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

T. Tarbell, Z. Frank, C. Gilbreth, R. Shine, A. Title,
K. Topka, J. Wolfson (Lockheed Palo Alto Research Labs)

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

Aperture	30 cm
Type	f/15 Cassegrain
Wavefront Quality	0.06 waves rms at 6328 Å
Spatial Resolution	0.5 arcsec

COARSE POINTER (offset pointing and drift compensation)

Range	±40 arcmin
Slew Rate	30 arcsec/s
Drift Compensation Rate (peak)	1 arcsec/s

FINE GUIDER (jitter compensation)

Range	±15 arcsec
Servo Sensor	4 photodiode limb sensors on movable mounts
Servo Actuators	Secondary mirror on PZT mounts
Residual Jitter	< 0.01 arcsec rms

BROADBAND IMAGING SYSTEM

Focal Length	1800 cm (f/60)
Field of view: film	168 × 260 arcsec
video	103 × 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 × 72 or 143 × 143 arcsec (selectable)
film	138 × 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 mÅ (selectable)
6500 Angstroms	78 or 128 mÅ
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 × 1024 18 micron pixel CCD
Image Format	512 × 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.

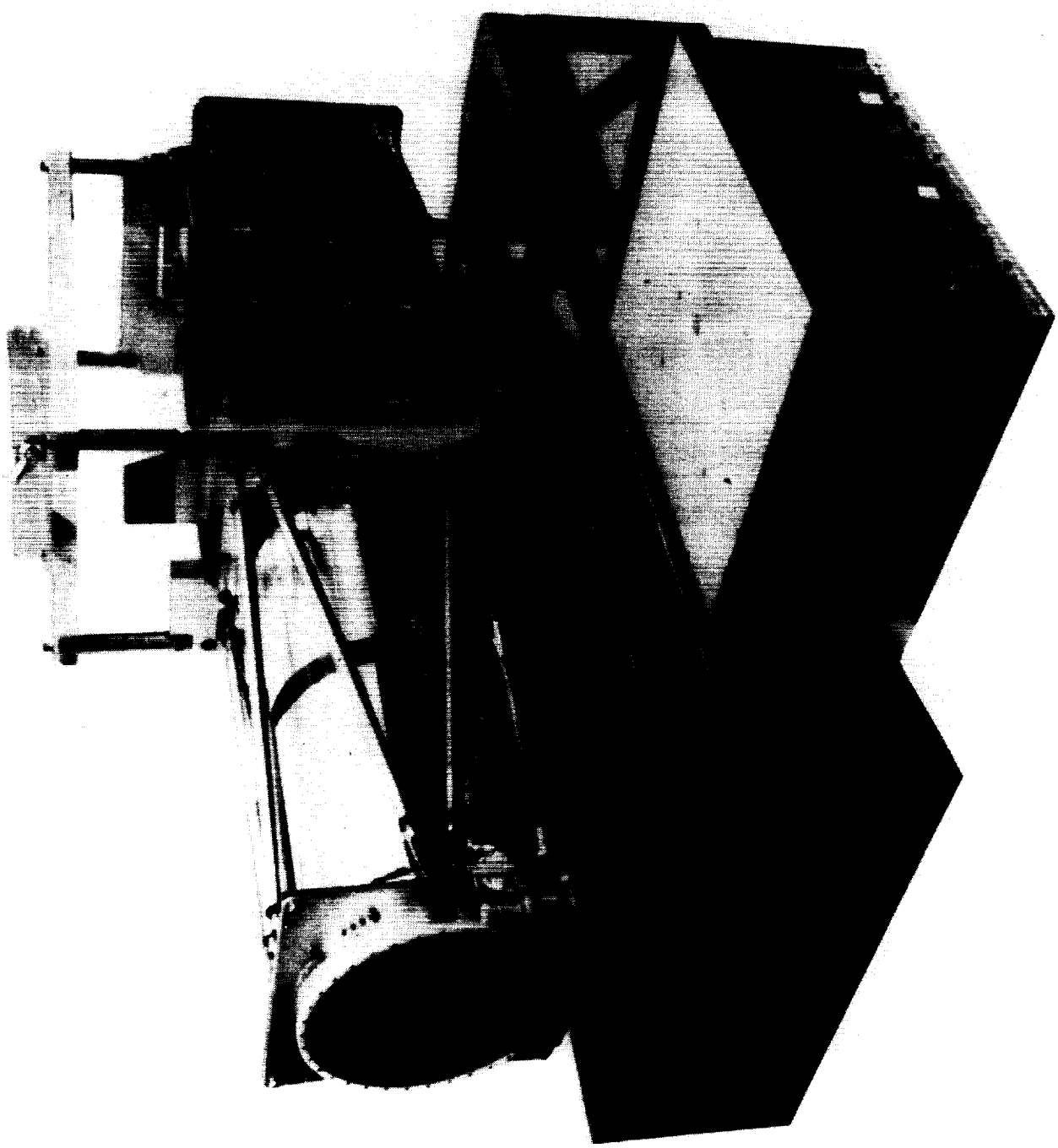
Figure 2. SOUP telescope and focal plane package optical/mechanical schematic.

