The East-West Response versus Scan-angle Performance of GOES-16/17 ABI Solar Reflective Bands

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Acknowledgements: L3Harris and Dan Lindsey for the GOES-16 and GOES-17 color moon images, the GOES-R PRO for the coordination effort, the GOES-R MOST and operation teams for the lunar image collections, and the GSICS community for sharing the GIRO model

Introduction

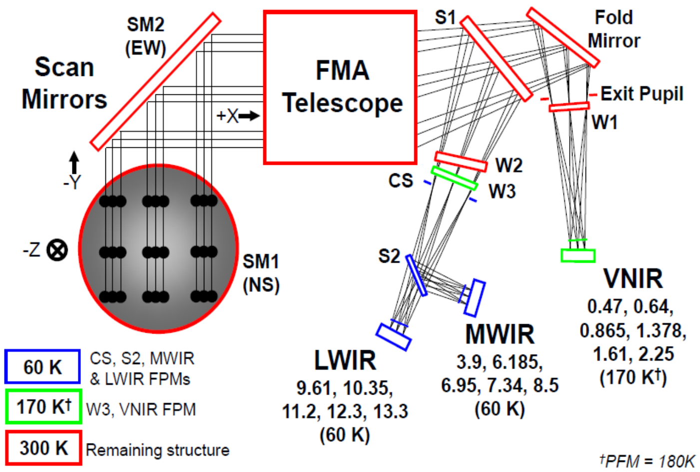
- **NOAA has a long history in using the Moon for the calibration of instruments on the GEO platforms**
  - Started with GOES-10 Imager in 2005

- **Broad interest in the Moon for GOES calibration, including**
  - In-orbit solar cal. validation
  - Instrument degradation trending
    (Long-term monitoring)
  - Response versus scan-angle (RVS) validation ← This talk
  - Modulation Transfer Function (MTF) evaluation
  - Detector response uniformity evaluation
  - Straylight/crosstalk/blooming assessments
  - Detector dynamic response range/nonlinear response validations
  - …

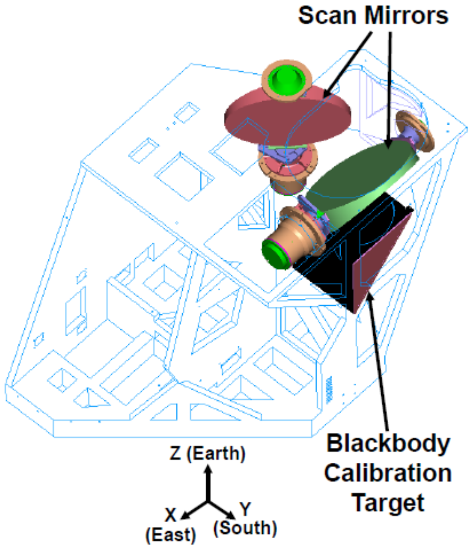
- **More opportunities and easier lunar collections for GOES-R ABI**
  - ABI can scan the Moon whenever the Moon appears within the Field Of Regard (FOR)
  - Lunar images can be collected at a large variety of phase angles
  - No need of spacecraft maneuver

GOES-R ABI Instrument

- ABI Bands: 16 bands
  - 6 visible and near-infrared (NVIR) 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

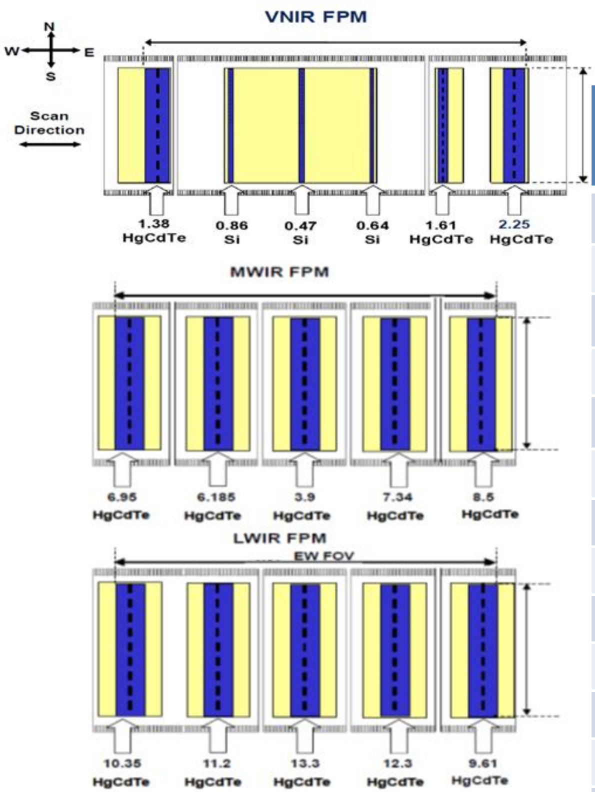


GOES-16 ABI Optical Architecture



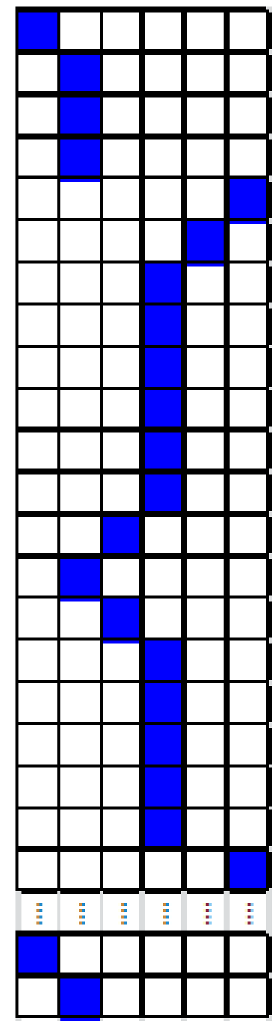
figures are courtesy of L3Harris)

