Time Variability of the Global Temperature Distribution of Mimas

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Abstract

Strong surface interaction of the inner Saturnian moon, Mimas, with energetic ions and MeV electrons has led to space weathering effect illustrated by albedo/color asymmetry and variation of the thermal inertia (*I*) between the leading and trailing hemisphere. The *I* value in a localized region of the leading hemisphere is about $67 \pm 30\, J \cdot m^{-2} K^{-1} s^{1/2}$, while the corresponding value in the neighboring area is $I < 16\, J \cdot m^{-2} K^{-1} s^{1/2}$ (Howett et al., 2011). We simulate the diurnal and seasonal variability of Mimas' global temperature distribution and examine the resultant effect on the possible formation of a surface bounded exosphere. **Figure 1** shows the geological map and the region of thermal anomaly map used in the proposed model of Mimas, and the control points are derived by Gaskell(2013).

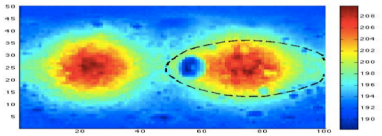

Figure 1, The geometric map in km of Mimas. And the dashed line enclosed the region of thermal anomaly.

Mimas' transit of Saturn

In the case of Mimas, the icy moon is tidal-locked and under Saturn's shadow for about 9% of one orbit. Ray-tracing is used to get the energy flux on the surface. Figure 2 shows the map of solar flux received by Mimas in Saturn transit, and the control points are derived by Gaskell (2013). Figure 3 shows 2 images captured by Cassini CIRS FP3 in flyby 126, 139 and 144.

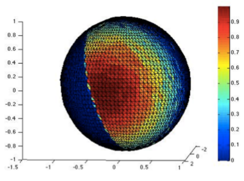

Figure 2, Normalized solar radiation received by Mimas in the transit.

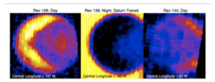

Figure 3, Three images taken by Cassini FP3 Howett et al., 2011

Thermal model

The proposed thermal model considers sublimation, thermal conduction and blackbody radiation, and 580 facets used in this model. The temperature map in Figure 7 and 8 is the result after 100 orbits of Mimas. The proposed work uses shape model derived by Gaskell (2013), and the definition and thermal parameters of egions outside/inside thermal anomaly derived by Howett et al.,2013. Table. 1 lists thermal parameters.

Target	Outside Anomaly	Inside Anomaly
Bolometric Bond albedo	0.60 ± 0.11	0.59±0.03
Thermal inertia (MKS)	<16	66±23
Skin depth (cm)	< 0.49	1.31-2.71

Table 1. List of the thermal parameters of Mimas.

$$S(1-A)\cos\theta \cos\emptyset = \varepsilon\sigma T^4 + k\left.\frac{dT}{dz}\right|_{z=0} + L\dot{M} \quad (1)$$

ollowing to the work of J. J. Cowan & M. F. A'Hearn (1979), we use formula as followed to derive the sublimation ate within different temperature:

$$mZ(T) = p(T)\left(\frac{m}{2\pi KT}\right)^{\frac{1}{2}} \quad (2)$$

Vhere sublimation rate Z(T) is a function of temperature *T*, and *m* is the molecular weight, and K is the Boltzmann onstant. Vapor pressure, i.e. p(T), is derived by the followed equation [Washburn, 1928]:

$$log\, p = \frac{-2445.5646}{T} + 8.2312\, logT - 0.01677006T + 1.20514\times10^{-5}T^2 - 6.757169 \quad (3)$$

Vhere p is in mm of Hg, and T in Kelvin. And the latent heat is derived followed Lebofsky [1975],

$$L(T) = 12420 - 4.8T \quad (4\text{-}7)$$

Vhere L is in cal-mole^{-1}, and T also in Kelvin. While using the three equations bellowed, we can derive the emperature when it gets the energy equilibrium

Bombardment model

Due to the orbit 126 image of Cassini find thermal anomaly on Mimas (Howett et al., 2011), the possible source, chemical reaction of sputtering in Saturnian inner magnetosphere, is discussed and also used in our thermal model to define the region of thermal anomaly. As Figure 4 shows the gyro motion and implanted to Mimas of protons.

Curvature and gradient drift:
In Saturn's inner magnetosphere, different sign of charge of the plasma would be driven by both curvature and gradient drift in different direction. As eq. (3) shows the angular velocity of plasma in the Saturn's magnetosphere (plus sign for protons, eastward. And minus for electron)(Hamlin et al., 1961; Lew, 1961; Thomsen and Van Allen, 1980)

$$\omega_D = \pm 2.083\times10^{-5} LE\left(\frac{E+2mc^2}{E+mc^2}\right)\left(\frac{F}{G}\right) \quad (3)$$

Where L is the equatorial crossing distance of a dipolar magnetic field line in units of radius of Saturn, E is the energy of one particle, F and G is the approximation of the whole bounce motion derived by Lew (1961).

