

DERIVATIONS OF ^{18}O ABUNDANCES IN COMETS USING THE ULTRAVIOLET BANDS OF ^{18}OH

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ABSTRACT

A fluorescent equilibrium model for the 1-0 band of the A-X system of ^{18}OH has been constructed. Line positions and intensities have been calculated for possible future spectroscopic observations of these bands from space in order to derive $^{18}\text{O}/^{16}\text{O}$ ratios in comets. It is demonstrated that the strong lines of the 1-0 band can be observable for a moderately bright comet using a high resolution spectrometer with a reasonable exposure time.

Key words: isotope, comet, abundance

1. INTRODUCTION

The derivations of isotopic abundances of major elements in the atmospheres of planetary objects are of great importance in understanding the formation and evolution of the solar system (e.g., Atreya et al. 1999, Irvine et al. 2000). Unlike other major isotopes detected in comets, spectroscopic observations of ^{18}O or ^{18}O containing molecules have not been made so far. The detections of ^{18}O in comets were only made by *in situ* measurements of the neutral mass spectrometer (NMS) (Eberhardt et al. 1995) and the high intensity sensor (HIS) of the ion spectrometer (IMS) (Balsiger et al. 1995) onboard Giotto during the close encounter with P/Halley in 1985. The derived $^{18}\text{O}/^{16}\text{O}$ ratios in the coma of P/Halley are $1.93 \pm 0.12 \times 10^{-3}$ (Balsiger et al. 1995) and $2.13 \pm 0.18 \times 10^{-3}$ (Eberhardt et al. 1995), which are close to the cosmic ratio of 2.0×10^{-3} and are also compatible with the telluric value of 2.06×10^{-3} (e.g., Irvine et al. 2000). The only measurement of the ^{18}O abundance in the outer solar system was made by the observation of a single line of $H_2^{18}\text{O}$ in the hot 5 micron continuum of Jupiter through the 5 micron atmospheric window (Noll et al. 1995). The derived Jovian $^{18}\text{O}/^{16}\text{O}$ ratio is 1 - 3 times the cosmic value of 2.0×10^{-3} . It is expected that the detection of the same $H_2^{18}\text{O}$ line in cometary spectra is difficult because of low 5 micron emission from comets compared with that of Jupiter.

Although the Giotto mass spectrometers successfully detected ^{18}O in P/Halley, it is greatly interesting to see any variation of ^{18}O abundances in other comets. In this paper, it is shown that the $^{18}\text{O}/^{16}\text{O}$ ratios in comets can be derived by observations of the near-ultraviolet bands of ^{18}OH and ^{16}OH . The near ultraviolet bands of ^{16}OH and ^{18}OH consist of the strong 0-0, 1-0, 1-1 bands of the A-X system, which usually appears between 2800 and 3200 Å in cometary spectra. These emission bands have been observed by IUE (International Ultraviolet Explorer) with a low or a

