OBSERVATION OF GLOBAL 160-MIN INFRARED (DIFFERENTIAL) INTENSITY VARIATION OF THE SUN*

V. A. KOTOV

Crimean Astrophysical Observatory, Nauchny, Crimea 334413, U.S.S.R.

S. KOUTCHMY

S.A.S. Institut d'Astrophysique, CNRS, 98 bis BD Arago, F 75014 Paris, France

and

O. KOUTCHMY

Laboratoire d'Analyse Numerique, Université P&M Curie, F 75006 Paris, France

Abstract. The method developed and the instrument designed for detecting variations of the solar limb darkening at the atmospheric transparency window of the solar opacity minimum region of λ 1.65 μ are described. This differential technique proved to be successful in rejecting undesirable low frequency noises due to the atmosphere and to the instrument. Analysis of observations made in 1977, 1978, and 1981 indicates the persistance of global fluctuations of the IR differential, center-to-limb intensity at the well-known 160 min period with an average amplitude of about $\pm 2 \times 10^{-4}$ in units of the 'average Sun' intensity near 1.65 μm.

1. Introduction

One of the principal activities of solar physicists in the last decade has been to tackle the measurements of solar oscillations. In addition to the well-known 5-min oscillation of the Sun, others, of longer periods (7 to 70 min), with small amplitudes were found by Hill *et al.* (1978) in measurements of the apparent solar diameter, which have been lately interpreted in terms of fluctuations in the limb darkening (Hill and Caudell, 1979). Using sensitive Doppler velocity measurements Severny *et al.* (1976, 1979) have found clear evidence for the existence of global oscillation of the Sun with a surprisingly stable period of 160.010 min which was also found to be highly phase coherent in time. This finding has been supported by observations of other groups (see Brookes *et al.*, 1976; Scherrer *et al.*, 1980; Grec *et al.*, 1980) and the period is now determined with an accuracy of about ± 0.002 min. It is worthwhile to note that irrespective of the history of this 160 min oscillation prior to 1974 both Crimean and Stanford data (Scherrer *et al.*, 1980) demonstrate the long term (over at least 8 yr) stability of an underlying 'clock' mechanism, whatever its' nature.

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For the purpose of the present paper, however, we stress the claim that this 160 min persistent oscillation is accompanied by synchronous variations in the solar radio emission and radio polarization at cm-wavelengths and, presumably, in the differential (central portion of the solar disk with respect to outer annulus) optical intensity of the Sun (see Kotov *et al.*, 1982, 1983).

Nevertheless, the 160 min oscillation has not been uniformly accepted by solar physicists, mainly because it is close to being an integral division ($\frac{1}{9}$th) of a day (see, for example, Dittmer, 1977; Grec and Fossat, 1979). Therefore, it becomes clear that at least a partial answer to the question on the nature of 160-min oscillation lies in the acquisition of a long reliable series of data together with a proper analysis of the observations.

In ground based measurements of the solar output and its variations at any wavelength, the major uncertainty arises in correcting for atmospheric transparency changes. In addition observations of long-period oscillations require very high instrumental stability. These difficulties may be reduced by the use of relative measurements, for instance, those of center-to-limb ratio of the solar intensity, especially in the near infrared.

The near IR spectral range seems to be much more favorable than the optical one for measurements of small variations in the solar intensity. This is because of the weakness of terrestrial atmospheric influences at the IR transparency windows, and also because the wavelengths observed (1.6–1.7 μm) correspond to the minimum of solar atmospheric opacity. In order to minimize further the remaining atmospheric and instrumental disturbances, we measure relative, center-to-limb variations in the IR brightness. In other words, we attempt to detect small changes in the limb darkening function supposed to be measurable at definite periods of solar global oscillations (see Hill *et al.*, 1978; Kotov *et al.*, 1982).

3. Instrumental Set-up

Our instrument uses an image of the Sun, 9 mm in diameter which is periodically scanned across the PbS detector [N.E.P. $\lesssim 10^{-12}$ (W Hz^{-1})] with a frequency of $2\omega/2\pi = 40$ Hz. The instrument is attached to the Crimean Solar Tower Telescope and has been used successfully since August 1977. The first results obtained by this differential technique were previously published by Koutchmy *et al.* (1980).

Figure 1 shows the Solar Tower and a general view of our device and Figure 2 shows the action of this device schematically. The entrance aperture, 1×1 mm^2 in size, is formed by crossing two narrow, rectangular slits denoted by S1 and S2 in Figure 2a, each of 1×10 mm in size; these slits are illuminated by a 'parallel' beam of solar light. This 'parallel' beam is directed into our instrument by two flat coelostat mirrors (see Figures 1b, c) which have a photoguiding system ensuring a pointing accuracy of about 1 arc sec (note the same beam is simultaneously used by Crimean observers for Doppler velocity measurements). At 1-m distance below the aperture (see Figures 1c and 2a) we get a pin-hole image of the solar disk feeding the PbS detector (with an open area of

