Computing the Radiant Energy Budget of Enceladus

Cindy Luu, Dr. Liming Li - Department of Physics

UNIVERSITY of HOUSTON

Introduction

Enceladus is a fascinating moon of Saturn that has become one of the top candidates for finding extraterrestrial life within our solar system. The Cassini-Huygens spacecraft orbited the Saturn system for several years, and discovered that Enceladus exhibited:

- **Warm linear depressions** known as blue "tiger stripes" about 500m deep and 130km in length
- **Plumes of liquid water/water ice** that extend ~500km outwards of the South Polar Terrain
- Reflectivity that resembles **"freshly fallen snow"**[1]

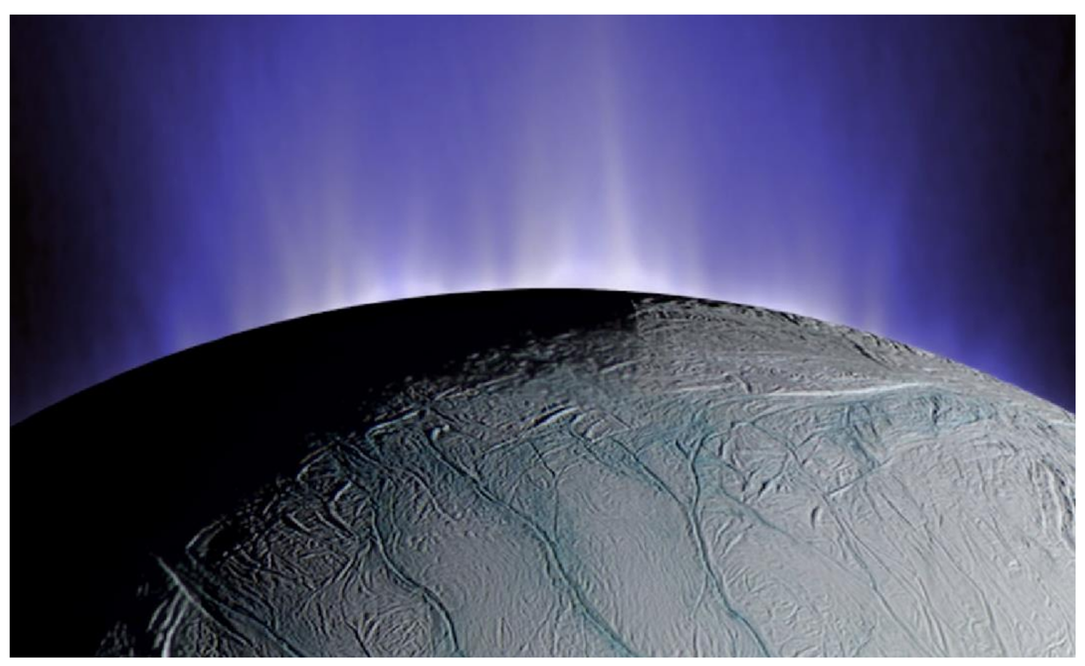

Figure 1. Plumes of water on Enceladus. Image credit: NASA/JPL

Objective

We aim to create a model of Enceladus' global radiant energy budget through calculating the absorbed solar energy and emitted thermal energy. The radiant energy budget is a critical parameter for understanding a planet/moon's:

- Thermal structure
- Evolutionary history
- Energy imbalances[2]

Calculating the radiant energy budget allows us to find the moon's internal heat, which is crucial for explaining Enceladus' unique geography and the existence of plumes.

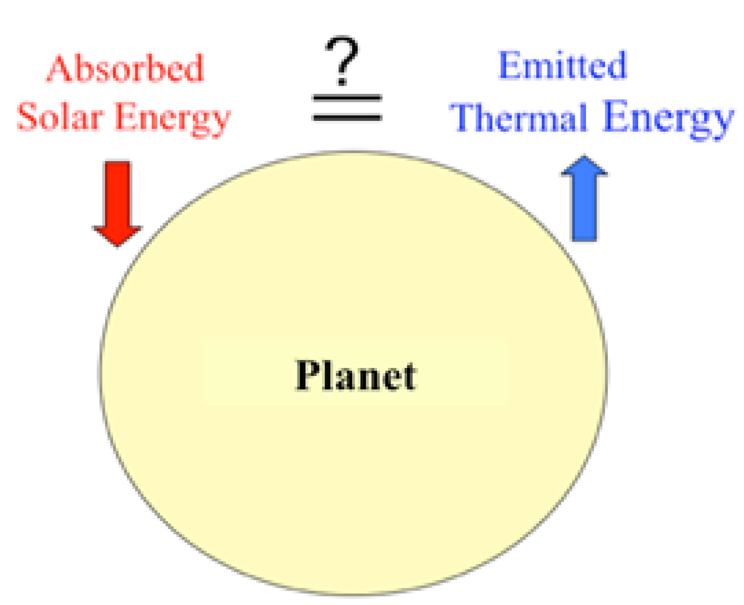

Figure 2. Two energy components for the radiant energy budget of a planet/moon.

