MEASUREMENT OF ATMOSPHERIC ULTRAVIOLET RADIATION FROM A LOW EARTH ORBIT SATELLITE

Steven K. Clegg, Richard W. Eastes
Phillips Laboratory
Ionospheric Modeling & Remote Sensing Branch
Ionospheric Physics Division
Hanscom AFB, MA 01731-5000
Tele: (617)377-3484, FAX: (617)377-3550

Michael E. Gangl, John H. Middlestadt
Research Support Instruments, Inc.
10610 Beaver Dam Road
Hunt Valley, MD 21030
Tele: (410)785-6250, FAX: (410)785-2283

Abstract

The design and expected measurements of the Atmospheric Ultraviolet Radiance Analyzer (AURA) are presented. The goal of AURA is to provide global measurements of the ultraviolet emissions (1150 Å to ~1900 Å) from the Earth's atmosphere. These measurements will include spectra and images. AURA is expected to fly in a near circular, high inclination angle orbit.

AURA is designed to have sufficient sensitivity to observe relatively weak emissions in the nighttime tropical arcs or the diffuse aurora. It will also provide excellent signal to noise measurements of the day airglow and discrete auroral arcs. The measurements will provide information on atmospheric background emissions and can be used to test remote sensing techniques for ionospheric parameters such as electron density profiles. The AURA instrument will provide two channels of UV observations. Each channel uses a ⅛ meter Ebert-Fastie spectrometer mated to a telescope with a scanning mirror. The scan mirrors and grating angles will be precisely controlled by stepper motors and will use optical fiducials to determine absolute positioning. The two channels operate independently in mode (imaging, spectral, or photometer), viewing direction, or observed wavelength. This independence allows for imaging the two channels on the same area of observation at slightly shifted times. The field-of-regard of these channels is a 180° swath perpendicular to the orbital path (spacecraft velocity vector). The angular field-of-view of these channels will be approximately 2° by 0.2°. From the orbital altitudes anticipated (~700 to 1000 km), this will provide higher spatial resolution than previous auroral images from spacecraft.

1.0 Introduction

The AURA experiment is designed to collect ultraviolet image data at two wavelengths simultaneously. Most UV auroral imagery from satellites (EXOS-A, DE, HILAT, and EXOS-D) has been at a single wavelength or wavelength band [Hirao and Itoh, 1078; Frank, et al., 1981; Schenkel, et al., 1985; and Oguti, et al., 1990]. Multispectral information has been collected by previous instruments such as the AIRS instrument [Schenkel, et al., 1986] flown on the Polar BEAR satellite or the UV imagers on the Viking satellite [Murphree and Cogger, 1988]. However, these instruments had characteristics which restricted their usefulness for quantitative, multispectral analysis. The Viking imager lacked the needed wavelength selectivity, and AIRS had a fixed separation (240 Å) between the wavelengths observed.

Existing multispectral data have additional limitations. For example, most of the data from the Polar BEAR satellite is from the northern auroral latitudes, and this data typically observes a portion of the auroral oval for only 5-6 sequential orbits. Also, the sensitivity characterization of many UV imagers has been less than ideal.

AURA has been designed to provide a data set without some of the constraints of previous observations. Such data will help provide answers needed for further quantitative use of UV imagery. The data collected by AURA will aid in developing remote sensing algorithms for DoD users, and it will help extend UV remote sensing of the ionosphere to a global scale. Such remote sensing will have direct consequences on RADAR, communications, and missile defense operations.

2.0 System Description

The AURA experiment consists of two identical instruments mounted on a plate to the spacecraft deck, and an electronic control module (ECM) which can be located separately (Figure 1). The experiment is designed for a minimum 3 year lifetime, and is anticipated to fly on a class C satellite such as the Air Force's Space Test Experiments Platform (STEP). The expected orbit for the experiment has an altitude from 700 to 1000 km, and an inclination of 65° to 85°.

