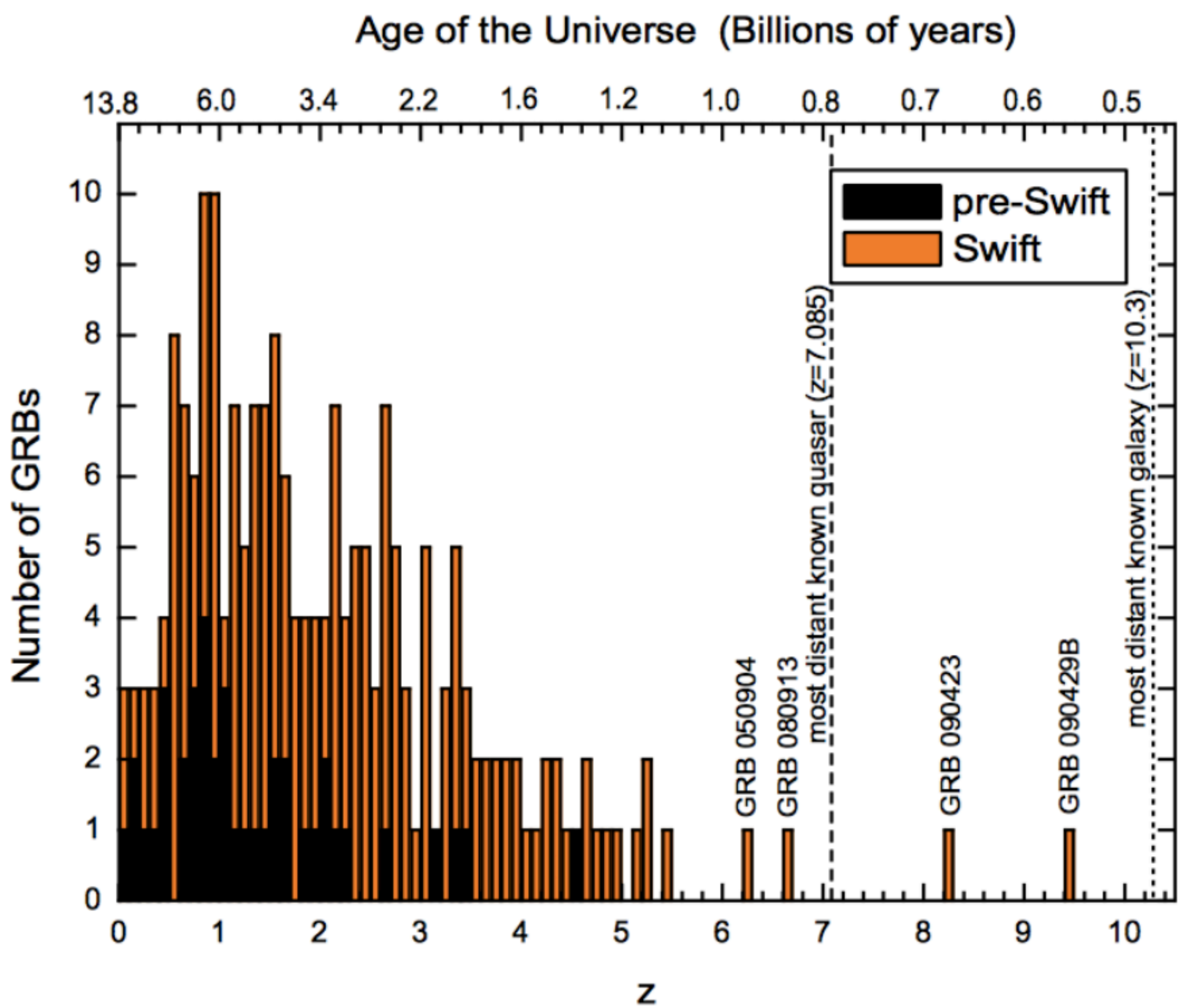
Spectrum



Briggs et al. 1999

γ-ray bursts

Distance



A. Gomboc 2012

$$< z > \sim 2$$

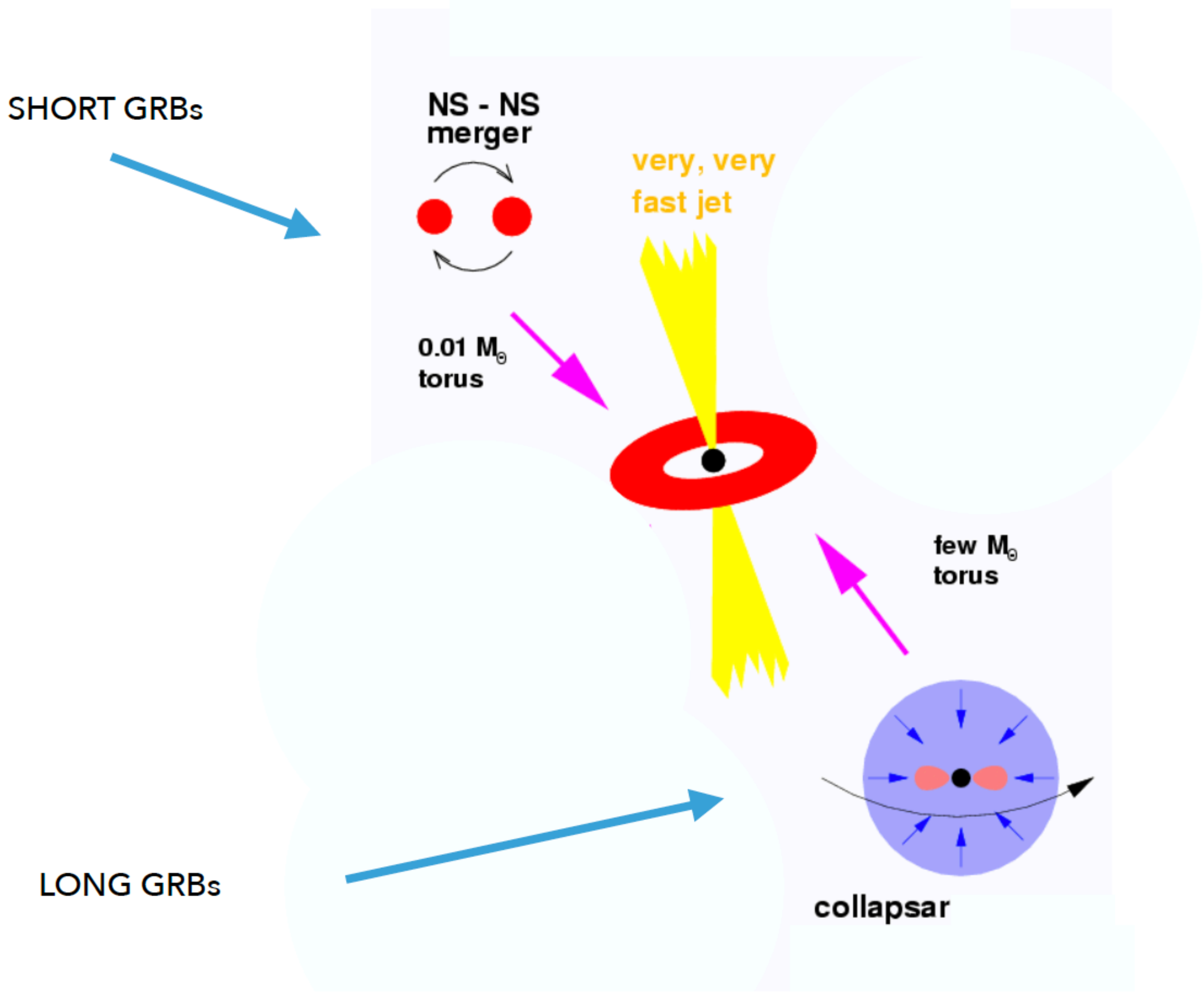
fluence

$$\sim 10^{-6}\,\mathrm{erg\,cm^{-2}}$$

$$E_{iso} \sim 10^{52}\,\mathrm{erg}$$

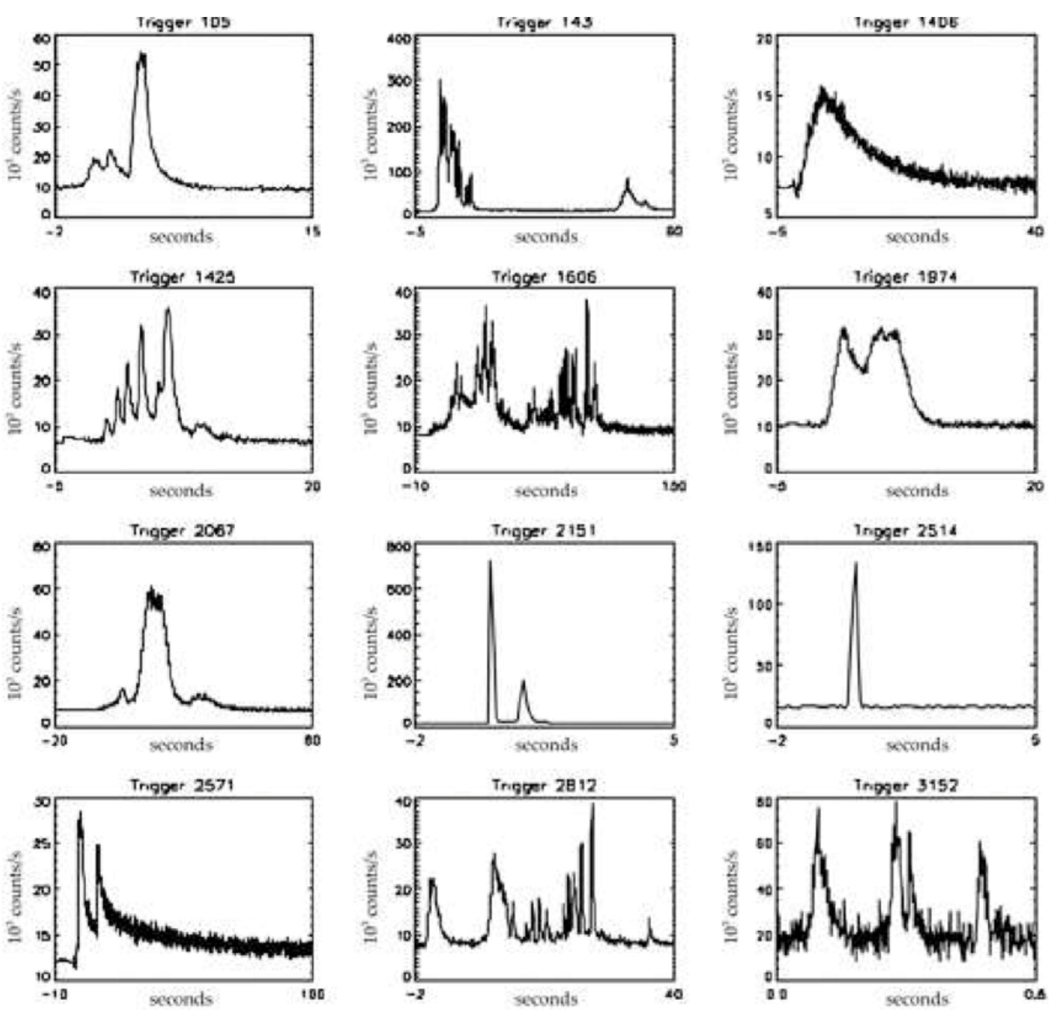
γ-ray bursts

Source

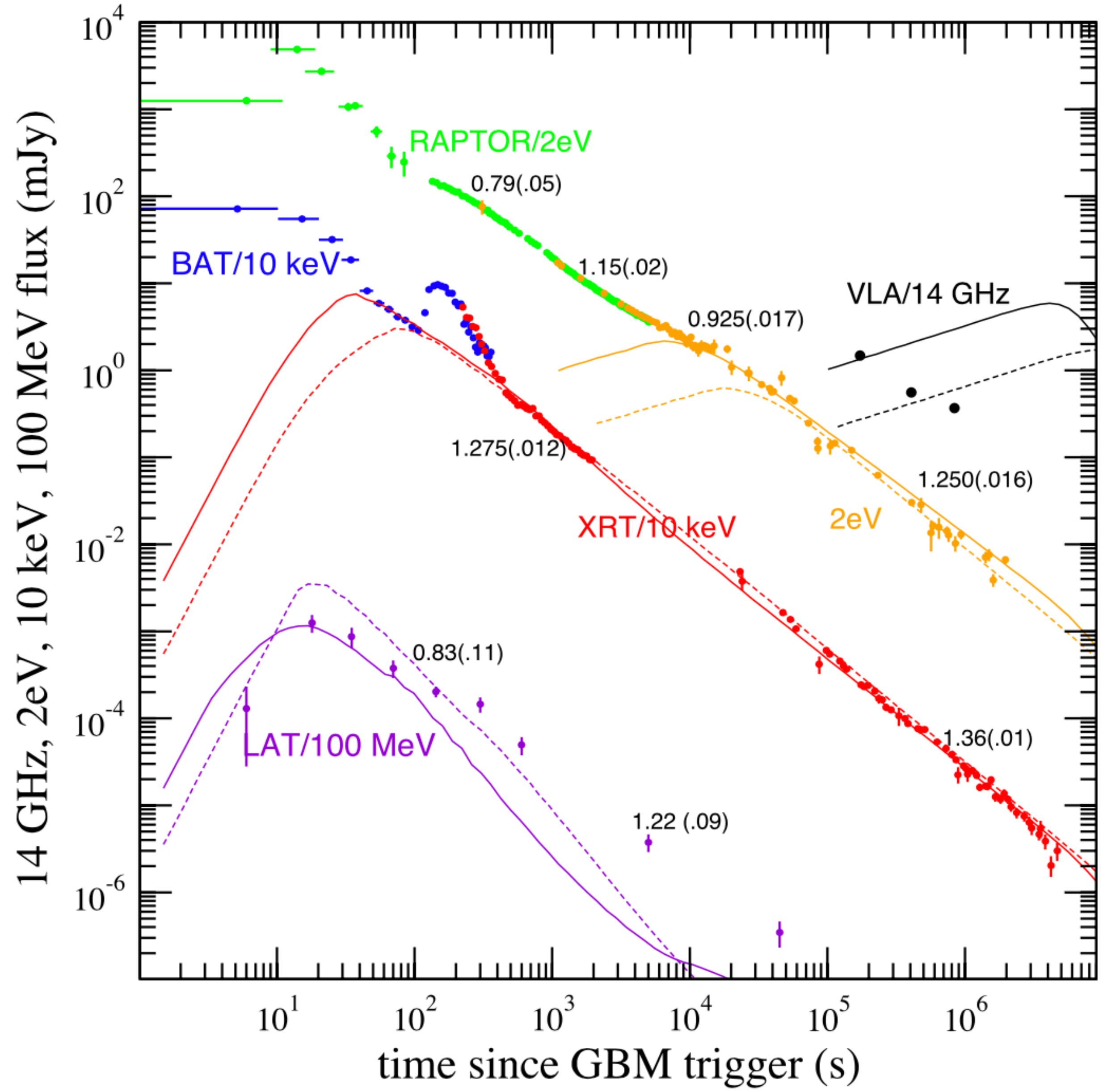


γ-ray bursts

Prompt emission

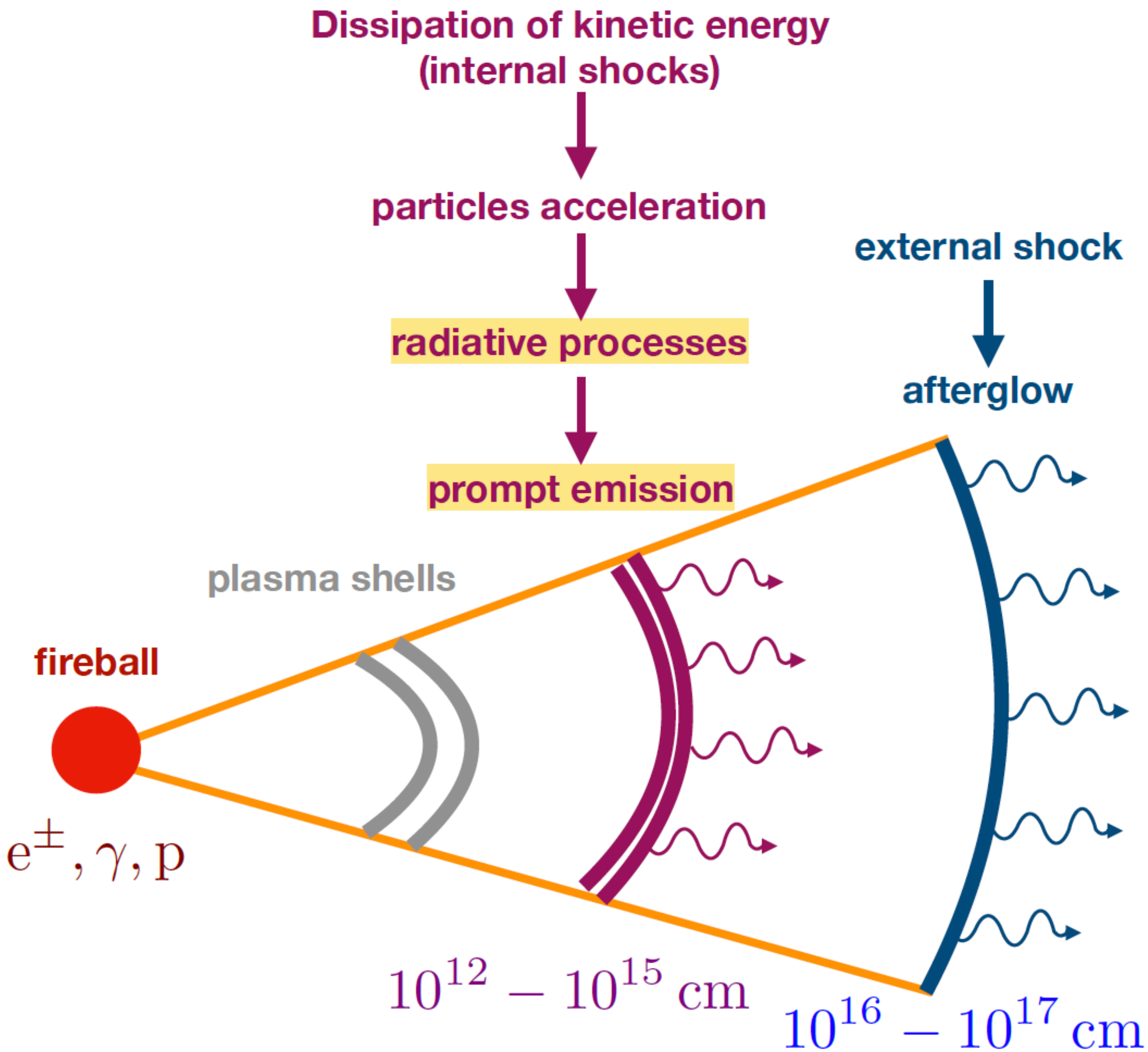


Afterglow

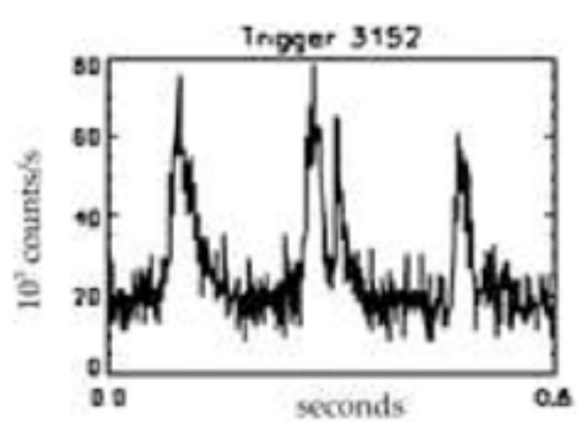


Panaitescu et al. 2013

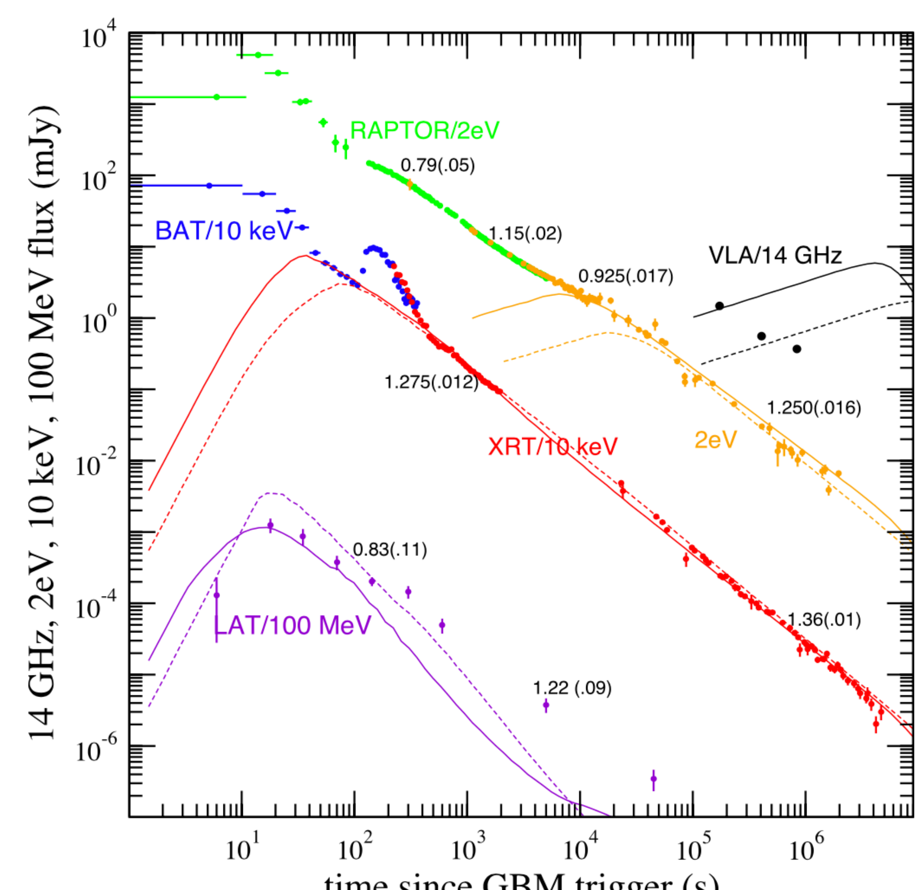
The model



Dissipation of kinetic energy
(internal shocks)
particles acceleration
radiative processes
prompt emission
external shock
afterglow
plasma shells
fireball
