Far Ultraviolet Spectroscopy of Rhea

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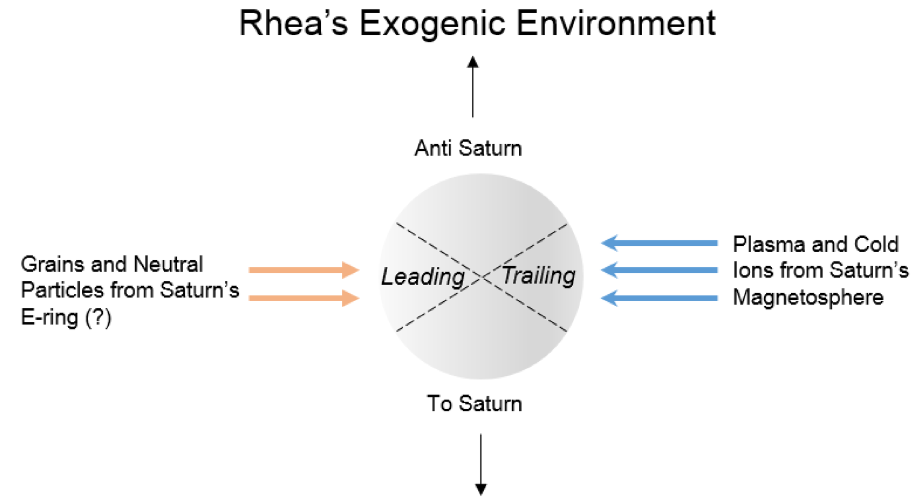
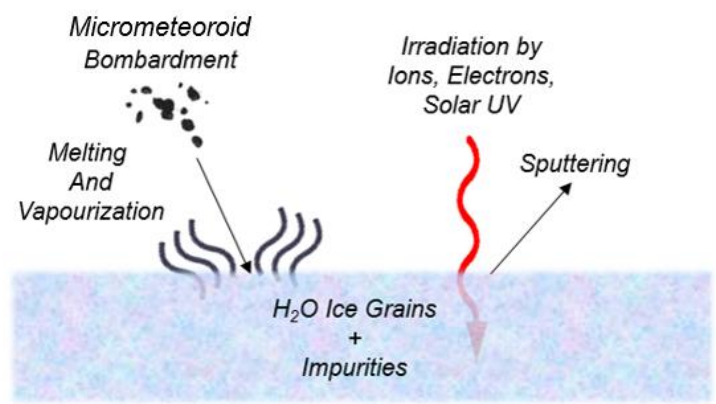
Introduction

Rhea is Saturn's second largest moon and has been subject of several flybys in the Cassini-Huygens mission. Rhea is an ice covered moon that orbits Saturn with a velocity that is slower relative to the co-orbiting plasma generated in Saturn's magnetosphere. Thus, the moon's trailing hemisphere is preferentially irradiated by plasma and cold ions while the leading hemisphere is irradiated with neutral particles and possible E-ring material.



Such radiolysis of Rhea's surface may trigger physical and chemical changes in the nascent ices as well as creating defects (bubbles and voids). In particular organic compounds in the ice can be dissociated by energetic particles leading to the formation of more complex compounds. Such physical and chemical transformations may be observed by monitoring the UV spectra of the ice surface.



