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NASA TECHNICAL MEMORANDUM

NASA TM X-64805

(NASA-TM-X-64805) CONCEPTUAL DESIGN OF THE SCIENTIFIC INSTRUMENT ARRANGEMENT FOR THE LARGE SPACE TELESCOPE (NASA) 28 p HC $3.50 CSCL 20F

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CONCEPTUAL DESIGN OF THE SCIENTIFIC INSTRUMENT ARRANGEMENT FOR THE LARGE SPACE TELESCOPE

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February 13, 1974

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. NASA TM X-64805	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Conceptual Design of the Scientific Instrument Arrangement for the Large Space Telescope		5. REPORT DATE February 13, 1974
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) J. Zurasky and D. Korsch*		8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D.C. 20546		13. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Prepared by Astrionics Laboratory, Science and Engineering.
*Employed by Space Support Division, Sperry-Rand Corp.

16. ABSTRACT

This report documents the work of the Astrionics Laboratory, Technology and Electromechanical Engineering Divisions (S&E-ASTR-R and M), at the Marshall Space Flight Center in support of the Large Space Telescope Working Group (LSTWG). A description of the Scientific Instrument arrangement for the Large Space Telescope (LST) is given, with some of the rationale for selecting this concept. The first section of this report, entitled Initial Design, describes the basic configuration and was designed for an f/20 telescope focal plane. The subsequent LSTWG meeting held in November gave some redirection to the scientific requirements, and these changes are described in the section, Configuration Update.

17. KEY WORDS	18. DISTRIBUTION STATEMENT James L Zurasky Unlimited - Unclassified

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	29	NTIS

MSFC - Form 3292 (Rev December 1972)

For sale by National Technical Information Service, Springfield, Virginia 22151

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INTRODUCTION

The Phase A report generated for the Large Space Telescope (LST) included a conceptual design for the Scientific Instruments (SI) that had in many ways overlooked basic parameters that would help optimize the performance. As part of the Science, Engineering and Integration (SE&I) Phase B LST effort, S&E-ASTR-(RPO & M) was directed to develop a configuration that would optimize the Scientific Instrument complement. This report is considered to be an interim report which documents our efforts between August and December 1973.

INITIAL DESIGN

Basic Guidelines

A perusal of the LST Phase A, Volume 4, report indicated that some basic design parameters for the Scientific Instruments had been overlooked. These were:

a. Provide autonomous instruments.

b. Decrease alignment sensitivities.

c. Decrease number of reflections.

d. Decrease instrument sizes.

e. Optimize accessibility.

f. Increase growth potential.

g. Use standard components where possible.

[redacted]

Instruments

The Phase A guidelines document listed the possible instrument candidates for the LST. The highest priority instruments were:

a. An f/96 relay for the high resolution camera.

b. Two (2) high resolution spectrographs.

c. Three (3) faint object spectrographs.

As a result of the August LSTWG and Instrument Definition Team (IDT) meetings, this preferred instrument group was expanded to include two more instruments. These were:

a. An astrometric instrument.

b. An infrared instrument.

LSTWG Suggestions and IDT Critical Design Goals

This group requested that the primary telescope focal ratio be increased from f/12 toward a goal of f/24. This would increase the physical size of the primary focal plane and thus allow more instruments access to the diffraction limited field.

In addition, some of the IDT's listed critical design goals for their instruments.

For the High Resolution Camera (HRC) team these were:

a. Match the relay obscuration to the telescope obscuration.

b. Develop a flexible design which can be easily modified for use with improved detector resolution and increased field size.

For the High Resolution Spectrograph (HRS) team these were:

a. Develop a flexible design for varying resolution requirements.

b. Design toward a spectral resolution ($\lambda/\Delta\lambda$) of 3×10^5.

c. Include an adjustable slit mechanism (width, height, orientation).

And for the Faint Object Spectrograph (FOS) team these were:

a. Minimize the number of reflections.

b. Include an adjustable slit mechanism (width, height, orientation).

Instrument Complement Analysis

The desired instrument complement was analyzed to determine the scientific requirements. These requirements would then dictate the design of the scientific instruments which would then in turn influence the requirements to be achieved by the telescope.

Two instruments dictated the most critical design requirements. The high resolution camera re-imaging optics were to have a final focal ratio of f/96, a 50 mm square focal plane, a total length of approximately 2.5 meters and be all reflective. This could be accomplished by use of a Martin relay consisting of an ellipse and fold flat (figure 1). Parametric tradeoffs for the HRC under these guidelines were made with the following results:

a. The critical distance from the telescope focal plane to the elliptical mirror increases with increasing telescope f/#.

b. The total length of the relay is approximately constant for all f/#'s if reasonably sized components are to be used.

The high resolution spectrograph resolution ($\lambda/\Delta\lambda$) requirement goal of 3×10^5 dictates that the beam size incident at the dispersing element must be 3 cm, assuming a blaze angle of 80.5° for the echelle grating. This requirement demands that the distance from the telescope focal plane to the collimator be increased with increasing telescope f/#.

Telescope Analysis

A parametric study of the telescope focal plane as a function of f/# was performed to ascertain the diffraction limited field size. Two basic parameters were used for this analysis. They were:

a. Intravertex distance (primary to secondary) $\leq$ 6.5 meters.

b. Back focal length $\approx$ 1.5 meters.

Using these parameters, the following results were obtained:

a. The diffraction limited angular field size remains constant for focal ratios between f/12 and f/24.

b. The physical size of the focal plane increases with increasing f/#.

f/# and Instrument Complement Selection

After consideration of these results, a reasonable trade was concluded to be a telescope focal ratio of f/20. This value gives adequate spatial area at the focal plane to include the suggested instrument complement and would hopefully not overtax the structural and thermal support systems.

For this focal ratio the instrument group depicted in figures 1-4 was selected as representative of what could be used to satisfy the IDT's and the LSTWG. No instrument had been suggested for the infrared, so only an access to a portion of the telescope field satisfying its resolution requirements has been provided.

Structural Support System

Autonomy for this report was established as operational autonomy instead of complete autonomy. This meant that each scientific instrument had its own optical elements whose failure would in no way jeopardize the other instruments. With this as a guideline, the support structures were then designed with the possibility of a single support being used to attach optical elements for several different instruments. This meant that partial instrument changes could be made, and the degree of difficulty in making this change was dictated by the portion being altered. Some portions are capable of being changed by EVA while other changes require earth return. Those changes that can be made during EVA were designed with a forgiving alignment tolerance.

The primary focal plane aperature fold flat and elliptical mirror for the relay microscope along with the slit mechanism and collimating mirror for each spectrograph were designed into a rigid unit, firmly attached at the primary focal plane (figure 5). This unit would only be serviceable as a major focal plane alteration after earth return. The remaining portion of each instrument would interface with the optical bundle of collimated light at these points. In this way, interface alignment tolerances were such that these subunits consisting of the gratings and detectors could be easily interchanged by an EVA.

At this point, the instruments were integrated into a package (figures 6 and 7). A slit-jaw mechanism which varied all spectrograph apertures simultaneously was also designed (figure 8).

Alignment and Stability Tolerances

The only instrument that had been designed in sufficient detail to calculate an alignment and stability tolerance for was the high resolution camera. To simulate a tolerance guideline for the structural and thermal analysis that was to follow this activity, the following budget was calculated (figure 9):

Alignment tolerances

$$2.85 \mid \Delta Z_1 \mid +2 \mid \Delta Z_2 \mid + \mid \Delta Z_3 \mid \ +2.5 \times 10^4 \ \mu m \mid \Delta\alpha 3 \mid \leq 150 \ \mu m$$

where

$\Delta\alpha$ is given in radians

ΔZ is given in μm

ΔR is given in μm

and

$$\Delta\alpha_1 = \pm 3 \times 10^{-4} \text{ rad}$$

$$\Delta\alpha_2 = \pm 3 \times 10^{-4} \text{ rad}$$

During an exposure, in addition to the alignment tolerances, the following stability had to be maintained:

$$3.85 \mid \Delta R_1 \mid +6 \times 10^6 \ \mu m \mid \Delta\alpha_1 \mid +5.5 \times 10^6 \ \mu m \mid \Delta\alpha_2 \mid + \mid \Delta R_3 \mid \leq 3 \ \mu m$$

where

$$\Delta R^2 = \Delta X^2 + \Delta Y^2$$

THE NOVEMBER 1973 LSTWG MEETING

The focal plane arrangement developed by MSFC was presented to the LSTWG at their November meeting. The group accepted the concept as a very good tutorial exercise for the exact complement of instruments selected before this exercise. Individual instruments were positioned and surrounded in such a way that very little space was provided for subsequent change or improvement.

Another weak point of this concept was the difference in the definition of the word autonomous between them and MSFC. They wanted each instrument to be both structurally and operationally autonomous. This meant that each instrument should be packaged in such a way that all its components could be interchanged as a single unit, and this alteration would have no effect on the other instruments.

