The detection of VHE emission in the deep afterglow of GRB 180720B

TeVPA 2019. Sydney, Australia

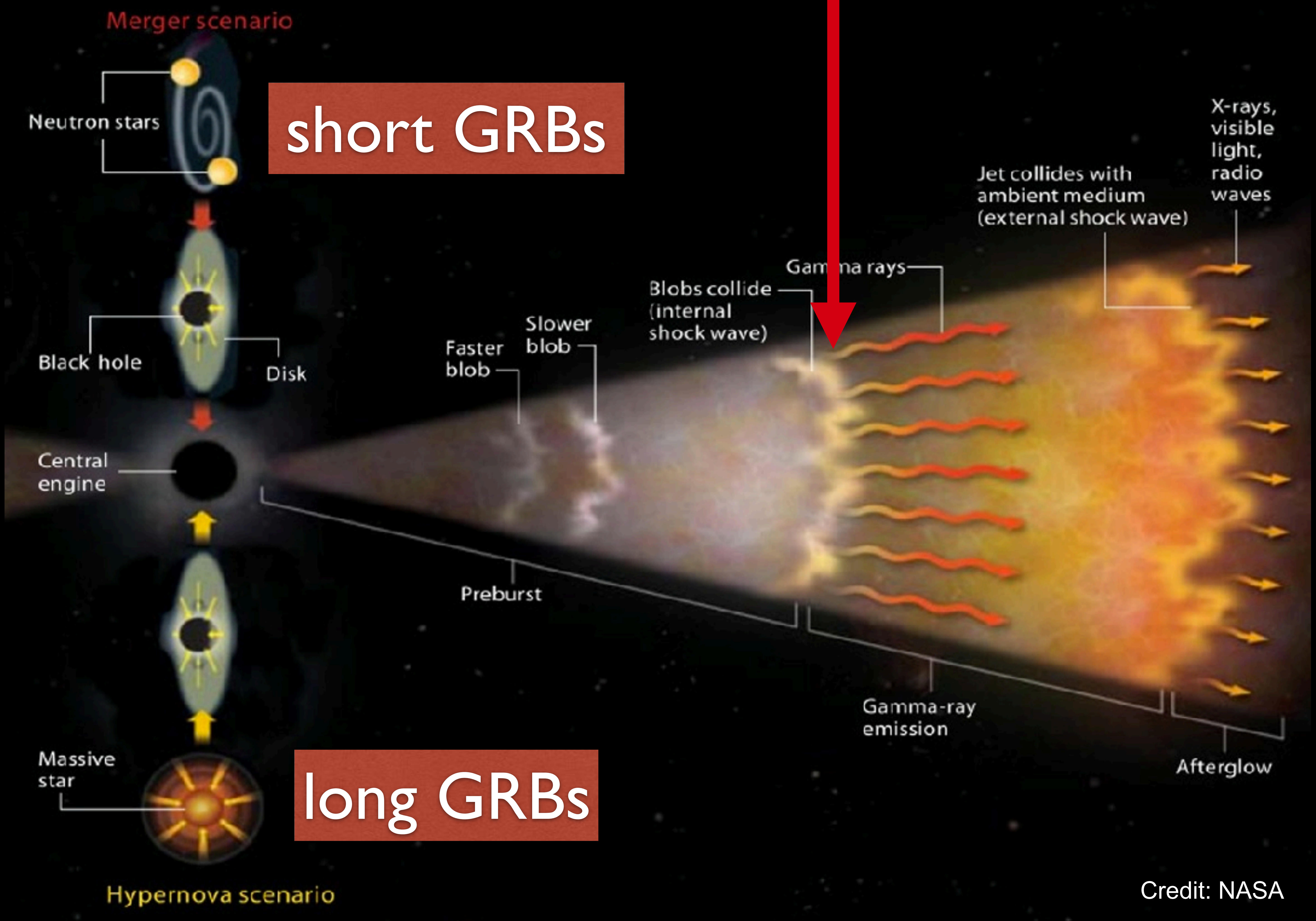
Edna L. Ruiz-Velasco (MPIK) for **the H.E.S.S. Collaboration**

Gamma-ray burst

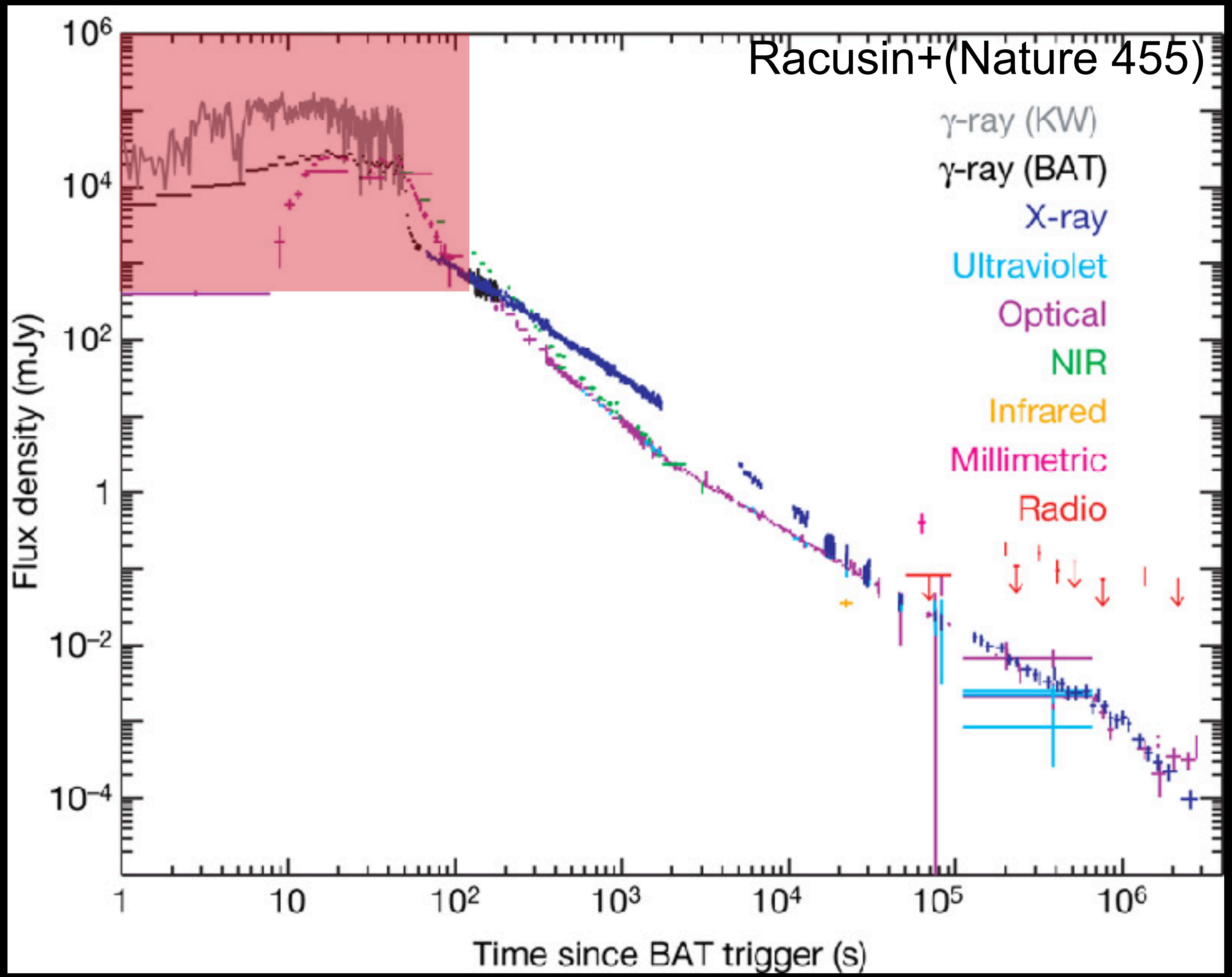
Prompt

short GRBs

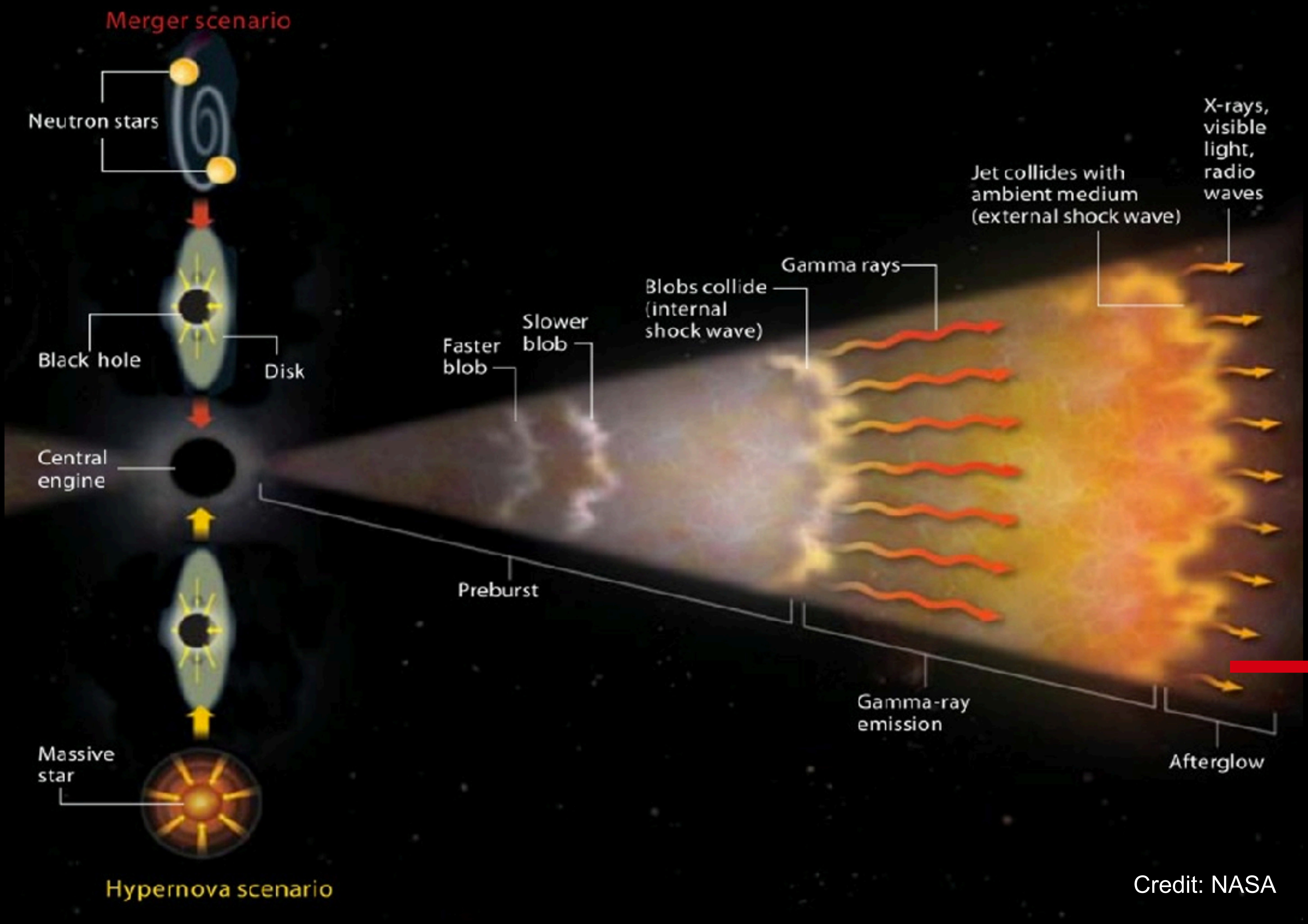
long GRBs



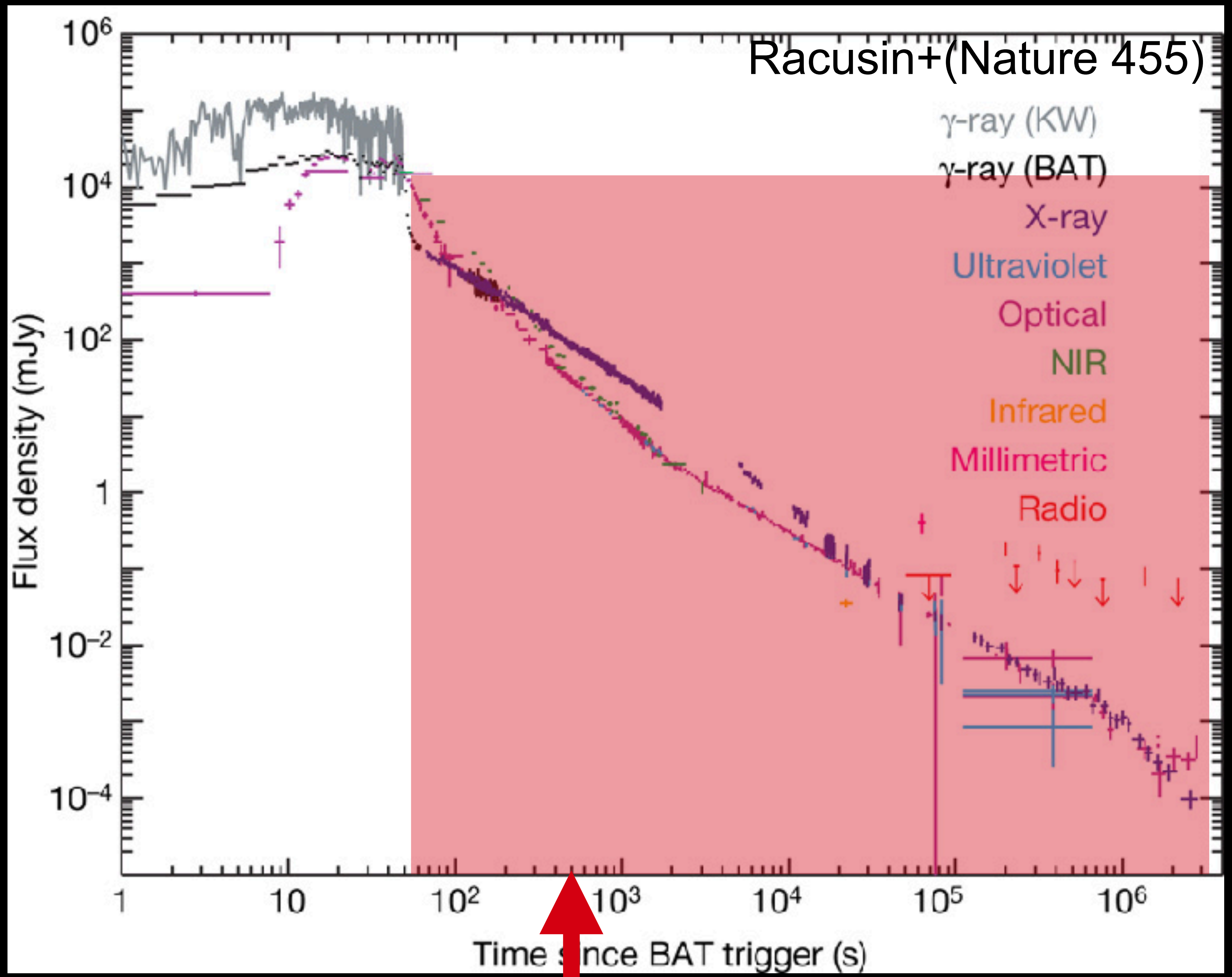
Credit: NASA



Gamma-ray burst

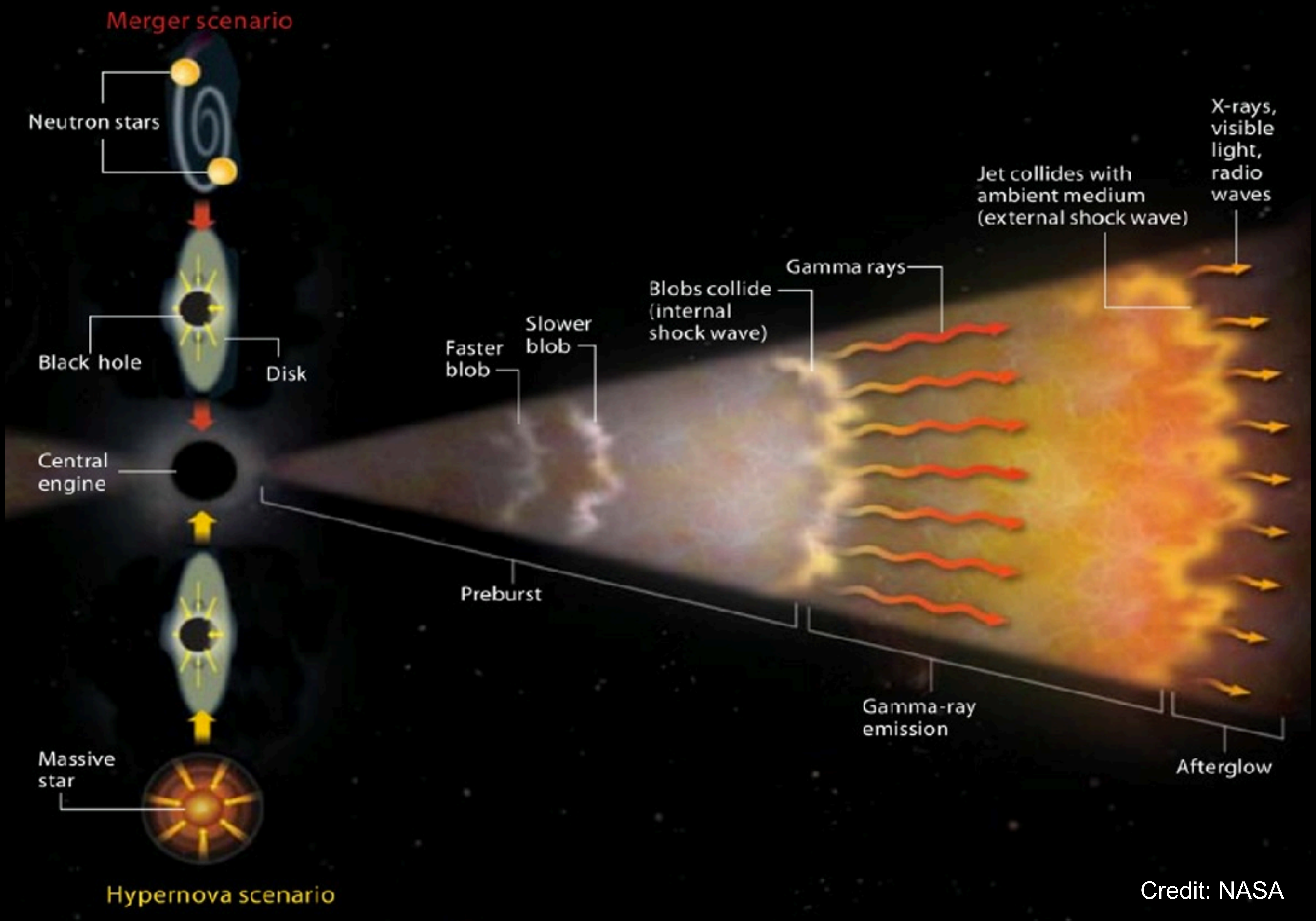


Credit: NASA



Afterglow

Gamma-ray burst



Credit: NASA

- GRBs at HE and VHE:
  ~12 GRBs per year Fermi-LAT
  - GRB130427A: Extended HE emission, 94 GeV max energy photon.

