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# SOLAR EUV, XUV AND SOFT X-RAY TELESCOPE FACILITIES

NASA Contract NAS5-24151

Final Report

for the Period 1 May 1977 to 31 December 1981

Principal Investigator

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January 1982

Prepared for

National Aeronautics and Space Administration
Greenbelt, MD 20771

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# SOLAR EUV, XUV AND SOFT X-RAY TELESCOPE FACILITIES

## Final Report of the Facility Definition Team

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# PREFACE

This final report was prepared for the NASA Goddard Space Flight Center by the Solar EUV-XUV-Soft X-ray Telescope Facility Definition Team established by NASA. It discusses the scientific rationale for facility class instruments operating in the EUV, XUV and soft X-ray spectral ranges and describes possible configurations for these facilities.

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## 1. INTRODUCTION

A fundamental difficulty in understanding the complex physical conditions in the outer solar atmosphere and the mechanisms responsible for these conditions is the lack of high quality observations for diagnostic analyses. The available data has suffered from incomplete spectral coverage, insufficient spatial, spectral or temporal resolution, and/or a lack of accurate photometric calibration. With facility class, high resolution instrumentation it will be possible to overcome many of these limitations.

Observations at EUV, XUV and soft x-ray wavelengths can provide unique data on a wide variety of solar problems. Lines and continua found in this portion of the spectrum, from 1.8 to 1400Å, cover a broad range of temperatures, from about 4500 K near the chromospheric temperature minimum, to nearly $10^8$ K (Fe XXVI Ly$\alpha$ line) in the hot kernels of flares. In order to realize the full potential of measurements made in this spectral range, it is essential to make observations with accurate photometric calibration and a combination of high spatial resolution ($\lesssim$ 1 arc sec), high spectral resolution ( $\lambda/\Delta\lambda$ between $10^3$ and $10^6$, depending on the problem) and high temporal resolution (from a fraction of a second to minutes depending on the phenomena). Large instrumentation is needed to accomplish this with good statistical accuracy in time intervals shorter than those over which significant physical changes occur in the features being studied. High spatial resolution is required because the characteristic dimensions of the fine structure of almost all features observed in the chromosphere, transition region and corona are of the order 1 arc sec or less. High spectral resolution is required for measuring intensities or profiles of individual spectral lines which can provide temperature and density diagnostic information ($\lambda/\Delta\lambda \gtrsim 10^3$) or velocity information ($\lambda/\Delta\lambda \gtrsim 2 \times 10^4$). Accurate photometric calibration is essential for most diagnostic techniques.

The major scientific objectives of facility class instrumentation operating at EUV, XUV and soft X-ray wavelengths are:

(1) To investigate the mass and energy flow in the chromosphere, transition region and corona.

(2) To investigate energy deposition in the chromosphere and corona by waves, currents and magnetic field annihilation.

(3) To investigate mechanisms for deposition of mass in the corona.

(4) To investigate mechanisms responsible for the storage and release of the energy responsible for flare phenomena.

Table 1-1. Scientific Objectives of EUV, XUV and Soft X-Ray Telescope Facilities

| Area | Problem | Observational Objectives |
|---|---|---|
| I. FLARES | How are slow mass motions of the convection zone converted into metastable magnetic configurations? | To investigate the temporal and spatial evolution of chromospheric and coronal structure and its relationship to mass motions and magnetic field structure at photospheric levels where the field lines are tied. |
| | What are the mechanisms of plasma heating and particle acceleration in flares? | To determine the spatial and temporal variations of the physical conditions in the chromosphere, transition region and low corona in order to obtain information on the spatial and temporal variations of energy deposition. To relate these to measurements made at higher energies of the higher temperature ($T>3x10^6K$) plasma and accelerated particles. To determine relationships between plasma motions, heating and the temporal and spatial evolution of the magnetic field. |
| | How is the energy of a flare transformed? | To determine the spatial and temporal variations of the physical conditions in the chromosphere, transition region and low corona in order to obtain information on the spatial and temporal variations of energy deposition. To relate these to measurements made at higher energies of the higher temperature plasma and accelerated particles. To determine relationships between plasma motions, heating and the temporal and spatial evolution of the magnetic field. |
| II. ATMOSPHERIC HEATING AND STRUCTURE | Role of wave propagation and dissipation in heating the chromospheric and coronal plasma. | To detect non-thermal motions associated with wave propagation by studying line profiles. To detect spectroscopic signatures of dissipation mechanisms. To determine the spatial and temporal variations of heating in the chromosphere and low corona. |
| | Role of magnetic field in chromospheric and coronal heating | To determine the relationship between plasma heating at chromospheric and coronal levels and the strength and configuration of the photospheric magnetic field and their temporal variations. Of particular interest are regions with small scale closed magnetic configurations for which there presently exists some circumstantial evidence for impulsive heating by rapid dissipation of magnetic energy. |
| | What is the chemical composition of the low corona and does it exhibit spatial and temporal variations? If variations are found, what are the responsible mechanisms? | To determine the chemical composition of the low corona, its spatial and temporal variations, and relationship to the physical conditions and structure of the corona. |
| III. ACTIVITY CYCLE | How does the energy deposition in the chromosphere and low corona vary with the activity cycle? | To determine the chromospheric and coronal energy deposition in different classes of phenomena (regions with different spatial scales and/or magnetic configurations) as a function of the solar cycle. To determine at different times in the solar cycle the relative contribution of energy releases at different temporal scales (i.e. rapid energy release via flares and other transient phenomena and by quasi-steady-state energy release that appears to be responsible for heating in long lived features). |

Table 1-1 continued

| Area | Problem | Observational Objectives |
|---|---|---|
| IV. INTERNAL DYNAMICS | How are magnetic fields generated and dissipated in the sun? | To study the spatial and temporal evolution of coronal structures in order to acquire information on the evolving configuration of the coronal magnetic field on different spatial and temporal scales. Of particular interest are studies of the short-lived (hours) regions with small scale closed magnetic configurations (e.g. ephemeral active regions and coronal bright points) which appear to be associated with the emergence of a substantial fraction of the magnetic flux emerging from the solar surface into the corona. |
| V. CORONAL STRUCTURE AND DYNAMICS | Role of dynamical phenomena in coronal mass balance. | To investigate the spatial and temporal evolution of small scale dynamical phenomena such as spicules which may deposit large amounts of mass, energy and/or momentum in the low corona. To monitor this evolution at chromospheric and coronal heights. |
| | Role of mass flows in the exchange of mass and energy between the chromosphere and corona. | To determine whether the exchange of mass between the chromosphere and corona plays a fundamental role in controlling the coronal mass and energy balance in magnetically closed regions. To determine the rate at which mass and energy are exchanged between the chromosphere and corona. To determine which mechanisms (e.g. convection and thermal conduction) are responsible for this exchange and to establish their relative importance in different circumstances. |
| | What mechanisms control the flow of mass and energy in prominences? | To determine the physical conditions (temperature, density, velocities, vector magnetic field) in the elemental thread-like structure of prominences and the relationship of these parameters to the surrounding coronal plasma and the configuration of the coronal magnetic field. To determine the radiative input and output for the cool prominence material. |
| VI. SOLAR WIND | Role of dynamical phenomena (e.g. spicules) in solar wind acceleration. | To investigate the spatial and temporal evolution of dynamical phenomena such as spicules, particularly those with high velocity, which may deposit large amounts of mass, energy and/or momentum in the low corona and possibly drive or help drive the solar wind. To investigate the role of polar plumes and their underlying coronal bright points in the acceleration of the solar wind by determining the physical conditions in these features and determining if mass flows outward from them. |

Table 1-1 lists several specific questions and the corresponding observation objectives. The substantial improvements in spectral and spatial resolution, sensitivity and photometric accuracy that can be realized with EUV, XUV and soft X-ray facility instrumentation promise significant, and in many cases *definitive* new observational advances in addressing these problems. Measurements of EUV, XUV and X-ray spectral lines can be used to derive the fundamental plasma parameters of temperature, density and velocity, while spectroheliograms and broad-band images will show the structural configurations (*i.e.* the magnetic topology) within which the spectroscopic measurments are made. The result will be a probe of the plasma dynamics and energetics of the upper solar atmosphere of unprecedented detail.

Section 2 discusses EUV, XUV and soft X-ray telescope facilities and their priorities for development, while section 3 provides further discussion of the scientific rationale for these instruments. Section 4 contains a brief summary.

## 2. INSTRUMENTATION

As indicated in the introduction, the solar spectrum from 1.8 to 1400 Å contains spectral lines and continua formed over a wide range of temperatures, from 4500 K to nearly $10^8$ K. In order to obtain the maximum performance (spatial, spectral and temporal resolutions) over this broad spectral range, several different types of instruments are required. At wavelengths greater than approximately 500 Å normal incidence optical systems offer the optimum performance, while grazing incidence optical systems offer the best overall performance at XUV and soft X-ray wavelengths shortward of 500 Å.

The construction of a telescope with very high spatial resolution (few tenths arc sec) is more easily accomplished for an instrument operating at normal incidence than for an instrument operating at grazing incidence and is well within the state of the art. The image quality also tends to be superior in a normal incidence optical system, because the wings of the instrumental profile are usually narrower than in grazing incidence systems, resulting in a larger fraction of the incident light from a point source focused within a spatial resolution element. This is important for spectroscopy. Shortward of approximately 500 Å normal incidence optical systems lose photon collection efficency due to the sharp decrease with decreasing wavelength in the reflectivity of mirror coatings at normal incidence. There are special coatings that provide high reflectivity at normal incidence over narrow wavelength bands (see Spiller *et al.* 1980; Underwood and Barbee 1981; Underwood, Barbee and Shealy 1981). These coatings have potential for use in specialized normal incidence telescopes which could acquire XUV and soft X-ray observations with very high spatial resolution. However, because of their narrow bandpasses they are not suitable for facility telescopes which must be capable of feeding a variety of

XUV and soft X-ray focal plane instruments. For general purpose facilities grazing incidence telescopes offer signficant advantages over normal incidence systems for wavelengths shortward of approximately 500 Å. This advantage of mirrors operated at grazing incidence results from their high reflectivity over a broad range of wavelengths above the short wavelength limit of the mirror (which is a function of the grazing angle employed).

Although it is possible to design a grazing incidence telescope capable of spanning the wavelength range 1.8 to 500 Å, superior performance is attained by constructing two separate grazing incidence facilities, one optimized for $\lambda <$ 100 Å, the Solar Soft X-ray Telescope Facility, and the other optimized for $100 < \lambda < 600$ Å, the Solar XUV Telescope Facility. The reason for this is the desire to have one facility optimized for high wavelength resolution XUV spectroscopy of the coronal plasma (XUV Telescope) and another (Soft X-ray Telescope) optimized for x-ray imaging hot coronal and flare plasmas while still having good performance for spectroscopy of hot plasmas ($10^6 < T < 10^8$ K). The third facility, the Solar EUV Telescope Facility, is designed to offer maximum performance at wavelengths greater than 500 Å where the solar spectrum is rich in spectral features formed at temperatures between $10^4$ and $2 \times 10^6$ K.

## 2.1. Soft X-Ray Telescope

The soft X-ray telescope is the ideal instrument for studying the corona. It operates in the wavelength range 1.75 to 300 Å and provides a capability for studying the sun with emission lines formed at temperatures ranging from $10^6$ K (O VII) to nearly $10^8$ K (Fe XXVI). Line emission from large scale coronal structures and active regions dominates the spectrum of wavelengths longer than 20 Å. Lines produced in the coronal portions of active regions dominate between 6 and 20 Å. The spectral region from 1.5 to 6 Å contains the line and continuum radiation from the highest temperature portion of solar flares. Moreover, there is no photospheric, chromospheric or transition region background radiation at these wavelengths; therefore, coronal structures can be seen in projection against the solar disk.

There are a great many problems in coronal physics that can be studied with the soft X-ray instrumentation. They divide into four general areas: (1) the relationship between the large scale structures of the corona and the large scale solar magnetic field; (2) the structure and dynamics of coronal plasma loops and arches; (3) solar flares; (4) and the mass and energy balance of the corona. Although the EUV and XUV parts of the solar spectrum also contain coronal lines, the soft X-ray measurements provide superior coronal plasma diagnostics and include many more lines formed at temperatures between $5 \times 10^6$ K and $10^8$ K.