Detector Focal Plane Modules and BDS



Band	FMP	Central Wvlen (µm)	IFOV EW (urad)	IFOV NS (urad)	Columns	Rows
1	VNIR	0.47	22.9	22.9	3	676
2		0.64	12.4	10.5	3	1460
3		0.87	22.9	22.9	3	676
4		1.38	51.5	42.0	6	372
5		1.61	22.9	22.9	6	676
6		2.25	51.5	42.0	6	372
7	MWIR	3.9	51.5	47.7	6	332
8		6.2	51.5	47.7	6	332
9		6.9	51.5	47.7	6	332
10		7.3	51.5	47.7	6	332
11		8.5	51.5	47.7	6	332
12	LWIR	9.6	51.5	47.7	6	332
13		10.4	34.3	38.1	6	408
14		11.2	34.3	38.1	6	408
15		12.3	34.3	38.1	6	408
16		13.3	34.3	38.1	6	408

Best Detector Selected (BDS) in each row

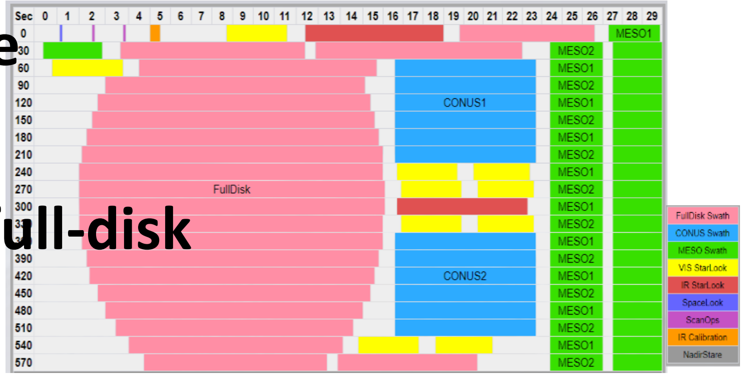


Each band has hundreds to thousands of detector rows. Each row has 3 or 6 detector columns.

These figures and table values are courtesy of L3Harris)

NOAA GOES-R ABI Lunar Scans

GOES-16 ABI Mode 6 timeline



- **ABI images are collected with timeline**
- **Each normal ABI timeline consists of full-disk scans, CONUS scans, MESO scans and calibration targets' scans**
- **MESO scan is used to collect the lunar images**

- **Each MESO scan has two swaths. The Moon is scanned in one swath**

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

ABI Calibration Algorithm

- **Two-point, offset calibration:**
  - **Bright target: solar calibration target (SCT) – solar diffuser**
  - **Dark target: deep space**
- **Compensating for the reflectivity contributions from the two scan mirrors**

Updated after solar cal. event

fixed

$$R_{target} = \frac{m\Delta C_{target} + q\Delta C_{target}^{2}}{\rho_{EW}^{target}\ \rho_{NS}^{target}}$$

Pre-launch measured parameters

Where R_{target} is the radiance of scanned target; m is the calibration coefficient determined in-orbit; q is the quadratic term, fixed; ΔC_{target} is the target count offset to the space; ρ_{NS}^{target} and ρ_{EW}^{target} are the reflectance of the NS and EW scan mirror at the incident angle of the scanned target, respectively.

Lunar Image Collections for RVS Validation

- **This method was first applied at GOES-15 during its post-launch product testing (PLPT) period in 2010**
  - **The GOES-15 spacecraft was rolled northward for the Imager to consecutively collect the Moon images at a variety of scan angles**
  - **No need of any spacecraft maneuver for ABI to chase the Moon across the ABI FOR**

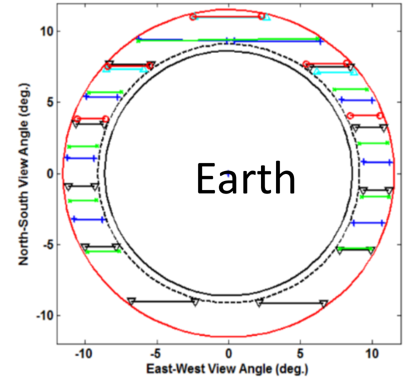
- **The Moon is a stable bright calibration source within the FOR**

- **Global Satellite Inter-Calibration System (GSICS) Implementation ROLO (GIRO) model used to simulate the lunar irradiance**
  - **GIRO/ROLO is well known for the relatively calibration accuracy within a certain phase angle range, especially at short time period**

