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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

Prepared for the Proceedings of Twenty-First Annual Meeting of the AAS, August
26-28, 1975 Denver, Colorado

ATMOSPHERIC X-RAY EMISSION
EXPERIMENT FOR SHUTTLE*

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ATMOSPHERIC X-RAY EMISSION EXPERIMENT FOR SHUTTLE*

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The Atmospheric X-ray Emission Experiment (AXEE) for Shuttle is designed to measure the spatial, temporal, and energy distribution of X-ray aurorae produced by precipitating electrons. It will provide vital data on solar-terrestrial relationships that may lead to defining the transfer mechanism that causes certain terrestrial weather events and climatological behavior. The instrument concept is based on a spatially sensitive multiwire proportional counter, combined with collimators to produce X-ray images of the aurorae. It will be mounted on an instrument pointing system to provide the required attitude control and is operated by the Spacelab payload specialist who has full control over its observing and data taking modes.

INTRODUCTION

The concept that certain terrestrial weather events and climatological behavior are induced by solar phenomena is based on statistical correlations. These include variability with solar activity¹, solar magnetic boundary passage^{2,3}, the single and double sunspot cycles^{4,5}, and others. To understand such statistical relationships, we must determine the physical processes required to stimulate the observed correlations and trace the sequencing between cause and effect. A look at the energetics involved, e.g.,⁶ demonstrates that the energy supplied to the Earth's atmosphere by specific solar events is inadequate to feed a typical tropospheric storm system. This suggests instead, that solar events might generate terrestrial weather events through triggering^{7,8}, i.e., small bursts of

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energy input might provoke weather disturbances by modulating stratospheric and tropospheric centers of unstable equilibrium.

The ideas outlined above have been a primary motivation for our proposing a Solar — Terrestrial Weather Facility for the Applications Spacelab program, in order to study the various processes and mechanisms responsible for relating weather formation to solar activity. In this facility, we envision performing observational experiments with a compatible grouping of instruments designed to study the pertinent physical processes. The full grouping would conceivably observe solar, magnetospheric, ionospheric, and atmospheric processes simultaneously, to inquire into the validity of any suggested theories.

This paper offers a possible mechanism for triggering the observed correlation and introduces the Atmospheric X-ray Emission Experiment (AXEE) as a new observational means to investigate the proposed concept. AXEE is designed to serve as a primary experiment in the proposed Spacelab Solar — Weather Facility, but would also be suitable for flights on other Spacelab missions.

The Spacelab provides a good platform for AXEE and the Solar — Weather Facility. It can nicely support the instrumental and operational requirements for the experimental investigation. It will also permit multiple 7 to 30 day missions under various conditions of solar activity and seasonal weather.

SCIENTIFIC RATIONAL AND CRITERIA FOR AXEE

Solar disturbances are often associated with geomagnetic storm activity, and the appearance of electron showers precipitating into the upper atmosphere at auroral zone latitudes. The energy spectrum associated with such electrons lies below 150 keV⁹, causing the electrons to deposit most of their available energy in the vicinity of 90 km altitude. A small percentage of this energy is then locally converted into X-ray bremsstrahlung radiation¹⁰ which appears as X-ray aurorae. Downward directed X-ray transfer the energy to stratospheric levels¹¹ where modification of ozone concentrations, ionization, and of other parameters is induced. If under certain conditions, such modification can affect the troposphere

through filtering of solar ultraviolet radiation or through changes in conductivity, then the final link in the suggested trigger mechanism may be identified.

The bremsstrahlung formed radiates nearly isotropically¹⁰. Thus a top-side X-ray camera (AXEE), as depicted in Fig. 1, can remotely sense this radiation to determine the emitted X-ray energy spectrum, as well as the temporal and geographical extent of the energy deposition. The measured X-ray energy spectrum can be used to reconstruct the electron flux and energy spectrum responsible for the emitted radiation and, most important, determine the stratospheric depths to which this radiation penetrates. More energetic X-rays penetrate deeper thereby producing more significant modification of important minor constituents at lower altitudes.

Although the principal source of such X-ray bremsstrahlung occurs in the auroral region from large fluxes of precipitating electrons, recent evidence

