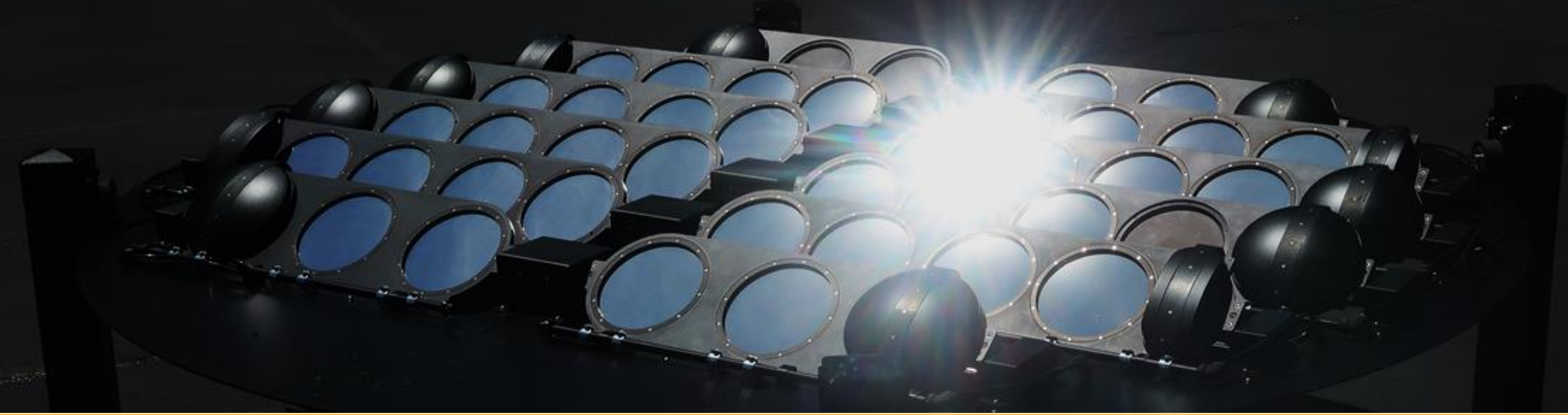
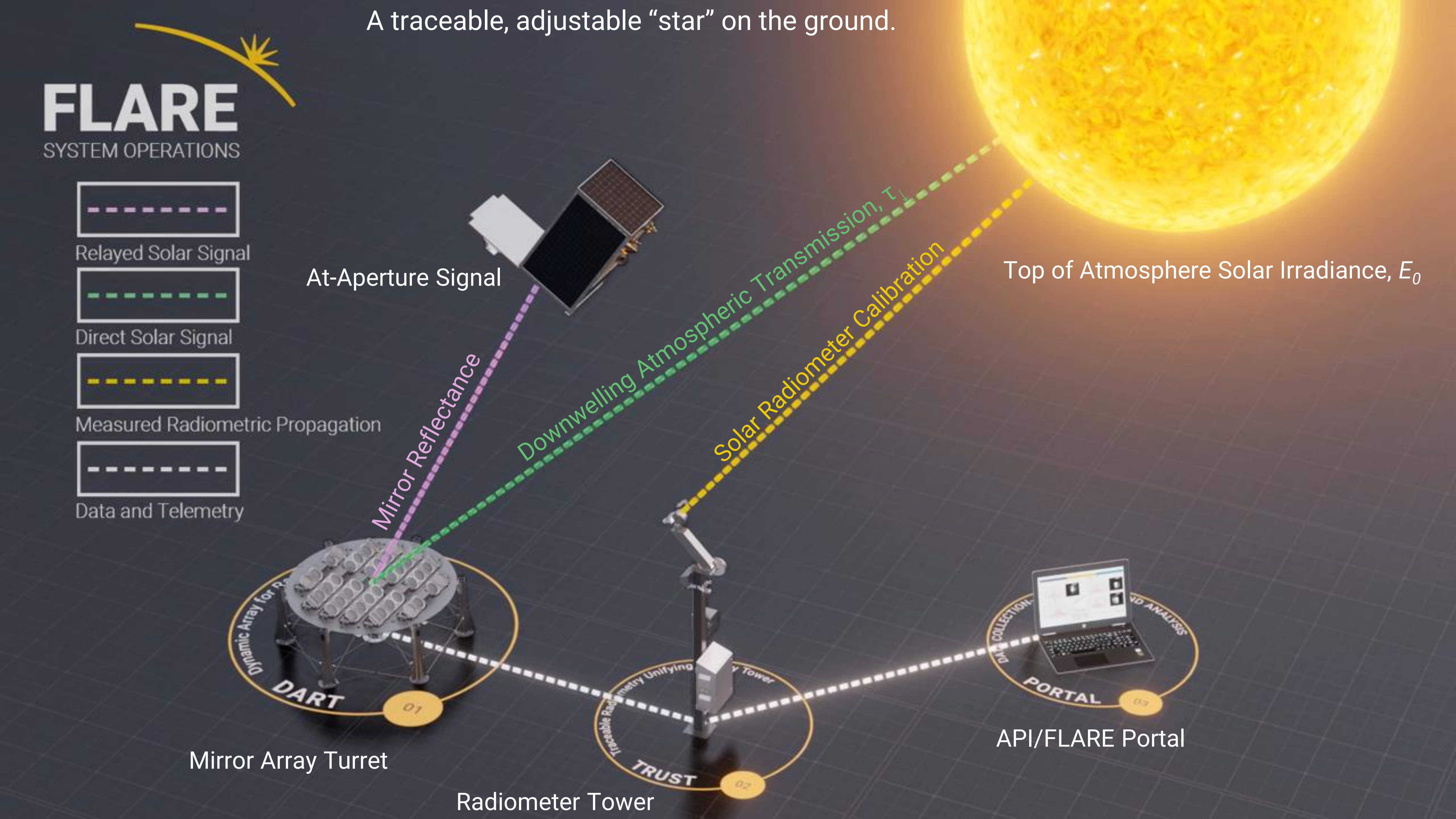
The FLARE Network
Vicarious Cal/Val for Earth Observation Satellites



Brandon Russell [a], Jeff Holt [a], Will Arnold [a], Chris Durell [a], David Conran [b], Arin Jumpasut [c], Colm Lynch [c], Stephen Schiller [d]

[a] Labsphere, Inc., North Sutton, NH USA
[b] Rochester Institute of Technology, Rochester NY USA
Planet Labs, Inc., San Francisco, CA USA
[c] Raytheon Technologies, El Segundo, CA USA

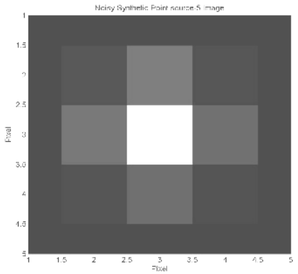
Better Calibration | Better Data | Better Decisions

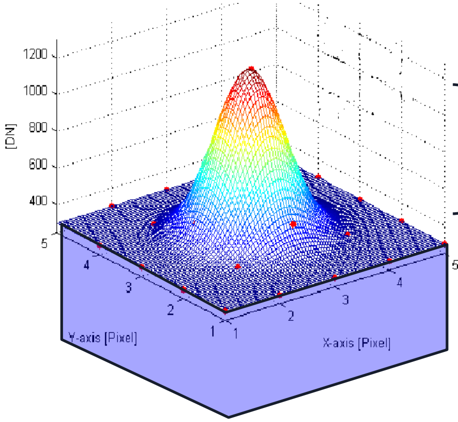

A traceable, adjustable "star" on the ground.
FLARE
SYSTEM OPERATIONS
Relayed Solar Signal
Direct Solar Signal
Measured Radiometric Propagation
Data and Telemetry
At-Aperture Signal
Top of Atmosphere Solar Irradiance, E_0
Mirror Reflectance
Downwelling Atmospheric Transmission, $\tau_{\downarrow}$
Solar Radiometer Calibration
DART
01
TRUST
02
PORTAL
Mirror Array Turret
Radiometer Tower
API/FLARE Portal

Lambertian vs Specular Targets

Target signal embedded in a uniform scene is elevated above the low spatial frequency background (sky path radiance, adjacency effect, stray light, etc.) and is separable

