Stephen J Schiller, Ph.D.
Raytheon Intelligence and Space
Lead Calibration Scientist
NASA IRIS Co-Principal Investigator
stephen.j.schiller@rtx.com
626-664-5577

Raytheon Intelligence & Space, 2000 East El Segundo Blvd., El Segundo, CA, USA 90245

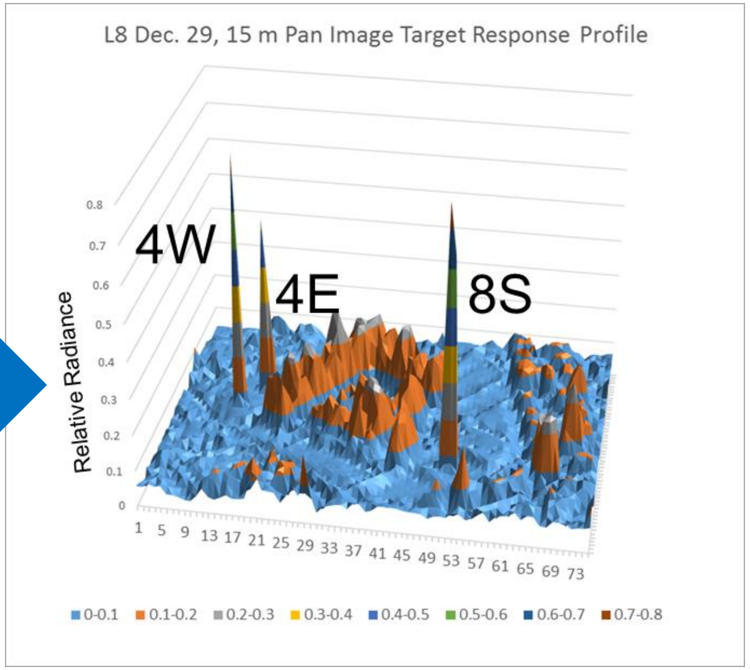
Trending and Intersensor Calibration Using SPARC/FLARE Point Targets

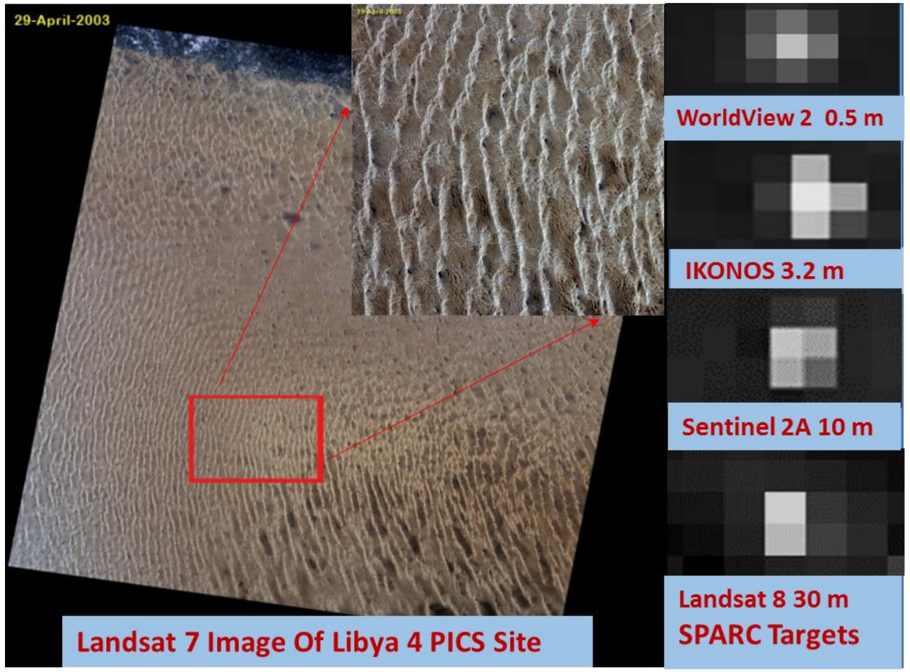
CEOS WGCV IVOS 34, USGS Reston, VA
August 29, 2022

Spatial Consistency of Point Targets For All Sensor Systems

Landsat 8 Pan image of SPARC targets

PICS cal targets compared to point targets





- Natural radiance targets for vicarious calibration vary in their geospatial properties depending on the sensor FOV and GSD
- Point intensity targets for vicarious calibration are consistent for each sensor
- They each look like their spatial response function (system point spread function)

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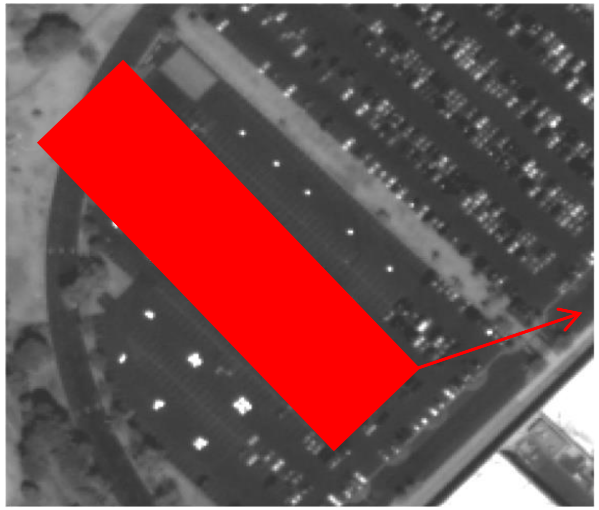
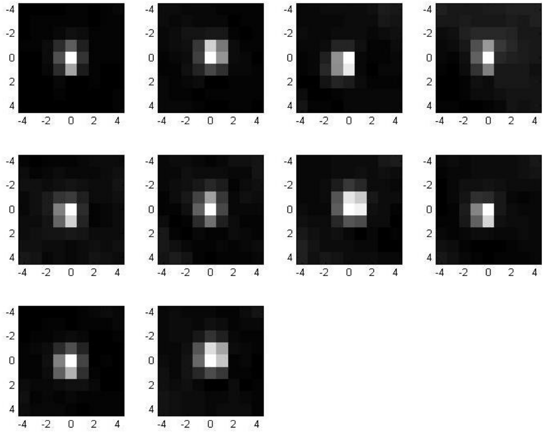
The System Response Function can be Characterized in Detail by Oversampling with the Same Point Targets

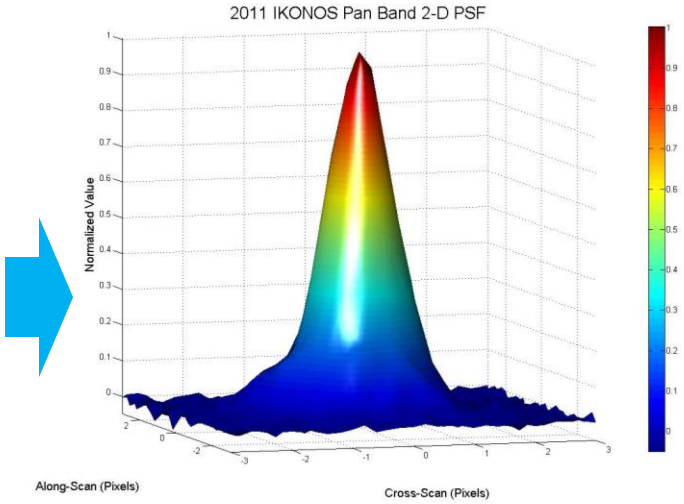
SPARC uses a grid of spherical reflectors to create an oversampled point spread function (PSF).



