

INFRARED MONITORING OF THE SPACE STATION ENVIRONMENT

Theodor Kostiuik, Donald E. Jennings and Michael J. Mumma

NASA/Goddard Space Flight Center
Planetary Systems Branch (Code 693)
Greenbelt, MD 20771

Introduction

The measurement and monitoring of infrared emission in the environment of the Space Station has a twofold importance - for the study of the phenomena itself and as an aid in planning and interpreting Station based infrared experiments. Spectral measurements of the infrared component of the spacecraft glow will, along with measurements in other spectral regions, provide data necessary to fully understand and model the physical and chemical processes producing these emissions. The monitoring of the intensity of these emissions will provide background limits for Space Station based infrared experiments and permit the determination of optimum instrument placement and pointing direction. Continuous monitoring of temporal changes in the background radiation (glow) will also permit better interpretation of Station-based infrared earth sensing and astronomical observations.

The primary processes producing infrared emissions in the Space Station environment are: 1) Gas phase excitations of Station generated molecules (e.g. CO₂, H₂O, organics...) by collisions with the ambient flux of mainly O and N₂. 2) Molecular excitations and generation of new species by collisions of ambient molecules with Station surfaces. These processes were discussed and modeled by Fraser et al. (1988). They provide a list of resulting species, transition energies, excitation cross sections and relevant time constants. The modeled spectrum of the excited species occurs primarily at wavelengths shorter than 8 μm . Emissions at longer wavelengths may become important during rocket firing or in the presence of dust.

To measure this Station infrared emission spectrum a simple and inexpensive monitoring instrument is desired. It must also have adequate spectral coverage and resolution and a successful spaceflight heritage.

A circularly variable filter (CVF) infrared spectrometer has been developed for studying the induced spacecraft glow on the Space Shuttle. This instrument is part of the Spacecraft Kinetic Infrared Test (SKIRT) with investigators from NASA Goddard Space Flight Center (M. J. Mumma, D. E. Jennings), Air Force Geophysics Laboratory (M. Ahmadjian) and Aerospace Corporation (C. Rice, R. Russell). It is part of an approved Shuttle Hitchhiker program and will be ready for flight in 1990. The spectrometer is being built by Utah State University and Space Systems Engineering and is a modified version of their cryogenic spectrometer which has flown on numerous rocket and space missions (Wyatt and Frodsham, 1977). The spectrometer consists of a CVF covering the 0.7 to 5.5 μm spectral region with a spectral resolution of $\sim 2\%$. The InSb detector is cooled to below 60K using solid N₂ cryogen pumped to space. The instrumental sensitivity (noise equivalent spectral radiance, NESR = 1.5×10^{-13} W/cm²-sr-cm⁻¹) for a

2°x2° field-of-view and a 1.52 cm aperture allows the system to reach the zodiacal background limit after 15 min integration. A long wavelength radiometer channel also monitors the 10-12 μm spectral band with a HgCdTe photovoltaic detector. The instrument, solid cryogen dewar and electronics will be mounted in a Get Away Special (GAS) can and will use the Hitchhiker-G Avionics package. An early concept of the instrument is described in Mumma and Jennings (1985).

Instrumentation

The SKIRT infrared spectrometer satisfies the basic requirements for an infrared monitor on the Space Station. It is a simple infrared spectrometer with adequate resolution, space flight heritage and low cost. However, the SKIRT CVF spectrometer will require certain modifications to satisfy the unique Space Station requirements.

In order to permit long term monitoring, as required on the Space Station, the solid N₂ dewar will be replaced by a closed-cycle refrigerator. Closed-cycle helium refrigerators capable of cooling to 65K with long operating lifetime between servicing are available and versions are to fly in space (e.g. the ISAMS experiment on UARS). Due to the large increase in data and possible increase in instrumental flexibility, on board data storage and a data processor will be required. By the time a Space Station monitor will be needed SKIRT will have flown and its data analyzed. These results would be used to optimize the spectral coverage and resolution for a space station version of the instrument. Sensitivity can also be improved by enlarging the field-of-view and increasing the integration time within the constraints imposed by infrared phenomena on the Space Station. A multichannel radiometer covering the 7-15 μm region will replace the SKIRT single channel 10-12 μm radiometer.

