Tenth International Fermi Symposium

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GeV emission from a compact binary merger

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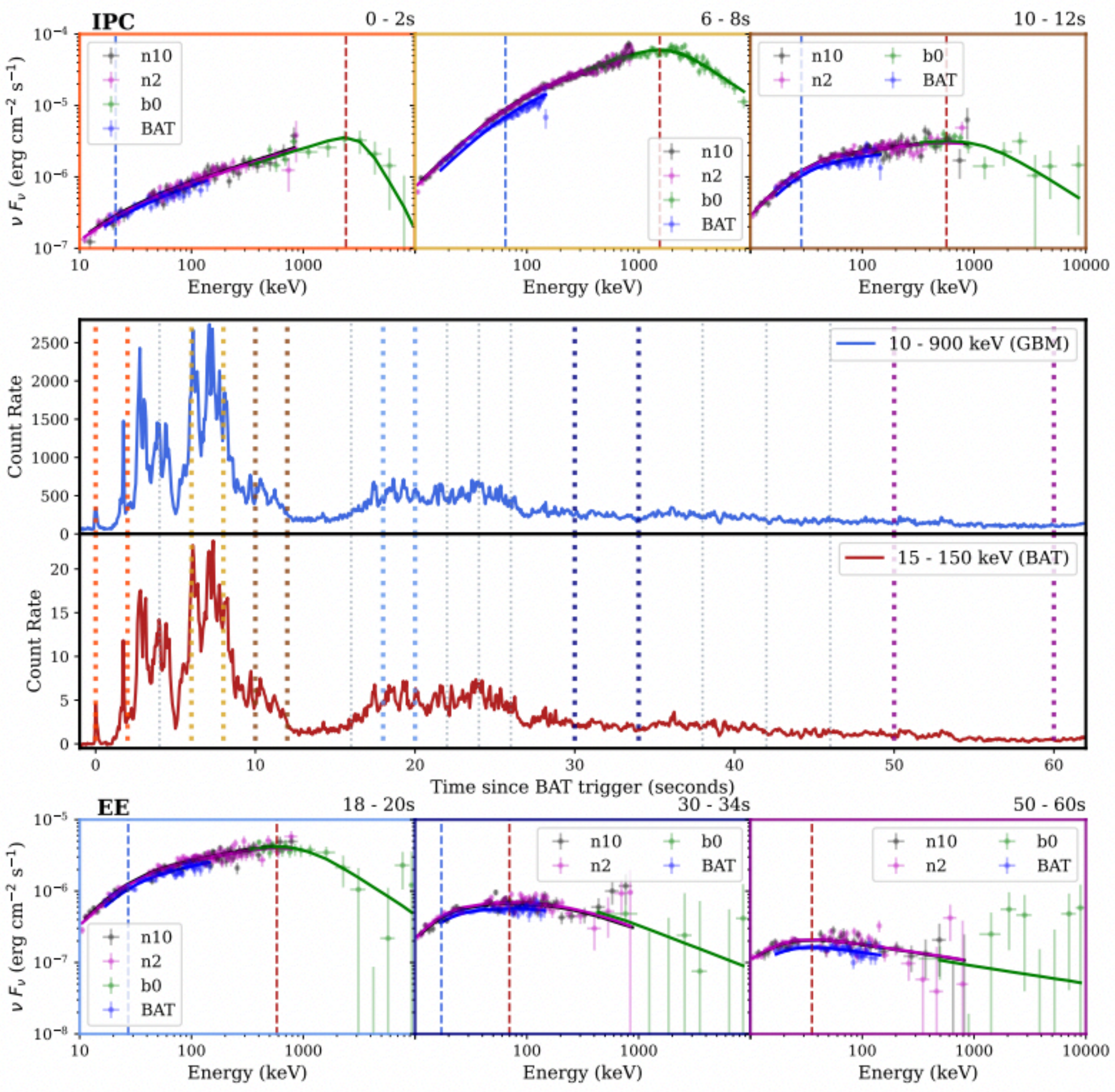
GRB 211211A: A long luminous source



Gompertz et al. 2022

- 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 ~60 s)

Long duration GRB!

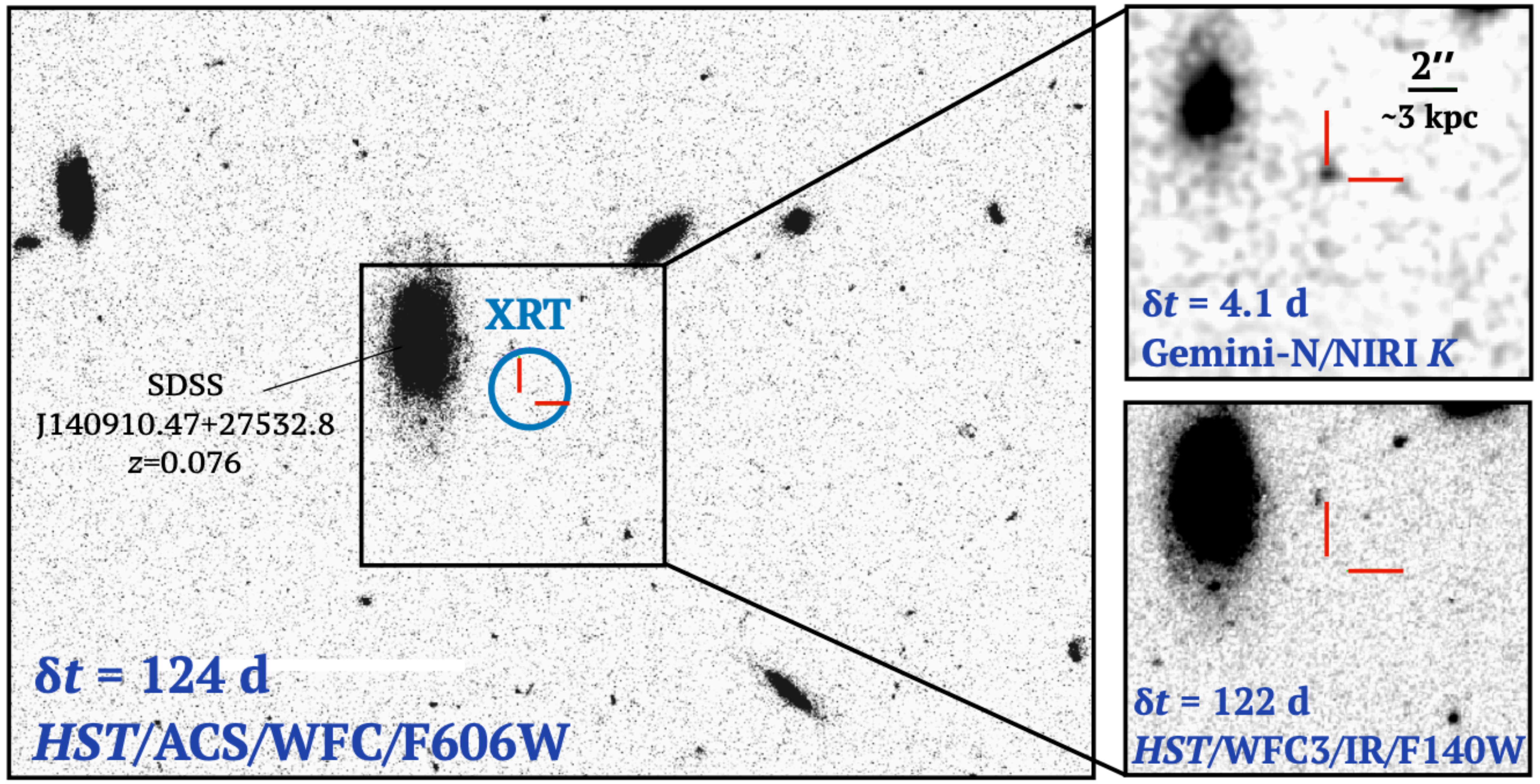
GRB host galaxy

- 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)
- ~ 5 arcsec (~8 kpc in projection) offset from the closest galaxy (z=0.076).

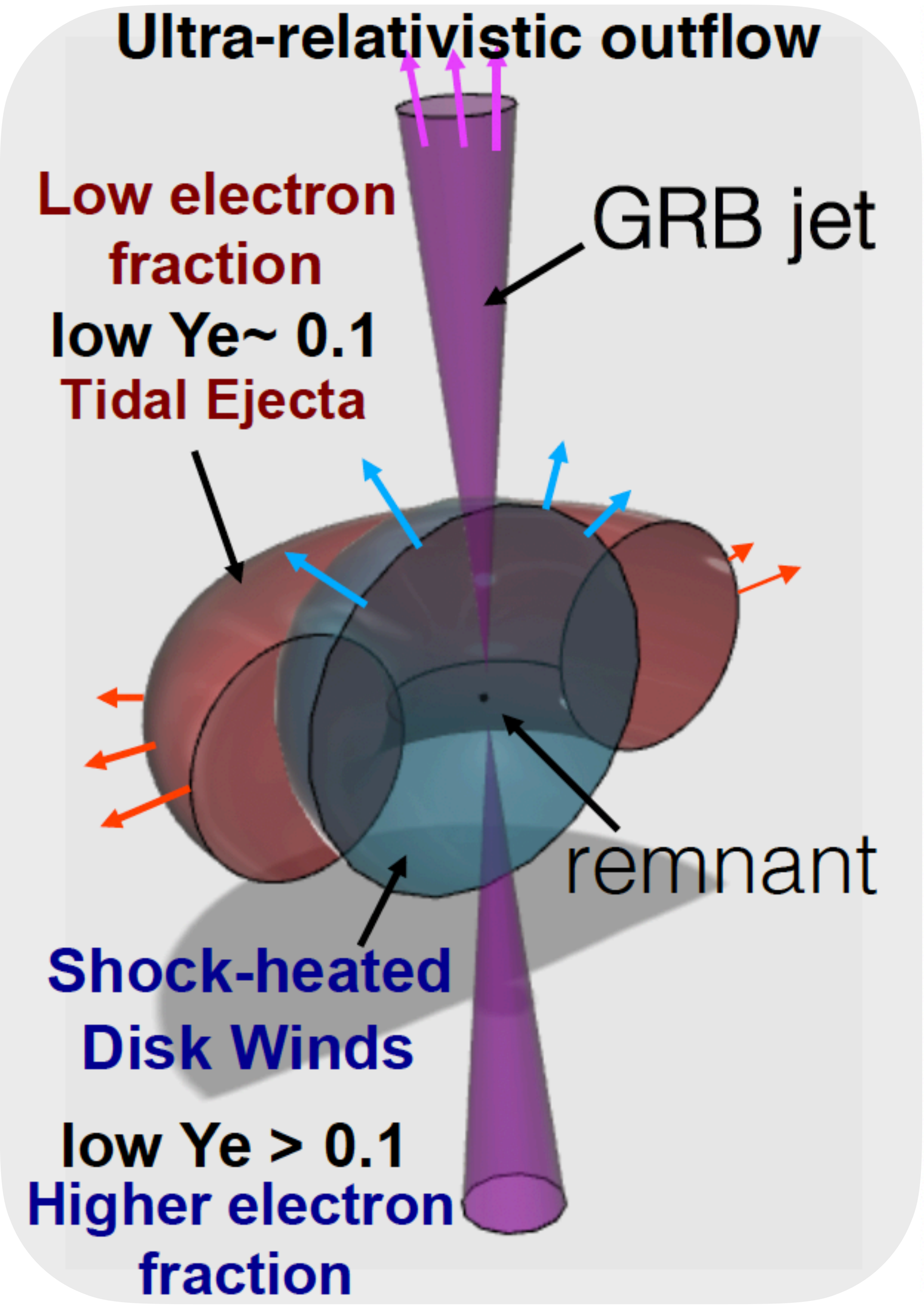
Hubble deep observations confirmed the redshift of this source (Rastinejad+ 2022)

Where is the supernova?

