H.E.S.S. detection of extremely energetic afterglow in Gamma-Ray Bursts

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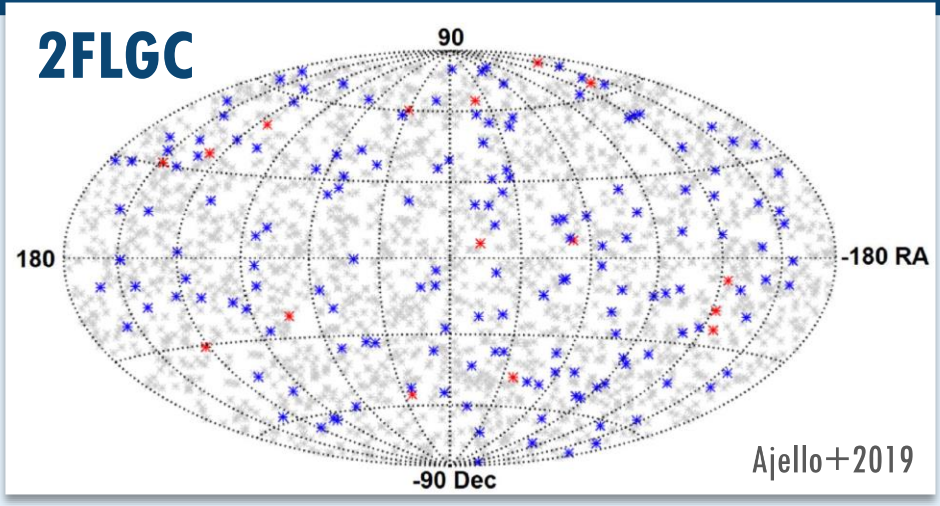
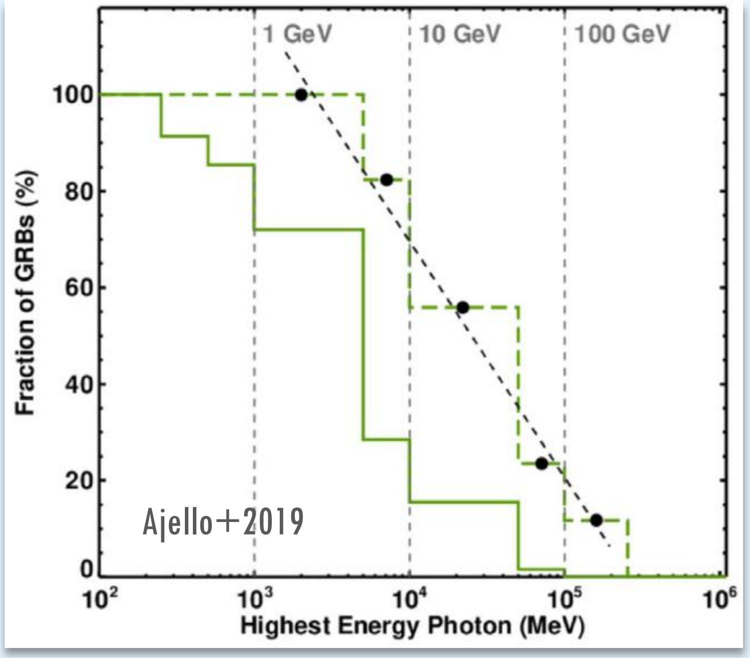
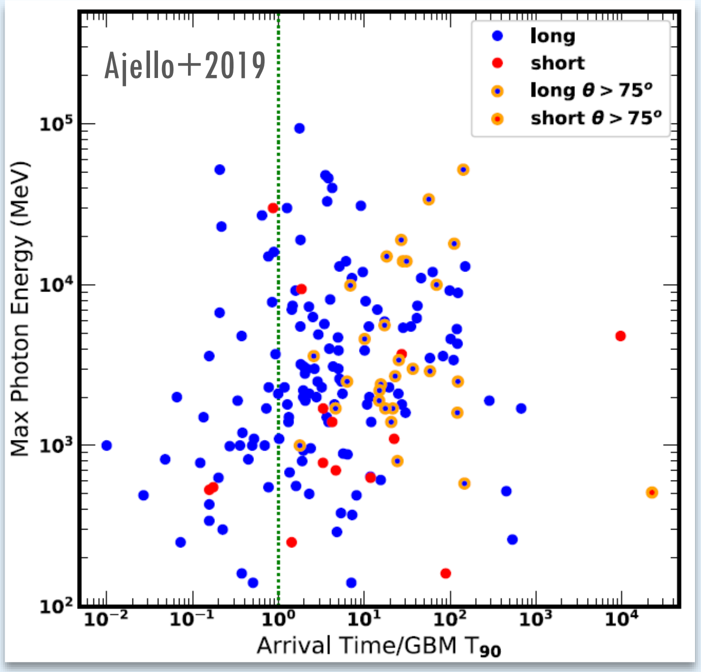
GRB observations at high energies

- **Fermi-GBM + Swift-BAT rates:**
  - ~300 GRBs/yr
    - **~6%** detected by Fermi-LAT (E > 100 MeV)
- **Fermi-LAT GRBs (2FLGC)**
  - **<20%** reach E > 10 GeV in the observer frame
  - Max. energy
    - **94 GeV** (GRB 130427A)
  - Temporal delay between low- and high-energy emission

