

The High Energy Detection of GRB 190114C with Swift and Fermi



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On behalf of the Fermi and Swift instrument teams



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 $T_0+0.56$ s
- Swift XRT and UVOT observations began at $T_0+68.27$ 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 T_0+50 s

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

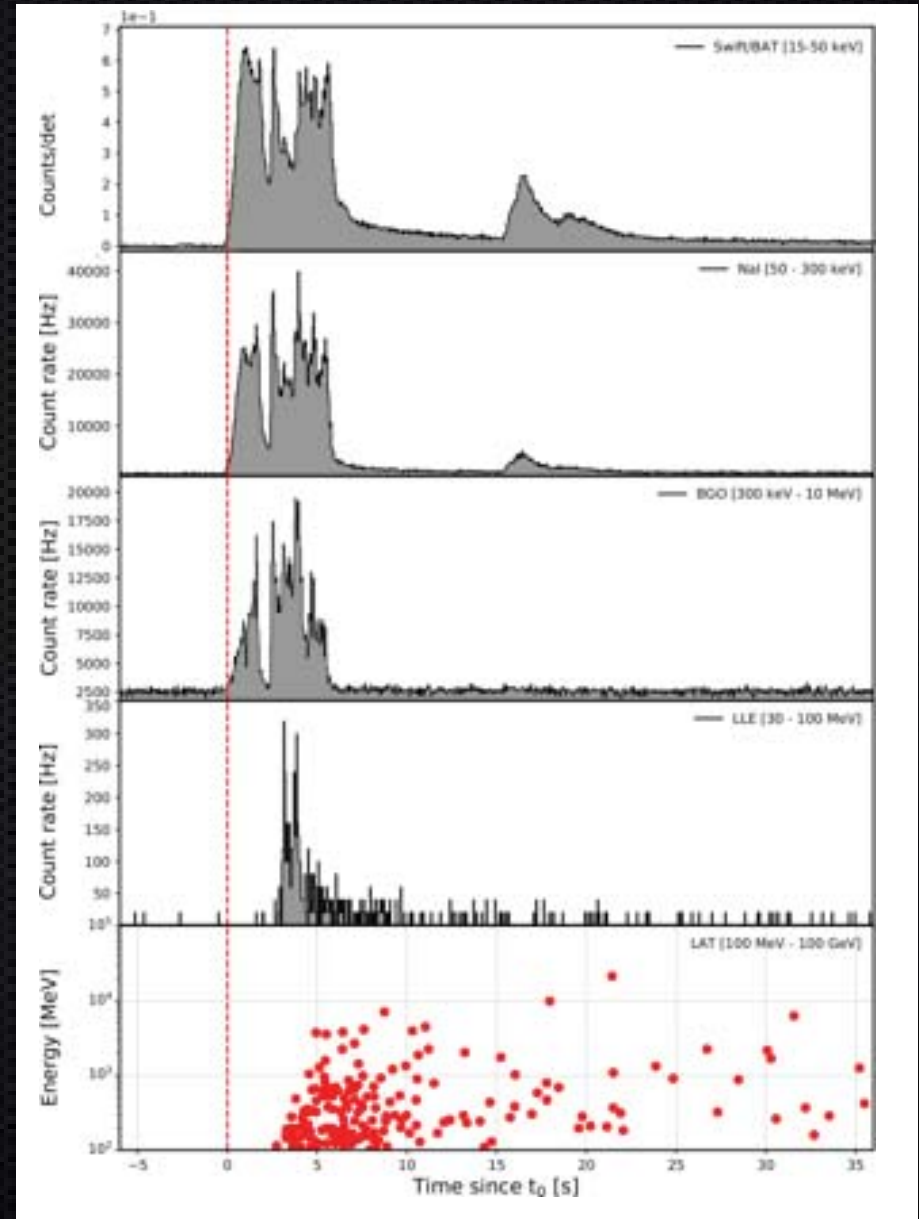
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The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, Selsing et al. GCN 23695). This observation was triggered 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.

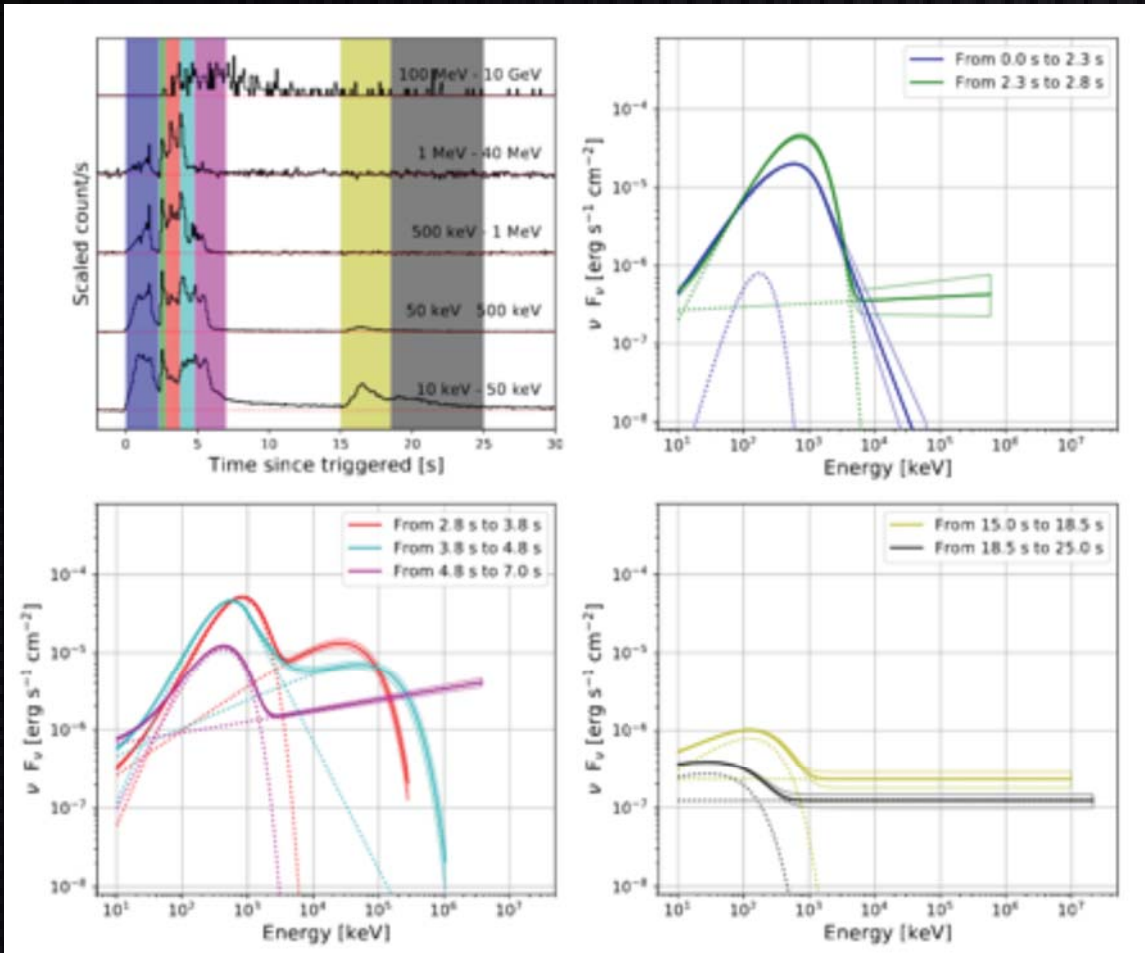
- Observations began T0+50s with > 20 sigma detection
- Lower energy limit of 300 GeV and an implied high energy limit < 1 TeV
- Koji Noda will talk more about the MAGIC observations

GRB 190114C - Prompt Emission

- Highly variable emission within T_0+10 s and a soft bump at about T_0+15 s
- Minimum variability of ~ 6 ms in GBM
 - Haar wavelets method - Golkhou et al. (2015)
- Very prominent delay in the LAT photons
 - High energy delay already significant at 30 MeV
- Highest energy photon of 21 GeV is observed at $T_0+20.9$ s
- Evidence for a smoothly decaying emission component in both GBM and BAT is already evident at about T_0+7 s
- High energy emission above 100 MeV continues long after the BAT and GBM is over
- Very similar to other LAT detected GRBs



