Fermi and Swift Observations of GRB 190114C: Tracing the Evolution of High-Energy Emission from Prompt to Afterglow

Daniel Kocevski

and many other fine authors (see slide 3 for contributions)

Publication Overview

- MAGIC Discovery Paper (Nature)
  - Focuses on summarizing the MAGIC observations
  - Qualitative comparison of MAGIC data to Swift and Fermi data (analyzed in house)
- Fermi-Swift Paper (ApJ)
  - Focuses on the characterization of the the early and late-time Fermi and Swift data
  - Includes GBM, LAT, XRT, BAT, and UVOT observations
  - Includes broadband spectral fits from both the early and late-time data
- MAGIC Multiwavelength Paper (Nature)
  - Multi-wavelength paper including contributions from 10 instruments across 14 teams
  - Focuses on modeling the multi-wavelength data to put the MAGIC data in context
- The Fermi-Swift and the MAGIC MWL papers will be presenter together

Contributions

- Daniel Kocevski - LAT burst advocate
- Nicola Omodei - LAT data analysis and LLE generation
- Peter Veres - GBM data analysis and theoretical modeling
- Donggeun Tak - Prompt and afterglow spectral fitting
- Makoto Arimoto - Afterglow spectral fitting, theoretical modeling, and interpretation
- Ramandeep Gill - Theoretical modeling and interpretation
- Jonathan Granot - Theoretical modeling and interpretation
- Lara Nava - MAGIC: Theoretical modeling and interpretation
- Stefano Covino - MAGIC: Afterglow spectral fitting
- Elena Moretti - MAGIC: Data analysis
- Antonio Stamerra - MAGIC: Data analysis
- Magnus Axelsson - LAT internal referee
- Soeb Razzaque - LAT internal referee

GRB 190114C

- Fermi GBM triggered on January 14, 2019 at 20:57:02.63 UTC (GCN 23707)
- Extremely well detected by both GBM and LAT
  - Produced 30,000 counts/s in the most illuminated GBM NaI detector
  - But unlike GRB 130427A, no saturation of the GBM detectors
  - TS > 2800 in LAT integrating over 100s with P8R3_TRANSIENT020_V2
- Swift-BAT detection at T0+0.56 s
- UVOT and X-ray observations began at T0+68.27 s
  - Counterpart successfully identified and quickly reported via GCN
- Ground based observations resulting in a host galaxy redshift of z = 0.42
- Report of a MAGIC detection at > 20 sigma starting at T0+50s

MAGIC Detection

First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C

ATel #12390; ***Razmik Mirzoyan on behalf of the MAGIC Collaboration***
*on **15 Jan 2019; 01:03 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

Referred to by ATel #: 12395

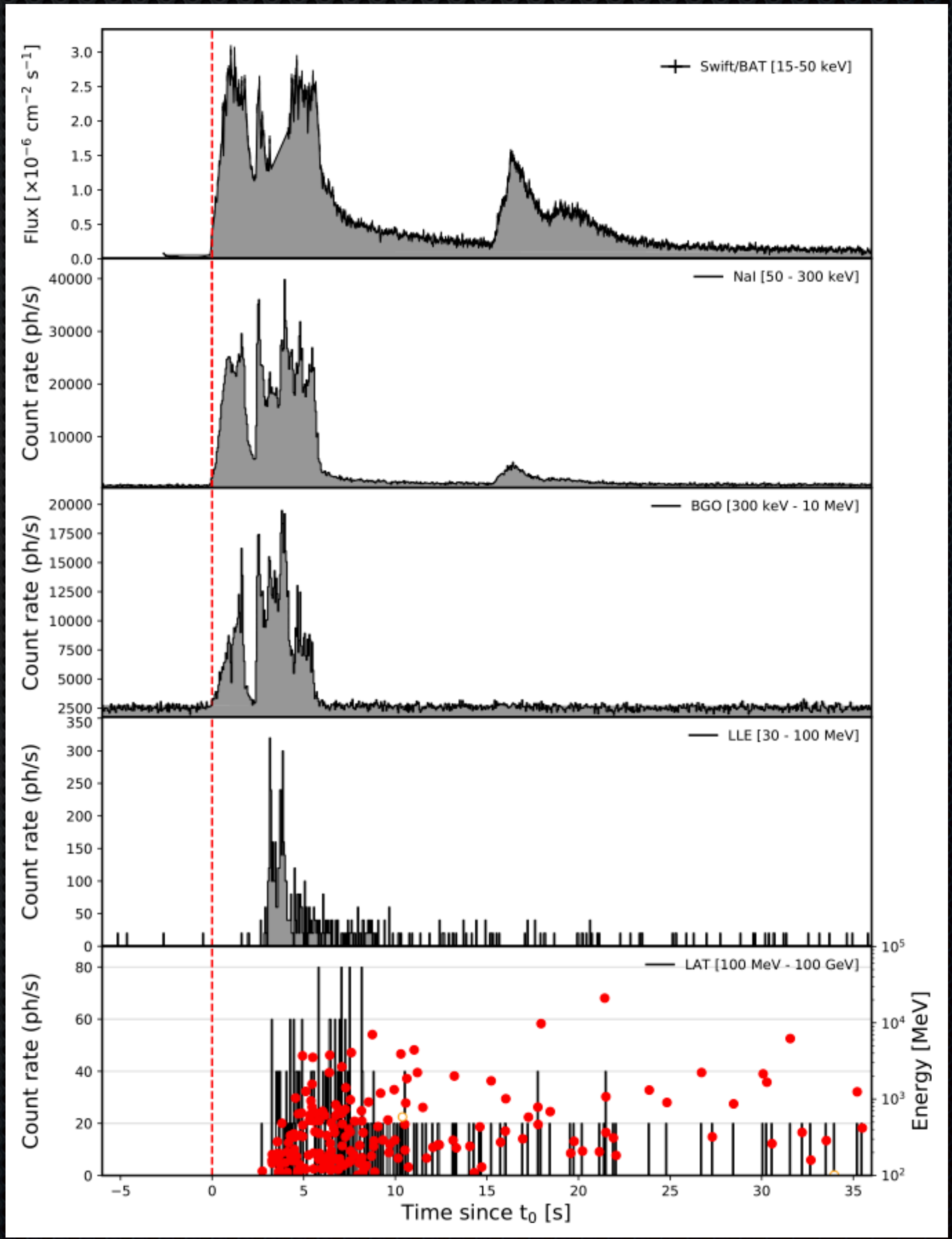
Tweet

The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, Selsing et al. GCN 23695). This observation was triggered by the Swift-BAT alert; we started observing at about 50s after Swift T0: 20:57:03.19. The MAGIC real-time analysis shows a significance >20 sigma in the first 20 min of observations (starting at T0+50s) for energies >300GeV. The relatively high detection threshold is due to the large zenith angle of observations (>60 degrees) and the presence of partial Moon. Given the brightness of the event, MAGIC will continue the observation of GRB 190114C until it is observable tonight and also in the next days. We strongly encourage follow-up observations by other instruments. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and K. Noda (nodak@icrr.u-tokyo.ac.jp). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

