Gamma-Ray Bursts at TeV energies

Lara Nava

INAF

Osservatorio Astronomico di Brera

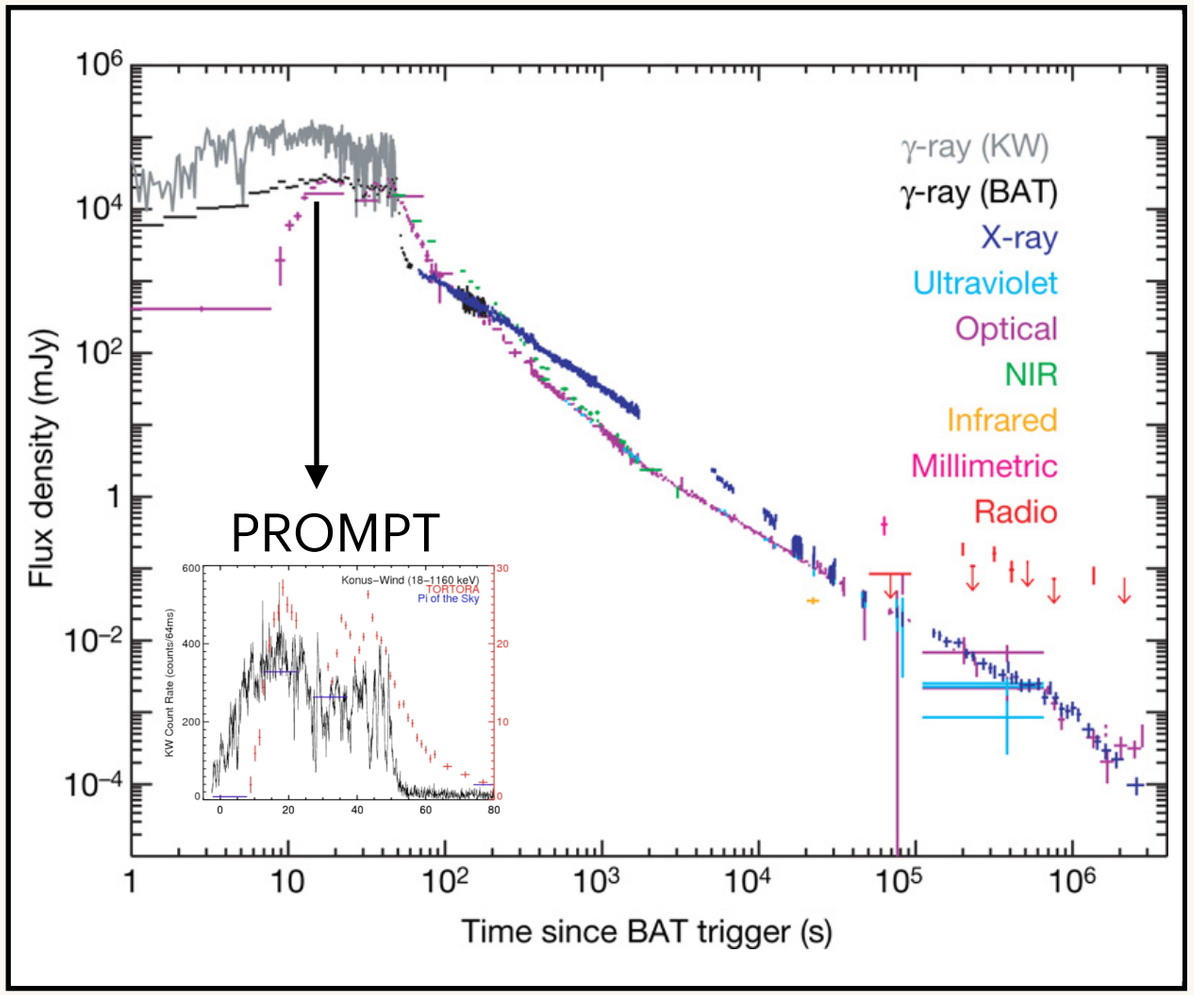
13 JULY 2021

ICRC 2021

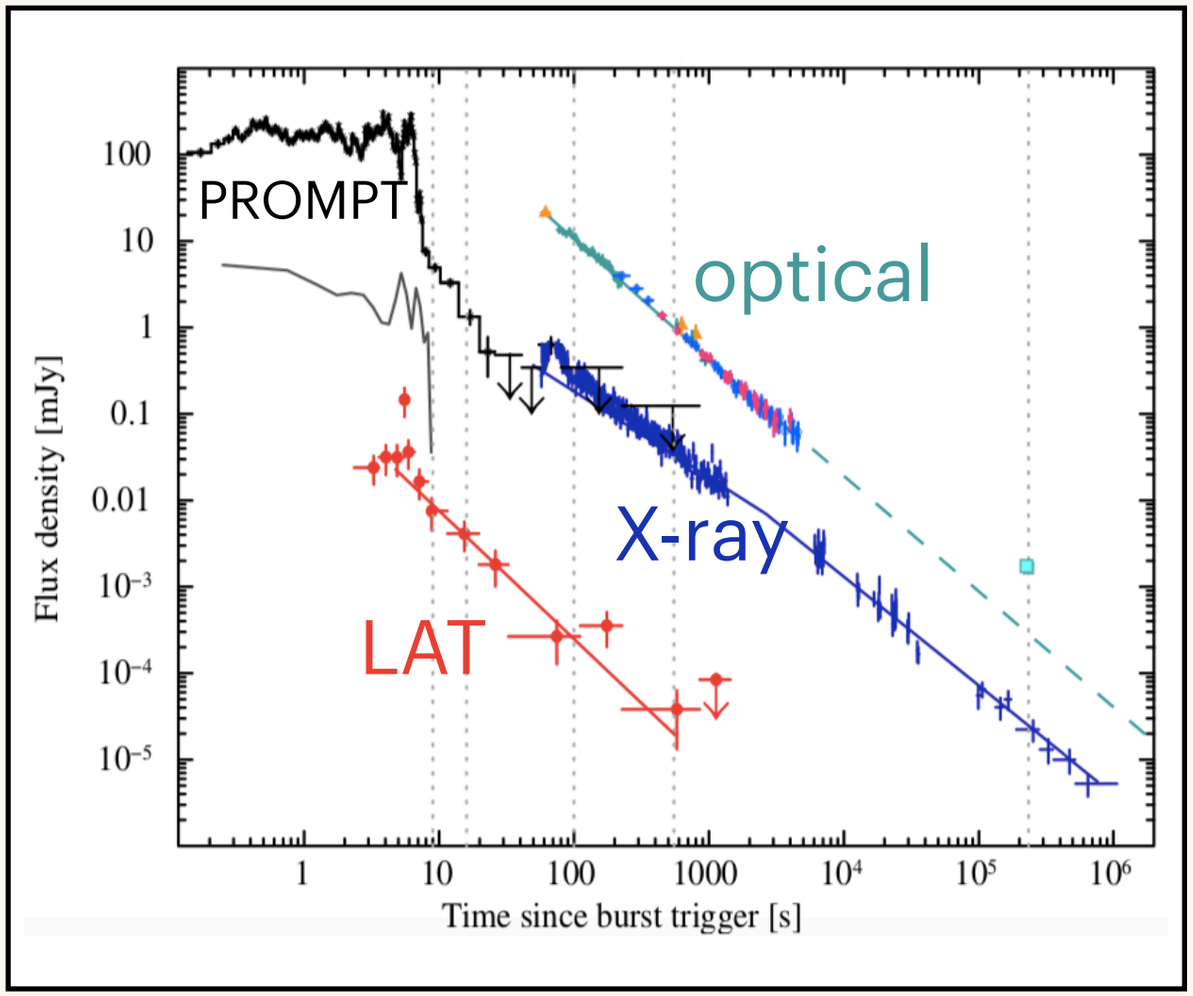
Emission from GRBs

Two examples of multi-wavelength radiation from GRBs

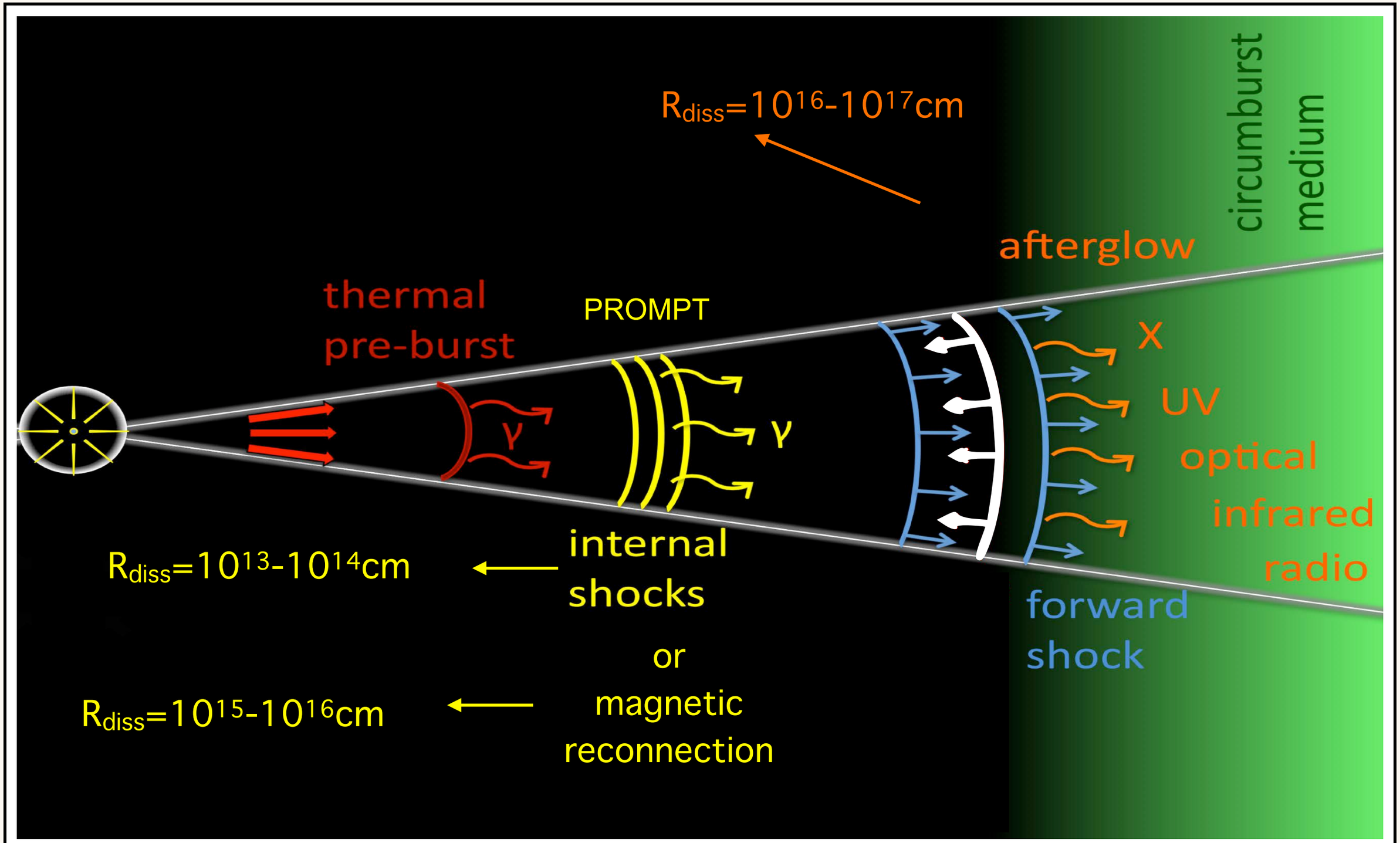
GRB 080319B
Racusin et al., 2008



GRB 110731A
Ackermann et al., 2013



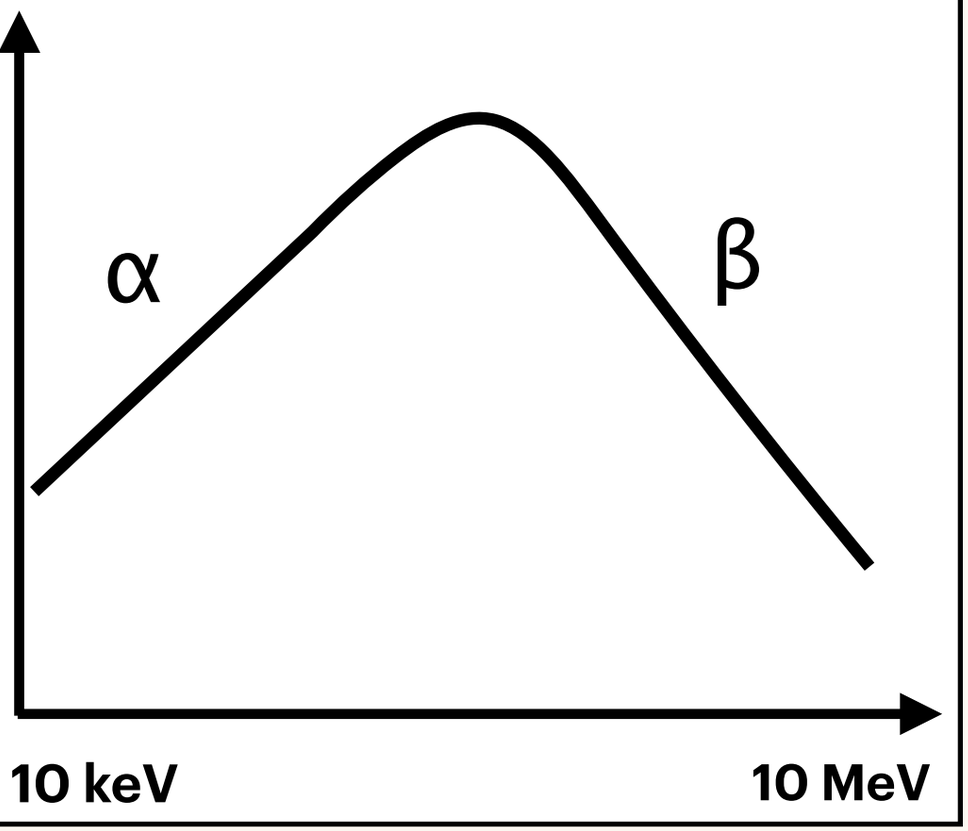
The Standard Model



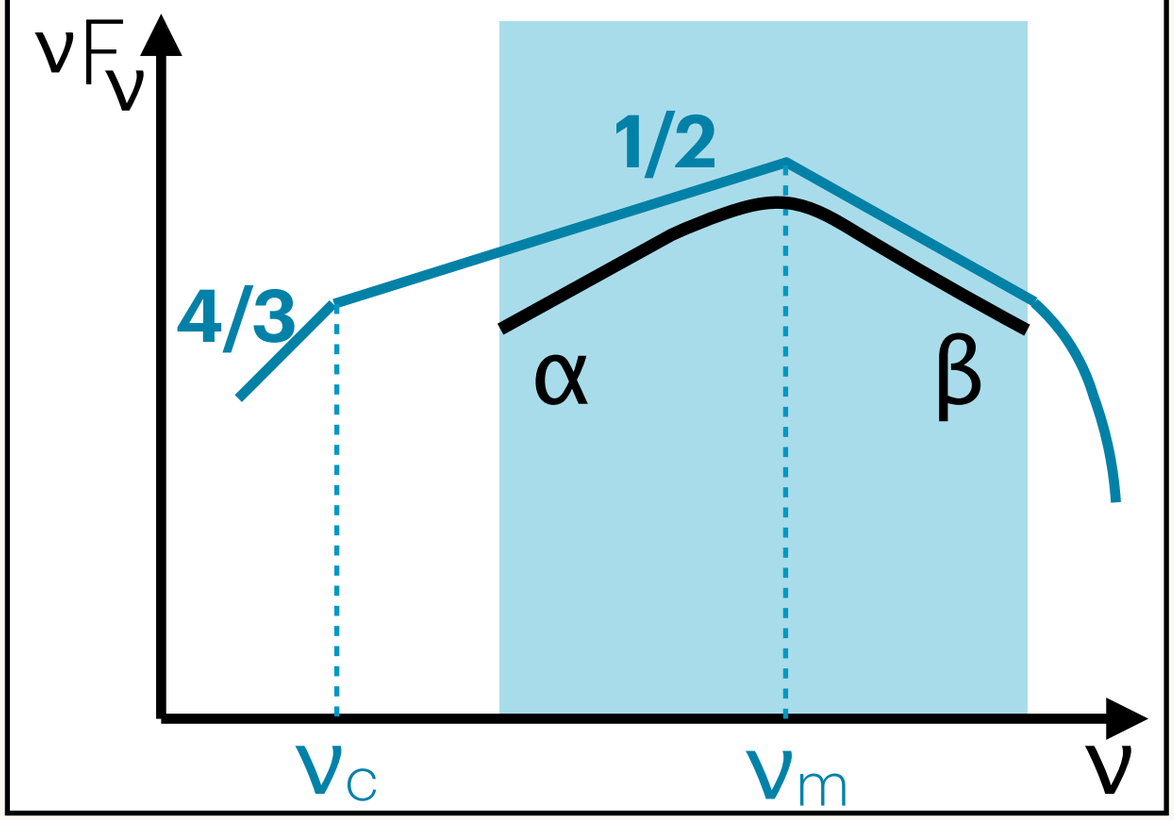
Prompt Emission: open issues

Unknown radiative mechanism

typical GRB spectrum



