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Backward peaking radiation pattern from a relativistic particle accelerated by lightning leader tip electric field

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Charged particles being accelerated by the lightning leader tip electric field emit electromagnetic radiation due to the Bremsstrahlung process (Celestin et al., JGR, 2012). Bremsstrahlung has a continuous spectrum of radiation which includes radio waves and ionising radiation such as gamma rays which can be recorded by detectors on board the ASIM payload on the International Space Station, the forthcoming TARANIS satellite, or on the ground (Abbasi et al., JGR, 2018).

The radiation pattern of this Bremsstrahlung is not well known. Displays of radiation patterns of accelerated particles are normally limited either to a low frequency approximation for radio waves, or to linear acceleration in a high frequency approximation for gamma rays. Here we report the radiation patterns from accelerated relativistic particles at low and high frequencies of the Bremsstrahlung process. It is found that the radiation patterns have four relative maxima with two backward peaking and two forward peaking.

The shape of the radiation pattern is only determined by the velocity of the particle whilst the intensity of the radiation pattern is determined by the velocity and the acceleration of the particle. For example, relativistic particles with a large velocity exhibit a radiation pattern which is more forward peaking when compared to a non-relativistic particle with a smaller velocity. Similarly, relativistic particles with a large acceleration exhibit a radiation pattern with a larger intensity when compared to relativistic particles with a smaller acceleration. All these radiation patterns exhibit backward peaking radiation. The asymmetry of the radiation pattern, I.e., the different intensities of forward and backward peaking lobes, is controlled by the asymmetric frequencies of the Bremsstrahlung radiation caused by the Doppler effect.

These results are important because they enable a determination of particle properties which can be inferred from observations with networks of radio receivers and arrays of gamma ray detectors.