GRAN SASSO SCIENCE INSTITUTE

CENTER FOR ADVANCED STUDIES
INFN

The gamma-rays analysis and the modelling of the BOAT GRB 221009A

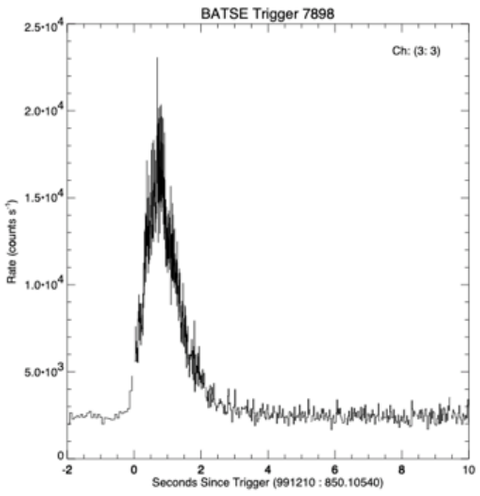
Gor Oganesyan

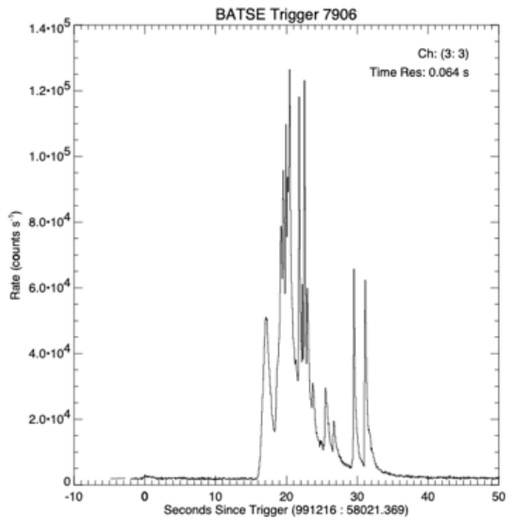
V Gravi-Gamma-Nu workshop, Bari, 9 October 2024

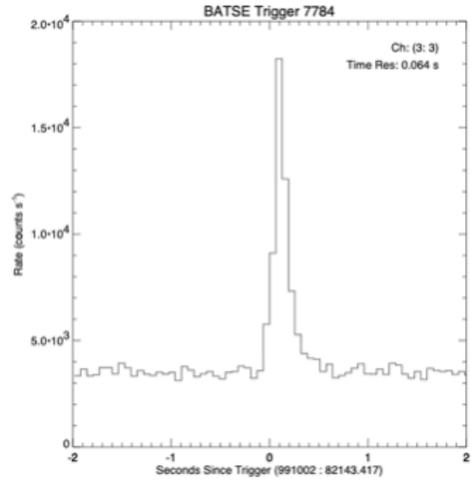
γ-ray bursts

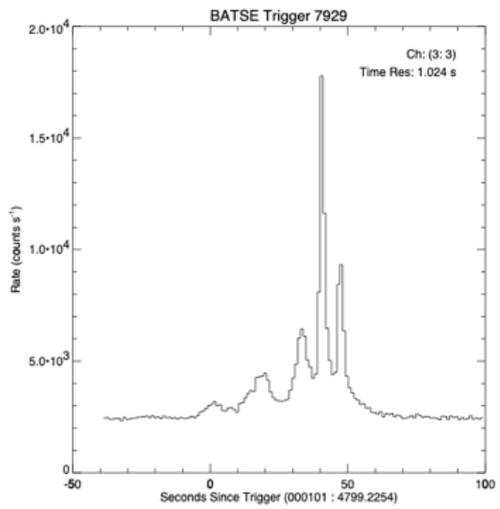
The prompt emission

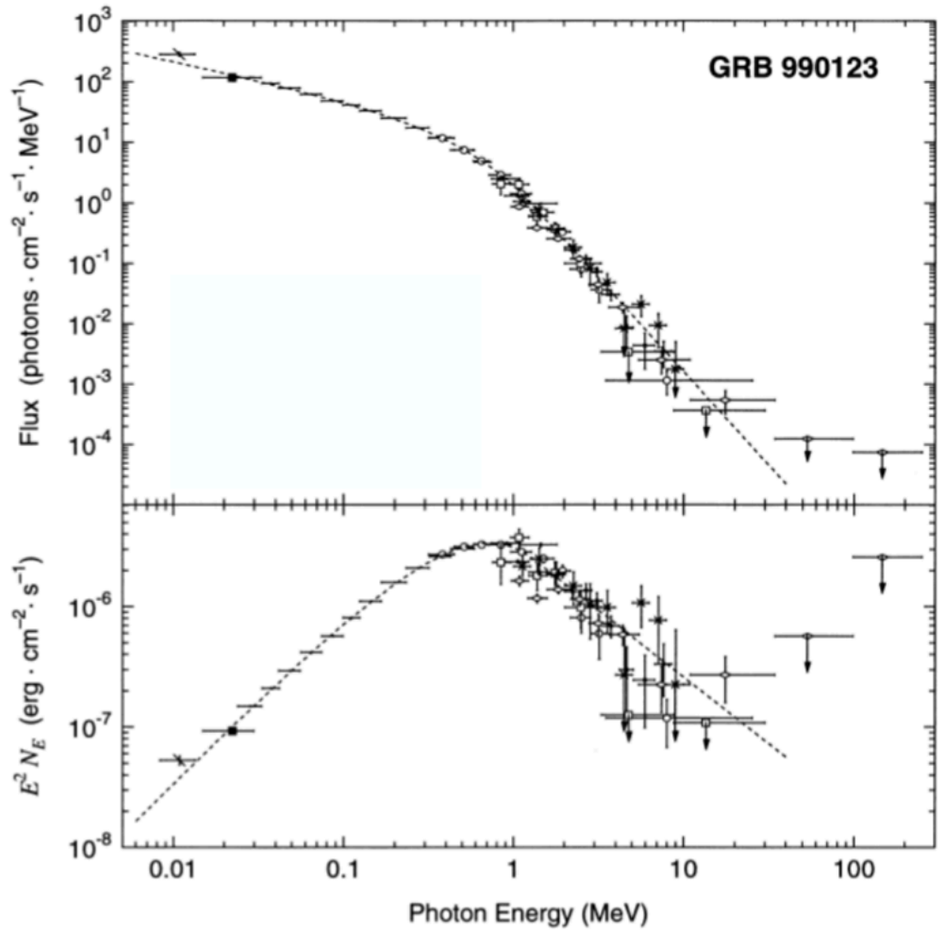
γ-ray bursts











Briggs et al. 1999

energy (iso) $\sim 10^{50} - 10^{54}\,\mathrm{erg}$

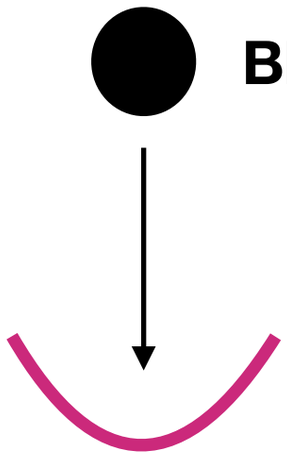
photons ~ MeV

$$E_{peak} \sim 100\,keV - 1\,MeV$$

variability 0.01-1 s

duration 0.1 - 1000 s

Pair fireball



BH $\sim 1 - 10 M_\odot$

$e^\pm, \gamma$

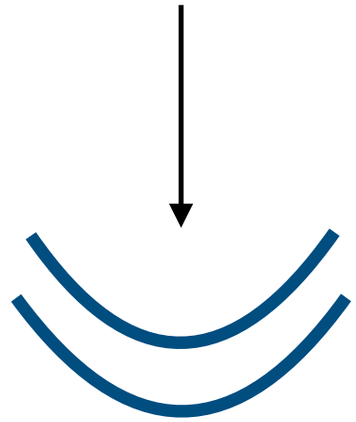
$L_\gamma >> 10^{10} L_{Edd}$

$T_{BB} \sim MeV$

Cavallo & Rees 1978
Paczýnski 1986
Goodman 1986

Baryon poisoning

Cavallo & Rees 1978
Shemi & Piran 1990
Paczýnski 1990



$R_{coll} \approx 2c\,\delta t\,\Gamma_s^2$

$T_{BB} \rightarrow L_k \rightarrow L_\gamma$

Rees & Mészáros 1994

(Narayan et al. 1992, Paczýnski & Xu 1994)

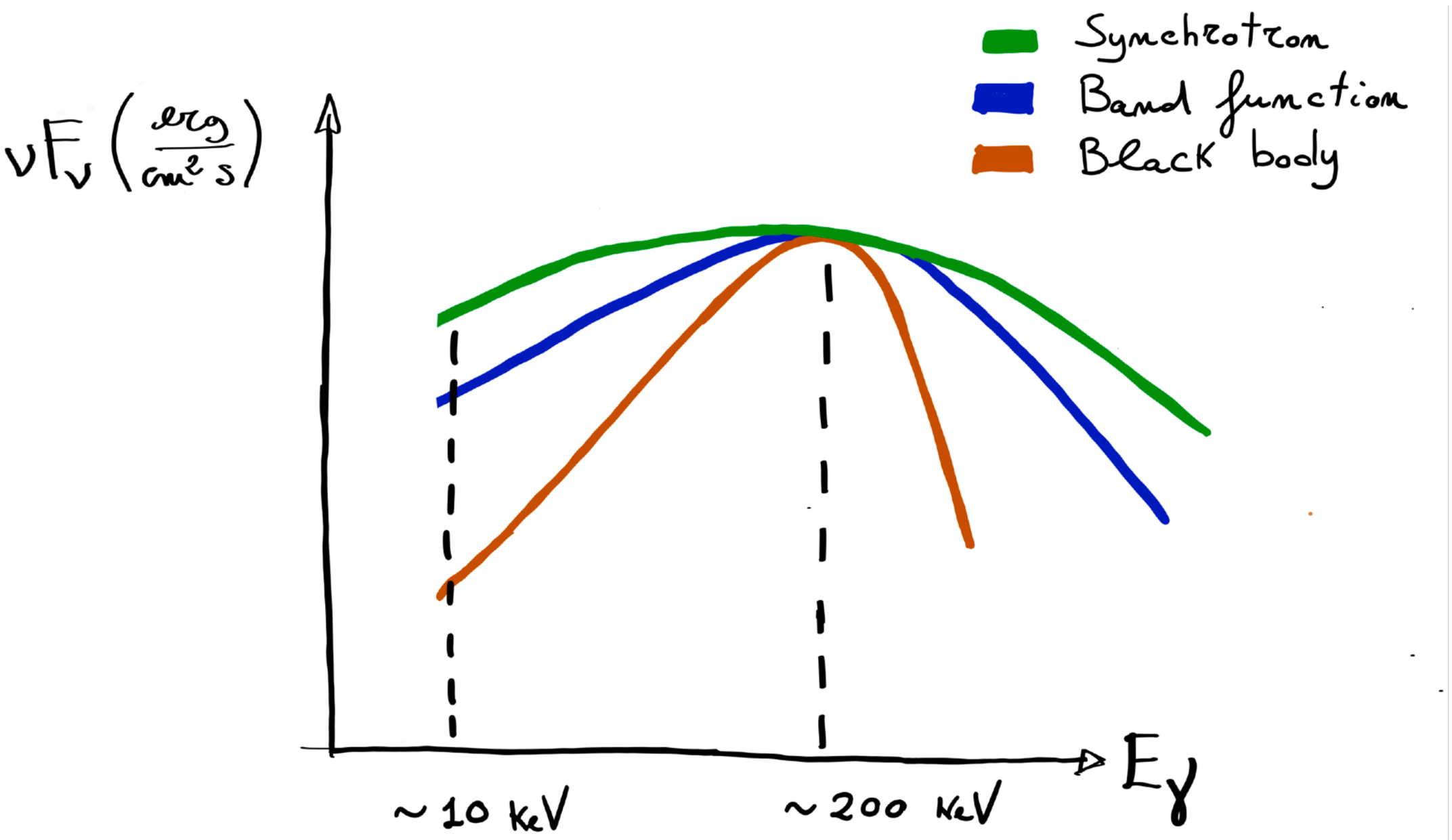
Daigne & Mochkovitch 1998

Internal shocks beyond the photosphere - Spectra

$$t_c = \frac{\gamma m_e c^2}{P_{syn}} \frac{1+z}{\Gamma} \sim 1.1 \times 10^{-5} \frac{\epsilon_B^3 \Gamma_2}{E^2_{2,peak[keV]}(1+z)} s << t_{obs}$$

Ghisellini et al. 2000

Synchrotron vs Thermal emission



Possible dissipation models

$$R_{coll} \approx 2c\,\delta t\,\Gamma_s^2$$

collisional heating

Beloborodov 2010, Vurm et al. 2011

RMS

Levinson & Nakar 2020 review

photosphere

magnetic dissipation

Drenkhahn & Spruit 2002

Giannios & Spruit 2005
Thompson 2006
Giannios 2008

standard internal shocks

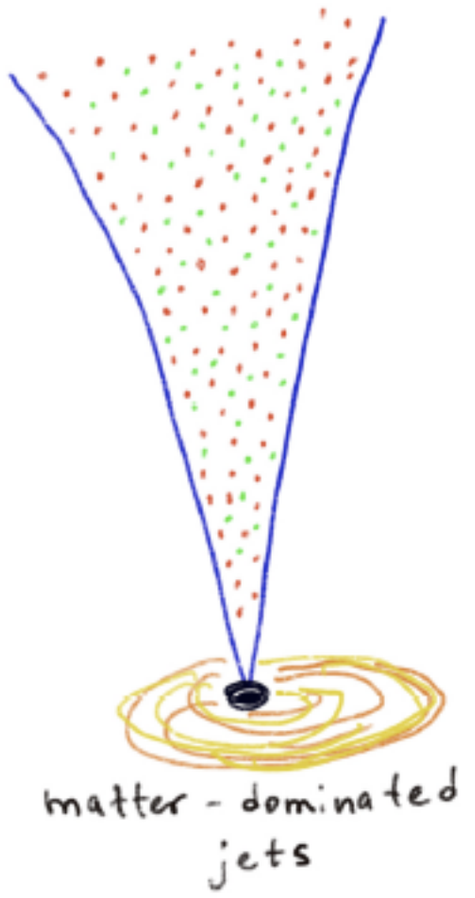
Rees & Mészáros 1994

ICMART

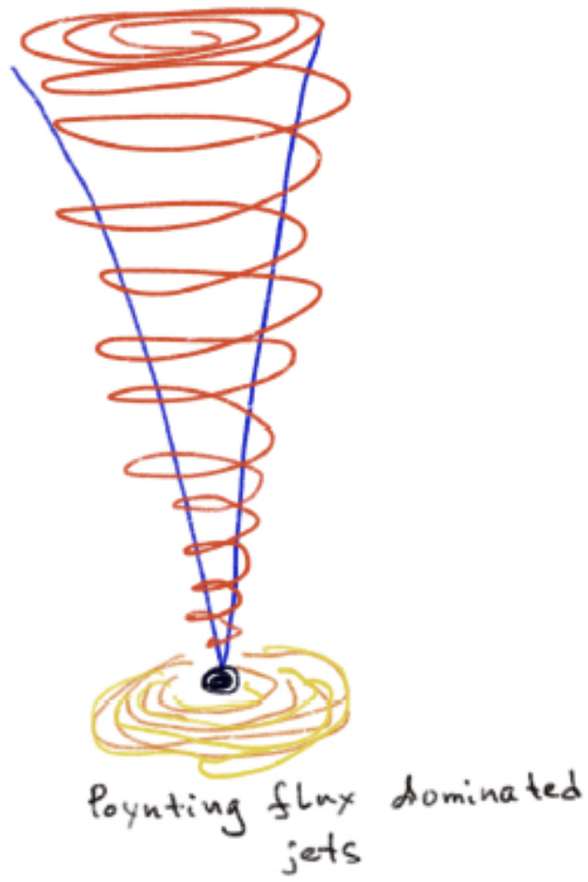
Zhang et al. 2011

external dissipation

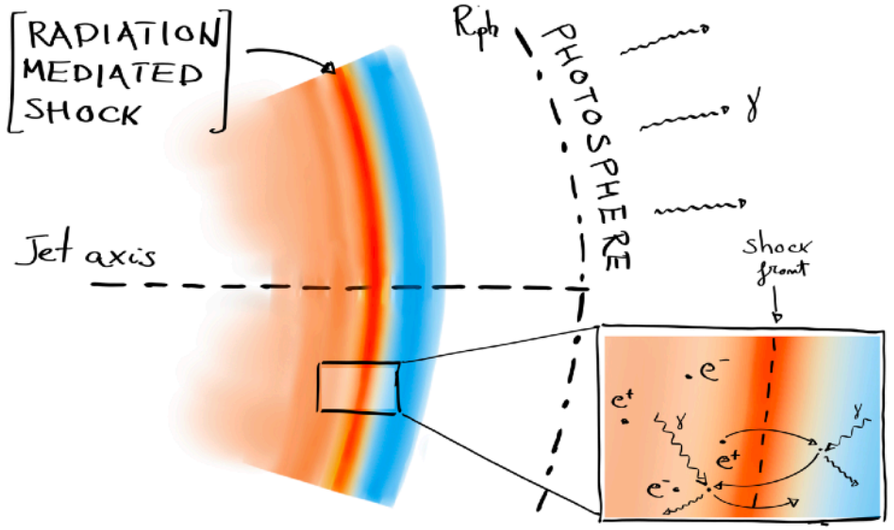
GRB jet mystery

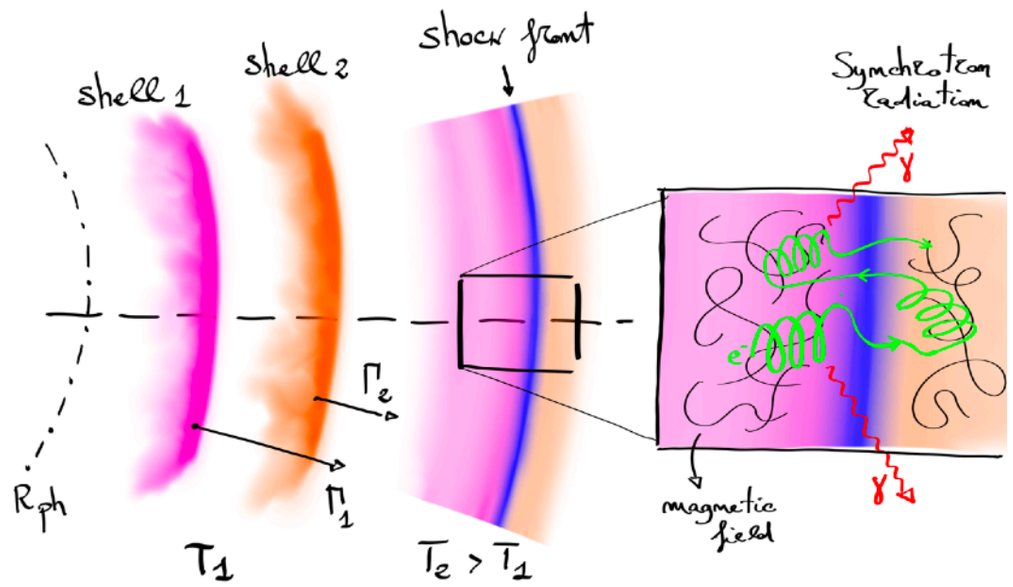


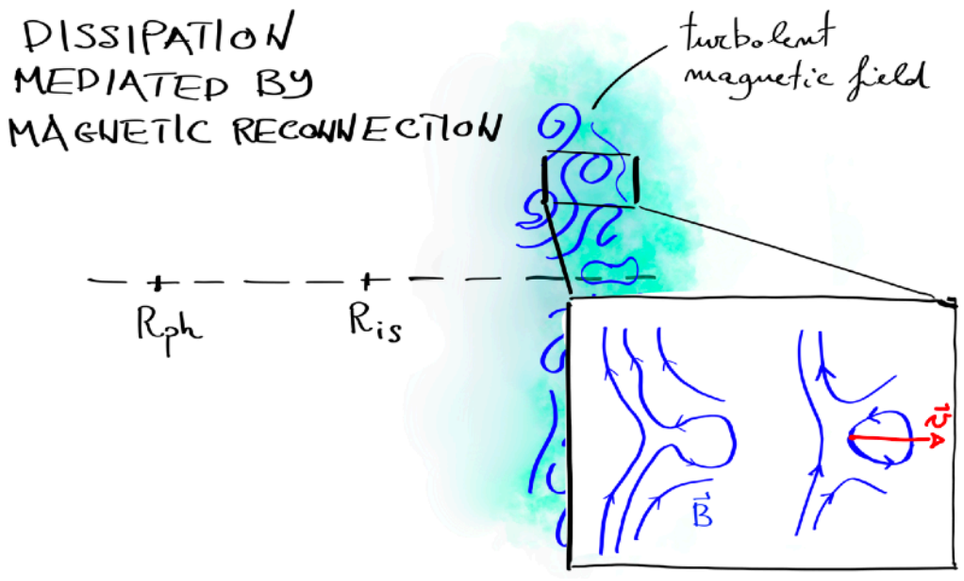
Cavallo & Rees 1978
Paczýnski 1986
Goodman 1986
Shemi & Piran 1990