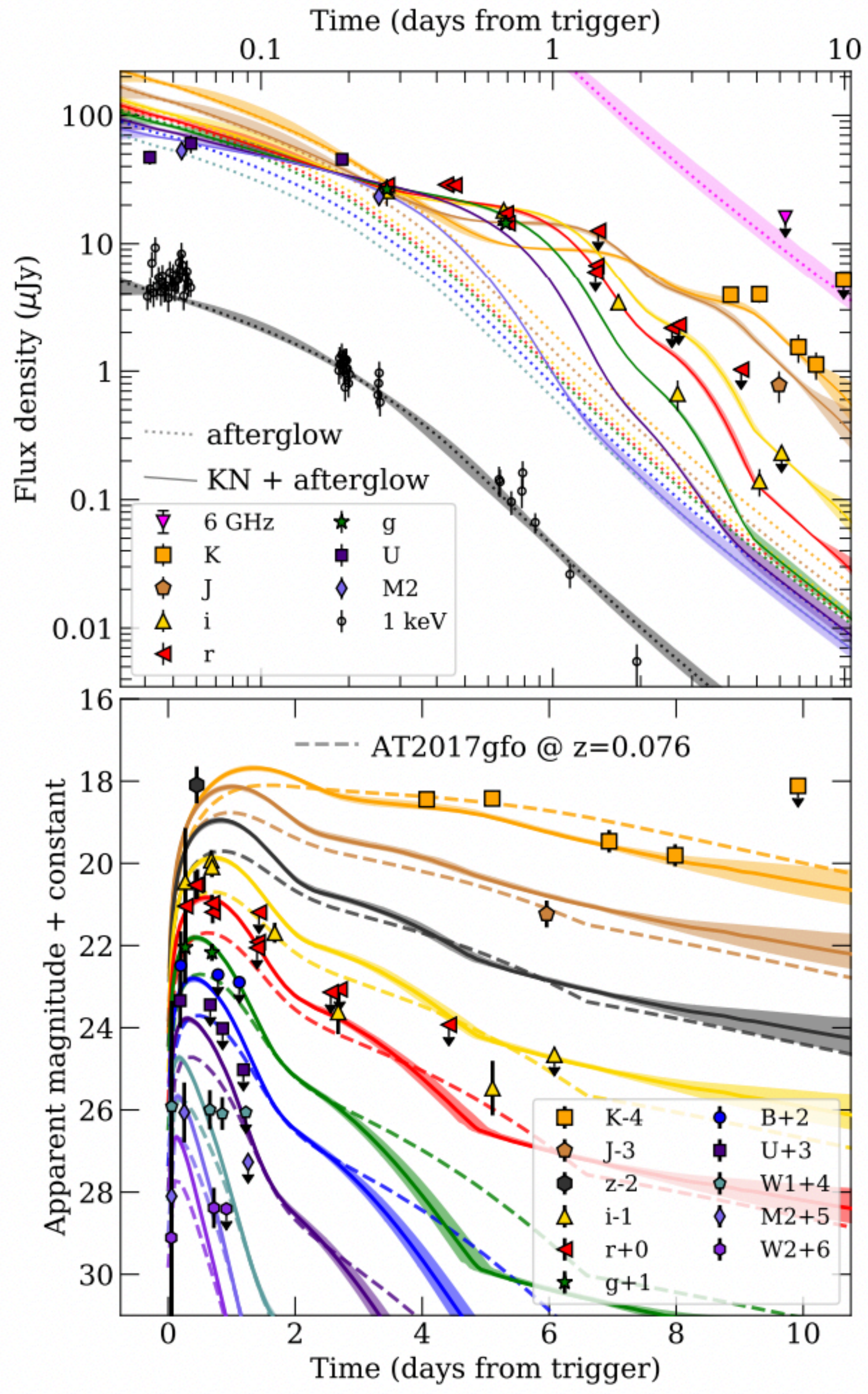
Rastinejad et al. 2022



The turning point: Kilonova detection



Rastinejad et al. 2022



Three-component kilonova fit

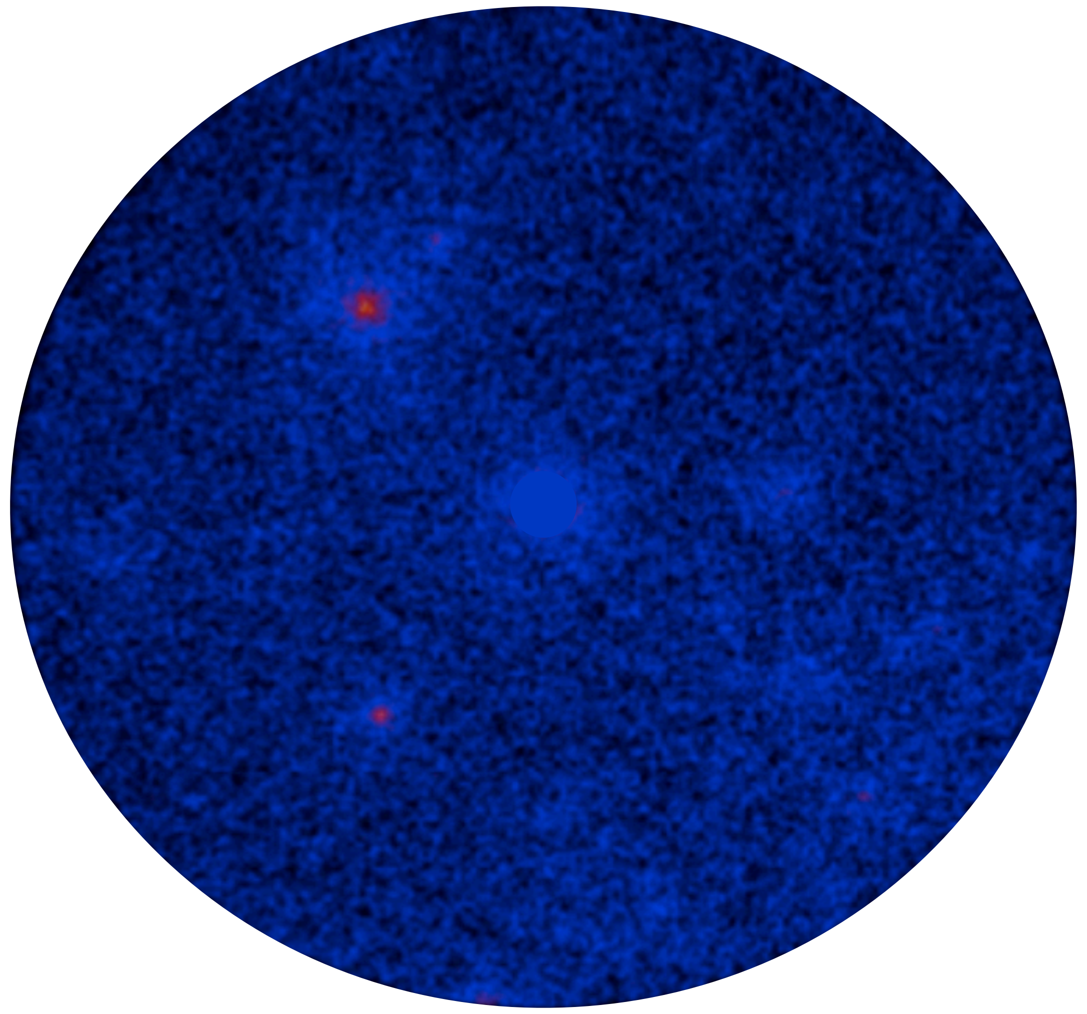
- $M_{ej} = 0.04 \pm 0.02\ M_{\odot}$, almost all lanthanide-rich, in reasonable agreement with at2017gfo.
- $v_{ej} \simeq 0.25 - 0.3\ c$
- Associated to compact object merger in a binary system, likely BNS

Long merger-driven GRB!

But, see Bromberg et al. 2013

Source detection with Fermi/LAT

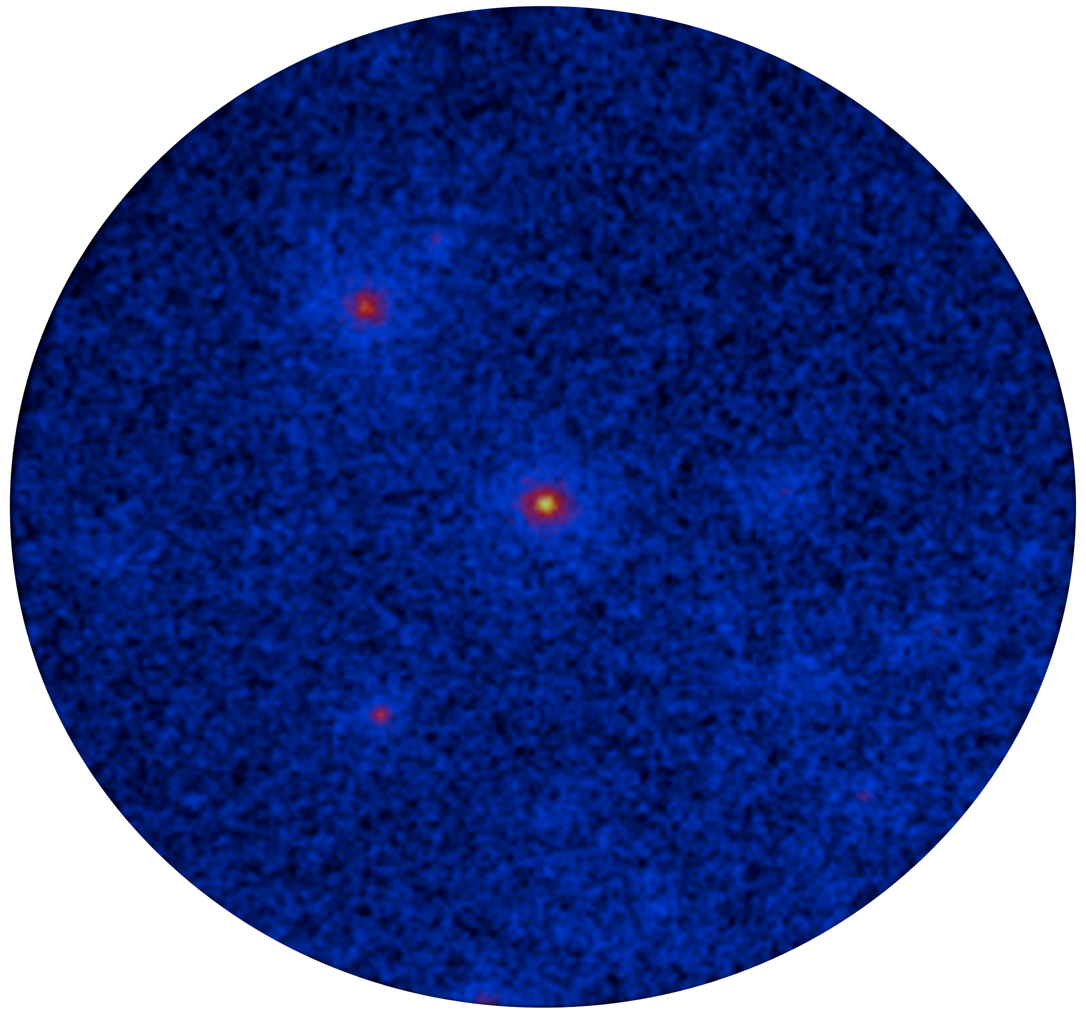
Likelihood ratio test (LRT) → $\mathrm{TS} = -2\log\left(\frac{\mathscr{L}_0}{\mathscr{L}_1}\right) \approx (\text{detection significance})^2$



$\mathscr{L}_0$

Null model

(Observation <u>without</u> source)



$\mathscr{L}_1$

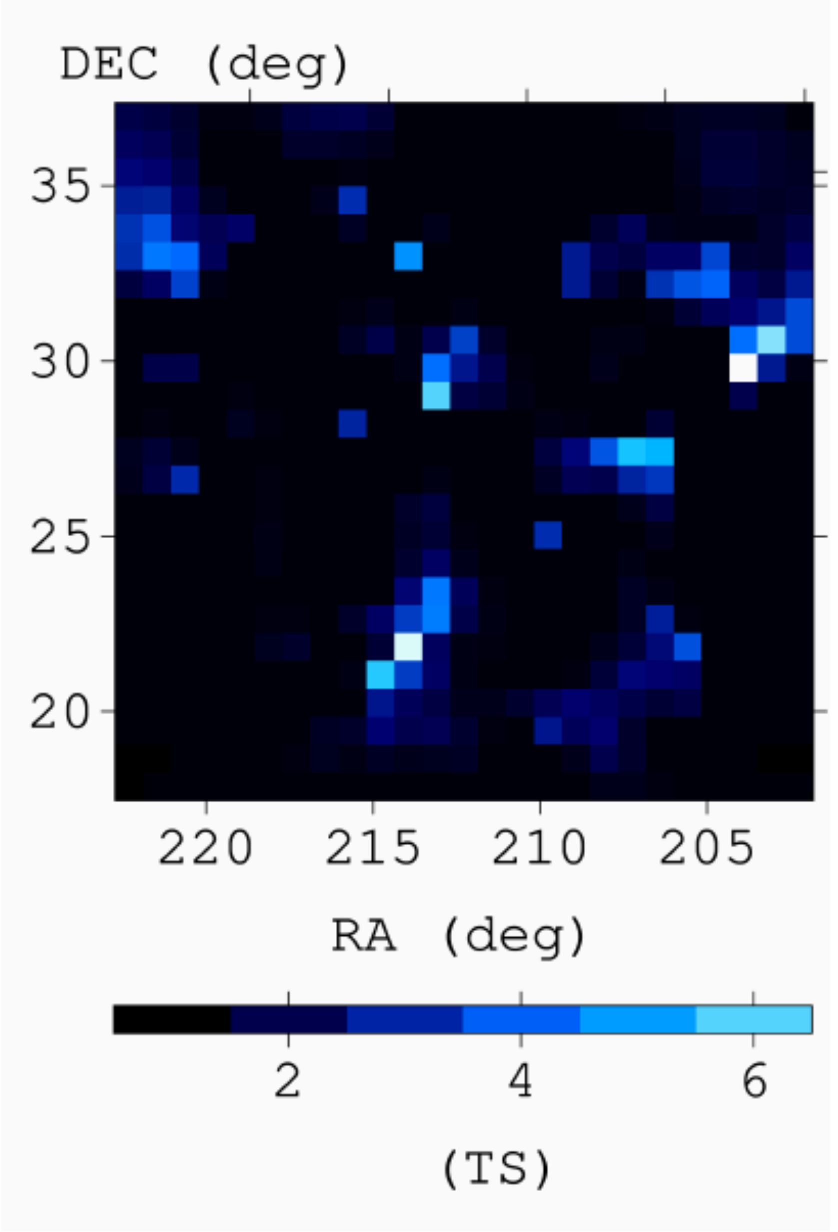
Alternative model

(Observation <u>with</u> source)

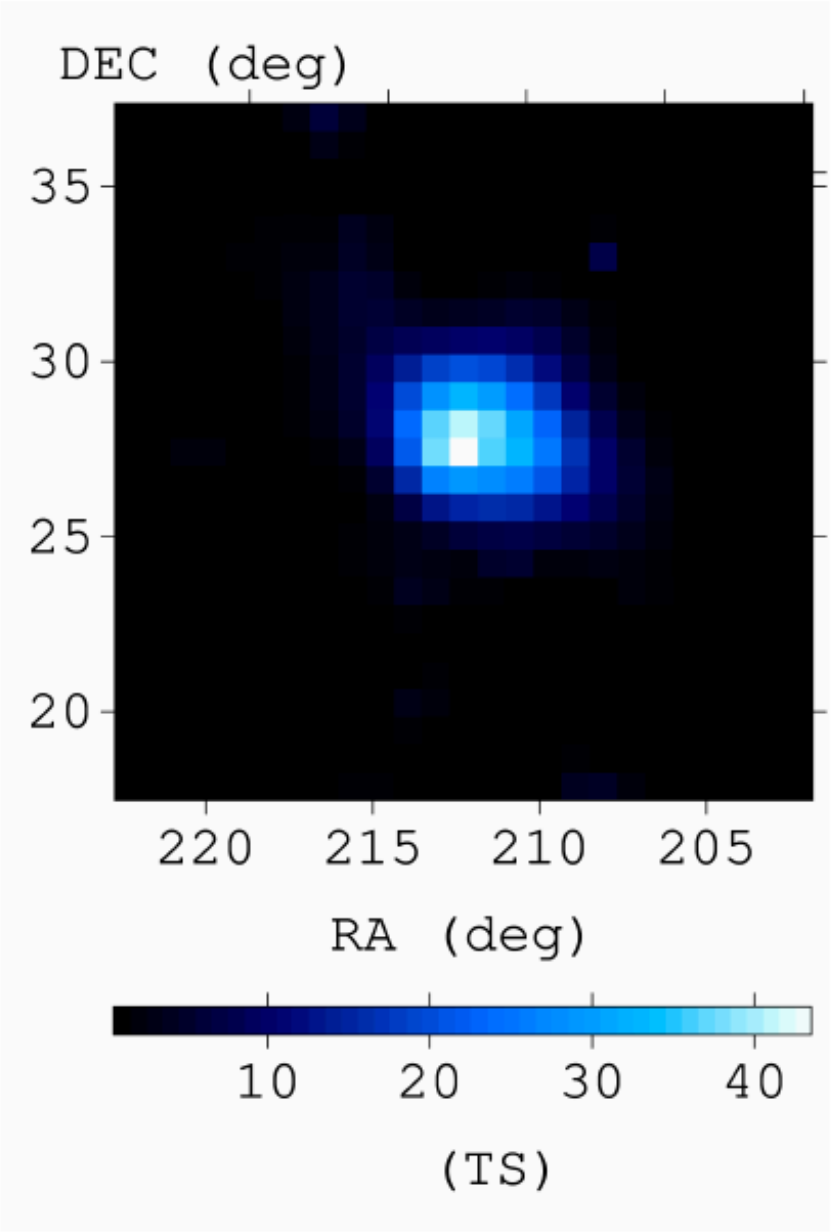
- We define a Region of Interest (ROI) of 12 deg around the GRB position.
- We account for the isotropic particle bkg, galactic and extragalactic high energy components from Fermi 4th catalog (F4GL).
- We assume a PL spectral model for the GRB as well as for the other sources in the ROI, the latter with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

