Some Applications of ABI Lunar Irradiance Calibration

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with contributions from GOES-R CWG team

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Moon seen by GOES-16, courtesy of L3Harris


Moon seen by GOES-17, courtesy of GOES-R Program

Third Joint GSICS/IVOS Lunar Calibration Workshop

Acknowledgements: GOES-R MOST and operation teams for the lunar image collections, GOES-R PRO for the coordination effort, and the GSICS community for sharing the GIRO model

Introduction

- **NOAA has a long history in using the Moon for the calibration of instruments on the GEO platforms**
  - **Started with GOES-10 Imager in 2005**

- **More opportunities and easier lunar collections for GOES-R ABI**
  - **ABI can scan the Moon whenever the Moon appears within the Field Of Regard (FOR)**
  - **Lunar images can be collected at a large variety of phase angles**
  - **No need of spacecraft maneuver**

- **Broad interest in the Moon for GOES calibration, including**
  - **In-orbit solar cal. validation & Instrument degradation trending**
    - **G16: ~3 years in operation, G17: ~1.5 years in operation**
  - **Response versus scan-angle (RVS) validation**
  - **Modulation Transfer Function (MTF) evaluation**
  - **Detector response uniformity evaluation**
  - **Straylight/crosstalk/blooming assessments**
  - **Detector dynamic response range/nonlinear response validations**
  - **…**

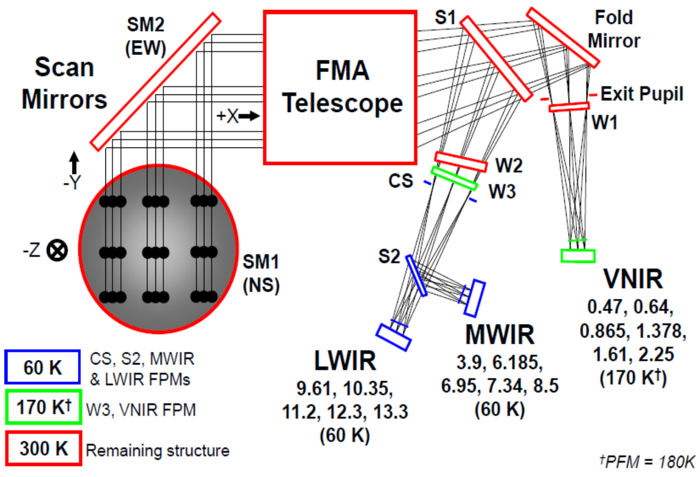
Applications of lunar irradiance cal.

Objectives

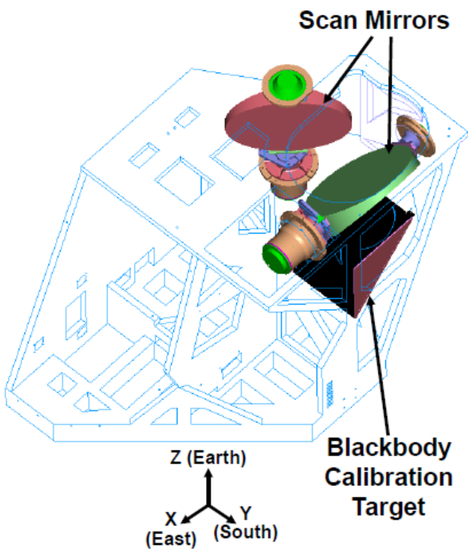
- **Present the ABI lunar irradiance calibration algorithm**
- **Introduce some applications of ABI lunar irradiance calibration**
  - **Performance of the GIRO model**
  - **Improvement in ABI lunar irradiance measurement**

GOES-R ABI Instrument

- **ABI Bands: 16 bands**
  - 6 visible and near-infrared (VNIR) bands
  - 10 infrared (IR) bands
- **Two independent scan mirrors**
  - North-South (NS)
  - East-West (EW)
- **On-orbit calibration for all the bands**
  - On-orbit solar diffuser (SD) for VNIR bands
  - Blackbody for IR bands



GOES-16 ABI Optical Architecture



figures are courtesy of L3Harris)

