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A NEW TECHNIQUE TO STUDY THE VARIABILITY OF THE SUN

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Abstract

A method has been developed to take the high resolution spectra in ionized calcium K line at different latitudes and integrated over visible 180° longitude These spectra have been analysed to study the variability of the line profile as a function of latitude The spectra are being obtained on regular basis and large data base will be used to study rotation differential rotation, activity and variability of K-line parameters in various latitudes with the phase of solar cycle

1 Introduction

Attempts were made in the past to measure the total solar irradiance from the ground to study the variability of the Sun but the data have limited use because of different atmospheric transparencies at different times Recently total solar irradiance data have been obtained from space using the cavity radiometer aboard the Earth Radiation Budget (ERB) experiment on the Nimbus 7 satellite (Hickey and Alton, 1984) and by Active Cavity Radiometer Irradiance Monitor (ACRIM) on NASA's Solar Maximum Mission (SMM) The ACRIM data having very good accuracy of ± 0 02 percent for the period 1980 84 (Willson, 1984) show that total solar irradiance varies with the phase of solar cycle being more at the maximum phase The data have been obtained only during the declining phase of the solar activity Therefore, the observed variation in the irradiance may be real or due to loss of sensitivity of the instrument with time Only the increase in irradiance if observed after making measurements with the same detector during the next maximum phase in year 1991 will confirm the results

The other method to study the long term variability of the Sun is to monitor calcium K line profiles of the Sun as a star White and Livingston (1978), Oranje (1983), Keil and Worden (1984) and Sivaraman et al (1987) have used various techniques to record the calcium K line profiles integrated over the visible solar surface Livingston, Milkey and Slaughter (1977) imaged the Sun on the grating of spectrograph and scanned the spectra photoelectrically Keil and Worden (1984) used a small cylindrical lens of 5 mm focal length in one direction and no curvature in the other direction to form 50 μ x 10mm line image of the Sun within the spectrograph slit and recorded the spectrum with photoelectric scanner The setup used by Sivaraman et al (1987) is shown in Figure 1 Two mirror coelostat installed at 11 m high tower collected the light from the Sun and fed it to the third mirror which in turn directed the light to the 18 m spectrograph Littrow arrangement in the spectrograph with 18 m focus lens and 600 lines per mm grating blazed at 5000 A yields a dispersion of 9 34 mm/A around calcium K in 6th order To integrate the spectra over the whole of visible disc, third mirror of the coelostat system was covered with a aluminium cover painted with white pigment (TiO_2) which scatters almost all the light in all directions Therefore, a point at the spectrograph slit receives the light from the whole visible Sun The integrated spectrum is recorded on Kodak 103 a0 film The data obtained by all these observers have confirmed that the Sun is a variable star if observed in 1 A window centred around calcium K line and line profile varies with the phase of solar cycle

