APOLLO SOILS PHYSICAL PROPERTIES LINKED TO M^3 SPECTRA COMBINED WITH ROLO PHOTOMETRY. Jay D. Goguen[1], [1]Jet Propulsion Laboratory, California Institute of Technology, MS 183-401, 4800 Oak Grove Dr., Pasadena, CA 91109, Jay.D.Goguen@jpl.nasa.gov.

Introduction: The lunar surface consists of a layer of fine particles that are the result of eons of meteorite bombardment called the "regolith". The Apollo and Luna missions returned many regolith samples, referred to as lunar "soils", which have been studied in great detail. Because we know that the Moon's surface is dominated by these small particles, the fundamental physics that determines ***both the wavelength and angular distribution of the radiance*** is scattering of sunlight by a particle, or more precisely, by an ensemble of particles. All spacecraft and telescopic images and spectra across the visible and near infrared wavelengths (350 nm < λ < 2500 nm) reflect this 'light scattering by a particle' physics.

Our goal is to use the known properties of specific returned lunar surface soil samples, i.e. the particle size distribution, composition, particle shape, etc., as inputs to a radiative transfer model that calculates the dependence of the scattered radiance on the incidence, emission and phase angles for each wavelength across the visible and near-ir spectrum. Because the particle size distribution is the same for each wavelength, and because the particle composition determines the complex index of refraction for each wavelength, both the angular distribution of the radiance (the bidirectional reflectance) and the spectrum will depend on only these few inputs that can or have been measured for the returned Apollo soils. We can 'close the loop' by comparing the calculated radiances to the measured radiances of the *in situ* lunar surface at the specific sites from which the returned soils were collected. Extensive measurements of spectra of the Apollo sites with sufficient spatial resolution were acquired, for example, by the M^3 instrument and the geometric dependence of the radiance over the full range of geometries observable from Earth are part of the ROLO data set [1]. By reconciling the remote sensing measurements of the undisturbed lunar surface at the Apollo sampling sites with the measured properties of the returned soils through a radiative transfer model, we will develop a tool that can be used to improve our physical interpretation of remote sensing data for other lunar regions without returned samples and for regoliths in general.

Example – The Difference Between the Radiance of Lunar Sites Observed Before & After Full Moon:

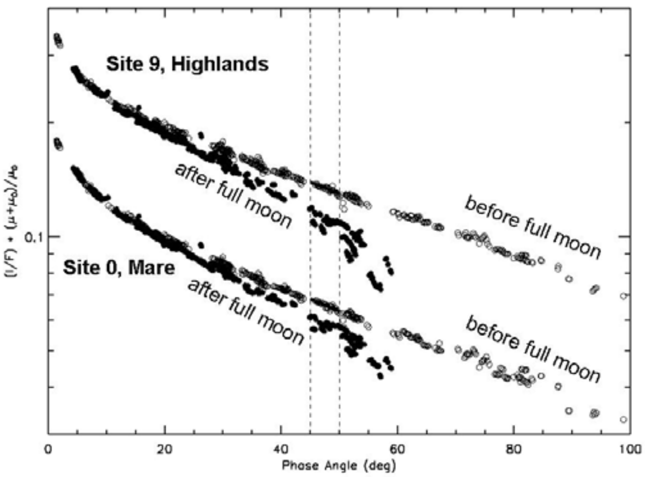

Figure 1. ROLO 553 nm photometry $(I/F)(\mu+\mu_0)/\mu_0$ for representative lunar highland (top) and mare (bottom) sites. Note the divergence with increasing phase angle between the before (open circles) and after (filled circles) full moon observations. The dotted lines indicate the region between 45 and 50 degrees phase angle where the before and after full moon difference is large and well characterized by the observations.

As an example, we apply a simple forward radiative transfer model to ROLO photometry [2] of a lunar site throughout a full lunation (Fig.1). We investigate the difference in the radiance before (i~30º) vs after (i~65º) full moon at 45º to 50º phase angle at these sites and show that this phenomenon can be quantitatively reproduced by scattering from the published size distribution of particles for lunar soil 72141,1 [3] (fig. 2) and complex index of refraction m=1.65-0.003 i [4]. This forward radiative transfer model [5] requires only 4 parameters, 3 of which are fixed at values determined from Apollo soils. Only the imaginary part of the complex index of refraction (the absorption coefficient) is allowed to vary to match the overall albedo.