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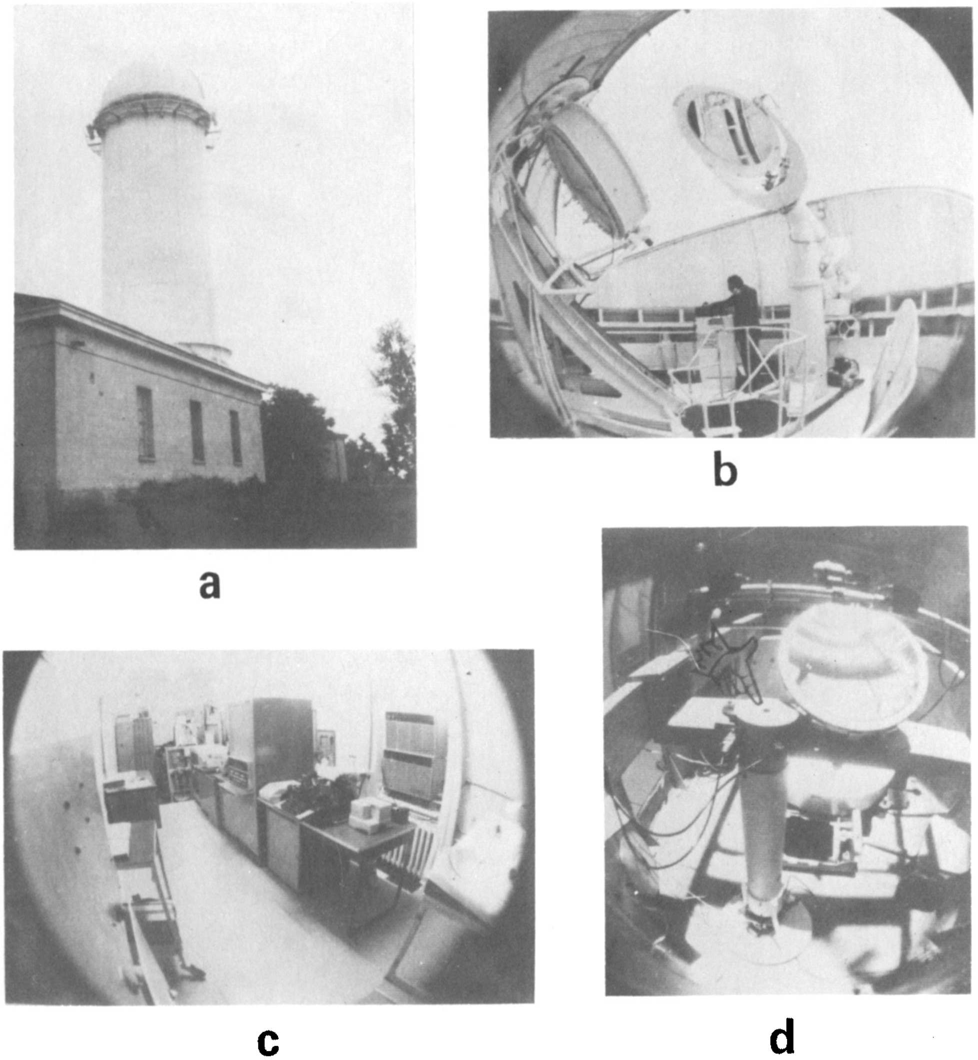

Fig. 1. General view of the Crimean Solar Tower Telescope and the instrumentation. (a) Solar Tower; (b) coelostat mirrors (about 24 m above the ground level); (c) the solar magnetograph (used also for Doppler velocity measurements and, partially, for the recording of IR observations) and the computer; (d) the diagonal flat mirror used for the Doppler velocity measurements and the IR device (its entrance aperture is indicated) illuminated by a parallel beam.

1 × 0.4 mm) which is coupled to the analog electronics; the working voltage of the detector is given by a stable 90 V battery. Just above the detector we place a Ge interference filter with 60% transmission at the 1.65 μm wavelength with FWHM = 0.06 μm (for some of the 1977 measurements the filter was set for the wavelength 1.75 μm).

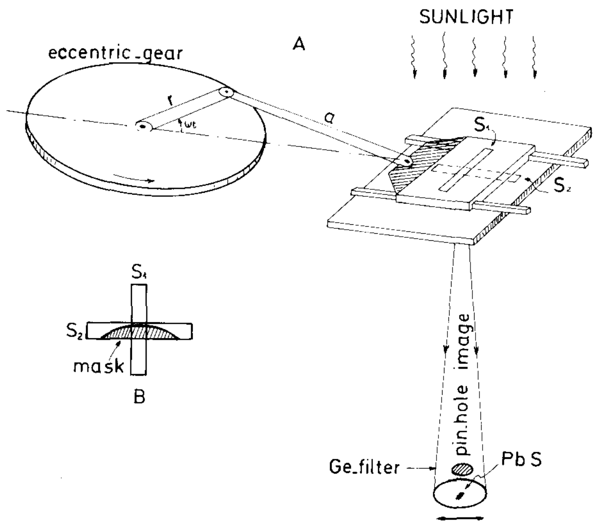

Fig. 2. Schematic drawing of the device used for the IR intensity measurements (dimensions are quite arbitrary); for the explanation see text.

Before each observation the PbS detector was positioned by hand to place it approximately in the center of a light beam; then the remaining errors in position were corrected (in two coordinates, X and Y) by small movements of the detector-platform performed by two stepping-motors (not shown in Figure 2) to obtain the maximum output at the frequency of modulation.