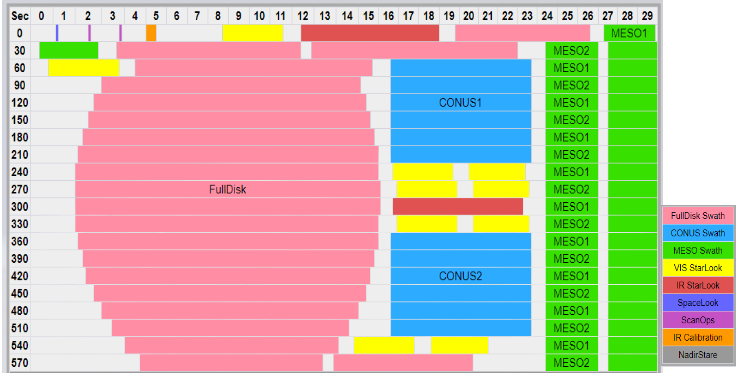
GOES-16/17 ABI VNIR Data

- **GOES-16 ABI:**
  - Launched on 19 Nov. 2016, became operational as GOES-East at 75.2^{o}W on 18 December 2017, operated as designed
  - Stable solar calibration operation since May 2019

- **GOES-17 ABI**
  - Launched on 1 March 2018, became operational as GOES-West at 137.2^{o}W on 12 Feb 2019, operated at floating focal plane module (FPM) temperature due to the malfunction of the cryocooler system
  - Stable solar calibration operation since May 2019

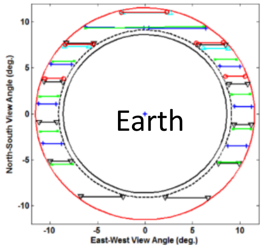
ABI Lunar Image Collections

GOES-16 ABI Mode 6 timeline



- **Each normal ABI timeline consists of full-disk scans, CONUS scans, MESO scans and calibration targets' scans**

- **ABI lunar images are collected with the MESO scans**
  - **Scanned within one swath**

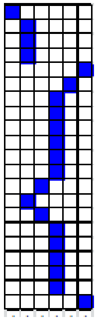


- **Lunar phase angle range, in general:**
  - **$5^o < |\text{Lunar phase angle}| < 60^o$**

G16 ABI Channel 1 (0.47µm) image scanned with one swath

ABI Lunar Images: High Spatial Resolution

Band	Central wvlen (µm)	IFOV EW (µrad)	IFOV NS (µrad)	Columns	Rows
1	0.47	22.9	22.9	800	636
2	0.64	14.5	10.5	1600	1380
3	0.87	22.9	22.9	800	636
4	1.38	51.5	42.0	400	352
5	1.61	22.9	22.9	800	636
6	2.25	51.5	42.0	400	352



Lunar Irradiance Measurement

- **Lunar Irradiance:**

$$I_{obs} = \sum_{i}^{row} \sum_{j}^{col} \frac{\Omega_{i,j}}{oversampl\_fa_{i,j}} radiance_{i,j}$$

- **Ω: Sample solid angle, IFOV projected from the instrument**
- **Oversampl_fa: oversampling factor**
- ***Radiance*$_{i,j}$: calibrated sample radiance at (i,j) image coordinate**

ABI Oversampling Factor Calculation

$$Oversampling\_factor = \frac{Measured\_Sample\_SolidAngle}{Sample\_SolidAngle}$$

$$Sample\_SolidAngle = EW\_ASD * NS\_ASD$$

Determine the image spatial resolution

$$Measured\_Sample\_SolidAngle = EW\_ADist * NS\_ADist$$

Scan rate of the EW scan mirror.
It is very stable and constant for ABI

$$EW\_ADist = EW\_ScanRate * SampleFrameTime$$

Frame time between two neighboring samples

$$NS\_ADist = NS\_AngularBDSDist$$

Mean angular sample distance at NS direction

ASD: Angular sample distance, BDS: Best detector selection

ABI sample solid angle and oversampling factor are constant values

Uncertainty in ABI Lunar Irradiance

- **Irradiance measurement:**

$$I_{ABI} = \frac{\Omega}{Oversampl\_fa} \sum_{i}^{row} \sum_{j}^{col} Rad_{i,j}$$

$Radiance_{i,j}$: calibrated radiance at (i,j) image coordinate in a subset lunar image

Band	Columns	Rows
1	800	636
2	1600	1380
3	800	636
4	400	352
5	800	636
6	400	352

#samples = 1.48E+5 – 2.2E+6

- **Number of lunar image samples: 0.14 millions to 2.2 millions, depending on channel**

- **Lunar irradiance can be very sensitive to an extremely small uncertainty (bias) of**
  - **Sample solid angle**
  - **Oversampling factor**
  - **Straylight impact on Radiance**

