AN EXTREME ULTRAVIOLET SPECTROMETER EXPERIMENT FOR THE SHUTTLE GET AWAY SPECIAL PROGRAM

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ABSTRACT

An extreme ultraviolet (EUV) spectrometer experiment developed as a Get Away Special (GAS) payload for the Space Shuttle operated successfully on June 20, 1980 during the STS-7 mission. The objective of the experiment is to measure the global and diurnal variation of the EUV airglow. The spectrometer is an f 3.5 Wadsworth mount with mechanical collimator, a 75 x 75 mm grating, and a bare microchannel plate detector providing a spectral resolution of 7 Å FWHM. Read-out of the signal is through discrete channels or resistive anode techniques. The experiment includes a microcomputer, 20 Mbit tape recorder, and a 28V, 40 Ahr silver-zinc battery. It is the first GAS payload to use an opening door. The spectrometer's 0.1 x 4.2 deg field of view is pointed vertically out of the Shuttle bay. During the STS-7 flight data were acquired continuously for a period of 5 hours and 37 minutes, providing spectra of the 570 Å to 850 Å wavelength region ofthe airglow. Five diurnal cycles of the 584 Å emission of neutral helium and the 834 Å emission of ionized atomic oxygen were recorded. The experiment also recorded ion events and pressure pulses associated with thruster firings. The experiment will fly again on Mission 41-F scheduled for August 1984.

INTRODUCTION

Observations of the earth's ultraviolet airglow from rockets and satellites have been carried out for more than twenty years and the interpretation of these measurements has played an important role in our understanding of the upper atmosphere. However, it is only during the last few years that the airglow spectrum in the EUV wavelength region, below 1200 Å, has been measured spectroscopically (Ref. 1, 2, 3, 4). It is now known that the EUV spectrum is dominated by the emission lines of neutral and ionized nitrogen and oxygen atoms. These lines result either from the absorption of sunlight directly or from collisions with energetic photoelectrons.

As part of a program to develop continuous global monitoring of the ionosphere, our group at the Naval Research Laboratory is actively developing both the flight instrumentation and the theoretical models necessary to measure and analyze ionospheric emissions from earth orbit. An EUV spectrograph has been developed as a Shuttle GAS payload (Ref. 5,6). It was successfully flown on STS-7, launched on June 18, 1983 and is scheduled to fly again on Mission 41-F in August, 1984. Called the Space Ultraviolet Radiation Environment experiment (SURE), the experiment is sponsored by the Air Force Space Test Program. It was the first GAS payload to utilize the opening lid with the standard GAS cannister and was also the first EUV spectrometer experiment to operate on the Space Shuttle.

The scientific objectives of the SURE experiment are to obtain EUV spectra of the earth's airglow and to measure its global and diurnal variation. By modelling the interaction of the atmosphere with sunlight and comparing the results with the SURE data we obtain a better understanding of the variations of the densities of atoms, molecules, ions and electrons that constitute the region above an altitude of 100 km.

THE INSTRUMENT

The Spectrograph

The spectrograph consists of a mechanical collimator, a concave diffraction grating with a radius of curvature of 50 cm, and a bare microchannel plate (MCP) detector. These elements are arranged in a Wadsworth configuration with an instrumental f/number of 3.5, and the instrument is operated in first order. The light path is shown in Figure 1. The collimator is assembled from fifteen molybdenum grids 75 mm square with vertical slits 0.0075 inches wide separated by 0.005 inches. The grating is also 75 mm square, and its spherical surface was holographically ruled to a density of 4800 grooves/mm. The

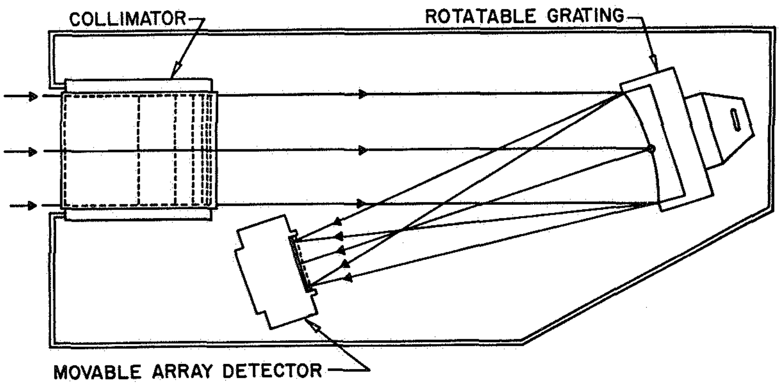

Figure 1. Light path for the SURE spectrometer.