A preliminary definition study for the Solar Soft X-Ray Telescope Facility was performed by American Science and Engineering (see AS&E report ASE-3930, Krieger *et al.* 1976). A pictoral view of the resulting concept for the facility is shown in Figure 2-1. The design of the telescope is based on that of the telescope flown on HEAO-2 (Einstein Observatory). The primary telescope mirror consists of seven nested surfaces of the Wolter Type I paraboloid-hyperboloid configuration. The outer set of 5 mirrors has a collecting area of 1140 $cm^2$, a value approximately twice that of HEAO-2, obtained by adding a fifth mirror to the 4 used in HEAO-2. Two smaller mirrors are used for short wavelengths and have a collecting area of 47 $cm^2$. The focal length of the mirror system is 440 cm. The design goal for the spatial resolution is 0.5 arc sec over a field of view of a few arc min (with lower resolution over a larger field of view). Technology studies planned for the AXAF mirror will provide information on the quality of x-ray mirrors fabricated using the current state-of-the art. Two x-ray mirrors will be fabricated, polished and tested to verify the AXAF goals for angular resolution and point response. The results of these studies will be applicable to the Solar Soft X-Ray Telescope Facility, hence no additional technology studies for the mirrors of the latter facility will be required.

The AS&E study envisioned a soft x-ray facility operating between 1.8 and 100 Å. The FDT subsequently recommended extending the operating range to 300 Å. This would insure that some capability would be available in the XUV in the event that the European XUV facility GRIST is not funded for development or a NASA supplied XUV facility is not available until significantly later than the soft X-ray facility (see sections 2.2 and 2.4).

In order to insure that the accomodations for focal plane instruments would be adequate for a wide range of instruments, preliminary design concepts were developed for a number of candidate focal plane instruments (see Perkin-Elmer engineering report ER-510, Bunner *et al.* 1981; Ball Aerospace Systems Division Report F80-14, Fowler 1980). A list of candidate instruments is given in Table 2-1. Several of these focal plane instruments make use of grazing incidence relay optics (GIRO). The latter optical elements provide a means of coupling two optical systems (*e.g* telescope and spectrometer) with different f-numbers. AS&E conducted a study to determine what capabilities these devices can provide for the Soft X-Ray Telescope Facility (see "Solar Soft X-Ray Instrument Study" 1981). Their results show that suitably configured GIRO optical elements can serve as magnifiers or collimators. They can also be used for rastering images.

Figures 2-2 and 2-3 show two configurations for GIRO optical elements. Figure 2-2 shows a Cassegrain configuration in which the secondary optical

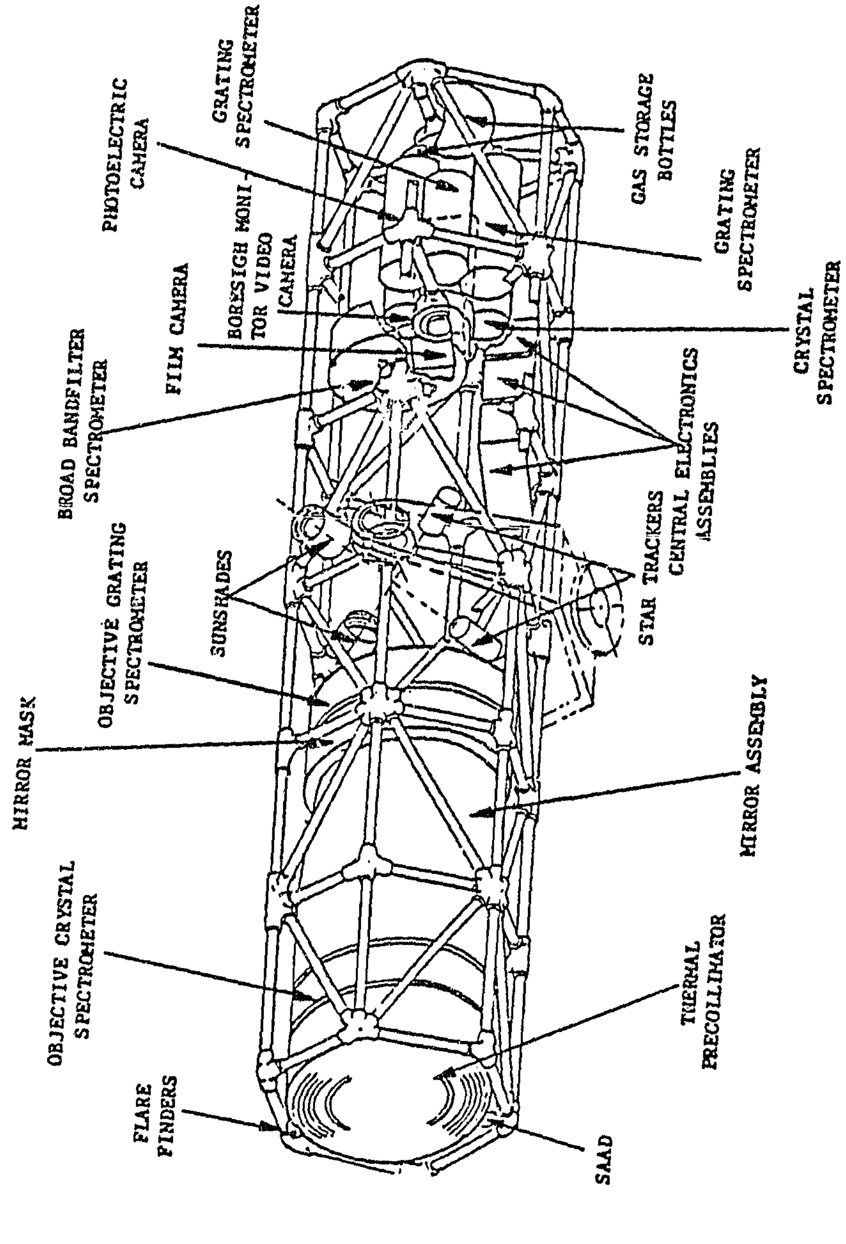


Figure 2-1. Soft X-Ray Telescope Facility (Pictoral View)

TABLE 2-1. FOCAL PLANE INSTRUMENTATION FOR SOFT X-RAY TELESCOPE

| Instrument | Field of View* | $\lambda/\Delta\lambda$ | Wavelength Range (Å) |
|---|---|---|---|
| I-1 X-ray Finder | Variable up to 40'x40' | 3-15 | 1.5-300 |
| S-1 Objective Crystal Spectroheliograph | Variable up to 1'x16' | 10,000 | 1.5-8 |
| S-2 Stigmatic Focal Plane Crystal Spectrometer | Variable up to 1'x8' | $10^3$-$10^4$ | 5-25 |
| S-3 High Resolution Crystal Spectrometer/Polarimeter/ Polychromator | Variable 1"x1" to 5"x5" | $10^2$-$3x10^4$ | 1.5-300 |
| S-4 Objective Grating Spectroheliograph | Variable up to 16'x16' | 100 | 8-300 |
| S-5 Stigmatic Focal Plane Grating Spectroheliograph | Variable up to 2'x8' | $10^4$-$3x10^4$ | 8-300 |
| S-6 Non-Stigmatic Grating Polychromator | 1"x1" to 5"x5" | $10^3$ | 25-300 |
| I-2 Wide Field Photoelectric (MCP) Camera/Filter Spectroheliograph | 16'x16' | 3-15 | 1.5-100 |
| I-3 High Resolution Photo-electric (CCD) Camera/ Imaging Polychromator | 5'x5' | 3-15 | 1.5-100 |
| I-4 Ultra High Resolution Photogrpahic Camera/ filter/spectroheliograph | 48'x48' | 3-15 | 1.5-100 |
| I-5 Wide Field (IPC) Camera/ Imaging Polychromator | 16'x16' | 3-15 | 1.5-60 |
| I-6 Bore Sight monitor (Slit Jaw Camera) | 16'x16' | 50-5000 | visible |

* Fields of view for S-2,S-3,S-5,S-6 can be extended to 8'x8' by rastering.

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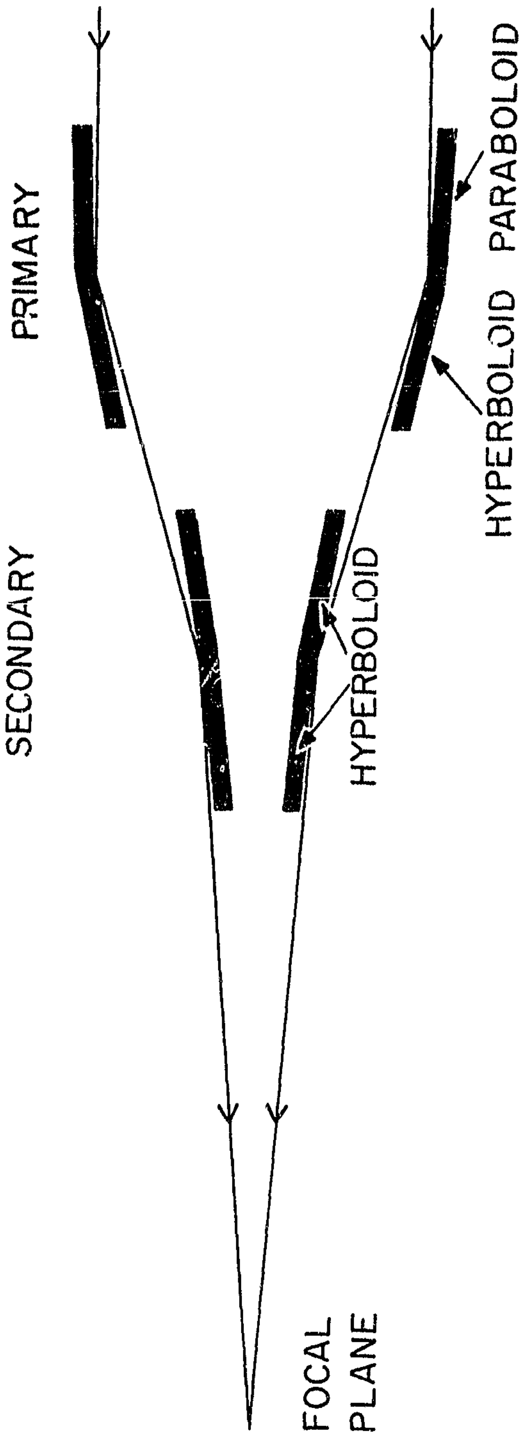


Figure 2-2. Cassegrain Secondary Wolter Optics

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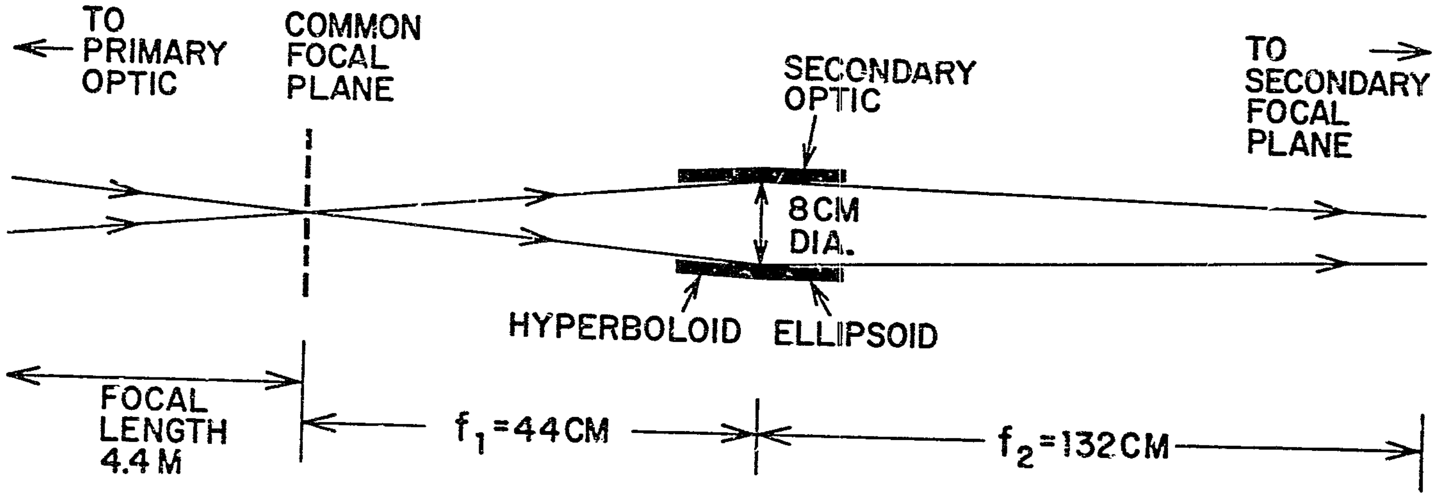


