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advancing the technology of light

On Demand Vicarious Calibration Service
The FLARE Network

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VH-RODA Nov 18-21 – Presentation 3X5

Better Calibration | Better Data | Better Decisions

Discussion

- Vicarious Calibration today
- Raytheon SPARC Technology overview
- What is the FLARE network concept
- How it can solve problems in Vicarious Calibration
- How it can change the paradigm of calibration

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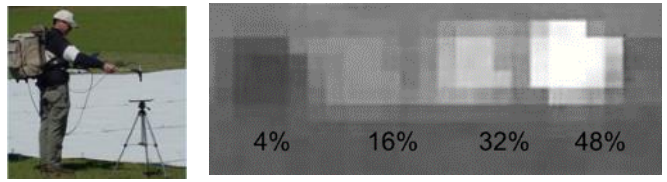
Room for Improvement – Space and Airborne Image Quality

- Sensor Calibration is Fundamental to the Future!
  - **Bad or No Calibration = Data/Images are less valuable!**
- Calibration is difficult & requires expert knowledge
  - Infrequent = low number of available sites
  - Uncertain = inconsistency of methods & within constellations
  - Expensive = national agencies & high cost assets needed
- Data Harmonization Hindered by Inconsistent Calibration
  - Sensor-to-sensor mismatch within a constellation
  - Space-to-airborne mismatch when harmonizing across platforms
- Shortcomings/Issues with Current Methods
  - Atmosphere is not constant & hard to measure in real time
  - Large area targets are often misused and don't provide full calibration results across all imaging platforms
  - No single method for airborne to space calibration convergence
  - Other types of sensor performance data are hard to get
    - MTF/PSF difficult with normal terrestrial targets

Using too-small Lambertian target for DN



Using natural targets for sensor MTF

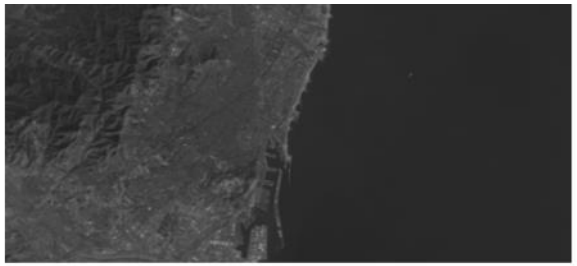


Figure 3. View of Barcelona Spot-5 Image in Panchromatic Modality

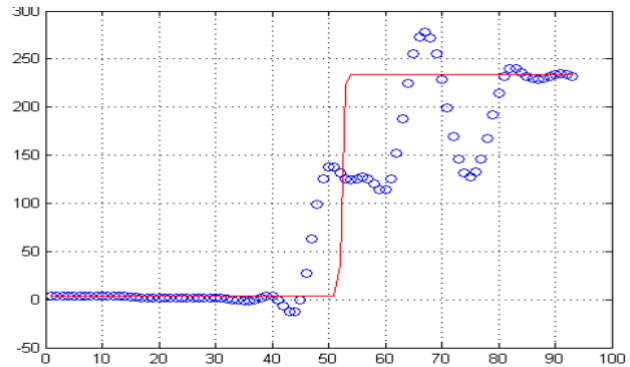


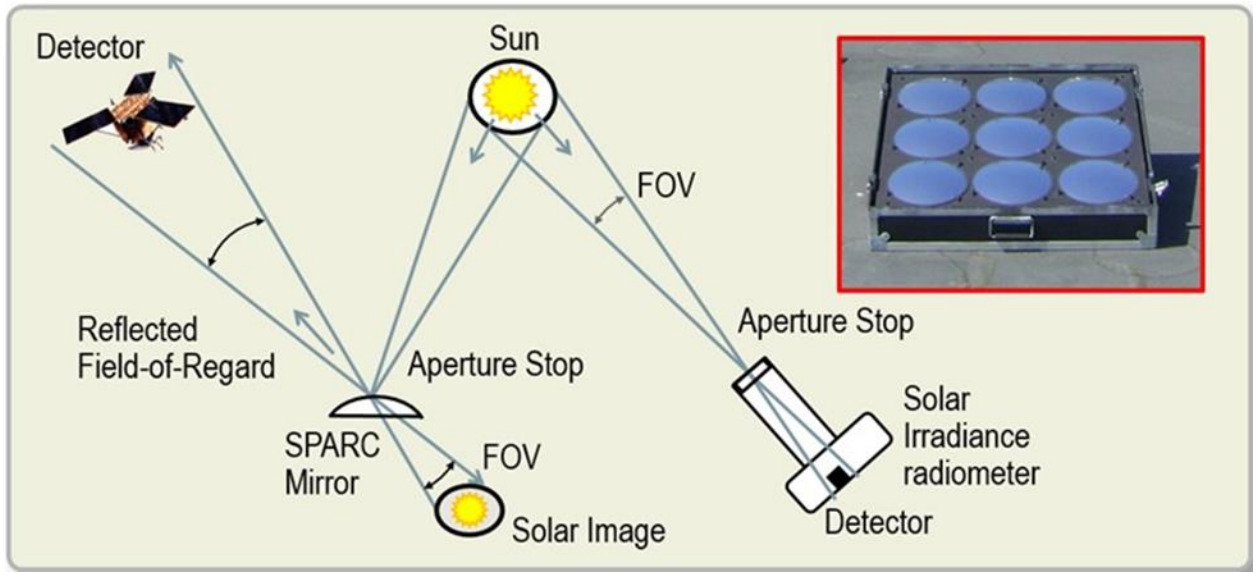
Figure 8. Fitted ESF by logistic function

http://www.wseas.us

Conceptualizing The SPARC Vicarious Method

- The Specular Array Calibration (SPARC) method allows any earth observing sensor to be calibrated to the solar spectral constant just like a solar radiometer.
- The mirror acts as a Field-of-View (FOV) aperture stop allowing the sun to be imaged directly as an absolute reference.

12+ Papers
6 Patents



"Initial results for the vicarious calibration of Landsat 8 using the specular array radiometric calibration (SPARC) method", Schiller et al, SPIE 2016

- The curvature of the spherical mirror scales down the brightness of the sun to an intensity that does not saturate the sensor focal plane.