The two instruments are mounted so as to spatially scan perpendicular to the spacecraft

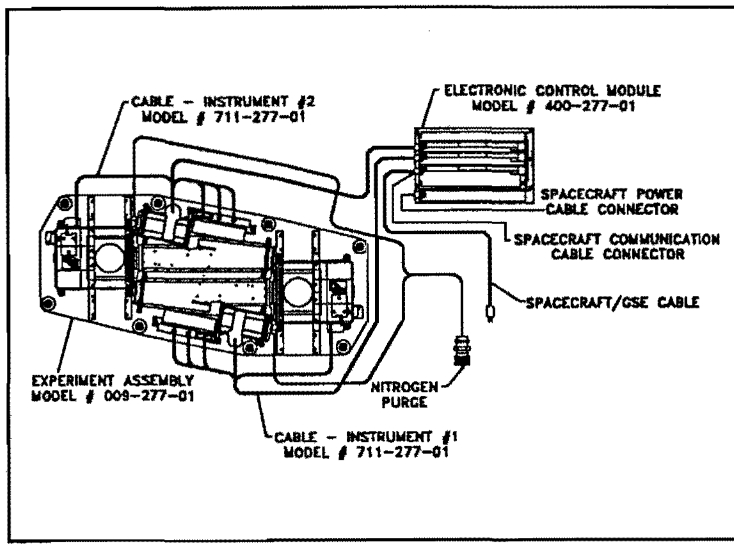

Figure 1
AURA Experiment

velocity vector. Each instrument consists of a ⅛ meter Ebert-Fastie spectrometer mated to a 2° x 0.2° field-of-view telescope, a scanning mirror assembly, and an integrated detector package. The spectral range of the instruments is 1150 to 1900 Å. The brightness from atmospheric emissions is monitored using CsI photomultiplier tubes in a photon counting mode. Spectral wavelength is varied by rotating a 3600 l/mm ruled grating (blazed at 1216 Å) with a stepper motor. The spectral resolution is 20 Å. An optical fiducial provides the position of the grating, and removes the possibility of cumulative wavelength error due to motor slippage.

The scan mirror mechanism is capable of scanning $\pm$ 90° from nadir, and can rotate 180° from nadir for launch stowage. A scanning aluminum mirror is driven by a 4 phase stepper motor with gear reduction to provide an angular resolution of 0.03° at a rotating speed of 6°/second. The movement of the scan mirror has the effect of rotating the spectrometer slit area as a function of the cosine of the angle. Therefore, the footprint size is a function of the viewing angle as well as the distance to the viewing area.

Reflective type optical fiducials provide absolute positioning at nadir and stow, while two more fiducials are used as indexing references for every 3° of rotation. Position knowledge is achieved by the correlation of the absolute position fiducials, the indexing fiducials, and the appropriate stepper motor phase pattern. The fiducial system will not allow more than 0.12° offset, with the system having a fiducial reference every 3°.

The spectrometer cam mechanism is unidirectional, so spectrometer modes involve a complete spectral scan before returning to the same wavelength position. The period for a complete spectral scan is 3 seconds. On each instrument there are two sun sensors with fields-of-view larger than the instrument's. In conjunction with a torque-motor-activated dark shutter, they are used to ensure that there will be minimal direct solar illumination into the instrument.

The instruments are attached to the spacecraft bottom deck via a secondary mounting plate. The plate serves as an alignment base for the two instruments with respect to themselves and to the spacecraft velocity vector. The optical alignment will be ensured using a laser, pentaprisms, and mirrors placed upon the instruments (Figure 2). The mounting of each instrument will be held to within ±0.5° relative to the deck. The secondary plate also provides thermal paths to the spacecraft thermally controlled deck. The operating temperature range of the experiment is between -10° C and +50° C. Copper straps are used to conduct the heat generated from the motors to the eight mounting points of the plate.

