NASA
Report on Cal/Val Activities

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NASA/GSFC

Agency Report

WGCV Plenary # 41

September 5-7, 2016

Working Group on Calibration and Validation

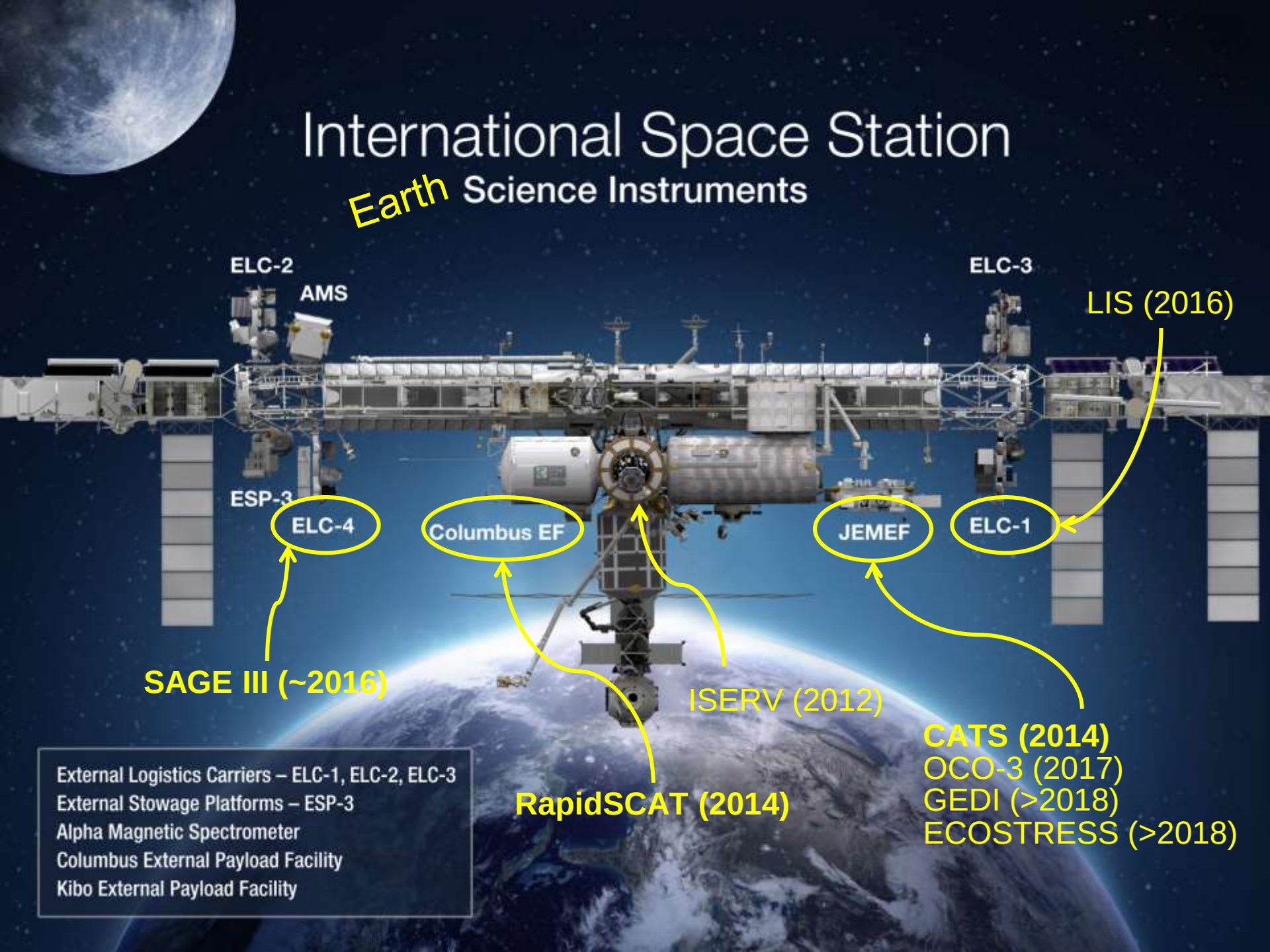
Regular update – Agency overview discussion

