Ground-based and Space-borne Lunar Observation in China and Prospective Improvement for lunar reference model

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National Satellite Meteorological Center(NSMC), CMA

An SI-Traceable Space-based Climate Observing System
CEOS WMO-GSICS Workshop
9-11 September 2019, NPL, UK

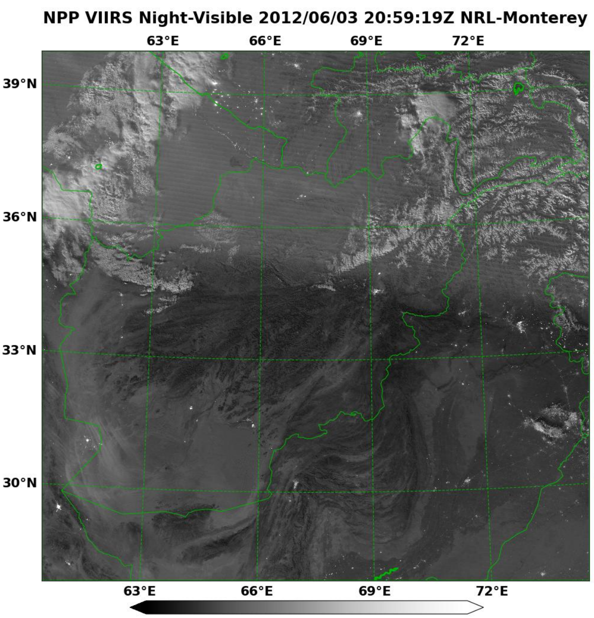
Outline

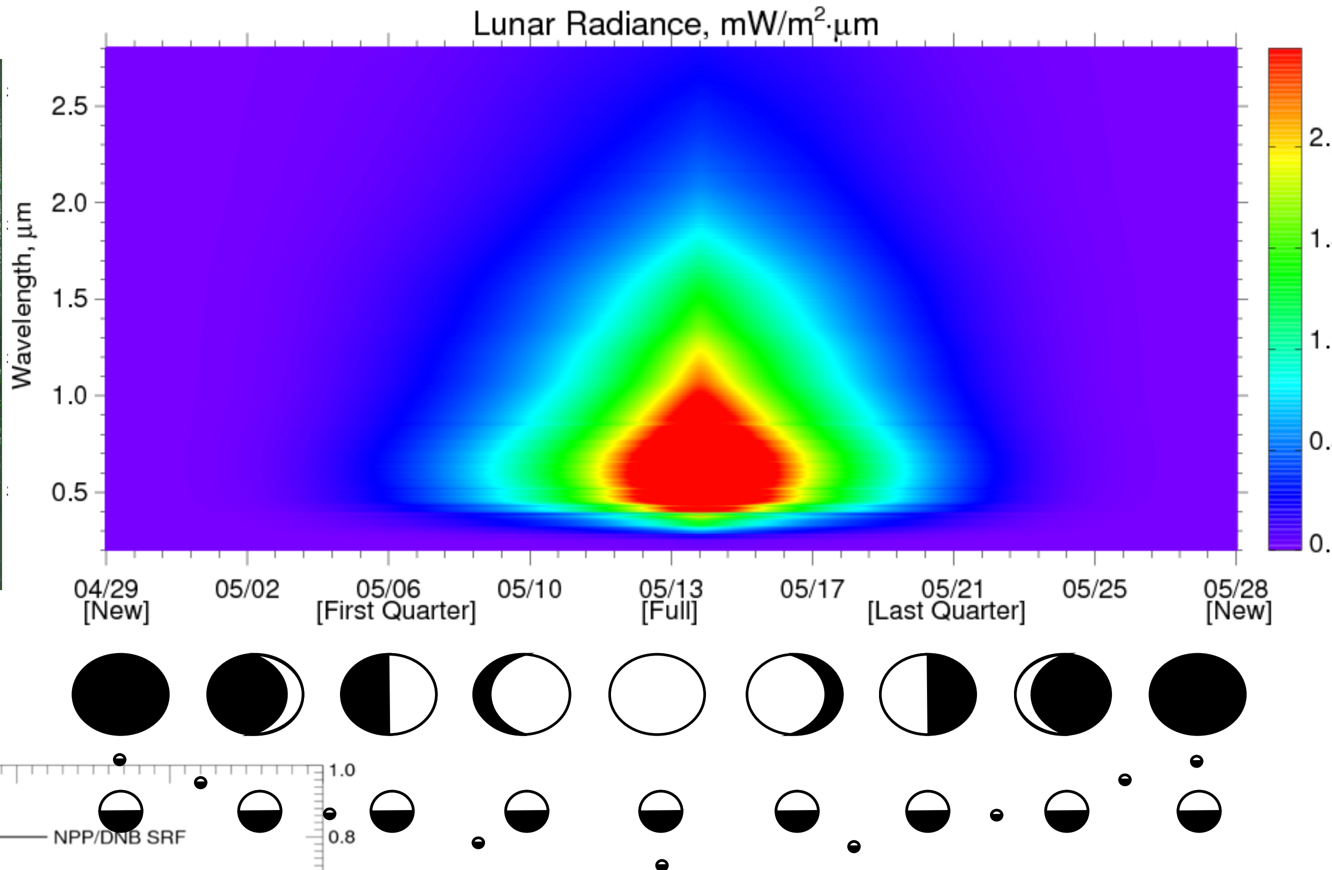
- ***Background and Motivation***
- ***Ground-based Lunar instruments***
- ***Data Processing and Lunar irradiance intercomparison***
- ***New Instruments and Space-borne Obervation***
- ***Discussion Topics***

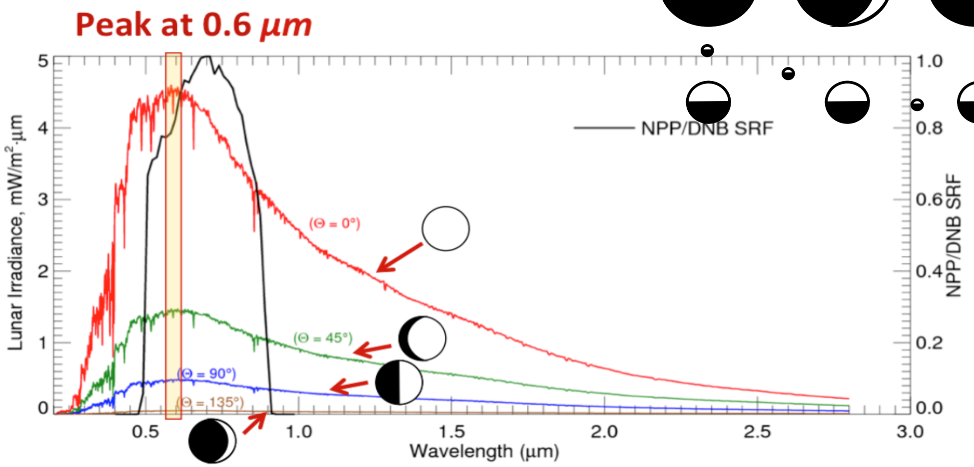
Background

- The Moon as an On-orbit Calibration Target, “solar diffuser” , extremely photometrical stable(<10-8/year) is very suitable for space-borne sensor calibration.
- But Lunar non-uniform reflectance and complex photometric behavior in different lunar phase angle and libration. For this, Lunar model need to be developed by lunar measurement/observation.
- ROLO model was established in 2005 based on 8+ years in operation, phase angle coverage from eclipse to 90° at VNIR 23 bands, 350-950 nm and SWIR 9 bands, 950-2500 nm with absolute uncertainty 5-10% and relative uncertainty 1% (Kieffer, H. H. & T. C. Stone 2005, Astron J)
- Chinese space-borne sensor, especially meteorological satellite instruments (FY-2/FY-3/FY-4), has the moon observation function and provide the calibration chance using moon. Lunar calibration become an important method for FY sensors.
- Lunar Ground-based measurement in China had explored since 2015. Lunar model need to be validated and improved by more and more ground-based observation, especially hyper-spectral measurements. CMA hope to make the contribution in lunar model improvement.