A conceptual schematic of the Space Station infrared contamination monitor is shown in Fig. 1. Performance specifications, along with mass, power, data rate and cost are given in Table 1. The instrument will be housed in a truncated GAS cannister or similar container to simplify qualification, transportation and mounting. The instrument can be mounted at any location on the Space Station, but a pointing platform is preferred because this would permit targeting of various areas of the Station. Radiation enters through a door at the top of the cannister. The door will be closed when not in use to protect the optics and detector.

Details of the optical head are shown in Fig. 2. This type of optical head has been built and flown in Air Force space programs for many years by Utah State University and Space Systems Engineering. A baffle at the input rejects stray light. The 1.5 cm primary mirror images the 4°x4° field at a field stop. The primary (pupil) is imaged at an inverse Ritchey-Chretien telescope, which in turn reimages the field at the 0.7-5.5 micron circular variable filter (CVF). The filtered field is then imaged at the InSb detector. A central portion of the collimated beam before the Ritchey-Chretien mirrors is diverted by a flat to a set of radiometer channels, the 7-15 micron part of the spectrum. A series of dichroics divides the spectrum into preselected wavelength bands and each band is focused on a HgCdTe photovoltaic detector.

The optical head will be cooled to 65K with a closed-cycle helium refrigerator. The lifetime between servicing of the refrigerator will be 5 years. A stepping motor mounted on the ambient surface will drive the CVF via a thin-walled stainless-steel shaft (Fig. 1). Electronics and mass data storage units will also be housed within the container.

The mass, power, data rate, and cost listed in Table 1 are inferred from SKIRT and our proposed modifications for Space Station use. Much of the proposed instrument mass (40lbs), power (70W) and cost is driven by the closed-cycle refrigerator. The listed total mass and power requirements can be lowered with future technical advances. The cost (in FY 88 dollars) includes \$300K for changing the design to use a mechanical refrigerator instead of a solid N₂ dewar to cool the optics and detectors. The cost does not include transportation on the Shuttle and integration with Shuttle and Space Station, since we expect that the station monitor program would handle all instruments as a package. Also, the cost does not include post-launch operations and data analysis.

Sensitivity

In Table 1 the spectrometer field-of-view and scan time have been increased over those in SKIRT. The resultant sensitivity (corresponding to an NESR $\sim 2.7 \times 10^{-14}$ W/cm²-sr-cm⁻¹) is sufficient to detect $\sim 10^4$ Rayleighs/ μ m at 3 μ m in a single scan (10 sec). Integrating for 100 scans will bring the sensitivity close to the zodiacal limit over the entire 0.7-5.5 μ m range.

In Fig. 3 we compare the spectrometer sensitivity (minimum detectable intensity in Rayleighs/ μ m) to the expected Space Station glow spectrum calculated for a 460 km orbit by Fraser et al. (1988) from a molecular excitation model. The zodiacal background radiation level is shown in the figure. The band centers of several molecular species which contribute to the emission are also shown. Many features will be detected in one scan and the entire spectrum will be measured with longer integration times.

Conclusions

We conclude that a developed CVF infrared spectrometer (SKIRT) and existing technology can be extended to meet the requirements of an infrared contamination monitor on the Space Station. The simplicity of the SKIRT design and its Space Shuttle heritage means that the Space Station infrared monitor can be built for a modest cost with assurance of reaching desired detection limits.

References

Fraser, M. E., A. Gelb, B. D. Green and D. G. Torr. Calculations of Space Station Infrared Irradiance from Atmosphere Induced Emissions. Space Station Contamination Workshop Proceedings, Hilton Head Island, South Carolina, October 29-30, 1987. NASA Marshall Space Flight Center, Space Science Laboratory Preprint Series No. 88-113, pp. 61-69, 1988.

Mumma, M. J. and D. E. Jennings. Planned Investigation of Infrared Emissions Associated with the Induced Spacecraft Glow: A Shuttle Infrared Glow Experiment (SIRGE). Second Workshop on Spacecraft Glow Marshall Space Flight Center Huntsville, Alabama May 6-7, 1985. NASA Conference Publication 2391, pp. 250-259, 1985.

Wyatt, C. L. and D. G. Frodsham. Short Wavelength Rocketborne Infrared Spectrometer. SPIE vol. 124, pp. 236-243, 1977.

