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Final Report

Contract NAS5-31056

A Study of Low Mass X-ray Binaries

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## Final Report

Contract NAS5-31056

Covering the period 1 July 1991 thru 31 March 1994

### SPECTROSPAS STUDY

The entire effort under this contract during the period thru January 1992 was devoted to a study of the cost and schedule required to put an upgraded Aries payload on the ASTRO-SPAS carrier provided by the German space agency, DARA. The ASTRO-SPAS is flown on the Space Shuttle, deployed by the crew for 5 to 7 days of free-flying observations and then recovered and returned to earth. The spectrograph was to be provided by a collaboration involving the Lockheed Palo Alto Research Laboratory (LPARL), the Center for Astrophysics and Space Astronomy (CASA) at the U. of Colorado and the Mullard Space Science Laboratory (MSSL) in England. The payload for the ASTRO-SPAS mission included our own spectrograph and an instrument provided by Dr. Joachim Trumper of the Max Planck Institute (MPI) in Garching, Germany

A meeting was held in late July, 1991 with German scientists, DARA representatives and MBB, the ASTRO-SPAS spacecraft contractor. Sufficient information was exchanged to allow us to complete the study and the name LEXSA (Low Energy X-ray Spectrograph on ASTRO-SPAS) was given to our instrument and HERTA (High Energy x-Ray Telescope on ASTRO-SPAS) to the German instrument. The combination was called SPECTRO-SPAS. On October 1, 1991 CASA and LPARL submitted a cost and brief technical proposal to NASA on results of the study. The total cost over 4 fiscal years was \$6.16M, including CASA costs (more detail below). NASA Headquarters was briefed on 3 October on details of the proposal. They found our costs reasonable, but indicated that the NASA Fy '92 budget is extremely tight, they could not readily identify where the ~ \$2.3M for LEXSA could be found and it was not clear that Fy '93 would improve.

On 29 October, NASA's advisory committee, the High Energy Astrophysics Management Operations Working Group (HEAMOWG), was briefed on the science and programmatics of the LEXSA investigation. A recommendation for NASA to proceed with LEXSA was given by the HEAMOWG.

LEXSA is a very capable spectrograph, having a spectral resolution of 100 and an effective area of 100 cm<sup>2</sup> in the .15 to 2 keV range. Its capabilities are within a factor of 2-4 of those of AXAF or ESA's XMM. It can be flown in 1995, probably 5 years before either of these missions. LEXSA fits the recommendations of the Bahcall Committee, as well as those of several other NASA advisory committees, that opportunities for low cost and quick access to space be made more readily available.

A summary of the cost derived from the study is given below:

LPARL COST

	Fy '92	Fy '93	Fy '94	Fy '95	TOTAL
LABOR	\$1,393K	\$1,110K	\$795K	\$102K	\$3,400K
MATERIAL	\$417K	\$50K	----	----	\$467K
SUBCONTRACTS	\$222K	\$49K	\$21K	----	\$292K
TRAVEL	\$27K	\$22K	\$132K	\$46K	\$227K
TOTAL LPARL COST	\$2,059K	\$1,231K	\$948K	\$148K	\$4,386K
COST IF LEVELED IN FY '92 & '93 AS BELOW	(\$1,696K)	(\$1,594K)			

The funding requirements could be leveled somewhat without affecting schedule (as shown in parenthesis above) by the following shifts:

1836 hrs can be moved from Fy '92 to Fy '93 ~ \$213K

Material ~ \$150K could be shifted from Fy '92 to Fy '93

TOTAL US COST INCLUDING U. OF COLORADO

	Fy '92	Fy '93	Fy '94	Fy '95	TOTAL
TOTAL US COST	\$2,695	\$1,826	\$1,488	\$148	\$6,157
COST FOR FY '91 & '92 IF LEVELED AS ABOVE	(\$2,332)	(\$2,189)			

Copies of viewgraphs used during presentations of the LEXSA investigation and other materials produced during the study are included in this report as Appendix 1.

FLIGHT OF ARIES 24.017

A PIC for the reflight of Aries 24.017 was held on 20 April 1992 at the NASA Wallops Flight Facility. The only changes to the experiment payload were to the imaging proportional counter. The high voltage for this detector was potted to prevent the breakdown that occurred on 24.011.

The telescope was dis-assembled for cleaning and the mirrors inspected. They were found to be covered with a hazy film. This film was not apparent unless the mirror surface was illuminated by an intense collimated visible light in a dark room. Under these conditions the mirror scattered some of the

light and the film was visible. Witness samples to the mirror's lacquer and gold depositions did not show this effect. During re-entry a cork heat shield on the aft bulkhead of the service module burned. Some of this gaseous material entered the payload thru vents at the aft of the experiment. These vents are shrouded to prevent air flow into the payload during launch, but serve as scoops on re-entry. These thin aluminum shrouds were also burned during re-entry and it is believed that the aluminum and oxidized cork vapors were deposited as a film on the mirrors.

Efforts to clean the mirrors were begun. A rinse with a detergent solution followed by de-ionized water, high purity isopropyl alcohol with a final rinse of de-ionized water that was blown dry with nitrogen gas was tried on the witness flats. X-ray reflectivity measurements before and after the process indicated the reflectivity was unchanged from that measured after deposition in March 1990. This cleaning process was tried on the smallest hyperboloid mirror, without success. A cleaning process using dry ice "snow" was tried next. This technique used liquid CO<sub>2</sub> in a high pressure bottle. The liquid is exhausted from the bottle thru a small orifice where the expansion cools it to form the "snow". This is similar to what occurs in dry ice fire extinguishers. The snow is then directed at the surface to be cleaned. This process has been used to clean mirrors of large optical telescopes and even the surface of CCDs. Measurements on the witness flats indicated that this type of cleaning did not disturb the reflectivity. When this cleaning was tried on the smallest hyperboloid and paraboloid it improved the surfaces but they still did not appear as clean as the witness flats. Because of their large size it would require a major effort to measure the x-ray reflectivity of the telescope mirrors. Thus, it was decided to strip and re-lacquer the mirrors.

Since the technician who was involved in the mirror finishing for Aries 24.011 in 1990 had left Lockheed, many of the techniques had to be re-established, including the lacquer coating and gold evaporation processes. This required considerably more effort than was included in the proposal for refurbishment of the telescope for flight on Aries 24.017. A small crane was installed in the self-contained coating facility to lift the mirrors into and out of the methyl ethyl ketone bath used to strip the old gold-coated lacquer from the mirrors. The six mirrors were lacquer coated and baked at 130 C for 1 hour. Gold was vacuum evaporated onto the lacquer by placing a mirror, with its axis vertical, on a rotary table in a large vacuum chamber. A tungsten filament, wrapped with .25 mm diameter gold wire, was positioned along the mirror's axis. A baffle, whose purpose was to restrict the angle of incidence of the evaporated gold atoms with respect to the mirror's surface to within 20 deg of normal incidence, surrounded the filament. After evacuating the chamber, the filament current was increased to its maximum of 70 amps in about 15 sec, held there for 30 sec and returned to zero. The evaporation must be done quickly to reduce the heat input to the lacquer and to prevent the liquified gold from running down the filament. The telescope mirrors for Aries 24.017 were successfully completed in early May of 1993. X-ray reflectivity measurements of witness samples agreed very well with those calculated from the optical constants of gold. The mirrors were mounted on the center support plate and this mirror assembly was installed in the experiment payload.

Collaborators at the Mullard Space Science Laboratory (MSSL) were unable to obtain funding from the UK Science and Engineering Research Council for explicit expenses to support Aries 24.017. Labor costs could be covered under the MSSL block grant from the SERC but travel costs and major hardware purchases could not be made. Thus, 20 new bellows actuators of the type used to open the imaging proportional lid were purchased under this contract. During

the flight of 24.011 two such actuators failed to deploy even though their bridge wires were successfully fired. The newly purchased actuators were x-rayed and the results examined by people at the GSFC Wallops Island Flight Facility (WFF). Eleven were deemed acceptable; two were test fired successfully and two were chosen for flight from the remaining nine. The residual actuators are currently in the possession of WFF.

Personnel at MSSL potted the high voltage system which suffered electrical breakdown in the flight of Aries 24.011. This system was tested by slowly evacuating the entire assembly to a pressure of a few mtorr, where breakdown problems are most severe, over a period of several hours and then slowly returning to atmospheric pressure. The high voltage was turned on during the entire test with no breakdown problems.

Integration was begun on 3 May 1993 at the WFF. The integration went very well where the only problems encountered were in ground support equipment outside the payload.

The grating spectrograph was calibrated at the High Energy Laser System Test Facility (HELSTF) at White Sands Missile Range in early June. A subcontract was initiated with the U.S. Army Space and Strategic Defense Command to reimburse HELSTF for their support of the calibration. A copy of the test plan for this calibration is included in this report as Appendix 2. Also included, in Appendix 3, are representative plots of some spectra obtained during the calibration. The x-ray source anode and filter used are indicated on each plot, as well as the wavelength of the principal emission line. The diffraction order is indicated above each peak in the spectra. After calibration, the experiment payload and GSE were transported to the NASA VAB at WSMR for launch in late August to observe the soft x-ray spectrum of the crab nebula.

Aries 24.017 was launched from WSMR at 09:45:00.17 GMT (0345 MDT) on 28 August 1993. Following a nominal lift off and initial ascent, the vehicle experienced a series of drops in chamber pressure and anomalous flight dynamics beginning at approximately 25.41 seconds after launch. The vehicle experienced a large left yaw at approximately 26.12 seconds that severely increased the angle of attack, causing V-band joints to fail, and splitting the payload into three parts. The nose cone, impact absorbing section, forward and middle experiment sections remained together. The aft experiment section separated from the rest of the payload as did the service module which contains systems for attitude control, telemetry, instrumentation and recovery. Aerodynamic loads and impact with the ground scattered the experiment payload over an area of approximately 1/4 square mile, centered about 200 yds west and 400 yds north of the launch pad. Figures 1-4 are photographs of the debris. The x-ray telescope mirror assembly remained intact but is so severely damaged as to be useless. All of the experiment payload structures were destroyed. The booster, which was separated from the payload, continued to burn until T+42 sec when range safety personnel destroyed it. It was tracked by radar and impacted about 2.5 miles from the launch pad. One of the nozzles from the booster was found among the payload debris and the failure investigation report indicates that loss of this nozzle was responsible for the vehicle malfunction. This was to be the last Aries launched by NASA, although another flight may have been considered had 24.017 been successful.

## CCD CAMERA

We proposed to use a Tektronix 1024 by 1024 back-illuminated three phase CCD with 24 micron square pixels as the image sensor for an upgraded soft x-ray spectrograph. It is a Multi Pinned-Phase (MPP) device which provides reduced dark current. The back surface has been specially treated with a Tektronix proprietary process to provide high and stable quantum efficiency for soft x-rays. There is an anti-reflection (AR) coating of MgF<sub>2</sub> applied over the back surface to enhance visible light efficiency and further stabilize the CCD performance. The thinned CCD is fully supported over its area and is optically flat. We have measured the soft x-ray quantum efficiency (QE) of a 512 by 512 device, identical to the proposed CCD except in size, and the results are shown in Fig. 5. Since Tektronix will not discuss composition of the back surface and that dead layer is very thin, the QE of the CCD has been modeled using absorption in the MgF<sub>2</sub> coating and a 10 micron depletion depth. This model has been fitted to the measured data and the results are shown in Fig. 5 by the solid line. There is reasonable agreement except for the data point at .53 keV. It may be that the backside treatment involves nitride, whose absorption edge at .39 keV may explain the discrepancy of this point. Since the absorbing effects of the back surface are small at higher energies, the CCD QE is determined by the depletion depth and is well represented by the model above 1 keV. We plan to use a 1500 A Al filter to block visible light and the QE expected for the CCD and filter is shown by the dashed curve. The CCD will thus have a QE greater than 60 % over most of the .4 to 2 keV range of the spectrograph.

The CCD operates in single photon counting mode and provides sufficient non-dispersive energy resolution to separate orders in the spectrograph. The system will operate below 10 electrons rms noise level, providing an energy resolution of better than 100 eV below 2 keV. The various orders are separated by 150 eV, so it will be possible to distinguish one from another. The CCD will be cooled to -60 C by a cold finger attached to a thermal mass in a LN<sub>2</sub> dewar. Temperature regulation is maintained by a thermistor controlled heater on the cold finger. We have fabricated several of these coolers and they have been operating reliably in the laboratory for more than three years. The dewar will be sized appropriately for the flight and prelaunch preparations and will be vented through a one-way valve outside the payload. Because of the cooling requirement, the CCD must be in vacuum to avoid freezing condensates on its surface. The CCD and front end electronics will be housed in a small vacuum chamber with a gate valve that opens for the observations and closes before re-entry. A radioactive Fe-55 source will be mounted on the valve to illuminate the CCD with 5.9 keV x-rays for the purpose of monitoring system gain before and after the observations.

The spectrum will have a resolution element 50 by 250 microns in size and be dispersed over about 18 mm, including zero order. The CCD will provide 2 pixels per resolution element in the dispersion direction. Detection of zero order provides an in-flight reference for re-pointing the rocket attitude to compensate for absolute pointing errors and drift in the attitude control system. The CCD is operated in frame transfer mode with a 512 by 1024 image area sensitive to x-rays and the remaining area shielded by a mask. After an integration period, the image is shifted in 7 ms into the shielded area where it is read out at a rate of 75 kilo-pixels/sec. This sets the integration time of 7 sec. The 10 bit charge amplitude in each pixel is fed to the 800 kilo-bit/sec PCM encoder via a FIFO buffer and hand-shake electronics. The 512 by 1024 images will be displayed on a monitor for real time control of the

rocket pointing. The 7 ms frame transfer time is sufficiently short so that no shutter is required.

The 7 sec integration time poses no problem for single photon detection in the CCD since the image is dispersed across the device and an emission line falls onto 20 pixels. For detection of 3 photons per integration period (a line flux of .02 photons/cm<sup>2</sup>-sec) the probability of getting 2 photons in one pixel is less than 1 percent. For sources brighter than .02 photons/cm<sup>2</sup>-sec-keV, more than 5 photons will be detected in the zero order image of the source in 7 sec, sufficient to identify its location and perform the aspect corrections.

The camera design we proposed to use is that developed over several years by Jim Janesick at the Jet Propulsion Laboratory and a block diagram is shown in Fig. 6. As a part of a technology transfer effort, JPL has provided circuit designs and circuit board architecture for their proven low noise camera to Talktronics inc., a small firm who is now producing the cameras commercially. An electronic engineer and a mechanical engineer specializing in electronics packaging, both with over 30 years of experience in fabricating electronics for space flight, have visited Talktronics to inspect the camera's circuit board construction. Both are confident the camera can be ruggedized and repackaged for sounding rocket use. This will thus be a very cost effective way to obtain a low noise flight-worthy CCD camera. The following list describes some changes that will ruggedize the CCD camera and make it better suited for sounding rocket use and for cooled operation.

1. The CCD is to be operated in a "frame transfer" mode where the top half (I) of the chip is to perform image-sensing and the the bottom half (S) is to receive data from (I) by fast parallel transfer and store it for subsequent slow scan readout. During this transfer (I) and (S) are clocked identically. For the readout of (S) its gates are clocked appropriately, while the (I) gates are not clocked, but are biased for integration. The readout period for (S) is the integration period for (I). For a readout rate of 70 kpixels/sec the readout/integration period is about 7 sec. After this readout/integration period the cycle begins again with another frame transfer. A mask is placed over (S) so it recieves no exposure. The fast parallel frame transfer must be done in a time short compared to the 7 sec integration time so no shutter will be required. If one accepts a 1 % image smearing (ie 1 % of the photons are detected during frame transfer and are thus positioned wrongly) the parallel transfer can be at a 5 khz rate, if this would be of advantage in configuring the readout. Some software and hardware for the frame transfer must be developed to meet this frame transfer operation.

2. Since the CCD is to be cooled to reduce noise it must be in a vacuum to prevent water vapor from freezing on the chip. The head board and components must be of low out-gassing materials, as far as practical to minimize condensation of material on the cooled CCD that would degrade its soft x-ray quantum efficiency.. The board should be made from polyimide material and, if possible, without the solder mask, silk screen lettering and component outlines. Also, components should be low outgassing where practical. In order to reduce dark current sufficiently, the CCD should be cooled to -60 C. Any design changes to the head board/CCD mounting that would facilitate this cooling would be valuable.

3. The plated-thru holes on the connector edge of the boards should be placed closer together, on .100 inch center to center spacing, on each of two columns to fit connector pins indicated on Figure 7 and 8. No solder terminals are required, as are on the present boards. Also, the boards should have two holes

added to accommodate the connector mounting screws as shown in Fig. 8. Eliminate the plastic board extractors but leave the associated holes in the boards. If possible, place the signal chain components on a board similar to the other boards. (The signal chain board is to be separated from the other boards by a ground plane in the card cage). The power supply module is not required, since light-weight supplies will be purchased for the rocket flight. Eliminate the gold plated edge finger connectors and solder masks on the boards. The silk screen lettering and component outlines are OK except on the head board.

4. Conformal coating of the boards will be done here at Lockheed as well as securing larger components against vibration effects and provisions for dissipating power, where necessary.

5. The above changes will allow the camera electronics to be housed in an electronics box designed by the AEPI experiment for flight on the space shuttle. This box has successfully flown on the shuttle and details are shown in Figs. 9 and 10. The box has provision for 10 cards, while the CCD camera will require only 7. The remaining space will be used to house the power supplies and a telemetry interface.





Figure 1 Debris from the forward portion of the experiment payload.

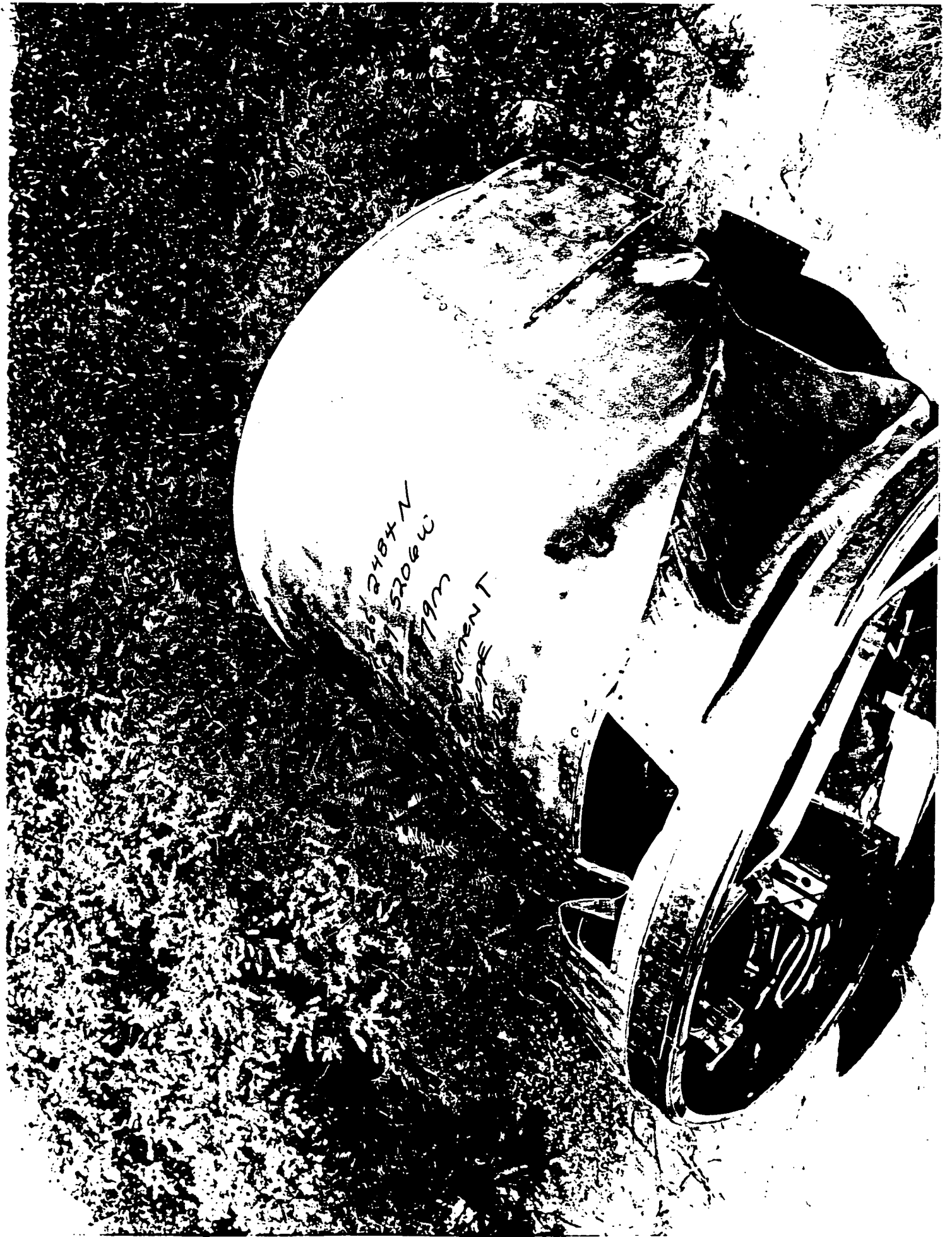


Figure 2 Forward experiment compartment housing the gratings.



Figure 3 Mirror assembly viewed from paraboloid end.

