INTERSTELLAR H_3O^+

T.G. Phillips[1], Ewine F. van Dishoeck[2] and Jocelyn B. Keene[1]

[1] *Div. of Physics, Math. & Astronomy, Caltech 320-47, Pasadena, CA 91125, USA*
[2] *Leiden Observatory, P.O. Box 9513, 2300 RA Leiden, The Netherlands*

1. Introduction

The H_3O^+ ion is a key species in the oxygen chemistry leading to H_2O, OH and O_2. Chemical models predict O_2 and H_2O to be the dominant oxygen–bearing molecules in interstellar clouds. However, neither of them can easily be observed in the bulk of the interstellar medium because of blockage from the Earth's atmosphere. Determination of the abundance and distribution of the precursor H_3O^+ ion might thus provide an important indirect measure of their abundances.

H_3O^+ has a complicated energy spectrum (see Bogey et al. 1985). It is isoelectronic with NH_3, but its inversion splitting is much larger, about 55 cm^{-1}, and comparable to the rotational splitting. As a result, the lowest transitions lie at submillimeter wavelengths, and only four lines at 307, 364, 388 and 396 GHz are accessible with ground–based telescopes.

Possible detections of the 307 GHz line of H_3O^+ have been presented by Wootten et al. (1986) and Hollis et al. (1986) in Orion OMC–1 and Sgr B2, but definite identification is difficult due to the huge complexity of lines in these sources. Recently, Wootten et al. have observed the 364 GHz line as well in these sources using the Caltech Submillimeter Observatory (CSO). Of the two remaining lines, only the 396 GHz line lies in a reasonably transparent region of the atmosphere. We have concentrated our searches on this line using the CSO. Encouraged by our success in detecting the 396 GHz line in a number of sources other than Orion and Sgr B2, we also searched for the 364 GHz and 307 GHz lines in the same regions, to secure the identifications.

2. Observations

The most impressive detection of the 396 GHz line is toward W3 IRS5, where the line is about $T_A^* \approx 0.4$ K. In contrast with Orion and Sgr B2, this spectrum shows virtually no other features over a 500 MHz bandwidth. The 364 GHz line is also seen toward W3 IRS5 at about one third of the strength of the 396 GHz line. Figure 1 shows a blow–up of the two lines. A marginal feature, probably better described as an upper limit with $T_A^* \lesssim 0.08$ K, is found at 307 GHz. By contrast, no detections were made toward W3 IRS4 and only a marginal 396 GHz feature is present toward W3 OH, even though the total hydrogen column densities are fairly similar in the three cases. Thus significant variations in the abundance and/or excitation of H_3O^+ appear to occur on small scales.

The 396, 364 and 307 GHz lines are all seen toward G34.3 +0.15, whereas the 396 and 307 GHz lines are only possibly detected toward W51. Toward Orion/KL, a strong feature with $T_A^* \approx 2$ K is present at 396 GHz, but toward Sgr B2, the 396 GHz line is only 0.2 K. No H_3O^+ lines were seen toward NGC 2024 FIR5, ρ Oph A and B2 and IRAS 16293 –2422, and toward a number of oxygen–rich stars.

P. D. Singh (ed.), Astrochemistry of Cosmic Phenomena, 191–192.

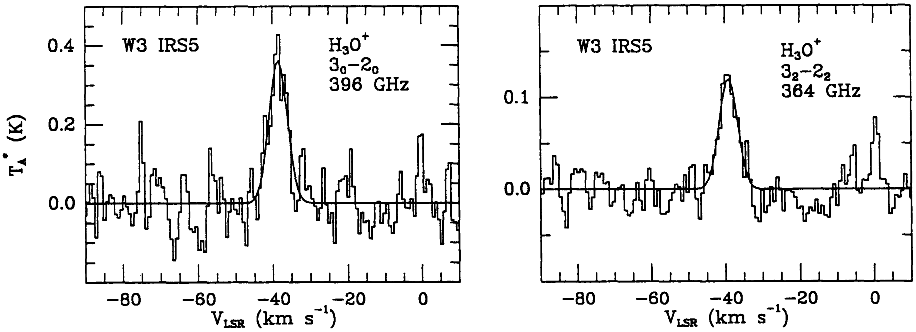

Fig. 1. The H_3O^+ 396 and 364 GHz lines toward W3 IRS5 obtained at the CSO

3. Excitation and Abundance

Excitation calculations have been performed for H_3O^+ under a variety of conditions using collisional cross sections based on a simple model potential (Offer, private communication). The 396 and 364 GHz lines are found to have comparable strengths (within a factor 2) under conditions typical for warm, dense molecular clouds such as W3 ($T \approx$50–100 K, $n \approx 10^6 - 10^7$ cm^{-3}). In contrast, the 307 GHz line is very weak in such models, consistent with the observations. Only for very high densities, $n > 10^7$ cm^{-3}, does the 307 GHz line become comparable in strength to the 396 GHz line. The different H_3O^+ line ratios observed toward Sgr B2 are most easily explained in a low density model ($n \approx 10^4 - 10^5$ cm^{-3}), in which the 364 GHz line is preferentially excited by far–infrared radiation.

The derivation of H_3O^+ column densities and abundances is hampered by uncertainties in the collisional rates and in the H_2 column densities. We derive $N(H_3O^+) \approx 10^{14}$ cm^{-2} toward W3 IRS5, resulting in an abundance with respect to H_2 of about 10^{-9}. Similar abundances around $10^{-10} - 10^{-9}$ apply to the other sources.

4. Conclusions

We have definitely detected H_3O^+ toward W3 IRS5 and G34.3 +0.15, and have obtained plausible identifications toward W3 OH, W51, Orion/KL and Sgr B2. The inferred abundances are consistent with gas–phase chemistry models within an order of magnitude (e.g. Herbst and Leung 1989; Millar et al. 1991), although they favor the lower values. The abundance of the ion toward W3 IRS5 implies an O_2 abundance of about 10^{-6}–10^{-5}. Searches for lines of $^{16}O^{18}O$ in these same sources are currently being performed (Keene et al. in preparation), and should provide important constraints on the oxygen chemistry.

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