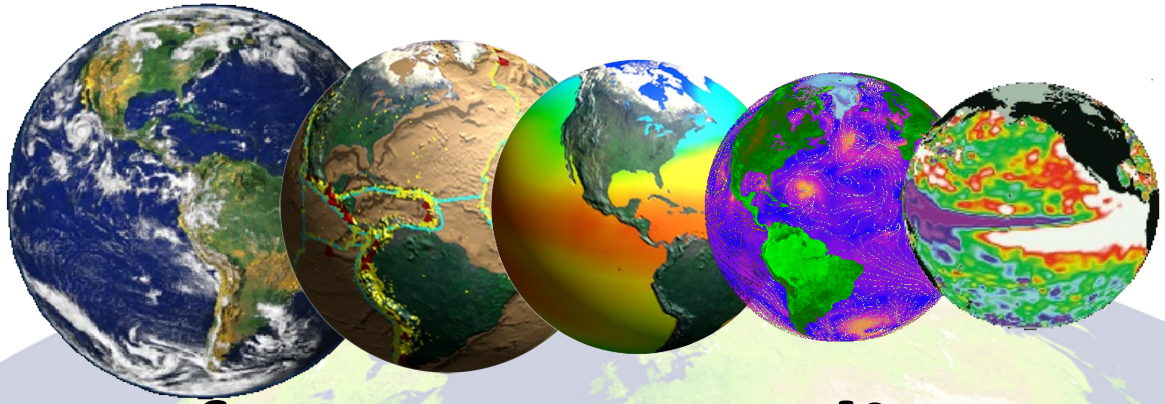
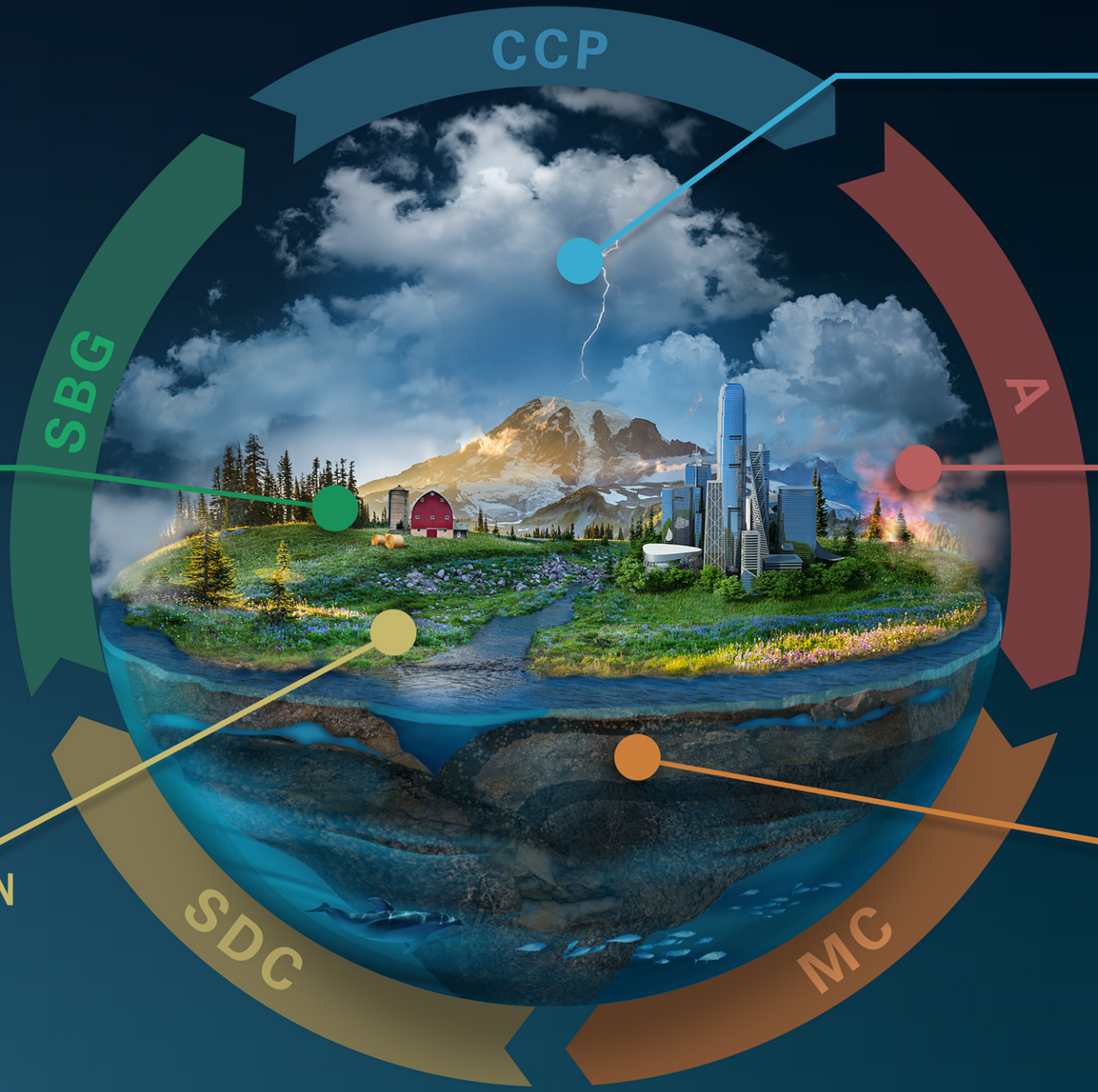