Methodology

Our calculations are made from public Cassini data sets recorded by the Composite Infrared Spectrometer (CIRS), the Imaging Subscience System (ISS), and the Visual and Infrared Mapping Spectrometer (VIMS).

Data from the CIRS was processed to calculate the emitted power (1) whilst data from the ISS and VIMS was processed to calculate the absorbed solar power (2).

Cassini has limited viewing geometries and thus there are observational gaps in Cassini's data sets. These gaps are filled by linear interpolation/ extrapolation with the least-squares-fitting method. Filling in these gaps introduces an uncertainty in our results, and this uncertainty is analyzed systematically.

Emitted power

$$P_{emit} = \int_{\nu_1}^{\nu_2} \int_{\omega} I_\nu(\delta, \phi) cos\delta \, d\omega \, d\nu \quad (1)$$

$$= \int_{\nu_1}^{\nu_2} \int_{0}^{2\pi} \int_{0}^{\pi/2} I_\nu(\delta, \phi) cos\delta \, sin\delta \, d\delta \, d\phi \, d\nu$$

where P_{emit} is emitted power, ν is wave number, δ is emission angle, ϕ is azimuth angle, ω is solid angle, and I_ν is spectral flux[3].

Absorbed solar power:

$$P_{absorb} = (1 - A) \pi S / D^2 \quad (2)$$

where P_{absorb} is absorbed solar energy per unit time over a unit area, A is bond albedo (defined as the ratio between reflected scattered radiation and incident solar radiation), πS is the solar constant at Earth, and D is the distance from the Sun[4].

Cassini Data

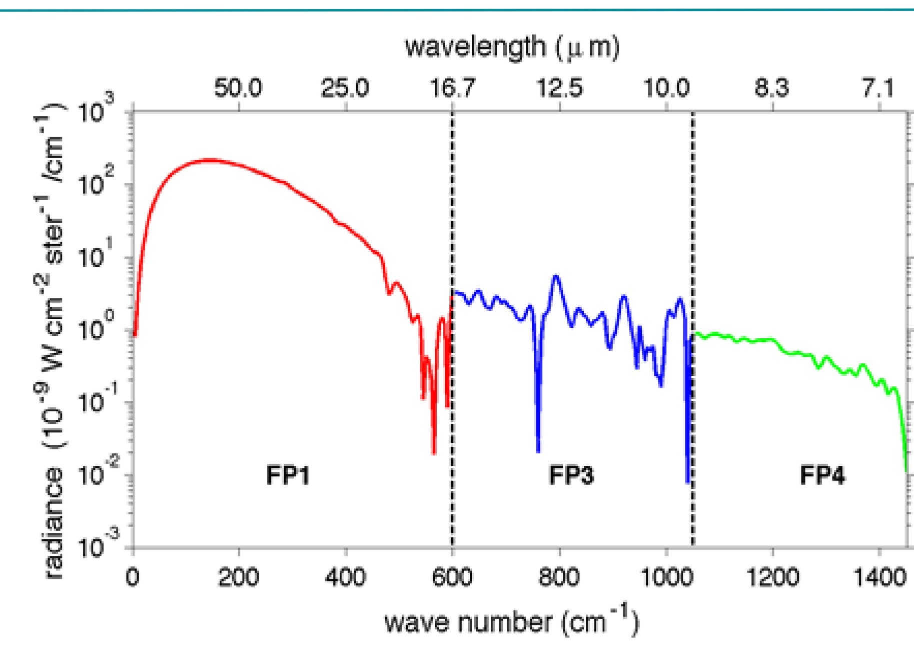

Figure 3. Enceladus' thermal spectra recorded by the CIRS three focal planes: FP1, FP3, and FP4.

From the radiance recorded by FP1, we see the majority of Enceladus' total emitted power is observed in this wavelength range (Fig. 3).

