CASSINI CIRS OBSERVATIONS OF THERMAL DIFFERENCES IN SATURN'S MAIN RINGS WITH INCREASING PHASE ANGLE.

L. J. Spilker[1], S. H. Pilorz[2], C. Ferrari[3], C. Leyrat[3], B. D. Wallis[2], S. M. Brooks[2], S. G. Edgington[2], N. Altobelli[2], F. M. Flasar[4], J. C. Pearl[4], M. R. Showalter[5], R. K. Achterberg[6], C. A. Nixon[7], P. N. Romani[3] and 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]CEA/Saclay/University of Paris 7, [4]Goddard Space Flight Center, [5]Stanford University, [6]SSAI, [7]University of Maryland.

Introduction: The Cassini Composite Infrared Spectrometer (CIRS) obtained spatially resolved temperature scans of Saturn's main rings (A, B and C, and Cassini Division) that show ring temperatures decreasing with increasing solar phase angle (the change of sun-ring-spacecraft angle) on both the sunlit and backlit sides of the rings [1]. These temperature differences indicate that Saturn's main rings contain a population of ring particles that rotate slowly. The ring particles that produce these temperature differences also have low thermal inertia as determined from eclipse heating and cooling curves [2].

Thermal Infrared Ring Data: The CIRS instrument on Cassini consists of two Fourier transform spectrometers, which together measure thermal emission from wavelengths of 7 μm to 1 mm (1400 to 10 cm^{-1}) at an apodized spectral resolution programmable from 0.5 to 15.5 cm^{-1} [3,4]. The far infrared interferometer, which was used for this set of observations, covers from 17μm to 1 mm (600 to 10 cm^{-1}) and has a 4-mrad field of view.

Thermal spectra of the rings have been obtained at a number of phase angles, ring local times and ring opening angles [5]. For each ring, fitting a blackbody curve to the CIRS FP1 thermal spectrum between 25 and 100 microns (400 and 100 cm-1), and accounting for the ring opacities, we derived ring temperatures that also accounted for the ring filling factor.

Phase Angle Results: The thermal characteristics of each main ring vary noticeably with phase angle. In Figure 1 we present four radial scans of the A, B and C rings and Cassini Division taken at different ring geometries with spatial resolutions of 2,000 to 2,600 km. Each ring shows a decrease in temperature with increasing phase angle for both the sunlit and backlit sides of the rings. Notice that the main rings are warmest on the sunlit side at low phase angles (red curve), with the C ring and Cassini Division warmest of all.

Sunlit Rings: The sunlit rings, at low (red) and high (gold) phase angle, are shown in Figure 1. At low phase angle, on the daysides of the particles, the C ring and Cassini Division are the warmest, between 100 and 105 degrees, while the B ring and A ring are cooler, between 85 and 95 degrees. The C ring and Cassini Division particles have lower albedos than the A and B ring particles, which may account for their temperature differences.

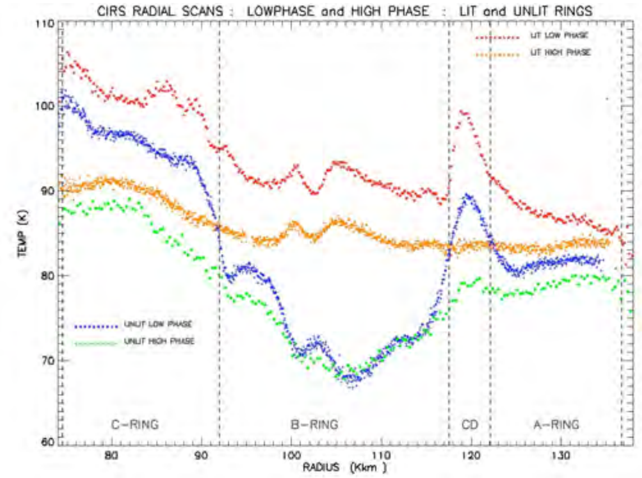

Figure 1: Radial scans of Saturn's rings. Sunlit, low phase (red), sunlit, high phase (gold), backlit, low phase (blue), backlit, high phase (green).

The high phase view of the rings (gold) cannot be seen from Earth. The ring particles at high phase angle are all cooler than the ring particles at low phase angle, and each ring has cooled by different amounts. The C ring is about 8-15 degrees cooler and the A and B rings are 3-10 degrees cooler. CIRS is primarily seeing the particle night sides, which would be cooler for a population of slowly rotating ring particles.

These temperature differences indicate that Saturn's main rings contain a population of ring particles that rotate slowly, less than a few rotations per orbit for a typical ring particle (6 to 14 hours). If one assumes that ring particles collide fairly frequently, it was originally thought that most of them would spin rapidly, producing temperatures that would be much more uniform with increasing phase angle.

Not only does the population of ring particles rotate slowly, giving their night sides an opportunity to radiate to space, they must also have a low thermal inertia so they can heat up and cool off quickly [2]. Finally, the ring particles that we are measuring must be larger than a few cm. The thermal wave would easily penetrate much smaller particles, and they would be isothermal. Ring particles that have high thermal inertia, or are small (less than about one centimeter in radius), or rotate quickly would possess essentially the same temperature at all phase angles, in contradiction of the CIRS thermal data.