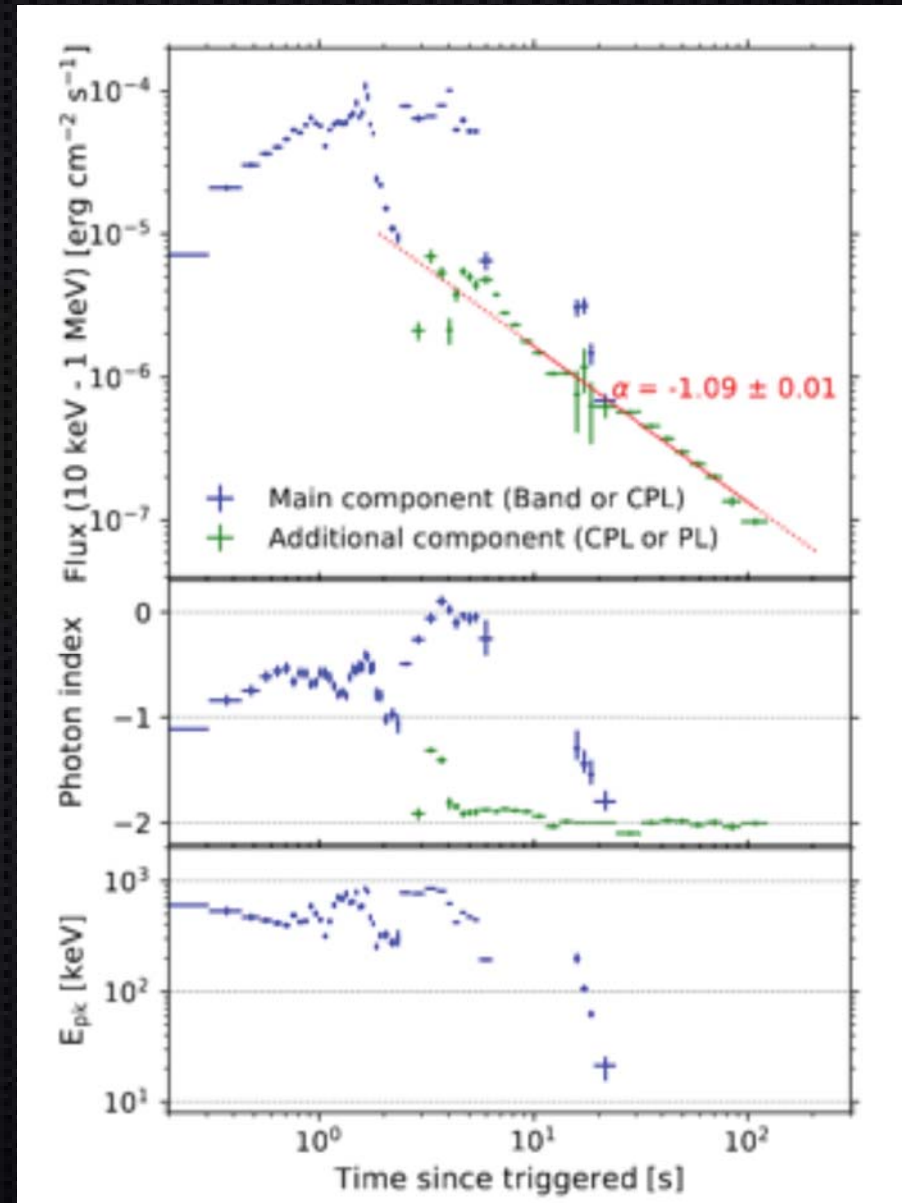
Joint Spectral Fits - Prompt Emission



- ✦ 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

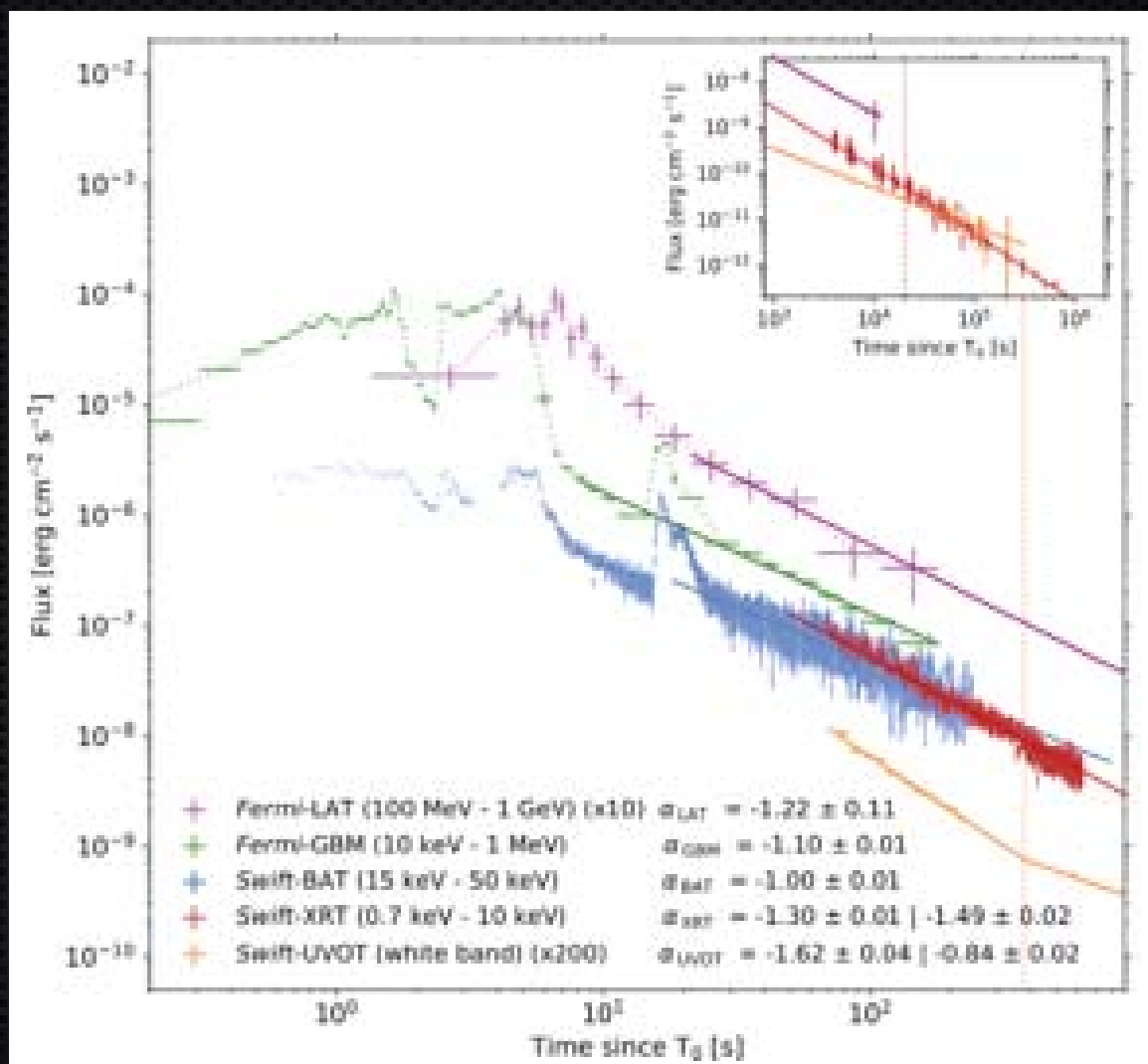
Separating the Spectral Components

- We can use the spectral 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/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
 - Similar interpretation by Ravasio et al. 2019
- Allows us to robustly estimate the afterglow deceleration timescale (i.e. onset)
- Also means that prompt emission can be “contaminated” by afterglow emission