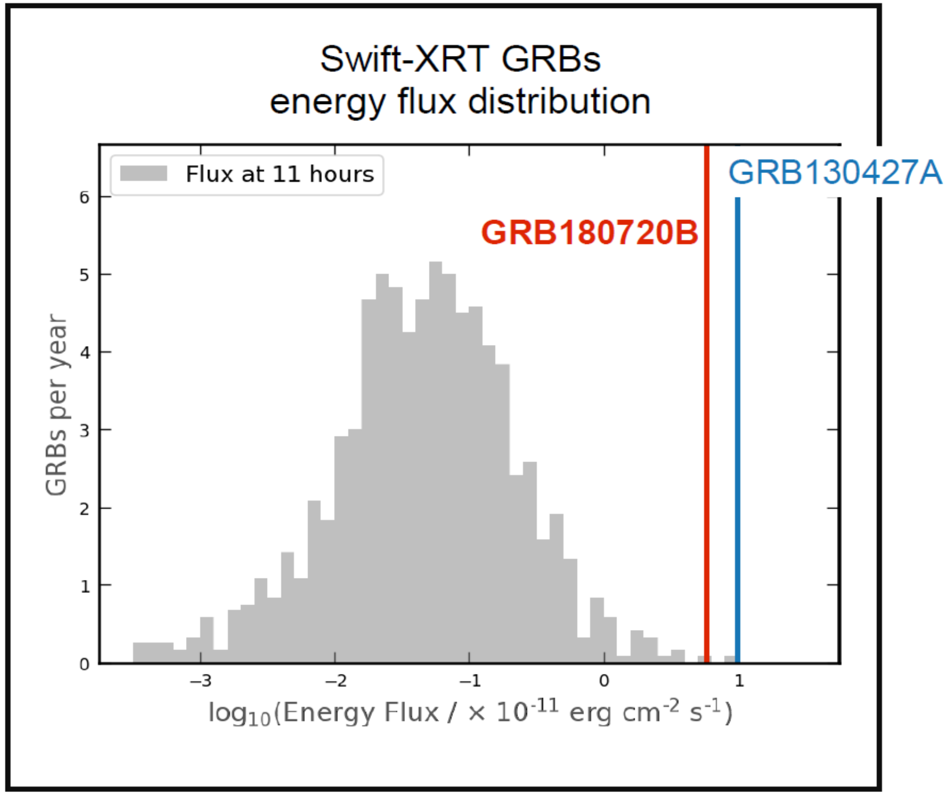






GRB 180720B – Fermi/Swift trigger info

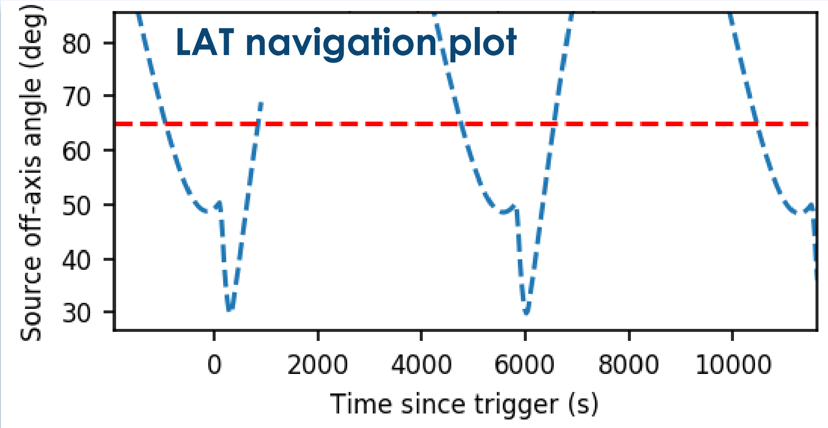
- Bright GRB on **July 20th, 2018**
  - Triggered **Fermi-GBM** at 14:21:39.65 UT (`Roberts+2018, GCN #22981`)
    - GBM T_{90} [50-300 keV] = **(48.9 ± 0.4) s – long GRB**
    - E_{iso} = (6.0 ± 0.1) · 10^{53} erg – **7° brightest** in GBM
  - Triggered **Swift-BAT** 5 s later, at 14:21:44 UT (`Siegel+2018, GCN #22973`)
  - Multiple **follow-up observations**
    - Redshift **z = 0.653** by VLT/X-Shooter (`Vreeswijk+2018, GCN #22996`)
    - Swift XRT: **2° highest energy flux** at T_0+11 hrs (after GRB130427A)
      - XRT **bright afterglow** remained detectable for ~30 days

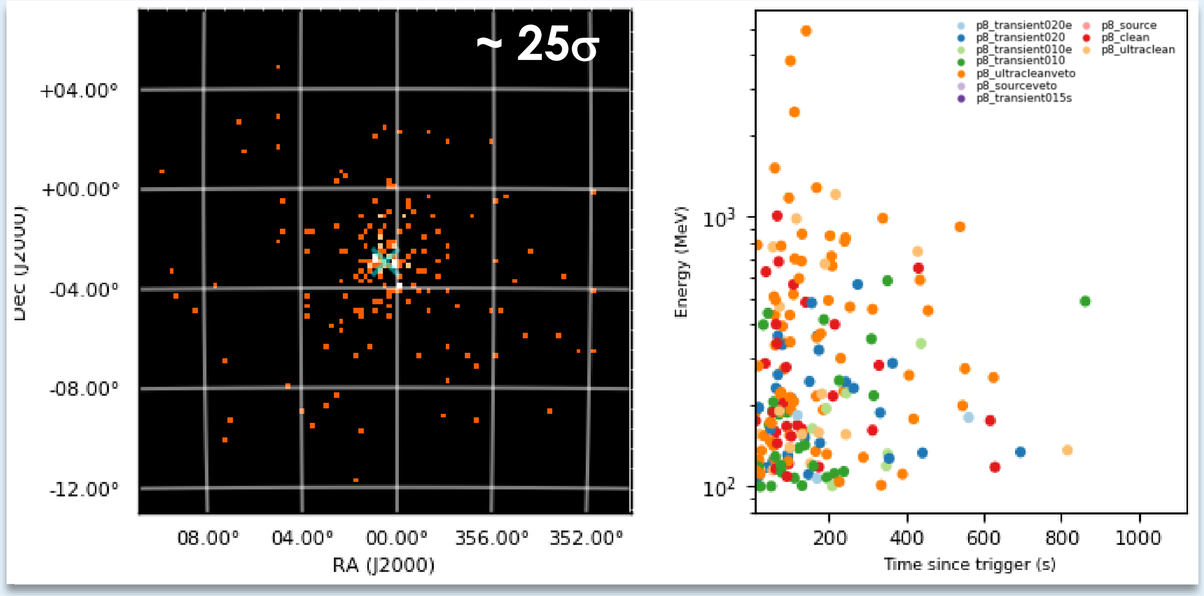


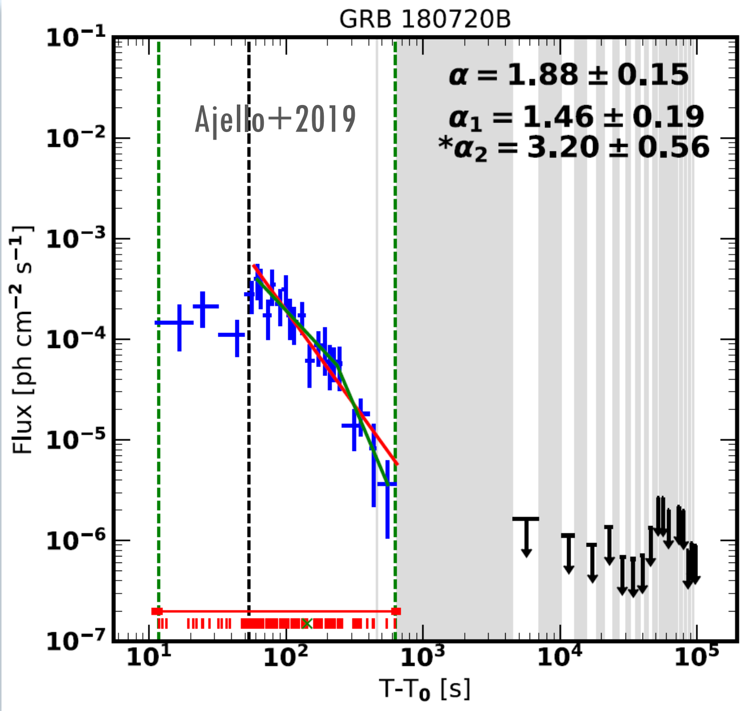
Seglar-Arroyo+(ICRC 2019)

GRB 180720B – Fermi-LAT observations

- Clear **Fermi-LAT detection** during first observational window (0 – 1000 s) (**Bissaldi+2018, GCN #22980**)
  - Max photon energy: **5 GeV** @T_0+142 s
- But: GRB rapidly moving **out of the LAT FoV**
  - ➔ **No further LAT detection** beyond T0+700 s

