INVESTIGATION OF VEHICLE GLOW IN THE FAR ULTRAVIOLET

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Abstract. To date, all vehicle glow observations have been conducted in the visible and near infrared wavelength regions. As the Space Telescope's wavelength coverage extends to the far ultraviolet range and current plasma theory of the spacecraft glow phenomena predicts bright glow intensities, we have begun a study of the ram glow effects in the 800-1400 Å region. The data were collected between March 21-28, 1979, from 600 km altitude near local midnight by the University of California, Berkeley's extreme ultraviolet spectrometer on board the polar orbiting STP78-1 satellite. Data from several nighttime orbits obtained outside the South Atlantic Anomaly region and within ±30° magnetic latitude range were separated into forward (south viewing) and backward (north viewing) bins. Each of these bins was subdivided into three directional categories: (1) up (zenith angles 30-80°), (2) side (zenith angles 80-100°), and (3) down (zenith angles 120-150°). The maximum ram glow effects are expected in the side viewing directions. Our data indicate possible effects of ram glow signatures in the 800–1400Å wavelength region.

Introduction

An unexpected optical phenomenon was discovered during the third flight of the space shuttle. Color photographs and low light level TV experiments showed that the Orbiter "glows" in the dark [Banks et al., 1983]. The glow phenomenon was found to be associated with the interaction of the ambient atmosphere with the Orbiter body and has since been referred to as shuttle glow, vehicle glow, or spacecraft glow.

The emission intensity was found to depend on the angle between the spacecraft velocity vector and either the line of sight vector or the surface being viewed. The brightest signal was observed from the spacecraft surface facing the direction of its motion, thus allowing the hypothesis that the emissions are due to the interaction of the ambient atmosphere with the spacecraft. Thruster firing was also found to emit light in the visible and near infrared region [Banks et al., 1983; Mende et al., 1983].

Similar observations were made earlier [Torr et al., 1977] from the Atmosphere Explorer C (AE-C) satellite. The investigators found that very large intensities of emissions (up to 2.5 kR at 7320Å at midnight) are due to the interaction of the satellite with the atmosphere. Banks et al. [1983] deduced an intensity of 10 kR for the glow while Mende et al. [1983] reported the intensity of the glow to be 300-400R. This huge difference in intensity can be attributed to both the difference in altitude of the two flights and the angle of attack.

Yee and Abreu [1983] examined AE-E photometric data and found that the emissions are brightest in the red and are considerably weaker shortward of 4000Å. They suggested that the glow has a diffuse or continuum spectrum. Later space shuttle experiments [Mende et al., 1983, 1984a,b; Swenson et al., 1985] have confirmed that the spectrum is diffuse in nature. They also found that the spectrum is consistent with the orange-red color found in the photographs and peaks near 7000Å.

Several mechanisms responsible for producing the emissions have been proposed. Yee and Abreu [1983] found a strong correlation between the glow emissions and atomic oxygen density above 160 km altitude. No correlation was found between the emission intensity and the molecular nitrogen density. Moreover, below 160 km, the glow intensity was found to be uncorrelated with O density. Although the authors did not propose any specific excitation mechanism, their data strongly suggest one involving atomic oxygen.

Slanger [1983] proposed that the emissions are due to the OH Meinel band system. This proposed mechanism was supported by the altitude distribution of the glow as observed by Yee and Abreu [1983] and the lifetime of these emissions. However, later spectroscopic observations

[Mende et al., 1984a] indicated that OH cannot be the primary source of these emissions.

The Imaging Spectrometric Observatory (ISO) experiment on the Spacelab 1 missions has studied the shuttle glow phenomenon using high resolution (2 – 3Å) spectrometers in the far ultraviolet (FUV) to near infrared region [Torr and Torr, 1984]. These observations indicated the presence of N_2 emissions in the glow spectrum. It is possible that this glow spectrum contains dayglow emissions and therefore, an independent verification of the N_2 emissions in the glow spectrum will also be needed.

