Preliminary results from ground-based lunar observations in China

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NSMC

GSICS Global Space-based Inter-Calibration System

Outline

- ***Preparation of Ground-based Lunar observation***
- ***Implementation of Lunar observation***
- ***Data processing and Preliminary Results***
- ***Lessons and Next***

Ground-based Lunar observation Implementation

- Lunar observation concept and Instrument development
  - Lunar Imaging spectrometer
  - Hyspectral lunar-photometer
- Ancillary measurement for lunar observation data processing
  - Aerosol: Lidar or photometer
  - Atmosphere sounding profile
  - on-site Instrument checking and calibration
- Observation site selection
  - High altitude (>2km)
  - Clean and arid atmosphere
  - More clear sky
- Observation plan design
- Data processing
  - Data calibration and quality control
  - Atmosphere correction
  - Lunar phase and angle calculation
  - Model validation and improvement

Ground-based Lunar instruments

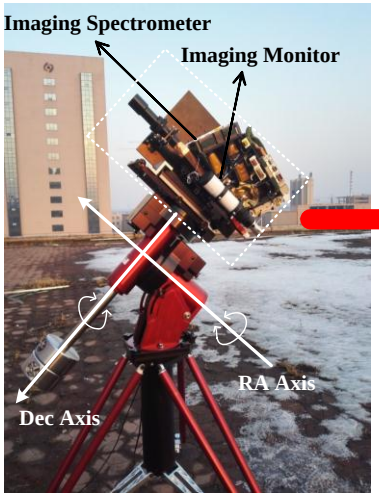
	Instruments	Vendor	Spectral	Location	Remarks
Lunar instruments	Lunar imaging spectrometer	Changchun	400-1000nm Resolution: 2~10nm	Lingshan, Dunhuang, Lijiang	Lunar imaging Autom tracking
	AOTF imaging spectrometer	SITP	450nm~1000nm，2~8nm	Lingshan, Dunhuang	Manual tracking
	Shortwave Infared imaging HSFTS	Xi an	900nm~2500nm，60 bands	Lijiang	Manual tracking and imagomg
	Hyspectral lunar-photometer	Changchun	350-1100nm 1~5nm	Lingshan, Dunhuang, Lijiang	Lunar irradiance Autom tracking
	CE318U-lunar-photometer	CIMEL	10 bands	Dunhuang, Lijiang	Lunar irradiance Autom tracking
Ancillary instruments	Lidar	704 Institute	532nm; 1064nm	Lijiang	Aerosol at night
	CE318 sun-photometer	CIMEL	9 bands	Lijiang	Aerosol at daytime
	Atmosphere sounding	VISALA		Lijiang	Atmosphere profile
Reference instrument	ASD FieldSpec® 3	ASD	350-2500nm	Lingshan, Dunhuang, Lijiang	Calibration and stability monitoring

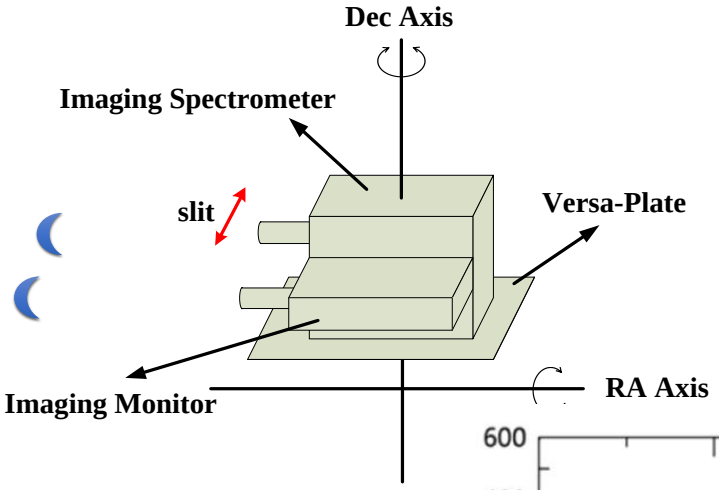
Instrument development:
Ground-based Lunar Imaging Spectrometer

Imaging Spectrometer	Specification
Spectral range	400-1000nm
Spectral channels	>260
Spectral sampling width	2-10nm
Field of view	0.7 degree
Instantaneous Field of view	0.0056 degree
Pixels across track	253

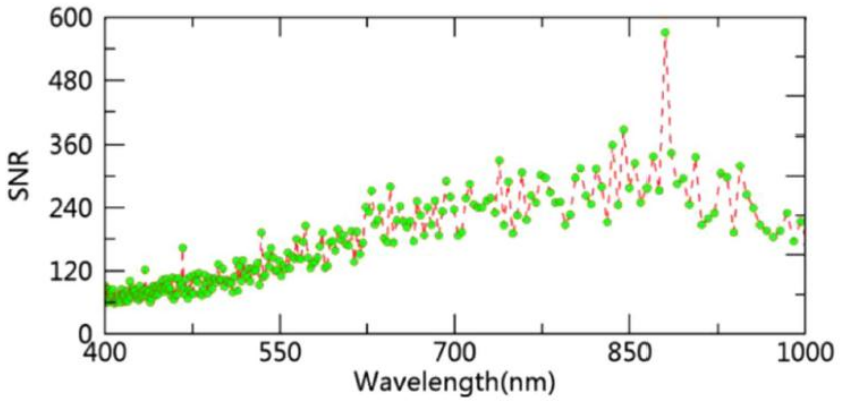
Imaging Monitor	Specification
CCD	1280×1024 pixel
Field of view	1.84° ×1.47°

Equatorial Mount	Specification
Tracking accuracy	±7"





Equatorial Mount



Ground-based Lunar Imaging Spectrometer (GLIS)

Automated Scanning Observations of the Moon

Sweeping method：

（1）park the spectrometer as the Moon moves across the field of view（IFOV）

Automated observation：

（1）orbit prediction of the moving Moon

（2）time bias

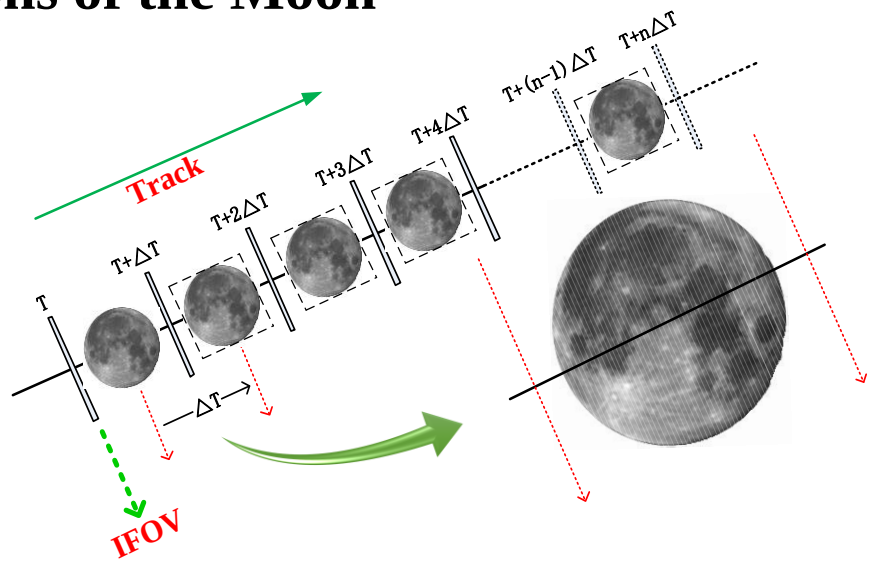
$$\psi = \omega_{track} \Delta T$$

IFOV: instantaneous Field of view

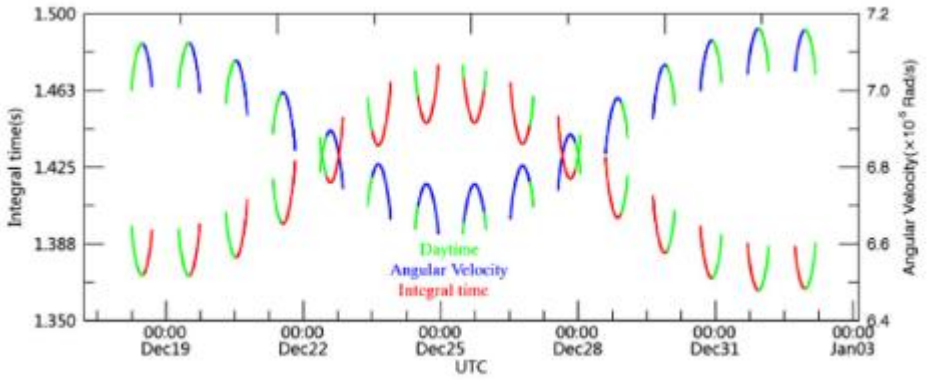
ΔT: time interval of one lunar disk

ω_{track} : angular velocity track of the Moon

ψ: rotation angle, >0.5°



Integration time and angular velocity with time



YANG WANG, YU HUANG, SHURONG WANG, ZHANFENG LI, ZIHUI ZHANG, XIUQING HU, PENG ZHANG, Ground-based Observation System Development of the Moon Hyper-spectral Imaging, Publications of the Astronomical Society of the Pacific, 2017,in Press.

Instrument development:

Large-aperture static imaging spectrometer (LASIS)

- The large-aperture static imaging spectrometer (LASIS) is a spatiotemporal modulating imaging interferometer.