Overview of NASA Sun-Climate Missions and Research Projects

David B. Considine
NASA Headquarters
May 17, 2022

EARTH SYSTEM OBSERVATORY

INTERCONNECTED CORE MISSIONS



CLOUDS, CONVECTION AND PRECIPITATION

Water and Energy in the Atmosphere

AEROSOLS

Particles in the Atmosphere

MASS CHANGE

Large-scale Mass Redistribution

SURFACE DEFORMATION AND CHANGE

Earth Surface Dynamics

SURFACE BIOLOGY AND GEOLOGY

Earth Surface & Ecosystems

Current and Planned NASA Solar Irradiance Missions and Studies

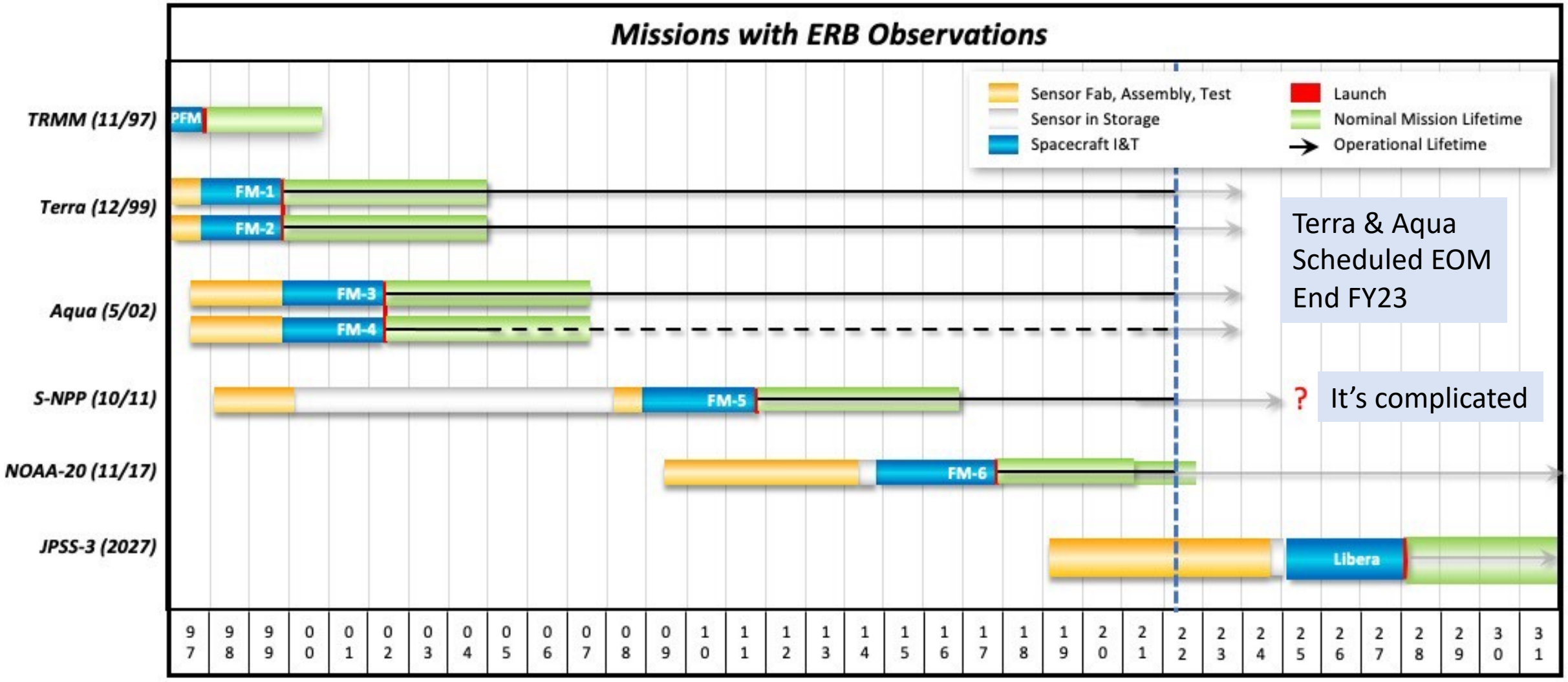
Mission	PI/IS/PS	Program	Status	Notes
TSIS-1	Peter Pilewskie (LASP)/Dong Wu (GSFC)	Earth Systematic Missions	Phase E (Operational)	Launched 12/2017 to ISS. Five year prime mission. ISS berth secured through 2027.
TSIS-2	Erik Richard (LASP)/Dong Wu (GSFC)	Earth Systematic Missions	Phase B, Launch scheduled August 2024	Free-flyer on General Atomics spacecraft. Launch Vehicle Needed. Three year prime mission. Built from spare parts.
CSIM – Compact Spectral Irradiance Monitor	Erik Richard (LASP)	ESTO InVEST QRS 2017	Phase F	Lasted for 3 years; Critical Technology demonstration, proved cubesat viability for SSI monitoring