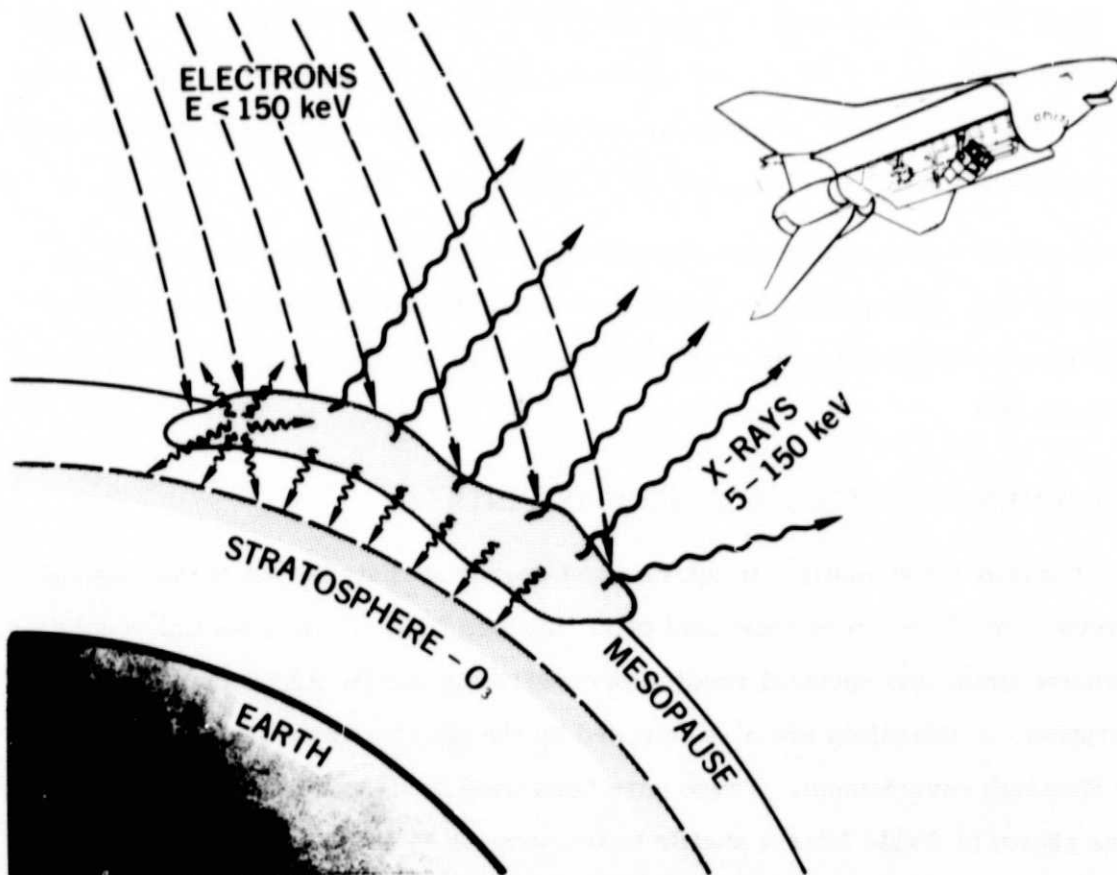


Fig. 1 Atmospheric X-rays under Observation from Spacelab

suggests the intermittent existence of an equally intense belt of quasi-trapped electrons at the magnetic equator^{12,13}. The experiment described here will also investigate the scope and variability of this intriguing equatorial belt; to assist in the explanation of the electron origin, and to determine the electron influence on equatorial stratospheric behavior.

The bremsstrahlung production process converts between 10^{-3} to 10^{-4} of the incoming electron energy¹⁰, and we have determined that electron source fluxes of 10^6 electrons $\text{cm}^{-2} \text{s}^{-1}$ would be the minimum suitable for our study. Such fluxes are typical during auroral substorm activity. On the high side, electron fluxes approaching 10^{11} $\text{cm}^{-2} \text{s}^{-1}$ with energy fluxes exceeding 10^2 ergs $\text{cm}^{-2} \text{s}^{-1}$ are possible¹⁴. Localized intense regions with a horizontal scale size less than 1000 km^{15,16} would also occur during relativistic electron precipitation events (REPS). Since other energetic features may be more localized than REP's, AXEE has been designed with an imaging capability to permit resolution of localized X-ray events with a linear scale of 200 km from line of sight distances up to 2000 km, or about 6° . The spectral range of greatest interest lies between 5 and 150 keV. Below 5 keV radiation cannot penetrate to sufficient depth to have any significant effect on stratospheric behavior.

These criteria also satisfy the necessary conditions for making the equatorial observations. Here, however, it will be desirable to have occasional viewing capability in the zenith when crossing directly through the equatorial energetic electron zone.

INSTRUMENT PERFORMANCE REQUIREMENTS

Investigation of the spatial, temporal, and energetic distribution of the auroral X-rays from Spacelab in a nominal orbit imposes field of view, spatial resolution, exposure time, and spectral resolution constraints for the AXEE camera and its operation. Constraints are also imposed by the physics of the phenomena and by the Spacelab environment. These have been used by us to develop the specifications shown in Table 1 for a shuttle based auroral X-ray camera system.

