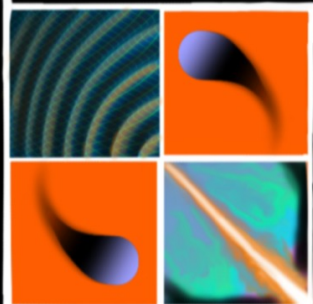


The dawn  
of a new astronomy



# GEV EXCESS DETECTED IN A MERGER-DRIVEN GRB

A. Mei, B. Banerjee, G. Oganessian, O. S. Salafia, S. Giarratana, M. Branchesi, P. D'Avanzo,  
S. Campana, G. Ghirlanda, S. Ronchini, A. Shukla, P. Tiwari

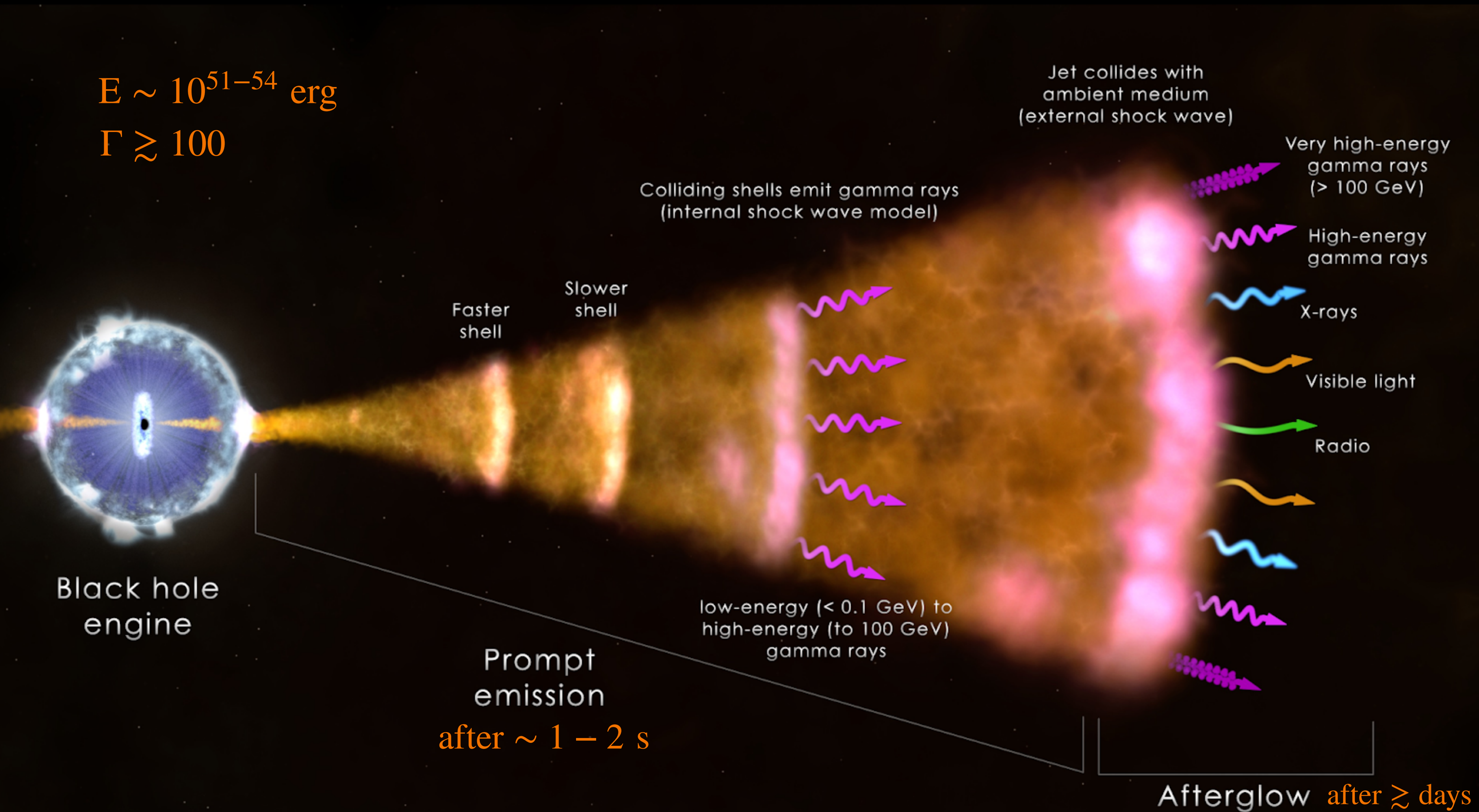




# The fireball model

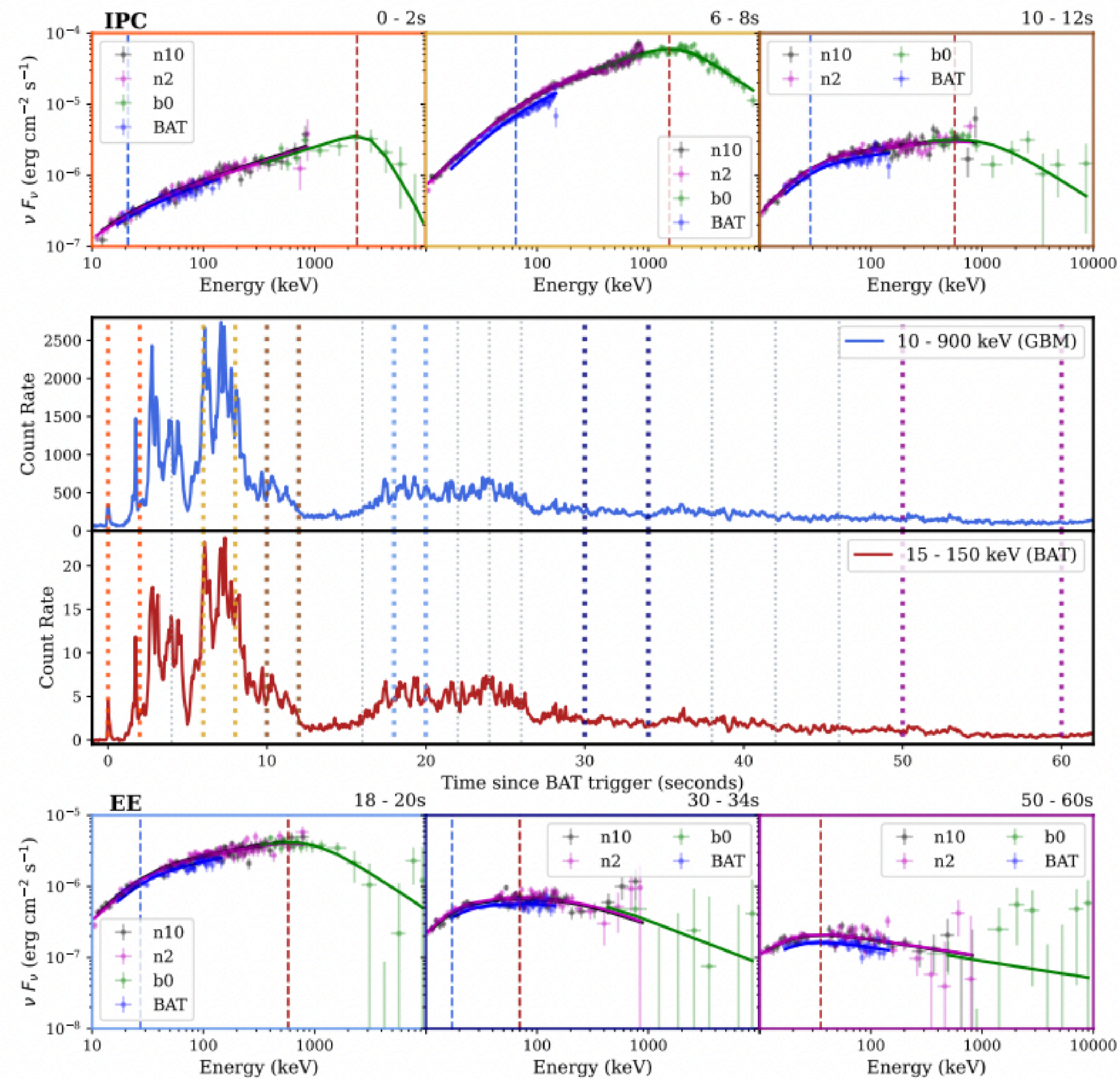
$$E \sim 10^{51-54} \text{ erg}$$

$$\Gamma \gtrsim 100$$





# GRB 211211A: A long luminous source



- On Dec. 11, 2021 a **bright** gamma-ray emission triggered **Fermi/GBM** (10 keV - 40 MeV) and **Swift/BAT** (15-150 keV).
- The **duration** of the prompt emission of this GRB is  $T_{90} \simeq 34$  s
- Presence of a **softer extended emission** at later times (up to  $\sim 60$  s)

**Long duration GRB!**

Gompertz et al. 2022



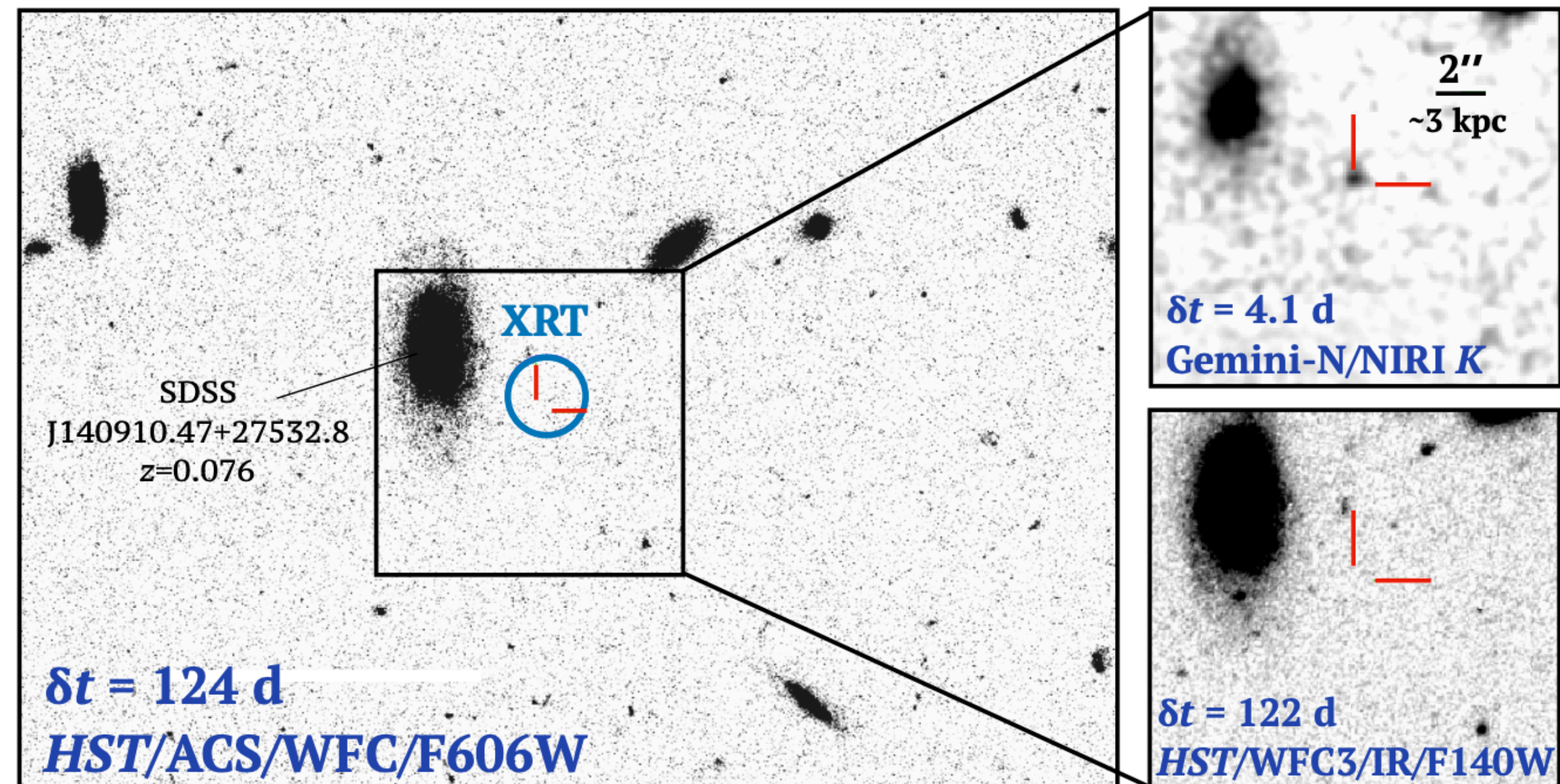
# GRB follow-up

- Extensive **follow-up campaign** from **radio** to **high energies** (HE, 100 MeV - 10 GeV)
- We joined the follow-up effort with **XMM-Newton** (X-rays, 0.5-10 keV) and **VLA** (radio, 3-10 GHz)
- $\sim 5$  **arcsec** ( $\sim 8$  kpc in projection) **offset** from the closest galaxy ( $z=0.076$ ).

Hubble deep observations confirmed the redshift of this source (Rastinejad+ 2022)

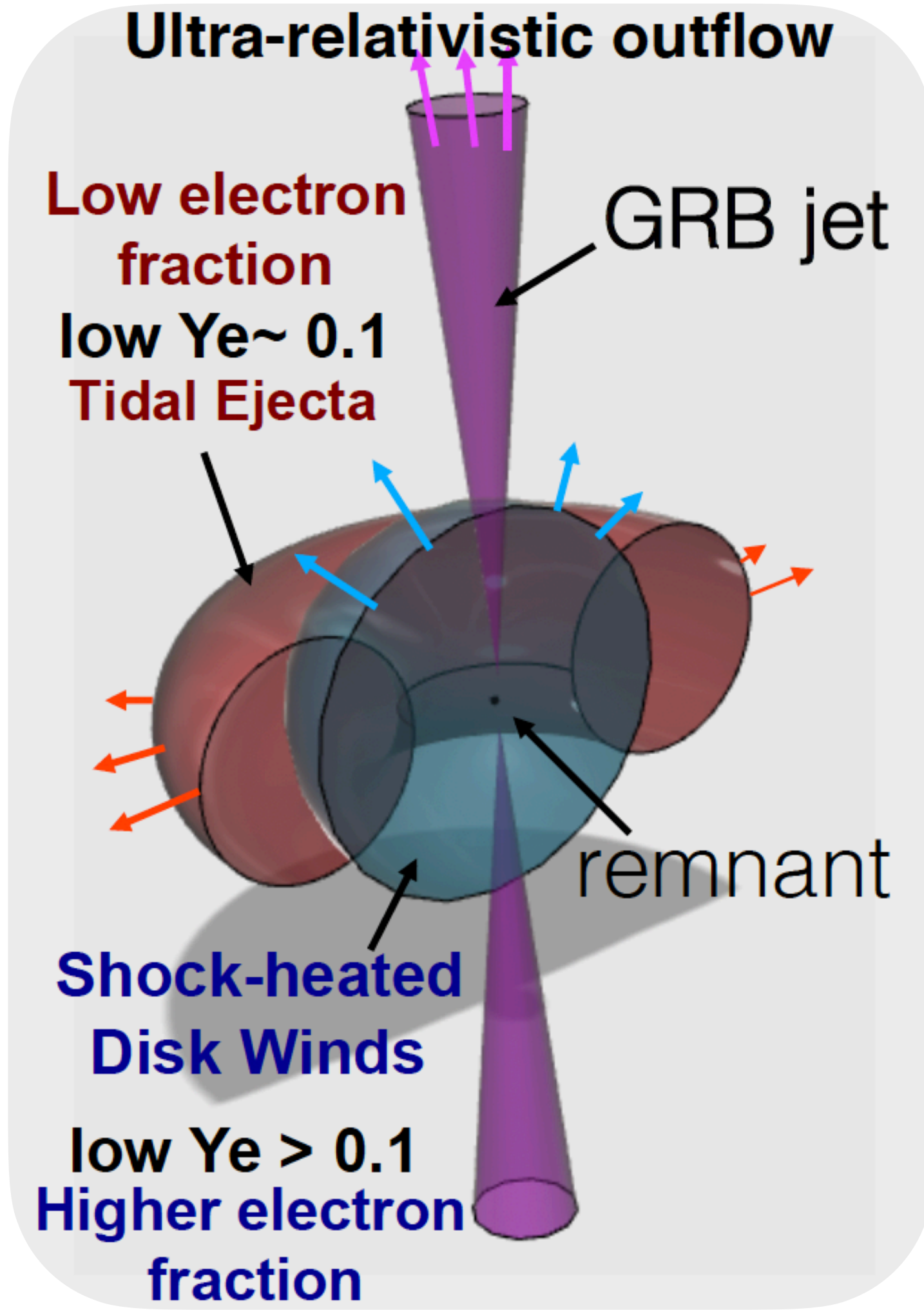
Where is the supernova?

