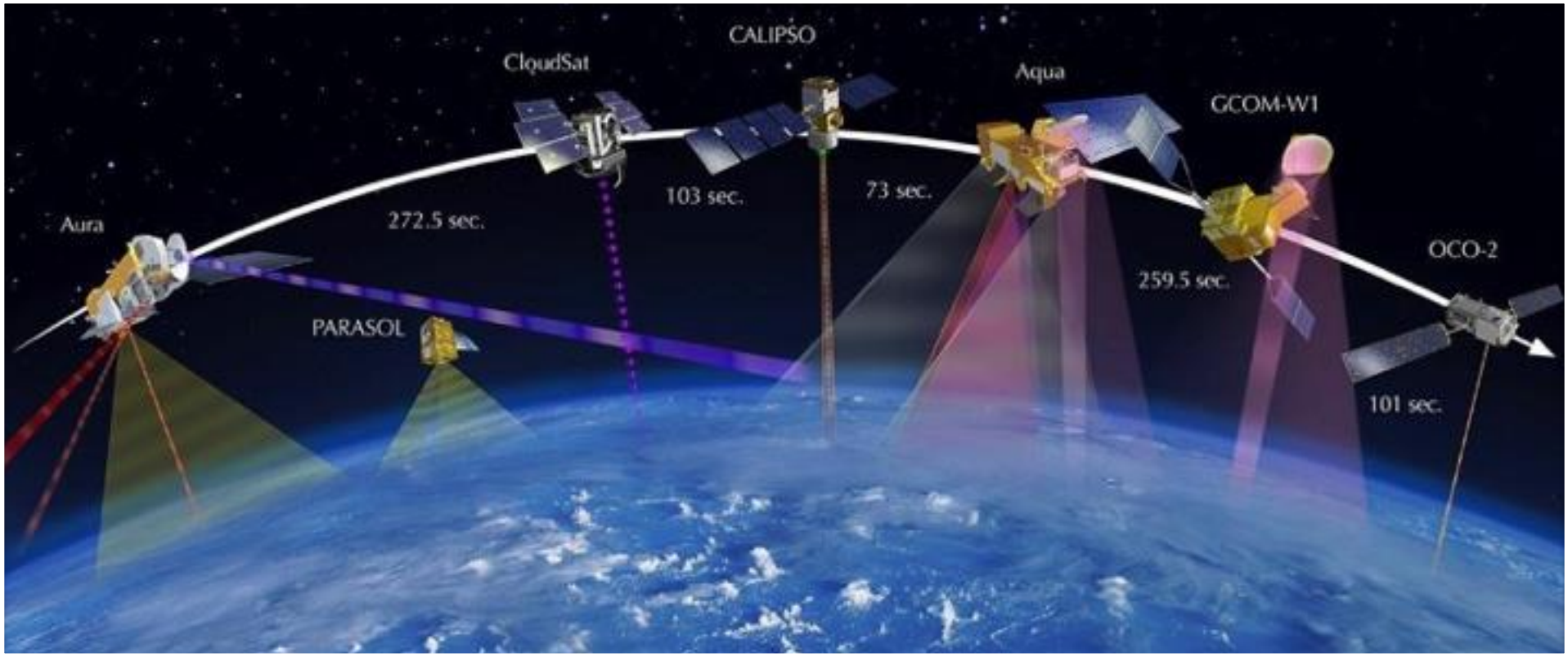
Strategic Missions - Earth Science

Dr. Michael Freilich

October 2016



Earth Science Division Objectives and Activities

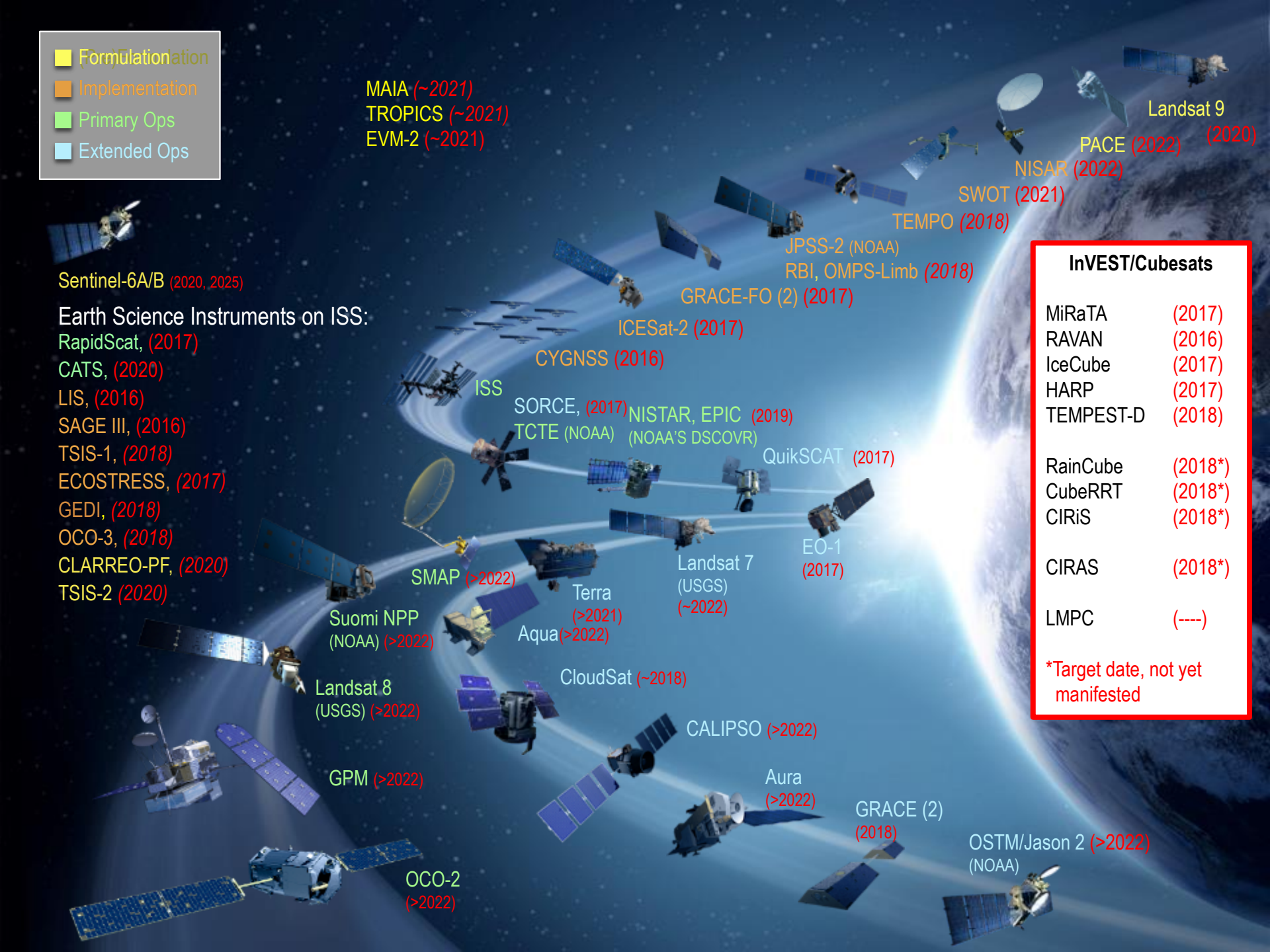
Understand the Earth as an integrated system, and develop and test applications to deliver direct societal benefit