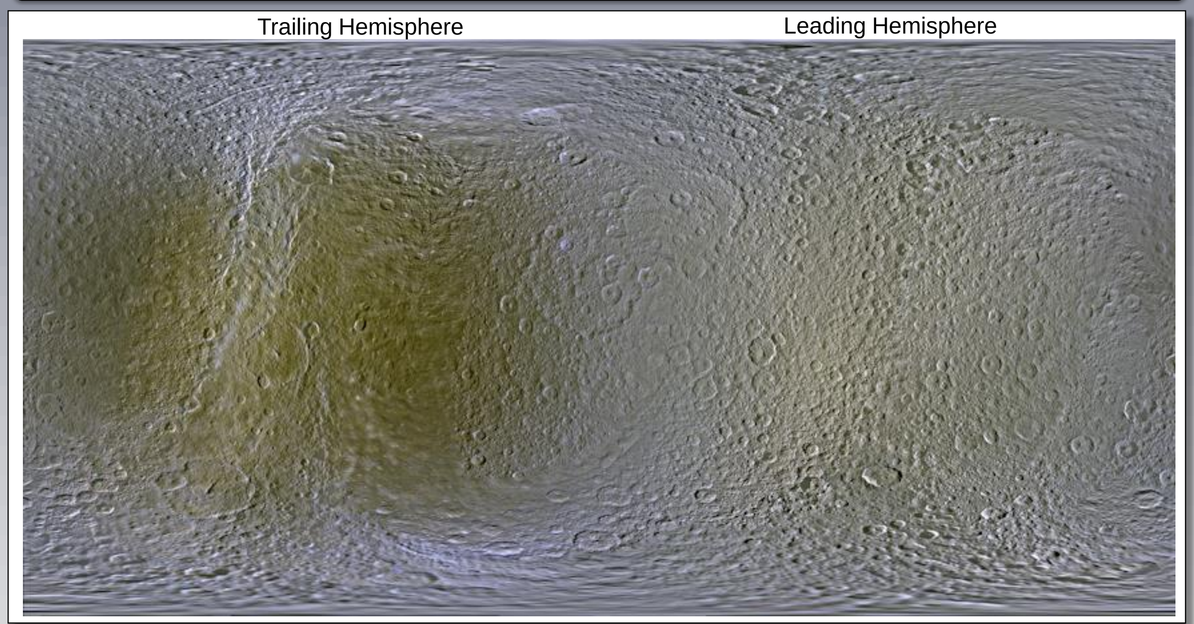
Far-UV reflectance spectra have been collected by the Cassini Ultraviolet Imaging Spectrometer (UVIS) (Figure 1) for five different flybys of the mid-sized icy satellite Rhea. The collection of such UVIS spectra sample Rhea's leading and trailing hemispheres and enable us to explore chemical composition variations across the icy surface.

In this poster we discuss the results of a detailed analysis of such flyby spectra. A technique known as "Derivative Spectroscopy" has been used to determine the appropriate ice grain size to use in producing model spectra for comparison with UVIS data. Modelled far-UV spectra have been prepared based on Hapke's formulism[2] (Eqn. 1) assuming intimate mixtures of chlorine, hydrazine, and water using equal grain sizes. These models were then fitted to the UVIS spectra and some examples (Figures 2, 3, and 4) are shown on this poster.

$$\underbrace{r(\theta_i,\theta_e,\phi)}_{\text{bi-directional reflectance}} = \underbrace{\frac{w}{4\pi}}_{\substack{\text{single-scatting albedo}\\\text{(explicit wavelength dependence)}}}\frac{\mu_0}{\mu_0+\mu}\left[\left(1+\underbrace{B(\phi)}_{\substack{\text{opposition effect}\\\text{(low phase angles)}}}\right)\underbrace{p(\phi)}_{\text{single particle phase function}}+\underbrace{M(\mu_0,\mu)}_{\substack{\text{multiple-scattering term}\\\text{interaction among ice grains}}}\right]\underbrace{S(\theta_i,\theta_e,\phi,\bar{\theta})}_{\text{roughness contribution}} \quad (1)$$

$$\underbrace{\mu=\cos(\theta_e)}_{\text{cosine of emission angle}},\quad \underbrace{\mu_0=\cos(\theta_t)}_{\text{cosine of incidence angle}},\quad \underbrace{w=\frac{\sum_i p_i\sigma_i w_i}{\sum_i p_i\sigma_i}}_{\substack{\text{weighted single-scatting albedo}\\\text{for mixtures of different grains}}}$$