Figure 3. SOUP tunable birefringent filter.

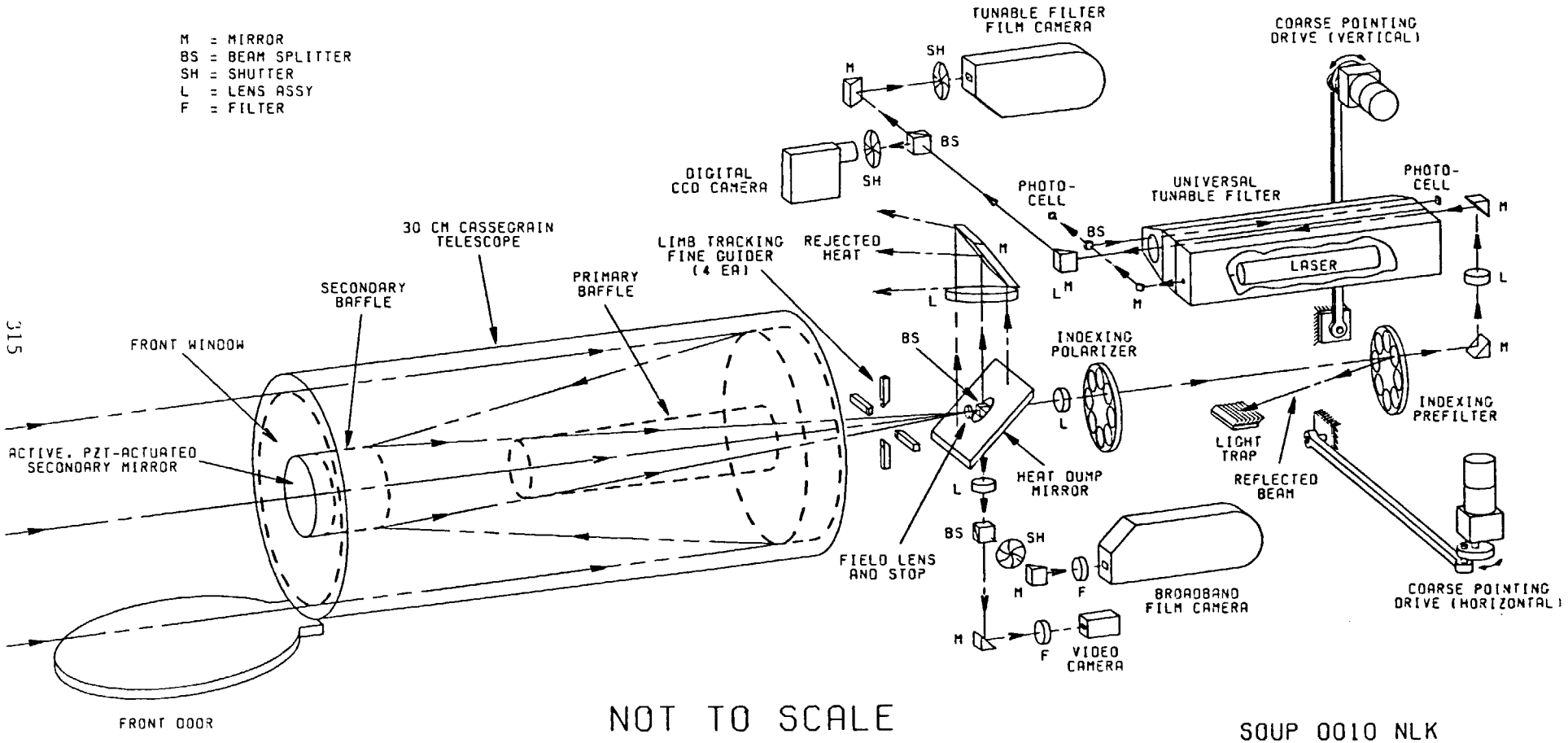
Figure 4. 1024 $\times$ 1024 pixel brassboard CCD camera.

