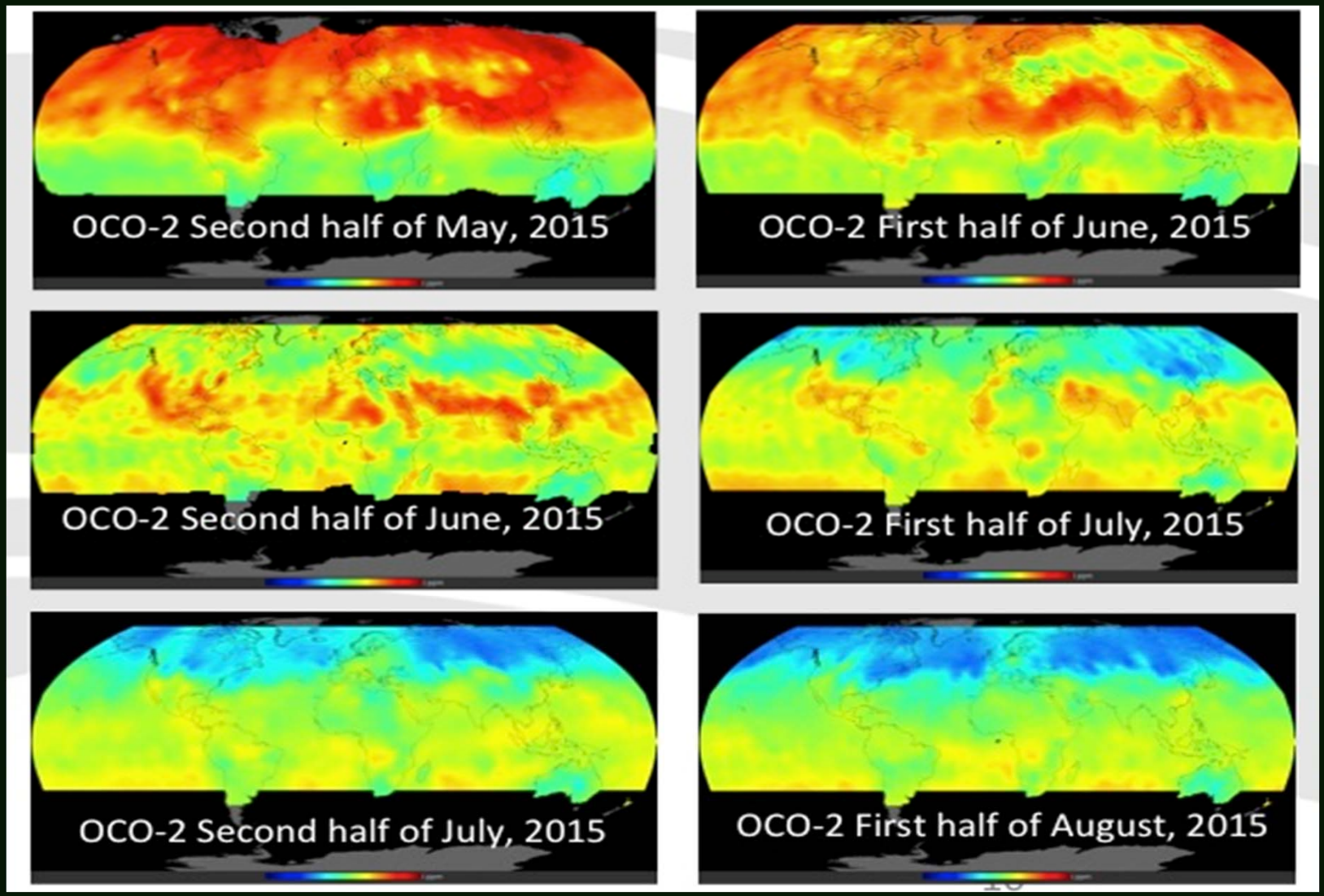
Earth Science Division Overview



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)

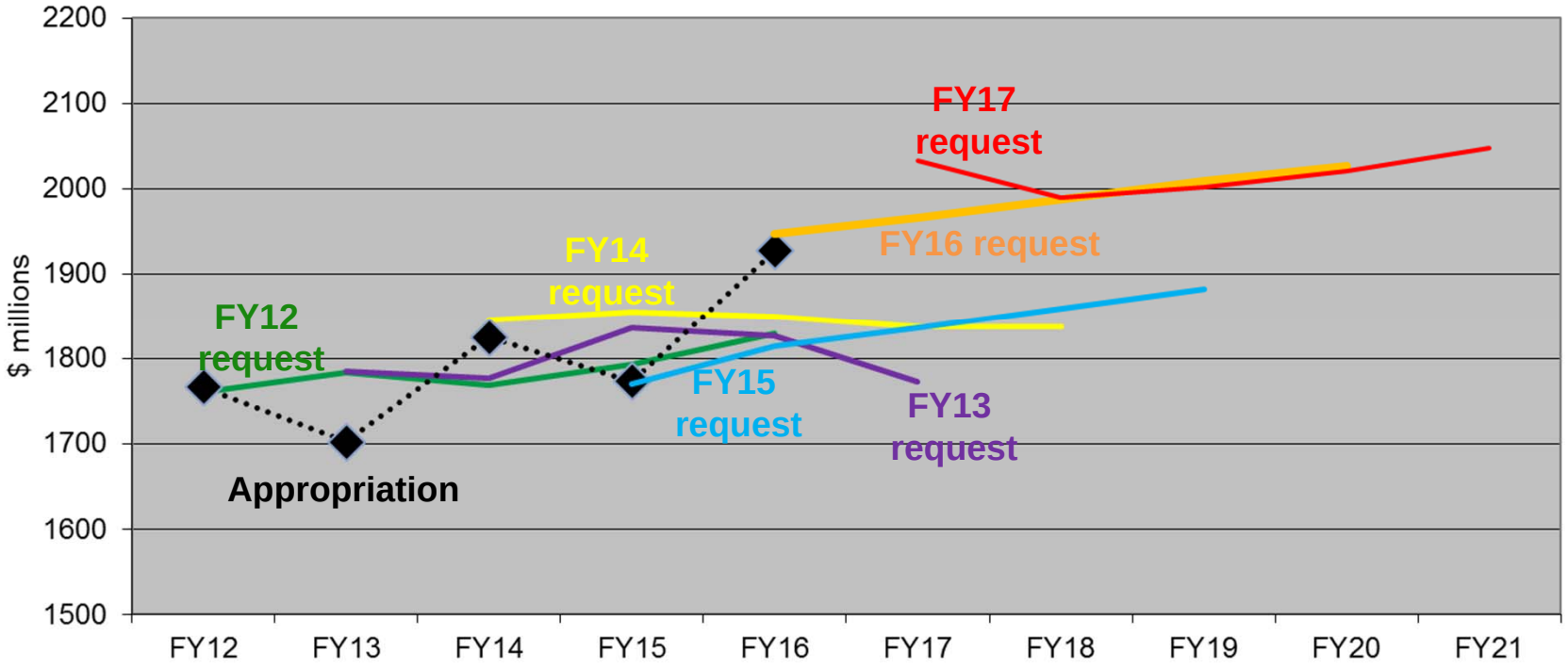
- **SOCIETAL BENEFIT and CAPACITY BUILDING:** **Develop and test new information products** that are **tailored to the needs of end users**; **increase users' capacity** to exploit the information

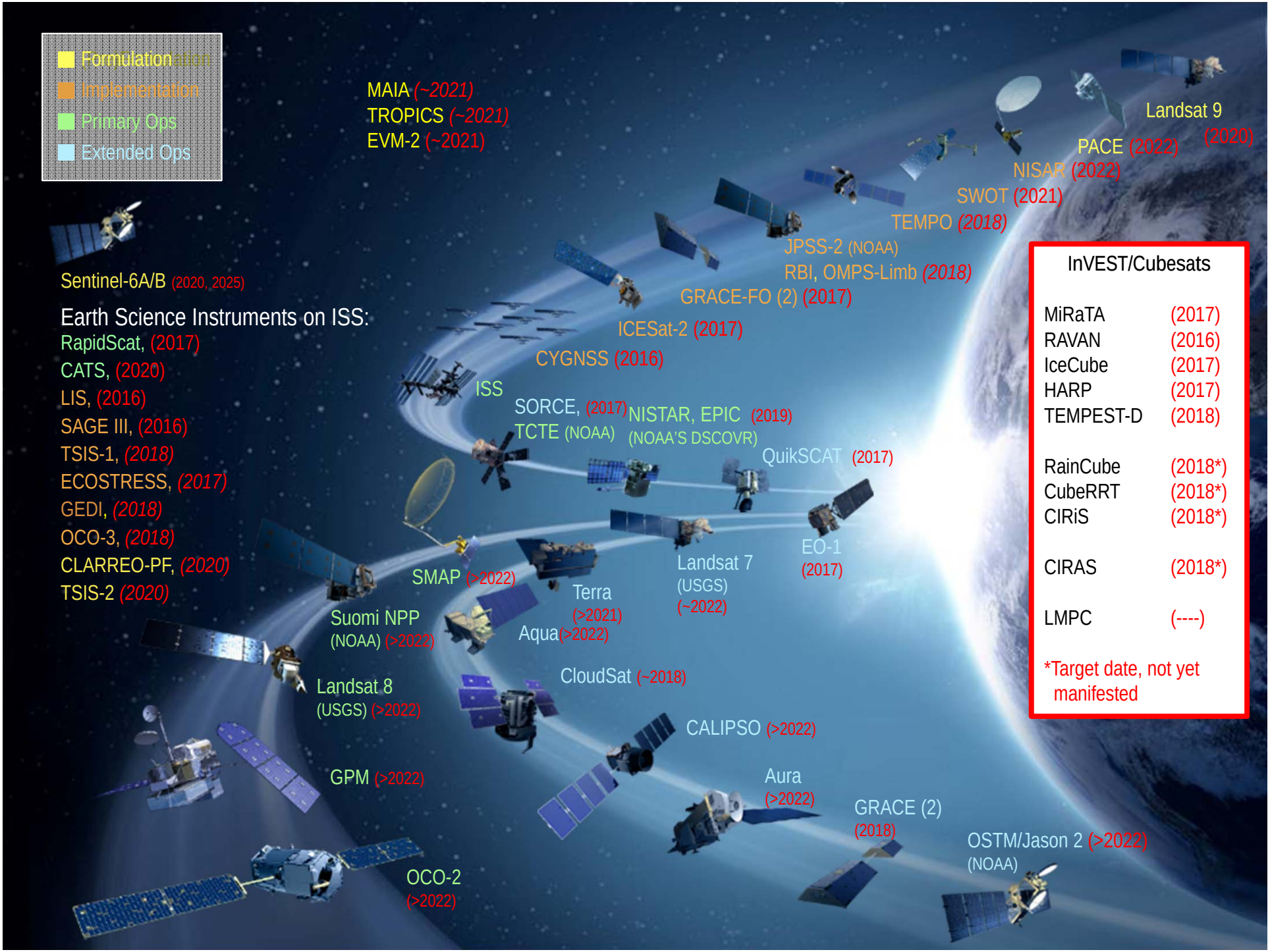
- **TECHNOLOGY DEVELOPMENT:** **Advance instrument, data processing, and communications technologies** to support new missions, research, and applications

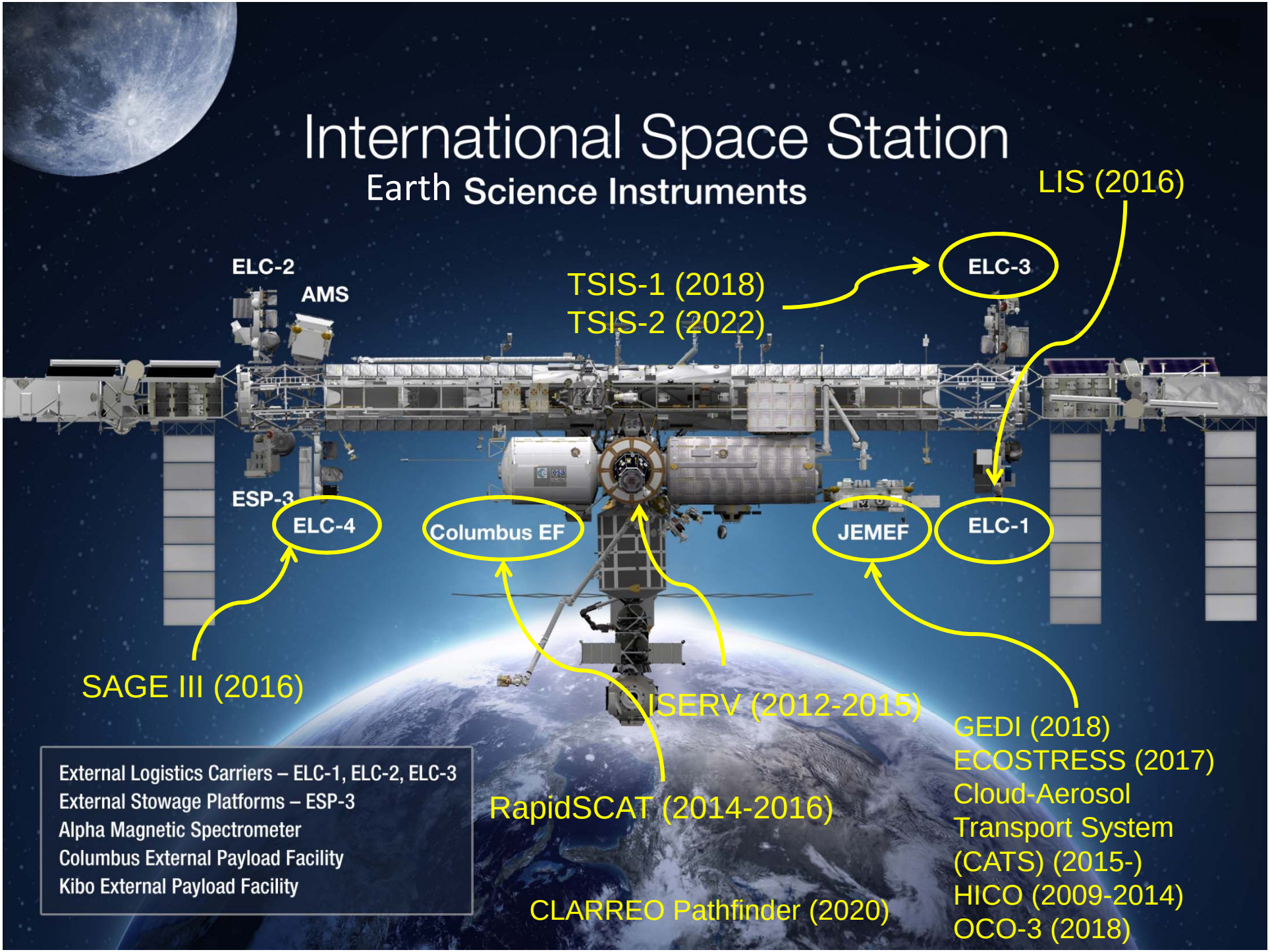
ESD Budget: FY17 Request/Appropriation

ESD Total						
$M	**FY16 (op plan)**	**FY17**	**FY18**	**FY19**	**FY20**	**FY21**
FY16 PBS	$ 1,927	$ 1,966	$ 1,988	$ 2,009	$ 2,027	
FY17 PBS		$ 2,032	$ 1,990	$ 2,001	$ 2,021	$ 2,048