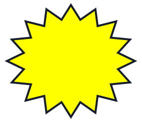
- Background becomes a bias and is subtracted out based on image data alone
- Sensor response to target radiance is integrated (DN) contained in the PSF
- Atmospheric, adjacency, multiple scattering effects reduce to transmittance only - measured with solar spectrometer coincident with overpass





Signal from SPARC

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



The convex mirror acts as an aperture stop isolating the direct solar irradiance as the only contributor to the effective at-sensor calibration radiance

Direct Solar Irradiance

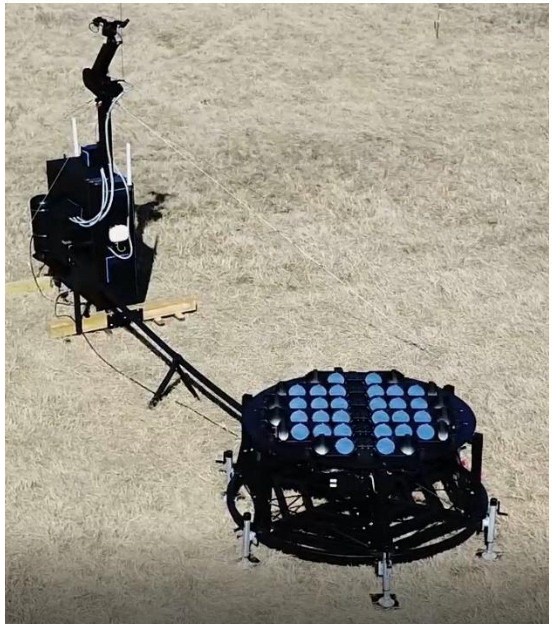
Surround

FLARE

FLARE Nodes

- **Alpha Node**
  - Arlington, SD
  - SDSU Evaluation partnership

- **Beta Node**
  - Ft. Worth, TX



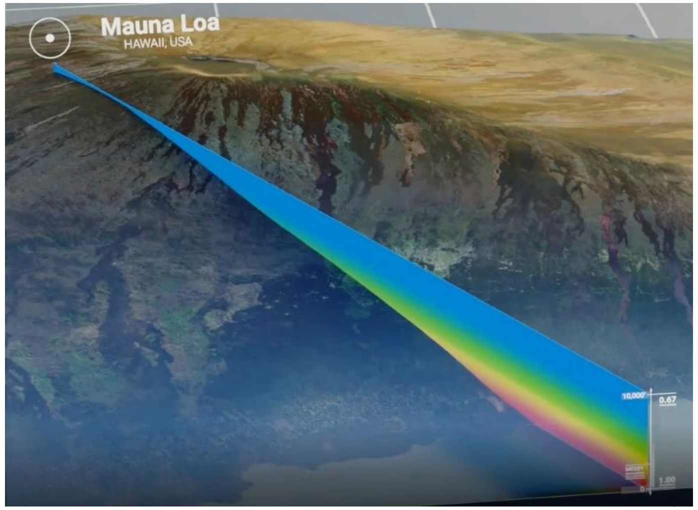
FLARE

FLARE Development

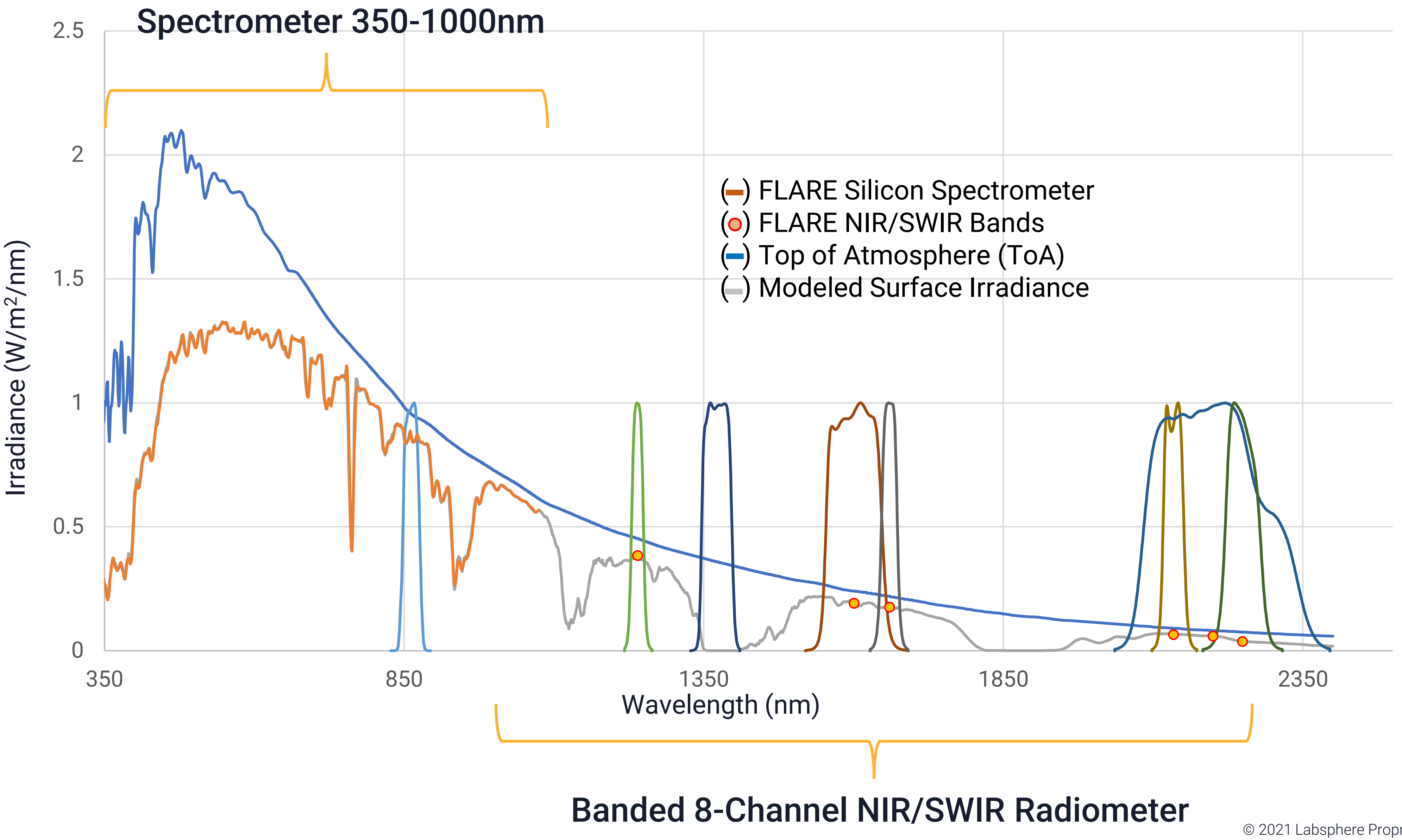
- Mobile Node future development
  - Summer ’21
  - Prototype at Beta site

- Custom Campaigns
  - Manual campaigns for targeted geometry
  - Commissioning Projects - individual assets or constellations

- Planned Nodes
  - **Mauna Loa (3300m)**
    - **Fall ‘21**
  - Railroad Valley Playa, Tenerife – TBD
  - Atacama, Australia, Gobabeb - TBD