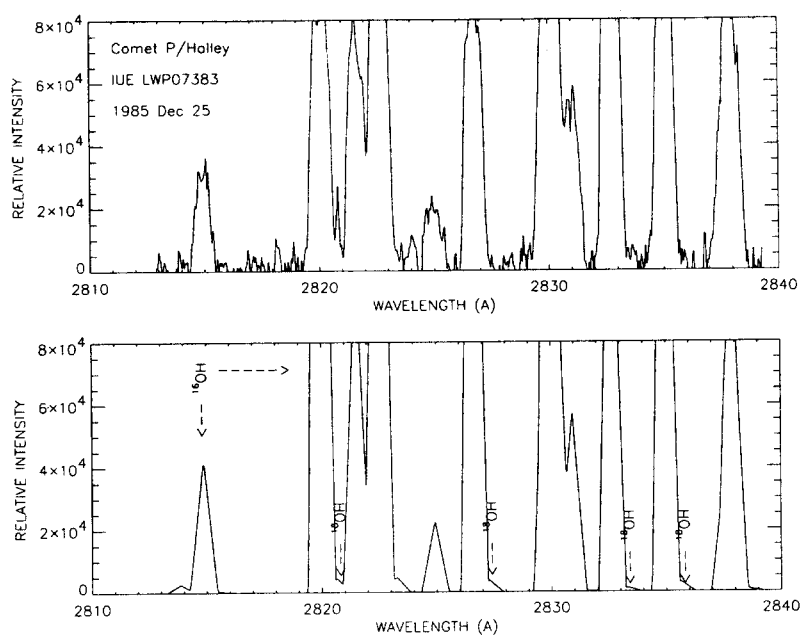


Figure 1. A comparison between a high dispersion IUE spectrum of comet P/Halley (upper figure) and a model spectrum of the 1-0 (A-X) bands of ^{16}OH and ^{18}OH (lower figure). The spectral resolution is 0.6 \AA (FWHM) and the exposure time was ~ 720 minutes. Comparing the observation with the model, an upper limit $^{18}\text{OH}/^{16}\text{OH}$ ratio of 1 % has been derived.

high dispersion mode; by HST (Hubble Space Telescope) with a relatively low spectral resolution; and even from ground through the edge of near-ultraviolet atmospheric window. OH in comets is the major oxygen containing radical, which is the direct photo-dissociation product of H_2O , the dominant constituent in comets. Therefore, an $^{18}\text{O}/^{16}\text{O}$ ratio derived from the ^{18}OH and ^{16}OH bands in a spectrum of a certain comet can be the representative $^{18}\text{O}/^{16}\text{O}$ ratio in that comet. In this paper, line positions and intensities of the ^{18}OH bands for a P/Halley-type comet (i.e., a moderately bright comet) are calculated in order to demonstrate the detectability of ^{18}OH in cometary spectra using a high resolution spectrometer, such as the STIS (Space Telescope Imaging Spectrograph) on the HST.

2. MODELINGS

The ^{18}OH lines occur very close to the corresponding lines of ^{16}OH . Nu β et al. (1982) first reported high resolution laboratory observations of the 0-0 band of the A-X system of ^{18}OH , and presented term values for the upper and lower states of the 0-0 band. The isotopic shifts of the 0-0 band lines are approximately 0.1 \AA . Cheung et al. (1995) investigated 0-0, 1-0, and 1-1 bands of ^{18}OH in detail. Kim (1996) extended the isotopic shift calculations to the 0-1, 2-0, 2-1, 0-2, 1-2, and 2-2 bands of ^{18}OH , of which isotopic shifts are usually greater than 0.1 \AA .

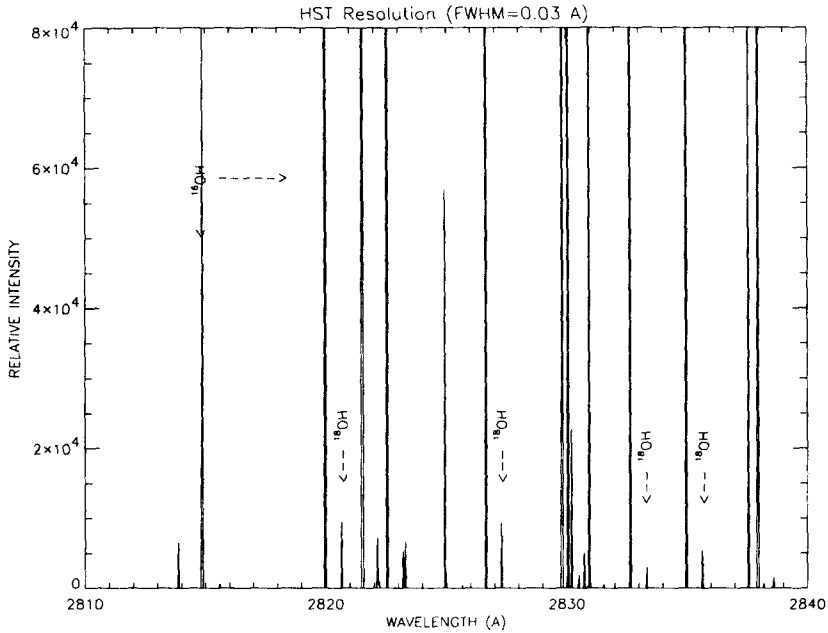


Figure 2. A model spectrum of the 1-0 bands of ^{16}OH and ^{18}OH with a spectral resolution of 0.03 \AA and an $^{18}\text{OH}/^{16}\text{OH}$ ratio of 1%. This spectral resolution can be achieved by the STIS on the HST. The ^{18}OH lines, which are clearly separated from the strong lines of the ^{16}OH band, are marked.

