NASA
Report on Cal/Val Activities

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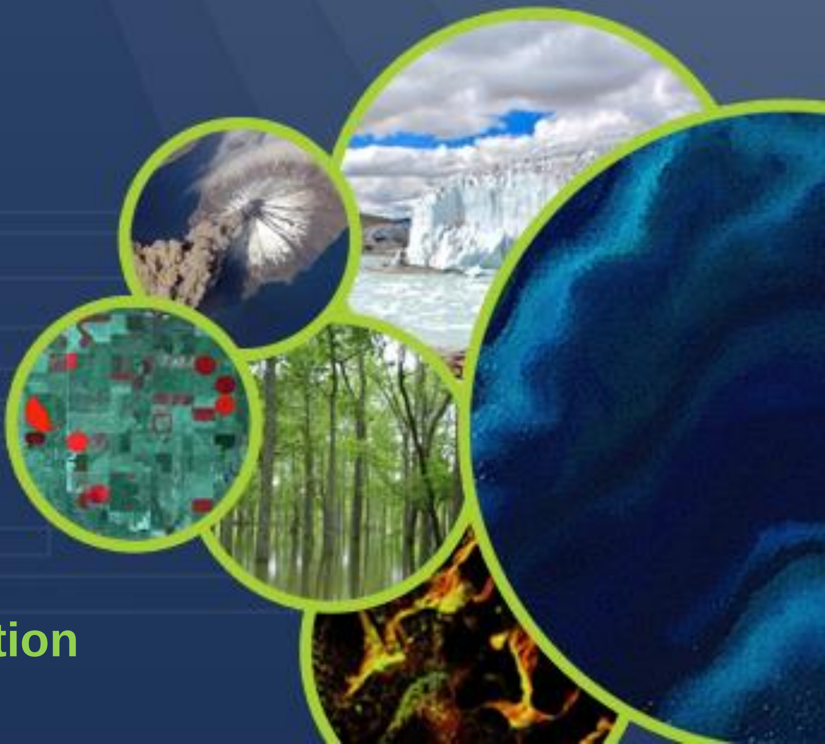
NASA