Figure 2-3. Gregorian Secondary Wolt‹ ; Optics

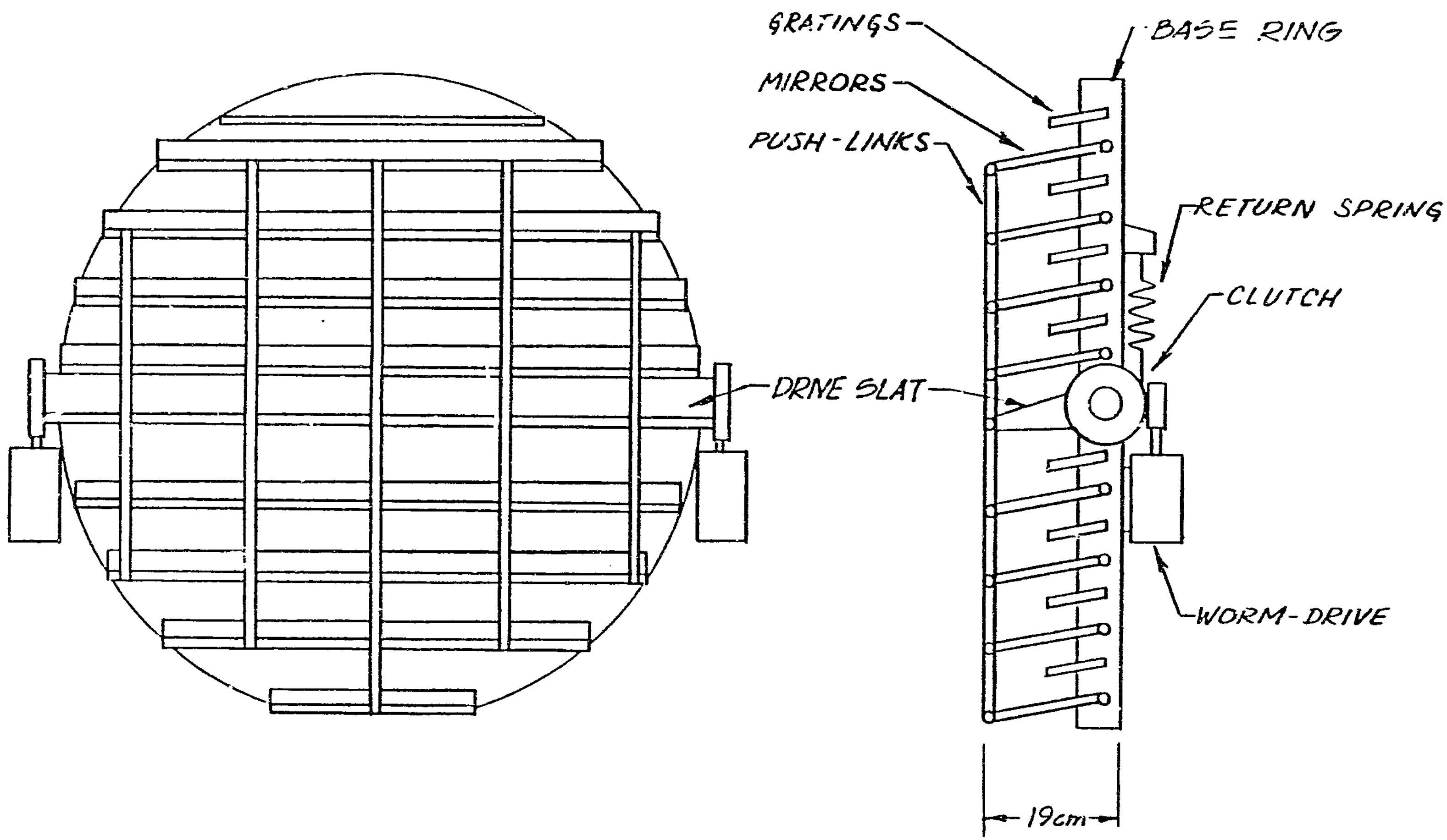


Figure 2-4. Schematic of Objective Grating Grating Spectroheiograph

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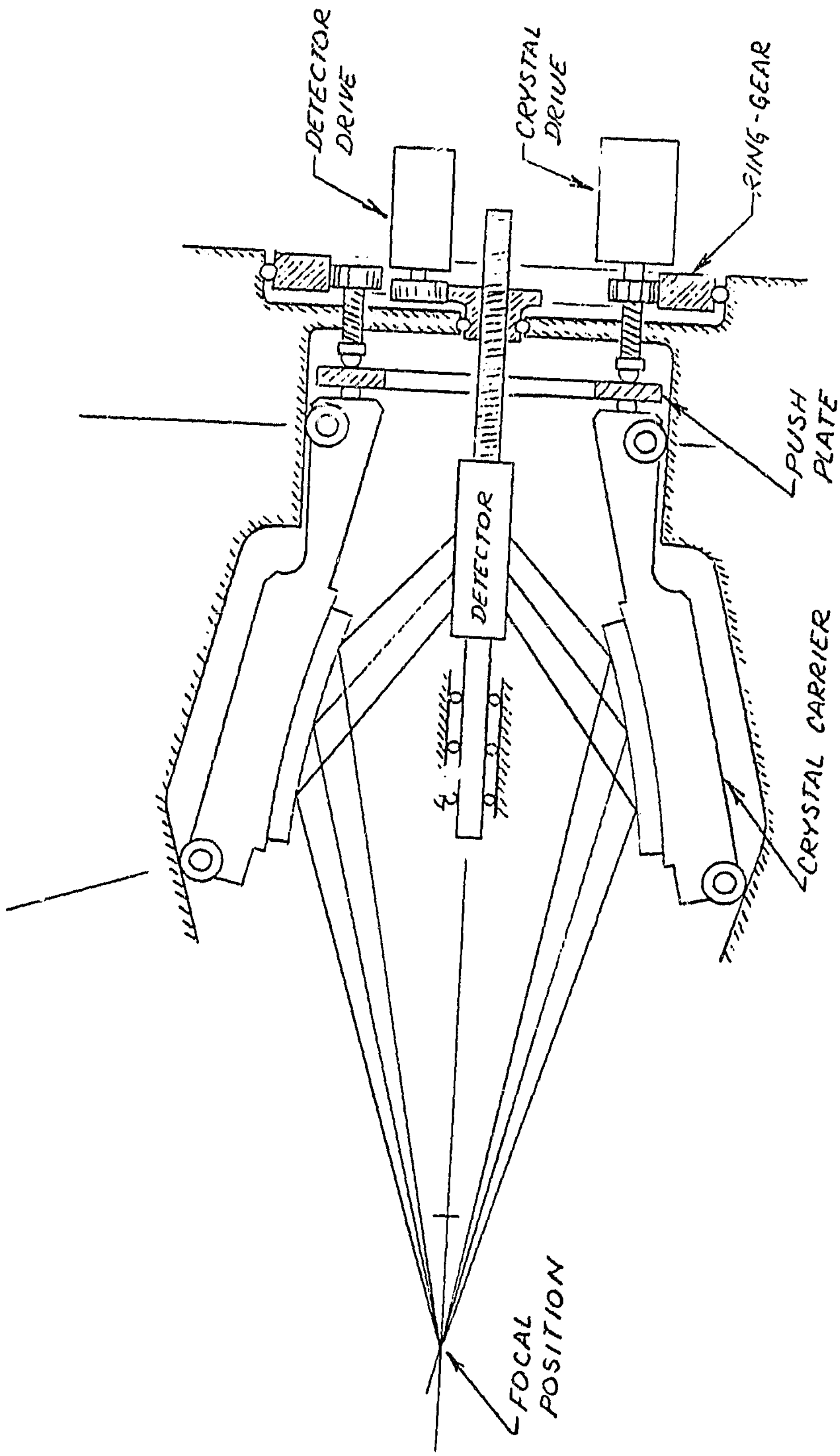


Figure 2-5. Schematic of High Resolution Crystal Spectrometer/
Polarimeter/Polychromator

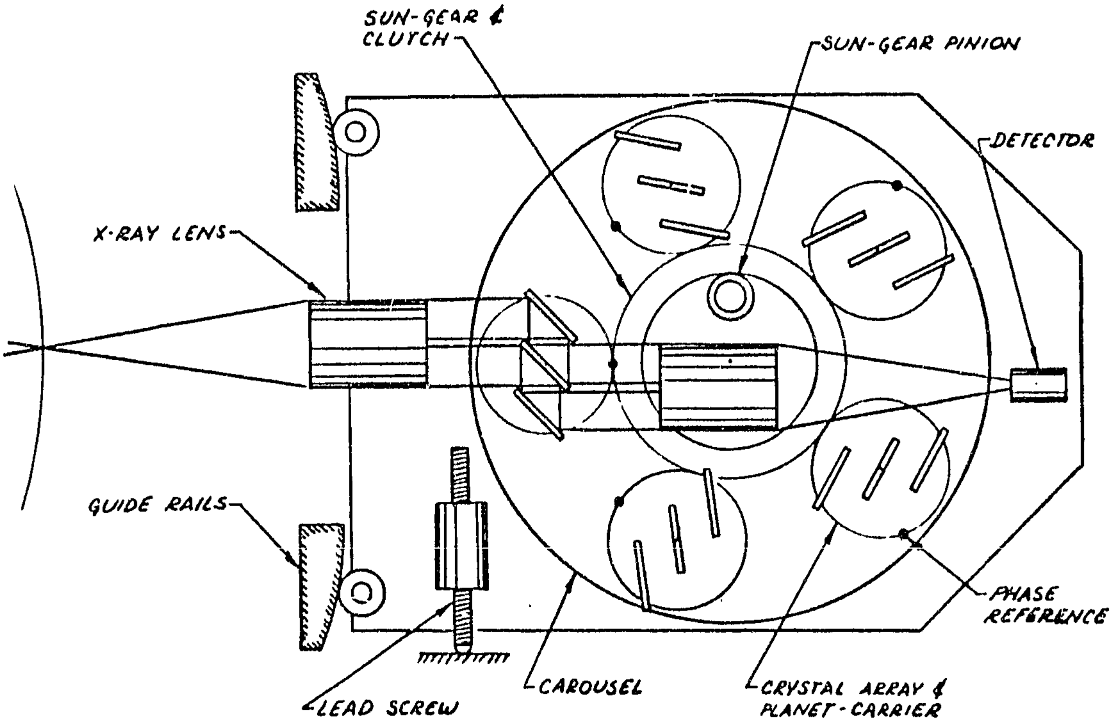


**Figure 2-6 Schematic of Stigmatic Focal Plane Crystal Spectrometer**

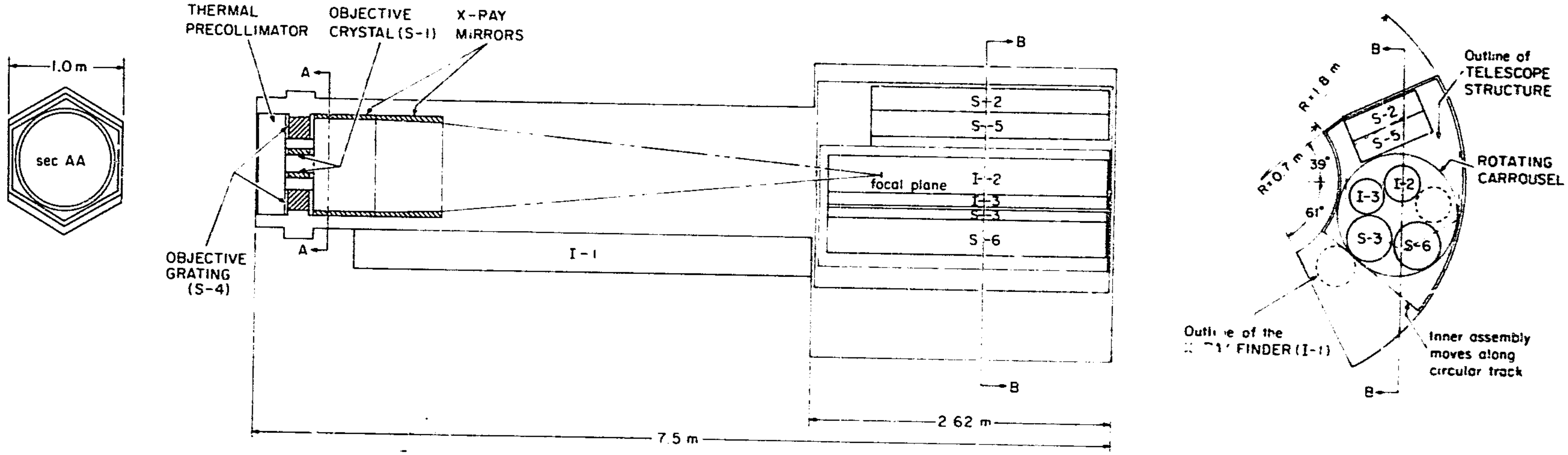


Figure 2-7. Schematic of Soft X-Ray Telescope Facility with Expanded Accomodations for Focal Plane Instruments

element (GIRO) is in front of the focal plane of the primary telescope. Figure 2-3 shows a Gregorian configuration in which the secondary optic is behind the primary focal plane. Because different types of GIRO elements are usually required for different focal plane instruments, these elements are considered to be part of the focal plane instrument in the Soft X-Ray Telescope Facility configuration illustrated in Figure 2-7. Figures 2-4, 2-5 and 2-6 show schematics of three candidate focal plane instruments, one of which employs GIRO optics (see Figure 2-6).