spectral coverage of the instrument is determined by the 2 x 3.46 cm size of the active area of the detector which is positioned to intersect the focal curve of the grating. Since the plate factor of the spectrograph at 640 Å is 8.1 Å/mm, a band pass of 280 Å is imaged on the front plate of the detector. In order to increase the spectral coverage the instrument can be operated in either of two modes with different angles of incidence. Changing modes is accomplished using a stepper motor to rotate the grating-detector assembly in the dispersion plane while translating the detector to maintain focus. The two modes give a coverage from 570 to 850 Å and from 810 to 1080 Å. The spectral resolution is determined by the divergence from a single angle of incidence of the light beam passing through the collimator. Preflight measurements in the laboratory and flight data indicate a resolution of 7 Å. The field of view of the instrument was measured in the laboratory to be ± 0.1° by ± 4.2°.

The Detectors

The detector used for the STS-7 flight consists of two 40 mm MCP's stacked in a tandem or chevron configuration and proximity focussed on an array of 128 anodes, each measuring 0.260 x 200 mm and separated by 0.010 mm. These components and the signal cable connectors are permanently mounted in an aluminum barrel. The charge collected by each anode is processed by a separate, minature, hybrid amplifier/counter circuit. The electrical connection to the MCP's put 1100 V across each plate and held the front plate at - 2800 V. No photocathode or filters were used. In order to prevent ions from entering the spectrograph and being attracted by the detector surface, all outgassing ports were covered by multiple-reflection caps.

This discrete-anode detector has subsequently been replaced by a two-dimensional resistive anode device and position determining electronics purchased from Surface Science Laboratories. As before, two MCP's are stacked in a chevron arrangement. However, the MCP's are biased so that the front plate is at ground and the anode is at +2400 V. In addition a fine nickel mesh is mounted in front of the MCP's and kept at -100 V to repel stray electrons and collect ions. During flight the collimator will be floated at +28 V to form a trap for ions which otherwise may stream into the spectrograph.

The Calibration

The instrument performance was characterized in the laboratory before flight using a variety of windowless discharge light sources. The relative channel-to-channel response of each of the detectors was measured by illuminating the detector through a 0.260 x 20 mm slit and moving the slit across the face. The full detector was also illuminated with diffuse light. The two measurements together characterize the flat-field response which must be divided into every spectrum. The relative response as a function of wavelength was measured by viewing a collimated, monochromatic beam with the instrument and comparing the resulting count rate with that of a calibrated reference channeltron detector. Finally, the absolute responsivity was measured by viewing an illuminated diffuser screen of aluminum-coated ground-glass with both the instrument and the reference channeltron. The screen was illuminated with He, Ne and Ar discharges and the resonance line emissions (He 584.3, Ne 743.7, Ne 735.9, Ar 1048.2, and Ar 1066.7) were observed. The measured responsivity of the instrument with the discrete anode detector, was 1.3 counts s^{-1} R^{-1} at 584 Å, 1.0 count s^{-1} R^{-1} at 834 Å in the short wavelength mode, and 0.2 counts s^{-1} R^{-1} at 1000 Å. The uncertainty of the absolute calibration is estimated at ± 30%.

Characterization of the resistive anode detector followed a process of baking in a vacuum for 48 hours and scrubbing with Ly α light. The plate voltages were set just below the levels at which the MCP's became noisy. These levels were found to increase over several days. The final voltages were set when the sensitivity was found acceptable and were not increased futher because of uncertainties in the pressure levels to be expected once the Shuttle arrives on orbit. The dark count of the detector is consistently between 5 and 10 counts s^{-1} over the whole 1250 mm^2. Figure 2 shows the measured flat field response. We did note that when total count rates exceeded 5 x 10^4 counts s^{-1} the flat field changed shape and became more peaked toward the center. Many of the emissions present in the EUV airglow of the upper atmosphere are produced from a discharge in a mixture of 10% O_2 in He. Figure 3 shows a spectrum of this discharge taken in the laboratory with the instrument using the resistive anode detector. The wavelength scale was determined by performing a least squares fit to the features identified in the figure as well as the rare gas resonance lines.

