A&A 583, A53 (2015)
DOI: 10.1051/0004-6361/201526830

Astronomy & Astrophysics

Search for HOOH in Orion[⋆,⋆⋆] *(Research Note)*

R. Liseau[1] and B. Larsson[2]

[1] Department of Earth and Space Sciences, Chalmers University of Technology, Onsala Space Observatory, 439 92 Onsala, Sweden
e-mail: `rene.liseau@chalmers.se`
[2] AlbaNova University Centre, Stockholm University, Department of Astronomy, 106 91 Stockholm, Sweden

Received 24 June 2015 / Accepted 22 September 2015

ABSTRACT

Context. The abundance of key molecules determines the level of cooling that is necessary for the formation of stars and planetary systems. In this context, one needs to understand the details of the time dependent oxygen chemistry, leading to the formation of O_2 and H_2O.
Aims. We aim to determine the degree of correlation between the occurrence of O_2 and HOOH (hydrogen peroxide) in star-forming molecular clouds. We first detected O_2 and HOOH in ρ Oph A, we now search for HOOH in Orion OMC A, where O_2 has also been detected.
Methods. We mapped a $3' \times 3'$ region around Orion H_2-Peak 1 with the Atacama Pathfinder Experiment (APEX). In addition to several maps in two transitions of HOOH, viz. 219.17 GHz and 251.91 GHz, we obtained single-point spectra for another three transitions towards the position of maximum emission.
Results. Line emission at the appropriate LSR-velocity (Local Standard of Rest) and at the level of $\geq 4\sigma$ was found for two transitions, with lower signal-to-noise ratio ($2.8-3.5\sigma$) for another two transitions, whereas for the remaining transition, only an upper limit was obtained. The emitting region, offset 18″ south of H_2-Peak 1, appeared point-like in our observations with APEX.
Conclusions. The extremely high spectral line density in Orion makes the identification of HOOH much more difficult than in ρ Oph A. As a result of having to consider the possible contamination by other molecules, we left the current detection status undecided.

Key words. astrochemistry – ISM: general – ISM: individual objects: Orion H2-Peak 1 – ISM: molecules – ISM: abundances – stars: formation

1. Introduction

Searches for the presumed key molecule O_2 (Goldsmith & Langer 1978) in numerous star-forming regions have been highly unawarding (e.g. Goldsmith et al. 2000; Pagani et al. 2003), with the definite detection of the molecule in merely two sources, viz. ρ Oph A (Larsson et al. 2007; Liseau et al. 2012) and Orion A (Goldsmith et al. 2011; Chen et al. 2014). Some cases have been either resolved or remained undecided (e.g. Goldsmith et al. 2002; Yıldız et al. 2013).

The observed scarcity of O_2 in the interstellar medium (ISM) called for the abandonment of pure gas-phase chemistry models and the invocation of grain-surface processes (Hollenbach et al. 2009). Specific models addressed the conditions of the Orion Bar PDR (photodissociation region), where searches had however been unsuccessful in detecting the molecule (Melnick et al. 2012). Surprisingly, perhaps, O_2 was detected towards the hot core, albeit at an LSR (Local Standard of Rest)-velocity of 10–12 km s^{-1}, i.e., significantly different from that of typical hot core molecules (∼5 km s^{-1}; Goddi et al. 2011, and references therein). These authors also found a small region of emission in NH_3 inversion lines with velocities of about 11 kms. Overall, line widths decrease with excitation from ∼5 km s^{-1} to ∼2 km s^{-1}.

Chen et al. (2014) were able to pinpoint the location of the 9″ O_2 source, near the position identified as H_2-Peak 1 and somewhat offset from the hot core centre. The non-detection of the O_2 line at 1121 GHz led the authors to conclude that gas temperatures do not exceed 50 K, with best-fit model values more like 30 K. The excitation conditions thus resemble those in ρ Oph A (Liseau et al. 2012).

Du et al. (2012) developed models for grain surface chemistry, and as an example, they considered the particular case of ρ Oph A. According to these models, the existence of O_2 in the gas phase is a transient phenomenon, lasting for some 10^5 years, and which may explain the extremely few detections. These models also predict the accompanying occurrence of hydrogen peroxide (HOOH or H_2O_2) and hydroperoxyl (HO_2), and water

---

[⋆] Based on observations with APEX, which is a 12 m diameter submillimetre telescope at 5100 m altitude on Llano Chajnantor in Chile. The telescope is operated by Onsala Space Observatory, Max-Planck-Institut für Radioastronomie (MPIfR), and European Southern Observatory (ESO).

