Radiometric Calibration of the Planet Labs PlanetScope Constellation

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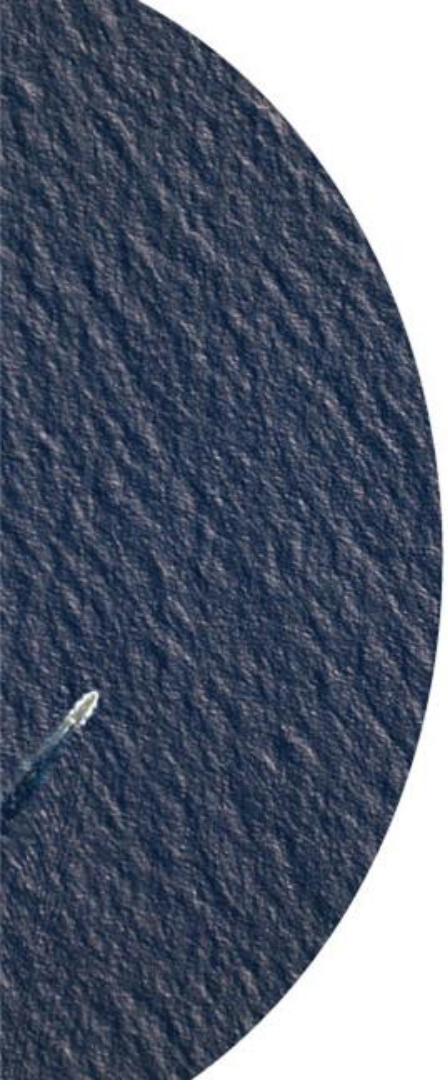
JACIE 2016



Outline

1. Planet Labs Overview
2. PlanetScope Constellation
3. Radiometric Calibration Strategy
4. Calibration Technique
5. Calibration Processing
6. Calibration Status

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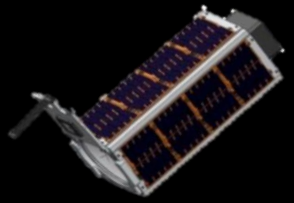
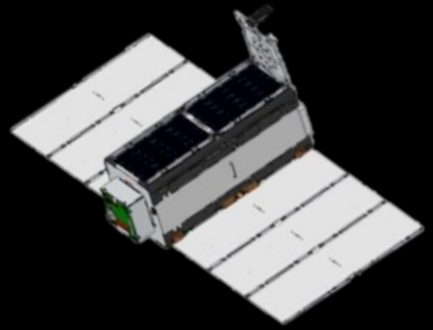
Agile Aerospace

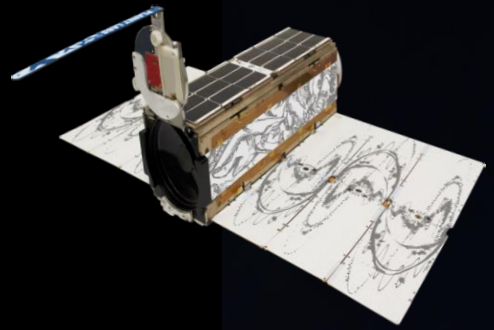
BUILD 1
APR 2012



BUILD 6
APR 2013



BUILD 13
JUN 2015



13 Builds in 4 years

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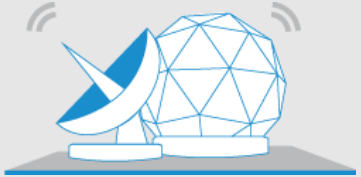
Planet's End-to-end System

130+
Satellites

475km
Altitude
Sun Synchronous
Orbit



24
Ground Stations

9
Sites

>1M
images per day

1000s of
virtual
machines

5-10TB
Downlinked
daily

API
For data pipeline
and platform
access

Mission 1: Image whole Earth everyday

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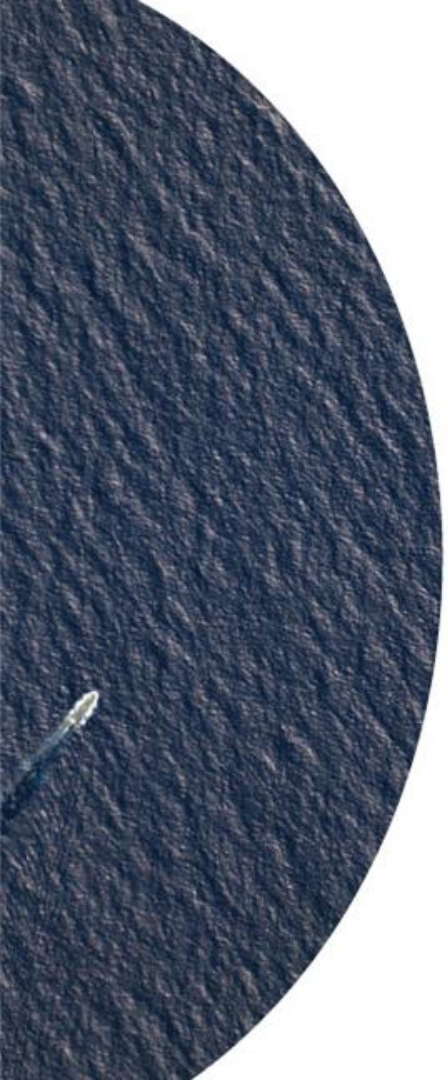