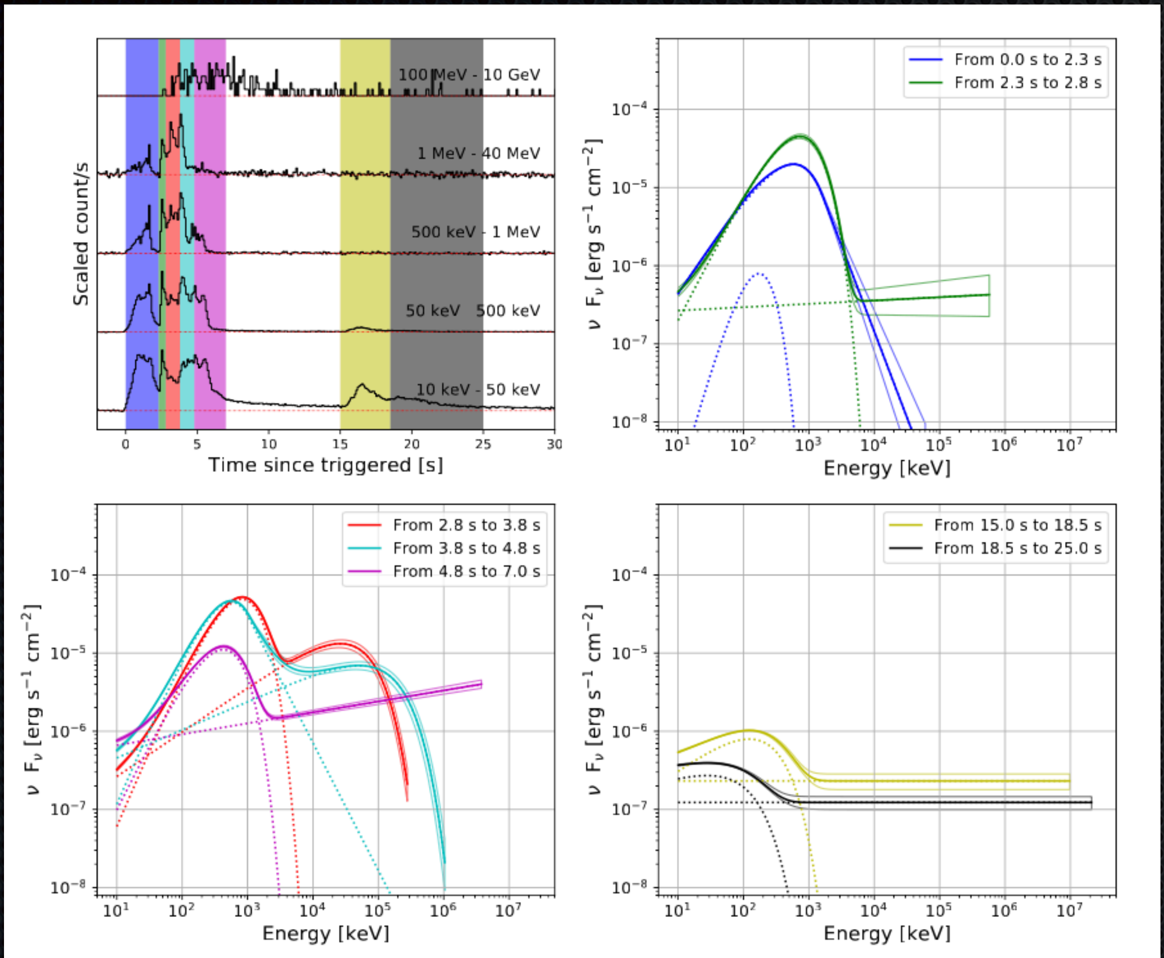
- Observations began T0+50s with > 20 sigma detection
- Lower energy limit of 300 GeV and an implied high energy limit < 1 TeV

GRB 190114C - Prompt Emission

- Highly variable emission within T0+10s and a soft bump at about T0+15s
- Minimum variability of ~ 6 ms in GBM
- Very prominent delay in the LAT photons in both LLE and standard analysis
- Highest energy photon of 21 GeV is observed at T0+20.9 s
- Evidence for a smoothly decaying emission component in both GBM and BAT is already evident at about T0+7s
- Very similar to other LAT detected GRBs