Figure 5. Broadband and tunable filter system schematics.

Figure 6. Data flow diagram for SOUP CCD and film observations.

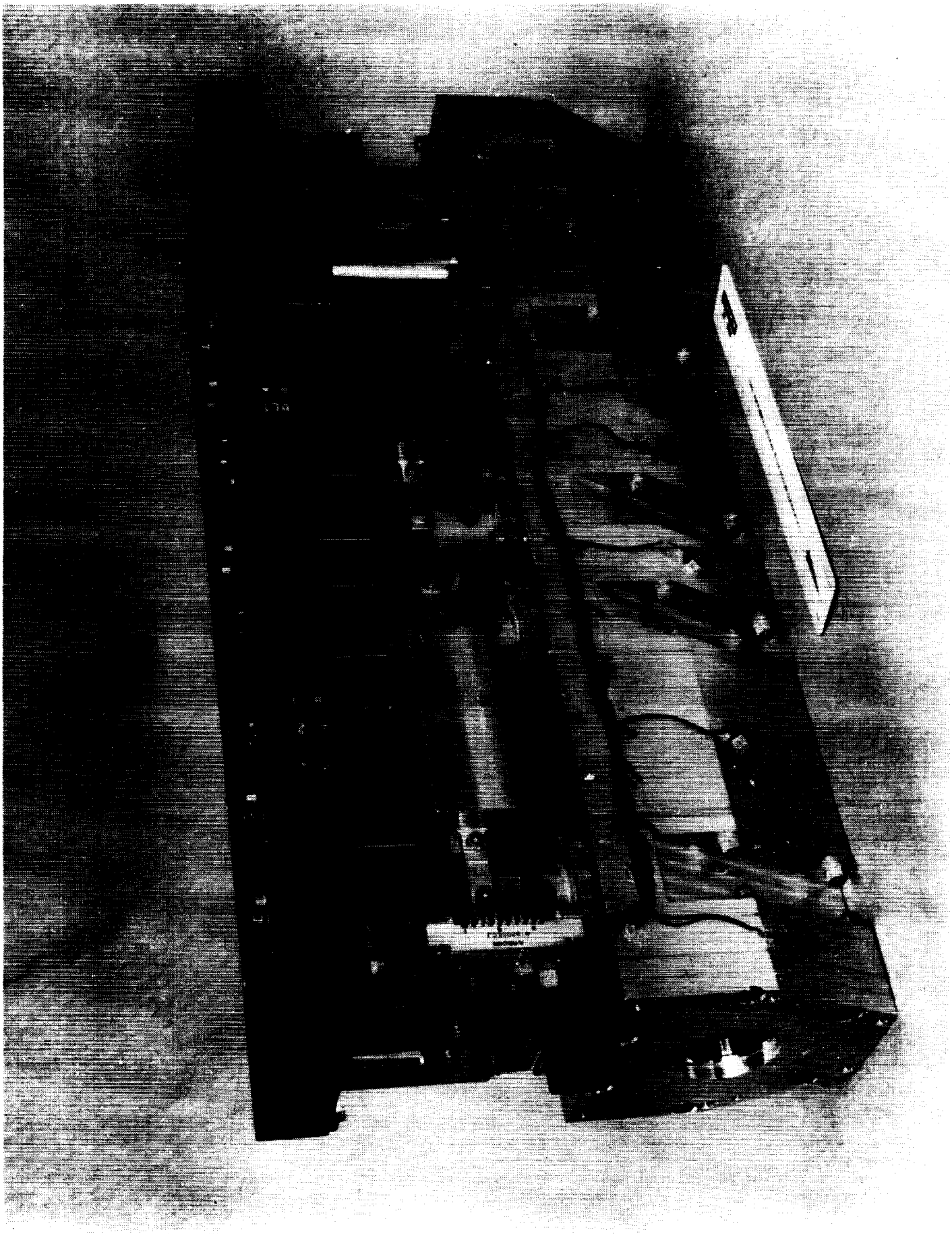


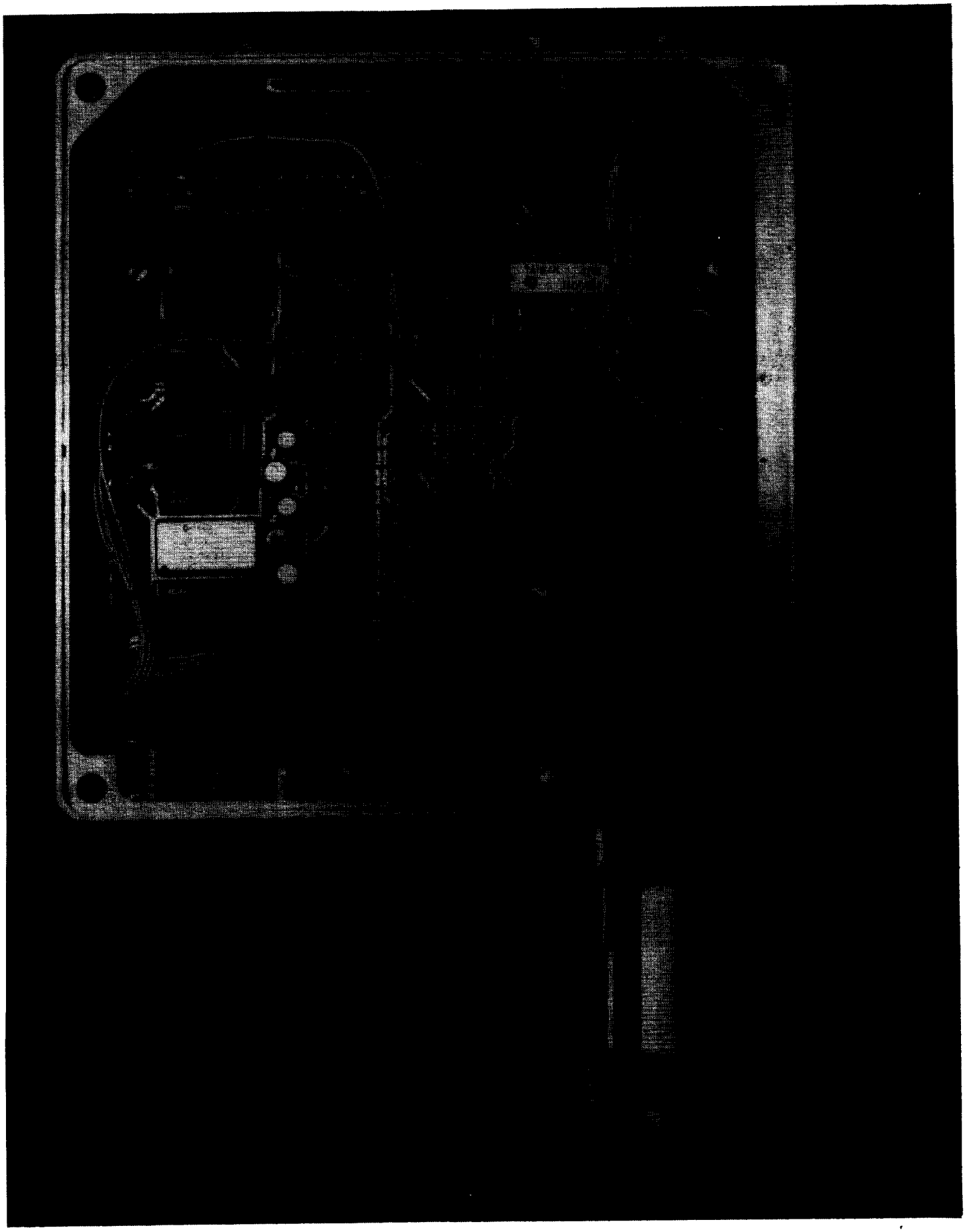
SOLAR OPTICAL UNIVERSAL POLARIMETER