PlanetScope Constellation

	ISS Orbit	Sun Synch Orbit (target)
Expected Lifetime	1 year per satellite	2-3 years per satellite
Mission Continuity	Up to 55 satellite constellation (continually replenish / upgrade satellites)	100-150 satellite constellation (continually replenish / upgrade satellites)
Inclination	52 deg	98 deg
Equator Crossover Time	varies	9:30-11:30am
Orbital Insertion Altitude	420km	475km
Ground Sampling Distance (Nadir)	2.7m-3.2m	3.7m-4.9m
Sensor Type	Bayer-masked CCD camera	
Spectral Bands	Red: 610-700nm Green: 500-590nm Blue 420-530nm	

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PlanetScope Sensor - ‘Dove’

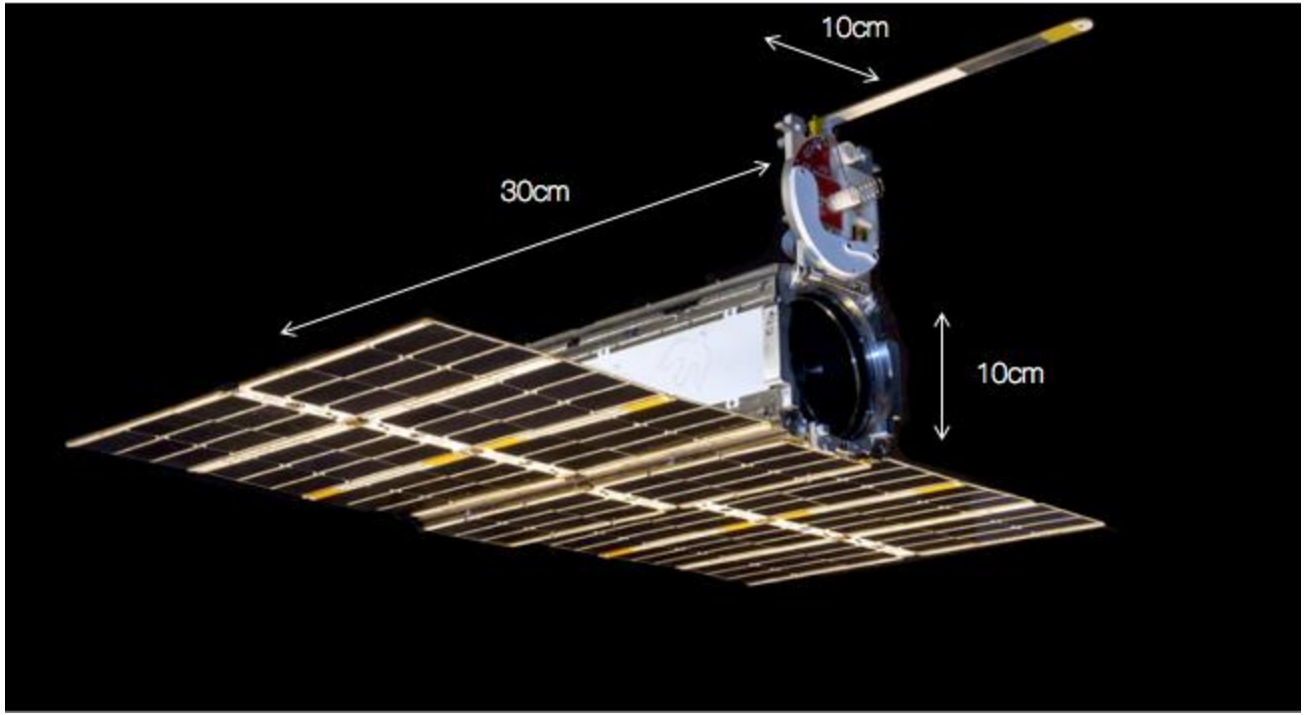


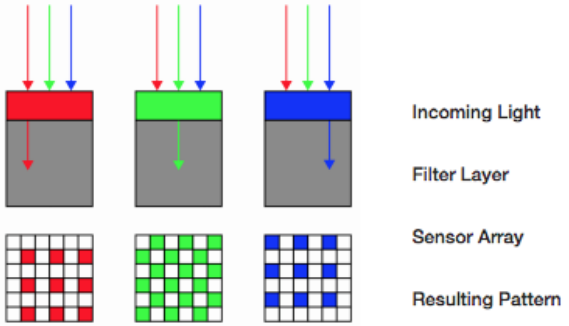
Image Collection

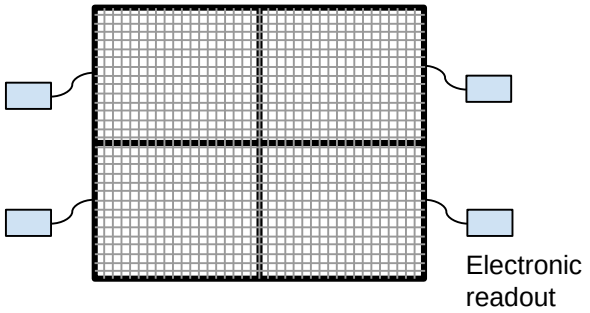
Src: [Product specification]

4-tap Bayer-Masked CCD Array

Bayer Mask

4-Tap Arrangement





Radiometric Calibration Strategy

- On-line
- Semi-automated
- Uses production pipeline
- Processing in the cloud
- Multiple calibration techniques

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Goal of Radiometric Calibration

- Radiometric Accuracy
  - Relative accuracy <15%
    - temporal + inter-sensor