This meeting also produced some alterations in the basic instrument priorities. The new instrument complement was:

a. f/24 camera.

b. Two (2) faint object spectrographs, each with a verification camera.

c. Two (2) high resolution spectrographs.

d. Astrometric device.

e. Infrared device.

CONFIGURATION UPDATE

Focal Plane Arrangement

As a result of the November LSTWG meeting, it was decided that the telescope focal ratio should be set at f/24. This would mean that no relay optics would be needed for the f/24 camera.

Initial investigations outlined the spatial sizes of the diffraction limited field as a function of wavelength. These results were:

WAVELENGTH		RATIOS		
a. 0.5 μm	≈	4.2 arc min.	=	88 mm
b. 1.0 μm	≈	5.7 arc min.	=	120 mm
c. 2.0 μm	≈	7.4 arc min.	=	155 mm

The instruments were then placed to show that they could access an area of the focal plane demanded by their resolution requirements (figure 10).

The f/24 camera has been designed to image a 2 arc min. square field. This is an area of 42 mm square in the center of the focal plane. Placing the fold mirror for this instrument 24 cm in front of the telescope focal plane yields a shadow of 62 mm square. This area is then inaccessible to any other instrument.

Also included at 24 cm in front of the focal plane is the fold flat for the 3 arc min. square field for the infrared instrument. This mirror casts a shadow of 83 mm square centered 120 mm from the optical axis.

Located in the f/24 focal plane is the astrometric modulator. This device is designed to access a 5 arc min. field. It physically occupies an area from 2 arc min. to 7 arc min. off-axis or 52.5 mm radius centered 94.5 mm from the optical axis. At this position, the resolution at the outside of the field matches the 0.1 arc sec. required for the instrument.

Spaced around and between these instruments are access areas for two faint object spectrographs, two high resolution spectrographs and another instrument.

Structural Concept

A conceptual support structure has been designed. This concept has been developed for completely autonomous instruments and for both axial and radial instrument compartments. Each instrument can be interchanged with no effect on the others, and has been allotted a volume of sufficient size to permit almost any forseeable alteration to be made (figures 11-16).

Advantages and Constraints

This arrangement of instruments has been designed to operate in the following manner.

The f/24 camera can be operated alone or in a serendipity mode in conjunction with any other instrument. The other instruments will be used serially. The verification sensor included in the FOS package will be used to insure that the desired object is in the slit before the spectrogram is made. Each spectrograph will have three slit sizes whose exact dimensions have not yet been determined. The undefined instrument has now been designated as the area photometer suggested at the December meeting of the LSTWG (figure 17).

CONCLUSIONS

While this focal plane scientific instrument arrangement does not represent an optimized system for the LST, it is felt that there are many advantages. The most important asset is its ability to accept change. The basic configuration was altered from an f/20 telescope focal plane, with integrated optical components to an f/24 telescope focal plane, with autonomous components and instruments. At the same time, one of the basic instruments was changed from a high resolution camera at f/96 to an imaging device at f/24.

The basic goals for this design have been met and the operational and scientific requirements can be achieved.

Work is continuing on the latest concept to develop a tolerance budget, which will be subjected to structural and thermal analyses to insure that overall system requirements can be attained.

The instruments included in this document depict the current LSTWG concensus. Alteration to this basic configuration will be made as this group changes their scientific requirements and objectives.

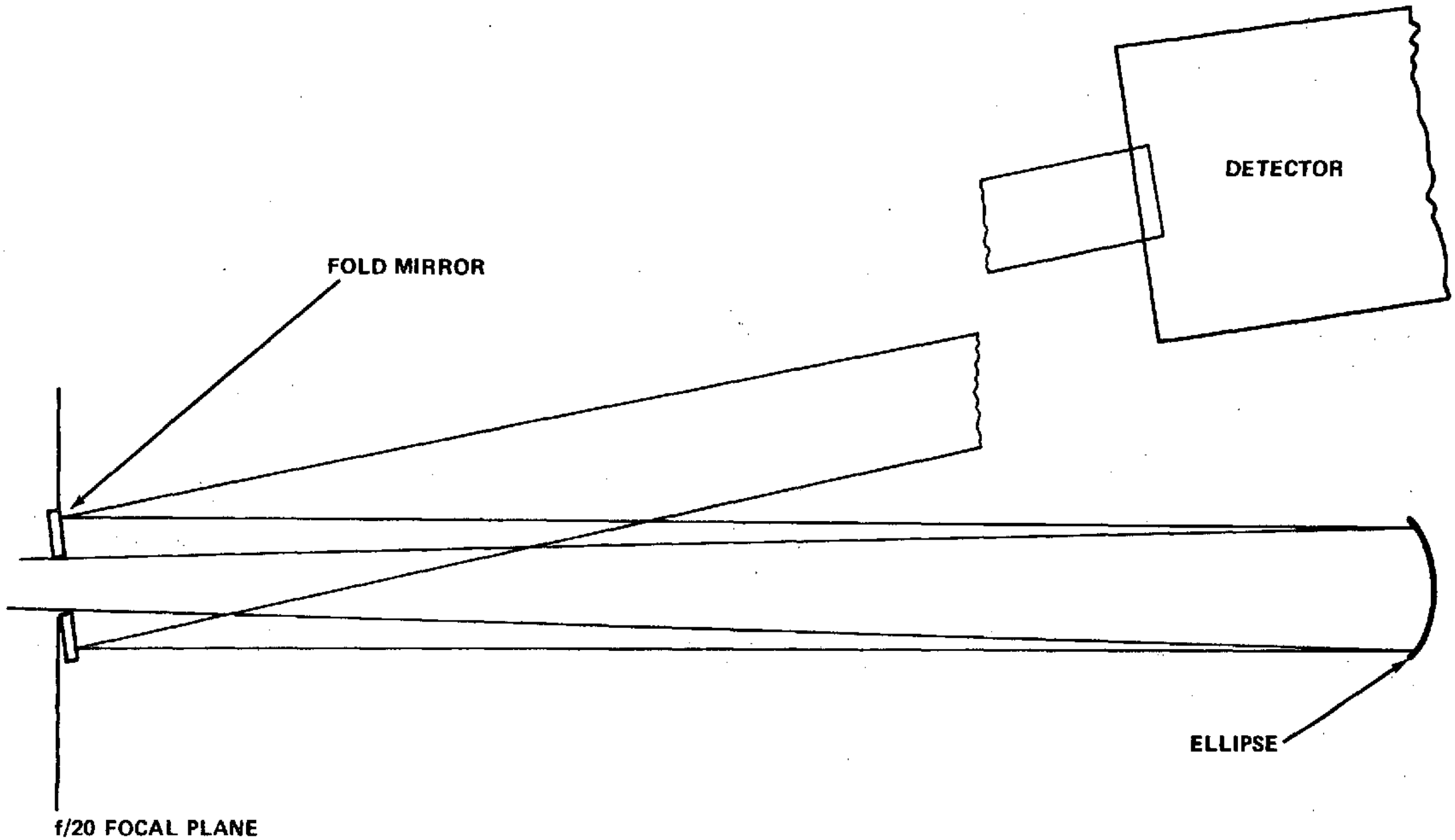


Figure 1. Martin relay.

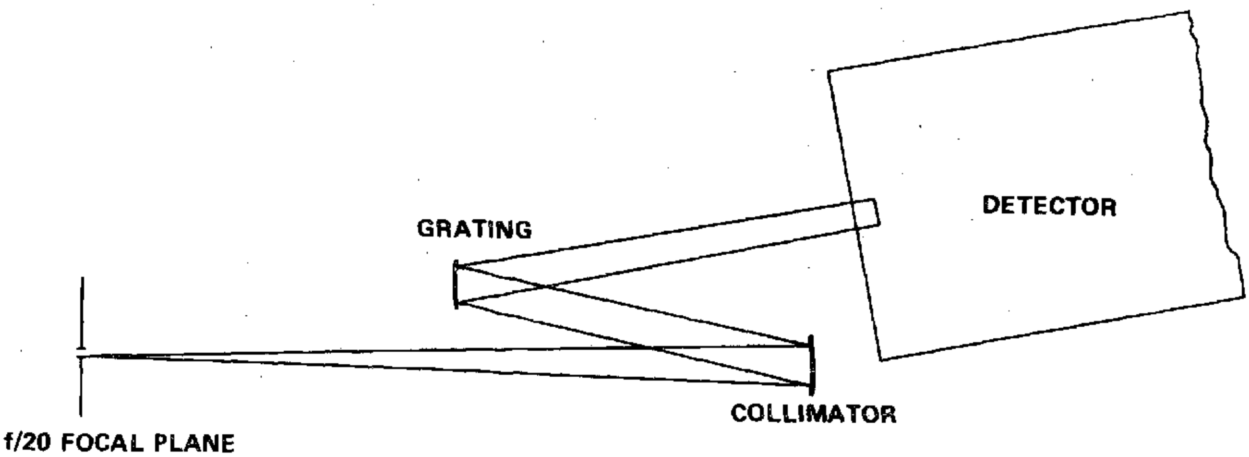


Figure 2. Faint Object Spectrograph.

