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# Mapping Ring Shadow Cooling and Thermal Inertia with Cassini CIRS

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## Abstract

We use data from Cassini's Composite Infrared Spectrometer to characterize ring shadow cooling and to document radial variations in ring thermal inertia. We show that shadow cooling is most distinct in the optically thin C ring and Cassini Division. More modest cooling is observed in the thicker B and A rings. These cooling rates across Saturn's rings correspond to observed variations in other ring parameters.

## Background

Observations of thermal emission from airless solar system bodies provide a unique window into the nature and characteristics of their surface layers. As these bodies rotate and expose different portions of their surfaces to sunlight, they re-radiate energy absorbed from the Sun. This re-radiation takes place in a layer several thermal skin depths thick. The composition and regolith grain size, as well as the timescale of the variation of insolation, determine the thermal skin depth of a body. Previous researchers have used observations of this thermal emission to constrain the surface properties of various asteroids ([1]), the Moon ([2]), Mars ([3]) and the Galilean satellites ([4]), for example.

The response of a material to a changing thermal environment is often characterized by its thermal inertia, a derived quantity that depends on the density, specific heat and thermal conductivity of that material. These parameters can in turn be related to the porosity of the regolith and the typical grain size of the particles that comprise it. Thus, determining the thermal inertia of a surface yields clues to the nature of that regolith. Researchers have in the past used groundbased observations to constrain the thermal inertia of Saturn's rings. [5] interpret observations of Saturn's rings at $10$ and $20$ microns to constrain the size of Saturn's ring particles. They conclude that mean particle sizes in the B ring are between $0.07$ and $1$ cm. More recently [6] analyzed infrared images of Saturn taken with the Canada-France-Hawaii Telescope. They derived thermal inertia values of $5^{+18}_{-2}\,\mathrm{Jm^{-2}K^{-1}s^{-1/2}}$ for the B ring and $6^{+12}_{-4}\,\mathrm{Jm^{-2}K^{-1}s^{-1/2}}$ in the C ring. These low values imply that the ring particles are fractured by cracks or covered with a regolith of porous particle aggregates. Herein we describe our efforts to model Cassini observations of Saturn's rings with the goal of learning more about the physical characteristics of the rings and its constituent particles.

## CIRS Shadow Observations

Cassini's Composite Infrared Spectrometer records infrared radiation between $10$ and $1400\,\mathrm{cm^{-1}}$ (7 and $1000\,\mu$m) ([7]). Far infrared radiation is recorded at focal plane 1, which detects photons between $10 - 600\,\mathrm{cm^{-1}}$ ($16\,\mu\mathrm{m} - 1\,\mathrm{mm}$). CIRS' spectral resolution can be set from $0.5$ to $15\,\mathrm{cm^{-1}}$, with higher spectral resolutions requiring longer integration times. Since its arrival at Saturn in 2004, CIRS has recorded tens of millions of mid- and far infrared spectra of Saturn's rings (*personal communication*, M. Segura). Thermal emission from Saturn's rings peaks at FP1 wavelengths, making FP1 data well suited to ring studies ([8, 9]). As shown in [8] and [9], thermal spectra of Saturn's rings are well described as blackbody emission at an effective temperature $T_e$, multiplied by a scalar factor $\beta$ related to the emissivity of the rings. Effective ring temperatures range from $\sim 50\,\mathrm{K}$ in the B ring at equinox to over $100\,\mathrm{K}$ in the C ring closer to solstice. At higher solar elevation angles, the rings exhibit larger temperatures and greater thermal contrast.

CIRS observations also benefit from Cassini's location in orbit around Saturn. Whereas groundbased observers are restricted to low phase angles ($< 6°$) and modest ring opening angles ($< 27°$), Cassini can explore a much wider range of geometries. Cassini can also directly observe that portion of the rings eclipsed by Saturn's shadow. The thermal budget of the rings

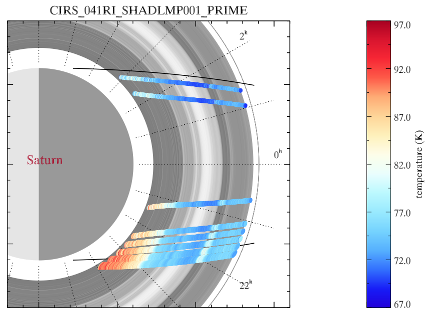


Figure 1: CIRS_041RI_SHADLMP001_PRIME, a 10-hour observation of the shadowed rings, was taken in March 2007. Overlapping CIRS FP1 footprints are color coded according to the effective temperature retrieved and plotted above.

is dominated by absorbed solar radiation. When ring particles enter Saturn's shadow this source of energy is abruptly cut off. As a result, ring particles cool as they traverse the shadow. Figure 1 depicts an observation of the rings' shadow region. FP1 scanned the main rings repeatedly with a constant offset from the ingress edge of Saturn's shadow. From shadow observations such as these we can create cooling curves at specific locations across the rings. Figure 2 shows this cooling at three distinct location in Saturn's A ring. Differences in cooling rates can be related to differences in ring thermal inertia with location within the individual rings, not just from ring to ring.

Whereas previous investigations analyzed azimuthal scans that document the cooling at a specific location in the rings, shadow scans like those in Fig. 1 can be used to map out ring thermal inertia. Producing thermal inertia values for the constituent ring particles from ring cooling curves requires a thermophysical model, such as that of [11], which describes the ring as a multilayer system of large and small particles (relative to their rotation and thermal cooling rates) that either bounce at the ring's midplane (as one might expect in the optically thick B ring core) or pass between the lit and unlit sides of Saturn's rings unimpeded (as particles in the lightly populated C ring and Cassini Division should do). Determing how thermal inertia varies across the rings provides evidence as to how physical properties of the rings, such as particle composition and regolith porosity, vary in the Saturn system. Such variations may be rooted in the origin of the ring system itself.

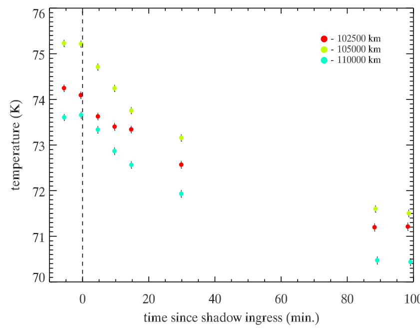


Figure 2: Cooling curves are shown for three locations in the A ring. At 135000 km, the ring cools more quickly than at the other two locations. Cassini RSS occultation experiments show this region to have unique properties ([10]). This suggests that we can relate ring thermal inertia to other dynamical and physical properties of the rings.

## Summary and Conclusions

We are using CIRS observations to map out differences in the thermal response of Saturn's rings upon entry into Saturn's shadow. We show that there are sensible differences in the cooling rates across Saturn's rings that correspond to observed variations in other ring parameters. Using a thermophysical model of the rings we can turn cooling rates derived from CIRS observations into thermal inertia values, which are indicative of ring particle properties. Future observations will help us address these questions during the Cassini Solstice Mission. More observations at higher solar inclination angles and a wider range of phase and emission angles will be very useful.

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