VHE emission was a decades-long mystery

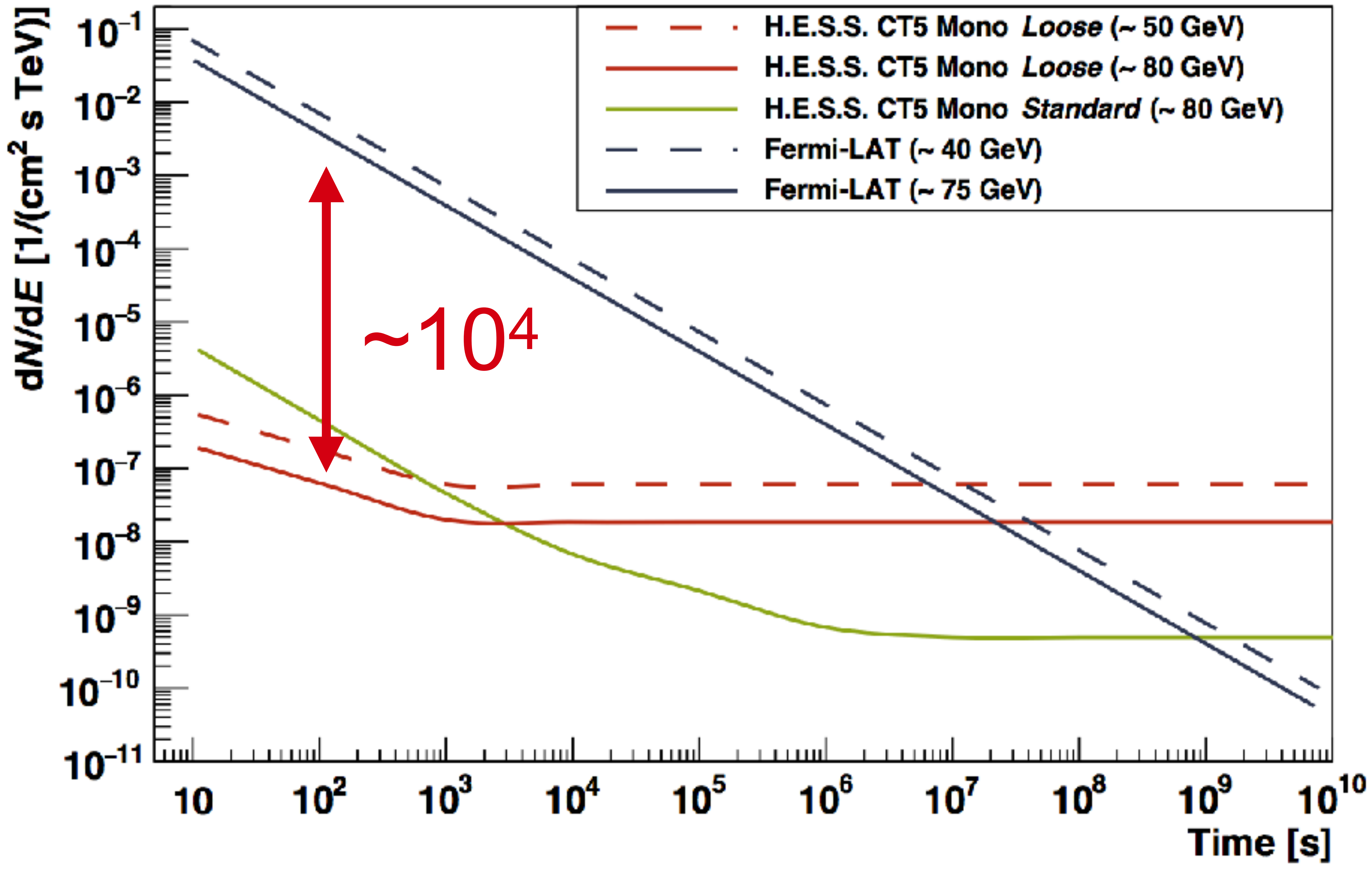
Now 3 detections in ~1.5 years!!!
GRB180720B
GRB190114C
GRB190829A

H.E.S.S. telescopes

- Site: Namibia, Africa
- Five (Atmospheric) Cherenkov telescopes
- Small telescopes CT1-4 + CT5 (HESSII) (GeV-TeV range)

H.E.S.S. telescopes

- Site: Namibia, Africa
- Five (Atmospheric) Cherenkov telescopes
- Small telescopes CT1-4 + CT5 (HESSII) (GeV-TeV range)
- 10^5 m^2 Effective area vs 1m^2 LAT



HESS Collaboration(ICRC2015)

CT5

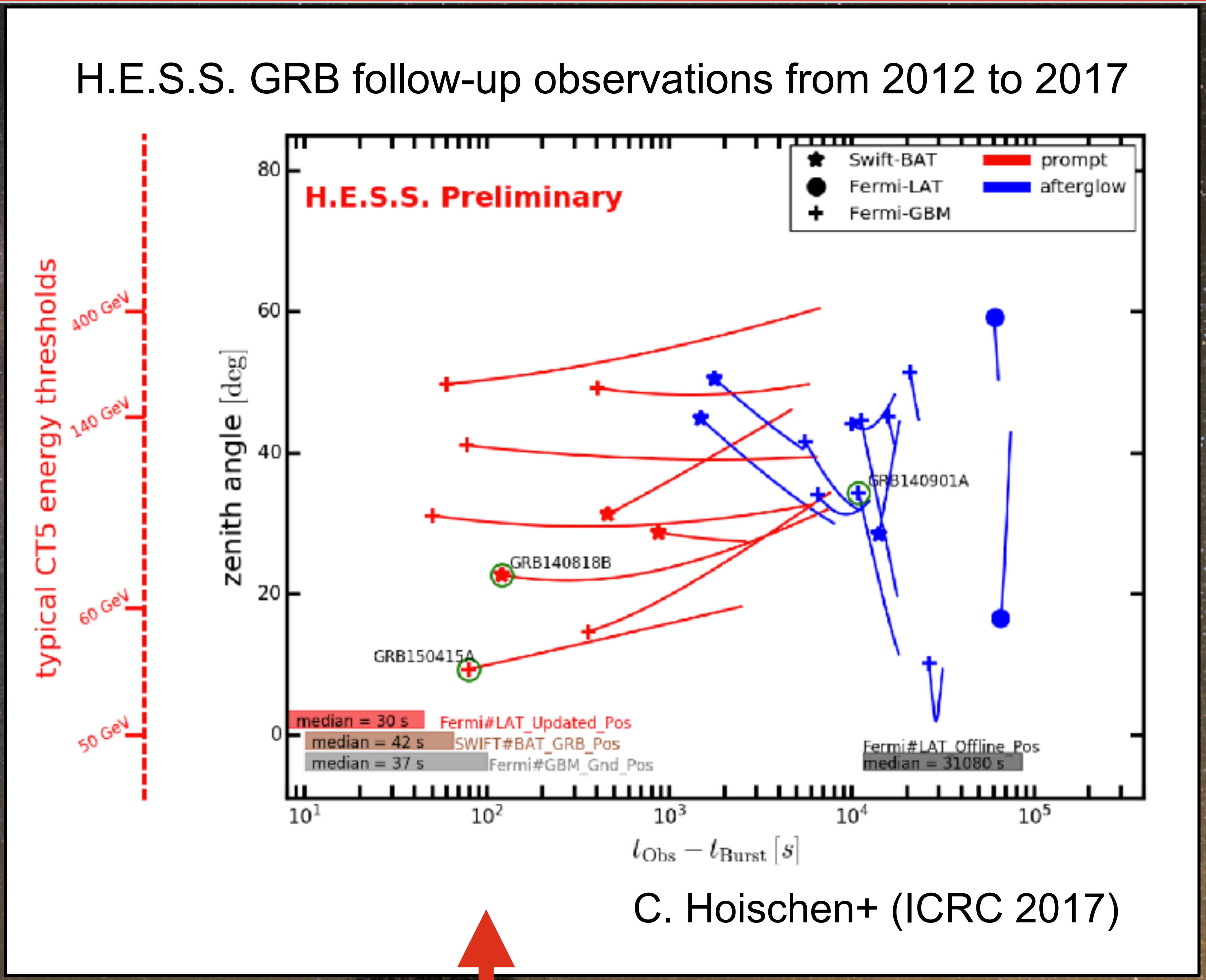
- 28 m telescope
- $E_{thr.}$ ~50 GeV
- 60 s slewing speed

Swift-BAT/XRT
Fermi-LAT/GBM
GW, Neutrinos

VoEvent

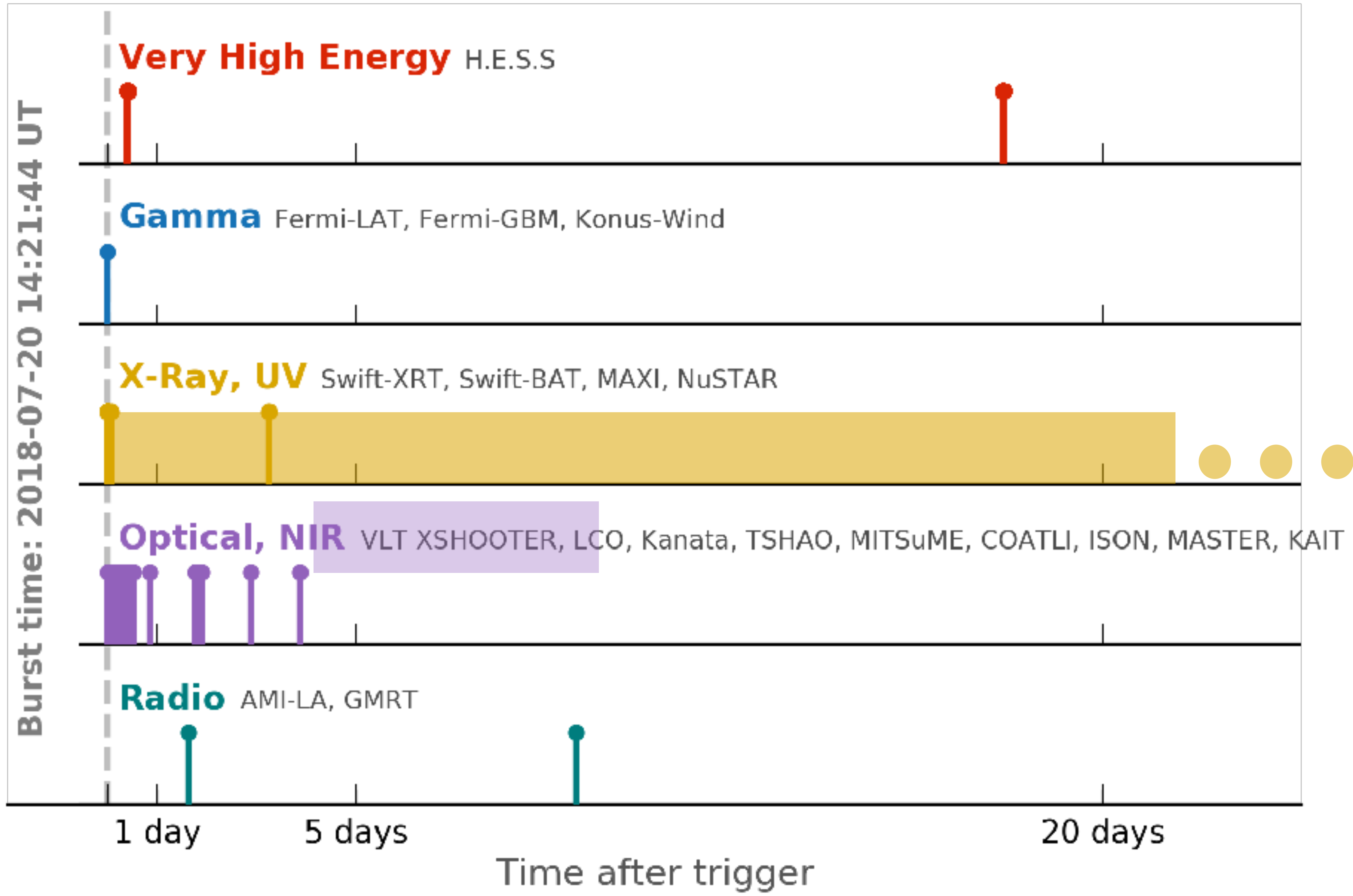
H.E.S.S.
(t, z, ++Criteria)

(~10 GRBs per year)



C. Hoischen+ (ICRC 2017)

GRB 180720B

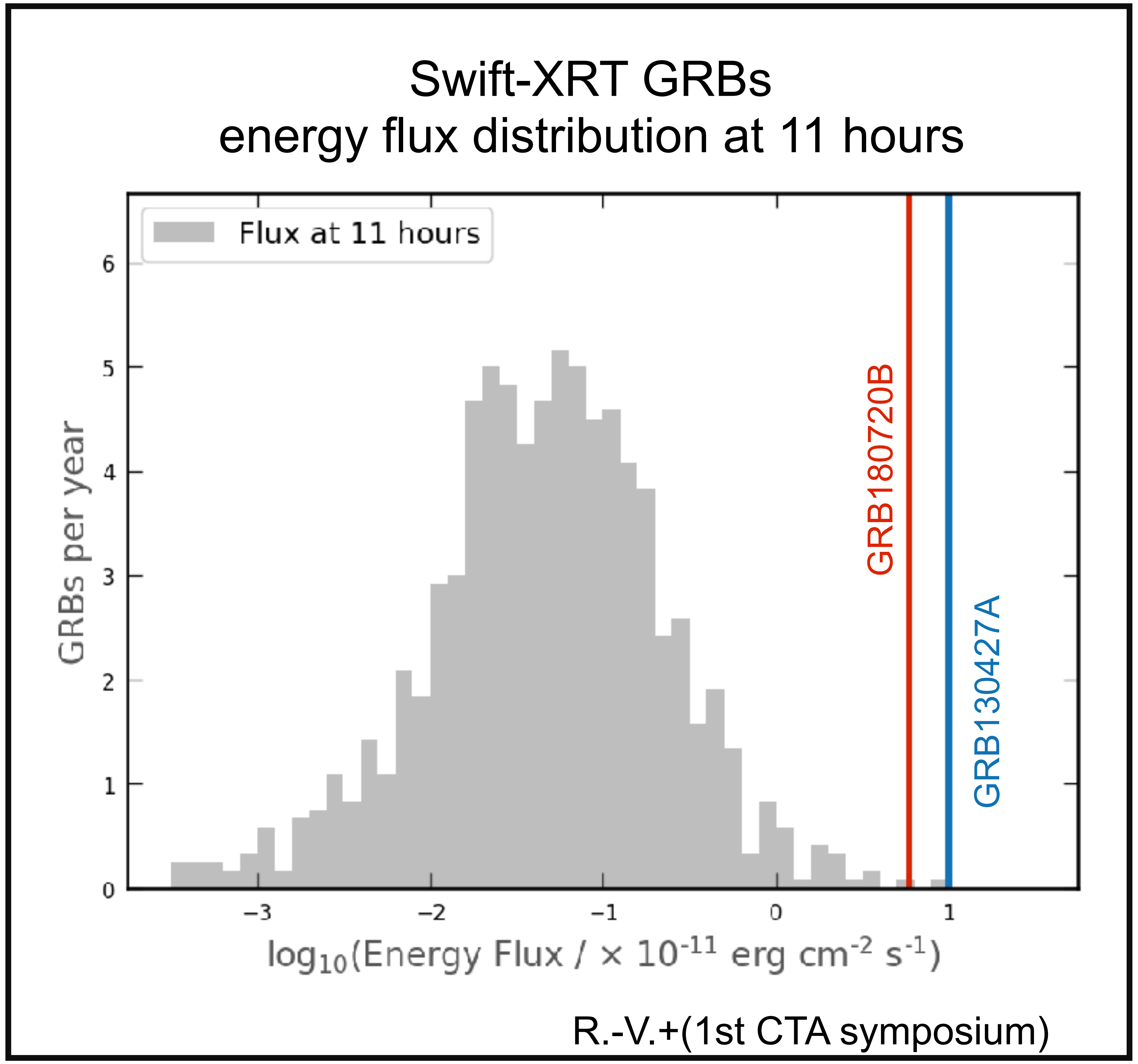


R.-V.+(1st CTA symposium)

z = 0.653

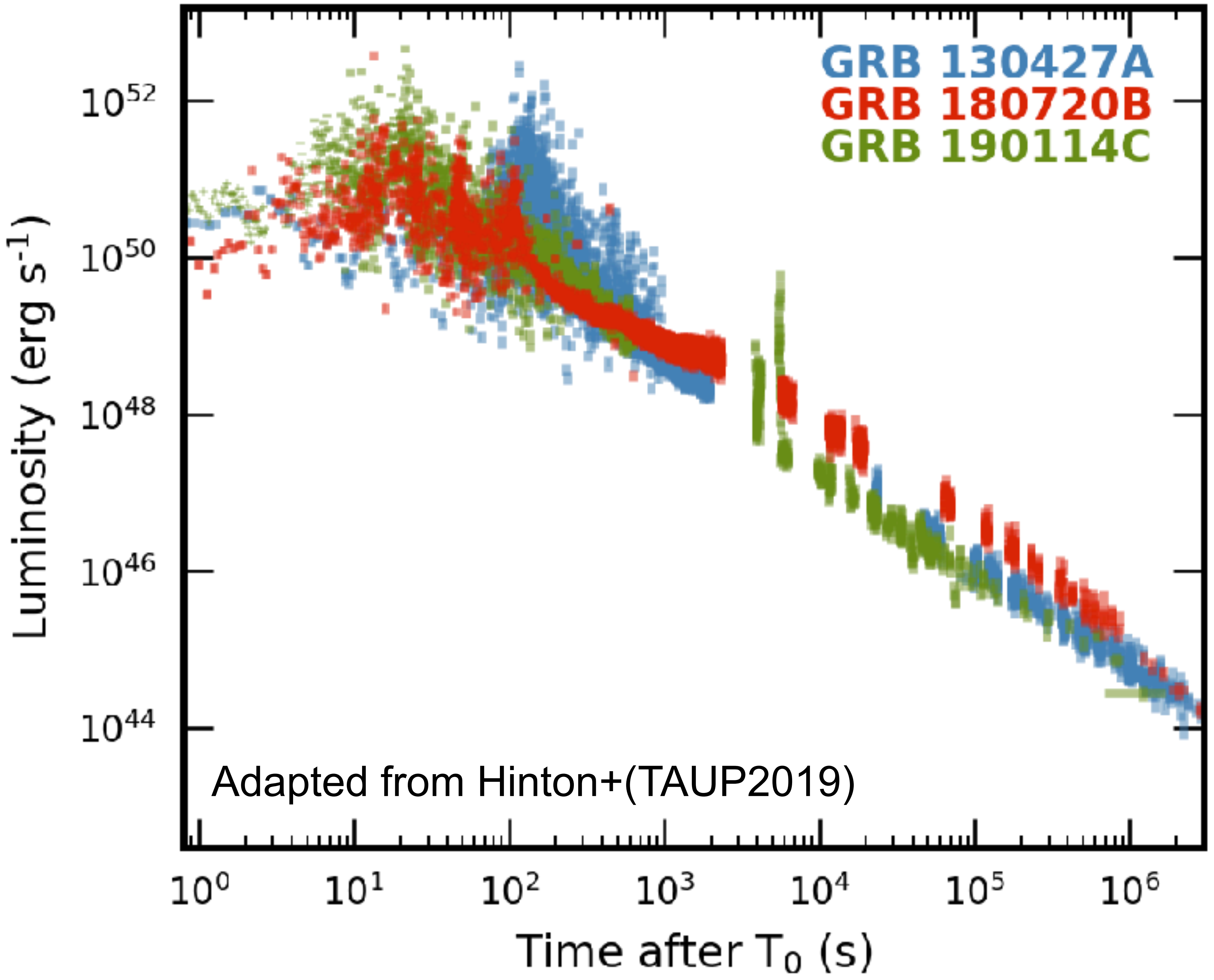
- Triggered Fermi-GBM and Swift-BAT (5 s later).
- Fermi-LAT detection from T_0 to T_0+700 s (max. energy photon 5 GeV).
- Extremely bright burst:
  - 2nd brightest afterglow measured by Swift-XRT.
  - 7th brightest prompt emission detected by Fermi-GBM.
- Very similar x-ray light curve to GRB130427A and GRB190114C.

