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4 MethaneSAT℠

Introduction

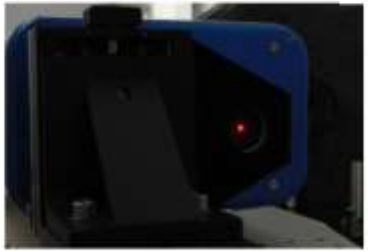
1. Ensures accurate retrieval of trace gases (CH_4 and CO_2)
2. Enables long-term monitoring of instrument performance
3. Builds on the calibration work of MethaneAIR (airborne precursor with near-identical specs)
4. Integrates flight system TVAC calibration with on-orbit LED lamp data

Conway, Eamon K., et al. "Level0-to-Level1B processor for MethaneAIR." Atmospheric Measurement Techniques.(2024):17, 1347–1362
Staebell, Carly, et al. "Spectral calibration of the MethaneAIR instrument." Atmospheric Measurement Techniques.(2021):14, 3737–3753

Flight System TVAC Calibrations

- Dark Collects
- Read Noise
- Dark Current
- Random Telegraph Signal
- Thermal Background Sensitivity
- Bad Pixel Mapping
- Photon Transfer
- Photo Response Non-Uniformity and Quantum Efficiency at Multiple Wavelengths with Repeatability
- Linearity with Reciprocity
- Residual Image (Persistence)

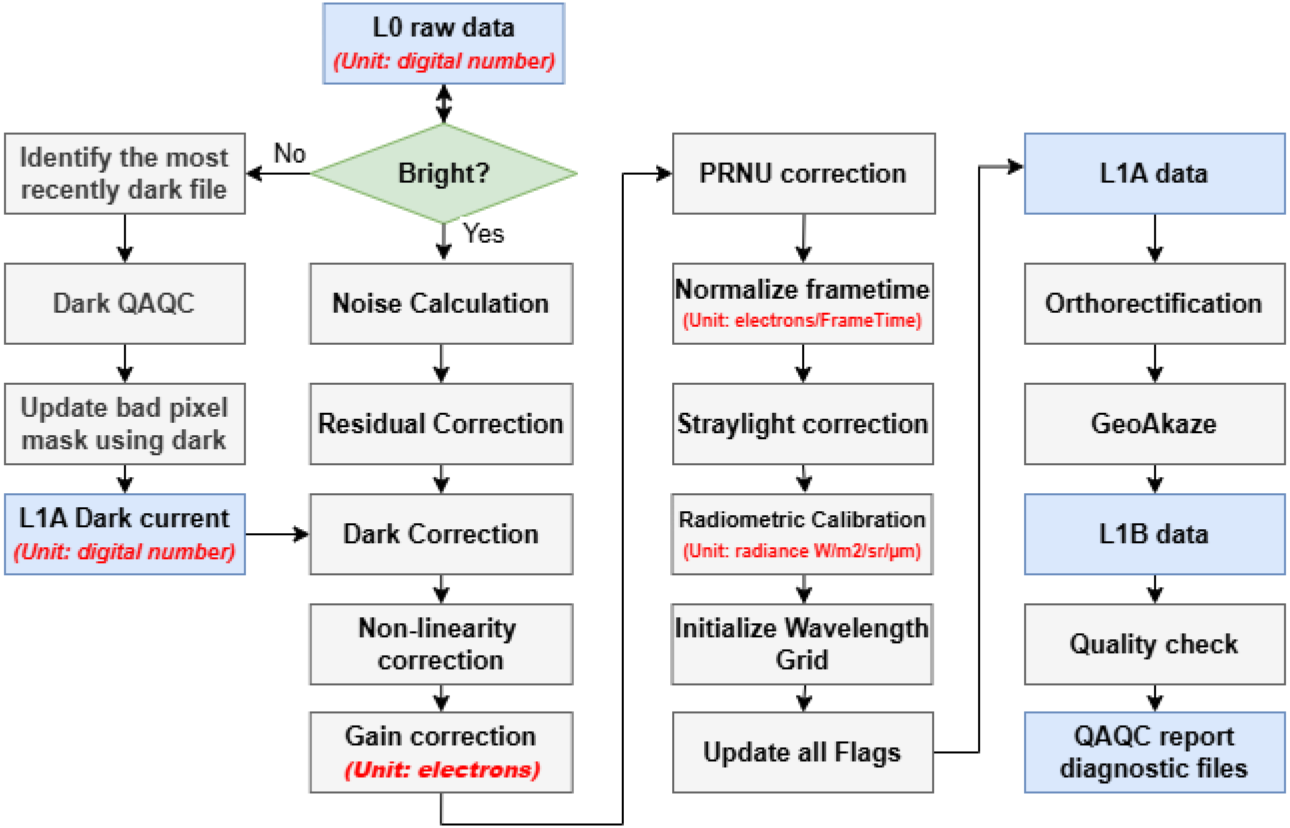
Dark Collects

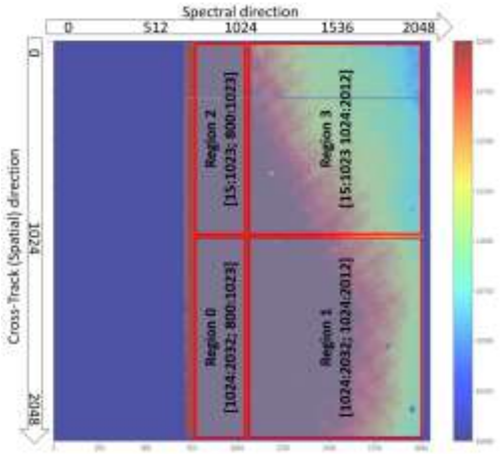
Straylight testing

Radiometric Calibration

MethaneSAT L1 flowchart



Focal Plane Array (FPA) Partition

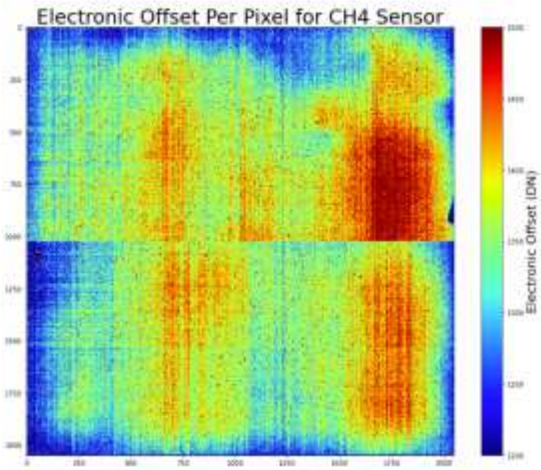


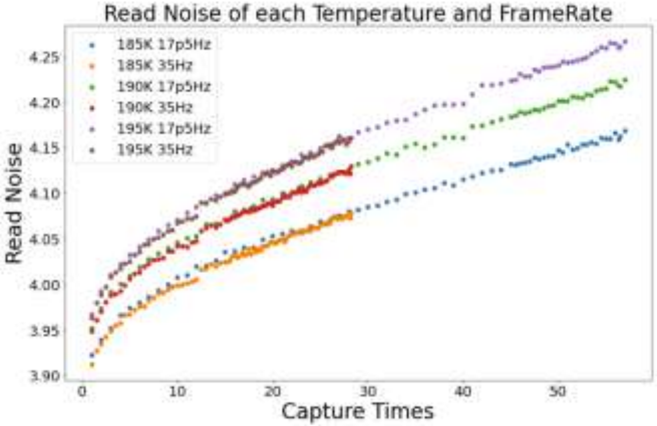
MethaneSAT Specifications	
Flight system mass (kg)	~366
Orbit altitude (km)	~525-585
Field of view (deg)	~21
Swath width @ nadir (km)	~220
O_2 passband (nm)	1249-1305
O_2 sampling / resolution (nm)	0.06 / 0.18
CH_4 passband (nm)	1598-1676
CH_4 sampling / resolution (nm)	0.08 / 0.24