- Second decadal survey underway by National Research Council
- Sustainable Land Imaging Program (w/USGS; NASA funds flight hardware)
- Continued development and launch of: SAGE-III/ISS, ECOSTRESS/ISS, GEDI/ISS, CYGNSS, TEMPO, GRACE-FO, ICESat-2, SWOT, NISAR, PACE
  - OCO-3 completion and flight to ISS in late 2017
  - CLARREO Pathfinder on ISS – officially started in April 2016 with launch in 2020

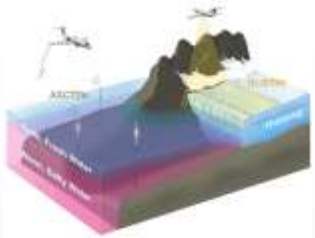

Formulation
Implementation
Primary Ops
Extended Ops
Sentinel-6A/B
Earth Science Instruments on ISS:
RapidScat, CATS,
LIS, SAGE III (on ISS), TSIS-1, OCO-3,
ECOSTRESS,
GEDI, CLARREO-PF
Landsat 9
PACE
NI-SAR
SWOT
TEMPO
JPSS-2 (NOAA)
RBI, OMPS-Limb
GRACE-FO (2)
ICESat-2
CYGNSS
ISS
SORCE,
TCTE (NOAA)
NISTAR, EPIC
(NOAA'S DSCOVR)
QuikSCAT
EO-1
Landsat 7
(USGS)
SMAP
Terra
Suomi NPP
(NOAA)
Aqua
Landsat 8
(USGS)
CloudSat
CALIPSO
GPM
Aura
GRACE (2)
OSTM/Jason 2
(NOAA)
OCO-2

NASA ESD Flight Portfolio 2013 - 2022

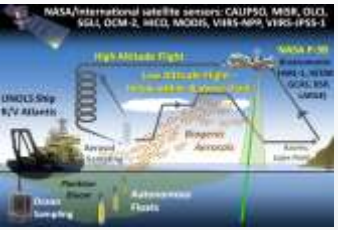
- The Earth Systematic Missions (ESM) ***development*** missions in this period include:
  - ICESat-2, SAGE III, GRACE-FO, SWOT, Landsat-9, RBI, TSIS-1 and -2, OMPS-Limb, NISAR, PACE, Jason CS/Sentinel 6A and -B, CLARREO Pathfinder
- The Earth Systematic Missions (ESM) ***on-orbit**** missions include:
  - SMAP (>2021), DSCOVR (2019), S-NPP (>2021), GPM (>2021), LDCM (>2021), Terra (>2021), Aqua (>2021), Aura (>2021), OSTM (>2021), QuikScat (2015), SORCE (2017), and EO-1 (2016); also RapidScat (2017) and CATS (>2016)
- The Earth System Science Pathfinder (ESSP) ***development*** missions in this period include:
  - OCO-3, CYGNSS, TEMPO, GEDI, ECOSTRESS, EVS-2 and -3 and Venture Technology selections (GrAOWL, Tempest), EVM-2 & 3, EVI-3, 4, 5, and 6
- The Earth System Science Pathfinder (ESSP) ***on-orbit*** missions include:
  - OCO-2 (>2021), GRACE (2018), CALIPSO (>2021), CloudSat (2018), Aquarius (>2021)


International Space Station
Earth Science Instruments
ELC-2
AMS
ELC-3
LIS (2016)
ESP-3
ELC-4
Columbus EF
JEMEF
ELC-1
SAGE III (~2016)
ISERV (2012)
CATS (2014)
OCO-3 (2017)
GEDI (>2018)
ECOSTRESS (>2018)
RapidSCAT (2014)
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

Sub-orbital missions



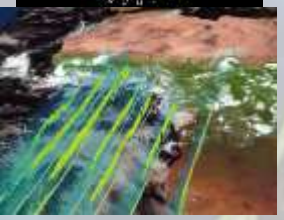
- **OMG** (Oceans Melting Greenland): Investigate role of warmer, saltier Atlantic subsurface waters in Greenland glacier melting; Josh Willis, JPL



