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CO IN THE ATMOSPHERES OF SATURN AND URANUS. OBSERVATIONS AT MILLIMETER AND SUBMILLIMETER WAVELENGTHS.

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Abstract. An external supply of oxygenated compounds exists in outer planets. Carbon monoxide has been detected in each giant planet. The source of CO has been proved to be dual (internal and external) in Jupiter and Neptune, but this is still unclear in the case of Saturn and Uranus. Therefore, constraining the amount of CO in the troposphere and stratosphere of these planets would help solve this problem. We performed observations of Saturn and Uranus at millimeter and submillimeter wavelengths in the CO (1-0), (2-1) and (3-2) lines. Observations were carried out with the IRAM 30-m telescope (Pico Veletta, Spain) in September 2006 and with the JCMT 15-m telescope (Hawaii, USA) in January 2008. We have recorded broad multi-band spectra of each planet. The results of these observations are presented and discussed.

1 Introduction

Water and carbon dioxide have been detected in the stratosphere of the outer planets (Feuchtgruber et al. 1997, 1999; Lellouch et al. 1997; Burgdorf et al. 2006). The large abundances detected above the tropopause cold trap implied an external supply for these compounds (Moses et al. 2000; Lellouch et al. 2002). The possible external sources are interplanetary dust particles (IDP), large comet impacts and local sources (rings and satellites).

Carbon monoxide has been detected in the atmospheres of the outer planets (Beer 1975; Noll et al. 1986; Encrenaz et al. 2004; Marten et al. 1993). The question of the origin of CO is more complicated to address because this compound does not condense at the tropopause of the giant planets. So, convective transport can bring CO from the deep interiors of the planets to the shallow atmosphere. Therefore, CO can be of internal and/or external origin. It is thus important to reliably measure the relative contributions of the internal and external sources of CO. A way of achieving these measurements is to observe independently the CO abundance in the troposphere and in the stratosphere.

Bézard et al. (2002) and Lellouch et al. (2005) have shown that there is an internal and an external source of CO on Jupiter and Neptune (respectively). In the atmospheres of Saturn and Uranus, the situtation is still unclear. The CO has been detected in the infrared range on both planets. From the latest published data, Noll & Larson (1991) could not distinguish between a internal source (1-ppb, uniform with altitude) and an external source (25-ppb above the tropopause). In the atmosphere of Uranus, Encrenaz et al. (2004) favored an external origin (30-ppb above the tropopause) but could not rule out an internal source (upper limit of 20-ppb, uniform with atitude). To better constrain the origin of CO, we have observed the J=1 $\rightarrow$ 0, J=2 $\rightarrow$ 1 and J=3 $\rightarrow$ 2 transitions of CO in the atmospheres of Saturn and Uranus, using the IRAM (Institut de RadioAstronomie Millimétrique) 30-m telescope and the JCMT (James Clerk Maxwell Telescope) 15-m telescope. The observations are presented in Sect. 2. Our radiative transfer model is described in Sect. 3. Preliminary results are given in Sect. 4.

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CO line	Single band width [GHz]	Tunings [GHz]
(1-0)	0.5	114.503, 114.887, 115.271
(2-1)	1.0	229.002, 229.770, 230.538, 231.306, 232.074
(3-2)	1.0	343.545, 344.045, 344.545, 345.045, 345.545
		346.045, 346.545, 347.045, 347.545, 348.045

Table 1. Tunings used during the observations of Saturn and Uranus as a function of the observed line. The width of each sub-band is also given.

2 Observations

Saturn and Uranus were observed at the frequency of the CO (1-0) and (2-1) lines with the IRAM 30-m telescope in September 2006. Besides, we observed the CO (3-2) line in the atmosphere of Saturn with the JCMT 15-m telescope in January 2008. Because synthetic computations predict that the lines are broad, we used Lellouch et al. (2005) observing technique. It consists in observing a large frequency range (3 to 5-GHz) by using multiple short integrations of 0.5 to 1-GHz sub-bands with significant overlaps between contiguous sub-bands. The different tunings which have been set are given in Table 1. The initial spectral resolution was 1-MHz. The observations have been carried out with heterodyne receivers in wobbler or position switching mode. The (1-0) line could not be explored beyond 115.5-GHz because of the presence of the terrestrial O_2 line. Contrary to the IRAM observations, observations of Mars have also been carried out at the same time as the observations of Saturn with the JCMT antenna in order to obtain an absolute calibration of the spectrum in terms of brightness temperature. So the IRAM observations are interpreted in terms of line-to-continuum ratios whereas the JCMT spectrum is interpreted in terms of absolute brightness temperature.