INFRARED CONTAMINATION MONITOR FOR SPACE STATION

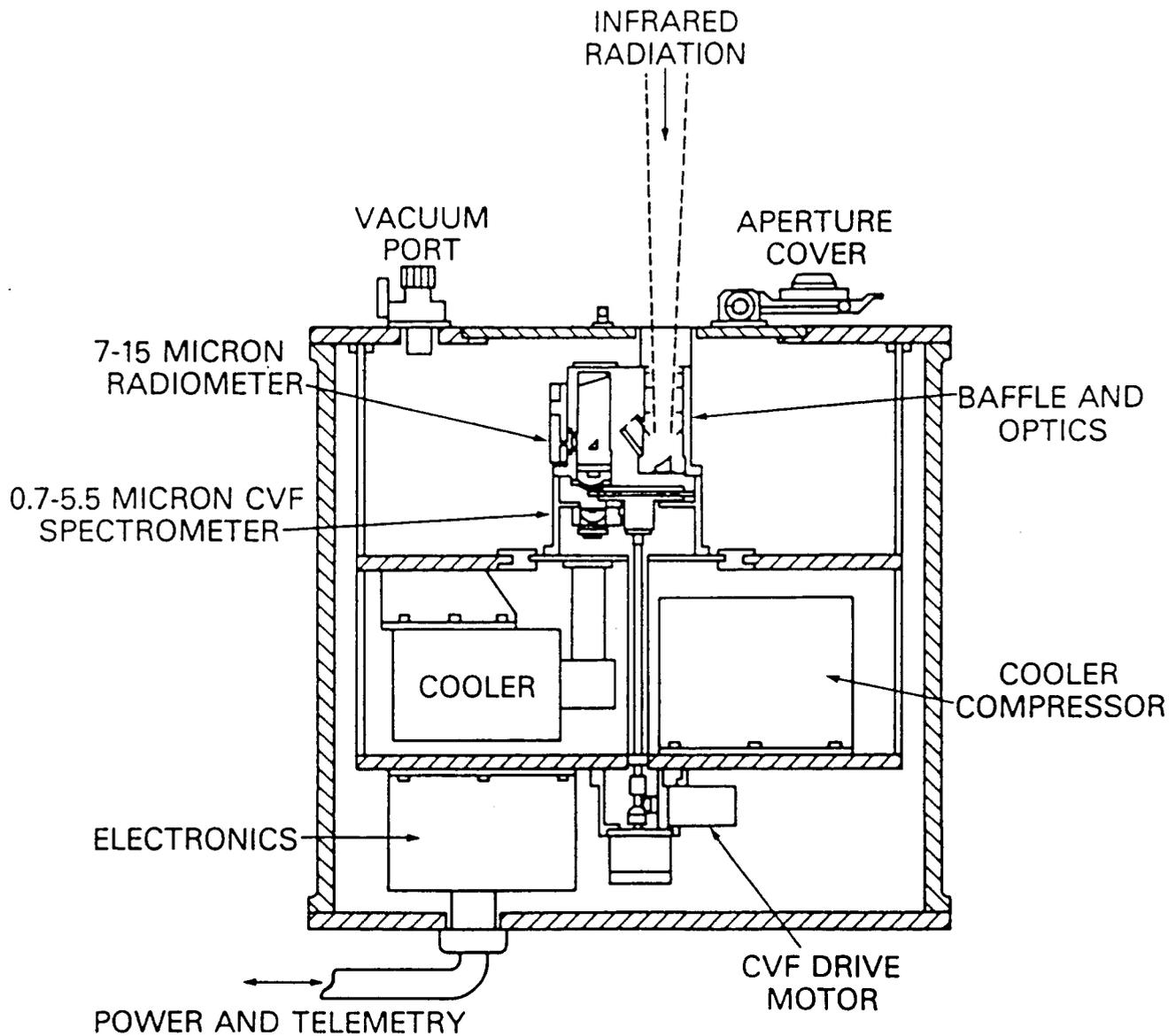


Fig. 1 Conceptual schematic of the Space Station infrared monitor. The optical head will be cooled by a closed-cycle refrigerator. The instrument will be housed in a GAS type container.

