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Sunspot continuum from 1 to 10 μm and the umbral temperature models

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Abstract : Infrared flux in Zwaan's (1974) and Boyer's (1980) sunspot models has been calculated in the wavelength range 1 to 10 μm, taking into account the molecular line haze opacity (Joshi *et al.* 1979). The calculations are compared with Sitnik's (1980) observations in the available wavelength region 1 to 2.1 μm and corrections in the corresponding models are suggested.

Key words : sunspot intensity—line haze opaciy—umbral model

1. Introduction

Tsuji (1966) pointed out the role of molecular line haze opacity in the infrared and made corresponding models for the M-type stars. Photosphere-to-umbra contrast observations are available for sunspots at very few wavelengths in the region 1 to 4 μm. Only Sitnik (1980) has made the absolute intensity measurements in the wavelength region 1 to 2.1 μm. Infrared transmission windows of the earth's atmosphere have been discussed by Neugebauer & Leighton (1970). New superheterodyne technique of making observations in the 8 to 14 μm wavelength region in the Jovian spectrum with a resolution of $\simeq 10^7$ has been demonstrated by Kostiuk *et al.* (1977) and in the region 1 to 8 μm by Glenar *et al.* (1982). Sinha & Joshi (1982) have shown that the infrared line haze opacity drastically changes the line strength of SiH and MgH lines in the range 4.6 to 7.7 μm, where the line haze is present. We have accordingly calculated the infrared intensity for sunspot models of Zwaan (1974) and Boyer (1980). Zwaan's model is based on continuum observations covering the wavelength span 0.5 μm $< \lambda <$ 4.0 μm whereas Boyer's model is based on 147 lines of TiO, for which scattering corrections have been made.

2. Calculations and results

The technique of determining the line haze opacity has been discussed by Tsuji (1966) and Joshi *et al.* (1979). Figure 1 shows log I for Zwaan (Z) and Boyer (B) sunspot