Before connecting the sub-bands together, each one was reduced individually. The ripples which appear on every sub-bands of one spectrum have been removed by a Fourier analysis and a polynomial baseline subtraction. Then, the sub-bands have been reconnected by averaging them on their overlaping parts and rescaled one to another. Finally, the spectral resolution has been smoothed to 16-MHz on each spectrum to decrease the noise level.

The CO is not detected on the IRAM spectra whereas an absorption feature is detected on the JCMT spectrum of Saturn. Thus, 3-σ upper limits have been determined from the IRAM spectra and simple CO vertical distributions have been tested in the case of the JCMT spectrum.

3 Modeling

Synthetic spectra have been computed with a standard 1D line-by-line non-scattering radiative transfer model, which accounts for the approximate spherical geometry of the planets. The planetary disk and limb contributions were taken into account. More details (opacity sources, thermal profiles) are given in Cavalié et al. (2008).

Two kinds of vertical distributions of CO have been tested. The first one (Type I hereafter) is modeled with two parameters: q_{CO} and the level below which q_{CO} is set to 0, noted p_0. This distribution reflects an external source. When fixing upper limits, the p_0 level is fixed to the tropopause level ($p_0 \sim$100-mbar). The second one (Type II) consists in a uniform distibution with altitude. This distribution reflects an internal source. The only parameter which has to be fixed is the CO mixing ratio q_{CO}.

4 Preliminary results

4.1 Upper limits

Because no absolute calibration has been performed on the IRAM spectra and because the rings do not contribute significantly to the total flux, the ring contribution has been neglected when modeling the (1-0) and (2-1) CO lines. The spectra which lead to the best upper limits are the spectra centered on the CO (2-1) line.

The upper limits derived from the IRAM observations of Saturn and Uranus are given in Table 2. The upper limits derived from the observation of Saturn improve the previously published ones (Rosenqvist et al. 1992) but are far from the detection level of Noll & Larson (1991). The values obtained in the case of Uranus are

	Saturn			Uranus		
Telescope	CO distribution	CO origin	q_{CO}	CO distribution	CO origin	q_{CO}
IRAM 30-m	Type I (p_0=100-mbar)	External	$<6.3\times10^{-8}$	Type I	External	$<2.7\times10^{-8}$
	Type II	Internal	$<3.9\times10^{-8}$	Type II	Internal	$<1.8\times10^{-8}$
JCMT 15-m	Type I (p_0=16-mbar)	External	2.5×10^{-8}			

Table 2. Upper limits derived from the 230-GHz spectra of Saturn and Uranus observed with the IRAM 30-m telescope (Cavalié et al. 2008) and detection level in the atmosphere of Saturn from the 345-GHz JCMT observations.

