ABUNDANT, HOT WATER TOWARD YOUNG STELLAR OBJECTS

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1. Introduction

The large amount of water vapour in the Earth's atmosphere makes it extremely difficult to observe water in interstellar space, except under unusual conditions (e.g., masers). The Short Wavelength Spectrometer (SWS; de Graauw et al. 1996) on board the Infrared Space Observatory (ISO) provides an unique opportunity to study the ro–vibrational fundamental bands of water in absorption against bright infrared continuum sources. Such absorption line data have several advantages over emission observations. For example, only a pencil beam to the infrared source is probed, which minimizes the complications due to the small–scale physical and chemical heterogeneity of star–forming regions. In addition, lines from all rotational levels are present within a vibrational band, so that the complete spectrum yields a direct estimate of the level populations and excitation temperature along the line of sight. Other molecules, such as CO, HCN and C_2H_2, can be observed with the same technique, leading to accurate relative abundances. The main limitation of the ISO-SWS grating is its low spectral resolving power, $\lambda/\Delta\lambda \approx 1350$ at 6 μm, since the lines are intrinsically much narrower. This limits the sensitivity, so that only high column densities can

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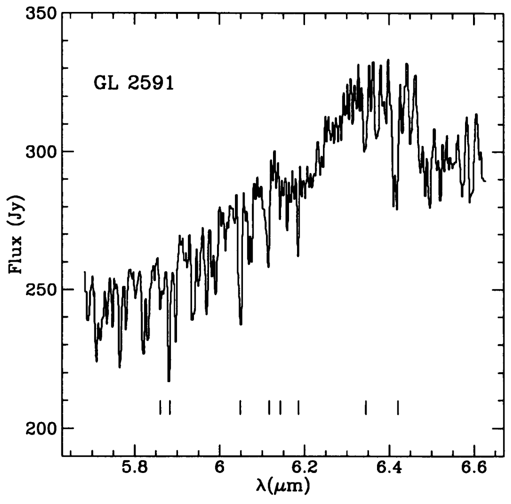

Figure 1. ISO–SWS spectrum of GL 2591 in the region of the H_2O bending mode. A multitude of water absorption lines superposed on the strong continuum can be seen. The tickmarks indicate the positions of lines originating from the lowest 0_{00}, 1_{01}, 1_{10} and 1_{11} levels.

be detected, and complicates the interpretation because detectable lines are often saturated. The low spectral resolution also blends the lines, making it difficult to determine the equivalent widths unambiguously. The ISO–SWS is therefore particularly sensitive to molecules in warm gas with relatively large line widths ($\Delta V > 3$ km s^{-1}).

2. Results and analysis

High-mass star-forming regions are extremely luminous in the infrared and have large quantities of gas and dust surrounding them. These properties make them excellent candidates for a study of the bending mode of thermal water. In the early ISO observations, we obtained data for four lines of sight, which cover a range in physical parameters (Helmich et al. 1996; van Dishoeck & Helmich 1996). Figure 1 shows the spectrum toward AFGL 2591. More than 30 lines due to ortho– and para–H_2O can be identified. The normalized spectra toward all four objects are shown in Figure 5 of Genzel et al. (this volume, p. 381).

Because the H_2O absorption is complex, model spectra were constructed to analyze the data. Details can be found in Helmich (1996) and Helmich et al. (1996). In the simplest case of LTE excitation, the main parameters are the excitation temperature $T_{\rm ex}$ characterizing the level populations, the total H_2O column density N and the Doppler parameter $b=\Delta V/2\sqrt{\ln 2}$.

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Model spectra were calculated for a range in column densities and temperatures and smoothed to the instrumental resolution. An example of a model is shown in Figure 5 of Genzel et al. (this volume). The large number of lines seen in Figure 1 can only be explained by high temperatures ($T_{ex} > 200$ K, up to 1000 K) in the gas toward AFGL 2591. Such high temperatures are consistent with those derived from ^{12}CO and ^{13}CO infrared absorption line observations of Mitchell et al. (1989, 1990). Similarly high temperatures are derived for the other two sources toward which H_2O is detected, AFGL 2136 and AFGL 4176. Only toward NGC 7538 IRS9, no H_2O lines are seen, in agreement with the much smaller fraction of warm gas for this object.

The inferred H_2O column densities for the three lines of sight toward which the molecule has been detected are high, $N(H_2O) \approx 2.\ 10^{18}$ cm^{-2}. Because so many lines are seen, the uncertainty in this value is less than a factor of two, even though the strongest lines are heavily saturated. This leads to H_2O abundances of typically a few$\times 10^{-5}$ in the warm and hot gas in these sources. No stringent limits can be put on the amount of H_2O in the cold gas along the lines of sight.

Two explanations for the observed large H_2O abundances have been proposed (van Dishoeck & Helmich 1996). A popular model invokes evaporation of icy mantles when the grains are heated up by the radiation from the protostar. The fact that the observed solid state H_2O abundances are comparable to those in the gas–phase indicates that this is a viable mechanism. The second possibility involves rapid gas–phase reactions of $O + H_2$ and $OH + H_2$ in warm ($T_{kin} > 400$ K) gas. Further observations of a larger number of sources with a range of physical parameters are needed to assess the relative importance of the two H_2O formation schemes.

Acknowledgements

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Discussion

Kroes: Did anybody ever look for H_2O dimers? Maybe from their presence a formation mechanism of H_2O could be inferred (i.e., evaporation). The binding energy is ≈ 5 kcal ≈ 2500 K.
Helmich: I am not an expert on dimers, but they probably do not survive long in the gas after evaporation. Chemical calculations show that if GL2591 is a hot core, evaporation started more than 10^{3-4} years ago.

Mauersberger: The H_2O column density toward the hot cores you obtain agrees well with the $H_2^{18}O$ results by Gensheimer et al. (1996, A&A 314, 281). Their high HDO/H_2O ratios would prefer that the water has evaporated from grains.
Helmich: I am aware of this work, but for this particular source further study is necessary. Our JCMT observations of the 464 GHz ground state line of HDO toward GL 2591 indicate a lower HDO column density than toward W 3(H_2O).

Langhoff: Have you seen any evidence in the ISO spectra of the OH Meinel system (vibrational-rotational bands in the $X^2\Pi$ state)? These are very strong in the 1–2 μm region, but extend out to much longer wavelenghs and thus in principal should be observable by ISO if OH concentrations were sufficiently high.
Helmich: We did not observe the Meinel bands, but it is unlikely that we see them toward GL 2591, because of the expected low OH abundance. Also, the low flux of GL 2591 at near-infrared wavelengths prohibits sensitive searches. Observations of the late-type oxygen-rich star NML Cyg do show OH absorption (Justtanont et al. 1996, A&A 315, L217).

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