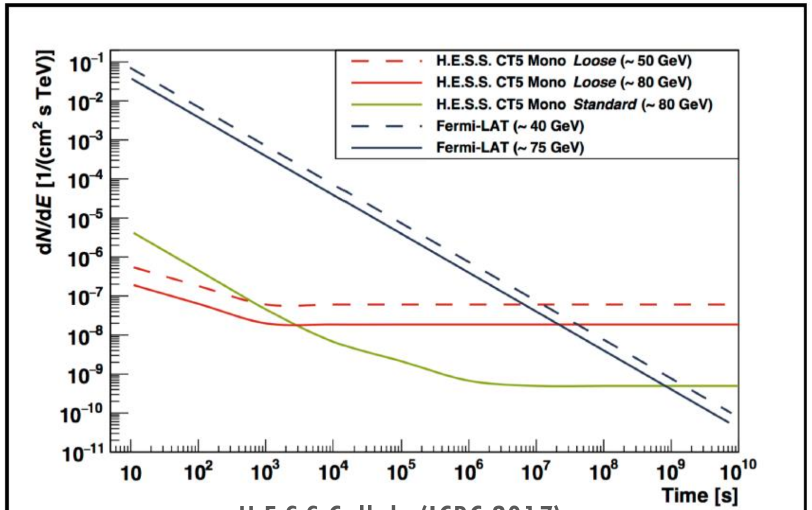




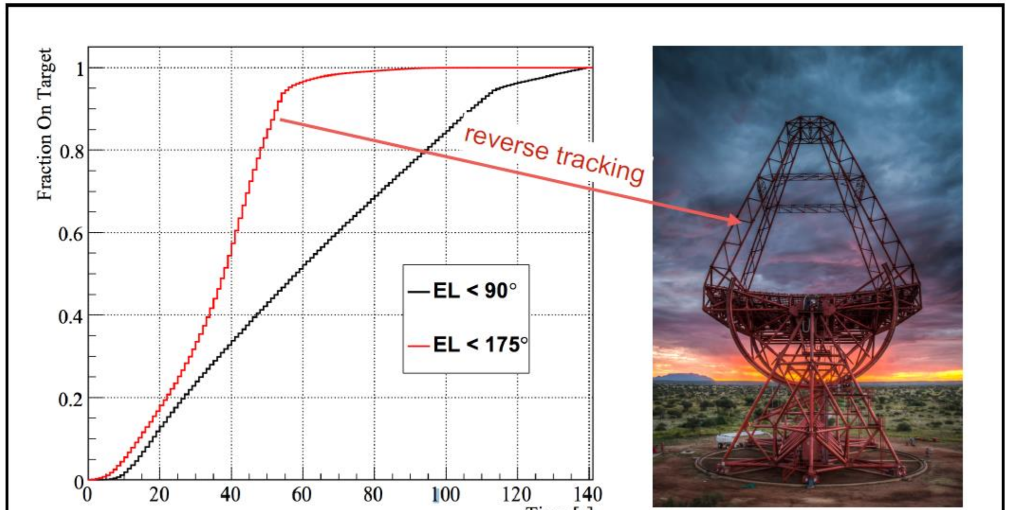


The H.E.S.S. GRB follow-up program

- Main design principles of the H.E.S.S. **28-m telescope (CT5)**
  - Large photon collection area:
    614 m^2 mirror (largest IACT worldwide)
    ➔ High sensitivity at **low E**
  - **Rapid response time**! Slew rate:
    - Small telescopes array: **100°/min**, CT5: **200°/min**
      ➔ Point to **any sky position** within 1 and 2 minutes, respectively



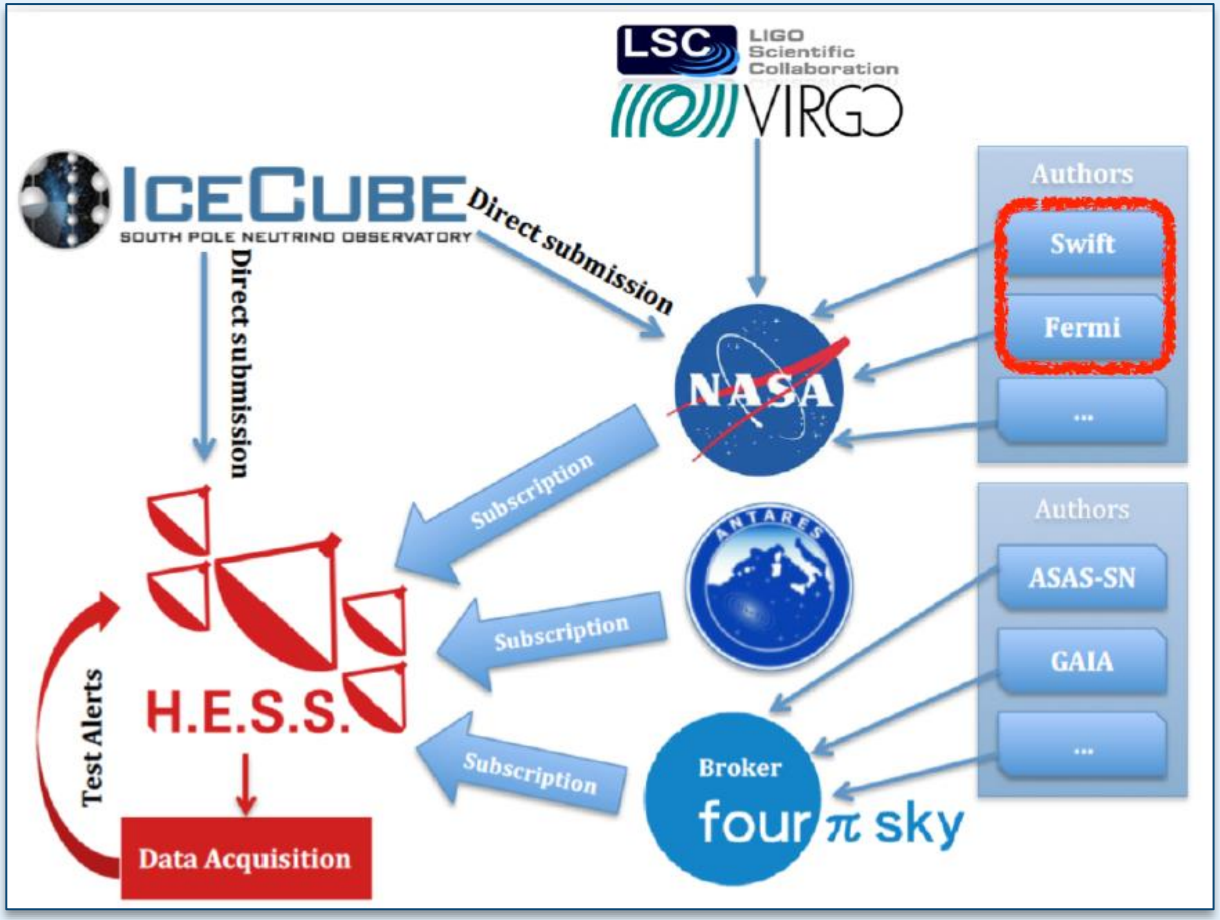
H.E.S.S.Collab. (ICRC 2017)



Hofverberg+(ICRC 2013)

H.E.S.S. automatic reaction to alerts

- Fully **automatic** procedures
  - Alert reception → filtering → slewing → data taking
- **Optimized repointing** and **data taking** procedures for CT5
- Alert reception using **VO standards** (VoEvents)
- **~10 GRB follow-ups/yr**
  - Typical exposure: **2hrs/follow-up**
    - For special cases >20 hrs/follow-up



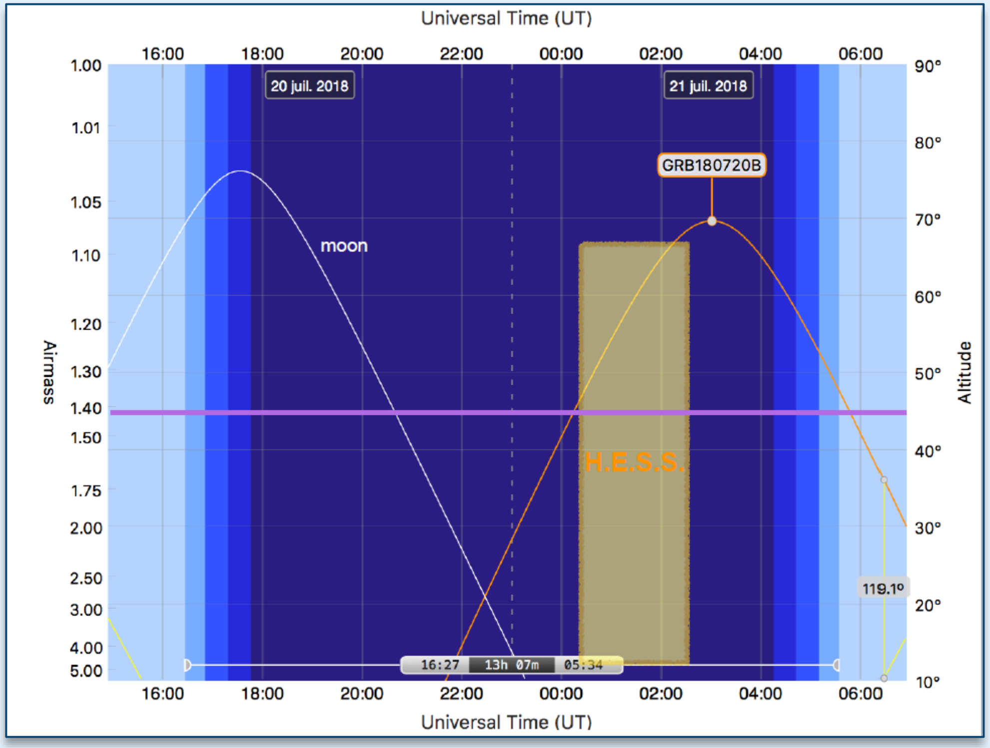
H.E.S.S. data analysis procedure

- Rigorous **data quality verification** and **blinding procedures**
  - Data quality assessment at various levels
    - **Atmospheric effects** (e.g. trigger rates, cloud monitors, etc.)
    - **Calibration stability** (e.g. detection of faulty pixels in the camera(s), pixel pedestal values, the distribution of events within the FoV, etc.)
  - **Two independent** data calibration and analysis **chains**
    - Need approved data quality within both chains before unblinding of gamma-ray data
    - A priori selection of main analysis + independent cross-check
  - Detailed **verifications** and **comparisons** of analysis results