  - Absolute accuracy <20%
- Scalability
  - Calibrate >150 satellites

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Radiometric Product

- 16-bit GeoTIFF
- Scaled to top of atmosphere spectral radiance
- Scaling factor constant across orbit
- Scaling factor given in metadata

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Calibration Techniques

In Progress

- Pre-launch calibration
- Lunar Calibration
- SDSU Calibration using PICS

Planned

- Ground-based vicarious calibration

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Pre-Launch Calibration

Benefits:

- Data available before satellite commissioning
- Excellent data quality

Drawbacks:

- Long lead time vs development rate
  - Not very agile!
- Cannot quantify effect of launch

Primary use:

- Initial absolute calibration
- Camera model (temperature, tdi, exposure time, ...)

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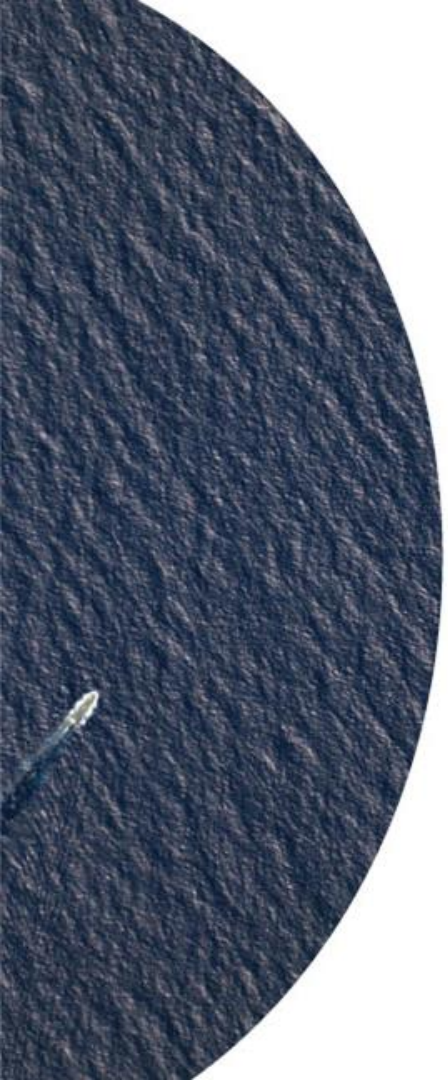

Lunar Calibration

Benefits:

- High availability
- Near-simultaneous collects
- Low relative calibration uncertainty

Drawbacks:

- Not available 2 weeks / month
- High absolute calibration uncertainty
- Heterogeneous pixel intensity

Primary use:

- Initial / continuous relative calibration

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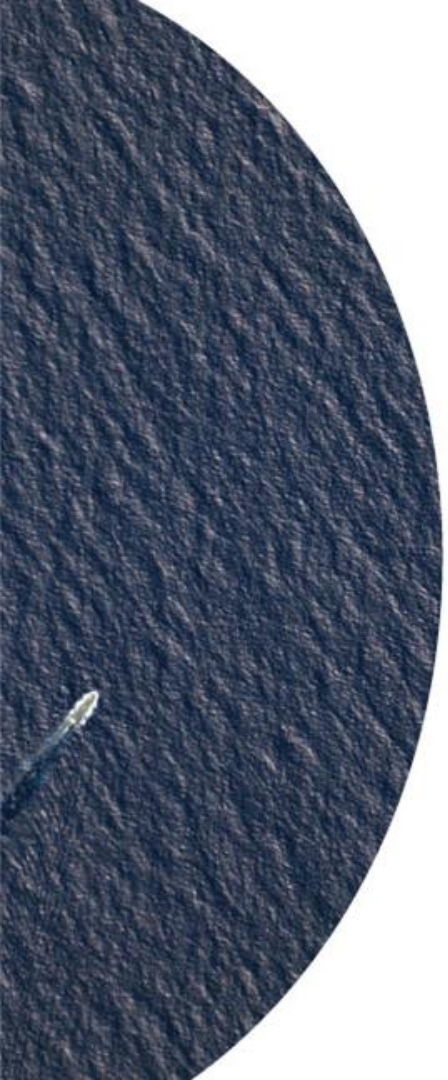

ROLO Model Implementation

- Based on Kieffer, Stone “The Spectral Irradiance of the Moon” [1]
- Implemented in Python by Planet Labs
- Reflectance validated against raw and adjusted ROLO lunar reflectance in “The spectral irradiance of the Moon” [1] (figure 8)
- Irradiance validated against ROLO lunar irradiance in “Radiometric calibration stability and inter-calibration of solar-band instruments in orbit using the moon” [2]

[1] H. H. Kieffer and T. C. Stone, “The spectral irradiance of the Moon,” *The Astronomical Journal*, vol. 129, no. 6, p. 2887, 2005.

[2] T. C. Stone, “Radiometric calibration stability and inter-calibration of solar-band instruments in orbit using the moon,” in *Optical Engineering+ Applications*, 2008, p. 70810X–70810X.

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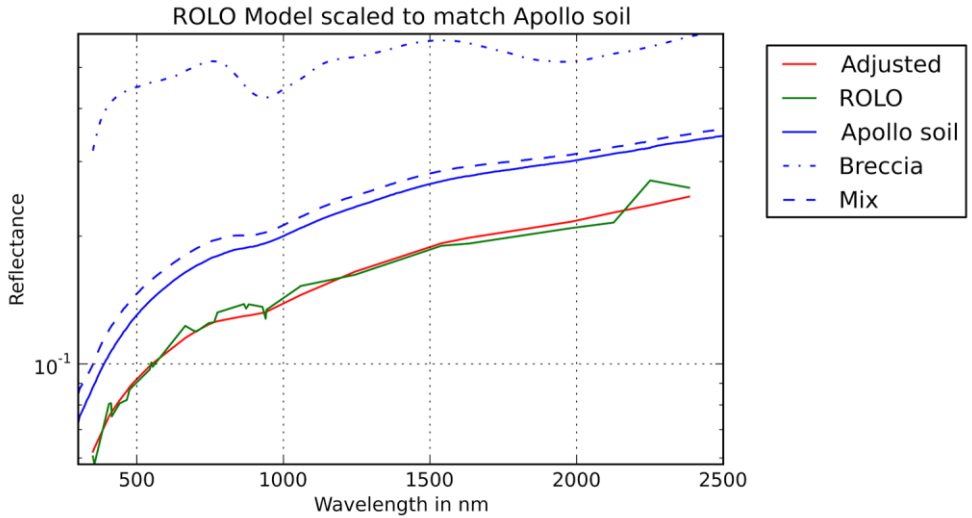
ROLO Model Validation

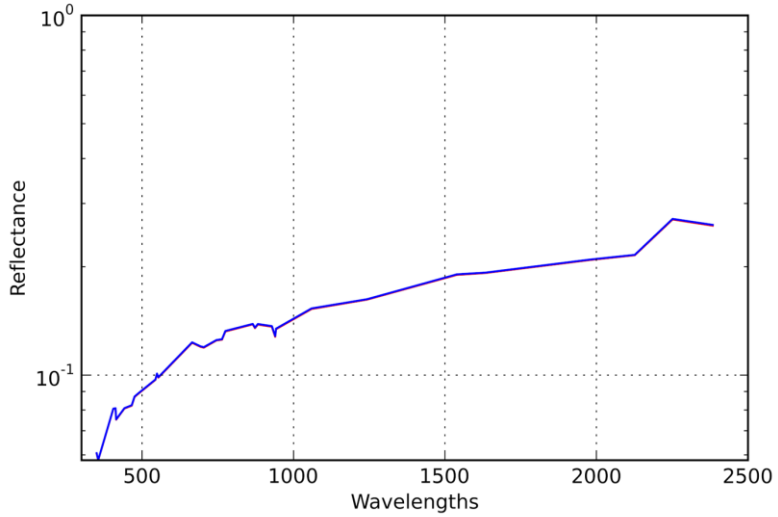
Raw and Adjusted Rolo Model (figure 8)