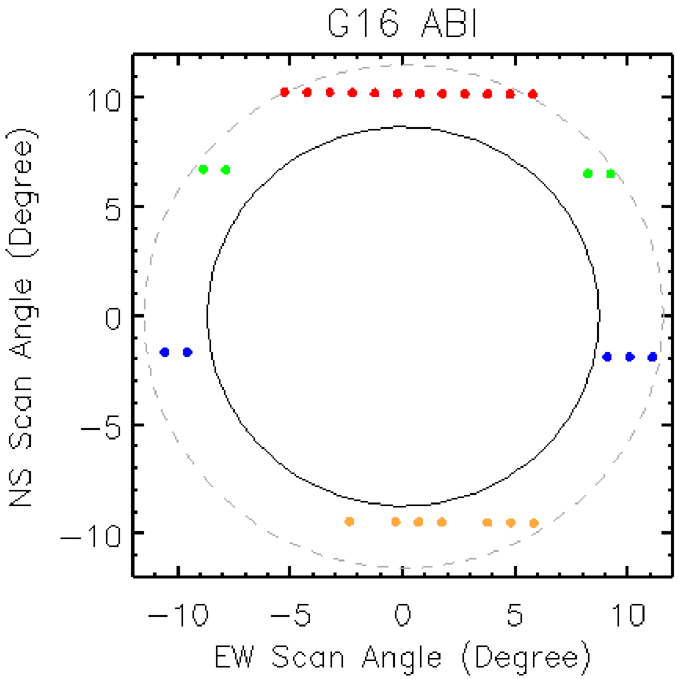
- **Chasing the Moon from the West to the East in the space**
  - **5° < |Lunar phase angle| < 60°**

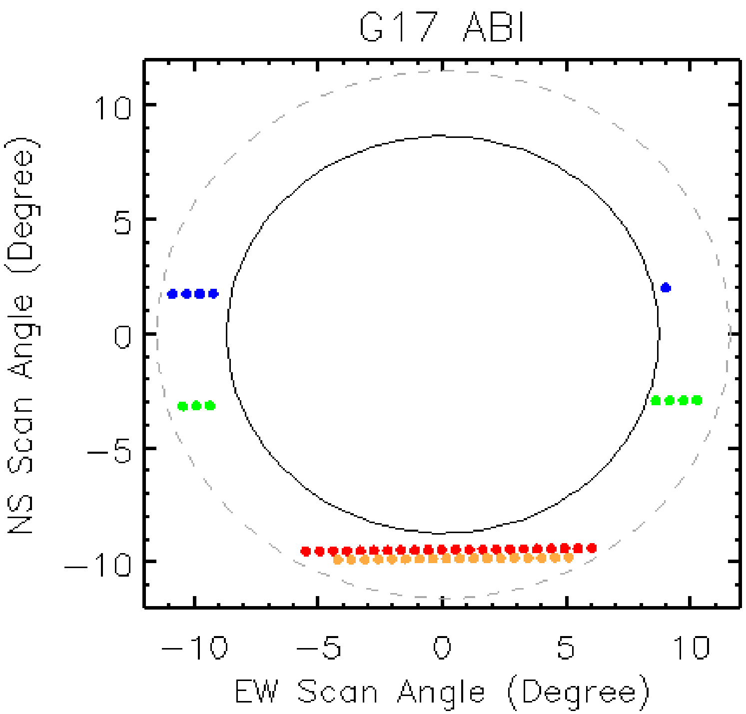
ABI Field of Regard (in dash circle), the Earth and the Moon

$$Ratio = \frac{I_{ABI}}{I_{GIRO}}$$



G16/G17 Lunar MESO LOS





GOES-16 ABI Lunar Images

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

ABI Lunar Irradiance Measurement

- **Lunar Irradiance:**

$$I = \frac{\Omega}{Oversampling\_factor} \sum_{i}^{row} \sum_{j}^{col} Radiance_{i,j}$$

Ω: Sample solid angle = Sr(EW_ASD * NS_ASD)

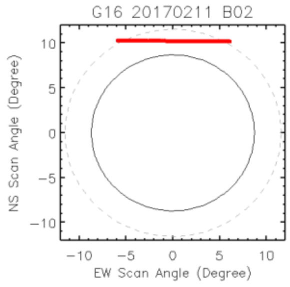
$Radiance_{i,j}$: calibrated radiance at (i,j) image coordinate in the subset lunar images

- **Normalized lunar irradiance ratio**
  - **Oversampling_factor is a fixed value for ABI and thus cancelled out**