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


RADIATION MEDIATED SHOCK
R_{ph}
PHOTOSPHERE
γ
Jet axis
shock front
e^-
e^+
γ
e^+
e^-
γ

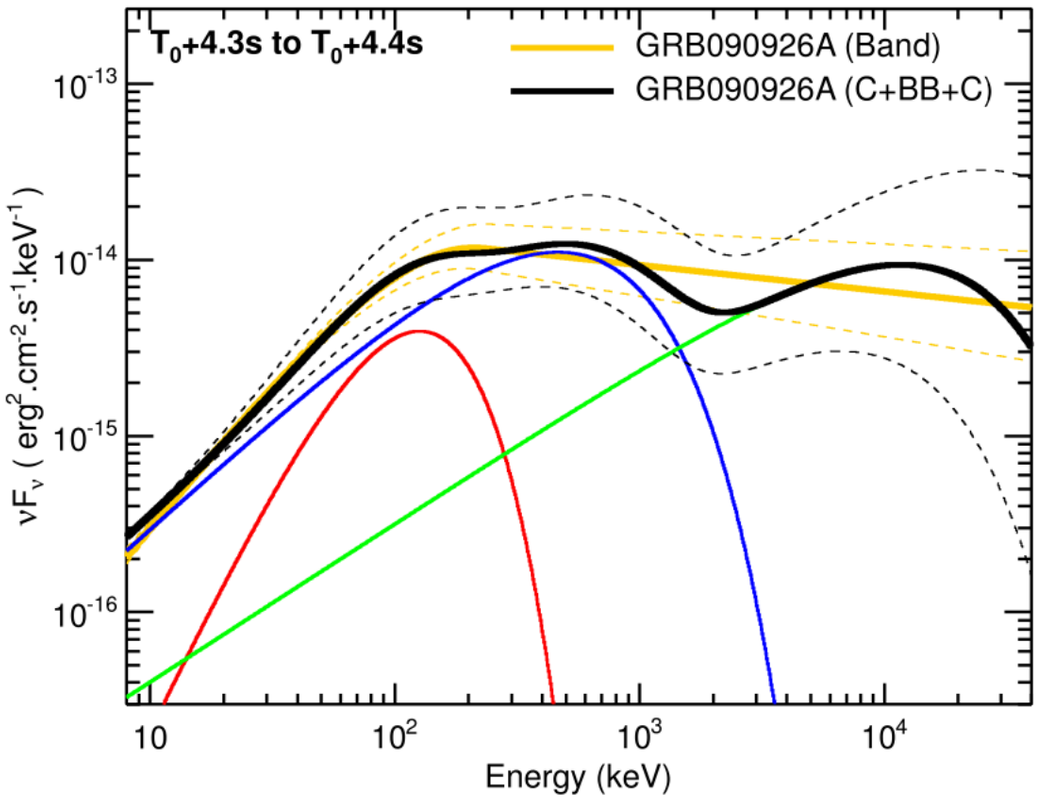

shell 1
shell 2
shock front
Synchrotron radiation
γ
Γ_e
Γ_1
R_{ph}
T_1
$T_e > T_1$
magnetic field
γ
e^-


DISSIPATION MEDIATED BY MAGNETIC RECONNECTION
turbolent magnetic field
R_{ph}
R_{is}
$\vec{B}$
$\vec{v}_A$

Looking for thermal components

multiple thermal and non-th. components

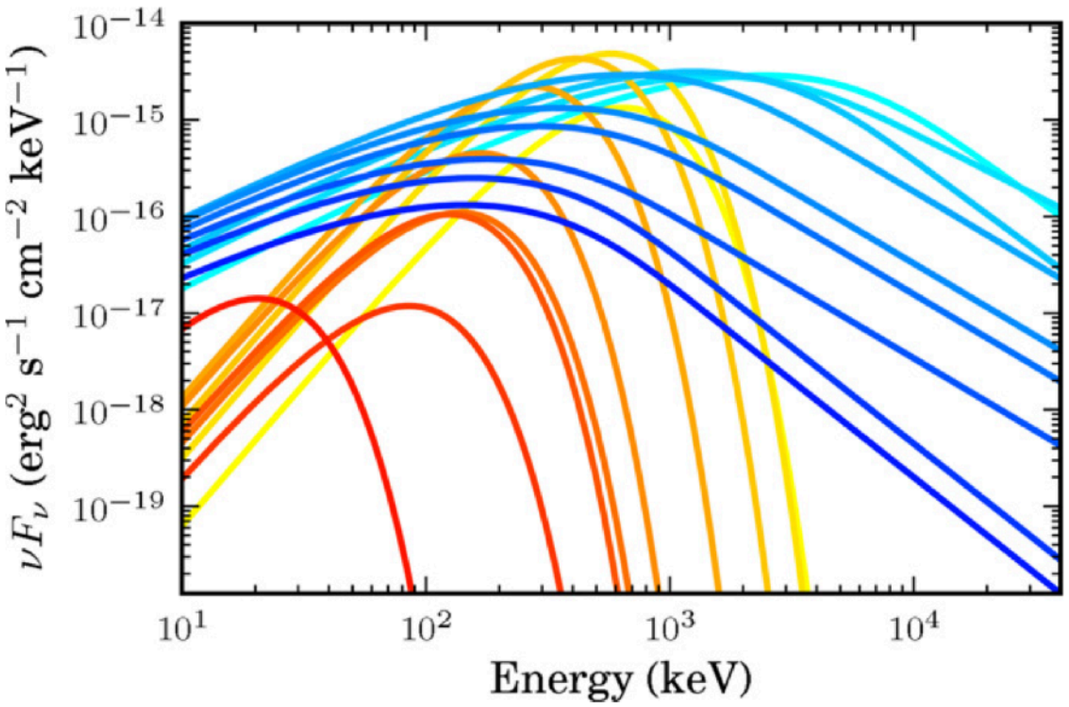
[10 GRBs]



Guiriec et al. 2011-2017

thermal + non.th. (fixed slow-cool synchrotron)

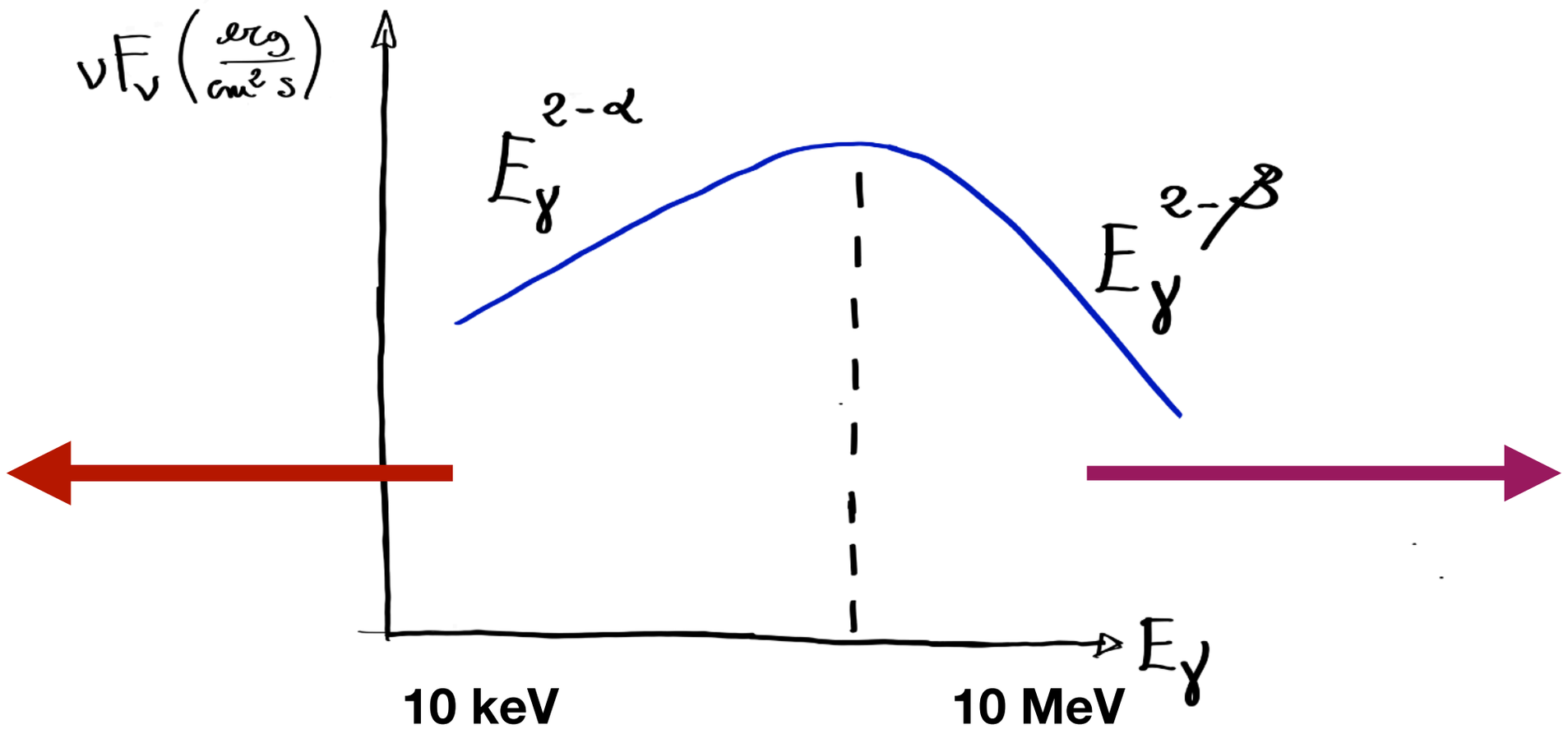
[9 GRBs]



Burgess et al. 2011-2014

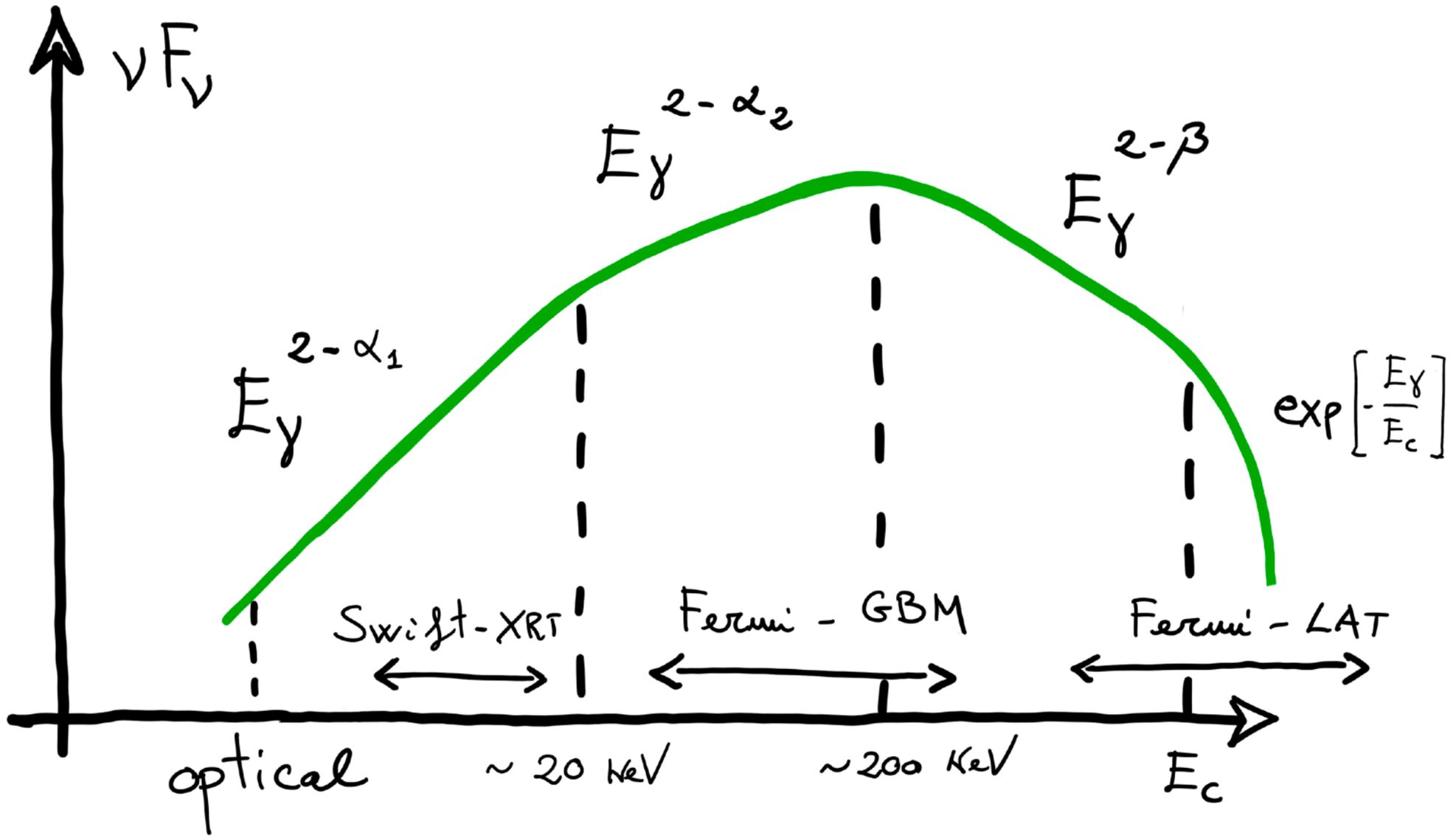
\+ many authors on individual GRBs with BB components

