

Thermal Infrared Spectroscopy of Saturn and Titan from Cassini

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Abstract: The Cassini spacecraft completed its nominal mission at Saturn in 2008 and began its extended mission. Cassini carries the Composite Infrared Spectrometer (CIRS), a Fourier transform spectrometer that measures the composition, thermal structure and dynamics of the atmospheres of Saturn and Titan, and also the temperatures of other moons and the rings.

1. Introduction

The Cassini spacecraft began orbiting Saturn in July 2004. The primary mission lasted until 2008 and an extended mission is now underway. Onboard Cassini is the Composite Infrared Spectrometer (CIRS), a Fourier transform spectrometer designed to map composition, temperature and dynamics in the atmospheres of Saturn and Titan (Flasar *et al.*, 2004). CIRS infrared mapping is performed at high spectral and spatial resolutions and covers two orders of magnitude in wavelength. On Saturn and Titan global mapping tracks changes as the season progresses toward northern spring. On Titan, CIRS probes altitudes from the stratosphere to the surface. CIRS also maps temperature and composition of Saturn's ring material and of the moon surfaces. The early portion of the Cassini mission was spent close to the equatorial plane, but recently the orbit has been tilted to allow a closer look near the poles. On Titan nitrile chemistry occurs in the north and on Saturn temperature extremes cause circumpolar thermal structures and a range of chemical abundances.

The completion of Cassini's nominal mission is an occasion to review the accomplishments of CIRS, to assess the improvements in our understanding of the Saturnian system that have resulted from Cassini, and to anticipate the advancements yet to come in the extended mission.

2. Description of Instrument and Operations

CIRS consists of two interferometers that share a telescope and scanning mechanism (Kunde, *et al.* 1996; Flasar *et al.* 2004). The far-infrared (10-600 cm^{-1}) is covered with a polarizing interferometer and the mid-infrared (600-1400 cm^{-1}) is covered with a conventional interferometer. The far-infrared uses wire-grid polarizers mounted on mylar and the mid-infrared uses a KBr beamsplitter. Apodized spectral resolution is selected in the range 0.5 to 15 cm^{-1} . In the far-infrared the focal plane uses two thermocouple detectors sensing the same 3.5-mrad field of view. In the mid-infrared two 10-element HgCdTe detector arrays (one photoconductive and the other photovoltaic) observe two adjacent fields of view, each 10 x 273 mrad². Cube corner retroreflectors are used in the mid-infrared and roof mirrors are used in the far-infrared. A diode laser reference interferometer is separated from the infrared interferometers, but has its beam in the center of the moving cube corner retroreflector. The instrument housing temperature is controlled at 170 K, and the mid-infrared detectors are cooled to below 80 K. The instrument temperatures are maintained with passive space-viewing radiators.

Each observation script is designed, tested and uploaded to Cassini well in advance of the actual CIRS observations. The operation mode for each observation is selected from among several with different detector spatial configurations, resolutions, and integration times, and is chosen to optimize the desired science product. Deep space reference spectra for calibration are recorded both within the observation sequence and during non-CIRS operations near the time of the observation. Instrument and spacecraft operational parameters can be chosen to minimize electrical and mechanical interferences. After each observation sequence the recorded interferograms are transmitted to Earth and processed. Calibrated spectra are placed in a database and are made available the science community.

3. Results from Saturn and Titan

CIRS has produced a wide range of new scientific results from observations of Titan, Saturn, its moons and rings (Flasar *et al.* 2005a, b). Atmospheric mapping both at the limb and in nadir show that the nitriles HCN, HC_3N and C_2N_2 are concentrated in the northern region of Titan, particularly above about 40° North latitude. Complex hydrocarbons also tend to increase in abundance at northern latitudes on Titan (Coustenis *et al.* 2007). In a window at 530 cm^{-1} CIRS penetrates the thick atmospheric haze on Titan to measure the surface thermal emission. In Saturn, hydrocarbon abundances increase dramatically at the south pole, apparently due to southward transport during southern summer (Hesman *et al.* 2008). In the rings, varying densities and particle sizes can be deduced from temperature distributions (Leyrat *et al.* 2008). Thermal maps of Enceladus identify warm fissures at the sites of the southern plumes that are seen in visible images (Spencer *et al.* 2006).

