OBSERVATIONS OF THE MARTIAN 1.2 μ CO_2 BANDS

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Abstract. A method to determine independently the Martian surface pressure from measurements of individual lines in the 1.2030 and 1.2177 μ CO_2 bands is presented. Observations obtained during the 1967 apparition and some preliminary results of the 1969 apparition observations yield CO_2 abundances near 100 m-atm and surface pressures of 4–8 mb.

The Martian surface pressure and CO_2 abundance can be determined from observations of the 1.2030 and 1.2177 μ CO_2 bands if the resolution and dispersion used are great enough to resolve the individual Martian CO_2 lines.

Since April 1967 we have been using an RCA Carnegie infrared image tube at the A camera coudé focus of the 82-inch Struve reflector at McDonald Observatory. The resultant dispersion of 3.1 Å/mm allows us a resolution of approximately 0.2 to 0.3 Å, which is quite sufficient to resolve the Martian CO_2 lines.

Figure 1 not only shows the wavelength of the major CO_2 bands between 0.87 μ and 1.6 μ but also indicates their change in strength with increasing pressure. Observations of the weaker bands below one micron, being essentially independent of pressure, give the CO_2 abundance; the stronger bands above 1 μ give a pressure-abundance product, in which the effect of the pressure becomes more dominant as the number of

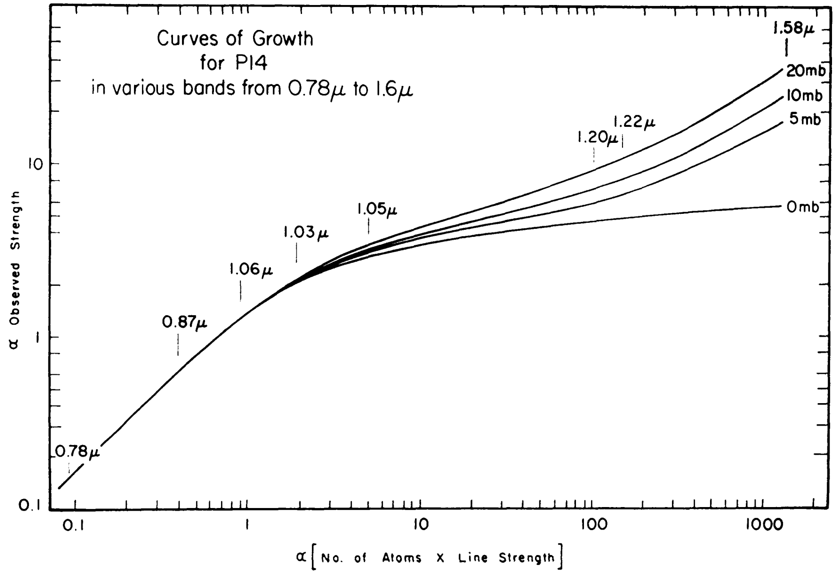

Fig. 1. Curves of growth for P14 in various CO_2 bands from 0.78 μ to 1.6 μ.

Sagan et al. (eds), Planetary Atmospheres, 191–195.

CO_2 molecules and line strength increases. The 1.2 μ bands lie in a transition region, since there are lines in the band that are near both the linear and square root regions.

1. Method

A non-linear least squares program has been developed which allows one to independently determine the 'best values' for the surface pressure and CO_2 abundance that fit the observed equivalent widths in a 1.2 μ band (Barker, 1969). This method linearizes the standard formula for the theoretical equivalent width of a line which is given in Equation (1).

$$W = \int_{-\infty}^{\infty} [1 - \exp(-P^1 \eta\omega H(a, \xi))] \, d\xi \tag{1}$$

The iterative solution is on the two curve of growth parameters; the total CO_2 abundance, $x = \eta\omega$, and the value of the surface pressure or a. a is the ratio of the Lorentz half-width at half-power, r_L, to the Doppler width r_D at which the absorption coefficient has dropped to $1/e$ of the absorption at the line center.

