LTP Perspectives: Policy, Opportunities, Challenges

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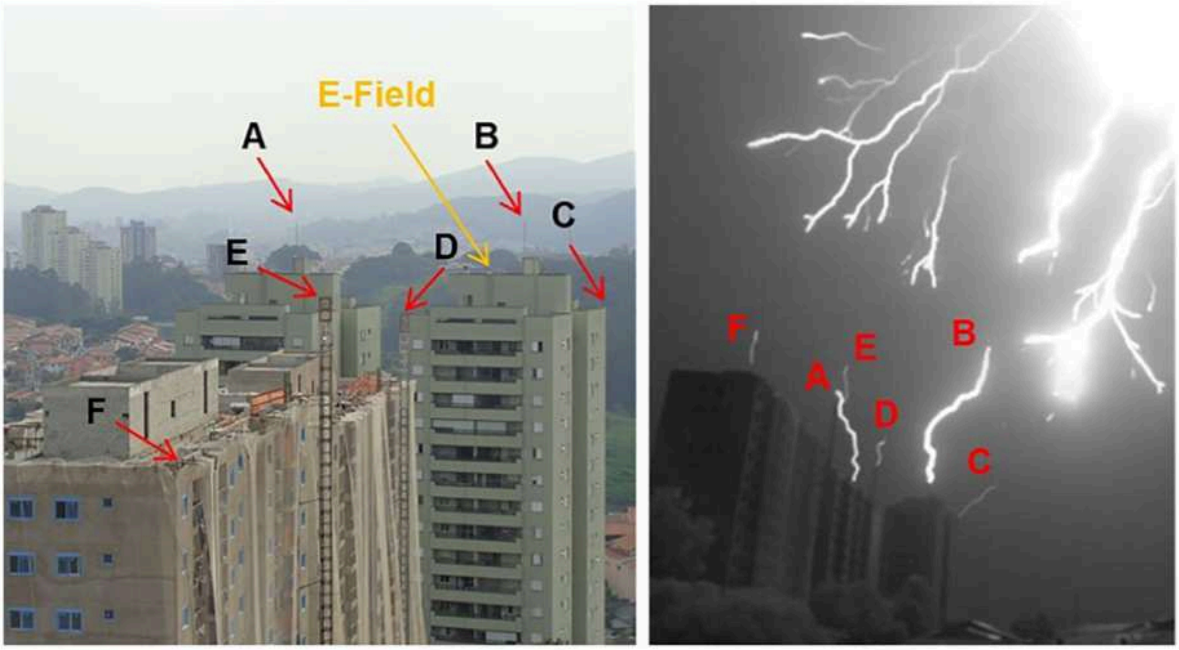
Lightning research between engineering and plasma science

When I visited a high voltage hall about 25 years ago with a group of lightning researchers, one of them told me: “ This Marx generator is very nice, but you know: lightning can never be reproduced in a lab. The hall and the available voltage are much too small and the electrodes would melt.” This statement refers to lightning as we see and hear it, and to the electric current that has to be guided safely to ground after lightning has attached to an object. But these bright conducting lightning channels do not appear out of nothing. Where do they come from, and where and when do they attach? Our vision on lightning phenomena and what to focus on, has changed substantially in past decades.

The completely unexpected observation of Terrestrial Gamma-ray Flashes (TGFs) from active thunderstorms and of Transient Luminous Events (TLEs) above storm clouds have triggered new research questions and methods, and new funding. While 30 years ago, lightning research seemed essentially focused on the engineering questions of lightning protection, the new phenomena revived the study of fundamental processes and drew a new group of researchers into the “prohibitively difficult problems” of lightning physics. Another important innovation were receivers of electromagnetic radiation in the frequency range from 8 Hz to 80 MHz that measured the dynamics of the invisible electric currents within the clouds.



Lightning leaders move downward, and counter leaders move upward from the lightning rods of tall buildings [4].