Data used as input for validation and radiance adjustments

ROLO Model Validation

Raw Lunar Reflectance (figure 8)



(blue) Published ROLO results (src: Tom Stone)

(red) Planet Labs ROLO implementation

Less than 0.5% difference

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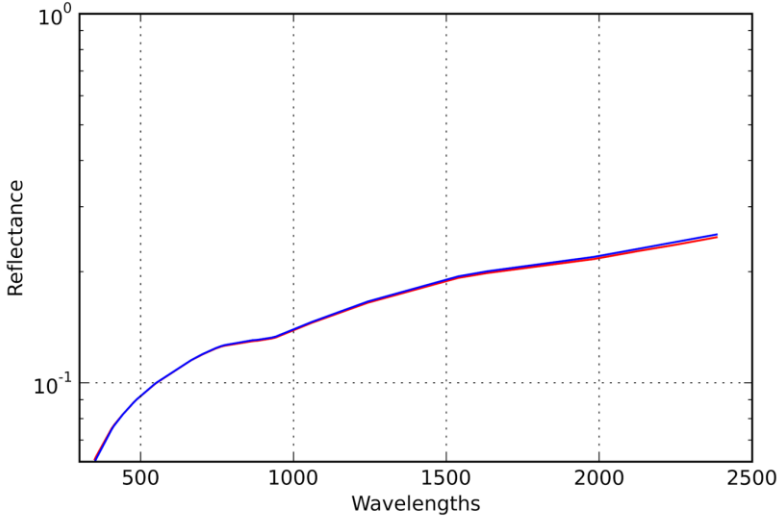
ROLO Model Validation

Adjusted Lunar Reflectance (figure 8)



(blue) Published ROLO results (src: Tom Stone)

(red) Planet Labs ROLO implementation

Used Apollo samples for smoothing

Less than 1.71% difference

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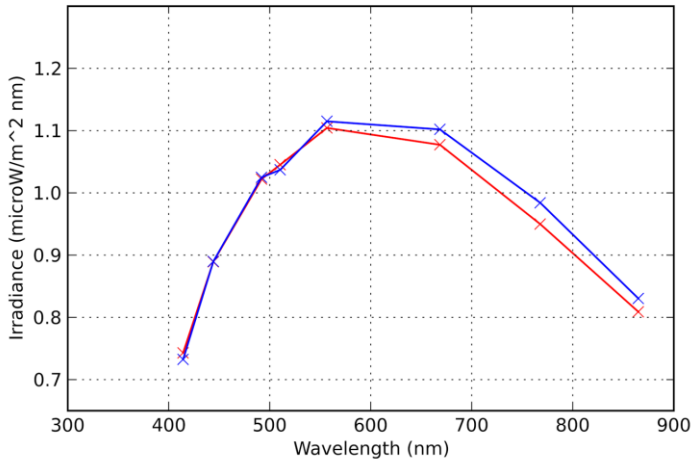
ROLO Model Validation

Lunar Irradiance (table 1)



(blue) Published ROLO results (SeaWiFS, 2006-12-09)

(red) Planet Labs ROLO implementation

Using Wehrli solar irradiance model provided by Tom Stone

Up to 3.77% difference

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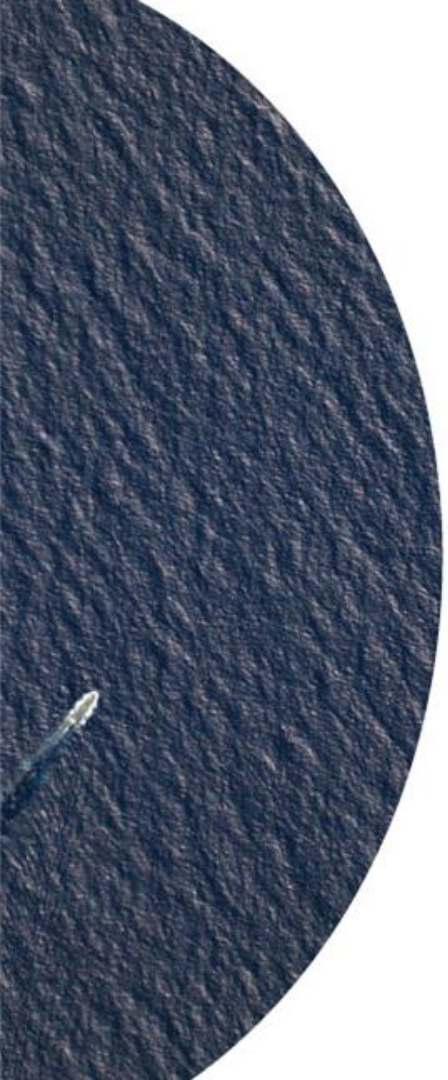