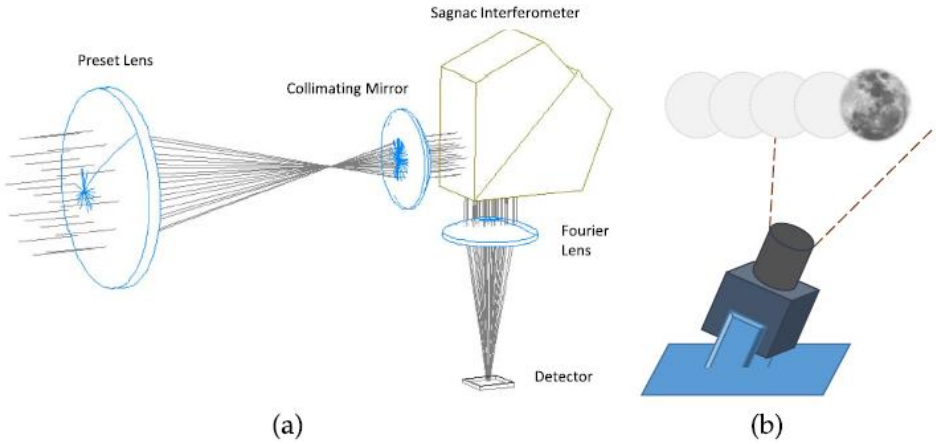


Fig. 1. (a) Imaging principle of LASIS. (b) Configuration of the ground-based lunar observation system.

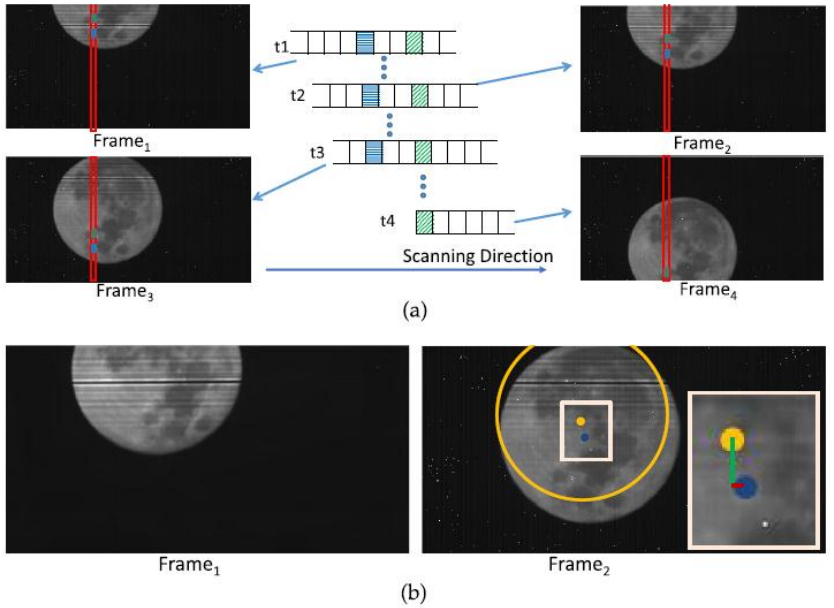
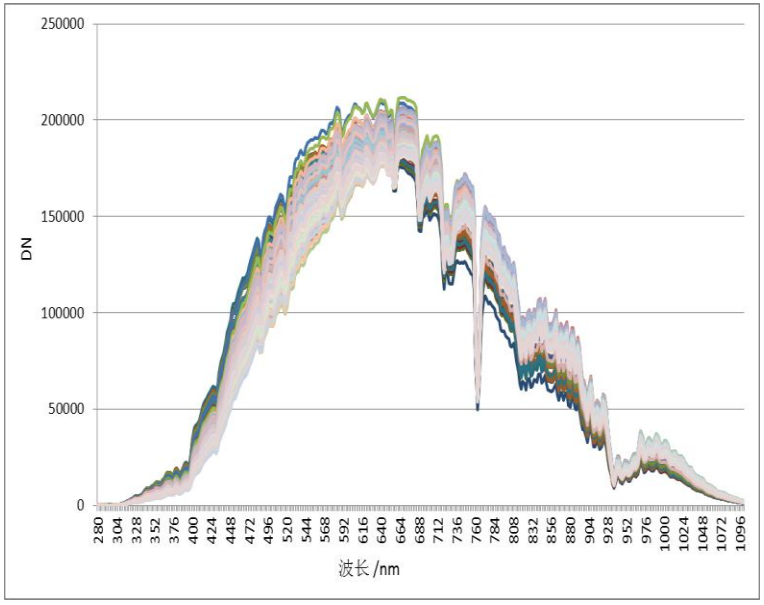


Fig. 2. (a) Scanning procedure. One column is used to demonstrate the corresponding relationships between LASIS frames. The green and blue grids correspond to images of two target points, respectively. (b) Demonstration of two kinds of translations. On $Frame_2$, the yellow circle is the desired position of the moon's image. In the zoom view, the green line and red line correspond to the two kinds of translations.

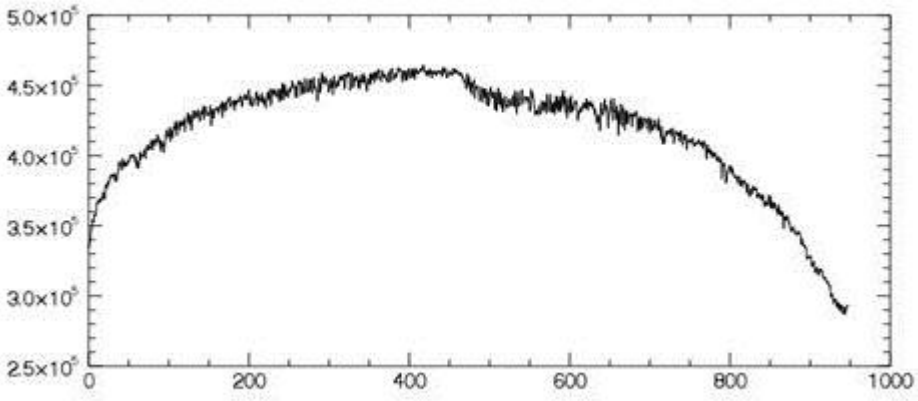
*Geng Zhang, Shuang Wang, Libo Li, **Xiuqing Hu**, and Bingliang Hu, "Interference data correction methods for lunar observation with a large-aperture static imaging spectrometer," Appl. Opt. 55, 8770-8778 (2016).*

Hyspectral Lunar-photometer

Measurement Results



Raw spectral data (DN) in different time



Irradiance evolution at 678nmm in Dec 22, 2016

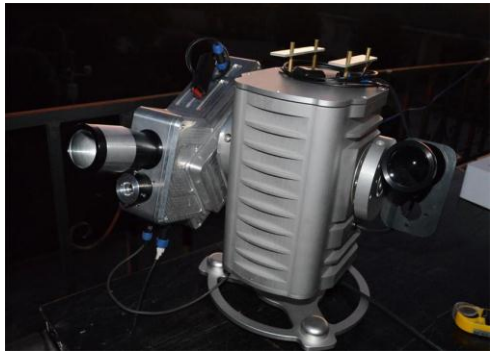
We found there is apparent fluctuation In the temporal . Deviation： 5.6%

Lunar Instruments Testing experiments

- First Instrument Testing experiment in Lingshan, Beijing （June 24--July 3, 2015)
- Second Instrument Testing in Dunhuang, Gansu Province （August 20--Sep 3, 2015)
- Formal ground-based Lunar Observation for three months in Lijiang, Yunnan (Dec 17, 2015-- March 1, 2016)

Key Instruments for Moon observation

Main Instrument for this observation



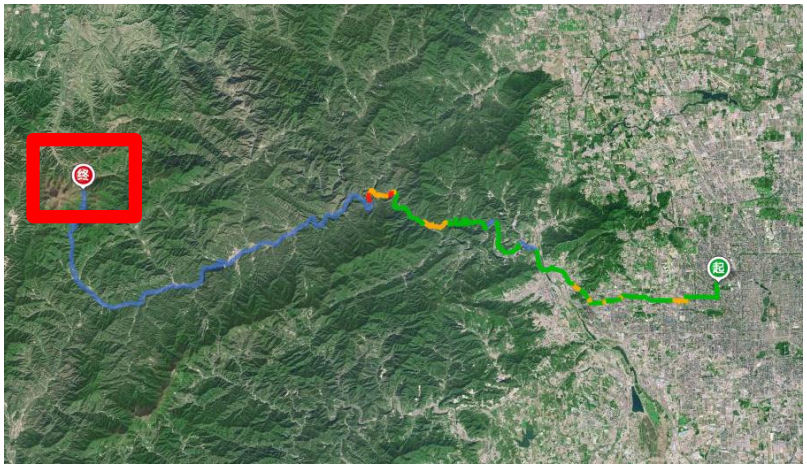
Intrument is Not stable and testing

Manual tracking; without good calibration

Manual tracking Need more improvement

Lunar observation location selection

- Lingshan
  - First instrument testing
  - Near from Beijing (122Km)
  - Latitude:2100m
  - No air pollution



- Lijiang
  - Formal experiment
  - Location:100° 01′51″E，26° 42′32″N
  - Latitude : 3193m
  - Near from Astronomy station