Another proposed mechanism to explain the shuttle glow effects involves hot electrons causing plasma discharge [Papadopoulos, 1984]. Support for this hypothesis was provided by the observation of the N_2^+ first negative system by the ISO experiment and from the observations of NO 2150Å emissions from the AE-D satellite. However, the absence of the N_2 second positive system in the ISO spectrum and the dependence of the glow intensity on the surface materials [Mende et al., 1984a] argue against this possibility. One interesting aspect of this mechanism is that it predicts glow emissions in both the blue and the ultraviolet (UV). Unfortunately, no systematic study of the glow has been conducted in the UV.

Torr et al. [1977] have suggested that the emissions are produced by the recombination of NO with O on the interior surface of their instrument. NO 2150 Å glow emissions observed spectroscopically from the AE-D satellite were found to have a brightness of ~2 – 3kR at 140 km altitude (A. I. Stewart, private communication, 1985). Recent spectroscopic measurements [Swenson et al., 1985] have indicated a continuum spectrum of the glow emission which is similar to the recombination continuum of NO_2 obtained in the laboratory.

Most of the glow studies have been conducted at altitudes equal to or less than 300 km. Yee and Abreu [1983] have reported observation of the glow to altitudes greater than 400 km, at least at 7320Å. This raises a potential concern for the Space Telescope; therefore, it is important that glow intensities be measured at the Space Telescope altitude (590 km) and all wavelengths covered by it. Unfortunately, from existing data, no experiment can provide answers to all of these questions.

We flew a spectrometer onboard an Air Force satellite at 600 km. The primary purpose of the experiment was to study the airglow emissions in the Earth's upper atmosphere. The experiment was conducted near solar maximum during 1979-1980, a condition likely to be experienced by the Space Telescope. In this report, we summarize our observations of possible glow-like phenomena in the 800–1400Å wavelength range.

Instrument and Orbital Operations

The instrument consists of a 0.5-mm-wide rectangular entrance slit, a concave reflection grating, and two redundant position-sensitive extreme ultraviolet (EUV) detectors lying on the Rowland cylinder. It has been described in full detail by Bowyer et al. [1981]. At any given time, a 650Å-wide window is observed every 0.2 second out of the full 300 to 1400Å operating range of the instrument.

The combination of slit dimension, grating size, spin, and telemetry rate of the spacecraft provides a triangular working field-of-view of 18° × 9°. The instrument has a full width at half maximum (FWHM) resolution of 8Å and a peak sensitivity of 0.1 counts sec^{-1} R^{-1} per wavelength bin at 550Å.

The satellite was placed in a 600 km altitude, Sun-synchronous, polar circular orbit lying essentially in the noon-midnight plane. The spectrometer was housed in the spinning wheel of the spacecraft in the so-called cartwheel configuration. The spectrometer's line-of-sight is oriented at 120° from the spin axis. As the wheel rotates at 11 rpm, the instrument's line-of- sight sweeps out a cone, alternately viewing the Earth and space and never looking closer than 30° to the Sun.

Results

Our instrument is housed in a spinning platform which enables us to study the dependence of the emissions with the angle of attack. However, since the emissions are considerably weaker in the EUV than in their red counterpart, we report here on only the spectra obtained in the side viewing direction (zenith angles between 80° and 100°) where the vehicle glow effects are expected to be strongest. Only nightside data obtained within ±40° magnetic latitude are considered in this study. All data obtained during a South Atlantic Anomaly (SAA) pass were discarded from this analysis.

The sketch shown in Figure 1 demonstrates how the spectra were selected for the forward (ram) and backward (wake) viewing directions. Also shown is the observing geometry for the up (zenith angles between 30° and 50°) and down (zenith angles between 120° and 150°) directions.

A large number of individual side viewing observations were selected according to the rules outlined earlier to yield an average forward looking and an average backward looking spectra as shown in Figure 2. Several bright features are present in these spectra and are indicated. Also shown are 1σ count statistics for each wavelength bin.

