'EIT' – SOLAR CORONA SYNOPTIC OBSERVATIONS FROM SOHO
WITH AN EXTREME-ULTRAVIOLET IMAGING TELESCOPE

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ABSTRACT

The Extreme Ultraviolet Imaging Telescope (EIT) will provide full disk images in emission lines formed at temperatures that map solar structures ranging from the chromospheric network to the hot magnetically confined plasma in the corona. Images in four narrow bandpasses will be obtained using normal incidence multilayered optics deposited on quadrants of a Ritchey-Chretien telescospe. A rotating mask, will allow the image from each single multilayer to reach alternatively the CCD detector, in order to sharply image distinct solar structures that normally coexist in the temperature range from 6×10^4 to 3×10^6 K. The EIT is capable of providing a uniform one arc second resolution over its entire 50 x 50 arc min field of view. Data from the EIT will be extremely valuable for identifying and interpreting the spatial and temperature fine structures of the solar atmosphere. Temporal analysis will provide information on the stability of these structures and identify dynamical processes. EIT images, issued dayly will provide the global coronal context to aid in unifying the SOHO/CLUSTER investigations and in forming the observing plans for SOHO coronal instruments.

1. SCIENTIFIC OBJECTIVES AND CAPABILITIES

1.1   Introduction

With the Extreme Ultraviolet Imaging Telescope (EIT) we wish to elicit coordinated studies, crucial to unify two closely related solar phenomena : coronal heating and solar wind acceleration. Using remote sensing techniques, we shall evaluate quantitatively the contribution of different coronal mechanisms to global balances.
The corona will be observed, on the disk, through the emission of selected XUV spectral lines produced in the appropriate temperature range. Two dimensional images taken at a selectable temporal sampling rate will reveal the topography and dynamics of magnetically constrained structures which play a dominant role in coronal physics.
Detailed kinematic analysis will differentiate steady state processes, such as wave propagation and dissipation in the solar atmosphere, from cataclysmic events due to congenital magnetic instabilities or chance encounters between magnetic structures, leading to reconnections.
EIT will routinely survey the entire portion of the solar corona visible from the Lagrange point, providing a perquisite data base for in-situ solar wind measurements.
Sizeable solar portions of particular interest will be monitored at a rate adequate to establish the time scale and balance of the principal identified mechanisms. It will be possible to determine the rate of occurence of the most significant types of events and infer their cumulated contribution to heating and acceleration with the help of detailed empirical/theoretical analyses conducted in coordination with the high resolution narrow field spectrometers.
Observations outside the solar limb will contribute to understanding the structure of the distant corona (stable or transient) which will be observed in the plane normal to the sun/earth line by the LASCO and UVCS coronographs, thus bridging the gap between the lower corona and the solar wind.

1.2   Objectives and significant aspects

1.2.1   The solar corona.

Early models of the solar corona were based upon the simplifying concept of a spherically symmetric medium in which the temperature did increase monotonically as a function of height, reaching a maximum of several million °K. These models are invalidated by many theoretical and observational difficulties :
- They are not physically self consistent because the heat conduction flux from the corona to the lower solar atmosphere would be too high to maintain the hot corona.
- Spectroscopic observations have raised the issue that material at lower temperature can frequently overlay hot material.
- Images of the solar corona and transition region, have shown the extremely inhomogeneous structure of the corona, dominated by emitting plasma constrained in loops defined by magnetic flux tubes.
This led to the construction of models where the plasma expands from very constricted regions in the chromospheric network, into open or closed loops in the corona. [1]. Flows of material have also been considered as an additional transport mechanism [2]. The stability of magnetic loops themselves has been found to be questionnable : segregation between loops at different temperature has been predicted.Complex models in which interweaved open and closed structures would stabilize each other are now emerging [3]. Small scale relaxation