GRB 180720B – H.E.S.S. observations

- H.E.S.S performed **follow-up observations** of GRB180720B based on GCN alerts:
  - Observations for GRBs that become observable only at later times are **scheduled manually** and triggered by burst advocates
  - GRB180720B was observed at **T_0+10 hours** (36–42 ks) and **T_0+18 days** (when it came back in the FoV)
  - Low energy threshold: analysis of **CT5 data in monoscopic** mode
    - Average zenith angle **~30.1°** => energy threshold **~100 GeV**

Seglar-Arroyo+(ICRC 2019)

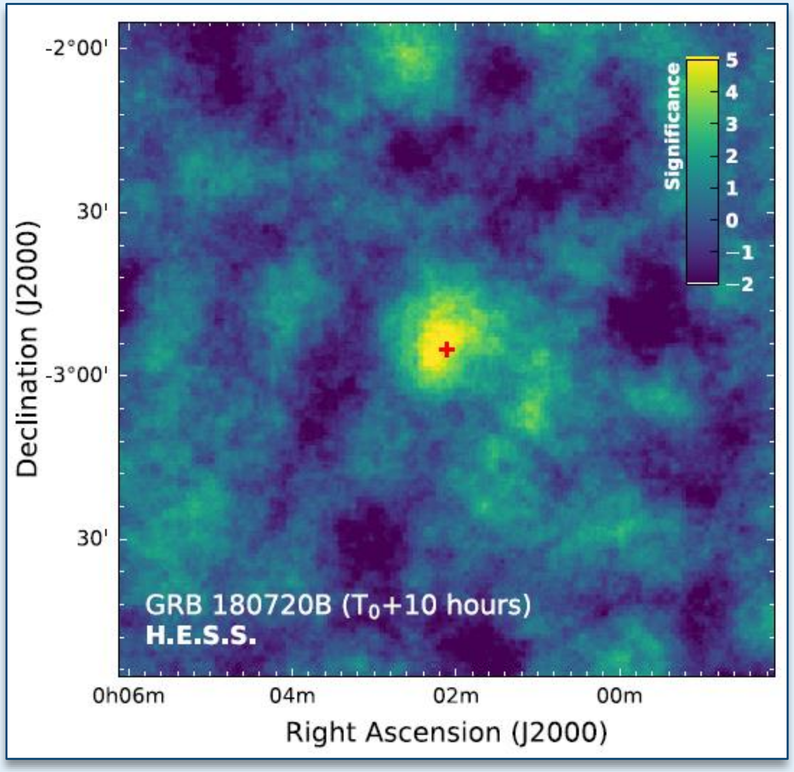


GRB 180720B – H.E.S.S. results

- H.E.S.S. detection: ~5.3σ pre-trial, **5.0σ post-trial** accounting for 5 similar searches
  - Detailed studies of **systematic uncertainties** have been performed
    - Cross-check analysis, background estimation methods, trigger rate stability, etc.

2 hrs exposure

@T_0+10 hrs

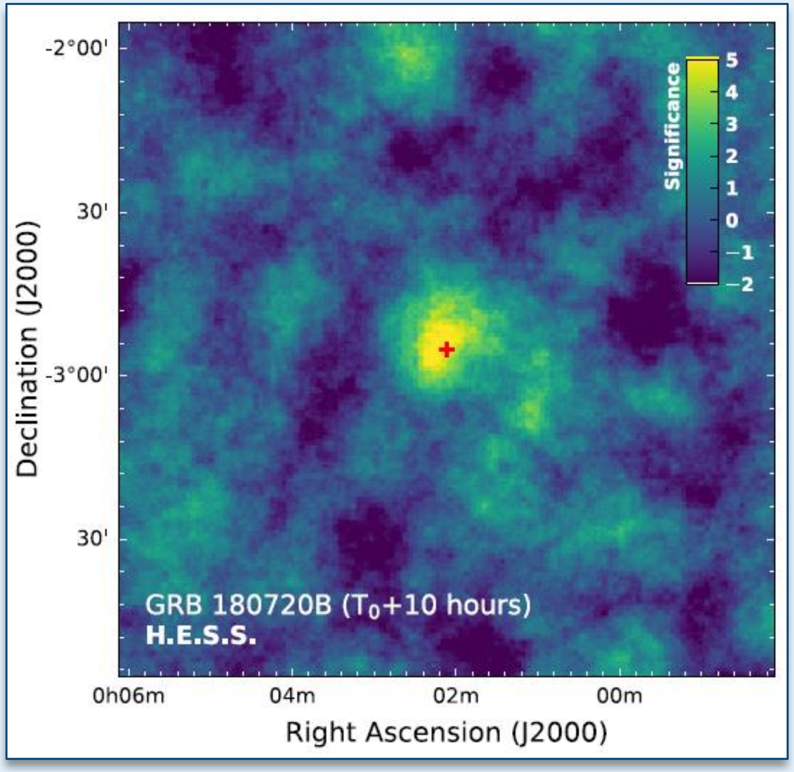


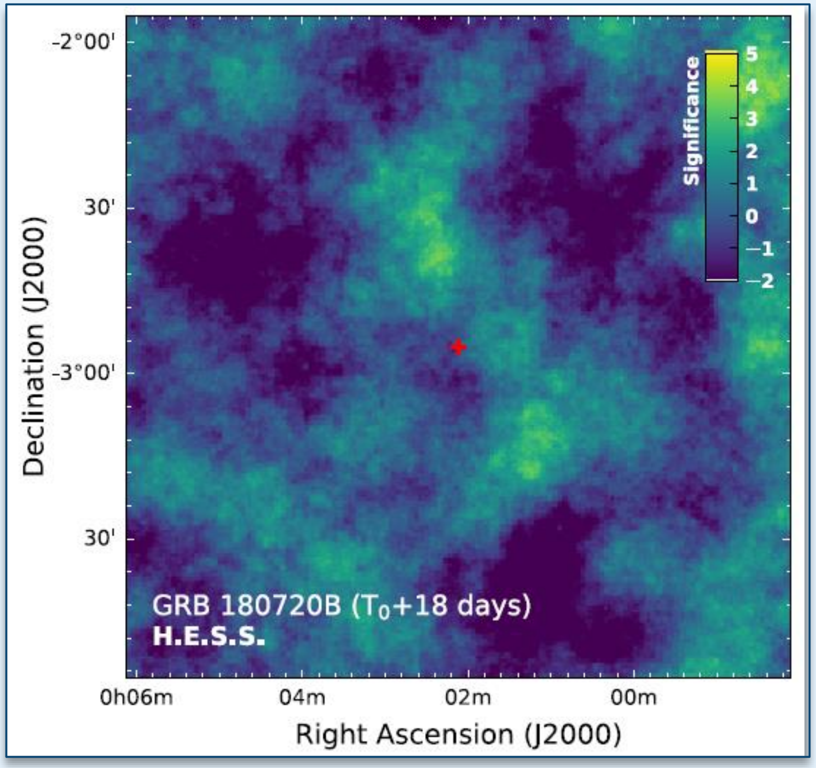
Abdalla+2019 Nature 575

- H.E.S.S. detection: ~5.3σ pre-trial, **5.0σ post-trial** accounting for 5 similar searches (excess of 119 γ-ray events)
  - Detailed studies of **systematic uncertainties** have been performed
    - Cross-check analysis, background estimation methods, trigger rate stability, etc.