In these measurements, the linear modulation is obtained by the rotation of a carefully balanced eccentric gear allowing long scans, up to 8 mm to be used. The eccentric gear (see Figure 2a) periodically moves the slit S1 within the range ± 4 mm and as a result, the image scans the detector twice during one rotation. The gear frequency is 20 Hz, so the resulting scan frequency is 40 Hz in a periodic pattern shown schematically in

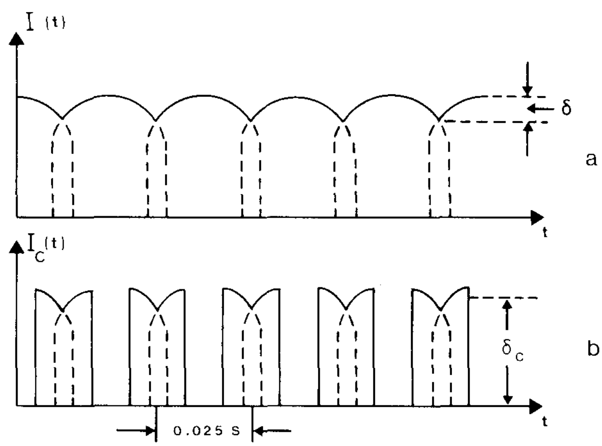

Fig. 3. Schematic plots of the PbS output for the recording of the differential intensity signal (a) and the calibration (b). Frequency of modulation is 40 Hz.

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Figure 3a. It is clear that the amplitude of the 40 Hz signal in the detector output $I(t)$ well reflects the limb darkening function (which is somewhat distorted, in reality, by diffraction):

$$I(\rho) = 1 - U_1 + U_1(1 - \rho^2)^{1/2} \tag{1}$$

within the scanning range $|\rho| < 0.9$; $U_1 = 0.23$ for $\lambda 1.65$ µm. Here ρ is a heliocentric distance which is determined, in our case, by a function of the position of the modulator; omitting the terms proportional to $(r/a)^n$, $n \geq 2$ (parameters of the eccentric gear r and a are indicated in Figure 2a; in our case $r/a \approx 0.06$), we get $\rho \sim \cos \omega t$.

However, what we actually measure is a harmonic amplitude of $I(t)$-modulation of the detector output, which is linearly detected within a specially designed Shebyshev-type narrow passband analog filter at the 40 Hz frequency:

$$\delta'(t) = \alpha(t) A\, FT^{-1} \left\{ \int_{2\pi}^{\infty} FT[I(t)]\, G(\omega)\, \mathrm{d}\omega \right\}, \tag{2}$$

where FT means Fourier transform, A is some instrumental constant, $\alpha(t)$ is slowly variable atmospheric transparencies (much smaller than the frequency of modulation); $I(t)$ is PbS output which includes not only variations caused by the limb darkening function (see Figure 3a and Expression (1)) but also fast variations produced by Earth's atmospheric effects (seeing, turbulence, etc. ...) at higher frequencies. $G(\omega)$ describes the frequency reponse of the detection system including the electronic filter. The effective passband was equal to ≈ 0.05 Hz, so the function $G(\omega)$ is well peaked at 40 Hz.

Further, in accordance with the linear modulation produced by the eccentric gear, we have $\rho(t) \approx 0.9 \cos \omega t$; therefore, substituting (1) into (2) we get for the measured differential (center-to-limb) signal we are looking for:

$$\delta'(t) \approx \alpha(t) B u_1(t), \tag{3}$$

where B = const., $u_1(t)$ the limb darkening parameter which is thought to be slowly variable (at frequencies much smaller than the modulation frequency 40 Hz). It is clear that any periodic variation in the center-to-limb ratio function will result in a similar variation of the measured electric output at the 40 Hz frequency.

To correct (3) for $\alpha(t)$-slow changes in atmospheric transparency, we detect also a 'calibration' signal recorded during certain time intervals when the central portion of the solar disk (as it is viewed from the PbS-cell) is screened by an opaque shield, ≈ 3 mm in width, inserted into the light beam (by chopping electromagnet) just under the stationary slit S2 and giving rise to a modulation pattern of the PbS output shown in Figure 3b. In mathematical form this type of modulation can be written as follows:

$$I_c(t) = I(\rho) H(|\rho|), \tag{4}$$

where again $\rho = 0.9 \cos \omega t$, $I(\rho)$ the limb darkening function (1) and

$$H(|\rho|) = \begin{cases} 1, & |\rho| \geq 0.67\,, \\ 0, & |\rho| < 0.67\,. \end{cases} \tag{5}$$

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It is easy to understand that in this last case the signal I_c' (calibration) being the result of an application of the Expression (2) to the $I_c(t)$-pattern shown in Figure 3b and given by (4) and (5), is equal to

$$I_c' \approx \alpha(t) A \frac{I_\odot}{K} , \qquad (6)$$

where $K \approx 1.33$ for our type of modulation, $I_\odot$ the intensity of the 'average Sun' supposed to be constant (in the frame of our investigation) because the instrument is not aimed, in principle, to detect fluctuations of the entire Sun's luminosity. Accordingly, taking the ratio δ'/I_c' we presumably completely reject the influence of atmospheric transparency changes on our measurements.

The observations in 1977 and 1978 were carried out with the use of a specially profiled mask (see Figure 2b) set onto the unmovable slit S2. The corresponding modulation pattern, really recorded as the PbS-output, is shown in Figure 4. Its shape is much more smoothed than the schematic patterns in Figure 3, due to the low spatial resolution employed: we use a 0.4 mm width of an open area of the PbS corresponding to a resolution of about (1/22.5) $D_\odot$; the solar image also is diffraction limited with a resolution of $\approx (1/10) D_\odot$.

