Journal of Physics: Conference Series



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To cite this article: V F Tarasenko *et al* 2017 *J. Phys.: Conf. Ser.* **927** 012062

IOP Conf. Series: Journal of Physics: Conf. Series **927** (2017) 012062 doi:10.1088/1742-6596/927/1/012062

# Laboratory demonstration in the air red and blue mini-jets

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**Abstract**. The properties of apokamps (miniature plasma jets) with length up to 60 cm at low pressures are studied. It is shown that several properties of apokamps resembles that ones for large-scale transient luminous events (sprites, starters and blue jets) observed in the Earth upper atmosphere. The images and spectra of apokamps in these conditions are presented. For the first time red downward directed mini jets in air at pressures of fraction of Torr were obtained.

## 1. Introduction

In the past decade, there has been considerable progress in the study of discharges in the upper atmosphere [1-6]. Experimental studies using a high-altitude stations and international space station [6] revealed several important regularities in the formation of blue jets, red sprites, and other types of atmospheric transient luminous events. In particular, some regularities in the formation of blue jets and red sprites were defined. The observations show a multitude of blue, kilometer-scale, discharges at the cloud top layer at ~18 km altitude and a pulsating blue discharge propagating into the stratosphere reaching ~40 km altitude [6]. The blue jets formed from the top of the thunderclouds. Red sprites as distinct from blue jets propagates not only up from the initial plasma, but also downwards in the direction of increased negative charge. The laboratory experimental studies of atmospheric discharges are strongly complicated because of their huge dimensions reaching tens and hundreds of kilometers.

In our works [7-9] we describe a new discharge type with plasma jets (apokamps) formation under atmospheric air pressure. They had a blue color and formed at a bend point (natural or induced) of the discharge channel in the electric field strengthening point. We termed this discharge apokampic (in Greek. από – from and καμπη – bend, turn), and, accordingly, plasma jets germinated in this case – apokamps. Apokamps are directed almost perpendicular to discharge channel. Apokamp is distinguished from other types of plasma jets [10] by its forming in open space without dielectric walls and absence of gas force-feed to discharge area. Details about apokamp properties and formation conditions published in [11-14]. Particularly, it has been shown, that apokamp close to the blue jets in appearance and emission spectra at pressures at hundreds of tens of Torr. The velocities of propagation of apokamps have been measured at various pressures. It has been found that the average values of these velocities are about the velocities of propagation of starters and blue jets in the atmosphere of the Earth. It has been shown that jets (apokamps) with the maximum length are observed in the pressure range corresponding to the altitudes of appearance and propagation of starters and blue jets. But downward directed apokamps formation has not been studied. In addition, there is no studies of laboratory-scale apokamps at a pressure values less than 9 Torr.

In this work, we present the downward directed apokamps at air pressure of shares-units of Torr. Let us note that downward propagation to the Earth is characterized for lower part of red sprites [1-4, 15], and as it has been found in [14] the apokamp color at decreasing pressure changes from blue to red.

## 2. Experimental setup

The study of pressure and voltage influence in apokamp were carried out with the use of one generator and two discharge chambers, having a height of 25 and 60 cm. They are made of quartz tubes and the electrodes in tubes could be located in different positions relative to the Earth's surface. This makes possible the observation of the diffuse jets (apokamps) formation as in straight up and down.

Downward directed apokamps were observed for the first time. Figure 1 shows a setup that we assembled for this aim.

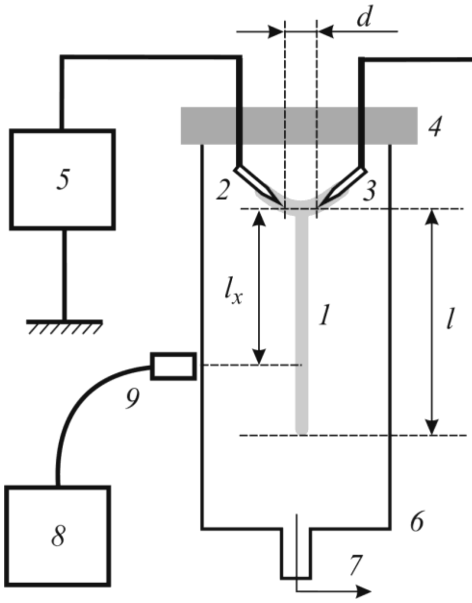


**Figure 1.** Schematic of the setup: *1* – apokamp; *2* – high-voltage electrode; *3* – floating potential electrode; *4* – dielectric flange; *5* – power supply; *6* – quartz bulb; *7* – gas inlet/outlet; *8* – spectrometer; *9* – collimator with optical fiber; *10* – photo camera. C = 5.6 pF – capacitor for increasing the voltage on the electrodes.