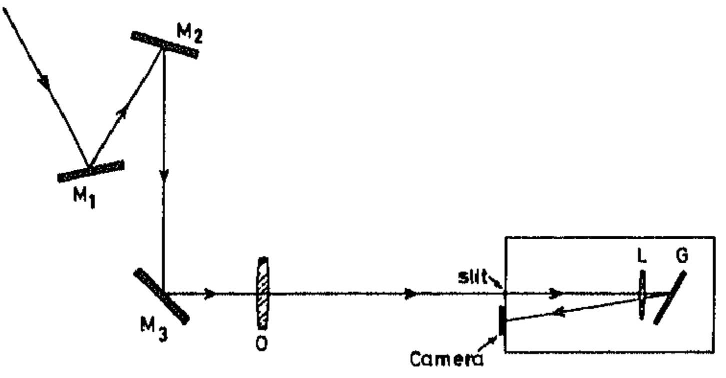

Fig. 1 Optical arrangement of Solar Tower telescope at Kodaikanal

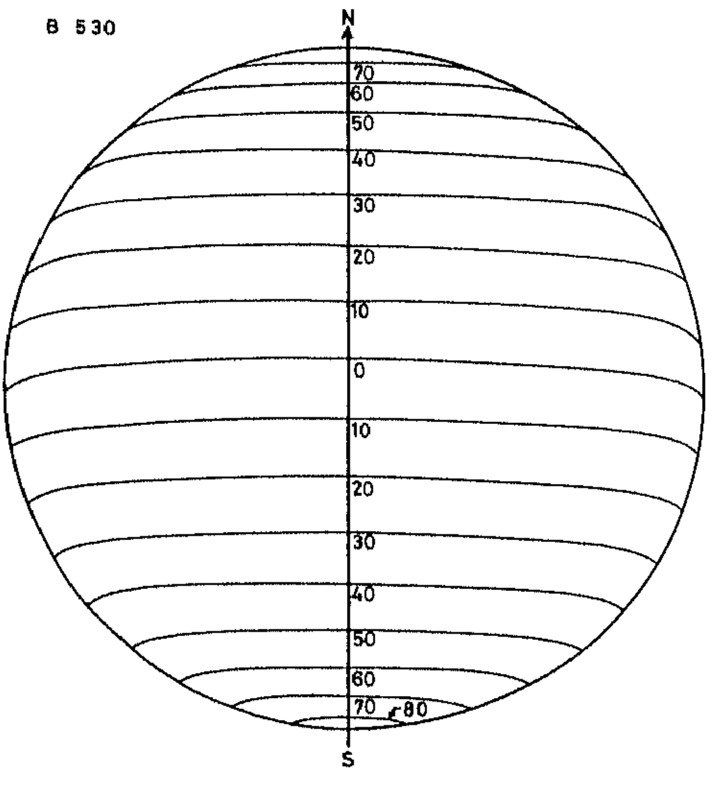

Fig. 2 A typical Sun chart prepared for making the observations

Most of the change in the profile are attributed to the development of plage regions on the Sun Skumanich et al (1984) proposed a three component model of the solar cycle variability of the calcium K emission using extant contrast and fractional area parameters for (1) cell (2) network and (3) plage components They were able to fit computed line profile with the observed one at the solar minimum by taking the contribution of only cell and network features and using extant limb darkening laws The occurrence of plages during the growth of the solar cycle was found to be insufficient to account for the increase in K emission and therefore they introduced an additional network component, Active network' in excess of the quite Sun value to explain the observed emission during maximum phase On the contrary measurements by White and Livingston (1978) over the centre of disc integrated over 1 x 3 do not show any change in K index with the solar cycle phase It may be possible that contribution to 'Active network comes from the higher latitude belts

Therefore, a new technique has been developed which will give information about the 'Active network contribution during different phases of solar cycle, chromospheric differential rotation, long period variation of rotation rate, activity and variability of calcium K line parameters in various latitude belts with the phase of solar cycle

2 Method and Observations

As shown in Figure 1, objective O' of 36 m focal length forms an image of the Sun 34 cm in diameter at the spectrograph To obtain the spectrum at a given latitude and integrate over the 180 longitude, a Sun chart corresponding to the image size and heliographic latitude of disc centre 'B' on that day is made on a thick sheet of paper as hown in Figure 2 with N S of the sun marked The latitude lines at an interval of 10 degrees are drawn on the Sun chart This is kept near the focal plane of the Sun's image in such away that N S axis marked on Sun chart become parallel to the axis of rotation of the image The height of the Sun chart adjusted in such a way that when North limb of the Sun's image is moved along a particular latitude line the Sun chart say 30°N the same latitude area of the solar image (30°N) falls on the centre of the spectrograph slit For integrating the spectra along the longitude, the second mirror M_2 of the coelostat is moved with a uniform speed using an electric motor from east to west along a given latitude line It takes 15 seconds to move the image from east to west at the equator during which exposure of the spectrum is made on Kodak 103 aO, 35 mm film A step wedge calibration is also recorded on the same film using unfocussed solar image and an area free from active regions The density curves of the recorded spectra were converted to intensity curves by standard photometric method to obtain the calcium K line profiles Two such typical profiles, one at a latitude of 80°N and other at equator are shown in Figure 3 The curves have been normalized at an intensity value of 13 percent at 3935 16 A on the red wing of calcium K line given by White and Suemoto (1968)

3 Results

We have analysed the 6 days data obtained between the period December 1985 January 1986 The visible solar surface was almost devoid of plages during this period Figure 3 how that all the parameters of calcium K line for the profile of 80°N latitude differ from that of profile at equator The model computations are required to be done to study these variations Some of the parameters to be investigated are listed below

K index As defined by Wilson (1968) for stellar measurements, the K index is the equivalent width in a 1 A band centered around calcium K line This index should be proportional to the total chromospheric emission from the star (Linsky and Ayres, 1978)

