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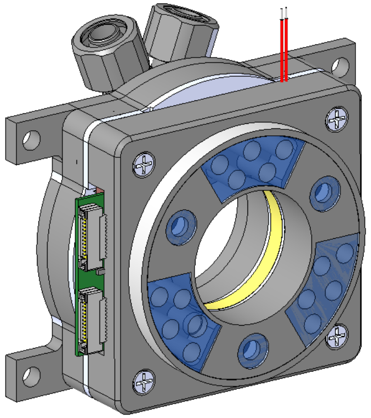

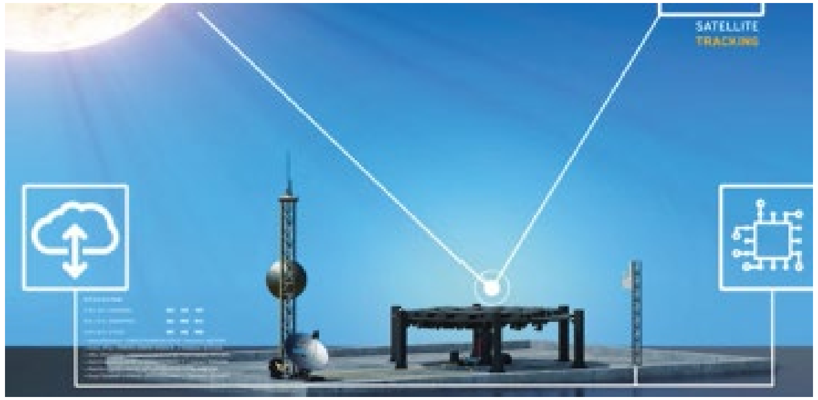

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Improved Radiometric calibration of Imaging Systems (IRIS) for next generation small satellite imagers

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  - Project Manager: Mandy Gadia
  - Chief Engineer: John Schlaerth
  - Calibration Source: Dr. Brandon Russell (Labsphere), Alexandria Rodriguez
  - Test Assembly Lead: Eric Griffin
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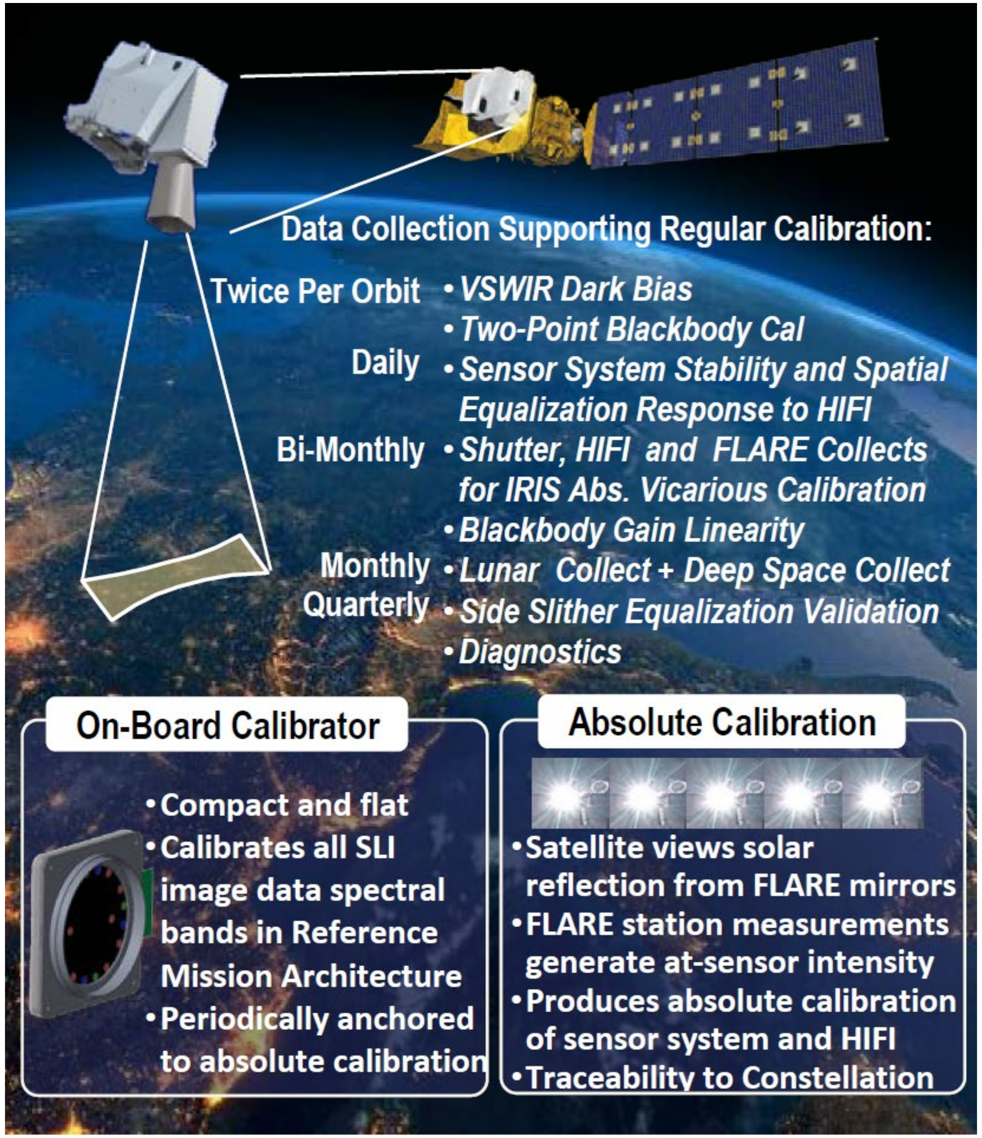
Improved Radiometric calibration of Imaging Systems (IRIS)