Table 1

MEASUREMENT REQUIREMENTS-SUMMARY

Parameter	Range Limitations	Instrument Requirements
Energy Range	5-150 keV	Imaging Below 30 keV
Sensitivity	0.1 Photons/cm ² s (=10 ⁶ Electrons/cm ² s)	Effective Collective Area = 500 cm ²
Energy Resolution	Bremsstrahlung Spectrum	FWHM = 20%
Spatial Resolution	200 km at 2000 km Range	2°
Field of View		
• Diverging Array	180° Scan	20° - 30°
• Parallel Array	2°	2°
Time Resolution	1-60 seconds	1-60 seconds
Dynamic Range	10 ⁶ - 10 ¹¹ electrons/cm ² s	6 decades of Sensitivity

The field of view and angular resolution have been adjusted to permit several "snapshots" during a preliminary search scan of approximately 180°. Once a suitable source is located, the instrument must be able to make a more detailed investigation of the source, with higher spatial and energy spectral resolution. The dynamic range for sensitivity should accommodate the full range of slant distance to the source during orbital passage.

Because of the steepness of the bremsstrahlung spectrum almost all information is contained in the energy range from 5 to 30 keV^{17,18,19} except for extremely hard spectra with e-folding energies exceeding 20 keV. Given an integration time of 1 minute and an electron source flux of 10⁶ cm⁻²s⁻¹ imaging is therefore confined to this energy range.

The lower limit to the sensitivity of 0.1 photon cm⁻²s⁻¹ has also been established by considering background effects and their influence on properly shielded and collimated X-ray detectors. The orbital and pointing characteristics of AXEE permit most X-ray observations to be conducted remotely, in a region where the number of background electrons are minimal²⁰. In determining the background effects, we have considered electrons, protons, alpha particles, and cosmic rays reaching the detector. In addition, bremsstrahlung photons caused by electron impact with detector materials, radioactivation of detector and

detector housing by impacting charged particles, and inherent detector noise have also been taken into account.

INSTRUMENT DESCRIPTION — AXEE

We have conducted a detailed study of candidate detectors based on the requirements listed in Table 1. The chosen AXEE detector represents the best compromise based on optimization of the scientific objectives and utilization of essentially existing technology.

Fig. 2 depicts an exploded view of the AXEE detector system. A spatially sensitive high pressure gas proportional counter is equipped with two multi-hole collimator arrays, one on each side of its sensitive volume. One array has parallel-holes; the other, diverging-holes. This dual configuration enables the single instrument to operate in either a field imaging or point source mode, when one on the other side is pointed toward the source.

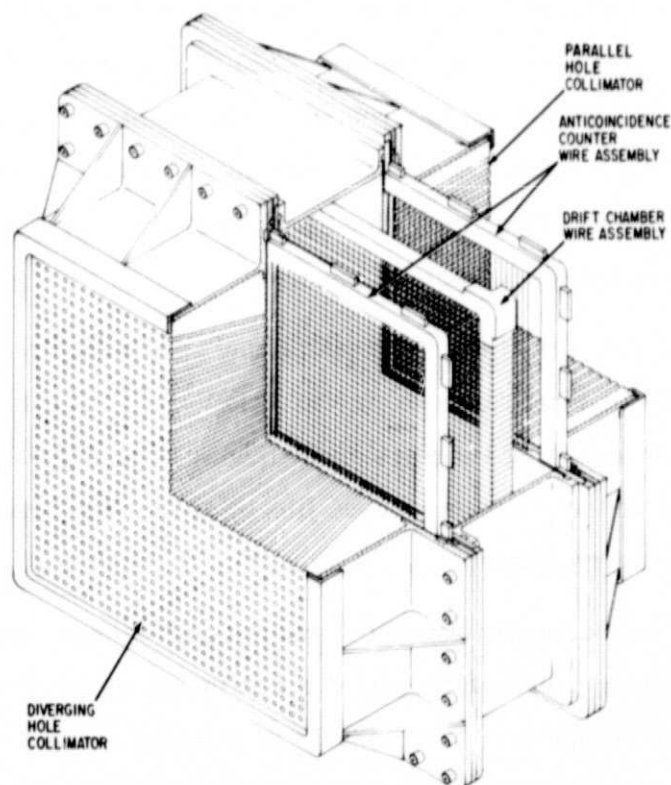


Fig. 2 AXEE Imaging Assembly

In the field imaging mode, with the divergent collimator side pointed at the source, a field image is obtained because each spatial element of the detector views a different angular element of the source field. Inverting the camera on

its mount through 180° restricts the detector to view only a single resolved spot of the source through the parallel hole collimator but with the full sensitive area of the ion chamber detector. The whole camera may then be scanned to build up a picture of the source field.

Fig. 3 illustrates the layout of the detector and of its image-forming electrode wire grids. The detector consists of a sandwich of three multiwire proportional counters, the outer two of which are used for anticoincidence shielding of the central imaging counter. These are used in conjunction with the collimators to minimize and discriminate against background effects. The anticoincidence counters are filled with 3-5 atmospheres of an argon methane mixture and contain a central anode plane with all anode wires tied together between two beryllium window pressure containment plates. Beryllium is chosen because of its low X-ray attenuation coefficient.