The instruments are operated by the electronic control module (ECM) via cables that are routed from the deck mounted instrument assembly

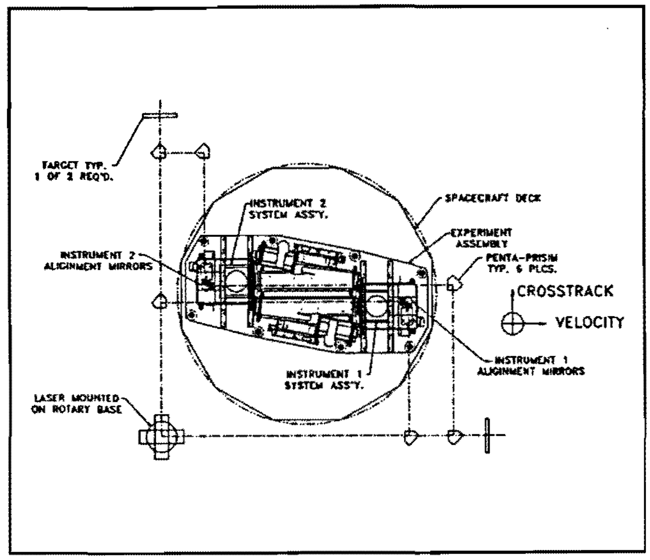

Figure 2
Instrument Alignment Setup

to the inside of the spacecraft. The ECM is a single electronics box that houses the PC cards required to operate the system. Unregulated 28 V ± 4 V power is supplied by the spacecraft to the ECM power supply board, which creates the ± 5 V, 12 V, and 20 V used by the electronics and mechanisms. There are two Instrument Interface Boards (IIB), one for each instrument. Each board contains the drive electronics and monitors such as the fiducial signals. The IIB's also include the receiving analog electronics for the temperature sensors, solar photodiodes, and high voltage monitors.

The experiment is controlled by the System Controller Board (SCB) which communicates with the spacecraft and relays the control signals to the IIB's. The SCB uses a Motorola 68332 microcontroller for instrument control, and a field programmable gate array (FPGA) for the photon counters. These IC's incorporate a significant quantity of peripheral electronics, thereby reducing the ECM size. The communication channels with the spacecraft consist of an RS-422 asynchronous bidirectional command uplink, and an RS-422 synchronous data link; of which the AURA experiment provides the clock, sync, and 16 bit data. Table 1 gives the experiment characteristics.

Table 1
AURA Physical Parameters

CHARACTERISTIC	PARAMETERS
Spectral Range	1150 -1900 Å
Spectral Resolution	20 Å
Spectral Step Increment	1.45 Å
Spectral Scan Period	3 seconds
Field of Regard	± 90° from nadir
Spatial Step Increment	0.03°
Telescope Focal Length	230 mm
Spectrometer Slit Size (curved)	0.962 mm x 8.0mm
Instrument Field-of-View	2.0° x 0.2°
Grating Description (classically ruled replica)	3600 l/mm blazed at 1216 Å
Instrument Sensitivity (1400Å)	6.64 counts/s/Rayleigh
Experiment Weight (Instruments & ECM)	23.3 kg
Experiment Power (operating)	8.7 to 23.6 watts (28 V)
Integration Period (nominal)	5 ms

3.0 Operational Scenarios

The experiment is designed to operate in several different modes selectable from the ground. These modes include spectral scanning, spatial scanning, photometer mode (staring both spatially and spectrally), selected spectral frequencies mode in which longer dwell times are given for key selected wavelengths, and system test mode. The two instruments operate independently. Since both instruments can scan ±90° from nadir, they provide complete coincident viewing, including the capability to calibrate on a single star. When the two instruments perform imaging, they can view different spectral bands within the same area, different areas at identical spectral bands, or simultaneous areas at identical spectral bands. The nominal integration period for all modes is 5 ms. Longer integration times are achieved as multiples of this period.

