NEW EXTENDED RANGE WAC TiO_2 MAP OF THE MOON. H. Sato[1], B. Hapke[2], M. S. Robinson[3], [1]Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa, Japan (sato.hiroyuki@jaxa.jp), [2]University of Pittsburgh, Pittsburgh, PA, [3]Arizona State University, Tempe, AZ.

Introduction: Accurate knowledge of the distribution and the abundance of TiO_2 of the lunar surface is key to understanding the magmatic history and thermal evolution of the Moon. TiO_2 abundance maps were derived by various studies using multiple remote-sensing datasets. The UV sensitivity of the Lunar Reconnaissance Orbiter Wide Angle Camera (WAC) enables quantification of the unique spectral shape of ilmenite that increases toward shorter wavelengths from visible to UV, whereas reflectance for other major lunar silicate minerals decreases into the UV. The WAC 321/415 nm ratio derived TiO_2 map [1] was sensitive down to TiO_2 abundances of 2 wt% (corresponds to the dominance of ilmenite in the total TiO_2 content). Below 2 wt% range for the WAC TiO_2 map, a new algorithm was proposed by [2,3]. It utilizes the 566/689 nm ratio that correlates with the content of pyroxene, the other TiO_2 bearing mineral. The algorithm is valid only for mature soils; for immature soils it gives a lower limit. Based on this new algorithm, here we created a new merged WAC TiO_2 map with no limit of the valid range, and we compared it with two pre-existing TiO_2 maps.

Methodology: We used the WAC seven color semi-global mosaic created by [4] (400 m/pixel at the equator, 70°S to 70°N in latitude). The new TiO_2 algorithm [2,3] first calculates two TiO_2 values:

$$\mathrm{TiO_2}(566/689) = 34.48 - 41.49 * r(566/689)$$

$$\mathrm{TiO_2}(321/415) = 169.8 * r(321/415) - 121.9$$

where r(566/689) and r(321/415) correspond to the I/F ratio of 566 nm over 689 nm and 321 nm over 415 nm, respectively. Then the final TiO_2 values (hereafter called WACTiO₂) are derived by the following condition:

$$\mathrm{TiO_2} = \begin{cases} \mathrm{TiO_2}(321/415), & \text{if } \mathrm{TiO_2}(321/415) > 3 \\ \mathrm{TiO_2}(566/689), & \text{otherwise} \end{cases}$$

$$\mathrm{TiO_2} = 0, \text{if } \mathrm{TiO_2} < 0$$

We compared the new WACTiO₂ with pre-existing TiO_2 maps derived from the Clementine UVVIS 415 and 750 nm bands (200 m/pixel) [5] (hereafter called CLMTiO₂) and the Lunar Prospector Gamma-Ray Spectrometer (GRS) (1 pixel/degree) [6,7] (hereafter called LPTiO₂).

Results: First, we examined the incompatible regions with the new TiO_2 algorithm [2,3]. From the scatter plot of TiO_2(321/415) vs. TiO_2(566/689) (Fig. 1), we defined the regions from R1 to R4. R2 and R4 are the incompatible regions where TiO_2(566/689) is higher than TiO_2(321/415) and lower than 0 wt%, respectively. In a map view (Fig. 2), R2 has less than 0.04% of areal fraction and is dominantly located in abnormal pixels such as shadows in high latitudes. Thus the R2 is likely caused by the artifacts.

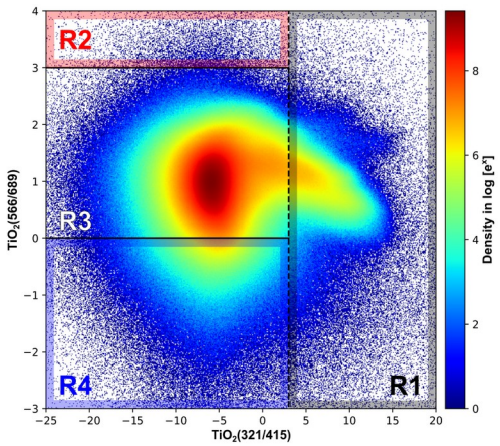

Figure 1. Density plot of TiO_2(321/415) vs TiO_2(566/689) for the whole area of WAC semi-global mosaic (70°S to 70°N). R# indicates the region number.