In order to form a plasma jet – apokamp *1*, we used a pulse periodic discharge between cylindrical steel electrodes *2* and *3*, which had a diameter of 1.8 mm and formed a gap of $d$ = 10 mm. The electrodes had needle-shaped ends and the angle between them was 120°. The inclination of the electrodes makes the electric field under the electrodes greater than above ones. The electrode *2* was connected to the secondary coil of the pulse transformer of a generator of high-voltage pulses *5*. The generator formed voltage pulses $U_p$ with a positive or negative polarity with the repetition frequency $f$ up to 50 kHz, the FWHM duration of the pulse $\tau_{1/2}$ = 1.5 μs, amplitude $U_p$ < 13 kV, and the pulse front ~0.8 μs. The electrode *3* had capacitive decoupling with the ground. With an increase in $U_p$, a discharge channel was first formed and apokamp with the length $l$ appeared. The maximum current of the discharge increased with $U_p$ and was ~ 0.2 mA at $U_p$ = 11 kV and atmospheric pressure of air. When the pressure of air was reduced to tens of Torr, the amplitude of the current was doubled. The time profile of the current and voltage detected by a TDS 3034 four-channel oscilloscope (Tektronics Inc.). The spectra of apokamp was registered in different points on the distance $l_x$ from the discharge channel. To obtain the total picture of luminescence, we used a Canon PowerShot SX60 HS camera in the mode of serial frame-by-frame recording with an exposure time of no less than 0.125 s.

## 3. Experimental results and discussion

In preliminary experiments, the electrodes in the discharge chamber (as in [7-9, 11-14]) was located at the chamber bottom and apokamps propagates upwards. In this case, apokamps color was blue at elevated pressures (see Fig. 2 (a)). Each apokamp consisted of bright branch forming from discharge channel and streamer launching from branch with average speed of about 200 km/s [8]. The dynamics of development of the apokamp was recorded by an HSFC-PRO four-channel high-speed camera (PCO AG) with the minimum duration of one frame of 3 ns. The camera was switched on with various time decays with respect to the time of appearance of the discharge.

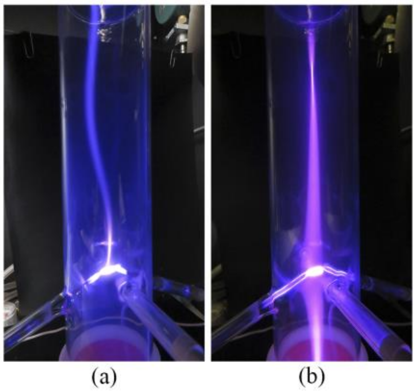

Figure 2. The color and shape of apokamp in air at 120 (a) and 15 (b) Torr. The vertical frame size is 22.2 cm. The electrodes are at the bottom. $U_p \sim 10$ kV.

The color of apokamp at pressure decreasing up to 30 Torr becomes red. In addition, with pressure decreasing the red color downward directed apokamp arise simultaneously with upward directed apokamp (Fig. 2 (b)).

In the current study, we focused on downward directed apokamps forming in discharge chamber shown in Fig. 1. Plasma jets were formed only at relatively low-pressure values and had a red color. At elevated pressures (> 30 Torr) the discharge was transferred to the sparks, that finished on wall of quartz bulb and stable apokamps failed to form. Figure 3 shows the effect of discharge voltage (a, b) and pressure (c, d, e) on apokamps length.