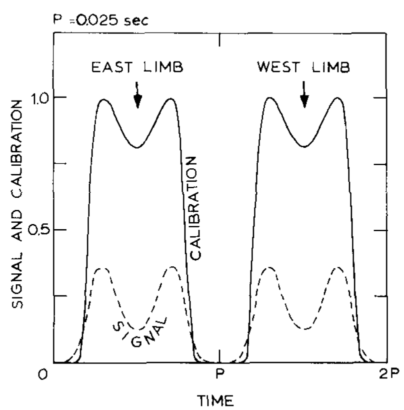

Fig. 4. Modulation pattern of the PbS output with the use of a profiled mask (see text).

The aim of the profiled mask (which reduces by a factor of two intensity of the central part of the solar disk, as it is viewed by PbS) was to minimize the off-set signal, i.e. to make the difference 'center minus limb' near zero. It was believed that any errors, of atmospheric or instrumental origin, are proportional to the off-set signal, i.e. to the 'centerlimb' difference; hence, the use of this mask seemed to be capable to diminish many undesirable noises. In practice, however, the use of the mask significantly alters the short-time noise and diurnal drifts neither for δ' nor for the ratio δ'/I_c', because (1) the mask did not influence the calibration signal I_c' and its errors, (2) the main sources of errors for the differential signal δ' (and for I_c' too) are guiding error and

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inhomogeneity of atmospheric transparency; all these sources are not affected significantly when we use the profiled mask. Therefore, in 1981 we made observations without using the mask.

The voltage of the PbS output is detected using the same 40 Hz electric filter and synchronous amplifier for both δ' and I_c' signals, then digitally recorded on a computer M6000 with integration time 30 (or 50) s, with 10 s dead time, in the following succession: $I_c' - \delta' - I_c' - \delta' - I_c' - \ldots$, to get 90 (or 60) values of δ' and I_c' per 1 hr of observing time. Then, for each δ'-value we compute the ratio

$$\Delta' = \frac{\delta'(t)}{KI_c''(t)} \approx \frac{0.56\, U_1(t)}{I_\odot} \approx \frac{I_c - I_L}{I_\odot}, \tag{7}$$

where $I_c''(t)$ is the average of two adjacent values of $I_c'(t)$, I_c and I_L are the intensities near the center and near the limb of solar disk.

It is obvious that by computing the ratio $\delta'(t)/I_c''(t)$ we (a) suppress considerably the influence of all spurious disturbances of instumental or atmospheric origin and (b) get the simplest way to convert our differential intensity signal Δ' into the intensity of the 'average Sun'. Some higher frequency noise and long-time diurnal drifts appearing in the original data series are due to (a) electronic noise, (b) nonhomogeneity of the atmospheric transparency, and (c) guiding errors.

The most serious error which might be thought as the source of persistent periodicities (in particular, at the 160-min period) in our IR measurements is, of course, the guidance error. Measurements showed that a 1 arc sec shift of the solar beam gives a decrease of about 0.2% and 0.04% of the δ' and I_c' signals, respectively, i.e. it produces approximately 1.7×10^{-4} error in the measured relative intensity. This is close to the mean amplitude of 160-min variations (see below); however, it is unlikely that such a guidance error might be a source of the 160-min periodicity because (1) the sign of a misalignment (guidance) error in our intensity measurements is distributed at random from day to day and (2) careful account of the guidance error of the telescope did not show the presence of any significant (and persistent for many days) periodicity at 160-min in excess of 0.1 arc sec (Kotov *et al.*, 1982).

3. Observations and Analysis

Each observation lasted at least one 2^h40^m cycle while many observations covered 2–3 successive cycles (i.e. $\approx$ 5–8 hr). Both signals, δ' and I_c' could be displayed on graphs to demonstrate the quality of the observations (see, for instance, Figures 5 and 6). Poor observations and offending points (well displaced from the record) could be identified and deleted from the analysis if desired (without information about exact UT of the observation). Then the series of Δ' data is treated using a computer data reduction program developed by Severny *et al.* (1979) and Koutchmy *et al.* (1980) to derive the superposed epoch plots or a power spectrum using a fast Fourier transform.

The slow drifts produced mainly by diurnal variation of the guidance system can reach the value of about 10–15% per 4–6 hr of observing time for the ratio $\Delta' = \delta'/I_c''$. These drifts, as a rule, can be easily approximated by quadratic polynomials $\Delta_0(t)$ and the residuals $\Delta = \Delta' - \Delta_0$ averaged over each 5-min interval of time form our basic data series subjected to further analysis.

