SOLAR OSCILLATIONS INSTRUMENT AT AN INFRARED WAVELENGTH OF 1.6 μm AT YUNNAN OBSERVATORY

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Abstract. A photometric solar seismograph, as part of an international network, was installed at Yunnan Observatory, the Chinese Academy of Sciences, and put into operation in the spring of 1991. This instrument is used to detect solar oscillations by measuring the continuum radiation intensity on the solar disk with a spatial resolution of 50 arcsec, in heliocentric coordinates, for research on p-modes and g-modes when $l < 50$, where l is the angular degree of the eigenfunction. The solar oscillations can be observed simultaneously at two wavelengths of the detector with a sensitivity of 10 of the average intensity. This paper reports on the optical system of the instrument. Also introduced in this paper is the compensation system for the noise signals produced by the changes in the transparency of the Earth's atmosphere. This is based on solar photometry at wavelengths of 0.55 mm and 1.6 mm.

Key words: infrared: stars – instrumentation: photometers – Sun: oscillations

1. Introduction

The 5-minute solar oscillation was first discovered by Leighton and collaborators in 1960 (Leighton, Noyes, and Simon, 1962). Ten years later, the prediction that there should be an acoustic resonant wave cavity below the solar surface was proposed by Ulrich et al. (1977) and by Leibacher and Stein (1971) to explain the 5-minute oscillations. Ulrich made an important prediction that there should be a dispersion relationship between k and l. This characteristic relation was respectively demonstrated in 1975 by Deubner (1975) while observing the Sun, and by Grec and Fossat (1983) while observing the low p-modes at the South Pole. Hill and Stebbins (1976) found a series of oscillations of the Sun's diameter with periods ranging from ten minutes to one hour. The observational method for the study of solar oscillations has been improved along with progress made in other aspects of research on solar oscillations. In order to research the structure and dynamics of the solar interior and the long-term period variation of the Sun, a cooperative observatory network has been set up by SCLERA of the University of Arizona, and Yunnan Observatory. The first solar seismograph of this network was installed at Yunnan Observatory in 1990-1991 and was put into operation in March 1991. In the near future, a network of these instruments will be set up to remedy the defect that arises when the Sun cannot be continuously observed at a single observatory. This instrument can be used to observe the Sun simultaneously at the two wavelengths of 0.55 mm and 1.6 mm, with the sensitivity of the detector being 10^{-6} of the average intensity of the Sun to monitor oscillations with $l < 50$.

D. M. Rabin et al. (eds.), Infrared Solar Physics, 283–286.

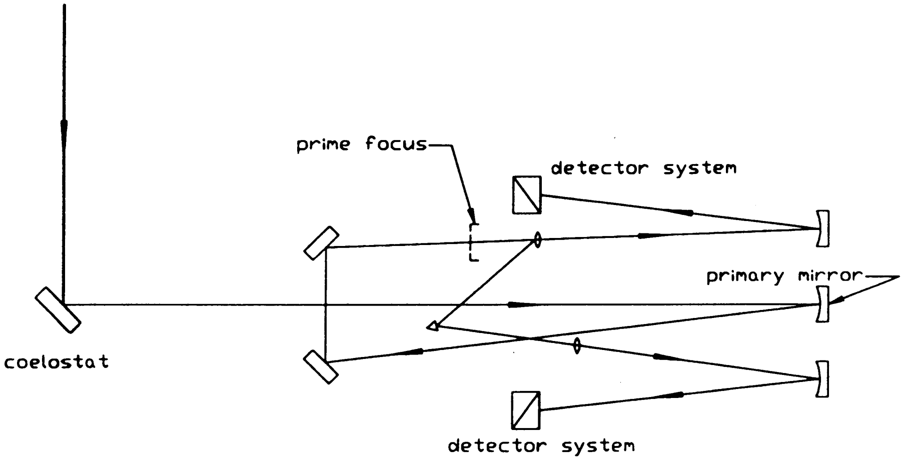

Fig. 1. The optical system

2. Optical System of the Solar Seismograph

The solar seismograph at Yunnan Observatory is used as a part of the network to observe solar oscillations by determining changes in the intensity of the continuum on the solar disk with a spatial resolution of ~ 50 arcsec in heliocentric coordinates. The optical system of the instrument consists of a coelostat, a primary mirror, and a detector system, as shown in Figure 1.

