TGF observations

N. Østgaard[1]

[1] *Birkeland Centre for Space Science, Department of Physics and Technology, University of Bergen, Norway*

In this paper recent results from the research of terrestrial gamma flashes (TGFs) will be reviewed. In order to be seen from space these flashes have been found to require about 10^{16}-10^{18} electrons accelerated to relativistic energies (up to ~40 MeV or even above) in less than a few hundred of microseconds. This paper will cover the latest observational results that can help us understand how these flashes are produced: the altitude of production, the connection to IC+ lightning, the duration of TGFs, do TGFs occure before or after the optical lightning, electron beams and positrons, and how common are TGFs? The observations will be discussed in the context of the two theories that have been suggested to explain the production of TGFs: the feedback-mechanism [34] and the streamer-leader electric field model [35].

1. Introduction

With the discovery of terrestrial gamma flashes (TGFs) above thunderstorms [1] by the Burst and Transient Source Experiment (BATSE) a new mechanism of the coupling between the lower atmosphere and space was discovered. The phenomenon involves gamma photons, relativistic electrons and positrons. Charged particles are accelerated in extremely strong electric fields (> 300 kV/m sea level equivalent) associated with lightning discharges and initiate a relativistic run-away process [2]. Through interaction with the neutral atmosphere bremsstrahlung is produced, resulting in the escape of electrons [3], positrons [4] and gamma photons into space. There are still many open questions related to TGFs. In this paper recent results of TGF observations will be reviewed.

2. Observed characteristics of TGFs

From the first observations it was believed that the TGFs are produced above 40 km and that they were related to transient luminous events [1]. However, results from Reuvan Ramaty High Energy Solar Spectroscopic Imager (RHESSI) ten years later indicated that their production altitude is most likely around 15-21 km [6]. Reanalyses of the BATSE data [7, 8, 9] and AGILE data [39] have also confirmed a production altitude of TGFs below 20 km [7, 8, 9]. Consistent with this production altitude and general lightning physics, Williams et al., [10] speculated that TGFs are related to positive intracloud lightning (IC+), a suggestion that has been supported by several studies comparing TGFs with electromagnetic characteristics of lightning [11, 12, 13, 14, 15, 36].

When first discovered TGFs were estimated to have ~1 ms duration [1]. More recent results indicate an average duration of 200-300 μs [9, 16, 38] but can be as short as 50 μs [17, 37].

Several studies indicate that TGFs are observed in the initial stage of an IC lightning [13, 14, 18, 36, 44]. New studies based on Fermi detection of TGF [15, 19] may indicate that TGFs occur simultaneously with the sferics, and that the VLF signal is produced by the TGF itself [37]. Detections of X-rays from cloud-to-ground (IC-) [e.g., 20] and from laboratory discharges [22, 41] show that X-ray bursts occur before the return stroke.

Some studies have estimated the spatial distribution of photons in a TGF and found that they are spread over a half cone-angle of about 30°-40° [23,24], which might be an indication of fairly vertical electric fields.

While BATSE identified energies >1MeV [1], RHESSI measured ~20 MeV [25] and Agile energies above 40 MeV [26] and even at 100 MeV [27]. From CG- lightning energies >1MeV [21] has been measured.

Recent studies have found that TGFs are more common [29, 38] than previously believed [16]. As IC lightning accounts for about 75% of all the lightning and most of these are IC+ lightning bringing negative charges upward, this may imply that TGFs are a rather common phenomenon. On the other hand, Smith et al. [30] reported only one TGF from more than 1000 discharges. However, by comparing TGF distributions by RHESSI and Fermi and taking into account the instruments different sensitivity, Østgaard et al., [31], despite the non-

detection by ADELE, found that from TGF observations so far, we can not rule out that all lightning may produce TGFs. The fluence distribution of TGFs as seen from space has been found by several studies to have a power index between 2.2 and 2.6 [31, 39, 40].

In this paper we will also discuss the recent TGF observations in the context of the two most compelling theories for explaining the TGF production. 1) The feed-back theory [34]: The seed electrons are provided by cosmic rays or streamer electric fields and a large ambient electric field provides a potential of ~100 MV, and the positron/gamma-ray feedback mechanism contributes to the RREA process by producing sufficient relativistic electrons to account for the observed flux of photons. 2) The leader/streamer theory [35]: The seed electrons are produced in the steamer electric fields and further accelerated in the stepped leader electric field. Modelling efforts of radio signals [42] or electric field configurations [43] have tried to relate observations of TGFs to these theories.

3. References

[1] Fishman, G. J., et al. (1994), Science, 264(5163), 1313–1316

[2] Gurevich, A. et al. (1992), Phys. Lett. A, 165, 5-6, 463-468, doi: 10.1016/0375-9601(92)90348-P

[3] Dwyer, et al., (2008b), Geophys. Res. Lett., 35, L02,815, doi:10.1029/2007GL032430.

