A SEARCH FOR SOLAR GLOBAL OSCILLATIONS IN THE Ca II K-LINE

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ABSTRACT

Recent models by Hill et al. explain the apparent \( \sim 50 \) oscilla-
tions of the solar diameter by a periodic change of the limb dark-
ening function. The variations in the physical parameters that
cause this change should also produce brightness oscillations in the inner wings of the Ca\(^+\) H and K
lines amounting to as much as 0.5% at \( \text{H}_1 \) and \( \text{K}_1 \). We do not confirm the presence of oscillations of
this amplitude.

Subject headings: stars: pulsation — Sun: atmospheric motions — Sun: spectra

I. INTRODUCTION

Hill, Stebbins, and Brown (1975) and Brown, Steb-
bins, and Hill (1976) observe oscillations of the apparent
solar diameter with a period near 50 minutes and an
amplitude of \( 6 \times 10^{-3} \) arc seconds or 4.4 km. Since such
oscillations, when interpreted as real diameter oscilla-
tions, would result in velocity oscillations of \( \sim 4 \text{ m s}^{-1} \),
and since observations (Brookes, Isaak, and van der
Raay 1976; Grec and Fossat 1977; Kotov, Severny, and
Tsap 1977) show the actual oscillations to be at least a
factor of 4 less, Hill, Caudell, and Rosenwald (1977) are
therefore forced into explaining the apparent diameter
oscillations in terms of a periodic brightness variation
in the limb darkening function. The cause of this limb
profile oscillation is to be found in oscillations of tem-
peratures associated with solar pulsations in the higher
layers of the solar atmosphere (\( r < 0.01 \)), which cause
changes in the apparent diameter as defined by the
FFTD (\( = \)finite Fourier transform definition) algorithm
used by Hill, Stebbins, and Brown (1975) and which ex-
ceed the true diameter changes by almost an order of
magnitude.

If the explanation by Hill et al. is correct, one expects
to observe brightness changes associated with the tem-
perature and density variations in the higher layers of the solar atmosphere (\( r < 0.01 \)), which cause
changes in the apparent diameter as defined by the
FFTD algorithm used by Hill, Stebbins, and Brown (1975) and which exceed the true diameter changes by almost an order of magnitude.

II. EXPECTED EFFECTS IN THE K-LINE WING

Following Hill, Caudell, and Rosenwald (1976, 1977)
one can express the general solution of the linearized
adiabatic wave equation in a semi-infinite plane iso-
thermal atmosphere by

\[
\frac{\delta r}{r} = A_+ \exp (\beta_+ z) + A_- \exp (\beta_- z),
\]

where the coefficients \( \beta \) are real for the periods con-
sidered. Normally only the \( \beta_- \) solution has been con-
sidered because the \( \beta_+ \) solution results in an infinite
energy when \( z \) is large; but as Hill et al. correctly point
out, one will have to consider the \( \beta_+ \) solution when a re-
flection or source region exists outside the atmosphere.

Hill, Caudell, and Rosenwald (1977) calculate the
variations in temperature (\( \delta T \)), in density (\( \delta p \)), and in a
term \( \delta S \) related to nonadiabatic effects for both \( \beta_- \) and
\( \beta_+ \) solutions for four different periods and for the solar
model used by Bahcall et al. (1973). For the periods of
interest (\( \sim 50 \) min), the \( \delta T \) and \( \delta p \) values are about two
orders of magnitude larger for the \( \beta_+ \) solutions than for the \( \beta_- \) solutions for equal \( \delta r/r \) values. For the 50
min period case we used the \( \delta T \) and \( \delta p \) results appropriate for \( \delta r/r = 6 \times 10^{-7} \) at \( r = 0.0023 \) (the amplitude needed by Hill et al. to explain their observations) to calculate the intensity
variations in the K-line wing. The resulting intensity
oscillation amplitude \( \delta I \) for the \( \beta_+ \) case for integrated
sunlight (\( l = 0 \) mode only) and for the light from the
disk center (any \( l \)) is shown in Figures 1 and 2 for both
the Bahcall et al. (1973) model and for the HSRA model
(Gingerich et al. 1971). The intensity oscillations for the
\( \beta_- \) case are orders of magnitude lower and will be ig-
nored. In the calculations we made the following as-
sumptions. (a) The wing of the K line outward from \( K_1 \)
can be treated either in LTE or in a partial coherent
scattering (PCS) approximation (Ayres 1975). (b) The
damping is a combination of van der Waals and natural
damping. (c) The \( \delta T \) and \( \delta p \) perturbations calculated by
Hill, Caudell, and Rosenwald (1977) for the Bahcall et
al. model can be applied to the HSRA model.

From Figures 1 and 2, we draw the following conclu-
sions: (i) One expects an intensity oscillation in K of about 0.5% which disappears rapidly away from the K-line center, reaching minimum at about K ± 1.5 Å. (ii) At larger distances from the K line, lower-amplitude oscillations remain with a different phase, becoming small when approaching the continuum (although not as small as in Hill's calculation, presumably as the result of the use of monochromatic opacities and of inaccuracies in reading the $\delta T$ and $\delta_\rho$ values).