The area to be viewed is determined from the 2° x 0.2° field-of-view, the angle off nadir, and the distance to the viewed area. The viewing angle from nadir is a factor due to the rotation of the imaged slit with angle. The viewing area is defined as the in-track length (X) multiplied by the cross-track length (Y). These are defined as:

$$X = L^*(34.91\cos\theta + 3.49\sin\theta) \times 10^{-3} \text{ km} \quad (1)$$

$$Y = L^*(3.49\cos\theta + 34.91\sin\theta) \times 10^{-3} \text{ km} \quad (2)$$

where L is the length to the viewing area in km, and θ is the viewing angle from nadir. If the viewing area is defined at the Earth's surface, then the equations become:

$$X = H^*(34.91 + 3.49 \tan\theta) \times 10^{-3} \text{ km} \quad (3)$$

$$Y = H^*(3.49 + 34.91 \tan\theta) \times 10^{-3} \text{ km} \quad (4)$$

where H is the altitude of the spacecraft.

Figure 3 shows a spatial scan that is contiguous around nadir from an altitude of 1000 km. The total swath period is 11 seconds, with a swing angle of $\pm16.5°$ covering a lateral distance of ±592 km. Figure 4 shows a similar contiguous scan, except centered around 30° from nadir. Here, the total swath period is 11.6 seconds, covering a total lateral distance of 866 km.

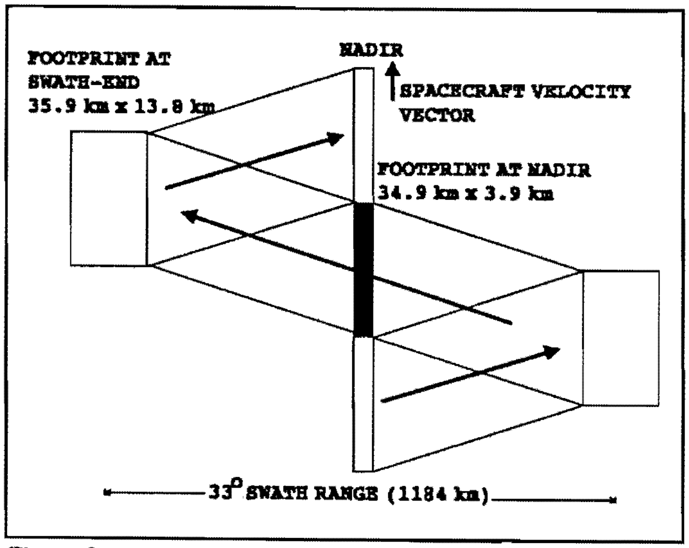

Figure 3
Spatial Scan Swath around nadir

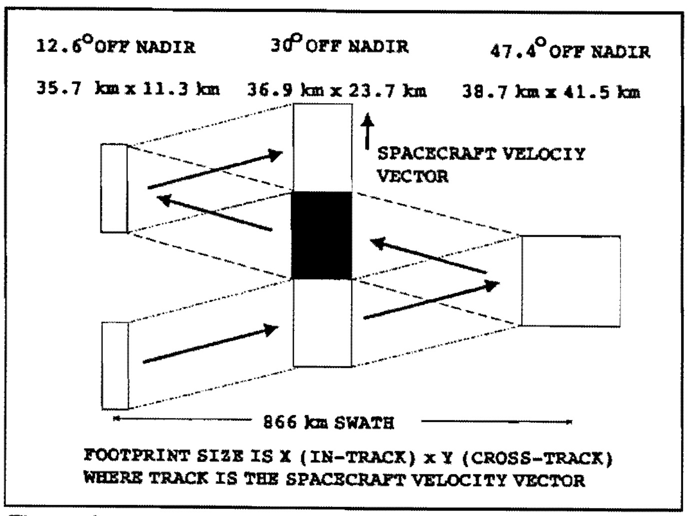

Figure 4
Spatial Scan Swath around 30° from nadir

In spectral scan and selected spectral frequencies modes the scan mirror is set at a particular viewing angle. The spectrometer grating is rotated through an effective spectral range of 1100 to 1900 Å at a step rate of 5 milliseconds. This is the nominal dwell time for each 20 Å bandpass where the step increments are 1.45 Å. Because the MgF_2 window of the PMT cuts off wavelengths shorter than 1150 Å, grating positions from 1100 to 1150 Å can be used as a dark count reference.