ABI Lunar Irradiance Measurement

- **Lunar Irradiance Calibration**

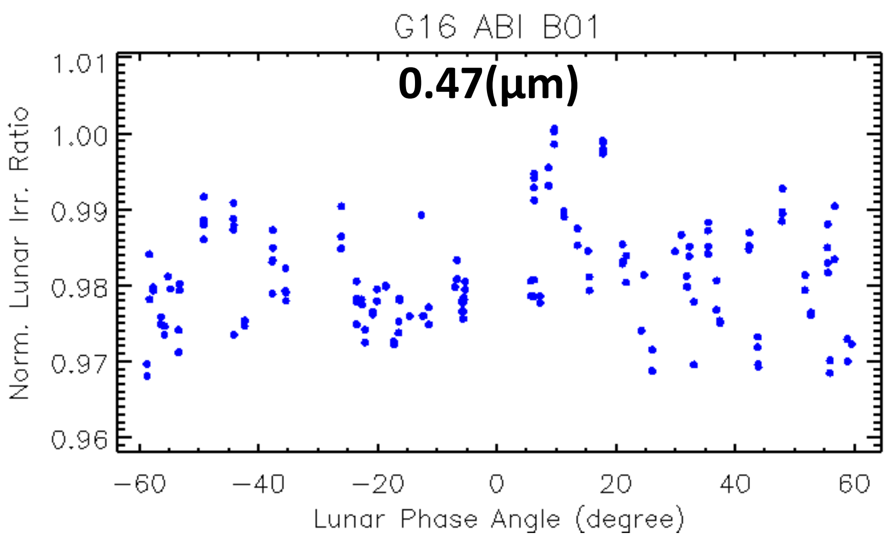
$$Ratio = \frac{I_{ABI}}{I_{GIRO}} \qquad I_{ABI} = \frac{\Omega}{Oversampl\_fa}\sum_{i}^{row}\sum_{j}^{col} Rad_{i,j}$$

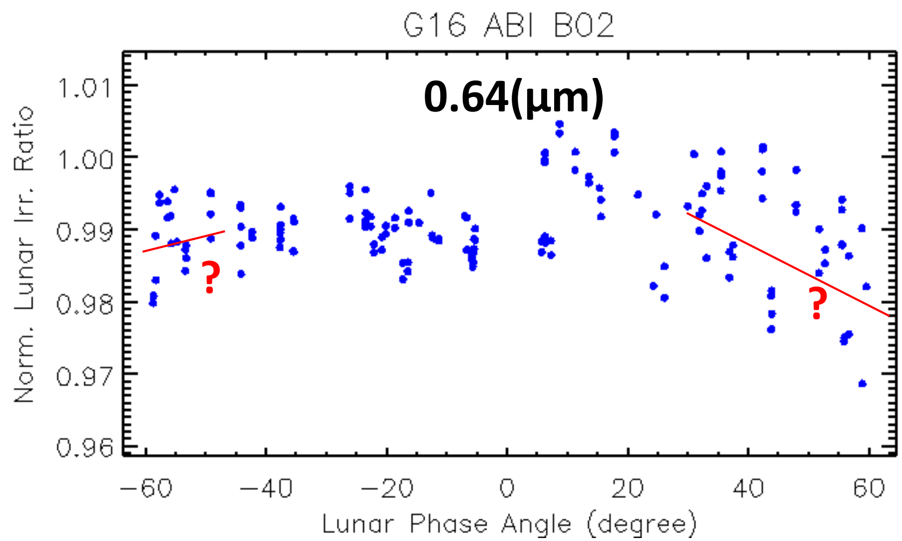
- **Normalized lunar irradiance ratio**
  - **Largely cancel out the uncertainty of the constant values of sample solid angle and the oversampling factor on the irradiance measurement**

