HIGH-FREQUENCY CORONAL OSCILLATIONS AND CORONAL HEATING

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Abstract. At the 1980 total solar eclipse, we searched for high-frequency (0.1–2 Hz) oscillations in the intensity of the 5303-Å coronal green line, as a test of predictions of theories of coronal heating via magnetohydrodynamic waves. Portions of the image 2.5- or 5-arc sec across were fed to cooled photomultipliers using fiber-optic probes. We detected excess power in Fourier transforms of the data for the region between 0.5 and 2 Hz at the level of 1% or 2% of the incident power. Such oscillations could be associated with Alfvén waves that are trapped on loops a few thousand kilometers long or with fast waves that are trapped on loops a few thousand kilometers in diameter. Additional observations at the 1983 eclipse are planned to resolve atmospheric and instrumental contributions.

1. Introduction

At the 16 February, 1980 total solar eclipse, we searched for short-period (1 to 10 s) oscillations in the corona to test observational predictions of new models of coronal heating by Alfvén waves. Such new models of coronal heating are of particular importance in view of the incompatibility of the traditional acoustic-heating models with observations both of the Sun from OSO-8, and of a wide range of spectral types in the ultraviolet and in the X-ray region with IUE and with the Einstein Observatory, respectively.

Our search for coronal oscillations was originally motivated by calculations of Ionson (1979) based on his earlier work on surface Alfvén waves (1978), and by calculations of Hollweg (1979b) based on his showing (1979a) that resonances can be driven by motions in the convection zone. The work by Ionson and by Hollweg indicated that velocity oscillations in small coronal loops could be detected in the 1 Hz range by their causing intensity oscillations on the level of a few per cent. A literature search and conversations with colleagues revealed no coronal visible-light observations with time resolution better than about 20 s, though higher frequency oscillations have been sometimes reported in radio bursts.

The problem of solar coronal heating has recently been reviewed by Kuperus *et al.* (1981). Since that time, Hollweg (1981) and Žugžda and Locāns (1982) discussed the excitation of standing waves by motions outside the corona. Hollweg (1982) calculated the rate of dissipation in the corona from a train of fast shocks. Further, Ionson (1982) made analogies with an LRC circuit. Edwin and Roberts (1982) and Gordon and Hollweg (1983) have discussed fast modes trapped in the corona by an effect similar

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to the way optical fibers trap light, resulting from an Alfvén velocity that differs from the interior to the exterior of a coronal loop. 1 Hz waves can result in loops a few thousand kilometers across.

Independently of particular models, the frequency spectrum of the corona is of interest to many theorists, and our search was ultimately motivated by a desire to extend this spectrum to the 0.1–10 Hz range that we could observe.

2. Observations

We observed the eclipse from the N.S.F. site at the Japal–Rangapur Observatory south of Hyderabad, India, as part of a larger U.S. expedition. We were searching for intensity oscillations of a few per cent with periods of about 1 s, much shorter than any previous limit set in coronal observations. The predictions of both Ionson and Hollweg indicated that we should look in coronal loops, and should limit our field of view to a few arc seconds. That the 1980 eclipse came near solar maximum was favorable to our finding suitable structures.

Figure 1 shows a block diagram of our equipment. Fiber-optic probes relayed 2.5- and 5-arc sec diameter regions of the coronal image from the prime focus to the detectors. We reimaged, observed, and recorded the remainder of the coronal image in real time with the eyepiece and on a video monitor, for alignment, guiding, and subsequent analysis. The fiber-optic probes were hooked at a right angle so as to receive the coronal image on their axis while providing suitable silhouettes for guiding and video recording.

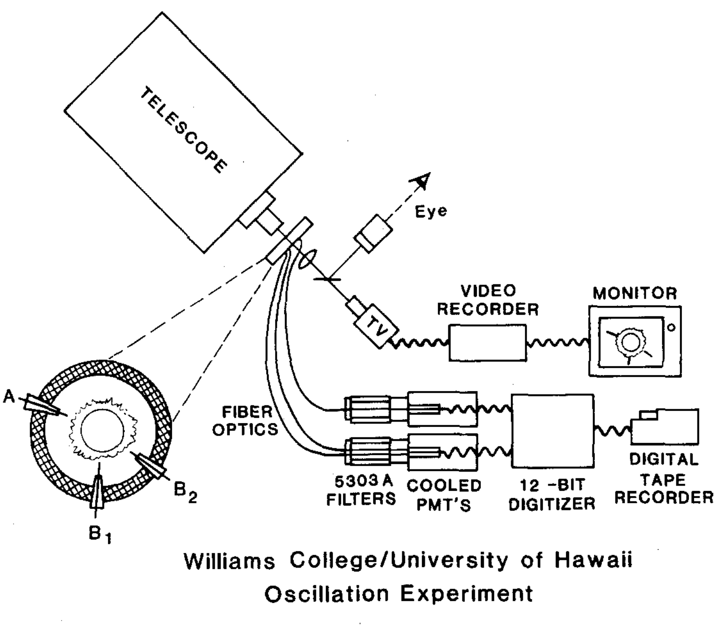

Fig. 1. Block diagram of the equipment.