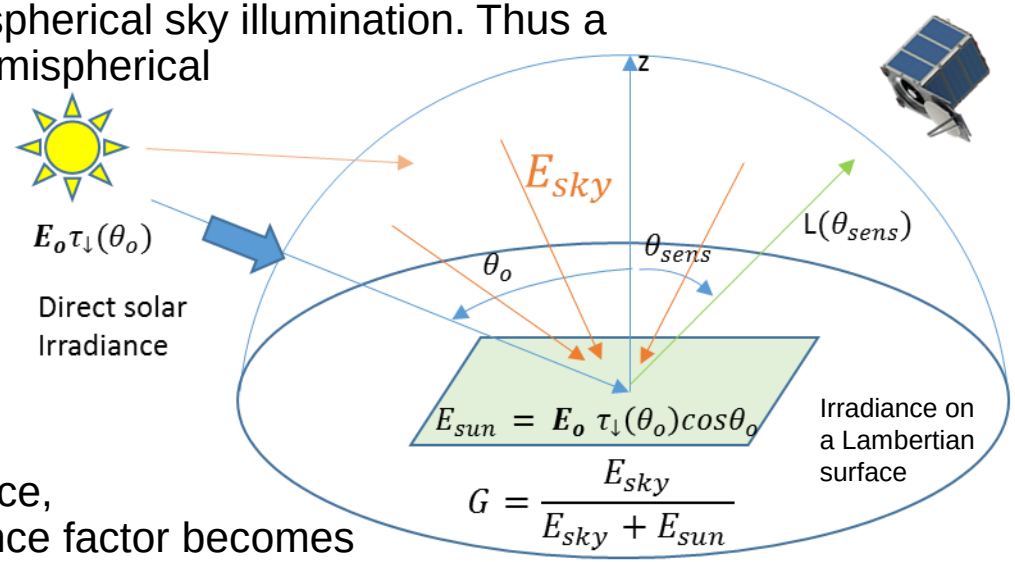
Calibrated Stars on the Ground!

Convex Mirror Specular/Diffuse Equivalence Equation

In field conditions, a Lambertian surface reflects both direct solar and hemispherical sky illumination. Thus a field reflectance factor (ρ_{RF}) must combine both bi-directional (ρ_{BRF}) and hemispherical illumination (ρ_{HRF})

$$\rho_{RF}(\theta_i, \phi_i, \theta_r, \phi_r) = (1 - G)\rho_{BRF}(\theta_i, \phi_i, \theta_r, \phi_r) + G\rho_{HRF}(\theta_r, \phi_r)$$

Where $G(\lambda)$ = Diffuse to global irradiance ratio (on a horizontal surface) measured at the mirror target location



Setting up the radiative transfer equations for SPARC targets producing the same at-sensor effective radiance, $L(\theta_{sens})$, as diffuse Lambertian surface, the transformation from a specular mirror to equivalent diffuse field reflectance factor becomes

$$\rho_{RF}^{mirror}(\lambda, \theta_i^m) = \left[\frac{1}{cos\theta_o} + \left(f - \frac{1}{cos\theta_o}\right)G(\lambda)\right]\frac{N\pi {R_c}^2}{4GSD_x GSD_y}\rho_m(\lambda, \theta_i^m) = \left[\frac{1}{cos\theta_o} + \left(f - \frac{1}{cos\theta_o}\right)G(\lambda)\right]\pi\rho_{BRDF}^{mirror}(\lambda, \theta_i^m)$$

Where

θ_o= Solar zenith angle (relative to a horizontal surface)

θ_i^m= Solar angle of incidence on mirror surface (relative to mirror surface normal)

$\rho_m(\lambda, \theta_i^m)$= Mirror specular reflectance spectrum measured in the laboratory at θ_i^m

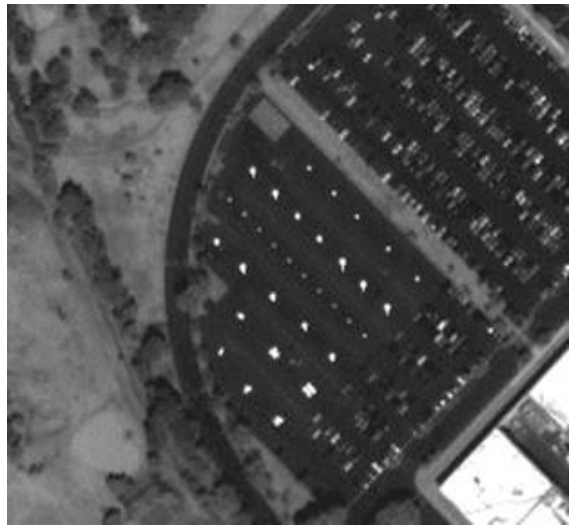
$f = 1 - cos2\theta_m$ = Fraction of the hemispherical sky reflected by the mirror dome of half angular width θ_m

The Lambertian reflectance factor, ρ_{RF}^{Mirror}, provides the reflectance value used to derive the DN-to-reflectance gain coefficient in a mirror-based empirical line method

SPARC Radiometric Calibration Capability Heritage

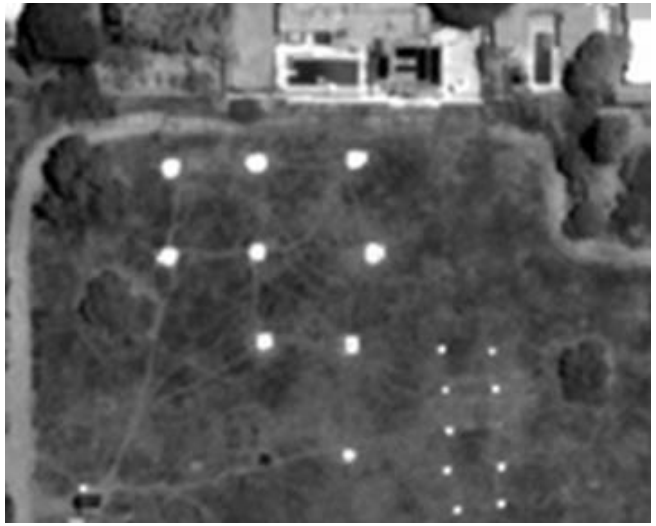
- Method has been demonstrated with IKONOS, Quickbird, Landsat-8, Sentinel-2A and more…

