TEMPERATURE DEPENDENCE OF LASER REFLECTANCE ON BENNU: SEARCHING FOR VOLATILES.
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Introduction: Bennu is a laboratory for volatile stability and can provide insights into the origin of volatiles in the inner solar system. OSIRIS-REx's exploration of Bennu provides the first global, thermal infrared case study of a likely volatile-rich [1,2] asteroid (using the OSIRIS-REx Visible and InfraRed Spectrometer and Thermal Emission Spectrometer (OVIRS and OTES). Such asteroids may have been a primary source of water and other life-essential volatiles on Earth and in the inner solar system. If temperatures remain cold, volatiles can remain stable on or near the surface for billions of years [3].

The OSIRIS-REx Laser Altimeter (OLA) [4] was designed for making regulated topographic representations of Bennu. However, OLA also records the relative brightness of the surface by measuring the energy of the laser returns. In a five-week campaign starting July 1, 2019 (Orbital B Global Mapping), the OLA instrument conducted a dense global altimetric survey of asteroid Bennu from approximately 700 m above the surface using its Low Energy Laser Transmitter (LELT) [5]. This Orbital B survey returned > 3 million precise measurements of range-to-surface, and auxiliary measurements of intensity at 1064 nm wavelength.

When corrected for range and instrument parameters, the altimeter provides a measure of reflectance independent of solar illumination by comparing the returned intensity to that of the outgoing laser light. In the case of Bennu, whose obliquity is ~4°, OLA is uniquely capable of distinguishing terrain features via their normal albedo (zero-phase reflectance at 1064 nm relative to Lambertian) at the poles. As well, the albedo variations may reveal aspects of surficial processes not resolvable by cameras, e.g., [6,7].

As was demonstrated on Mercury during the MESSENGER mission [6,8], the combination of surface reflectance and temperature can be a powerful tool for identifying potential surface volatiles. On Mercury, areas modeled to have maximum surface temperatures below ~350K were found to be dramatically darker than those on the rest of the planet [8]. This darkening is most likely due to the presence of Polycyclic Aromatic Hydrocarbon (PAH) materials that are commonly found in carbonaceous meteorite samples [9] which sublimate above this temperature [10].

Using topographic models also based on OLA data, the thermal model [8] calculates incident visible, reflected visible, and re-radiated infrared radiation based on a 1D heat diffusion model extending below each triangle. The model ray-traces incident solar light, then, with a given phase function, ray-traces several (4 in the nominal model) reflected bounces. All of these sources and sinks of heat are iteratively used as a surface boundary condition for the thermal model. We assume thermal inertia of 300 J m^{-2} K^{-1} $s^{-1/2}$.

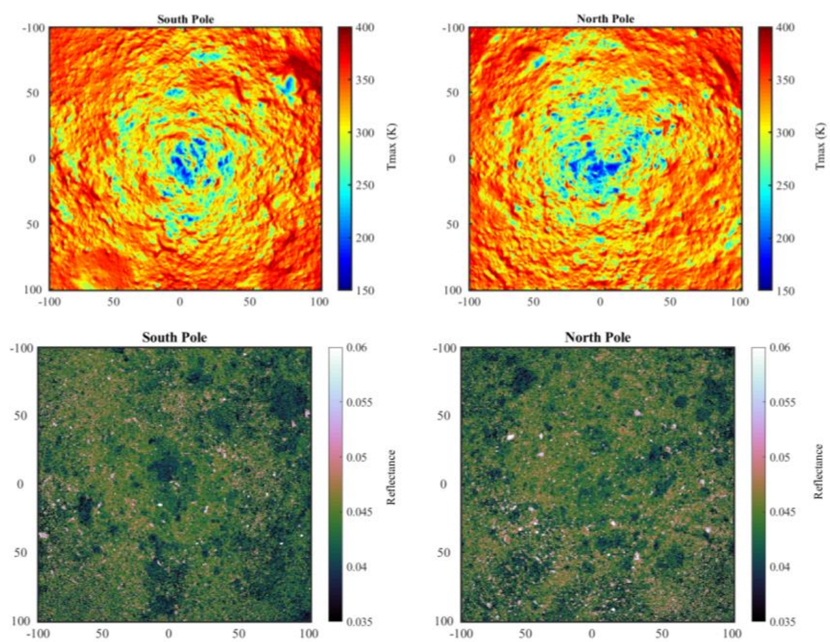

Fig. 1. Top: Yearly maximum temperatures for polar regions of Bennu calculated using the v42 (~80cm) shape model. Temperatures are scaled from 150 to 400K. Bottom: Surface OLA reflectance for the same regions. Reflectance is scaled tentatively to 1064 nm albedo, but these figures should not be taken as an exact albedo value. X and y units are stereographic distance from the pole in meters.