processes within stable loops which could thus emit a sizeable mean radiation field without self destruction have also been envisaged. Recent, but altogether too sparse, time resolved observations tend to emphasize possible large temporal variations within single loops or loops systems. [6]Temporal fluctuations in structures similar to X-ray bright points have been inferred from observations of SMM. The existence of very frequent hard X ray microflares has been reported from balloon observations. A prevalent downward velocity field is observed, at the transition region level, which must be compensated somehow by upward transport mechanisms in order to replenish the corona. These may be steady flows or of transient nature and thus difficult to observe. Velocities in the 100 km/sec range have been inferred from observations of polar plumes which seem to originate from X-rays bright points. Upward velocities in the closely related He dark points have been reported at temperatures as low as chromospheric CaII K. Numerous explosive events, involving motion of material at speeds in excess of hundreds of kilometers per second, have been observed with HRTS in the C IV transition region line. Models of diamagnetic plasmoids motions predict the possibility of such large acceleration [4]. Long duration dedicated measurements, at high spatial and temporal resolution, will be made available for the SOHO mission by EIT. A new picture of the corona dominated by the occurence of many small scale dynamic events might emerge. This would support the notion of a heating of the corona and generation of the solar wind via stochastic processes [5].

The origin of this suspected ebullient agitation lies in the lower atmosphere of the sun. Velocity and magnetic field measurements performed by the Michelson Doppler Imager compared to our coronal observations with the EIT should help to solve definitely the question.

1.2.2 Coronal balances and the solar wind.

Erratic solar events are statistically washed out when observed at approximately 0.99 AU by single point in-situ solar wind analyzers. Thus a global view of the sun is required to interpret solar wind data. Important solar parameters to monitor are the area of coronal holes and number of X-ray bright points emitting in the direction of the observer. Identification of travelling waves would be important.The structure inside the coronal holes must be observed and understood and the contribution of localized explosive events to the solar wind evaluated. This calls for global observations of all structures at a modest repetition rate but over a large temperature range. The EIT is well suited to study correlations between gradients of coronal parameters with altitude and solar wind composition variations. For this type of application EIT data may be averaged over the whole visible disk or over identified coronal holes. EIT observations will also provide clues to define the shape of magnetic field lines close to the sun and thus help to construct maps of the coronal magnetic fields (open or closed) in the corona.

1.3   Experimental approach

1.3.1   Nature of the observations.

EIT is a high resolution wide field telescope wich can obtain images of the corona on the disk and above

the solar limb. It will provide highly contrasted coronal images with an excellent dynamic range and adequate time resolution (as short as 10 sec) at a spatial resolution comparable to the best Skylab data. Individual coronal emission lines will be selected by appropriate interference coatings deposited on the mirrors of the telescope. As a baseline we propose to monitor four lines sensitive to coronal physical conditions in the temperature range $6 \, 10^4 - 3 \, 10^6 \, °K$. The three lines of ionized iron [Fe IX 171 Å, Fe XII 195 Å, Fe XV 284 Å] are among the most prominent coronal features of the solar spectrum. They are produced each in a different restricted temperature domain defined mainly by the ionization equilibrium of the corresponding ion. The relatively cool line of Fe IX should provide an extremely detailed image of the lower corona, even inside coronal holes. The He II line at 304 Å is produced at lower temperature in the transition region ($\approx 6 \, 10^4 \, °K$), however, it is sensitive also to coronal conditions (i.e. reduced emission in coronal holes).

1.3.2   Performances.

1) Image quality
EIT makes use of a normal incidence Ritchey-Chretien design for the telescope. This is optimal for wide field observations and will produce very concentrated spot diagrams for all points within a circular field of view 50 arc minutes in diameter.
The resolving power of the instrument will be limited by the detector format (1024 x 1024 pixels) which requires 3 x 3 arc second pixels in order to cover the square field of view 50 x 50 arc minutes wide illustrated in fig.1. The use of image processing techniques will make possible retrieval of the original image quality through ground based computations in those cases where the highest resolution (≈ 1 arc sec) proves to be necessary.
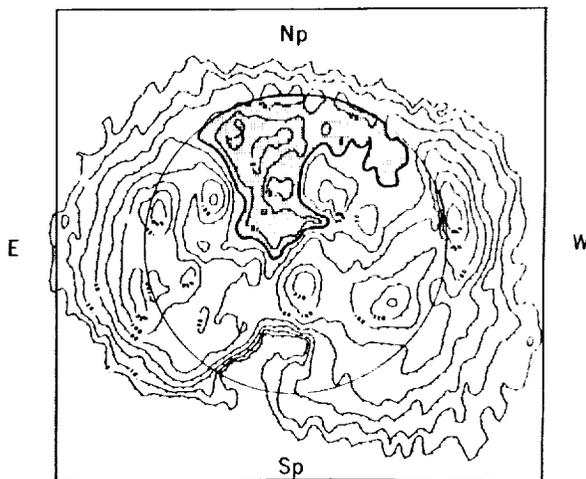