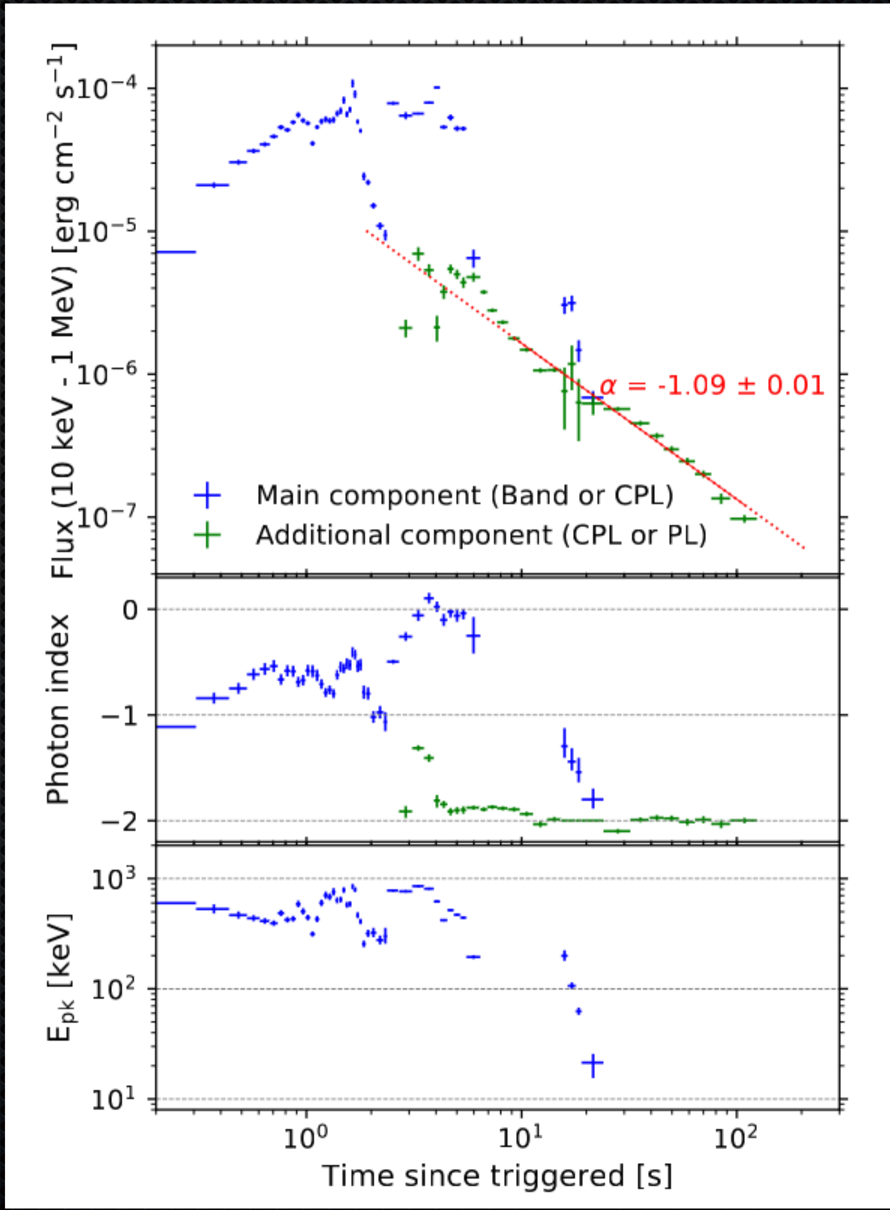
Joint Spectral Fits - Prompt Emission



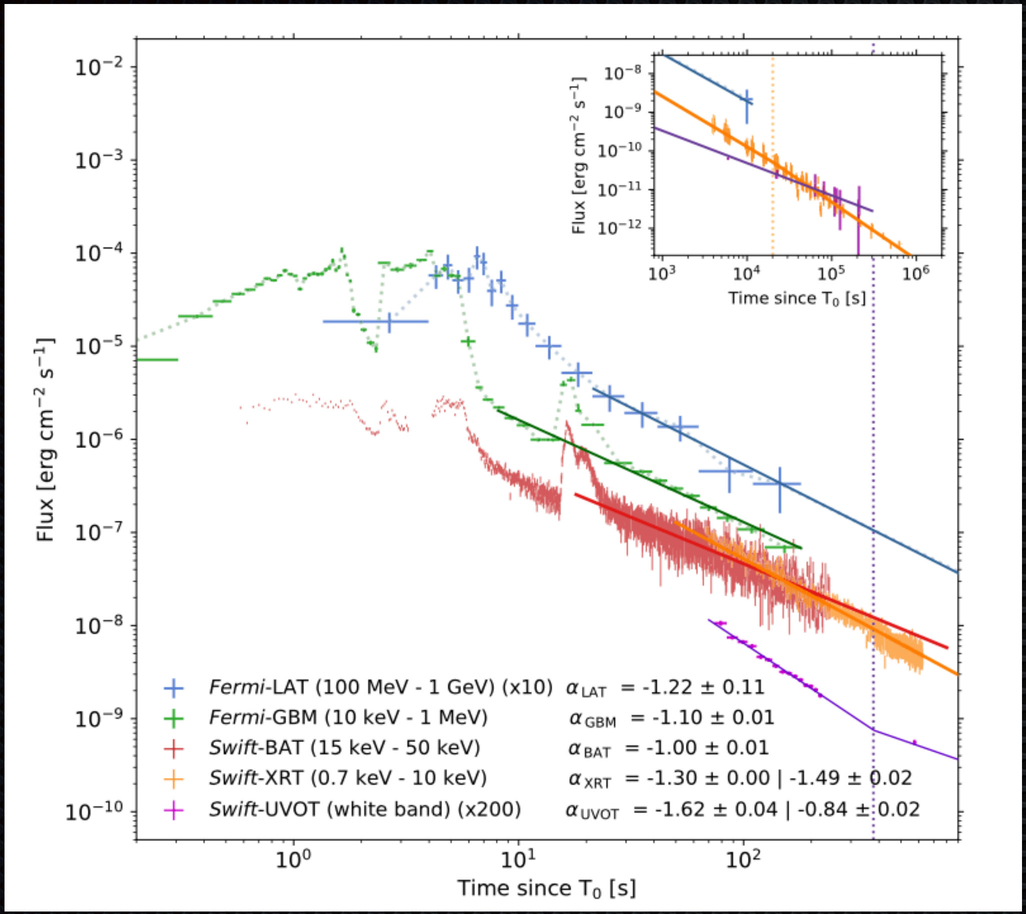
- The highly variable data is best fit by a CPL or Band model, with an additional black body component
- An extra power-law component later emerges, explaining the delayed LAT photons
- Strong evidence for time-evolving attenuation of the extra power-law attributed to pair production
- Spectral curvature due to pair production can allow us to calculate the bulk Lorentz factor
- The smoothly decaying emission is best fit by a simple power-law

Separating the Spectral Components

- We can use the fits to estimate the flux contribution from each component
- The time evolution of the components strongly suggests they originate from different emitting regions
- The CPL and Band emission is highly variable and due to emission at smaller radii
- The PL emission is smoothly decaying and suggests emission at larger radii
- Clear observations of transition from internal shock to external shock dominated emission
- Allows us to robustly estimate the onset of the afterglow