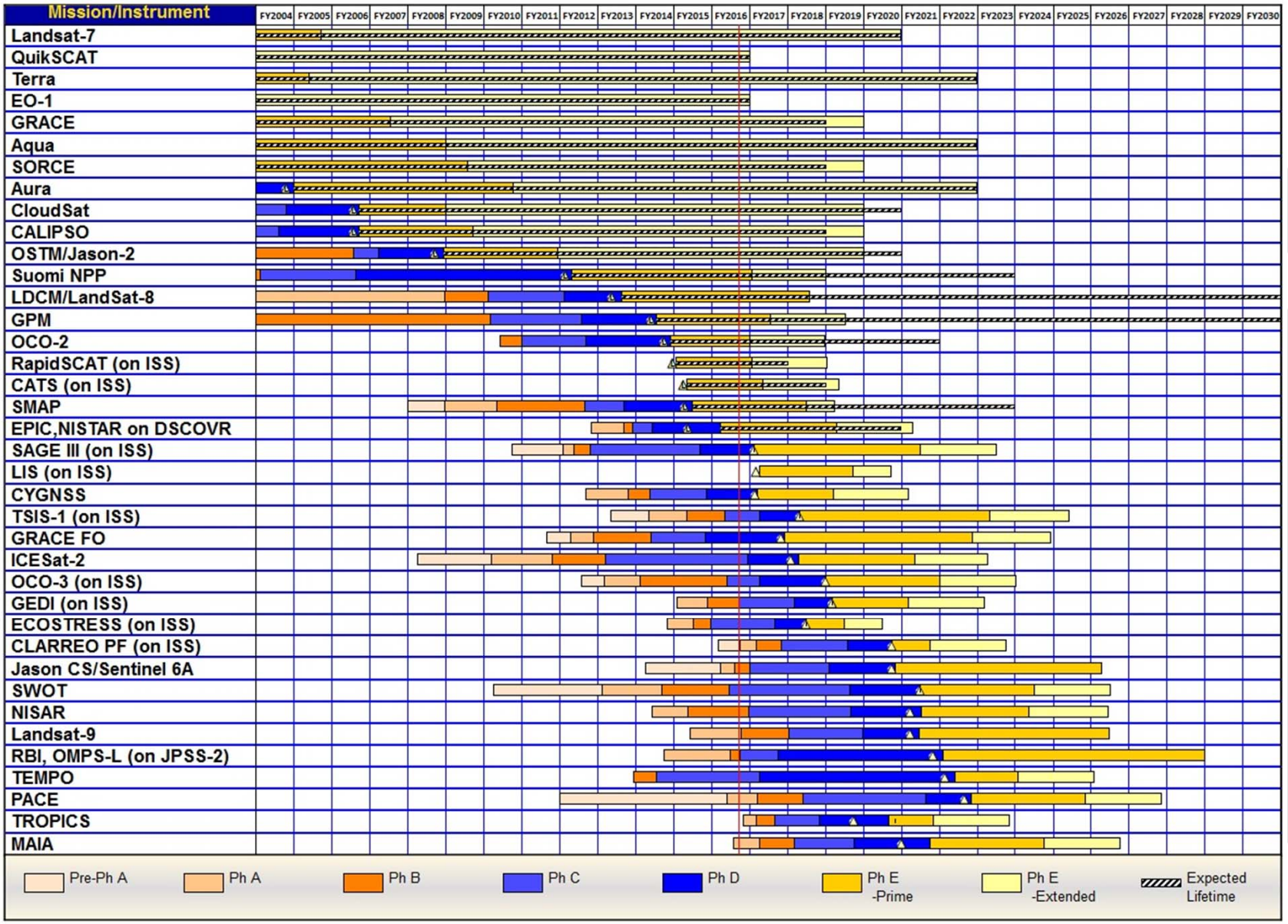
- *ESD budget jumps significantly in FY17 – then becomes consistent with FY16 President's Budget Request for the out-years*




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


International Space Station
Earth Science Instruments
LIS (2016)
ELC-2
AMS
TSIS-1 (2018)
TSIS-2 (2022)
ELC-3
ESP-3
ELC-4
Columbus EF
JEMEF
ELC-1
SAGE III (2016)
ISERV (2012-2015)
GEDI (2018)
ECOSTRESS (2017)
Cloud-Aerosol Transport System (CATS) (2015-)
HICO (2009-2014)
OCO-3 (2018)
RapidSCAT (2014-2016)
CLARREO Pathfinder (2020)
External Logistics Carriers – ELC-1, ELC-2, ELC-3
External Stowage Platforms – ESP-3
Alpha Magnetic Spectrometer
Columbus External Payload Facility
Kibo External Payload Facility

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.

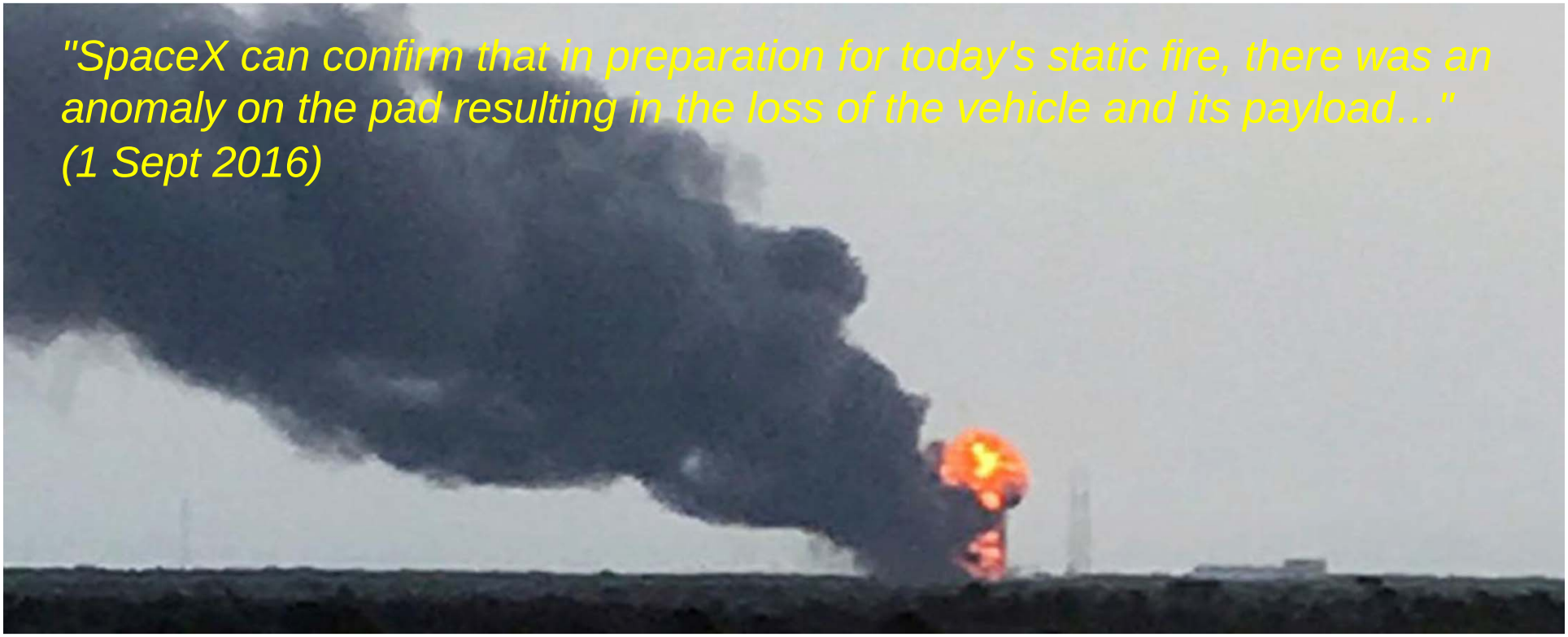
Recent Flight Mission Gate Review Progress

- 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~~

Impact of SpaceX Launch Vehicle Failure

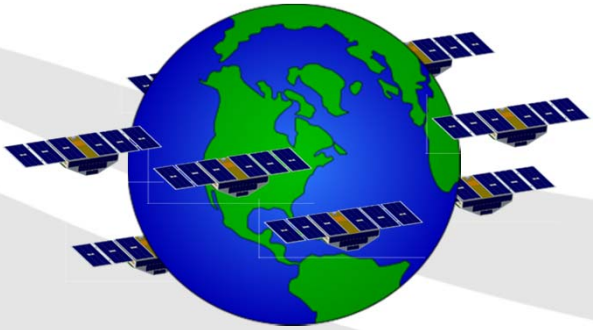
ESD has 6 missions planned for launch on Falcon 9, through 2018

	Current	With Project UFE	With HQ UFE
SAGE-III on ISS	January 2017	January 2017	June 2017
TSIS-1	September 2017	February 2018	March 2019
GRACE-FO	December 2017	February 2017	December 2019
ECOSTRESS	April 2018	April 2018	August 2020
OCO-3	October 2018	October 2018	> October 2020
GEDI	December 2018	December 2018	June 2019

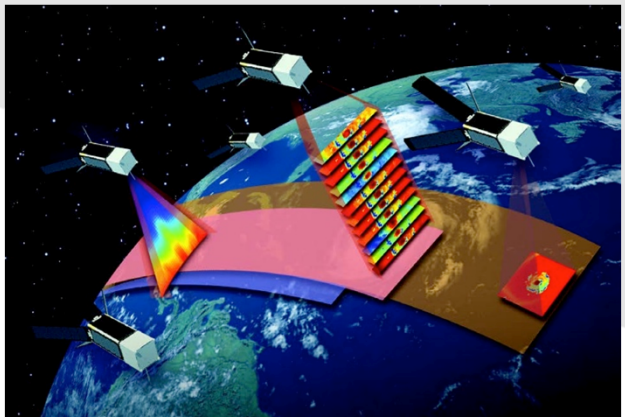


Small Satellite CONSTELLATIONS

- 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

Research & Analysis Element Major Program Areas

- Competed individual investigator science – ~1300 awards at NASA centers, universities, laboratories of other government agencies, and private/non-profit sectors
  - *Disciplinary-based programs* - Solicitations tied to individual and/or closely-related programs within each of NASA's six interdisciplinary science focus areas:
    - Carbon Cycle and Ecosystems
    - Climate Variability and Change
    - Atmospheric Composition
    - Global Water and Energy Cycle
    - Earth Surface and Interior
    - Weather
  - *Interdisciplinary and cross-disciplinary programs* – Solicitations that cut across traditional disciplinary and/or focus area boundaries, or support entire R&A program;
  - *Competed science teams for NASA missions* – Solicitations tied to individual or closely-associated NASA satellite missions;
  - *Field campaigns that integrate surface-based, airborne, and satellite observations using large scale models* - Solicitations for short-duration field campaigns to study Earth system processes and contribute to or benefit from satellite observations.
- Enabling capabilities
  - *Airborne Science* - Maintain and operate a fleet of aircraft and associated systems and associated systems that support the entire Earth Science program;
  - *Scientific Computing* - Maintain and operate high end computing systems that support Earth system modeling, data assimilation, and large scale data analysis;
  - *Calibration/Validation and Complementary Surface Observations and Facility Airborne Instruments* - Provide capability that supports and complements NASA's satellite program;
  - *Modeling and Assimilation Systems for Community Use* - Maintain and further develop modeling systems for use by the entire NASA earth science community.

