Reactor-like TGE model

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Introduction

Many previous works point to the fact that electric field inside the thundercloud is high enough to accelerate electrons and produce secondary electromagnetic showers [GMRD92, GZRD99, Dwy03, DB11]. The acceleration of electron is possible under two conditions:

- The strength of the field is higher than so-called critical field. The value of the field equals energy loss of minimally ionizing electron per length unit.
- The initial electron energy is high enough to be close to minimally ionizing energy.

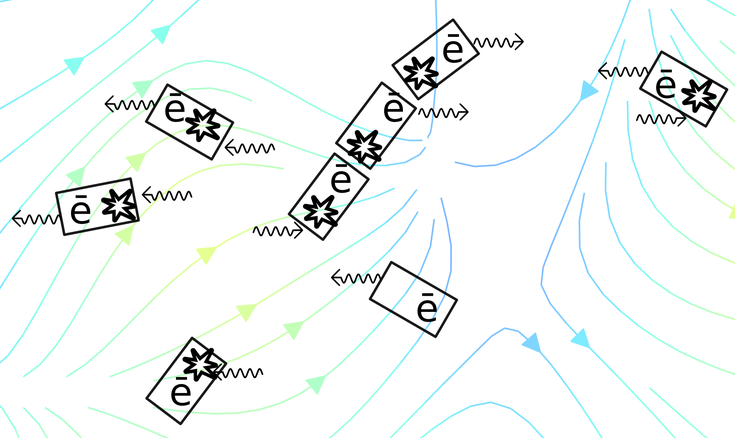
But these model have some disadvantages:

- The major problem of all of these models is that that while field strength is higher than critical field, the multiplication coefficient for showers is rather small and can't describe any observed effects.
- The crucial part of this work is additional account for escaping high energy gamma-rays in the acceleration process. Escaping photons with energy higher than 1 MeV could produce (via photo-effect or compton-effect) new electrons with energy high enough to start separate acceleration process. These electrons are produced not in vicinity of first accelerator, but separated by free path of gamma ray which could amount up to few km. Thus these secondary accelerators could not be accounted by any local model.

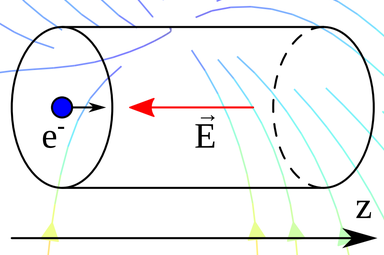
Additionally, the field map calculation shows that field directions in two points of a thundercloud separated by distances more than 500 m are mostly uncorrelated, meaning that direction of new accelerator is more or less random relative to the initial accelerator.

Reactor-Like TGE

If the size of a thundercloud is much larger than mean free path of gamma-ray, one can observe a chain reaction, where photons are produced in elementary accelerator cells with given local multiplication coefficient depending on local field strength and then create additional elementary accelerator cells in separate places. Some of photons could be absorbed without creating additional cell.



For example it could happen in case local field direction is opposed to photon and therefore produced electron momentum. Accounting for such effects as well as loss of photons through borders of a thundercloud, one can get a global coefficient. Obviously, in case global coefficient is larger than 1, one can observe an exponential rise in number of elementary accelerator cells and therefore total radiation level (gamma, infrared and neutron) and ionization. Also for coefficient slightly less than 1, one gets slow exponential decay of radiation background.