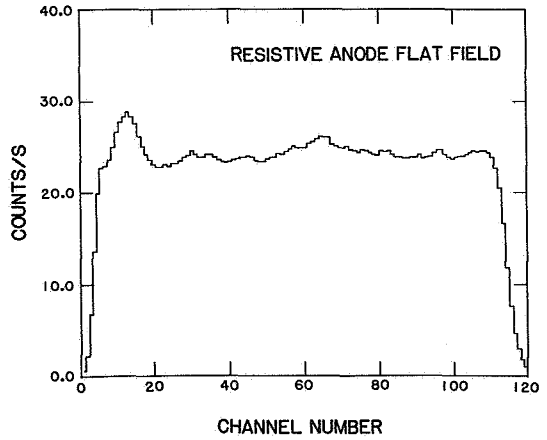

Figure 2. Flat field response of resistive anode detector.

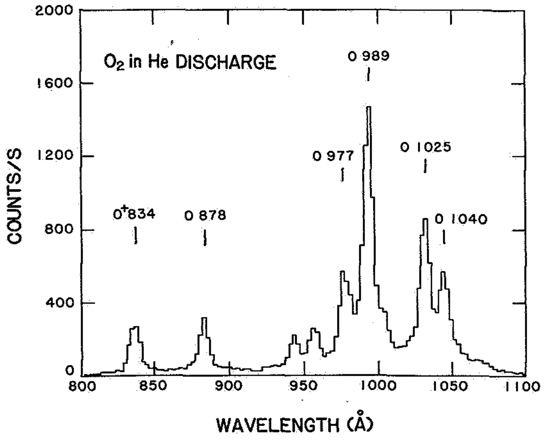

Figure 3. Laboratory spectrum of O_2 and the discharge measured with SURE spectrometer and resistive anode detector.

DATA AND POWER SYSTEMS

The operation of the SURE experiment, after it is powered up on orbit, is controlled by a Motorola 6800 microcomputer. Figure 4 is a block diagram showing the components of the computer and its interfacing to the experiment. The read-only memory contains the controlling program. When the experiment is active, data is temporarily stored in random-access memory (RAM) and periodically recorded on magnetic tape by the experiment tape recorder. The computer also performs regular health checks, including monitoring component temperatures, checking for the sun near the field of view, and recording voltage and current levels.

The degree of involvement of the processor in the photon-counting process depends on the detector electronics. The discrete-anode electronics includes a counter for each channel so the processor simply reads the counters at the end of every integration period (typically about 5 sec.). On the other hand, the resistive-anode electronics signals the processor each time a pulse position is encoded. The processor then must read the coordinates of the pulse and increment the corresponding pixel address in memory. The time required to execute the necessary code becomes an important part of the instrument dead-time.

The experiment tape recorder is the SETS-I manufactered by Sundstrand Data Control, Inc.. It is a four track recorder with a capacity of 20 Mbits. The recorder and its controller electronics are housed in a hermetic box measuring 12 x 13 x 25 cm. The data link between the controller and the experiment microcomputer uses a synchronous communications port.

Experiment power is provided by a battery constructed from 19 silver/zinc wet cells, each providing 40 Ah at 1.5 V. The battery is housed in a vacuum box measuring 32 x 22 x 22 cm and, when assembled, weighs 125 kilograms. Despite the delay of more than two months between the final charging and launch, very little charge depletion occurred.

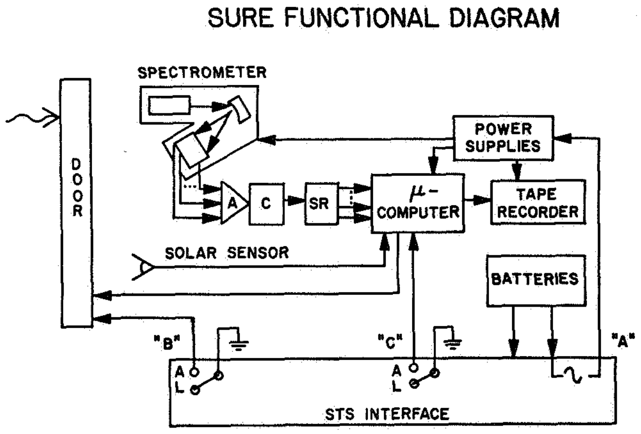

Figure 4. Block diagram of SURE control and data handling.

