**White Paper for *Frontiers of Plasma Science Panel***

| Date of Submission: | ***19 June 2015*** |
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| | "P", "S" |
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| • Plasma Atomic physics and the interface with chemistry and biology | P |
| • Turbulence and transport | S2 |
| • Interactions of plasmas and waves | |
| • Plasma self-organization | S1 |
| • Statistical mechanics of plasmas | |

Indicate type of presentation desired at Town Hall Meeting:

| | "X" |
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| Oral | X |
| Poster | |
| Either Oral or Poster | |
| Will not attend | |

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| Title: | **Dynamic Contruction in Weakly-Ionized Molecular Gas Flows** |
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**Research frontier and importance of the scientific challenge**

Contraction of the gas discharge, when current contracts from a uniform volume of weakly ionized plasma into a thin arc channel, was attracted attention of scientists for more than a century. Studies of the contraction mechanism, besides carrying interesting science, are of practical importance, especially when contraction should be prevented as in powerful gas lasers. Current contraction is a typical example of ***self-organization phenomena*** in weakly-ionized plasma. Previous research has examined the build-up dynamics of the contracted state. The experiments show that the formation of the contracted state occurs nonuniformly. This process involves growing the current filament from one electrode to another, and like a streamer, the filament eventually crossconnects the electrodes of discharge gap. A number of questions arise such as: is the growing filament analogous to the ionization wave type of a "thermal" streamer? What are the plasma properties behind the front of the rising channel? Does the field strengthening and increasing current which occur at the filament tip play an important role for the channel expansion? Those questions were discussed in literature, where analytical and numerical calculations were conducted mostly for non-self-sustained discharge. However, up to now, for self-sustained discharge, there is no presently comprehensive understanding of the dynamics of non-uniform contraction including formation of the steady state. In addition, the questions of why the nonuniform contraction occurs and what are the required conditions have never been asked.

Interest to study of the transition from volumetric to constricted gas discharge forms is stimulated by the fact that there are large number of experiments on the dynamic contraction of a glow discharge in

molecular gas flows and a many of possible applications: from powerful gas-discharge lasers to plasma assisted combustion and atmospheric electricity phenomena.

**The approach to advancing the frontier and indicate if new research tools or capabilities required**

Recently, a set of time-dependent two-dimensional equations for the non-equilibrium weakly-ionized nitrogen / air plasma is formulated and solved numerically for N2 [1] and air [2] flows. The process is described by time-dependent continuity equations for the electrons, positive and negative ions; gas and vibrational temperature; and by taking into account the convective heat and plasma losses by the transverse flux. Transition from the uniform to contracted state was analyzed. Typical example of computed dynamic contraction process in weakly ionized air plasma flow at 50 Torr and transversal flow velocity 50 m/s is shown in Fig.1.

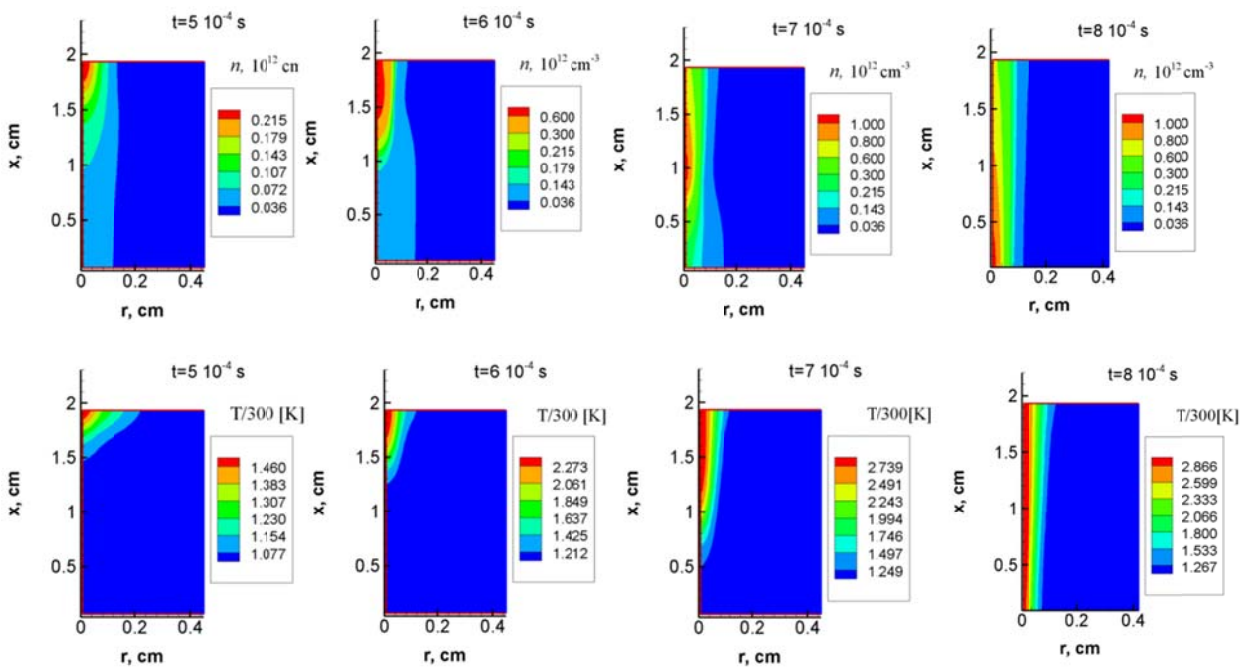


**Fig.1.** Electron density and translational temperature distributions at different times.

Obtained results are similar to that observed in known experiments [3,4]. It was shown that such transition experiences a hysteresis, and that the critical current of the transition increases when the pressure (gas density) drops. Possible coexistence of the contracted and uniform state of the plasma in the discharge where the current flows along the density gradient of the background gas was shown.

