1 Scientific/Technical/Management

In 2010 Cassini's Composite Infrared Spectrometer (CIRS) took its first spatially resolved observations of Mimas' leading hemisphere. The results (shown in Figure 1) were surprising, despite Mimas' neutral appearance in visible images its daytime temperatures showed a large lens-shaped thermally anomalous region on its leading hemisphere (Filacchione et al., 2016; Howett et al., 2011). The anomaly was quickly dubbed "PacMan" because of its resemblance to the 1980s arcade character. Follow-up observations showed that the anomaly is also warmer at night than surrounding areas. The thermal anomaly had strong spatial correlations with the dark lens observed on Mimas in the IR/UV (0.930/0.338 μm) color ratio maps produced using data from the Cassini Imaging Science Subsystem (ISS) (Schenk et al., 2011). Further investigations revealed a similar color and thermal anomaly, albeit with smaller latitudinal extent, on Tethys (Howett et al., 2012; Schenk et al., 2011).

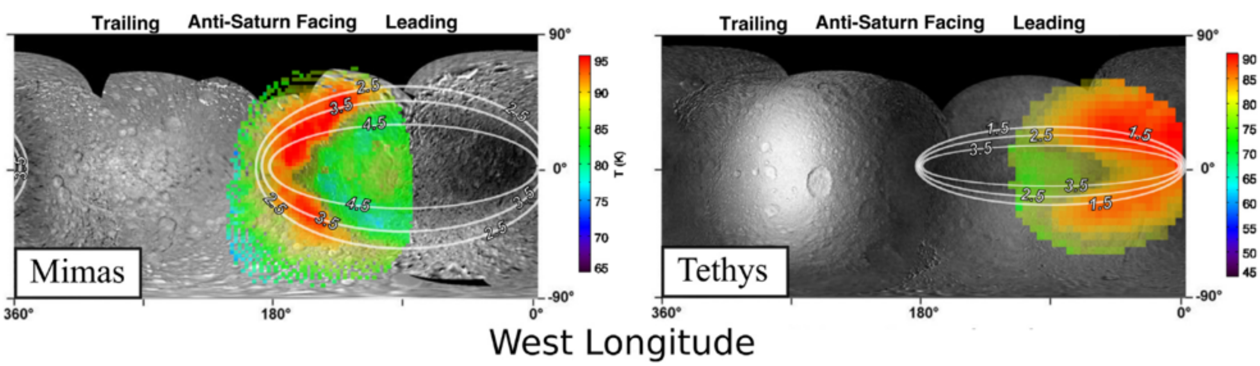

Figure 1 – The lens-shaped thermal inertial anomaly seen in surface temperature maps of Mimas (left) and Tethys (right) overlaying IR/UV ratio maps from Schenk et al., (2011). Shown in white are contours of total energy flux at the surface for MeV electrons from Paranicas et al., (2014).

Although no color anomaly was observed on Dione (Schenk et al., 2011), a subtle thermal anomaly was observed (Howett et al., 2014). In fact, the thermal anomaly on Dione was so subtle that it was not obvious in surface temperature maps (unlike those on Mimas and Tethys, Figure 1), but rather only possible to see in maps of Dione's thermal inertia. Thermal inertia (TI) describes a surface's ability to store and release heat. It is defined in terms of a surface's specific heat (c_p), conductivity (κ) and density (ρ), as $\sqrt{\kappa \rho c_p}$ with units of J m^{-2} K^{-1} $s^{-1/2}$ (here abbreviated to MKS). The TI of the non-anomalous (anomalous) terrain on Mimas, Tethys and Dione's leading hemisphere is: <16 (66), 5 (25), and 8 (11) MKS respectively (Howett et al., 2014, 2012, 2011).