GET AWAY SPECIAL SUPPORT SYSTEM

Motorized Door Assembly MDA

The EUV airglow is extremely faint and there are no window materials which transmit efficiently at wavelengths below 1050 Å. For this reason opening of the MDA on orbit directly exposes the SURE experiment to the Shuttle environment. The power to drive the door mechanism is drawn from batteries which are part of the NASA equipment; however, the experiment must provide power to a relay which enable the drive. Therefore when the experiment is active it has control over the door, but the door always closes when the experiment is deactivated. The SURE experiment opens the door immediately following activation and closes it only after it has completed its observing program. This is both to assure minimum pressure levels in the cannister and to prevent overheating.

GAS - User Interface

The electrical interface between a GAS payload and GAS interface to the Shuttle system includes:

1) power - all experiment power is routed through the Payload Power Contactor on the GAS Interface Equipment Plate (IEP). This gives the Shuttle system absolute control of experiment power - a requirement demanded by the overriding issue of safety on a manned mission.

2) commands - there are three latching relays whose states can be used by the payload to provide commands. One of those is dedicated to payload power control so the two states of the remaining two relays can be used for experiment control by the Shuttle crew.

3) door control - the interface allows the payload to activate the Motorized Door Assembly (MDA) and monitor the door position.

4) test connections - payload test points are passed through the IEP in order to provide Ground Support Equipment (GSE) access to the payload.

The SURE detector requires pressure levels less than $1\text{x}10^{-5}$ Torr. Higher levels cause the detector to become noisy and pressures above $1\text{x}10^{-4}$ can permanently damage the microchannel plates. In order to assure that the interior of the GAS cannister reaches operating levels as quickly as possible after the door has opened on orbit, the payload is kept clean and dry during integration and a 3 inch pumping port was added to the IEP to permit the cannister to be pumped following integration.

Crew Interaction

The use of a microcomputer as an experiment controller allows the observing program of the SURE experiment to be tailored to the mission time line for almost any flight. Once the periods of favorable operating conditions have been identified, the controller program can be optimized. Data can be acquired in a single 18 hour period or partitioned into as many as four shorter periods. Commands to the payload are sent by the crew using the Autonomous Payload Controller (APC). The experiment requires the following commands: 1) activation - this powers up the experiment computer and opens the door, 2) mode selection - this initiates data acquisition and 3) deactivation - this turns off the experiment and closes the door.

Postflight Pointing History

Unlike other GAS payloads, SURE is an optical experiment acquiring geophysical data. It is critical to the interpretation of those data that we are able to identify the orientation of the field of view and its geographic location for every spectrum. Although this information is not routinely provided to GAS experimenters it may be available in the Postflight Attitude and Trajectory History (PATH) products.

The SURE experiment uses the vectors to the sun and to the earth to determine solar illumination conditions, and the orbiter state vector referred to the Greenwich meridian to determine longitude, latitude and attitude. These vectors are available at 10 second intervals with accuracies of 0.2 degrees.

RESULTS OF THE STS-7 FLIGHT

The SURE experiment was integrated with the GAS equipment on March 29, 1983. It was installed aboard the challenger orbiter in late April, 1983 for the STS-7 mission, and launched on June 18, 1983. The activation command was issued at Mission Elapsed Time (MET) 1/05:40 (day/hours:minutes). At MET 2/08:17 the experiment was commanded to start taking data and was deactivated at MET 3/05:50. The crew confirmed that the door opened and closed as scheduled. Figure 5 shows the experiment and door during integration and Figure 6 is a photograph from the aft flightdeck showing the payload with the door open during the flight. The experiment was aligned so that the long axis of the field-of-view (0.1° x 4.2°) was nearly parallel with the long axis (x-body axis) of the orbiter and viewed directly up and out of bay. Except for short periods of Inertial Measurement Unit (IMU) alignments, the orbiter was in the bay-to-earth (-ZLV) attitude during the SURE observations.