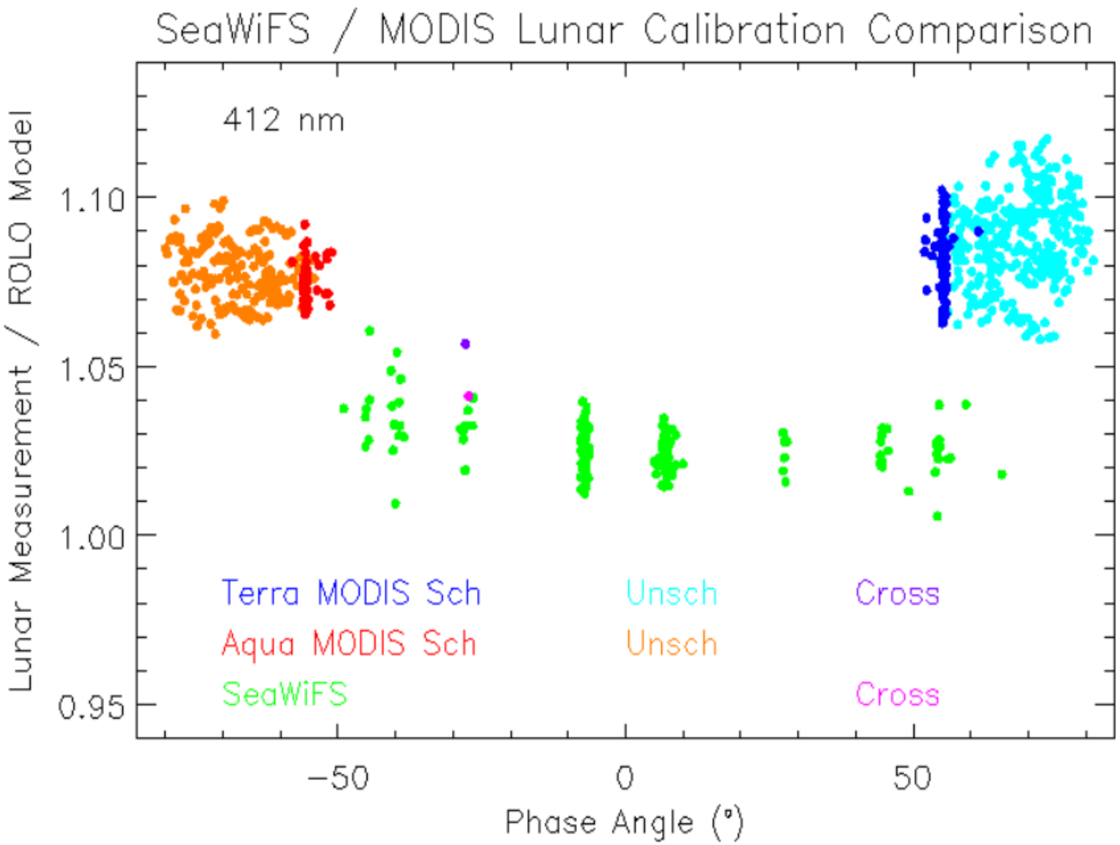
Moon: Source of Low Light at Night





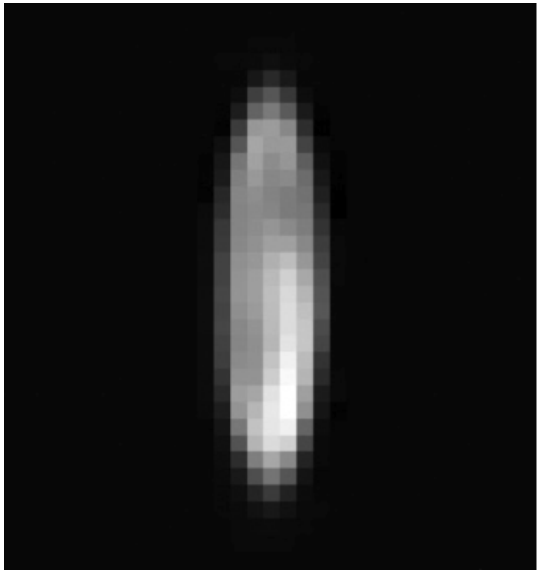


Lunar Calibration On-Orbit:



SeaWiFS gain stability 0.13% (k=1) achieved with Lunar calibration monthly !
Absolute biases up to 3% (k=1)

Lunar image by SeaWIFS

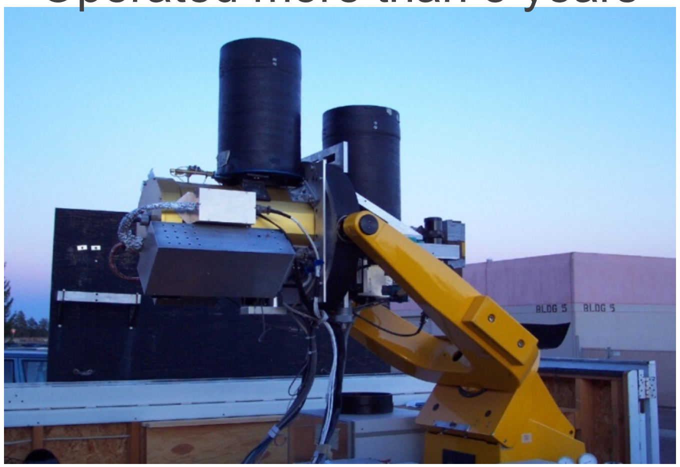


Need: Absolutely accurate irradiance for all lunar phase and libration states !

(Constantine Lukashin, 2017)

Typical Lunar observation Missions

ROLO Telescope Facility
Operated more than 8 years



Thomas C. Stone etal, 2005

Using CIMEL Lunar Photometer
Pico Teide On Island Tenerife (Spain)

Stefan Adriaensen, 2019
(ESA, NPL)

ARCSTONE Mission

NASA Langley Research Center
Constantine Lukashin,,2018

air-LUSI

Measuring Lunar Spectral Irradiance from a High-Altitude Aircraft
K. Turpie, 2019 NIST

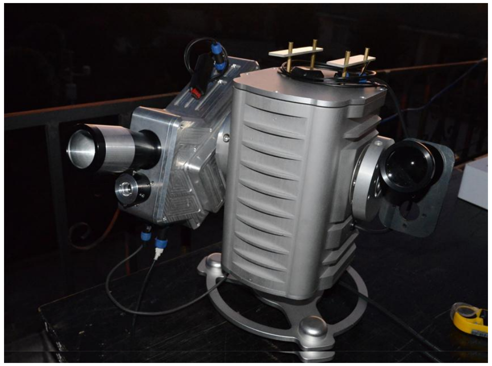
NASA ER-2 at 21Km

Previous Job Overview in CMA

- Instrument development and Observation Campaign
  - Lunar Imaging spectrometer
  - Hyspectral lunar-photometer
  - Lijiang was selected as the lunar Observation since 2015
    - High altitude 3.2km with 0.05 AOD
- Data processing and intercomparison
  - Data calibration and quality control
  - Atmosphere correction/Lunar phase and angle calculation
  - Model validation and intercomparison
- 2nd Joint GSICS/IVOS Lunar Calibration Workshop hosted in Xian
  - Organisation: CMA and Xi'an Institute of Optics and Precision Mechanics, in partnership with EUMETSAT, USGS, NOAA and NASA
  - Four days meeting and topics:
  - Measurements and Moon Observations (Scott) ;
  - Using the ROLO and the GIRO + Lunar Model Developments(Tome)
  - Inter-calibration and Inter-band Calibration (Seb)
  - Alternative uses of lunar measurements (Fangfang)

Lunar Observation in Lijiang, Yunnan 2015-2016

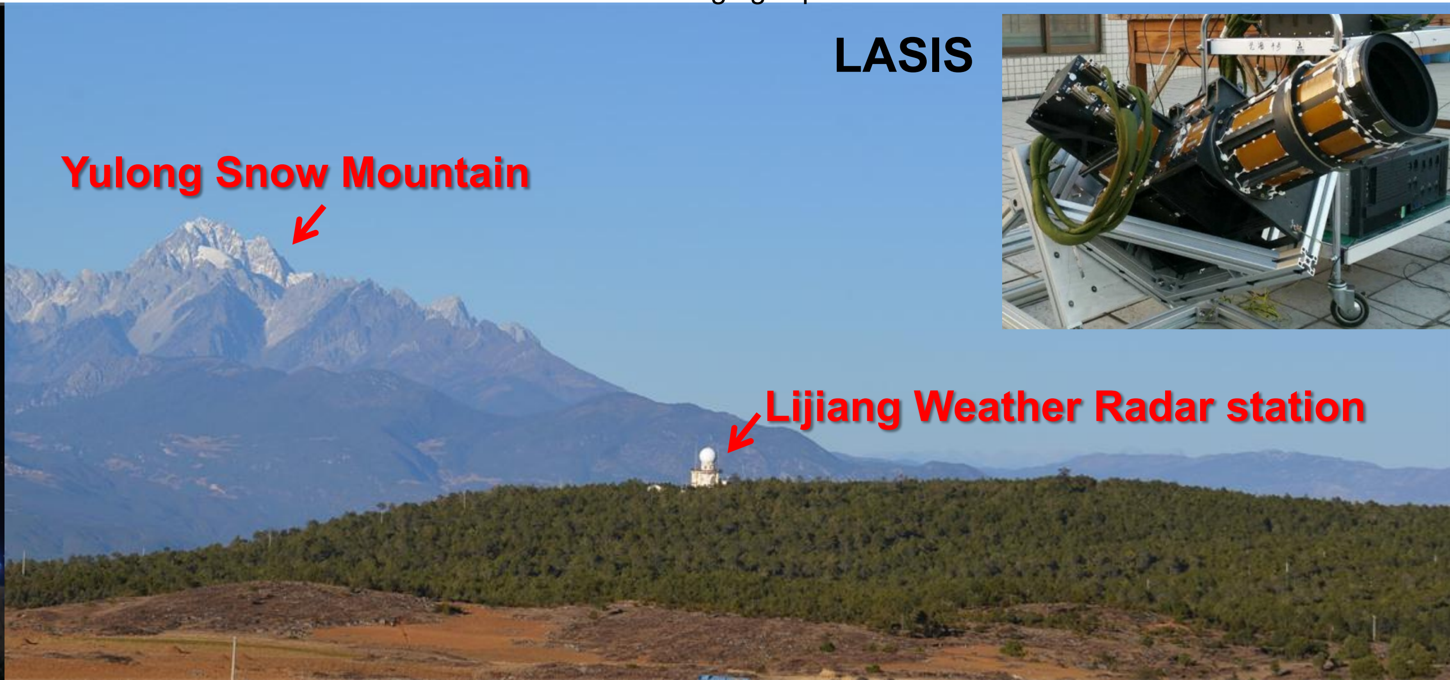
Lunar Imaging Spectrometer



Hyperspectral Lunar-photometer

AOTF Imaging Spectrometer

CE318U Lunar-photometer



Ground-based Lunar instruments(2015)