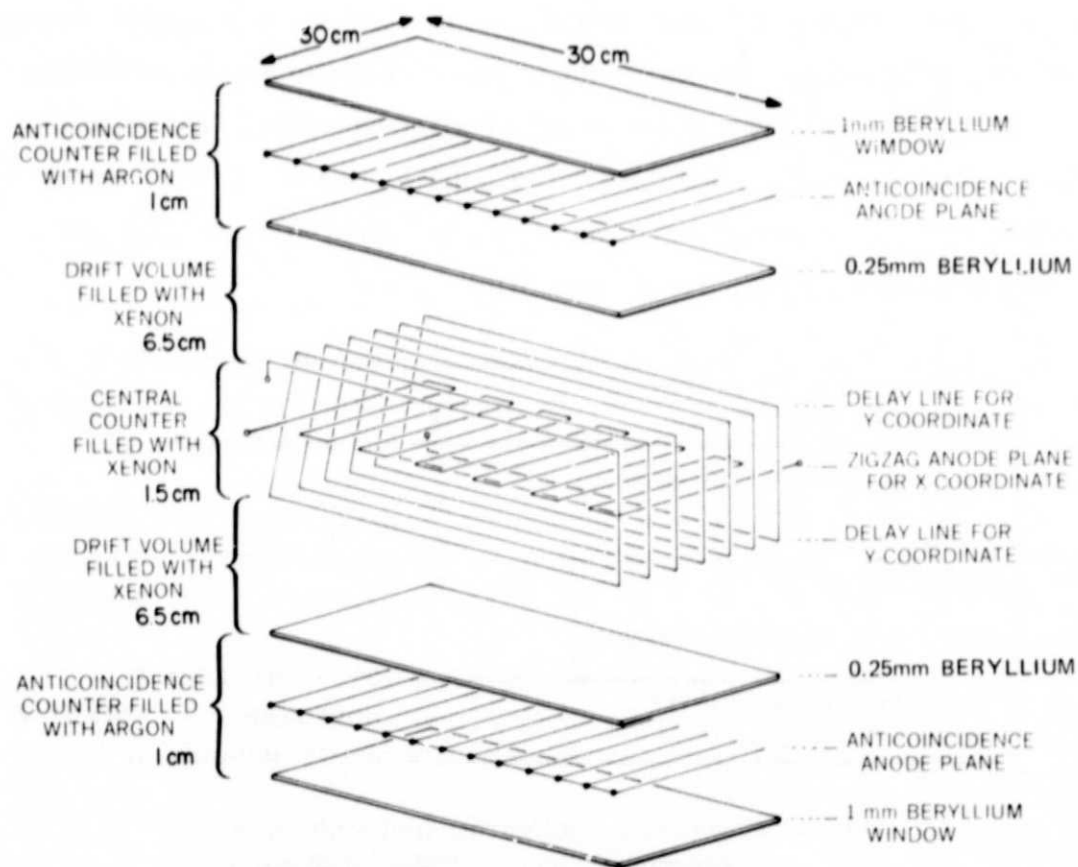


Fig. 3 Arrangement of Wire Planes and General Layout of Detector System

The central counter is filled with 3-5 atmospheres of a xenon-CO₂ mixture and consists of two wire planes symmetrically wound as a helical coil around a central anode plane. The anode consists of a planar zigzag array of thin parallel wires, orthogonal to the cathode helical windings. Spatial information on the position of a photon in the main gas volume is obtained by induced pulses on the zigzag (X-direction) and helical (y-direction) electrodes.

The position readout of this detector is based on the integral delay chamber concept developed by Emming and Gilland²¹ and the resistive anode wire readout system of Borkowski and Kopp²². Fig. 4 displays a cross section of the detector system. Consider a properly energetic photon which may interact with a xenon atom at a point P in the drift space. The emitted electron liberates other primary electrons, creating an electron cloud which drifts into the central counter through wireplane B. As the cloud approaches C, an avalanche of secondary electrons is generated. These electrons are collected by the anode wire. Simultaneously, positive ions are repelled from the wire and induce a positive charge on the helix and a negative charge on the anode. The anode acts as an RC-line and carries the induced pulse to the +x and -y wire end-points. The helix acts as an LC-delay line and carries the positive pulse to +y and -y. The arrival time difference of each pulse to the end of its appropriate line provides spatial information concerning the pulse position origin.

