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VIBRATIONAL KINETICS OF N_2 ($C^3\Pi_u$) IN AIR PLASMAS PRODUCED BY SPRITES IN THE MESOSPHERE

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This contribution deals with the vibrational kinetics of N_2 ($C^3\Pi_u$) excited in mesospheric air plasmas during the appearance of Sprites. Radiative de-excitation from different vibrational levels of N_2 ($C^3\Pi_u$) toward lower vibrational levels of N_2 ($B^2\Pi_g$) is the main responsible of the characteristic bluish optical emissions recorded from Sprites. The main goal of this work is to calculate and predict the vibrational distribution function (VDF) of N_2 ($C^3\Pi_u$) in Sprites as a function of time and speed recording of the cameras presently used in Sprite spectroscopy campaigns.

The approach used to model the kinetics of air plasmas induced by sprites in the Earth mesosphere is based on the present understanding of the chemical activity of sprites and how this activity influences the surrounding atmosphere [1], [2], [3]. The model used assumes that most of the chemical activity due to sprites begins in their brightest regions, that is, in their initial and very short living streamer heads. The duration of the sprite streamer heads have not yet been completely resolved in time but recent sprite imaging at 20000 frames per second (with 50 μs exposure time) [4], [5], [6] shows the expected point-like structure of the streamer heads. Thus, faster recordings at 50000 frames per second (fps) would be needed to completely resolve the timescale of sprite streamer heads. Therefore, the present kinetic model of sprite discharges considers sprites as impulsive discharges in air with pulse duration of 5 μs.

The present approach has allowed us to study the vibrational kinetics of the five (v = 0 – 4) lower vibrational levels of N_2 ($C^3\Pi_u$). The main production channel of vibrationally excited N_2 ($C^3\Pi_u$) in Sprites is direct electron-impact excitation from N_2 ($X^1\Sigma^+_g$), that is, N_2 ($X^1\Sigma^+_g$, v = 0) + e $\rightarrow$ N_2 ($C^3\Pi_u$, v = 0 – 4) + e. However, at 5 μs, the population of N_2 ($C^3\Pi_g$, v = 0 – 3) becomes controlled by process N_2 ($C^3\Pi_u$, v ≥ 1) + N_2 ($X^1\Sigma^+_g$, v = 0) $\rightarrow$ N_2 ($C^3\Pi_g$, v – 1) + N_2 ($X^1\Sigma^+_g$, v = 1). The loss of vibrationally excited N_2 ($C^3\Pi_u$) is mainly due to cascade radiative de-excitation towards different vibrational levels of N_2 ($B^3\Pi_g$).

The VDF of N_2 ($C^3\Pi_u$) for different times from 0.1 μs to 10 ms is shown in figure 1 (a). In addition, Boltzmann VDFs (straight dashed lines) have been fitted to the calculated VDFs. The agreement between the Boltzmann and the calculated VDFs is quite reasonable. The latter indicates that the VDF of N_2 ($C^3\Pi_u$) is in equilibrium and that a vibrational temperature (T^C_{vib}) can be associated to N_2 ($C^3\Pi_u$) for the different times investigated. It is found that T^C_{vib} takes the values ~ 10500 K (0.1 μs), ~ 3200 K (3 μs), ~ 2900 K (5 μs) and ~ 1660 K (100 μs, 10 ms and 100 ms).

The calculated VDF of N_2 ($C^3\Pi_u$) averaged over periods of times of 30 ms, 3 ms and 1 ms has been represented in figure 1 (b) together with Boltzmann (equilibrium) VDFs represented by straight lines. As can be seen in figure 1 (b), the calculated Sprite induced VDFs of N_2 ($C^3\Pi_u$) at 78 km are close to equilibrium values. The VDFs of N_2 ($C^3\Pi_u$) shown in figure 1 (b) are predictions about how field recorded VDFs of N_2 ($C^3\Pi_u$) would look like when using video cameras working

at different speeds (30 fps, 300 fps, 1000 fps and 10000 fps) coupled to imaging spectrographs tuned in the appropriate spectral range. So far, no measurements of N_2 ($C^3\Pi_u$) VDF are available and, consequently, the present model predictions can serve to stimulate future spectroscopic observations of Sprite emissions in the blue and near ultraviolet that could be used to estimate the experimental VDF of N_2 ($C^3\Pi_u$) excited during Sprite chemical activity in the upper atmosphere of the Earth.

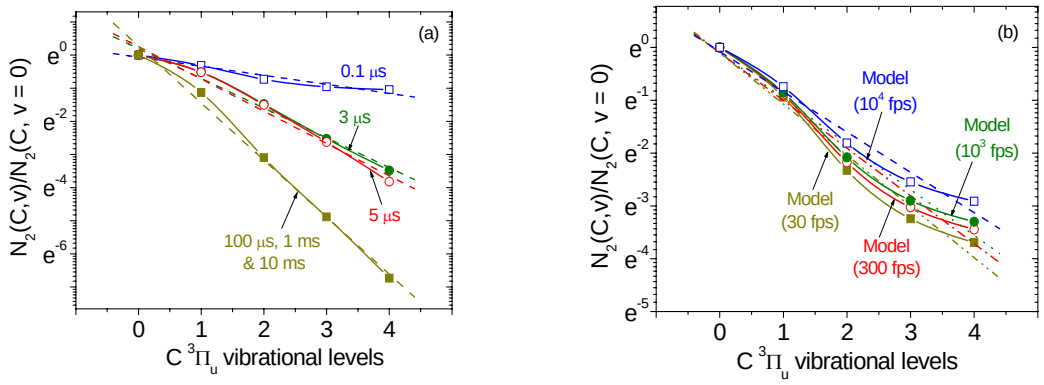

Fig. 1: (a) Calculated vibrational distribution function (VDF) of N_2 ($C^3\Pi_u$) for different times (0.1 μs – open squares; 3 μs – solid circles; 5 μs – open circles; 100 μs, 10 ms and 100 ms – solid squares) and corresponding fits to Boltzmann VDFs (dashed lines) which provides reasonable estimates for $C^3\Pi_u$ vibrational temperatures of 10500 K (0.1 μs), 3200 K (3 μs), 2900 K (5 μs) and 1660 K (100 μs, 10 ms and 100 ms); (b) calculated VDF of N_2 ($C^3\Pi_u$) averaged over 30 ms (solid squares); 3 ms (open circles), 1 ms (solid circles) and 0.1 ms (open squares), and their corresponding Boltzmann VDF fits (30 ms – dashed-dotted-dotted line; 3 ms – dashed-dotted line; 1 ms – dotted line; 0.1 ms – dashed line).

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