Extra-terrestrial sprites: Laboratory Investigations in Planetary Gas Mixtures

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We investigate streamers in gas mixtures representing the atmospheres of Jupiter, Saturn (H_2-He) and Venus (CO_2-N_2). Streamer diameters, velocities, radiance and overall morphology are investigated with fast ICCD camera images. We confirm experimentally the scaling of streamer diameters in these gases by studying streamers with minimal diameters. The brightness of laboratory streamers is investigated, and a scaling model for atmospheric sprites is proposed. Fitting the scaling model with measurements, we give an estimate of minimal sprite brightness on Earth, Jupiter and Saturn. The estimated brightness of terrestrial sprites agrees well with observations and with existing models, and may serve as a benchmark for space-based observations of TLEs by planetary missions such as Cassini and Juno.

1. Introduction

Lightning has been detected on several planets in the solar system. On Jupiter and Saturn storms may persist for several months and produce energetic lightning with high flash rates. The atmospheric conditions may be favourable for sprite generation up to several hundreds of kilometres above the visible cloud tops [1]. 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 streamers in gas mixtures which represent the atmospheres of Jupiter, Saturn (H_2-He) and Venus (CO_2-N_2).

2. Experimental setup and results

We study positive streamers 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. The vessel is filled with a gas mixture of our choice, and the pressure is controlled in the range of 25 to 1000 mbar. Streamer diameters, velocities, radiance and overall morphology are investigated using fast ICCD camera images. We confirmed experimentally that diameter scales as 1/density in the gas mixtures representing the atmospheres of Saturn, Jupiter and Venus [2].

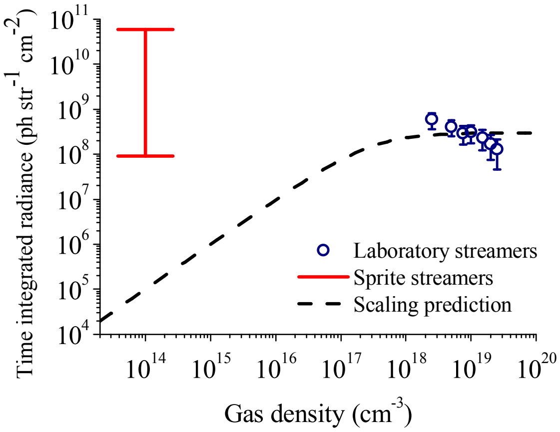

Figure 1 Time integrated radiance in air. Circles - experimental measurements in artificial air, point-plane geometry, dashed line - scaling law prediction. Red bar - sprite streamers, following observations by Stenbaek-Nielsen et al. [6].

A scaling law of the (time integrated) brightness of minimal streamers is proposed and tested in artificial air (N_2:O_2 – 80:20). The time integrated brightness L, referred to in this paper is the number of photons emitted per unit area, per solid angle. It is described by $L \sim d \cdot Q \cdot n^*$, where d is the diameter of the streamer head, n^* is the density of excited molecules and Q, the quenching factor, is the fraction of the excited molecules which de-excite by photon emission. Quenching means that the excited molecule is de-excited by a collision with another molecule. Q scales as 1/n if the gas density is above the quenching density, where collisions dominates. At low density the emission process dominates. The quenching density depends on the gas composition and the emission band of interest. The streamer diameters scale as $1/n$, and the density of excited molecules as n^2 [3].

The time integrated radiance of minimal streamers in air is of the order of 10^8 photons per steradian per cm^2 at lab densities $(10^{18}-10^{19}\,\mathrm{cm}^{-3})$. Light emission at this density is dominated by the second positive N_2 system (300-400 nm). Scaling to mesospheric densities, gives an estimate of $10^5 - 10^6\ \mathrm{ph/str\,cm^2}$ for the time integrated radiance of a minimal sprite streamer. This is a lower limit, while observed sprite streamer heads [6] are wider and are at least three orders of magnitude brighter than the minimal streamer in these conditions. This prediction agrees well with modelling of sprite brightness by Liu et al. [4].

The brightness of the brightest streamer heads in sprites is comparable with the brightness of an entire column sprite [7], and is therefore a useful parameter to study in order to predict the detectability of the entire discharge.

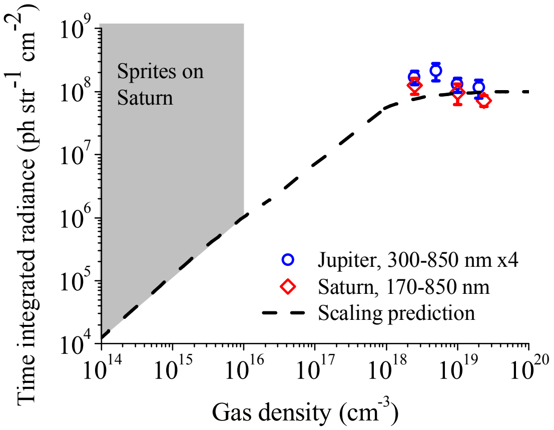

Figure 2 Time integrated radiance in gas mixtures representing the atmospheres of Jupiter and Saturn. Diamonds (circles) - experimental measurements in Saturn (Jupiter), dashed line - scaling law prediction, grey area – predicted density and brightness range of sprites on Saturn.

The scaling approach is used to provide an estimate of the brightness of sprites that may be found in the atmospheres of Jupiter and Saturn. Time integrated radiance of minimal streamers in$\mathrm{H_2-He}$, dominated by a UV continuum in the range 170-400 nm, is of the order of $10^8\,\mathrm{ph/str\,cm^2}$ at lab densities $(10^{18}-10^{19}\,\mathrm{cm}^{-3})$. Scaling to the gas density at predicted sprite altitudes (density $< 10^{16} cm^{-3}$) gives a lower bound for the brightness of extra-terrestrial sprites: 10^4 to $10^6\ \mathrm{ph/str\,cm^2}$. Owing to the high energy and rate of the lightning flashes, as observed in the recent giant Saturnian storm [4], sprites may be significantly brighter than this lower limit. This prediction may serve as a benchmark for planning space-based observations of TLEs by planetary missions such as Cassini and Juno.

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3. References

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