Active Optical Remote Sensing Sensors and Instrumentations for NASA's Future Earth Science, Planetary Science and Mars/Lunar Explorations Measurements/Missions

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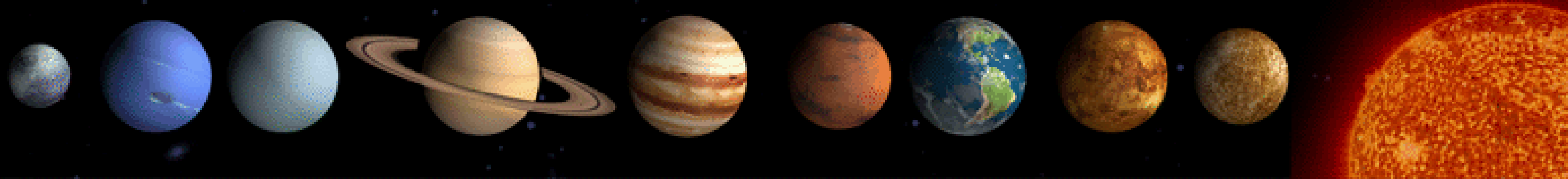


Outline

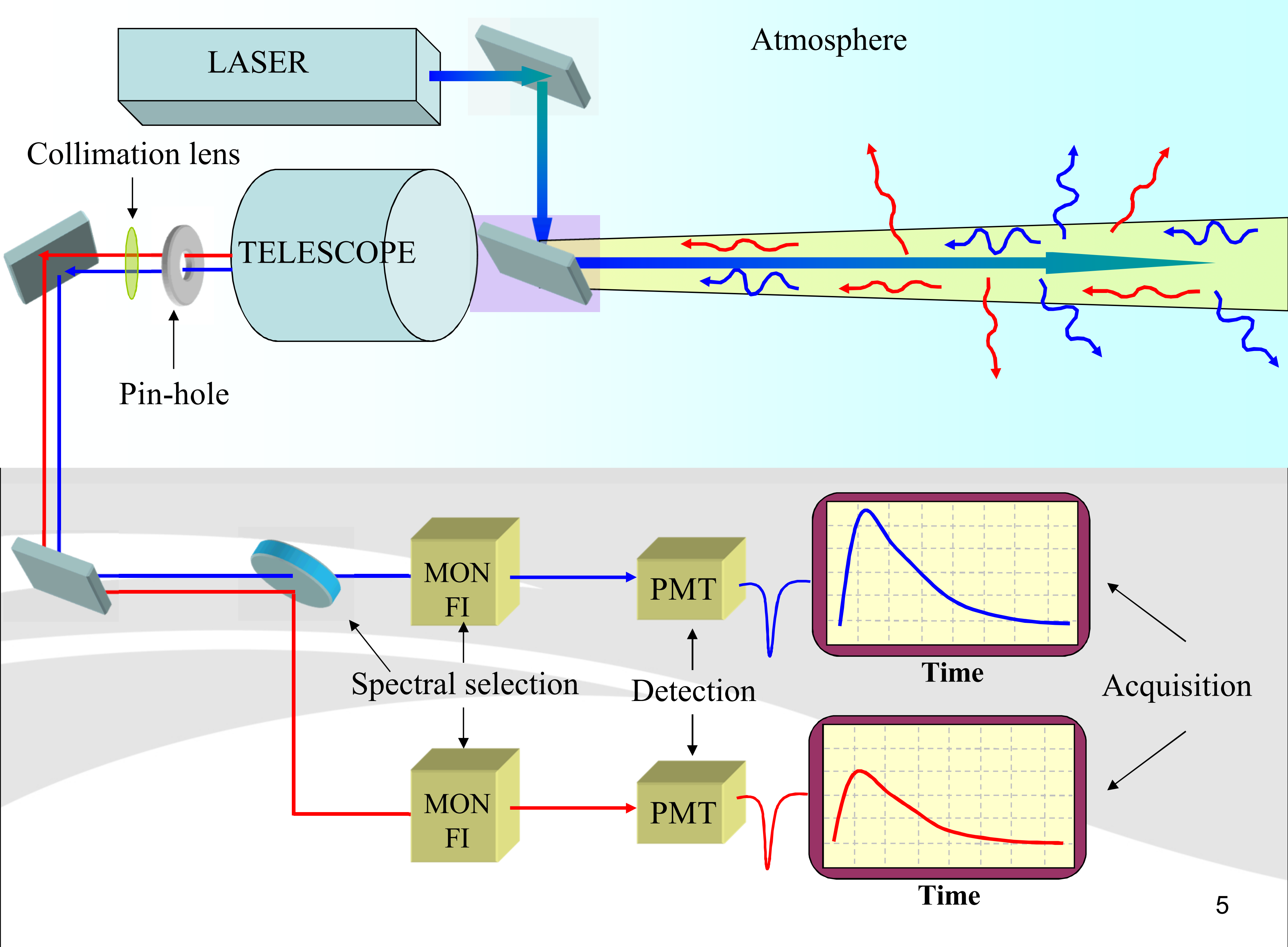
- Introduction
  - Active Optical Remote Sensing
  - Lidar Techniques
  - Lidar Applications in NASA's Missions/Measurements
- NASA Sensors and Instrumentation Capability
  - Assessments, findings, and challenges
  - Leveraging National and International Capabilities
  - Active Optical Strategy Formulation and Recommendations
- Satellite Missions in Orbit and in Formulation
  - CALIPSO, CATS
  - IceSat II, GEDI
- Conclusions

AORS Strategies

- Laser based instruments are applicable to a wide range of NASA's Earth Science, Planetary Science, Aeronautics, and Human Explorations and Operation Mission Directorate needs
- Risk in lidar missions can be significantly reduced by progress in a few key technologies
- Modest NASA investment towards proposed strategy will have significant impact on future space-based active remote sensing missions
- Strategic alliance with other government organizations, industry, and academia for leveraging and accelerating advancement of key technologies