Mission	Location(s)	Date(s)	Platform(s)	Summary of Mission
Aviris NG India	Hyderabad India	Dec 15 – Spring 16	B200 (ISRO aircraft)	Imaging spectroscopy science and application investigation over Indian territory
AfriSAR/G-TEC	Gabon Africa	Feb – Mar 16	B200, C20A	NASA/ESA collaboration on algorithm development and future mission cal/val activities for above-ground biomass and ecosystem structure and dynamics usint radar and lidar.
Korus-AQ	Korea	Spring 16	DC8, B200	Study sources of pollution in atmosphere over Korea and Western Pacific region using a mix of in situ and remote sensing capability while enhancing understanding of future geostationary atmospheric composition observations
Atmospheric Carbon and Transport – America	Eastern and Midwestern US	Summer 16, Spring 17, Fall 17, Summer 18	B200, C-130	Quantify the sources of regional carbon dioxide, methane and other gases, and document how weather systems transport these gases in the atmosphere; improve identification and predictions of carbon dioxide and methane sources and sinks over the eastern US
North Atlantic Aerosols and Marine Ecosystems Study (NAAMES)	Atlantic Ocean, flown from Canada	Sep 17, Mar/Apr 18,	C-130, Ship ((UNOLS) research vessel)	Environmental and ecological controls on plankton communities in the North Atlantic Ocean
Coral Reef Airborne Laboratory (CORAL)	FL, HI, Mariana Is., Palau, Australia	Apr 16 – Jan 17	Contracted GIV	Provide critical data and new models needed to analyze the status of coral reefs and to predict their future
ObseRvations of Aerosols Above Clouds and Their IntEractionS (ORACLES)	Namibia, Africa	Aug/Sep 16, Jul/Aug 17, Sep/Oct 18	P-3, ER-2	Investigate how smoke particles from massive biomass burning in Africa influences cloud cover over the Atlantic.
Oceans Melting Greenland (OMG)	Greenland	Sep/Oct 16 - + multiple till Sept/Oct 2019	Contracted Twin Otter, GIII, Ship (MV Cape Race)	investigate the role of warmer saltier Atlantic subsurface waters in Greenland glacier melting. The study will help pave the way for improved estimates of future sea level rise.
Atmospheric Tomography Experiment (ATom)	Around the Globe	Aug 16, Jan/Feb 17, Sep/Oct 17, Apr/May 18	DC-8	Study the impact of human-produced air pollution on multiple greenhouse gases, addressing transformation of various air pollutants, especially methane and ozone.
O2/N2 Ratio and CO2 Airborne Southern Ocean (ORCAS)	Southern Ocean	Jan/Feb 16	GV (NSF)	NASA brings remote sensing (PRISM) capability to NSF-led mission to Investigate the large-scale tropospheric distributions, gradients, and fluxes of O2 and CO2 over Southern Ocean.
HyspIRI	Hawaii	Winter 17	ER-2	Study the optical characteristics of coral reef and volcanic systems in and around Hawaii using MASTER and AVIRIS to assess value of HysPIRI-like observations
Operation IceBridge	Alaska, Greenland, Antarctica	Mar – May, Oct/Nov – FY16,17,18,19	P-3, DC-8	Study ice sheet thickness, sea ice distributions, and related parameters over Arctic and Antarctic to bridge gap between ICESat-1 and ICESat-2, complement lidar observations with those using related techniques (e.g., radar) and obtain coincident data with ESA CryoSat-2
UAVSAR	Various US and South America	Year round	C-20	Radar data collected for multiple NASA focus areas (Earth Surface and Interior, Carbon Cycle and Ecosystems, Global Water and Energy Cycle, Climate Variability and Change) and for Applications Uses (e.g., levee monitoring)
SPURS II	Eastern Sub-Tropical Pacific Ocean	Starting spring 2016, multiple sailings covering 18 month period	Schooner Lady Amber plus in-water observations (e.g., gliders, drifters, buoys)	Study processes that control sea surface salinity in higher salinity region than that sampled in SPURS I (sub-tropical North Atlantic)
ABoVE	Alaska, NW Canada	Beginning 2016, continuing	Surface measurements; airborne to follow	Study vulnerability and resilience of Arctic ecosystems to environmental change in the Arctic and boreal region of western North America

Applied Sciences

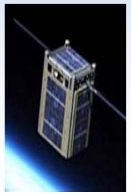
- The NASA Applied Sciences program leverages NASA Earth Science satellite measurements and new scientific knowledge to enable near-term uses of earth science knowledge and discoveries, demonstrates new applications, and facilitates early adoption of applications by public and private sector stakeholder organizations.
- The Program funds projects that enable innovative uses of NASA Earth science data in organizations' policy, business, and management decisions. The project results and enhanced decision making improve the quality of life and strengthen the economy.
- The Applied Sciences program includes three lines of business:
  - **Applications** address disasters, ecological forecasting, health and air quality, water resources, and wild fires.
  - **Capacity Building** works with users in the U.S. and developing countries to improve skills and workforce by applying Earth observations.
  - **Satellite Mission/Information Use Planning** engages users to envision potential applications for future Earth-observing satellites, helping them prepare to use the data and further enhance the value of each satellite mission.

Earth Science Technology

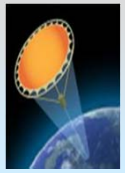
- Advanced technology plays a sustained role enabling Earth research, applications, and flight missions.
- The Earth Science Technology Program (ESTP) enables new science investigations; improves existing measurement capabilities; and reduces the cost, risk, and/or development time of earth science instruments 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



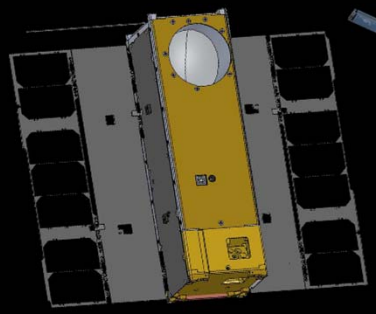
Instrument Incubator Program (IIP) - robust new instruments and measurement techniques
Future solicitations/selections planned in FY16 and FY19

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

ESTO InVEST 2012 Program

U-Class Satellites Advancing TRLs for Future Earth Science Measurements

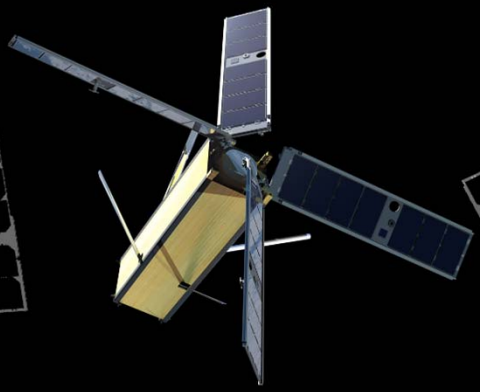
MiRaTA
MIT / MIT-LL



3 Frequency Radiometer and GPSRO

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

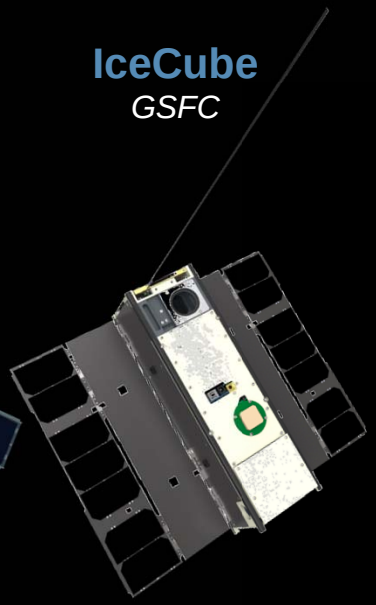
RAVAN
APL



Vertically Aligned Carbon Nanotubes (VACNTs)

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

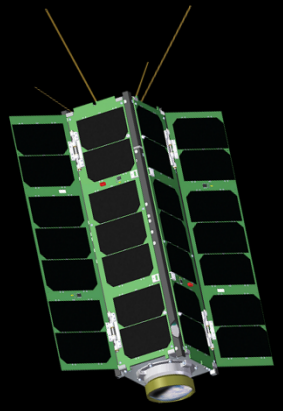
IceCube
GSFC



874 GHz submm-Wave radiometer

Validate sub-mm radiometer for spaceborne cloud ice remote sensing

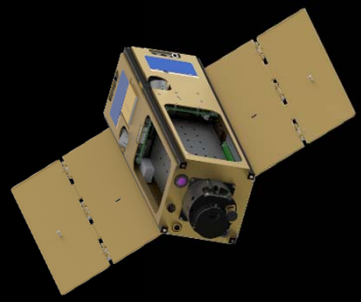
HARP
UMBC



Wide FOV Rainbow Polarimeter

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

LMPC
The Aerospace Corporation



Photon Counting InfraRed Detector

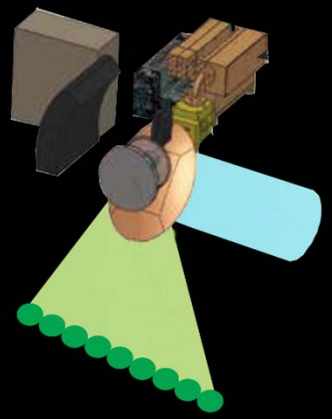
Demonstrate linear mode single photon detector at 1, 1.5, and 2 microns in space environment

U-Class Candidate Development Satellites

ESTO Technology Developments for Future Earth Science Measurements

Venture Tech

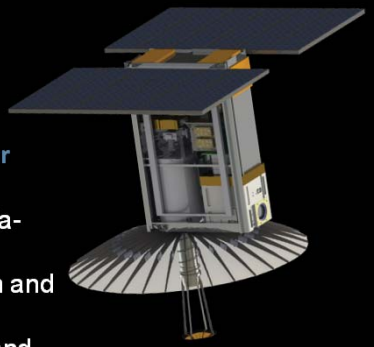
TEMPEST-D
Colorado State University



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

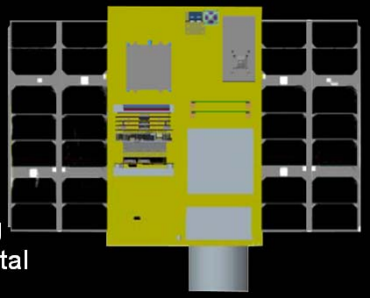
ESTO InVEST 2015 Program

RainCube
Jet Propulsion Lab

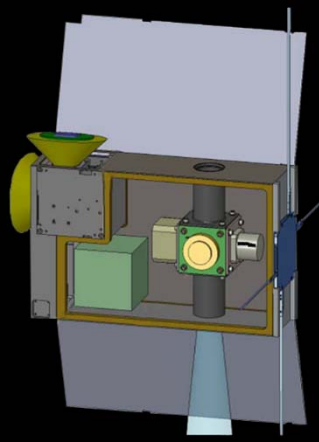


Precipitation Radar
Validate a new architecture for Ka-band radars on CubeSat platform and an ultra-compact deployable Ka-band antenna

CubeRRT
Ohio State University

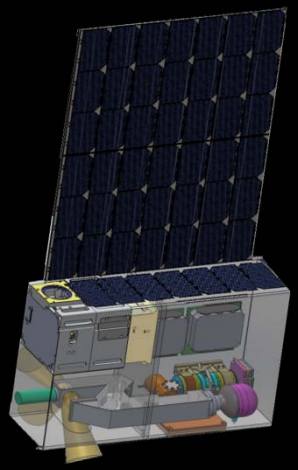


Radiometer RFI
Demonstrate wideband RFI mitigating backend technologies vital for future space-borne microwave radiometers



CIRiS
Ball Aerospace

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



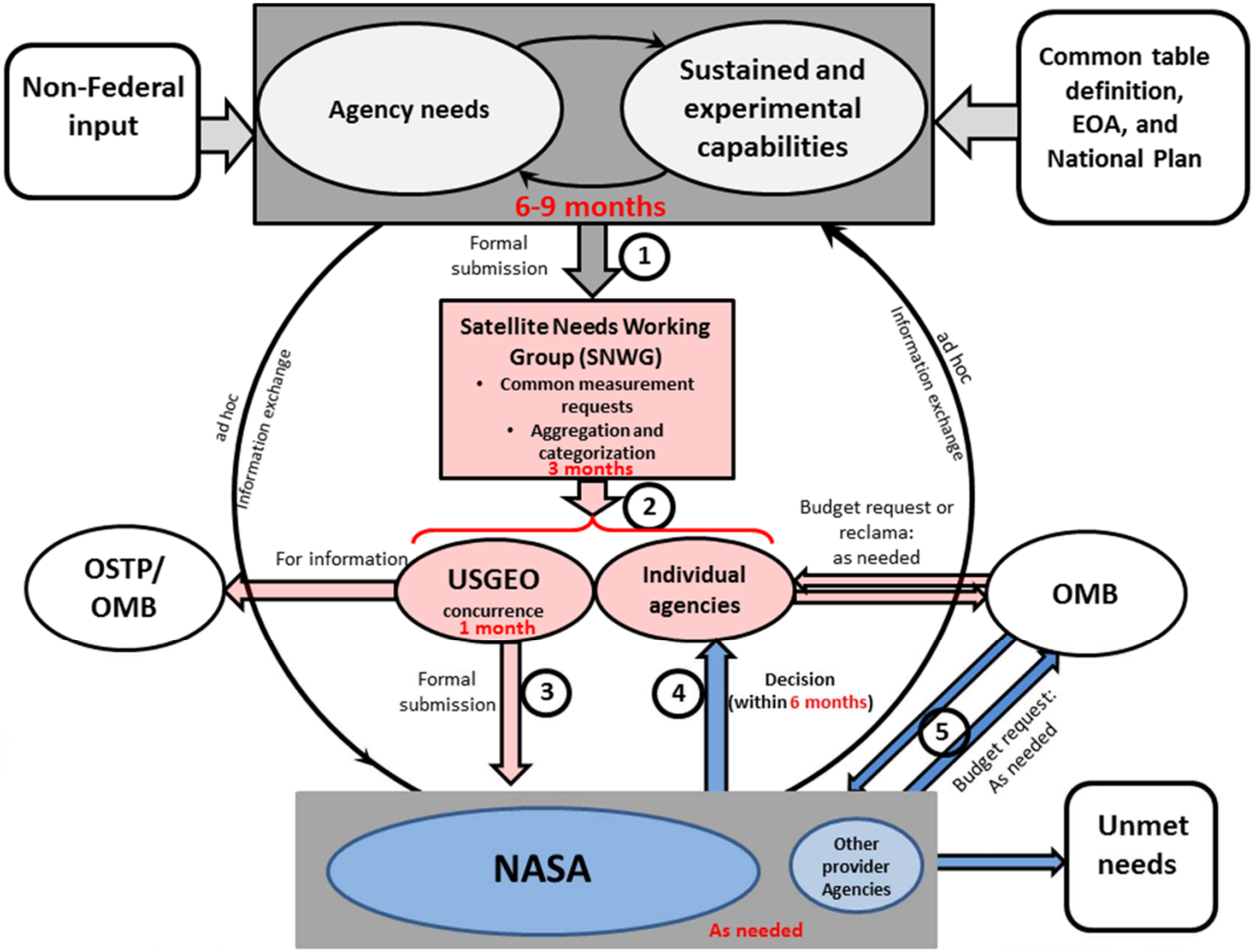
CIRAS
Jet Propulsion Lab

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

Production Cycle

Satellite Needs Process



NASA Role Summary

NASA Role/Responsibilities

The agencies' needs serve as inputs into NASA decisions on which satellite measurements to fund. NASA develops its own process to learn about the inputs and assess them.

NASA engages user agencies in trade-offs of end-to-end costs, capabilities, and risks to see to what extent it can serve the need.

NASA will look at creative ways to support inputs; it may take some iteration, and it may take seeing if an achievable 80% solution is better than an unachievable 100% one.

NASA Outputs

NASA provides to OMB and OSTP a supplement to its budget request that explains how it addressed user agency inputs.

Responses to user agencies are expected within 6 months of their submission. NASA may provide responses to an agency in stages based on the input and NASA's assessment of its ability to satisfy needs.

If the learning, assessment, and response on some inputs take more than 6 months, NASA notifies the agency and USGEO.

