Reflectance conversion methods for the VIS/NIR imaging spectrometer aboard the Chang'E-3 lunar rover: a preliminary investigation. Bin. Liu[1], Jianzhong. Liu[1], Guangliang. Zhang[1], Zongcheng. Ling[2], Jiang. Zhang[2], Zhiping. He[3], Benyong. Yang[4]. [1]National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China (liub@nao.cas.cn); [2]School of Space Science and Physics, Shandong University at Weihai, Weihai, Shandong 264209, China; [3]Shanghai Institute of Technical Physics, Chinese Academy of Science, Shanghai 200083, China; [4]Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Science, Anhui 230031, China

Introduction: The second phase of Chang'E Program(also named by Chang'E-3) is to land and perform in-situ detection on the lunar surface. A VIS/NIR imaging spectrometer(VNIS) will be carried on the CE-3 lunar rover to detect lunar minerals and resources distribution[1], The spectral range for VNIS is from $0.45\mu m$ to $2.4\mu m$, lunar minerals can be recognized effectively in this spectral coverage. VNIS is the first mission in the world to perform in-situ spectral measurement on the surface of the Moon, the reflectance data of which is fundamental for lunar composition interpretation, whose quality would greatly affect the accuracy of lunar elemental and mineral inversions.

Until now, imaging spectrometers' in-situ detection were only applied by Mars Rovers, we firstly reviewed reflectance conversion methods for Mars land rovers (Viking landers, Pathfinder and Mars Exploration rovers, etc)[2-5]. Secondly, we modified Mars Rover reflectance conversion method according to the difference between lunar and Mar's environment and applied the method to VNIS, by comparing VNIS' olivine reflectance data measured in the laboratory with standard spectrometer(ASD) got at the same time and the same observation conditions, the biggest spectral uncertainty is within 9.8%, our reflectance conversion method is suitable for lunar in-situ detection.

Methods: According to the difference of detection environment and geometry between lunar and Mars, we improved Mars reflectance conversion methods and derived two reflectance products: radiance factor data (I/F) and reflectance factor data (R*).

I/F conversion: We firstly calculate the solar irradiance at lunar surface through every AOTF imaging spectrometer's band pass, and then set up a look-up table. Dividing VNIS's radiance data which have been calibrated by look-up table's results, we get I/F data in a fast and simplistic way:

$$R_j = \frac{I_j}{L \int I_0(\lambda) R(\lambda) d\lambda}, \quad L = \frac{1}{\pi d^2} \ (1)$$

Where R_j is the jth band I/F, I_j is the jth band image radiance data, $I_0(\lambda)$ is solar irradiance, $R(\lambda)$ is the jth band imaging spectrometer's spectral responsivity, and d is the distance between the moon and the sun.

Reflectance factor(R*) conversion: The proposed procedures for spectrometer's reflectance factor conversion are as follows:

(1)   Measure and calculate reflectance factor data $R_{\lambda, lab}(i,e,g)$ of calibration target at every possible geometries in ground laboratory experiments;

(2)   Resampling calibration target's laboratory spectrum $R_{\lambda, lab}(i,e,g)$ into VNIS's every band's standard spectrum $R_{\lambda, std}(i,e,g)$;

(3)   Calculate imaging area's R* ($R_{\lambda, sample}(i,e,g)$)by equation (2):

$$R_{\lambda, sample}(i,e,g) = \frac{I_{\lambda, sample}(i,e,g)}{I_{\lambda, std}(i,e,g)} R_{\lambda, std}(i,e,g) \ (2)$$

$I_{\lambda, sample}(i,e,g)$ is the sample's radiance data at fixed geometry of light incident angle i, emergence angle e, phase angle g. $I_{\lambda, std}(i,e,g)$ is calibration target's radiance at the same geometry.

VNIS's work mode and geometry is different from Mars multispectral cameras. there is a dust cover aboard VNIS to prevent lunar dust felling on the calibration target, this dust cover will be opened when the spectrometer work and it will be closed when the spectrometer not work. So, we don't need to consider the dust effect on the calibration target. To avoid of high working temperature for the rover, VNIS's geometry is restricted at solar elevation angle from $15°$ to $33°$, thus the light incident angle will be changed from $57°$ to $75°$, The emission angle is fixed at $45°$. So a different BRDF model should be set up for calibration.

Methods Validation: Before VNIS brought to lunar surface, it should be done lots of ground validation experiments. Because laboratory light source is not sunlight, I/F conversion method could not be validated, but we can validate reflectance factor conversion method by comparing VNIS reflectance to a standard spectrometer(ASD)'s data. ASD instrument we used here is Field Spec 3, the performance and specification of which could be known from the web site (http://www.asdi.com).