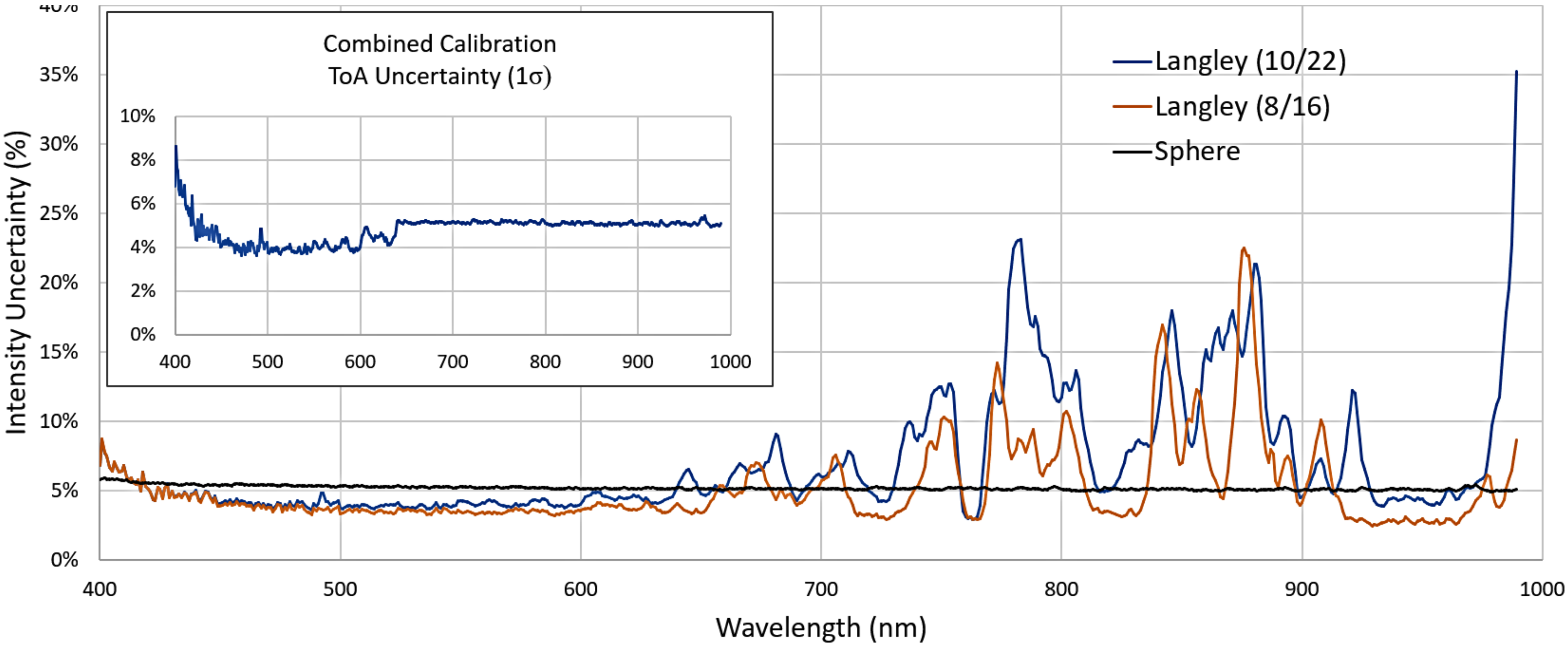


FLARE Radiometric Tower: VNIR Spectrometer & SWIR Bands



FLARE

Dual Traceability - Langley & Sphere Methods



Prelim. SWIR Uncertainty Analysis < 5%

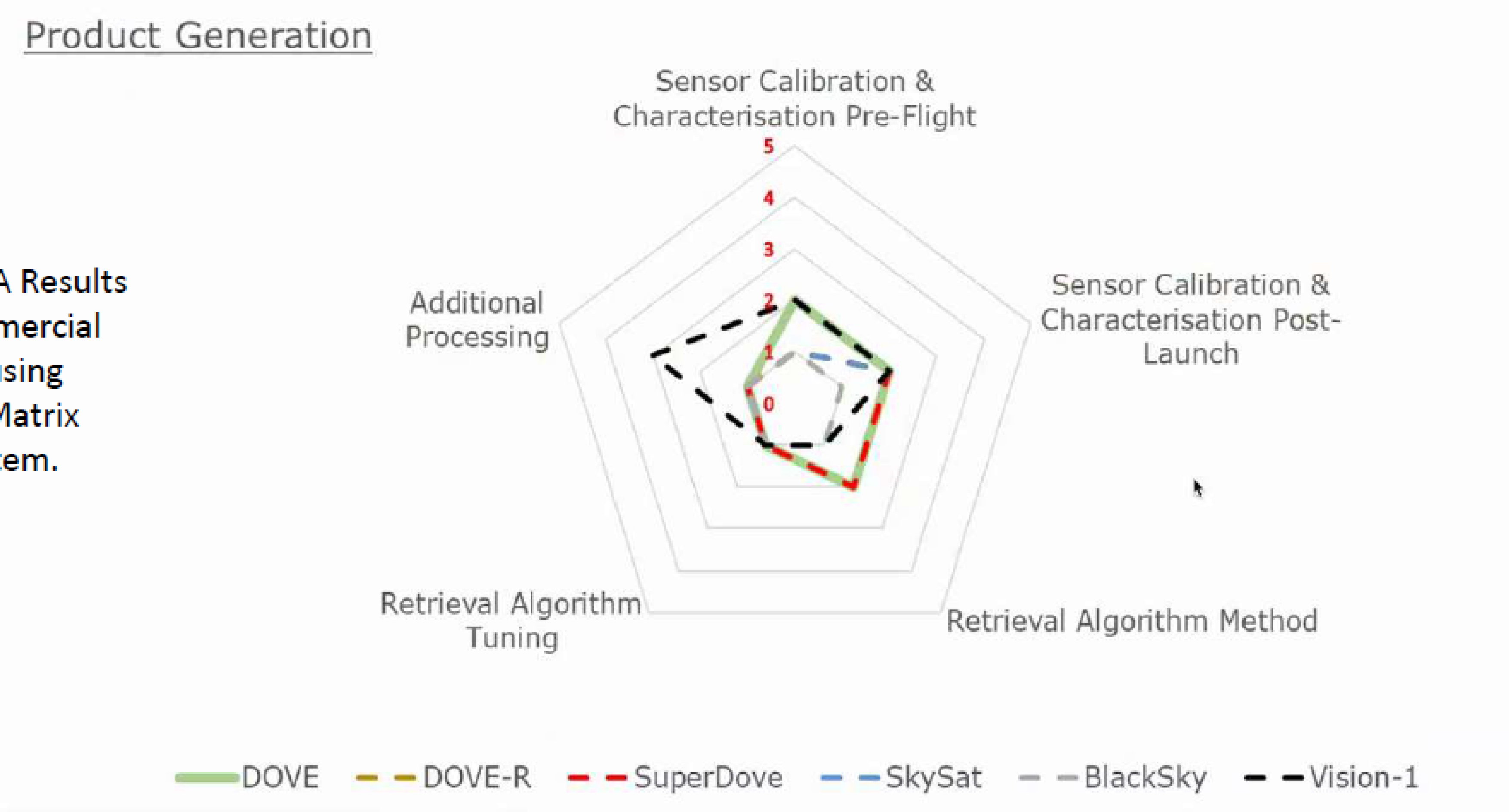
Small Sats and Analysis Ready Data - CEOS CARD4L

https://ceos.org/ard/

FLARE

Maturity Matrix Radar Plot: Transparent ARD ratings

NASA / ESA Results from Commercial Data buy using Maturity Matrix Rating system.



Not Assessed	Not Assessable	Basic	Intermediate	Good	Excellent
0	1	2	3	4	5

FLARE

Credit: Sam Hunt et al., VH-RODA Workshop, Apr 20, 2021

DQR and GIQE FLARE – Feed for Maturity Matrices

FLARE Enabled
Imagery Data Quality Report

Sensor: Sentinel 2B

Acquisition: Jan-March 2021

FLARE

Version 1.0 | March 2021

DQR = Data Quality Report

4. FLARE Operation and Sensor Acquisition Summary

4.1. Ground Station Operational Status

The LOOKS and EVALS (Table 2) utilized in this Data Quality Report were executed using the FLARE BETA node at Brock TX, USA (Lat: 32.664241°, Lon: -97.961547°). All LOOKS were calibrated using the Langley-derived fitting method with absolute SI traceability to the TSIS-1 instrument. No data quality issues were identified during any of the LOOKS.

