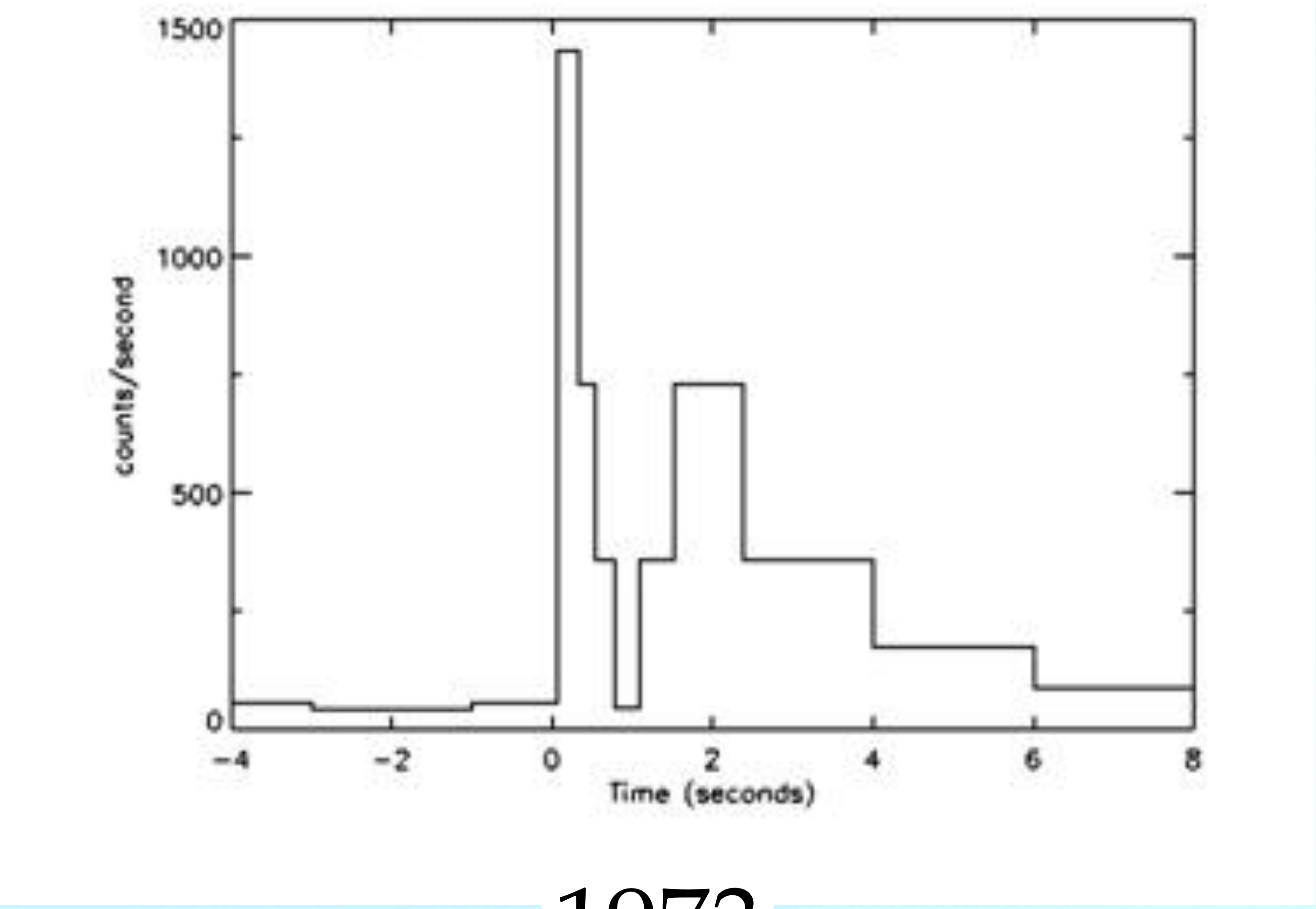
MWL + MM emission of GRBs
[GRBs: overview and recent facts]

Giancarlo Ghirlanda
giancarlo.ghirlanda@inaf.it
National Institute of Astrophysics, INAF
Osservatorio Astronomico di Brera
INFN-Milano Bicocca

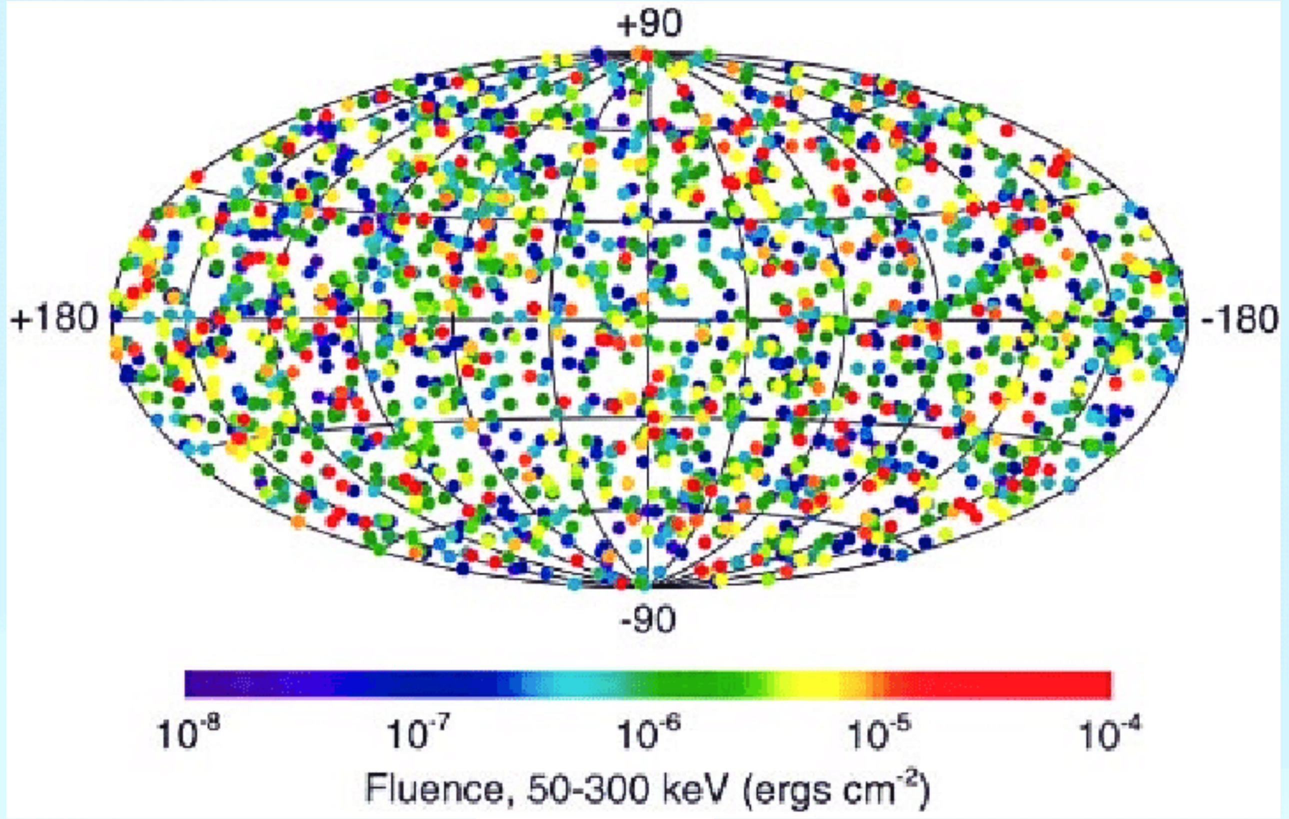
Gamma Ray Bursts: an amazing half century