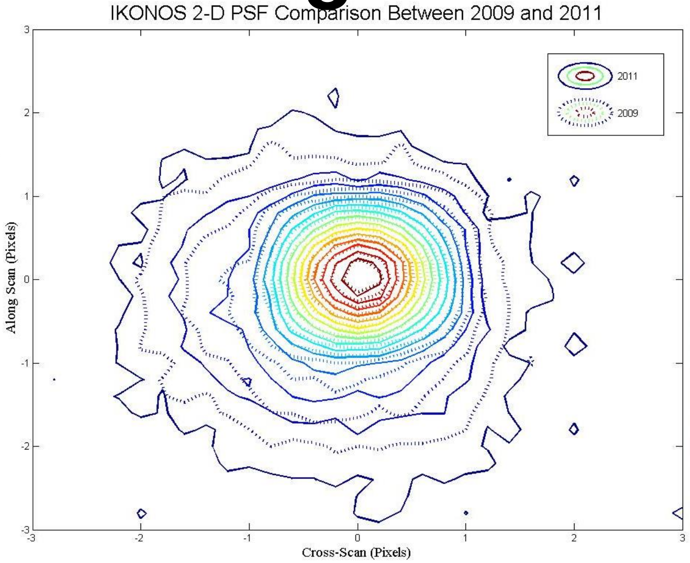
IKONOS Image Of point targets



Extracted images have different pixel phasing



After centroiding, images are combined to reveal oversampled 2-D PSF Profile



2-D PSF based on images taken two years apart show similar asymmetric profile

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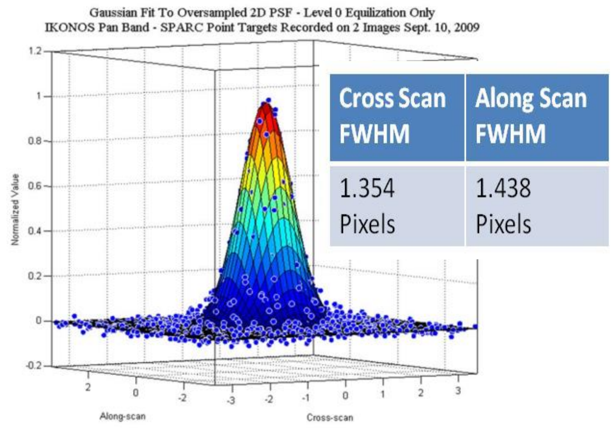
Analysis evaluates the PRF at each step along the image processing chain.

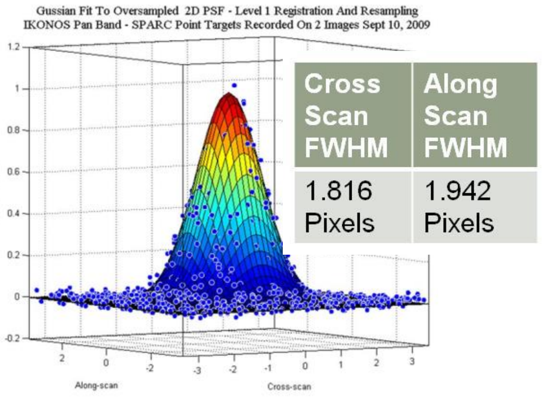
The target energy profile becomes well known for each sensor under calibration

Level 0



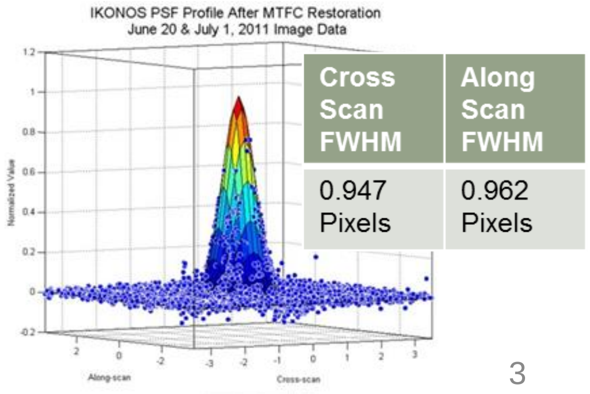
Cross Scan FWHM	Along Scan FWHM
1.354 Pixels	1.438 Pixels

Level 1 (Resampled)



Cross Scan FWHM	Along Scan FWHM
1.816 Pixels	1.942 Pixels

Level 1 + MTFC

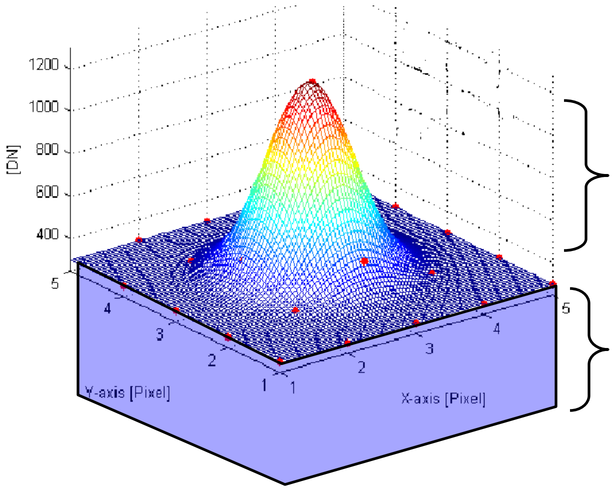


Cross Scan FWHM	Along Scan FWHM
0.947 Pixels	0.962 Pixels

Atmospheric Effects in TOA Intensity is limited to Transmittance

Target signal embedded in a uniform area is elevated above the low spatial frequency background and is separable

Background and atmosphere becomes a bias and is subtracted out based on image data alone

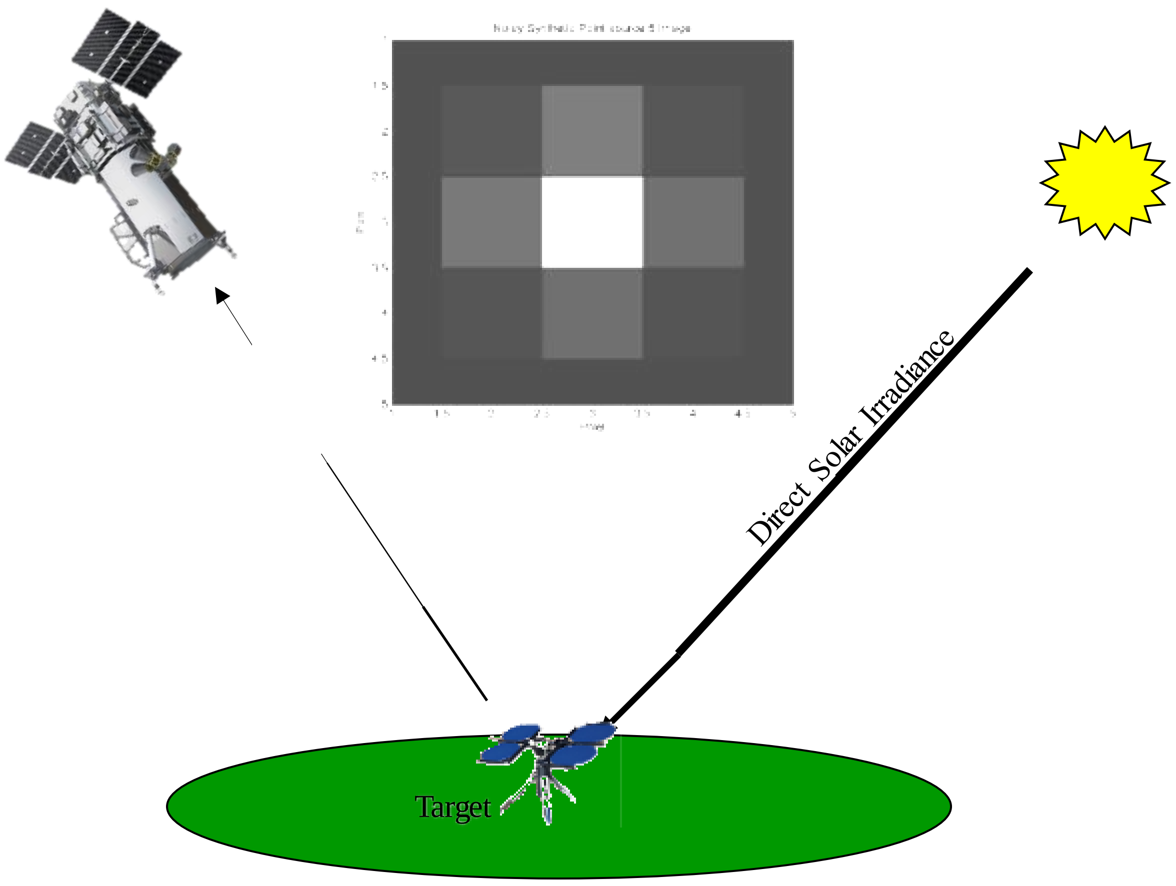


Signal from SPARC target alone.