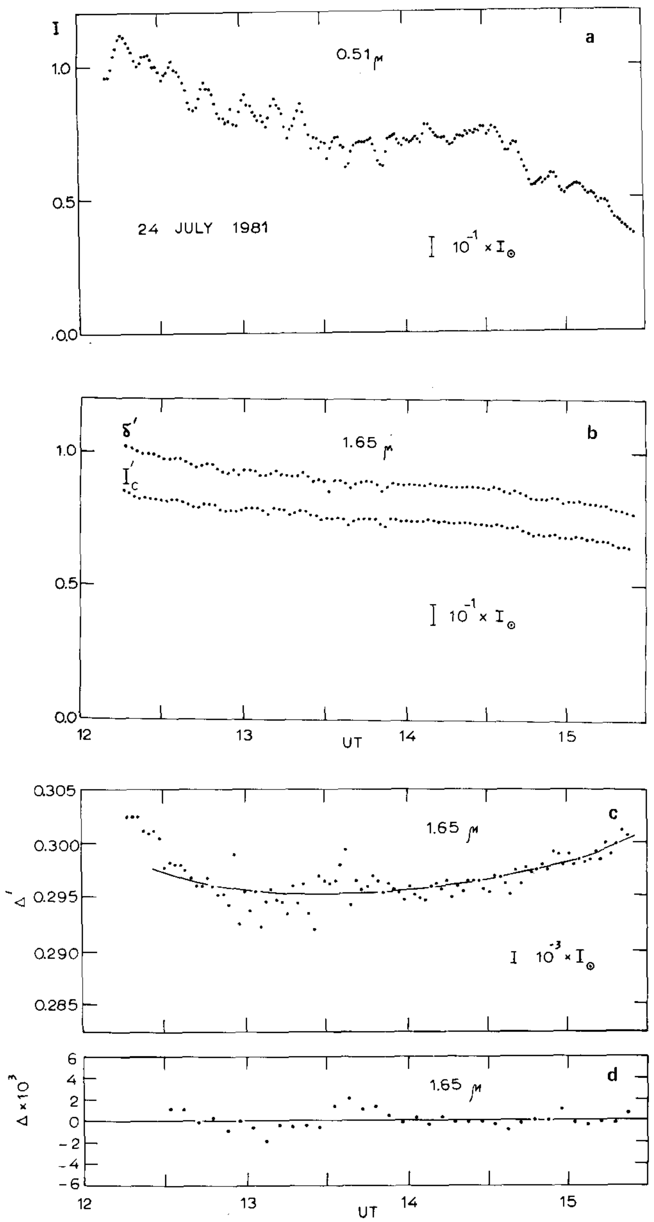

Fig. 5. An example of intensity records obtained on 24 July 1981 under poor atmospheric conditions (hazy sky): (a) the run of solar intensity measured at λ0.51 μm; (b) the same for λ1.65 μm (for the two IR signals, δ' and I_c'); (c) the ratio of two IR signals, $\Delta' = \delta'/I_c''$; (d) the plot of residuals $\Delta = \Delta' - \Delta_0$ (5-min averages).

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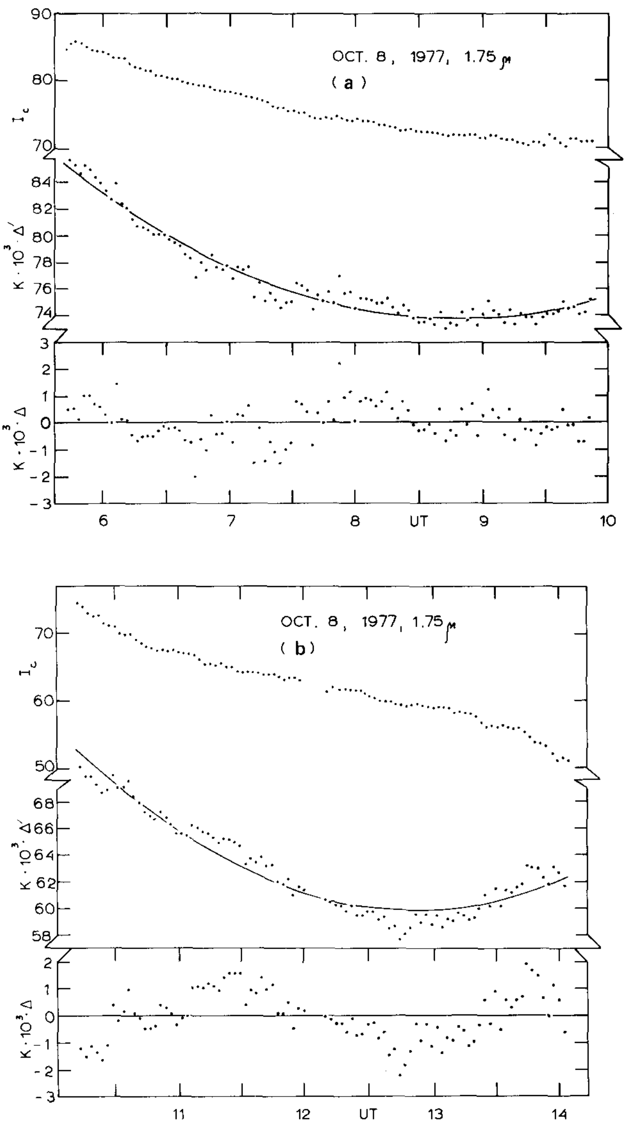

Fig. 6a–b. The plot of originally recorded calibration signal I'_c (top), of the ratio $K\Delta' = \delta'/I''_c$ together with the least squares fit by parabola (middle) and of the residuals $k\Delta$ (bottom), vs UT.