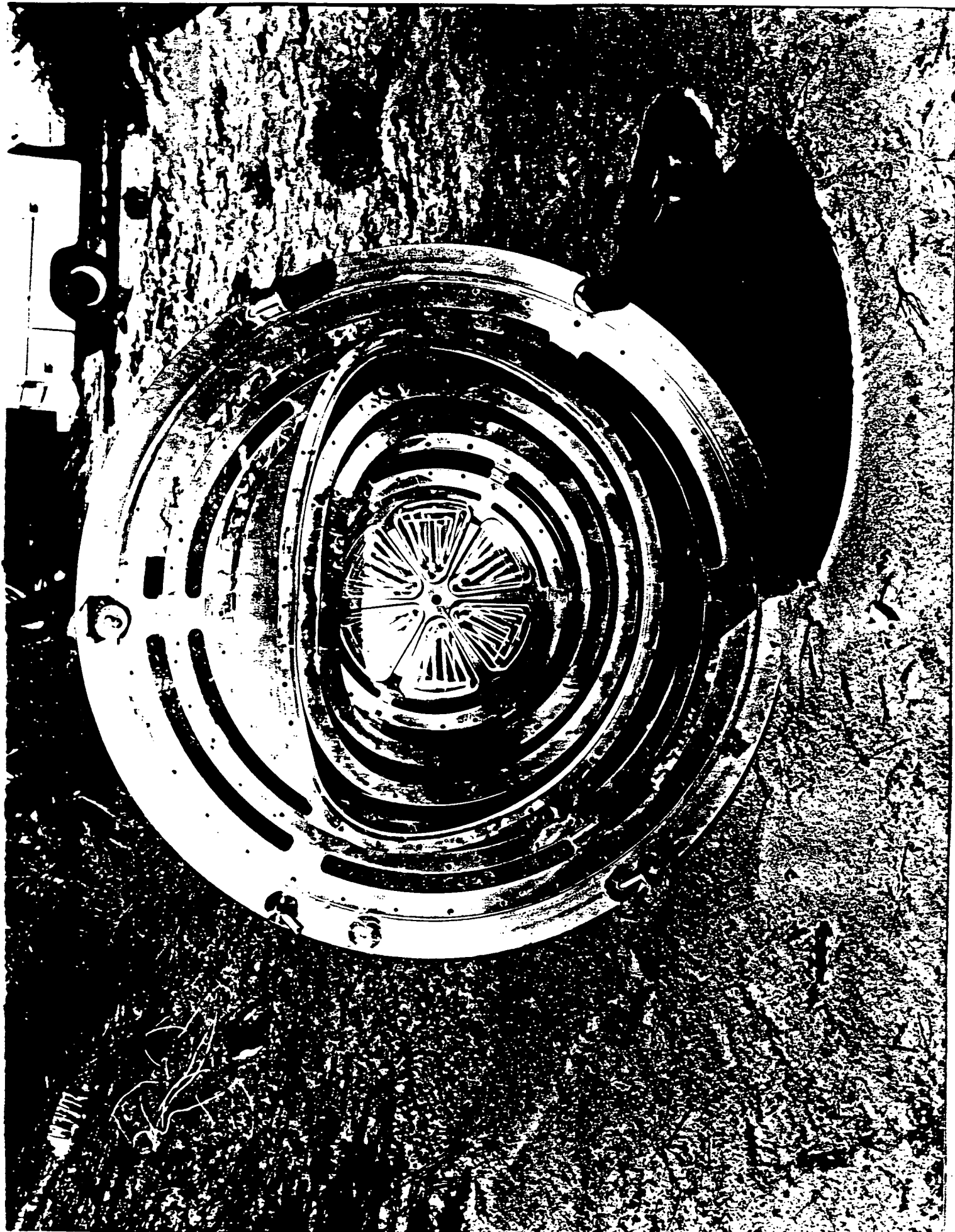


Figure 4 Mirror assembly viewed from horizontal side and

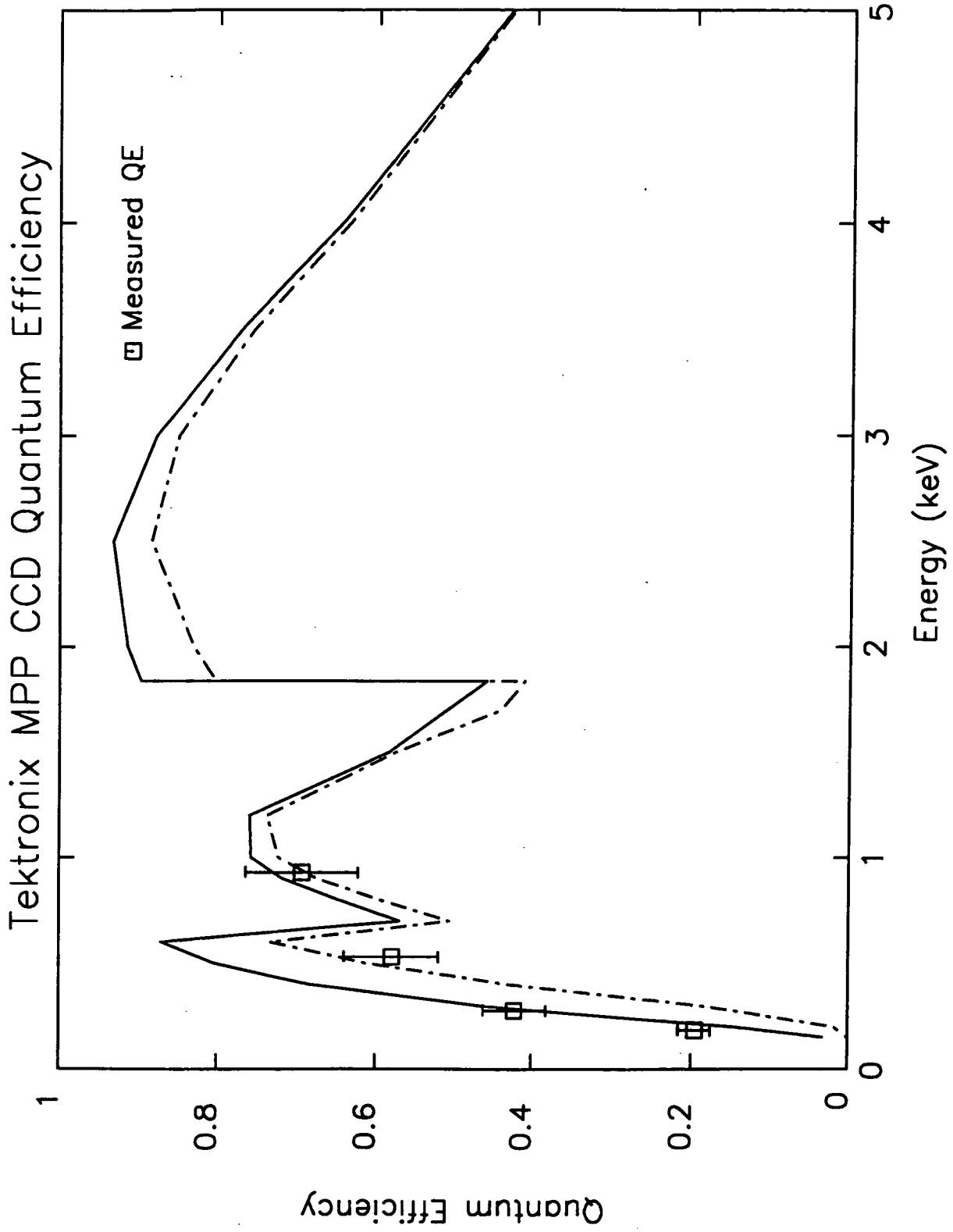


Figure 5 Quantum efficiency of the TEK MPP CCD.

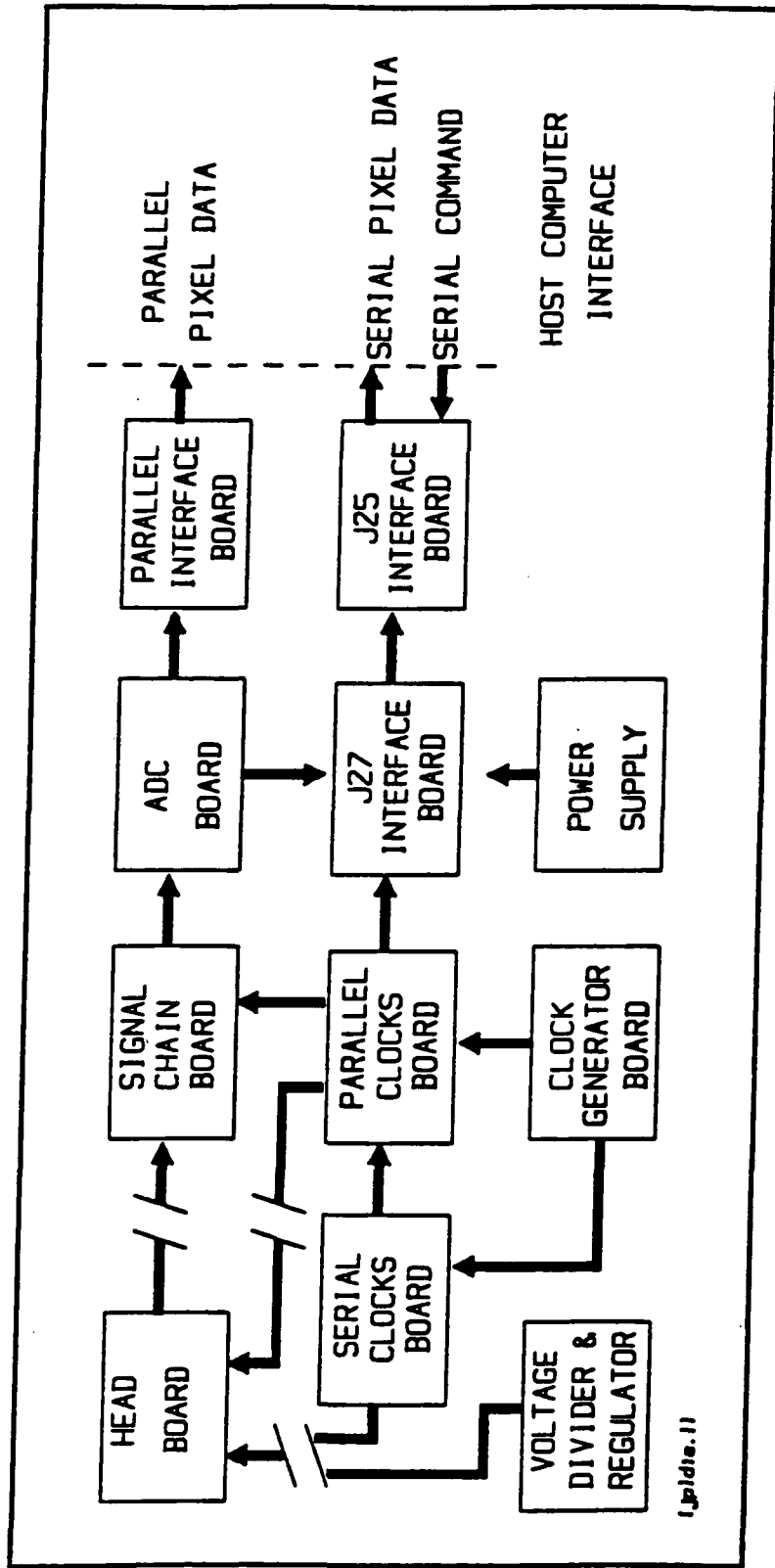
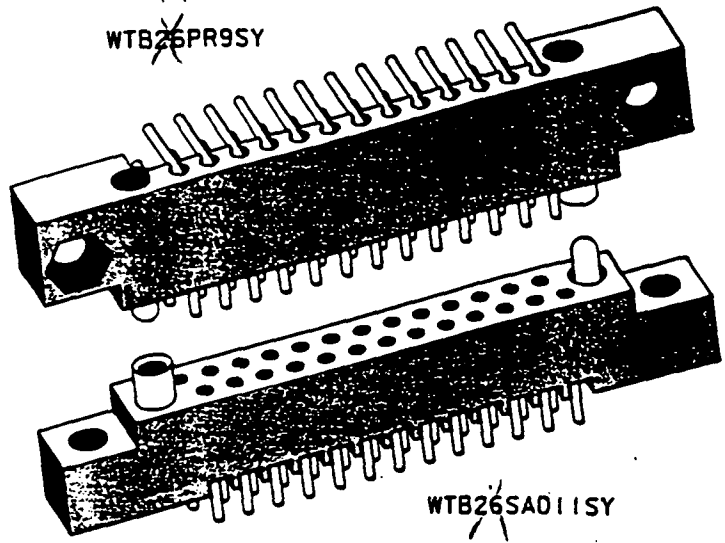


Figure 6 Block diagram of the CCD camera system.

WTB26PR9SY



WTB26SAD11SY



# 2 • ROW Connectors

PC Card to  
Chassis or  
Board

**WTB-WTB**

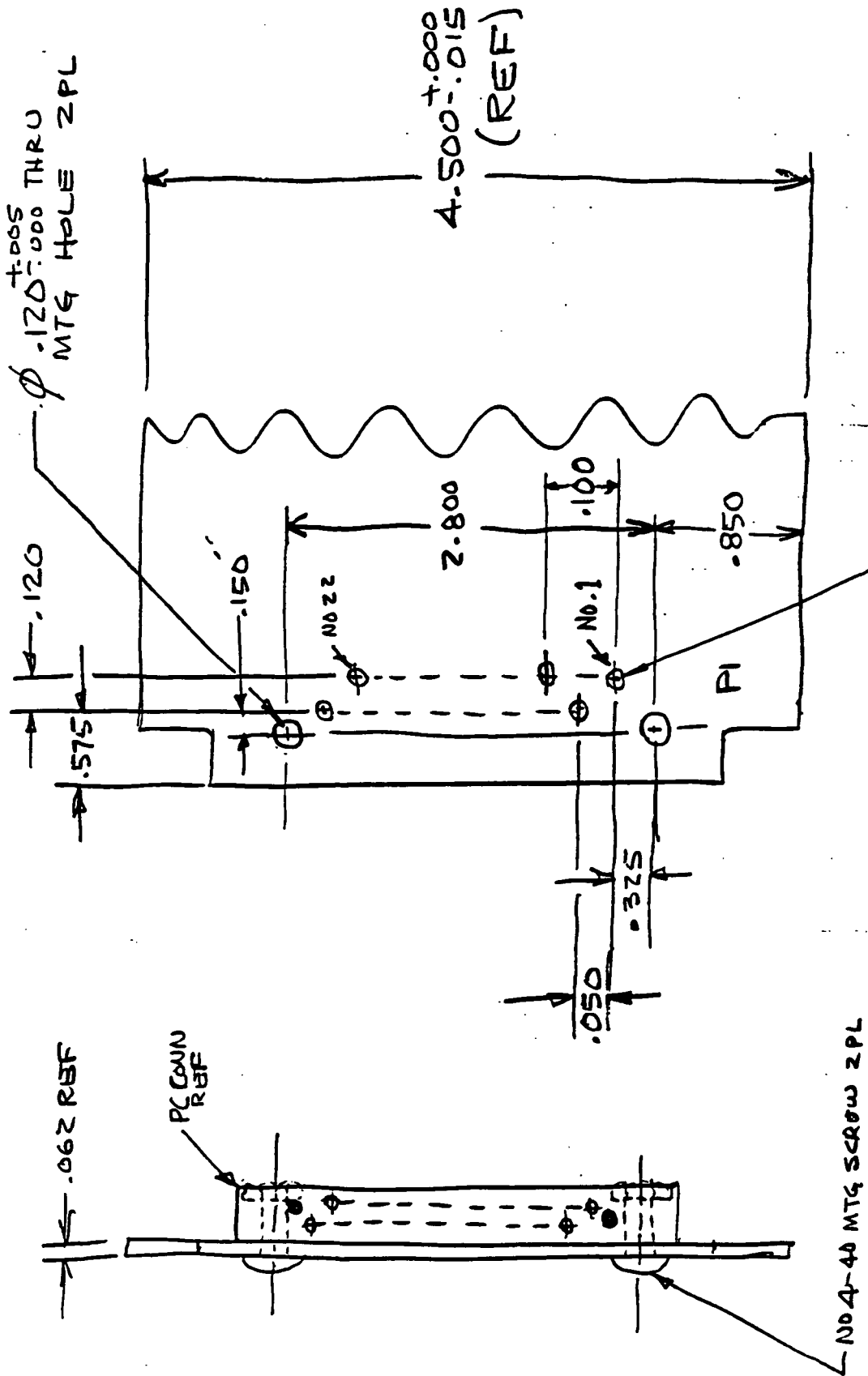
Examples:

PLUG	RECEPTACLE	PLUG: RECEPTACLE:	WTB WTB	26 26	PR9 SAD11	SY SY
<b>SERIES</b>						
WTB = 2-row, right-angle, plug, mntg. ears.	WTB = 2-row, straight, receptacle, mntg. ears.					
<b>NUMBER OF CONTACTS</b>						
10,14,20,24,28,30,36,40,44,50,54,56,60,66,70	10,14,20,24,28,30,36,40,44,50,54,56,60,66,70					
<b>TYPE OF CONTACTS</b>						
PR7 = Pin, right-angle, dip solder, .109	SAC = Socket, straight, solder cup, closed entry					
PR9 = Pin, right-angle, dip solder, .140	SAD9 = Socket, straight, dip solder, .140					
PR11 = Pin, right-angle, dip solder, .172	SAD11 = Socket, straight, dip solder, .172					
PRW40 = Pin, right-angle, Wire Wrap, .625	SAD15 = Socket, straight, dip solder, .234					
	SAF3 = Socket, straight, flex-circuit, .060					
	SAF6 = Socket, straight, flex-circuit, .083					
	SAW40 = Socket, straight, Wire Wrap, .625					
<b>TYPE OF HARDWARE</b>						
SY = Guide set	SY = Guide set					
<b>NOTE</b>						

- 342 = remove .250-long mounting ears. (Add "342" to part number. Example: WTB26PR9SY342.)
- 548 = Include nuts bonded into hex recess in mounting holes. (Add "548" to part number. Example: WTB26PR9SY548.)
- For polarized "D"-shaped guides, add dash and code number to part number (Example:-7). See "Polarization" under next tab for codes.
- Face seal gaskets: order separately. See "Gaskets" under next tab for instructions.
- 413 = Straight pin contacts in right angle plug molding with solder cup terminals extending .100" beyond molding. (Add "413" to part number. Example: WTB26PR9SY413.)

Figure 7 Ruggedized connectors to be used for rocket flight.

ORIGINAL PAGE IS  
OF POOR QUALITY

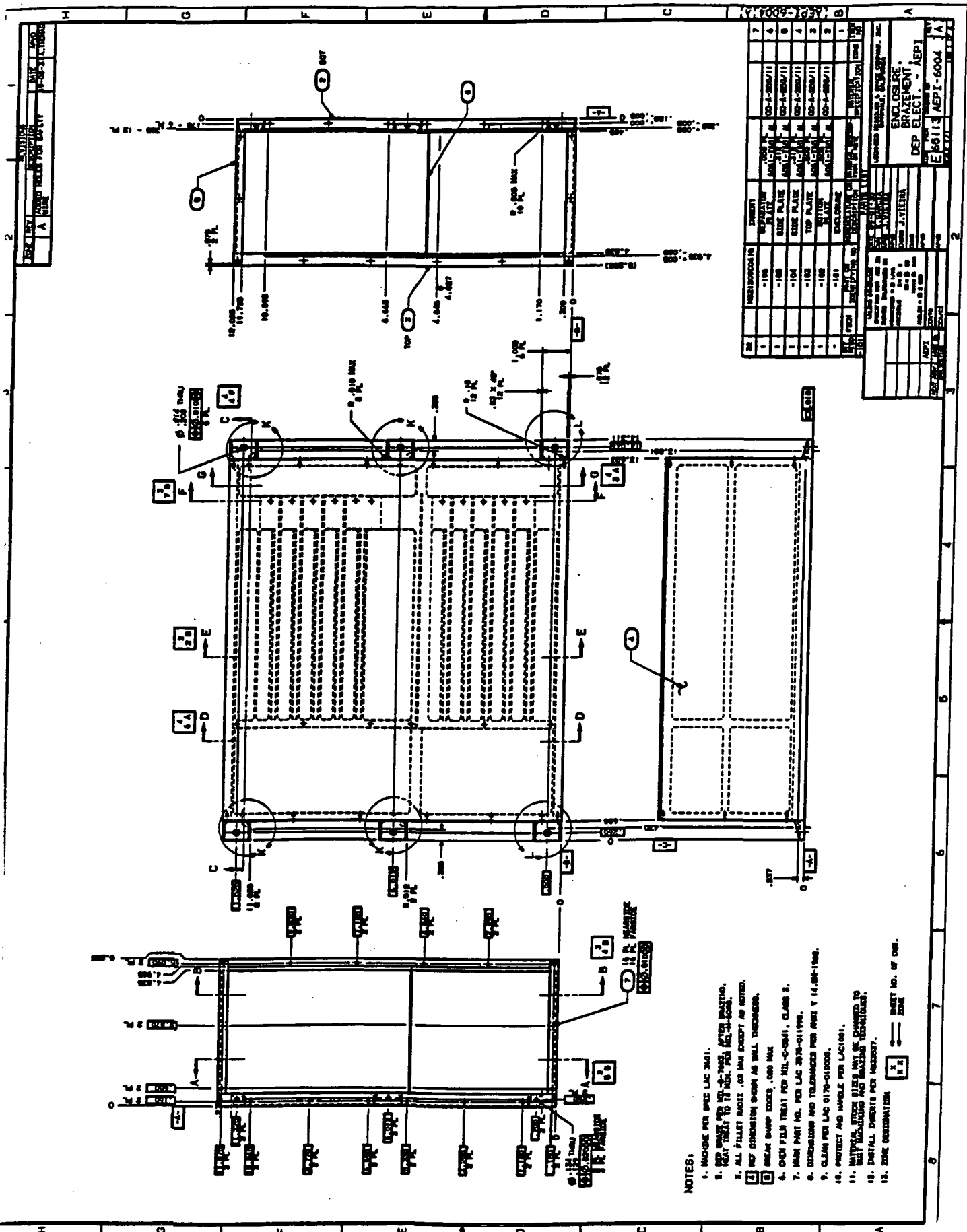


44 PIN AIRBORN CONNECTOR  
LAYOUT FOR 4.500 X 6.00 X .062  
PRINTED WIRING BOARD  
MOTHER BOARD CORN. PART NO. WTB44PR9SY  
BOARD CONNECTOR PART NO. WTB44SAD73Y

JOHN VIEIRA  
JAN 14, 1994  
(408) 424-3281

Figure 8 Proposed changes to circuit boards for ruggedized connectors.