2 hrs exposure

@T_0+10 hrs





Verification dataset

6.5 hrs exposure

@T_0+18 d

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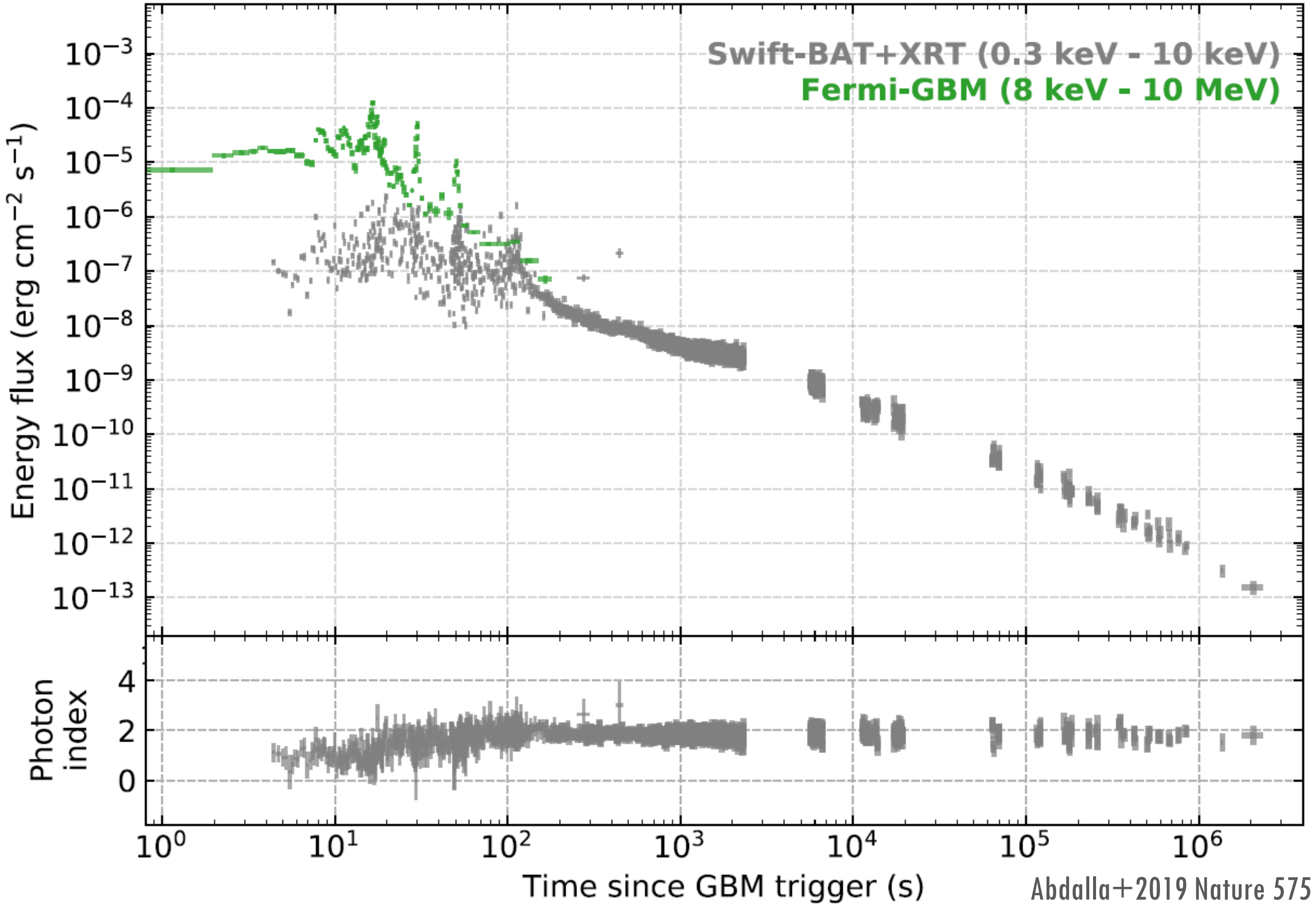
GRB 180720B – MWL Lightcurve



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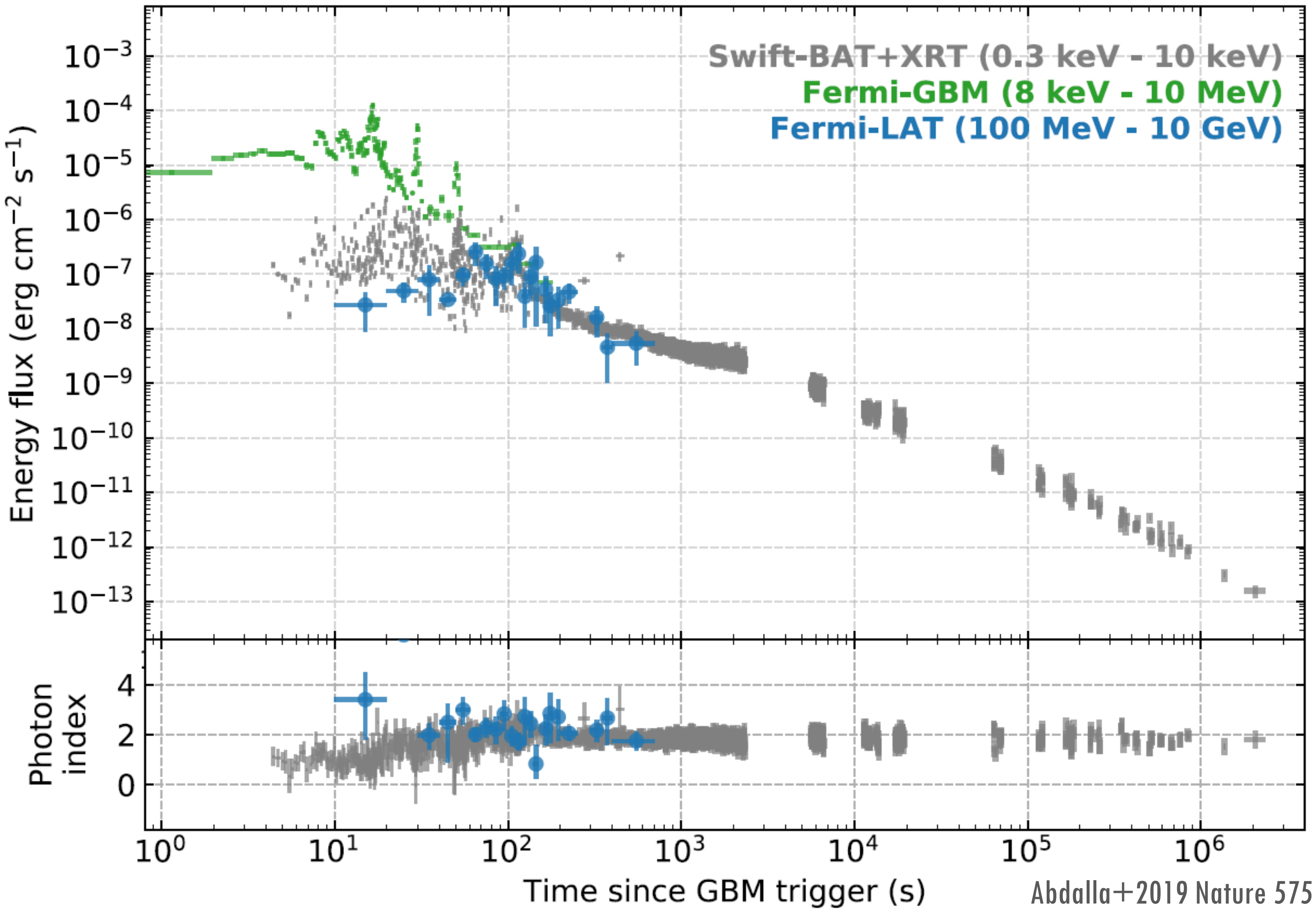
GRB 180720B – MWL Lightcurve



