Deriving Abundances and Chemistries of Minerals with Radiative Transfer Modeling. Lingzhi Sun[1], Paul Lucey[1], Zongcheng Ling[2], Jiang Zhang[2], Jian Chen[2], [1]Hawai'i Institute of Geophysics and Planetology, Dept. of Earth Sciences, University of Hawai'i at Mānoa, Honolulu, HI 96826, USA, lzsun@higp.hawaii.edu, [2]School of Space Science and Physics, Shandong Provincial Key Laboratory of Optical Astronomy & Solar-Terrestrial Environment, Shandong University, Weihai 264209, China.

Introduction: The Hapke radiative transfer model has been applied to derive mineral abundances from remotely sensed spectral datasets [1,2]. However, detailed compositions (e.g., Fo, Fs, Wo) for all the minerals are less frequently reported due to the limitation of optical constants.

In this study, we derived the optical constants by radiative function from lab measured reflectance of minerals with known chemistries. We then correlate these chemistries with the key parameter of spectra of optical constants that relating to absorption-the imaginary refractive index k [3]. We then build a new model that derives both major mineral abundances (plagioclase, olivine, low-Ca pyroxene and high-Ca pyroxene) and chemistries (Mg#, Fo for olivine and Fs, Wo for pyroxene) with spectra acquired by Chandrayaan-1 Moon Mineralogy Mapper (M^3).

We present our new model here and provide some validation with in spectral matching with M^3 spectra, and in mineral abundances and mineral chemistries with lunar sample data analyzed by Lunar Soil Characterization Consortium (LSCC).

Radiative transfer modeling: Supposing a medium filled with closely packed particles, and that the grain size of these particles is larger than wavelengths, then the reflectance of this medium can be described with radiative transfer theory [4]. Here, we introduce a new radiative transfer model in mineral abundance derivation considering both the chemical compositions (e.g., Mg', Fo, Fs, Wo) and space weathering effect. The radiative transfer function used in this study is expressed as Eq. (1), which includes lunar soil porosity and shadow-hiding opposition effect (SHOE) [4].

$$R(\mathrm{i,e,g}) = K\frac{\omega}{4\pi}\frac{\mu_0}{\mu_0+\mu}\{p(\mathrm{g})[1+\mathrm{B(g)}]+[\mathrm{H}(\mu_0/K)\mathrm{H}(\mu/K)-1]\} \qquad (1)$$

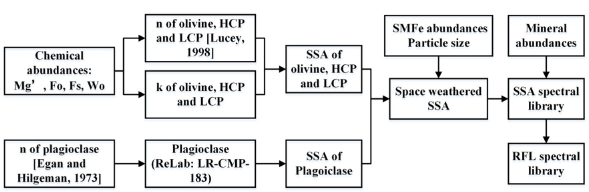

Fig 1. Flow chart of spectral library building process.

Here R refers to reflectance and ω refers to single scattering albedo (SSA). *i, e*, and *g* are the incident, emergence and phase angles respectively. In this paper, i = e = g/2 = 30 °. $\mu_0 / (\mu_0 + \mu)$ is the *Lommel-Seeliger* parameter, where $\mu_0 = cos(i)$ and $\mu = cos(e)$ [5]. *K* is the porosity factor, it increases as the particles of a medium are compacted. *P(g)* is the phase function, *B(g)* mainly describes the shadow-hiding opposition effect (SHOE) [5],

In this model, Mg# is set to range from 40 to 80 at intervals of 5, Fo is the same value as Mg#, and Wo of low-Ca pyroxene (LCP) is set to range from 0 to 20 at intervals of 5, and Wo of high-Ca pyroxene (HCP) ranges from 20 to 50 at intervals of 5. The ranges of mineral abundances for olivine, HCP and LCP are 0-60% at 2% intervals, with the total abundances of HCP and LCP being no more than 60%. The abundance of Plagioclase ranges from 0 to 100% at intervals of 2%. Spectral reddening and darkening effect that are caused of space weathering is simulated with the method described in Hapke (2001). We used the optical constants of iron metal measured by Cahill et al. (2012). The volume fraction of SMFe (Submicroscopic metallic iron) ranges from 0 to 0.15% at 0.05% intervals. We finally build a spectral library containing more than 10 million spectra.

Results and discussions: We will present our spectral matching results of major mineral endmembers, and comparing the modeled mineral and chemistries with those measured by LSCC.

Spectral Matching: Spectral matching is based on the method of Clark et al. (2003) [6]. During each spectral match, the continuum is removed both for the observed spectrum and library spectra, and then the best match is determined by their minimum RMS. The continuum of each spectrum is a straight line defined by two points, which are the local maximum reflectance between 0.62-0.89 µm and 1.3-1.8µm for olivine and between 0.62-0.79 µm and 1.1-1.6 µm for pyroxene. The average RMS for all the spectral matching is ~0.02, and Figure 2 shows spectral matching results for different mineral modes. It can be seen that our modeled spectra can match most of the features to the measured sample spectra.

