Solar coronal observations at high frequencies

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Abstract

The Solar Eclipse Coronal Imaging System (SECIS) is a simple and extremely fast, high-resolution imaging instrument designed for studies of the solar corona. Light from the corona (during, for example, a total solar eclipse) is reflected off a heliostat and passes via a Schmidt-Cassegrain telescope and beam splitter to two CCD cameras capable of imaging at 60 frames a second. The cameras are attached via SCSI connections to a purpose-built PC that acts as the data acquisition and storage system. Each optical channel has a different filter allowing observations of the same events in both white light and in the green line (Fe XIV at 5303 Å). Wavelet analysis of the stabilized images has revealed high frequency oscillations which may make a significant contribution on the coronal heating process. In this presentation we give an outline of the instrument and its future development.

1 Introduction

For the last 50 years one of the most important unexplained problems in solar physics is to explain the exact heating mechanism for the corona. At a temperature of $\sim 10^6$K the solar atmosphere is much hotter than the photosphere or chromosphere, ruling out the possibility of radiative heating. It is widely accepted that magnetic fields must be the reason for the high temperature, but there is disagreement about the exact mechanism. Parker (1988 and references therein) supported the idea of numerous small-scale magnetic reconnections (nanoflares) releasing enough energy to heat the corona, while Hollweg (1981) and others favoured dumping of energy from magnetohydrodynamic (MHD) waves. Both theories are supported by observational evidence.

Our project concentrates on the detection of MHD waves that can dissipate enough energy in their environment and heat the corona. Porter et al. (1994a & 1994b) produced theoretical simulations of such waves under a range of conditions and found that only high frequency (≥ 0.5 Hz) oscillations are capable of heating the coronal loops. Currently none of the spaced-based telescopes has instruments capable of detecting such fast events. Therefore a ground-based instrument was needed as a short term solution which could either observe the solar corona during a total eclipse or with a coronagraph. The first such instrument was developed by Pasachoff & Landman (1984) who reported some evidence of periodicity in the 0.5-2 Hz range during the total solar eclipse of February 1980. More evidence of this type of oscillation were found again during the June 1983 eclipse by Pasachoff & Ladd (1987) and Pasachoff (1997). Rusin & Minarovjech (1994) and Singh et al. (1997) have also reported short-period waves while Koutchmy et al. (1983) used the coronagraph at the National Solar Observatory/Sacramento Peak to produce evidence of oscillations with periods of 43s, 80s and 300s.

In this paper we will describe an instrument we have developed in conjunction with the Astronomical Institute of the University of Wrocław, Poland, called the

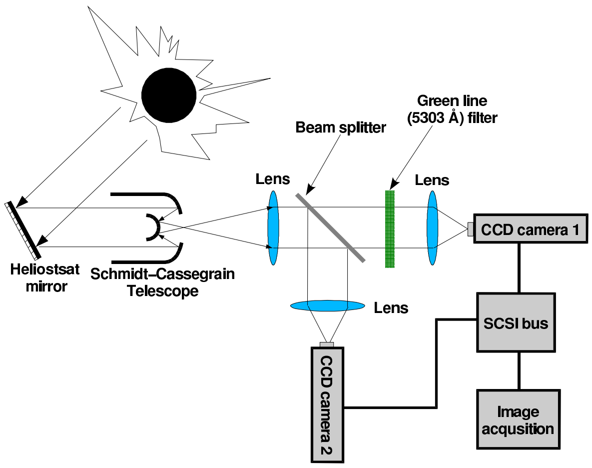

Figure 1: Schematic diagram of the SECIS instrument as published by Williams et al. (2001)

Solar Eclipse Coronal Imaging System (SECIS), which performs rapid observations of coronal loops. Some results from the August 1999 eclipse are also included (also see Phillips et al. 2000; Williams et al. 2001, 2002).

2 The SECIS instrument

Figure 1 contains a schematic diagram of the SECIS optical path as published by Williams et. al. (2001). The primary mirror of the Schmidt-Cassegrain telescope has a diameter of 20cm, the beam splitter allows 90% of the light to pass through and reflects the remaining 10%. The green filter in front of camera 1 has a bandwidth centred around the Fe XIV emission line at 5303 Å, and the measured full width half-maximum (FWHM) of this filter is 4 Å. Camera 2 has no filter, allowing simultaneous white light observations.

Both cameras are connected via a Personal Computer (PC) that acts as the data acquisition system. As each camera is capable of recording up to 60 frames per second (fps) with a 512 $\times$ 512 resolution and a pixel depth of 12 bits, a high data bandwidth was needed. To solve this problem we attached a Redundant Array of Inexpensive Disks (RAID) of 4 Small Computer System Interface (SCSI) disks each of 9 GByte capacity. During data acquisition, each image from each camera is split in two, and while the first two disks record the first half of the images produced by the two cameras, the other two disks place their heads to pre-allocated positions for the writing of the rest of the images. Once the first two disks finish, the other two start recording the second half while the first two disks position themselves for the next two images.

