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DETECTABILITY OF H_2-Ar AND H_2-Ne DIMERS IN JOVIAN ATMOSPHERES

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ABSTRACT

The detection of jovian hydrogen-hydrogen dimers through the clear telluric 2-micron window (Kim *et al.* 1995, Trafton *et al.* 1997) suggests possibility to detect noble gases in the form of dimer with hydrogen in jovian atmospheres. Since noble gases do not have spectral structures in the infrared, it has been difficult to derive their abundances in the atmospheres of jovian planets. If there is a significant component of noble gases other than helium in the jovian atmospheres, it might be detected through its dimer spectrum with hydrogen molecule. The relatively sharp spectral structures of hydrogen-argon and hydrogen-neon dimers compared with those of hydrogen-hydrogen dimers are useful for the detection, if an adequate signal-to-noise (S/N) is obtained. If we use a large telescope, such as the Keck telescope, with a long exposure time ($>$ 24 hours), then H_2-Ar spectral structure may be detected.

1. INTRODUCTION

Recent detection of 2-μm hydrogen dimer $(H_2)_2$ features in absorption in the spectra of Jupiter was possible because of the nice 2-μm atmospheric window and no strong jovian molecular absorption adjacent to the dimer features (Kim *et al.* 1995). $(H_2)_2$ dimer was previously identified in far-infrared Voyager IRIS (Infrared Interferometer Spectrometer) spectra of Jupiter and Saturn by McKellar (1984), after the features were first recognized in the spectra of Jupiter by Hanel *et al.* (1979). Subsequently Fox & Kim (1984) had attributed diminutive features in the far-infrared Voyager IRIS spectra of Titan to the H_2-N_2 dimer. Fox & Kim (1988) calculated mixing ratios of various dimers in planetary atmospheres. The detection of $(H_2)_2$ in the atmosphere of Jupiter also encouraged us to search for the same spectral structures from the hydrogen-dominant atmospheres of Saturn and Neptune. Trafton *et al.* (1997) reported the detection of the $(H_2)_2$ dimer in the atmospheres of Saturn and Neptune based on spectra of the 2 micron fundamental $S_1(1)$ collision-induced band of H_2.

The detection of jovian $(H_2)_2$ from the ground-based observations opens a new and easy way to monitor ortho-para ratio of hydrogen molecules in the jovian troposphere compared with expensive space far-infrared observations. In addition, the detection of jovian $(H_2)_2$ through the 2-μm window also suggests possibility to detect inert gases such as Argon utilizing sharp spectral structures of H_2-Ar dimer (McKellar 1995). Since inert gases do not have spectral structures in infrared, it has been difficult to derive their abundances in the atmosphere of Jupiter. In this paper, we will discuss the detectability of H_2-Ar and H_2-Ne dimers based on laboratory measurements (McKellar & Welsh 1974, McKellar & Welsh 1971, McKellar & Welsh 1972), and current technology of infrared observations.

2. DETECTABILITY OF H_2-Ar AND H_2-Ne DIMERS BASED ON LABORATORY SPECTRA

Figures 1 and 2 (a, b) show comparisons between Jupiter $(H_2)_2$ dimer spectral structures and a laboratory $(H_2)_2$ dimer spectrum (Kim *et al.* 1995) and Saturn and Neptune $(H_2)_2$ dimer spectral structures and a laboratory $(H_2)_2$ dimer spectrum (Trafton *et al.* 1997), respectively. These planetary spectra were obtained at the United Kingdom Infrared Telescope (UKIRT) using the CGS4 spectrograph. We used a spectral resolving power of $\sim$ 16,000 for Jupiter, Saturn, and Neptune, and an approximately the same slit size. The exposure times were 16 min, 4 min, and 80 min for Jupiter, Saturn, and Neptune, respectively. The obtained signal-to-noise (S/N) ratios are 10–40, 30–42, and 5–14 for Jupiter, Saturn, and Neptune, respectively. Although Saturn is 2 times far from Jupiter, and we used 4 times longer exposure times for Jupiter compared with Saturn, we obtained similar S/N ratios. This is mainly due to the sensitivity increase of the CGS4 spectrograph between 1994 and