- **NAAMES** (North Atlantic Aerosols and Marine Ecosystems Study): Improve predictions of how ocean ecosystems would change with ocean warming; Michael Behrenfeld, Oregon State Univ

- **ACT-America** (*Atmospheric Carbon and Transport – America*): Quantify the sources of regional carbon dioxide, methane, and other gases, and document how weather systems transport these gases; Ken Davis, Penn State Univ

- **ATom** (*Atmospheric Tomography Experiment*): Study the impact of human-produced air pollution on certain greenhouse gases; Steven Wofsy, Harvard Univ



- **ORACLES** (*ObseRvations of Aerosols Above CLouds and Their IntEractionS*): Probe how smoke particles from massive biomass burning in Africa influences cloud cover over the Atlantic; Jens Redemann, ARC

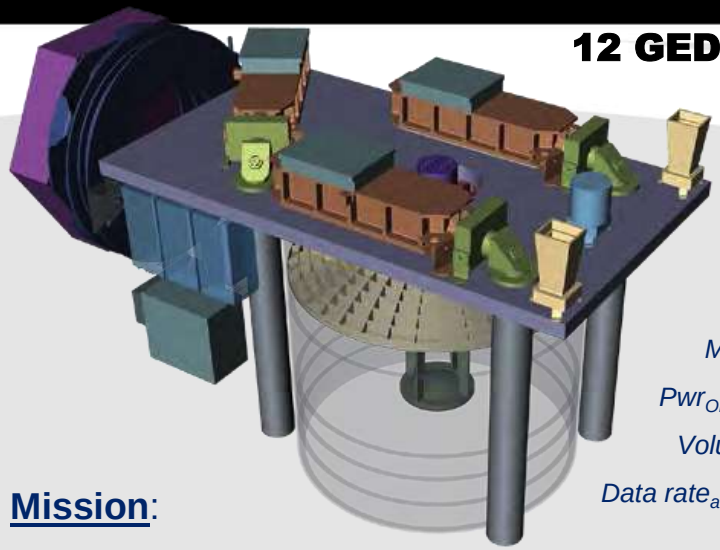
NASA's CubeSat Launch initiative (CSLI) provides opportunities on planned upcoming launches

- http://www.nasa.gov/directorates/heo/home/CubeSats_initiative
- NASA selected 20 small satellites to fly as auxiliary payloads in recent CSLI selection
- Other missions have Earth Science relevance in improving CubeSat platform robustness, platform stability, quality, etc.

NASA's CubeSats and Earth Sciences

- Earth Science measurements include
  - Canopy Near-IR Observing Project (CaNOP) for multispectral imaging of global forests
  - CubeSat Infrared Atmospheric Sounder (CIRAS) for Mid-Wavelength Infrared Radiance Grating Spectrometer
  - RainCube to demonstrate miniaturized Ka-band Atmospheric Radar
  - Micro-size Microwave Atmospheric Satellite CubeSat (MicroMAS-2b) microwave radiometers and cross-track scanning
  - Stratus CubeSat to measure cloud fraction, cloud top height and wind
  - Compact Infrared Radiometer in Space (CIRiS) imaging radiometer for 7 to 13 um

Venture Class Activities - GEDI



Mass = 230 kg

$Pwr_{Orb\ Avg}$ = 516 W

Volume = .xx m^3

$Data\ rate_{avg}$ = 2.1 Mbps

12 GEDI Lidar: Global Ecosystem Dynamics Investigation Lidar
PI: Ralph Dubayah

Mission:

GEDI will characterize the effects of changing climate and land use on ecosystem structure and dynamics, enabling improved understanding of Earth's carbon cycle and biodiversity. GEDI will provide the first global, high-resolution observations of forest vertical structure.

Goals:

GEDI will address the following questions:
- What is the above-ground carbon balance of the land surface?
- What role will land surface play in mitigating atmospheric CO2?
- How does ecosystem structure affect habitat quality and biodiversity?