IKONOS

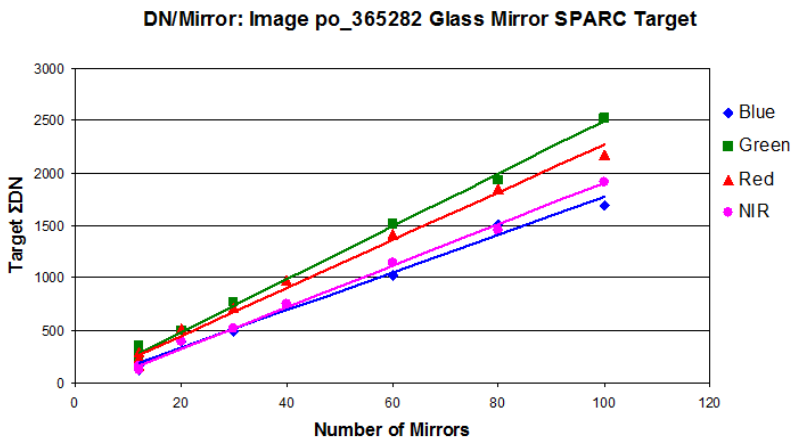


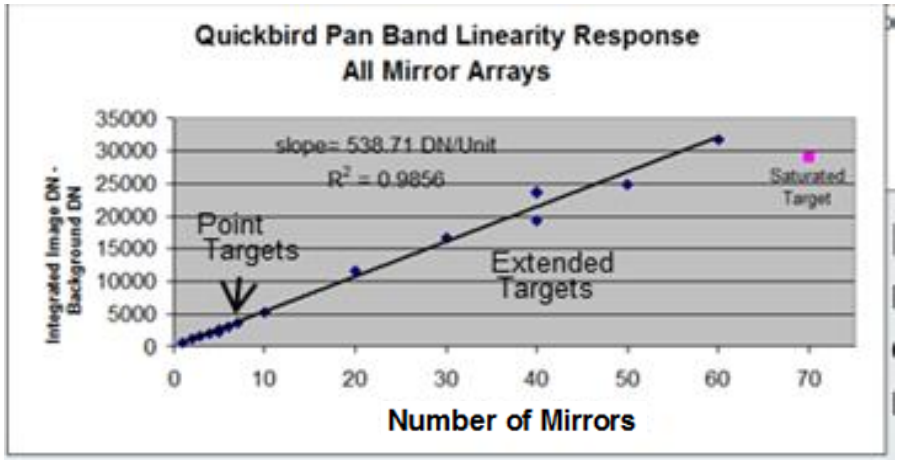
The SPARC method has been applied to small footprint sensors demonstrating its capability to achieve <3% absolute uncertainty using an array of targets with different numbers of mirrors.

Quickbird



"Initial results for the vicarious calibration of Landsat 8 using the specular array radiometric calibration (SPARC) method", Schiller et al, SPIE 2016

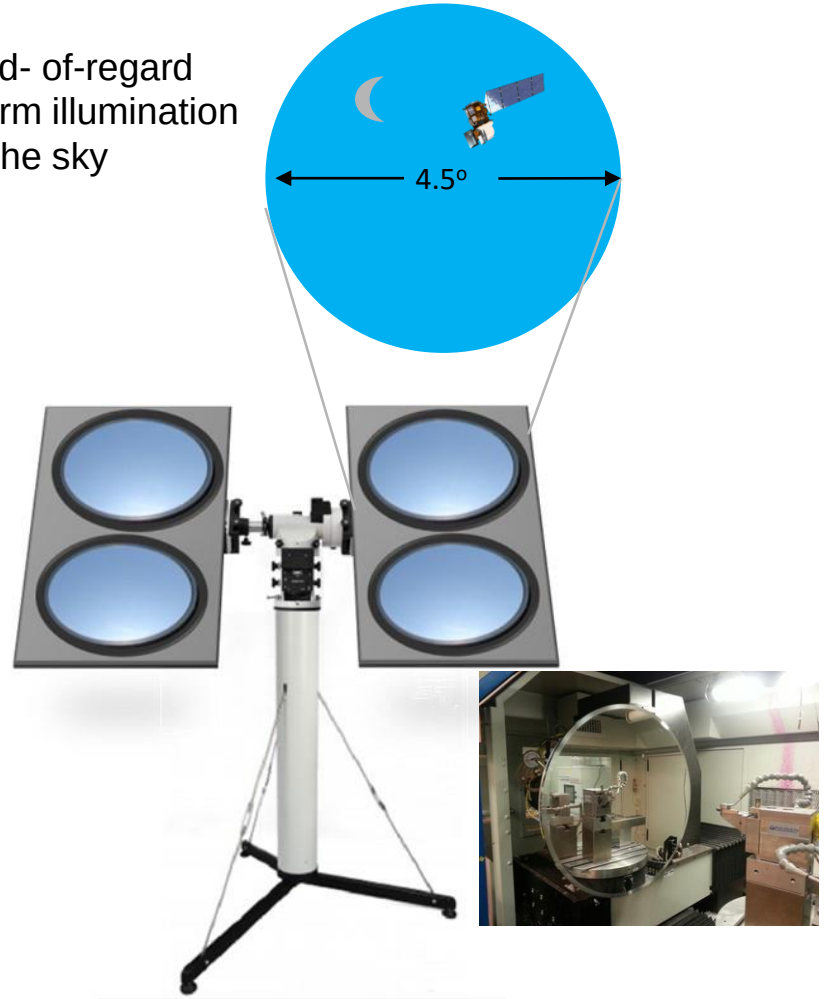




SPARC Target Design For Landsat 8 / Sentinel 2

Because SPARC targets are specular intensity sources and Landsat has a large GSD, the mirror radius of curvature is much larger than used with commercial sensors to produce the same effective radiance.

The reflected field- of-regard produces a uniform illumination intensity across the sky
= 4.5 degrees



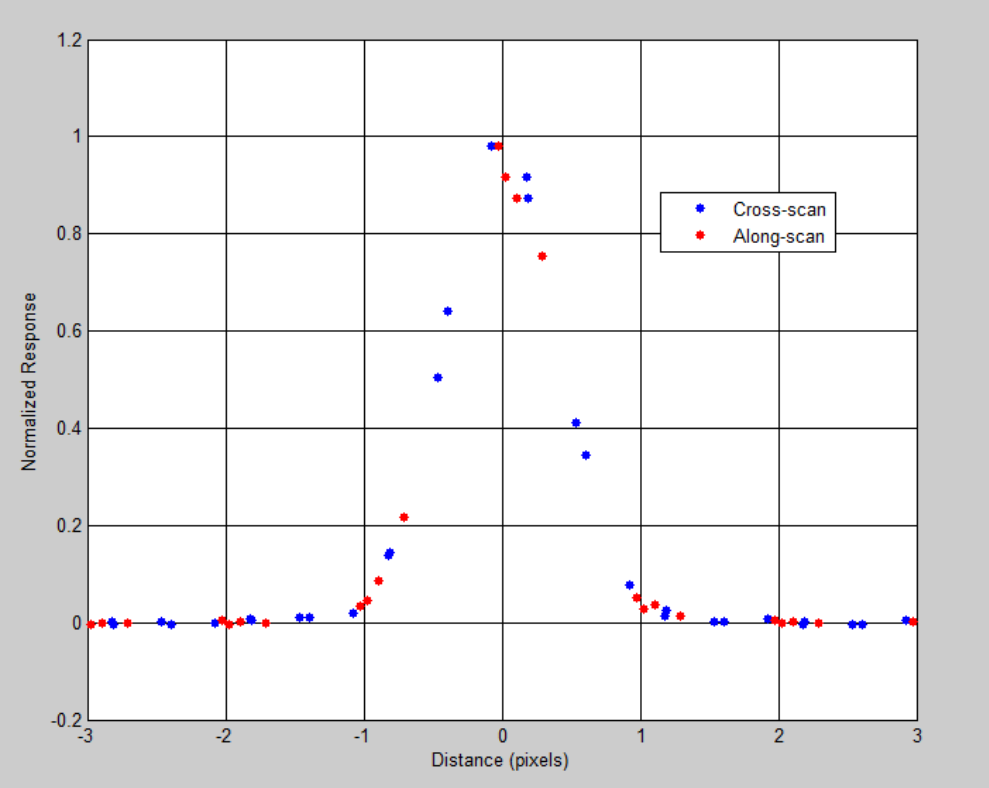
SPARC Calibration Panels:

- Four 18” diameter mirrors on each telescope mount (9 lbs each)
- 10 m Radius of curvature mirrors
- Clear Field-of-Regard (FOR) = 4.5º
- Deployed on a portable iOptron® iEQ45 ProTM alt-az telescope mount.
- Built-in 32-channel Global Positioning System (GPS).
- Payload mirror assembly on each mount is about 50 lbs
- Four deployable panels (each on separate mounts) are used to provide up to 3 calibration radiance levels in a single Landsat image collect.

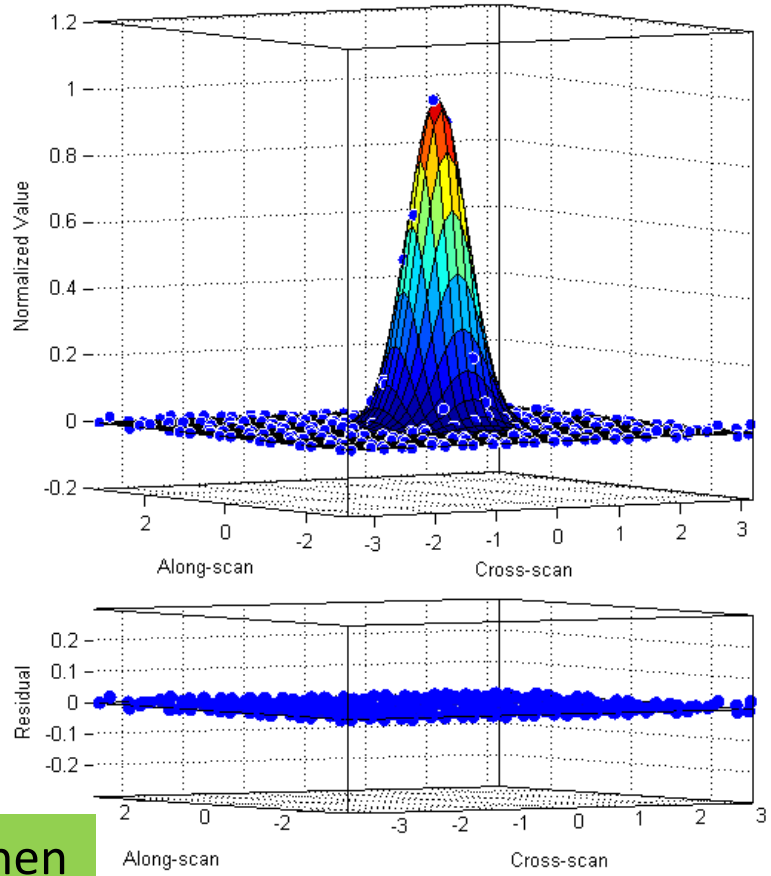
“Initial results for the vicarious calibration of Landsat 8 using the specular array radiometric calibration (SPARC) method”, Schiller et al, SPIE 2016

Sensor System Composite 2D PSF Profile For L8 Pan Band

Cross-scan and along-scan slices through the composite profile center



Composite 2D PSF Profile
Residuals show no outliers



"Initial results for the vicarious calibration of Landsat 8 using the specular array radiometric calibration (SPARC) method", Schiller et al, SPIE 2016

System level PSF shows negligible residuals when modeled as a Gaussian function.

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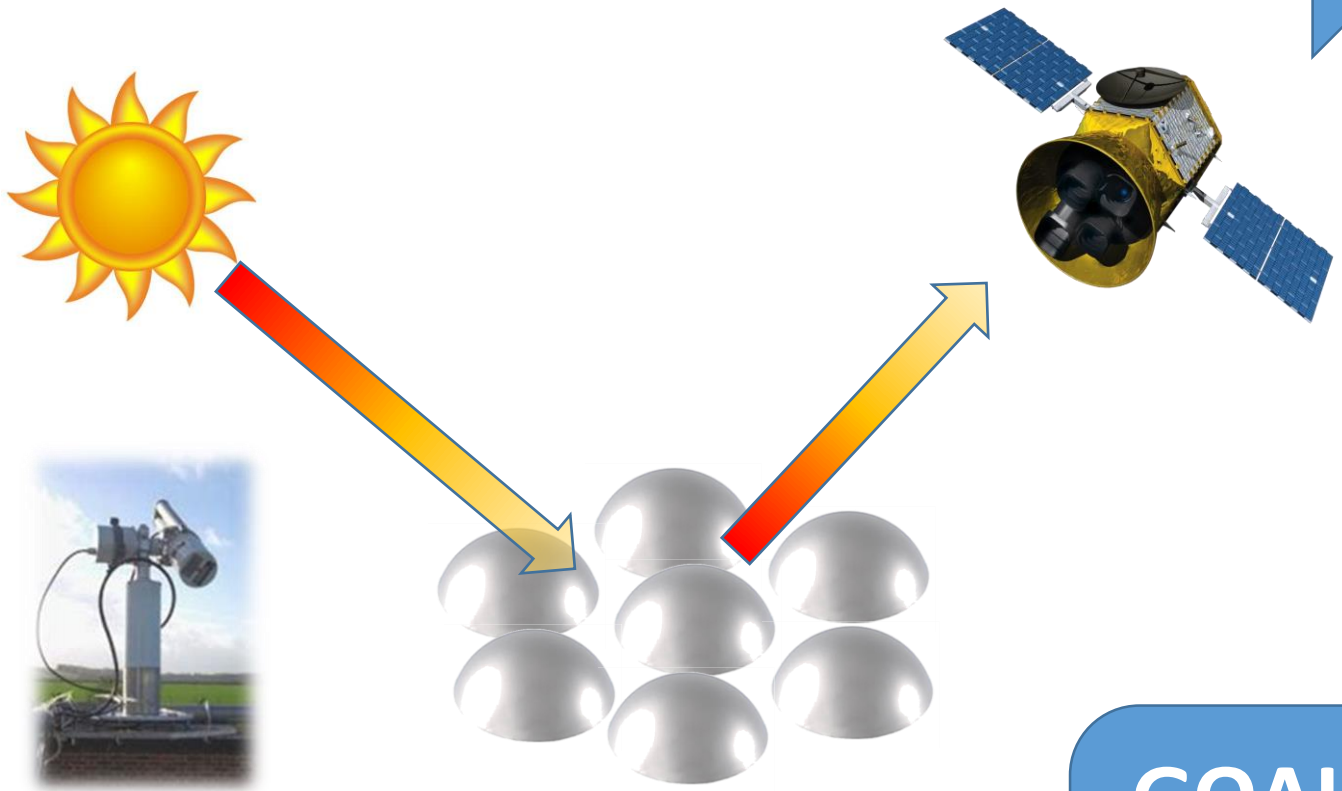
Sentinel 2A 10m GSD Image of SPARC Targets Level 1C (RBG)