The equivalent width of line (i) as given by Equation (2) is

$$W_i = 2r_D \int_0^y [1 - \exp(-kS_i H(a, \xi))] \, d\xi \tag{2}$$

where S_i is the line strength, k is a constant, and

$$H(a, \xi) = \frac{a}{\pi} \int_{-\infty}^{\infty} \frac{e^{-y2}}{a^2 + (\xi - y)^2} \, dy \tag{3}$$

The sum of the residuals $(0 - C)$ is given by

$$S = \sum_i (W_{i0} - W_i)^2 \tag{4}$$

where W_{i0} is the observed equivalent width and W_i the calculated value. We want to minimize S with respect to a and x.

$$\frac{\partial S}{\partial a} = \sum_i (W_{i0} - W_i) \frac{\partial W_i}{\partial a} \tag{5}$$

$$\frac{\partial S}{\partial x} = \sum_i (W_{i0} - W_i) \frac{\partial W_i}{\partial x} \tag{6}$$

Because Equations (2) and (3) are such complicated functions of a and x, we linearize W by making estimates for a and x

$$x_t = \dot{x}_e + X_c \tag{7}$$

and

$$a_t = \dot{a}_e + A_c \tag{8}$$

where the subscripts t, e, c refer to the true, estimated, and corrections values, respectively.

We can express W_i in a Taylor series about $\dot{a}$ and $\dot{x}$ (neglecting higher order terms),

$$W_i = W_i(\dot{x}, \dot{a}, S_i, k) + \left.\frac{\partial W_i}{\partial x}\right|_{\dot{x},\dot{a}} X + \left.\frac{\partial W_i}{\partial a}\right|_{\dot{x},\dot{a}} A \tag{9}$$

As a first approximation we can express the partial derivatives as

$$W_{i,\dot{x}} = \left.\frac{\partial W_i}{\partial x}\right|_{\dot{x},\dot{a}} \simeq \frac{W_i(\dot{x} + hx, \dot{a}) - W_i(\dot{x}, \dot{a})}{hx} \tag{10}$$

$$W_{i,\dot{a}} = \left.\frac{\partial W_i}{\partial a}\right|_{\dot{x},\dot{a}} \simeq \frac{W_i(\dot{x}, \dot{a} + ha) - W_i(\dot{x}, \dot{a})}{ha} \tag{11}$$

Substituting

$$W_i = \dot{W}_i + W_{i,\dot{x}}X + W_{i,\dot{a}}A \tag{12}$$

Now we can rewrite Equations (5) and (6), setting them equal to zero and introducing weights for each observed equivalent width, t_i.

$$\sum_i (W_{i0} - \dot{W}_i - W_{i,\dot{x}}X - W_{i,\dot{a}}A)(-W_{i,\dot{x}})t_i = 0 \tag{13}$$

$$\sum_i (W_{i0} - \dot{W}_i - W_{i,\dot{x}}X - W_{i,\dot{a}}A)(-W_{i,\dot{a}})t_i = 0 \tag{14}$$

Equations (13) and (14) are in the form of regular weighted normal equations and can be solved for the correction terms X and A. To improve the convergence properties of the solution, a weight matrix was introduced to damp the corrections and these weights were decreased, then set equal to zero before the final solution was obtained. This weight matrix was added to the normal equation matrix with the weights being the proper order of magnitude (starting out at 10% of value of input estimate).

Then the corrections were added to the initial estimates according to Equations (7) and (8). This type of iteration process was carried out until convergence in both a and x was obtained.

2. Observations

Only one good plate was obtained during the 1967 opposition, primarily due to the eight hours of exposure time required. This plate was taken when the Doppler shift was sufficient to separate the Martian and telluric CO$_2$ absorptions. Figure 2 shows the results obtained from this plate of the 1.2030 μ band.

This year in June we obtained six high quality plates of the 1.2 μ bands. Since reductions and observations are still in progress, one plate has been reduced as a sample for presentation at this meeting. Figure 3 shows the observed equivalent widths for the 1.2030 μ band, with only a preliminary correction having been made for the telluric CO$_2$ absorption which was super-imposed on the Martian absorption. The telluric absorption only affects the wings of the observed CO$_2$ lines since the Martian lines are black in the center. The equivalent widths for the telluric lines were calculated and

