VERY HIGH ENERGY EMISSION FROM GAMMA-RAY BURSTS WITH THE MAGIC TELESCOPES

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On behalf of the MAGIC Collaboration

V Congresso Nazionale GRB 2022, 13/09/2022

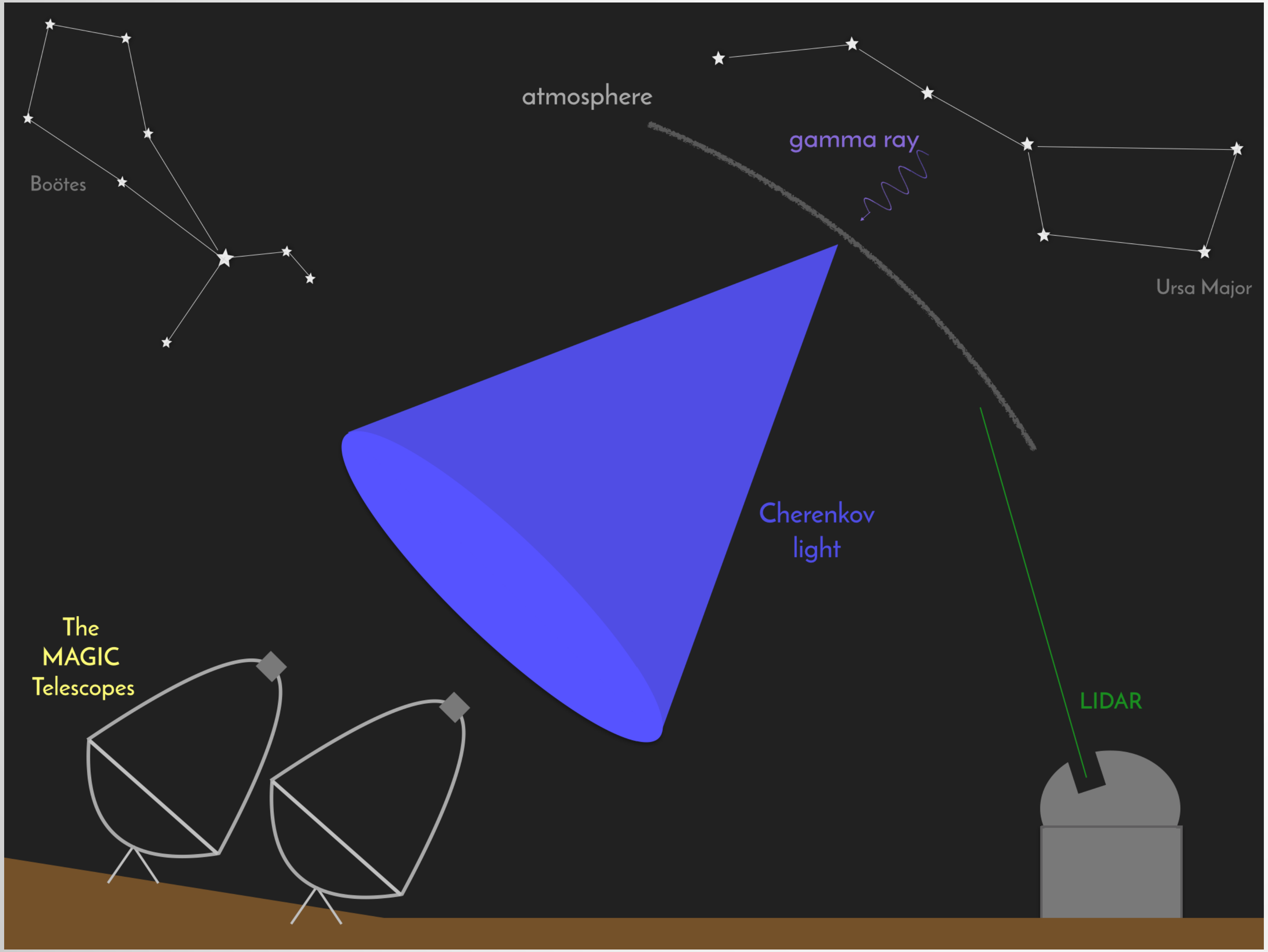
The MAGIC Collaboration

The **MAGIC Collaboration** is composed by ~150 physicists (230 members in total, including technical and administrative staff) from **13 countries**

The MAGIC Collaboration

Credit: ESA/Copernicus Sentinel-2

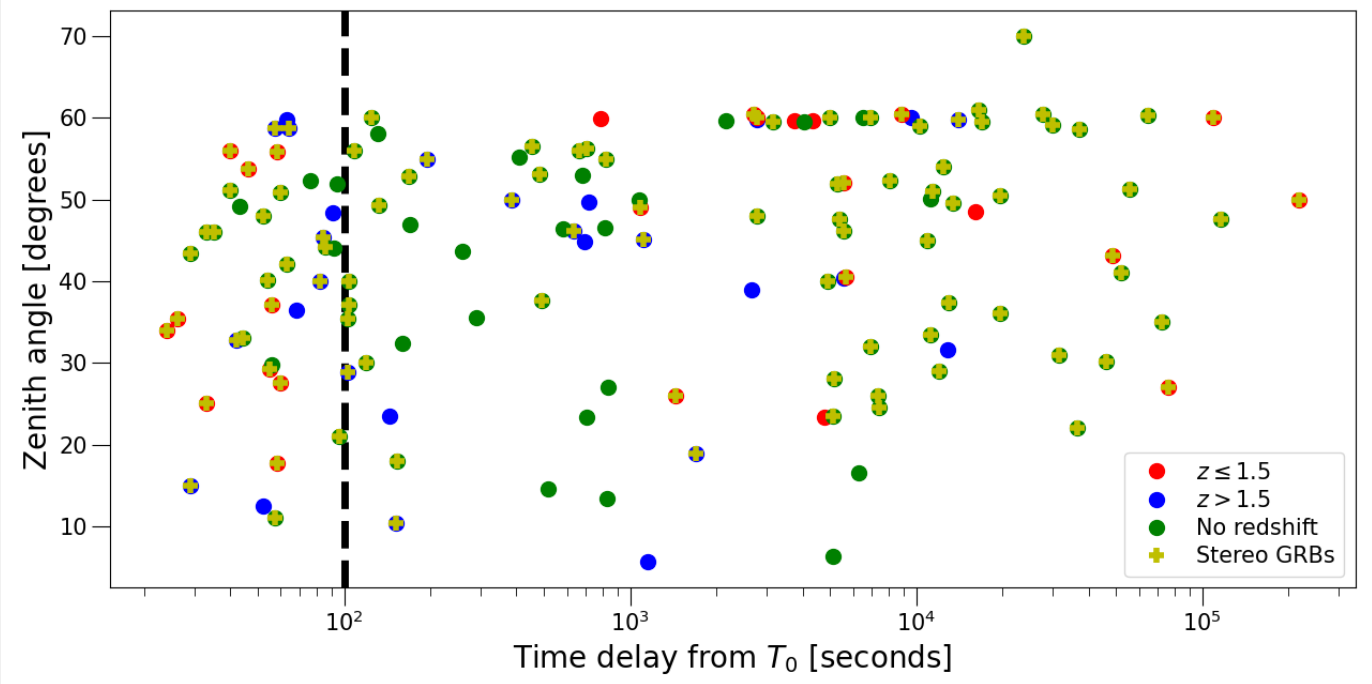
The MAGIC telescopes



- Stereoscopic system of two 17 m diameter Imaging Atmospheric Cherenkov Telescopes (IACT)
- Indirect detection of γ-rays
- Energy range: 50 GeV - ~ 50 TeV
- Atmospheric transmission evaluated by the LIDAR system