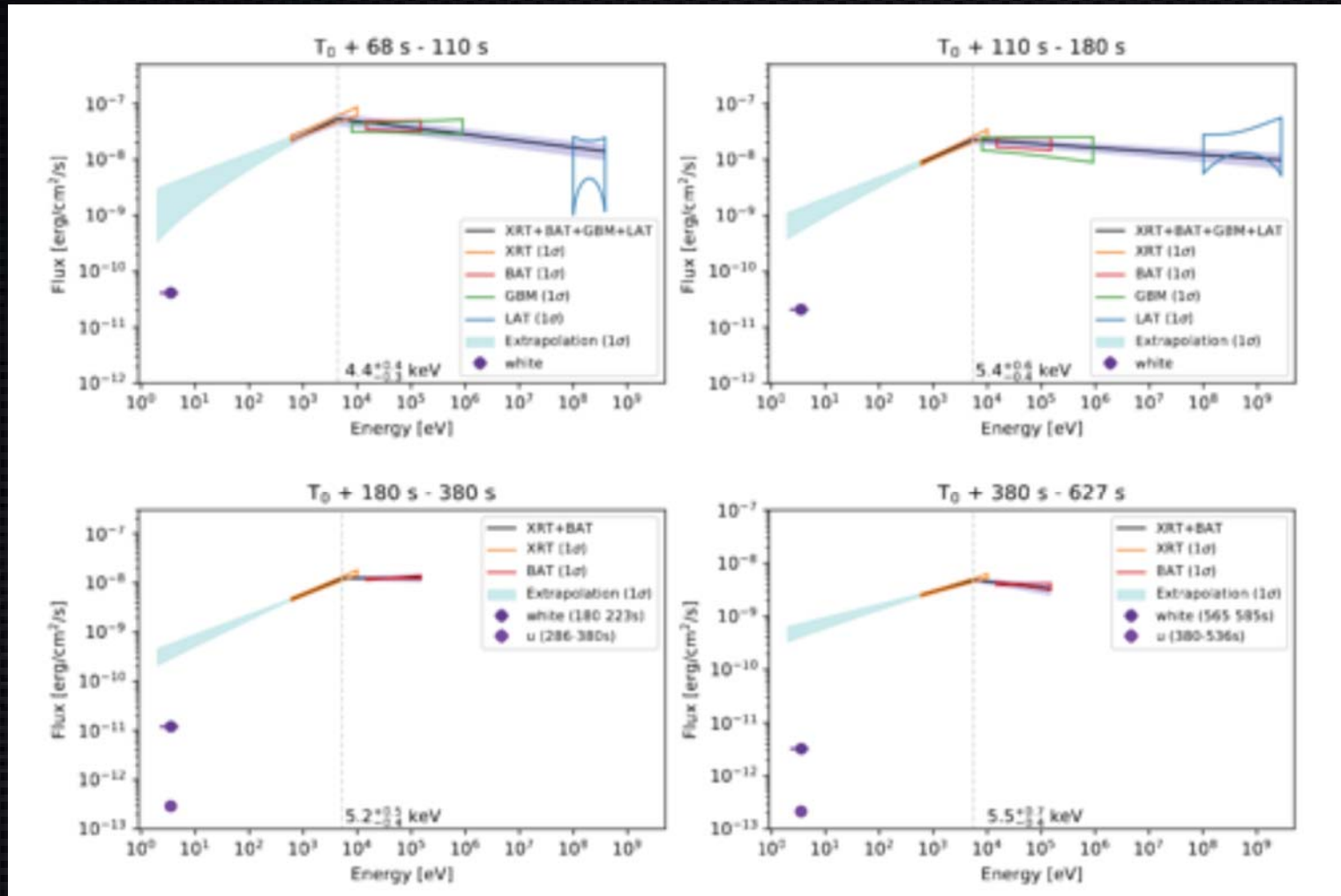


GRB 190114C - Extended Emission

- ✦ The smoothly decaying emission is observed in all Fermi and Swift instruments
- ✦ Clearly identified as the afterglow component that appears during the prompt emission
- ✦ 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

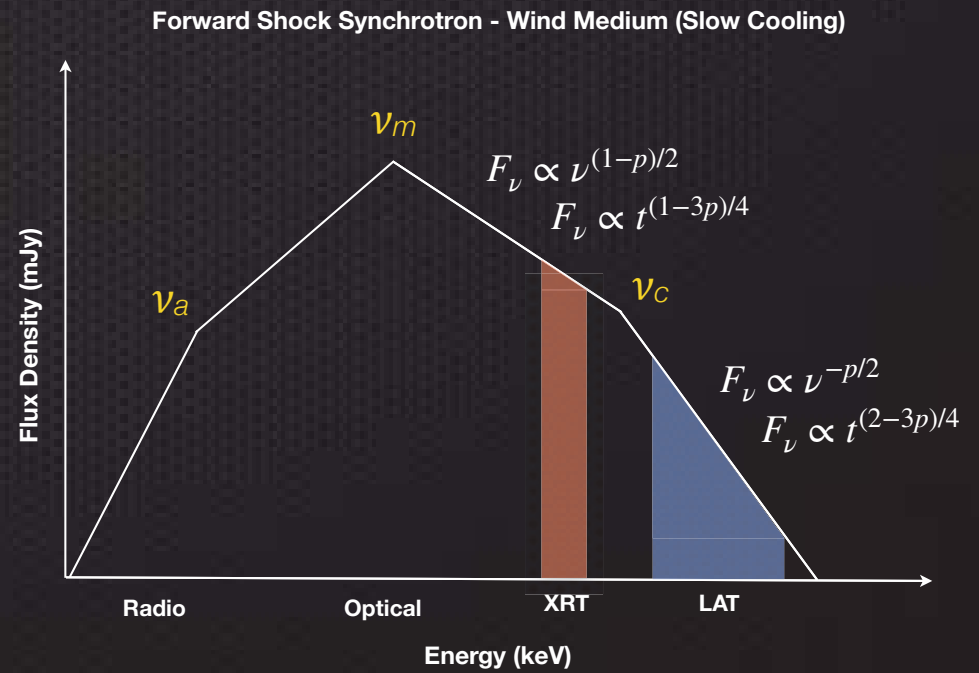
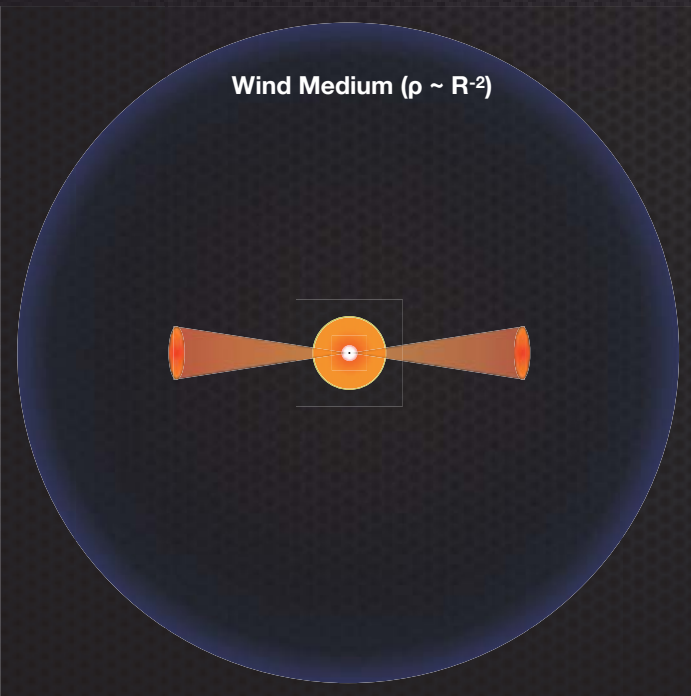
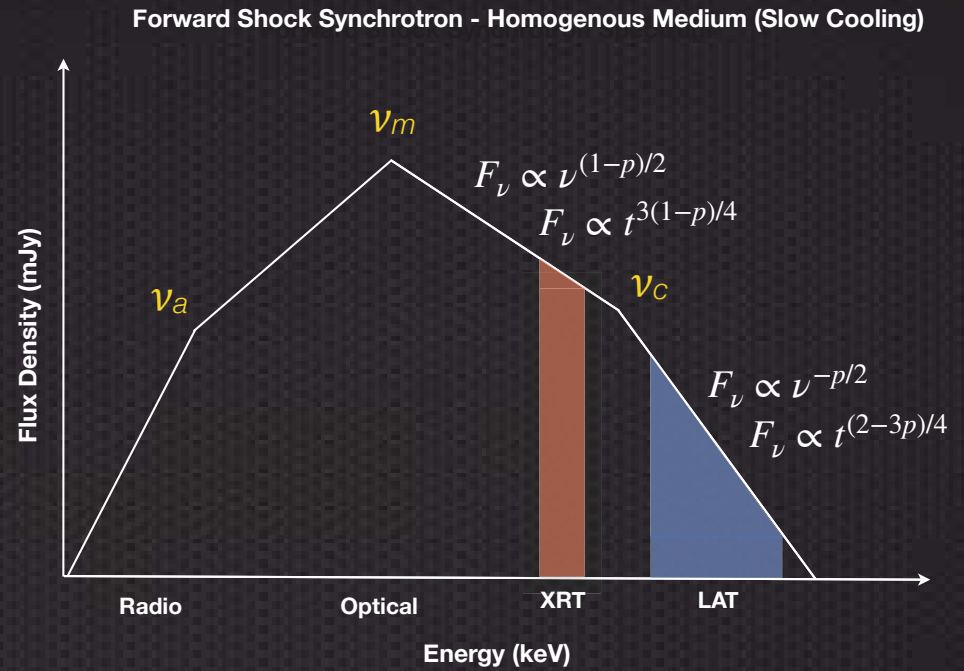
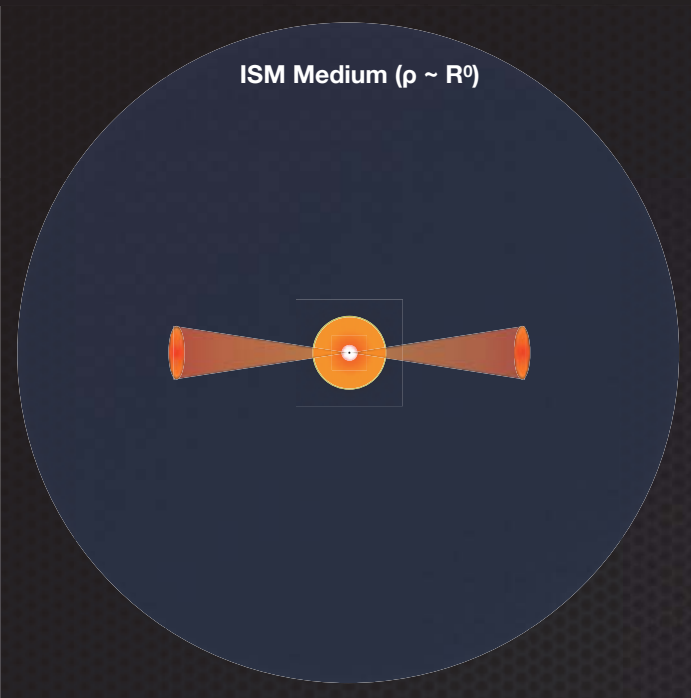