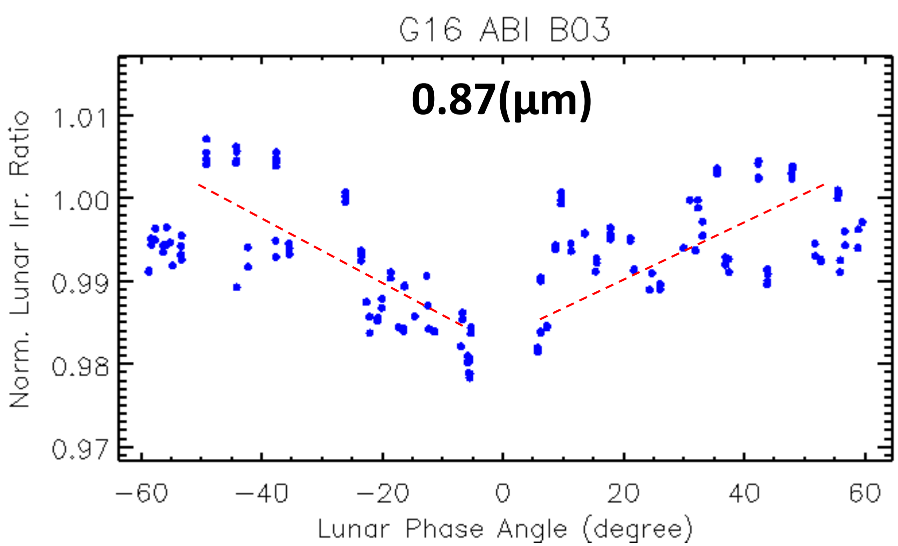
$$Normalized\_Ratio_t = \frac{Ratio_t}{Ratio_0} = \frac{\dfrac{\cancel{\frac{\Omega}{Oversampl\_fa}}\sum_i^{row}\sum_j^{col} Rad_{i,j,t}}{I_{GIRO,t}}}{\dfrac{\cancel{\frac{\Omega}{Oversampl\_fa}}\sum_i^{row}\sum_j^{col} Rad_{i,j,0}}{I_{GIRO,0}}}$$

  - **$Ratio_t$: ratio between ABI measured and simulated irradiance for event conducted at time t**
  - **$Ratio_0$: the first irradiance ratio**