USGEO/SNWG Production Cycle Timeline

June 17: Kick Off Meeting for 2016-2017 Satellite Needs Process

September 1: Needs submission cut off

September 12: SNWG returns submissions to agencies for senior review

October 7: Agencies' reviews returned to SNWG

Nov. 1: SNWG passes needs to USGEO Subcommittee for concurrence

Dec. 1: NASA receives inputs from USGEO and begins analysis and interactions

June 1, 2017: NASA completes analysis and provides responses to agency needs

Sept. 1, 2017: With budget submit, NASA submits info to OMB and OSTP on how it adjudicated the inputs

Selected Mission Descriptions/Status

ESSP Program/Missions – Overview

- The Earth System Science Pathfinder (ESSP) program now provides frequent, regular, Earth science flight and airborne data acquisition opportunities that address and advance new and emerging scientific priorities and measurement capabilities. Recommended in the 2007 Decadal Survey, ESSP funds relatively low-cost, schedule constrained, Principal Investigator-led, competitively selected, science-driven investigations and missions.

- The present ESSP Program consists of two primary sets of missions
  - **ESSP Missions:** On-orbit missions competitively selected and launched prior to the establishment of the Earth Venture program
    - ESSP AO-1: Gravity Recovery and Climate Experiment (GRACE; launched 3/2002)
    - ESSP AO-2: Cloudsat; Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO; launched 4/2006)
    - ESSP AO-3: Orbiting Carbon Observatory (OCO – launch vehicle failure 2/2009); Aquarius (joint with Argentine Space Agency; 6/2011– 6/2015)
    - Other: OCO-2 (launched 7/2014); OCO-3/ISS

  - **Earth Venture – 3 solicitation/mission strands**
    - Earth Venture – Suborbital: Airborne Investigations (solicited every 4 years)
    - Earth Venture – Instruments: Missions of opportunity on host platforms (solicited every 18 months)
    - Earth Venture – Missions: complete spaceflight missions (solicited every 4 years)

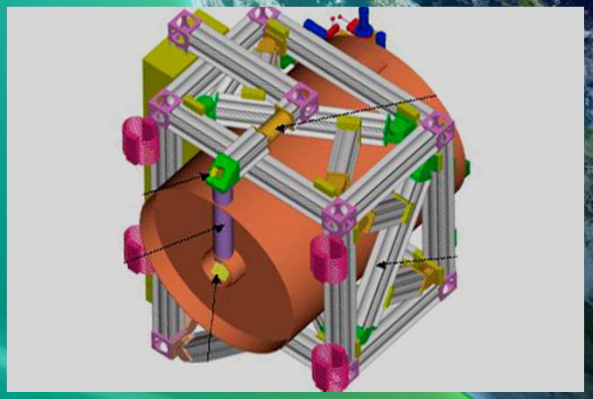
ESSP Missions – Earth Venture Overview

- 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

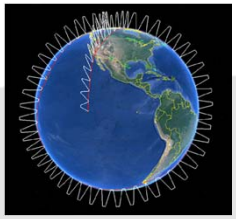
EVI-2: GEDI (2019; 2018 del.); ECOSTRESS (10/2017; 5/2017 del.)

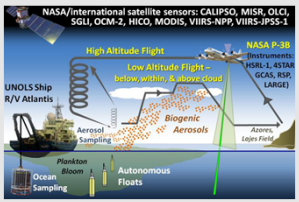
EVS-2: ATom, NAAMES, OMG, ORACLES, ACT-America, CORAL

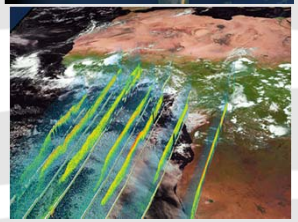
EVI-3: MAIA, TROPICS

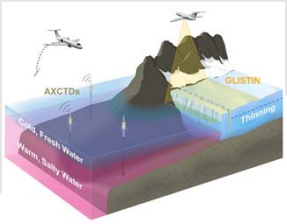
EVM-2: *Selection(s) likely in Q4 CY2016*

Earth Venture Suborbital-2 (EV-2) Investigations









Atmospheric Tomography Experiment (ATom) – Harvard University (Steve Wofsy)

Study the impact of human-produced air pollution on certain greenhouse gases. Airborne instruments will look at how atmospheric chemistry is transformed by various air pollutants and at the impact on methane and ozone which affect climate. Flights aboard NASA's DC-8 will originate from the Armstrong Flight Research Center in Palmdale, California, fly north to the western Arctic, south to the South Pacific, east to the Atlantic, north to Greenland, and return to California across central North America.

North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) – Oregon State U. (Mike Behrenfeld)

Improve predictions of how ocean ecosystems would change with ocean warming. The mission will study the annual life cycle of phytoplankton and the impact small airborne particles derived from marine organisms have on climate in the North Atlantic. The large annual phytoplankton bloom in this region may influence the Earth's energy budget. Research flights by NASA's C-130 aircraft from Wallops Flight Facility, Virginia, will be coordinated with a University-National Oceanographic Laboratory System (UNOLS) research vessel.

Atmospheric Carbon and Transport – America – Penn State University (Kenneth Davis)

Quantify the sources of regional carbon dioxide, methane and other gases, and document how weather systems transport these gases in the atmosphere. The research goal is to improve identification and predictions of carbon dioxide and methane sources and sinks using spaceborne, airborne and ground-based data over the eastern United States. Research flights will use NASA's C-130 from Wallops and the UC-12 from Langley Research Center in Hampton, Virginia.

ObseRvations of Aerosols Above Clouds and Their IntEractionS (ORACLES) – ARC (Jens Redemann)

Probe how smoke particles from massive biomass burning in Africa influences cloud cover over the Atlantic. Particles from this seasonal burning that are lofted into the mid-troposphere and transported westward over the southeast Atlantic interact with permanent stratocumulus "climate radiators," which are critical to the regional and global climate system. NASA aircraft, including a Wallops P-3 and an Armstrong ER-2, will be used to conduct the investigation flying out of Walvis Bay, Namibia.

Oceans Melting Greenland (OMG) – JPL (Josh Willis)

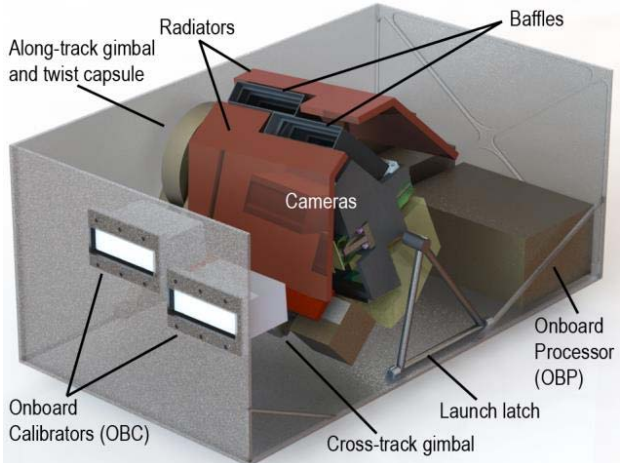
Investigate the role of warmer saltier Atlantic subsurface waters in Greenland glacier melting. The study will help pave the way for improved estimates of future sea level rise by observing changes in glacier melting where ice contacts seawater. Measurements of the ocean bottom as well as seawater properties around Greenland will be taken from ships and the air using several aircraft including a NASA G-III from Johnson Space Center and a Gulfstream III from Armstrong.

COral Reef Airborne Laboratory (CORAL) – Bermuda Institute of Ocean Sciences (Eric Hochberg)

Provide critical data and new models needed to analyze the status of coral reefs and to predict their future. CORAL will provide the most extensive picture to date of the condition of a large portion of the world's coral reefs and will reveal trends between coral reef condition and biogeophysical forcings, both natural and those arising from human activities. Measurements will be taken from commercial aircraft with the JPL PRISM Ocean Color instrument as well as by in water measurements of reefs in Palau, Mariana Islands, Hawaii, and the Great Barrier Reef in Australia.

MAIA

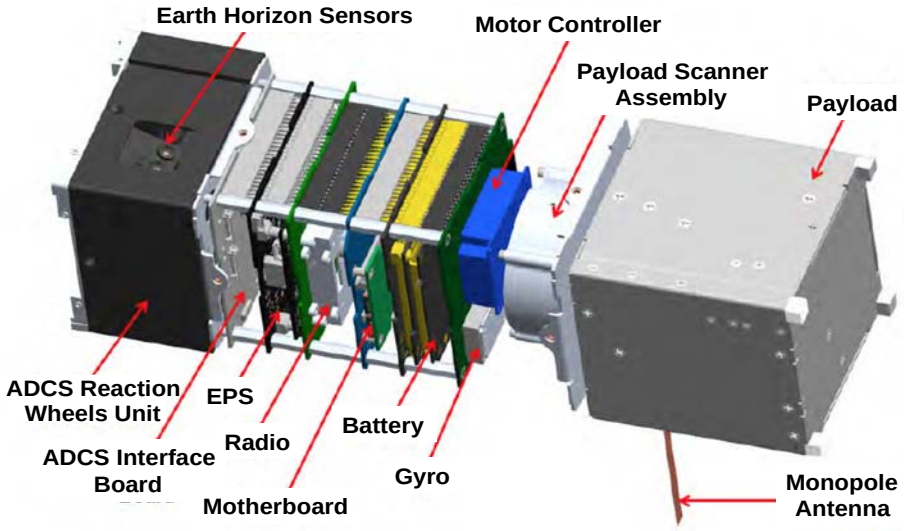
MAIA will determine the relative toxicity of different particulate matter (PM) types by size and species, and concentration, and assess the impacts of particle size and composition on adverse birth outcomes, cardiovascular and respiratory disease, and death.



- NASA will provide a unique air quality measurement at high spatial resolution for environmental health research that could have profound impact on society.
- As an instrument, MAIA is the most comprehensive and sophisticated aerosol measurement instrument ever put on a satellite. Multi-angle, multi-wavelength, polarimetric measurements will provide the most comprehensive retrievals of aerosol properties from space.
- Using satellites to get ground level PM concentration and their chemical compositions is novel and revolutionary to the environmental health community. Ground-stations are not sufficient for the assessment of correlations between exposure and health because of the sparse network and the large spatial variability of pollutants.
- The investigation responds to priorities of national and international institutions (research, health, and political), including the US EPA, NIH, and NAS, and the WHO.

TROPICS

TROPICS will use a global constellation of CubeSats to determine the relationships among rapidly evolving storm structures and storm intensity.

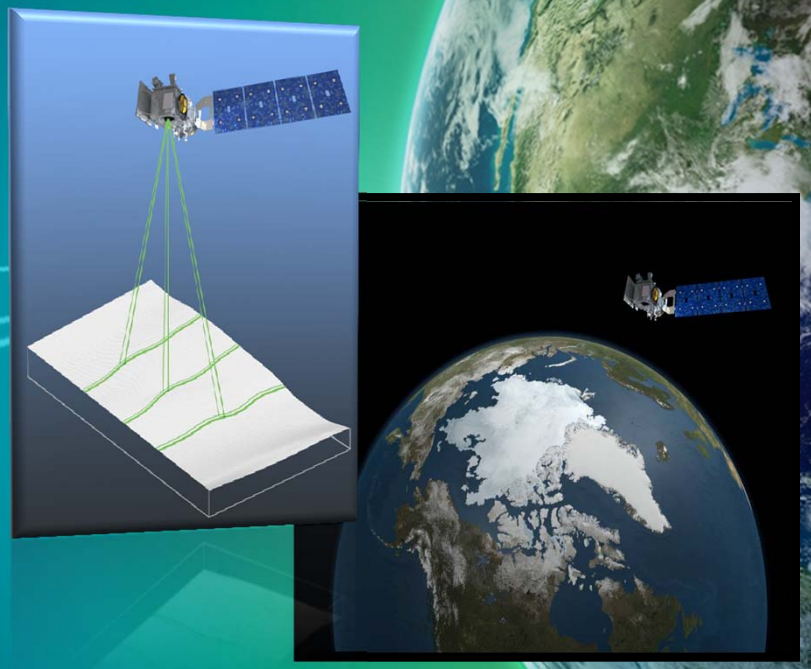


- This investigation will be the first demonstration that low-cost CubeSat technologies can push the frontiers of spaceborne monitoring of the Earth to enable system science. The constellation will also be the first demonstration of the high time resolution, resilient, networked observational capability of CubeSats.
- Mission will fill gaps in our knowledge of the short time scale—hourly and less—evolution of tropical cyclones. Our current abilities are an order of magnitude slower.
- TROPICS has the potential to make precipitation measurements globally, expanding on the coverage of the GPM core observatory mission and adding to the heterogeneous GPM constellation.
- The goals are well aligned with national and NASA priorities related to mitigating risk from extreme weather.

Ice, Cloud, and land Elevation Satellite (ICESat) – 2: Mission Summary

Benchmark Earth Observing System mission for measuring ice sheet mass balance, cloud and aerosol heights, as well as land topography and vegetation characteristic

- ICESat-2 is a Tier-One mission recommended by the 2007 *Earth Science and Applications* ***Decadal Survey***
- ICESat-2 is a spaceborne mission designed to collect precision laser altimeter measurements of the Earth's surface, ***optimized*** to measure ice sheet heights and polar ice freeboard, and ***contributing*** vegetation canopy height measurements for ecosystem studies.
- ICESat-2 is a Category 1 project (NPR 7120.5E) & payload risk class C (NPR 8705.4)
- ICESat is in Phase C
- Primary mission operation is planned for 3 years
- Life Cycle Cost: $1064M
- Development Cost: $764M
- Development Cost to go: $268M
- Launch Readiness Date: 6/2018 – *under review*



ICESat-2 Developments Since the Project KDP-C

- The ICESat-2 mission was baselined in December 2012 at the Key Decision Point-C (KDP-C) review and the Agency Baseline Commitment (ABC) parameters were established as indicated in the table below
- The single ICESat-2 instrument, the Advanced Topographic Laser Altimeter System (ATLAS), showed sharp cost and schedule performance erosion in January 2013 with missed milestones and increasing cost liens
- Throughout 2013, the project and instrument teams conducted in depth re-evaluations of all the mission systems with specific focus on the ATLAS instrument, leading to a revised assessment for the cost and schedule required to complete the ICESat-2 mission
  - This work was coordinated with the SMD and Agency stakeholders, including the Standing Review Board (SRB), GSFC, and the ESD
- On 28 May 2014 the re-baseline plan was reviewed and approved by the Agency Program Management Council. The new updated parameters are indicated below.