Rastinejad et al. 2022 (but see also Troja et al. 2022)

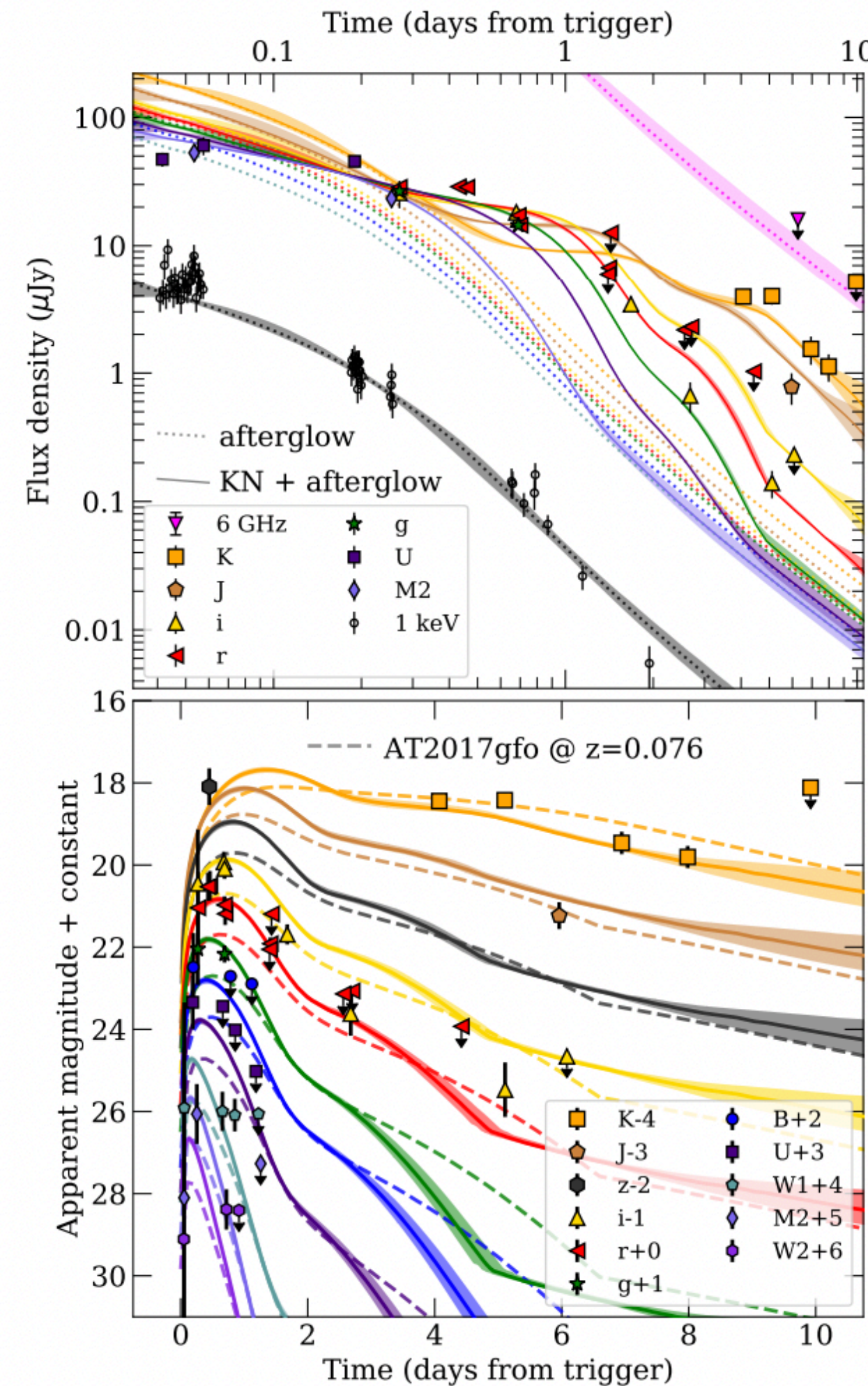




# The turning point: Kilonova detection



Rastinejad et al. 2022



## Three-component kilonova fit

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

**Long merger-driven GRB!**

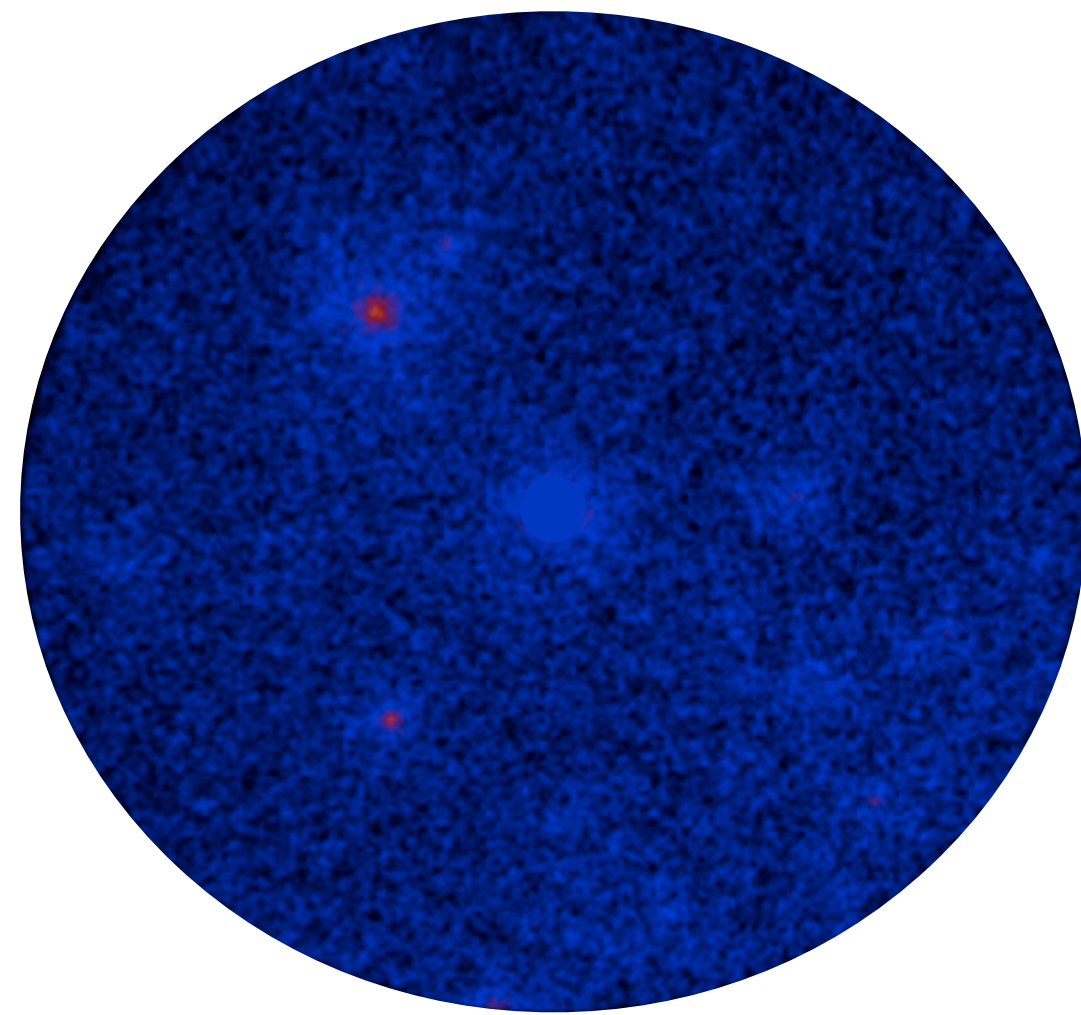


# Source detection with Fermi/LAT

**Likelihood ratio test (LRT)**



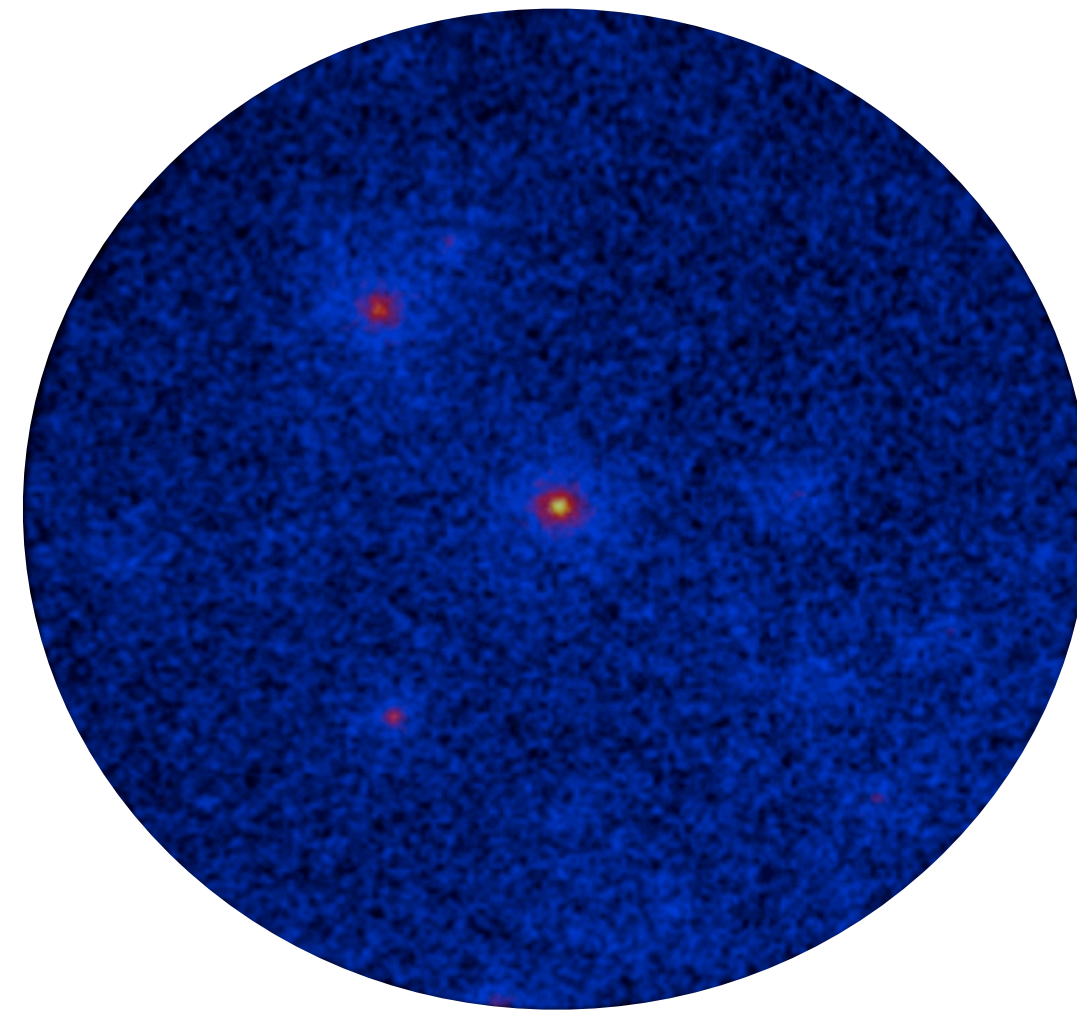
$$TS = -2 \log \left( \frac{\mathcal{L}_0}{\mathcal{L}_1} \right) \approx (\text{detection significance})^2$$



$\mathcal{L}_0$

Null model

(Observation without source)



$\mathcal{L}_1$

Alternative model

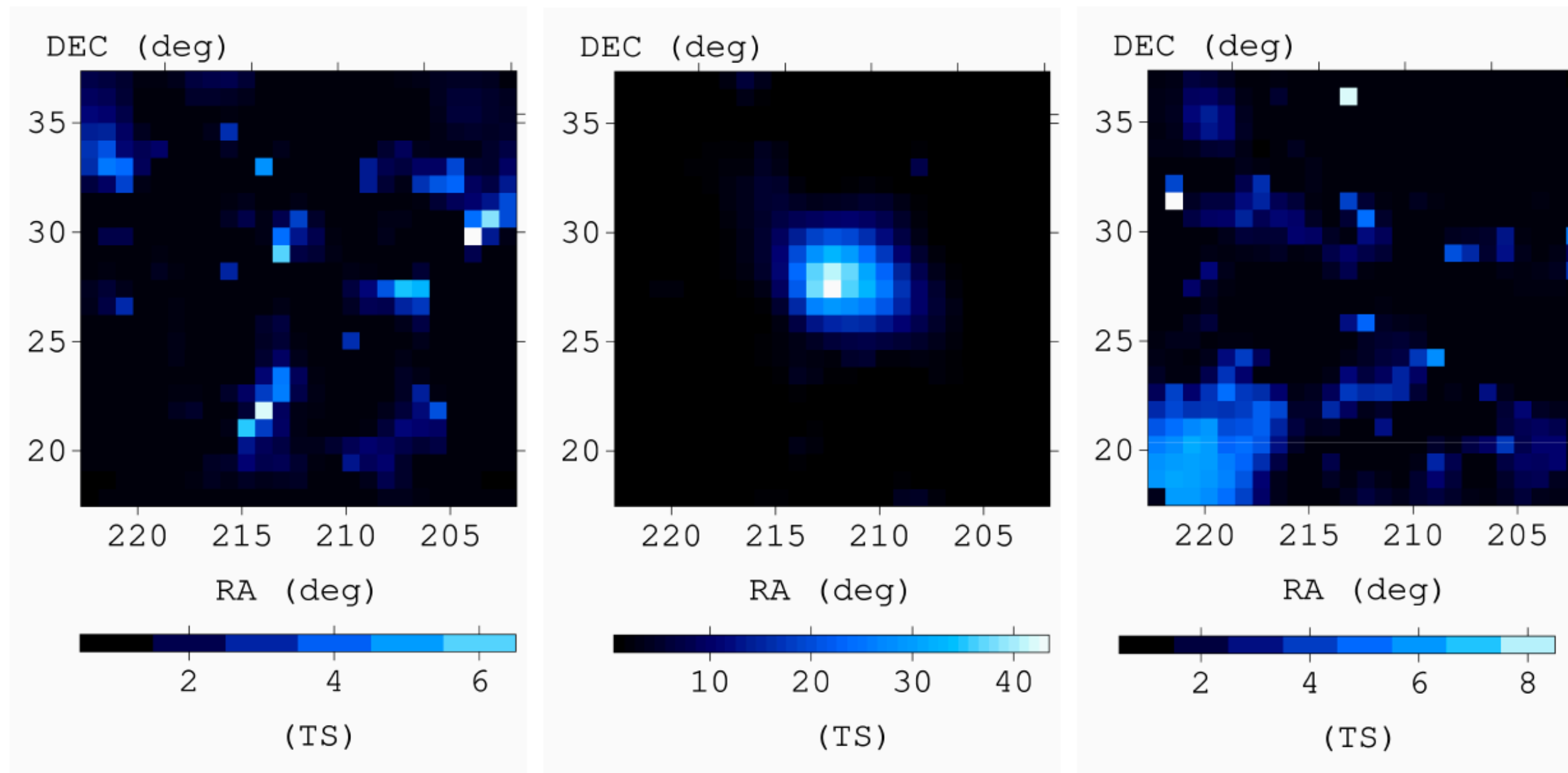
(Observation with source)

- We define a **Region of Interest (ROI)** of **12 deg** around the GRB position.
- We account for the **isotropic particle bkg**, **galactic** and **extragalactic high energy components** from Fermi 4th catalog (F4GL).
- We assume a **PL spectral model** for the GRB as well as for the other sources in the ROI, the latter with **fixed normalisation** and **spectral index**.
- We assess the **improvement of the fit** following the introduction of the GRB in the model through **LRT**.