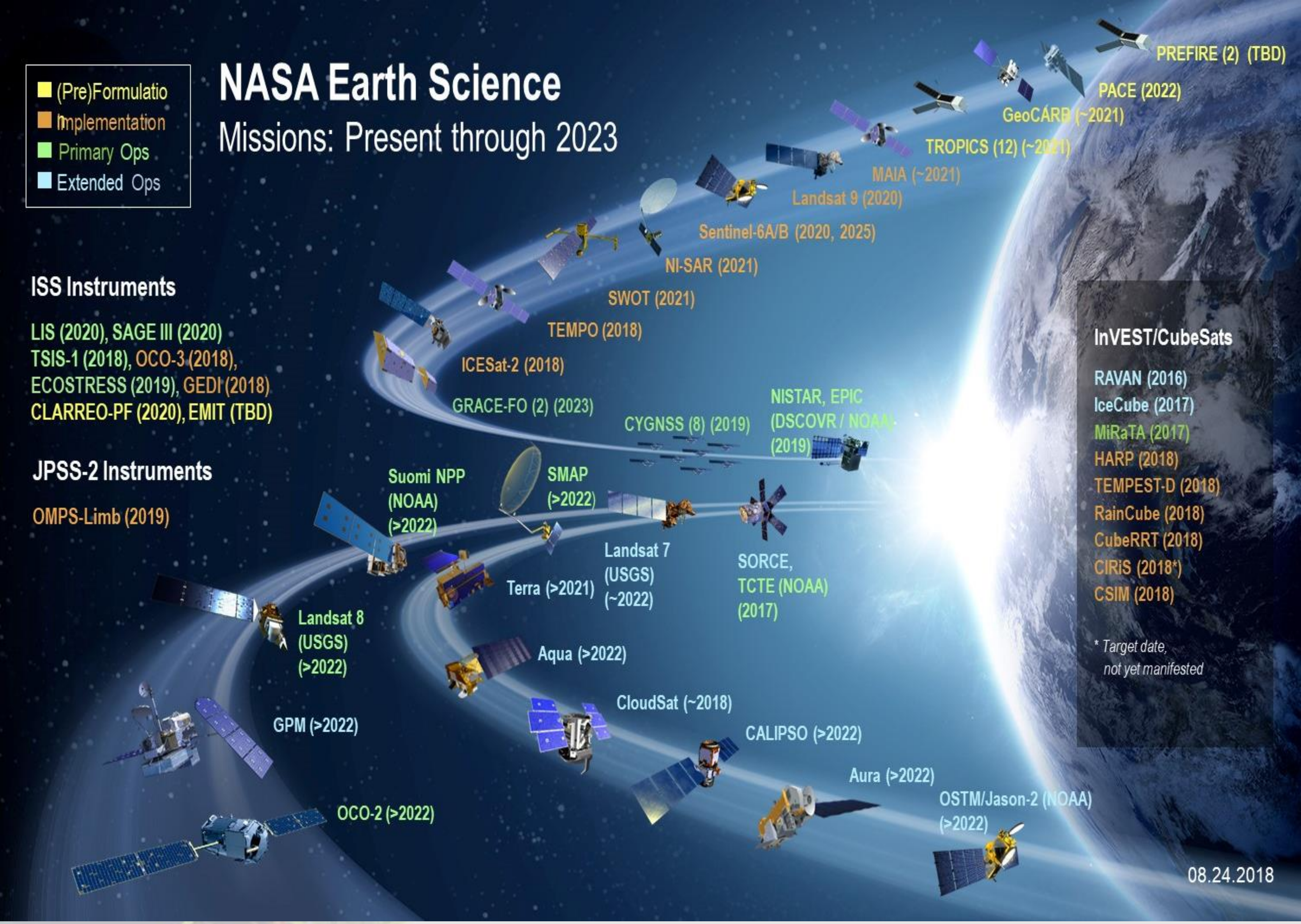
WGCV Plenary # 44

EUMETSAT, Darmstadt, Germany

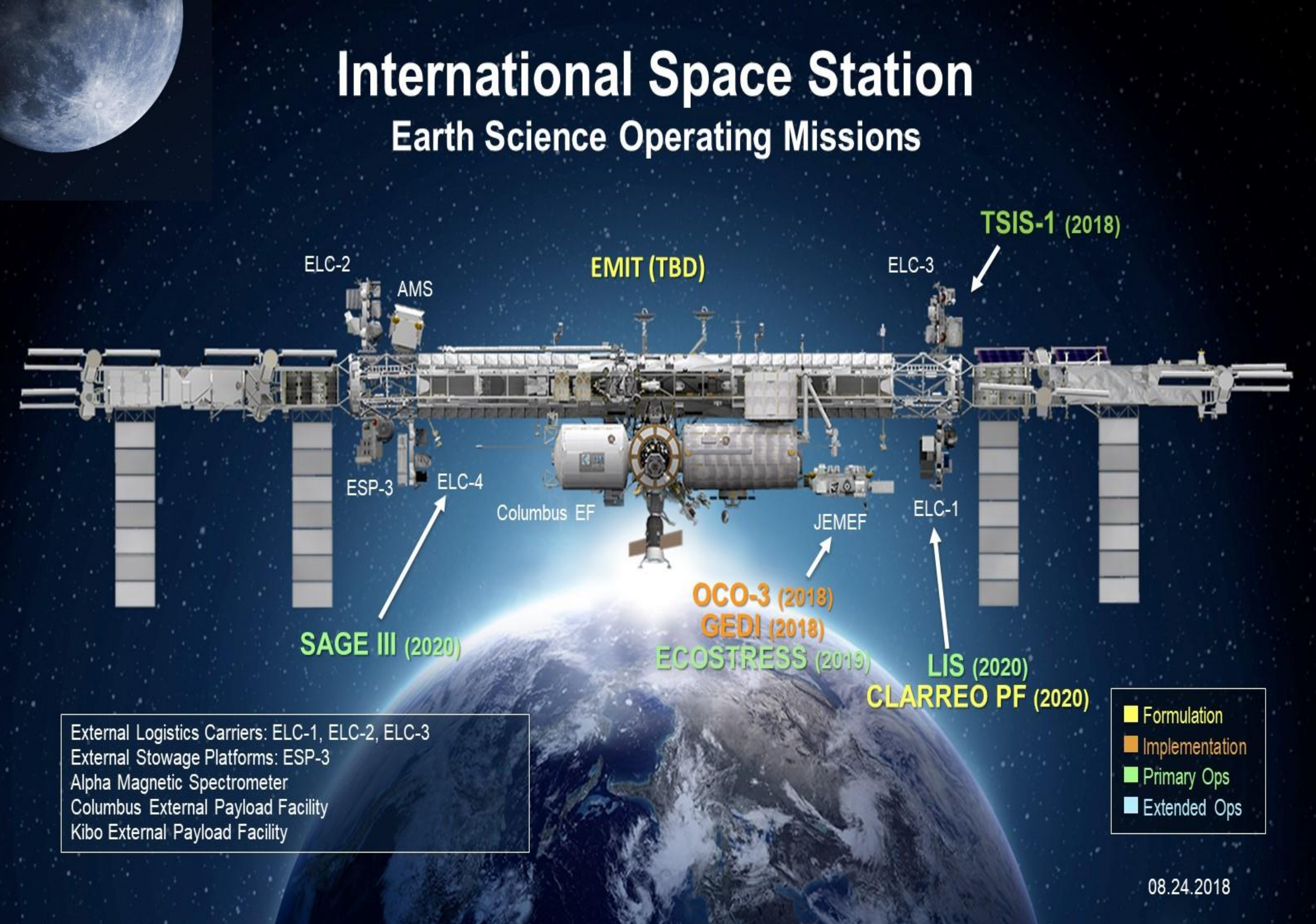
August 28-31, 2018



Working Group on Calibration and Validation



(Pre)Formulatio
Implementation
Primary Ops
Extended Ops
NASA Earth Science
Missions: Present through 2023
ISS Instruments
LIS (2020), SAGE III (2020)
TSIS-1 (2018), OCO-3 (2018),
ECOSTRESS (2019), GEDI (2018)
CLARREO-PF (2020), EMIT (TBD)
JPSS-2 Instruments
OMPS-Limb (2019)
PREFIRE (2) (TBD)
PACE (2022)
GeoCARB (~2021)
TROPICS (12) (~2021)
MAIA (~2021)
Landsat 9 (2020)
Sentinel-6A/B (2020, 2025)
NI-SAR (2021)
SWOT (2021)
TEMPO (2018)
ICESat-2 (2018)
GRACE-FO (2) (2023)
CYGNSS (8) (2019)
NISTAR, EPIC
(DSCOVR / NOAA)
(2019)
Suomi NPP
(NOAA)
(>2022)
SMAP
(>2022)
Landsat 7
(USGS)
(~2022)
SORCE,
TCTE (NOAA)
(2017)
Terra (>2021)
Landsat 8
(USGS)
(>2022)
Aqua (>2022)
GPM (>2022)
CloudSat (~2018)
CALIPSO (>2022)
Aura (>2022)
OSTM/Jason-2 (NOAA)
(>2022)
OCO-2 (>2022)
InVEST/CubeSats
RAVAN (2016)
IceCube (2017)
MiRaTA (2017)
HARP (2018)
TEMPEST-D (2018)
RainCube (2018)
CubeRRT (2018)
CIRiS (2018*)
CSIM (2018)
* Target date,
not yet manifested
08.24.2018


International Space Station
Earth Science Operating Missions
TSIS-1 (2018)
ELC-2
EMIT (TBD)
ELC-3
AMS
ESP-3
ELC-4
Columbus EF
JEMEF
ELC-1
OCO-3 (2018)
GEDI (2018)
ECOSTRESS (2019)
SAGE III (2020)
LIS (2020)
CLARREO PF (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
Formulation
Implementation
Primary Ops
Extended Ops
08.24.2018

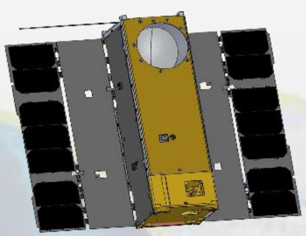
NASA Earth Science Missions through 2023

