National Aeronautics and Space Administration

DEMETER

NASA Langley Research Center

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

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Kory Priestley, Anum Ashraf
NASA Langley Research Center

Executive Summary

DEMonstrating the Emerging Technology for measuring the Earth's Radiation

DEMETER moves the Earth Radiation Budget observational constellation and processing streams into the future, capitalizing on innovative new technology to increase robustness, flexibility and scientific return while significantly reducing lifecycle costs.

- **Taken a systematic approach, including a fully integrated Science Advisory Group, that extends beyond simply replacing the 'CERES' instrument. *What observations are needed and how are they used.***
- **Defined an innovative and dedicated ERB observing system to optimize the spatial/spectral/temporal sampling and minimize reliance on external assets that weren't designed for ERB.**
- **Yields a simplification of the processing system while ensuring both continuity and greater capability to support the next generation of weather and climate models.**
- **First technology demonstration flight of conformable and reconfigurable platform (with committed funding) scheduled for 2024**
- **Gov't, Industry and Academic partners (competitively selected) compose the comprehensive team**

ERB Science Overview

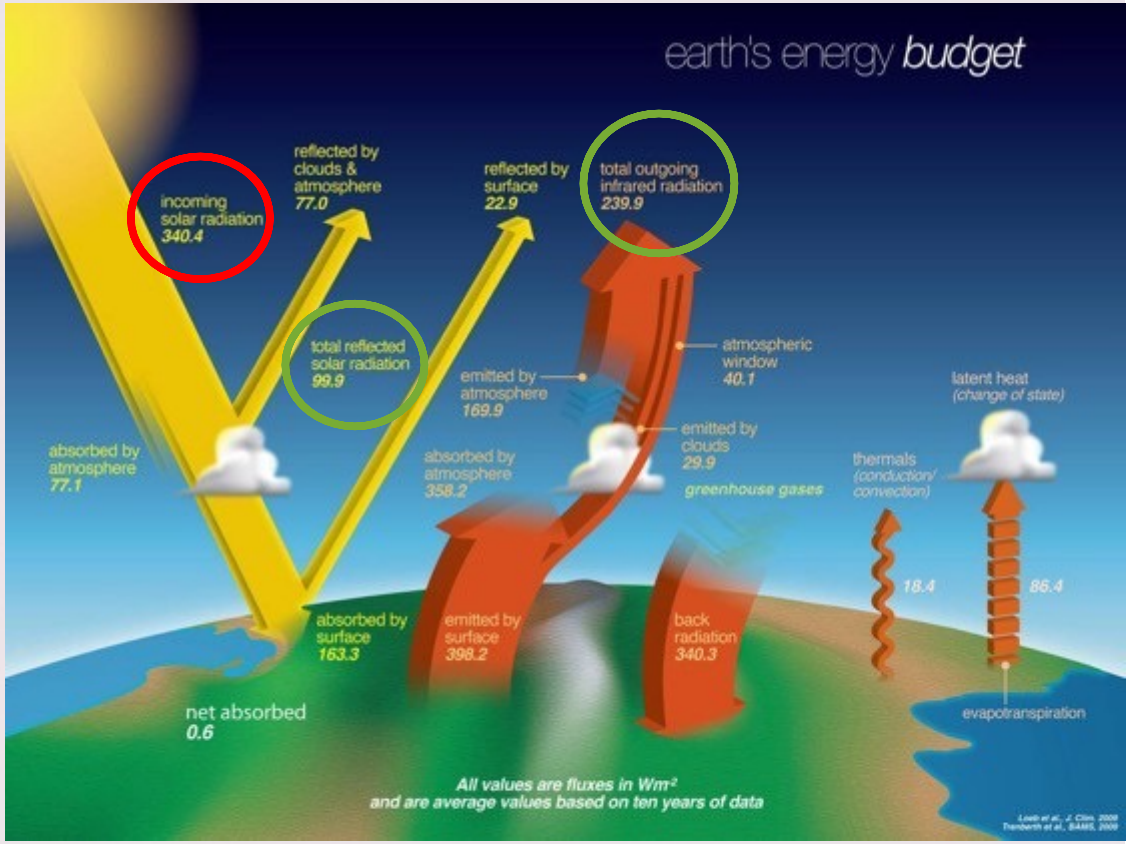
- ERB represents a balance between incoming solar radiation reaching the TOA with outgoing reflected solar and thermal radiant energy emitted by the Earth- atmosphere system

- Long-term, sustained, and accurate climate observations are essential as acknowledged in multiple national and international community reports and publications.

- Since 2000 CERES project has provided the continuous climate data record aboard flagship missions (Terra, Aqua, S-NPP and NOAA-20).

- Overlap in observations between ERB sensors is required to tie the measurements to a common radiometric scale and for data continuity.