# HE emission at late times

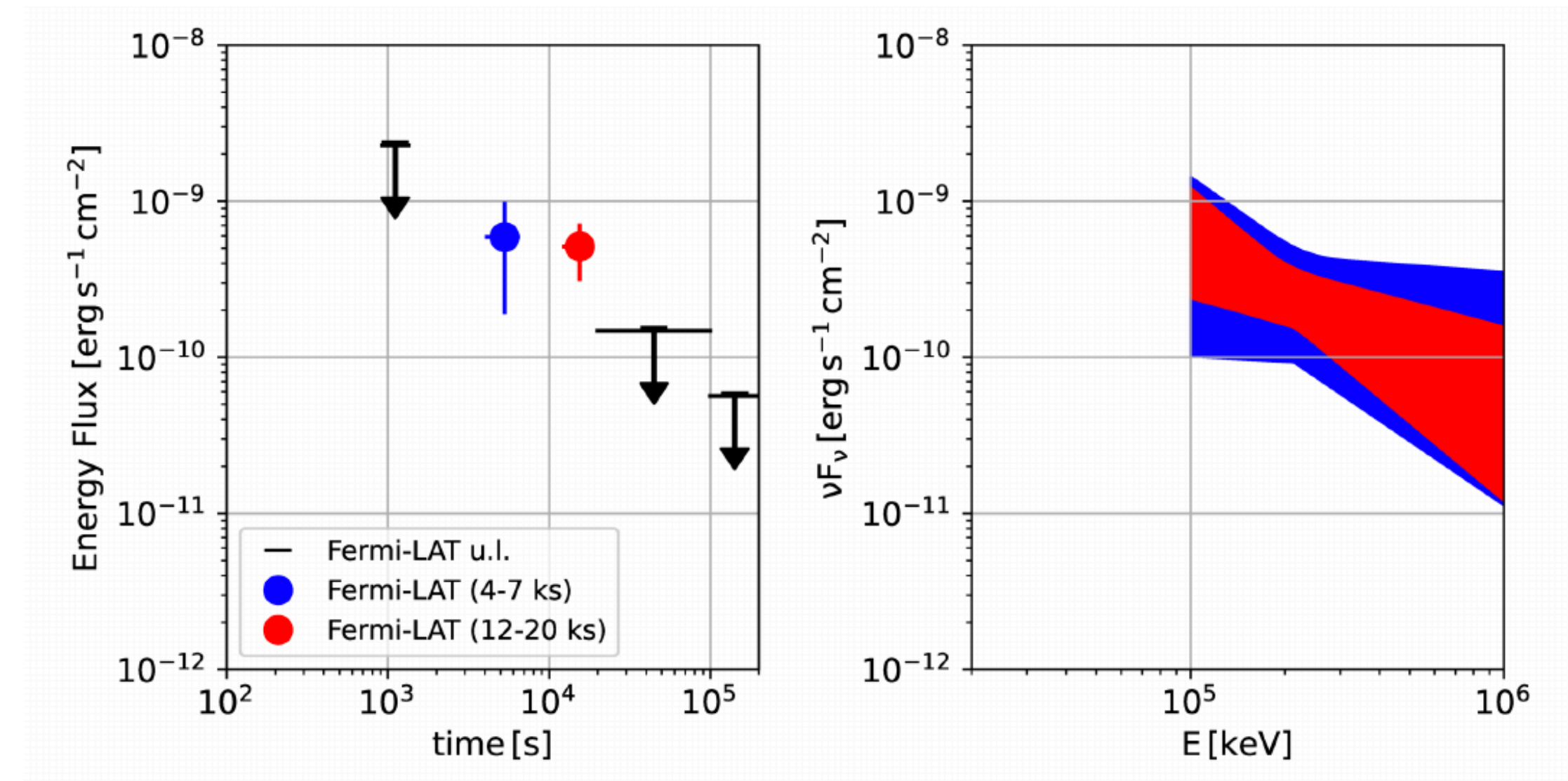
Mei et al. 2022, Nature



(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

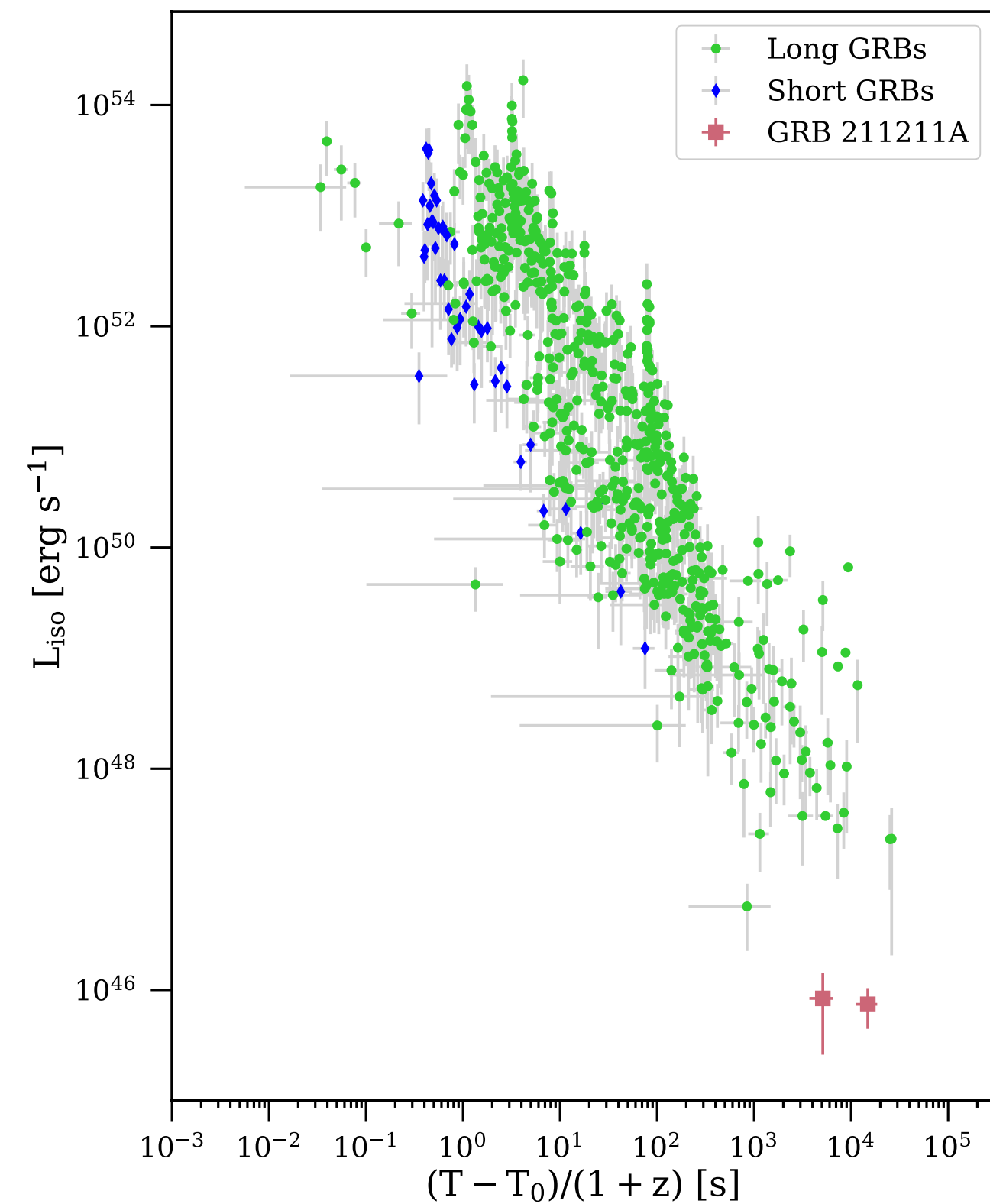
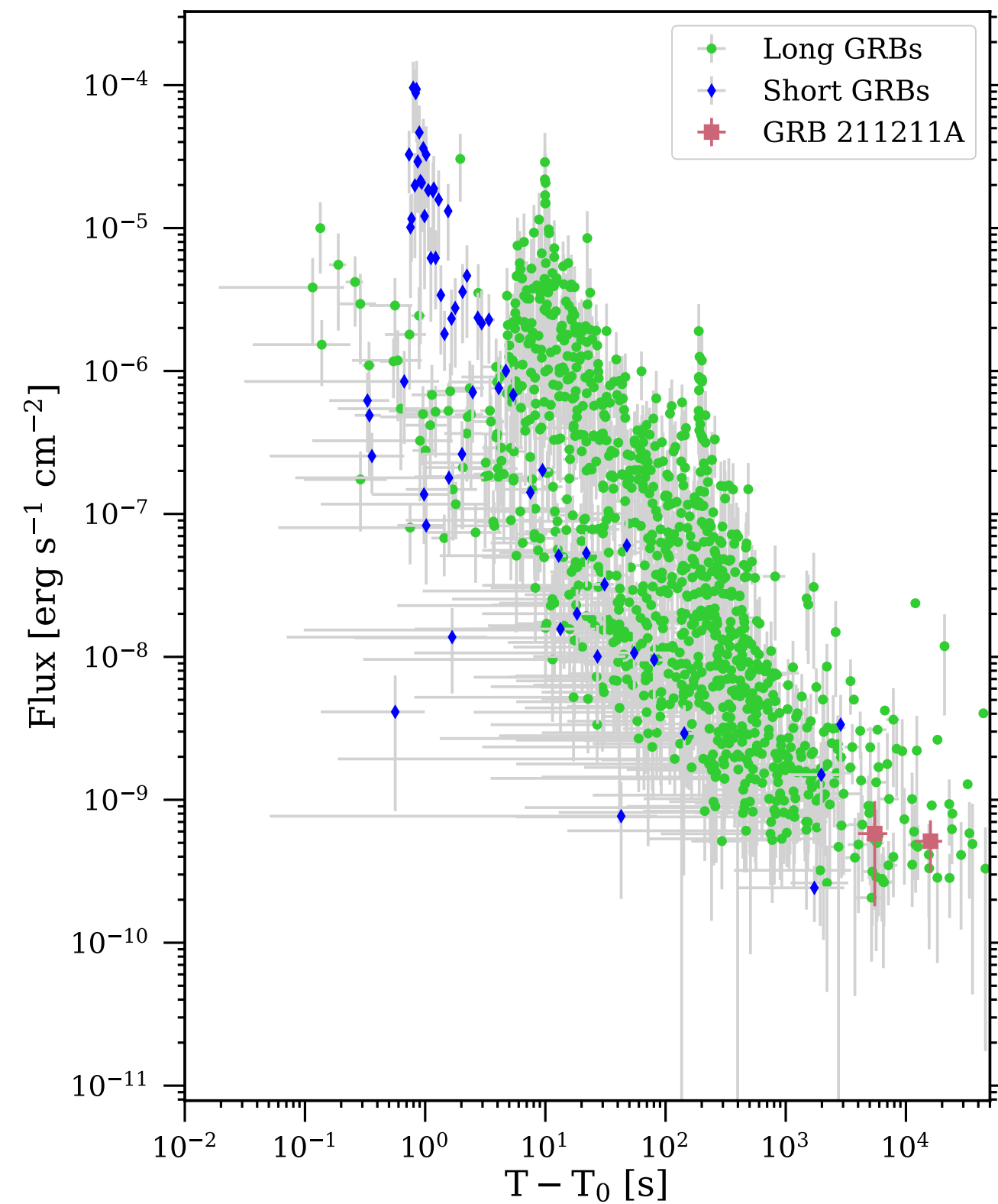