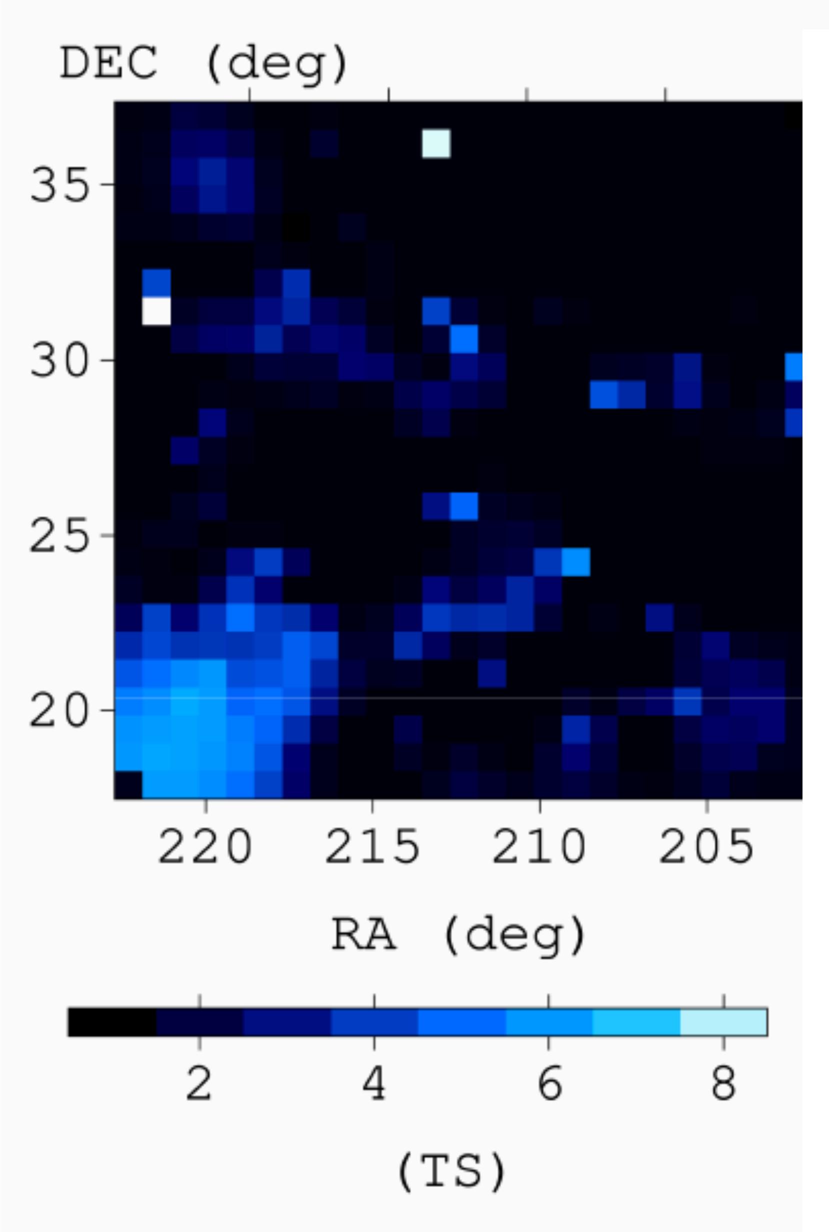
Mei et al. 2022, under review Nature



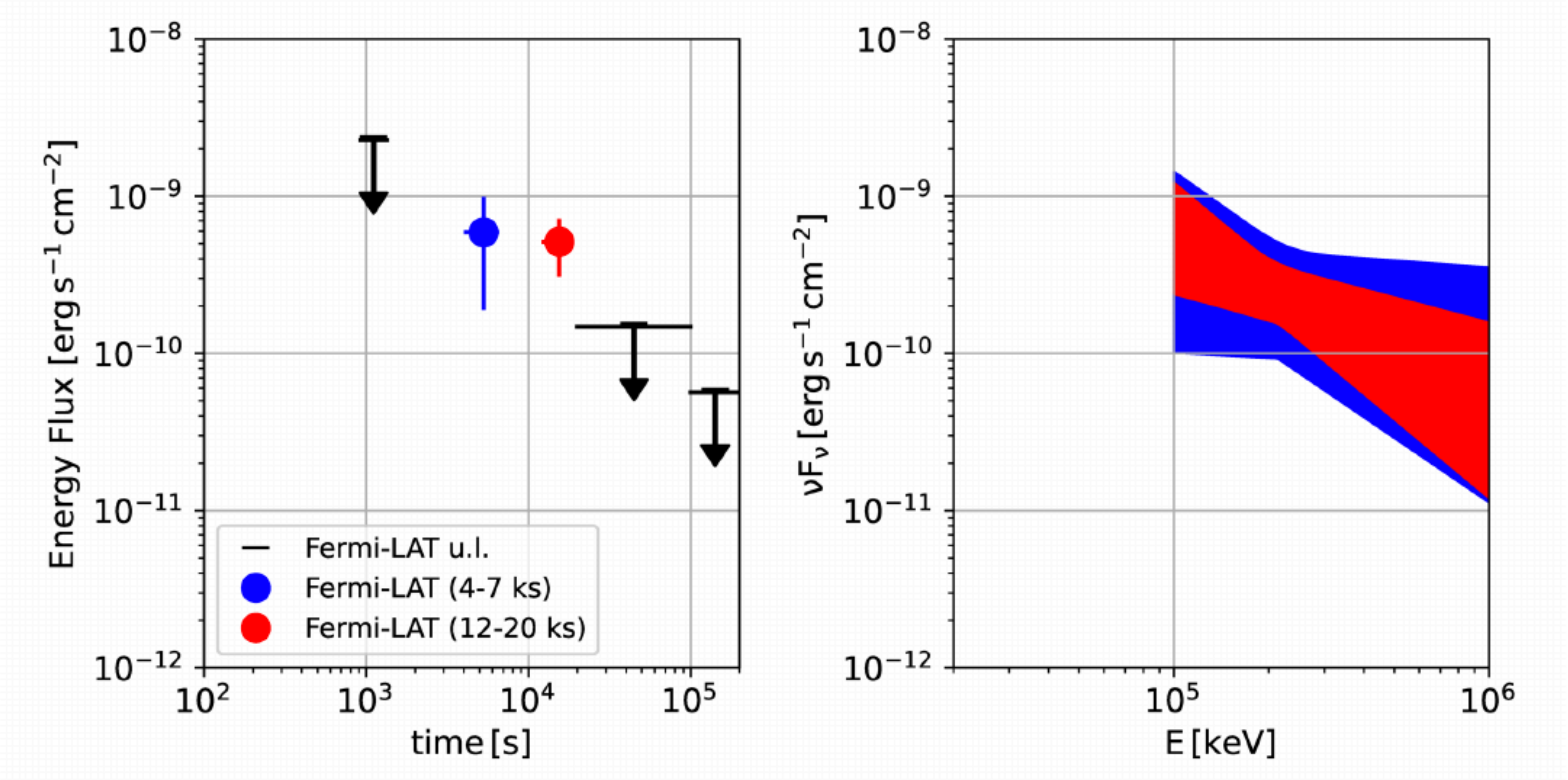
(a) t_0-1 d to t_0



(b) t_0 to t_0+20 ks



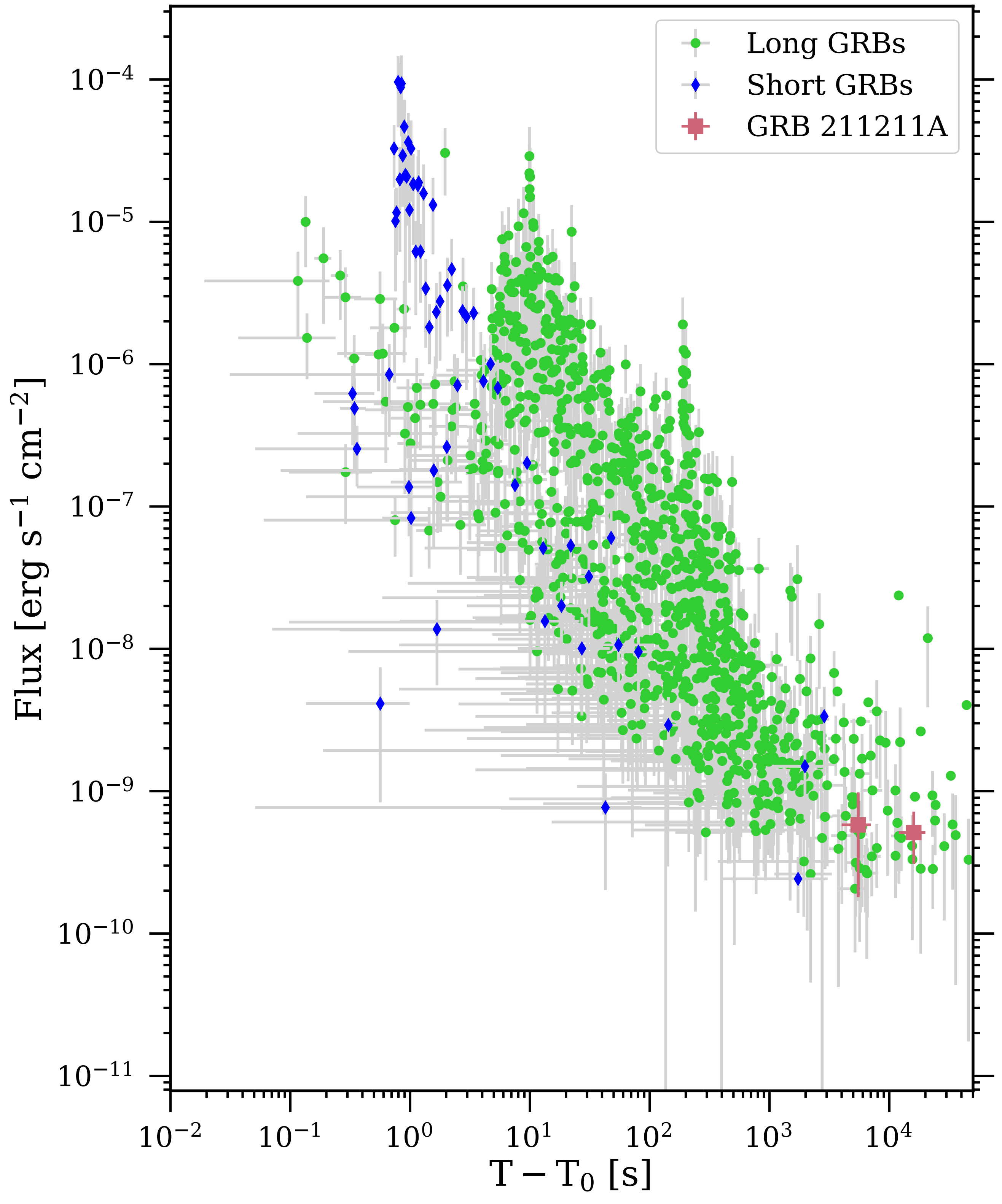
(c) t_0+1 d to t_0+2 d

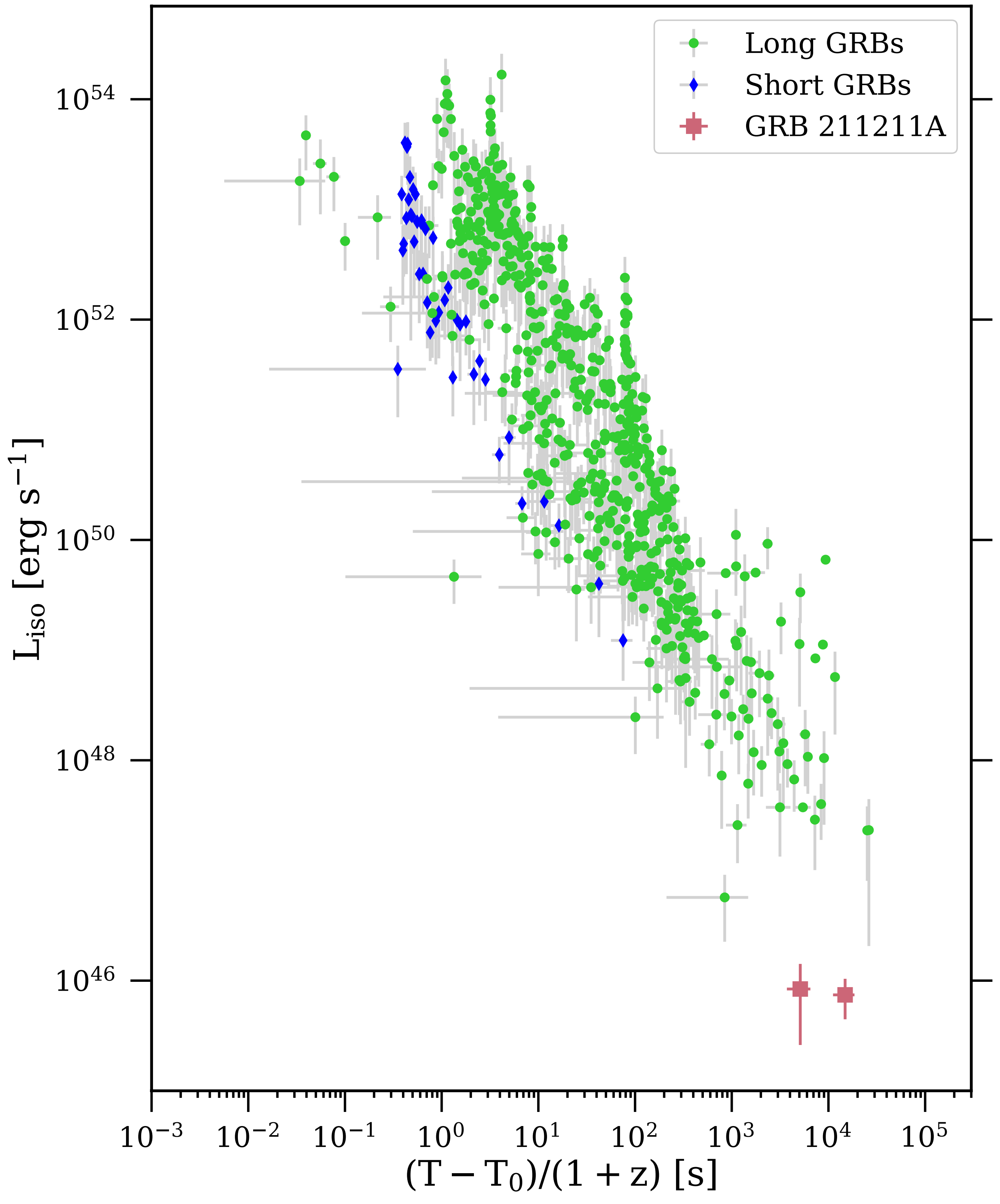


(d) t_0 to t_0+2 d

Comparison with other sources

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

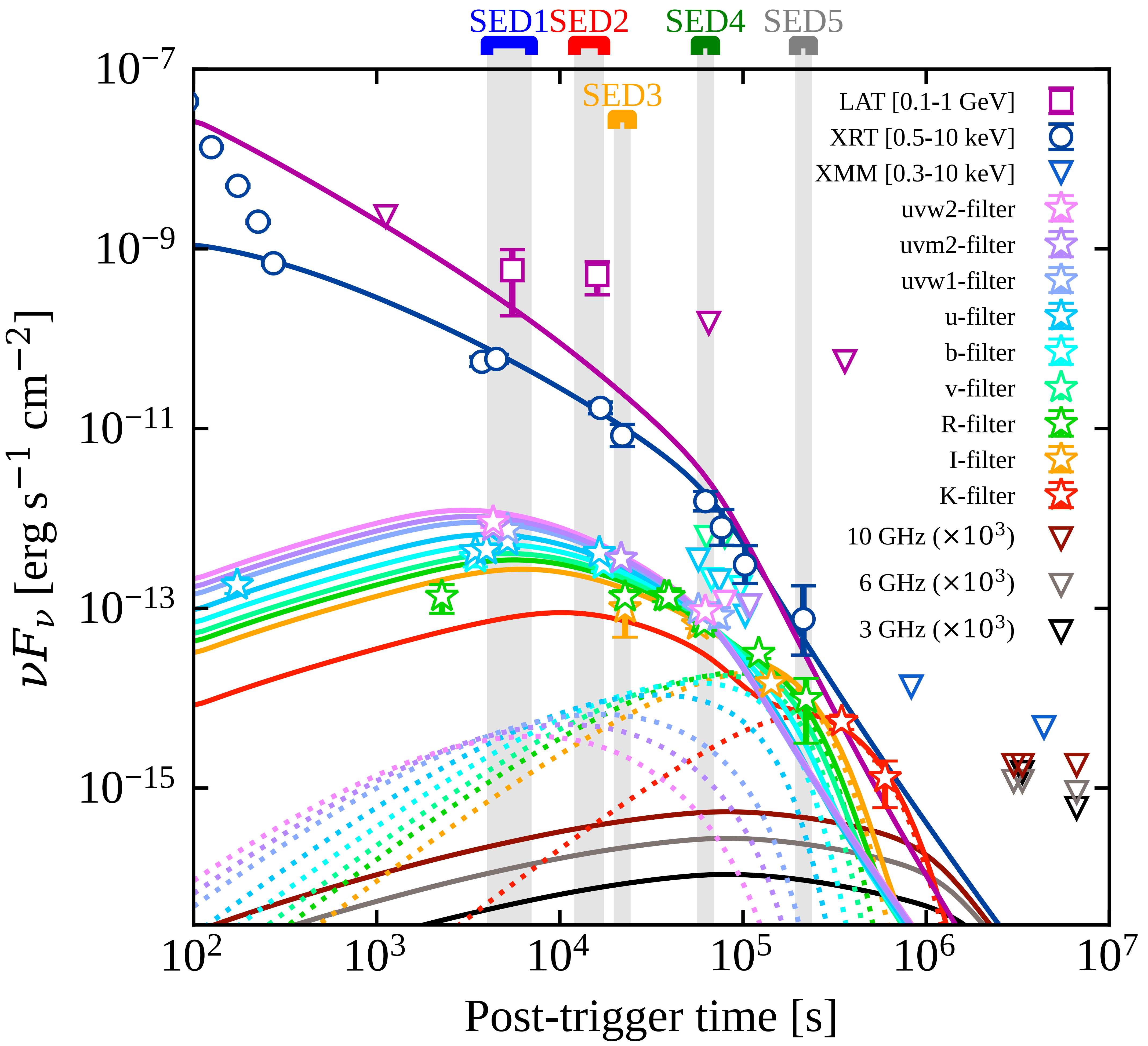




- GRB 211211A is intrinsically faint in the LAT energy band ($L_{iso} \sim 10^{46}$ erg/s).
- It is observable thanks to its proximity to Earth! (~350 Mpc)
- No other GRB with $d \lesssim 350$ Mpc shows significant LAT emission.
- GRB 170817A would be a good candidate, but no LAT observation due to South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