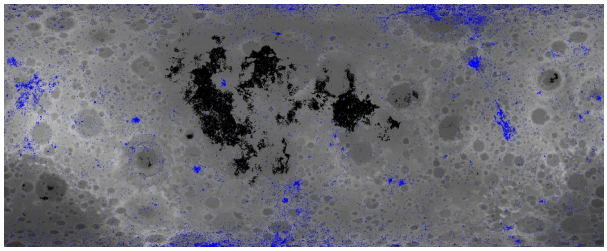

Figure 2. Spatial distribution of the R1 (black), R2 (red) and R4 (blue) in Fig. 1.

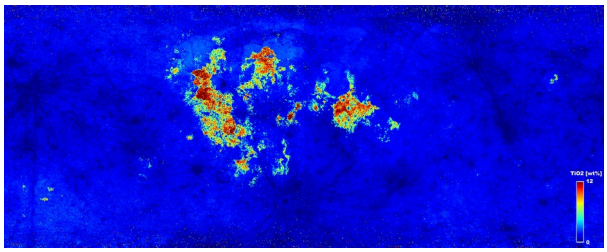

Figure 3. WACTiO₂ map based on the algorithm proposed by [2,3]. The spatial extent is from 180°W to 180°E, 70°S to 70°N.

The R4 is mainly located on immature highland ejecta, dominated by anorthositic materials [8] with TiO_2 values close to zero. Since the immature soil is not covered in the new algorithm [2,3] and can have a lower limit, negative values in the R4 are not surprising. The semi-global view of the new WACTiO₂ map (Fig. 3) has no noticeable offset at the 3 wt% transition.

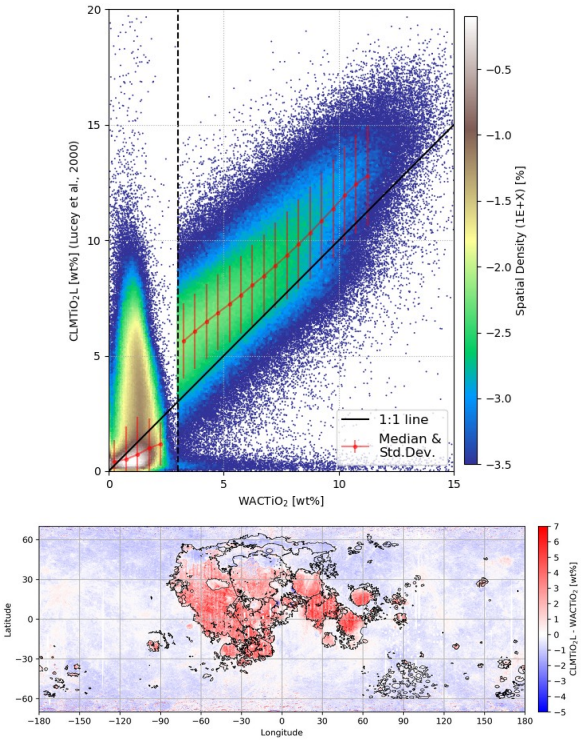

Figure 4. Density plot of $CLMTiO_2$ vs. $WACTiO_2$ (top) and difference map of $CLMTiO_2$ - $WACTiO_2$ (bottom). Bin size of the errorbar is 0.5 wt%. The mare boundaries are outlined by black line.

Compared to the $CLMTiO_2$, the $WACTiO_2$ is consistently lower (2.5 wt% on average; Fig. 4 top) above 3 wt% transition and is higher (up to twice on average) below 3 wt% transition, respectively. In the difference map (Fig. 4 bottom), the maria are dominantly red (= $CLMTiO_2$ > $WACTiO_2$) except Mare Frigoris and northern portions of Imbrium and Procellarum. In the highlands, mature regions are typically blue (= $CLMTiO_2$ < $WACTiO_2$), and the immature ejecta (set $WACTiO_2$ = 0 wt%) are light red.

