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Search for ammonia in comet C/2012 S1 (ISON)

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Abstract

Comets are pristine bodies and their studies can give precious hints on the formation of the Solar System. New comets originated from the Oort Cloud are at their first passage close to the Sun. They are particularly important because they are not differentiated by the solar radiation and they are supposed to have a large quantity of organic matter close to the surface. Here we report the results of a search for NH₃(1,1) emission at 23.7 GHz towards comet C/2012 S1 (ISON) using a new dual-feed K band receiver mounted on the Medicina 32-m antenna. We observed the comet close to its perihelion, from 2013 Nov. 25 to Nov. 29, when its heliocentric distance changed from 0.25 AU to 0.03 AU. We derive an upper limit of Q(NH₃) of about 2.5×10^{29} mol s⁻¹ on November 26, that is consistent with the last peak of water production rate of $\sim 2 \times 10^{30}$ mol/sec within the last few days before the perihelion.

Keywords:

comets: individual: C/2012 S1 (ISON), techniques: radio observations, ISM: molecules

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1. Introduction

Comet C/2012 S1 (ISON), hereafter ISON, was discovered on 21st September 2012 when it was at an heliocentric distance of $R_H = 6.3$ AU by the Russian and Biellorussian astronomers using a reflecting telescope of the International Scientific Optical Network (ISON) near Kislovodsk. Its orbit was parabolic with an inclination of 62.4° with respect to the ecliptic plane, thus it was classified as a new comet coming from the Oort cloud. Comet ISON was particularly important because it was a Sun-grazing comet which passed (for its first time) very close to the Sun, at about $q=0.012$ AU on 28th November 2013. The comet also passed at 0.072 AU from Mars on 1 October 2013 and at 0.42 AU from Earth on 26th December 2013.

Comet ISON showed a strong activity at high heliocentric distances that, together with the close passage to the Sun, indicated a supposed exceptional brightness at perihelion. For this reason, NASA organized the CIOC (Comet ISON Observing Campaign)¹ to create a massive net of observations from space to ground-based, from professionals to amateurs, to follow this fresh comet. Many space-based observatories, as for example the Hubble and Spitzer Space Telescopes, the EPOXI spacecraft, the SOHO (NASA/ESA) satellite and many planetary missions, including MESSENGER, JUNO and Venus Express that were not designed to study comets, were adapted to take observations of comet ISON as it performed its passage into the inner Solar System. Together with space observations, many ground-based observations of ISON were performed from the main observatories around the world. Results of the observing campaign were reported in Lisse et al. (2014).

Many molecular lines were observed. CO emission at 230.5 GHz was observed in March 2013 at $R_H=4.45$ AU by O' Rourke et al. (2013) who derived $Q(\text{CO})=3.5 \times 10^{27}$ mol s⁻¹. HCN, HNC, HCO⁺ and CH₃OH were detected by Agúndez et al. (2014), and a detailed description of water production rate was reported by Bonev et al. (2014). The $Q(\text{H}_2\text{O})$ was deduced during the observations from 17th to 22th of November 2014, from 0.53 to 0.35 AU from the Sun, where $Q(\text{H}_2\text{O})=1.75 \times 10^{29}$ and 4.01×10^{29} mol s⁻¹ respectively. Finally, in the optical wavelength region from 5500 to 8200 Å, NH₂ was detected during the last outburst on 14th November 2014 (Shinnaka et al. 2014). NH₂ is the main product of photodissociation of ammonia (NH₃), directly released from the cometary nucleus (Huebner et al. 1992). NH₃

¹<http://www.isoncampaign.org/>

detection in the IR was reported by Di Santi et al. 2014 and by Dello Russo et al. 2014.