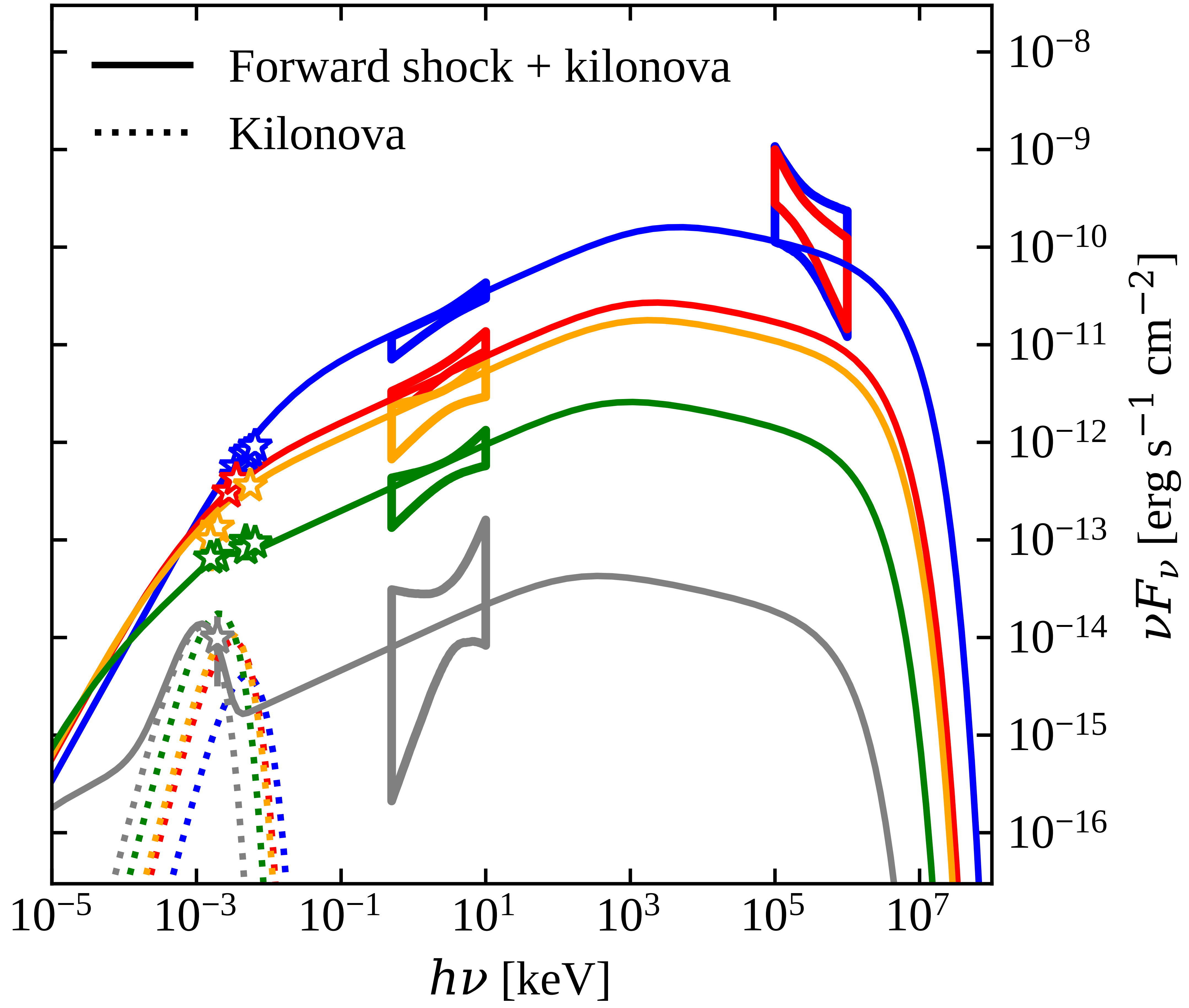
HE excess at late time

Light curves



(a)

Spectra (SED)

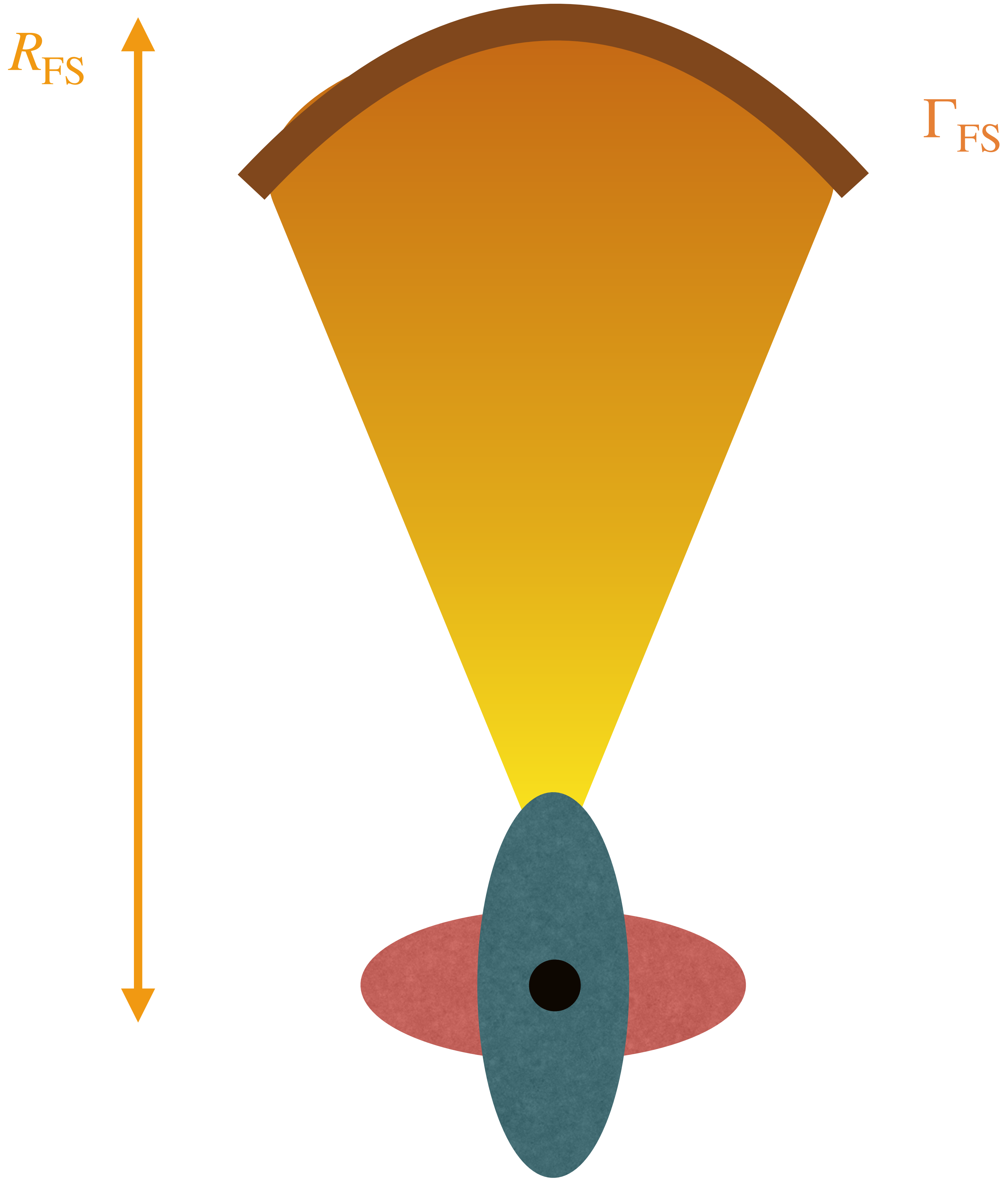


(b)

Low power jet at late times

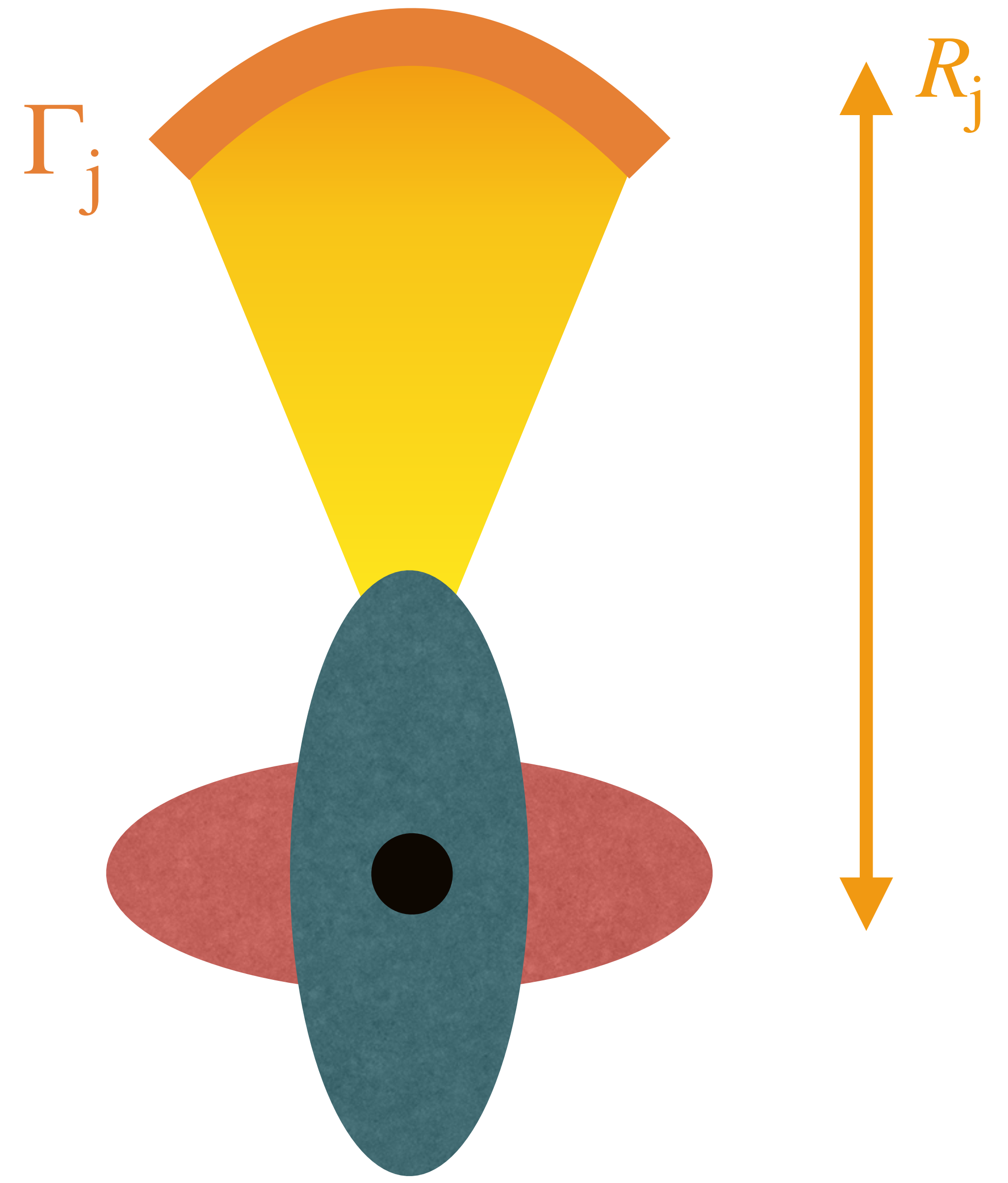
Deceleration phase $T_1 > T_0$

Late-time activity $T_2 = T_0 + 10^4\ \mathrm{s}$



Accretion onto the newly born compact object:

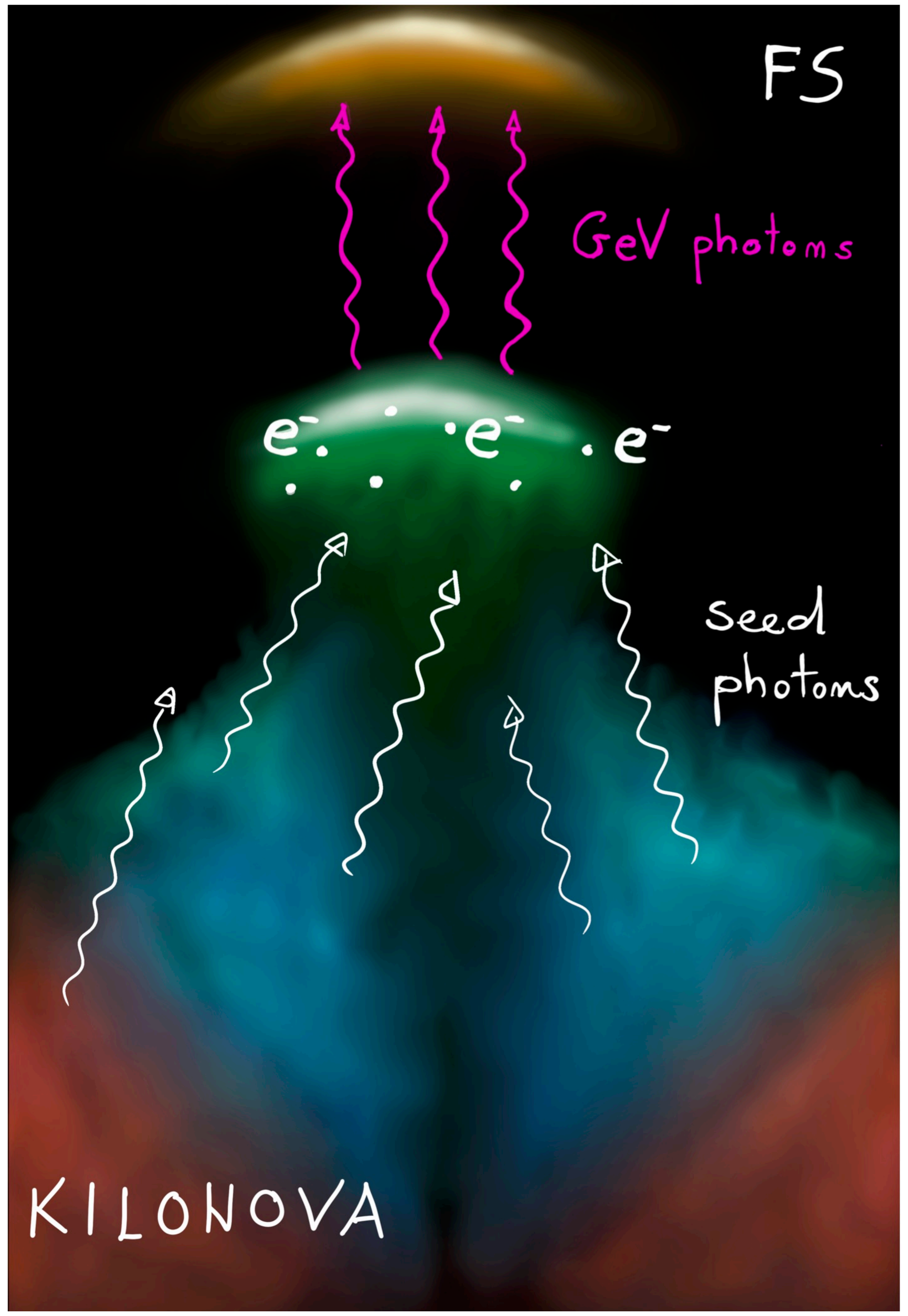
$$\dot{M} \propto t^{-5/3}$$



Low power jet-KN interaction

$T_0 + 10^4$ s

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

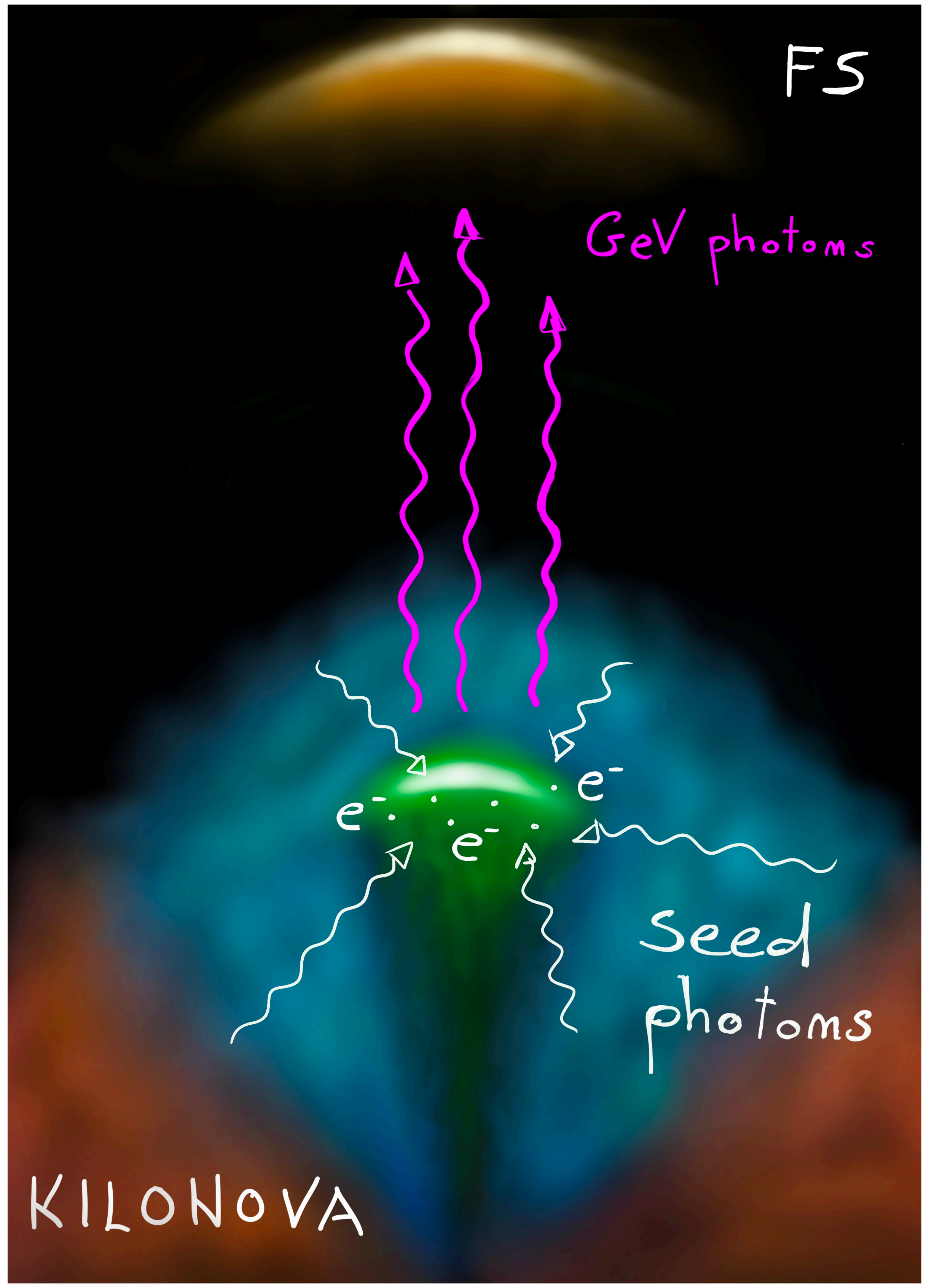


Credits: S. Ronchini

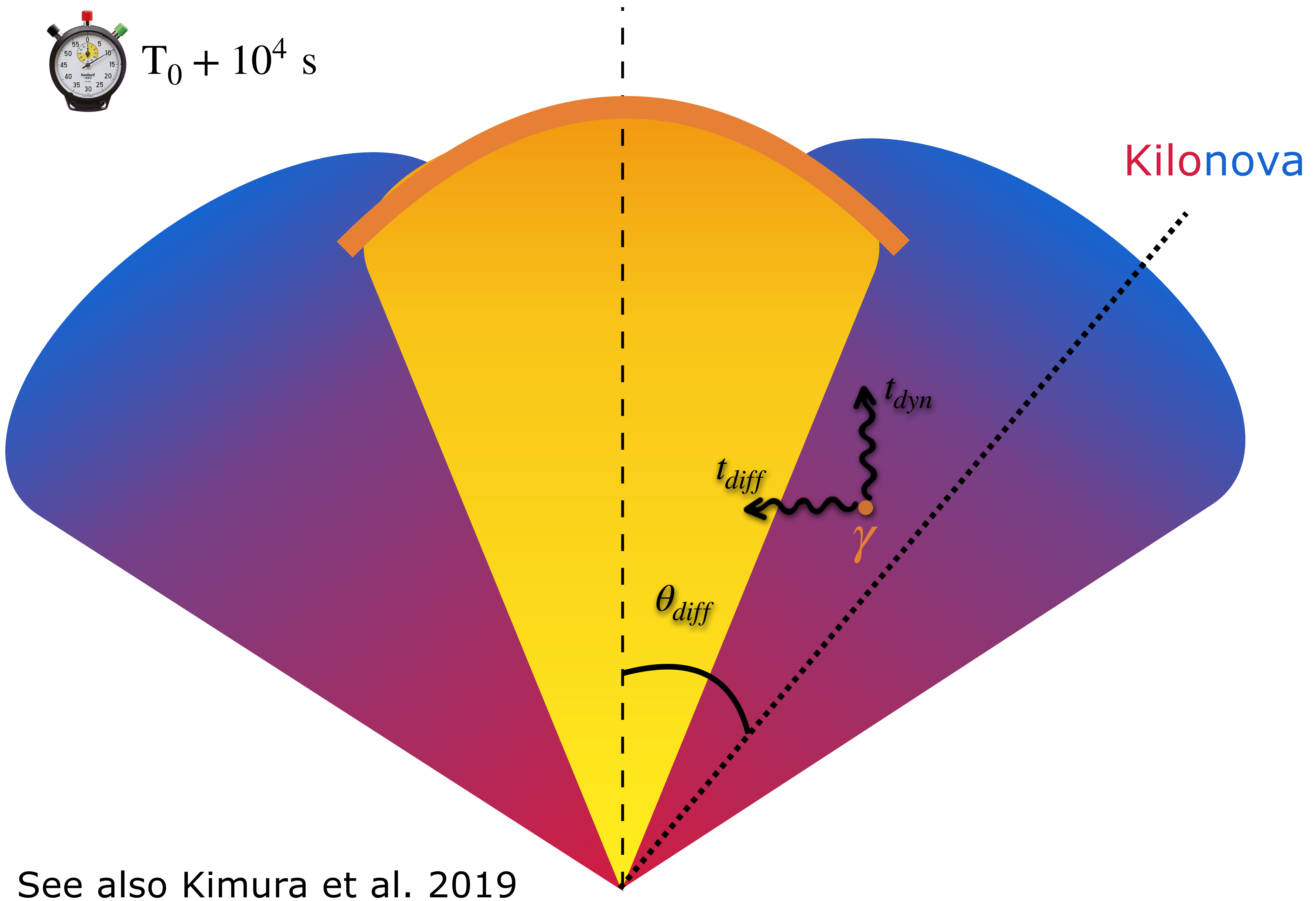
- If the hot electrons are **above** the kilonova photosphere, the photons are **de-beamed** in the jet comoving frame.
- This scenario requires an unrealistically low jet magnetisation ($\epsilon_B \lesssim 3 \times 10^{-10}$)

- 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 ($\epsilon_B \lesssim 8 \times 10^{-6}$)

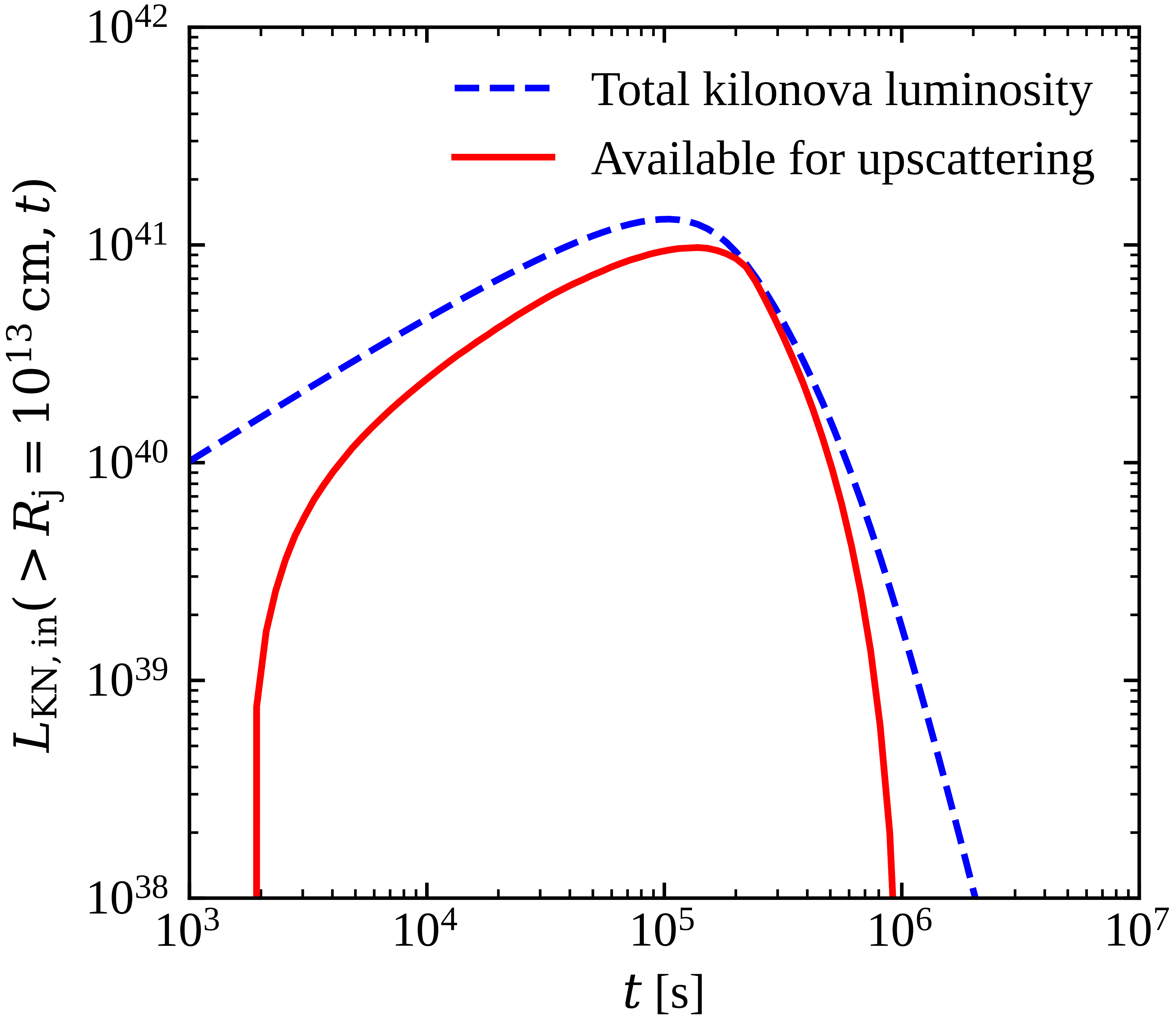
Beamed scenario ($R_j < R_{KN}$)



Low power jet-KN interaction



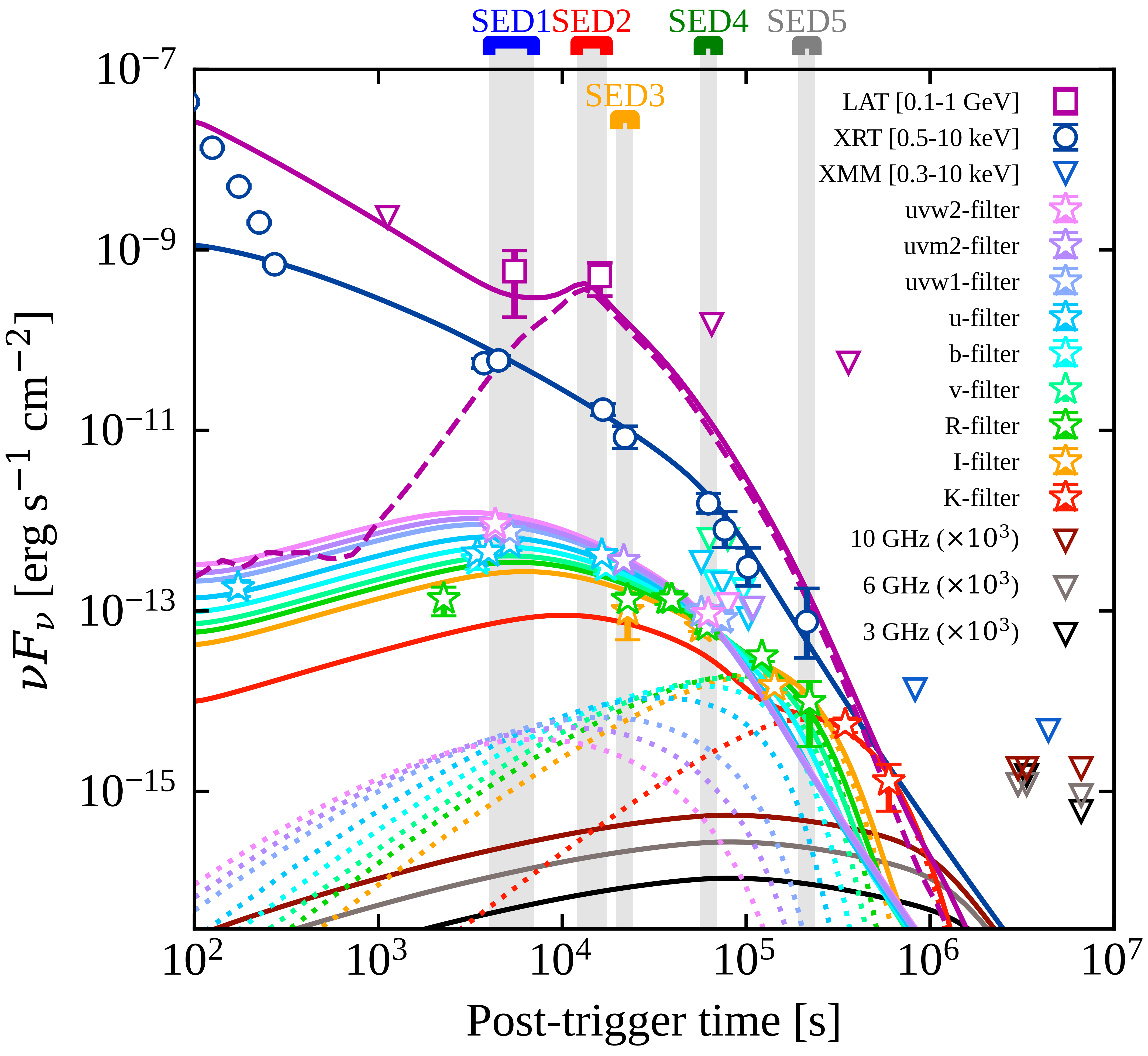
See also Kimura et al. 2019



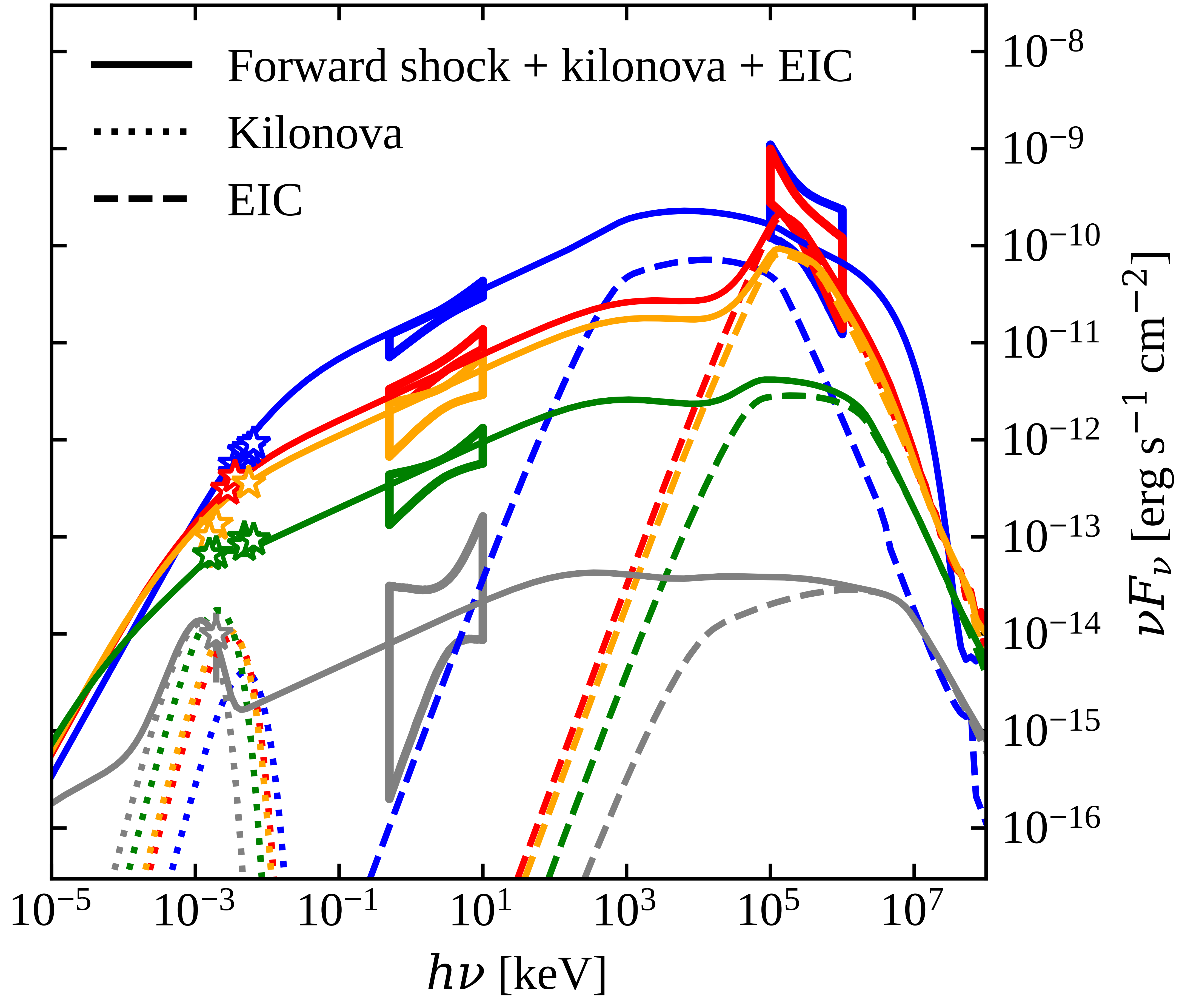
External Inverse Compton component

Light curves

Spectra (SED)



