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WHAT THE VOYAGER INFRARED INVESTIGATORS HOPE TO LEARN ABOUT THE SATURN SYSTEM

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ABSTRACT

The Voyager infrared investigation uses a Michelson interferometer (IRIS) covering the spectral range from 200 to 3000 cm^{-1} (3.3 to 50 μm) and a bore sighted radiometer covering the range from 5000 to 25000 cm^{-1} (0.4 to 2 μm). The spectral resolution of the interferometer is 4.3 cm^{-1} and the field of view is 0.25°. Scientific results anticipated from the investigation of the Saturnian system are discussed; these are contrasted to those which were expected from the advanced interferometer (MIRIS), which was not qualified in time for flight.

INTRODUCTION

This paper summarizes what the Voyager Infrared Investigator Team expects to learn about the Saturnian system. The discussion addresses Saturn, its rings, Titan and the other smaller satellites. The format of this summary is similar to that of the team paper published in Space Science Review (Hanel, *et al.*, 1977), hereafter called paper one. However, in contrast to paper one the present discussion concentrates on Saturn, and takes account of the fact that the IRIS, rather than the MIRIS instrument, is on board Voyager.

An in-flight IRIS calibration is now available for the 200-2000 cm^{-1} range which shows that the instrumental performance is somewhat below expectation. The near infrared part of the spectrum (above 2000 cm^{-1}) will be calibrated shortly by viewing the spacecraft mounted solar diffusing target. Figure 1 (similar to Figure 9 of paper one) shows the actually measured noise-equivalent-radiance (NER) of the Voyager 1 interferometer. The response has not changed since the initial cool down after launch is close to that during the final thermal vacuum test. The NER of the Voyager 2 interferometer after launch was similar to that of the Voyager 1 instrument, but has apparently not yet stabilized.

Also shown in Figure 1 are the NER values of the flight qualified MIRIS instrument as measured in a thermal vacuum chamber. Unfortunately, the instrument was qualified too late for the Voyager mission. Figure 2 illustrates the degree of improvement in the NER which can be obtained by averaging of spectra over indicated time intervals. Several radiometric data points obtained from the ground by Morrison *et al.* (1972) and Gillet *et al.* (1973) for Titan are shown for comparison. The Voyager scientific objectives defined in paper one are definitely affected by the substitution of IRIS for MIRIS. Objectives based on the analysis of the spectral range between 1000 cm^{-1} and about 3000 cm^{-1} will suffer in precision; objectives based on data from the 3000–7000 cm^{-1} range can not be accomplished at all. On the other hand the lower NER of IRIS compared to MIRIS between 200 and 900 cm^{-1} will benefit some objectives based on data in this spectral range; the lower spectral resolution of the IRIS instrument will affect other objectives, however. The discussion below treats the individual scientific objectives at Saturn following the overall format of paper one.

ATMOSPHERIC GAS COMPOSITION, ELEMENTAL ABUNDANCES AND ISOTOPIC RATIOS

Hydrogen to Helium Ratio

The hydrogen to helium ratio for Saturn will be derived primarily from the far infrared spectrum (200-800 cm^{-1}). Since the derivation will be made by using a large number of spectra the difference in performance between instruments becomes insignificant. The limit in the precision of the derived hydrogen to helium ratio is expected to be due to uncertainties in the knowledge of gas absorption coefficients and aerosol properties, rather than to random instrumental errors in the spectra. Thus, the objective of determining the H_2/He ratios as discussed in paper one seems obtainable.