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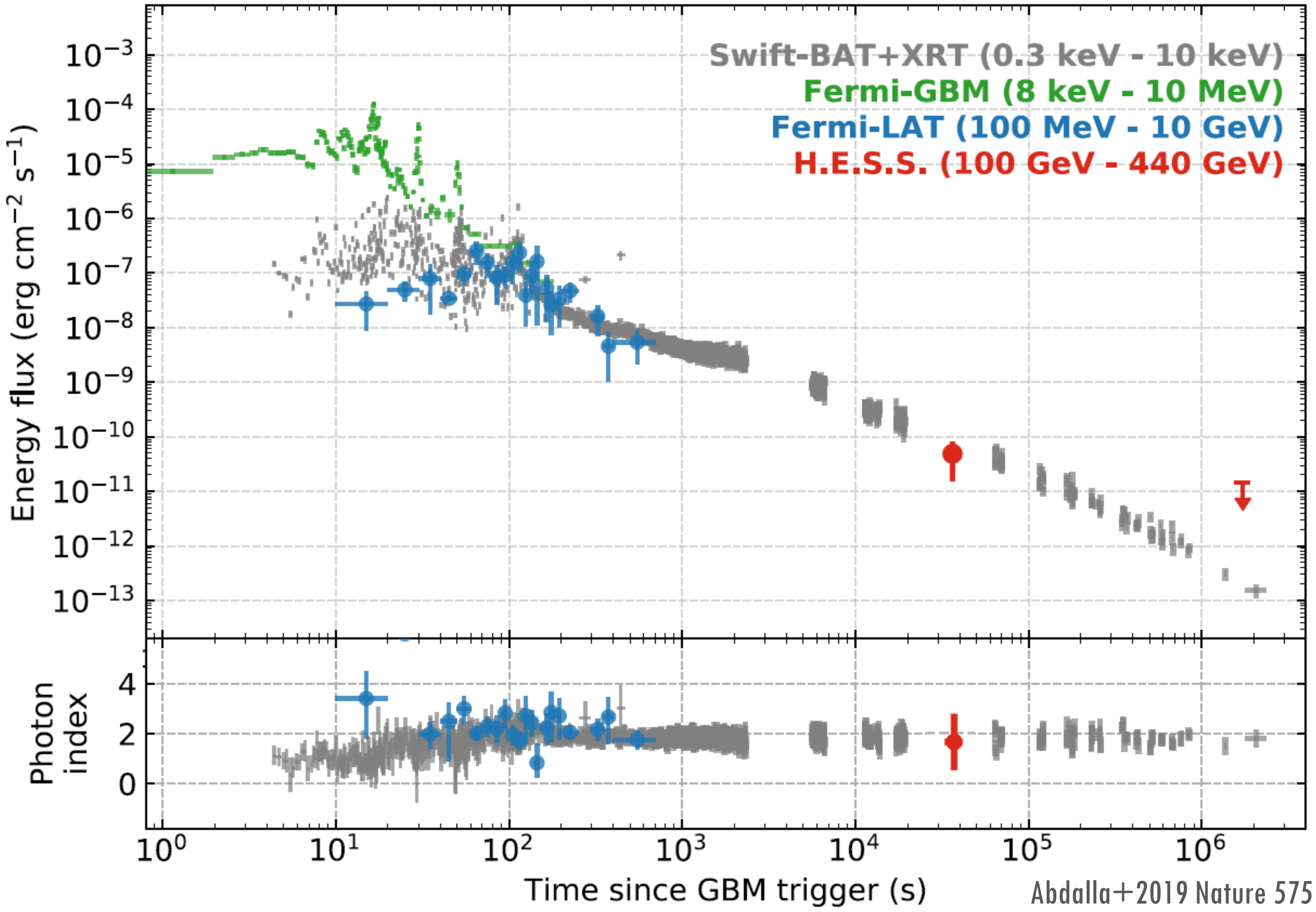
GRB 180720B – MWL Lightcurve



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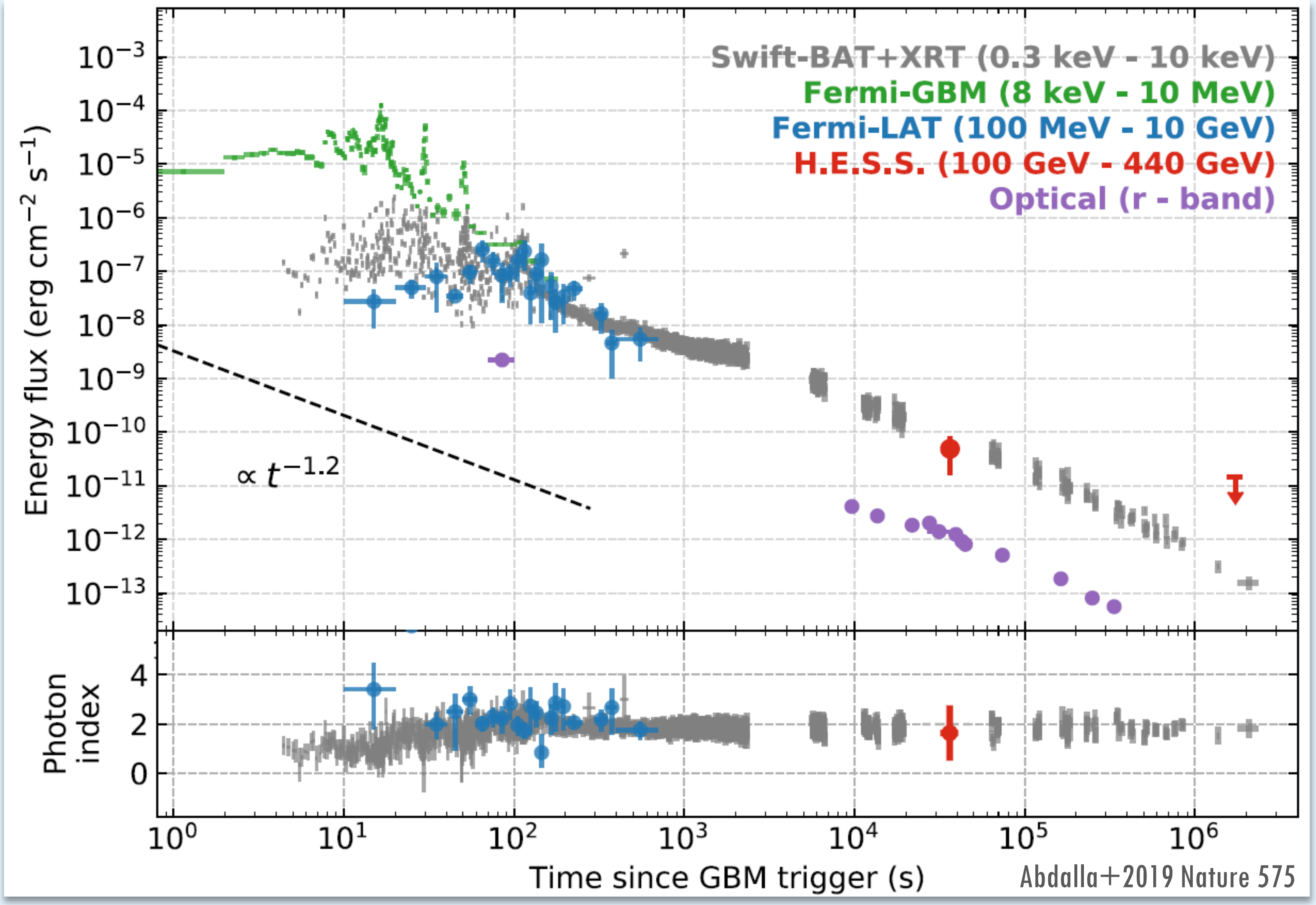
GRB 180720B – MWL Lightcurve