GRB 180720B



- Triggered Fermi-GBM and Swift-BAT (5 s later).
- Fermi-LAT detection from T_0 to T_0+700 s (max. energy photon 5 GeV).
- Extremely bright burst:
  - 2nd brightest afterglow measured by Swift-XRT.
  - 7th brightest prompt emission detected by Fermi-GBM.
- Very similar x-ray light curve to GRB130427A and GRB190114C.

GRB 180720B



- Triggered Fermi-GBM and Swift-BAT (5 s later).
- Fermi-LAT detection from T_0 to T_0+700 s (max. energy photon 5 GeV).
- Extremely bright burst:
  - 2nd brightest afterglow measured by Swift-XRT.
  - 7th brightest prompt emission detected by Fermi-GBM.
- Very similar x-ray light curve to GRB130427A and GRB190114C.

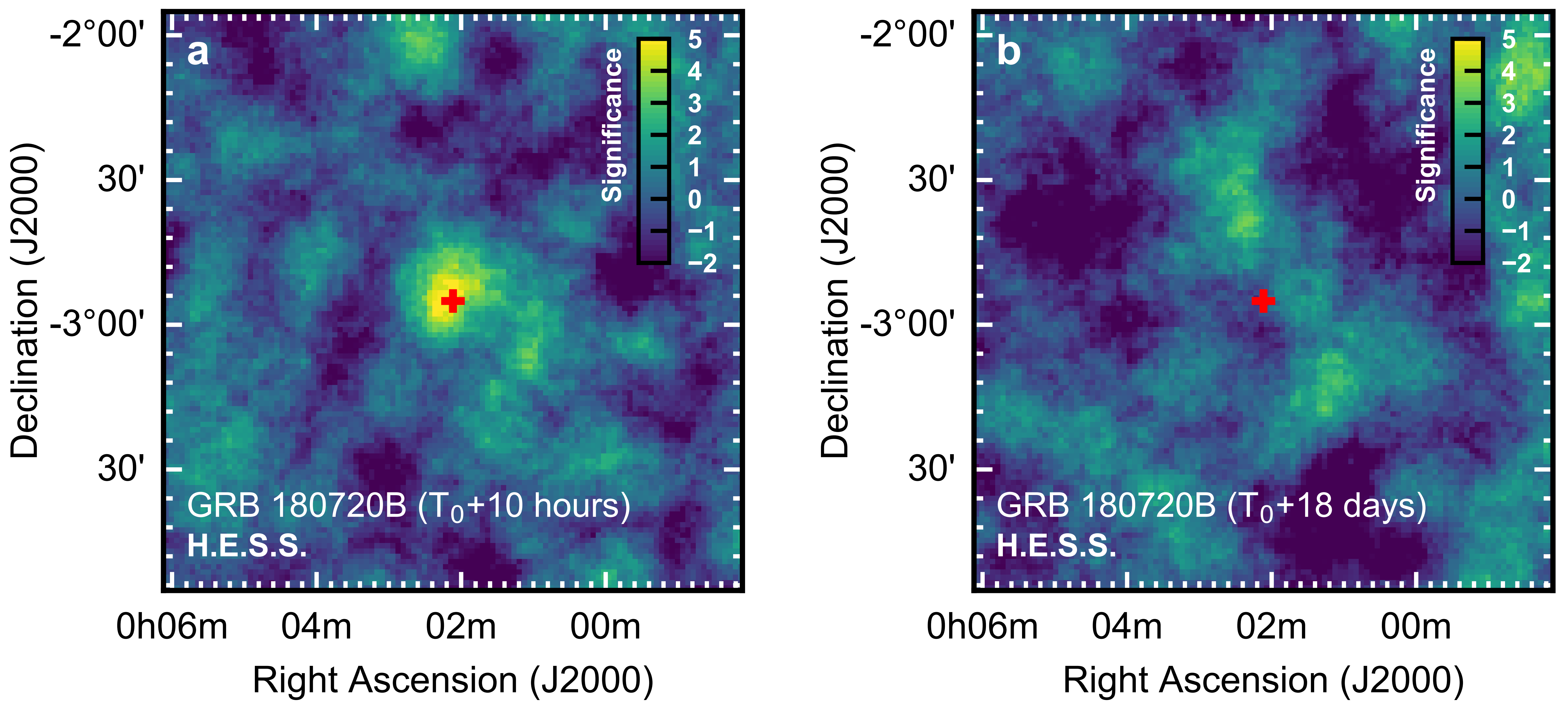
T_{90} ~ 48.9 seconds
z = 0.653

GRB 180720B H.E.S.S. detection

- Observation started ~10 hours after the burst.
- Follow-up performed for ~2 consecutive hours (zenith 40º to 25º)

H.E.S.S. detection: ~5.3σ pre-trial, 5.0σ post-trial (5 similar searches).

- Gone in re-observation 18 days after T_0.
- Cross-check analysis (totally independent calibration and analysis chain), influence weather conditions and other systematics

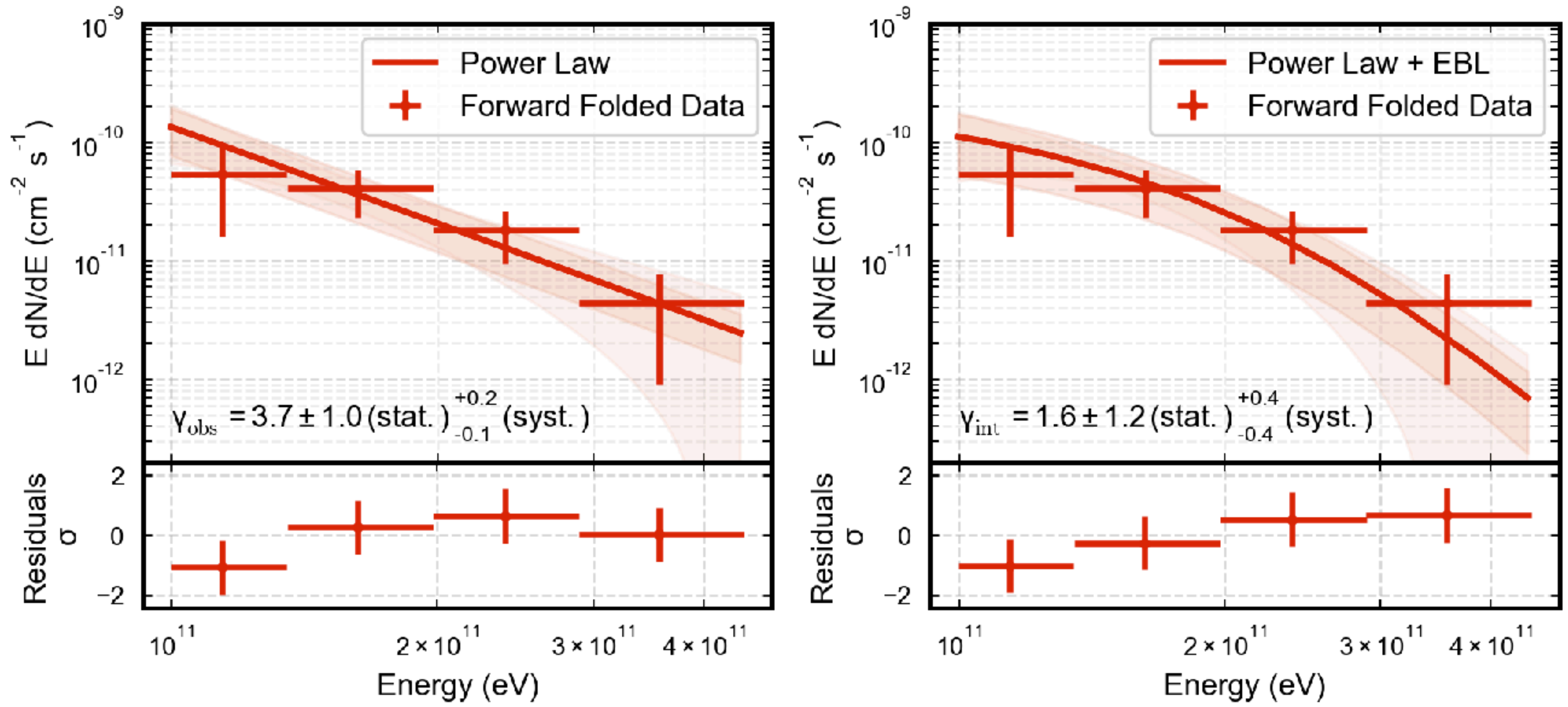


HESS Collaboration *Nature* **575,** 464–467 (2019)

GRB 180720B H.E.S.S. detection

Steep spectrum from 100 GeV to 440 GeV

$$\frac{dN}{dE} = \Phi_0 \left(\frac{E}{E_0}\right)^{-\gamma_{int}} \times exp(-\tau(E,z))$$

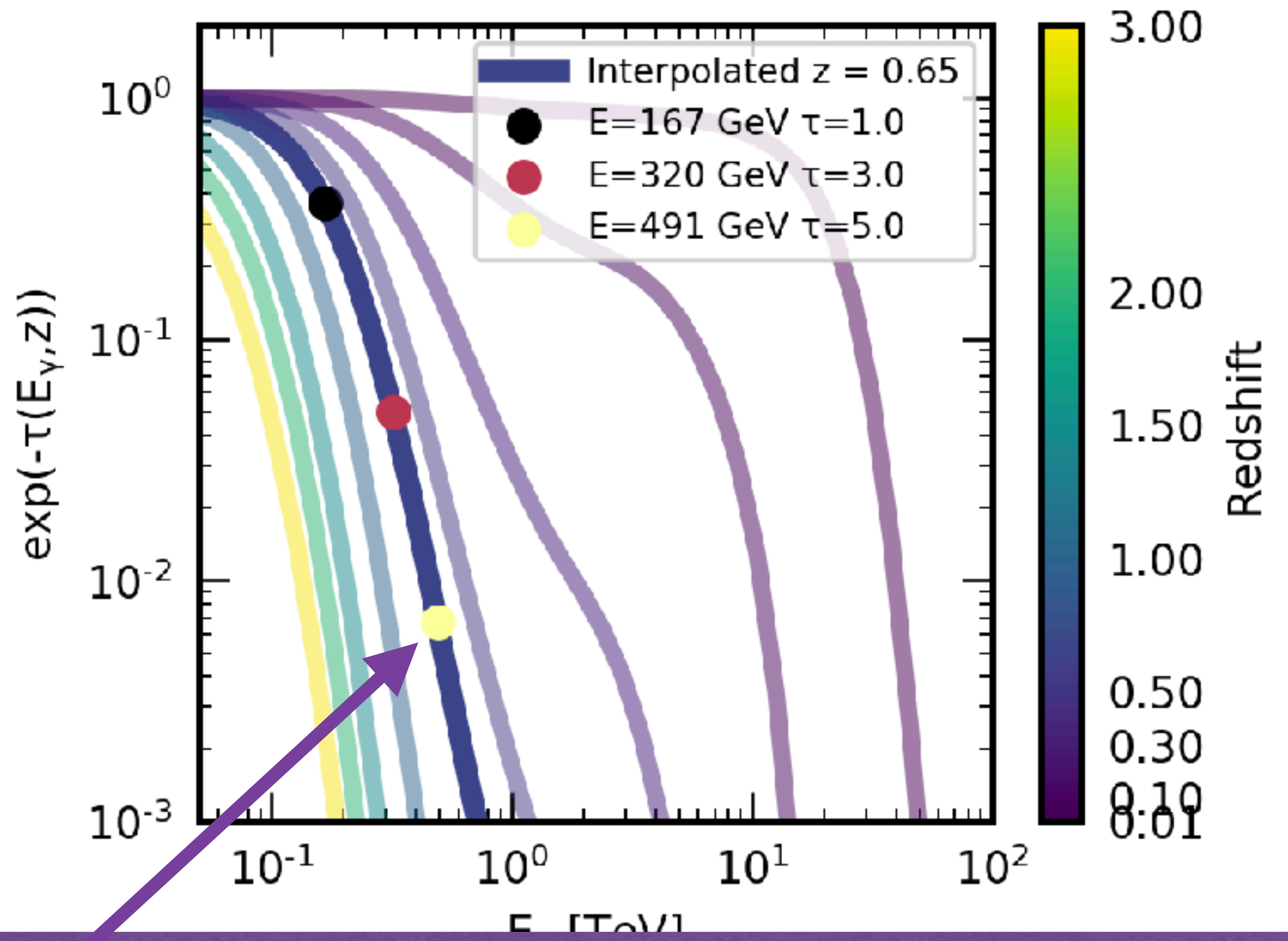


HESS Collaboration *Nature* **575,** 464–467 (2019)

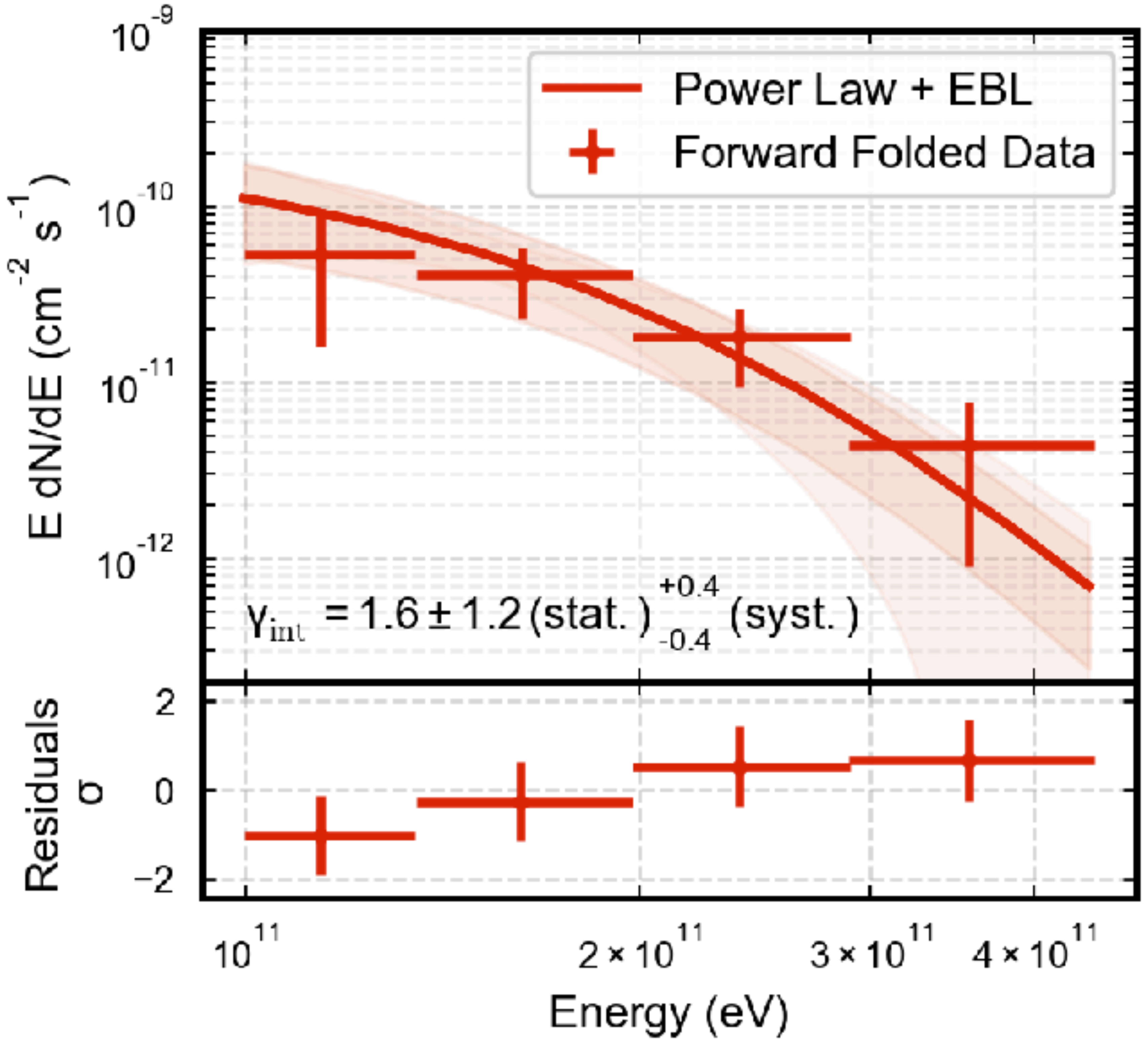
GRB 180720B H.E.S.S. detection

Very hard intrinsic spectrum (EBL de-absorbed), redshift 0.65 (most distant GRB from the 3 detected at VHE)

$$\frac{dN}{dE} = \Phi_0 \left(\frac{E}{E_0}\right)^{-\gamma_{int}} \times exp(-\tau(E,z))$$