Vela Satellites



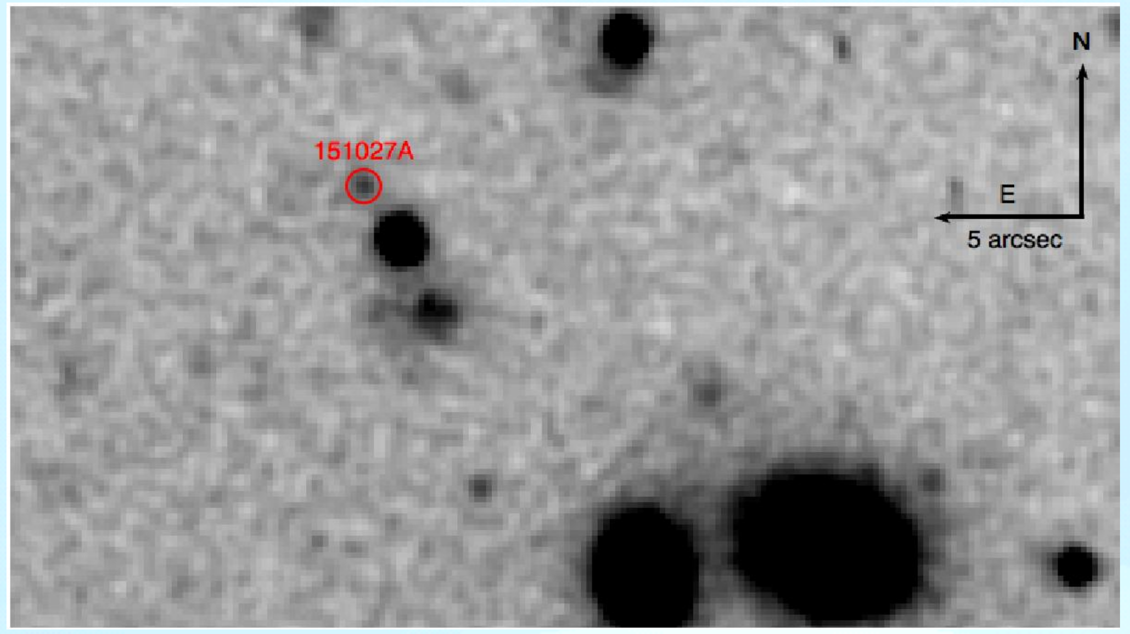
1973

CGRO



1992

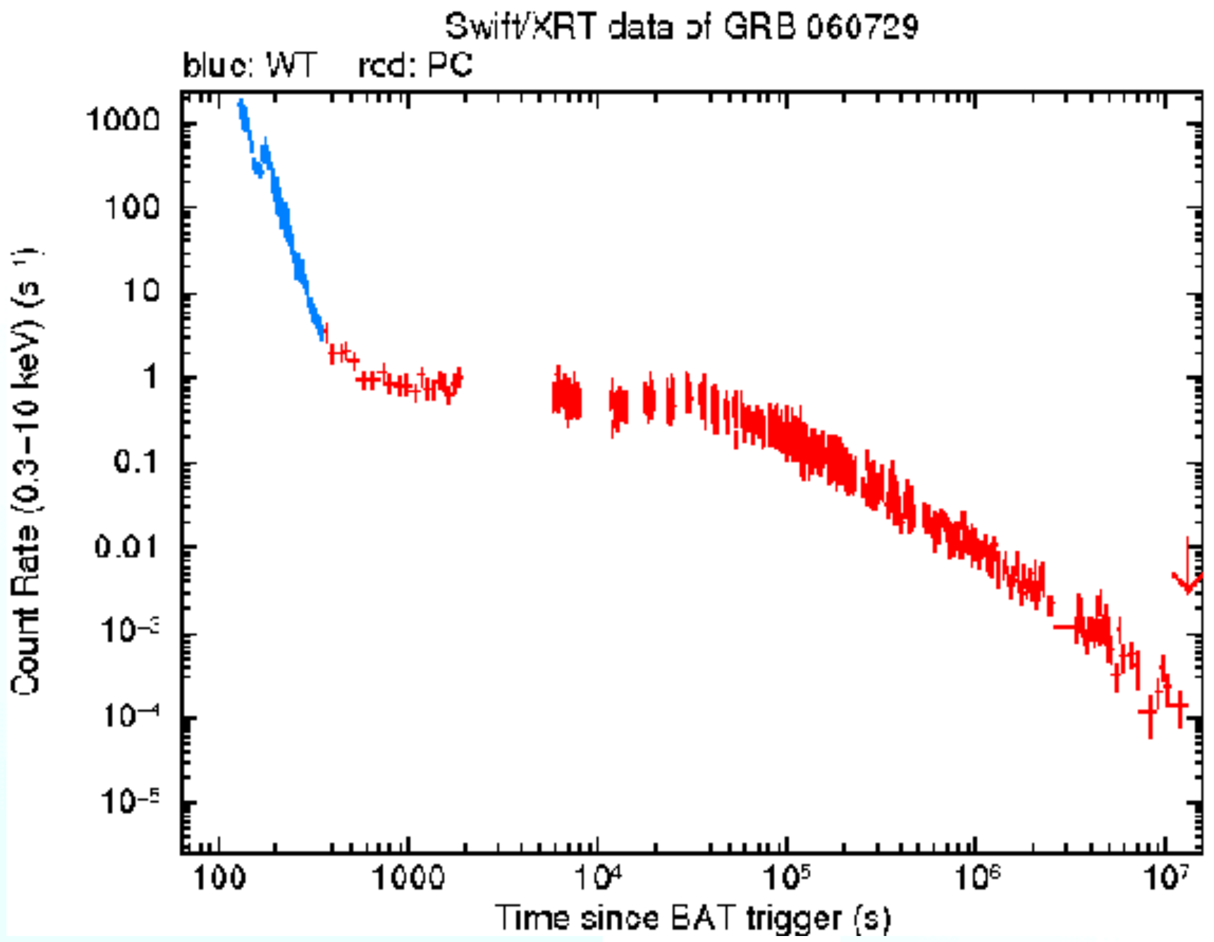
BeppoSAX+Ground



1997

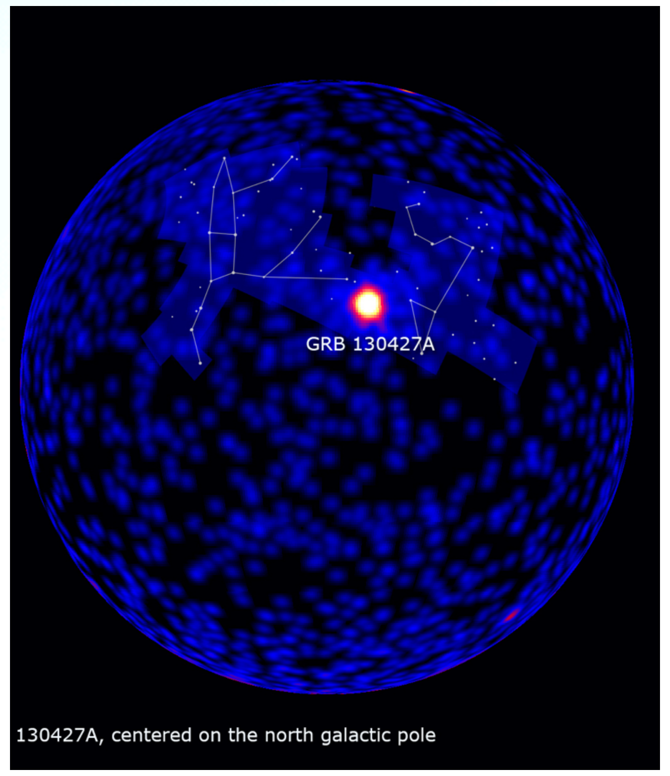
1998

Swift



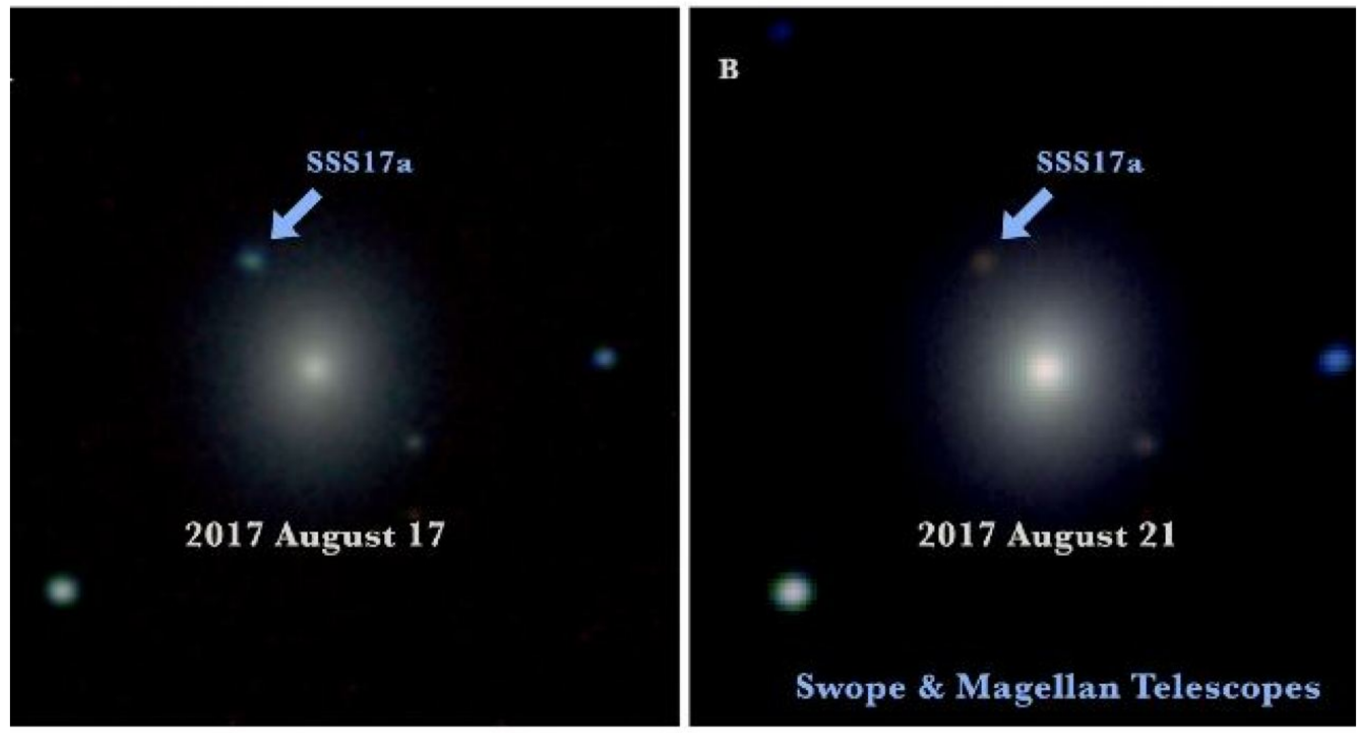
2005

Fermi



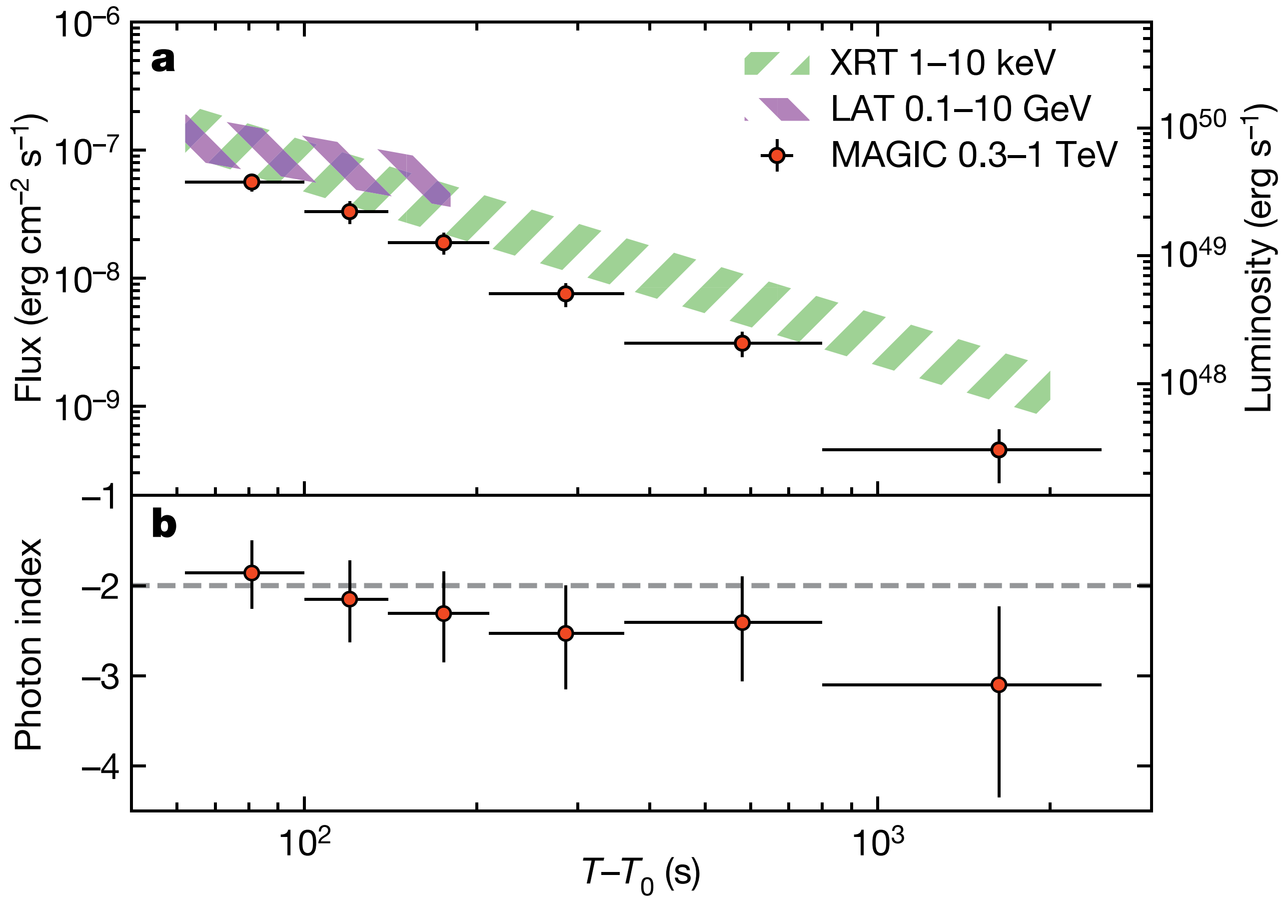
2008

LVC+Space+Ground



2017

Magic/HESS

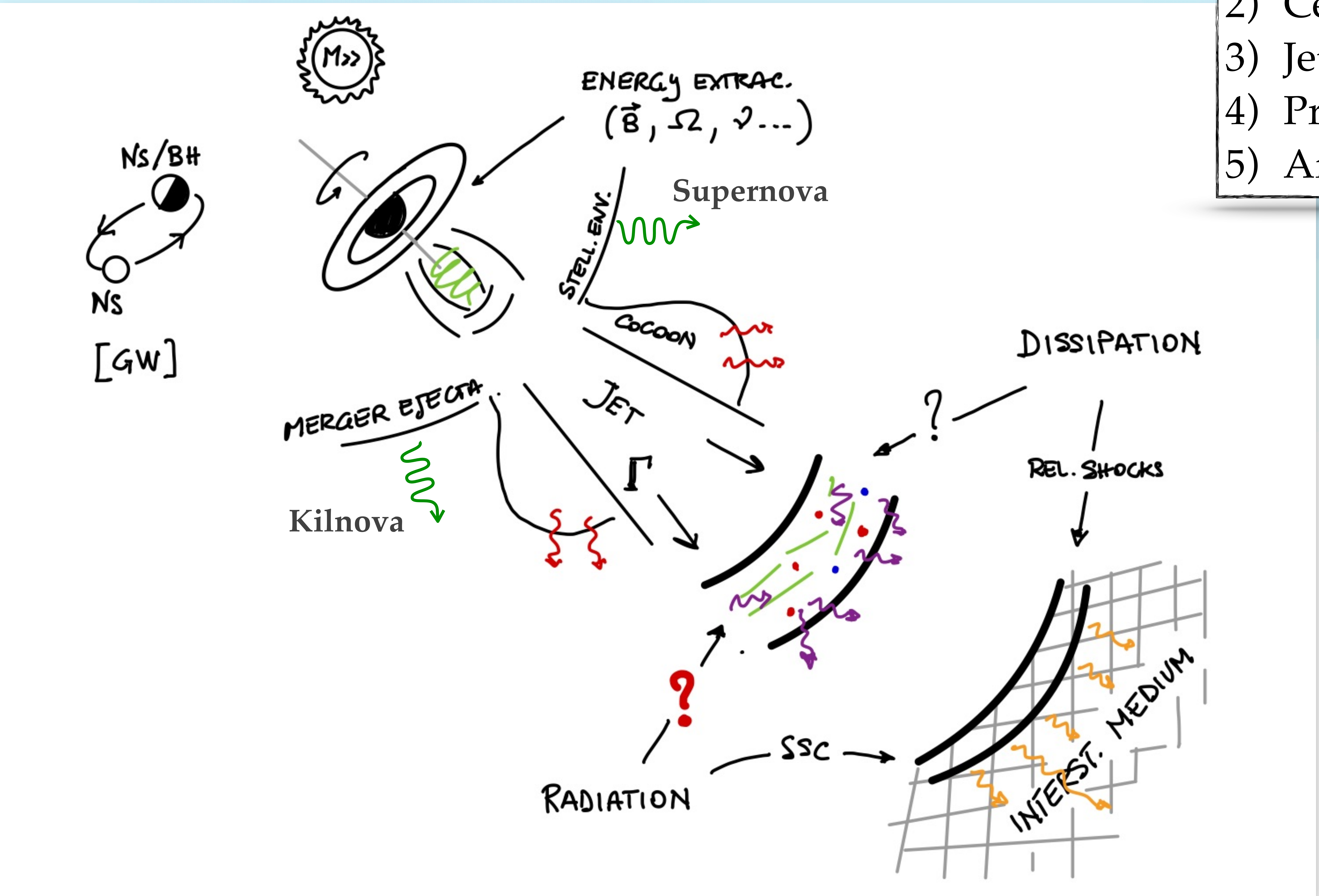


2019

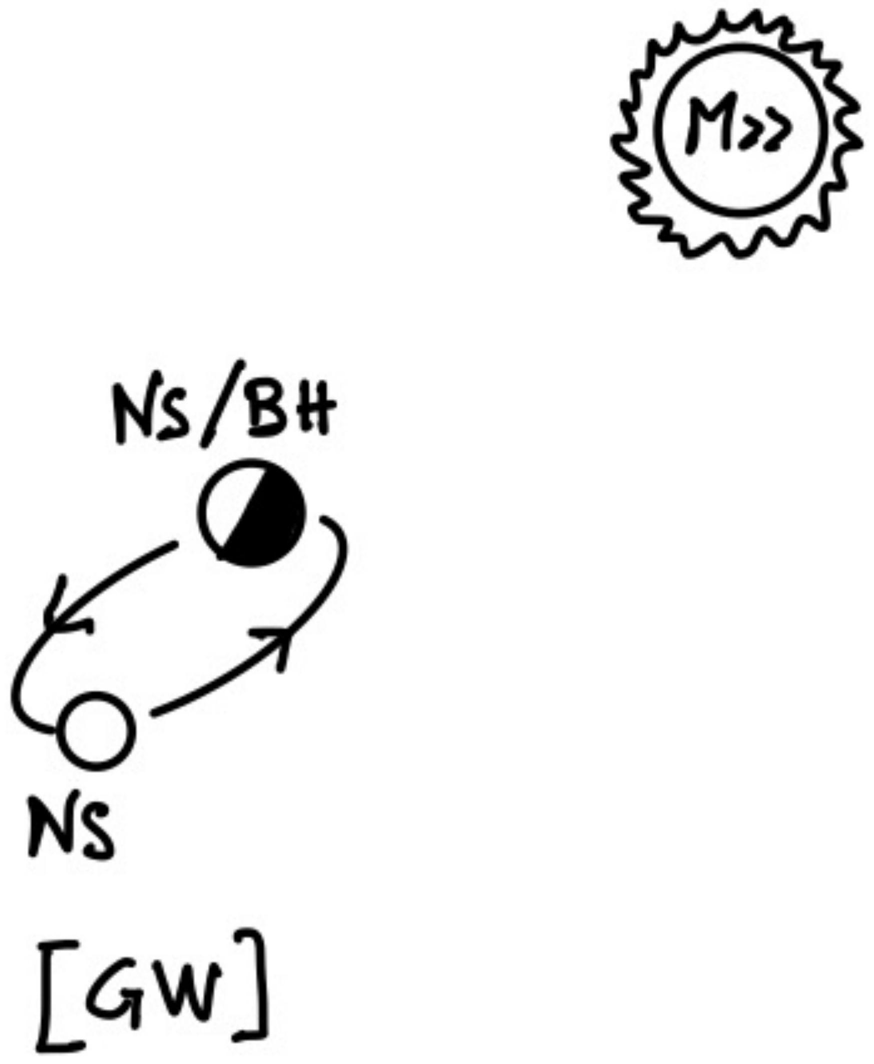
G. Ghirlanda @ AstroColibri, Paris, 20-24 Nov 2023