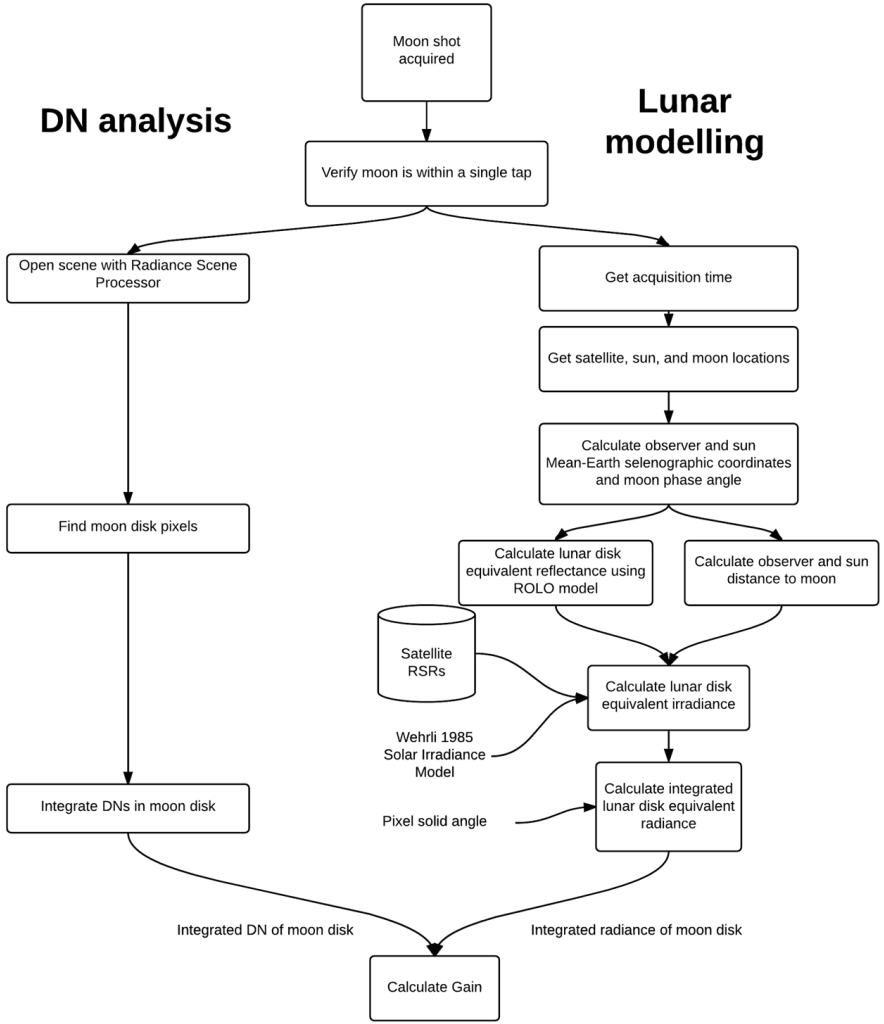
DN analysis
Lunar modelling
Moon shot acquired
Verify moon is within a single tap
Open scene with Radiance Scene Processor
Find moon disk pixels
Integrate DNs in moon disk
Get acquisition time
Get satellite, sun, and moon locations
Calculate observer and sun Mean-Earth selenographic coordinates and moon phase angle
Calculate lunar disk equivalent reflectance using ROLO model
Calculate observer and sun distance to moon
Satellite RSRs
Wehrli 1985 Solar Irradiance Model
Calculate lunar disk equivalent irradiance
Pixel solid angle
Calculate integrated lunar disk equivalent radiance
Integrated DN of moon disk
Integrated radiance of moon disk
Calculate Gain

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SDSU Calibration using PICS

Goals

- 3rd-party calibration validation
- Assess feasibility of using PICS models for relative calibration targets

Work in Progress (SDSU)

- Develop relative radiance models for 6 PICS sites to compliment Libya-4 and Algodones Dunes sites
- Assess sensor dark noise stability
- Radiometric calibration of 2 PlanetScope sensors