Lunar Observation in Lijiang, Yunnan

Lunar Imaging Spectrometer

Hyperspectral Lunar-photometer

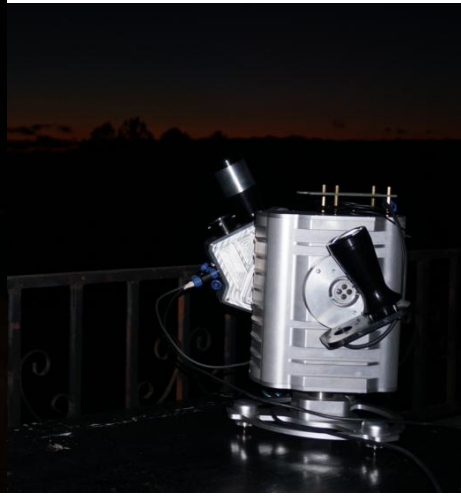
AOTF Imaging Spectrometer

CE318U Lunar-photometer

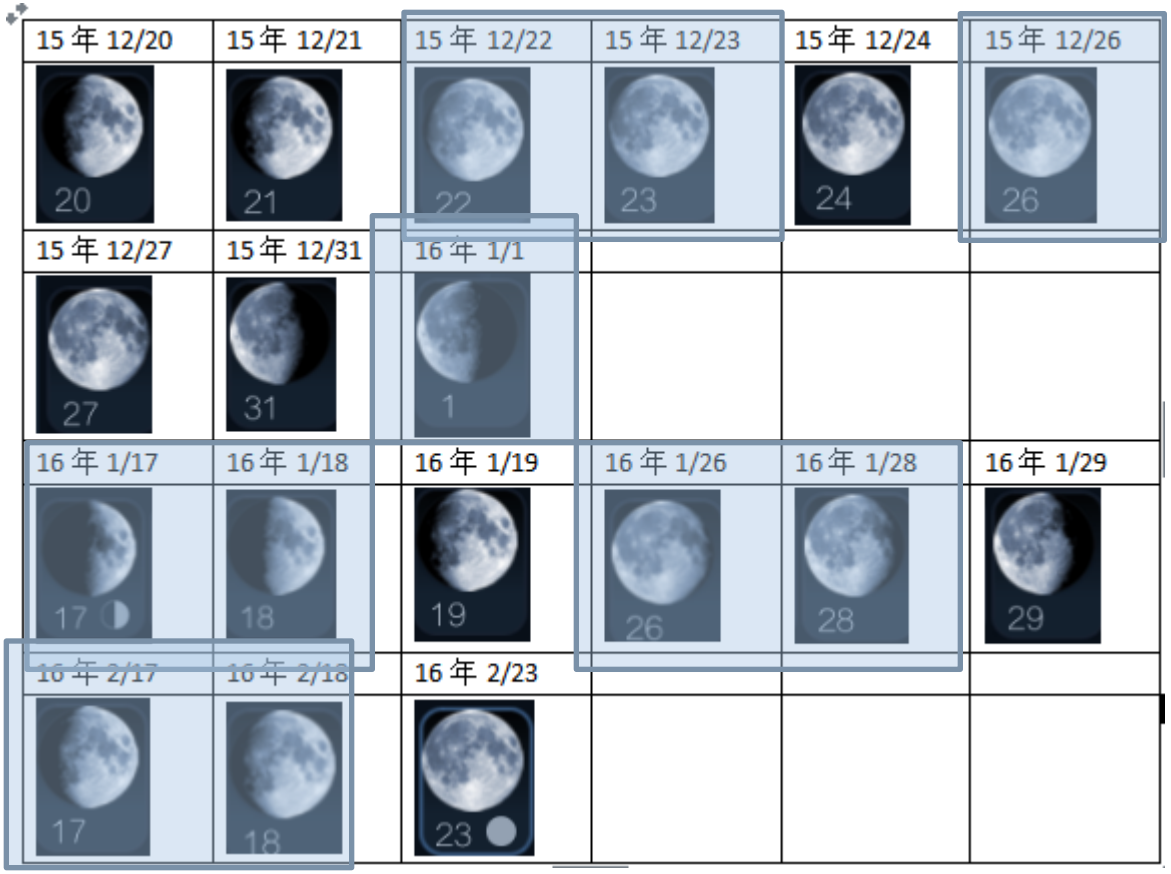
LASIS

Yulong Snow Mountain

Lijiang Weather Radar station



Valid Experiments Data



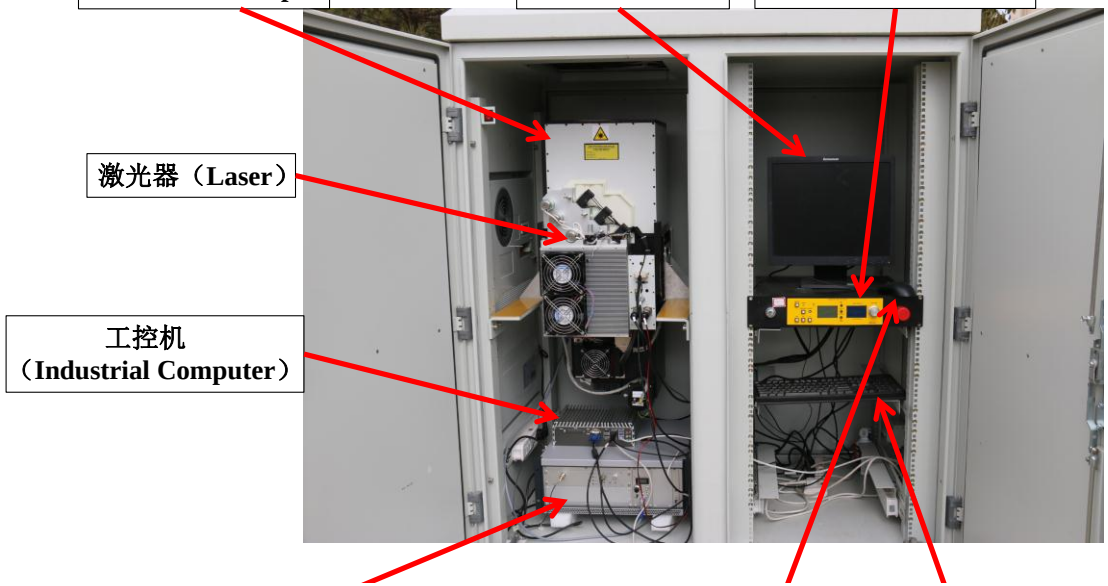
Weather Records

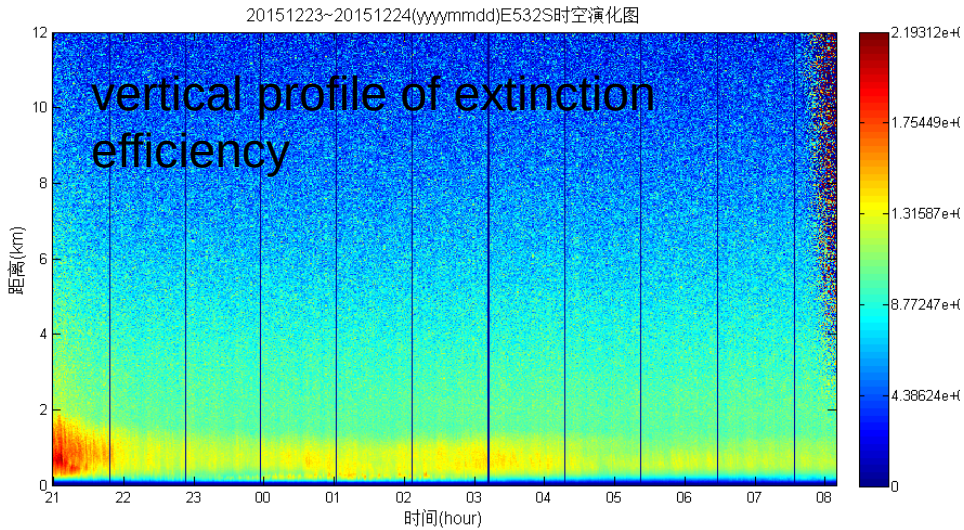
2015/12/27	27日夜间21:44至28号06：59	少量云
2015/12/31	1月1日00：58至1日07：07	少量云
2016/1/1	02日00:02至02日07:51	晴
2016/1/2	----------	多云
第二周期		
2016/1/16	16日19:55至17日01:00	晴
2016/1/17	17日19:58至18日02:08	晴
2016/1/18	18日20:12至19日03:08	晴
2016/1/19	19日19:29至18日04:13	夜间有薄云
2016/120-25	----------	天气过程，降雪
2016/1/26	26日21:36至27日06:31	晴
2016/1/28	28日23:34至18日07:08	晴
2016/1/27	----------	降雪
2016/1/29	30日00:38至18日07:04	夜间薄云
2016/1/30	----------	降雪
第三周期		
2016/2/17	17日19:50至18日03:54	夜间气溶胶较大
2016/2/18	18日20:17至19日04:52	薄云
2016/2/19-22	----------	降雪
2016/2/23	23日20:49至18日07:44	有云
2016/2/24-28	----------	降水

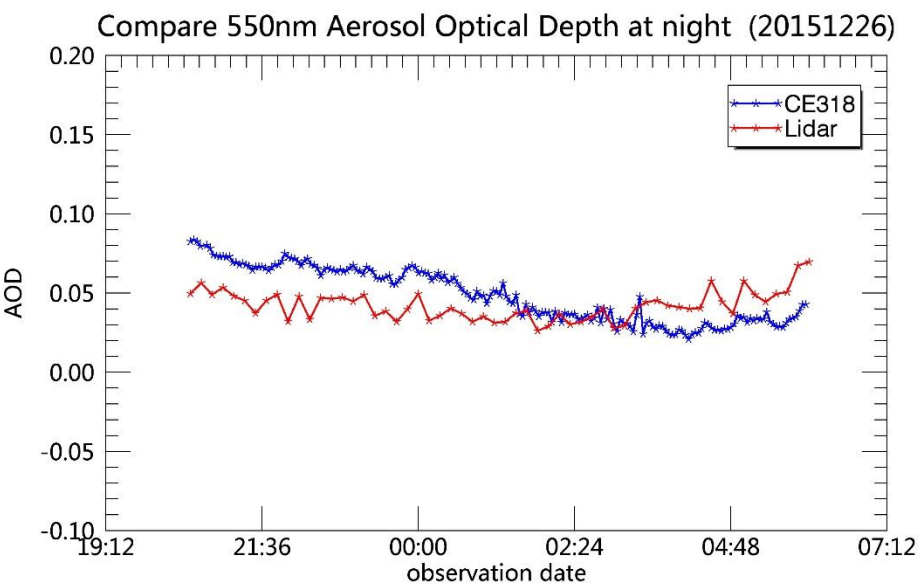
This figure shows the experiments days in Lijiang. According to the weather records, we selected 10d valid experiment data for analysis processing.