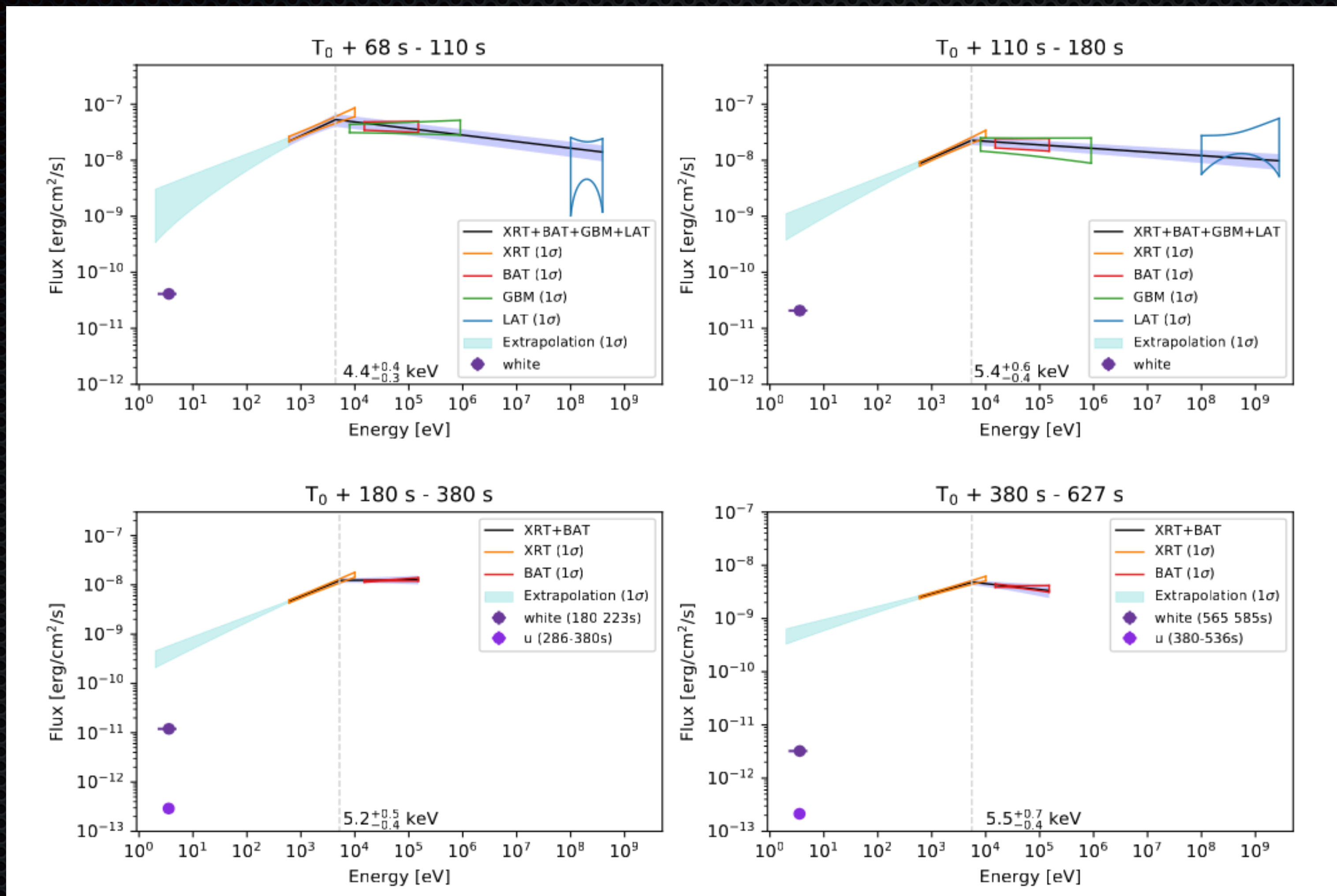


GRB 190114C - Extended Emission

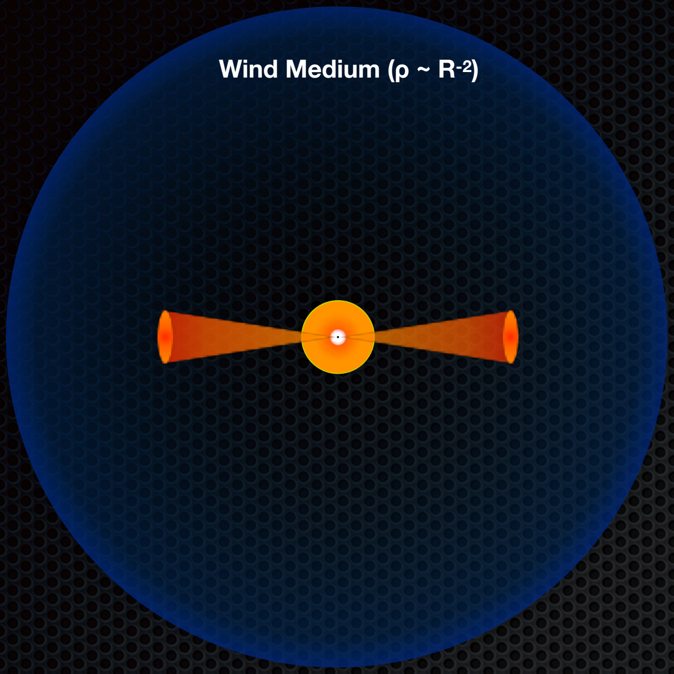


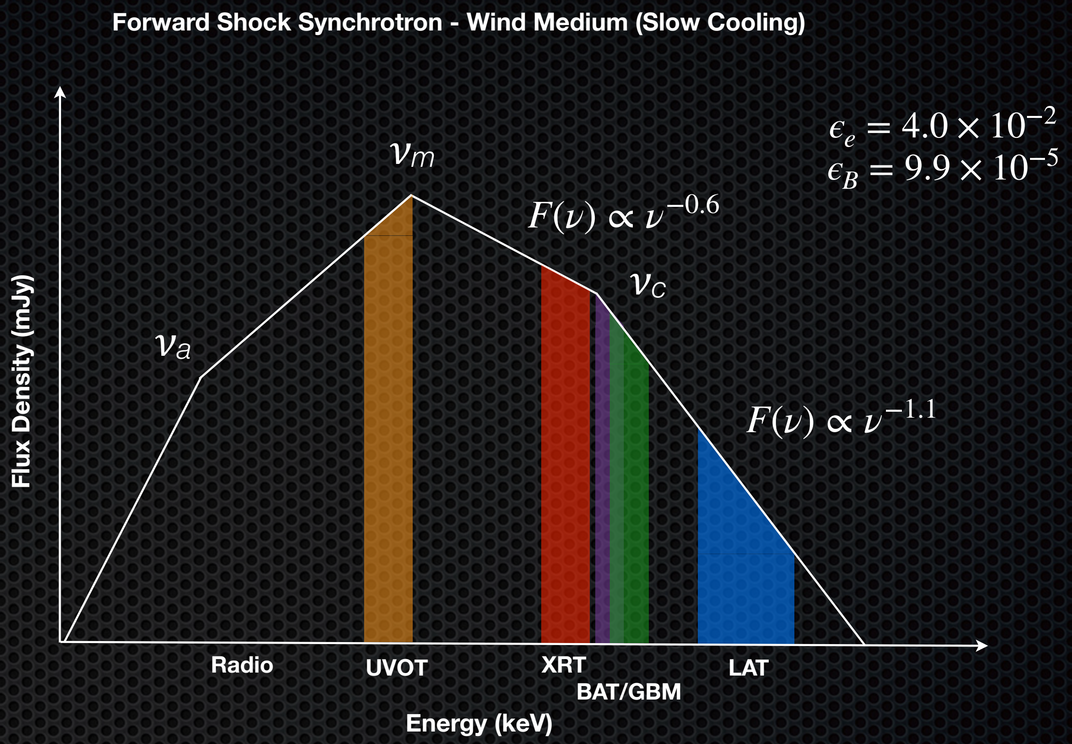
- The smoothly decaying emission is observed in all Fermi and Swift instruments
- Clearly identified as the afterglow component that appears during the prompt emission
- One of the first observations of afterglow emission in the GBM
- The BAT, GBM, and LAT data all decay with consistent slopes
- The XRT and UVOT data decay at steeper slopes
- Varying temporal slopes point to different underlying spectral indices

Joint Spectral Fits - Afterglow Emission



- We find a spectral break between the XRT and BAT, GBM, and LAT data
- The difference in the spectral slope is consistent with $\Delta\Gamma = 0.5$

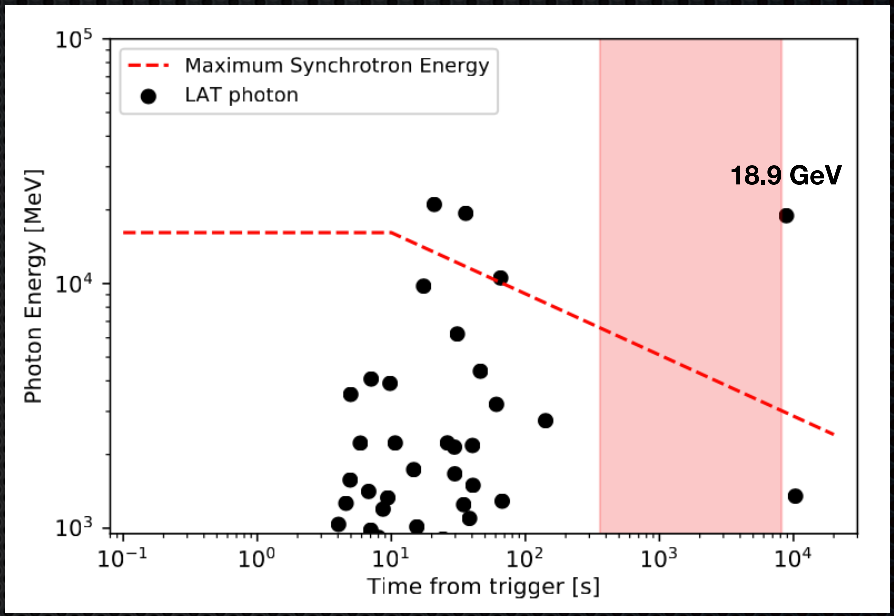




- The afterglow emission is interpreted as synchrotron radiation from shock accelerated electrons in a blast wave that is decelerating into circumstellar or interstellar material
- The resulting emission is broadband and exhibits breaks at characteristic frequencies
- The location of these spectral breaks affects the temporal decay seen in each instrument
- The relationship between the spectral and temporal decay slope favors a wind like medium for the surrounding circumstellar environment
- Matches previous conclusions that LAT detected GRBs may preferentially probe wind environments