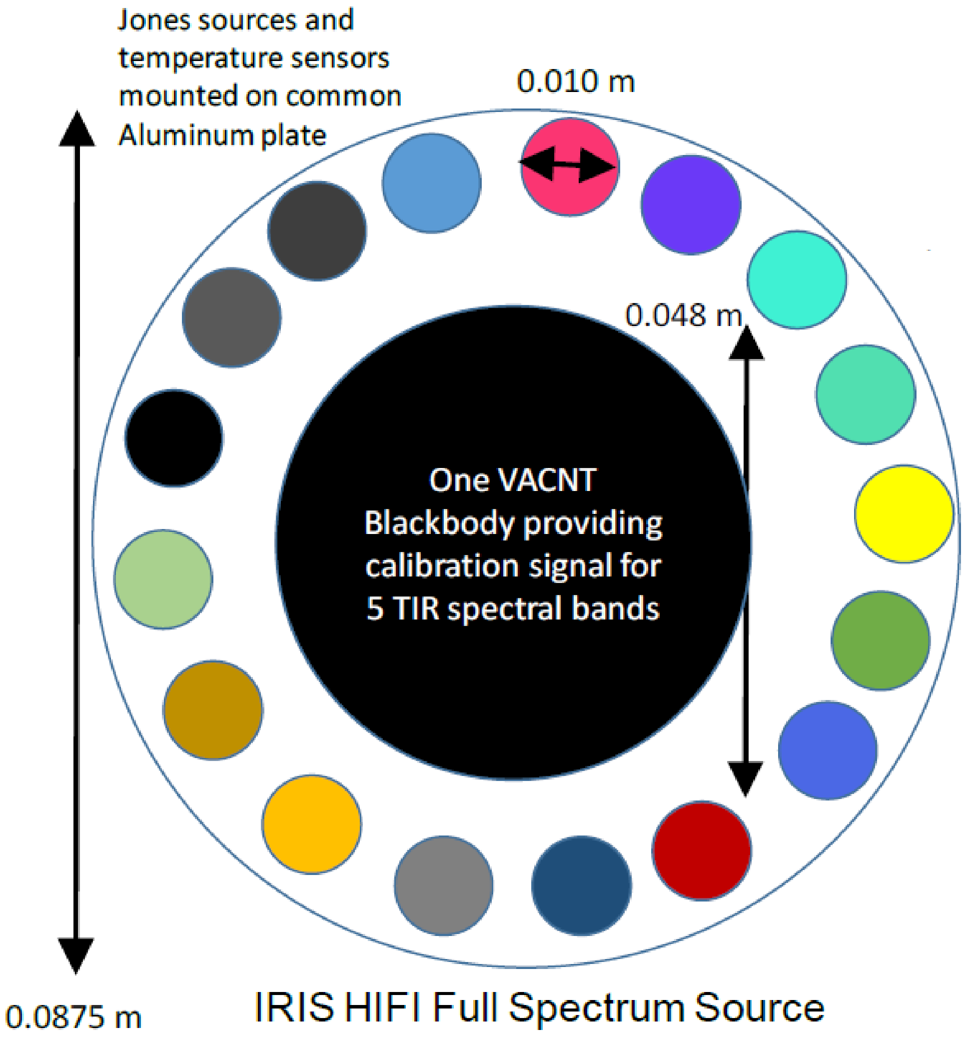
- **SLI-T 2019 project that addresses key SLI program objectives by developing and demonstrating technology to reduce risk, cost, size, volume, mass, and development time for next generation SLI instruments, while meeting or exceeding current land imaging program capabilities as described by the SLI-T Reference Mission Architecture 2019 (RMA 2019 or RMA)**
- **IRIS addresses these SLI objectives in two different, but complementary ways**
  – Designing and building an ultra-compact, full-RMA-spectrum (0.4μm to 2.3μm and 6μm to 13μm) end-to-end calibration source and testing this source with the existing NASA ESTO SLI-T 2015 ATLIS-P free form reflective triplet (RT) telescope and VNIR FPA along with SWIR and TIR FPAs acquired in IRIS
  – Calibrating lamp assemblies onboard Landsat 8 and 9 Operational Land Imager (OLI) to absolute radiometric standards using Raytheon's patented vicarious SPARC method commercialized by Labsphere into the FLARE network

