MILLIMETER AND SUBMILLIMETER OBSERVATIONS OF ASTEROIDS FROM THE ROSETTA SPACECRAFT.
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Introduction: The European Space Agency's Rosetta spacecraft has flown by two main-belt asteroids on its way to a 2014 rendezvous with comet 67P/Churyumov-Gerasimenko. These two asteroids are quite different in size and spectral class. Asteroid (2867) Steins is a small (~5 km in diameter) E-type asteroid, while (21) Lutetia is large (~100 km diameter) and somewhat difficult to spectrally categorize but generally considered C- or M-class [1]. We used the microwave radiometer and spectrometer on-board the Rosetta spacecraft, MIRO [2], to study the properties of these asteroids. MIRO uses continuum observations at wavelengths of 0.5 and 1.6 mm to probe regions roughly 1 to 15 mm below the surface. These data allow us to infer the presence of a lunar-type regolith on Lutetia with extremely high thermal gradients, as large as 50 K/cm within 1 cm of the surface [3]. Combining our measurements with the surface temperature as seen by an infrared instrument, VIRTIS [4], suggests that Lutetia's surface roughness is similar to what would be expected from at least 50% areal coverage by unresolved hemispherical mini-craters [5]. We find the much-smaller asteroid Steins' surface to have a larger thermal inertia and smaller vertical gradients [6]. The MIRO spectrometer, sensitive to lines of H_2O, $H_2{}^{17}O$, $H_2{}^{18}O$, CO, NH_3, and CH_3OH gases, all near a frequency of 560 GHz, did not detect an exosphere at either asteroid.

In this talk we will review the above results and discuss their implications for asteroids in general.

Discussion: Our results at Steins and the much larger Lutetia suggest two conclusions applicable to other asteroids. First, we note that Lutetia seems covered by a very low-thermal inertia [< 20 J/(K m^2 $s^{0.5}$)] and high-emissivity (>0.9) fine powder, forming a lunar-like regolith. In analogy with lunar work, this is interpreted as the result of impact gardening and compaction with depth [3]. The much smaller Steins has a larger thermal inertia [~650 J/(K m^2 $s^{0.5}$)] and lower emissivity (~0.8) indicative of a more rock-like surface material. The trend of larger asteroids having lower thermal inertias has been noted previously [e.g. 7]. Our data are consistent with the hypothesis that any airless body with a gravity field strong enough to retain the finest impact ejecta will eventually become covered by a lunar-like, low thermal inertia powder. This means that the thermal properties of all large asteroids are likely to be similar, and not controlled by the bulk composition of the bodies.

A second important result is that these large asteroids, covered by fine powder, will have extremely large temperature gradients within the upper centimeters of their daytime surfaces. Submillimeter and longer wavelength observations of the dayside, sensing significantly cooler regions at depth, will have a much smaller thermal flux than might be expected from the dayside surface temperature as measured by infrared instruments. Previous researchers, seeing this discrepancy, have postulated a large drop in emissivity at submillimeter, millimeter and centimeter-wavelengths relative to the IR [8-12]. We have reanalyzed the asteroid thermal flux data from three large asteroids (Vesta, Pallas, Hygiea) using the thermal property model derived for Lutetia by MIRO and a radiative transfer model that accounts for very large dayside temperature gradients. We find that a Lutetia- and lunar-like model of near surface properties produces a match with the asteroid flux density measurements without invoking scattering mechanisms that vary with wavelength. Our best fitting model requires a fairly uniform emissivity of ~0.9 from IR to cm wavelengths.

Acknowledgements: This research was carried out at the Jet Propulsion Laboratory (JPL), California Institute of Technology, under a contract with the National Aeronautics and Space Administration. This work was funded by the NASA-Rosetta project.

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