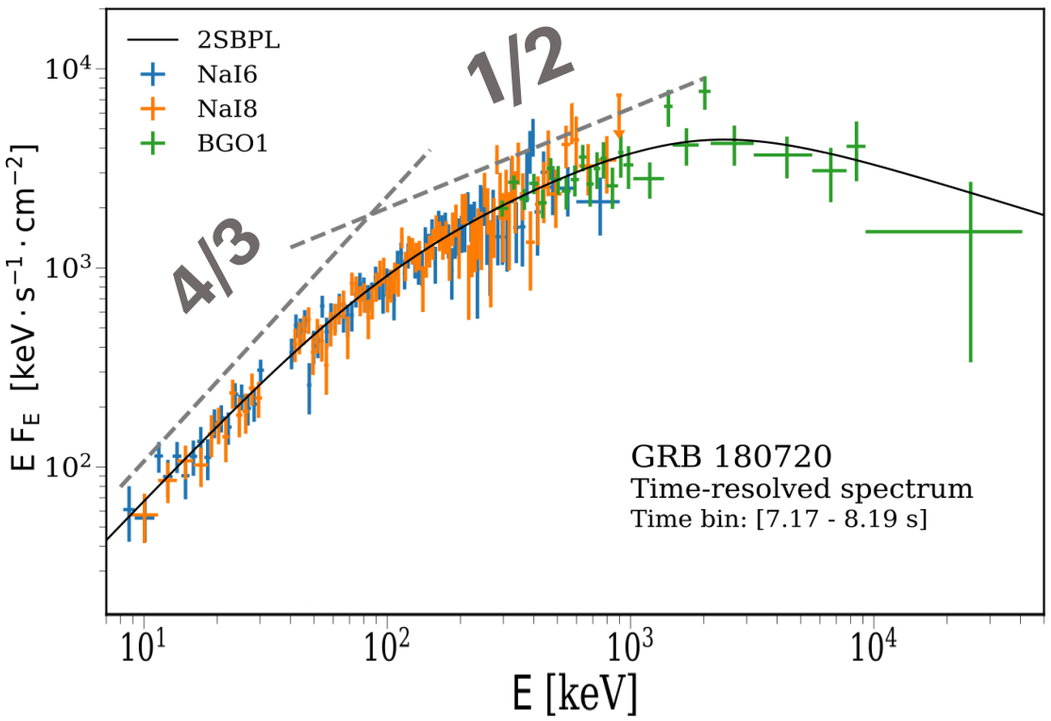
synchrotron spectrum



Prompt Emission: open issues

Recent advances

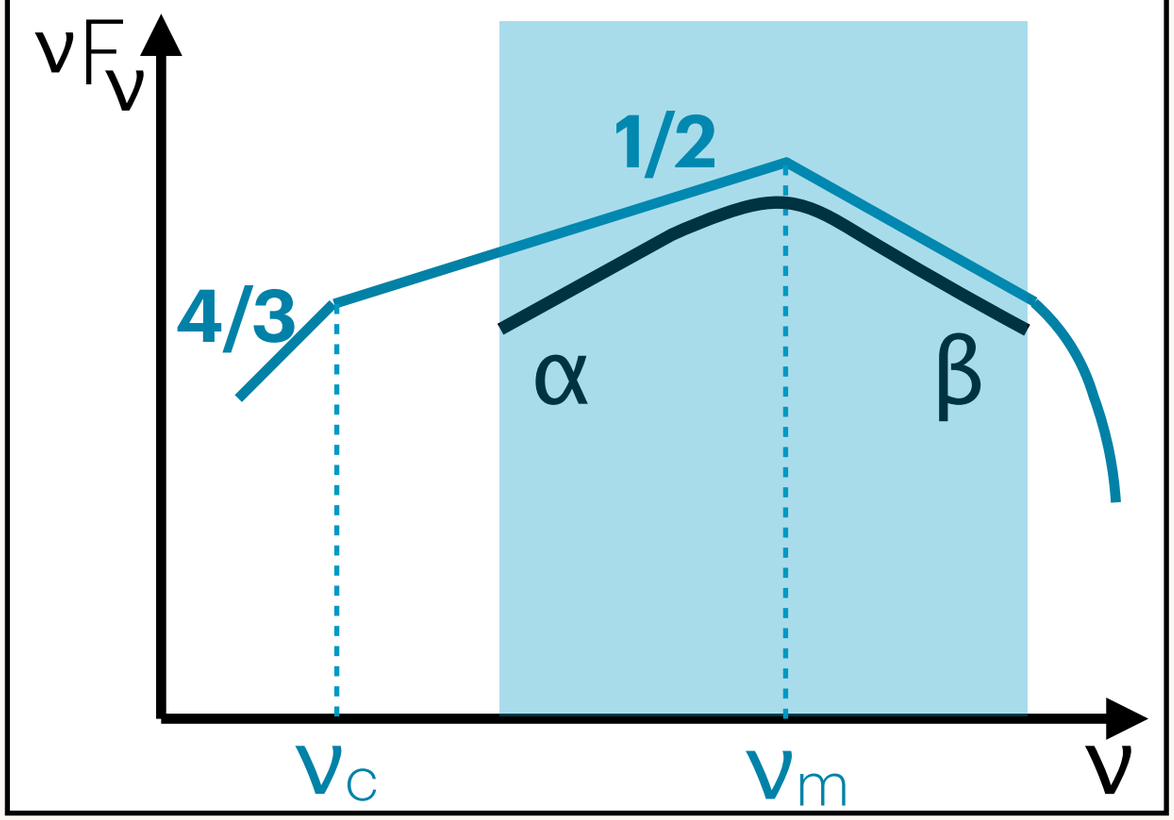
example of real GRB spectrum



Ravasio et al., 2019

Oganesyan et al., 2017, 2018, 2019

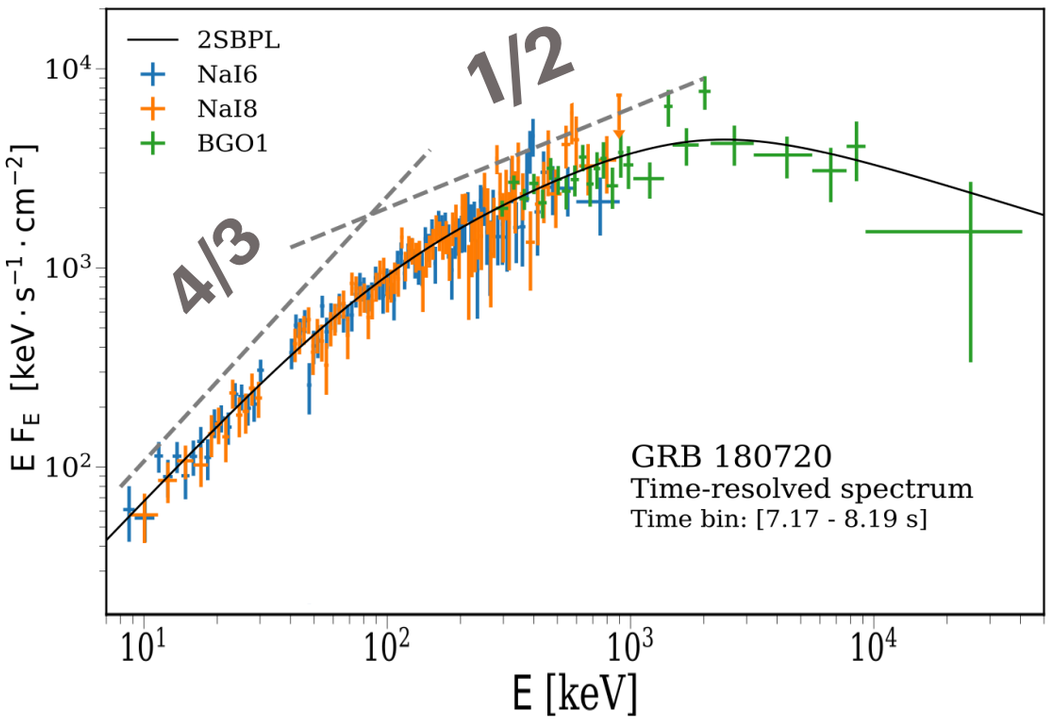
synchrotron spectrum



Prompt Emission: open issues

Recent advances

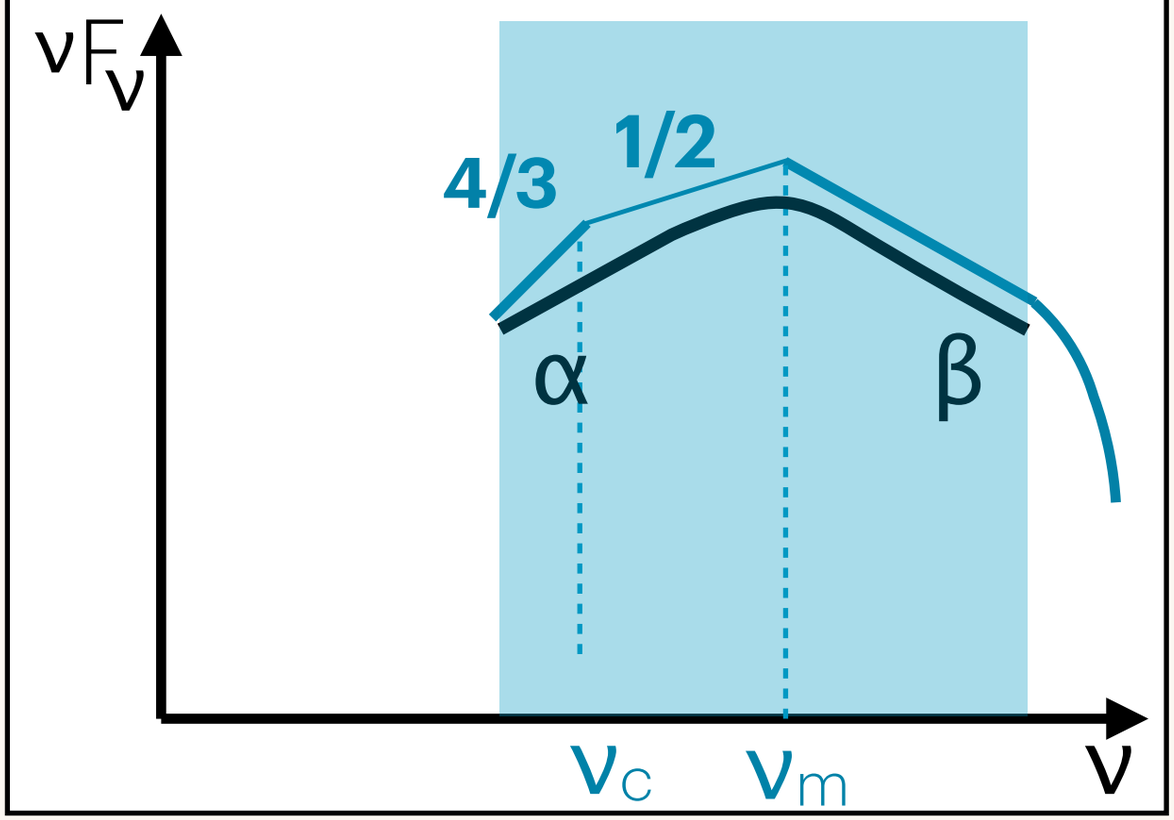
example of real GRB spectrum



Ravasio et al., 2019

Oganesyan et al., 2017, 2018, 2019

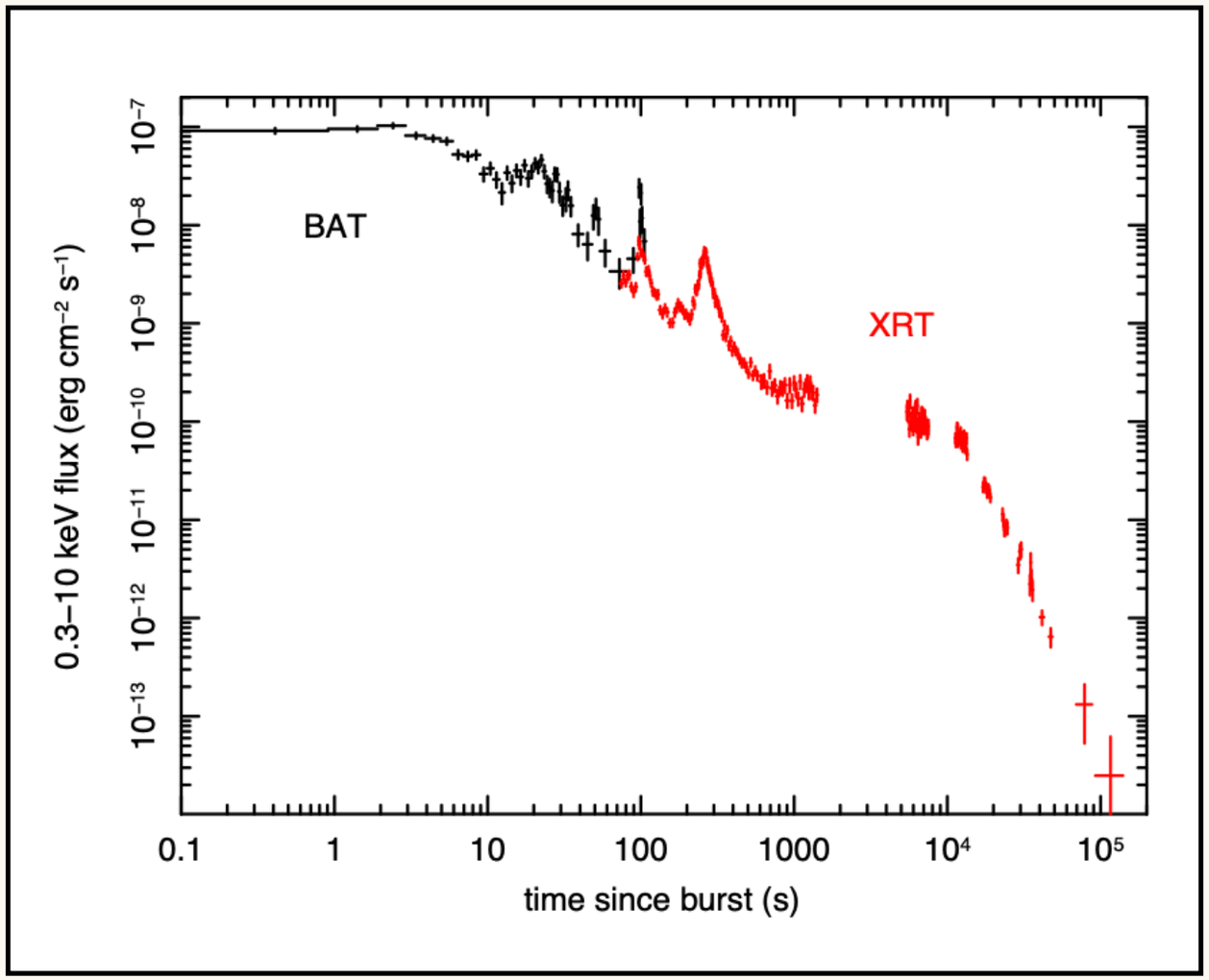
synchrotron spectrum



Afterglow Emission: open issues