GEDI measurements will quantify the following:
- Distribution of above-ground carbon at fine spatial resolution
- Changes in carbon resulting from disturbance and subsequent recovery
- Spatial and temporal distribution of forest structure and its relationship to habitat quality and biodiversity
- Sequestration potential of forests over time w/changing land use, climate

Instrument: Lidar

Heritage: HOMER (laser); GLAS, CALIPSO (optics); IceSat, (detectors)

Mission & Science Team:

Principal Investigator: Ralph Dubayah, UMD
Project Manager: TBD, GSFC
Instrument System Engineer: Cheryl Salerno, GSFC
Deputy PI Instrument / Instrument Scientist: Bryan Blair, GSFC
Deputy PI Science: Scott Goetz, WHRC
Instrument Deputy Project Manager: Thomas Johnson, GSFC

Mission & Science Team:

University of Maryland, College Park
Goddard Space Flight Center
Woods Hole Research Center
US Forest Service
Brown University

Instrument Details:

- Self-contained laser altimeter
  - 3 lasers are split into 7 beams dithered to produce 14 ground track spot beams.
  - Beams have a 25 meter footprint and are spaced 500 m cross-track and 60 m along-track to produce fine grids of forest structure.
- 70 cm diameter telescope/receiver.
  - Detector has 75% transmission and 50% quantum efficiency.
  - Si:APD detectors: Near-photon-noise limited, >500:1 dynamic range
  - IFOV matched to contain return spot beams
- GPS, IMU, Star Trackers give precise ranging, attitude and position.
- A single-axis mechanism rotates the instrument about the roll axis, providing off-nadir pointing for global coverage.
- Canopy profile accurate to 1 m
- Geolocation < 10 m for plot calibration
- Biomass error < 20% at pixel level

FY16 Cost: $94.034M, $18.652M reserve, $2.815 contribution

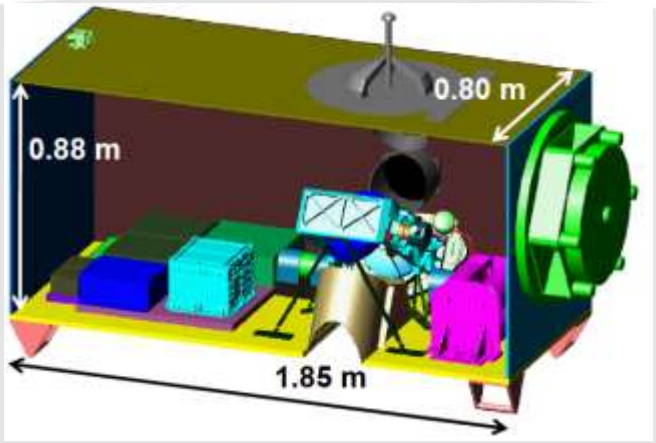
Descopes: Reduce lasers from 3 to 2, elim. dithering unit.: $11.4M (FY16 $)

Threshold: Acquire canopy vertical profile to estimate above-ground woody carbon density for vegetated areas at <1 km.

Schedule: 40.5 mo. A/B/C, 19.5 mo. E/F, 12 weeks reserve

Venture Class Activities - ECOSTRESS

ECOSTRESS: ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
PI: Simon Hook



Mass = 266 kg

$Pwr_{Orb\ Avg}$ = 527 W

Volume = 1.30 m^3

$Data\ Rate_{avg}$ = 2.32 Mbps

Mission:

An Earth Venture Instrument-2 selection, ECOSTRESS will provide the first high spatiotemporal resolution thermal infrared measurements of Earth's surface from ISS. Measurements at varying times over the diurnal cycle will reveal answers related to water stress in plants and how selected regions will respond to future climate changes.