[⋆⋆] The final reduced data cube (FITS files) is only available at the CDS via anonymous ftp to `cdsarc.u-strasbg.fr` (`130.79.128.5`) or via
`http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/583/A53`

Table 1. Log of observations.

HOOH-transition $(J_{K_\mathrm{a}K_\mathrm{c}})' - (J_{K_\mathrm{a}K_\mathrm{c}})''$	Frequency (GHz)	Date yy–mm–dd	t_int (min)	Sp.
$3_{03}{-}2_{11}$	219.16686	14-08-14	60.0	map
		14-08-18	60.0	map
		14-08-19	60.0	map
		14-10-06	88.0	sngl
$6_{15}{-}5_{05}$	251.91468	14-08-15	60.0	map
$4_{04}{-}3_{12}$	268.96117	14-10-06	73.1	sngl
		14-10-08	21.9	sngl
		14-12-04	167.9	sngl
$5_{05}{-}4_{13}$	318.22325	14-10-08	58.6	sngl
		14-10-10	40.3	sngl
$5_{14}{-}6_{06}$	318.71210	14-10-08	58.6	sngl
		14-10-10	40.3	sngl

Notes. Maps have their origin at $\alpha_{2000} = 05^\mathrm{h}35^\mathrm{m}13\overset{\mathrm{s}}{.}70$, $\delta_{2000} = -05^\circ\,22'\,09\overset{\prime\prime}{.}0$ (Chen et al. 2014), and single position spectra refer to the offset $(0'', -18'')$.

of course, via the following major reactions on grain surfaces (Tielens & Hagen 1982; Parise et al. 2014):

$$O_2 + H \rightarrow HO_2$$

$$HO_2 + H \rightarrow HOOH$$

$$HOOH + H \rightarrow H_2O + OH,$$

and these two species were then also firstly detected in ρ Oph A (Bergman et al. 2011; Parise et al. 2012). As was the case with O_2, the observation of ten other targets in lines of HOOH gave null results (Parise et al. 2014), supporting the O_2-HOOH association. This included low- and high-mass star formation regions, where in particular the high-mass star formation regions had strong UV fields, shocks and maser emissions. It was natural, therefore, to search for the hydrogen peroxide molecule in Orion A, a site that was not listed in Table 4 of Parise et al. (2014).

The organisation of this Research Note is briefly outlined as follows: in Sect. 2, the observations and data reduction are reported, with the results provided in Sect. 3. A brief discussion, together with our conclusions, follows in Sect. 4.

2. Observations and data reduction

The region around the position "Orion H_2-Peak 1" (Chen et al. 2014) was observed with the Atacama Pathfinder Experiment (APEX[1]) in 2014 during the time August to December (Table 1). APEX is a 12 m single dish telescope at 5100 m altitude in northern Chile. We used two receivers from the SHeFI[2] suite, i.e., APEX-1 for $(3_{03}{-}2_{11})$ 219 GHz and $(6_{15}{-}5_{05})$ 252 GHz and APEX-2 for $(4_{04}{-}3_{12})$ 269 GHz and $(5_{05}{-}4_{13})$, $(5_{14}{-}6_{06})$ 319 GHz, respectively[3]. At these frequencies, the HPBW of APEX is 20″ to 28″. The rms value of the telescope pointing accuracy is 2″.

Table 2. Measurements of HOOH features.

HOOH line	E_up/k (K)	υ_LSR (km s^{-1})	*FWHM* (km s^{-1})	T_rms (mK)	$\int T_\mathrm{A}\mathrm{d}\upsilon$ (K km s^{-1})	*S/N*
$3_{03}{-}2_{11}$	31	10.0	1.4	26.1	0.172	4.6
$6_{15}{-}5_{05}$	66	11.6	0.8	257.0	0.242	1.2
$4_{04}{-}3_{12}$	41	10.3	1.0	41.9	0.118	2.8
$5_{05}{-}4_{13}$	53	11.8	0.9	28.8	0.102	3.5
$5_{14}{-}6_{06}$	67	12.3	1.5	31.5	0.174	4.0

As seen in Table 1, maps were obtained on-the-fly in the 219 GHz and 252 GHz lines, with a sampling rate of 9″/pxl, oversampling the $3' \times 3'$ region in these lines. The central J2000-coordinates are RA = $05^\mathrm{h}35^\mathrm{m}13\overset{\mathrm{s}}{.}70$, Dec = $-05^\circ\,22'\,09\overset{\prime\prime}{.}0$. Towards the offset position $(0'', -18'')$, single position spectra were obtained at 269 GHz and 319 GHz.