LIDAR - LIght Detection And Ranging

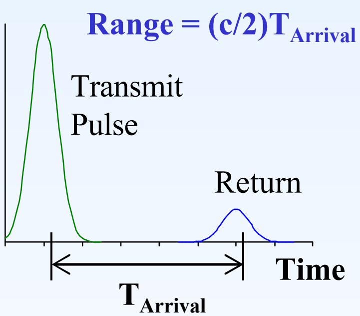
- LIDAR is an important technique that contributes to NASA's overall efforts in Earth System Science
- LIDAR can make unique contributions, especially in terms of high vertical resolution (accurate time measurements -> accurate height measurements!)
- Since LIDAR involves "bring your own signal" (or "create your own") there is a possibility of obtaining results not available from passive measurements that utilize "the signal nature gives you"
- LIDAR measurements can be important complements and/or validation measurements for those from other approaches
- LIDAR technology has advanced to the point that deployment from surface, aircraft, and satellites is now possible; continuing advances offer even greater possibilities in the future.
- NASA has strong scientific and technical capability that is applied to development and utilization of LIDAR approaches



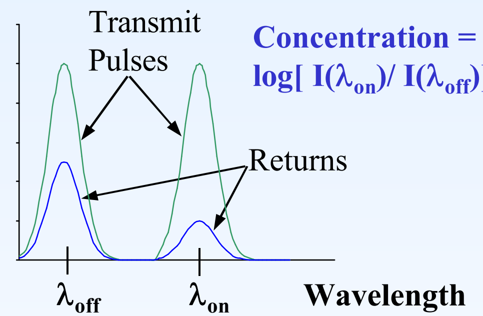
LASER
Atmosphere
Collimation lens
TELESCOPE
Pin-hole
MON
FI
PMT
Time
Spectral selection
Detection
Acquisition
MON
FI
PMT
Time

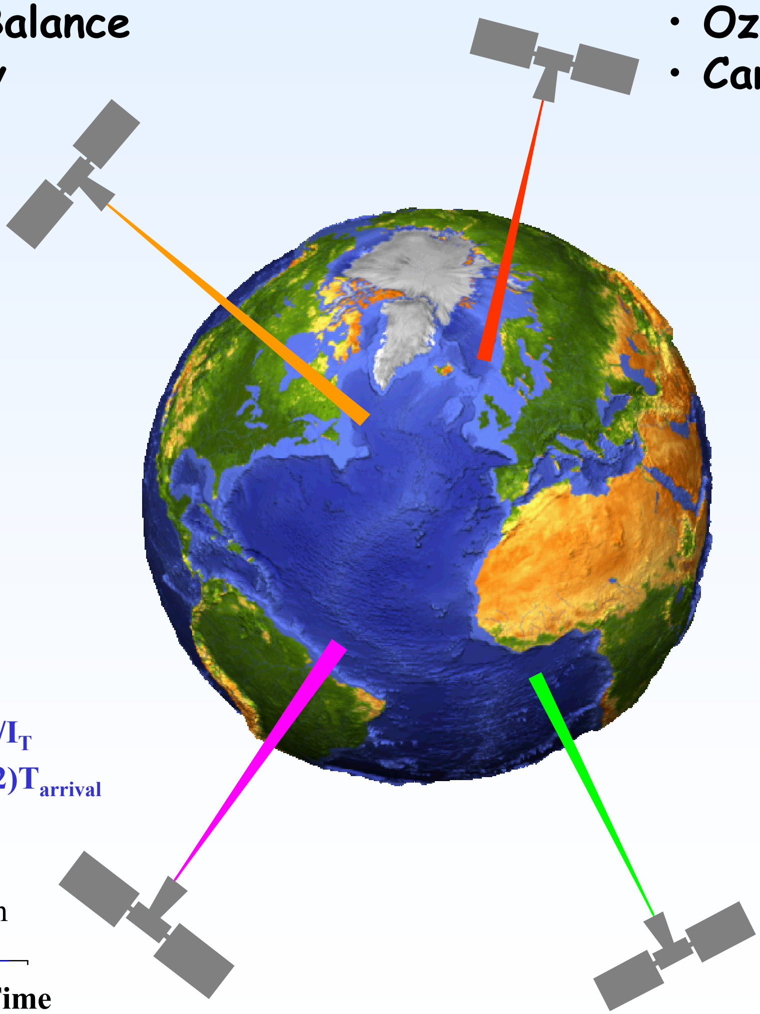
Lidar Techniques

Altimetry Lidar
- Ice Sheet Mass Balance
- Vegetation Canopy
- Land Topography

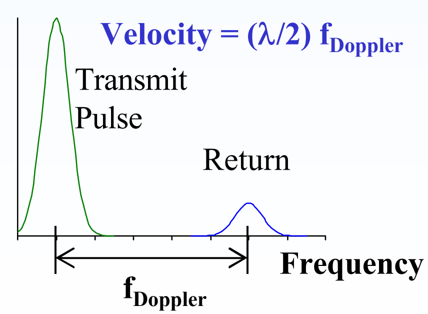


Differential Absorption Lidar (DIAL)
- Ozone
- Carbon Dioxide

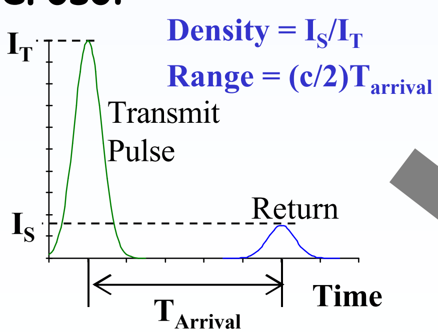




Doppler Lidar
- Wind Fields



Backscatter Lidar
- Cloud
- Aerosol



LIDAR is a Multi-Enterprise Need

NASA Enterprises Needs

LIDAR

Science

- *Clouds/Aerosols*
- *Tropospheric Winds*
- *Ozone*
- *Carbon Dioxide*
- *Biomass Burning*
- *Water Vapor*
- *Surface Mapping*
- *Laser Altimetry*
- *Oceanography*
- *Surface Topography*
- *Molecular Species*
- *(H_2O, CO_2, Methane)*