2. Ammonia in comets

Ammonia is expected to be among the more abundant volatile parent molecular constituents of cometary nuclei (Bockelée-Morvan et al. 2004), with a relative abundance with respect to H₂O of 1% (Charnley & Rodgers 2002, Mumma & Charnley 2011). Given that the NH₃ (1₀ - 0₀) fundamental rotational transition occurs in a submillimeter spectral region not accessible from ground, an alternative way to detect ammonia comes from its inversion transitions, as the NH₃(1,1) and NH₃(2,2), at 23.7 GHz (e.g. Ho & Townes 1983). Historically, ammonia in comets at 23.7 GHz was detected with the MPIfR Effelsberg telescope in C/1983 H1 (Altenhoff et al. 1983) and C/1995 O1 Hale-Bopp (Bird et al. 2002) and with the NRAO Green Bank antenna in C/1996 B2 Hyakutake (Palmer et al. 1996). The estimate NH₃/H₂O abundance ratio in comet Hale-Bopp was 1%-2%, a value consistent with the in situ value of 1.5% measured during the flyby of the Giotto spacecraft around Halley comet (Meier et al. 1994). However, Hatchell et al. (2005) searched for NH₃ emission using Effelsberg antenna towards four comets: C/2001 A2 (LINEAR), 153P/ Ikeya-Zhang, C/2001 Q4 (NEAT) and C/2002 T7 (LINEAR) but no detection was reported, questioning the theoretical predictions. They derived the following 3σ upper limits on ammonia production rate: $Q(\text{NH}_3) < 1.9 \times 10^{26} \text{ s}^{-1}$ for C/2001 A2 (LINEAR), $Q(\text{NH}_3) < 2.7 \times 10^{26} \text{ s}^{-1}$ for C/2001 Q4 (NEAT), $Q(\text{NH}_3) < 2.3 \times 10^{27} \text{ s}^{-1}$ for C/2002 T7 (LINEAR), and $Q(\text{NH}_3) < 6.3 \times 10^{26} \text{ s}^{-1}$ for 153P/ Ikeya-Zhang. Finally, Biver et al. (2012) detected ammonia towards comet 10P/Tempel 2 thanks to the Herschel satellite, and measured a fractional abundance of 0.5%.

3. Dual-feed K-band received at the Medicina antenna

Observations of NH₃(1,1) emission at 23694 MHz towards the comet ISON were performed at the Medicina antenna (Bologna, I), managed by IRA (Institute for Radio Astronomy), part of INAF (National Institute for Astrophysics). The 32-m antenna dish operates in the range of about 1-26 GHz. We used a 4096-channel autocorrelator with a maximum instantaneous bandwidth of 160 MHz and a maximum resolution of 40 Hz.

The present observations were performed from 25th to 29th of November 2013 (Table 1). A K-band dual beam receiver was used. The angular resolu-

DATE (UT) dd/mm/yy	RA <i>hms</i>	DEC ° ' "	R _H AU	Δ AU	Δ̇ km/s
25/11/2013					
7:00	15 06 11.27	-20 24 55.8	0.24	0.88	28.55
15:00	15 11 41.70	-20 46 38.8	0.22	0.89	32.41
26/11/2013					
7:00	15 23 07.05	-21 27 24.8	0.19	0.91	39.52
15:00	15 29 01.95	-21 46 08.9	0.17	0.91	44.52
27/11/2013					
7:00	15 41 32.51	-22 19 16.0	0.13	0.93	55.17
15:00	15 48 14.53	-22 32 42.4	0.11	0.94	63.13
28/11/2013					
7:00	16 03 36.07	-22 46 16.5	0.06	0.97	86.07
15:00	16 13 51.74	-22 28 48.9	0.02	0.99	97.24
29/11/2013					
7:00	16 23 04.54	-18 32 56.5	0.06	0.95	-119.74
11:00	16 22 42.64	-17 56 57.5	0.07	0.94	-108.13

Table 1: Geometric aspects of comet ISON during this investigation: R_H is the heliocentric distance, Δ is the geocentric distance and Δ̇ is the velocity with respect observer direction.

tion (Half Power Beam Width) is about 100 arcsec while the beam separation in the sky is 380 arcsec (i.e., about four beamwidths). The receiver (placed at cryogenic temperatures inside a dewar) operates in circular polarization detecting both Left-hand and Right-hand components with less than -30dB polarization cross-coupling in the frequency range between 18 GHz and 26 GHz. The maximum instantaneous IF bandwidth is 2 GHz, the antenna gain is about 0.12 K/Jy and the system temperature is about 70 K.