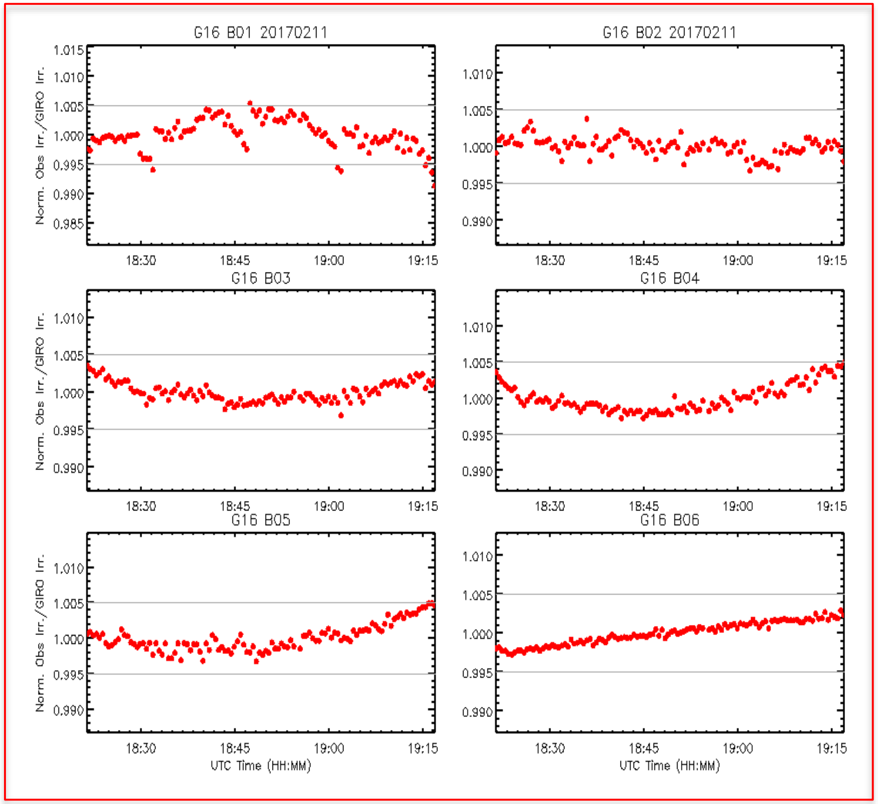
$$Ratio = \frac{I_{ABI}}{I_{GIRO}}$$

$$\text{Normalized\_Ratio} = \frac{Ratio}{mean(Ratio)}$$

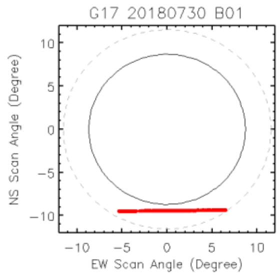
Time-series of G16/17 Norm. Lunar Irr. Ratio

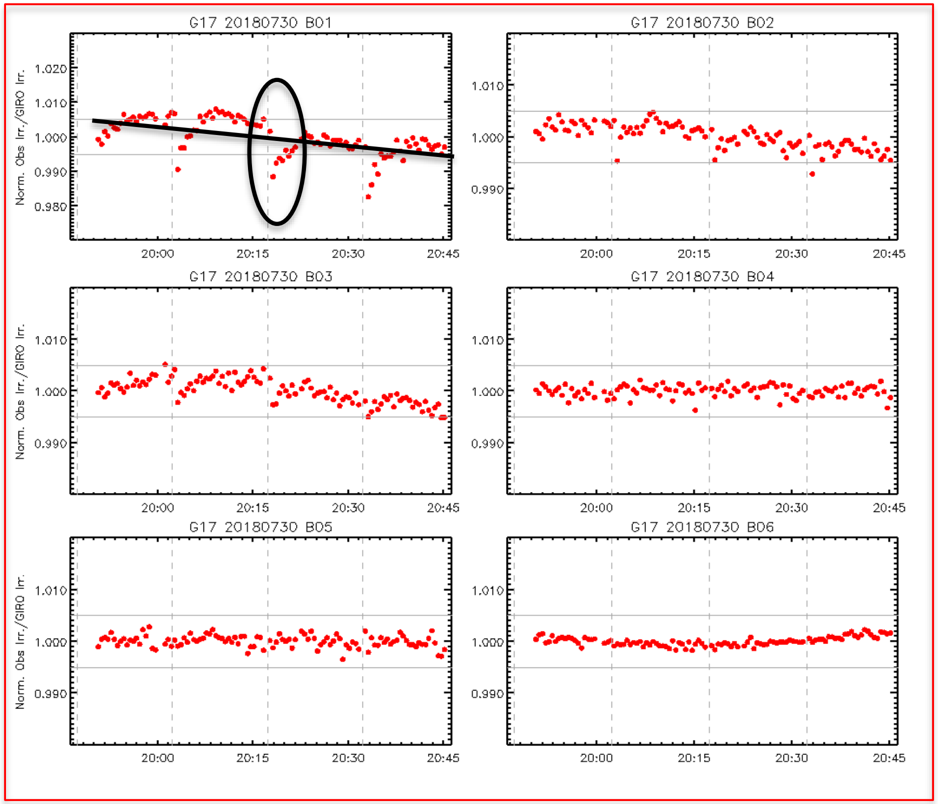


G16



G17





Uncertainty in ABI Lunar Irradiance

- **Irradiance measurement:**

$$I = \frac{\Omega}{Oversampling\_factor} \sum_{i}^{row} \sum_{j}^{col} Radiance_{i,j}$$

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

Band	Columns	Rows
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#samples = 1.48E+5 – 2.2E+6

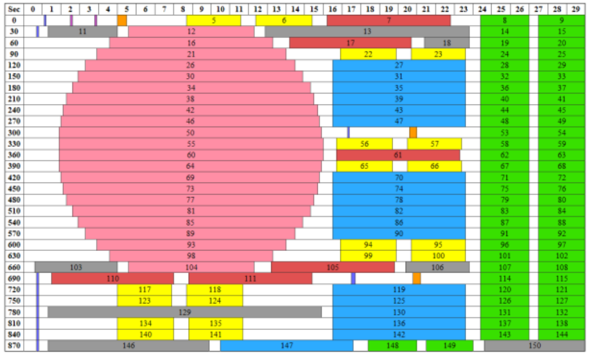
- **Accumulated from ~1.5E+5 to 2.2E+6 number of lunar image samples per channel**
  - **Lunar irradiance can be very sensitive to extremely slight straylight at each pixel**