	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

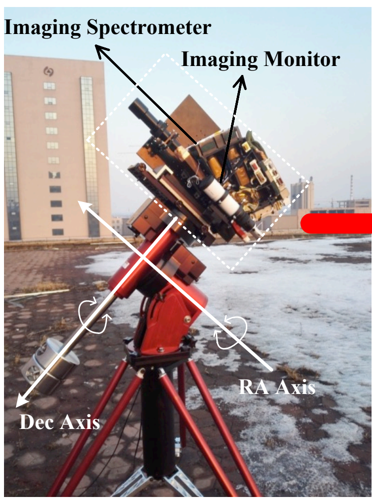
Instrument development:

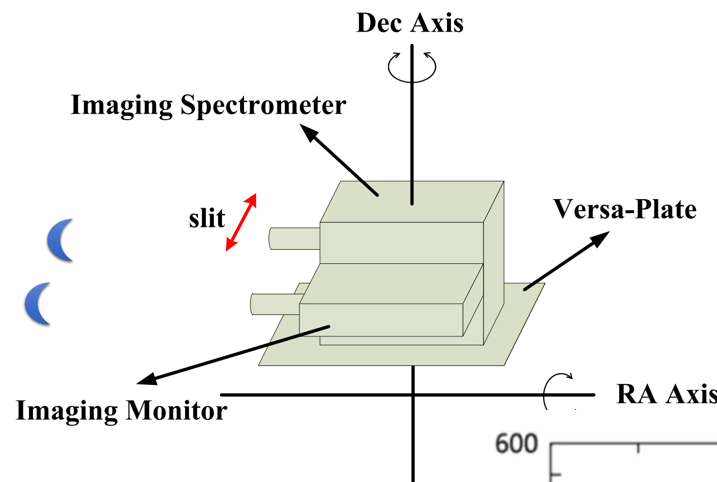
Ground-based Lunar Imaging Spectrometer (GLIS)

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

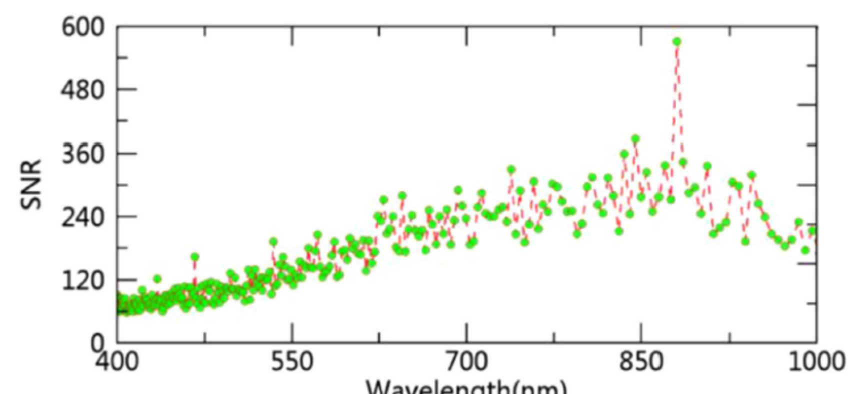
Imaging Monitor	Specification
CCD	1280×1024 pixel
Field of view	1.84° ×1.47°

Equatorial Mount	Specification
Tracking accuracy	±7"



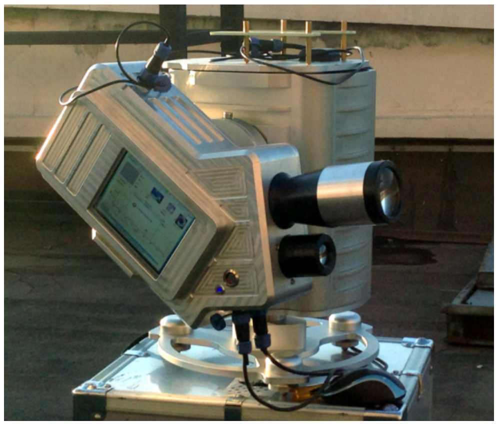


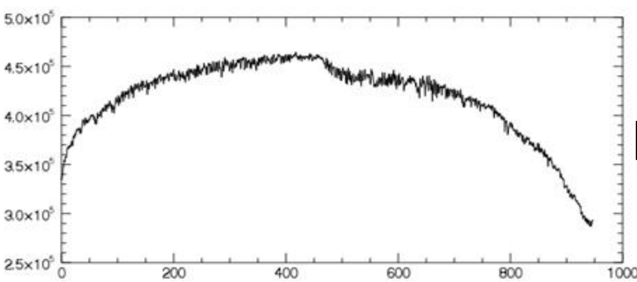
Equatorial Mount



Hyperspectral Lunar-photometer

Measurement Results from Version1

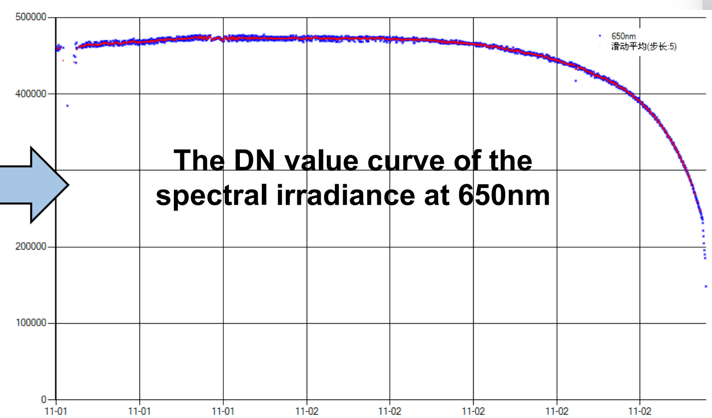




Irradiance evolution at 678nmm in Dec 22, 2016

Version 2 Improvement

- The false light elimination aperture effectively reduce the influence of the false light.
- The fine fiber makes less influence to the measurement result when bend the fiber.
- The telescope system and the active tracking system has the common optical path which will reduce the sensitivity of tracking accuracy.



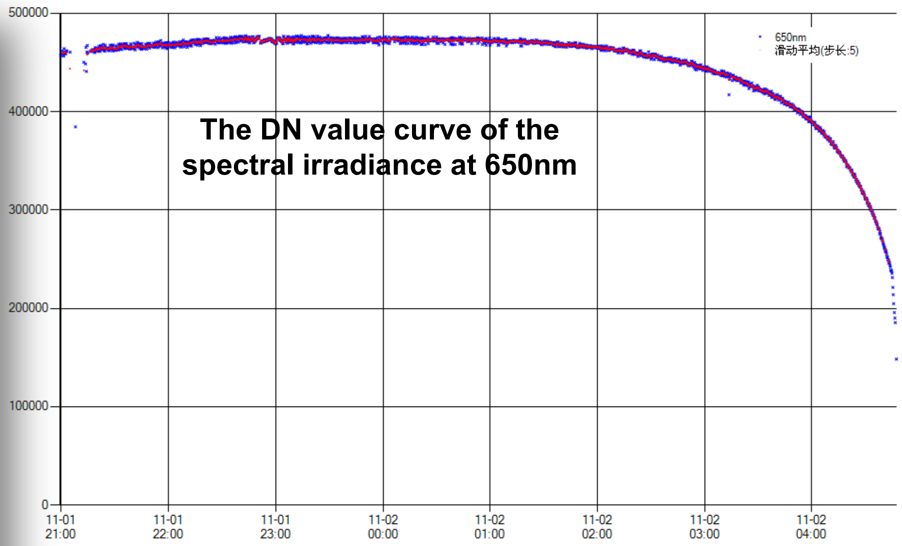
Apparent oscillation In the temporal .

Deviation： 5.6%

Mean value	449644
Standard deviation	1662
percentage(%)	**0.37%**

Improvement of Lunar-photometer

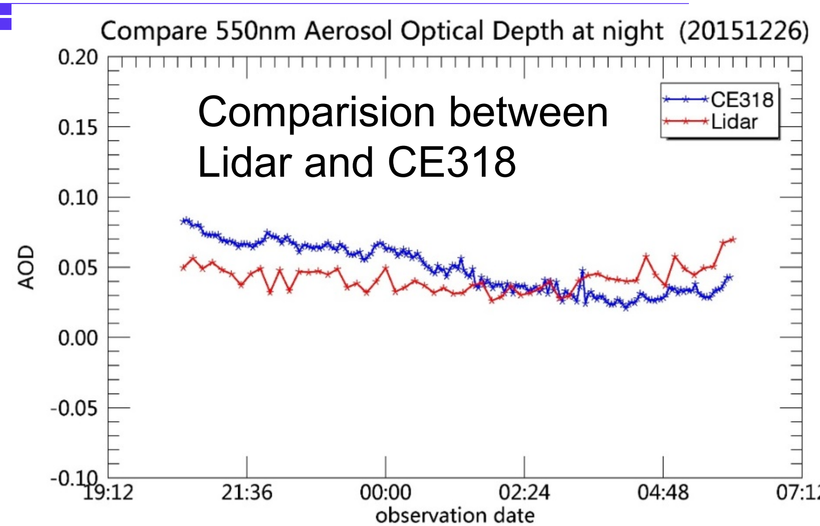
- Version 2 Improvement：
  - The false light elimination aperture effectively reduce the influence of the false light.
  - The fine fiber makes less influence to the measurement result when bend the fiber.
  - The telescope system and the active tracking system has the common optical path which will reduce the sensitivity of tracking accuracy.