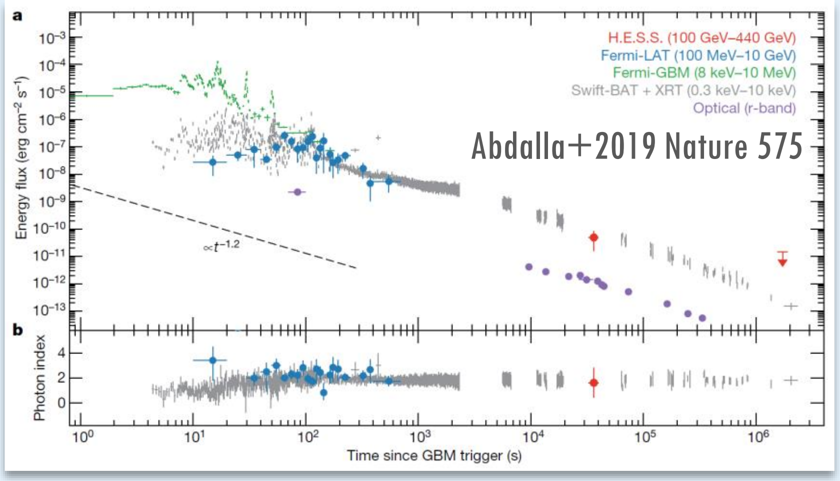


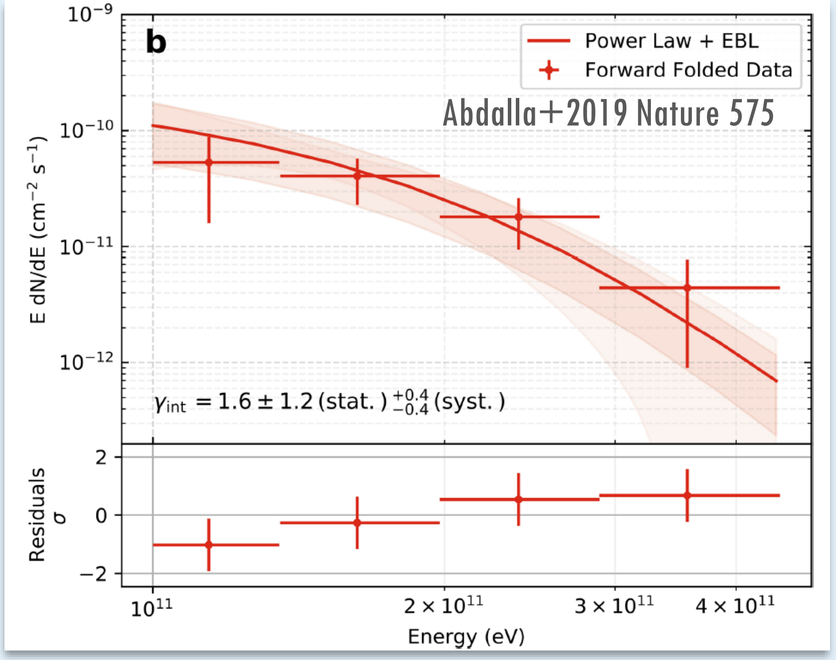
GRB 180720B – Interpretation

- Energy Flux features:
  - Exceptionally high flux level
  - Similar PL behavior $F(t) \propto t^{-\alpha}$ in the X-ray and optical afterglow
    - $\alpha_{XRT} = 1.29 \pm 0.01$, $\alpha_{OPT} = 1.24 \pm 0.02$
      - Note that $\alpha_{LAT} = 1.83 \pm 0.25$, but: $\bar{\alpha}_{LAT} = 0.99 \pm 0.04$)

  ➔ Synchrotron origin of the broadband afterglow?
  ➔ Disfavoured by strong requirements for synchrotron emission to extend up to the VHE regime

- Advantage of the SSC scenario that emission up to VHE at late times is energetically easily achievable
  - H.E.S.S. spectral-fit constraints are consistent within present uncertainties
    - $\gamma_{HESS} = 1.6 \pm 1.2$ (statistical) $\pm$ 0.4 (systematic), for comparison $\gamma_{LAT} = 2.1 \pm 0.1$





Summary and future prospects

- **First GRB detection with H.E.S.S.**: GRB180720B detected afterglow emission (T0 + 10.1h) between 100 GeV – 440 GeV
  - The detection of **GRB 190114C** by **MAGIC** (in the prompt to early afterglow) nicely **complemented** this late-time H.E.S.S. observation

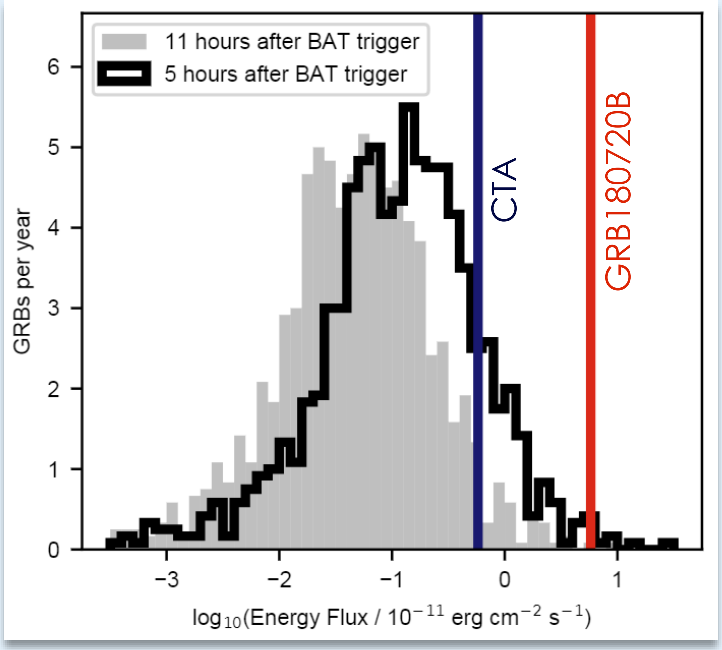
➔ **NEW** H.E.S.S. detection of **GRB 190829A**: over 3 nights!!!
Another important confirmation of VHE GRB emission!

➔ **See S. Zhu's talk on Thursday 15/4**

Thank you!