Multi-wavelength approach



γ-ray bursts

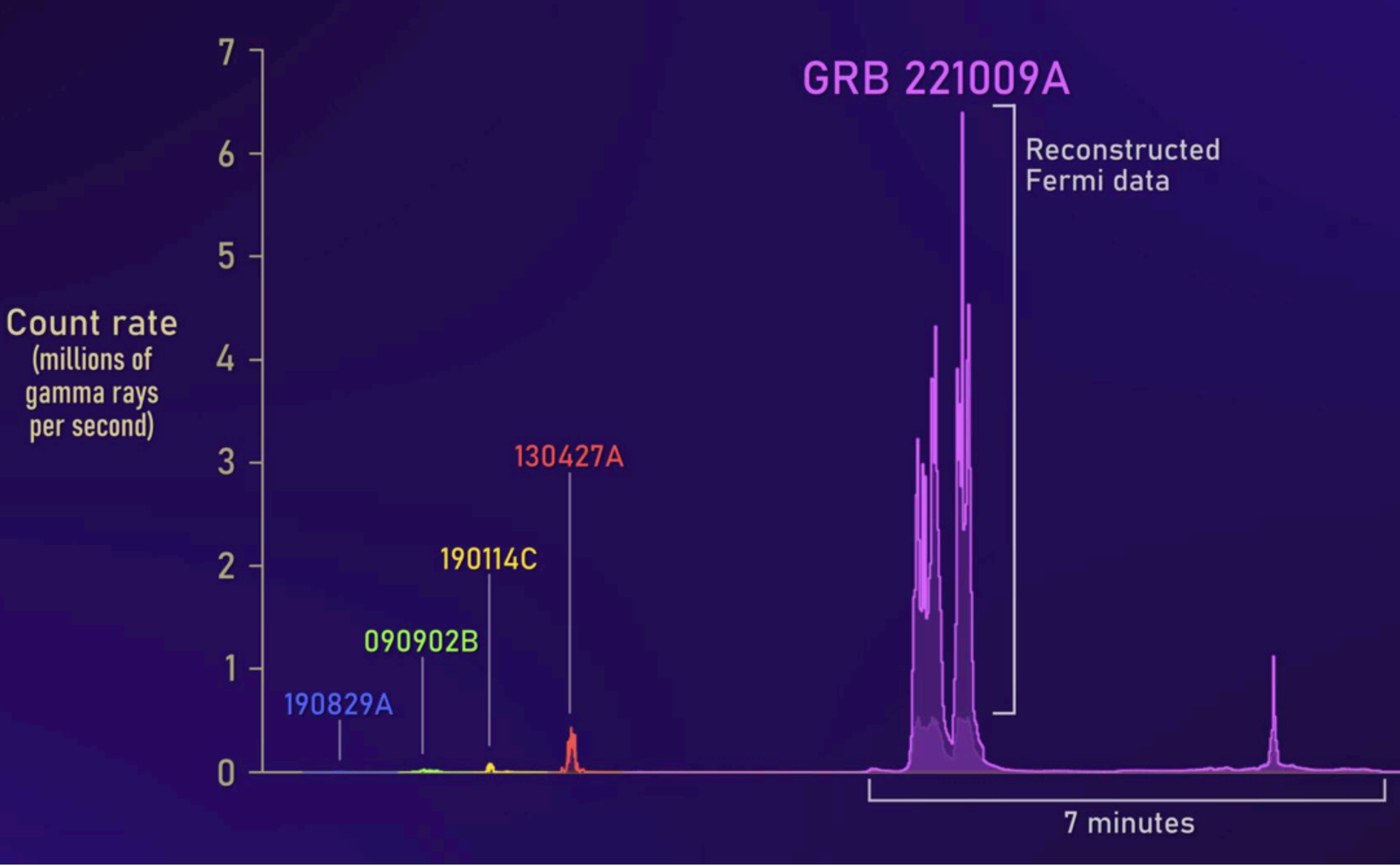
the prompt emission



γ-ray bursts

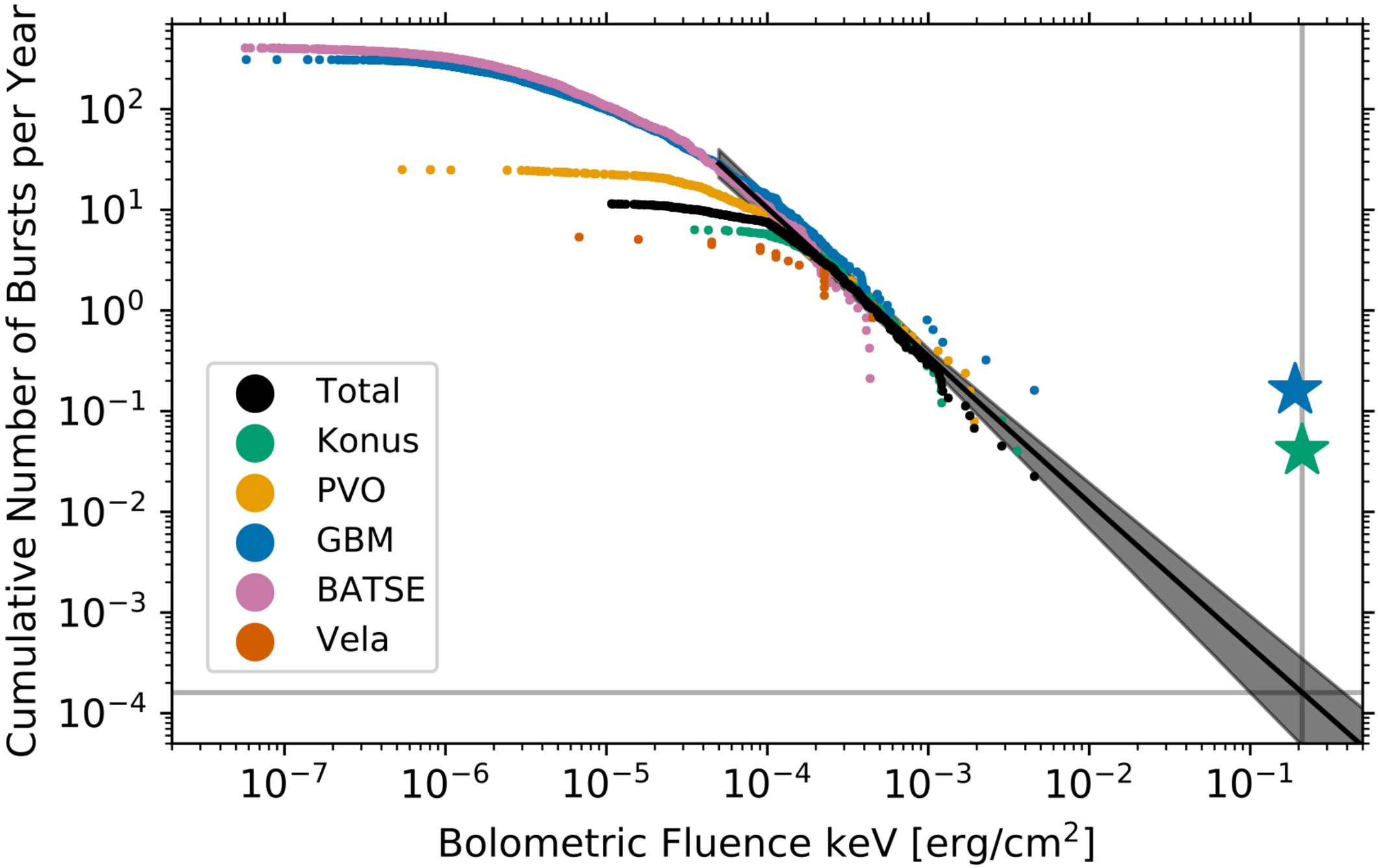
The prompt emission

BOAT 221009A



NASA Goddard Space Flight Center, Adam Goldstein (USRA)