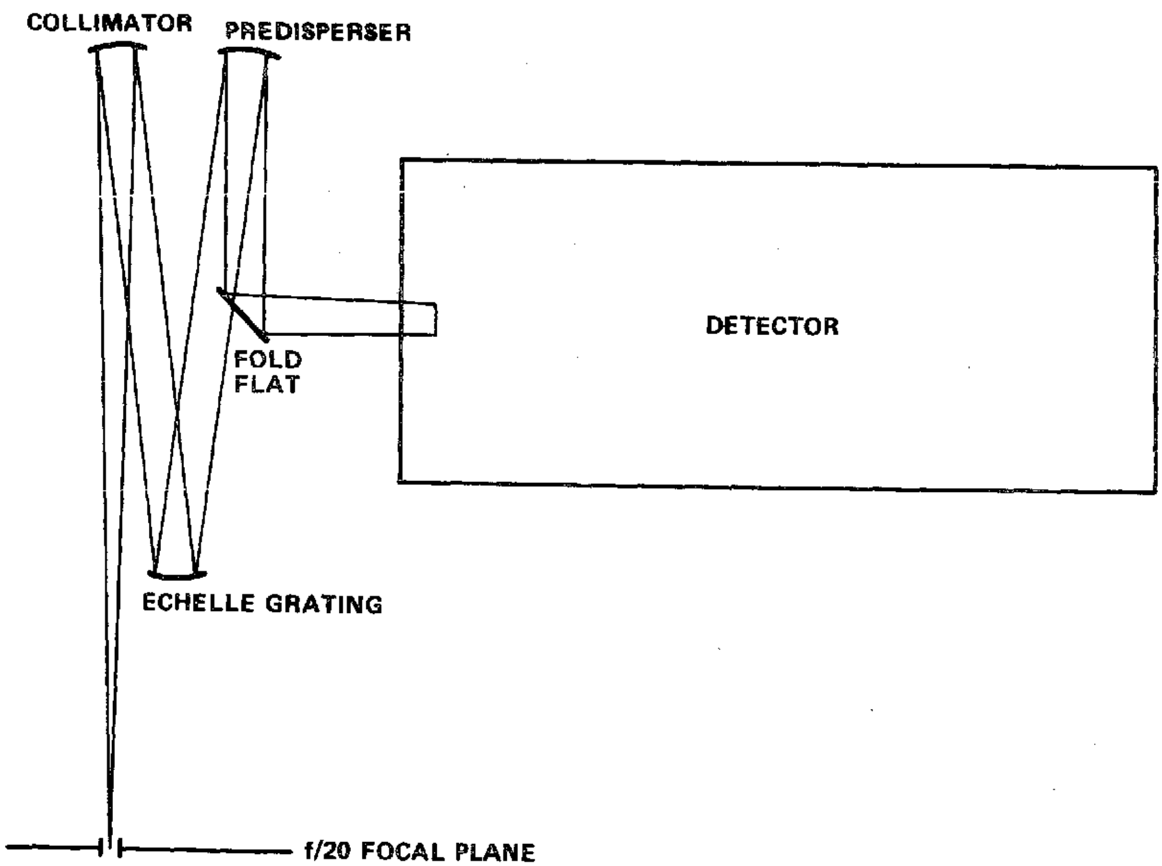


Figure 3. High Resolution Spectrograph.

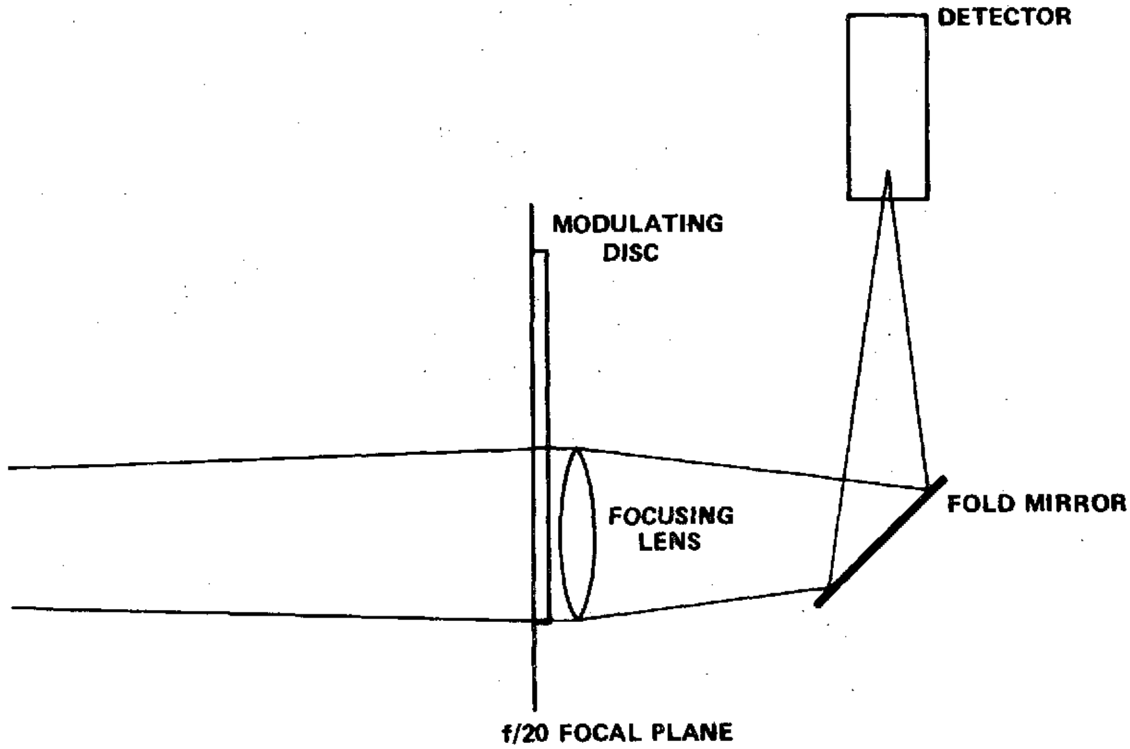


Figure 4. Astrometric device.

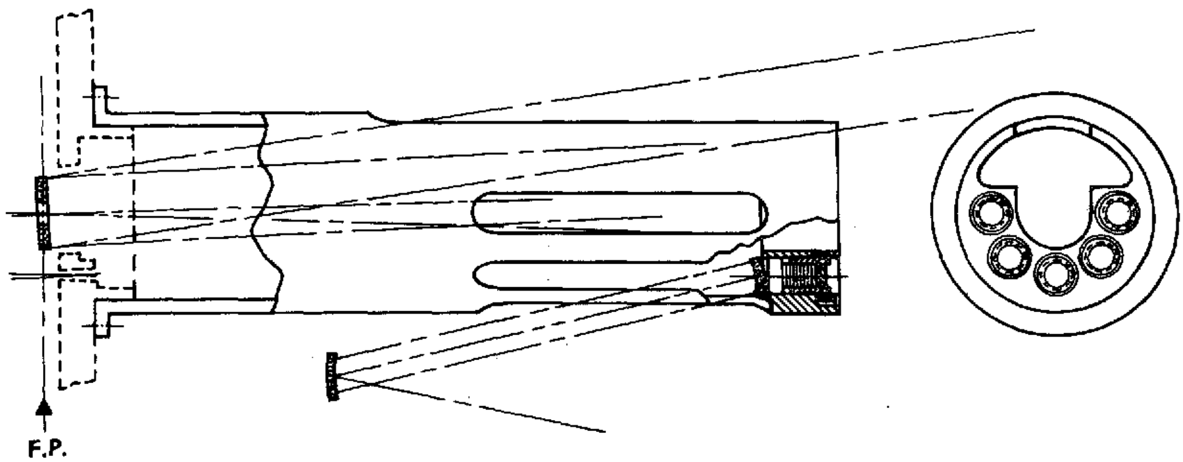


Figure 5. f/20 collimator adapter.