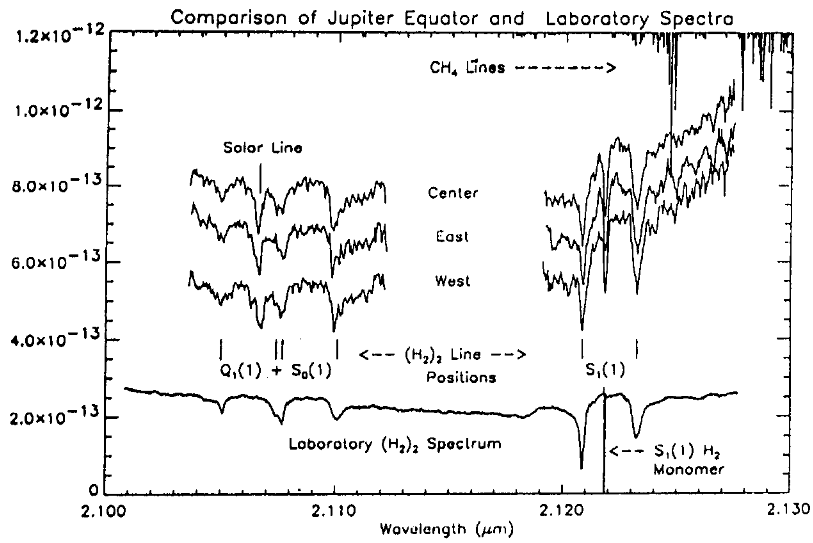

Figure 1. Spectra of Jupiter at 2.10-2.13 μm compared with a laboratory spectrum of the $(H_2)_2$ (bottom). The positions of five branch lines of $(H_2)_2$ and of the $S_1(1)$ line of the H_2 are indicated. Solar lines are also indicated (Kim *et al.* 1995).

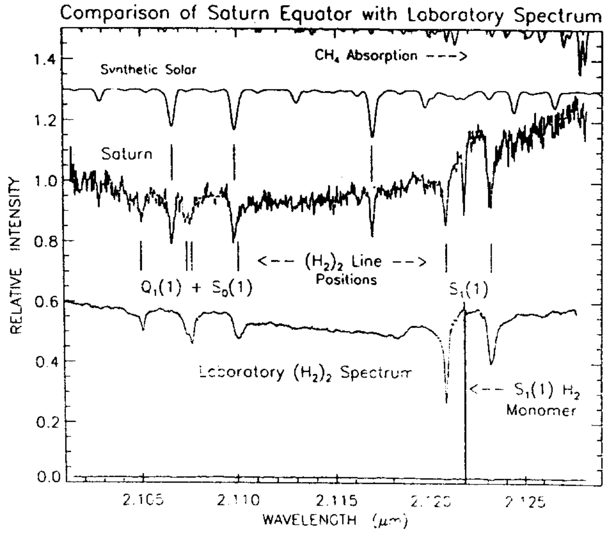

Figure 2a. $(H_2)_2$ dimer features in Saturn's near-infrared spectrum. A laboratory absorption spectrum of H_2 is shown below Saturn's spectrum; it includes both the H_2 $S_1(1)$ quadrupole line and the associated $(H_2)_2$ dimer spectrum, as indicated. A schematic spectrum for CH_4 is shown near the top for comparison and Saturn's propagated error spectrum is shown at the bottom. A schematic solar spectrum is also shown (Trafton *et al.* 1997).

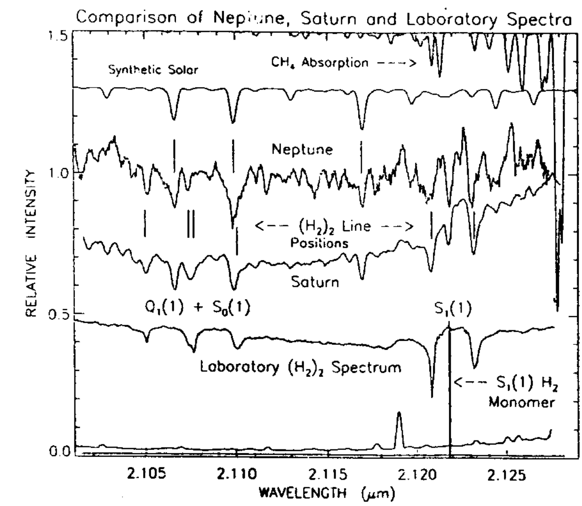

Figure 2b. Same as Figure 2a except for both Neptune and Saturn spectra were smoothed by a boxcar function over 9 pixels. A schematic solar spectrum is also shown. The stronger solar lines are evident in Neptune's spectrum. The propagated error spectra for the smoothed Neptune and Saturn spectra are shown at the bottom (Trafton *et al.* 1997).