In the selected spectral frequency mode, selected wavelengths may be observed for longer than one integration period. The grating positions are sent from the ground along with the desired number of 5 millisecond integration times at each position. This allows for better statistical intensity measurements at key wavelengths.

In spatial scan mode, the spectrometer is set to the desired wavelength and the scan mirror is rotated. Starting and ending angles can be selected. The mirror rotates to the starting angle and proceeds to scan in 0.03° steps to the ending angle. Upon achieving this angle, the mirror is rotated in the reverse direction back to the starting angle. This scanning action is repeated until the mode is changed via the command link. Using this scanning action, along with the perpendicular motion of the satellite, a two dimensional spatial map can be made at any desired wavelength.

Other options include the photometer mode, in which data at a selected wavelength is collected at a set viewing angle, and system test mode. System test mode provides feedback to the ground of functions such as ROM and RAM memory, photon counting electronics, and motor tests. In each mode, the parameters of the system such as sun sensor threshold levels, or enabling and disabling of fiducials, temperature sensors, and high voltage sensors can be modified.

4.0 Scientific Objectives and Data

In the auroral region, AURA will generate two types of information. The first type is morphological. Although information of this type has been collected previously, AURA has significant design differences which enhance its ability to measure desired quantities and phenomena. AURA's independently operable, identical instruments allow the experiment to perform spatial scanning with a variable, temporal offset; the two instruments can be simultaneous, separated by only a few pixels, or they can observe completely different areas. The AIRS instrument on the Polar BEAR satellite, which observed each pixel only once, left questions on whether variations were temporal or spatial. Also, one instrument can image the aurora at a single wavelength while the other instrument performs spectral or photometric observations. This allows AURA to collect information on the location of the auroral boundary using one instrument, and the atmospheric constituents (O, N_2, etc.) with the other. Figure 5 shows expected the maximum spatial scan image width for a single pass through the auroral region at either 30° off nadir or at nadir, left and right respectively, in which contiguous data can be gathered.

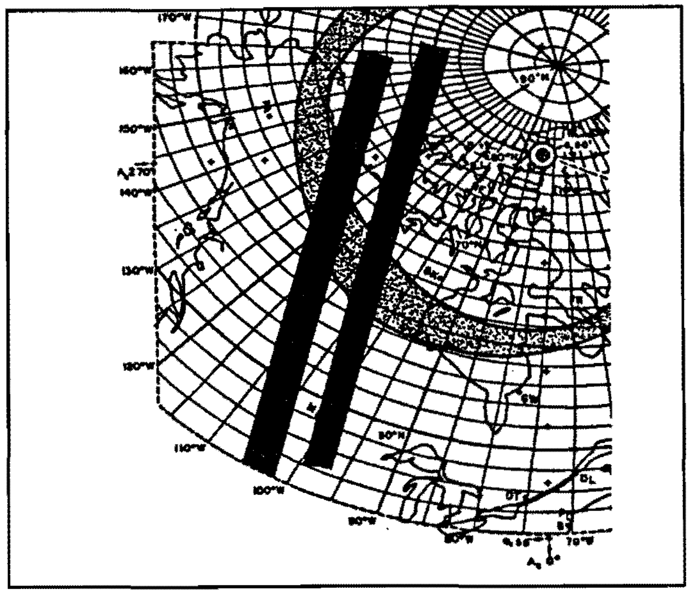

Figure 5. Auroral Oval plotted over North America for Q=1, low solar activity. (Jim Whalen, 1972)

The second type of auroral information AURA will collect involves particle precipitation. A spectral resolution of 20 Å and the ability to calibrate the instruments on stars, provide confidence that a single instrument will be able to measure the total particle precipitation energy deposited in the auroral region in either imaging or photometric mode. This endeavor is enhanced by having two independent instruments recording separate wavelengths simultaneously, whether in imaging or photometric measurement modes. Intensity measurements at the proper wavelengths provide insight into the characteristic energy of particles producing the aurora [Strickland, et al., 1983]. For example, in the upper region of the atmosphere (170 to 200 km and up) the main emission is from atomic oxygen, while lower altitudes are dominated by molecular nitrogen emissions. By comparing the molecular nitrogen and oxygen emissions, the energy of the incoming particles can be determined. Typically, as the energy of incoming particles increases, the N_2/O emission ratio increases. This measurable difference in emission is generated because the higher energy particles penetrate further into the atmosphere.