Table 2: LOOK Event and Condition Summary

Date	Time (UTC)	Solar El. (°)	Satellite El. (°)	Signal Level	Data Ident.
04 Jan 2021	17:24:52	32.1	88.5	6	S2B_MSIL1C_20210104T171719_N0209_R112_T14SNB_20210104T192056
23 Feb 2021	17:24:44	43.5	88.4	6	S2B_MSIL1C_20210223T171309_N0209_R112_T14SNB_20210223T192416
05 Mar 2021	17:24:45	47.2	88.5	6	S2B_MSIL1C_20210305T171109_N0209_R112_T14SNB_20210305T204742

Figure 1: Example Imagery from LOOK Events

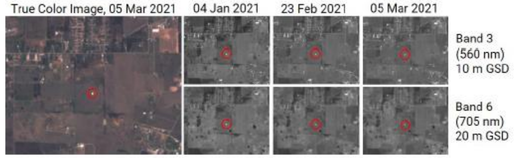
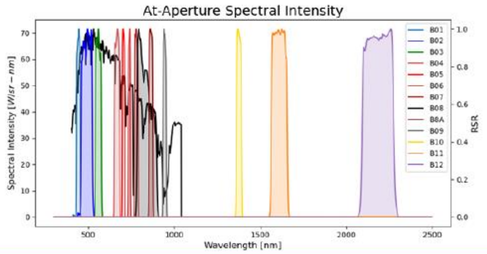


Figure 2: Spectral Intensity – during overpass with instrument RSR's



FLARE Enabled
GIQE Report

Sensor: Example

Acquisition: Example

FLARE

Version 1.0 | March 2021

GIQE = General Image Quality Equation

8. GIQE 5 and NIIRS Projection Results

8.1. FLARE Enabled NIIRS Calculated for Reference Conditions

NIIRS values as calculated by GIQE are dependent on operational conditions under test. Using analysis of sensor performance as characterized by FLARE, atmospheric modeling, and specific solar and satellite positions, FLARE-Enabled GIQE can be used to project NIIRS values for any given operational condition.

Below is a table of NIIRS values calculated for the Sensor Under Test projected to example operational conditions. These conditions assume a representative atmosphere (mid-latitude summer) with varying sensor and solar angles at time of acquisition.

Table 4: Projected NIIRS for Reference Conditions

NIIRS Values Predicted for Sun/Sat Elevations	Sat @ 90° GSDw = 0.70m	Sat @ 60° GSDw = 0.93m	Sat @ 30° GSDw = 2.5m
Sun @ 90°	4.6	4.2	2.6
Sun @ 60°	4.6	4.2	2.6
Sun @ 30°	4.6	4.1	2.4

8.2. SDNR Calculated for Reference Conditions

The Signal to Noise coefficient (SNDR) is calculated from predicted sensor response to reference solar constant, atmosphere, and simulated surface reflectance standards.

Table 5: Signal to Noise Parameters for Reference Conditions

SDNR	Sat_El = 90°	Sat_El = 60°	Sat_El = 30°
Sol_El = 90°	42.01	39.30	15.59
Sol_El = 60°	38.59	35.70	13.93
Sol_El = 30°	25.37	23.08	8.26

8.3. FLARE Enabled NIIRS Calculated for Test Conditions

For the acquisition(s) reported here, the atmosphere, solar, and sensor conditions were known. These inputs were used to calculate a predicted NIIRS rating using GIQE for the FLARE test conditions.

Table 6: NIIRS Under Test Conditions

Calculated NIIRS	SDNR	GSD_w	RER
4.2	37.4	0.94m	0.3771

Finally, the projected NIIRS value for the sensor under test with test pose and solar angle using the reference atmosphere is provided below.

Table 7: Projected NIIRS under Test Pose with Reference Atmosphere

Calculated NIIRS	SDNR	GSD_w	RER
4.2	37.4	0.94m	0.3771

FLARE Mission Quality Metrics

IMAGE QUALITY PARAMETER	DESCRIPTION
Absolute Radiometric Performance	Imagery reported in-band radiance relative to uncertainty requirements.
Absolute Geolocation	Location error of imagery reported coordinates for FLARE signal center position relative to known values.
Multi-Spectral Registration	Inter-channel spatial band co-registration error based on evaluation of FLARE signal center position in reported bands.
Modulation Transfer Function	Nyquist MTF, other sensor resolution metrics (Point Response Function, Line Response Function, Rayleigh/Sparrow Criterion, Ground Spot Size, etc.).
National Imagery Interoperability Rating Scale	NIIRS value for provided imagery with FLARE target in-scene, derived through General Image Quality Equation v 5. Predicted NIIRS rating for sensor under alternative atmospheric conditions and solar/sensor geometries.

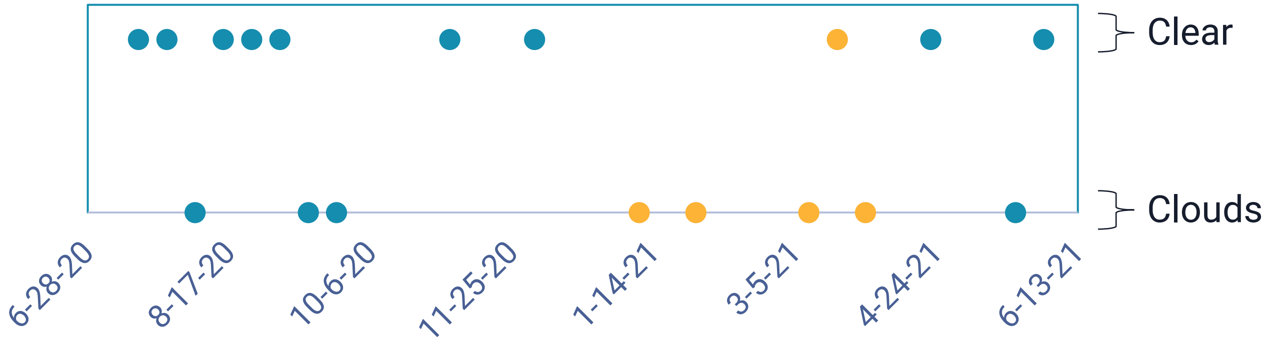
FLARE

Successful Engagements with Small Sat and Agency Assets

Current Agency Archive

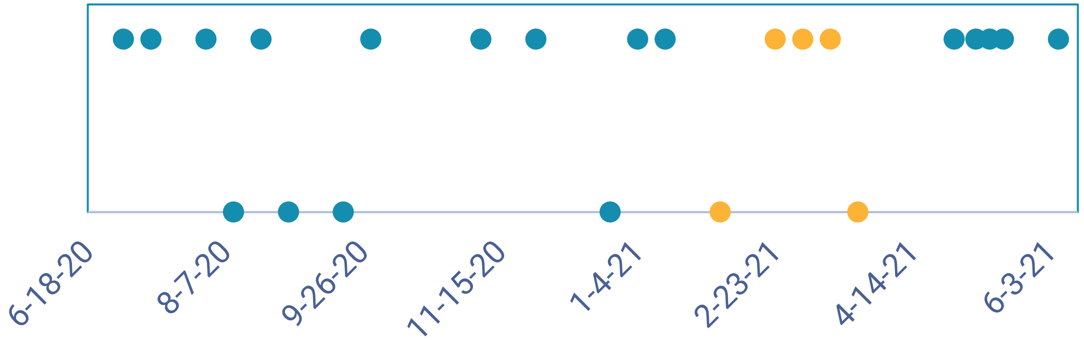
- Alpha
- Beta

Sentinel 2A

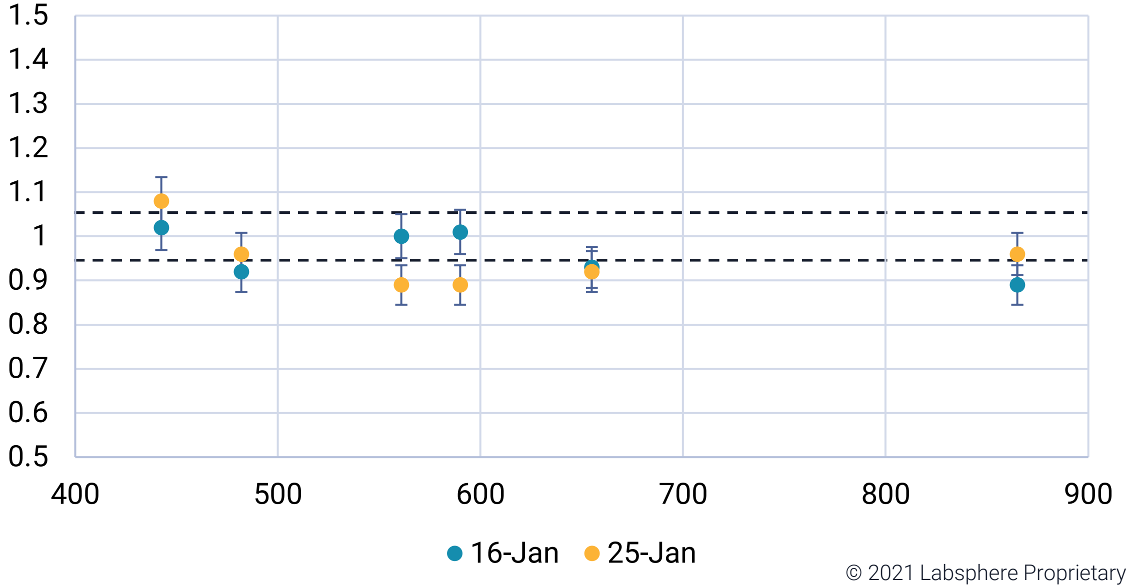


Landsat 8

Sentinel 2B



Landsat 8 Normalized Radiance (FLARE = 1)

