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POSSIBLE PRESENCE OF LATERAL INFLUX OF THE PHOTOSPHERIC RADIATION WITHIN SUNSPOTS*

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ABSTRACT

The reduced profiles of C_2 5150.56, CN 3864.32, MgH 5150.20 and FeI 5150.84 lines, representing the penumbra, the penumbra-umbra boundary and the umbra of SPO 6403 have been analyzed by comparing them with the synthetic profiles computed from a set of umbral and penumbral models. The results are presented and discussed. It is suggested that there may be a significant lateral flow of photospheric radiation into the umbral and penumbral regions of the sunspots.

I. INTRODUCTION

Sunspot spectra show many lines due to molecular absorption. Some of the molecular species are known to be present only in sunspots, while others are seen in the solar disk as well. This suggests that their spectral details are very sensitive to the physical conditions of the line forming region.

At present, there are numerous sunspot models published in the literature. These models differ widely from each other. The diversity of these models may be in part attributed to the computational procedures and types of the observed data employed in model construction and in part it reflects the true diversity of their physical structures among themselves. For example, we may note that spots' thermal structures are spatially and temporally rather complex due to their intrinsic dynamical fluctuation (e.g. Mattig and Kneer 1978; Yun and Beebe 1982). Such dynamic conditions requre simultaneous observations in order to obtain a physically meaningful set of line profiles.

Recently, Lee, Yun and Lee (1981) made a preliminary investigation by calculating equilibrium abundances of various diatomic molecules and theoretical profiles of a number of molecular absorption lines under various sunspot conditions. Their study suggested that C_2 5150.56, CN 3864.32, CH 4218.73, MgH 5150.20 and TiO 5257.32, for example, form a good set of lines to investigate physical characteristics of umbral and penumbral atomspheres. Therefore, high spatial and spectral resolution spectra of these molecular lines have been taken over a sunspot (SPO 6403) with the Echelle spectrograph at the Vacuum Tower Telescope, Sacramento Peak Observatory.

The prime purpose of the present work is (1) to reduce the observed spectra, (2) to represent detailed profiles, (3) to use these profiles to assess the umbral and penumbral models suggested by Lee, Yun and Lee (1981) and (4) to explore the possibility of indicating observationally the presence of photospheric radiation field within sunspots.

In section II, we describe the observational techniques used in this work and present the reduced profiles. Section III presents the calculated umbral and penumbral profiles and compares them with the observations. Finally, the proposed umbral and penumbral models are assessed and a brief summary is given in section IV.

II. OBSERVATIONAL DATA

For the present work, we made use of the observational materials obtained from high resolution spectra made over a sunspot (SPO 6403)

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Table 1. Spectroscopic Parameters Used

Line(Å)	Element	Order	Dispersion(mm/Å)	Filter	Film(size)
5150.56	C_2	44	9.5	OG515	2415(70)
3864.32	CN	59	13.1	UG 1	5375(70)
5150.20	MgH	44	9.5	OG515	2415(70)
5150.84	FeI	44	9.5	OG515	2415(70)

at Sacramento Peak Observatory on 9 December, 1981 by Yun and Beebe. The observed spot, SPO 6403 was round and single, and it was located near disk center. The size was about 10 arc seconds in diameter.

We followed exactly the same observing procedure as in our earlier observing run (Yun et al. 1980); namely we first observed the disk center and the sunspot, including several frames in which the spot was blocked by an opaque wedge. The blocked frames were used to estimate the amount of the scattered light inside the spectrograph. Calibrations of the film rolls were made by employing a neutral density filter stepwedge before and after each sequence. All the spectra were taken with an exposure time of 16 seconds. The spectroscopic parameters for the observed lines are summarized in Table 1.

The observed spectra of sunspots and the blocked spots were scanned by the SPO's fast microdensitometer. These spectra were scanned spatially from the surrounding photospheric region across the spot. The scanned density data were stored on tapes to convert them to relative intensities by using characteristic curves obtained for individual spectral lines. (See Yun et al. (1980) for details). The raw relative intensity data were corrected for the scattered light by substracting the corresponding blocked spot intensities. The observed data represent typical regions sampled by 200μm slit width which corresponds to approximately 2/3 arc seconds on the solar surface.