Gamma Ray Bursts: how do we cook them

1) Progenitor
2) Central Engine
3) Jet
4) Prompt dissipation/emission
5) Afterglow dissipation/emission



Progenitors



1. Spectroscopically identified SNe Ibc associated
2. SN bumps @ few weeks
3. Star forming hosts
4. Tracing the SFR in hosts

$$t_{ff} \sim 680 \left(\frac{M}{20M_{\odot}}\right)^{-1/2} R_{11}^{3/2} \ \mathrm{sec}$$

If central engine is an HA BH —> $t_{\mathrm{eng}} \sim t_{\mathrm{ff}}$

$$t_{ff} \sim \frac{1}{(G\rho)^{1/2}}$$

$$t_{ff} \sim 2 \times 10^{-4} \left(\frac{\bar{\rho}}{10^{14} \ \mathrm{g\ cm^{-3}}}\right)^{-1/2} \ \mathrm{sec}$$

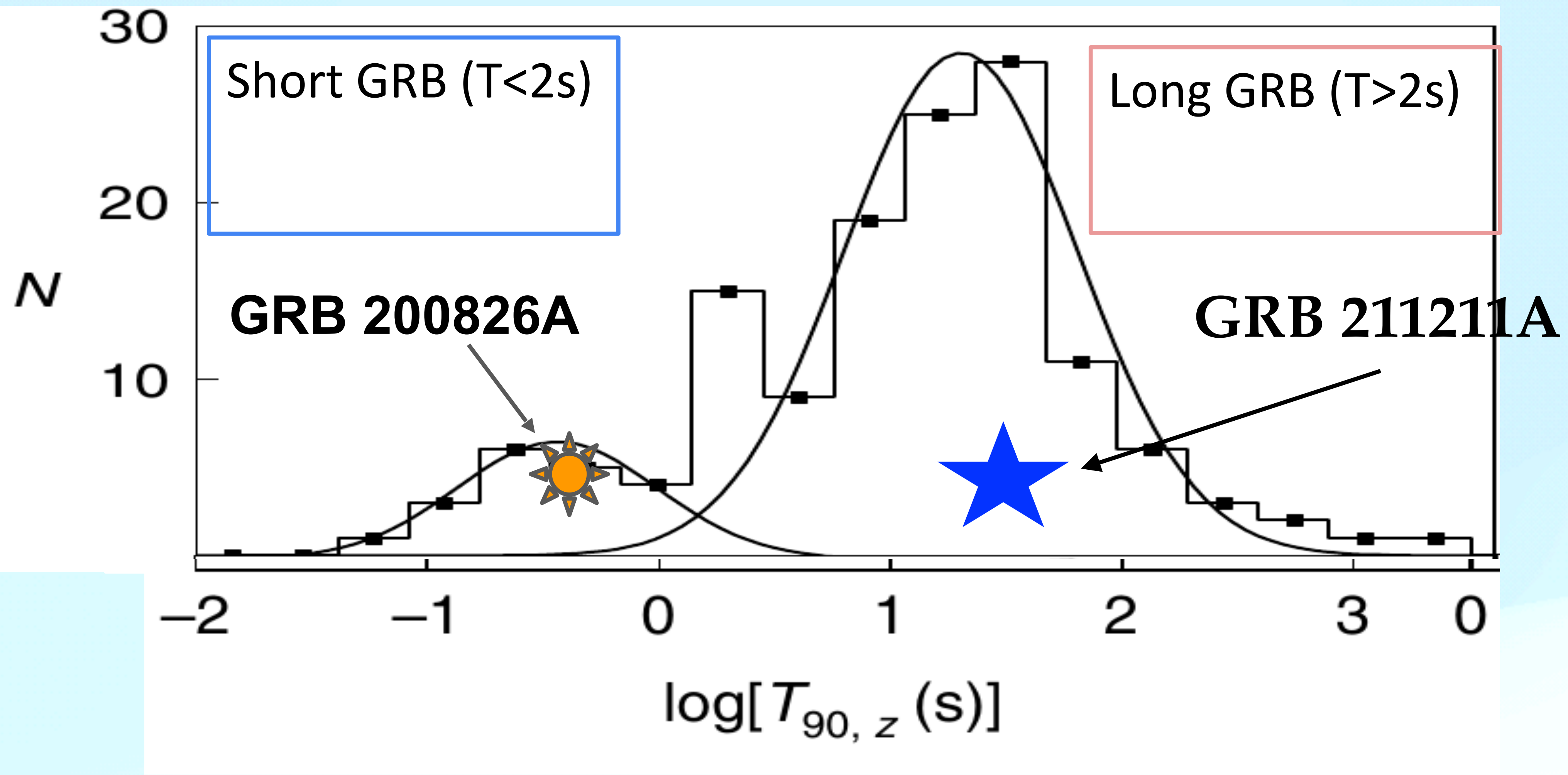
SHORT GRBs

1. GW / GRB 170817
2. Kilonova AT2017gfo
3. Host morphologies
4. Large offsets

Progenitors: the short/long divide ?

GRB 200826A

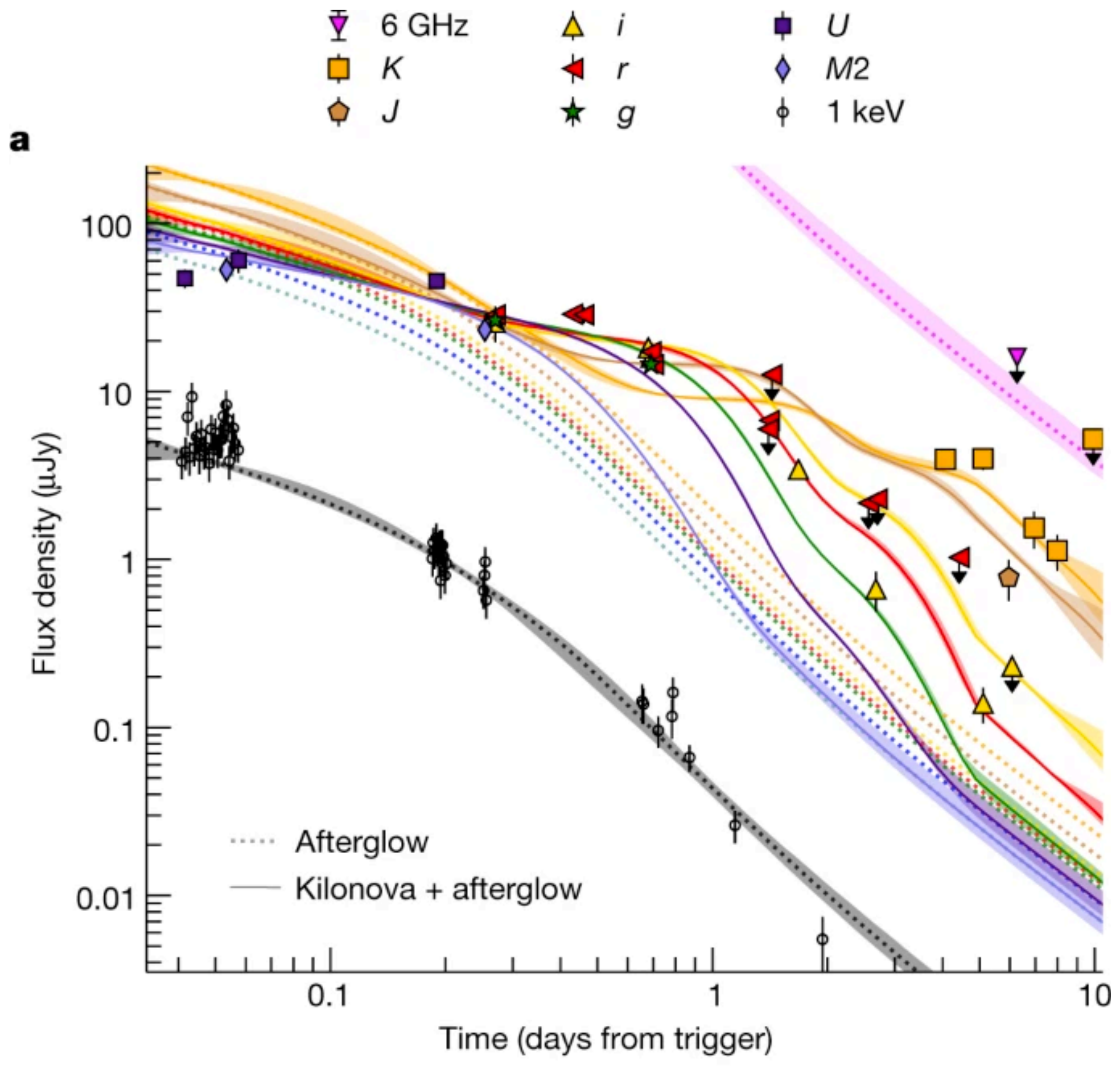
- Rest frame duration ~0.5 sec
- Soft spectrum (L)
- SN signature (L)
- Ep-Eiso correlation (L)
- Host (L)



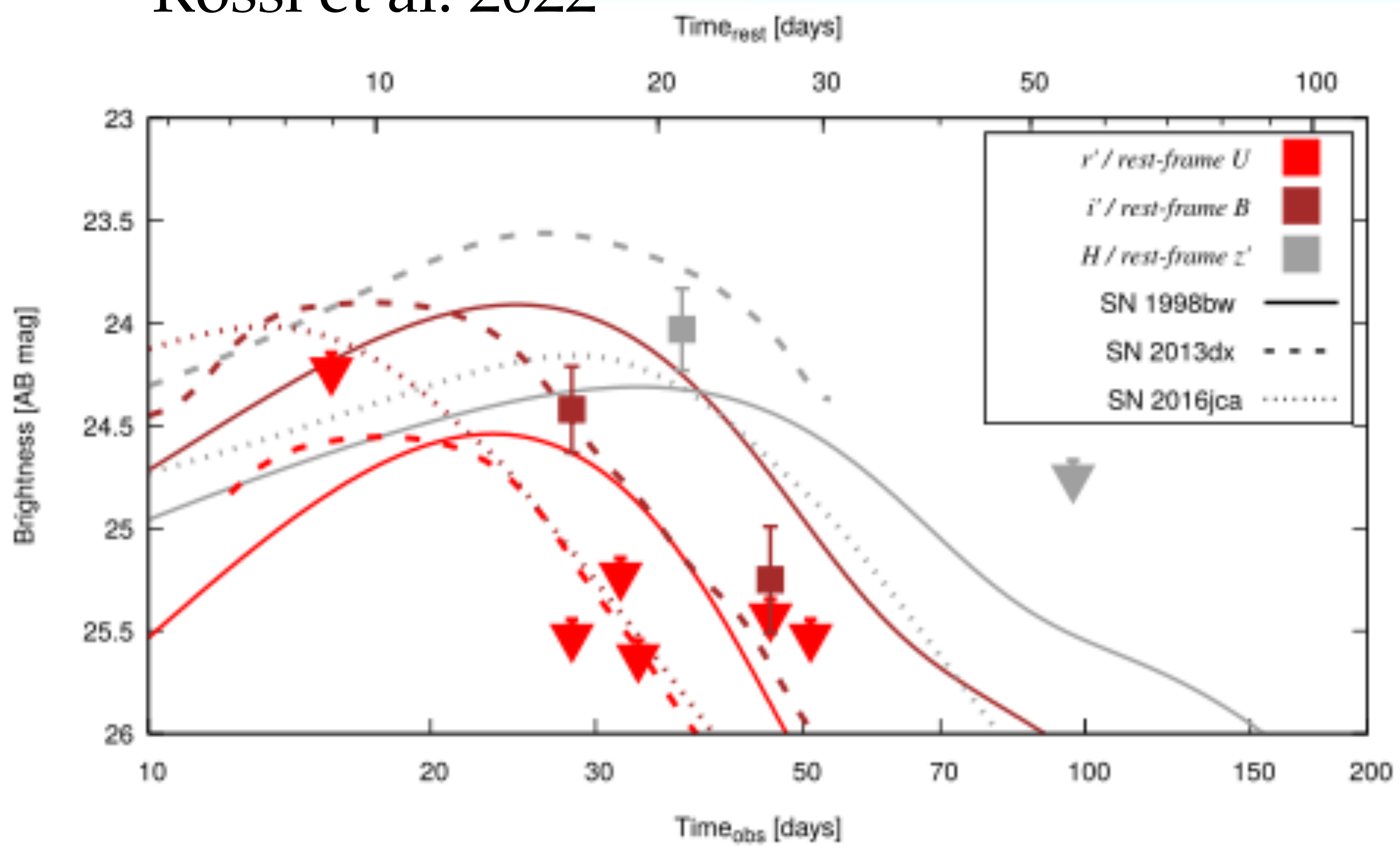
GRB 211211A

- Rest frame duration ~60 sec
- KN signature [Rastinejad+2022] (S)
- Host offset (S)
- Hour-timescale GeV emission

