MAGIC observations of the nearby short GRB 160821B

MAGIC: Major Atmospheric Gamma Imaging Cerenkov Telescopes

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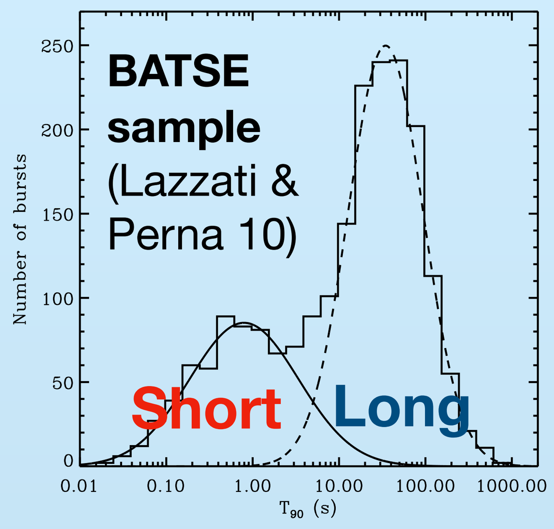
Abstract: Gamma-ray bursts (GRBs), the most luminous explosions in the universe, have at least two types known. One of them, short GRBs, have been thought to originate from binary neutron star (BNS) mergers. The discovery of GW170817 together with a GRB was the first and only direct proof of the hypothesis, and thus the properties of the short GRBs are poorly known yet. Aiming to clarify the underlying physical mechanisms of the short GRBs, we analyzed GRB 160821B, one of the nearest short GRBs known at z=0.162, observed with the MAGIC telescopes. A hint of a gamma-ray signal is found above 0.5 TeV at a significance of >3 sigma during observations from 24 seconds until 4 hours after the burst, as presented in the past.
Recently, multi-wavelength data of its afterglow emission revealed a well-sampled kilonova component from a BNS merger, and the importance of GRB 160821B increased concerning GRB-GW studies. Accordingly, we investigated GRB afterglow models again, using the revised multi-wavelength data. We found that the straightforward interpretation with one-zone synchrotron self-Compton model from the external forward shock is in tension with the observed TeV flux, contradicting the suggestion reported previously. In this contribution we discuss the implication from the TeV observation, including alternative scenarios where the TeV emission can be enhanced. We also give a brief outlook of future GeV-TeV observations of short GRBs with imaging atmospheric Cherenkov telescopes, which could shed more light on the GRB-BNS merger relation.

1. Introduction

Long GRBs: T_{90} > ~2 s,
core collapse SNe
tens of confirmations

Short GRBs: T_{90} < ~2 s,
neutron star mergers (?)
only 1 example 170817A



Classification with T_{90} has a difficulty in ~1-10 s
Need to confirm supernova or **kilonova (KN)**
However,

- Short GRBs are intrinsically dimmer than Long
- Far & dim Long may be obesrved as a Short
- KN component is dimmer than supernova