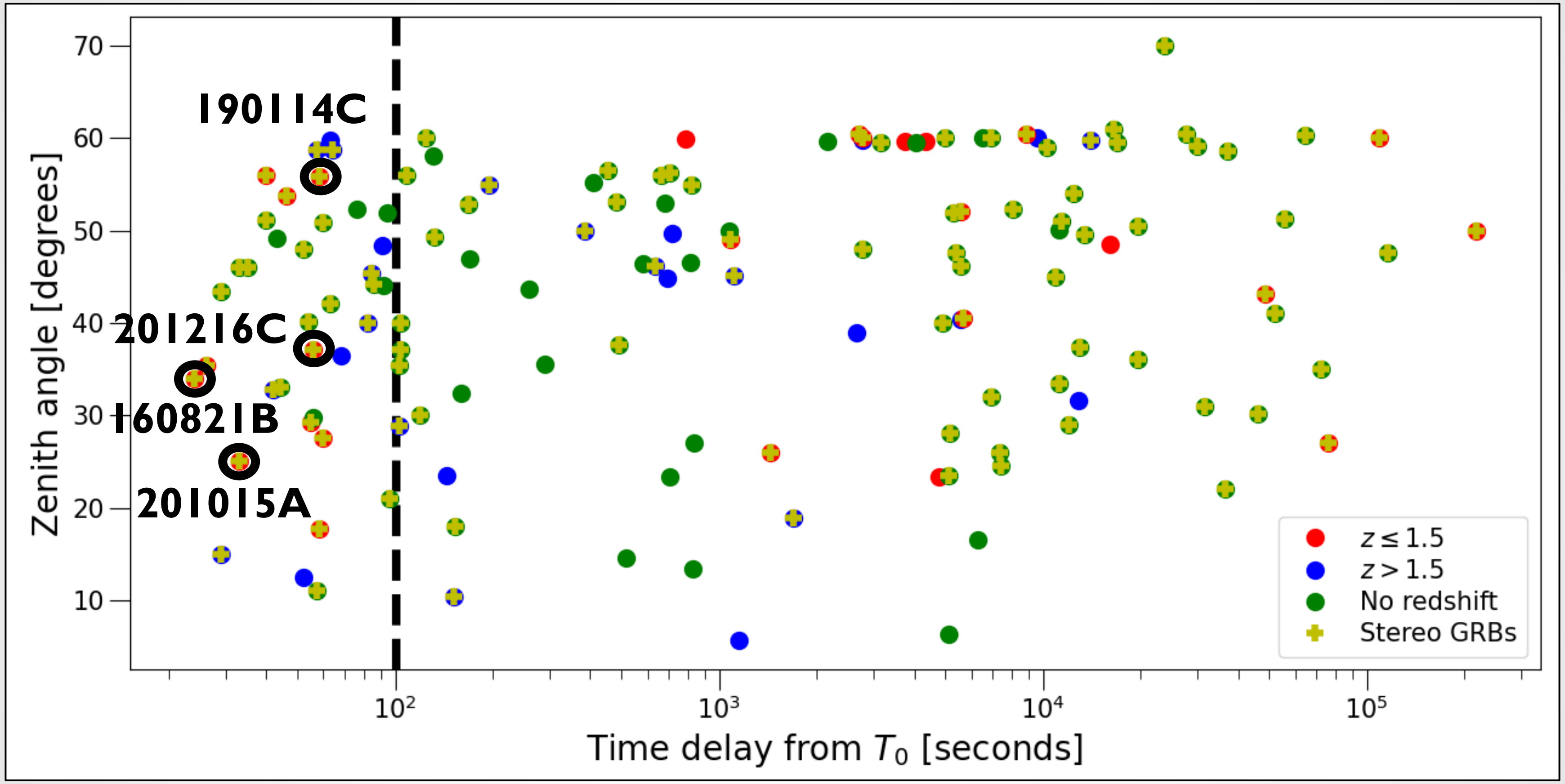
The MAGIC telescopes

GRB observations with MAGIC



- Suitable instruments for GRB follow-ups:
  - low energy threshold (~ 50 GeV or lower with SumTrigger)
  - automatic alert system and fast repositioning (~7deg/s)
  - observations in non-standard conditions (moon time, high zenith angles)

The MAGIC telescopes



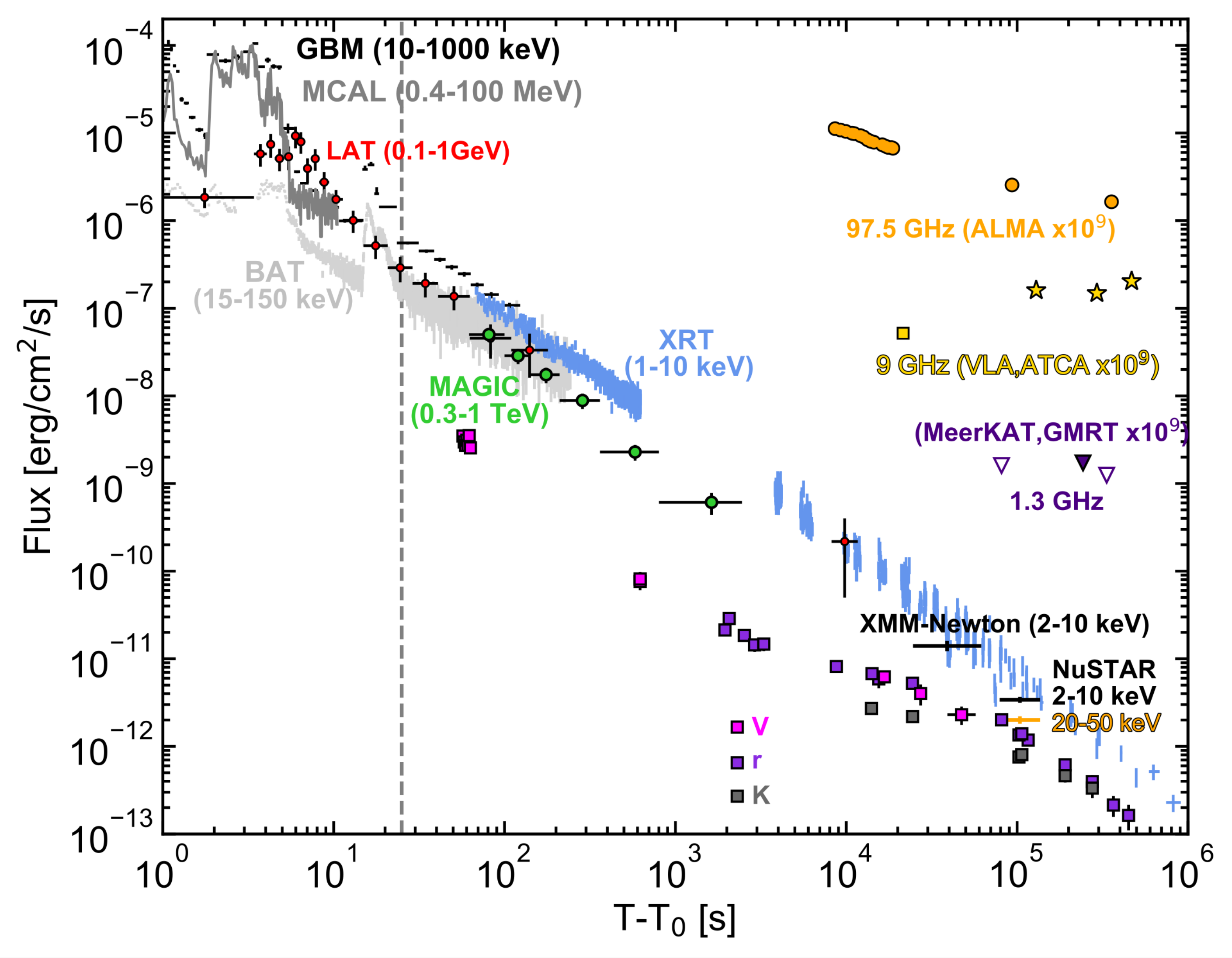
- ~ 140 GRBs observed since 2005
- 2 detections (> 5σ excess): GRB190114C, GRB201216C
- 2 hints of detection (≳ 3σ excess): GRB160821B and GRB201015A