IRIS builds on the success of the SLI-T 2015 ATLIS-P project to ***demonstrate a functionally complete full-spectrum prototype land imager with much reduced size and mass*** *by verifying calibration performance across the full RMA spectral range and full imager field of view by comparison with well-understood NIST traceable full aperture laboratory sources*

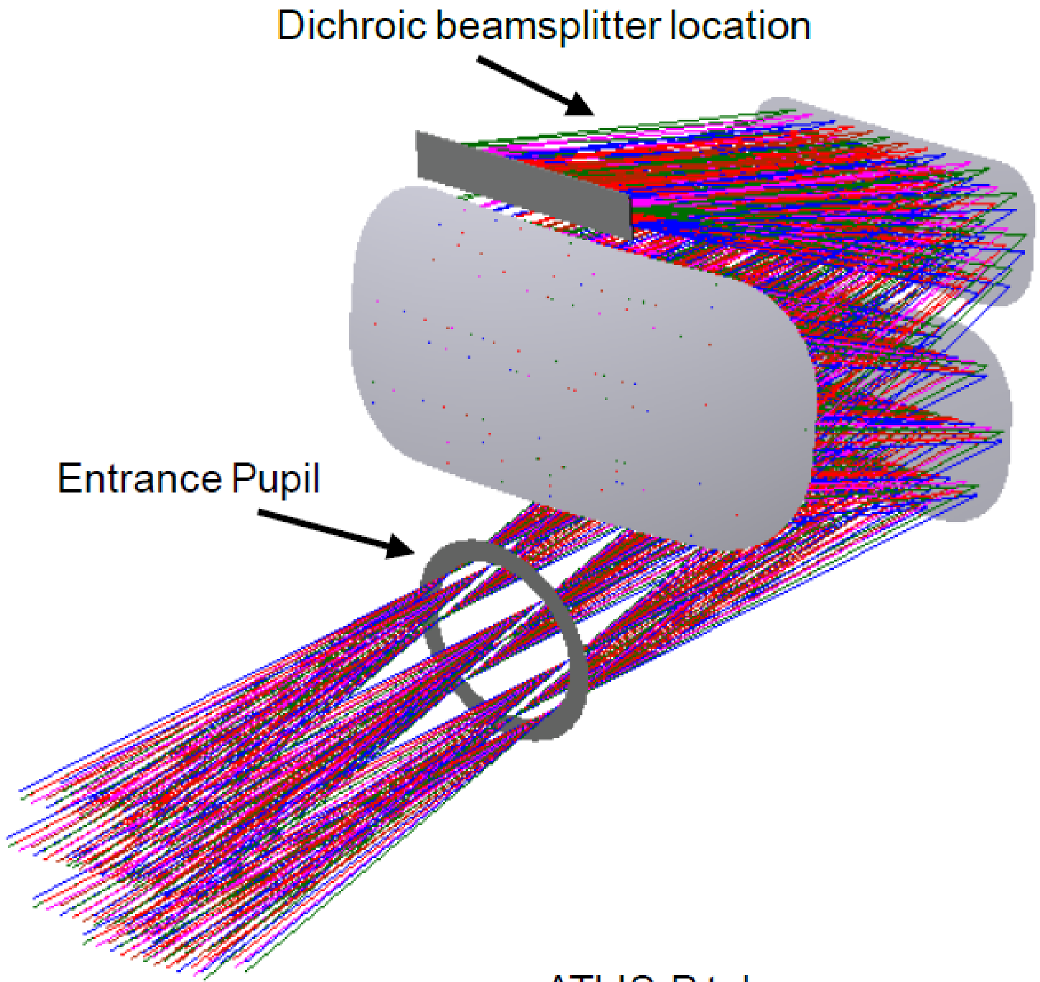
IRIS is developing a compact, full spectrum, end-to-end onboard source that can be calibrated in radiance by repeated observations of high altitude mirrors reflecting the sun toward the imager, as demonstrated in proof-of-concept for lamps onboard OLI



IRIS full spectrum Jones Source (notional sketch)



