The Global Radiant Energy Budgets of Titan and Mars. E. C. Creecy[1], L. Li[2], X. Jiang[1], R. A. West[3], C. A. Nixon[4], P. M. Fry[5], [1]Department of Earth and Atmospheric Sciences, University of Houston, Houston, TX, USA. [2]Department of Physics, University of Houston, Houston, TX, USA, [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [4]NASA Goddard Space Flight Center, Greenbelt, MD, USA, [5]Space Science and Engineering Center, University of Wisconsin-Madison, Madison, WI, USA. *Correspondence email:* eccreecy@central.uh.edu.

Introduction: Radiant energies of planets and moons are of wide interest in the fields of geoscience, astronomy, and planetary sciences. Examining radiant energy budgets gives insight into atmospheric thermal structure, atmospheric circulation, and weather and climate patterns [1-3]. The radiant energy budget for terrestrial bodies is determined by the emitted thermal energy and absorbed solar energy.

Here we present our current work measuring the energy budgets of Titan and Mars. Titan is the only satellite in our solar system with a thick atmosphere, made of mostly nitrogen, as well as an active methane cycle that produces large permanent liquid bodies on the surface. Mars has many unique features to affect energy transport mechanisms, such as polar ice caps, large-scale dust storms, large orbital eccentricity (0.0935), and large obliquity (25.19°). Both of these terrestrial bodies have complex characteristics that create a very interesting energy budget picture.

For Titan, we use long-term multi-instrument Cassini observations covering three Titan seasons (2004-2017) [4-6] to examine the seasonal variations of Titan's global energy budget. We acquire data from Cassini from the following three instruments: Composite Infrared Spectrometer (CIRS), Visual and Infrared Mapping Spectrometer (VIMS), and Imaging Science Subsystem (ISS). The wavelength coverage is 7-1000 μm, 0.35-5.1 μm, and 0.26-1.0 μm for CIRS, VIMS, and ISS respectively. For Mars, we are using observations from the Thermal Emission Spectrometer (TES) onboard the Mars Global Surveyor (MGS) [7] and the Mars Climate Sounder (MCS) onboard the Mars Reconnaissance Orbiter (MRO) [8] to investigate Mars' radiant energy budget from 1997 to 2020. TES has wavelength coverage 5.5-100 μm and 0.3-2.7 μm, for the broadband thermal emission sensor, and the broadband solar reflectance sensor, respectively.

Titan's Radiant Energy Budget: Using Cassini observations provides an unprecedented opportunity to measure temporal variations of Titan's radiant energy budget for the first time. We found that Titan's global-average emitted power decreased by 6.8 ± 0.4% during the Cassini period [9]. The magnitude of this temporal variation, which represents the seasonal cycle of emitted power, is one order of magnitude stronger than the seasonal cycle of Earth's emitted power (<0.5%). In order to measure temporal variations of Titan's absorbed solar radiance, we first measure the Bond albedo. We found Titan's Bond albedo stayed relatively stable over time, only increasing 0.76±0.53% during the Cassini period. Titan's total absorbed solar power decreased 18.69 ± 0.11% [10].

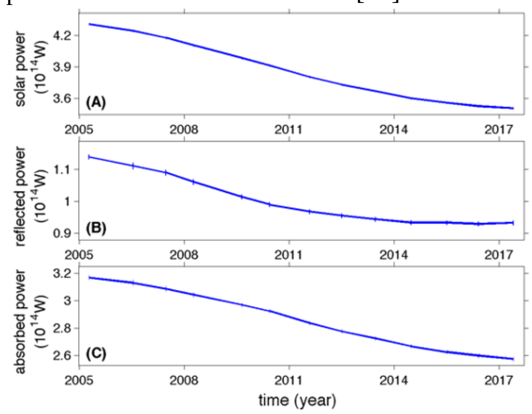

Fig 1. Titan's (A) Total solar power, (B) Reflected power, and (C) absorbed solar power from 2004-05 to 2017 [10]

The global-average emitted energy is not balanced by the absorbed solar energy, with an average global energy imbalance of 2.73±0.46%.