98% absorption at ~500 GeV due to EBL

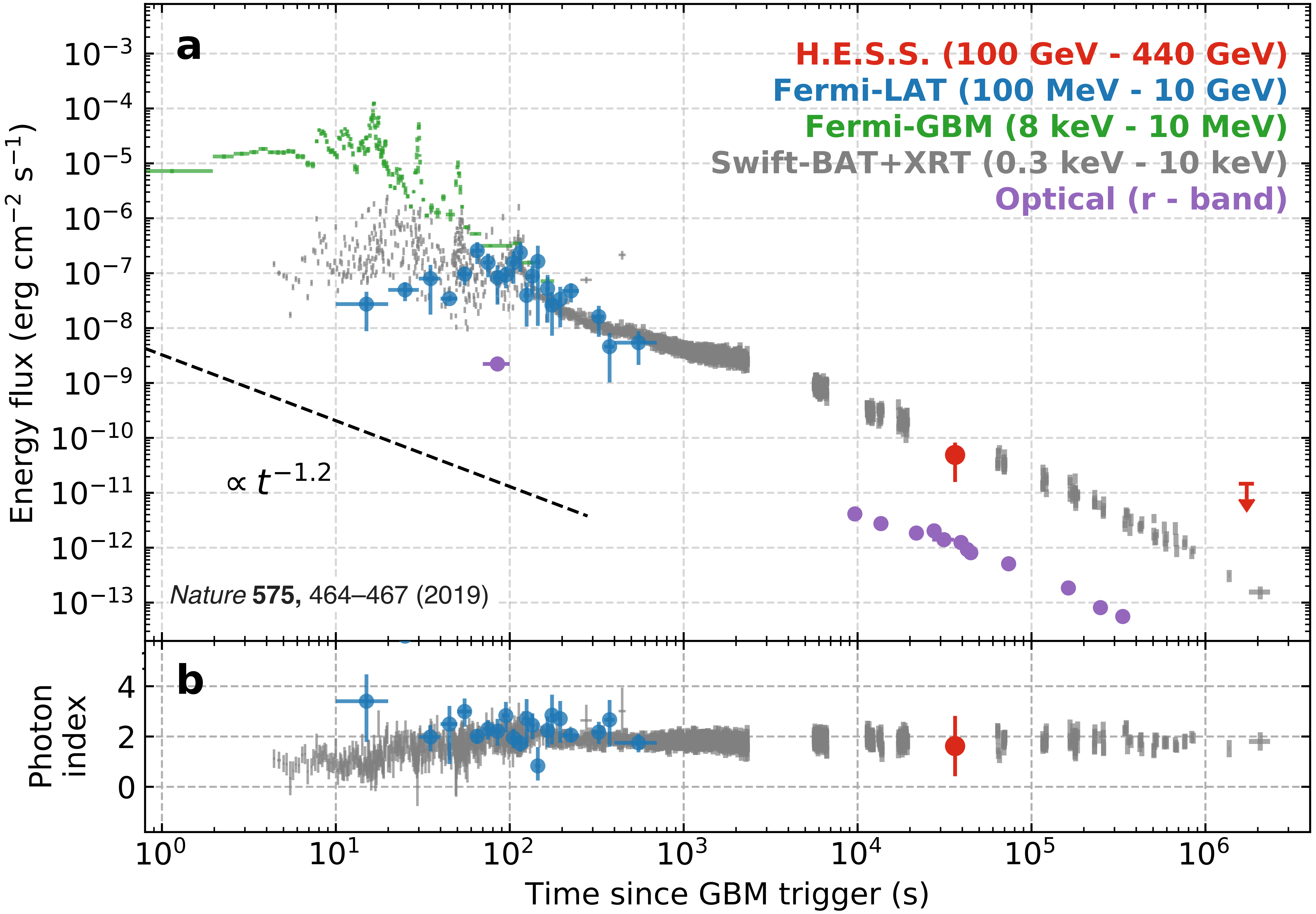


HESS Collaboration *Nature* **575**, 464–467 (2019)

GRB 180720B Multi-wavelength light curve

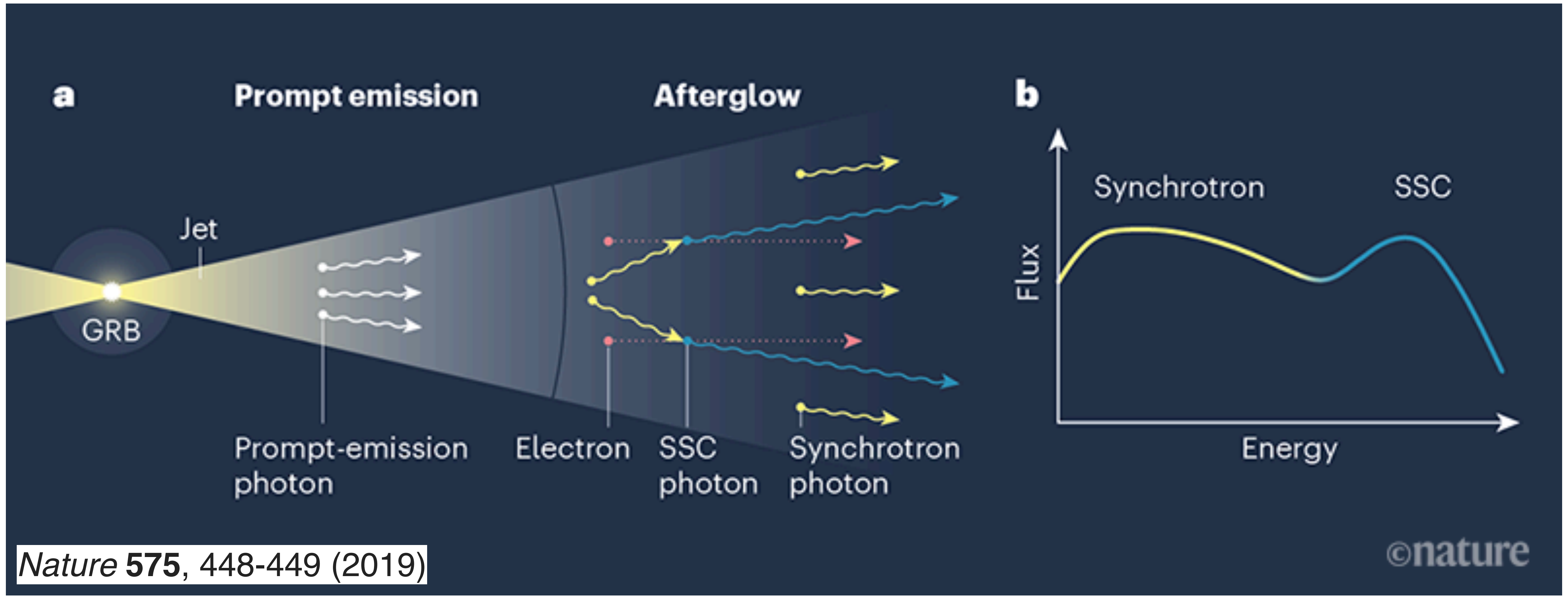
- Multi-peaked and very bright prompt emission.
- Fermi-LAT detection up to 700 s after trigger. Photon index -2.0.
- H.E.S.S. flux (100 - 440 GeV). Photon index consistent with -2.0.
- Gamma-ray energy flux at same level as X-Ray.
- Afterglow falling at same rate in all wave-lengths.

HESS Collaboration *Nature* **575,** 464–467 (2019)



Plausible emission mechanisms

- Higher efficiency favours leptonic mechanism.
- Lack of MWL coverage to rule out one or the other scenario (SYN, SSC).
- NO evidence of second bump in SED.



Nature **575**, 448-449 (2019)

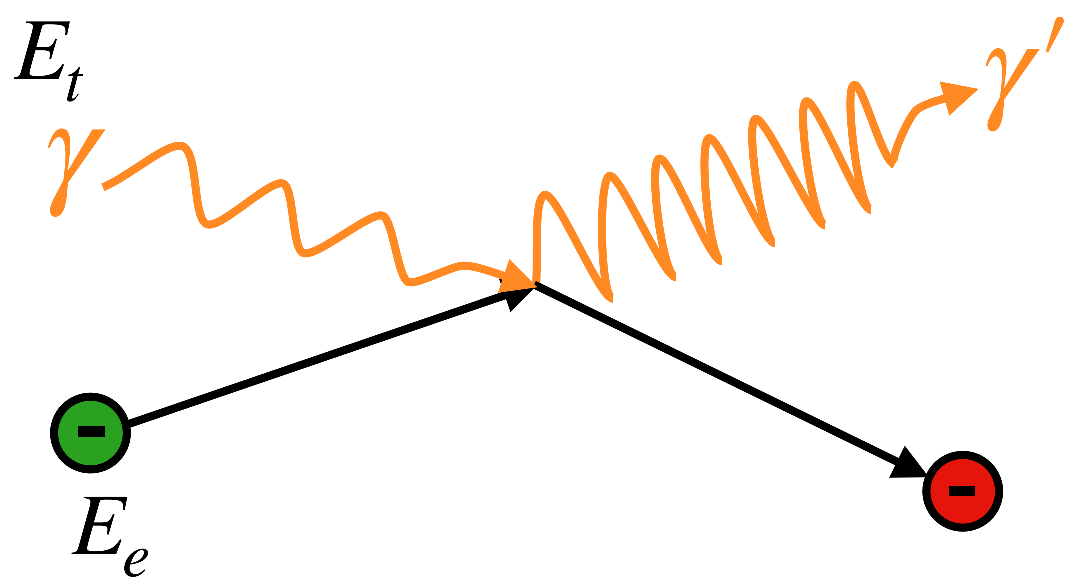
Synchrotron

$$E_{\rm sync}^{\rm max} = 100\Gamma\,{\rm MeV}$$

Γ>1000 at 10hrs!
while Γ~O(10) expected

Achieved with small scale magnetic turbulence OR E_e~O(PeV)

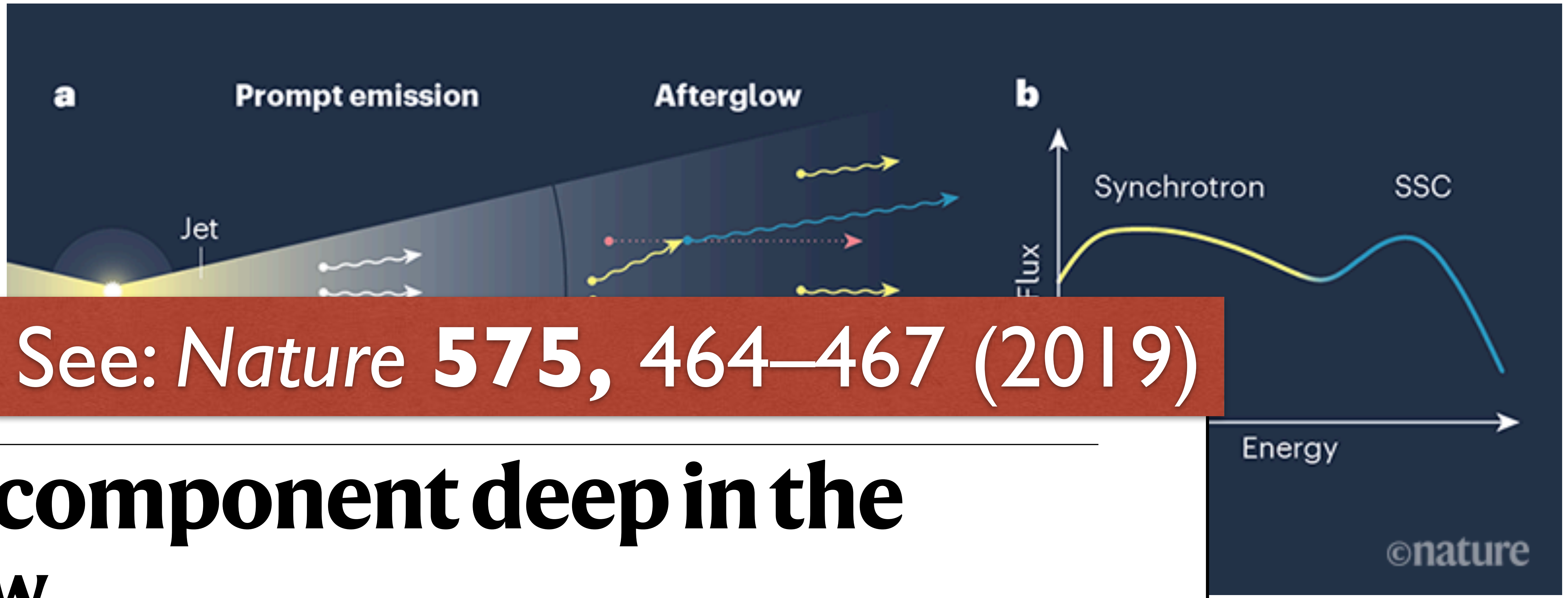
Synchrotron self-compton



$$min\left[E_t\left(\frac{E_e}{m_e c^2}\right), \Gamma E_e\right]$$

i.e. Requires E_t~1keV for E_e~10GeV boosted with Γ~20

Plausible emission mechanisms



See: *Nature* **575**, 464–467 (2019)

- Higher efficiency favours leptonic mechanism.
- Lack of MWL
  the other sce
- NO evidence

Article

A very-high-energy component deep in the γ-ray burst afterglow

https://doi.org/10.1038/s41586-019-1743-9
Received: 5 June 2019
Accepted: 30 September 2019
Published online: 20 November 2019

A list of authors and affiliations appears at the end of the paper.

Gamma-ray bursts (GRBs) are brief flashes of γ-rays and are considered to be the most energetic explosive phenomena in the Universe[1]. The emission from GRBs comprises a short (typically tens of seconds) and bright prompt emission, followed by a much longer afterglow phase. During the afterglow phase, the shocked outflow—produced by the interaction between the ejected matter and the circumburst medium—slows down, and a gradual decrease in brightness is observed[2]. GRBs typically emit most of

$$E_{\rm sync}^{\rm max} = 1$$

W

Achieved with small scale magnetic turbulence OR E_e~O(PeV)

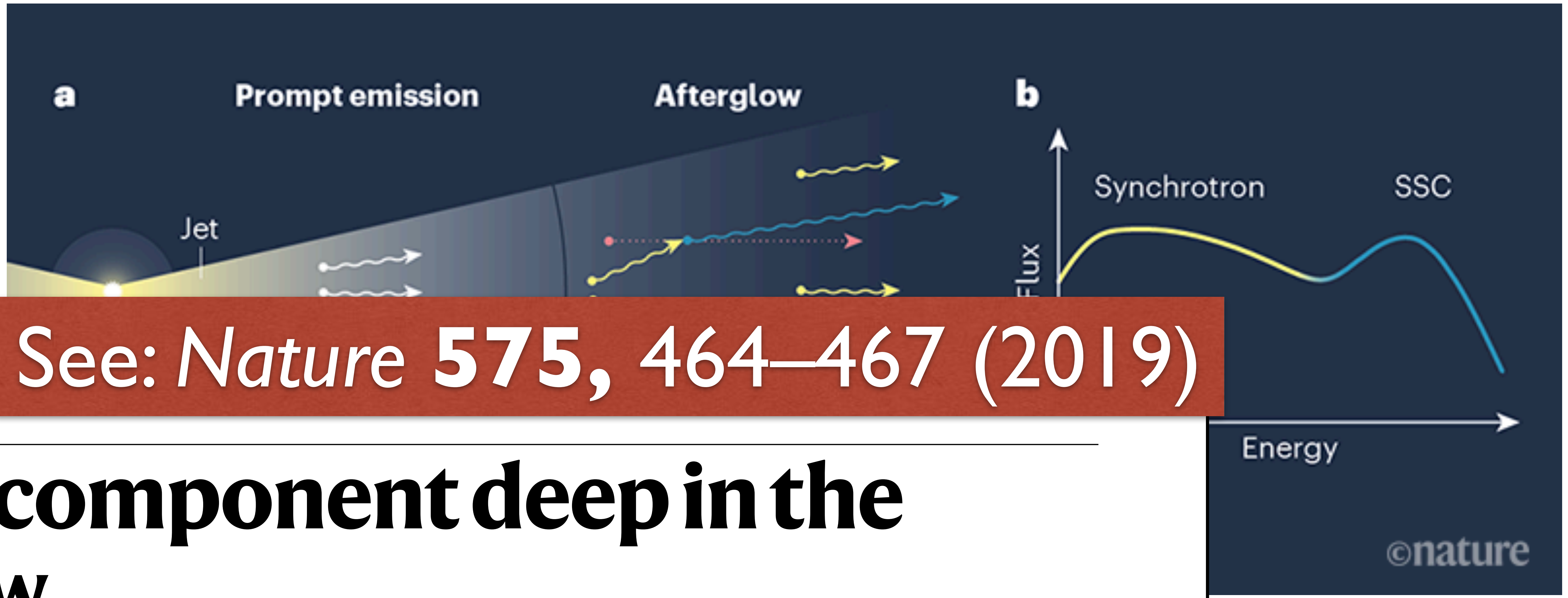
pton

E_e $_ec^2$ $\Big)$ $, \Gamma E_e \Big]$

i.e. Requires E_t~1keV for E_e~10GeV boosted with Γ~20

Plausible emission mechanisms

- Higher efficiency favours leptonic mechanism.
- Lack of MWL ... the other sce...
- NO evidence...