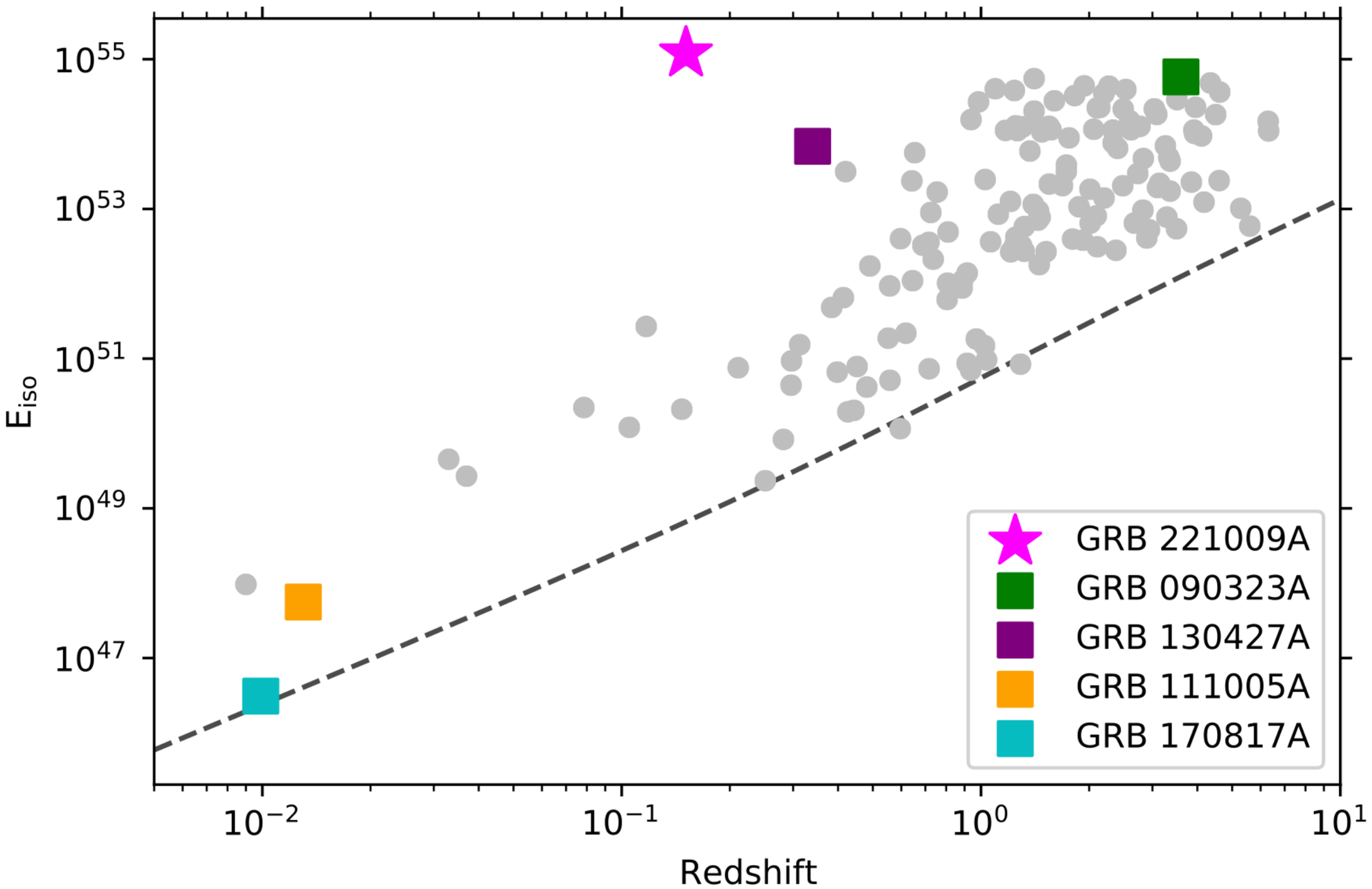
the observed fluence



1/10000 yrs event

Burns et al. 2023

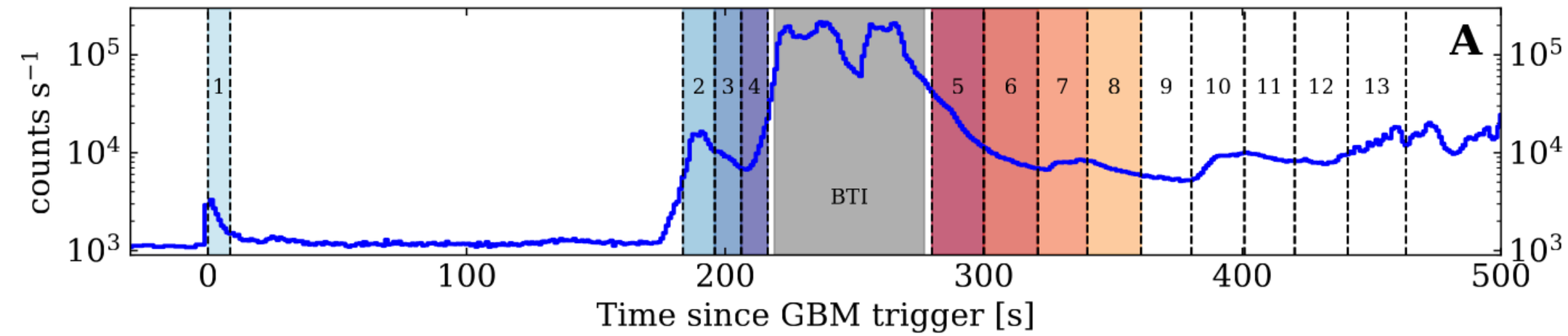
energetics

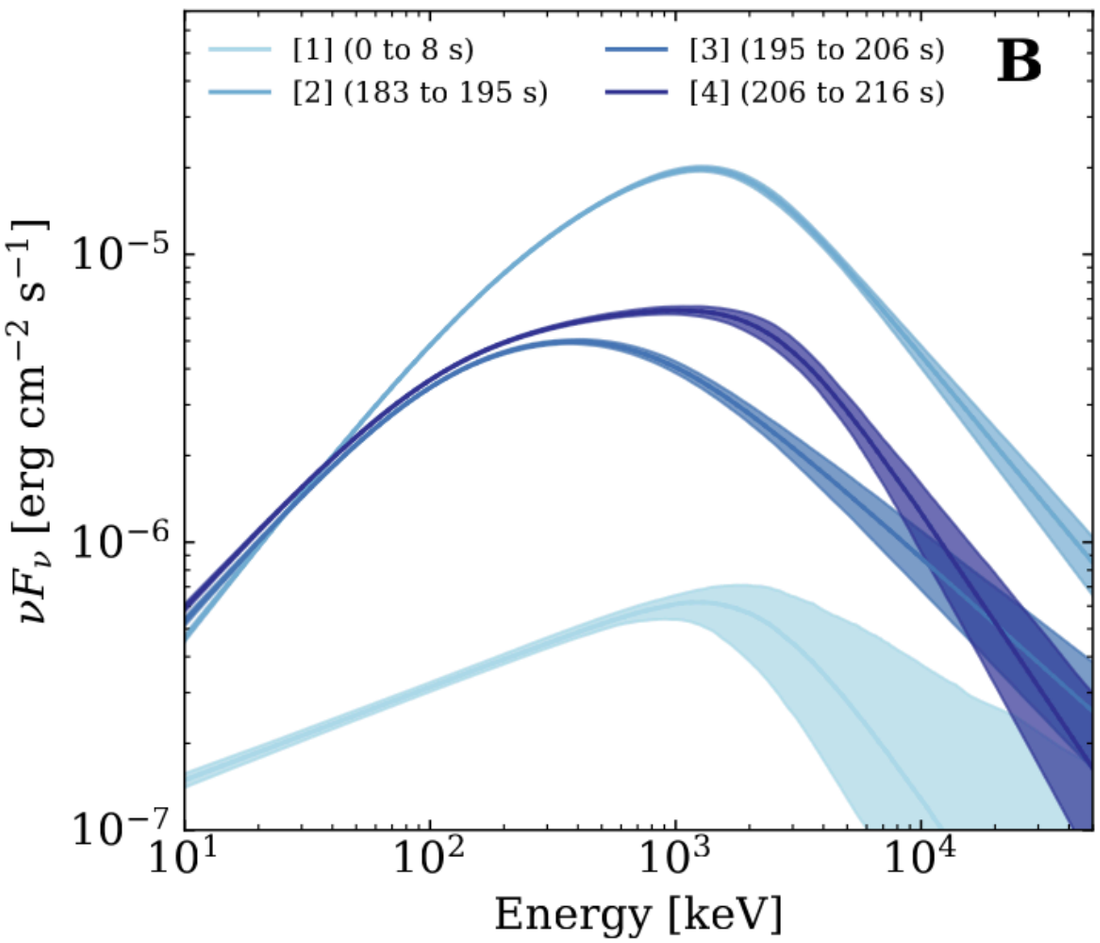


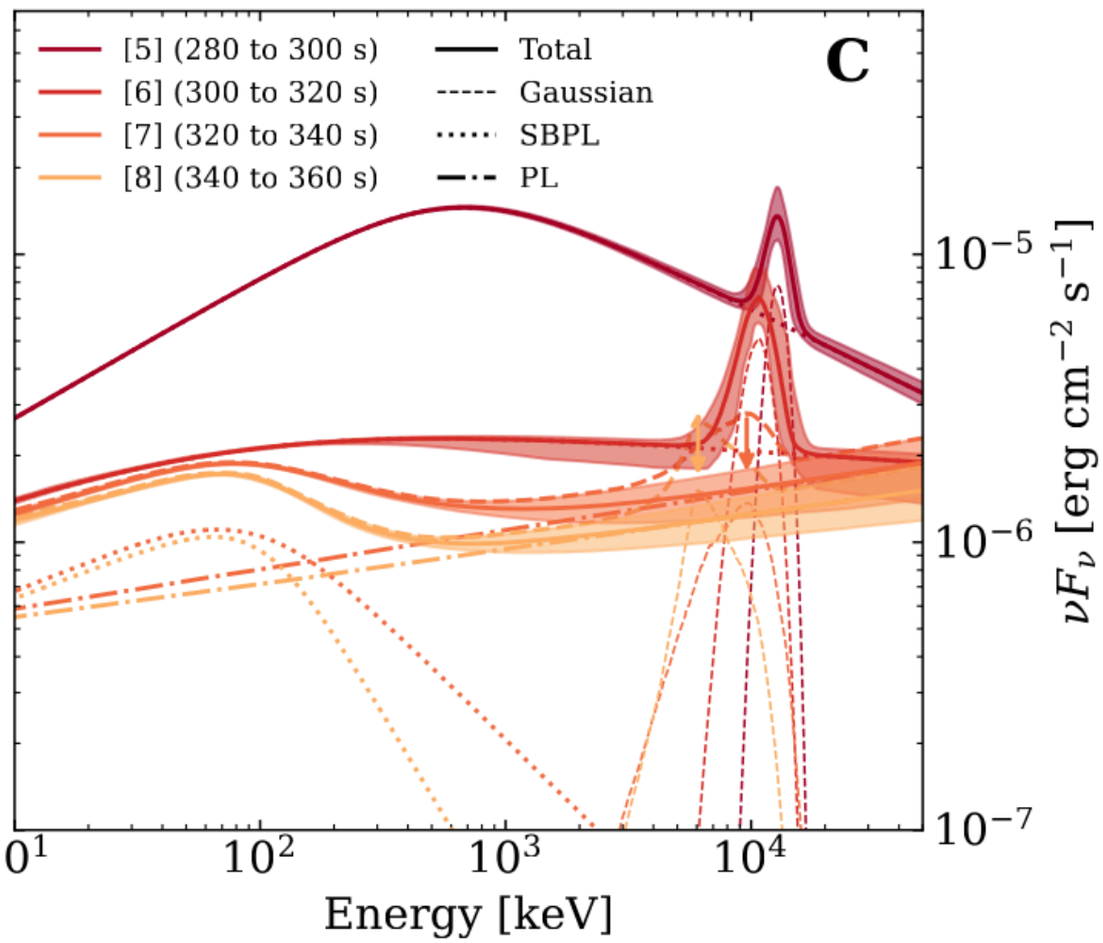
1/10000 yrs event

Burns et al. 2023

Discovery of the ~ 10 MeV line

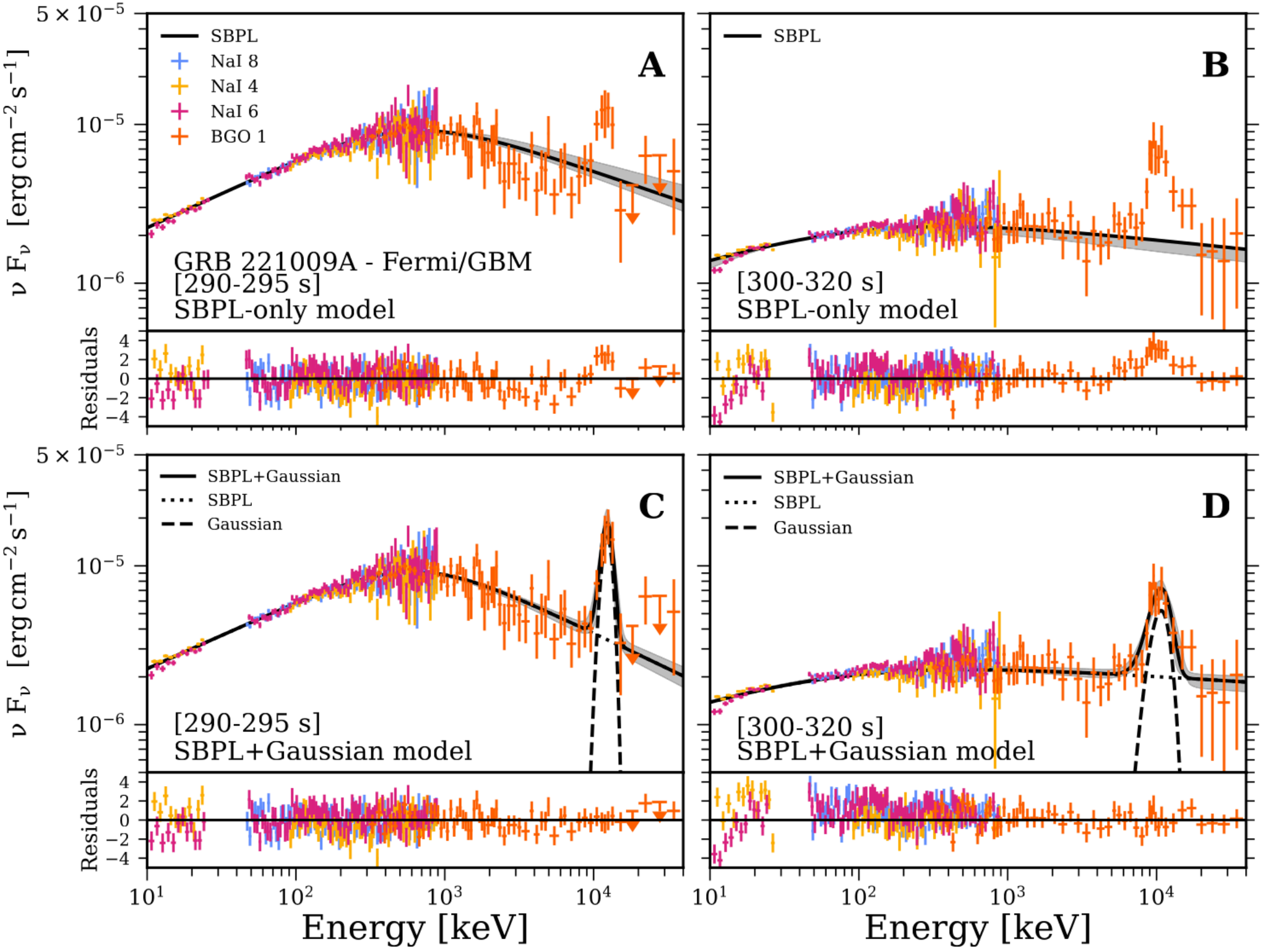






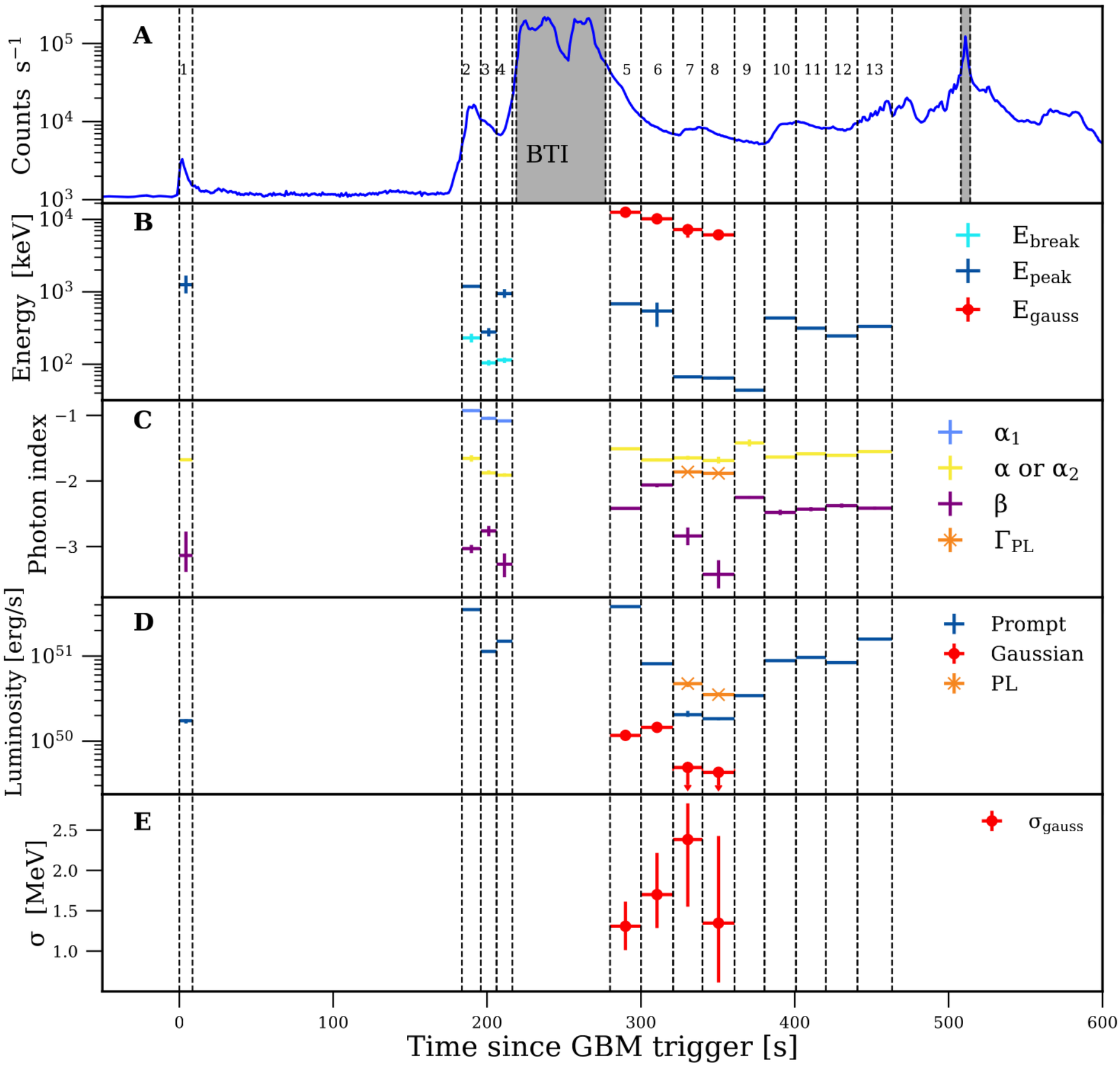
Ravasio et al. 2024, Science

Discovery of the ~ 10 MeV line

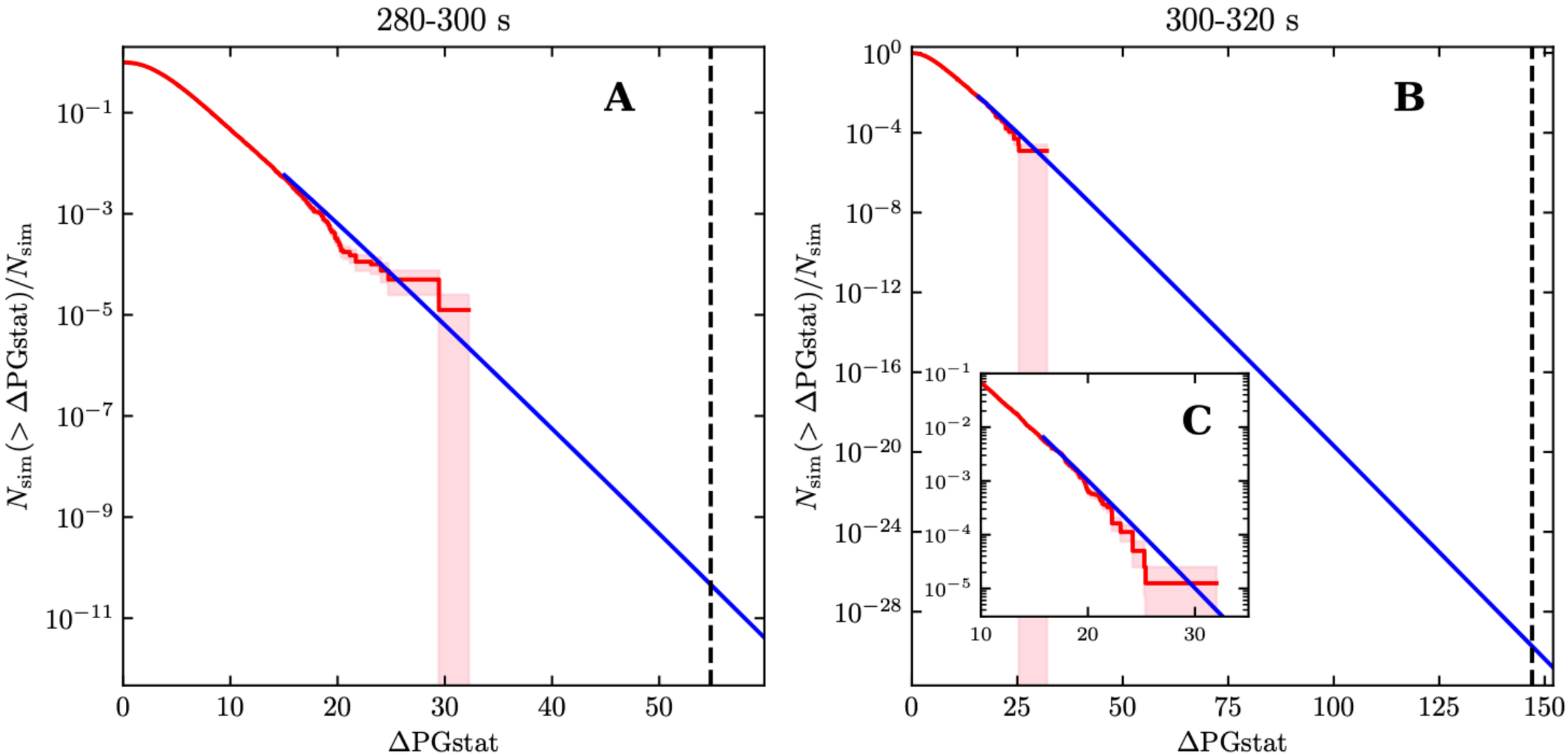


Ravasio et al. 2024, Science

Time-evolution of the MeV line



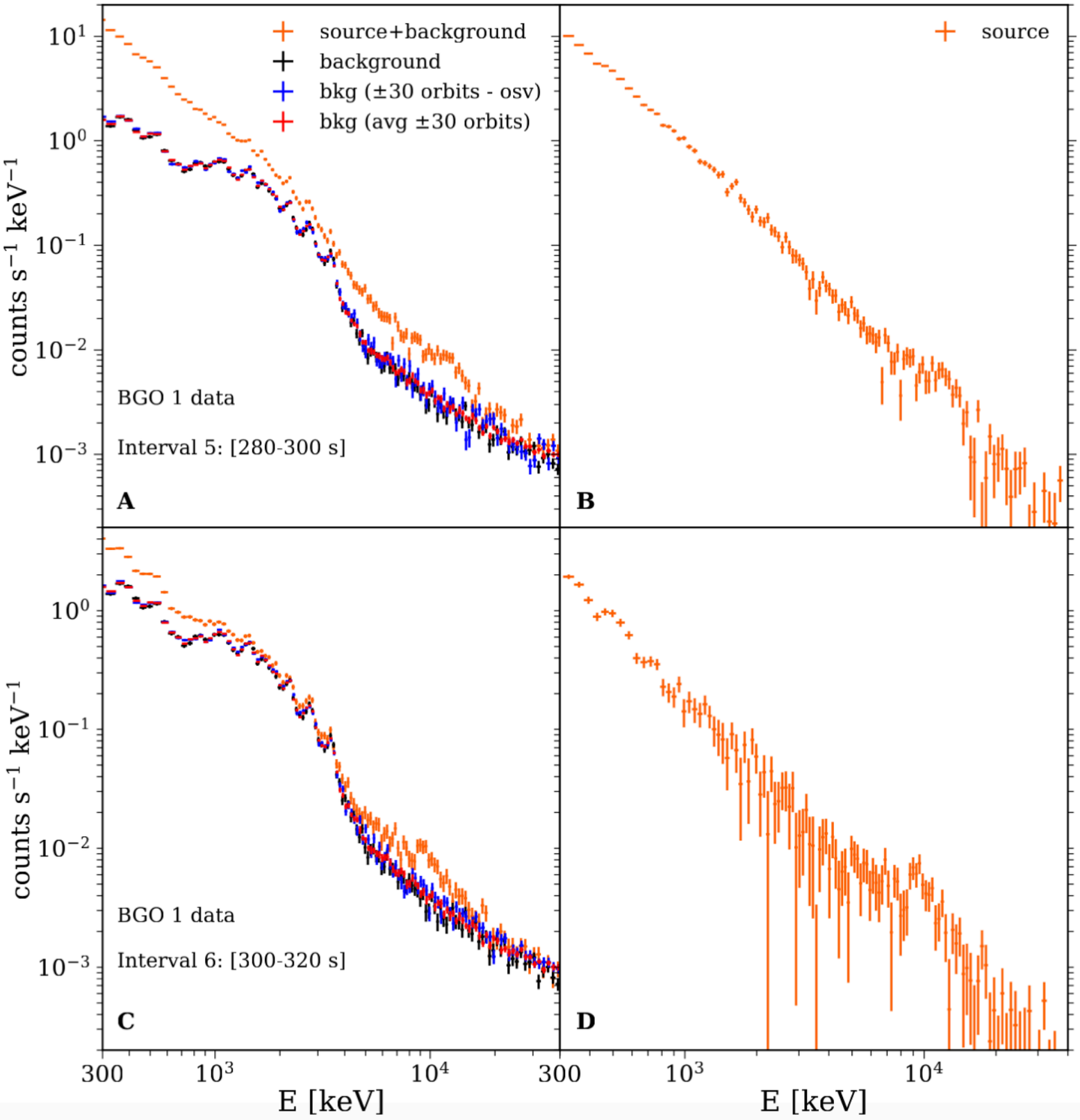
Significance



6 and 11 sigma post-trial

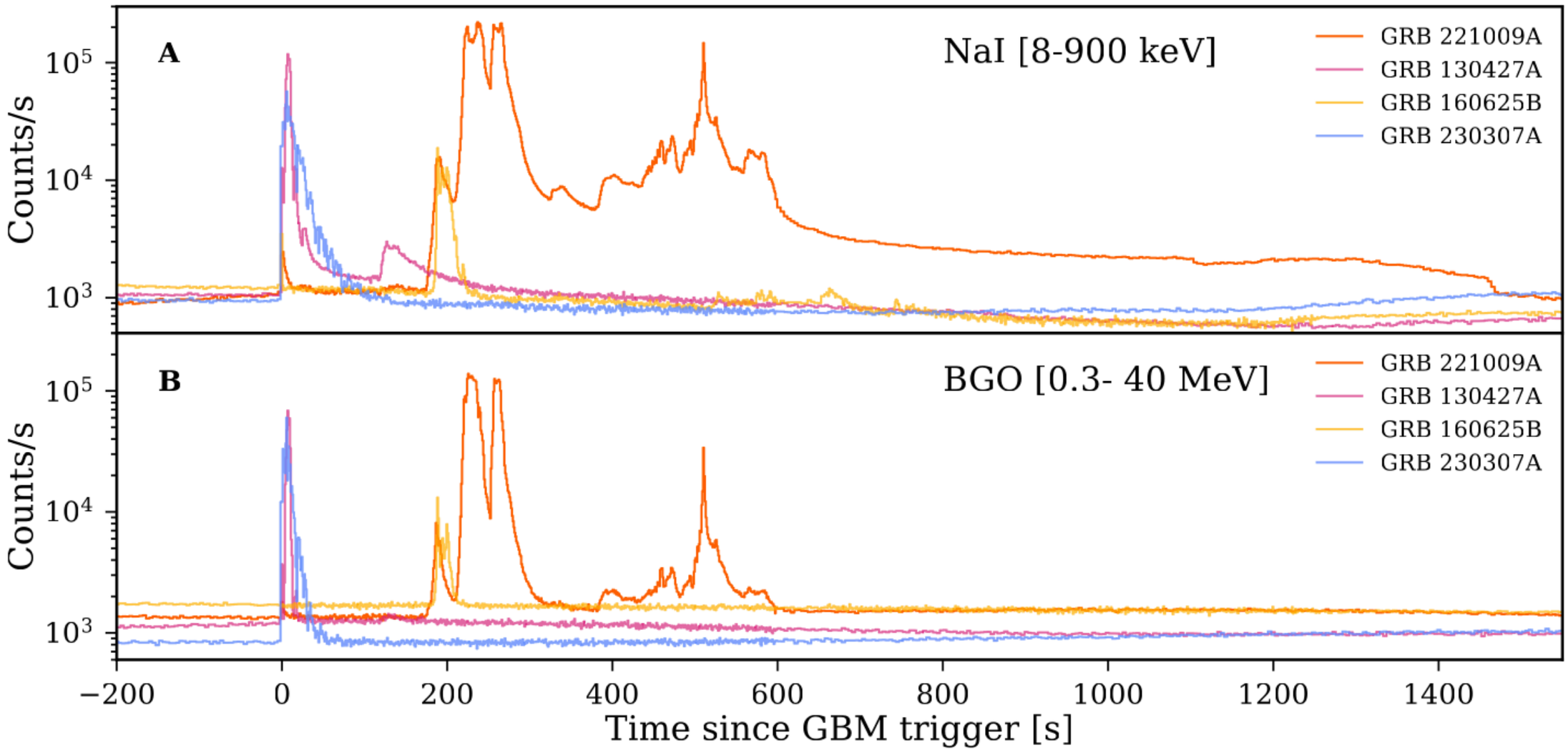
Ravasio et al. 2024, Science

Background



Ravasio et al. 2024, Science

Other monster GRBs



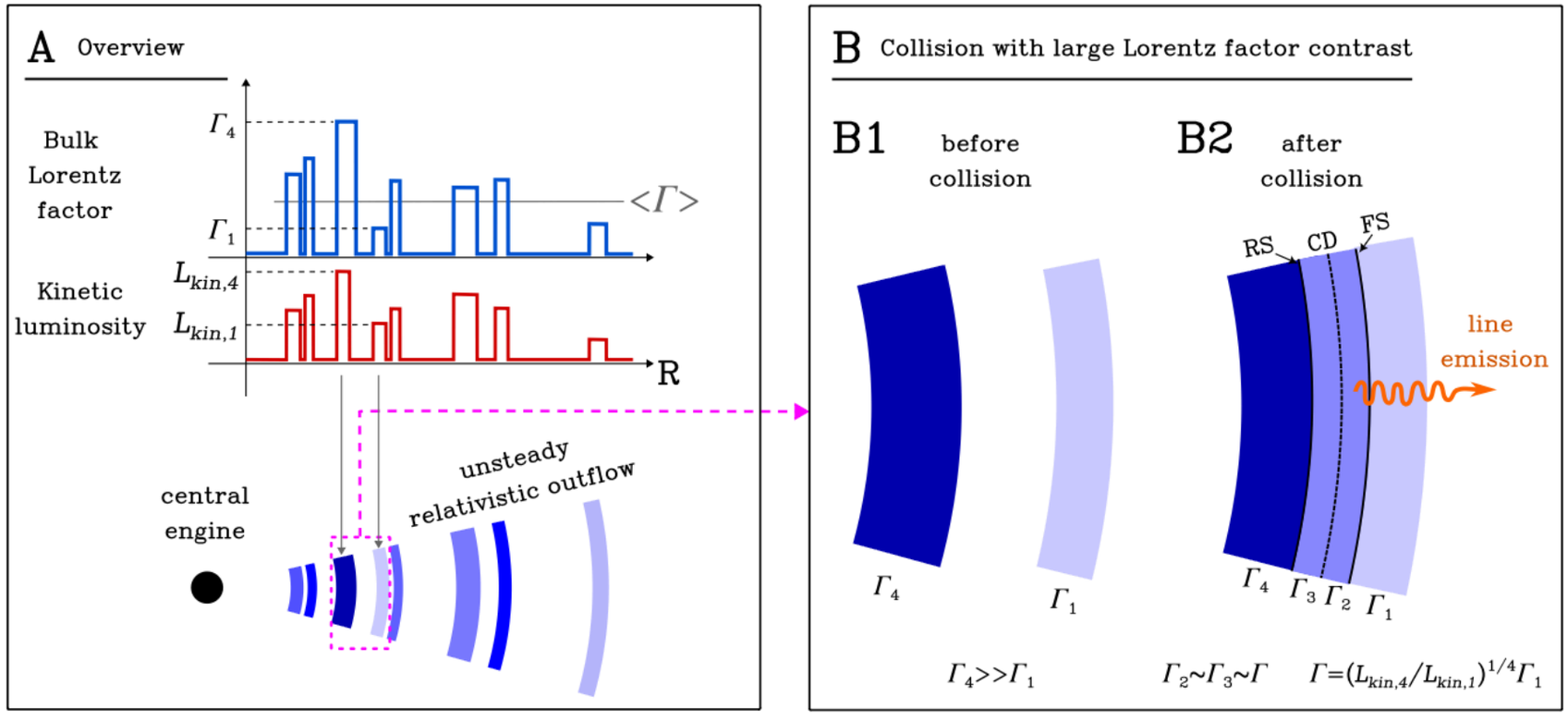
Ravasio et al. 2024, Science

Origin of the MeV line