$e^{\pm}, \gamma, p$
$10^{12} - 10^{15}$ cm
$10^{16} - 10^{17}$ cm

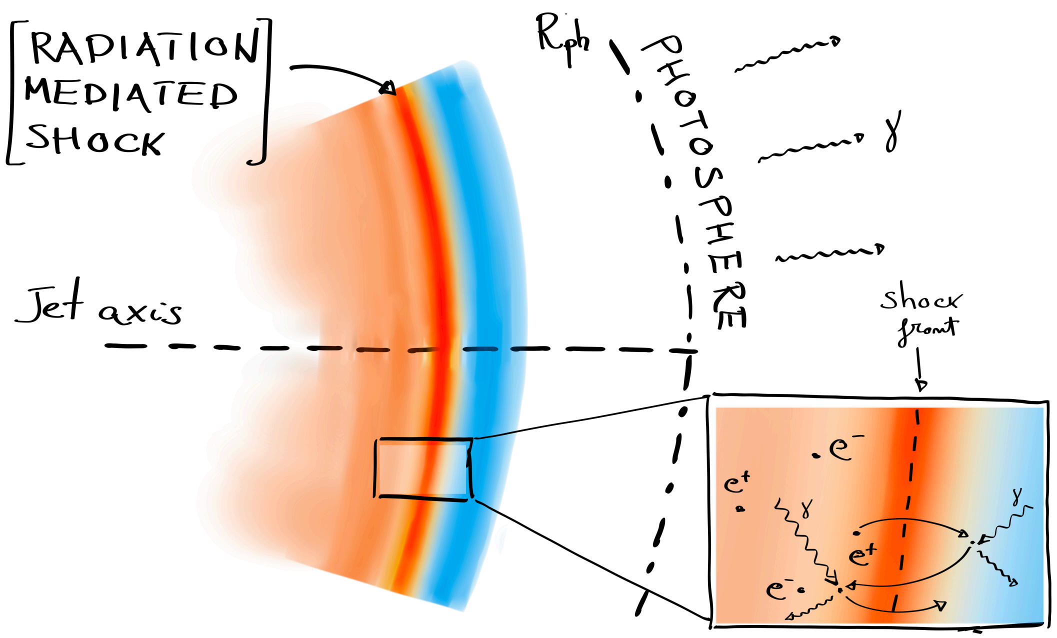


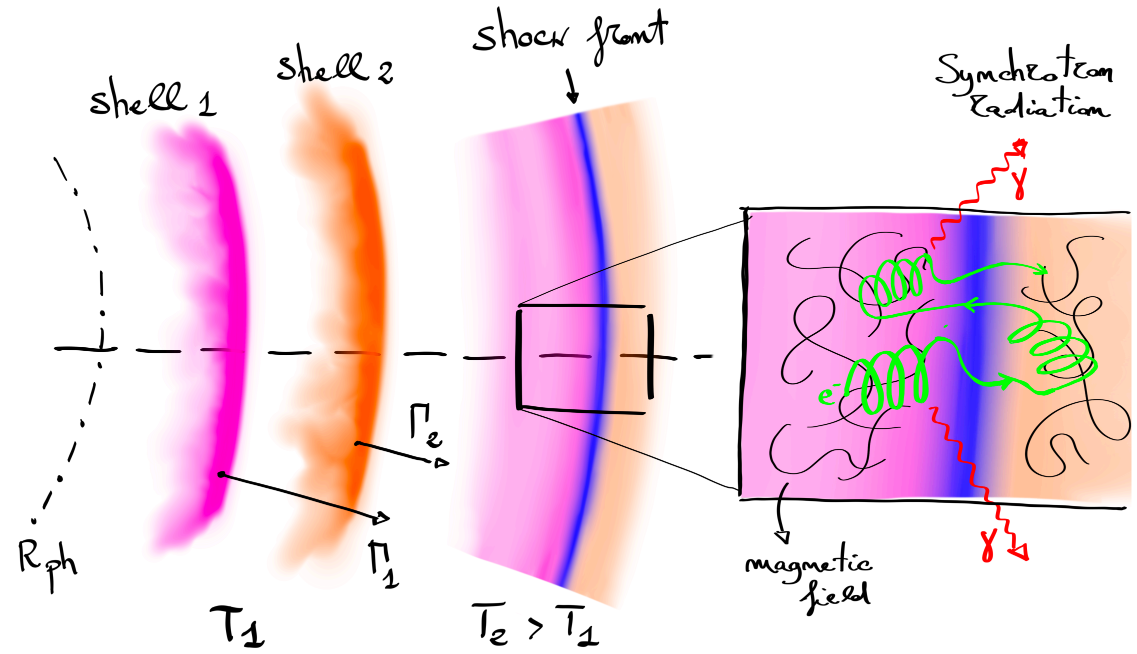
Trigger 3152
seconds

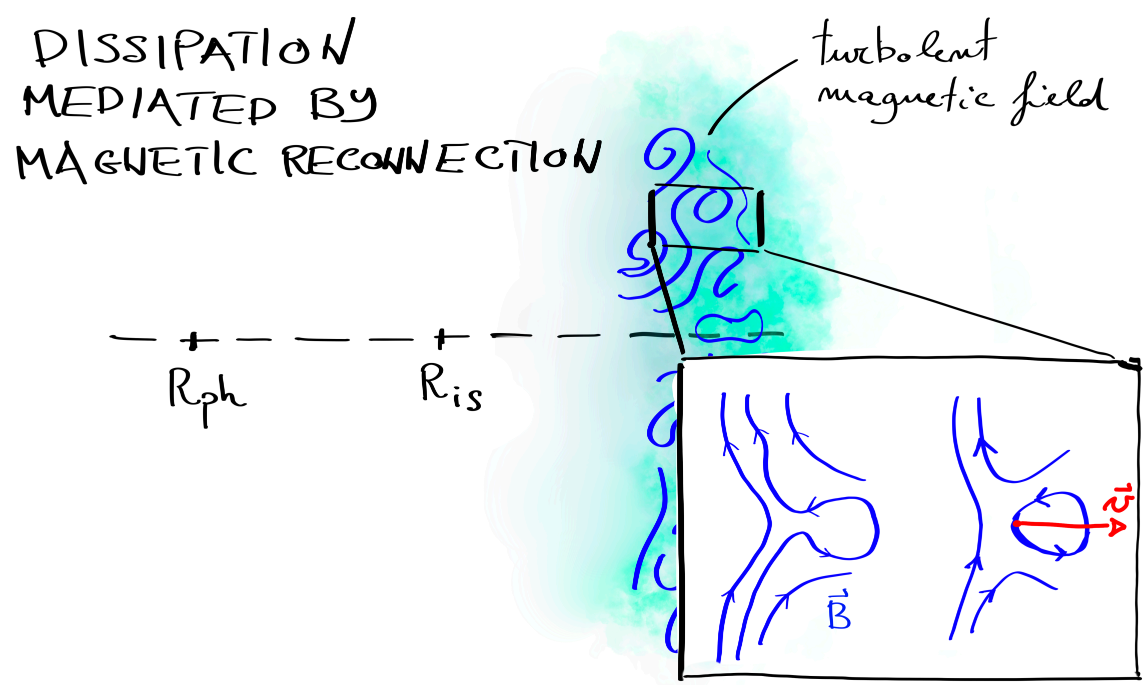


RAPTOR/2eV
0.79(.05)
BAT/10 keV
1.15(.02)
0.925(.017)
VLA/14 GHz
1.275(.012)
1.250(.016)
XRT/10 keV
2eV
0.83(.11)
LAT/100 MeV
1.36(.01)
1.22 (.09)
14 GHz, 2eV, 10 keV, 100 MeV flux (mJy)
time since GBM trigger (s)

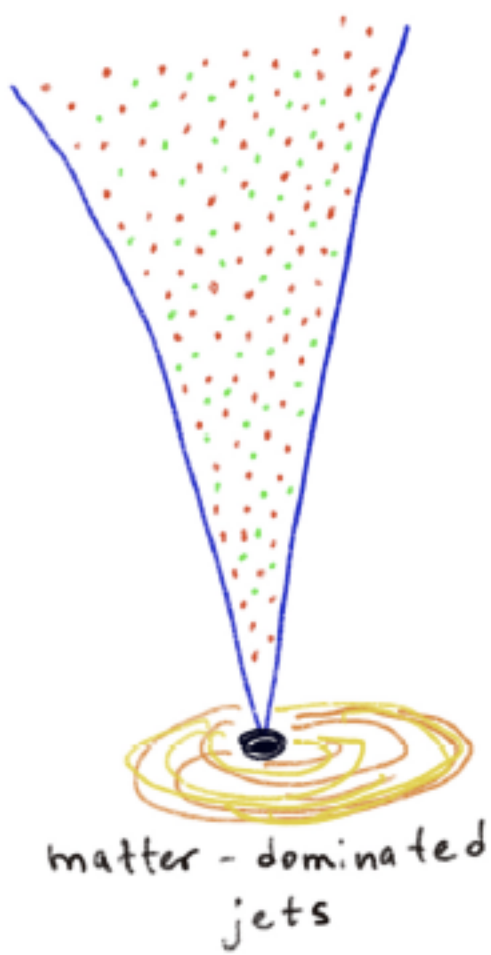
Open questions



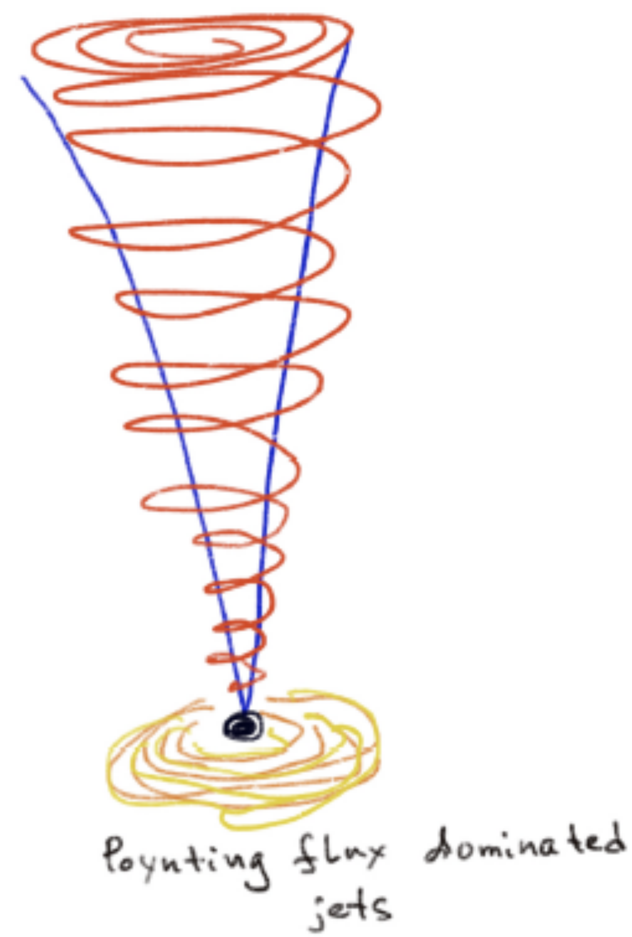




Open questions



Cavallo & Rees 1978
Paczýnski 1986
Goodman 1986
Shemi & Piran 1990



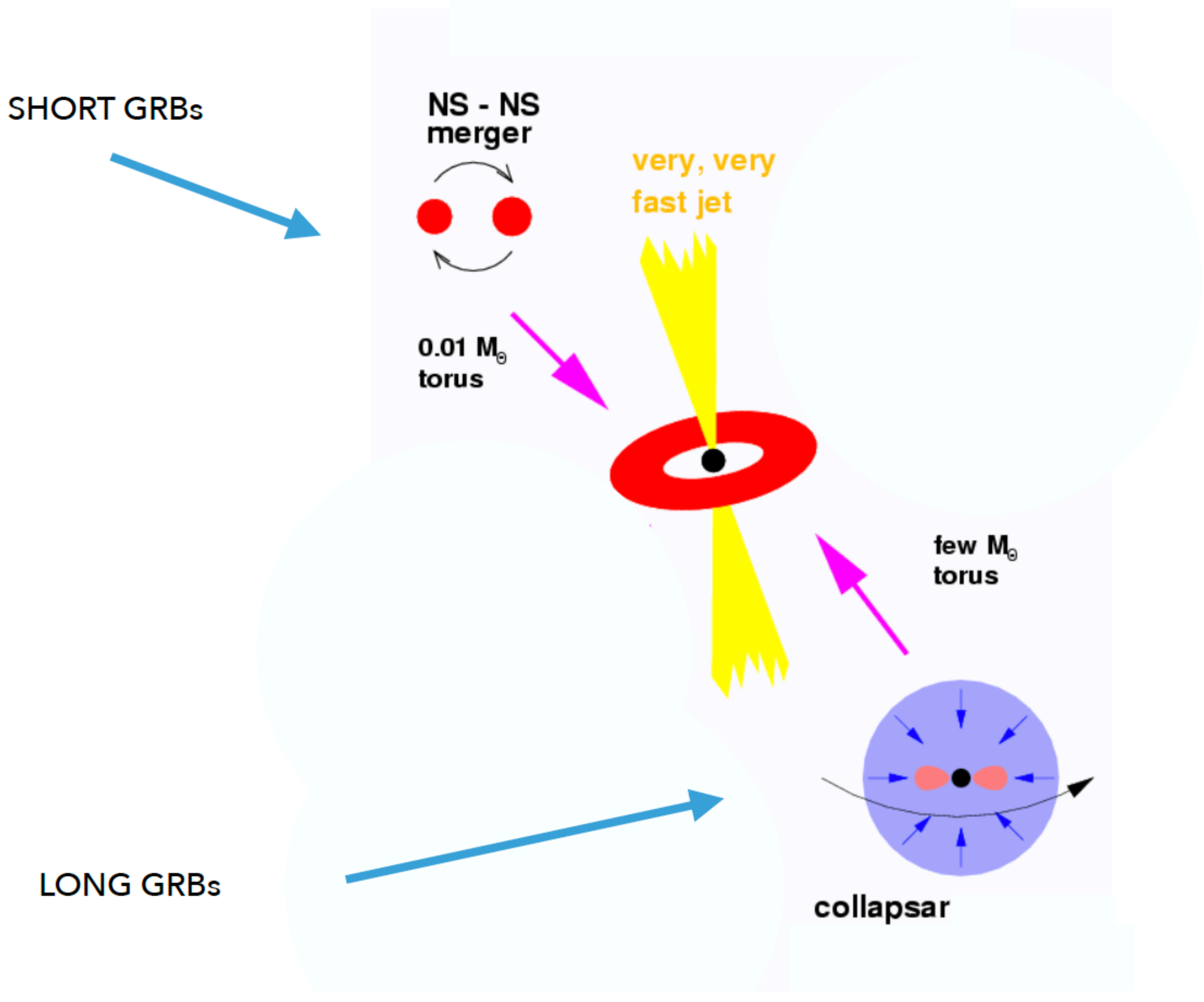
Usov 1992
Thompson 1994
Mészáros & Rees 1997
Lyutikov & Blandford 2003