FIG. 1 : EIT Field of view compared to a Fe XV coronal image from OSO-7 (GSFC)

2) Bandpass
The narrow banpass selectivity in wavelength will be achieved through interference effects within layered synthetic materials (LSM) coating deposited on the primary and secondary mirrors.
Narrow bandpass will allow effective selection of the solar emission lines which we want to observe. The

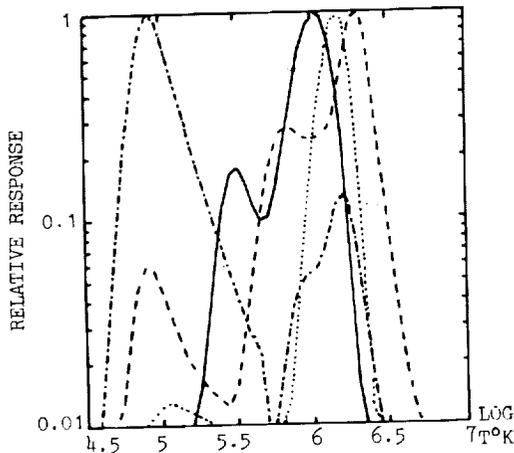resulting discrimination in the temperature domain is illustrated in fig.2.

FIG. 2 : Temperature domains observed
EIT bandpasses 304 —·—·— 171 ——
195 ········ 284 ——————

1.4 Observational programs

A prime objective of the EIT investigation is to achieve comprehensive information on the structure and dynamic evolution of the corona within the limited data rate assigned to the instrument. To this end, we have tentatively planned a number of observing modes that are basically trade-offs between field of view, temporal resolution and the number of spectral bands that are observed. We have baselined operational modes that execute major observational objectives as we now conceive them. The three major observing modes are as follows :

1. Full-Sun, High Resolution Synoptic Mode : full disk images with highest spatial resolution will be recorded in each wavelength band once per day to establish a long-duration archival record of the EUV corona. These records will form the basis for studies of the evolution of the corona over a multiyear period so that slowly changing characteristics, associated, for instance, with the solar sunspot cycle, may be detected, and the evolution of long-lived features such as coronal holes can be followed over many solar rotations.

2. Partial Image, Moderate Resolution Survey Mode : through on-chip summation, many more data frames can be returned to Earth within the allotted telemetry rate. This particular mode, which will provide up to six full field images in each wavelength band in every 24 hours period, will be especially valuable in SOHO science planning and will be scheduled to provide SOHO operations planners with near real time images of portions of the corona that will be targeted for detailed spectrometric studies. Many more images at this resolution can be obtained by reducing the spatial coverage on the sun.

3. High Resolution, Selected Solar Areas Mode : by electronically reducing the imaged area to a FOV as small as 4 x 4 arc min, which is still appreciably larger than the anticipated fields of view of the major spectrometric instruments, up to 100 consecutive images can be stored in the EIT memory for later transmission. Each image can be read into memory in about 2-3 sec, so a temporal resolution of 10 sec for an observing interval of 1000 sec in conjunction with SUMER and CDS is entirely feasible

In any one 24 hr planning period we expect to devote approximately 50% of the total telemetry time to Mode 1 operation and 25% of the time to each of Mode 2 and Mode 3 operations.

2. CORRELATIVE STUDIES PLAN

Because of the wide field of view of the EIT and its ability to image the corona in three temperature ranges, as well as in He II, this instrument will be a valuable asset to coordinated observing programs and scientific analysis.