1. Take a keV line and boost it to MeV —-> too fast SN ejecta

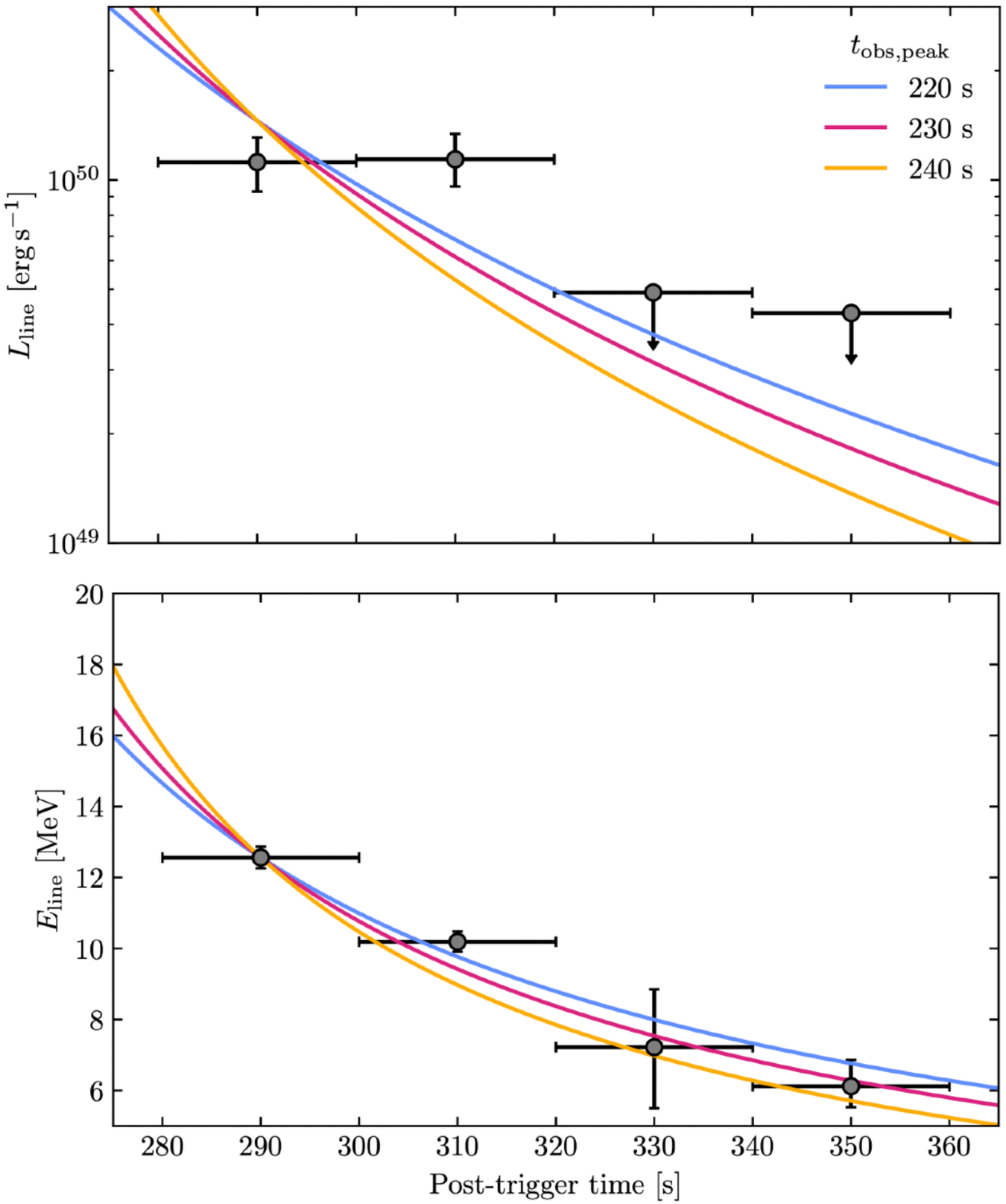
2. Take an annihilation line and boost it to MeV —-> small bulk LF

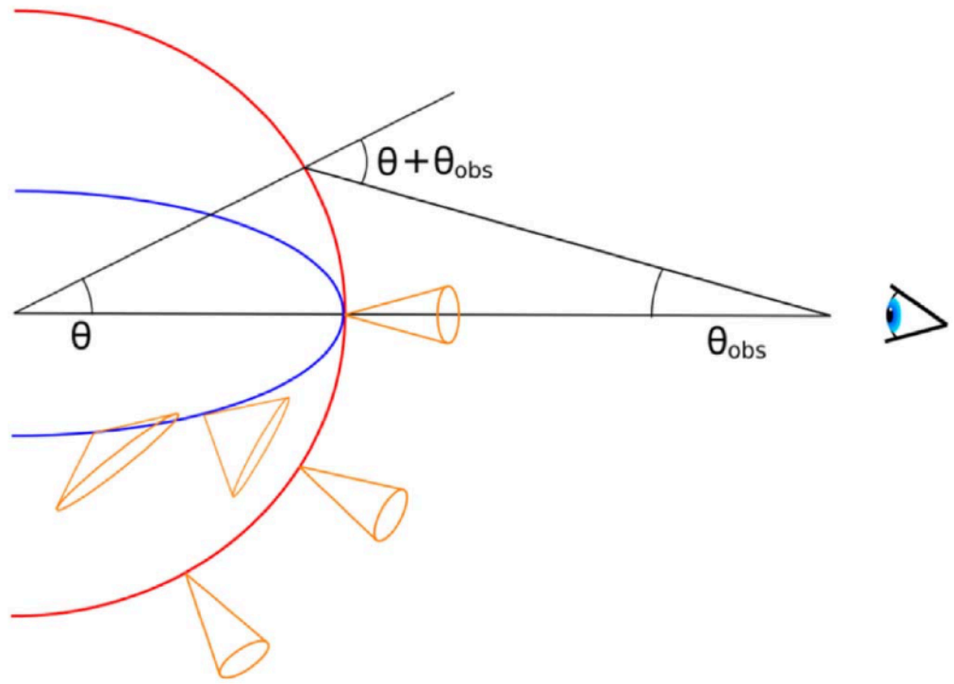
2.1 Slow shells in the internal shocks model



Ravasio et al. 2024, Science

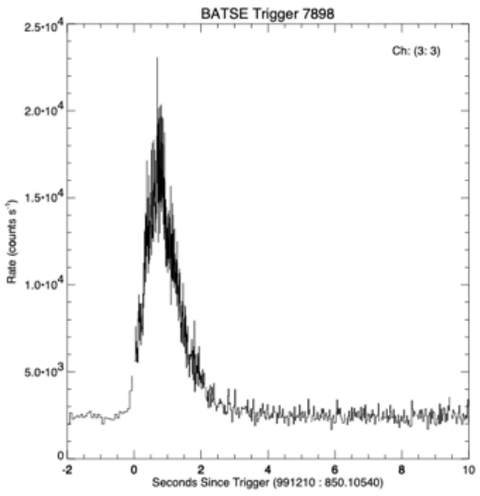
2.2 Fast or a slow shell observed later on

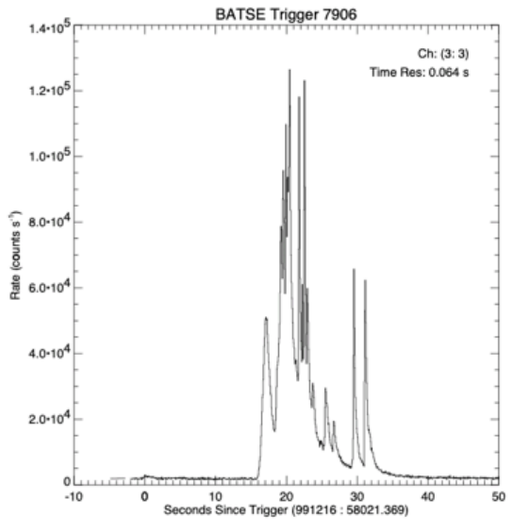


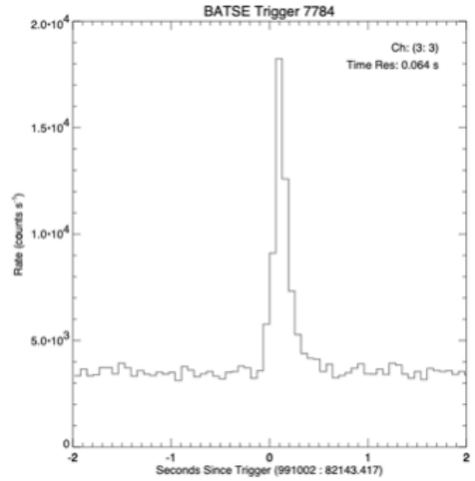


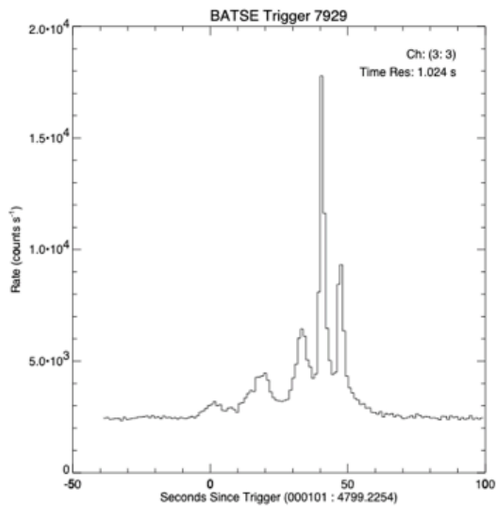
Ravasio et al. 2024, Science

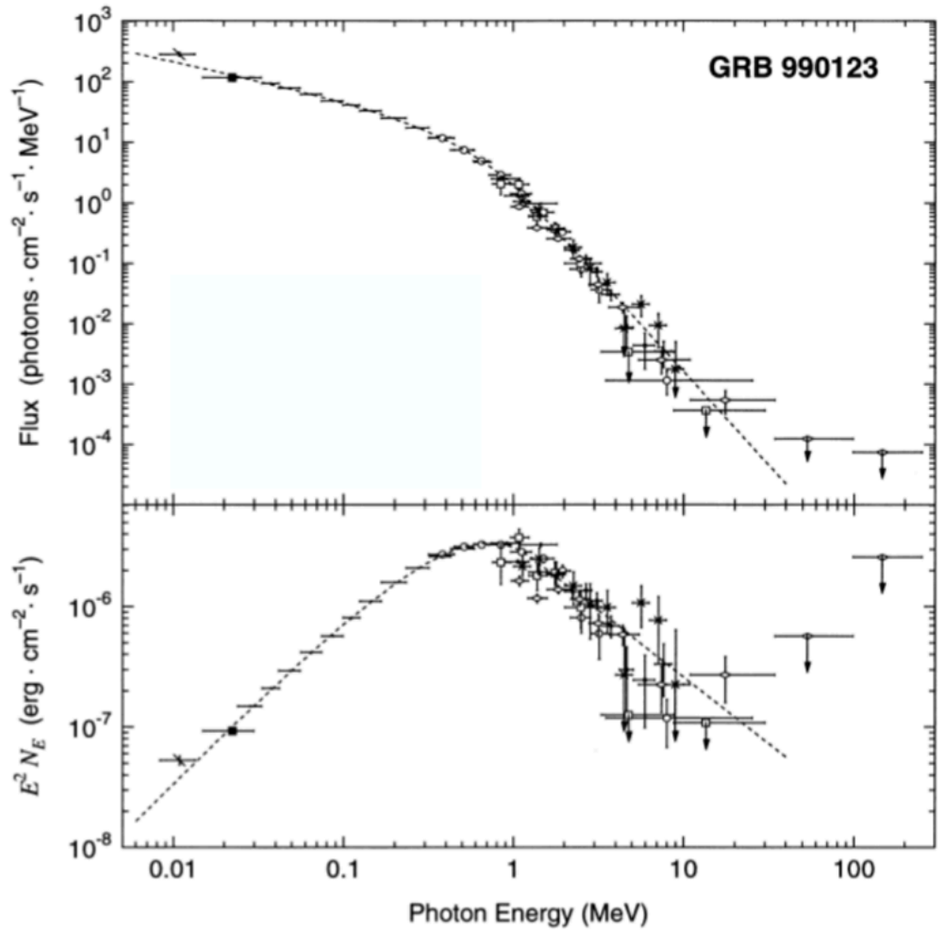
γ-ray bursts











Briggs et al. 1999

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photons ~ MeV

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variability 0.01-1 s

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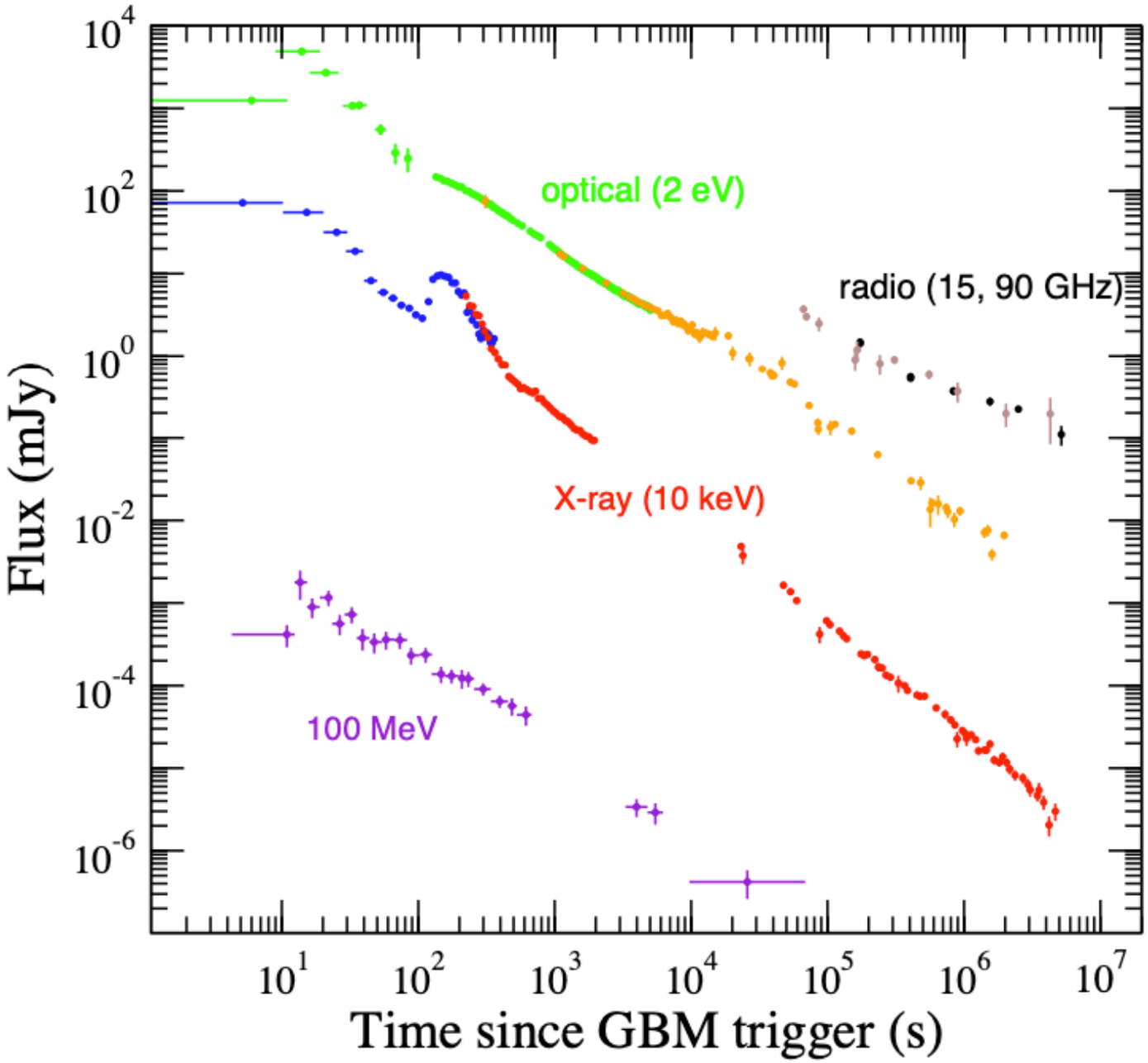
γ-ray bursts

