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Mercury

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Recent Advances in Ground-Based Observation of Mercury

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Abstract. The last decade has seen an efficient use of ground-based telescopes for remote-sensing studies of Mercury's surface at optical, infrared and microwave wavelengths. This has resulted in a substantially improved knowledge of its regolith composition, material and light scattering properties and structures on the poorly known hemisphere. This paper summarizes recent observations and results on the regolith properties of Mercury.

1. Important observational studies

We may identify three main types of observational methods that have been contributed significantly, and in which efforts in the near future will probably be concentrated. Radar has been used to investigate topographical units and for probing fundamental material properties; spectroscopy and imaging spectrophotometry to identify the surface composition, particularly in the thermal infrared; and high-resolution imaging in the optical and near-infrared to map the albedo distribution of the surface with the ultimate goal of identifying geologic provinces on the poorly known hemisphere (i.e., the longitudes 180–360° which were not imaged by Mariner 10).

Remarkable km-scale spatial resolution images of the surface have been obtained at microwave and radar wavelengths through delay-Doppler and full-disk imaging with the Goldstone/Very Large Array and Arecibo radio telescopes (Harmon et al. 2001, Harmon & Campbell 2002), and are our best source of information regarding topographic features on the poorly known hemisphere. Small areas of very high radar backscatter intensity within high latitude craters have been interpreted as due to either buried water ice or sulfur deposits (Slade et al. 1992; Sprague, Hunten, & Lodders 1995). Microwave radar studies (Mitchell & de Pater 1994; Jeanloz et al. 1995) and related laboratory studies have shown that the material properties are consistent with those of alkaline silicates, with a greater transparency and smaller dielectric loss tangent than that of the Moon, signifying a lower abundance of opaque minerals such as iron and titanium in a predominantly feldspathic crust.

The infrared regime have provided us with the best opportunities to extract information about the mineralogical composition of Mercury's regolith. Instrumentation on the Infrared Telescope Facility (IRTF), the McMath-Pierce and Steward telescopes at Kitt Peak, and the Kuiper Airborne Observatory have been used to obtain spectra and images at thermal infrared wavelengths (Emery et al. 1998; Cooper et al. 2001; Sprague et al. 2002). Such spectra are often

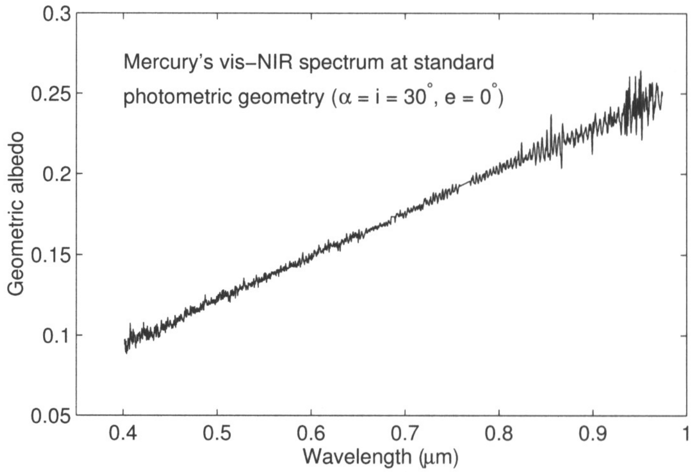

Figure 1. An average Mercury spectrum for the wavelength range 0.4–1.0 μm obtained with the Nordic Optical Telescope (Warell and Blewett 2003), scaled with a geometric albedo of 0.136 at 0.55 μm from Warell (2004). The vis-NIR spectrum of Mercury is linear and lacks any detectable mineralogical absorption features.

complex and emission features vary in terms of location and intensity between different longitudes on the surface. This is taken as evidence of a compositionally heterogeneous surface composed of intermediate and basic soils, pyroxenes and anorthosite, possibly with geologic units of highly different thermal properties.

The situation is superficially different for spectra obtained in the optical and near-infrared range, which are similar for all longitudes (Blewett et al. 1997). The 0.9 μm absorption band due to Fe^{2+} crystal field transitions in ferrous silicates and a characteristic of lunar spectra is absent on Mercury, indicating a very low abundance of iron (Sprague et al. 2003; Warell 2003a; Warell & Blewett 2003). Albedo features around 200 km in size have been detected on the non-Mariner 10 hemisphere with the Mt. Wilson 1.5-m reflector (Baumgardner et al. 2000) and the Swedish Vacuum Solar Telescope (Warell & Limaye 2001), showing that there is no statistical difference between the morphology and distribution features on a global scale. This provides evidence for a similar post-heavy bombardment geologic evolution of both hemispheres.

A new V-band phase curve from photometric observations from the ground and with the Solar and Heliospheric Observatory was published by Mallama et al. (2002), and signifies the first good data set for very low and very high phase angles. That work and Warell (2004) indicate a microscopically smoother surface than determined previously (Veverka et al. 1988).

2. Mercury's regolith: summary of best knowledge

In terms of composition, recent observations indicate that Mercury's surface is primarily feldspathic with intermediate plagioclase as the dominant phase. Minor low-iron hypersthene and mafic basalts may be present locally. Volatile minerals, possibly water ice or sulfur, are mixed in the subsurface at permanently shaded locations at the poles.

Hapke (1993, 2002) modeling indicates a chemical composition of FeO ~1–2 wt%, TiO_2 ~0 wt%, and Fe^0 ~0.2 wt% (Warell and Blewett 2003). This supports the observed small microwave dielectric loss tangent characteristic of a surface low in opaques. The original unweathered rock types of the present crust may thus have been iron-free, with iron (oxidized and native) and volatiles delivered by infall during and following the late bombardment era.

The average optically active grain size appears to be about 30 μm or half the dimension of lunar highland grains, which is consistent with the stronger maturation at Mercury (Cintala 1992). The physical porosity of the optically active top soil is similar to the Moon's and is consistent with a small radar cross section (Pettengil, Dyce, & Campbell 1967) and negative branch of polarization (Dollfus & Auriere 1974). Though the maturation induced metallic iron abundance appears to be at most half of the Moon's, the maturation appears more evolved in terms of a probably higher abundance of semi transparent and strongly backscattering complex agglutinates.

The optical scattering properties are lunar-like, but Mercury appears to have a stronger backscattering efficiency and dependence of color on geometry. The backscattering anisotropy increases with wavelength, which supports microwave opacity data. The average particle angular scattering function corresponds more closely to that of lunar maria than highlands. At least some surfaces, consistent in location with smooth plains imaged by Mariner 10, have a small photometric roughness of $\bar{\theta}$ ~10°, though the typical regionally averaged surface appears consistent with a roughness twice as high.

In terms of Mercurys evolution, the available evidence indicate that it either sampled only a limited feeding zone during the protoplanetary accretion phase, and/or experienced subsequent post accretion volatilization or impact ejection of the bulk silicate component. This would account for a very low abundance of iron, facilitated by the gravitational sinking of high density minerals in a magma ocean. Such an event would also allow thorough mixing of the present crustal material to effectively average out strong compositional variations.

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