- **Extended:**
  - Terra (2021), Aqua (2022), Aura (2022), GPM (2022), CloudSat (2018), CALIPSO (2022), OSTM/Jason-2 (2022), SORCE (2018), Landsat-7 (2022)
- **Primary:**
  - S-NPP (2022), Landsat-8 (2022), OCO-2 (2022), SMAP (2022), GRACE-FO (2023), CYGNSS (2019), DSCOVR (2019)
- **Implementation:**
  - ICESat-2 (2018), TEMPO (2018), OMPS-Limb (2019), SWOT (2021), Landsat-9 (2020), NISAR (2021), MIAI (2021), Sentinel 6A/B (2022/2025)
- **Pre-Fomulation:**
  - TROPICS (12) (2021), PACE (2021), GeoCARB (2021), PREFIRE (2) (TBD)
- **International Space Station (ISS):**
  - TSIS-1 (2018), SAGE-III (2020), LIS (2020), ECOSTRESS (2019); OCO-3 (2018), GEDI (2018); CLARREO Pathfinder (2020), EMIT (TBD)
- **In-Space Validation of Earth Science Technologies (InVEST)**:
  - CubeSats

CubeSats in NASA's In-Space Validation of Earth Science Technologies (InVEST) Program

- InVEST program sponsored by NASA's Earth Science Technology Office (ESTO) to provide opportunities to test and demonstrate new technologies in space via CubeSats (as risk reduction for science missions)
- InVEST CubeSats launched or awaiting for launch:

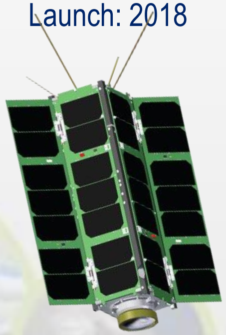
MiRaTA
MIT / MIT-LL
Launched: July 2017



3 Frequency Radiometer and GPSRO

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

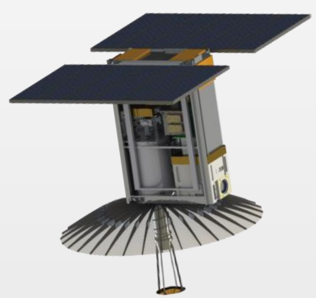
HARP
UMBC
Launch: 2018



Wide FOV Rainbow Polarimeter

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

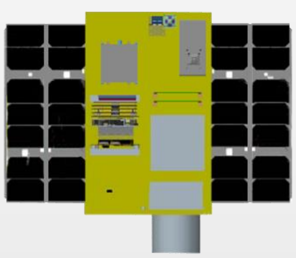
RainCube
Jet Propulsion Lab
Launched: May 2018