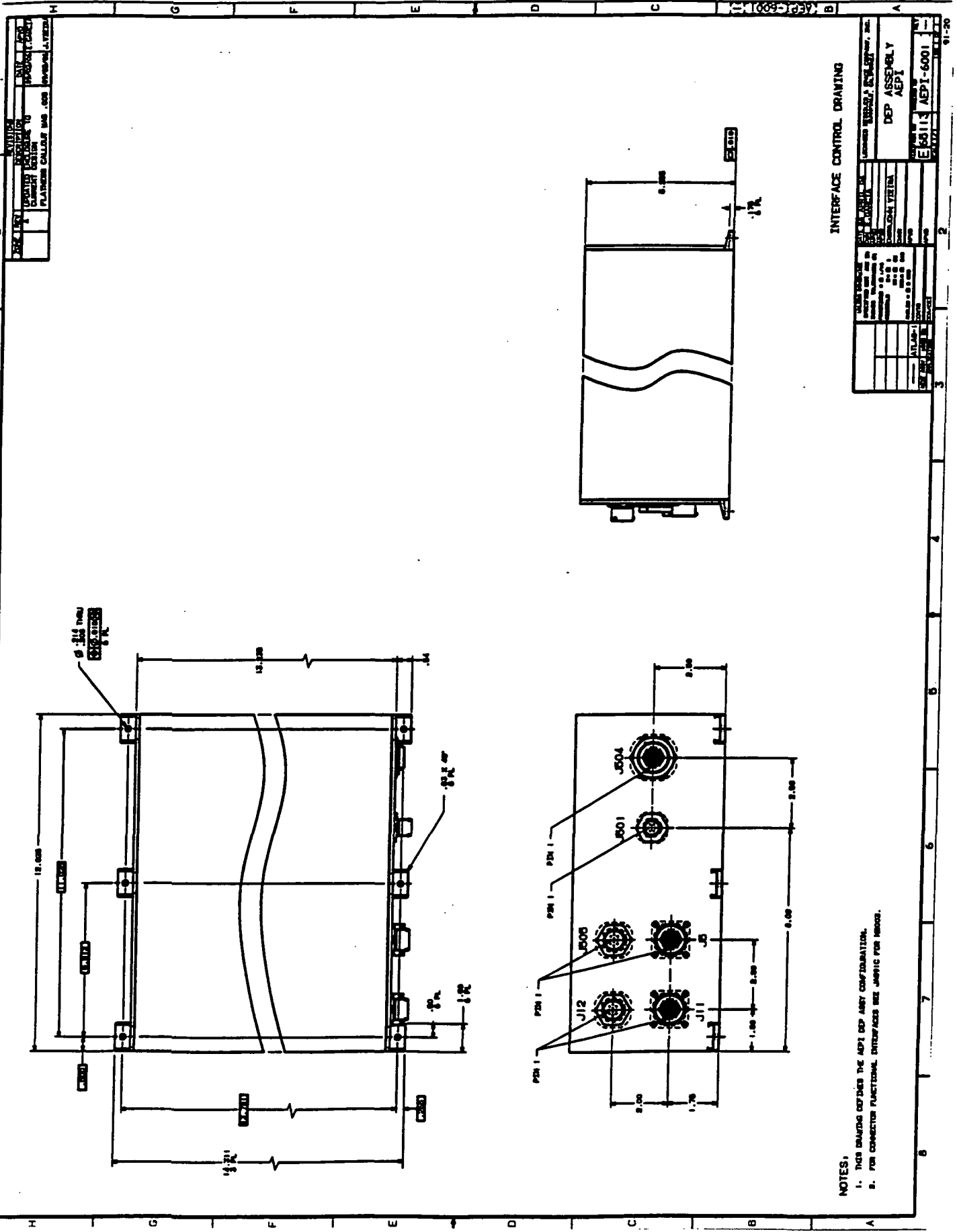


AVIATION  
 AIRCRAFT  
 PARTS  
 SECTION  
 A  
 DRAWING  
 TITLE  
 1-85-11-1000

NO.	DESCRIPTION	QTY	UNIT	REF. DES.
1	BASE PLATE	1	PCB-A-2000/11	7
2	EDGE PLATE	1	PCB-A-2000/11	8
3	TOP PLATE	1	PCB-A-2000/11	4
4	SPACER	1	PCB-A-2000/11	2
5	INSULATOR	1	PCB-A-2000/11	3
6	SPACER	1	PCB-A-2000/11	2
7	SPACER	1	PCB-A-2000/11	2

- NOTES:
1. FINISH PER SPEC LAC 2401.
  2. ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED.
  3. ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED.
  4. ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED.
  5. ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED.
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  10. ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED.
  11. ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED.
  12. ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED.
  13. ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED.

Figure 9 Design of flight card cage.



**NOTES:**

- 1. THIS DRAWING REFERS TO THE AEP1 DEP ARMY CONFIGURATION.
- 2. FOR CONNECTOR FUNCTIONAL INTERFACES SEE JAS91C FOR INFO.

Figure 10 Assembly drawing of flight card cage.

APPENDIX 1

VIEW GRAPHS AND OTHER MATERIALS DEVELOPED IN THE SPECTROSPAS STUDY

SPECTRO-SPAS  
LOW ENERGY X-RAY SPECTROGRAPH ON ASTRO-SPAS (LEXSA)  
HIGH ENERGY X-RAY TELESCOPE ON ASTRO-SPAS (HERTA)

SCIENCE STRATEGY:

LEXSA and HERTA will obtain high sensitivity medium resolution x-ray spectra of a wide variety of both galactic and extra-galactic x-ray sources. Low energy dispersive spectroscopy complimented by simultaneous and overlapping broad band non-dispersive spectroscopy will provide definitive x-ray spectral measurements in the 0.15 to 10 keV energy range.

MISSION TYPE:

International

OBJECTIVES:

Spectroscopic investigation of cosmic x-ray sources in the .15 to 10 keV range will be performed to better understand the emission mechanisms and physical conditions in the sources. The high sensitivity of SPECTRO-SPAS will provide a medium resolution ( $E/dE \sim 100$ ) catalog of the spectra of nearly all classes of galactic and extragalactic x-ray sources. The temperature and elemental abundances of the interstellar medium can also be studied from the absorption spectra of material along the line of sight.

DESCRIPTION:

SPECTRO-SPAS consists of a grating x-ray spectrograph, LEXSA, operating in the 0.15 to 2 keV range and a non-dispersive spectrometer, HERTA, sensitive to x-ray energies from 0.2 to 10 keV. The LEXSA involves a 5 mirror-pair Wolter I telescope, a radial groove grating array and a CCD image sensor to provide an effective area of 100 cm<sup>2</sup> and a spectral resolution of better than 100 over most of its spectral range. It will be developed by the Lockheed Palo Alto Research Laboratory (LPARL), the Center for Astrophysics and Space Astronomy (CASA) at the University of Colorado and the Mullard Space Science Laboratory (MSSL) in the United Kingdom. The HERTA involves a 3 mirror-pair Wolter I telescope with a pn CCD image sensor to provide an effective area greater than 25 cm<sup>2</sup> over most of its spectral range and an energy resolution ranging from 3 to 60 between 0.2 and 10 keV, respectively. It will be developed by the Max Planck Institut Fur Extraterrestrische Physik-Garching (MPE), Max Planck Institut-Bonn and the University of Tübingen. These instruments are mounted in the ASTRO-SPAS Carrier, a spacecraft that provides attitude control and data handling/transmission during the observations. The ASTRO-SPAS is provided by the German Space Agency, DARA and manufactured by Messerschmitt-Bolkow-Blohm GmbH.

The payload is carried to low-Earth orbit by the Space Shuttle and deployed by the Remote Manipulator System. The payload operates at distances up to 40 km from the Shuttle. Most of the data are recorded on board, with sufficient data transmitted to the ground to allow SPECTRO-SPAS to be commanded and operated from the Payload Operations Control Center at the Kennedy Space Center. The SPECTRO-SPAS is subsequently recovered and returned to Earth.

PAYLOAD/PI LIST:

LEXSA: Richard Catura (LPARL)

HERTA: Joachim Trumper (MPE)

LAUNCH DATE: February 1995

PAYLOAD: Two telescope-spectrographs, one dispersive,  
one non-dispersive.

ORBIT: 300 km at 28.5 degree inclination

MISSION DURATION: 6-7 days

LENGTH: 3.5 meters

WEIGHT: 1200 kg

LAUNCH VEHICLE: Space Shuttle

FOREIGN PARTICIPATION: DARA, the German Space Agency (through  
Max Planck Institut-Garching, Max Planck  
Institut-Bonn and University of Tübingen)  
supplies HERTA. Also DARA provides the  
ASTRO-SPAS Carrier.

PAYLOAD SPECIALISTS: None

CURRENT PHASE:

Phase B Completed

STATUS:

LEXSA and HERTA are awaiting Phase C/D funding

MISSION EVENTS:

Phase B study completed 1 October 1991

MANAGEMENT:

NASA Headquarters

W. Huddleston, Program Manager (Flight Systems Division)

L. Kaluzienski, Program Scientist (Astrophysics Division)

Lockheed Palo Alto Research Laboratory

R. C. Catura, Principal Investigator

R. A. Stern, Project Scientist

University of Colorado, CASA

W. C. Cash Jr., Lead Investigator

J. Green, Project Scientist

Mullard Space Science Laboratory  
J. L. Culhane, Lead Investigator  
A. Smith, Project Scientist

Max Planck Institut Fur Extraterrestrische Physik  
J. Trumper, Lead Investigator

DARA  
G. Hartmann, Program Manager  
J. Tjaden, Payload Manager

MAJOR CONTRACTORS:

U.S.  
Lockheed Palo Alto Research Laboratory  
University of Colorado, CASA

U.K.  
Mullard Space Science Laboratory

Germany  
Max Planck Institut Fur Extraterrestrische Physik  
Max Planck Institut-Bonn  
University of Tübingen  
Messerschmitt-Bolkow-Blohm GmbH

## TRIP REPORT

CONTRACT NAS5-31056

TRIP OF 20 THRU 25 JULY, 1991

Travel to Munich, Germany was undertaken during July 20-25 1991 for purposes of initiating discussions relative to a definition study for placing an upgraded Aries spectrograph on ASTRO-SPAS 3. Discussions were held in three separate locations, described below. Agendas for the first two days meetings are attached to this report: the discussions at the Panter x-ray calibration facility were informal, with no agenda.

### MEETING AT MAX PLANCK INSTITUTE (MPE) ON 22 JULY

Presently known details of our investigation, the Low Energy X-ray Spectrograph for Astro-spas (LEXSA), were presented as indicated on the attached copies of view graphs.

After lunch Dr. Aschenbach of MPE presented information on their instrument, the High Energy x-Ray Telescope for Astrospas (HERTA). Because of cost and schedule problems they have found it necessary to descope HERTA from the initially proposed telescope from an effective area of 125 cm<sup>2</sup> at 6keV to 25 cm<sup>2</sup>. Instead of 12 nested mirrors, 3 mirrors fabricated on aluminum substrates are proposed. This poses no problem in the region of overlap of the two instruments, between 0.2 and 2 keV, since the higher resolution of LEXSA requires separating the counts into many more bins than HERTA so that counting statistics in each bin will be comparable. However the factor of 5 reduction in area at higher energies reduces the sensitivity to iron-line emission near 7 keV and will require increased observing time for HERTA to acquire adequate spectra on fainter objects for joint analysis with LEXSA. MPE will use a CCD detector that is 280 microns deep with less than a 400 Å dead layer on the entrance surface. There was a large overlap in common scientific interests and in the objects to be observed, so there should be little difficulty in establishing a mutually acceptable joint observing plan. It was made clear that on ASTRO-SPAS 3 The U.S. has the major instrument, as opposed to the first two missions where Germany has taken the lead. Data rights were discussed in a preliminary way and agreed that data from objects of mutual interest from both HERTA and LEXSA should be shared between U.S. and German investigators. The remaining observing time should be allocated 50-50 between U.S. and German interests. These agreements, of course, require NASA approval and should be reviewed in light of the data split between ORFEUS and IMAPS on ASTRO-SPAS 1, where Germany provides the major instrument.

### MEETING AT MESSERSCHMITT-BOELKOW-BLOHM (MBB) ON 23 JULY

A slightly briefer version of the LEXSA mission was presented at MBB as well as that for HERTA, emphasizing the hardware aspects of the instruments and their requirements from the ASTROSPAS spacecraft. Characteristics of the ASTROSPAS were discussed and both the spacecraft and its mission support equipment were shown to the group. Some of the major points of the discussions are:

1. Safety of the instruments are the major concern and QA will apply only to safety aspects and not to whether the instrument will operate properly.

2. The star tracker can operate within 40 deg of the sun and 10 deg of the earth's limb.
3. The attitude control is in 3 axes so the CCD thermal radiator may always be pointed in the most advantageous direction. An aspect solution is possible five times per second. Maximum slew rate is 0.2 deg/sec, but is done in all three axes simultaneously.
4. A breadboard of the ASTROSPAS interface electronics is recommended.
5. Recommended cable insulation is Ray Chem Viton.
6. Instruments must be demounted from the ASTROSPAS spacecraft for shipment to KSC because otherwise it won't fit into a commercial aircraft.
7. Data are formatted by each experiment into blocks of 512 words. If data rate exceeds allocation, the data are lost.
8. The combined LEXSA and HERTA instruments will be called SPECTRO because their scientific objectives entirely involve spectroscopy and the mission will be called SPECTRO-SPAS.

We were supplied with several large documents, detailing the requirements for the mission. The personnel at MBB appear to be very competent, helpful and experienced at interfacing with JSC.

#### DISCUSSIONS AT THE PANTER X-RAY CALIBRATION FACILITY ON 24 JULY

The MPE x-ray calibration facility will be used in calibrating LEXSA so a visit to this laboratory was made to understand its capabilities and the interfaces required. It consists of a 130 m long evacuated tube with an x-ray source at one end and a large vacuum chamber, housing the instrument under test, at the other end. The facility is very clean so that contamination of the payload should be no problem. A variety of x-ray lines are available and the alignment capabilities and provisions for rotating the payload for off-axis measurements are excellent. The entire facility appears well-suited for calibrating LEXSA.



