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AN IMAGING VECTOR MAGNETOGRAPH FOR THE NEXT SOLAR MAXIMUM

A Progress Report

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We describe the conceptual design of a new imaging vector magnetograph currently being constructed at the University of Hawaii. The instrument combines a modest solar telescope with a rotating quarter-wave plate, an acousto-optical tunable prefilter as a blocker for a servo-controlled Fabry-Perot etalon, CCD cameras, and on-line digital image processing. Its high spatial resolution (1/2 arcsec pixel size) over a large field of view (5 by 5 arcmin) will be sufficient to significantly measure, for the first time, the magnetic energy dissipated in major solar flares. Its millisecond tunability and wide spectral range (5000 - 7000 A) enable nearly simultaneous vector magnetic field measurements in the gas-pressure-dominated photosphere and magnetically-dominated chromosphere, as well as effective co-alignment with Solar-A's X-ray images. We expect to have the instrument in operation at Mees Solar Observatory (Haleakala) in early 1991.

We have chosen to use tunable filters as wavelength-selection elements in order to emphasize the spatial relationships between magnetic field elements, and to permit construction of a compact, efficient instrument. This means that spectral information must be obtained from sequences of images, which can cause line profile distortions due to effects of atmospheric seeing. To ensure that sequential images sample the same solar features, we plan to use two techniques for seeing compensation. First, a tip-tilt mirror will correct for average image motion, using a sunspot in the field for guiding. Second, we will use two identical CCD cameras coaligned to high precision. The first camera will measure polarimetrically modulated images to derive monochromatic Stokes images; the second will observe unmodulated, broad-band images at the same time, to determine the instantaneous distortion due to seeing. The latter set will be used to separate atmospheric effects from modulation due to polarization.

1. INTRODUCTION

Solar high energy phenomena cannot be understood without accompanying vector magnetic field measurements. To ensure adequate continuity, frequency, and reliability of vector magnetic field measurements for interpretation of coordinated solar X-ray and γ-ray data obtained with Solar A, Gamma-Ray Observatory (GRO), balloon and rocket payloads during the Max '91 time period (1991-1994), and to compensate in part for the lack of space-borne vector magnetographs, the National Aeronautics and Space Administration, the National Science Foundation, and the University of Hawaii funded the development of a ground-based vector magnetograph, called the Imaging Vector Magnetograph (IVM). This instrument is now under development at the University. Work was begun in August, 1988, and is expected to be completed by the end of 1990, in time for the August 1991 launch of the Solar-A spacecraft. The IVM will be put into operation at Mees Solar Observatory of the University of Hawaii, Haleakala, Maui.

2. PROGRESS TO DATE

2.1. Conceptual design

The design includes a Cassegrain reflector telescope, an acousto-optic tunable prefilter (AOTF), a single Fabry-Perot interferometer, and a two CCD cameras (for white-light and magnetic images). White-light reference images will be used for real-time image motion compensation and post-observation separation of solar and atmospheric components of the magnetic-field images. Using array processors for on-line post-processing, we expect to do flat-fielding, remove intensity fluctuations due to five-minute oscillations, and apply subsonic filtering. Available array processors can complete these tasks within about ten minutes of the polarimetric data acquisition.

3. Performance Specifications

Performance specifications for the final IVM design and hardware are as follows: 1.84 x 10^7 electrons per second per square arcsecond flux, 0.6 arcsecond pixel size, 0.04 second waveplate time , 16 waveplate angles, 8 wavelengths, 48 useful frames per rotation. For the CCD of choice the instrument will have a 5.1 x 5.1 arcminute field of view, and will achieve a signal-to-noise ratio of 10^4 in the quiet sun in 310 seconds or 10^3 in a sunspot in 77 sec, including all processing to produce a magnetogram corrected for supersonic image distortions. Roughly speaking, a signal to noise ratio of 10^4 corresponds to a longitudinal field of 10 Gauss and a transverse field of 100 Gauss.

3.1. Current Activities

At the present time the major mechanical and optical work is taking place on the Cassegrain telescope, rather than the polarimeter (an engineering drawing is shown in this paper). The top-level data flow scheme has been worked out. We have received most of the IVM computer hardware and software. We have the Bitbus approach to control iterfacing worked out and the initial equipment purchases started. On the hardware side, within the next ten months we expect to complete the procurement of the analysis hardware, the CCD camera, the Fabry-Perot filter, the AOTF, and the imager stabilizer. We expect to complete the design and fabrication of the calibrator, modulator, and blocking filter. On the softare side we expect to complete the codes for data proccessing, camera control, filter control, pointing and image stabilization, calibration, modulator control, and the operator interface.

PERFORMANCE SPECIFICATIONS

- **Spatial resolution: 1.2 arcsec.** Detector pixel spacing 0.6 arcsec over a 5.1 x 5.1 arcmin field of view.
- **Spectral resolution: 70 mÅ at 6000Å.**
- **Flux: 1.9×10^7 electrons per second per square arcsec in** the continuum at 6000Å.
- **Spectral range: 5000 - 6500 Å.** We expect to observe a three-line set: one photospheric magnetic line (Fe I λ6302), one chromospheric magnetic line (Mg I λ5173), and Hα (line center only).
- **Temporal cadence: typically one minute for strong fields.** Signal-to-noise ratio of 10^4 in the quiet sun in 310 seconds, 10^3 in a sunspot in 77 seconds, including all magnetogram processing.
- **Sensitivity: 10 Gauss longitudinal fields and 100 Gauss transverse fields.** Simultaneous velocity measurements to 10 m/s. Temporal cadence can be traded for sensitivity.
- **Co-alignment: A simultaneous photospheric white-light image of the full field of view,** for precise co-alignment with Solar-A images and Max'91 ground and balloon-borne experiments.

DESIGN FEATURES

- **Telescope: 30-cm Cassegrain reflector.**
- **Monochromator: Air-spaced tunable Fabry-Perot, 70mÅ bandpass.** Order-sorting using an acousto-optic tunable filter (AOTF) with bandpass of 2 Å, a contrast of 1000:1, a large field of view, rapidly tunable over the full wavelength range.
- **Polarization Modulator: Rotating quarter-wave plate.** The AOTF will double as a beam-splitting analyzer.
- **Detectors: High-resolution commercial CCD cameras.** No mechanical shutter is necessary; turning off the radio-frequency signal to the AOTF turns off the diffracted beams imaged on the cameras. 512 x 512 pixel detector arrays.
- **Data Acquisition: 68020-based computer in a VME-bus chassis.** A minimum modulation sequence consists of a half-rotation of the wave plate, i.e. eight camera reads, which are combined to derive Stokes parameters. Recording on 8mm digital video cassettes.
- **Analysis and Archiving**: Off-line analysis on a Sun workstation. Archival medium is the original 8mm video cassette. Digital optical disk for archiving working datasets. Video disk recorder for time-dependence studies.