- **MEASUREMENTS:** **Monitor/observe the Earth and our environment from space** to advance science, develop applications for societal benefit, and support other mission agencies. NASA designs, implements, and operates present and future spaceborne observing systems

- **RESEARCH:** **Understand the Earth as an integrated system** through multidisciplinary research, using all relevant measurements (not just spaceborne, not just NASA)

- **SOCIETAL BENEFIT and CAPACITY BUILDING:** **Develop and test new information products** that are **tailored to the needs of end users**; **increase users' capacity** to exploit the information

- **TECHNOLOGY DEVELOPMENT:** **Advance instrument, data processing, and communications technologies** to support new missions, research, and applications

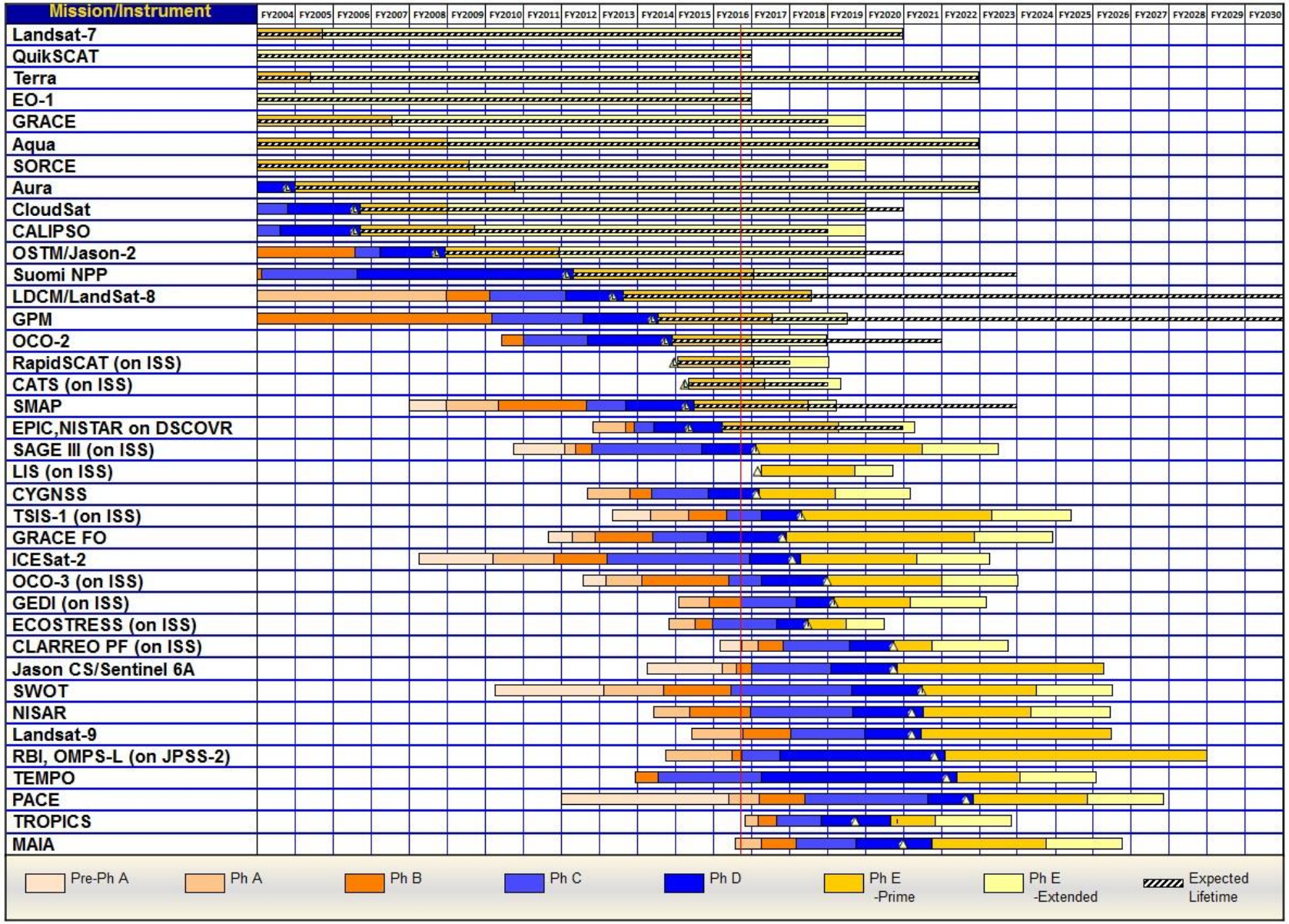

Formulation
Implementation
Primary Ops
Extended Ops
MAIA (~2021)
TROPICS (~2021)
EVM-2 (~2021)
Landsat 9 (2020)
PACE (2022)
NISAR (2022)
SWOT (2021)
TEMPO (2018)
JPSS-2 (NOAA)
RBI, OMPS-Limb (2018)
GRACE-FO (2) (2017)
ICESat-2 (2017)
CYGNSS (2016)
Sentinel-6A/B (2020, 2025)
Earth Science Instruments on ISS:
RapidScat, (2017)
CATS, (2020)
LIS, (2016)
SAGE III, (2016)
TSIS-1, (2018)
ECOSTRESS, (2017)
GEDI, (2018)
OCO-3, (2018)
CLARREO-PF, (2020)
TSIS-2 (2020)
ISS
SORCE, (2017)
TCTE (NOAA)
NISTAR, EPIC (2019)
(NOAA'S DSCOVR)
QuikSCAT (2017)
EO-1 (2017)
Landsat 7 (USGS) (~2022)
SMAP (>2022)
Terra (>2021)
Aqua (>2022)
Suomi NPP (NOAA) (>2022)
CloudSat (~2018)
Landsat 8 (USGS) (>2022)
CALIPSO (>2022)
GPM (>2022)
Aura (>2022)
GRACE (2) (2018)
