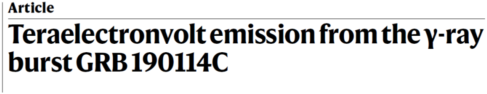
GRB 190114C

Emission of γ-rays at energies of the order of teraelectronvolt has been theoretically predicted but it has not been previously detected.


Article

Teraelectronvolt emission from the γ-ray burst GRB 190114C


Article

Observation of inverse Compton emission from a long γ-ray burst

The paper reports observations of teraelectronvolt emission from the γ-ray burst GRB 190114C. γ-rays were observed in the energy range 0.2–1 teraelectronvolt from about one minute after the burst (at more than 50 standard deviations in the first 20 minutes).

Alert

14 January 2019, 20:57:03 universal time (T_0) by the Burst Alert Telescope (BAT) onboard the Neil Gehrels Swift Observatory (Swift) and the Gamma-ray Burst Monitor (GBM) instrument onboard the Fermi satellite.

Subsequently, it was also detected by several other space-based instruments, including Fermi-LAT, INTEGRAL/SPI-ACS, AGILE/MCAL, Insight/HXMT and Konus-Wind.

General properties of GRB 190114C

- The measured duration of $T_{90} \approx 116s$ by Fermi-GBM and $T_{90} \approx 362s$ by Swift-BAT puts GRB190114C in the long-duration subclass of GRBs.
- Its redshift was reported as z $= 0.4245 \pm 0.0005$ by the Nordic Optical Telescope and confirmed by Gran Telescopio Canarias.
- The isotropic equivalent energy and luminosity at 1–10^4 keV are $E_{iso} \approx 3 \times 10^{53}$ erg and $L_{iso} \approx 1 \times 10^{53} erg\, s^{-1}$, respectively.

MAGIC telescopes and automatic alert system

- The MAGIC telescopes comprise two 17-m diameter imaging atmospheric Cherenkov telescopes, with a fiel of view of $\sim$10 square degree.
- They rely on external alerts provided by satellite instruments with larger fields of view to trigger follow-up observations.
- An automatic alert system (AAS) has been developed, it performs different tasks, such as connecting to the GCN(Gamma-ray Coordination Network) servers, receiving GCN notices that contain the sky coordinates of the GRB and sending commands to the Central Control (CC) software of the MAGIC telescopes.

The Major Atmospheric Gamma Imaging Cherenkov (MAGIC) telescopes observed GRB190114C from $T_0 + 57$ s until $T_0 + 15912$ s. Observations were performed in the presence of moonlight, implying a relatively high night sky background (NSB) and the total exposure time was 4.12h.

EBL

- The EBL is the diffuse background of infrared, optical and ultraviolet radiation that permeates intergalactic space, constituting the emission from all galaxies in the Universe.
- Absorption of γ-rays is more severe for higher photon energies and higher redshifts.
- Correction for the EBL attenuation (intrinsic spectrum).

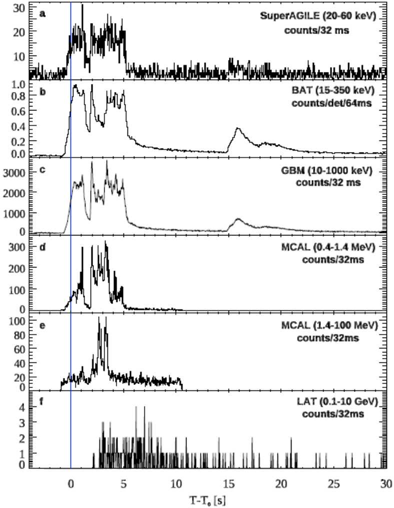
Emission phase

- The ‘prompt’ emission phase is characterized by a brief but intense flash of γ -rays, primarily at megaelectronvolt energies: it exhibits irregular variability on timescales shorter than milliseconds and lasts up to hundreds of seconds for long-duration GRBs.
  These γ-rays are generated in the inner regions of collimated jets of plasma, which are ejected with ultrarelativistic velocities from highly magnetized neutron stars or black holes that form following the death of massive stars.
- The ensuing ‘afterglow’ phase is characterized by emission that spans a broader wavelength range and decays gradually over much longer timescales compared to the prompt emission. This originates from shock waves caused by the interaction of the jet with the ambient gas (‘external shocks’). Its evolution is typified by a power-law decay in time owing to the self-similar properties of the decelerating shock wave.

