# Diagnostics of hollow cathode low pressure air discharges as a tool for understanding Halo spectral features in the Earth mesosphere

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Low pressure dc air discharges produced in a hollow cathode reactor are studied by emission spectroscopy in the near UV- near IR spectral range, quadrupole mass spectrometry, and a double Langmuir probe. Several emission spectral bands of $N_2$ and $N_2^+$ are analysed in order to obtain the gas temperature, whereas mass spectrometry is employed to observe the production of nitrogen oxides, and the Langmuir probe provides charge densities and electron temperatures. The spectroscopic results are compared with theoretical models developed to study halo emissions from TLEs in the upper atmosphere.

## 1. Introduction

Hollow cathode discharges are characterized by the homogeneous low temperature plasmas that they produce, which span uniformly through the whole negative glow volume, where the electric field is negligible. In the past, these discharges have been used with different geometries and cathode dimensions to study low pressure air plasmas over different pressure ranges, covering the interval ~ 0.5 - 100 Pa [1,2].

On the other hand, the spectroscopic analysis of transient luminous events (TLE) occurring in the upper atmosphere at different altitudes and under varied conditions, and its comparison with model predictions [3], are at present issues of increasing interest. They are expected to provide key information on the kinetic mechanisms which determine some of the characteristics of these events.

Current TLE studies can benefit much from measurements on laboratory plasmas, which can be of help in the optimization of diagnostic techniques for field investigations. Laboratory data can also be useful for the validation of model assumptions, although the differences between laboratory and TLE plasmas should be taken into account carefully.

In this work, a hollow cathode reactor has been employed to measure the emission spectra of several bands of $N_2$ and $N_2^+$ air discharges at low pressures in the spectral range extending from near UV (275 nm) to near IR (1100 nm) in order to compare with those proceeding from halos occurring in the mesosphere of the Earth between 75 km and 85 km. From the analysis of these spectra, the gas temperature can be inferred. Charge densities and electron temperatures have been obtained with a double Langmuir probe. Additionally, quadrupole mass spectrometry has allowed to test the formation of stable plasma products.

## 2. Experimental set-up

The hollow cathode reactor (Fig. 1) is described elsewhere [1]. It has a symmetrical electrode geometry and consists of a cylindrical hollow cathode of stainless steel (16 mm inner diameter, 90 mm length), and two circular copper anodes placed at the ends of the cathode, supported by Pyrex holders. The electrodes are water cooled. The cell has a modular configuration, suitable for emission spectroscopy, mass spectrometry and electrical probes, with just the proper selection of the different adaptors or windows to be employed at its two ends. A needle valve at the gas input, and a rotary pump with a regulating valve at the exit allow the control of the discharge pressure (~ 7 - 100 Pa) and flow rate. It is fed by a 2000 V, 200 mA dc source.

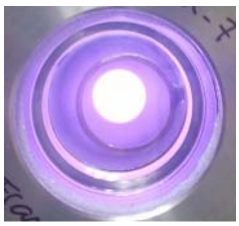

**Figure 1.** Photograph of the discharge.

Emission spectra are obtained with two dispersive spectrometers depending on the required spectral resolution, a Jovin-Ybon high resolution spectrometer, model FHR1000 with CCD and photomultiplier, and a low resolution Ocean Optics spectrometer, model QE65000. Mass spectrometry is performed with a Balzers Prisma-200 quadrupole mass spectrometer with electron impact ionization. This spectrometer is located in a differentially pumped vacuum chamber connected to the discharge trough a 100 μm diaphragm. A double Langmuir probe, made in the laboratory, is used for the estimate of electron temperatures and densities.

## 3. Results

Figs. 2 and 3 display raw (uncalibrated for instrumental efficiency) preliminary spectra of air discharges taken with the Ocean and the Jovin-Ibon spectrometers, respectively.

