OBSERVING PROGRAMS IN SOLAR PHYSICS DURING
THE 1973 ATM SKYLAB PROGRAM

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1. Introduction

In mid-1973 the National Aeronautics and Space Administration will carry out a series of three extended manned orbital spaceflights known collectively as the Skylab mission. During the three flights, of length 28, 56 and 56 days (respectively), three-man crews will test their ability to live and carry out useful tasks for long periods in a space environment. One of the major scientific tasks assigned to them is to undertake an extensive series of solar observations using a cluster of X-ray, ultraviolet, and visible-light telescopes known as the Apollo Telescope Mount (ATM).

The ATM instruments show promise of making an invaluable and unique contribution to solar physics, owing to their large size and light-gathering power, their high spatial resolution, their extensive combined spectral coverage, and the presence at the control panel of an astronaut thoroughly trained in solar physics. An observational program has been designed by the scientists involved in order to take fullest advantage of the above capabilities. In addition, however, it is evident that an optimum program must involve closely coordinated ground-based observations. A communications network is being set up to facilitate such coordination, thus permitting the possibility of a concerted attack on common problems by many solar physicists around the world during the Skylab mission.

In this paper we shall describe the ATM and its capabilities, the principal scientific goals and the planned observing program, and methods of coordinating the observations with ground-based and other types of solar observations. The ATM experimenters wish to provide the information necessary to allow other solar physicists to plan coordinated observing programs during the Skylab mission.

2. Instrumentation

A. THE ATM

Figure 1 shows a drawing of the Skylab in its orbital configuration, where the orbital workshop at the right has been joined at the left by the command and service modules, used by the astronauts to journey to and from the space station. The cylindrical section on the center line of the assemblage, the multiple docking adaptor, provides the attachment for the ATM, oriented vertically in Figure 1. It also provides docking ports for the command and service modules, access to the workshop, and airlock viewing ports for certain non-ATM experiments. The multiple docking adaptor also houses the control console for the ATM, from which astronauts control the pointing
and operation of the solar instruments. A large cruciform array of solar panels radiates from the ATM and provides power for both ATM and other Skylab systems.

The solar experiments occupy the central core of the ATM in a space approximately 2 m in diam and 3.3 m long. The experiments include an X-ray spectroheliograph provided by American Science and Engineering Company (ASE), an X-ray telescope by Marshall Space Flight Center (MSFC), a white-light coronagraph from the High Altitude Observatory (HAO) of the National Center for Atmospheric Research, an ultraviolet spectrograph and an XUV spectroheliograph from the Naval Research Laboratory (NRL), and an EUV spectrometer-spectroheliometer from the Harvard College Observatory (HCO).* Two Hz telescopes are carried to provide video images to the astronaut for instrument-pointing at selected solar features, and one of these contains a photographic film camera for a permanent pointing record. With the exception of the Harvard instrument the ATM instruments are predominantly photographic and require the recovery of film canisters by astronaut extra-vehicular activity. The Harvard instrument is photoelectric and its data are recorded and then transmitted to Earth by telemetry every orbit. The individual instruments will be described in more detail in the following section.

Fig. 1.

The telescopes are pointed at selected solar features by moving the entire spar assembly, with attached instruments, in pitch, yaw, and roll by use of either the video displays of the Sun in Hz or the numerical readout from a fine Sun-sensor located on the forward end of the spar. Roll is maintained with reference to a star tracker. The stability of the pointing is expected to be better than \( \pm 2.5^\circ \) over a 15-min period.

The astronaut will point the instruments in response to instruction and predictions from the ground, and will also act on his own interpretation of several onboard visual displays. These include not only the two Hz images mentioned earlier, but also an

* In this paper distinction is maintained between the extreme ultraviolet (EUV) region between 300 and 1300 Å and the shorter wavelength region between 150 and 600 Å, denoted XUV because it borders on the soft X-ray region.
XUV image in a broad spectral band from 170 to 630 Å, a soft X-ray image in the region 2 to 10 Å, a white-light coronal image, an X-ray history chart record, a 6 cm radio monitor and a 0–8 Å X-ray scintillation detector.

The two Hz telescopes have zoom lenses permitting the astronaut to select a field of view between 4.4 and 35'. Spatial resolution of the Hz video display is about 2". Hz wavelength discrimination is provided by solid etalon Fabry-Pérot filters with 0.7 Å half width. The Hz telescopes have movable crosshairs, which will be aligned to the entrance apertures of the Harvard and NRL ultraviolet spectrometers; pointing for the other instruments is less critical since they have wide fields of view.

The broadband XUV monitor (provided by NRL) has spatial resolution of only 20", but it will reveal features in the transition layer and low corona such as 'holes', bright coronal knots, or coronal flaring regions that are not evident in the Hz display. Images from the XUV monitor will be transmitted to the ground on a daily basis to assist in-flight support activities at the Mission Control Center in Houston.

The X-ray monitor (part of the ASE instrument) will provide the astronaut with X-ray images having a spatial resolution of about 1' and will be used to monitor the X-ray emissions of active regions.

The above displays may be used, for example, to determine the location of a flare when the 0–8 Å scintillation detector, an automatic device in the ASE instrument, indicates the onset of an X-ray burst with intensity above a predetermined threshold. Other indicators of flare onset include the 6-cm radio burst detector and the X-ray history event record (provided by MSFC) which will indicate whether the general level of soft X-ray activity has been rising or falling over the preceding hours.

The white-light coronal display (derived from the HAO coronagraph) has a spatial resolution of 30" and sensitivity of 10-10 of the solar disk intensity; it should reveal the presence of coronal streamers, although its main purpose is to check alignment of the coronagraph.

The ATM is generally operated by the astronaut at the control console, who directly initiates instrument observing sequences. However, during unattended periods when astronauts are on board Skylab but not present at the console, limited operation of several of the instruments is possible by ground command. Furthermore, the Harvard spectrometer, the ASE X-ray telescope, and the HAO coronagraph will also be operated for 8–12 hr per day during the two unmanned intervals between the 3 manned visits. Finally, the Harvard instrument is capable of unmanned operation for an unspecified period after the last manned mission. During this last period the photographic instruments will not be operable, since their film cannot be recovered.