It is evident that the spectra are dominated by emissions from neutral hydrogen and neutral oxygen. These emissions and their morphology have been discussed by Chakrabarti et al. [1984], Chakrabarti [1984], and Abreu et al. [1984]. The hydrogen emissions are excited by multiple scattering of solar Lyman α emissions generated by geocoronal hydrogen atoms. The OI emissions, on the other hand, are excited by radiative recombination of ionospheric O^+ ions and show strong latitudinal dependence. To find the spectral characteristics of the glow emissions in this wavelength range, the spectrum obtained in the wake was subtracted from that obtained in the ram direction. The resulting spectrum is shown in Figure 3.

Discussion

The residuals in the spectrum shown in Figure 3 are positive for most of the detected features shown in Figure 2. This implies that the HI and OI emission features are brighter in the ram direction than in the wake viewing direction. The geocoronal hydrogen Lyman α emissions have been studied extensively [see for example, Meier and Mange, 1973] and have been found to depend primarily on the solar zenith angle. Because our observations were made near equinox and the satellite is in a noon-midnight orbit, any possible solar zenith angle effects are nullified due to the accumulation of spectra obtained in the north and south hemispheres. Figure 1 shows that the closest altitude where the line-of-sight crosses the auroral zone is $\geq$ 700 km. Thus, the observed $\sim$ 1.5 kR Lyman α excess intensity in the forward viewing direction is not likely to be due entirely to an auroral source. Any spatial variation of the intensity distribution giving rise to the observed effect must also be time varying at roughly 15 minutes or less. Otherwise, the accumulation of forward and backward viewing spectra from every latitude point along the spacecraft orbit will cancel out such an effect. Another mechanism which can produce such asymmetry in the Ly α intensity is the contribution of interplanetary Ly α emissions. Such a mechanism can produce up to 1000R intensity difference (R. R. Meier, private communication, 1985). It is also possible that the interplanetary hydrogen emissions contribute to the observed directional dependence of the Ly α signal. However, there still remains a portion of the excess Ly α signal in the forward viewing direction.

We now are faced with the question: is it possible that we are observing the spacecraft glow effects produced by hydrogen atoms? We need $\sim 1.5 \cdot 10^5$ photons sec^{-1} along the line-of-sight to produce the required intensity. MSIS predicts $5.3 \cdot 10^4$ H atoms per cubic centimeter for our observing condition. If the Ly α glow extends only 20 cm, then it would be unlikely that a kilorayleigh glow could be produced from $\sim 10^{-5}$ production efficiency. The Lyman β "glow", on the other hand, has an intensity of $\sim$10 R which has a greater probability of being produced by an atmospheric interaction. Although no conclusions can be drawn from these data, it is possible that some of these hydrogen emissions are excited by the spacecraft glow phenomenon.

We observe that two OI emissions at 911 and 1356Å are brighter in the ram direction. The intensities are $\sim$15 R and might be produced by vehicle interaction. However, the OI 1304Å emission does not show the same directional dependence, and argues against it.

From energy arguments, one can rule out collision excitation mechanism for the hydrogen emissions. The Lyman α and β emissions need $>$ 10 eV energy for their excitation which is larger than that attainable by the 7 km/sec satellite velocity. These emissions are most likely due to recombination of protons at the satellite surface. Hydrogen recombination continuum at 912 Å provides support to this hypothesis.

We did not observe any N_2 LBH emissions in the individual spectra shown in Figure 2. However, the residual spectrum shown in Figure 3 contains a slight indication of the (6,0) band at 1273 Å. Taking these data at their face value then implies that we are observing an excess of ~400 R of total LBH emissions in the forward viewing direction. Very bright N_2 LBH emissions of unexplained origin have been observed in several experiments [for a review on this subject see Meier and Conway, 1983] . These emissions were found to be limited to the summer and north hemisphere. We searched for such emissions in our data and have not found them [Chakrabarti et al., 1984].