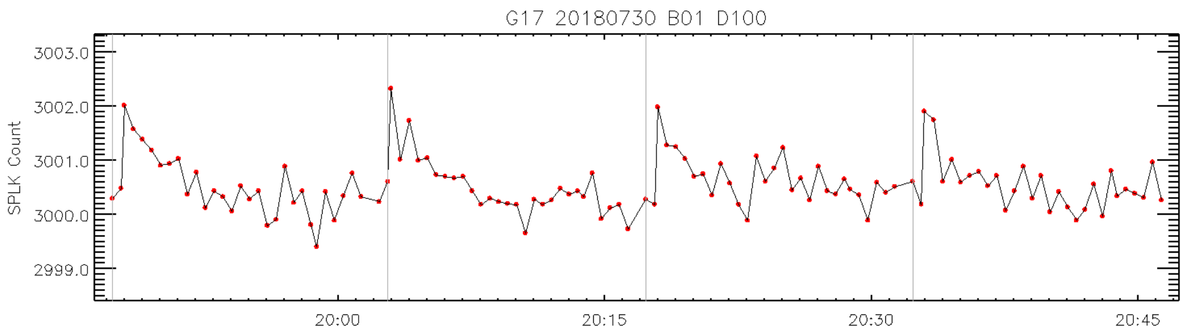
- **L3Harris indicated the small and negligible straylight may be scattered into the light-of-sight of ABI**
  - **Prelaunch & in-orbit data**

- **Two types of straylight impacts on sample radiance**
  - **Possible contaminated spacelook count**
  - **Possible scattered straylight on the space samples**

Impact of Contaminated Spacelook

- **Delta count**
  - $L_{ev} = \dfrac{m(C_{ev} - C_{sp}) + q(C_{ev} - C_{sp})^2}{p_{ew}p_{ns}}$
  - **ABI calibration data is of 14 bit-depth**
  - **The mean contamination is less than 2 count**





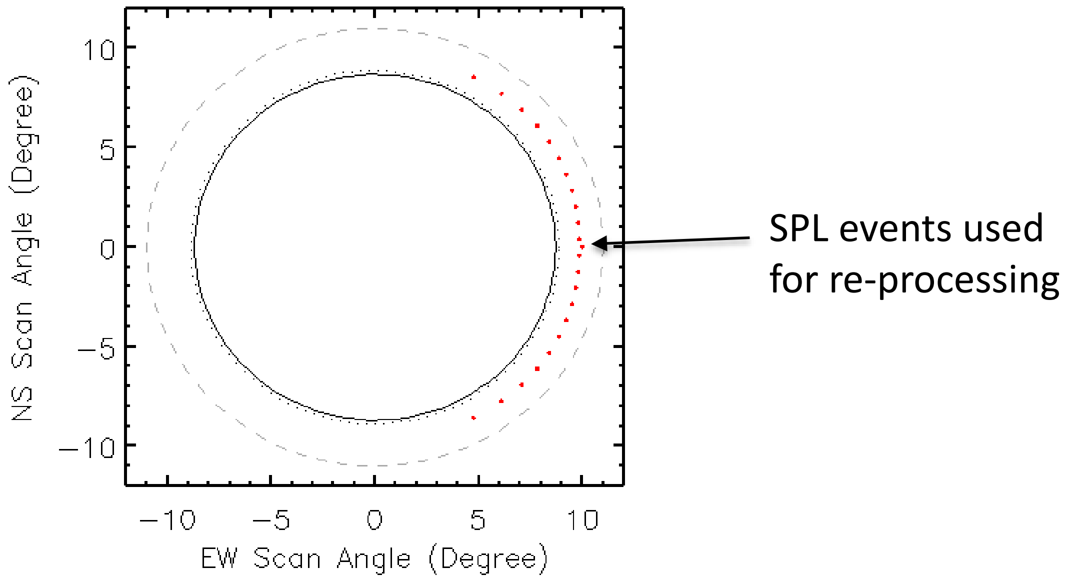
	Time	Det#	Max SPL Count	Mean SPL count at Equator	DN at 100%	Impact on 100% Albedo Pixel (%)
B01	10/20/2018 15:00.02.3 – 15:15:02.3Z	100	2999.97	2997.97	11247	**0.0178%**

Confirmed that the impact of the contaminated spacelook on the pixel radiance is very small.

