Streamer propagation in the atmosphere of Titan and other N₂:CH₄ mixtures compared to N₂:O₂ mixtures

Streamers, thin, ionized plasma channels, form the early stages of lightning discharges. Here we approach the study of extraterrestrial lightning by studying the formation and propagation of streamer discharges in various nitrogen-methane and nitrogen-oxygen mixtures with levels of nitrogen from 20% to 98.4%. We present the friction force and breakdown fields $E_k$ in various N₂:O₂ (Earth-like) and N₂:CH₄ (Titan-like) mixtures. The strength of the friction force is larger in N₂:CH₄ mixtures whereas the breakdown field $E_k$ in mixtures with methane is half as large as in mixtures with oxygen. We use a 2.5-dimensional Monte Carlo particle-in-cell code with cylindrical symmetry to simulate the development of electron avalanches from an initial electron-ion patch in ambient electric fields between 1.5$E_k$ and 3$E_k$. We compare the electron density, the electric field, the front velocities as well as the occurrence of avalanche-to-streamer transition between mixtures with methane and with oxygen. Whereas we observe the formation of streamers in oxygen in all considered cases, we observe streamer inceptions in methane for small percentages of nitrogen or for large electric fields only. For large percentages of nitrogen or for small fields, ionization is not efficient enough to form a streamer channel within the length of the simulation domain. In oxygen, positive and negative streamers move faster for small percentages of nitrogen. In mixtures with methane, electron or streamer fronts move 10–100 times slower than in mixtures with oxygen; the higher the percentage of methane, the faster the fronts move. On Titan with methane percentages between 1.4% and 5%, a successful streamer inception would require a large electric field of 4.2 MV m⁻¹ (3$E_k$). Such large fields might not be present and explain the non-detection of Titan lightning by the Cassini/Huygens mission.

General information
Publication status: Published
Organisations: National Space Institute, Astrophysics and Atmospheric Physics, University of Belgrade
Corresponding author: Köhn, C.
Contributors: Köhn, C., Dujko, S., Chanrion, O., Neubert, T.
Pages: 294-305
Publication date: 2019
Peer-reviewed: Yes

Publication information
Journal: Icarus
Volume: 333
ISSN (Print): 0019-1035
Ratings:
BFI (2019): BFI-level 1
Web of Science (2019): Indexed yes
Original language: English
Electronic versions:
1_s2.0_S0019103518307863_main.pdf
DOI:
10.1016/j.icarus.2019.05.036

Bibliographical note
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Source: FindIt
Source-ID: 2450257470
Research output: Contribution to journal › Journal article – Annual report year: 2019 › Research › peer-review