Signal from surround background surface, sky path radiance, adjacency effect, stray light, etc.

This, again, can be the same for all sensor point sources using background subtraction

Image of target



Direct Solar Irradiance

Target

Surround

However, intensity converted to effective radiance varies with distance via the inverse square law

SPARC Radiative Transfer Equations Predicting At-sensor Intensity and Radiance

TOA Intensity (Sensor Independent)

$$I(\lambda,\theta_r)_{TOA} = \frac{1}{4}\rho\left(\lambda,\theta_r\right)\tau_{\downarrow}(\lambda)\tau_{\uparrow}(\lambda)E_o\left(\lambda\right)R^2 \qquad [1]$$

Watts/(sr micron)/mirror

At-Sensor Radiance/Mirror (sensor and collection geometry specific)

$$L_{at-sensor}(\lambda,\theta_r) = \rho(\lambda,\theta_r)\tau_{\downarrow}(\lambda)\tau_{\uparrow}(\lambda)E_o(\lambda)\frac{R^2}{4GSD(x)GSD(y)} \qquad [2]$$

Watts/(m^2 sr micron)/mirror

$\rho\ (\lambda,\theta_r)$ = Mirror specular reflectance at the reflectance angle θ_r

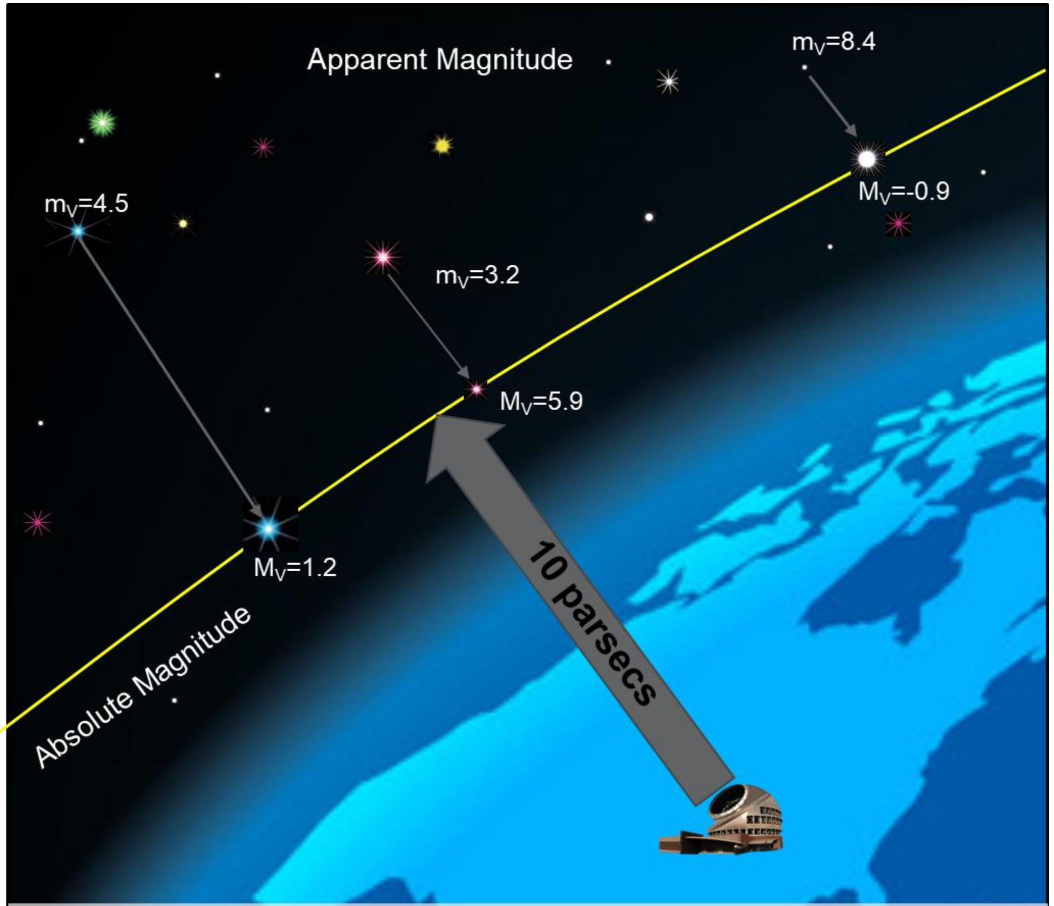
$\tau_{\downarrow}\ (\lambda)$ = Sun to ground transmittance

$\tau_{\uparrow}\ (\lambda)$ = Ground to sensor transmittance

$E_o\ (\lambda)$ = Solar spectral constant
R = Mirror radius of curvature (m)
GSD = Line-of-site ground sample distance (m), cross-scan and along-scan

Because SPARC targets are intensity sources, the apparent at-sensor radiance response for absolute calibration depends on sensor line-of-sight Ground Sample Distance (GSD)

Absolute Calibration to Intensity Targets can be Treated Like Absolute Magnitude in Astronomy



Absolute Magnitude in Astronomy represents a sensor’s radiometric response to the intrinsic luminosity of a star with the effects of distance removed

Absolute Magnitude represents the radiometric response of a sensor if all the stars were at the same distance

It removes the effects of varying distance in the radiometric measurements of a set of stars allowing intercomparison to be based on their intrinsic properties

In the same way, the radiometric response (DN) of a sensor to a point target can be corrected to a reference distance (DN_o) for trending and intercomparison

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Zero Airmass Response Constant - DN_o

With SPARC, the equivalent calibration requires determining the “Zero Airmass Response Constant” (ZARC) for each spectral band.

This is the orbiting sensor’s digital number (DN) response to a solar illuminated SPARC reflector when the atmospheric transmittance = 1 (or atmospheric airmass = 0)

- Setting $\tau_\downarrow$ =1 and $\tau_\uparrow$=1 when at the reference GDS , the SPARC radiative transfer equation [2] at the reference GSD becomes

$$L_{at-sensor}(\lambda)_o = \rho(\lambda)E_o(\lambda)\left(\frac{R}{2GSD_o}\right)^2 \qquad [3]$$