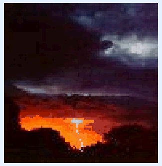
Space Exploration

- *Lander Guidance/ Control*
- *Lander Hazardous Winds/Dust Avoidance*
- *Mars Atmospheric Winds*
- *Biological Elements (C, N, H, S, P)*
- *Optical Communication*
- *Spacecraft Automatic Rendezvous/Capture*
- *Wind Profiling for Launch Vehicles*

Aeronautics

- *Turbulence detection*
- *Wind shear detection*
- *Wake vortices*

Active Optical Measurements in the Earth Sciences

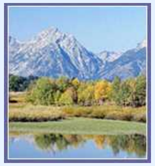


Weather

- Tropospheric Winds
- Atmospheric Temperature and Water Vapor
- Cloud Particle Properties
- Cloud System Structure
- Storm Cell Properties

Climate Variability

- Ocean Surface Currents
- Deep Ocean Circulation
- Sea Ice Thickness
- Ice Surface Topography

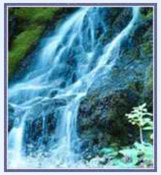


Earth Surface & Interior

- Land Surface Topography
- Surface Deformation
- Terrestrial Reference Frame

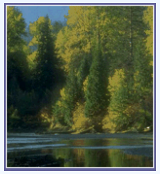
Atmospheric Composition

- Aerosol Properties
- Total Aerosol Amount
- Cloud Particle Properties
- Cloud System Structure
- Ozone Vertical Profile & Total Column Ozone
- Surface Gas Concentrates



Water & Energy Cycle

- Atmospheric Water Vapor
- River Stage Height



Carbon Cycle & Ecosystems

- Biomass
- Vegetation Canopy
- Fuel Quality & Quantity
- CO_2 & Methane
- Trace Gas Sources
- Land Cover & Use
- Terrestrial & Marine Productivity

Doppler Altimetry DIAL Backscatter

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NASA Sensors and Instrumentation Capability

- Sensors and Instrumentation Capability Observations and Challenges
- S&I Capability Observations, Findings and Recommendations to APMC for developing integrated agency-level strategy for Active Optical (Laser/Lidar)
- APMC Formal Action Item
- Active Optical Tiger Team Approach
  - Work Plan and Strategy for Assessment and Recommendation
  - Outcomes and Reporting

S&I Technology Challenges

- **Findings:**
  - Opportunities for TRL 1-2 Sensor/Instrument development funding are limited
  - Opportunities for academia to participate in basic research to advance capabilities are limited and have shrunk over the years (e.g. GSRP and NASA/ASEE faculty fellowship programs are going away)
  - On-boarding new hires with chances to develop their careers through growing new technologies and applying them to mission concepts is limited
  - Improving methods for crossing the "Valley of Death" will result in reductions in both the rate and the magnitude of cost overruns occurring during mission development.
  - Improved methods for technology maturation will likely require increased technology investment in the early stages of mission development, but will result in significant risk reduction for missions/instruments. In turn, this will reduce both schedule and budget overruns, likely resulting in net savings. Further, it will enable an increased cadence for world-leading science missions.
- **Forward Work:**
  - Partner with OCT to review current S&I roadmap, review valley of death and assess distribution of TRL funding to work through these challenges

Capability Leadership Team Assessment, 2017
Sensors and Instrumentation

- **Findings:**
  - **Active optical (Laser/Lidar)** is critical for future NASA Earth, Planetary Science, and Mars Explorations. Six out of fifteen missions recommended by 2007 NRC Earth Science Decadal Survey require active optical remote sensing for successful mission implementation. Laser/Lidar is also critical for enabling human-rated EDL capabilities for a crewed Mars mission
  - The existing competitive model to fund technologies to develop, mature, advance, and demonstrate TRL advancement in a relevant environment is not working and often results in massive cost growth and schedule slips for Laser/Lidar missions.
  - Need to produce more flight-ready Laser/Lidar technologies ready for mission infusion with the accompanying reduction in mission cost, schedule slips, and performance degradation.
  - Need to enhance inter-Center collaboration and leveraging between SMD and HEOMD missions.

New Formal Action Item - APMC

- 09-13-2017 Action #7:

Charter an Active Optical (Laser/Lidar) tiger team, which includes representation from SMD, STMD and HEOMD to address an increased emphasis in Active Optical technology which is critical for future NASA Earth, Planetary Science and Mars Exploration. Team to provide agency-level strategy and solutions for advancing high-risk Laser/Lidar technologies that are not currently being sufficiently planned or developed or risk reduced to meet NASA missions requirements.

- Assigned to: Sensors/Instruments Capability Lead/U. Singh
- Due March 2018 (status); September 2018 (completion)

Active Optical Strategy Approach

- Active Optical will be a multi-directorate teaming of the Science Mission, Human Exploration and Operation Mission, Aeronautics Research Mission Directorate and Space Technology Mission representatives to provide the guidance and list of priority measurements requirements to meet their critical future needs.
- An Active Optical Tiger team consisting of MD's representatives, CLT/TDT leads/co-leads and an external assessment team will work together to seek national and international community inputs to formulate an integrated Agency level strategy
- An essential part of the augmentation strategy will be to engage with other US Government entities, as well as industry and academia, to leverage common Active Optical interests and complementary skills/expertise resident in those sectors
- Develop a cross-cutting strategy based on "Lead, Leverage and Collaborate" approach with NASA and external entities, national and international, to meet NASA Science, Aeronautics and Exploration needs
- An integrated technology development and investment plan, which will address each directorate agency's requirements in a cross-cutting, synergistic and cost-effective manner, to meet the Agency-level, priority Active Optical space based measurements/missions.