Surface modification by high-energy electrons has been invoked as a cause of both the observed color and thermal anomalies (Howett et al., 2011; Paranicas et al., 2014; Schenk et al., 2011) as these electrons are expected to preferentially bombard the leading hemispheres of the satellites in similar lens-shaped patterns to those observed by CIRS and ISS (Howett et al., 2011; Nordheim et al., 2017; Paranicas et al., 2014; Schenk et al., 2011). The proposed mechanism for this modification is due to mobilization of molecules in the ice grains produced by the incident electrons, ultimately leading to growth in the contact area between grains (Howett et al., 2011;

Schaible et al., 2016; Schenk et al., 2011). This process is often referred to as sintering, and results in increased thermal conductivity, and thus also thermal inertia of surface material. These same electron-induced radiation effects may also produce defects locally in the ice that can increase UV scattering and thus explains the increased UV/IR color ratio seen in ISS observations (Schenk et al., 2011). From the distinct signatures seen in the Cassini remote sensing observations it therefore appears that energetic electron bombardment represents a major source of surface modification at these moons. However, to date, only preliminary work has been carried out to accurately quantify the processes by which energetic electrons modify surface material and to describe how these modifications relate to the surface properties inferred from the Cassini remote sensing observations.

1.1 Objectives and Expected Significance

We propose to carry out an investigation of electron-induced surface modification at the Saturnian moons Mimas, Tethys, Dione and Rhea using a combination of computer modelling and analysis of observations from in-situ and remote sensing instruments onboard Cassini. Building on our previous work done to quantify the radiation induced diffusion effects in icy regoliths and using detailed electron deposition maps created using simulations based on Cassini MIMI instrument data, we propose to develop a fully quantitative model of radiation-induced diffusion in water ice and the resultant sintering of ice grains. The outputs of this quantitative model will subsequently be compared to thermophysical properties for icy moon surfaces derived from Cassini CIRS observations allowing us to investigate the physical surface properties at each of the moons and determine the importance of energetic electron weathering relative to other weathering factors in the Saturnian system. Our proposed investigation will address the following objectives:

Objective 1 (O1): Investigate the bombardment pattern and the energy deposition of energetic electrons at each of the inner mid-sized moons.

Objective 2 (O2): Characterize and quantify the modification of surface regolith by energetic electrons.

Objective 3 (O3): Compare model predictions to Cassini observations of the moons and evaluate the effect that energetic electron bombardment has on observable surface properties.

1.2 Perceived Impact to State of Knowledge

This work will provide new quantitative insights into charged particle weathering as a surface modification process at icy bodies. By doing so we aim to gain a better understanding of how these bodies interact with their external environment and how their surface properties have evolved over time. An increased understanding of these processes will not only inform our understanding of the Saturn system and interpretation of Cassini remote sensing observations, but also our general understanding of how icy surfaces are modified by charged particles. We propose to develop a fully quantitative model of radiation-induced diffusion in water ice and sintering of ice grains. Although there is strong evidence linking electron radiation-induced diffusion to changes in the thermal conductivity of the regolith, materials simulations tested against the extensive Cassini data are critical. Using the unique environment of the Saturnian moons where distinct radiation-induced features are observed and the radiation environment is well characterized, the possibility of developing a fully quantitative model of space weathering effects in icy regoliths is possible for the first time.

1.3 Relevance to Element Programs and Objectives in the FA

Proposed work will utilize spacecraft in-situ and remote sensing data from the Cassini mission as well as several existing computer models to further our understanding of electron-induced weathering at the inner mid-sized Saturnian moons. The proposed work involves analysis of Cassini data from the CIRS instrument as well as computer modeling that will help to inform our interpretation of Cassini remote sensing observations at these moons. Data from the MIMI-LEMMS instrument will be used as an input to the proposed computer modeling. The proposed work is therefore relevant to NASA and the Cassini Data Analysis program, which calls for investigations that "… conduct scientific investigations utilizing or enhancing the utilization of data obtained by the Cassini mission". The proposed work will address the following Cassini mission objectives:

- Map the satellite surfaces in order to help constrain their geologic histories.
- Determine the physical processes responsible for the appearance of the surfaces.
- Investigate the icy satellite interactions with Saturn's magnetosphere and ring system.