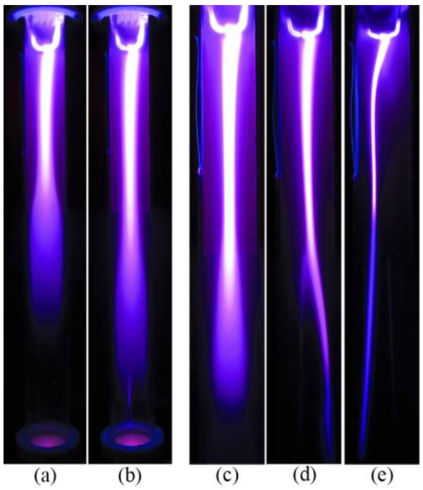

**Figure 3.** The effect of discharge voltage (a, b) and pressure (c, d, e) on apokamp length and shape in air at $p = 0.1$ Torr, $U_p = 3.9$ kV (a); $p = 0.1$ Torr, $U_p = 6.5$ kVкВ (b); $p = 0.1$ Torr, $U_p = 4.9$ kV (c); $p = 3$ Torr, $U_p = 6.3$ kV (d); $p = 9$ Torr, $U_p = 7.2$ kV (e). The vertical frame size is 72.8 (a, b) and 54.6 (c, d, e) cm. The electrodes placed at the top.

The following main properties of the plasma jets are evident from obtained experimental data. As one would expect, the increasing of voltage pulse amplitude leads to apokamp length increasing (Fig. 3 (a, b)). The pressure relief leads to increasing of apokamp length and diameter (Fig. 3 (c, d, e)). At elevated pressure values are clearly visible two parts of plasma jet. The first part is the bright reddish branch connected to discharge channel, and the second one is blue color jet (Fig. 3 (e)). The diameters of these parts are the same. It should be noted that the natural color of the sprites is also changed from red to blue during their propagation to the Earth [5, 15].

Figure 4 show the apokamp emission spectrum in logarithmic scale. The second positive system spectral band of nitrogen have maximal intensity. Visually we observe a blue color. Although at low-pressure values the second positive system band intensity is much more than the first positive system, visually the color of the apokamp at low pressures is red.

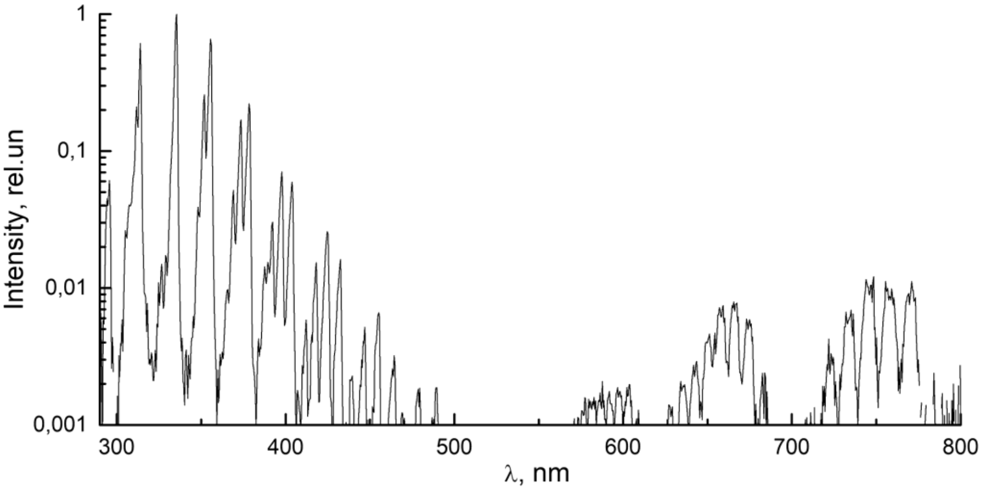


**Figure 4.** Apokamp spectrum in air at p = 0.1 Torr.

We are going to continue our studies and plan to increase the discharge chamber height (of a meter in size) and create a physical model that will describe the color, shape, and velocity of plasma jets.

## 4. Conclusion

To summarize, the possibility of red sprites and blue jets analogues forming in laboratory conditions was demonstrated. Red mini sprites and mini blue jets (apokamps) were obtained at voltages of units-tens kV by the use of pulse-periodic discharge with a pulse duration of positive polarity FWHM of 1.5 μs. The downward directed red color apokamps has been formed. The apokamp color depends on air pressure and changed from blue at elevated pressures to red when the pressure units of Torr. Moreover, at the same pressure the apokamp color varies lengthwise from red to blue when the distance from electrodes increase.

## 5. Acknowledgments

The work is performed in the framework of the State task for HCEI SB RAS, project #13.1.3.

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