	Agency Baseline Commitment (ABC)	
	KDP-C	**Rebaseline**
Development Costs (Phases C & D)	558.8	763.7
TOTAL COSTS	860.2	1063.5
Schedule – Launch Readiness Date	May 2017	June 2018
Years of Operations	3 years	3 years

- Section 103(d)(2) Breach Report sent to Congress July 2014
- Progress from May 2014 Rebaseline to June 2016 was excellent
  - May 2015 DPMC provided $11M HQ-held UFE to adjust MA LRD from 31/10/2017 to 19/12/2017 owing solely to range manifest issues
- ***A recent serious anomaly with one of the flight lasers requires re-design and/or re-work***

ICESat-2 Technical Status Summary

- Spacecraft
  - The following issues have been closed with successful rework as needed: Reaction Wheel Assembly Drag Torque, Mux Failure on the TIB2A board on the IEM A side, Solar Array Release Mechanism firing sequence, and Solar Array Hinge Design
  - The S-band Transceiver experienced an anomaly during environment testing
    - At the cold plateau in thermal vacuum when in the low data rate, the receiver toggled between being locked and not locked when no up link signal was present
    - The responsible vendor (General Dynamics) continues to investigate – this issue is expected to be resolved with minimal impact
- Ground System
  - Mission Operations Review successfully completed Aug 2-3, 2016
  - Observatory Operations Simulator used for successful simulation at Mission Operations Center in July 2016
  - Mission Operations Center Build 4.1 SW installed; associated System Acceptance Test ongoing
  - SIPS Operational hardware received and being configured in the Operations Environment
- Launch Services
  - United Launch Alliance and the NASA Launch Services Program (LSP) remain on schedule with all mission launch integration activities
  - The ICESat-2 / Delta II Launch Vehicle ICD is mature
  - United Launch Alliance Mission-Specific Critical Design Review on-track for 29 September 2016
  - All Delta II Launch Vehicle production activities will complete by October 2016

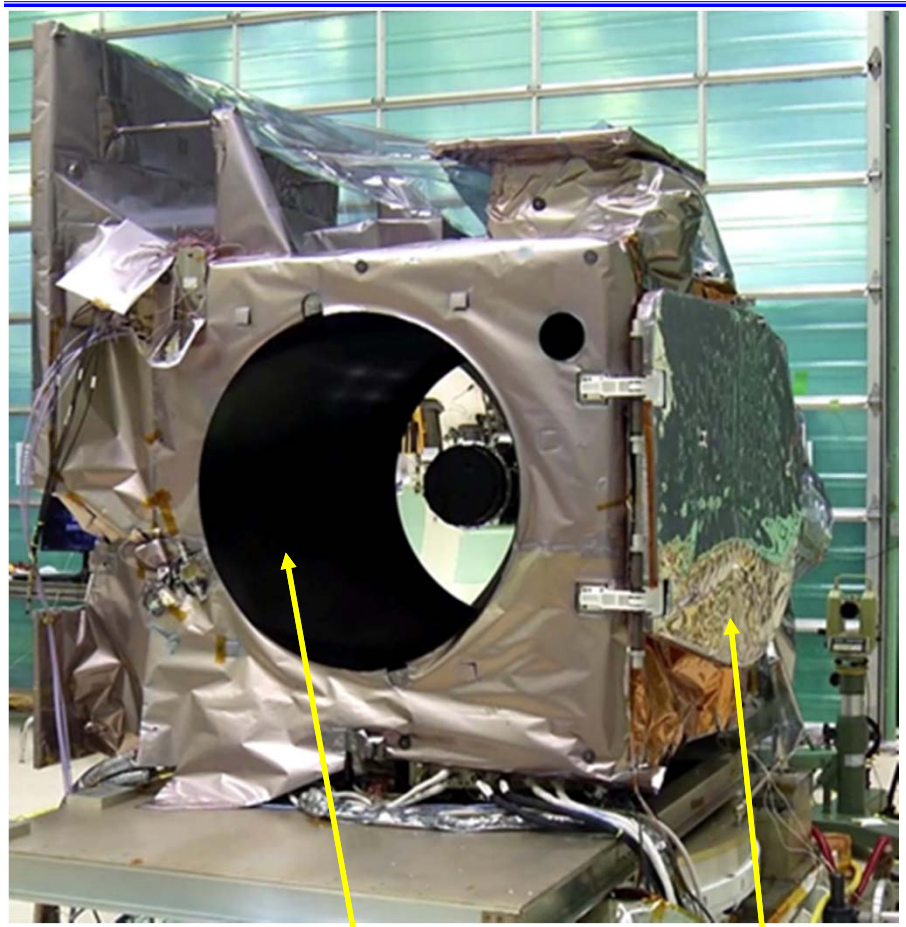
ATLAS Instrument – Technical Issue with Laser002

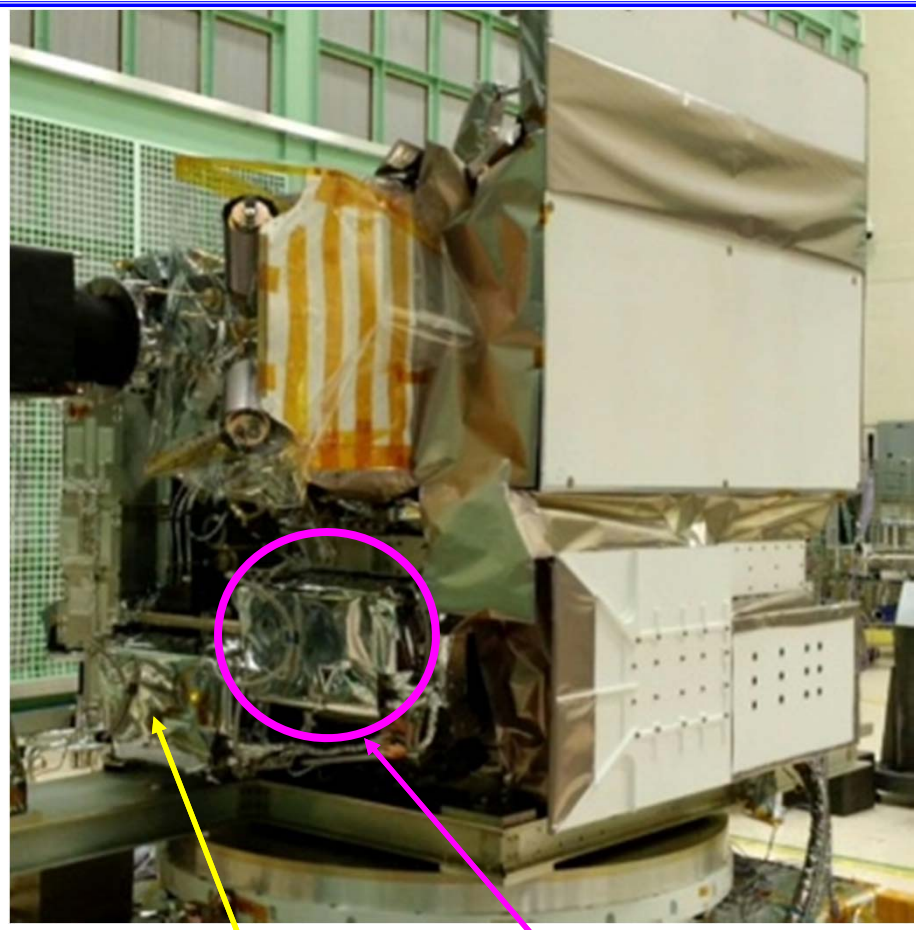
- The ATLAS instrument completed integration and testing campaigns for Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) and Vibration
- During Thermal Vacuum (TVac) testing, Laser002 (the second of two onboard flight lasers) exhibited a performance anomaly
  - During one of several start-ups, the Laser002 pre-amplifier, amplifier, and Second Harmonic Generator (SHG) energy monitors dropped suddenly
  - After the drop, the pre-amplifier, amplifier, and SHG energy levels increased, and started to oscillate
  - Subsequent turn-ons of Laser002 (post-anomaly) energy monitors and ATLAS Start Pulse Detector (SPD) energy readings slowly varied, eventually stabilizing at lower than nominal values (~70 to 80% of nominal)
- Ongoing investigation and repair of Laser002
  - The Thermal Vacuum testing was suspended and Laser002 was de-integrated from ATLAS and returned to the vendor, Fibertek
  - Fibertek completed disassembly and initial inspection of Laser002 pre-amplifier assembly
  - The crystal optical slab within the pre-amplifier assembly fractured towards the center at a point where thermal stress is low indicating proximate cause was mechanical stress from mount clamp assembly (~1cm from pump face)
  - Observed uneven intermetallic growth on mount and clamp surface indicating poor contact between these surfaces
  - Completed X-ray tomography of Laser002 pre-amplifier assembly and observed non-uniform intermetallic growth between slab and clamp/mount surfaces
  - Ongoing review of mount re-work/re-design options with Fibertek

ICESat-2 Executive Summary

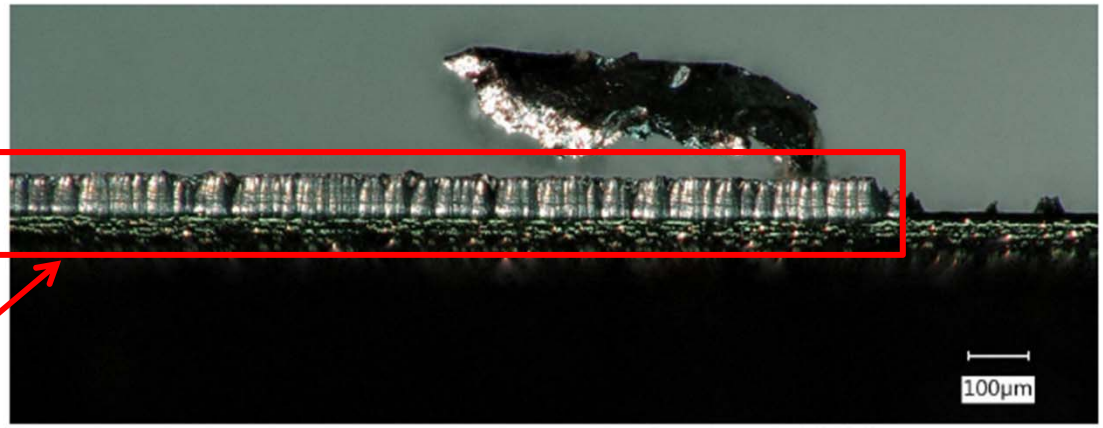
- ICESat-2 remains an important mission for Science and for NASA
  - –NASA is committed to its successful completion
- The mission addresses key issues in climate and cryospheric science while providing foundational supporting measurements for ecosystem, carbon, and vegetation studies
- The ICESat-2 team has consistently held its new schedule since the Rebaseline (May 2014)
- Beyond the ATLAS instrument, all other ICESat-2 systems are nearing completion including spacecraft, launch vehicle, algorithms, operations planning, and ground systems
- The mission requirements remain intact through the ongoing flight Laser002 repair
  - –The ATLAS management and engineering team has crafted and is implementing a conservative plan to address the recent Laser002 optical slab fracture
  - –Ongoing analysis, testing, re-design, and re-work of the flight lasers will likely delay launch by 9-11 months from the Management Agreement
- Although planning and schedule impact remains a work in progress, the new launch readiness date will probably be July-September 2018, 1-3 months beyond our Agency Baseline Commitment
- The cost impact of laser re-work will most likely be covered within the existing ICESat-2 ABC budget of $1064M

The Integrated ATLAS Instrument



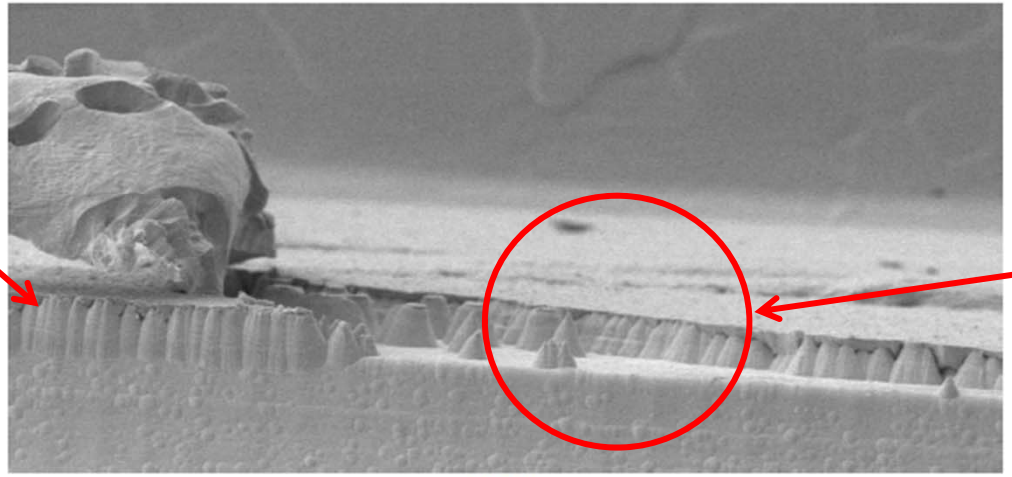


Laser002 Pre-Amp Gold-Indide Growth (1 of 2)



Optical

Gold-Indide intermetallic growth



SEM

Non-uniform intermetallic growth

Scanning Electron Microscope (SEM) and optical images show non-uniform intermetallic growth between the crystal slab and the clamp

Factors Contributing to Crystal Slab Fractures

1. Externally applied stresses
   - Clamp/mount packaging induced stresses that were exacerbated by non-uniform growth of gold-indide intermetallic
     - The amount of gold-indide was significantly higher than expected suggesting that the gold layer may not have been controlled
   - Clamping force was on the crystal (not on the clamp as intended)
   - The flight assemblies have a high pre-load
2. Slab defects
   - Crystal flaws and microcracks resulted in latger-than-expected strength variations
3. Internally generated stresses
   - The crystals have residual stress
   - The manner in which the slabs are pumped induces thermal gradients, which results in stress on the slab