Atmospheric observation

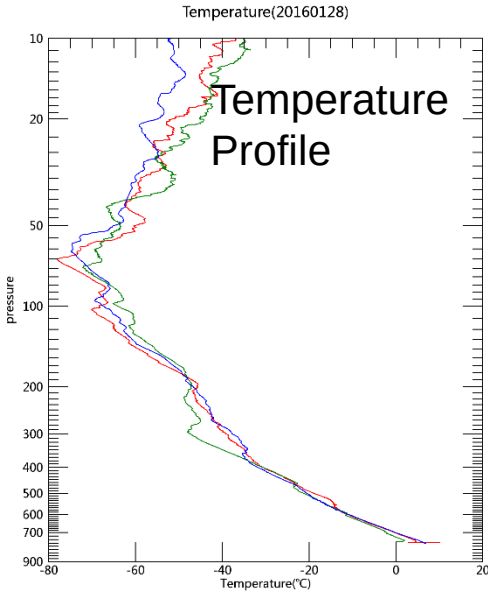
Lidar and CE-318-Lunar for day-night aerosols optical depth

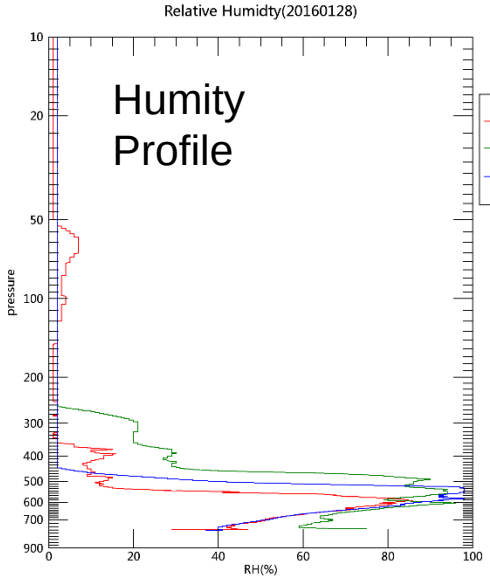


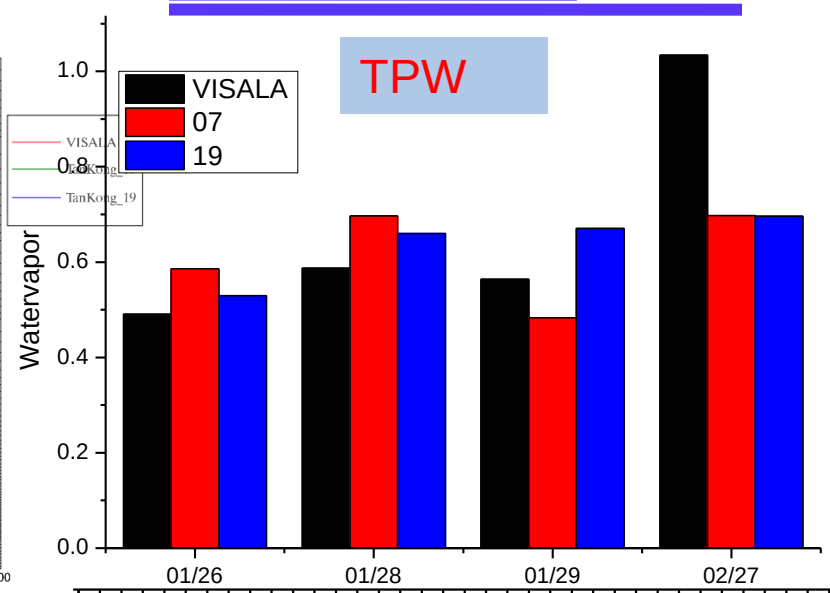


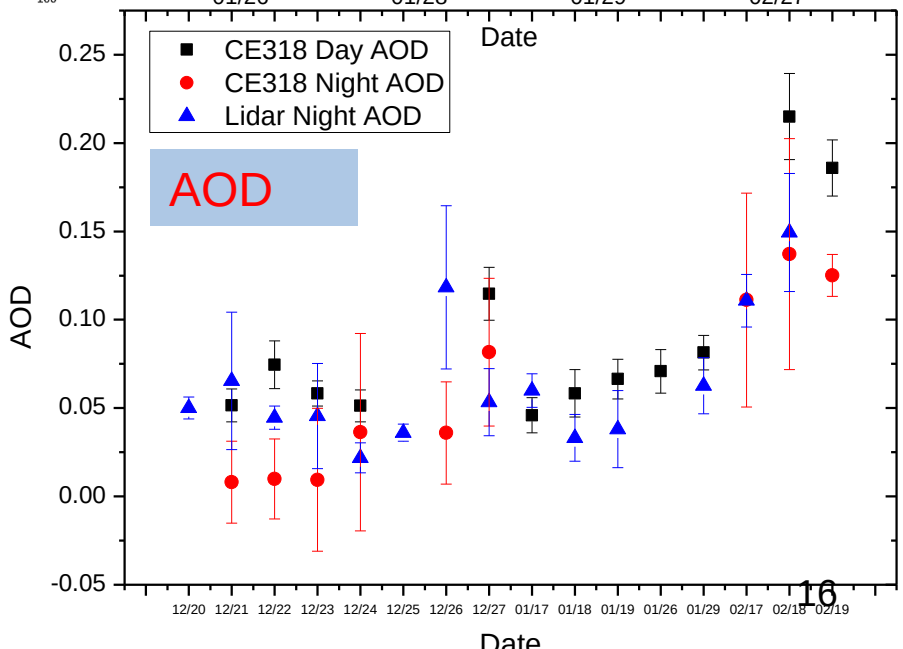


Atmospheric observation

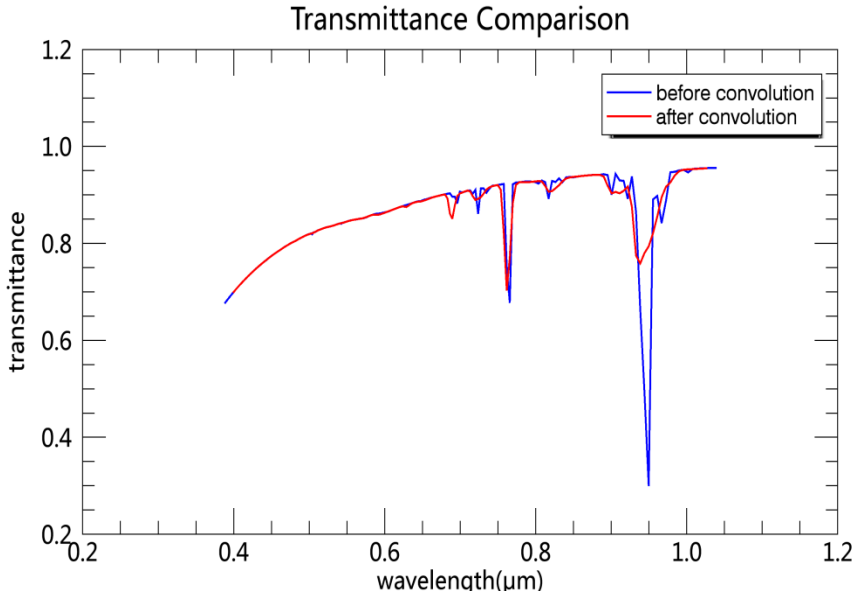


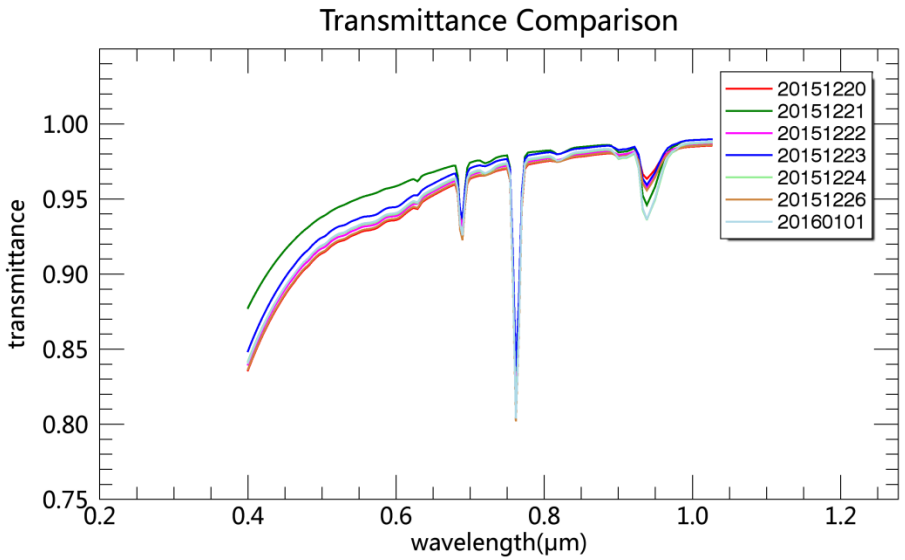


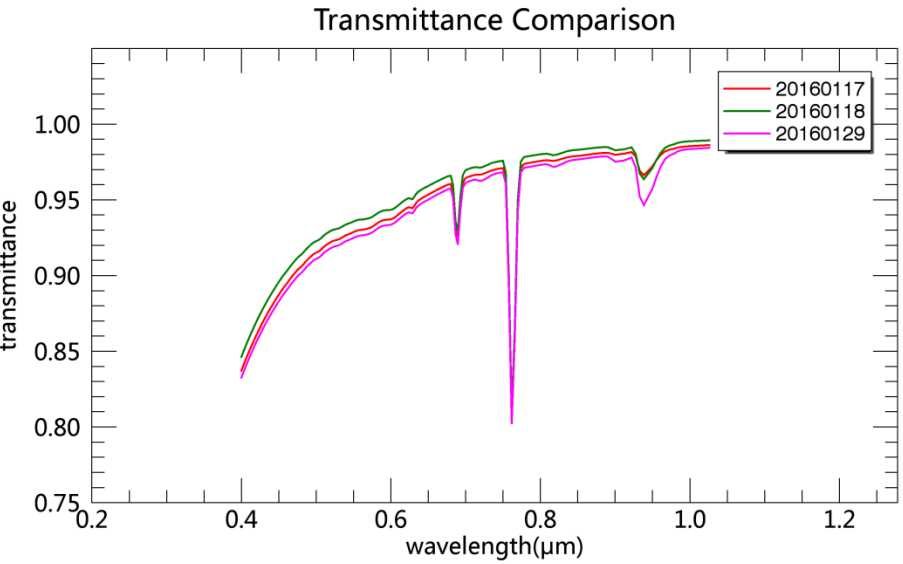


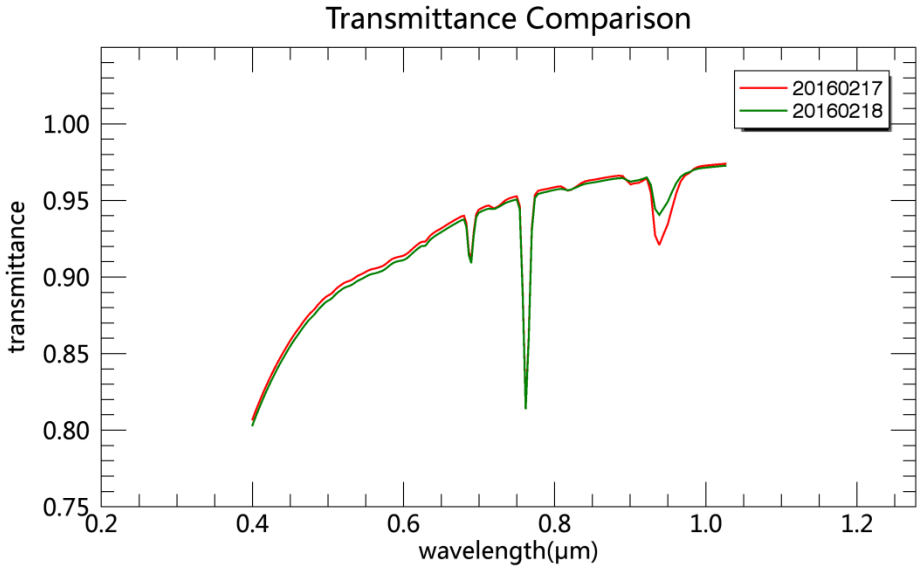


Atmospheric Correction

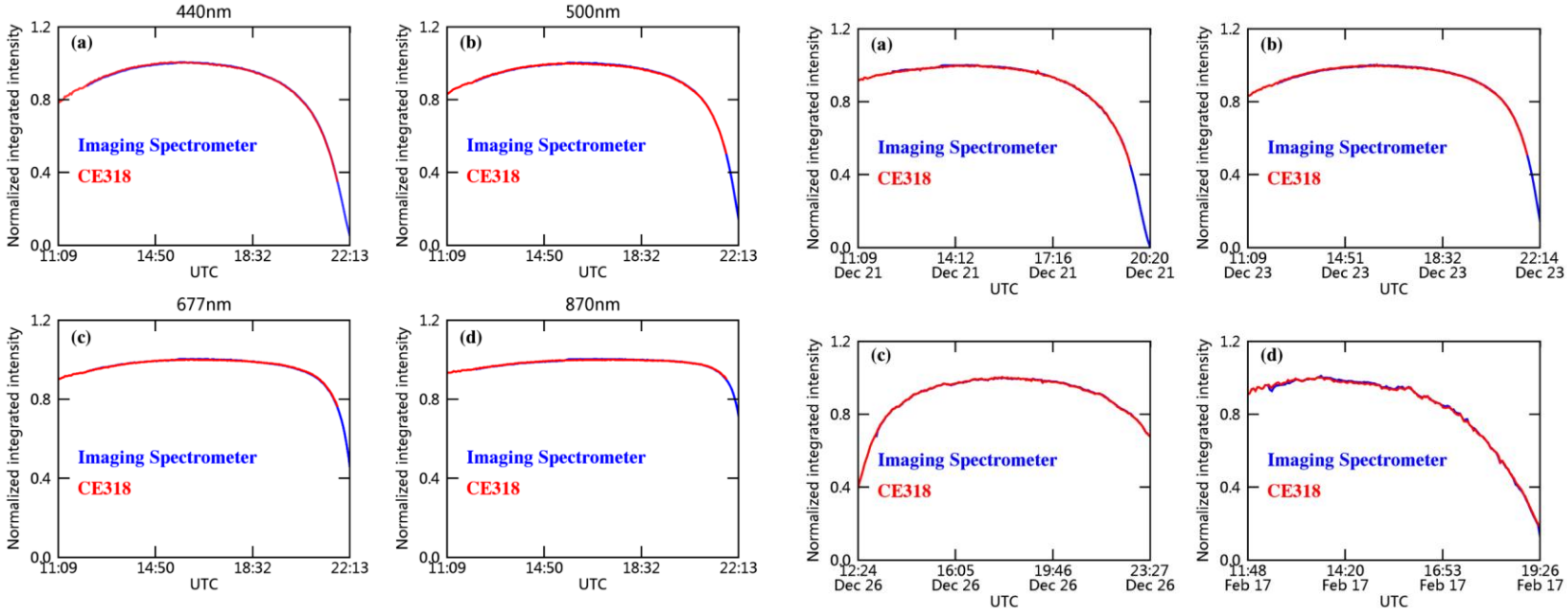








Comparison between Lunar Imaging Spectrometer and CE318-lunar



(1) wavelength **(2) time**

