SEARCH FOR SHORT PERIOD CORONAL PLASMA OSCILLATIONS SECIS RESULTS FROM 1999 AND 2001 TOTAL ECLIPSES

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ABSTRACT

Results of the analysis of the high-cadence observations of the solar corona, taken with the Solar Eclipse Coronal Imaging System instrument during joint British-Polish expeditions during the total solar eclipses of 1999 August 11 in Bulgaria (12 768 images) and 2001 June 21 in Zambia (16 000 images) are presented. Using data collected during the both solar eclipses we searched for possible periodic changes of the 530.3 nm line intensity emitted by the selected points of the solar corona in the frequency range up to 10 Hz.
The time resolution of the collected data is close to 0.05 sec and the pixel size is approximately 4 seconds of arc. The standard photometric processing and correction of the image motions caused by temporal drifts of the instrument pointing were made. Using classical Fourier spectral analysis and wavelet analysis tools we investigated temporal changes of the 530.3 nm coronal line brightness of many thousands of points at various heights and position angles above the solar limb. We did not find any statistically important evidence of periodicity in the frequency range from 1 to 10 Hz in any of the investigated points.

Key words: Sun: eclipses, oscillations; MHD-waves.

1. INTRODUCTION

The solar corona has a temperature of 1-2 MK and locally much more (Phillips 2000). The detailed heating mechanism is still unknown, but it is certainly related to the magnetic field and is probably due either to dissipation of MHD waves (e.g. Hollweg 1981) or to numerous small-scale magnetic reconnections that result in energy releases of about 10^{23} erg, called ``nano-flares" (Parker 1988). Wave heating may be an important contributor and in certain regions may dominate, e.g. where there are open field lines since at these locations magnetic reconnections are likely to result in plasma acceleration rather than heating. Wave heating may result in periodic modulation of the intensity of coronal structures, e.g. in white-light or in the Fe XIV "green" coronal line (wavelength 530.3 nm, emitted at a temperature of about 2 MK). Theoretical studies of MHD wave heating show that only high frequency (>0.5 Hz) waves are capable of significant heating (Porter et al. 1994). Previous searches with some degree of success have been made by the Williams College (Massachusetts) group observing the green-line corona with photomultiplier tubes (Pasachoff at al. 1987); modulations of 1% in the coronal intensity with frequencies in the range 0.5-2 Hz were reported. In more recent eclipses this group has used CCD cameras with fast-frame imaging. Results (Pasachoff et al. 2000) from the 1994 (through thin clouds) and 1998 eclipses (clear skies) did not show any periodicity above a level >2% of coronal intensity, but during the August 11, 1999 eclipse (observed in clear skies from Romania) enhanced power was found in the 0.75-1 Hz range at the 1% level (Pasachoff at al. 2002). Investigations by other groups (e.g. Cowsik et al. 1999) during eclipses and with coronagraphs (Koutchmy et al. 1994) have found significant periodicities in the frequency range 0.003-0.14 Hz.
Here we report on analysis of data taken during the August 11, 1999 and June 21, 2001 total eclipses with the Solar Eclipse Coronal Imaging System (SECIS). In the following, we outline the instrument, observations and necessary corrections to the data. We then describe a Fourier analysis that we carried out in order to search for periodicities in the coronal intensity and the results of the investigations.

2. SECIS INSTRUMENT AND OBSERVATIONS

Full instrumental details about SECIS are given by Phillips et al. (2000). The set-up of the instruments for the 1999 and 2001 eclipses was as illustrated in Fig. 1. A 250 mm aperture heliostat directed sunlight into a horizontal beam of constant azimuth incident on to a 200 mm, f/10 Meade Schmidt-Cassegrain telescope mounted on an optical bench. Light from the telescope was collimated and then split by a beam splitter into a transmitted beam passing through an interference filter isolating the green-line (the peak transmission was equal to 27% at 530.4 nm in 1999 and about 50% in 2001; central wavelength have only a slight dependence on ambient temperature), then on to one of two cameras,

Proc. 10th. European Solar Physics Meeting, 'Solar Variability: From Core to Outer Frontiers', Prague, Czech Republic, 9-14 September 2002 (ESA SP-506, December 2002)