OSTM/Jason 2 (>2022) (NOAA)
OCO-2 (>2022)
InVEST/Cubesats
MiRaTA (2017)
RAVAN (2016)
IceCube (2017)
HARP (2017)
TEMPEST-D (2018)
RainCube (2018*)
CubeRRT (2018*)
CIRiS (2018*)
CIRAS (2018*)
LMPC (----)
*Target date, not yet manifested

Missions - Classification

Large Observatory	Focused	PI-Led	Instrument	Smallsat
Aqua	GPM	GRACE	RapidSCAT	CYGNSS* (8)
Aura	OCO-2	Cloudsat	CATS	TROPICS* (12)
Terra	Landsat-7		TEMPO*	RAVAN
Suomi-NPP	Landsat-8		RBI	MiRaTA
[JPSS-2]	Landsat-9		TSIS-1/2	ICECube
	GRACE-FO		MAIA*	HARP
	QuikSCAT		SAGE-III	TEMPEST-D
	EO-1		ECOSTRESS*	RainCube
	Calipso		GEDI*	CubeRRT
	NISAR		OCO-3	CIRAS
	ICESat-2		OMPS-Limb	CIRIS
	SWOT			
	NISAR			
	PACE			
	SMAP			
	Jason-2			
	Jason-3			
	Sentinel-6A/B			
	SORCE			
	PACE			
	[DSCOVR]			

*Earth Venture Instrument or Mission

Mission Schedules (Pre-Phase A through Phase E)



Note. Continuity for Jason CS/Sentinel 6A and Landsat-9 are planned through Jason CS/Sentinel 6B and Landsat-10, respectively.

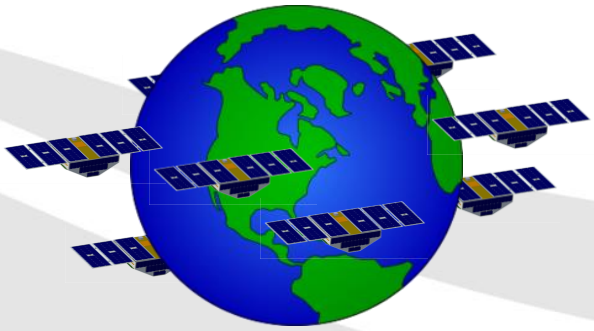
Recent Flight Mission Gate Review Progress

- RBI KDP-B: 29 March 2016
- **OCO-3 KDP-C: 12 May 2016**
- **SWOT KDP-C: 19 May 2016**
- **TSIS-1 KDP-C: 6 June 2016**
- **GEDI KDP-C: 9 June 2016**
- ***PACE KDP-A: 16 June 2016***
- ***Landsat-9 KDP-B: 14 July 2016/17 Aug 2016 (APMC)***
- **RBI KDP-C: 26 July 2016**
- **NISAR KDP-C: 23 Aug 2016**
- SAGE-III KDP-E: 27 Sept 2016
- CYGNSS KDP-E: 21 Oct 2016
- *CLARREO-PF KDP-A: Dec 2016*
- ~~ICESAT-2 KDP-D: Sept 2016~~

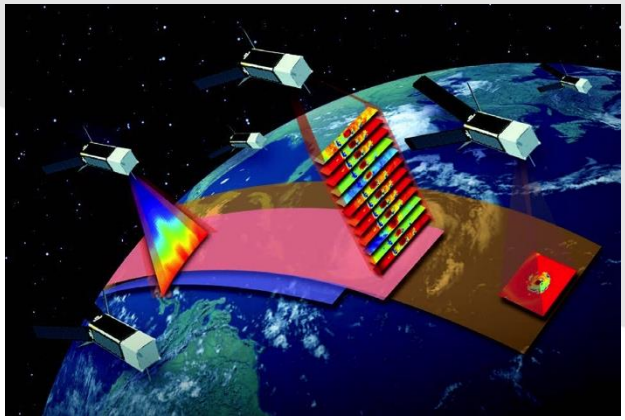
Legend:
Bold: Confirmation/KDP-C
Red: Initiation of new mission
Green: Near-future