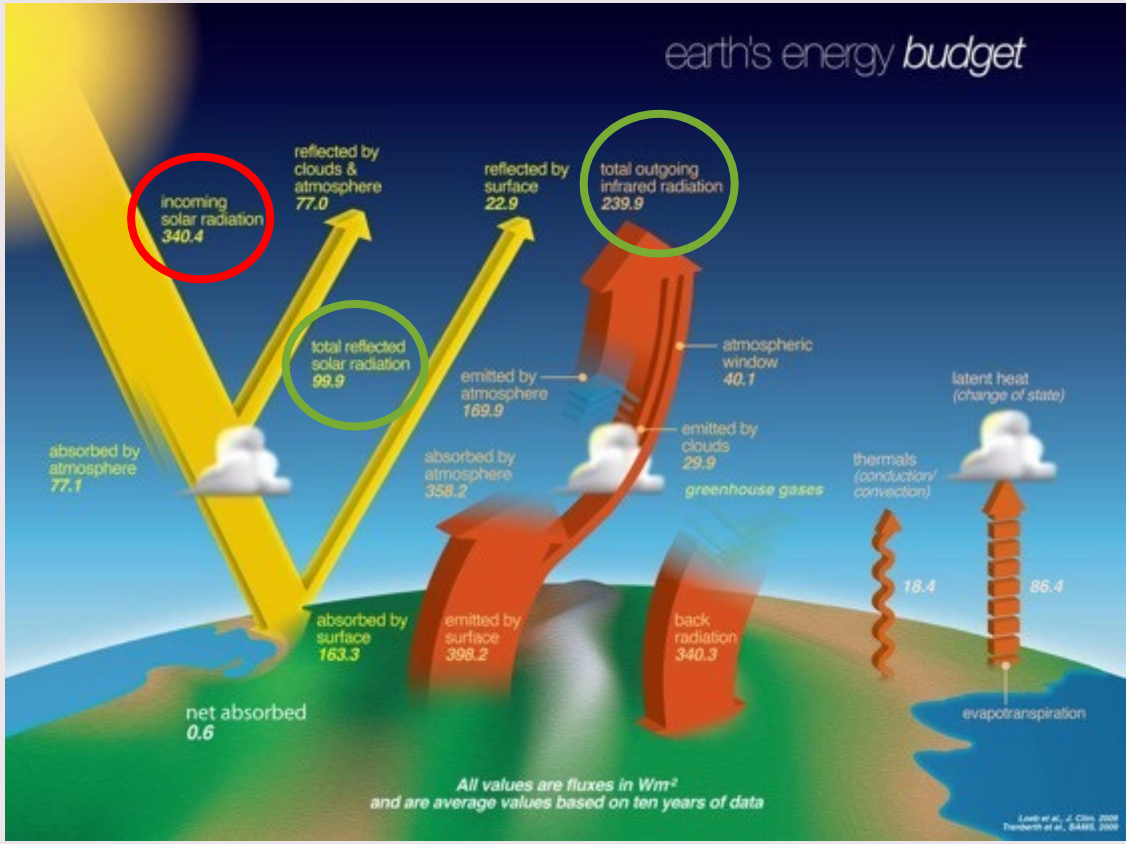
- ***The current approach relies on flying ERB instruments as hosted payloads on large and expensive flagship missions.***



Next Generation Solution

DEMonstrating the **E**merging **T**echnology for measuring the **E**arth's **R**adiation

- Proposed approach is a ***"right size", free-flying sensorcraft solution*** and a revolutionary approach for making an enhanced Fundamental Climate Data Record (ERB-FCDR) from LEO as its predecessor CERES
- Next-generation ERB sensor hosted on a cellular, configurable, conformable architecture (SLEGOs).
- Reduces mass, power, and cost, by an order of magnitude over current state-of-the-art techniques.
- ***Eliminates the classic boundaries of a payload and spacecraft***, replacing it with an integrated system that shares resources, eliminating duplicity while increasing redundancy in a small package.



DEMETER moves ERB observations forward with an innovative, low cost/risk, strategic approach

ERB Science Traceability Matrix

DEMonstrating the Emerging Technology for measuring the Earth's Radiation

Sample every 1° x 1° grid box on the earth every hour.

Science Questions	Strategy	Science Product Characteristics: Physical Parameters	Science Product Characteristics: Resolution (As applicable)	Science Measurement Characteristics: Observables	Science Measurement Characteristics: Instrument Requirements	Minimum Mission Requirements
Q. 1 What is the magnitude of cloud feedback in response to climate forcing?		OLR and RSR radiative flux for all-sky and clear-sky conditions[1].	Vertical: TOA only Spatial: @ 25km, 1°x1°, regional, zonal, global. Temporal: Instantaneous, hourly, 3-hourly, daily, monthly.	Geolocated and calibrated OLR and RSR radiances	OLR and RSR TOA Radiance Observations See Table 1	Sunsynchronous 1:30 pm ascending orbit. Global coverage daily. Overlap with CERES record (1 yr min)
Q. 2 What cloud types/properties are changing in response to climate warming in different regions? How do the changes impact TOA and SFC ERB?		Cloud properties (f, τ, r_e, *phase*, T) of imager pixels within larger OLR and RSR footprint measurement[2].	Spatial: @ 25km, 1°x1°, regional, zonal, global. Temporal: Instantaneous, daily, monthly.	Geolocated and calibrated spectral radiances	LEO Imager Radiances See Table 2	Within 3 min of and in the same viewing geometry as the OLR and RSR obs. Global coverage daily.
Q. 3 How will changes in the ERB at the TOA and SFC impact atmosphere and ocean circulations, surface temperature, precipitation and sea-level?	O.1 Provide long-term climate data records of TOA and SFC ERB together with the associated atmospheric and surface properties that seamlessly continue CDRs from CERES project.	Hourly cloud properties and narrow-to-broadband OLR and RSR fluxes.	Spatial: 1°x1°, regional, zonal, global. Temporal: hourly, 3-hourly, daily, monthly.	Geostationary imager and spectral radiances	Geostationary Imagers Consistent with available weather observing system obs.	Coverage over 60°S-60°N, All longitudes
		Solar Irradiance	Spatial: @25km, 1°x1°, regional, zonal, global. Temporal: Instantaneous, hourly, 3-hourly, daily, monthly.	Total solar irradiance measurements	Solar Irradiance Consistent with the SORCE, TSIS solar irradiance CDRs	Daily Coverage
Q. 4 How will the total direct radiative effect of aerosols change in the future?		Computed upward and downward all-sky and clear-sky SW and LW surface radiative fluxes	Vertical: TOA, surface, w/in atmosphere Spatial: @ 25km, 1°x1°, regional, zonal, global. Temporal: Instantaneous, hourly, 3-hourly, daily, monthly.	All of the above + Other ancillary data: aerosol retrievals; snow/ice maps; meteorology, ozone & aerosol assimilation.		Meteo. Assimilation – hourly. Others: Daily