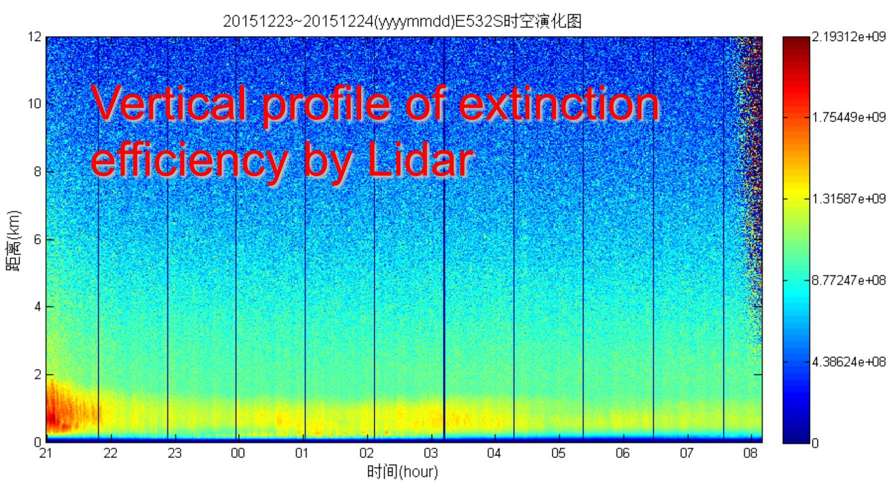


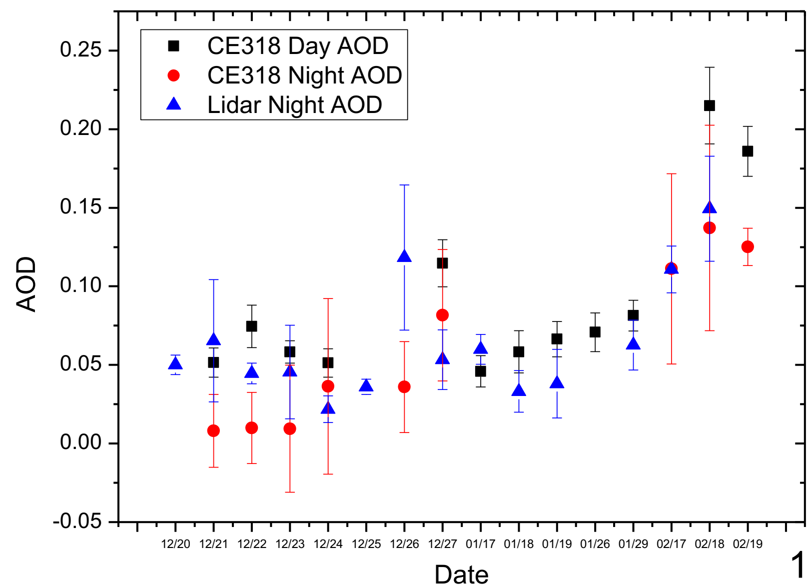
Mean value	449644
Standard deviation	1662
percentage(%)	**0.37%**

Atmospheric observation

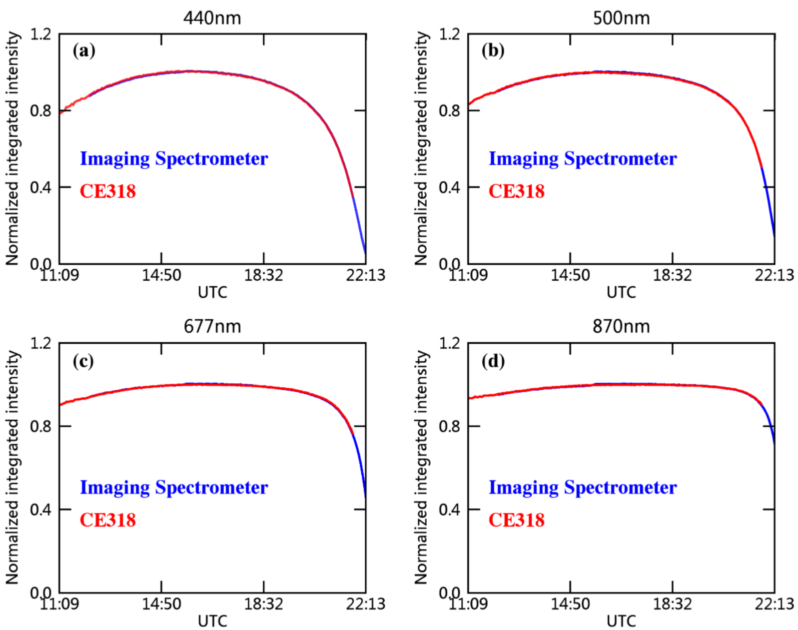
Lidar and CE-318-Lunar for day-night aerosols optical depth



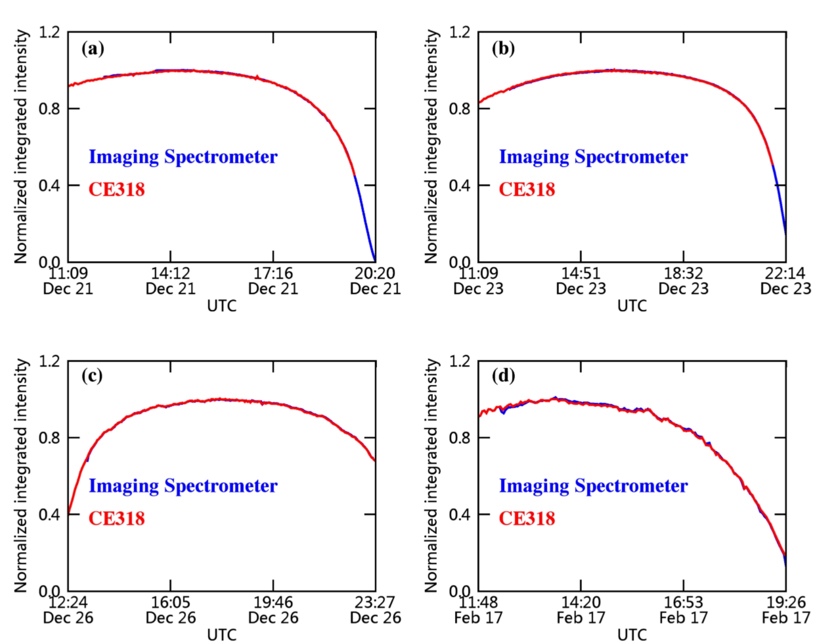




Raw data Comparison between GLIS and CE318 lunar



(1) wavelength



(2) time

Normalization Imager data and CE318 Lunar data

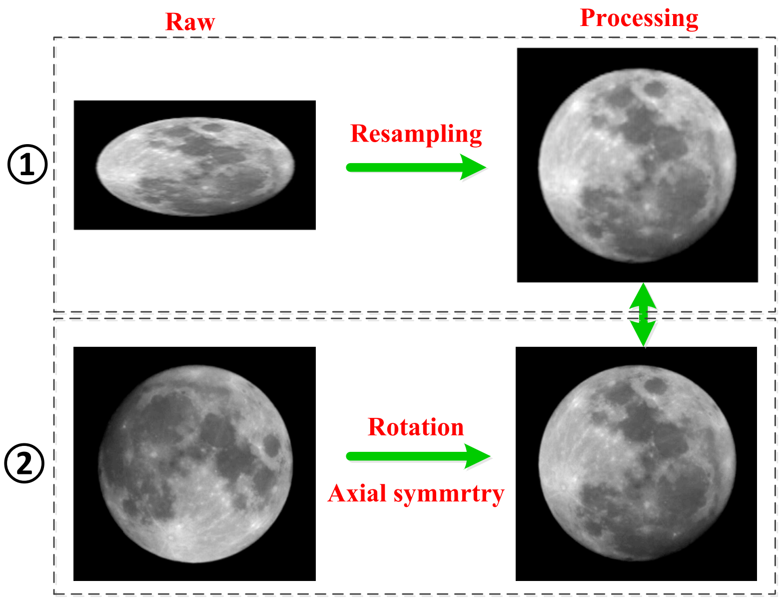
Lunar Imaging Spectrometer and CE318 lunar Cross-Comparison :