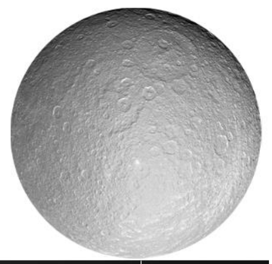
Cassini IR/Green/UV Map of Rhea

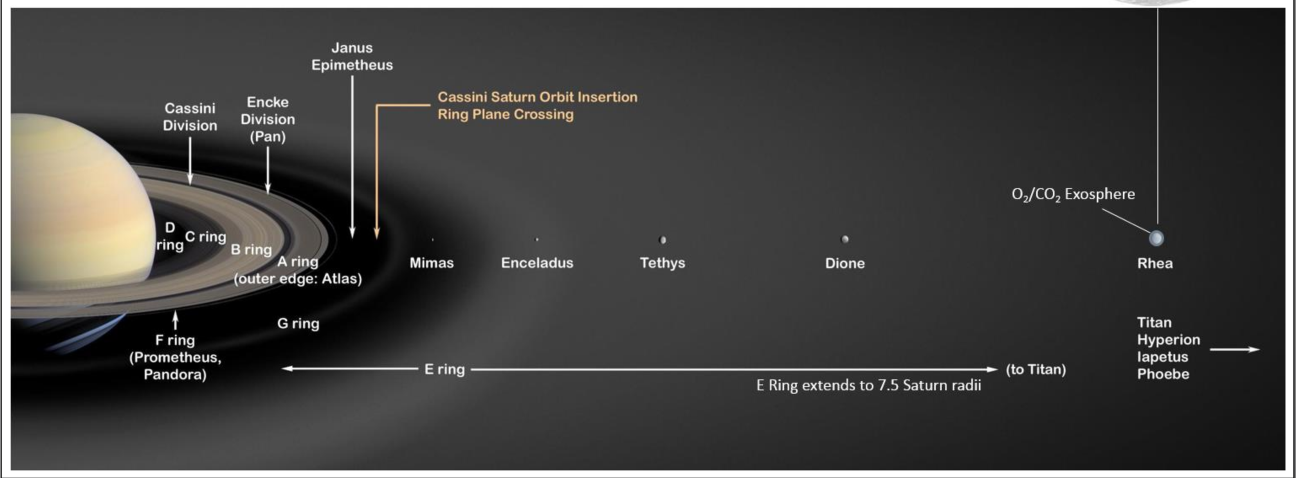


Color composite map construction by Dr. Paul Schenk (LPI, Houston)
Cylindrical map projection at 400 m/pixel (at Equator)