As a result of the selection of the Solar Optical Telescope (SOT) as the first solar facility for flight on the Shuttle, a study of the feasibility of mounting the Soft X-Ray Telescope Facility within the SOT cannister was undertaken by General Electric (see GE final report "Spacelab Soft X-Ray Facility (SXTF) Interface Study", 1981). No major obstacles to mounting the X-ray facility in the SOT cannister were found, however more detailed studies of the interfaces should be undertaken once the SOT cannister design is finalized.

Given the great scientific potential of simultaneous observations by SOT and the Soft X-Ray Telescope, the FDT recommends joint operation of these facilities. Consequently, mounting the Soft X-Ray Telescope Facility in the SOT cannister is highly desirable. A schematic of one possible configuration is shown in Figure 2-7. This is a "full up" configuration with multiple focal plane instruments (see Table 2-1). Early flights would have only a few basic focal plane instruments. Once the final design for the SOT cannister is available, the optimum configuration of the Soft X-Ray Telescope Facility can be developed. For the configuration shown schematically in Figure 2-7 the Soft X-Ray Telescope Facility extends beyond the front end of the SOT cannister by about 1.5 meters.

## 2.2. XUV Telescope

The XUV telescope is an extremely powerful, versatile instrument operating in the spectral range from approximately 100 to 1200 Å. It can be used to study the chromosphere, transition region and corona with lines and continua formed over temperatures ranging from $10^4$ K (hydrogen Lyman lines and continua) to $2 \times 10^7$ K (Fe XXIV lines). Because of the wide temperature range covered; variety of lines giving temperature, density and velocity diagnostics; and capability of measuring emission from individual spectral lines with high spatial resolution ($\approx$1 arc sec); the XUV instrument can provide unique information on many solar features and investigate a wide range of problems.

High resolution spectrally resolved XUV measurements with good temporal resolution require an optical system with large collecting area. The high spectral resolution needed to exploit the powerful diagnostic capabilities of the XUV spectrum implies a facility optimized for spectroscopy. This combination of requirements resulted in the selection of an optical design for the solar XUV facility that is similar to that employed for the Grazing Incidence Solar Telescope (GRIST) studied by the European Space Agency (see "GRIST, the Phase A Study" 1978). A conceptual study of two different sized XUV facilities was performed by Ball Aerospace Systems Division (formerly Ball Brothers Research Corporation). One size has nearly the same collecting area as GRIST, 277 $cm^2$, the other has 2.2 times more collecting area or 624 $cm^2$. The results of the BASD study are contained in Goddard Space Flight Center Report X-682-76-102.

The configuration of the larger version of the XUV facility is illustrated in Figure 2-8. The telescope is a sector shaped Wolter Type II paraboloid-hyperboloid mirror pair with 624 $cm^2$ collecting area, 618 cm focal length and 5x5 $(\text{arc min})^2$ field of view. The maximum grazing angle is 13°. Since a sector telescope is used, the focal ratio varies and ranges between 20.46 and 30.16. The defraction limit at 500Å is approximately 0.13 arc sec. The design goal for the spatial resolution is 0.5 arc sec. The smaller version of the XUV facility, whose configuration is illustrated in Figure 2-9, has a collecting area of 277 $cm^2$, 412 cm focal length and 0.2 arc sec defraction limit.

Three representative focal plane instruments were included in the conceptual design in order to provide constraints on the overall size of the facility and to insure that the adopted configuration would be able to feed a variety of different types of focal plane instruments.

The facility concept employs a scanning or raster mirror that can be rotated in order to direct the light beam from the primary telescope to one of three focal plane instruments. This mirror can also be used for image motion compensation and/or rastering. An alternative possibility is to mount the primary mirror in a two-axis gimbal and use the primary mirror for rastering. The latter arrangement is used for the current concept for GRIST.

Three representative focal plane instruments for the XUV facility are: a high resolution grazing incidence spectrometer shown schematically in Figure 2-10, a tandem-Wadsworth spectrometer (Figure 2-11) and a Sirks focus spectrometer (Figure 2-12). The characteristics of these three spectrometers are given in Table 2-2. There are a number of alternative types of focal plane instruments that could be utilized including a normal incidence toroidal grating spectrometer, an objective grating spectrometer and a moderate resolution grazing incidence spectrometer optimized for producing spectroheliograms.

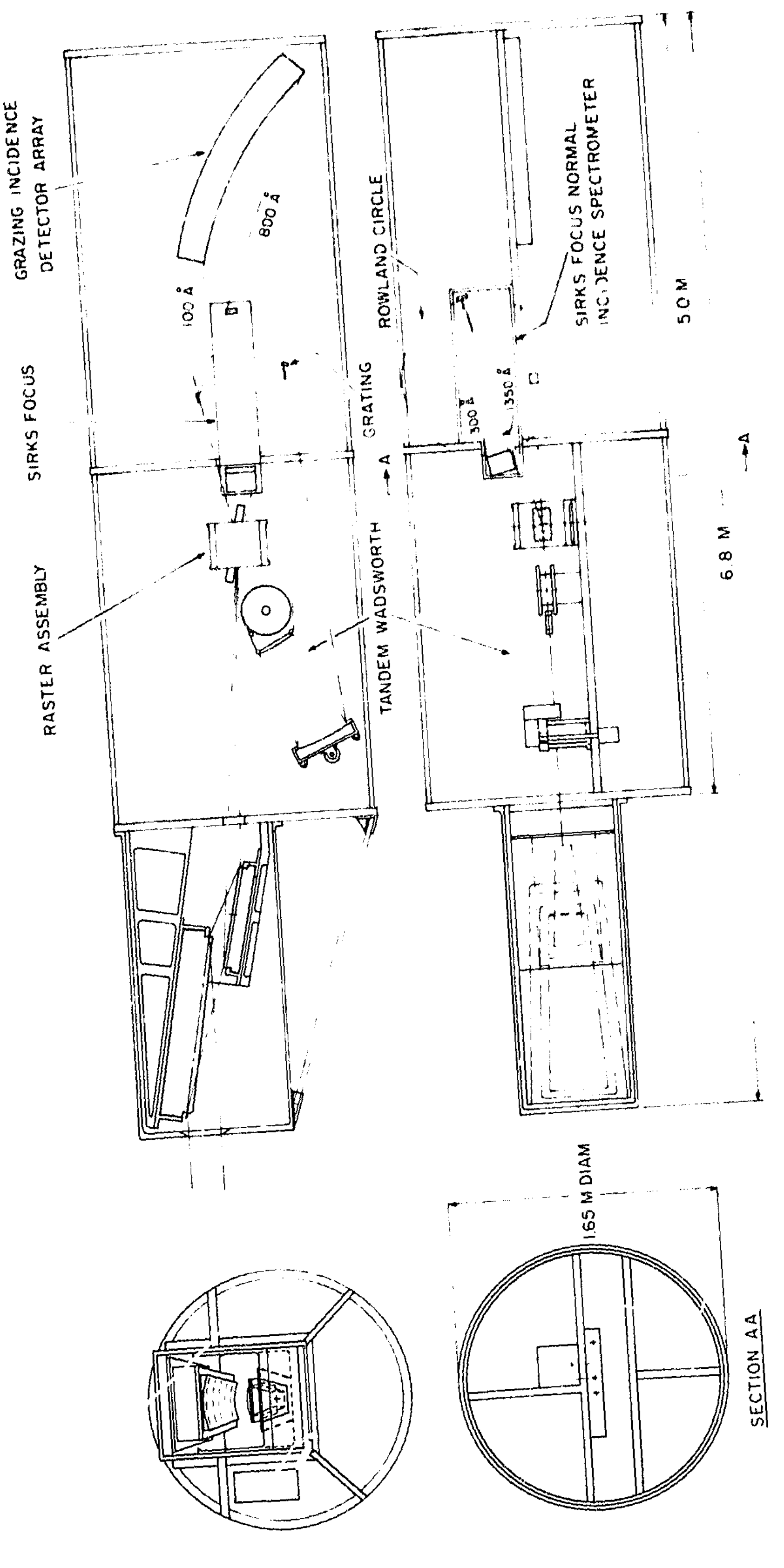


Figure 2-8. XUV Telescope Facility Concept (624 $cm^2$ collecting area)

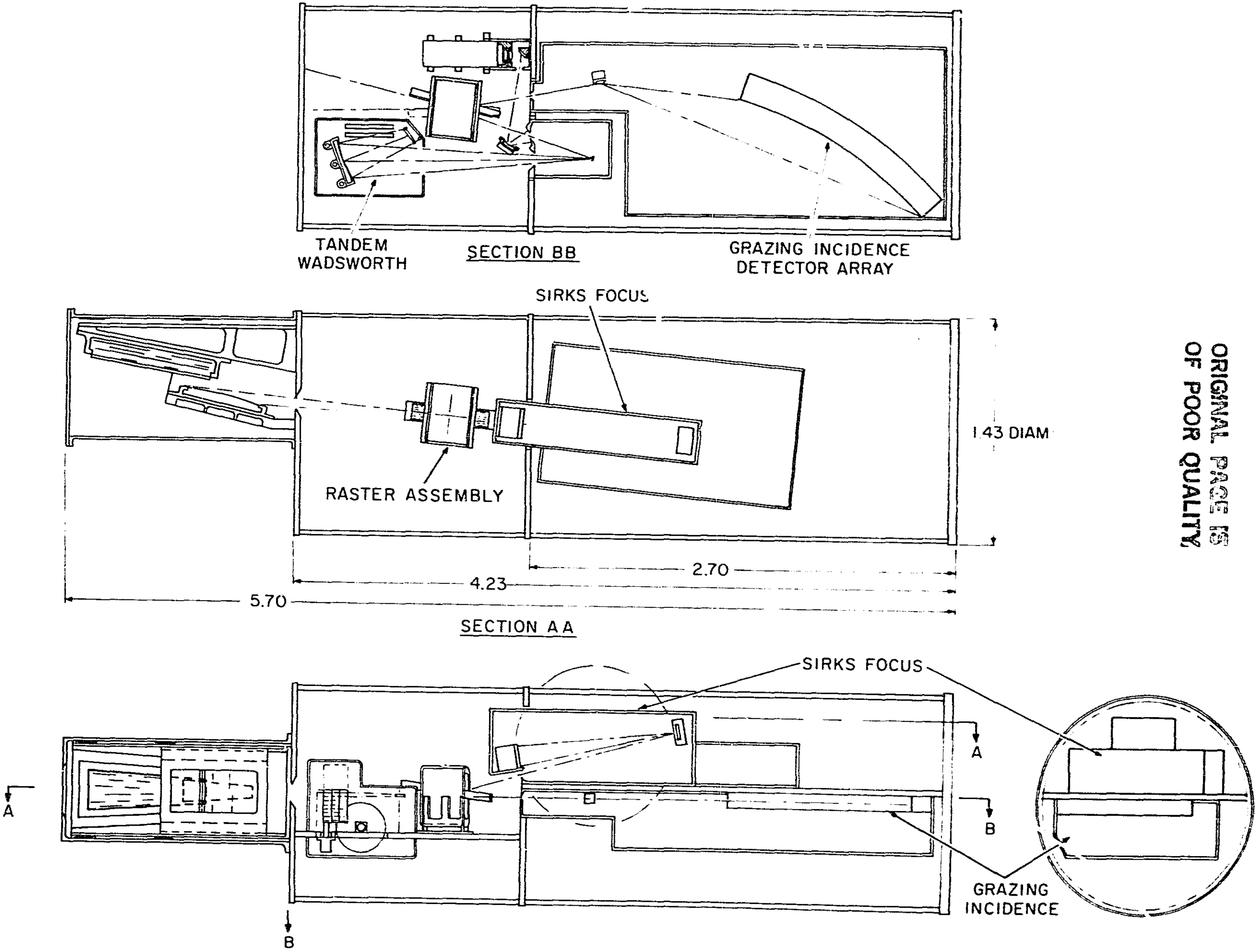


Figure 2-9. XUV Telescope Facility Concept (277 $cm^2$ collecting area)