See: *Nature* **575,** 464–467 (2019)

Article

A very-high-energy component deep in the γ-ray burst afterglow

by the interaction between the ejected matter and the circumburst medium—slows down, and a gradual decrease in brightness is observed[2]. GRBs typically emit most of

GRB 180720B Strong input on follow-up strategy ——
——> GRB190829A detection (see ATel #13052 +GCNs)

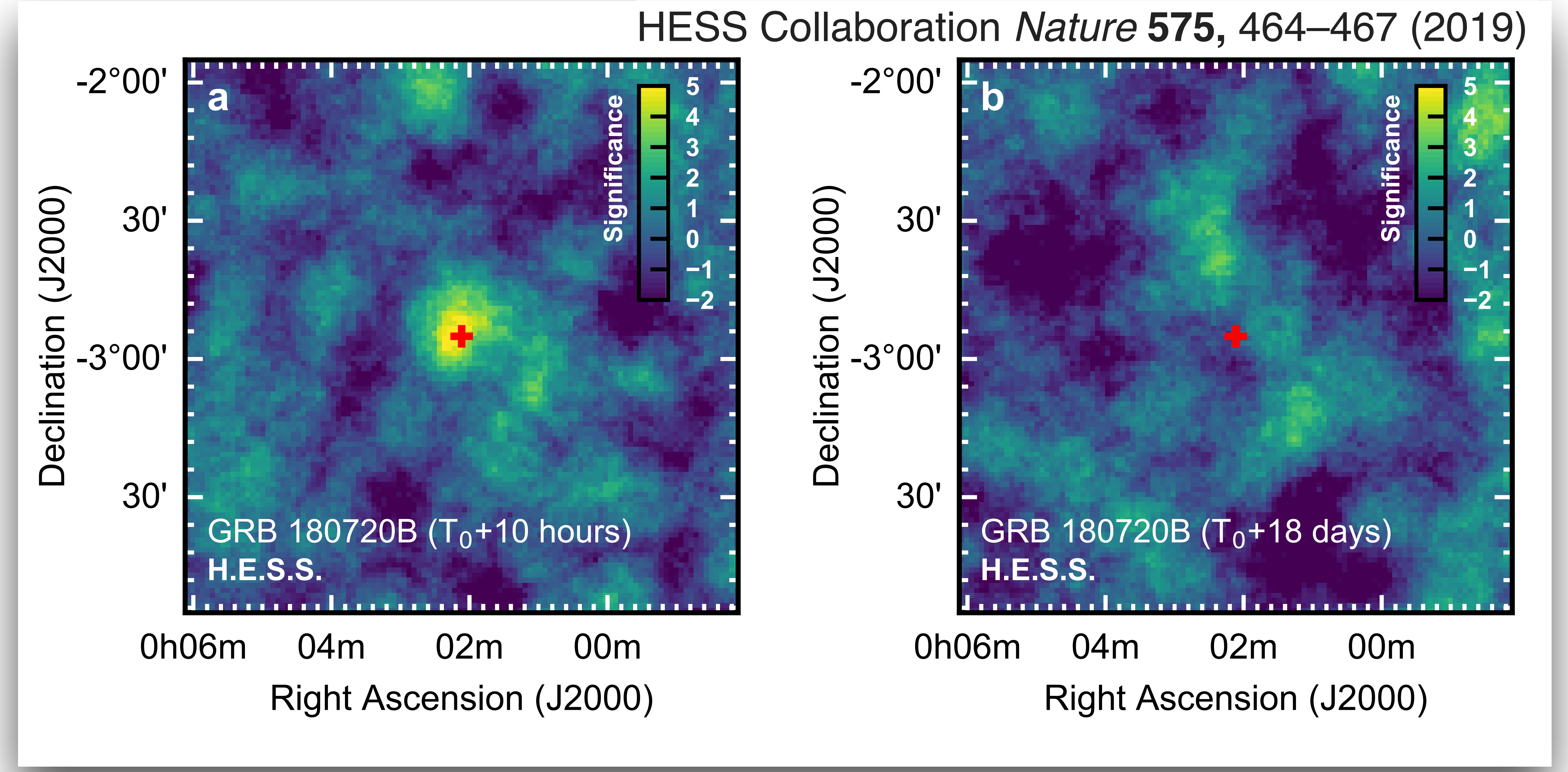
W...

Achieved with small scale magnetic turbulence OR E_e~O(PeV)

i.e. Requires E_t~1keV for E_e~10GeV boosted with Γ~20

Summary GRB 180720B at VHE

- First detection of a GRB at VHE.
- +Recent detections have solved the decades long mystery of VHE emission from GRBs.
- GRB 180720B is detected up to 440 GeV at very-late times (redshift 0.653).
- Most distant/late from the 3 detected at VHE
- Great achievement for IACTs - extremely high sensitivities and aggressive GRB follow-up programmes.
- Requires either extreme synchrotron or SSC.



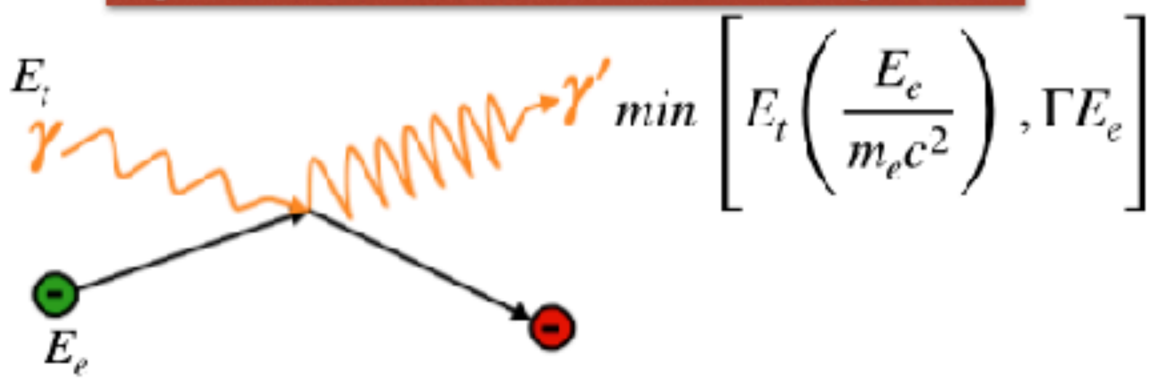
Synchrotron

$$E_{\rm sync}^{\rm max} = 100\Gamma\,{\rm MeV}$$

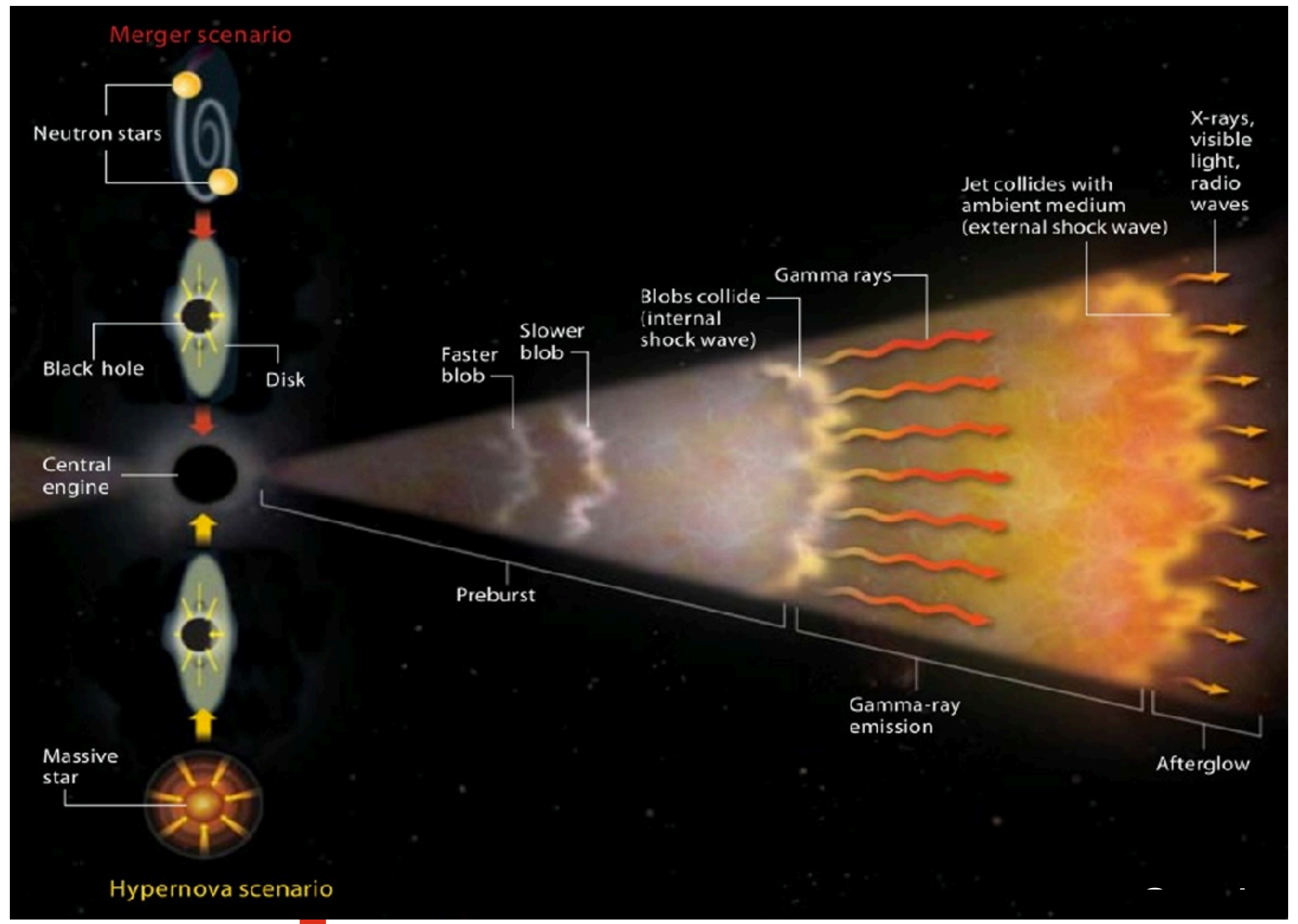
Γ>1000 at 10hrs!
while Γ~O(10) expected

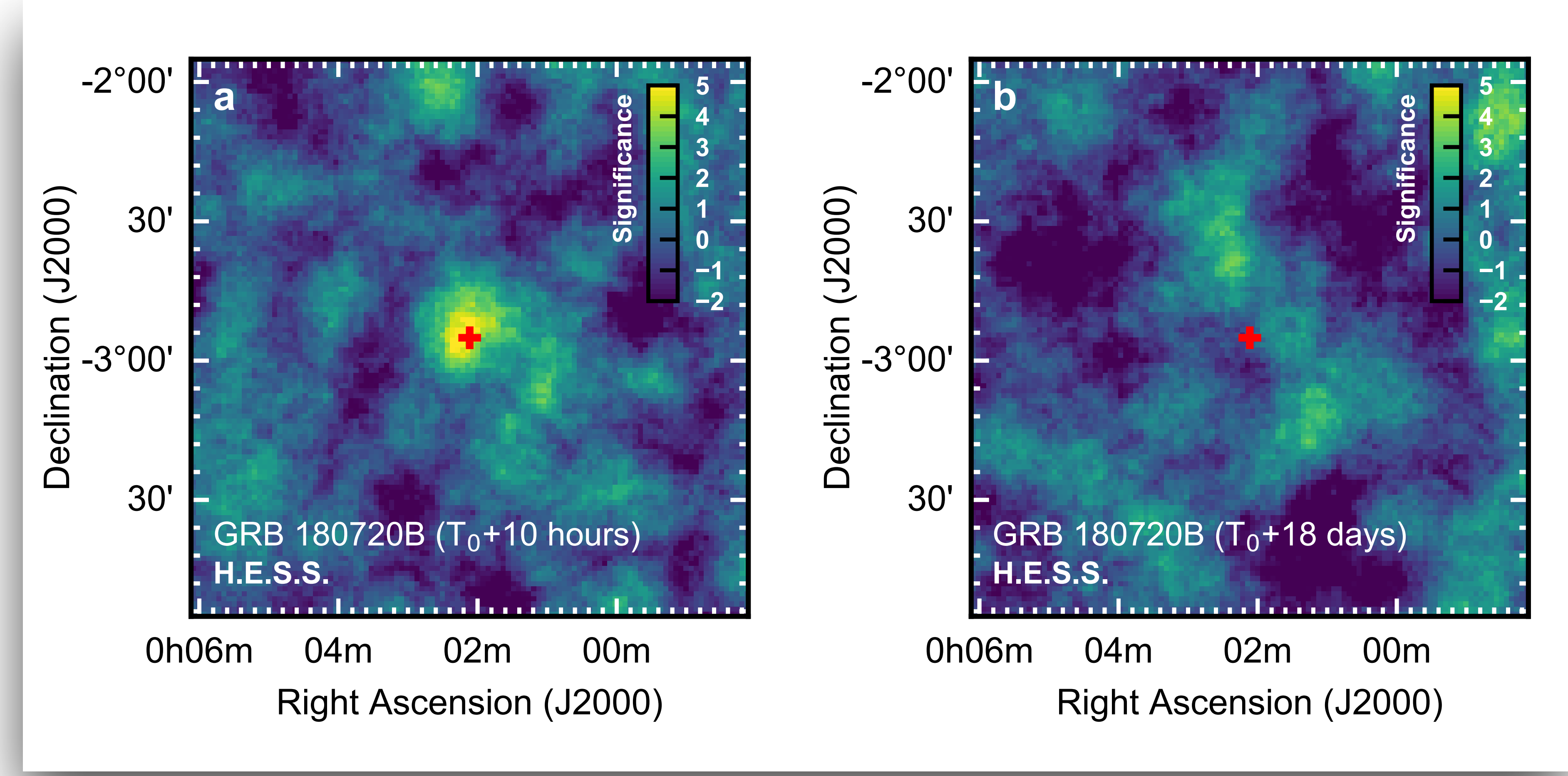
Achieved with small scale magnetic turbulence OR E_e~O(PeV)

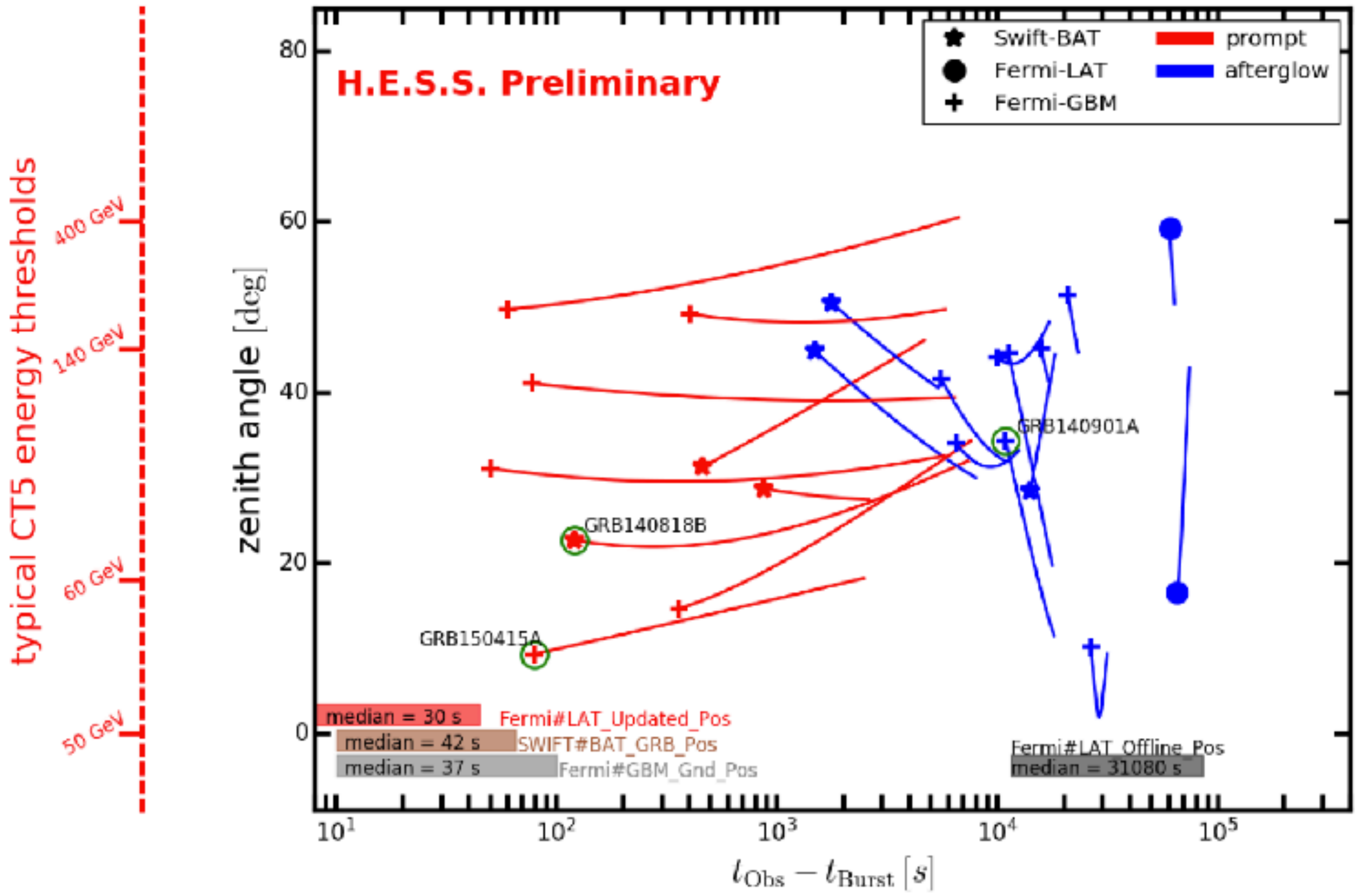
Synchrotron self-compton



i.e. Requires E_t~1keV for
E_e~10GeV boosted with Γ~20







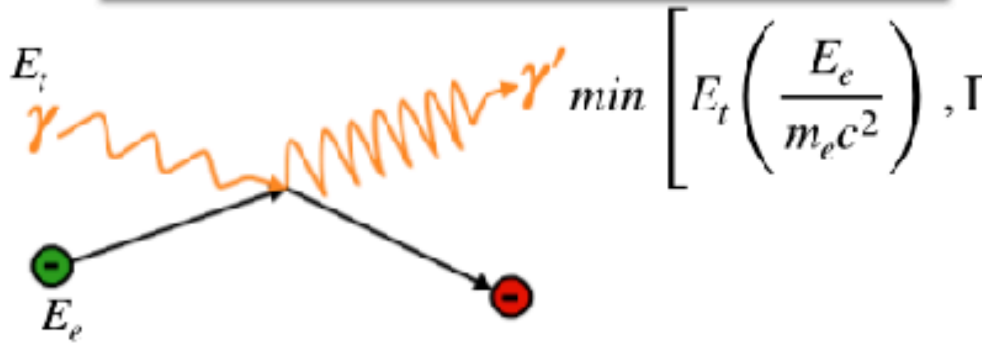
Synchrotron

$$E_{sync}^{max} = 100\Gamma \text{ MeV}$$

Γ>1000 at 10hrs!
while Γ~O(10) expected

Achieved with small scale magnetic turbulence OR E_e~O(PeV)

Synchrotron self-compton



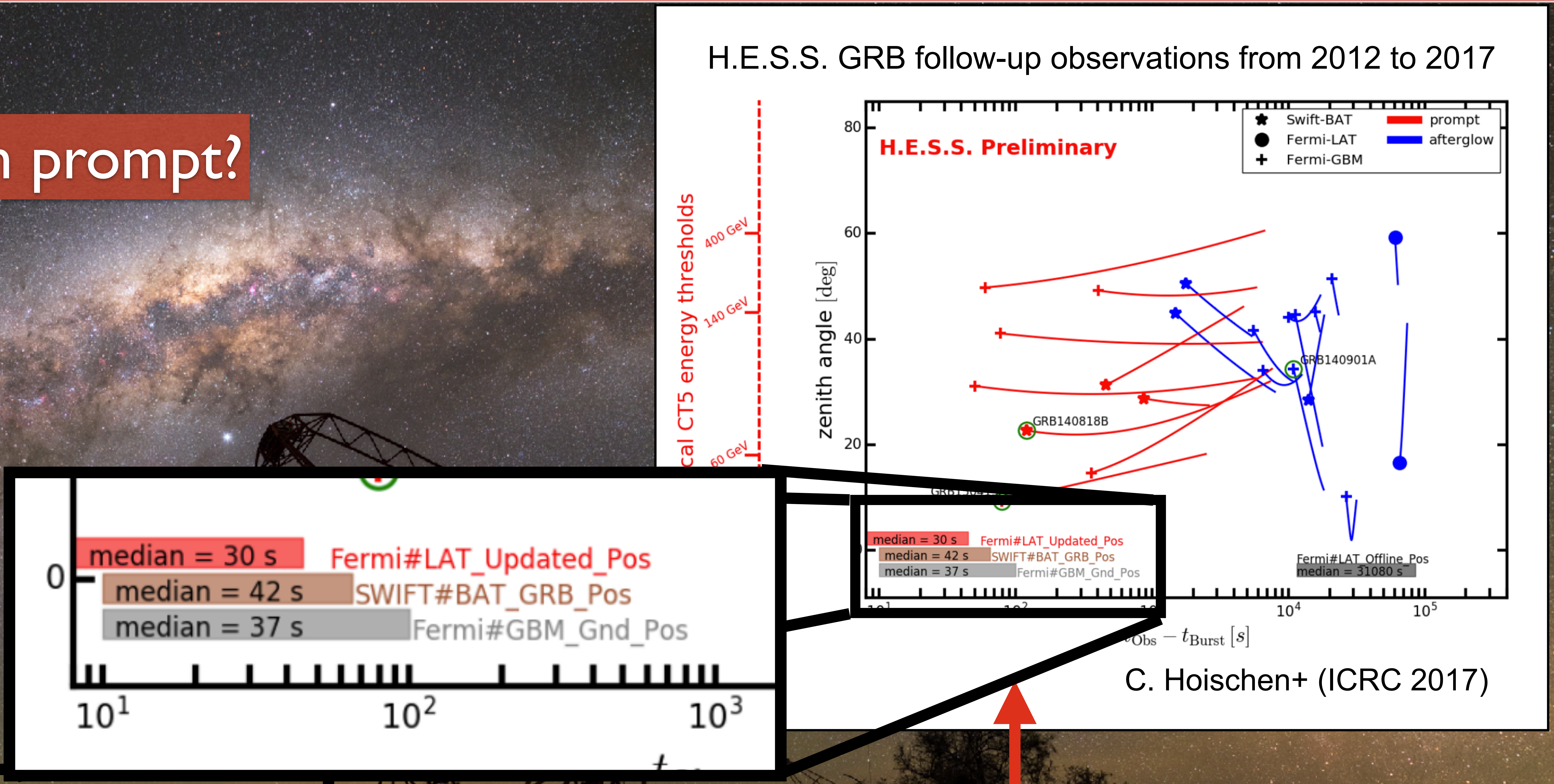
i.e. Requires E_t~1keV for E_e~10GeV boosted with Γ~20

Will we ever catch prompt?