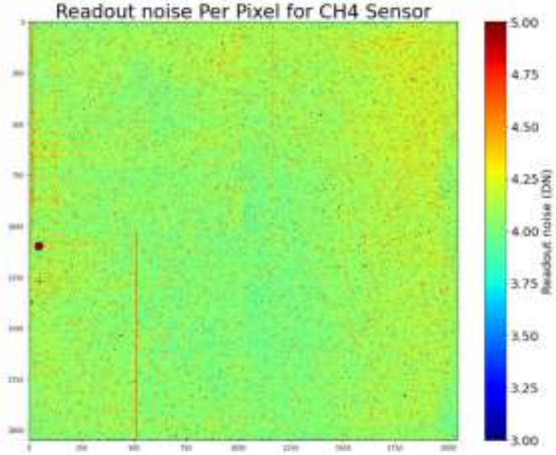
Noise calculation

To determine the uncertainty of the observed radiance populating the covariance matrix of observations.

$$\text{noise} = \frac{1}{\text{gain}}\sqrt{(\text{L0\_digital\_number} - \text{electronic\_offset}) \cdot \text{gain} + \frac{(\text{dark\_mean} - \text{electronic\_offset}) \cdot \text{gain}}{\text{num\_of\_frames}} + (\text{read\_out\_noise} \cdot \text{gain})^2}$$







Dark current processing

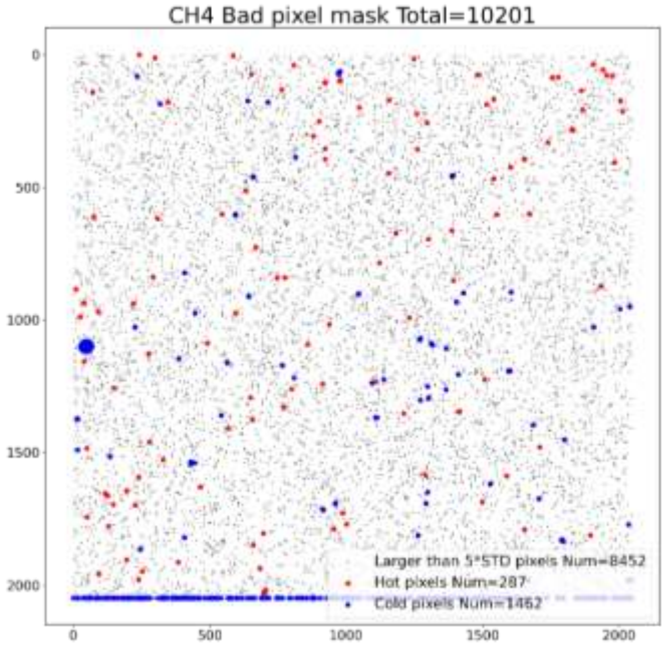
Identify the most recently dark file → Dark QAQC → Update bad pixel mask using dark → L1A Dark current *(Unit: digital number)*

- We used the pre flight dark files to derive the baseline bad pixel mask.

- Daily dark collection: 4 dark files (20 frames/each) per day.