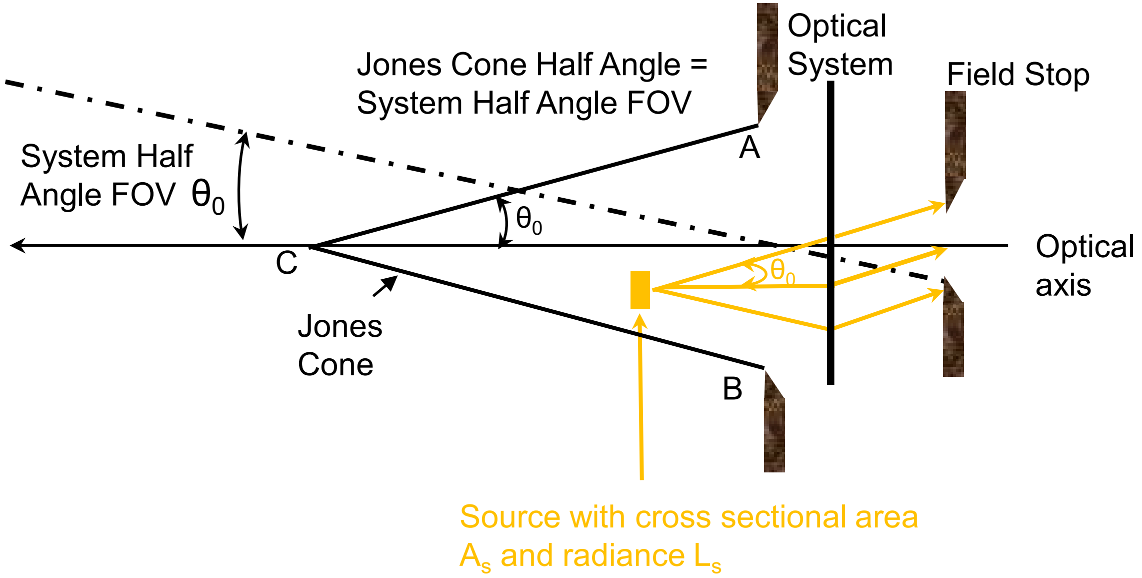
IRIS HIFI Full Spectrum Source



ATLIS-P telescope

Jones source placed near entrance pupil illuminates the full focal plane and calibrates the full optical path

- IRIS HIFI compact calibrator comprises a collection of 19 small sources (18 LEDs and 1 blackbody) on a common plate near the entrance pupil - each source uniformly irradiates an area in the imager focal plane
- Jones sources, named in honor of R. Clark Jones of Polaroid Corporation who first described this calibration method, enable an exceptionally compact full spectrum source well suited for small, high-performance space-based imagers
- Panel articulates into and out of the entrance pupil of the imager and serves as a light tight shutter when the sources are not active
- Jones source legacy includes three incandescent bulbs that flew along with a full aperture blackbody source onboard SABER (10 bands across 1-17 µm spectral range) as part of the NASA TIMED mission launched in 2001 - Tansock et al. reported agreement of 1.1% or better between Jones sources and full aperture source, except for one unstable bulb

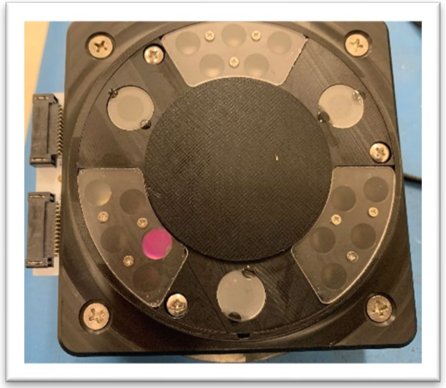


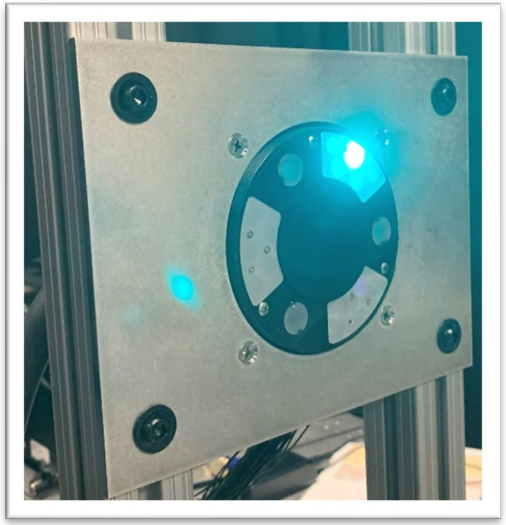
For imager focused at infinity, radiation in Watts (Φ) on an individual detector of area A_d with Jones source radiance L_s (W m^{-2} sr^{-1}) and solid angle Ω defined by source area divided by the focal length squared is given by $\mathbf{\Phi = L_s A_d \Omega}$

Detector responsivity calibration follows by dividing the signal digital number for a specific detector by the source radiation on the detector, following correction for background radiation from inactive parts of the calibrator