(d)  $t_0$  to  $t_0 + 2$  d



# Comparison with other sources

## 2nd Fermi/LAT GRB catalog (Ajello et al. 2019)

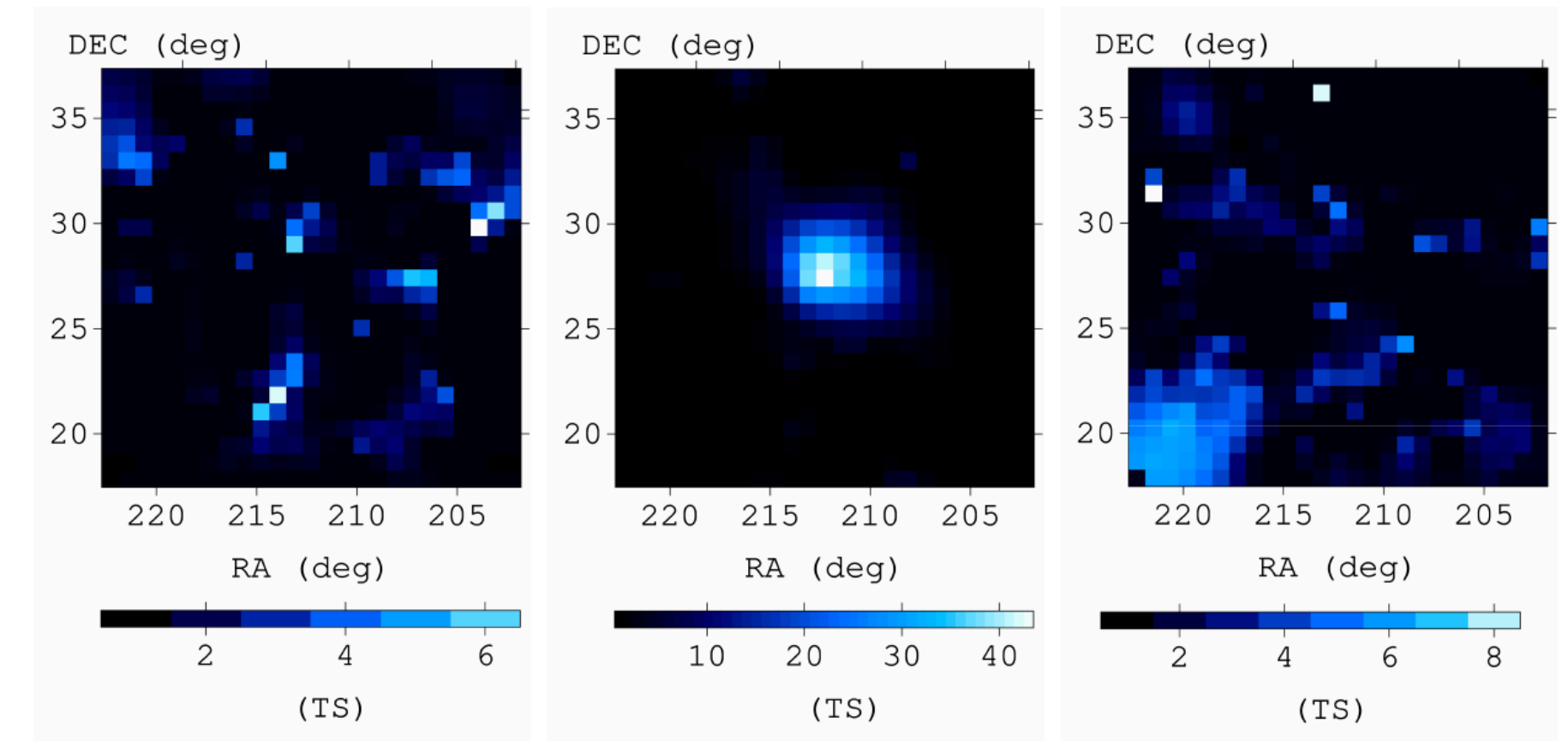
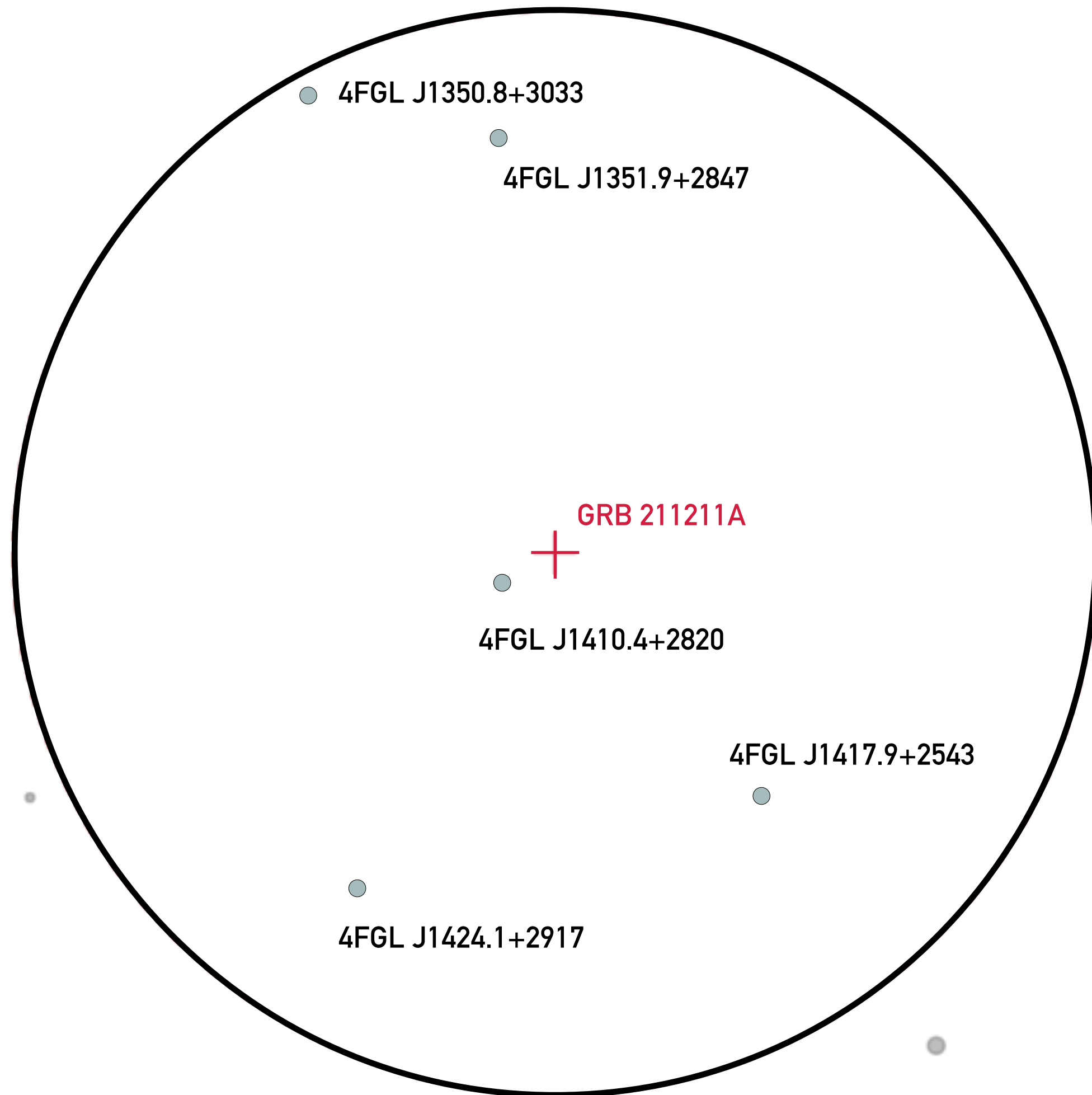


- GRB 211211A is **intrinsically faint** in the **LAT energy band** ( $L_{\text{iso}} \sim 10^{46}$  erg/s).
- It is **observable** thanks to its **proximity** to Earth! ( $\sim 350$  Mpc)
- No other GRB with  $d \lesssim 350$  Mpc shows **significant LAT emission**.
- GRB 170817A would be a **good candidate**, but no LAT observation due to **South Atlantic Anomaly** before 1ks, while after 1ks there is **no detection** (TS<9).



# Ruling out contaminations from the bkg

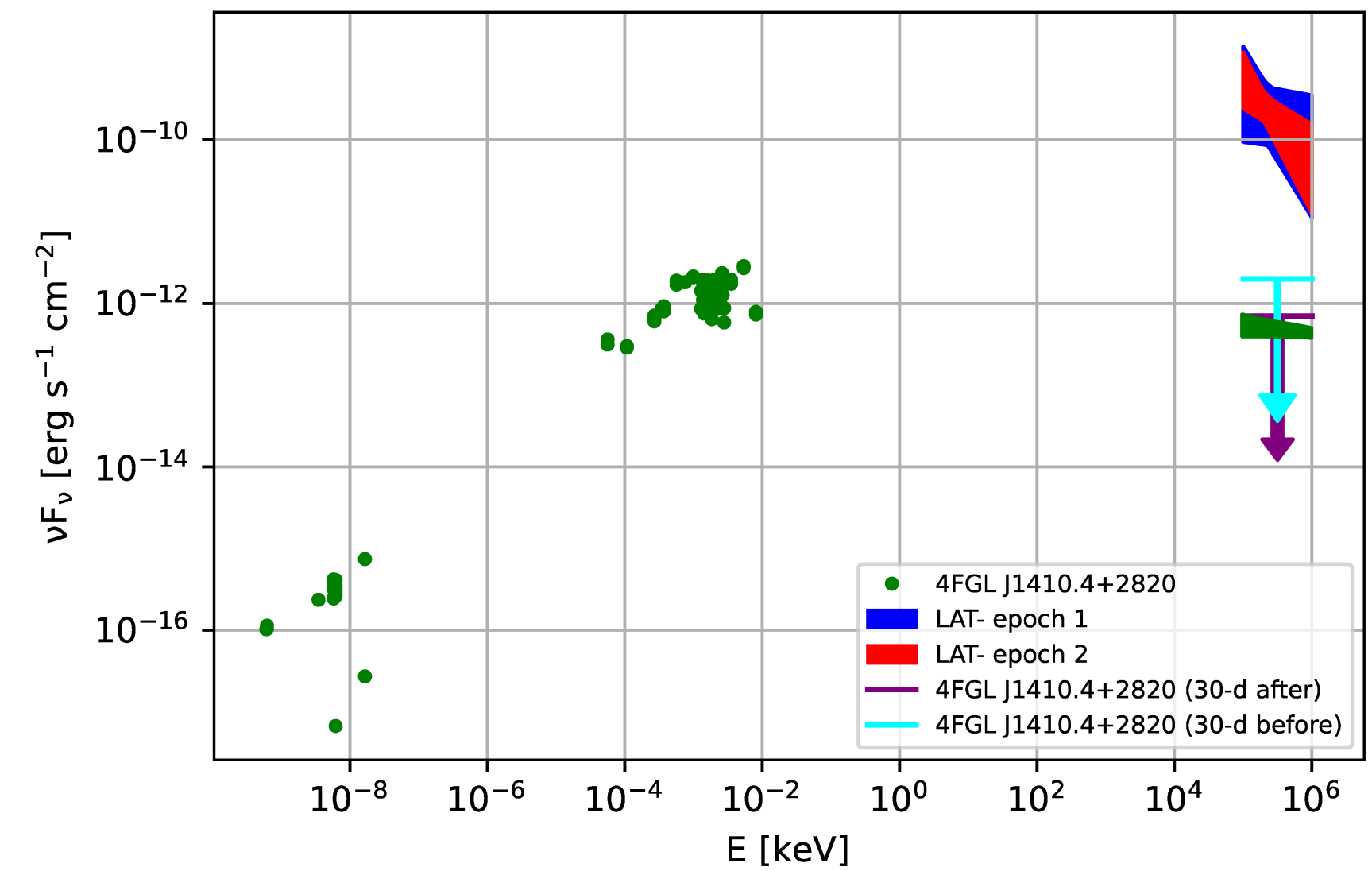
## Fermi 10-year Source Catalog (4FGL)



(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

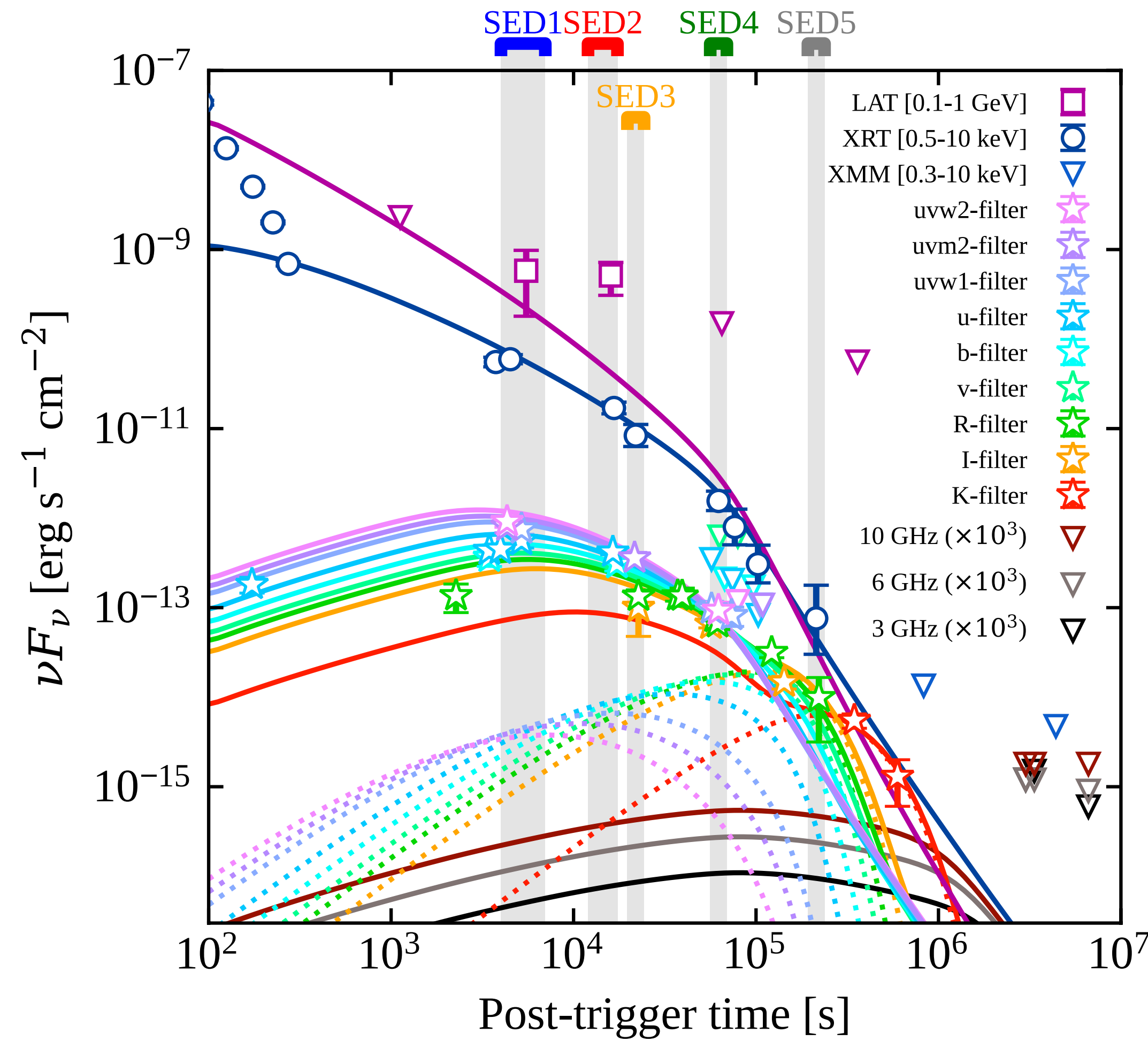




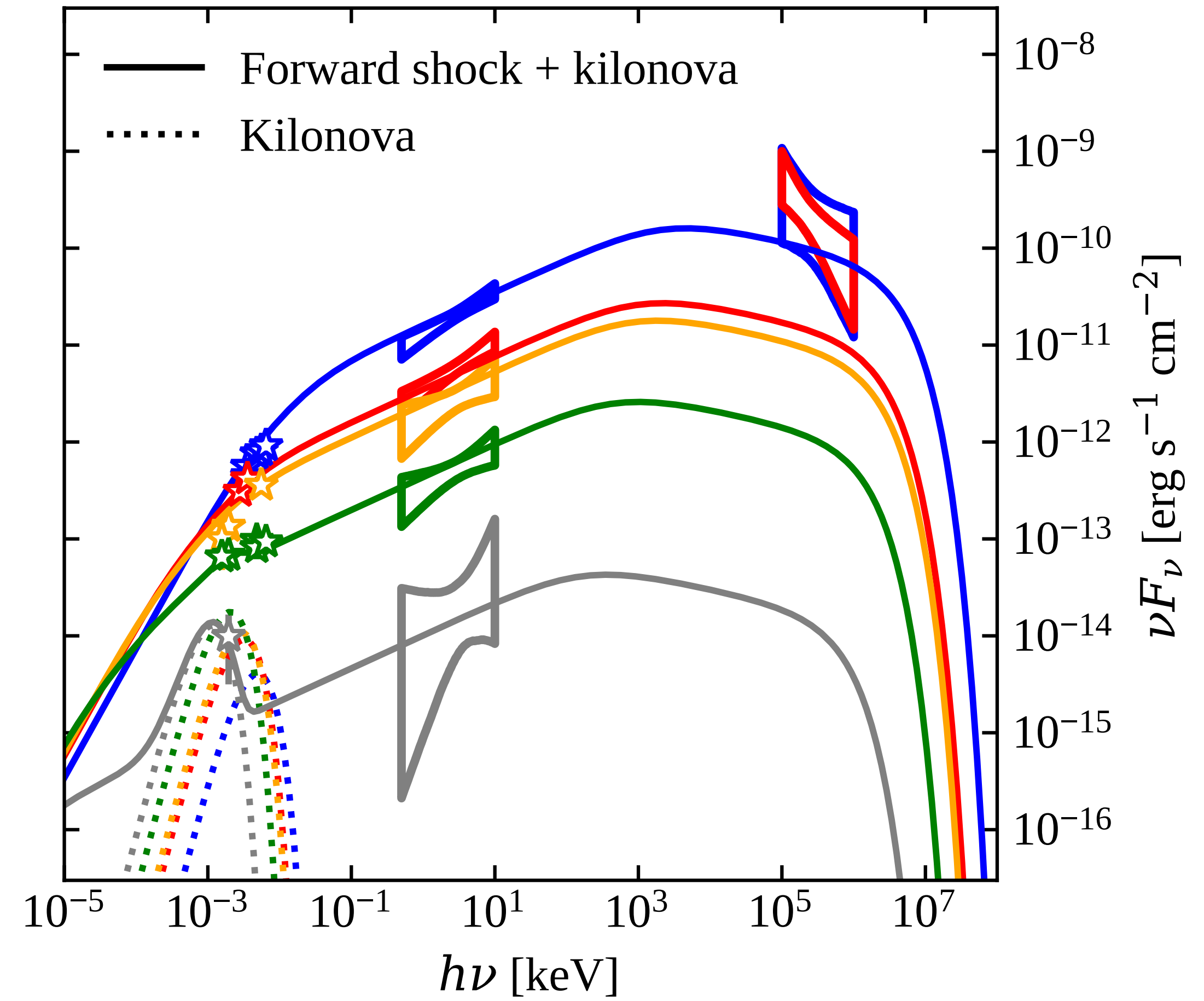
# HE excess at late time

## Light curves

## Spectra (SED)



(a)