the afterglow

Afterglow



example GRB 130427A Panaitescu et. al. 2013

discovered

Costa et al. 1997

predicted

Paczýnski & Rhoads 1993

Mészáros & Rees 1997

dynamics

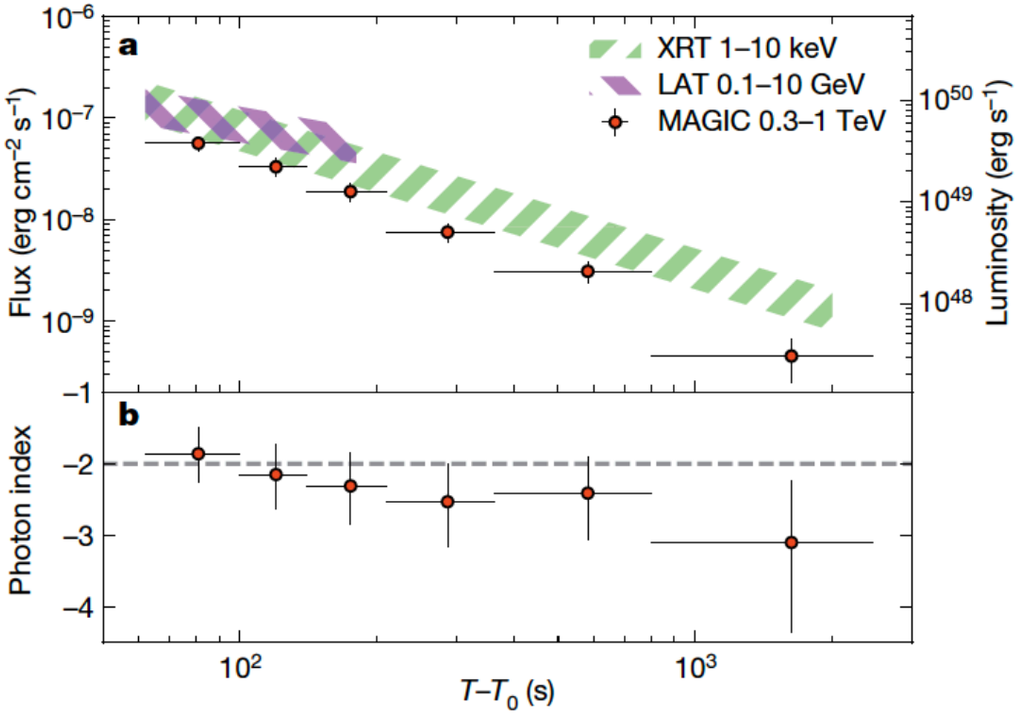
Blandford & McKee 1976

phenomenology

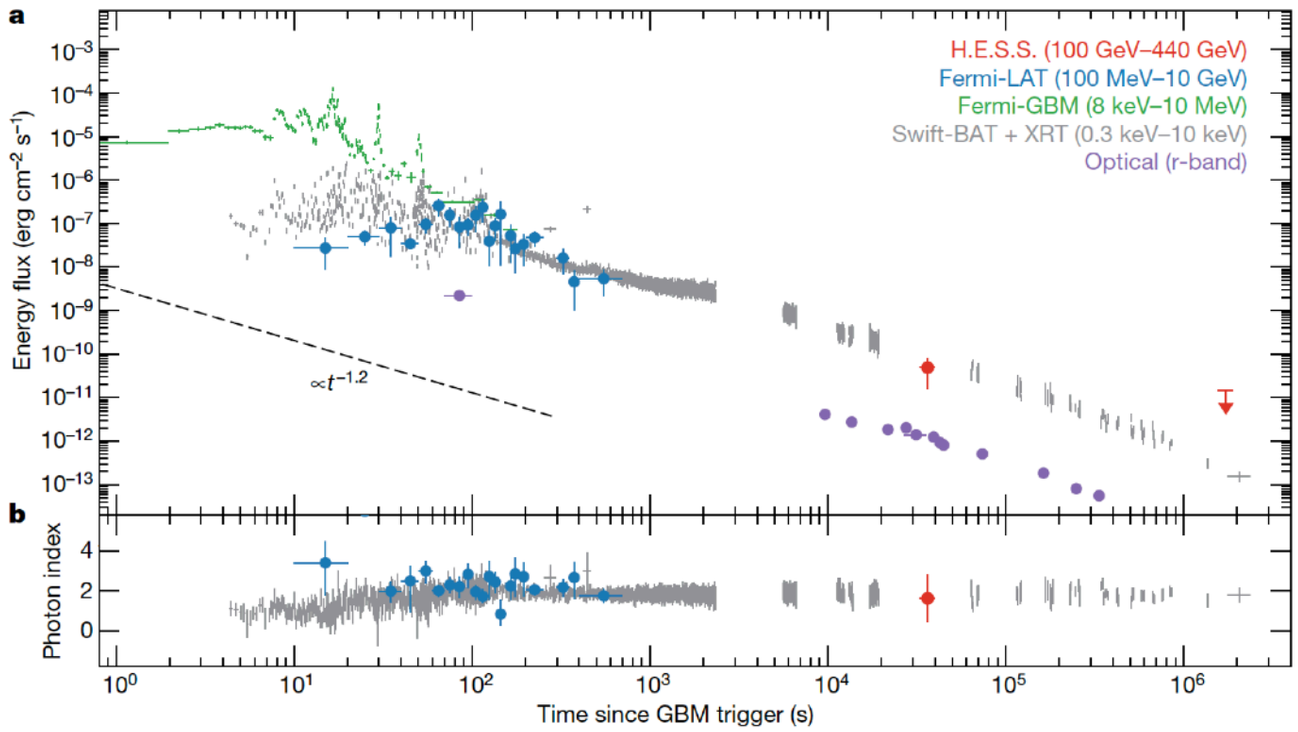
Sari et al. 1998

GRBs at Very High Energies - the discoveries of 2019

MAGIC and H.E.S.S. collaborations



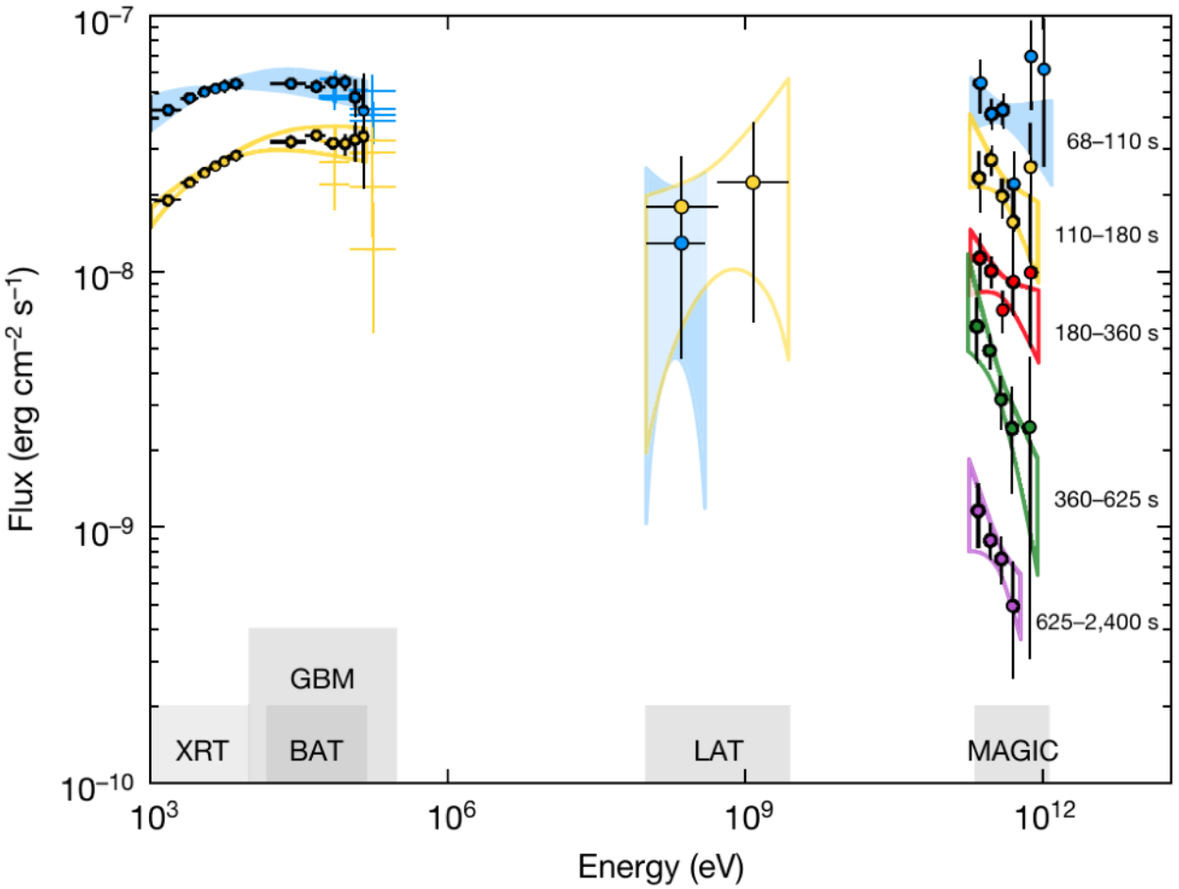
MAGIC collaboration
Nature 2019



H.E.S.S. collaboration
Nature 2019

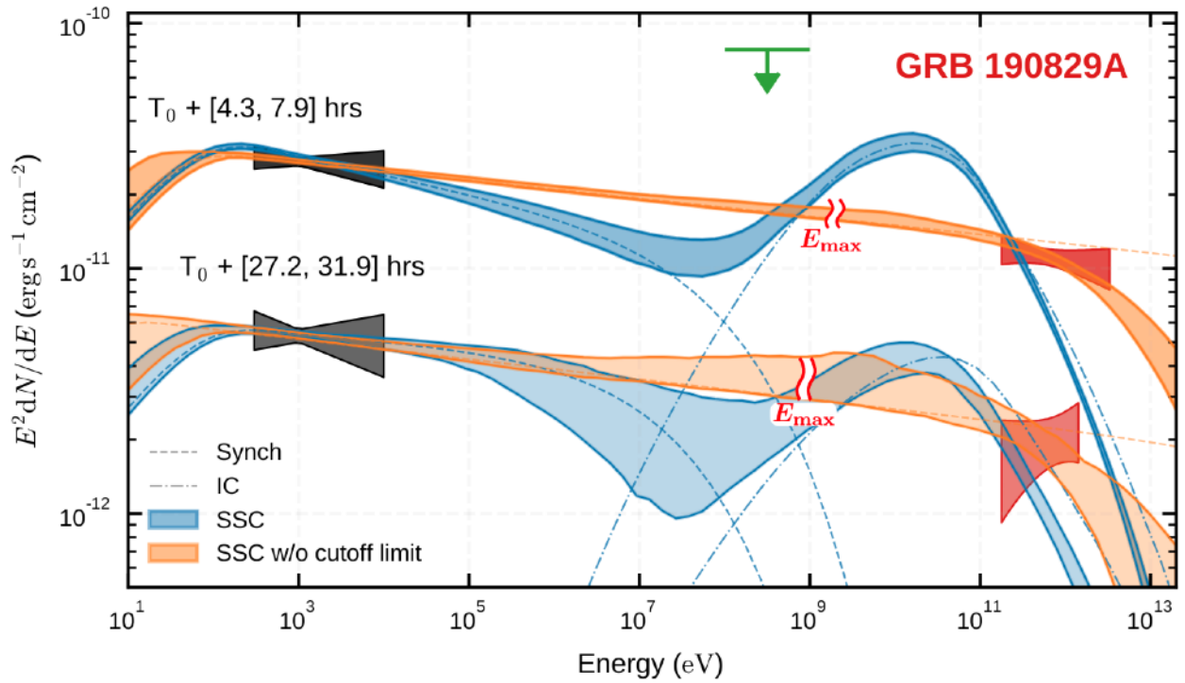
Spectra

GRB 190114C



MAGIC collaboration
Nature 2019

GRB 190829A



H.E.S.S. collaboration
Science 2021

GRBs in the TeV gamma-rays

GRBs	Time ($t-T_0$)	0.3 keV – 10 keV – 100 keV – 1 MeV – 100 MeV – 10 GeV – 100 GeV – 1 TeV
GRB 180720B	~10 hr	? ? ? ? H.E.S.S.
GRB 190114C	68–110 s	XRT GBM BAT ? LAT (~3σ) MAGIC@20
	110–180 s	XRT GBM BAT ? LAT (~5σ)
GRB 190829A	4.3–7.9 hr	XRT ? ? LAT (U.L.) H.E.S.S.
	27.2–31.9 hr	XRT ? ? LAT (U.L.)
GRB 201216A	60–1.2 ks	XRT ? ? LAT (U.L.) MAGIC@20

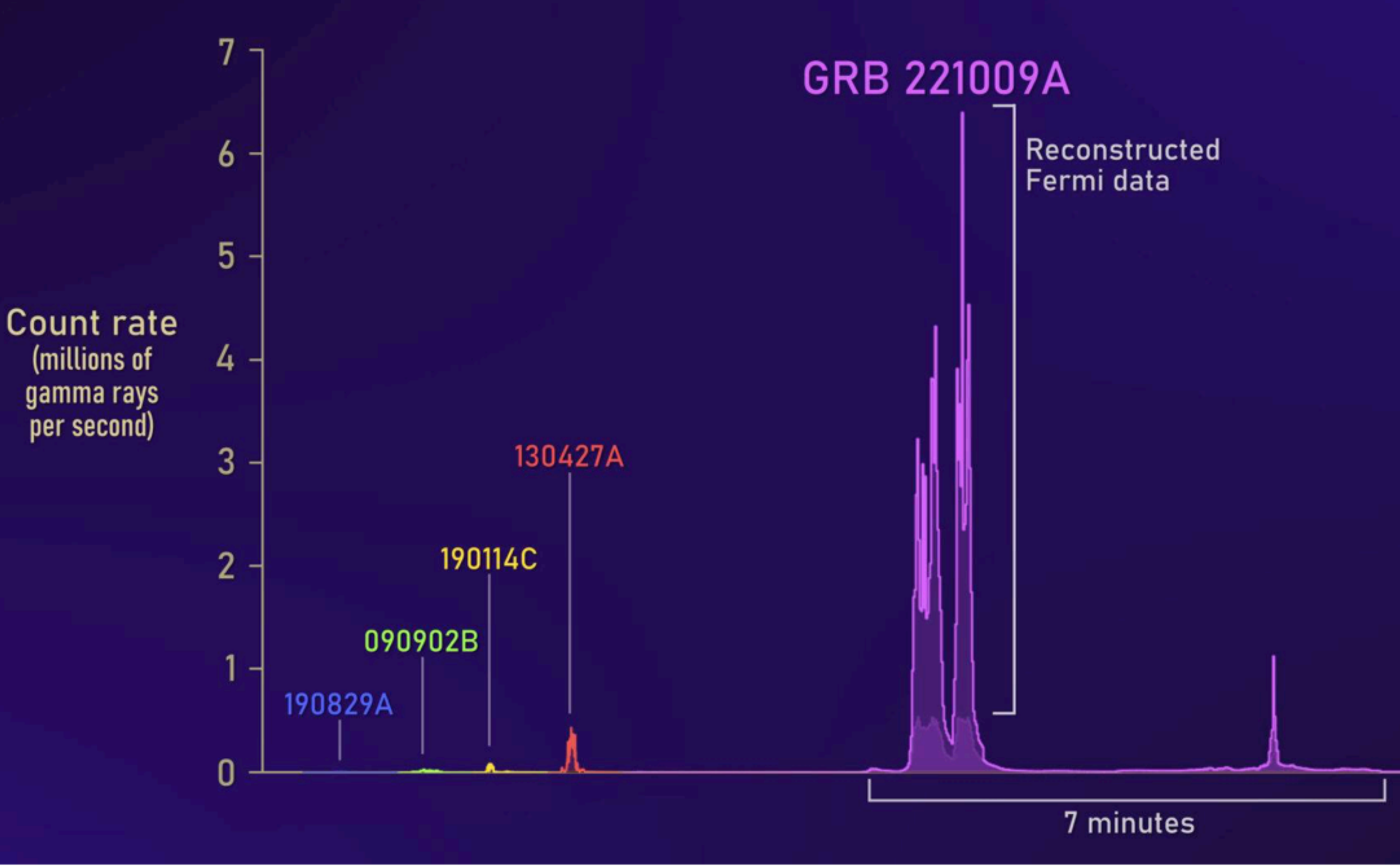
XRT BAT GBM LAT IACTs

MAGIC Collaboration:
Nature v. 575, p. 455–458 (2019) and
Nature v. 575, p. 459–463 (2019)
H.E.S.S. collaboration, Nature, 2019
H.E.S.S. collaboration, Science, 2021
MAGIC Collaboration, MNRAS, 2024

γ-ray bursts

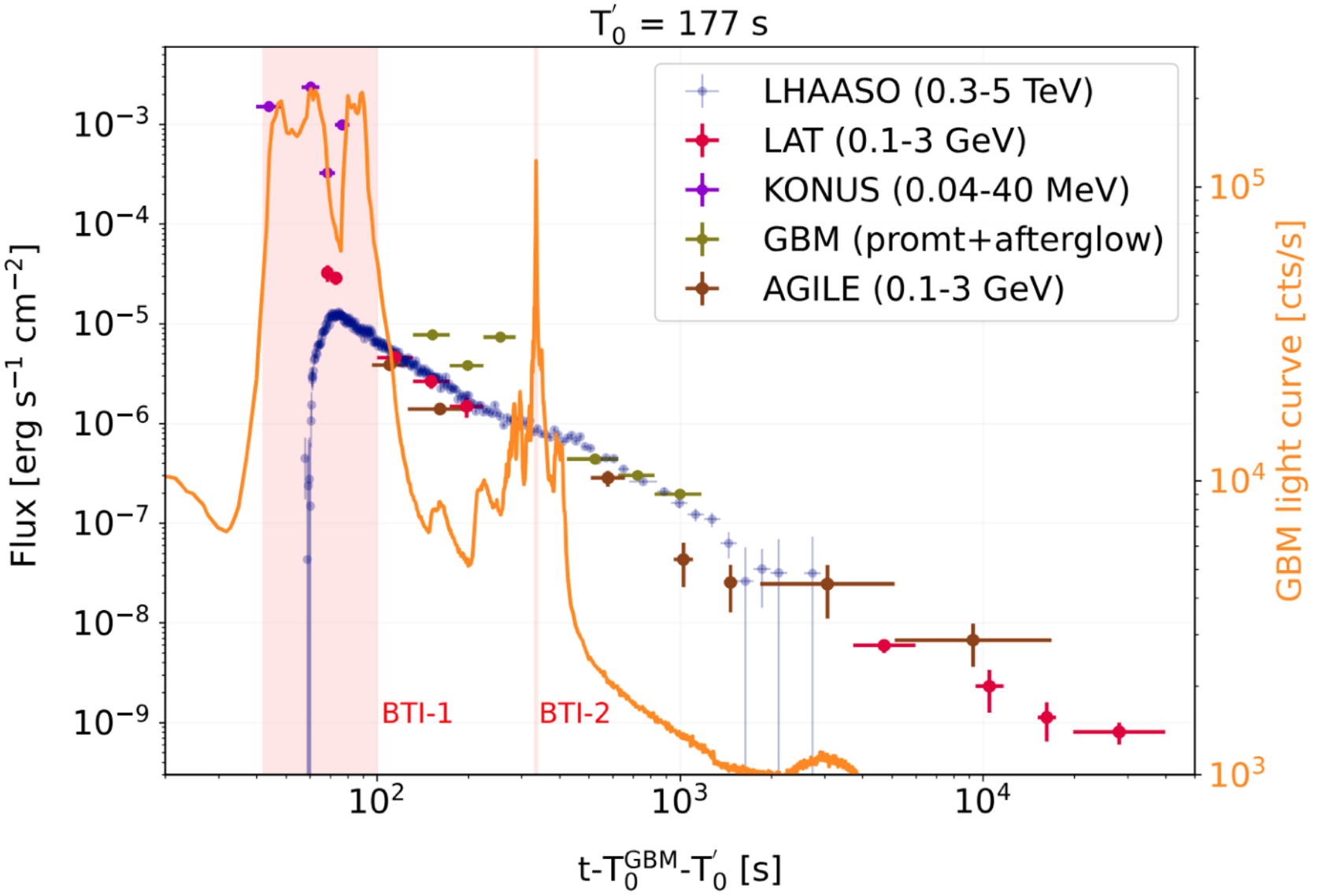
The afterglow emission

BOAT 221009A



NASA Goddard Space Flight Center, Adam Goldstein (USRA)

GRB 221009A - BOAT



Banerjee et al. 2024

LHAASO Collaboration, Science (2023)