Sunlight passes through a window to the 20-cm-diameter coelostat mirror and then to the primary mirror with an aperture of 7.0 cm and a focal length of 200 cm. After the sunlight passes through the prime focus, two solar images are formed in the optical system. One of them has a diameter of 19 mm for measurements at disk center; the other has a 28 mm diameter for measurements at the solar limb. The solar images are scanned across three Ge 1 × 16 diode arrays at 0.55 μm, and across a second set of 3 Ge arrays at 1.6 μm. In front of each linear array is a mask which is designed to yield a spatial resolution of approximately 3° in solar latitude and longitude (viewed normally at the solar equator) per pixel. Scanning is implemented to give a coverage of ±90° in longitude and ±60° in latitude.

3. Data Acquisition

The operating system and data acquisition system of the telescope are controlled with a Masscomp 5500 on-line computer. The signals received by the detectors are sampled every 50 ms with a 12-bit A/D converter. Signals for a given location on the solar disc are filtered by a digital triangle filter with a width of 16 s. The output of the triangle filter is sampled every 4 s and recorded. This data- acquisition system can produce 31 Mbytes of data in 10 hours, and the data is recorded on

1/4-inch cartridge tape. The data are exchanged between Yunnan Observatory and SCLERA.

4. Compensation Role of Simultaneous Observations at Wavelengths of 0.55 and 1.6 μm.

Since the original solar signals produced by oscillations are measured through the Earth's atmosphere, the measured results include both of the solar signals and signals produced by temporal variations in the transparency of the Earth's atmosphere. Care must be taken to minimize the transparency effects due to water vapor. In this regard, there are no absorption bands of water vapor at the two wavelengths of 0.55×0.01 μm and 1.6×0.015 μm (Oglesby, 1987).

However, the variation in the solar intensity depends on wavelength and satisfies the radiation transfer equation

$$\mu \frac{dI_\lambda(\tau_\lambda, \theta, \phi)}{d\tau_\lambda} = I_\lambda(\tau_\lambda, \theta, \phi) - S(\tau_\lambda) \tag{1}$$

where $d\tau_\lambda = -\rho\,\kappa_\lambda\,dz$, κ_λ is the opacity at wavelength λ, ρ the density, S the source function, and μ is the cosine of the angle between the line of sight and the normal to the surface.

If solar oscillations are regarded as small perturbations, the basic equation for the Eulerian perturbation I' can be expressed as follows:

$$I'(r,t) = I(r,t) - I_0(r) \tag{2}$$

Under the linearized perturbation, equation (1) can be written as

$$\mu \frac{dI'_\lambda}{d\tau_\lambda} = I' - S' + \frac{(\rho\,\kappa)'}{\rho\,\kappa}(I - S) \tag{3}$$

where the superscript prime denotes the Eulerian perturbation. The solution of this equation is:

$$I'_\lambda = \int_0^\infty [S' - \frac{(\rho\,\kappa)'}{\rho\,\kappa}(I - S)] e^{-\tau_\lambda/\mu}\, d\tau_\lambda/\mu \tag{4}$$

The properties of I'/I were studied by Hill and Rosenwald (1986) of SCLERA, with the following results:

$$\frac{I_{0.55}}{I} \approx 7.4 \times 10^{-5} \tag{5}$$

and

$$\frac{I'_{1.6}}{I} \approx -5.5 \times 10^{-5}. \tag{6}$$

The characteristics of I' in the above results at the two wavelengths are opposite in sign to each other, and in particular are different from the wavelength dependence of changes in I due to transparency changes in the Earth's atmosphere. Therefore, this kind of characteristic can be used to discriminate true solar variations from changes in transparency in the Earth's atmosphere.

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