- Targets are subpixel, > 1.5 m in size.
- The intensity step size is incremental from 1 to 4 without saturation.
- Targets are visibly affecting pixels up to a 6 x 6 pixel area (processing includes resampling for ortho-rectification).
- Coloring in the wings of the profile indicates that the effects of the resampling are band dependent

- Resampling methods need to be improved so as to use the PSF/MTF information to direct the energy back into the pixel that contains the target.

FLARE = GSD Specific Array (Big Sat, Small Sat, UAV)



Labsphere Instruments at Site Measure Sun Radiance, Irradiance, Weather, etc.

Mirrors direct sun to satellite

- Imager sees sun reflected from mirrors
- Quantitative spectral radiance information communicated to User
- Image quality metric can also be generated

GOAL: Imager is calibrated

Geometric, Spatial and Radiometric

SI-Tracable, Physics Based

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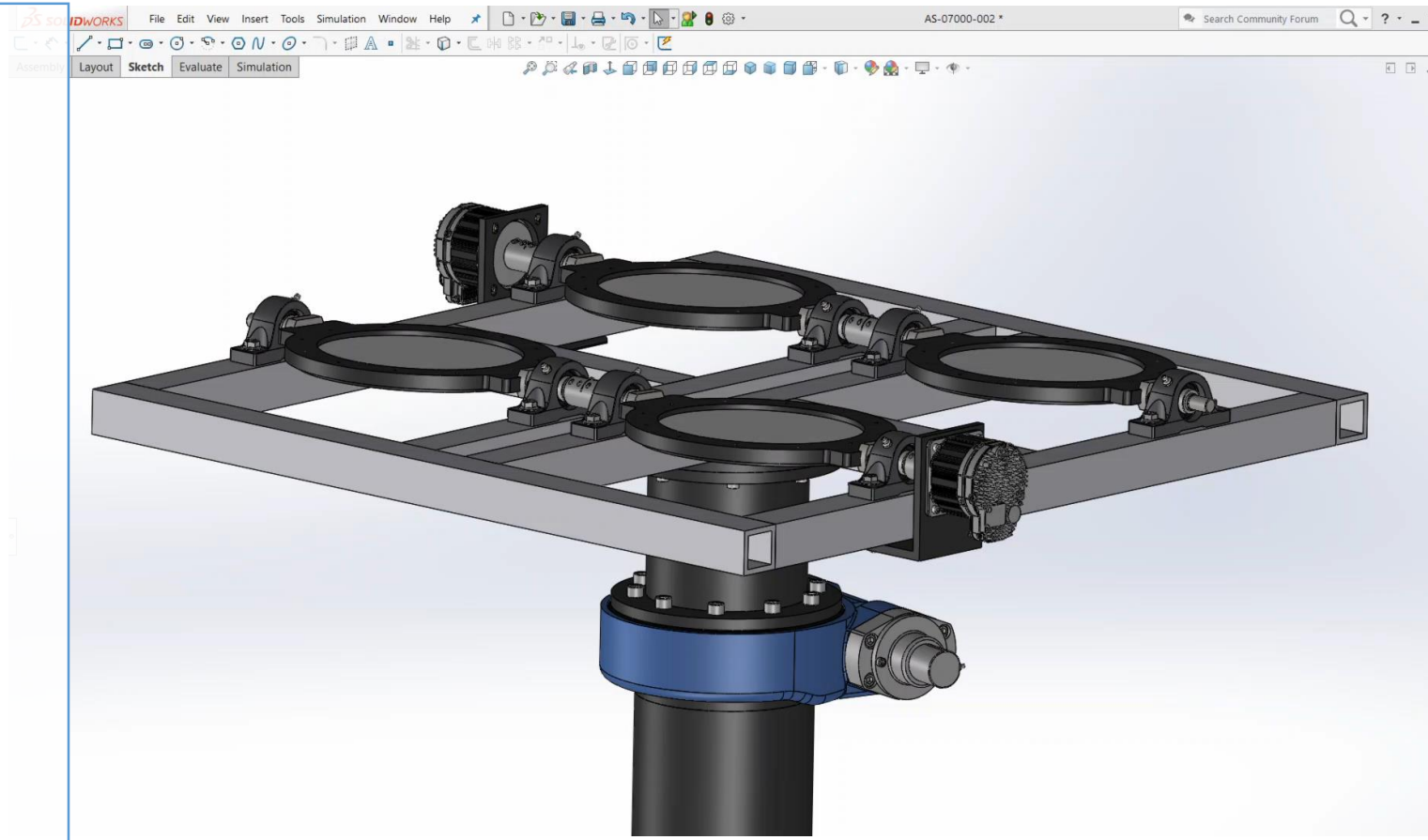
FLARE – Multiple “Bays” to Calibrate Multiple Imagers

Digital and Fully Automated

- Calibration On-Demand – Look is scheduled, mirrors open and target Sun to Satellite
- Precise instrumentation for Radiometric Ground-Truth (atmospheric correction)
- Image data + FLARE ground truth data package = absolute radiometric calibration across all sensor bands with GSD Specific system
- Different bays can have different GSDs and independent tracking (serve multiple imagers)