Interpreted as synchrotron radiation from forward shock

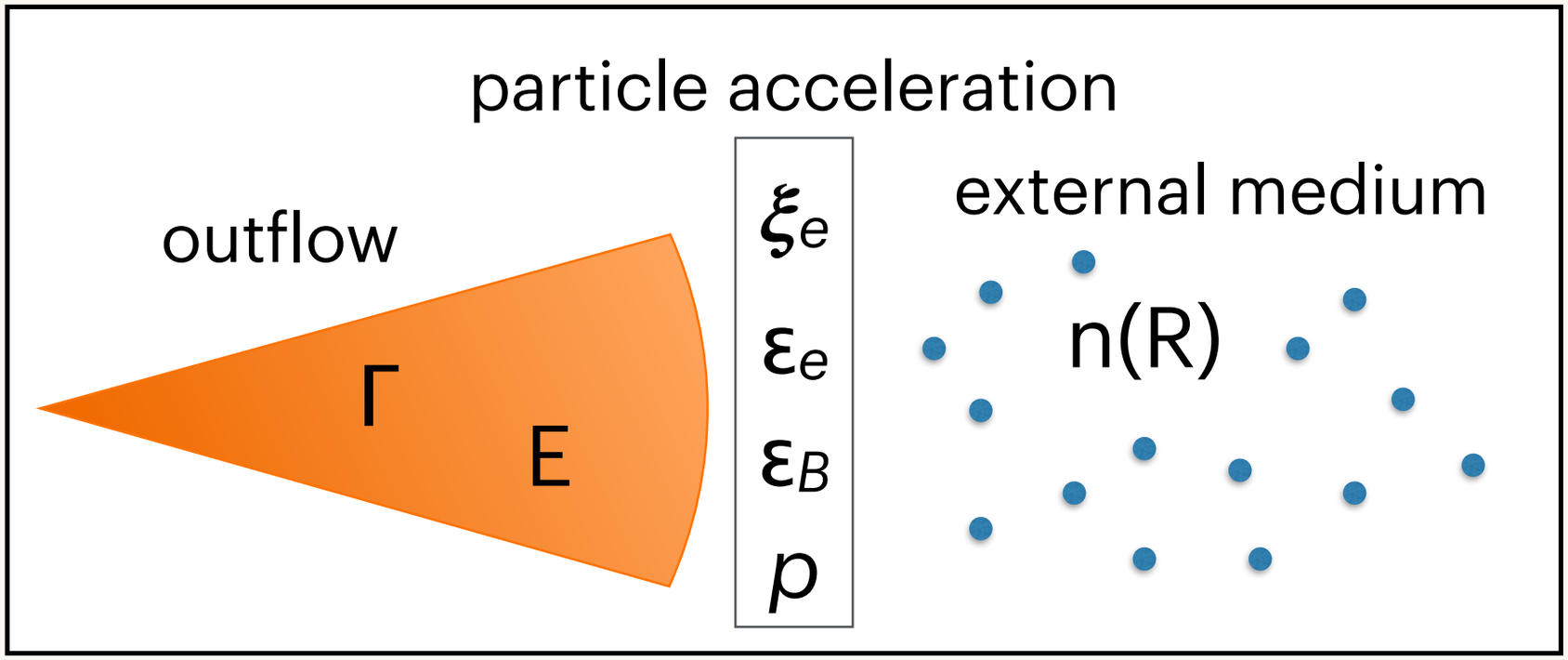
flares/plateaus still miss an interpretation



Afterglow Emission: open issues

Interpreted as synchrotron radiation from forward shock

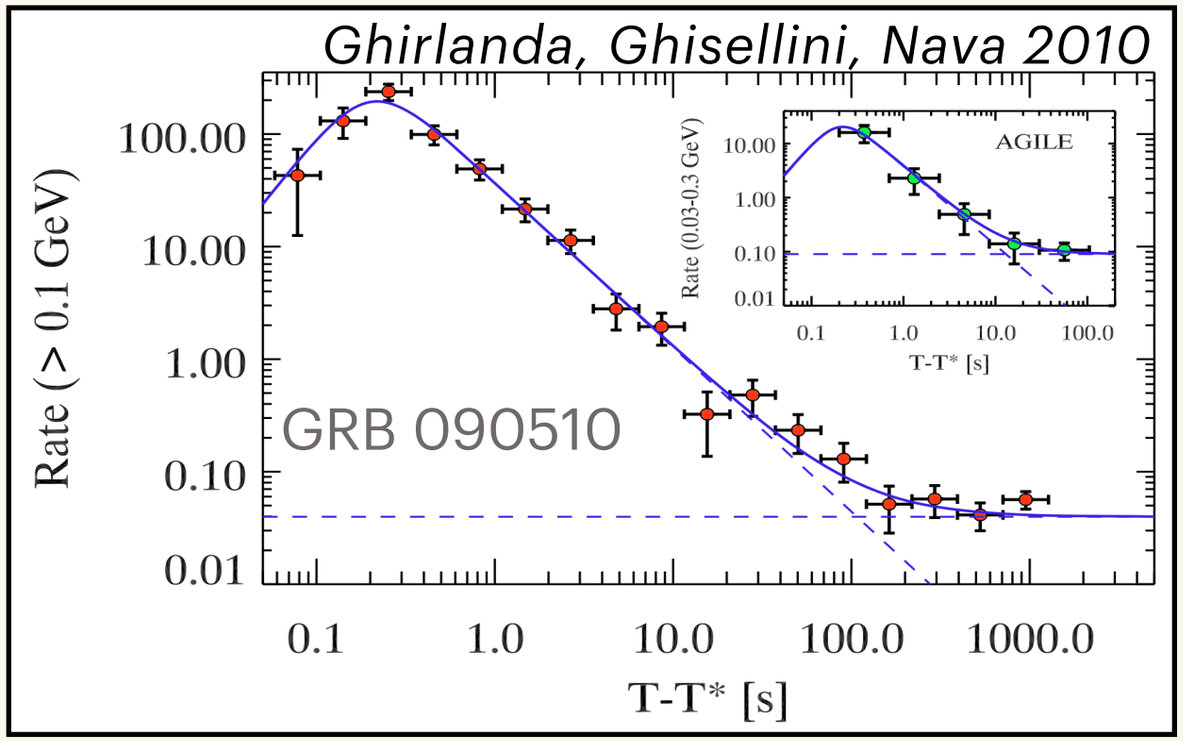
lack of constraints on the parameters of the forward shock

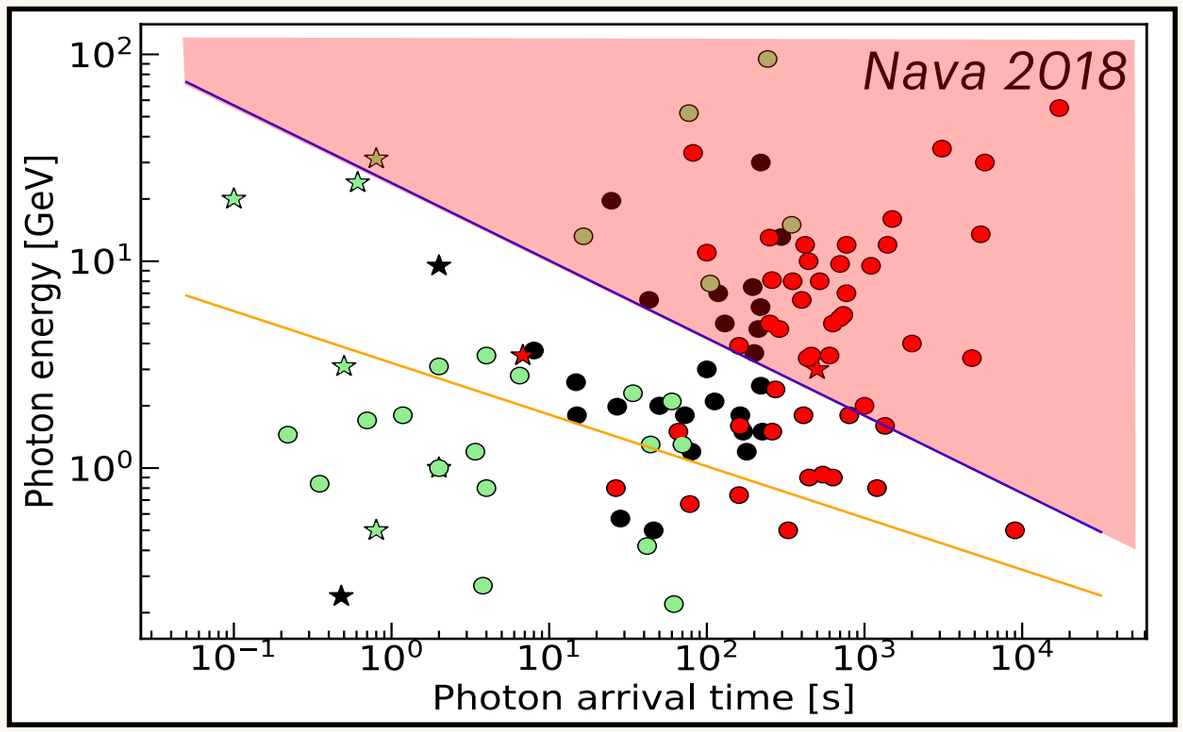


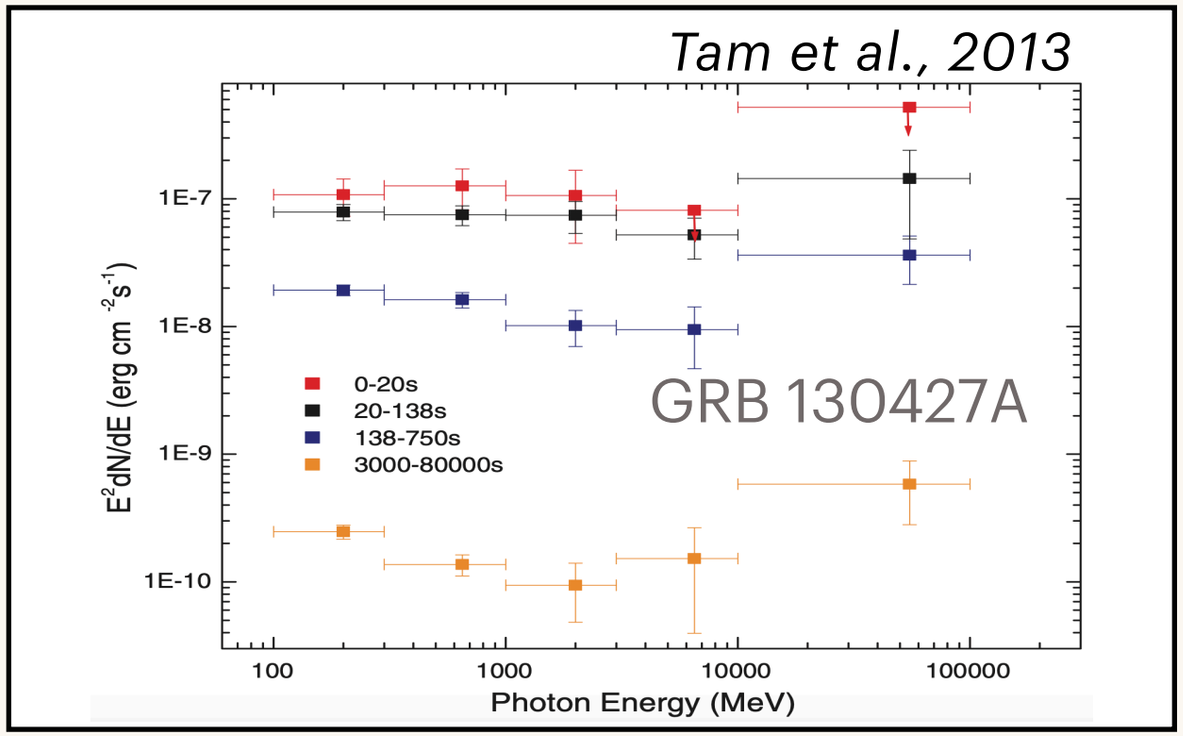
High-Energy Emission: open issues

Afterglow emission

- Consistent with synchrotron afterglow radiation
- Extra-component in spectra??
  (no clear evidence)
- Photons with *E>Emax,syn*