In this paper, for a model demonstration the 1-0 band has been chosen because isotopic shifts are greater than those of the 0-0 band, and the line intensities are strong. The line positions and term values of the rotational states of this band are adopted from Cheung et al. (1995). Einstein A coefficients for the electronic, vibrational, and rotational transitions of the ^{18}OH band are not available in literature. The oscillator strength of the A-X system of ^{18}OH is expected to be very similar to that of ^{16}OH , since the oscillator strengths of the A-X systems of OH and OD are very similar each other according to Huber & Herzberg (1976), for example. Furthermore, the rotational and vibrational constants of ^{18}OH are even closer to those of ^{16}OH compared to those of OD. We, therefore, adopt the Einstein A coefficients of ^{16}OH for those of ^{18}OH . This adoption will not compromise our discussions here, because the main purpose of this work is to demonstrate that strong lines of ^{18}OH are well separated from strong ^{16}OH lines when we use a high resolution spectrometer.

In order to calculate fluorescence intensities of the 1-0 band of ^{18}OH and ^{16}OH , we use a fluorescent equilibrium approximation, which has been shown to be a satisfactory model by Schleicher and A'Hearn (1982) for the most cases of cometary emissions of the ^{16}OH band. We use a similar but modified program code for the ^{16}OH band used by Schleicher and A'Hearn for calculating an equilibrium population of each rotational state of the ^{18}OH band.

In Figure 1, we show a comparison between a high dispersion IUE spectrum of P/Halley (upper figure) and a model spectrum of the 1-0 bands of ^{16}OH and ^{18}OH (lower figure). The IUE spectrum was obtained on December 25, 1985 (UT), and the exposure time was exceptionally long (~ 720

minutes) allowing the saturation of strong ^{16}OH lines in order to reveal any diminutive features beside the strong ^{16}OH lines. The mean heliocentric and geocentric distances were 1.1045 and 1.033 AU, respectively; and the mean heliocentric and geocentric velocities were -26.78 and 34.60 km/sec, respectively, at the time of the observation. The spectral resolution was 0.6 Å(FWHM) for extensive objects, such as P/Halley. Comparing the observation with the model presented in Figure 1, we derive an upper limit $^{18}\text{OH}/^{16}\text{OH}$ ratio of 1 %, which approximately 5 times higher than the results of the Giotto mass spectrometers mentioned above in the introduction section. From this comparison, we note that the IUE spectrum, which was obtained with an unusually long exposure time and with a high dispersion mode, is not enough to reveal the ^{18}OH lines.

In Figure 2, we present a model spectrum of the 1-0 bands of ^{16}OH and ^{18}OH with a spectral resolution of 0.03 Å and an $^{18}\text{OH}/^{16}\text{OH}$ ratio of 1 %. This resolution can be achieved by the STIS on the HST. As shown in this figure, the ^{18}OH lines are comfortably separated from the strong lines of the ^{16}OH band. With the improved sensitivity and light gathering power of the STIS compared with that of the IUE, we estimate a signal-to-noise ratio of 5 or higher for those strong lines of ^{18}OH for a P/Halley-type comet when we use an exposure time of ~ 1 hour assuming an $^{18}\text{OH}/^{16}\text{OH}$ ratio of 0.20 %, which is the cosmic abundance.

3. CONCLUSIONS

It is demonstrated that the strong lines of the 1-0 band (A-X system) of ^{18}OH can be observable for a moderately bright comet using a high resolution spectrometer (ex. STIS on HST) with an exposure time of ~ 1 hour. The results propose a new way of observations of ^{18}O remotely from Earth orbit, compared with the costly *in situ* observations of ^{18}O in P/Halley by the mass spectrometers on Giotto (e.g., Eberhardt et al. 1995, Balsiger et al. 1995).

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