DIAGNOSTIC TOOLS FOR SUNSPOTS: THE MOLECULES C_2, Mg H AND Ti O

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Abstract. The aim of the present communication is to draw attention to the value of simultaneous observations of sunspot umbrae and the quiet Sun in selected molecular lines. It is felt that such observations may lead to an array of sunspot models which account for sunspot sizes, magnetic field strengths, and the solar activity cycle.

Key words: Sun: activity – Sun: magnetic fields – sunspots

1. Introduction

Because molecules are sensitive to their astrophysical environs, they serve as diagnostics for model atmospheres. The occurrence of the molecules C_2 and Ti O both in the quiet Sun and sunspots seems mutually exclusive. Also, the Mg H lines become stronger in sunspots than in the quiet Sun. Sunspot models that satisfy the C_2 and the Ti O lines should also be required to explain the Mg H line intensities. These molecules were selected for analysis for the additional reason that their lines fall into a narrow spectral region where the behavior of the opacity is well known. Careful, simultaneous observations of sunspots and quiet Sun will allow us to correct for scattered light—a common obstacle to sunspot investigations.

2. Results and Discussions

We shall only outline our procedures here, as the details are published elsewhere (Sinha and Tripathi, 1991*a,b*). Under the influence of the magnetic field, the photospheric medium cools and changes in the spectrum become noticeable. However, in the literature, sunspot models with a range in magnetic field are sparse. Also, for obvious reasons, observations of large, stable umbrae are preferred. Stankiewicz (1967) constructed sunspot models as a function of magnetic field strength, and Sobotka (1985), using atomic lines, studied sunspots with different diameters and magnetic fields. His "hot", "intermediate", and "cool" sunspot models are referred to as models 12, 22, and 13 respectively. Maltby *et al.* (1986) proposed that sunspots formed in different phases of the solar activity cycle might be different from one another. If t is the time elapsed since the last cycle minimum, of duration t_0, then $t/t_0 = 0.1$, 0.5, and 0.9 refer to the early, middle, and late phases of the solar activity cycle, respectively. Accordingly, a set of three models, E, M, and L, have been presented by Maltby *et al.* (1986). To facilitate a comparison and to help us see how different these models can be, we present them in Figure 1.

Equivalent widths for molecular lines of C_2, Mg H, and Ti O are listed for these models in Table I. In actual observations one may wish to choose better quality lines. An inspection of Table I leads to the conclusion that in the Stankiewicz (1967) models the C_2 line is insensitive to the magnetic field strength, whereas the Mg H and Ti O lines are stronger in the cooler spots (*i.e.*, where the magnetic field is strong). Our calculations give larger equivalent widths than are observed

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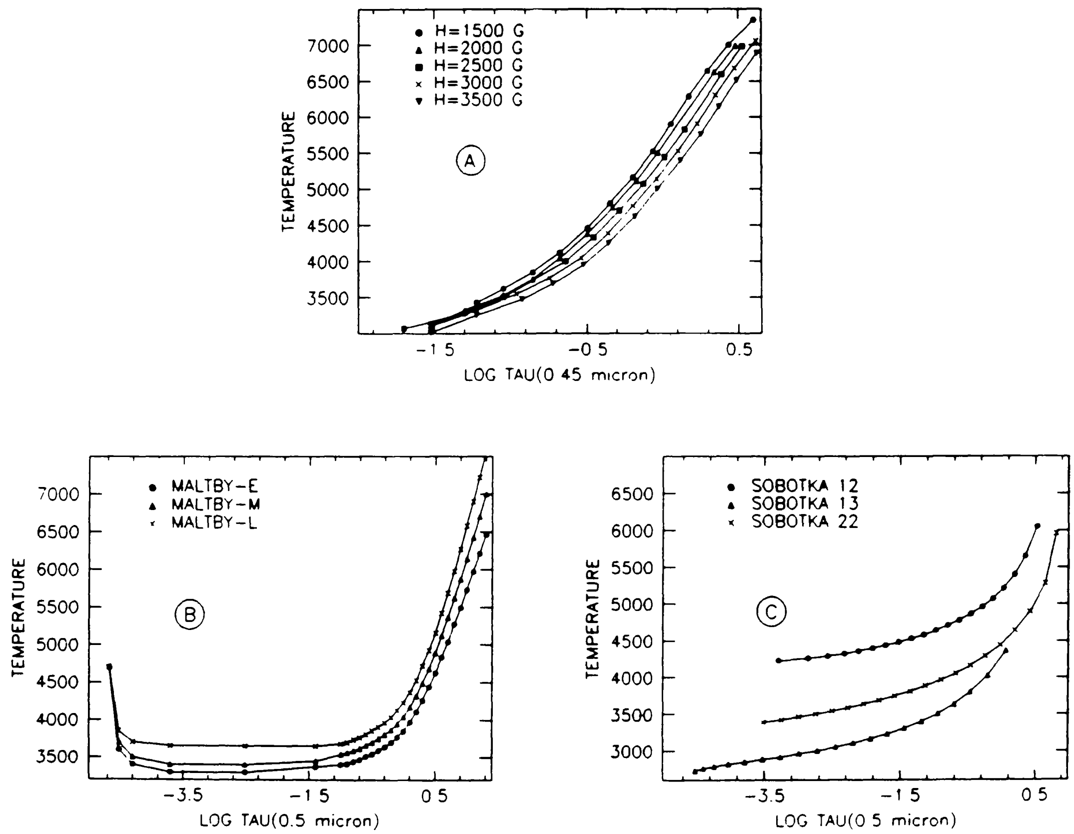