Rastinejad et al. 2022



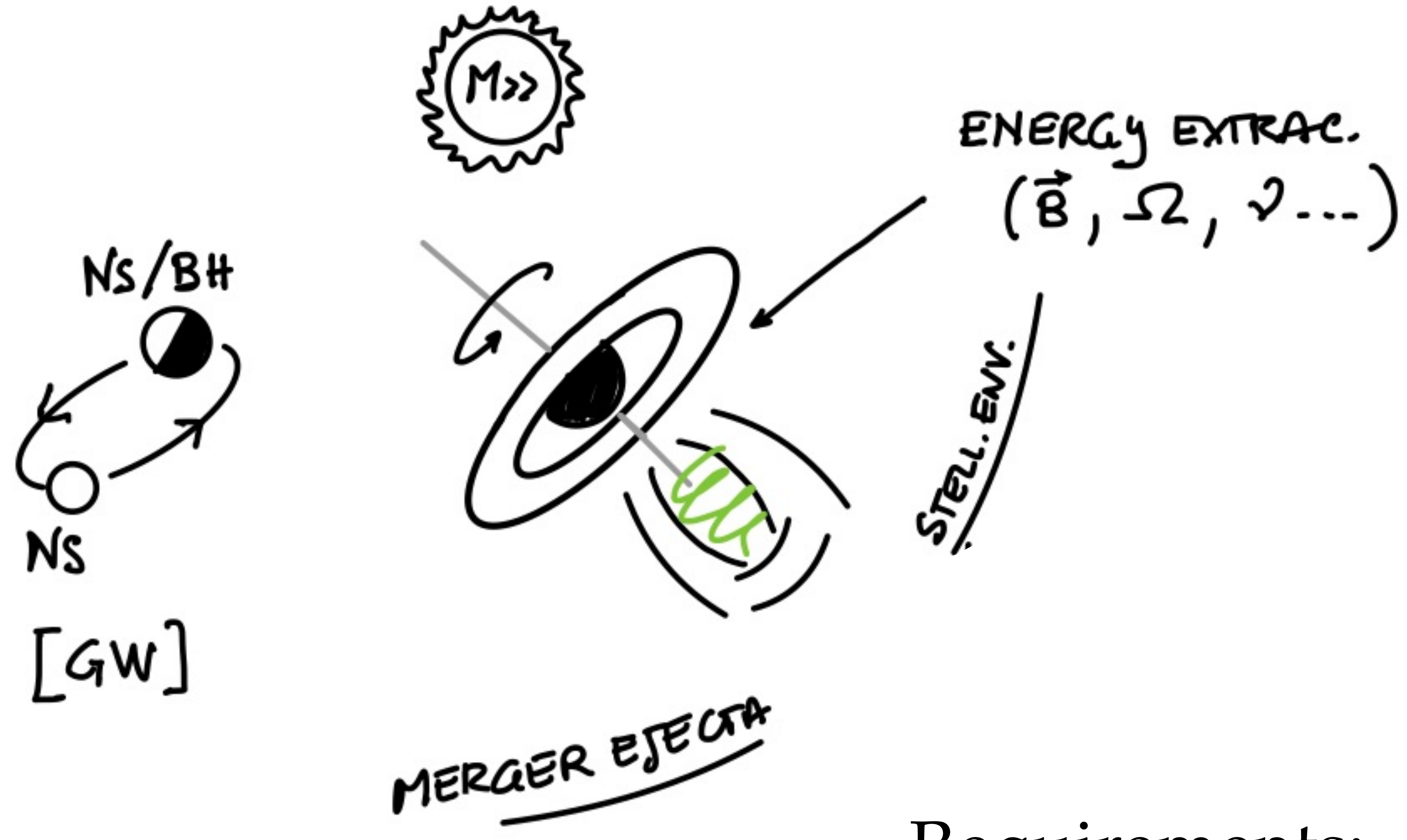
Rossi et al. 2022



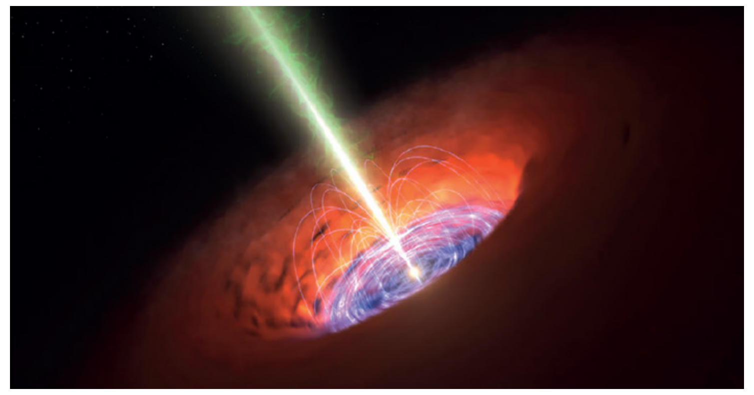
Prolong a short GRB and quench a long GRB ?

See also **230307A** -> Levan, et al. 2023

Central Engine: BH



BH



$L_{\nu\bar{\nu}}\,|\,\dot{M}, M_{BH}, s$

$L_{BZ} \propto B^2 a_\star^2 M^2$

Requirements:

1. Collimated jet with enough energy
2. Jet should reach large $\Gamma \sim 100$
3. $t_{eng} \sim t_{GRB}$
4. Long lived (T~1e4 s)

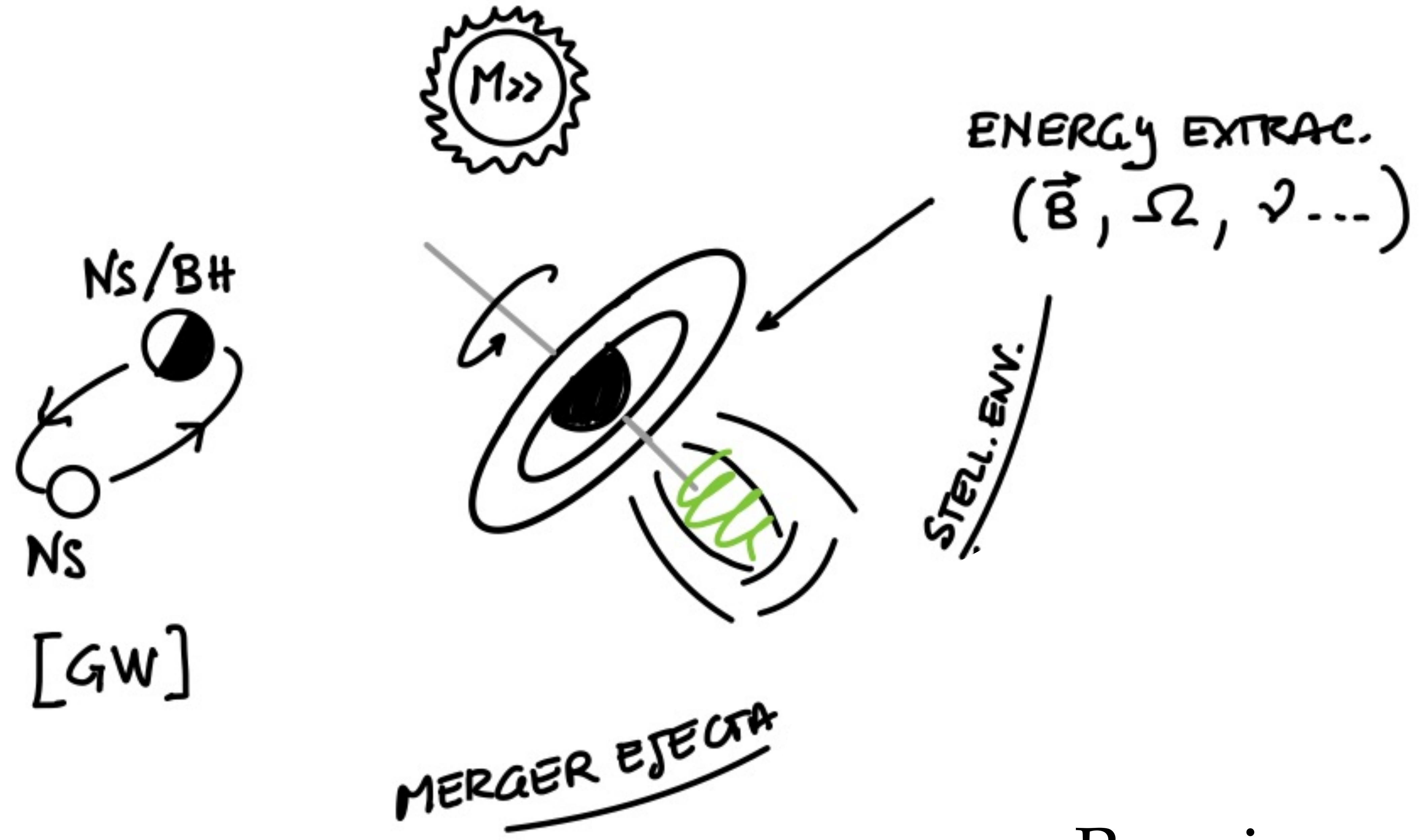
However plateau:

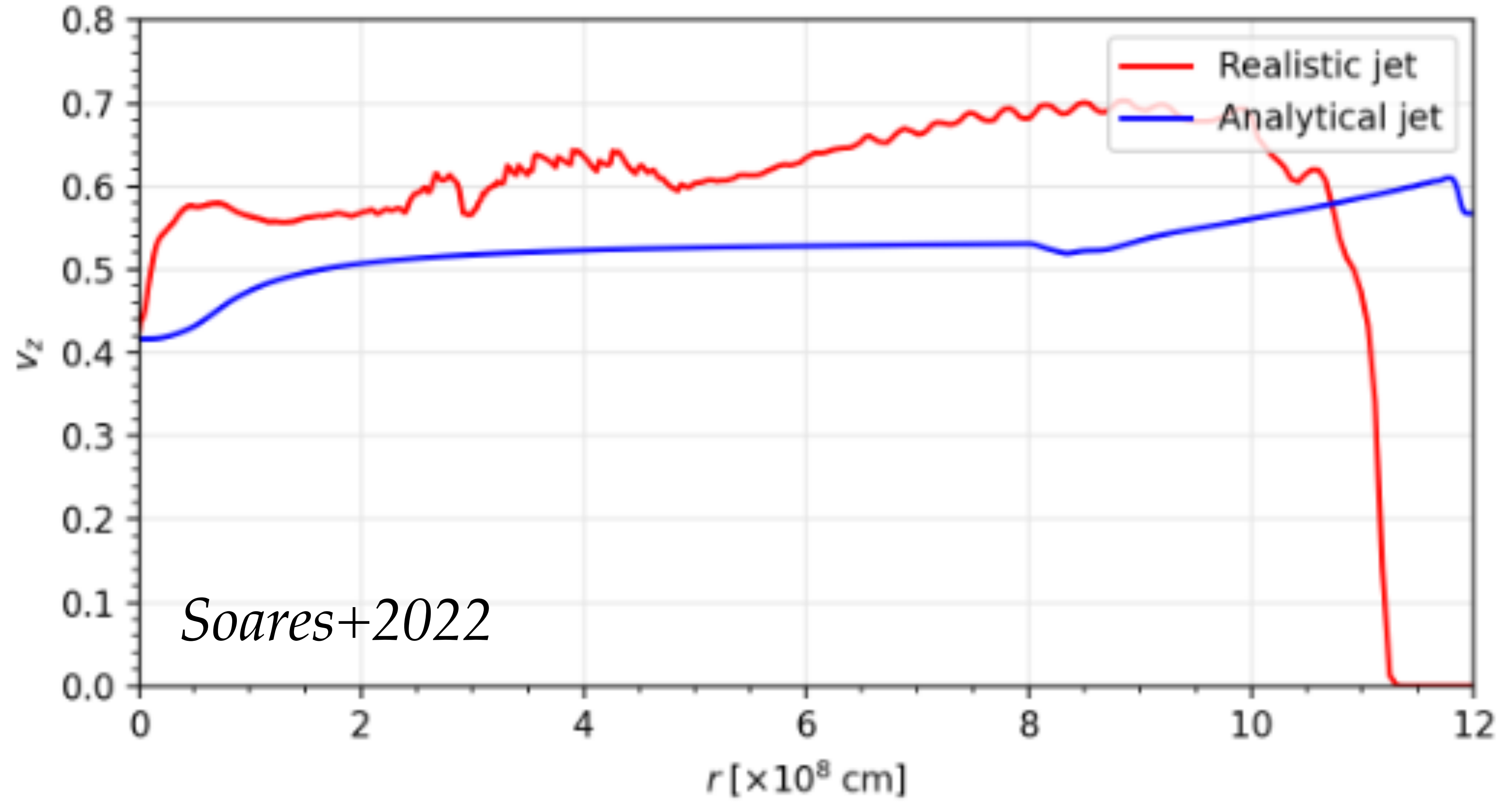
- Structured jet ES (*e.g. Beniamini+2020*)
- Structured jet internal diss. (*Oganesyan+2020, Ascenzi+2021*)

However Flares

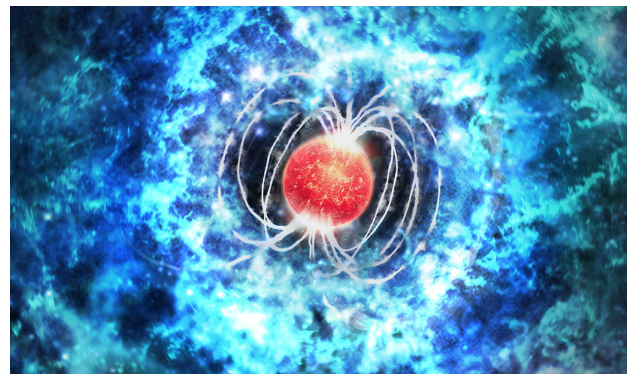
- (early) Off axis core activity (*Duque+2022*)
- Fallback (*Lazzati+2009*)

Central Engine: Magnetar





Magnetar



$$L_{sd}(t) = \frac{L_i}{(1+at)^2}$$

$$L_{acc}(t) = B, \Omega \ldots$$

Requirements:

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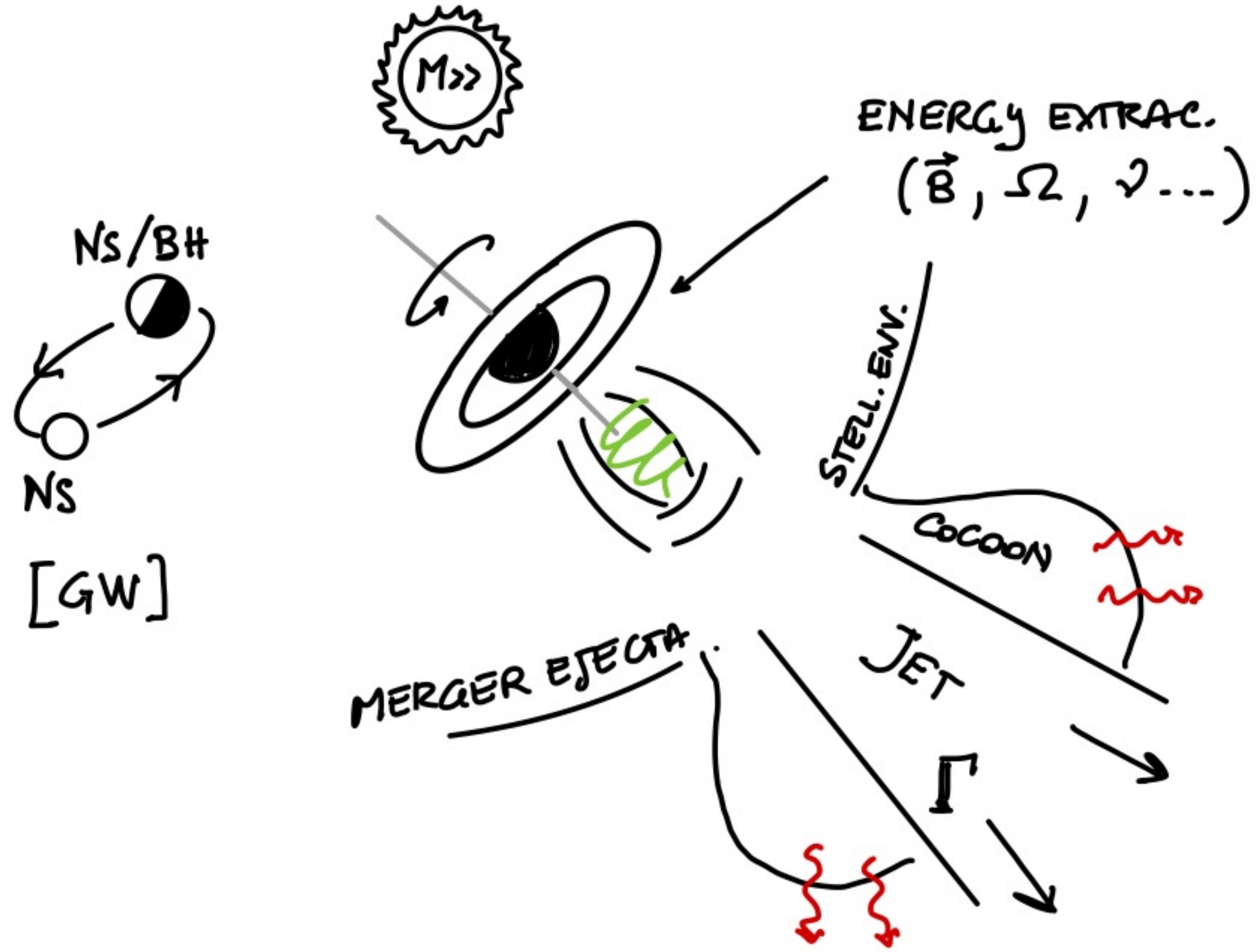
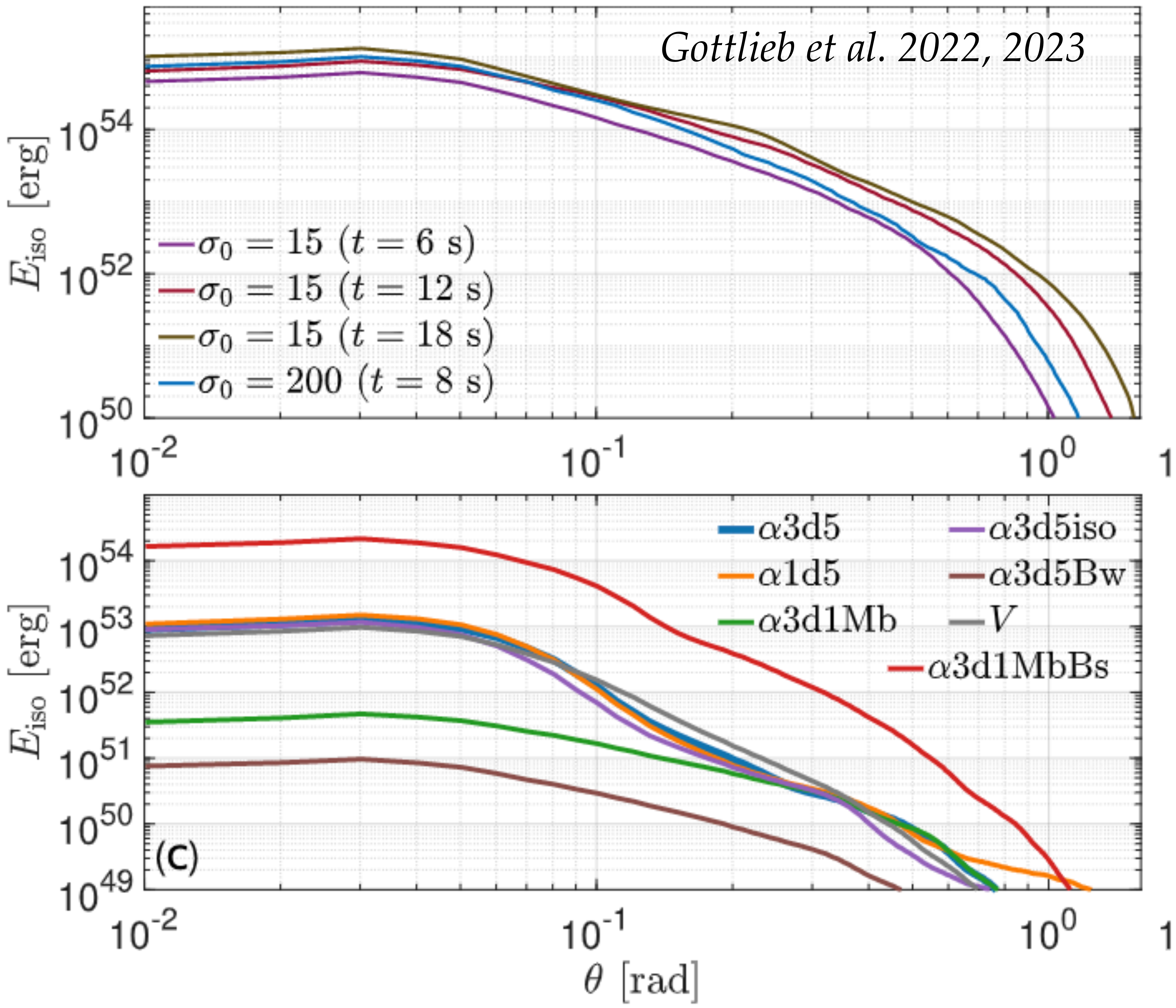
3. $t_{eng} \sim t_{GRB}$
4. Long lived (T~1e4 s)

The jet structure

1) development of a core $(E, \Gamma) \sim$ const

2) $\propto \theta^{-3}$ for $\theta > \theta_c$

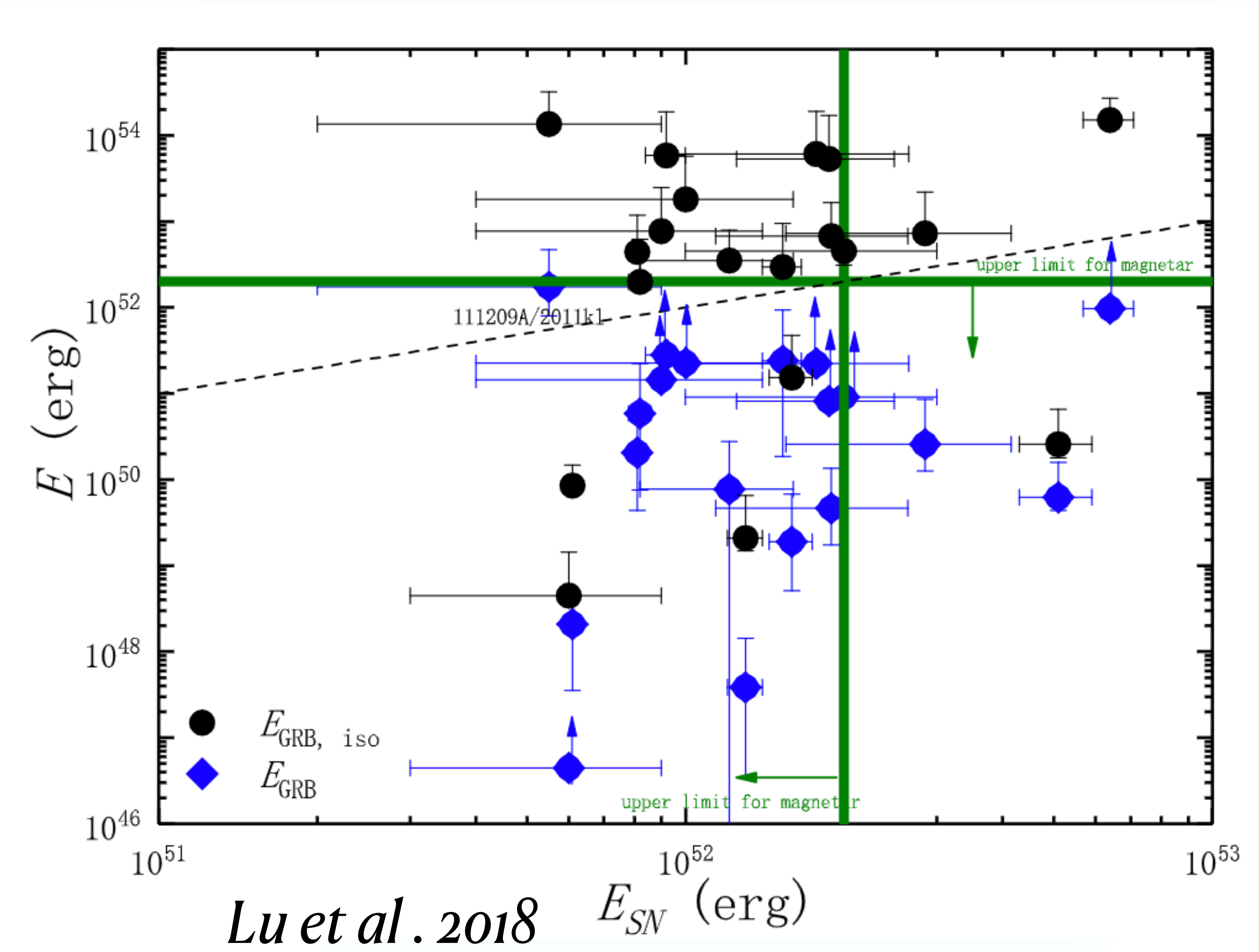




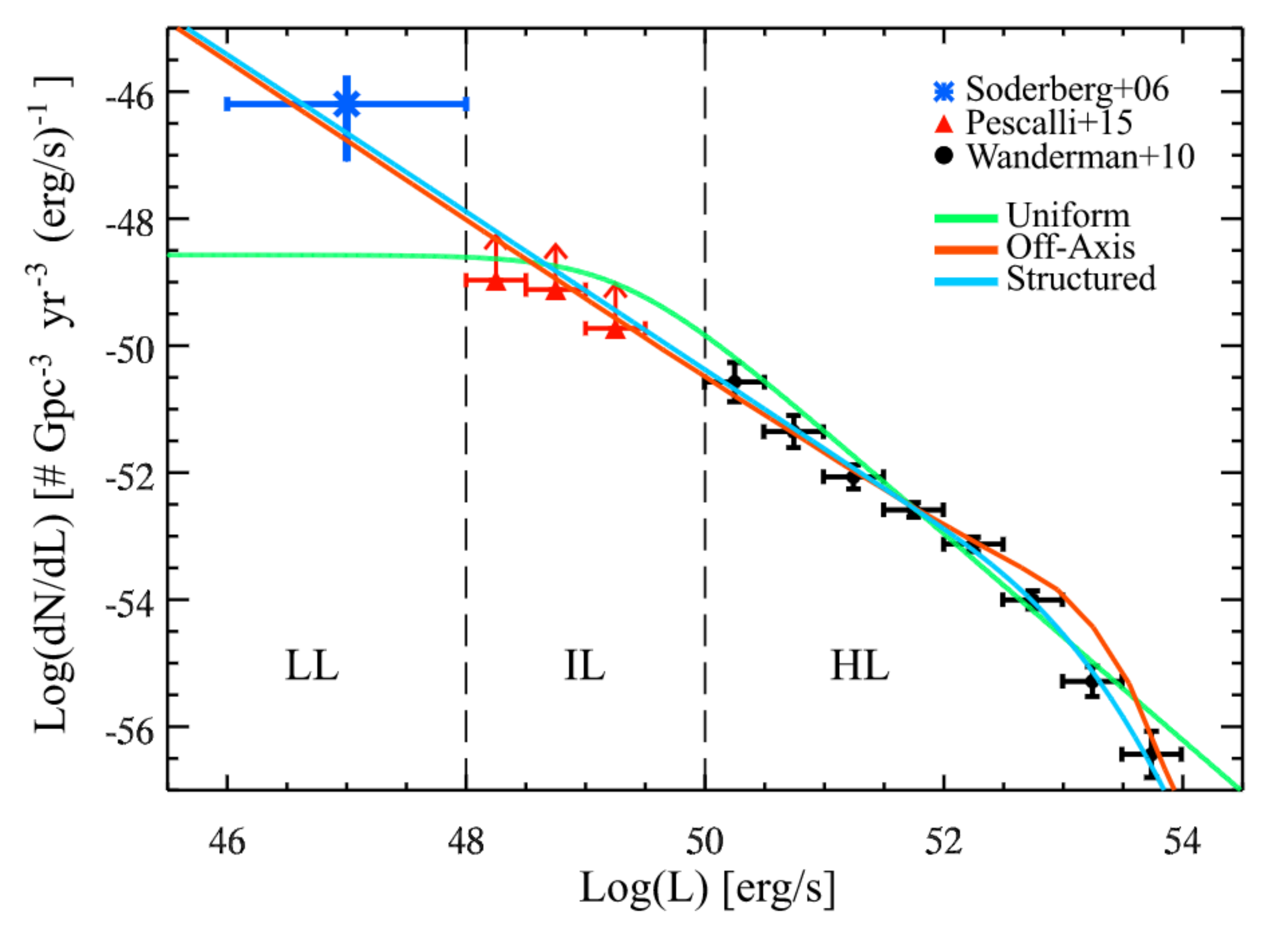
Collapsar

BNS

The jet structure (long)