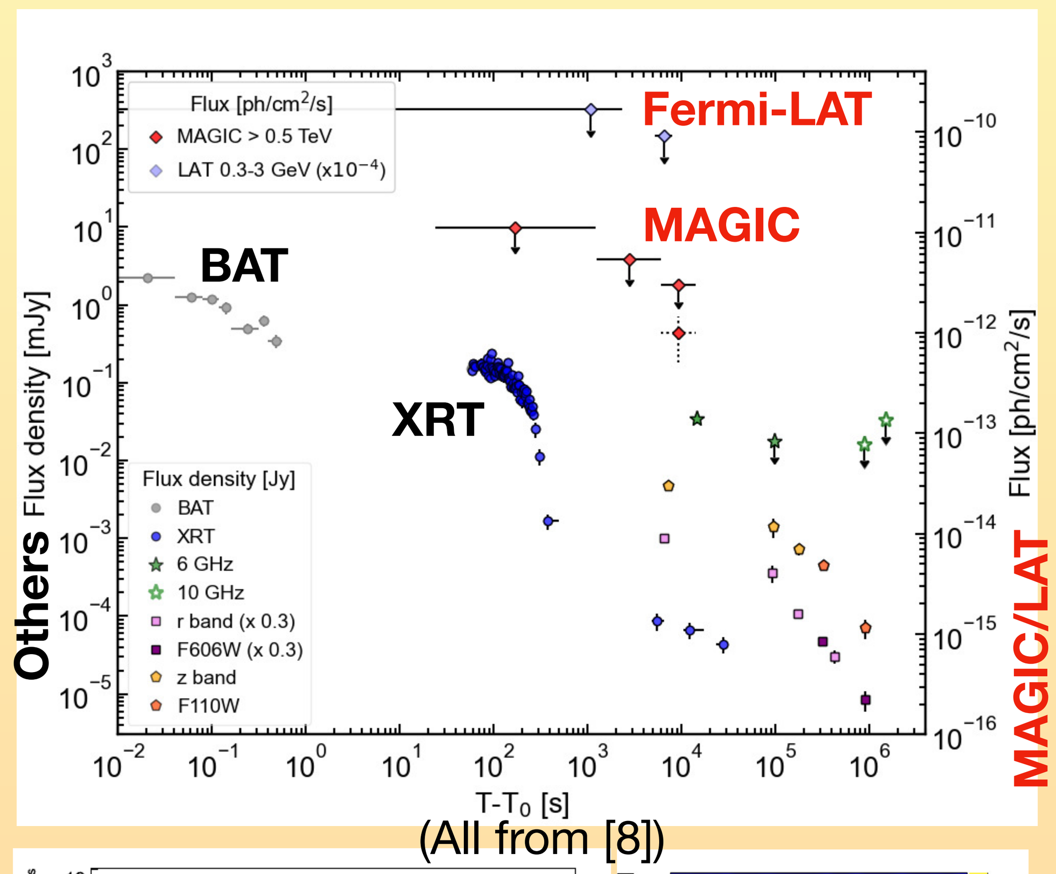
So far, only few Short GRBs were observed with a KN: 130603B, 170817A, and **160821B**
Important for GRB-GW connection!

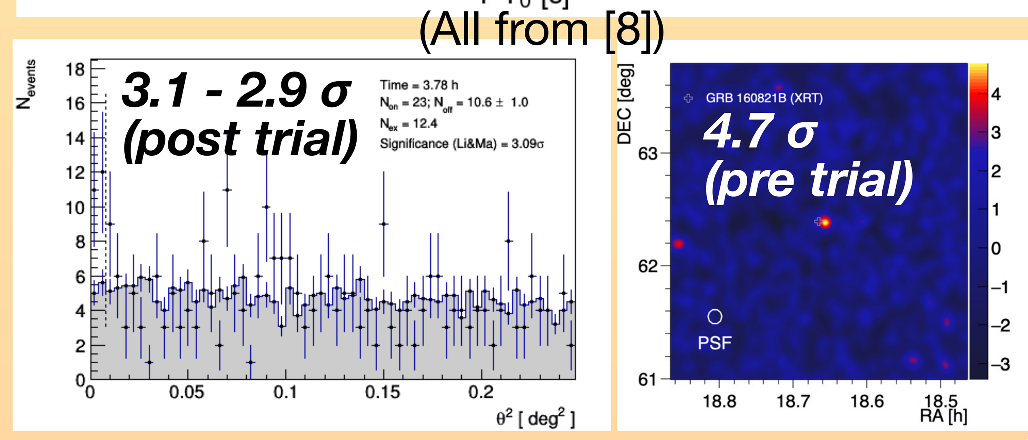
2. Observations

Swift/BAT trigger (T_{90} = 0.48 s, 22:29:13 UT on 2016 August 21 = T_0), followed by XRT, Fermi-GBM/LAT, Optical (NOT, WHT, GTC, HST) and radio (VLA), etc.

