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INTENSITY OSCILLATIONS ACROSS THE Ca II K LINE

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Intensities at various wavelengths in the Ca II K line over a 10 minute duration time series spectra have been examined for oscillations. Three components have been observed: 1) large period, $\geqq 1000$ second, due to the slowly evolving coarse network; 2) 300 second resonant oscillations; and 3) the 180 second transient recurrent phenomenon. Life history of a typical small scale K_{2v} emission feature is given.

Изменения интенсивности в К линии Са II

Исследовались колебаниа яркостей для различных длин волн К линий Са II по сериям спектров продолжительностю в 10 минут. Наблюдались три компонента: 1) долгопериодический, $\geqq 1000$ сек, вызванный медленными изменениями крупных структур; 2) 300 секундные резонансные колебания и 3) 180 секундные переходные рекуррентные явления. Описывается течение типичной мелкомасштабной эмиссии K_{2V}.

Introduction

Quasi-periodic oscillations in K_1, K_2 and K_3 intensities, K_{2V}/K_{2R} intensity ratio and K_{232} profile shape have been observed by Jensen and Orrall (1963). Orrall (1966) has determined velocity oscillations in K_3 by the method of Evans and Michard (1962).

The consistency of these measurements, that they represent velocity oscillations, have been questioned by Pasachoff (1970), who found that most of the chromospheric emission features have single peaked asymmetric profile. Since then the coexistence of single peaked, double peaked and no K_2 peak profile features have been shown by Wilson and Evans (1971), Bappu and Sivaraman (1971) and Liu and Smith (1972).

Wilson and Evans (1971) and Wilson et al. (1972) have shown how the single peaked features evolve into double peaked features in few tens of seconds, Athay (1970) and Cram (1972) have, on the other hand, shown that how the velocity gradients in the K_2 and K_3 forming regions could give rise to these types of profiles, though the velocities can not be directly inferred from the profile distortions.

In this paper we have attempted to analyse how these quasi-periodic changes manifest themselves at various wavelength positions in the K line profile and also described the morphological development of small emission features.

2. Observations and Reduction

Ten minutes of time series spectra, centered at the CaII K line, taken at 30 seconds interval by Dr. Bappu at the Kodaikanal tower telescope (Bappu and Sivaraman, 1971) were traced along the slit at a set of $\Delta\lambda$'s with an effective tracing aperture of 16 mA × × 500 km. Unfortunately, the trace magnification changed from trace to trace. A detailed matching showed that a linear scale adjustment coincided all the features in different traces. Traces were then reread, by linear interpolation by a computer program, at an interval of 760 km, for 216 points (154, 160 km), after each trace was smoothened by a three point running mean.

Since the seeing was not consistently uniform, so instead of determining the mean autocorrelation function for the 216 points, mean serial correlation functions (SCF) were determined, after each trace was corrected for instrumental vignetting, as:

$$C(T) = \frac{I}{N-T} \sum_{T=0}^{N-T} \frac{216 \sum_{i=1}^{216} I(x_i, t_j)\, I(x_i, t_{j+T}) - \sum_{i=1}^{216} I(x_i, t_j) \sum_{i=1}^{216} I(x_i, t_{j+T})}{\{[216 \sum_{i=1}^{216} I^2(x_i, t_j) - (\sum_{i=1}^{216} I(x_i, t_j))]^2\, [216 \sum_{i=1}^{216} I^2(x_i, t_{j+T}) - (\sum_{i=1}^{216} I(x_i, t_{j+T}))^2]\}^{1/2}} .$$

This SCF also takes care of the difference in exposure in various spectra.

The consistency of this estimator has been questioned by Jenkins and Watts (1968), but it has the merit that it weights each spectrogram according to its RMS amplitude.

This SCF gives too much power, in its Fourier transform, at low frequencies, which was eliminated by the following three methods: (1) By applying the first difference filter,

$$I'(x_i, t_j) = I(x_i, t_j) - I(x_i, t_{j-1}) ,$$

directly to the SCF as

$$C'(T) = -c(T-1) + 2c(T) - c(T+1)$$

and correcting the resulting transform for its transmission properties, at the frequencies of interest, as:

$$G(f) = |H(f) = 2 + 2\cos(2\pi f \Delta)|^2 ,$$

where Δ is the reading interval. (2) By subtracting out an exponential function fitted for $T = 2\Delta$ to 20Δ from the $c(T)$ and normalizing it such that $C(0)$ is unity. (3) By subtracting out a mean "a" for $C(T)$, $T = 2\Delta$ to 20Δ and again normalizing it for $C(0) = 1$ by the $1/(1-a)$ factor.

The resulting SCF's were apodized by Connes (1961) data window and Fourier transformed to give the desired power spectra. Four spectra obtained by the three methods are compared in Fig. 1. (Plate 3) These prove to be almost equivalent for the frequencies of interest and so ultimately the process (3) was used for all the traces.