Maximum Synchrotron Energy

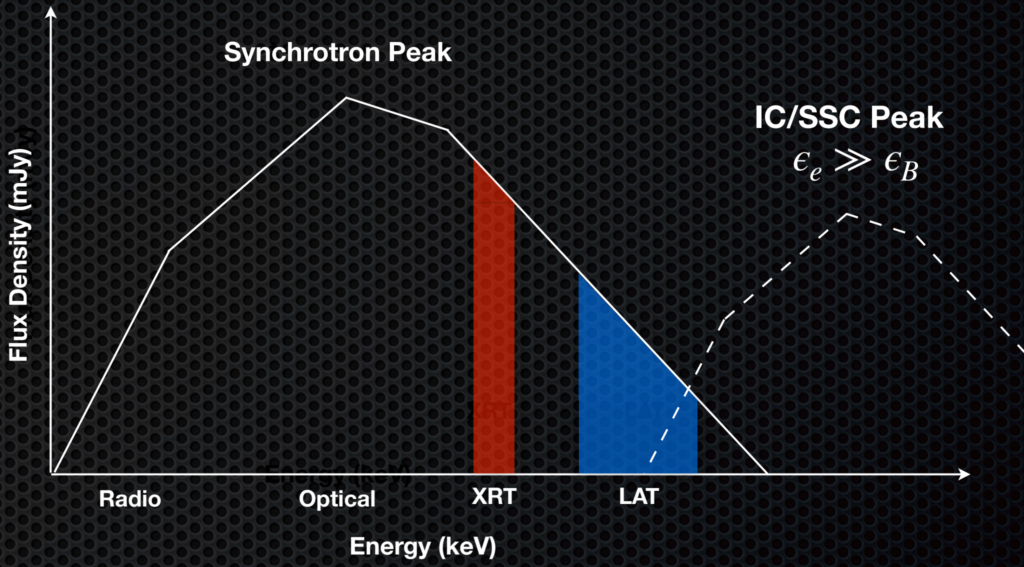
- The broadband data is extremely well fit by the standard forward shock synchrotron model
- There is a theoretical maximum photon energy that the synchrotron process can create from shock accelerated electrons
  - $E_{max} \sim 50\ \mathrm{MeV} \times \Gamma_{Bulk}$
- We can use the minimum variability timescale and the pair production turnover to estimate Lorentz factor of the forward shock
- We also know the deceleration time when the forward shock begins to radiate its energy
- This allows us to estimate a maximum synchrotron energy as a function of time
- Already in the LAT energy range there are photons that cannot be explained by shock accelerated electron synchrotron emission

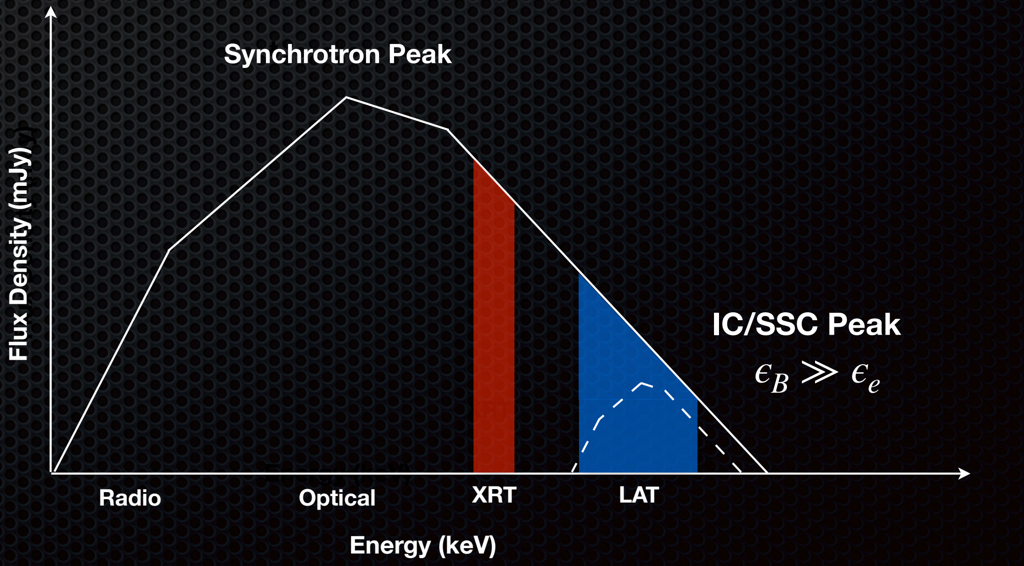


- Possible solutions include:
  - Magnetic reconnection
  - Gradients in the downstream magnetic field
  - IC and SSC contributions that are not easily distinguished from simple synchrotron emission

IC/SSC Constraints

- Previously no evidence for late-time IC/SSC emission within the LAT energy range
  - No IC scattering from x-ray flare photons, plateau emission, or SSC from the forward shock has ever been seen
- Blast wave with large fraction of total energy in energetic electrons and/or a very low magnetic field density will generate a prominent SSC peak
- A magnetically dominated blast wave with $\varepsilon_B >> \varepsilon_e$ could explained previous LAT data
- Other possibility is the SSC peak is outside the LAT energy range
  - If we assume the synchrotron peak is in the x-ray, this would require a very high electron Lorentz factor of $Y_m > 1000$