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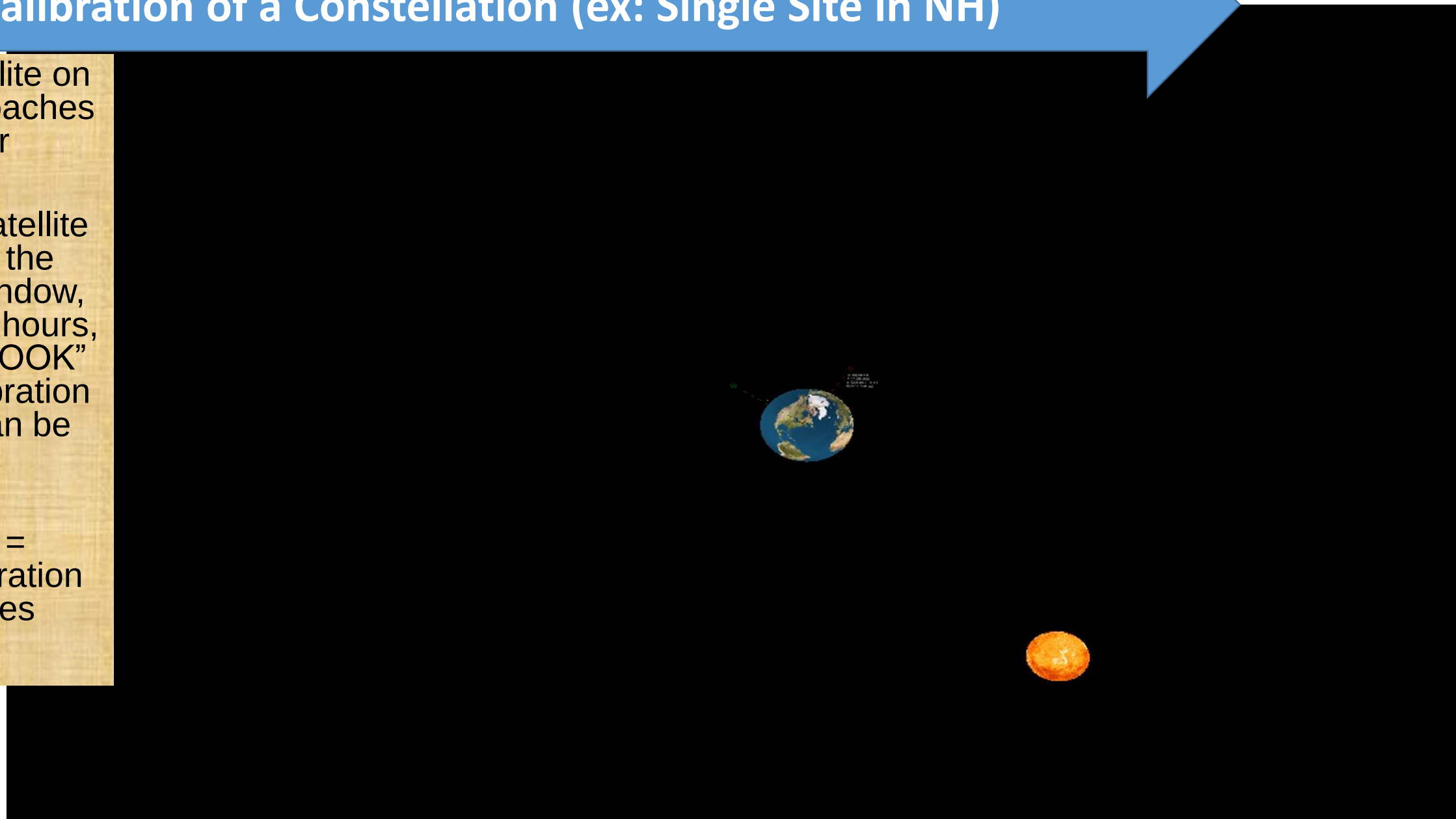
FLARE – Calibration of a Constellation (ex: Single Site in NH)

- Each satellite on orbit approaches the angular window
- As each satellite falls within the angular window, in sunlight hours, it gets a “LOOK” at the calibration site and can be calibrated (GREEN)
- More sites = more calibration opportunities



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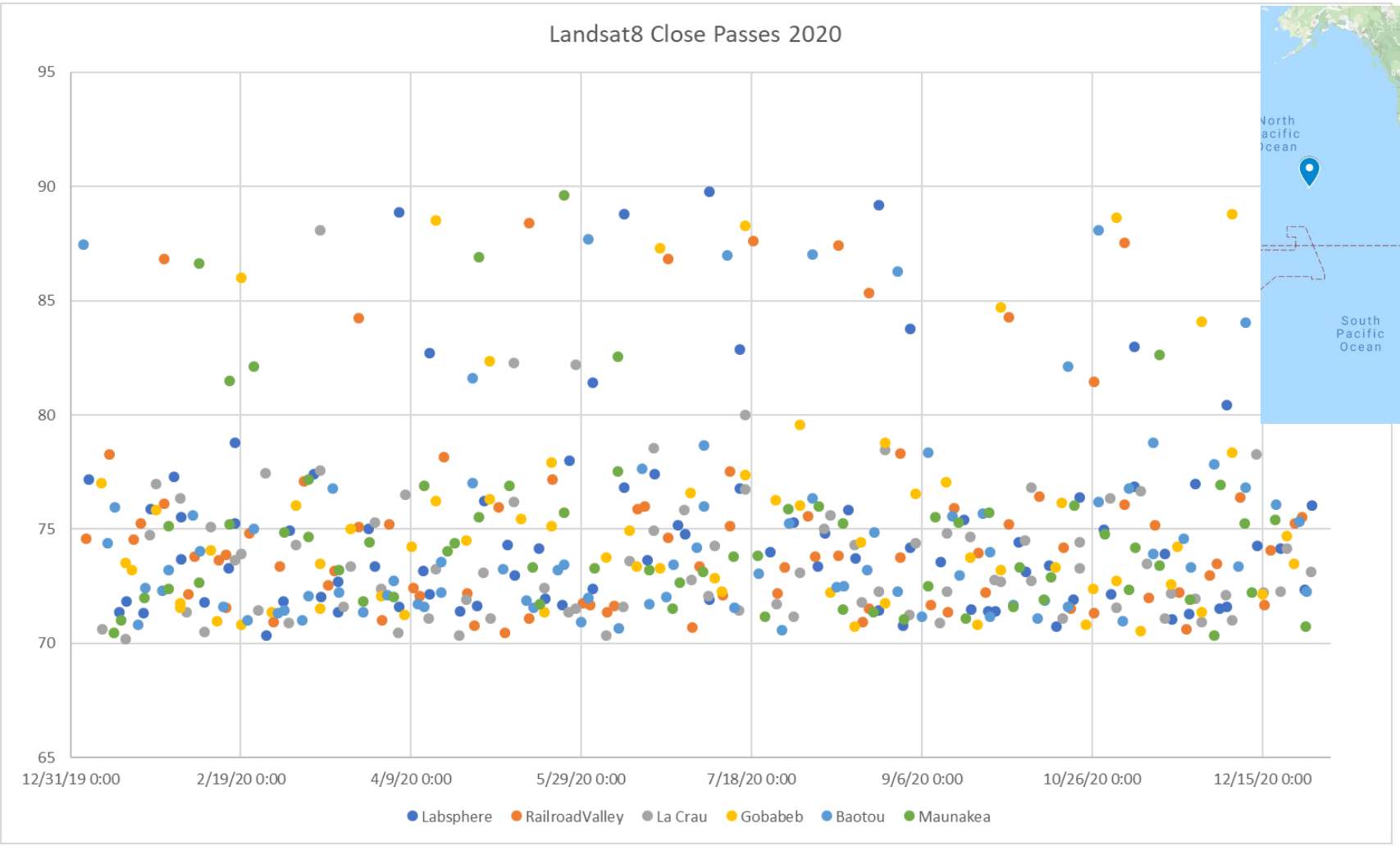
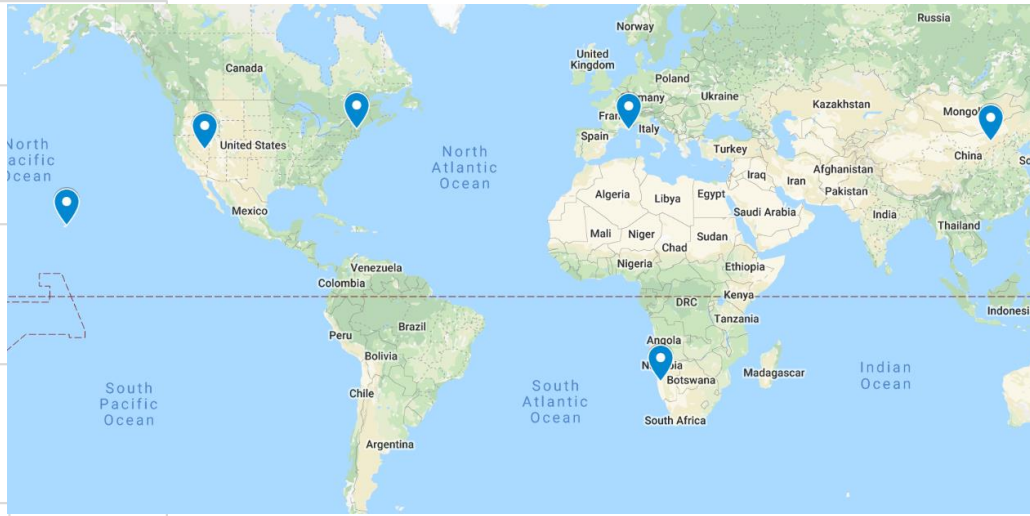
Calibration with Multiple FLARE Sites (Ex: Landsat 8)