Precipitation Radar

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

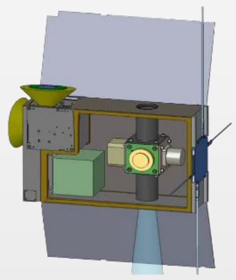
CubeRRT
Ohio State University
Launched: May 2018



Radiometer RFI

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

CIRiS
Ball Aerospace
Launch: 2018



Infrared Radiometer

Validate an uncooled imaging infrared radiometer designed for high radiometric performance from LEO

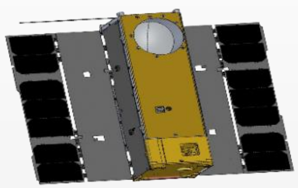
CubeSats in NASA's In-Space Validation of Earth Science Technologies (InVEST) Program

Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS)

MiRaTA

MIT / MIT-LL

Launched: July 2017

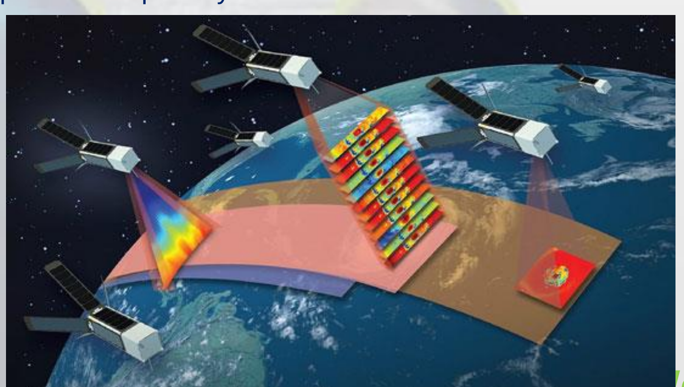


3 Frequency Radiometer and GPSRO

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

↓

6-3U CubeSats with scanning microwave radiometers to study the development of tropical cyclones

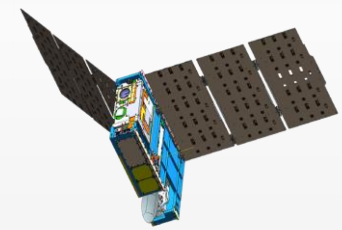


Temporal Experiment for Storms and Tropical Systems Technology (TEMPEST)

TEMPEST-D

Colorado State University

Launched: May 2018

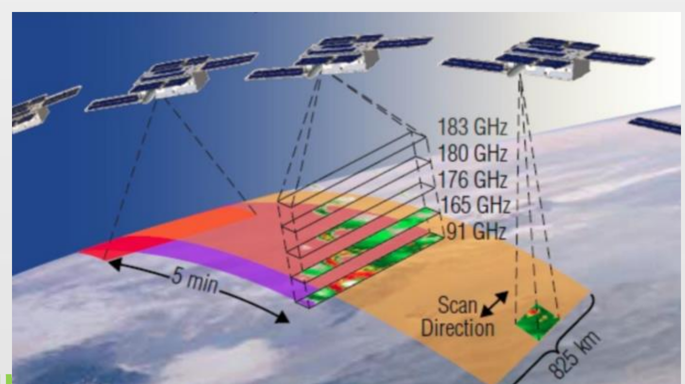


5 Frequency mm-Wave Radiometer

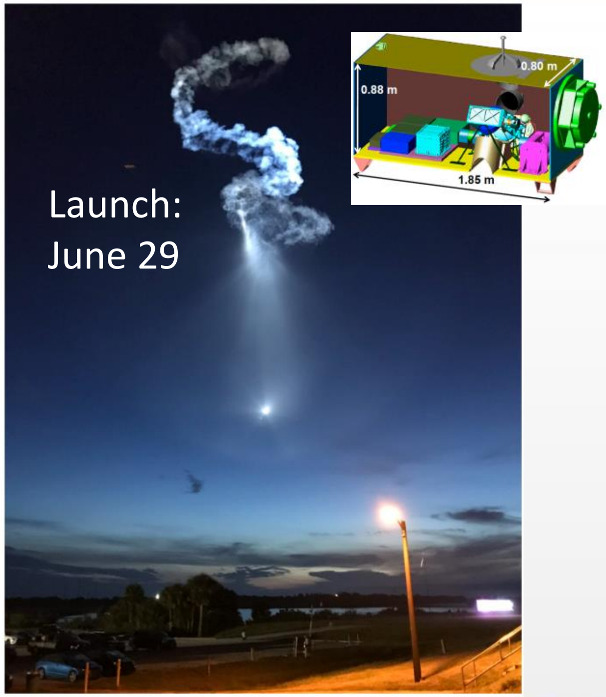
Technology demonstrator measuring the transition of clouds to precipitation