GSD_o =Sensor’s Reference GSD

GSD_o (IKONOS Pan) = 0.8m

GSD_o (IKONOS MSI) = 3.2m

- Assuming a linear, bias subtracted response for the imaging sensor then

$$DN_o = g(\lambda)L_{at-sensor}(\lambda)_o \qquad [4]$$

At Reference GSD, GSD_o

$$DN = g(\lambda)\, L_{at-sensor}(\lambda) \qquad [5]$$

At Operational GSD, GSD

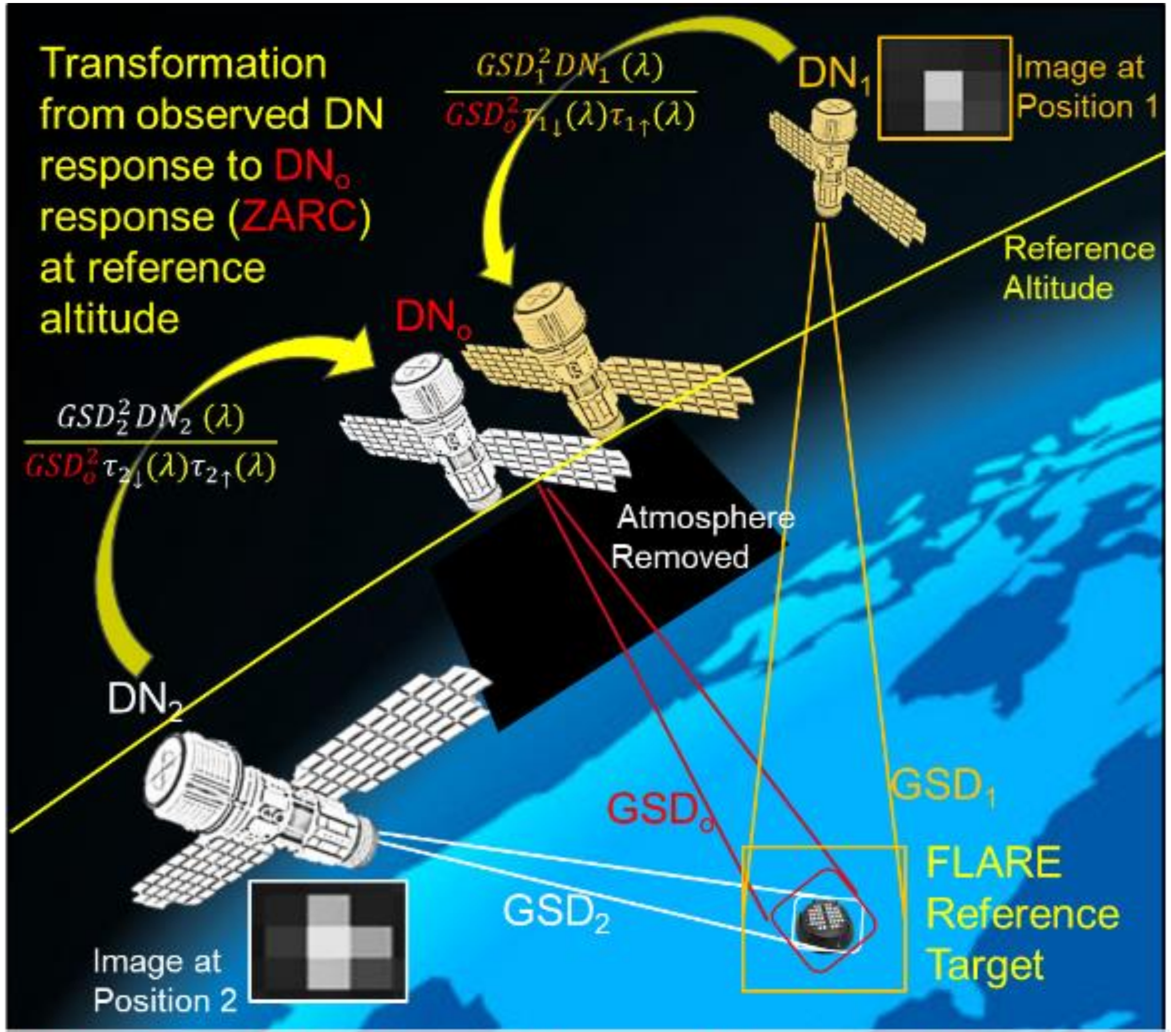
- Taking the ratio of [4] and [5], the zero airmass response constant (ZARC) is derived in terms of the observed integrated SPARC target image response ($DN(\lambda)$) and the atmospheric transmittance [$\tau_\downarrow(\lambda)\tau_\uparrow(\lambda)$] measured at its operational collection distance

$$DN_o(\lambda) = \frac{GSD^2 DN(\lambda)}{GSD_o^2 \tau_\downarrow(\lambda)\tau_\uparrow(\lambda)} \qquad [6]$$

Interpretation of a sensor’s ZARC radiometric parameter

$$DN_o(\lambda) = \frac{GSD^2 DN(\lambda)}{GSD_o^2 \tau_\downarrow(\lambda)\tau_\uparrow(\lambda)}$$

In the same way the ZARC value, $DN_o(\lambda)$, represents the intrinsic response of the sensor to a FLARE vicarious radiometric reference characterizing the sensor’s repeatability and collection reproducibility

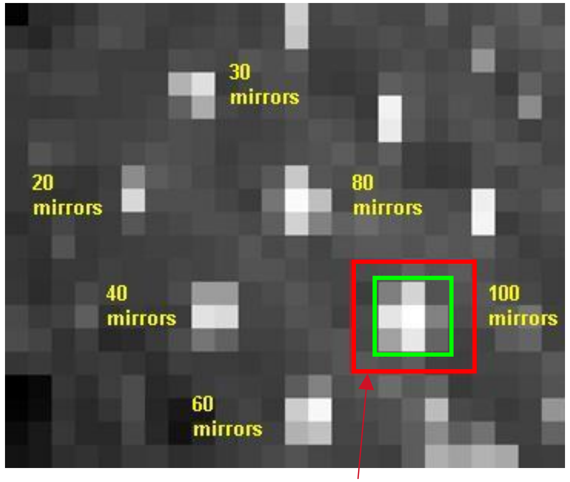


Concept of the Zero Airmass Response Constant (ZARC) for tracking temporal response stability

Zero Airmass Response Constant (ZARC) Applied to IKONOS

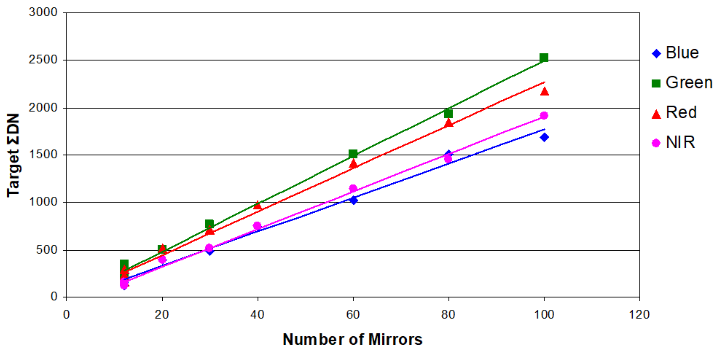
Results from 10 images for 5 overpasses over 4 months

	Individual Images				
Date	DN_o - Pan	DN_o - Blue	DN_o - Green	DN_o - Red	DN_o - NIR
23-Jul	554.14	38.07	45.57	39.94	31.30
23-Jul	562.67	34.23	48.51	41.39	33.33
31-Jul	597.59	39.59	45.94	37.50	30.76
31-Jul	573.68	36.26	48.91	40.76	32.25
2-Sep	567.98	36.37	47.22	36.99	30.83
2-Sep	582.93	35.62	45.34	39.16	31.89
10-Sep	608.58	36.42	46.16	37.21	32.02
10-Sep	575.66	36.37	47.10	39.71	30.62
15-Nov	508.28	36.45	45.88	38.77	31.15
15-Nov	596.02	37.60	46.51	39.87	32.40



Background pixels

DN/Mirror: Image po_365282 Glass Mirror SPARC Target



Spectral Band	Slope: DN/Mirror	R^2
Blue	17.9	0.9898
Green	25.2	0.9972
Red	22.8	0.9917
NIR	19.8	0.9965

Values adjusted to Sun/Earth Distance = 1AU

Reproducibility of Zero Airmass Response Constant (ZARC)

		DN_o - Pan	DN_o - Blue	DN_o - Green	DN_o - Red	DN_o - NIR
Average	DN_o	572.75	36.70	46.71	39.13	31.66
Std Deviation		17.17	0.79	0.52	0.99	0.41
Std Deviation	%	3.00	2.15	1.11	2.54	1.29

$$DN_o(\lambda) = \frac{GSD^2 DN(\lambda)}{GSD_o^2 \tau_\downarrow(\lambda) \tau_\uparrow(\lambda)}$$