γ-ray bursts

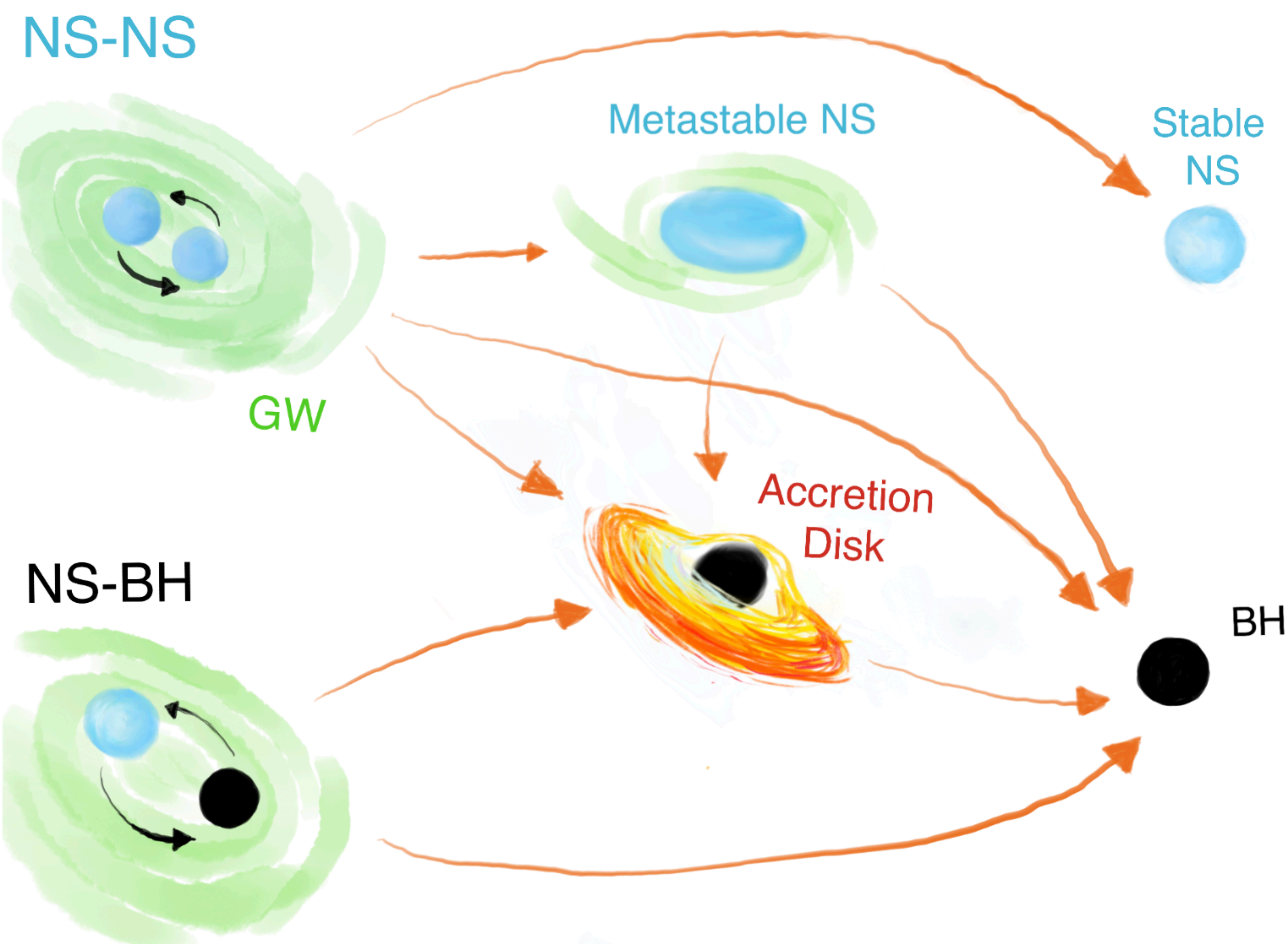
discovery	dark ages	afterglow era	multi-wavelength era	multi-messenger era
1967	1970-1990	1997 - …	2004 - …	2017 - …

γ-ray bursts

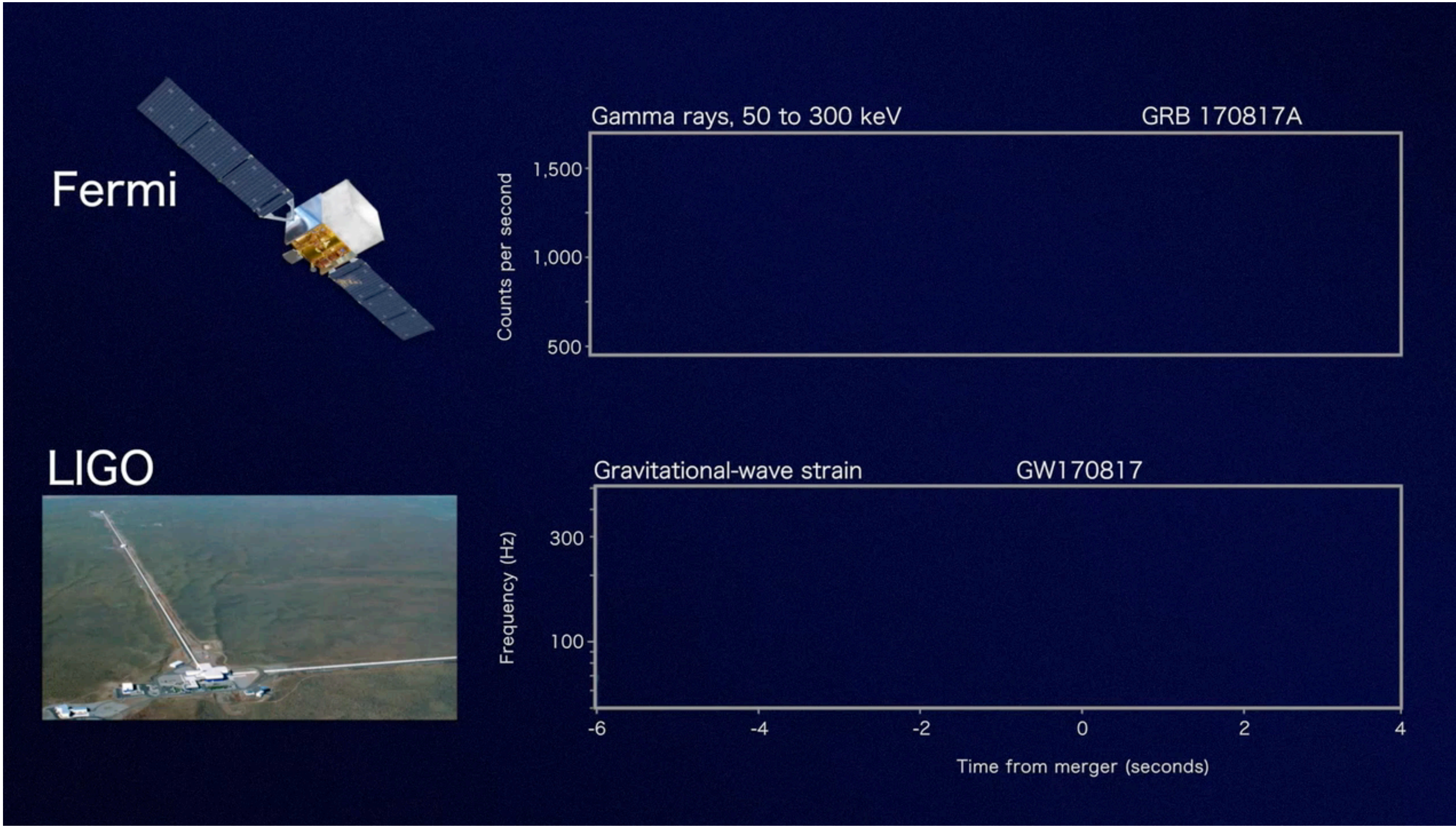
Source



Compact Binaries Coalescence
(NS+NS and NS+BH)



stolen from Stefano Ascenzi's drawings catalog


Fermi
LIGO
Gamma rays, 50 to 300 keV
GRB 170817A
Counts per second
1,500
1,000
500
Gravitational-wave strain
GW170817
Frequency (Hz)
300
100
-6
-4
-2
0
2
4
Time from merger (seconds)

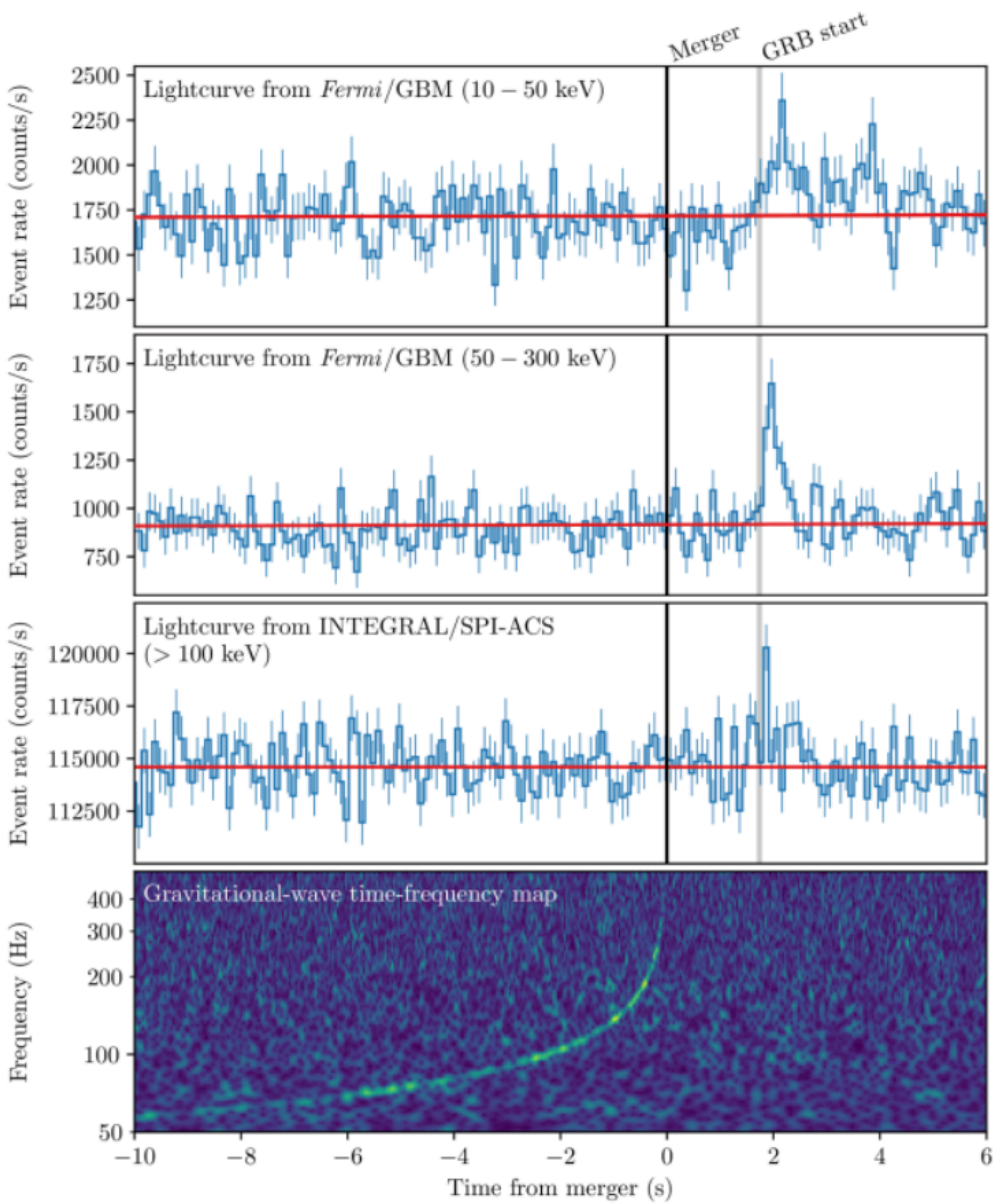
Compact Binaries Coalescence
(NS+NS and NS+BH)

observations - GWs and the GRB

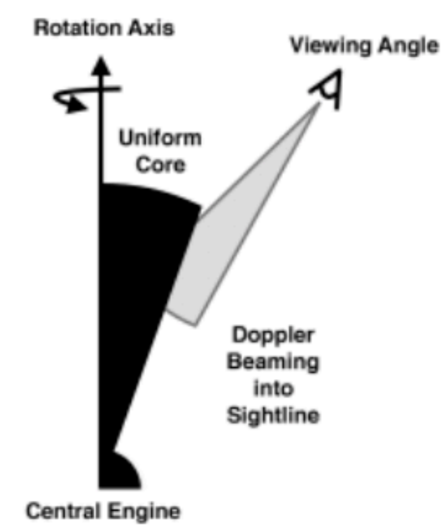
Lipunov et al. 2001; Dai & Gou 2001; Rossi et al. 2002; Zhang & Meszaros 2002

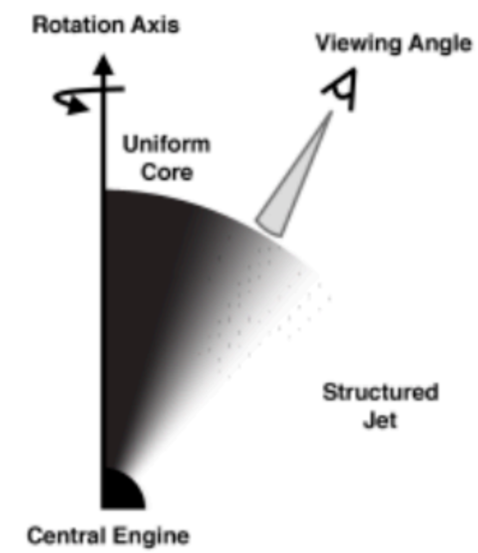
What is it?

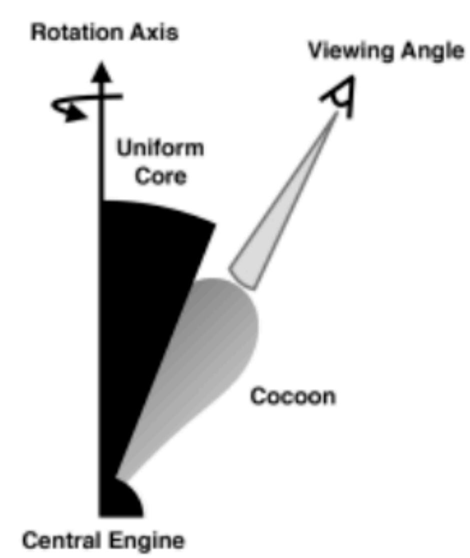
GRB 170817/GW 170817



Abbott et al. 2017





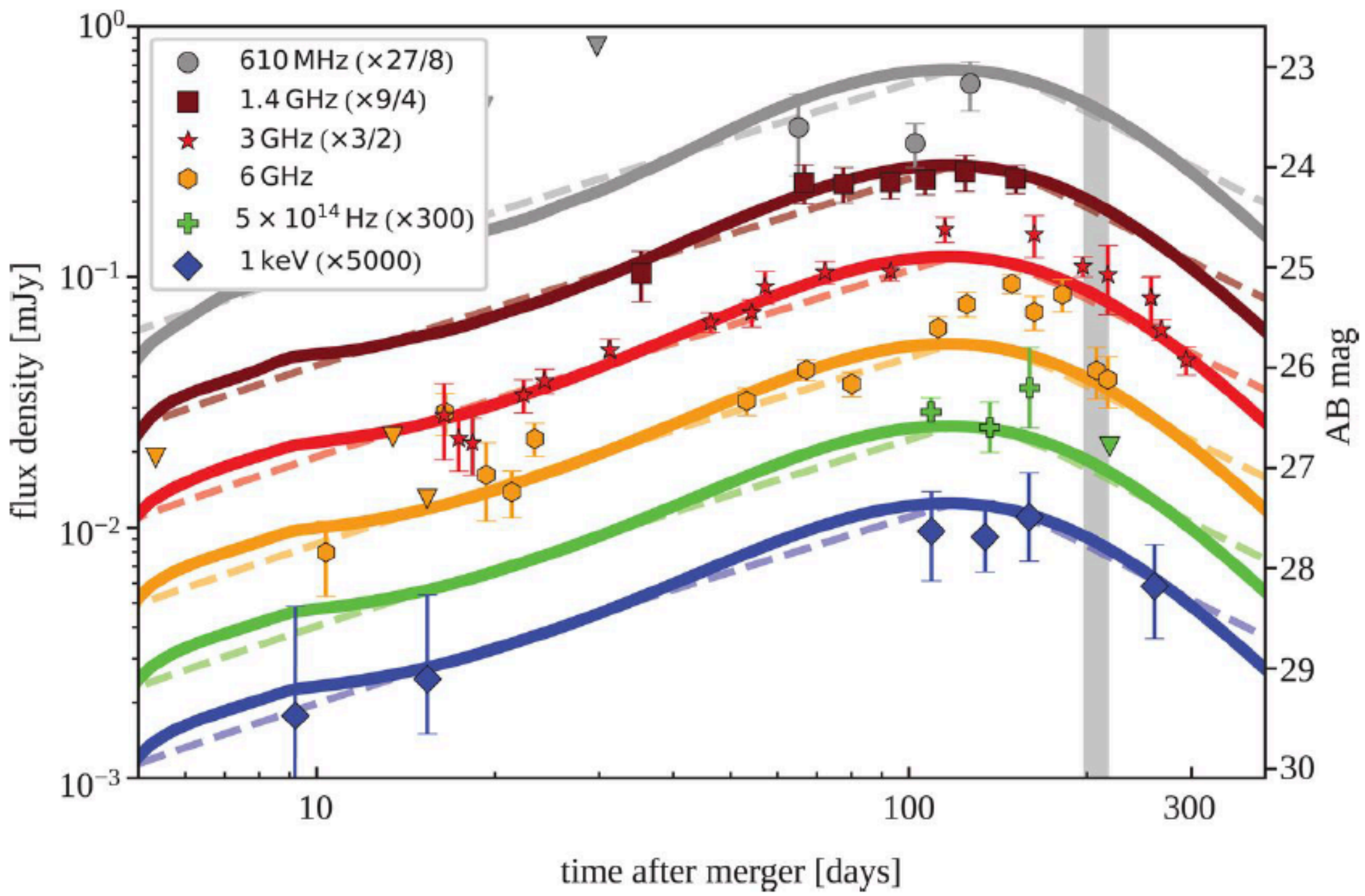


Kasliwal et al. 2017
Ioka&Nakamura 2018
Salafia et al. 2018
Lazzati 2018
Bromberg et al. 2018
Matsumoto et al 2018
....