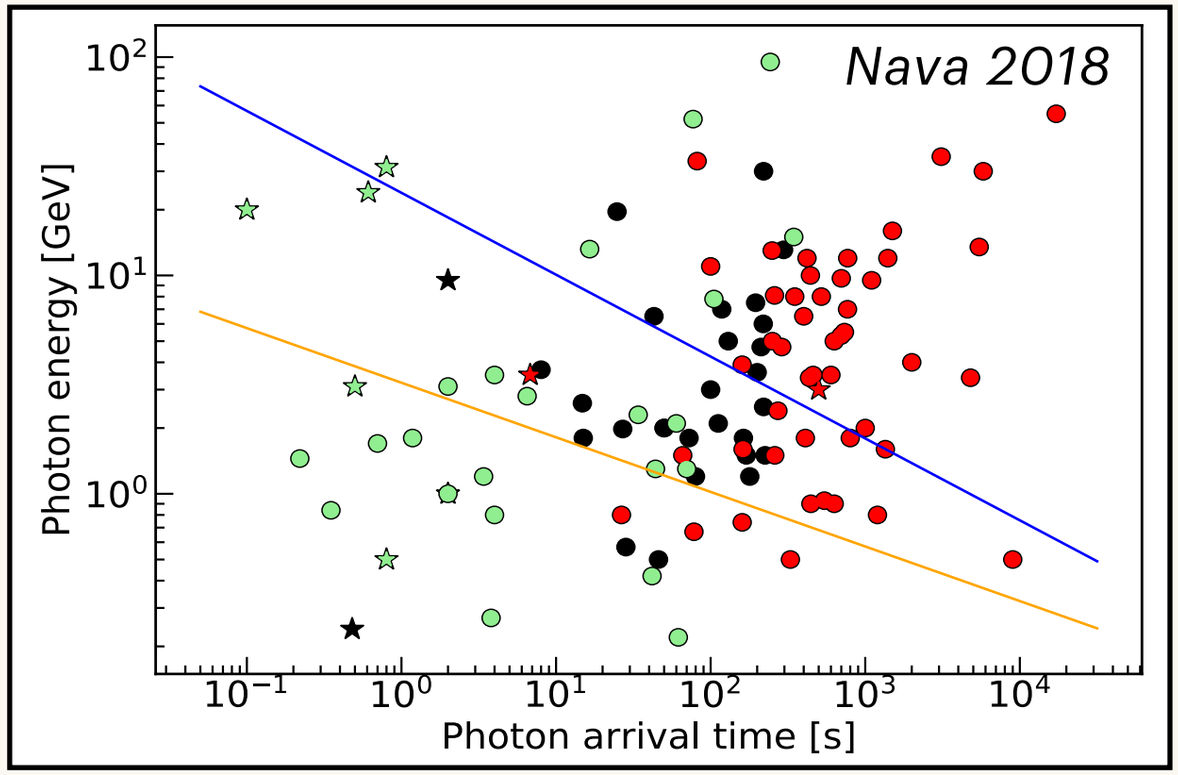


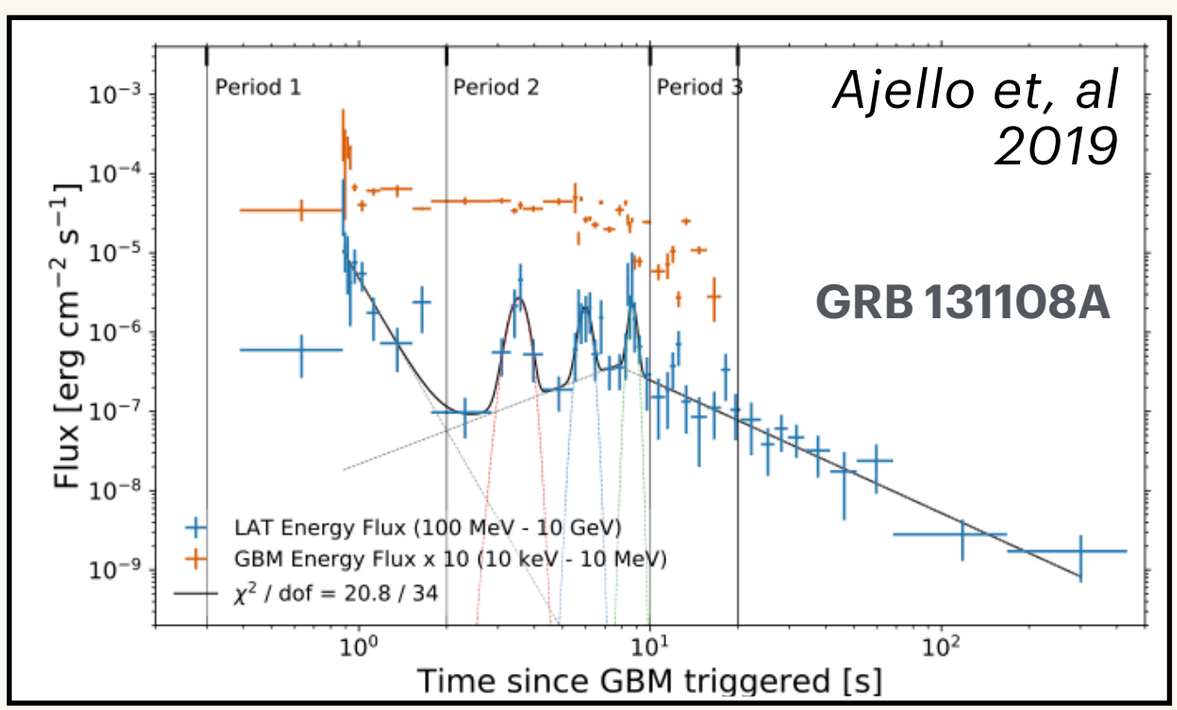


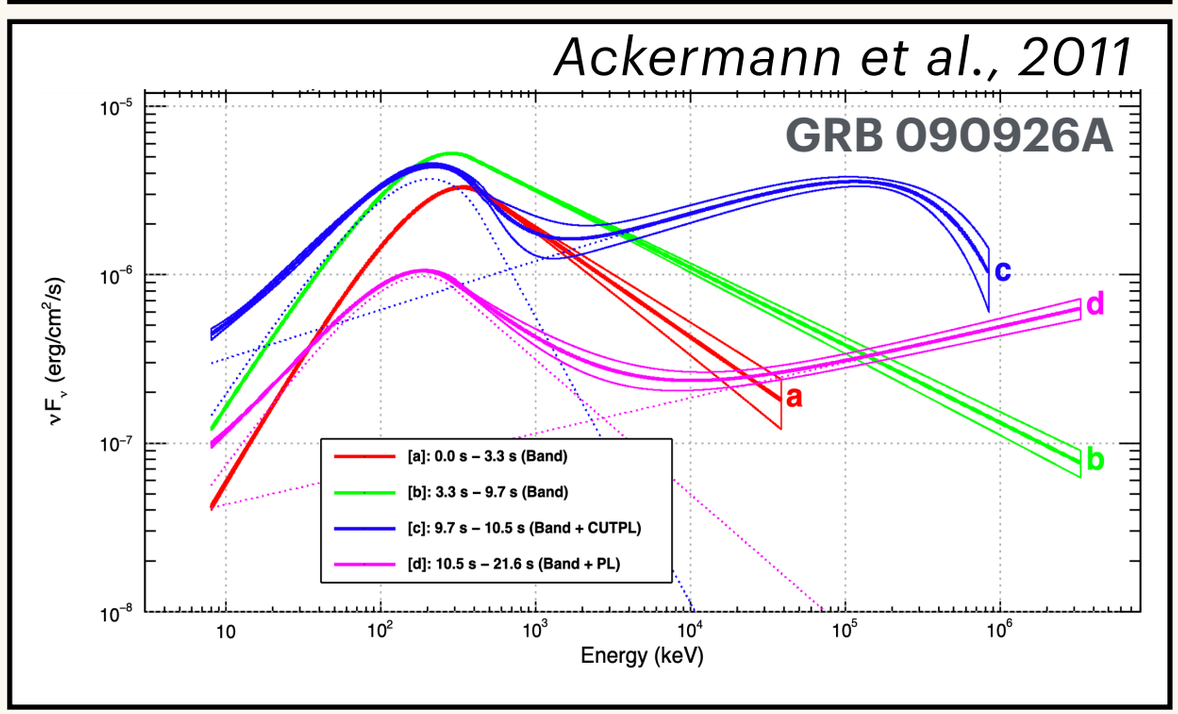
High-Energy Emission: open issues

Prompt emission

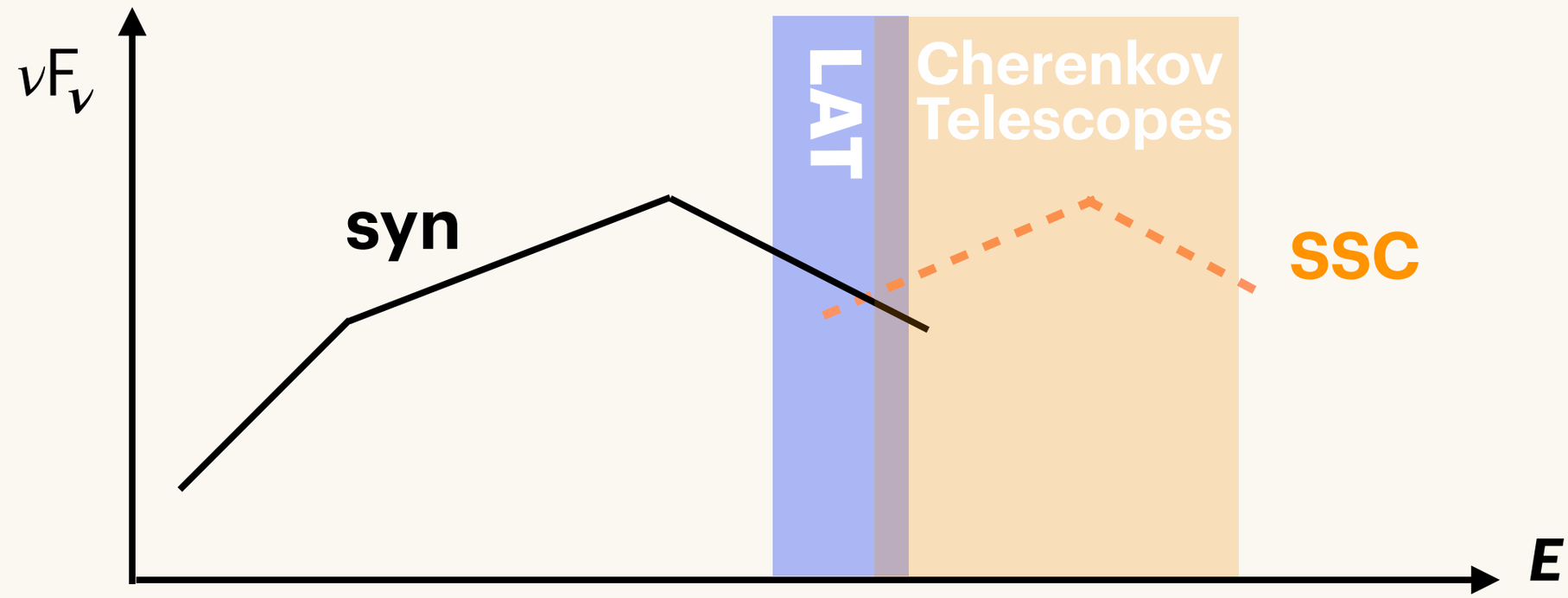
- photons > 1 GeV have been detected during the prompt (green symbols)
- extra-component in spectra?? (no clear evidence)
- evidence for GeV / multi-GeV variability?