Goals:

- Identify critical thresholds of water use and water stress in key climate-sensitive biomes.
- Detect the timing, location, and predictive factors leading to plant water uptake decline and/or cessation over the diurnal cycle
- Measure agricultural water consumptive use over the contiguous United States (CONUS) at spatiotemporal scales applicable to improve drought estimation accuracy

Mission & Science Lead:

Principal Investigator: Simon Hook, JPL

Major Partners:

Jet Propulsion Laboratory

Instrument Details:

- Thermal infrared radiometer
- Cross-track whisk broom scanner
- Swath width: 384 km (51°)
- Spatial resolution: 38 m x 57 m (nadir) pixels
- Five thermal IR bands between 8.3 and 12.1 microns
- Noise equivalent delta temperature: ≤ 0.1 K
- Two COTS cryocoolers for 60 K focal plane
- Typical revisit of 90% of CONUS every 4 days at varying times over diurnal cycle

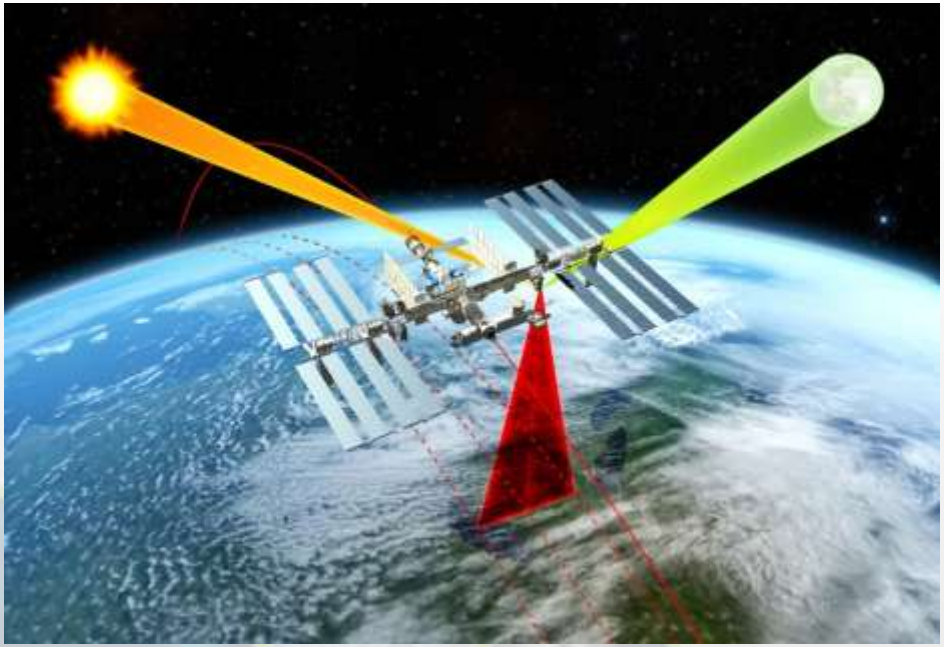
Heritage:

Prototype Hyperspectral Infrared Imager (HyspIRI) Thermal Infrared Radiometer (PHyTIR; a laboratory instrument); Algorithms: ASTER, MODIS, Landsat