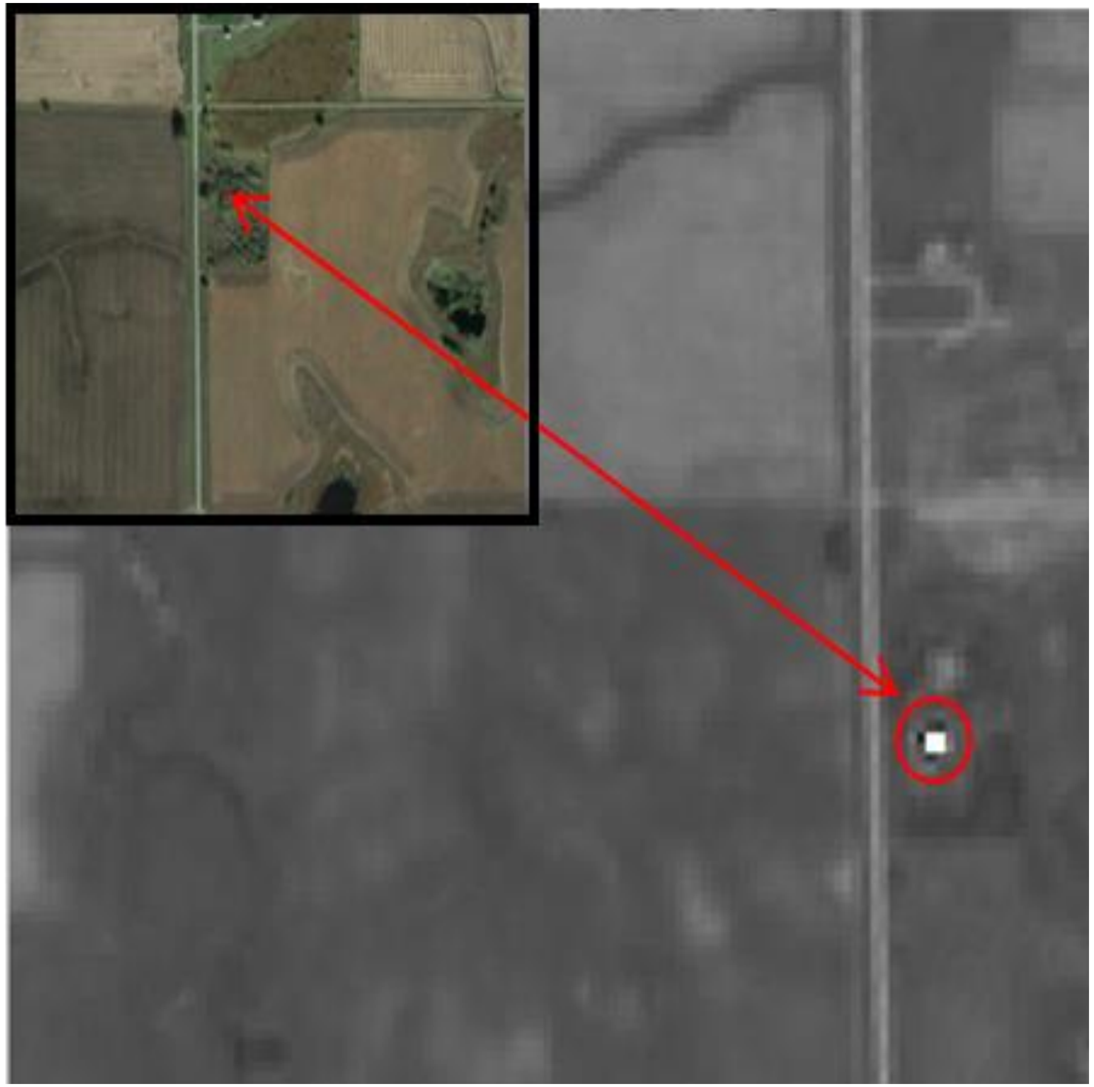


FLARE

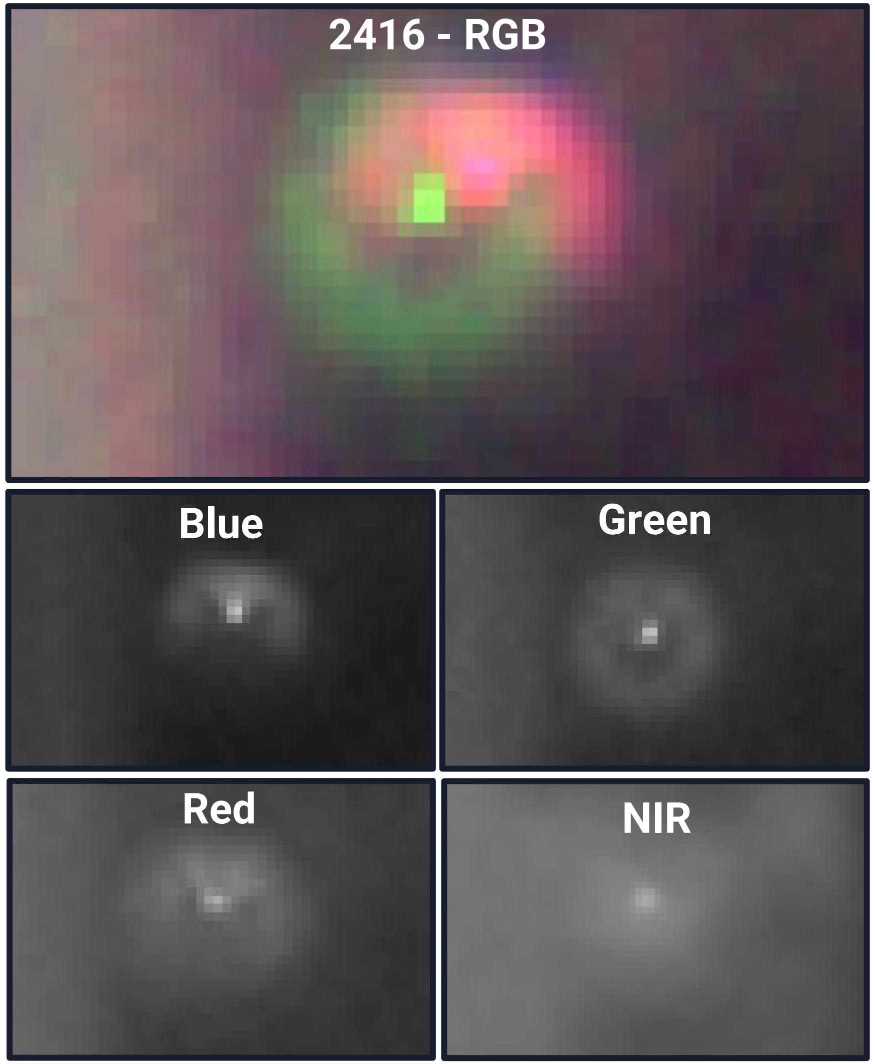
~60% yield including partly cloudy days.

Successful LOOKS with PRISMA, ISRO LISS-3 also added.