Joint Spectral Fits - Extended Emission



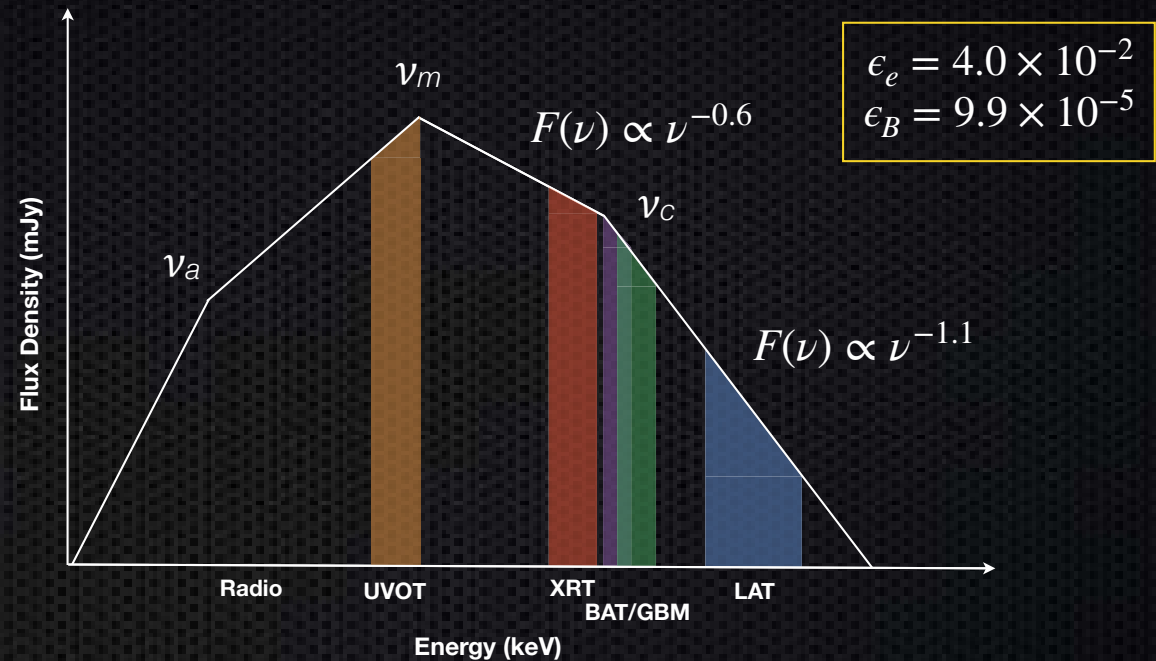
✦ We find a spectral break between the XRT and BAT, GBM, and LAT data

✦ The difference in the spectral slope is consistent with $\Delta\Gamma = 0.5$





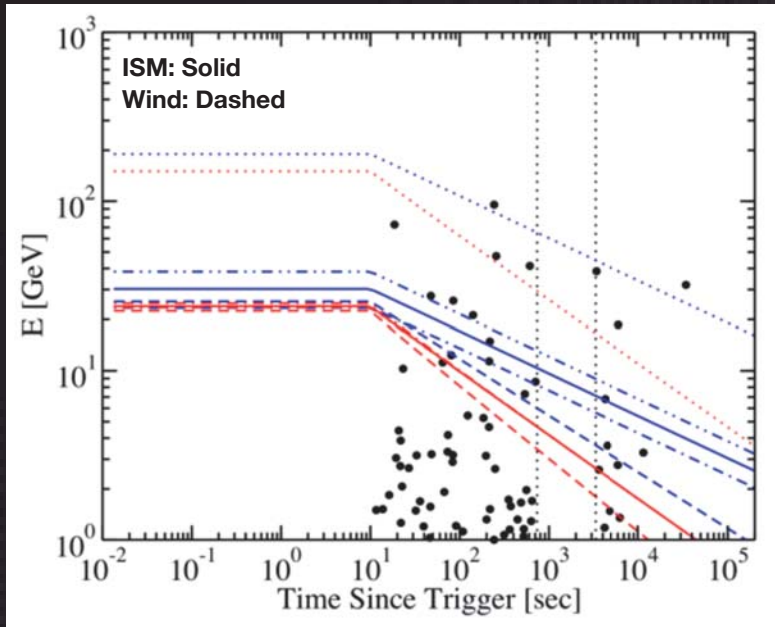
Forward Shock Synchrotron - Wind Medium (Slow Cooling)



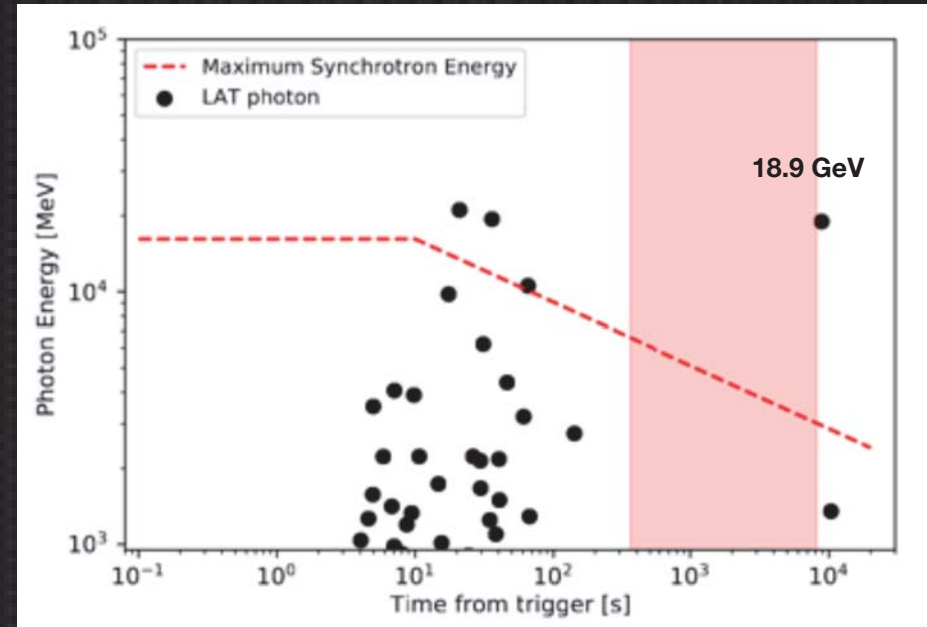
- ✦ The afterglow emission is interpreted as synchrotron radiation from shock accelerated electrons in a blast wave that is decelerating into circumstellar or interstellar material
- ✦ The resulting emission is broadband and exhibits breaks at characteristic frequencies
- ✦ The location of these spectral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