Straylight Correction (Step #1)

For each detector, use the mean spacelook count conducted near the Equator within the timeline ($\overline{C_{sp}}$)

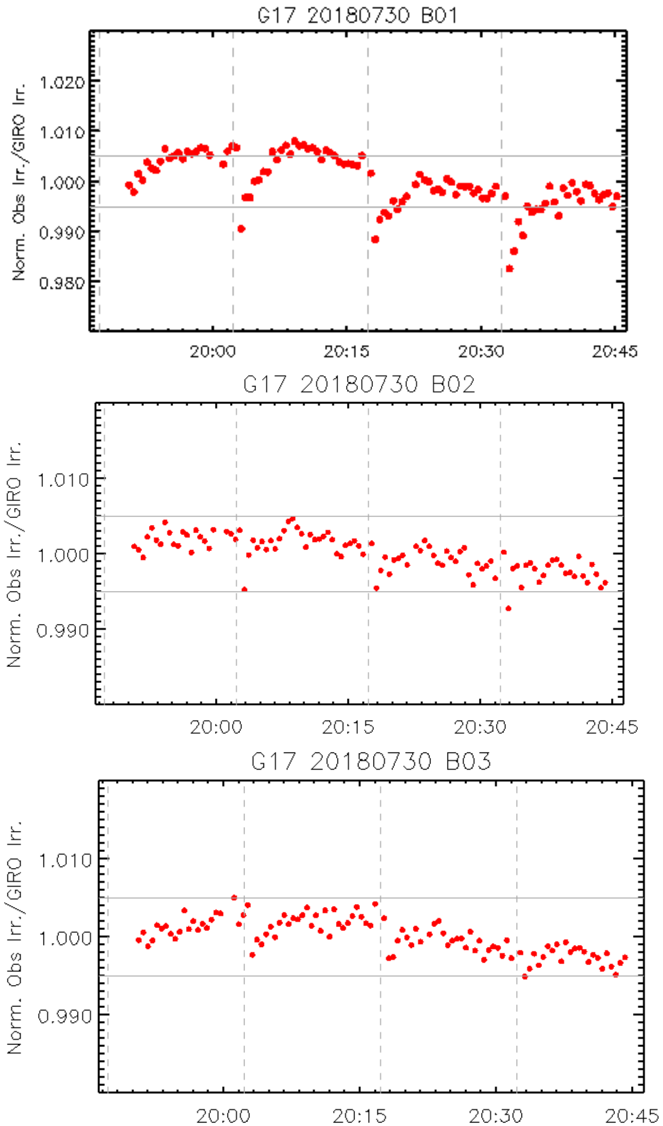
$$L_{ev,step1} = \frac{m(C_{ev} - \overline{C_{sp}}) + q(C_{ev} - \overline{C_{sp}})^2}{p_{ew}p_{ns}}$$



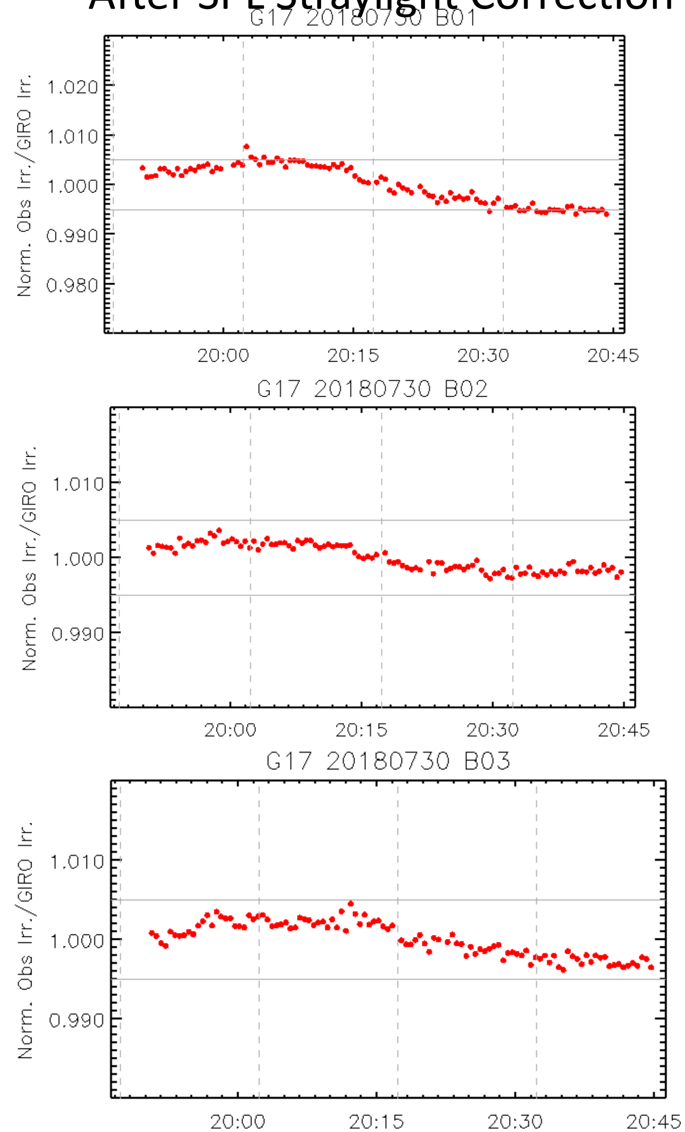
location of the G17 SPL events at a time-line