Post-Launch Commissioning and Trouble Shooting

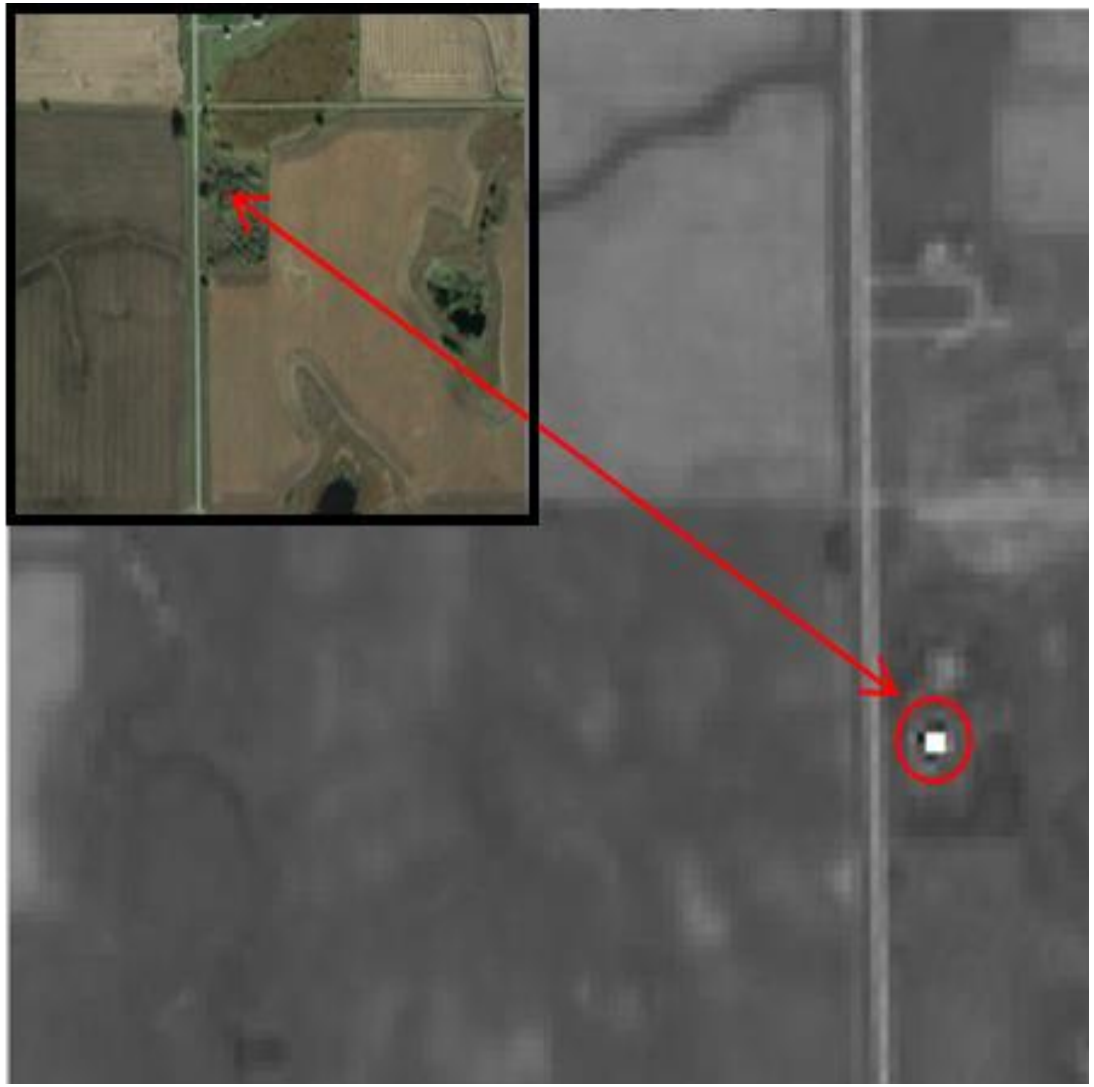


ALPHA Node – Arlington, SD USA. Imaged by Sentinel 2B July 16 2020

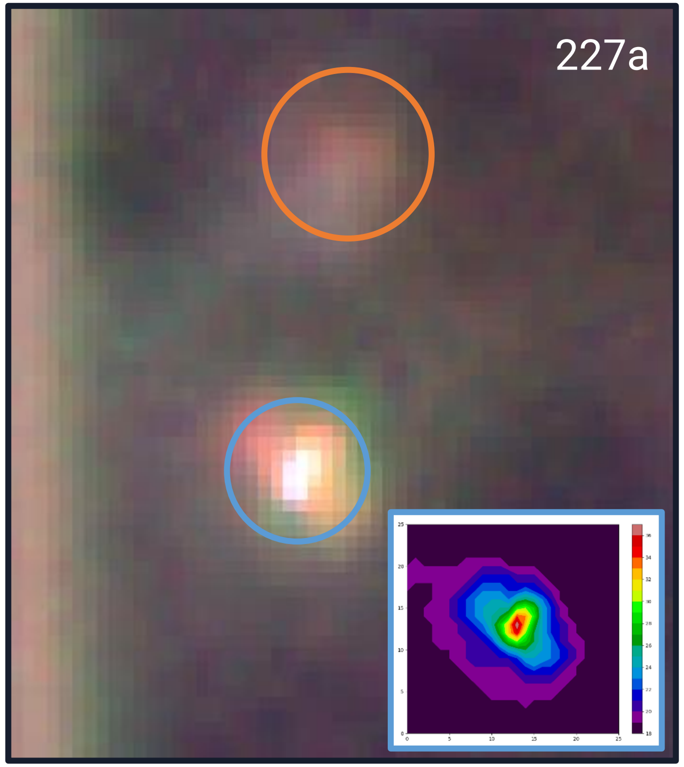


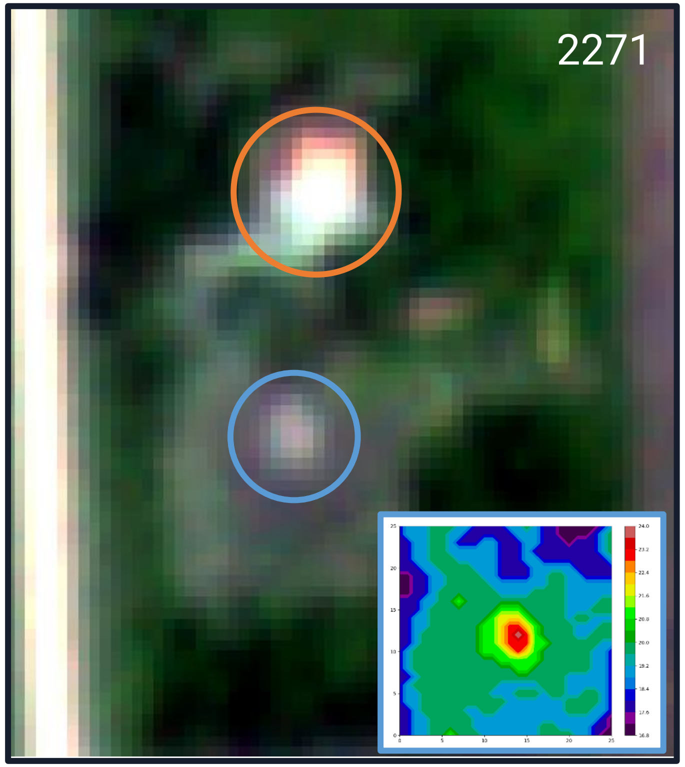
Band-dependent halo/ringing, misregistration