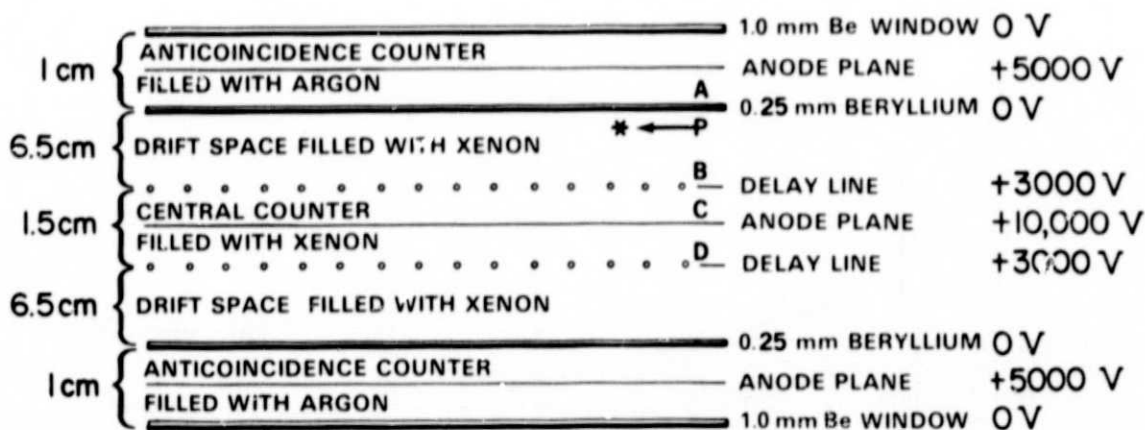


Fig. 4 Conceptual Configuration of Multiwire Proportional Counter Detector System

Fig. 5 illustrates the system block diagram for the AXFE electronics. The signal processing for the x and y pulses are substantially identical. Both pulse sets arrive at their respective delay line terminators where they are first amplified by voltage sensitive pulse amplifiers, then passed through an additional stage of amplification and pulse shaping. Discriminators direct the timing signals to a time-to-height converter (THC). The THC is a linear ramp activated by the start signal and terminated by the stop signal. The voltage obtained by the THC measures the difference in arrival time of the x and y signals and thereby provides the spatial origin of the avalanche pulse. Additional delay is programmed in the stop signal to guarantee that the start pulse always precedes the stop pulse. Analog-to-digital converters (ADC) digitize the outputs of the THC's, and the ADC outputs for each event are stored in accumulators. Analog-to-digital converters (ADC) digitize the outputs of the THC's, and the ADC outputs for each event are stored in accumulators.

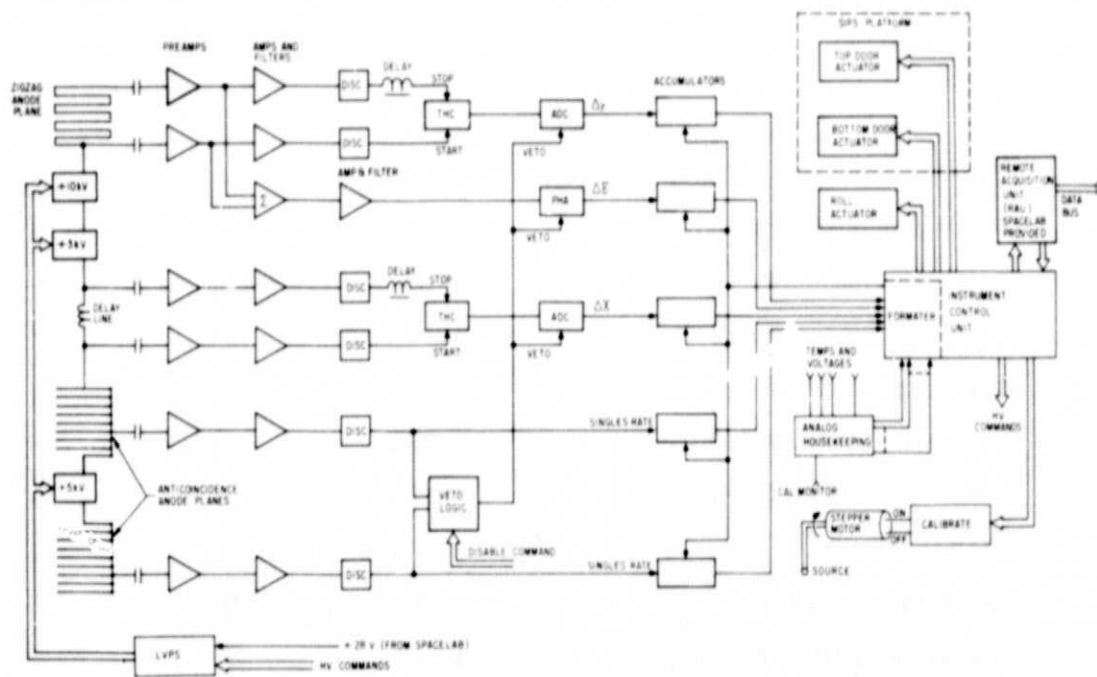


Fig. 5 AXEE System Block Diagram

The two preamplifier signals of the anode plane are also summed, integrated, and amplified in a separate chain, to register the energy deposited in the chamber by the X-ray event. This signal is analyzed by a pulse height analyzer (PHA) and also stored in an accumulator. Hence, each X-ray event generates pulse height (energy) and spatial information.