Small Satellite CONSTELLATIONS

- Cyclone Global Navigation Satellite System (CYGNSS)
  - Selected under Earth Venture Mission-1 AO
  - 8-satellite Microsat Constellation to measure winds and air-sea interactions in tropical storms, using reflected GPS
  - Ready for launch scheduled for 21 Nov 2016
  - PI-led (C. Ruf, U. Michigan, plus SWRI)



- Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS)
  - Selected under Earth Venture Instrument-3 AO
  - 12-satellite Cubesat Constellation
  - First ***science-focused*** cubesat constellation
  - Targeted for launch in 2020, may use VCLS vehicle
  - PI-led (W. Blackwell, MIT, plus Lincoln Labs and WFF)



Small Satellite Constellation Initiative

- FY18 Budget augmentation to ESD to explore strategic approaches for the ***acquisition of measurements*** by small-satellite constellations, and the potential of these products to advance NASA's Earth system science and applications development goals.
- RFI ***NNL16ZB1006L*** released July 12, 2016; 4 responses received by August 12, 2016
  - Requested information about the feasibility of ***purchasing from the private sector, and evaluating, small-satellite data products*** that might augment or even replace NASA-collected data
  - Identified GNSS Radio Occultation (GRO) and moderate resolution, multispectral, spatially and temporally extensive land imaging data as possible acquisition targets
  - Strong industry responses (Planet, GeoOptics, Surrey, UrtheCast), including one cover letter stating, *"We applaud NASA for the foresight shown in this RFI call to move beyond the historical government-to-contractor relationship in favor of putting itself in the position of an interested consumer."*
- Will likely proceed with an RFP if Congress appropriates the FY17 budget request for ESD
  - The RFI noted that NASA may invest up to $25M total in ~2 data purchases in FY18

Venture Class Launch Services (VCLS)

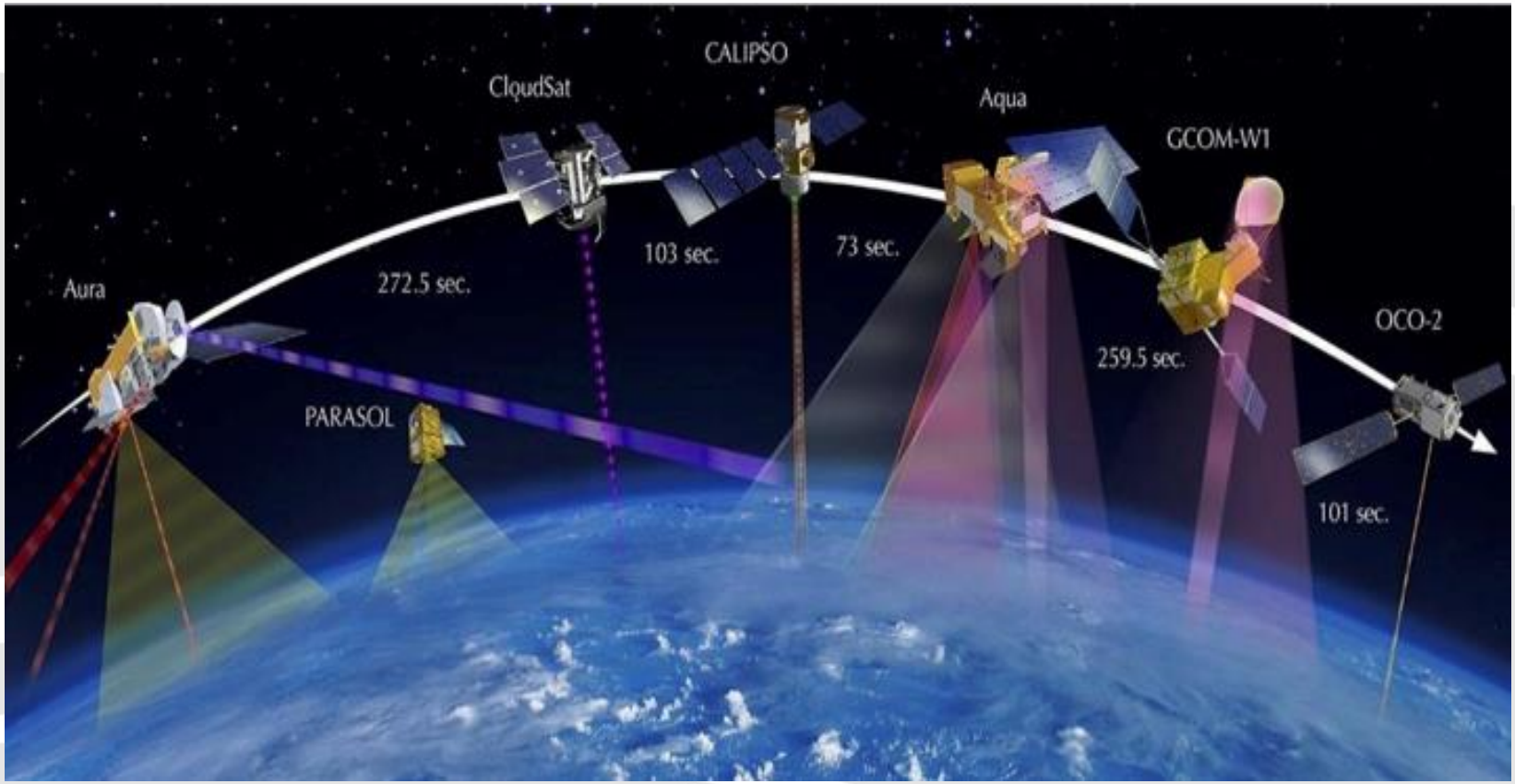
- Joint ESD/NASA Launch Services Program initiative
- RFP released 12 June 2015; Selections announced 14 Oct 2015
- Funded with $10M from ESD
  - Selected launches will:
    - Accommodate 132 pounds (60 kilograms) of CubeSats on 1 or more launches
    - Launch(es) must occur by April 15, 2018
- Selectees:
  - Rocket Lab USA, Inc. (first VCLS launch 6/2017)
  - Virgin Galactic LLC (first launch 7/2017, 1st VCLS launch 11/2017-4/2018)
  - Firefly Space Systems, Inc. (first VCLS launch 3/2018)
  - Total NASA costs per selectee/launch are < $15M