Figure 5 demonstrates an advantage of the near IR spectral range (here λ 1.65 μm) for a detection of solar brightness variations as compared with optical (λ 0.51 μm) observations; fluctuations of both IR signals, δ' and I'_c are one order of magnitude smaller than transparency fluctuations seen in the green light (top) (note that both sets of measurements were made simultaneously with the use of the same 'parallel' beam, and under quite poor atmospheric conditions (hazy sky). Figure 5c shows the time behaviour of the ratio $\Delta' = \delta'/KI''_c$ approximated by the best-fitted parabola Δ_0; at the bottom we plotted the residuals $\Delta = \Delta' - \Delta_0$ average over each 5-min interval. One may conceive that yet under poor atmospheric condition the instrument is capable of detecting fluctuations of the differential signal of the order of $\sim 10^{-3}$–10^{-4}, of solar and/or atmospheric origin. Let us point out that all our measurements were carried out under 'quite good' to 'excellent' atmospheric condition with a clear sky, by contrast the example of record obtained during poor sky conditions is shown in Figure 5. By statistical analysis of records collected during many days, ≈ 30 or more, one can achieve an accuracy of about 1 part in $\sim 10^{-4}$ to 10^{-5} – especially when we are interested in oscillations maintaining a phase over many days like the known 160-min pulsation of the Sun, and when all the records are considered as continuous data series, with gaps caused by a lack of observations.

To do more detailed analysis we investigated further the data obtained in 1977 (11 August – 6 November, in all 32 days) and in 1978 (21 July – 21 October, in all 35 days); a total of 354 hr of observations during 67 days were suitable for a reduction. The results where further reinforced by analysis of the latest data of 11 days in 1981 made, as it was previously noted, without the use of the profiled mask.

4. The Results

A number of the 1977 year records showed fluctuations of the differential intensity signal $\Delta = \Delta' - \Delta_0$ with a characteristic times of 2–3 hr. An example of an original record made on 8 October 1977 and exhibiting a clear ≈ 160-min variations may be seen in Figure 6 where we plotted I_c' values (top), the run of the ratio $K\Delta' = \delta'/I_c''$ (middle) and the residuals $K\Delta = K(\Delta' - \Delta_0)$ (bottom).

One particular feature can be noted: maxima on many records of 1977 tended to concentrate near almost the same UT-moments: $\approx 6^{\mathrm{h}} \approx 9^{\mathrm{h}} \approx 11^{\mathrm{h}}20^{\mathrm{m}}$ and $\approx 14^{\mathrm{h}}$ with about $2^{\mathrm{h}}40^{\mathrm{m}}$ mean spacing – despite the fact that all these records were obtained in different months and did show quite various character of diurnal drifts (see, for example, the same Figure 6).

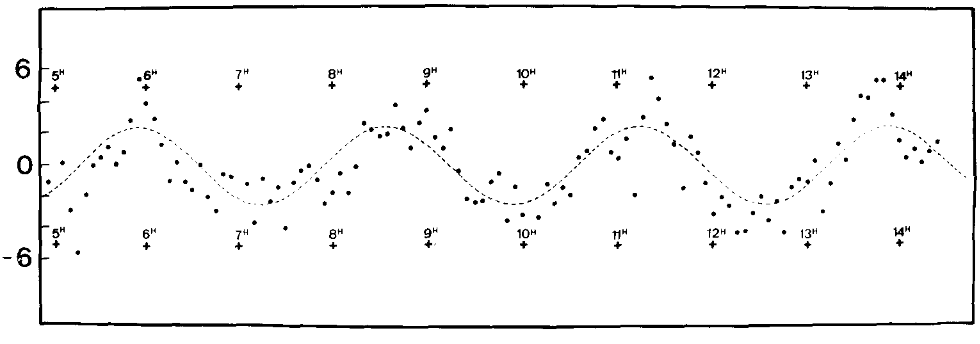

Fig. 7. The averaged measurements of 1977 (a total of 156 hr corresponding to 32 days) arranged using the superposed epoch method. Time is UT and amplitude is in units of 10^{-4} of the 'average Sun'. Dotted line represents the best fitted 160-min sinusoid.

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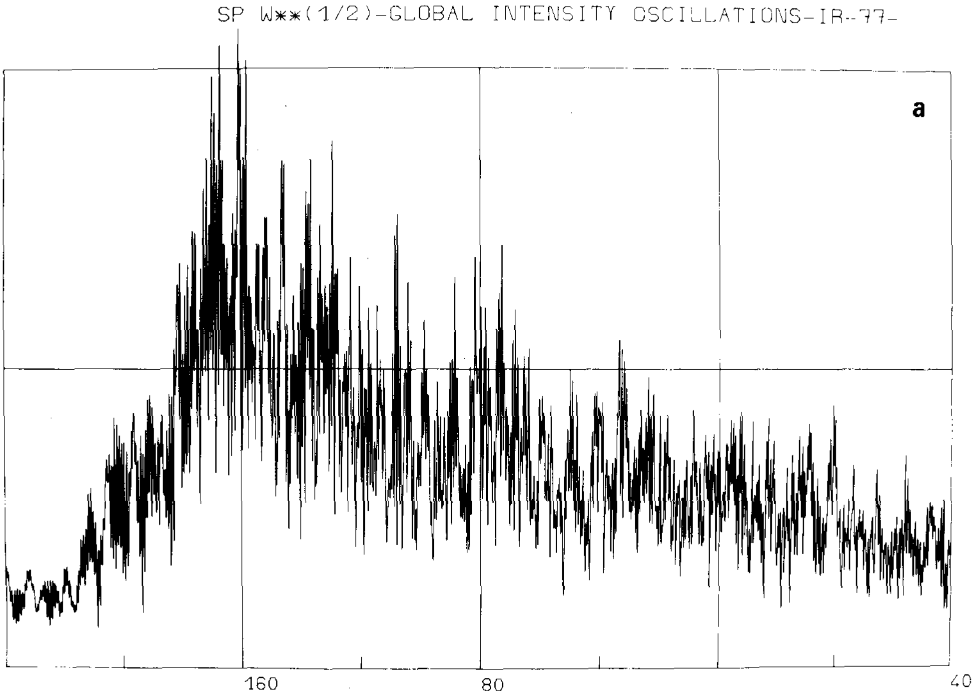
Strong indication of the presence of the 160-min variation in 1977 data can be judged from Figure 7 which is the result of averaging the whole set of 1977 year observations (32 days). Plotting this average result of 1977 we assumed that the 160-min oscillation remained in phase from day to day (as it does from daily velocity observations), so we added the daily sums coherently in time (i.e. keeping in mind that 160 min = 1/9 of a day). One can see that the differential IR intensity signal reveals here a remarkable 160 min variation through a whole sunny day from about 05:00 UT to $\approx$ 14:00 UT, with a mean amplitude $\approx 2.5 \times 10^{-4}$ in units of the 'average Sun' intensity.