G17 Norm. Lunar Irr. Ratio – 07/30/2018

Before correction



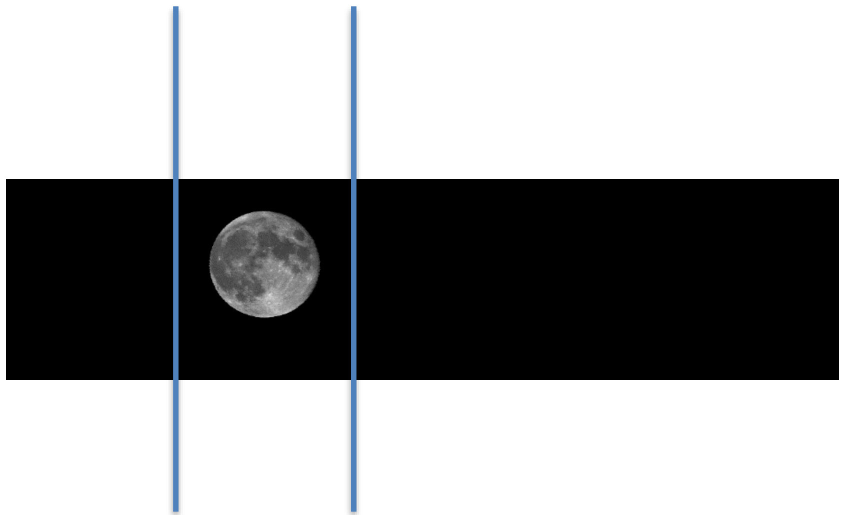
After SPL Straylight Correction



The re-processed data removed the discontinuity between the time-line, yet the overall variations still exist at B01-B03

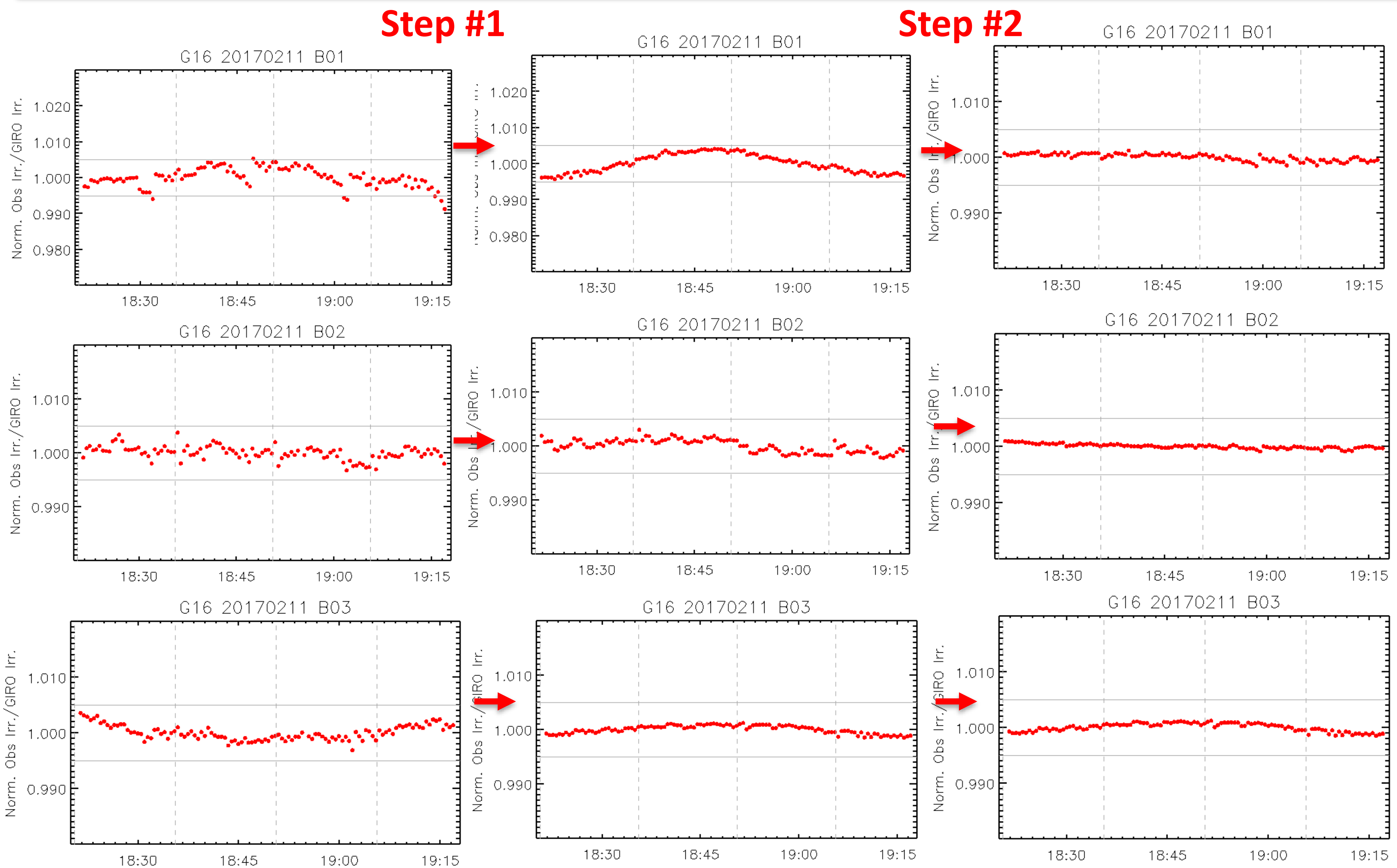
Straylight Correction (Step # 2)

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



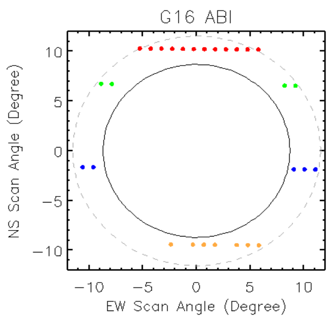
$\overline{L_{space}}$ is the mean re-processed (step #1) radiance for the samples which is at least 0.0044 radian away from the center of the Moon.