\*SPECTRO-SPAS\*

INTRODUCTION

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ASTRO-SPAS--A JOINT US-GERMAN COLLABORATION

SPAS--SHUTTLE PALLET SATELLITE

LEXSA--LOW ENERGY X-RAY SPECTROGRAPH ON ASTRO-SPAS

LOCKHEED PALO ALTO RESEARCH LABORATORY  
UNIVERSITY OF COLORADO

MULLARD SPACE SCIENCE LABORATORY

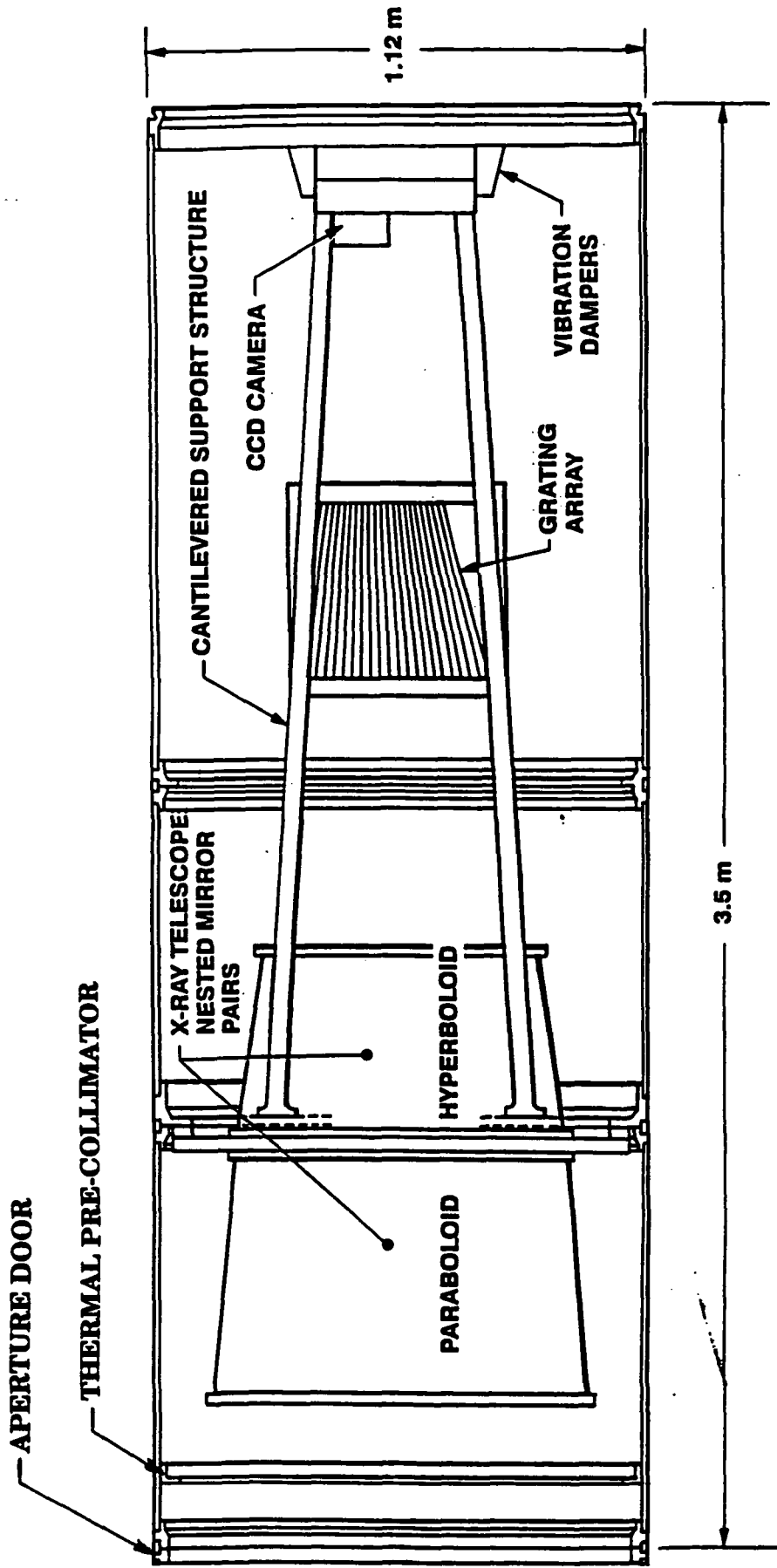
HERTA--HIGH ENERGY X-RAY TELESCOPE ON ASTRO-SPAS

MAX PLANCK INSTITUTE GARCHING  
MAX PLANCK INSTITUTE BONN  
UNIVERSITY OF TUBINGEN

SPECTRO-SPAS--COMBINED LEXSA AND HERTA INVESTIGATIONS

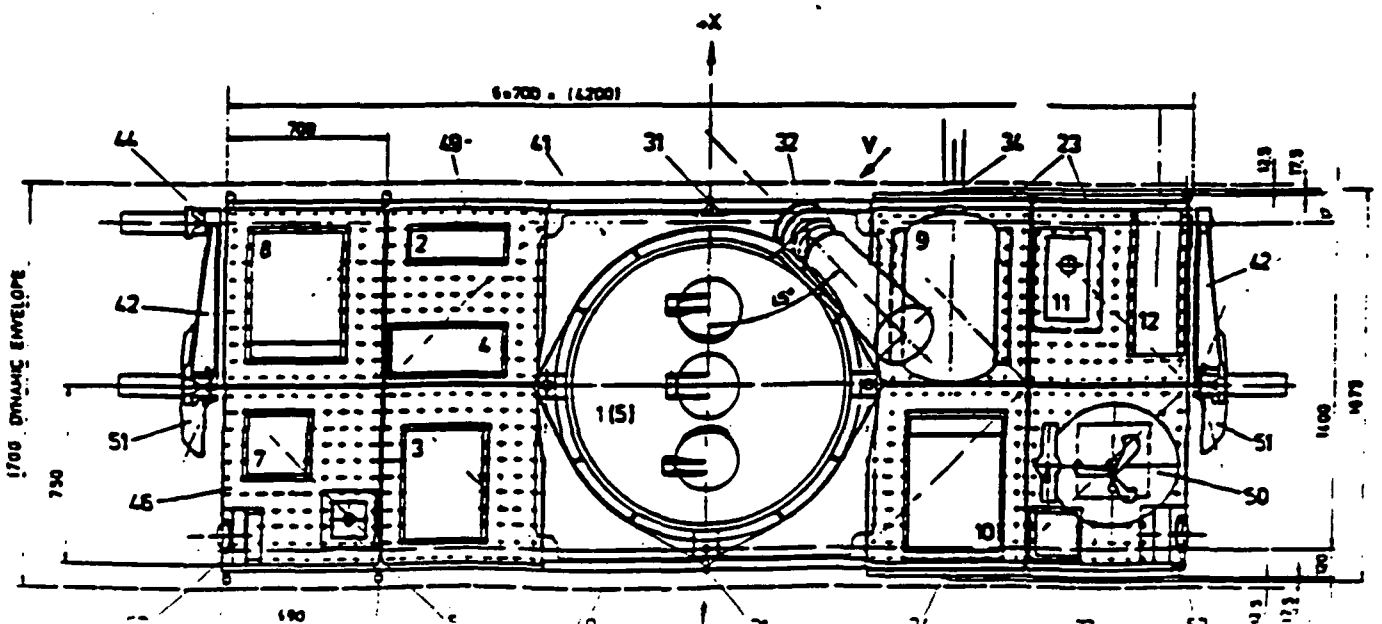
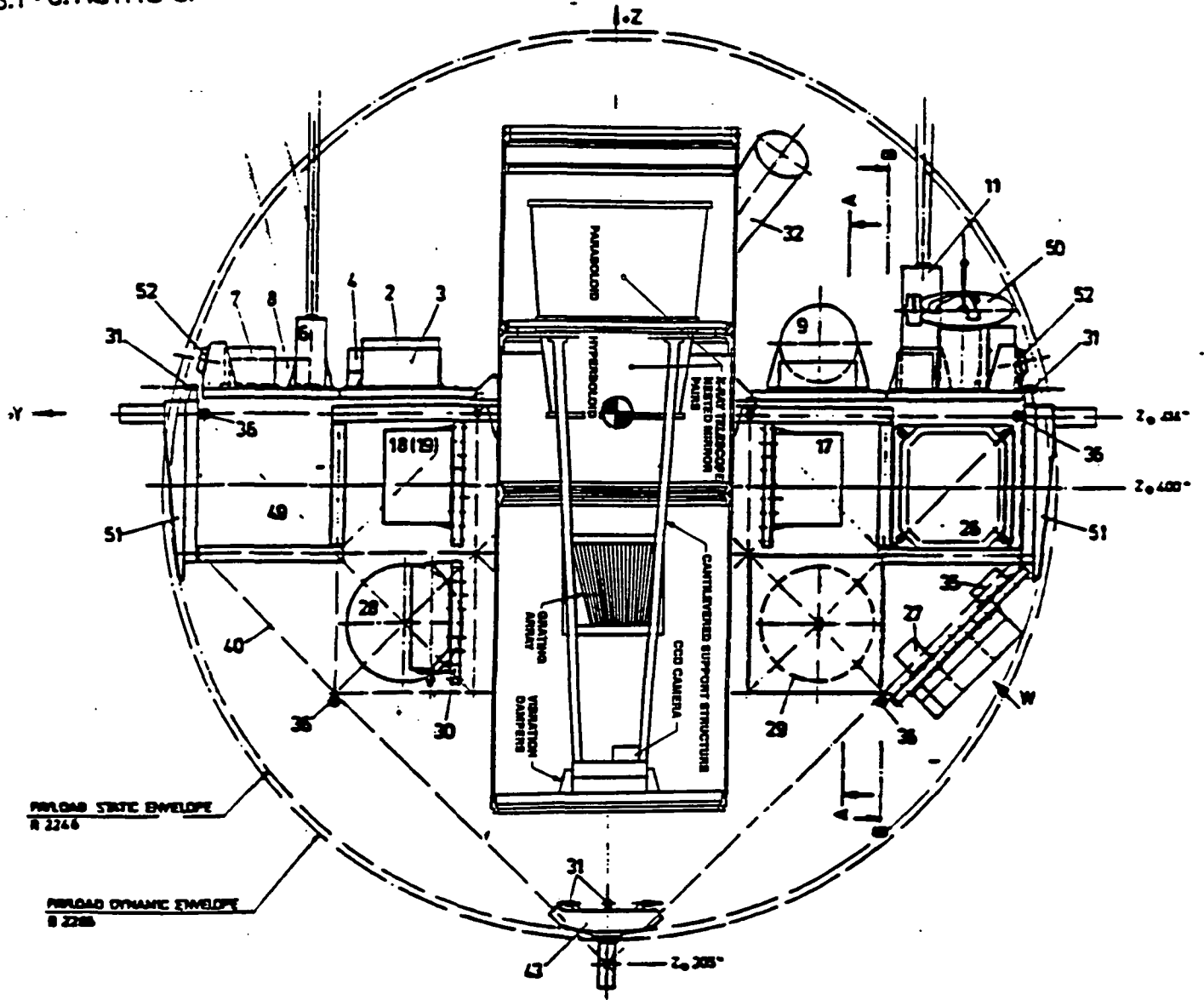
\* SPECTRO-SPAS\*

LEXSA



SCHEMATIC OF THE LOW ENERGY X-RAY SPECTROGRAPH FOR ASTRO-SPAS (LEXSA) INSTRUMENT

Fig. 3.1 - 3: ASTRO-SPAS ALLOWABLE CARGO ENVELOPE



TARGET

ACTIVE GALACTIC NUCLEI

CLUSTERS OF GALAXIES

MASS TRANSFER BINARIES

INTERSTELLAR MEDIUM  
(ALL OBSERVATIONS)

STARS  
(MANY OBSERVATIONS)

SUPERNOVAE REMNANTS

OBJECTIVE

ABSORPTION TROUGHS

COOLING FLOWS

MASS OF CYG X-1  
SPECTRAL SURVEY  
ACCRETION DISK PHYSICS

OXYGEN ABUNDANCES  
TEMPERATURES  
DENSITIES

EMISSION MECHANISMS  
STELLAR EVOLUTION

TEMPERATURES  
DENSITIES

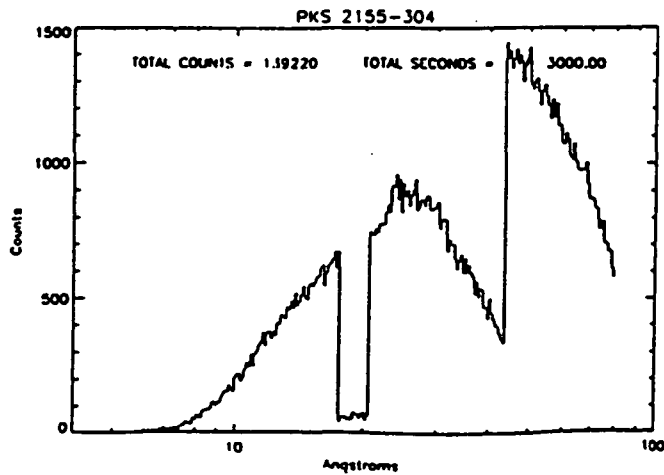
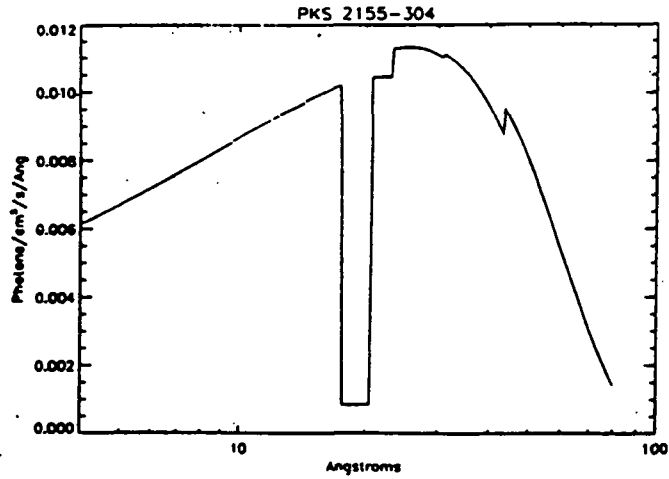
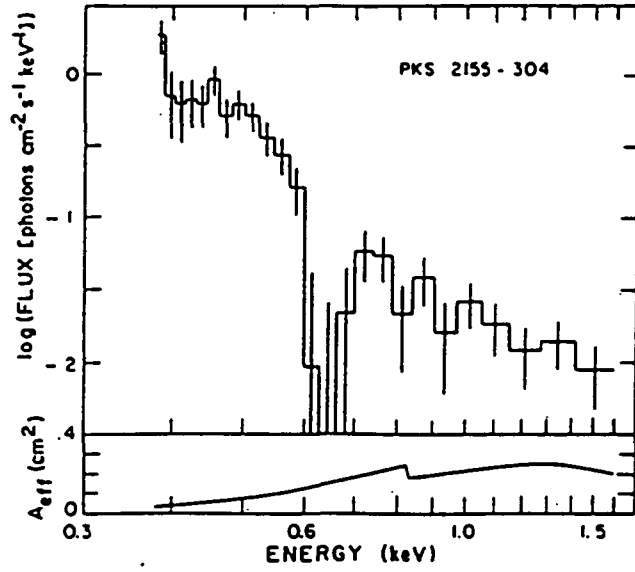
THE FOLLOWING ARE GRAPHS OF COSMIC X-RAY SPECTRA FROM THE INDICATED SOURCES

The format is: Top Graph is best current measured spectrum

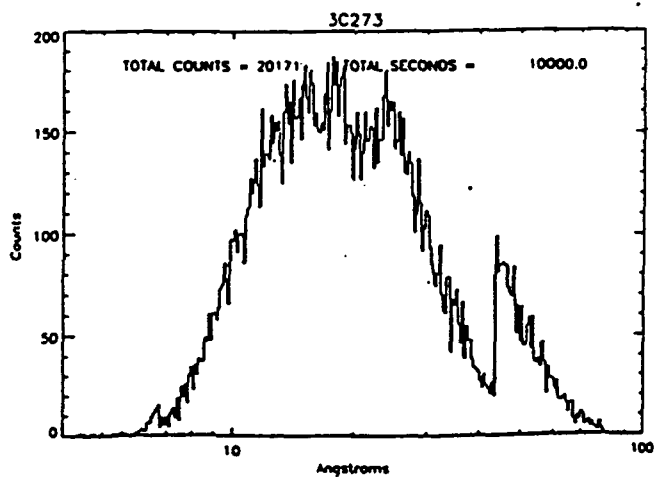
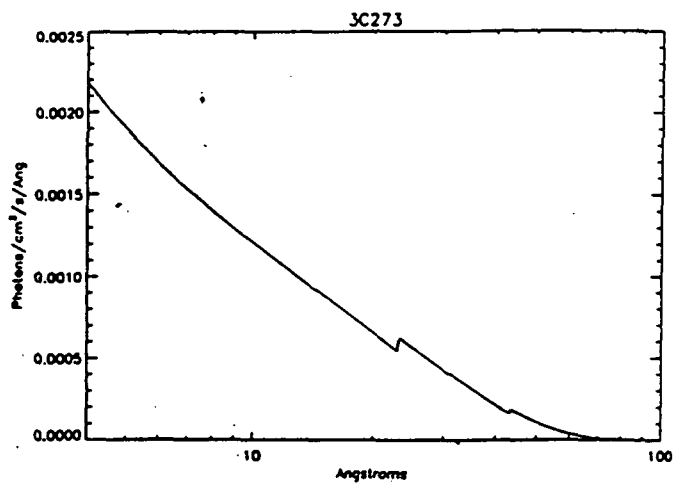
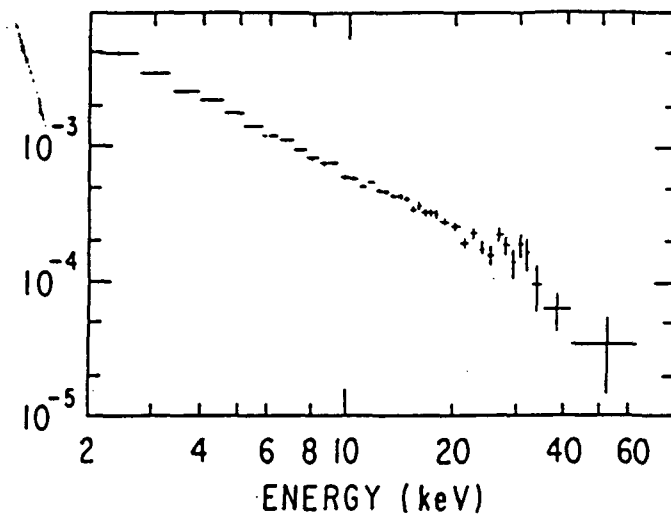
Middle Graph is a spectrum simulated from the measured data as an input to the LEXSA spectrograph.

Bottom graph is the spectrum expected to be measured by LEXSA in the observing time indicated.

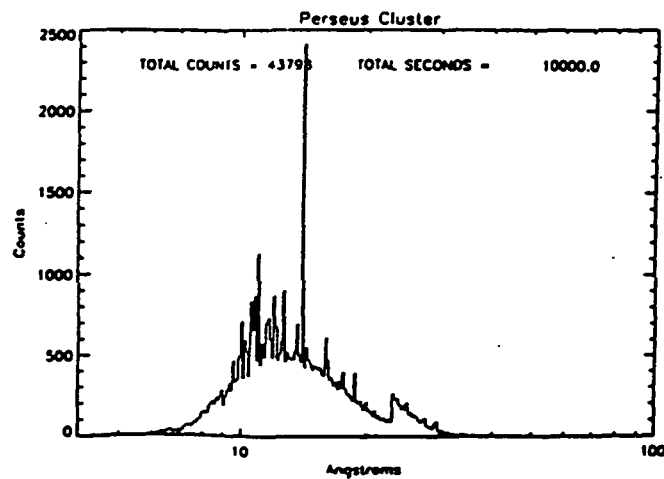
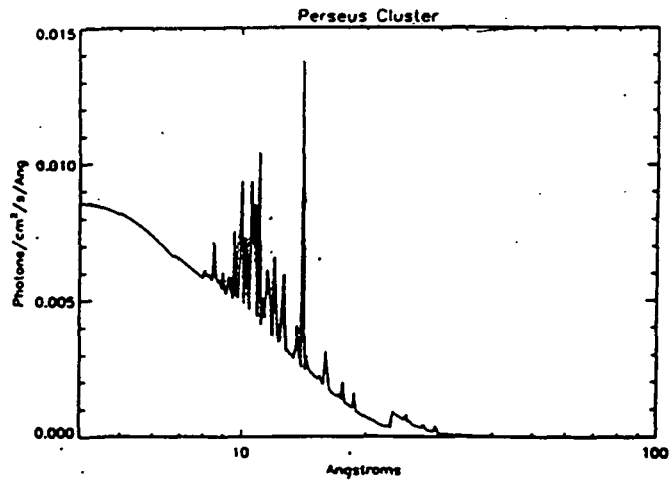
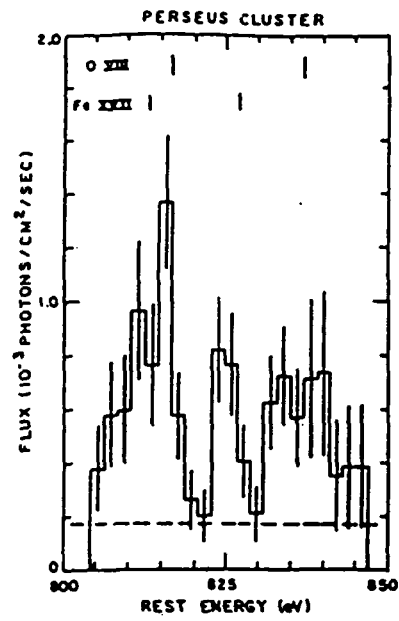
# PKS 2155-304



# 3C273

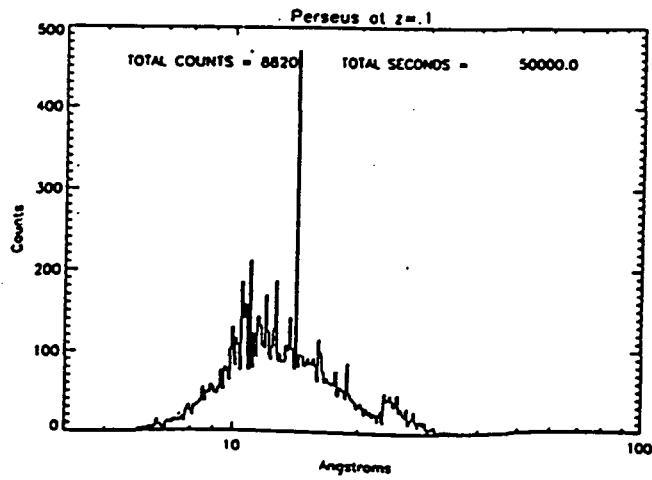
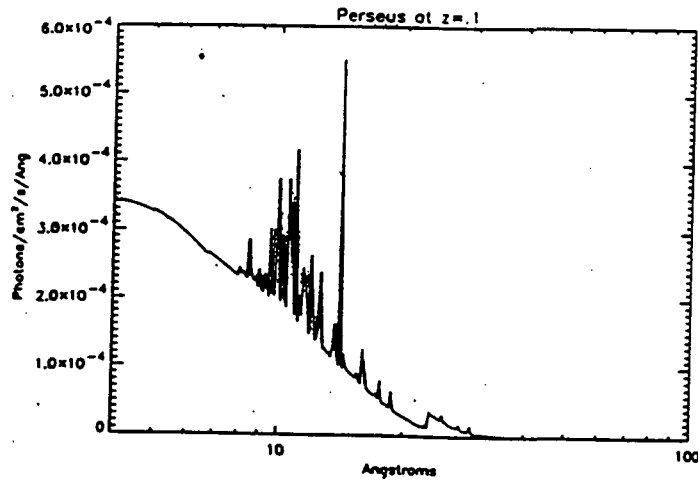


# Perseus Cluster

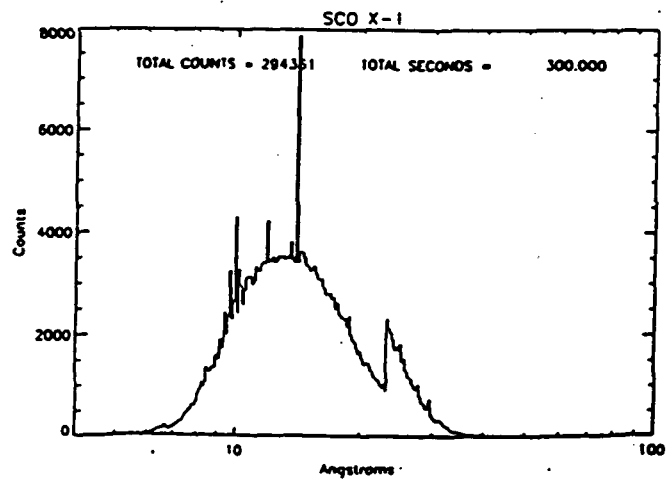
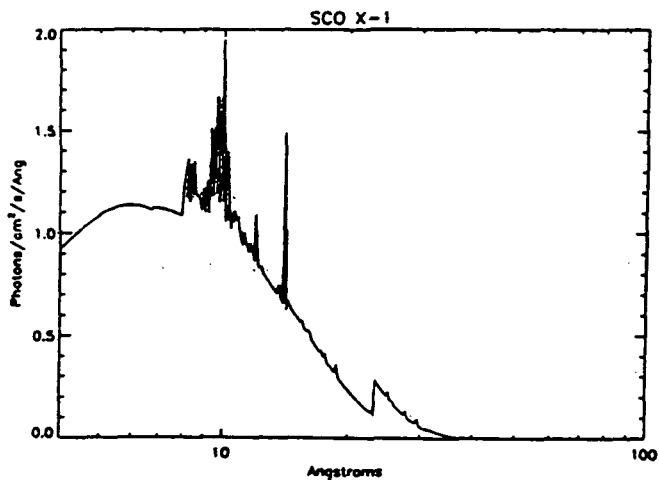
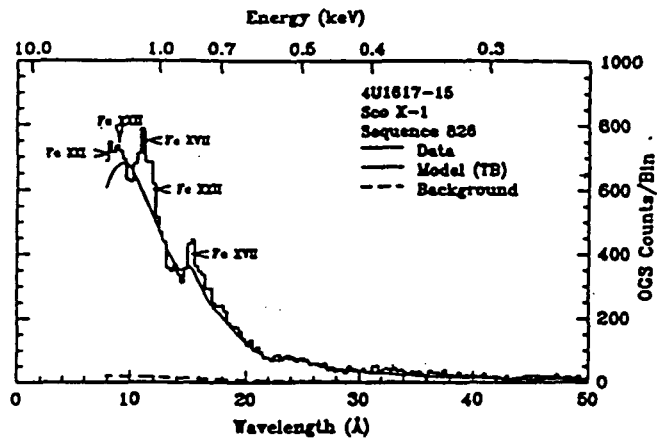