MAGIC started to obs. at T_0 + 24 s (fastest!) until T_0 + 4 hrs
first ~1.7 hr: non-optimal weather, less moon light, later ~2.2 hr: better weather, but more moon light => E_{th} > ~0.5 TeV
Fermi-LAT (t-T_0): 0-2315 s, 5285-8050 s

MAGIC found a hint of detection at ~3 sigma > 0.8 TeV, reported in 2017.
The second best sampled kilonova emission, reported in 2019 [1, 2]





3. Results

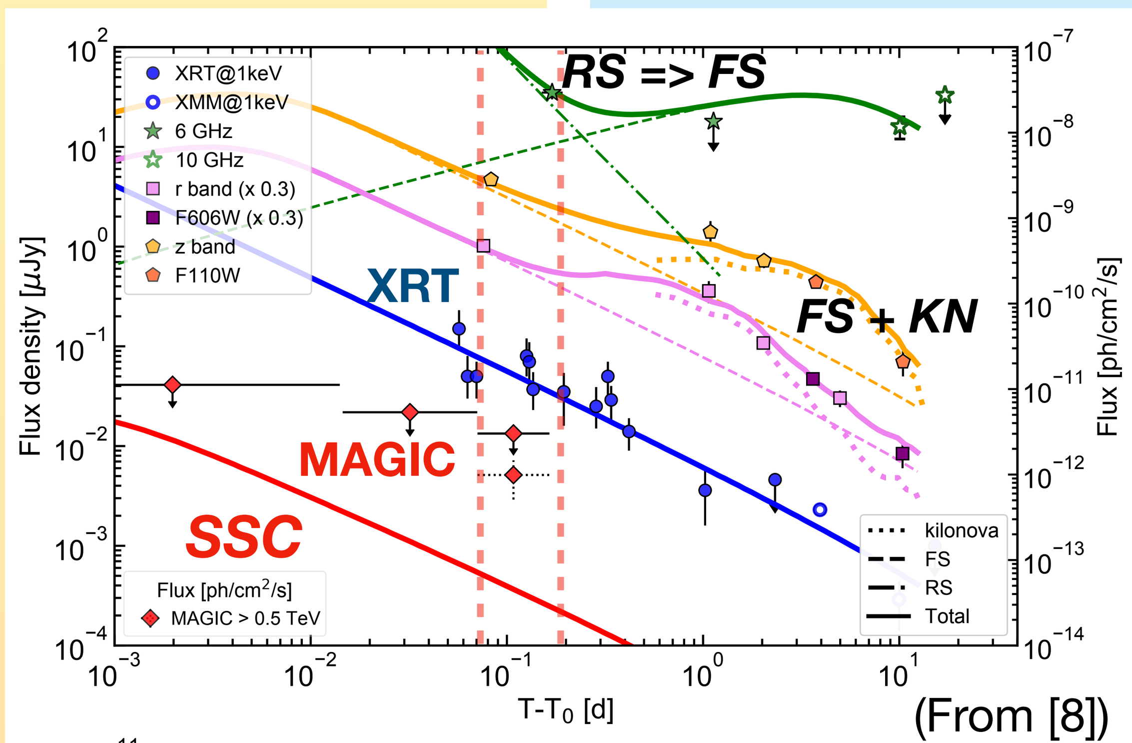
MWL (radio - X) data are well modeled by the synchrotron from electrons accelerated in the external **forward shock** (FS, in X), **reverse shock** (RS, in radio), **KN** (in opt/nIR, updated in 2019), and the **extended emission** (EE, in X, not shown here), in a good agreement with Troja+ (2019) [2]