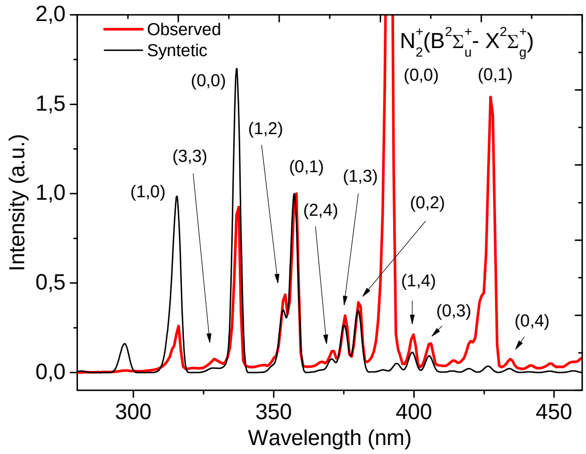


**Figure 2.** Normalized emission spectra of an air laboratory dc discharge (55 mA, 480 V) at 20 Pa (corresponding to aprox. 65 km altitude), acquired with the Ocean spectrometer (spectral resolution = 2 nm) (red-wide line) and simulated with the same resolution for halos at a gas temperature of 220 K (black-narrow line). Most of the observed bands are assigned to the second positive system of $N_2$. The (0,1) transition of this system at 357.6 nm was used to normalize the signal intensity. Transitions corresponding to the first negative system of $N_2^+$ are also present. Apart from the indicated $N_2^+$ vibrational transitions (0,0) and (0,1), there are weaker contributions from the $N_2^+$ transitions (4,3), (3,2), (2,1) and (1,0) in the 353.6 - 358.3 nm range.

Previous estimations by IR absorption spectroscopy in analogous discharges [1] rendered gas temperatures of ~ 300 K (about 25 % higher than the gas temperature typical at halo altitudes). In this work we intend to use (after a careful calibration of the equipment) line emission intensities of different vibro-rotational bands of the first and second positive systems of $N_2$ in combination with synthetic spectra and a kinetic model of air plasmas [4,5] for the estimation of gas temperatures and vibrational distribution functions (VDF) of $N_2(B^3\Pi_g)$ and $N_2(C^3\Pi_u)$ in air plasmas generated in conditions that could approximately mimic spectroscopic features recorded in halos. In this way, we will assess in the lab the procedure later to be used for field spectral recording of halos and sprites using the instrument GRAnada Sprite and Polarimeter (GRASP).

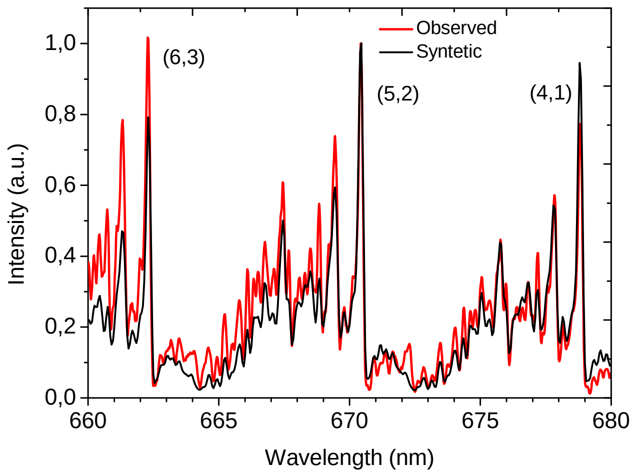


**Figure 3.** Normalized emission spectra of an air laboratory dc discharge (60 mA, 480 V) at 60 Pa (corresponding to aprox. 60 km altitude) recorded with the Jovin-Ibon spectrometer with a spectral resolution ~ 0.1 nm, with the CCD detector and a slit width of 250 μm, (red-wide line) and simulated for halos at a resolution of 0.14 nm and a gas temperature of 220 K (black-narrow line). The assignments of the most intense lines of the first positive system of $N_2$ are indicated. The transition at 662.3 nm was used to normalize the signal intensity. A red filter was employed to eliminate second order lines in the experimental spectrum.

Electron temperature and charge density, measured with the double Langmuir probe, provides values of 2.3 ± 0.5 eV and $(1.0 \pm 0.2)\cdot 10^{11}$ $cm^{-3}$ respectively for the conditions of Fig. 1, that is, ionization ratios of ~ $10^{-5}$ are found.

Analysis of the results and comparison with the conditions of halos is in progress.

## 3. References


[1] M. Castillo, V. J. Herrero, I. Méndez, I. Tanarro. Plasma Sources Sci. Tech. **13** (2004) 343.

[2] M. Castillo, I. Méndez, A. M. Islyaikin, V. J. Herrero, I. Tanarro, J. Phys. Chem. A, **109** (2005) 6255.

[3] F. J. Gordillo-Vázquez, A. Luque, M. Simek, J. Geophys. Res. 116 (2011) A09319.

[4] F. J. Gordillo-Vázquez, J. Phys. D, **41**, (2008) 234016.

[5] F. J. Gordillo-Vázquez, J. Geophys. Res: Space Phys. **115** (2010), A00E25.