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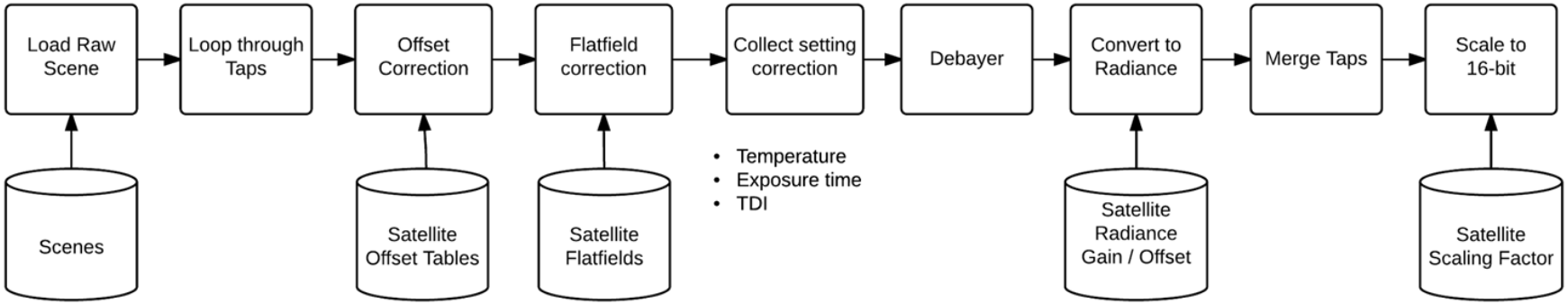
Calibration Processing

Goals:

- Accurate
- Scalable
- Timely

Radiance Scene Processing

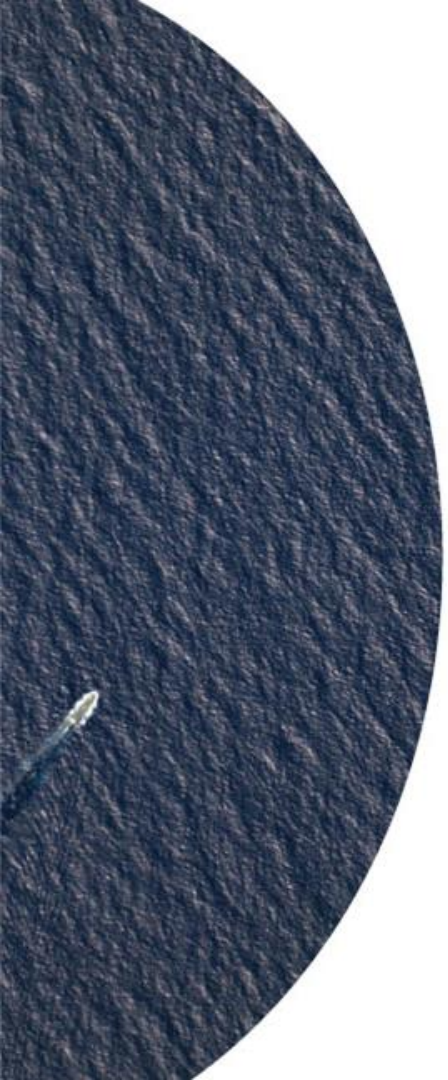


Processed Scene

Debayer Only

Corrected

Converted to Radiance



Calibration Automation

- Calibration imagery automatically detected
- Detecting a calibration collect triggers a calibration process
- Processing is in the cloud alongside production imagery
- Each process generates a calibration data point
- Calibration data points processed at regular interval to update satellite calibration
- Manual check before satellite calibration is updated

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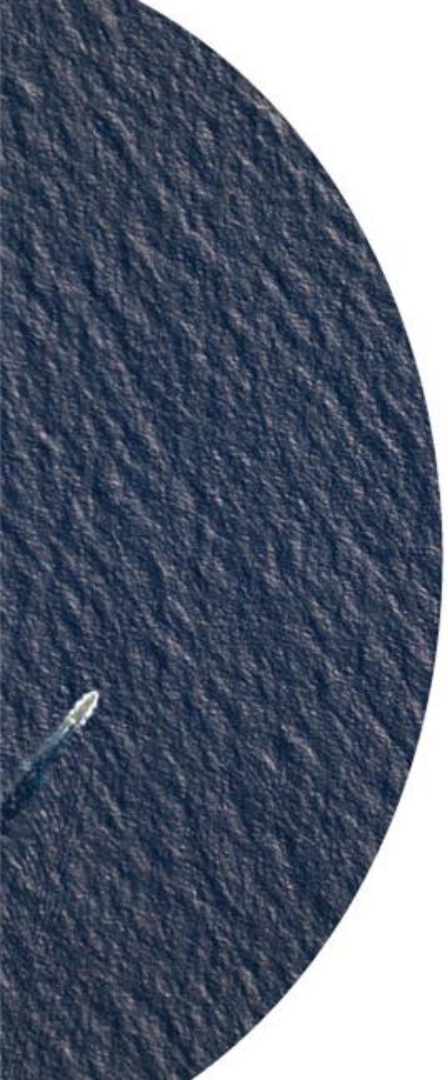