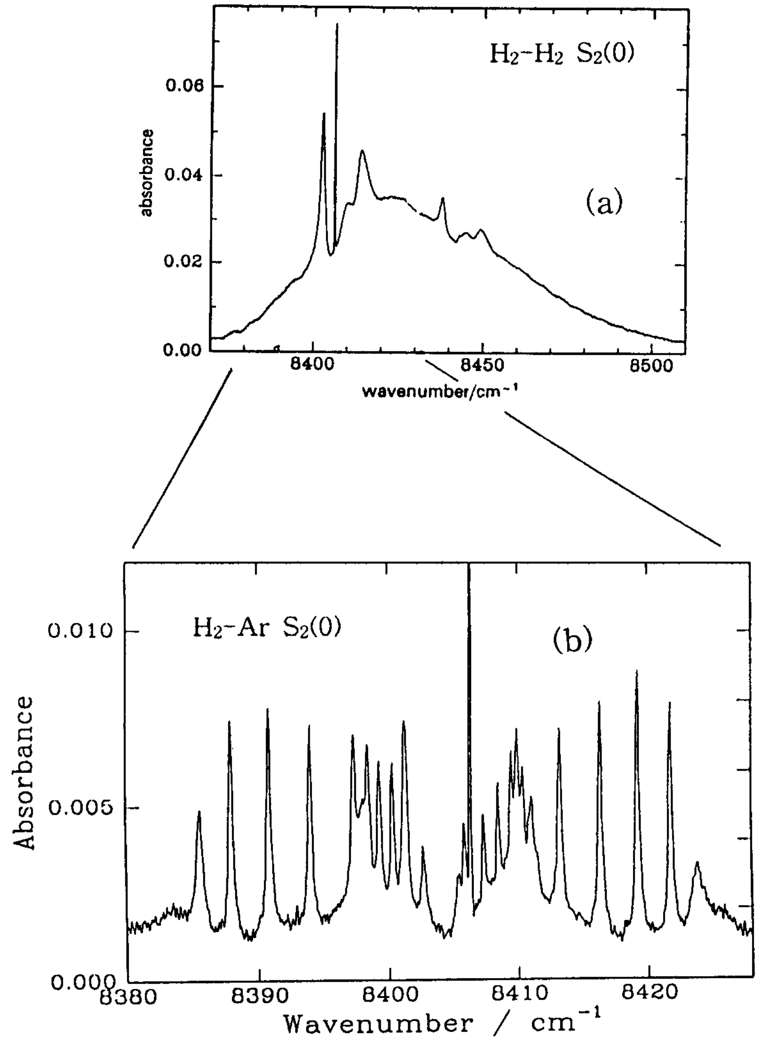

Figure 3. a) Observed spectrum of *para*-hydrogen in the v=2-0 first overtone region at 171 Torr, 21 K, a path of 112 m and a spectral resolution of 0.14 cm^{-1}. The broad underlying feature is due to collision-induced absorption, and the sharp line at 8406 cm^{-1} is the $S_2(0)$ quadrupole line of the H_2 monomer. The remaining features of intermediate width are due to $(H_2)_2$ (McKellar 1994). b) Spectra of H_2-Ar accompanying the $S_2(0)$ transition of H_2 in the first overtone band. The temperature was 77 K, the path was 154 m, the spectral resolution was 0.1 cm^{-1}, and the pressures were about 190 Torr *para*-H_2 plus 111 Torr Ar (McKellar 1995).

1995, because the 58 × 62 array was replaced with a 256 × 256 array in the spring of 1995. If we now use a longer exposure time and use a large telescope, such as the Keck telescope of which mirror diameter is 2 times of the UKIRT's, then we will be able to obtain much higher S/N ratios, as discussed in the following paragraph.

For Jupiter, if we use the same CGS4 spectrograph, an exposure time of 24 hours, and use the Keck telescope, then we will be able to increase signal about 5760 times compared with the Saturn dimer spectrum. On the other hand random photon noise will increase about $5670^{0.5}$ times. In the Saturn CGS4 spectrum, we estimate that about 70% of the noise is due to systematic noise, which is caused by incomplete data reduction processes. We believe that the systematic noise will not increase when we use longer exposure times and the Keck telescope. Only 30% of the noise in the Saturn dimer spectrum is believed to be due to the photon noise caused by the nature of the Poisson distribution of light. Therefore, the photon noise will increase $5670^{0.5}$. The resultant S/N is approximately 10,000 for Jupiter dimer spectra.