TABLE 2-2. FOCAL PLANE INSTRUMENTATION FOR XUV TELESCOPE

| Instrument | Field of view | $\lambda/\Delta\lambda$ | Wavelength Range (Å) |
|---|---|---|---|
| High Resolution Grazing Incidence Spectrometer | 0.5-5" | $4\times10^4$ | 100-800 |
| Moderate Resolution Grazing Incidence Spectrometer | 0.5-5" | $4\times10^3$ | 100-800 |
| Sirk's Focus Spectrometer | Variable, to 5'x5' | $10^3$-$10^4$ | 300-1400 |
| Tandem-Wadsworth Spectrometer | 0.5"x8' | $3\times10^4$ | 400-1700 |
| Toroidal Grating Spectrometer | 4'x4' | $10^4$ | 300-1400 |
| Objective Grating | 1'x4' | $10^4$ | 200-1400 |

The type of XUV facility that is developed depends on several factors. If ESA proceeds with the development of GRIST, then the XUV facility should be an advanced facility with significantly larger collecting area than GRIST, comparable or better spatial resolution and better accommodations for focal instrumentation. This implies a facility as large or larger than the bigger version of the XUV facility described above (624 cm$^2$ collecting area). A facility of this size may be too large to fit within the SOT cannister without placing tight constraints on the accommodations for focal plane instruments. Once the final SOT design is available, a configuration for the XUV facility can be designed that satisfies the constraints imposed by the SOT cannister and maximizes the capabilities of the XUV facility. Alternatively, a large XUV facility with the configuration shown in Figure 2-8 could be flown with other smaller (than SOT) facilities and/or PI instruments on the Shuttle or be operated from a platform such as the proposed Advanced Solar Observatory (ASO). If GRIST is not developed, a smaller XUV facility may be attractive due to lower cost and the reduced difficulty of fitting it within the SOT cannister. The packaging of the focal plane instrumentation may have to be modified from that shown in Figure 2-9 in order to satisfy constraints imposed by the final SOT design.

The major technical problem in the development of the XUV facility is the design and fabrication of the primary telescope mirror. In order to evaluate the feasibility of fabricating a suitable mirror within the desired time and cost constraints, a smaller test mirror should be fabricated, polished and thoroughly tested before entering the hardware phase of the XUV facility.