(a)



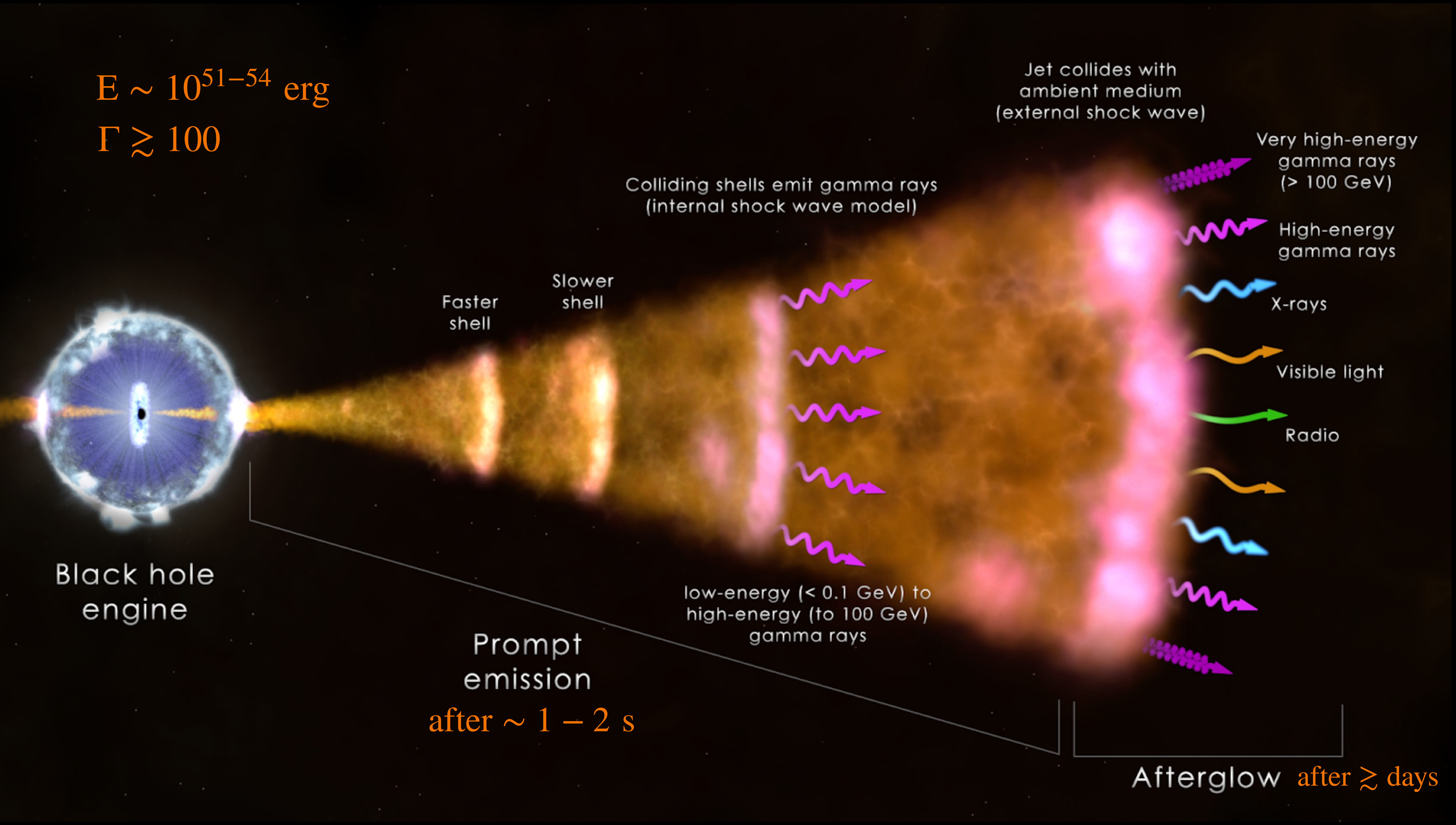
(b)

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!

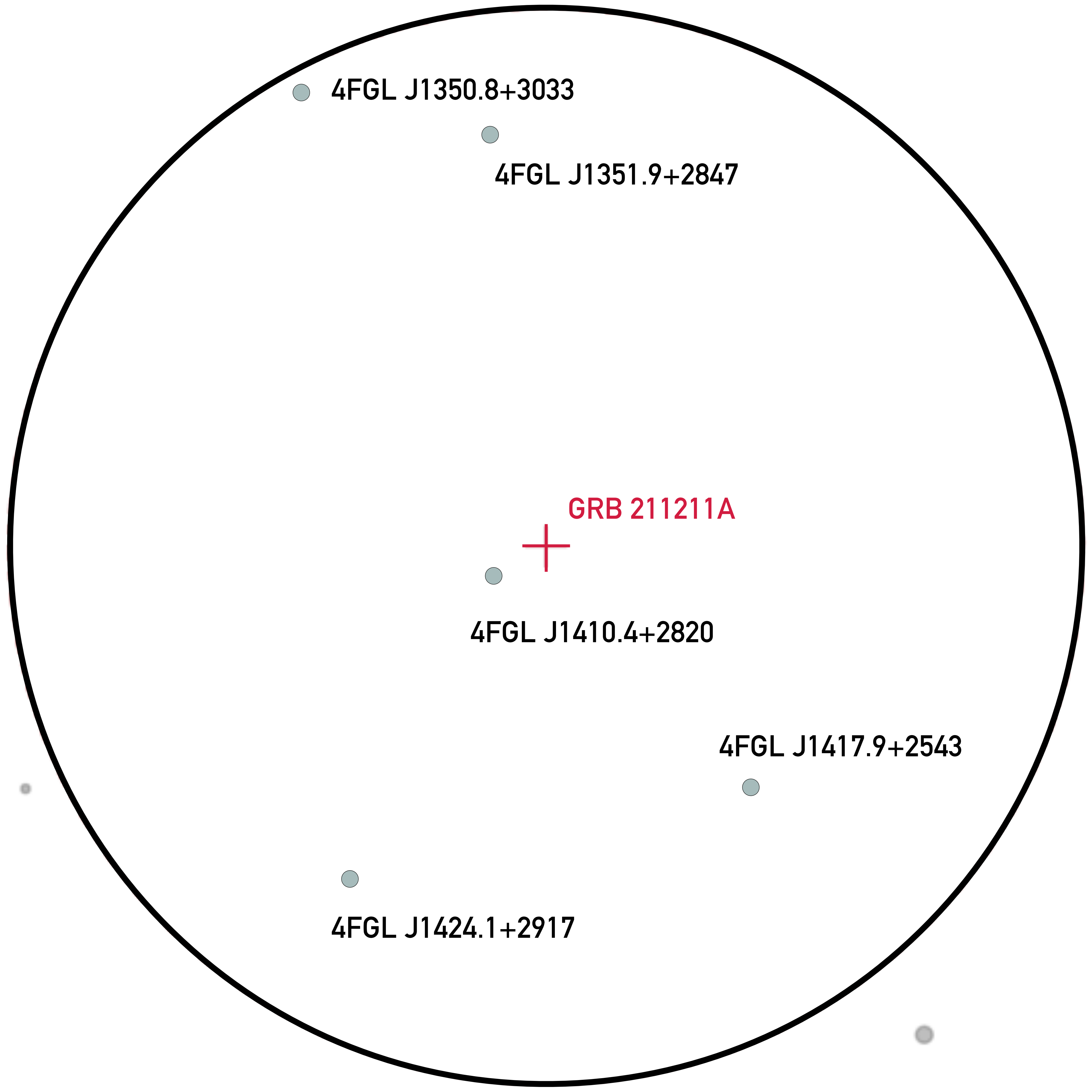
BACKUP SLIDES

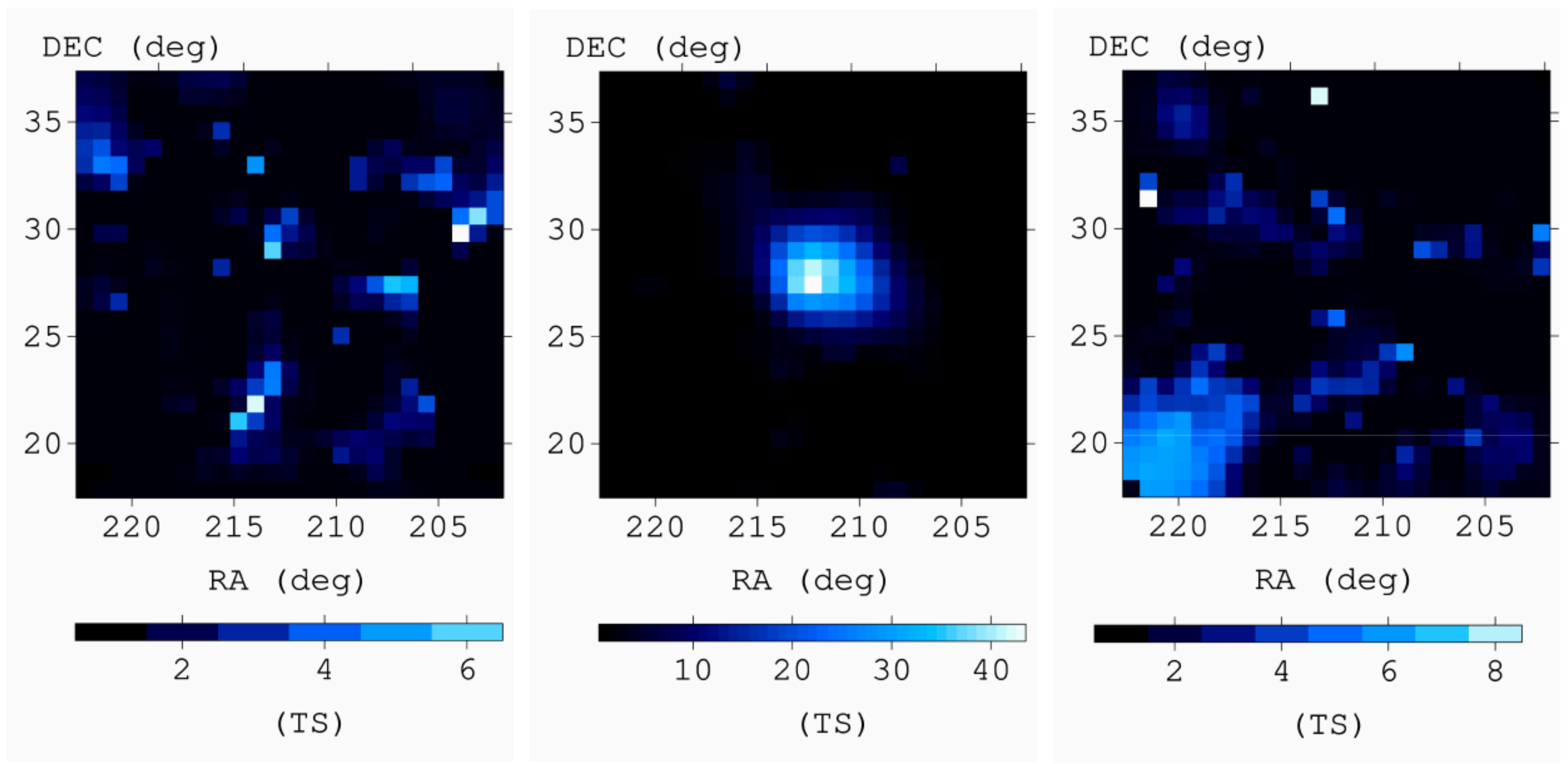
The fireball model



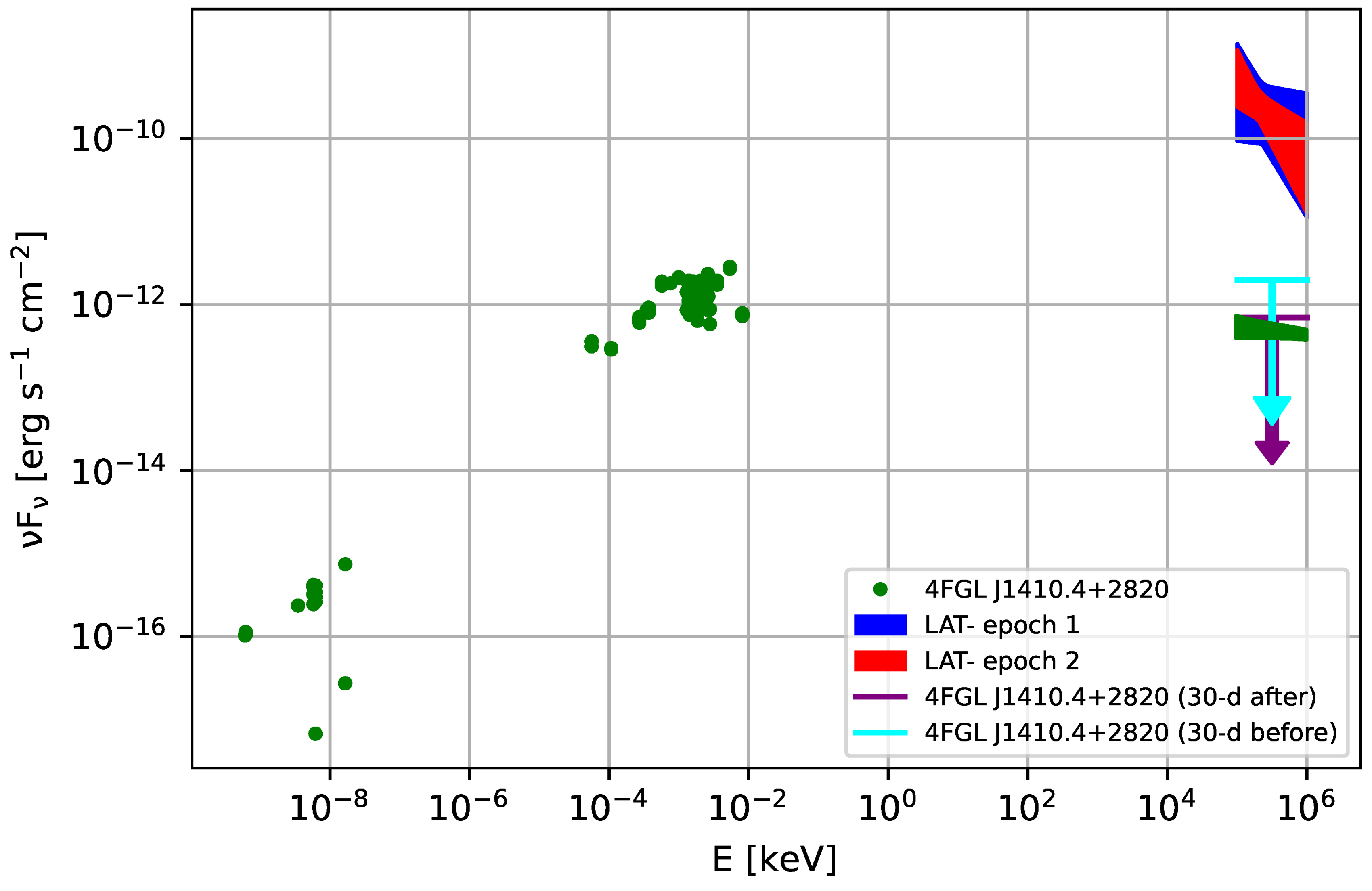
Ruling out contaminations from the bkg

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 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