3. Results

The corrected SCF's and their Fourier transforms for all the intensity (INTY) and four pairs of mean (MEAN) and difference (DIFF) series obtained by taking the mean and difference of intensities at the two wings of the K line at K_1-min, K_2-wing, K_2-peak and K_3-wing are shown in Fig. 2 (see Plate 4).

The statistical reliability of the resulting spectra can be adjudged from the number of degrees of freedom "k" associated with a χ^2 variate (Blackman and Tukey, 1958), which for maximum lag $T_m = T$, the length of record, reduces to $k = 2P$, where P is the number of independent records. With 4000 km as the average size of K_{232} elements (Punetha, 1971), this gives $k = 70$ for the length covered along the spectrograph slit. This for 50% confidence limit yields a range of factor 0·9 – 1·12 (Edmonds, 1966). With total lag $T_m = 10$ minutes the theoretical observational limits on the angular frequency scale are $\pi/600 \leqq \leqq \omega \leqq \pi/60\ \mathrm{sec}^{-1}$.

The $\Delta\lambda$ variation of the constant term "a" obtained by process (3) and the exponential decay period "T" obtained by process (2) are shown in Fig. 3. Because of the short span of observations (only 10 minutes), these provide a crude estimate of the fractional temporal power that is contained in the slowly evolving coarse mottle and network features. The value of

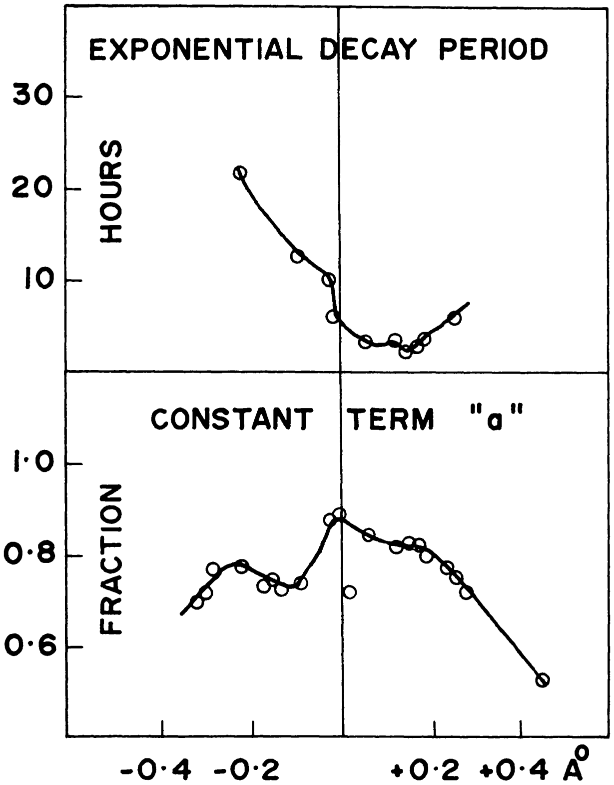

Fig. 3. $\Delta\lambda$ variation of the constant term "a" and the exponential decay period "T".

"a" (0·6 – 0·9) is much larger than what could be inferred from the two values of σ (RMS variations) obtained from the spatial and temporal variations observed in K_2 intensity by Jensen and Orrall (1963). This component has its maximum at K_3 and it is more pronounced at K_{2R} than at K_{2V}. Correspondingly, the exponential decay period "T" (range 3 – 20 hours) has its minimum at K_{2R}.

The lag functions (SCF) initially decrease exponentially and then oscillate due to quasi-periodic variations. The initial decreases, as seen in the power spectra, are due to the low frequency (period $\geqq$ $\geqq$ 1000 seconds) component, the fractional power in which is maximum at K_{2R} and decreases monotonically on either side of this $\Delta\lambda$.

The fluctuating part of the SCF's is not sinusoidal but shows various forms of skewness as $\Delta\lambda$ changes. This, as the corresponding power spectra show, is due to the change in the relative strengths of the two frequency components, one with a primary period of 300 seconds and the other 180 seconds. The frequencies of the two components are constant. No decrease in their periods with height, as observed by Noyes and Leighton (1963), is noted across the K line. The primary period of 300 seconds is distinguished at all the $\Delta\lambda$'s. The 180 second component is apparent near K_3 minimum ($\Delta\lambda = -0{\cdot}015$ A) and it increases in strength towards K_{2V} and decreases thereafter in K_{1V}. The corresponding red wing of the line shows it only as a high frequency tail.

The increase in the strength of the third maxima in SCF at 10 minutes lag interval, as compared to that at 5 minutes, is genuine and is due to the beating of the two frequencies. It is not due to instrumental guiding effects, as relatively stable features are well matched in all the 21 exposures that are used here.