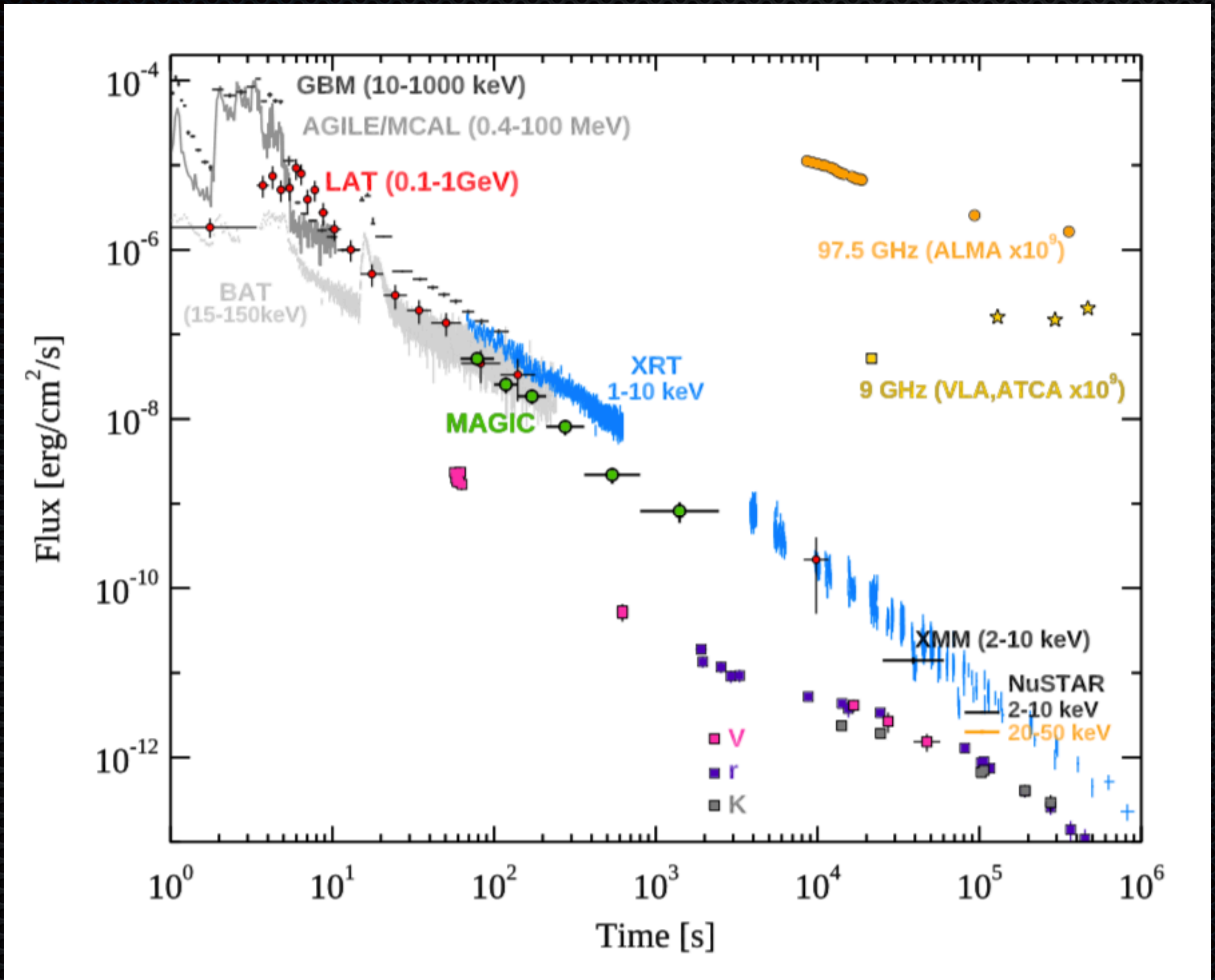




MAGIC Observations & Analysis

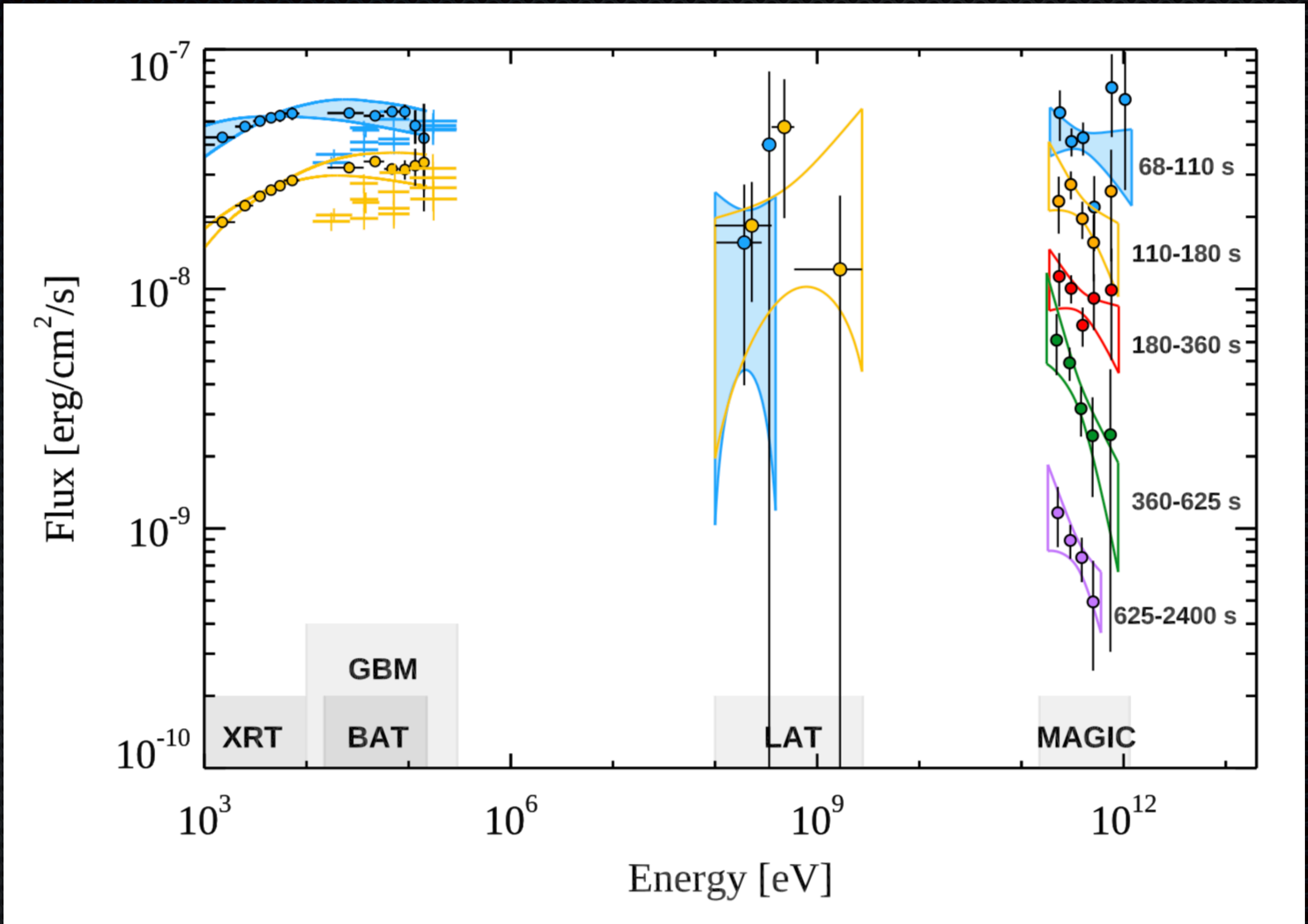
- MAGIC consists of two 17-meter diameter Cherenkov Telescope
  - Located at 2200m in La Palma Canary Island
- MAGIC received the Swift-BAT GCN at T0+22s
- MAGIC observations began at about T0+50s and lasted 4.12 hrs
- Observations were at a high zenith angle and in half moon condition
  - Zenith = 55.8 and azimuth = 175.1
  - Resulting energy range of 0.3 to 1 TeV
- MAGIC MWL includes data from 7 instruments on 3 missions and 14 telescopes
- The final analysis covers 17 orders of magnitude in energy from 1 GHz to 1 TeV

