8

MICROWAVE BRIGHTNESSES OF 1 CERES AND 4 VESTA

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The brightnesses of Ceres and Vesta were observed at 3 mm wavelength. For Ceres, pure rock cannot reproduce the observed values, and a dust layer is required, much similar to lunar material. For Vesta, its different thermal characteristics appear to require a more compacted layer of material on its surface.

INTRODUCTION

Among the large diameter asteroids, 1 Ceres is classified as a carbonaceous object, whereas 4 Vesta with its high albedo is unique, perhaps representing the differentiated core of a larger body (Chapman, Morrison, and Zellner 1975). To investigate possible differences below the surface of these objects requires observations at radio wavelengths where the emission originates in the layers below the surface. To this end we observed these asteroids at 3 mm wavelength using the 11-meter telescope of NRAO.* The data were compared with models of the surface layers in order to estimate the thermal and electrical properties of the material.

DATA

The data were obtained in December 1975, when both objects were near opposition, using procedures described by Ulich and Conklin (1976). The results, shown in Table I, include a 4% uncertainty in absolute calibration but contain no uncertainty for the adopted radius, a point to which we shall later return. Infrared data also exist for both sources and, for Ceres, longer wavelength radio measurements are available. The data for Ceres are also shown in Figure 1, along with some representative model spectra.

THE MODELS

To construct the models we adopted a two-layer surface for the objects: a base region of rock with an overlying layer of less compacted material. The

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TABLE I

COMPARISON OF OBSERVED AND MODELLED BRIGHTNESS TEMPERATURES

CERES (assumed diameter 980 km)

	Models			Observed	
λ	Pure Dust	1/2 cm dust above rock	Pure Rock	Brightness Temperatures	Reference
20 μm	202 K	203	172 K	221 K	Cruikshank and Morrison (1973)
3 mm	139	142	130	151 ± 11	this paper
2.8 cm	146	137	129	108 + 50	Andrew (1974)
3.7 cm				175 + 58	Briggs (1973)

VESTA (assumed diameter 538 km)

λ	Pure Dust	uncompacted dusty snow	Pure Rock		
20 μm	212 K	207 K	179 K	180 K	Morrison (1973)
3 mm	147	157	138	181 + 24	this paper

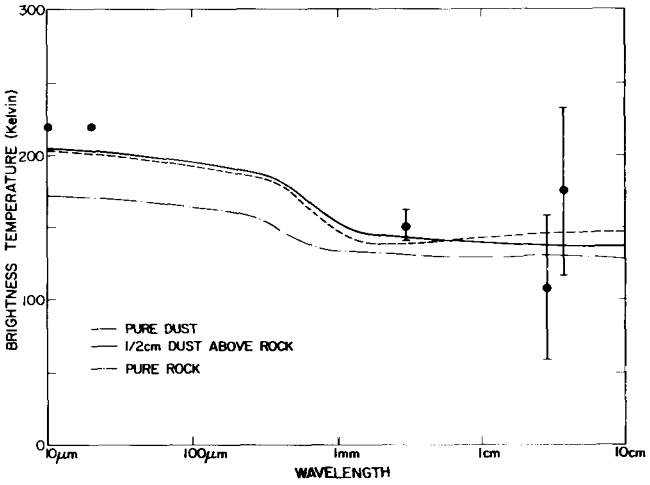

Figure 1. Brightness temperature spectrum of 1 Ceres. The observed values referenced by the points are references in Table I. The models represented by the lines are for different combinations of dust and rock layers as described in the text.

fitting procedure involved variation of the thickness of the top layer as well as the thermal and electrical properties of both materials.

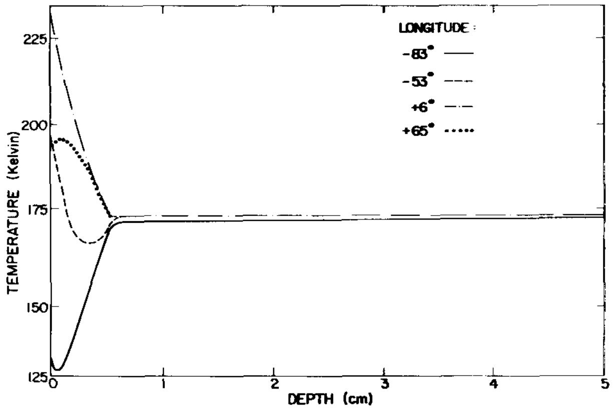

Figure 2. Profile of the temperature distributions with depth into Ceres for several phase angles using the model parameters given in Table II.