Tropical arcs are areas of high electron and ion densities occurring immediately after dusk in the equatorial region. They are centered around two peaks at approximately ± 15° dip latitude (See Figure 6). Recombination of oxygen ions and electrons within the equatorial arcs creates oxygen emissions, for example, at 1304 Å and 1356 Å after dusk and into the night. The emission intensity after dusk is proportional to the square of the electron density. Therefore, an order of magnitude increase in the electron density will correspond to two orders of magnitude increase in the measured emission. The oxygen recombination is greatest just after dusk and decreases throughout the night as the source of the emissions is depleted. Figure 6 shows typical 1356 Å emissions versus dip latitude in degrees. The peak emission intensity of 100 Rayleighs corresponds to 2.9×10^6 electrons per cm^3. The horizontal line at 50 Rayleighs indicates the intensity where the signal-to-noise ratio per pixel of AURA becomes 5 for imaging, assuming continuous coverage. The signal to noise ratio was determined using the sensitivity for 1356 Å, the intensity at this wavelength, and the amount of multiple sampling achieved per pixel while imaging. When imaging, AURA samples each pixel 6 times due to the cross-track motion of the scan mirror, and 2 times due to in-track sampling for scans providing contiguous coverage. With pixel smoothing, the signal-to-noise ratio can be increased.

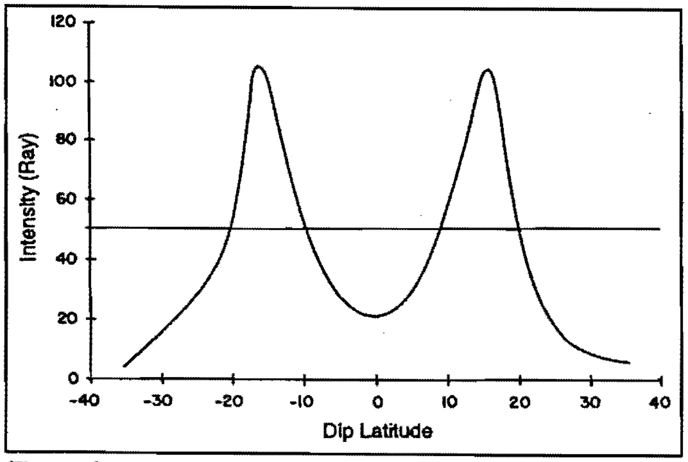

Figure 6
Concentrations of Tropical Arc Emissions

Within the tropical arcs are areas which contain low concentrations of electrons and ions relative to the surrounding areas of the arcs. How and why these "depletions" are created has not yet been determined. AURA will observe the depletions as dark areas or a lack of emission within the arcs. Although the depletions have been imaged from below, top-side imaging has not been successful because adequate spatial resolution and sensitivity have not yet been simultaneously achieved. The sensitivity of the AURA experiment will be sufficient to image them. Figure 7 shows the sensitivity curve for each AURA instrument. This curve was generated by calculating the expected sensitivity at 1400 Å for AURA and scaling the measured sensitivity of the Polar BEAR AIRS instrument to the calculated value of AURA. The exact sensitivity will not be known until calibration of the completed AURA instrument.