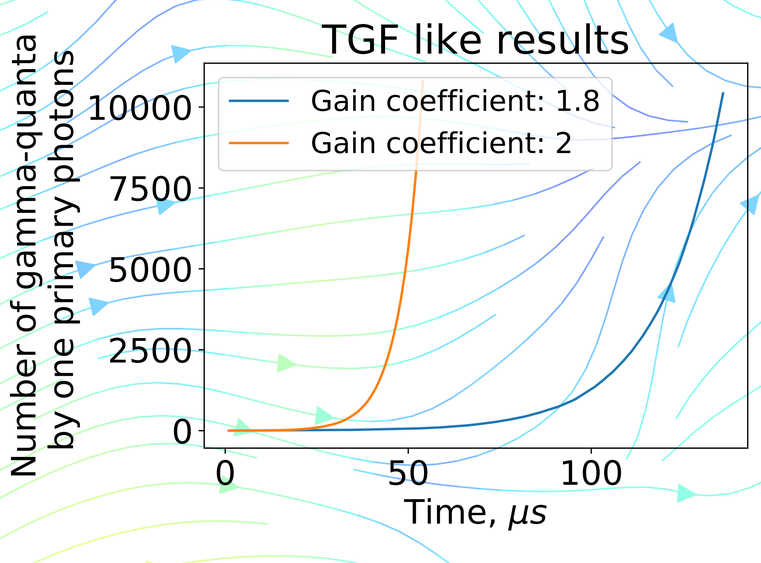
The described model is not unlike chain reaction process in nuclear reactor, so it could be called reactor-like terrestrial gamma enhancement model (RL-TGE).

Proof of concept

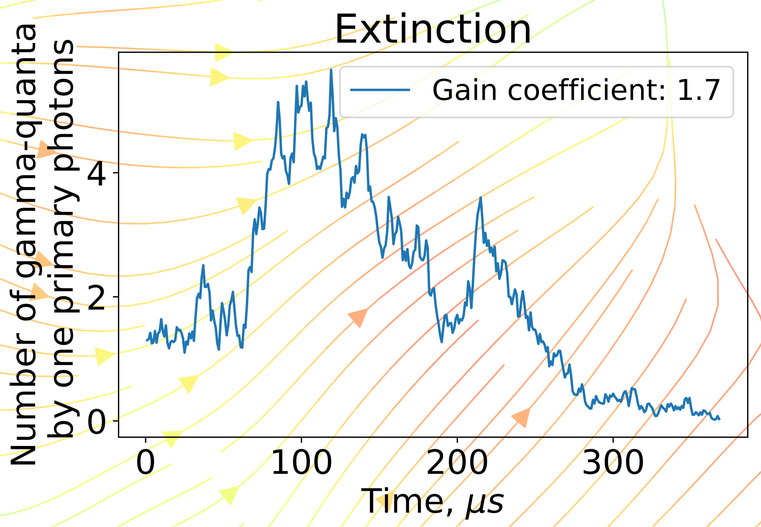
For fast checking the potential of our idea, we considered a next simplified model:

- There are only one tuning parameter — the local coefficient of gamma multiplication, describing usefulness of atmosphere for generating secondary particles;
- Production of Gamma in cell occurs by Poisson distribution, momentum direction of generated gamma is defined by the electric field direction;
- Electric field is chaotic: in point of cell ignition, direction of field is generated by uniform distribution, but magnitudes is constant for whole cloud;
- Energy of particle not taken into account, propagation of gamma simulated with exponential distribution with fixed mean free path;
- Cloud size is equals 1 kilometer and tracking of particle leaving volume stopped.

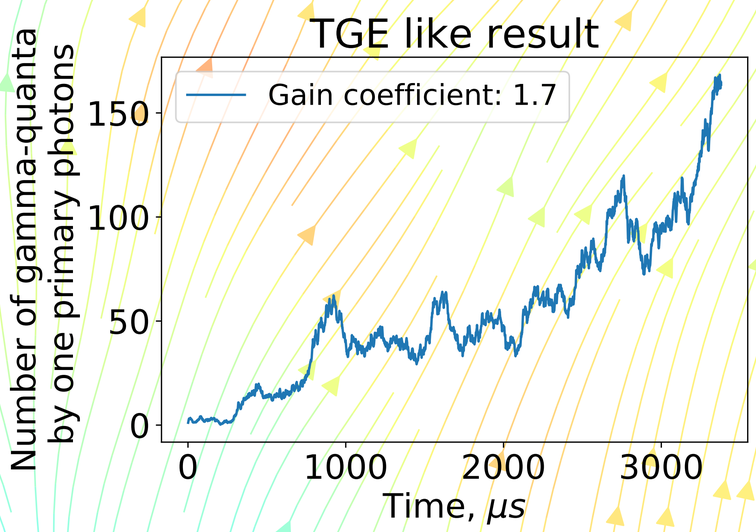
This model is implemented as program on Kotlin programming language. The first figure shows the case of an explosive growth in the number of secondary photons that are well suited to the phenomenon of TGF.