Post-Launch Commissioning and Trouble Shooting



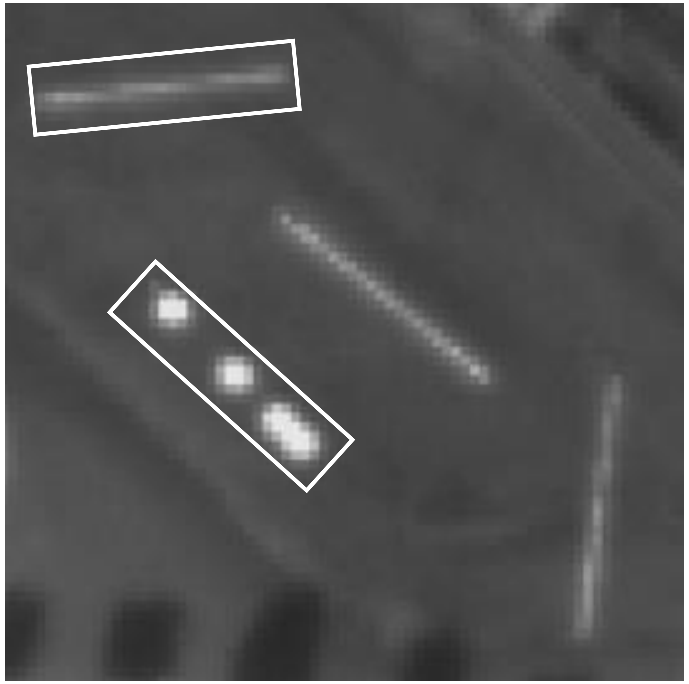
ALPHA Node – Arlington, SD USA. Imaged by Sentinel 2B July 16 2020

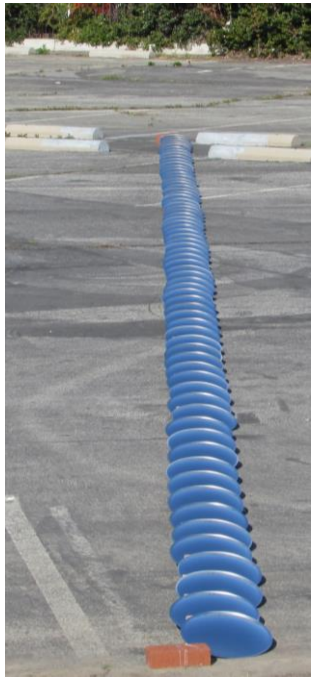


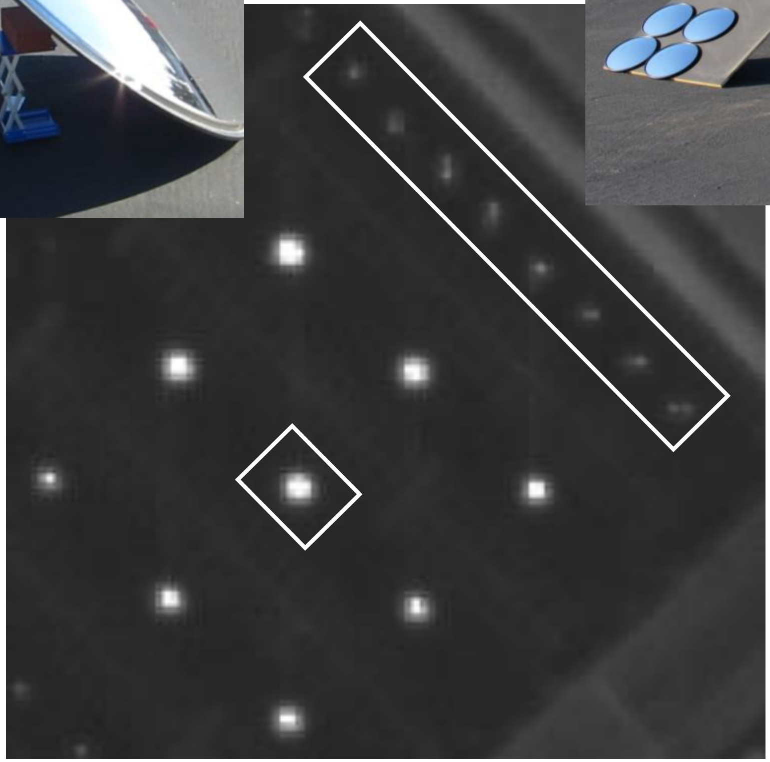


Across-track smear, thermal defocusing

Campaigns – Rapid Baseline Characterizations

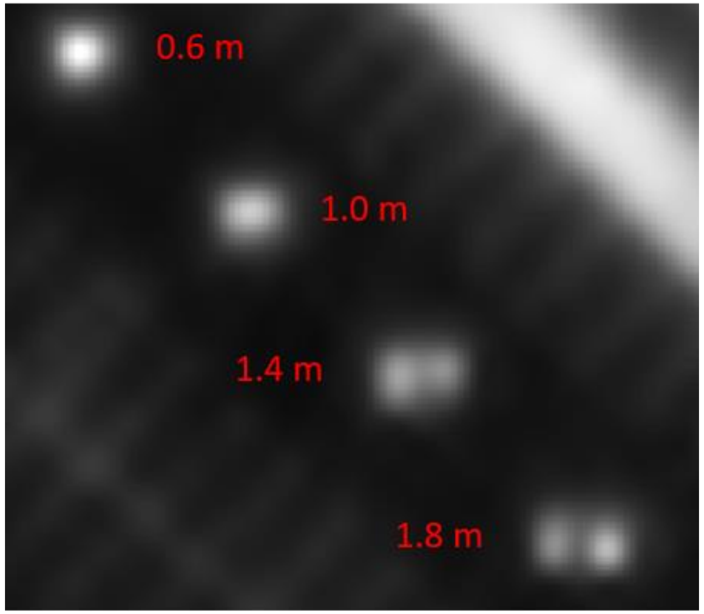






Resolution Enhancement Experiment

Satellite Image (L1A)



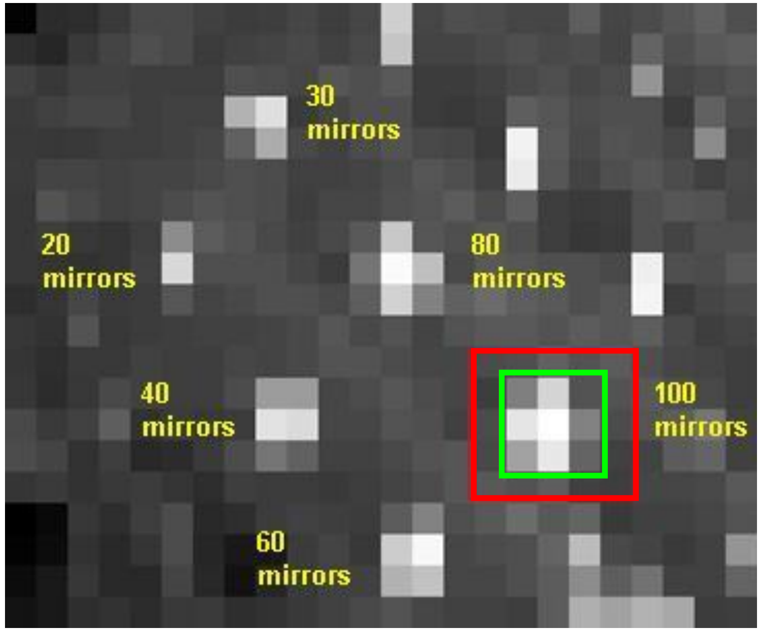
	ORBITAL ALTITUDE			
	500 km		450 km	
RESOLUTION METRIC	Cross (m)	Along (m)	Cross (m)	Along (m)
Rayleigh (15.3%)	1.55 ± 0.05	1.61 ± 0.07	1.37	1.39
GSS (0.9%)	1.23 ± 0.04	1.26 ± 0.05	1.09	1.10
Sparrow (0%)	1.17 ± 0.03	1.20 ± 0.08	1.07	1.05

FLARE provided proof that lowering orbital altitude improved resolution capabilities and Ground Sample Distance, *before* a constellation wide maneuver