In retrospect, the observation of sprite discharges at 40 to 90 km altitude in the atmosphere (i.e., at a pressure of 300 to 1 Pa) was a case of luck for the community. As they propagate tens of km vertically, sprite discharges attract quite some publicity. And they are not hidden within clouds, but with some experience they can be seen above them. Sprite discharges are essentially streamers, with length and time scales proportional to the inverse air density, hence about 10^5 times larger at 80 km altitude than at ground level. The scaling laws relating phenomena at different gas densities work quite well. In fact, measuring streamer dynamics at normal pressure over centimeters to meters in the lab at velocities of 10^5 to 10^7 m/s requires intensified CCD cameras and challenging trigger schemes, while fast movie cameras can record the sprite propagating over km distances with the same velocities. (But you have to point your camera to the right spot at the right time, and stereo and current measurements are very valuable, but scarce.)

However, while TLEs like sprites are nice, most of our air mass and most of our cloud volumes are within the troposphere, and most lightning dynamics is within the clouds. This is logical: in the turbulent convection of the thundercloud, charge separation occurs between colliding ice particles that are then separated by gravity. Therefore most discharges appear within these clouds – sometimes over horizontal distances of over 700 km [1] if the opposite charges are torn apart by wind shear. Within these discharges there is a whole hierarchy of phenomena. Lightning starts from accumulations of positively charged ice particles and forms space charge dominated streamers and then heat stabilized leaders. These leaders mostly propagate in a stepped fashion, behind streamer coronas that pave their way. Recent lightning measurements with the radio telescope LOFAR [2] reveal streamers of meter length and pulsating structures (“needles’) within existing plasma channels. Here high voltage experiments and lightning phenomena finally meet at the same length scales and the same air density! And plasma fluid simulations based on tabulated cross sections now can capture such meter scale streamer discharges quantitatively as well.

That pulsed air discharges produce NO_x is well known, and currently being used in a number of application fields like disinfection, medicine or agriculture. NOx is a green-house gas, and a well-known product of lightning as well, but of which stage of lightning? It was assumed that the hot visible return stroke channels would be the source, but what about the very extended network of invisible discharges (streamers?) that have been found in air plane missions to also produce large amounts of HO_x (= OH and HO_2)? Lightning has been declared an essential climate variable [3] because of this (measured, but not yet explained) impact on atmospheric composition.

On the other hand, high energy emissions, from x-rays and gamma-rays through electron positron beams to nuclear reactions in the nuclei of N_2 and O_2 are clearly a product of the stepped propagation of streamers and leaders in lightning. The correlation between leader stepping and high energy emissions has been measured both in nature and in the lab, and the ASIM mission [https://asim.dk] on the international space station is dedicated to measure occurrence conditions and energy spectra. But the dynamic conditions for electron run-away to high energies are still not fully understood.

Finally, the problem of lightning protection, e.g., of new generations of higher wind turbines comes up again, but at an earlier stage: can we understand the streamer coronas around the wings so well that we can prevent lightning attachment?

Clearly this is an intriguing field with applications in many disciplines, and there are still many fundamental questions to solve on these multiscale, deeply nonlinear, and nonequilibrium plasma phenomena that occur in nature and technology, and that can be studied in the lab and also in our simulations.

[1] https://wmo.int/news/media-centre/wmo-certifies-two-megaflash-lightning-records
[2] https://www.astron.nl/telescopes/lofar/
[3] https://gcos.wmo.int/en/essential-climate-variables/lightning
[4] https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2022JD038082

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Erratum – About LIF and TALIF techniques. Historical retrospective and perspectives.

With this message we would like to clarify [1] that the first use of LIF for molecular diagnostics was reported in 1968 [2]. A team from the Joint Institute of Laboratory Astrophysics, Boulder, Colorado, used He-Ne laser to check the spectroscopic constants of the ground state of K_2 molecule.

[1] M. Laroussi, C. O. Laux, private communication
[2] W. J. Tango, J. K. Link, and R. N. Zare, “Spectroscopy of K_2 Using Laser-Induced Fluorescence”, J. Chem. Phys., Vol.49, No. 10, (1968).

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Leaders of the LTP Community: Career Profiles

Prof. Michael Keidar – From Micro-Propulsion and Nanotechnology to Plasma Medicine and Machine Learning

After his PhD graduation from Tel-Aviv University, Israel, and postdoctoral training in the USA (Universities of Berkeley, Cornell, and Michigan), Michael Keidar founded his research group at The George Washington University (GWU) in 2007. Michael was among the