THE PRECISION CALCIUM PHOTOMETER:
A New Instrument for Astroseismology

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ABSTRACT. The Precision CAlcium Photometer (PCAP) has been built with characteristics optimized for amplitude astroseismology. The instrument consists of two units: an on-telescope optical system that forms and stabilizes a stellar image onto a 200 micron optical fiber; and a spectrometer unit that accepts the light from the fiber and integrates the Calcium II H and K lines (3968.5 Å and 3933.7 Å), along with adjacent continuum regions, in a photon-counting mode. Some key system characteristics include active image stabilization, a 12-meter optical fiber with ~70% transmission at 3950 Å, and a thermally and mechanically stable spectrometer. A description of the instrument and of laboratory and on-telescope test runs are discussed below.

1. The PCAP Instrument

The Precision CAlcium Photometer (PCAP) is a new instrument built at the Harvard-Smithsonian Center for Astrophysics which measures the flux in the Ca II H and K line cores relative to the adjacent continuum flux. PCAP is conceptually almost identical to the H-K photometer at the Mt. Wilson Observatory. A crucial difference however will increase the attainable signal-to-noise ratio of PCAP by a factor of order 100. The current HK photometer is limited by "seeing" noise at the entrance slit to about 1% per integration, independent of photon flux. By contrast, PCAP uses an optical fiber feed, fabricated at Penn State University (Barden et al. 1981), which scrambles the input beam and therefore (in combination with a fast chop rate betwen the HK emission and the reference continuum band) greatly reduces the seeing problem. The remainder of the instrument is a traditional plane grating spectrometer (except for the fast and efficient chopping system at the output beam). Additional advantages accrue because the instrument is coupled to the telescope only by the optical fiber. This means it will be stable (it sits on a bench) and is easily mated to any telescope.

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Layouts for the two instrument packages are shown in the accompanying figures. The on-telescope front end optics package is contained in a 24" x 24" x 12" box (Figure 1). This package includes optics for adjusting the f-number at different observational sites, a low light video camera for target acquisition, two reference sources used for calibration, and an image stabilizing active mirror and quadrant detector. The light from the star is transmitted through the 200 micrometer diameter fiber optic cable to the spectrometer section of the system, with an F/6 input beam.

The spectrometer is built on a 36" x 24" optical breadboard (Figure 2). It operates in a Littrow mode, using a 30-inch focal length collimator (5 inch diameter) and a plane reflective grating (blazed for 760 nanometers) in second order. In the slit plane, a mask selects the Calcium H and K lines as well as continuum regions on either side of the lines. The bandpass is selectable, with one to five Angstroms the typical bandpass for the lines, and 10 to 30 Angstroms the bandpass for each continuum region. A tuning fork type chopper cycles at 100 hertz and swaps reflected and transmitted beams between two cooled photomultiplier detectors. This rapid swapping should eliminate any systematic effects introduced by power supply ripple or other detector instabilities. The output from the photomultipliers is amplified and single photon events are selected with a discriminator. The output pulses are standard TTL and are integrated in a pair of 32-bit counters. The signals from the counters are synchronized with a signal from the chopper so that line and continuum counts are summed independently. The integrated counts are read out into a controlling computer at intervals which are software selectable.

The computer that controls the operation and processes and stores the data is an IBM PC compatible (a COMPAQ). Either floppy disks or direct transfer of the data via Modem brings the data stream to a mainframe computer or a workstation for reduction, display, and analysis, though initial on-telescope data analysis programs are installed on the COMPAQ.

2. Laboratory and On-Telescope Results

Laboratory tests confirm that the PCAP system is operating in the photon noise limited regime. Figure 3 shows the power spectrum calculated from data recorded with laboratory light sources, and 0.1% modulation imposed with an input test source modulated at a 5 mHz frequency.

PCAP has been operated twice on the 60-inch telescope at the Oak Ridge Observatory of the Smithsonian Astrophysical Observatory in Harvard, Massachusetts. The front-end optics package and guider worked satisfactorily, although the weather allowed tracking of only bright stars. Weather problems at Oak Ridge have not permitted recording of the long stable data sets needed for oscillation detection. However,

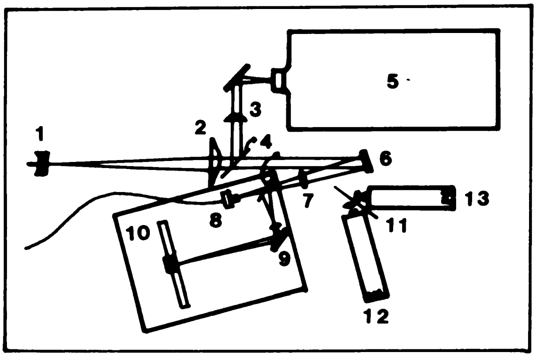

Figure 1. PCAP telescope optical system: 1) scaling lens, 2) collimator, 3,7) relay lenses, 4,11) beam splitters, 5) intensified videcon, 6) active tilt mirror, 8) fiber input, 9) microscope objective, 10) PMT quad cell, 12,13) reference sources.