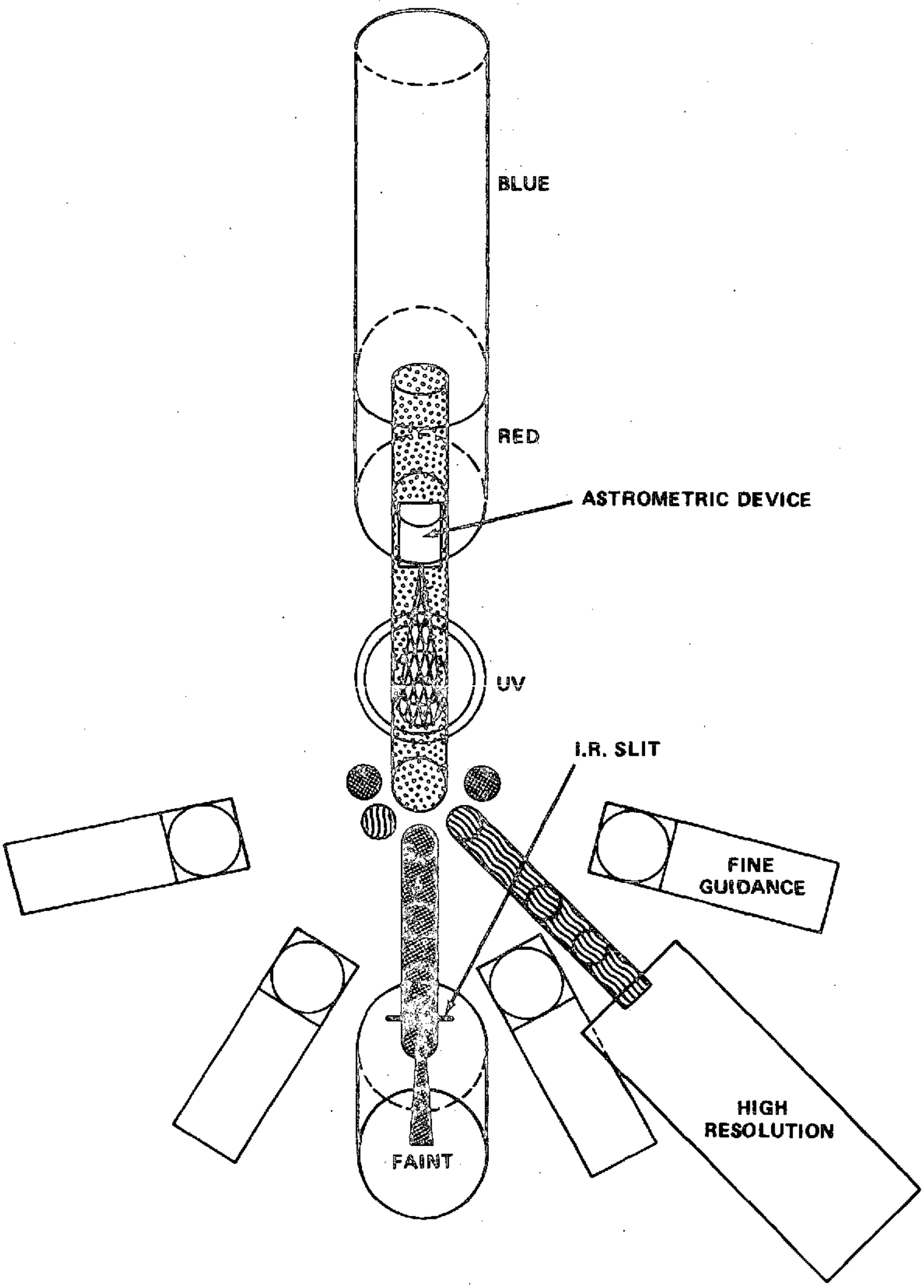


Figure 6. f/20 focal plane concept (axial view).

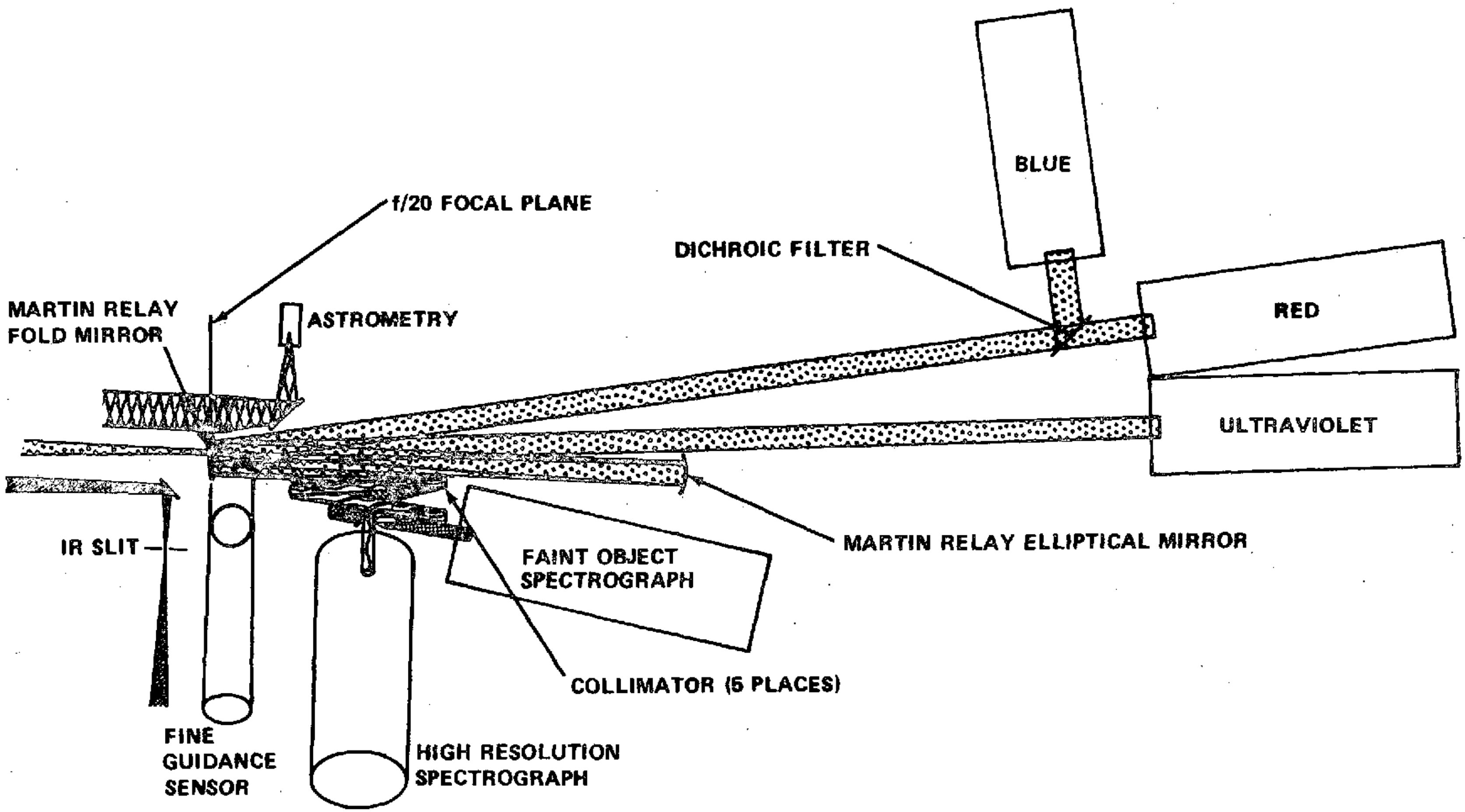


Figure 7. f/20 focal plane concept (radial view).