B. THE INSTRUMENTS

1. White-Light Coronagraph (HAO)

The white-light coronagraph experiment will photographically monitor the coronal brightness and polarization from 1.5 to 6.0 solar radii over a wavelength band extending from 3500–7000 Å. The instrument consists of an externally occulted corona-
graph designed to reduce the instrumentally scattered light to levels on the order of $10^{-10} B_\odot$, where $B_\odot$ is the mean solar radiance. A removable camera contains a 750-ft. roll (8025 exposures) of Kodak special film 026-02, a Panatomic-X type emulsion with improved reciprocity characteristics. The camera is detachable and will be replaced with additional film-loads during astronaut extravehicular activity.

The net angular resolution of the coronagraph film combination has been measured to be 8.2", corresponding to a distance of about 6000 km in the corona. Because this resolution corresponds to a system response of about 3% for an input contrast ratio of 1.6:1, a somewhat higher spatial resolution should be achieved in the actual coronal photographs.

Because of the vignetting function caused by the presence of the external disk assembly, the effective coronal radiance is 'flattened' over the field of view. The net mean coronal brightness at the film plane varies by a factor of only 5 from 1.5 to 6 $R$, because of the vignetting action.

A step wedge, illuminated by sunlight, and calibrated relative to the intensity of the mean solar disk over the range of $10^{-8} B_\odot$ to $10^{-10} B_\odot$ is imaged on each picture frame by a supplementary optical system. In addition, a television display at the ATM console previously mentioned provides means for improving the quality of the data through direct astronaut observation of the coronal image and the pointing and internal alignment.

Four picture-taking modes are available to the coronagraph experiment. Two modes cycle three linear polaroids through the field of view to allow determination of line-of-sight electron densities in the corona. Two additional modes provide rapid film-taking sequences for following transient phenomena in the corona.

2. X-Ray Spectrographic Telescope (ASE)

The ASE X-ray spectrographic telescope has a primary optical system consisting of a nested pair of coaxial and confocal grazing-incidence mirrors of paraboloid-hyperboloid design. These mirrors provide a geometrical collecting area of 42 cm$^2$ and form an image of the Sun in soft X-rays 1.92 cm in diam. The field of view is 48' and the on-axis resolution is 2". The image is recorded photographically on 70 mm Kodak SO-212 film, a Panatomic-X type emulsion without an overcoating.

A filter wheel with five filters and a blank opening is in the optical path and provides broad band X-ray filtergrams in the 3.5–60 Å range. Filter bandpasses are listed in Table I. An X-ray transmission grating with 1440 lines mm$^{-1}$ can be inserted into the optical path to provide spectrally dispersed images. The spectral resolution is 0.15 Å and the grating will work best for bright, small features such as flares.

Several operating modes are possible. In the Single mode one sequence of exposures each a factor of four longer than the last from $\frac{1}{16}$ s to 256 s through a single filter is obtained. This mode provides sufficient dynamic range to encompass virtually all expected coronal X-ray phenomena. To observe rapidly varying features, such as flares, the instrument can be switched into High rate mode wherein an abbreviated sequence (e.g. $\frac{1}{64}$ s to 1 s) is repeated with an interval between exposures of 0.2 seconds.
Less rapid time variations can be observed in the Low rate mode in which the interval between exposures is 12 s. A Programmed mode is available in which the instrument is operated in the High rate for four minutes and the Low rate for 9 min. In the Flare Auto mode operation is initiated automatically by the X-ray scintillation detector.

<table>
<thead>
<tr>
<th>Filter</th>
<th>Bandpass</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0013 cm Beryllium</td>
<td>3.5–17 Å</td>
</tr>
<tr>
<td>0.0003 cm Teflon</td>
<td>3.5–14 Å, 19–23 Å</td>
</tr>
<tr>
<td>Blank a</td>
<td>3.5–36 Å, 44–60 Å</td>
</tr>
<tr>
<td>0.00057 cm Parylene</td>
<td>3.5–19 Å, 44–47 Å</td>
</tr>
<tr>
<td>0.0051 cm Beryllium</td>
<td>3.5–11 Å</td>
</tr>
<tr>
<td>0.0025 cm Beryllium</td>
<td>3.5–14 Å</td>
</tr>
</tbody>
</table>

* All positions include a filter composed of 3000 Å aluminum plus 0.0001 cm Polypropylene, used primarily to absorb heat and exclude visible light.

In addition to the above primary system, the instrument contains an uncollimated X-ray scintillation detector and an X-ray ‘finder’ telescope. The scintillation detector, which monitors the 0–8 Å X-ray flux, provides a visible and an audible alarm to alert the astronaut to the onset of a flare, controls automatic operation of the film camera, and provides eight-channel pulse-height spectra in the range 10–80 keV. The 0–8 Å flux is displayed on the astronaut’s display panel and is updated every second. By logarithmic compression a dynamic range in flux of five decades is possible. The pulse height data are telemetered to ground and a complete spectrum is generated every eight seconds. The ‘X-ray finder’ telescope provides the astronaut with a T.V. image of the Sun, 1’ in resolution, in the wavelength band 2–10 Å. The ‘finder’ is aligned with the main telescope so that the astronaut can use it to point to bright features such as flares.

The instrument can be operated during manned, unattended, or unmanned periods of the Skylab. However, during the latter two periods, the capability of varying the experimental modes is limited.

3. X-Ray Telescope (MSFC) and Aerospace Corporation

The Marshall Space Flight Center (MSFC)-Aerospace instrument employs a glancing incidence telescope to produce an image of the Sun on SO-212 film. The telescope has two optical elements: an internally reflecting paraboloidal primary element and a hyperboloidal element, one focus of which is coincident with the focus of the paraboloid. It has an effective focal length of 190.5 cm and a collecting area of 14.8 cm², giving an effective photographic f-ratio of f/44. The resolving power of the instrument on-axis is limited by the film to approximately 3’. Off-axis the resolution is slightly degraded by coma and curvature of field. These alterations, together with vignetting, limit the useful field of view to approximately 38’.
The telescope operates at all X-ray and EUV wavelengths above about 5 Å, but the response is limited to certain wavelength bands of interest defined by thin metal foils. The filters are carried on a wheel immediately in front of the film plane; their characteristics are listed in Table II.