Broadband Radiance Sensor — 6 – CERES

Spectral Radiance Sensor — 4 – ModIS/VIIRS

Diurnal Coverage — 5 – Geo-Imagers

Ancillary Dataset Assets

DEMETER Science Traceability Matrix

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Smaller footprint enables reporting on ***smaller*** grid boxes on the earth every hour

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Broadband Radiance Sensor (IIP)

Spectral Radiance Sensor (Partner)

Single ERB Sensorcraft that carries both sensors

Diurnal Coverage

Increased spatial resolution (<25km) enables better 'clear-sky' identification and reporting at smaller spatial grids.

Constellation of 3 orbits samples diurnal cycle and eliminates dependence on Geostationary observations

Sensorcraft Provide Observational Robustness

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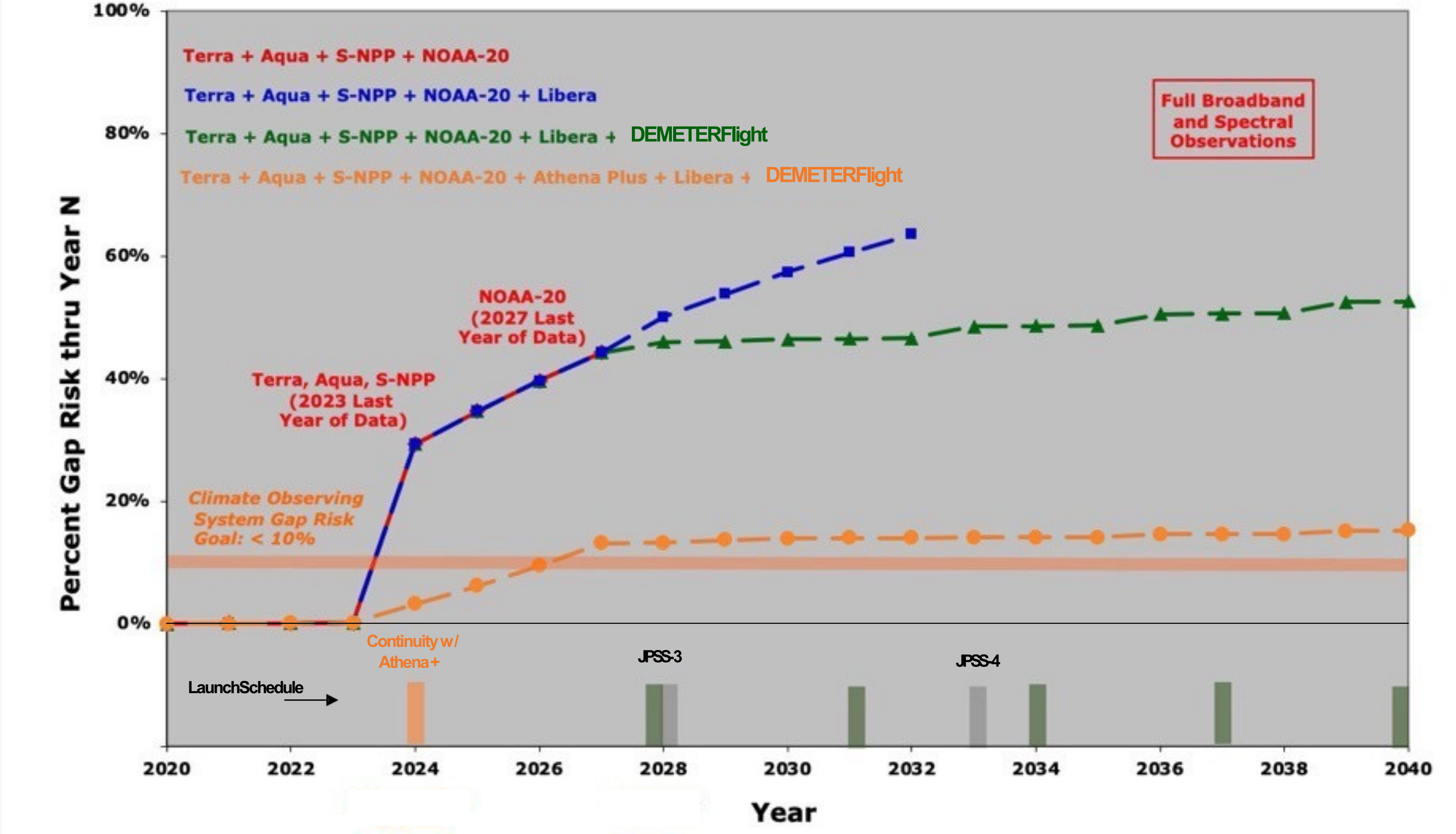
Example: Global ERB CDR Data Gap Risk



