# SUN AS A STAR: ROTATION RATES FROM THE Ca K-INDEX

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**Abstract.** Daily measurements for 18 months made at Tucson of the Ca K-index in integrated sunlight have been used to derive solar rotation rates. Power spectral analysis shows that one can obtain a well defined value of solar rotation rate in a period of six months, provided the data are fairly continuous. One might suppose it is possible to study the variation of solar (or stellar) rotation rate with time, a variation arising from a combination of differential rotation and shifts in the active latitude. A comparison between our observed rates and the prevailing dominant activity zones does not support this supposition, at least for the interval studied. Rather, our rates seem to depend on the circumstances of sampling and active region birth and decay.

## 1. Introduction

The time variation of apparent plage area on the visible hemisphere of the Sun provides a clear signature of the solar rotation (Bappu and Sivaraman, 1971). Singh and Prabhu (1985) have studied the variations in solar rotation rate using power spectral analysis of total calcium plage areas. This variation of plage area on the visible disc also modulates the intensity of the Ca K line in integrated light. White and Livingston (1981) have monitored the integrated light Ca K line profiles at Kitt Peak using a double pass spectrometer continuously since 1974 on a monthly basis; whereas Keil and Worden (1984) have made similar observations on a daily basis, beginning more recently, at Sacramento Peak. Keil and Worden (1984) find that daily plage area correlates well with K-index variations over periods of a solar rotation, and power spectral analysis of the K-index gives an acceptable value for the solar rotation rate. LaBonte (1982) proposes, however, that although the average rotation rate of the Sun can be determined from the disk-integrated data, the accuracy is not sufficient to measure differential rotation.

With a view to improving the temporal resolution necessary for assessing the K-index as a rotation and flare indicator, and for studying the correlation between the K-index and solar UV (1000–2000 Å) irradiance, Livingston *et al.* (1984) monitored the K-index on daily basis at Tucson between January 1983 and July 1984. The K-index data are used herein to evaluate the solar rotation rate and its variation. The objective of this note

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is not to study the intrinsic variation in the rotation rate, if such exists, but to attempt to correlate the rotation rate to the shift of active latitudes with time.

## 2. Observations and Data Analysis

The Tucson observations for computing the K-index were obtained using a Littrow spectrograph with a Reticon diode array in the focal plane. The signal-to-noise ratio in the resulting spectra is high (> 1000) but there may exist zero-point errors due to the variations in grating illumination and due to the fact that the spectrometer is single pass.

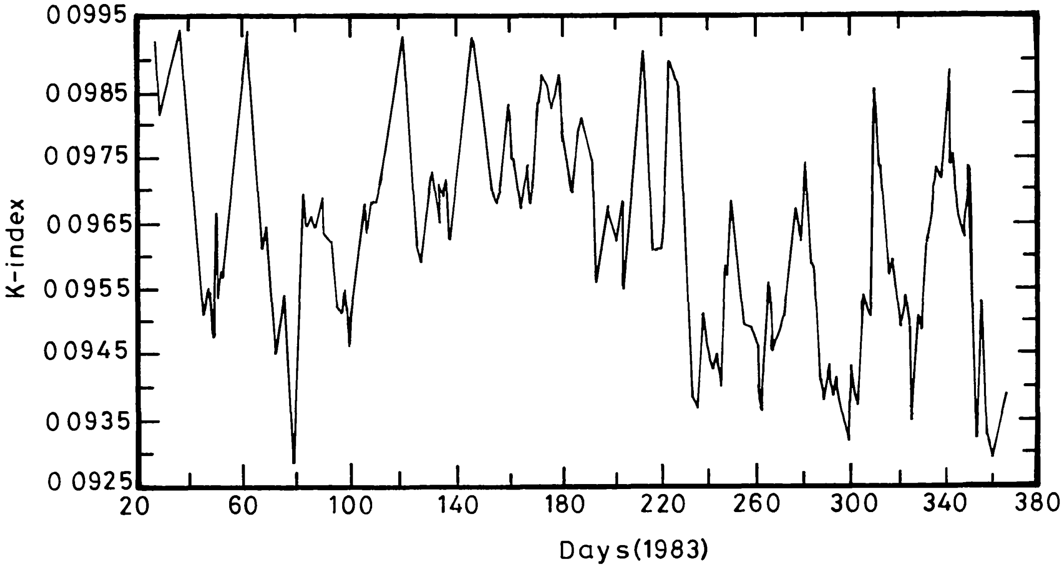

Fig. 1. Variation of K-index of the Sun as star for the period January 1983–December 1983.