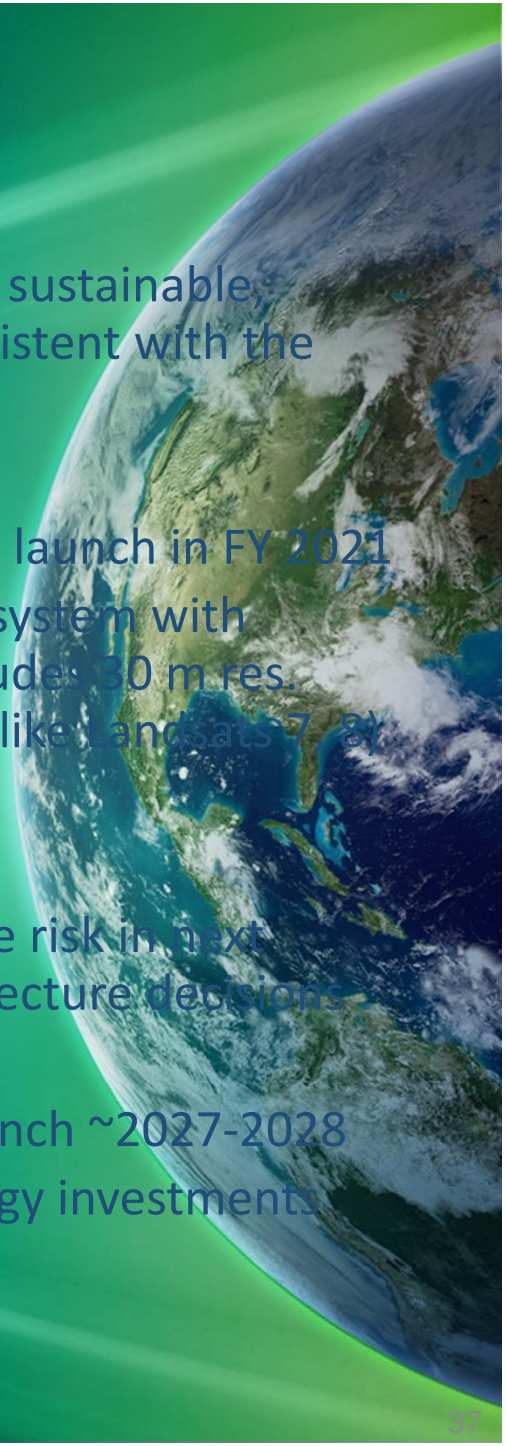
- The Failure Review Board investigation has identified several factors that contributed to the slab fracture
- A path forward to mitigate each of these factors is in progress
- Currently testing a new method to use wavefront distortions to evaluate stress on the slab during assembly

ICESat-2 Programmatic Strategy

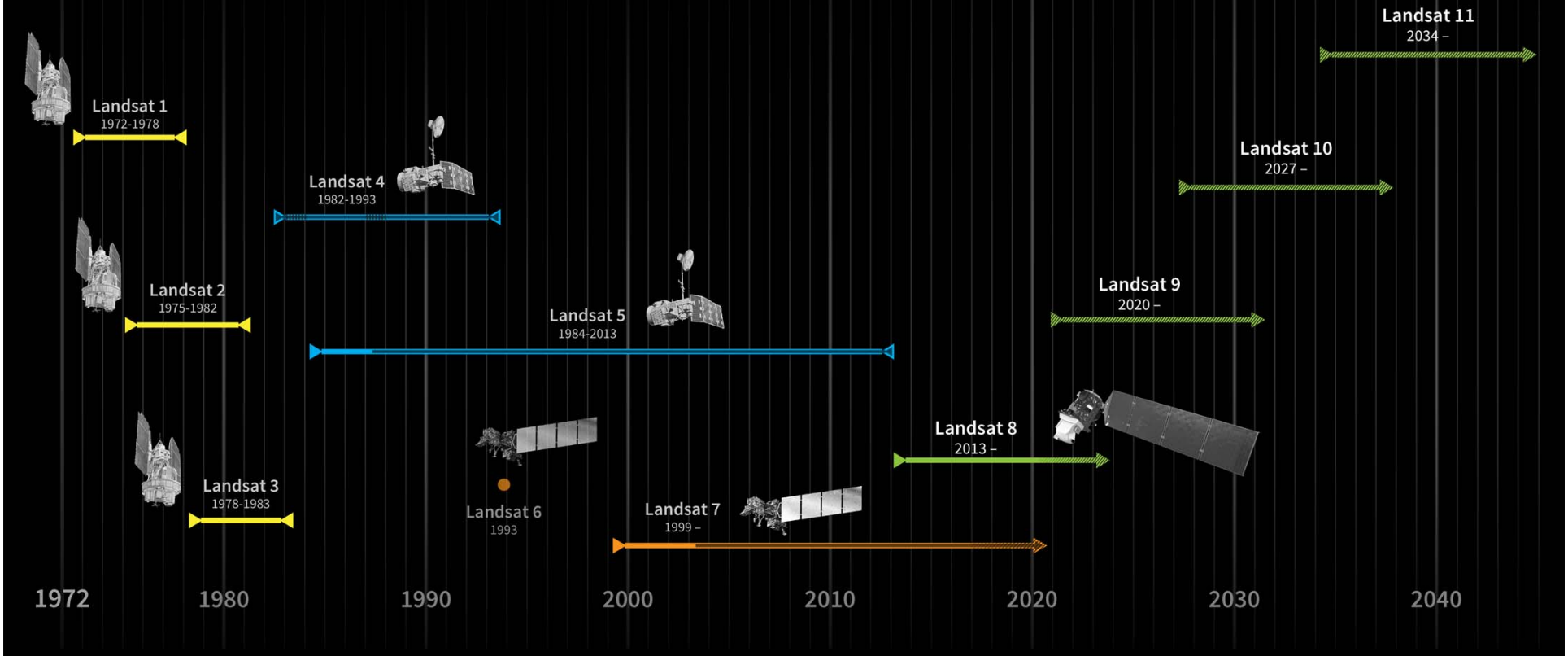
- Near-term plan is to ship ATLAS (with Laser001 and mass simulator in lieu of Laser002) to Orbital-ATK (Gilbert, AZ) in early November
  - Will start shipping Ground Support (test) Equipment in mid-October
    - Allows staging and test checkout before ATLAS instrument arrives
  - ~1 month of ATLAS instrument stand-alone testing
  - Mechanical integration of ATLAS to the spacecraft ("completing" the ICESat-2 observatory for test purposes) starts in mid-December
- ATLAS corrective action plans will be finalized, corrective actions implemented, and regression testing performed on Laser002 and Laser003 (the current spare laser) in parallel with Observatory Integration and Testing
  - Includes additional qualification and/or proof-testing of design changes
  - Includes laser environmental testing (Vibration and Thermal Vacuum) and then comprehensive performance testing
  - Other crystal optical slab assemblies must be evaluated for inherent risk of fracture and redesigned/remanufactured if deemed necessary

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 45-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



Building on the Landsat Legacy

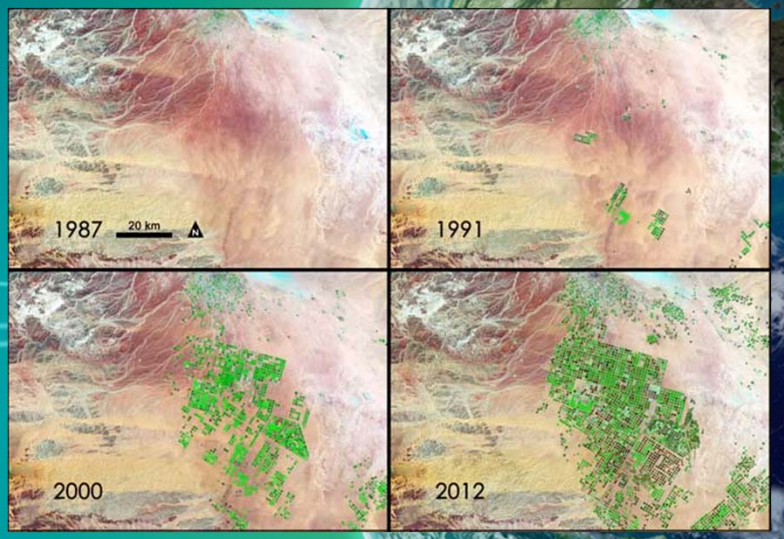


NASA-USGS Interagency Partnership
- NASA: Space Segment and Launch
- USGS: Operations & Data Processing/Distribution

Landsat 9: Mission Overview

Landsat 9 will provide continuity in the multi-decadal land surface observations to study, predict, and understand the consequences of land surface dynamics

- Landsat 9 is a core component of the Sustainable Land Imaging Program
- Partnership: NASA & United States Geological Survey (USGS)
- Landsat 9 will retrieve data on surface properties, land cover, and vegetation condition utilizing reflective-band push-broom imager (15-30m res) with 9 spectral bands at 15 - 30m
- Landsat 9 will retrieve surface temperature, supporting agricultural and climate applications, including monitoring evapotranspiration utilizing a thermal infrared (TIR) push-broom imager with 2 TIR bands @ 120m resolution
- Landsat 9 is a Category 1 project (NPR 7120.5E) & payload risk class B (NPR 8705.4)
- Landsat 9 is in Phase B
- Primary mission operation is planned for 5 years
- Life Cycle Cost range: $851-928M
- Targeted launch: NET Dec 2020



Increase in pivot irrigation in Saudi Arabia from 1987 to 2012 as recorded by Landsat. The increase in irrigated land correlates with declining groundwater levels measured from GRACE (courtesy M. Rodell, GSFC)

Landsat 9 NASA / USGS Partnership

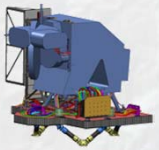
- **Independently funded agency partnership**
  - Not reimbursable like the NOAA missions
- **NASA & USGS responsibilities largely the same as on the Landsat Data Continuity Mission (LDCM)**
  - NASA responsible for
    - Mission success through launch and checkout
    - Development of Space and Launch Segments
    - Mission operations readiness, launch, and on-orbit checkout
    - Providing basic MOC/BMOC facilities (room, physical security, utilities, networks, SN/NISN/NEN, FDF) and Launch Support Room
    - Providing support for on-orbit anomalies post on-orbit acceptance
  - USGS responsible for
    - Development of the Ground Segment
      - Mission Operations Center (and backup) at GSFC
      - Ground Network Element – GNE
      - Data Processing and Archive System (DPAS) at USGS/EROS in Sioux Falls, South Dakota
    - Assuming operational control of mission after on-orbit checkout and handover from NASA
    - Assuming cost of GSFC facilities after on-orbit acceptance
    - Operating the satellite, and provide data processing, distribution, and archive
- **Differences from LDCM**
  - USGS provides MOC development and Flight Operations Team
  - Spacecraft and OLI-2 contracts will not transition to USGS at handover

Mission Segments and Elements

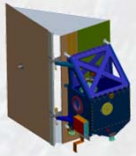
NASA

Space Segment

Operational Land Imager 2 (OLI-2)
- Multi-Spectral Imaging Instrument
- Pushbroom VIS/SWIR sensor
- Four mirror telescope
- Focal Plane consisting of 14 SCAs



Thermal Infrared Sensor 2 (TIRS-2)
- 2 thermal channels
- Pushbroom design
- Quantum well detectors
- Actively cooled FPA



Spacecraft
- 3-axis stabilized
- Accommodates OLI-2 & TIRS-2

NASA

Launch Segment

Atlas V 401 or Falcon 9

USGS

Ground Segment

Mission Operations Center (MOC)
- Command & telemetry
- Trending & analysis
- Flight dynamics
- Science acquisition planning
- Primary and backup MOCs at GSFC
  - (NASA is responsible for basic facility and launch support room costs prior to on-orbit acceptance)

Operations
- Flight Operations Team
- NASA leads (USGS supports) mission operations readiness activities, pre-launch, launch and early orbit activities
- USGS leads operations following on-orbit acceptance

Data Processing and Archive System (DPAS)
- Ingest, product generation, & image assessment/processing
- User Portal web interface for data discovery, product selection & ordering (for Cal/Val), & product distribution
- Storage and archive services

Ground Network Element (GNE)
- Ground stations/antennas for X-Band image & S-Band telemetry data downlink
- Generation of S-Band command uplink

Earth Science Technology Highlight

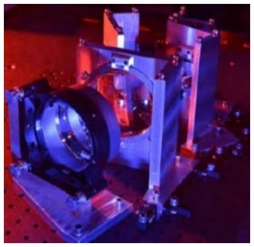
Six Projects Awarded under Sustainable Land Imaging-Technology (SLI-T)

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:

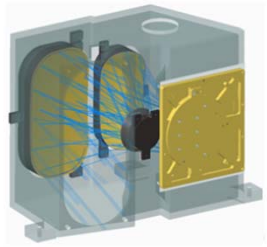
- Demonstrate **improved, innovative, full-instrument concepts** for potential infusion into the architecture and design of Landsat-10; and
- Develop and mature technologies that have **long-term potential to significantly improve future land imaging instruments and systems** through substantial architecture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

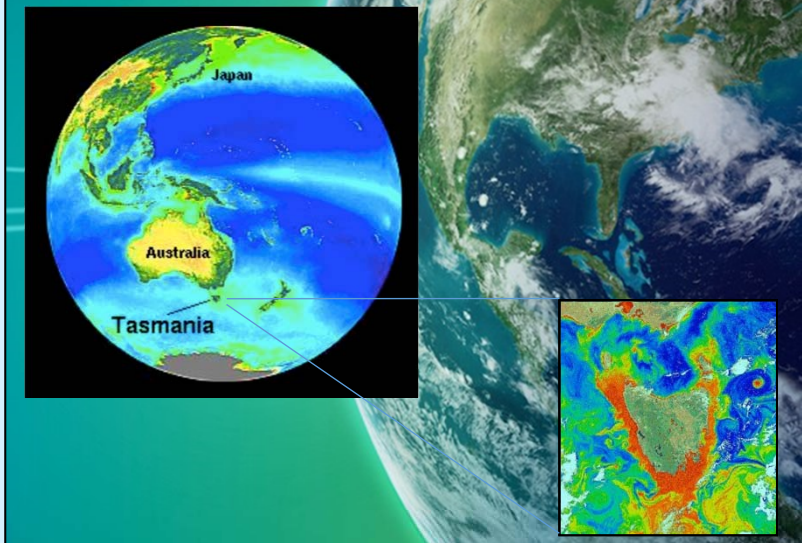
Long Wavelength Infrared Focal Plane Array for Land Imaging
PI: David Ting, Jet Propulsion Laboratory