[4] Briggs, M. S., et al., (2011) Geophys. Res. Lett., 38 (L02808), doi:10.1029/2010GL046259

[6] Dwyer, J. R., and D. M. Smith (2005), Geophys. Res. Lett., 32, L22,804

[7] Carlson, B. E. et al., (2007), Geophys. Res. Lett., 34, L08,809, doi:10.1029/2006GL029229.

[8] Østgaard, N. et al., (2008), J. Geophys. Res., 113(A12), 2307, doi:10.1029/2007JA012618.

[9] Gjesteland, T et al., J. Geophys. Res.,115, A00E21, doi: 10.1029/2009JA014754.

[10] Williams, E., et al. (2006), J. Geophys. Res., 111, D16209, doi:10.1029/2005JD006447

[11] Cummer, S. A. et al. (2005), Geophys. Res. Lett., 32, L08,811, doi:10.1029/2005GL022778.

[12] Stanley, M. A. et. al., (2006), Geophys. Res. Lett., 33, L06,803.

[13] Shao, X-M. et al., (2010) J. Geophys. Res.,115, A00E30, doi:10.1029/2009JA014835.

[14] Lu, G. et al. (2010). Geophys. Res. Lett., 37(11), 1-5. doi: 10.1029/2010GL043494.

[15] Cummer, S. A. et al., (2011), Geophys. Res. Lett., 38, L14810, doi:10.1029/2011GL048099.

[16] Grefenstette, B. et al., J. Geophys. Res. A—Space Physics, 114(A2).

[17] Fishman, G. J. (2011), J. Geophys. Res 116, A07304, doi:10.1029/2010JA016084.

[18] Collier, A. et al. (2011) J. Geophys. Res, Vol. 116, A10320, doi:10.1029/2011JA016612.

[19] Connaughton, V., et al. (2010), J. Geophys. Res., 115, A12307, doi:10.1029/2010JA015681

[20] Dwyer, J. R. et al. (2005), Geophys. Res. Lett., 32, L01803, doi:10.1029/2004GL021782.

[22] Nguyen, C. V. Et al., J. Phys. D: Appl. Phys. 41, 234012

[23] Hazelton, B. et al., Geophys. Res. Lett., 36(1), L01,108.

[24] Gjesteland, T. et al., J. Geophys. Res, 116, A11313, doi:10.1029/2011JA016716

[25] Smith, D. M. et al., Science, 307(5712), 1085–1088, doi:10.1126/science.1107466.

[26] Marisaldi, M. et al. (2010), J. Geophys. Res, 115, A00E13, doi:10.1029/2009JA014502.

[27] Tavani M.et al. (2011), Phys. Rev. Lett., 106, 1,018501

[29] Gjesteland, T., et al., (2012) Geophys. Res. Lett., Vol. 39, L05102, doi:10.1029/2012GL050899

[30] Smith, D. M., et al., Geophys. Res. Lett., 38, L08807, doi:10.1029/2011GL046875, 2011.

[31] Østgaard, N. et al., (2012) J. Geophys. Res, doi:10.1029/ 2011JA017365, in press

[32] Lehtinen, N. G. et al., (1999), J. Geophys. Res., 104, 24,699– 24,712.

[33] Inan, U. S., and N. G. Lehtinen (2005), Geophys. Res. Lett., 32, L19,818, doi:10.1029/2005GL023702.

[34] Dwyer, J. R. (2012), J. Geophys. Res., doi:10.1029/2011JA017160.

[35] Celestin S. and V. P. Pasko (2011), J. Geophys. Res., 116, A03315.

[35] Carlson, B. E. et al.(2011), J. Geophys. Res, 114, A00E08, doi:10.1029/2009JA014531.

[36] Østgaard et al., (2013) Geophys. Res. Lett., Vol. 40, 1-4, , doi:10.1002/grl.50466

[37] Connaughton et al., (2013), J. Geophys. Res, 118, 2313–2320, doi:10.1029/2012JA018288.

[38] Briggs et al., (2013), J. Geophys. Res, 118, 3805–3830, doi:10.1002/jgra.50205.

[39] Marisaldi et al., (2014), J. Geophys. Res, 119, 1337-1355, doi: 10.1002/2013JA019301.

[40] Tierney et al., (2013), J. Geophys. Res, 118, 6644-6650, doi: 10.1002/jgra.50580.

[41] Kochkin et al., (2012), Journ. Of Physics D, Appl. Phys. 45, 425202.

[42] Dwyer and Cummer, (2013), J. Geophys. Res, 118, 3769-3790, doi: 10.1002/jgra.50188.

[43] Pasko (2014), Geophys. Res. Lett., Vol. 41, doi: 10.1002/2013GL058983

[44] Marshall et al, (2013), J. Geophys. Res, 118, 10,907-10,925, doi: 10.1002/jgrd.50866