In summary, we have studied the dependence of the EUV and FUV emissions at 600 km. Our data show that several of these emissions are brighter in the ram direction than in the wake. It is possible that the ram glow phenomena are contributing to the observed excess intensity in the EUV. Further studies using higher sensitivity instruments will be needed to completely understand these effects.

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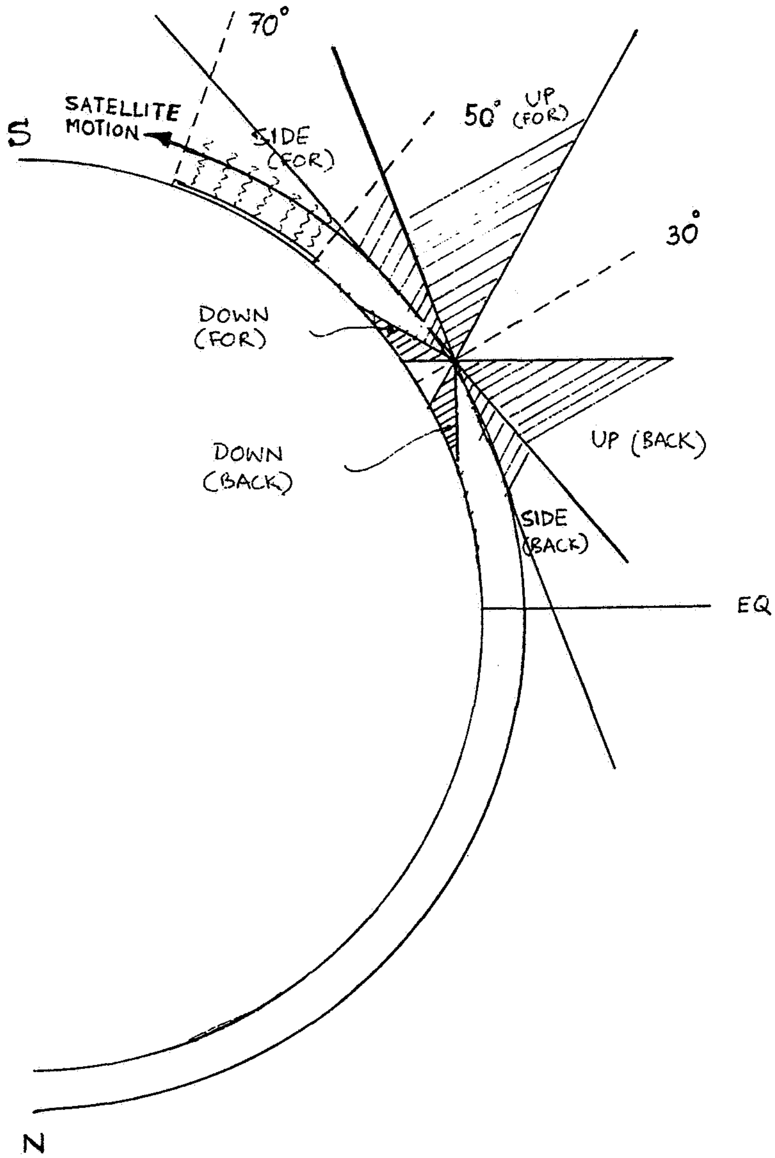
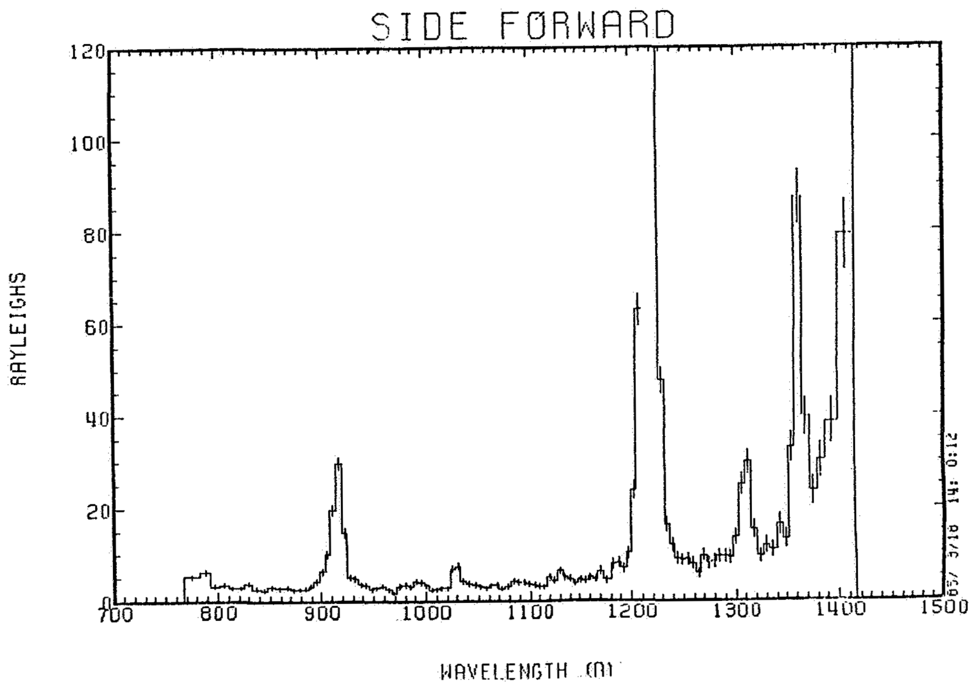