DN_o= response at reference GSD (distance)

Results indicate that MSI ZARC can be tracked to better than about 2.5% for SPARC targets at sea level

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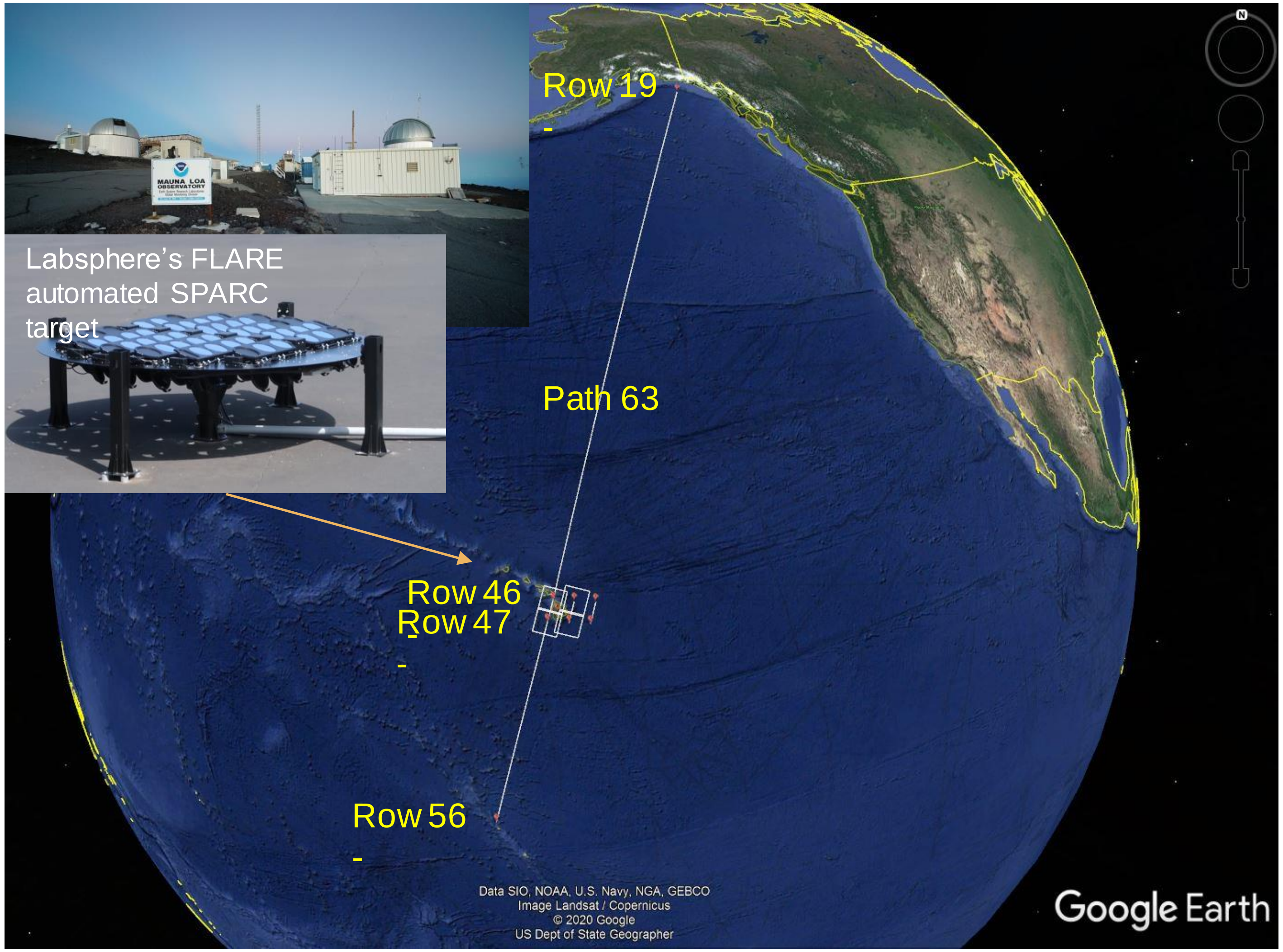
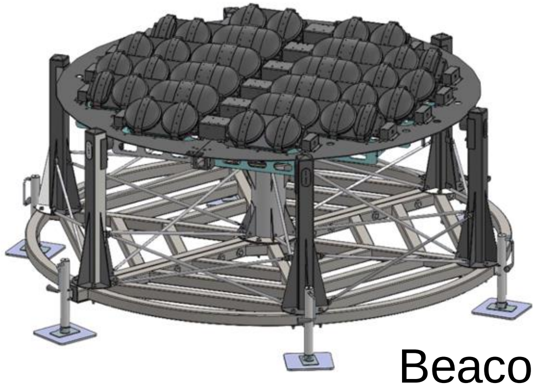
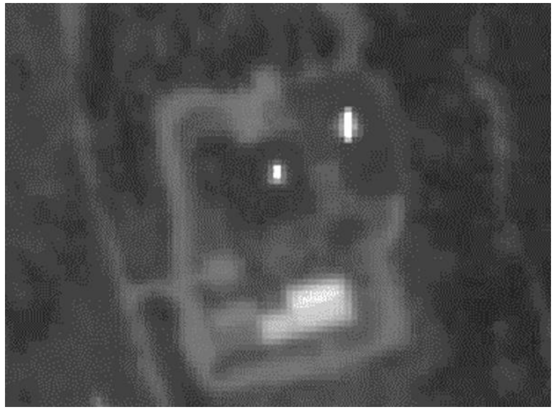
Future: Deployment of FLARE for High Altitude, Dark Background SPARC Calibration at Mauna Loa Observatory