2.1 Planning of SOHO observing programs

The large FOV of EIT can be used to identify and provide pointing coordinates of types of coronal features that the major spectrometers may then study in detail. The EIT's moderate resolution mode, providing partial solar images with reasonable temporal frequency, will probably be the most useful in observing slowly varying but sometimes dynamic phenomena such as the evolution of coronal hole boundaries, bright points and emerging active regions in time to plan detailed observations with the major spectrometers. The instrument will have sufficient sensitivity to detect coronal regions just appearing behind the east limb of the Sun in time to initiate coordinated observations of the transition region and chromospheric counterparts of such regions as they subsequently appear on the limb. It is doubtful whether the initiation of individual dynamic events, such as coronal transients, can be identified in time to provide coordinates to the SOHO coronographs, and we do not plan to transfer to or receive information directly from other instruments on SOHO. However, early detection of transients at the Science Operations Center may provide a useful tool for the operation of CLUSTER and we expect to contribute to the fullest extent in planning the transfer of such information.

2.2 Coordinated observing programs

In addition to providing coronal survey data for planning purposes, the EIT will have observing modes that will make unique scientific contributions to multi-instrument observing programs. By electronically scanning only a portion of the CCD, the EIT's frame readout rate can be increased to once every 10 sec for durations of time limited by memory size, thereby providing the ability to record transient events in the low corona while still maintaining a large enough FOV to record the coronal context of the dynamic event. Such electronically extracted portions of the solar image will be selected to coincide with targets being observed by the major spectrometers. Any increase in the data rate assigned to the EIT would naturally result in a longer observing duration or a wider FOV of a rapid phenomena such as "coronal bullets" and eruptive prominences that must be investigated with excellent time resolution to properly determine their role in producing the solar wind and high speed streams.

2.3 Coordination with space-based/ground-based observatories

We expect to participate in coordinating SOHO observations with ground-based observatories, as well as with other instrumentation in space that may be relevant to SOHO. Although the exact planning is not known, a reasonable overlap between SOHO and ISPM/ULYSSES observations is still expected to occur. Our data will be very important to support

ULYSSES in situ solar wind measurement when the spacecraft overflies the solar poles. Of direct interest to EIT are ground-based observations of monochromatic coronal emission lines, such as those of Fe X (6374 Å) Fe XIV (5303 Å), and Ca XV (5694 Å). These emission lines, which cover approximately the same temperature range as the EIT coronal lines, can be observed at the solar limb outside of total solar eclipses at coronal observing stations when appropriate coronal regions are present. Comparison of the two data sets may therefore permit a new insight into the relative importance of the physical processes by which the coronal ions are excited.

2.4   Coordinated scientific analysis

The EIT observations will be made available to other SOHO experimenters in the Science Operations Center so that comprehensive analysis can be carried out expeditiously. The data will be provided on optical disks, in a format that will be negotiated. A typical disk will hold up to 2 weeks of EIT observations. We might also be able to provide selected data subsets, such as our once-a-day high resolution full-Sun images. These could be disseminated rapidly outside the SOHO community by publication as daily coronal maps in a suitable journal, such as NOAA's Solar-Geophysical Data Bulletin. In turn we expect to make use of selected data from other instruments to arrive at the most scientifically sound interpretations of our own observations.

3. DATA REDUCTION AND SCIENTIFIC ANALYSIS PLANS AND FACILITIES

3.1   Overall concept

The EIT data reduction and analysis systems will be designed to provide daily survey images to serve the planning needs of the coronal instruments, and to enable scientific analysis of the data on a longer timescale. The processing of EIT data involves two broadly defined phases : (1) data reduction and (2) data analysis. In the reduction phase the telemetry data will be converted to photon flux as a function of position, time, and wavelength band. Corrections will be applied to account for the response of the CCD, mirrors, and filters. As this task must be routinely performed to all data received, it will be most efficient to provide for initial data reduction processing at the Experiment Operations Facility (EOF) at GSFC. Backup data reduction processing will also be available at LPSP, NRL, GSFC and LPARL.

3.2   Delivery of data and software to NSSDC

The NASA funded NRL, GSFC and LPARL group will be responsible to provide the NSSDC with data formats, calibration data, reduced data, and analysis software and full documentation. We propose to supply processed data via optical disks. The NSSDC may also wish to archive raw telemetry data. Routine up-dates of calibration data, software, and

documentation will be supplied. GSFC has the responsibility for planning this task.