GRB190114C

- Long GRB
- $E_{\gamma,iso} \sim 2.5 \times 10^{53}$ erg
- z = 0.42

MAGIC detection info:

- $T_{delay} \sim 57$ s
- > 50σ in 20 minutes
- detection up to 40 min
- 0.3 - 1 TeV energy range
- moon conditions and Zd>50



MAGIC Coll. et al., 2019

GRB190114C

X-ray + GeV + TeV

↓

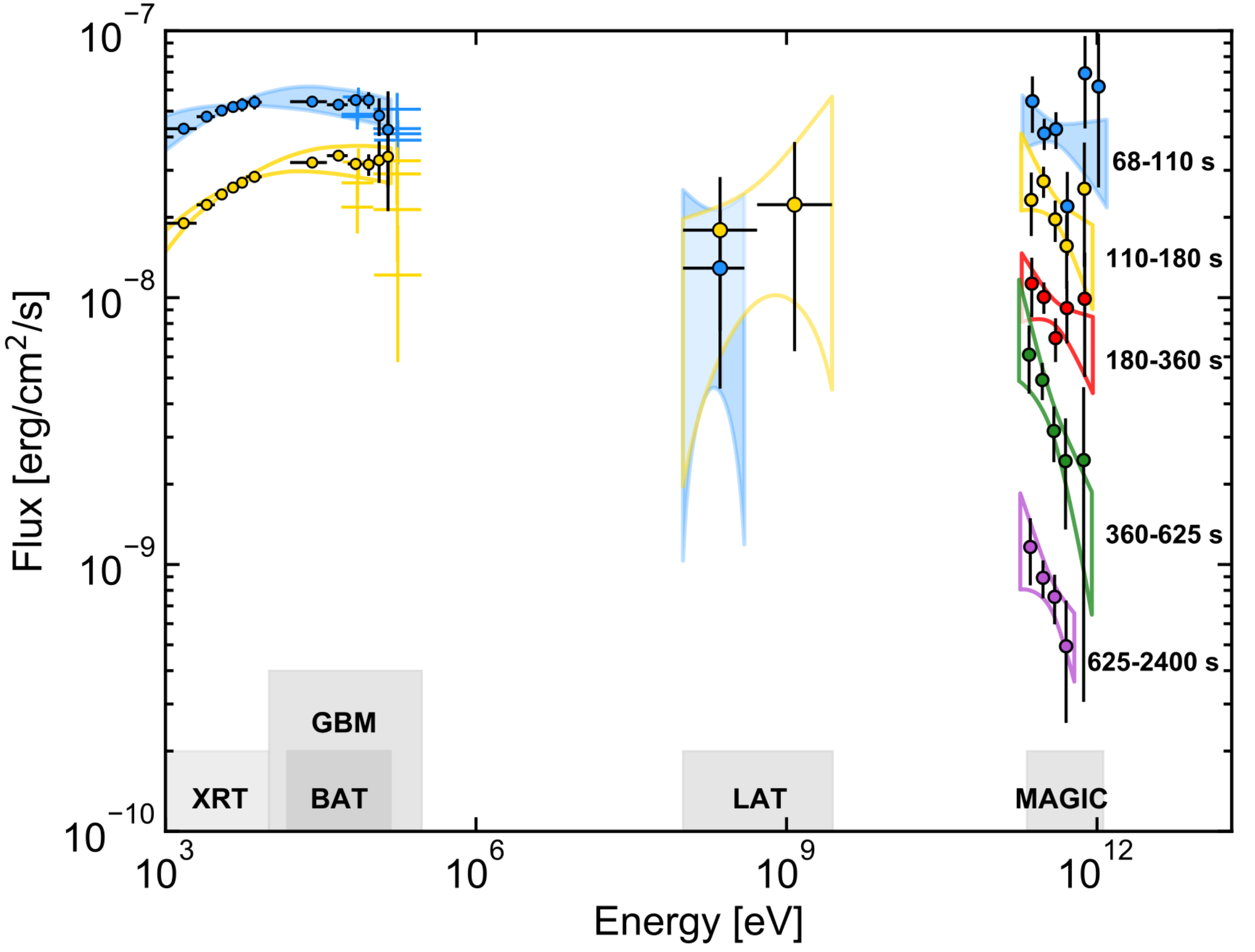
Spectral hardening for E > 0.2 TeV

↓

Can't be extention of Synchrotron component

↓

New emission component at VHE



MAGIC Coll. et al., 2019

Modeling of GRB190114C

Observed

No γ-γ opacity

EBL-deabsorbed

MAGIC soft spectrum:

- Klein-Nishina
- γ-γ internal absorption

GRB afterglow parameters:

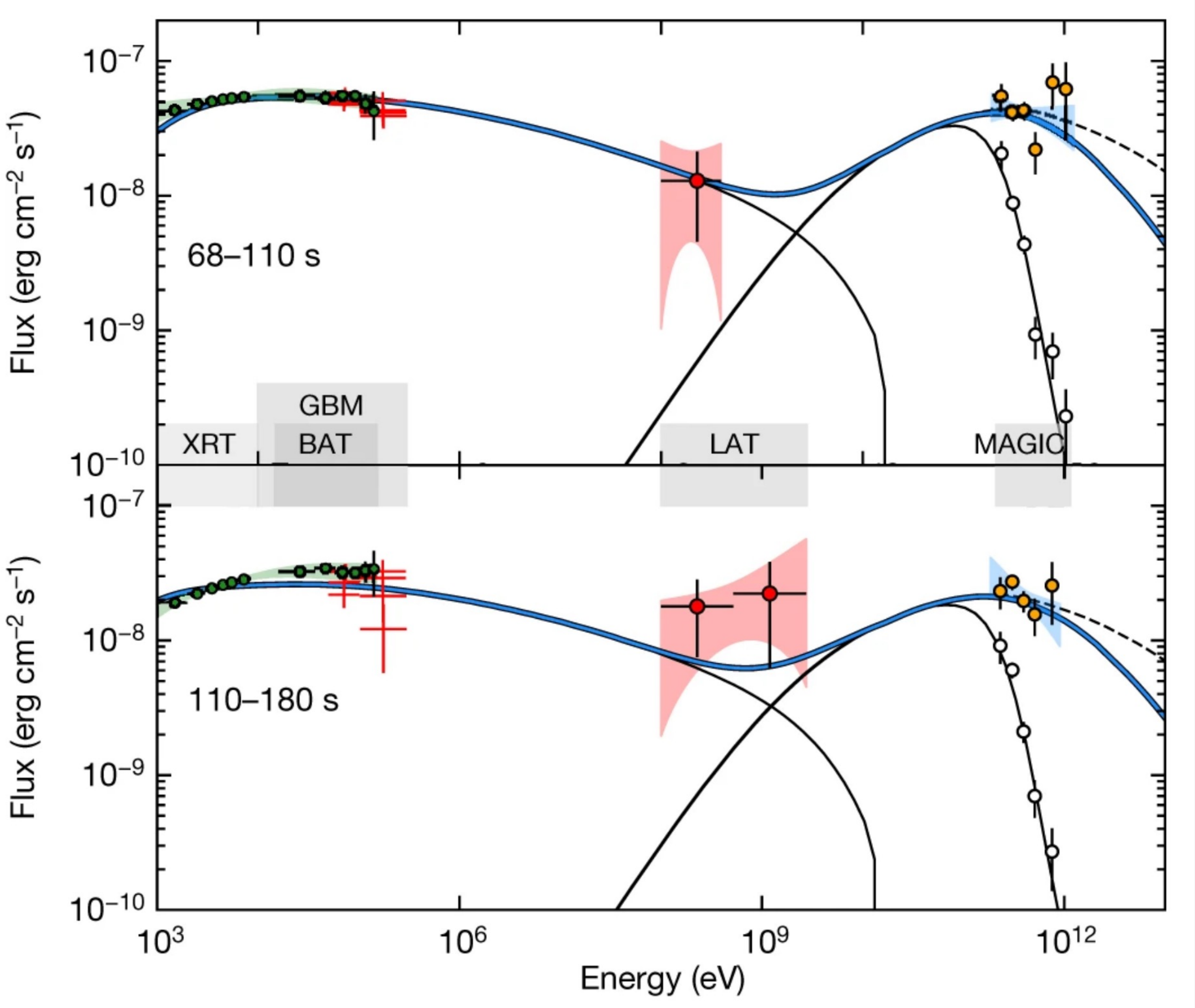
$E_k \gtrsim 3 \times 10^{53}$ erg

$\varepsilon_e \approx 0.05\text{-}0.15$

$\varepsilon_b \approx 0.05\text{-}1 \times 10^{-3}$

$n \approx 0.5\text{-}5$ cm^{-3}

$p \approx 2.4\text{-}2.6$



MAGIC Coll. et al., 2019

GRB190114C: impact on other physics

Lorentz Invariance Violation (LIV) studies

$$\Delta t = s_{\pm} \frac{n+1}{2} D_n(z) \left(\frac{E}{E_{\mathrm{QG,n}}} \right)^n$$

Photon energy at the detector

$$\Delta t(E, \eta_1) = \eta_1 \cdot 17\ \mathrm{s/TeV} \cdot E$$
$$\Delta t(E, \eta_2) = \eta_2 \cdot 25\ \mathrm{s/TeV^2} \cdot E^2$$

Assuming η_n **= 1** a **1 TeV** gamma should have a **time delay** of
- **17 seconds** (n=1)
- **25 seconds** (n=2)

Where we have defined **η** as the **ratio** between the **Planck energy** and the **Q.G. energy scale**

$$\eta_1 = s_{\pm} \cdot E_{\mathrm{Pl}}/E_{\mathrm{QG,1}} \qquad \eta_2 = 10^{-16} \cdot s_{\pm} \cdot E^2_{\mathrm{Pl}}/E^2_{\mathrm{QG,2}}$$

From the GRB 190114C data we got the following 95% lower limits on the Q.G. energy scale

	superl.	subl.
$E_{\mathrm{QG,1}}$ [10^{19} GeV]	0.55	0.58
$E_{\mathrm{QG,2}}$ [10^{10} GeV]	5.6	6.3

95% lower limit on the Q.G. energy scale for
← linear scenario
← quadratic scenario

$$E_{Pl} \sim 1.2 \cdot 10^{19}\ \mathrm{GeV}$$

COMPARISON WITH PREVIOUS LIMITS

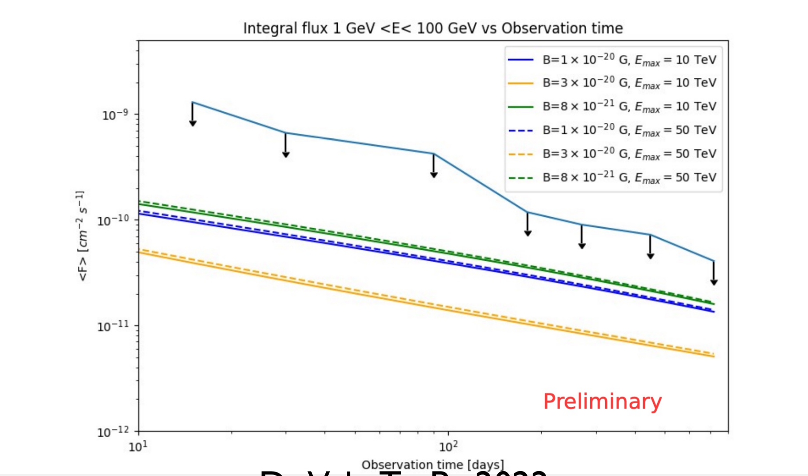
Source	Source type	Redshift	$E_{\mathrm{QG,1}}$ [10^{19} GeV]	$E_{\mathrm{QG,2}}$ [10^{10} GeV]	Instrument
GRB 090510	GRB	0.9	9.3	13	*Fermi*-LAT[1]
GRB 190114C	GRB	0.42	**0.58**	**6.3**	MAGIC
PKS 2155-304	AGN	0.116	0.21	6.4	H.E.S.S.[2]
Mrk 501	AGN	0.034	0.036	8.5	H.E.S.S.[3]
Mrk 501	AGN	0.034	0.021	2.6	MAGIC[4]
Mrk 421	AGN	0.031	pending	pending	MAGIC
Crab Pulsar	Pulsar	2.0 kpc	0.055	5.9	MAGIC[5]

← **this work**

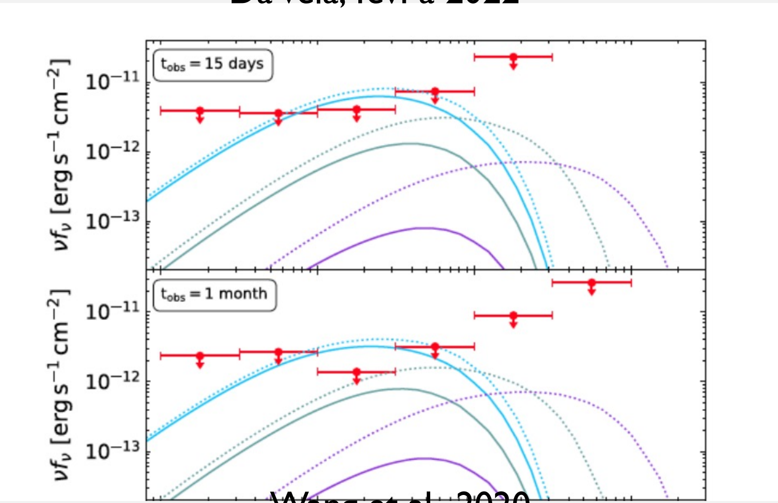
[1] Vasileiou+ (2013)
[2] Abramowski+ (2011)
[3] Abdalla+ (2019)
[4] Albert+ (2008)
[5] Ahnen+ (2017)