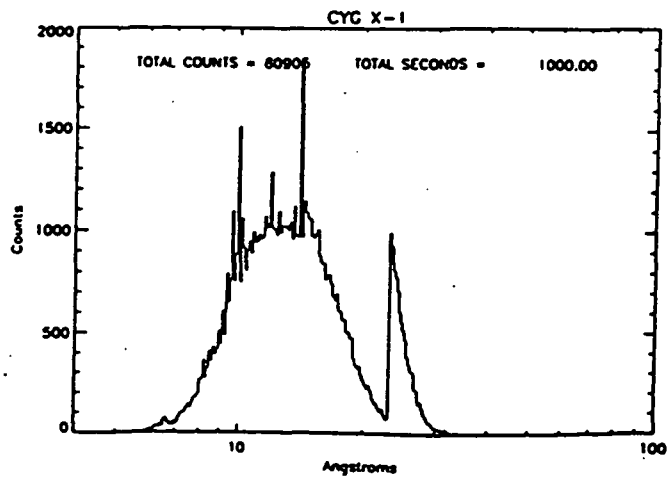
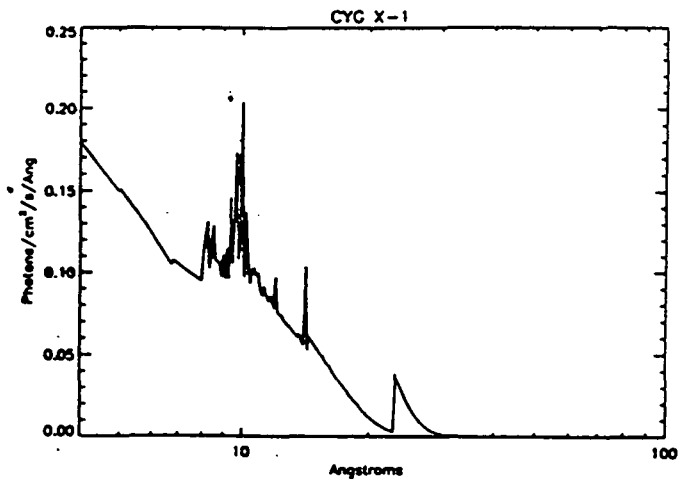
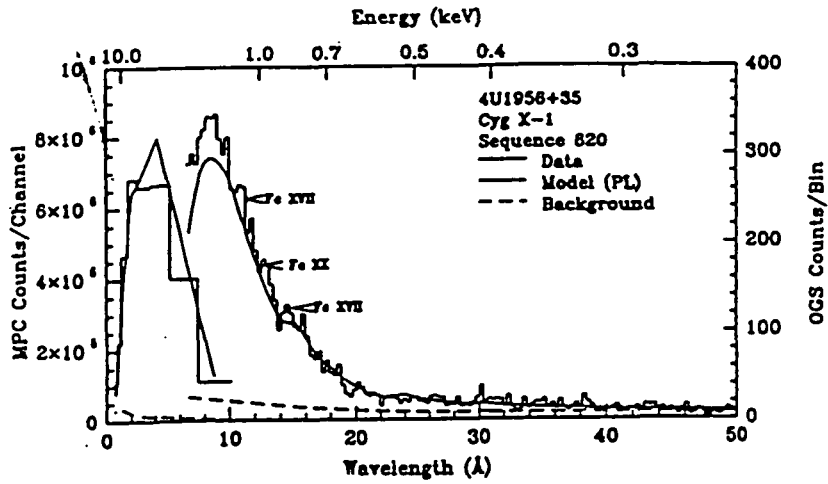
# Perseus at $z = .1$



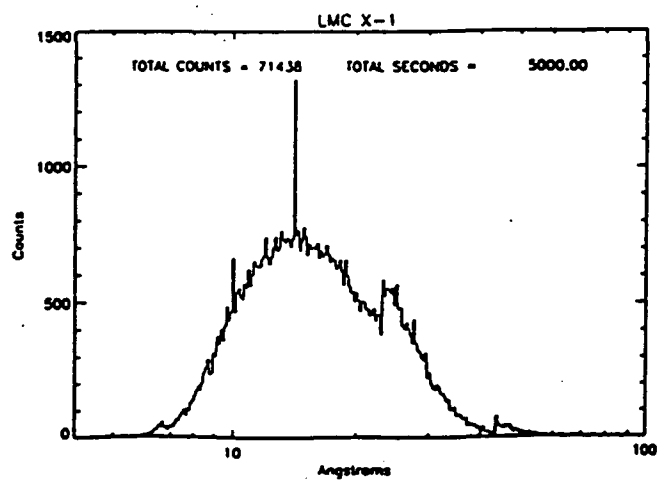
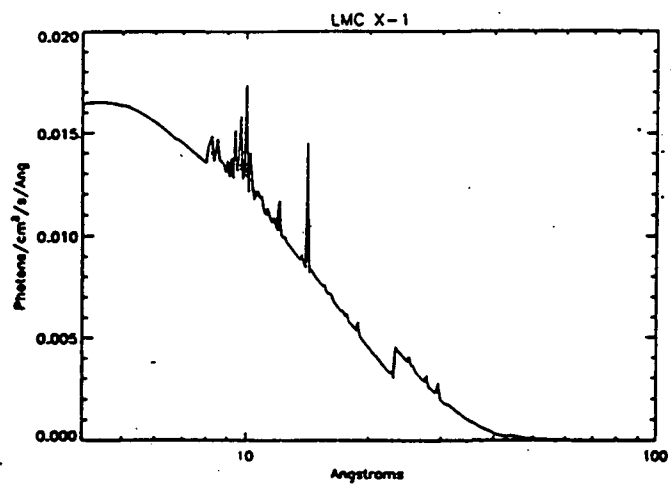
# SCO X-1



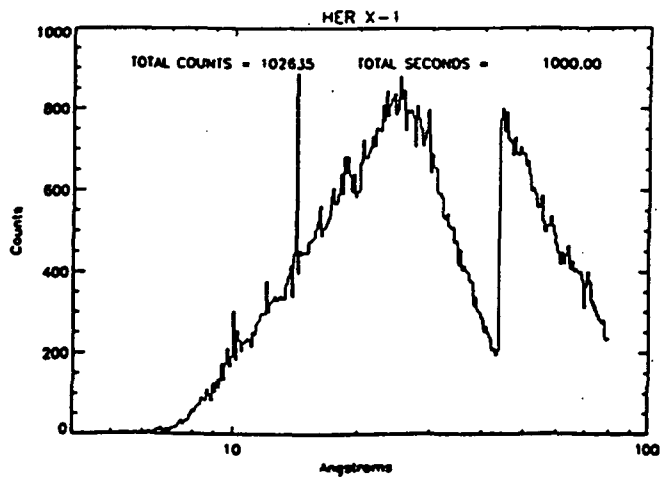
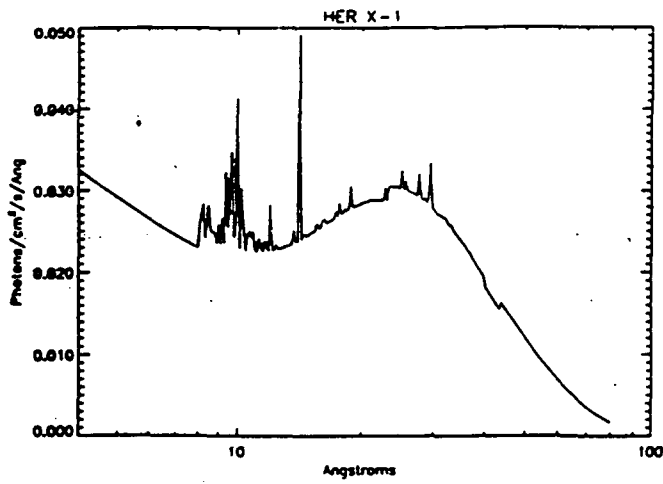
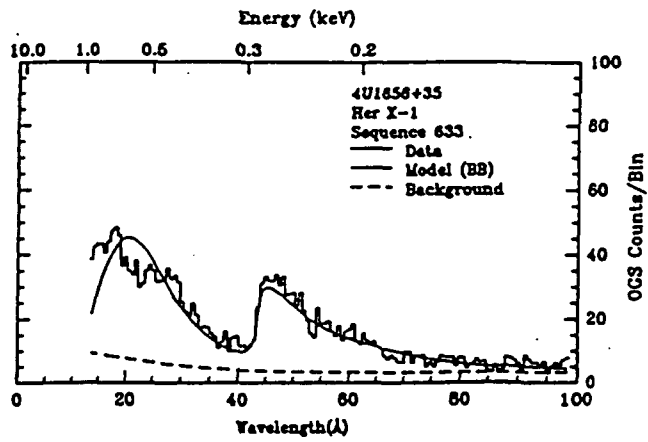
# CYG X-1



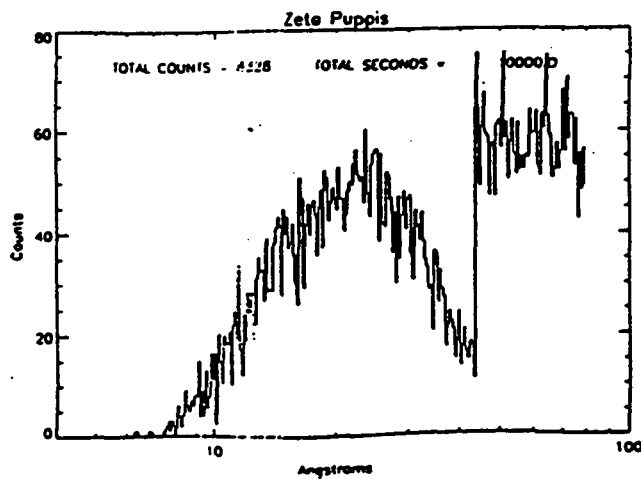
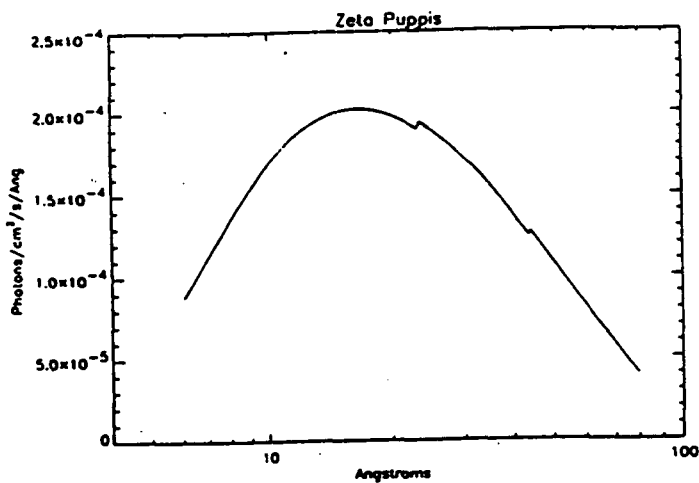
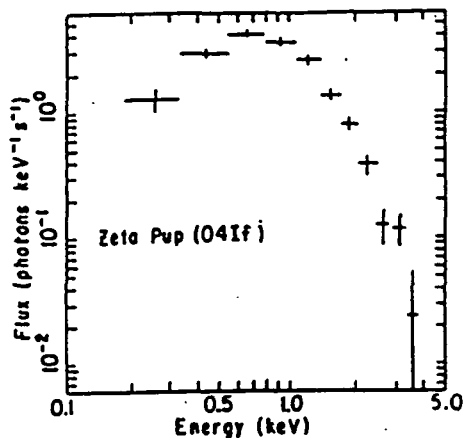
# LMC X-1



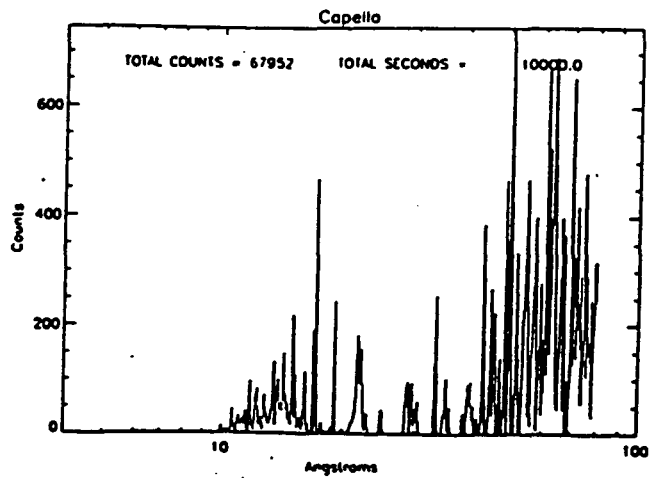
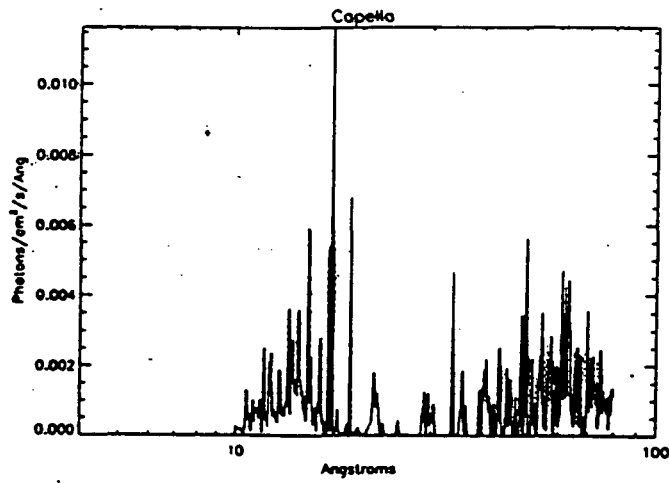
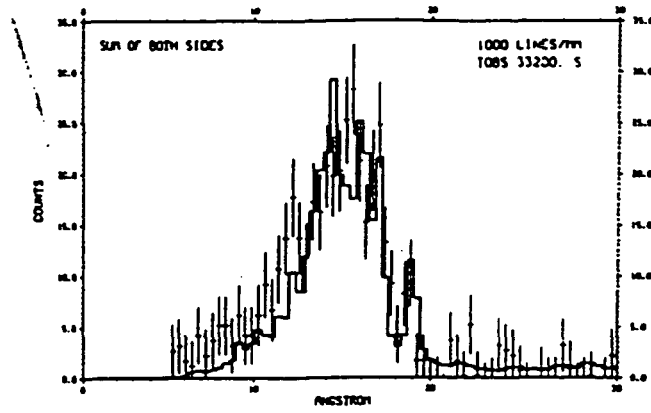
# HER X-1



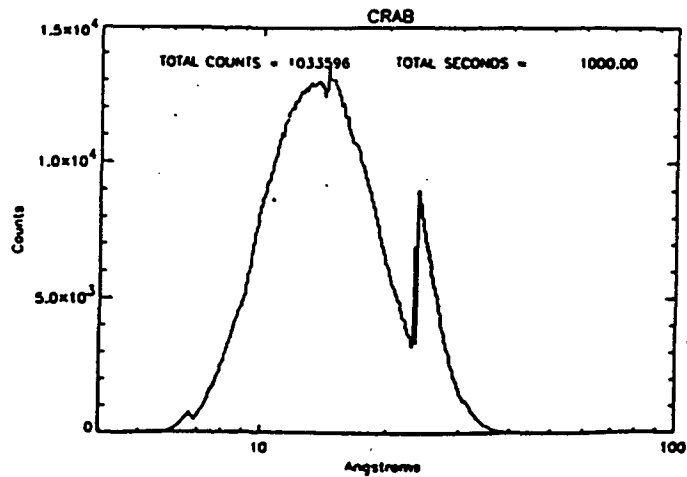
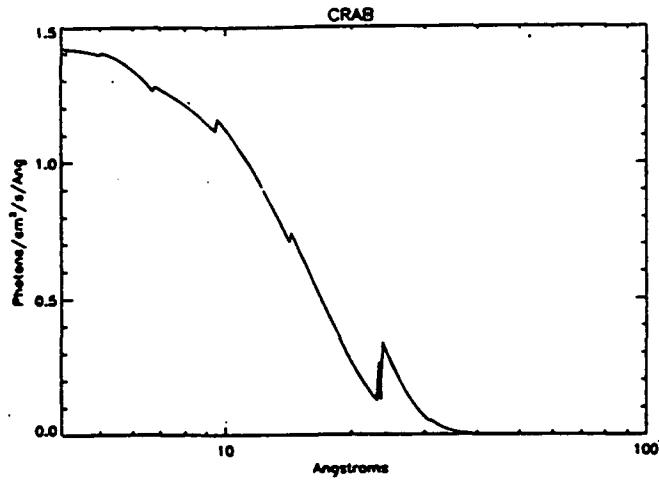
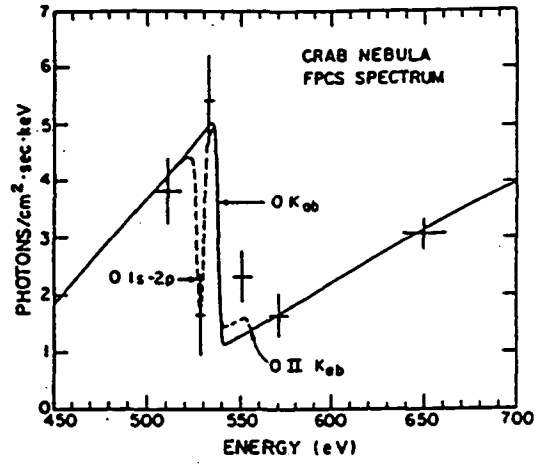
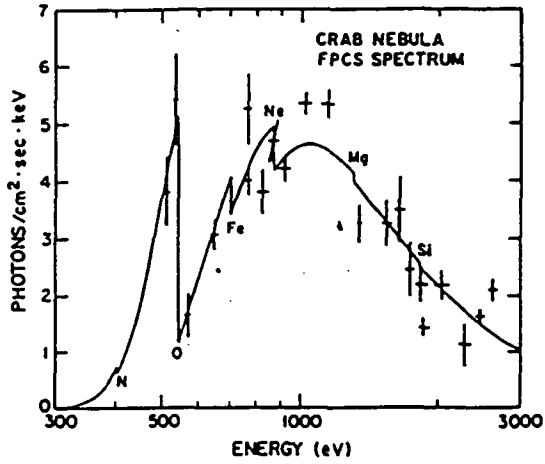
# Zeta Puppis



# Capella



# CRAB





\*SPECTRO-SPAS\*

SAMPLE LEXSA OBSERVING PLAN

CATEGORY	OBJECTS	OBSERVATIONS	TIME ALLOCATION
AGN	3C 273, PKS 2155, 4 OTHERS	6	40 Ks
CLUSTERS	M87, 2 OTHERS	3	70 Ks
X-RAY BINARIES	20 GALACTIC SOURCES	20	20 Ks
BLACK HOLE MASS	CYG X-1	10	10 Ks
STARS	2 LATE-TYPE, IRS CVn, 1 OB	4	20 Ks
SNR	N132D, CAS-A + 2 OTHERS	4	20 Ks
CVs	Am Her, U Gem, SS Cygni	3	20 Ks
COOLING FLOW GALAXIES	1 OBJECT	1	20 Ks
TOTALS		<u>51</u>	<u>220 Ks</u>

\*SPECTRO-SPAS\*

LEXSA COMPARISON WITH PREVIOUS MISSIONS

	LEXSA	OGS	EXOSAT
PEAK EFFECTIVE AREA (cm <sup>2</sup> )	100	.65	1.1 @ 80 A, .3 @ 15 A
SPECTRAL RESOLUTION	>100	100	35 @ 250 A, 5 @ 15 A
SPECTRAL RANGE (Angstroms)	6 TO 85	5 TO 60	6 TO 250

TOTAL OGS OBSERVING TIME FOR ENTIRE EINSTEIN MISSION:  $6.2 \times 10^5$  sec

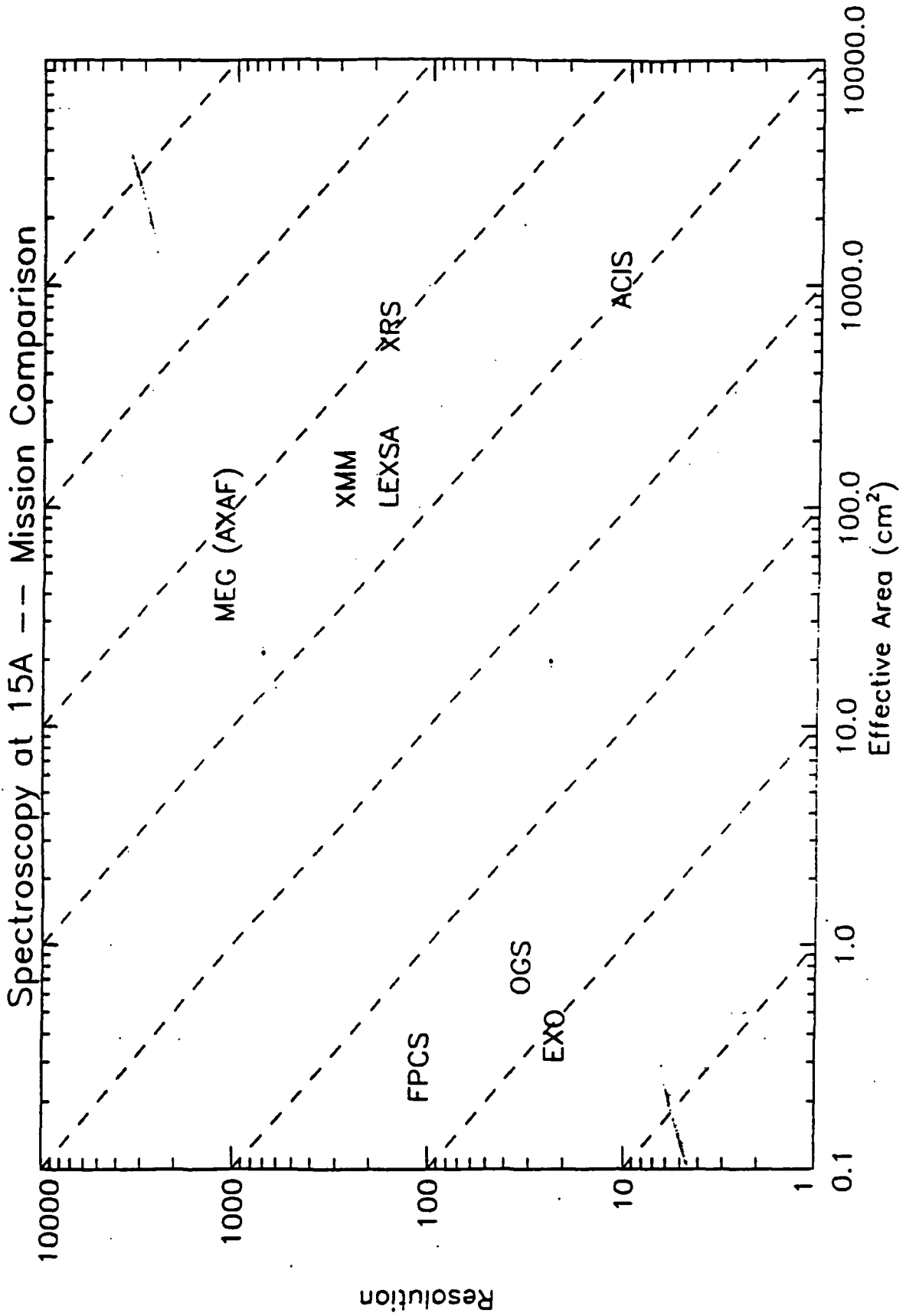
TOTAL OGS EXPOSURE FOR MISSION:  $.65 \text{ cm}^2 \times 6.2 \times 10^5 \text{ sec} = 4.0 \times 10^5 \text{ cm}^2 \text{ sec}$

OBSERVING TIME FOR ASTROSPAS MISSION: 5 d x .5 x 24h x 3600sec =  $2.2 \times 10^5$  sec

TOTAL LEXSA EXPOSURE FOR 5d MISSION:  $100 \text{ cm}^2 \times 2.2 \times 10^5 = 2.2 \times 10^7 \text{ cm}^2 \text{ sec}$

TOTAL LEXSA EXPOSURE	$2.2 \times 10^7$
-----	= 55
TOTAL OGS EXPOSURE	$4.0 \times 10^5$

OGS HAS THE LARGEST HIGH RESOLUTION CATALOG OF SPECTRA AVAILABLE PRIOR TO AXAF. LEXSA WILL DRAMATICALLY EXPAND THIS CATALOG IN BOTH QUALITY AND DIVERSITY.