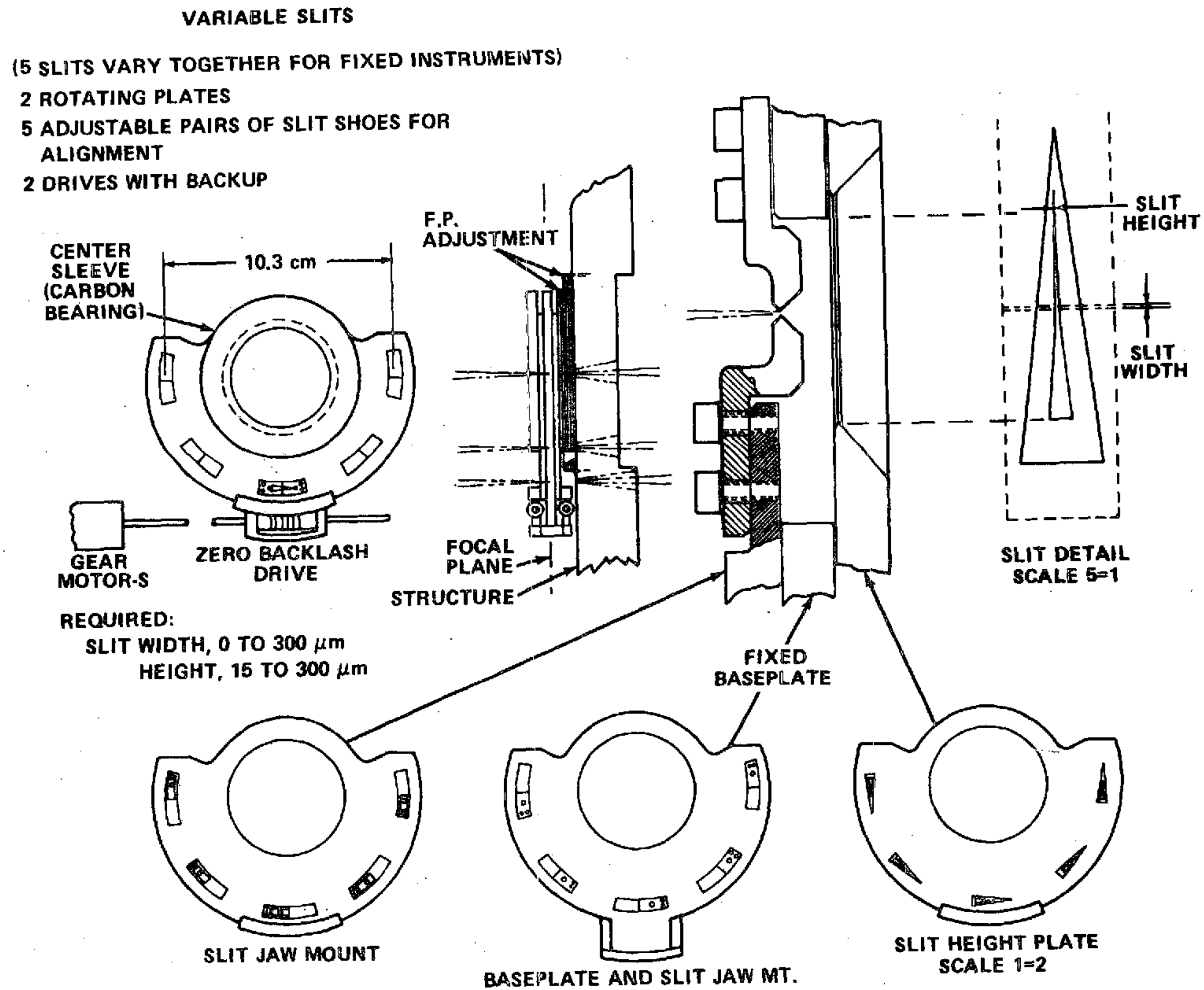


Figure 8. f/20 slit mechanism.

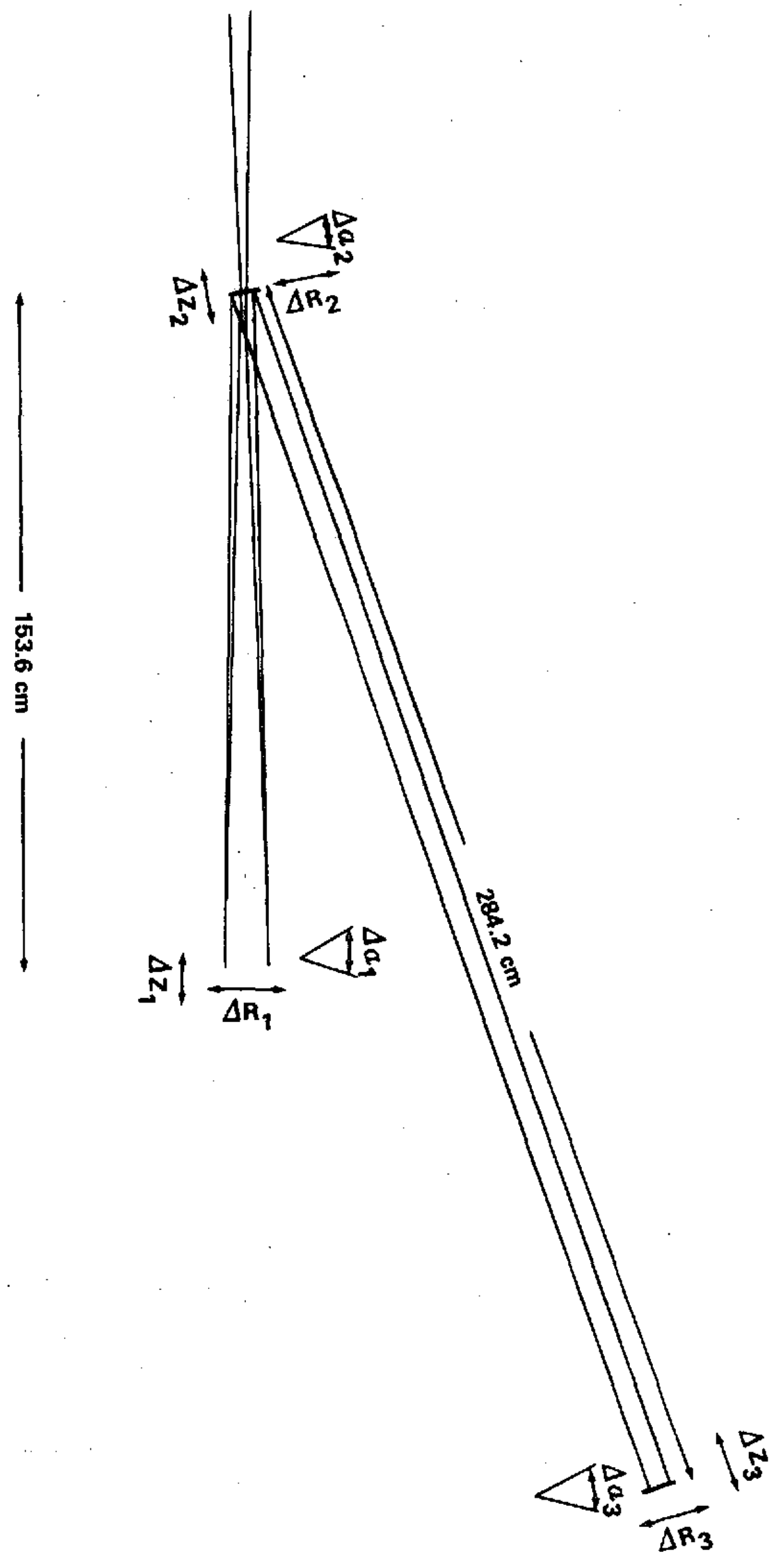


Figure 9. f/20 to f/57 High Resolution Camera relay optics.

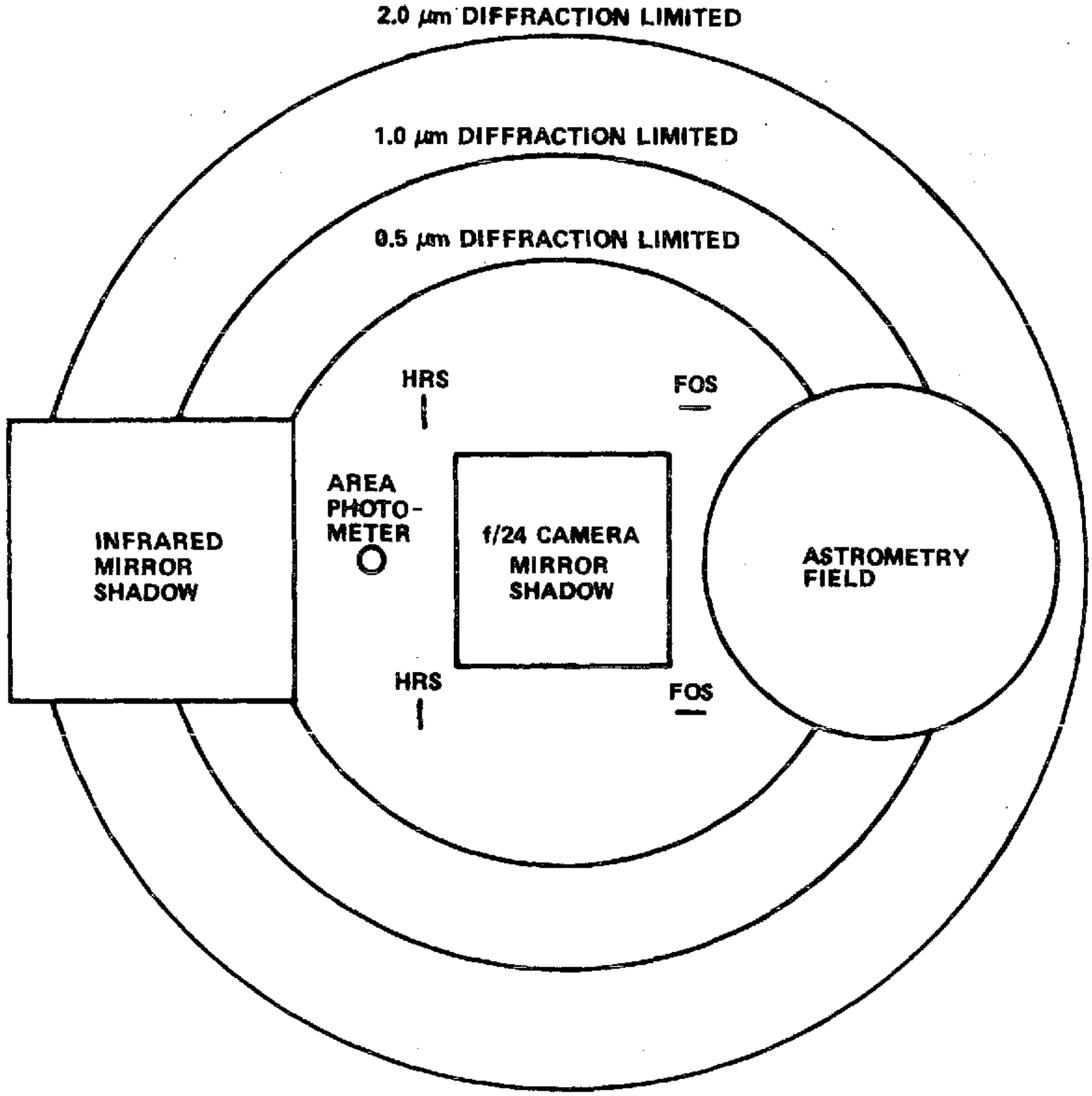


Figure 10. f/24 focal plane spatial layout.