- Use on-orbit dark to update the bad pixel mask regularly

- Supports L1A dark current generation



- **Hot Pixels**

Mean DN > 3000 and STD < 1

- **Cold Pixels/Dead Pixels**

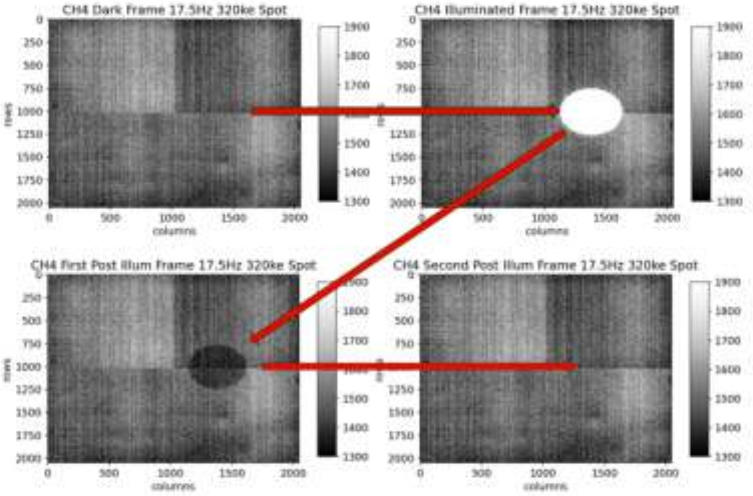
STD < 1

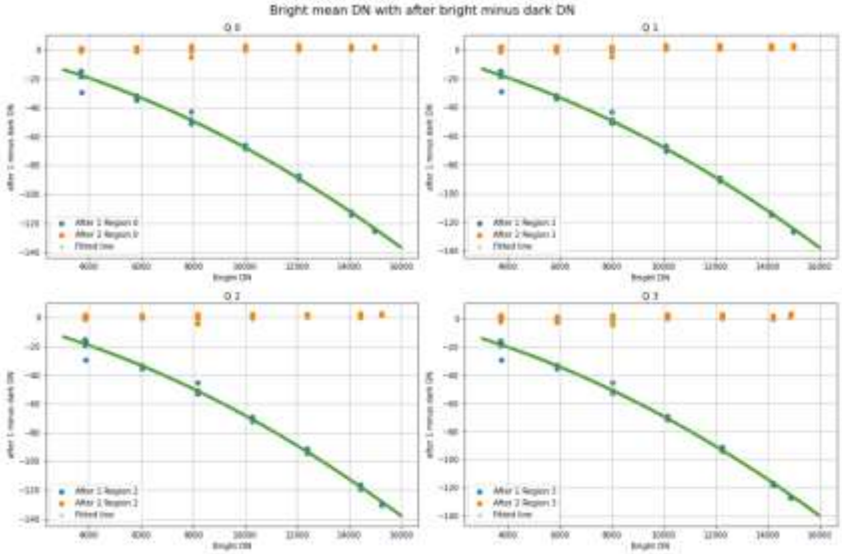
- **High Variability Pixels**

Excessively variable signal, 5× typical sensor STD

O_2 sensor: STD > 19.45 DN CH_4 sensor: STD > 22.11 DN

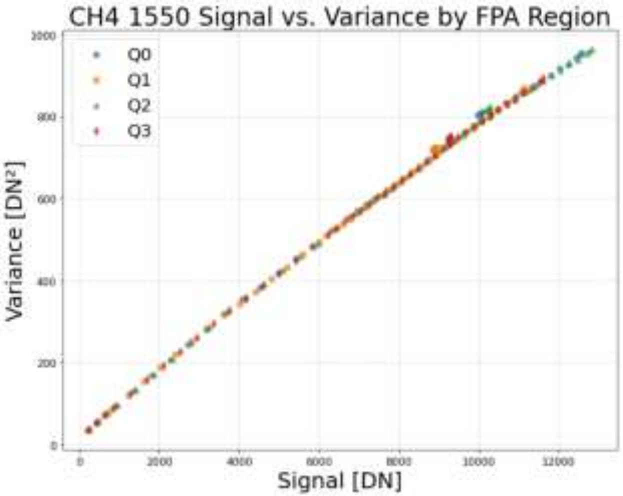
Residual Image correction

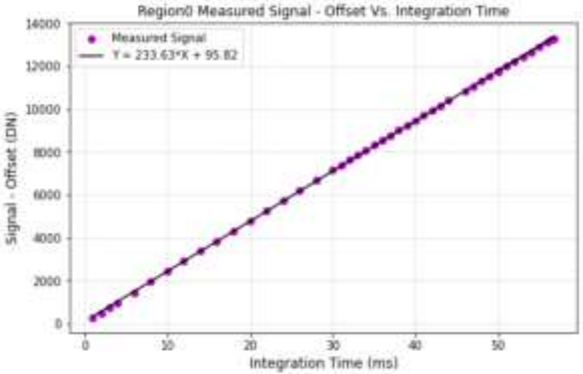


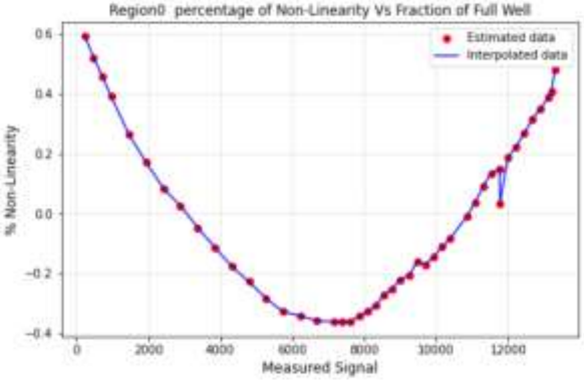


- The residual image affects only the first frame (~0.75%) after illumination and has no impact on the second frame.
- Corrected using 2nd-order polynomial fit vs. frame brightness

Gain and Non-linearity Correction





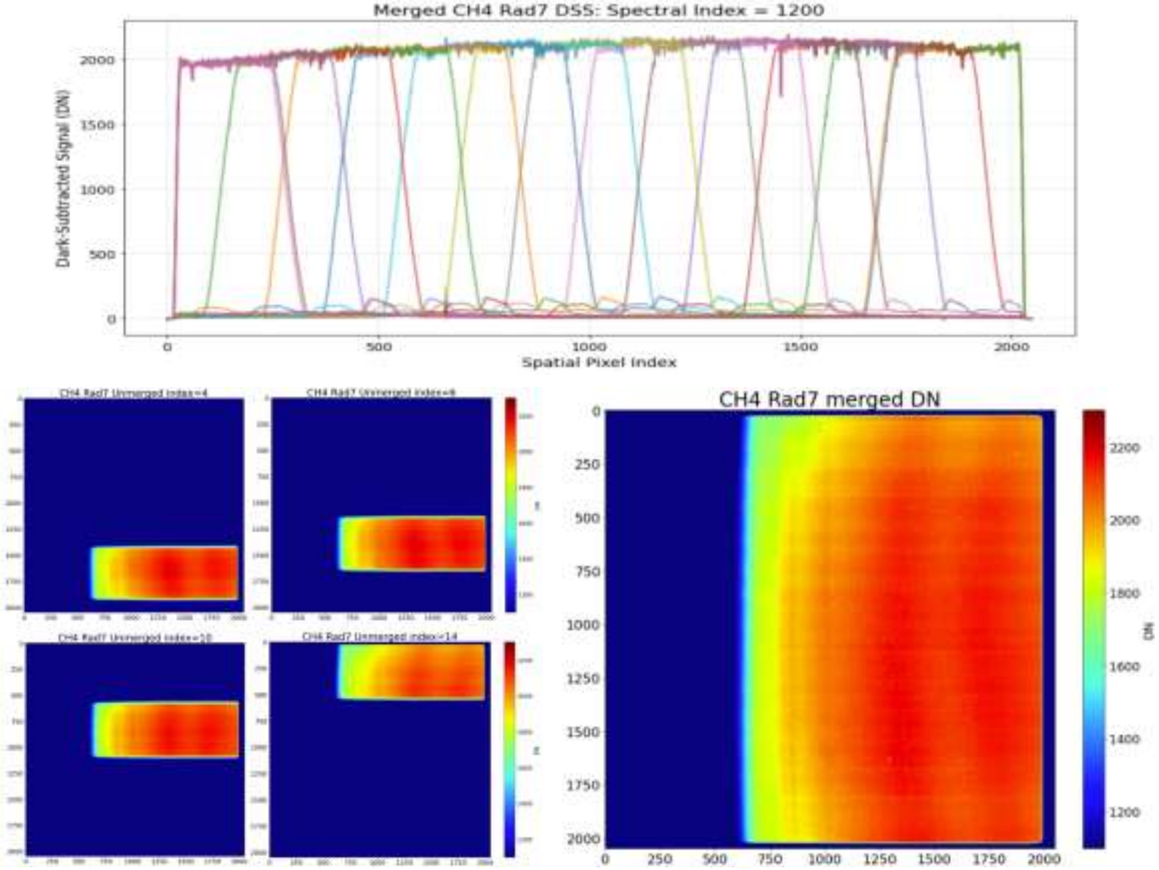


Gain Correction:
- Converts L1A from DN → electrons
- Based on slope of variance vs. mean signal
- We utilize on-orbit LED Lamp Sweep data to monitor and track sensor gain stability.

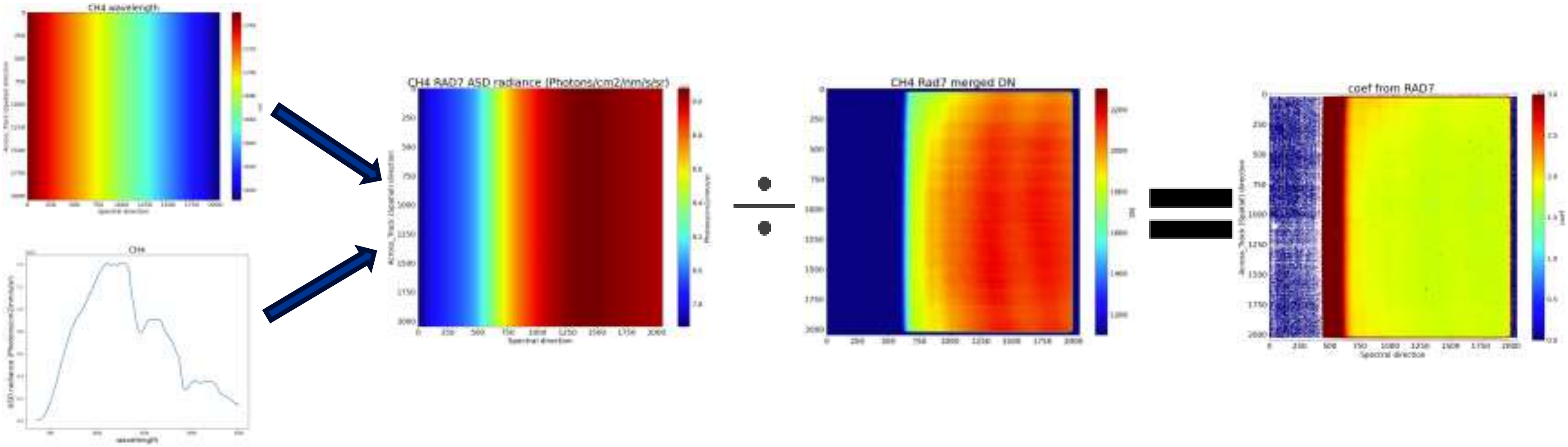
Non-linearity Correction:
- Sensor measurements may deviate from a linear response.
- Nonlinearity correction ensures detector output matches expected physical values.
- Lookup tables are used to adjust the raw readings.