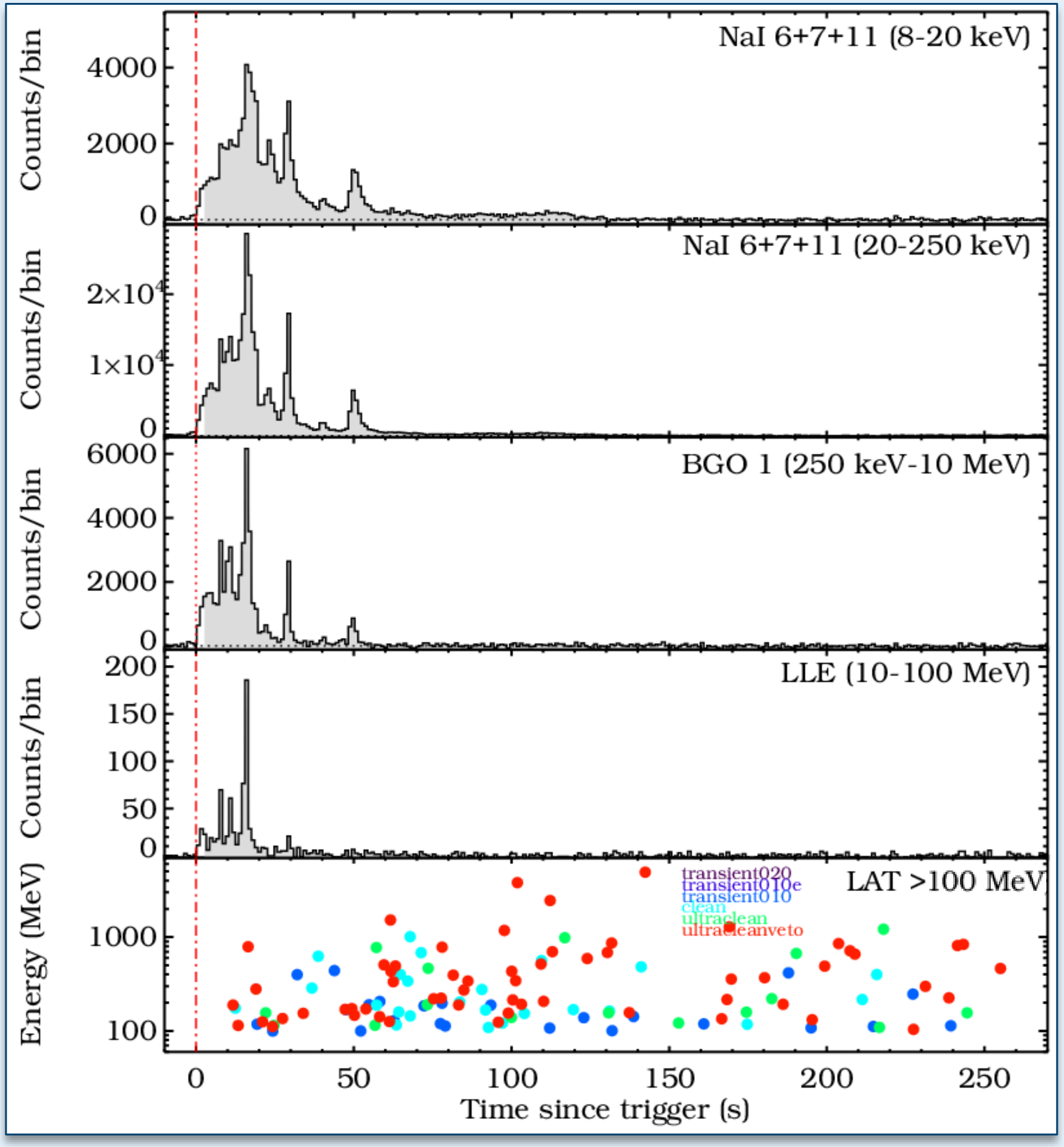
- Such observations provide additional insight into the **nature of GRBs and their VHE detectability**
  - **CTA** will have ~10 times better sensitivity than H.E.S.S.!
    - **Boost** the detection of GRBs at VHE in both **prompt** and **afterglow** emission phases

Swift-XRT GRBs energy flux distribution



Back-up slides

GRB 180720B – GBM+LAT Lightcurves



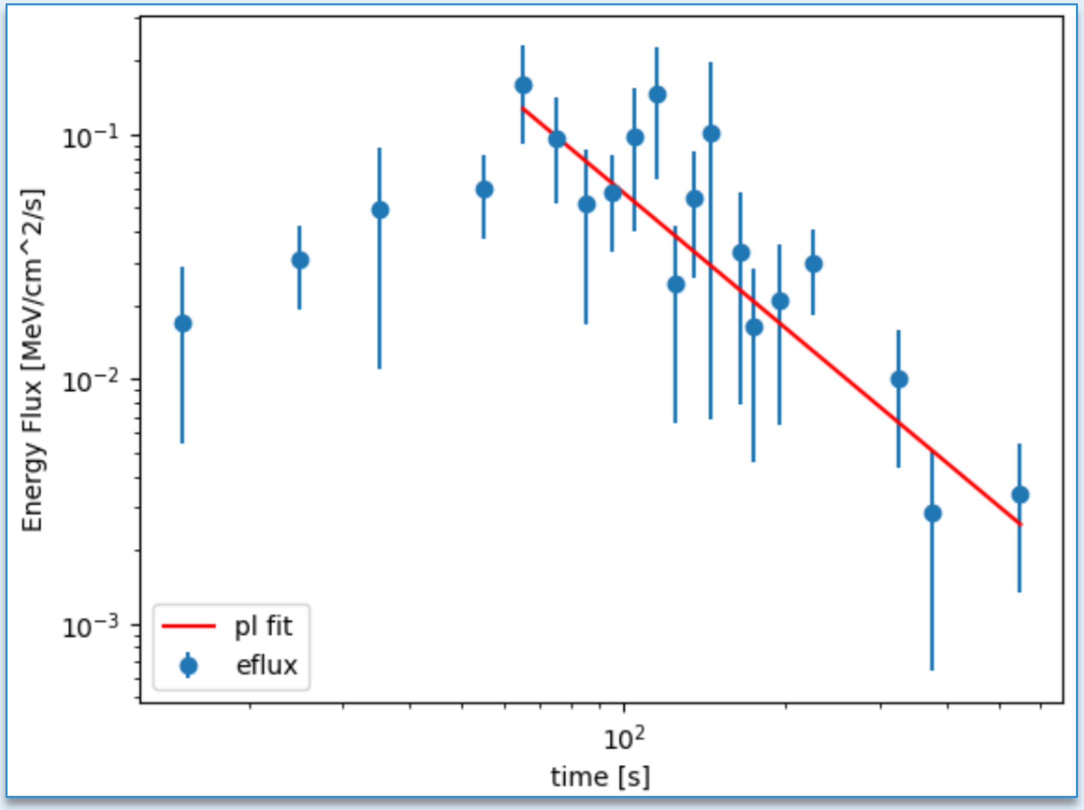
GBM
σ = 450

LLE
TS=24

LAT
TS=660

GRB 180720B – LAT analysis

- LAT dedicated analysis (from 0 to 700 s)
  - P8R3 data
  - Spectral index: **γ = -2.10 ± 0.10**
  - Temporal index (energy flux): **α = -1.83 ± 0.25**

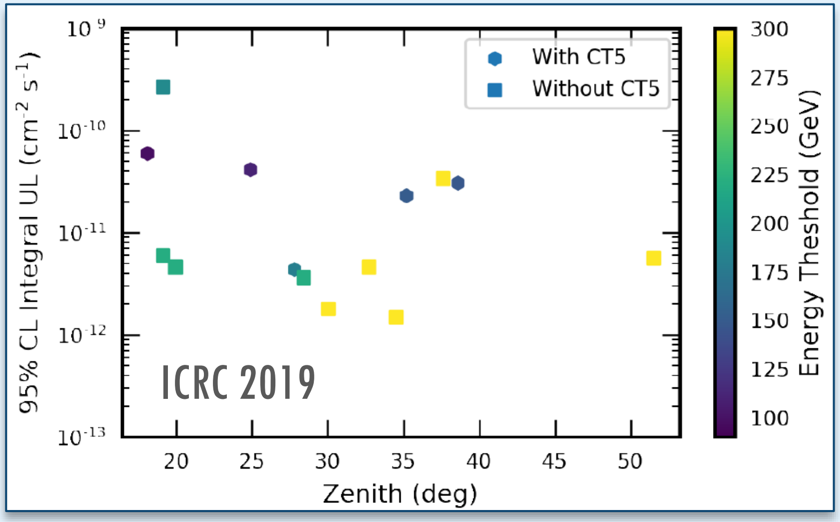


➔ Cross check with **2FLGC** (Ajello+2019)

H.E.S.S. GRB follow-up analysis

- Since 2008: **66 GRB follow ups**
  ➔ H.E.S.S.-II: since inauguration of CT5 (Dec 2012) → 56 observations
  - **20 observations removed** (technical issues, bad weather conditions, insufficient statistics, etc.)
  - 21 observations still **under analysis**
  - **25 analysed GRB observations**
    - 15 bursts with **localisation uncertainties <0.1deg** (e.g. Swift-BAT)
      → integral flux upper limits at the source position
      - **➔ 5 bursts with CT5 data**
        (good loc.+low thresh.)
    - 10 bursts with **larger localisation** uncertainties (e.g. GBM)

→ Map of integral upper limits



GRB 180720B – Observations Timeline