observations - the off-axis afterglow

GRB 170817/GW 170817

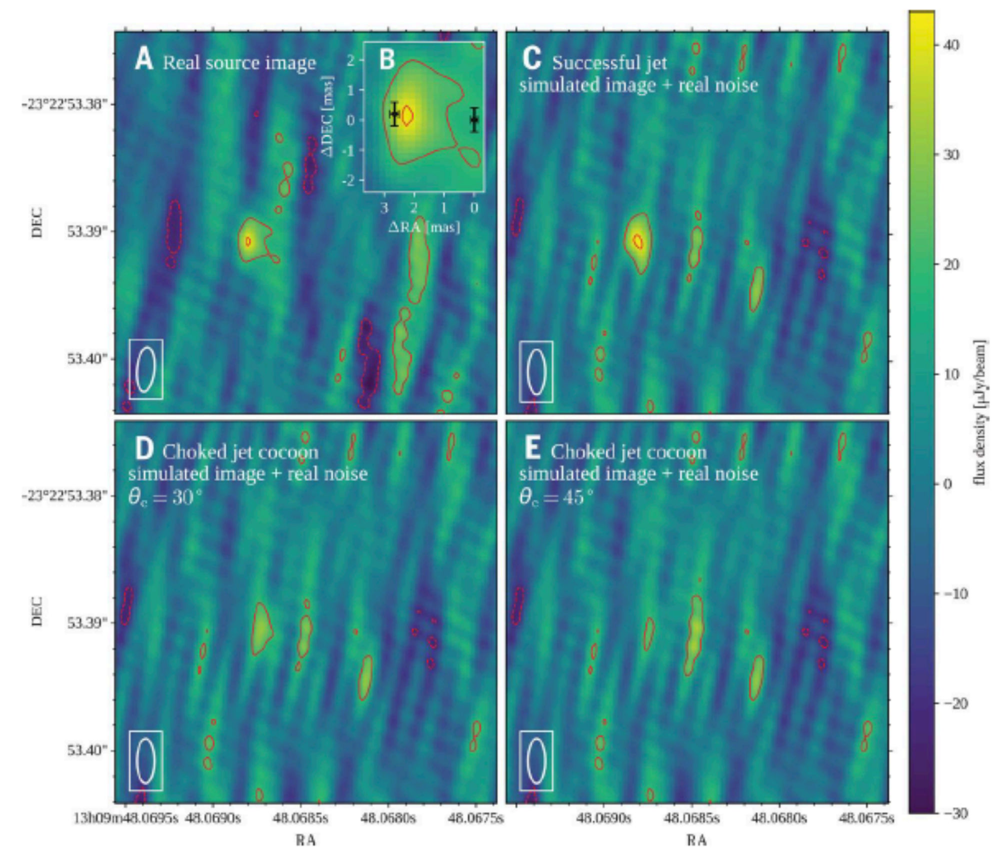
multi-wavelength LCs of the afterglow



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

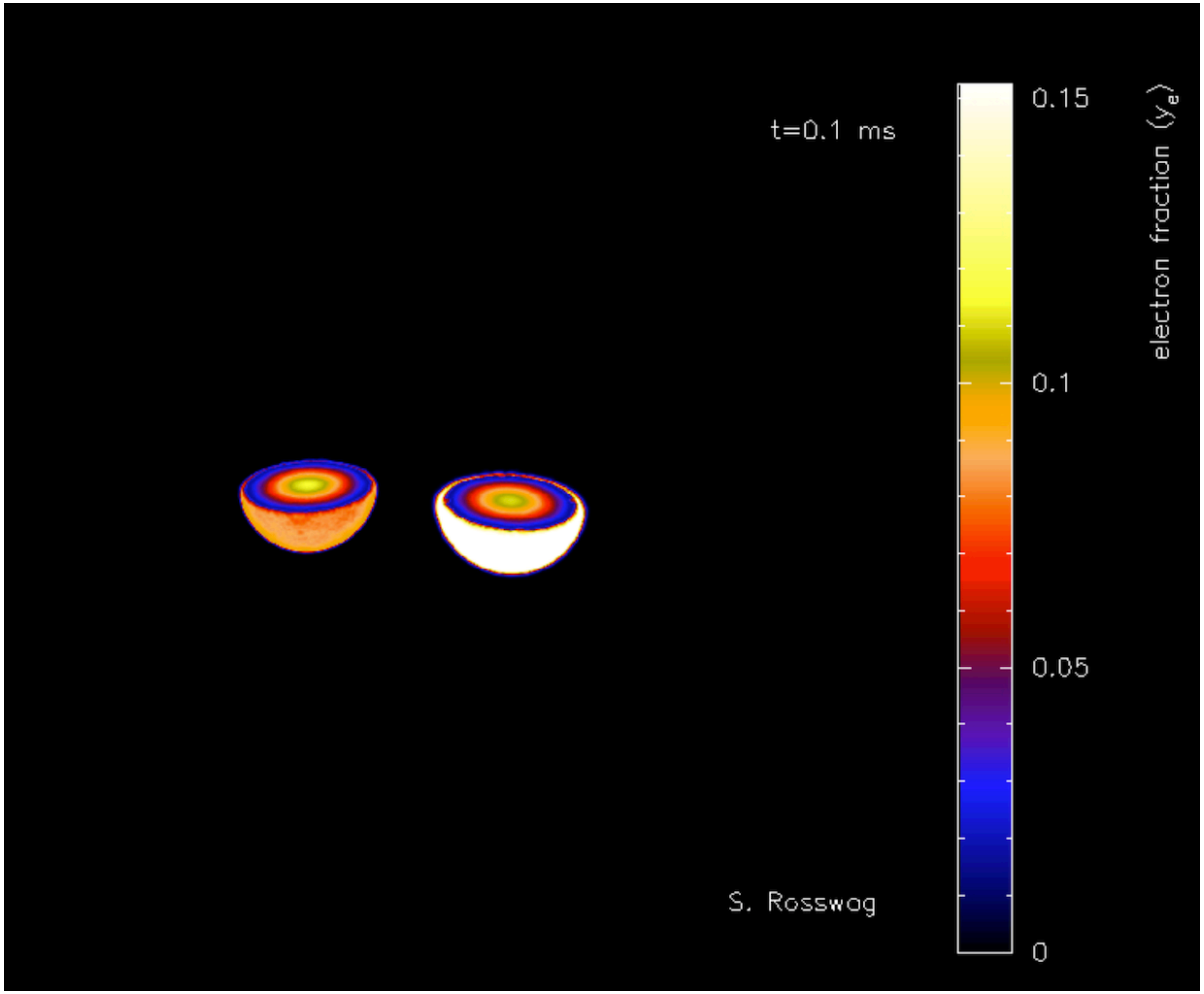
Ghirlanda et al. 2019

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



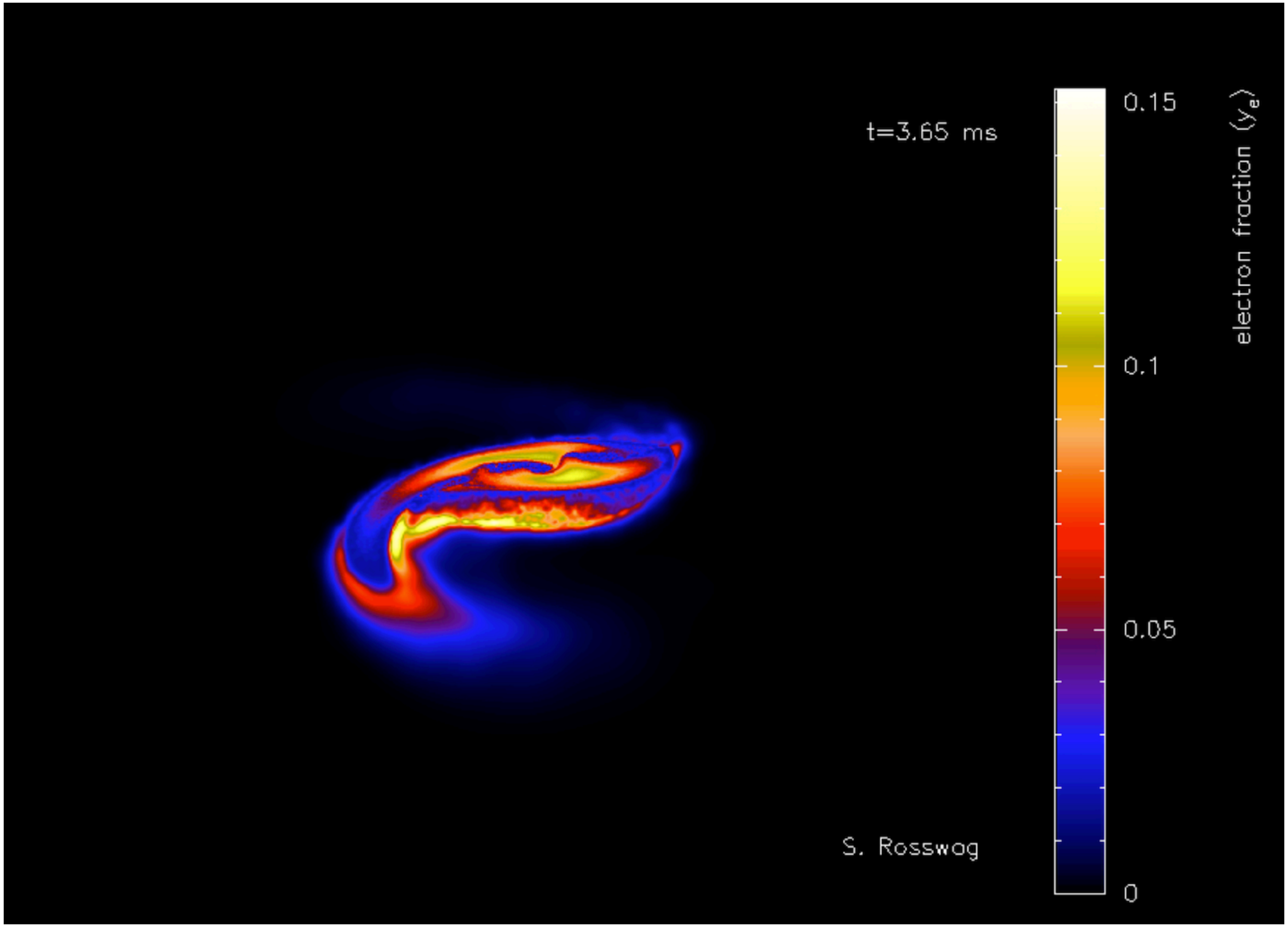
see also **Mooley et al. 2018**

Compact Binaries Coalescence
(NS+NS and NS+BH)



Credit: Stephan Rosswog

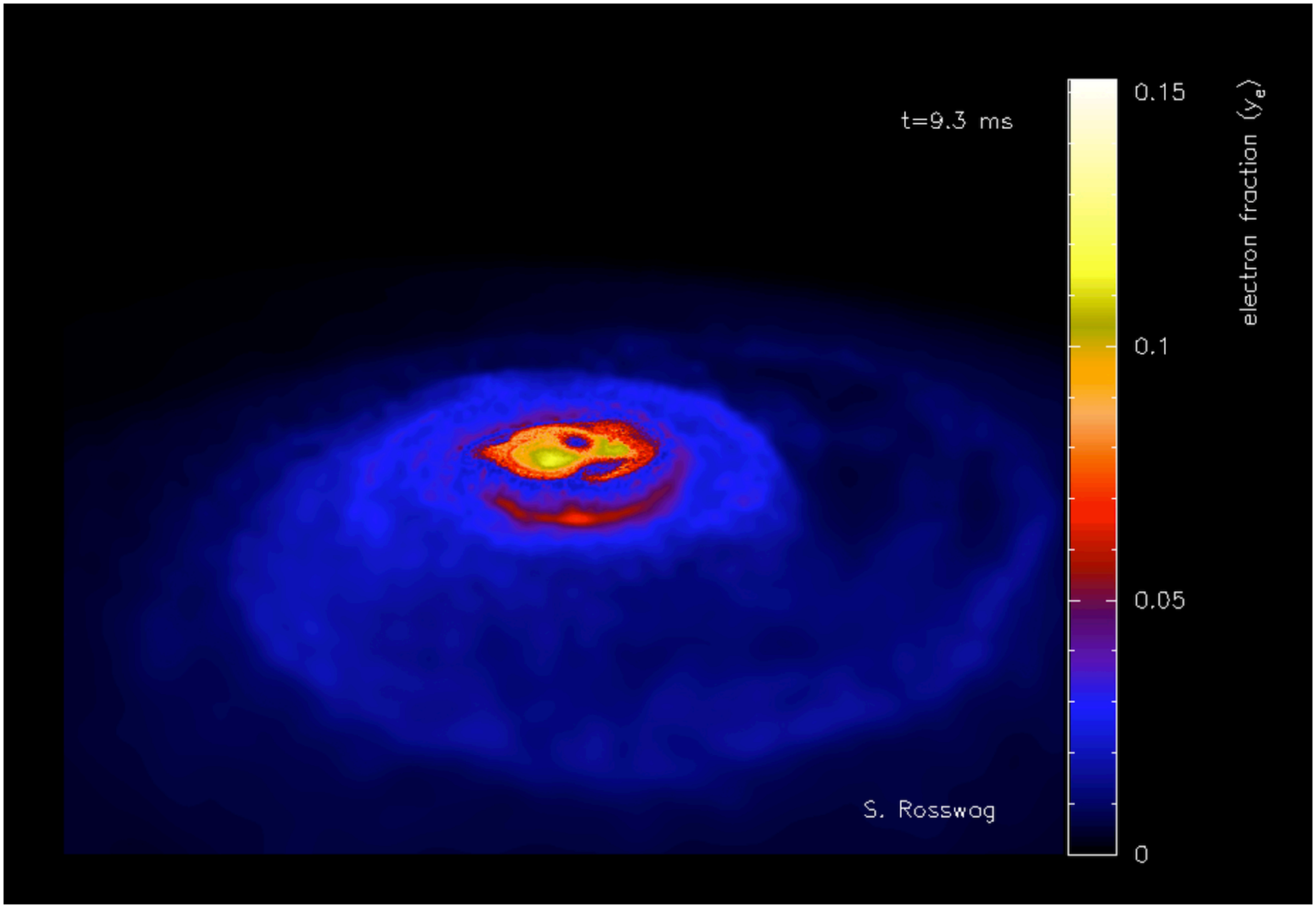
Compact Binaries Coalescence
(NS+NS and NS+BH)



Credit: Stephan Rosswog

Compact Binaries Coalescence
(NS+NS and NS+BH)

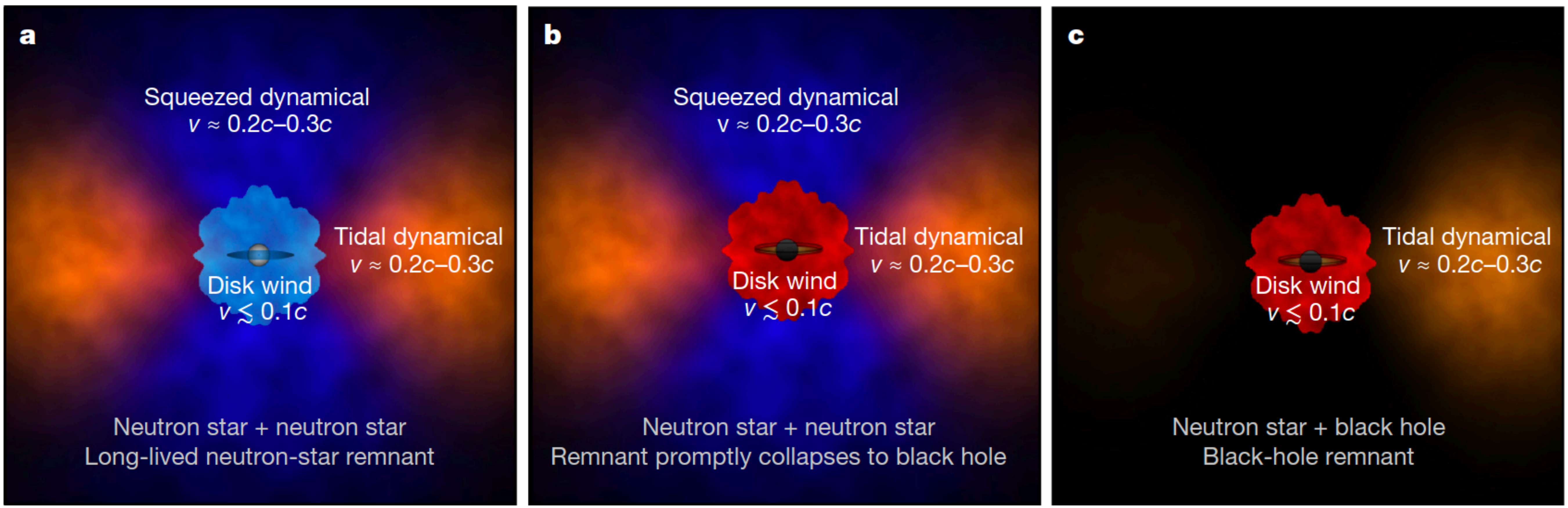
pre-merger phase



Credit: Stephan Rosswog

Compact Binaries Coalescence
(NS+NS and NS+BH)