Radiometric correction and TVAC radiometric characterization

- Sensors illuminated with NIST-traceable light source
- 5 light levels used across dynamic range (pre-thermal cycles)
- 17 overlapping collects merged due to MethaneSAT's large FOV
- Collects combined per sensor per light level for full-FOV coverage



Radiometric correction and TVAC radiometric characterization



- Radiometric calibration is applied to convert L1A (e^{-}/s) → Radiance ($W \cdot sr^{-1} \cdot m^{-2} \cdot \mu m^{-1}$) for each pixel.
- We can multiply the coefficients to get the radiance.

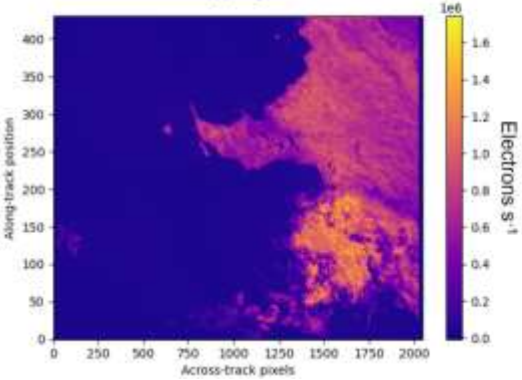
Stray-light correction

Led by David Miller

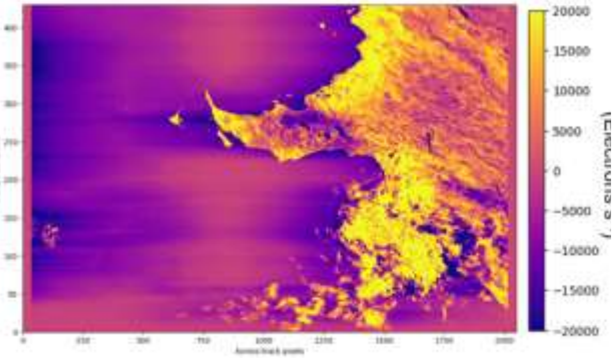
Median values across spectral science window

Sensor: CH_4
Target ID: 38
Collection ID: 01540260
Collection date: 20240912

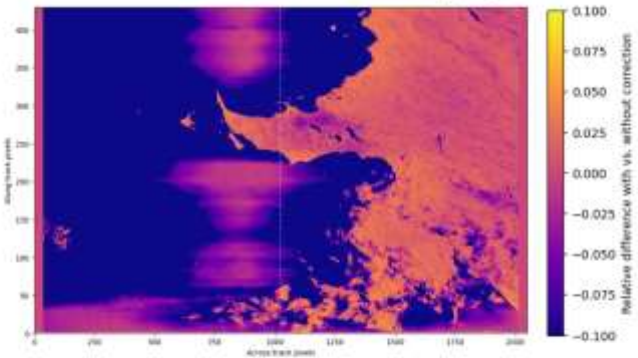
Before stray-light correction



Absolute difference (with – without correction)



Relative difference with vs. without stray-light correction



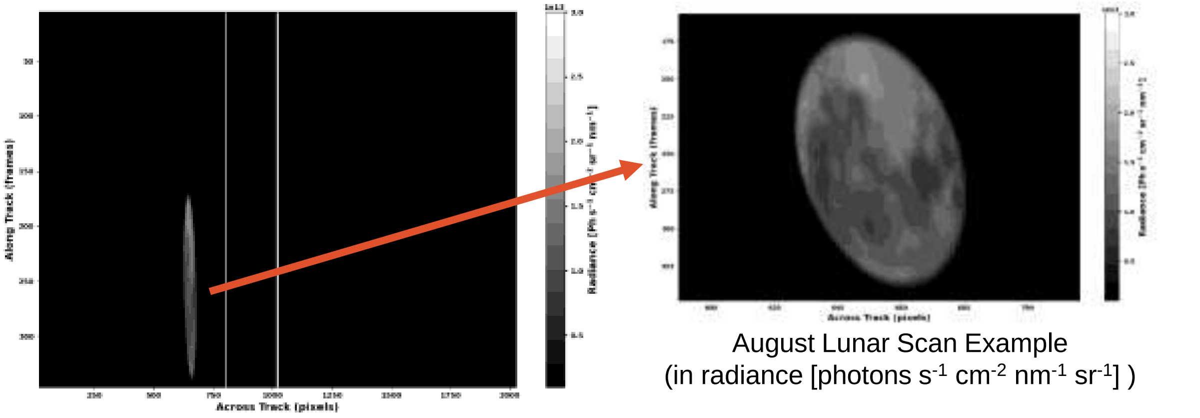
- Stray-light correction performed using iterative deconvolution with peak kernel following by reflective spatial ghost kernel based on Tol et al. (2018)
- Correction redistributes stray-light signals over water back onto higher signal pixels over land/clouds
- Coastline signal gradient exhibits smaller decreases over water where spatial ghost reflection appears

Please refer to David Miller's poster: **4.16.** Pre-launch and on-orbit spectral calibration of MethaneSAT

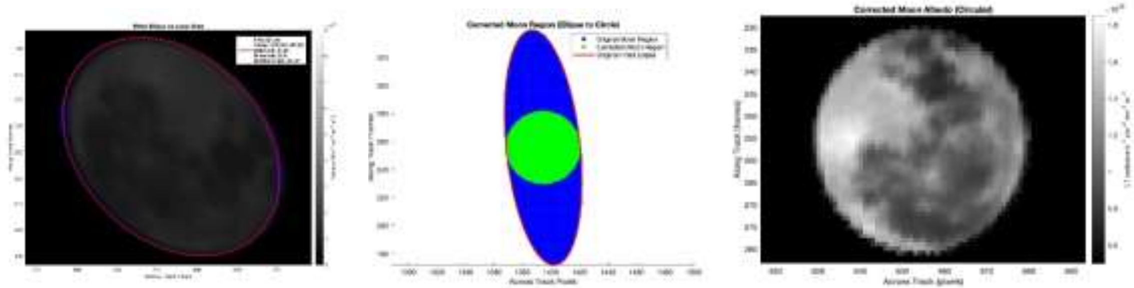
Lunar Correction

Led by Maya Nasr

MethaneSAT Lunar scanning pattern currently consists of 5 scans of 20 seconds each, to image the Moon nominally once per lunar month at the same phase angle (5-9°) and same Moon phase.



August Lunar Scan Example
(in radiance [photons s^{-1} cm^{-2} nm^{-1} sr^{-1}])



Ellipse fitting to produce corrected Moon before calculating the full disc integrated radiance.

We use **Lunar Irradiance Model of the European Space Agency (LIME)** for comparison.

