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MODELS OF INTERACTING STREAMERS

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Streamers are transient, thin plasma channels that propagate into a non-ionized medium due to the self-enhanced electric field at their tip. They are widely encountered in nature where they play an important role in building up lightning strokes, they are also encountered as electric discharges called sprites [1]. Streamers are also of industrial relevance: their applications include ozone generation and the treatment of polluted gases.

Streamers most frequently appear aggregated in bunches and several observations [2] indicate that the interaction between them plays a significant role in their propagation. However, until recently streamer theory has focused almost exclusively on the propagation of single streamers.

We present here two complementary approaches to the investigation of interacting streamers: first we analyze the three-dimensional interaction between a pair of streamers and then an idealized system of infinitely many streamers propagating in parallel.

The numerical investigation of a pair of interacting streamers poses several difficulties and only recently has it been viable, thanks to the increase in computational power and the development of improved algorithms. Adaptively refined grids [4] are designed to handle the multi-scale nature of streamers; a transformation from an integral formulation to partial differential equations [5]

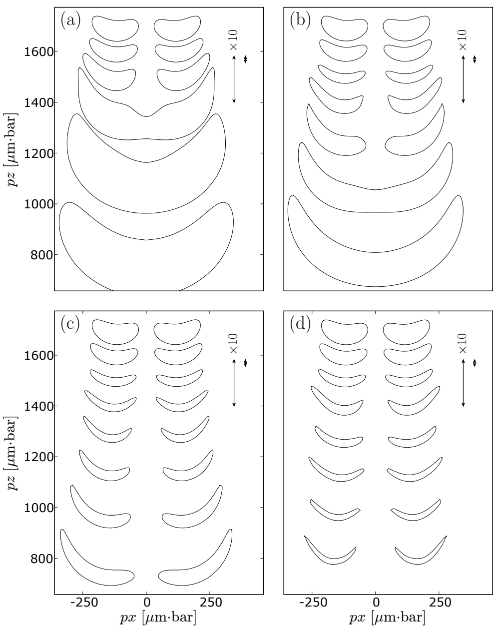

FIG. 1: Evolution of the space-charge layers of two interacting streamers in air at pressures (a) $p = 0.07$mbar (atmospheric pressure at $\sim$ 70 km) of altitude, (b) $p = 1$ bar, (c) $p = 50$ bar, (d) $p \to \infty$ which is equivalent to pure nitrogen. The typical ranges of photo-ionizing radiation are shown to the right. At low pressures ((a) and (b)) the photo-ionization of the space between the two streamer heads makes them coalesce. On the other hand, for increasing pressure the excited N_2 states that the emit photo-ionizing radiation are collision-ally quenched and hence the two streamers repel due to the charge in their heads. Taken from [3].

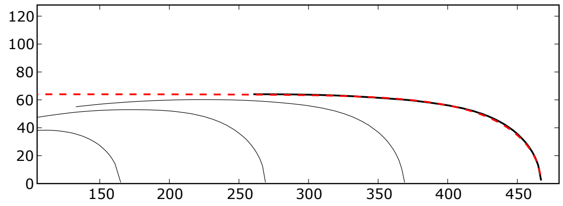

FIG. 2: Convergence of a streamer front towards a uniformly translating front. The converged shape is remarkably well described by the Saffman-Taylor finger that fills half the width of the available space (dashed line).

simplifies the calculation of the non-local photo-ionization source and, finally, a pseudo-spectral method allowed a three-dimensional code to take advantage of multi-processor machines [3].

There are two possible outcomes of the interaction between two streamers: they can repel electrostatically or they can coalesce due to the photo-ionization of the space between them [3]. Which process is dominant is decided by the interplay of various parameters such as gas composition, pressure and distance between the streamers.

On the other hand, since streamers often appear in bunches, another approach to understand the effect of interactions between them is to model these bunches as regular arrays of identical streamers [6]. This description is particularly convenient since the effect of all neighbouring streamers can be summarized by boundary conditions thus transforming a multi-streamer model into a single-streamer one. The system thus formulated strongly resembles other systems studied in pattern formation physics and fluid dynamics, such as Hele-Shaw flows and kinetic undercooling. To further stress this connection we initially focused on 2D (planar) systems.

Also in this model the interaction of streamers strongly affects their propagation, which now shows remarkable properties: (1) For any localized initial ionization seed, after a transient time the streamer reaches a state of uniform propagation, which implies that (2) the electric field behind the front is completely screened. (3) The profile of the uniformly translating front is that of a Saffman-Taylor [7] finger whose diameter is always half of the distance to the next streamer.

We have shown two approaches to the study of interacting streamers which, provide a first insight into this phenomenon. Many extensions and improvements are currently being investigated, such as the extension to 3D streamer arrays, and the extension to interactions between the head of a streamer and the tail of another. Work in these directions will provide crucial insights into multi-streamer discharges.

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