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# INFRARED SPECTRAL MEASUREMENT OF SPACE SHUTTLE GLOW

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Abstract. The U.S. Air Force and NASA successfully conducted infrared spectral measurements of the space shuttle glow during STS-39. Preliminary analysis indicates that NO, $NO^+$, OH, and CO produce infrared glow during quiescent orbiter conditions. During orbiter thruster firings the glow intensities in the infrared are enhanced by factors of 10X to 100X with significant changes in spectral distribution. These measurements were obtained with the Spacecraft Kinetic Infrared Test (SKIRT) payload which included a cryogenic infrared circular variable filter infrared spectrometer covering the 0.7 to 5.4 $\mu$m wavelength region. Approximately 14,000 spectra of shuttle glow, airglow, aurora, and the orbiter environment were obtained during the eight day mission. The STS-39 Space Shuttle Discovery was launched from the NASA Kennedy Space Center on 28 April 1991 into a 57 deg inclination circular orbit at an altitude of 260 km.

## Introduction

Previous observations and measurements show that spacecraft in low earth orbits produce a visible glow above surfaces which are oriented into the direction of motion. This was photographically observed during space shuttle mission STS-3 [Banks et al., 1983] and confirmed on other shuttle flights [Mende and Swenson, 1985] as well as during satellite operations [Torr et al., 1977; Yee and Abreu, 1982].

The glow is caused by the interaction of spacecraft, travelling at approximately 8 km/sec, with the high altitude atmosphere. A number of papers provide excellent reviews of this data base [Green, 1985; Mende et al., 1987; Garrett et al., 1988; Slanger, 1989]. Based on these studies it is apparent that various reactions between spacecraft surfaces and the ambient atmosphere are likely taking place and there is not a single reaction mechanism solely responsible for glow emissions at all wavelengths.



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Our experiment, Spacecraft Kinetic Infrared Test (SKIRT), was designed to obtain detailed measurements of space shuttle glow in the infrared, visible, and ultraviolet with particular emphasis on the previously unstudied infrared. It was launched on 28 April 1991 on board the STS-39 Space Shuttle Discovery into a 260 km altitude circular orbit at an inclination of 57 deg for an eight day mission.

In this paper, we report measurements of the space shuttle glow at infrared wavelengths (0.7 to 5.4 $\mu$m). Preliminary analysis shows vibrational band structure consistent with that of NO, $NO^+$, OH, and CO. The glow intensity is enhanced and changes in its spectral signature during thruster firings.

SKIRT also operated during "non-glow" measurement times to provide an extensive infrared data base on the in situ orbiter environment in support of infrared measurements conducted by the Cryogenic Infrared Radiance Instrumentation for Shuttle (CIRRIS-1A) payload [Ahmadjian et al., 1990]. By measuring the near field shuttle environment while CIRRIS-1A was conducting far field atmospheric measurements, SKIRT provided a complementary data base which will permit identification of local infrared background emissions in the CIRRIS-1A data. Analysis of data taken during the CIRRIS-1A measurement periods, when the orbiter environment was constrained to be as benign as possible, shows that shuttle contamination levels are acceptable for sensitive cryogenic infrared sensors operating from the cargo bay.

## Experiment Description

SKIRT consisted of two separate payloads, designated as SKIRT CVF (Circular Variable Filter) and SKIRT GLOS (Gaseous Luminosity/Optical Surfaces). SKIRT GLOS contained six radiometer assemblies covering the wavelength region from 200 nm to 5.4 $\mu$m in 42 bandpasses. SKIRT GLOS data have yet to be analyzed and will not be discussed in this paper.

SKIRT CVF featured an infrared circular variable filter spectrometer and a long wavelength infrared radiometer, both sharing common collecting optics and cooled with