Flagship Missions ($200M inPayload $2Bin Observatory)

DEMETER SensorcraftMissions ($200M TotalCost)

Early launch SensorcraftMissions

Note: SensorcraftAssumption,5-year lifetime, 3 year launch cadence

DEMETER Continues the Evolution

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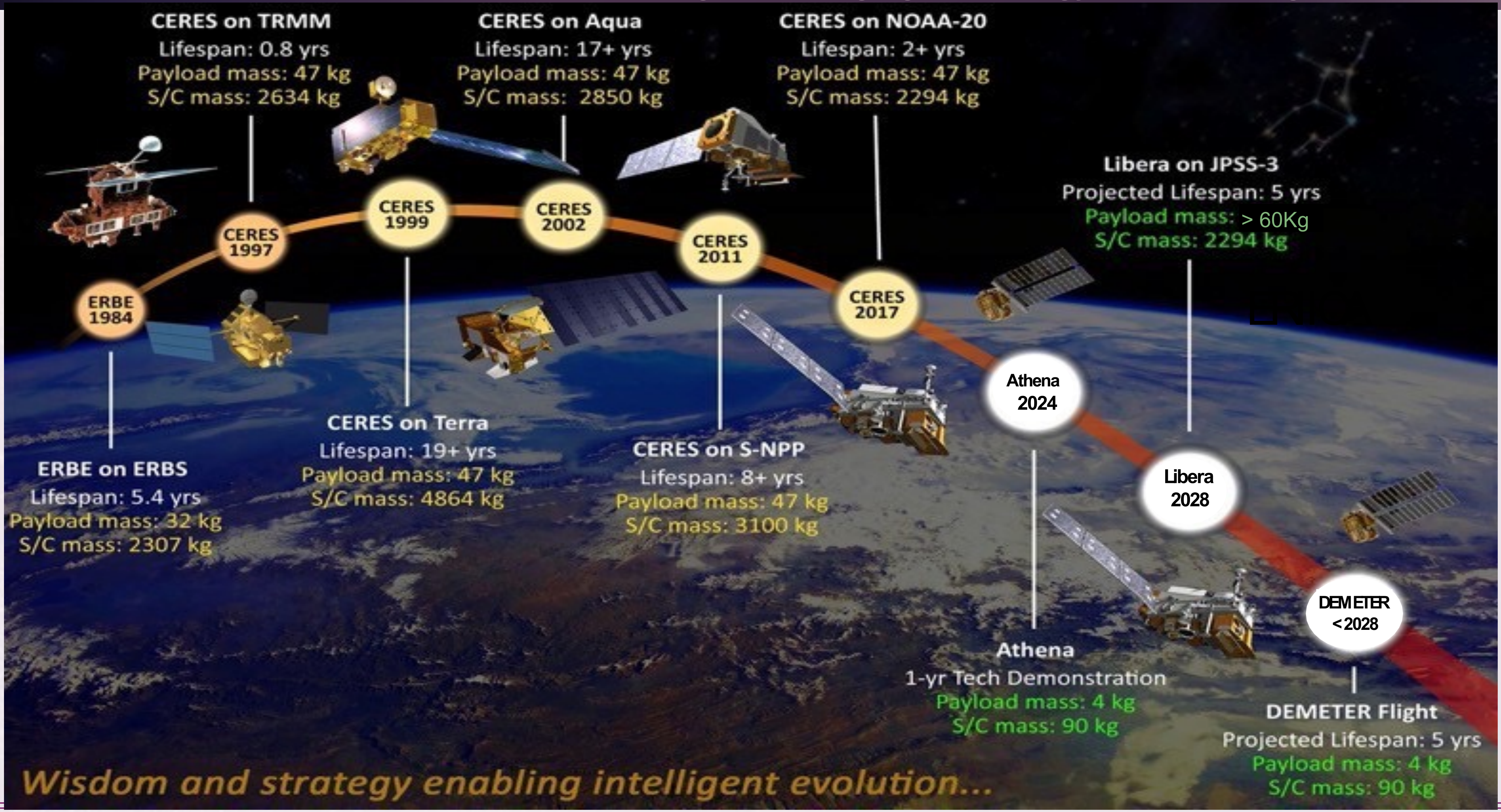


Strategic Development Path for Future ERB Missions

Science Advisory Group

DEMETER

Stakeholders
SMD, ESTO, LaRC, NOAA

Athena
(in execution)

Enables new observational platform for multiple science payloads

Launches 2024

IIP
(in execution)

Development of ERB sensor and sensorcraft architecture

Transition to flight 2024

Flight Constellation
(Future)