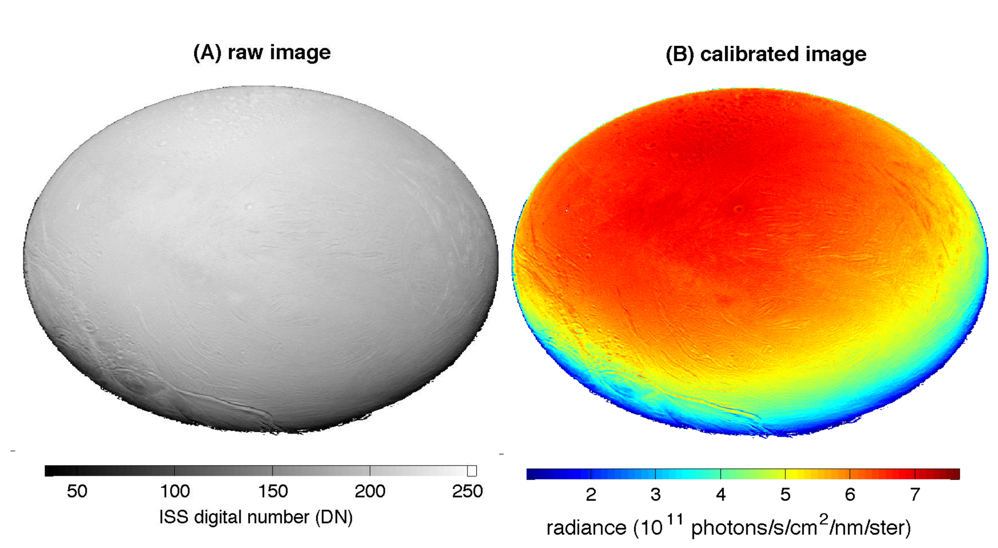

Figure 4. Examples of the ISS raw and calibrated images.

Panel (A) shows the brightness of Enceladus represented by the digital number. Panel (B) is the raw image calibrated to radiance using the Cassini ISS CALibration (CISSCAL) software (Fig. 4).

Preliminary Results

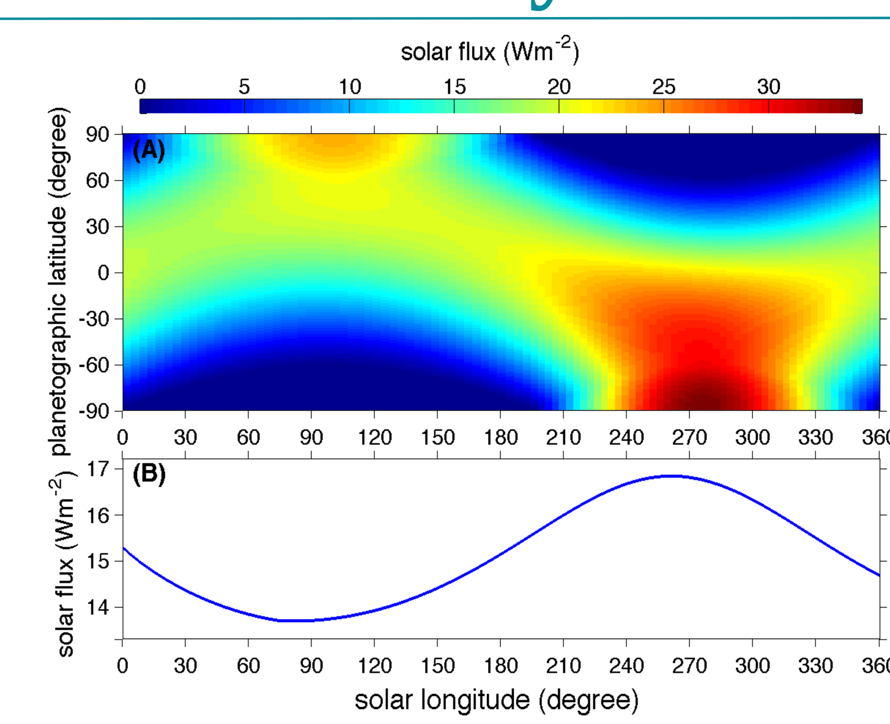

Figure 5. Seasonal cycle of solar flux at Enceladus. Panel (A) shows solar flux in the plane of latitude and solar longitude. Panel (B) shows global average solar flux.

Panel (B) shows a significant difference between the solar flux of ~13.5 Wm^{-2} at aphelion to ~ 16.8 Wm^{-2} at perihelion (Fig. 5).