OPTICAL LAYOUT OF INFRARED MONITOR

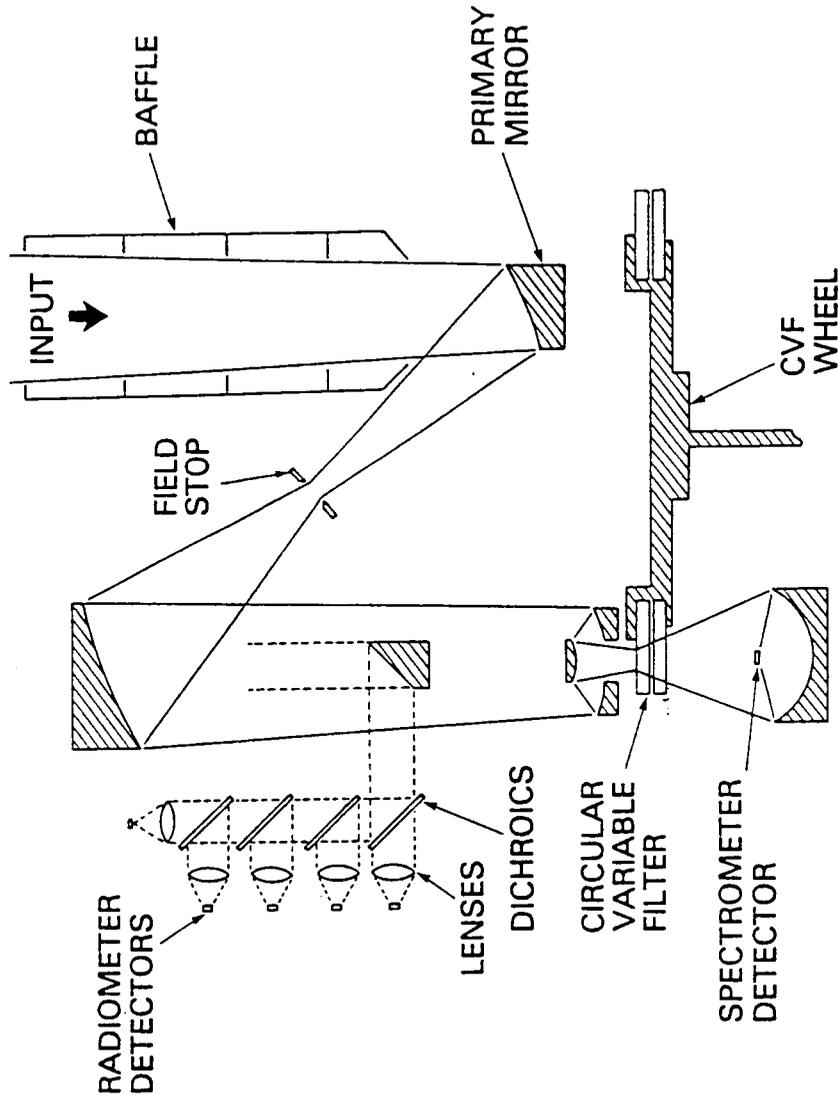


Fig. 2 Schematic of the optical assembly. 0.7-5.5 micron radiation from a $4^\circ \times 4$ field passes through a rotating CVF and is imaged on an InSb detector. A portion of the radiation is sent to a set of HgCdTe radiometers in the 7-15 micron range. This optical design has been built and flown many times by Utah State University and Space Systems Engineering.