Results: As volatile sublimation is exponentially dependent on temperature, surface volatile stability is controlled by the maximum that a surface ever reaches, even if it is for only a short time [3]. Figure 1 (top) shows thermal model results for the maximum yearly temperatures experienced at the south and north polar regions, respectively (x and y units are stereographic distance from the pole in meters). Figure 2 (top) shows these same results plotted globally. We find that yearly maximum temperatures range between approximately 150 and 400 K. Even small, permanently shadowed re-

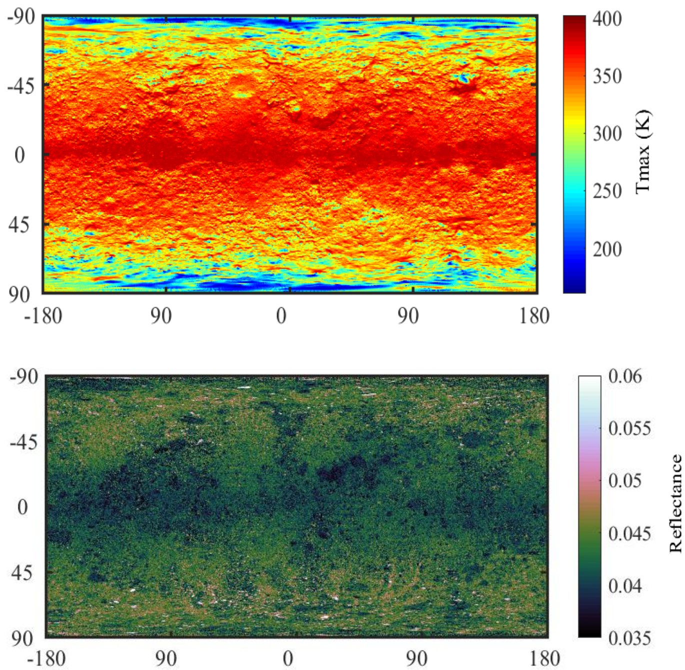

Figure 2: Global (top) maximum temperature and (bottom) OLA reflectance.

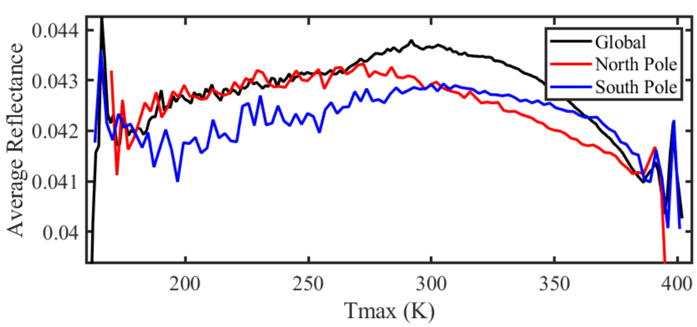

Figure 3: Average OLA reflectance vs. maximum temperature.

gions near the poles appear to remain above temperatures able to support surface water ice. This differs from the Moon primarily due to the higher thermal inertia of Bennu's average surface material (Lunar thermal inertia ~80 J m^{-2} K^{-1} $s^{-1/2}$). Small pockets with lower thermal inertia near the poles could feasibly retain subsurface ice.

It is possible, however, that simple hydrocarbon molecules, which can be stable at higher temperatures, could exist at the surface of Bennu. Simple molecules like anthracene would be stable over much of the polar region, while more complex ones, like coronene, would be stable globally. Volatile outgassing from Bennu's interior could provide a source for such materials [11]. Locally sourced volatiles of many species may be plentiful, mobile, and could be responsible for Bennu's dark color [12, 13].

Preliminary comparison shows a general trend of darkening of the surface toward the warm equator, which can be seen in Fig. 2 (lower). Mid-latitudes are generally brighter, but then near polar regions are again darker. This near polar darkening can be seen at both poles in Fig 1 (lower). In terms of temperature, we see a general trend with average reflectance peaking at ~300K, as shown in Fig. 3., which is not dissimilar from trends used to identify complex volatiles on Mercury. This reflectance peak could be due to stability of a brighter material around 300K (which would point to a volatile with molecular mass ~250-300 amu [10]) or darkening from volatiles stable at colder temperatures. However, a change in reflectance due to rotational stresses [14] or space weathering [15] is not ruled out [16]. Notably, shadowed regions show a lack of bright reflectance features below ~185K which could be due to a dark volatile of ~100-150 amu limited to very near polar areas.

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This material is based upon work supported by NASA under Contract NNM10AA11C issued through the New Frontiers Program. OLA and funding for the Canadian authors were provided by the Canadian Space Agency.