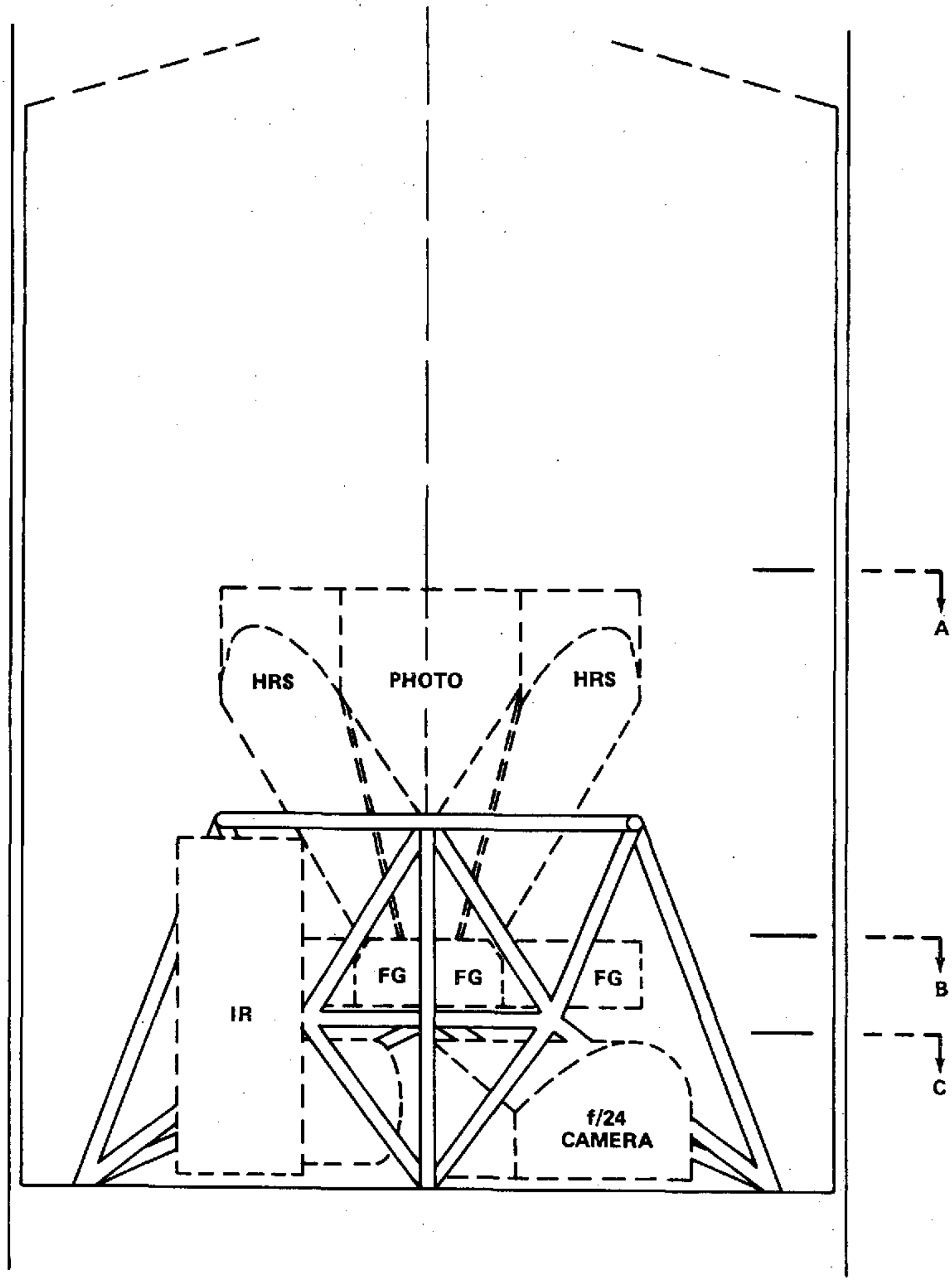


Figure 11. f/24 SI volume focal plane concept (radial view).

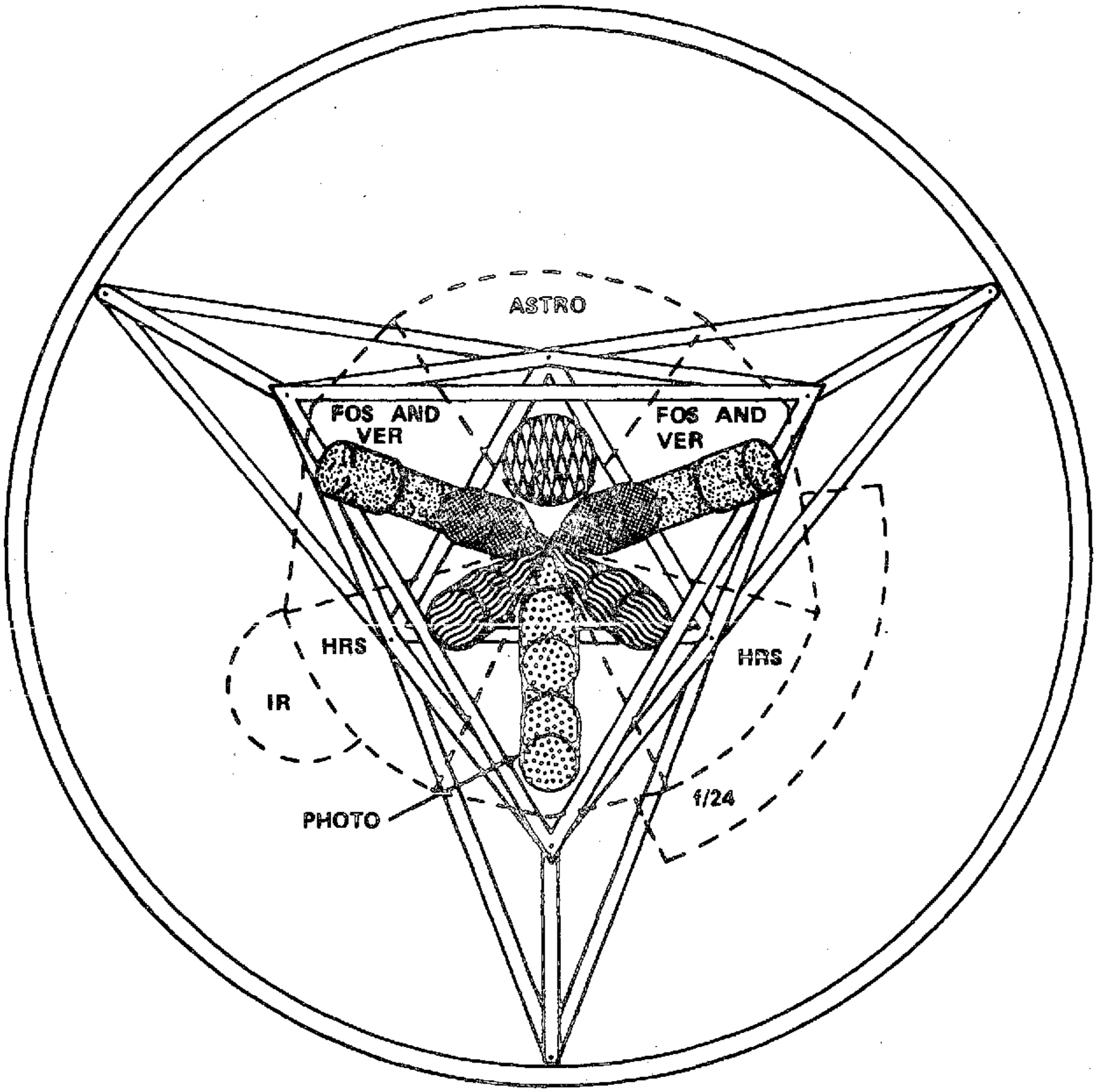
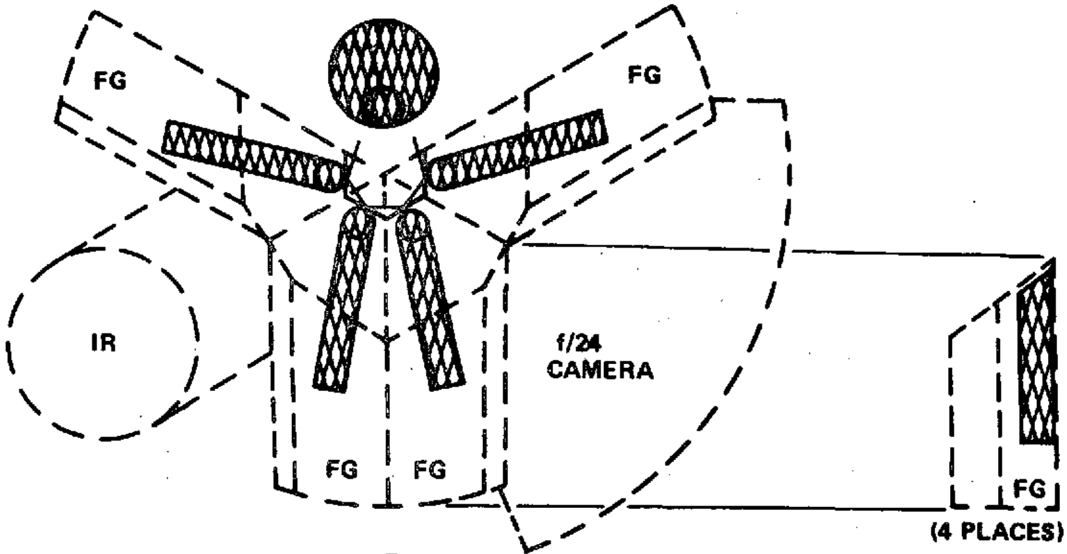
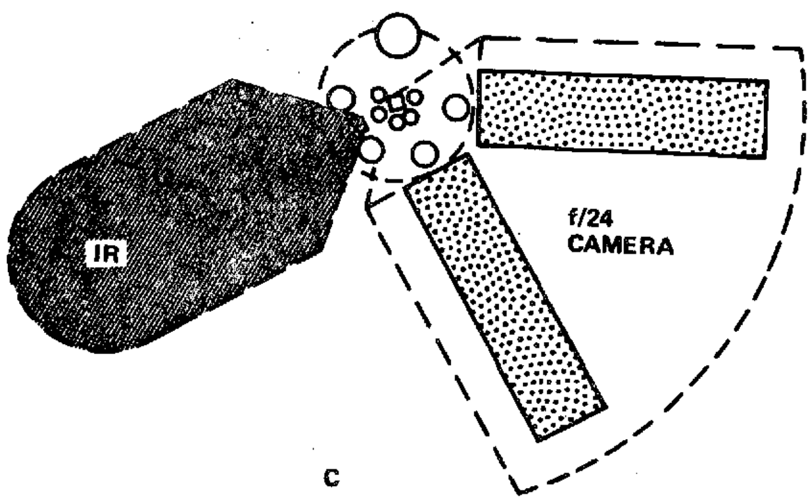