Prompt emission

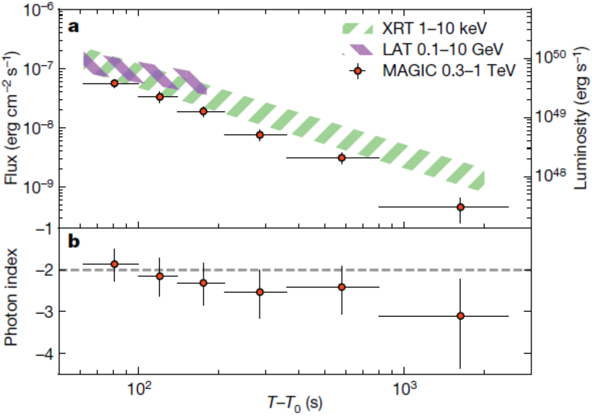
- The prompt emission lasts for approximately 25 s, when the last flaring emission episode ends.
- Nominally, T_{90} is much longer ($>$100 s, depending on the instrument), but it is clearly contaminated by the afterglow component.
- The prompt light curve shows a complex temporal structure with several emission peaks and total radiated energy of $E_{\gamma,iso} = (2.5 \pm 0.1) \times 10^{53} erg$ in the energy range 1–10^4 keV.

Prompt-emission observations



Light curves

The figure shows the light curve for the EBL-corrected intrinsic flux in the energy range $\epsilon = 0.3$–1 TeV.



The flux is well fitted with a simple power-law function $F(t) \propto t^{\beta}$ with $\beta = -1.60 \pm 0.07$.

MAGIC data analysis forGRB 190114C

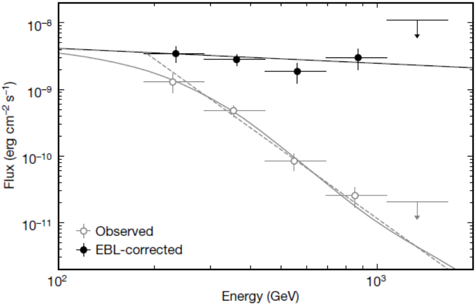
Data collected from GRB190114C were analysed using the standard MAGIC analysis software and with the analysis chain tuned for data taken under moonlight conditions.
The spectra were derived by assuming a simple power-law function for the intrinsic spectrum

$$\frac{dF}{d\epsilon} \propto \epsilon^{-\alpha_{int}}$$

.

The time evolution of the intrinsic spectral photon index α_{int}, determined by fitting the EBL-corrected, time-dependent differential photon spectrum with the power-law function, is consistent with $\alpha_{int} \approx -2$, indicating that the radiated power is nearly equally distributed in ϵ over this band.
The absolute energy scale for MAGIC measurements is systematically affected by the imperfect knowledge of different aspects: the atmospheric transmission, the mirror reflectance, the properties of photomultipliers and the EBL models.

Spectrum above 0.2 TeV

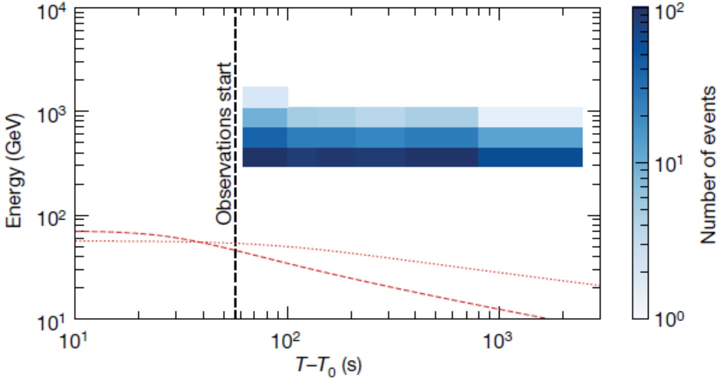


The figure presents both the observed and the EBL-corrected intrinsic spectra above 0.2 TeV, averaged over $(T_0 + 62\text{ s},\ T_0 + 2{,}454\text{ s})$. The observed spectrum can be fitted in the energy range 0.2–1 TeV with a simple power law with photon index $\alpha_{obs} = -5.43 \pm 0.22$.

Synchrotron burnoff limit for the afterglow emission

- Much of the observed emission up to gigaelectronvolt energies for GRB190114C is probably afterglow synchrotron emission from electrons, similar to that of many previous GRBs.
- The teraelectronvolt emission observed here is also plausibly associated with the afterglow. However, it cannot be a simple spectral extension of the electron synchrotron emission.
- The energy of afterglow synchrotron photons is then limited to a maximum value, the so-called synchrotron burnoff limit of $\epsilon_{syn,max} \approx 100(\Gamma_b/1000)$ GeV, which depends only on the bulk Lorentz factor Γ_b. The latter is unlikely to considerably exceed $\Gamma_b \approx 1000$.

Distribution of the number of teraelectronvolt-band γ-rays in time and energy

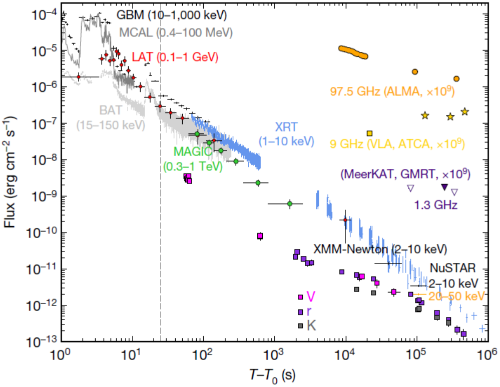


Here, even the lowest-energy photons detected by MAGIC are considerably above $\epsilon_{syn,max}$ and extend beyond 1 TeV.