Normalization Imager data and CE318 Lunar data

Lunar Imaging Spectrometer and CE318 lunar Cross-Comparison :

（1）2015.12.23： 440，500，677，870nm

（2）500nm: 2015.12.21，201512.23，2015.12.26, 2016.2.17

Consistent trendency ⟹ stability of the imaging spectrometer

LASIS data Processing

- A. Translation Estimation
  - Boundary-Based Image Correlation Approach
  - Circle-Matching Approach for Full Moon Observation
- B. Interferogram Extraction
- C. Spectral Datacube Reconstruction

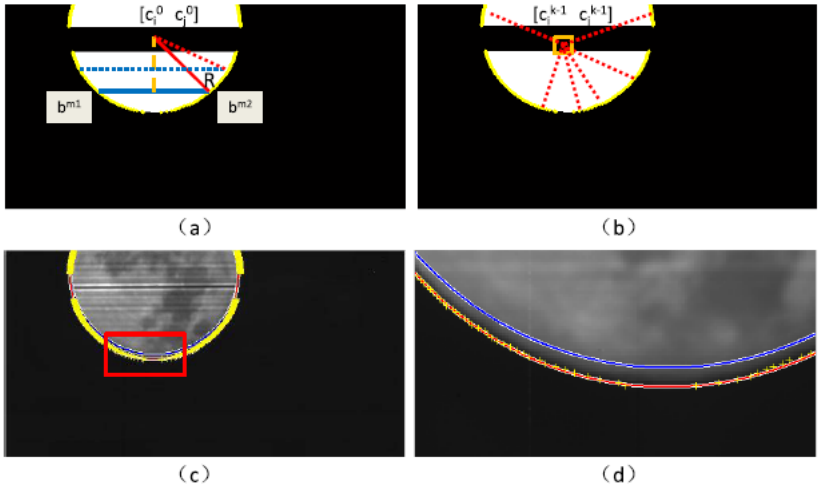
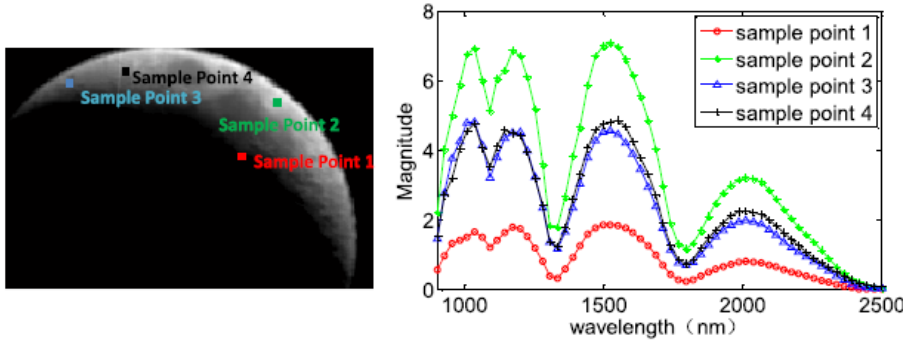
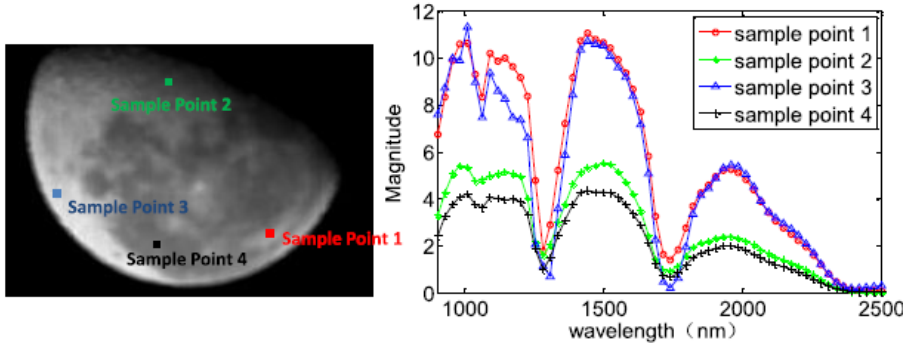