Phase Angle vs. Norm. Lunar Irr. Ratio: B01-B03



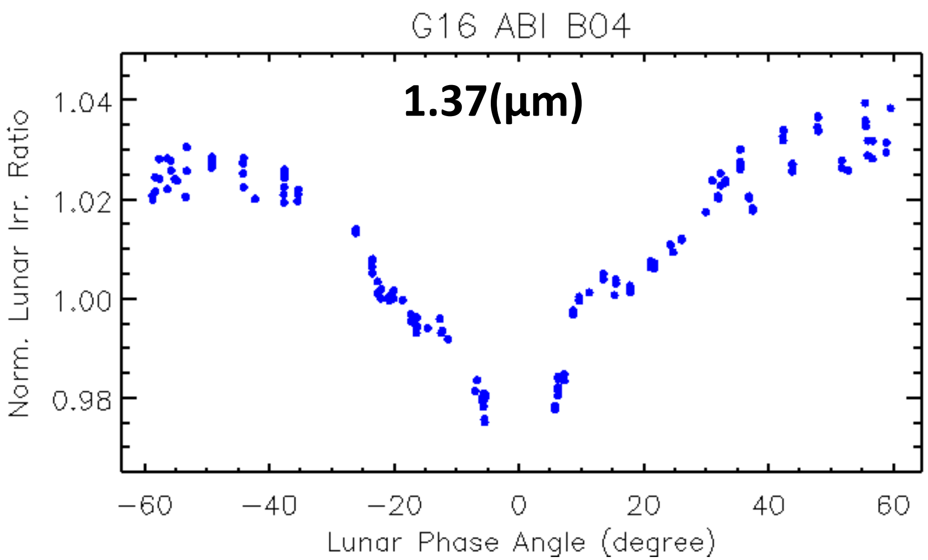


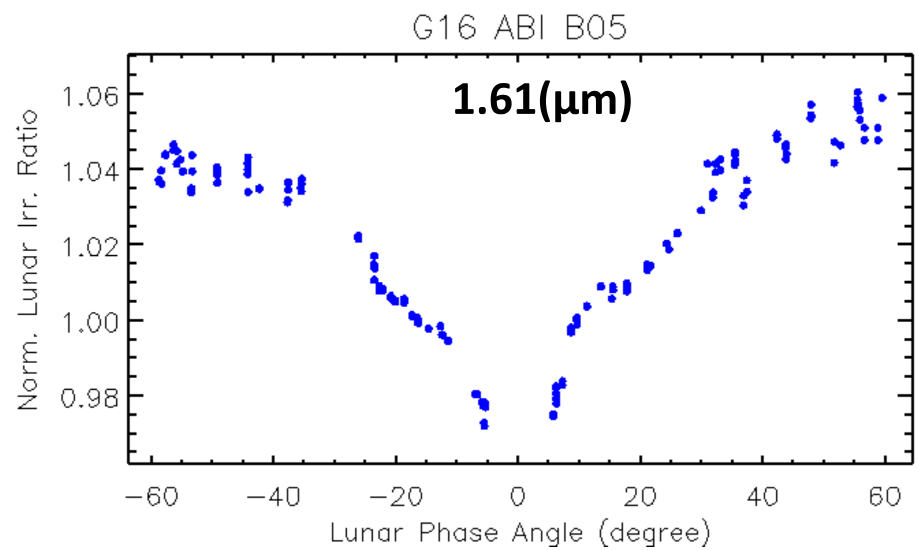


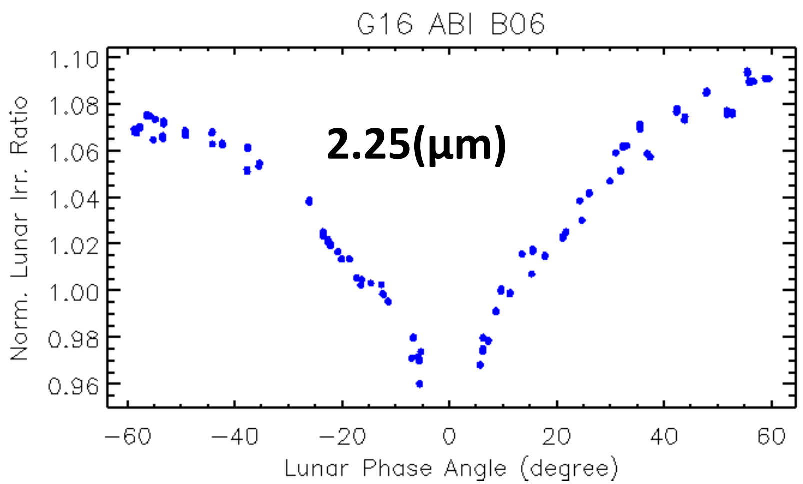
Data: GOES-16 from June 2019 – August 2020

- **B01: Much scattered, no strong apparent phase angle dependent ratio**
- **B02: Phase angle dependent at relatively large absolute phase angles, >30° and <-40°?**
- **B03: Phase angle dependent bias appears**

Phase Angle vs. Norm. Lunar Irr. Ratio: B04-B06







- **Strong phase angle dependent calibration accuracy at B04-B06**
- **Magnitude Increases with the wavelength**

Application on ABI Instr. Characterization

- **Characterization of ABI Response Versus Scan-angle (RVS) for the VNIR bands with controlled lunar phase angle variation**
  - **Assumed that the relative calibration accuracy of GIRO can meet the requirement for the RVS assessment**
  - **ABI Lunar images were intensively collected at different time (phase angles), yet within one hour at each event**
    - **Absolute phase angles for all the events: between 5 – 50 degrees**
    - **Phase angle variation within each event: <2 degrees**

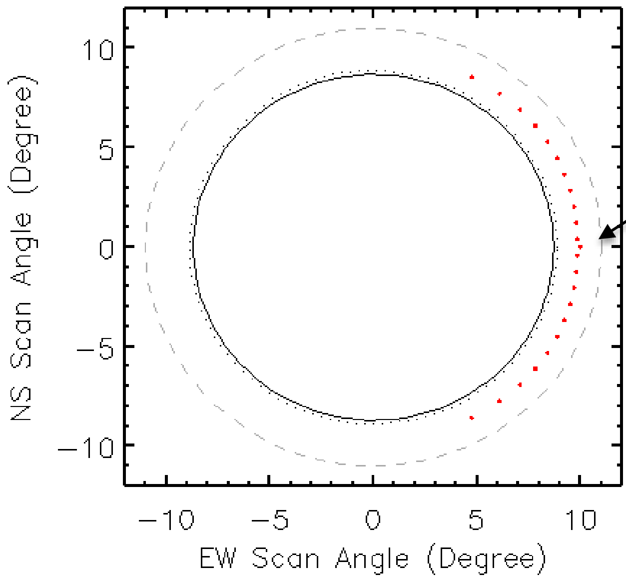
- **Extremely low scattered straylight sometimes may be present in the ABI B01/B02/03 images**
  - **Possible contamination in the spacelook count used for calibration**
  - **Possible earth shine at the lunar image**
  - **Most strongest at B01**

