NEW GROUND-BASED SPECTRAL OBSERVATIONS OF MERCURY AND COMPARISON WITH THE MOON. D. T. Blewett[1] and J. Warell[2], [1]NovaSol, 1100 Alakea Plaza, 23rd Floor, Honolulu, HI 96825 USA, dave.blewett@nova-sol.com; [2]Institutionen för Astronomi och Rymdfysik, Box 515, SE-751 20 Uppsala, SWEDEN, johan.warell@astro.uu.se.

Introduction: Spectroscopic observations (400-670 nm) of Mercury were made at La Palma with the Nordic Optical Telescope (NOT) in June and July of 2002. Extensive observations of solar analog standard stars and validation spectra of 7 Iris and a variety of locations on the Moon were also collected. The 2002 Mercury data were also combined with previous observations (520-970 nm) from the Swedish Solar Vacuum Telescope (SVST) [1]. A spectrum (400-970 nm) calibrated to standard bidirectional geometry (α=i=30°, e=0°) was constructed based on the spectral slopes from 2002. The combined spectrum permits analysis with the Lucey lunar abundance relations for FeO and TiO_2 [2].

Validation of Mercury Spectra: A well-studied asteroid and locations on the Moon were observed on the same nights with the same instrument as the Mercury observations. These observations provide a check on the calibration procedures used for the more difficult collection and reduction of data for Mercury.

Spectra were successfully obtained for five lunar sites. All the sites have previously been observed with Earth-based telescopes and published spectra are available for comparison. The five sites include Mare Serenitatis-2 (MS2), an often-observed spectral standard site; a sample-return site (Apollo 12); and three locations composed of pure anorthosite (Alphonsus central peak, Mersenius C, and Gassendi E). "Pure anorthosite" is a lithologic term used to describe lunar rock containing over 90% plagioclase feldspar [3]. Pure anorthosite has a low-Fe composition and is a plausible analog for Mercury [4, 5]. All NOT spectra for the validation targets show good agreement with previously collected data. This boosts our confidence in the quality of the NOT data and calibration procedures for Mercury.

Examining the NOT data in terms of the Hapke model for reflectance of a silicate regolith: Hapke [5] conceived a general model for the reflectance properties of a lunar-like silicate regolith. The model considers the reflectance to be largely controlled by these regolith components: transition ions (chiefly Fe^{+2}) in silicate minerals and glasses, submicroscopic metallic iron created by reduction and vapor-phase deposition of the iron in the silicates by space-weathering processes, and opaque phases (such as ilmenite or coarse-grained metallic iron). This model was used by Lucey and coworkers [2 and references therein] to develop algorithms for quantitative compositional mapping of lunar FeO, TiO_2, and optical maturity using Clementine images. It is instructive to examine the NOT spectra in terms of the Hapke model.

Opaque phases. Lucey expressed the major features of the Hapke model by use of plots of a reflectance ratio vs. visible reflectance, somewhat analogous to the color-magnitude (H-R) diagrams used by stellar astronomers. The ratio-reflectance plots illustrate variations related to the regolith's composition and state of maturity. In the UV-VIS portion of the spectrum, spectral characteristics are largely controlled by the opaque mineral content, dominated in the lunar case by variations in the abundance of ilmenite ($FeTiO_3$). Ilmenite is dark and has a flat or "bluish" spectrum compared to normally reddish lunar material, and lacks strong absorption features. A plot of UV/VIS vs. VIS (415-nm reflectance/750-nm reflectance vs. 750-nm reflectance for Clementine) displays two main trends (Figure 1). The figure shows the location of Apollo and Luna sample-return stations [2], farside mature pure anorthosites [5], and three nearside immature pure anorthosites – all as observed by Clementine. One trend corresponds to ilmenite variations in the maria, with high-Ti samples, which are darker and bluer, falling at the upper left portion of the plot, and brighter, redder low-Ti mare basalts near the middle of the plot. The other trend, roughly from the middle of the diagram to the upper right, tracks changes governed by maturity and ferrous iron content, mostly in the highlands. The mature pure anorthosite locations are darker and redder than the immature pure anorthosites. Mercury, as recorded by the NOT observation, is more extreme in 415-nm/750-nm ratio than any of the plotted lunar locations. The low ratio value indicates a more strongly red-sloped spectrum than even the mature lunar anorthosites. This should correspond to an extremely low abundance of lunar-like opaques on Mercury. If the lunar calibration of Lucey [2] is applied to the NOT Mercury spectrum, the predicted TiO_2 content is essentially zero.