Compact Total Irradiance Monitor Flight Demonstration (CTIM)	Dave Harber (LASP)	ESTO InVEST 2017	Launch in Q3 F22, 1 year mission	Benefits from CSIM lessons learned, will demonstrate cubesat approachh for TSI monitoring
Compact Total and Spectral Solar Irradiance Sensor (CTSIS) Mission Concept Study	Dave Harber (LASP)	ESTO Instrument Incubator Program - 2021	1/2022 – 1/2023 POP; Entry TRL: 2, Exit TRL: 3	Design based on CSIM, CTIM – will test several configs of a combined total and spectral SI mission

NASA Current Earth Radiation Budget Missions and Research Projects

Mission	PI	Program	POP	Stage	Comment
PREFIRE	Tristan L'Ecuyer	EVI-4	Launch in 2023		5-45 micron spectral flux on 2 6U cubesats
Libera	Peter Pilewskie	EVC-1		Phase C	Scheduled Launch 12/2027 on JPSS-3
DEMETER: DEMonstrating the Emerging Technology for Measuring the Earth's Radiation	Anum Ashraf, Langley Research Center	ROSES 2019 IIP	1/1/2020 – 12/31/2022	Entry: TRL 2 Exit: TRL 4	The long-term goal is maturation the sensorcraft's TRL to an operational system for future flight opportunities by 2025.
Black Array of Broadband Absolute Radiometers for Imaging Earth Radiation (BABAR-ERI)	Odele Coddington, CU	ROSES 2019 IIP		Entry: TRL 3 Exit: TRL 6	