Fig. 1. The observing geometry for a nightside pass is shown. The satellite motion is indicated with an arrow from the north to the south pole at 600 km altitude. Boundaries of the up, side, and down looking directions chosen for this study are shown with hatches for a satellite location of 30° south latitude.



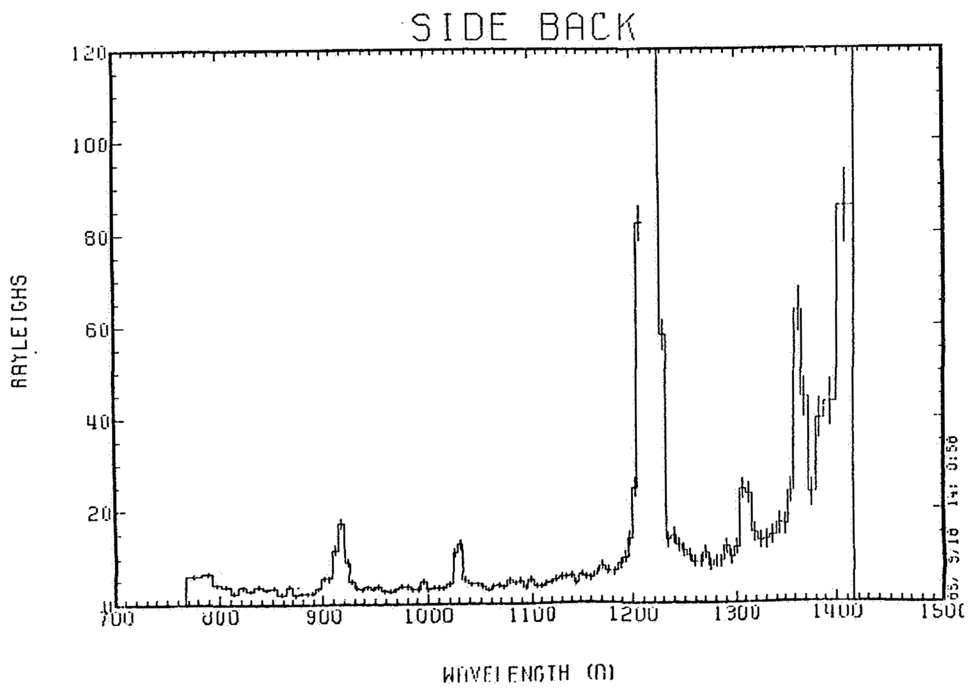


Fig. 2. Side viewing spectra obtained while the satellite was within ±30° magnetic latitude range are shown for the forward and backward looking directions. The viewing geometry is shown in Figure 1.