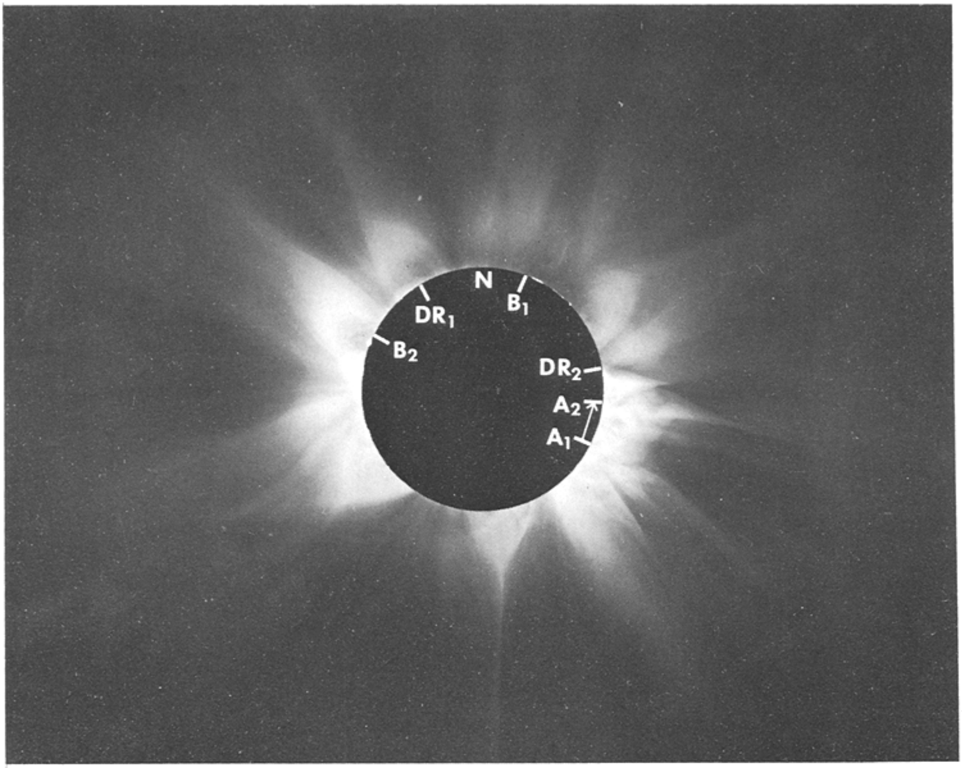

Fig. 2. The Lacy/Street radial-filter photograph, taken with the Newkirk camera. The positions of the diamond rings and of our signal probes are marked. (Photo courtesy of the High Altitude Observatory, National Center for Atmospheric Research.)

Three independent fiber-optic probes were available; their positions are shown on Figure 2. Light from pairs of probes passed through 5303-Å coronal green-line filters to cooled EMI 9658R photomultipliers. The signals were digitized with a 12-bit processor. We switched twice during the eclipse between probes B_1 and B_2, which used the same photomultiplier. The location of probe A was changed halfway through totality to move it to a brighter coronal region.

Data were digitized at a 30 Hz rate, making us sensitive to frequencies lower than about 10 Hz. Figure 3 shows a printout of all the data recorded during the 130 s of totality. The time at which probe A was moved is evident, as are also some gain adjustments in B.

Since we anticipated signals of only a few per cent coherent over a region only a few arc seconds across, accurate and stable guiding was of particular concern. The videotape showed that our larger probe moved less than its width over at least an 8-s period; if the coherence region of an oscillation is larger than the probe, we would have stayed within the coherence region for even longer.

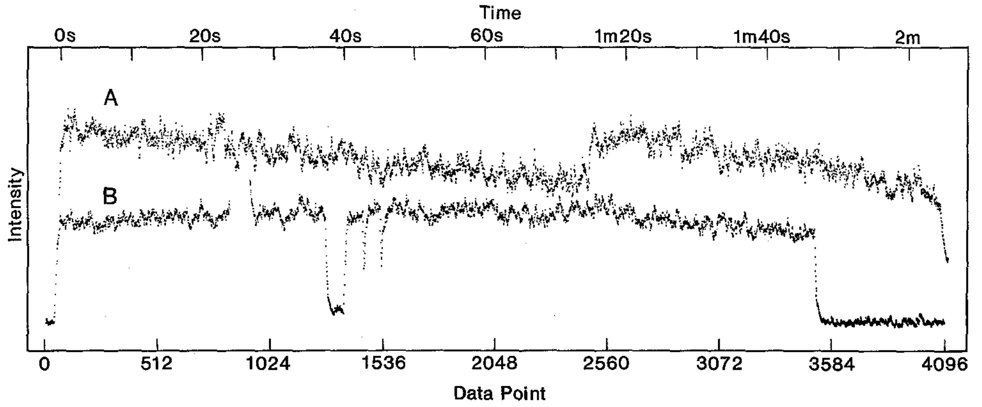

Fig. 3. The entire data set, with data from photomultiplier A, fed by probe A, shown above and from photomultiplier B, fed by probes B_1 and B_2, shown below. The position of probe A in the coronal image was moved at $t = 115$ s. The gain of photomultiplier B was adjusted between $t = 25$ s and $t = 50$ s.