- **Accurate straylight correction was required for accurate lunar irradiance measurement**

Spacelook Contamination Correction

Straylight correction at spacelook, once it is confirmed:

$$L_{ev,step1} = \frac{m(C_{ev} - \overline{C_{sp}}) + q(C_{ev} - \overline{C_{sp}})^2}{p_{ew}p_{ns}}$$



location of the G17 SPL events

Corrected with the mean spacelook (SPL) count conducted near the Equator within the timeline ($\overline{C_{sp}}$)

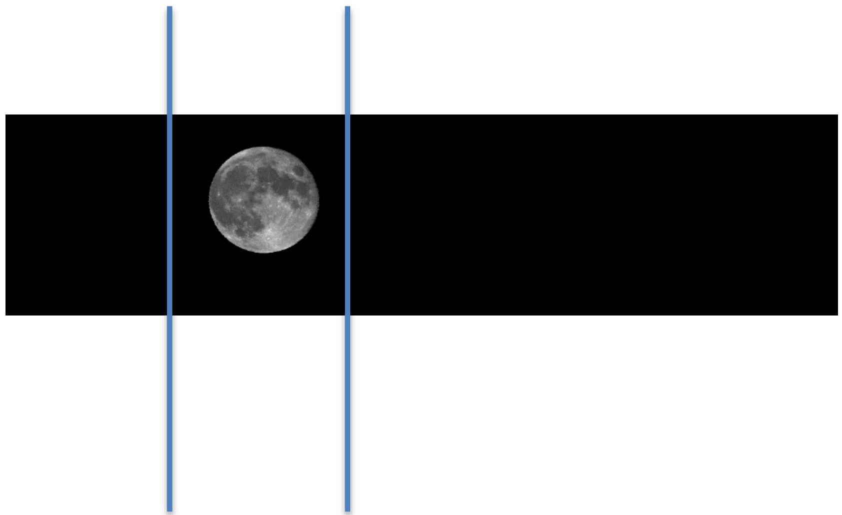
Straylight contamination is very small at sample level, <0.015% at 100% albedo

Manuscript on the ABI lunar image straylight correction is to be submitted for peer review purpose

Straylight Correction (Step # 2)

Earth-shine correction, once exists:

$$L_{ev,step2} = L_{ev,step1} - \overline{L_{space}}$$



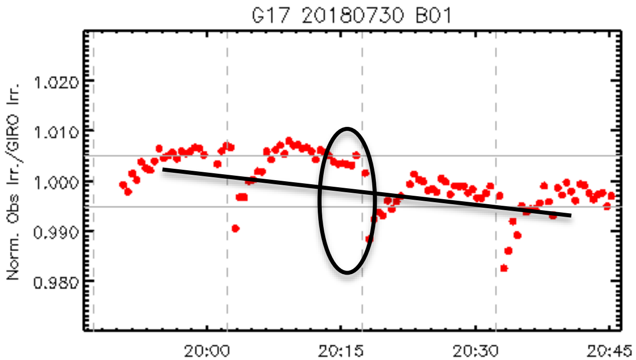
$\overline{L_{space}}$ is the mean radiance for the samples which is at least 0.0044 radian away from the center of the Moon

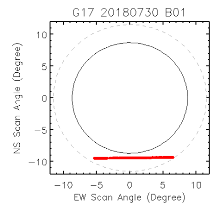
Straylight contamination is very small at sample level, <0.01% albedo

Manuscript on the ABI lunar image straylight correction is to be submitted for peer review purpose