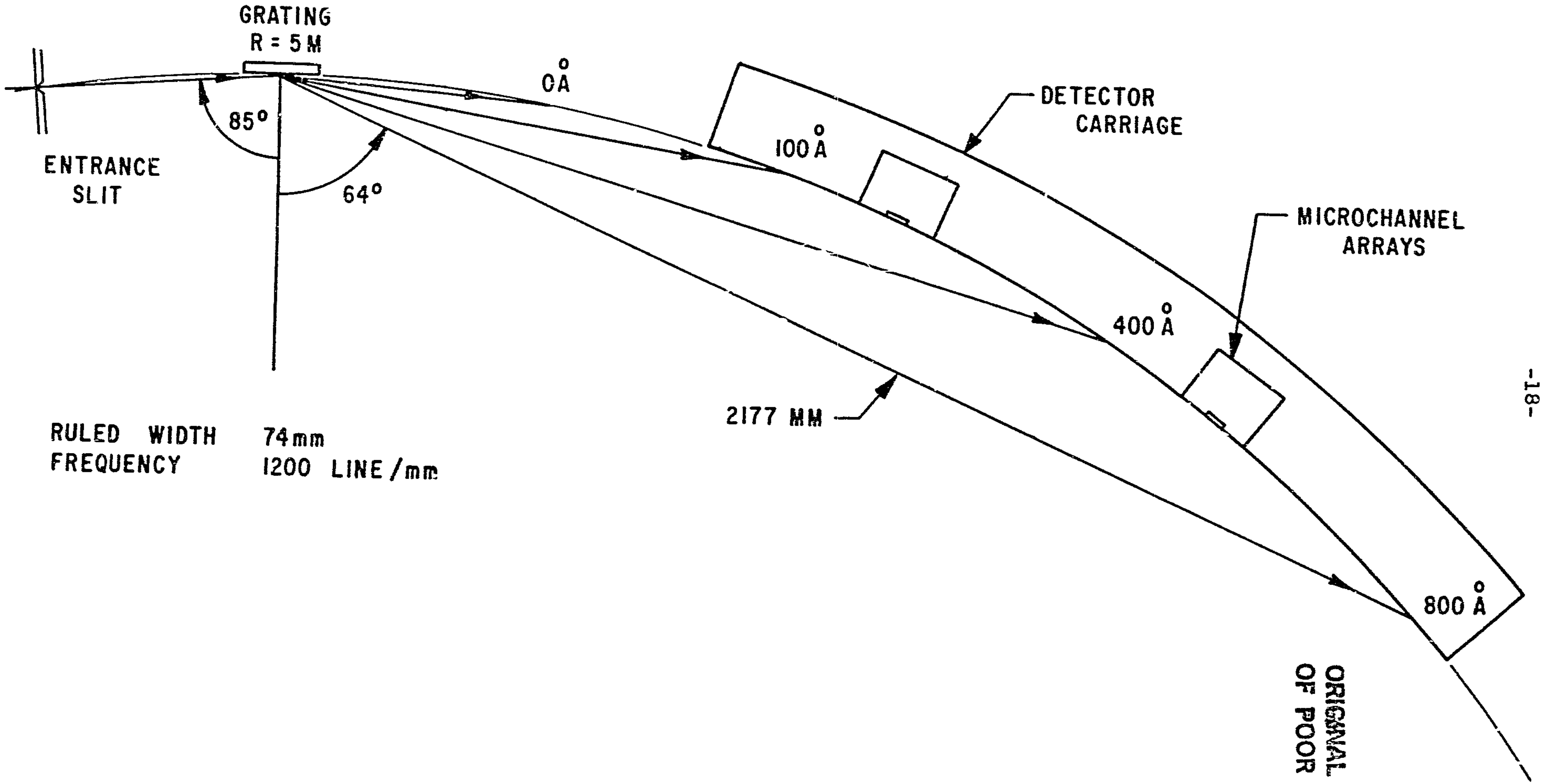


Figure 2-10. Grazing Incidence Spectrometer

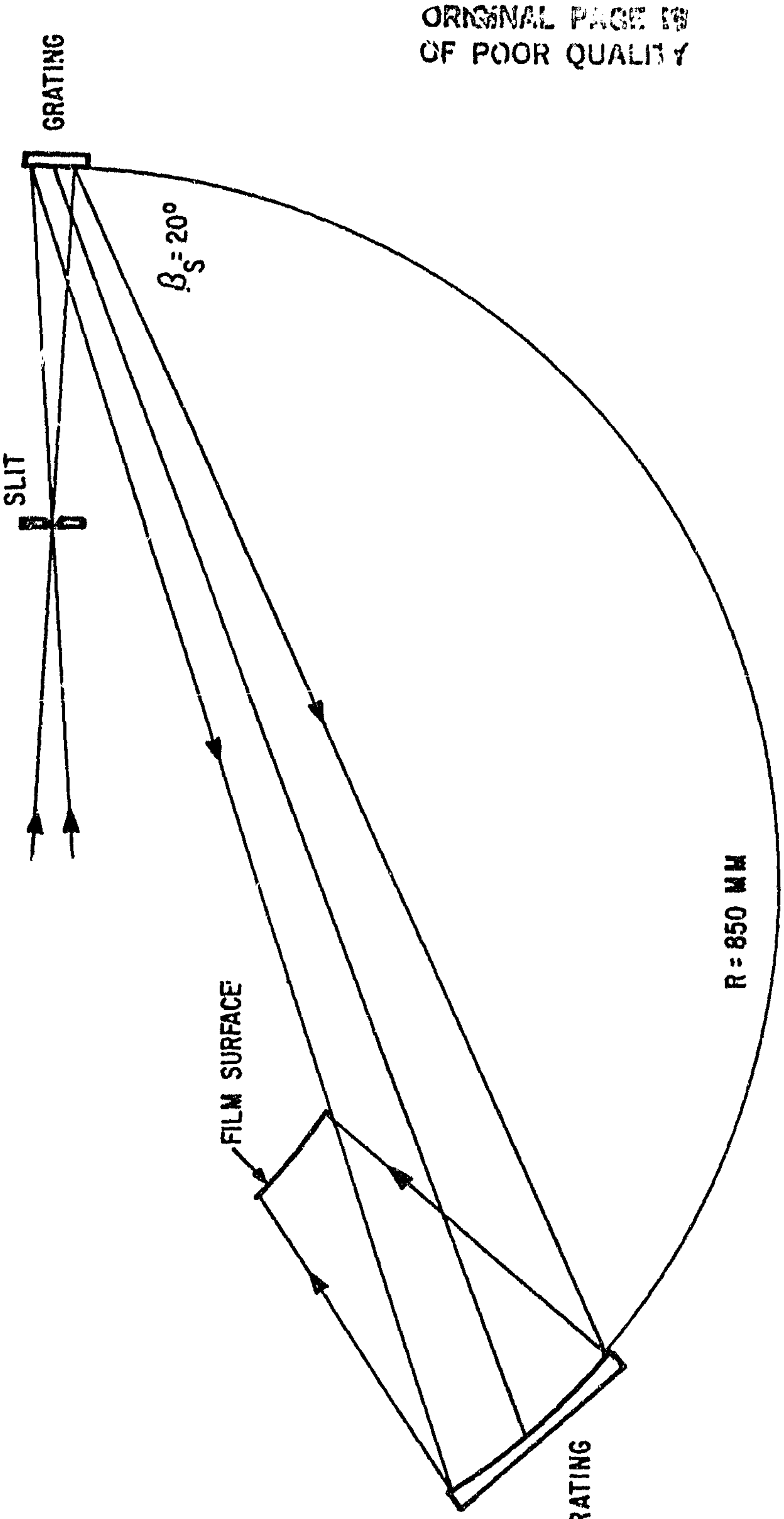


Figure 2-11. Tandem-Wadsworth Stigmatic Spectrograph

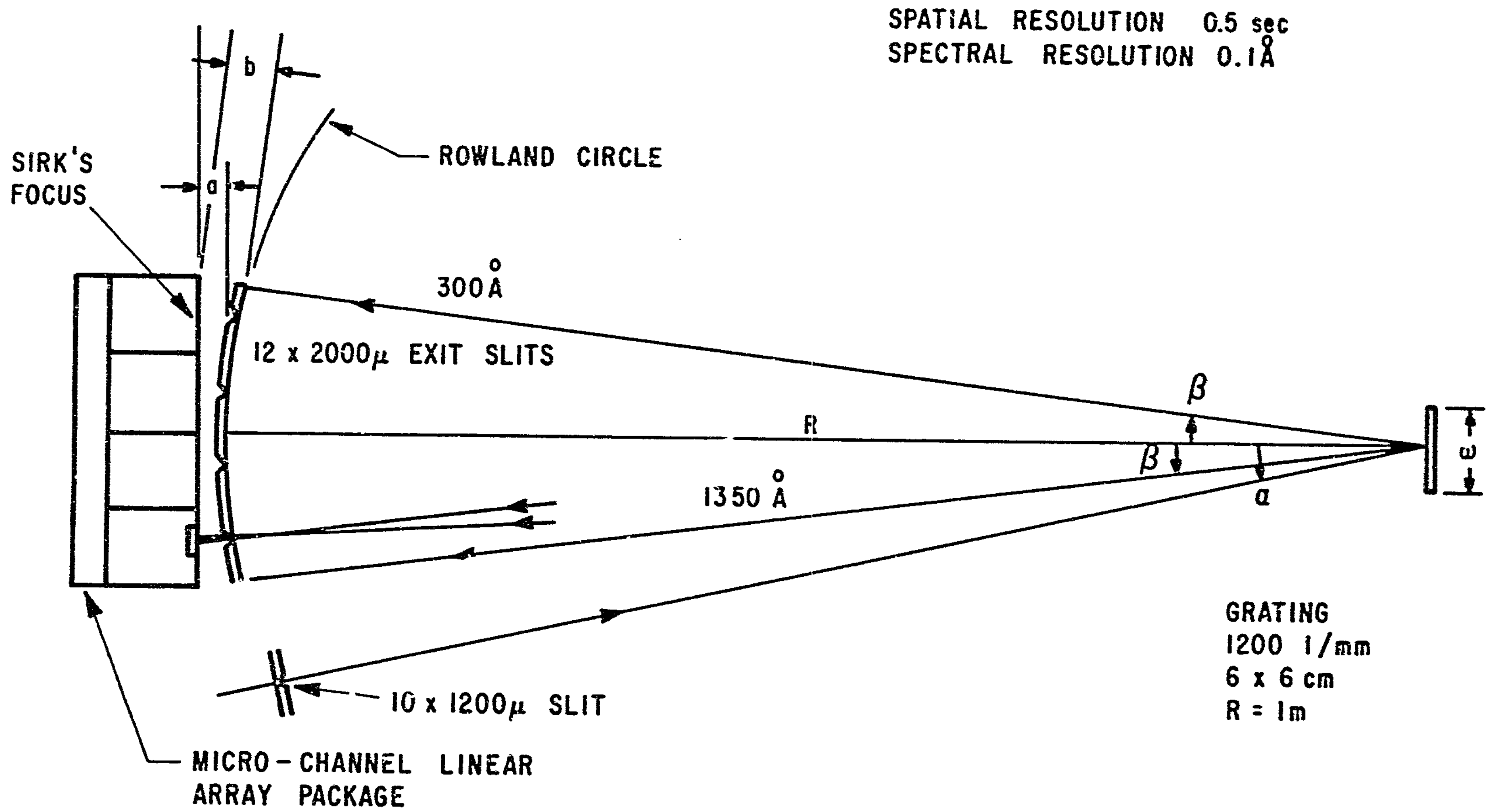


Figure 2-12. Sirk's Focus Spectrometer

## 2.3. EUV Telescope

The EUV telescope, like the XUV telescope, is a very powerful, versatile instrument. It operates at normal incidence in the spectral range from about 360 to 1400Å and can be used to study the chromosphere, transition region and corona with lines and continua formed at temperatures ranging from 4500 K (Si I continuum) to $3 \times 10^6$K (Fe XVI lines). Because of the wide temperature range covered; variety of lines giving temperature, density and velocity diagnostics; and capability of measuring emission from individual spectral lines with sub arc sec spatial resolution ($\leq$ 0.3 arc sec) the EUV instrument can be used to investigate a wide range of problems.

There are several possible configurations for an EUV facility. The two basic configurations are (1) a telescope employing an off-axis paraboloid similar to the configurations of the S055A EUV telescope on ATM and (2) a folded telescope with a Gregorian configuration. The advantage of the off-axis telescope is its high efficiency for collecting photons. At wavelengths less than 1000Å the reflectivity of the mirror coatings that have good reflectivity over the entire EUV $500 < \lambda < 1200$Å is typically 20 to 30%, hence telescopes with multiple reflections have significantly lower collecting area than a single mirror system with the same aperture. Folded optical systems have the advantage of being more compact, having a larger field of view and providing significantly longer focal lengths than a single mirror system of the same overall length. This permits higher spatial resolution, which tends to be limited by the minimum pixel size on the detection systems, rather than the spatial resolution of the telescope. (Magnifying optics are usually not used in EUV spectrometers because of the above mentioned problems resulting from low reflectivity of mirror and grating coatings). Since high spatial resolution is a prime objective of new solar facilities, this is an important consideration.

A conceptual study of an EUV telescope facility employing an off-axis primary mirror was conducted by BASD. Results of this study are summarized in "EUV Facility Study, Final Report", FY77-12, prepared by BASD. The facility concept is shown in Figure 2-13. The primary mirror has an aperture of 57.5 cm, focal length of 460 cm, off-axis angle of 5.9° and f-number of 8. The spatial resolution is 0.5 arc sec with a 0.1 arc sec design goal. A modular design is used which permits incorporation of different complements of focal plane instruments through attachment of alternative instrument modules. For the conceptual study the two representative focal plane instruments were a tandem-Wadsworth spectrometer and Sirks focus spectrometer similar to those utilized in the study of the XUV facility (see Figures 2-11 and 2-12). With these focal plane instruments the EUV facility has an overall length of 6.2 meters. Other types of focal plane instruments such as the toroidal grating spectrometer

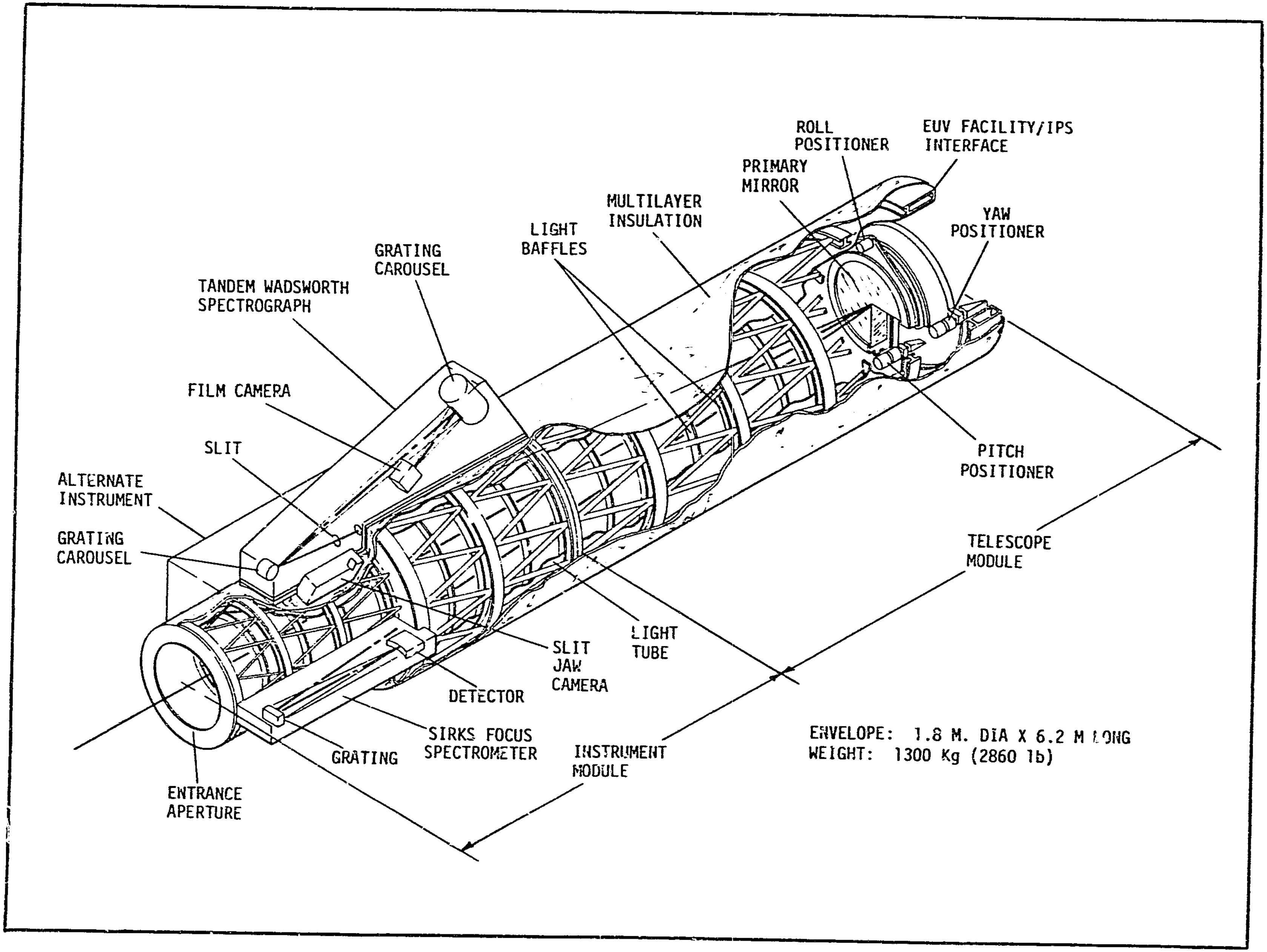


Figure 2-13. EUV Telescope Facility Isometric (off axis configuration)

discussed below would require a longer instrument module. An EUV facility of the size and envelope illustrated in Figure 2-13 is close to the limits available in preliminary designs of the SOT cannister, consequently some modifications to the concept may be required to insure that the EUV facility is compatible with the final SOT design.

An alternative concept for an EUV facility is shown in Figure 2-14. This concept uses a 75 cm Gregorian telescope with a 1125 cm focal length operating at f/15. The longer focal length and larger f-number (as compared to the off-axis telescope described above) yield a facility that is more suitable for high resolution spectroscopy with single optical element focal plane instruments such as the 1.75 meter toroidal grating spectrometer illustrated in Figure 2-14. The spatial resolution, which is likely to be limited by the detector pixel size, is better than the off-axis system by a factor of 2.5 at the focal plane ($10\mu$ = 0.2 arc sec). The disadvantages of the Gregorian configuration are (1) the lower photon collecting capability ($\approx$ 20 to 30% that of the off-axis system) due to the extra reflection and (2) accommodating more than one large focal plane instrument requires a mechanical system for moving focal plane instruments into focal plane of the primary mirror system and (3) need for an active alignment system. Because of its large f-number and long focal length, the advantages of the Gregorian system appear to outweigh the above mentioned disadvantages, suggesting that this is the type of facility that should be developed for the EUV. However, before development of the EUV facility is initiated, a scientific and engineering tradeoff study should be undertaken to insure that the optimum configuration is selected.

Operation of the EUV facility within the SOT cannister offers significant advantages for joint science on Shuttle sortie missions. Whether or not deployment within the SOT cannister is desirable for extended operation on a platform such as ASO will depend on the configuration of the platform (e.g. how many solar instruments will be operated and number of pointing systems that will be utilized). If the size limitations of the SOT cannister are eliminated, larger EUV facilities than those shown in Figures 2-13 and 2-14 could be considered.

TABLE 2-3. FOCAL PLANE INSTRUMENTATION FOR EUV TELESCOPE

| Instrument | Field of view | $\lambda/\Delta\lambda$ | Wavelength Range (Å) |
|---|---|---|---|
| Sirk's Focus Spectrometer | Variable, to 5'x5' | $10^3$-$10^4$ | 400-1400 |
| Tandem-Wadsworth Spectrometer | 0.3"x8' | $3\times10^4$ | 400-1700 |
| Toroidal Grating Spectrometer | 4'x4' | $10^4$ | 400-1400 |
| Objective Grating | 1'x4' | $10^4$ | 400-1400 |

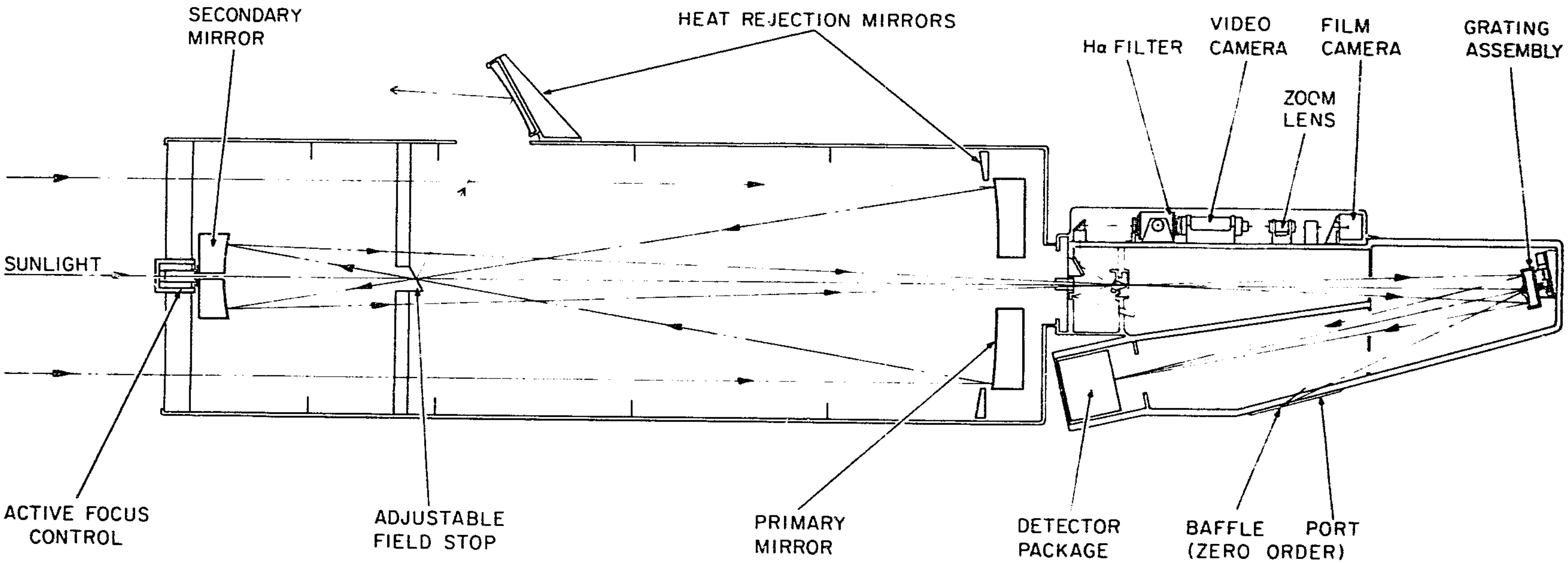


Figure 2-14. EUV Telescope (Gregorian configuration) with 1.75 Meter Spectrograph. The overall dimensions are approximately 1 x 6 meters.