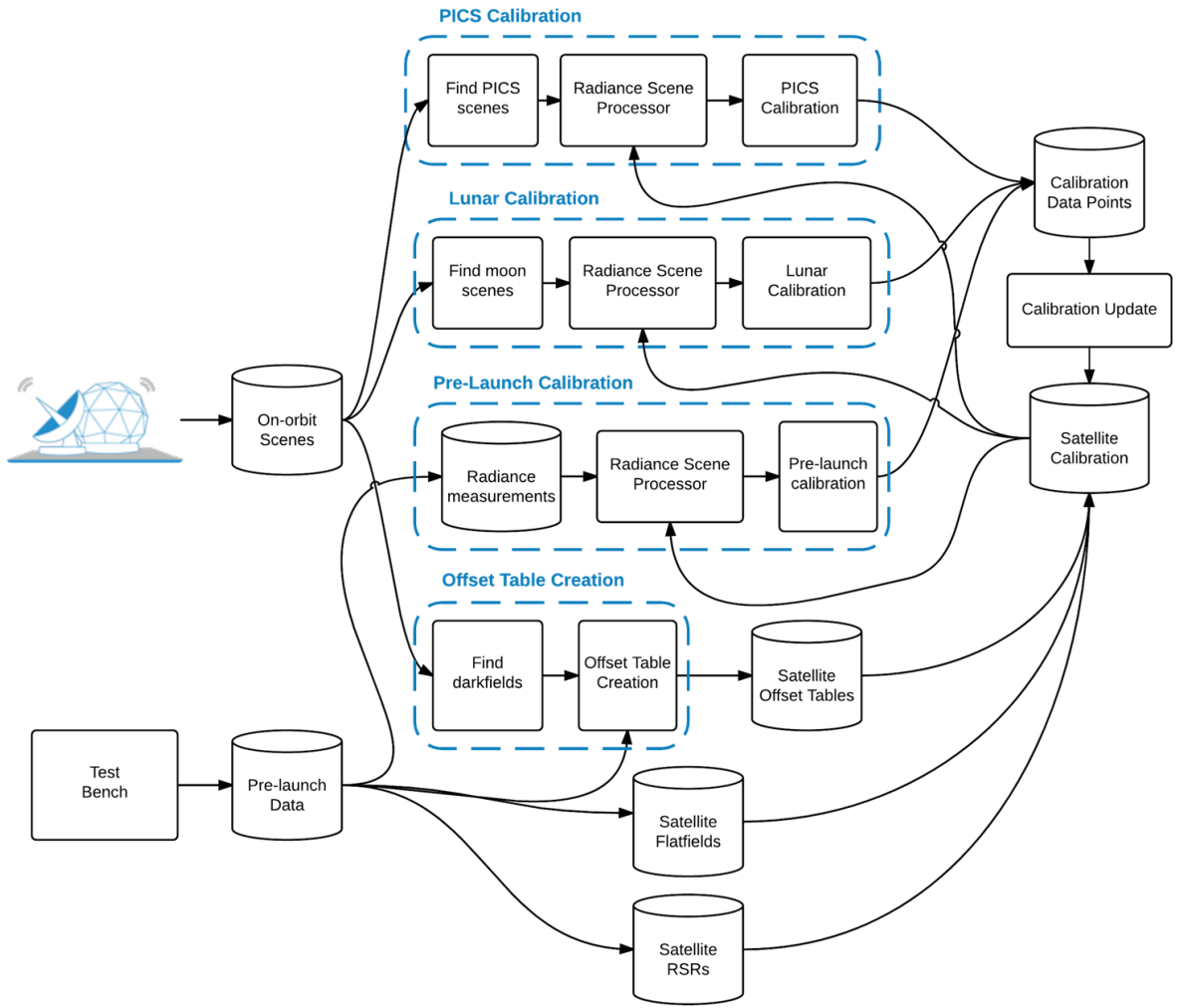
PICS Calibration
Find PICS scenes
Radiance Scene Processor
PICS Calibration
Lunar Calibration
Find moon scenes
Radiance Scene Processor
Lunar Calibration
Pre-Launch Calibration
Radiance measurements
Radiance Scene Processor
Pre-launch calibration
Offset Table Creation
Find darkfields
Offset Table Creation
Satellite Offset Tables
On-orbit Scenes
Test Bench
Pre-launch Data
Satellite Flatfields
Satellite RSRs
Calibration Data Points
Calibration Update
Satellite Calibration

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Calibration Status

- Developing lunar and PICS techniques
- Building automated infrastructure
- Looking forward to satellites with latest pre-launch calibration being deployed!

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Thank You!

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