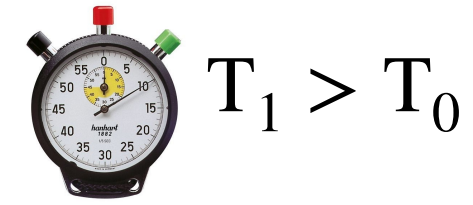


(b)

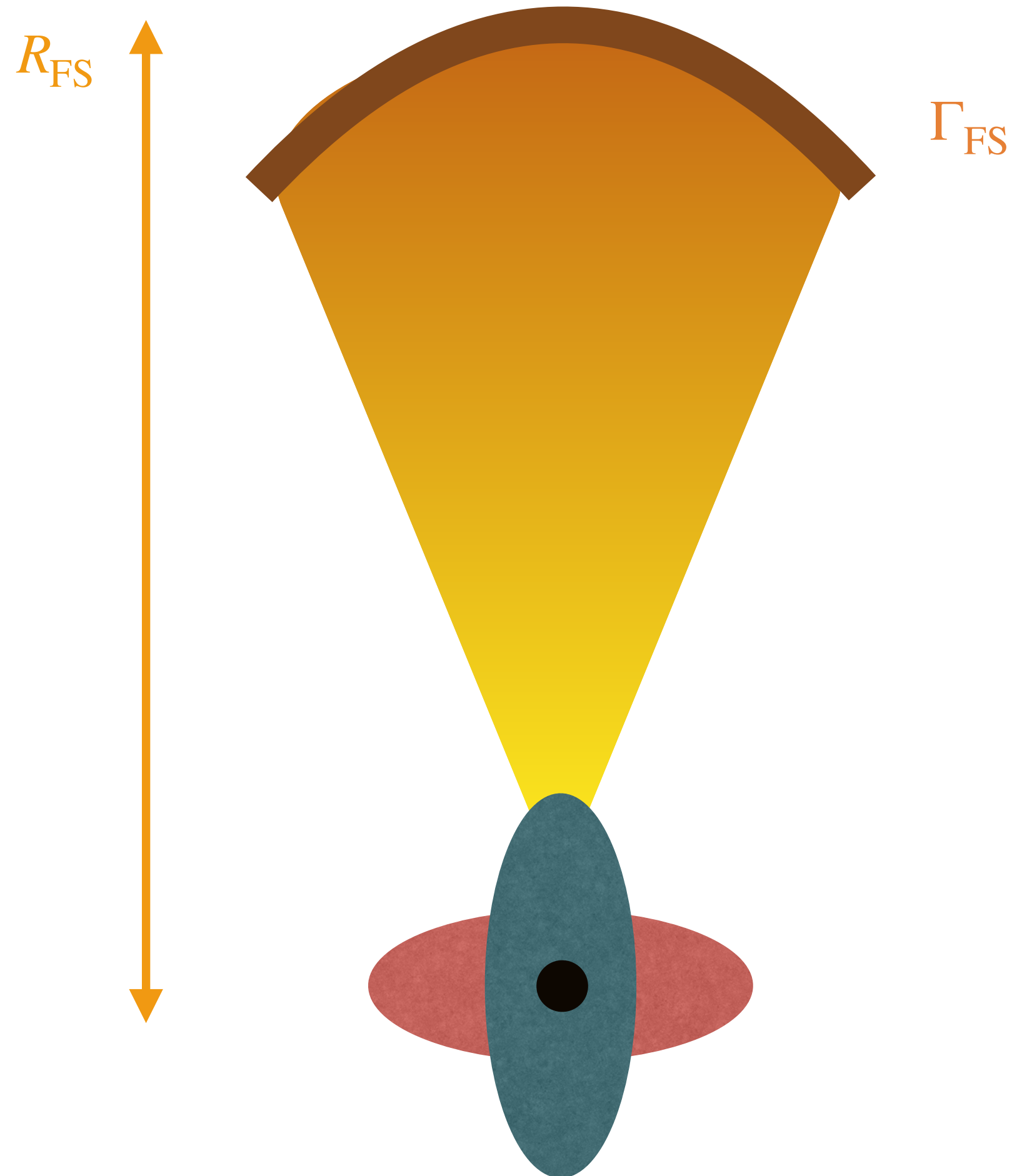
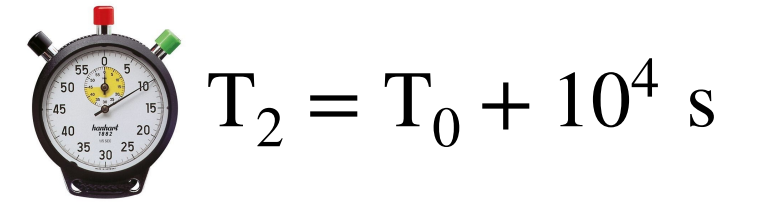


# Low power jet at late times

Deceleration phase

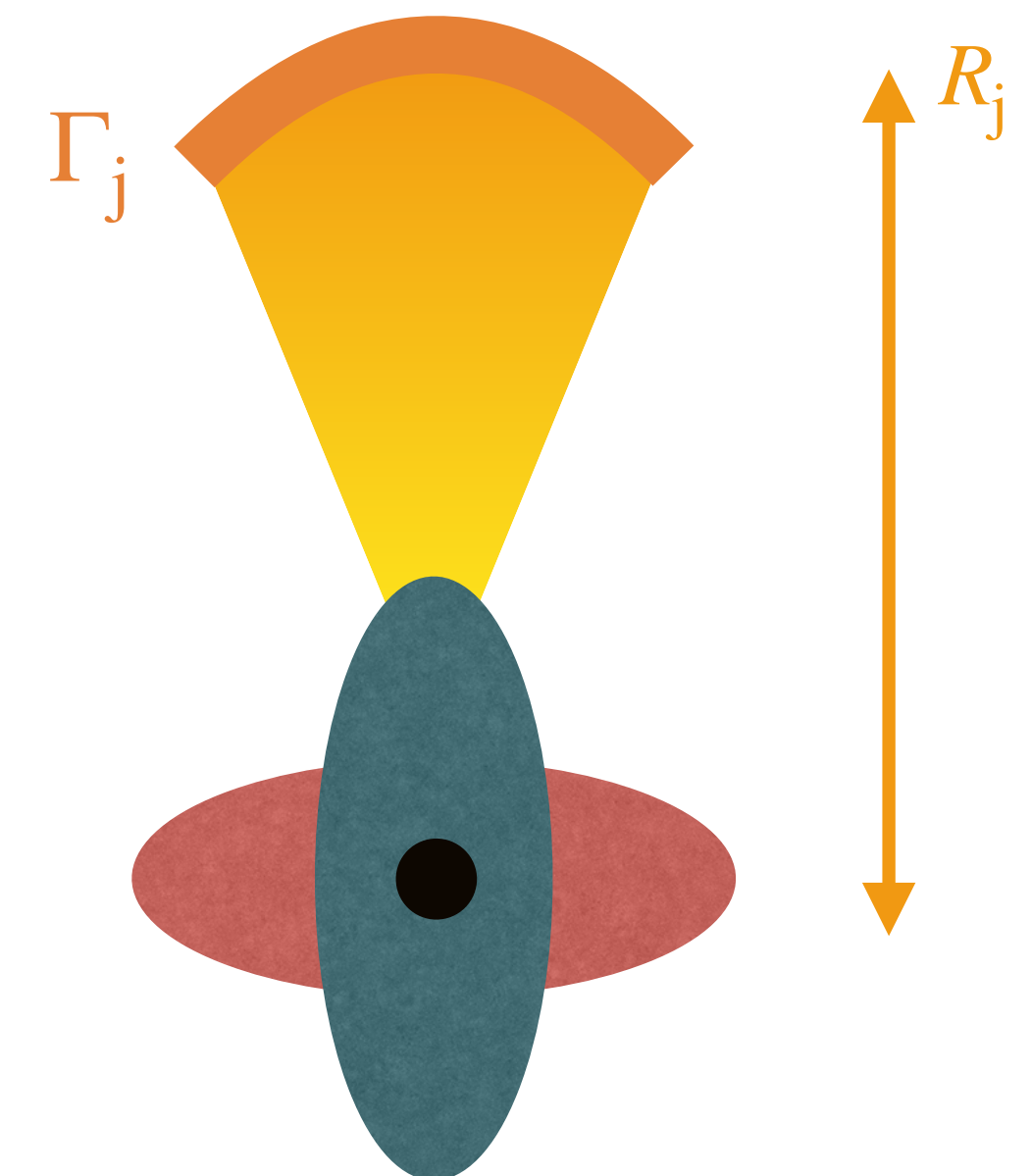


Late-time activity




Accretion onto the newly born compact object:

$$\dot{M} \propto t^{-5/3}$$

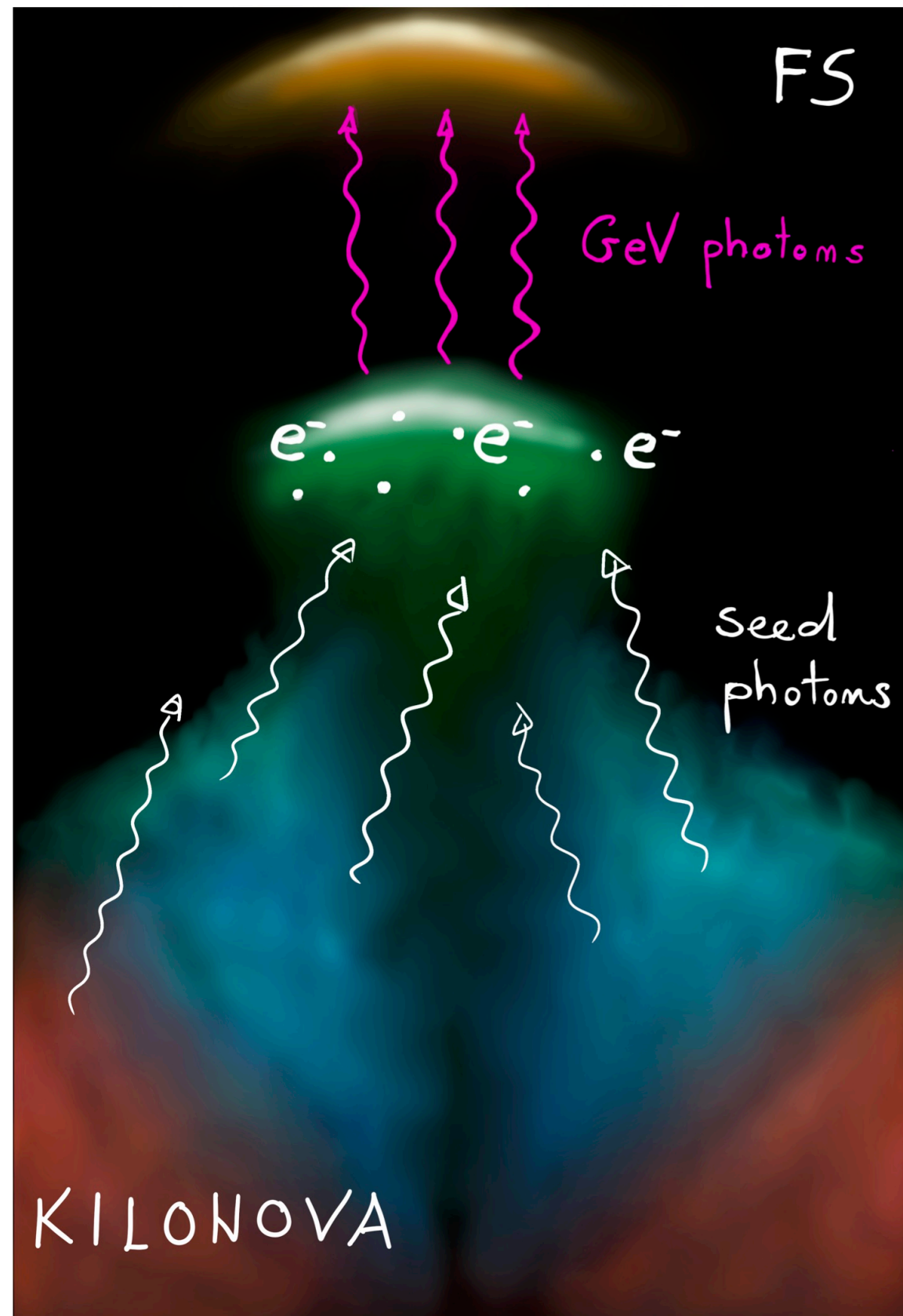




# Low power jet-KN EIC

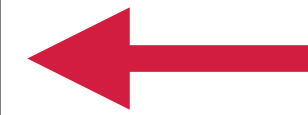
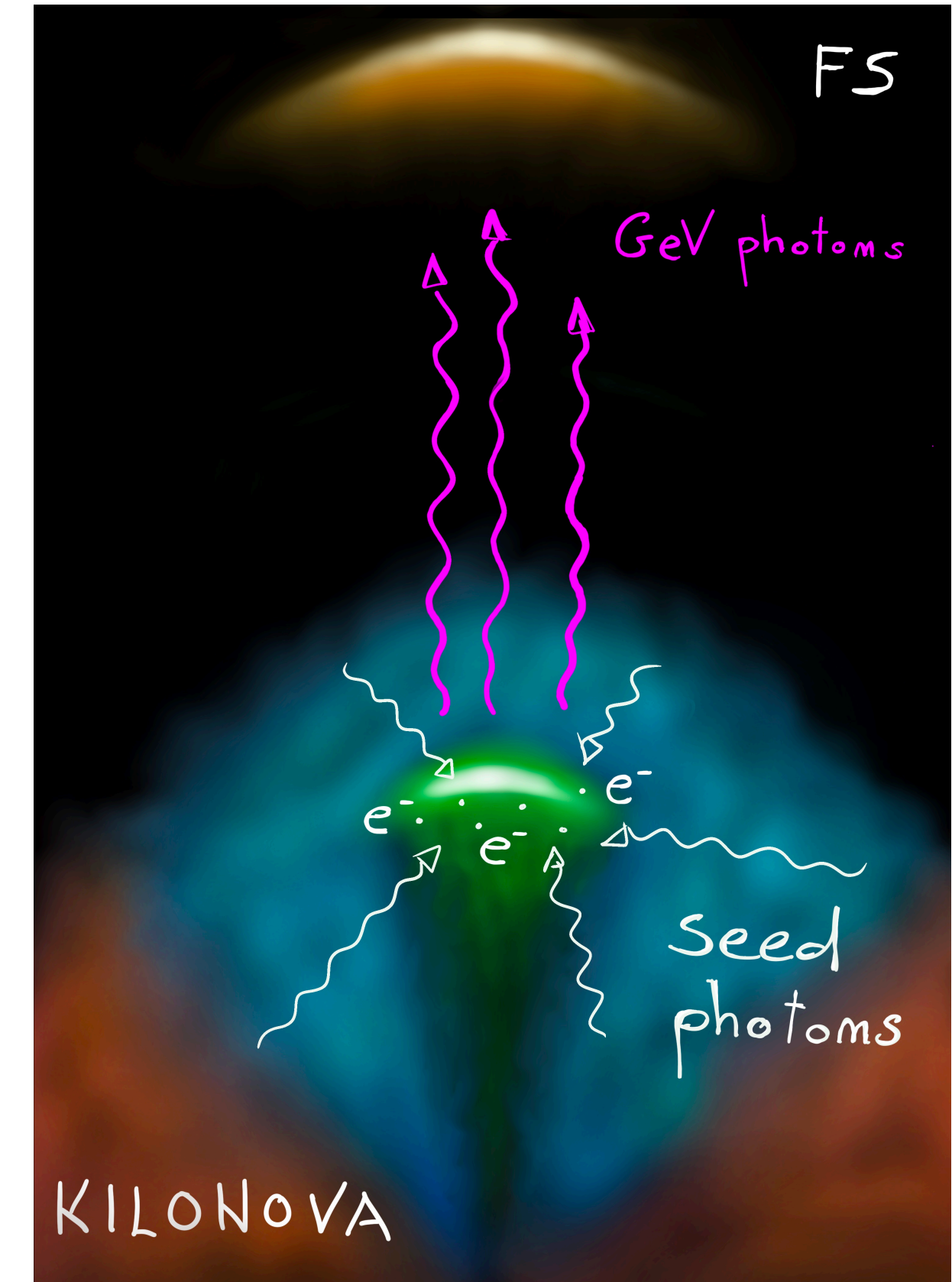
  $T_0 + 10^4 \text{ s}$

**De-beamed scenario ( $R_j > R_{KN}$ )**



Credits: S. Ronchini

**Beamed scenario ( $R_j < R_{KN}$ )**



- If the **hot electrons** are **above** the kilonova photosphere, the photons are **de-beamed** in the jet comoving frame.
- This scenario requires an unrealistically low jet magnetisation ( $\epsilon_B \lesssim 3 \times 10^{-10}$ )
- If the **hot electrons** are **below** the kilonova photosphere, the photons are **beamed** in the jet comoving frame.
- This scenario requires a low, but reasonable, jet magnetisation ( $\epsilon_B \lesssim 8 \times 10^{-6}$ )