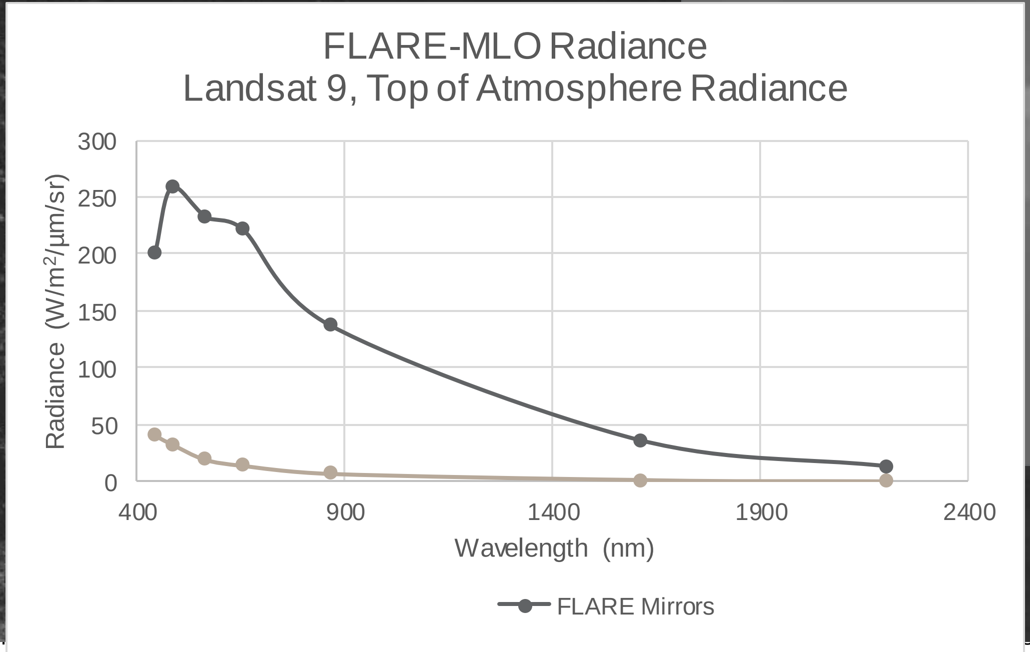
Beacon

Lantern



Two-Point FLARE

FLARE @ MLO Provides an Ideal High Altitude Dark Background Site

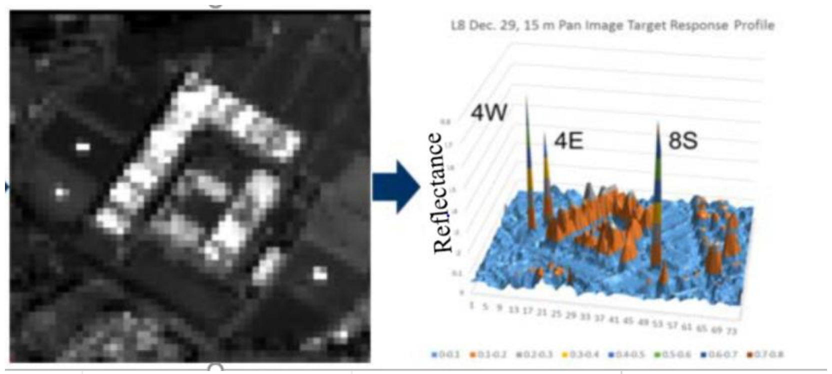


SDAV
UH HILO

Mauna Loa Caldera with Snow

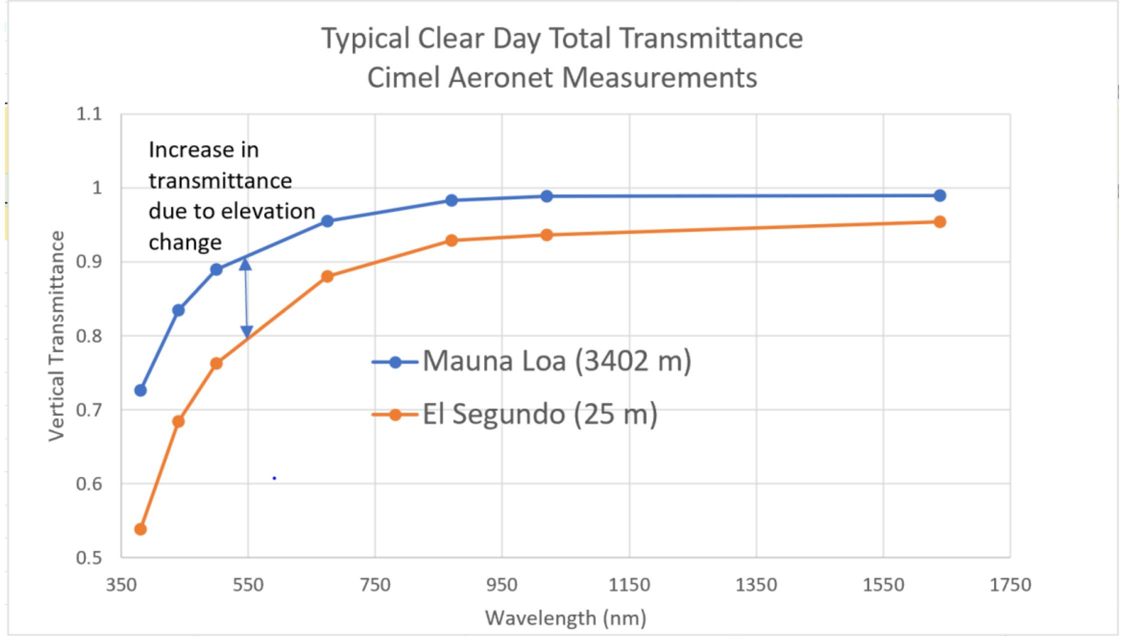
MLO high elevation significantly improves at-sensor radiance accuracy

Better than 3% reproducibility in predicted at sensor radiance has been demonstrated at the Raytheon El Segundo SPARC test site (sea level) using multiple targets. 3-5% using a single target.



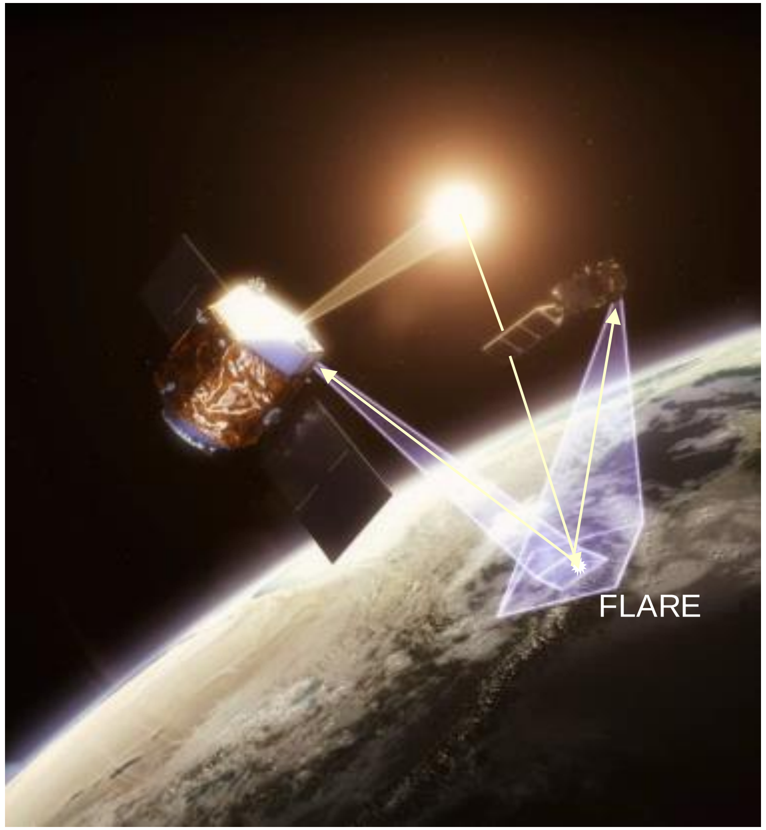
SPARC radiative transfer accuracy is dominated by uncertainty in atmospheric transmittance (all other atmospheric contributors subtract out)

Transmittance accuracy knowledge will be significantly improved with MLO FLARE operations



FLARE < 2% absolute at-sensor radiance uncertainty should be achievable from MLO

Tracking DN_o – Assessment of Sensor Stability and Multi-Sensor Interoperability.



- Tracking the ratio of ZARC values for similar bands between two sensors provides a parameter on a common radiometric scale for evaluating interoperability performance.
- TRUTHS, a UK-led operational Earth Observation mission, will initiate a space-based calibration observatory providing a primary SI reference.
- **TRUTHS will act as a fiducial reference to cross-calibrate other sensors by imaging a common ground target.**
- **The Labsphere FLARE vicarious network provides such reference targets establishing a robust vicarious traceability path between these systems and temporal interoperability knowledge**

Cross-comparison of the ZARC sensor band response between satellites does not require simultaneity of collects when imaging a SPARC/FLARE target to evaluate relative stability and interoperability