Keplerian velocity of Mimas

$$w_K = \left(\frac{4.1905\times10^{-4}}{a^{3/2}}\right)\left(1 + \frac{1.25\times10^{-2}}{a^2}\right)$$

Corotational drift:
$\Omega = 1.637\times10^{-4}\, rad \cdot s^{-1}$

At the orbit of Mimas,
$\mathbf{w_K} \sim 7.71 \times 10^5\ rad \cdot s^{-1}$
And considering the relativity, velocity of one proton can be derived by the kinetic energy (E) and the rest energy of protons (E_{rest}).

$$v = \left(\frac{-1}{\left(\frac{E_k}{E_{rest}}\right)^2 + 1} + 1\right)c$$

Gyrovelocity varies of one proton with different energy lists in Table. 2.

E (MeV)	Pitch angle	ω_D (10^{-5} rad/s)	Gyro velocity (10^3 km/s)	Gyro radius (km)
0.1	90°	1.29	4.38	67.5
0.5	90°	6.44	9.78	151
1	90°	12.9	13.8	214
	60°		11.9	185
	30°		6.92	107
	10°		2.40	37.1
5	90°	64.2	30.8	478

Table 2. Comparison of energy, pitch angle and the gyro motion

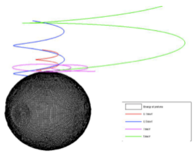

Figure 4. Trajectories of protons with different energy of interested protons implanted to Mimas. The gyro-radius of particles relates to the distribution of bombardment events.

Temperature map

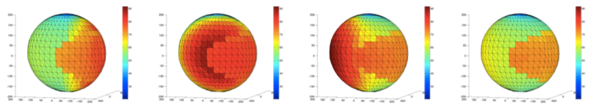

Figure 5. The side facing Saturn of Mimas, from left to right shows the subsolar point at SMF (Saturn Moon Frame) 90°, 180°, 270°, 0°

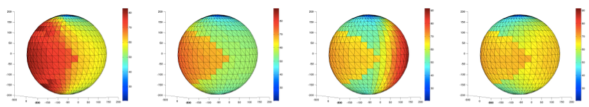

Figure 6. The backside of Mimas, from left to right shows the subsolar point at SMF (Saturn Moon Frame) 90°, 180°, 270°, 0°. And in the right-hand side first panel with lower temperature due to in Saturn's shadow.

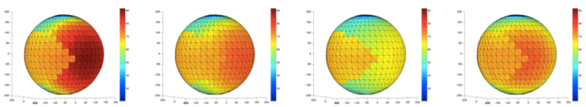

Figure 7. The temperature maps of Mimas when it starts to blocked by Saturn's shadow (a), after 2hrs (b), before leaving Saturn's shadow 2hrs (c) and starts to be warmed up by solar radiation (d). Outside the anomaly temperature cool down quickly due to thermal inertia is small there in our model.

Energy and the bombardment distribution

Since the different gyro-radius of protons would build different distribution of implantation. Figure 8 shows the comparison of bombardment distribution produced by 0.1, 0.5 and1 MeV protons when the pitch angle is large (pitch angle=85°±5°)

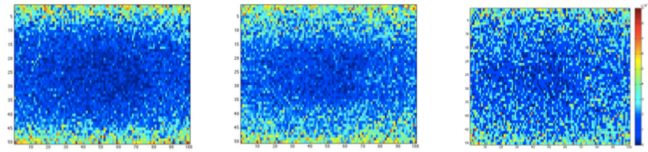

Figure 8. Comparison of distribution of 0.1, 0.5, 1 MeV protons.

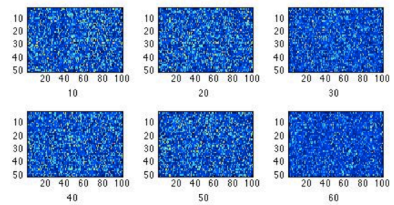

Figure 9. Comparison of the low pitch angle of 0.5 MeV protons

Discussion

Sputtering induced by different types of plasma on the icy surface of moons would also produce different types of molecules implanted in the mantle. In the case of protons interest water icy mantle, it would alter the surface components, H_2 and O_2 might be produced by the chemical reactions. And this might be the reason that thermal anomaly forms. We can use the bombardmen model to define the region of thermal anomaly exists and use thermal model to get the range of thermal parameters.

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