4. TECHNICAL DESCRIPTION

4.1   Design goals

The main assets of the EIT instrument are :
- high spatial resolution within a large field of view
- good spectral resolution sufficient to isolate individual solar emission lines

- adequate sensitivity in the 171 Å - 304 Å wavelength range
- capability to provide data in real time to support other coronal instruments
- economy of weight and volume.

These properties derive from the selected concept which has been fully studied and verified.

4.2   Main characteristics

The experiment consists in a wide field Ritchey Chretien telescope. The spatial resolution is better than 1 arc second for a circular field of 50 arc minute diameter.

Four multilayer reflecting coatings are vacuum deposited on quadrants of the telescope mirrors. A rotating mask covering 3/4 of the primary mirror allows one of the four wavelengths to be selected (FIG 3). The bandpass of these coating is : $\Delta\lambda/\lambda$ = 0,07 to 0,01

The image of the solar disk produced at the focal plane is recorded by a CCD detector. The resulting characteristics are the following.
- Equivalent angular size of pixels 3.0 x 3.0 arcseconds
- Equivalent angular size of image 50 x 50 minutes (format 1024 x 1024)
- Sensitivity at 304 Å : 1000 e-/pixel/sec average
- Dynamic range 2 10^5
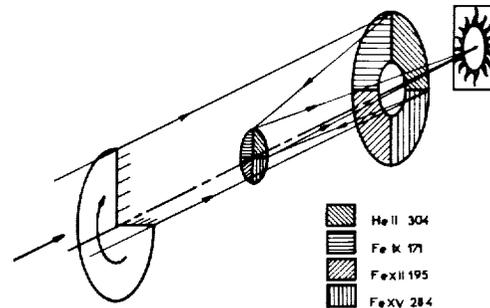- Temporal resolution 10 sec.

FIG. 3 : Optical principle

4.3   Principal Subsystems

Telescope :
- Ritchey- Chretien with zerodur mirrors
- Coated with multilayer coatings of high reflectivity in selected narrow bandpasses of the extreme ultraviolet spectrum (304 Å - 170 Å)
- Mirrors reflectivity > 10 % per mirror (measured, 20 % design goal)
- Four quadrants tuned to different wavelengths
- Equivalent focal length : 1.65 meter
- Collecting aperture : 10.5 cm diameter

Filters :
a) One aluminium filter reflecting all solar flux above 750 Å at the entrance of the telescope
b) Two insertable filters near the focal plan mounted on a rotating wheel for redundancy (choice of the best filter in flight) one insertable magnesium fluoride filter mounted in the same wheel for stray light level measurement in flight

C.C.D. detector :
- device : TEKTRONIX thinned back illuminated 1024 x 1024 pixels pixel size : 24 x 24 micrometers
- data compression
  * square root compression prior to telemetry
  * pixel summation : 2 x 2 pixel summing on the CCD chip may be selected
- cooling : passive cooling (- 20° C - 40° C)

Mechanisms :
- One aperture door in front of the telescope, closed for launch and during transfer phase, opened during operating phase. One shot if cold gas used as propellant by spacecraft. If hydrazine is used, this door may need to be actuated during spacecraft maneuvers for protection.
- One rotating mask in front of telescope to select one among four wavelengths (several operations per day).
- One filter wheel near the focal plane (used only for in flight calibration).
- One shutter used for selecting esposure time and masking CCD during read out (one operation per image exposed). Opening and closing time < 0.2 second.

4.4. Critical components

Multilayer coatings :
The mirrors are coated with Layered Synthetic Material (LSM) which have high reflectivity in the extreme ultraviolet spectrum. This kind of coating , working as an interference filter allows to obtain a selected wavelength in the spectrum by the choice of materials and the thickness of layers. The coating is a periodic stack of pairs of alternating materials. One material is absorbing and reflecting and the corresponding layer is thin in comparison to the wavelength ; the other material is transparent ; the period of the stack is adjusted to produce constructive interference by reflection [7].