### TABLE II

<table>
<thead>
<tr>
<th>Thickness (mg cm⁻²)</th>
<th>Material</th>
<th>Bandpass</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.6</td>
<td>Beryllium</td>
<td>5–12 Å</td>
</tr>
<tr>
<td>1.71</td>
<td>Aluminum</td>
<td>8–18 Å</td>
</tr>
<tr>
<td>0.99</td>
<td>Titanium</td>
<td>5–13 Å, 27–42 Å</td>
</tr>
<tr>
<td>4.53</td>
<td>Beryllium</td>
<td>5–18 Å</td>
</tr>
<tr>
<td>3.42</td>
<td>Aluminum</td>
<td>8–12 Å</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>Visible</td>
</tr>
</tbody>
</table>

Up to 7000 frames of solar X-ray photographs may be taken with one film cassette, containing 1000 ft of SO-212 film. Four such cassettes will be used during the full Skylab mission. The instrument may be operated in several modes: a ‘patrol’ mode for observations of the quiet Sun and in the presence of moderate activity, and ‘active’ and ‘flare’ modes employing shorter exposure times for the observation of active regions and flares.

In addition to the telescope, the MSFC/Aerospace instrument contains two proportional counters which monitor the soft X-ray flux from the whole Sun. One of these has an aluminum window (1.71 mg cm⁻²) and is sensitive in the wavelength region 8–20 Å, while the other has a beryllium window (45.3 mg cm⁻²) and is sensitive in the region of 2–8 Å. The pulses from each counter are sorted electronically into amplitude bands to perform coarse spectral analysis of the solar X-radiation, as tabulated in Table III. The output from either counter can be displayed on the history plotter on the astronaut’s console, to give a guide to the rate of change of the solar X-ray flux, and hence to the level of solar activity.

### TABLE III

<table>
<thead>
<tr>
<th>Channel</th>
<th>Range (Å) Be filter</th>
<th>Range (Å) Al filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00–7.25</td>
<td>16.0–20.0</td>
</tr>
<tr>
<td>2</td>
<td>5.50–6.00</td>
<td>12.0–16.0</td>
</tr>
<tr>
<td>3</td>
<td>5.00–5.50</td>
<td>8.0–12.0</td>
</tr>
<tr>
<td>4</td>
<td>4.50–5.00</td>
<td>6.1–8.0</td>
</tr>
<tr>
<td>5</td>
<td>3.75–4.50</td>
<td>–</td>
</tr>
<tr>
<td>6</td>
<td>2.50–3.75</td>
<td>–</td>
</tr>
</tbody>
</table>
4. Ultraviolet Spectrometer-Spectroheliometer (HCO)

The Harvard experiment is designed to perform solar observations in the extreme ultraviolet (EUV) wavelength range from approximately 280–1350 Å with a spatial resolution of 5". An off-axis parabolic mirror images the Sun on the entrance slit of the 0.5 m concave-grating spectrometer. Small rotations of the mirror permit the instrument either to (a) build up two-dimensional rasters of 5' region of the Sun in 5 min of time, or (b) to scan a single raster line of 5' a length every 5 s of time, in order to study more-rapidly evolving phenomena. The iridium coated f/12 mirror has a 2.3 m focal length, producing a solar image 21.4 mm in diam.

Light from a 5" square portion of the solar image enters an EUV concave-grating spectrometer containing an original gold grating, ruled at 1800 lines mm⁻¹, and the spectrum is imaged at a focal surface which contains seven independent, open-channel, electron-multiplier detection systems. In the reference grating position, the intensity from the selected portion of the Sun is recorded simultaneously at seven important wavelengths, as listed in Table IV. These wavelengths contain spectral lines which span the temperature range from 10⁴ to 2 x 10⁶ K, covering the chromosphere, transition region, and corona. A slight rotation of the grating places Lα, Lβ, Lγ, and the Lyman continuum in position for simultaneous recording. Many other polychromatic positions of the grating produce chance coincidences of interesting groups of lines. The grating can also be positioned to select for study any desired single wavelength in the range 280 Å < ω < 1350 Å. After the grating position is selected, square rasters, single-line rasters, or continuous monitoring of any desired point (40 ms time resolution) may be performed. In an important alternative mode, the instrument with stationary mirror is positioned at a selected solar feature and the grating is scanned continuously, thus obtaining a complete spectrum of the feature with 1.6 Å resolution in 3.8 min.

The instrument is capable of operation in the manned, unattended, or unmanned modes. However, in the latter two cases the capability for precision pointing at selected fine-scale structure is much reduced.

<table>
<thead>
<tr>
<th>Detector Δλ (Å)</th>
<th>Position 1</th>
<th>Position 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Line, T_{max}⁸)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.6</td>
<td>C II 1335, 5 x 10⁴ K</td>
</tr>
<tr>
<td>2</td>
<td>8.3</td>
<td>Lα 1216, 10⁴ K</td>
</tr>
<tr>
<td>3</td>
<td>4.0</td>
<td>O VI 1032, 3 x 10⁵ K</td>
</tr>
<tr>
<td>4</td>
<td>4.0</td>
<td>C III 977, 10⁵ K</td>
</tr>
<tr>
<td>5</td>
<td>8.3</td>
<td>LC 896, 10⁴ K</td>
</tr>
<tr>
<td>6</td>
<td>4.0</td>
<td>Mg x 625, 1.5 x 10⁶ K</td>
</tr>
<tr>
<td>7</td>
<td>4.0</td>
<td>O IV 554, 2 x 10⁵ K</td>
</tr>
</tbody>
</table>