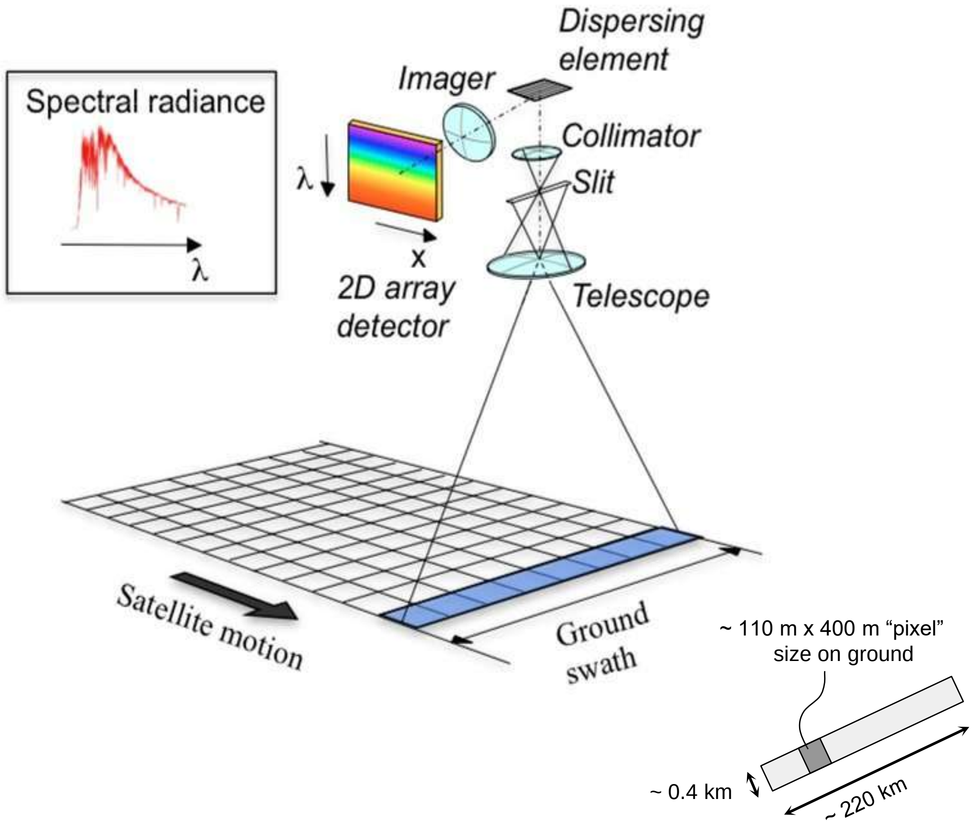
Reminder: Moon is 1/40th of FoV

Telemetry Orthorectification

- Estimate spacecraft forward direction using telemetry (pitch/roll/yaw) → define instrument center vector

- Derive per-pixel boresight vectors using optical lens model

- Intersect each vector with Earth surface to get geolocation



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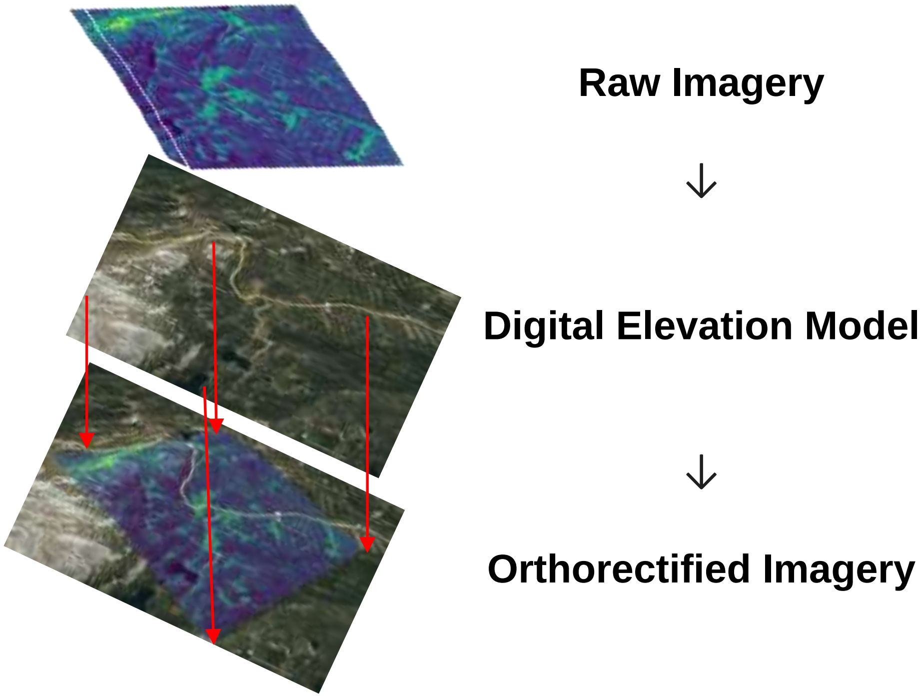
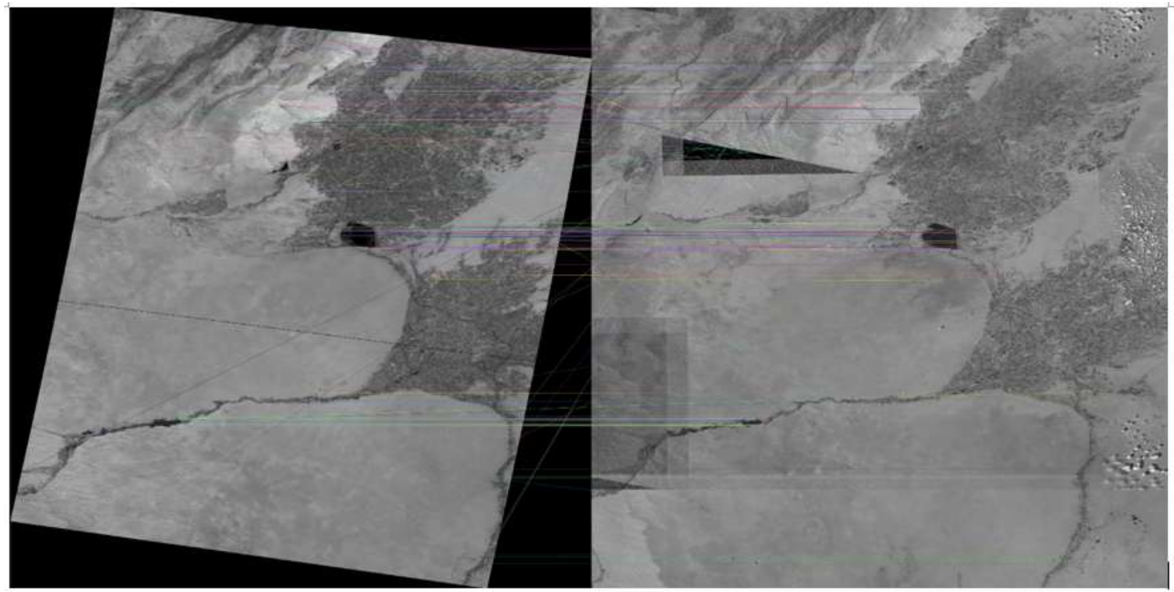


GeoAkaze-Image-Based Geolocation Correction

- Compare L1b geolocation to high-accuracy Sentinel-2 cloud-free MSI reference
- Use **RANSAC** algorithm to match features and reject outliers
- Correction accuracy depends on image resolution and feature scale