Jones source characteristics for RMA spectral bands

Requirements						Devices Used					
Band	CWL	BW	Low	High	In Band Radiant Intensity Specification	Power	CWL	BW	Low	High	Measured Average In-band Intensity over +/-10°
	nm	nm	nm	nm	mW/sr	mW	nm	nm	nm	nm	mw/sr
1a	410	20	400	420	16.3	710	405	14	398	412	926.4
1	443	20	433	453	18.6	480	450	20	440	460	168.4
2	490	65	457.5	522.5	60	240	490	26	477	503	830.9
3	560	35	542.5	577.5	32.3	280	450	600	400	1000	34.2
4a	620	20	610	630	16.3	190	620	15	613	628	194.7
4	665	30	650	680	23.4	250	660	17	652	669	478.6
5	705	15	697.5	712.5	8.1	250	700	17	692	709	331.1
6	740	15	732.5	747.5	7.4	320	740	22	729	751	524.3
7	783	20	773	793	9.7	500	780	24	768	792	316.2
8	842	115	784.5	899.5	85.4	1400	850	37	832	869	1201.6
8a	865	20	855	875	7.6	440	870	50	845	895	159.2
9	945	20	935	955	1.3	1300	940	47	917	964	212.5
8b	1035	20	1025	1045	0.21	350	1050	50	1025	1075	331.9
10	1375	30	1360	1390	0.65	17	1450	90	1405	1495	12.4
11	1610	90	1565	1655	1.3	16	1650	120	1590	1710	24.9
12a	2040	30	2025	2055	0.44	15	2040	80	2000	2080	8.4
12b	2100	40	2080	2120	0.52	15	2100	80	2060	2140	7.0
12c	2210	40	2190	2230	0.44	15	2210	80	2170	2250	10.5