## 2.4 Priorities for Development

One of the principal difficulties with the establishment of priorities for the development of solar facilities is that several types of optical instruments are required to exploit fully the advantanges of operation above the Earth's atmosphere at wavelengths not accessible from the ground. One generally needs different types of optical systems for the UV ($\lambda > 1100$ Å), EUV ($500 < \lambda < 1200$ Å), XUV ($100 < \lambda < 500$ Å), soft X-ray ($2 < \lambda < 100$ Å), and hard X-ray ($0.1 < \lambda < 2$ Å) regions if one is going to obtain the maximum performance in each spectral range. Each of these ranges is capable of providing unique measurements needed for investigating a variety of fundamental solar problems and all are required simultaneously to approach any problem completely. Consequently, the FDT recommends that three new facilities be developed, the Solar EUV Telescope Facility, the Solar XUV Telescope Facility and the Solar X-ray Telescope Facility. These will complement facilities designed for the UV (Solar Optical Telescope) and hard X-ray (Pinhole/Occulter Facility) spectral ranges.

Because of the funding limitations expected for the foreseeable future, priorities for the development of these three facilities (EUV, XUV, Soft X-ray) must be established. The FDT recommends that the order of priority be (1) the Solar X-ray Telescope Facility, (2) the Solar EUV Telescope Facility and (3) the Solar XUV Telescope Facility. This decision is based on consideration of the current state of development of instrumentation for the $2 < \lambda < 2000$ Å range and the status of other facilities. The Solar Optical Telescope (SOT), currently under development, will provide a powerful facility for $\lambda > 1100$ Å, while European Space Agency may provide a facility class XUV facility (GRIST) capable of operation in the XUV and EUV. The FDT believes that between SOT, GRIST and/or PI class instruments, it should be possible to satisfy the near-term requirements for high resolution EUV and XUV observations. For this reason the Solar Soft X-ray Telescope Facility, which will provide high resolution soft X-ray observations, has been given highest priority. The EUV Telescope Facility has been given second priority because of the above mentioned possibility for alternative near-term methods for acquiring EUV data. However, because it has the potential for achieving the highest possible spatial resolution in resonance coronal lines using technology within the current state of the art, it has high priority. The XUV Telescope Facility was given third priority due to the possible alternative provided by GRIST, if it is developed, and because it is the most technologically demanding.

## 3. SCIENTIFIC RATIONALE

Observations of solar phenomena made with X-ray and EUV imaging instruments on Skylab have revealed that the basic structural components of the solar atmosphere are magnetically confined loops of plasma. The loops were observed to have lengths ranging from a few arc min down to the instrumental resolutions of several arc sec. These observations have provided the basis for numerous investigations (constituting essentially a new field of study) into the physics of loops. The object of these studies has been to explain the structure -- pressure, temperature, electric currents, and gradients of these parameters -- and heating sources of the loops.

The relevant physical theories are expressed as differential equations involving spatial gradients of the thermal conductive flux, mass density, and pressure, as well as the heating function, bulk plasma velocity, radiative loss, and density and pressure at a given point on the loop. While the integration of these equations over entire loop structures can yield parametric relations which may be tested with observational data of poor spatial resolution, the essence of the physical relationships will be lost and the critical information about loop structure and heating processes will be severely limited by considerations of integral properties. Studies of loop properties require information on differential properties which implies the observation of spatial gradients of physical parameters both along and across the loop axis. These parameters must be obtained from spectroscopic measurements with a spatial resolution adequate to insure that one is observing only a small region of a loop rather than averaging over the entire cross section of a loop or, worse, over an ensemble of loop structures.

The existence of a coronal fine structure organized into loops and arches has been recognized for decades. The general morphological behavior of coronal structures was first described by Lyot (1944) who observed the typical brightening and dimming of the emission from plasma structures confined by the magnetic field. Unfortunately, only limited progress has been made since then in understanding the nature of these structures.

The problem is that we do not understand the magnetohydrodynamic processes that govern the form and energy budget of coronal structures. This is really the study of the dynamics of a tenuous plasma in the presence of changing magnetic fields. Currents which are flowing distort the plasma and field distributions, as they must be in other astrophysical objects. The fields that thread galaxies and nebulae will never be studied in as much detail as the coronal structures, but we may come to understand the structure and evolution of distant objects better by understanding the dynamics of the solar corona.

In solar physics, the study of problems ranging from the evolution of global solar magnetic field patterns and their extension into the interplanetary medium to the physics of solar flares requires a better understanding of the physics of the structures observed in the corona and of their response to changes in the underlying magnetic field pattern. It is obvious that the magnetic fields of isolated active regions must reconnect to form the large scale interconnections seen in X-ray and XUV photographs and eclipse observations and that the large scale coronal structures must respond to the motion of photospheric fields. But what are the processes? For example, how long does it take after the emergence of an active region for its influence to be manifested by changes in the field structures at large distances? How much can the photospheric motions distort the coronal fields before instabilities set in and reconnections occur? What role, if any, is played by electric fields in the corona? Are current sheets required to account for the form and behavior of the coronal structures?

Several theoretical and observational steps are necessary in order to understand the processes taking place in the corona. The first is the development of an acceptable equilibrium model of a coronal plasma structure. Such an effort requires as observational input the distribution of temperature, density, velocity, and magnetic field throughout the structures. The second is a detailed analysis of the dynamic behavior of structures. A categorization of the observed changes in terms of time scales, length scales, magnetic field changes, and macroscopic velocities is required as preliminary input here. More advanced observations would describe the detailed changes of the field and the plasma through a single event.

At least two observational approaches are therefore required: One in which the physical parameters of coronal loops and arches are determined with sufficient spatial resolution and precision to permit the development of a static model of a coronal plasma structure; and a second in which a variety of morphological changes in coronal structures are observed with high temporal resolution to permit study of the dynamic behavior of such structures. These two observational approaches require instrumentation of high spatial resolution and flux collection power. These characteristics can only be provided by facility class instruments.

Determination of the physical parameters, such as temperatures, densities, and velocities of coronal structures must be accomplished by means of EUV, XUV and X-ray spectra and spectroheliograms with high angular resolution and (for structures outside active regions) high sensitivity. These measurements must be obtained with an angular resolution of at least 1 or 2 arc sec, if one is to provide meaningful information for the development of models of coronal features, because coronal green line photographs and ATM ultraviolet and X-ray results show that individual loops in the corona may be as narrow as a few arc sec. Because such loops are components of large structures and because the structures vary on time scales of minutes or less, the individual spectra and spectroheliograms must be acquired fairly rapidly. For example, consider a point scan rastering spectroheliograph. There are $9 \times 10^4$ (1 arc sec)$^2$ picture elements or pixels in a $5 \times 5$ (arc min)$^2$ area. If this field is to be examined in a time which is small compared to the temporal variations under study, only a fraction of a second may be spent on each pixel. Practical line scan rastering instruments improve the situation but not enough. Therefore, the collecting area of the telescope feeding such a spectroheliograph must be quite large in order to gather the required photon flux. Some of the diagnostically important lines are fairly weak. Thus, one is forced to conclude that the establishment of the input parameters for an equilibrium model of a coronal plasma structure requires construction of Shuttle "facility class" telescopes equipped with spectroheliographs and high resolution spectrometers in the EUV, XUV and soft X-ray spectral regions. Indeed, this problem is one of the principal justifications for the large "facility class" instrumentation.

The body of this section is devoted to a brief discussion of the types of results that could be obtained with the telescope facilities discussed in section 2.

### 3.1 Mass and Energy Transport in the Solar Atmosphere

In attempting to understand the physics of the solar atmosphere, it is important to realize the close interrelation between the physical structure, heating mechanisms, energy balance, distribution of nonthermal velocities, magnetic configurations and mass flow. The temperature and density structure can be thought of as the result of some coronal heating mechanism, in conjunction with energy balance determined by conduction and radiation of heat. Nonthermal velocity modes can either represent stored energy or can be related directly to the heating mechanism as propagating mechanical waves. The magnetic configuration can act as a channeling mechanism for mechanical and heat flow, as a means of propagating additional mechanical modes, or as a direct source of magnetic energy. Mass flow can be an additional means of energy transport. A sound theoretical understanding of the atmosphere must therefore take account of all these factors. From an observational point of view, data must be obtained on the temperature and density structure, nonthermal velocity modes, magnetic fields and mass flow.

**3.1.1 Structure.** Over the years various models of the solar atmosphere have been constructed, giving average values of various physical parameters as a function of height (*i.e.*, the so-called spherically symmetric models). The averaging involved is subject to weighting factors, which vary with the type of observation and the direction of viewing. It is therefore not surprising that there are differences between models obtained from different observations, and uncertainties about which model to apply in a given situation.

An alternative approach to atmospheric modeling takes account of the fact that individual flux tubes in the corona and transition zone are magnetically insulated from each other by the relatively low value of cross field transport processes. Loops may therefore be viewed as the basic building blocks out of which an entire atmosphere may be constructed. Individual loops can be viewed as "mini-atmospheres" to which the full range of theoretical and empirical modeling techniques can be applied. A correct description of the atmosphere would therefore consist of ensembles of loops with widely varying parameters. ATM observations have shown that the physical conditions (temperature and density) can vary widely from loop to loop. Generally the emission measure, $\int N_e^2 \, dV$, in a loop peaks at some temperature $T_{max}$, but $T_{max}$ can vary from the order of $10^4$ K for prominence-like features to coronal temperatures ($T > 10^6$ K). In flares, plasma temperatures exceeding $10^7$ K are observed in loops.

The existing observations indicate that many loops in active regions have cross-sections of a few arc sec or less. To develop reliable models for these features the loops must be spatially resolved, so that one can determine both the density and the path length over which each emission line is formed. Use of density-sensitive line ratios provides an alternative means of separating the effects of density and path length, but are difficult to calibrate reliably on an absolute scale. Both types of observations on the same feature would be ideal. Studies of loop stability require an accurate assessment of the physical conditions in these features.

Clearly one of the most interesting problems to be investigated with facility class EUV, XUV and soft X-ray telescopes is the nature of these coronal loops, their thermal and dynamic stability, and their role in the transfer of mass and energy between different atmospheric layers of active regions. EUV, XUV and soft X-ray observations with high spatial and temporal resolution can yield fundamental new information about the conditions in these features and their time variations. Because the physical conditions change on a time scale of minutes or less, good time resolution is required. A two dimensional field-of-view comparable to the size of active regions is required, since loops typically span the width of an active region and often connect different regions. In addition, a resolution of one arc sec is required to resolve loops adequately. In studies of the roles of loops in transient events, high spatial ($\leq$ 1 arc sec) and temporal ($<$ minutes and sometimes seconds) resolutions are required to separate in time and space the different phases of a transient event and the effects that precede or follow the transient. Spectral resolution adequate to resolve line profiles and/or Doppler shifts also provides valuable information on the flow of material and turbulent motions in the plasma. The requirements for high spatial, temporal and spectral resolution imply a requirement for large instrumentation such as provided by a facility class instrument.

**3.1.2. Velocity Fields.** There are now many observations of profiles of solar emission lines in the EUV and XUV region. They often show a large nonthermal component corresponding to velocities of the order 30 km $s^{-1}$ in the transition region and low corona. With the exception of UV measurements made by the NRL HRTS rocket experiment and the UVSP experiment on SMM, the available measurements have very poor spatial resolution. The high resolution observations from HRTS and UVSP have shown that flows are ubiquitous across the solar surface, consisting of both upflows and downflows with some features exhibiting large velocities, several hundred km $s^{-1}$. Because of the limited temperature range of these high resolution measurements, which have been limited to the lower transition region, the mechanisms responsible for the observed motions and nonthermal spectral line broadening are poorly understood. Some motions appear to result from mass flows while others may be due to waves. The waves may be stationary, random or propagating, and may or may not be of shock amplitudes. They may propagate horizontally or vertically. Their correlation with structures such as network or spicules is unknown. What is needed now are observations at high wavelength resolution, having spatial resolution of ~ 1 arc sec and over a number of lines simultaneously covering a wide range of temperatures. Good time resolution is important for measuring phase delays in orders to obtain propagation velocities for waves and for observing the behavior of transient phenomena such as the energetic high velocity features observed in the UV.