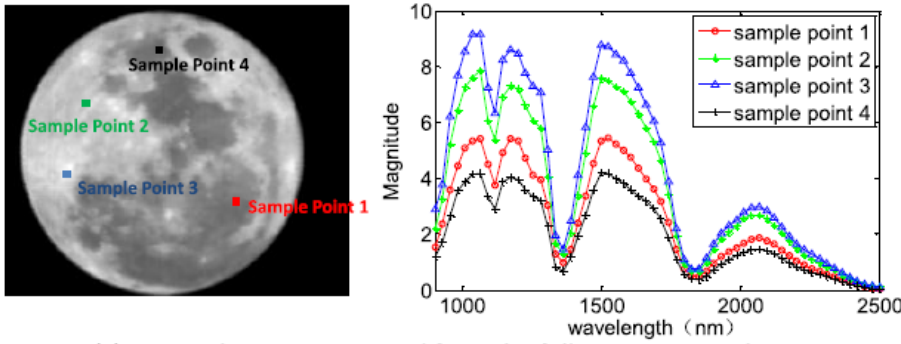
Fig. 6. (a) Visualization of the chord voting process. The red lines represent the radius R, and the blue lines are the chords. (b) Visualization of the pyramid search process. The orange box is the searching range in the kth level. Red lines are the candidate radii. (c) Lunar boundary circle found by chord voting method (shown in blue) and the more accurate one found by the pyramid searching scheme (shown in red). (d) Zoomed view of the boxed area in (c).



(a) Spectral curves generated from the new moon data with P1



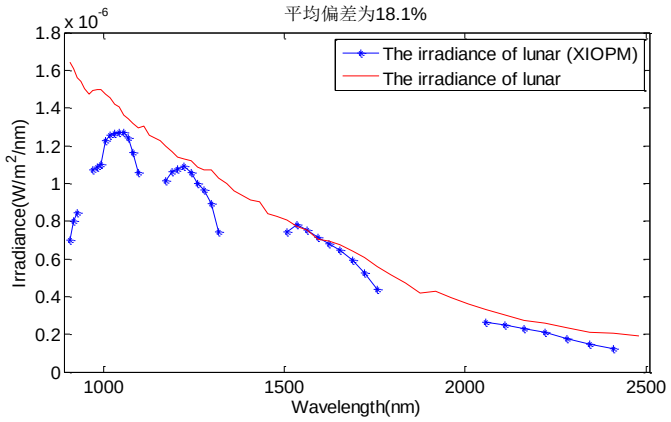
(b) Spectral curves generated from the gibbous moon data with P1



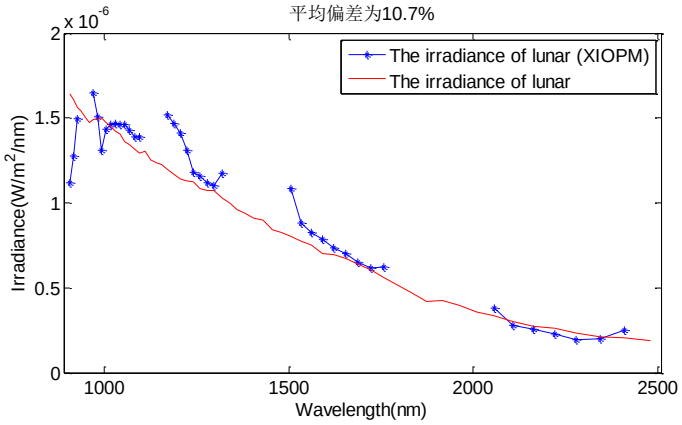
(c) Spectral curves generated from the full moon case with P2

LASIS Comparison with ROLO

◆ Disk Irradiance



Before atmosphere correction
Irradiance Mean Bias=18.1%
2月24日（2016-02-24-00-02-42）



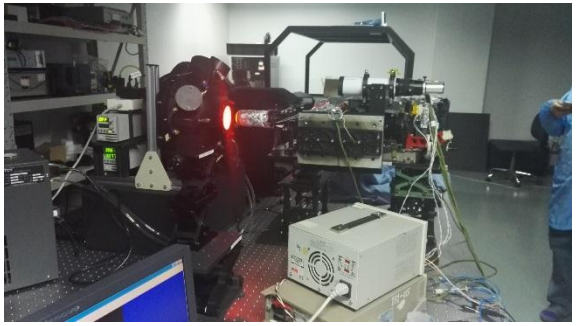
Before atmosphere correction Using MODTRAN
Irradiance Mean Bias=10.7%
2月24日（2016-02-24-00-02-42）

Lab Instrument Characterization and calibration

(1) **Spectral calibration** :

laser+

Integrating sphere(SIRCUS)

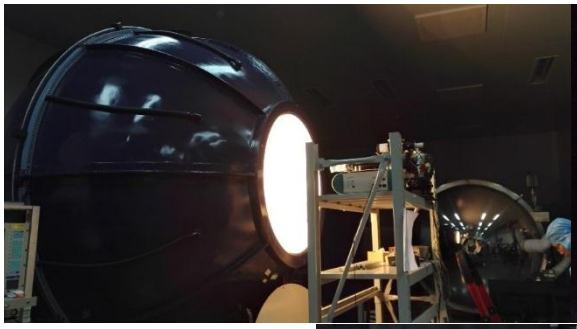


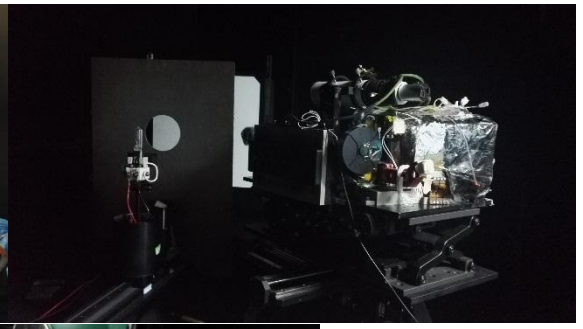
(2) **radiometric calibration**:

Lamp + Reference plate

Reference detector+

Integrating sphere（lamp/leds）





(3) **stray light measurement**

LEDs integrating sphere（tunable）

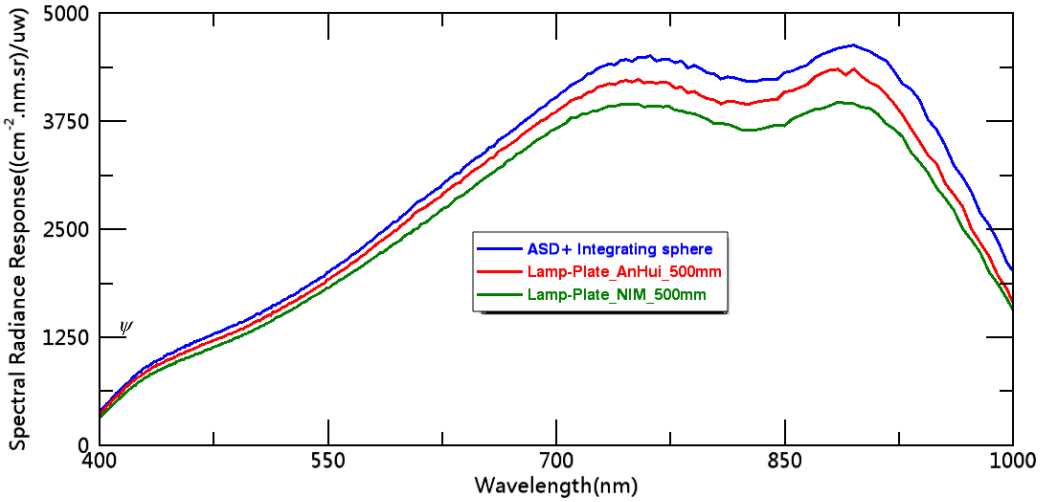
Instrument Characterization and calibration

Spectral radiometric response

(1) Lunar imaging spectrometer with a slit:
$IFOV_{cross} \times FOV_{along}$ ($0.0056^\circ \times 0.7^\circ$)