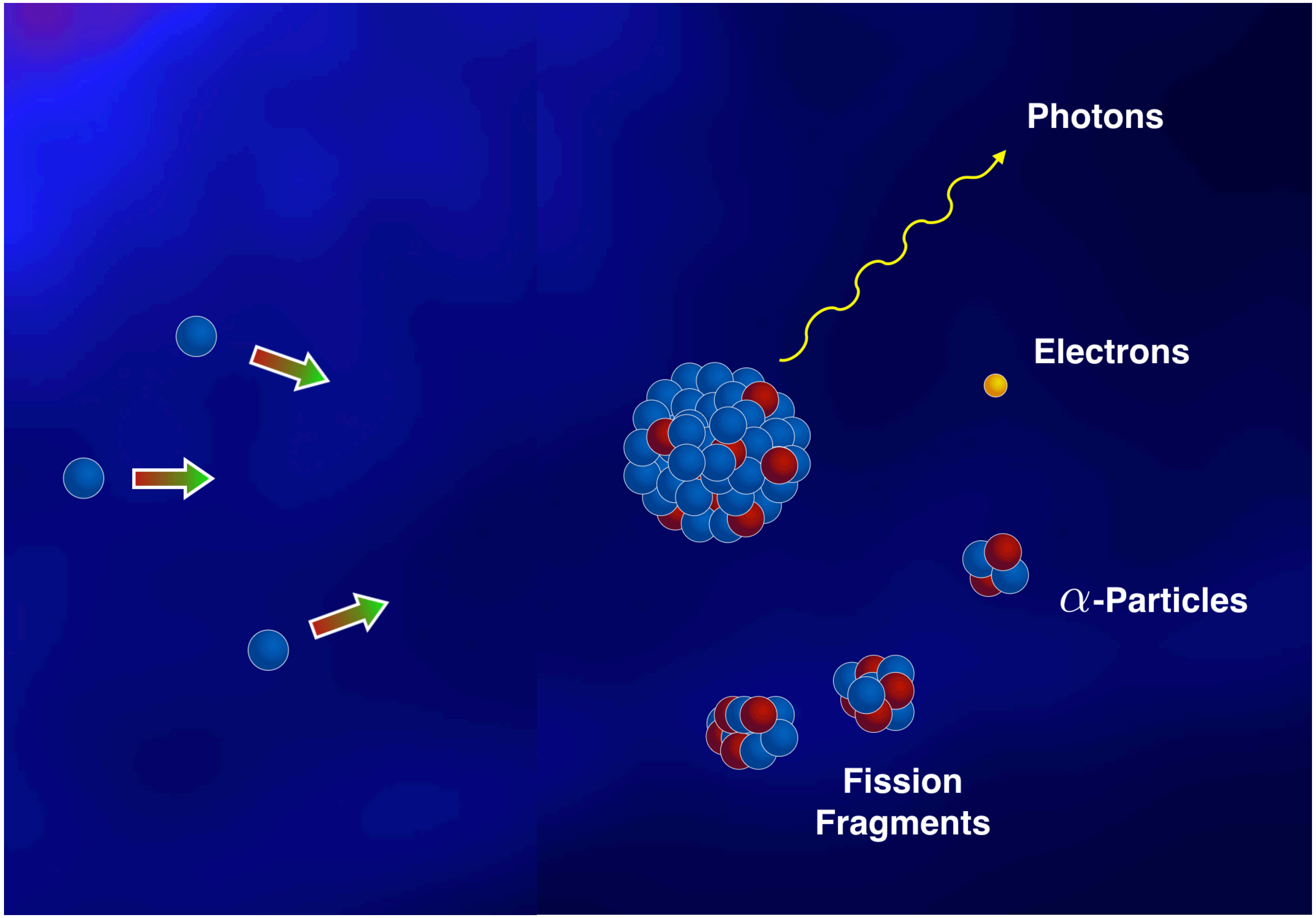
Sub-relativistic ejecta composition



Credit: Daniel Kazen et al. 2017

Compact Binaries Coalescence
(NS+NS and NS+BH)

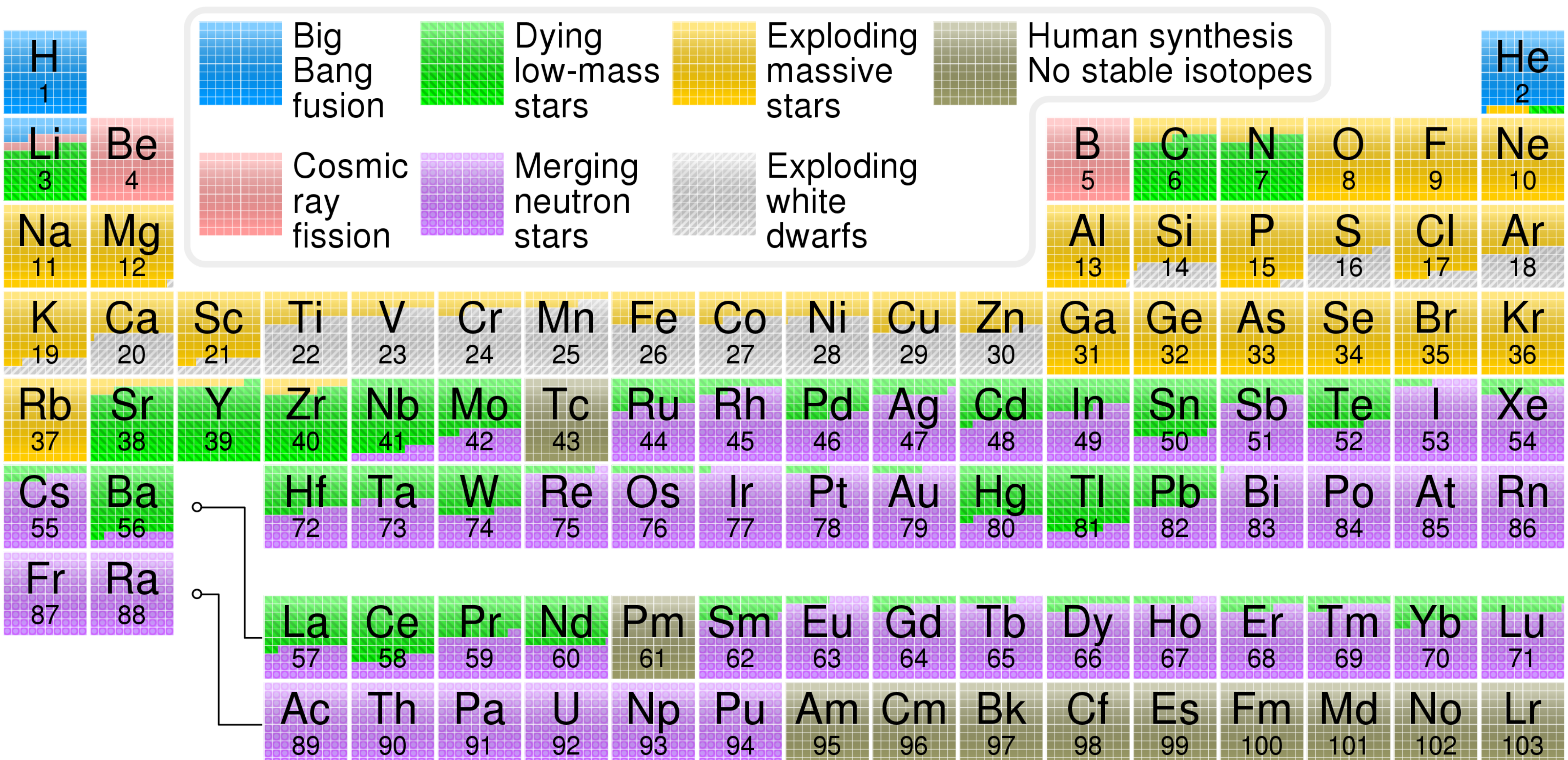
nucleosynthesis



Credit: Stefano Ascenzi

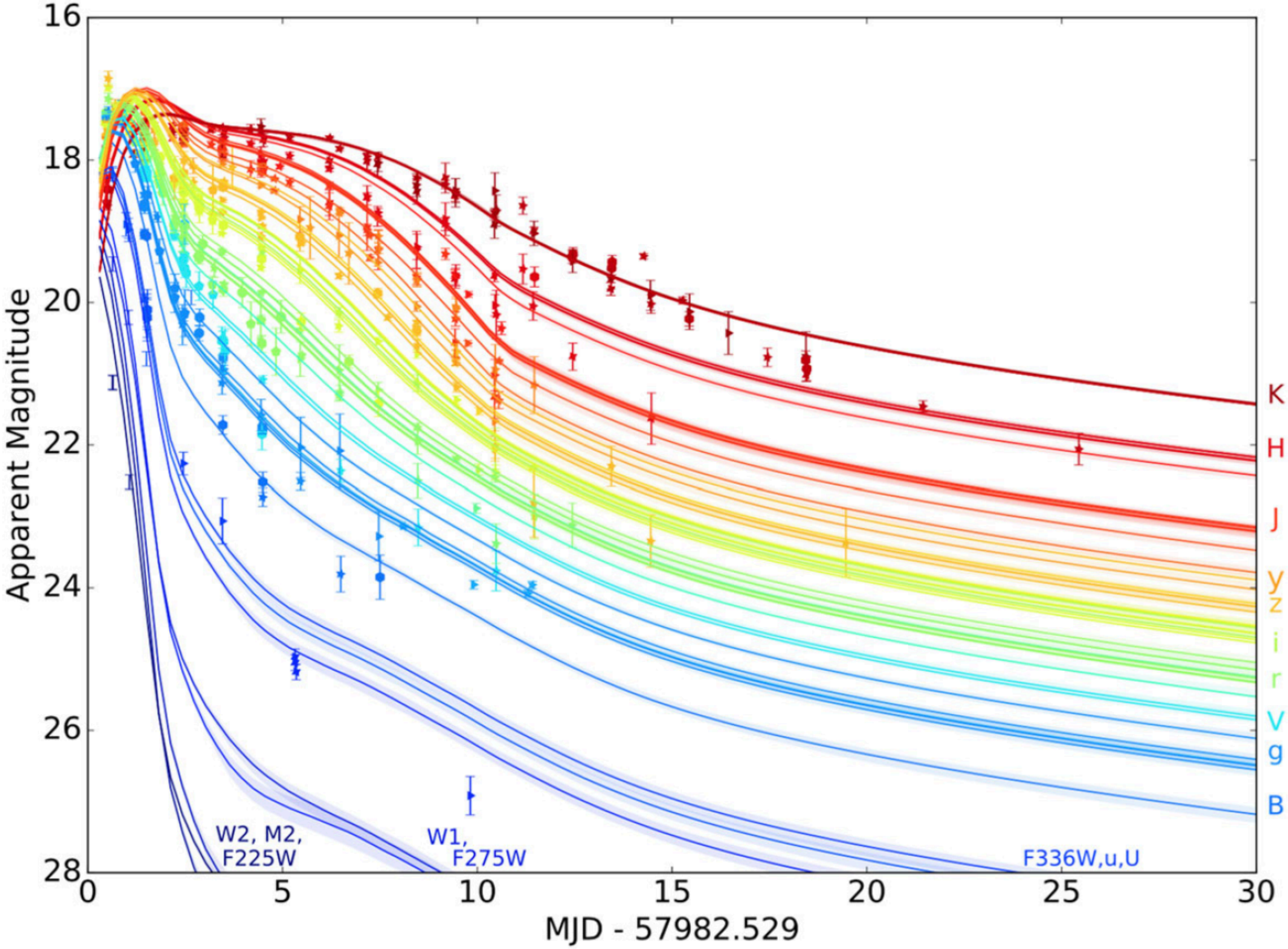
Compact Binaries Coalescence
(NS+NS and NS+BH)

nucleosynthesis

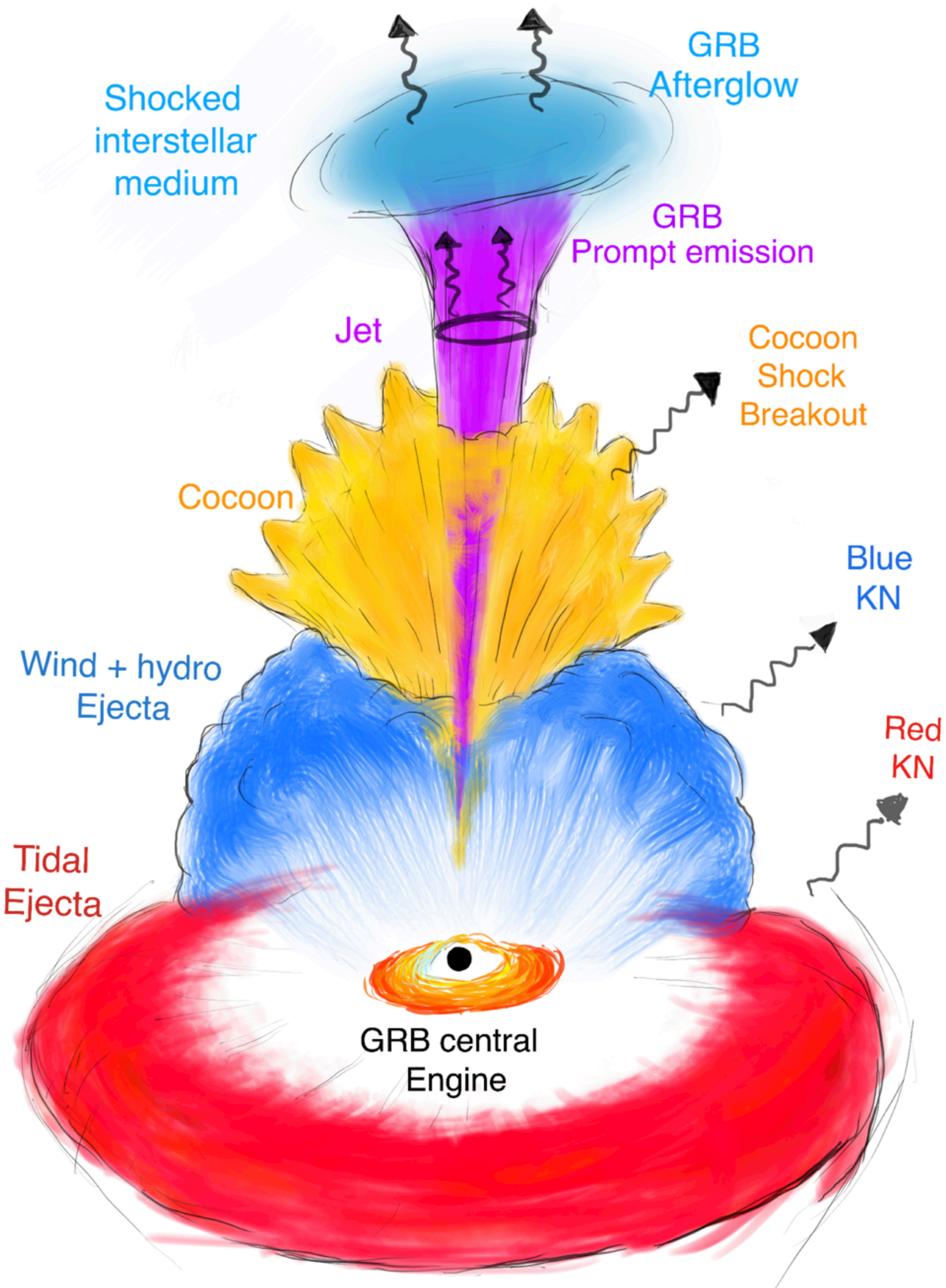


Compact Binaries Coalescence
(NS+NS and NS+BH)

Blue and Red kilonova



Compact Binaries Coalescence
(NS+NS and NS+BH)



Credit: Stefano Ascenzi

γ-ray bursts

discovery	dark ages	afterglow era	multi-wavelength era	multi-messenger era
1967	1970-1990	1997 - ...	2004 - ...	2017 - ...

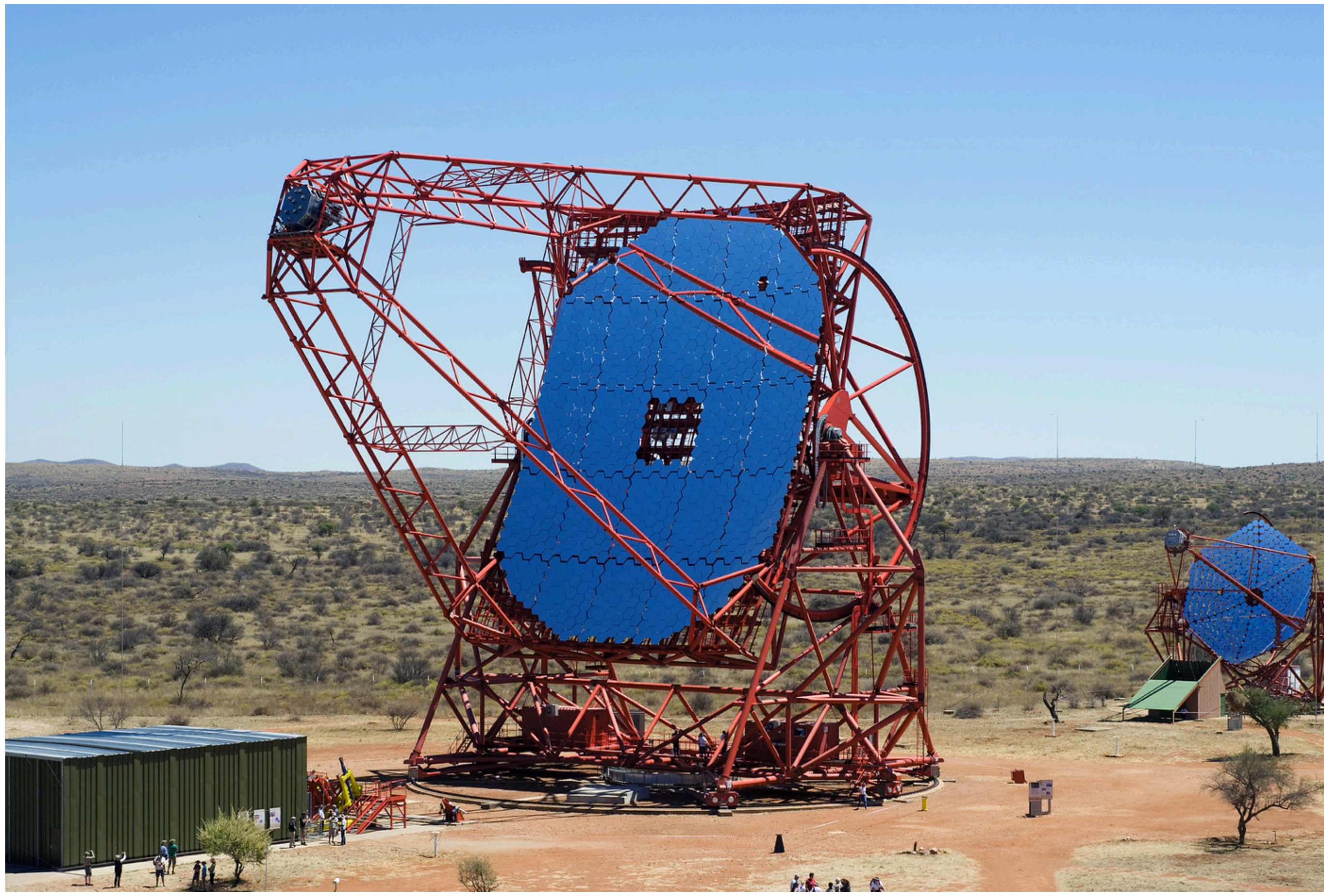
VHE era

2019 - ...