The resulting reduced profiles of C_2 5150.56, CN 3864.32, MgH 5150.20 and FeI 5150.84 sampled over a typical disk center, the umbra, the umbra-penumbra boundary and the penumbra are shown in Figure 1. As seen from the figure we note that the observed C_2 5150.56 and CN 3864.32 are enhanced in the penumbra, while they become rather weak under umbral conditions in accordance with our earlier molecular equilibrium calculations under sunspot conditions (Lee et al. 1981). MgH 5150.20 and FeI 5150.84, on the other hand, are getting stronger as one moves from the solar disk center to the penumbra, the penumbra-umbra boundary and finally to the umbra.

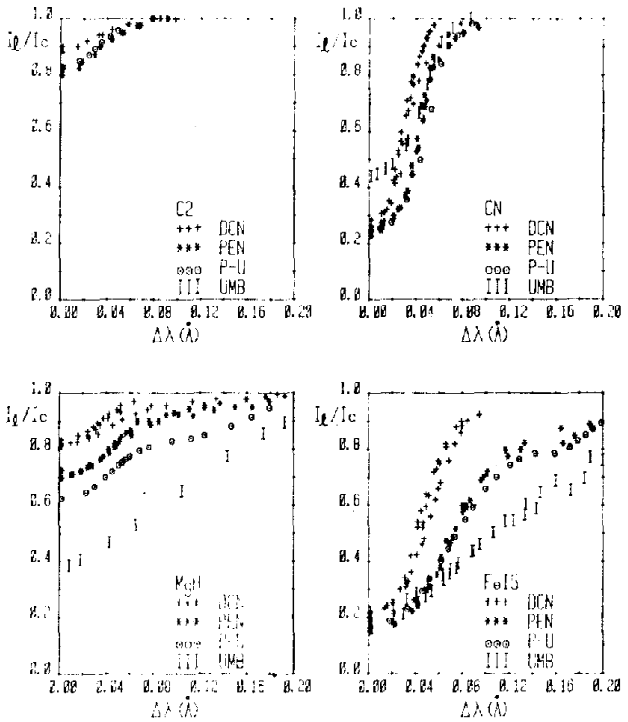

Fig. 1. Reduced Profiles of C_2 5150.56, CN 3864.32, MgH 5150.20 and FeI 5150.84 Sampled over *Disk Center*, *the Penumbra*, *the Penumbra-Umbra Boundary* and *the Umbra* of SPO 6403.

III. RESULTS AND DISCUSSIONS

Assuming the molecular and atomic lines are formed under LTE condition, the line profiles are computed. The proper values of oscillator strength and the damping constant of the lines have been determined by fitting the computed photospheric profiles (HSRA solar model used) to the observations (see Figure 2).

In order to assess our proposed set of models of an umbra and a penumbra (See Lee, Yun and Lee 1981 for details), we calculated the umbral

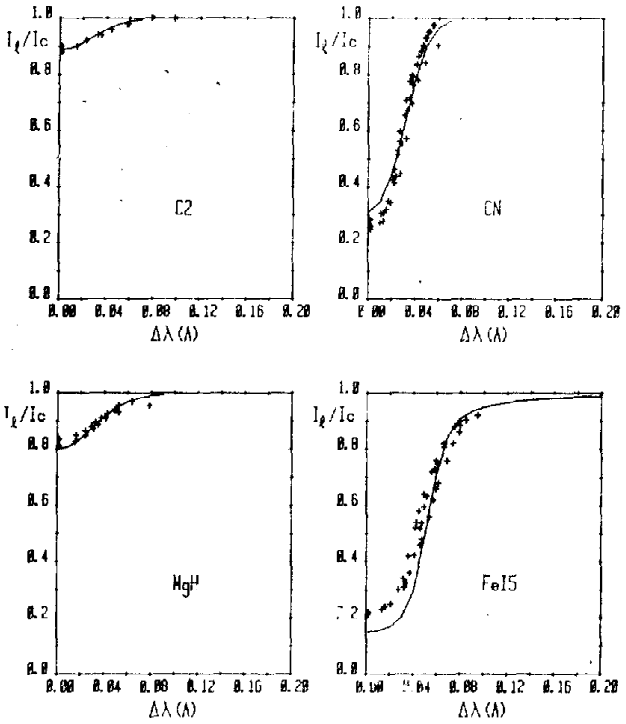

Fig. 2. Comparisons of the Computed(——) and Observed(+++) Photospheric Line Profiles (Based on HSRA Model)