Lu et al . 2018



θ^{α} with $\alpha < -4$
Or Gaussian

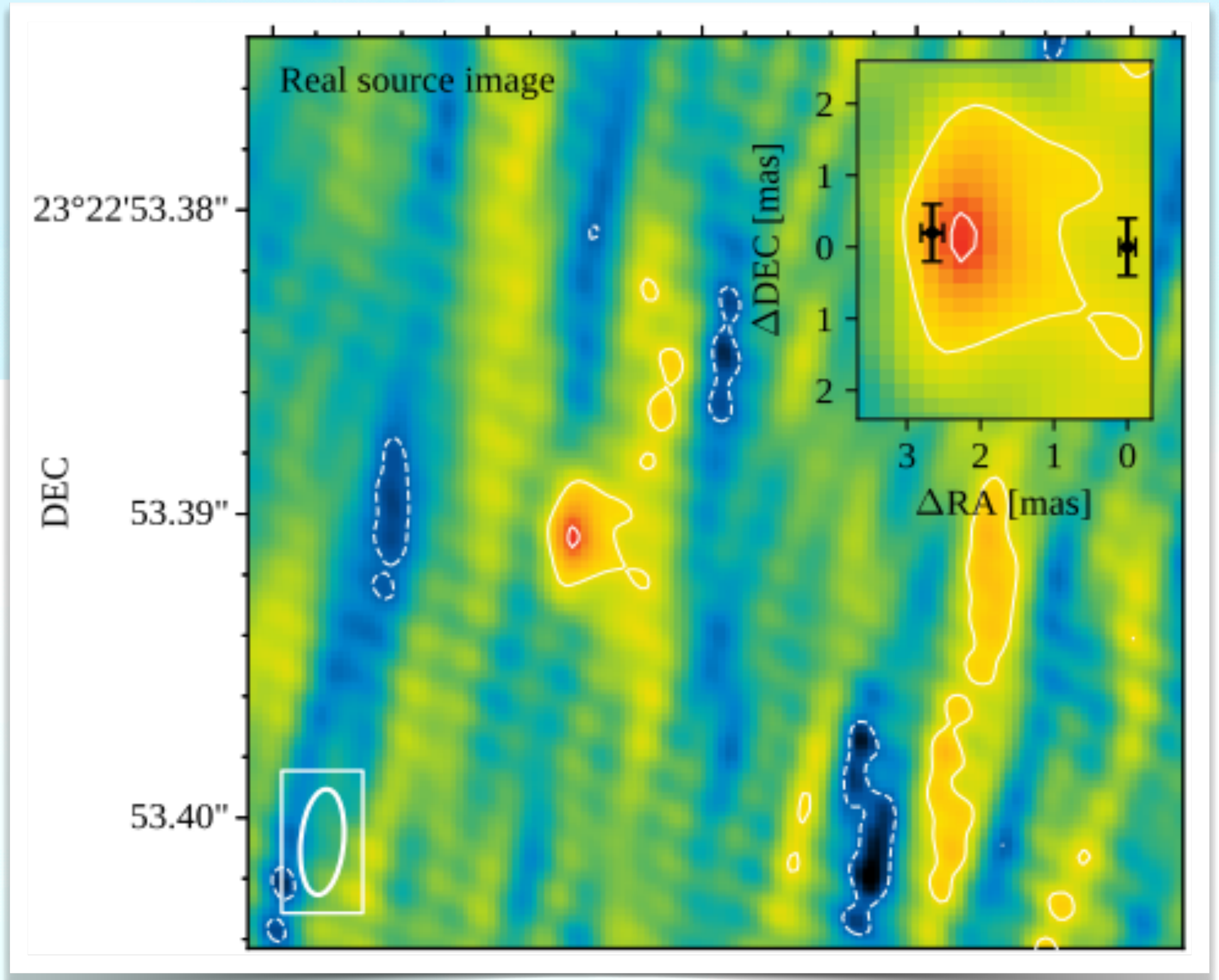
Pescalli et al. 2015, 2016; Salafia 2015; Ghirlanda & Salvaterra 2022

The jet structure (short)

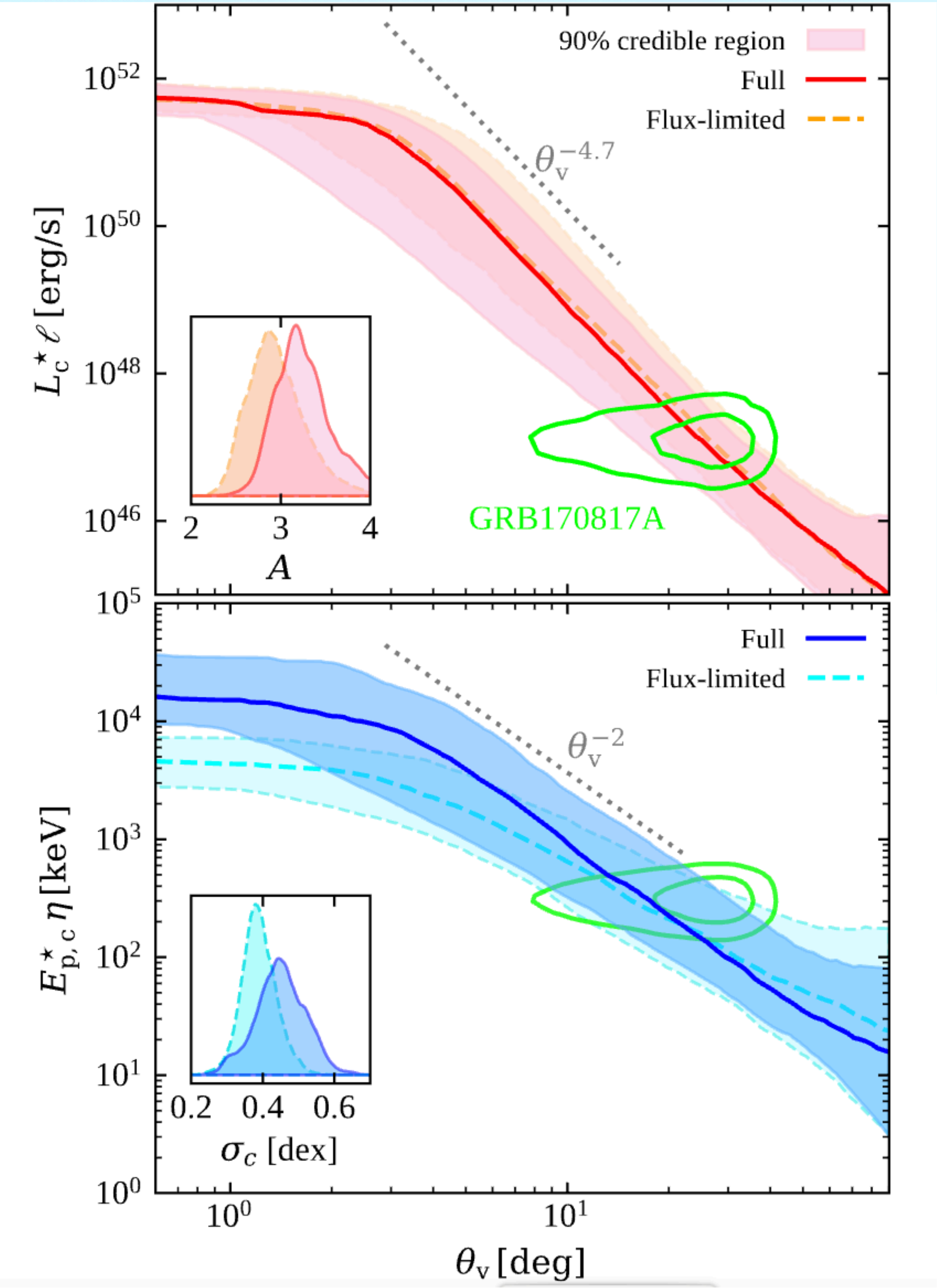
GRB 170817:

$$E \propto \theta^{-5.5}$$

$$\Gamma \propto \theta^{-3.5}$$



D'Avanzo 2019, Mooley et al. 2019, Ghirlanda & Salafia et al. 2019



Salafia et al. 2023

Prompt emission

1) $t_{\rm var} \sim 10 - 100$ ms → $R_{\rm diss} \sim 10^{13}$ cm

2) $L \sim 10^{52}$ erg/s →(BZ)→ $B \sim 10^{4-6}$ G

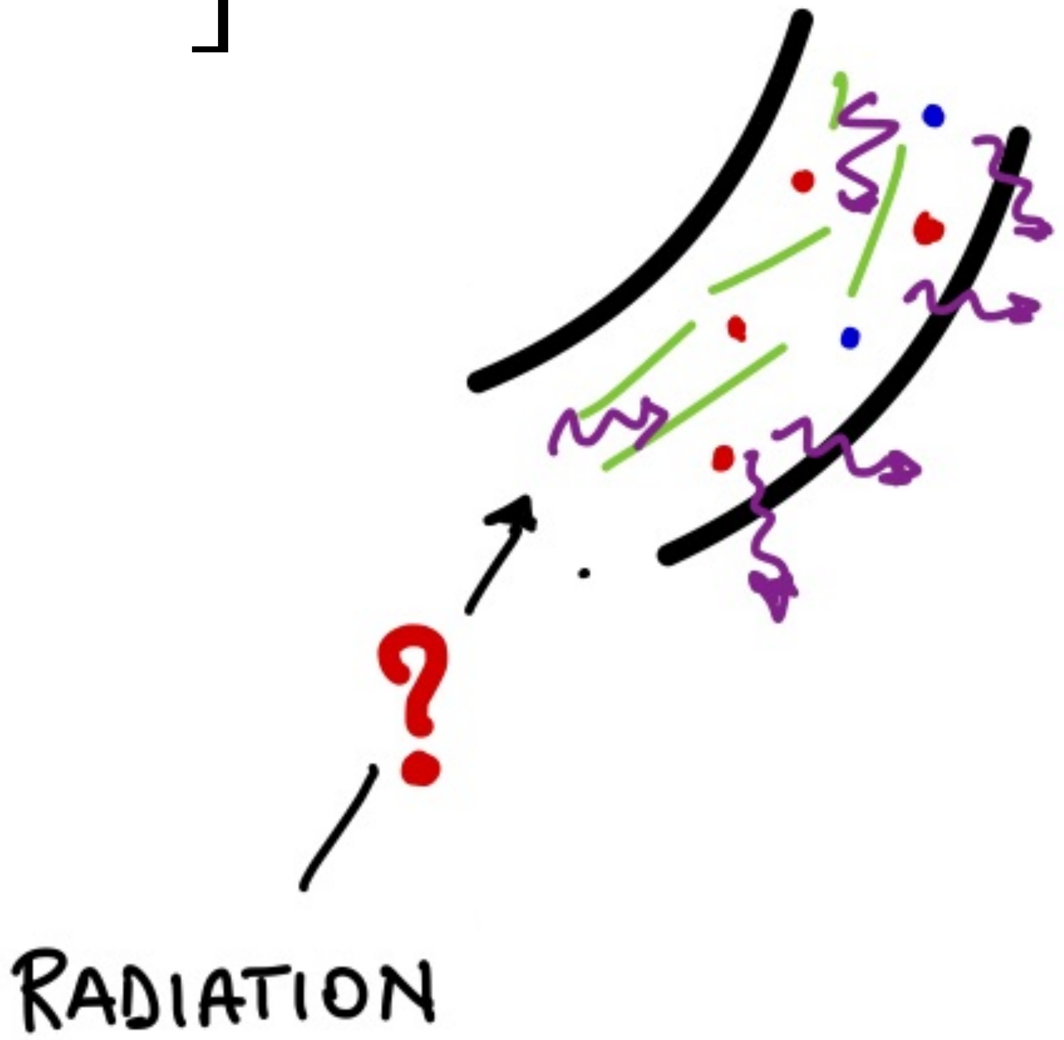
3) Non-thermal spectrum

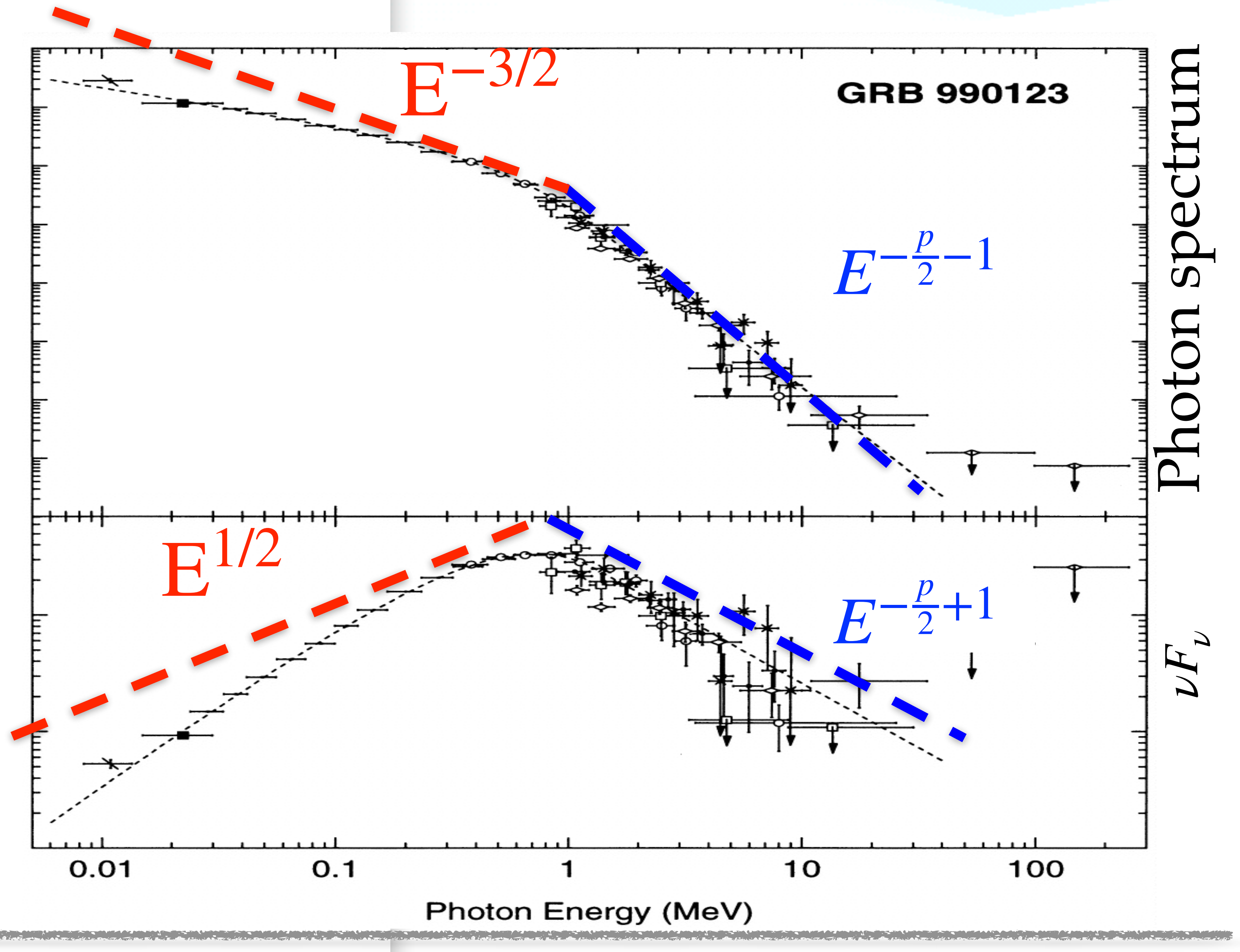
⇒ Synchrotron + SSC

BUT

Ghisellini & Celotti 2000

$$t^{cool}(\gamma) = \frac{6\pi m_e c^2}{\sigma_T c B'^{3/2}} \left[\frac{2e}{3\pi m_e c \nu^{syn}_{peak}} \frac{1+z}{\Gamma} \right]^{1/2} << \quad t_{dyn} \approx \delta t = \frac{R}{2c\Gamma^2}(1+z)$$