Analysis executed with 6 virtual FLARE sites

- **Labsphere Headquarters**
- **5 RADCALNET Sites**

More than 400 “Looks”

- One year at <20º from Nadir during optimal daylight hours

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What is an “Breakthrough” Calibration system?

- Tailored to imagers, FOVs & instruments (GSD, angle indep., & bands)
- Tied to “Big Sat” Uncertainty & Quality Metrics
- Traceably together airborne and high resolution “underfly” data
- Available when and where needed…and as often as needed
- Fractional & controlled cost of conventional calibration methods
- Enables Analysis Ready Data as close as possible to *first image*.

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Atmospheric & Situational problems FLARE can address:

PROBLEMS	FLARE SOLUTION
• Low Uncertainty Calibration	• High Altitude placement of sites (reduced atmosphere)
• Atmospheric Extinction	• Direct reflected path extraction using the Sun/Aeronet
• Partially Cloudy Days	• Relay of sun with mirrors does not require clear sky
• Variable angle atmospheric passes	• FLARE tracks Sat & Sat tracks back (angular path length)
• Mobility	• Deployed where & when needed

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Spatial & Spectral problems FLARE can address:

PROBLEMS	FLARE SOLUTION
• Unconventional Orbits	• Can be placed anywhere on the planet
• BRDF of targets	• FLARE tracks sat / Sat points back at angles & FLARE
• Large footprint targets	• FLARE site size driven by sub-pixel GSD
• Polarization	• Mirrors or Bays with different polarizations
• Spectral Signatures	• Mirrors w/different coating bands = signature targets or cross-band calibrations. MWIR also possible

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Imaging & Inter-calibration problems FLARE can address:

PROBLEMS	FLARE SOLUTION
• Ocean leaving radiance	• Scalable sun target on dark ocean = high dynamic range
• PSF / MTF	• Single targets, lines or patterned layouts
• Under-Fly and Over-Fly with different instruments.	• Point at multiple imagers and/or GSDs at same time (SNO not required)
• GEO & LEO intercalibration	• Works for both. FLARE can be a constant multi-point sun radiometer for GEO.
• AM/PM & Night Calibration	• Any time of day. Lunar radiance looks

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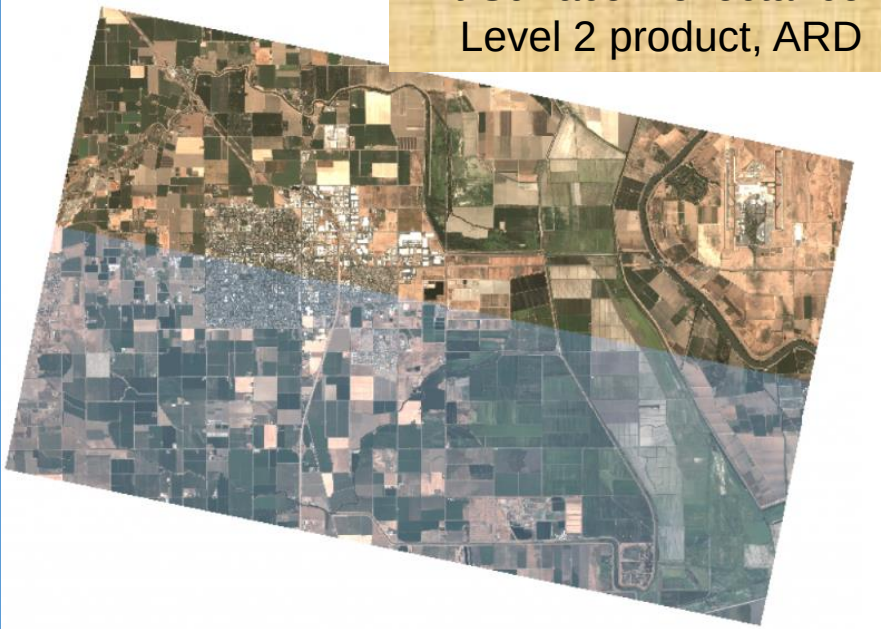
FLARE – Enabling Analysis Ready Data (ARD)

Required Components of ARD

- Radiometry – Calibration & Atmosphere Correction
- Geometry – Register Image to the Planet
- Metadata – Filter out "Good Data"
  - Bad data identification – cloud, no data, or instrument
- Interoperability – Sensor-to-Sensor Normalization
  - FLARE allows everyone to use the same method
- Framing – Reduce image to what customer wants

At-Surface Reflectance
Level 2 product, ARD



Top-of-Atmosphere Reflectance
Level 1 product

The commercial data provider is now expected to provide ARD products

Source: https://www.planet.com/pulse/planets-framework-for-analysis-ready-data

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FLARE – Enabling Image & Data Harmonization