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

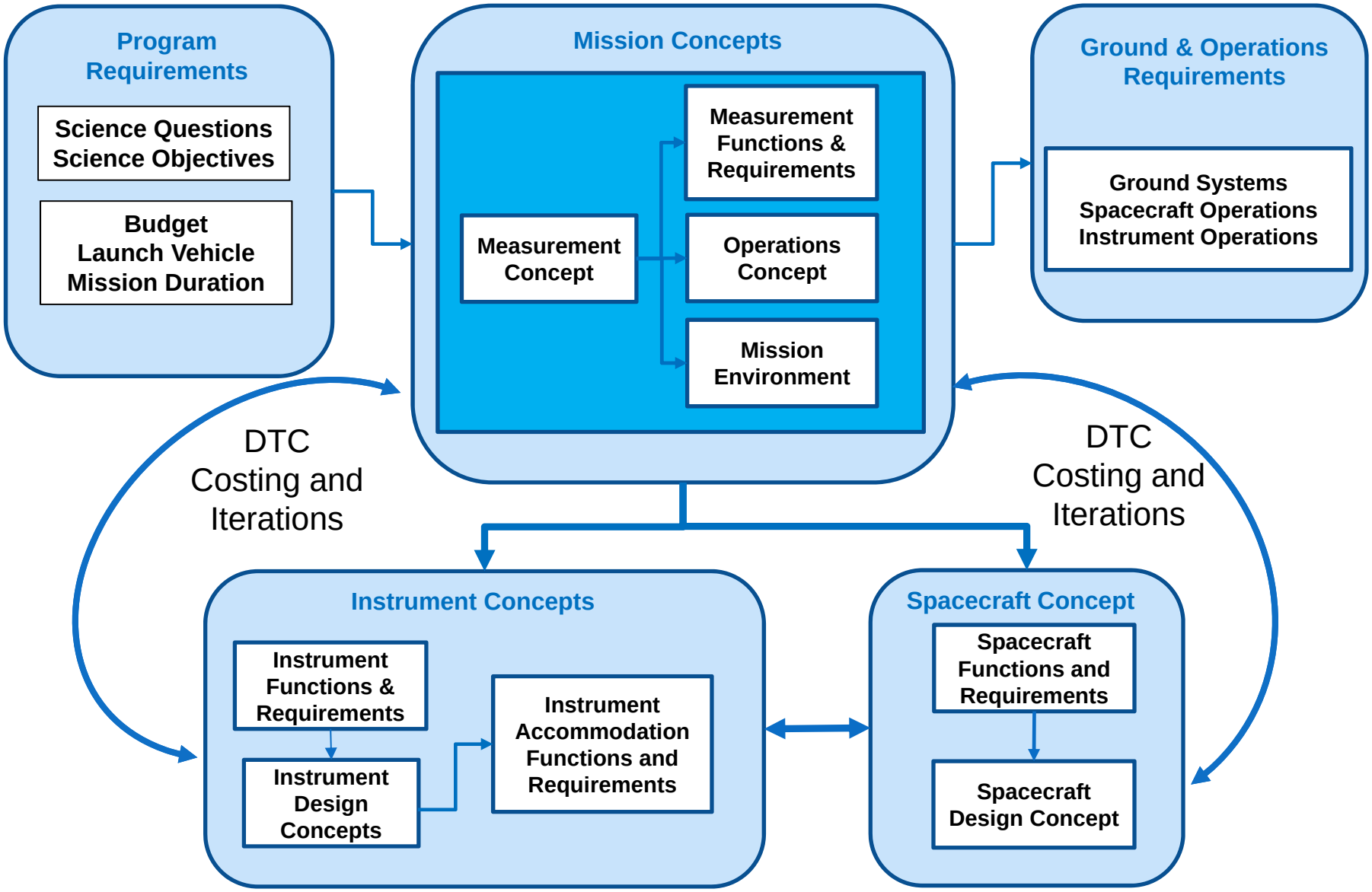
Plankton, Aerosol, Cloud, and ocean Ecosystem (PACE): Mission Overview

PACE will expand on-going global observations of ocean ecology, biology, and chemistry, required to quantify aquatic carbon storage and ecosystem function in response to human activities and natural events

- The PACE mission is being formulated with a **design-to-cost** approach where the mission studies will be used to define the appropriate approach while maximizing the science capability at a high cost confidence.
- The PACE mission will utilize a hyperspectral scanner to make global ocean color measurements essential for understanding the carbon cycle and how it both affects and is affected by climate change, along with aerosol polarimetry measurements to extend data records on clouds and aerosols.
- PACE will make these measurements until the readiness of the more advanced Aerosol, Cloud, and Ecosystems (ACE) mission recommended as a Tier 2 mission by the 2007 National Academies **Decadal Survey**.
- Recommended as a Climate Continuity Mission for global Ocean Color, Aerosol and Cloud science in NASA's 2010 Climate Architecture document, *Responding to the Challenge of Climate and Environmental Change*.
- PACE is a Category 2 project (NPR 7120.5E) & payload risk class is to be determined by the start of Phase B (NPR 8705.4).
- PACE is in Phase A.
- Primary mission operation is planned for 3 years
- Life Cycle Cost range: $805-850M
- Targeted launch: NET 2022



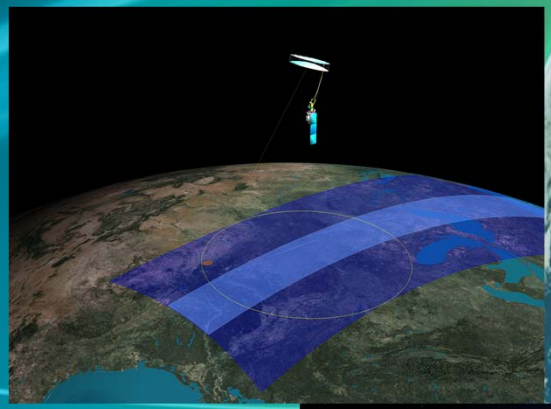
PACE Design-To-Cost is an Iterative Process Trading Science Capabilities, Cost, Schedule, and Risk

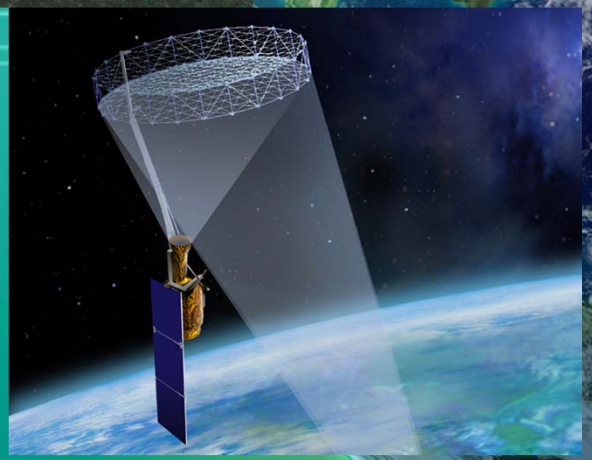


Soil Moisture Active Passive (SMAP): Mission Summary

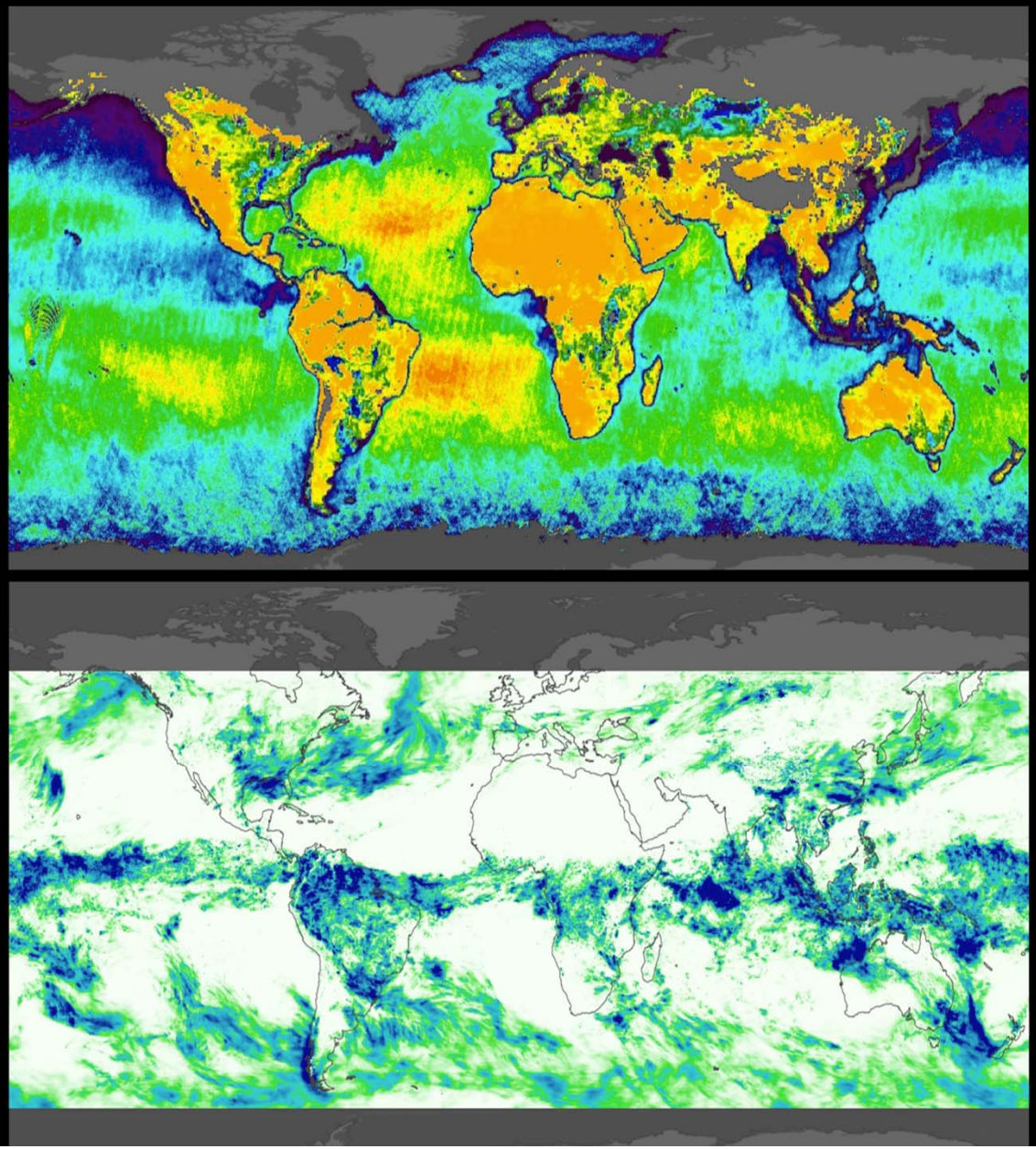
SMAP is providing global measurements of soil moisture and its freeze/thaw state

- SMAP is a Tier-One mission recommended by the 2007 *Earth Science and Applications* ***Decadal Survey***
- SMAP was designed to combine low-frequency microwave radiometer and synthetic aperture radar measurements of surface emission and backscatter to estimate soil moisture and freeze-thaw cycling globally
- Following failure of the active radar instrument, SMAP continues to provide unprecedented measurements of soil moisture
- SMAP is a Category 2 project (NPR 7120.5E) & payload risk class C (NPR 8705.4)
- SMAP is in Phase-E (operations) with primary mission operations planned for 3 years
- Life Cycle Cost: $890M
- Development Cost: $454M
- Development Cost to go: $0 (in operations)
- **Launch Date: January 31, 2015**





Soil Moisture and Ocean Salinity (SMAP); Precipitation (GPM)



Soil Moisture (cm^3/cm^3)

0.0 — 0.6

Sea Surface Salinity (psu)

30 — 40

Apr 17–Apr 24

Apr 17 — Jul 26

Precipitation (mm)

0 — 160

SENTINEL 6: Mission Summary

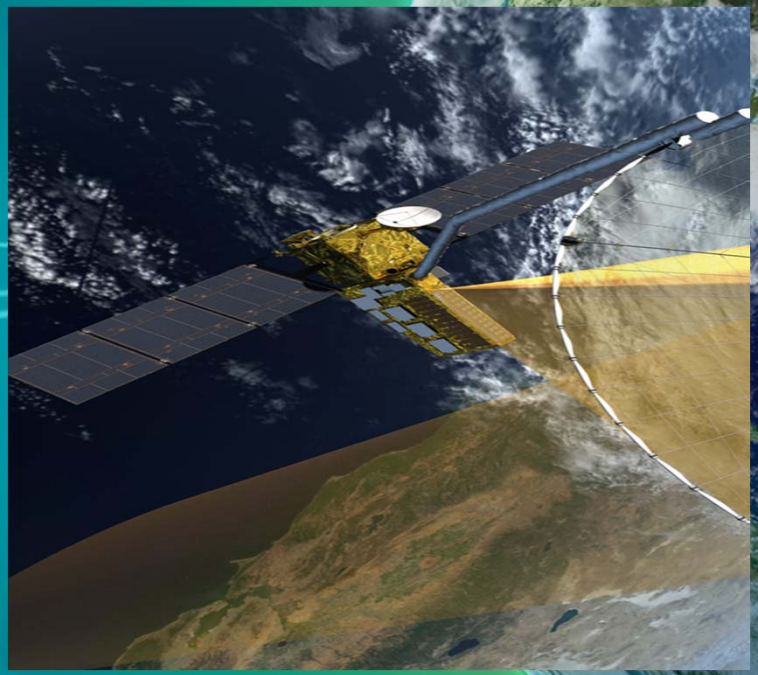
The Sentinel-6 radar altimeter mission is a component of the European Copernicus Program of Earth observing satellites. Sentinel-6 will provide high-precision measurements of global sea-level, extending continuous ocean topography measurements beyond the TOPEX/Poseidon and Jason-1/2/3 time period (1992-present).

- The Sentinel-6 mission is a US-European cooperation involving NASA, NOAA, ESA, EUMETSAT, and the European Commission; NASA will provide the payload and launch the Sentinel-6A and -6B satellites.
- In the FY16 President's Budget, NASA assumed responsibility for the US portion of the Sentinel-6 mission from NOAA.
- Sentinel-6 will continue high precision ocean altimetry measurements in the 2020–2030 time-frame.
- Sentinel 6 is a Category 2 project (NPR 7120.5E) & payload risk class B for the Altimetry payload and risk class C for the GNSS-RO payload. (NPR 8705.4)
- Sentinel – 6 is in Pre-Formulation (combined KDP-A/B scheduled for Oct 2016)
- Primary mission operations is planned for 7.5 years
- Life Cycle Cost range: $480-530M
- Launch Readiness Date range: NET 2020 (Sentinel-6A) and 2025 (Sentinel-6B)

NASA-ISRO SAR Mission (NISAR): Mission Summary

The NISAR mission will be the first NASA radar mission to systematically and globally study the solid Earth, ice sheet and glacier motion, and ecosystems.