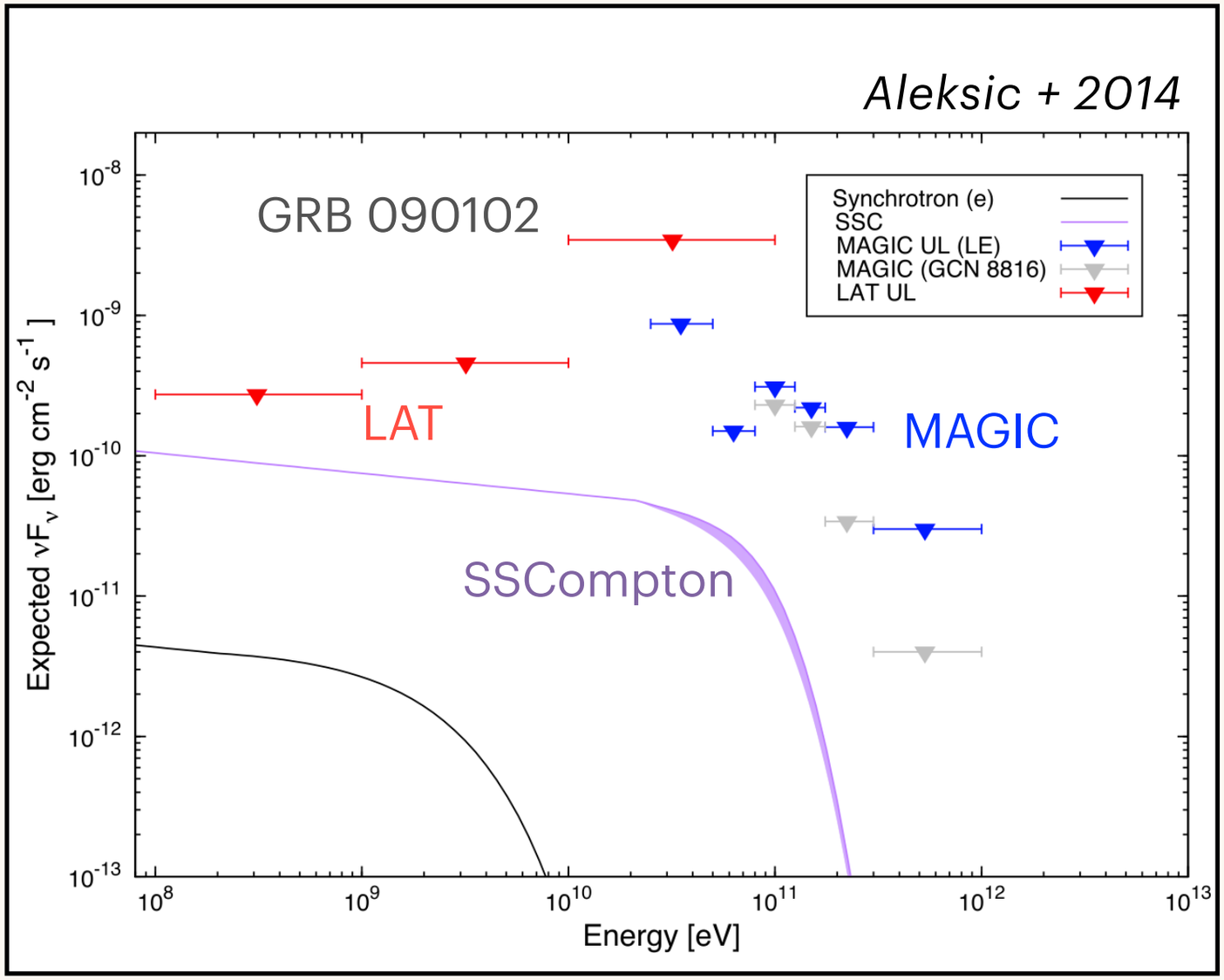
Evidence for High-Energy additional spectral components from GeV observations



TeV Observations: Cherenkov Telescopes

Current generation on IACTs

- MAGIC / HESS / VERITAS
  - number of observed GRBs:
    - hundreds
  - low energy threshold:
    - 50 / 50 / 100 GeV
  - time delay:
    - < 100 s / 100-1000 s

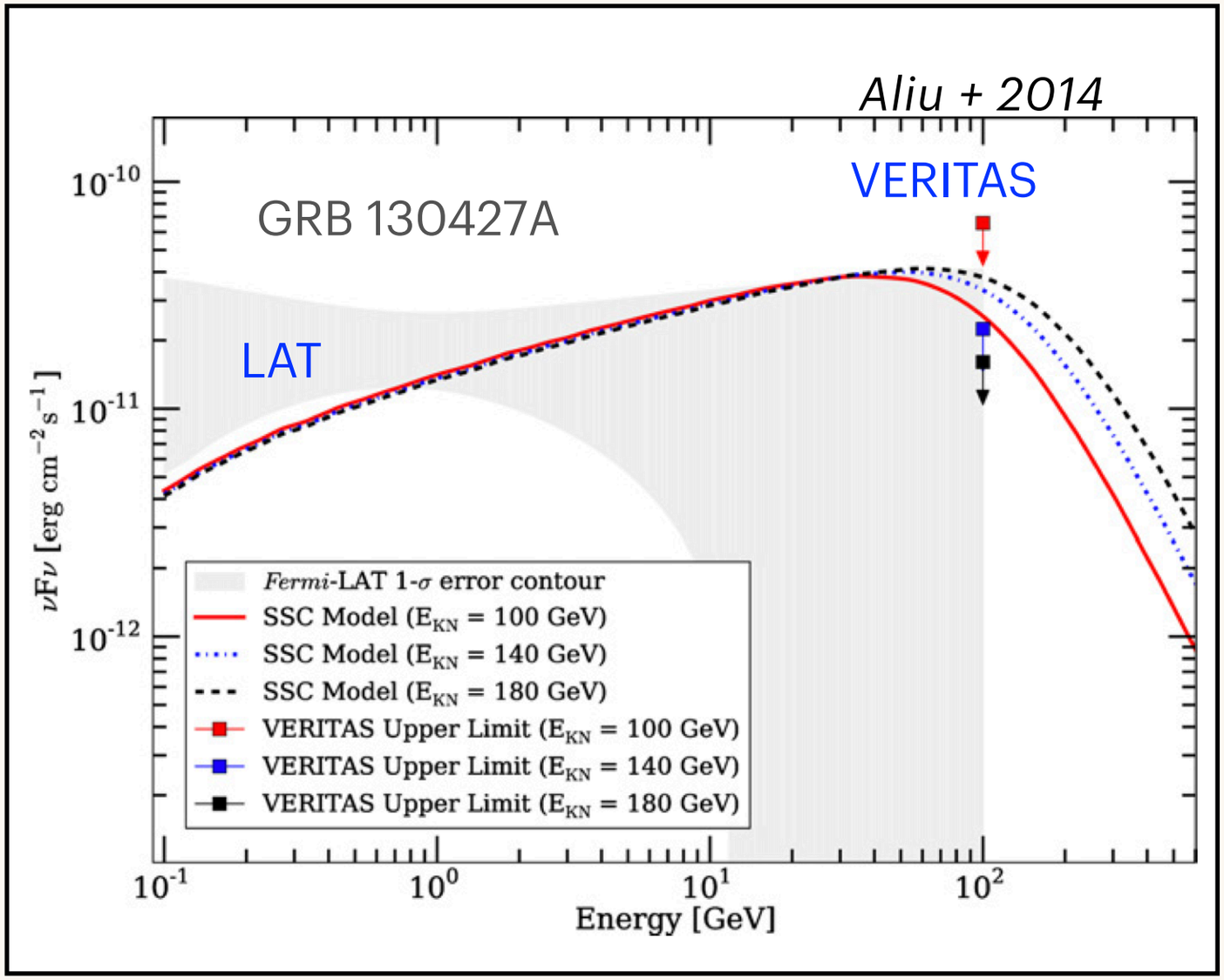


— until 2019: no detections, only upper limits —

TeV Observations: Cherenkov Telescopes

Current generation on IACTs

- MAGIC / HESS / VERITAS
  - number of observed GRBs:
    - hundreds
  - low energy threshold:
    - 50 / 50 / 100 GeV
  - time delay:
    - < 100 s / 100-1000 s



