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

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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 receivers and plasma reactors for laboratory simulations of astrophysical observations.

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 (see Figure 1). 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.

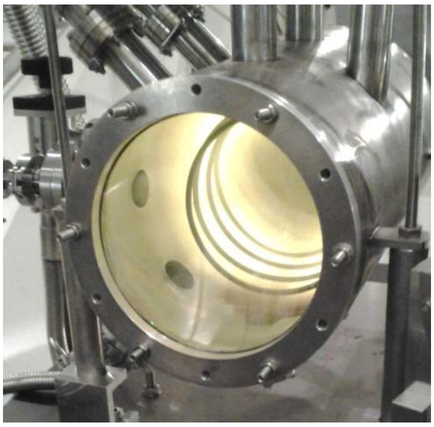

Figure 1. Image of the reactor. The colour of the plasma is determined by the optical transmission of the brown Upilex windows.

The radio-receiver operated in the 41-49 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.

Results

OCS was selected for preliminary gas detection in the observing emission band, displaying maximum equivalent radiation temperatures of ~ 3 K at 0.3 mbar (applying the Rayleigh-Jeans approximation to the line flux I_ν and using a brightness temperature, T_B, so that $I_\nu(T) = 2\nu^2 k_B T_B/c^2$).

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 (Figure 2, left). 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 (Figure 2, right).

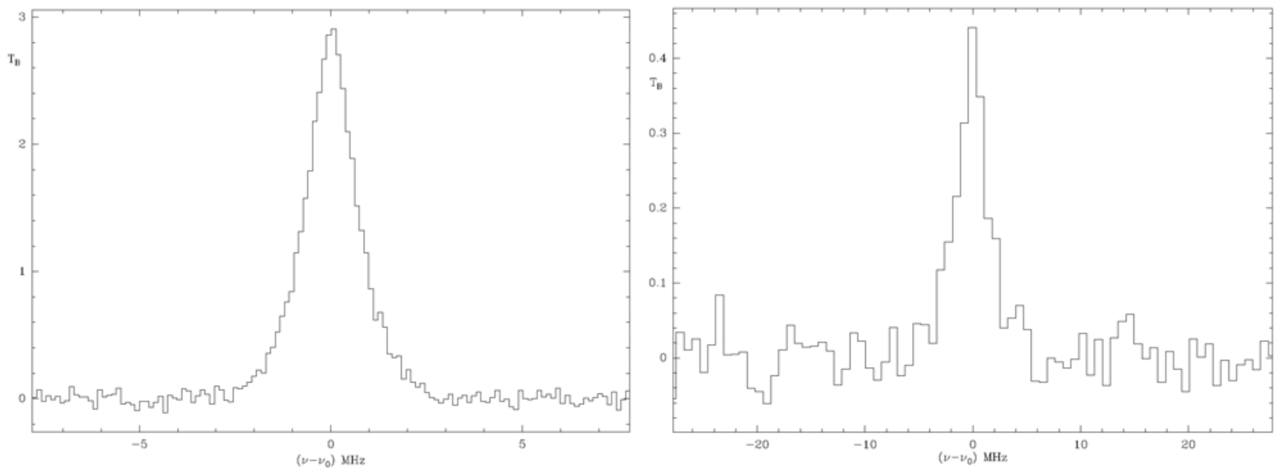

Figure 2. Left: Observed CS J=1-0 signal (centered at 48990.957 MHz) at 0.15 mbar and 50W, OCS plasma. The integration time was 2 min. The spectral resolution is 160 kHz. Right: Observed SO_2 $14_{2,12}$-$13_{3,11}$ signal (centered at 47913.427 MHz) during the cleaning of the cell through an O_2 plasma at 0.1 mbar, 50 W. The integration time was 5 min. The derived partial pressure of SO_2 is 0.04mbar.The spectral resolution is 640 kHz.

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 [1].

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References

[1] I. Tanarro et al, *Astronomy & Astrophysics*, submitted.