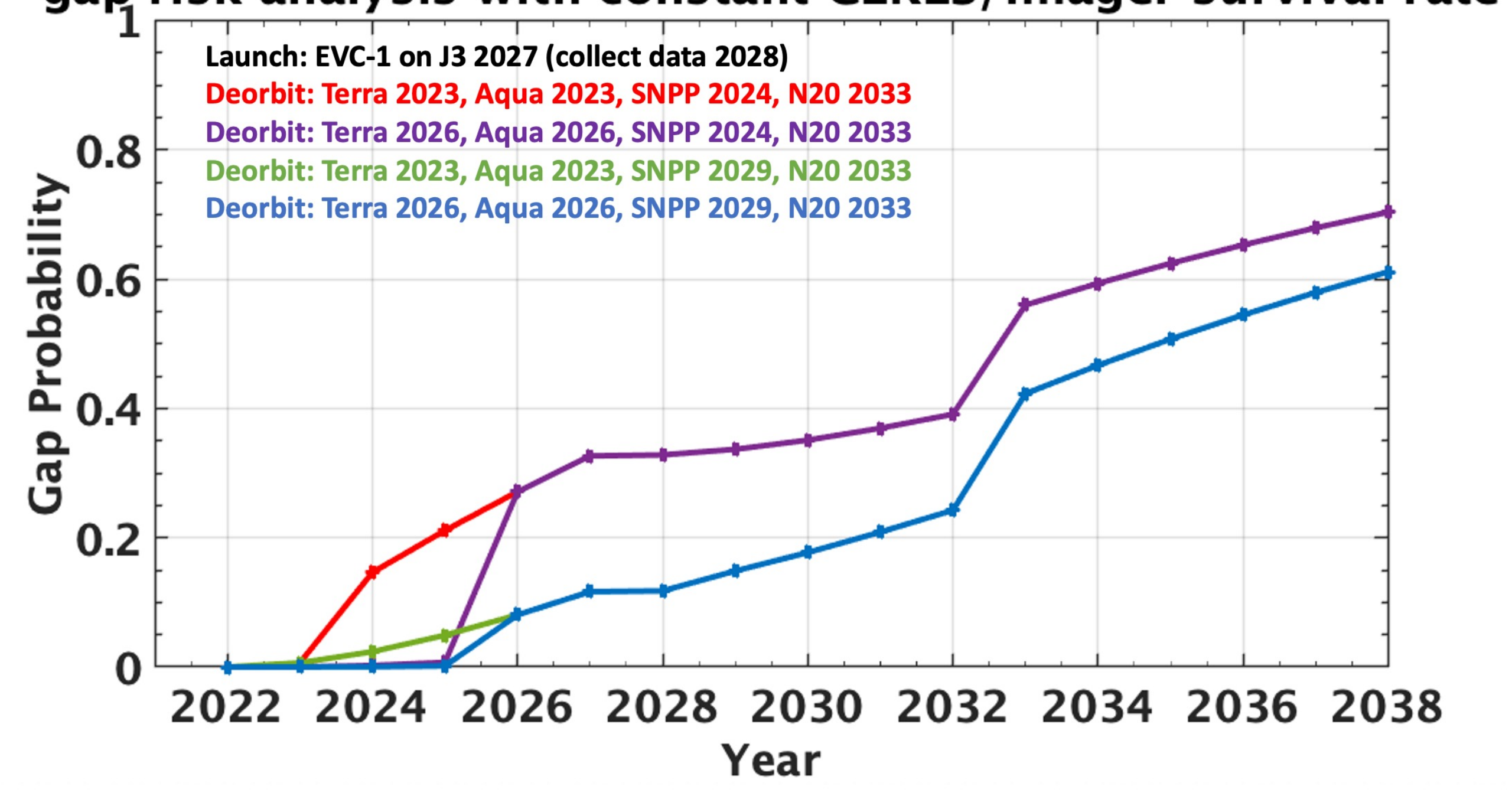
- DEMETER and BABAR-ERI are low-cost BBR alternatives which ditch the cross-track scan method
- Currently no plans for a broadband radiometer on JPSS-4; JPSS-4 instrument readiness date is 3/2025
- Future of ERB appears to be a free-flyer, perhaps in formation with JPSS-4.
- Unclear whether DEMETER or BABAR-ERI can result in viable follow-on to Libera in time.