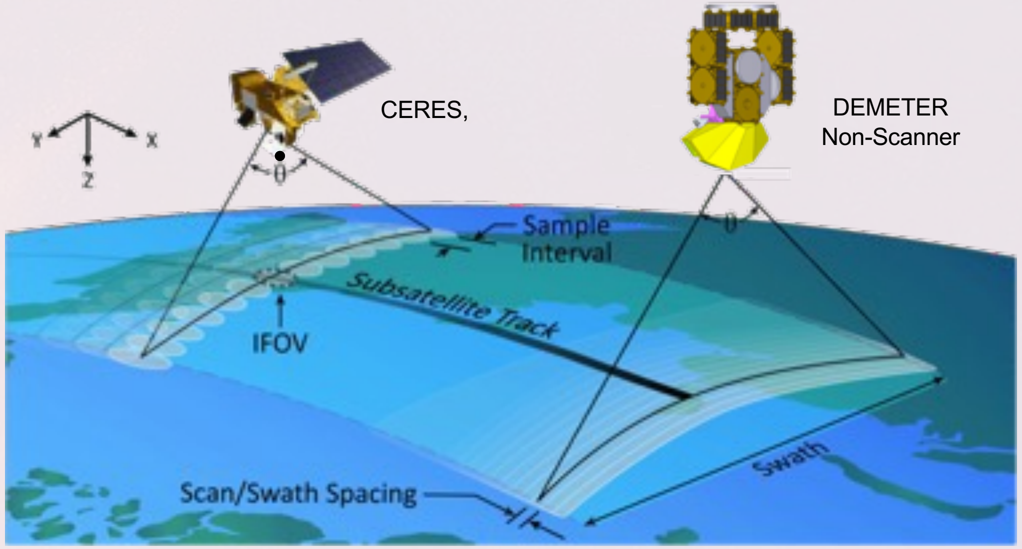
Provides fundamental measurements (broadband + spectral) to the science community to produce ERB CDR

Flight Readiness 2026

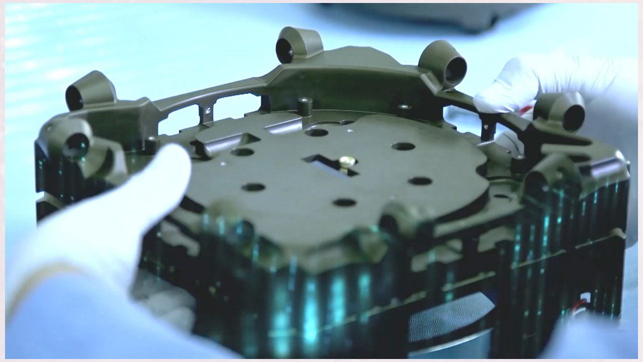
Strategic Evolution

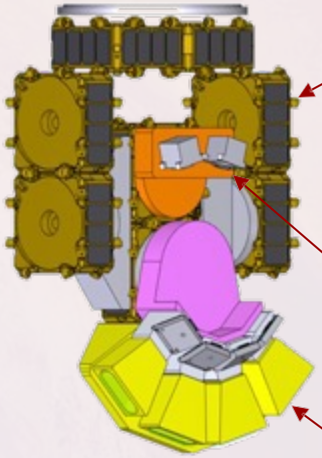
Sensorcraft Concept of Operations

- **Non-scanning, Pushbroom, wide field of view** radiometer to measure limb-to-limb TOA radiances, while integrated with a NovaWurks Hyper Integrated Satlet (HISat) sensorcraft.
- Detector array oriented perpendicular to the satellite ground track to simultaneously collect a single limb-to-limb swath.
- Successive readouts of the array represent consecutive swaths providing the necessary spatial coverage of the TOA radiation fields for nominal observations.



