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Spectroscopic diagnosis of laboratory air plasmas as a benchmark for spectral diagnosis of TLEs

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Abstract

Laboratory low pressure (0.1 mbar ≤ p ≤ 2 mbar) glow air discharges are studied by optical emission spectroscopy to discuss several spectroscopic techniques that could be implemented by field spectrographs, depending on the available spectral resolution, to experimentally quantify the gas temperature associated with Transient Luminous Events (TLEs) occurring at different altitudes including blue jets, giant blue jets and sprites.

Laboratory air plasmas have been analysed from the near UV (300 nm) to the near IR (1060 nm) with high (up to 0.01 nm) and low (2 nm) spectral resolution commercial grating spectrographs and by an in-house developed intensified CCD grating spectrograph (GRASSP) recently developed by our group (www.trappa.es) at IAA-CSIC for TLE spectral diagnostic surveys with ≤ 0.45 nm spectral resolution. We discuss the results of lab tests and comment on the convenience of using one or another technique for rotational (gas) temperature determination during TLE spectroscopic campaigns.

1. Introduction

The ocurrence of different types of TLEs in the Earth's upper atmosphere can contribute to the heating of the surrounding air. In particular, air heating is possible in different layers of the atmosphere in streamers of sprites [1], giant blue jets and blue jets as well as in the streamer to leader transition in the bottom of blue jets and giant blue jets [2]. Therefore, the chemistry and electrical properties of the atmosphere can be influenced by these "hot spot" regions associated with TLE activity.

The aim of this investigation is to use 3 different methods of gas temperature determination using optical spectral diagnosis of air plasmas produced under laboratory conditions similar to the most common TLEs (halos and sprites). Lab spectral diagnosis will also allow us to derive the vibrational distribution function (VDF) of key excited molecular species like $N_2(B^3\Pi_g)$ (responsible of TLE optical emissions) and to compare them with $N_2(B^3\Pi_g)$ VDF derived from observed sprites [3]-[4] and from recent theoretical predictions of $N_2(B^3\Pi_g)$ VDF in halos and sprites [5]-[8].

The lab recorded spectra were also used as a test for the GRAnada Sprite Spectrograph and Polarimeter (GRASSP) instrument in order to start spectroscopic field campaigns of TLEs in Spain as ground support of the Atmosphere Space Interaction Monitor (ASIM) and the Tool for the Analysis of RAdiation from lightNIng and Sprites (TARANIS) missions of, respectively, the ESA and CNES, to be launched in late 2015.

2. Experimental set up

The experimental set up is a hollow cathode discharge with cylindrical electrode geometry and consists of a grounded stainless steel hollow cathode, 16 mm inner diameter, 90 mm long, and two circular copper anodes, placed symmetrically at the ends of the cathode (see Figure 1) to ensure the uniformity and extension of the negative glow along the whole cathode length. The total volume of the cell is 130 cm^3 and the electrodes are refrigerated by circulating water. Plasma currents of 20 - 100 mA and DC voltages between 350 V and 450 V were applied during the present experiments. Complete emission spectra of the air plasmas were recorded in the 300-1060 nm wavelength range.

The light emitted by the discharge was transmitted by an optical fibre imaged on the entrance slit spectrometer with spectral resolution spanning from

0.006 nm to 0.13 nm, depending on the slit widths, grating and detector used.

In order to test GRASSP, the spectra of three different commercial lamps of N_2, air and Ne at 0.2 mbar were used. The spectra obtained from these commercial lamps were corrected by the instrument spectral sensitivity response function and compared to the spectra of air plasmas produced in DC hollow cathode reactors under similar gas pressure (0.23 mbar) to check the instrument reliability.

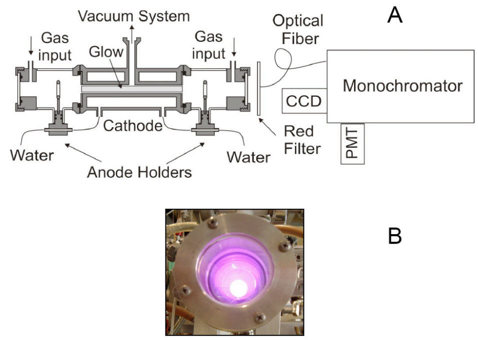

Figure 1: Experimental set up (panel A) of the DC hollow cathode discharge used for spectroscopic diagnosis and an image (panel B) of the generated air plasma where a more intense pink light emission can be seen in the center of the discharge.

3. Results

The rotational (gas) temperatures measured in glow discharges produced in DC hollow cathode reactors are almost the same (410 K-320 K, depending on the pressure used) when the two methods employing $N_2(B^3\Pi_g)$ as the probing species are used. Higher temperatures (with a maximum difference of 100 K at 2 mbar or 45 km altitude) are found when $N_2^+(B^2\Sigma^+_u)$ is tracked.

The gas temperatures obtained by GRASSP in the air commercial lamp discharges (at 0.2 mbar or 60 km altitude) were around 680 K. In addition, the partial N_2 1 PG spectrum recorded by GRASSP in air commercial discharge lamps exhibit the same features as the spectrum obtained with commercial spectrographs in air hollow cathode discharges. This result supports the reliability of GRASSP for TLE field spectroscopic recordings.

Acknowledgements

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