EPSC Abstracts
Vol. 8, EPSC2013-367-1, 2013
European Planetary Science Congress 2013

Dielectric and thermal modeling of Vesta's surface

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Abstract

We generate a dielectric model for the surface of Vesta from thermal observations by Dawn's Visible and Infrared (VIR) mapping spectrometer. After retrieving surface temperatures from VIR data, we model thermal inertia, and derive a theoretical temperature map of Vesta's surface at a given UTC. To calculate the real part of the dielectric constant (ε') and the loss tangent (tg δ) we use the dielectric properties of basaltic lunar regolith as a first-order analog, assuming surface density and composition consistent with fine basaltic lunar dust. First results indicate that for the majority of the surface, ε' ranges from 2.0 to 2.1 from the night to day side respectively, and tg δ ranges from 1.05E-2 to 1.40E-2. While these regions are consistent with a basaltic, desiccated ~55% porous surface, we also find anomalies in the thermal inertia that may correspond to a variation in local surface density relative to the global average, and a consequent variation in the local dielectric properties.

1. Introduction

Protoplanet Vesta is a key body in understanding the history of planetary formation in our solar system, and has been observed by Earth-based radar at a number of microwave frequencies: the S- and X-bands at Goldstone and Arecibo respectively [e.g. 1], and the Ku- and C-bands with the Very Large Array (VLA) [e.g. 2]. The measured radar backscatter from the surface of an asteroid is affected by variations in topography, in surface roughness (at the scale of the radar wavelength) and in the dielectric properties of the surface (the reflection and attenuation mechanisms of a particular material at a given frequency), yet the contribution of each property to the total backscattered return are difficult to disentangle, especially the contribution from dielectric variation, which is the smallest of the three. This leads to significant uncertainty in both the textural and physical surface properties that might be inferred from the radar observation. Few estimates of an asteroid's dielectric properties are offered for this reason. For example, while Mitchell et al. [1] infer that Vesta is rougher than the Moon on both decimeter and centimeter scales from the measured radar backscatter, and using a reliable tri-axial ellipsoid shape model derived from speckle interferometry, they do not estimate the contribution of the surface's dielectric properties. Johnston et al. [2] use a different approach and observe that the passive microwave emissions from Vesta do not match those expected of a rotating blackbody, and suggest instead that the asteroid may be covered by a thin layer of fine dust, suppressing the body's microwave brightness. To estimate the depth of this layer, they rely on general, theoretical models of the dielectric properties [3] of powdered rock, and assume a value of 2.9 for the real part of the dielectric constant ε' (describing reflectivity) and 1.50E-2 for the loss tangent tg δ (describing attenuation) for the upper 2 cm of Vesta's regolith. Their value for the real part of the dielectric constant, however, is inconsistent with measurements of powdered basaltic samples at the same densities.

The Dawn mission offers a unique opportunity to improve our estimates of the dielectric properties of Vesta's surface, having collected orbital data around Vesta for over a year. Using thermal observations by Dawn's Visible and Infrared (VIR) mapping spectrometer, and assuming a surface density and composition analogous to that of the lunar regolith (as confirmed by the most recent mineralogical mapping by Dawn), we generate a first-order, global dielectric model for the surface of Vesta. In turn, our dielectric model can be combined with Earth-based radar observations of Vesta to constrain the textural and physical surface properties inferred from radar backscatter measurements.

2. Method

The correlation between a planetary surface's thermal and dielectric properties is supported by studies at Mars, where Jakosky and Muhleman [5] find a correlation between the surface's thermal inertia (the ability of a material to retain its daytime heat) and the dielectric constant for over 75% of the studied longitudes, attributing this to the dependence of both thermal and dielectric properties on the grain-to-grain bonding of surface materials.