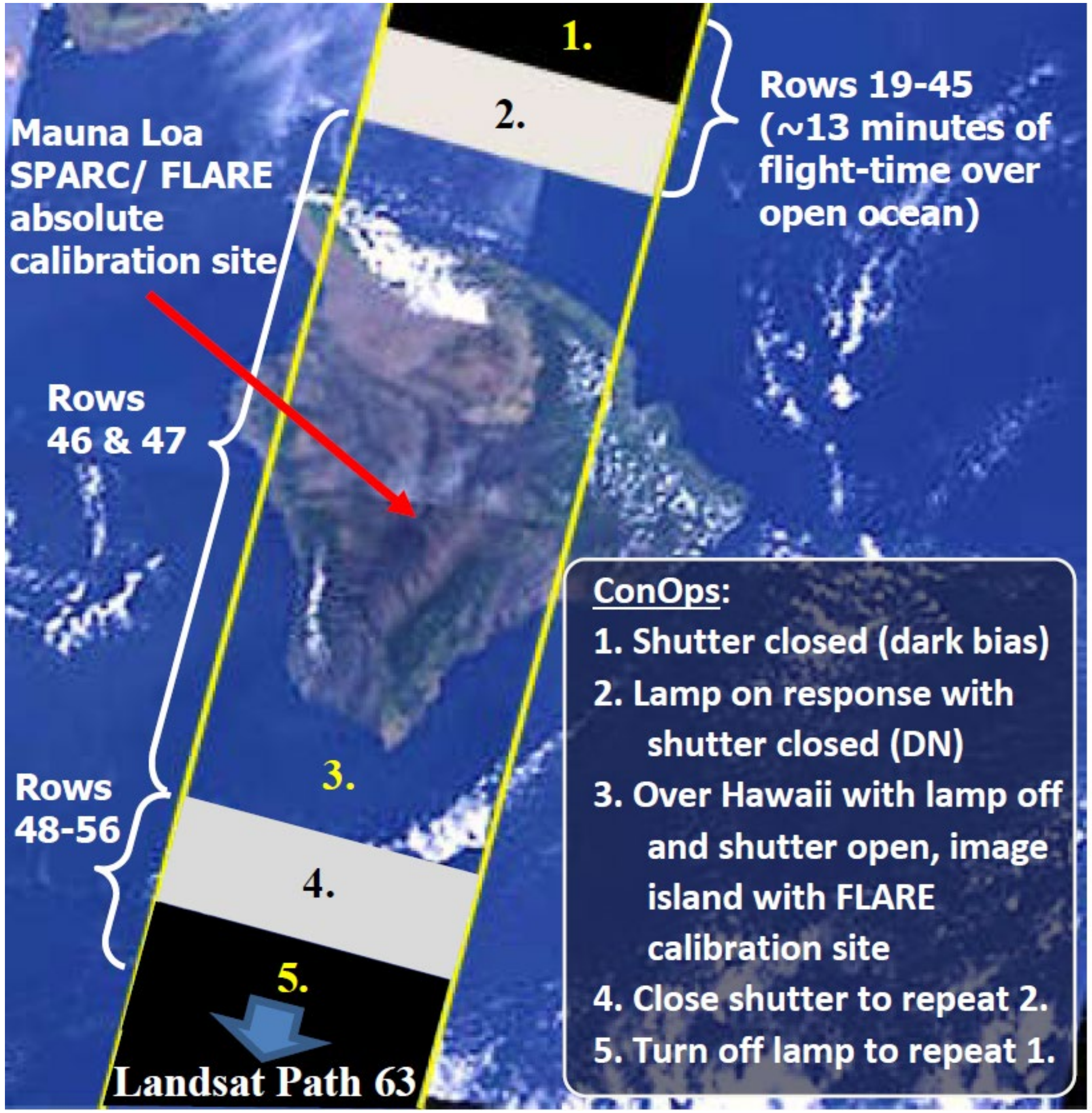


IRIS breadboard sources exceed requirements in all spectral bands – parts availability issues created challenges at 560 nm that were overcome successfully

IRIS-V concept of operation for Landsat 8/9

IRIS-Vicarious (IRIS-V) demonstrates the feasibility of tracking changes in on-board calibration sources by repeated observations of the SPARC/FLARE site on Mauna Loa

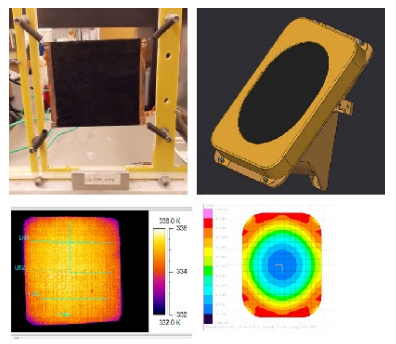
The high elevation site (3402m) will significantly reduce atmospheric effects providing accurate and routine radiometric calibration events based on using a FLARE reference source

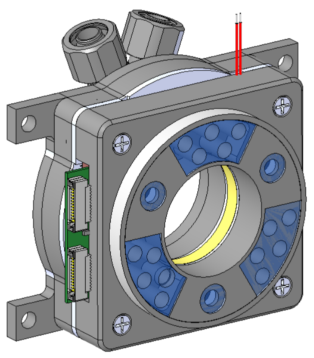


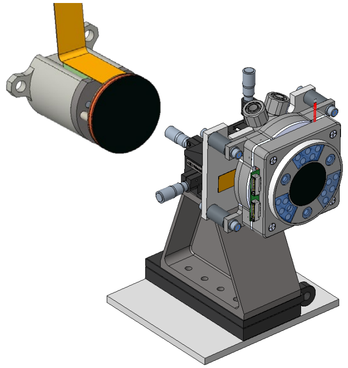
SPARC targets imaged by L8 OLI in 2016 demonstrated capability of this vicarious calibration technique for radiometric and image quality characterization

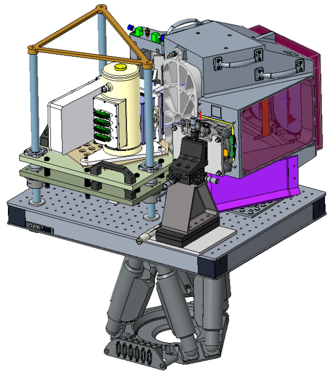
The study showed that small reproducible vicarious reference targets could be deployed as portable point sources for vicarious calibration at almost any location

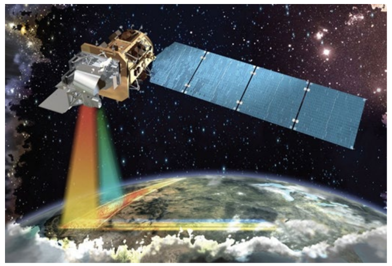
Spiral calibration source development yields more mature product for future technology insertion – IRIS now at Phase 3