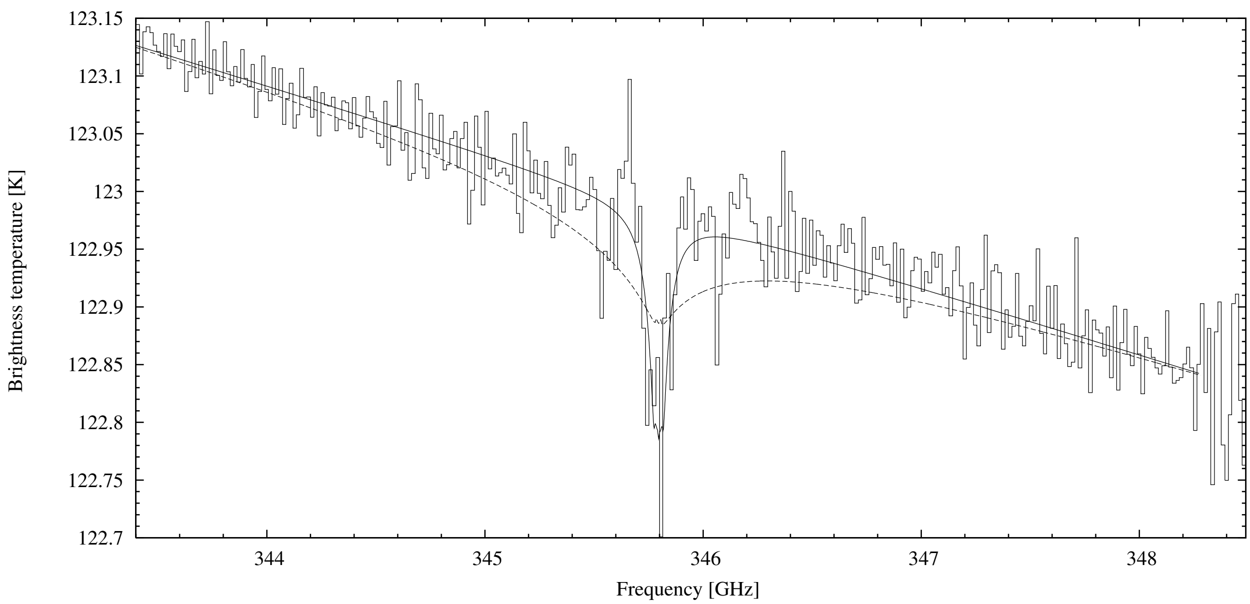

Fig. 1. Observed spectrum of Saturn at 345-GHz. The CO (3-2) line is detected. Solid line: best fit model with a Type I distribution (q_{CO}=2.5×10^{-8} and p_0 = 16-mbar); long-dashed lines: best fit model with a Type II distribution (q_{CO}=1×10^{-9}).

consistent with previously published upper limits (Marten et al. 1993) but are slightly lower than the detection level of Encrenaz et al. (2004).We suggest that their detection level might have been slightly overestimated from their modeling.

4.2 Absolute brightness temperature of Saturn at 345-GHz

The observations of Saturn with the JCMT telescope at 345-GHz have been calibrated by observing Mars at the same time. Following Griffin et al. (1986) and using Ulich (1981) and Wright (1976), the brightness temperature of Mars at the time of the observations is 205.5±5.7-K at 345-GHz. From this value, we can determine the brightness temperature of Saturn at 345-GHz. We obtain:

$$T_b = (123 \pm 13)\ \mathrm{K}$$

This measurement gives a new absolute determination of Saturn brightness temperature in the submillimeter range. The ring inclination angle was 7°.

4.3 Detection of the CO (3-2) line at 345-GHz in the spectrum of Saturn

The CO (3-2) line has been detected from our observations of Saturn (see Fig. 1). The line contrast has an uncertainty of a factor of 2 because of the data reduction scheme. If we use the Noll & Larson (1991) CO

Type I distribution (q_{CO}=2.5×10^{-8} and $p_0 \simeq$ 100-mbar), we obtain an absorption which is too large. The best fit model is computed by adjusting the p_0 level to 16-mbar. By testing the Type II distribution, we only obtain a rough fitting of the observed line. The absorption feature obtained is too broad.

The main result of these observations are the derival of new upper limits on the CO mixing ratio in the atmospheres of Saturn and Uranus from millimeter observations (Cavalié et al. 2008) and the detection of the CO (3-2) line in the atmosphere of Saturn. This observation confirms the detection of CO in the infrared. The values of the CO mixing ratio we derive from this observation are consistent with Noll & Larson (1991). They also permit to better constrain the p_0 level of the simplified Type II vertical distribution. From our observations, we favor an external origin for CO in the atmosphere of Saturn, but new observations should be performed to directly measure the CO abundance in the stratosphere of the planet. Moreover, photochemical modeling of the supply of oxygenated compounds to the atmosphere of Saturn should provide more realistic vertical profiles to test and compare with this observation.

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