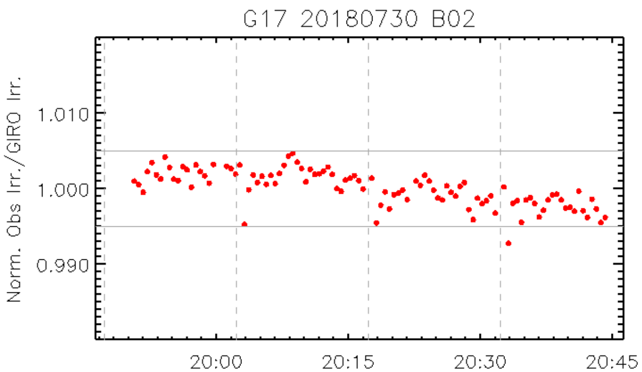
Impact of Straylight Corrections

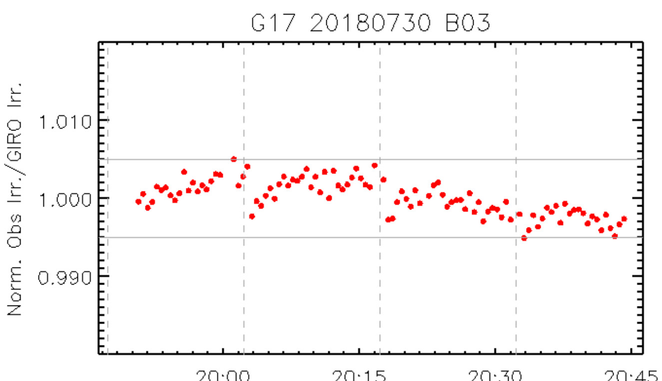
Before correction



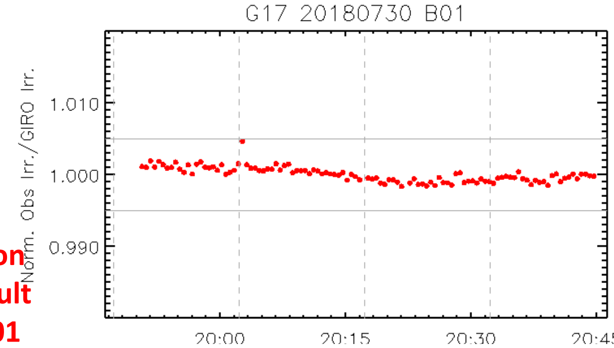


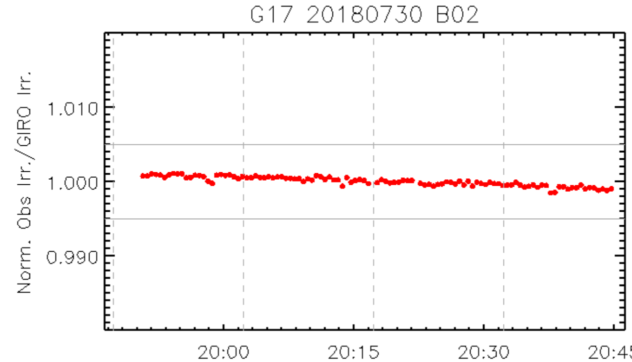
A very small straylight contamination (<0.03% albedo at sample) may result in >1% calibration uncertainty at B01