Table 1. SKIRT CVF/Radiometer Specifications

| | |
|---|---|
| Spectrometer | |
| Wavelength Range | 0.7 to 5.4 μm |
| Spectral Resolution | 2% nominal |
| Detector | In:Sb |
| NESR (60 K, 5 μm, 17 Hz) | 6 x $10^{-12}$ W/cm$^2$ sr cm$^{-1}$ |
| Scan Time | 5s |
| Field-of-View | 2 x 2 deg (full) |
| Aperture Size | 1.52 cm (diameter) |
| Optical Transmission | >0.4 |
| Operating Temperature | <60 K |
| Instrument Power | 30W |
| Heater Power | 30W |
| Radiometer | |
| Spectral Bandwidth | 10.4 to 11.8 μm |
| Detector | Hg:Cd:Te |
| NESR (60 K, 11 μm, 17 Hz) | 9 x $10^{-9}$ W/cm$^2$ sr |
| Field-of-View | 2 x 2 deg (full) |
| Aperture Size | 1.52 cm (diameter) |
| Optical Transmission | >0.4 |
| Operating Temperature | <60 K |
| Instrument Power | 30W |
| Heater Power | 30W |
| Dewar | |
| Cryogen | $N_2$ solid |
| Pumping Method | Vent to ambient |
| Hold Time | 5 days preflight<br>60 days on-orbit<br>(closed cover) |

solid nitrogen. The spectrometer (using an In:Sb detector) covered the wavelength region from 0.7 to 5.4 μm at 2 to 3% spectral resolution and completed a spectral scan in five seconds. The radiometer had a Hg:Cd:Te detector and sampled a single wavelength interval (9.9 to 10.4 μm) which is an atmospheric transmission "window" for infrared sensors. The detectors and optical components were cooled to 57 K. An aperture cover is opened during on orbit measurement times to expose the 2 x 2 deg field of view along a line of sight directed perpendicularly to the shuttle cargo bay (-Z axis). SKIRT CVF specifications are given in Table 1 and a detailed description of the sensor is provided elsewhere [Ahmadjian et al., 1991).

The sensor was mounted into a modified Get Away Special (GAS) can which attached to the NASA Hitchhiker-M payload support structure (Figure 1). Electrical power was supplied by the orbiter via the Hitchhiker-G avionics which also provided real time commanding and telemetry down-link to the ground. Based on analysis of real time calibrated spectra generated at the Payload Operations Control Center we were able to modify and optimize our data collection opportunities.

STS-39 SKIRT / HITCHHIKER

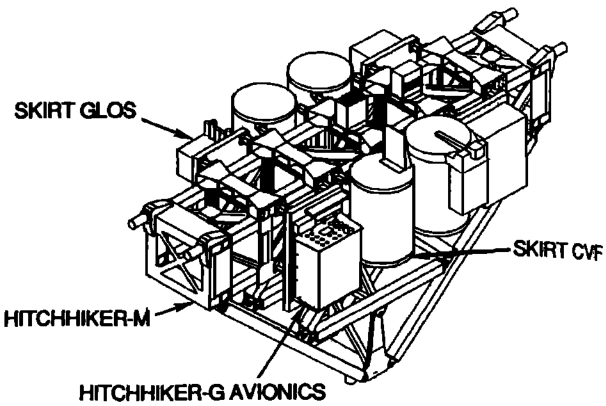


Fig 1. STS-39 SKIRT/Hitchhiker payload configuration. The SKIRT field of view looked straight up and out of the shuttle cargo bay (-Z axis in orbiter body coordinates). During dedicated glow measurements the shuttle attitude was oriented such that ram was directly into the cargo bay onto the SKIRT payload and surrounding structures.

## Flight Operations

SKIRT was commanded on at Mission Elapsed Time (MET) 00/02:56 (Day 00, hour 02, minute 56) and continued to operate through MET 07/22:00. Glow measurements were conducted at specific times during the mission when the orbiter attitude was oriented with the SKIRT payload and surrounding surfaces exposed directly to ram, away from ram, and looking at the earthlimb. Over 14,000 spectra of shuttle glow, airglow, aurora (IBC III), calibration objects, and of the orbiter environment were recorded. These data provide a detailed record of the on-orbit environment associated with large spacecraft structures.

## Results and Discussion

Figure 2a is a spectrum of space shuttle glow measured when the orbiter was flying bay to ram in a vehicle attitude such that the SKIRT CVF sensor field of view was between 3 and 40 degrees from the velocity vector (sensor pointing into ram while looking above the horizon).

Figure 2b is a glow spectrum taken during a thruster firing showing different spectral features and an increase in the overall signal intensity.

Figure 2c is spectrum of the earthlimb airglow, taken when the orbiter was in a nose down gravity gradient attitude with thrusters and contamination events inhibited (SKIRT CVF field of view was looking into wake at the 80 km earthlimb). This earthlimb spectrum provides a well characterized reference to compare with the shuttle glow spectra.