OPTICAL/MECHANICAL SCHEMATIC



NOT TO SCALE

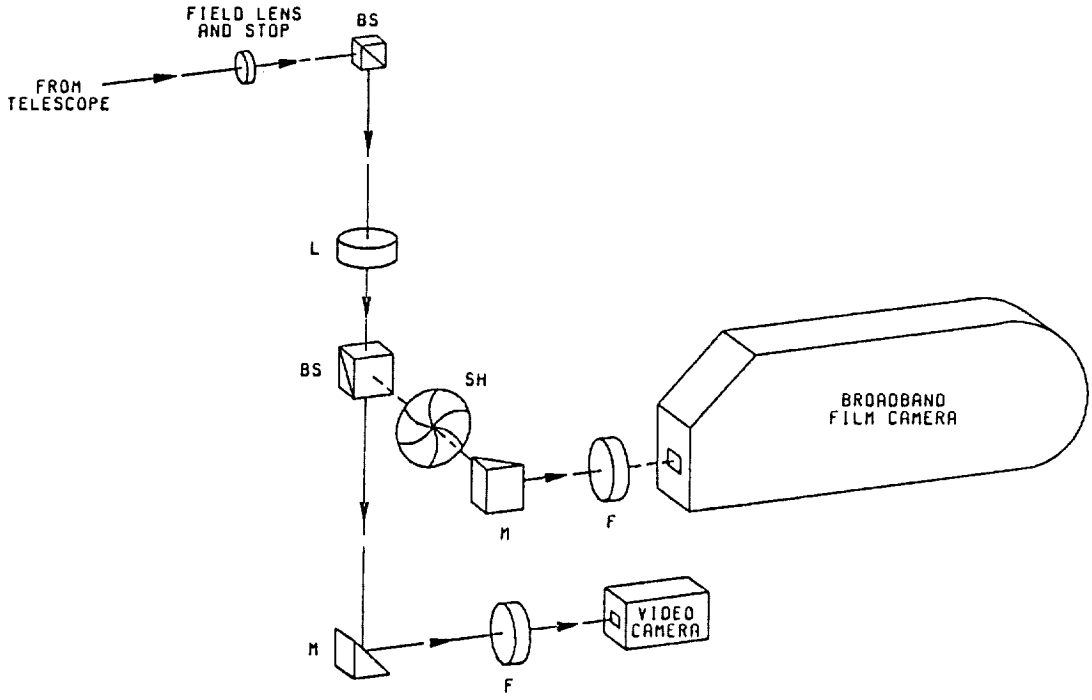
SOUP 0010 NLK
NOAH KATZ 20 JUL 88
REV DATE 21 JUL 88