Figure 12. f/24 SI volume focal plane concept (axial view).

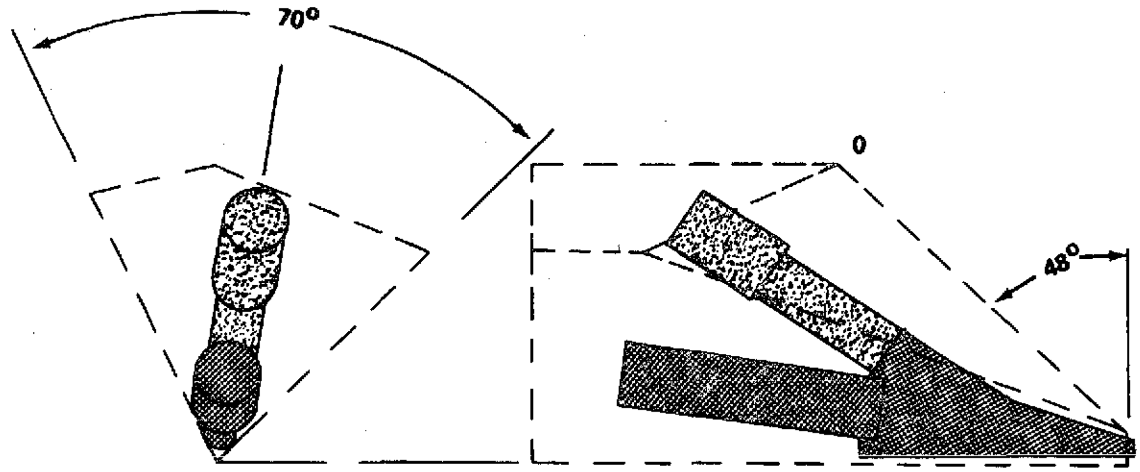


B

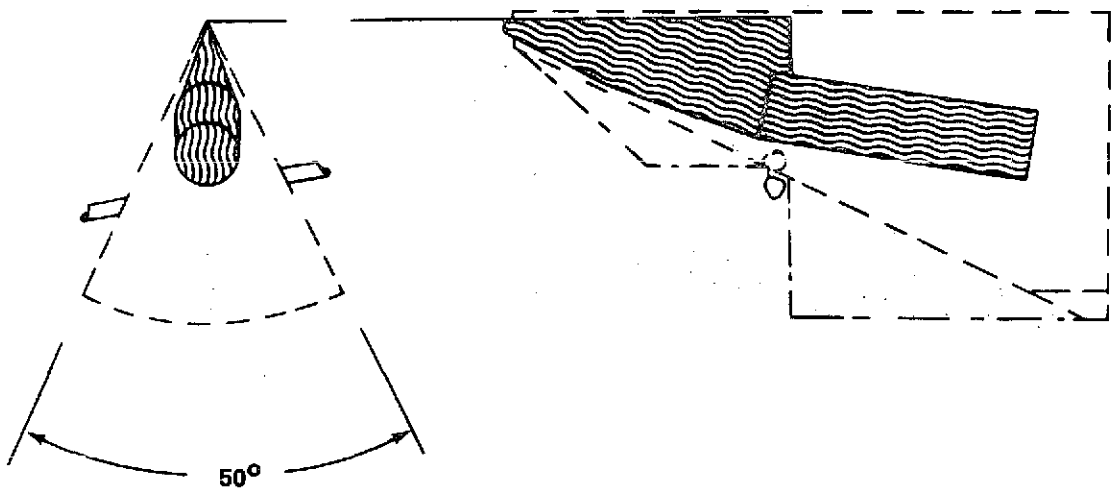


C

Figure 13. f/24 SI volume focal plane concept
(B and C axial views).

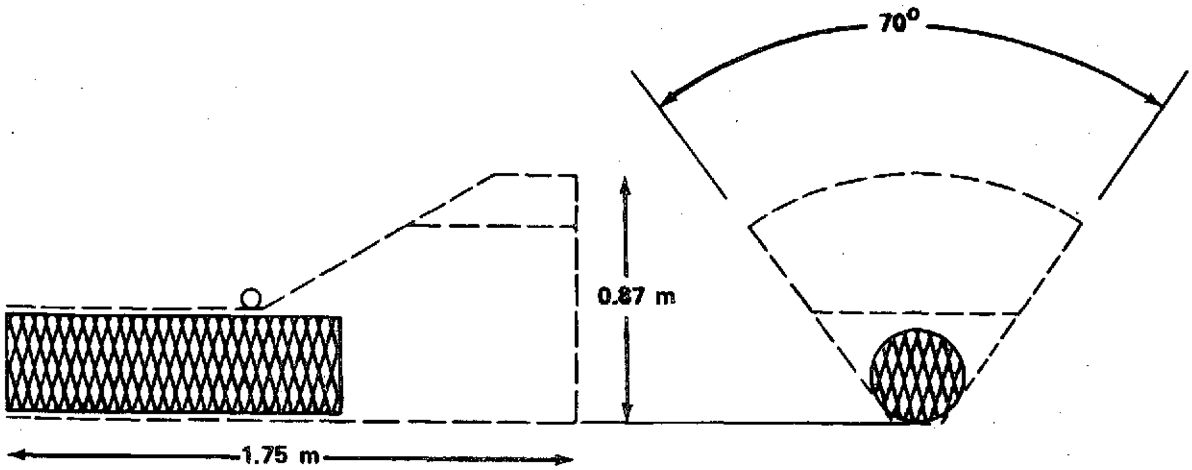


a. Faint Object Spectrograph and verification camera.