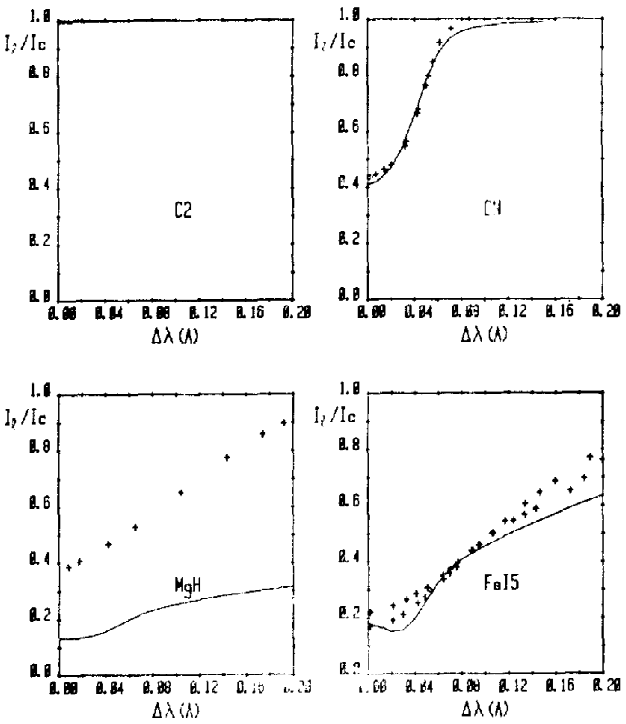

Fig. 3. Observed(+++) and Computed(——) Umbral Profiles.

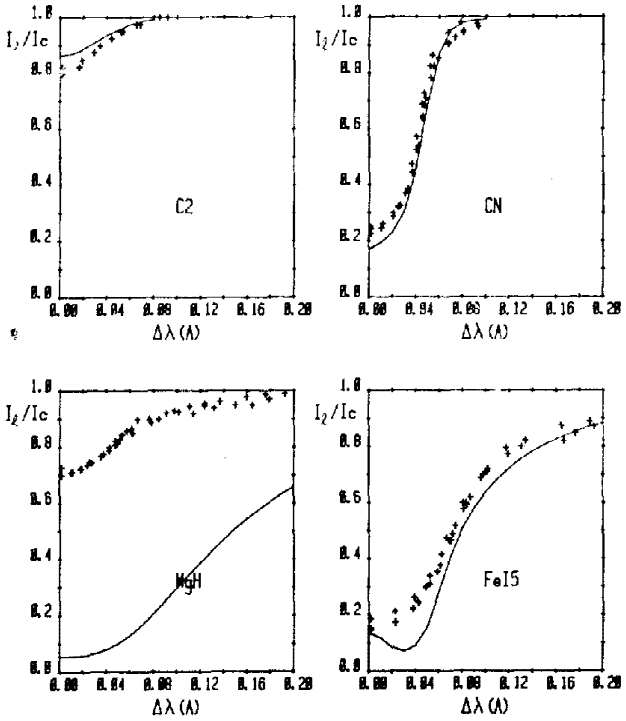

Fig. 4. Observed(+++) and Computed(——) Penumbral Profiles.

and the penumbral profiles of C_2 5150.56, CN 3864.32, MgH 5150.20 and FeI 5150.84 based on these models. These models have been constructed primarily based on Non-LTE analysis of high resolution sunspot spectra of CaII K and H lines made over SPO 5007 (Beebe et al. (1982) and Yun et al. (1983)). The photospheric part of our umbral model has been taken from Albregsten and Maltby's model (1981).