（1） 2015.12.23： 440， 500， 677， 870nm

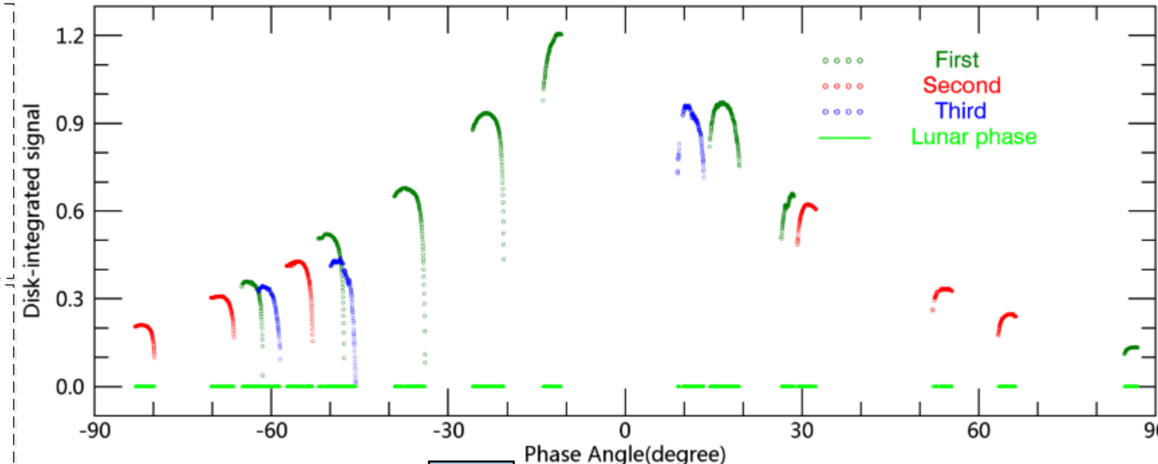
（2） 500nm: 2015.12.21， 201512.23， 2015.12.26, 2016.2.17

Consistent Trend → stability of the imaging spectrometer

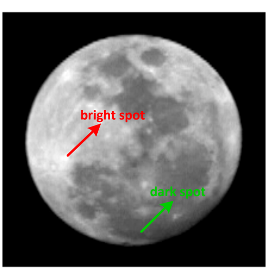
Overall of Observation Results by GLIS

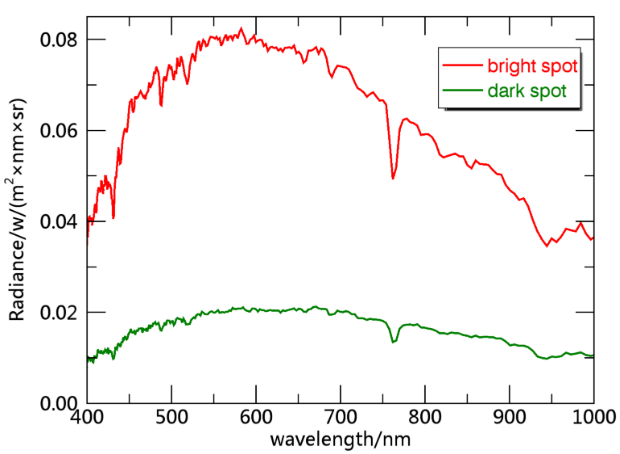


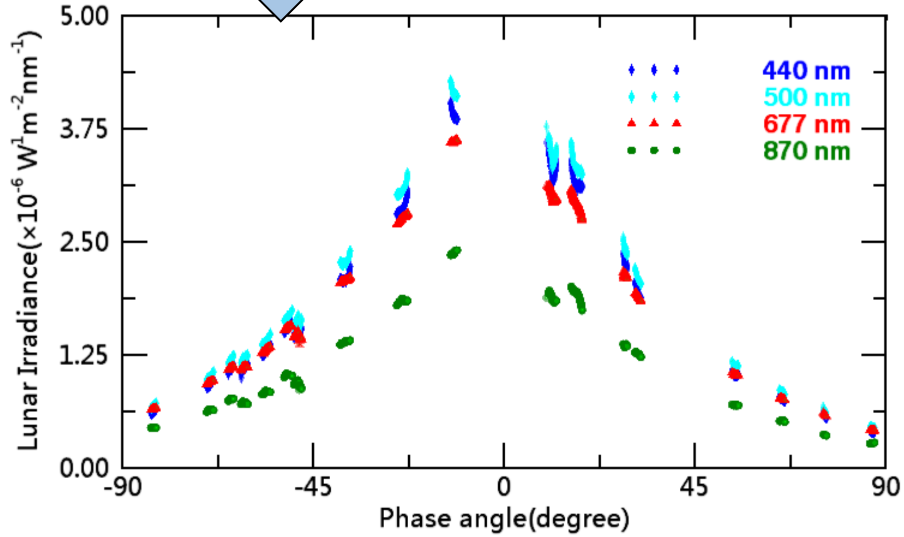
①Imaging spectrometer ②Imaging monitor



Atmosphere correction







Comparison and Analysis

Measured/model irradiance comparisons

Percent disagreement between the imaging spectrometer and lunar model is

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

Bias/Difference： 5-10%

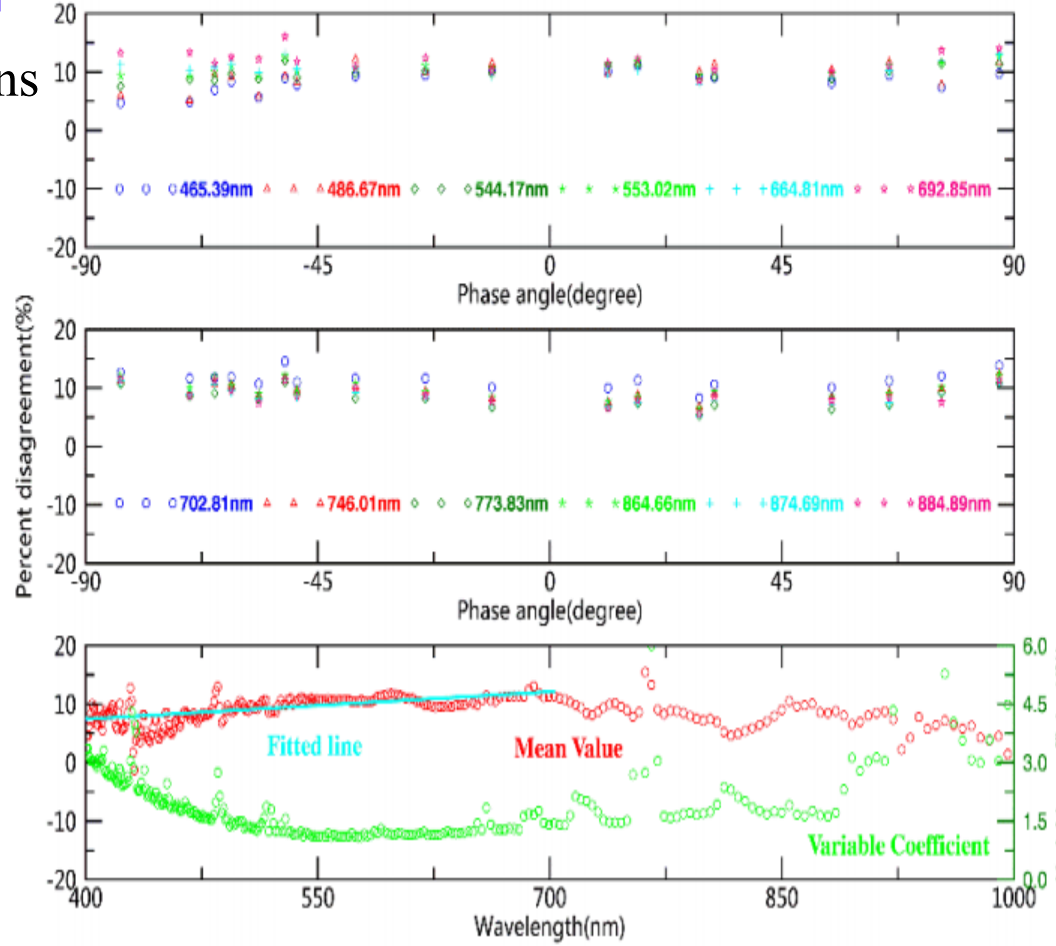
Uncertainty： 1-1.5%（deviation）

Lunar observations in Lijiang:

Absolute: 7-12%, shape ~**Mean value**

Relative: 1-3% ~**Variable coefficient**

ROLO Over Time



ROLO model——GIRO model

- **Monday**: Measurements and Moon Observations

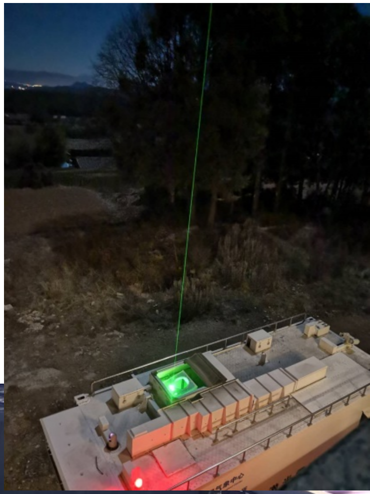
Current Jobs of CMA Lunar observation

- CMA is leading an important activity in collaboration with other institutes from the Chinese Academy of Science on the development of new instruments and dedicated ground-based lunar measurement campaigns.
- The objectives are to develop new lunar calibration models both in irradiance and in radiance with a significantly reduced level of uncertainties and to achieve traceability to SI standards. Several campaigns took place in 2015, in 2016, in 2017 and 2019.
- **Long term observation by remote automatic control since winter of 2018.** Automated acquisitions, broader spectral coverage and long time series for the lunar model improvement
- Lunar Measurements from space at different phase angles are acqired using current Chinese small Satellites such as GF-1/6 and JILIN-1