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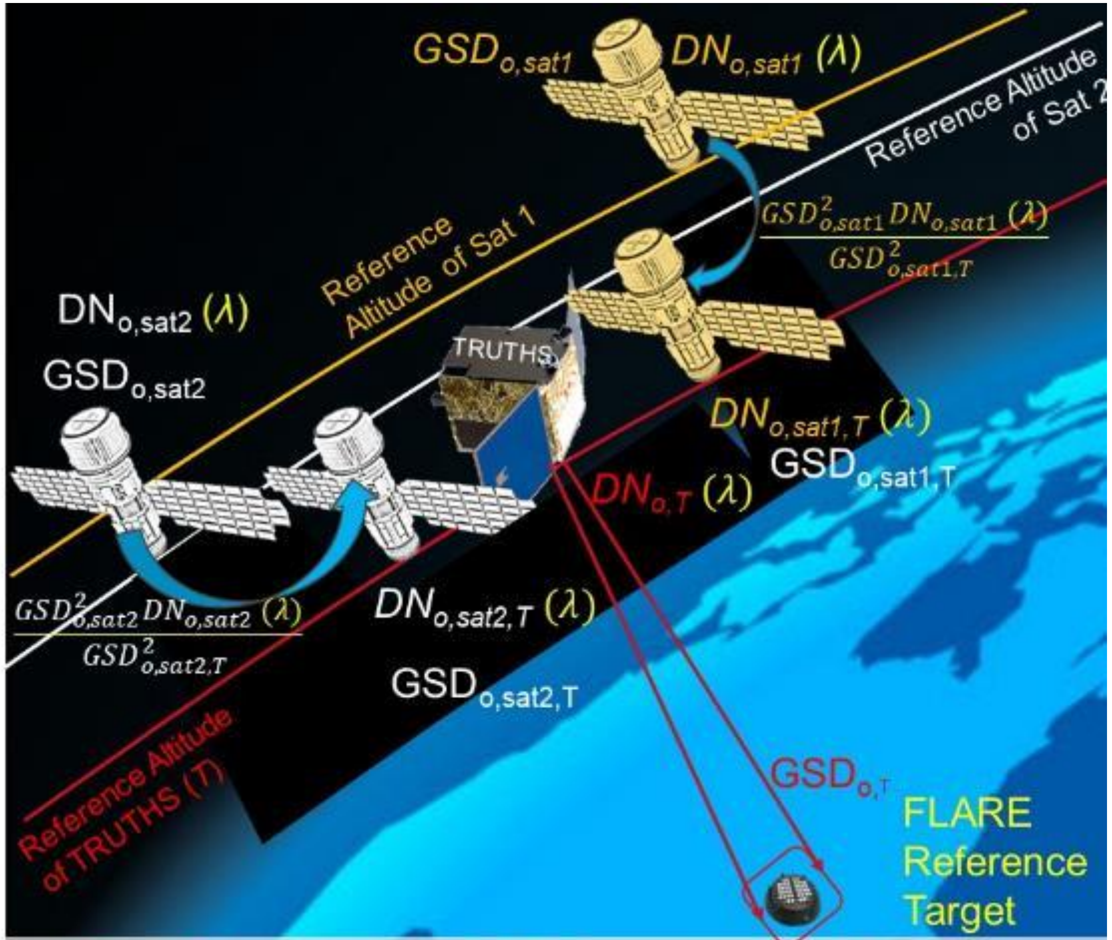
Intersensor Calibration to a Reference Satellite for a Virtual Constellation

Imaging the FLARE targets as an intermediate cal reference, each satellite in the constellation and the metrology reference satellite are calibrated using the SPARC method to derive their spectral ZARC values, $DN_o(\lambda)$, at their individual reference altitudes.

The only need is to scale the DN values by the ratio of the GSDs (effectively applies the inverse square law)

The method quantifies a DN response for each satellite to a common reference for intersensor calibration

It is accomplished as if all sensors were viewing the reference side by side without atmospheric effects



Transforming the ZARC response (DN_o) for a virtual constellation to the reference Altitude of the Reference Sensor (i.e. TRUTHS)

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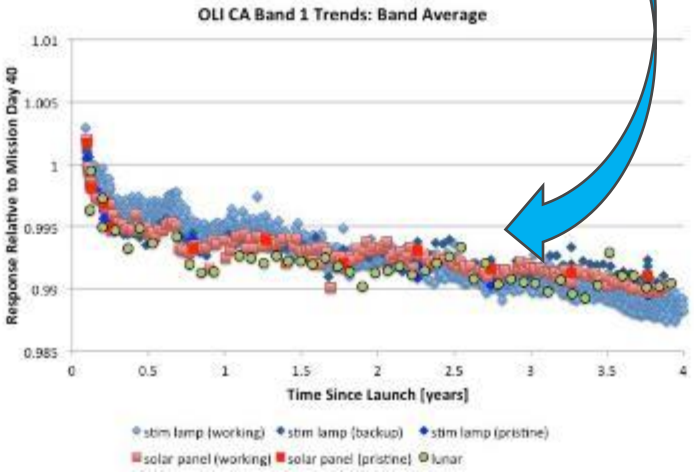
Summary

- Vicarious Specular Array Calibration (SPARC) targets provide a way for a sensor in-flight to record the direct solar irradiance as an absolute intensity reference imbedded within an operational earth scene collect (Inserting solar stars in an operational scene collection)
- The SPARC targets have a nearly constant BRDF without off-nadir foreshortening simplifying response characterization
- The sensor under calibration responds in the same way as a solar radiometer where the only atmospheric parameter that needs to be characterized is transmittance
- Thus the satellite can be calibrated to determine a spectral zero airmass response constant (ZARC) that can be used to establish and track the absolute radiometric response of and between sensor systems on the same radiometric scale
- The implementation of the SPARC method in Labsphere's FLARE network makes this capability readily available to evaluate repeatability and reproducibility within a virtual constellation important to creating interoperable data sets

The ZARC value represents the sensors intrinsic digital number (DN) response to the stable and repeatable at-sensor radiance from a SPARC target. ZARC can be tracked for temporal trending, monitoring radiometric stability similar precision as an on-board lamp, solar diffuser or the moon

The ZARC value provides a new parameter for sensor response trending with SI traceability