**3.1.3. Mass Flows.** These velocity data may be fundamental to the whole problem of coronal mass balance which remains unresolved. The area integral of the solar wind flux leaving the sun is well known. The corresponding bulk velocity of the outflowing plasma becomes comparable with thermal velocities in the outer corona. At lower heights the wind velocity should be much smaller than thermal, unless it can be shown to originate from small fractions of the surface area. Theorists differ as to the importance in the lower corona of wind effects generated high up. This is particularly important for understanding coronal holes.

At the present time the exchange of mass and energy between the chromosphere and corona is poorly understood. There is some evidence that upward moving spicular material is heated to coronal temperatures and thereby deposits mass in the corona. The resulting upward mass flux is much higher that the observed solar wind mass outflow, hence most of the spicular material must eventually return to the chromosphere. It has been suggested that the systematic spectral line redshifts observed in UV lines formed in the transition region are caused by the downward flow of coronal material that has cooled and is returning to the chromosphere to balance that carried upward by spicules. This hypothesis, which introduces a fundamental change in the understanding of the mass and energy flow in the transition region and low corona, requires more direct observational confirmation. Facility class instruments could acquire critical observations for testing this hypothesis.

**3.1.4. Magnetic Fields.** High resolution (spatial and temporal) EUV, XUV and soft X-ray observations made over two dimensional fields of view can also yield fundamental data with regard to magnetic fields. ATM has demonstrated that EUV, XUV, and soft X-ray observations provide powerful tools for mapping the configuration of the coronal magnetic field. In active regions coronal loops were apparent when viewed in lines formed over a wide range of temperatures ranging from the hydrogen Ly$\alpha$ lines formed at temperatures of the order $10^4$ K, through transition region lines such as C III, O VI and Ne VII, to coronal lines such as Mg X, Si XII and Fe XVI. With a resolution of 1 arc sec many smaller loops will be seen which should give vital information on the detailed configuration of the magnetic field. Recent rocket observations demonstrate the existence of fine structure at the arc sec level even at temperatures above $10^6$ K. Often loops observed in "cool" lines are invisible in "hot" lines and vice versa.

If there is dissipation of magnetic field energy, the energy release should produce detectable changes in the EUV, XUV and soft X-ray emissions. The magnetic field also plays other important roles as in channeling heat flow or other important mechanical energy modes, such as Alfvén waves. A knowledge of the field configuration may allow a clear evaluation of the importance of Alfvén heating in the corona. Because of the small spatial scale of the magnetic field structure ($\lesssim$ 1 arc sec), high spatial resolution is vital to such studies. In addition good time resolution and signal-to-noise discrimination is desired. This means that a telescope with large collecting area and efficient detection systems is required.

## 3.2. Heating

There are two types of mechanisms that may be responsible for heating the corona and transition region: (1) dissipation of mechanical energy carried upward from the solar convection zone and (2) dissipation of energy stored in the magnetic field. Either or both of these mechanisms may be responsible for the heating in a variety of ways. As mentioned in the discussion of velocity fields, heating by waves can be studied in detail with EUV, XUV and soft X-ray observations acquired with high temporal, spatial, and spectral resolution.

Exploring differences between quiet regions, active regions, regions of high or low magnetic field strength, *etc.*, should provide empirical data suitable for detailed investigation of this heating mechanism.

**3.2.1. Magnetic Heating.** Because of the greatly increased requirements for heating in active regions as compared to quiet areas, heating mechanisms which utilize the energy stored in the magnetic fields are strong candidates as heating sources in active regions. EUV, XUV and soft X-ray images with high spatial resolution provide tracers for the coronal magnetic field configuration. High spatial resolution (~ 1 arc sec) is particularly important for resolution of coronal loops, especially in areas where many loops converge to a relatively small area of the photosphere. By studying the configuration of the coronal magnetic field as it evolves in time, it should be possible to determine how much energy is stored in the field and how much energy is converted into other forms of energy when the magnetic field configuration changes. This requires not only good EUV, XUV and/or soft X-ray data, but also high quality photospheric magnetic field maps. ATM data already suggest reconnection of field lines in or between active regions and there is evidence for the existence of magnetic field configurations which require the presence of currents.

New and much better measurements are required, particularly with regard to (1) spatial resolution, (2) simultaneous mapping of loop configurations in a variety of lines formed at different temperatures, and (3) thorough temporal coverage of the evolution of individual active regions. Because changes in the field configuration happen rapidly, most likely on a time scale of minutes or less, good time resolution is important. Observations in a wide variety of lines is important, because the temperature of the plasma in individual loops often appears to change along the length of the loops. In addition, most of the material in a given loop may be confined to a fairly narrow range of temperature. Hence, loops visible in one spectral line or group of spectral lines are not visible in lines formed at higher or lower temperatures.

**3.2.2. Nonthermal Particles.** Another possible source of heating is nonthermal particles stored in magnetic loops or generated by transient phenomena. If these particles stream into denser layers of the atmosphere, they may cause heating which could be detected with EUV, XUV and soft X-ray observations. Measurements in a variety of lines are required so that one can detect at what level in the atmosphere the energy is deposited and then how the energy is dissipated by radiation and conduction to other atmospheric layers. Such observations would be nicely complementary to those of the hard X-ray imager on Pinhole/Occulter Facility for observing the effect on the atmosphere of the particles giving rise to the hard X-ray radiation. In this way one can discriminate among alternative models for generating the hard X-ray emission.

**3.2.3. Infalling Material.** Another source of heating is the infall of material from the corona. This material could be prominence material or material ejected by a surge located, for example, at the other footpoint of a magnetic arch or loop. Soft X-ray and XUV observations with high temporal, spatial and spectral resolution could provide valuable information on this type of heating, particularly if coordinated with simultaneous observations in the UV with SOT. Because of the wide temperature range covered, from $10^4$ to a few times $10^7$ K, it is possible to detect all the material streaming into the chromosphere and determine its mass and velocity. Wide temperature coverage is important, because a number of examples in ATM data have been found in which the effects of infall of prominence material were visible only in upper chromosphere or lower transition layer lines. The ATM X-ray data also contain numerous examples of coronal heating in association with filament eruptions unaccompanied by any evidence of chromospheric heating. With high quality UV, EUV, XUV and X-ray data, one can observe the infall of material and how the different levels of the atmosphere respond to the impact of the infalling matter. Such observations would provide fundamental data for testing the infall/impact mechanism in some types of flares, such as subflares near active filaments.

### 3.3. Physics of Prominences and Filaments

Prominences present intriguing problems in their mass and energy balance. The maintenance of their low temperature in the midst of the much hotter corona is presumably due to shielding by magnetic fields against thermal conduction. Analyses of OSO and ATM measurements indicate that individual threads of prominence material are sheathed by a transition layer with a thickness comparable to that above the quiet chromosphere, and that a magnetic field perpendicular to the temperature gradient prevents conductive flux into the core from exceeding radiative losses from the core. The individual prominence threads are very narrow, a few arc sec or less. Hence high spatial resolution, an arc sec or better, is required to resolve individual threads. XUV measurements of the intensities and diameters of individual threads will yield vital information about the physical conditions in the cool core of the threads and the transition sheath between the cool core and hot surrounding corona. Simultaneous measurements of the prominence magnetic fields with, for example, an H$\alpha$ magnetograph, is also important. The study of prominence structures would be an excellent candidate for joint observations by this facility and a high resolution visible light system such as SOT.

By using high spatial resolution EUV and XUV observations in a variety of lines, the radial and axial variations of temperature and density and the conductive and radiative fluxes can be determined for individual threads. Measurements of the temporal variations of emissions from individual threads and the soft X-ray emission of the surrounding corona are needed to develop a self-consistent model, making possible a detailed understanding of how a prominence interacts with its surroundings. Because of its capabilities of monitoring plasma temperatures ranging from $10^4$ to $10^6$ K, EUV, XUV and soft X-ray instrumentation provide unique capabilities for studying this problem. The spatial resolution of the data acquired by ATM is generally inadequate to resolve individual threads of prominence material. With spatial resolution nearly an order of magnitude better, these facility telescopes could provide a substantial advance in observing capabilities for prominence studies.

EUV and XUV spectrometers with sufficient spectral resolution line profiles and/or measure Doppler shifts will make it possible to measure the effects of mass motions for material at temperatures intermediate between coronal and chromospheric temperatures. Clearly, measurements of intensities, line profiles, and Doppler shifts for a range of spectral lines covering the temperature range $10^4$ to $10^6$ would yield considerable insight with regard to the dynamics and physical conditions in prominences and how prominences interact with their surroundings.

### 3.4. Physical Processes in Flares

Solar flares are of fundamental importance as examples of high energy astrophysical phenomena. The proximity of the sun yields a tremendous advantage for detailed studies of the electromagnetic and particle emissions that characterize the energy release processes. Solar flare observations have been carried out over a large dynamic range of the electromagnetic spectrum from kilohertz frequencies to gamma rays. In addition, nonthermal partical fluxes from flares have been measured in the interplanetary medium and their characteristics related to the observed characteristics of the flares themselves.

Observations with the EUV, XUV and soft X-ray Telescope Facilities will enable us to study the corona and transition region where the flare energy is thought to be released. The magnetically confined loop structures that constitute flares are presumed to be preexisting entities. Observations of these pre-flare loop structures should yield insights into the conditions required for the flare process. Combined observations of the photospheric magnetic field and active region coronal structures should be a powerful tool to seek the flare "trigger". It has been suggested that regions of emerging magnetic flux will, under appropriate circumstances, give rise to flares. Such observations will allow us to follow the history of new flux regions and their relationship to active region loops. The temperatures and densities can be determined for flare loops before and during the critical rise phase by observations of appropriate spectral lines. Other aspects of the physics of flares (heating by nonthermal particles, mass transfer in flare loops) have been discussed above. It suffices to say that the availability of coronal and transition region observations of unprecedented spatial and temporal resolution should provide key plasma parameters and lead to new insights for flare models.

## 4. SUMMARY

The Facility Definition Team recommends development of three facilities to provide optimum coverage of the spectral range from 1.8 to 1200 Å in order to take maximum advantage of the plasma diagnositic information provided by the spectral lines and continua found there. The Soft X-Ray Telescope Facility is optimized for imaging hot coronal and flare plasmas while still having good performance for spectroscopy of hot plasmas ($10^6<T<10^8$ K). The XUV facility is optimized for high wavelength resolution spectroscopy of the coronal plasma using the powerful plasma diagnostic capabilities of XUV spectral lines. The EUV Telescope Facility will provide the highest spatial resolution ($\lesssim$ 0.3 arc sec) in coronal resonance lines, as well as excellent coverage of spectral lines and continua formed in the chromosphere and transition region.

These facilities can probe the plasma dynamics and energetics of the upper solar atmosphere in unprecedented detail and provide critical measurements needed to address fundamental problems involving the flow of mass and energy in the solar atmosphere. Lines and continua found in the spectral regions accessible to these instruments cover a broad range of temperature, spanning four decades, $10^4$ to $10^8$ K. Each facility is an extremely powerful, versatile instrument for investigating the physics of the solar atmosphere. However, the scientific capability of each is strongly enhanced when operated simultaneously with one or more complementary solar facilities or PI instruments. Many solar phenomena are of short duration and have manifestations at photospheric, chromospheric and coronal levels. Furthermore, mechanisms believed to be responsible for plasma heating, solar wind acceleration and transport of mass, momentum and energy have characteristic temporal scales of seconds to minutes. Consequently, there is a critical need for probing simultaneously or nearly simultaneously a wide range of heights and plasma temperatures. For example, the Solar Optical Telescope and Soft X-Ray Telescope provide a powerful combination for studying the photospheric, chromospheric and coronal plasmas in coronal structures whose feet are rooted in the photosphere. Similarly, the Solar Optical Telescope and EUV Telescope provide a powerful package for achieving the highest possible spatial resolution at photospheric, chromospheric and coronal heights. Ultimately, the objective is to combine several facility class and PI instruments on a platform such as the proposed Advanced Solar Observatory.

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