### III. OBSERVATIONS AND ANALYSIS

The observations of the K-line intensity variations were made using the Sacramento Peak Observatory Coelostat and Coronagraph telescopes combined with the photoelectric scanner of the large Littrow spectrograph. The wavelength interval of 4 Å centered on the K line was scanned about seven times per minute for durations varying from 3 to 8 hours and on seven different days and recorded digitally. Table 1 summarizes the

![Graph](image_url)

**Fig. 1.**—Intensity oscillations amplitudes (in % of the local intensity) and phases (with respect to the displacement phase) for the Bahcall et al. model. Abscissa is the intensity in the K-line wing (continuum = 100). Curves a and b are for the LTE calculations, a for the full disk, b for Sun center. The crosses are the results for the PCS calculation for full disk radiation.

![Graph](image_url)

**Fig. 2.**—Same as Fig. 1 but for the HSRA model.
data. Temporal variations were studied for 40 wavelengths 0.1 Å apart centered on the K$_3$ line. Two types of observations were obtained: (i) observations of integrated sunlight using the arrangement described elsewhere (Beckers, Bridges, and Gilliam 1976) which utilizes a 5 mm focal length, cylindrical lens as telescope objective to make a starlike image of the Sun; and (ii) observations of the center of the solar disk, covering an area 5' in diameter. To avoid solar rotation effects (Worden and Simon 1976), the telescope tracking was adjusted so that the same area of the Sun was observed during the entire observing run.

The effects of extinction variations are very pronounced in the region of the K line, the dominant variation (factor of 2) being related to the zenith-angle variation of the Sun. All the intensity measurements are therefore normalized to the intensity of a point 2 Å shortward of K$_3$ where, according to the calculations in § II, the intensity varies less and is 90° out of phase with the variations in K$_1$. Occasionally there were short (up to 15 min) data dropouts resulting from clouds, equipment failure, the need to reposition the coelostat, and periods of rapid extinction variations. These made it impossible to use the normal Fourier transform techniques to analyze the data. Instead we elected to search for periodic variations of the intensity by fitting the intensity sequence by least squares with a sine function of a given temporal frequency and then examining the amplitude of this function as a function of temporal frequency.

Figures 3 and 4 show the resulting amplitude spectra for K$_1$ (K ± 0.25 Å and K ± 0.35 Å; $\tau_{eff} = 3 \times 10^{-8}$) as well as for K$_2$ (K ± 0.15 Å; $\tau_{eff} = 2 \times 10^{-7}$) and K$_3$ (K ± 0.05 Å; $\tau_{eff} = 1 \times 10^{-7}$) both for integrated sunlight and for the Sun center. No peaks appear either in these K$_1$ spectra or in the spectra at larger distances from the center of the K line at any period between 10 and 100 minutes with amplitudes near 0.3%. For the integrated sunlight we put an upper limit of 0.02% to the amplitude of persistent oscillations (over 8 hours) in the range of periods 30–80 minutes which near K$_1$ is at least 25 times less than predicted by the analysis of Hill et al. The Sun center observations are noisier, probably as the result of seeing and guiding errors. The upper limit is therefore higher ~0.05% or at least 10 times less than predicted. Similar upper limits can be placed on oscillations in K$_2$ and K$_3$, but these limits cannot be compared with any predictions. Individual spectra in the blue and red wings of K$_1$, K$_2$, and K$_3$ show no oscillations either.

IV. DISCUSSION

The present observations are inconsistent with the hypothesis of an oscillating limb darkening function to explain the apparent diameter oscillations. In Table 2 we compare the upper limit to the diameter and Doppler shift dictated by our observations for both $\beta_+$ and $\beta_-$ solutions with the observations of $\delta$ and $v$. Also shown in Table 2 are results for 160 min period oscillations.

![Fig. 3.—Spectrum of the K$_1$, K$_2$, and K$_3$ oscillations for integrated sunlight.](image1)

![Fig. 4.—Same as Fig. 3 but for the center of the solar disk.](image2)
using Hill, Caudell, and Rosenwald's (1977) analysis for a 125\text{m} period oscillation.

From Table 2 we draw the following conclusions: (i) The oscillations in solar diameter with \(~50\text{m}\) period observed by Hill, Stebbins, and Brown (1975) and Brown, Stebbins, and Hill (1976) have to be of the $\beta_-$ type to be consistent with our $K_1$ results. (ii) The 80 cm s$^{-1}$ amplitude, 58 min period, Doppler shift oscillation observed by Brookes, Isaak, and van der Raay (1976) is consistent with this conclusion. (iii) The apparent discrepancy of the solar diameter and Doppler shift oscillation observations therefore has to be explained without inferring $\beta_+$ solutions for the diameter observations. One possible explanation in terms of a $\beta_-$ solution only would be in terms of nonradial oscillations. (iv) The 160 min Doppler shift oscillation of \(~100\text{ cm s}^{-1}\) amplitude reported both by Brookes, Isaak, and van der Raay (1976), Severny, Kotov, and Tsap (1976), and Kotov, Severny, and Tsap (1977) also has to be of the $\beta_-$ type.

Future efforts will be directed toward improving by an order of magnitude the sensitivity of the $K_1$ oscillation measurements by sampling the wavelengths of interest continuously and by normalizing them to the continuum radiation. For the $\beta_-$ solution and for $\delta r/r = 3 \times 10^{-6}$ one expects a $K_1$ intensity oscillation of \(~0.008\%\), so these future observations should confirm the $\beta_-$ nature of the \(~50\text{ min oscillations or set upper limits to these oscillations.}

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## REFERENCES