**\*SPECTRO-SPAS\***

**LEXSA AND HERTA CHARACTERISTICS**

**LEXSA**

**HERTA**

**OPTICS**

LACQUER COATED WOLTER I  
5 NESTED MIRRORS  
GRATING ARRAY

WOLTER I  
3 NESTED MIRRORS

**DETECTOR:**

BACK-ILLUMINATED CCD

BACK ILLUMINATED PN CCD

**SPECTRAL RANGE**

6 TO 85 ANGSTROMS  
0.15 TO 2 keV

1.2 TO 60 ANGSTROMS  
0.2 TO 10 keV

**SPECTRAL RESOLUTION  
(E/DELTA E)**

100 MINIMUM

3 TO 80

**PEAK EFFECTIVE AREA**

100 cm<sup>2</sup> @ 1 keV

25 cm<sup>2</sup> @ 7 keV

**SPECTRO-SPAS COMBINES LOW ENERGY DISPERSIVE WITH SIMULTANEOUS AND OVERLAPPING  
BROAD BAND NON-DISPERSIVE SPECTROSCOPY.**

**\*SPECTRO-SPAS\***

**LEXSA DIVISION OF RESPONSIBILITY**

**MSSL**

**CYLINDRICAL CONTAINER-INCLUDING DOOR/SUNSHADE  
MECHANICAL INTERFACE TO ASTRO-SPAS  
THERMAL MODEL  
RADIATOR FOR CCD THERMAL ELECTRIC COOLER (TEC)  
OPTICAL BENCH  
LEXSA INTEGRATION AND QUALIFICATION TESTING**

**CASA**

**OPTICAL DESIGN  
GRATING ARRAY  
MIRROR BLANKS AND FIGURING**

**ALL**

**SCIENCE PLANNING  
QUALIFICATION TESTING  
SAFETY QUALIFICATION  
CALIBRATION  
MISSION SIMULATIONS**

**LPARL**

**CCD CAMERA, TEC AND GSE  
ELECTRICAL INTERFACE TO ASTRO-SPAS  
CABLING  
HEATERS AND THERMAL CONTROL HARDWARE  
THERMAL PRE-COLLIMATOR  
INTEGRATION SUPPORT  
PROJECT MANAGEMENT**

**\*SPECTRO-SPAS**

**TIMELINE FOR THE LEXSA INVESTIGATION**

TASK	1991	1992	1993	1994	1995
Definition Study	***	.	.	.	.
Agree on S/C Resources	^	.	.	.	.
Experiment Development	.	*****	*****	.	.
Initial IIP	.	^	.	.	.
Safety Review II	.	.	^	.	.
I/F Check W/Breadboard	.	.	^	.	.
Ship to England	.	.	.	^	.
Experiment Integration	.	.	.	*	.
Qualification Testing	.	.	.	***	.
Ship to Panter Facility	.	.	.	^	.
Calibration	.	.	.	**	.
Delivery to MBB	.	.	.	^	.
Integration with ASTRO-SPAS	.	.	.	***	.
Transport to KSC	.	.	.	*	.
Integration with Shuttle	.	.	.	***	*
Launch	.	.	.	.	^

\*SPECTRO-SPAS\*

SUMMARY

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SPECTRO-SPAS WILL OBTAIN SPECTRA OF A QUALITY AND DIVERSITY UNPRECEDENTED  
PRIOR TO AXAF/XMM

SIMULTANEOUS LOW ENERGY DISPERSED SPECTRA WITH OVERLAPPING BROAD  
BAND NON-DISPERSIVE SPECTRA, WITH IMAGING-----UNIQUE UNTIL XMM

ABLE TO ADDRESS FUNDAMENTAL PROBLEMS IN ASTROPHYSICS

MEASUREMENT OF  $H\alpha$  and  $Q_0$

MEASUREMENT OF BLACK HOLE MASS

TEMPERATURE, DENSITY AND OXYGEN ABUNDANCE IN THE ISM

PHYSICS OF CLUSTER AND AGN X-RAY EMISSION

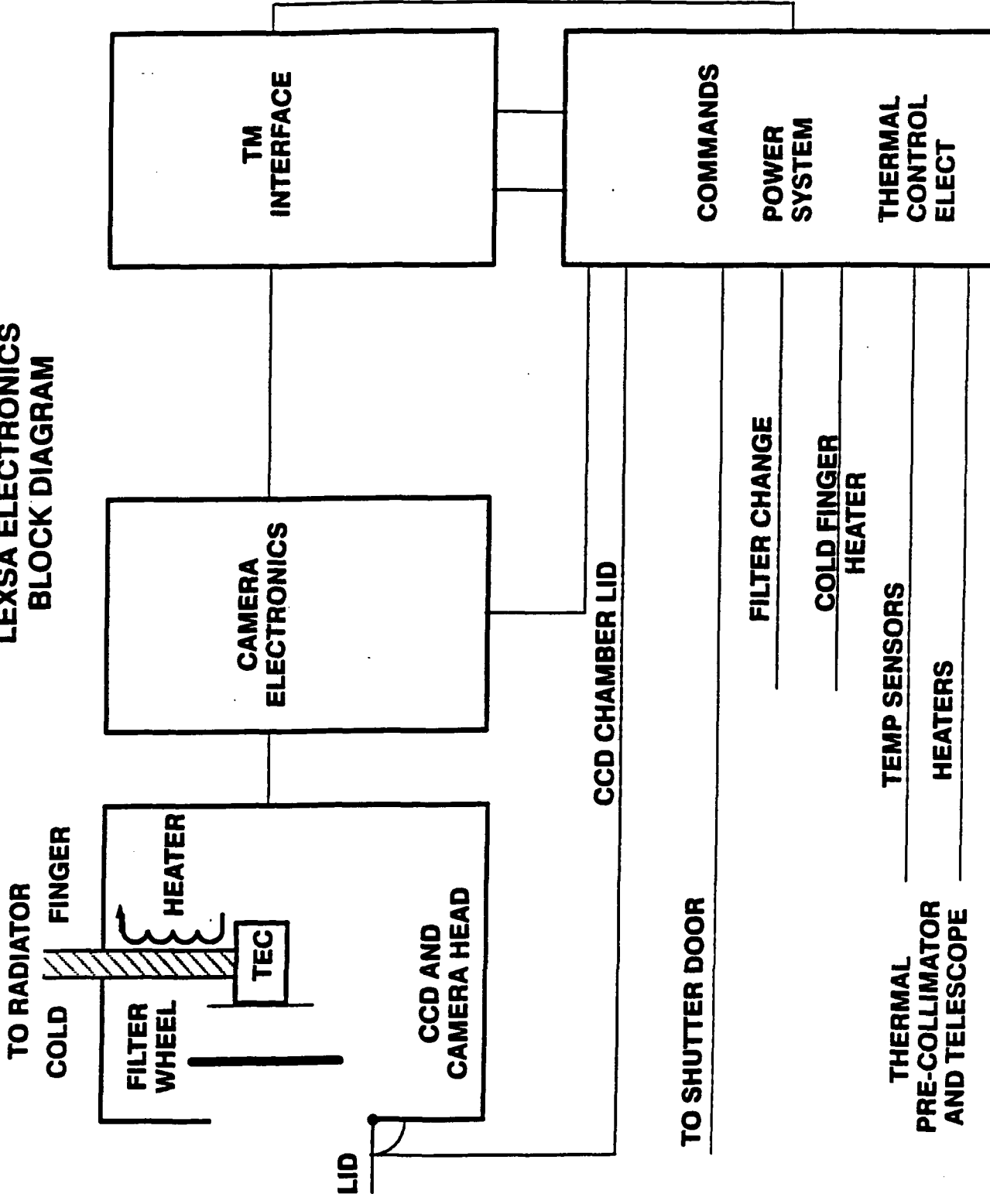
PHYSICS OF STELLAR X-RAY EMISSION

SPECTRAL ATLAS WILL GUIDE FUTURE OBSERVATIONS AT ALL WAVELENGTHS

SPECTRO-SPAS IS OF MODEST COST

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**LEXSA ELECTRONICS  
BLOCK DIAGRAM**



1586ms

1586ms



**\*SPECTRO-SPAS\***

**LEXSA CCD CAMERA**

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**CCD:** BACK-ILLUMINATED TEKTRONIX 1024 X 1024

**PIXEL SIZE:** 24 MICRON SQUARE

**OPERATIONAL MODE:** SINGLE PHOTON COUNTING

**READ OUT:** FRAME TRANSFER MODE, 50 K PIXELS/sec

**ENERGY RESOLUTION:** 50-90 eV IN THE .15-2 keV RANGE (5 e- NOISE)

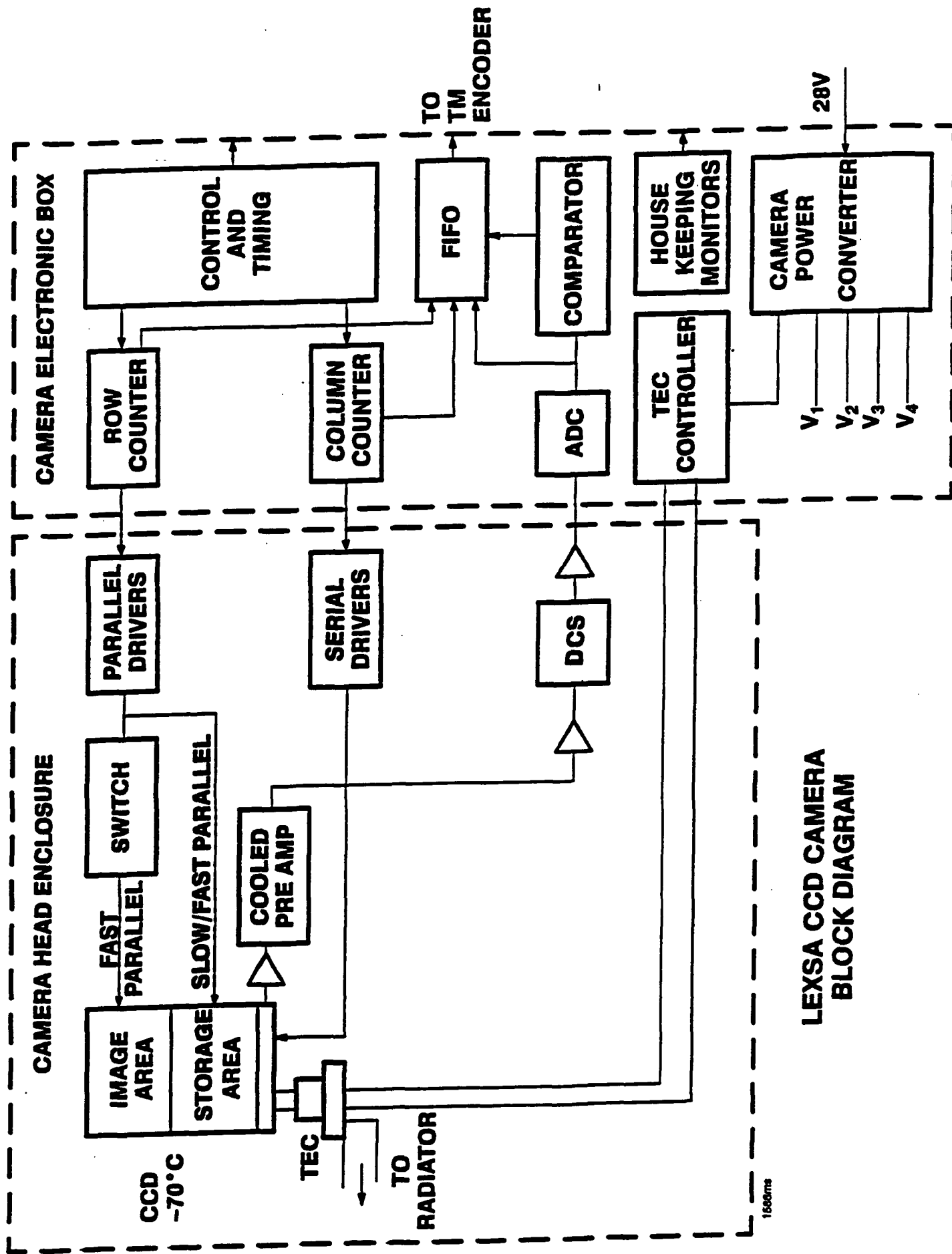
**COOLING:** -90 C BY TEC WITH RADIATIVE COOLING

**EVENT ENCODING:** 13 BITS ENERGY, 10 BITS X, 9 BITS Y

**INTEGRATION TIME:** 10 sec

**FRAME TRANSFER TIME:** 10 ms

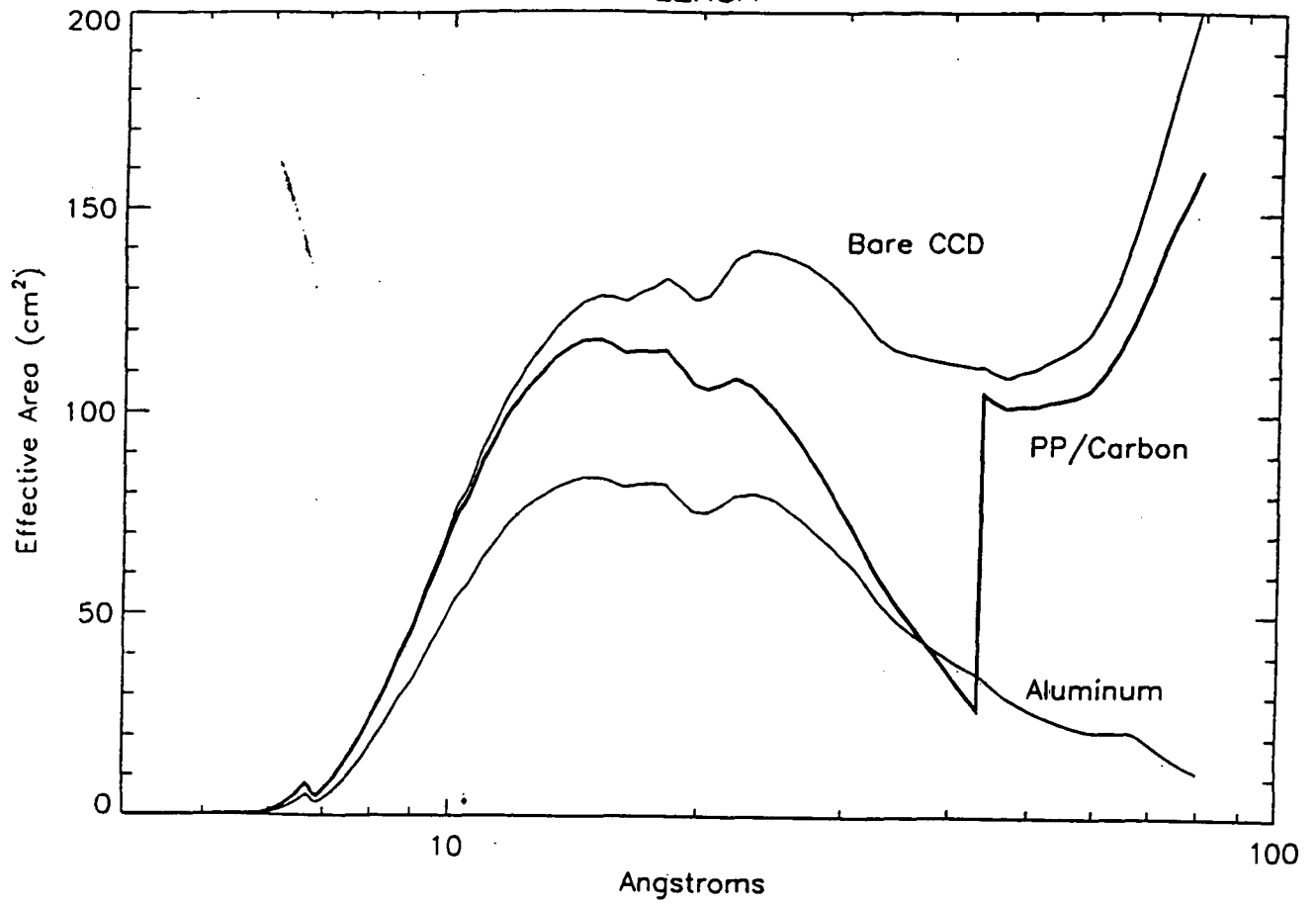
**PIXELS PER RESOLUTION ELEMENT:** 260



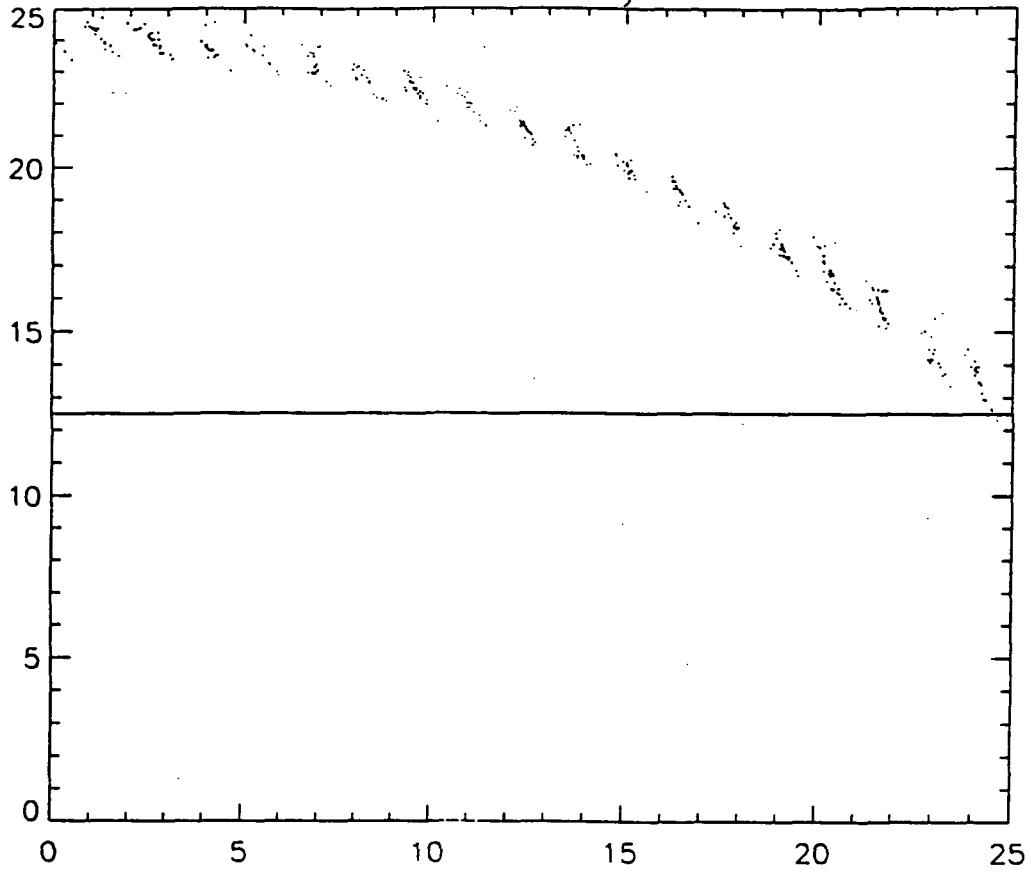
LEXSA CCD CAMERA  
BLOCK DIAGRAM

1560ms

LEXSA



LEXSA CCD Layout



PARAMETERS OF THE LEXSA TELESCOPE MIRRORS

Mirror	Entrance Radius (mm)	Exit Radius (mm)	Entrance Flange Width (mm)	Exit Flange Width (mm)	Nominal Cone Angle (deg)	Nominal Grazing Angle (deg)	Geom. Area (cm <sup>2</sup> )	Weight (kg)
P2	399.3	376.4	25.4	38.3	2.25			40
H2	373.3	316.2	36.4	25.4	7.00	2.3	570	30
P3	328.2	309.2	24.9	36.3	1.85			27.8
H3	309.2	261.7	36.6	25.2	5.76	1.9	400	20.2
P4	274.2	258.5	24.9	32.3	1.56			27.0
H4	256.3	217.1	33.0	25.0	4.84	1.6	275	19.8
P5	225.5	212.5	25.2	30.7	1.27			21.7
H5	210.8	178.5	30.2	25.2	3.97	1.3	185	15.9
P6	181.1	170.7	29.0	25.4	1.02			19
H6	169.3	143.4	25.4	29.4	3.19	1.0	110	14
Total							1540	235

Mirror Designation, eg. P3 indicates Paraboloid that is the third largest or third paraboloid in from the outside of the mirror array. P1 and H1 are not included since only the five innermost mirrors are present in this array.