Swift-BAT/XRT
Fermi-LAT/GBM
GW, Neutrinos

VOEvent

H.E.S.S.
(t, z, ++Criteria)



(~10 GRBs per year)

Bonus…

[Previous | Next | ADS]

GRB190829A: Detection of VHE gamma-ray emission with H.E.S.S.

ATel #13052; *M. de Naurois (H. E.S. S. Collaboration)*
on ***30 Aug 2019; 07:12 UT***
Credential Certification: Fabian SchÃ Â¼ssler (fabian.schussler@cea.fr)

Subjects: Gamma Ray, >GeV, TeV, VHE, Gamma-Ray Burst

Tweet

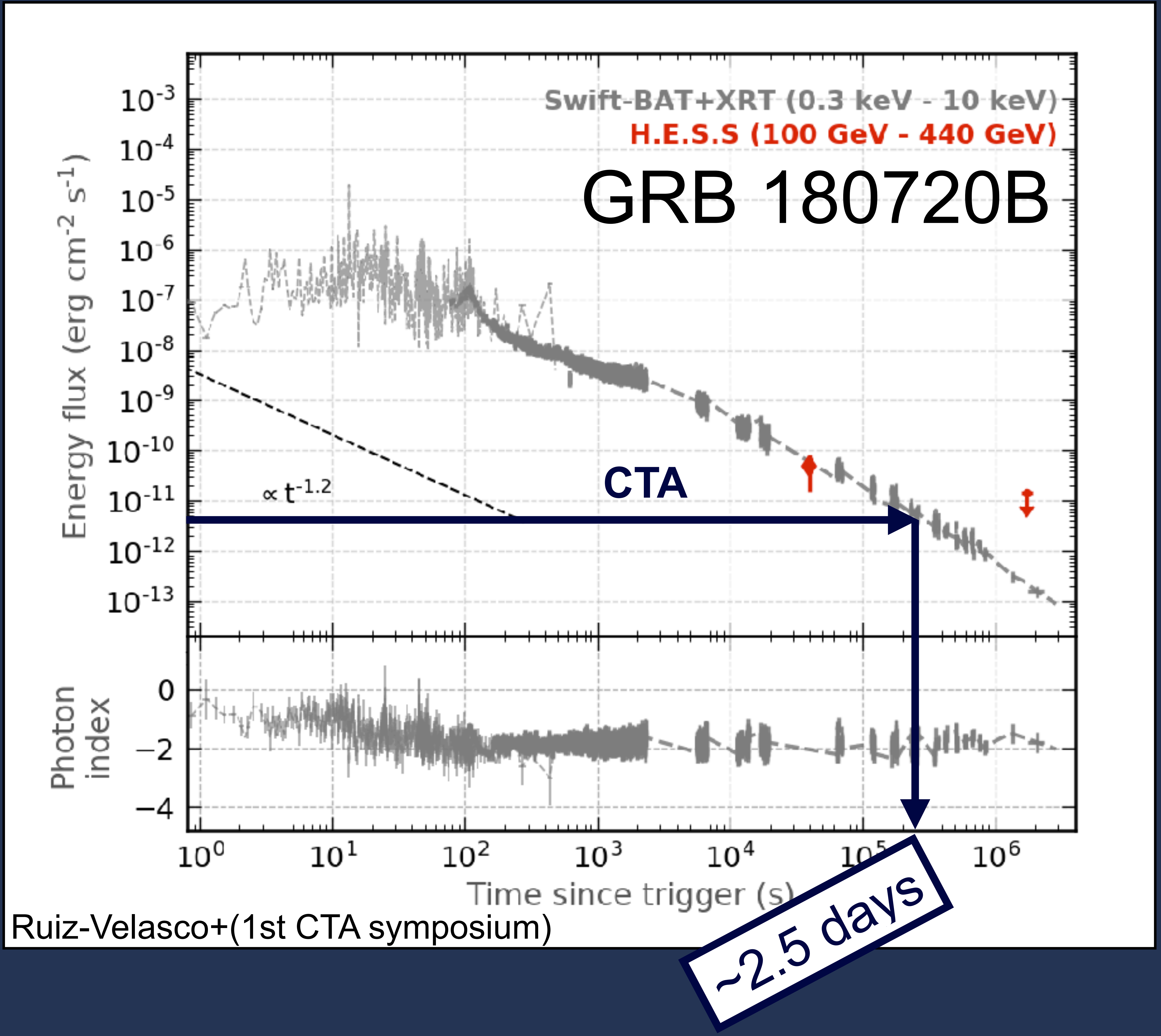
T90 ~ 60 seconds
z = 0.078

The H.E.S.S. array of imaging atmospheric Cherenkov telescopes was used to carry out follow-up observations of the afterglow of GRB 190829A (Dichiara et al., GCN 25552). At a redshift of z = 0.0785 +/- 0.005 (A.F. Valeev et al., GCN 25565) this is one of the nearest GRBs detected to date. H.E.S.S. Observations started July 30 at 00:16 UTC (i.e. T0 + 4h20), lasted until 3h50 UTC and were taken under good conditions. A preliminary onsite analysis of the obtained data shows a >5sigma gamma-ray excess compatible with the direction of GRB190829A. Further analyses of the data are on-going and further H.E.S.S. observations are planned. We strongly encourage follow-up at all wavelengths. H.E.S.S. is an array of five imaging atmospheric Cherenkov telescopes for the detection of very-high-energy gamma-ray sources and is located in the Khomas Highlands in Namibia. It was constructed and is operated by researchers from Armenia, Australia, Austria, France, Germany, Ireland, Japan, the Netherlands, Poland, Sou[...] country, Namibia. For more details see https://www.mpi-hd.mp[...]

Paper in preparation

Prospects for future observatories

- Have ~10 times better sensitivity than H.E.S.S.
- Be able to detect flux over many decades in time with detailed spectra information.
- Boost the detection of GRBs at VHE.
  - ~ 3 GRBs per year at 11 hours after burst.
  - ~ 11 GRBs per year at 5 hours after burst

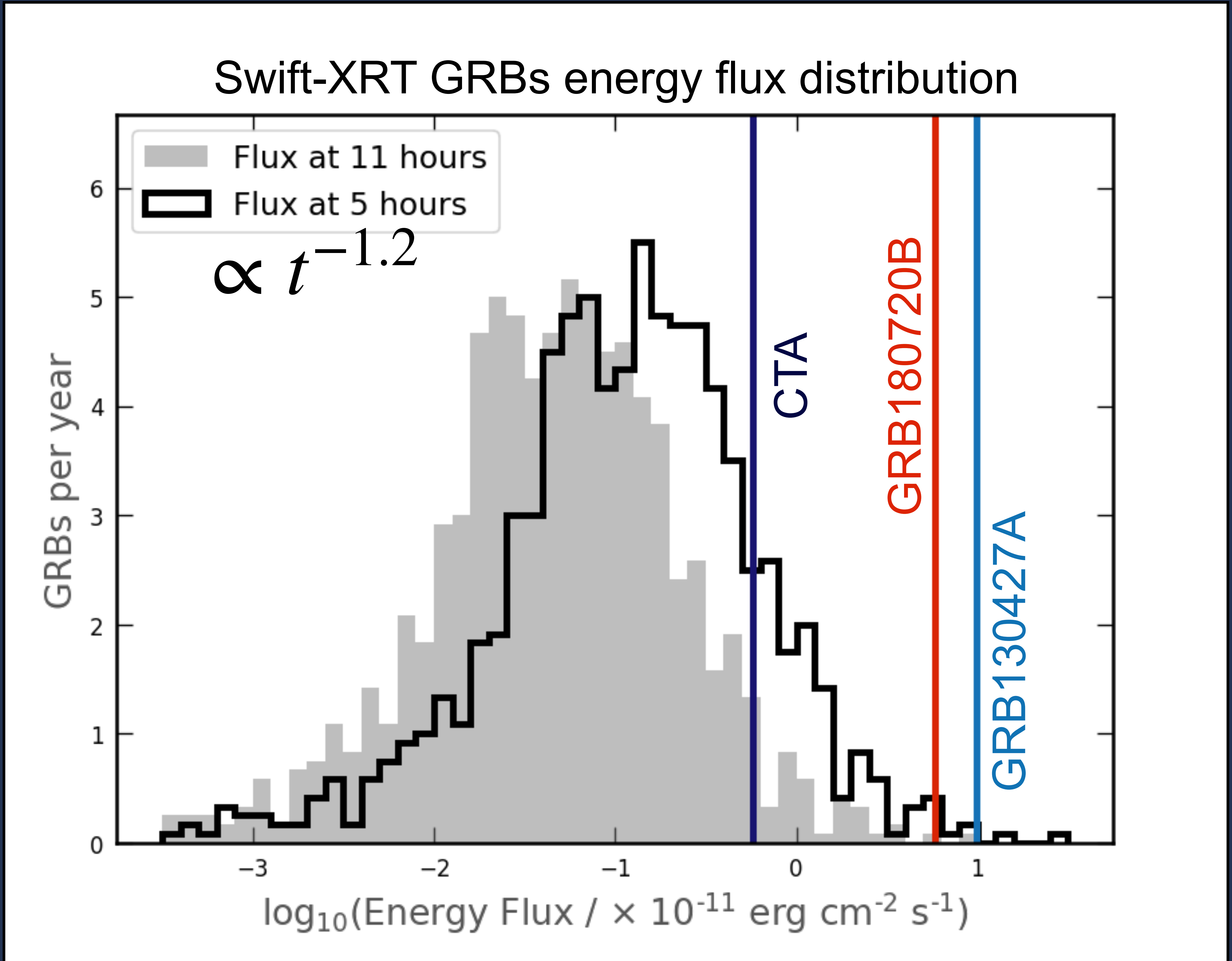


Ruiz-Velasco+(1st CTA symposium)

Edna Ruiz-Velasco (MPIK) H.E.S.S. Collaboration. The detection of VHE emission in the deep afterglow of GRB 180720B. TeVPA 2019

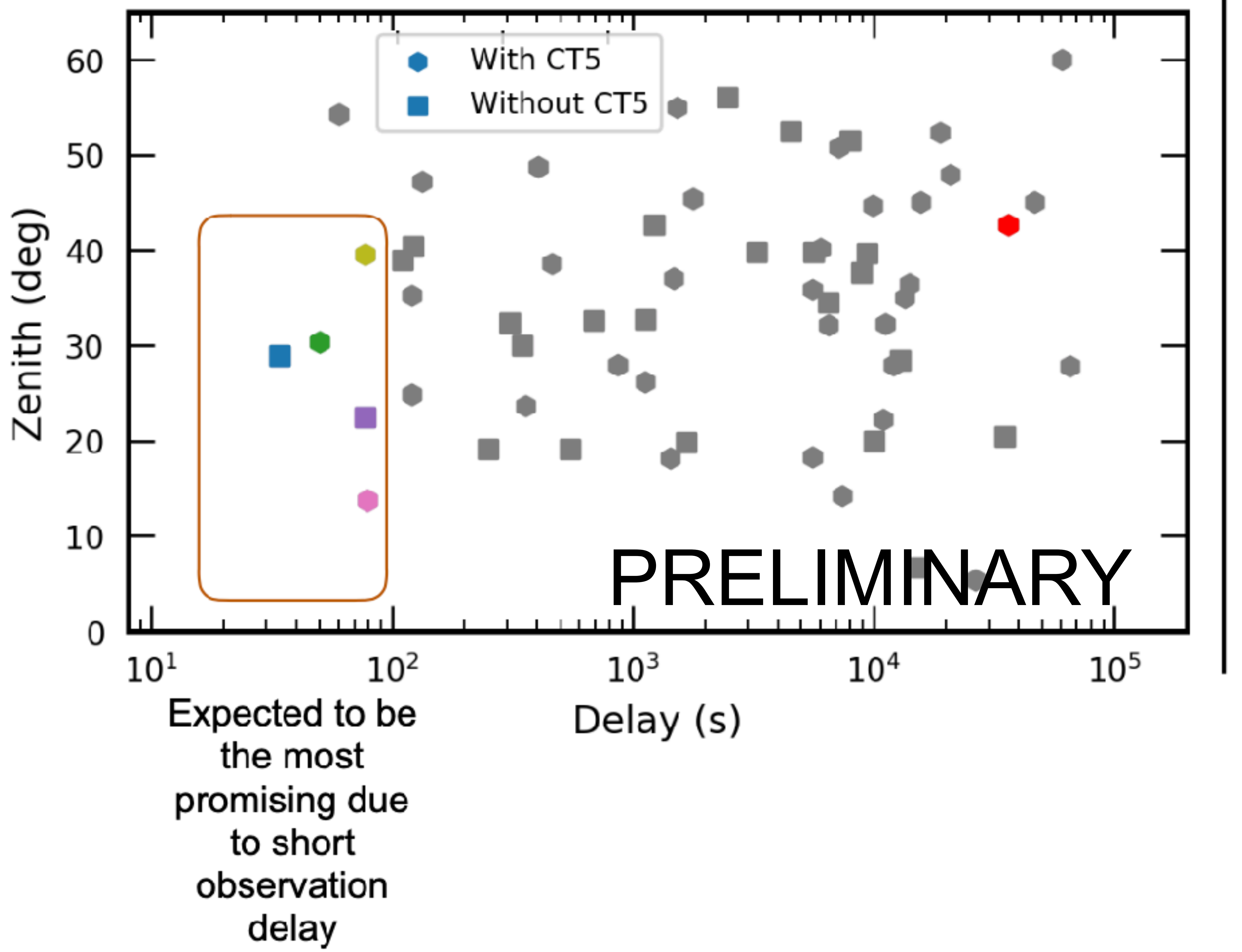
Prospects for future observatories

- Have ~10 times better sensitivity than H.E.S.S.
- Be able to detect flux over many decades in time with detailed spectra information.
- Boost the detection of GRBs at VHE.
  - ~ 3 GRBs per year at 11 hours after burst.
  - ~ 11 GRBs per year at 5 hours after burst



Ruiz-Velasco+(1st CTA symposium)