Since noble gases do not have spectral structures in the infrared, it has been difficult to derive their abundances in the atmospheres of jovian planets. If there is a significant component of noble gases other than helium in the jovian atmospheres, it might be detected through its dimer spectrum with hydrogen molecule (Niemann *et al.* 1996). Figures 3a and 3b show a comparison of laboratory spectra of $(H_2)_2$ and H_2-Ar dimer spectral structures near 8400 cm^{-1}, respectively (McKellar 1994, McKellar 1995). Figures 4a and 4b show another comparison of laboratory spectra of $(H_2)_2$ and H_2-Ar dimer spectral structures near 4700 cm^{-1}, respectively (McKellar & Welsh 1974, McKellar & Welsh 1971). The relatively sharp spectral structures of H_2-Ar dimers compared with those of $(H_2)_2$ dimers are useful for the detection, if an adequate S/N is obtained.

The laboratory condition for Figure 4a is as follows: Spectral resolution = 0.15 cm^{-1}, total cell length = 110 m, temperature = 16.5 K, and normal H_2 density = 2.28 amagat. The peak absorption is about 2.5×10^{-9} /(amagat)^2. The laboratory condition for Figure 4b is as follows: Spectral resolution = 0.15 cm^{-1}, total cell length = 165 m, temperature = 86 K, total pressure = 0.5 atmosphere, and H_2 and Ar partial pressures = 50% and 50%. The peak absorption is about 6×10^{-9}/(amagat)^2. Based on the above data, we note that the laboratory conditions are similar for H_2-H_2 and H_2-Ar dimers, and we also note that the H_2-Ar absorption is somewhat greater than H_2-H_2 absorption.

According to Niemann *et al.* (1996), Ar mixing ratio in Jupiter is about 1 x 10^{-5}. Since H_2-Ar spectral structure is significantly sharper than the $(H_2)_2$ structure, we estimate that if we obtain a S/N ratio of 10,000 for the Jupiter dimer spectra, the H_2-Ar spectral structure should be discernable. As we discussed before, if we use the same CGS4 spectrograph, an exposure time of 24 hours, and use the Keck telescope, then we will be able to obtain a S/N ratio of 10,000 for the Jupiter dimer spectra. Therefore, if we use an exposure time longer than 24 hours at the Keck telescope, then we may be able to detect the H_2-Ar spectral structure. However, at this S/N ratio, there may be weak lines of other molecular bands and/or weak solar absorption lines, which will make the detection complicate. Figure 5 shows an only available laboratory spectrum of H_2-Ne dimer in literature (McKellar & Welsh 1972). Clearly, we need better and higher resolution laboratory spectra of H_2-Ne. These dimer structures should be much weaker than the nearby hydrogen-hydrogen features because noble gases are expected to be minor constituents of these atmospheres.