CLARREO Pathfinder passed MCR

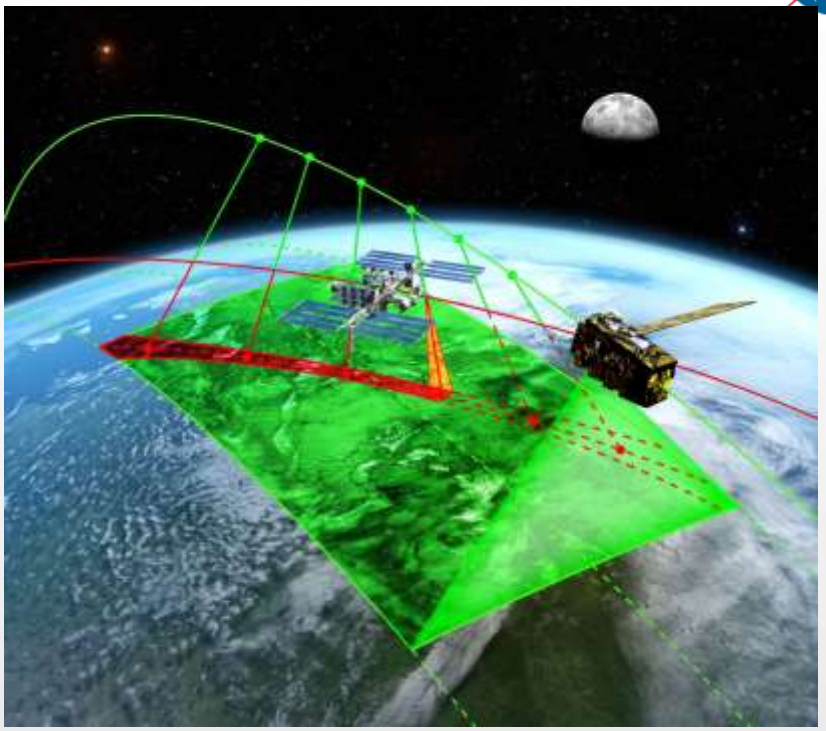
- Authority to Proceed received April 11, 2016 with target instrument launch date as early as CY2020
- Demonstrate
  - Essential measurement technologies for the Reflected Solar portion of the full Tier 1 Decadal Survey-recommended CLARREO mission
  - On-orbit, high accuracy, SI-Traceable calibration
  - Ability to transfer calibration to operational sensors
- Formulation, implementation, launch to ISS, and operation of a Reflected Solar (RS) Spectrometer
- Class D Mission with Nominal 1-year mission life
- Additional 1 year science data analysis

Demonstrate high accuracy SI-Traceable Calibration



Objective #1: Conduct, on orbit, SI-Traceable measured scene spectral reflectance, with an advance in accuracy over current sensors.

Demonstrate Inter-Calibration



Objective #2: Serve as an in-orbit reference for inter-calibration of key satellite sensors across RS spectrum

Satellite calibration interconsistency studies

- Provides an opportunity for quantitative comparison of multiple satellite data products to facilitate the development of multiinstrument/multiplatform data sets involving satellites from multiple providers
- MUST address interconsistency issues of two or more satellites
  - One of which must be one currently supported through NASA's Earth Science Program
  - One must be supported by some other organization (U.S. or foreign)
- Document their responsiveness to ongoing efforts of CEOS/WGCV, GSICS, and/or other broadly recognized national and/or international efforts

Satellite calibration interconsistency studies selections

- Brian Barnes/University of South Florida, Tampa
  - Synergistic Multi-Sensor Calibration for Global and Coastal Observations of Aquatic Environments
- Andreas Colliander/Jet Propulsion Laboratory
  - Intercalibration of Low Frequency Brightness Temperature Measurements for Long-Term Soil Moisture Record
- Jeffrey Czapla-Myers/University of Arizona
  - Intercalibration of GEO and LEO Sensors Using the Radiometric Calibration Test Site (RadCaTS) at Railroad Valley, Nevada
- David Doelling/NASA Langley Research Center
  - Open Access Spectral Band Adjustment Factors for Consistent Inter-Satellite Calibration and Retrievals
- Eric Fetzer/Jet Propulsion Laboratory
  - A Merged Temperature and Water Vapor Record from Modern Sounders
- Mathew Gunshor/University of Wisconsin, Madison
  - Re-Calibrate Water Vapor Bands from International Geostationary Satellites for Consistency with AIRS

Satellite calibration interconsistency studies selections

- Christian Kummerow/Colorado State University
  - A Long-Term Satellite Climate Data Record of Global Precipitation
- Can Li/University of Maryland, College Park
  - Producing Consistent Trace Gas Retrievals Through Inter-Calibration of Hyperspectral UV Measurements from OMI and GOME-2A
- Hamidreza Norouzi/New York City College of Technology
  - A Multi-Sensor Calibration Algorithm for Improving Emissivity Retrieval by Integrating Microwave Brightness Temperature Diurnal Cycle
- Lawrence Strow/University of Maryland Baltimore County
  - A Homogenous Infrared Hyperspectral Radiance and Level 3 Climate Record Combining NASA AIRS, JPSS CrIS, and EUMETSAT IASI
- Eric Vermote/NASA Goddard Space Flight Center
  - Toward a Consistent Land Long Term Climate Data Record from Large Field of View Polar Orbiting Earth Observation Satellites
- Juying Warner/University of Maryland, College Park
  - Tropospheric Ammonia Derived from AIRS and CrIS for a More Continuous Data Record Using a Uniform Retrieval Algorithm