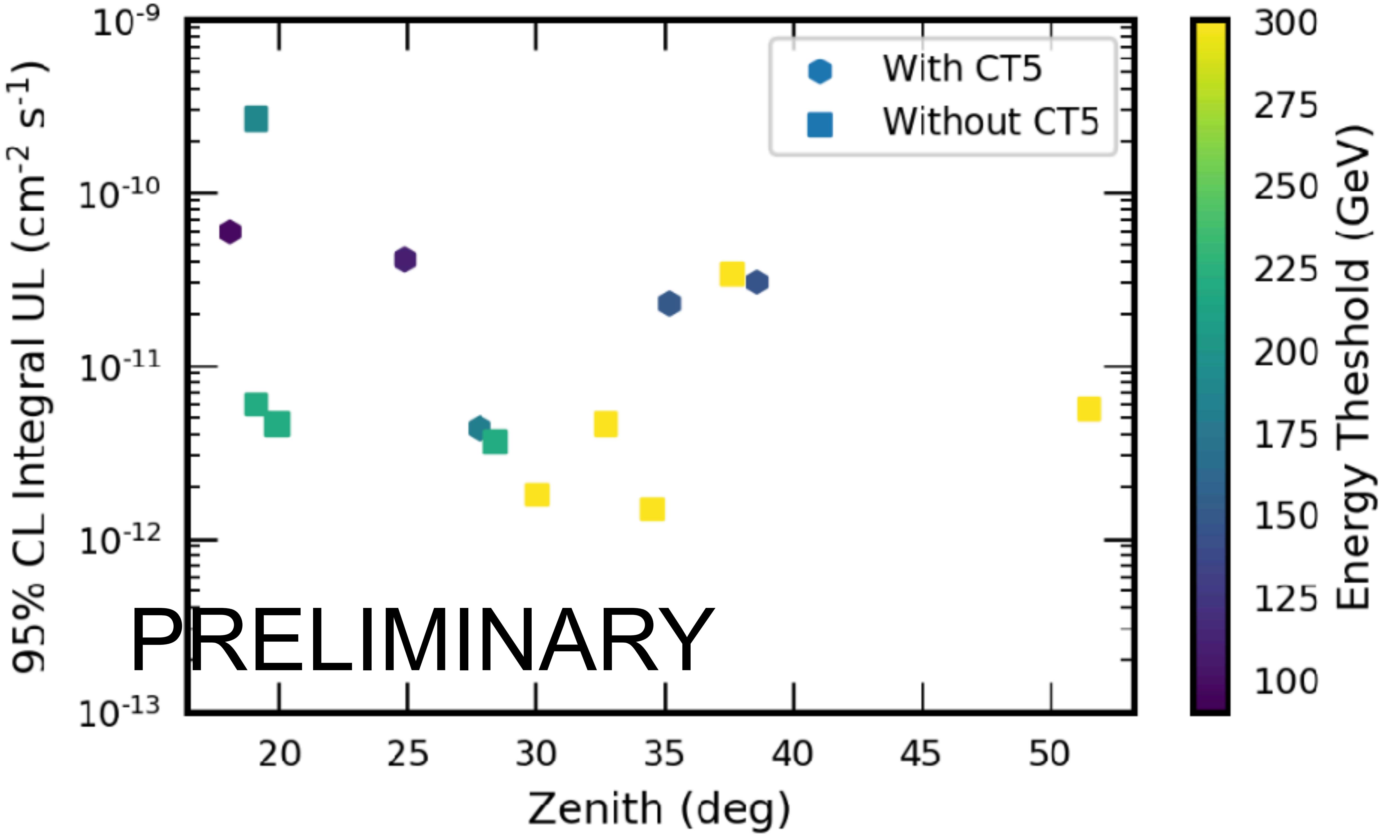
66 GRB follow-up observations since 2008



increasing energy threshold

15 Swift-BAT GRBs have been analyzed:

- Integral ULs derived for 14 observations

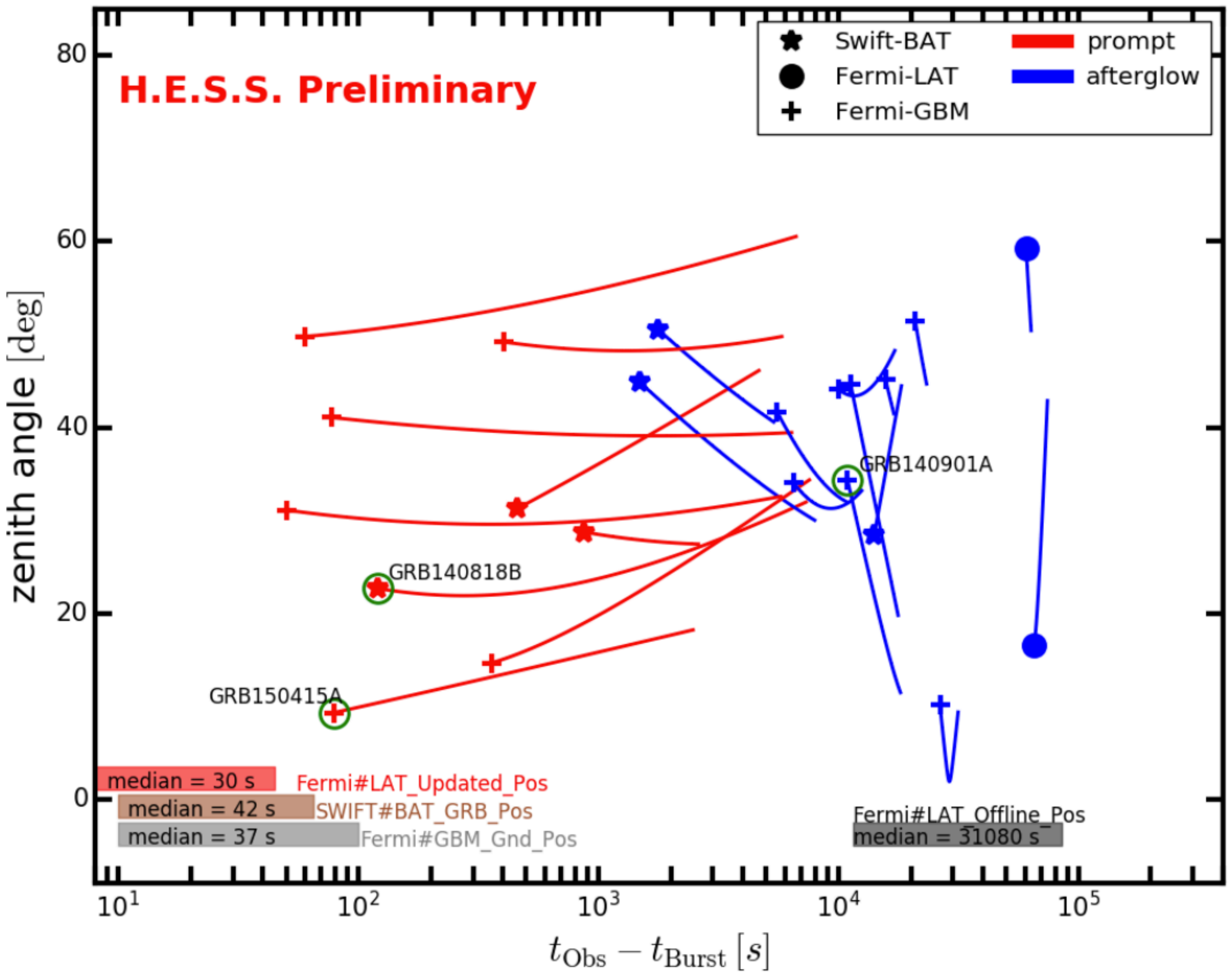


reported in the literature[62], corresponding to weaker magnetic fields by several orders of magnitude. Assuming that synchrotron emission beyond the 100 MeV energy limit in the co-moving frame can be achieved, the energy of the emitting electrons can be estimated as $E_e \approx 4[E/(100\,\mathrm{keV})]^{1/2}(\Gamma/20)^{-1/2}[B/(0.1\,\mathrm{G})]^{-1/2}\eta_{\mathrm{turb}}^{-1/2}$ TeV. The production of 100-GeV γ-rays through a synchrotron scenario therefore requires electrons of ultrahigh-energy, $E_e \approx 4$ PeV, unless a configuration with a very-small-scale turbulence is present. The energy of particles that provide the dominant contribution to the inverse Compton emission depends strongly on the spectrum of the target photons and the bulk Lorentz factor. An electron with energy E_e up-scatters a target

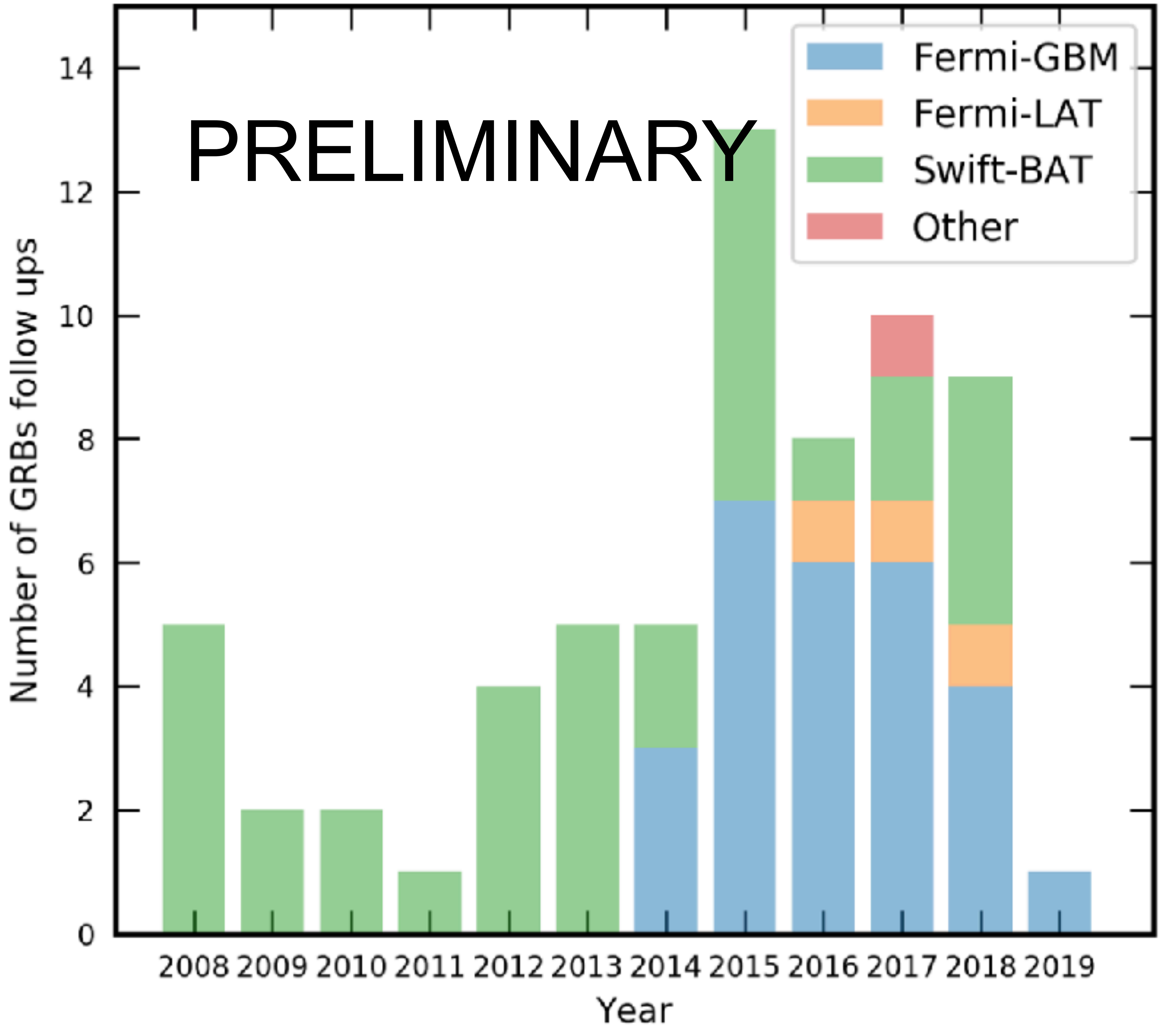
The H.E.S.S. GRB programme: Trigger criteria

- GRBs followed up automatically if in FoV at time of alert
- Monthly shift of GRB expert decides in a case by case for afterglows/extend observations.
- Redshift-delay dependant trigger:
    - 24h after trigger if z < 0.1
    - 12h after trigger if z < 0.3
    - 6h after trigger if z < 1.0
    - 4h after trigger if z unknown.

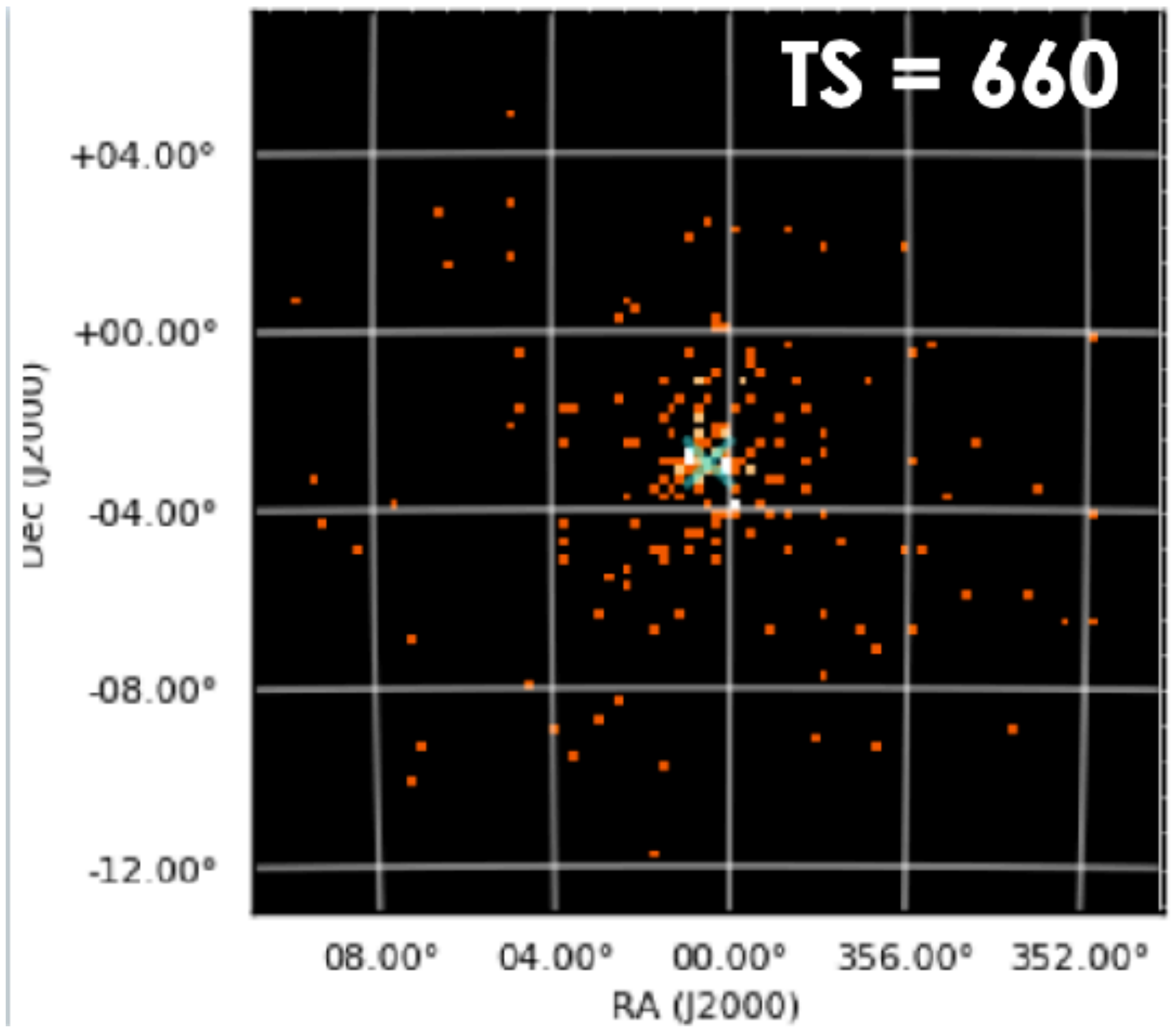
H.E.S.S. GRB follow-up observations from 2012 to 2017