In Figure 1 we have plotted the K-index for the period January 1983–January 1984. This figure indicates that the K-index varies with a period of about 27 days presumably related to solar rotation. A raw power-spectral analysis of this data was done by using FFT technique described by Deeming (1975). An analysis of the total data (January 1983–July 1984) have two peaks around 27 days indicating the presence of two rotation rates. These two rotation rates might correspond to consecutive periods of differing conditions within the sample interval. To test this idea, the data were split into three intervals of six months each. The power spectral curves (Figure 2) for two such periods (January 1983–July 1983; July 1983–January 1984) are different, with the rates being given in Table I. These results may be compared with a similar analysis of the K-index data of Keil obtained at Sacramento Peak Observatory, and He 10830 data measured at the vacuum telescope at Kitt Peak National Observatory.

To correlate the observed changes in the rotation rate with activity zone, we have plotted the calcium K-plage areas for three latitude belts in Figure 3. Variation of calcium K-plage area with time is shown only for 0–10°, 10–20°, and 20–30° latitude belts in both hemispheres because most of the activity existed in these belts during the

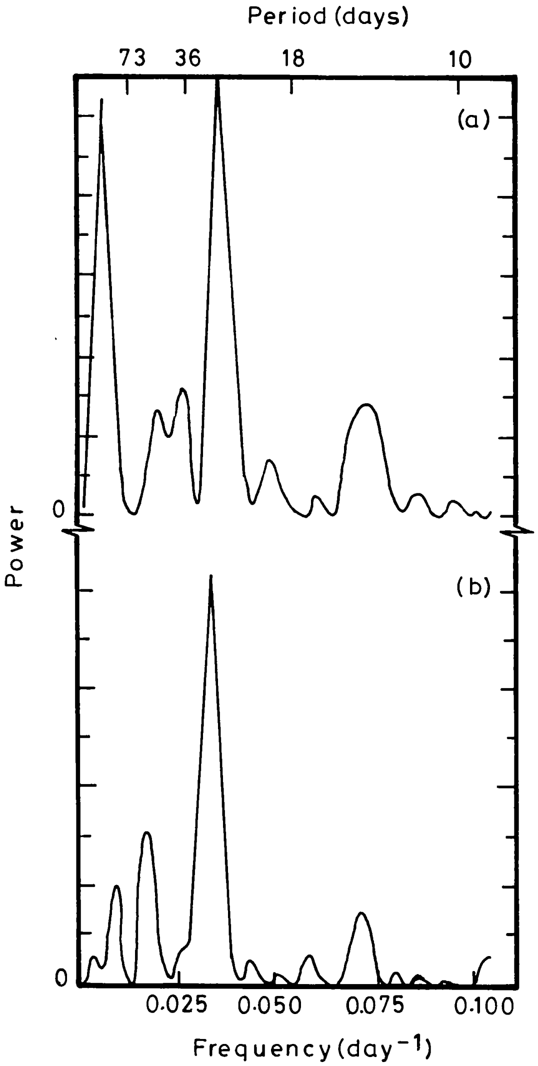

Fig. 2. Power spectrum of K-index data: (a) is for the period January 1983–July 1983 and (b) for July 1983–January 1984.

TABLE I

Derived solar rotation rate per day

| Tucson City<br>K-index | Sac Peak<br>K-index | Kitt Peak<br>He 10830 equiv. width |
|---|---|---|
| 13°.98<br>(Jan. 83–July 83) | 14°.44<br>(Jan. 83–Dec. 83) | 14°.64<br>(Jan. 83–July 83) |
| 13°.07<br>(Jan. 84–Jan. 84<br>(130 days) | 13°.97<br>(July 83–June 84) | 14°.32<br>(July 83–Jan. 84) |
| 14°.92<br>(Apr. 84–July 84)<br>(112 days) | 14°.80<br>(Jan. 84–Dec. 84) | 14°.20<br>(Jan. 84–June 84) |