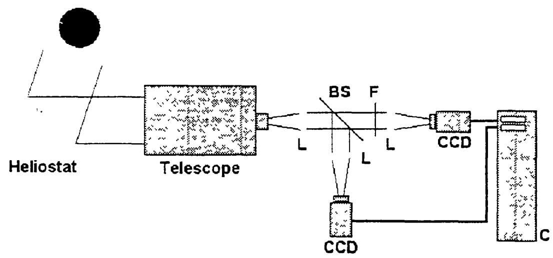

Figure 1. The optical scheme of the SECIS instrument CCD--cameras, C--main computer with camera interfaces, F--530.3 nm line filter, BS--beam splitter, L-lenses.

and a reflected beam passing to the second camera with no filter in place. This second, "white-light" camera was thus able to view prominences as well as coronal features, which was useful for alignment purposes. Images from this camera also serve as a monitor for atmospheric transmission or any instrumental changes during totality.
The cameras (EEV, U.K.) have a 512×512 pixels format (pixel area 15 μm×15 μm). The image data are digitised to 12 bits, though the least significant bits of data are judged to be noise, so the effective dynamic range of the data is approximately 1000:1. The cameras speed and exposure times can be set by the user via an adapted personal computer system (Carr Crouch Computer Company, UK) which captures the data streams from the two cameras and stores them on to a disk drive. The spatial scale of the images was close to 4 arcsecond per pixel, giving a field of view of 0.57°×0.57°.

During the 1999 eclipse we chose a frame rate of 44.4 images per second. At our observing site, a Bulgarian Army establishment at Shabla, 60~km north of Varna on the Black Sea coast and near the mid-totality line, totality was close to 143 s. We started our exposure sequence immediately after the eclipse diamond ring and collecting a total of 12728 images (6364 per camera). The field of view included two bright active regions on the north-west limb (NOAA 8651 N25W90, NOAA 8656 N14W86) and one on the south-west limb (NOAA 8661 S14W70). In 2001 we have observed the eclipse from the roof of the Institute of Physics of the University of Zambia in Lusaca. The length of the totality was close to 194 s. We chose rate of 39 images per second and we collected a total of 16 000 images (8000 per camera). The field of view included a bright active region located on the north-east limb (see Fig. 2).
With almost ideal weather conditions during the both eclipses (cloudless skies and calm air), the image quality matched our expectations, with correct exposure of the white-light images, though with rather low signal-to-noise ratio for some regions of the green-line images.

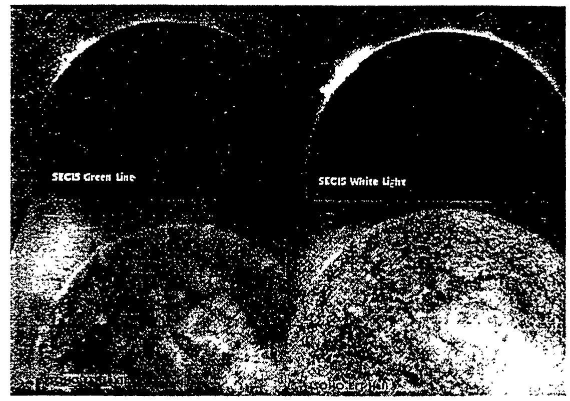

Figure 2. Examples of the "green line" and white-light images taken with SECIS during the 2001 June 21 eclipse (upper panels) compared with SOHO EIT images in Fe XII 19.5 nm line (lower left panel) and He II 30.4 nm line (lower right panel).

3. PROCESSING OF DATA

Despite pre-eclipse precautions and completely calm conditions, the solar image moved across the detector area of both cameras by up to about 1 minute of arc during the 1999 eclipse and up to 8 seconds of arc during the next one. The recorded motions consist of slow drifts, glitches lasting of order 1 s and with amplitude approximately 1 pixel or less and small, noise-like changes. Fig. 3 shows, as example, the temporal changes of the relative positions of the Moon's centre measured from the white-light camera images collected during the 2001 eclipse.
To correct for the image motions, we measured the positions of the Moon's centre as well as some motionless coronal structures visible in the white-light images for each image. The centre of the Moon was found by least-squares approximation to the visible part of the lunar limb with a section of a circle. A single-mirror heliostat such as the one we used gives rise to a rotation of the image. To minimise the errors caused by the rotation, we broke the complete sequences of images into sub-sequences containing 1000 images (i.e. about 25 s long). We improved next the co-alignment of the images in a frame of each sub-sequence by evaluating the necessary residual shifts of less than 1 px using a correlation of the images of stable coronal structures at the reference and actual images, both rebinned to 10-times-smaller pixels.
The standard deviations of the measured final positions of the Moon from the expected position in the white-light camera images for the 1999 eclipse are equal to 0.053 px in x and 0.049 px in y while in the green-line camera images these deviations are equal to 0.098 px and 0.069 px. In the all analysed time sets more than 99% of the white-light image positions fell within a 3σ band. For the 2001 eclipse the results are similar; the

standard deviations of the measured final positions of the Moon in the white-light camera images are equal to 0.049 px in x and 0.044 px in y.