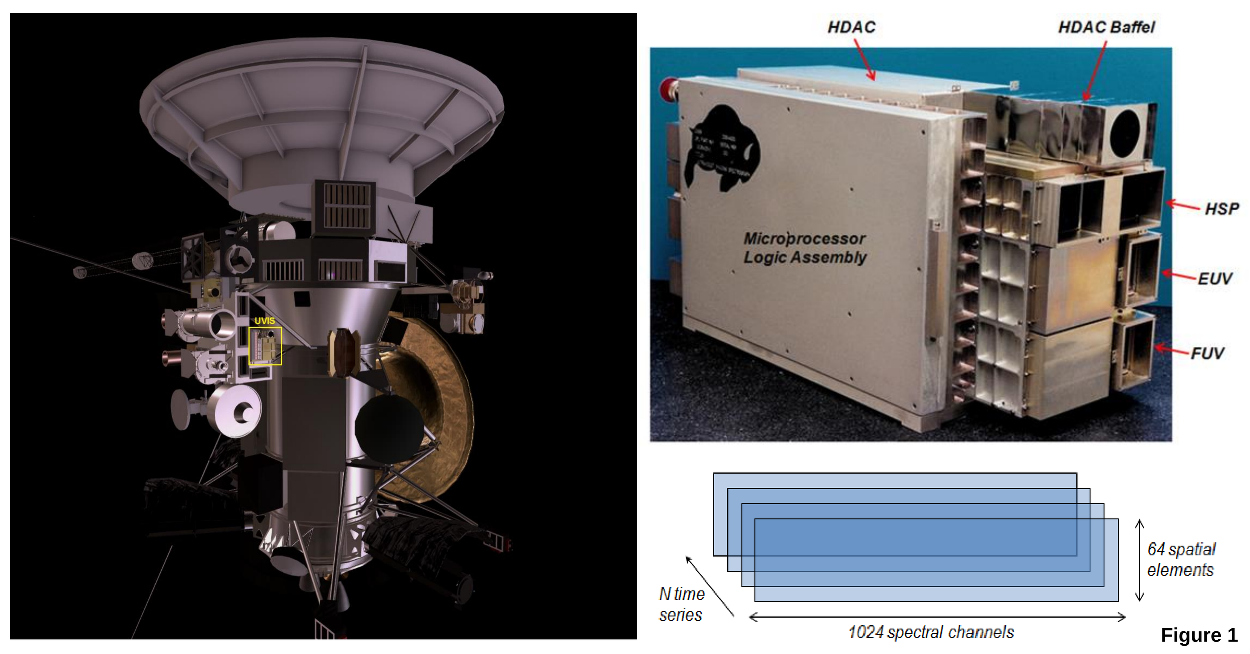
Rhea's Location in the Saturnian System

Radius	764 km
Density	1236 kg/m^3
Mass	2.3×10^{21} kg
Temperature	50 – 100 K
Orbital Period	4.518 days
Bond Albedo	0.42 – 0.55
Exosphere	O_2/CO_2





The Cassini UVIS/FUV Instrument[1]

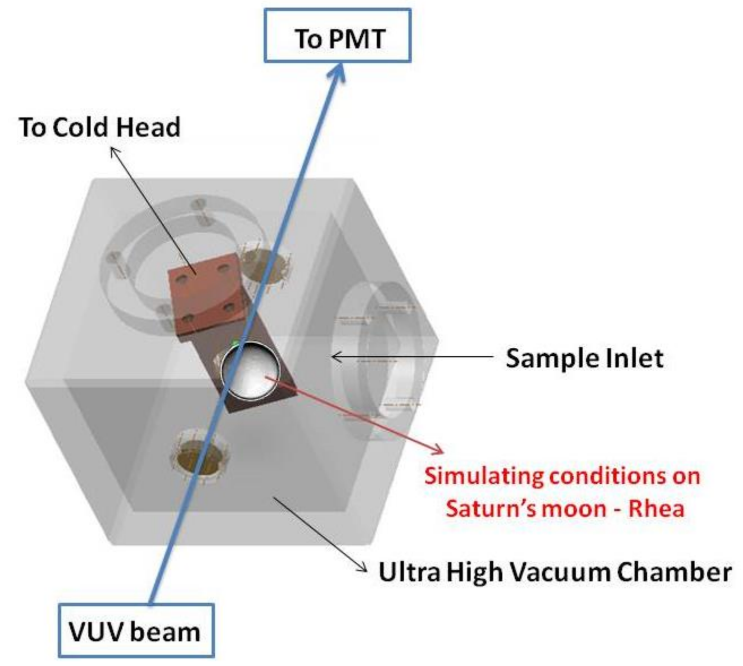


The Cassini far-UV instrument (UVIS/FUV) is sensitive across the wavelength range of ~110 – 190 nm. The low and high resolution slit widths are 150 and 75 microns, respectively, and the IFOVs (Instantaneous Field-of-View) for the low and high resolution slit states are 1.5 and 0.75 mrad. The spectral resolution for the high-resolution slit is 0.24 nm, and for the low-resolution slit 0.48 nm. The UVIS/FUV instrument is a spatial-spectral detector, with 1024 spectral channels and 64 spatial elements. The data can be averaged over spatial elements to increase the SNR..

References
[1] L. Esposito, *Space Science Reviews* **115**, 299-361, 2004.
[2] B. W. Hapke, *Icarus* **157**, 523-534, 2002.