National and International Community Inputs

- **NASA Technical Interchange Meeting (TIM) on Active Optical Systems for Supporting Science, Exploration, and Aeronautics Measurements Needs**
  - **July 31-August 3, 2018**
  - Universities Space Research Association (USRA) Headquarters, Columbia, MD 21046
  - TIM will bring together Active Optical experts from NASA Centers, NASA HQ, Industry, Academia, National Labs, and DoD who are engaged in developing concepts and systems to support NASA measurements needs

    https://www.nasa.gov/nesc/tim-active-optical-systems

- **Second International IEEE-GRSS Workshop on Space-based Lidar Remote Sensing Techniques and Emerging Technologies**

  Chairs: Upendra N. Singh[1] and Georgios Tzeremes[2]

  [1]NASA Langley Research Center, USA; [2]European Space Agency, ESTEC, The Netherlands
  - **June 4-8, 2018** at Milos Conference Center, Adamas, Milos Island, Cyclades, Greece
  - Workshop will bring together Active Optical Experts from NASA, ESA, JAXA, CNES, and DLR policy makers and experts from various agency engaged in advancing Space missions/measurements in Active Optical area for Science and Exploration

Purpose for TIM and Workshop

- TIM is a forum to exchange perspectives on the current state of the discipline's technologies and the direction NASA needs to take in the future to raise the TRL of the measurement technologies to meet these measurement needs in the applications domains
- TIM inputs will be used in formulating the agency-level strategy and solutions for advancing high-risk Laser/Lidar technologies that are not currently being sufficiently planned, developed, or risk reduced to meet NASA missions requirements
- The TIM aims at focusing NASA's directions to attain the necessary technology TRL levels to meet the Agency-level priority Active Optical measurements in Space and Aeronautics
- The TIM presentations and strategic inputs will be synthesized by the NASA Active Optical Tiger Team and presented to the NASA APMC with a suggested strategy to address the Agency's needs in a cross-cutting, synergistic and cost-effective manner
- Workshop inputs will be used to incorporate international synergies and collaborative opportunities between NASA and other international space agencies, for consideration in future planning

Mission I - To Understand and Protect our Home Planet
Earth Science Foci

- *Atmospheric Composition* sounding measurements in the troposphere including aerosol and cloud properties and profiling, water vapor profiling, and Planetary Boundary Layer height
- *Earth's Surface & Interior* via geodetic imaging including wide-swath laser altimetry
- *Climate Effect Monitoring* including ice mass changes, global ice characterization, snow depth, and snow-water equivalent measurements
- *Weather Prediction* including global tropospheric wind measurements
- *Carbon, Ecosystems, & Biogeochemistry* including measurements of CO_2 and CH_4 fluxes and trends, vegetation 3D structure, biomass, and disturbance, ocean mixing layer

Mission II - To Explore the Universe and Search for Life

Planetary and Exploration of Mars, Lunar and Outer Planets foci

- *Lunar Exploration* including landing navigation and hazard avoidance, and surface exploration and characterization
- *Jovian Moons* including surface features and characterization, and tidal signatures
- *Jovian Environment* including atmospheric cloud and wind structure, atmospheric composition
- *Mars Exploration* including atmospheric winds, density, and dust profiling, surface topography, surface exploration and characterization, search for organic signatures, moisture distribution, and cloud characterization
- *Martian Mission Support* including precision landing, navigation, and hazard avoidance, sample return rendezvous and capture, atmospheric characterization to support entry, descent, and landing
- *Titan and Venus* including balloon-borne active optical instrumentation
- *Situational awareness of space weather phenomena*
- *Laser interferometry, active –optical sensing of telescope and satellite swarm elements to enable observations*

Mission III: Active Optical for Aeronautics

- *Detection of turbulence* (current activities by Boeing and JAXA)
- *Detection of and situational awareness for atmospheric hazards* (e.g., volcanic ash, ice, snow)
- *Sense and avoidance for autonomous UAVs and future autonomous urban mobility aircraft*
- *LIDARs on airport ground to control taxing, takeoff, and landing of aircraft* (eg.,wake vortices)
- *Imagery of various targets using UAVS*
- *Miniaturized, low power active optical sensors and instrumentation* for Unmanned and Personal Air Vehicles for sensing and avoiding hazards in the National Air Space

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Earth Science Missions
FY17 Program of Record

ISS Instruments

CATS *(2020)*, LIS *(2020)*, SAGE III *(2020)*
TSIS-1 *(2018)*, OCO-3 *(2018)*, ECOSTRESS *(2017)*, GEDI *(2018)*
CLARREO-PF *(2020)*, TSIS-2 *(2020)*

JPSS-2 Instruments

RBI *(2018)*, OMPS-Limb *(2018)*

- Formulation
- Implementation
- Primary Ops
- Extended Ops

Landsat 9 *(2020)*
PACE *(2022)*
GeoCARB *(~2021)*
TROPICS (12) *(~2021)*
MAIA *(~2021)*
Sentinel-6A/B *(2020, 2025)*
NI-SAR *(2021)*
SWOT *(2021)*
TEMPO *(2018)*
GRACE-FO (2) *(2018)*
ICESat-2 *(2018)*
CYGNSS (8) *(2019)*
NISTAR, EPIC (DSCOVR / NOAA) *(2019)*
SMAP *(>2022)*
Landsat 7 (USGS) *(~2022)*
QuikSCAT *(2017)*
SORCE, TCTE (NOAA) *(2017)*
Suomi NPP (NOAA) *(>2022)*
Terra *(>2021)*
Landsat 8 (USGS) *(>2022)*
Aqua *(>2022)*
CloudSat *(~2018)*
CALIPSO *(>2022)*
GPM *(>2022)*
Aura *(>2022)*
GRACE (2) *(2018)*
OSTM/Jason 2 (NOAA) *(>2022)*
OCO-2 *(>2022)*