↓

5-6U CubeSats each with a 5 channel Mm-wave radiometer

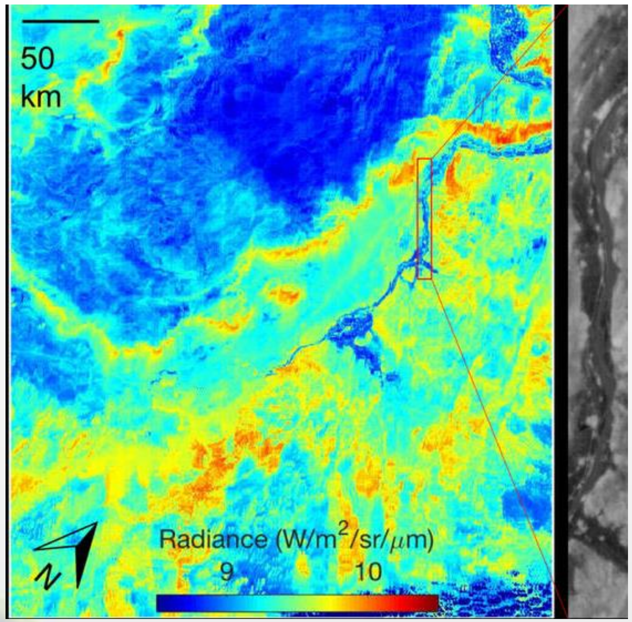


ECOSTRESS

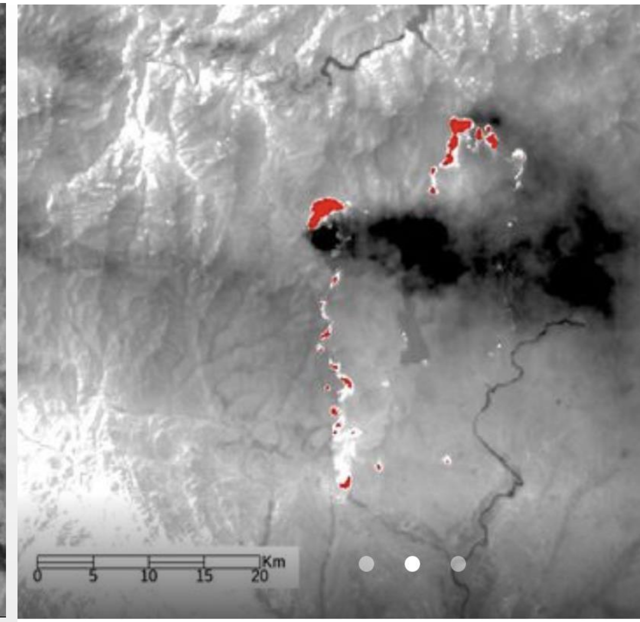


The SpaceX Falcon 9 rocket leaves a vapor trail over Kennedy Space Center's Launch Complex 39 area following the 5:42 a.m. EDT launch of the company's 15th commercial resupply mission to the International Space Station. Photo credit: NASA/Dan Casper

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (PI: Simon Hook/JPL)



River Nile at night (July 9)



Carr fire in California (July 23)

Instrument Details:

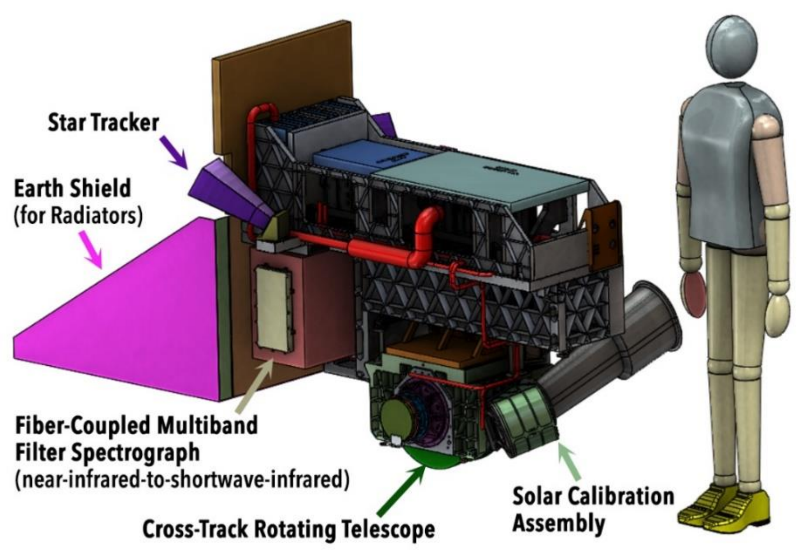
- Thermal infrared radiometer
- Cross-track whisk broom scanner
- Spatial resolution: 38 m x 57 m (nadir) pixels
- Five thermal IR bands between 8.3 and 12.1 microns
- Noise equivalent delta temperature: ≤ 0.1 K
- Two COTS cryocoolers for 60 K focal plane