Maximum Synchrotron Energy

GRB 110731



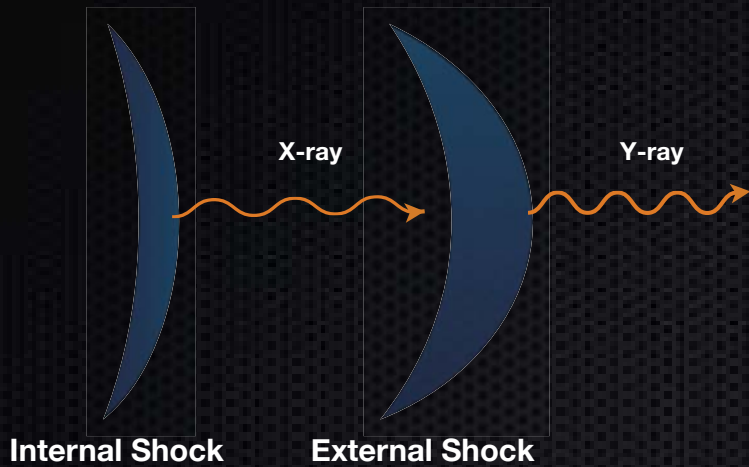
GRB 190114C



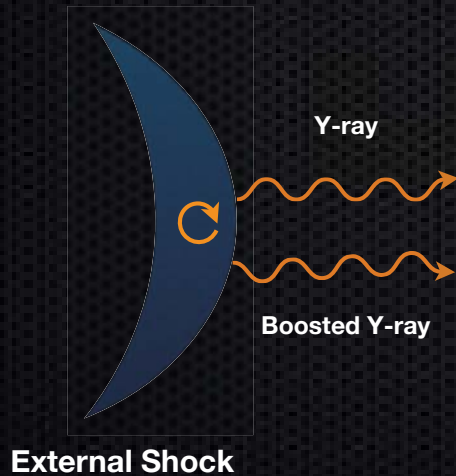
- There is a theoretical maximum photon energy that the synchrotron process can create from shock accelerated electrons: $E_{\text{max,ssc}} \sim 50 \text{ MeV} \times \Gamma_{\text{Bulk}}$
- We can estimate the Lorentz factor of the forward shock from the variability timescale and γ - γ attenuation
- We also know the deceleration time when the forward shock begins to radiate its energy
- There are high-energy photons that are difficult to explained by shock accelerated electron synchrotron
- Several processes have been proposed to elevate this problem, but IC/SSC emission is the most obvious