D'Amico, ICRC2021

InterGalactic Magnetic Field (IGMF) studies



Da Vela, TevPa 2022



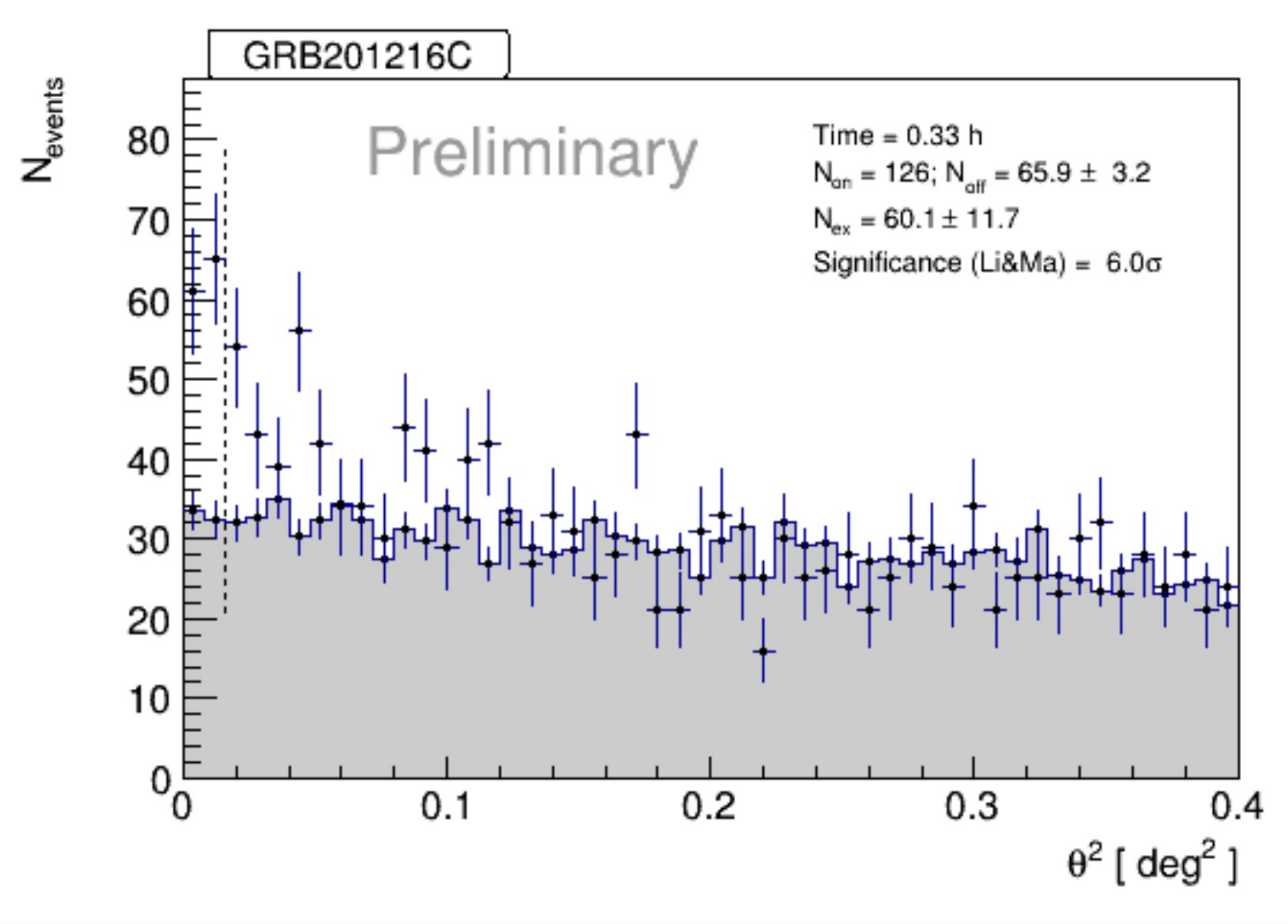
Wang et al., 2020

GRB201216C

- Long GRB
- $E_{\gamma,iso} \sim 4.7 \times 10^{53}$ erg
- z = 1.1

MAGIC detection info:

- Tdelay ~ 56 s
- 6σ in 20 minutes
- 0.1 - ? TeV energy range



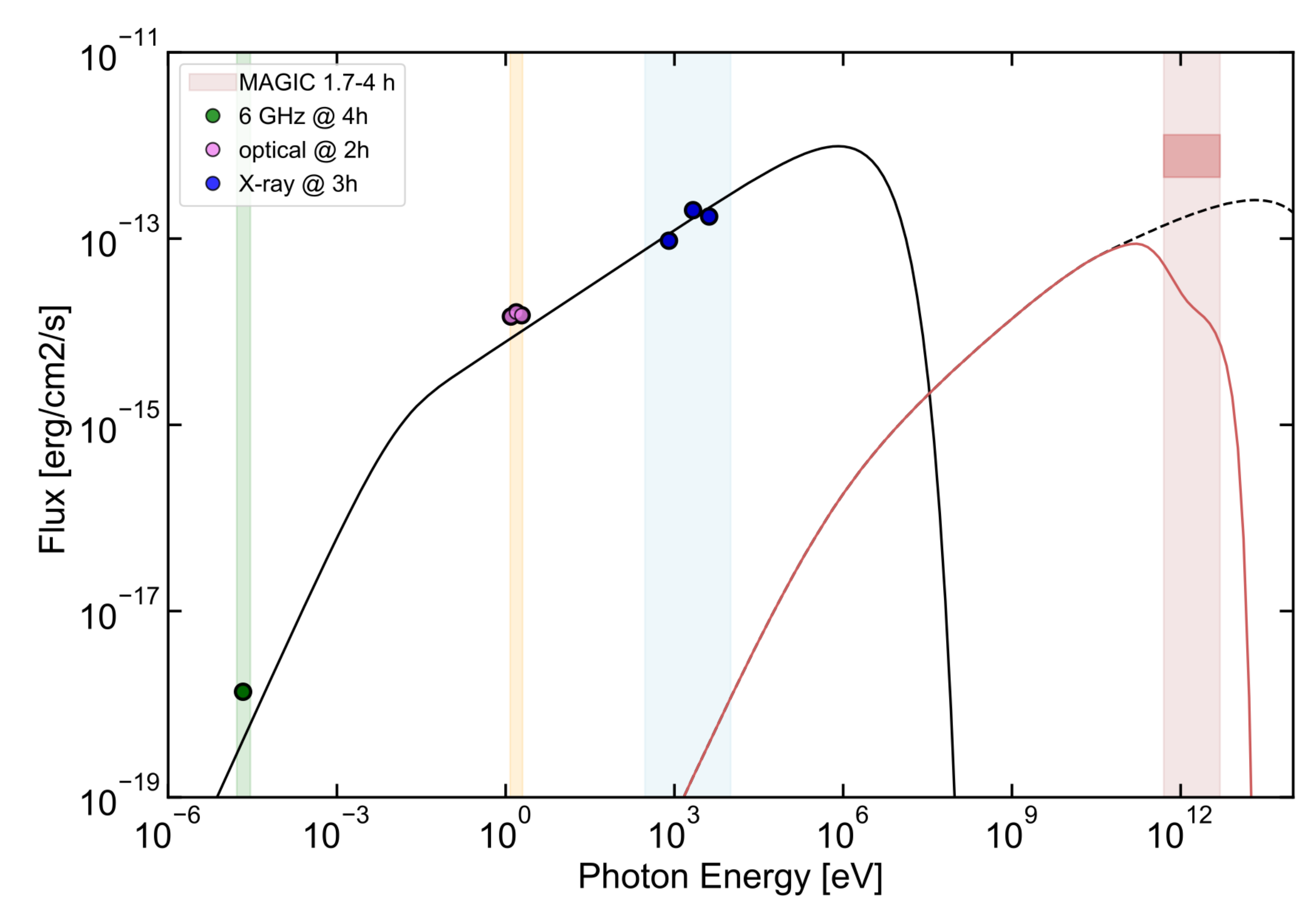
Suda et al., 2021, ICRC

GRB160821B (3σ excess)

- short GRB
- $E_{\gamma,iso} \sim 1.2 \times 10^{49}$ erg
- z = 0.162

MAGIC info:

- Tdelay ~ 24 s
- 3σ in 4 hrs
- 0.5 - 5 TeV energy range
- moon conditions, dedicated analysis



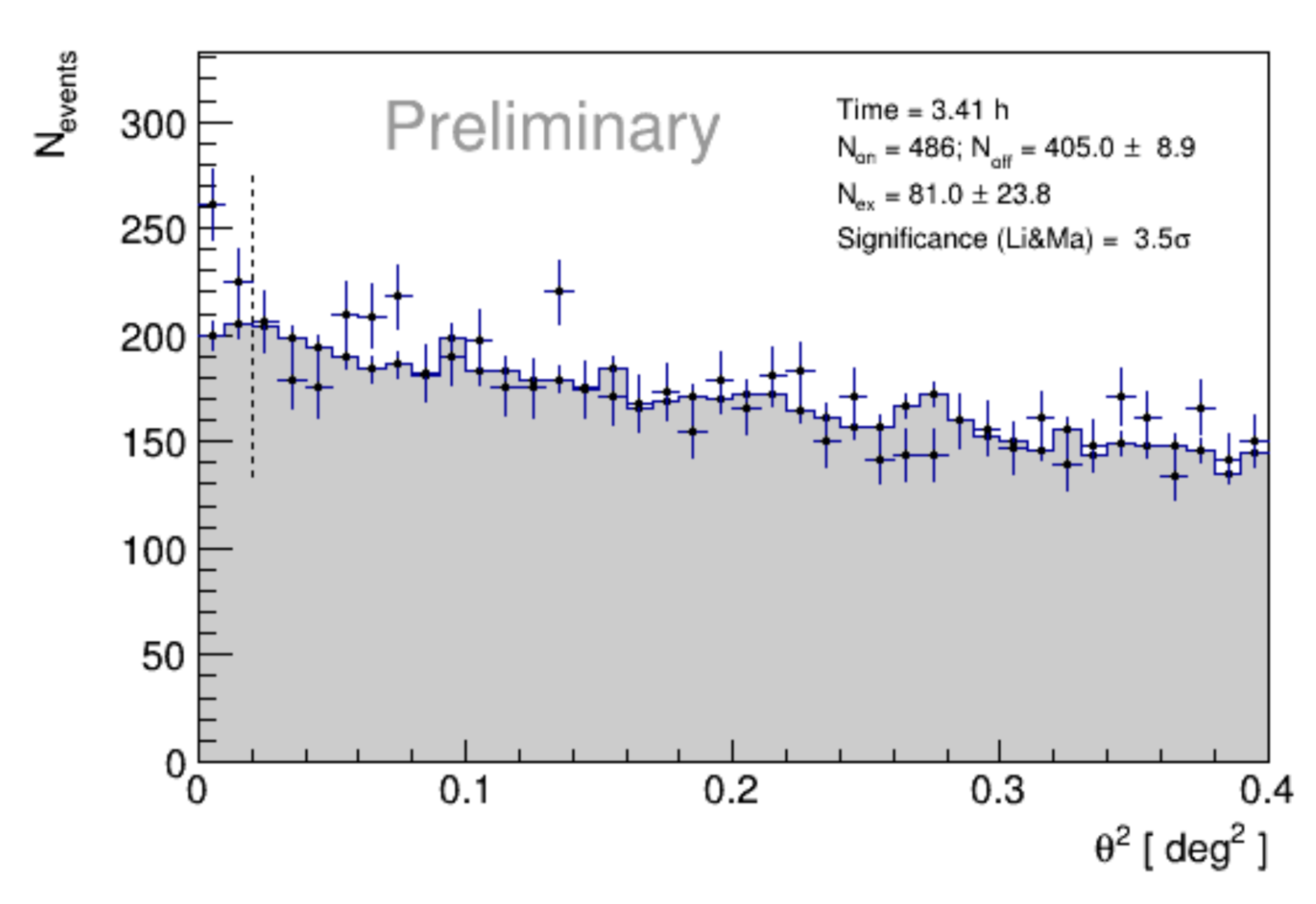
MAGIC Coll., 2021

GRB201015A (>3σ excess)

- long GRB
- $E_{\gamma,iso} \sim 1.1 \times 10^{50}$ erg
- $z = 0.426$

MAGIC info:

- Tdelay ~ 33 s
- 3.5σ in 3.4 hrs
- 0.14 - ? TeV energy range

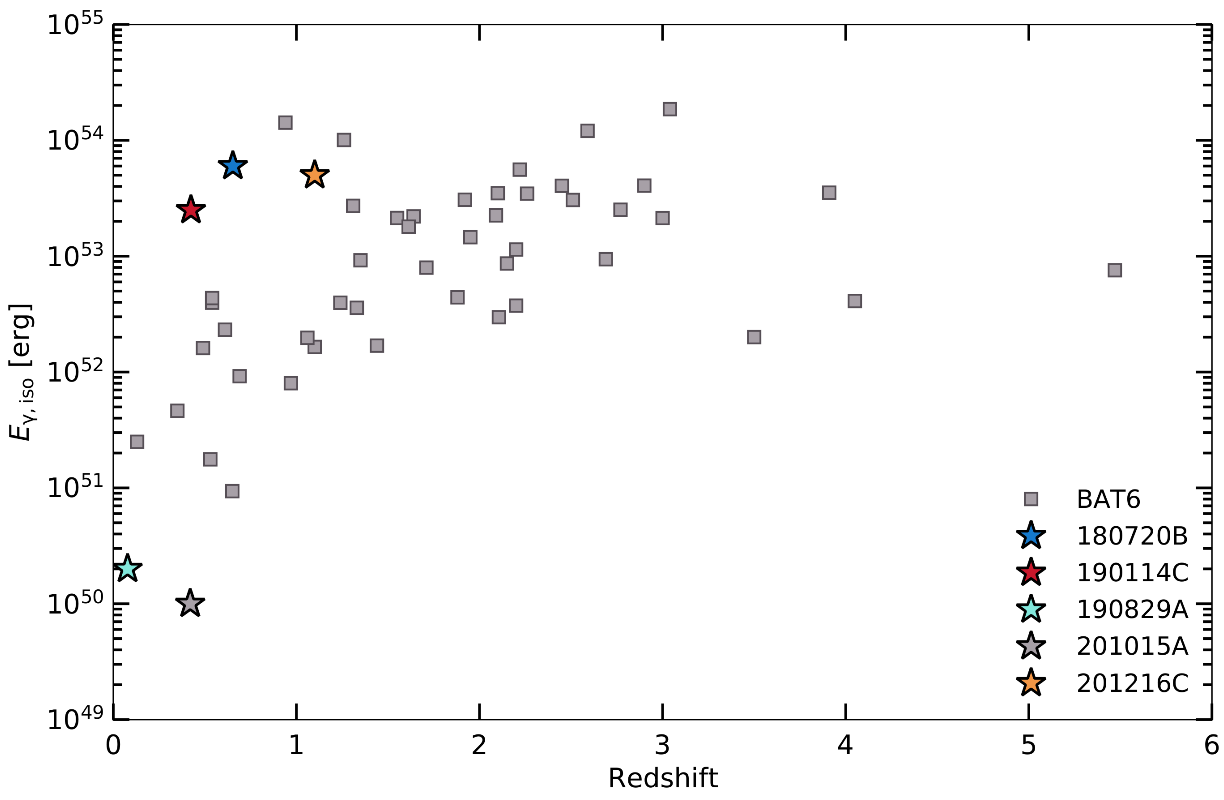


Fukami et al., 2021, ICRC

Population of GRBs at VHE

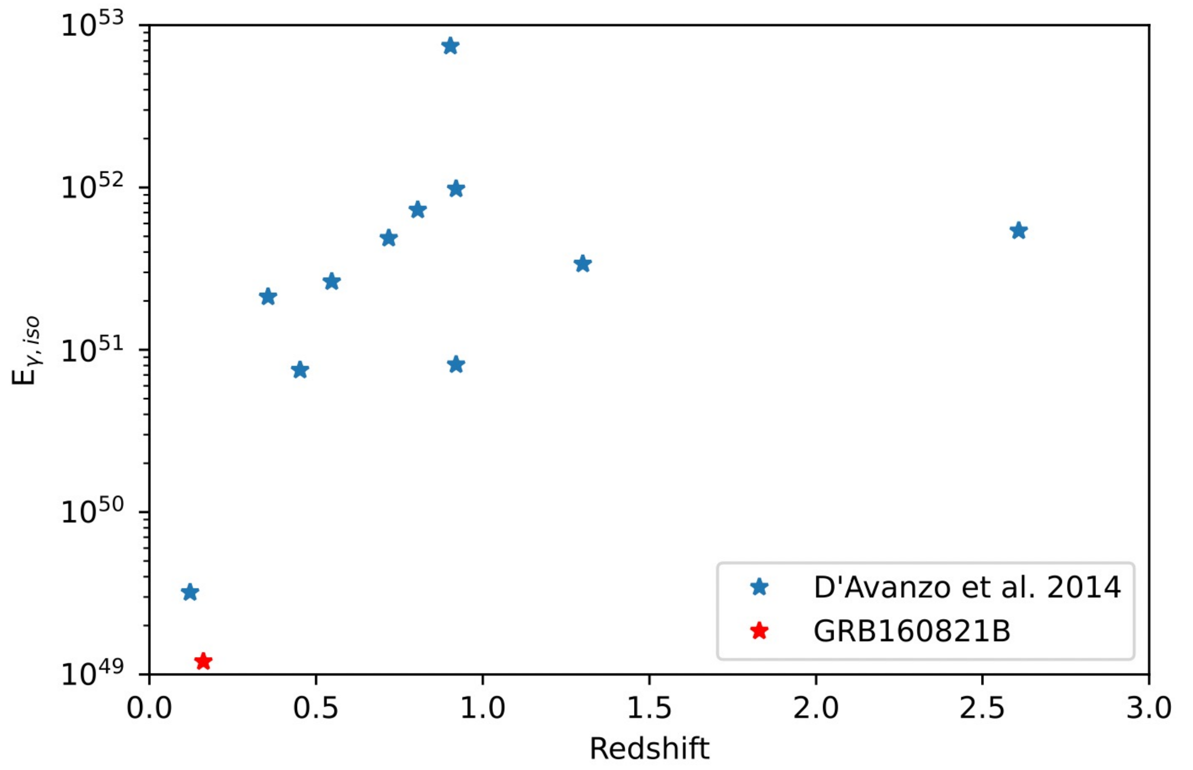
Energetics

long GRBs



Nava, 2021

short GRBs



MAGIC Upper Limit (UL) catalog

MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

Upper limits on the very high energy emission from GRBs observed by MAGIC

ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International
Cosmic Ray Conference
12–23 July 2021

Francesco Longo[1,2,3], Alessio Berti[4], Zeljka Bosnjak[5], Alice Donini[2,6,7], Satoshi Fukami[8], Jarred Gershon Green[9], Davide Miceli[2,6,10], Elena Moretti[7], Lara Nava[2,3,11] and Koji Noda[8] on behalf of the MAGIC Collaboration

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The MAGIC collaboration has developed a dedicated observational strategy to repoint rapidly towards gamma-ray bursts (GRBs). In this contribution we present the information extracted from the large sample of the GRBs observed by MAGIC from 2013 to 2019. None of these GRBs were significantly detected, and this study aims to shed light on the reasons behind those non-detections. The same strategy had led to the successful detection of two GRBs at Very High Energies (VHE, E>100GeV). We describe the details of the MAGIC GRB observational procedure and the general properties for each observed GRB. The lack of detection can be attributed either to unfavourable conditions or GRB intrinsic properties, such as the magnetic field's energy density, the bulk Lorentz factor, or the emitting region's size. For the presented sample of GRBs, we show the methods used to obtain flux upper limits in the VHE range, and propose physical implications of the non-detection of VHE emission. These results constitute an essential reference point to study the broadband emission of GRBs, and for the Cherenkov telescope community to organize future follow-ups of GRBs at VHE energies.