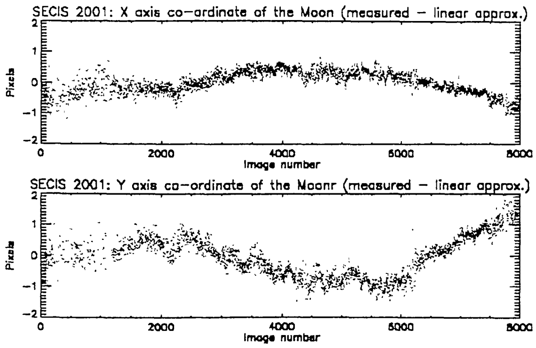

Figure 3. Temporal changes of the position of the Moon's centre at the SECIS white-light images taken during the 2001 eclipse. The coordinates are plotted in an arbitrary reference system. Formal uncertainties in the plot are too small to be shown here.

We note in this context that several previous eclipse experiments have looked for brightness changes of small regions of the solar corona using fibre optics in the focal plane of the telescope coupled to photo multipliers. These observations rely entirely on the perfect guiding of the heliostat used, which, as we have shown here, cannot be guaranteed and reliably checked for such data after the eclipse is over.

The white-light images were used not only for correction of the pointing errors of the instrument, but also for monitoring of the temporal changes of the atmospheric transmission and temporal stability of the instrument's photometric properties. Any hidden periodic instability of the photometric properties of the whole instrument or its selected elements (for example one of the cameras) can cause spurious periodic changes of the recorded signal of the coronal green-line. In order to detect such periodicities, we analysed the power spectra of the signals averaged over the selected areas of images taken with both cameras.

In order to avoid any misidentification of the detected increases of the calculated power spectra as a real periodicity, we used a significance test due to Fisher (1929) for the largest peak in the power spectrum and an extension to Fisher's test due to Shimsoni (1971) for maxima smaller than the largest one, since according to Shimsoni and authors cited therein Fisher's test tends to be too severe in rejecting peaks as insignificant.

Using Fisher's test we did not find any statistically important increases in the power spectra of the averaged white light data and "green" line. Nevertheless, during further analysis of the coronal green-line emission we decided to apply a more restrictive limitation, ignoring all the oscillations with frequencies for which the local maximum of the power spectrum of the white-light averaged signal exceed its linear approximation by more than 2σ. Recently we have found also a possible quasi-periodic long-period instabilities of the instrument. The analysis of this problem is under way presently.

As mentioned before, there was appreciable motion of the images in both channels. It is possible that residual motions after applying the corrections described before might give rise to intensity changes, particularly in regions of high intensity gradient. In order to detect any periodicities of the image positions we analysed the power spectra of the temporal changes of the measured positions of the lunar images in both cameras.

The power spectra were calculated and analysed in exactly the same way as previously and they did not reveal any statistically important increases, but, as before, we applied our 2σ limitation.

4. TEMPORAL CHANGES OF THE LOCAL BRIGHTNESS IN GREEN CORONAL LINE

The analysis of the temporal changes of the brightness of the various coronal structures observed in the green coronal line during the 1999 eclipse was made for a area measuring roughly 18×7 arcminutes, including nearly 6500 pixels having sufficient coronal emission. For 2001 eclipse we have analysed up to now about 20% of usable data only.

For each investigated pixel we applied wavelet analysis as well as we calculated power spectra for data sub-sets referred to in Section 3. The power spectra were calculated using a standard Fourier transformation every 0.01 Hz. Fig. 4 shows an example having what appears to be a strong peak. All power spectra showing such peaks were statistically tested using the Fisher test. It is possible that periodic behaviour can appear in particular solar structures over very short time periods, so we investigated not only the whole data set but also numerous subsets having various durations and arbitrary start times in a subsequence. The points with the highest power of the spectrum at given frequency were selected for further detailed investigation.

A very small number of the analysed pixels were found to show peaks that at first sight seemed to be of interest. For 1999 eclipse we found 17 points with local maxima of the power spectra greater than 4σ (4, 7 and 6 points in a frame of the first, second and fourth sets of images, respectively) and four points with the local maxima greater than 5σ. For the eclipse observed in 2001 we have found up to now more than 40 points with local maxima of the power spectra greater than 5σ but no one with the local maxima greater than 6σ. However we found not a single one of these peaks satisfied the Fisher test at the α=0.05 level (where α is the significance level). Thus these peaks of the power spectra are most likely the result of random statistical fluctuations. All the remaining pixels showed no peaks in the Fourier power spectra >4σ for any of the four time series.