Tangible and substantial ESD investment in small launch vehicles

Committee Questions: Strategic Science

- For Earth system science and applications development/demonstration, strategic, integrative science requires sustained, frequent measurements of many different quantities (e.g., the GCOS “Essential Climate Variables”)
- Measurements are accumulated from the overall NASA (and other-organization) on-orbit portfolios
- Near-simultaneous sampling of different quantities from heterogeneous constellations has been demonstrated and used routinely (A-Train; TIR for Sentinel-2A planned by Europeans)
- Assimilative global, system models are developed both outside and within the NASA R&A program, with model outputs often used as proxy “data.”
- 2007 ESAS Decadal Survey did not recommend a single “flagship” mission for ESD or the nation – breakthrough science does not come from analysis of measurements from any single mission
- Overall Administration and private sector foci emphasize robust constellations of (possibly heterogeneous) small satellites/missions, not large flagship, strategic, single missions

Heterogeneous Mission Constellations: A-Train



Aqua (2002-present) - NASA
Aura (2004-present) - NASA
CALIPSO (2006-present) – NASA/CNES
CloudSat (2006-present) - NASA
GCOM-W1 (2012-present) - JAXA
PARASOL (2004-2013) – CNES
OCO-2 (2014 launch) - NASA

- **Coordinated formation-flying Multi-mission integrated, "near-instantaneous" products**
- **International participation (ex-PARASOL, GCOM-W)**

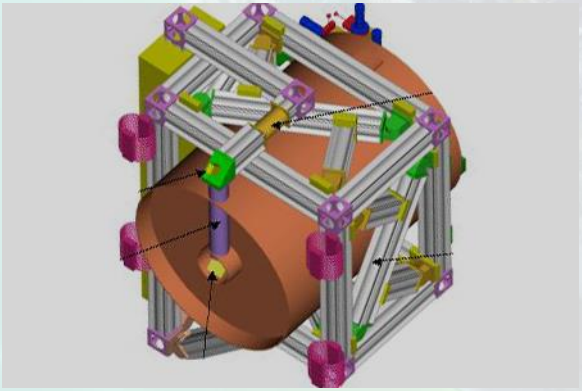
ESSP Missions – Earth Venture Overview

- A sustained, successful Venture-class element is a priority from the Decadal Survey
  - Advances science/applications and promotes community involvement through frequent, regular proposal opportunities
  - Ensures overall program scientific flexibility and responsiveness through constrained development schedules
- Complement the systematic missions, provide flexibility to accommodate scientific advances and new implementation approaches
- Can provide complementary science to the Decadal Survey Missions but does not replace them.
- ***All ongoing and planned investigations, solicitations, and selections are on track and fully funded***

3 “Strands”

Sub-Orbital

Small-sat/Missions



Instrument

Venture Class Selections/Solicitations

Mission	Mission Type	Release Date	Selection Date	Major Milestone
EVM-2	Full Orbital	FY15	FY16	Launch ~2021
EVI-4	Instrument Only	FY16	FY17	Delivery NLT 2021
EVS-3	Suborbital Airborne Campaigns	FY17	FY18	N/A
EVI-5	Instrument Only	FY18	FY19	Delivery NLT 2023
EVM-3	Full Orbital	FY19	FY20	Launch ~2025
EVI-6	Instrument Only	FY19	FY20	Delivery NLT 2024
EVI-7	Instrument Only	FY21	FY22	Delivery NLT 2026
EVS-4	Suborbital Airborne Campaigns	FY21	FY22	N/A
EVI-8	Instrument Only	FY22	FY23	Delivery NLT 2024

Open solicitation

Completed solicitation

EVS-1: CARVE, ATTREX, DISCOVER-AQ, AirMOSS, HS-3

EVM-1: CYGNSS (21 Nov 2016 LRD)

EVI-1: TEMPO (2019-; 2017 instrument delivery) – hosted payload on GEO comm sat

EVI-2: GEDI (2019; 2018 del.); ECOSTRESS (10/2017; 5/2017 del.)

EVS-2: ATom, NAAMES, OMG, ORACLES, ACT-America, CORAL

EVI-3: MAIA, TROPICS

EVM-2: *Selection(s) likely in Q4 CY2016*

Committee Questions: Capability and Leadership

- What concerns do you have about how long flagship missions take for development and the difficulty for young researchers or even potential future PIs to gain experience?
  - N/A
  - Vigorous program of directed instruments, cubesats (InVEST), Venture Class –Instrument and –Mission provide many frequent and varied opportunities for instrument PI's
- What is the value of flagship missions for science base concerns? Talent pools, corporate knowledge, continuity of capabilities etc., and the impact on the future health of this support base?
  - None
- What is the role of international [interagency] partnerships in strategic and flagship missions? How is this different for other classes of missions?
  - Only ESA has flown flagship ***research*** missions in the past 12 years; and now, with the Copernicus system, all future missions are focused
  - NOAA and EUMETSAT continue to develop and fly multi-instrument, strategic large observatories to support meteorological prediction
  - ESD participates in partnerships for focused and small missions

Committee Questions: Technology Development

- Do you have a separate technology development line?
  - Yes: The Earth Science Technology Office (ESTO) - ~$60M/year

Earth Science Technology

- Advanced technology plays a sustained role enabling Earth research, applications, and flight missions.
- The Earth Science Technology Program (ESTP) enables new science investigations; improves existing measurement capabilities; and reduces the cost, risk, and/or development time of earth science instruments and information systems.
- A rigorous approach to technology development is used through analyses of science requirements for technology needs; selecting and funding technologies through competitive solicitations and partnership opportunities; actively managing funded technology development projects; and facilitating the infusion of mature technologies into science campaigns and missions.