MSAT image **Sentinel 2 MSI**

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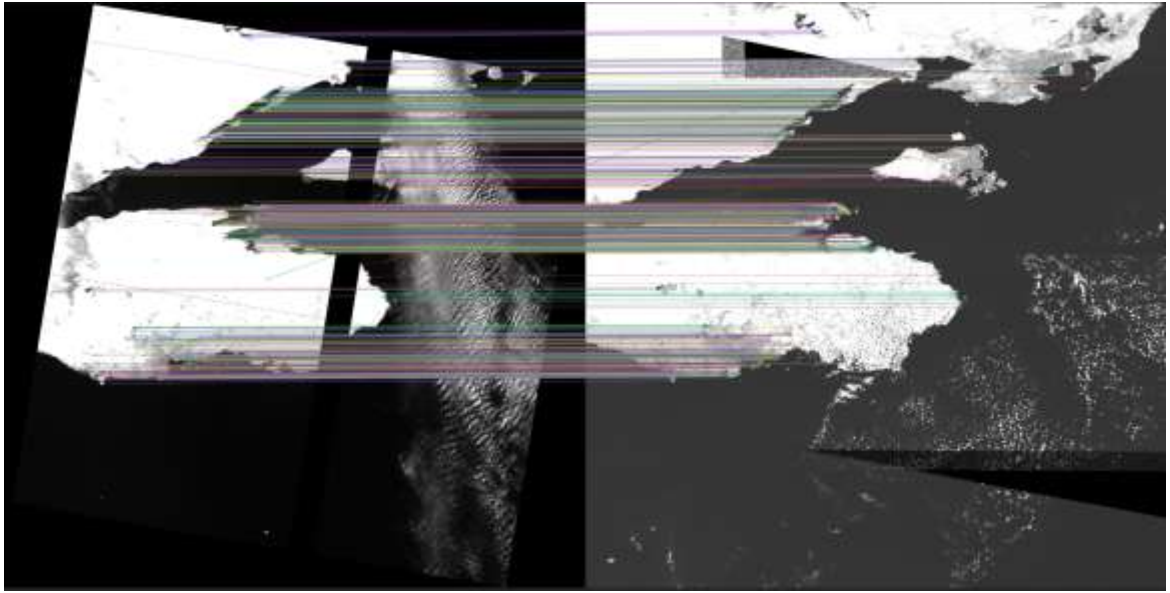

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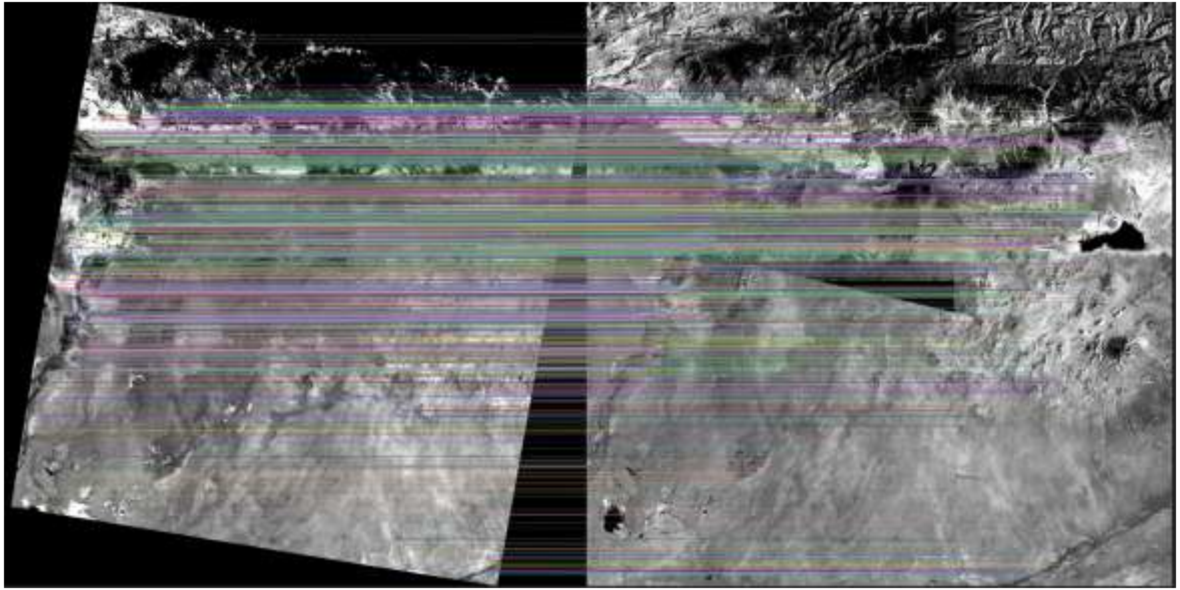
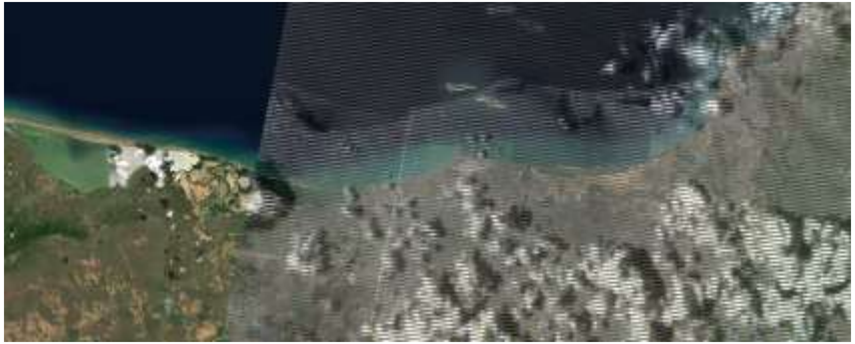


MSAT image **Sentinel 2 MSI**

Telemetry Orthorectification - Improve Camera Model

- Apply boresight/forward vector adjustments to refine image alignment in spacecraft coordinates
- Tuned Instantaneous Field of View, boresight, IMU frame time offset
- GeoAKAZE-derived camera model improves baseline L1B accuracy