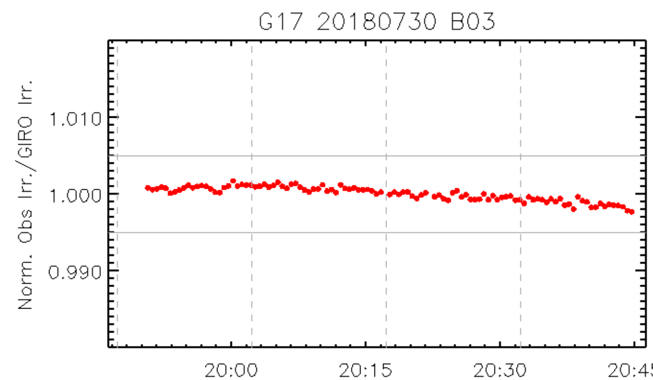




After SPL Straylight Correction

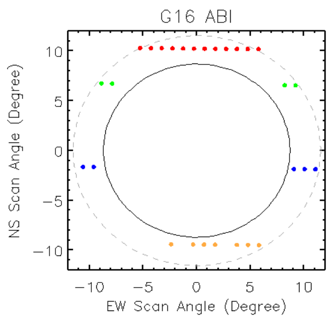


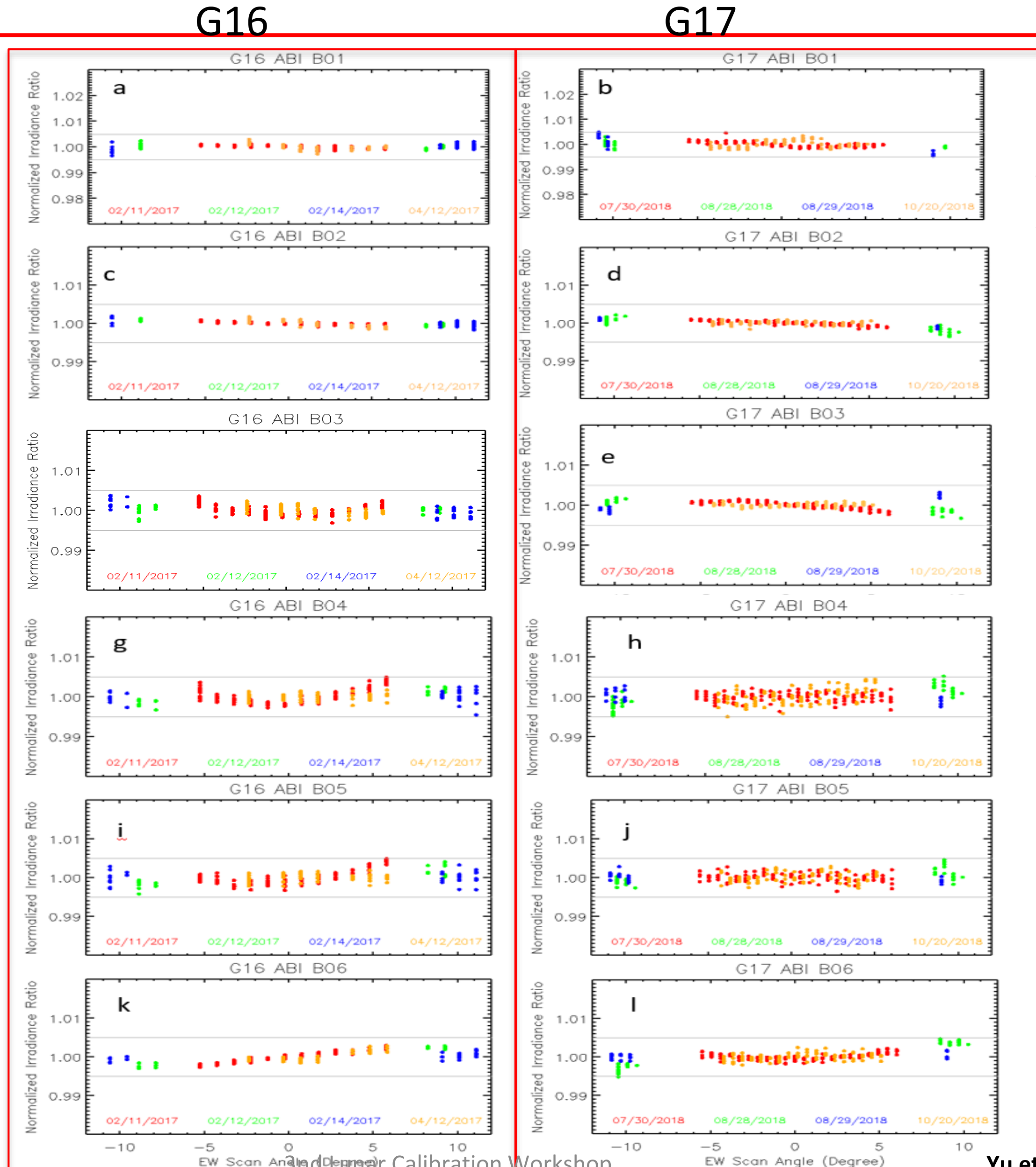


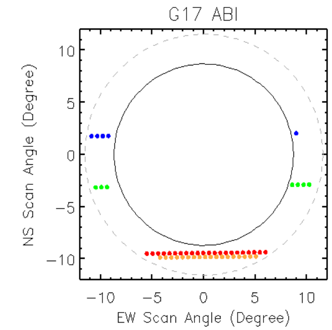


ABI EW RVS variation is well within 1%

G16/17 RVS after Straylight Correction







- Consistent results from different data collection events with different phase angle at each VNIR band indicates the high stability of GIRO model when data were collected at short period, including B06(2.25µm)

Summary

- The normalized irradiance ratio is used for the ABI solar calibration variation validation and instrument characterization

- Confirms that GIRO model has lunar phase angle dependent calibration accuracy above certain wavelength and the uncertainty increases with channel wavelength.

- However, when the phase angle variation is well controlled, the GIRO model is adequately consistent for the ABI RVS evaluation
  - ABI EW RVS well within 1%

- Accurate lunar irradiance calibration for the high spatial resolution lunar images can be very sensitive to straylight effects.
  - Straylight contamination less than 0.03% may result in calibration uncertainty at >1%
  - Straylight correction can be time consuming

- High accurate solid angle and oversampling factor values are also required for the accurate absolute calibration and sensor-to-sensor inter-comparison for instruments with high spatial lunar images.