Tavani et al 2023
ApJL 956 L23, 2023

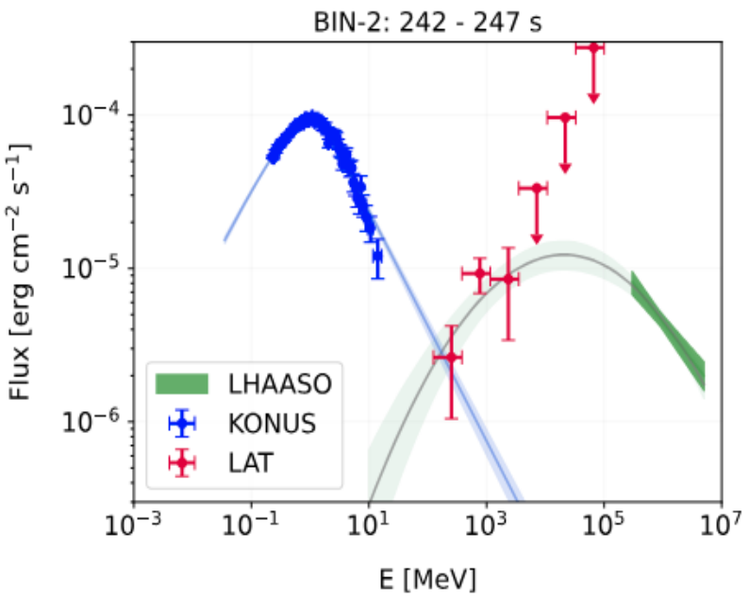
Bissaldi et al 2023

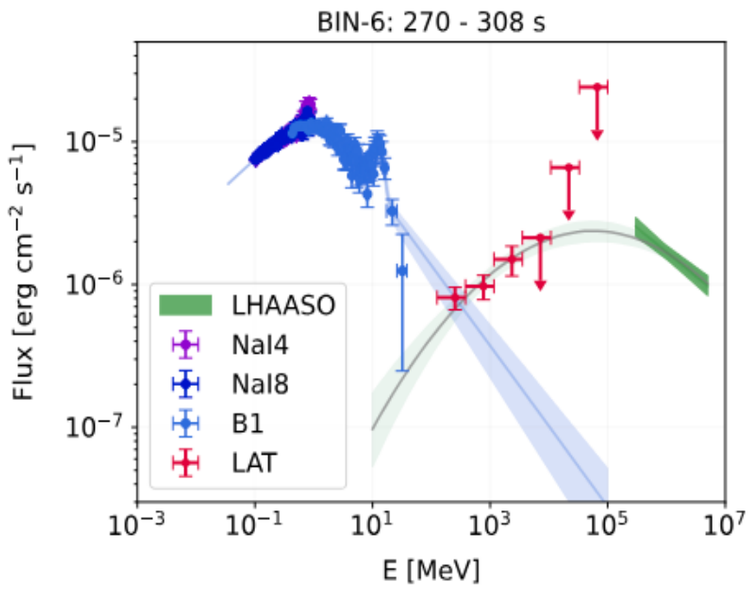
Frederiks et al 2023
ApJL, 949, L7 (2023)

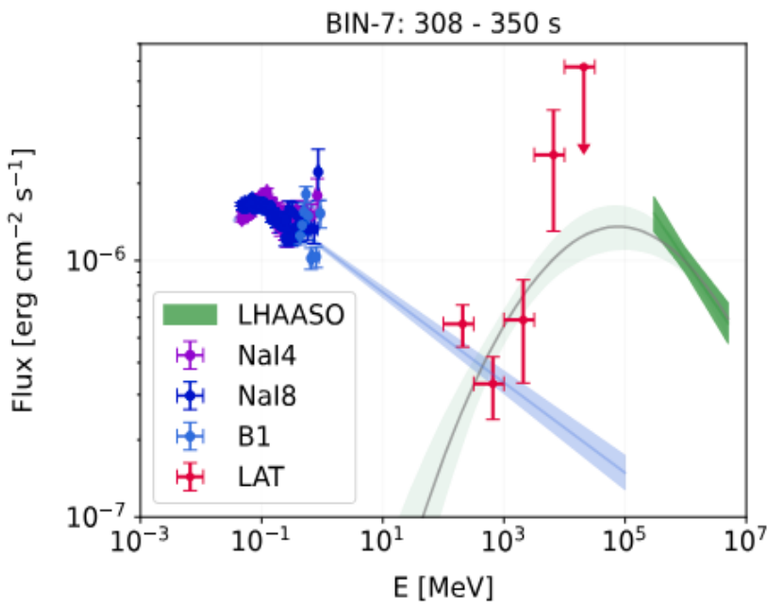
Lesage et al 2023,
ApJL 952 L42

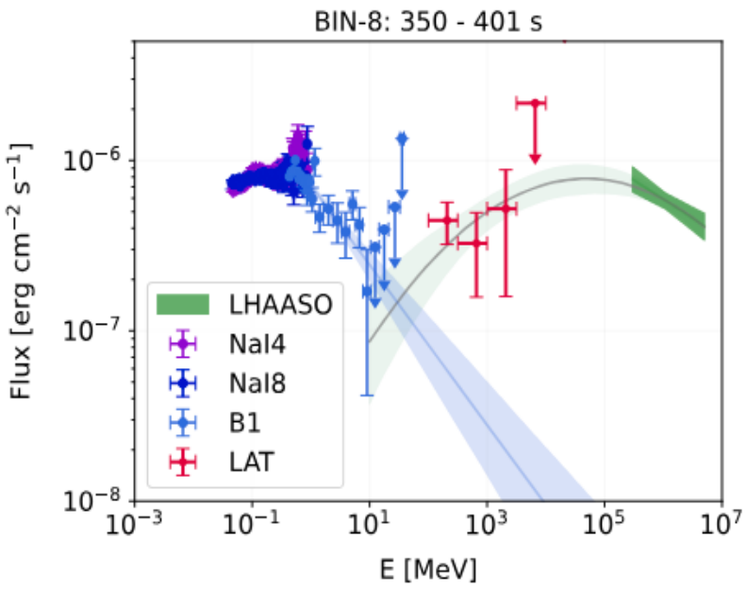
Burns et al 2023,
ApJL 946 L31

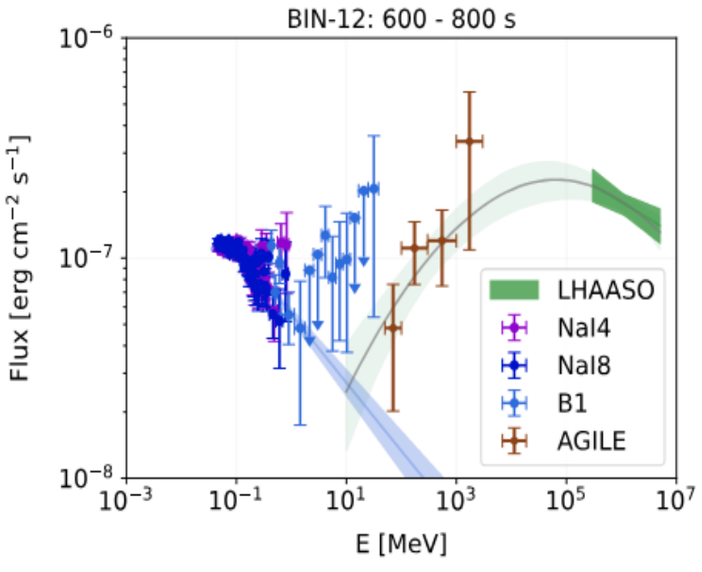
GRB 221009A - BOAT

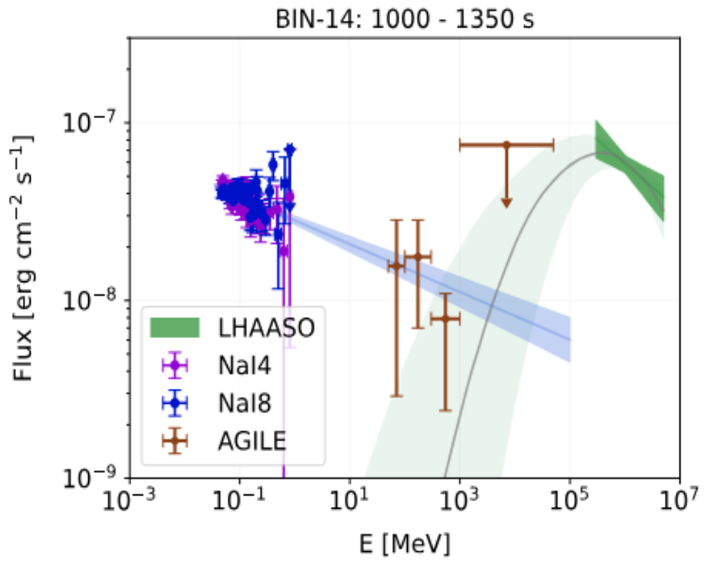




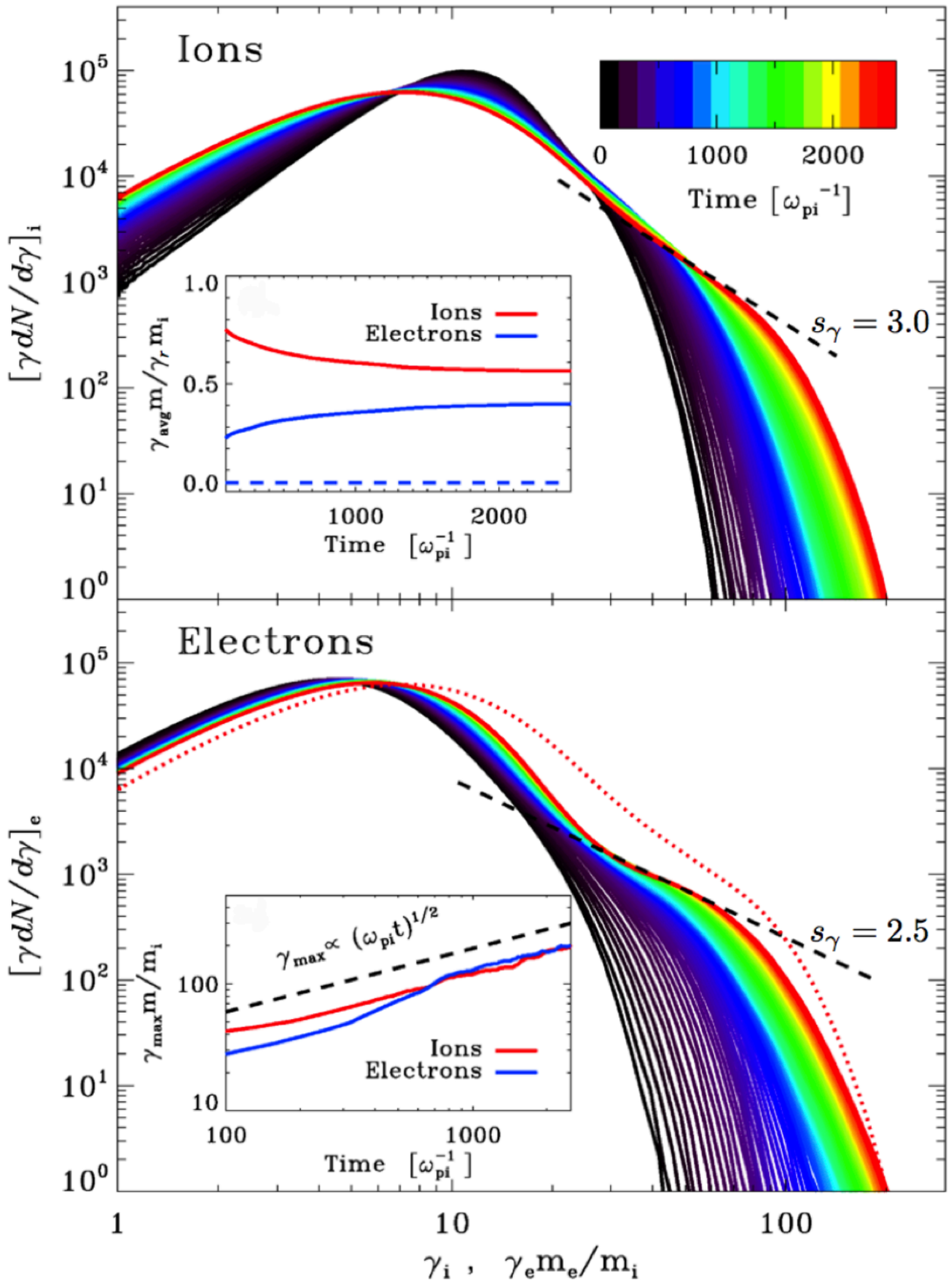








Banerjee et al. 2024



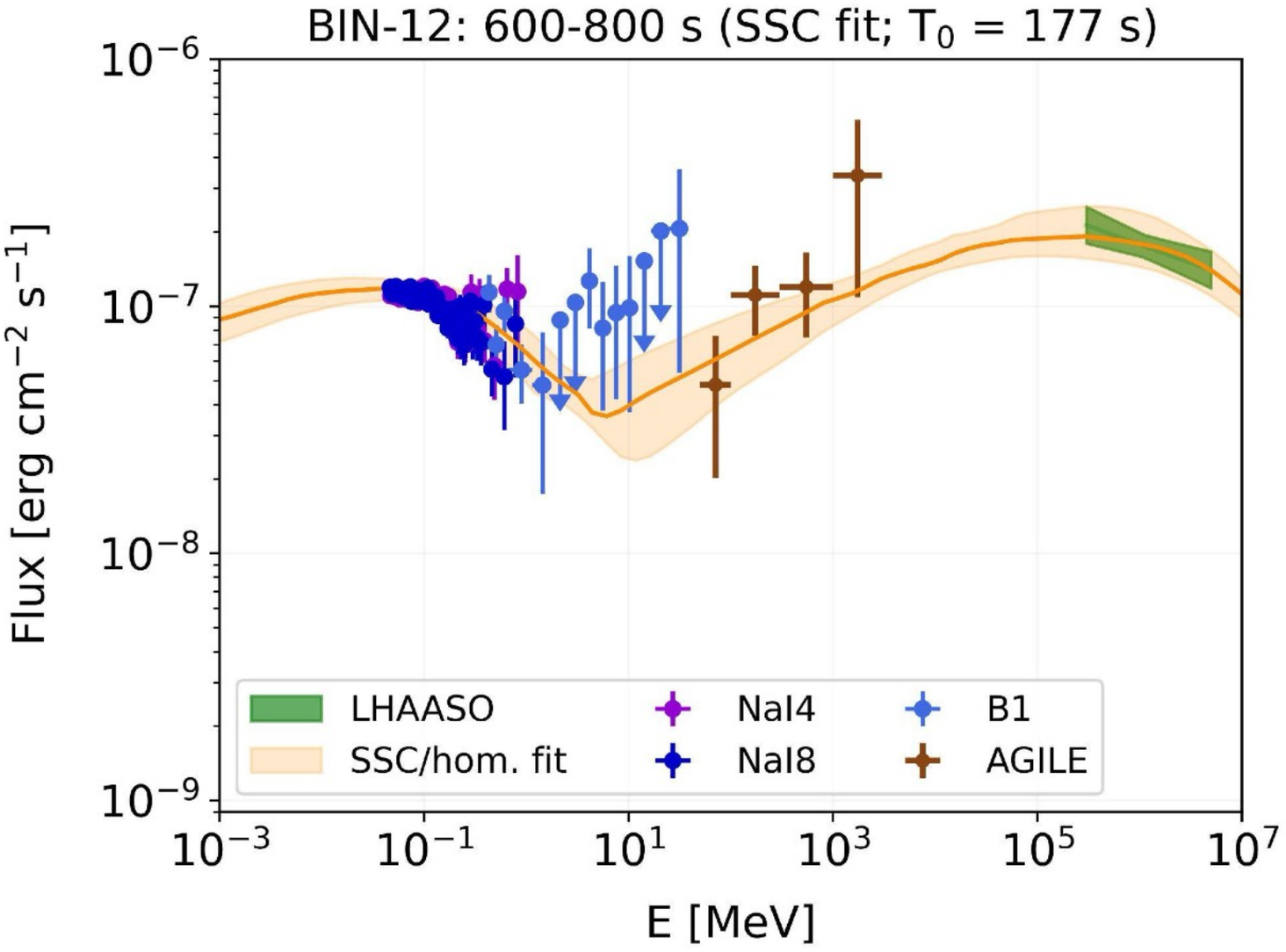
$$m_i/m_e = 25$$

$$\sigma = 10^{-5}$$

$$\gamma_r = 15$$

Sironi et al. 2015

GRB 221009A - BOAT



$$B \sim 100\mathrm{mG}$$

$$\gamma_{\mathrm{max}} \approx 10^{6}$$

Banerjee et al. 2024

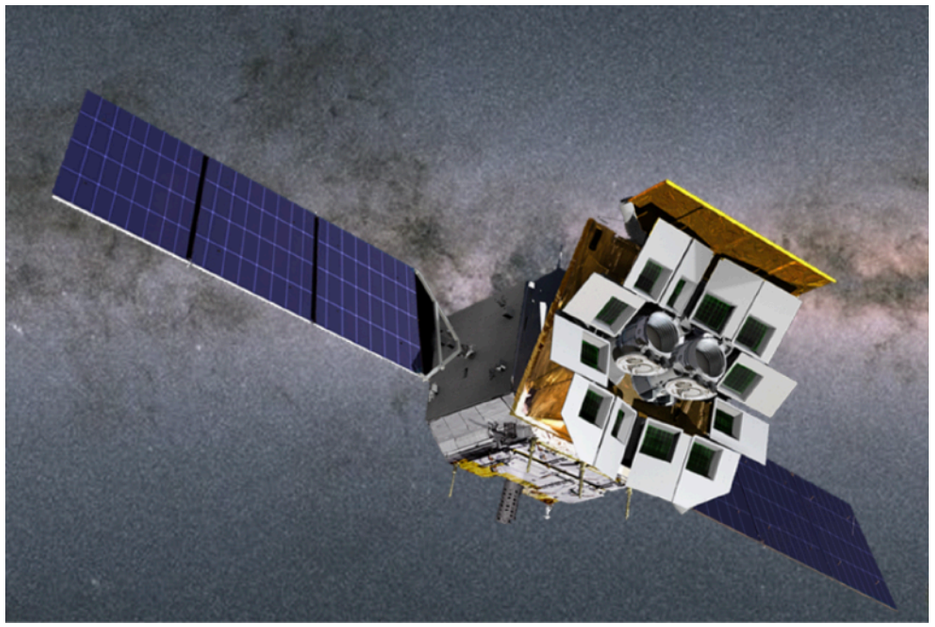
SSC: **LeHaMoC** Stathopoulos et al 2023