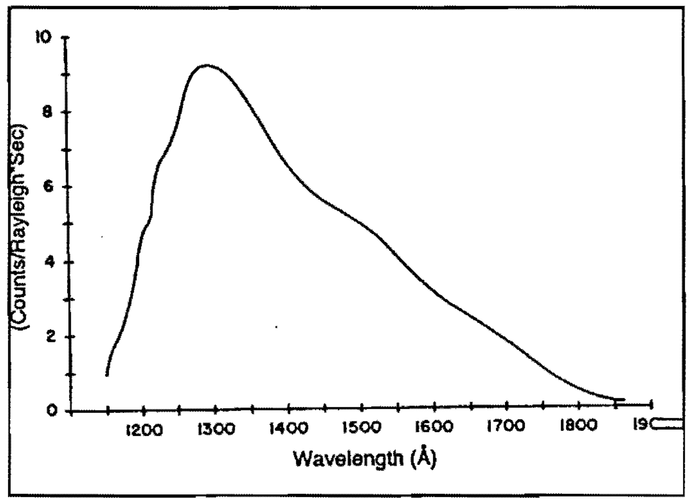

Figure 7
AURA Sensitivity Curve for each instrument at 20 Å resolution.

The spatial resolution of AURA, a ground footprint of approximately 35 X 3.5 km from a 1000 km altitude, provides greater resolution than the observed size (50-200 km) of the depletions. This small footprint enables high resolution mapping of the region. AURA will provide measurements near the terminator, where depletion zones are typically created, as well as provide information on the northern and southern arcs at approximately the same time and longitude. This is important because the emissions are not always symmetrical about the magnetic equator. Asymmetry in the emission intensity is believed to be indicative of neutral wind effects. By comparing the northern and southern arc emissions near the terminator, we hope to understand conditions conducive to the formation of the depletions.

The previous discussion of the tropical arcs is for low magnetic activity; however, during periods of high magnetic activity, the observed 1304 Å and 1356 Å emissions near the equator increase unexpectedly [Abreau, et al., 1986]. It has been suggested that precipitation of energetic neutral particles produce the extra emission. One way AURA can test this suggestion is by having one instrument image the area at 1356 Å (or 1304 Å) while the second instrument operates in photometer mode in the molecular nitrogen wavelength band. If energetic neutral particle precipitation is responsible, molecular emissions should be observable.

Measurements performed at night will be used to collect information on N_{max}, the quantity of charged particles at the maximum point of the electron density profile. The electron density is defined as the quantity of electrons per unit volume, with the electron density profile being a mapping of the electron density versus altitude.

By scanning the limb, AURA can generate coarse information on the height of N_{max} in the electron density profile. The height resolution at the limb (~35km) is sufficient for useful information on N_{max} at night. If N_{max} is very high this maximum emission will pass through the field-of-view when AURA scans the limb. The relative position is determined by relating the scan mirror angles as N_{max} passes into and out of the field-of-view.

In the daytime AURA will be used to measure the airglow. This data will be used to determine electron densities, O/N_2 neutral density ratios and solar flux proxies. Table 2 shows the signal-to-noise calculations for the AURA instruments. The conditions for the emission intensity are F10.7 = 123 and a solar zenith angle of 9.0°.

Table 2
Signal and Noise Figures for AURA Versus Wavelength

L(Å)	Intensity(Ray)	Signal(cts)	Noise(cts)
1216	15,500	5569.200	74.627
1304	1,490	812.994	28.513
1356	801	394.141	19.853
1383	180	77.760	8.818

Intensity generated by AURIC Code for 179th day of 1982 at approximately 11:20 pm.

5.0 Acknowledgements

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7.0 Biographies

Steven K. Clegg graduated from the University of California Irvine in 1991 with a BS in Electrical Engineering and a BA in Economics. He is a commissioned officer in the US Air Force and is stationed at Phillips Laboratory, Geophysics Directorate at Hanscom AFB where he is the project officer for the AURA experiment.

Michael E. Gangl received a BS in Electrical Systems Engineering from Wright State University and a MS in Electrical Engineering from the Johns Hopkins University. He is the manager of electrical engineering at Research Support Instruments, and the project manager of AURA.

Richard W. Eastes received his Ph.D. in physics from the Johns Hopkins University in 1985. He now works at the Air Force's Phillips Laboratory in the Geophysics Directorate and is the principle investigator for the AURA experiment.

John H. Middlestadt received a BS in Mechanical Engineering from the University of Maryland. He is employed by Research Support Instruments, and is the lead mechanical engineer on AURA.