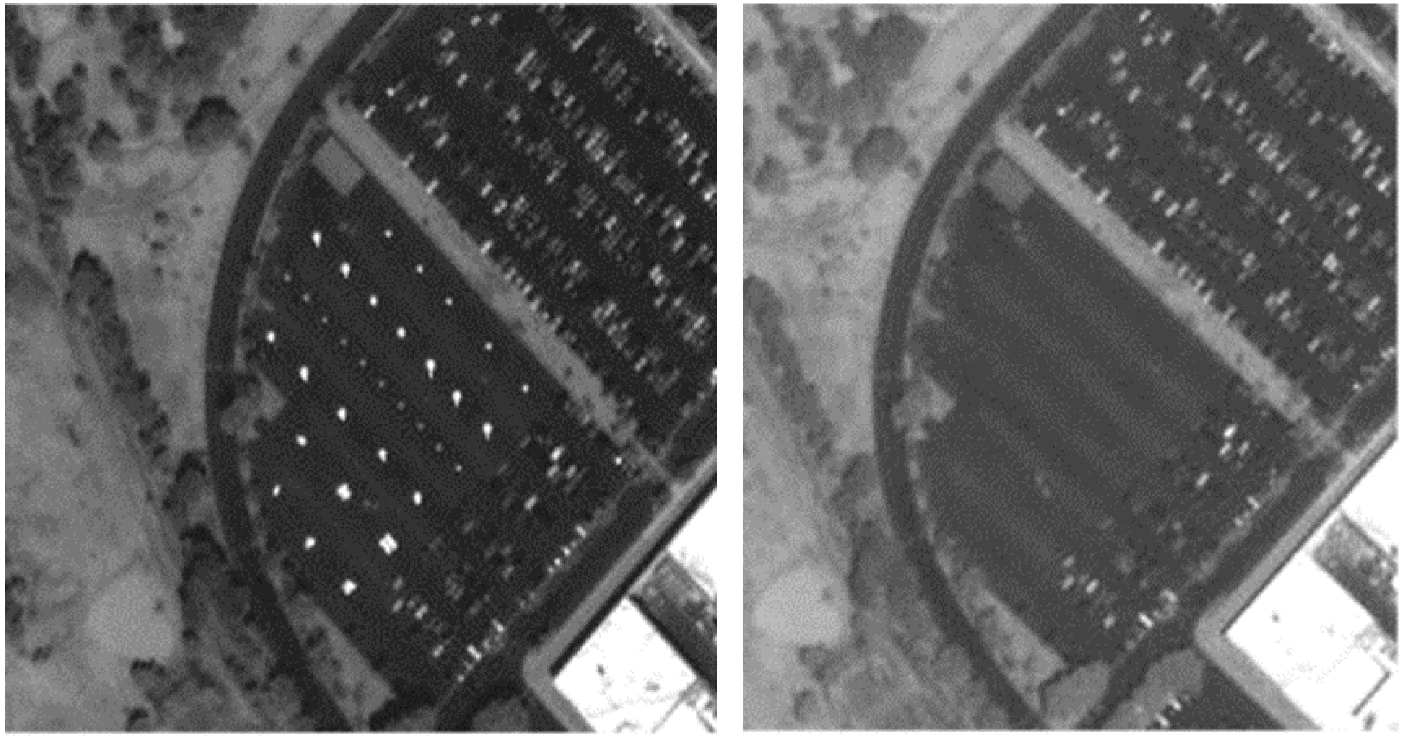
Response Trending
Landsat 8



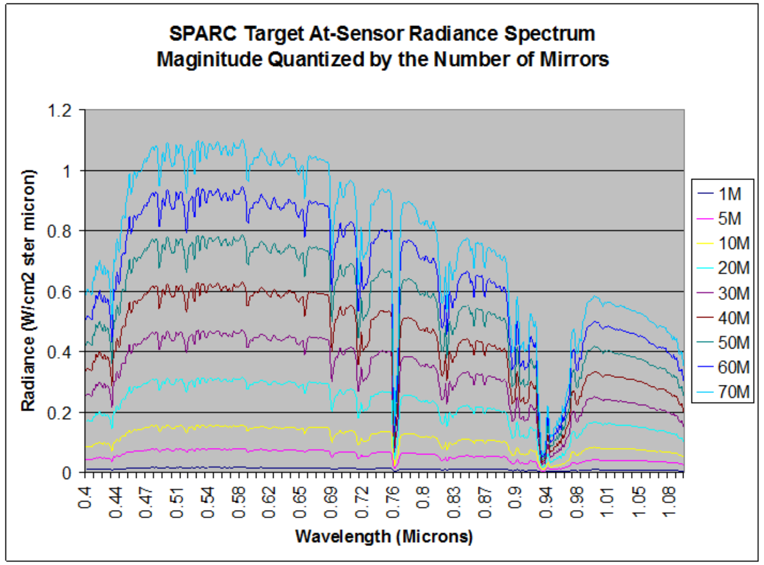
Backup Charts

SPARC Targets Isolate the Direct Solar Signal

The SPARC reflectors act as a spectrally flat neutral density filter allowing the sensor to look directly at the sun through the same atmosphere as the rest of the scene.



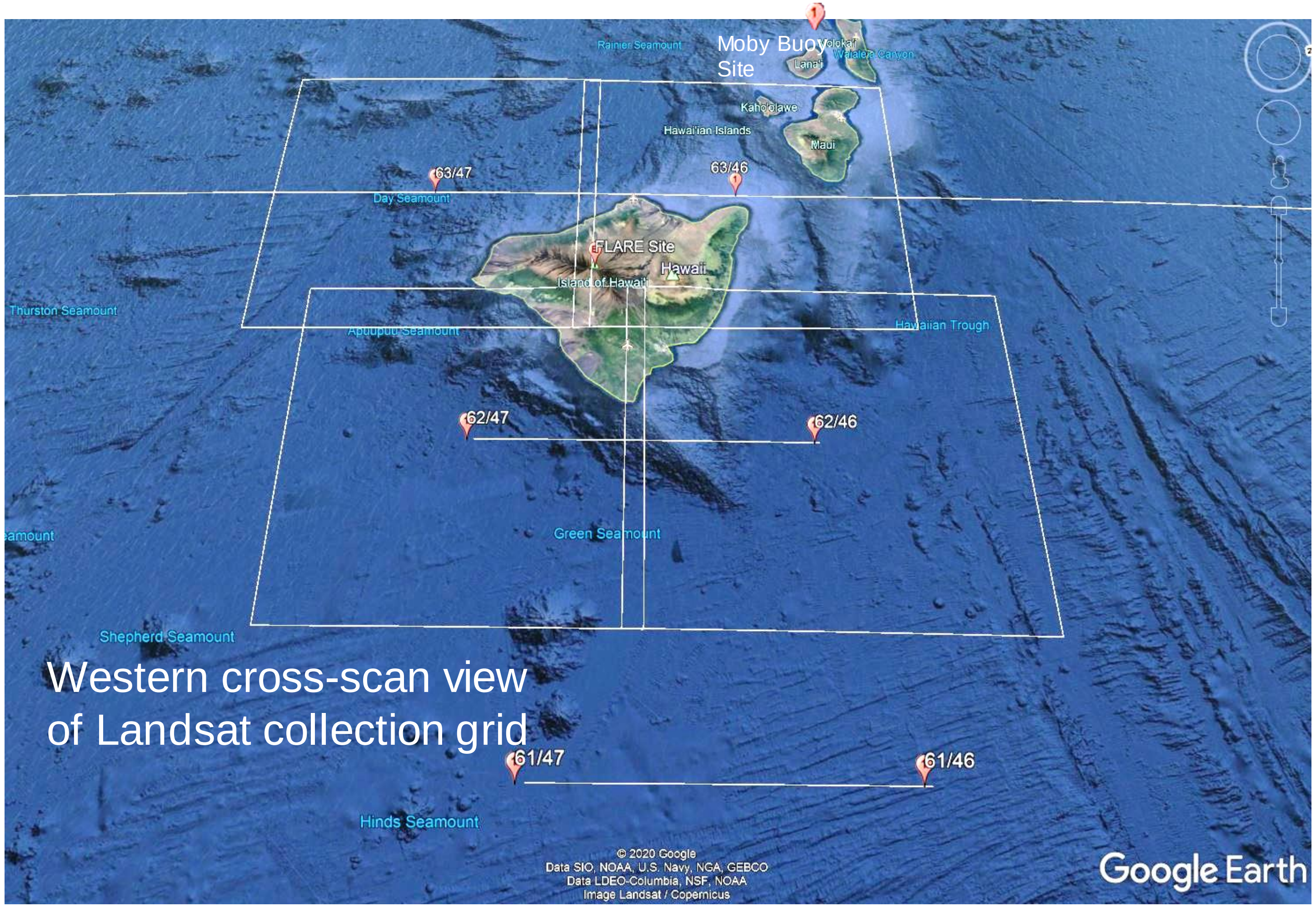
Two sequential IKONOS images recorded on the same overpass.



Total at-sensor radiance of each target is quantized by the number of mirrors.

When the sensor moves outside the mirror’s field-of-regard, the images show how the direct solar component “turns off” demonstrating its independence from the background and atmospheric radiance pattern.

Radiometric performance at off-nadir angles using MLO FLARE



Western cross-scan view of Landsat collection grid

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Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Data LDEO-Columbia, NSF, NOAA
Image Landsat / Copernicus

1. FLARE at MLO enables a design approach to ensure that calibration stability is maintained during any off-nadir imaging

- .The FLARE calibration target can be imaged at multiple view geometries (nadir or off-nadir pointing) without any significant change in BRDF
- FLARE point target radiometric performance maintains a constant off-nadir radiometric reference at any view geometry (point target - no target shape or cosine effect with view angle)
- Can validate the off-nadir radiometric response of the sensor at all potential look angles and provide correction coefficients if needed.

2. Off-nadir geometric calibration and terrain occultation mask validation

- The vast geological relief of the island and accurate point location of FLARE target provide the means to validate computations of ground locations where the line-of-sight is obstructed by terrain.
- Validates geometric calibration occultation mask and image resampling logic