Advanced Technology Initiatives (ATI)

Advanced Component Technologies (ACT) - development of critical components and subsystems for instruments and platforms
Future solicitations planned in FY17 and FY20

In-Space Validation of Earth Science Technologies (InVEST) - on-orbit technology validation and risk reduction for small instruments and instrument systems that could not otherwise be fully tested on the ground or in airborne systems
Future solicitations planned in FY18 and FY21

Instrument Incubator Program (IIP) - robust new instruments and measurement techniques
Future solicitations/selections planned in FY16 and FY19

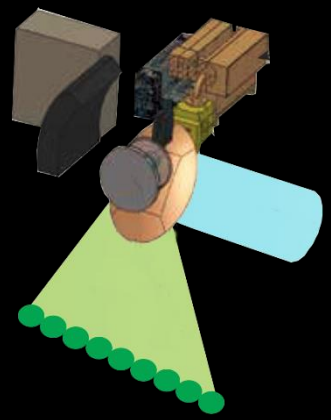
Advanced Information Systems Technology (AIST) - innovative on-orbit and ground capabilities for communication, processing, and management of remotely sensed data and the efficient generation of data products
Future solicitations/selections planned in FY16, FY18 and FY20

U-Class Candidate Development Satellites

ESTO Technology Developments for Future Earth Science Measurements

Venture Tech

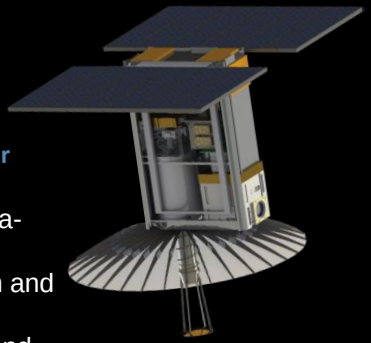
TEMPEST-D
Colorado State University



5 Frequency mm-Wave Radiometer
Technology demonstrator measuring the transition of clouds to precipitation

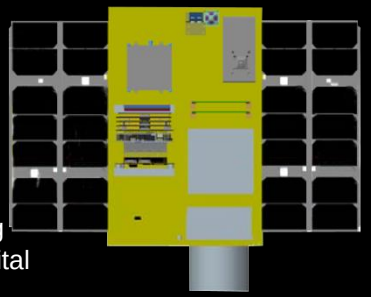
ESTO InVEST 2015 Program

RainCube
Jet Propulsion Lab

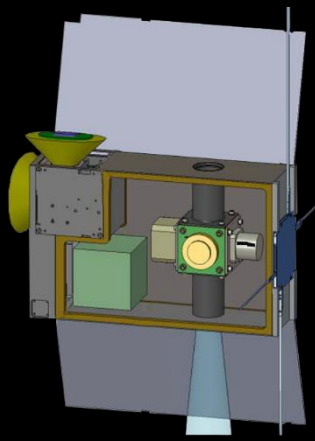


Precipitation Radar
Validate a new architecture for Ka-band radars on CubeSat platform and an ultra-compact deployable Ka-band antenna

CubeRRT
Ohio State University

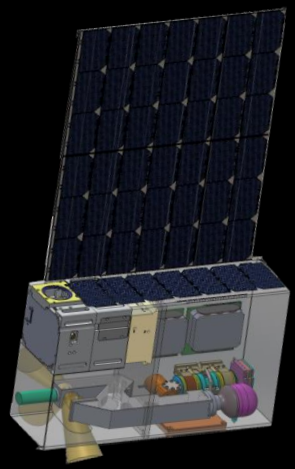


Radiometer RFI
Demonstrate wideband RFI mitigating backend technologies vital for future space-borne microwave radiometers



CIRiS
Ball Aerospace

Infrared Radiometer
Validate an uncooled imaging infrared (7.5 um to 13 um) radiometer designed for high radiometric performance from LEO



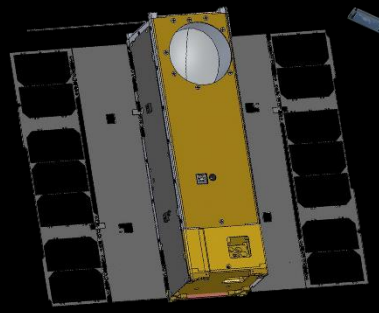
CIRAS
Jet Propulsion Lab

Infrared Atmospheric Sounder
Demonstrate ability to measure spectrum of upwelling infrared radiation and validate 2D infrared detector material, a micro pulse tube cryocooler, and a grating spectrometer