We have computed also the power spectra of these two, 1977 and 1978, data sets, with zeros put in for the time intervals not covered by observations; thus, here the data were also analysed as a coherent time series. Both spectra (Figure 8) showed prominent peak just at the 160 min period; the same signature of the presence of a significant and dominating 160 min oscillation may be seen in the power spectrum averaged for 1977 and 1978 years, see Figure 2 in Koutchmy *et al.* (1980).

It is well-known that reports about an existence of 160 min global pulsation of the Sun were regarded with skepticism by some solar physicists due to the fact that 160 min = $(1/9)^{d}$; it explains why the existence and significance of this 160 min period was subject to controversial discussion during the last 5 years. However, if real, the phenomenon of this sharply tuned and long-period phase-coherent oscillation might have an important issue for the structure of solar interior (Severny *et al.*, 1979; Gough, 1980). To make alternative explanations, it was suggested by several authours (see for instance, Dittmer, 1977; Grec and Fossat, 1979) that 160-min period in velocity measurements might be a pure result of a 1-day regularity in the observations (sampling effect) and daily trends caused mainly by the differential atmospheric extinction. Further, it was noted that the use of data series of about 5.4 hr duration, i.e. $\approx 2 \times 160$ min, can favour 1/9th harmonic of a day.

In our IR data, however, the histogram of data series lengths for 1977 plus 1978 exhibited two maxima, around 3.4 and 7.8 hr, with a minimum, instead of a maximum, near 5.5 hr. To test further this 1/9-day hypothesis, we used again our IR data obtained in 1977–1978, and after numerical analysis of the distribution of the observing 'windows', the conclusion was reached that 160-min periodicity in IR intensity measurements (and, similarly, in velocity measurements, since the latter were made simultaneously with IR records) could not be produced by a 1-day sampling, or by noise and diurnal trends (see extensive discussion of this subject in Koutchmy *et al.*, 1980; Kotov *et al.*, 1982). In essence, we established that there was virtually no evidence of 160-min regularity in the time distribution of 'windows' for IR records at all.

It should be also noted that diurnal trends of the ratio $\delta'(t)/I''(t)$ which are greatly reduced by low-frequency filtering using a 2nd order polynomial approximation do not reveal any systematic behaviour from day to day; these trends are presumably caused by the instruments (mainly by the guiding error slowly changing throughout a day) rather than by the differential atmospheric effect; these trends appear very much like low-frequency noise and certainly cannot be modelled as a differential effect of the atmospheric extinction, as supposed by Grec and Fossat (1979).



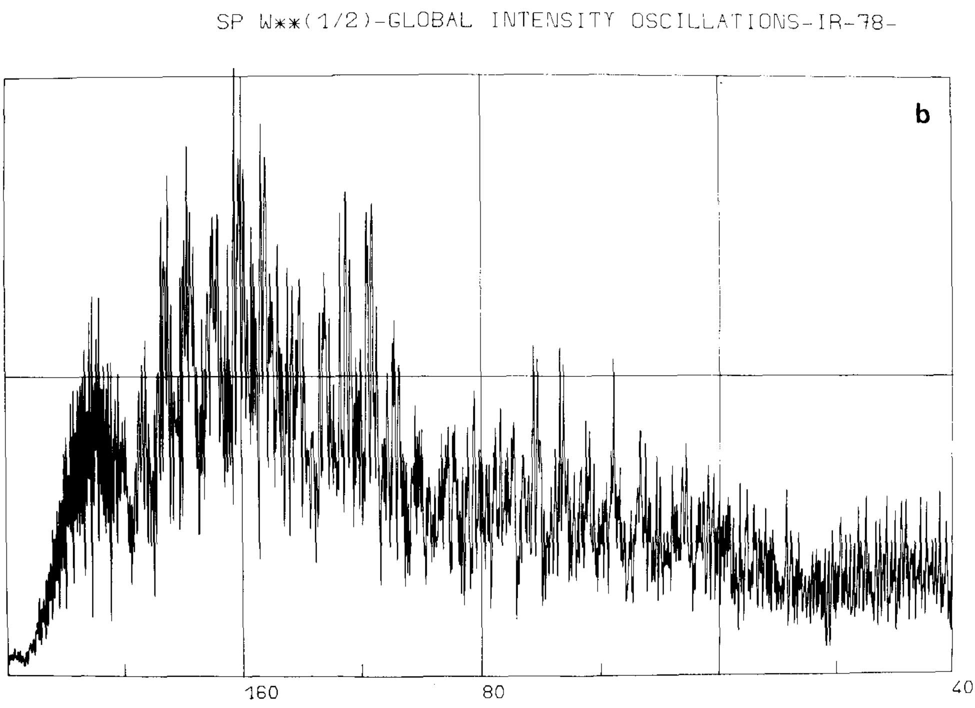


Fig. 8. Power spectra of the IR intensity measurements for 1977 (a) and 1978 (b) years data. A harmonic amplitude $W^{1/2}$, in arbitrary units, is plotted vs period expressed in minutes.