— until 2019: no detections, only upper limits —

Discovery of TeV emission from Gamma-Ray Bursts

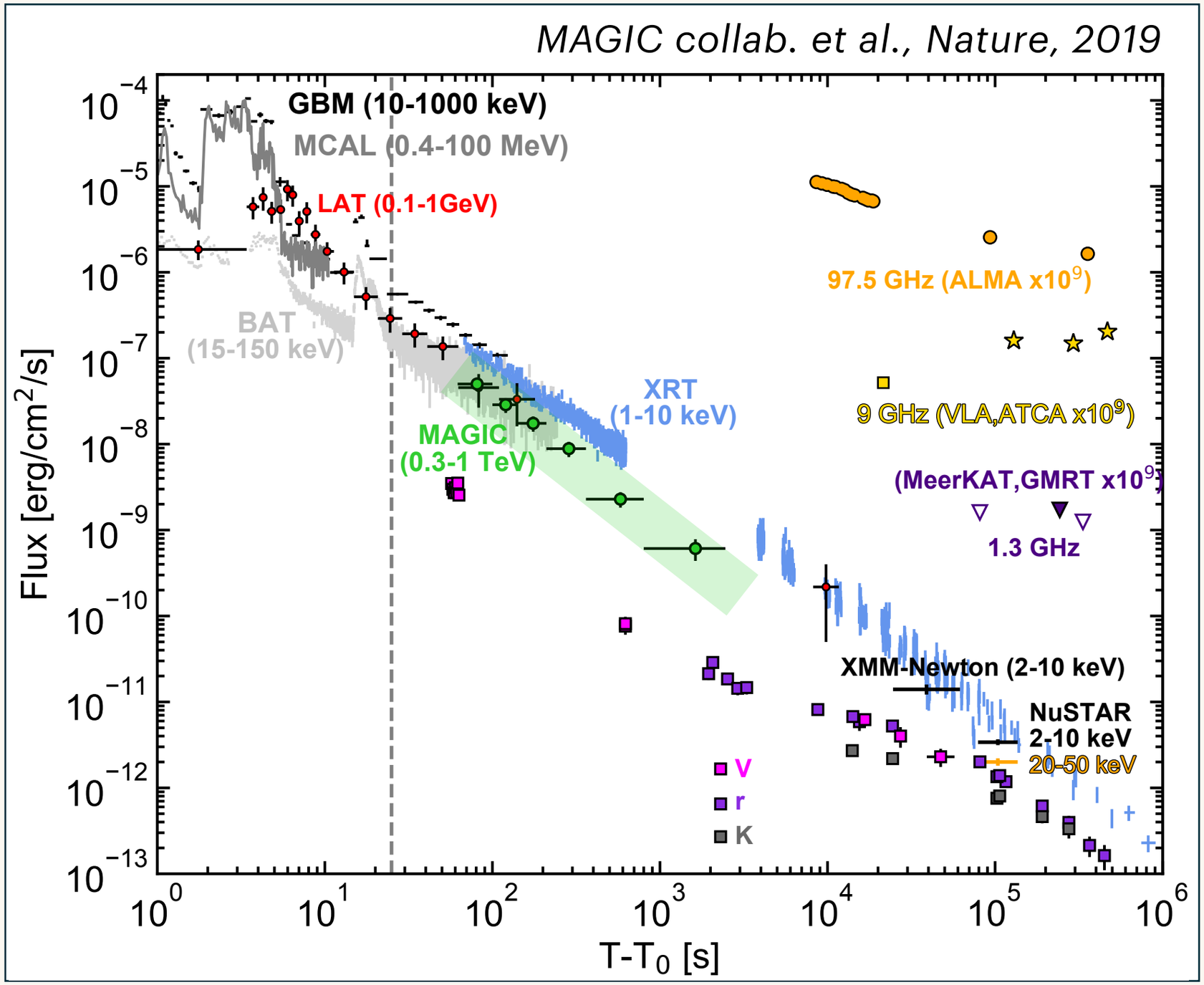
LARA NAVA - INAF

MAGIC Detection of GRB 190114C

- Long GRB
- E_{prompt} = 2.5x10^{53}erg
- z = 0.42

MAGIC detection

- 1-40 minutes after the GRB
- in the energy range 0.3-1 TeV

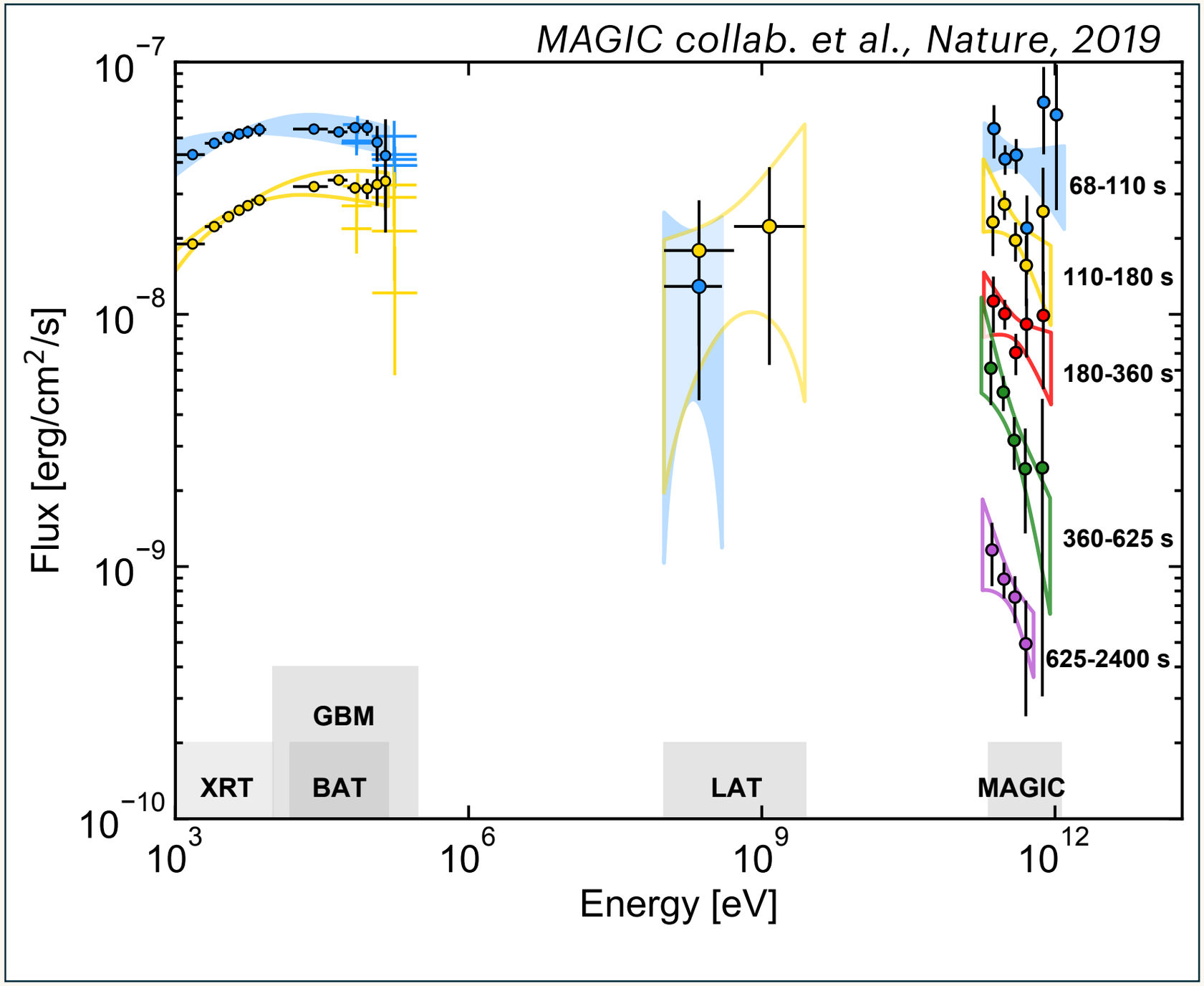


MAGIC Detection of GRB 190114C

- Long GRB
- E_{prompt} = 2.5x10^{53}erg
- z = 0.42

MAGIC detection

- 1-40 minutes after the GRB
- in the energy range 0.3-1 TeV



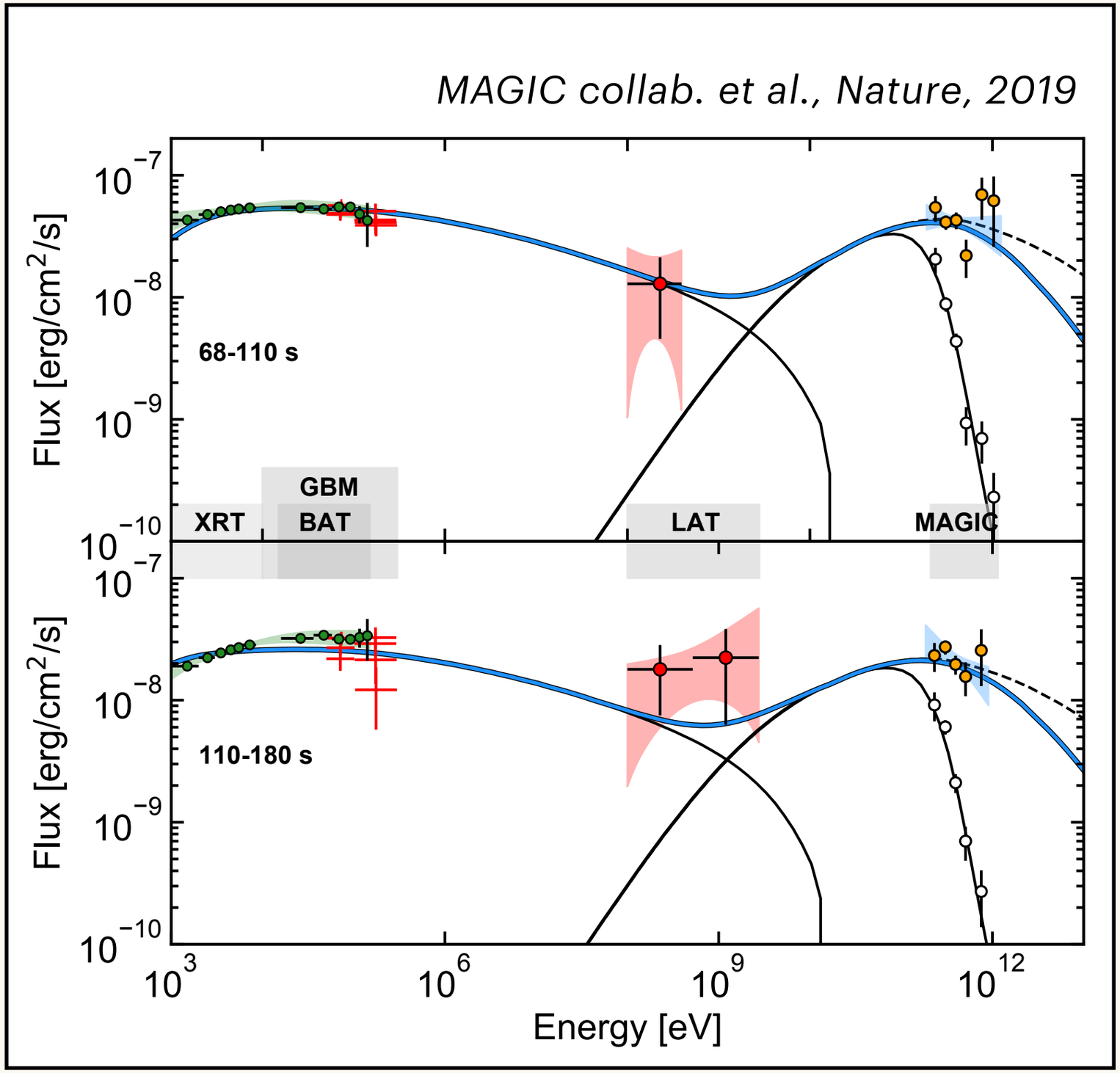
MAGIC Detection of GRB 190114C

SED modeling

- Long GRB
- E_{prompt} = 2.5x10^{53}erg
- z = 0.42

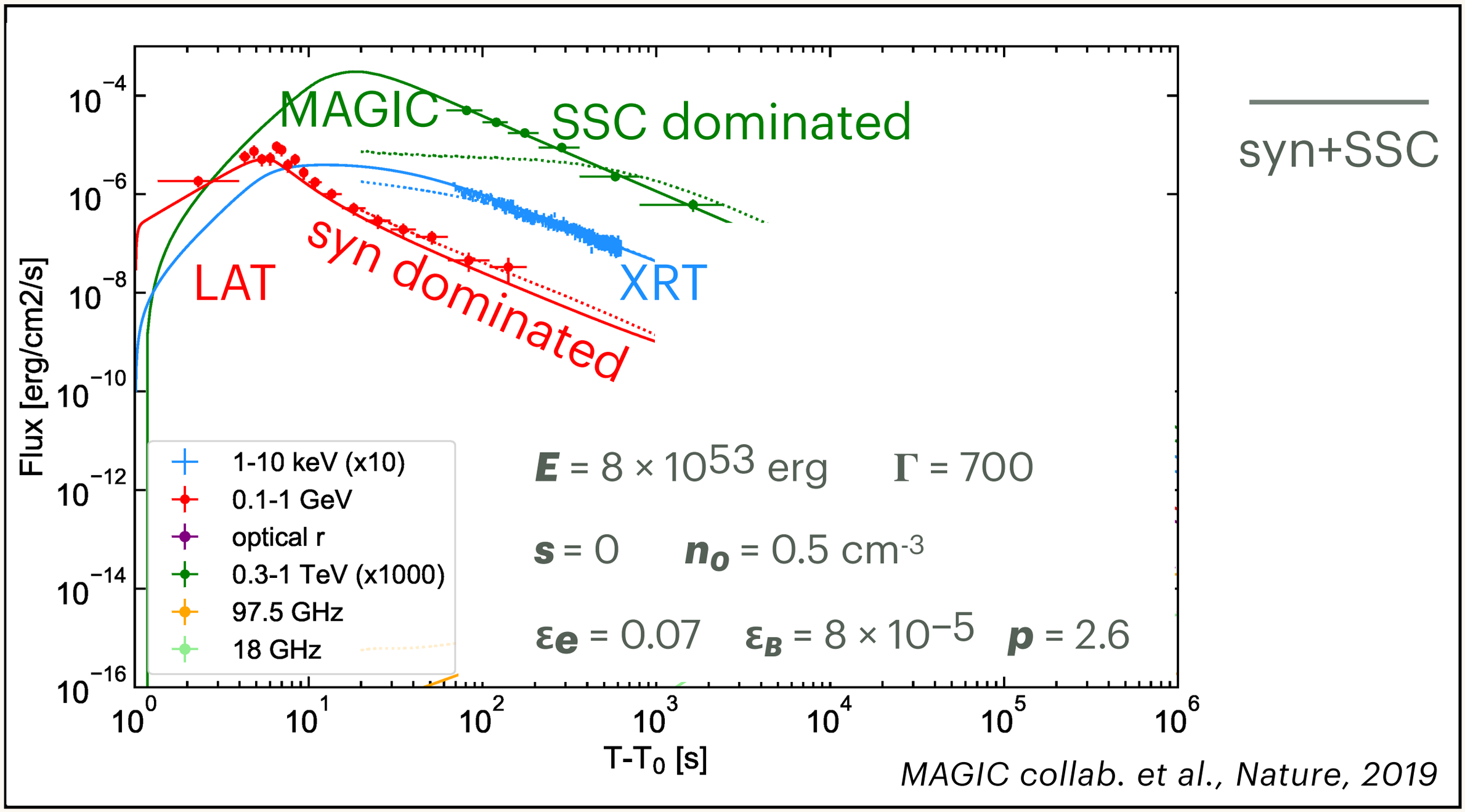
MAGIC detection

- 1-40 minutes after the GRB
- in the energy range 0.3-1 TeV



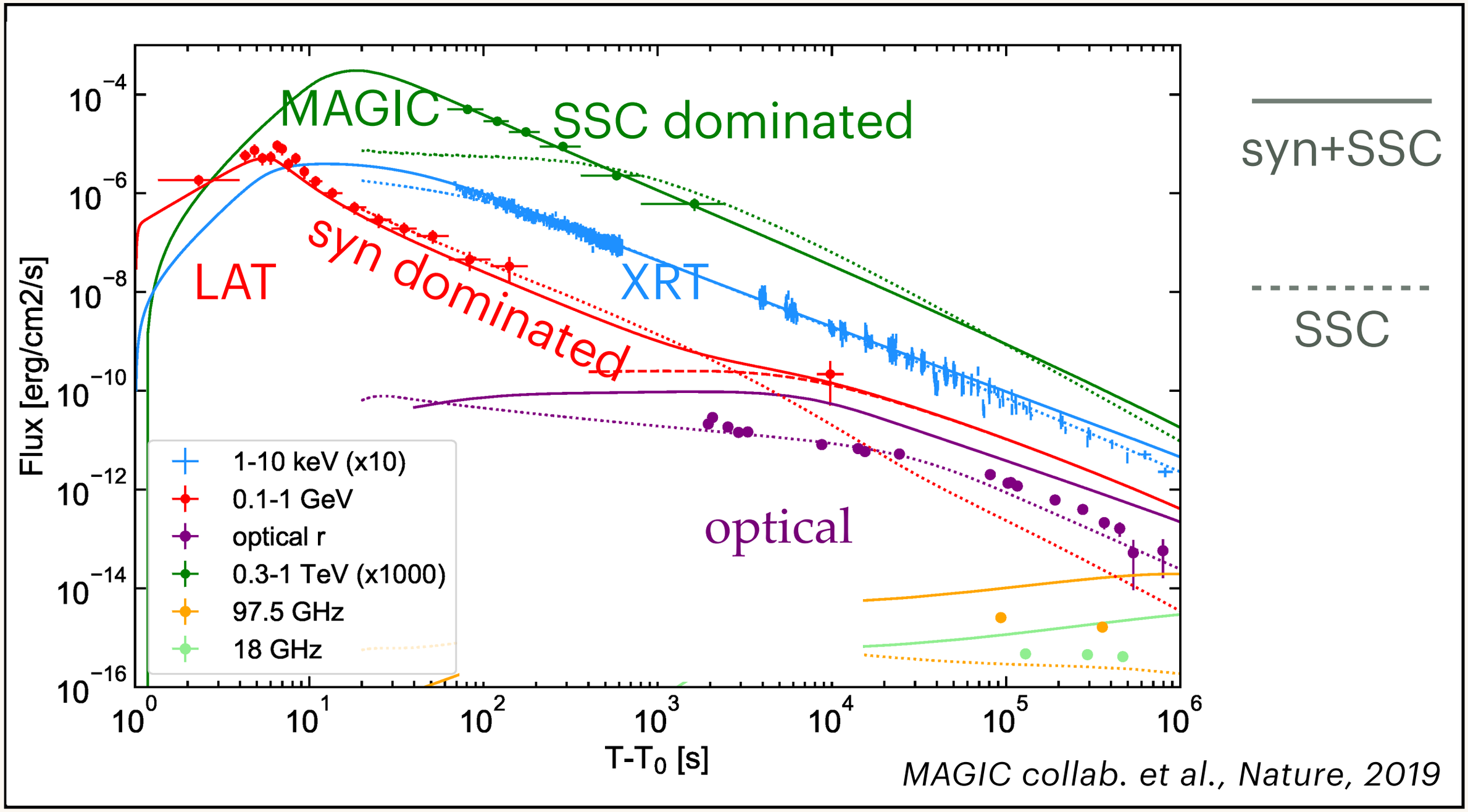
MAGIC Detection of GRB 190114C

Light curve modeling



MAGIC Detection of GRB 190114C

Light curve modeling



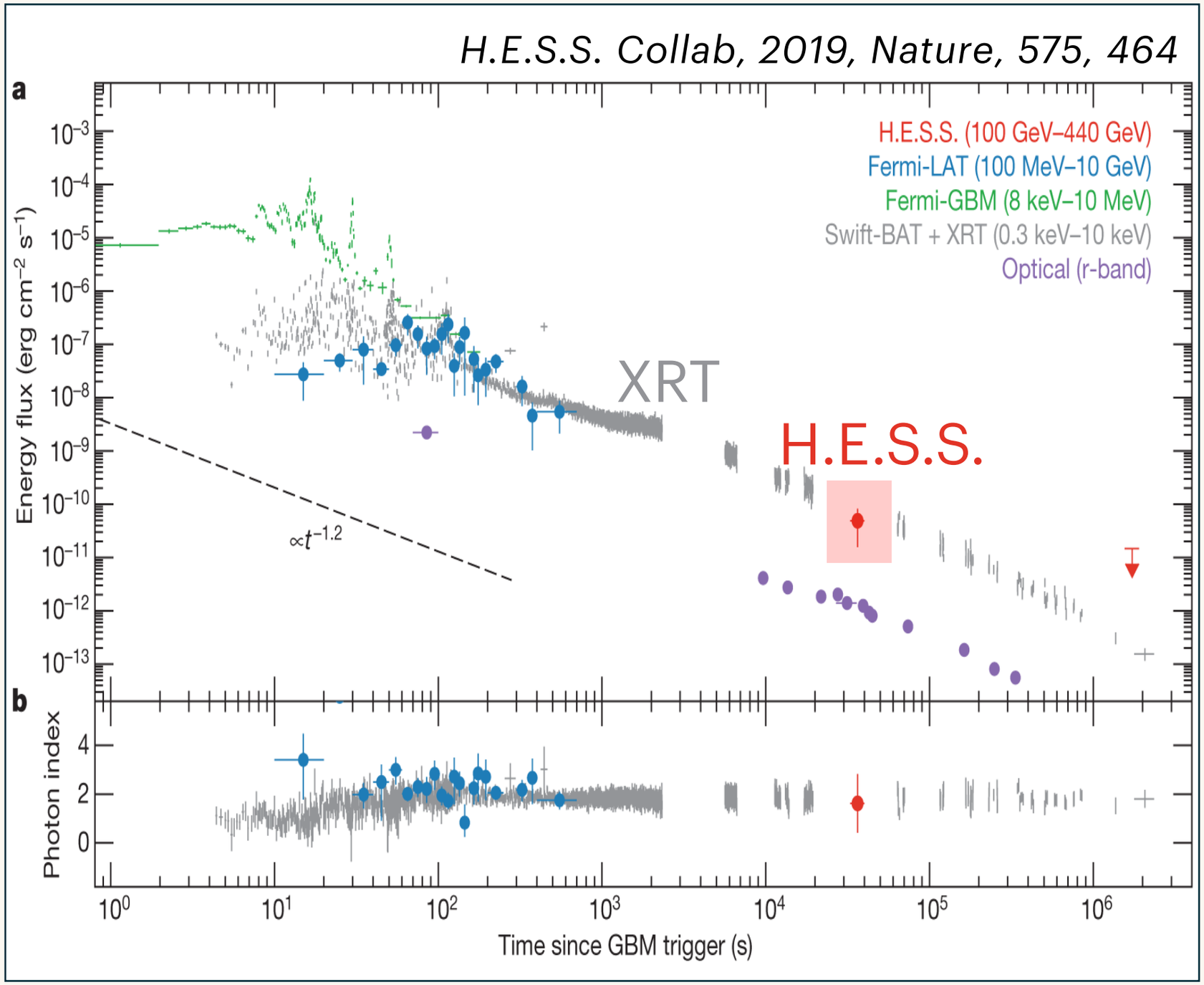
H.E.S.S. Detection of GRB 180720B

