Ca II K LINE PROFILE OF THE TRULY QUIET SUN

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Abstract. While evaluating the chromospheric variability (solar cycle related or any other) using the Ca II K line (λ3933.684 Å) as an indicator, an essential prerequisite is the knowledge of the profile of a truly quiet Sun in the integrated light. Such a profile can serve as a bench mark over which enhancements can be measured, particularly when modelling variability. This paper describes how such a K-line profile has been derived for the quiet Sun using disc-integrated light.

1. Introduction

The H and K lines of ionized calcium have been extensively used as a diagnostic parameter to study the solar chromosphere in a variety of aspects both at high spatial resolution as well as the Sun as a star. The success in this endeavour has provided the way to establish the solar-stellar connection and make progress in the study of the chromospheres of stars similar to the Sun. In all these attempts, the behaviour of the Ca II H and K lines on the Sun has served as a reference and also as a testing ground for many hypotheses and theories, the conclusions of which have been used to interpret the observed behaviour of the emission component of these lines in Sun-like stars considering known phenomena relating to the K line on the Sun. These interpretations pertain to many phenomena like stellar rotation, detection of solar like cycles, magnetic structures, their evolution, etc., in late type stars (see, e.g., Noyes, 1980). The two main parallel streams of study on the Sun during the last couple of decades have been to examine in detail the Ca II K (or H) line profiles of individual inhomogeneities at high spatial resolution as well as of the disc-averaged Sun (i.e., the K-line profile of the Sun as a star). There has been a certain measure of success in modelling the globally averaged K line profile by synthesising the high spatial resolution profiles pertaining to the various inhomogeneities (Skumanich *et al.*, 1984).

Now, coming back to the Sun, the K-line profiles (whatever is described for the K line holds true for the H line also) seen under high spatial resolution, have myriad shapes and forms and each one of these forms, corresponds to a particular chromospheric feature. The integrated sunlight in the Ca II K displays an emission feature and the identifiable contributors to this emission are the quiet network, the bright points in the interior of the network,the active network, and plage. The bright points, the unresolved quiet chromosphere, and the network form the 'quiet' chromosphere component. Active regions fragment in the final stages of their evolution and disperse by a random-walk process, and ultimately mix with the

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quiet network elements to form the active network component that considerably enhance emission from the network. This last named contributor, the plage, is strikingly bright on the solar surface because of the excess emission. During the peak of solar activity plages occupy about 10% of the solar surface. Although this is only a fraction of the area occupied by all the network elements put together, the contribution from the plages to the integrated flux is overwhelmingly large compared to those of the remaining contributors because of its high intensity constrast.

To represent the quiet profile of their model (network + cell) Skumanich *et al.* (1984) used the mean value of the K 1A index of White and Livingston (1978, 1981) who derived this by averaging over a quiet region near the centre of the disc. They then derived the full disc K index for the quiet Sun by applying the limb darkening function to this disc centre value. To this they added the plage component of the appropriate area and the active network and, using the extant contrast, arrived at the three component model to explain the variability in the Ca II K line of the Sun as a star. Such a treatment has ignored the contribution from the network which are likely to be different from the sample used and also the contribution from polar faculae which are conspicuous during the solar minimum. The quiet value of the K index most appropriate for modelling would be the one which is truly representative of the disc-averaged Sun. The latter will include contributions from network elements in the higher latitude zones as well as from the polar faculae. Bappu and Sivaraman (1977) compared the K-line profiles obtained by averaging over the slit, as well as by averaging over a small quiet region at the centre of the disc with the disc-integrated profile, and demonstrated that the latter is strikingly different from the two averaged profiles in terms of the intensity, K2 width, central depth, etc. It is therefore unlikely that the quiet profile obtained by extrapolation from the average over a small region on the Sun at the centre with limb darkening corrections would simulate the disc-integrated quiet-Sun profile. Thus there is an obvious need in the literature for a truly integrated profile for the quiet Sun which would serve as a bench mark above which the contributions from the various features to the K emission and hence the variability can be properly modelled. Our aim in this paper is to provide the K-line profile of a truly quiet Sun in the integrated light derived from profiles obtained during the minimum activity epoch. An even quieter representation would be a profile obtained at high spatial resolution on the quiet disc within the network and avoiding the bright points, but this cannot represent a disc-averaged quiet profile.

2. Observations and Data Reduction

We have a regular on-going K-line program at the Kodaikanal solar tower since 1969 and this has resulted in a good archive of these disc integrated K-line profiles. The instrumentation set up for these observations are described in Sivaraman *et al.*

TABLE I

Details of observations

Date	Exposure (min)	Number of profiles obtained	Plage area in millionths of the visible hemisphere
29 Jan., 1985	45	5	0
31 Jan., 1985	50	2	0
24 Sept., 1986	40	3	0
12 Jan., 1987	45	3	0

(1987). During the last minimum period of 1985–1987, there were extended periods when the Sun was very quiet, with only the weak network, the cell interior with the bright points and the polar faculae (Makarov and Sivaraman, 1989; Sheeley, 1991) which is a concomitant feature at the higher latitudes. The K 1A index was lowest in 1985, 1986, and early 1987 as seen from the Kodaikanal data as well from the 1 Å K index plots of Livingston (1994). We have examined the daily K_{232} spectroheliograms of Kodaikanal of this period and have picked out the K line spectra in the integrated sunlight of four days when the Sun was very quiet and free of even the tiniest plage for this study. Furthermore, the network was free of the remanants of active regions, exhibited weak emission the pattern of which is broken and incomplete as is typical of the truly quiet Sun.