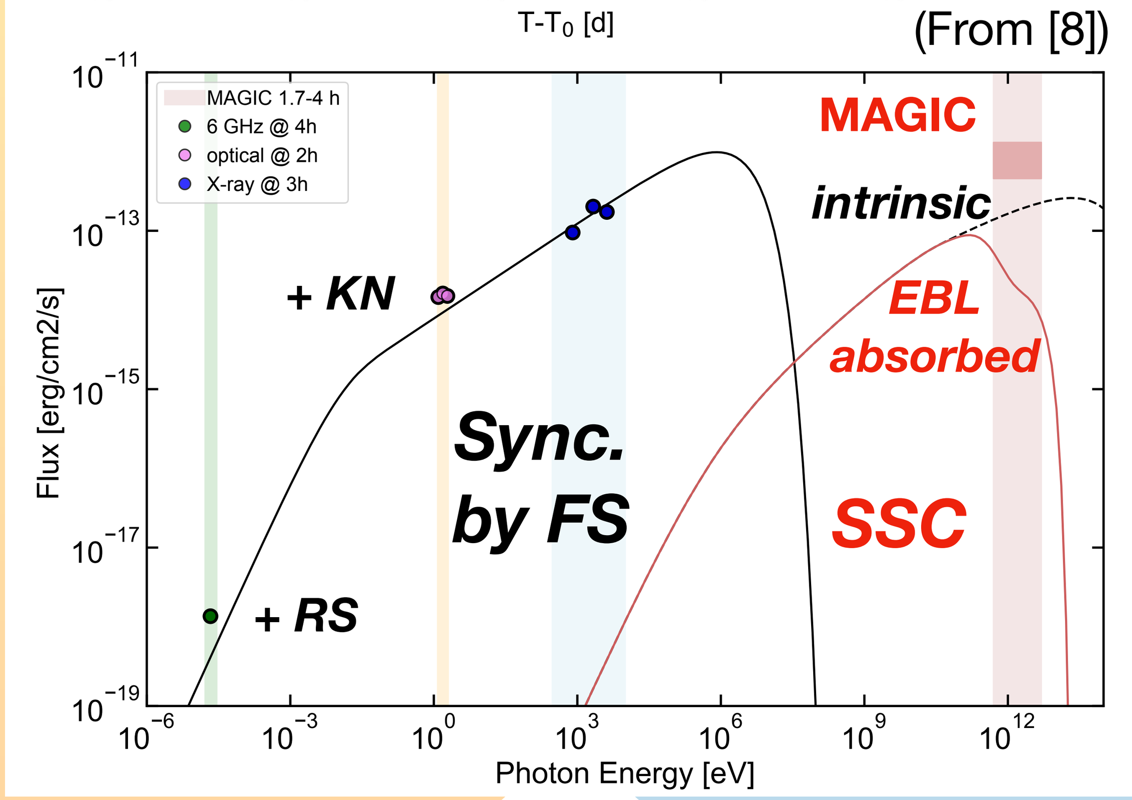
Lamb+ (2019) [1] proposes a multi-zone interpretation with a late energy injection, driven by double peaks in X-ray

Then, TeV flux is estimated with the **synchrotron self-Compton (SSC, *red lines, EBL absorbed*)**

MAGIC observation divided into 3 intervals.
The last bin <u>T_0 + 1.7-4 hr under a good weather enabling a flux estimation.</u>
SED modeling at **T_0 + 2-4 hr.** MAGIC ph flux converted to an energy flux (0.5-5 TeV) with PL index -2 assumed. Fermi-LAT not constraining.

Even though the MAGIC flux is just indicative, **SSC underpredicts the TeV flux by an order of magnitude, in tension with the observation.**





4. Discussions

Other possibilities than SSC (of FS)

- **Proton synchrotron** [3]:
max. sync. E > 0.5 TeV at t ~ 2 hr requires n_0E_k /10^{51} erg /cm^{-3} > 6000, while it is typically 10^{-5} -10 for short GRBs. Similar discussion for TeV flux constrains further the material density and kinetic E.
Thus, it is **strongly disfavored.**

- **Photohadronic cascade** [4] similarly disfavored

- **External Compton** [5] is one of plausible scenarios, with candidate target soft photons from EE, cocoon, KN, two component jet, thermal X from FS, etc.

- **RS with the SSC** process [6], possibly with a **continuous energy injection** [7]

Plenty of possibilities, need more inputs from the observations

5. Summary and Outlook

Short GRBs with a well-observed kilonova emission are a key to understand the nature of the GRB class, in the context of the GW followup observations. GRB 160821B with a hint of TeV emission by MAGIC put more emphasis on the context. It revealed that the simple SSC model does not work well, but other valid interpretations exist. In order to nail down the possibilities, we need more inputs from observations, not only with MAGIC but also with CTA-LST, together with MWL / MM instruments. **Stay tuned**

References [1] G. P. Lamb, N. R. Tanvir, A. J. Levan, et al. ApJ, **883** (2019) 48.
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