Combined Straylight Corrections

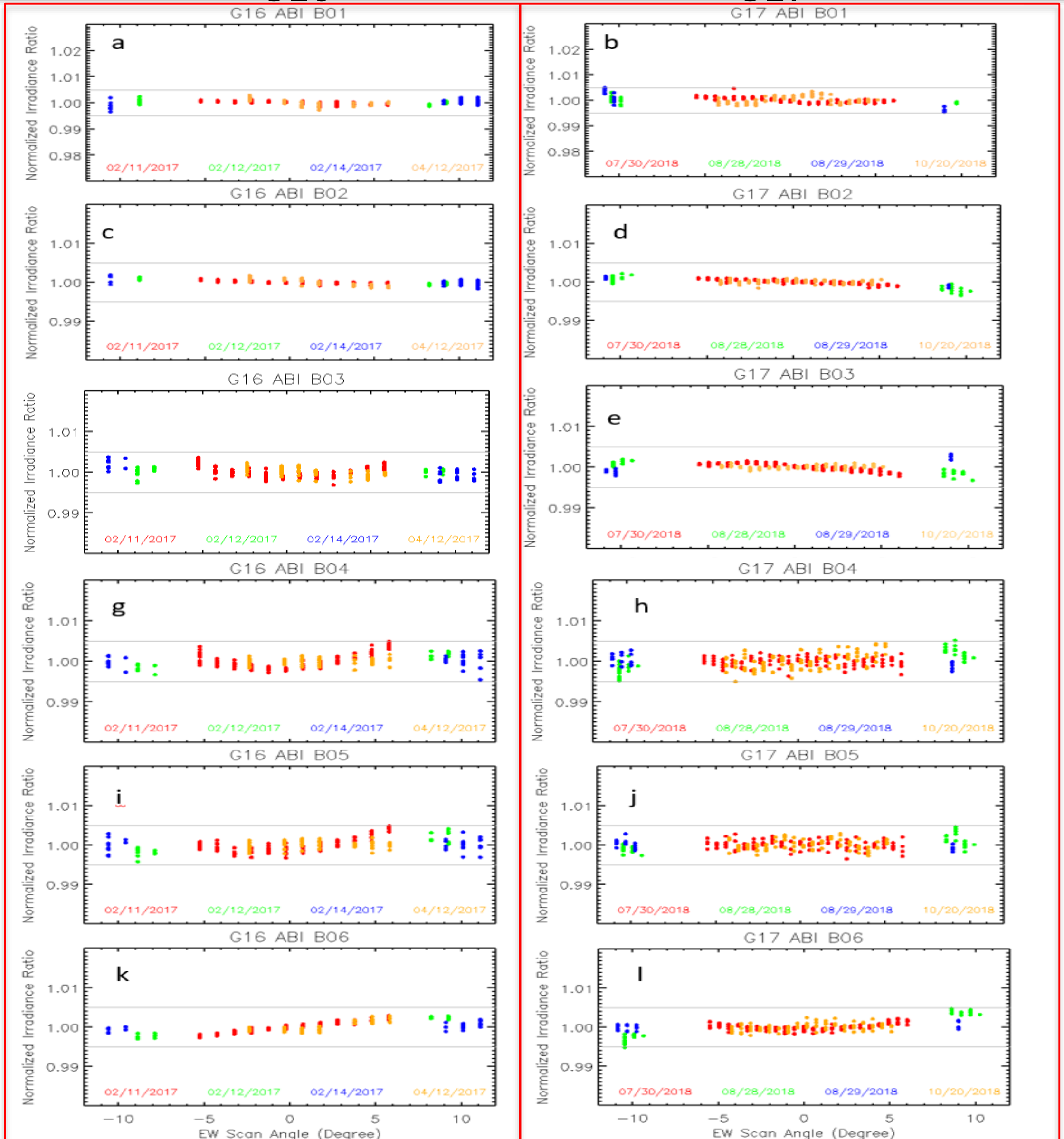


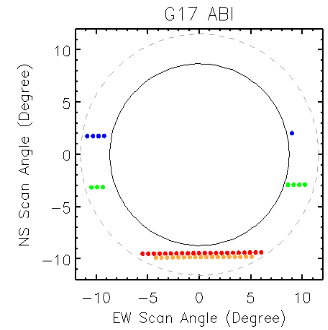
RVS EW variation is less than 1%

G16/17 RVS for VNIR Bands



G16 G17





Summary

- The Moon can be used as the bright reference for the ABI instrument spatial uniformity study
- G16/17 RVS variation is well within 1% at the E-W direction for all the VNIR bands
- Lunar irradiance of high spatial resolution of lunar images can be very sensitive to straylight effects. Accurate straylight correction may be required for the accurate lunar irradiance calibration.
- GIRO(ROLO) displays a very good relative calibration accuracy when the lunar images of a bright moon were collected in a short period
  - Including ABI B06 (2.26µm)