A MONTE CARLO MODEL OF THE EXOSPHERE OF SATURN's MOON, RHEA

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Abstract

From the Cassini observations, it was found that carbon dioxide and oxygen exist in Rhea's exosphere. Their origin might have to do with ion sputtering, meteorite impact vaporization, photodesorption, and surface thermal sublimation. We use a Monte Carlo method to construct a three dimensional model of the exosphere of Rhea which can, in turn, be used to study the corresponding magnetospheric interaction.

Introduction

Since the discovery of Rhea's O_2 and CO_2 exosphere by the Cassini observations (Teolis et al., 2010), much attention has been paid to the source and loss mechanisms of these atmospheric components. Recent work by Teolis et al. (2011) pointed out that Rhea's exospheric content also displays significant seasonal variation. This is because solar radiation plays an important role in the production of Rhea's exosphere via photosputtering and desorption of O2 and CO2 from the icy surface of this satellite.

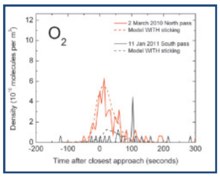

Figure.1
The molecular oxygen density distribution is from 2010 and 2011 Cassini's data. (From Teolis, 2011)

The goal of the present work is to construct a Monte Carlo model to simulate the bounce motion of the gas molecules across Rhea's surface once released until being lost to photodissociation or photoionization. From a statistical study of the orbital distribution of the test particles, the density distribution of O2 and CO2, respectively, could be computed.

Model

1. Thermal Model

The temperature map Fig.3 is derived by the followed equations:

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

$$k\frac{\partial^2 T}{\partial z^2} = \rho c_p \frac{\partial T}{\partial t}$$

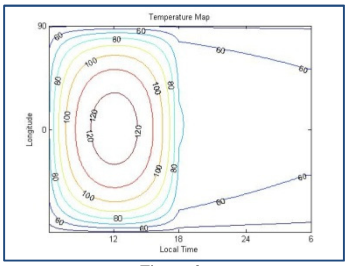

Figure. 2
This contour describes the temperature map of Rhea.

The temperature is derived between z=0 and z= -1 meter and using the Crank-Nicolson finite difference routine.

The boundary condition is: $\begin{cases} \left.\frac{\partial T}{\partial z}\right|_{z=0} = 0 \\ \left.\frac{\partial T}{\partial z}\right|_{z=-1} = 0 \end{cases}$

Symbol	Physical meaning	Amount
S	solar radiation at the equator of Rhea	16.7099 $[J\cdot s^{-1}m^{-2}]$
A	surface albedo	0.05
θ	Latitude	
∅	Longitude	
σ	Stefan-Boltzmann constant	$5.6704*10^{-8}$ $[J\cdot s^{-2}m^{-2}K^{-4}]$
k	thermal conductivity	$6*10^{-4}$ $[J\cdot s^{-1}m^{-1}K^{-1}]$
T	Temperature	
ρ	mass density	$1.25*10^{-3}$ $[Kg\cdot m^3]$
c_p	specific heat	670 $[J\cdot Kg^{-1}K^{-1}]$

Table. 1
The physical meaning of this thermal model

2. Source Mechanics and Loss mechanics

When the solar radiation interacts with the icy surface, oxygen would be sputtered into Rhea's exosphere because of the photodesorption.
After the molecular oxygen has absorbed solar radiation during a certain time interval (lifetime), it would be ionized by solar UV and x-rays. For the case of CO_2, the sublimation occurs when the temperature is higher than 80K, and CO_2 would condense again when temperature is lower than 60K.

Photodesorption :
$H_2O + h\nu \rightarrow H+OH$
$OH+OH \rightarrow H_2O+O$
$O+OH \rightarrow O_2+H$

Photo-ionization
$O_2 + h\nu \rightarrow O_2^+ + e^-$

	CO_2	O_2
Sources	Temperature>80K	Day side
Formation mechanics	Sublimation	Photodesorption by UV
Loss mechanics	Thermal escape Photo-dissociation Photo-ionization Condensation	Thermal escape

Table. 2
This is the source and loss mechanics of the exospheric molecules.

3. Monte Carlo method

The initial position of a particle is randomly chosen within the source region. Both the zenith angle and azimuth angle are also determined randomly.
And then we choose the velocity randomly from the maxwellian distribution of the local temperature, We use the following equations to find out the velocity of molecular oxygen to do the bounce motion.

$$v = \frac{\sum_{i=1}^{j}\frac{\kappa T}{mg}*R}{\sqrt{\frac{j}{12}}}$$, R is randomly chosen from 1 to j

(we set j=12).

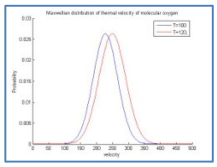

Figure.5
Here is the maxwellian distribution of O_2 and CO_2's thermal velocity when temperature is 100K and 120K.

Result

On Rhea, the scale height of its exosphere is: $\frac{\kappa T}{mg}$~100km-170km

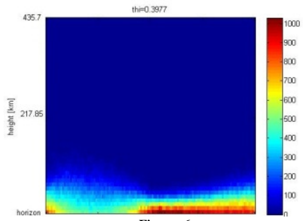

Figure. 6
Oxygen exosphere locates at the latitude ~ 22.9o, we can figure out the altitude is in the range of the scale height.

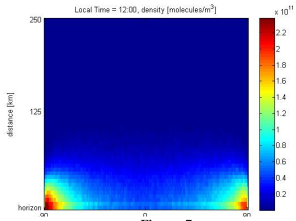

Figure. 7
This profile describes the density of the different latitude at local time is 9:00.

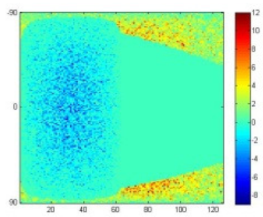

Figure. 8
This describes the condensing CO_2 density at Rhea's surface.

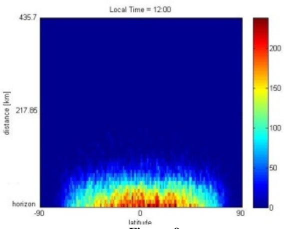

Figure. 9
This profile describes the CO_2 density of altitude vs. latitude at local time = 12:00.

Summary & Future Work

This model describes the bounce motion of molecular oxygen and carbon dioxide based on thermal velocity, and
The thermal model do not consider about the sublimation of CO_2. If the local sublimation rate is clear, the density of the exosphere would be more accurate.
This model can be used in other planets, such as Dione, Triton, and Tephis.

Reference

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