As we may note from Figure 3 and Figure 4 the computed profiles of umbral and penumbral C_2 5150.56, CN 3864.32 and FeI 5150.84 lines appear to be in fair agreement with the observations. The absence of the umbral C_2 line profiles in Figure 3 is due to the fact that the observed C_2 lines are very weak and severely blended and the computed line strength also turns out to be extremely weak. Better fitting to the observations could be made by improving the temperature distributions of our model atmospheres. However, in the present work, we have not attempted to make such fine refinement, because our proposed models represent fairly well the overall gross physical characteristics of the thermal structures of the sunspot SPO 6403. Nevertheless, one has to explain why the proposed models fail to account for the observed MgH 5150.20 profiles.

The weakening of the observed sunspot MgH lines was once reported by Branch(1970), where he found that the observed profiles of MgH are usually weak relative to the computed profiles obtained from Zwaan's umbral model (1965).

We would like to interpret the weakening of MgH lines observed in sunspots as being attributed to the lateral influx of the photospheric radiation flowing into spots. We first noted that the dissociation energy E_D of MgH molecules is extremely low, only 1.34 eV (as compared to the dissociation energies of C_2 and CN molecules, $E_D(C_2)=6.21$ eV and E_D (CN)=7.76 eV and ionization energy of FeI, I(Fe)=7.87 eV). MgH molecules are, therefore much more readily dissociated under the same exposure of the photospheric background radiation. Secondly, we noted MgH lines are formed much higher in the atmosphere(i.e., $10^{-4}<\tau_0<10^{-2}$) than the C_2 and CN lines (i.e., $10^{-2}<\tau_0<1$). Consequently, when the Wilson depression of 500 Km to 800 Km is taken into account, MgH molecules are likely to be exposed by far to greater degree by the lateral photospheric radiation.

In order to corroborate such evidence, we recalculated the line profiles of MgH 5150.20 by using the new equilibrium number densities of MgH computed by raising the temperature of our proposed models by 500°K (Case A) and 1000°K (Case B). The resulting profiles are shown in Figure 5, where the dotted lines refer to Case A and the dashed lines to Case B. As seen from the figure, we note that the agreement between the observations and the computations has been improved by raising the dissociation temperature and the trend is evident.

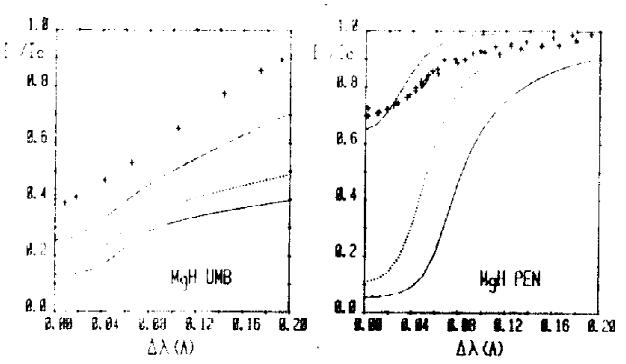

Fig. 5. Observed and Computed Profiles of MgH 5150.20. +++=Observed; ——=Normal Case (ΔT=0°K); ···=Case A (ΔT=500°K); ---=Case B (ΔT=1000°K)

IV. SUMMARY AND CONCLUSTONS

High resolution spectra of C_2 5150.56, CN 3864.32, MgH 5150.20 and FeI 5150.84 observed over a sunspot (SPO 6403) at Sacramento Peak Observatory have been reduced and the resulting reduced profiles are presented for theoretical interpretation.

The reduced profiles have been analyzed by comparing them with synthetic profiles computed from a set of umbral and penumbral model atmospheres. The calculated umbral and penumbral profiles are presented. The present analysis shows that our proposed umbral and penumbral model atmospheres represent reasonably well the thermal structure of the observed sunspot SPO 6403.

Finally, an attempt has been made to interpret the weakening of the observed sunspot MgH line. It is found that there may be a fair amount of the background photospheric radiation floating around within the spot, which probably flows from the surrounding photosphere through the umbral and penumbral walls. It is found that careful study is needed in order to corroborate the presence of the photospheric radiation field within the sunspot.

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