Four different multilayers coatings will be deposited on each quadrant of the primary mirror. Bandwidth of multilayer coating can vary from 10 Å to 2 Å FWHM as shown in FIGS. 4-5. Appropriate selectivity can be obtained even for the FeXV line at 284 Å in which case rejection of the very strong the He II line at 304 Å is a challenging issue (see FIG. 6).
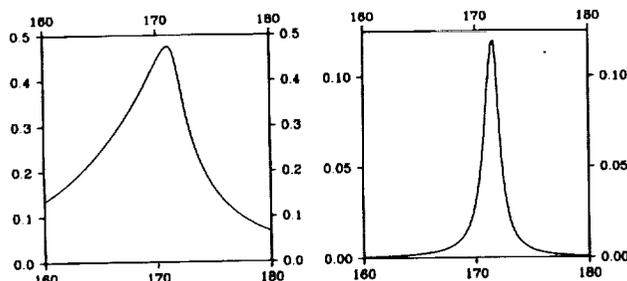
FIG. 4-5 : Standard and narrow LSM bandpasses for Fe IX

CCD detector and camera :
The choice of a detector for the EIT is crucial to successfully fulfilling the SOHO science and mission objectives. In particular, the detector must have adequate XUV quantum efficiency, pixel size and format matched to the EIT focal length, reasonable cooling requirements, and large dynamic range for quiet sun, coronal hole, and active region studies.

We plan to use a 1024 x 1024 back-illuminated CCD presently being developed by Tektronix. This device is expected to have a QE of 30-50 % in the 171-304 Å range since we have measured a QE of nearly 30 % at 304 Å for an existing Tektronix 512 x512 CCD [8]. In addition, as a result of NASA -sponsored detector development programs at LPARL and NRL, we should be able to increase this QE to > 80 % within the next several years. The Tektronix CCD will provide the EIT with high sensitivity and large dynamic range. The camera itself will derive directly from the detector design for LASCO.
CCD cooling and temperature control will be achieved using a combination of radiative cooler, copper rod or heat pipe, and a heating resistor in a feedback loop to control the CCD temperature to ± 1°.C.
The operating temperature of the CCD will be in the range of -50 to -70°C to reduce dark current.
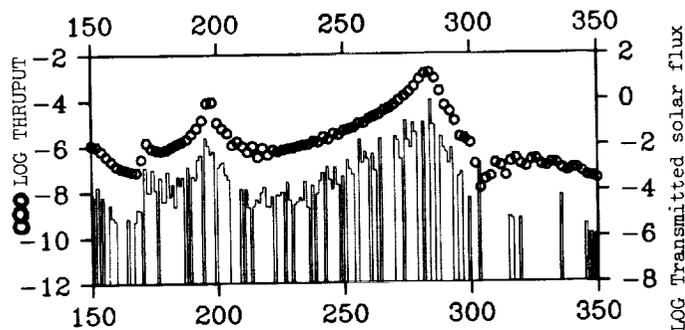
FIG. 6 : Selection of the Fe XV 284 line by EIT

Container :

In order to protect the filters and optical coatings against acoustic noise at launch and pollution during storage the instrument will be confined in a vacuum tight container. The external dimensions of this container are shown FIG. 7.

4.5 Calibration

The essential properties of the instrument will be measured, on ground, before launch : these include image sharpness and dynamic range, bandpasses selectivity and sensitivity.
Monochromatized light at variable wavelengths from a high energy positron storage ring, emitting known amounts of synchrotron radiation, will illumitate a target placed at great distance (d > 50 m) from the telescope. Secondary transfert standards will be used to evaluate the incident light flux.
In flight calibration will be performed once a month by measuring the response of the instrument through a set of selectable filters, showing possible evolutions in through put and strong light level.

5. SUMMARY OF SCIENTIFIC OBJECTIVES

Using a basically new experimental approach which has been demonstrated recently in flight [9], [10], [11], the EIT will bring to SOHO images of similar quality to those obtained by large instruments on board SKYLAB, with notable improvements in dynamical range, speed of access and photometric accuracy. The experiment will be extremely flexible and should satisfy all requests from the mission within allocated ressources. The main objectives will be to :

1 Study space - time evolution of coronal small scale structures (high resolution time series)
2 Establish a quantitative balance of dominant processes for coronal heating, solar wind acceleration (synoptic maps)
3 Define the topological and temporal context for high resolution coronal spectrometers (high resolution time series)
4 Conduct correlative studies using data from :
SOHO :
  - Coronographic instruments (LASCO, UVCS, SUMER, CDS)
  - Photospheric velocity and magnetic field observations (MDI)
  - In-situ solar wind analysers (CELIAS, COSTEP, ERNE)
  - Remote sensing solar wind monitors (SWAN)
ULYSSES : In-situ solar wind measurements
GROUND-BASED coronographs, radiohelio-graphs, magnetographs.