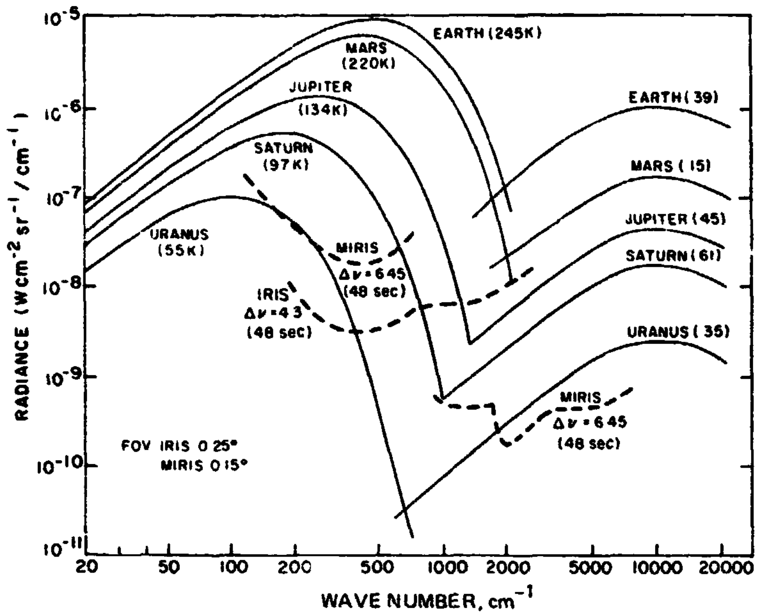

Figure 1 shows emitted and reflected radiance levels schematically for indicated brightness temperatures and albedos. Measured noise-equivalent-radiance values (NER) are shown for Voyager 1 (middle dashed line) and the far infrared (upper dashed line) and near infrared (lower dashed line) channels of MIRIS.

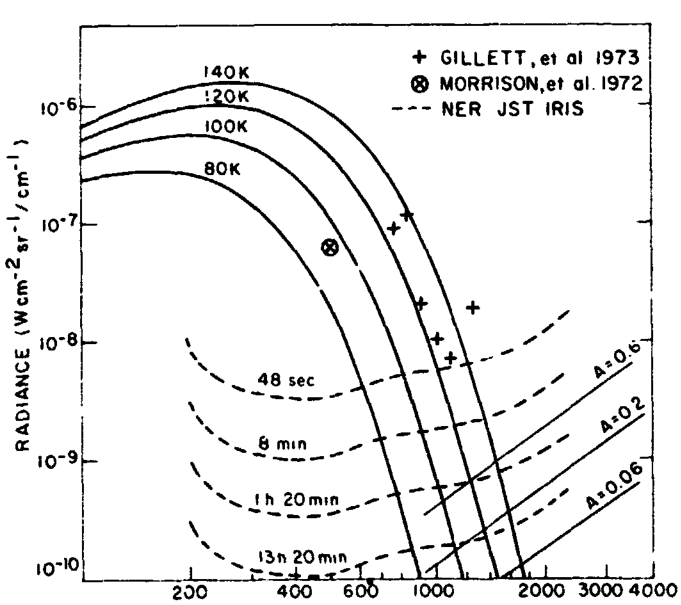

Figure 2 shows radiance versus wave number similar to Fig. 1, but on an expanded scale. The NER of IRIS is shown by dashed curves for individual spectra (48 sec) an average of 10 (8 min), 100 (1 h 20 min) and a total of 1000 spectra (13 h 20 min). Also illustrated are a few ground based measurements of Titan.

Methane

Information on the methane mixing ratios on Saturn and Titan will be based primarily on the 1306 cm^{-1} methane band in conjunction with temperatures derived from pressure induced H_2 lines. Instead of using individual MIRIS spectra an average over several hours of IRIS spectra will be required to obtain adequate precision. Since one hemisphere of Saturn fills the 0.25° field of view of IRIS about 10 days before encounter, and Titan fills the field of view about one day before closest approach to Titan, the original objective seems to be obtainable. However, an independent measurement of the mixing ratio in the upper stratosphere, based on the 3019 cm^{-1} CH_4 band, will probably not be possible.

Ammonia

Only the 200 to 275 cm^{-1} part of the rotation spectrum and the region near 900 cm^{-1} will be available. The 100 to 200 cm^{-1} range may have been useful to see uncondensed NH_3 in the lower atmosphere of Titan. However, the higher sensitivity of IRIS between 200 and 300 cm^{-1} might compensate for its more restricted spectral range.

Trace Constituents

The lack of sensitivity in spectral ranges of potential atmospheric windows (2000, 3700 and 6200 cm^{-1}) will hamper the search for unknown minor constituents severely. The availability of the 700 to 900 cm^{-1} range, on the other hand, may make a search for hydrocarbons (C_2H_2, C_2H_6) in the atmospheres of Saturn and Titan more productive.

Elemental Abundances

Without the prospect of good measurements in spectral ranges of potential atmospheric windows it seems probable that only the H_2/He and possibly the C/N ratios will be measurable with precision.

Isotopic Ratios

An observation of the D/H and C^{12}/C^{13} ratios may be possible by averaging all available Saturn spectra (20 days). The 2200 cm^{-1} CH_3D band and the 1306 cm^{-1} CH_4 band may then also provide adequate data for analysis. For Titan the same task seems marginal.