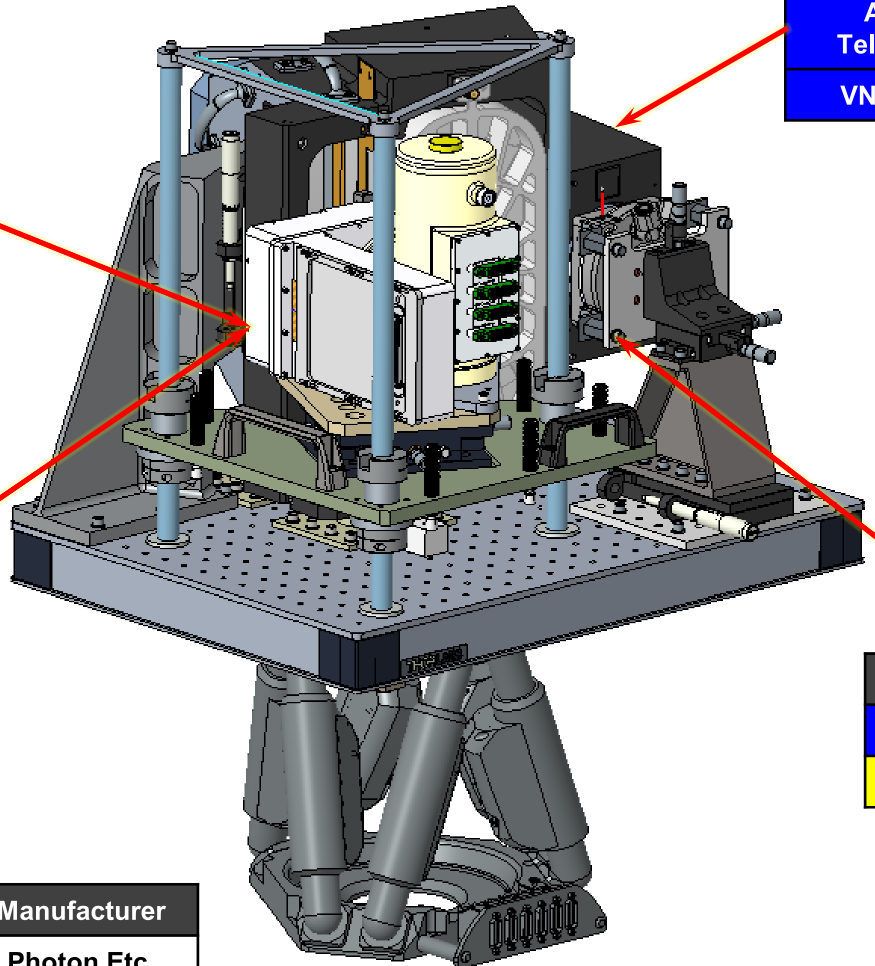


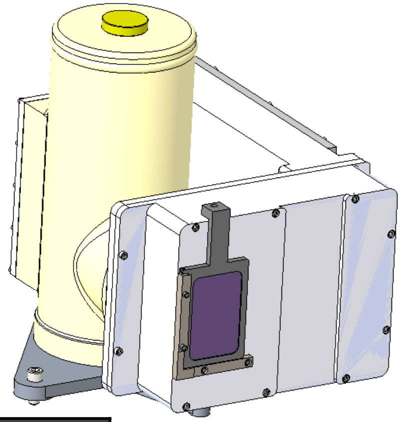
Blackbody Design & Demonstration	Breadboard Design & Procurement	Breadboard Characterization & Brassboard Design	Brassboard MAI&T	Flight Design & Qualification
Phase 0	**Phase 1**	**Phase 2**	**Phase 3**	**Phase 4**
• Demonstrate thermal uniformity and responsivity • Demonstrate active temperature control • Demonstrate high (>0.995) emittance	✓ Generate supplier statement of work and specification ✓ Procure VSWIR sources ✓ Define test setup and equipment	✓ Receive and test breadboard VSWIR sources • Design, analyze, and procure brassboard and thermal infrared sources	• Demonstrate and characterize the brassboard design with ATLIS-P telescope • Demonstrate and characterize mechanical functionality	• Finalize Flight design and qualify thru full environmental testing including radiation
Metrics	***Metrics***	***Metrics***	***Metrics***	***Metrics***
• Design for thermal infrared blackbody emitter • Measurements that anchor thermal model and optical parameters	✓ Generate SSOW and Spec for calibrator procurement ✓ Procure FPA, Dewar, and Electronics ✓ Finalize test equipment list and procure	• Integrate VSWIR calibrator with ATLIS-P telescope • Characterize breadboard VSWIR calibrator • Identify space qualified sources	• Stable, uniform illumination of FPAs across FOV • Demonstrated compliance with 2019 RMA • Exit TRL 5+	• Calibrator passes environmental qualification • Calibrator successfully tested on Engineering Development Unit

Test Assembly integrates system elements into a prototype land imager with full-spectrum, end-to-end calibration capability to enable technology validation and characterization

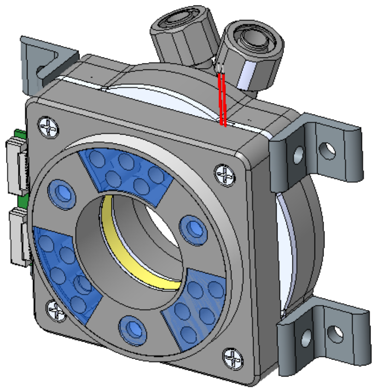
Design in Work
On PO / In Build
Received