ESTO InVEST 2012 Program

U-Class Satellites Advancing TRLs for Future Earth Science Measurements

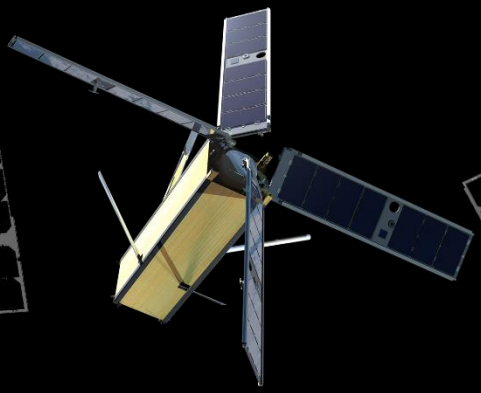
MiRaTA
MIT / MIT-LL



3 Frequency Radiometer and GPSRO

Validate new microwave radiometer and GPSRO technology for all-weather sounding

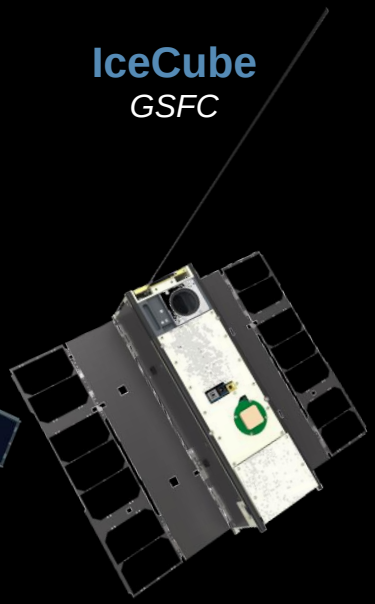
RAVAN
APL



Vertically Aligned Carbon Nanotubes (VACNTs)

Demonstrate VACNTs as radiometer absorbing material and calibration standard for total outgoing radiation

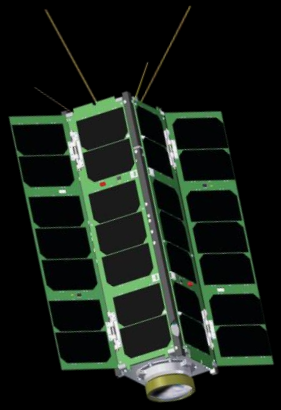
IceCube
GSFC



874 GHz submm-Wave radiometer

Validate sub-mm radiometer for spaceborne cloud ice remote sensing

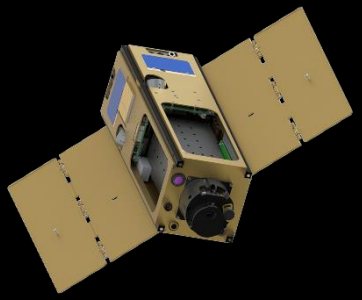
HARP
UMBC



Wide FOV Rainbow Polarimeter

Demonstrate 2-4 km wide FOV hyperangular polarimeter for cloud & aerosol characterization

LMPC
The Aerospace Corporation



Photon Counting InfraRed Detector

Demonstrate linear mode single photon detector at 1, 1.5, and 2 microns in space environment

Sustainable Land Imaging (SLI)

- A 3-component program – in partnership with USGS – for a sustainable, continuous, global land imaging system through 2035, consistent with the existing 44-year Landsat record:
  - **Landsat 9** (fully Class-B rebuild of Landsat 8) targeted to launch in FY 2021
    - Low programmatic risk implementation of a proven system with upgrades to bring the whole system to Class B – includes 30 m res. multispectral and 120-m thermal IR measurements (like Landsats 7, 8)
  - **Land Imaging Technology and Systems Innovation**
    - Hardware and data processing investments to reduce risk in next generation missions and inform future system architecture decisions
  - **Landsat 10** (Class B multispectral and Thermal IR) to launch ~2027-2028
    - Mission architecture to be informed by the technology investments (2015-), leading to mission definition ~2020

Earth Science Technology Highlight

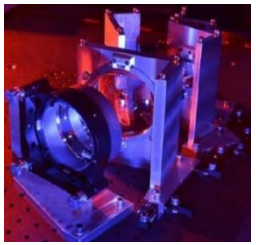
Six Projects Awarded under Sustainable Land Imaging-Technology (SLI-T)

On August 2, six new projects (of 33 received proposals) were announced under the first solicitation of the Sustainable Land Imaging-Technology (SLI-T) program (element A.47 of ROSES-15). The SLI-T program was created to research, develop, and demonstrate new measurement technologies that improve upon current land imaging capabilities, while at the same time reducing the overall program cost for future measurements.

This first solicitation sought proposals to:

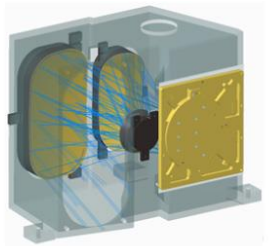
- Demonstrate **improved, innovative, full-instrument concepts** for potential infusion into the architecture and design of Landsat-10; and
- Develop and mature technologies that have **long-term potential to significantly improve future land imaging instruments and systems** through substantial architecture changes.

The first-year funding for these investigations is approximately $6.5M.



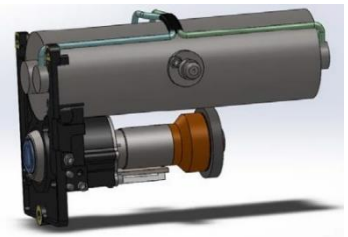
Compact Hyperspectral Prism Spectrometer (CHPS)
PI: Thomas Kampe, Ball Aerospace & Technologies Corporation

Advanced Technology Land Imaging Spectroradiometer (ATLIS)
PI: Jeffery Puschell, Raytheon Corporation



Integrated Photonic Imaging Spectrometer
PI: Stephanie Sandor-Leahy, Northrup Grumman Systems Corporation