γ-ray bursts

Future

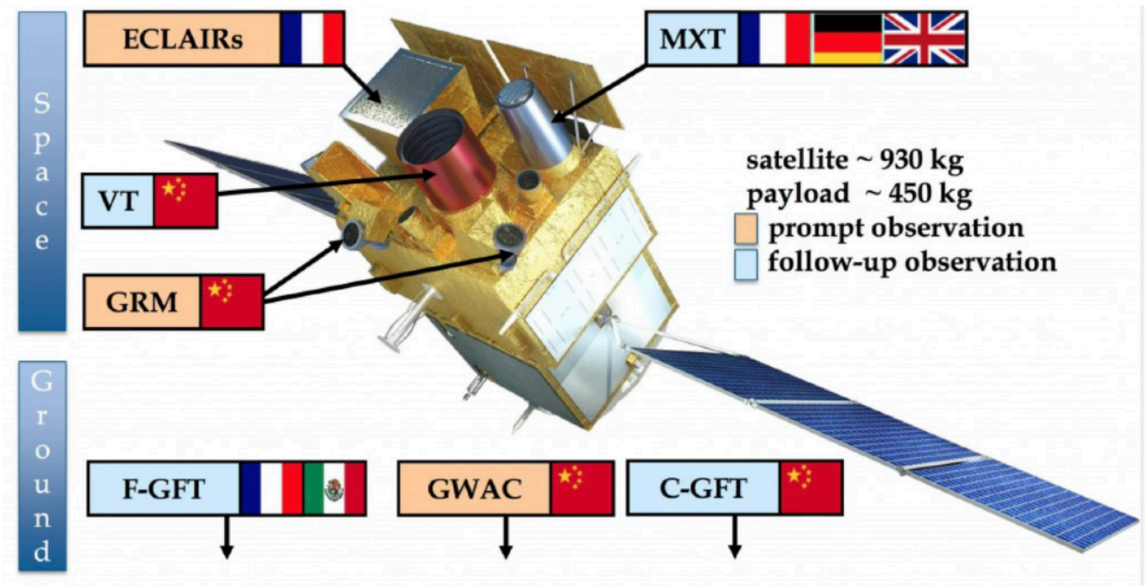
Future/now

Einstein Probe



0.5-4 keV

SVOM



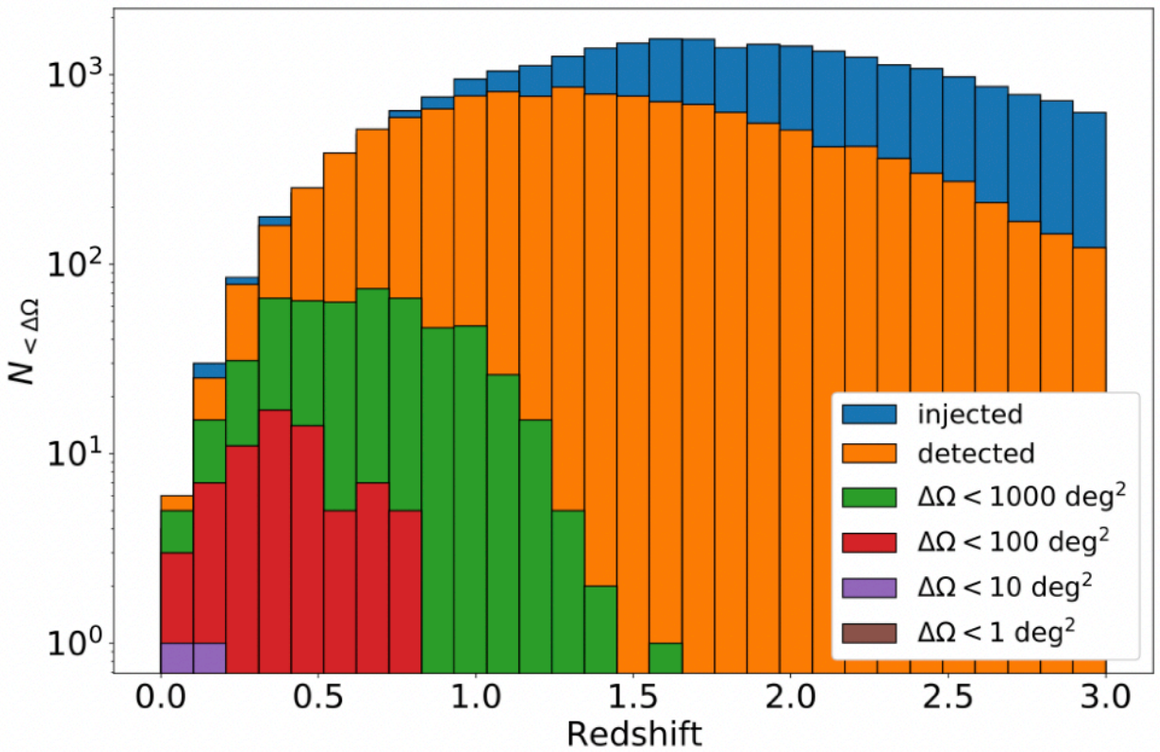
ECLAIRs > 4 keV

Lobster-eye Angel 1979

gravitational waves

high freq.

Einstein Telescope, v.a.<15 deg



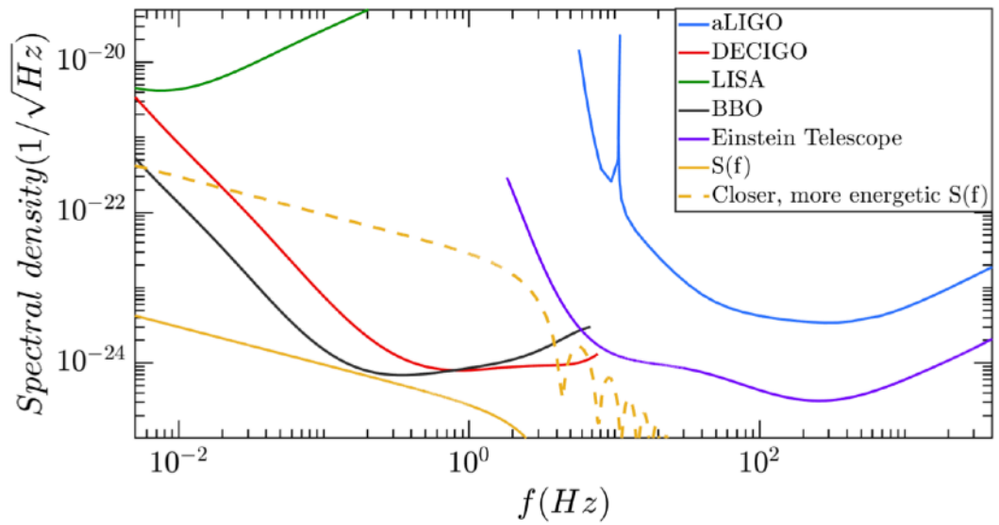
Ronchini et al. 2022

accretion-to-jet efficiency Salafia & Giacomazzo 2021

jet dissipation > jet core Ascenzi et al. 2020, Duque et al. 2022

low freq.

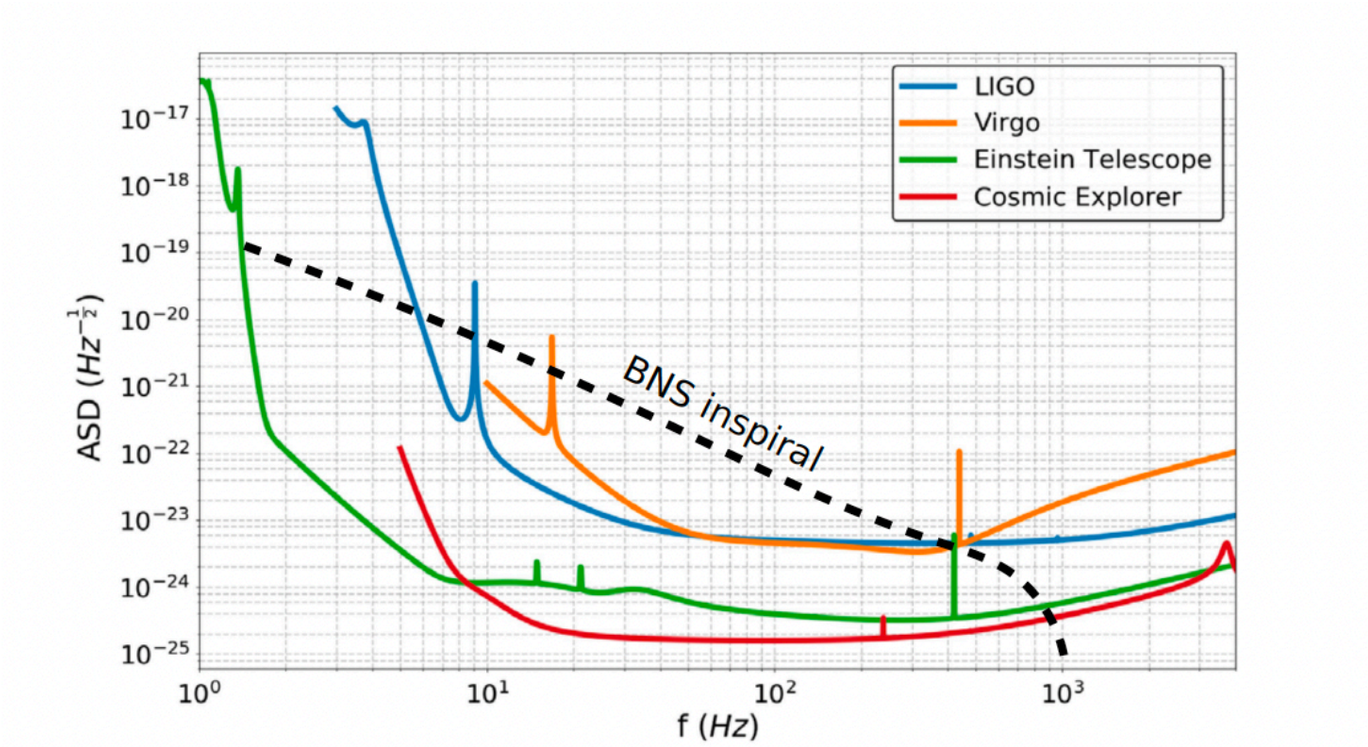
Jet GWs

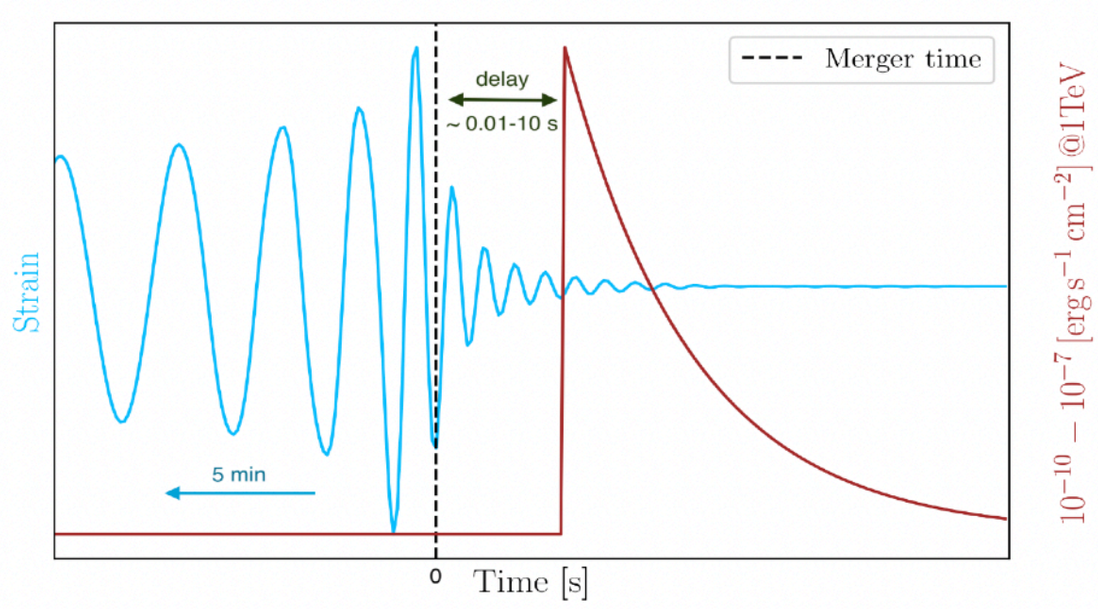


Leiderschneider & Piran 2022

Segalis & Ori 2001

short GRBs & gravitational waves



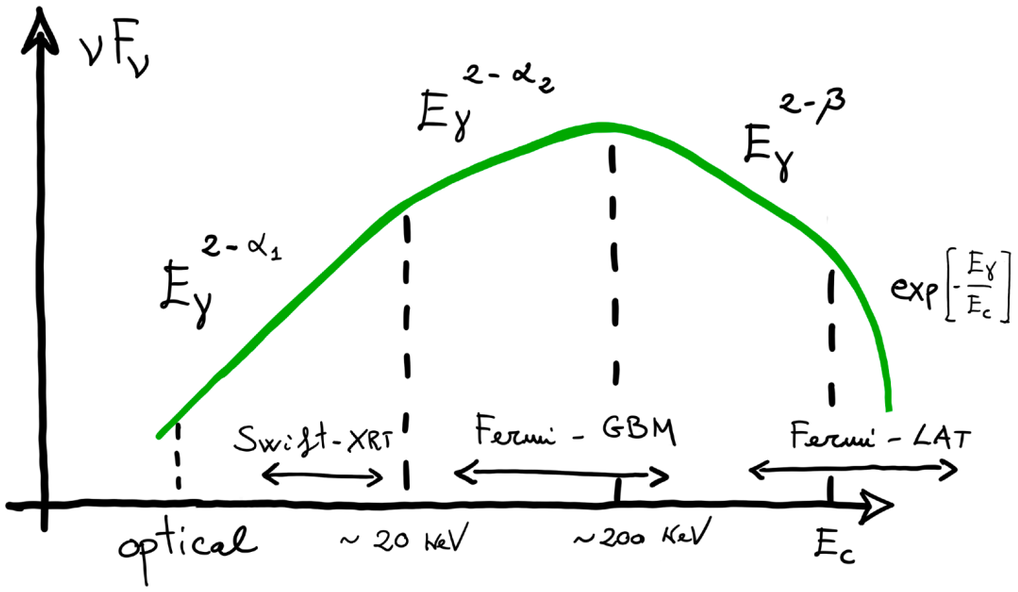


Banerjee et al. 2023

γ-ray bursts

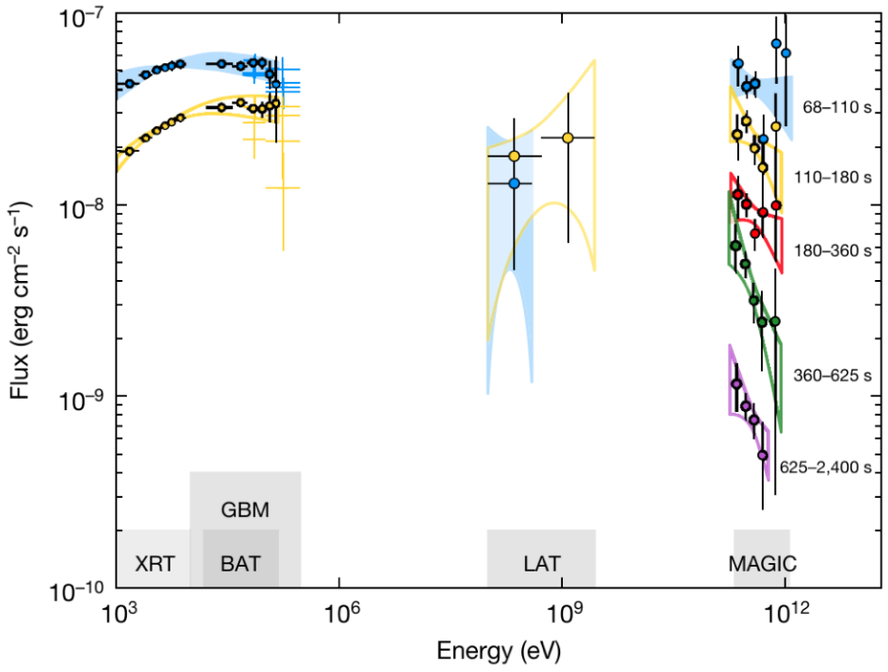
Summary

prompt emission



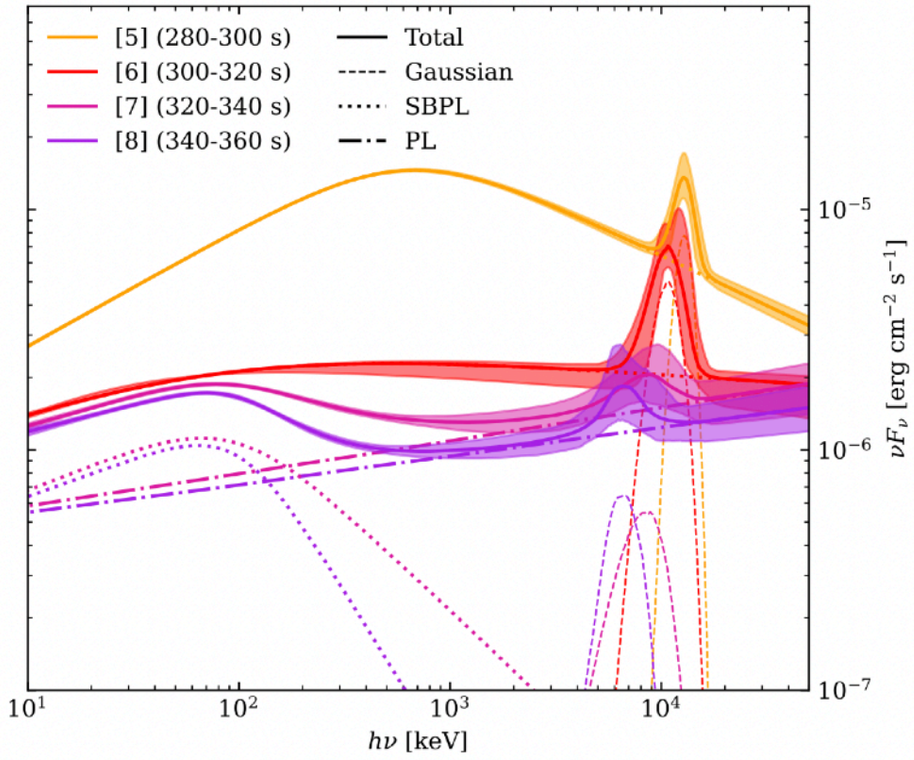
afterglow

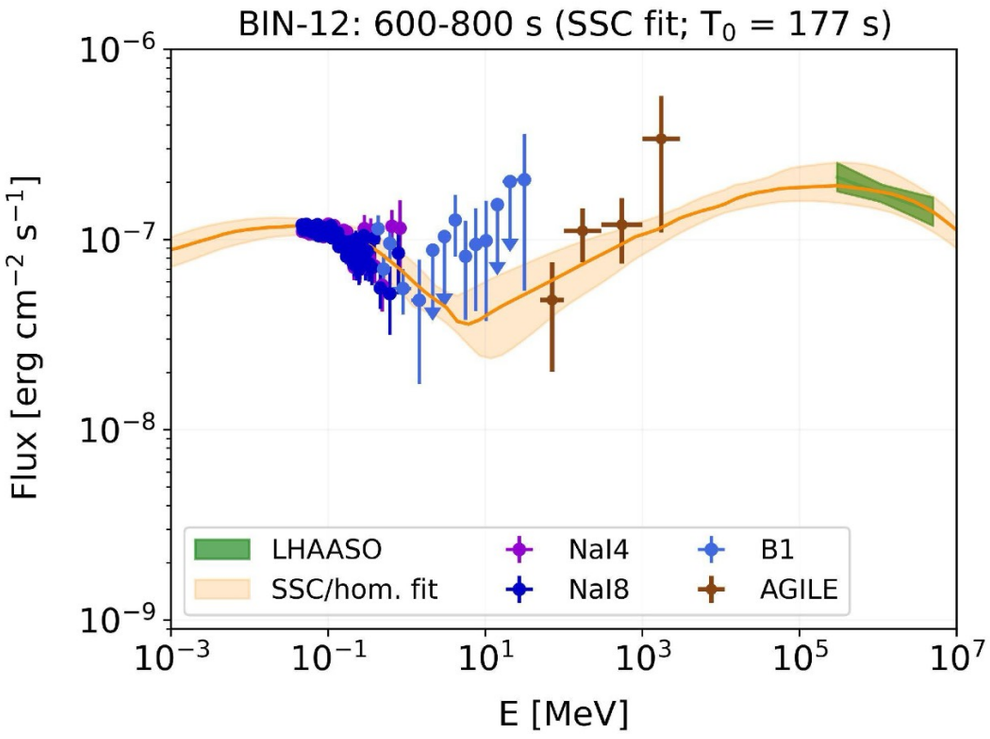
laboratory for relativistic shocks



MAGIC collaboration
Nature 2019

BOAT





Thank you!