BIDIRECTIONAL SURFACE REFLECTION MODELED USING MICROSCOPIC ROUGHNESS

Deborah Domingue, Lunar and Planetary Institute, Andrew Cheng, Applied Physics Laboratory

Photometry and spectroscopy are fundamental to remote sensing of planetary surfaces. A photometric model based upon radiative transfer theory (1,2,3) has come into wide use for analyzing measured spectral reflectances to infer scattering properties of particulate surfaces, compositions of surface materials, and textural parameters. This photometric model included effects of microscopic extinction shadow hiding and multiple scattering. The model disagreed significantly with observation only in that it predicted a sharp brightening near the poles and illuminated limb of low albedo bodies. To remove this so-called 'limb brightening' effect from the model, Hapke (3) introduced a macroscopic roughness correction, involving the surface tilt parameter $\bar{\theta}$ that accounted for macroscopic slopes and shadowing on the surface of the body, without attempting to model the surface structure in detail.

Another photometric model based upon a radiative transfer approach has been given by Lumme and Bowell (4). The Lumme-Bowell model and the Hapke model have been fitted to the observed photometry of a wide range of solar system bodies, and their properties are compared in detail by Bowell et al. (5). The model we present here is more easily understood in relation to Hapke's.

The main virtues of a radiative transfer approach to the calculation of spectral reflectances were stated by Hapke (1): this approach yields relatively simple expressions that can be readily fitted to data, so as to enable estimates for physically significant parameters such as the single particle scattering albedo $\omega$ as a function of wavelength. This approach involves important approximations as will be discussed below, but the ultimate test is the extent to which it can describe observations.

The goal of this work is to present a unified bidirectional reflectance model based upon radiative transfer theory, while at the same time making useful improvements to earlier work. In the present model, as in earlier work, we include microscopic extinction shadow hiding and multiple scattering effects, but we extend the Hapke model in two principal ways. First, we use a single microscopic surface roughness model to describe the opposition surge and to demonstrate that there is no limb brightening effect. Second, we include anisotropic scattering in the multiple scattering terms, whereas the Hapke and Lumme-Bowell models do not.

In what follows, we adopt the view that a realistic planetary surface can be modeled by approximating it with planar 'macroscopic' surface elements at some length scale $L$, and that all scales larger than $L$ should be modeled explicitly. We suppose that the bidirectional reflectance of each macroscopic surface element can be described by a radiative transfer solution. We then recognize that the planetary surface also has topography and structure on 'microscopic' scales much smaller than $L$, and we introduce two separate microscopic structure corrections using a
particulate surface model like that of Irvine (6) or Hapke (3). One correction yields an opposition surge, and the other removes the limb brightening. These corrections are made in the single scattering term only, as in the Lumme-Bowell model, although the detailed corrections are different. With microscopic surface roughness treated in this way, there is no limb brightening and no need for an additional macroscopic roughness correction (as in 2) on scales that are still too small to be modeled in detail.

Below are examples of fitting our model to disk-resolved data as compared to similar solutions to Hapke’s model. The examples are of Rhea, but similar solutions to the Moon have also been found. While our model does fit observational data as well as Hapke’s model, there is no vast improvement in the quality of fit. There seems to be no difference in the quality of fit whether surface roughness is modeled macroscopically or microscopically.