Experimental Results

Vacuum-UV spectra of ice films were recorded at a temperature of ~70K under ultra high vacuum conditions under a joint agreement between the PRL (India), NSRRC (Taiwan) and The Open University (UK). The laboratory vacuum-UV spectra were measured in transmittance mode and subsequently converted to absorbance spectra. Data were deposited into the AstroChemical Ices Database (ACID) at https://www.prl.res.in/~dinesh/acid/

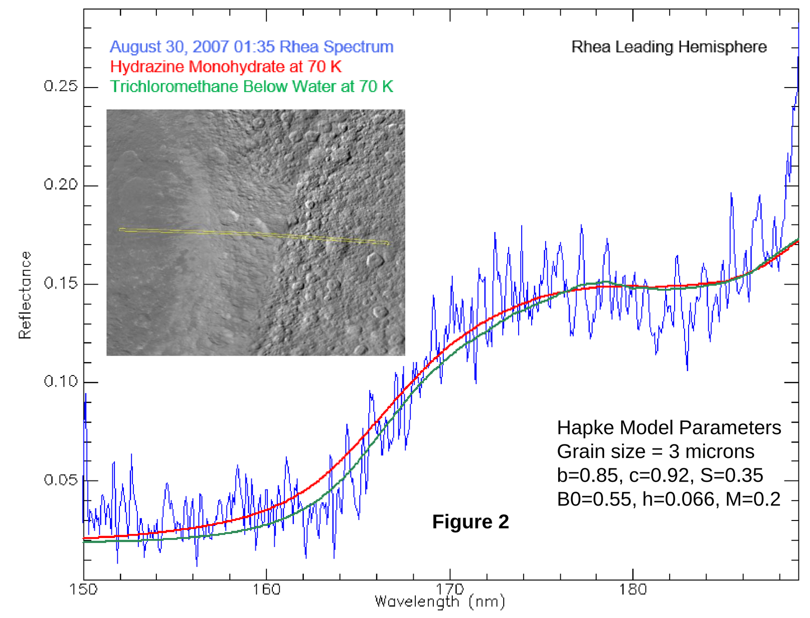


The derived absorbance measurements were then used to calculate the absorption cross-section and, using the optical constants for chemical species, model spectra were generated. The modelled spectra of water-ice, various organics, halogens, and alcohols suspected to exist on the surface of icy satellites in the outer solar system were then compared to the observed UVIS spectra.

The UVIS/FUV spectra were calibrated to radiance units, followed by division by the solar irradiance, scaled to the distance of Rhea from the Sun. The final UVIS spectra are in units of I/F. I/F is the ratio of measured radiance to solar irradiance scaled by a factor of pi, and is unitless. It is the reflectance measured by the instrument.