TABLE 2
PARAMETERS FOR CERES

Radius	490 km
Albedo	0.04
Rotation Period	9 hours
Heliocentric Distance	2.72 a.u. (Dec 1975)
Geocentric Distance	1.77 a.u. (Dec 1975)
Phase Angle	8.2 degrees (Dec 1975)
Observing Wavelength	3.33 mm
Observed Flux	0.374×10^{-23} erg sec^{-1} cm^{-2} Hz^{-1}

MODEL PARAMETERS	UPPER LAYER	LOWER LAYER
Composition	dust	basalt
Thickness	0.5 cm	--
Absorption length	2.1	0.36 cm
Dielectric Constant	2.9	7.2
Loss Tangent	0.015	0.054
Density	1.0	2.6 gm cm^{-3}
Specific Heat	0.09	0.10 cal gm^{-1} K^{-1}
Thermal Conductivity	2×10^{-6}	4×10^{-3} cal cm^{-1} sec^{-1} K^{-1}
IR Emissivity	0.99	
Scale Depth for Thermal Variation	2.9 cm	
Predicted Brightness Temp.	142 K	

We solved the heat equation using a finite difference technique, with a flux boundary-condition at the surface and an asymptotic fixed-temperature boundary at some large depth in the lower layer. The amplitude of the subsurface heat wave due to insolation is controlled by a single parameter, the thermal inertia, given by $(K\rho C)^{1/2}$ where K is the thermal conductivity, ρ is the density, and C is the specific heat. Figure 2 shows sample profiles of the temperature distribution with depth at different phase angles for the model of Ceres described in Table II. The low thermal inertia in the upper layer causes large variations in the surface temperature with phase angle and a steep gradient with depth; in the rock, the greatly increased thermal inertia allows a much deeper thermal wave but of much lower amplitude.

During integration of the outgoing radiation, account was taken of reflections at the layer interfaces. The reflection coefficient depends upon the dielectric constant and the attenuation of a medium is determined by its loss tangent. The emergent intensity was integrated over the visible disk to give the disk averaged brightness temperature--the observable quantity, assuming the radius is known exactly.

The dusty layer has a low thermal inertia, and thus a shallow thermal wave, but it also has a low loss tangent, so that the radio wave arises deep down; both features reverse in rock. Variations of the thermal and dielectric properties of a given layer by as much as a factor of two generally affect the results less than the uncertainties in the observations, so in the discussion to follow, we have adopted the parameter values in Figure 2 except where noted.

RESULTS

Table I shows a comparison of the observed brightness temperatures of Ceres with three different models having various depths of dust on top of basaltic rock. Clearly pure rock cannot reproduce the observed values and a dust layer is required. The current data do not allow us to establish the thickness of the dust layer, however. As can be seen from Figure 1, only a very accurate measurement at a wavelength of 10 cm or longer can provide some discrimination of the depth of the dust.

Vesta is a more serious problem. Its high 20 μm temperature (relative to a blackbody) and fast rotation rate require a surface layer with low thermal inertia. But such a layer also has low conductivity; and so the radio emission, coming from well below the surface, should have a low brightness temperature relative to the infrared values. Instead the radio and infrared temperatures are approximately equal. Some loose material is required, however, to get the high observed values of the infrared brightness temperature, and the best fit is obtained for a layer of mixed dusty snow. The fit would be improved by assuming a larger diameter for Vesta; a 5% increase to 565 km brings the data into fairly good agreement with the dusty snow model. Alternatively, the calibration of the mm wavelength observations might be high by 10%, but this is unlikely.

In summary, with the limited data and hence large uncertainties in model parameters, it is not possible to make a detailed evaluation of the surface properties of these objects; but we do find that Ceres has surface properties which are similar to those of lunar material, whereas the higher albedo object, Vesta, must have different thermal characteristics. Its ratio of radio to optical disk brightness temperature is significantly larger than for Ceres, and appears to require a more compacted layer of material on its surface. The apparent presence of dust on the surfaces of both these objects is consistent with the idea that they have undergone collisions and have some pulverized material remaining.

ACKNOWLEDGEMENTS

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DISCUSSION

WETHERILL: Long before Apollo, similar data was obtained for the moon, which also indicated a very thin dust layer overlying more consolidated material. Surveyor photography and Apollo landings showed this had nothing to do with what lunar geologists wanted to know, namely the thickness of 3 m - 150 m regolith overlying solid basalt. If this is also the case for Ceres and Vesta, it could be that there is no way of relating your data to regolith thicknesses calculated by Monte Carlo simulations of impact "gardening."

ARNOLD: I understand from Dr. Yves Langevin that his Monte Carlo gardening model developed for the moon suggests that asteroidal regolith will have a much coarser particle size for the regolith of an asteroid like Ceres or Vesta. What effect would this have on your results?

DICKEL: Most of the action is in the dust layer which we require on the very surface so that the relatively small differences in thermal inertia between rock and very compressed regolith in the lower layer cannot be distinguished from our data (probably a total uncertainty of almost 10%). The same is still true for the moon.

MORRISON: If the thermal conductivity of the surface of Vesta is high enough to reduce the subsurface temperature gradient significantly, the basic assumption on which radiometric diameters are calculated is violated. This is the assumption that each surface element on the illuminated side has a temperature very near its instantaneous equilibrium value. If the conductivity is high, these temperatures are lower and the "radiometric diameter" will be only a lower limit to the true diameter. Such a conclusion will complicate the interpretation of your data as well as of mine.

DICKEL: True, but the rough indication, at least, is that the conductivity is low.