

A NEW TREATMENT OF WATER VAPOR OPACITY

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ABSTRACT. Although the bands of H₂O are strong in cool stars, water vapor opacity has generally not been accurately treated due both to the inadequacy of laboratory data and the difficulty of treating the millions of lines involved. We report a new treatment based upon a statistical representation of the water vapor spectrum derived from available laboratory data. The statistical spectrum of water follows an exponential distribution of line strengths and random positions of lines to reproduce the line spacings and mean opacities observed in the laboratory. This statistical spectrum is then randomly sampled in the spirit of opacity sampling. Significant improvements are made in both the opacities and in the thermal structure and emergent fluxes of the model atmospheres.

1. INTRODUCTION

A principal difficulty in modeling the atmospheres of cool giant stars is the computation of the opacity, for the principal absorbers are molecules, which may have millions of individual lines. Much of the recent progress has been due to better molecular data and opacity treatments (cf. Johnson, 1986). Previous treatments of H₂O opacity include harmonic mean opacities (Auman, 1967); straight mean (SM) opacities (Johnson, Bernat and Krupp, 1980); and VAEBM opacities (Tsuji, 1976). We here present the results obtained by a new, accurate method of opacity sampling (a statistical representation of the water vapor spectrum). Additional details are provided in a more comprehensive paper (Alexander *et al.* 1986).

2. CALCULATIONS

To incorporate water vapor opacity correctly into an opacity sampling calculation requires that the monochromatic absorption coefficient be available at a few hundred frequencies. What is important is that profiles of the absorption coefficient of each absorber be appropriately sampled, including line centers, wings, and inter-line gaps (cf. Carbon 1984). Necessary input data are wavelength, line strength, and energy of the lower level of the transition. Unfortunately, this information is not available for water vapor. However, since the OS method randomly samples the spectrum, hypothetical lines yield the same effect as real lines so long as their distribution of line strengths and line positions closely

matches the real spectrum. Based upon an analysis of laboratory data, Ludwig, *et al.*, (1973) have shown that an exponential distribution of line strengths adequately reproduce the opacity of hot water vapor. They also tabulate the average line spacing and mean opacity as functions of wavelength.

To utilize this data statistically, we consider a molecule with an exponential distribution of line strengths (S): $P(S) = \exp(-S/S_0)/S_0$. To determine S_0 , the average line strength, we require the average absorption over a 25 cm^{-1} interval to equal that observed in the laboratory. At each chosen frequency, we then sample the number of lines expected from the mean line spacing at that frequency within ± 4 doppler half widths. For each line, a random displacement within this range and a random line strength, (but with an exponential distribution) are selected.

3. RESULTS

Four model atmospheres (solar abundances, $3200 \geq T_{\text{eff}} \geq 2750 \text{ K}$, $\log g = 0$; $T_{\text{eff}} = 3200$, $\log g = 2$) were computed with the new H_2O opacities using the ATLAS6 model atmosphere program (Kurucz 1970). Plane-parallel, horizontally homogeneous media are assumed. The CN, CH, C_2 , CO, OH, NH, and MgH were included through the OS method.

The thermal structure ($T(\tau)$) of the models is not radically altered from that of a SM opacity by the use of the OS treatment of water vapor, but the pressure in the OS model is significantly less than in the SM model, indicating that the OS opacity is actually higher than the SM. This is due to the fact that the opacities tabulated by Ludwig, *et al.*, (1973) are often greater than those by Auman (1967), on which the SM opacities were based, and to the fact that the OS treatment of water vapor includes far larger numbers of weak lines.

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