CIRS-*lite*, a Fourier Transform Spectrometer for Low-Cost Planetary Missions

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Abstract. Passive spectroscopic remote sensing of planetary atmospheres and surfaces in the thermal infrared is a powerful tool for obtaining information about surface and atmospheric temperatures, composition, and dynamics (via the thermal wind equation). Due to its broad spectral coverage, the Fourier transform spectrometer (FTS) is particularly suited to the exploration and discovery of molecular species. NASA's Goddard Space Flight Center (GSFC) developed the CIRS (Composite Infrared Spectrometer) FTS for the NASA/ESA Cassini mission to the Saturnian system. CIRS observes Saturn, Titan, icy moons such as Enceladus, and the rings in thermal self-emission over the spectral range of 7 to 1000 μm. CIRS has given us important new insights into stratospheric composition and jets on Jupiter and Saturn, the cryo-geyser and thermal stripes on Enceladus, and the winter polar vortex on Titan.

CIRS has a mass of 43 kg, contrasted with the earlier GSFC FTS, pre-Voyager IRIS (14 kg). Future low-cost planetary missions will have very tight constraints on science payload mass, thus we must endeavor to return to IRIS-level mass while maintaining CIRS-level science capabilities ("do more with less"). CIRS-lite achieves this by pursuing:

- more sensitive infrared detectors (high Tc superconductor) to enable smaller optics
- changed long wavelength limit from 1000 to 300 μm to reduce diffraction by smaller optics
- CVD (chemical vapor deposition) diamond beam-splitter for broad spectral coverage
- single FTS architecture instead of a dual FTS architecture
- novel materials, such as single crystal silicon for the input telescope primary.

Keywords: remote sensing, spectroscopy, planetary atmospheres, infrared

1. FTS at GSFC: IRIS, MIRIS, CIRS

Fourier transform spectroscopy provides a wealth of information via nadir and limb sounding of planetary atmospheres and surfaces. NASA GSFC spectrometers [Fig. 1] include IRIS on Voyager [ref. 1], and CIRS currently operating within the extended Cassini mission in the Saturnian system [ref. 2].

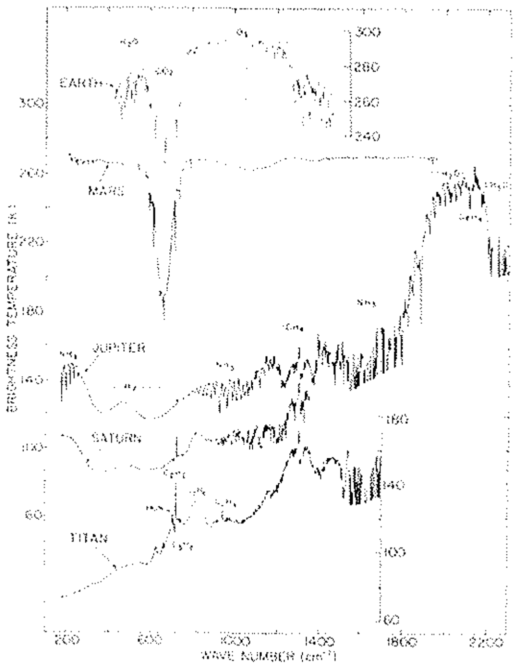

Figure 1. IRIS-measured planetary spectra

2. Science Products: Radiance, brightness temperature, molecular identification, and thermal winds

An emission-mode FTS such as IRIS or CIRS is intensity calibrated to produce radiance spectra, equivalent to brightness temperature [Fig 2]. Molecular identification is established via previous knowledge of line positions. Limb and nadir sounding produces horizontal and vertical fields of temperature and composition. The thermal wind equation (vertical shear of the geostrophic wind) ingests the temperature data to produce the wind speed, except near the equator [Fig. 3]. The data of Figure 3 were captured during the Jupiter flyby of 2000-2001 at 140 RJ, and show a strong stratospheric jet at 3 mbar. We know there are cycles in the temperature fields, and future missions will help to characterize the seasonal and long-term trends.