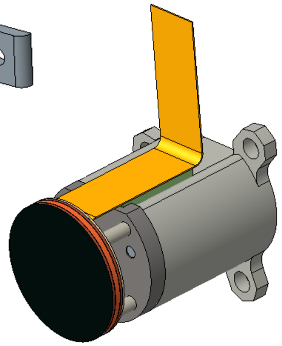
Item	Manufacturer
ATLIS Telescope	RTX
VNIR FPA	RVS



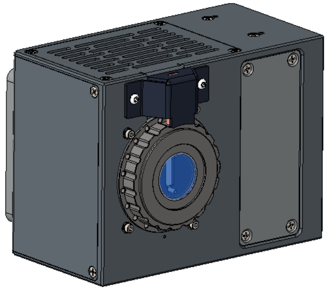


Item	Manufacturer
SB 586 IR FPA	RVS
FPA Filter	RVS
Dewar	Senseeker
FPA Electronics	Senseeker





Item	Manufacturer
VSWIR Source	Labsphere
BB Source	RTX



Item	Manufacturer
SWIR Camera	Photon Etc.
TIR Camera	INO

Key IRIS technologies benefit SLI and other small satellite imagers

Proposed Technology	Function and IRIS Characteristic	Related SLI Objective	Benefits to SLI
WFOV free form RT prototype land imager	Collect upwelling broadband radiance from the Earth and bring it to a focus with minimal distortion and convert irradiance at detector into digital electronic signals that can be interpreted within context of RMA 2019 requirements	Extend ATLIS spectral range and functionality by integrating existing prototype imager with SWIR and TIR FPAs and ultra-compact Jones calibration source and characterize radiometric calibration performance at different FOV points by comparison with NIST traceable full aperture calibration sources	WFOV free form RT provides swath width needed to meet SLI spatial and temporal coverage; collection area with high sensitivity, high image quality; low distortion across WFOV with an instrument much smaller than previous land imagers; IRIS extends demonstrated capability to absolute radiometric calibration across full spectral range; analysis shows ATLIS architecture scalable to full spectrum and disaggregated SLI architectures
In-flight absolute solar radiometric calibration of onboard lamp and other VSWIR source assemblies and in-flight image quality validation	Provide in-flight absolute radiometric calibration and sensor image quality validation achieved at a high level of repeatability and accuracy by imaging ground-based arrays of convex mirrors reflecting sunlight	Image the Labsphere FLARE beta site on Mauna Loa using OLI instruments onboard L8 and L9 (when available) nearly simultaneously with active onboard calibration lamp measurements to enable the first direct in-flight absolute solar radiometric calibration of an onboard lamp assembly	Maintain absolute radiometric calibration of onboard VSWIR source meeting or exceeding requirements independent of an onboard solar diffuser, over full mission lifetime, along with routine validation of image quality
Ultra-compact Jones Calibration Source	Provide stable known radiance source across the full SLI spectral range and full ATLIS FOV to enable onboard calibration with a thin source illuminating all focal planes uniformly	Characterize IRIS laboratory prototype calibration performance across the full SLI spectral range with multiple FPAs; verify performance by comparison with full aperture NIST traceable sources	Provides compact, low mass source of radiance across full SLI spectral range to enable onboard characterization of gain, offset and nonlinearities needed for full spectrum or disaggregated SLI architectures

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Project status

- VNIR-only and VSWIR breadboard sources received from Labsphere are being characterized at Raytheon
  - Work continues at Labsphere on the brassboard source, with delivery expected in September
- Test Assembly for integrating the ATLIS-P telescope with cal sources, the ATLIS-P Si:PIN VNIR FPA and cooled HgCdTe FPAs to extend spectral coverage to cover all SLI-T RMA 2019 spectral bands is finished
- All focal plane assemblies have been delivered
- Labsphere continues to move forward with deployment of a FLARE vicarious calibration node at the Mauna Loa Observatory delayed by the recent eruption – current expectation is FLARE site operation in 2024
- Initial IRIS-V data processed for L8 OLI collections of the Mauna Loa calibration site using a NASA-owned SPARC test set – results demonstrate concept feasibility

Summary

- IRIS technology reduces risk, cost, size, mass, and development time for next generation small satellite instruments by simplifying onboard calibration systems – compact, full-spectrum source reduces onboard source size by ~90%
- IRIS benefits other space-based imaging systems by advancing enabling technology to flight qualification threshold
- IRIS-V involves in-flight absolute solar radiometric calibration of L8/L9 OLI onboard lamp assemblies based on imaging a commercial SPARC site on Mauna Loa developed by Labsphere - establishes process for maintaining IRIS absolute calibration during extended (10+ year) flight operation
- Progress has been slower than originally planned due to COVID-19 related staffing challenges, supply chain delays and a volcanic eruption, but we continue to progress toward a completely characterized full-spectrum compact calibration source