DEMETER enlarged for comparison



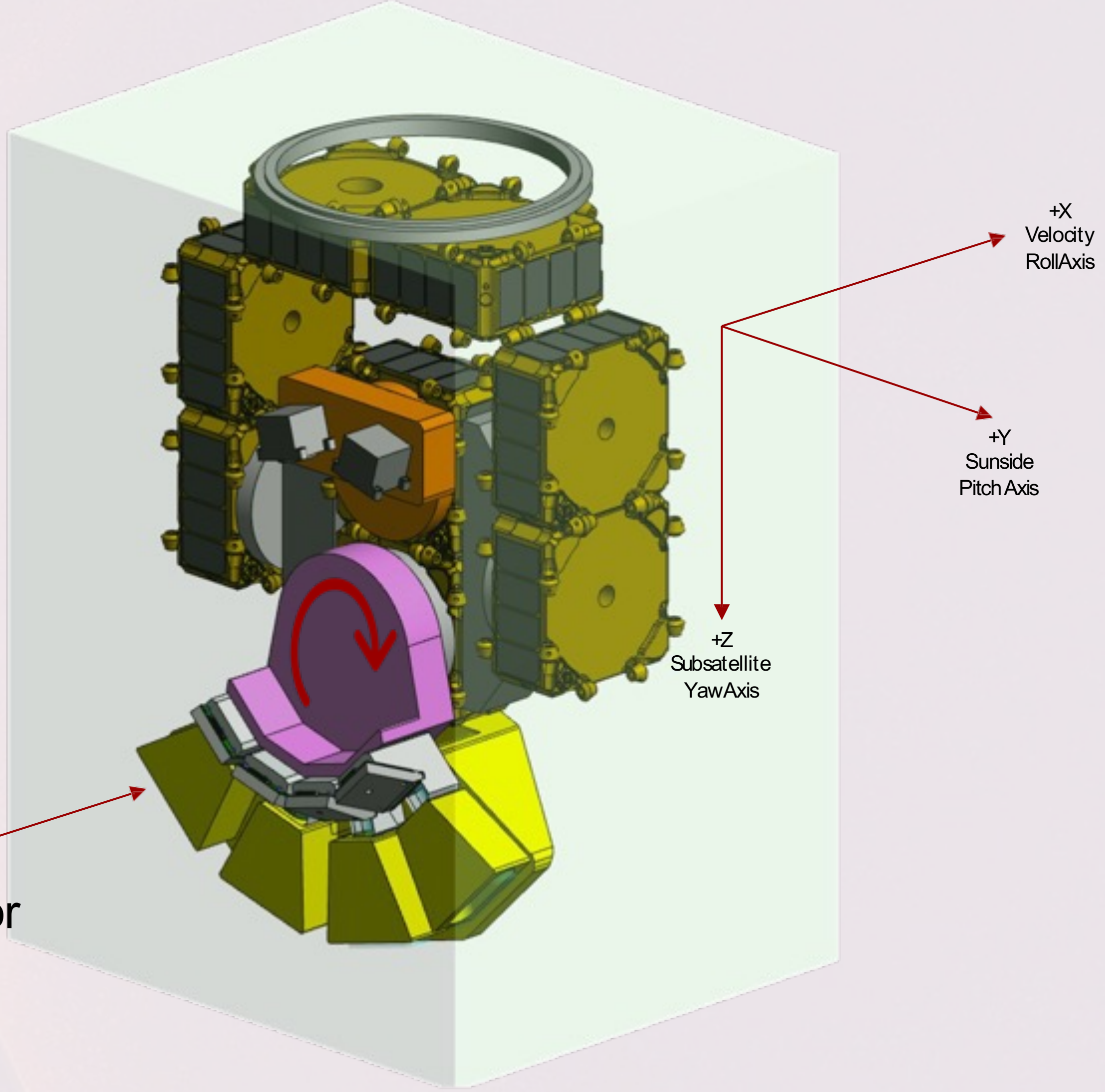


Spectral coverage includes **broadband** (CERES-like) plus **spectrally resolved** (VIIRS-like)

