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# $K_{2V}/K_{2R}$ ASYMMETRIES IN THE SUN AND STARS

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## ABSTRACT

The $K_{2V}/K_{2R}$ asymmetry in the self-reversed emission peaks of the Ca II K line in the Sun is the result of the redward displacement of $K_3$. This redward displacement is explained as caused by the dark condensations in $K_3$ and not due to the supergranulation flow pattern. Arguments are presented to show that such asymmetries in the spectra of stars provide evidence for the presence of these structures in their chromospheres.

*Subject headings:* Ca II emission — stars: chromospheres — Sun: chromosphere

## I. INTRODUCTION

Considerable effort, particularly during the last one and half decades, has been focused on the study of the emission cores of the two Ca II resonance lines—the H and K lines—to understand the physical properties of the chromosphere of the Sun and other similar late type stars. The general appearance of a high quality K-line spectroheliogram of the quiet Sun may be summarized as follows: The coarse network, cospatial with the underlying supergranulation cell, has a linear size of about 30,000 km. The coarse mottles populate the boundaries of the network. In the interior of the network are the bright points, measuring 1″ or less, and the dark condensations (Bappu and Sivaraman 1971; Zirin 1974). The bright points inside the cells are seen in $K_{2V}$ and $K_{2R}$, particularly in the former. In $K_3$, the bright points are much less apparent, while the dark absorbing clouds are seen most prominently.

## II. OBSERVATIONAL MATERIAL

In the case of the Sun, the integrated K profile over the cycle has been examined by White and Livingston (1978). An unchanging feature of this profile is the excess of emission in the violet wing over the red wing which is commonly represented by $K_{2V} > K_{2R}$. The inequality in the case of the Sun has been attributed by Bappu and Sivaraman (1971) to the partial obscuration of $K_{2R}$ emission by the downflowing dark condensations seen in $K_3$, which are absorbing columns of matter of about 4000 km in size that rain into the chromosphere with velocities of 5–8 km $s^{-1}$. This local redward displacement of $K_3$ causes either a partial or a complete obscuration of $K_{2R}$ of the individual profiles depending upon the magnitude of the redward velocity. Thus the $K_{2V} > K_{2R}$ situation is the direct manifestation of these dark condensations in the solar integrated spectra. An examination of the spectra of 32 stars, some showing $K_{2V} > K_{2R}$ and others its reverse $K_{2V} < K_{2R}$ along with the corresponding $K_3$ displacement, shows that the inequality is explained satisfactorily with this concept (Bappu and Sivaraman 1977). Stencel (1978) has studied this inequality in G, K, and M giants and has drawn the interesting conclusion that the ratio could be used as an indicator of mass loss.

The integrated light K-profile of the Sun shows a redward displacement of $K_3$ of the order of 0.015 Å (Bappu and Sivaraman 1977). A small change in this value over the sunspot cycle has also been noticed (White and Livingston 1981). From an examination of several high quality spectroheliograms obtained at Kodaikanal during the solar minimum phase, we find that on an average these dark absorbing clouds occupy about 25–30% of the area within the Ca II network. Of the total number of 3000 network cells on the solar surface, about 2500 may be taken as the effective number, the rest being too close to the limb to contribute effectively to the integrated profile. From the total number of the dark condensations present inside the effective number of the network cells over the solar surface during such a phase, we can obtain the velocity $v$ which we would expect to see in $K_3$ in integrated light by smearing the redward velocity of all these over the entire Sun. Taking the linear size of the supergranulation cell as 26,000 km and assuming 25% of its area to be covered by dark condensations with a downflow of 5 km $s^{-1}$, we find:

$$\pi \times 2500 \times \frac{(26{,}000)^2}{4} \times \frac{25}{100} \times 5$$

$$= \pi \times v \times (6.96)^2 \times 10^{10}, \quad v \sim 1.1 \text{ km s}^{-1}.$$

## III. DISCUSSION AND CONCLUSION

This value of the shift in $K_3$ agrees well with the one observed in the integrated spectrum of the Sun. Therefore, when we observe the $K_{2V}/K_{2R}$ inequality, we are observing the cumulative performance of these structures. Linsky *et al.* (1979) interpret this asymmetry $K_{2V} > K_{2R}$ in the case of the Sun as due to the downflow at the supergranulation cell boundaries and proceed further to infer that the presence of such asymmetries in the spectra of dwarfs is evidence for a similar flow pattern in their atmospheres.

In the following we estimate the combined effect of this flow over the entire Sun and the downward velocity it would give rise to in the integrated case. We adopt a cell size of 26,000 km, a boundary thickness of 3000 km, and a flow velocity of 0.5 km $s^{-1}$. Assuming the boundary of the cell to be an annular ring and the number of cells over the solar surface to be 300, the area of the boundary is $2\pi \times 13{,}000 \times 3000$ km$^2$. The combined effect of all this downflow will give a net downward velocity on the integrated Sun of 0.24 km $s^{-1}$. Even with the most optimistic values for the cell area and velocity, the $K_{2V}/K_{2R}$ asymmetry actually observed cannot be explained by such a low value for the downward velocity.

We therefore believe that the $K_3$ redward displacement of 1.2 km $s^{-1}$ observed in the integrated spectra of the Sun, which causes the $K_{2V}/K_{2R}$ asymmetry is the manifestation of the cumulative effect of the downflow in the dark condensations. If this is true in the case of the Sun, the inequality $K_{2V} > K_{2R}$ observed in other dwarfs and perhaps in giants should be taken as an evidence for the presence of such dark clouds with downflowing absorbing matter in the atmospheres of these stars. The question of mass conservation remains to be settled in all problems of downflows and upward flows on the Sun, and the present case of downflow in the dark condensations is no exception.

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