6. ACKNOWLEDGMENTS

EIT rests on firm technical grounds based on previous development activities in the field of space qualified optical systems, multilayer coatings and CCD detectors. We thank all members of the technical staffs who contributed to this essential work. We also acknowledge decisive scientific contributions from all associated investigators who will, we hope, pursue their participation to the science team until the final analysis is completed.

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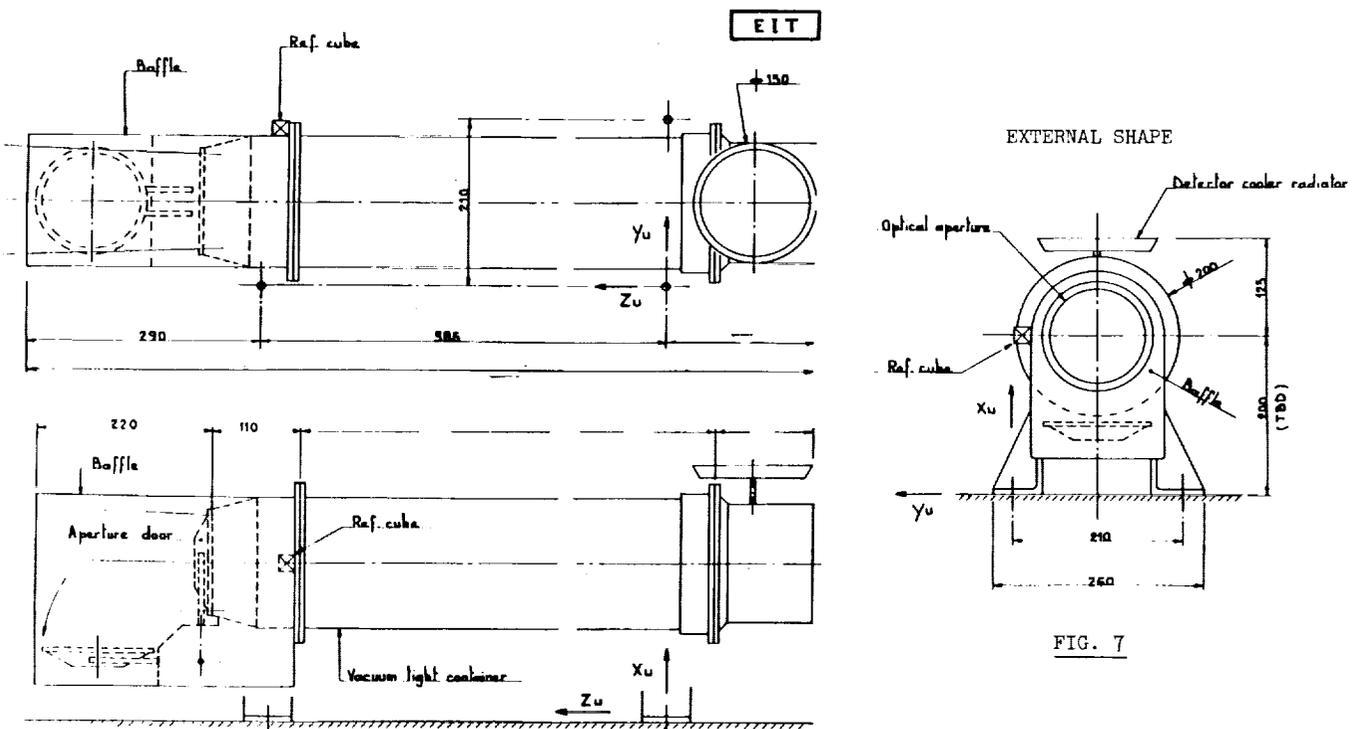11. Zhitnik I. 1988, XUV solar images from the Phobos Space Probe, Private communication

FIG. 7