Charged particles such as electrons will leave an ionization trail in either or both multiwire anticoincidence counters. The outputs from these counters are used to veto the main counter outputs. The veto signal is generated in the logic by combining the anticoincidence counter signals. Individual rates of each counter are accumulated separately to give a measure of the charged particle background. By pulse shape analysis, lower energy X-rays may also be detected in the outermost thin counter.

Table 2 summarizes the AXEE characteristics and Table 3 provides a weight summary. A mechanical design has been prepared for AXEE leading to the numbers given here. The greatest uncertainty at this time concerns the choice of collimator material. The collimator weight shown is for a worst case (heaviest) situation, where solid lead is employed. The data here refer to weight and power of the camera itself, excluding any affiliated support systems, such as the camera mount.

Table 2
AXEE CHARACTERISTICS

Parameter	Dimension
Overall Dimensions	44.3 by 44.3 by 35.4 cm ³
Physical Detector Area	1000 cm ²
Effective Detector Area	~ 500 cm ²
Weight (excluding SIPS)	192 Kg
Power (excluding SIPS)	10.2 Watts
Energy Range	5 to 150 keV
Energy Resolution	~20 percent FWHM
Angular Resolution	1°-5°
Field of View:	
• Diverging Array	20-30°
• Parallel Array	2°
Pointing Arc	90° x 360°
Data Rate	20 kbit s ⁻¹

Table 3

WEIGHT SUMMARY FOR AXEE

Component	Weight (kg)
Housing (center portion, av 0.375 steel)	21.1
Collimator housing (AL)	16.0
Collimators (two each of Pb)	140.0
Wire frames (ceramic)	3.1
Be windows	2.2
Electronics	5.0
Gas components plus miscellaneous	5.0
Total	192.4 kg

OPERATION OF AXEE FROM SHUTTLE

The primary observing goals with the AXEE are to examine the Earth's auroral regions for X-ray sources and study these in detail once they are located. On each orbital pass toward or over the auroral zones, the AXEE must be maneuvered to point in their direction, to scan the horizon, and to track on specific features. This must occur while the Spacelab swings by with rapid changes in the relative orientation of the source with respect to the stabilized Spacelab. It is therefore necessary to mount the AXEE on an independent pointing system capable of providing the pointing accuracy, stability, track rates, and raster increments required by the experimental observations.

Of the various pointing systems under consideration for Spacelab use, the intermediate sized small instrument pointing system (SIPS) appears to be the best choice for AXEE. The SIPS is an alt-azimuth type instrument mount which is attached to a Spacelab Pallet as shown in Figs. 6 and 7. It will permit the AXEE to be pointed to any part of the hemisphere outside the Shuttle Bay, and to hold that orientation or track a source to within ± 1 arc second. The AXEE is mounted within the SIPS instrument canister which also provides the thermal control shroud and the roll control of the AXEE about its optical axis. Roll-orientation will allow the AXEE field of view to maintain tangency to the X-ray auroral horizon during an orbital pass. Protective doors on either end of the canister will be opened during observations.