Clouds and Hazes

Lack of good near IR coverage will have a strong impact on specifying the particle composition and size, and the distribution of clouds and aerosols. Averages of carefully sorted groups of spectra (rather than individual measurements) may be usable. However, this will only allow parametrization of large areas, such as belts and zones rather than of local phenomena.

Temperature Profiles

Atmospheric temperatures are derived from the pressure induced lines caused by collisions between hydrogen molecules or between hydrogen and helium or methane molecules. On Titan collisions between methane molecules may also be important. Many of these pressure induced lines fall within the 200 cm^{-1} to 1000 cm^{-1} range where IRIS is sensitive. In the upper atmospheric layers (up to the 5 mbar level for Saturn and up to much lower pressures for Titan) the 1306 cm^{-1} methane band can be used. Depending on the actual atmospheric temperatures, spectra averaged over times ranging from 10 minutes to an hour will be required to obtain temperature profiles with adequate precision. In the 100 to 1000 mbar range individual spectra will be sufficient to yield a precision of 1 to 2 K with a vertical resolution of approximately one scale height. Thus, the task of deriving atmospheric temperatures on Saturn and Titan seems to be possible.

Dynamics and Heat Balance

Information on atmospheric motions is derived from the temperature field. For Saturn, good temperature data from the hydrogen lines will allow determination of the north-south temperature gradient; this will then be used to derive the east-west wind field.

Energy balance calculations require knowledge of both the total reflected and emitted energy. The radiometer provides a measure of the first and the interferometer of the second component. Derived compositional and temperature data will be used to extrapolate over part of the thermal spectrum. In this case MIRIS would have been preferable but an adequate estimate of the local and total heat balance of Saturn can be expected from IRIS.

Satellites

The absence of the near infrared spectrum will make the identification of surface minerals and ices much more difficult; however, some far infrared features such as the 230 cm^{-1} water and the 280 cm^{-1} ammonia lattice modes fall within the IRIS range, as do features in the spectrum of silicates.

The measurement of the surface temperature and thermal inertia of the surface material can be carried out even if the satellite does not fill the field of view. This condition will occur more often with IRIS (0.25°) then it would have with MIRIS (0.15°). In the absence of strong spectral features a precise surface temperature can be established by fitting a Planck function to the measured spectrum.

Saturn's Rings

All properties of the rings derived from the thermal part of the spectrum and its variation with emission and phase angles and time can be accomplished by IRIS, while tasks based on the near infrared reflectivity will be severely limited. Particle sizes or thermal inertia can be estimated from the cooling curves depending on the mean size of particles.

SUMMARY

The scientific objectives formulated in anticipation of MIRIS being on board Voyager have to be modified because of the different parameters of the IRIS instrument. Tasks which depend on data in the 3000–7000 cm^{-1} range cannot be accomplished with IRIS. This will curtail but not eliminate the search for minor atmospheric constituents, the characterization of aerosols, and the surface composition of satellites and rings. Investigations based on data between 1000 and 3000 cm^{-1}, will suffer in precision or in spatial resolution due to longer averaging times required to compensate for the higher NER of IRIS compared to MIRIS. Finally, tasks based on the interpretation of the 200–1000 cm^{-1} range, such as temperature and hydrogen to helium measurements, will even gain to some degree by the lower NER of IRIS compared to MIRIS in this spectral region.

REFERENCES

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DISCUSSION

J. CALDWELL: What spectral range will you use to look for the cloud features on Titan? If the clouds are methane ice, I'm skeptical that there will be features that you can identify. Certainly, the solids will have absorption features, at least at 8 μm and to shorter wavelengths, but there the gas which overlies the clouds will probably be completely opaque.

J. POLLACK: Water ice has a strong lattice band at about 45 μm, so he has some hope.

D. MORRISON: Could you say a few words about the capability of the instrument as a thermal radiometer for measuring the eclipse cooling and heating rates of the rings or the satellites? How low a temperature can you measure, and will your sequences allow you to observe dark side temperatures on the satellites or eclipse measurements of the rings?

R. HANEL: For a black body of 55 K, the radiometric signal to noise ratio is about 50 to 1.

D. MORRISON: Do you anticipate making measurements of ring eclipses or of the dark sides of the satellites?

R. HANEL: Yes.