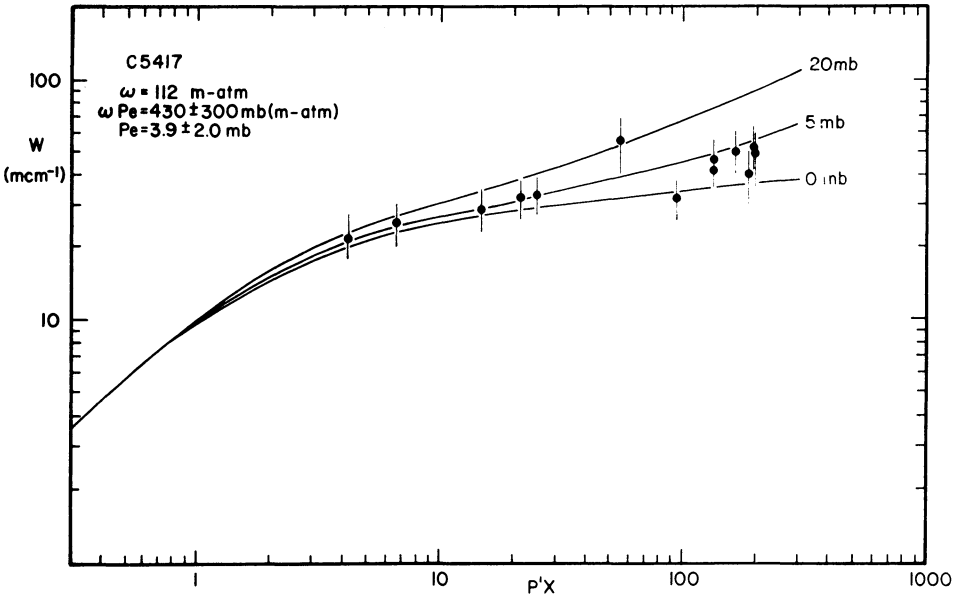

Fig. 2. Curve of growth for plate no. 5431 (1.2030 μ band).

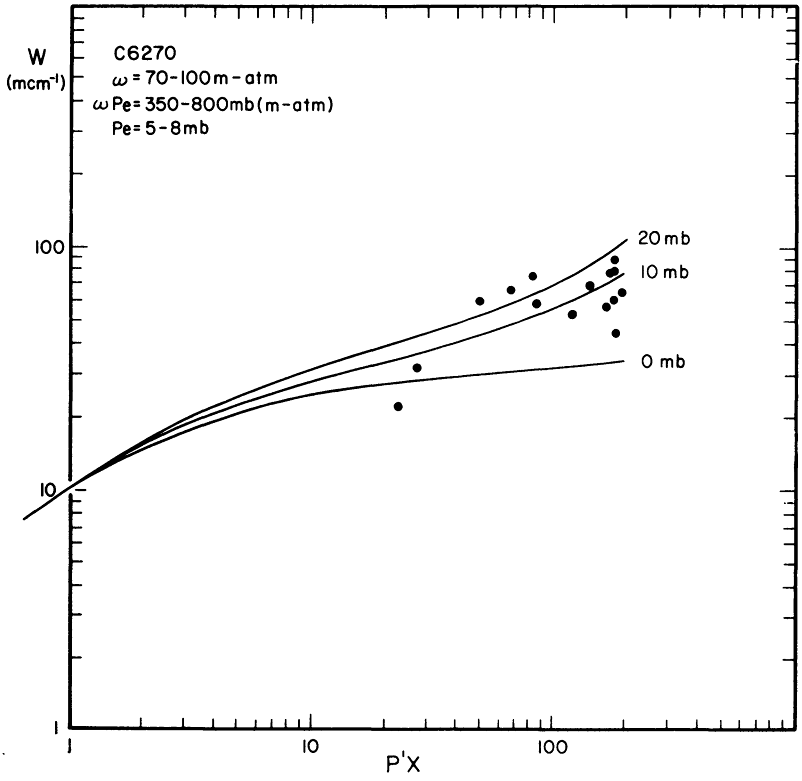

Fig. 3. Curve of growth for plate no. 6270 (1.2030 μ band).

the absorption in the wings of the telluric lines beyond the half-width of the Martian lines was subtracted from the observed equivalent widths. Obviously a more detailed analysis is required and will be used to completely remove the telluric absorption from the observed equivalent widths.

In late September when the Doppler shift was sufficient to separate the telluric and Martian absorptions, we obtained two excellent plates of the 1.2 μ bands which have not yet been reduced.

3. Summary

High-dispersion observations of the 1.2 μ bands give CO_2 abundances near 100 m-atm and surface pressures of 4–8 mb. But their observation is limited to periods of time when the Doppler shift is sufficient to resolve the telluric and Martian lines and when the lines are directly superimposed at opposition. Further reductions of the available spectrograms taken during the 1969 apparition will lead to improved values of the Martian CO_2 abundance and surface pressure at the corresponding periods during the Martian season.

Acknowledgment

The support of the National Aeronautics and Space Administration Office of Lunar and Planetary Programs is gratefully acknowledged.

Reference

Barker, E. S.: 1969, unpublished Ph.D. Dissertation, The University of Texas.