DEMETER Flight Configuration

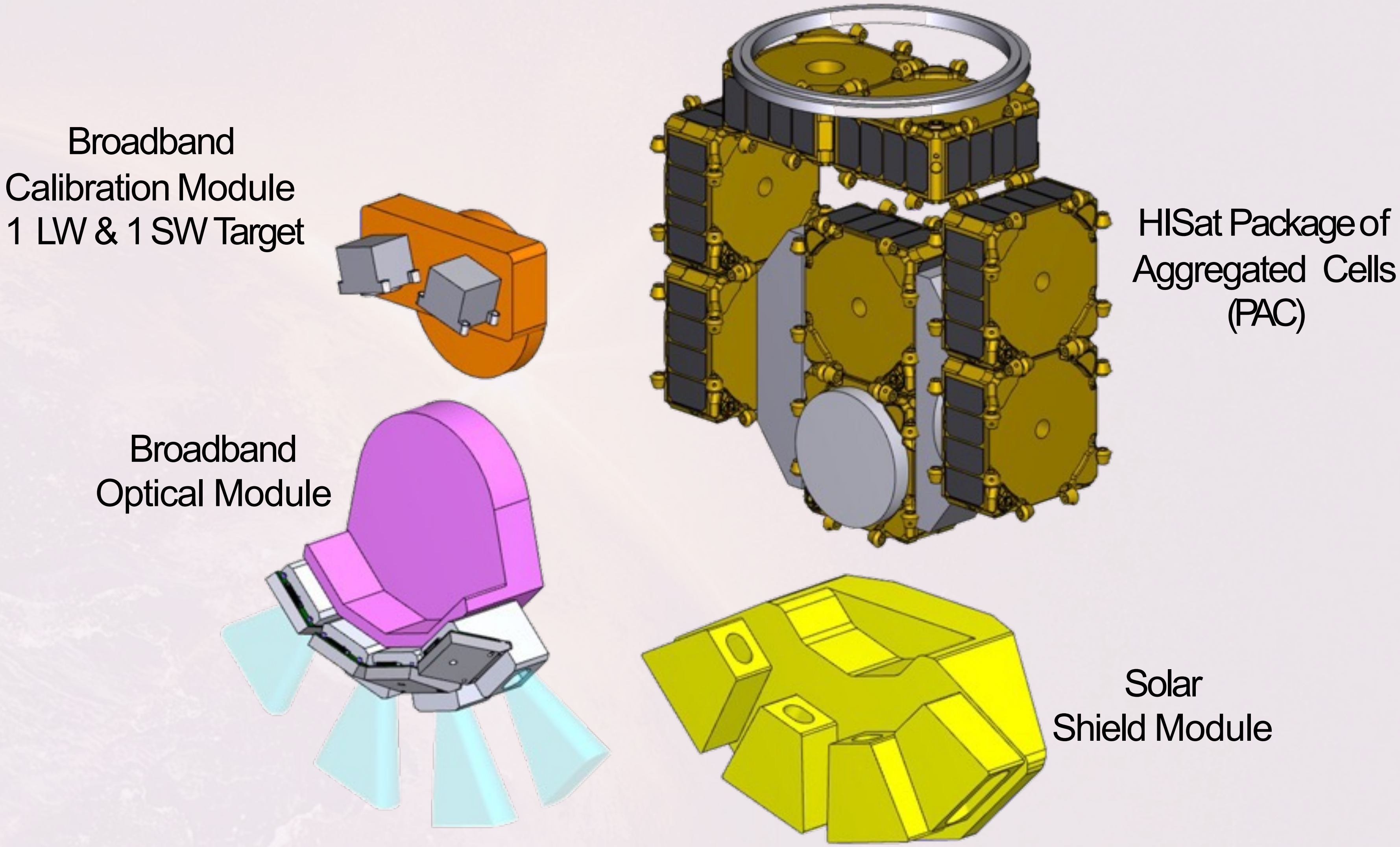
<u>Nominal Earth Viewing</u>

Encapsulated within a
standard ESPA SWAP volume
24 x 28 x 38 inches



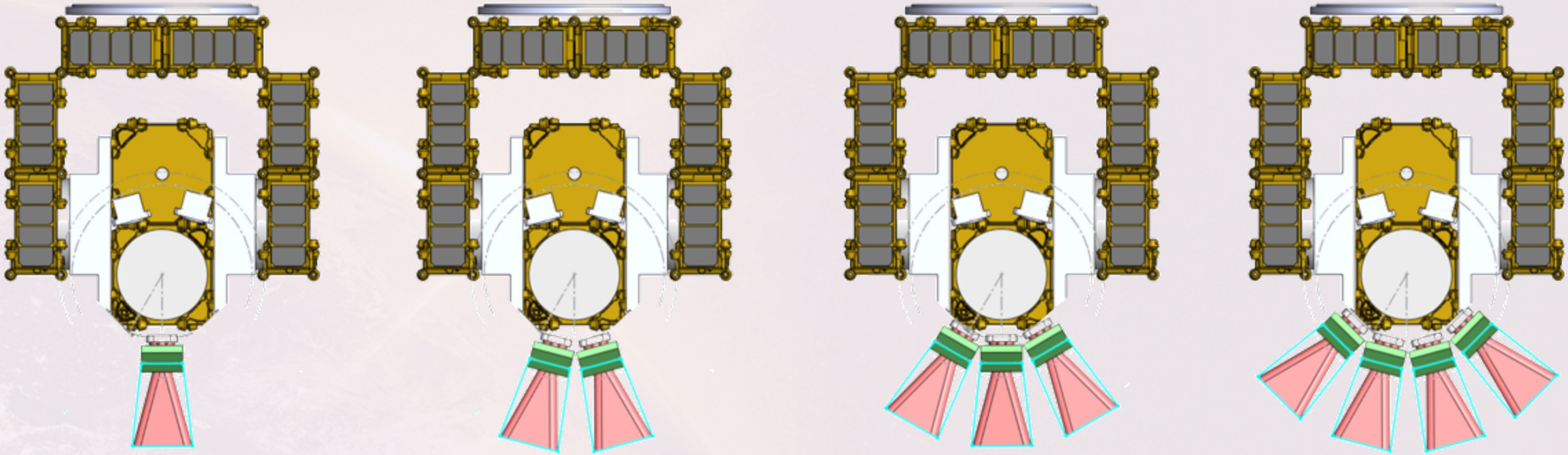
Broadband sensor
4-tiled telescopes

DEMETER Major Elements



DEMETER is configurable

Swath width can be tailored to meet different science instantiations to achieve global coverage



$FOR_{system} = N_{telescope} * FOV_{telescope}$

For global coverage in <u>24 hours</u>
from ~600 Km Altitude Constellation

- 1 orbital plane
- 1 sensorcraft per orbit

DEMETER-IIP Execution Team

Industry/Gov't/Academic Partners

- Quartus Engineering
- NovaWurks
- VT
- Jet Propulsion Laboratory, California Institute of Technology
- Space Dynamics Laboratory, Utah State University
- SSAI

Advisory
Authority

Earth Science Technology Office
Program Manager: Parminder Ghuman
Technology Manager: Keith Murray
Financial Manager: Dana Marie Avery

Science Advisory Group
Norman Loeb
Wenying Su
Seiji Kato
David Doelling
Paul Stackhouse
Kathleen Moore

Project Leadership Team
PI/PM: Anum Ashraf
Project Scientist: Mohan Shankar/Kory Priestley
Scheduler: Jeff Guilbert
Cost Analyst: Laura Dover

LaRC Mgmt.
Science Directorate
Engineering Directorate
Mentor: Dave Johnson

Athena Project
PI: Kory Priestley
PM: Chad Rice

Payload Optical and Calibration Module

Bus
NovaWurks

Calibration
SDL

Optics
Quartus

Electronics
LaRC

Thermal
Quartus/LaRC

FPM
JPL

Software
LaRC

Structure
Quartus/LaRC

Radiometry/ Modeling
VT/Quartus

Flat Sat Emulator
NovaWurks

Instrument Incubator Program
Advancing the Broadband Sensor

- **IIP addresses the technology gap of the broadband sensor**
  - Awarded by ESTO; Kick-off Jan 2020
- **Advances the Technology Readiness Level of the sensor assembly (optical module + focal plane module) from TRL 2 to TRL 6**
  - Develop a prototype unit enabling a follow-on transition to a low-risk flight mission
    - Sensor assembly and on-board calibration system
  - Focused studies of modular architecture to host broadband + spectral sensor and calibration module on a single sensorcraft
- **Team**
  - Co-Investigators from Langley's ERB science group
  - Internal and External partnerships (NASA, industry, academia)