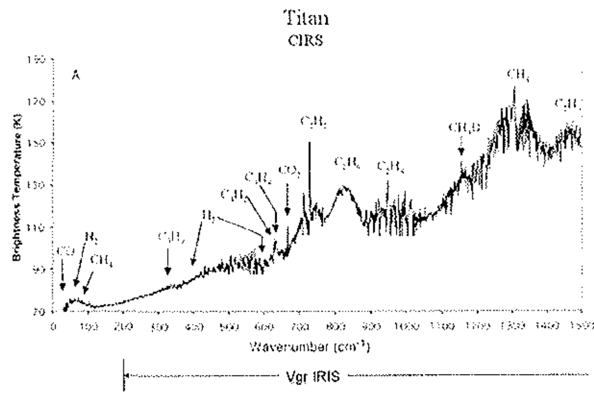

Figure 2. Titan brightness temperature (CIRS)

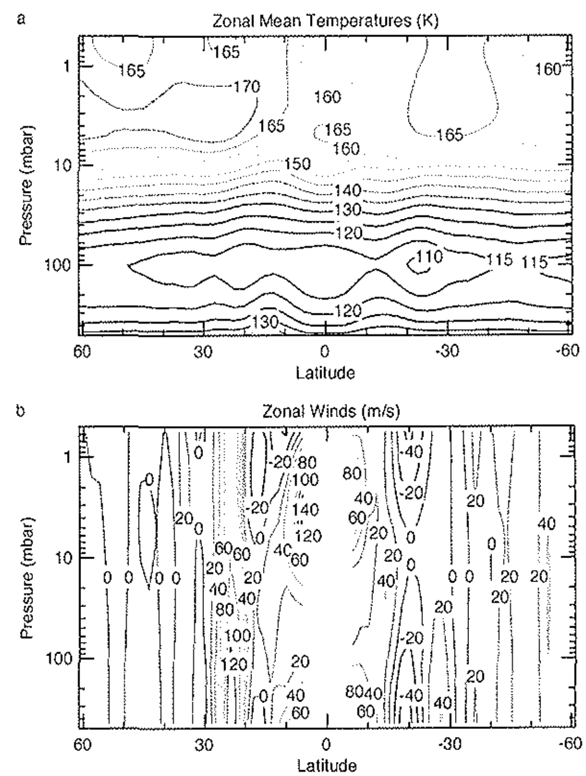

Fig. 3 Jupiter temperature and wind fields (CIRS)

Figure 4 shows the latitudinal distribution of stratospheric HCN and CO2 on Jupiter. Explaining the offset of the peaks of the two constituents is a task for photochemical and dynamical models.

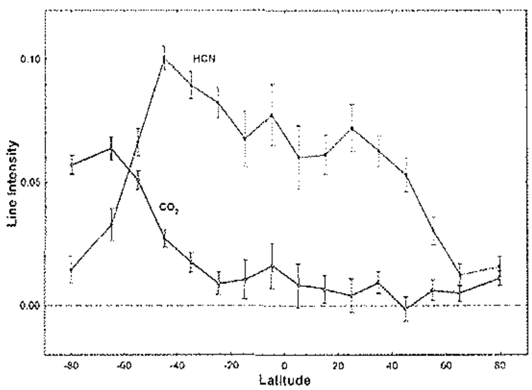

Figure 4. Jupiter constituent distributions (CIRS)

3. Technology advances for mass reduction for future planetary FTS

The era of orbiter-based remote sensing of planetary atmospheres is not over, however the opportunity to fly instruments such as CIRS may be past. The historical mass growth at GSFC planetary FTS is:

- -14 kg, Earth, Mars IRIS, 1969-1971
- -18 kg, Voyager IRIS, 1979
- -27 kg, Voyager MIRIS (not launched), dual FTS with 140K HgCdTe detectors
- -43 kg, Cassini CIRS (80K stage), 1997.