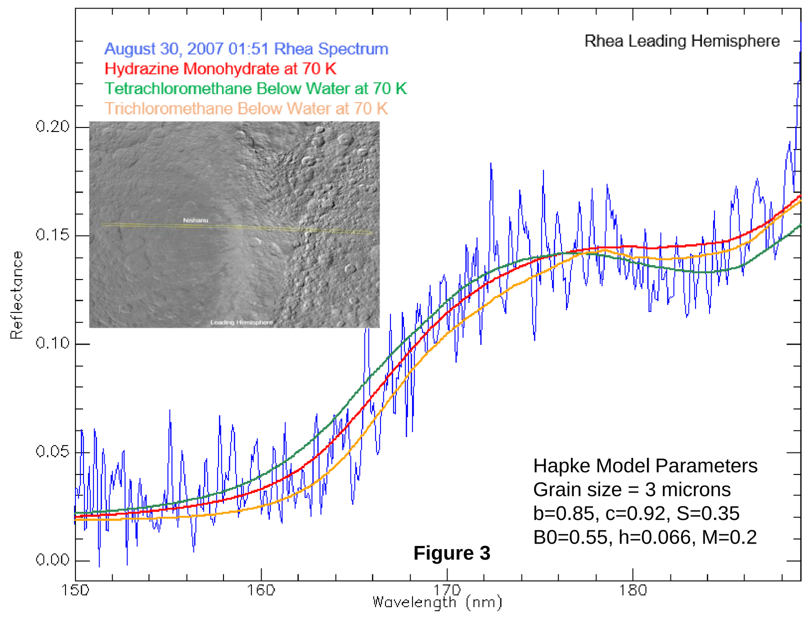
Early Results

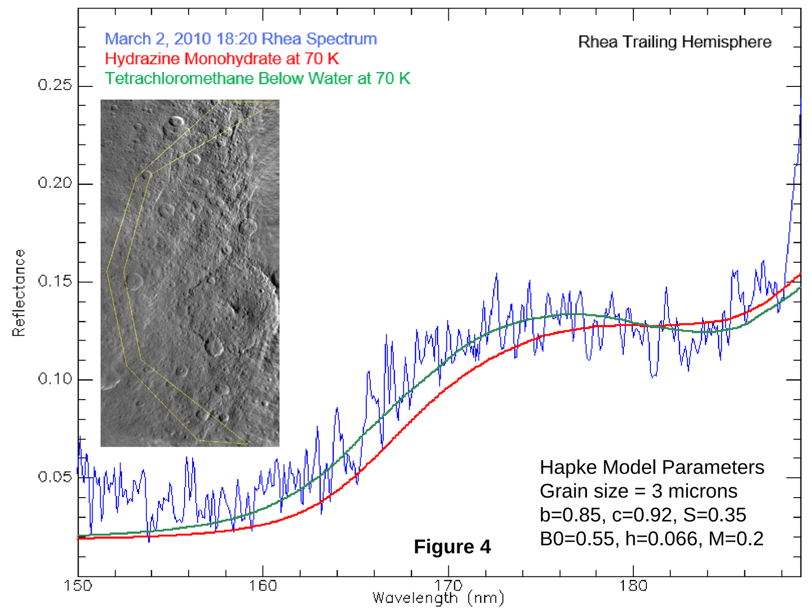
A surprising result of the analysis shows that the UVIS observations can be modelled by two molecular compounds: simple chloromethane compounds beneath a thin layer of water-ice (5:1 of water-chlorine) and hydrazine monohydrate in the solid phase.



b_0 = width of forward and backward scattering lobes, c = relative amplitude of scattering lobes, S = roughness parameter, B_0, h = amplitude and angular width of shadow-hiding opposition effect, M = multiple scattering term (interaction among different grains)

The yellow box represents the spectral footprint projected on the surface of Rhea as calculated using the "Geometer" code developed by the Cassini UVIS team.





The UVIS far-UV spectra on both hemispheres on Rhea can be modelled using both hydrazine monohydrate and a layer of tetrachloromethane below water-ice. Hydrazine monohydrate ($H_2N_4{\cdot}H_2O$) can be produced from reactions among water-ice and ammonia:

$$H_2O + h\nu \rightarrow H + OH;\quad H_2O + h\nu \rightarrow H_2 + O$$
$$NH_3 + OH \rightarrow NH_2 + H_2O;\quad NH_2 + O \rightarrow NH + OH$$
$$NH + NH \rightarrow N_2H_2 \rightarrow N_2 + H_2$$
$$N_2 + 2H_2 \rightarrow N_2H_4$$

An alternative possibility is that hydrazine could be produced in the atmosphere of Titan (rich in nitrile compounds), and is then transferred inward towards Rhea.

Tetrachloromethane (CCl_4) can be produced from the following chemical reactions: [*note: very slow, low-T solid phase reactions*]

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl;\quad CH_3Cl + Cl_2 \rightarrow CH_2Cl + HCl$$
$$CH_2Cl + Cl_2 \rightarrow CHCl_3 + HCl;\ CHCl_3 + Cl_2 \rightarrow CCl_4 + HCl$$

The source of Cl_2 could originate from a deep subsurface ocean layer inside Rhea, where migration of the chlorine occurs through cracks in the ice. An alternative explanation is an exogenic source of chlorine from impacts of chondritic bodies over the history of Rhea. However, the presence of chlorine on Rhea is more difficult to explain, since no evidence of current endogenic activity exists on Rhea. Evidence for past endogenic activity on Rhea does exist in the form of geomorphological evidence. If minor amounts of ammonia exist on Rhea, then it is far easier to explain the presence of hydrazine monohydrate on Rhea than chlorine compounds.

Conclusions

The first detailed geochemical survey of Rhea's icy surface in the far-UV region indicates the possible presence of chloromethane compounds or hydrazine monohydrate, or possibly both chemical species.