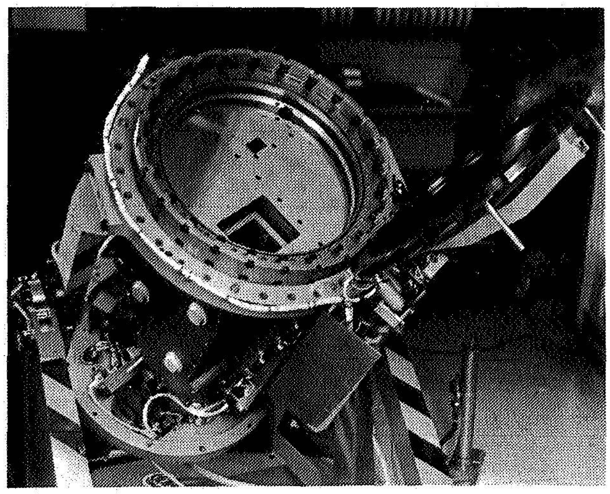

Figure 5. SURE mated with door assembly and interface equipment during integration.

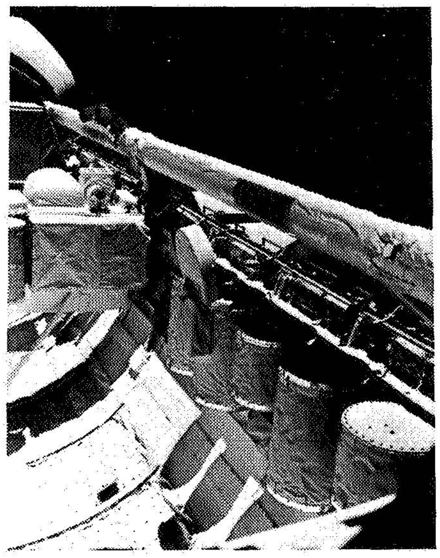

Figure 6. SURE with open door during STS-7 mission.

The Dayglow

The emissions which comprise the EUV dayglow are primarily either the direct result of the absorption of sunlight by the neutral atoms and molecules in the earth's upper atmosphere (above an altitude of 100 km) or the result of collisions with photoelectrons - the energetic electrons formed when sunlight is absorbed. In the wavelength region below 850 Å, two of the brightest dayglow emissions are the line at 584 Å due to resonant scattering of sunlight by atmospheric helium, and the set of three lines around 834 Å resulting from the ionization and excitation of atomic oxygen by fast photoelectrons. The oxygen emission (called O^+ 834 Å), is particularly important as a diagnostic tool for characterizing the ionosphere (ref. 7). Understanding the intensity of this emission is complicated because although the initial excitation and emission takes place at altitudes around 135 km, the free O^+ which constitutes the ionosphere at higher altitudes (above 300 km) is very efficient in scattering the radiation and forms a kind of fog layer at shuttle altitudes which is brightened by the illumination from below. Extensive modelling is required to disentangle the physics of this emission but it promises to be very important to global monitoring of the ionosphere.

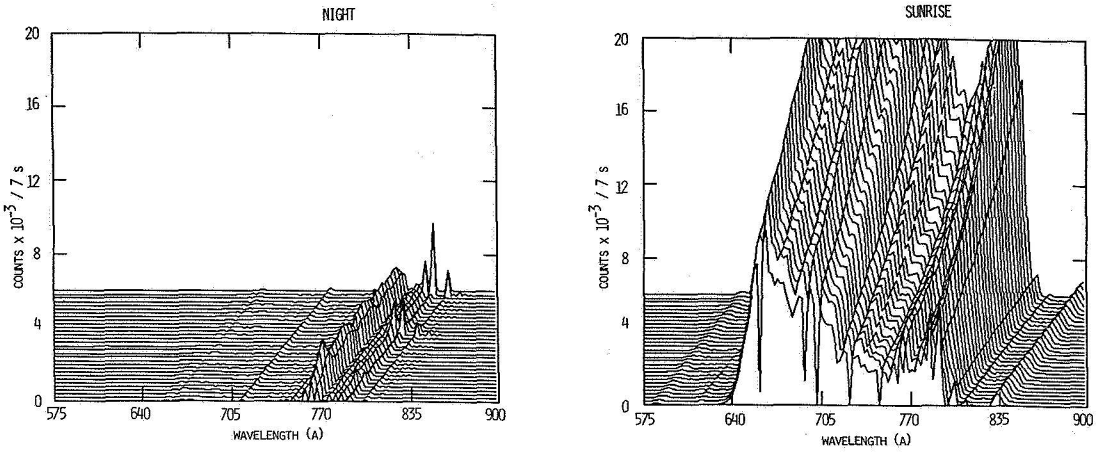

Figure 7. Time series of spectra from STS-7 mission. Series on left is night data and series on right is recorded just after sunrise. Each spectrum is integrated for 7s.

