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Lightning Initiation in Low Thundercloud Fields: Role of Hydrometeor Collisions and Photoionization Effects

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Photoionization processes due to extreme ultraviolet emissions are important for understanding of lightning induced plasma irregularities and lightning initiation processes at higher [e.g., Liu and Pasko, Journal of Geophysical Research, 109, A04301, 2004] and lower [e.g., Jansky and Pasko, Journal of Geophysical Research, 125, e2019JD031337, 2020] altitudes in the Earth's atmosphere. The lightning initiation in low thundercloud fields, in particular, represents an unsolved problem in lightning discharge physics. One of the initial conditions required for formation of a hot leader channel is initiation of non-thermal streamer discharges that naturally can develop from electron seeds undergoing avalanche multiplication in high electric fields. The maximum electric field in thunderstorms measured by balloons is typically ∼3-4 kV/cm/atm, that is significantly smaller than the breakdown electric field needed for avalanche multiplication of electrons E_k=28.7 kV/cm/atm. Hydrometeors can greatly intensify the local electric field and that stimulated renewed interest to accurate numerical modeling of related gas discharge processes [Dubinova et al., Physical Review Letters, 115, 015002, 2015; Sadighi et al., Journal of Geophysical Research, 120, 3660, 2015; Babich et al., Journal of Geophysical Research, 121, 6393, 2016]. In this presentation we review some of the important milestones in understanding of photoionization processes in air, including the most recent studies [e.g., Janalizadeh and Pasko, Plasma Sources Science and Technology, 28, 105006, 2019, and references therein]. We then present results of Monte Carlo modeling that quantitatively investigates an idea that Rayleigh scattering of ultraviolet photons in the range 98-102.5 nm, that are responsible for photoionization in air [e.g., Janalizadeh and Pasko, 2019], can lead to production of seed electrons for initiation of gas discharges (i.e., streamers) in regions of space that normally would be shielded by opaque objects and would not have direct line of sight exposure to ultraviolet photons produced by gas discharges occurring at other locations. This problem has relevance to initiation of streamers during collisions of two hydrometeors when the initial discharge in the gap between two hydrometeors can stimulate the subsequent streamer discharges developing on the outer periphery of two hydrometeors [e.g., Cooray et al., Proceedings of 24th International Conference on Lightning Protection, Bermingham UK, 1998; Jansky and Pasko, 2020; and references therein]. We note that the measured Rayleigh scattering cross section in deep-UV spectral region [Ityaksov et al., Molecular Physics, 106, 2471, 2008] when extrapolated to 98-102.5 nm is orders of magnitude lower than the photoabsorption cross section of molecular oxygen. However, our results demonstrate that this process can lead to production of seed electrons for initiation of streamers. The Monte Carlo modeling also allows direct, first principles, testing of previously proposed photoionization models. This presentation also includes related quantitative tests on propagation, photoabsorption and photoionization produced under typical conditions in the Earth's atmosphere by extreme ultraviolet photons originating from Birge-Hopfield I, Birge-Hopfield II, Worley-Jenkins, Worley, and Carroll-Yoshino band systems of molecular nitrogen [Janalizadeh and Pasko, 2019, and references therein].