- Long GRB
- z = 0.65
- E_{prompt} = 6 x 10^{53}erg

H.E.S.S. detection

- ~10 hours after the GRB
- in the energy range 0.1-0.44 TeV

H.E.S.S. Collab, 2019, Nature, 575, 464



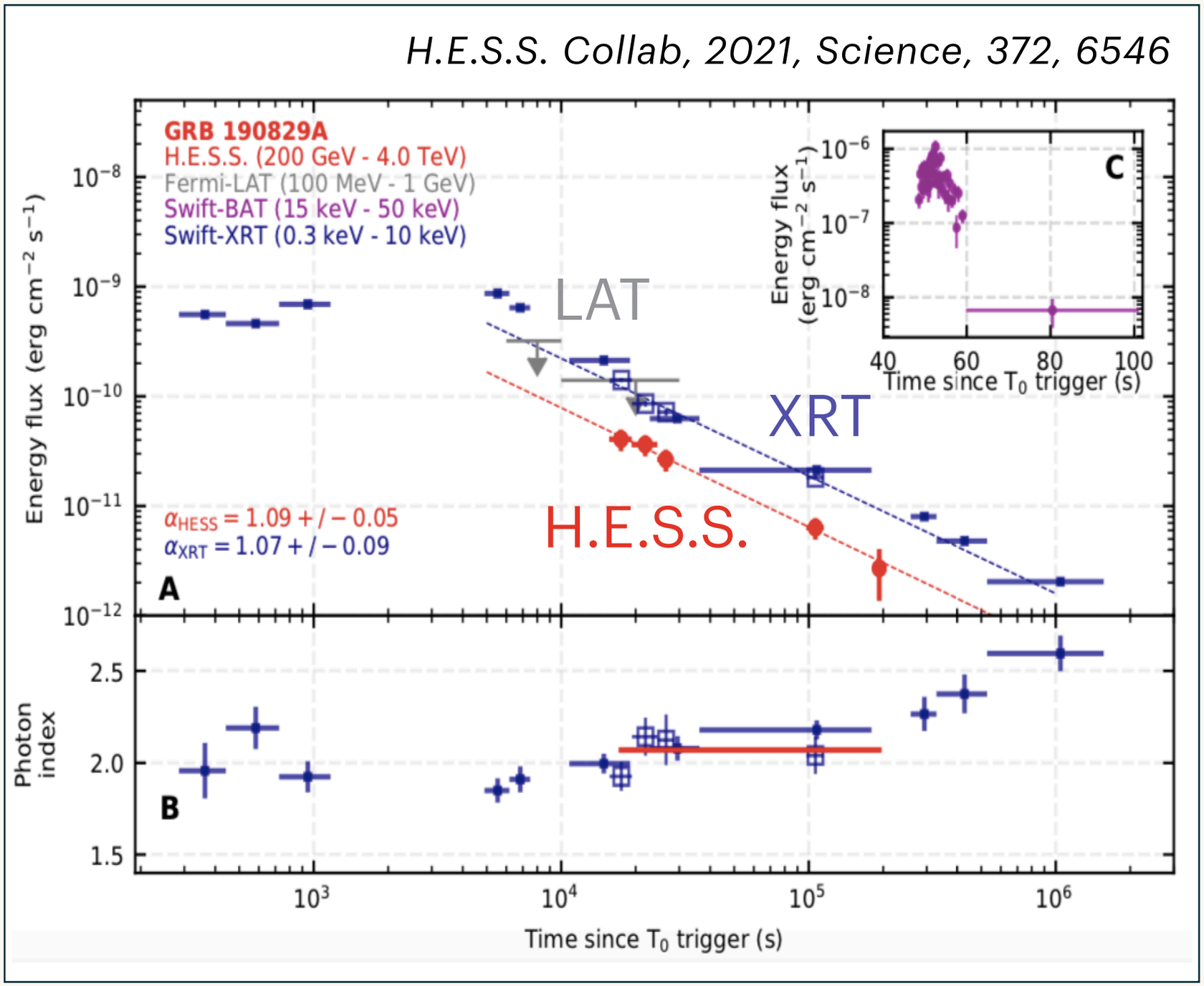
H.E.S.S. Detection of GRB 190829A

- Long GRB
- z = 0.078
- E_{prompt} = 2 x 10^{50}erg

H.E.S.S. detection

- 3 nights, from 4.3 to 55.9 hrs
- in the energy range 0.18-3.3 TeV

H.E.S.S. Collab, 2021, Science, 372, 6546



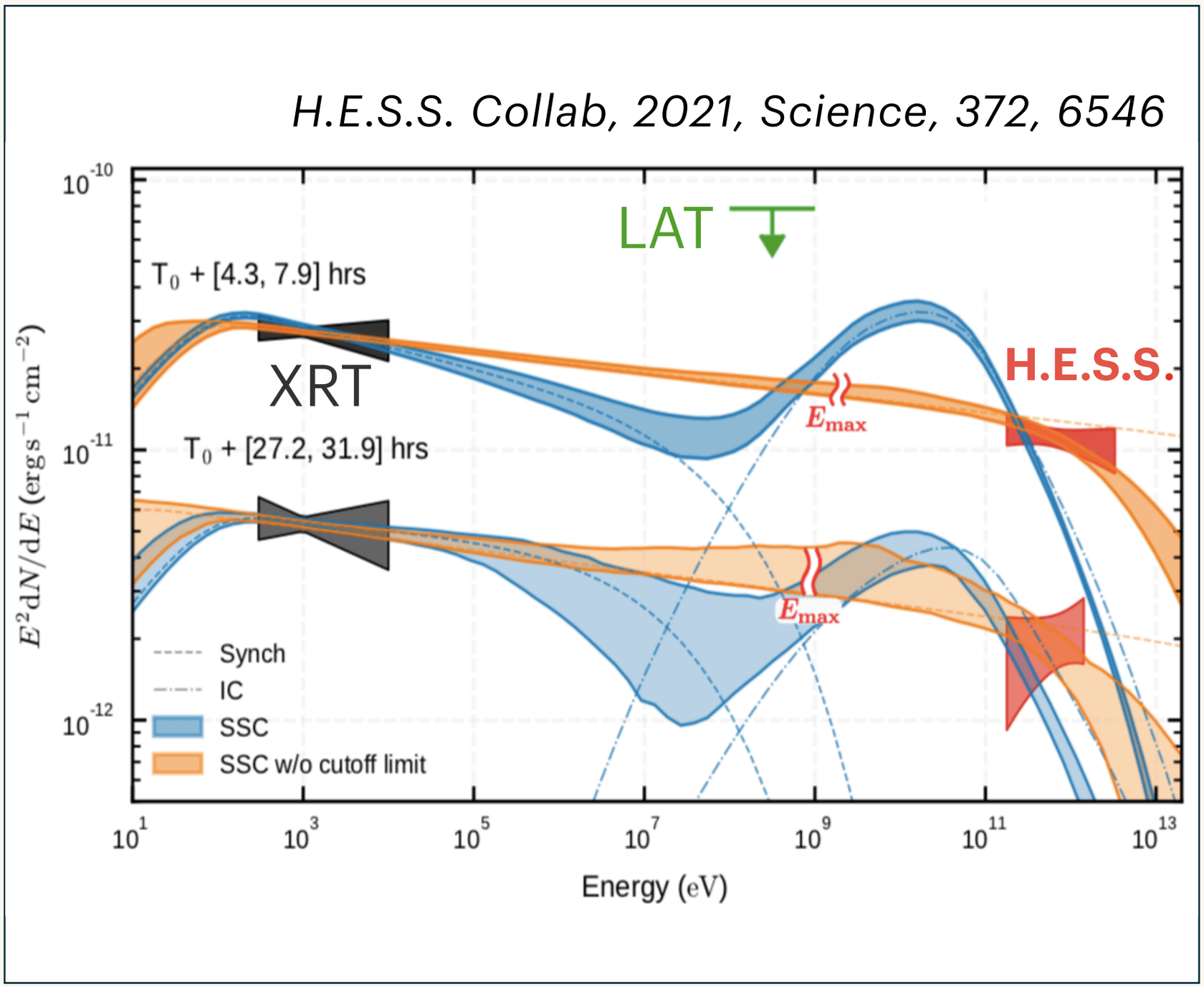
H.E.S.S. Detection of GRB 190829A

- Long GRB
- z = 0.078
- E_{prompt} = 2 x 10^{50}erg

H.E.S.S. detection

- 3 nights, from 4.3 to 55.9 hrs
- in the energy range 0.18-3.3 TeV

H.E.S.S. Collab, 2021, Science, 372, 6546



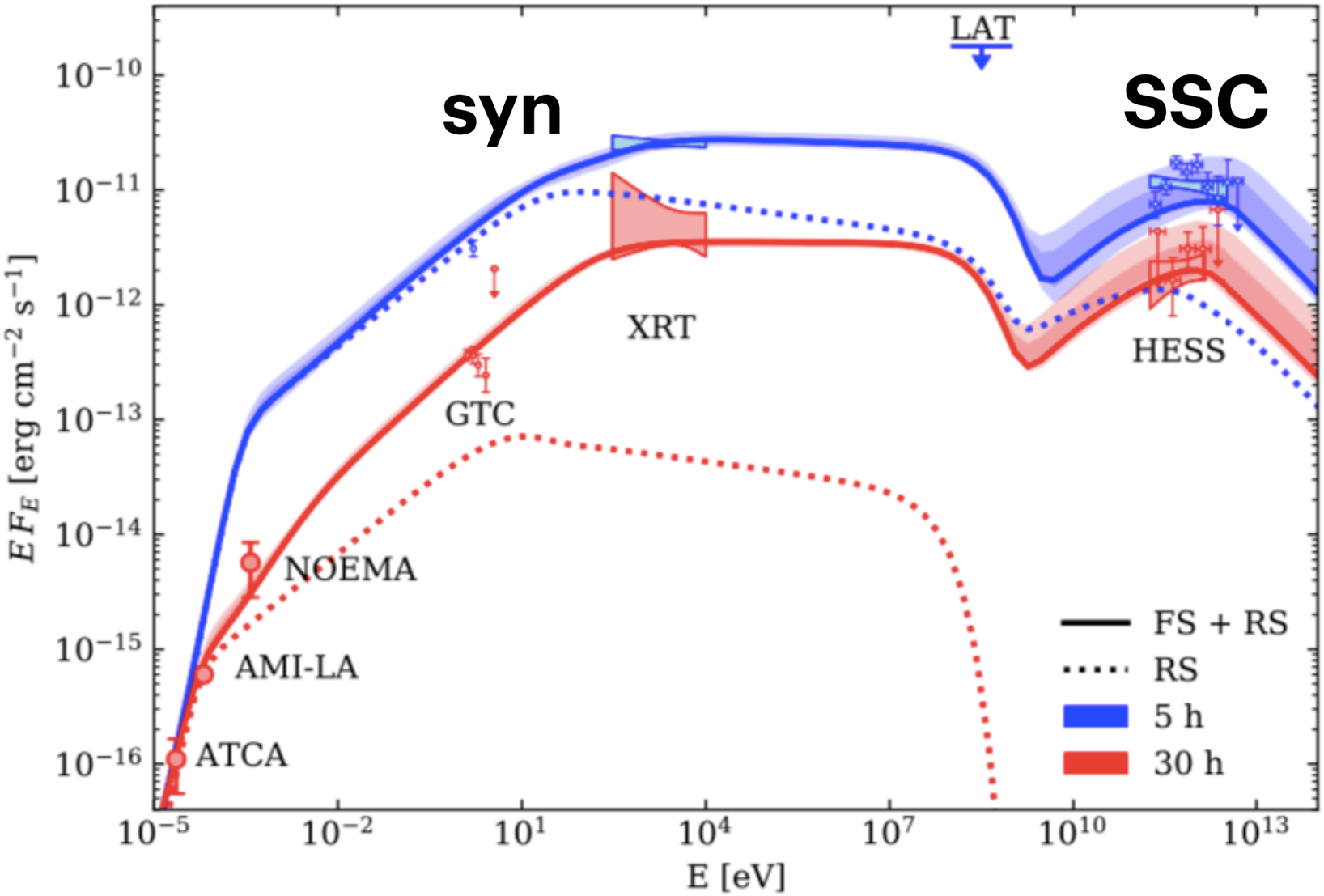
H.E.S.S. Detection of GRB 180720B

- Long GRB
- z = 0.078
- E_{prompt} = 2 x 10^{50}erg

H.E.S.S. detection

- 3 nights, from 4.3 to 55.9 hrs
- in the energy range 0.18-3.3 TeV

Salafia et al. 2021, arXiv:2106.07169, submitted to Nat. Astr.