The second figure demonstrates the case when there was a dissipation of an avalanche that had just begun to develop.



The third figure demonstrates the case of a slower and less intensive growth. Such processes with some minor adjustments and assumptions about field dynamics could describe TGE phenomenon.

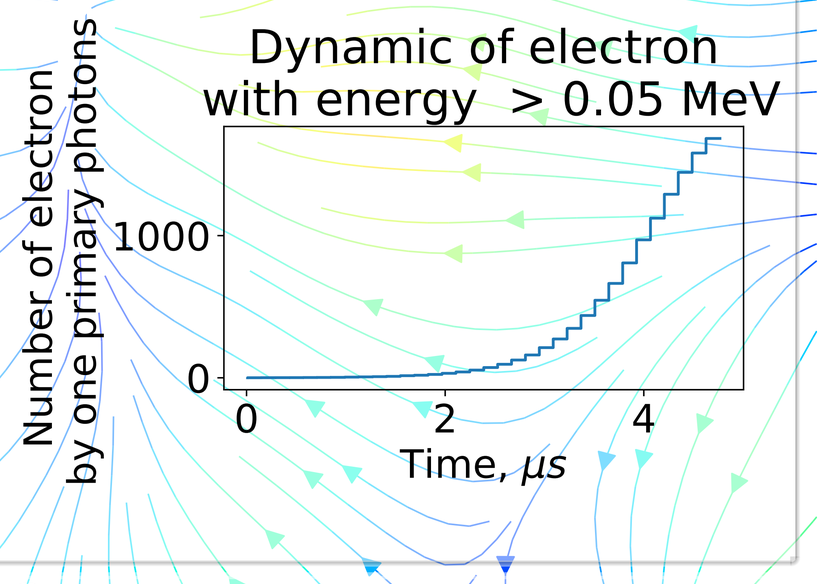


Improved model

Our simple implementation of reactor like model show potential possibility, but its use a mean value of parameter. Improved model clarify rough approximations of simple model, namely:

- For generating electric field map used fractal model developed by Dr. Iudin; [IDG+18]
- The photons cross-section and energy-angular distribution sampling is computed exactly, for tracking used algorithm of maximal cross-section;
- The spectrum of secondary particle from burned cell is simulated by GEANT4 [A+16]

Also we improved output simulation information and made calculation is parallel. By now we conduct only first simulation with improved model and we can only say, what conclusion received from simple model haves been confirmed. For example on this figure shows evolution of number of relativistic electron for small time interval.



Conclusion

- Reactor-like model is very good to describe TGF and other fast processes;
- Slow processes like TGE could be described with additional assumptions about field dynamics;
- The model could describe both TGE and TGF with the same mechanism depending on the state of the cloud.

Also reactor like model give next experimentally verifiable consequences:

- Contrary to Dweyer and unmodified Gurevitch models, reactor model predicts quasi-isotropic (according to field distribution) emmittance of gamma-rays from a thundercloud.
  Measurement of the angular distribution of gamma-rays is required to proove or disproove the concept
- At first approximation, the energy spectrum of photons produced in RL model does not depend on radiation intensity (the spectrum depends on cell field and intensity on cell number).

Moreover reactor like TGE model can be used to investigate intercloud interaction.

Literature

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