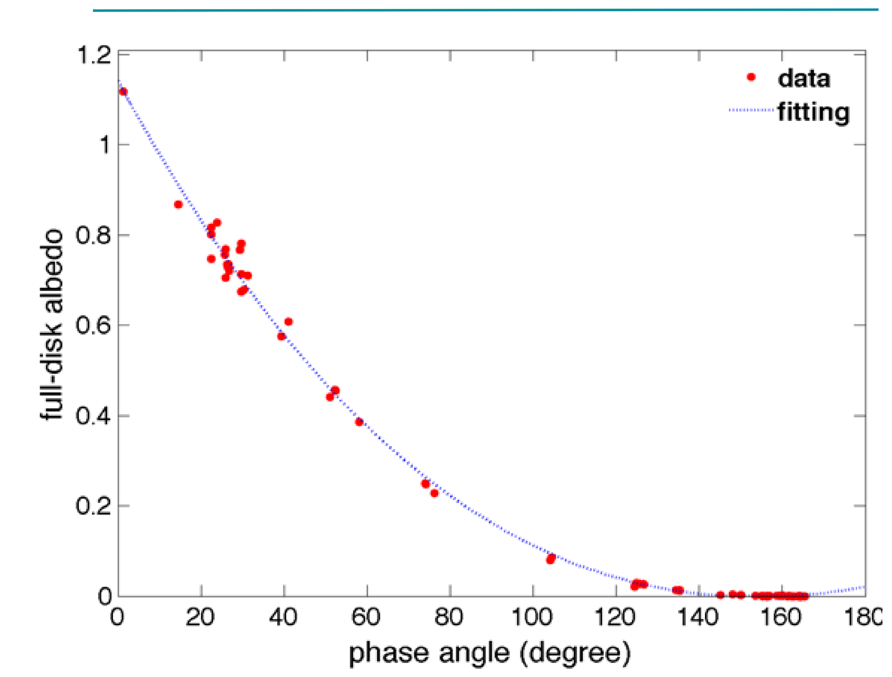

Figure 6. Full-disk albedo of Enceladus recorded by the Cassini ISS observations.

The full disk albedo at 0° is called the geometric albedo, which is observed to be > 1 (Fig.6).

Conclusion

Preliminary results suggest that there's a seasonal cycle in solar flux and hence a seasonal cycle of absorbed solar power. As a result, we expect that Enceladus will have a dynamic radiant energy budget that coincides with distance from the Sun.

Our measurements of Enceladus' radiant energy budget will help us examine some unique thermal and optical characteristics. The large albedo can be explained by the coherent backscatter opposition effect (CBOE), an optical effect produced when "scattered light...constructively interferes as it exits a particulate medium at opposition"[5]. This effect is related to regolith porosity and can be used to research the properties of Enceladus' particulate matter.

Future Work

- We will continue measuring Enceladus' full disk albedo, Bond albedo, and absorbed solar power.
- We will continue measuring Enceladus' emitted power and its seasonal variations, to then determine the seasonal variations of the radiant energy budget.
- We will explore applications of the new measurements of Enceladus' radiant energy budget (e.g., better constrain the internal heat and its role in driving jet plumes on Enceladus)

References

[1] Porco, C.C., Helfenstein, P., Thomas, P.C., Ingersoll, A.P., Wisdom, J., West, R., Neukum, G., Denk, T., Wagner, R., Roatsch, T. and Kieffer, S., 2006. Cassini observes the active south pole of Enceladus. *science*, *311*(5766), pp.1393-1401.

[2] Li, L., X. Jiang, R. A. West, P. J. Gierasch, S. Perez-Hoyos, A. Sanchez-Lavega, L. N. Fletcher, J. J. Fortney, B. Knowles, C. C. Porco, K. H. Baines, P. M. Fry, A. Mallama, R. K. Achterberg, A. A. Simon, C. A. Nixon, G. S. Orton, U. A. Dyudina, S. P. Ewald, 2018. Less Absorbed Solar Energy And More Internal Heat For Jupiter, *Nature Communications*, doi:10.1038/s41467-018-06107-2.

[3] Chandrasekhar, S., 1950. Radiative Transfer. Oxford Univ. Press, New York.

[4] Li, L., B. Conrath, P. Gierasch, R. Achterberg, C. A. Nixon, A. A. Simon-Miller, F. M. Flasar, D. Banfield, K. H. Baines, R. A. West, A. R. Vasavada, A. Mamoutkine, M. Segura, G. Bjoraker, G. S. Orton, L. N. Fletcher, P. Irwin, P. Read, 2010. Emitted power of Saturn. J. Geophys. Res.,115, E11002, doi:10.1029/2010JE003631.

[5] Verbiscer, A.J., French, R.G. and McGhee, C.A., 2005. The opposition surge of Enceladus: HST observations 338–1022 nm. *Icarus*, *173*(1), pp.66-83.

Acknowledgements

A special thank you to Dr. Robert West, who developed and maintains the CISSCAL software. We also gratefully acknowledge the Cassini CIRS, ISS, and VIMS teams for recording the data sets of Enceladus, as well as the support of the Planetary Data System. Lastly, we acknowledge the Summer Undergraduate Research Fellowship program and the Office of Undergraduate Research and Major Awards for this opportunity.