MAGIC Light Curve



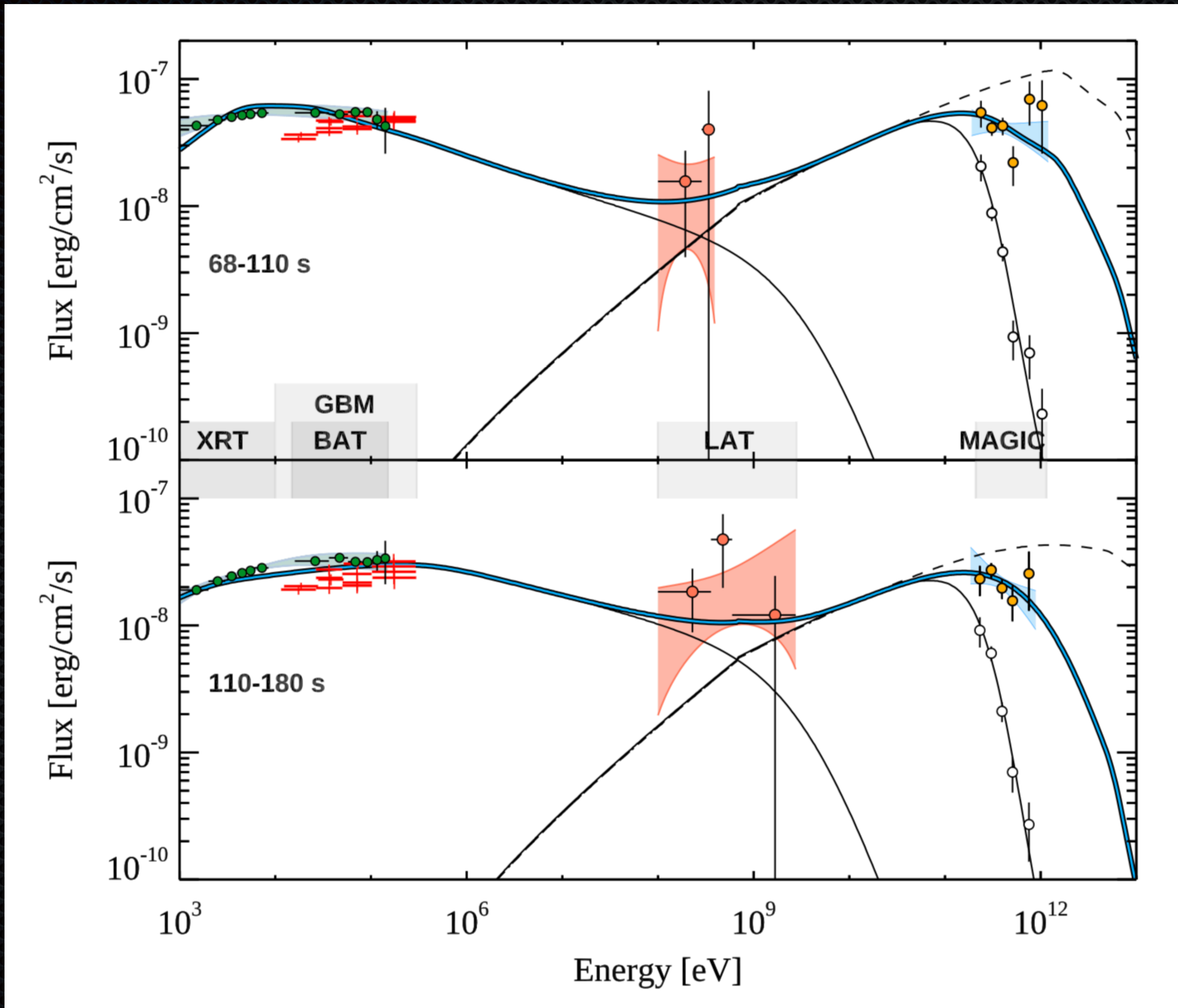
- The MAGIC temporal decay slope is roughly $F \sim t^{-1.4}$

Broad-band Spectra

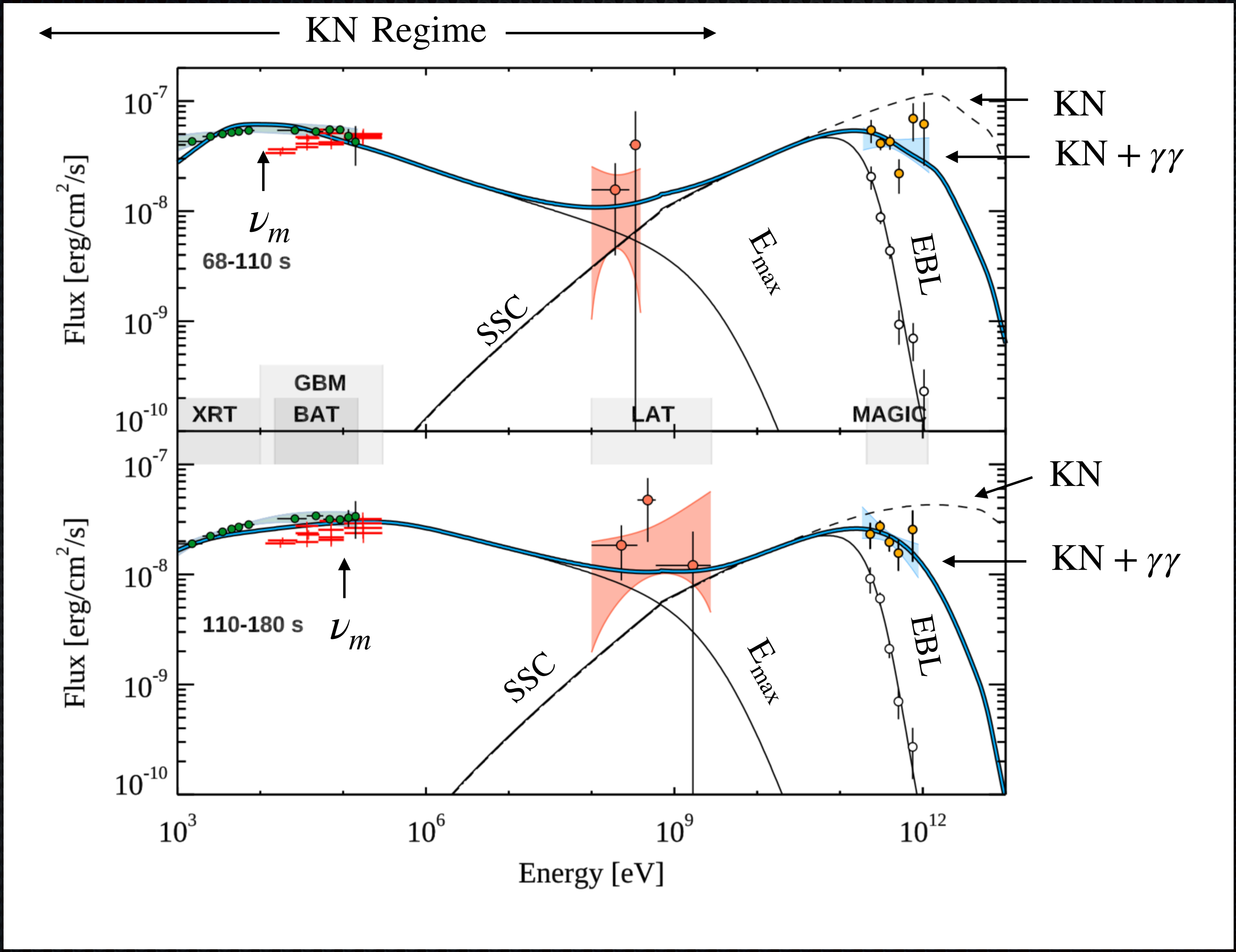


- Broad-band spectra for five intervals from top to bottom
- 68-110 s, 110-180 s, 180-360 s, 360-625 s, 625-2400 s

