**TeV photons challenge standard explanations**

Gamma-ray bursts (GRBs) are the result of the most violent explosions in the universe. They are named for their bright burst of high-energy emission, mostly in the keV to MeV region, which can last from milliseconds to hundreds of seconds, and are followed by an afterglow that covers the full electromagnetic spectrum. The extreme nature and important role in the universe of these extragalactic events – for example in the production of heavy elements, potential cosmic-ray acceleration or even mass-extinction events on Earth-like planets – makes them one of the most studied astrophysical phenomena.

Since their discovery in 1967, detailed studies of thousands of GRBs show that they are the result of cataclysmic events, such as neutron-star binary mergers. The observed gamma-ray emission is produced (through a yet-unidentified mechanism) within relativistic jets that decelerate when they strike interstellar matter, resulting in the observed afterglow.

But interest in GRBs goes beyond astrophysics. Due to the huge energies involved, they are also a unique lab to study the laws of physics at their extremes. This once again became clear on 9 October 2022, when a GRB was detected that was not only the brightest ever but also appeared to have produced an emission that is difficult to explain using standard physics.

Eye-catching emission

“GRB 221009A” immediately caught the eye of the multi-messenger community, its gamma-ray emission being so bright that it saturated many observatories. As a result, it was also observed by a wide range of detectors covering the electromagnetic spectrum, including at energies exceeding 10TeV. Two separate groundbased experiments – the Large High Altitude Air Shower Observatory (LHAASO) in China and the Carpet-2 air-shower array in Russia – claimed detections of photons with an energy of 18TeV and 251TeV, respectively. This is significantly higher, by an order of magnitude, than the previous record for TeV emission from GRBs reported by the MAGIC and HESS telescopes in 2019 (CERN Courier January/February 2020 p10). Adding further intrigue, such high-energy emission from GRBs should not be able to reach Earth at all.

For photons with energies exceeding several TeV, electron–positron pair production with optical photons starts to become possible. Although the cross section for this process only just exceeds its threshold at an energy of 2.6TeV, it is compensated by the billions of light years of space filled with optical light that the TeV photons need to traverse before reaching us. Despite uncertainties in the density of this so-called extragalactic background light, a rough calculation using the distance of GRB 221009A (z = 0.151) suggests that the probability for an 18TeV photon to reach Earth is around 10–8.

The reported measurements have thus far only been provided through alerts shared among the multi-messenger community, while detailed data analyses are still ongoing. Their significance, however, led to tens of beyond-the-Standard Model (BSM) explanations being posted on the arXiv preprint server within days of the alert. While each differs in the specific mechanism hypothesised, the overall idea is similar: instead of being produced directly in the GRB, the photons are posited to be a secondary product of BSM particles produced during or close to the GRB. Examples range from light scalar particles or right-handed neutrinos produced in the GRB and decaying within our galaxy, to photons that converted into axions close to the GRB and turned back into photons in the galactic magnetic field before reaching Earth.

Clearly the community needs to wait for the detailed analyses by the LHAASO and Carpet-2 collaborations to confirm the measurements. The published energy resolution of LHAASO keeps open the possibility that their results can be explained with Standard Model physics, while the 251TeV emission from Carpet-2 is more difficult to attribute to known systematic effects. This result could, however, be explained by secondary particles resulting from an ultra-high energy cosmic-ray (UHECR) produced in the GRB which, although would not represent new physics, would still confirm GRBs as a source of UHECRs for the first time. Analysis results from both collaborations are therefore highly anticipated.

Further reading

S Balaji et al. 2023 arXiv:2301.02258.

Z-C Zhao et al. 2022 arXiv:2210.10778.

A L Melott et al. 2004 IJA 3 55.

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