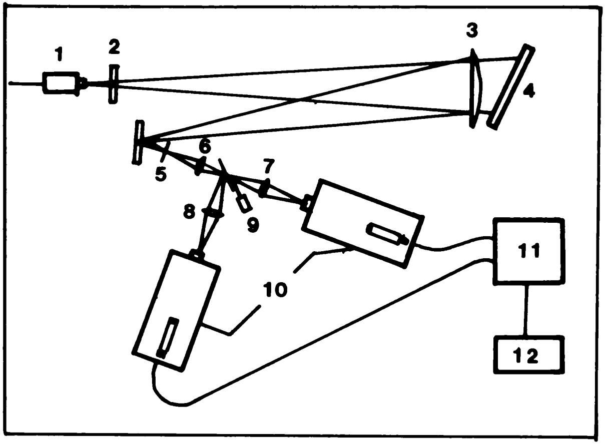

Figure 2. PCAP spectrometer: 1) fiber output, 2) blocking filter, 3) collimator, 4) grating, 5) slit, 6,7,8) relay lenses, 9) chopper, 10) PMT housings, 11) pulse counter, 12) computer

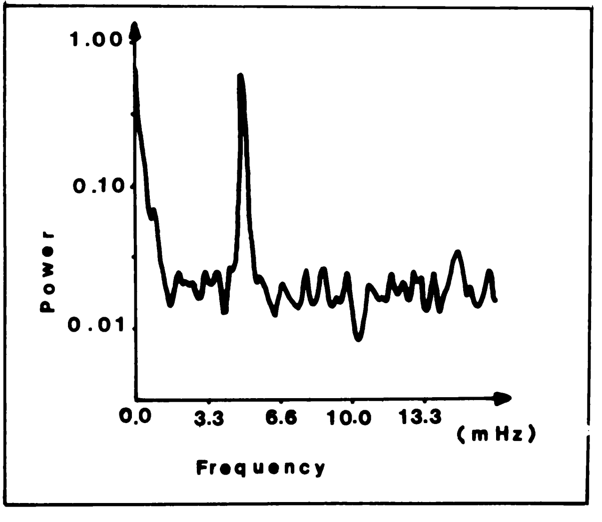

Figure 3. Power spectrum of laboratory calcium lamp with 0.1% modulation imposed on the source.

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the instrument appears to be working as predicted, and at least one data set on α Ursa Minoris (Procyon) shows the possibility of 1.2 mHz and 4.1 mHz peaks, though intermittent clouds made the data processing difficult and a confirming data set was not obtained.

3. Future Program

PCAP was designed to attain a precision of $\Delta I/I \leq 10^{-4}$ in 6 hours for a star with apparent visual magnitude of 5. To date, the evidence we have indicates that this design goal can be achieved. We intend to follow up on the preliminary indications of the presence of global oscillations in the chromospherically active K dwarf star ϵ Eridani that were found by Baliunas *et al*. (1981) in the form of a peak in fluctuation power near a 10-minute period. More recently, Noyes *et al*. (1984) obtained stronger evidence for global oscillations in this star, by detecting individual groups of p-modes, with the characteristic frequency spacing expected for a star of the known radius of ϵ Eridani. However, the signal-to-noise ratio was marginal, and new observations are needed to confirm this result.

The detection of Ca II intensity oscillations in this and other accessible dwarf stars is a high priority application for PCAP. In addition, PCAP can observe stars fainter than those now included in the Smithsonian-Mt. Wilson Program of Stellar Activity, and thus extend monitoring of stellar magnetic activity to stars in open clusters and to M dwarfs.

Baliunas, S. L., Hartmann, L., Vaughan, A. H., Liller, W., and Dupree, A. K. 1981, *Ap. J.*, **246**, 473.

Barden, S. C., Ramsey, L. W., and Truax, R. J. 1981, *P.A.S.P.*, **93**, 154

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