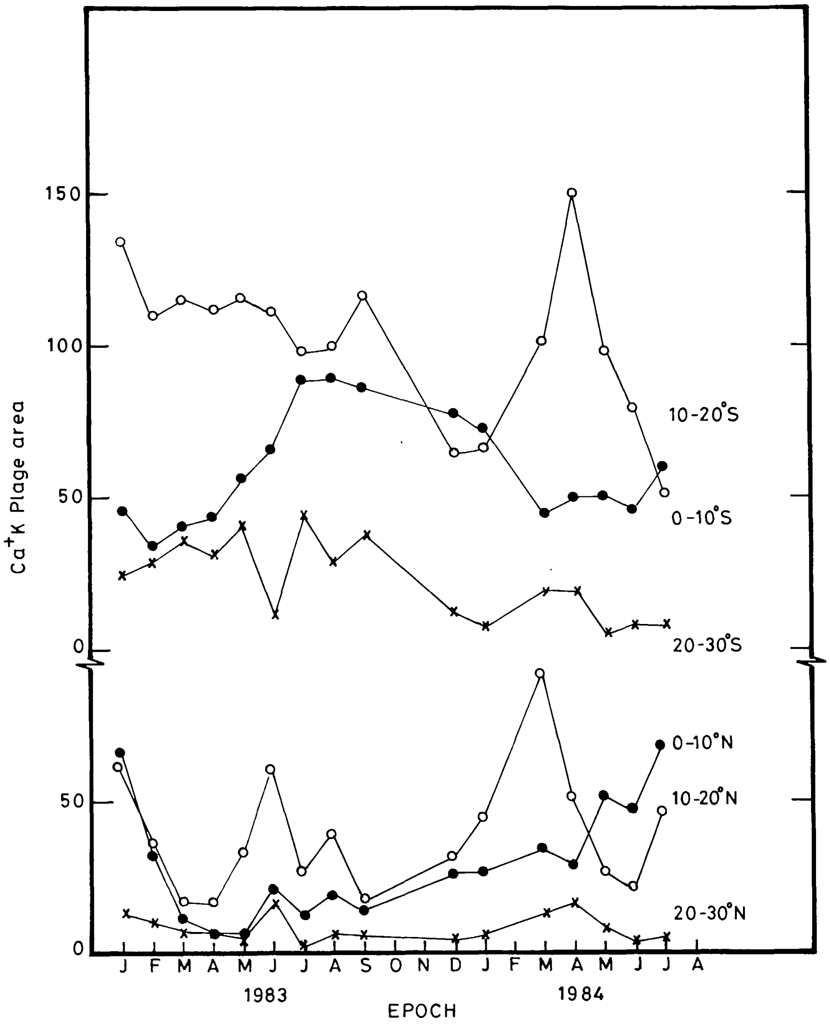

Fig. 3. Monthly mean of Ca$^+$ K plage area of active latitudes for the period January 1983–July 1984.

period of interest. Spectroheliograms in Ca K-line taken at Kodaikanal on the days for which observations at Tucson were made were the source of plage area in these latitude belts. Monthly means of the plage area in each latitude belt was computed and plotted.

## 3. Results and Discussions

We see from Figure 2 that the power spectra for six months of K-index data yields a well determined rotation rate, but that the rate for each six month interval is significantly different. To see if these differences could arise from variability in the latitude of the activity zone we consult Figure 3. For the purpose at hand, call the rotation rate for 0–10° latitude *fast*; 10–20° *medium*; and 20–30° *slow*. In fact the nominal rates expected for these zones are 14.43, 14.37, and 14.26 deg day$^{-1}$ siderial. During the first period, January–July 1983, the activity signal is clearly dominated by regions lying 10–20° S or *medium* in rate. The 2nd epoch, July 1983–January 1984, is about equal in 10–20° S and 0–10° S, or something less than *fast*; and the final interval April–July

1984 is again *medium*. From Table I the pattern in rate of 13.98, 13.07, and 14.92 clearly disagrees with this *medium*, *fast*, *medium* expected if the latitude of activity is the determining factor.

What then is the source of the observed variability in rates? The Sac Peak K-index and Kitt Peak He 10830 entries in Table I provide clues. Concerning the Sac Peak data there are many missing days because of clouds. Even if we compute power spectra for a longer series, for example January–December 1983, these discontinuities cause discordant rates compared to the Tucson archive. Notice that the spread in deduced rates for He 10830 is relatively small ($0\overset{\circ}{.}44$) compared to the spread in Ca K Tucson rates ($1\overset{\circ}{.}85$), even though the continuity of these data archives is comparable. Perhaps the lifetimes of Ca K features, as tracers, is short compared to the larger scale, more nebulous, structure seen in He 10830, and this leads to Ca K errors in the power spectra for rotation purposes.

## 4. Conclusions

Continuity in the observations is critical for the determination of rotation rates from the K-index of the Sun viewed as a star. In agreement with LaBonte, we find an interval of 18 months, as examined here, is insuffient to detect the signature of differential rotation.

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