CASSINI CIRS OBSERVATIONS OF SATURN'S RINGS. Linda J. Spilker[1], Stuart H. Pilorz[2], Brad D. Wallis[2], Shawn M. Brooks[2], Scott G. Edgington[2], F. Michael Flasar[3], John C. Pearl[3], Mark R. Showalter[4], Cecile Ferrari[5], Richard K. Achterberg[6], Conor A. Nixon[7], Paul N. Romani[3] and the Cassini CIRS Investigation Team, [1]Jet Propulsion Laboratory, 4800 Oak Grove Dr., M/S 230-205, Pasadena, CA 91109, (Linda.J.Spilker@jpl.nasa.gov), [2]Jet Propulsion Laboratory, [3]Goddard Space Flight Center, [4]Stanford University, [5]CEA/Saclay/University of Paris 7, [6]SSAI, [7]University of Maryland.

Introduction: In the spring of 2004, during Cassini's approach to Saturn, the Cassini Composite Infrared Spectrometer (CIRS) began acquiring thermal spectra of Saturn's rings. CIRS is a Fourier-transform spectrometer that measures radiation in the thermal infrared from 7 microns to 1 millimeter (1400 to 10 cm^{-1}). CIRS has a set of 21 detectors, consisting of two 1 x 10 linear arrays with a pixel size of 0.3 mrad, and one 4 mrad circular detector.

Just after the completion of the Saturn orbit insertion (SOI) burn, CIRS performed an especially high spatial resolution scan of portions of Saturn's A, B and C rings. In the months following SOI, additional ring measurements have been obtained, including radial scans on the lit and unlit sides of the rings, and azimuthal scans across the shadowed regions of the A, B and C rings.

Saturn Orbit Insertion (SOI) Ring Scan: Immediately following the SOI burn, the spacecraft flew just 10,000 km above the unilluminated side of the main rings, ten times closer to the rings than it will be at any other time during the prime mission. For 65 minutes, CIRS obtained thermal spectra of the main rings, except for the innermost C ring and the central region of the B ring, at a radial resolution of 100-200 km with a spectral resolution of 15.5 cm^{-1}. Just after the outbound ring plane crossing, CIRS obtained a single scan of the outer portion of the lit A ring at 600 to 700 km radial resolution, comparable to the highest resolution Voyager infrared ring data [1, 2].

*Derived Temperature*s: Using a model which considers the ring as a thin, homogeneous, nonscattering slab radiating as a blackbody, the observed thermal emission from the ring, I_ν, as a function of wave number, ν, is given by:

$$I_\nu = \varepsilon B_\nu(T) (1 - e^{-\tau/\cos\theta})$$

where ε is the physical emissivity, $B_\nu(T)$ is the ring blackbody emission, and T is the effective temperature. The last term is a filling factor for the ring particles where τ is the normal infrared optical depth of the ring and θ is the emission angle. Temperatures and filling factors were derived by fitting a blackbody function to the shape of the spectrum between 100 and 450 cm^{-1} (100 µm to 22.2 µm), a range which includes the peak of the ring's thermal emission. To first order, we find that the product of the emissivity and filling factor terms is independent of wavelength over this range.

Retrieved SOI Temperatures: We retrieved temperatures for the SOI scans [3]. Temperatures varied from approximately 70° K to 110° K. The warmest temperatures are found in the optically thin C ring and in the Cassini Division. The optically thicker A and B rings are 20° K to 40° K cooler than the C ring and the Cassini Division. Compared to these CIRS results, the unlit A and B rings are ≈ 25° K cooler in Voyager data [1, 2] and ≈ 30° K cooler in Pioneer 11 data [4] . These large differences are probably a seasonal effect, due to the lower solar elevation angles during the Voyager and Pioneer flybys.

For the radial scans resolved by our data we find a strong anti-correlation between optical depth, τ, and temperature on the unlit side of the rings, which indicates that ring material can inhibit the flow of heat from the lit side to the unlit side of the rings. This result applies even in the optically thin C ring, where τ is small, typically 0.1 to 0.4. The small increase in mutual shadowing at $\tau = 0.4$ appears sufficient to reduce ring temperatures, as these optically thicker regions in the C ring and in the Cassini Division are about 10° K cooler than the more transparent segments.

Ring Optical Depth and Ring Emissivity: Assuming a value for ε, the radial profile of optical depth can be derived. For the unlit rings, for $\varepsilon = 1$, our result is very similar to the optical depth profile obtained by the Voyager photopolarimeter (PPS) experiment [5].