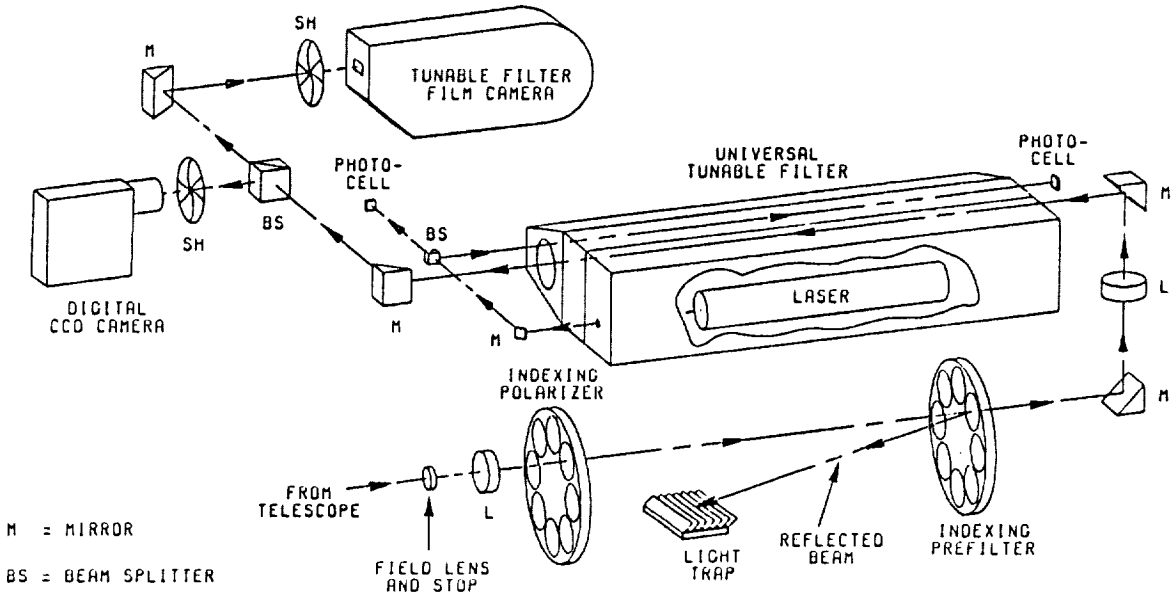


SOUP OPTICAL/MECHANICAL SCHEMATICS

BROADBAND



TUNABLE FILTER



M = MIRROR

BS = BEAM SPLITTER

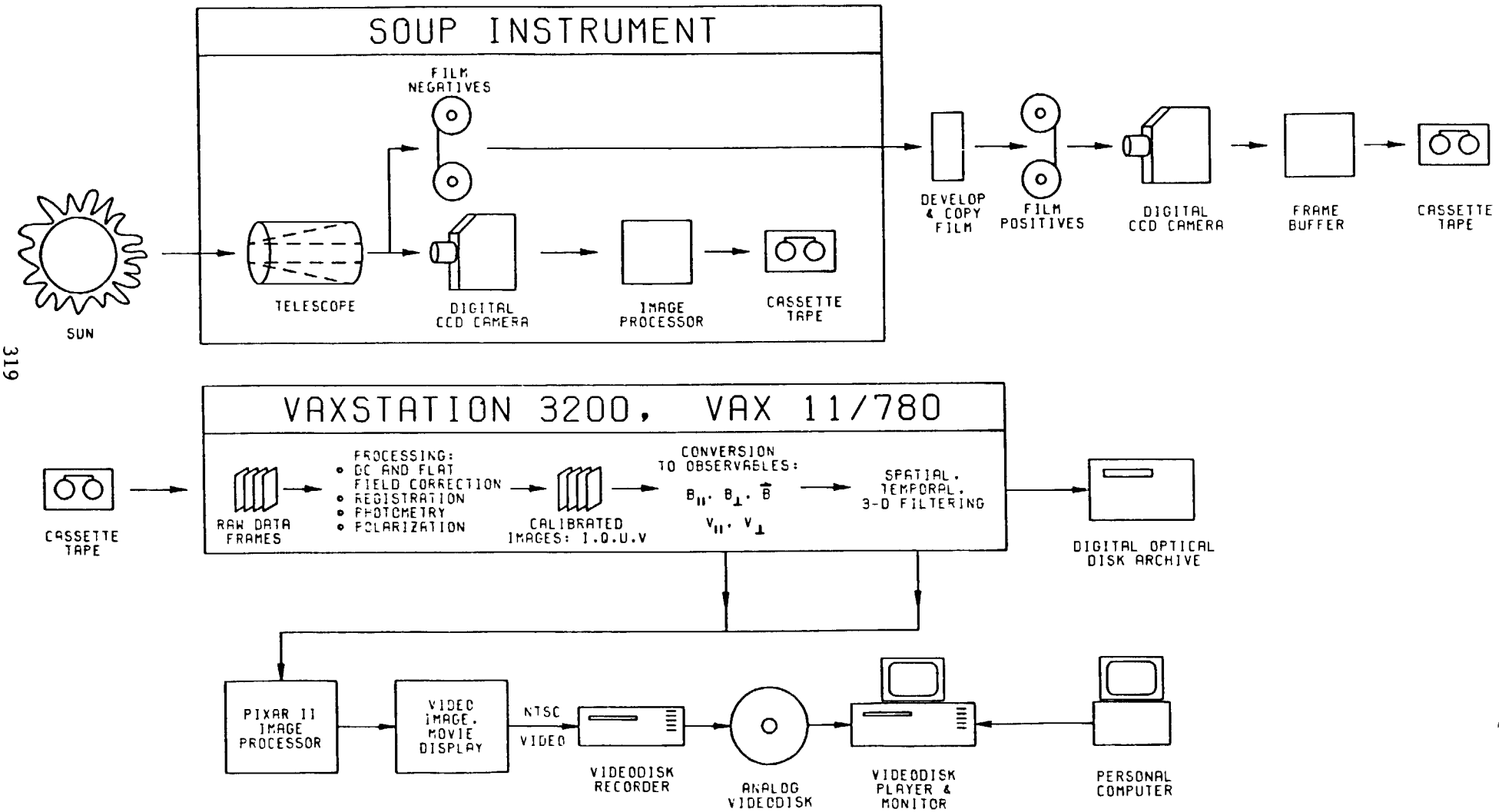
SH = SHUTTER

L = LENS ASSY

F = FILTER

NOT TO SCALE

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


SOUP INSTRUMENT
FILM NEGATIVES
SUN
TELESCOPE
DIGITAL CCD CAMERA
IMAGE PROCESSOR
CASSETTE TAPE
DEVELOP & COPY FILM
FILM POSITIVES
DIGITAL CCD CAMERA
FRAME BUFFER
CASSETTE TAPE
VAXSTATION 3200, VAX 11/780
CASSETTE TAPE
RAW DATA FRAMES
PROCESSING:
DC AND FLAT FIELD CORRECTION
REGISTRATION
PHOTOMETRY
POLARIZATION
CALIBRATED IMAGES: I.Q.U.V
CONVERSION TO OBSERVABLES:
$B_{\parallel}$, $B_{\perp}$, $\vec{B}$
$V_{\parallel}$, $V_{\perp}$
SPATIAL, TEMPORAL, 3-D FILTERING
DIGITAL OPTICAL DISK ARCHIVE
PIXAR II IMAGE PROCESSOR
VIDEO IMAGE, MOVIE DISPLAY
NTSC
VIDEO
VIDEODISK RECORDER
ANALOG VIDEODISK
VIDEODISK PLAYER & MONITOR
PERSONAL COMPUTER