Without Correction



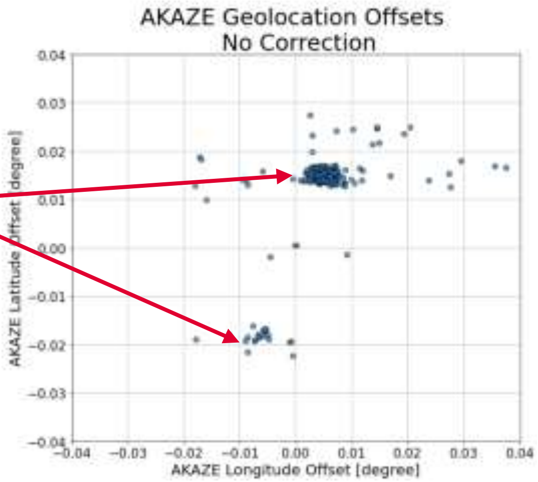
With Correction

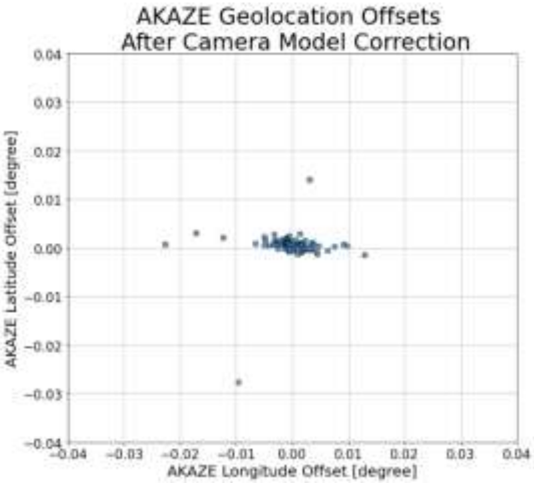
Without Correction

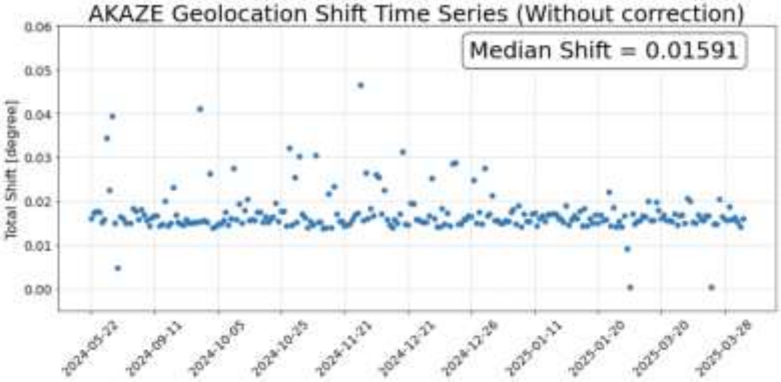
With Correction

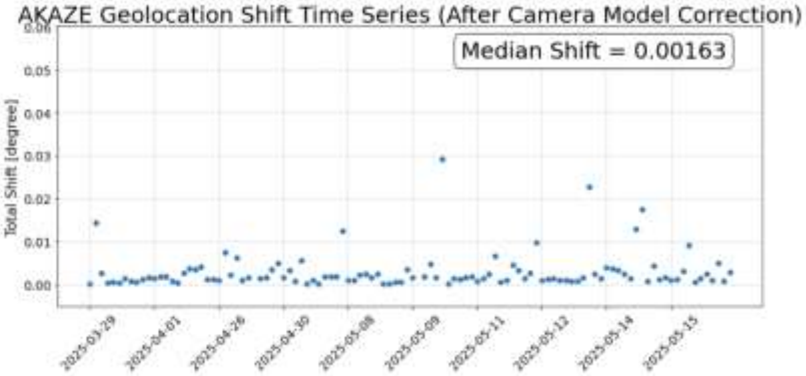
Performance - Geolocation

Hemisphere difference → opposite camera rotation





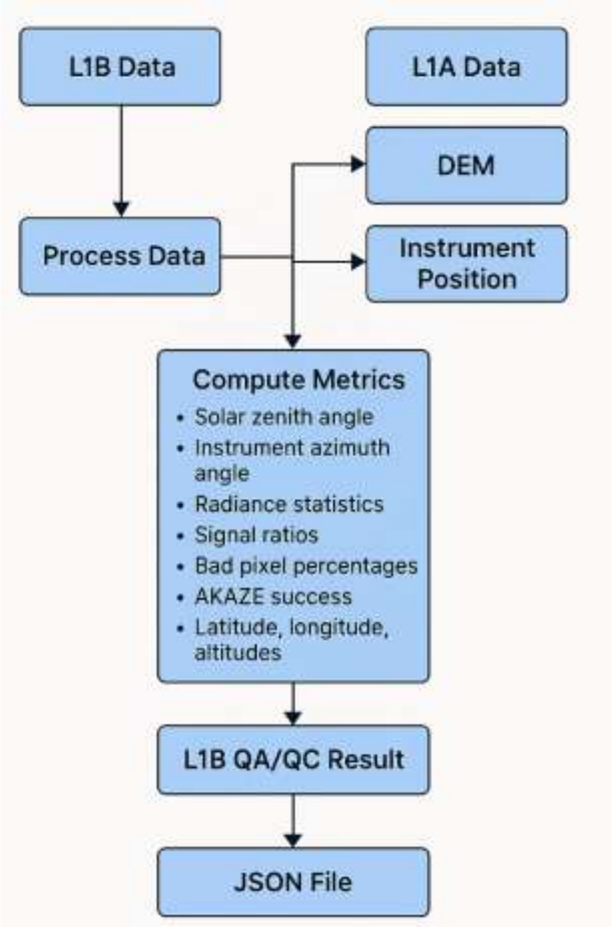




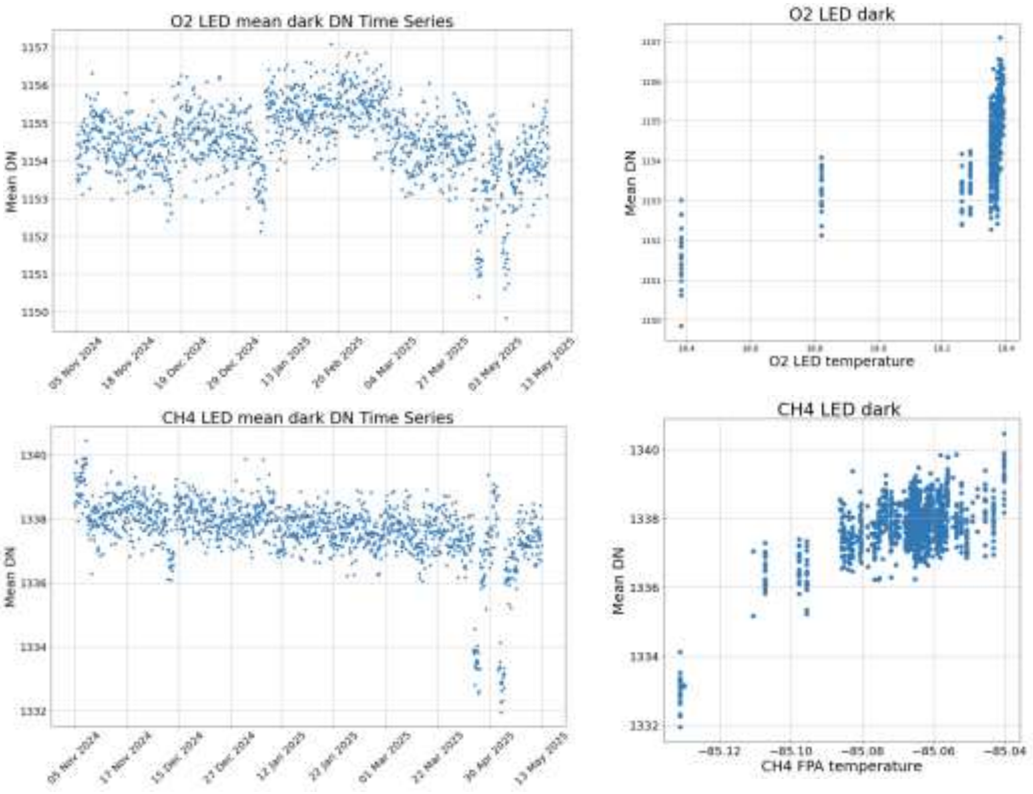
Performance-QAQC

Generates a JSON report of L1B geolocation and radiometric quality metrics

- **Geolocation Validation:**
  - Computes solar and instrument angles
  - Checks invalid (NaN/Inf) latitude, longitude, and radiance
- **Radiance QA Checks:**
  - Flags abnormal values (low signal, saturation, out-of-range radiance)
  - Evaluates bad pixels (dead, hot, cold, over/underexposed, high STD)
  - Calculates bad pixel ratios and identifies bad frames
- **Pass/Fail Criteria:**
  - QA fails if >75% bad pixels, missing geolocation, or >30% bad frames
- **Output:**
  - Summary statistics, AKAZE success, altitude, zenith/azimuth, signal quality, and error reasons saved to JSON