INFRARED MONITOR SENSITIVITIES COMPARED WITH PREDICTED SPACE STATION IRRADIANCE

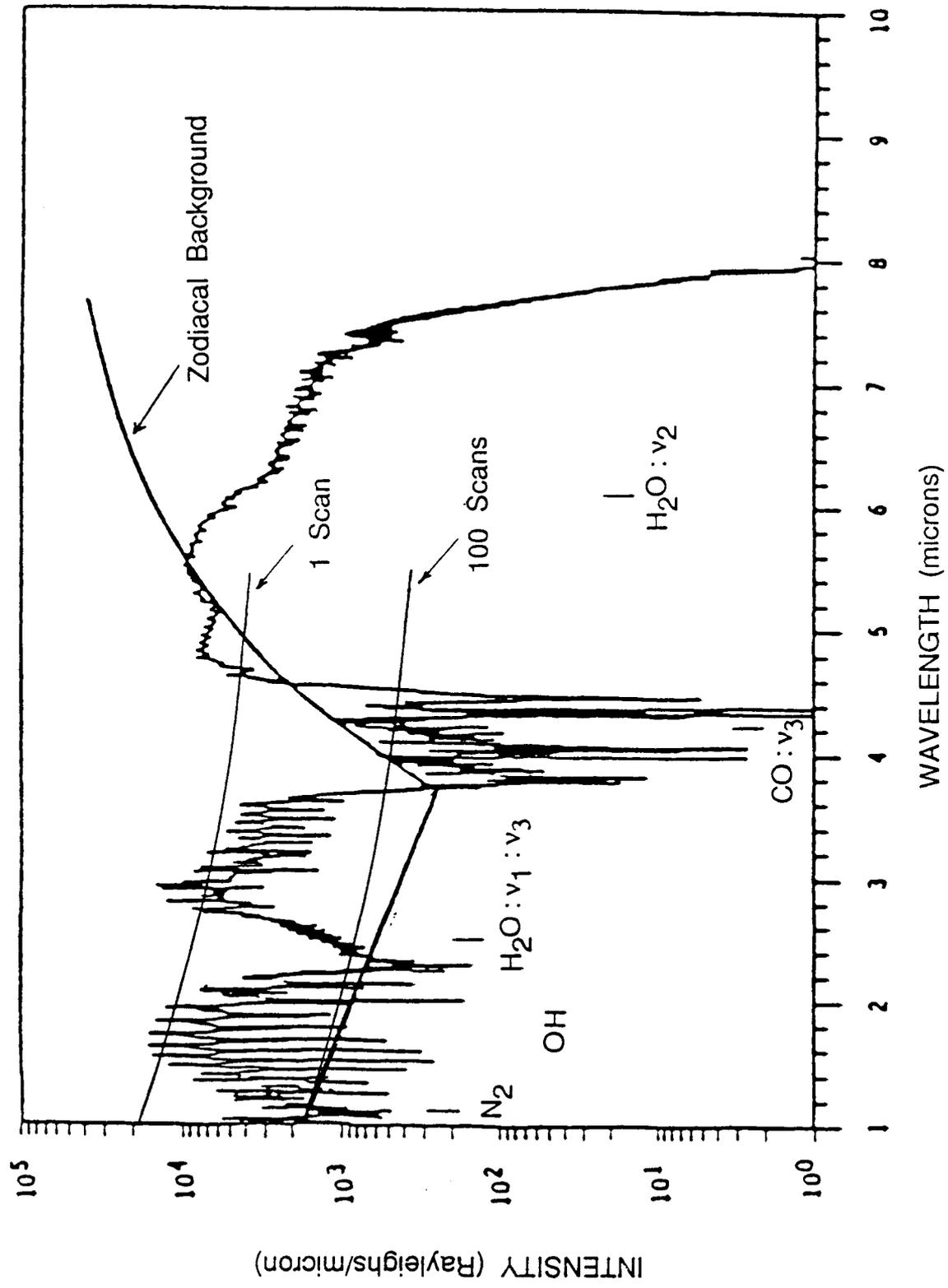


Fig. 3 Comparison of the infrared monitor sensitivities with expected Space Station and zodiacal radiation levels. Adapted from Fig. 2. of Fraser et al. (1988).

Table 1

INFRARED CONTAMINATION MONITOR SPECIFICATIONS

TYPE: Circular Variable Filter Spectrometer
and Single Filter Radiometer

SPECTROMETER:

wavelength coverage	0.7 - 5.5 μm
spectral resolution	2%
detector	InSb
scan time	10 sec
field-of-view	4 ^o x4 ^o
aperture diameter	1.5 cm
sensitivity (NESR)	2.7x10 ⁻¹⁴ W/cm ² sr cm ⁻¹

RADIOMETER:

spectral bandwidth	7 - 15 μm (multichannel)
detector	HgCdTe (PV)
integration time	0.5 sec
field-of-view	4 ^o x4 ^o
aperture diameter	0.6 cm
sensitivity (NER)	2x10 ⁻⁹ W/cm ² sr

OPERATING TEMPERATURE: 65 K

COOLER: Closed-cycle Helium Refrigerator

LIFETIME (before service): 5 years

CONTAINER: GAS cannister or similar

LOCATION: Pointing Platform

SIZE: 20 in dia x 20 in high

MASS: 275 lbs

POWER: 160 W

DATA RATE: 40 kbs⁻¹ (on-board storage)

COST: 850 K