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Detectability of sprites above lightning storms on the giant planets

D. Dubrovin (1), Y. Yair (2), Y. Takahshi (3), C. Price (1), S.Nijdam(4), E.M. Van Veldhuizen (4) and U. Ebert (4,5)
(1) Tel-Aviv University, Israel.
(2) The Open University of Israel, Ra'anana, Israel.
(3) Hokkaido University, Japan.
(4) Eindhoven University of Technology, The Netherlands.
(5) Centrum Wiskunde & Informatica (CWI), Amsterdam, The Netherlands.

Abstract

Large sprite discharges at mesospheric altitudes on Earth have been found to be physically similar to streamer discharges in air at sea level density. Based on this understanding, we investigate possible sprite discharges on the Gas Giant planets through laboratory experiments on streamers in H_2-He gas mixture. Streamer diameters, radiance, and emission spectra are investigated and compared to similar discharges in artificial air and to terrestrial sprites. We evaluate the possible luminosity of planetary sprites based on relationships between electric charge moment change during a lightning strike and its optical energy as inferred from satellite data.

1. Introduction

Large sprite discharges at low air density are upscaled versions of small streamer discharges at high air density that dominate the initial breakdown of large gas volumes in a sufficiently strong electric field. They are related through scaling relations in terms of gas density [2]. They are due to the fact that the basic length scale of the streamer discharge is the mean free path of the electron, which is inversely proportional to the gas density n. Streamer velocity, as well as velocity and energy distributions of individual electrons are independent of gas density, while streamer length and time scale as $1/n$, electric field as n, and electron density as n^2. The number of emitted photons is proportional to the number of energetic electrons, if the radiating states are not quenched; therefore density of emitting molecules also scales as n^2, while the emission from the complete discharge scales like density times volume $n^2/n^3 = 1/n$.

2. Experimental Setup

Streamers are created in a point-plane 16 cm gap contained within a large cylindrical stainless steel vacuum vessel, specifically designed to maintain the purity of the gases in use. Pressure is controlled in the range of 25 to 1000 mbar at room temperature, therefore number densities range from 10^{23} to 10^{25} m^{-3}. The gas mixtures we use are listed in Table 1. Short positive voltage pulses with a repetition rate of 1 to 14 Hz are applied to the anode tip, causing the initiation of positive streamers near the tip. The streamers are imaged using a fast intensified CCD camera, with exposure times as short as 1 nsec. The imaging setup is sensitive in the range 300 to 800 nm (for Saturn 200 to 800 nm). Three small spectrometers are used to study the spectrum in the range 230 to 940 nm. A detailed description of the setup and some of the experiments can be found in [1, 4].

Table 1: Gas mixtures used to simulate planetary atmospheres.

Planet	Species	Number density ratios
Jupiter	H_2:He	89.8:10.2
Saturn	H_2:He:CH_4	92.2:7.4:0.4
Earth	N_2:O_2	80:20

3. Results

Scaling laws are tested by examining streamers of minimal diameter (they will be referred to as minimal streamers). Streamers approach this diameter when they hardly can exist, either because the applied voltage is marginal, or because they are approaching their maximal length, typically after branching several times. We find that the radiance of minimal streamers (radiated photons per unit area) is independent of density. This means that the relevant emitting states are not quenched, and that the spectrum can be extrapolated to lower gas densities. We note, that thicker streamers, are always brighter than the minimal streamers. Taking the spectrum into account (see next paragraph) we can compare the radiance of minimal streamers in air and in the H_2:He mixtures. In the wavelength range 200-800 nm the streamers in air are brighter than in the H_2:He mixtures by one order of magnitude.

We measure the emission spectrum of a pulsed glow discharge with a repetition rate of 10 to 14 Hz. We find that the spectra in the Saturn and Jupiter mixtures are practically identical. This spectrum is dominated by continuum radiation in the UV, primarily at wavelengths 230 nm (the lower bound of our equipment) to 300 nm and higher. It corresponds well with the H_2 radiative dissociative continuum modelled analytically by Lavrov et al. [3], and therefore is expected to persist at wavelengths as low as 170 nm. The spectrum in air is dominated by the N_2 second positive group (N_2-2P), radiating in 300-400 nm. The N_2 first positive group (N_2-1P) is quenched at the densities we work with, however it contributes substantially to emissions of sprites.

4. Discussion

Recently, Takahashi et al. [5] found a positive correlation between the parent lightning Charge-Moment-Change and the luminosity of column sprites, as measured by the ISUAL experiment onboard the FORMOSAT satellite. Such a metric can be used to evaluate the brightness of planetary sprites. Yair et al. [8] incorporated a simplified model of the charge structure in clouds for predicting the atmospheric altitude (below the planets' ionosphere) and density of dielectric breakdown in the planetary atmospheres, by assuming several values for the hypothetical CMC values that can occur in thunderstorms on several planets. Spacecraft observations (Galileo on Jupiter, Cassini on both Jupiter and Saturn) show that on average, the optical energy of lightning on these planets is larger by several orders of magnitude as compared to Earth. By inference, we can scale the optical energy to the source (thunderstorm) electrical power and deduce the generative CMC, from which the brightness can be estimated. However, the fact that the air on those planets is a H_2-He mixture means that the CMC - sprite optical energy relationship may not be immediately applicable.

Our observations of streamers in a set of gas mixtures simulating the atmospheres of Jupiter and Saturn indicate that streamer discharges are possible in these gases, giving firmer ground to the possibility of observing sprites on these planets by orbiting spacecraft. We find that minimal streamers, in terrestrial air are one order of magnitude brighter that in Saturnian air, and this ratio is independent of density. Based on this result we can give a lower bound estimation for the brightness of sprites on the Gas Giants; the reported luminosity of sprites is 8-160 MR [5], where 10 to 40% of the photons originate from the N_2-2P band. Therefore we can expect sprite brightness of at least 0.08 MR on Saturn and Jupiter. As these emissions are expected to occur above the highest cloud deck, their observation from orbiting spacecraft is feasible with standard imaging systems.

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