FLARE

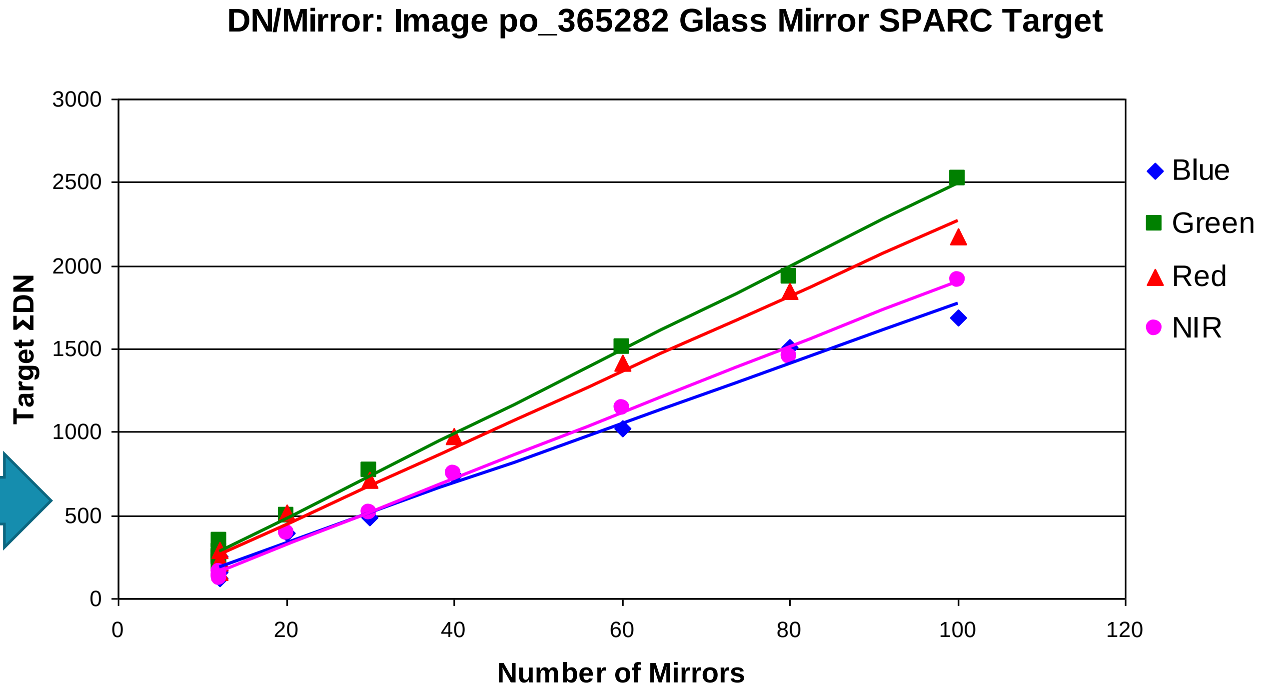
Mirror Empirical Line Method (MELM)

Different mirror in targets = multiple levels in a scene



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

Results for Sept. 10, 2009 IKONOS collect.



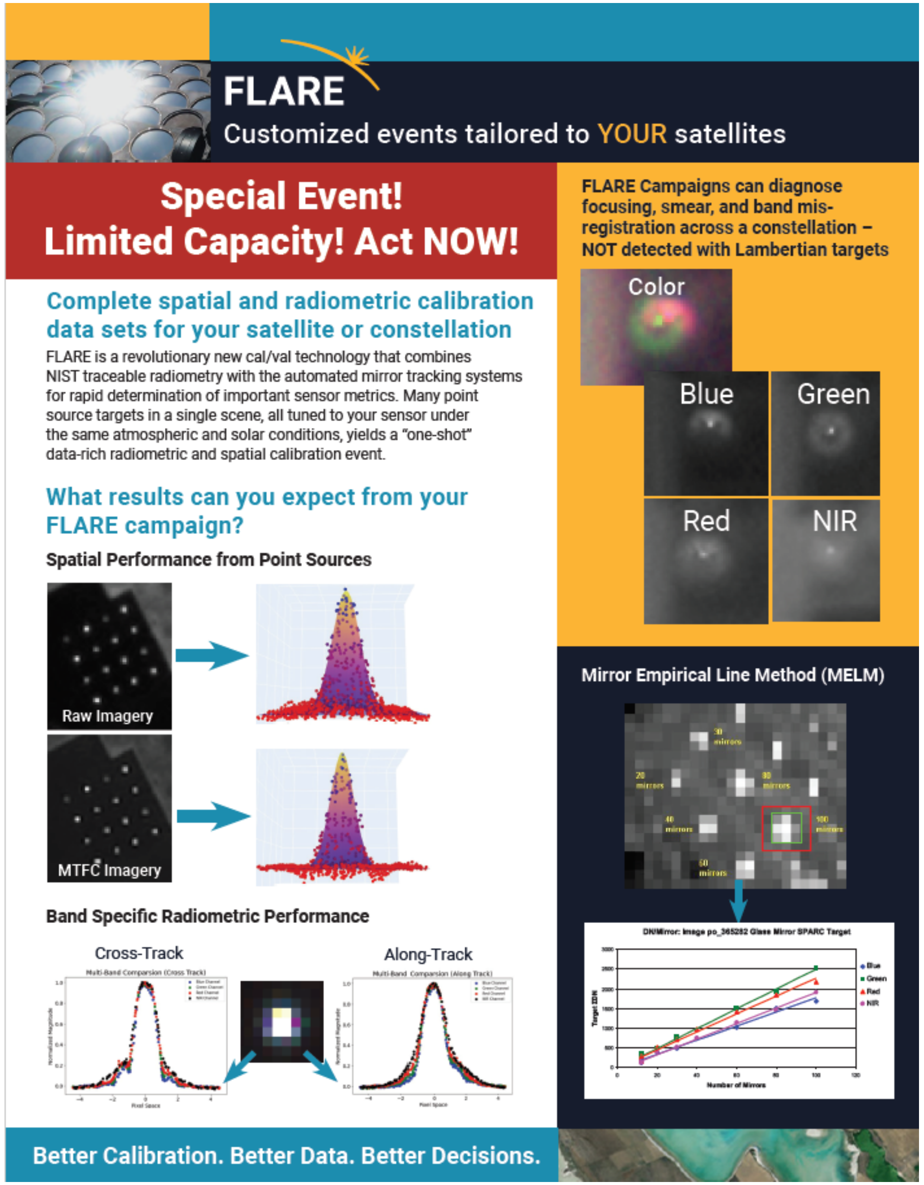
- MELM via Multi-LOOK events or Multi-Points in scene both provide
  - **Low reflectance signal verification**
  - **Absolute gain**
  - **Linearity assessment**
  - **SNR**

FLARE

FLARE 2021 Summer Campaigns for UAVs and Satellites

June 30-July 9, Hawaii Tests
July 5-15, Texas
Aug 9-13, South Dakota
Aug 28-Sept 5 South Dakota:
Landsat 8 Surface Validation

Contract;
Dr. Josh Hudson, FLARE Sales Manager –
jhudson@labsphere.com M: 817-771-4847


FLARE
Customized events tailored to YOUR satellites

Special Event!
Limited Capacity! Act NOW!

Complete spatial and radiometric calibration data sets for your satellite or constellation

FLARE is a revolutionary new cal/val technology that combines NIST traceable radiometry with the automated mirror tracking systems for rapid determination of important sensor metrics. Many point source targets in a single scene, all tuned to your sensor under the same atmospheric and solar conditions, yields a "one-shot" data-rich radiometric and spatial calibration event.

What results can you expect from your FLARE campaign?

Spatial Performance from Point Sources

Band Specific Radiometric Performance

FLARE Campaigns can diagnose focusing, smear, and band mis-registration across a constellation – NOT detected with Lambertian targets

Mirror Empirical Line Method (MELM)

Better Calibration. Better Data. Better Decisions.

FLARE

Video & Flyer HERE➔ https://flare-network.com/latest-news/

FLARE Primary Benefits

New and independent method vs. classic vicarious calibration

- Radiometry & Spatial in ONE EVENT
- Fully automated synthetic target
- Small or Large target radiometry
- Impulse system response
- Band registration
- Geospatial Control Points
- Applies to all levels (L0, L1, L2, etc.)
- One-Sigma <3.5% VNIR Uncertainty

Scales and applies to Airborne, UAV & Satellite calibration (mirror changes)

- Common radiometric calibration & harmonization for all data sources
- FLARE can be scaled from 0.01m to ≥1km GSD Pixels (OLCI, MODIS, etc.)
- Rapid identification of imaging or radiometric errors
- Speed commissioning and satellite interoperability

FLARE

FLARE

www.flare-network.com

Better Calibration. Better Data. Better Decisions.

Thank you!

Questions and Comments may be directed to:

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Dr. Brandon Russell, Science Lead – brussell@labsphere.com M: 203-241-7253

Jeff Holt, Principal Architect – jholt@labsphere.com M: 603-401-7471