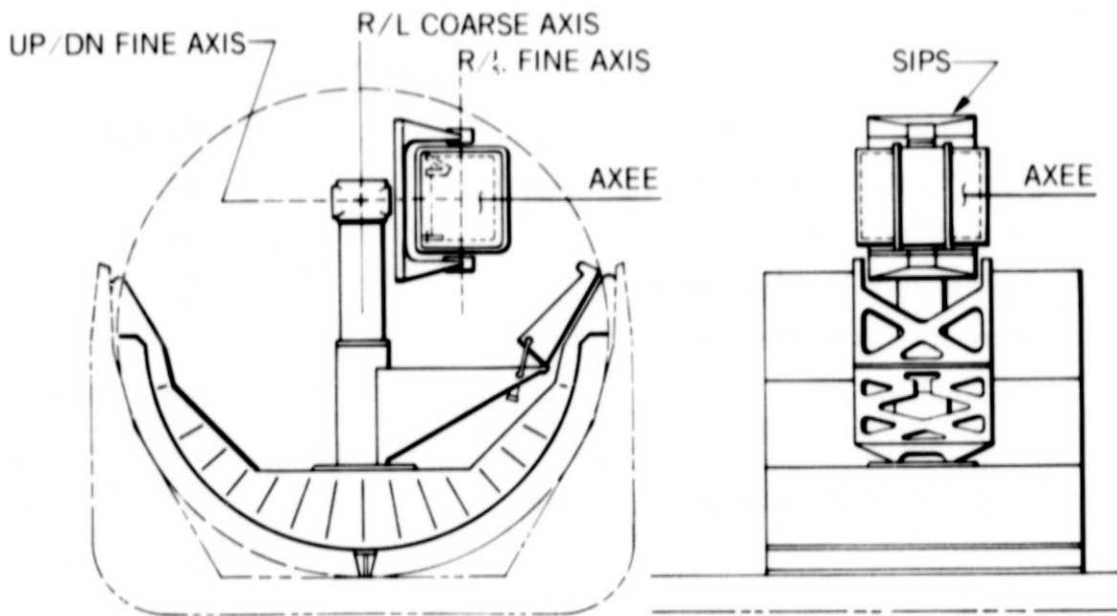


Fig. 6 Small Instrument Pointing System (SIPS)
Mounted on Spacelab Pallet

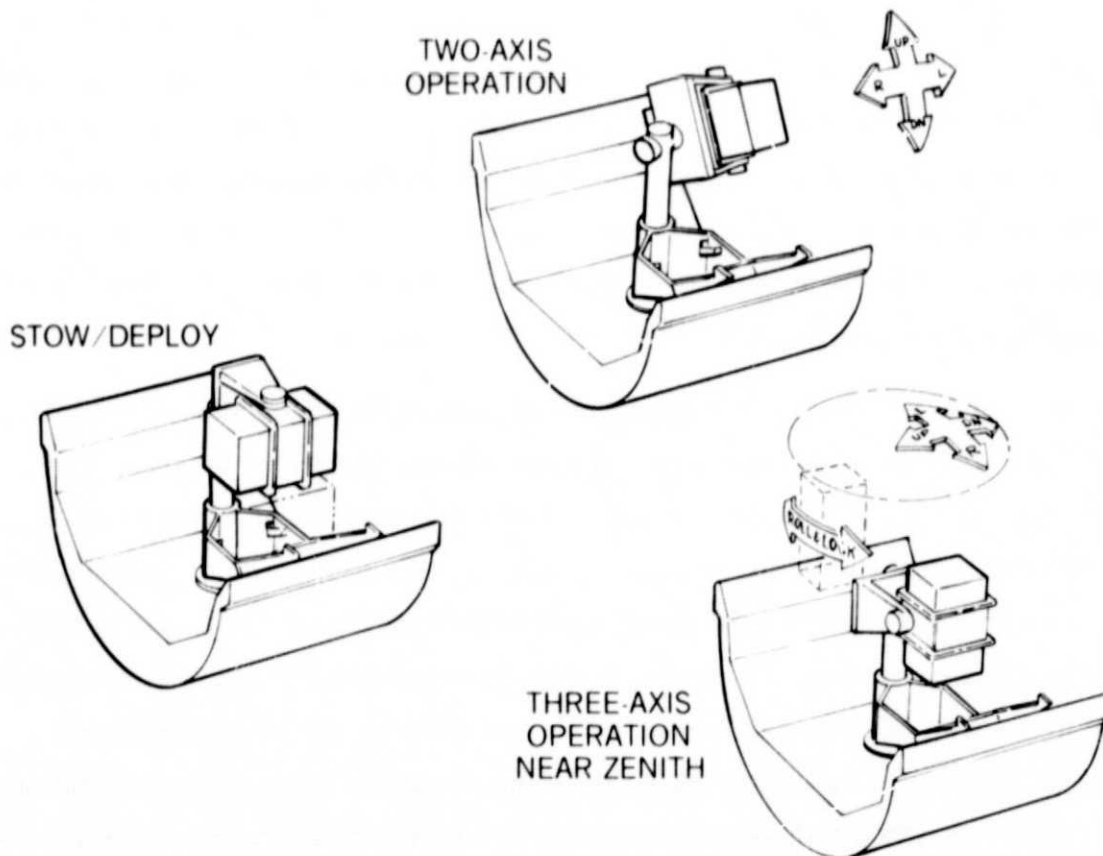


Fig. 7 Small Instrument Pointing System —
General Arrangement

The pointing drive signals can be derived from internal sensors or from the Spacelab computer. This permits the payload specialist to direct the observing program by interacting through the Spacelab computer.

Since the AXEE is designed to change from a wide angle field imaging mode to a spot resolution angle field for low intensity source studies by reversing the optical axis orientation, the SIPS must be reoriented through 180° from the selected point. This is illustrated in Fig. 8. It is performed by a combination of a 180° rotation about the course azimuthal gimbal and a 90° rotation about the elevation gimbal. The total time for the reversal maneuver, including closing and opening of sensor doors, is estimated to be 1.5 minutes.