Two sets of spectra are shown in Figure 7. The set on the left is a time series taken at night and the set on the right is a series shortly after sunrise. Each spectrum is integrated for 7 seconds. The night spectra demonstrate the inherent noise level of the detector and are similar to the preflight calibration data taken in the laboratory. The sunrise series clearly shows the He 584 Å and O^+ 834 Å features brightening as the solar zenith angle gets smaller. The very strong signal in the central region of the spectra is probably due to ions which were allowed to enter the instrument as a result of the misconnection of the instrument's ion repeller. Post-flight simulation with an ion source produced very similar signals but did not achieve the flight levels. The edges of the detector (where the He 584 Å and O^+ 834 Å features are focussed) were protected from ions by a grounded aperture plate.

The experiment operated successfully for about five hours before the tape recorder controller apparently malfunctioned, causing the recorder to run continuously to the end of the tape. The recovered data samples five diurnal cycles of the helium and oxygen emissions and is of very high quality. Figure 8 compares the variation of the O^+ 834 Å emission and a simple theory which predicts the changes in the initial excitation efficiency in response to changes in the solar zenith angle. More detailed analyses are expected to yield information on the affect of winds in the upper atmosphere on the structure of the ionosphere.

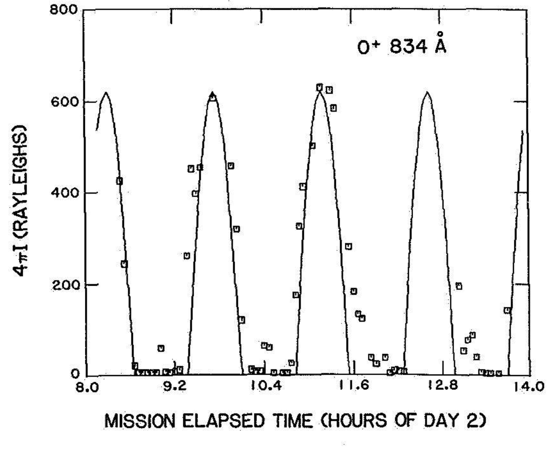

Figure 8. Diurnal variation of O^+ 834 Å emission compared to optically thin theory. Instrument was viewing the nadir.

Orbiter Environment

At the moment the experiment began taking data on the STS-7 mission, the orbiter was in the process of maneuvering for an IMU alignment. The field of view was swept from an earth viewing attitude, through the horizon and out into space. About 40 minutes later, when the orbiter was in darkness, the vernier thrusters were fired to begin the maneuver back to an earth viewing attitude. At the same moment the SURE detector saw an impulse of signal which is indicative of both increased ion densities and increased pressure levels inside the GAS cannister. The sudden onset of these signals is shown in Figure 9.

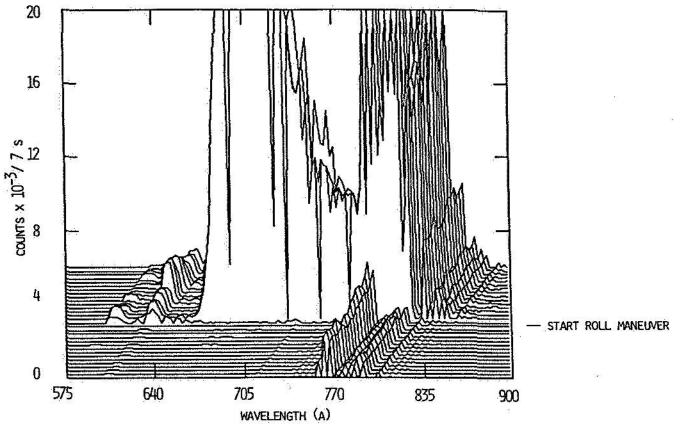

Figure 9. Sudden impulse of signal during the night coincident with start of orbiter maneuver.

These data point out the susceptibility of Shuttle experiments to the various contaminates created by orbiter systems. On the other hand we have demonstrated that high quality EUV spectra can be obtained from the Shuttle platform. Further analysis using the PATH data will provide information on the effects of regions of high particle flux such as the South Atlantic Anomaly.

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