PoS PROCEEDINGS OF SCIENCE

ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
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Upper limits on the very high energy emission from GRBs observed by MAGIC

Conclusions

- MAGIC demonstrates current generation IACTs are able to detect GRB afterglow emission
  - Hardware and software upgrades played a crucial role
    - alert system and fast repointing (but also late-time follow-up)
    - observations in non-standard conditions (moon, bad weather, high zenith angles)

- Broad GRB intrinsic properties: VHE emission may be present in a larger sample of GRBs → we are ready to catch it to enlarge VHE GRB population

- 160821B is a promising hint for short GRBs

- MWL data and synergies with other instruments are crucial

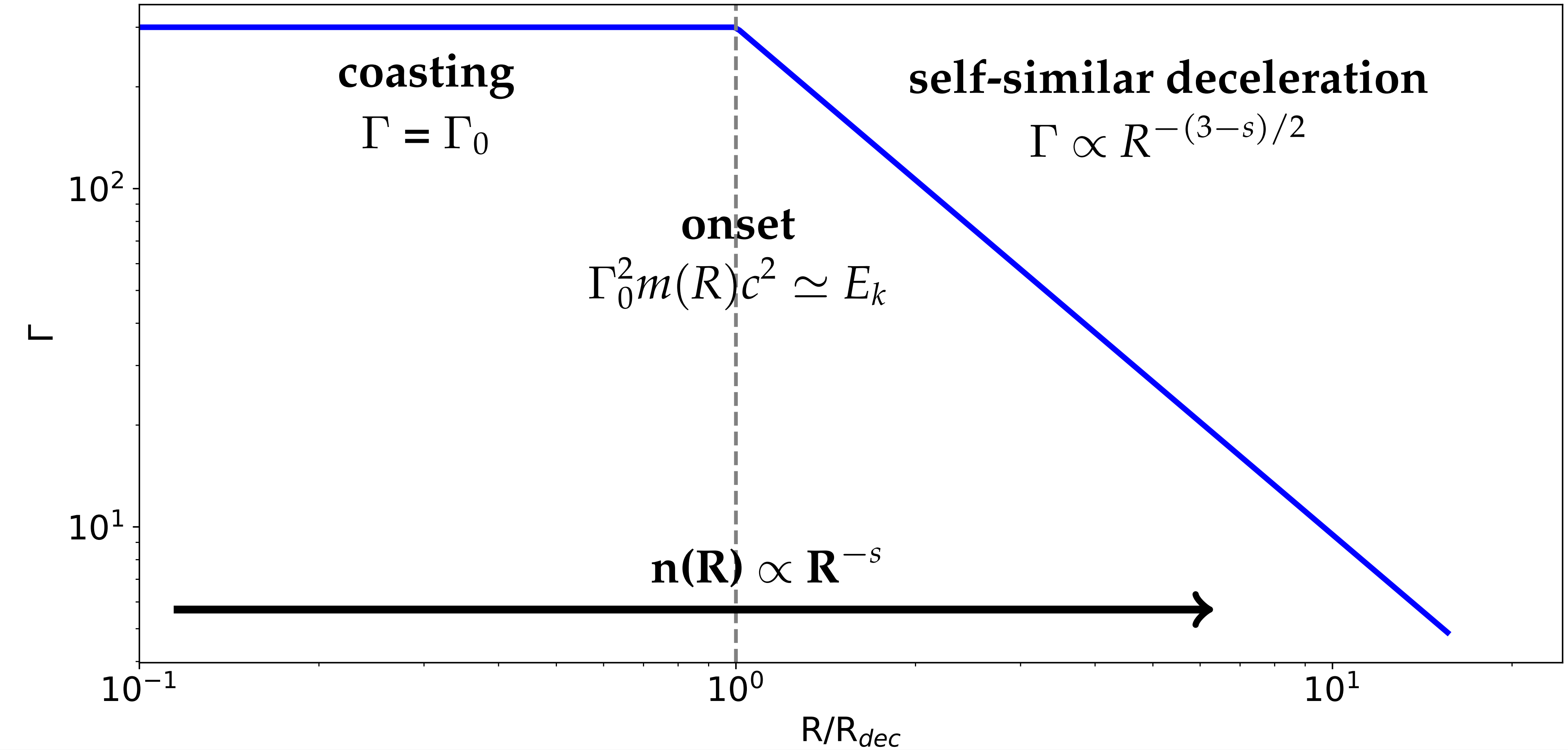
Future challenges

- Nature and properties of afterglow emission still debated (SSC/sync, external medium, microphysics parameters)
- VHE emission in prompt phase
- VHE from short GRBs, connection with GW searches (O4 starting in March 2023)
- Explore new physics field with GRBs (LIV, IGMF, EBL)
- Future generation instruments (LSTs, CTA) will increase VHE GRB detections
- Upcoming papers: GRB201216C, GRB201015A and UL GRB catalog

BACKUP

Afterglow: the external forward shock scenario

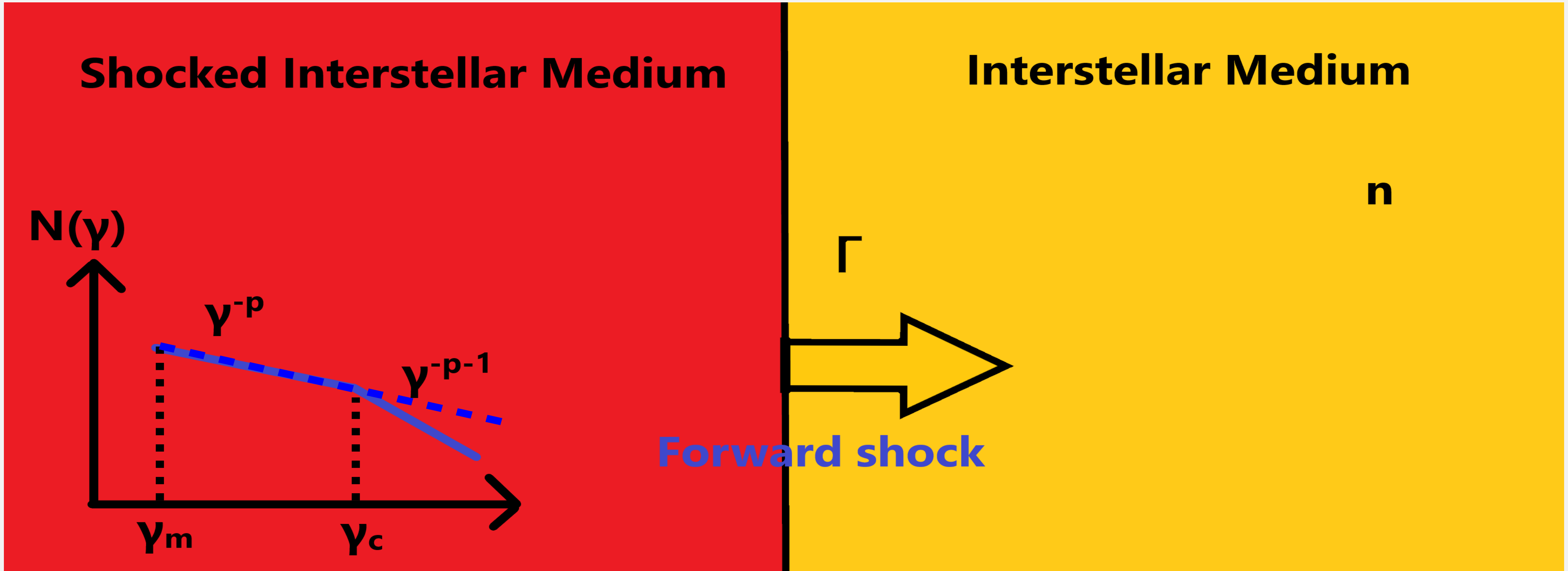
Jet dynamics



See Blandford & Mckee, 1976; Nava et al., 2014

Afterglow: the external forward shock scenario

Relativistic shocks in GRB afterglow



$u' = (\Gamma - 1)n'm_p c^2$ $u'_e = \xi \langle\gamma\rangle m_e c^2 n'$

$u'_e = \varepsilon_e u'$ $u'_p = \varepsilon_p u'$

$u'_B = \varepsilon_B u' = B^2/8\pi$

GRB190114C: Timeline