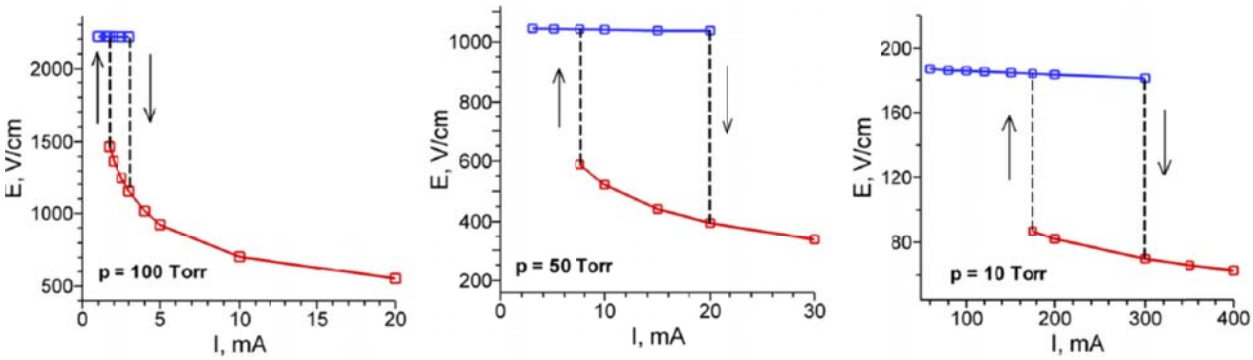


**Fig.2.** The "current-voltage characteristic" of the glow discharge in air flow at the different pressures. The critical current Icr is shown by the bold trace. If I<Icr the discharge is uniform, if I>Icr the contracted channel is formed.

The presence of hysteresis provides additional opportunities to control the transition to the constricted state.

The contraction model was used to discuss formation of Blue Jets [5]. The latter consists of the contracted hard core (leader) surrounded by diffusive halo. When the leader moves up in the atmosphere the critical current required for the contraction increases. The leader reaches its termination height when the current it carries becomes smaller than the local critical contraction current (see Fig. 3). Figure 3 shows the critical BJ current in the atmosphere vs. altitude. To horizontal bars centered at 28 and 48 km obtained from the observations. The insert shows the image of BJ.

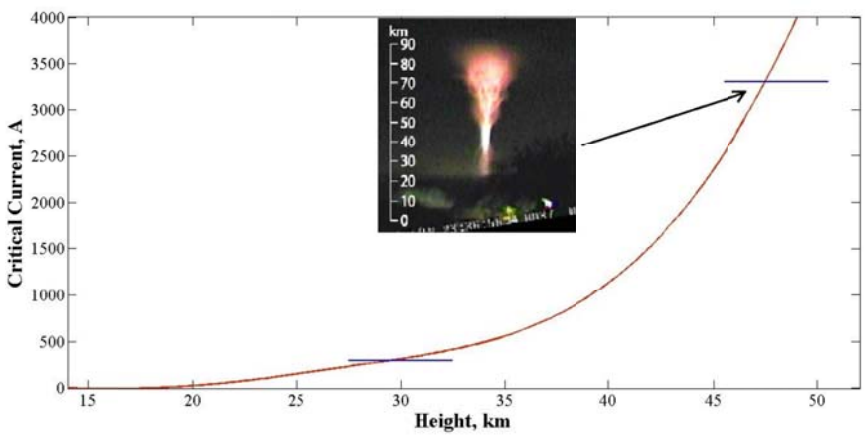


**Fig. 3.** The critical current in the atmosphere vs altitude. Two horizontal bars centered at 28 and 48 km obtained from the observations by Van der Velde et al. [6] and Lu et al. [7], respectively. The insert shows the image of GBJ obtained by van der Velde et al. [6].

Despite the importance of the above problems and the progress achieved, a large number of issues have to be resolved. First of all, it concerns

**Theory:**

- Advanced kinetics of molecular weakly-ionized plasma in regime of thermal-ionization instability development

- We developed simplified 2D model of contraction. Analysis of the current contraction in the gas flow is laborious since the discharge channel is always 3D due to the presence of the gas flow. 3D computer modeling is more adequate
- 2D and 3D stability analysis
- Role of near-electrode sheaths in contraction development, especially for hysteresis regime

**Experimental studies:**

- Controllable contraction stimulation in molecular gas flow
- Contraction and ignition in air-fuel mixtures
- Apply modern laser-based diagnostics to study instantaneous nonequilibrium plasma parameters, such as local plasma components distributions, translational, vibrational and electron temperatures

## The impact of this research on plasma science and related disciplines and any potential for societal benefit

**Intellectual Merit and Broader Impact:** Theoretical and computational studies of the thermal-ionization instability in weakly ionized plasma will contribute to the understanding of the formation and evolution of current channel in gases. In particular, the effects of varying discharge geometry, density gradient, gas composition, pressure, temperature, and external circuits will provide a deeper understanding of gas discharges. Potential applications include: extending fundamental knowledge in the physics of gas discharge and weakly ionized plasma and influencing the design of powerful lasers and plasma chemical reactors through a quantitative understanding of current contraction. In particular, the models of current contraction may have direct relevance to the recently discovered atmospheric phenomena of Blue Jets, the narrowly collimated beams of blue light propagating upwards from the top of thunderstorms. It is broadly accepted that Blue Jets are produced by a lightning leader running upward in the nonuniform atmosphere, which is governed by the current contraction [5].

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