Fig. 1. Optical depth versus temperature for (A) the Stankiewicz (1967), (B) Maltby *et al.* (1986) models E, L, and M, and (C) Sobotka (1985) models 12, 13, and 22.

for C_2, which is not unexpected in view of the preliminary nature of these models. Moreover, these models are derived from a now-obsolete photospheric model due to Minnaert (1953).

Sobotka's (1985) models clearly demonstrate the mutual exclusiveness of the C_2 and Ti O lines. As the sunspot cools, C_2 weakens and Ti O strengthens. The Mg H lines, as expected, intensify. It should be noted here that the lines of the (0-0) band of Mg H are saturated and therefore may not be as sensitive for diagnostic purposes as the lines of the (0-1) band. Also, the equivalent widths for model 13 should be interpreted with caution, as this model does not go deeper than $\tau_{5000} = 0.06$.

The models of Maltby *et al.* (1986) provide ample proof that the umbrae of large, stable sunspots formed at different phases of the solar activity cycle are different in temperature structure. The mutually exclusive nature of the C_2 and Ti O lines in cool atmospheres is again evident (*cf.* Table I). The behavior of the Mg H lines is as generally expected.

Table I suggests that the C_2 lines are greatly reduced in strength in sunspots.

TABLE I
Equivalent Widths (mÅ) for Lines of C_2, Mg H, and Ti O.

Model	C_2 (0 - 0)	Mg H (0 - 1)	Mg H (0 - 0)	Ti O (0 - 0)
	Swan bands 5132.360 Å R_1 (18)	Green bands 5520.23 Å R_1 (13)	Green bands 5061.536 Å Q_2 (37)	α system 5189.80 Å P_1 (31)
Stankiewitz				
H = 1500 G	14.5	11.0	55.6	14.4
H = 2000 G	12.1	17.8	69.9	30.0
H = 2500 G	13.4	22.4	78.7	39.3
H = 3000 G	13.8	24.2	75.2	34.9
H = 3500 G	13.1	29.1	78.2	37.4
Sobotka				
Model 12	10.3	0.3	10.1	0.0
Model 22	3.3	8.1	60.4	3.2
Model 13	0.0	8.5	62.3	53.6
Maltby *et al.*				
Model E	0.7	29.3	86.5	42.2
Model M	1.6	24.7	91.6	44.6
Model L	3.1	16.9	82.8	15.2
Observations				
Quiet Sun[1]	8.0	–	2.9	–
Spot[2]	–	16	58	10

[1] Sinha (1984), Lambert *et al.* (1971).
[2] Sotirovski (1971) .

However, they might still be observed if it is possible to detect lines as weak as about 3 mÅ in sunspots.

3. Conclusions

We believe that simultaneous observations of C_2, Mg H, and Ti O lines in the quiet Sun and in sunspot spectra should lead to a significant improvement in models of sunspots.

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