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

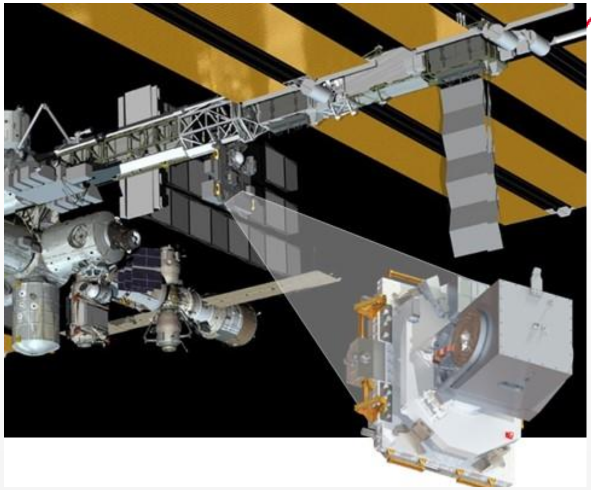
PACE: Ocean Color Instrument

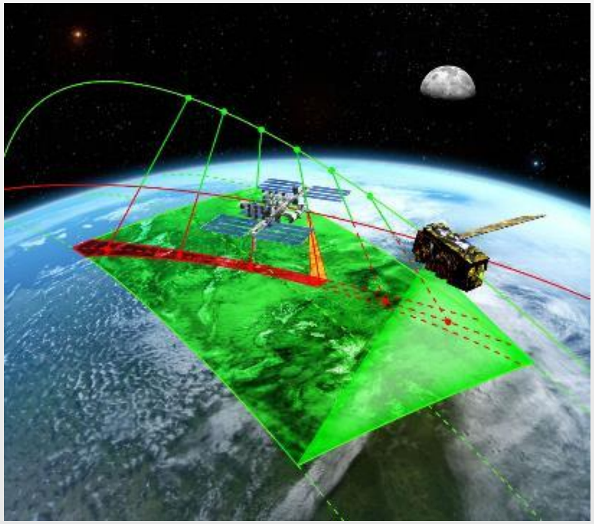
- Projected Launch Date: September 2022
- Main payload: OCI (Ocean Color Instrument)
  - 1km spatial resolution, +/-57deg swath
  - 2 day global coverage, +/-20deg tilt
  - Hyperspectral from 340nm to 885nm
  - 7 bands from 940nm to 2260nm
  - Lunar calibration twice a month
  - 2 bright solar diffusers
  - 1 dim diffuser for linearity verification
- **OCI PDR: May 2018**
- **OCI ETU testing: spring 2019**
- **OCI Flight Unit delivery: summer 2021**
- Secondary payloads: 2 polarimeters for aerosol/cloud research
  - HARP2: multispectral, wide swath
  - SPEXone: hyperspectral, narrow swath



CLARREO Pathfinder

- Demonstrate
  - 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
- Instrument: LASP Hyper Spectral Imager for Climate Science (HySICS):
  - Field of View (cross-track): 10°
  - IFOV: 0.2°
  - Wavelength Range: 350 – 2300 nm
  - Wavelength Resolution: 6 nm, constant, Nyquist sampled
  - Nominal frame rate: 15 Hz
- **EPR: September, 2018**
- **PDR: February 2019**





NASA CAL/VAL Activities

- **Pre-launch calibration and characterization**
  - For sensors developed for NASA ES mission and other agencies
- **On-orbit calibration and validation**
  - MODIS, VIIRS, Landsat-8, OCO-2, …
- **Calibration inter-comparisons**
  - SNO, LEO-LEO, GEO-GEO, DCC, CEOS reference sites, …
  - Collaboration with other agencies/organizations, including GSICS activities
- **RadCalNet and Landnet activities**
  - See Kurt's presentations
- **Lunar calibration activities**
  - Including collaboration with other agencies
  - The airborne LUnar Spectral Irradiance (air-LUSI) mission (2 successful flights)
- **Development and application of new calibration techniques and testing equipment**
- **Effort to address future demands and challenges**

VIIRS Calibration: DNB

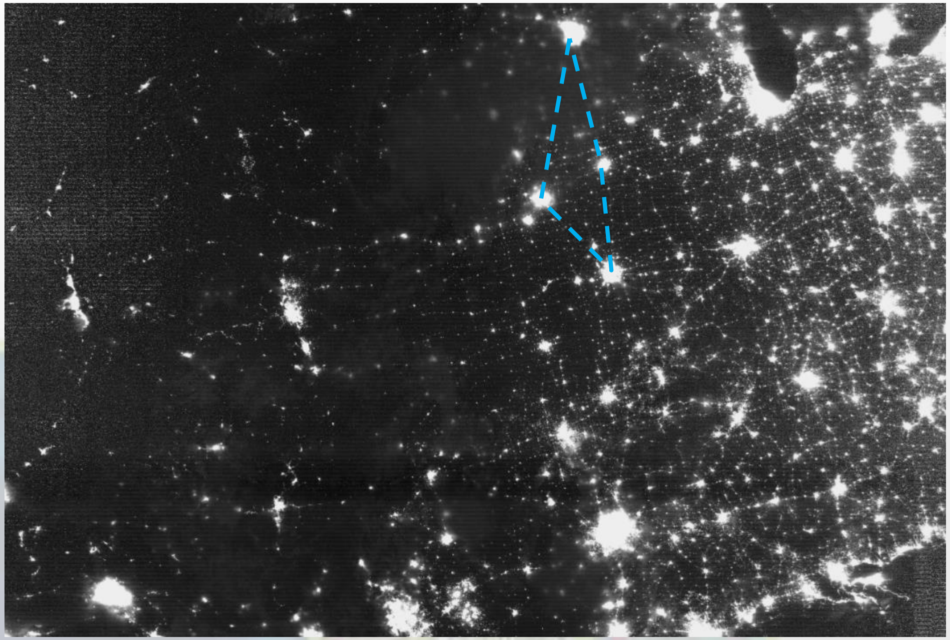
S-NPP DNB: 08:35:00, 07/13/2018
(North America)