For the instantaneous bandwidth of 2.5 GHz, we used as backend the Fast Fourier Transform Spectrometer (FFTS) with 32768 spectral channels. We selected a spectral resolution of 76.3 kHz per channel, corresponding to a velocity resolution of ~0.1 km s^{-1}. The data were reduced with the software packages GILDAS/CLASS[4] and `xs`[5].

3. Results

An overview of the mapped region is shown in the left panel of Fig. 1, revealing that the core region near the centre is very compact. A blow-up, 36″ in size, is shown in the right panel, where a weak emission feature is shown on the wing of a stronger line. That feature corresponds to the $(3_{03}{-}2_{11})$ line of HOOH at the LSR-velocity of 10.0 km s^{-1}, i.e., consistent with that of the O_2 lines (Chen et al. 2014). It can also be seen that this feature is not merely due to noise, but is repeatedly seen in different positions, albeit at lower intensity. The fact that HOOH is not detected outside this limited region implies that the emission in the 219 GHz line is point-like to the 28″ telescope beam.

From the data in Table 2, it appears that only two out of five lines were clearly detected ($\geq 4\sigma$), and two were possibly detected at low signal-to-noise ratio ($2.8{-}3.5\sigma$). The quoted line widths (FWHMs) are only lower limits because of the difficulty in accurately determining the local continuum on sloping backgrounds. These HOOH widths are smaller than those for O_2 reported by Chen et al. (2014). The 252 GHz line was not detected. However, the noise level of that spectrum is very much higher than for the other observations (Table 2).

4. Discussion and conclusions

The LSR-velocities of the HOOH features are clearly outside the hot core window, but seem consistent with those obtained for O_2. This could also indicate that in Orion HOOH can be tied to O_2. A major shortcoming, though, is the extremely high line density towards the hot core region, which makes proper line identification difficult. In fact, several molecules in the 219 GHz spectrum display similar hump features on their red wings (Fig. 2). This

---

[1] `http://www.apex-telescope.org/`

[2] Swedish Heterodyne Facility Instrument.

[3] Energy level diagrams are found in Bergman et al. (2011).