Radiation Budget Instrument Flight Schedules



- Currently, 6 instruments fly on 4 satellites: Terra (L1999), Aqua (L2002), SNPP(L2011), NOAA-20 (L2017)
- Libera scheduled for launch 12/2027 on JPSS-3

gap risk analysis with constant CERES/imager survival rate



Summary

- NASA HQ is very focused on developing and funding the Earth System Observatory
  - Terra, Aqua, and Aura are funded for operations through October, 2023, when shutdown is planned.
  - Managing the transition from the EOS era to the ESO era presents an exceptional challenge for the NASA community.

- NASA HQ management recognizes that solar irradiance and Earth radiation budget measurements are important and are budgeting for their continuation.
  - Missions by agency and international partners would be welcomed and are being sought as part of the solution – “it doesn’t have to be us.”

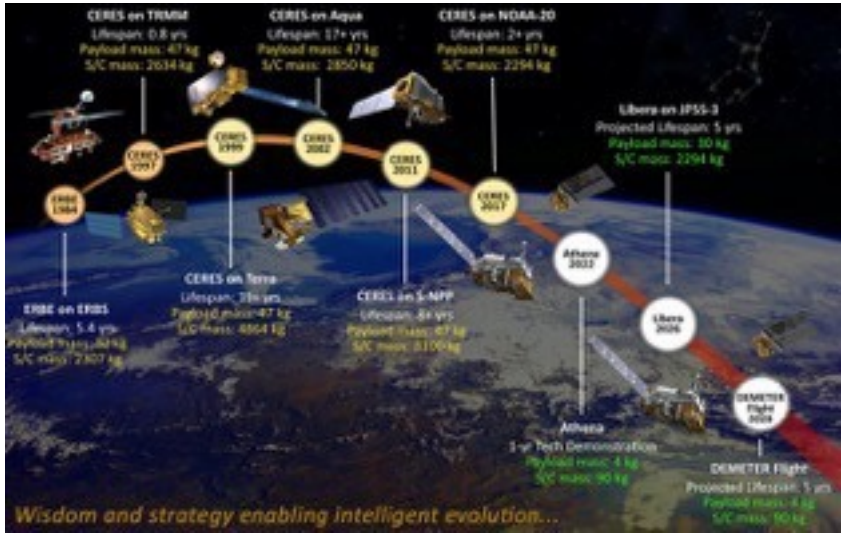
- It is unclear what is coming after TSIS-2/Libera. ESTO-funded efforts exist that could show a path forward
  - It is unlikely that a Libera instrument will fly on JPSS-4 – official instrument need date is 2025, there has been no discussion of this option.
  - Consider formation-flying for imager utilization or free-flyer solution.

DEMETER: DEMonstrating the Emerging Technology for Measuring the Earth's Radiation

PI: Anum Ashraf, NASA LaRC

Objective

- Develop an integrated instrument and platform capability that demonstrates a sustainable approach for measuring outgoing Earth radiation from 0.2 ∝m to >50 ∝m to support fundamental climate data records.
- Advance science capabilities by:
  - Increasing spatial resolution by a factor of ~10;
  - Incorporating intelligent on-board data processing; and
  - Reducing mass, power, risk and cost by an order of magnitude.
- Enable low-cost flight opportunities to provide more complete global diurnal sampling of radiation fields and significant risk reduction for a gap in the multi-decadal climate data record.



