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A High-Amplitude Thermal Anomaly of Probable Magnetospheric Origin of Saturn's Moon Mimas

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Abstract

Spectral maps of Mimas' daytime thermal emission show a previously unobserved thermal anomaly on Mimas' surface. A sharp V-shaped boundary, centered at 0° N and 180° W, separates relatively warm daytime temperatures from a cooler anomalous region occupying low- to mid-latitudes on the leading hemisphere. Subsequent observations show the anomalous region is also warmer than its surroundings at night, indicating high thermal inertia. Thermal inertia in the anomalous region is 67±30 $Jm^{-2}K^{-1}s^{½}$, compared to <16 $Jm^{-2}K^{-1}s^{½}$ outside the anomaly. Bolometric Bond albedos are similar between the two regions, 0.49 - 0.70. The mapped portion of the thermally anomalous region coincides in shape and location to a region of high-energy electron deposition from Saturn's magnetosphere, which also has unusually high near-UV reflectance. It is therefore likely that high-energy electrons, which penetrate Mimas' surface to the centimeter depths probed by diurnal temperature variations, also alter the surface texture dramatically increasing its thermal inertia.

1. Introduction

Mimas is the innermost and smallest of Saturn's mid-sized satellites. Its surface is dominated mainly by water ice and appears bland and heavily cratered. Cassini's Composite Infrared Spectrometer (CIRS) had two opportunities in 2010 (orbits 126 and 139) and another in 2011 (orbit 144) to observe thermal emission from Mimas' anti-Saturn hemisphere.

CIRS is a Fourier Transform Spectrometer with three focal planes, known as FP1, FP3 and FP4 that cover 10 to 1400 cm^{-1} (7.1 to 1000 μm). Mimas' surface temperatures are determined in this analysis from 600 to 1100 cm^{-1} (9.1 to16.7 μm) data taken by CIRS' FP3, as it gives the best compromise between spatial resolution and spectral coverage. Three FP3 data sets will be used from Cassini's orbits 126, 139 and 144. However, since the first two orbits provide higher spatial resolution observations it is results from these orbits that will be primarily focused upon.

2. Method and Results

2.1 Determining Surface Temperature

The pointing of all data was refined using the location of Mimas' limb in the data. The orbit 126 and 139 CIRS data was binned into 2.5°x2.5° bins, whilst the lower spatial resolution orbit 144 data was binned into 5.0°x5.0° bins. The surface temperature of each bin was determined by fitting a single blackbody curve to the mean spectra of the FP3 CIRS observation that fall in that bin. The resulting daytime and nighttime temperature maps are shown in Figure 1. Both maps show a V-shaped boundary, sharp at CIRS resolution, separating warmer and cooler temperatures. The apex of the V is at 0° N and 180° W, and the boundary extends in a northeast and southeasterly direction, approximately symmetrically about the equator. Extrapolation of the daytime data taken during orbit 144 indicates the eastern edge of the thermal anomaly is near 0° W longitude.

The region east of the boundary, on Mimas' leading hemisphere is considered to be the thermal anomalous regions, as its diurnal temperatures variations have a smaller-amplitude than majority of Mimas' surface and of most of the surfaces of Mimas' neighboring icy satellites.

2.1 Determining Mimas' Surface Thermal Properties

The thermal surface properties of Mimas were determined for two regions shown in Figure 1. Using

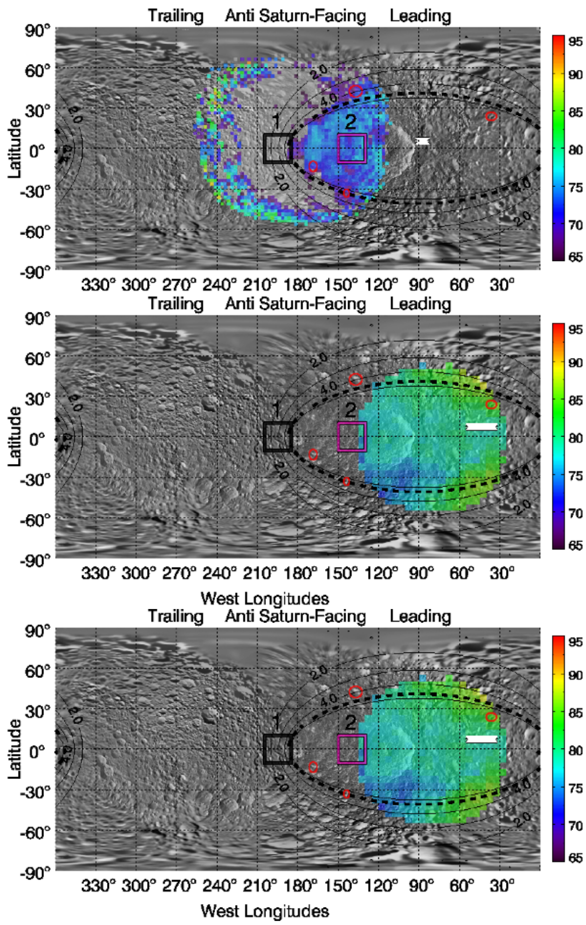

Figure 1 Surface temperature maps of Mimas from orbits 126 (daytime, top), 139 (nighttime, middle) and 144 (daytime, bottom). Light grey shading indicates regions that have CIRS FP3 data coverage but are too cold for temperature determination. The white stars indicate the sub-solar points during each orbit. The locations of two regions are shown whose surface thermal properties are discussed in the text. The red circles on each sub-figure identify the same craters, to facilitate spatial comparisons.

Using the local time coverage of orbits 126 and 139 the surface thermal properties in Regions 1 and 2 were determined by fitting the results of a 1-D thermal model [1]. The lower-limit of CIRS temperature sensitivity (65 K) was used as an upper-limit for Region 1's nighttime temperatures. The resulting range of bolometric Bond albedo required to fit the Region 1 and 2 data overlap: 0.49 to 0.70 and 0.56 to 0.62 respectively. This is consistent with the lack of a noticeable albedo boundary in visible-wavelength images. The thermal inertias able to produced the observed temperatures in Regions 1 and 2 vary significantly, <16 MKS and 67±30 MKS respectively. The bolometric Bond albedos observed are comparable with those observed on Mimas' neighboring satellites [2], as is the thermal inertia observed in Region 1. Thus making Region 2, the area west of the thermal boundary, anomalous. The higher thermal inertias in the anomalous region indicate the surface here is less porous.

3. Discussion

The thermal anomaly is spatially closely correlated with a previously observed IR/UV color ratio anomaly [3]. Both anomalies lie on the leading hemisphere, a region of high-energy electron bombardment [3]. 1 to 10 MeV electrons penetrate depths comparable with that of Mimas' thermal skindepth (a few centimeters) [4], exciting water molecules along their path. If these high-energy electrons are able to mobilize ice grains as they pass through these depths in the ice then the thermal conductivity, and hence thermal inertia, could be increased as the contact area increases (essentially gluing grains together). Such an effect has been witnessed in a laboratory [5]. The same process may result in local defects in the ice it could increase UV scattering.

Acknowledgements

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