The shuttle glow spectrum in Figure 2a was obtained from 29 coadded spectra which were recorded during a time interval of MET 06/16:16:11 through 06/16:18:39 (1304 through 1345 hours orbital local time). Emission features for this "quiescent glow" when there were no thruster firings, water dumps, flash evaporators, and other

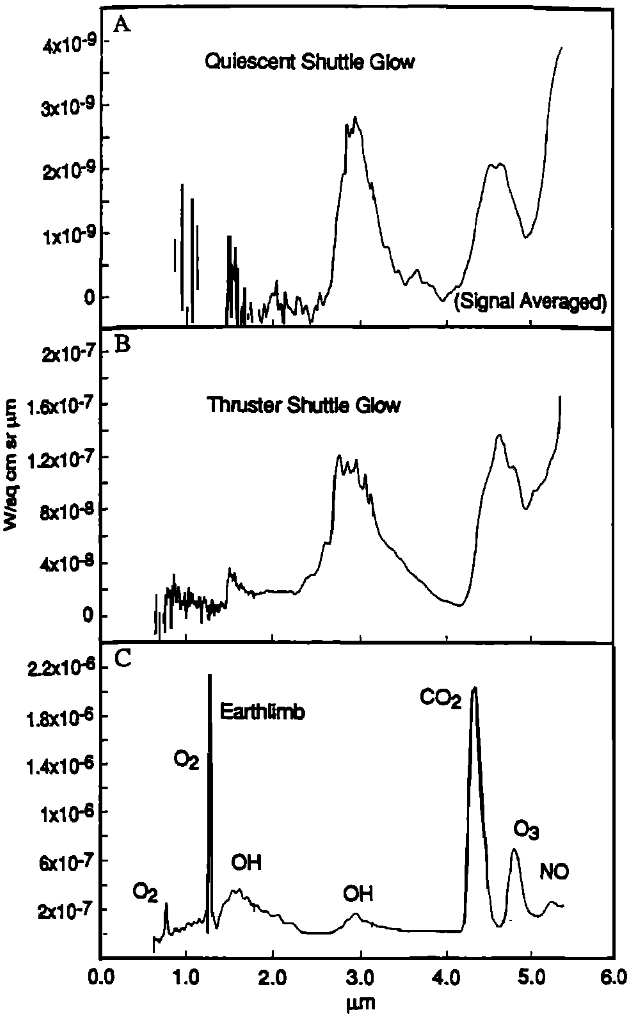


Fig 2a-c; a. Signal averaged spectrum of quiescent shuttle glow; b. Spectrum of shuttle glow during a thruster firing; c. Earthlimb spectrum. Shuttle attitude is nose down gravity gradient with bay toward wake.

contamination generating activities, have been assigned as:

| | | |
|---|---|---|
| 2.7 $\mu$m | NO | $\Delta V=2$ |
| 5.3 $\mu$m | NO | $\Delta V=1$ |
| 4.3 $\mu$m | $NO^+$ | $\Delta V=1$ |
| 1.4 $\mu$m | OH | $\Delta V=2$ |
| 2.8 $\mu$m | OH | $\Delta V=1$ |
| 4.6 $\mu$m | CO | $\Delta V=1$ |

Emission features from $NO_2$ are not readily apparent from the initial analysis. $NO_2$ $\nu_1 + \nu_3$ may be created on surfaces [Kofsky and Barrett, 1985]. Emission from $NO_2$ at 3.6 $\mu$m cannot be clearly discerned in the data. Unfortunately, the wavelength coverage of the nitrogen cooled SKIRT CVF did not include the strong $NO_2$ $v_3$ band at 6.17 $\mu$m.

During quiescent ram conditions the shuttle glow radiances in the SWIR/MWIR are on the order of $10^{-9}$ W/cm$^2$ sr $\mu$m. Spectra taken during the day are twice as intense as those taken at night. The assumed reaction precursors, O and $O^+$, are also similarly enhanced during the day.

A comparison of the SKIRT spectral data to previous visible shuttle glow measurements [Mende et al., 1985] cannot be made due to the low responsivity of the SKIRT CVF In:Sb detector at near visible wavelengths. Measurements taken by the SKIRT GLOS radiometer silicon detectors, however, should provide this comparison and will be reported on at a later date.