⁸ T_{max} is the temperature of maximum contribution to the line intensity.
5. XUV Spectroheliograph (NRL)

The NRL extreme ultraviolet spectroheliograph is a slitless objective grating spectrograph operating over the wavelength range 150–630 Å. Sunlight entering the instrument is both dispersed and focused by a single concave grating (focal length 200 cm, 3600 lines mm$^{-1}$) which is rotated between two positions to select either the short wavelength range 150–335 Å or the longer range 321–630 Å. The only other active optical element is a thin (0.1 μ) aluminum filter in front of the individual Kodak 104 (formerly SWR) film strips (35 × 258 mm), which acts to exclude stray light of wavelength longer than 835 Å. The resultant solar spectrum appears as a series of superimposed monochromatic images of the Sun, one for each emission line in the wavelength range. Some images are overlapped, especially those below approximately 230 Å that arise from highly stripped iron (Fe v–xvi), but other images such as He I 584 Å, He II 304 Å, Mg IX 368 Å, Fe XV 284 Å, and Fe XVI 335 Å are fairly well separated. Because small, intense features are well separated, spectroheliograms of flares and active regions can be obtained in several hundred emission lines. The field of view of the instrument is approximately 60′ and the dispersion is 1.29 Å mm$^{-1}$. Spectral and spatial resolutions are interdependent. The spatial resolution is 2″–10″, depending on the wavelength, and is best at the central portion of each range and degraded at the ends of the range. The spectral resolution is approximately 0.13 Å for a well defined feature 10″ in extent. Time resolution depends on the exposure time, which varies from the shortest exposure of 2.5 s to prolonged manual exposures of up to 48 min. On the three manned missions there are respectively 200, 400, and 200 film strips available.

6. UV Spectrograph (NRL)

The NRL ultraviolet spectrograph is a double-dispersion, high-resolution spectrograph with spatial and spectral fields defined by an entrance slit. A primary mirror (focal length 100 cm) forms a solar image on a fixed slit. Light from the slit is diffracted by either of two pre-disperser gratings, which select the wavelength band (970–1970 Å, or 1940–3940 Å), for final dispersion by the main concave grating (radius of curvature 200 cm; 600 lines mm$^{-1}$), which focuses the slit spectrum on the photographic film. The pre-disperser gratings are ruled in 10 strips of differing dispersion, approximating a continuously changing dispersion. This technique increases the speed of the instrument by reducing the residual astigmatism to approximately 1′; it does not produce a spectrum having spatial resolution along the slit. Eight spectra are recorded on each Eastman Kodak type 104 film strip. The entrance slit defines the spatial resolution of 2 × 60″, and the two values of wavelength resolution, 0.04 Å and 0.08 Å, in the short and long wavelength ranges respectively, result from the slit width and dispersions of 4.2 Å mm$^{-1}$ and 8.3 Å mm$^{-1}$ in the two wavelength ranges. Time resolution varies from the shortest exposure of 0.15 s to long manual exposures up to 48 min. The instrument contains a white-light, slit-jaw, video camera system using an image dissector tube which presents the astronaut with a display for pointing
the instrument very near the solar limb. This is also used to secure coalignment between the NRL spectrograph, the HCO spectrometer, and the Hα video display, thus making it possible to observe the same solar features with the UV and EUV instruments and also have a photographic record in Hα that establishes the identity of the feature. A third use of the white-light video system is to operate a servo-system that controls the primary mirror so that spectra across the limb can be made at automatically selected positions that are held stable to ±1″. In the three missions there are, respectively, 200, 400, and 200 filmstrips available, each capable of eight exposures.

7. Summary of Instrument Characteristics

The principal characteristics of the six ATM instruments are summarized in Table V.

3. The ATM Joint Observing Program

A. THE JOINT-OBSERVING PROGRAM CONCEPT

The ATM instruments are capable of coordinated observations of solar features. In many cases the coordinated data are far more valuable than those obtained by the same instruments operating independently. For example, the ATM will obtain simultaneous photographs of the corona at visible, XUV, and X-ray wavelengths; together the data will permit a unified study of the inner and outer corona.

The ATM experimenters have developed a number of observing programs designed to take best advantage of this capability for coordinated observations. These Joint Observing Programs (JOPs) are designed around specific problems in solar physics. In general, relevant ATM instruments observe the same feature either simultaneously or in close succession during the performance of a JOP.

The JOPs are carried out by executing a succession of fundamental observing sequences or ‘Building Blocks’, of which 23 have been defined. Each unit Building Block provides for a specific type of observation, such as spatially resolved observations of faint or of bright features, spectral studies of faint or bright features, high time resolution. The Building Blocks consist of prescribed switch settings for the various instruments, plus a few additional settings to be specified by the ATM experimenters just before execution (for example, specifying the wavelength to be observed by the Harvard spectroheliometer). Since the operation of the Building Blocks will be thoroughly rehearsed before the mission, astronaut operations in orbit are somewhat simplified, and the astronauts may concentrate on telescope pointing or other scientific decisions.