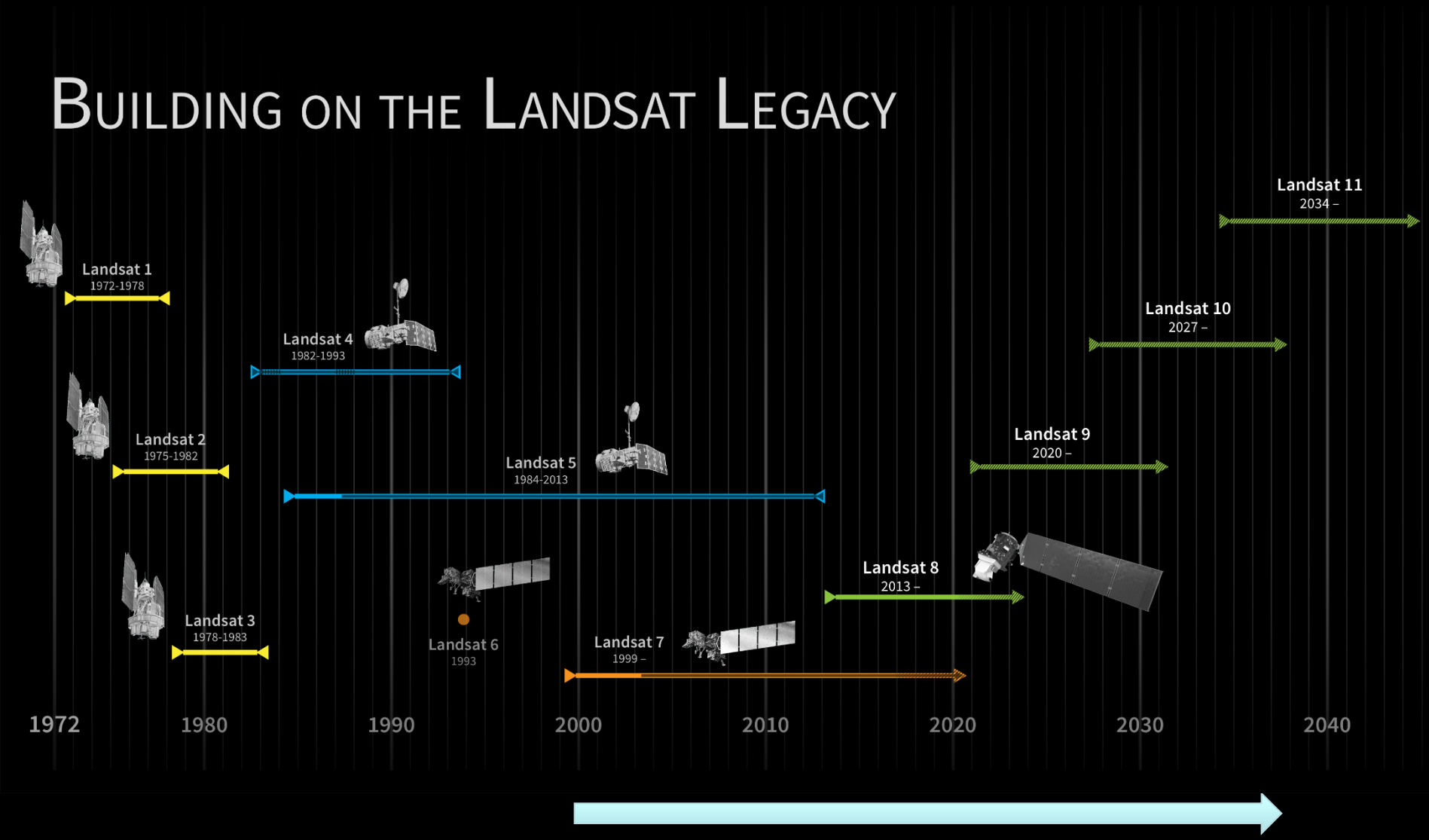
Reduced Envelope Multi-Spectral Imager (REMI)
PI: Paula Wamsley, Ball Aerospace & Technologies Corporation



Long Wavelength Infrared Focal Plane Array for Land Imaging
PI: David Ting, Jet Propulsion Laboratory

Multi-Spectral, Low-Mass, High-Resolution Integrated Photonic Land Imaging Technology - PI: Ben Yoo, University of California, Davis

Building on the Landsat Legacy



NASA-USGS Interagency Partnership
- NASA: Space Segment and Launch
- USGS: Operations & Data Processing/Distribution

Committee Questions: Technology Development

- Do you primarily use flagship missions for technology development?
  - No. Technology development is done primarily – almost exclusively – in ESTO.
  - Cat-III selections as technology development (not mission) elements are managed by ESTO (e.g. TEMPEST-D, Green-OAWL, both resulting from EVI-2)
- Can you afford the risk of including new technologies on flagship missions?
  - No. ESD does not originate flagship missions. Bad experiences with partner-developed new-technology instruments on partner-originated flagship missions (e.g., VIIRS on Suomi-NPP). Focused-but-strategic missions (e.g. Landsat) generally involve partner (non-space) agencies and communities who are risk-averse and schedule/performance sensitive.
- Can you do technology development with smaller size missions?
  - Yes. When developed in a mission context outside of ESTO, the new technology is confined to non-threshold capabilities (e.g. Laser Ranging Interferometer on GRACE-FO)
- Do you treat new technology at all differently on flagship missions vs. small missions (by, for example, incentivizing missions to use new technologies)?
  - N/A

Committee Questions: Cost Control for Large Missions

- How do cost overruns on flagship class missions affect the other mission classes in your portfolio?
  - N/A – No ESD flagship missions. Any cost overrun on a directed mission is accommodated within the ESD budget (or mission is terminated - e.g. GPM LIO) with due regard to balance and priorities into the future.
  - Venture Class budget and solicitation cadence are never changed to accommodate other ESD budget needs.
- How do you address cost overruns on flagship missions vs. how you address cost overruns on smaller class missions?
  - N/A – No difference, no flagship missions.
  - Venture Class cost caps are ***scrupulously*** observed – no exceptions, ever.