The comparison of the Apollo soil constrained model and the ROLO observations is shown in fig. 3. The radiance difference is explained as a consequence of multiple scattering by realistic particles.

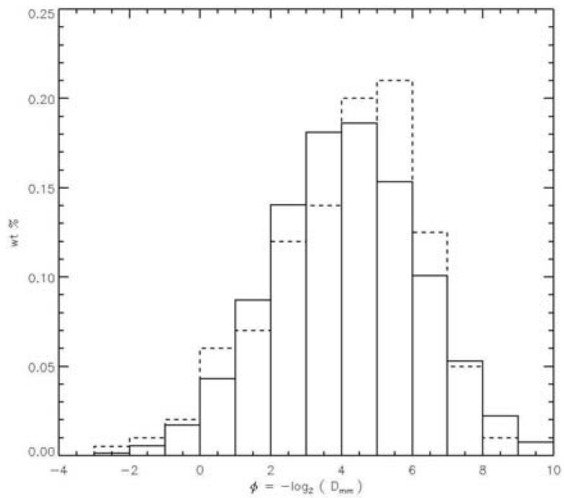

Figure 2. The measured weight % vs particle diameter histogram for lunar soil 72141,1 (dashed lines, reproduced from McKay et al [3]. The weight % histogram for the model log normal particle *number* distribution that reproduces the measured M_z and σ_I for 72141,1 (solid lines) is shown for comparison. For reference, $\varphi = 10$ corresponds to a ~1 µm diameter particle.

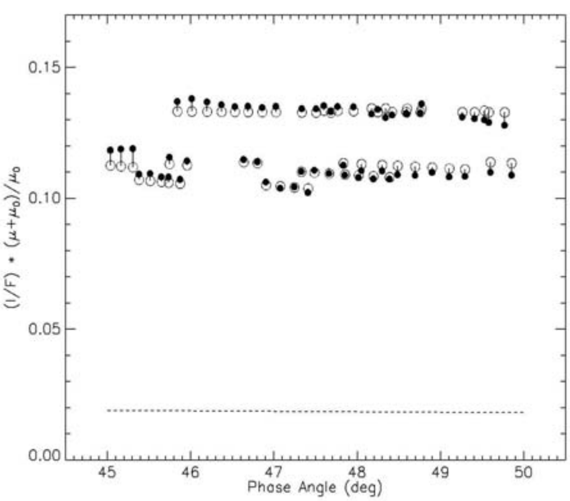

Figure 3. ROLO photometry for site 9 (filled circles: before full moon, top; after full moon, bottom). Model points (open circles) are the exact solution of the radiative transfer equation for the log normal number distribution that matches the measured weight % distribution for lunar soil 72141,1 (fig. 2) and complex index of refraction 1.65 – 0.003 i. The contribution due to photons scattered once is indicated by the dashed line at bottom.

Relationship to Other Work: An extensive body of research has focused on understanding the relationship between the measured reflectance spectra of the returned lunar soil samples and their composition. Noble et al [6] find that the optical properties of lunar soil are dominated by the smallest size fractions <45µm, consistent with the calculation by Goguen et al [2] that the effective radius for scattering for lunar soil 72141 is 8 µm. McKay et al [3] report that the finest lunar soils have the highest agglutinate content and that agglutinate content correlates with soil maturity. The Lunar Soil Characterization Consortium (LSCC) made detailed studies of the mineralogy, petrology, chemical composition and reflectance spectra of a representative suite of lunar soils. Taylor et al [7] found that the composition of successively smaller grain size fractions of Apollo 17 mare soils approaches that of the agglutinitic glass. Taylor et al [7, 8] show that the <10µm size fraction has Is/FeO, a measure of the proportion of pure metallic Fe or nanophase Fe^0 (npFe^0), nearly twice that of the 20-45µm size fraction.

Conclusions and Future Work: This successful forward radiative transfer model approach can be extended to spectra simply by constraining the wavelength variation of the complex index of refraction to follow that for a appropriate silicate glass containing the known amount of npFe^0. This approach applied to the observed bidirectional reflectance and spectra of the specific Apollo sample sites with models constrained by the measured physical properties of the returned samples promises to advance our ability to characterize the regolith from remote sensing data.

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