Investigation of Active Regions at High Resolution by Balloon Flights of the Solar Optical Universal Polarimeter (SOUP)

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SOUP is a versatile, visible-light solar observatory, built for space or balloon flight. It is designed to study magnetic and velocity fields in the solar atmosphere with high spatial resolution and temporal uniformity, which cannot be achieved from the surface of the earth. The SOUP investigation is carried out by the Lockheed Palo Alto Research Laboratory, under contract to NASA's Marshall Space Flight Center. Co-investigators include staff members at a dozen observatories and universities in the US and Europe.

The primary objectives of the SOUP experiment are:

1. To measure vector magnetic and velocity fields in the solar atmosphere with much better spatial resolution than can be achieved from the ground;
2. To study the physical processes that store magnetic energy in active regions and the conditions that trigger its release;
3. To understand how magnetic flux emerges, evolves, combines, and disappears on spatial scales of 400 to 100,000 km.

SOUP is designed to study intensity, magnetic, and velocity fields in the photosphere and low chromosphere with 0.5 arcsec resolution, free of atmospheric disturbances. The instrument includes: a 30 cm Cassegrain telescope; an active mirror for image stabilization; broadband film and TV cameras; a birefringent filter, tunable over 5100–6600 Å with 0.05 Å bandpass; a 35 mm film camera and a digital CCD camera behind the filter; and a high-speed digital image processor. The filter bandpass is narrow enough to resolve the absorption lines in the solar spectrum, and therefore measurements of line profiles can be made over the entire field-of-view from sets of filter images. The lines available using the tunable filter include Hα, He D3, Na D1, Mg b, and several Fe I lines for magnetic and Doppler measurements. An analyzer allows precise measurement of circular and linear polarization for making longitudinal and transverse magnetograms. In addition, images spaced at intervals across the Hα line show the paths of chromospheric fibrils, allowing the connectivity of magnetic field lines to be inferred. The broadband frames are used to measure transverse velocities; thus
the flow patterns which shear the magnetic fields of an active region can be measured independently of the fields themselves.

SOUP flew on the shuttle Spacelab 2 mission in August, 1985, and one day of observing time was available for SOUP during the flight, during which 6000 frames of diffraction-limited white light data were collected. A second shuttle flight on the Sunlab mission was planned, but this has been cancelled following the "Challenger" disaster. High-resolution imaging on balloon flights was achieved by Project Stratoscope in the late 1950's, and has been exploited since then by German, Russian, and Japanese groups for additional white light studies. Balloon flights of SOUP will produce our first views of active region magnetic fields at resolution approaching the size of the basic flux tubes themselves.

As of July, 1989, the project has just begun a four-month definition phase. The gondola and solar pointing system will be provided by NASA and their specification is under way. If NASA approval and funding for flight are forthcoming at the end of this phase, then the first flight could still take place in 1991.

This project is supported by NASA Contract NAS8-32805 (SOUP). Development of the CCD camera has been supported by NASA Contract NAS5-26813 (CIP for OSL). Data analysis is also supported by the Lockheed Independent Research Fund.

**INSTRUMENT SUMMARY**

**TELESCOPE**

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<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Aperture</td>
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</tr>
<tr>
<td>Type</td>
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<tr>
<td>Wavefront Quality</td>
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<tr>
<td>Spatial Resolution</td>
<td>0.5 arcsec</td>
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**COARSE POINTER (offset pointing and drift compensation)**

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<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Range</td>
<td>±40 arcmin</td>
</tr>
<tr>
<td>Slew Rate</td>
<td>30 arcsec/s</td>
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<tr>
<td>Drift Compensation Rate (peak)</td>
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**FINE GUIDER (jitter compensation)**

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<tbody>
<tr>
<td>Range</td>
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</tr>
<tr>
<td>Servo Sensor</td>
<td>4 photodiode limb sensors</td>
</tr>
<tr>
<td></td>
<td>on movable mounts</td>
</tr>
<tr>
<td>Servo Actuators</td>
<td>Secondary mirror on PZT mounts</td>
</tr>
<tr>
<td>Residual Jitter</td>
<td>&lt; 0.01 arcsec rms</td>
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</table>
BROADBAND IMAGING SYSTEM