During thruster firings the signal intensities increased up to $10^{-8}$ to $10^{-7}$ W/cm$^2$ sr $\mu$m. Comparison of Figures 2a and 2b indicates that the quiescent glow spectra and thruster glow spectra are different both in signal intensity and in spectral content. The glow intensity increase is consistent with previous visual observations and is probably due to increased concentration of reaction precursors in the exhaust available for reaction with the ambient atmosphere. The thruster glow spectrum appears to contain at least NO, $NO^+$, OH, and CO.

Deep space background spectra (not shown) taken during non-ram quiescent conditions show an absence of significant shuttle produced contamination features. The shuttle environment appears suitable for in-bay cryogenic infrared sensor measurements down to a sensitivity level of $10^{-9}$ W/cm$^2$ sr $\mu$m. These preliminary findings will be refined and expanded to other wavelengths by future analysis.

We have calculated synthetic spectra using the Strategic High Altitude Radiance Code - SHARC [Sharma et al., 1989] to help analyze the SKIRT spectra. For example, to distinguish between $H_2O$ ($\nu_1 + \nu_3$) and NO ($\Delta V=2$) emissions, we generated spectra for NO and $H_2O$. By including a highly vibrationally excited NO distribution we can produce a good match to the SKIRT data in the 2.7 and 5 $\mu$m regions where the NO fundamental and overtone emissions occur. Emission from water, in this 2.7 $\mu$m region, is broader and peaks at a shorter wavelength than the observed glow signal. However, water vapor cannot be ruled out and may be a component of the infrared glow. Figure 3 compares the glow spectrum to synthetic spectra for NO and $NO^+$. We are continuing work in this area and will provide more detailed analysis at a later date.

Ground based laboratory reactions of fast oxygen atom/nitrogen interactions are also providing guidance in the analysis of these data. In these experiments, beams of

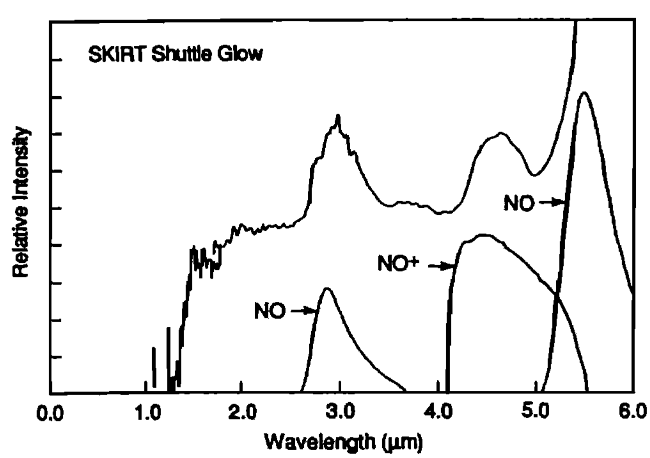


Fig 3. SKIRT shuttle glow spectrum compared with NO and $NO^+$ synthetic spectra.

atomic oxygen (with trace $O^+$) moving at selectable velocities of 8 to 12 km/s intersect a $N_2$ flow under single collision conditions. Radiances are observed in the same bandpasses and intensity ratios as the SKIRT orbital data. Under laboratory conditions, the processes giving rise to the emissions are:

$$O\ (8\ km/s) + N_2 \dashrightarrow NO\ (V) + N$$

and

$$O^+(8\ km/s) + N_2 \dashrightarrow NO^+(V) + N$$

These experiments and associated radiance predictions are described in the companion paper by Upschulte et al. [1992].

The spectra for Figure 2a were acquired after the shuttle had been on orbit for over 160 hours. The orbiter surfaces (top and bottom) had been heated by the sun during the first day on orbit to bake out water and other adsorbed molecules. By the time the data shown in Figure 2a were collected, outgassing from external surfaces is believed to have been minimized. All maneuvering thrusters were also suppressed during this measurement time. Thus, Figure 2a is representative of the infrared radiance induced by the ambient environment around quiescent orbital spacecraft.

## Summary

The SKIRT payload on board the STS-39 Space Shuttle Discovery obtained infrared spectra of quiescent and thruster enhanced space shuttle glow. Analysis indicate that NO, $NO^+$, OH, and CO are components of the quiescent glow. During thruster firings there are 10- to 100-fold enhancements in the infrared glow radiance intensities, as well as significant changes in the observed spectral distribution. During non-glow attitudes, when contamination producing activities are suppressed, the orbiter environment appears suitable for sensitive cryogenic infrared in-bay measurements. Further data analysis is underway.

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