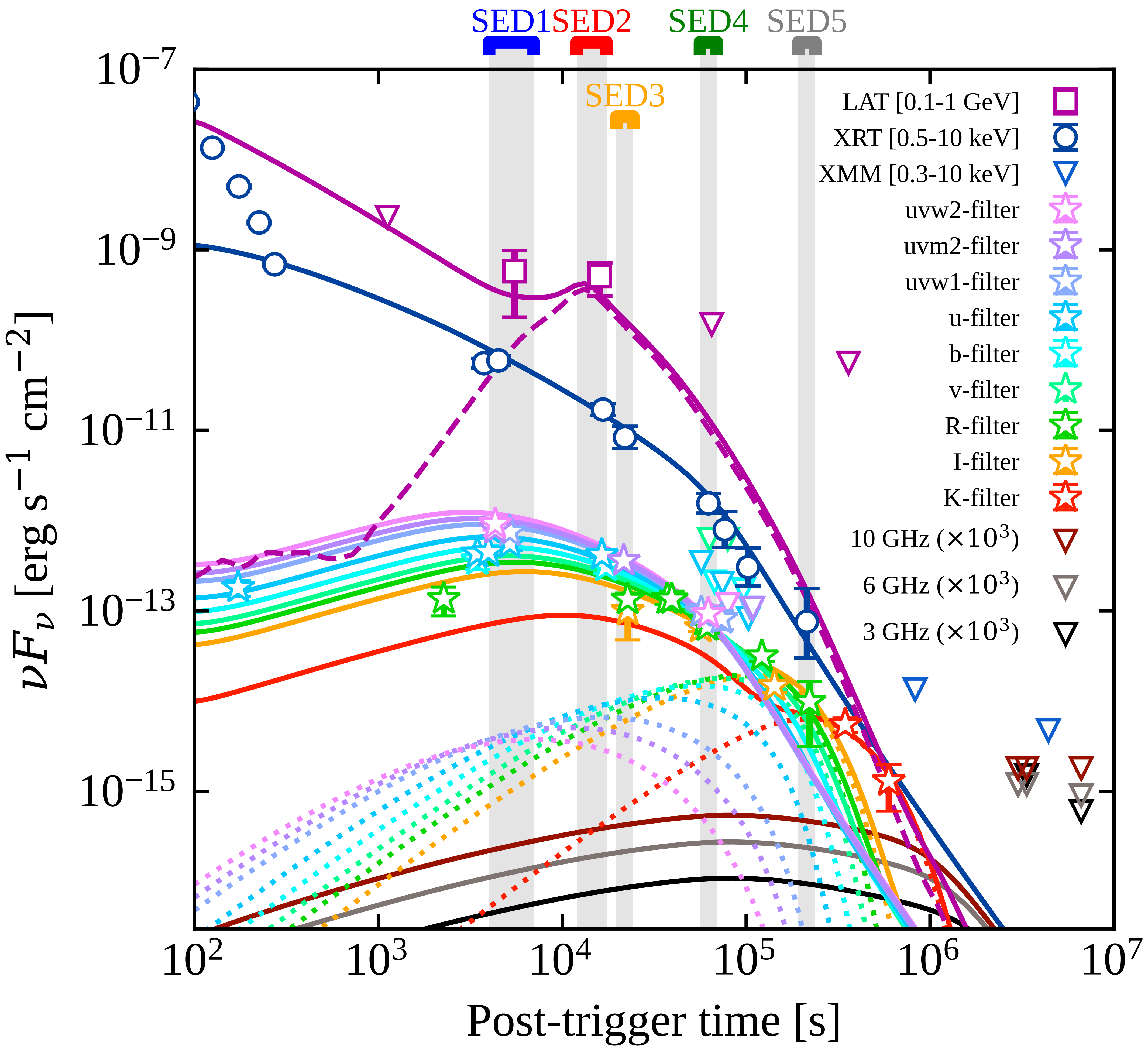
- Standard criteria for GRB detection: at least 3 photons associated to the GRB with probability $p > 0.9$
- We observe 9 photons with probability $p > 0.9$ to be emitted by the GRB.
- The highest energy photon is detected after 13 ks with energy ~1.5 GeV.

Duration dichotomy

Bromberg et al. 2013

HE excess at late time

Light curves



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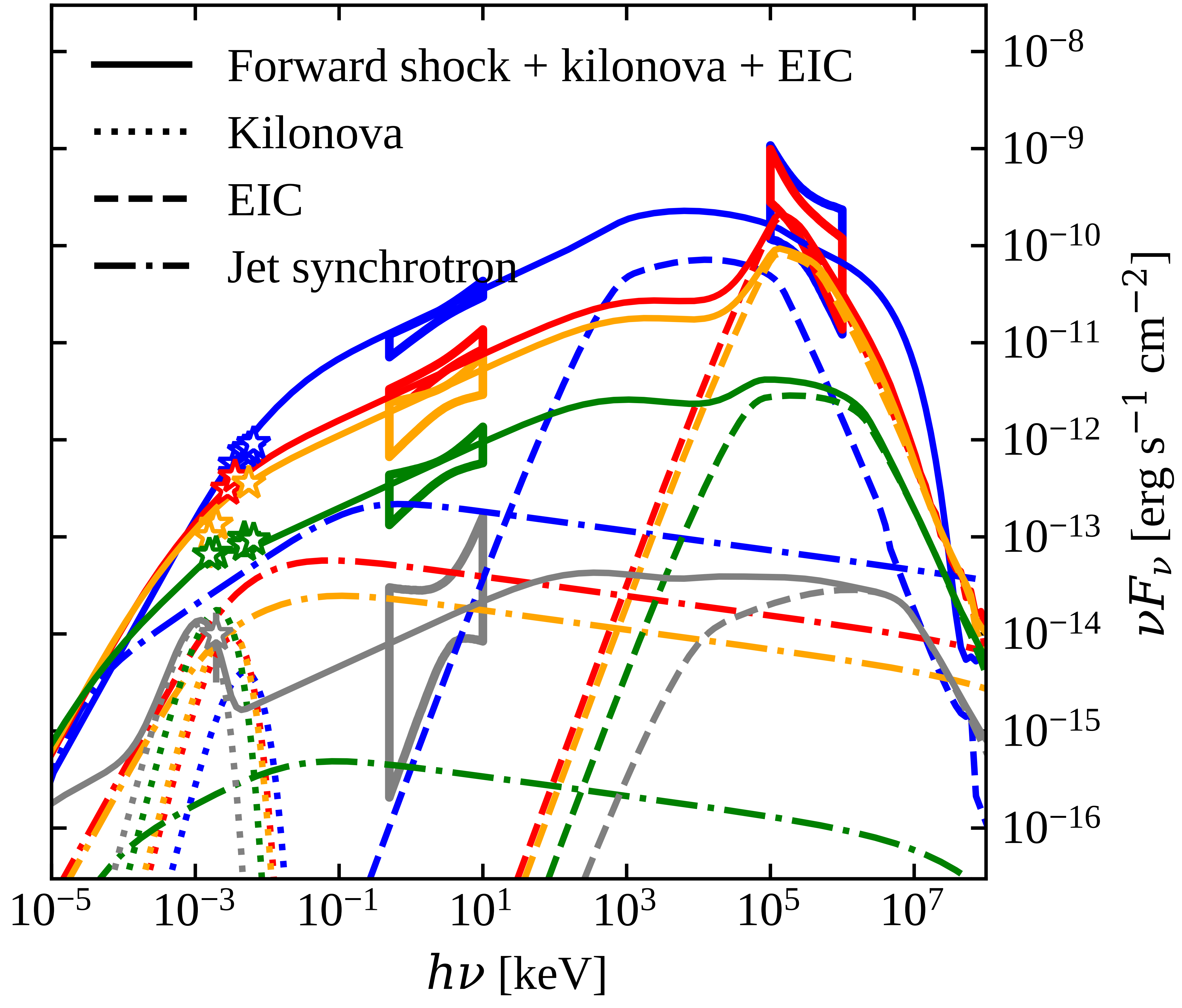
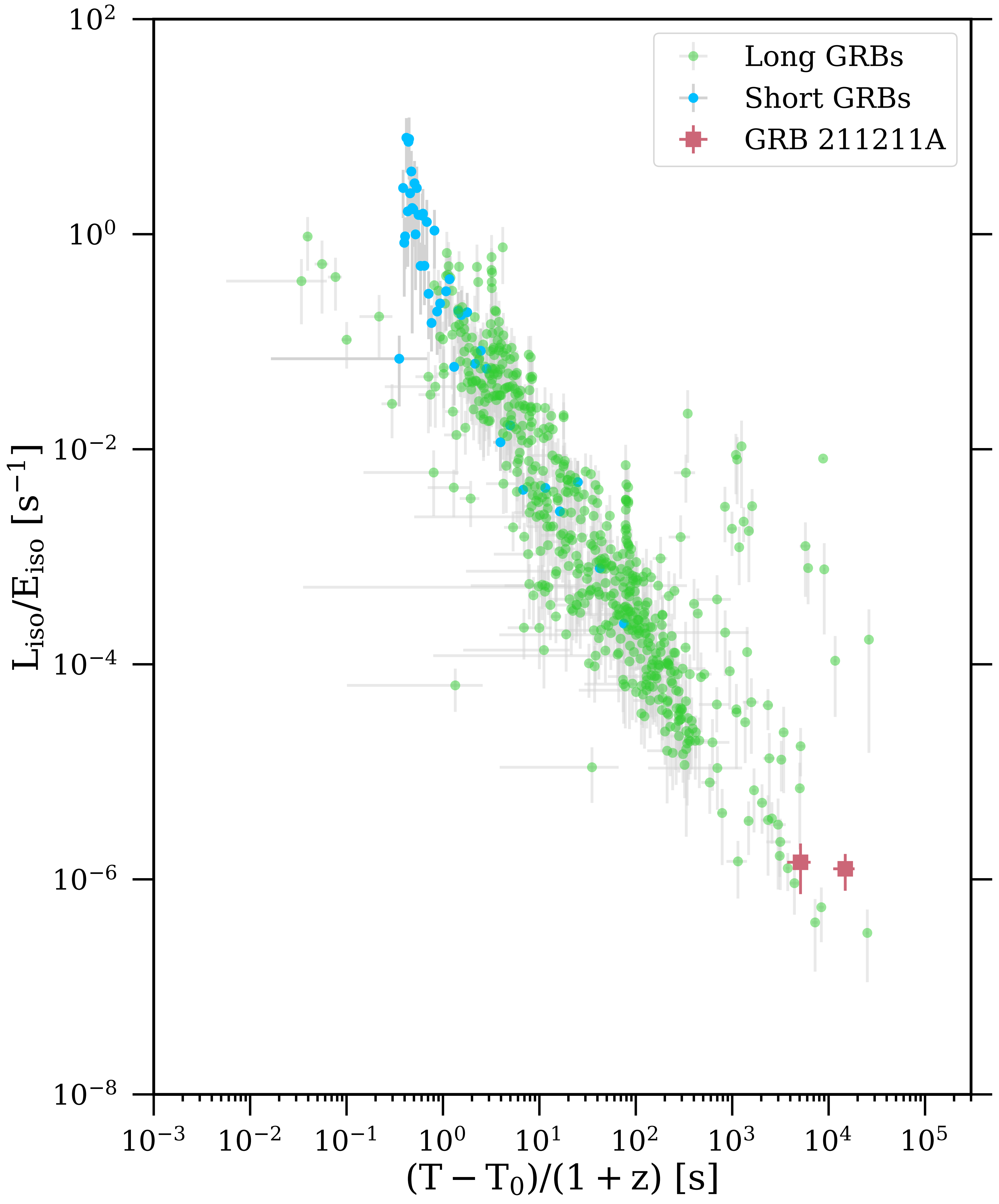
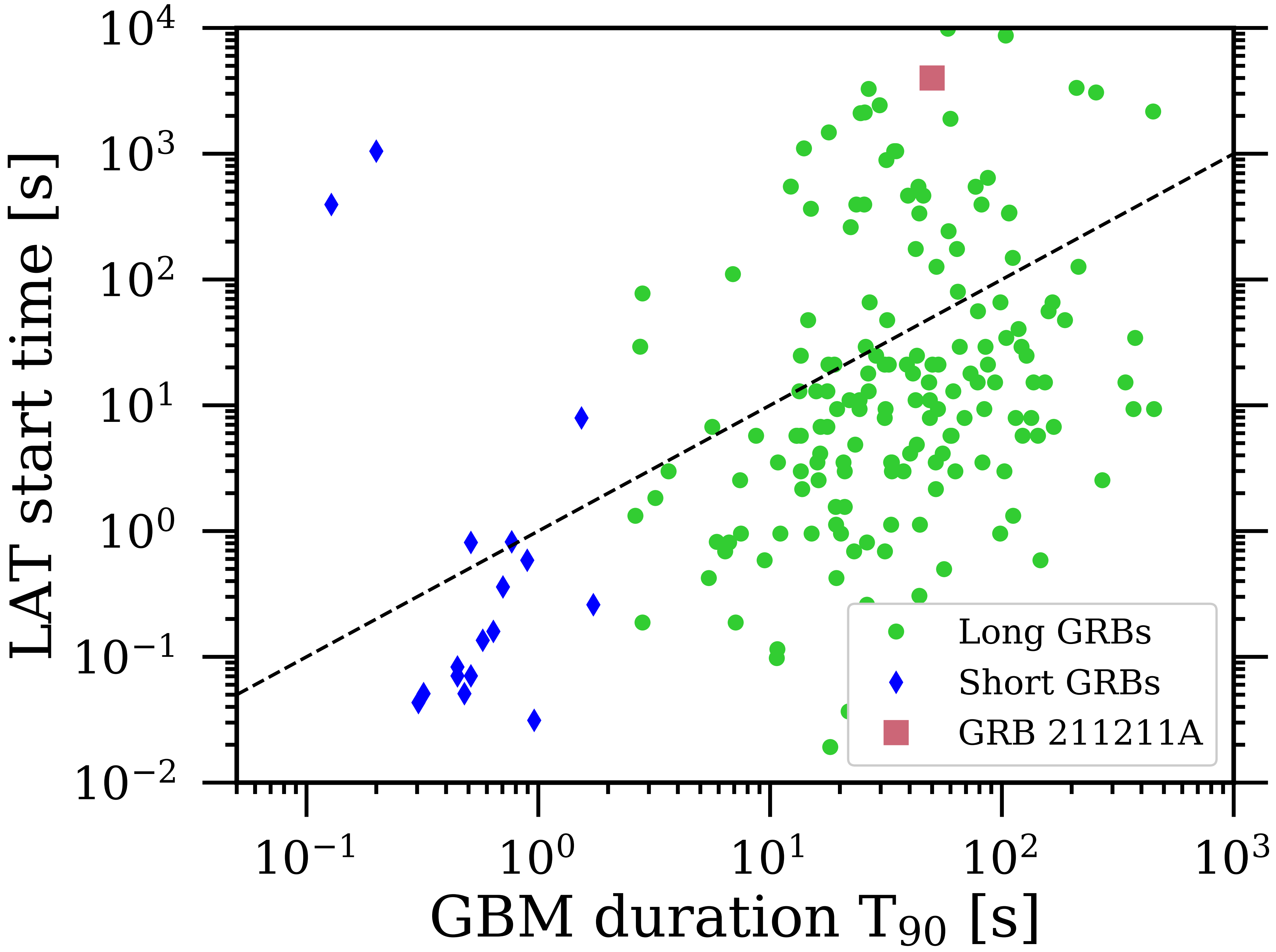


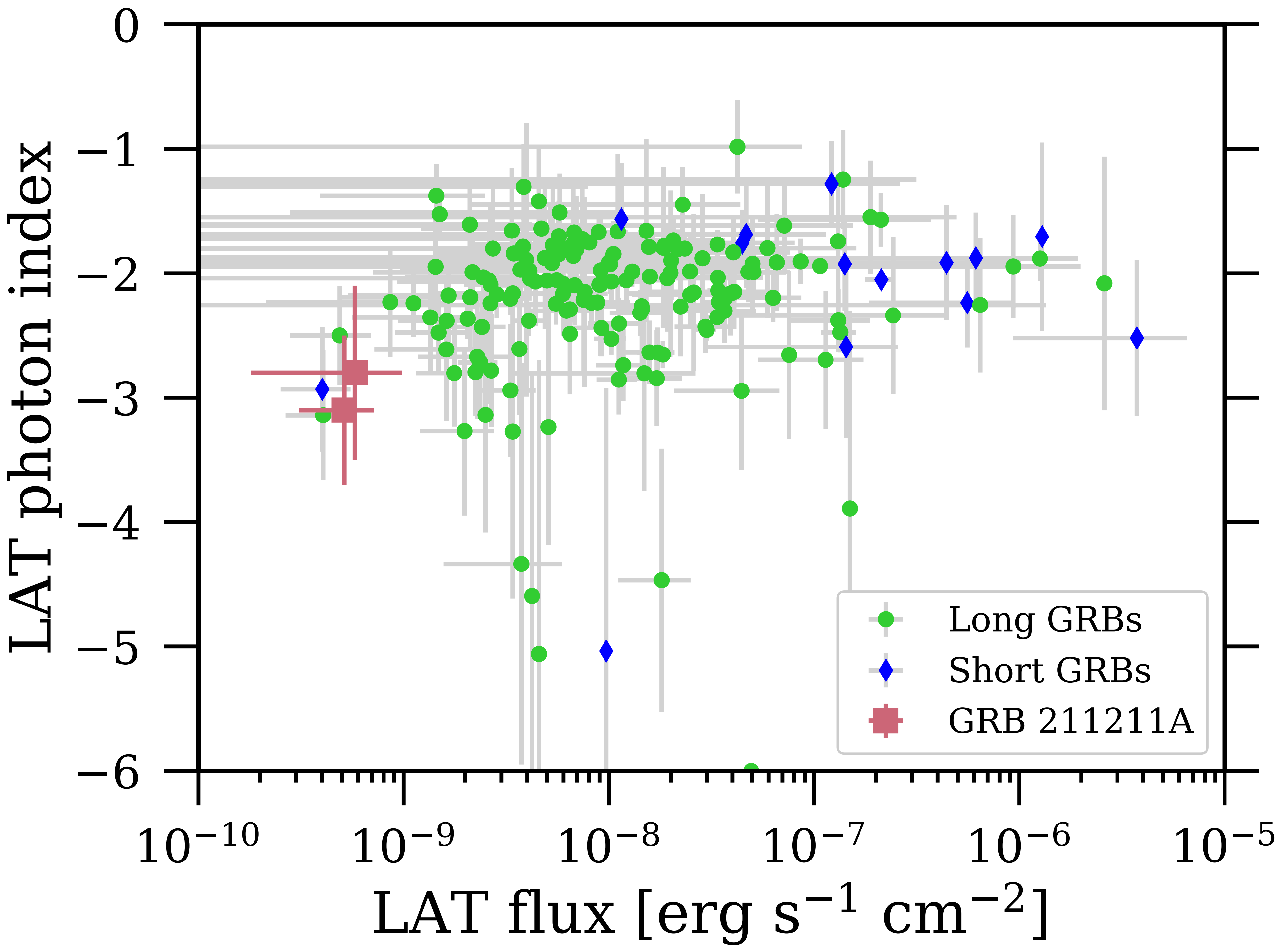
(b)