(2) Spatial stray light:
Stray light outside the field of view of the instrument

(3) Spatial Response using star observation



Spectral radiometric response

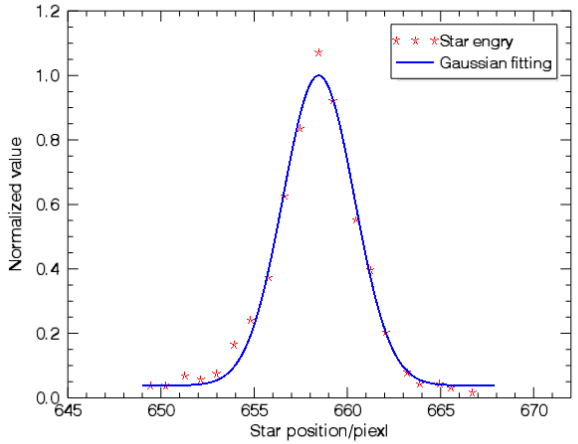
ψ : field angle of the object space with respect to the instrument

$$\psi_{Integrating} > \psi_{Anhui} > \psi_{NIM}$$

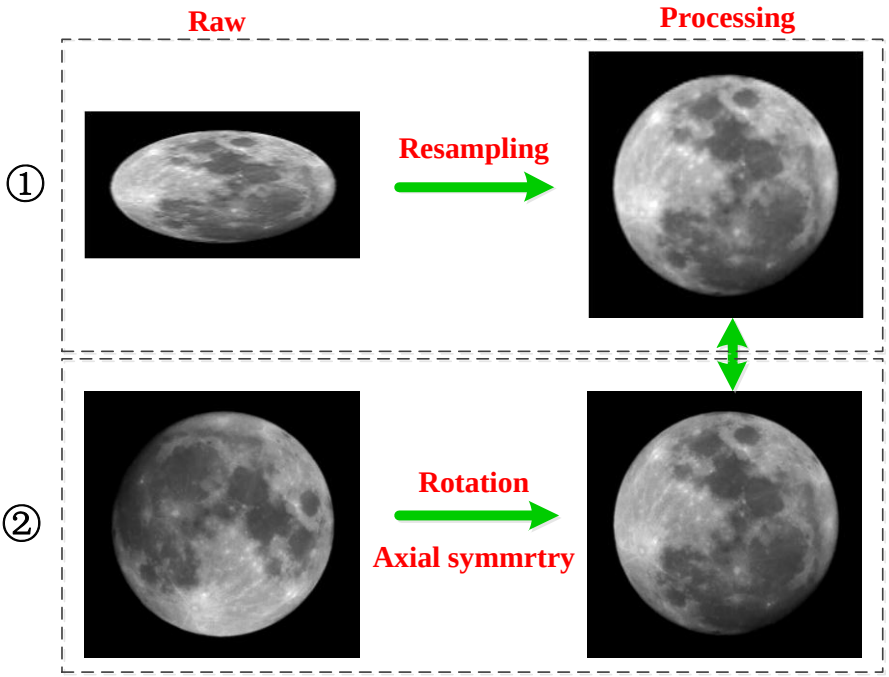
$$Stray_{Integrating} > Stray_{Anhui} > Stray_{NIM}$$

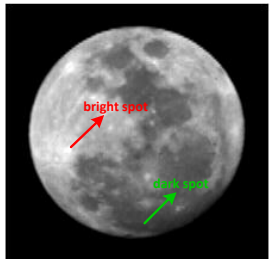
→ Lunar model

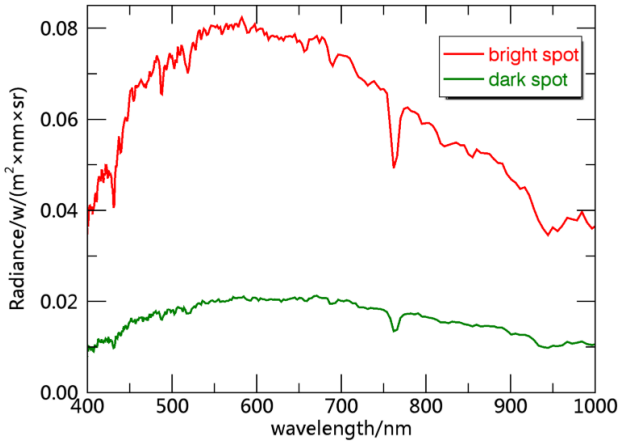
Spatial Response using star observation



Overall of Observation Results by GLIS

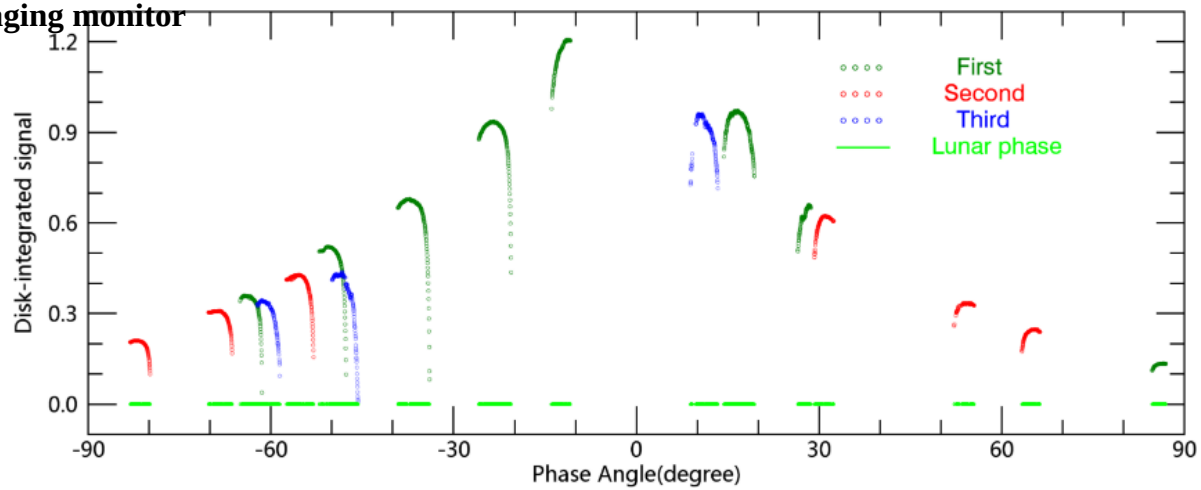






① Imaging spectrometer

② Imaging monitor

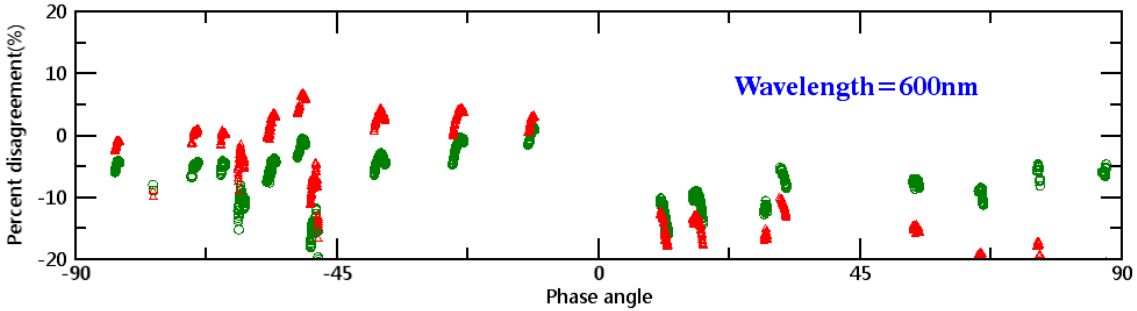


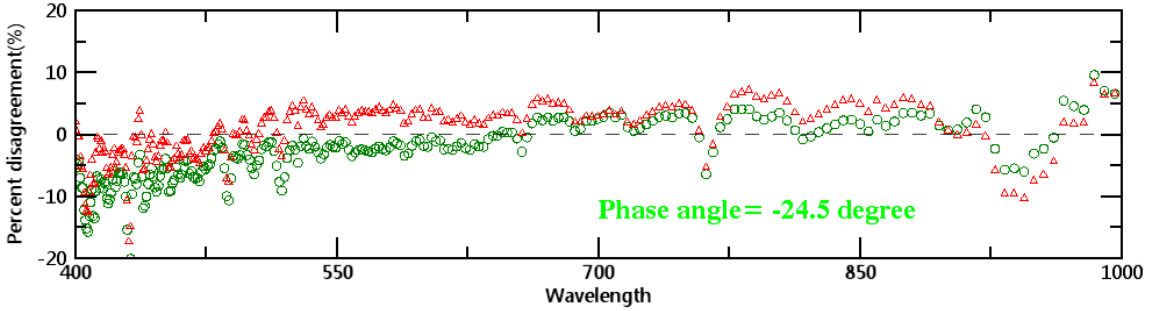
2017/3/24

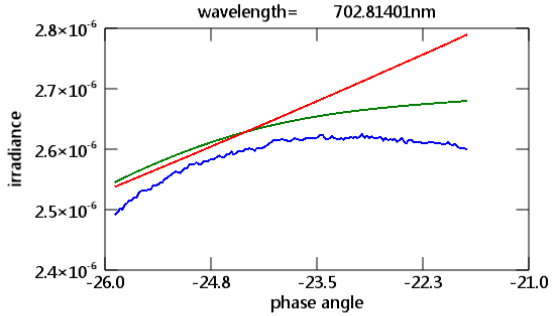
Comparison of Measurements with the Lunar Model

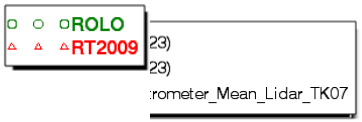
Percent disagreement between the imaging spectrometer and lunar model is