Synchrotron Self-Compton and Inverse Compton Emission

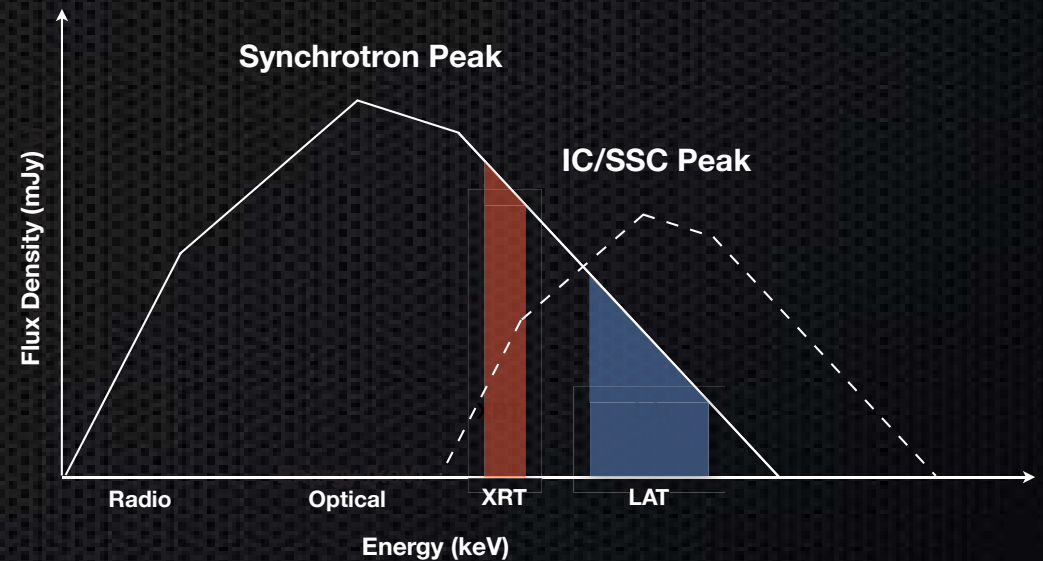
IC Emission



SSC Emission

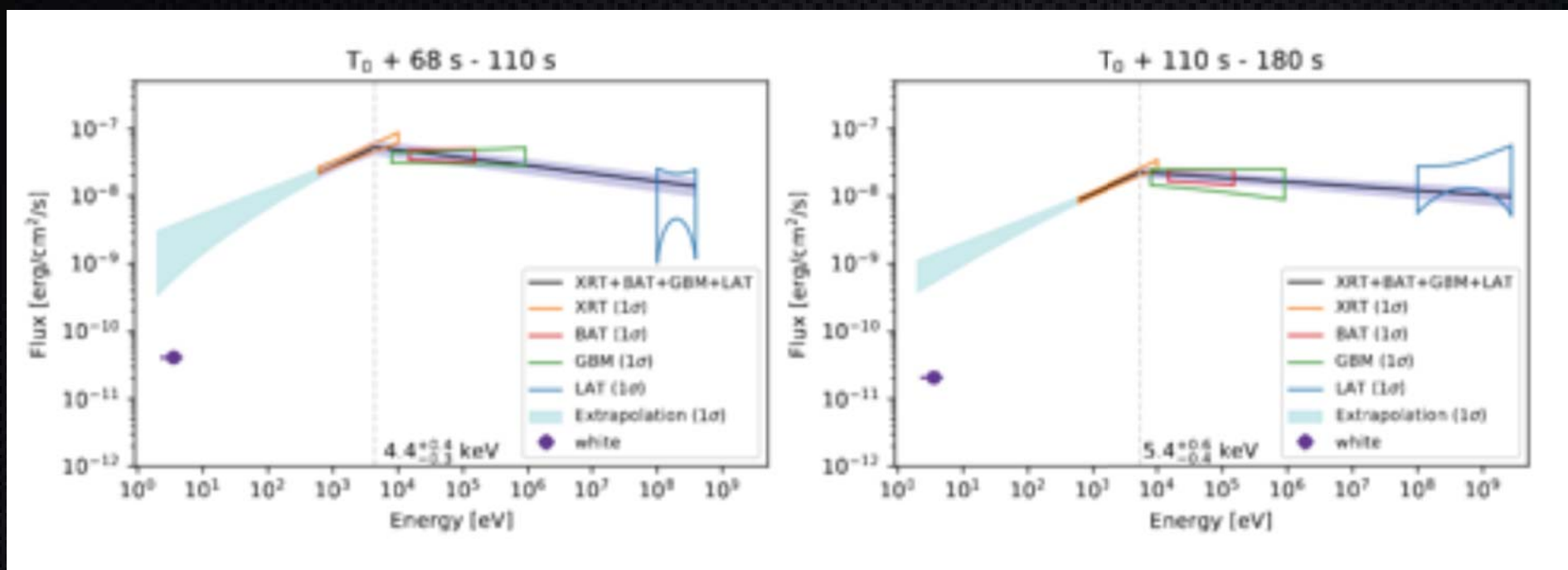


Forward Shock Synchrotron with IC/SSC Component



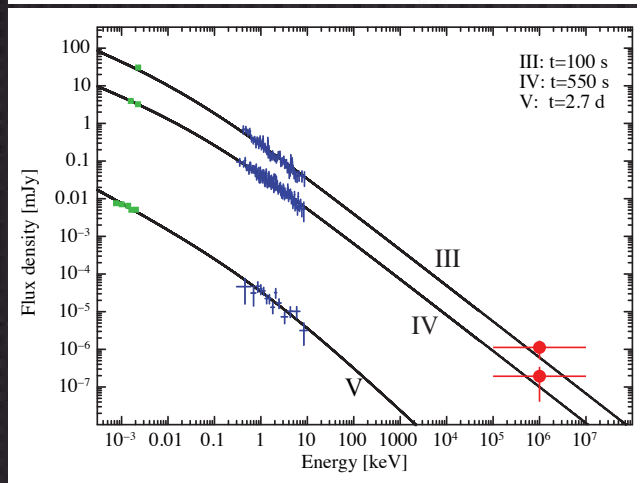
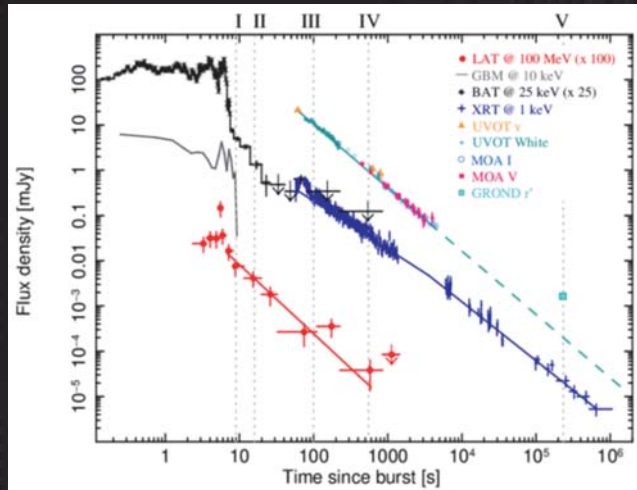
- ✦ Shock accelerated electron synchrotron emission should be accompanied by synchrotron self-Compton (SSC) or IC emission
- ✦ Should manifest as a spectral hardening or deviations from a power-law as the IC/SSC component emerges in the LAT range

Single High-Energy Spectral Component

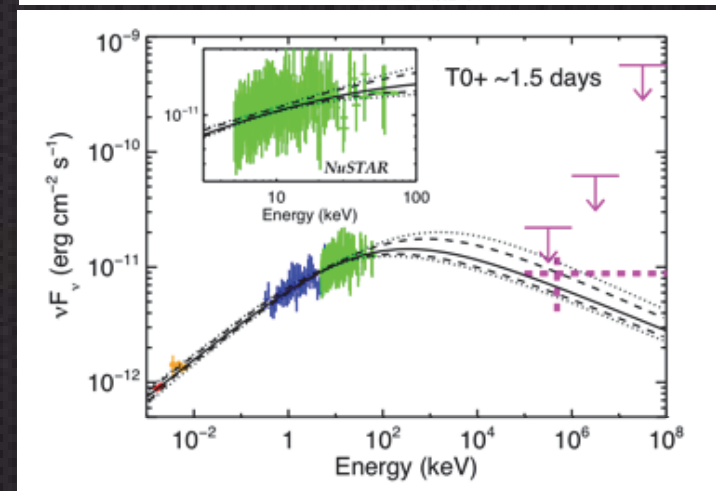
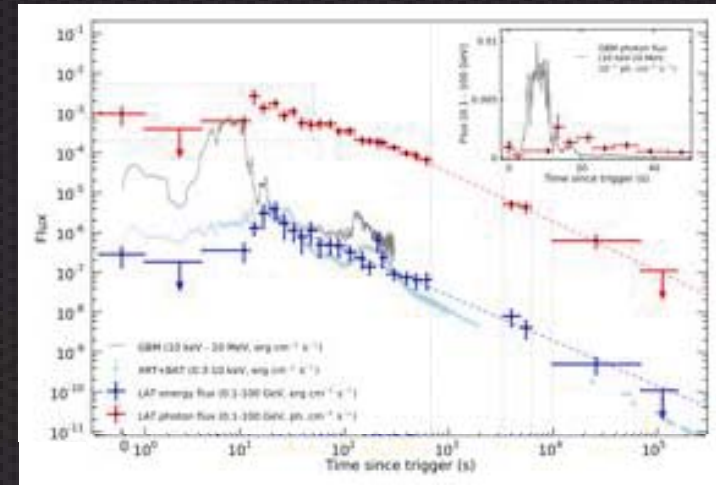


- The broadband data is extremely well fit by a single power-law from ~5 keV to 10 GeV
 - Interpreted as the standard forward shock electron synchrotron spectrum
- The Swift and Fermi data alone do not necessitate an extra spectral component at high energy
- Similar to conclusions drawn from multi-wavelength observations of GRBs 110731 & 130427A