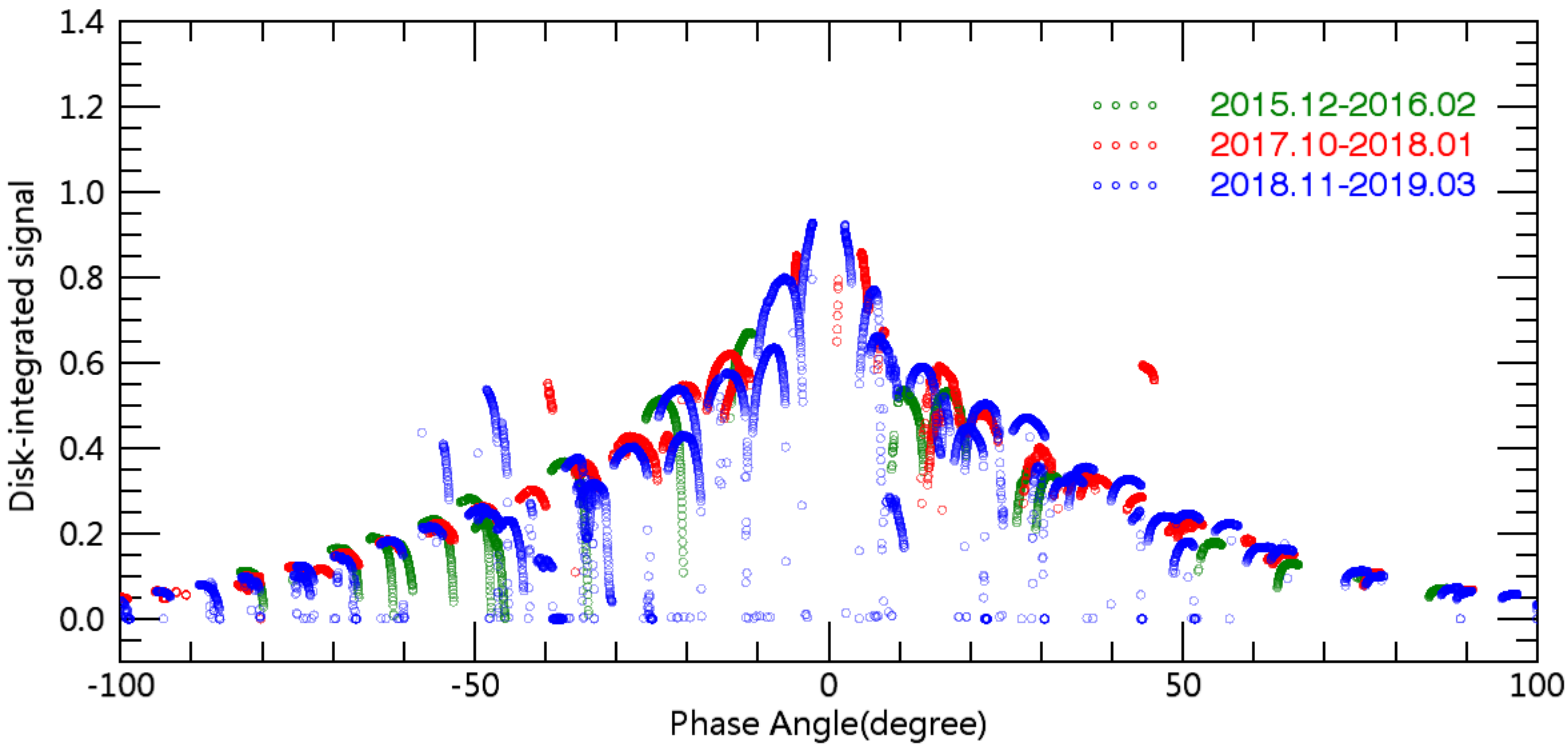
Automatic lunar ground measurement

– Realization of Long term observation with automatic control by remote and local Maintenance

- Location: 100°2′33” , 26°45′40”
- Atitude: 3175km
- Press: 695.75hpa
- Aerosol AOD: 0.05
- High opportunity of cloud free
- No light contamination
- Near from Lijing astronomy observatory



More and more Data acquisition



New Hyperspectral VNIR imager Lunar Instrument

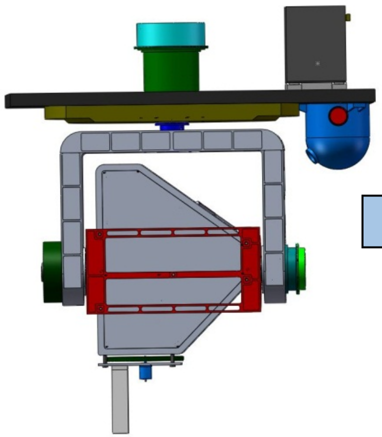
SI-traceable demo instrument development on FY-3RM rainfall mission (2022)

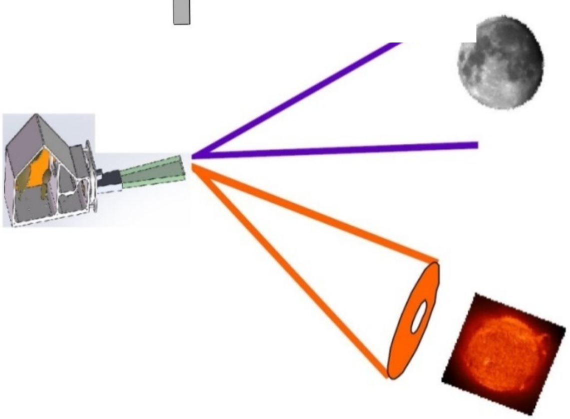
LeSIRB-Lunar and Earth Spectral Imager Radiometry Benchmark

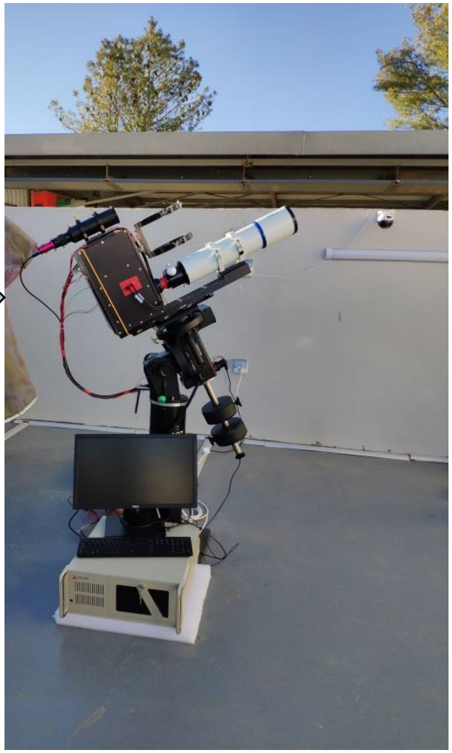
Mission Goal: Demonstration of SI traceability instrument and experiment for inter-calibration between current Fengyun satellite optical imagers to improve calibration accuracy

Parameter items	Specification	
Ground spatial resolution	250m	
Spectral resolution	4nm	
Spectral range	400nm~1060nm	
Ground Swath width	50Km	
S/N Ratio	>150	
Radiance Dynamic	Similar to MERSI-3	
MTF	>0.2@f/f_nyq=1.0	
Radiometric uncertainty	2%	
Spectral calibration	2nm	
Polarization sensitivity	<1%	
Observation Model	Earth/Lunar/Sun/Calibrator	