Design: Wolter I, Five nested mirror-pairs

Focal Length: 2313.5 mm

Paraboloid Axial Length: 584 mm

Hyperboloid Axial Length: 465 mm

Center Support Plate Thickness: 38.1 mm

Center Support Plate Weight: 66 kg

Plate Scale: 89 arc-sec/mm

Nominal Wall Thickness: 10 mm

Material: 5083 Aluminum in O Condition

Reflecting Surface: Lacquer, Overcoated by Gold

Nominal Flange Thickness: 12.5 mm

## LEXSA DISCREET COMMANDS

1. Power System on
2. Power System off
  
3. Camera Electronics on
4. Camera Electronics off
  
5. TM Interface on
6. TM Interface off
  
7. Thermal Elect. Cooler on
8. Thermal Elect. Cooler off
  
9. Cold Finger Heater on
10. Cold Finger Heater off
  
11. Thermal Control Telescope Heaters on
12. Thermal Control Telescope Heaters off
  
13. Precollimator Heaters on
14. Precollimators Heaters off
  
15. CCD Lid open
16. CCD Lid open
17. CCD Lid close
  
18. Shutter Door open
19. Shutter Door open
20. Shutter Door close
  
21. Filter Change

LEXSA MONITORS

1. + 28 V on/off to Power System Input
2. Power on/off to CCD Camera
3. Power on/off to TM Interface
4. Power on/off to TEC
5. Power on/off to Cold Finger Heater
6. Power on/off to Telescope Thermal Control Heaters
7. Power on/off to Thermal Precollimator Heaters
8. Power on/off to CCD LED Calibrator
9. CCD Lid Closed
10. CCD Lid Open
11. Shutter Door Closed
12. Shutter Door Open

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LOW ENERGY X-RAY SPECTROGRAPH FOR ASTRO-SPAS

BRIEFING TO

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
HIGH ENERGY ASTROPHYSICS DIVISION

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BY

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MULLARD SPACE SCIENCE LABORATORY



# LOW ENERGY X-RAY SPECTROGRAPH FOR ASTRO-SPAS

## STATEMENT OF WORK

### 1.0 INTRODUCTION

The Low Energy X-ray Spectrograph for ASTRO-SPAS (LEXSA) is to fly on the ASTRO-SPAS, a spacecraft launched, deployed, retrieved and returned from orbit by the Space Shuttle. The ASTRO-SPAS is provided by the German Government thru a contractor, the Messerschmitt-Boelkow-Blohm (MBB) Co. of Otterbrunn, Germany. The LEXSA is being developed jointly by the Lockheed Palo Alto Research Laboratory (LPARL), the University of Colorado Center for Astrophysics and Space Astronomy (CASA) and the Mullard Space Science Laboratory (MSSL) of the University College London in the United Kingdom. The division of responsibility among these three institutions is given in Section 6.0 and in more detail in the Work Breakdown Structure.

### 2.0 SCOPE

LPARL shall provide the necessary skills, services, materials, equipment, documentation, software and facilities to complete the tasks listed below. The division of labor in the LEXSA investigation between LPARL, CASA and MSSL is given in detail in the Division of Responsibility. This statement of work only includes the responsibilities assigned to LPARL and does not include the efforts assigned to CASA and MSSL in Section 6.0 of this document. In discharging their assigned responsibilities MSSL is to be funded by the United Kingdom and CASA by the NASA under a separate grant. This statement of work and the attached cost proposal assumes that CASA and MSSL provide their efforts and fulfill their responsibilities in a complete and timely manner. Further, this statement of work assumes that MBB provides the services described in the Memorandum of Understanding between NASA and the German space agency, DARA. This Statement of work covers the LPARL efforts in the instrument development phase and ends with launch of the Space Shuttle, carrying the LEXSA. A separate investigation for flight operations, data analysis and publication is to be covered under a follow-on contract.

### 3.0 PERIOD OF PERFORMANCE

The period of performance proposed for this contract is 38 months, from 1 January 1992 to February 28 1995.

#### 4.0 CONTRACTOR TASKS

The Lockheed Palo Alto Research Laboratory shall provide the necessary personnel, material and services to complete the following tasks in conducting a scientific investigation involving a Low Energy X-ray Spectrograph for flight on the ASTRO-SPAS.

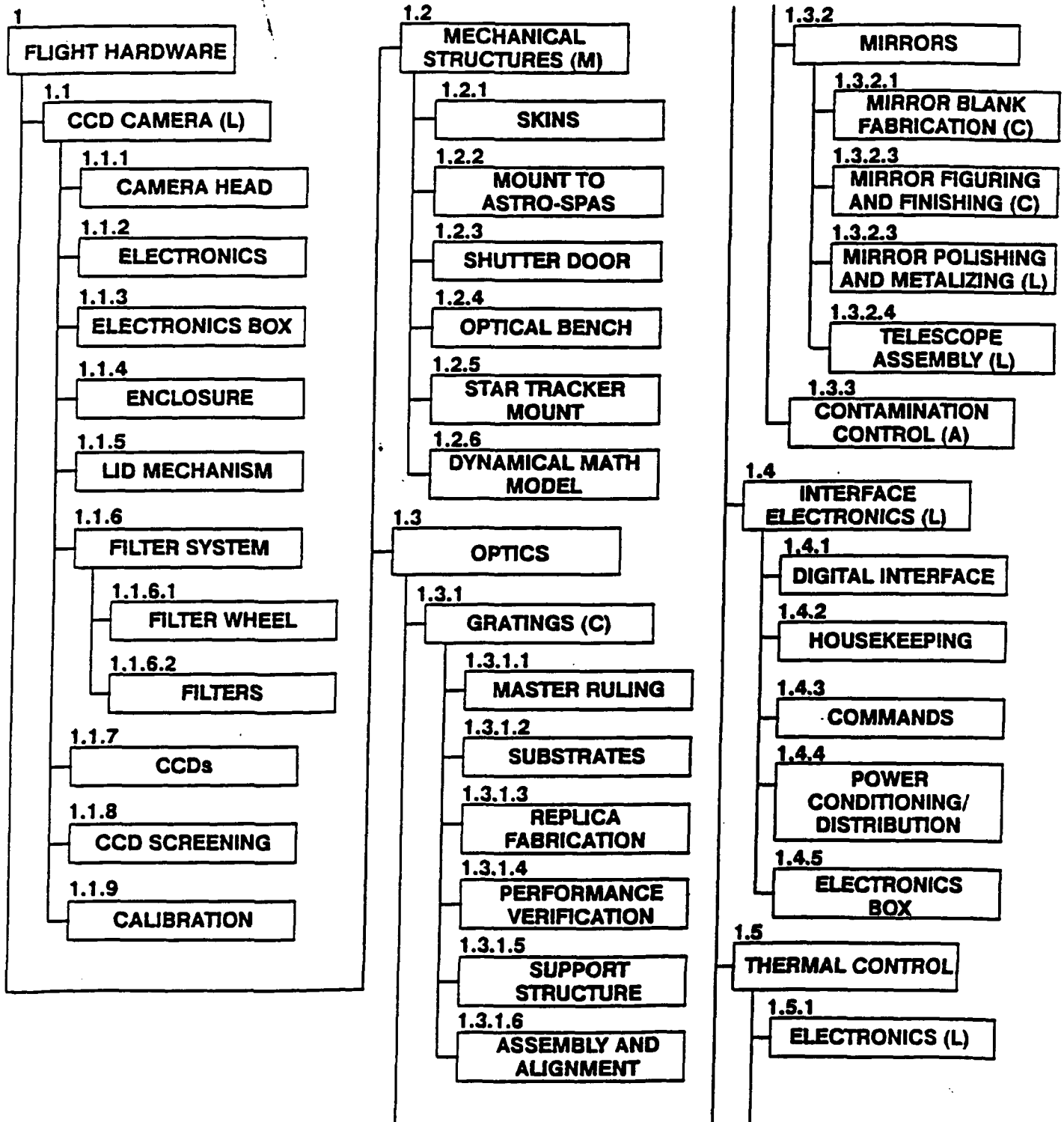
1. Design, fabricate and calibrate a CCD camera system involving a 1024 by 1024 pixel CCD operated in single photon counting mode.
2. Lacquer coat and vacuum deposit gold on the reflecting surfaces of five grazing incidence mirror-pairs, two of which are to be supplied by CASA.
3. Design, fabricate or procure the necessary power conditioning, thermal control and command and data handling electronics, including cabling, necessary to operate the LEXSA payload and present the data to the ASTRO-SPAS interface for recording and transmission to the ground.
4. Perform the necessary analyses and tests to qualify the LPARL portion of the LEXSA for integration with the ASTRO-SPAS and flight on the STS.
5. Provide a Principal Investigator for the LEXSA investigation and assume the associated responsibilities in seeing the investigation to a successful conclusion.
6. Design, fabricate or procure the necessary ground support equipment to operate the LEXSA electronics, issue commands and capture and display the data.

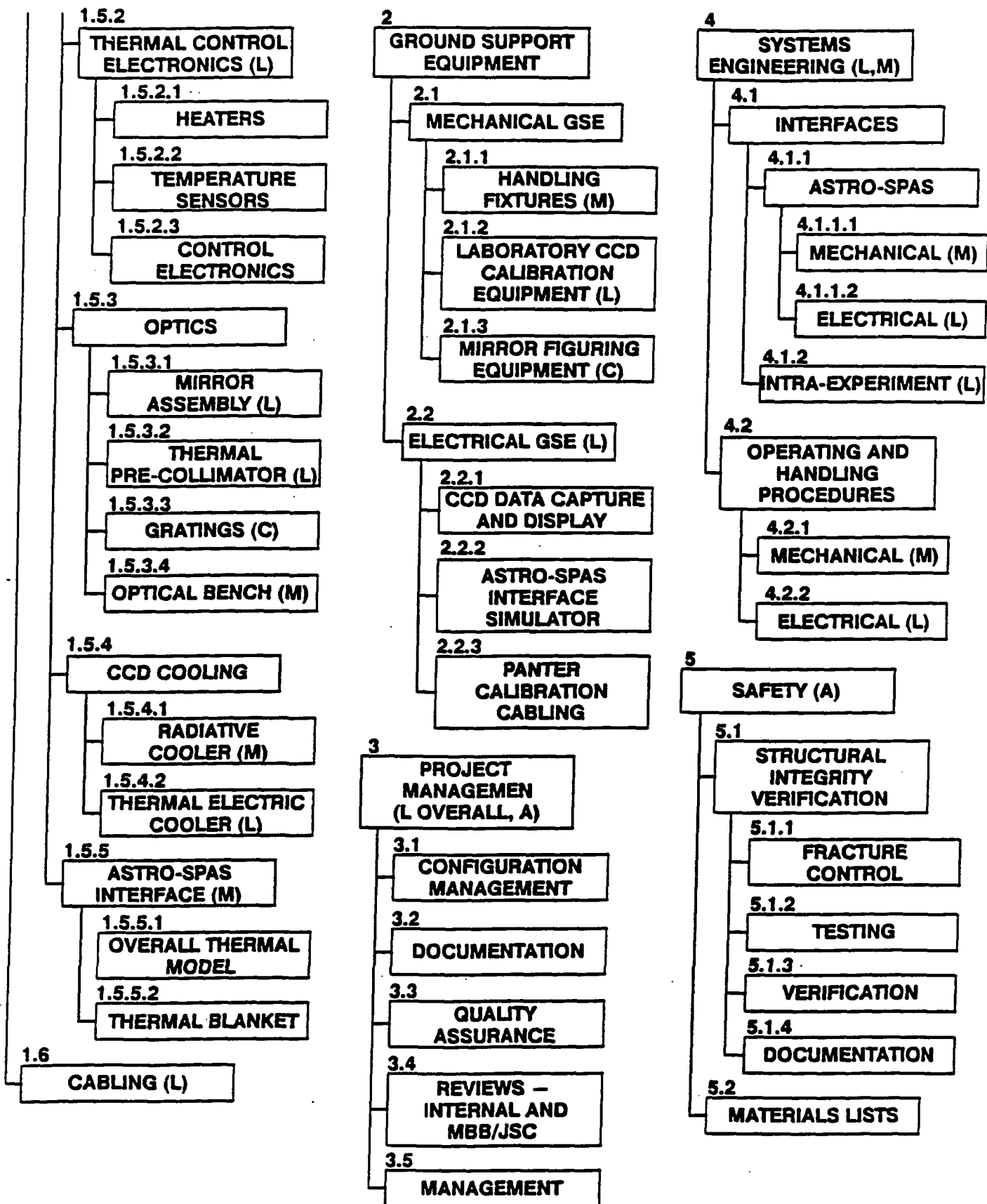
#### 5.0 ASSUMPTIONS MADE IN THE LEXSA COST PROPOSAL

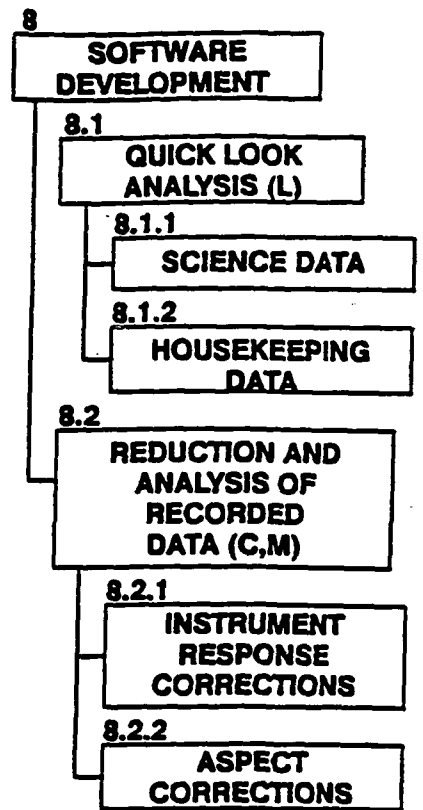
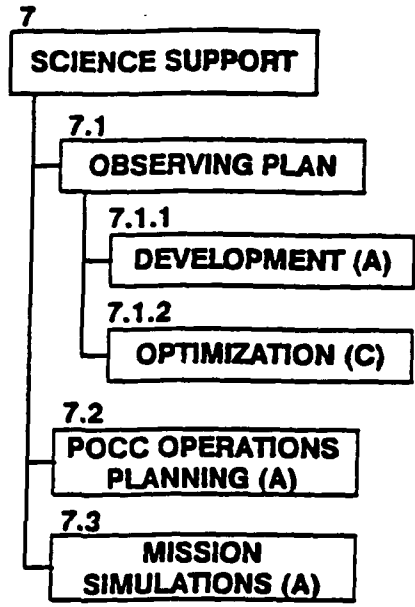
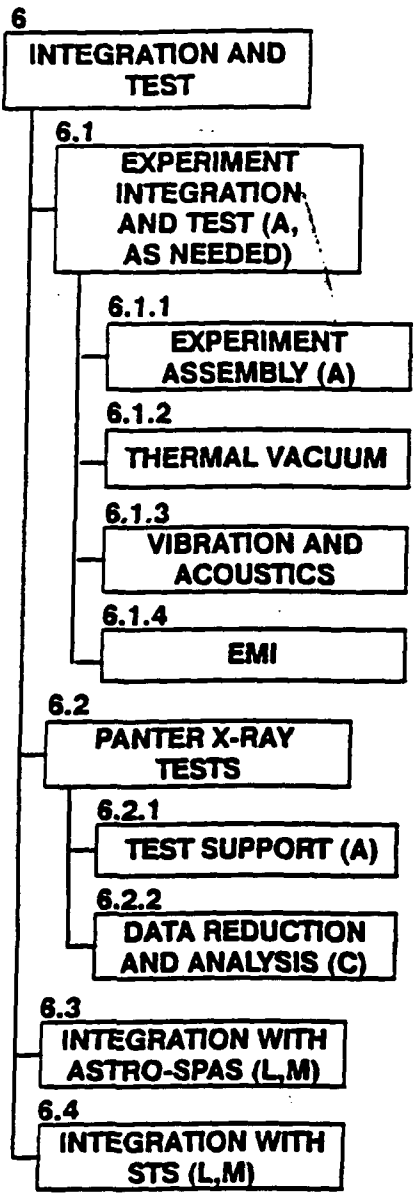
1. Vibration test of the full-up LEXSA shall be provided at no cost to LPARL except for experiment support personnel required for the test.
2. Use of the MPE Panter facility for x-ray calibration of the LEXSA shall be provided at no cost to LPARL except for experiment support personnel required for the test.
3. Experiment integration, thermal vacuum testing and EMI testing of the LEXSA will be performed in England. Except for the labor of LPARL experiment support personnel, no costs for qualification testing the assembled LEXSA experiment have been included in the associated cost proposal.

# WORK BREAKDOWN FOR LEXSA COST PROPOSAL FOR PERIOD FROM PROJECT INITIATION TO LAUNCH

RESPONSIBILITIES: (L) = LPARL, (M) = MSSL, (C) = CASA, (A) = ALL







APPENDIX 2

TEST PLAN FOR 24.017 AT THE HIGH ENERGY LASER SYSTEM TEST FACILITY

# Test Plan for the Lockheed Palo Alto Research Laboratory Aries Payload

## 1.0 PURPOSE

The purpose of this test is to calibrate an x-ray spectrograph to be launched on a NASA-Aries sounding rocket in early July of this year. The instrument is an objective grating spectrograph having 12 large gratings in front of a nested 3 mirror-pair Wolter I x-ray telescope. The gratings disperse the x-ray spectrum, diffracting x-rays of different energies thru different angles, while the telescope images the dispersed x-rays to different positions at its focal plane. An image sensitive proportional counter (PGI) encodes the position of each detected x-ray. During the rocket flight the spectrograph will measure the x-ray spectrum of a bright binary source, Sco X-1 in the energy range from .2 to 2.5 keV. While at HELSTF the spectrograph will be calibrated at selected energies in this range. We expect to arrive at HELSTF the last week in May and perform the set-up and testing in approximately a period of 5 working days.

## 2.0 Calibration Goals

The goals of this test are to measure the effective area and energy resolution of the spectrograph, verify optical-mechanical alignment, and verify ability to perform order separation using the non-dispersive energy resolution of the PGI. X-ray energies of .277, .705, .932, 1.25, and 1.5 keV will be used for these tests.

## 3.0 Participants

The calibration will be conducted by personnel from the Lockheed Palo Alto Research Laboratory (LPARL), the Mullard Space Science Laboratory (MSSL) in England and the University of Colorado's Center for Astrophysics and Space Astronomy (CASA). The experiment personnel will consist of Richard Catura and Lawrence Shing of LPARL, Jon Lapington and Jason Tandy from MSSL and Dennis Gallagher (and possibly Webster Cash) from CASA. Dick Catura will serve as coordinator of the tests.

## 4.0 Test Components

Some support hardware (proportional counter and x-ray source/filter wheel) for this test will be the same as that used for the CASA test of 36.095 UH.