K_1 width This is the width between the two minima of core emission and the line wings

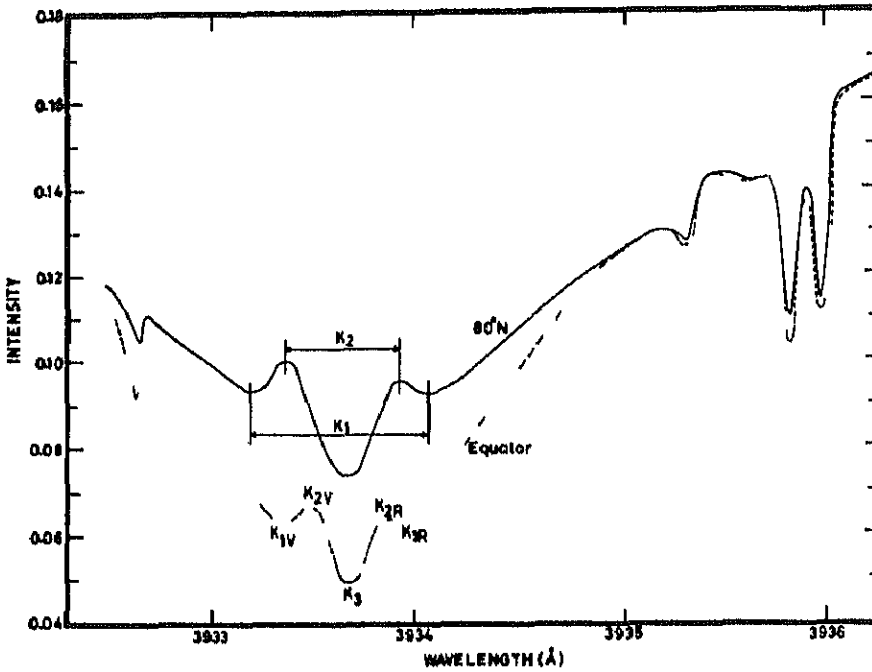

Fig.3 Typical calcium K line profile, obtained on Jan 1, 1986 at the solar equator and 80 N and integrated over the visible 180 longitude The various K line features are marked in standard K line rotation

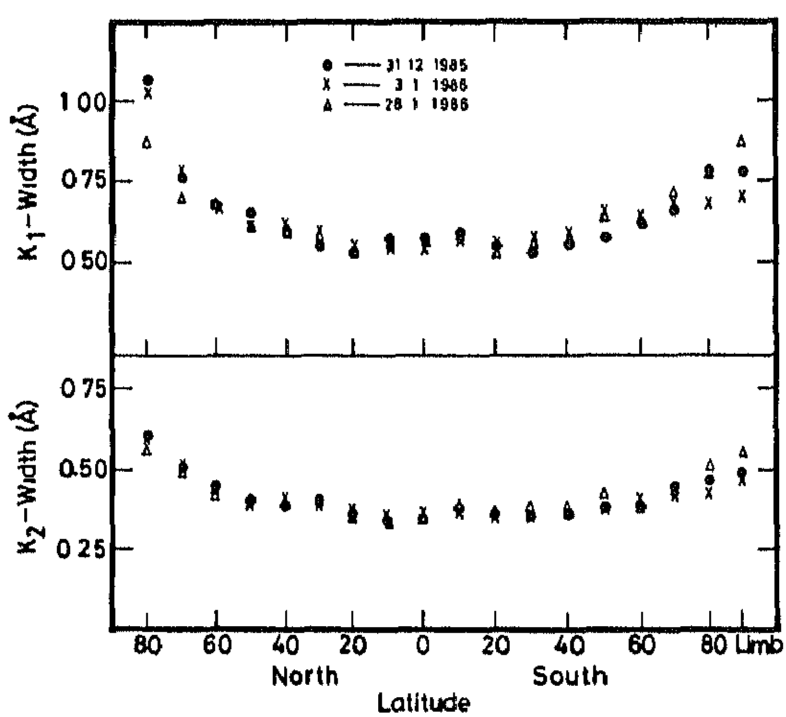

Fig.4. K_1 and K_2 widths as function of latitude of the Sun

K_2-width This is defined as the width between the emission cores, K_{2V} and K_{2R}