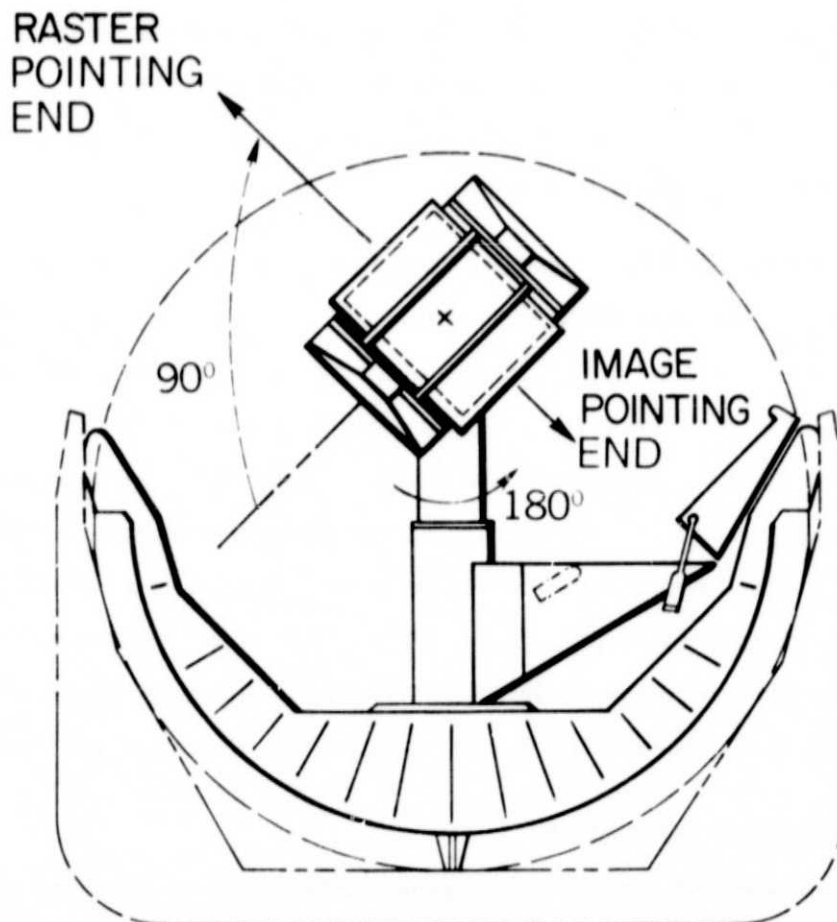


Fig. 8 Reorientation of SIPS to change from Image Pointing End to Raster Pointing End

All data generated by AXEE is formatted by the instrument control unit and sent to the standard remote acquisition unit (RAU) which is provided by Spacelab. The RAU communicates with the orbiter experiment control and display systems, including commands sent to the experiment, via the data bus. Such commands would control switching and adjusting the high voltage supplies used by the proportional counters, instrument calibration, protective door closures, and AXEE roll position adjustment.

The payload specialist will observe the X-ray sources on a two dimensional video monitor at the payload specialist station. From these image displays he can determine the occurrence and location of specific sources. The ensuing command sequence through the RAU would be an iterative process, with updated imaging providing information necessary to establish decisions relating to integration time, source point vs. image mode, and raster size. Some imaging would also be relayed to ground to permit real time consultations between the payload specialists and ground based specialists.

We have also evaluated the expected time in each observing zone assuming a nominal orbit at 400 km with an inclination of 55° . The calculations assume that AXEE could view an auroral event at a maximum observing distance of 2000 km, and that $L=5$ constitutes the lowest magnetic latitude at which an auroral event may be located. These calculations have established an average viewing time of 28 minutes per orbit (Northern and Southern hemisphere combined). If a specific localized event were located near 60° latitude, it would be observable for four minutes per orbit and for six consecutive orbits. These numbers are useful to appraise the expected time that a payload specialist might be required to devote to AXEE, especially after discovery of an important localized event.

SUMMARY AND CONCLUSIONS

We have proposed AXEE as an experiment for Spacelab, to investigate certain physical processes responsible for energy transfer from the thermosphere to the stratosphere, which are hypothesized as explanations for certain types of solar-terrestrial weather correlation. We have also proposed the establishment of a Shuttle Solar - Weather Facility of which AXEE would be a part, to

permit a more comprehensive study of the suggested physical processes and interactions. The definition of such a facility has been undertaken within our current effort.

AXEE will measure the spatial, temporal, and energy distribution of auroral X-rays produced by precipitating electrons. The instrument is composed of a spatially sensitive multiwire proportional counter, combined with collimators to produce X-ray images of the aurora. It will be mounted on an intermediate size precision pointing platform such as the SIPS, to provide the required attitude control. The system will be under operational control of the payload specialist in orbit, augmented by real time contacts with the ground science team. It will also feature automatic computer controlled observing features.

Following are the most important study results which have an impact on the instrument design.

1. The energy range of the instrument will cover 5 to 150 keV, with imaging for the spectrum below 30 keV. Energy resolution of the observed spectrum will be 20% FWHM.
2. The instrument will have a sensitivity of 0.1 photons/cm²s as dictated for a source of linear dimension 200 km at a range of 2000 km, caused by an electron source flux of 10⁶/cm²s. This will require an effective detector collection area of 500 cm².
3. The horizontal spatial resolution will be 3-5°, as specified by the linear dimension-range requirements above.
4. The horizontal field of view will be 20-30°. Hence for a scan of 180°, we will obtain 6-9 images.
5. Time resolution for image formation should be 1 to 60 seconds. The upper limit is required to image events at maximum sensitivity without smearing due to platform motion. The lower limit will permit imaging of bright but short term events.
6. The dynamic range of the detector will be 6 decades, to cover anticipated variability in flux and source distance.

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