Sprites and Energetic Radiation Above Thunderstorms

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Abstract

The discovery of transient airglows above thunderstorms, known as sprites and jets, have shed a fresh new light on a 'terra incognita' in the Earth's atmosphere, the area above thunderstorms. The fast discovery pace of novel phenomena has spurred studies of energetic radiation, relativistic particles and anti-matter emanating from inside thunderclouds and above thunderlcouds. These observations mark a profound advance in our understanding of the Earth's atmospheric electrodynamic behaviour. Namely, the discoveries mandate the inclusion of cosmic rays, relativistic electron beams, large scales, and energetic feedback processes in our thinking about the Earth's atmosphere, perhaps best collectively summarised as relativistic atmospheric electrodynamics.

1 Summary

Transient luminous events above thunderstorms are arguably the most dramatic recent discovery in solar-terrestrial physics. They are indicative of the dissipation of lightning electromagnetic energy in the middle atmosphere and thereby form an electrical short-circuit between weather in the troposphere and space weather in the ionised upper atmosphere. In particular, gigantic jets and sprites are luminous leader and streamer discharges resulting from conventional breakdown in the middle atmosphere which is possibly associated with relativistic runaway breakdown above thunderclouds. The newly-recognised runaway breakdown mechanism inside thunderlcouds requires $\sim$1/10 of the conventional breakdown electric field threshold plus energetic seed particles ($\sim 10^{15} - 10^{16}$ eV) from primary cosmic rays to initiate an electromagnetically radiating non-linear electron avalanche growth. This relativistic runaway breakdown discharge results in a population of electrons with energies as high as tens of MeV inside the thundercloud. Whether these relativistic electron beams also occur above thunderclouds is currently not known. The recent detection of narrow beams of relativistic electrons on board the BATSE, RHESSI and FERMI spacecraft along with the detection of antimatter in the form of positrons strongly suggests that beams of relativistic particles emanating from thunderstorms propagate along the geomagnetic field lines into near-Earth space emitting bursts of gamma-rays and highly beamed low frequency electromagnetic radiation. Here we report the detection of non-luminous relativistic electron beams above thunderclouds by radio remote sensing in the VLF/LF/MF frequency range with a novel wideband digital radio receiver. The detected radio signals exhibit a relatively flat spectrum from $\sim$40 kHz to 400 kHz and they originate from the area above thunderstorms below or shortly after luminous sprites as inferred from the time delay between the arrival of the ground wave and the first hop sky wave produced by the impulsive acceleration of electrons up to relativistic energies. Numerical simulations show that the beamed electrons reach a mean energy of $\sim$7 MeV and transport a total charge of $\sim$10 mC upwards to discharge the over-volted area above thunderclouds following lightning discharges within a few ms. The observed relativistic electron beams above thunderclouds occur simultaneously with $\sim$5 % of optically observed sprites and they are thus very rare. But it is interesting to note that one example of two consecutive positive lightning discharges was detected which are followed $\sim$5 ms later by an electromagnetic radiation burst which is very similar to the radio signal from relativistic electron beams. This singular observation is indicative of a non-luminous relativistic electron beam without any sprite occurrence as evidenced by two video cameras. This preliminary result suggests that lightning discharges may also cause relativistic electron beams above thunderclouds without producing sprites because the relativistic breakdown threshold is only $\sim$1/10 of the conventional breakdown threshold. The small number of photons possibly emanating from non-luminous relativistic electron beams and sub-visual streamers may be identified in future studies by combining more sensitive optical observations with interferometric radio recordings to map the low-frequency radio sky above thunderclouds.

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