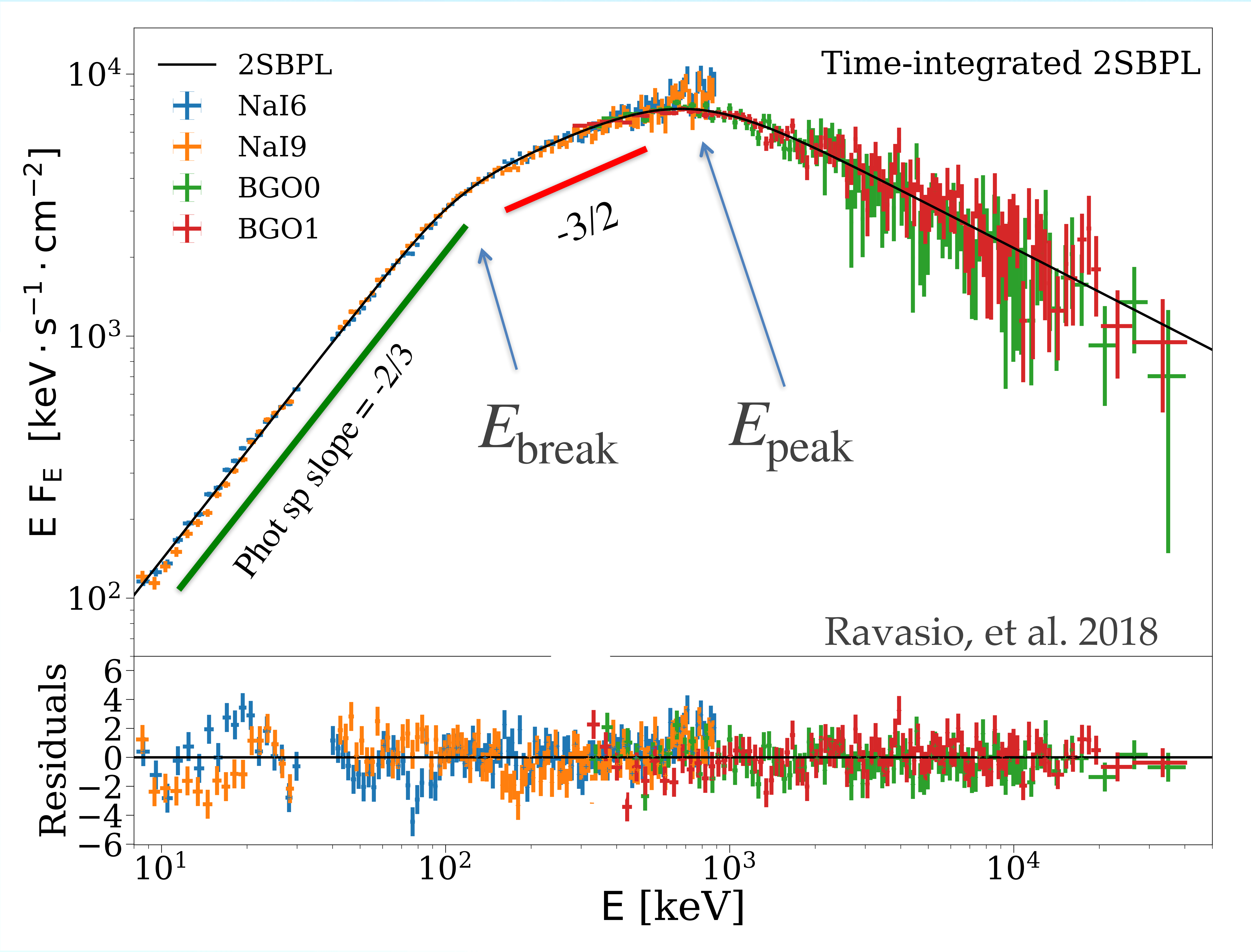


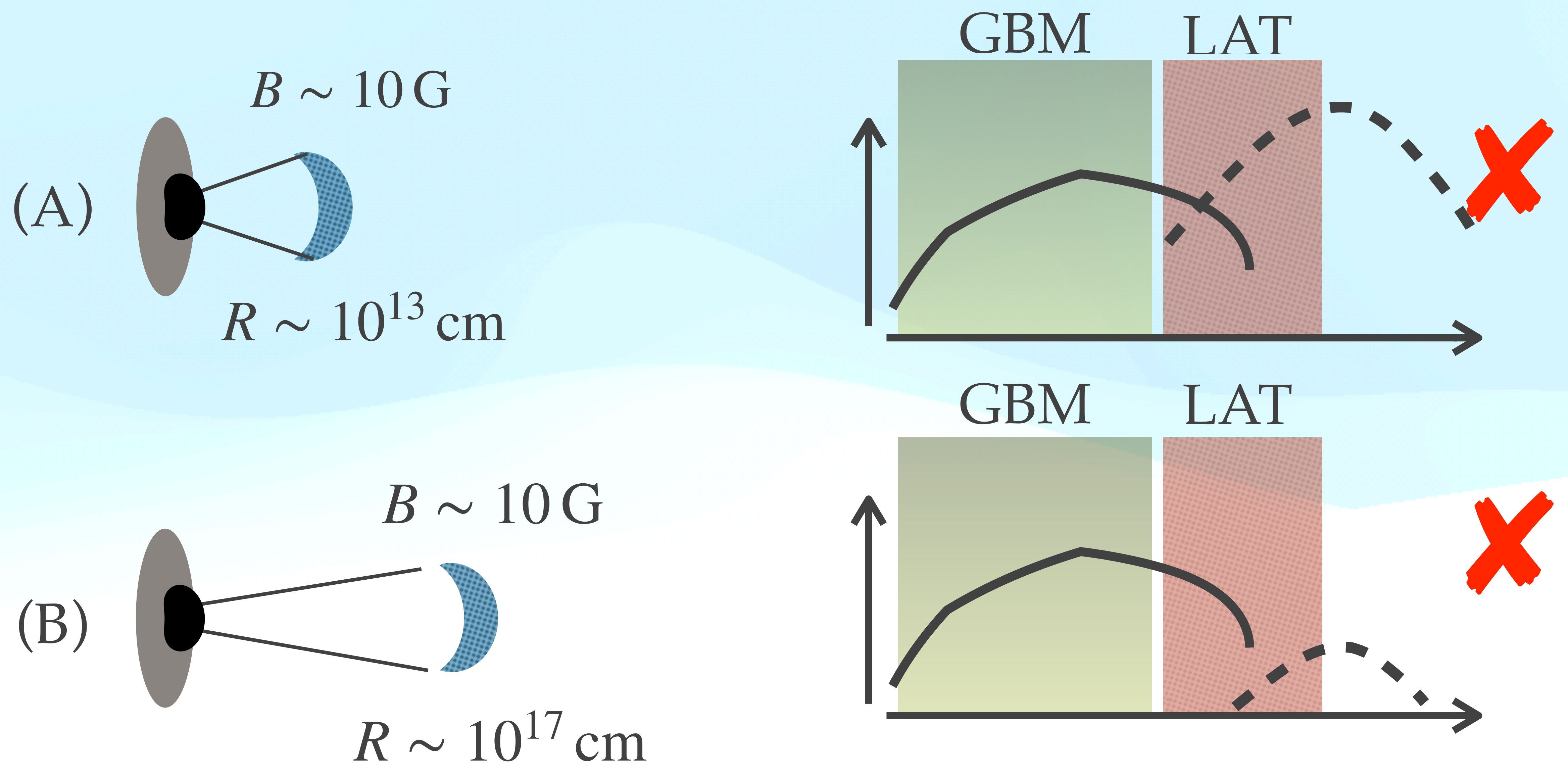
"prompt emission should be synchrotron but it doesn't look like"

Inefficient cooling

"Back to the data" (Oganesyan+2017,2018; Ravasio, et al. 2018, 2019; Ronchi, et al. 2020, Toffano, et al. 2021)

Eureka! The prompt looks very much like synchrotron





(C)
- B↓ downstream
- Acceleration clumps (reconn)

(D) Protons cool at a lower peace owing to their larger mass (Ghisellini, Ghirlanda +2019)

Afterglow physics

$\Gamma(t)$

θ

1) Jet energy $E_{\rm k} \approx E_{\rm prompt}/\eta$
2) Dissipation mechanism
3) Ambient medium n

$\epsilon_e \quad \epsilon_B \quad p \quad \gamma_{\rm min} \quad \gamma_{\rm max} \quad \xi_e$

Ultra relativistic shocks in weakly B e-p plasma

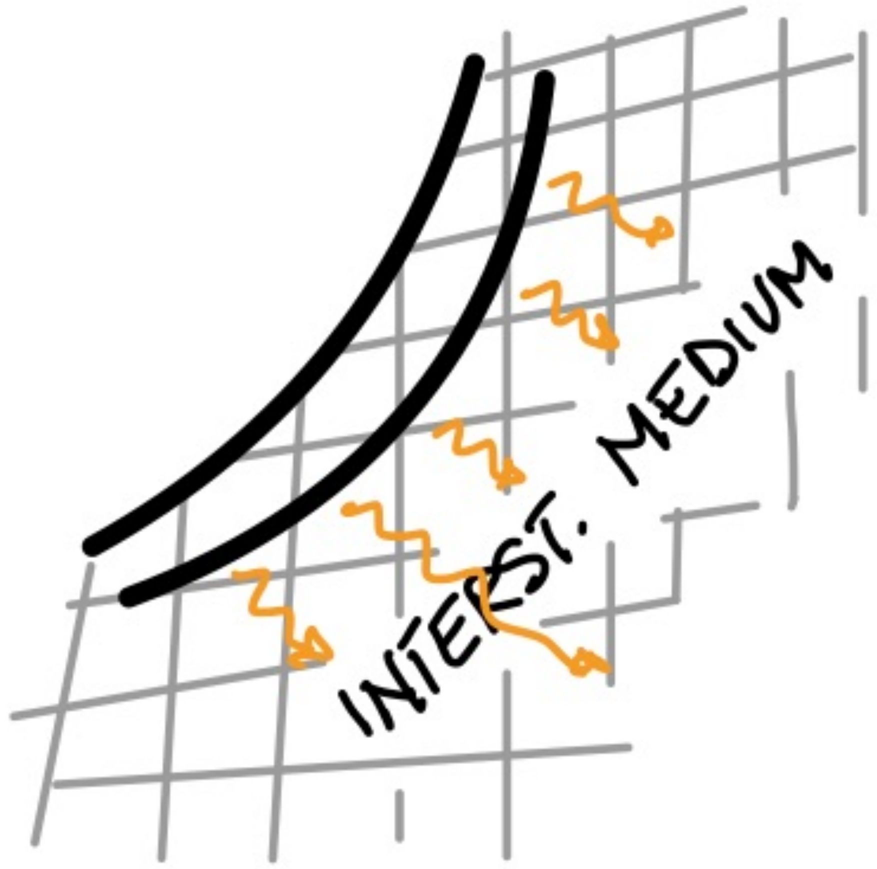
BUT

$$\frac{c}{\omega_{p,e}} \ll \text{AG pc-scale}$$

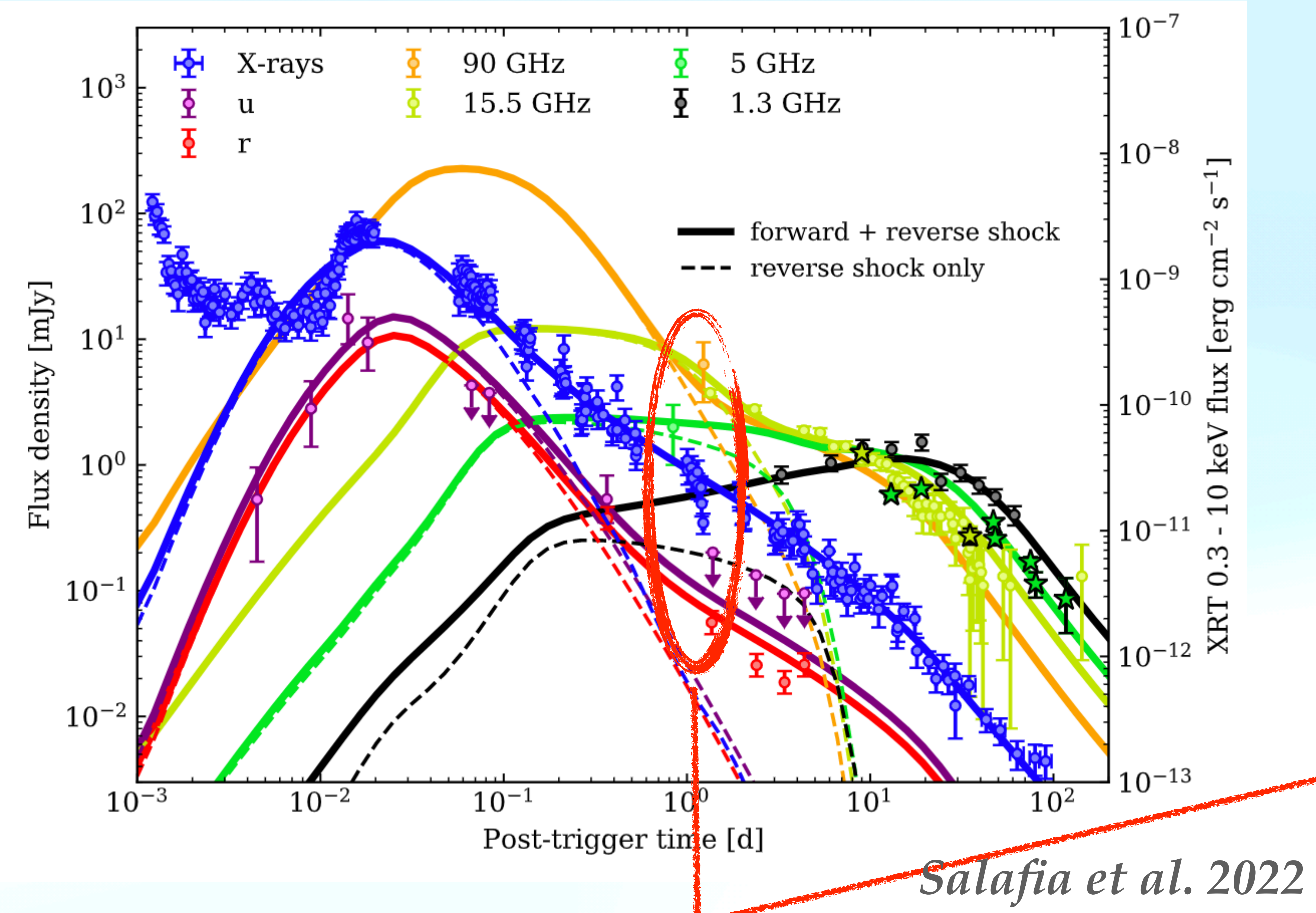
"bridge the gap: parametrize shock microphysics and compare parameter posteriors with theory"