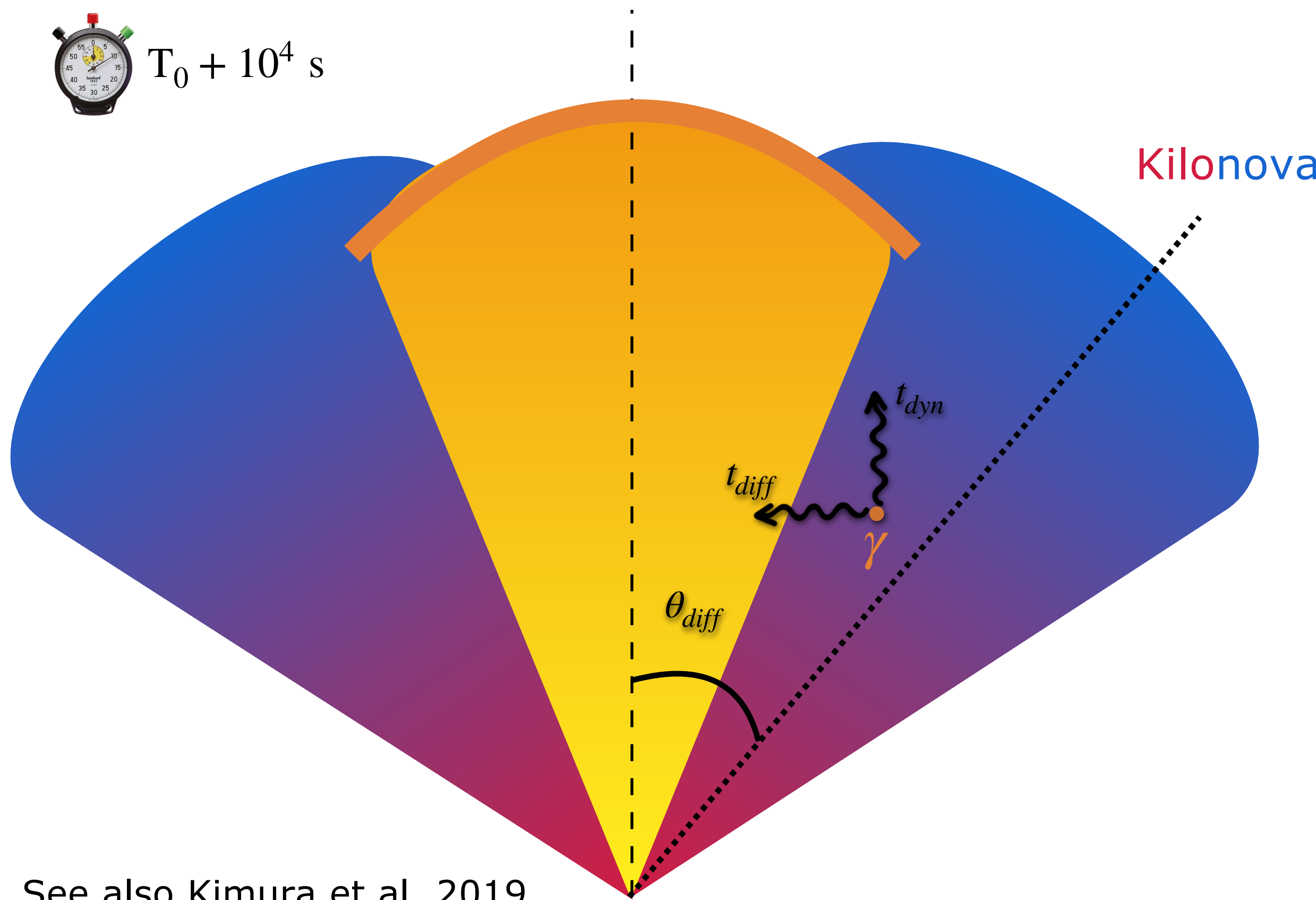


# Low power jet-KN interaction

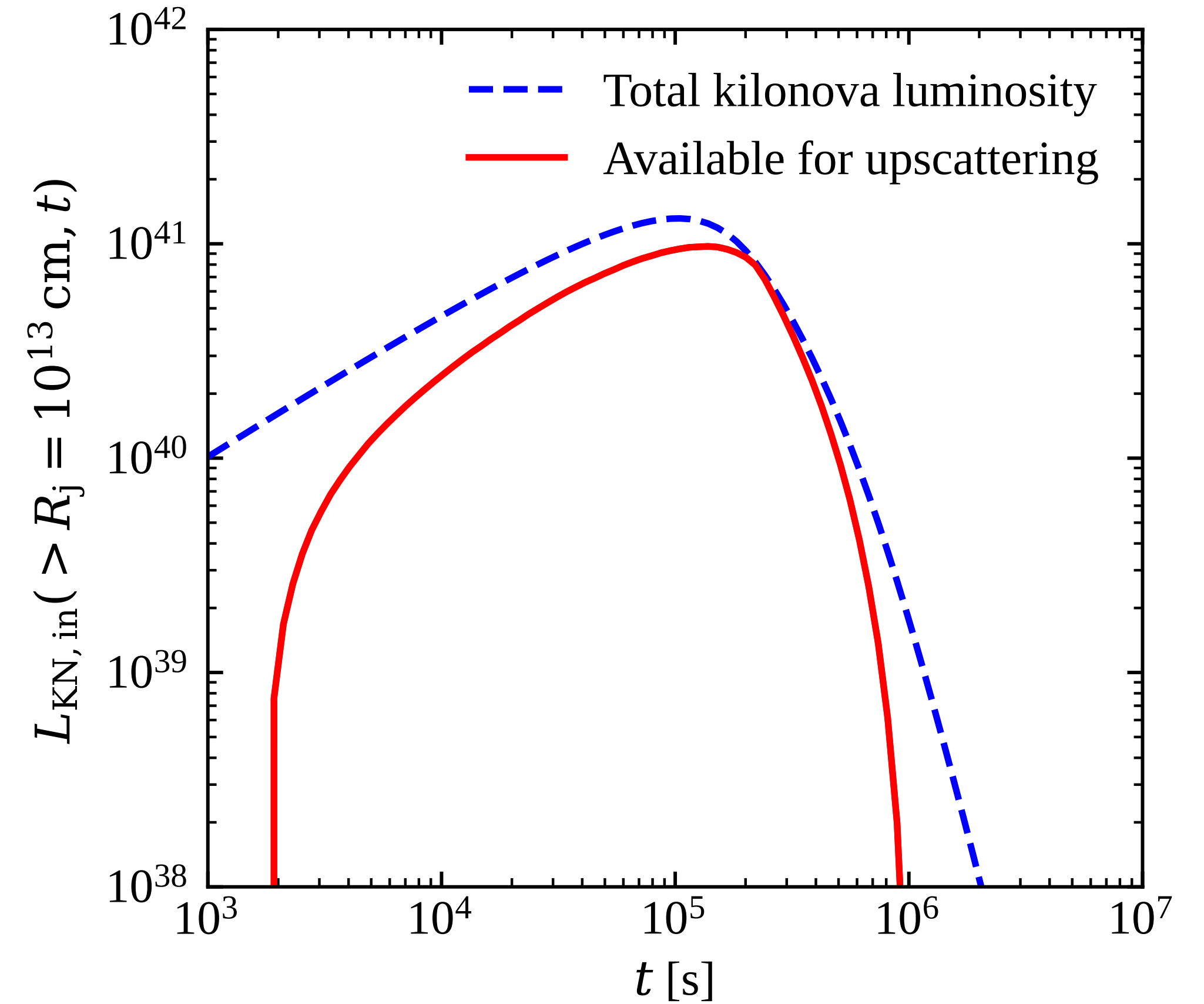
Low-power jet



$T_0 + 10^4$  s



See also Kimura et al. 2019

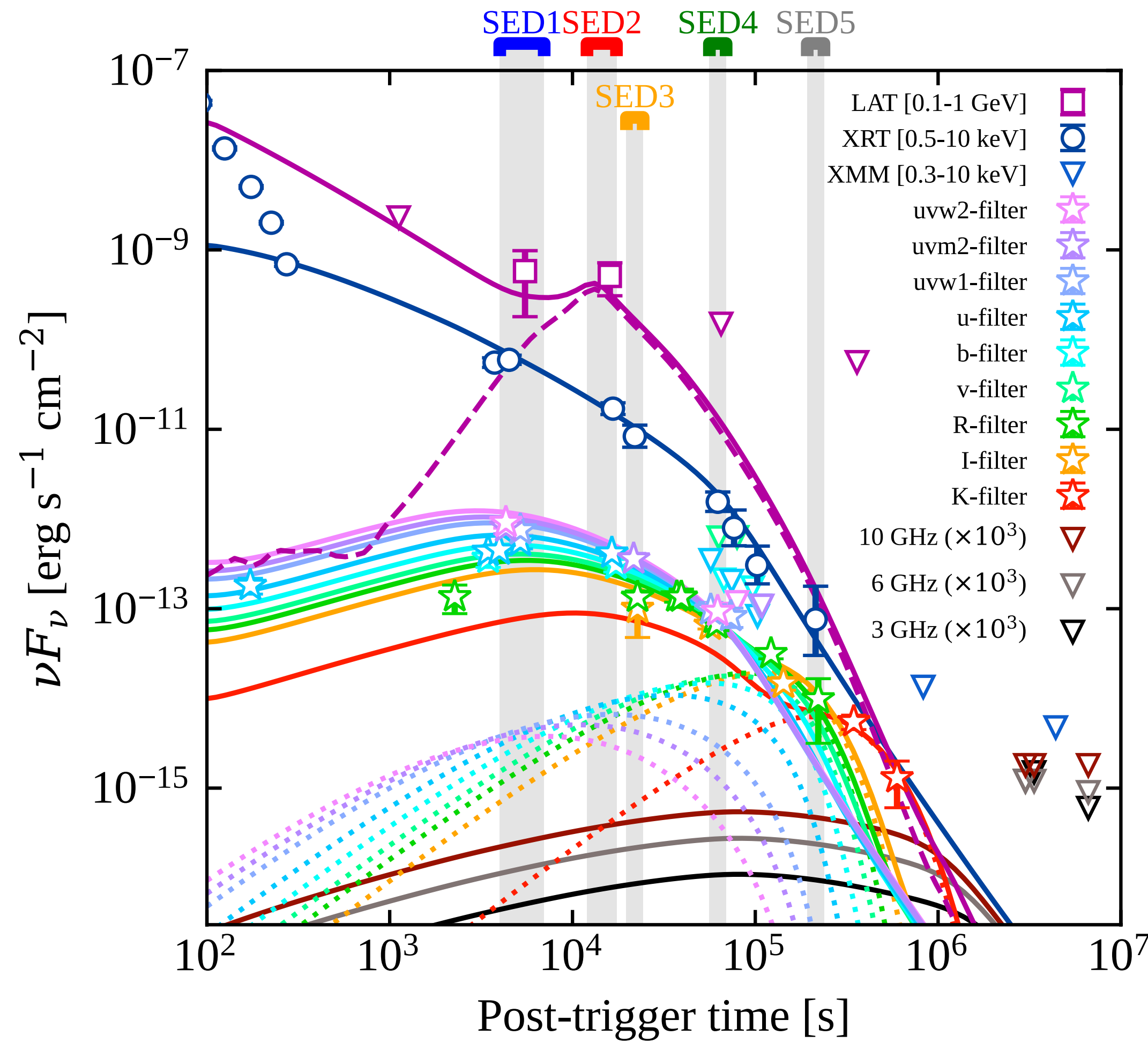




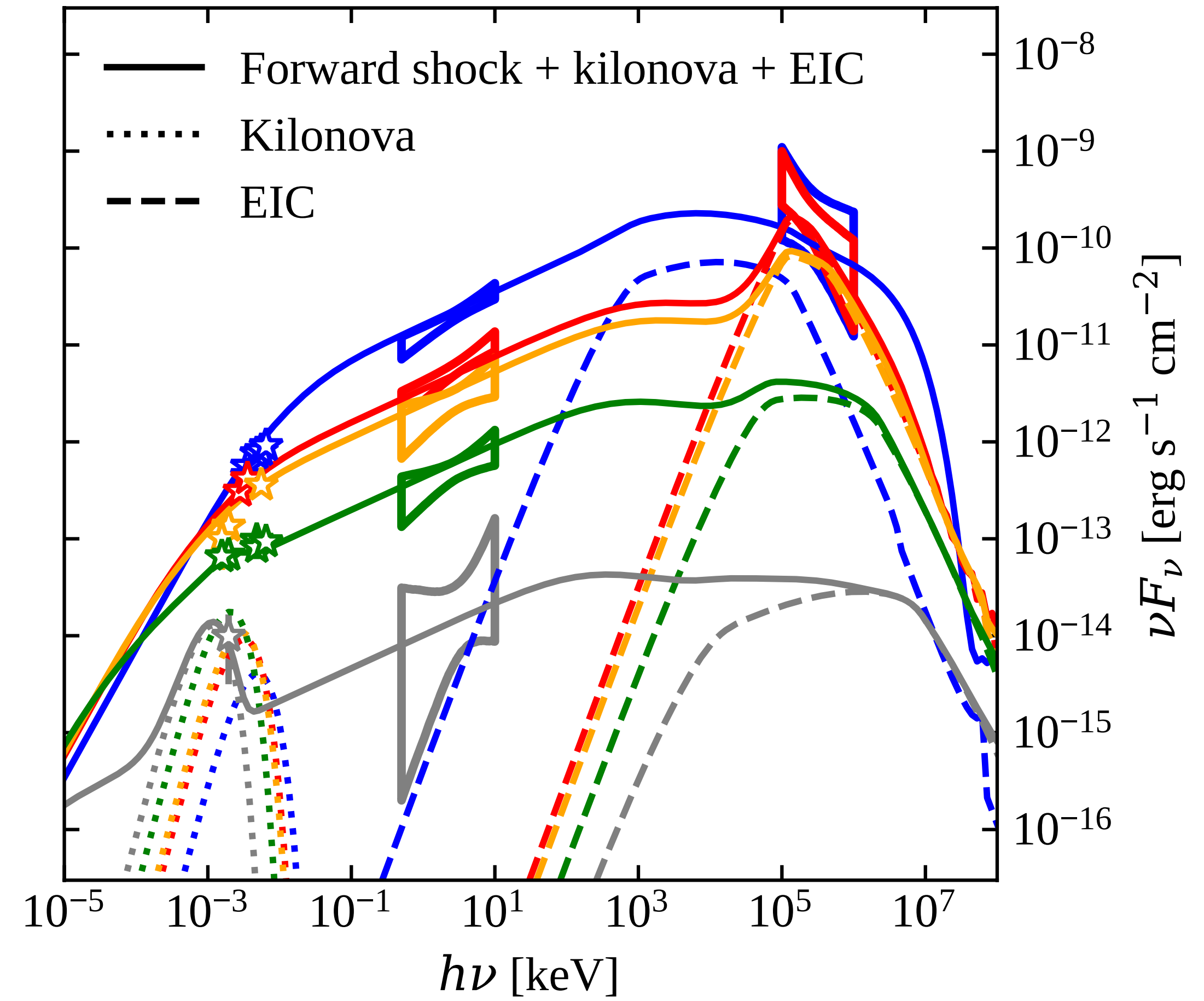
# External Inverse Compton component

## Light curves

## Spectra (SED)



(a)

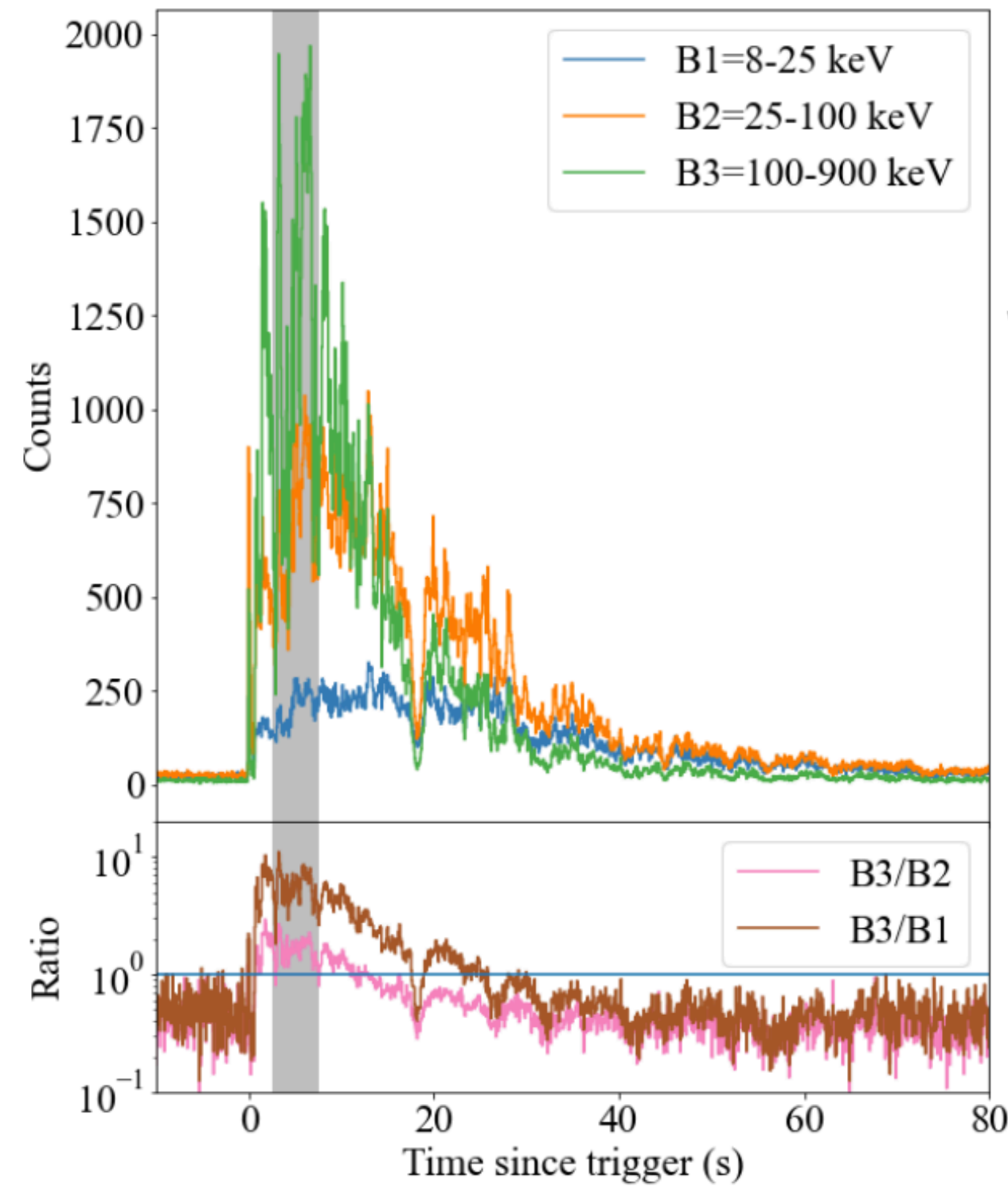


(b)



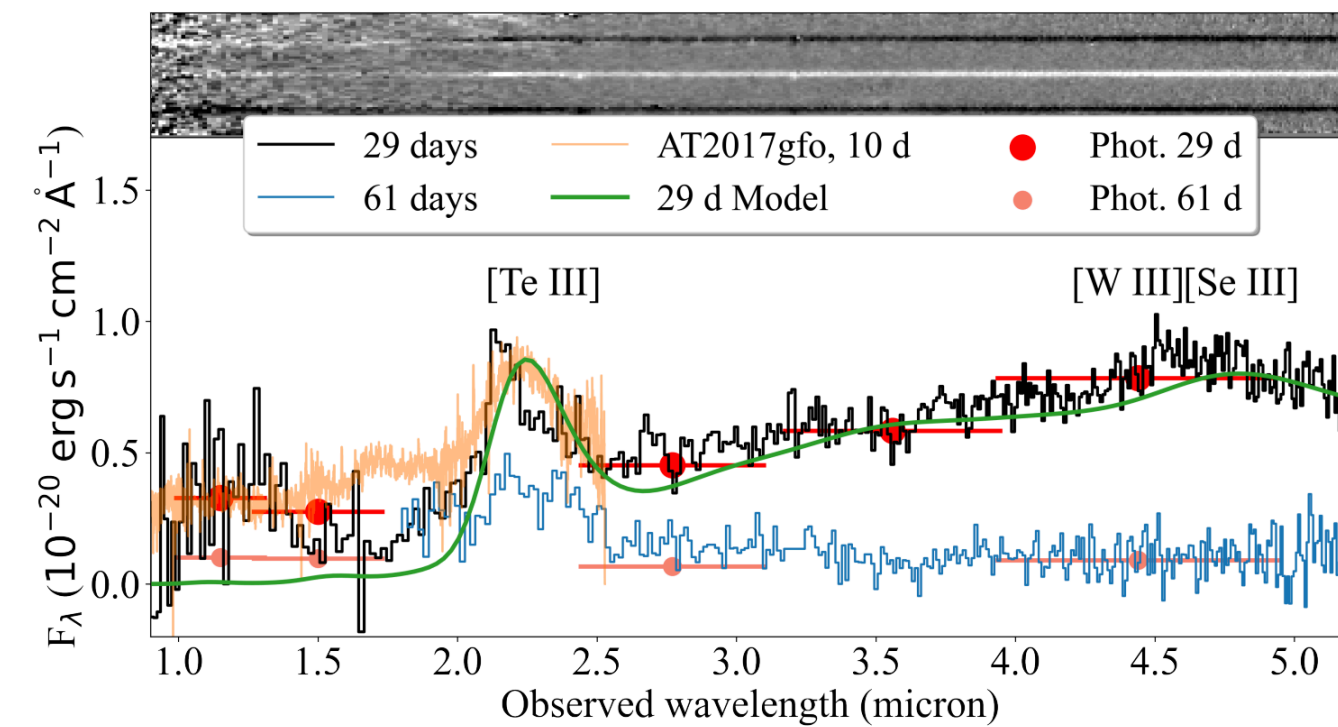
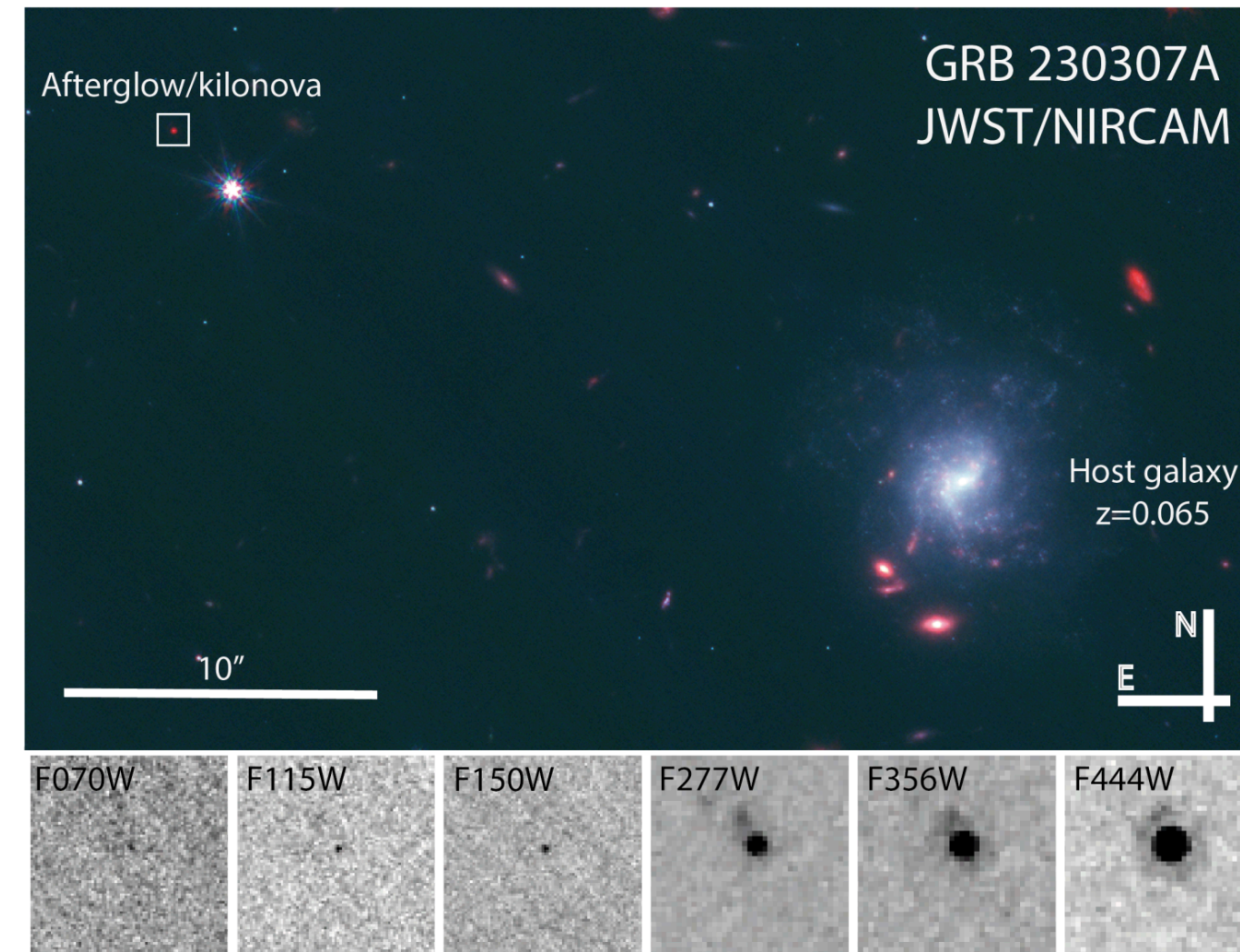
# The “2<sup>nd</sup>”: GRB 230307A

The 2nd brightest GRB ever



Levan et al. 2023

The 2nd merger-driven GRB (“confirmed”)