Land Imaging Evolution

- **While recognizing the scientific need for continuity with the 43-year Landsat record, we are seeing new trends & opportunities in land remote sensing**

- *Evolving user needs for…*
  - *Improved temporal revisit*
  - *Additional spectral coverage & resolution*
  - *Integration with other modalities (lidar, radar)*
- *Increasing use of "small sat" platforms and distributed architectures*
- *Increasing number of commercial imaging systems*
- *Potential synergy with international systems (e.g. Sentinel-2)*
- *High-performance computing and increased emphasis on information rather than images*

Our challenge is to advance the measurement capability, while preserving continuity and constraining program costs

Sustainable Land Imaging

- A 3-part program for a sustainable and responsible land imaging program through 2035:

1. **Landsat 9** (fully Class-B rebuild of Landsat 8) anticipated to launch in FY 2021
   - Low programmatic risk implementation of a proven system with upgrades to bring the whole system to Class B

2. **Land Imaging Technology and Systems Innovation**
   - Hardware, operations, and data management/processing investments to reduce risk in next generation missions

3. **Landsat 10**, Class B full spectrum, to launch ~2027-2028
   - Mission architecture to be informed by the technology investments (2015-), leading to definition ~2020

SLI present status

- **Landsat 9 Project initiated with FY15 funds**
  - Directed to NASA's Goddard Space Flight Center (GSFC)
  - Project Office established and substantially staffed
  - OLI-2 Instrument and Landsat 9 spacecraft procurement actions in work
  - TIRS-2 development in progress
  - Launch ASAP, likely NET 12/2020 – there is sufficient funding authority for FY16
- **Technology studies underway for Landsat 10 definition and long-term technology infusion**
  - Detector component development
  - Overall instrument size reduction using advanced technologies
  - ROSES SLI Technology call released (ROSES 2015 A.47 released 23 Dec 2015 with proposals due 30 Mar 2016)

SLI Present Status

NASA solicited, selected, and initiated science investigations focused on construction of multi-system fusion data sets ("Multi-Source Land Imaging Science")

- "…[W]e solicit for efficient use and seamless combination with Landsat, of satellite sensor data from international Landsat-type moderate resolution (~30 m ground resolution), multispectral sources on continental to global scales. A primary focus is on developing algorithms and prototyping products for combined use of data from Landsat and Sentinel-2 toward global land monitoring. However, we also welcome proposals combining Landsat with other sources of moderate resolution data, such as IRS and/or CBERS…"
- 7 investigations selected, $1.3M/year total, 3-year studies (see later slide)