N20 DNB: 07:44:45, 07/13/2018
(North America)

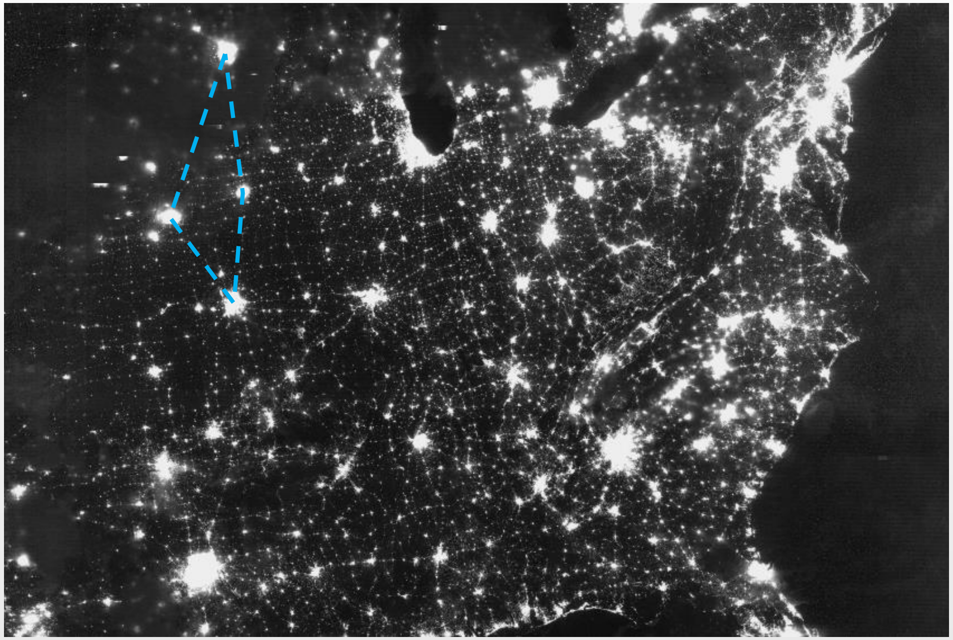
Before stray light correction

VIIRS Calibration: DNB

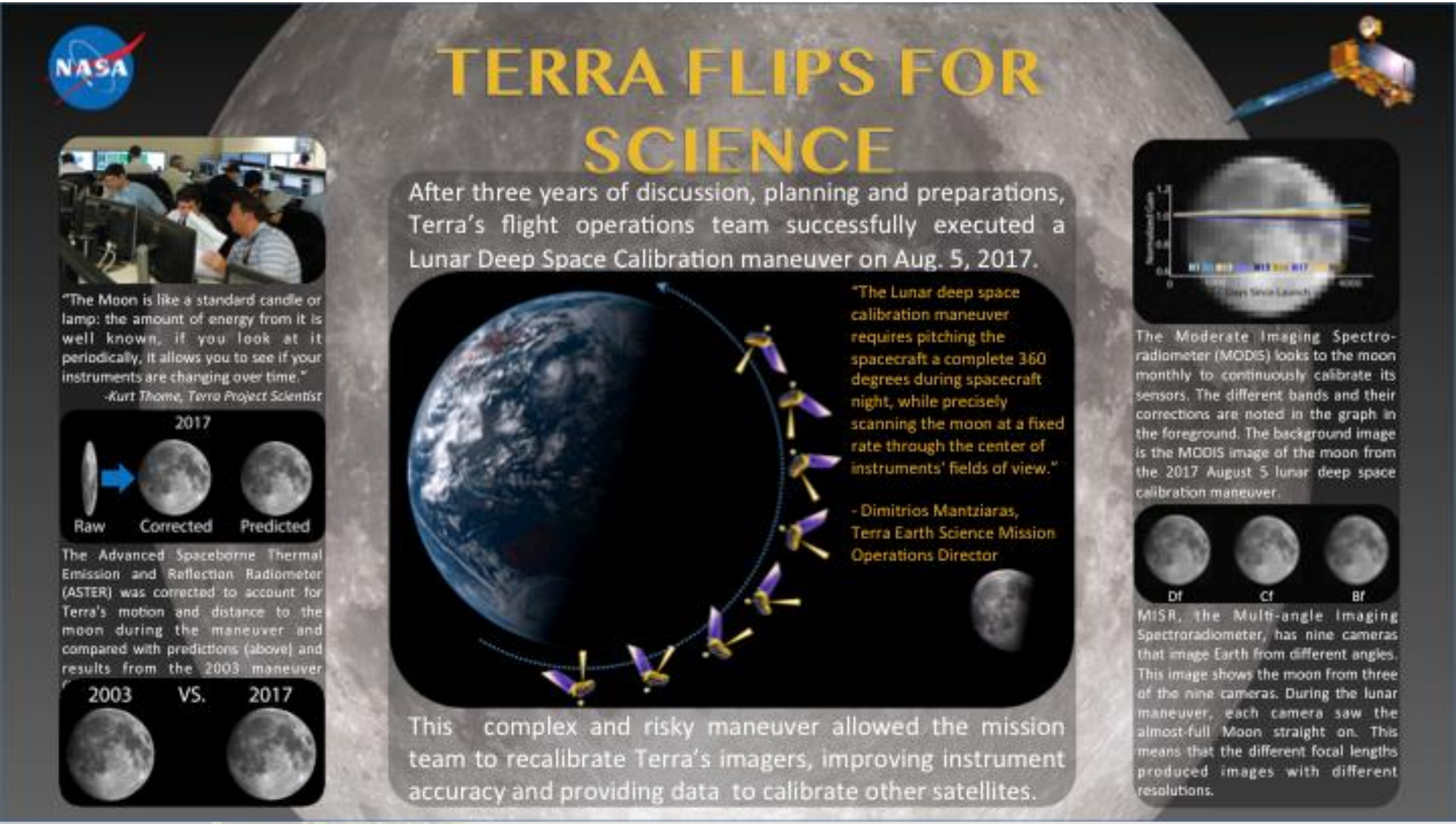
S-NPP DNB: 08:35:00, 07/13/2018
(North America)