Ferrous iron. In the near-infrared (NIR) spectral region around 1000 nm, color properties are dominated by the abundance of ferrous iron (Fe^{+2}). On a plot of NIR/VIS vs. VIS (950-nm reflectance/750-nm reflectance vs. 750-nm reflectance), the points are located according to the intrinsic iron content (Fe^{+2}) and optical maturity of a surface (Figure 2). Optical maturation proceeds as exposure to the space environment leads to the production and vapor-phase deposition of submicroscopic grains of metallic iron (SMFe). SMFe is a darkening and reddening agent, so as a surface matures its spectrum will tend to move to the upper left on the diagram. Increasing the ferrous iron content of a mineral will also produce a decrease in VIS reflectance, but the stronger "1 μm" band will cause a decrease in the NIR/VIS ratio. Therefore, samples with higher iron content will plot toward the lower left. Lucey found that an angular measure (θ_{Fe}) of a sample's location on such a plot is highly correlated to the bulk FeO content of the sample, divorced from the degree of maturity. In Figure 2, the lunar pure anorthosites are found at their expected location above the Apollo 16 sampling stations (i.e., at a smaller value of θ_{Fe}). The NOT observation again shows Mercury to have an extremely red spectrum compared to the Moon. According to the Hapke model, the high 950-nm/750-nm ratio is indicative of a highly mature surface lacking a ferrous iron absorption band. Since Mercury falls above the optimized reference line established for the lunar sampling stations, its negative value of θ_{Fe} leads to a large negative value for FeO content when the Lucey calibration [2] is applied.

Discussion: Well-calibrated ground-based spectrometry of Mercury allows the color properties of the mercurian regolith to be confidently examined in terms of the lunar paradigm. The ratio-reflectance plots shown in the Figures demonstrate that Mercury must be extremely low in spectrally neutral opaque phases and in ferrous iron. The steep positive spectral slope however indicates that SMFe must be abundant as a reddening agent [e.g., 7]. The SMFe could have been derived from the country rock, or brought in from extramercurian sources [8]. The highly mature state of the regolith is consistent with the high rates of meteoritic bombardment and space weathering predicted for Mercury [9]. Lucey's algorithms for lunar compositional analysis need to be generalized for application to airless bodies other than the Moon.

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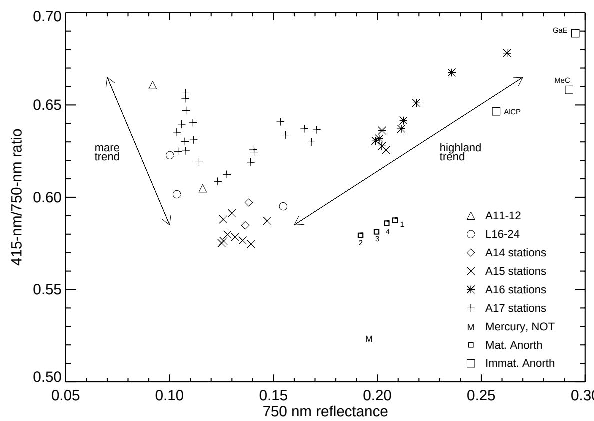

Figure 1. UV ratio-reflectance plot for Clementine observations of lunar sample-return sites, mature and immature pure anorthosites, and for the NOT Mercury data. The three immature pure anorthosites are the craters mentioned in the text. The four areas of mature pure anorthosite are on the farside and were discussed by [5]. "Redder" corresponds to lower 415-nm/750-nm ratio.

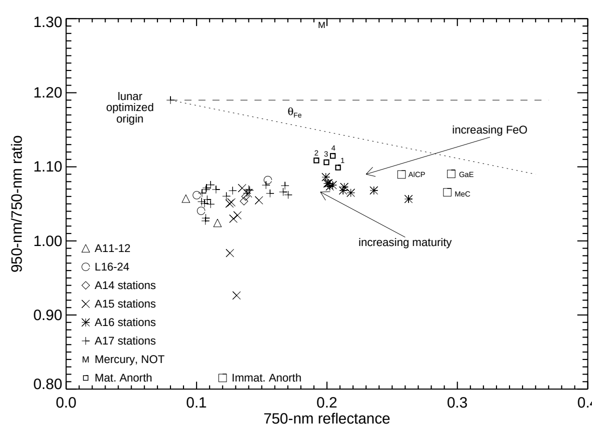

Figure 2. NIR ratio-reflectance plot for Clementine observations of lunar sample-return sites, mature and immature pure anorthosites, and for the NOT Mercury data. The angle θ_{Fe} is a measure of the ferrous iron content of the surface, decoupled from maturity. "Redder" corresponds to a higher 950-nm/750-nm ratio.