Invests/Cubesats

RAVAN	(2016)
IceCube	(2017)
MiRaTA	(2017)
HARP	(2017)
TEMPEST-D	(2018)
RainCube	(2018*)
CubeRRT	(2018*)
CIRiS	(2018*)
CIRAS	(2018*)
CSIM	(2018*)
LMPC	(TBD)

*Target date, not yet manifested

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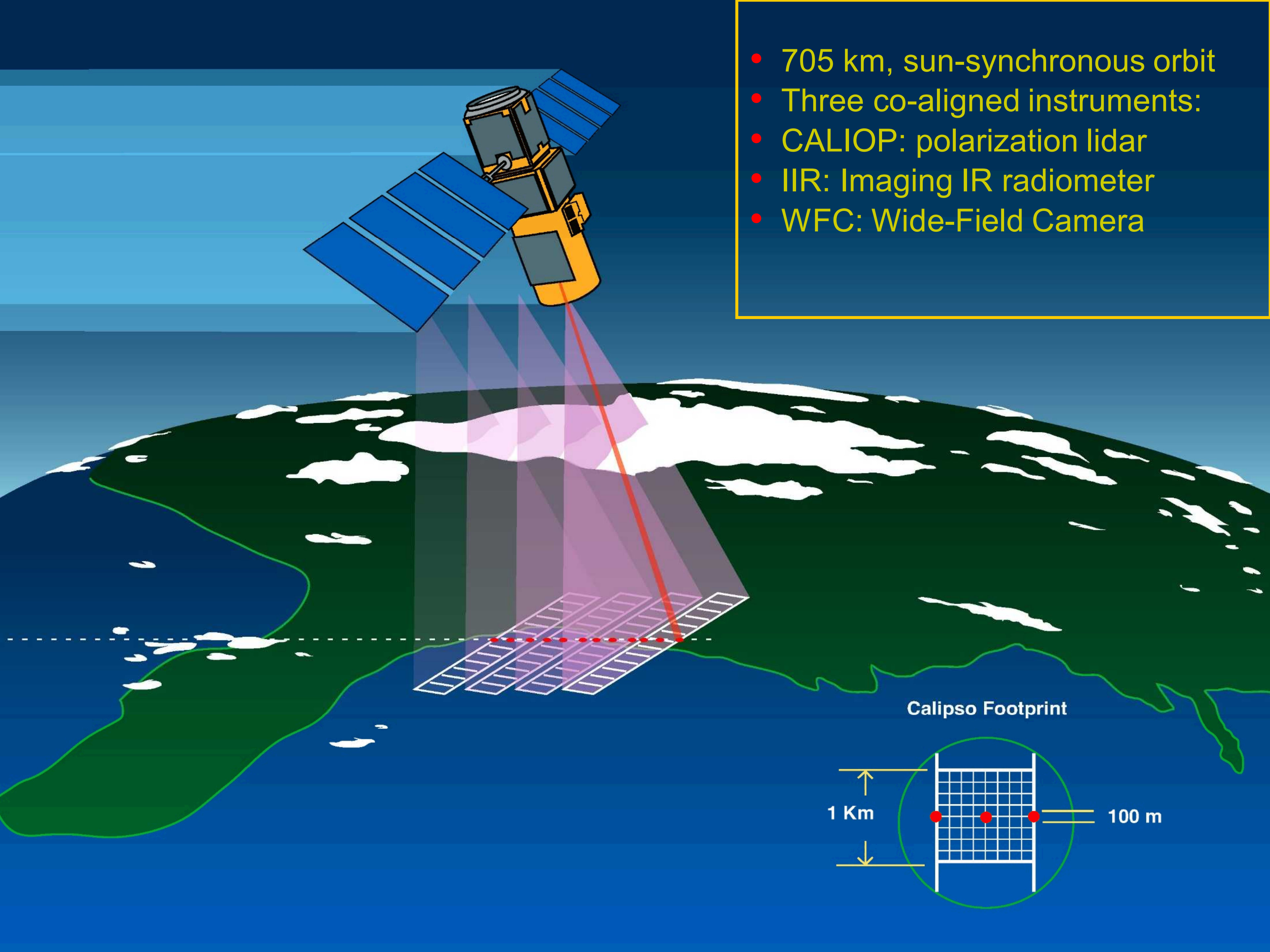
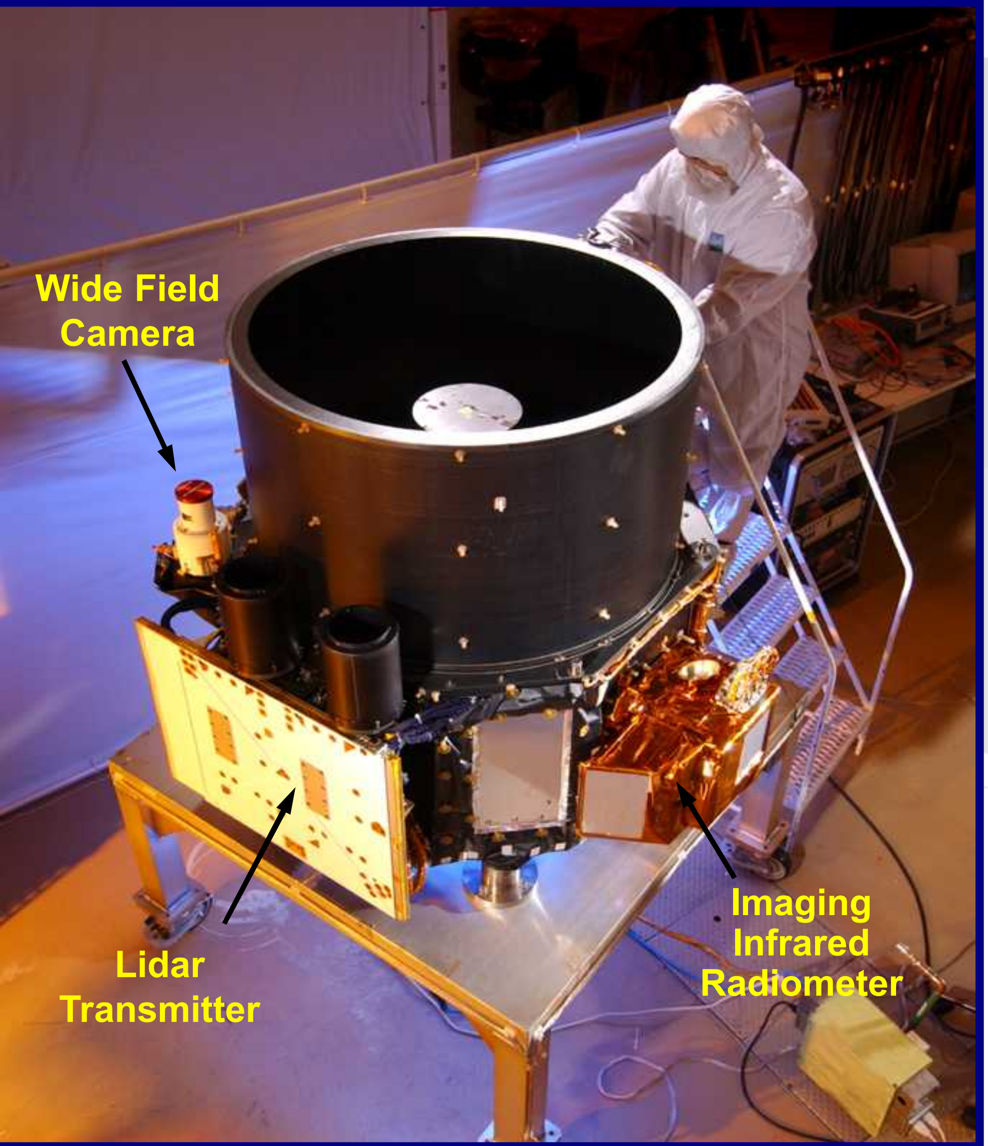
Observing Clouds and Aerosols with CALIPSO