In Table I we list the details of the data we have used to derive the quiet-Sun profile. These spectra were obtained in the sixth order on 103a-0 emulsion at a dispersion of $\sim$ 9.4 mm Å^{-1} and have their own photometric calibration. The digitized density values of the line profiles obtained at two or more independent locations along the slit were converted to the relative intensity scale following the regular photometric reduction procedure. These profiles were converted to the absolute intensity scale using the residual intensity value at λ3935.16 Å on the red wing of the K line as a reference. Residual intensity at this wavelength in the K-line wing is 13.8% of the continuum (White and Suemoto, 1968). This value is applicable only to the disc centre measurements and must be corrected for the limb darkening when used for converting full disc measurements. When corrected for limb darkening the value is 16.7% of the continuum (Skumanich *et al.*, 1984).

3. Results

The Kodaikanal spectrograph is the single pass Littrow type. We have set up a double pass spectrograph system at the Bangalore campus which has a similar program of acquiring K-line profiles of the disc-integrated Sun since February 1989. This system uses a photomultiplier and is near scatter free. Using the K-line

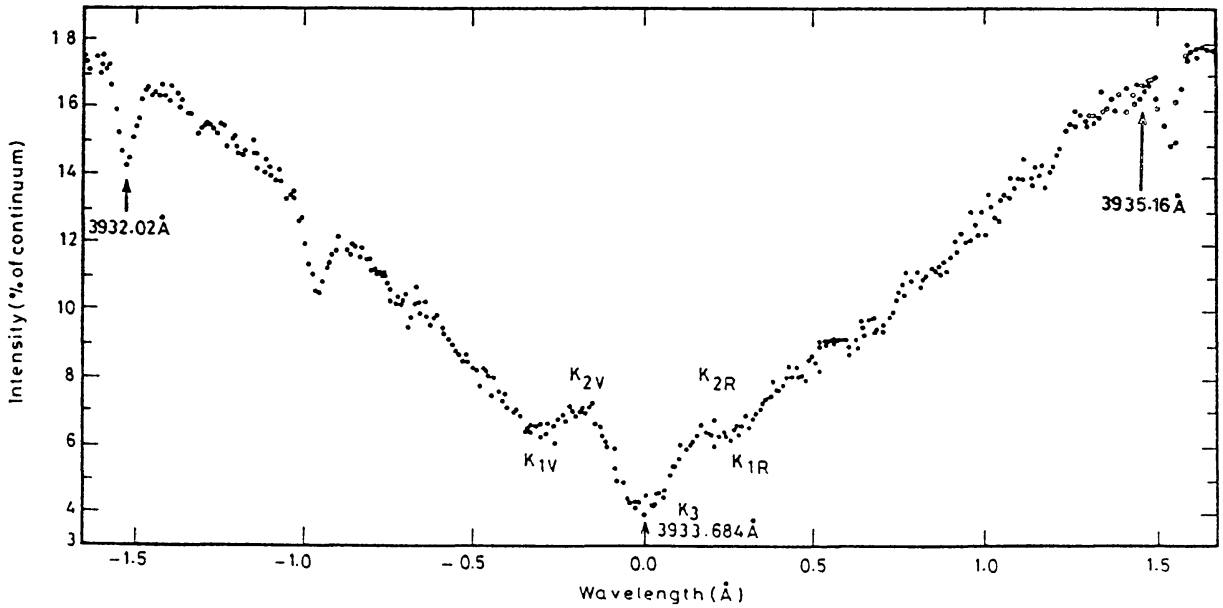

Fig. 1. Disc-integrated K-line profile of the truly quiet Sun corrected for the scattered light (derived from Kodaikanal photographic spectra). The reference continuum is at λ3935.16 Å.

TABLE II

Parameters of the quiet-Sun profile (averaged over the whole disc)

Locations	K_{1V}	K_{2V}	K_3	K_{2R}	K_{IR}
Mean correction for scattered light	0.72	0.55	1.00	0.73	0.75
Intensities after correcting for scattered light (in % of I_c)	6.46	7.22	3.84	6.57	6.19

profiles obtained on the same days from the spectrographs at the two stations we have evaluated the scattered light corrections to be applied to the single pass profiles of Kodaikanal at the locations K_{1V}, K_{2V}, K_3, K_{2R}, and K_{1R} of the line profile. These are set out in Table II. The mean correction at K_3 is $\sim 1\%$. In Figure 1 we present the disc integrated profile typical of a truly quiet Sun corrected for the scattered light. In Table II we also present the parameters of the corrected profile of Figure 1. The K_2 width of the corrected profile from peak to peak is 30.6 km s^{-1} and at the e^{-1} level is 38.1 km s^{-1}. The latter agrees perfectly with the value of the width derived by Bappu and Sivaraman (1977). The e^{-1} width is the width which one would measure if a micrometer were used for the measurement as was done for the stars by Wilson and Bappu (1957).

The width for the plage is different, and the plages themselves exhibit a variety of widths (Smith, 1960; Bappu and Sivaraman, 1971; Shine and Linsky, 1972).

TABLE III

K-line central intensities

Source	K averaged over the whole disc
Goldberg, Mohler, and Muller (1957) as corrected by Teske (1967)	3.47
Teske (1967)	4.09
White and Suemoto (1968)	5.04
Present study	3.84

As a consequence of this, the widths also exhibit variability over the cycle (White and Livingston, 1981; Sivaraman *et al.*, 1987). In view of the variability of the width, we feel, these widths should be defined explicitly among other parameters characterising the profile to make the definition complete.

Finally in Table III we present our value along with the central intensities obtained by earlier workers after converting them from disc-centre to disc-averaged values.

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