GRBs at Very High Energies - the discoveries of 2019

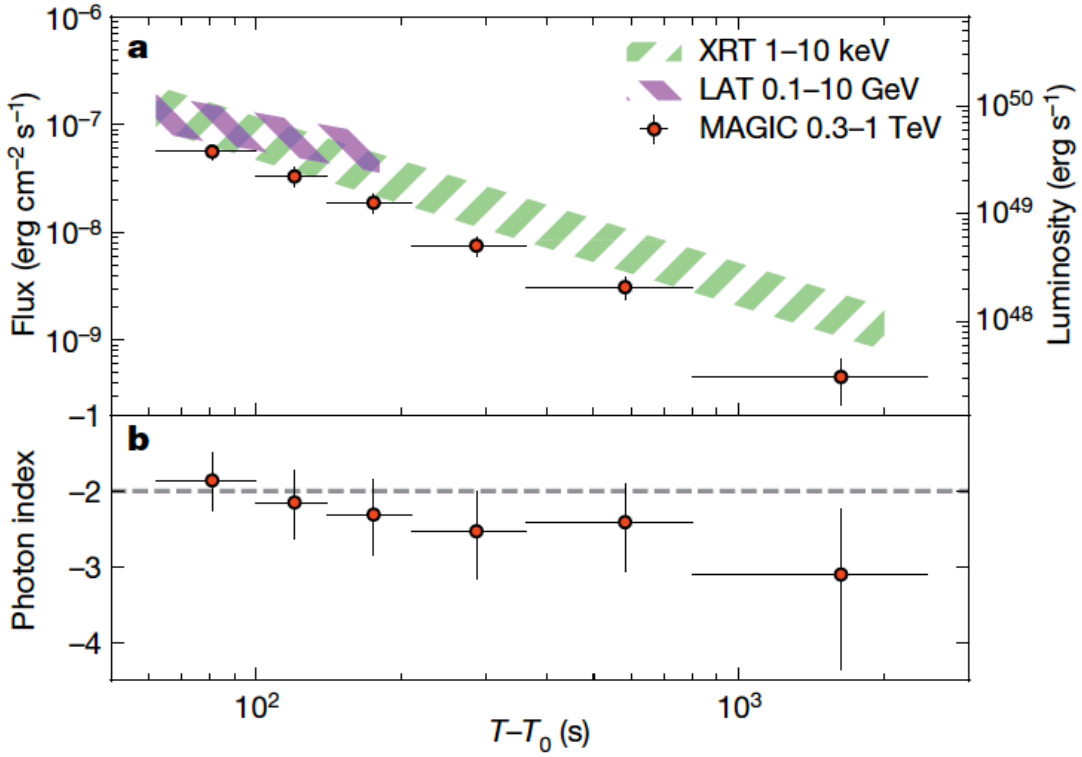
MAGIC and H.E.S.S.

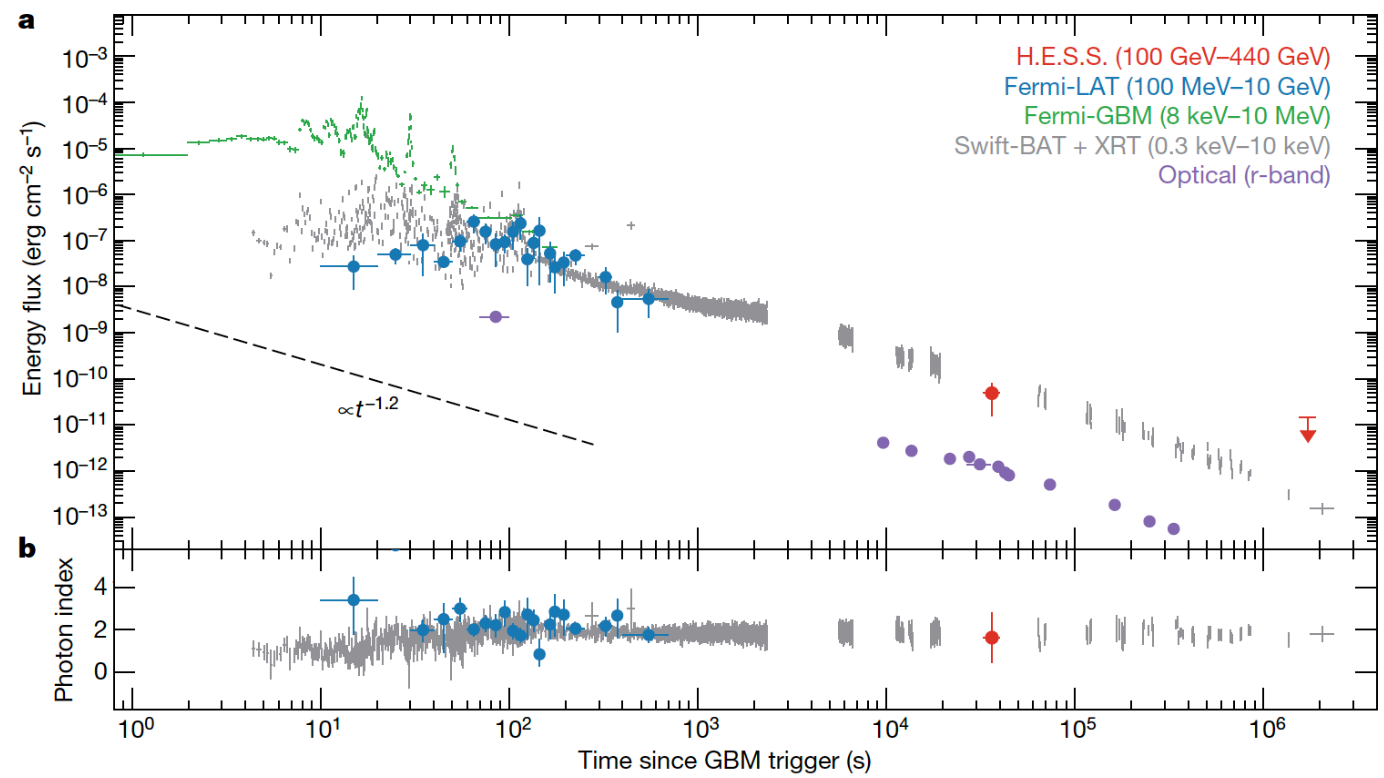
Towards TeVs!



GRBs at Very High Energies - the discoveries of 2019

MAGIC and H.E.S.S. collaborations



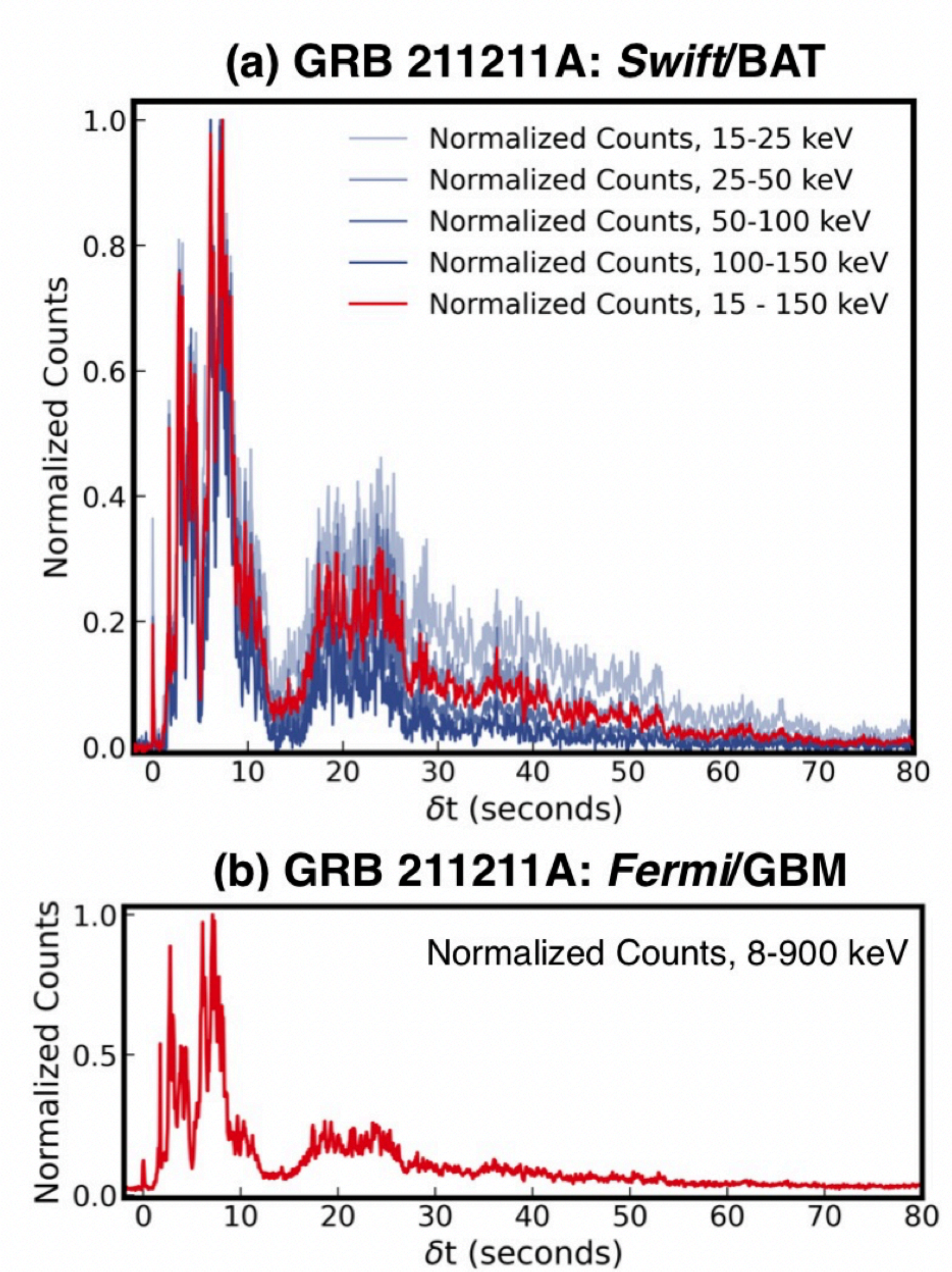


γ-ray bursts

discovery	dark ages	afterglow era	multi-wavelength era	multi-messenger era
1967	1970-1990	1997 - ...	2004 - ...	2017 - ...

VHE era	Oddballs
2019 - ...	2021 - ...

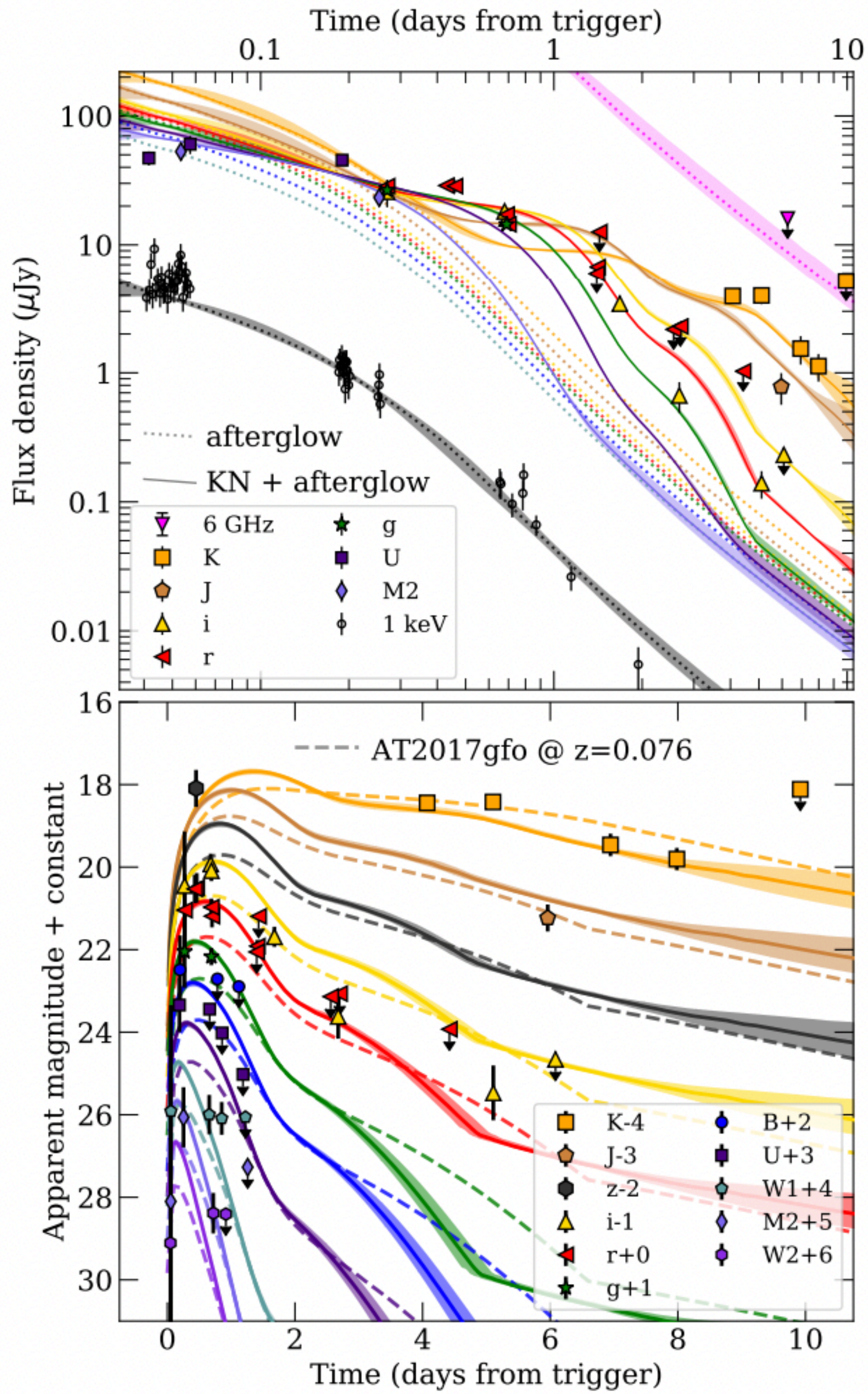
GRB 211211A   T90 ~ 34 s   z = 0.076
350 Mpc



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

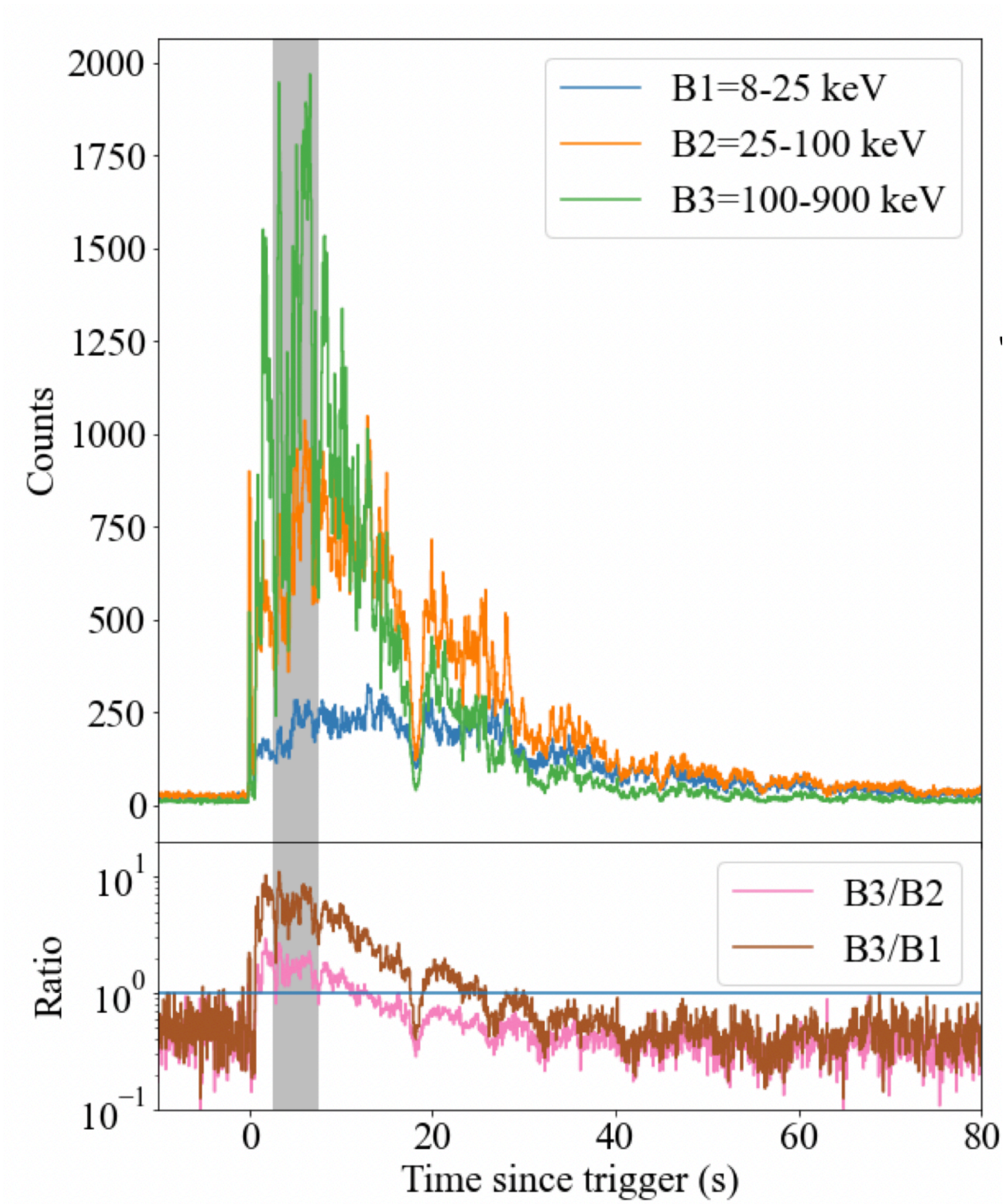
Rastinejad et al. 2022, Nature

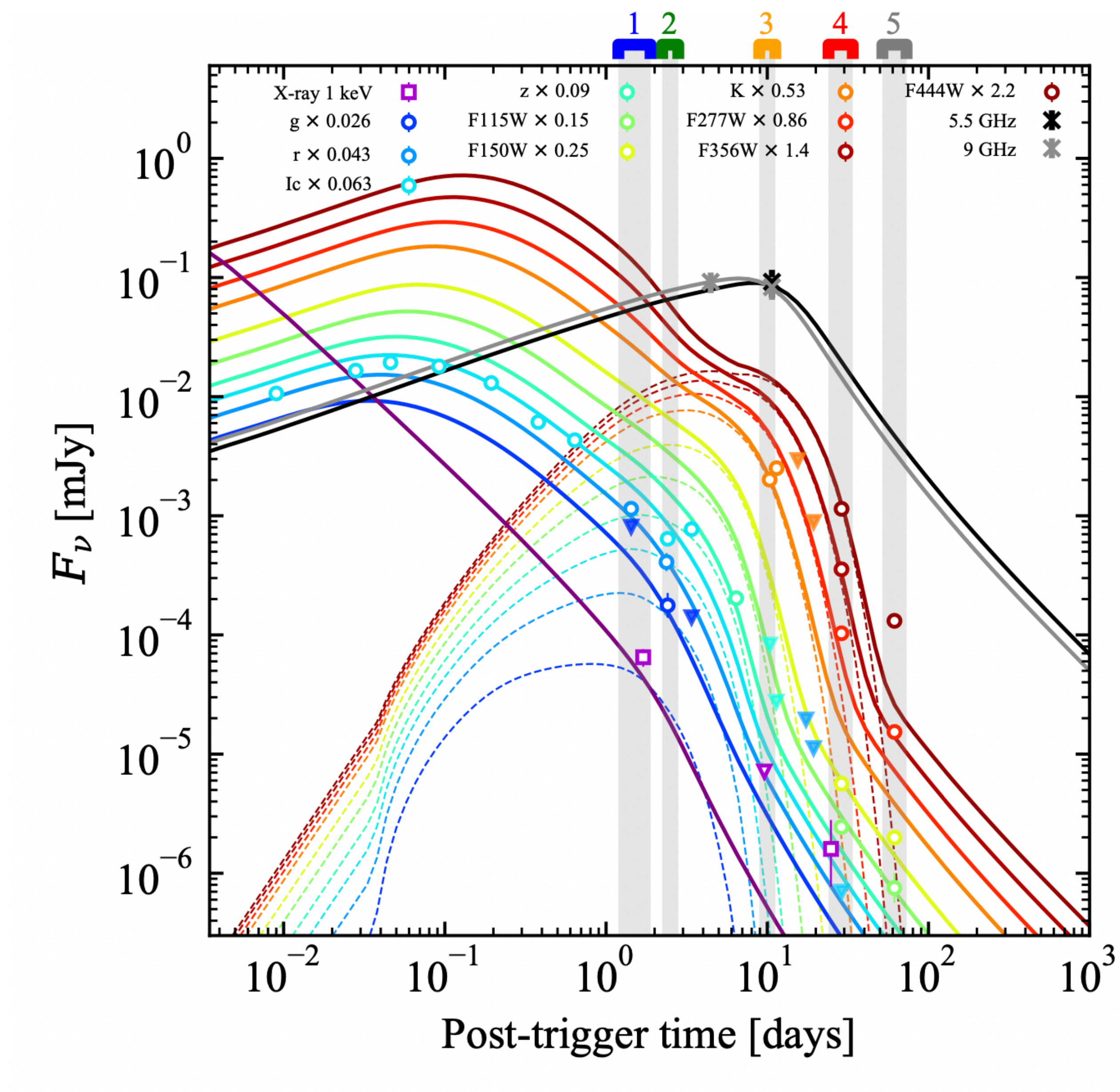
(see also **Troja et al. 2022, Nature**)