[4] `http://www.ira.inaf.it/~brand/gag.html`

[5] `ftp://yggdrasil.oso.chalmers.se/pub/xs/`

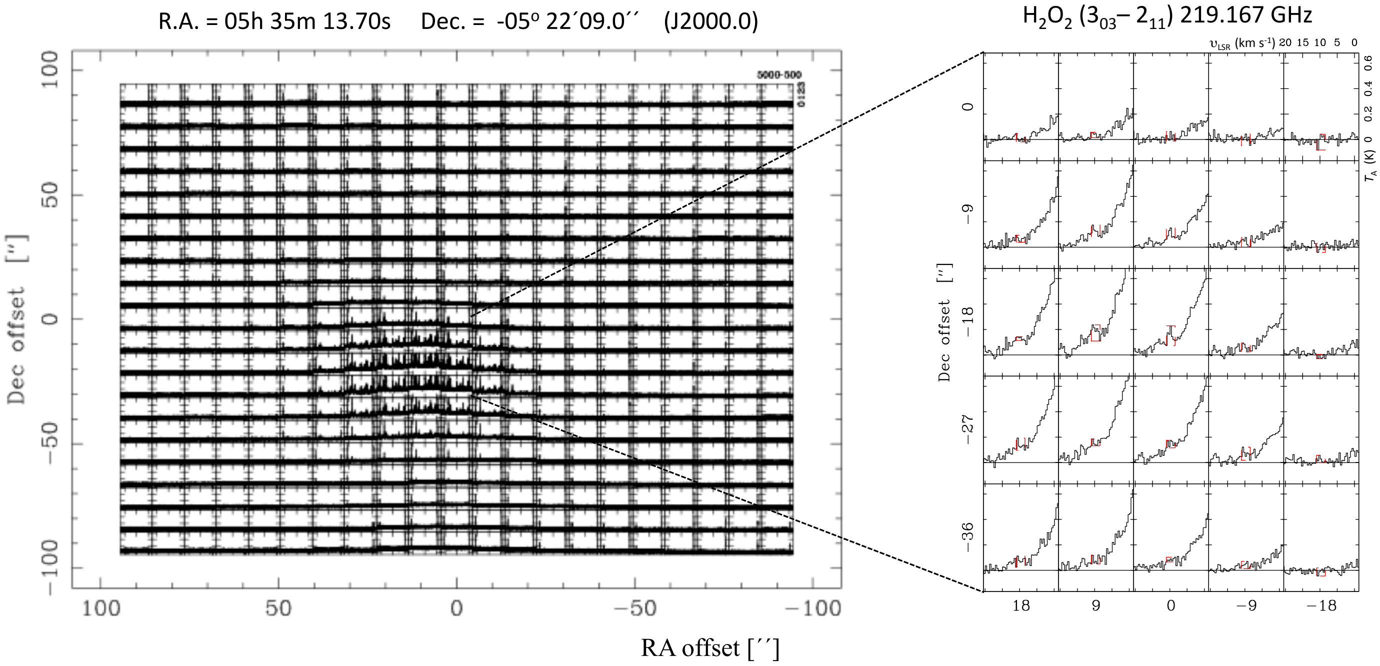

Fig. 1. *Left*: the $3' \times 3'$ mapped area, sampled at $9''$ with the origin at the Orion H_2-Peak 1 position, i.e., $\alpha_{2000} = 05^h35^m13\overset{s}{.}70$, $\delta_{2000} = -05° \, 22' \, 09\overset{''}{.}0$. A core of intense emission is clearly seen just below the centre. *Right*: centred on $(0'', -18'')$, this partial map demonstrates that the 219.17 GHz feature is a point source to the $28''$ beam. This weak spectral feature is identified inside the red markers. It is sitting on top of the red wing of a much stronger line (HC_3N ($\nu_7 = 3$), Sutton et al. 1985).