The latest IR data obtained in summer of 1981 also indicated the presence of 160-min intensity variations. Records suitable for reduction were made during 11 clear days in the interval 20 July–15 August, in all about 71 hr of data string. The superposed epoch plot of these data (subjected again to low frequency filtering by 2nd order polynomials, prior to analysis) for the period 160.010 min showed statistically significant ($2A/\sigma \approx 4$) sinusoidal wave with a harmonic amplitude $A \approx 2 \times 10^{-4} I_{\odot}$, see Figure 9, bottom; of great interest is that the phase of the maximal IR signal (i.e. the time of maximum of a sinusoid assigned to the data points), $\approx 01^h45^m$ UT, happened to be in close agreement with the phase of maximum line-of-sight velocity, $\approx 01^h37^m$ UT, inferred from the Crimean velocity observations in 1974–1981 (top); the zero phase everywhere corresponds to the UT moment 00^h00^m on 1 January 1974, and the phase of 160-min modulation at a given epoch is determined by fitting the data with a 16-points numerical (sinusoidal) approximation to the mean 160-min oscillation shape.

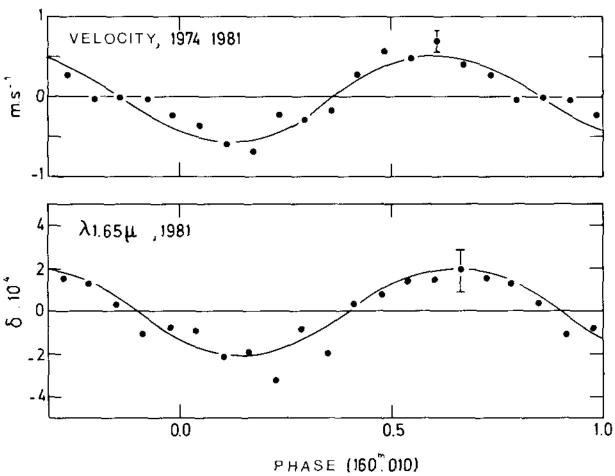


Fig. 9. Superposed epoch plots of the Doppler velocity according to Crimean observations in 1974–1981 (top) and that of the solar IR differential intensity in 1981 (bottom) for the period 160.010 min. The error flags are standard deviations from the mean.

One should note, however, that immediate comparison of phases – at 160.010 min period – of the IR intensity oscillations inferred from data of different years, 1977, 1978, and 1981, could be misleading since the late measurements in 1981 (Figure 9, bottom) were made with the profiled mask removed, in contrast to observations undertaken in previous years. The removal of the mask can inevitably change the weighting function for measurements of the amplitude of intensity variations over the Sun's disk and, hence, to unknown phase shift for the 160.010-min superposed epoch plot.

5. Conclusions

A differential technique for the detection of time variations in the solar limb darkening law has been developped and proved to be quite sensitive, up to 10^{-4} in units of 'the average Sun' intensity, when it is used at the atmospheric transparency window of the near infrared (λ 1.65 μm). When a statistical analysis, based on the power spectrum and superposed epoch routine is applied to a sufficient amount of data, then the oscillatory component and the prevailing phase-coherent oscillations (16.010 min) can be easily extracted from the available data.

On the basis of our IR differential intensity measurements made in 1977, 1978, and 1981 (a total of 78 days) and analysis of the data series we conclude that the limb darkening function in the near IR does undergo 160-min oscillations with a mean amplitude of about $\pm 2 \times 10^{-4}$ in units of the 'average Sun' intensity. The phase of the 160-min oscillations in 1981 data obtained without the profiled mask (see Figure 2), i.e., when measured as almost pure 'center minus limb' difference, is found strongly correlating with the peak of the line-of-sight velocity (see Figure 9).

This 160-min periodic variation cannot be explained by either a 1-day regular sampling of observations or influences of a broad band noise source (see also Koutchmy *et al.*, 1980). Since atmospheric and instrumental explanations have also failed to give a significant effect for the appearance of the 160-min periodicity (see Severny *et al.*, 1979; Kotov *et al.*, 1982), one may conclude that the IR differential intensity observations strongly support the solar origin of the 160-min oscillations. Thus, efforts towards a more elaborate modeling of the adiabatic or non-adiabatic processes and the solar convection zone are now warranted not only by velocity, but also by other types of observational data available in optical, radio, and IR spectral ranges.

However, the precise physical mechanisms (presumably connected with periodic temperature variations in the photosphere) responsible for the IR variations are still not clear; also the relation of the limb darkening variations to the solar constant monitoring (see Deubner, 1977; Woodard and Hudson, 1983) is open to question.

We expect that in the near future the intensity (particularly, IR) observations will be increasingly used to refine our understanding of solar global oscillations and the Sun's structure, in particular, – of the nature of 160-min oscillations for which no completely satisfactory explanation has yet been avanced.

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