Two Additional Detections

GRB 201015A (MAGIC)

- Long GRB
- z = 0.42
- E_{prompt} = 10^{50} erg
- obs. started ~40 s after the prompt
- Significance of detection > 3 sigma

Contribution at this ICRC:
Presenter: **Satoshi Fukami**
Observation of a relatively low luminosity long duration GRB 201015A by the MAGIC telescopes
Presenter forum 16. July - 18:00

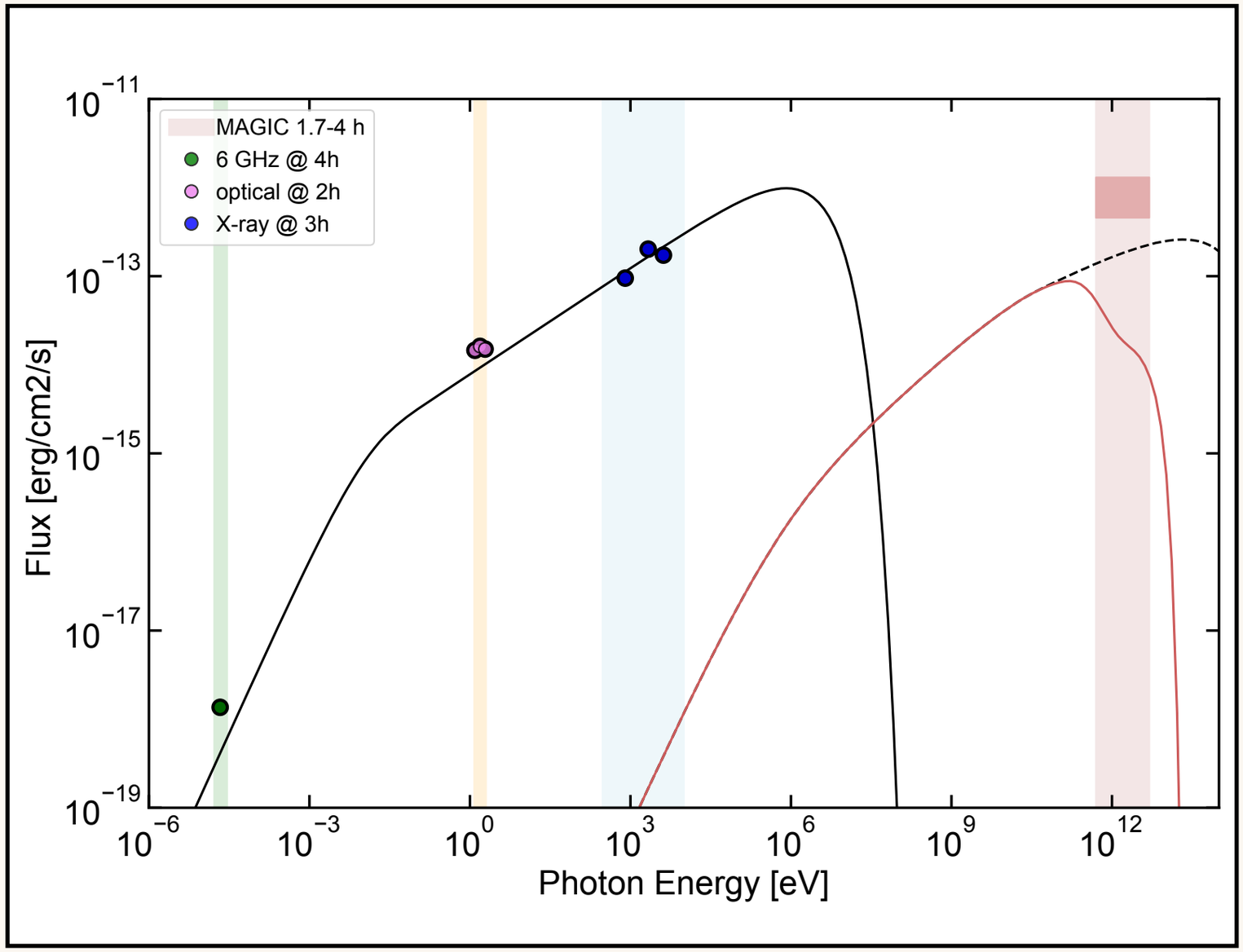
GRB 201216C (MAGIC)

- Long GRB
- z = 1.1
- E_{prompt} = 5 x 10^{53} erg
- 57 seconds after the prompt
- Significance of detection > 5 sigma

Contribution at this ICRC:
Presenter: **Yusuke Suda**
Very-high-energy gamma-ray emission from GRB 201216C detected by MAGIC
Discussion session on 21. July - 12:00

Short GRB 160821B

- z = 0.16
- Kilonova emission
- MAGIC: excess ~3 sigma



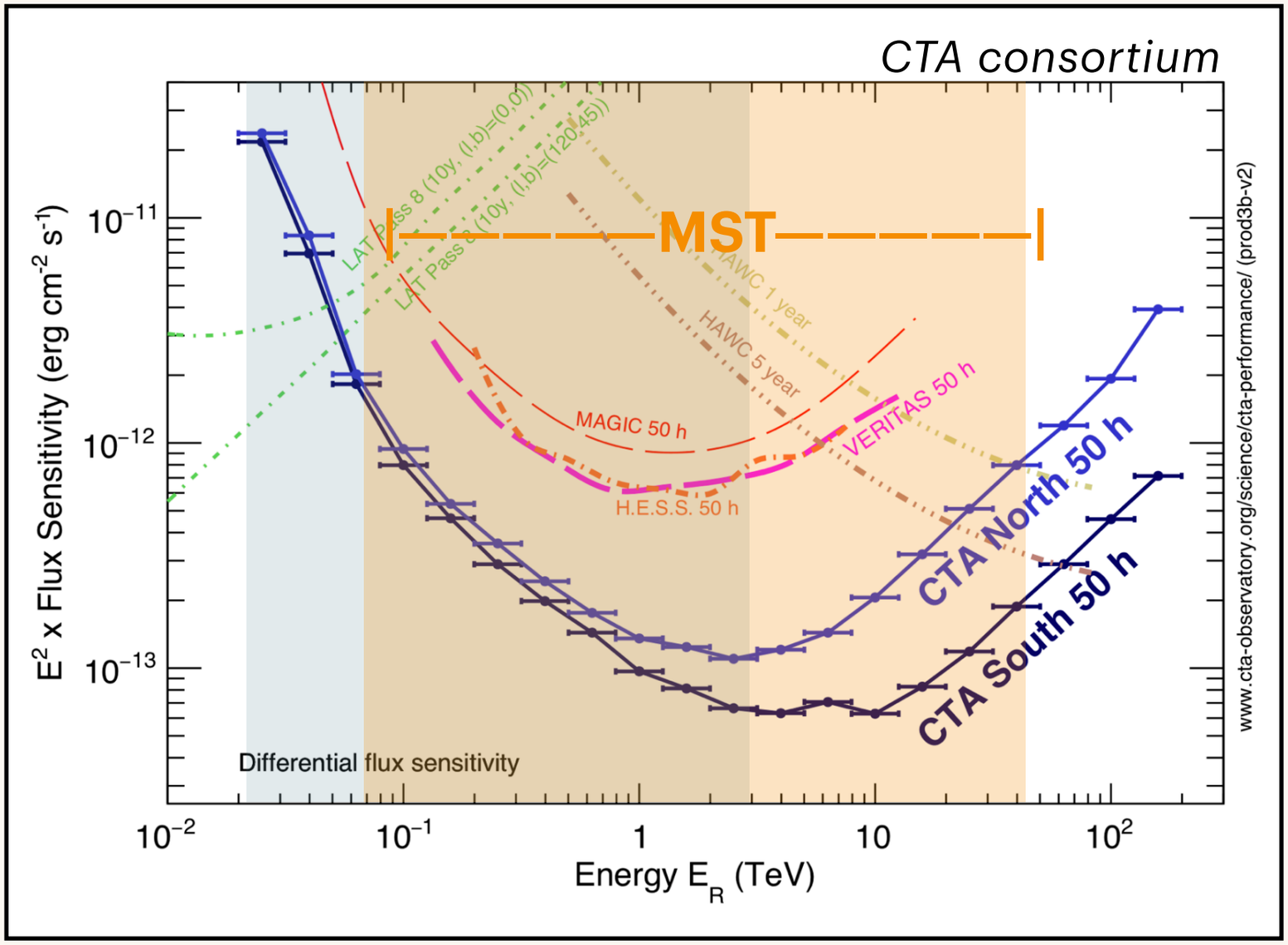
MAGIC Collab., ApJ, 2021

CTA - Cherenkov Telescope Array

LST: 20GeV - 3 TeV

MST: 80 GeV - 50 TeV

SST: 1 TeV - 300 TeV



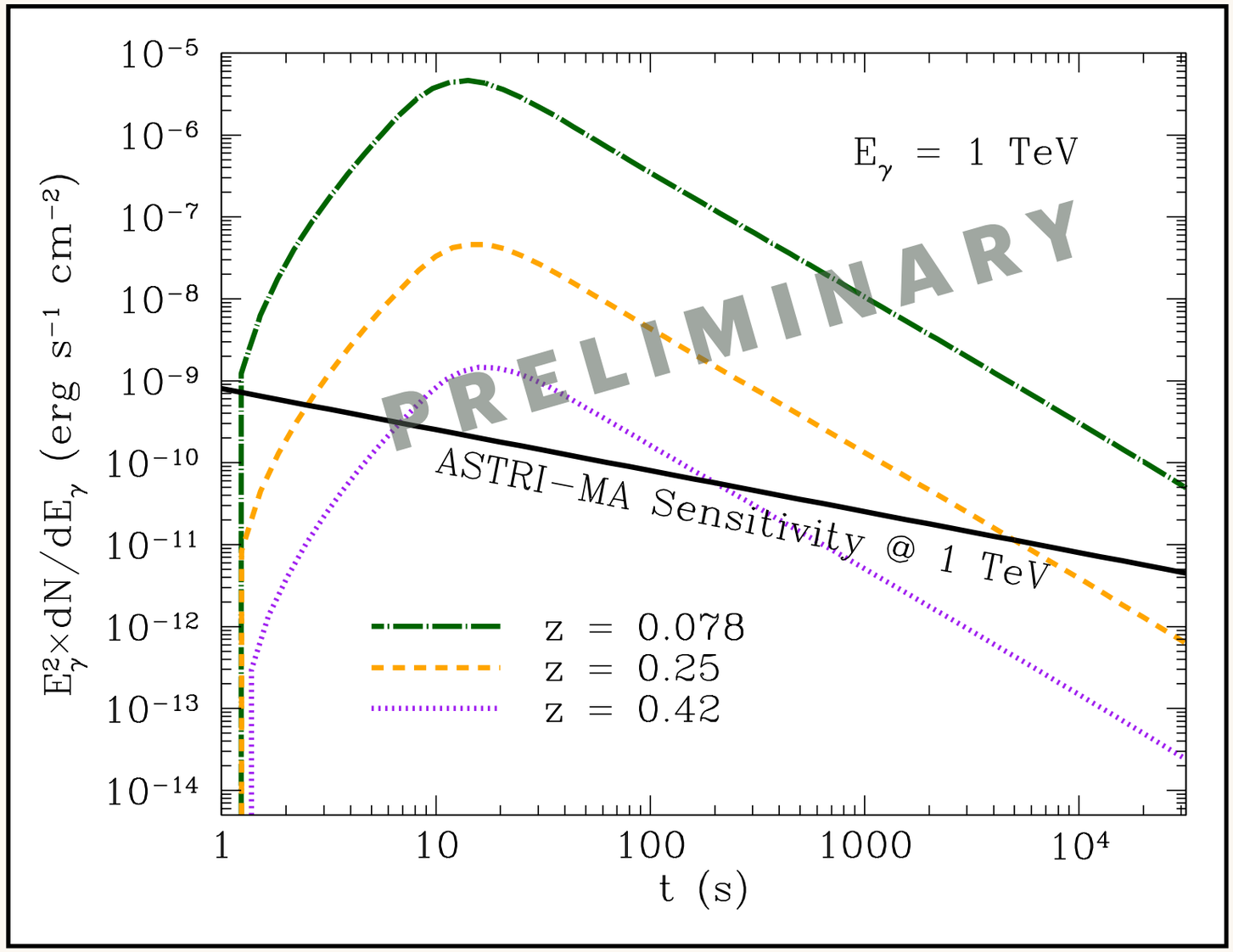
Consortium paper on prospects for CTA observations of GRB in preparation

ASTRI - MINI ARRAY

SIMULATIONS

- 190114C as a template

- moved at 3 different z
  - z = 0.42 (original z)
  - z = 0.25
  - z = 0.078 (same as HESS GRB 190829A)



Paper on core science with ASTRI-MA in preparation

Open Questions & Future Challenges

- Does SSC interpretation hold for all detected GRBs?
- Which conditions are required to produce VHE component? How common are these conditions?
- Nature of TeV emission always the same or competing processes can dominate the TeV range?
- VHE observations during the prompt: unique tool to understand the origin of prompt radiation
- VHE emission in short GRBs: understand differences short/long (environment, jet,...)

Discussion session: GRBs in the VHE regime

Conveners: B. Reville and L. Nava

Radiation from Gamma-Ray Bursts, from radio to soft gamma-rays, is commonly interpreted as synchrotron emission from non-thermal electrons. In the afterglows of the prompt event, the upscattering of synchrotron photons by the same energetic electrons (the SSC mechanism) is expected to take place at some level, contributing to the GeV-TeV emission. External Compton and hadronic mechanisms have been proposed to play an important role in the production of VHE radiation. After several years of effort, significant TeV detections of long GRB afterglows are at last a reality. The nature of the VHE emission and the implications on GRB physics will be discussed, including exciting prospects for the detection of prompt and afterglow emission with current and future facilities.