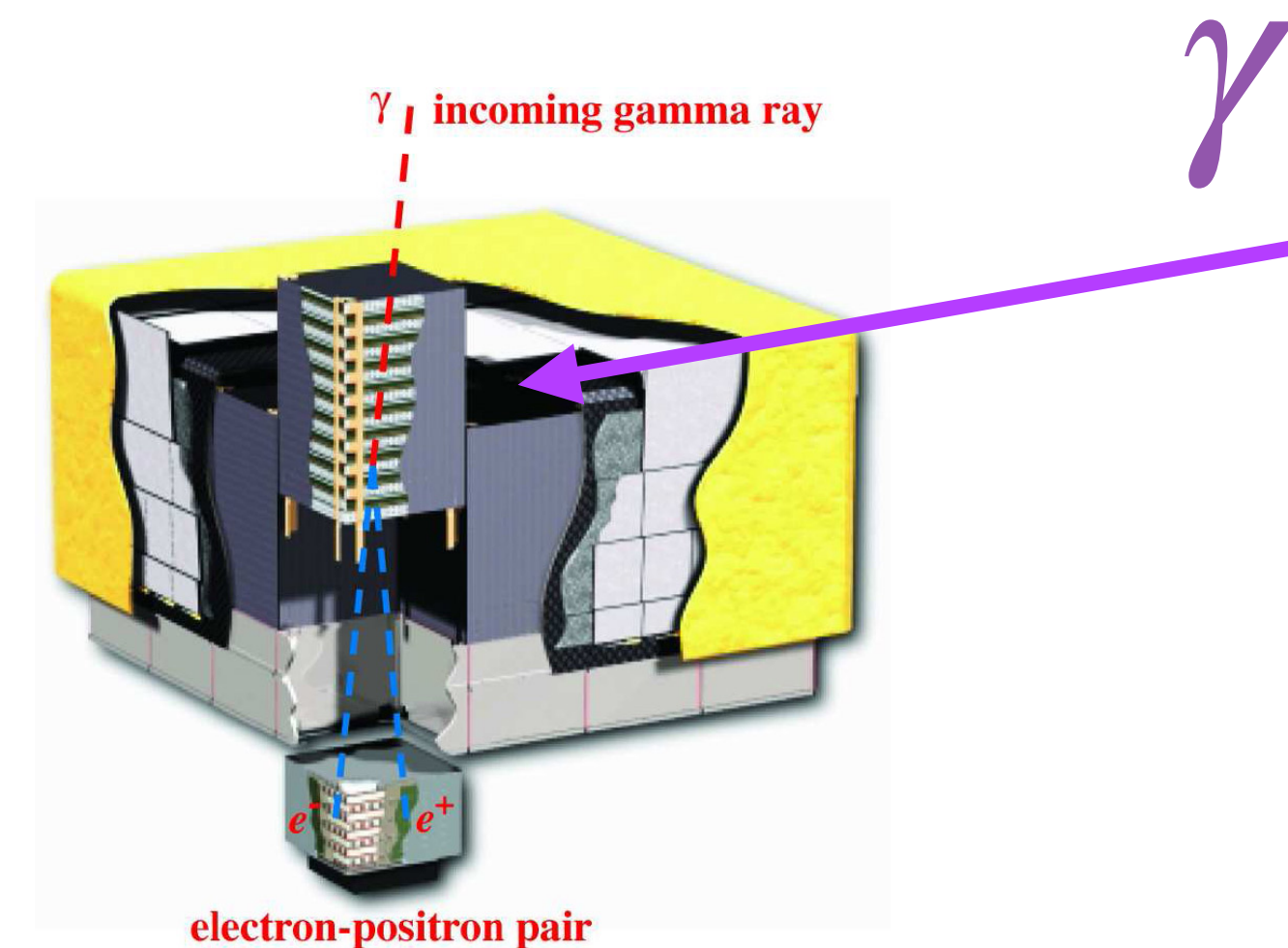


4th Gravi-Gamma-Nu Workshop

NO LAT EMISSION DURING THE AFTERGLOW

PRELIMINARY

- Outside LAT FOV before  $\sim 2$  ks
- No clear detection ( $> 3\sigma$ ) until  $\sim 5$ ks
- Off-axis around  $\sim 10$  ks





# Conclusions

- GRB 211211A is a bright long GRB likely produced, together with a kilonova emission, by the merger of two Neutron Stars.
- We have observed for the first time a late GeV emission coming from a compact binary merger, in clear excess with respect to the synchrotron emission from external shock-accelerated electrons.
- We show that such emission can be matched by External Inverse Compton interaction between the optical Kilonova photons and the hot electrons accelerated in a low-power jet.
- This discovery opens a new observational channel for GRBs, Kilonovae, and GW counterparts, possibly detectable at late times in the high energy band!





# BACKUP SLIDES



# HE photons from the GRB

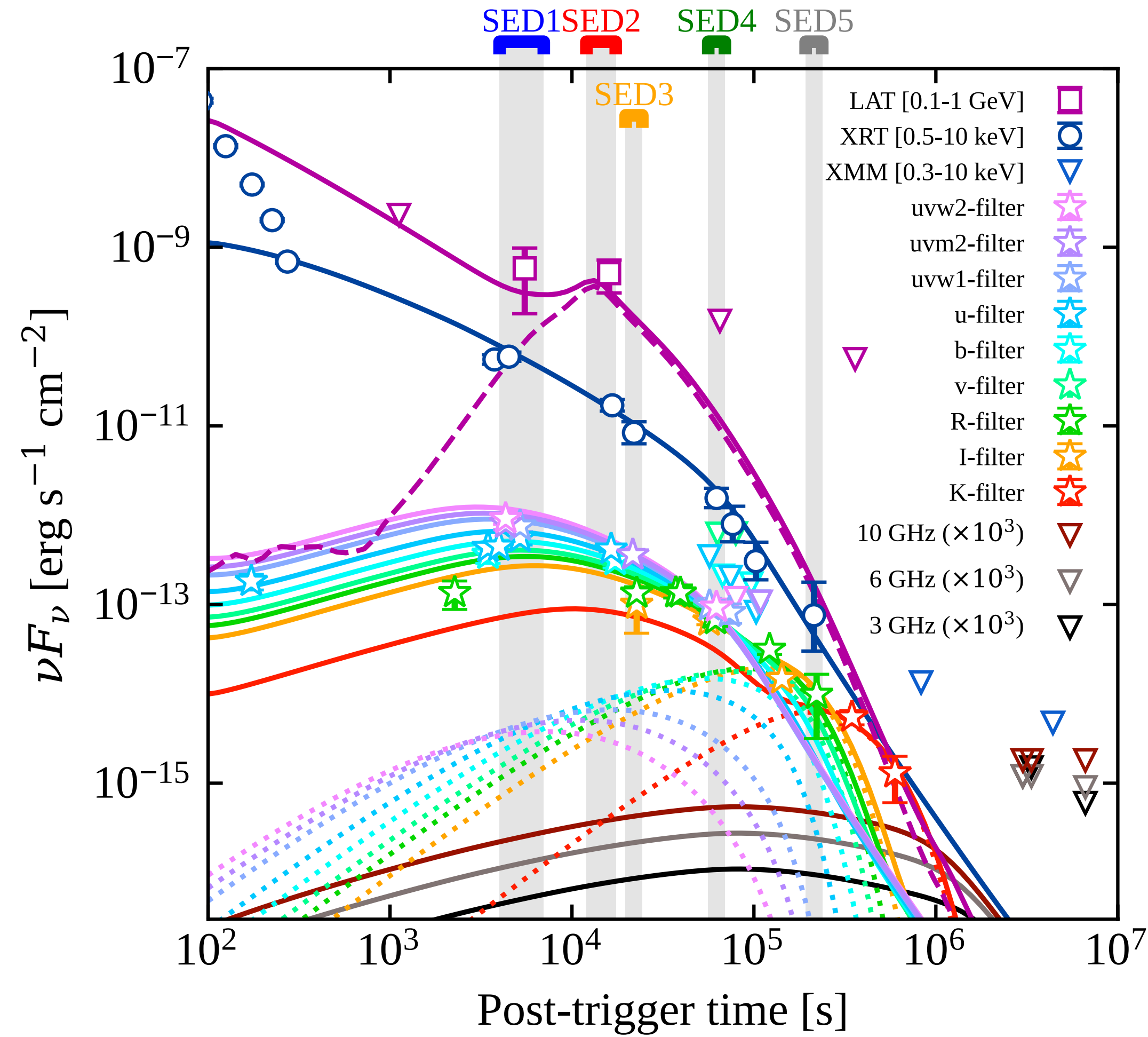
Energy (GeV)	Probability	Distance (deg.)	Arrival time (sec.)
0.21	0.94	0.36	6438.18
0.19	0.95	1.04	6647.43
0.16	0.93	1.34	12493.41
0.12	0.96	0.71	12612.52
1.74	0.97	0.32	12966.74
0.10	0.96	0.77	13053.43
0.12	0.92	1.69	13292.13
0.29	0.91	1.22	17860.45
0.23	0.97	0.67	18127.51

- Standard criteria for GRB detection:  
at least **3 photons** associated to the GRB  
with probability  $p > 0.9$
- We observe **9 photons** with probability  
 $p > 0.9$  to be emitted by the GRB.
- The **highest energy** photon is detected  
after **13 ks** with energy  **$\sim 1.5$  GeV**.



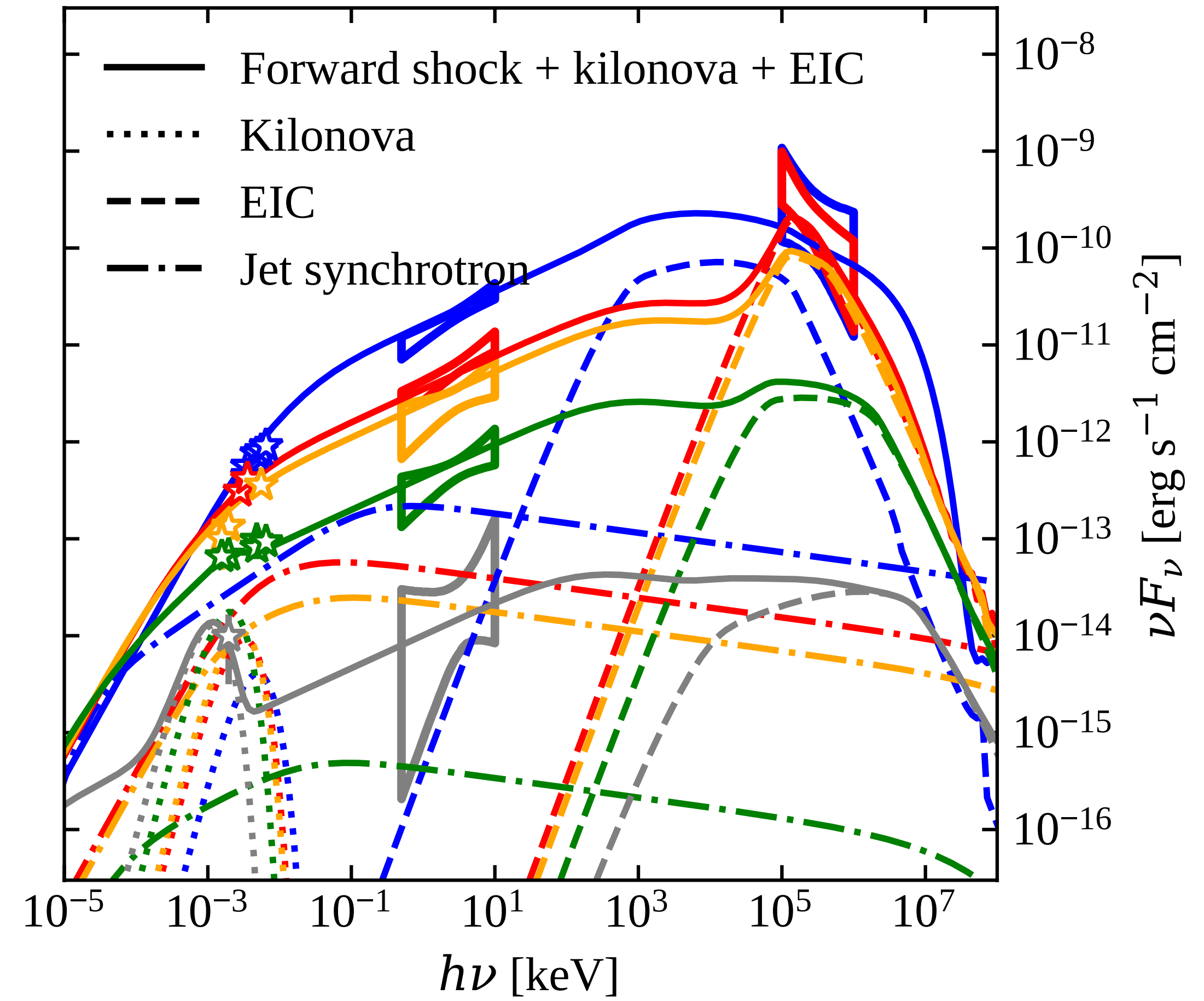
# HE excess at late time

## Light curve



(a)

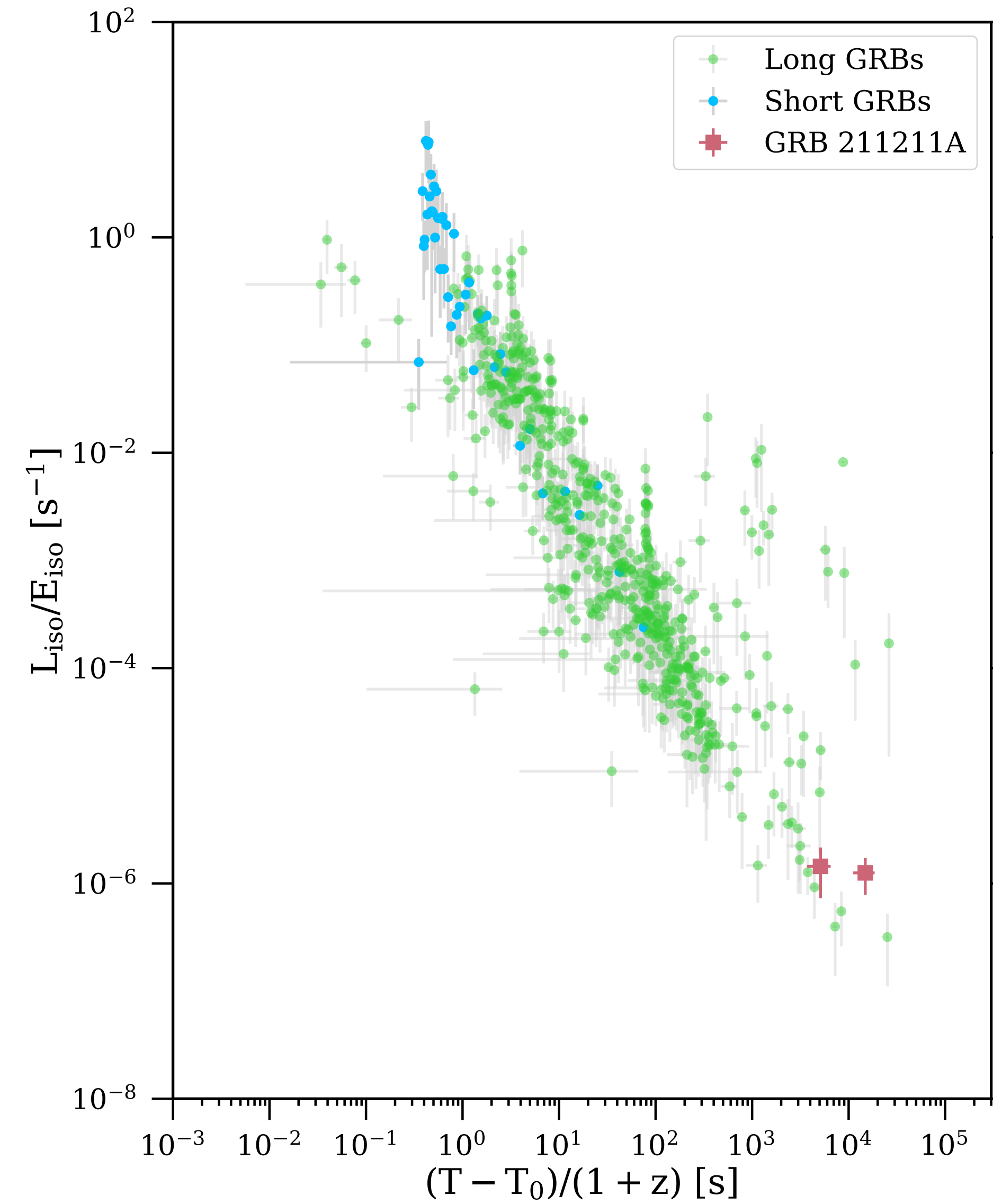
## Spectra (SED)



(b)



# Comparison with other LAT GRBs





# Comparison with other LAT GRBs