Focal Length .......................... 1800 cm (f/60)
Field of view: film .................. 168 x 260 arcsec
video .................................. 103 x 138 arcsec
Wavelength Band ..................... 5000 - 5500 Å
Typical exposure time ................. 0.10 sec

TUNABLE FILTER IMAGING SYSTEM

Focal Length ................................ 2700 cm (f/90)
Field of view: CCD ..................... 72 x 72 or 143 x 143
arcsec (selectable)
film ........................................ 138 x 183 arcsec
video ...................................... same as CCD
Wavelength Band ..................... 5100 - 6600 Å
Typical exposure time .................. 0.5 - 2 sec

TUNABLE FILTER

Universal birefringent filter, alternate partial polarizer design
Bandpass: 5200 Angstroms .............. 50 or 80 mA (selectable)
6500 Angstroms ......................... 78 or 128 mA
Wavelength Reference .................. HeNe Laser (6328 Å)
Polarization analyzers ................. RCP, LCP, 4 linear orientations
Spectral prefilters ..................... 8 regions, 7 - 10 Å wide

TUNABLE FILTER CCD CAMERA

Sensor Type ............................. 1024 x 1024 18 micron pixel CCD
Image Format ............................ 512 x 512 pixels, 12 bits/pixel
Readout Time ........................... 0.6 sec
Full Well ................................ 200,000 electrons
Photometric Accuracy (1 read) ........ 300:1 or 600:1

TUNABLE FILTER SPECTRAL LINES

Continuum ............................. Temperature, Horizontal Flows
Fe I 5250 Å ............................. Magnetic Field Strength
Fe I 5247 Å ............................. Magnetic Field Strength
Fe I 5576 Å ............................. Doppler Shifts (g=0)
Fe I 6302 Å ............................. Vector Magnetograms
Ni I 6768 Å ............................. Doppler Shifts (GONG & SOI Line)
Mg I 5173 Å ............................. Magnetograms, Dopplergrams
Na I 5896 Å ............................. Magnetograms, Dopplergrams
Hα 6563 Å ............................. Chromospheric Morphology, Flows, Flares
He I 5876 Å ............................. Chromospheric & Coronal Morphology, Flares
FIGURE CAPTIONS

Figure 1. SOUP instrument: telescope, focal plane package, and flight computer.

Figure 2. SOUP telescope and focal plane package optical/mechanical schematic.

Figure 3. SOUP tunable birefringent filter.

Figure 4. 1024 × 1024 pixel brassboard CCD camera.

Figure 5. Broadband and tunable filter system schematics.

Figure 6. Data flow diagram for SOUP CCD and film observations.
SOLAR OPTICAL UNIVERSAL POLARIMETER
OPTICAL/MECHANICAL SCHEMATIC

M = MIRROR
BS = BEAM SPLITTER
SH = SHUTTER
L = LENS ASSY
F = FILTER

30 CM CASSEGRAIN TELESCOPE
SECONDARY BAFFLE
PRIMARY BAFFLE

DIGITAL CCD CAMERA
LINM TRACKING FINE GUIDER (4 EA)
REJECTED HEAT

FIELD LENS AND STOP
HEAT DUMP MIRROR

COARSE POINTING DRIVE (VERTICAL)
UNIVERSAL TUNABLE FILTER

COARSE POINTING DRIVE (HORIZONTAL)
INDEXING PREFILTER

NOT TO SCALE

SOUP 0010 NLK
NOAH KATZ 20 JUL 88
REV DATE 21 JUL 88
NOT TO SCALE

SOUP OPTICAL/MECHANICAL SCHEMATICS

BROADBAND

TUNABLE FILTER

M = MIRROR
BS = BEAM SPLITTER
Sh = SHUTTER
L = LENS ASSY
F = FILTER

SOUP 0013 NLK
NOAH KATZ 25 JUL 88
REV DATE 26 JUL 88