Intrinsic + extrinsic

Parameter degeneracies

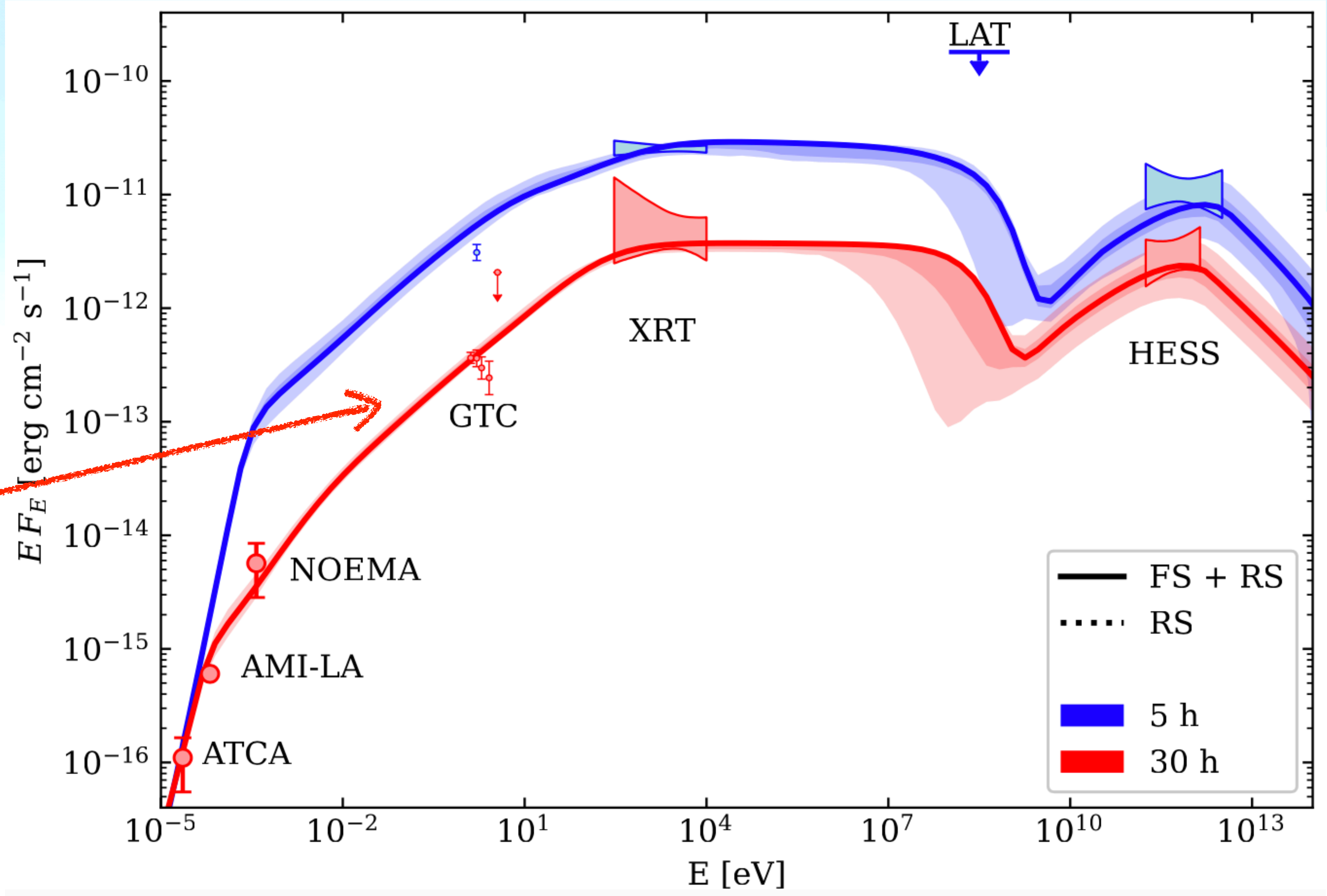


GRB 190829A



$L_{SSC}/L_{syn} \sim U_r/U_B$

$\gamma_e \sim \sqrt{\nu_{SSC}/2\nu_{syn}}$



Notable:

- Low prompt efficiency
- 7% acc. Electrons
- Jet orientation <2 deg off
- $\epsilon_B \sim 10^{-5}$

The BOAT

GRB 221009A [55 Refereed articled + 180 non ref @ 21/09/2023]

Fluence = 0.2 erg/cm2 z=0.151 —> Eiso~1e55 erg ; Liso~1e54 erg/s

Saturated several instruments

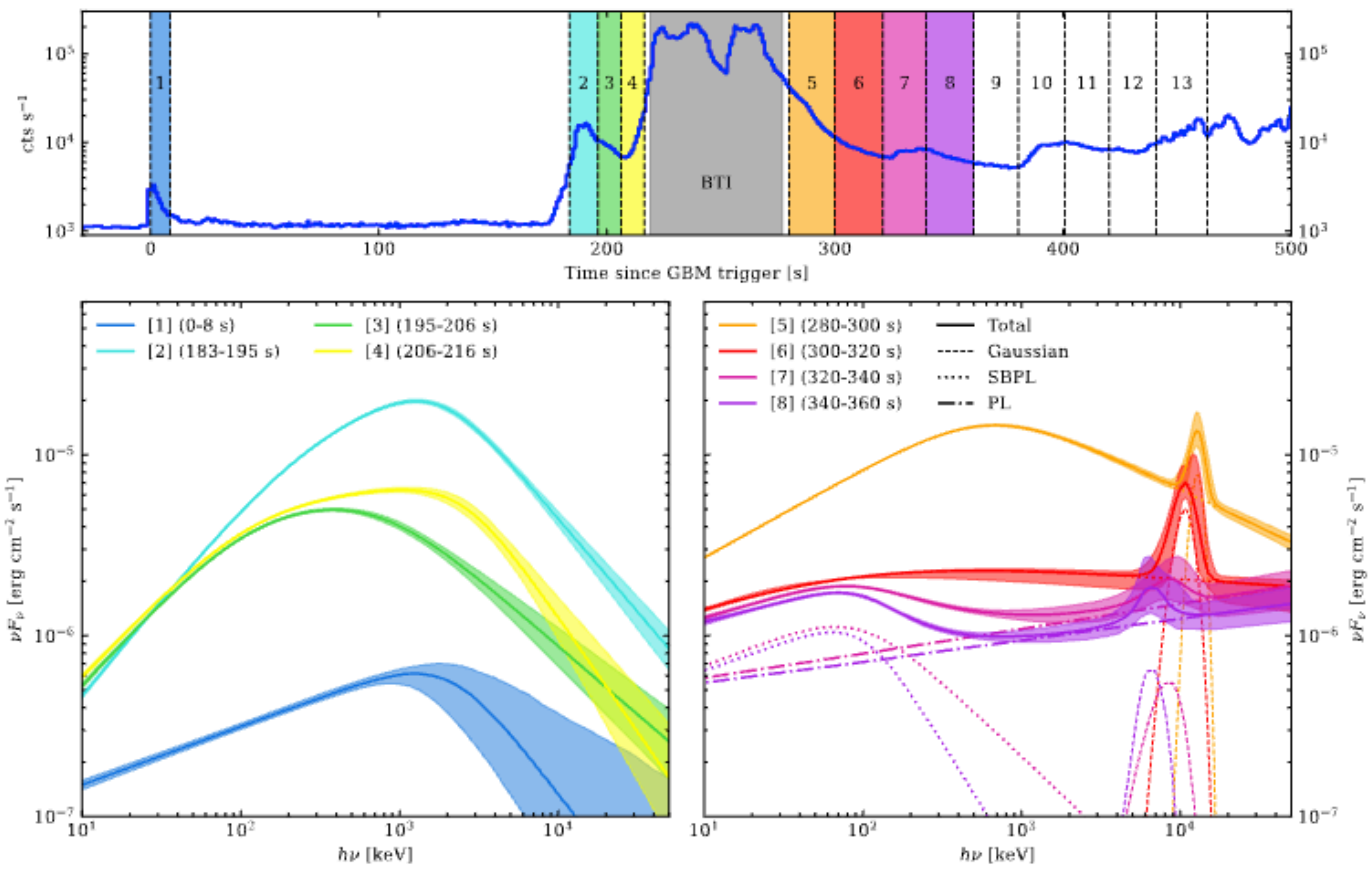
~ 18 TeV photons LHAASO .—> 12 TeV

~Once per -thousand years (Malesani et al. 2022; Burns 2023)

~first JWST spec (Levan 2023)

Afterglow model challenges

First ever significant emission line in a GRB at MeV energies (Ravasio, Salafia et al. 2023)



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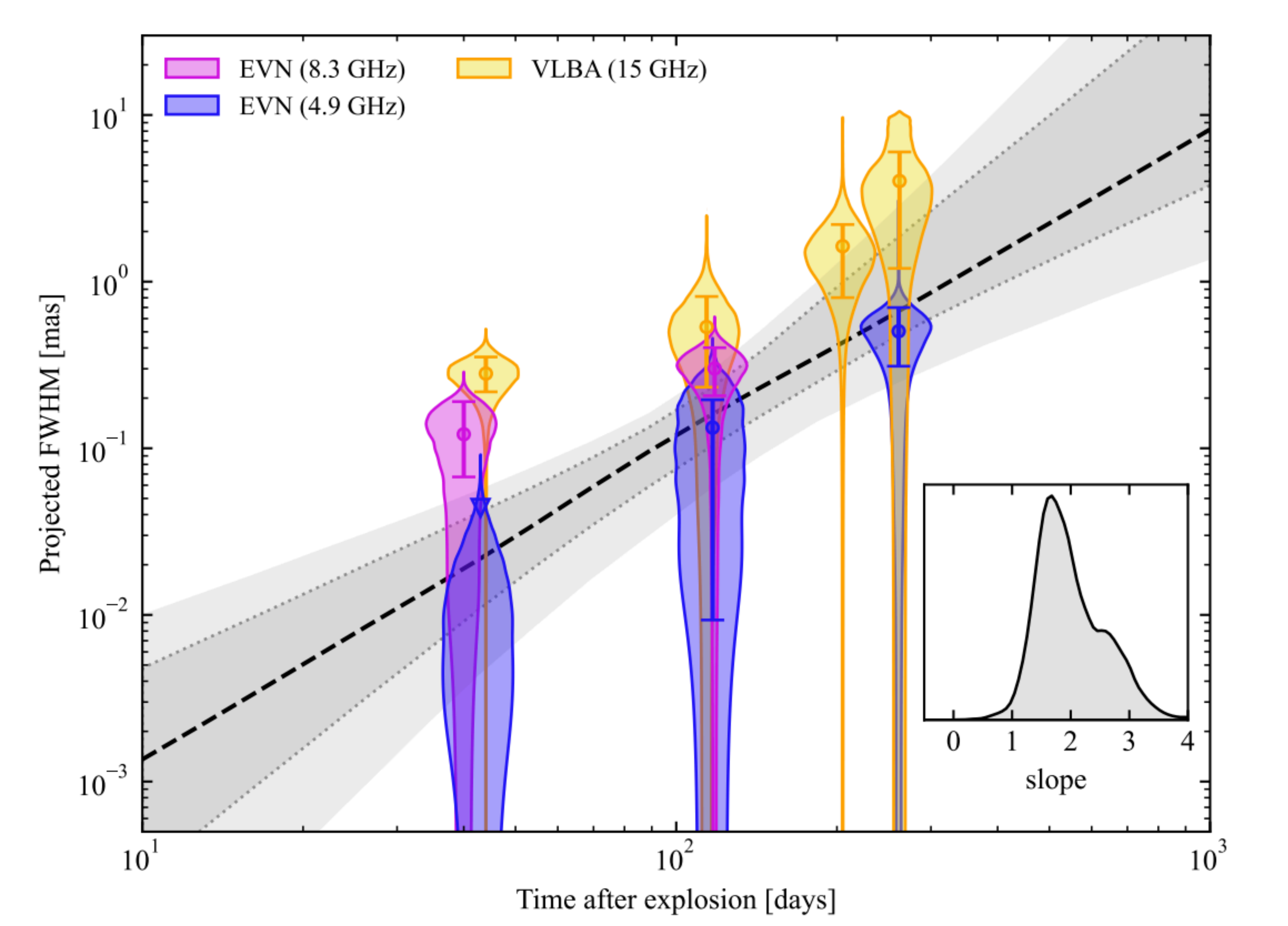
Second ever measurement of size expansion (Giarratana et al. 2023) + support FS+RS modelling



Thank you

(Honoured to take questions)