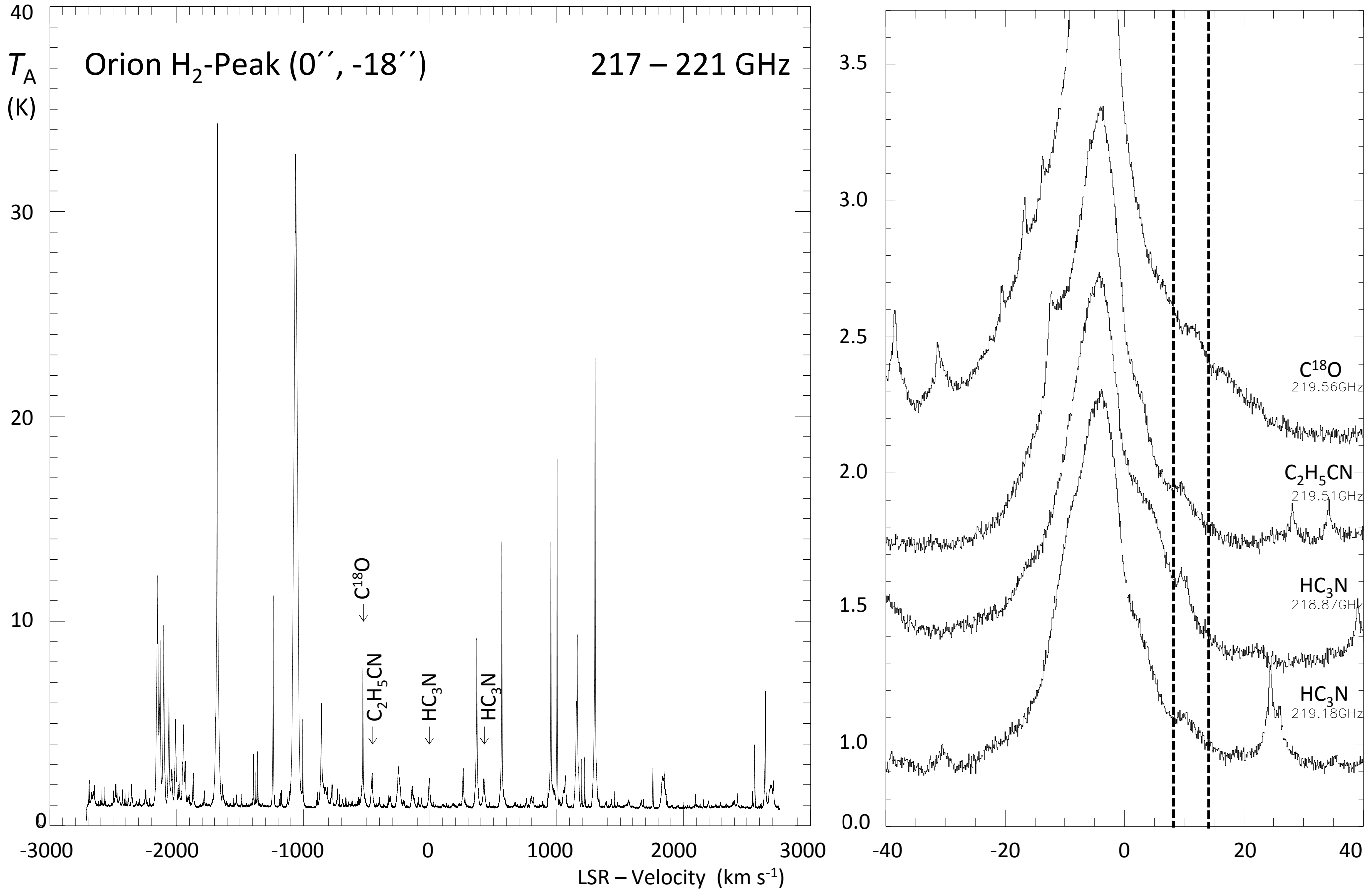

Fig. 2. *Left*: the 4 GHz wide spectrum, centred on 219 GHz, towards the offset position $(0'', -18'')$ relative to Orion H_2-Peak 1. Line identifications for the entire spectral region can be found in the paper by Sutton et al. (1985). Blow-ups of the labelled lines are found in the *right-hand panel*, where the LSR-velocity range of the putative HOOH line is indicated with the dashed vertical lines.

is not evidenced by the other transitions, but in view of the relatively lower signal-to-noise ratio makes the HOOH identification apparently non-unique.

Acknowledgements. The contributions by P. Bergman, including the interesting discussions, are highly appreciated. We also thank the Swedish APEX team and the APEX staff on site for their help with the observations. As part of our Odin and *Herschel* work, this research has been supported by the Swedish National Space Board (SNSB).

References

Bergman, P., Parise, B., Liseau, R., et al. 2011, A&A, 531, L8
Chen, J.-H., Goldsmith, P. F., Viti, S., et al. 2014, ApJ, 793, 111
Du, F., Parise, B., & Bergman, P. 2012, A&A, 538, A91
Goddi, C., Greenhill, L. J., Humphreys, E. M. L., Chandler, C. J., & Matthews, L. D. 2011, ApJ, 739, L13
Goldsmith, P. F., & Langer, W. D. 1978, ApJ, 222, 881
Goldsmith, P. F., Melnick, G. J., Bergin, E. A., et al. 2000, ApJ, 539, L123
Goldsmith, P. F., Li, D., Bergin, E. A., et al. 2002, ApJ, 576, 814
Goldsmith, P. F., Liseau, R., Bell, T. A., et al. 2011, ApJ, 737, 96
Hollenbach, D., Kaufman, M. J., Bergin, E. A., & Melnick, G. J. 2009, ApJ, 690, 1497
Larsson, B., Liseau, R., Pagani, L., et al. 2007, A&A, 466, 999
Liseau, R., Goldsmith, P. F., Larsson, B., et al. 2012, A&A, 541, A73
Melnick, G. J., Tolls, V., Goldsmith, P. F., et al. 2012, ApJ, 752, 26
Pagani, L., Olofsson, A. O. H., Bergman, P., et al. 2003, A&A, 402, L77
Parise, B., Bergman, P., & Du, F. 2012, A&A, 541, L11
Parise, B., Bergman, P., & Menten, K. 2014, Faraday Discussions, 168, 349
Sutton, E. C., Blake, G. A., Masson, C. R., & Phillips, T. G. 1985, ApJS, 58, 341
Tielens, A. G. G. M., & Hagen, W. 1982, A&A, 114, 245
Yıldız, U. A., Acharyya, K., Goldsmith, P. F., et al. 2013, A&A, 558, A58