Approach

- Use industry, academia partners, advanced modeling and simulation, and emerging technologies and platform capabilities to create a high science value sustainable Earth Radiance measurement capability.
- Design and build a non-scanning wide-angle optical module that reduces IFOV and increases spatial resolution.
- Build and test a technology demonstration unit consisting of the wide-angle optical module integrated with sensor craft elements.

Co-Is/Partners: Kory Priestley, Mohan Shankar, Wenying Su, Seiji Kato, Dave Doelling, Paul Stackhouse, Norman Loeb, NASA LaRC; Alex Halterman, Quartus Engineering; Prof. Mahan, Virginia Tech.

Key Milestones

• Requirements definitions complete	03/20
• Downselection of optical architecture	06/20
• Stray light analysis (Prelim)	10/20
• Freeform optical design complete	11/20
• Preliminary calibration analysis complete	02/21
• Optics correlation test complete	09/21
• Stray light analysis (Final)	11/21
• Long leads procurement spec complete	04/22
• Baffled correlation testing complete	10/22

$TRL_{in} = 2$ **$TRL_{current} = 2$**

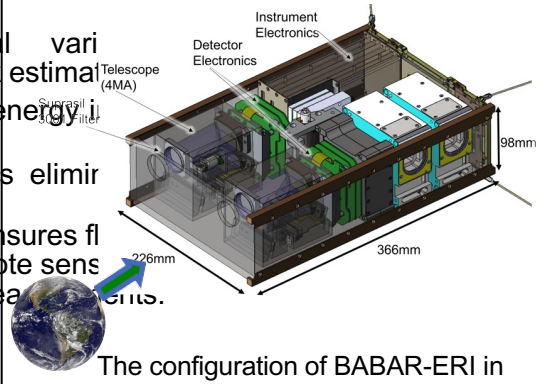
Black Array of Broadband Absolute Radiometers (BABAR) Earth Radiation Imager (BABAR-ERI)

PI: Odele Coddington, University of Colorado, LASP

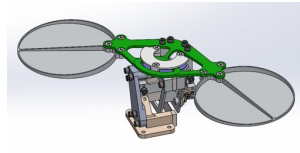
Objective

- Develop and demonstrate an instrument using a linear array of electrical substitution microbolometers for imaging outgoing Earth radiation from 0.2 μm to 100 μm with a 1 km spatial footprint and <1% uncertainty.
  - Cloud-resolving spatial footprint resolves the spatial vari Earth's radiation budget and constrains cloud feedback estima
  - High-accuracy improves the best estimate of Earth's energy i at the top of the atmosphere.
  - Closed-loop, absolute, electrical substitution radiometers elimir for an on-board calibration source.
  - 6U CubeSat form factor or small Satellite form factor ensures fl observing and implementation strategies for Earth remote sens reduces risks of data gaps in Earth radiation budget mea ents.

BABAR-ERI measures Earth's out-going shortwave and total radiance at cloud-resolving footprint from two co-registered telescopes.



The configuration of BABAR-ERI in a 6U CubeSat form factor.



A flexure-based chopper, with extremely long-life, designed to modulate incident radiation on each telescope at 7 Hz.

A BABAR microbolometer detector array with VACNT absorber under test.

Approach

- Leverage extensive LASP/NIST technology investments from previous and ongoing programs:
  - BABAR ambient-temperature, microbolometer linear array detector utilizes electrical substitution for absolute radiometry.
  - Vertically aligned carbon nanotube (VACNT) absorber provides ultra-high absorptance from 0.2 μm to 100 μm.
  - Two telescope design simultaneously images the shortwave and total radiance from the same ground patch.
- Calibrate BABAR-ERI end-to-end over the full wavelength range against an absolute detector tailored for the instrument power levels.