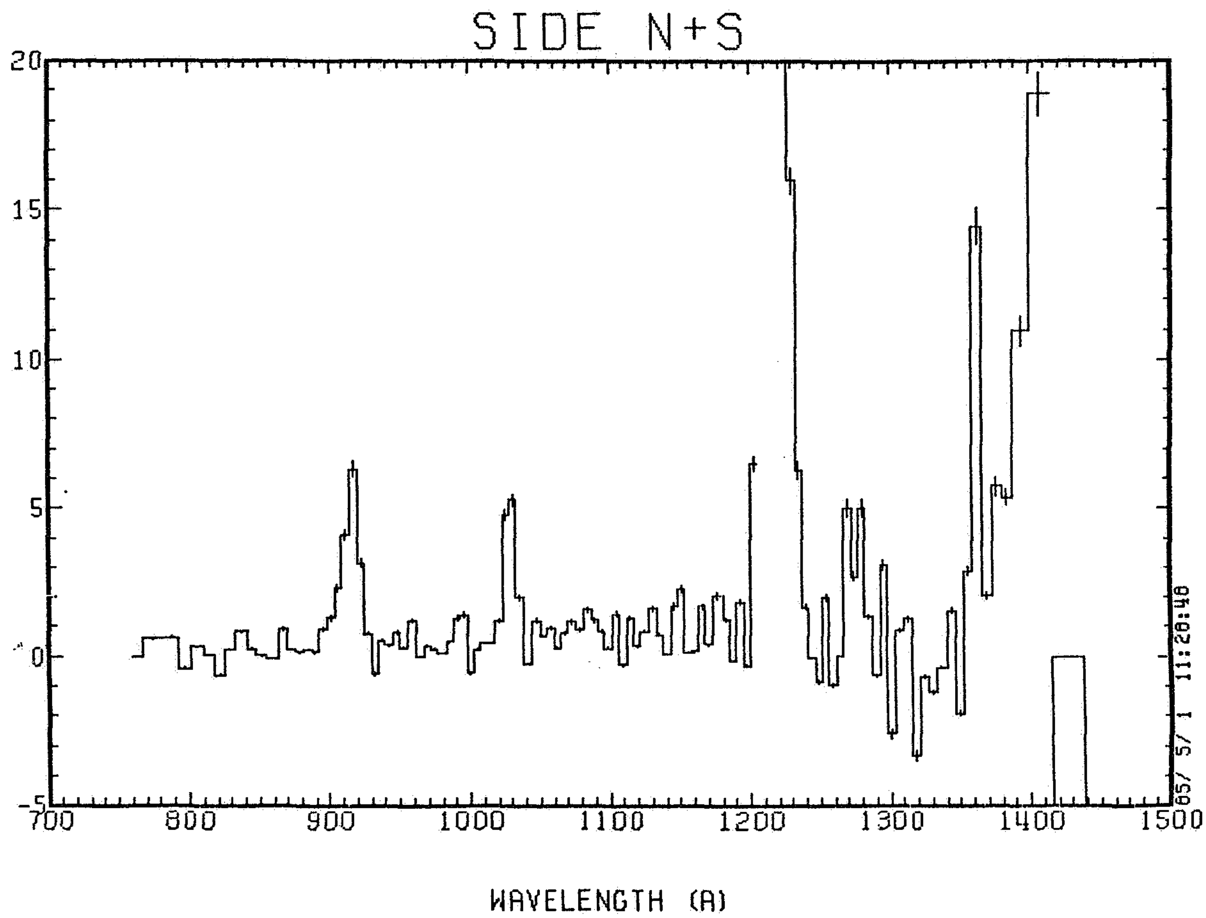


Fig. 3. The spectrum obtained by subtracting the backward looking spectrum from the forward viewing spectrum.