4. Results and conclusions

In Table 2 we report the 1σ T_{MB} rms estimations for a spectral resolution of 1km/s for all the observations. The typical integration time was ~200 min that corresponds to a $1\sigma(T_{MB})$ rms of ~30 mK. The total integration time,

from 25th to 29th of November 2013, was 947 min and consequently the total rms was 8 mK. We analyzed the data using the model reported by Crovisier et al. (2004). In particular, we used the 26th November spectrum, i.e. that associated with the longest integration time (280 min) and consequently the highest sensitivity (10 mK). On 26th November the comet was at $R_H = 0.17$ AU and $\Delta = 0.91$ AU. Probably, this was the optimum day for ammonia searches before ISON disintegrated, because it has the right compromise between proximity to Sun and coordinates accuracy. We estimated that the

DATE gg/mm/yy	time on source min	$1\sigma(T_{MB})_{rms}@1km/s$ mK
25/11/2013	106	20
26/11/2013	280	10
27/11/2013	210	32
28/11/2013	171	44
29/11/2013	180	30
total 25-29/11	947	8

Table 2: ISON comet results from data reduction with GILDAS-CLASS.³The table shows the observation date, the total time on source and the 1σ limit of T_{MB} with 1km/s of resolution from which we estimate ammonia upper limits.

3σ limit of our observations corresponds to $Q(NH_3) < 1.0 \times 10^{30} \text{ s}^{-1}$ for $Trot = 100$ K and $Q(NH_3) < 2.5 \times 10^{29} \text{ s}^{-1}$ for $Trot = 30$ K. The actual rotational temperature of ammonia is unknown. Indeed, Agúndez et al. (2014) estimated a kinetic temperature of 90 K from the methanol lines observed in comet ISON at $R_H = 0.60$ AU. However, the temperature at $R_H = 0.17$ AU may be expected to be higher, as well as the upper limit on ammonia.

We thus verified that our observations are consistent with the production rates collected during the whole ISON Campaign. Considering the drastic decrease of $Q(H_2O)$ that occurred immediately after the second main outburst of 20th November (when $Q(H_2O) = 2 \times 10^{30} \text{ mol s}^{-1}$), comet ISON was much less active than was expected, and thus our measurements do not place significant constraints on its activity. One should note that at $R_H = 0.17$ AU, the lifetime of NH_3 against photodissociation is only ~ 200 s, hence the diffi-

³<http://www.iram.fr/IRAMFR/GILDAS/>

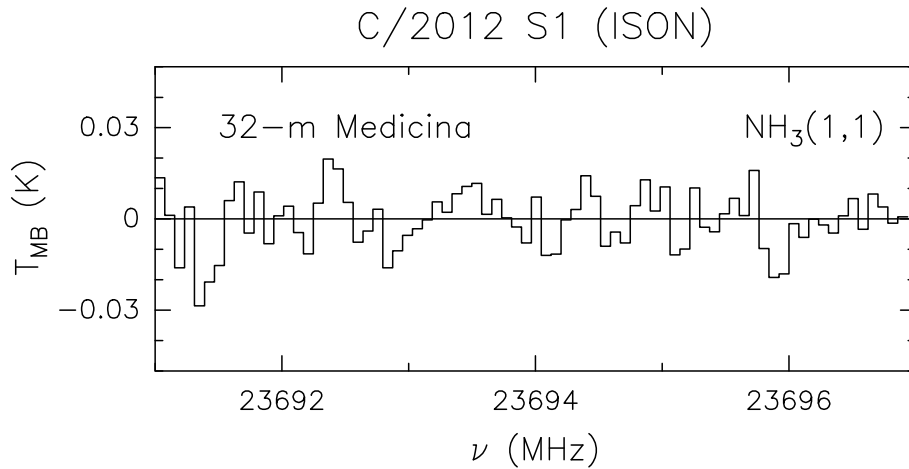


Figure 1: Spectrum at 23.7 GHz of C/2012 S1 ISON observed on November 26th, 2013 with the 32-m Medicina antenna.

culty to detect this species. Our NH_3 measurements are in agreement with such behavior: indeed the derived upper limits confirm that probably the bulk of the volatile compounds were released during the last outbursts.

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