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Comment on "High altitude discharges and gamma-ray flashes: A manifestation of runaway breakdown" by Yuri Taranenko and Robert Roussel-Dupré

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In a recent letter *Taranenko and Roussel-Dupre* [1996] (subsequently referred to as TR) presented "a detailed comprehensive model of red sprites and blue jets that yields optical and γ-ray results in excellent agreement with observation". The purpose of this comment is to demonstrate that the model is flawed.

The TR model attempts to extend the runaway breakdown model developed by *Gurevich et al.* [1992] and later by *Roussel-Dupre et al.* [1994] (subsequently referred to as GMR) for altitudes below 15 km, to altitudes in excess of 30 km and up to 90 km. According to the TR model quasistatic electric fields created by a discharging cloud during lightning, encounter energetic, cosmic ray generated, relativistic electrons inducing a runaway discharge. The discharge creates an upward propagating relativistic electron beam (REB). The REB subsequently generates three observed phenomena: blue jets at 20–40 km altitude, red sprites at 60–80 km and γ-ray bursts at all altitudes.

In extending the GMR model from the original altitude range of 0–10 km to altitudes of up to 90 km, TR made an error in physics. The error in physics is the same made in a previous paper by *Chang and Price* [1995] and subsequently noted in a published GRL comment by *Papadopoulos et al.* [1996] to which Chang and Price did not reply. The GMR model neglects the effects of the geomagnetic field on the accelerated runaway electrons. This is completely justified for altitudes below 20 km, since at this altitude range the runaway electron mean free path for energy loss (due to ionization of low energy electrons), for small angle scattering and for the generation of runaway secondaries is smaller than their gyroradius. Therefore, for altitudes below 20 km the GMR formalism correctly describes the runaway discharge, as well as the accompanying electron transport. However, this is not the case for altitudes exceeding 20 km.

The importance of the magnetic field for altitudes exceeding 20 km can be appreciated by rewriting the condition for runaway breakdown for the unmagnetized case given by eq. (17) of *Gurevich et al.* [1994] in the form

$$eE\lambda > mc^2 \tag{1a}$$

$$\lambda = \frac{(mc^2)^2}{4\pi N_m Z e^4}\frac{1}{a} \equiv \frac{1}{4\pi r_o^2}\frac{1}{N_m}\frac{1}{Z}\frac{1}{a} \tag{1b}$$

where $a \approx 11$ is the usual Coulomb cutoff function, N_m the neutral density, $Z \approx 14.5$ the molecular charge, and r_o the classical electron radius. Equation (1) clarifies the meaning of the runaway breakdown threshold in the presence of a laminar electric field. Namely, the field should be large enough so that an electron gains energy larger than $mc^2 \approx .5$ MeV in a distance λ. Namely, the field should be large enough so that an electron gains energy larger than $mc^2 \approx .5$ MeV in a distance λ. The physical reason for such a requirement is that a subsequent ionizing collision will result with high probability in two runaway electrons with approximately the same relativistic energy, thereby perpetuating a discharge that involves only relativistic electrons. The mean free path for the generation of such runaway secondaries is given by eq. (22) of *Gurevich et al.* [1994] as

$$\lambda_{ion} \approx \frac{1}{4\pi r_o^2}\frac{1}{N_m}\frac{1}{Z}A \tag{2}$$

where A is a factor of order unity for relativistic electrons.

Let us next examine what happens if there is a magnetic field perpendicular to the laminar electric field as expected in the equatorial regions where γ-rays are produced. The electron will reverse its direction on a time equal to the gyrotime $\frac{1}{\Omega}$ and will lose the energy it gained when it was moving in the direction of the electric field. As long as $\frac{E}{B} < c$, it will perform a drift motion perpendicular to $\mathbf{E}$ and $\mathbf{B}$. If the gyroradius R_e given by

$$R_e = 33\frac{P_\perp(\frac{MeV}{c})}{B(Gauss)}\ meters, \tag{3}$$

is smaller than λ, the maximum energy gain by the

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laminar field is smaller than eER_e. From eq. (1b) using $a = 11$ and $Z = 14.5$

$$\lambda = 640(\frac{10^{17}\#/cm^3}{N_m})\, m. \quad (4)$$

From eq. (3) and assuming an MeV electron with $p_z \simeq p_\perp$, so that its kinetic energy in the transverse direction is .5 MeV $\approx mc^2$, we find

$$R_e = 95(\frac{.3G}{B})m. \quad (5)$$

From eqs. (4) and (5) is clear that for 35 km, corresponding to Nm = 1.7 $\times 10^{17}$ #/cm^3 and for B = .3G, the value $\frac{\lambda}{R_e} = 4$ invalidates the unmagnetized model and increases the threshold value by at least a factor of four. The situation becomes exponentially worse at higher altitudes. For example at 50 km $\frac{\lambda}{R_e} = 30$ and at 70 km $\frac{\lambda}{R_e} = 400$. This implies that the required charge Q is not 100 C but 3×10^3 C and 4×10^4 C correspondingly. Totally unrealistic values.

We briefly comment on the role of the small angle scattering referred to in the authors reply. As derived from the Boltzmann's equation, descrived in *Roussel-Dupre et al.* [1994], the mean free path λ_e [*Jackson*, 1962] for small angle elastic scattering of relativistic electrons is given by

$$\lambda_e = \frac{1}{4\pi r_o^2}\frac{1}{N_m}\frac{1}{Z}\frac{1}{a}\left[\frac{2\gamma^2}{(Z/2+1)}\right] \quad (6)$$
$$\approx \lambda\left[\frac{2\gamma^2}{(Z/2+1)}\right] \leq \lambda.$$

This is consistent with *Roussel-Dupre et al.* [1994], in that backscattering due to small angle collisions does not prevent the runaway discharge. We therefore fail to see how small angle collisions will prevent the equivalent magnetic "backscattering".

Runaway breakdown induced by a laminar electric field at an arbitrary angle θ to the geomagnetic field was recently discussed by *Gurevich et al.* [1996]. It was shown that for large angles ($\theta < 80^o$) the runaway threshold significantly exceeds the GMR unmagnetized threshold. The threshold approaches the GMR value for $\theta < 30^o$. However, in this case the electron beam is strongly magnetized and the resultant effects (blue jets or red sprites) will have a preferential field aligned direction. This is totally inconsistent with experimental observations, which show no magnetization effect [*Wescott et al.*, 1995; *Sentman et al.*, 1995].

While the above are sufficient reasons for invalidating the contentions of the TR paper, the analysis of the emission processes (sprites) is also incorrect. For example: In attempting to explain sprites TR comment that the optical spectrum caused by the runaway discharge is similar to the one generated by a high energy electron beam propagating in air [*Davidson and O'Neil*, 1964; *Mitchell*, 1970]. However recent spectral measurements by *Mende et al.* [1995] show that the sprite spectra lack features such as N_2^+ Meinel or the N_2^+ 1st negative measured during the beam experiments. Even taking into account that the emissivity of the Meinel band is reduced 2–3 times due to the collisional quenching at 80 km [*Piper et al.*, 1985] where the peak of a sprite brightness is located, this emission still has to be observable. This is a clear indication that the excitation of the red sprites is due to low rather than high energy electrons.

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