There are other advantages of the coordinated JOP approach to the ATM observations. The observing time available to the ATM can be scheduled more efficiently. Determining the daily observing program and near-real time changes to that program is greatly simplified, since it is necessary only to schedule different Building Blocks. The difficulty of coordinating ATM observations with related ground-based observations is greatly lessened, because the entire ATM is concentrated on a single objective at a given time.
<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Wavelength range</th>
<th>Wavelength resolution</th>
<th>Spatial field</th>
<th>Spatial resolution</th>
<th>Temporal resolution</th>
<th>Unmanned/unattended operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>White-light coronagraph EUV</td>
<td>HAO</td>
<td>3700–7000 Å</td>
<td>–</td>
<td>1.5–6.0 (R)</td>
<td>8.2&quot;</td>
<td>≥ 40.5 s</td>
<td>Yes</td>
</tr>
<tr>
<td>spectrometer-spectroheliometer</td>
<td>HCO</td>
<td>280–1350 Å</td>
<td>1.6 Å</td>
<td>5 × 5'</td>
<td>5&quot;</td>
<td>5 min</td>
<td>Yes</td>
</tr>
<tr>
<td>X-ray spectrographic telescope</td>
<td>ASE</td>
<td>3.5–60 Å</td>
<td>(see text)</td>
<td>48'</td>
<td>2&quot;</td>
<td>≥ 2.5 s</td>
<td>Yes</td>
</tr>
<tr>
<td>X-ray telescope</td>
<td>MSFC/Aerospace</td>
<td>3–53 Å</td>
<td>(see text)</td>
<td>38'</td>
<td>2&quot;</td>
<td>≥ 3.5 s</td>
<td>No</td>
</tr>
<tr>
<td>XUV spectroheliograph</td>
<td>NRL</td>
<td>150–630 Å</td>
<td>0.13 Å (10&quot; feature)</td>
<td>60'</td>
<td>2–10&quot;</td>
<td>≥ 2.5 s</td>
<td>No</td>
</tr>
<tr>
<td>UV spectrograph</td>
<td>NRL</td>
<td>970–3970 Å</td>
<td>0.04–0.08 Å</td>
<td>48'</td>
<td>2 × 60&quot;</td>
<td>≥ 0.15 s</td>
<td>No</td>
</tr>
</tbody>
</table>
The JOPs, useful as they are, would be incomplete if they involved only observations by the ATM instruments. A number of important studies that can be carried out only from the ground are necessary to provide a truly comprehensive view of the phenomenon under study. We shall list some of the relevant ground-based observations as we describe the JOPs below.

B. JOINT OBSERVING PROGRAMS

The Joint Observing Programs can be divided into several general areas.

1. Synoptic observations of the chromosphere and corona.
2. Observations of active regions.
3. Observations of quiet regions.
4. Observations of prominences and filaments.
5. Observations of flares and other transient phenomena.
6. Non-solar observations.

1. Synoptic Observations of the Chromosphere and Corona

One of the major objectives of the ATM is the acquisition of a long uninterrupted series of observations showing the daily evolution of important solar features over many solar rotations. The primary ATM data obtained under this program will be photographs acquired by the HAO white-light coronagraph, the ASE and MSFC X-ray experiments, and the NRL XUV spectroheliograph. White-light and X-ray observations will be obtained at least every 12 hr over a period of up to 8 months by using the manned and unmanned operating capabilities of ATM. The NRL spectroheliograph will obtain full-disk XUV spectroheliograms every 3 days during the times when ATM is manned.

In addition to the ATM observations, it is desirable to obtain a variety of ground-based measurements:

a. Daily magnetograms are especially needed to provide information on photospheric magnetic fields. These data can be used to calculate coronal fields, for comparison with the coronal fields deduced directly from the X-ray, XUV, and white-light observations.

b. Measurements of the polarization of coronal emission lines are also important for determining the structure of coronal magnetic fields.

c. Forbidden coronal emission-line intensity and profile measurements can yield temperature, density, and structural information to supplement the ATM X-ray, EUV, and XUV data.

d. White-light K-coronometer data between 1.0 and 1.5 R are needed to cover the area not seen by the ATM coronograph.

e. ATM provides primarily data on the high chromosphere and corona in this observing program. Therefore, it would be useful to have regular coverage of the low chromosphere and photosphere with full disk spectroheliograms or filtergrams in Ca+ K, Hz, and other appropriate lines, as well as the visible continuum.
2. Active Regions

A second important ATM Joint Observing Program is the study of active regions. Some of the objectives of this extensive program are:

(a) To obtain data on the three-dimensional temperature and density structure of active regions and how this structure evolves with time.

(b) To observe how this structure changes before, during, and after solar flares and other transient phenomena such as filament activations, surges, etc.

(c) To relate the temperature and density structure of active regions to the three-dimensional structure of the magnetic field.

(d) To detect transient phenomena associated with chromospheric and coronal heating processes.

(e) To detect velocity fields in the transition zone and corona above active regions.

The ATM will be used to observe individual active regions of different types: young regions, rapidly developing regions, regions that are prolific producers of flares, quiescent, stable regions, etc. Several regions will be observed at least once a day as they pass across the disk from limb to limb.

ATM will obtain many different types of active region data. The HAO coronagraph will provide data on the density and structure of the outer corona. The ASE and MSFC X-ray experiments will yield temperature and density information on the inner corona. The NRL XUV spectroheliograph and the Harvard EUV spectrometer in the raster mode will provide information on temperature and density in the inner corona, transition layer, and chromosphere in lines ranging from coronal lines such as Fe xvi λ335 and Fe xv λ284 to chromospheric lines such as the H I, He I, and He II resonance lines. The NRL spectrograph and the Harvard spectrometer in the spectrum-scanning mode will obtain spectral measurements between 300 and 4000 Å at selected positions in active regions. These spectra will contribute a wealth of information on conditions throughout the upper photosphere, chromosphere, transition layer, and inner corona. Thus the ATM data permit the study of active regions, in a manner never before possible, by inter-relating physical conditions in a region from its base in the photosphere to its outermost extension into the corona.

Obviously many types of ground-based data will be a valuable complement to the ATM observations. By observing in collaboration with ATM, the solar physics community can make unique contributions to our knowledge of solar activity, especially if a reasonably complete set of observational programs can be arranged. The combination of ATM and ground-based observations should then provide a storehouse of data from which the astronomical community will draw for many years.

Several examples of useful ground-based observations are:

(a) Observations of the photospheric layers of active regions, that is, photospheric faculae. Valuable observations can be obtained in the visible continuum as well as in atomic lines or molecular lines such as CN and CO. These data will be important for constructing models of photospheric faculae that can be tied into models for the high layers derived from ATM and other data.
(b) Magnetic observations with high spatial resolution and sensitivity are clearly essential to understanding the structure of active regions. Numerous structures in X-ray photographs appear to be related to the structure of the coronal magnetic field, and suggest that the joint analysis of X-ray, XUV, and magnetic data will be very fruitful.