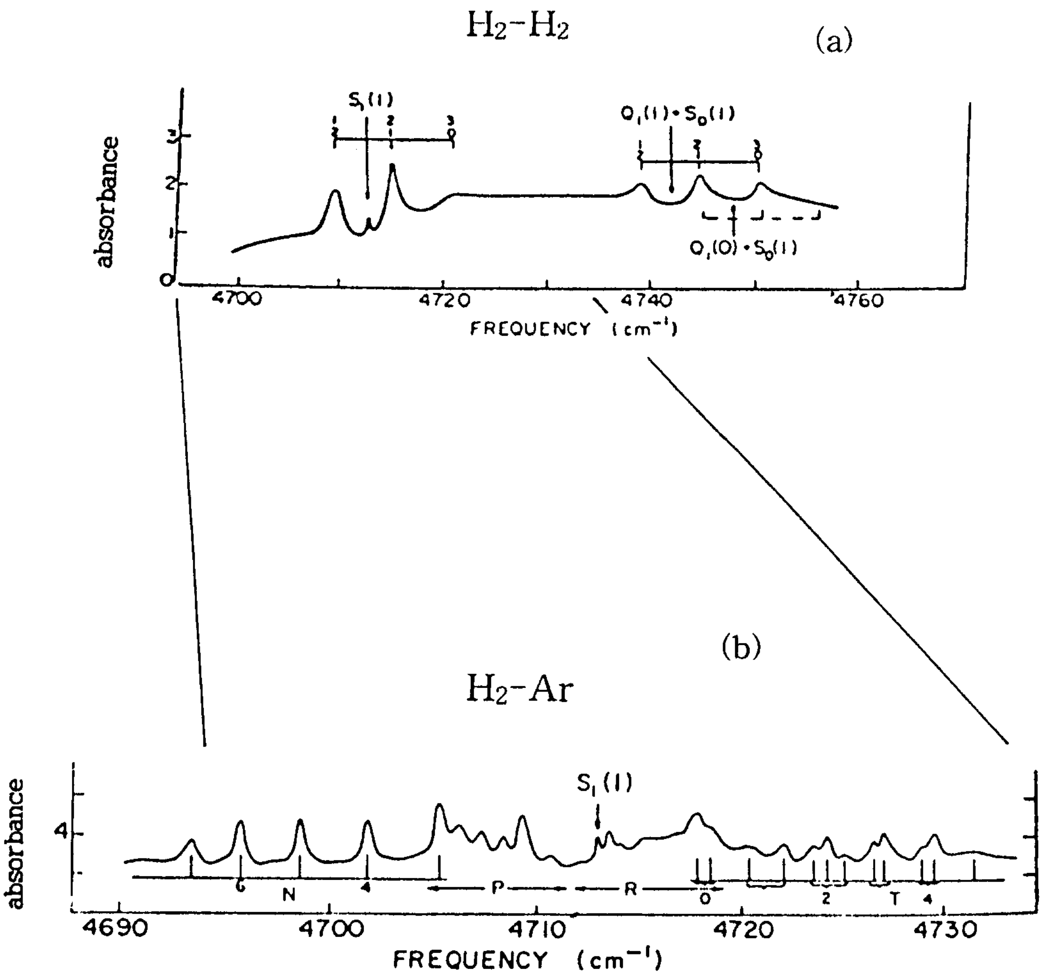

Figure 4. a) The observed spectrum of $(H_2)_2$ accompanying the various components of the collision-induced spectrum. The arrows indicate the calculated frequencies of the hydrogen molecular transitions. Assignments of transitions of the $(H_2)_2$ complex are given in terms of the initial (l'') and final (l') values of the rotational quantum number of $(H_2)_2$ (McKellar & Welsh 1974). b) The observed spectrum of H_2-Ar. The spectrum was obtained with gaseous mixtures of *ortho* or *para* hydrogen with Ar at a total pressure near 0.5 atm and a temperature of about 86 K. The absorption path was 165 m. Contributions due to collision-induced absorption have been subtracted out (McKellar & Welsh 1971).

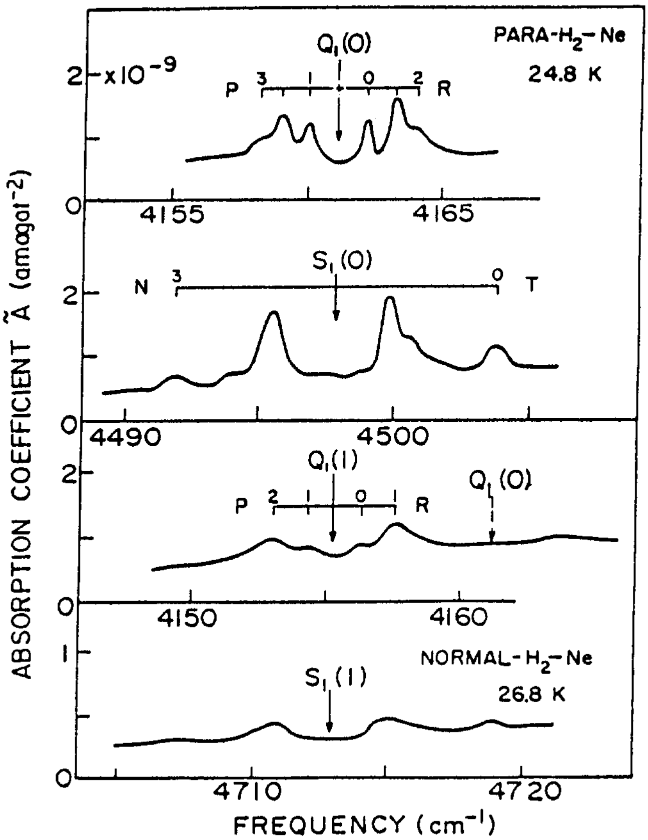

Figure 5. Observed structure due to H_2-Ne dimers accompanying transitions in the H_2 fundamental band at $\sim$ 25 K (McKellar & Welsh 1972).

3. CONCLUSIONS

Encouraged by the detections of hydrogen-hydrogen dimers in the atmospheres of Jupiter, Saturn, and Neptune through the 2 micron atmospheric window (Kim *et al.* 1995, Trafton *et al.* 1997), we investigated possibility to detect argon and neon in the form of dimer with hydrogen in jovian atmospheres. We utilized the relatively sharp spectral structures of hydrogen-argon and hydrogen-neon dimers compared with those of hydrogen-hydrogen dimers for the detection. We conclude that if we use a large telescope, such as the Keck telescope, with a long exposure time (> 24 hours), then H_2-Ar in the Jupiter's atmosphere may be detected.

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