GRBs 110731A & 130427A



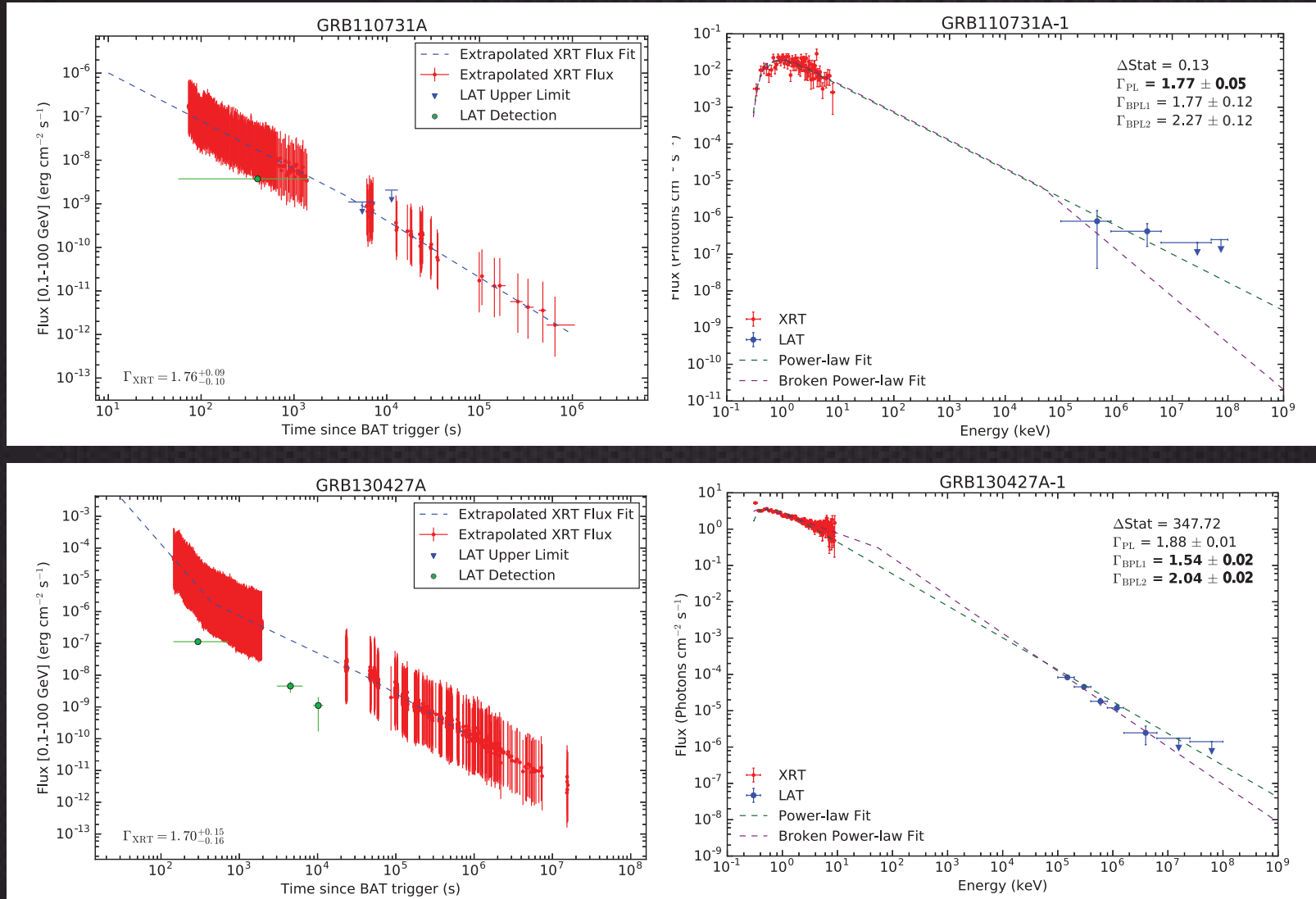
Ackermann et al. 2011



Ackermann et al. 2014, Kouveliotou et al. 2014

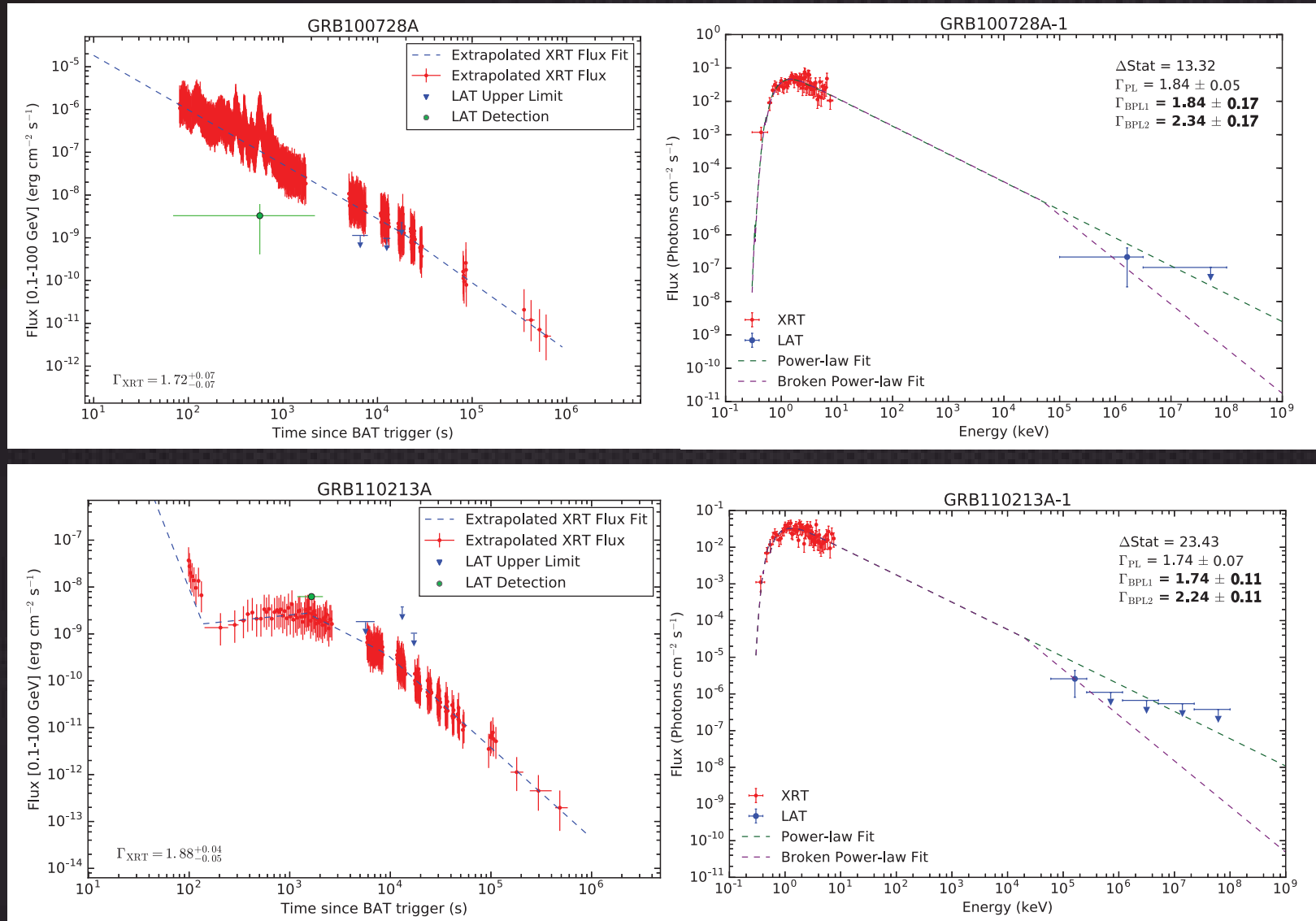
- GRBs 110731A & 130427A support a single spectral component originating from an external shock
- Neither light curve shows any deviations from a power-law decay due to additional components

Joint XRT-LAT Spectral Fits



- The standard forward shock synchrotron model is adequate to fit the broadband XRT and LAT data

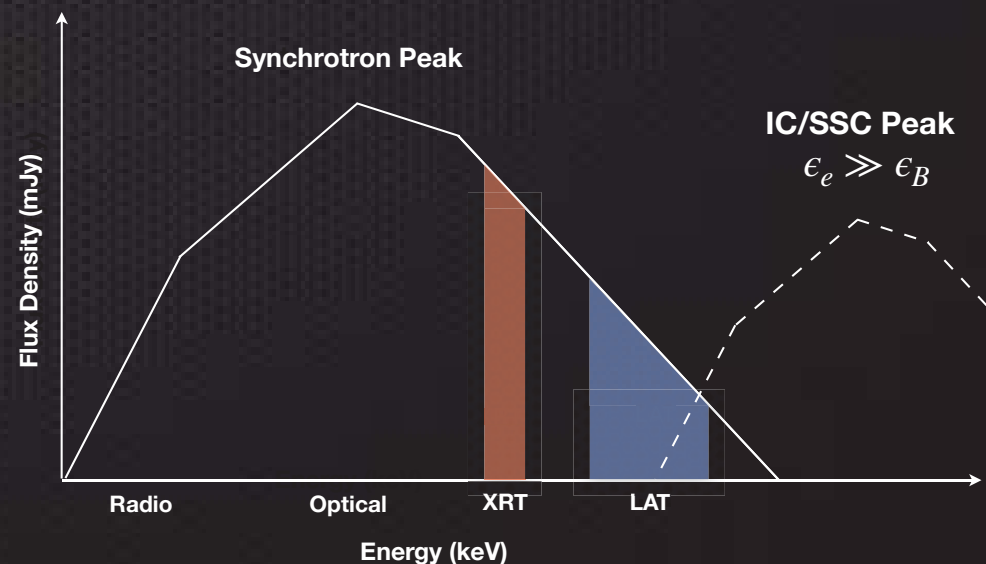
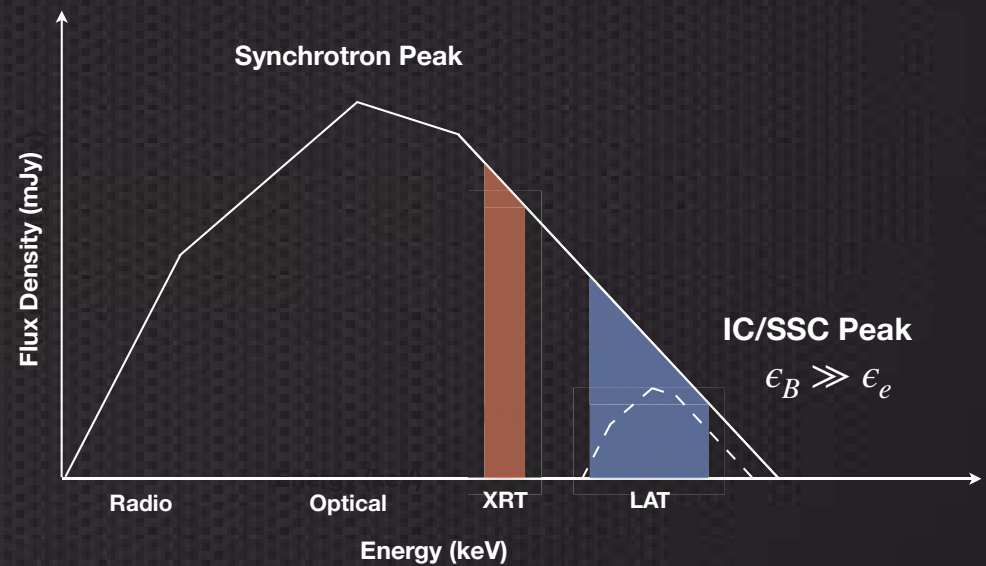
Joint XRT-LAT Spectral Fits (continued)