Comparison with other LAT GRBs



Comparison with other LAT GRBs



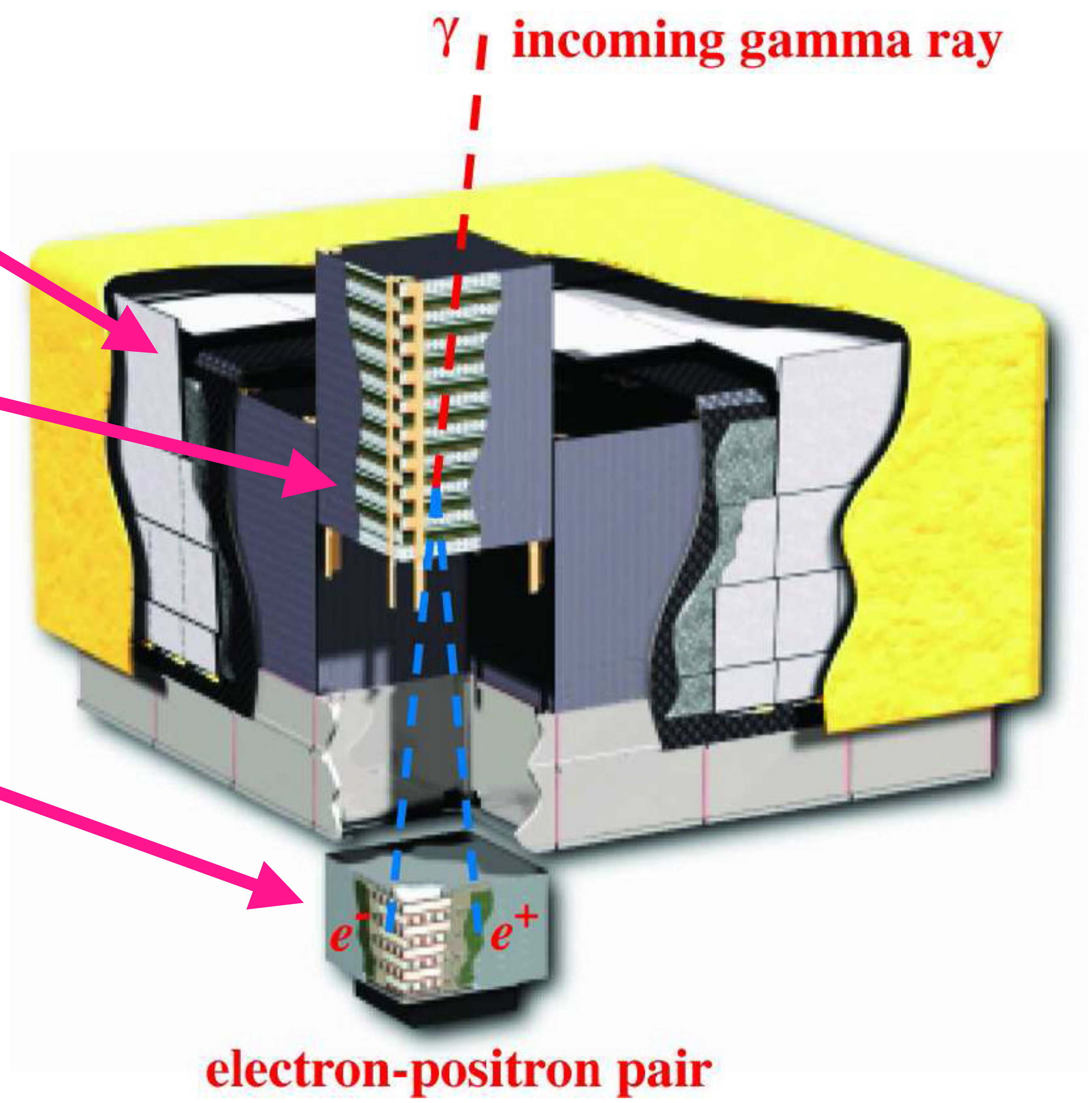


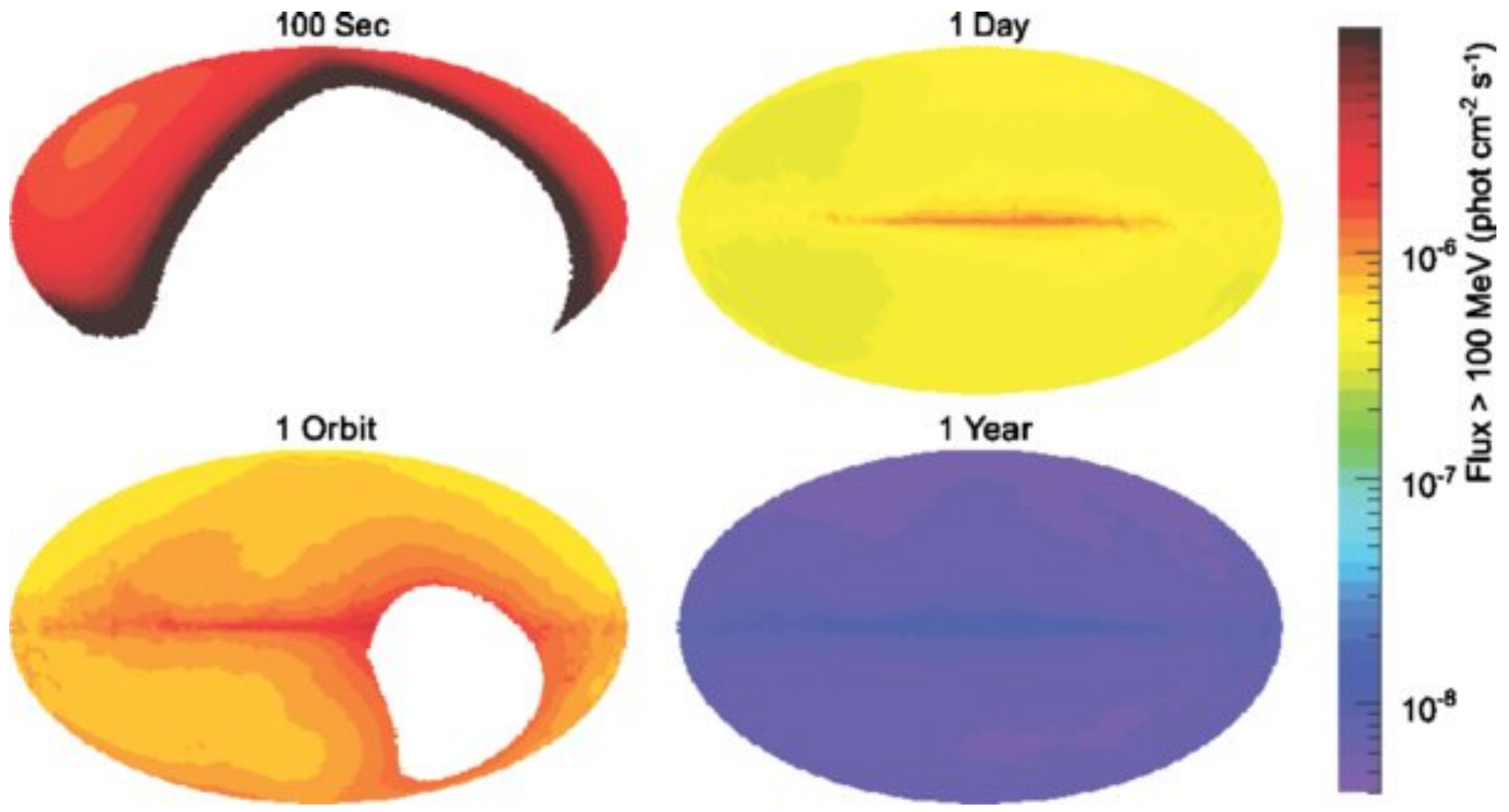
Fermi Large Area Telescope

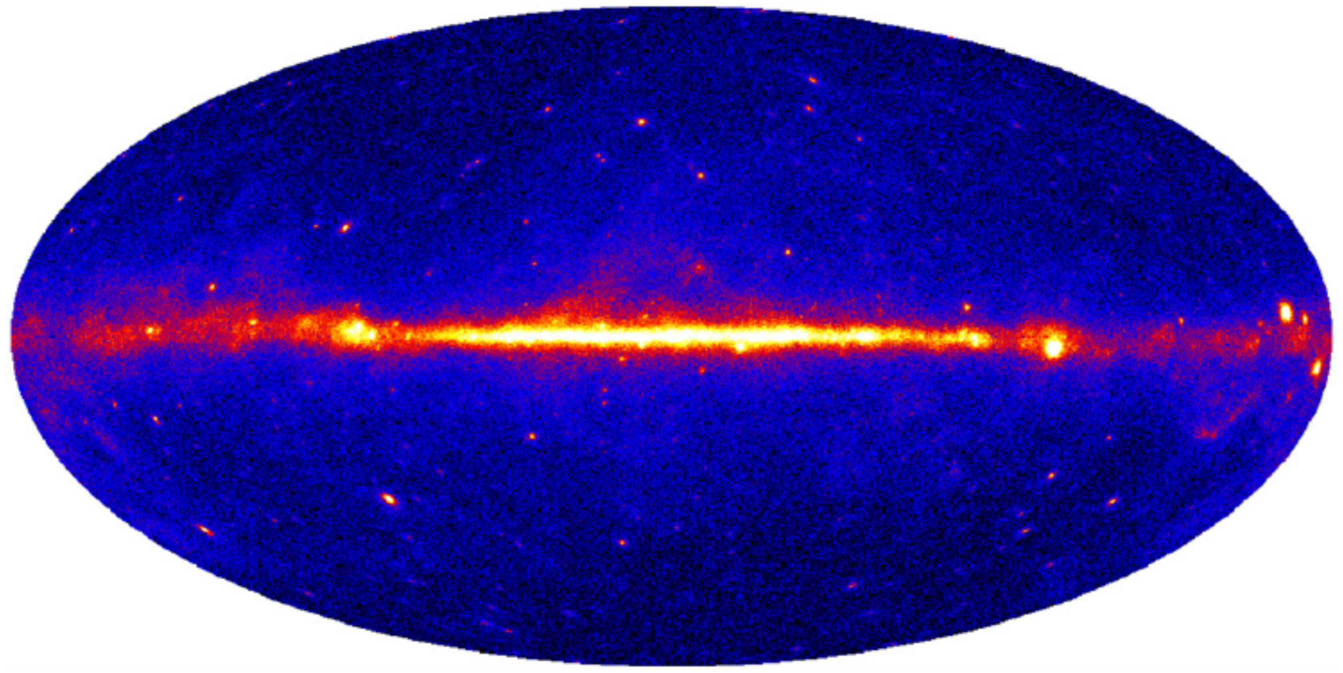
Anticoincidence detector: rejects background and CR events. Segmentation eliminates self-veto at high energies

Tracker: measures the photon direction and ID

Calorimeter: measures the photon energy and image the shower.

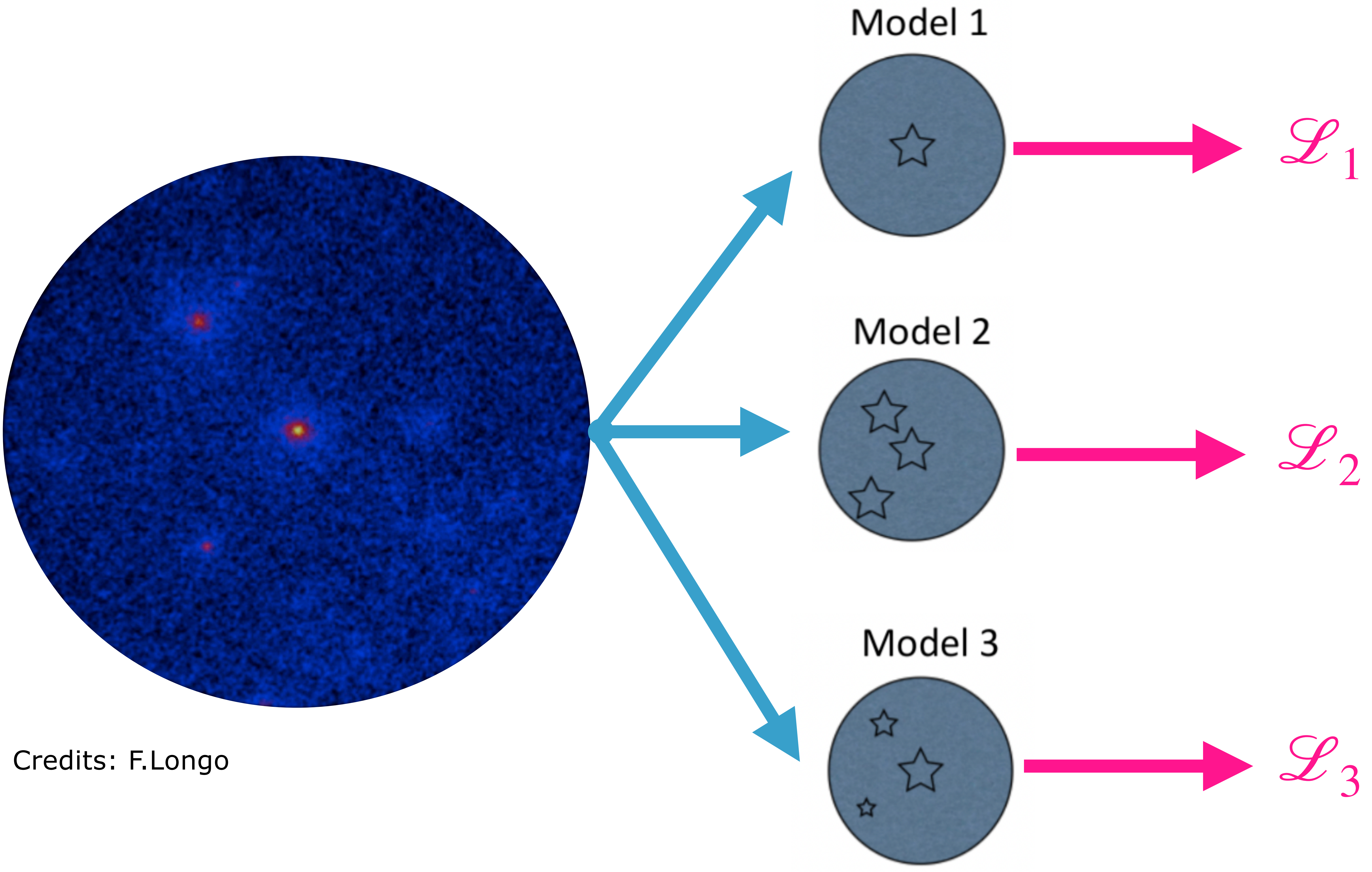






- Large sky coverage (~ 20%)
- Poor angular resolution (PSF ~ 1 deg @ 1GeV)

Fermi/LAT data analysis in a nutshell



Credits: F.Longo

- High energy γ-rays have limited statistics and strong and structured background
- Necessity of including statistical tools to analyse data, like maximum likelihood estimation (MLE)
  1. Assume a model
  2. Convolve it with the instrument response function
  3. Change the model parameters in order to maximise the likelihood $\mathscr{L}$