Mineral and Chemistries content validation: The Lunar Soil Characterization Consortium (LSCC) has measured the spectra, modal mineral abundances and chemistries for 19 lunar soils under four different grain sizes [7,8]. In this work, we mainly consider the samples sized from 10-20 µm. We derived mineral abundances and chemistries content using LSCC spectra and our model, then compare to those measured by LSCC, shown in Figure 3. The major mineral abundances derived by our model and those measured by LSCC show a very good correlation, with their regression coefficient R being as high as 0.9. The chemistries for minerals also show a good correlation, with R being 0.73.

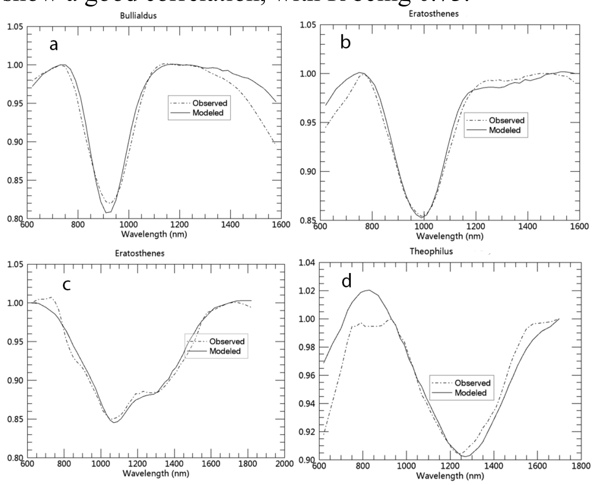

Fig. 2 Spectral matching result for (a) LCP, (b) HCP, (c) Olivine and (d) Plagioclase.

Conclusions: We built a new model with radiative transfer theory to derive mineral abundances and their chemistry contents, and by comparing to those mineral and chemistry contents of lunar samples measured by LSCC, our modeled results show a good correlation with LSCC results, showing that our model is valid in deriving mineral and chemistry content.

In the future, we will apply this model to remote sensed spectral images to study the central peaks of lunar impact craters, and inspect both the mineral abundances and chemical variation within the lunar crust.

References: [1] Cahill et al., (2009) JGR, 114(E9). [2] Lemelin et al., (2015), JGR, 120(5):869-887. [3] Trang et al., (2013), JGR, 118(4):708-732. [4] Hapke B., (2012), Cambridge University Press. [5] Hapke B., (1981), JGR, 86(B4):3039-3054. [6] Clark et al., (2003), JGR, 108(E12). [7] Pieters et al., (2000), LPS XXXI, 1865. [8] Taylor et al., (2001), JGR, 106(E11): 27985-28000

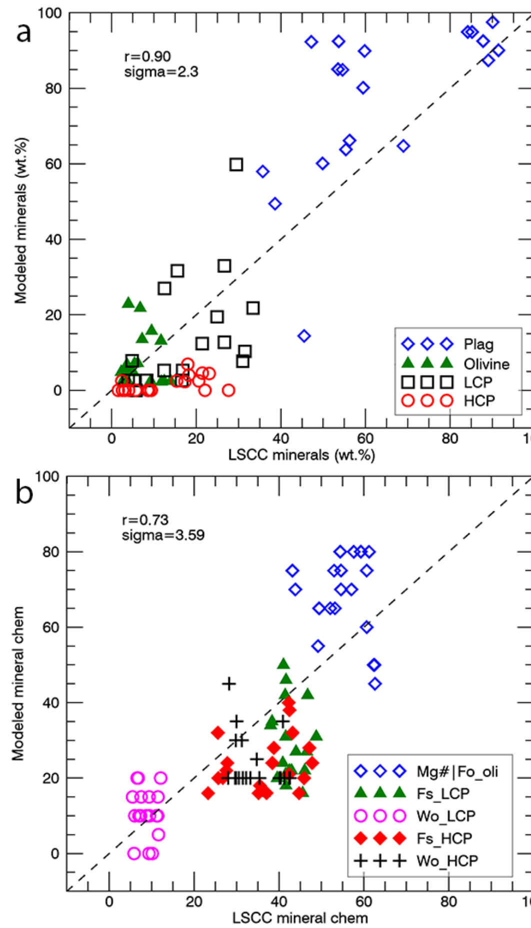

Fig 3 (a) Modal mineral abundances and (b) chemistries derived by radiative transfer model vs measured by the Lunar Soil Characterization Consortium.