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Astronomical radio-reception techniques for emission spectroscopy of molecular and short lived species in cold plasmas

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In this work we describe the proof of concept of the use of standard radio-astronomy receivers to conduct emission spectroscopy of different molecular precursors and products at room temperatures in low pressure plasmas. The goal is to obtain in laboratories valuable spectroscopic information on rotational transitions of molecular species of astrophysical interest at high spectral resolution. An inductively coupled RF discharge was employed to generate the plasma. OCS, CS_2 and O_2 were used as plasma precursors. The experiment was performed with the 33-50 GHz band HEMT detector available in the Observatory of Yebes (Spain), where the beam of its radio-telescope of 40 m diameter pointing towards the zenith was used as cold emission background.

1. Introduction

With the increasing use and continuous development of powerful radio-telescopes (like ALMA), spectral line surveys at mm and sub-mm wavelengths have enhanced tremendously the detection of stable molecules and transient species in interstellar molecular clouds and other astronomical regions. Evaluation of these data takes great advantage of laboratory information on the spectral fingerprints and reactivity of these species. In this work we describe the successful joint use of standard radio-astronomy High Electron Mobility Transistor (HEMT) receivers and plasma reactors for laboratory simulations of astrophysical observations.

2. Experimental set-up

The plasma was produced in a 25 cm diameter, 42 cm length SS vacuum chamber by an inductively coupled RF discharge (13.56 MHz) through a refrigerated Cu coil inserted axially. Upilex windows of 75 μm thickness were placed at both ends of the chamber. A differentially pumped mass spectrometer was used to identify the plasma precursors and stable products. Gas pressures ~ 10-30 Pa allowed stable plasma operation and produced similar column densities to those of typical interstellar clouds.

The radio-receiver operated in the 33-50 GHz spectral band, with 2 GHz bandwidth and 38 kHz spectral resolution. Data were acquired with a Fast Fourier Transform Spectrometer. A frequency switching method for background subtraction was used for stable gas detection, whereas turning on and off the plasma was most convenient to detect short lived species. Depending on the weather conditions, the background for emission measurements came from the antenna of the radio-telescope pointing towards the zenith (clear blue sky) or from a blackbody load of liquid N_2 (cloudy or rainy weather), implying 42 K or 77 K, respectively, at 45 GHz spectral frequency.

3. Results

OCS was selected for preliminary gas detection in the observing emission band, displaying maximum equivalent radiation temperatures of ~ 4 K. At the lowest pressure (5 Pa), its linewidth was due in part to thermal broadening and at the highest one (60 Pa), it was dominated by pressure broadening. OCS and CS_2 were selected as plasma precursors of the CS radical, which emits also in this region. It was routinely detected in different plasma conditions, with equivalent temperatures up to 3 K. O_2 discharges applied after sulphur deposition on the reactor walls by the previous S rich containing OCS and CS_2 plasmas allowed the surface generation of SO_2 and the detection of its rotational transitions in different bending vibrational states, v_2 = 0,1,2, the intensity of the transitions from upper levels increasing with discharge power.

The RF discharge didn't induce any electromagnetic spurious signals in the receivers, and astronomical detection of a SiO maser in the AGB star TX Cam showed identical results with plasma on and off.

In conclusion, these experiments confirm the viability of using standard radio-astronomy receivers to detect molecular and short lived species in gas simulation chambers based on plasma reactors.