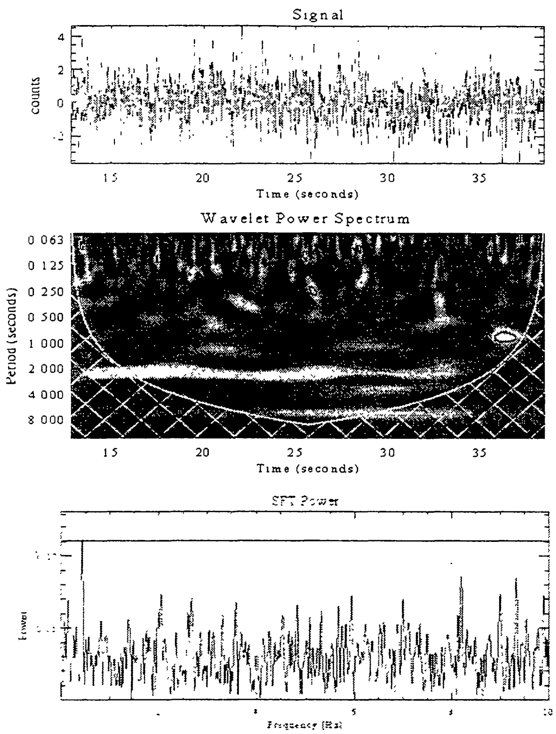

Figure 4. Upper panel: temporal variation of the "green line" emission of the selected point. The mean value of the analysed data was subtracted and the trend was removed. Middle panel: the corresponding wavelet power transform, where contours indicate a region with the suspected significance level of 95%. The cross-hatched area represents the cone of influence region. Lower panel: classical Fourier power spectrum shows the local maximum of 5σ for about 0.5 Hz but it did not satisfy the Fisher test at the α=0.05 level.

5. CONCLUSIONS

To rule out the possibility that apparent periodicities in the data taken in various points of the observed solar corona are due to instrumental or atmospheric effects, we analysed the effects of various factors, such as the variation of the tracking rate and possible vibrations of the heliostat and the whole instrument, the photometric and other errors associated with the CCDs, possible instabilities of the electronics, variation of the sky transparency and atmospheric seeing and several others. In summary, our analysis of several thousand pixels in the SECIS green-line images taken during the 1999 and 2001 solar total eclipses, which included careful correction of several instrumental effects has not shown any undoubted examples of periodic fluctuations in the data over the 1-10 Hz frequency range. The absence of significant peaks would argue against the presence of any large oscillatory power in coronal structures that is the signature of MHD wave heating of the corona. It may be that the optical thinness of the green-line emission, which allows more than one coronal loop to be seen along a single line of sight, results in a confusion of several possible MHD wave trains so that individual peaks in the power spectra would be difficult to detect. However, there are a few features in our images that are distinguishable as separate loop structures but even here we do not see peaks in the power spectra. A companion work (Williams et al. 2001) has claimed already evidence for low-frequency oscillation along one half of a clearly distinguishable loop observed in 1999, but presently we are re-checked this result again.

ACKNOWLEDGEMENTS

We thank the Leverhulme Trust (UK), Rutherford Appleton Laboratory (Space Science and Technology and Instrumentation Depts.) and the Committee for Scientific Research (PL) for financial support. We are grateful to Bulgarian colleagues who arranged the eclipse site at Shabla so well. We would like to mention specifically Prof. Dr Dimitar Mishev (Bulgarian Academy of Sciences, Sofia) and Dr Maria Madjarska (now at Armagh Observatory, U.K), and particularly the late Prof. Dr. Vladimir N. Dermendjiev (Bulgarian Academy of Sciences) for his tireless help before, during and after the eclipse. We also thank the staff of the Bulgarian Army Air Defence Establishment for their help in setting up our base there. We thank Dr Francisco Diego for his help with post-eclipse calibration of the green-line filter. We also thank the several colleagues who gave us technical help, especially Dr Serge Koutchmy, Prof. Jay Pasachoff and Dr Ray Smartt. Wavelet software was provided by C. Torrence and G. Compo, and is available at URL: http://paos.colorado.edu/research/wavelets/.

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