The feedback theory concerning the production of terrestrial gamma-ray flashes

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The production of terrestrial gamma-ray flashes is a relatively new field of research. Scientists are still working to produce a feasible theory to explain the large amount of radiation measured by satellites. This paper will give a basic introduction of the leading theories behind the production of terrestrial gamma-ray flashes. In particular the feedback theory presented by Dwyer [1], but also a theory presented by Celestin and Pasko [2] involving potential differences in streamer tips and development of leader channels. The aim of the paper will be to give insight into the methods and progress plan of my master through presenting what I think will be the key points of interest as well as the tools I plan to use.

1. Introduction

Terrestrial gamma-ray flashes (TGF's) are bursts of energetic photons originating in the earth's atmosphere from thundercloud regions. They appear as one or more bursts and last <1 millisecond each. Based on average RHESSI measurements TGF's are probably produced at heights between 10km and 20 km [3]. The amount of photons produced is highly dependant on initial height and may be in the order of 10^{17} at 15 km, but closer to 10^{19} at an initial height of 12 km and probably initiated at heights between 10 and 20 km. As shown by Østgaard et. al. [3] even more photons may be produced in the lower energy spectrum, but the lower energy threshold which still can be considered a TGF is not yet determined.

A correlation between TGF's and lightning has been proven and is generally accepted. The mechanisms directly involved in its production, however, are still being disputed. A few, but compelling theories which explain how this amount of extremely energetic photons can be produced in the electric fields of thunderclouds have been presented, but no consensus has been reached so far.

2. Two leading theories

2.1. Feedback

In general a lightning discharge is produced in response to a critical electric field strength attained through ionization and charge separation in the thundercloud. This is believed to initiate a burst of high energy photons. Dwyer [1] suggests that the electric field set up by the charge separation may accelerate a relativistic seeding electron (probably arising from cosmic rays) initiating a complicated multiplication process known as an electron avalanche [4] which in turn will produce a large amount of photons through bremsstrahlung. This is the initial step, but does not explain the massive amount of photons detected. The second and most crucial step presented by Dwyer is the feedback process. This is in essence the same as the above stated electron avalanche, but is a result of the downward scattered positrons and photons from the initial avalanche, hence "feedback", which initiates multiple secondary avalanches and may in fact account for the remaining photons.

2.2. Additional source of seeding electrons

Celestin and Pasko [2] suggest a different source of seeding electrons to account for the large amount of photons, and propose streamer tip potential difference to be sufficient for the acceleration of electrons to runaway energies.

If the ambient electric field strength exceeds that of the stability field (~32kV/m sea-level equivalent) the potential difference from the streamer head to the region ahead of the streamer increases exponentially by time. This exponential increase is directly related to acceleration of electrons to energies up too ~100 keV and an average closer to ~60 keV. This energy is above the threshold kinetic energy required for further acceleration and the electrons can now be considered runaway. The reduction in the probability to collide with atoms, particles or molecules in the atmosphere in response to the increase in electron energy as presented by Moss et. al. [5] allows for further acceleration of the electrons in the electric field generated by lightning leader tips. Celestin and Pasko [2] also show that only during the expansion of a negative leader channel may these runaway electrons be further accelerated to the few MeV required to produce the high energy photons. The amount of electrons produced in this process is consistent with measured the amount(~10^{17}).

This theory suggests that other explanations may not be required for the production of TGF's and that streamer and leader expansion is sufficient to account for the total measured amount of photons.

3. Future work

The emphasis of my thesis will be to study the feedback theory presented by Dwyer [1]. As the two theories discussed in section 2. both give reasonable arguments towards explaining the production of TGF's it is reasonable to assume that neither process excludes the other, however, one may still be dominant compared to the other. The first part of my work will include a detailed study of both theories and the involving mechanisms. Secondly I will consider the feedback process in more detail, by testing the effects resulting from different initial conditions on the electric field, amount of seeding electrons and the amount of energy needed by the seeding electrons may present itself useful to determine to which extent this process may be the cause of TGF's.

4. References

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