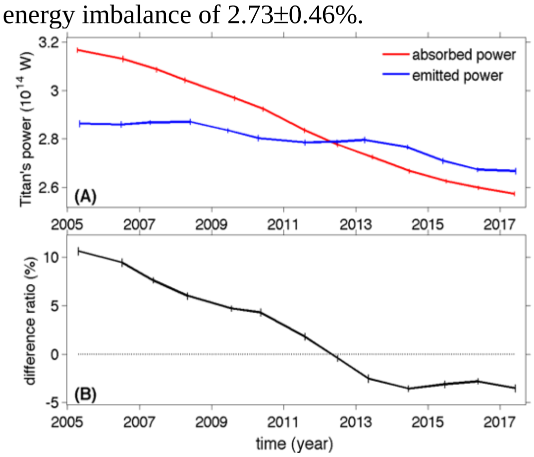

Fig 2. (A) Comparison between the absorbed solar power and the emitted thermal power during the Cassini epoch. (B) The ratio between the net radiant energy and the emitted power [10].

Mars' Radiant Energy Budget: In addition to our work with Titan, we are currently conducting the first long-term observational studies of Mars' energy budget using MGS/TES (1997-2006) [7] and MRO/MCS (2006-) [8]. Given the many factors that influence energy transport and thermal structure on Mars, we believe that Mars has a significantly dynamic energy budget. Studies covering Mars' radiant energy budget are relatively few, with focus near the polar region [3, 11-16]. Our work will be the first to measure potential seasonal and long-term (e.g., inter-annual) variations. Here we show preliminary results of the thermal radiance recorded by the TES broadband thermal emission sensor during daytime and nighttime.

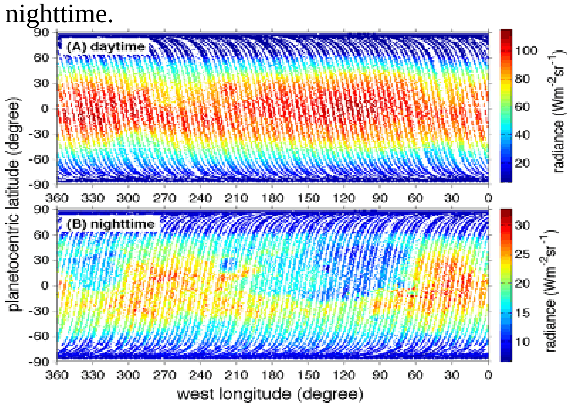

Fig 3. Thermal radiance recorded by the TES broadband thermal emission sensor. (A) Daytime thermal emission. (B) Nighttime thermal emission. The spatial resolution of the observations is ~ 3 km.

Using the TES dataset, we plan to compute the meridional and temporal variations of emitted radiance. By measuring the emitted power, we can compute the effective temperature, which will allow us to investigate any warming/cooling trends on Mars. We also have preliminary results for the reflected solar radiance, recorded by the TES broadband solar reflectance sensor.

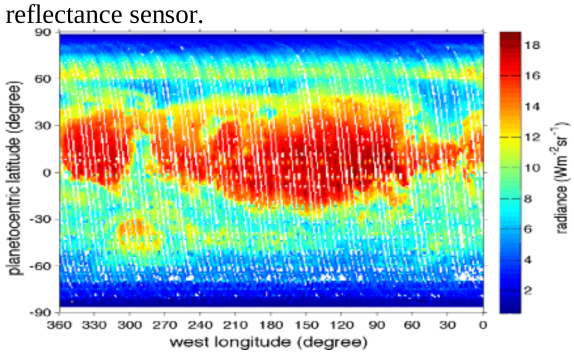

Fig 4. Reflected solar radiance recorded by the TES broadband solar reflectance sensor. The radiance shown in figure is for the TES daytime observations with phase angles around 30° (28-32°).

We will use the observations of reflected radiance to compute the Bond albedo, and therefore, the absorbed solar power. We plan to compute global and hemispheric averages of the radiant energy budget in order to examine any spatiotemporal variations.

Significance and Future Work: Studying the energy budgets of terrestrial bodies is fundamental to understanding energy transport, circulation, and climate patterns. Exploring the radiation budgets of other planets and satellites in our solar system also allows for assumptions made about Earth to be validated. For Titan, current theories and models assume the energy budget to be balanced [3,17]. Revisiting these models and theories to account for the temporal variations that we measured is important to better understand potential climate change. Our observations for Mars will be the first to systematically measure spatiotemporal variations of the radiant energy budget. Our preliminary results using TES observations are promising, and we believe our research will give insight into the red planet's energy dynamics.

Acknowledgments: We gratefully acknowledge the Cassini CIRS, ISS, and VIMS teams for recording the data sets of Titan, and the MGS/TES and MRO/MCS teams for recording data sets of Mars. We also acknowledge Dr. Armin Kleinboehl, Dr. David Kass, Dr. Matthew Kenyon, and Dr. Michael Smith for their help with this project.

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