In order to establish an empirical relation between the thermal and dielectric properties of Vesta's surface, we first identify basaltic lunar regolith as a sufficient first-order analog to the surface of Vesta in terms of mineralogy and surface density [4]. We then use laboratory measurements by Alvarez [6] of a sample of powdered lunar basalt to correlate the dielectric constant with surface temperature—the maximum of which, for a given material, is determined by its thermal inertia. We derive the following first-order temperature dependence of the dielectric constant, where T is temperature and ρ is bulk density:

$$\varepsilon'(T) = 1.72^{\rho} + 3\times10^{-4}T \qquad (1)$$

$$\mathrm{tg}\delta(T) = 1.03\times10^{-2}\ \mathrm{e}^{0.001T} \qquad (2)$$

Next, we retrieve daytime surface temperatures from VIR infrared measurements (observed under different local solar times and in different mission phases) and apply to these a thermophysical model that computes the thermal inertia at each site. Thermal inertia controls the minimum and maximum surface temperatures of a material during its diurnal cycle, so from the global map of thermal inertia values, we derive a global model of theoretical surface temperatures at a given UTC. Finally, we incorporate the temperature dependence of the dielectric constant as derived from laboratory measurements [6], where we assume a global surface density consistent with the highly porous, basaltic dust at the Moon's surface (~1300 kg m^{-3}). We apply Equations 1 and 2 to the global model of surface temperatures, and generate a first-order, global dielectric model of Vesta's surface.

3. Preliminary Results

We derive a preliminary map of theoretical surface temperatures at a given UTC, where each pixel spans 10° longitude by 5° latitude (Fig. 1). Surface temperatures range from 20 to 290 K, yielding ε' ~ 2.0 to 2.1, and tg δ ~1.05E-2 to 1.40E-2 (Fig. 2).

From these preliminary global models, we find that the dielectric constant varies minimally with temperature over regions that are consistent with our assumptions of lunar-like mineralogy and surface density. However, as we develop higher resolution maps, we are finding local anomalies in the thermal inertia. These may indicate areas of coarser regolith or higher porosity relative to the global average, and consequent variation in the local dielectric properties.

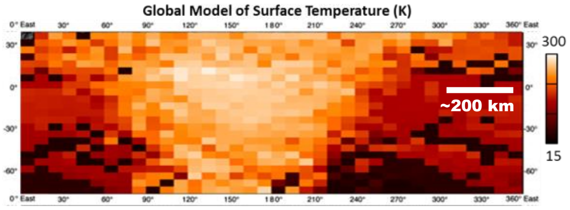

Figure 1. Global model of theoretical surface temperatures. The sub-solar point is at a latitude of -26.7° and a longitude of 160.6°, with a Vesta-Sun distance of ~2.9 AU. Modeled temperatures range from 20 to 290 K. Results are confined between ~75°S and 40°N due to the availability of VIR data limited by illumination.

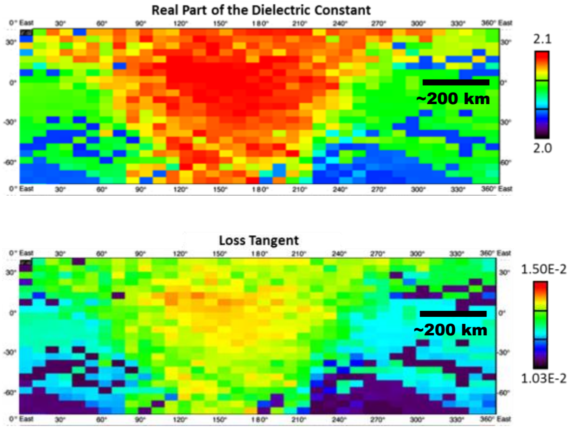

Figure 2. Global model of ε' (top) and tg δ (bottom), derived from the global temperature model of Figure 1. ε' ranges from 2.0 to 2.1, and tg δ from 1.05E-2 to 1.40E-2, assuming lunar-like mineralogy and surface density.

Acknowledgements

Part of this work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. VIR was developed under the leadership of INAF-Italian National Institute for Astrophysics, at IAPS in Rome, Italy.

Selected References

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