(c) The measurement of forbidden line intensities and profiles when active regions are at the limb, when combined with ATM observations, should produce extensive data in lines covering a wide range of excitation and ionization, thereby making possible an excellent determination of temperature and density.

(d) White-light observations of the inner corona between 1.0 and 1.5 \( R \) are needed to supplement the ATM coronagraphic data.

(e) Spectra and spectroheliograms in chromospheric lines such as Hz, Ca\(^+\) K, He \( \lambda 10830 \) and others would be valuable. For example it would be useful to study He \( \lambda 10830 \) along with the ATM observations of the He I and He II resonance lines and the He I continuum.

(f) Observations of photospheric and chromospheric velocity fields are also needed. This is particularly true when ATM is attempting to observe velocity fields in the transition zone and corona above active regions.

(g) High resolution X-ray spectra by rocket-borne instruments will complement the ATM broad-band X-ray images in the determination of inner corona temperature and density structure.

3. The Quiet Sun

A third area of interest is the study of the quiet Sun. The ATM X-ray and XUV instruments are able to resolve structures on a scale of a few arc sec. This is adequate for observing the chromospheric network and how it changes with height from the chromosphere into the corona. The ATM data will be used to construct three-dimensional models for typical quiet areas and areas with unusually faint or bright network. The observations and resulting models should provide insight into the energy balance of the chromosphere transition layer and corona. One outstanding problem in this regard is determining where, relative to the network, the heat conducted downward from the corona is deposited in the chromosphere and how it is dissipated by radiative or mechanical mechanisms.

Another area of investigation is the study of the evolution of the network in the chromosphere and higher layers, both over a short time (hours) and over a longer period of up to two days.

Important coordinated ground-based observations for network studies include:

(a) Magnetograms with high spatial resolution (a few arc sec) and high sensitivity.

(b) Observations of the photospheric and chromospheric network in appropriate lines in the visible.

(c) Measurements of photospheric and chromospheric velocity fields in relation to the network.

Center-to-limb observations are another field of interest. The NRL UV spectrograph will obtain spectra at precisely-defined positions from center to limb. These
spectra may be obtained at the equator, along other lines of constant latitudes, over the poles, or crossing the limb over active regions or coronal 'holes'. At the same time the Harvard instrument will obtain spectra and spectroheliograms at corresponding locations, and the X-ray instruments as well as the NRL XUV spectroheliograph will obtain highly resolved images at the limb. Among other things they will study the coronal effects of spicules and other chromospheric limb phenomena.

To supplement the ATM data it is desirable to acquire ground-based spectra and spectroheliograms showing spicular structure in Hz, Ca K, He λ 10830, or He D3, as well as center-to-limb data in various lines. Forbidden coronal-line observations and white-light corona data are also important.

The study of oscillations in the chromosphere and corona is another important area of investigation. Present evidence for an extension of the '5-min' chromospheric oscillation into the high chromosphere and corona is rather weak, largely owing to the lack of good spatial resolution of the observations. The Harvard instrument on the ATM, operating in the line-scan mode, will attempt to observe intensity fluctuations through simultaneous observations over a range of heights from the chromosphere to the corona with 5 s time resolution. The X-ray telescopes and the XUV spectroheliograph will also obtain coordinated data, but with time resolution of about 1 min.

The ATM will observe an area whose coordinates can be easily specified to a ground-based observer. The most suitable place is probably the center of the disk.

Desirable ground-based observations are:

(a) Measurements of the variation with time of continuum and line intensities and of velocities, preferably measured with lines formed at a variety of heights in the photosphere and chromosphere. Precise timing is essential so that phase information can be obtained from the ATM and ground-based data.

(b) Measurements of magnetic fields with high spatial resolution and the best possible time resolution and sensitivity.

4. Prominences and Filaments

A fourth area of interest is the study of prominences and filaments. The ATM will provide important new observational data for these objects. For example, observations of H I, He I, and He II resonance lines and continua will contain new information about the temperature and density of the cool layers of prominences that are observed from the ground in the Balmer lines and continuum, helium lines, and metallic lines. In addition the ATM will observe intermediate stages of ionization of carbon, nitrogen, oxygen, neon, silicon, magnesium and iron lines that provide information on the interface between cool prominence material and the hot coronal gas in which it is imbedded. Finally, the ATM will also observe XUV and X-ray emission from the corona surrounding the prominence or filament. Observation of prominences both at the limb and when they are on the disk as filaments will yield information about the three-dimensional structure of prominences and the related coronal features.
A variety of coordinated ground-based observations are important:
(a) Magnetic field measurements both in the prominence and in underlying photosphere.
(b) Spectra of emission lines of H\textsc{i}, He\textsc{i}, He\textsc{ii}, metallic lines, and the Balmer continuum.
(c) Observations of the coronal structure associated with the prominence, by use of forbidden lines and white-light emission.
(d) Measurements of proper motions and Doppler shifts in the prominence.

5. Flares

For the study of flares and other transient phenomena the ATM has several unique and powerful capabilities. Because of the presence of a trained astronaut-observer, the ATM can respond quickly to the occurrence of transient events. For the first time it will be possible to study the simultaneous development in time and space of the UV, EUV, and X-ray emitting portions of the flare plasma. This will permit simultaneous observation of the flare over the very wide temperature range between 4000 and 10^7 K.

In addition to the flare itself, the ATM will study the region surrounding the flare before, during, and after the flare. To this end solar forecasters from NOAA will be working closely with the ATM experimenters and providing information on active regions likely to flare. The objective of ATM observations in the flare program is to obtain a diverse and extensive collection of data that can be used to determine physical conditions (temperature and density) in the flare plasma and the surrounding medium, and to determine how these conditions changed before, during, and after the flare.

The ATM will observe flares either by pointing at the flare in order to get simultaneous UV, EUV, XUV, and X-ray observations or by using Sun-center pointing so that the coronagraph can observe the response of the outer corona to the flare; in the latter case the wide field-of-view instruments (NRL spectroheliograph and the two X-ray telescopes) can observe the flare, although the NRL spectrograph and HCO spectrometer cannot.