Courtesy: Dave Winker, NASA Langley Research Center



• 705 km, sun-synchronous orbit
• Three co-aligned instruments:
• CALIOP: polarization lidar
• IIR: Imaging IR radiometer
• WFC: Wide-Field Camera
Calipso Footprint
1 Km
100 m

Instrument Specifications



CALIOP

Laser	Nd: YAG, 2x110 mJ
Wavelength	532 nm, 1064 nm
Repetition rate	20.25 Hz
Receiver telescope	1.0 m diameter
Polarization	532 || and ⊥
Footprint/FOV	100 m / 130 μrad
Vertical resolution	30 - 60 m
Horizontal resolution	333 m
Lin. dynamic range	22 bits

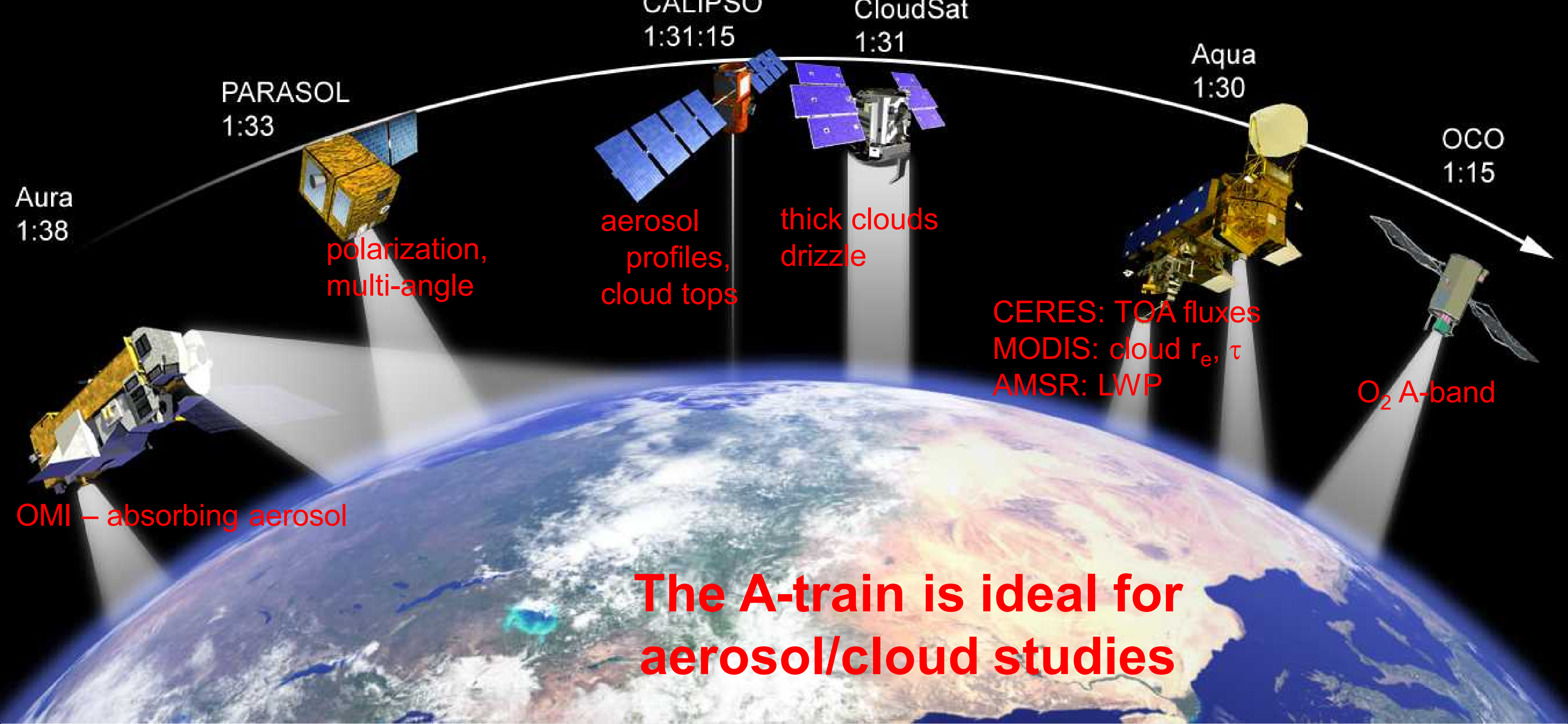
Wide-Field Camera (WFC)