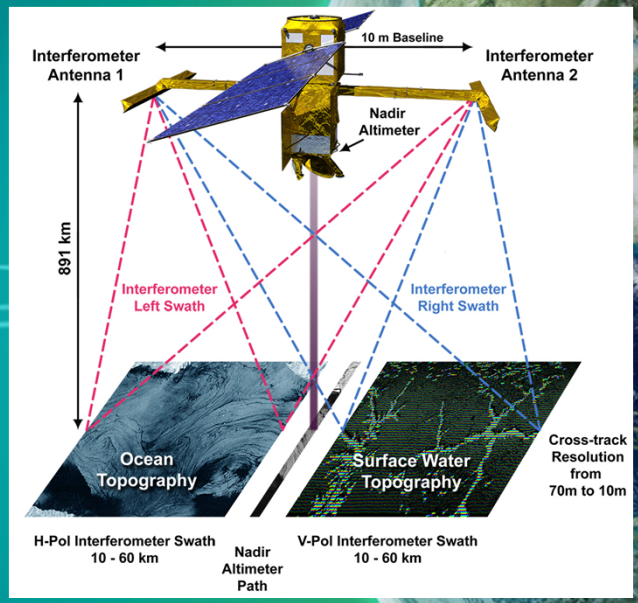
- NISAR is a Tier-One mission recommended by the 2007 NRC *Earth Science and Applications* ***Decadal Survey***
- The NISAR Mission is a collaboration between NASA and the Indian Space Research Organization (ISRO)
- NISAR is a dual frequency (L+S band) Synthetic Aperture Radar Mission
- NISAR is a Category 2 project (NPR 7120.5E) & payload risk class C (NPR 8705.4)
- Primary mission operation is planned for 3 years
- NISAR is in Phase C
- Life Cycle Cost: $867M
- Development Cost: $661M
- Development Cost to go: $656M
- Launch Readiness Date: 09/2022



Surface Water Ocean Topography (SWOT): Mission Summary

SWOT is the first *wide-swath* altimetry mission to measure ocean topography completely covering the world's oceans and freshwater bodies with repeated high-resolution elevation measurements.

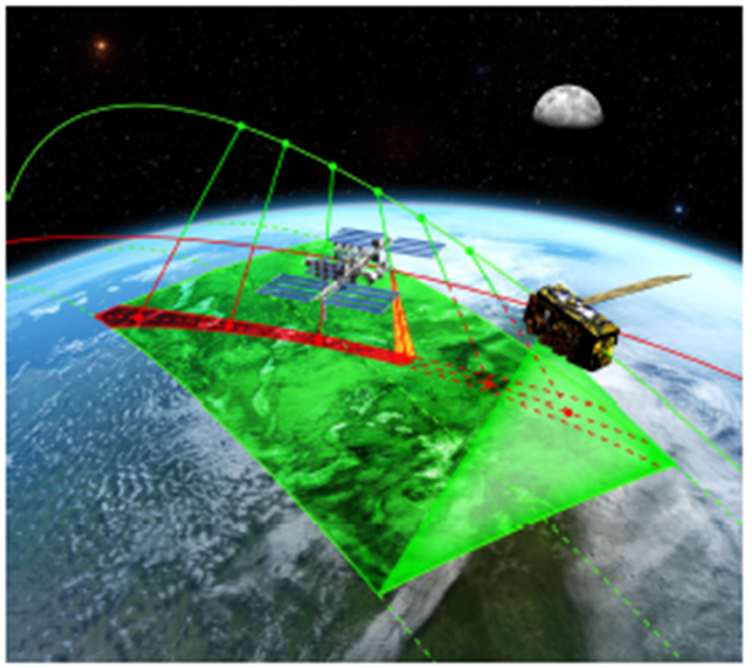
- SWOT is a Tier-One mission recommended by the 2007 NRC *Earth Science and Applications* ***Decadal Survey***
- SWOT uses a Ka-band SAR interferometric system with 2, 50 km-wide swaths, to produce sea-surface and lake/river heights
- Partnered mission with Centre National d'Etudes Spatiales (CNES) & Canadian Space Agency (CSA)
- SWOT is a Category 2 project (NPR 7120.5E) & payload risk class C (NPR 8705.4)
- SWOT is in Phase C
- Science mission duration of 3 years
- Life Cycle Cost: $755M
- Development Cost: $571M
- Development Cost to go: $553M
- Launch Readiness Date: 04/2022



Climate Absolute Radiance and Refractivity Observatory (CLARREO) *Pathfinder*: Mission Summary

CLARREO-PF will demonstrate highly accurate climate records and trend detection to test climate projections to improve models and enable sound policy decisions.

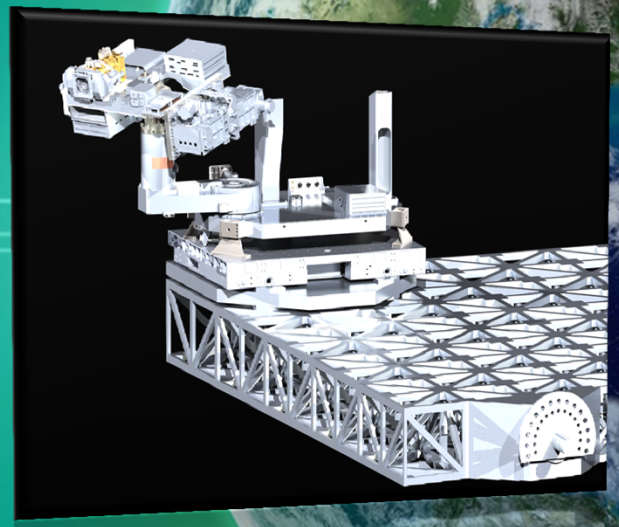
- CLARREO is a Tier-One mission recommended by the 2007 NRC *Earth Science and Applications* ***Decadal Survey***
- In 2016, the CLARREO Pathfinder (CPF) was initiated to demonstrate essential measurement technologies required for the full CLARREO mission.
- CPF, an instrument hosted on the ISS, will provide high accuracy measurements of reflected solar radiation
- CLARREO is a Category 3 project (NPR 7120.5E) & payload risk class D (NPR 8705.4)
- CLARREO PF is in Pre-Formulation (KDP-A on 7 Oct 2016)
- Life Cycle Cost range: $65-80M
- Target launch date: NET 2020



Total and Spectral Solar Irradiance (TSIS – 1 & 2): Mission Summary

TSIS 1&2 will continue a 36 year data record of the Total and Spectral energy output of the Sun, measured at the top of the Earth's atmosphere

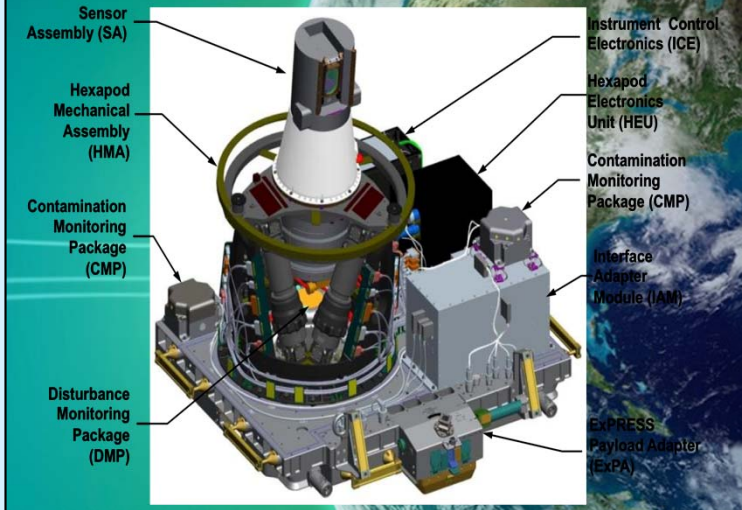
- TSIS was originally planned to be implemented by NOAA and to fly on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) spacecraft.
- In 2010, TSIS was re-planned for the Joint Polar Satellite System (JPSS) Polar Free Flyer (PFF).
- In the FY14 budget, NASA assumed responsibility for the TSIS mission; the instruments will fly on the ISS
- TSIS instruments will provide absolute measurements of the total solar irradiance (TSI) and spectral solar irradiance (SSI), important for accurate scientific models of climate change and solar variability.
- TSIS-1 is a Category 3 project (NPR 7120.5E) & payload risk class C (NPR 8705.4)
- TSIS -1 is in Phase C
- Primary mission operations is planned for 5 year mission
- TSIS-1
  - Life Cycle Cost: $86M
  - Development Cost: $50M
  - Cost to go: $37M
  - LRD: 04/2018 (instrument manifested on SpaceX-13)
- TSIS-2
  - Life Cycle Cost range: $120-150M
  - Target launch date: NET 2022
- TSIS-2 will continue the measurements in the 2020 time-frame



Stratospheric Aerosol and Gas Experiment (SAGE) III - International Space Station (ISS): Mission Summary

SAGE III will provide global, long-term measurements of the vertical distribution of aerosols and ozone from the upper troposphere through the stratosphere.

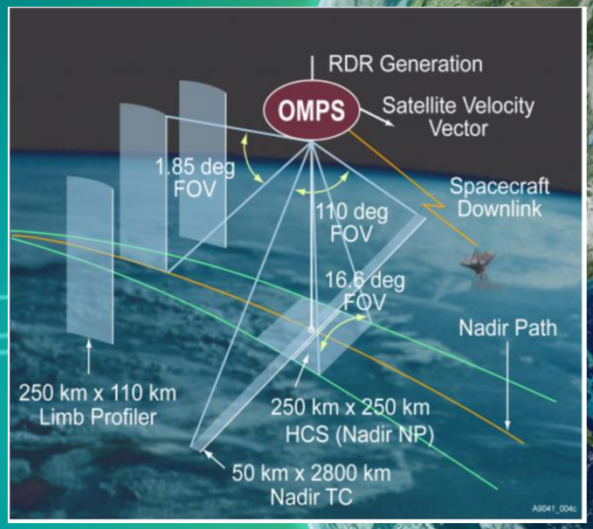
- SAGE III is the third generation of solar occultation instruments consisting of a grating spectrometer that measures ultraviolet/visible energy.
- SAGE III will be robotically mounted on the ExPRESS Logistics Carrier on the International Space Station (ISS).
- SAGE III is a Category 3 project (NPR 7120.5E) & payload risk class C (NPR 8705.4)
- SAGE III is in Phase D (KDP-E scheduled for Sept 2016)
- Life Cycle Cost: $133M
- Development Cost: $92M
- Development Cost to go: $19M
- SAGE III is currently scheduled to launch on a SpaceX Falcon 9 on 17 November 2016.



Ozone Mapping and Profiler Suite (OMPS) - Limb): Mission Summary

The advanced Ozone Mapping and Profiler Suite (OMPS)-Limb tracks the health of the ozone layer and measures the vertical profiles of stratospheric ozone in the Earth's atmosphere.

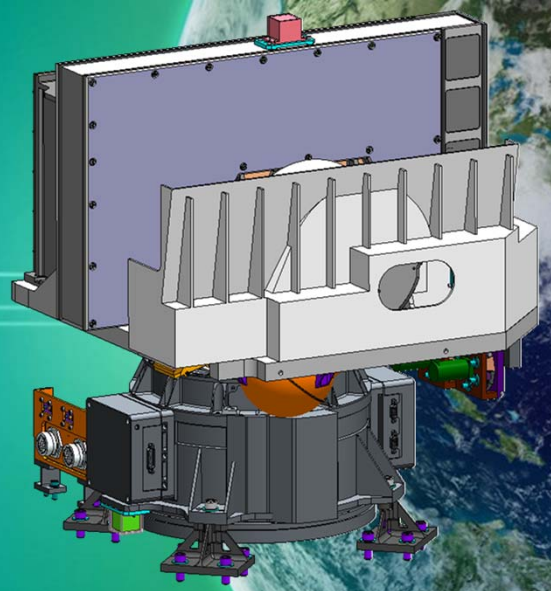
- The OMPS suite consists of three spectrometers: a downward-looking nadir mapper, a nadir profiler and alimb profiler (OMPS-Limb).
- In the FY14 President's Budget, NASA assumed the responsibility for the OMPS-Limb profiler from NOAA.
- The entire OMPS suite currently flies on board the Suomi-NPP spacecraft
- OMPS-L is scheduled to fly on the JPSS-2 satellite mission.
- OMPS-L is a Category 3 project (NPR 7120.5E) & payload risk class C (NPR 8705.4)
- OMPS-L is in Phase C
- Life Cycle Cost: $20M
- Development Cost: $20M
- Development Cost to go: $13.7M
- Launch Readiness Date: Launch date driven by JPSS-2, scheduled for launch July 2021



Radiation Budget Instrument (RBI): Mission Overview

RBI will make accurate global measurements of Earth's emitted radiation, to help understand the links between the Earth's incoming and outgoing energy, and the properties of the atmosphere that affect it.

- In the FY14 President's Budget, NASA assumed the responsibility for RBI development from NOAA.
- RBI is a scanning radiometer that will measure the sunlight reflected by Earth and the radiation the planet emits; RBI will extend the unique global measurements of the Earth's radiation budget provided by the Clouds and the Earth's Radiant Energy Systems (CERES) instruments since 1998.
- RBI is scheduled to fly on the JPSS-2 satellite mission.
- RBI is a Category 2 project (NPR 7120.5E) & payload risk class B (NPR 8705.4)
- RBI is in Phase C
- Life Cycle Cost: $305M
- Development Cost: $202M
- Development Cost to go: $102M
- Launch Readiness Date: Launch date driven by JPSS-2, scheduled for launch July 2021



Gravity Recovery and Climate Experiment Follow-on (GRACE-FO) : Mission Summary

The GRACE missions measure variations in gravity over Earth's surface, producing a new map of the gravity field every 30 days. Data are used to monitor aquifer levels, ice mass balance, drought conditions, and climate-related changes in the hydrologic cycle

- GRACE-FO is a partnership between NASA and the German Research Centre for Geosciences (GFZ).
- GRACE-FO is a successor to the original GRACE mission, which began orbiting Earth on March 17, 2002.
- GRACE-FO will extend the GRACE precision gravity time series while testing a new Laser Ranging interferometer technology designed to dramatically improve the already remarkable precision of its measurement system.
- GRACE-FO is a Category 2 project (NPR 7120.5E) & payload risk class C (NPR 8705.4) (LRI is Risk Class D)
- Primary mission operation planned for 5 years.
- Life Cycle Cost: $432M
- Development Cost: $263M
- Development Cost to go: $131M
- Launch Readiness Date: 02/2018