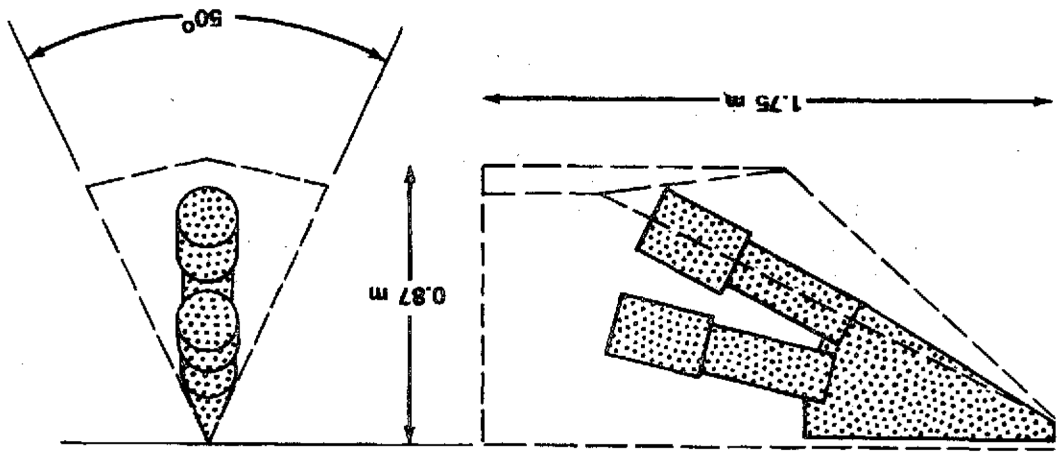


b. High Resolution Spectrograph.

Figure 14. FOS and HRS volume and conceptual instrument.



a. Astrometric device.



b. Area photometer.

Figure 15. Area photometer and astrometric device volume and conceptual instrument.

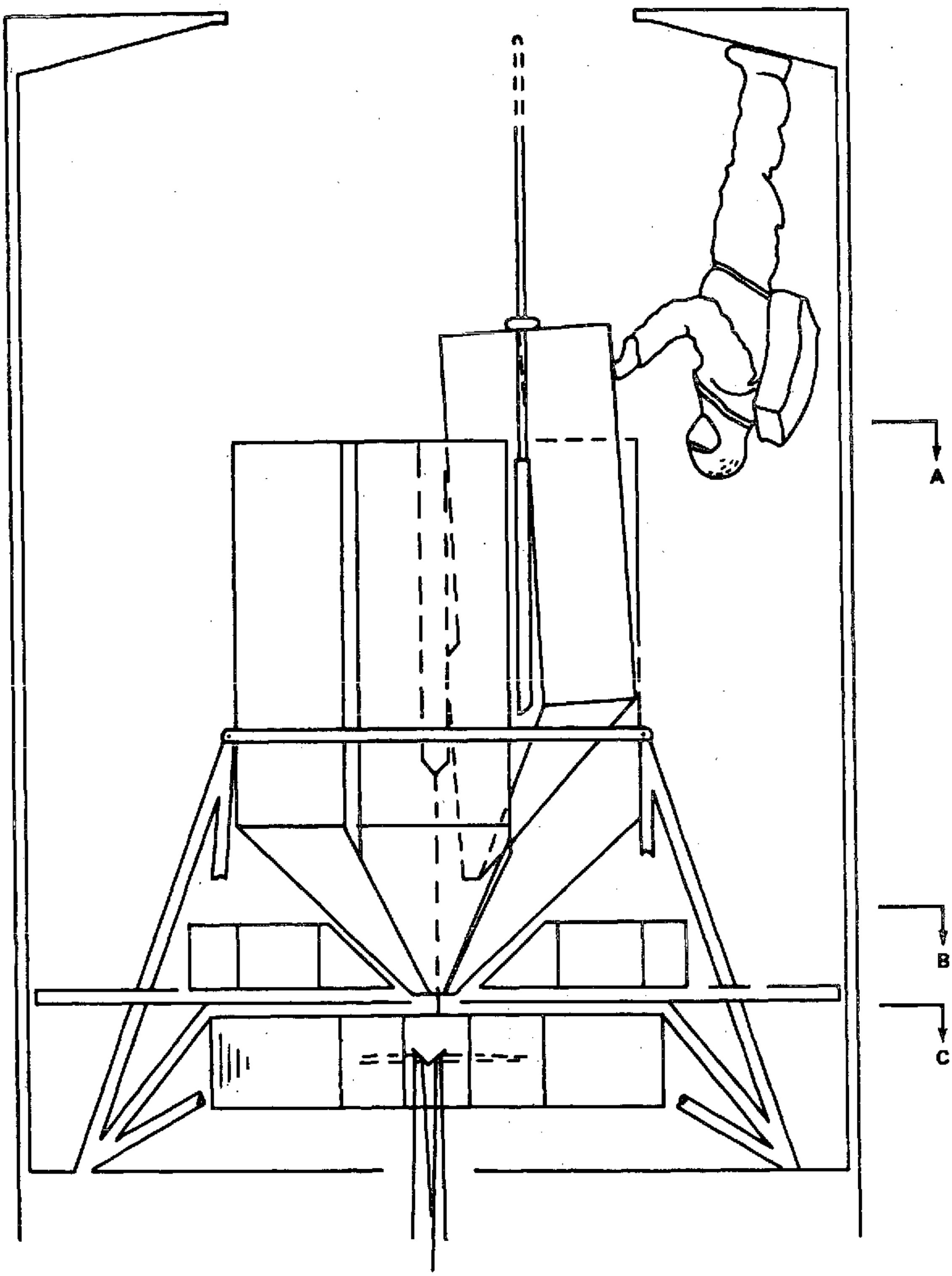


Figure 16. Instrument exchange.

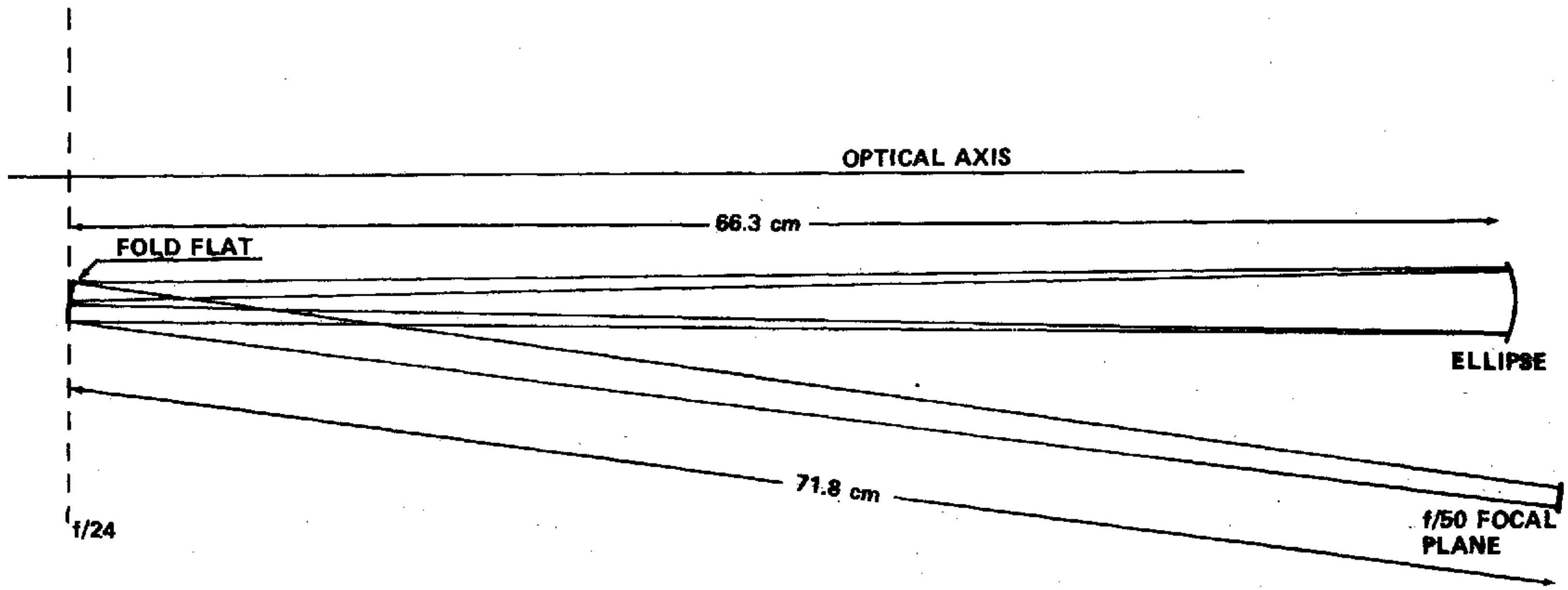


Figure 17. Area photometer f/24 to f/50 Martin relay.

APPROVAL

CONCEPTUAL DESIGN OF THE SCIENTIFIC INSTRUMENT ARRANGEMENT FOR THE LARGE SPACE TELESCOPE

By J. Zurasky and D. Korsch

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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