Wavelength	645 nm
Spectral bandwidth	50 nm
IFOV / Swath	125 m / 61 km

Imaging Infrared Radiometer (IIR)

Wavelength	8.65, 10.6,12.05 μm
Spectral resolution	0.6-1.0 μm
IFOV / Swath	1 km / 64 km
NETD @ 210K	0.3 K
Calibration	±1 K

The A-train



Cloud ice/water mass	CloudSat MLS AMSR
Cloud microphysics	MODIS CloudSat PARASOL
Precipitation	CloudSat AMSR

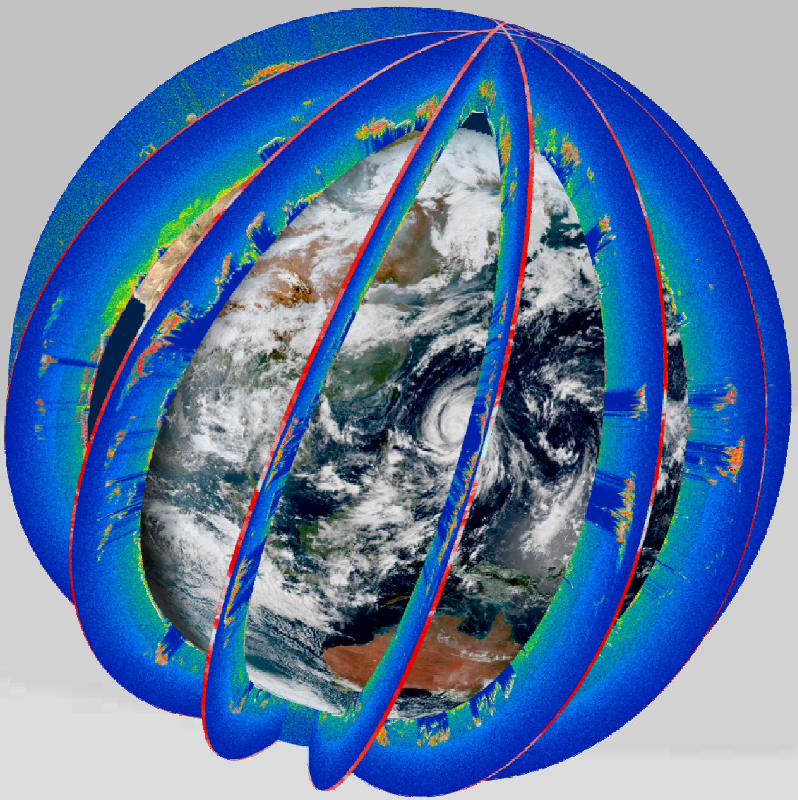
Aerosol optics	CALIPSO MODIS PARASOL OMI
Cloud optics	CALIPSO, MODIS, and PARASOL
Chemistry	AURA
Radiative Fluxes	CERES

CALIPSO Continues to Extend its Long Record of Global Measurements

New and improved data products are available for the entire lidar record.

CALIPSO backup laser is expected to become inoperable within the next 6 months because of a slow air leak.

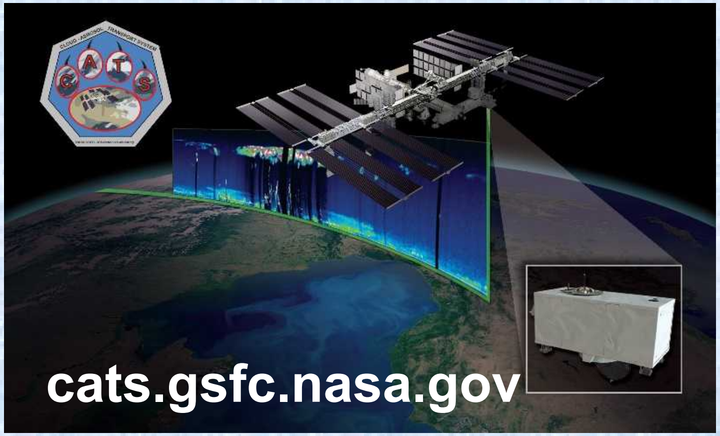
The project will restart the primary laser that became inoperable in 2009 and, hopefully, will continue the mission.