Co-Is/Partners: Dave Harber, Peter Pilewskie, Sebastian Schmidt, LASP; Michelle Stephens, NIST

Key Milestones

• Complete engineering design review	10/20
• Complete wheel mechanism	12/21
• Complete critical design review	01/22
• Complete microbolometer subsystem	12/22
• Complete instrument system	04/23
• Evaluate system performance	06/23
• Complete environmental test	07/23
• Complete final calibration	02/24

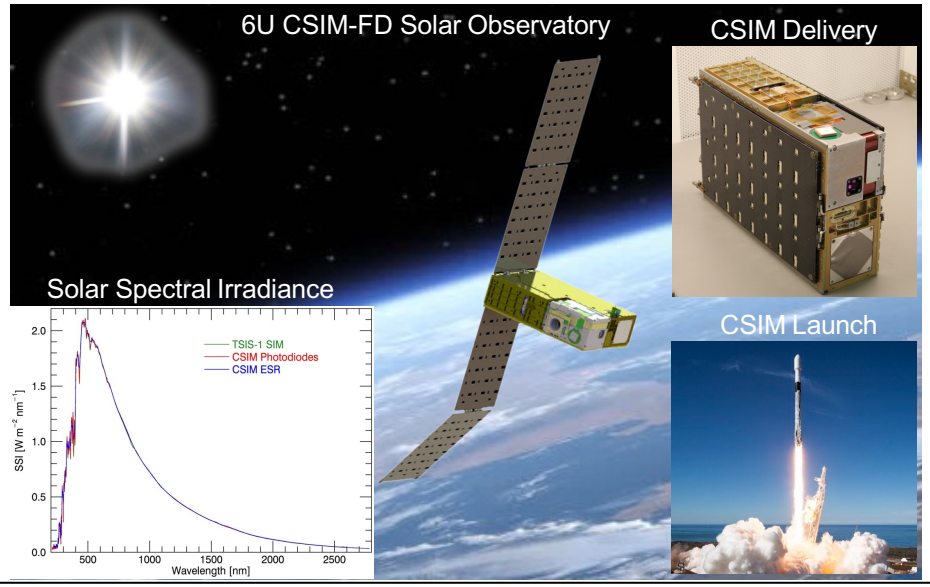
$TRL_{in} = 2$ **$TRL_{current} = 2$**

Compact Solar Spectral Irradiance Monitor Flight Demonstration: CSIM-FD

PI: Erik Richard, LASP-Univ. of Colorado

Objective

- Demonstrate solar spectral irradiance (SSI) measurement utilizing a 6U CubeSat and compare the performance with current space assets including TSIS and SORCE.
  - Achieve 0.2% uncertainty (k=1) SI-traceable SSI over spectral range 200-2400 nm, with 100 ppm/year relative stability for 1-year baseline solar observations.
  - Technologies include VACNT Electronic Substitution Radiometer (ESR) detector and precision prism drive rotational stage (~0.1 arc second repeatability)
- Demonstrate 18 months of solar observations at LEO overlapping SORCE and TSIS SSI observations to provide SSI-continuity level science capability in a miniaturized and more cost-effective package.
- Advance emerging technologies that will open opportunities, increase mission flexibility, and improve the reliability of maintaining long-term SSI data record stewardship.



Approach

- Leverage existing IIP and ACT technologies and investments to develop the CSIM-FD CubeSat:
  - Integrate IIP CSIM with the BCT bus to create CSIM-FD 6U CubeSat observatory
  - Flight qualify the observatory and perform full end-to-end SI-traceable spectral irradiance calibrations across 200 – 2400 nm.
- Launch CSIM-FD through SpaceFlight launch opportunity.
- CSIM-FD will use the same observing strategy as TSIS Spectral Irradiance Monitor (SIM) to make concurrent SSI observations allowing direct comparison to both TSIS and SORCE SIM.