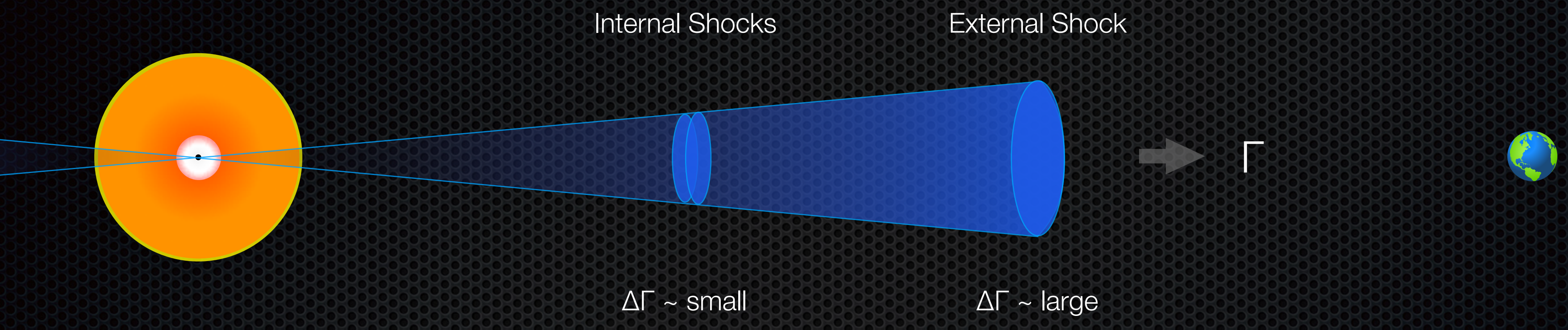
MAGIC Board Band Spectra



MAGIC Broad Band Spectra

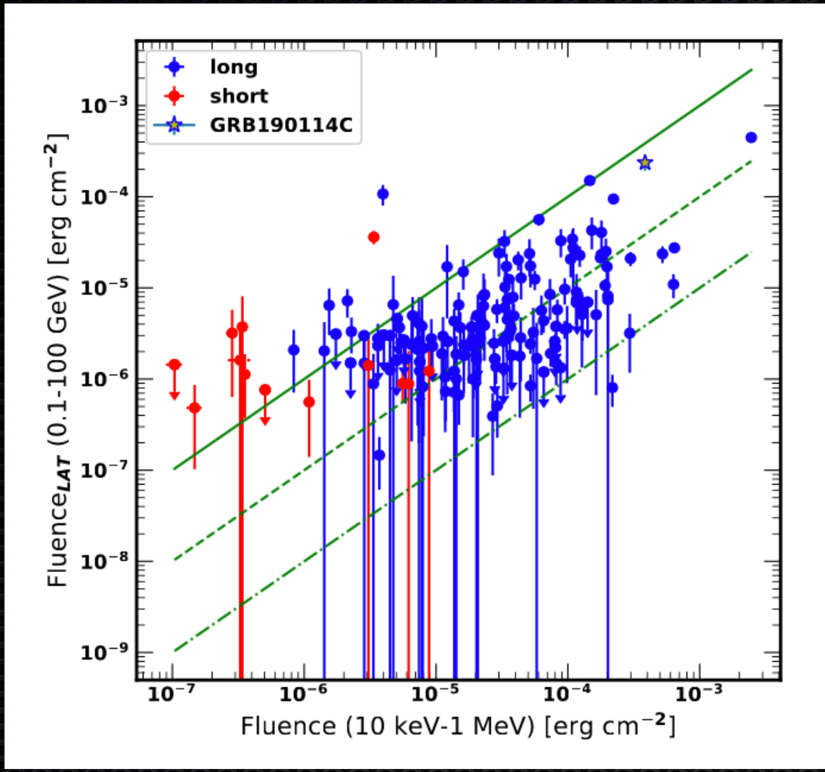


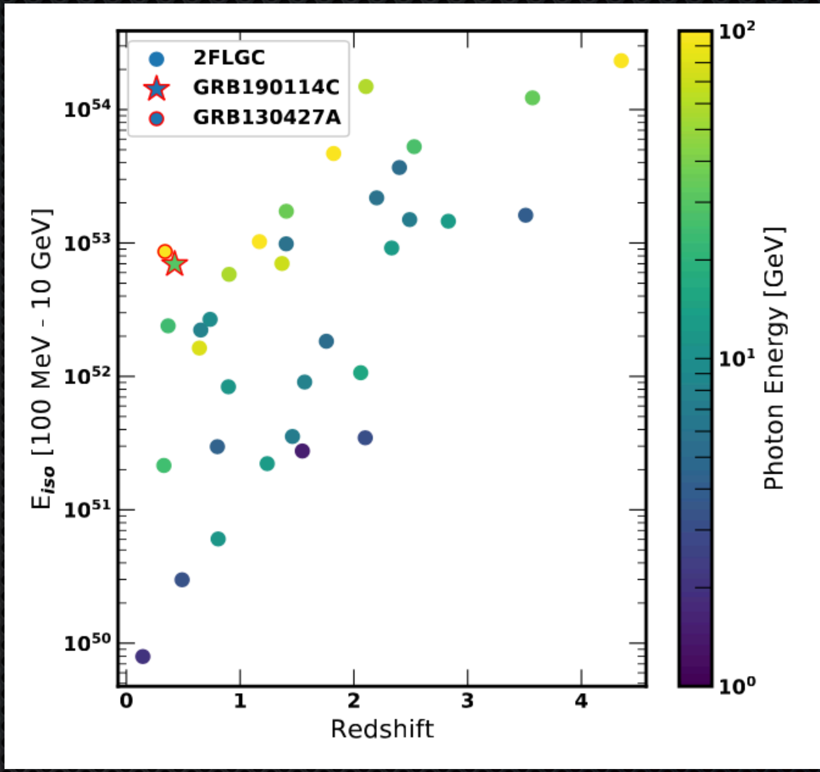
Implications For GRB Energetics



- The total energy of a GRB afterglow is about a factor of 10 less than the prompt emission
- The relative Lorentz factor for internal shocks should be much smaller than for the external shock
- One naturally would expect the afterglow to be as bright, or brighter, than the prompt emission
- The MAGIC results helps alleviate this energetics problem by showing that afterglow energy is being transferred to wavelengths that have been traditionally outside our ability to detect

What Was Special About GRB 190114C?





- GRB 190114C was the 4th brightest in peak flux and the 5th most fluent GRB detected by GBM
- It is also the second most fluent GRB detected by the LAT
- GRB 190114C is the second most luminous GRBs detected below redshift of $z < 0.5$
- The combination of luminosity and proximity surely helped enable its detection

Conclusions

- GRB 190114C well detected across the electromagnetic spectrum
- Fermi & Swift observations can constrain its energetics, bulk Lorentz factor, and afterglow onset
- We show that LAT detected photons are already in disagreement with the theoretics maximum synchrotron energy
- MAGIC observations show a prominent emission component at ~ 1 TeV
- Component is consistent with being due to SSC emission that is heavily attenuated due to the EBL, Klien-Nishina suppression, and opacity due to pair production
- MAGIC observations effectively rule out a highly magnetized fireball
- Evidence for SSC emission helps elevate a long standing energetics problem in GRBs
- May indicate that SSC emission is a common feature in GRB afterglows
- GRB 190114C was one of the brightest bursts within $z < 0.5$, helping enable its detection