N20 DNB: 07:44:45, 07/13/2018
(North America)



After stray light correction


NASA
TERRA FLIPS FOR SCIENCE
After three years of discussion, planning and preparations, Terra's flight operations team successfully executed a Lunar Deep Space Calibration maneuver on Aug. 5, 2017.
"The Lunar deep space calibration maneuver requires pitching the spacecraft a complete 360 degrees during spacecraft night, while precisely scanning the moon at a fixed rate through the center of instruments' fields of view."
- Dimitrios Mantziaras, Terra Earth Science Mission Operations Director
This complex and risky maneuver allowed the mission team to recalibrate Terra's imagers, improving instrument accuracy and providing data to calibrate other satellites.
"The Moon is like a standard candle or lamp: the amount of energy from it is well known, if you look at it periodically, it allows you to see if your instruments are changing over time."
-Kurt Thome, Terra Project Scientist
2017
Raw
Corrected
Predicted
The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) was corrected to account for Terra's motion and distance to the moon during the maneuver and compared with predictions (above) and results from the 2003 maneuver
2003
VS.
2017
The Moderate Imaging Spectro-radiometer (MODIS) looks to the moon monthly to continuously calibrate its sensors. The different bands and their corrections are noted in the graph in the foreground. The background image is the MODIS image of the moon from the 2017 August 5 lunar deep space calibration maneuver.
Df
Cf
Bf
MISR, the Multi-angle Imaging Spectroradiometer, has nine cameras that image Earth from different angles. This image shows the moon from three of the nine cameras. During the lunar maneuver, each camera saw the almost-full Moon straight on. This means that the different focal lengths produced images with different resolutions.

RVS Characterization Results (MODIS RSB)

- Pitch maneuver lunar observations at nadir AOI (38^o): 2003 and 2017
- Roll maneuver lunar observations at SV AOI (11^o): near-monthly

Band	λ (µm)	2003_D (NAD)	2003_R (SV)	Ratio	2017_D (NAD)	2017_R (SV)	Ratio	R/R (%)
1	0.647	1.037	1.027	**1.009**	1.047	1.046	**1.002**	**1.007**
2	0.857	1.077	1.075	**1.003**	1.079	1.094	**0.986**	**1.017**
3	0.466	1.099	1.088	**1.010**	1.099	1.084	**1.014**	**0.996**
4	0.554	1.063	1.054	**1.008**	1.056	1.050	**1.006**	**1.003**
8	0.412	1.107	1.105	**1.002**	1.116	1.097	**1.018**	**0.984**
9	0.442	1.102	1.082	**1.019**	1.100	1.074	**1.024**	**0.995**
10	0.487	1.085	1.087	**0.998**	1.068	1.075	**0.994**	**1.004**
11	0.530	1.068	1.062	**1.006**	1.055	1.055	**1.000**	**1.006**
12	0.547	1.084	1.077	**1.007**	1.070	1.070	**1.001**	**1.006**
17	0.904	1.137	1.139	**0.998**	1.125	1.140	**0.987**	**1.011**
18	0.935	1.177	1.175	**1.002**	1.160	1.172	**0.990**	**1.012**
19	0.936	1.174	1.172	**1.002**	1.160	1.175	**0.988**	**1.015**

Measured lunar irradiance normalized to ROLO