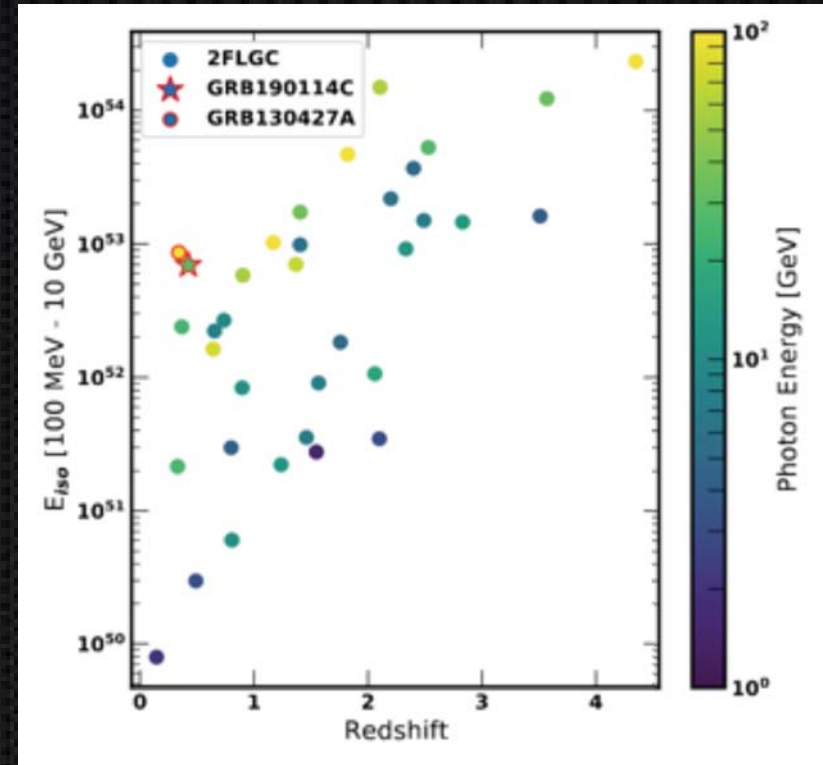
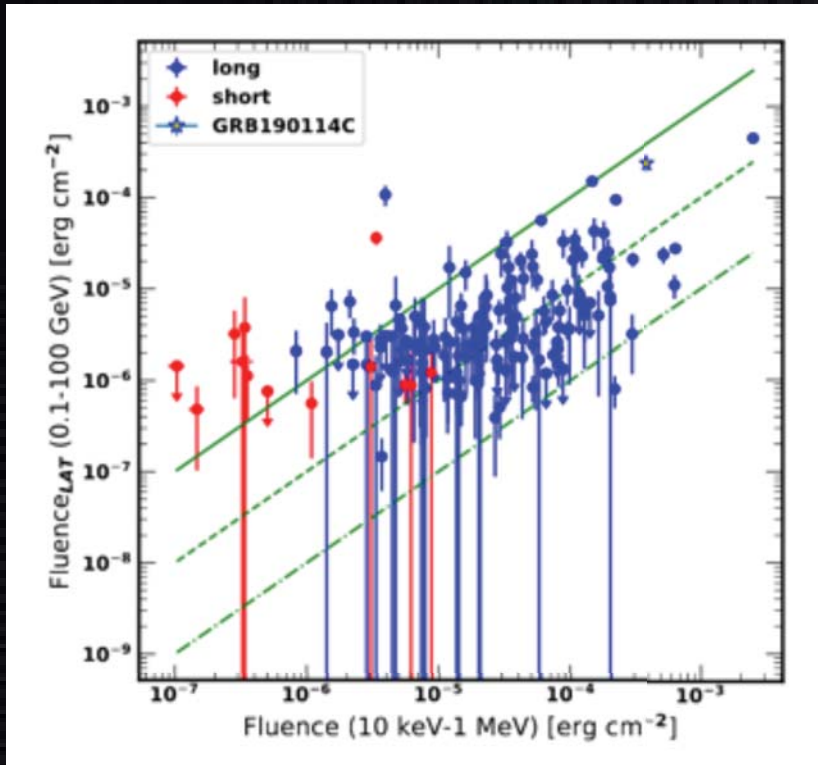
✦ No excess LAT emission during the flaring or plateau phases

LAT Constraints on High-Energy IC/SSC Emission

- No previously evidence for IC/SSC emission in the LAT
 - No IC scattering from x-ray flare photons, plateau emission, or SSC from the external shock
 - No evidence for power-law decay deviations
- A magnetically dominated blast wave with $\epsilon_B \gg \epsilon_e$ could produce a weak SSC peak and has been previously used to explain the LAT observations
- A blast wave with more energy in the energized electrons $\epsilon_e \gg \epsilon_B$ could produce a stronger SSC peak that is outside the LAT energy range
 - This scenario is favored for 190114C
- The SSC component naturally explains the photons in excess of max synchrotron energy
- The SSC component must be difficult to distinguish from the synchrotron component in the LAT energy range
 - Similar suggestion by Fan et al. 2013 for 130427A

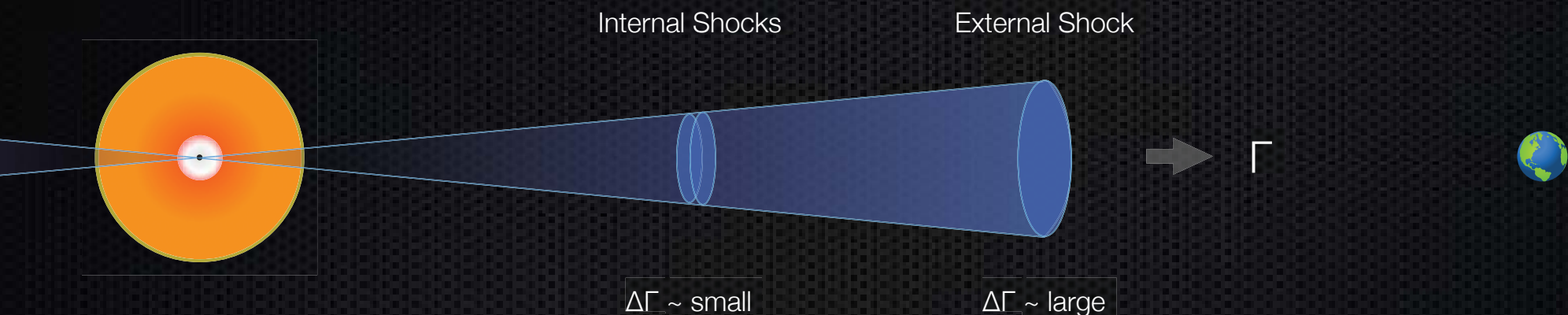


What Was Special About GRB 190114C?



- ✦ 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 helped enable its detection by MAGIC

Implications For GRB Energetics



- The total energy of a GRB afterglow is about a factor of 10 less than the prompt emission
 - See, for example, Margutti et al. 2014
- 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

Conclusions

- ✦ GRB 190114C well detected across the electromagnetic spectrum
- ✦ One of the first prominent examples of afterglow emission in the GBM
- ✦ 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 theoretical maximum synchrotron energy
- ✦ The MAGIC detection disfavors a highly magnetized fireball as the explanation for the lack of inverse Compton and/or synchrotron self-Compton emission
- ✦ Evidence for SSC emission helps elevate a long standing energetics problem in GRBs
- ✦ GRB 190114C was one of the brightest bursts within $z < 0.5$, helping enable its detection
- ✦ May indicate that SSC emission is a common feature in GRB afterglows
- ✦ The Fermi & Swift paper on GRB 190114C is now online: [arXiv:1909.10605](https://arxiv.org/abs/1909.10605)