Co-Is/Partners: Tom Woods, Peter Pilewskie, LASP; BCT

Key Milestones

• Preliminary Design Review (PDR)	08/17
• Critical Design Review (CDR)	11/17
• CSIM instrument modifications complete	05/18
• CSIM-FD Mission Readiness Review (MRR)	08/18
• CSIM-FD Delivery (SpaceFlight Industries)	09/18
• CSIM-FD Launch (SSO-A SmallSat Express)	12/18
• CSIM-FD commissioning complete	03/19
• CSIM-FD initial science data release	03/20

  – CSIM website (http://lasp.colorado.edu/home/csim/data)
  – LISIRD website (http://lasp.colorado.edu//lisird/)

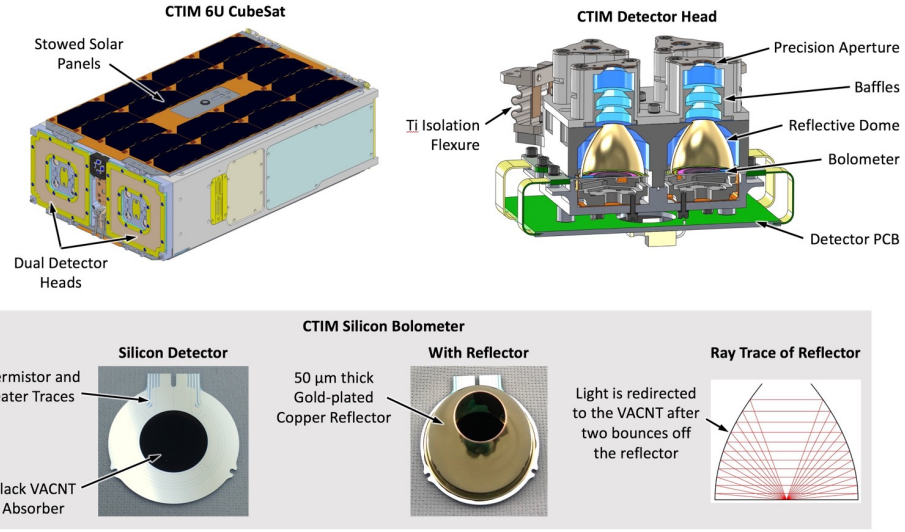
$TRL_{in} = 6$ **$TRL_{current} = 9$**

Compact Total Irradiance Monitor Flight Demonstration (CTIM-FD)

PI: David Harber, University Of Colorado, LASP

Objective

- Develop a 6U CubeSat form factor instrument to measure Total Solar Irradiance (TSI) from 200nm to 2400nm.
- Build, test, and launch a 6U CubeSat system and demonstrate science performance validated against existing TSIS TIM TSI capabilities:
  - Performance goals: Achieve 100 ppm uncertainty (k=1) absolute, with 10 ppm/year relative correction stability for 1-year CubeSat operations
  - Technologies include new Vertically-aligned Carbon Nanotube (VACNT) Electrical Substitution Radiometer (ESR) detector head, embedded m-processor, silicon ion-etched precision apertures



Approach

Leverage existing IIP & ACT technologies and investments to develop the CTIM-FD CubeSat:

- Integrate CTIM detector heads into 6U CubeSat based on CSIM design with changes to increase system robustness
- Flight qualify complete system and perform total radiometric validations of TSI requirements and irradiance scale
- Launch CTIM-FD through CubeSat Launch Initiative (CSLI) opportunity
- Demonstrate measurement performance through 1-year of solar observations at LEO overlapping TSIS TSI observations

Co-Is/ Partners: Greg Kopp, Peter Pilewskie, LASP; NIST

Key Milestones

• FCC radio licenses application submission	04/19
• Spacecraft critical design review	06/19
• Instrument complete	06/20
• Observatory launch ready	10/21
• Commissioning complete	03/22
• Initial science data release	07/22

$TRL_{In} = 5$ $TRL_{Current} = 6$