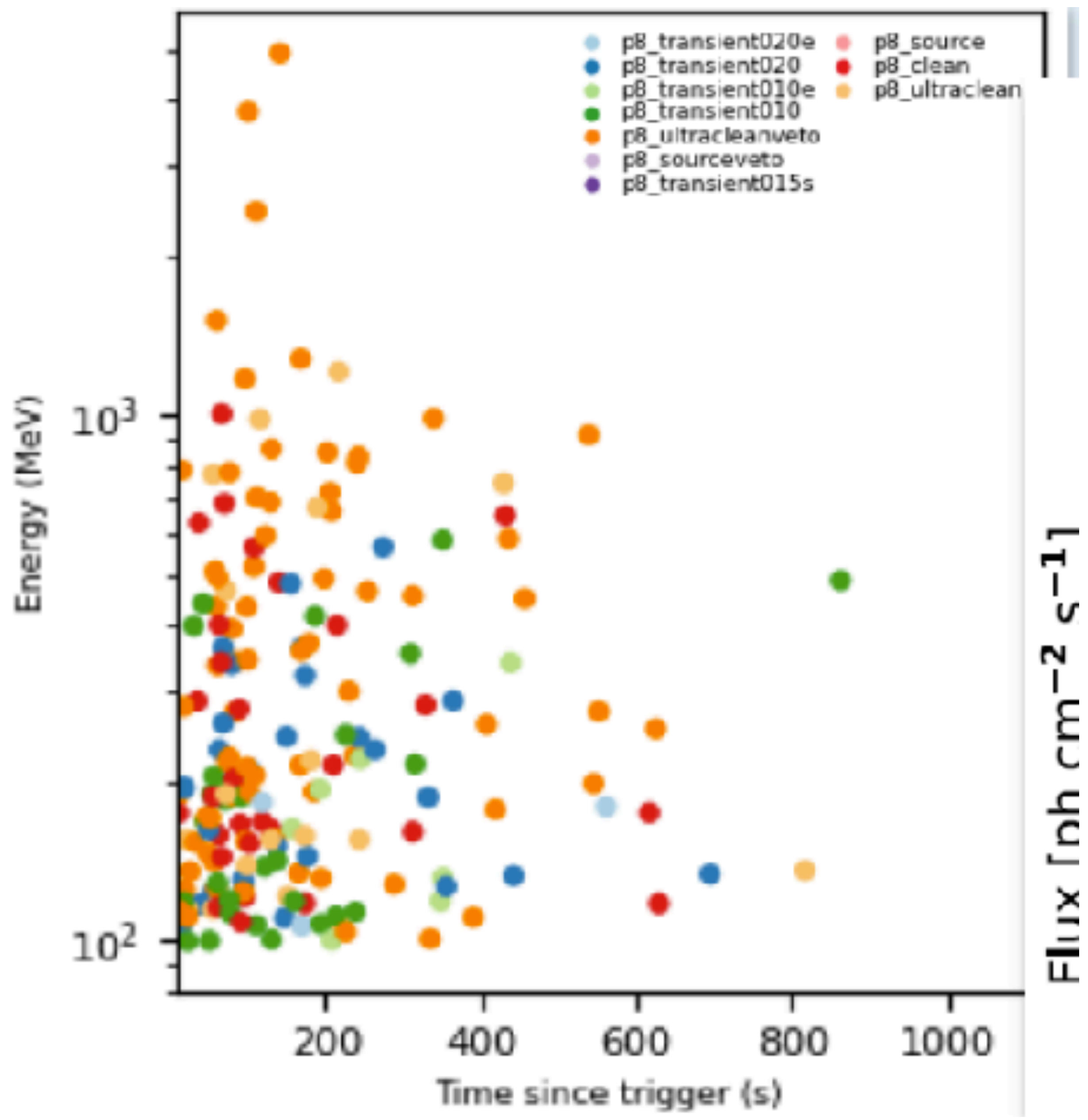


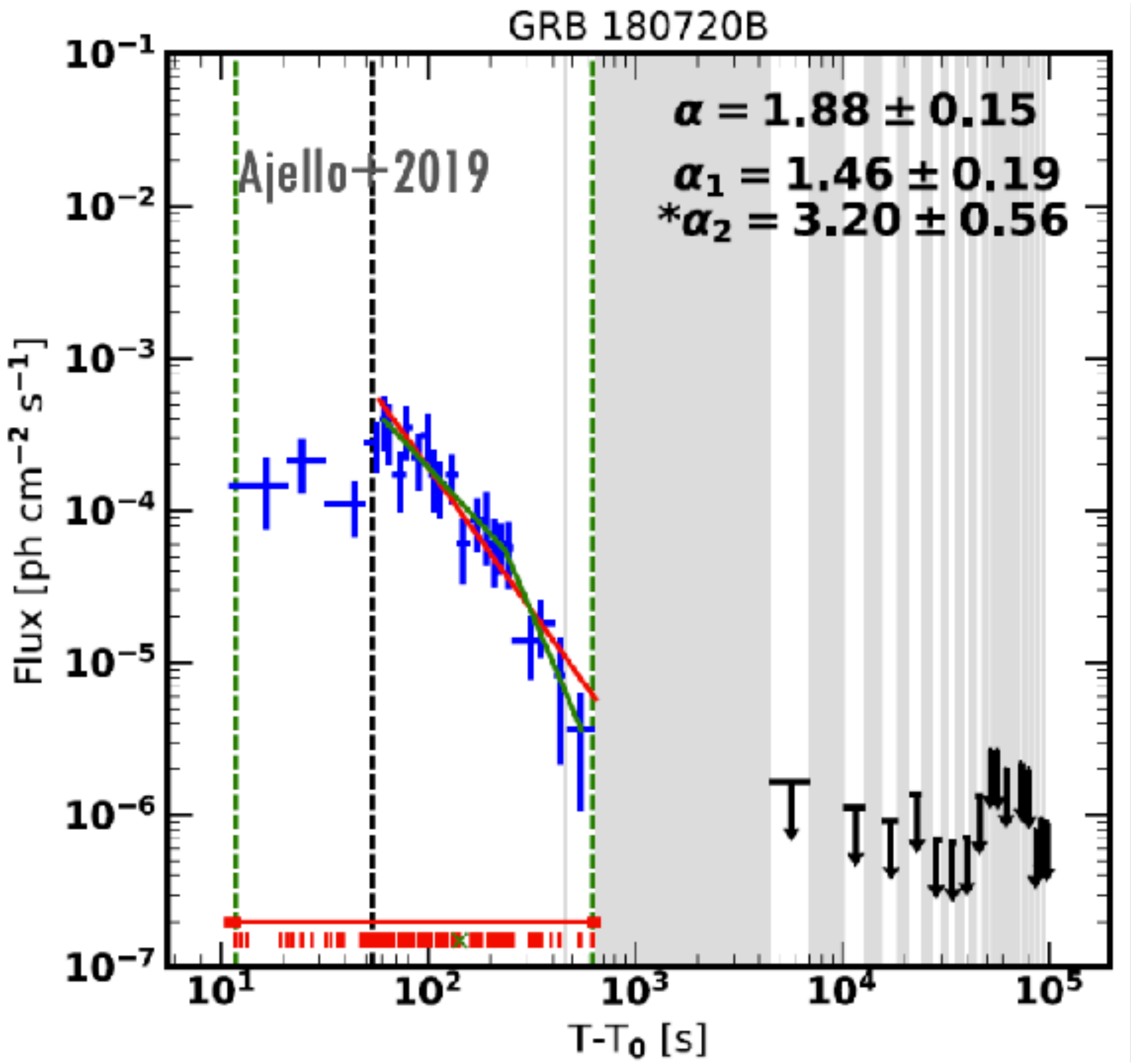
C. Hoischen+ (ICRC 2017)

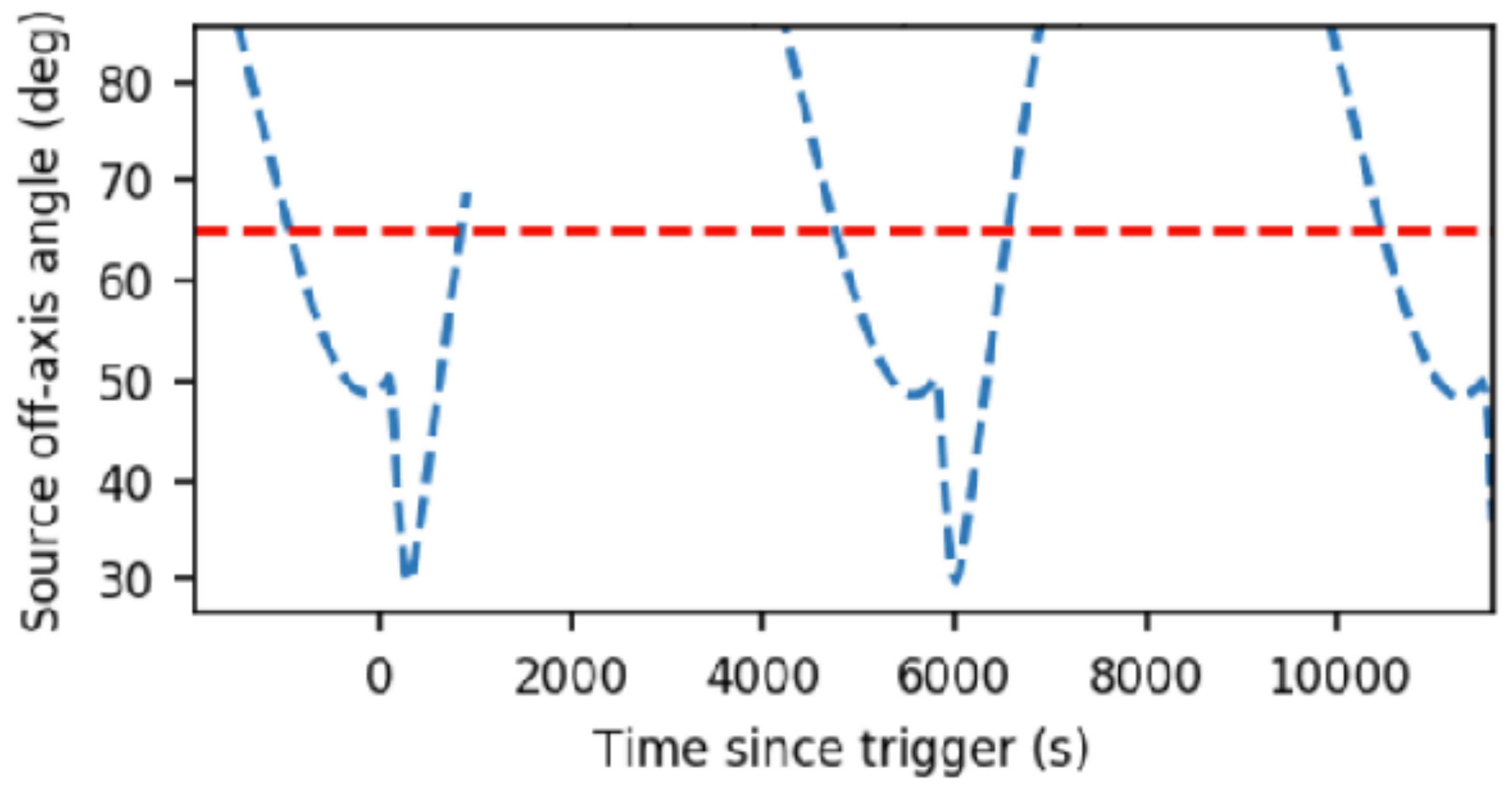

PRELIMINARY
Fermi-GBM
Fermi-LAT
Swift-BAT
Other
Number of GRBs follow ups
Year
0
2
4
6
8
10
12
14
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019

Fermi-LAT analysis

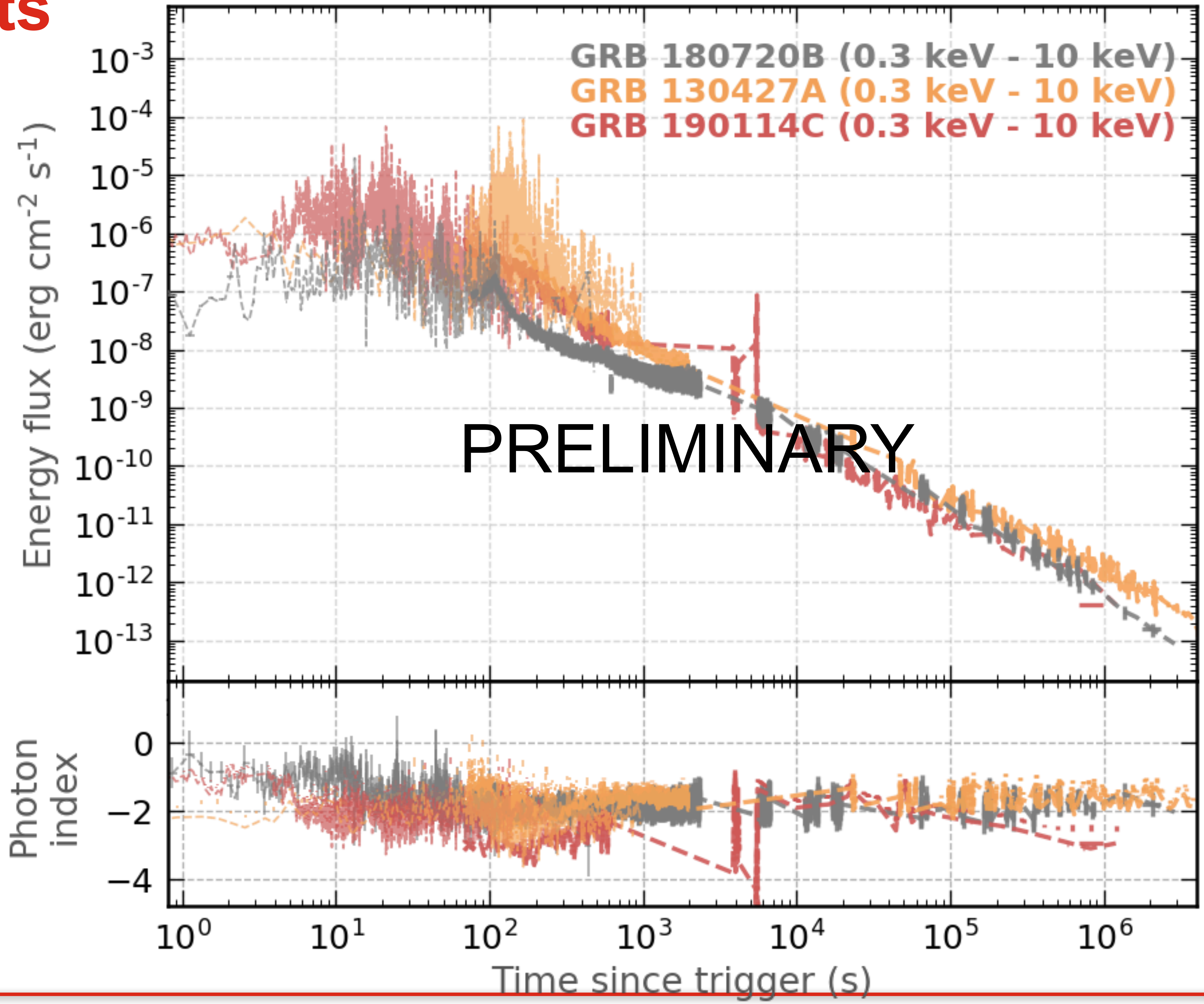






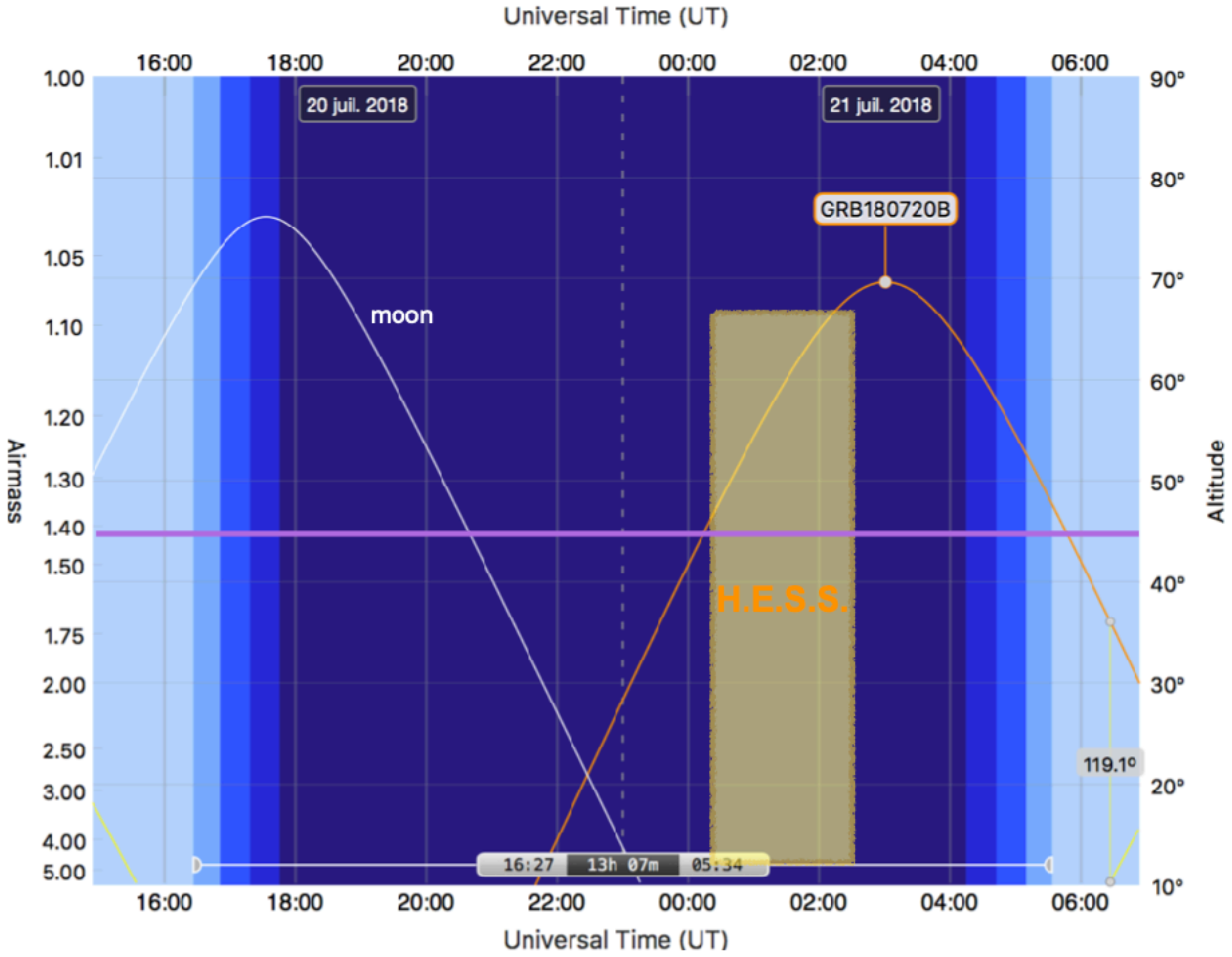


The three giants

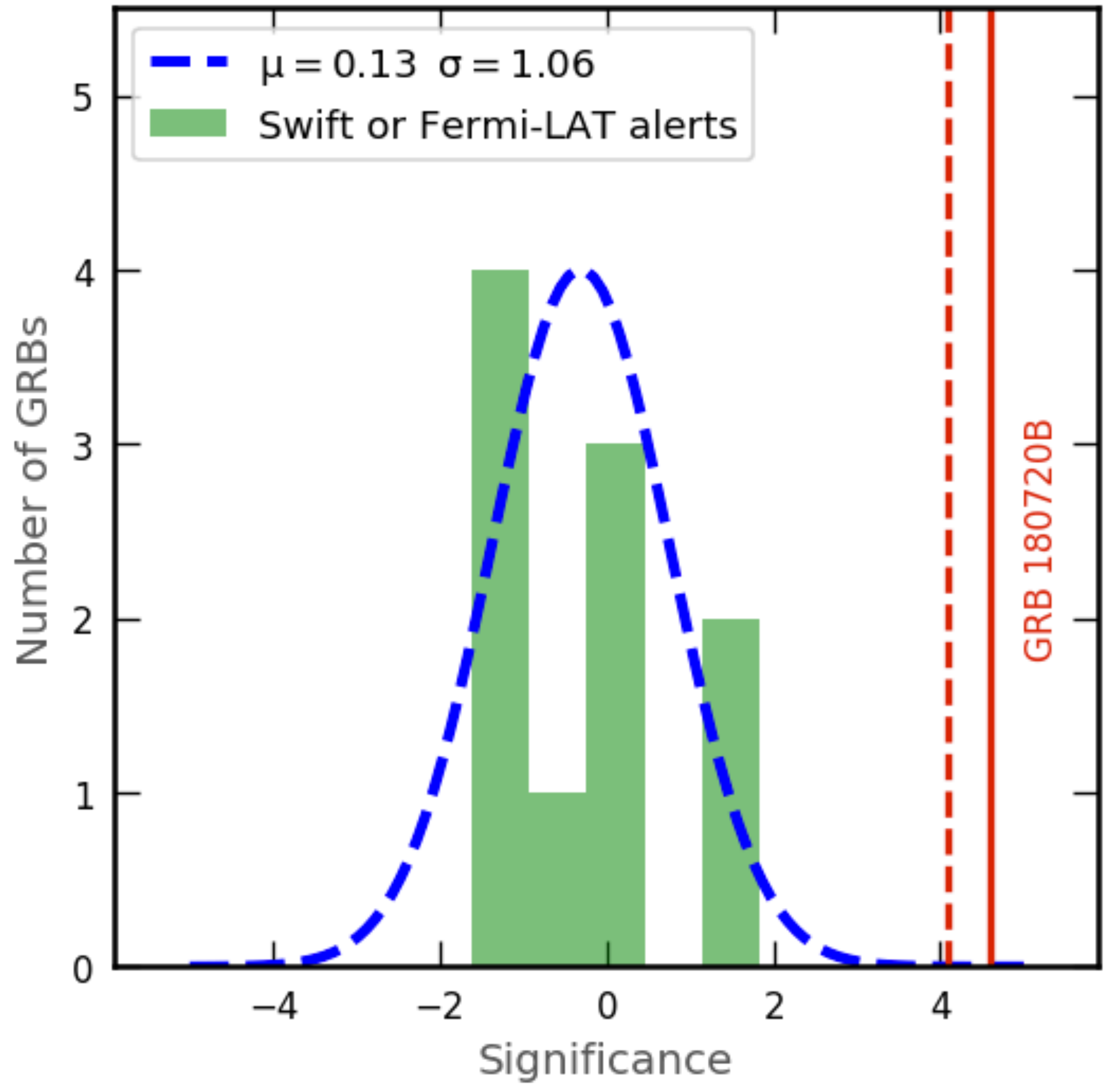


H.E.S.S. observations

- Observation started ~10 hours after the burst.
- Follow-up performed for ~2 consecutive hours (zenith 40º to 25º)
- Moderate presence of clouds at the beginning not affecting the observations.



Trials / FAR



10 well localised GRBs year < 2018

$$\sigma_{post}(4.6,10) = 4.1$$

$$\sigma_{post}\left(\sigma, N_t\right) = \sqrt{2}\, erfcinv\left(1 - \left(1 - erfc\left(\frac{\sigma}{\sqrt{2}}\right)\right)^{N_t}\right)$$