The ATM will also be used to study other types of transient phenomena such as surges, filament activations, eruptive prominences, and coronal phenomena associated with type II, type III, and type IV radio bursts.

In order to understand the complex phenomena associated with flares it appears necessary to have a very diverse and extensive collection of observations of many kinds. In addition to the ATM data it is important to have magnetograph data, K-coronameter data, radio noise information, coronal observations with forbidden lines, extensive Hz coverage and other satellite data such as gamma-ray, X-ray, and solar wind measurements.

6. Non-Solar Observations

Although ATM was designed for solar observations, it is capable of making other types of observations. These may be divided into three classes:
(a) Study of the terrestrial atmosphere.
(b) Observation of the lunar libration points.
(c) Observation of night sky sources.

ATM can be used to study the Earth's atmosphere through measurements of the absorption of solar UV and X-ray radiation by the terrestrial atmosphere near the times of spacecraft sunrise and sunset. The variation with height of the densities of major atmospheric constituents such as O, O₂, and N₂, as well as some minor constituents, can be determined from the extinction measurements made at different wavelengths.

Observations of the lunar libration points will be acquired with the HAO coronagraph. The object will be to verify the accumulation of dust particles at several lunar Lagrange points, and to determine the density and dimensions of the accumulation region.

ATM may also be used to acquire EUV and X-ray observations of a variety of night sky sources such as early type stars, X-ray sources, nebulae, and galaxies. Through use of pictures of the star field acquired with the coronagraph and X-ray filtergrams, accurate positions of a number of X-ray sources can be determined. Absolute X-ray fluxes may also be measured for selected sources. The HCO instrument may be able to measure the EUV radiation from many early type stars and other objects emitting strongly in the EUV.

4. Coordinated Observing Programs

A. METHODS OF COORDINATION

The description of the JOPs in the previous section emphasizes the usefulness of synchronized observations of the same feature by ground-based observers all over the world. In this section we describe the methods proposed by the ATM scientists to facilitate coordination with these observations.

The ATM scientists plan to carry on close collaborative programs with a few ground-based observers, involving joint participation in the planning, acquisition, and analysis of both ground-based and ATM data. A much wider participation is also envisioned, whereby any observer who cares to may make relevant coordinated observations. This is best arranged before Skylab launch, but if after the data are acquired it appears that a coordinated analysis of ATM and other sets of data would be useful, this can also be arranged. All ATM data will be placed in the National Space Science Data Center for general access as soon as possible (beginning about 12 months after the end of the mission).

In order to encourage participation by interested observers, a ground-based analogue of the Joint Observing Programs is being organized, consisting of a set of Coordinated Observing Programs (COPs).

Planning activities for the COPs were initiated jointly by the ATM Principal Investigators, and resulted in an exploratory meeting at Kitt Peak National Observatory in September 1971. Approximately 120 scientists were invited from 13 countries as representatives of groups involved in theoretical and experimental solar physics.
The purpose of this initial meeting was to discuss which coordinated observations would optimize the interpretation of both ATM and ground-based solar data in terms of the physical phenomena in the solar atmosphere under study. Also included in the discussions were certain related technical areas such as magnetograph requirements, and use of densitometers in data reduction.

As a result of the discussions at Kitt Peak Observatory a number of Task Groups were formed. Each of these groups is under the chairmanship of a non-ATM scientist. Table VI lists the groups, together with chairmen and their affiliations and addresses. This listing is not necessarily final and can be modified in response to scientific interest, for example to include stellar observations or studies of the earth's inner atmosphere through its UV or X-ray absorption.

Each problem-oriented COP group is concerned with ground-based observations relevant to a particular JOP. The chairmen of the problem-oriented task groups have

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<tr>
<th>Problem-oriented</th>
<th>Task groups and chairmen</th>
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<tbody>
<tr>
<td>Active regions</td>
<td>J. B. Zirker, Sacramento Peak Observatory, Sunspot, N.M. 88349, 505-473-6511</td>
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<td>Corona</td>
<td>G. A. Newkirk, Jr., High Altitude Observatory, Boulder, Colo. 80302, 303-444-5151</td>
</tr>
<tr>
<td>Prominences and filaments</td>
<td>E. Tandberg-Hanssen, High Altitude Observatory 80302, 303-444-5151</td>
</tr>
<tr>
<td>Flares</td>
<td>L. Peterson, Dept. of Physics, University of California, La Jolla, Calif. 92037, 714-453-2000</td>
</tr>
<tr>
<td>Quiet chromosphere</td>
<td>J. W. Beckers, Sacramento Peak Observatory, Sunspot, N.M. 88349, 505-473-6511</td>
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<th>Technique-oriented</th>
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<tbody>
<tr>
<td>Coronagraph</td>
<td>G. A. Newkirk, Jr., High Altitude Observatory, Boulder, Colo. 80301, 303-444-5151</td>
</tr>
<tr>
<td>Eclipse, July 1973</td>
<td>W. J. Wagner, Sacramento Peak Observatory, Sunspot, N.M. 88349, 505-473-6511</td>
</tr>
<tr>
<td>Magnetographs</td>
<td>W. C. Livingston, Kitt Peak National Observatory, Tucson, Ariz. 85717, 602-327-5511</td>
</tr>
<tr>
<td>Microdensitometers</td>
<td>A. Title, Lockheed California Company, Dept. 7433, Burbank, Calif. 91503, 213-847-6121 × 131-257</td>
</tr>
<tr>
<td>Monochromatic images</td>
<td>H. Zirin, Hale Observatory, Pasadena, Calif. 91109, 213-795-6841 × 1013</td>
</tr>
<tr>
<td>Patrots and communications</td>
<td>J. F. Humphreys, Marshall Space Flight Ctr., Huntsville, Ala. 35812, 205-453-5682</td>
</tr>
<tr>
<td>Radio</td>
<td>J. Warwick, University of Colorado, Dept. of Astrogrophysics, Boulder, Colo. 80302, 303-443-2211</td>
</tr>
<tr>
<td>Rockets, balloons, and</td>
<td>A. B. C. Walker, Jr., Aerospace Physics Laboratory, F1909, El Segundo, Calif. 90045, 213-648-7084</td>
</tr>
<tr>
<td>satellites</td>
<td>N. R. Sheeley, Jr., Kitt Peak National Observatory, Tucson, Ariz. 85717, 602-327-5511</td>
</tr>
</tbody>
</table>
prepared initial summaries of the state of theoretical understanding of the relevant solar phenomenon and the critical ground-based observations needed. Scientists interested in participating in any of the problem-oriented COPs are urged to contact the chairman and become a member of that particular COP task group.