GRB 230307A

T90 ~ 30 s

z = 0.065

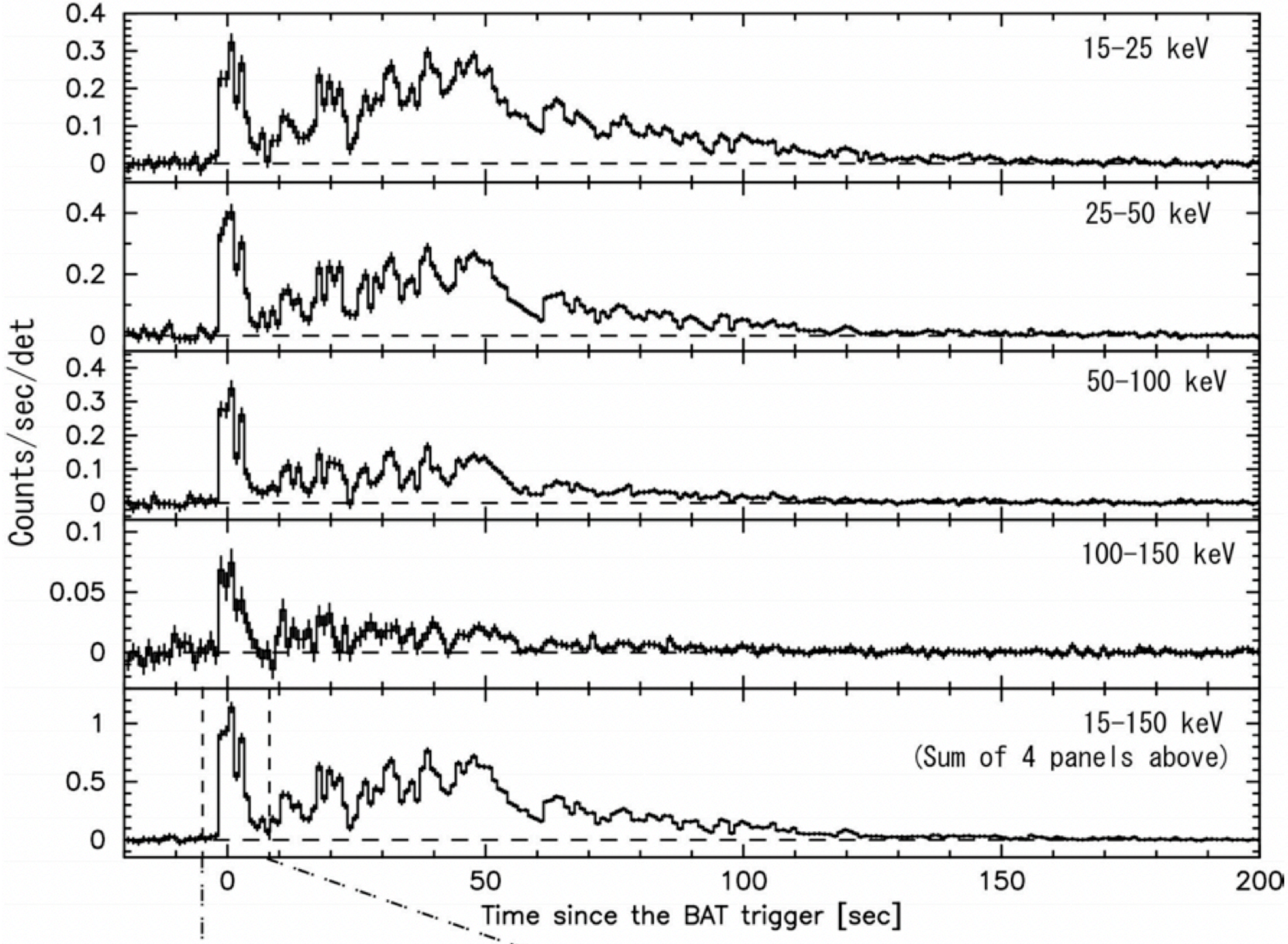




Levan et al. 2023, arXiv

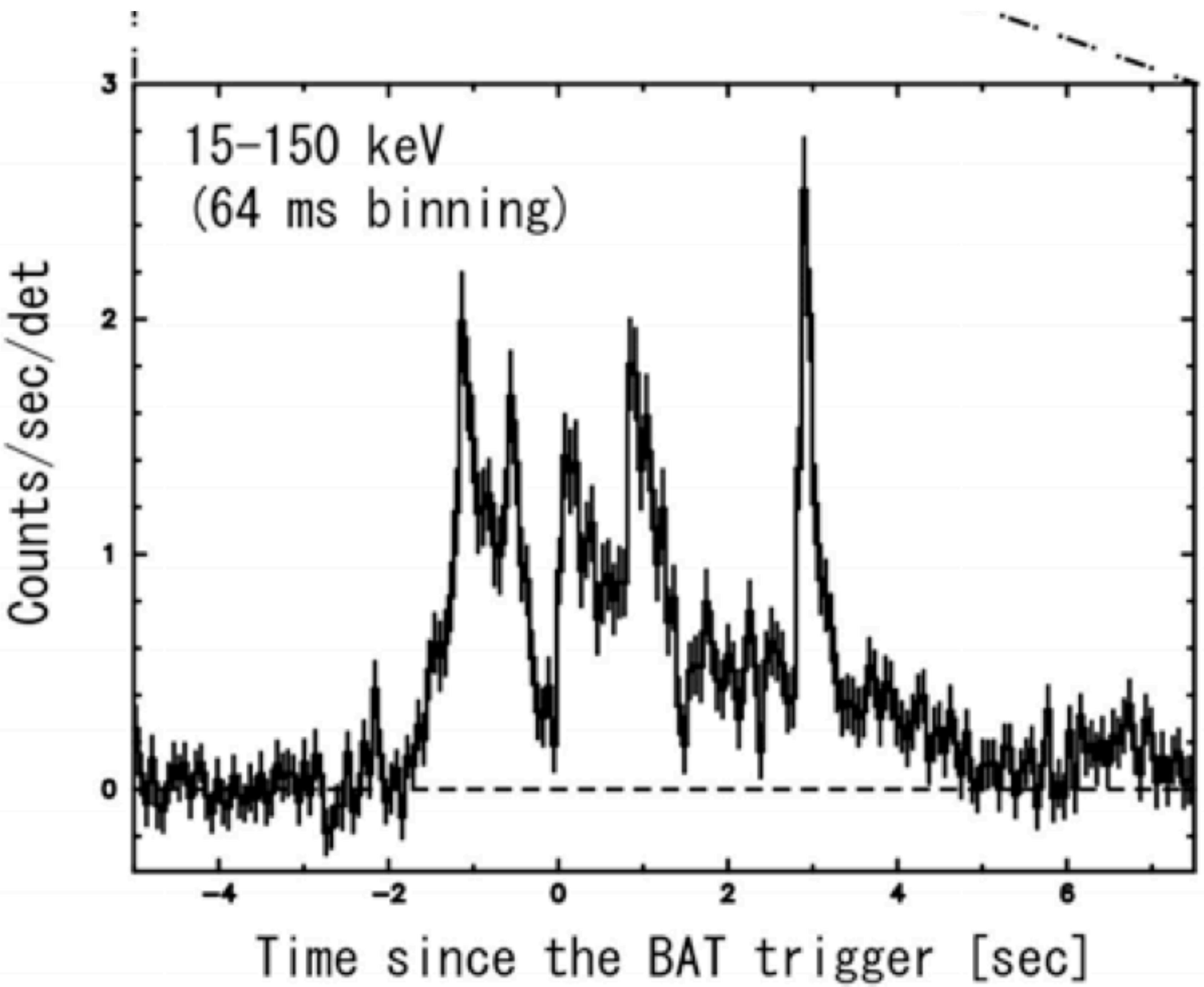
Anything similar from the past?

GRB 060614



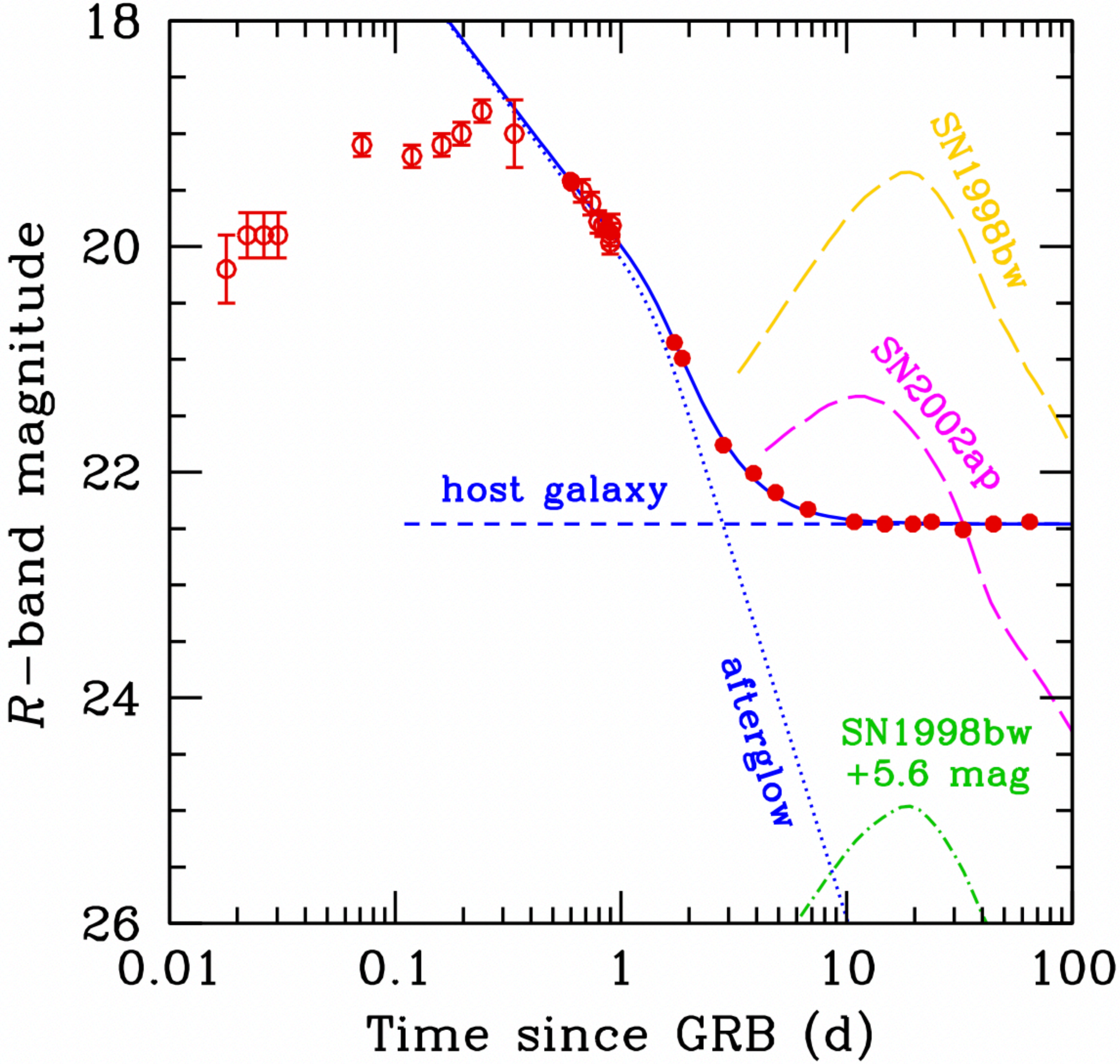
Gehrels et al. 2006, Nature

GRB 060614



Gehrels et al. 2006, Nature

GRB 060614

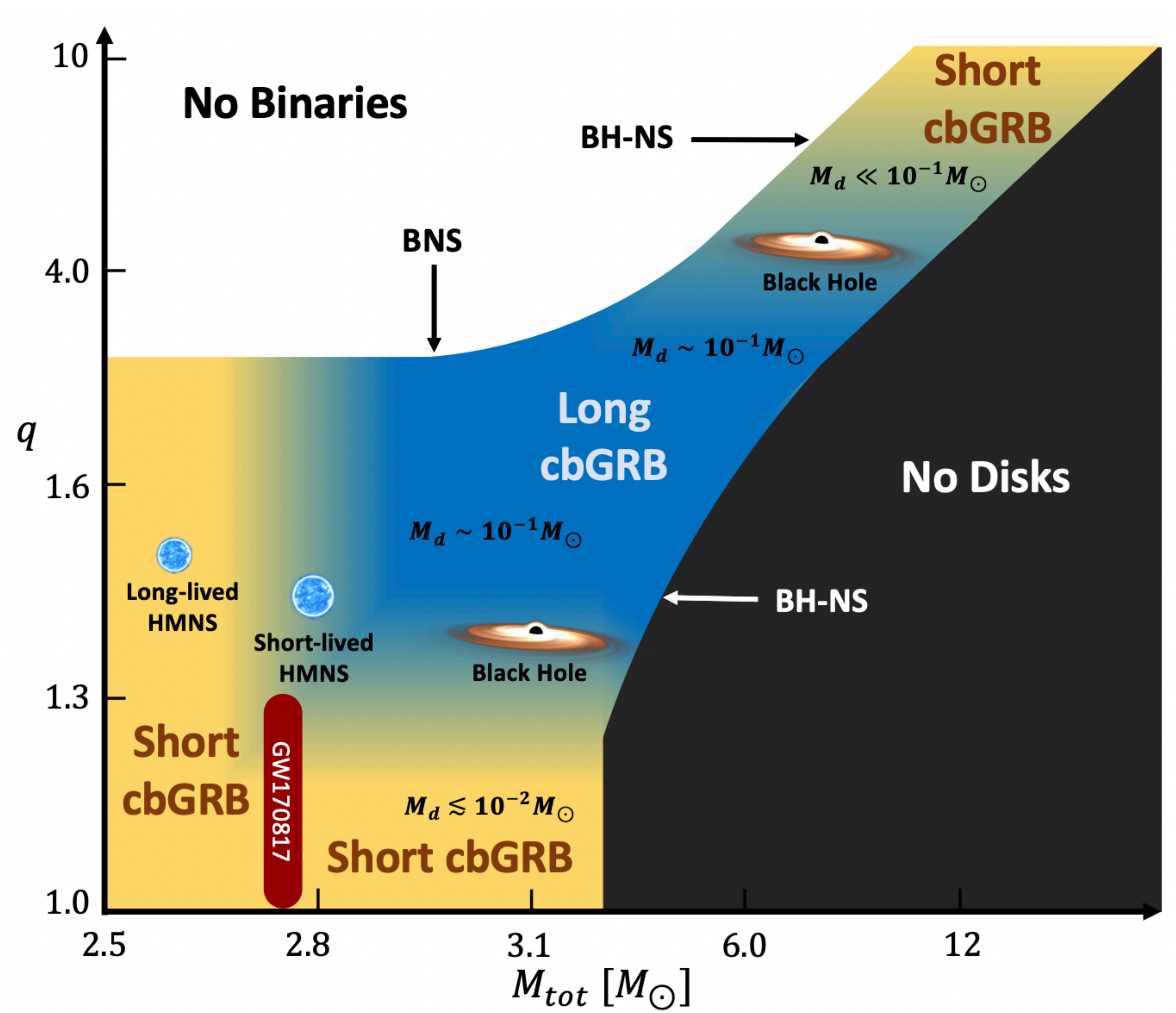


any SN should be x100 fainter

Della Valle et al. 2006, Nature

Gal-Yam et al. 2006, Nature

Possible progenitors



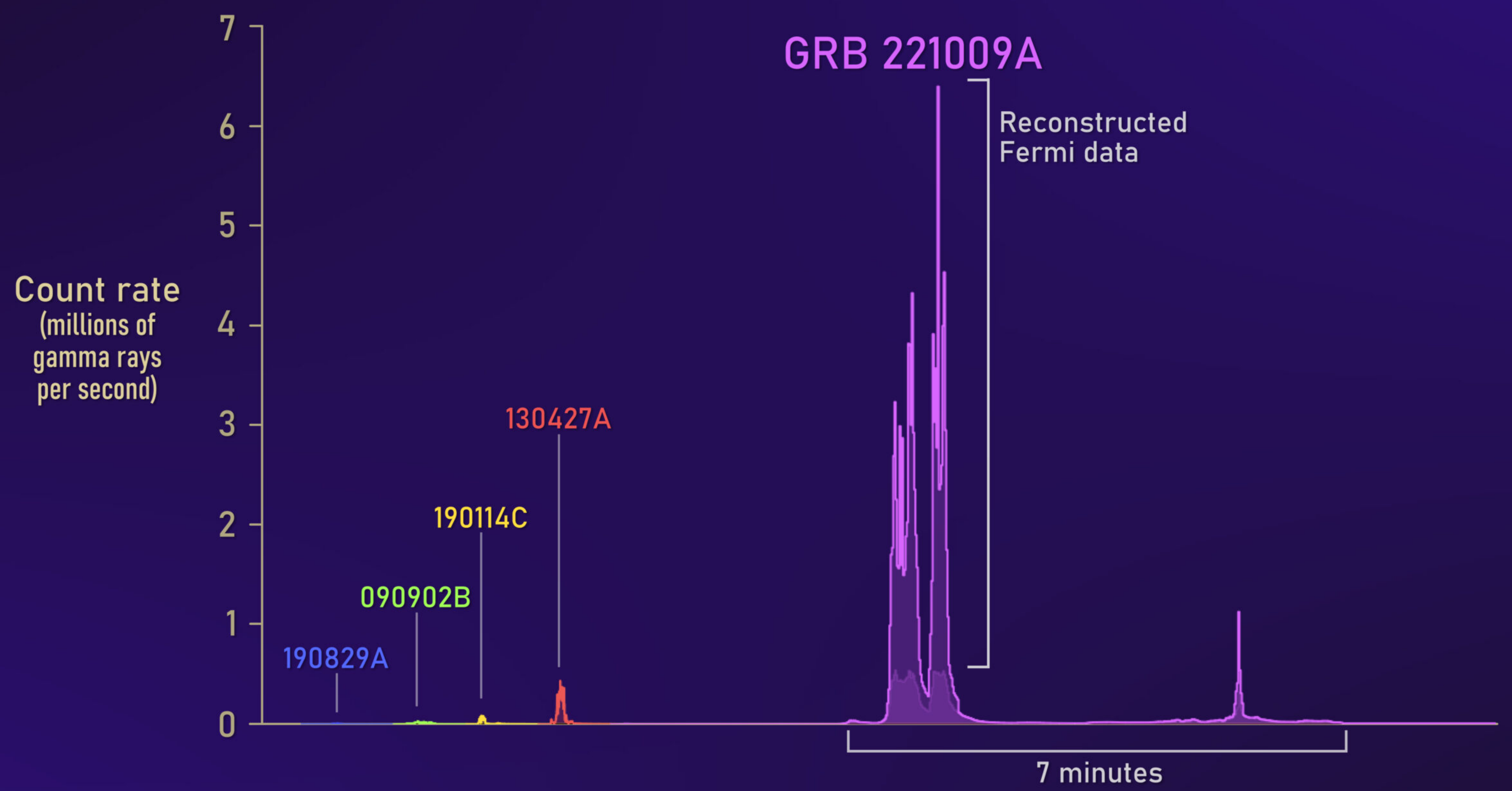
Gottlieb et al. 2023, arXiv

γ-ray bursts

discovery	dark ages	afterglow era	multi-wavelength era	multi-messenger era
1967	1970-1990	1997 - ...	2004 - ...	2017 - ...