4.1 Instrument: The instrument is contained in a section of an Aries sounding rocket payload. It is 44 inches in diameter, 13 ft 8 in in length and is about 1200 lbs in weight. The payload is self contained but requires an electrical umbilical cable and 3 gas lines for its' operation. The required vacuum feed-thrus will be provided on an 8 inch ISO flange. MSSL will provide the gas for the proportional counter. HELSTF is requested to provide a small vacuum roughing pump. The payload and its' support fixture are so large that the vacuum chamber must be opened and a crane used to lift them into position and remove them after the test. HELSTF is requested to provide this crane.

4.2 Alignment Fixture: LPARL will provide a fixture to support the payload during the tests. This fixture places the centerline of the payload 48 inches above its base. The payload centerline is to be aligned with that of the 1000 ft tube and blocks should be provided by HELSTF for this purpose.

4.3 Proportional Counter: A proportional counter will be provided by

CASA that will be mounted stationary in the BSAF. CASA will provide the necessary vacuum gas feed through to operate the counter. CASA will need a bottle of P-10 gas and about 30 feet of 0.25 inch OD tubing to supply the counter with gas from the vacuum side of the feed throughs to the proportional counter. The 8 inch vacuum flange from CASA will have the necessary electrical feed throughs for operation of the proportional counter. This flange is in addition to the 8 inch ISO flange for the Aries payload. The gas feed throughs are on a 2.75 inch conflat vacuum flange so these will need to be attached to the BSAF.

4.4 X-ray Source/Filter Wheel: CASA will provide a Manson Soft X-ray source, a filter wheel to isolate X-ray energies and associated power supplied for its operation. The X-ray source/filter wheel is a single unit that is to be attached to the end of the LBP. This unit contains a single 5 inch 6-bolt flange that contains an o-ring and groove for a vacuum seal to the LBP. This unit also contains a 2.5 inch hand operated vacuum gate valve to isolate the source from the LBP. This is so the source chamber can be brought up to atmospheric pressure to facilitate source anodes changes without having to bring the LBP up to air pressure. This source will be operated by CASA/LPARL personnel.

## 5.0 ACTIVITIES

The activities for these tests divide into four periods: installation and check-out of equipment, alignment of the instrument to the source, the actual calibration, and deinstallation. We expect the total time at HELSTF to be 5 working days.

5.1 Installation: Installation is expected to take one working day. This involves installation of the instrument into the BSAF and attaching the vacuum feed throughs. The source/filter wheel at the end of the LBP and the Manson proportional counter with gas feed throughs may still be in place or will be installed concurrently by CASA.

5.2 Instrument alignment: The next activity is to align the instrument optical axis to the source. Reference mirrors on the payload will be used to retro-reflect a laser beam sent from the source position. Alignment will be accomplished vertically by shimming beneath the aft part of the support fixture and horizontally by its' lateral shift. Thus the base of the fixture should be supported on blocks to allow freedom for the alignment. This activity requires the 1000 ft tube to be at atmospheric pressure. We expect it will take less than 0.5 days for the alignment. The entrance aperture of the spectrograph is 30 inches in diameter so that the full un baffled 36 inch diameter of the tube will be required.

5.3 Calibrations: The main activity to take place is the calibration of the instrument. Verification of grating and telescope alignment and instrument resolution will be done simultaneously while measuring the instrument's effective area. This will involve recording spectra of the source output at the five different energies. This activity will require only one cycle of the main vacuum, but will require six to ten cycles of the source vacuum which will be isolated from the main vacuum by a gate valve. We expect this activity to take from two to three days.

5.4 Deinstallation: The last activity is deinstallation of our equipment and packing. We expect this activity to take 0.5 day.



## 6.0 OPERATING PROCEDURES

The operating procedures required for a successful test can be divided into five main categories: Compliance with HELSTF safety procedures throughout our test, compliance with HELSTF pump down/up to air procedures, source operating procedures, pump down/up air procedures for the proportional counters and power-on procedures for the instrument.

The first two of these procedures will be strictly followed by all experiment personnel during all phases of the test.

### 6.1 Source operating procedures are as follows:

The source contains high voltages so all procedures that require personnel near or touching the source will require that power be turned off to the source. Only experiment personnel will operate the source. The source generates Soft X-rays (1.5 keV) that do not have the energy necessary to pass through the source vacuum enclosure or fuse silica windows, so exposure of X-rays to personnel is not possible with this source. The source emits some UV radiation so during source operation the fuse silica window mounted on the source vacuum chamber will be shielded with UV absorbing plastic.

Before opening the gate valve of the source to the LBP while the LBP is under vacuum, verification of the source chamber vacuum will be made by an ion gauge that is attached to the source chamber. The source chamber will only be opened to the LBP vacuum if its pressure is below  $8 \times 10^{-5}$  torr.

To change a source anode the source power is turned off and the gate valve closed. The source chamber is then brought up to air. The source anode is then replaced and the source chamber evacuated to below  $8 \times 10^{-5}$  torr before opening the gate valve.

Selection of one of the six filters on the filter wheel is easily done by turning a knob. This presents no risk to the vacuum or electrical systems and requires only communication between experiment personnel to determine which filter is in place.

We will require a video transmission of the source current and high voltage settings to a trailer located next to the BSAF.

### 6.2 Pump down procedures are as follows:

The proportional counter gas valves need to be configured for pump down. The source gate valve needs to be in the closed position. Communication to HELSTF personnel by experiment personnel that the following has been done and that pump down can proceed.

Pump down procedures for the PGI to be supplied by MSSL.

### 6.3 Up to air procedures are as follows:

The main reason for these up to air procedures is to protect the thin plastic window on the monitor proportional counter from breakage from excessive pressure differentials across the window.

The source gate valve is in the closed position and the source power is turned off. The instrument power is turned off.

The proportional counter power is switched off. The gas line supplying the proportional counter with P-10 gas V3 is shut off. (CASA)

The proportional counter and gas lines are then evacuated by a small pump, N2 fully opened. CASA will provide this pump. (CASA)

Communication to HELSTF personnel by CASA personnel that the cryogenic pump gate valve is to be closed. (CASA)

Communication to CASA personnel by HELSTF personnel that the gate valve has been closed. (HELSTF)

The small amount of gas in the proportional counter is then vented into the BSAF/LBP by opening V4. (CASA)

The proportional counter vent line V7 is then opened to let air into the proportional counter and into the BSAF/LBP. The vent rate is then adjusted to maintain the pressure in the proportional counter at 200 torr. (CASA)

Communication to HELSTF personnel that venting of the BSAF/LBP can begin.

During this time the pressure inside the BSAF/LBP is to be communicated to CASA personnel in increments of 50 torr until a BSAF/LBP pressure of 400 torr is reached. (CASA/HELSTF)

Up to air procedures for the PGI to be supplied by MSSL.

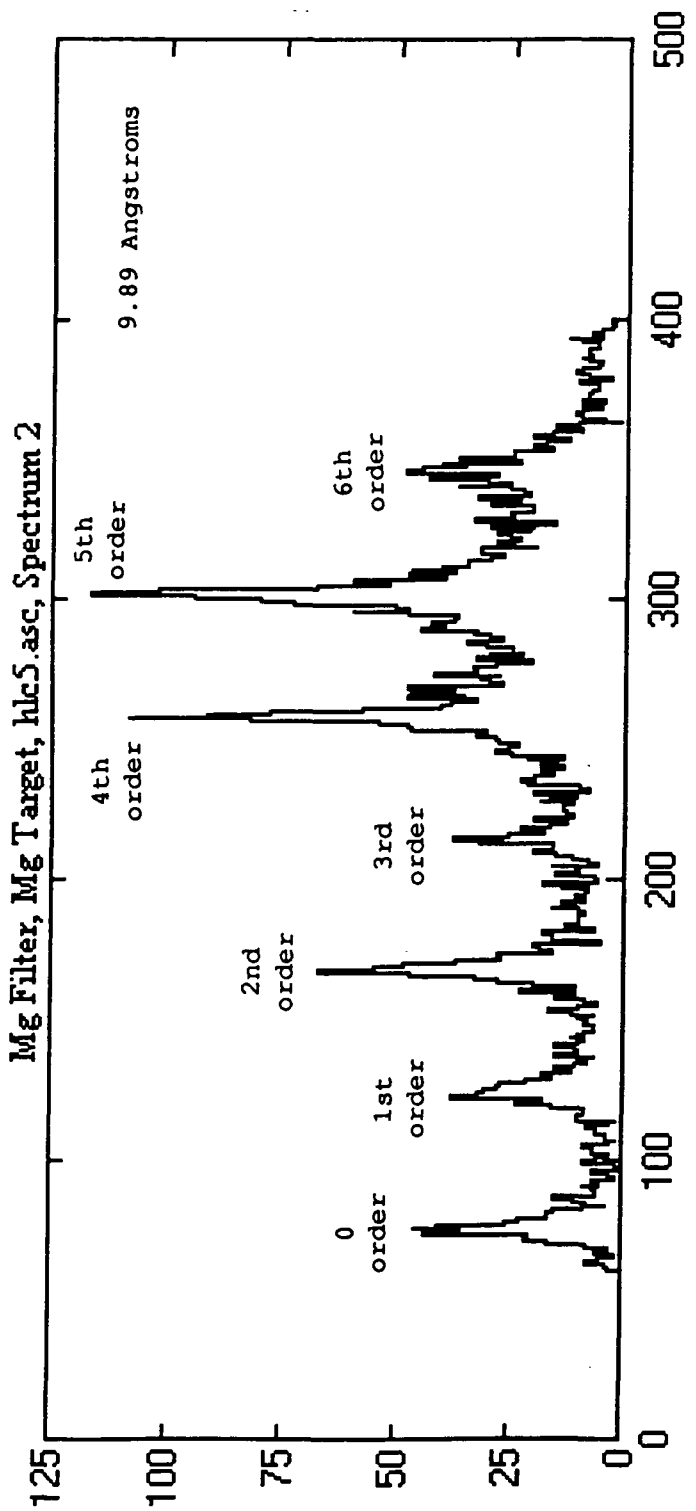
Communication to experiment personnel by HELSTF personnel that the BSAF/LBP is at atmospheric pressure and ready to enter. (HELSTF)

#### 6.4 Instrument turn on procedures:

Instrument turn on procedures require communication by HELSTF personnel to experiment personnel that the BSAF/LBP pressure is below  $5 \times 10^{-5}$  torr. Power is then applied to the instrument by experiment personnel and the experiment begun.

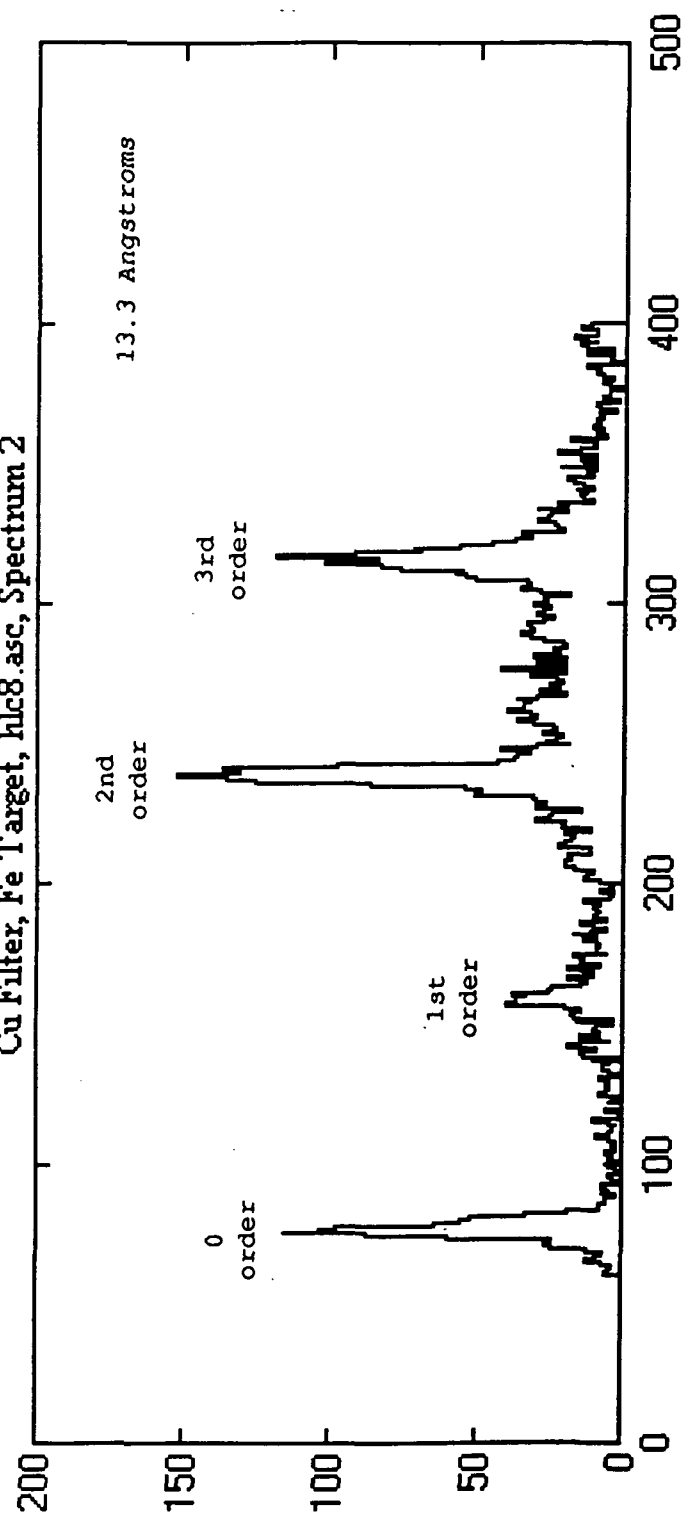
APPENDIX 3

SOFT X-RAY SPECTRA ACQUIRED BY THE SPECTROGRAPH DURING THE HELSTF CALIBRATIONS



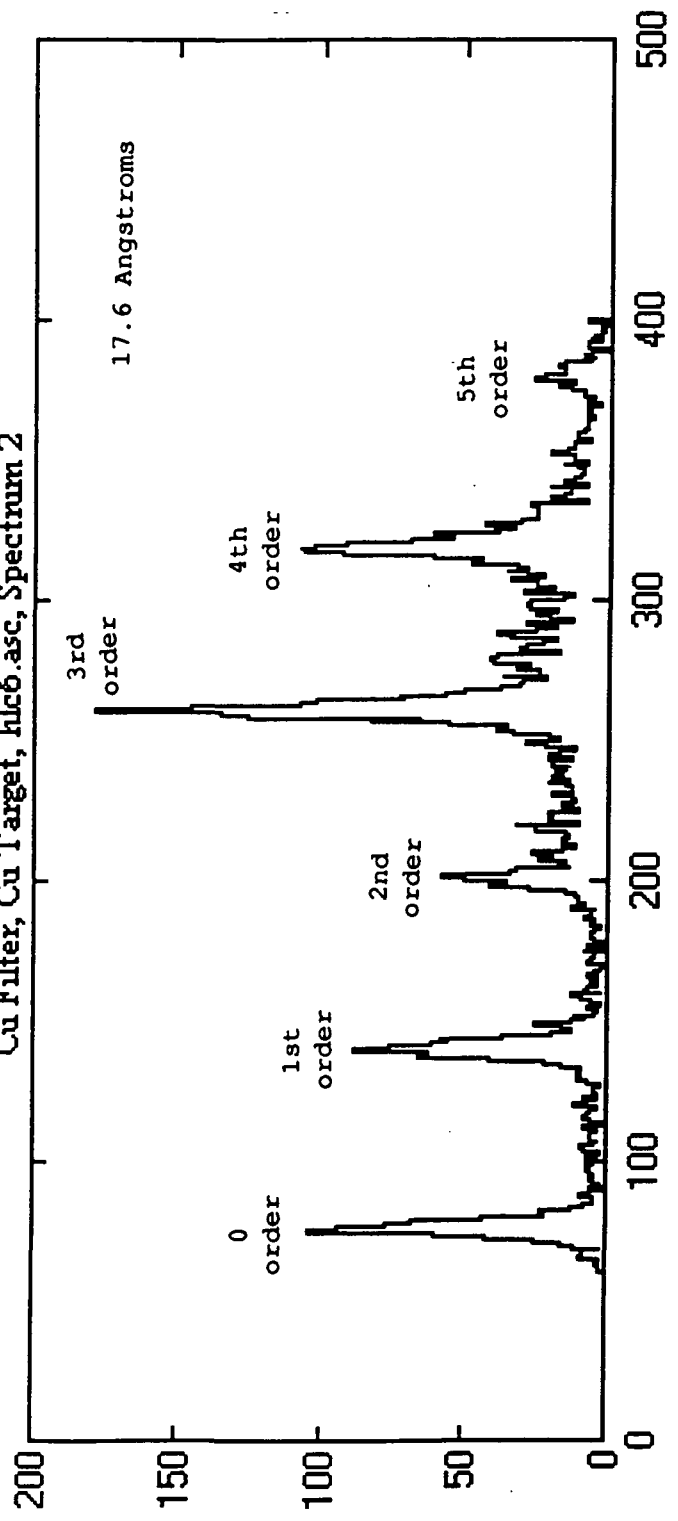
Jun 12 1993

Cu Filter, Fe Target, hlc8.asc, Spectrum 2



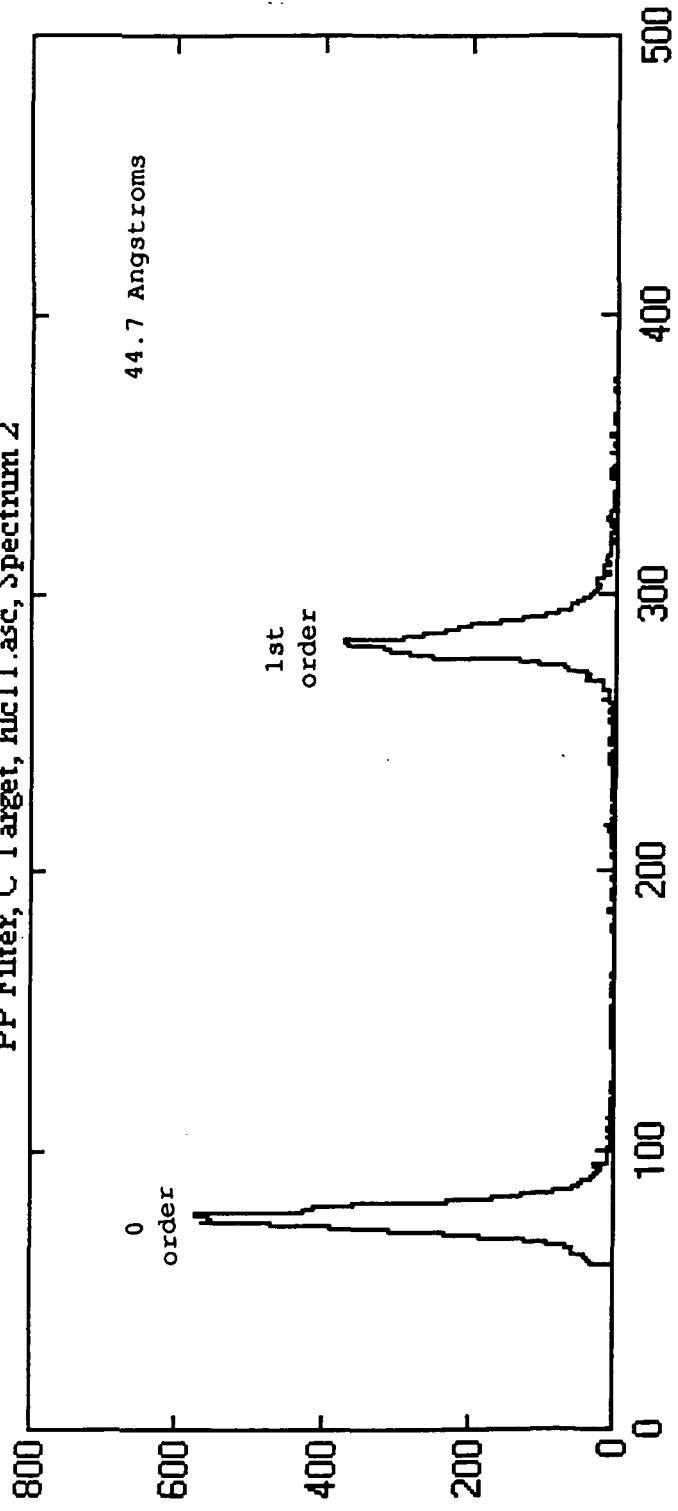
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Cu Filter, Cu Target, hlc6.asc, Spectrum 2



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PP Filter, C Target, klc11.asc, Spectrum 2



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16. Abstract The overall scientific objective of this investigation was to measure the soft x-ray spectra of sources of cosmic x-ray emission in the range from 6 A to 60 A and from analysis of these data to better understand the nature of these sources. The emission and absorption features in these spectra provide information on the temperature, elemental abundance and density of the emitting plasma as well as that of the intervening x-ray absorbing material. The investigation employed an objective reflection grating spectrograph that was flown on a NASA Aries sounding rocket. This spectrograph consists of twelve 3600 lines/mm gratings that disperse incoming x-rays over a range of angles, depending on their wavelength. A Wolter I grazing incidence x-ray telescope images these dispersed x-rays onto a position sensitive proportional counter, converting the angular displacements to dispersion in position. The proportional counter records the position of each detected x-ray and a low resolution measure of the x-rays energy. By analysis and calibration, the x-ray position measurement is converted to a determination of the x-ray energy using the low resolution energy measurements to aid in separating the diffraction orders from the gratings.					
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