The technique-oriented groups are concerned with use of equipment or techniques that clearly cut across all of the COPs. The chairmen of these groups have surveyed the existing and proposed instrumentation in their fields, as well as the degree of participation by various observatories. Scientists particularly interested in the application of a particular technique are urged to contact the chairman of that task group.

Participation of task group members in COP activities ranges from simple exchange of information and discussion, through general agreements to acquire relevant data, to expressions of intent to coordinate their observations with ATM rather closely. In several cases detailed collaborative arrangements are being made with individual ATM experimenters.

The number of participants in the Coordinated Observing Program has now risen to approximately 200, who are kept advised of activities in the task groups of interest through the Coordinated Observing Program Office at Harvard College Observatory. General program information or specific information such as the details of the JOPs and Building Blocks and lists of proposed COP observations can be obtained by writing to Dr. Robert O. Doyle, Harvard College Observatory, 60 Garden Street, Cambridge, Mass. 02138 (U.S.A.).

B. COMMUNICATIONS

Rapid and widespread communication is vital for successful coordination of observations during the ATM mission. Through the facilities of the National Oceanic and Atmospheric Administration (NOAA), the ATM Principal Investigator Teams operating the mission from the Manned Spaceflight Center in Houston, Tex., will be provided with descriptions of the current state of solar activity and up-to-date forecasts, to aid in scheduling ATM observations. Except in a few unusual circumstances it will not be possible to tailor the ATM observations to the programs of ground-based observatories on short notice. The ATM objectives for a particular day (as represented by the JOPs), the solar coordinates of the region of interest, and specific observing modes (Building Blocks) will be available 8–12 hr before the beginning of the astronaut observing day (approx. 1300 UT). This complete observing sequence will be disseminated through a teletype network operated by NOAA as part of their service under IUWDS (International Ursigram and World Days Service). Other Regional Warning Centers throughout the world may relay the teletype message to observers in other areas if requested to do so. The observing program and hourly revisions will be disseminated also through broadcasts on WWV and WWVH. Of interest predominantly to those scientists in the USA will be recorded messages on the status of ATM, available by dialing a recorded message on the commercial or federal telephone system. The ATM center at Houston will also be staffed 24 hours per day with a communicator to receive specific calls for information. Individual experimenter
groups can also be reached for discussion as required. For all communications systems a special dictionary of terms is being prepared to minimize length; it will be distributed to all participants when ready.

C. ATM MISSION SCHEDULE

The Skylab mission involves four separate vehicle launches. The first, currently scheduled for April 30, 1973, will place the unmanned Skylab, including ATM, in circular orbit at an altitude of about 220 nautical miles. The second launch, a day later, will carry three astronauts to the Skylab, where they will dock and remain for a period of up to 28 days. During this time various solar, medical, Earth-resources and corollary experiments will be carried out. Upon return to Earth the astronauts will carry exposed film from the ATM experiments.

The third launch, currently scheduled for July 27, 1973, will carry a second team of three astronauts to Skylab, where they will remain for up to 56 days carrying out further experiments and observations. One month after they return, a fourth launch (scheduled for October 21, 1973) will carry a third team of astronauts to Skylab for another period of up to 56 days.

Because the ATM manned-experiment time must be shared with medical, Earth-resources, and corollary experiments, the total time available for manned solar observations is severely limited – to 100 hr on the first mission and about 200 hr on each of the second and third missions. Observations are of course confined to the periods when Skylab is in sunlight, about 55 min out of each 90 min orbit. Manned observations are further limited to periods between 1300 UT and 2300 UT, when it is daylight over the continental United States. At other times the ATM control console will be unattended. As stated earlier certain of the observations may be carried out during unattended operation, if they do not require rapid response to transient events or great accuracy in pointing of the ATM spar. Most instruments have a wide enough field of view so that the latter limitation is not serious. The ASE, HAO, and HCO instruments in addition will be capable of remote operation during the unmanned intervals between Skylab missions. Finally, the Harvard instrument, which does not require film retrieval, may be operated for several months after the end of the last mission.

The scientific teams for the ATM experiment include the following persons:

*American Science and Engineering*: G. Vaiana, Acting Principal Investigator

  J. Davis, R. Giacconi, S. Kahler, A. Krieger, A. Timothy, K. Silk, M. Zombeck

*Harvard College Observatory*: E. M. Reeves, Acting Principal Investigator


*High Altitude Observatory*: R. M. MacQueen, Principal Investigator

  J. T. Gosling, E. G. Hildner, R. Munro, A. I. Poland
Marshall Space Flight Center/Aerospace Corporation: J. Milligan, Principal Investigator

Naval Research Laboratory: R. Tousey, Principal Investigator
J. D. Bohlin, J. D. Bartoe, G. E. Brueckner, N. P. Patterson, J. D. Purcell, V. E. Scherrer, K. C. Winding

This report on the ATM solar experiments and of the planned arrangements for close coordination with other solar observations was prepared on behalf of the ATM experiment teams and is endorsed and supported by each. The instrumentation descriptions were provided by the individual groups, and the details of the ATM Joint Observing Programs were planned by a working group representing all experiment teams. The ATM program is funded by the National Aeronautics and Space Administration through contracts from Marshall Space Flight Center.

E. M. Reeves
R. W. Noyes
G. L. Withbroe