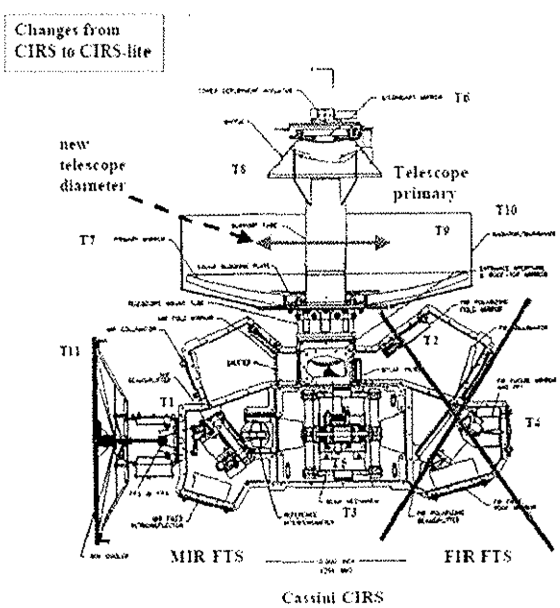

Figure 6. From CIRS to CIRS-lite

To be a strong contender for future missions, the mass must be brought back to the early IRIS box, roughly a reduction by 3. This is achieved by (1) using a very broad band beam splitter (7 to ~ 1000 microns), CVD diamond [ref. 3] [Fig. 5], to replace the dual FTS with a single FTS [Fig. 6] (2) replacing thermoelectric FIR detectors with more sensitive (4 to 5x) YBCO high-Tc superconductor bolometers [ref. 4] [Fig. 7] enabling telescope and optics reduction by a linear factor of 2 to 3; (3) double-passing the moving mirror for improved spectral resolution; and (4) utilizing novel single-crystal-silicon [ref. 5] for the telescope primary for increased flexibility with light-weighting.

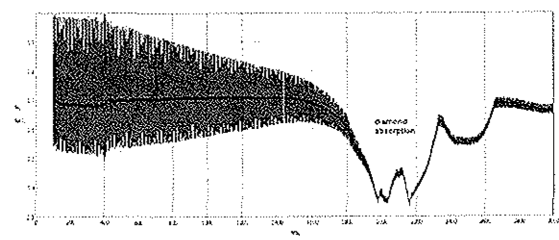

Figure 5. diamond transmission vs. wave number

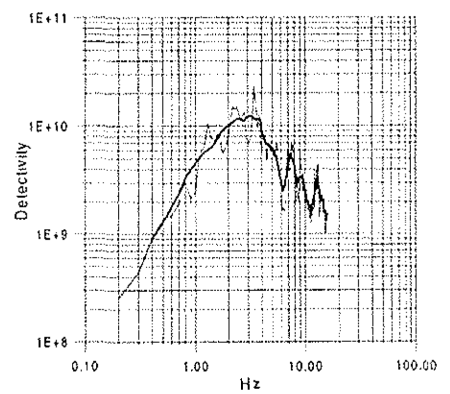

Figure 7. YBCO S/N (cmHz$^{1/2}$/W) at transition mid-point

4. The cirs-lite concept

Relative to CIRS, CIRS-lite [Table 1 and Fig. 8] reduces the telescope diameter and longest wavelength by a factor of 3, to control diffraction. The optics temperature (excluding the detector) is in the range of 150K to 170K (CIRS temperature).

Parameter	CIRS	CIRS-*lite*	IRIS Mars	TES	PFS
band-pass (μm)	7 to 1000	7 to 333	5 to 50	6 to 50	0.9 to 45
resolution (cm^{-1}) apod.	0.5	0.125	2.4	5	1.5
telescope diameter (cm)	50	15	4	15	5/4
detectors	HgCdTe thermopile	HgCdTe high Tc	thermistor bolometer	DTGS pyroelec	PbSe, PbS $LiTaO_3$
detector temperature (K)	75 170	75 89	250	uncooled	210 290
point-able mirror	no	TBD 1 kg	no	yes	yes
footprint (km @ 250 km)	1 & 0.05	1 & 0.4	16	2	7 & 14
mass (kg)	43	15 to 20	14	14	31

Table 1. GSFC and other planetary FTS

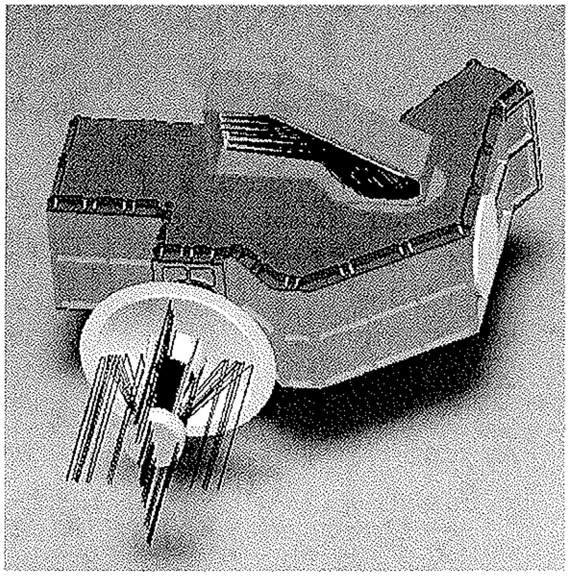

Figure 8. CIRS-lite mechanical design

The CIRS mass is 43 kg: 13 kg for the electronics, and 30 kg for the opto-mechanical unit. The initial projected CIRS-lite masses are 12 kg for the opto-mechanical unit and 5 kg for the electronics. The optical design is complete (Fig. 9), and the mechanical design is almost complete.