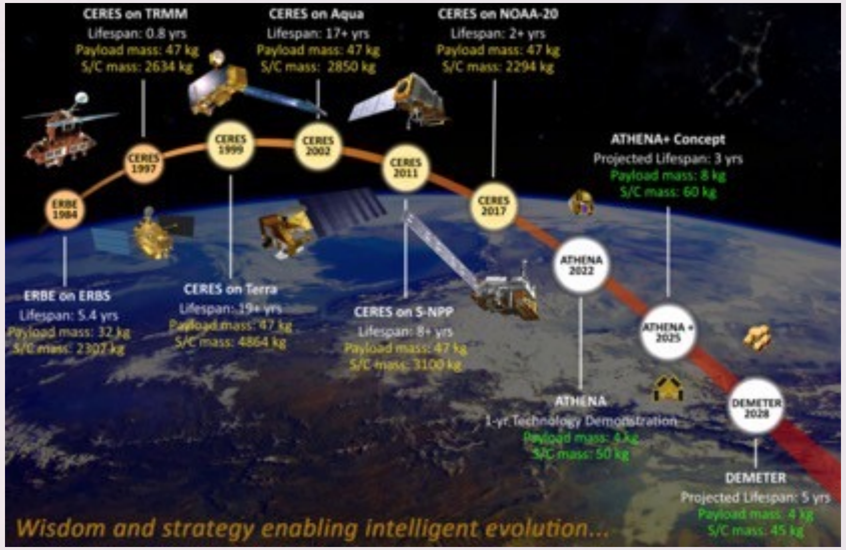
DEMETER

DEMonstrating the Emerging Technology for measuring the Earth's Radiation

PI: Dr. Anum Ashraf, LaRC

Objective

- Develop a sensorcraft that demonstrates a **game-changing** approach for measuring the Earth Radiation Budget Fundamental Climate Data Record.
- Exploit the science capability and greatly exceed data quality of current measurement by:
  - Increasing spatial resolution by factor of 10
  - Incorporating **intelligent** on-board data processing
- **Innovative** and **integrated** solution that reduces mass, power, risk, and cost, by an order of magnitude over current state-of-the-art techniques.
- Drastically reduced form-factor enables low cost flight opportunities providing more complete global diurnal sampling of radiation fields and significant risk reduction of a gap in the multi-decadal climate data record.



Approach

- Leverage 100+ years of direct experience to pro-actively influence the design and address trades involved in an integrated and intelligent manner
- Design and build a non-scanning wide-angle telescope that reduces IFOV and increases spatial resolution
- Build and test a technology demonstration unit consisting of the wide-angle telescope integrated with sensorcraft elements

Co-I's: Kory Priestley, Wenying Su, Seiji Kato, Dave Doelling, Paul Stackhouse, Mohan Shankar, J. Robert Mahan, Alexander Halterman
Collaborator: Norman Loeb
Partners: Science Systems and Applications Inc., Quartus Engineering Incorporated, NovaWurks Inc., Virginia Tech.

Key Milestones

• Project Kick-off	01/20
• Requirements Definitions Complete	03/20
• Downselection of optical architecture	05/20
• Calibration Analysis Complete	02/21
• Optics Correlation Test Complete	09/21
• Flight Optical Prescription Finalized	02/22
• Stray Light PST Analysis	06/22
• Prototype Detector Delivery	04/23
• Sensor Assembly (SA) Integration Complete	07/23
• Form Fit Function and Performance Test of SA	08/23
• On-board Calibration System Design Complete	09/23
• Full System-level RTM test	01/24
• Project Close Out Review	05/24

$TRL_{in} = 2$ $TRL_{current} = 4$ $TRL_{out} = 6$

Goddesses of Harvest and Agriculture

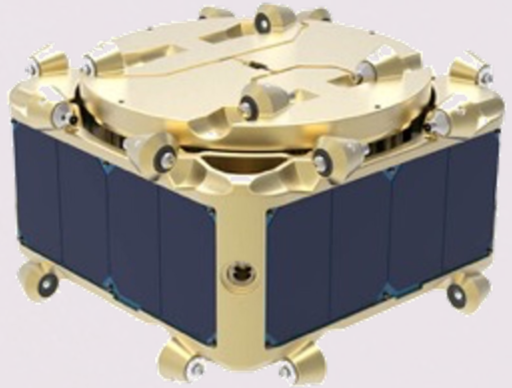
Ceres (Roman)

Demeter (Greek)

DEMETER

NovaWurks Hyper Integrated Satlet Building Blocks

Individual HISats are connected to aggregate performance as a PAC (Package of Aggregated Cells)



SmallSat Bus Advantages and Characteristics

- High Performance Bus can be built in months, not years
- Satellite bus is a configuration, low NRE, not a design
- Supports all orbits (LEO-GEO) with scalable life (2, 5, 8+ Year life)
- Payload Centric : Configured to adapt to payload and Launch Vehicle
- Integrated processor, memory, carousel, thrusters, cameras in each HISat
- HISat’s share resources power, fuel, data, and thermal
- Fast on-board processing capability
- Allows for technology infusion
- Open source Simplified Interface – Plug-n-Play by design
- Mass produced, driving quality and cost efficiencies
- Design provides Significant radiation shielding

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Broadband Radiance Sensor

Spectral Radiance Sensor

Single ERB Sensorcraft that carries both sensors.

Diurnal Coverage

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Broadband Radiance Sensor → IIP

Spectral Radiance Sensor → Partner

Diurnal Coverage