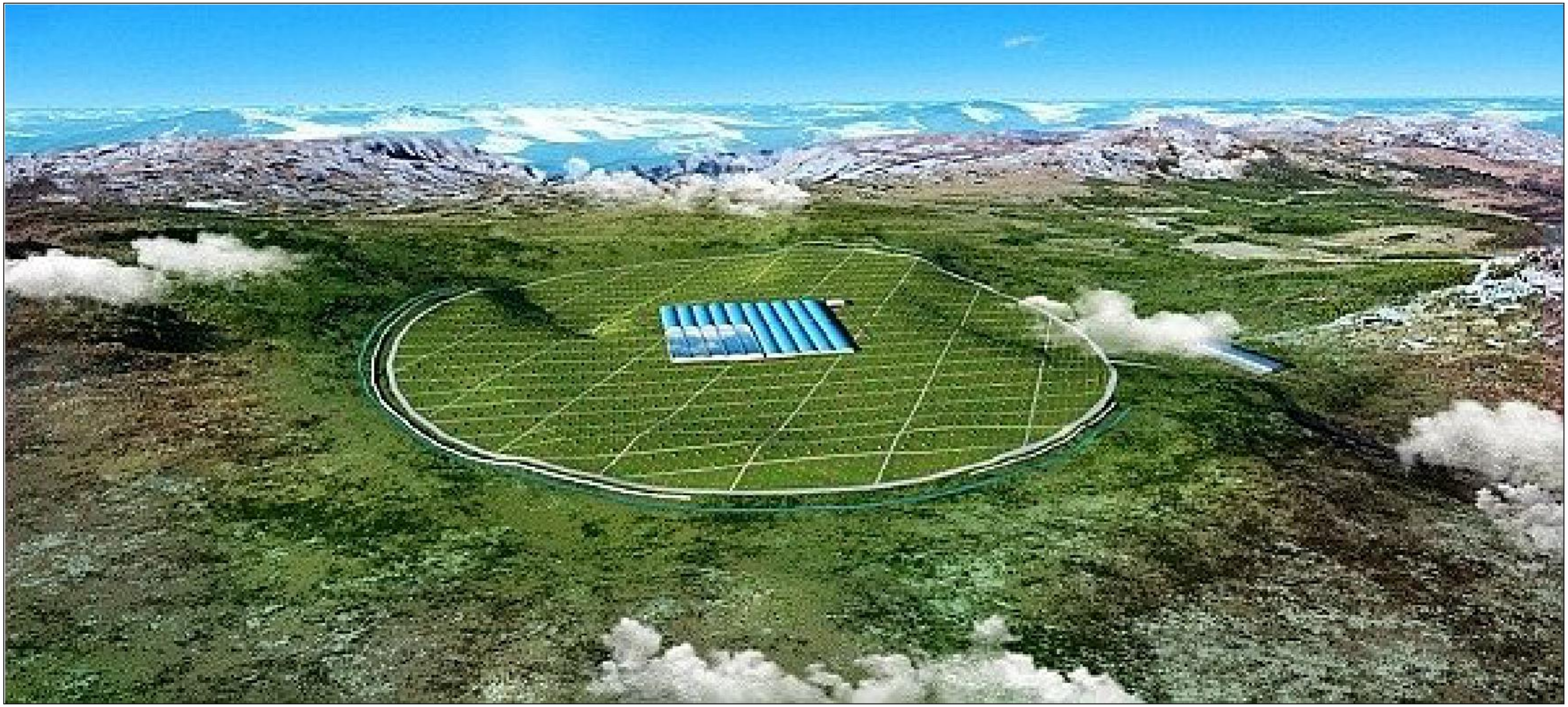
VHE era	Oddballs	BOAT
2019 - ...	2021 - ...	2022

The BOAT GRB in Context



LHAASO

Large High Altitude Air Shower Observatory



>1000 photons until ~10 TeV!

Summary, applications and hopes

GWs + SGRBs (& oddballs?)

1. **EoS of neutron stars**
   numerical GR + GW and kilonova data

2. **Nucleosynthesis**
   pop.synthesys and kilonova interpretation

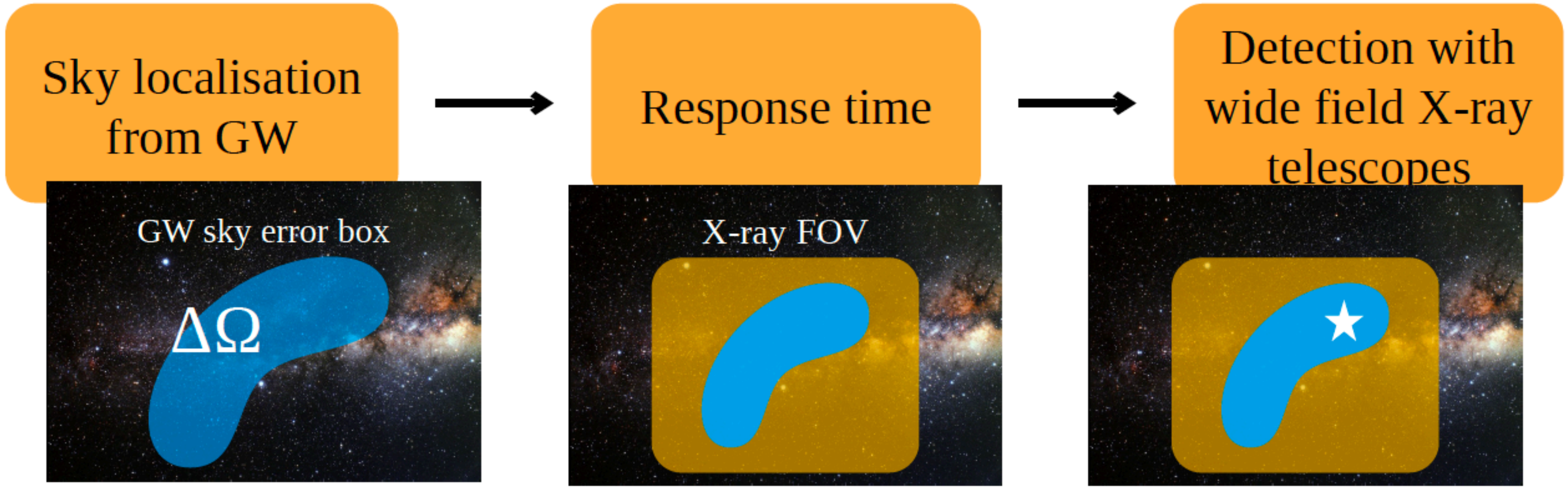
3. **Fundamental Physics**
   GW and GRB timing

4. **Relativistic astrophysics**
   numerical GR + GW and GRB data

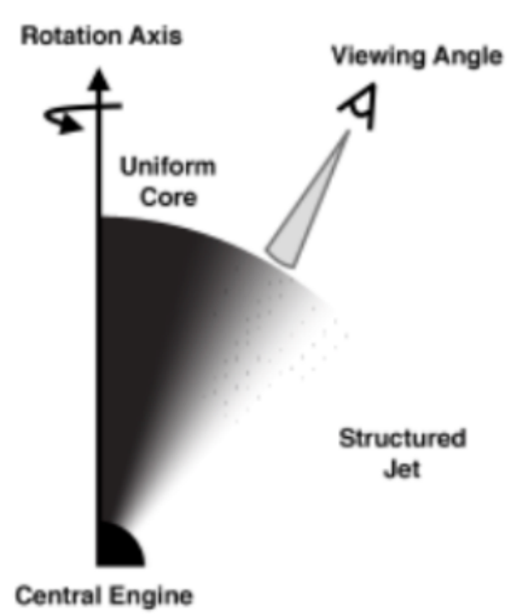
5. **Cosmology**
   GWs (distance) + GRB/kilonova (velocity)

Joint X-ray - GW detections

low-z MM astronomy



	THESEUS-SXI	TAP	Einstein Probe	Gamow
Energy band	0.3-5 keV	0.3-5 keV	0.5-4 keV	0.3-5 keV
Field of view	0.5 sr	0.4 sr	1.1 sr	0.4 sr



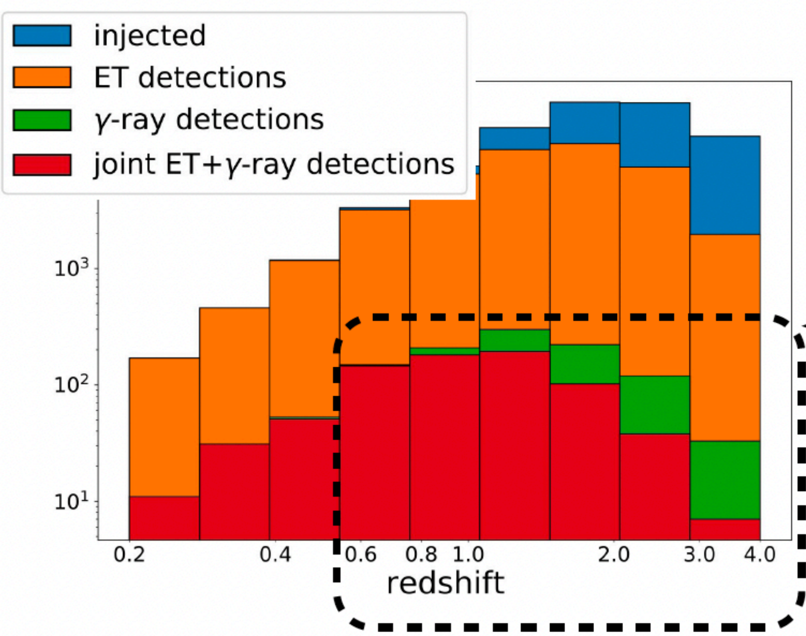
Joint MeV - GW detections

high-z MM astronomy

INSTRUMENT	band MeV	$F_{\rm lim}$ erg cm^{-2} s^{-1}	FOV/4π	loc. acc.	Joint ET $+\gamma$-ray	N_{JD}/N_γ	Joint (ET+CE) $+\gamma$-ray	N_{JD}/N_γ
Fermi-GBM	0.01 - 25	0.5(*)	0.75	5 deg (^{a})	33^{+14}_{-11}	$68^{+13}_{-18}\%$	47^{+14}_{-14}	$95^{+5}_{-7}\%$
Swift-BAT	0.015 - 0.15	2×10^{-8}	0.11	1-3 arcmin	10^{+3}_{-3}	$62^{+11}_{-14}\%$	13^{+5}_{-4}	$94^{+6}_{-7}\%$
SVOM-ECLAIRs	0.004 - 0.250	1.792(*)	0.16	< 10 arcmin	3^{+1}_{-1}	$69^{+10}_{-9}\%$	4^{+1}_{-1}	$95^{+5}_{-4}\%$
SVOM-GRM	0.03 - 5	0.23(*)	0.16	~ 5 deg	9^{+4}_{-3}	$59^{+6}_{-6}\%$	14^{+6}_{-4}	$92^{+3}_{-3}\%$
THESEUS-XGIS	0.002 - 10	3×10^{-8}	0.16	< 15 arcmin	10^{+5}_{-4}	$63^{+13}_{-13}\%$	15^{+6}_{-4}	$94^{+6}_{-7}\%$
HERMES	0.05 - 0.3	0.2(*)	1.0	1 deg	84^{+42}_{-30}	$61^{+10}_{-11}\%$	139^{+54}_{-36}	$94^{+6}_{-6}\%$
TAP-GTM	0.01 - 1	1(*)	1.0	20 deg	60^{+24}_{-24}	$67^{+13}_{-14}\%$	84^{+30}_{-24}	$95^{+5}_{-6}\%$

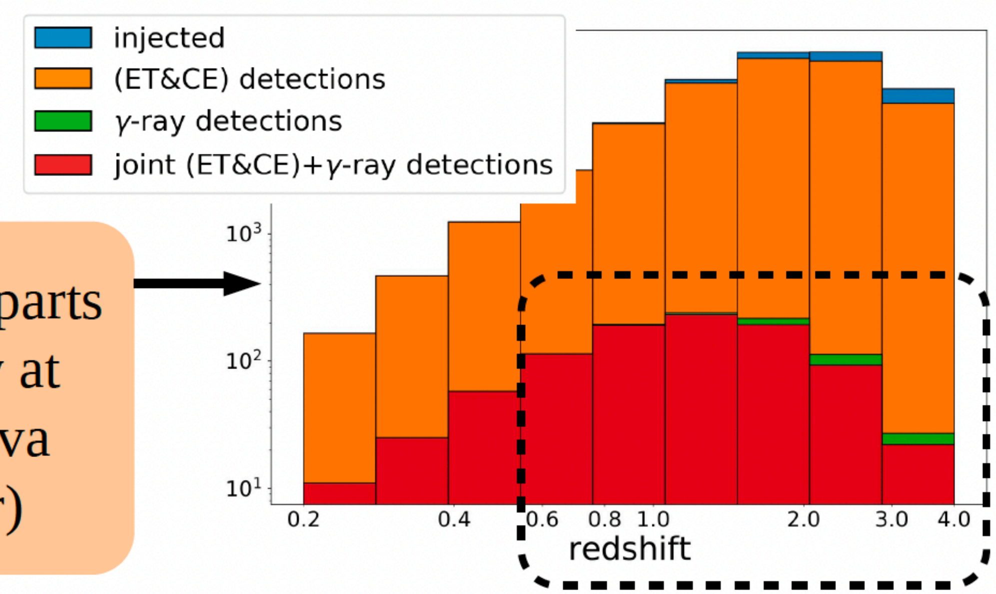
Few but **well localised** events

Fermi GBM+ET



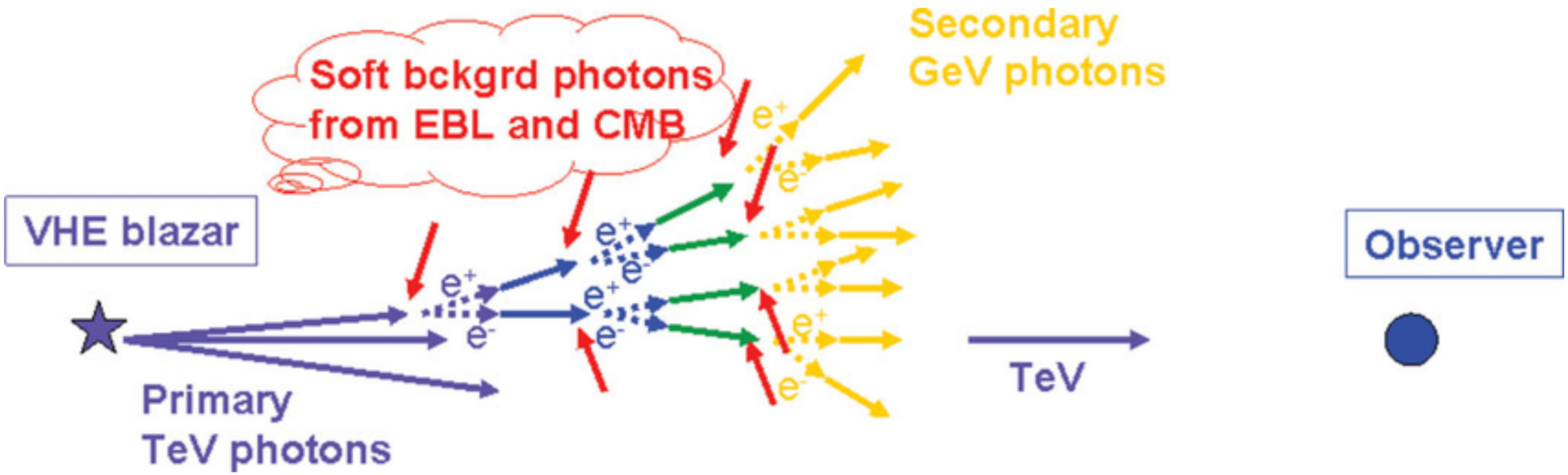
High-z GW counterparts can be detected **only** at high-energy (kilonova intrinsically fainter)

Fermi GBM+(ET&CE)



Ronchini et al. 2022

GeV-TeV photons from GRBs



Sketch from Sol et al. 2012

Next talks!

Thank you!