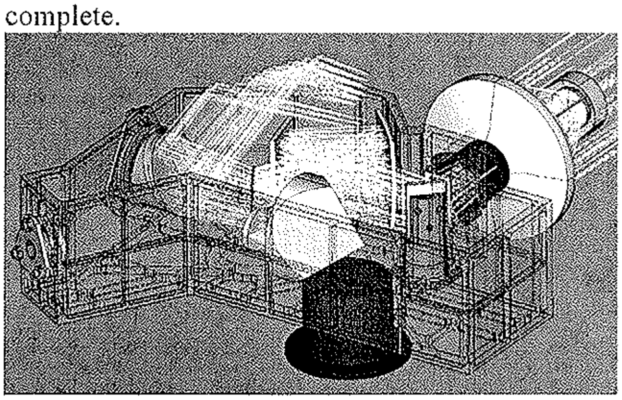

Figure 9. CIRS-lite ray-trace

Most of the mirrors and mounts have been rough machined from aluminum blanks, and diamond turning is underway to produce the final optical surfaces. The fabrication of the bench and cover is about to begin.

Unlike CIRS, CIRS-lite employs a double-passed moving mirror to increase the spectral resolution while lessening the demand on the accuracy of the moving-mirror translation. By doubling the physical travel and double-passing the mirror, CIRS-lite achieves a four-times better spectral resolution, critical for separating out isotopic variants of planetary molecules [Fig. 10].

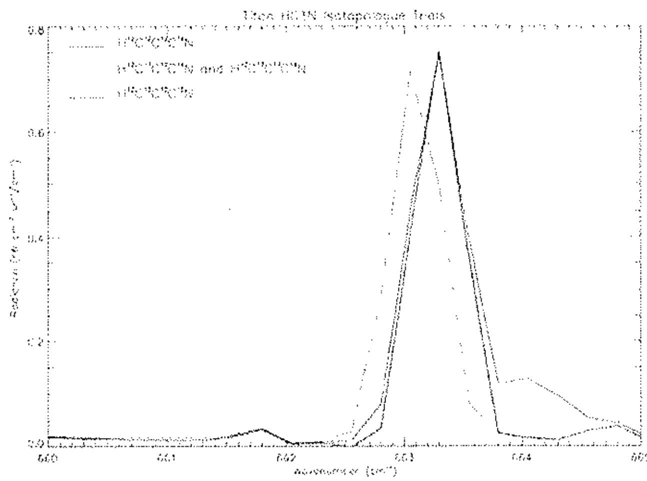

Figure 10. Isotope shifts for HC3N

5. Future Missions

Cassini CIRS has revealed the rich organic chemistry of Titan and has discovered heat escaping from polar fractures on Enceladus, showing potential for life. We need continued monitoring of seasonal, inter-annual effects in the Saturnian system, such as Titan's complex atmosphere and methane-driven hydrological cycle. Thus we look forward to future missions, including planetary flagship missions such as Titan Saturn System Mission and Europa Jupiter System Mission (both of which will require cost-descoping); an Enceladus Orbiter mission; possible participation in an ESA Ganymede Orbiter (via SALMON); and other such recent concepts as an Enceladus/Titan multi-flyby mission, or a Uranus Orbiter/Probe mission. CIRS-lite could also benefit the CLARREO Earth mission, for mid to far-IR (100 microns or so) spectroscopy of radiation balance for climate studies.

For the so-called Uranus pathfinder mission [2021 launch] CIRS-lite could contribute to mission goals such as:

- characterize abundances of minor species (water, methane, ammonia, trace hydrocarbons) in the Uranian Atmosphere to further understanding of planetary evolution;
- investigate the dynamics of the Uranian atmosphere and the apparent lack of an internal heat source.

Acknowledgements

Development of the CIRS-lite brassboard has been funded by internal NASA-GSFC seed money, and through the ROSES PIDD program at NASA Headquarters. We thank C. Nixon (U. Maryland and NASA GSFC) for calculating the HC3N spectra.

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