Figure 1 shows a composite spectrum of Saturn at 0.5 cm^{-1} resolution from all three focal planes, covering the entire spectral range of CIRS. Saturn spectra are rich in molecular emission and absorption lines. Among the spectral features seen are absorption from pressure-induced H_2 , absorption from rotational and vibrational PH_3 , and emission and absorption from CH_4 , C_2H_2 and C_2H_6 . Other features in Saturn spectra but not seen in the figure are absorption from rotational HD and NH_3 , and emission from the minor hydrocarbons C_3H_4 and C_3H_8 and C_4H_2 . Saturn is presently moving seasonally toward northern Vernal Equinox and should begin to exhibit changes in the meridional distribution of minor constituents. The changes in continuum temperature and molecular emissions will be tracked during the extended Cassini mission.

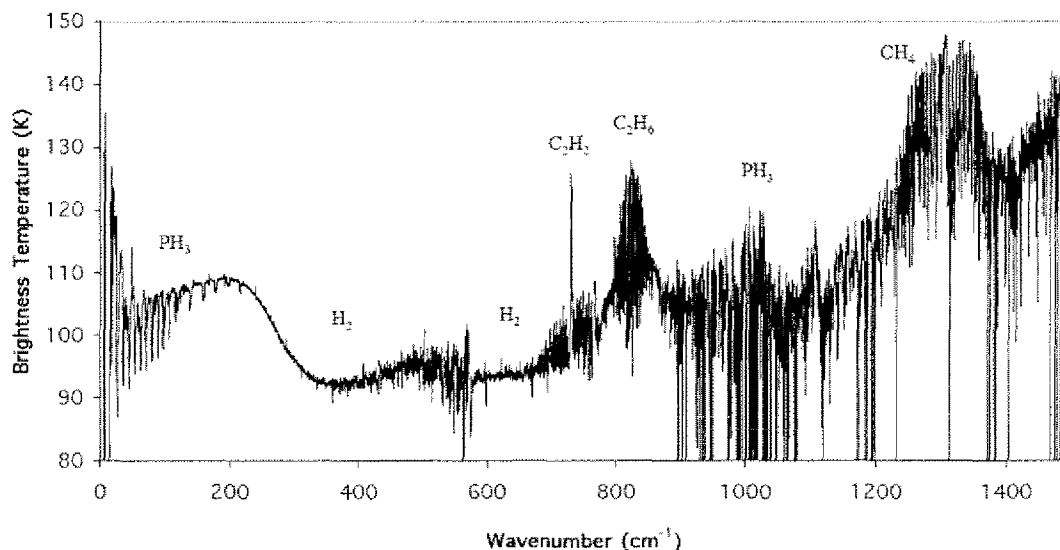


Figure 1. CIRS spectrum of Saturn displayed in brightness temperature. This is a composite spectrum recorded with all three spectral channels of CIRS and covers the entire spectral range of the instrument. Molecular species in Saturn's atmosphere are identified by their emission and absorption spectra. The spectral resolution is 0.5 cm^{-1} . The large downward excursions in the data are due to noise.

Titan spectra from CIRS show the presence of many hydrocarbons and nitriles. The principal component of Titan's atmosphere is N_2 , whose pressure-induced spectrum can be seen in CIRS spectra at 60 cm^{-1} . A complete list of atmospheric molecules also includes H_2 , CO , CO_2 , CH_4 , HCN , HC_3N , CH_3D , C_2H_2 , C_2H_4 , C_2H_6 , C_3H_4 , C_3H_8 , C_4H_2 , and H_2O . This variety demonstrates the complex photochemistry that takes place in Titan's atmosphere. Isotopic variants of several of these molecules have been detected by CIRS and the measured isotopic enrichments contribute to an understanding of the history of Titan's atmosphere.

CIRS will continue to collect spectra in the thermal infrared throughout the extended Cassini mission. Combining results from CIRS with those from other instruments on Cassini as well as from other spacecraft and ground-based observations is yielding a detailed, ever improving picture of Saturn, Titan and the rest of the Saturnian system.

4. References

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