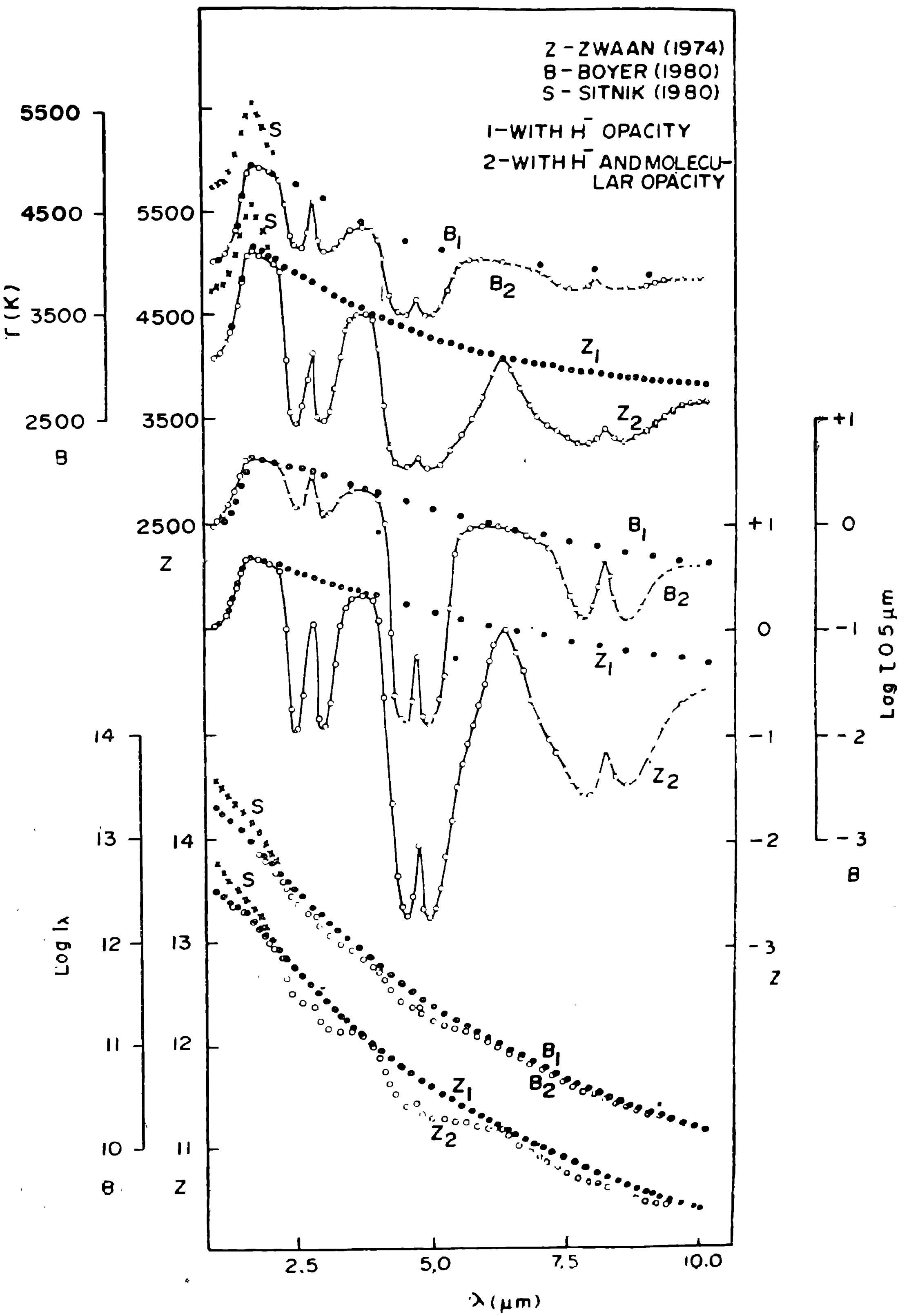

Figure 1. Lower : a plot of log (intensity) *vs* wavelength.
Middle : mean depth of the formation of the continuum *vs* wavelength.
Upper : temperature corresponding to the intensity *vs* wavelength.

models without line haze opacity (Z_1 and B_1) and with line haze opacity (Z_2 and B_2) for the wavelength region 1 to 10 μm. The middle part of the figure gives the effective depth of the formation of the continuum for the 1 to 10 μm region reduced to the $\tau_{0\cdot5\mu m}$ scale. The top of the figure gives T (effective) for these layers. Here a comparison with Sitnik's (1980) observed T (Planckian) has also been made.

3. Conclusions

The infrared (1 to 10 μm) intensity of the sunspots shows considerable variation due to line haze opacity; much more in the Zwaan (Z_2) model than in the Boyer (B_2) model. Boyer's model temperatures are systematically lower than those of Zwaan in the $\tau_{0\cdot5\mu m}$ range of 1 to 4.2. Sitnik's observed intensities are much higher than those calculated by us in the 1 μm range and gradually drop down to the model fluxes at 2.1 μm, even when line haze opacity is ignored. Line haze opacity is not effective in the 1 to 2.1 μm range. So it is suggested that the measured intensities be revalidated as Zwaan (1974) had emphasized. Also, with a view to reproducing the intensity observed by Sitnik, we have tried to correct the model temperatures in the first approximation without changing the corresponding opacities (Sauval 1968). See table 1. Temperature in both the models needs to be increased but still the corrected temperatures do not come out to be the same for the two models. The corrected temperatures for the Boyer model are less than those for the Zwaan model up to $\tau_{0\cdot5\mu m} \simeq 3.9$ and then the trend gets reversed. Thus both these models require corrections.

Table 1. Model temperature T_m and suggested temperature T_i in the Zwaan and Boyer sunspot models

$\tau_{0\cdot5\mu m}$	T_m		T_i	
	Zwaan	Boyer	Zwaan	Boyer
1.0	4060	4010	4850	4840
1.2	4170	4070	4970	4890
1.4	4260	4130	5090	4950
1.6	4350	4180	5200	5010
1.8	4430	4240	5300	5080
2.0	4500	4310	5380	5150
2.2	4560	4370	5450	5230
2.4	4620	4440	5520	5310
2.6	4680	4520	5570	5380
2.8	4730	4600	5630	5460
3.0	4790	4660	5670	5530
3.2	4830	4720	5720	5600
3.4	4870	4770	5760	5660
3.6	4910	4810	5800	5740
3.8	4960	4850	5840	5830
4.0	5000	4890	5880	5920

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