Astronomical radioreception techniques to detect the emission of molecular and short lived species in a cold plasma/gas chamber

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In this work we prove the viability of the use of standard radioastronomy receivers to detect rotational spectral lines emitted at room temperatures by different molecular precursors and plasma products introduced or generated in a low pressure plasma chamber, placed in the beam path of the 40 m Yebes observatory radiotelescope.

The selected radioreceiver operates in the 41-49 GHz (Q) band. In the present case, right and left circular polarization signals were sampled over 500 MHz bandwith. The data acquisition was performed with a Fast Fourier Transform Spectrometer. Spectral resolution was 30 kHz. A frequency switching method for background subtraction proved to be more practical and time saving for stable gas detections than a chamber filling and evacuating procedure, whereas turning on and off the plasma was the most convenient method for the detection of short lived species. Depending on the weather conditions, the background for emission measurements came from the antenna pointing towards the zenith (clear blue sky) or from a near blackbody load at liquid N_2 temperature (cloudy or rainy weather), implying 42 K or 70 K temperatures, respectively, at 45 GHz.

The plasma was produced in a cylindrical, 25 cm diameter, 42 cm length, stainless steel vacuum chamber by an inductively coupled (5 - 60 W, 13.56 MHz) RF discharge, stablished through a refrigerated copper coil (4 turns, 10 cm length, 17 cm diameter) inserted axially and located where the gaussian beam of the receivers narrows to its minimum width. Windows of 75 μm thickness × 22 cm diameter made of Upilex were placed at both ends of the chamber at slightly divergent planes to avoid standing waves. A differentially pumped quadrupole mass spectrometer (0-100 amu) allowed to identify the stable species introduced or generated during the on/off plasma intervals and follow their time evolution. Gas pressures of ≈ 0.7-90 Pa produced similar column densities to those of a typical interstellar cloud $\approx 10^{17}$ cm^{-2}. A pressure range of ≈10-30 Pa at gas flow conditions proved to be more appropriate during plasma operation.

OCS and CH_3OH, which have quite different line intensities, were selected for static gas detection in the observing emission band, displaying maximum equivalent radiation temperatures of ≈ 4 K for carbonyl sulfide and 0.3 K for methanol. In the lower pressure regime, the linewidths were mainly due to thermal broadening and at high pressure they were dominated by pressure broadening. OCS and CS_2 were selected as plasma precursors of the CS radical, which emits also in the 41-49 GHz region and was regularly detected at different plasma conditions, with equivalent temperatures up to 3 K. O_2 discharges applied after sulfur deposition in the reactor walls by the previous S rich containing plasmas allowed to generate SO_2 by heterogeneous plasma processes and detect its rotational transitions in different vibrational (bending) states v2 = 0,1,2; the intensity of the transitions from upper levels increasing with discharge power. With the plasma ON no spurious signals were induced in the resulting spectra from electromagnetic coupling of the RF discharge with the IF signal generated by the receivers. Radioastronomical observations of a SiO maser in TX Cam have shown identical results with the plasma ON or OFF.

In conclusion, these proof of concept experiments confirm the applicability of standard radioastronmy receivers to detect molecular and short lived neutrals in plasma reactors and gas simulation chambers.