Wilson-Bappu parameters As defined by Wilson and Bappu (1957), this is the width measured between the outer edges of the K_2 emission peaks as seen on photographic stellar spectra We estimate this parameter with the method suggested by Smith (1960), that is, a line width measured on the outsides of the red and violet emission peaks and at an intensity level midway between the K_2 maximum and K_1 minimum on each side of the line

Central Intensity Thi is the minimum residual intensity in the K_3 line core and should be proportional to the emission loss from the upper chromosphere

Violet Red Ratio This parameter K_{2V}/K_{2R} measures the asymmetry in the net emission above the level of central intensity

K_2 Emission Strength The relative strength of emission from the lower and upper chromosphere is measured by this ratio of violet emission peak to the central intensity (K_{2V}/K_3)

In Figure 4, we how the variation of K_1 and K_2 widths as a function of latitude of the Sun for three days of data to get an idea about the variation or scatter in the values for each day The average variation of 6 days of observations and the standard deviation for various latitudes i plotted in Figure 5 The other parameters of the line profiles are being determined from the raw data

4. Advantages of this technique

Here we list the major advantages of this method of observation over the usual observations of the Sun as a star

i) The sunspots and related features generally used for activity studies, give information only between 10 to 40 degree latitude belts on the Sun The changes in the polar regions are not well known The data obtained from the above method will yield this vital information about polar regions

ii) Skumanich et al (1984) have incorporated an 'Active network' component to explain the observed line profile There are no measurements of this component The above method would give plage free profiles of the same latitude belts during the different phases of the solar cycle and hence the value of 'Active network' during various phases

iii) Singh and Livingston (1987) have shown that power spectral analysis of K index observed at fairly regular basis gives the value of chromospheric rotation rate Therefore similar analysi of the data obtained for different latitude belts would yield rotation rate for various latitudes and hence help in determining the value of chromospheric differential rotation rate

iv) Singh and Prabhu (1985) from the analysis of plage areas have shown that chromospheric rotation rate varies with time but the analysis is restricted to only few latitude belts due to occurrence of plages in those latitudes The analysis of the present data will yield the values of rotation rate with time in all latitudes and thus, would give a clue to the slow and fast rotating bands on the solar surface

v) The data will provide information about the variation of calcium K line profile in various latitudes as a function of solar cycle phase and therefore, a detailed picture of activity and magnetic flux movement on the solar surface

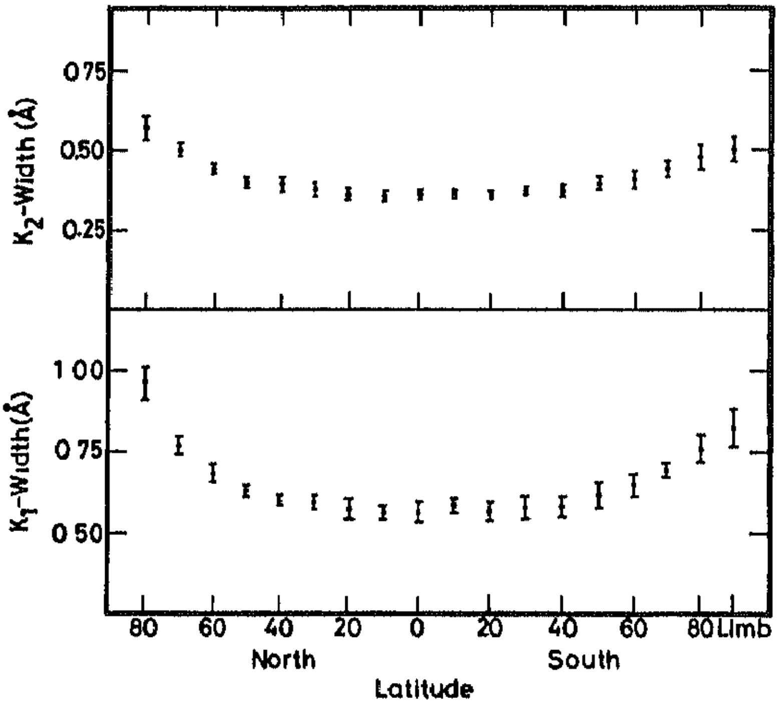

Fig.5 Average values of K_1 and K_2 widths for 6 days of data as a function of latitude The standard deviation of each value is also shown

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