Comment

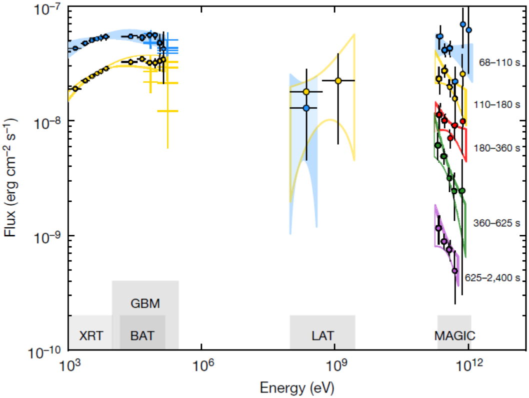
- This observation provides the first unequivocal evidence for a new emission component beyond synchrotron emission in the afterglow of a GRB.
- The fact that GRB 190114C was the first to be clearly detected may be due to a favourable combination of its low redshift and suitable observing conditions.
- The similarity of the radiated power and temporal decay slopes in the teraelectronvolt and X-ray bands suggests that this component is intimately related to the electron synchrotron emission.

Multi-wavelength light curves of GRB190114C



Light curves decay with time as a power law $F \sim t^{\alpha}$ with decay indices of $\alpha_X \propto -1.36 \pm 0.02$ and $\alpha_{TeV} \approx -1.51 \pm 0.04$. The 0.3–1-TeV light curve was obtained after correcting for attenuation by the extragalactic background light (EBL).

Multi-band spectra in the time interval 68–2400 s

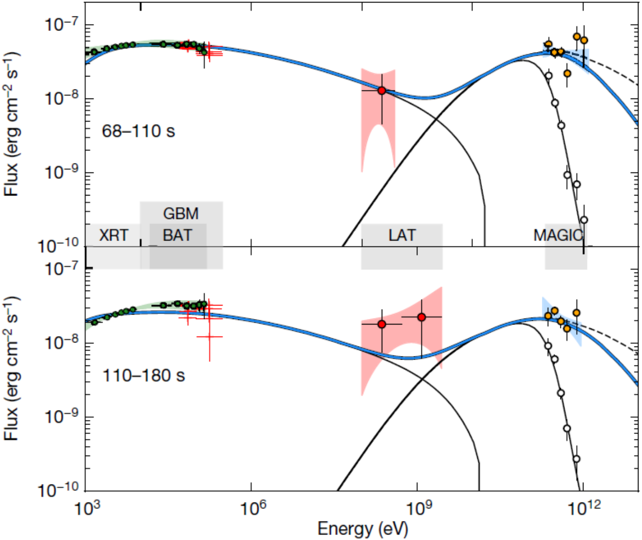


At the highest energies, the MAGIC flux above 0.2 TeV implies a spectral hardening.

Afterglow model

- Natural candidate : synchrotron self-Compton (SSC) radiation in the external forward shock.
  The same population of relativistic electrons responsible for the afterglow synchrotron emission Compton up-scatters the synchrotron photons, leading to a second spectral component that peaks at higher energies.
- Other candidate: hadronic processes, such as synchrotron radiation by protons accelerated to ultrahigh energies in the forward shock.
  But they have typically low radiation efficiency, that would imply unrealistically large power of accelerated protons to reproduce the luminous teraelectronvolt emission observed.

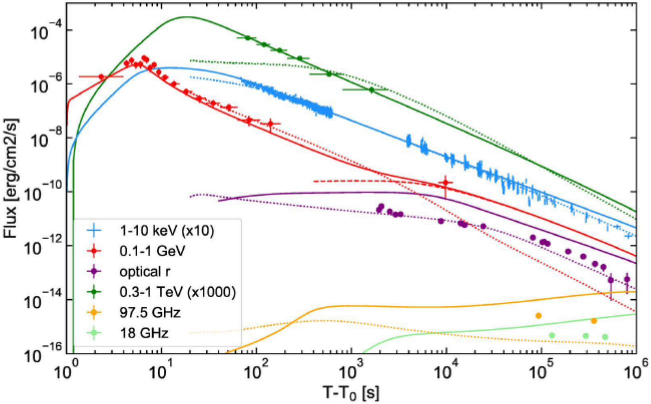
Modelling of broadband spectra



Modelling of broadband spectra

- The prompt-emission mechanism must then have dissipated and radiated no more than half of the initial jet energy, leaving the rest for the afterglow phase.
- The modelling of the multi-band data also allows us to infer how the total energy is shared between the synchrotron and SSC components. The resultant powers of the two components are comparable.

Modelling of broadband light curves



Solid lines show the total flux (synchrotron and SSC) and the dashed line refers to the SSC contribution only. Dotted curves correspond to a better modelling of observations at lower frequencies, but fail to explain the behaviour of the teraelectronvolt light curve.