Prototype lunar imager was test Dec, 2018

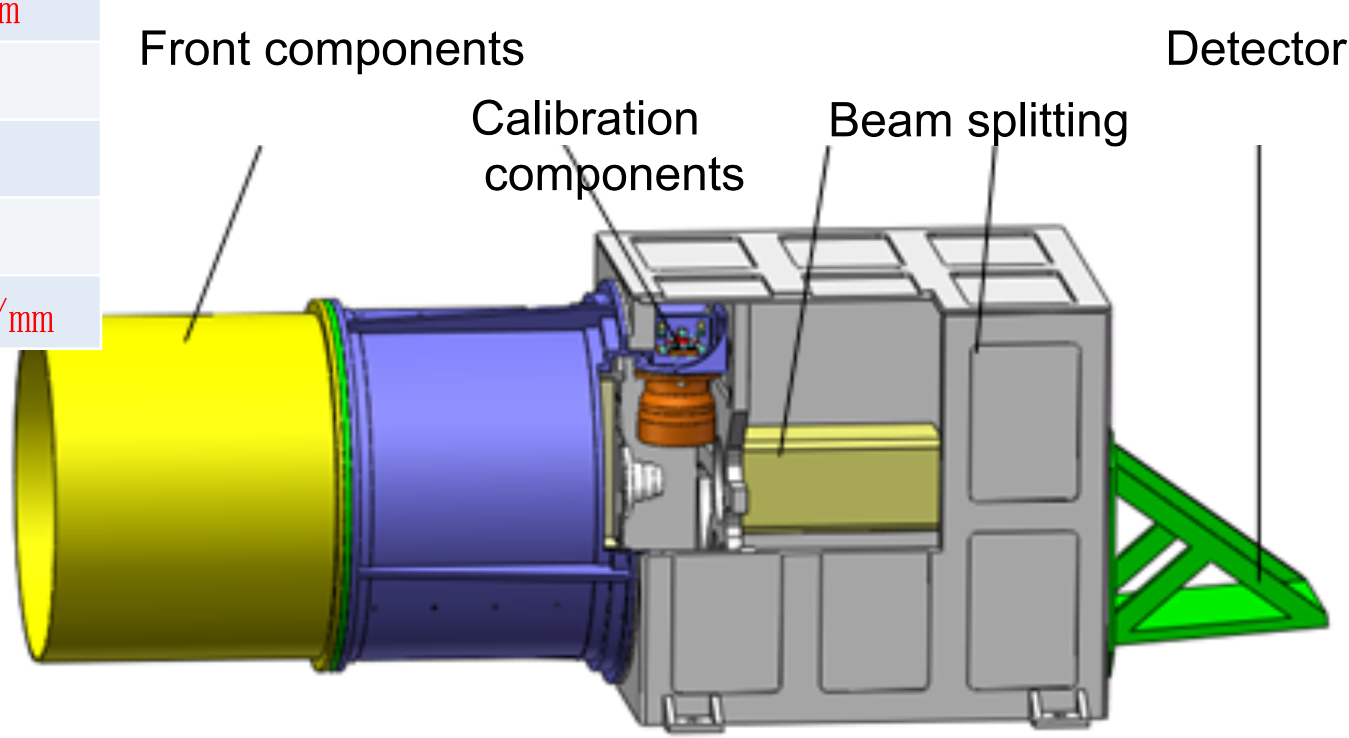






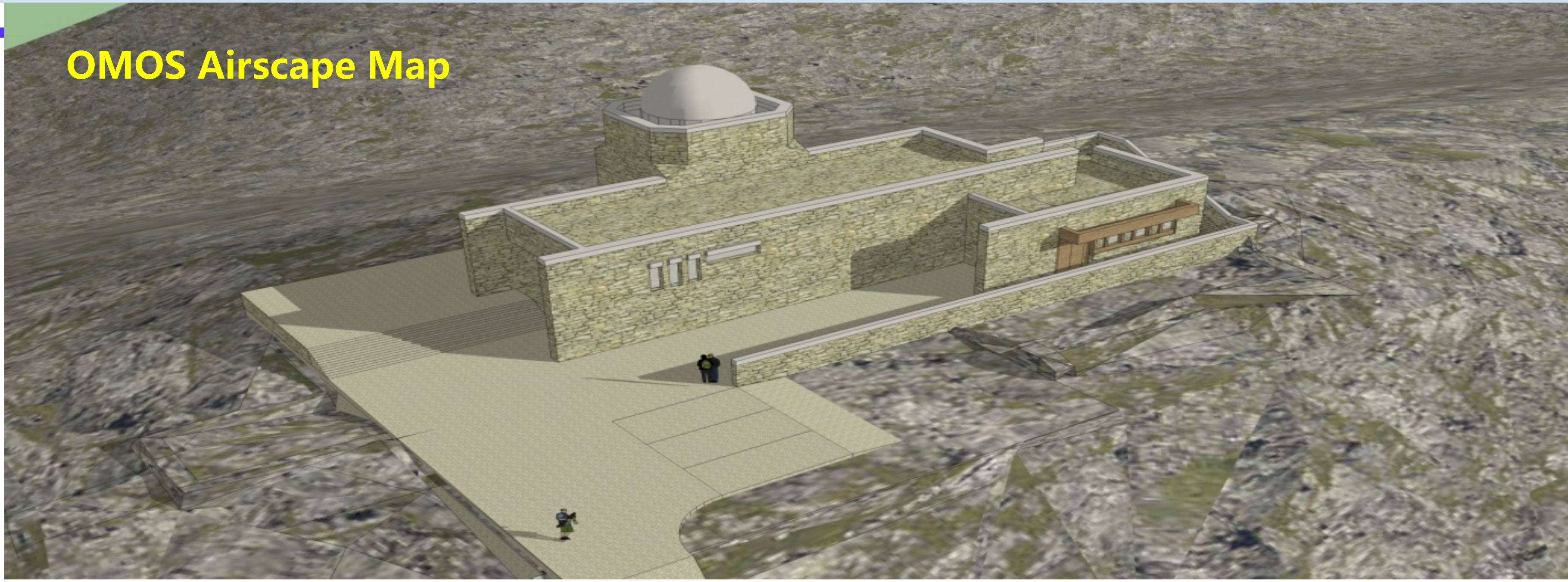
New Hyperspectal SWIR imager Lunar Instrument

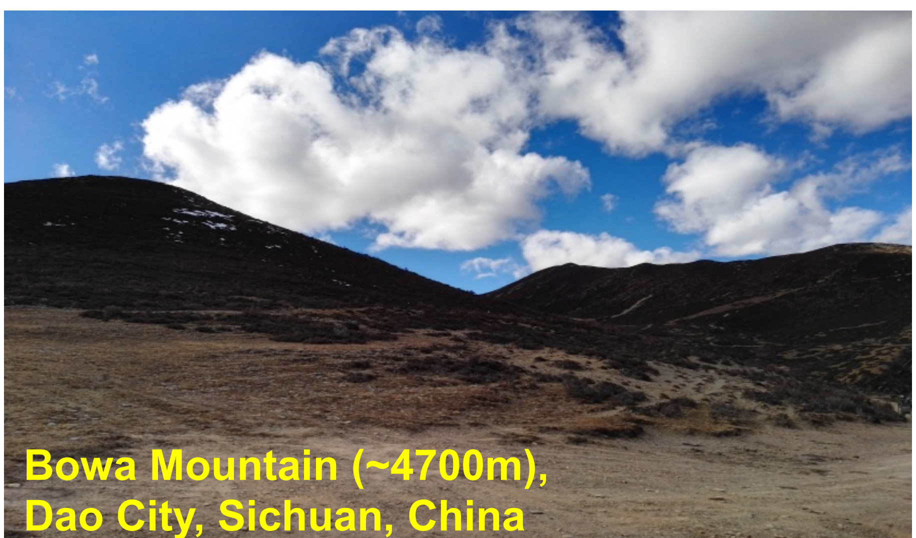
	Specification
Spectral	1000~2500nm
Focus	850.005mm
FOV	2ω≥0.62°
Apture	221mm
MTF	>0.68@20lp/mm



Size 790x315x265mm， Weight: 38kg

On-ground Moon Observation System (OMOS) is being established at Daocheng, Sichuan province





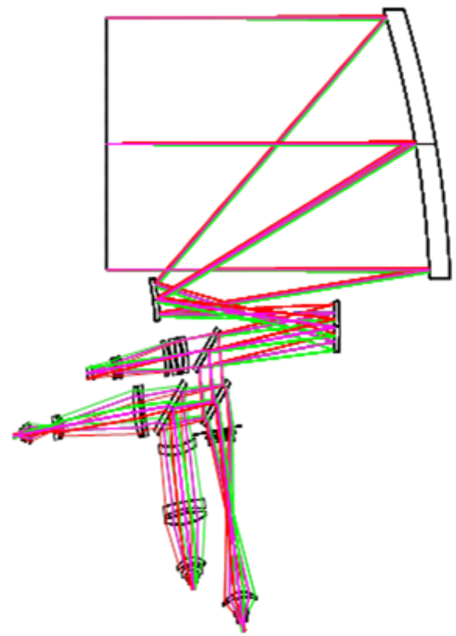
Ground-based Lunar Imager

NSMC

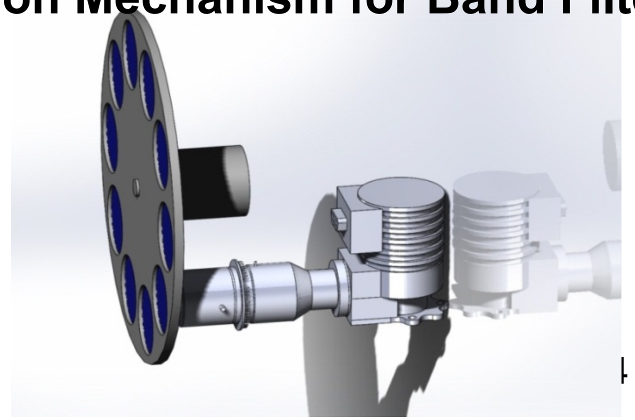
Main Specifications

Band	Spectral Range	SNR/NEDT
VIS	0.55~0.625μm	≥6@ρ=1%
	0.675~0.697μm	≥6@ρ=1%
	0.662~0.671μm	≥6@ρ=1%
	0.686~0.703μm	≥6@ρ=1%
	0.697~0.714μm	≥6@ρ=1%
	0.71~0.75μm	≥6@ρ=1%
	0.55~0.75μm	≥6@ρ=1%
NIR	1.58~1.64μm	≥6@ρ=1%
	1.626~1.650μm	≥6@ρ=1%
SIR	2.104~2.159μm	≥6@ρ=1%
	2.232~2.280μm	≥6@ρ=1%
	2.10~2.35μm	≥6@ρ=1%
MIR	3.70~4.75μm	50mK@300K
LIR	10.3~11.3μm	50mK@300K
	11.3~12.5μm	50mK@300K