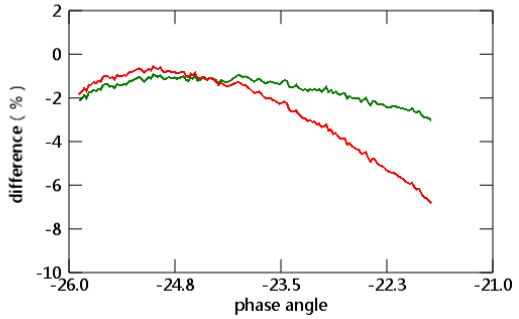
$$p = \frac{I_{instrument} - I_{model}}{I_{\ldots\ldots}}$$





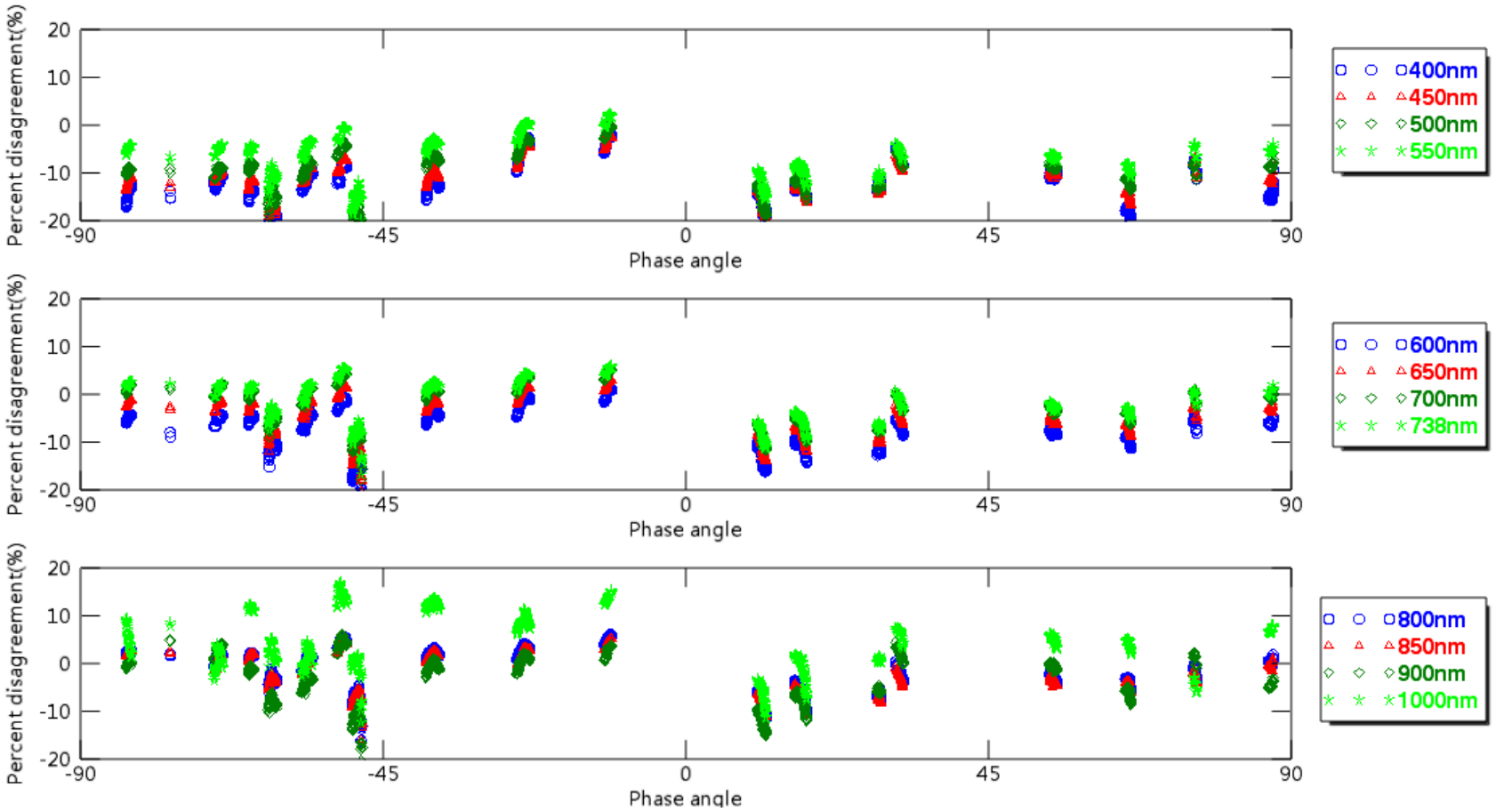






VS. ROLO and RT2009

Compare with ROLO Over Time in different WL



Phase Reddening Analysis

The ratio between the irradiance $I(\theta, \lambda)$ and the irradiance $I(\theta_0, \lambda)$ is

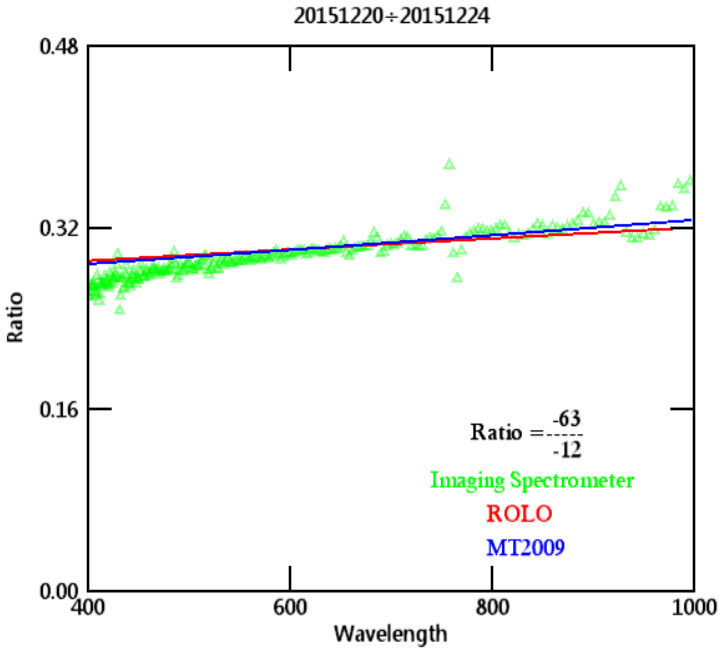
$$Ratio_i(\theta \mid \theta_0, \lambda) = \frac{I_i(\theta, \lambda)}{I_i(\theta_0, \lambda)} = a_i(\theta \mid \theta_0)\lambda + b_i(\theta \mid \theta_0)$$

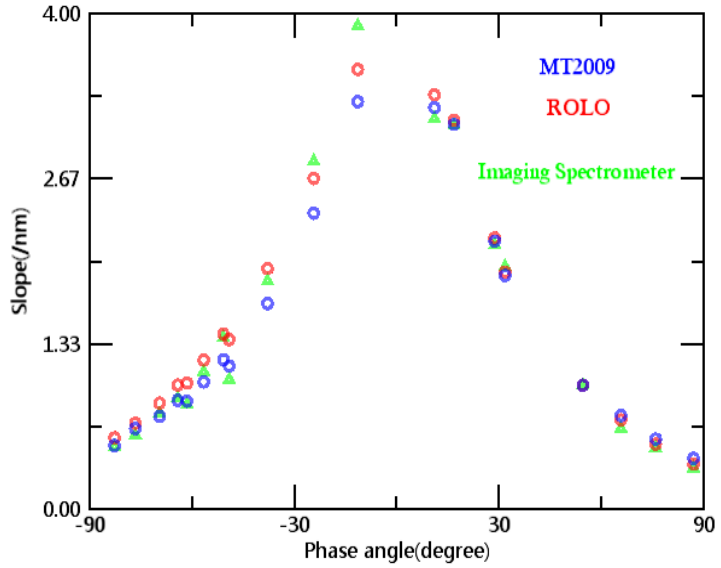
θ : phase angle **λ: 400nm-1000nm**
a_i : slope **b_i: intercept**

i=1： imaging spectrometer
i=2： ROLO
i=3： MT2009

(1): $Ratio_i \sim \lambda$

(2): Slope(a_i)~ θ





Comparison Conclusion by now

- **ROLO VS RT2009 :**

- **5-10% absolute**
- (1) Instrument: absolute calibration (spatial stray light)
- (2)Atmosphere: extinction correction
- (3) Lunar model: wavelength

Wavelength ↑ Percent disagreement ↑

- **1-2% relative (zenith angle > 40)**
- (1)Atmosphere: extinction correction
  ROLO Over Time (Bad days)
- (2) Lunar model: phase angle

$(\psi_{\mathrm{IFOV}} / \psi_{\mathrm{FOV}}) << \psi_{NIM}$

$\psi_{moon}(\sim 0.5) << \psi_{NIM}$

$Radiometric\ Calibration \rightarrow Stray_{\min}$

↓

Radiometric response **Systematic deviation**

Continue ! ! !

Summary

- **Experiences and Lessons:**
  - Full Preparation for this experiment is very important including location selection, Instrument testing, observation procedure demon, ancillary measurement
  - Lijiang is a excellent place for ground-based Lunar observation
  - Instrument improvement and accurate calibration is challenging and kept ongoing
  - Data quality control, Atmospheric correction and other data processing need to be done step by step
  - How to inter-compare and validate the current lunar models and other observation result
- **Next steps:**
  - Instrument improvement based on previous experience.
  - Long term observation need automatic control by remote
  - Accurate calibration and Data quality control
  - Data processing for model validation and improvement
  - International cooperation is welcome and example data will be open for checking

Thanks