The $\Delta\lambda$ behaviour of the MEAN and DIFF spectra is important in that the DIFF spectra show only the 180 second component and that too only at the K_3-wing, K_2-peak and K_3-wing. This implies that the 300 second oscillations are produced by symmetric intensity changes over the K line, whereas the 180 second component is due to asymmetric intensity changes in the two wings of the line.

We have determined spatial autocorrelations function for the MEAN and DIFF series, derived from another set of plates taken by Dr. Bappu at the Kitt Peak National Observatory, with spatial resolution reaching 1 second of arc. These show that the average width of 2500 km of DIFF features, as determined from the Full Width at Half Maxima (FWHM) is less than that of the MEAN features (2700 – 4000 km). Their smaller size and their comparable lifetime show that they correspond to the bright cell points (Liu et al., 1972) discussed by Pasachoff (1970) and Wilson and Evans (1971), which have linear dimensions of 1000 – 1500 km. Thus we expect that their relative amplitude is underrepresented in the power spectra due to 3 point spatial running mean taken to circumvent the microphotometer linear magnification changes.

Due to the non-uniformity of seeing during the 10 minute time series run of the spectra, their complete life history could not be established, but we find these small features to follow the following course of evolution. To begin with a bright streak appears at K_{1V} and K_{1R} between $0{\cdot}4 < |\Delta\lambda| < 0{\cdot}8$ Å, at which time K_3 is violet shifted and K_2 emission is bright on both the wings and shows a violet excess. Within 30 seconds, the K_1 emission streak reaches K_2, K_2 becomes very bright with violet side more pronounced and K_3 red shifted. At $t = 60$ seconds, the emisson becomes weaker at all wavelengths excepting K_{2V} but it is visible; K_3 displacement is uncertain. At $t = 90$ seconds, only the K_{2V} component remains and it projects well into K_3; at K_{2R} there is almost no emission. At $t = 120$ seconds, the K_{2V} emission is hardly visible or has vanished; its place is taken up by a dark streak running from $-0{\cdot}7$ A to $0{\cdot}7$ A. At $t = 150$

seconds, the dark streak decreases in length and becomes fainter; it is symmetrical about K_3. These dark streaks have the dimension $\simeq 1000-1500$ km and thus are different from the dark condensations described by Bappu and Sivaraman (1971) and Liu and Smith (1972). This cycle may be regenerated after 200 seconds (Liu et al., 1972). Wilson and Evans (1971) and Wilson et al. (1972) have described the time evolution of K_2 features, which differs from that of ours in detail. An independent confirmation is therefore desirable.

4. Discussion

The CaII K line spans a range of height of some 2000 km, from temperature minimum upwards, from K_1 to K_3 (Athay, 1970). The K_{232} profile is a complicated functional of vertical chromospheric structure above the temperature minimum (Athay and Skumanich, 1968) wherein different models (Liu and Smith, 1972) and different velocity gradients (Cram, 1972) give rise to different types of profile. For intensity changes the basic parameters are the optical depth of temperature rise and the temperature gradient following this rise. If these fluctuate, the line profiles change from strong K_{232} reversal to a very incipient reversal. The radiative relaxation time of the corresponding part of the atmosphere is large enough (100–200 seconds) that the atmosphere is heated up and cooled significantly as difference phases of waves pass through it.

The 180 second frequency tail in the chromospheric oscillations have been observed by the following: in $\lambda 8542$ A line by Evans et al. (1963) and Mein (1967), in Hβ by Bhattacharya (1972), in Hα by Bhatnagar and Tanaka (1972), and in K_3 by Orrall (1966) and Noyes and Leighton (1963) and it is now a well established feature. Our observations differ from the accepted version that this component gains in prominence with increasing height, in that we find that it is most prominent in K_{2V} rather than at K_3. We suggest that it is due to the periodic resurgence of small scale cell points (Liu et al., 1972), which are transient wave phenomena that progress upwards from the temperature minimum region. But it should be mentioned that we do not find any phase lag with period greater than 30 seconds, the resolution limit of our observations, in the cross correlograms of K_1 and K_3, and K_2 and K_3 intensities. Direct phase and coherence spectra should resolve this discrepancy.

The 300 second oscillations are evidently due to standing oscillations excited at the resonance frequency of the atmosphere (Frazier, 1968). The upward gradual decrease of the mean period of oscillations reported by different observers (Noyes and Leighton, 1963; Evans et al., 1963; Howard et al., 1968; Bhattacharya, 1972) may thus be a fortuitous effect caused by the mixing up of the two frequencies.

The low frequency tail and the constant term "a" have their maxima at K_{2R} and these reflect the slowly evolving chromospheric coarse structure.

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