Harmonizing Data Across Sensors in a Fleet

- 100's in a constellation

Harmonizing Across Industry

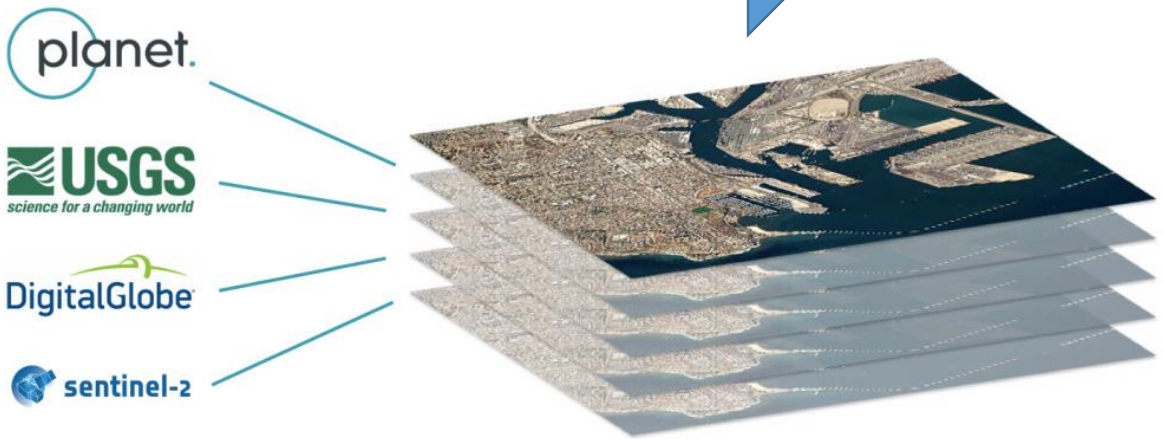
- Big sat/small sat/UAV

Harmonizing Across Technology

- Satellite and Airborne

Harmonizing Data with Software

- Extracting more information/value



https://www.planet.com/pulse/satellite-interoperability-workshop/

https://www.colorado.edu/earthlab/science/data-harmonization

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Change the Paradigm:
FLARE is Pay Per Use & On-Demand **SERVICE**

Calibration Today is:	**Calibration with FLARE:**
• Maintain Calibration Team ($$$s)	• Look & Cost available on demand.
• Maintain Image Processing Team (IPT)	• Reduce IPT hours and costs for ARD
• There is no ARD Standard…yet…	• Demonstrate data value to your customer
• Low frequency of valid opportunities	• High Frequency based on need & quality
• Human intervention	• Fully Automated and Cloud-based Service

Control the cost, timing and value of calibration to your system

WHEN?

- We are funded to start the initial sites and are looking for partners and users.
  - We can run demonstrations for specific tasks.

- Operations will be available for looks in early 2020

- Seeking industry & agency support for expansion and adoption.

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FLARE: The new tool in the Cal/Val Toolkit

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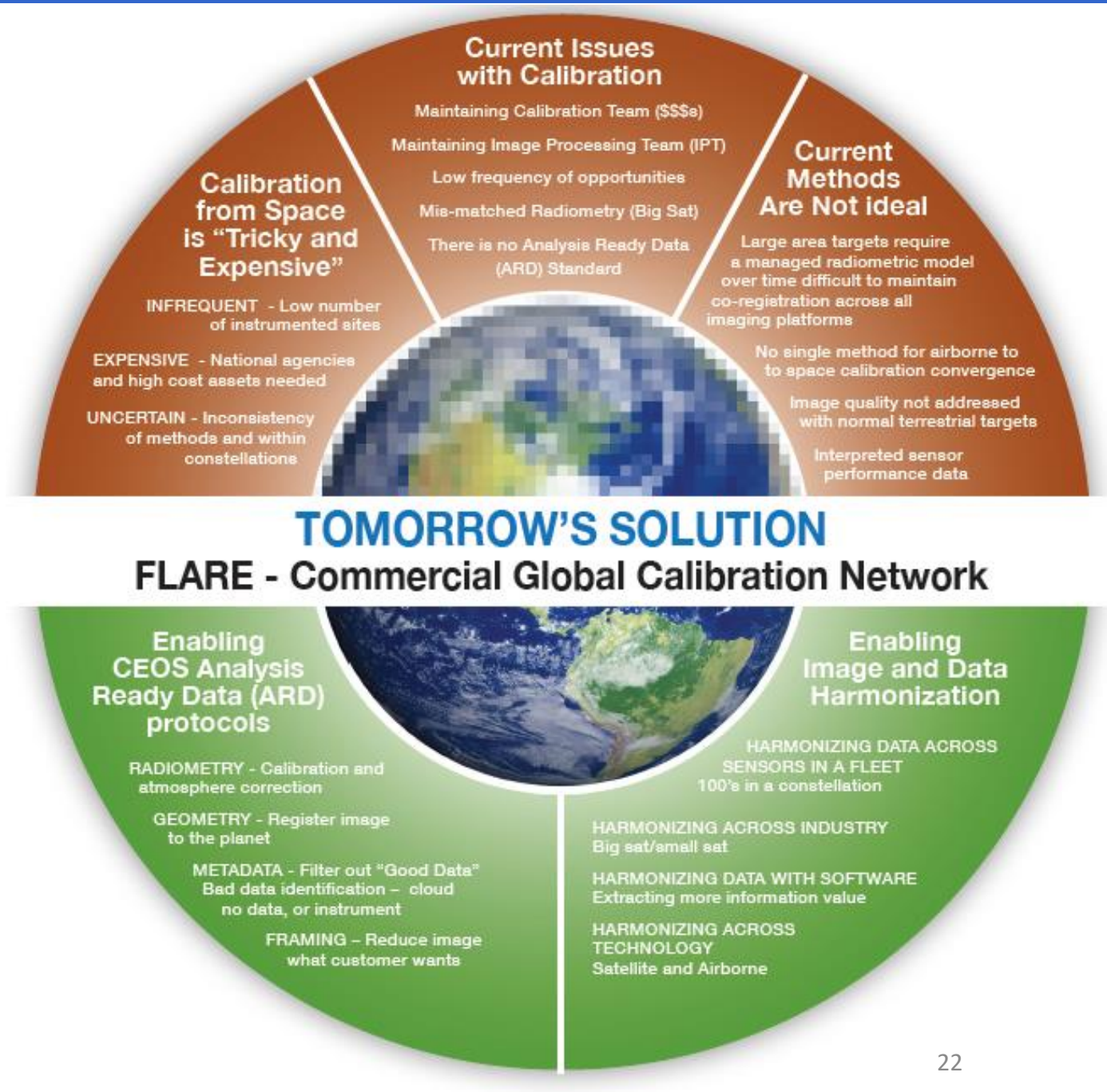
Test as you Fly…

Fly as you Test…

TEST WHILE FLYING



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