Backlit Rings: A similar temperature effect is seen for the backlit rings at low (blue) and high (green) phase angle. The C ring and Cassini Division again display large changes in temperature, 10-15 degrees. In the backlit case, the thickest parts of the B ring are the same temperature at both high and low phase angles. The large temperature contrast in the B ring suggests that very little sunlight reaches the backlit side of the thickest part of the B ring and little vertical mixing occurs there.

Ring Particle Thermal Modeling: The magnitude of the temperature variation with phase angle is indicative of the particle spin rate. Our derived temperatures are compared to a model that assumes ring particles are spherical, identical in size, distributed in a monolayer and have finite, but small thermal inertia [6]. In the model the spin rates and obliquities are fixed.

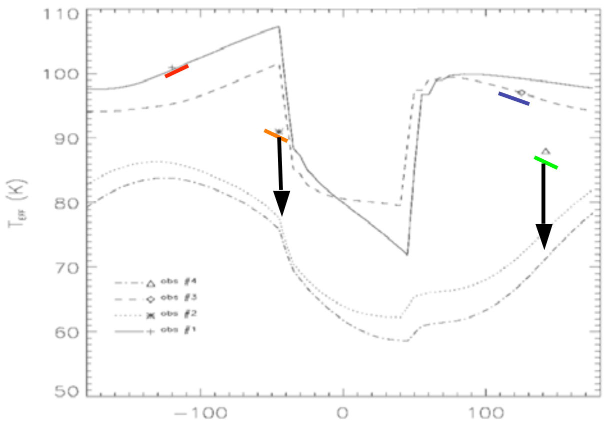

Figure 2: Model of C ring behavior assuming slow (synchronous) rotators. Temperature is plotted vs. local hour angle, which is zero at midnight, negative on the dusk ansa and positive on the dawn ansa.

To test our assumptions, a region of the C ring at 80,000 km was selected, and modeled for the geometries of each of the four scans shown in Figure 1, assuming a particle albedo of 0.25. Figure 2 shows the model results for synchronously rotating ring particles, with spin axes perpendicular to the ring plane. The temperatures of the two low phase points (red and blue underlines) are well fit by the model while the temperatures of the two high phase angle points (gold and green) are too warm compared to the synchronous rotator model.

Figure 3 shows model results for relatively fast rotators (ring particles rotate 10 times for each orbit they make around Saturn). In this case, the temperatures of the low phase ring particles (red and blue) are too warm compared to the fast rotator model while the temperatures of the high phase ring particles (gold and green) are well fit by the model.

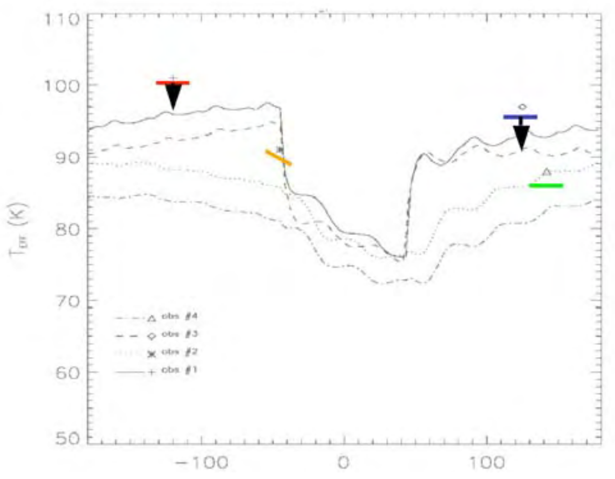

Figure 3: C ring model assuming fast rotators. Temperature is plotted vs. local hour angle, which is zero at midnight, negative on the dusk ansa and positive on the dawn ansa.

These model results suggest that in this region of the C ring a single particle size and a single spin rate cannot fit both the high and low phase angle temperature data. Instead, a distribution of particle sizes and particle spin rates is needed. Dynamical models predict rotation rates that range from 0.1 Ω for larger particles to 10 Ω for smaller particles, where Ω is the orbital period [7, 8].

Conclusions: Ring particle temperatures decrease with increasing phase angle for the A, B, and C rings and Cassini Division. This decrease in temperature is indicative of a population of slowly rotating ring particles. However, a single population of slowly rotating ring particles cannot explain the differences observed in the CIRS C ring temperature data. A distribution of particle spins, as well as a distribution of particle sizes, is needed to explain the C ring thermal behavior with changing phase angle.

References: [1] Spilker, L. *et al.* (2005) AAS *Bull.*, Vol. 37 No. 3, 764. [2] Ferrari, C. *et al.*, (2005) *Astron. & Astrophys*, Vol. 441, #1, 379-389. [3] Kunde, V. *et al.*, (1996) SPIE Proceedings, **2803**, 162 [4] Flasar, F.M. *et al.*, (2004) *Space Science Rev.*, **114**, 169. [5] Flasar, F.M. *et al.*, (2004) *Science* **307,** 1247. [6] Ferrari et al., (2006) *Astron. & Astrophys.* (accepted). [7] Salo, H. and R. Karjalainen, (2003) *Icarus*, **164**, 428. [8] Ohtsuki, K., (2005), *Astrophy. J.*, Volume 626, Issue 1, L61-L64.