3. Analysis

Figure 4 shows a sample section of data and the corresponding power spectra for a 4-s period, i.e., 128 points. Figure 5 shows a 17-s sample. Many such data sets show enhanced power in the 0.5 to 2 Hz range at the level of about 2% of incident power.

Many instrumental or atmospheric effects are expected to be be exactly in phase or exactly 180° out of phase between the two probe signals. For example, an oscillation in the tracking of the solar image might cause the intensities to vary 180° out of phase with each other. We searched for such phase effects through subtraction and ratio tests. Probes B_1 and B_2 were perpendicular to each other and B_2 was located on opposite the side of the Sun from probe A, to provide suitable data for these tests.

Analysis of the Fourier-transform phases indicates that oscillations on opposite sides of the Sun are not necessarily in or out of phase by 180°. But not all atmospheric and instrumental effects, such as sky-transparency variations, can be ruled out by such considerations, so we are not now prepared to make definitive statements about the

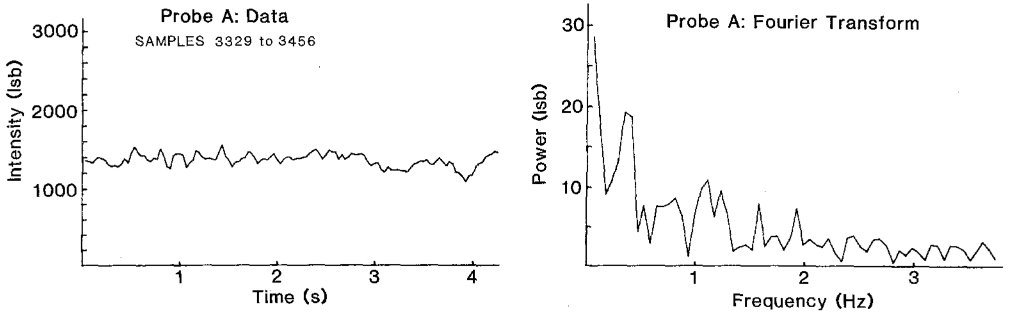

Fig. 4. Data (left) in units of least-significant bits (lsb) and Fourier-transform power (right) for a 4-s interval. The data were recorded with 12-bit accuracy, so full scale is 4096 least-significant bits.

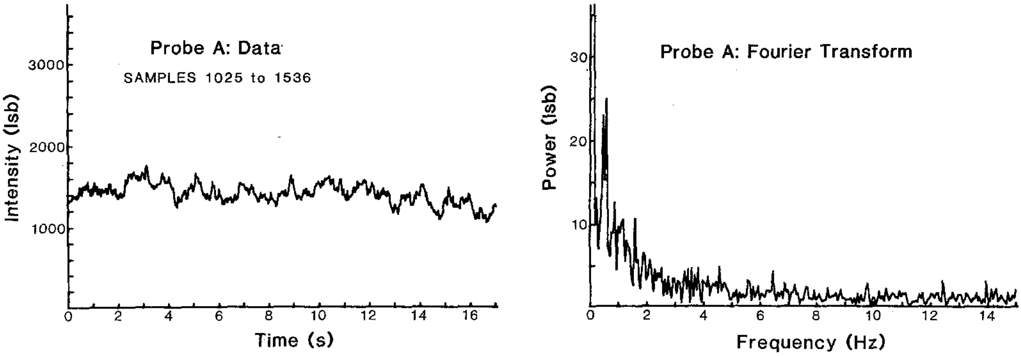

Fig. 5. Data (left) and Fourier-transform power (right) for a 17-s interval.

existence of high-frequency coronal oscillations. At the 11 June, 1983 total solar eclipse in Indonesia, we plan additional observations in which we will observe simultaneously through on-band and off-band 5303-Å filters. Since oscillatory signals are expected predominantly in the coronal-line channel, this should provide a more conclusive test of the solar origin of the oscillatory power.

In sum, we studied time-series of 5303-Å green-line intensity from 2.5- and 5-arc sec diameter coronal regions with 30-Hz temporal resolution. In many of the time intervals examined, some enhanced power is evident in the 0.5 to 2 Hz range at a level of 1 or 2% of incident power, as predicted by the Alfvén-wave heating models of Ionson and Hollweg for coronal loops of suitable size, or by trapped fast waves as suggested by Edwin and Roberts and by Gordon and Hollweg. We are working to resolve the relative contributions of solar, instrumental, and atmospheric effects through additional observations at the 1983 eclipse.

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