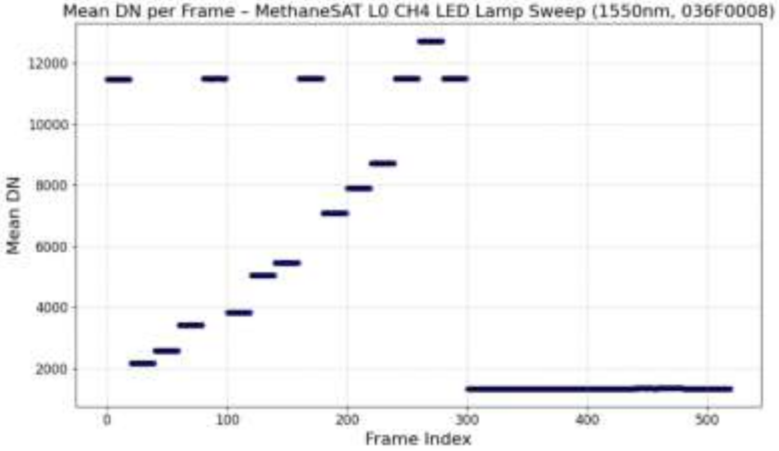
Performance-Dark DN



- CH_4 and O_2 sensors show stable dark DN values
- DN levels correlate with FPA temperatures
- Low DN observed after **Safe Mode** operations

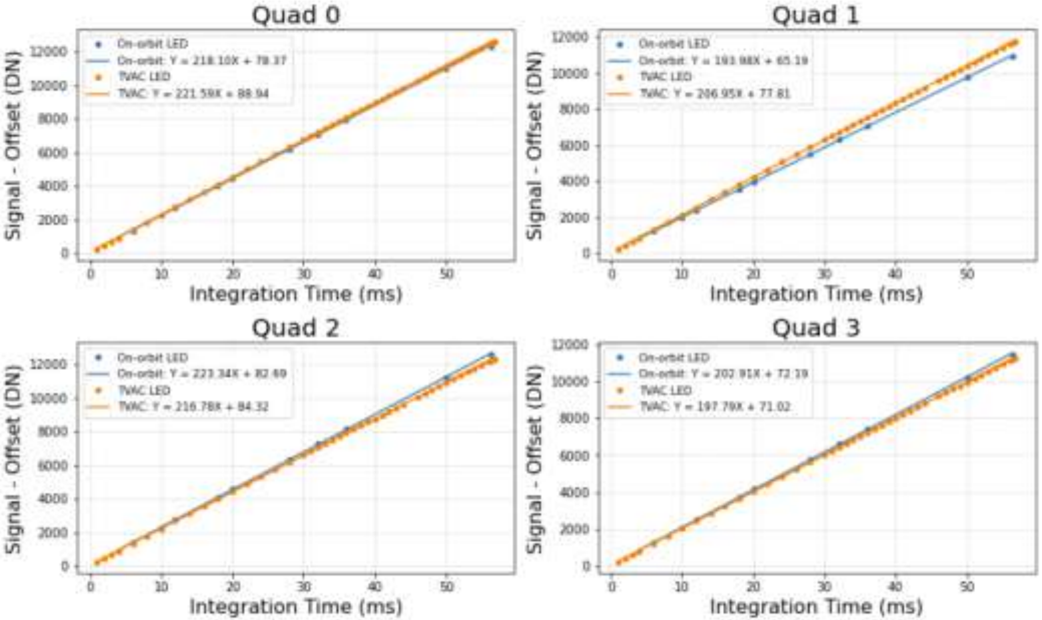
Performance - On-orbit LED Lamp Sweep

Records the detector response across a range of integration times



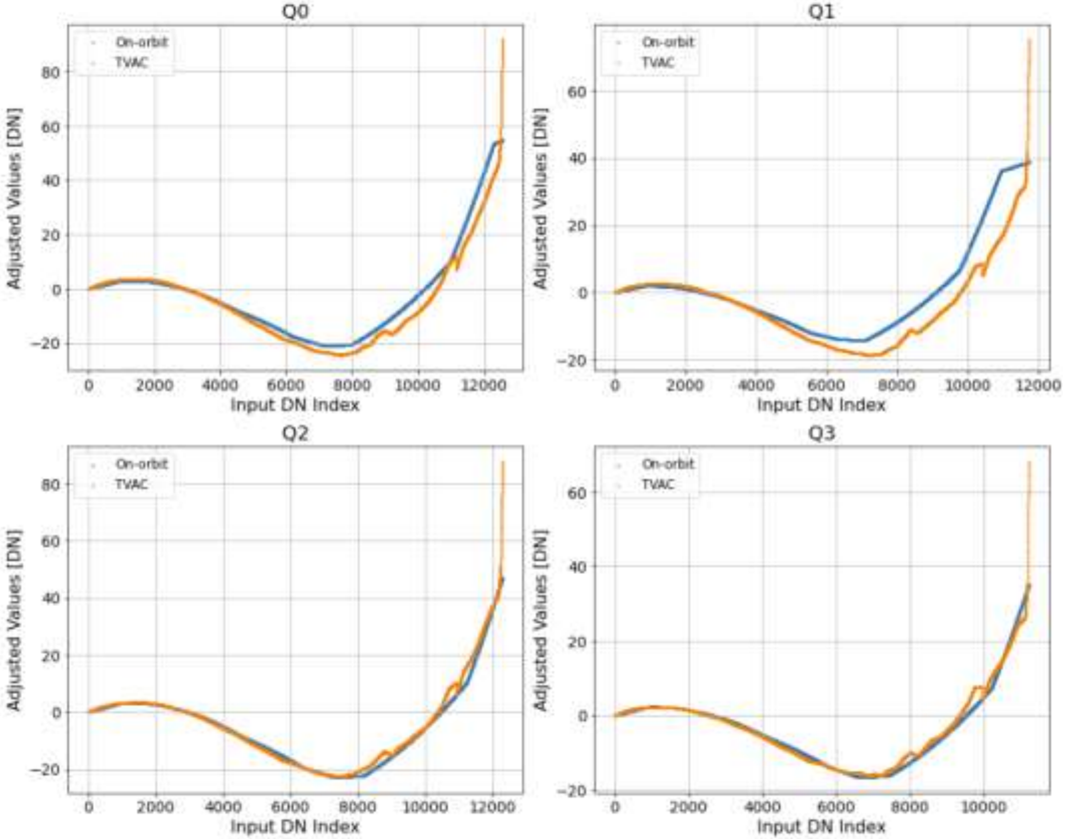
Uses of On-Orbit LED Lamp Sweep:

1.Linearity Characterization
2.Gain Stability Monitoring
3.Flat-Field and Pixel Response Characterization
4.Saturation Limit and Full-Well Capacity Estimation



Linearity Analysis for All Quads (On-orbit and TVAC)
Measured Signal vs Integration Time

On-orbit vs TVAC non-linearity



Quadrant Residuals: Adjusted Values vs Input DN Index