3 Wavelet analysis

The detection of oscillations requires the analysis of time series observations of individual pixels. Although Fourier analysis appears to be the most popular frequency analysis method, there is a new tendency toward the use of wavelets (for

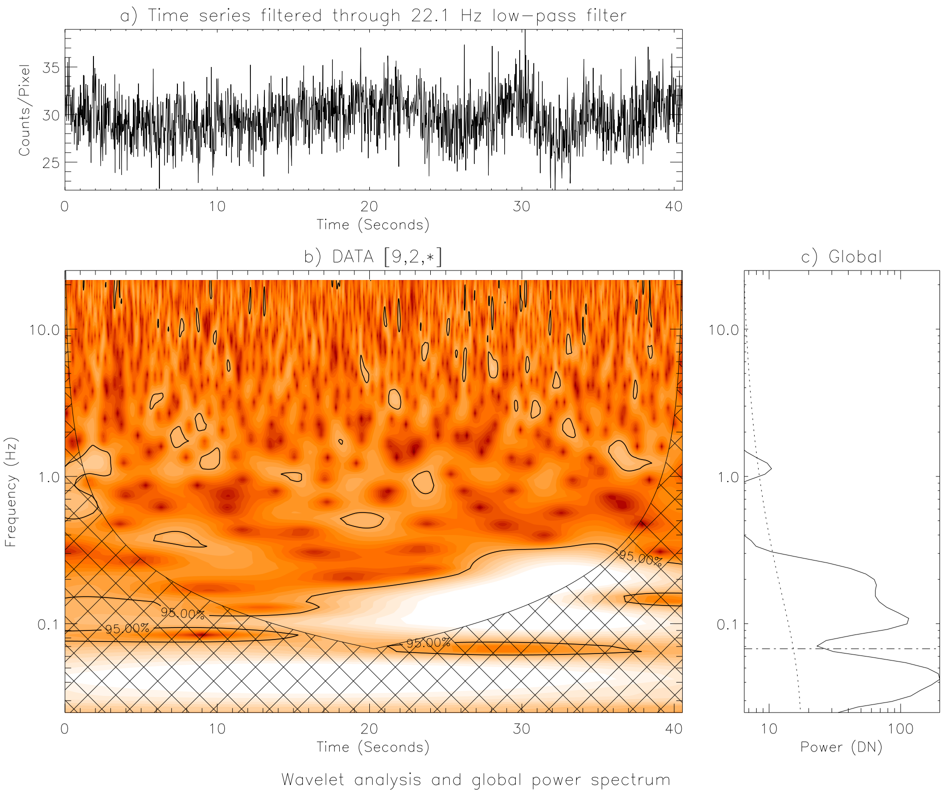

Figure 2: Wavelet analysis of a pixel located near the peak of a coronal loop during the August 1999 total solar eclipse. See text for details.

example Mallat 1998, Ireland et al. 1999, Gallagher et al. 1999). The main reason is that although this analysis is computationally more intensive, it helps to isolate oscillations localized in both time and frequency. The authors believe that this is the best way to detect transient oscillations and rapid changes, while comparing with the quality of data at the same time.

The wavelet used in our transform is the Morlet wavelet given by the formula:

$$\psi(\eta) = \pi^{-1/4} \exp(i\omega_0\eta) \exp(\frac{-\eta^2}{2}) \tag{1}$$

where η is the dimensionless time parameter, ω_0 is the dimensionless frequency parameter and $\pi^{-1/4}$ is a normalization term (Torrence & Compo 1998).

Williams et al. (2001, 2002) have already detected a number of oscillations during the August 1999 eclipse using SECIS observations and wavelet analysis. The waves have periods around 0.16 Hz providing us with observational evidence that coronal heating via short-period MHD waves is feasible. Figure 2 demonstrates yet another detection of a coronal oscillation at a nearby frequency using the same data as Williams et al. (2001, 2002). It is located in the apex peak of another loop in the same active region (NOAA AR 8561).

In Figure 2a a plot of the time series analyzed is included while at the right-hand side (Figure 2c) is the global wavelet spectrum, analogous to a Fourier power spectrum. In Figure 2b (the wavelet power transform), the lightly shaded area indicates a good match between the wave given by the equation (1) for a given frequency (specified by the y-axis) for a given point at the time sequence (specified by the x-axis). The contoured line surrounding the white area indicates areas with more than 95% confidence. The cross-hatched area is polluted by edge effects and should be ignored.

The authors would like to emphasize that this is not the only detection of high frequency periodicities in this particular coronal loop. There are another three oscillations found in pixels surrounding the one from which Figure 2 was produced, and we believe this is strong evidence in favour of the credibility of the presented detection. It indicates that there was an actual wave along the loop and became visible only at the peak because of surrounding emission from other coronal loops.

Acknowledgments

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