Off-axis Optics with Φ=500mm

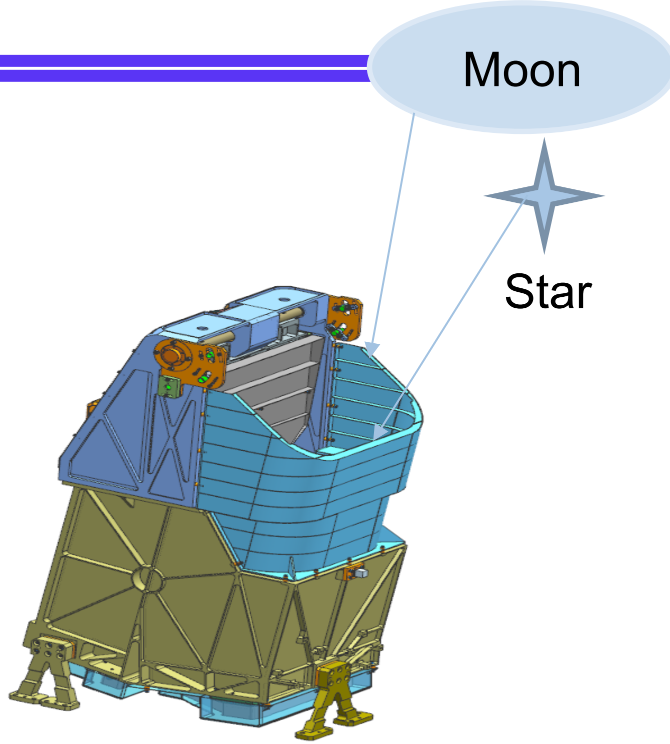


Rotation Mechanism for Band Filtering



Currently, 15 channels; Maximum: 39 channels

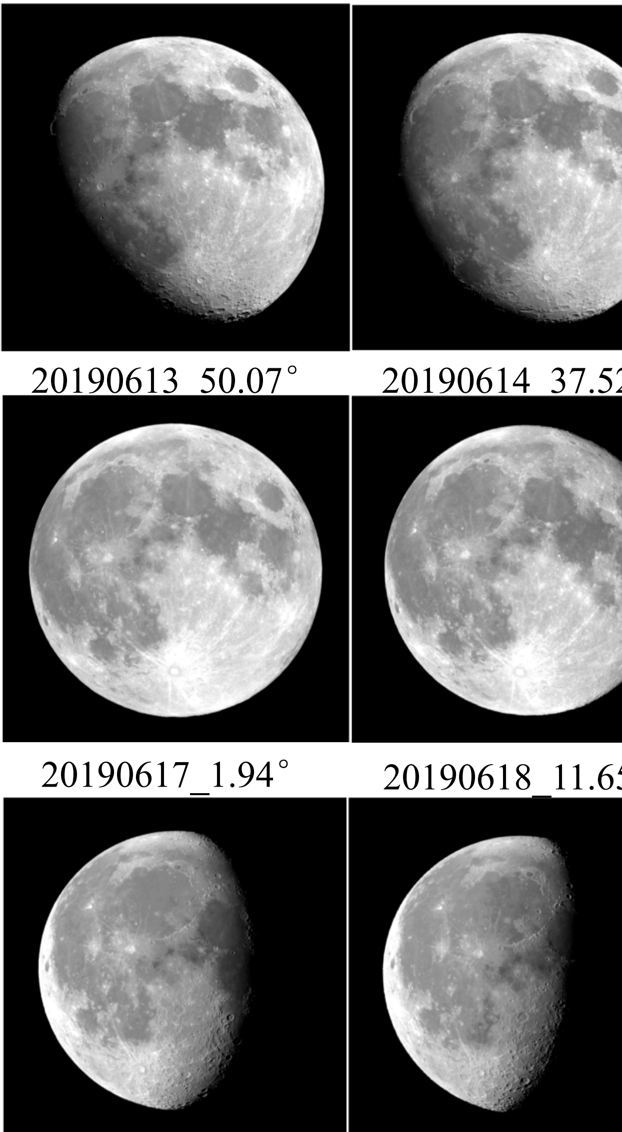
JL-1 Small satellite for lunar observation Maneuver



Parameters	Specification
launch time	2018.01
sensor	PMS、SWIR、MWIR、LWIR
orbit type	sun-synchronous orbit
Mean altitude	528 km
Swath	110km
inclination	97.51 degrees
local time	10:00 AM

Band	Wavelength(nm)	IFOV(m)
B0	450-800	5
B1	403-423	5
B2	433-453	5
B3	450-515	5
B4	525-600	5
B5	630-680	5
B6	784.5-899.5	5
B7	485-495	10
B8	615-625	10
B9	650-680	10
B10	699-719	10
B11	732.5-747.5	10
B12	773-793	10
B13	855-875	20
B14	660-670	20
B15	677.5-685	20
B16	750-757.5	20
B17	758.75-762.5	20
B18	935-955	20
B19	1000-1040	20
SW1	1195-1225	100
SW2	1360-1390	100
SW3	1550-1590	100
SW4	1610-1690	100
MW1	3700-4950	100
LW1	7500-13500	150

Space-borne Lunar Imager



20190613_50.07°

20190614_37.52

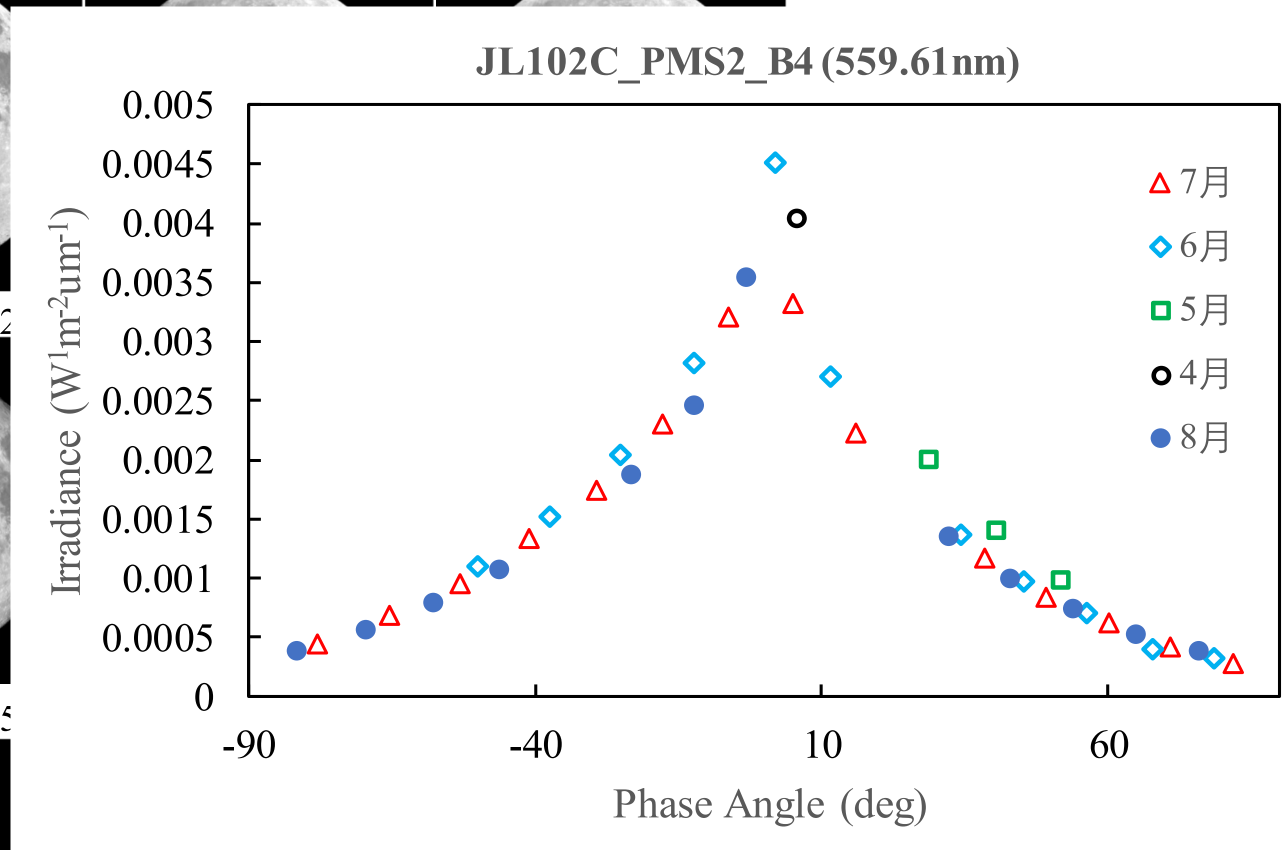
20190617_1.94°

20190618_11.65

20190622_56.14°

20190623_67.67°

20190624_78.46°



JILIN-01-09/B4 lunar image (559.61nm)

Data_Phase Angle

Discussion Topics

- Which kind of measurement and observation from ground-based and space-borne method is required for lunar model improvement and refining the current lunar calibration reference.

- What kind of instruments and their specification should be developed for the above goals.
  - Wavelength coverage, SNR, spectral resolution, tracking accuracy, calibration accuracy
  - Lunar imager, lunar photometer

- How to be traceable to SI benchmark for these Measurement
  - Lab characterization/calibration, traceable standard
  - Star radiance traceability

- Data quality and data processing common steps and methods
  - Atmosphere correction
  - Data pre-processing, geometric calibration
  - Lunar phase angle and libration
- Inter-comparison method from different instrument measurements

- How these measurement/observation are utilized to improve or be incorporated into current lunar model.

Thank you !

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National Satellite Center, CMA, Chia