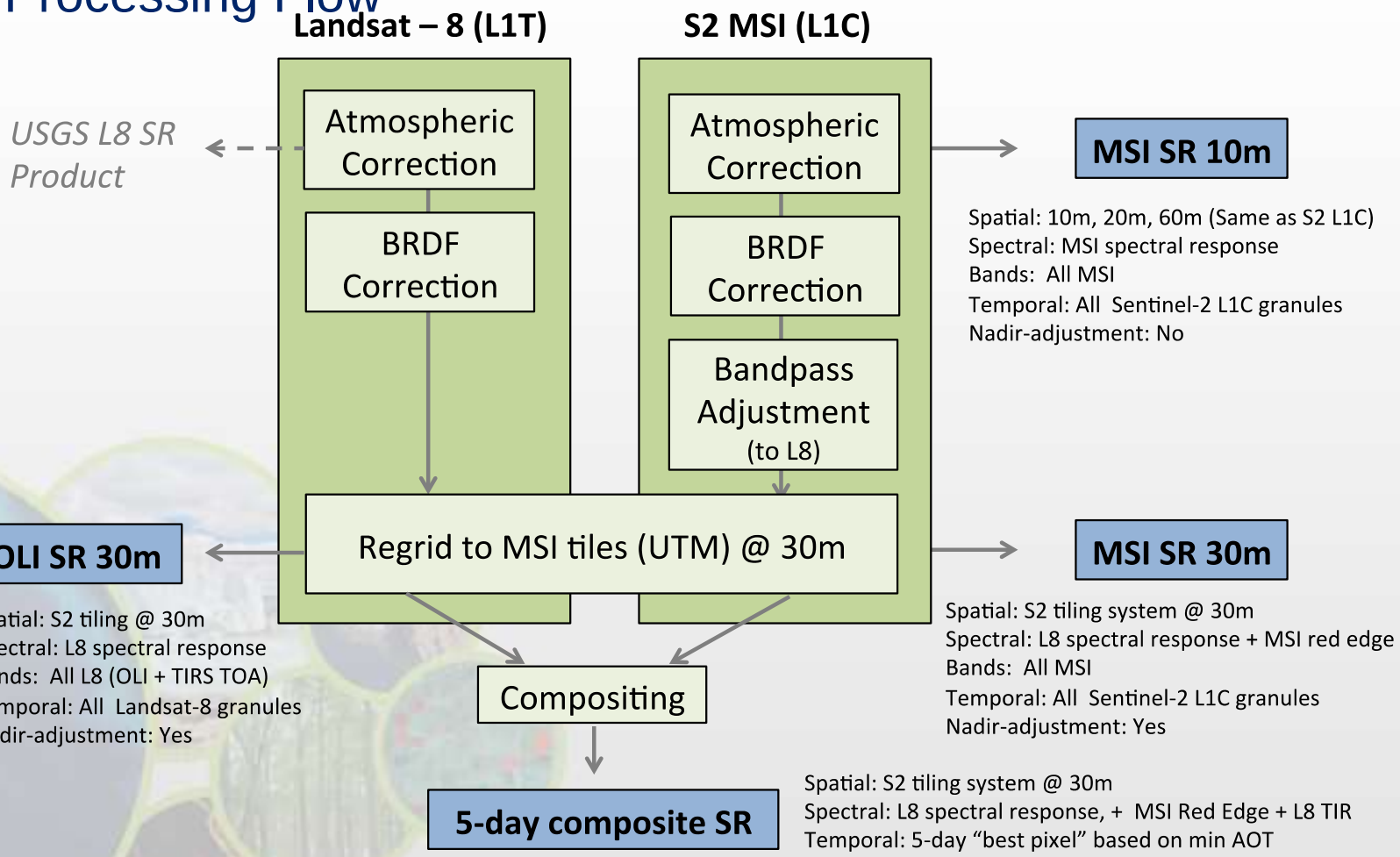
- **Copernicus data access agreements with EU signed (including all Sentinel-2 data)**

NASA Science Activities Relevant to SLI

- NASA is investing in synergistic use of international data sources to improve land monitoring
- Multi-Source Land Imaging Science (MuSLI) Team
  - Solicited through the Land Cover / Land Use Change (LCLCU) research program
  - 3-year activity to prototype land products from fusion of international systems, with focus on Sentinel-1,2 and Landsat (see next slide)
  - Coordinated with ESA SEOM (Scientific Exploitation of Operational Mission) Program
- Harmonized Landsat / Sentinel-2 (HLS) Reflectance Products
  - Goal: seamless, near-daily 30m surface reflectance record from Landsat-8 and Sentinel-2a,b
  - Includes common atmospheric correction, spectral & BRDF adjustment, resampling to common grid & frame ("data cube" concept)
  - Collaboration among NASA GSFC, ARC, and UMD
  - Implemented on NASA Earth Exchange (NEX) – initially as a series of test sites.

Regular update – Agency Cal/Val discussion

HLS Processing Flow



Recommendations- For Cross-cutting tasks and Sub-group projects

- None