During the process of experiment, ASD and VNIS firstly measured the calibration target's spectrum at the same time and the same viewing geometry, After calibration target detected, we changed the objective to the mineral sample of olivine. Figure 1 shows the vali-

dation pipeline, VNIS raw data calibration process include bias and dark current subtraction and radiance calibration. Figure 2 shows VNIS validation experiment devices and measurement principle. Figure 3 demonstrates the olivine sample's reflectance spectrum comparison results between ASD and VNIS . From the picture we could know that the shape and value of VNIS reflectance data is similar and close to standard ASD reflectance data, but we also noted that at some wavelengths, the VNIS reflectance spectrum is not as smooth as ASD. this is mainly because the standard ASD's reflectance data is averaged by ten times measurement results, but VNIS reflectance data is not averaged.

Spectral uncertainty is an assessment parameter which could tell us the deviation of VNIS reflectance to ASD data.We calculate spectral uncertainty parameters between VNIS and ASD reflectance data, the calculation function is as follow:

$$\delta s = \left| \frac{S_{VNIS,i} - S_{SS,i}}{S_{SS,i}} \right| \times 100\%$$

Where δs is spectral uncertainty parameter, $S_{VNIS,i}$ is VNIS the ith band reflectance factor, $S_{SS,i}$ is ASD the ith band reflectance factor. Figure 4 demonstrates every band's spectral uncertainty results, the biggest olivine's spectral uncertainty between VNIS and ASD is within 9.8%, which tell us that VNIS reflectance factor data fit standard ASD data well, our conversion method is suitable for lunar in-situ detection.
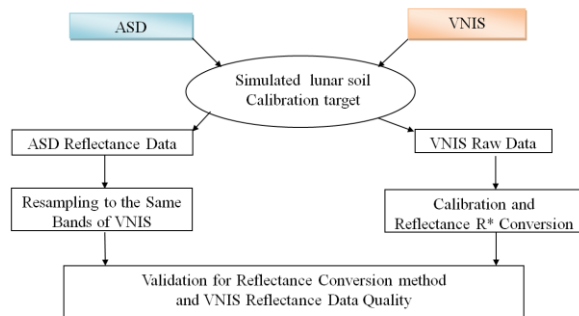

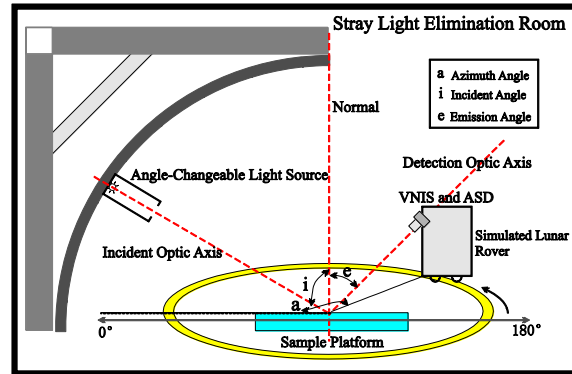**Figure 1.** VNIS Reflectance factor data (R*) conversion method validation pipeline.

Figure 2. VNIS ground science validation experiment devices and measurement principle. The validation experiment simulates the condition of CE-3 lunar rover's work mode on lunar surface.
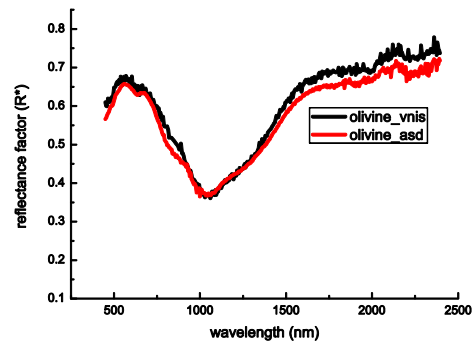

Figure 3. Olivine sample's reflectance factor spectrum comparison between VNIS and ASD.
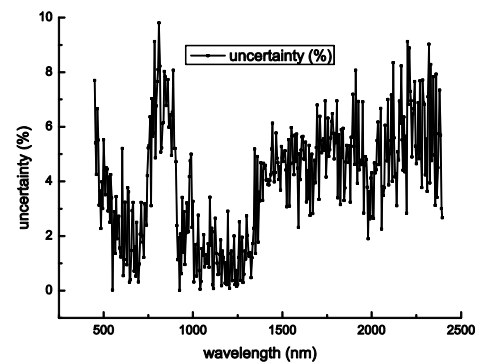

Figure 4. Olivine sample's spectral uncertainty between VNIS and standard ASD.

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