However, the derived optical depth profiles for the lit and unlit sides of the A ring are very different. The lit side τ is several times smaller than unlit τ. This inconsistency can be resolved if we assume that the particle emissivity is slightly less than one. A value of $\varepsilon = 0.95$ brings the optical depths into agreement. This lower value for the emissivity may indicate that surface roughness plays an important role in the emission properties of the ring particles. Surface grains which are considerably smaller than the wavelength of light are less efficient emitters than large particles, with emissivities less than one. One possible interpretation is that the rings' thermal properties can be described by large particles covered with a layer of much smaller grains. This is consistent with determinations that the rings and inner moons are loose agregrates, with densities in some cases much less than that of pure water ice.

Roll-off in Ring Temperature at Submillimeter Wavelengths: One of the more intriguing features of Saturn's rings has been the steepness of the decrease in brightness temperature with increasing wavelength between 50 and 100 µm, first revealed in earth-based observations [6, 7]. However, because of limited spatial resolution of these observations, it has been difficult to separate the ring and planet contributions to this effect.

CIRS resolved the rings in the far-infrared, measuring the brightness temperature at wavelengths of tens of µm to sub-mm. The CIRS measurements unambiguously reveal a trend in brightness temperature that is much less steep between 50 and 100 µm than previously reported (Fig. 1). Larger particles do not show any significant variation in emission over the 50–100 µm wavelength range [7]. Therefore, the more gradual trend implies that the rings are not dominated by particles smaller than ~1 mm; This conclusion is consistent with results from particle eclipse cooling [8] and high phase angle Voyager imaging observations [6]. The roll-off in brightness temperature measured by CIRS may be due to particles' surface roughness and/or the varying emissivity of the materials.

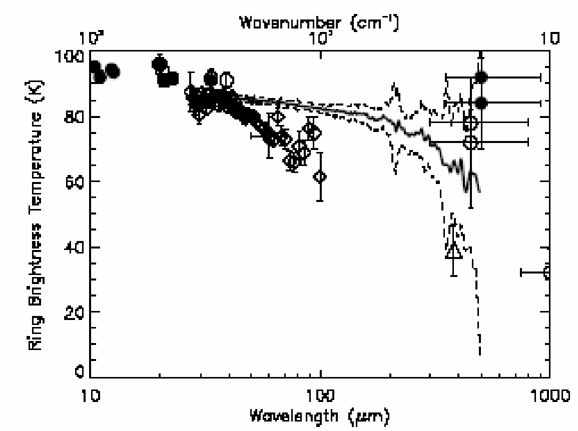

Figure 1. Brightness temperature of the B ring as a function of wavelength (and wavenumber). Heavy solid line: CIRS 6-hour spectrum at 1-cm^{-1} resolution, acquired on 22 June 2004, when the spacecraft was 99 R_S away, and the B ring's afternoon ansa nearly filled the instrument's 4-mrad far-infrared circular field of view. The dashed lines represent 1σ uncertainties. The phase angle of the observation was 67°. Earth-based brightness temperature observations: (filled circles) at solar angles of ~ 25° (comparable to the Cassini sun angle of 24.4°), and (open circles and diamonds) at solar angles of ~20° (see Table VIII in [6]). The triangle is from reference [9].

Shadow Boundary Scans: During the azimuthal scans across the shadow boundaries, ring particles entering the shadow cooled relatively quickly, indicating a low thermal conductivity. C ring particles cooled more than 10° K after entering the shadow. The total amount of cooling is not as pronounced in the B ring where the cooling was about 5° K. In the A ring, which is only partially shadowed at this epoch, the total cooling was only about 2° K.

Future Plans: In the coming months and years, Cassini CIRS will obtain additional observations of Saturn's rings at a variety of emission, inclination and phase angles, These observations will allow us to distinguish between variations arising from viewing geometry and those due to the ring itself, and will assist ring scientists in determining ring particle properties.

This work was performed at JPL under contract with NASA and at CEA Saclay supported by the "Programme National de Planetologie".

References: [1] R. Hanel et al. (1981) *Science* **212**, 192-200. [2] R. Hanel et al. (1982) *Science* **215**, 544-548. [3] F.M. Flasar et al. (2004). *Science*, in press; published online 23 December 2004 (10.1126/science.1105806). [4] L. Froidevaux and A. P. Ingersoll (1980) *J. Geophys. Res.* **85**, 5929. [5] L. W. Esposito, M. O'Callaghan, and R.A. West (1983) *Icarus* **56**, 439-452. [6] J. N. Cuzzi et al. (1984), in *Planetary Rings*, R. Greenberg, A. Brahic. Eds. (Univ. of Arizona Press, Tucson), 72-198. [7] L. W. Esposito et al. (1984), in *Saturn*, T. Gehrels, M.S. Matthews, Eds. (Univ. of Arizona Press, Tucson), 463-545. [8] . L. Froidevaux (1981) *Icarus* **46**, 4-17. [9] T. L. Roellig, M.W. Werner, E. E. Becklin (1988) *Icarus* **73,** 574-583.