The difference between the $LPTiO_2$ and $WACTiO_2$ is small (-0.1 wt% on average with σ = 0.5 wt%, Fig. 5 top), which is likely within the measurement errors of LP. The difference map (Fig. 5 bottom) shows locally red regions (= $LPTiO_2$ > $WACTiO_2$; up to +6 wt%) near Kepler and Aristarchus craters. A similar trend was also found in [1], possibly related to the sensible depth of GRS (~30 cm [9]) and the WAC (a few millimeters [10]). Immature highland ejecta are relatively red, but boundaries are not as sharp in Fig. 4 (bottom), likely due to the resolution effects. The difference in the highlands is -0.4 wt% on average, with σ = 0.7 wt%. For the mature highland surfaces, difference is greater (> -2 wt%), which is consistent trend as seen in Fig. 4.

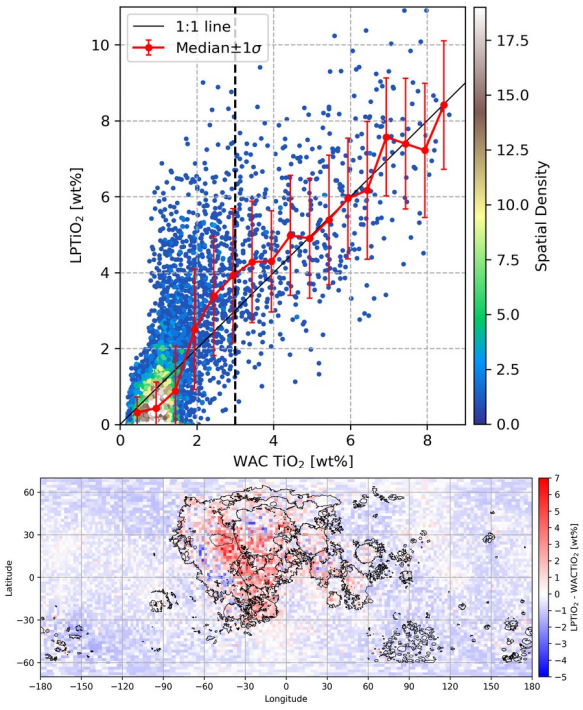

Figure 5. Density plot of $LPTiO_2$ vs. $WACTiO_2$ (top) and difference map of $LPTiO_2$ - $WACTiO_2$ (bottom). Bin size of the errorbar is 0.5 wt%.

Discussion: The sharp discontinuity of $WACTiO_2$ in Fig. 4 (top) corresponds to the transition of TiO_2(321/415) and TiO_2(566/689). The cause of this discontinuity is unknown. More local study along the 3 wt% transition boundaries in the $WACTiO_2$ map will help to clarify the cause and possibly improve the current algorithm.

The blue shift in Mare Frigoris and northern portions of Imbrium and Procellarum from the other red maria located in the lower latitudes in Fig. 4 (bottom) is not clear in Fig. 5 (bottom). This trend possibly corresponds to a latitudinal artifact in the $CLMTiO_2$.

Conclusion: The new $WACTiO_2$ based on the new algorithm has more relative offsets with the $CLMTiO_2$ than the $LPTiO_2$. More low-TiO_2 samples from the highlands (and the maria) are required for more accurate estimates of spectral reflectance for low-TiO_2 abundance, particularly in 0-1.5 wt% range.

References: [1] Sato et al. (2017) *Icarus* 296, 216-238. [2] Hapke et al. (2019) *Icarus* 321, 141-147. [3] Hapke et al. (2019) *Icarus*, in press. [4] Sato et al. (2014) *JGR-Planets*, 119, 1775-1805. [5] Lucey et al. (2000) *JGR,* 105 (E8), 20297-20305. [6] Elphic et al. (2000) *JGR-Planets,* 107 (E4), 5024. [7] Prettyman et al. (2006) *JGR*, 111 (E12), E12007. [8] Ohtake et al. (2009) *Nature*, 461 (7261), 236-40. [9] Lawrence, et al. (2002) *JGR* 107 (E12), 5130. [10] Hapke Hapke (2012) Cambridge University Press, New York.