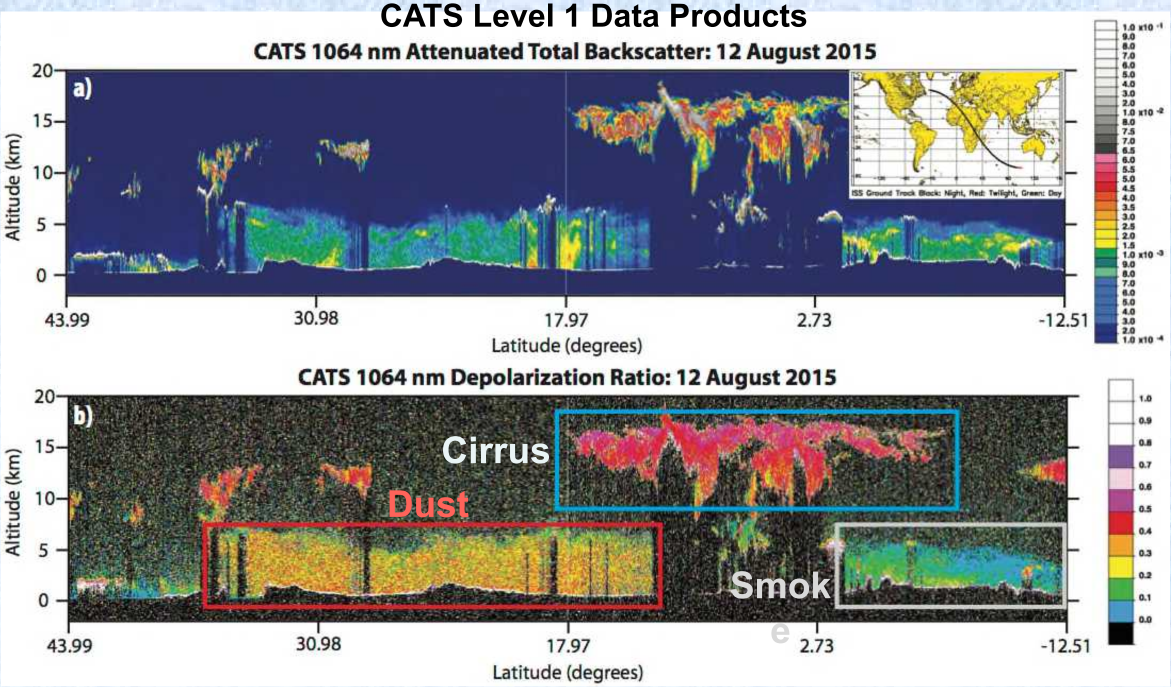


CATS on the ISS

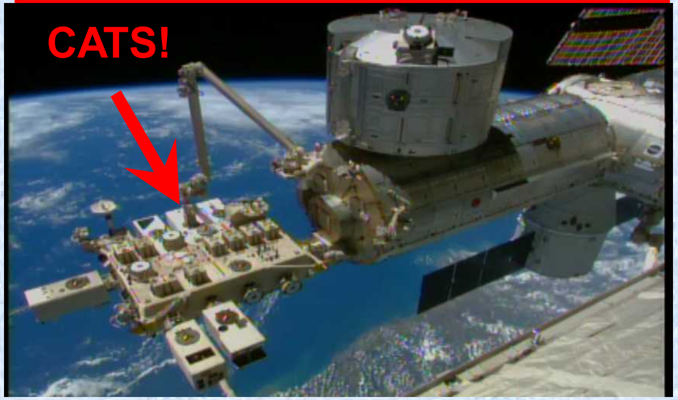
CATS is utilizing ISS as an affordable platform to:

- Complement the lidar data record with diurnally varying cloud and aerosol vertical profiles
- Monitor dynamic events (wildfires/volcanic eruptions)
- Demonstrate new technologies for future missions
- Demonstrate build-to-cost project development





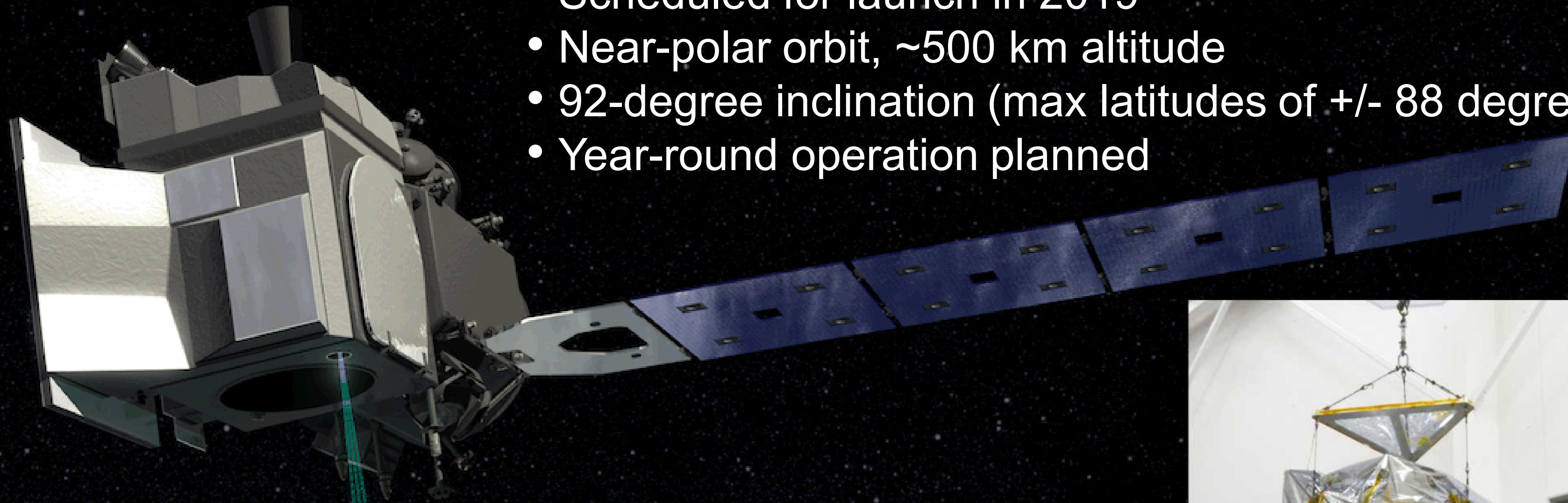
CATS has now been operating on the ISS for over 2 years (since 05 Feb 2015) and has fired >150 billion laser shots!



ICESat-2:
Next Generation Laser Altimetry from Space

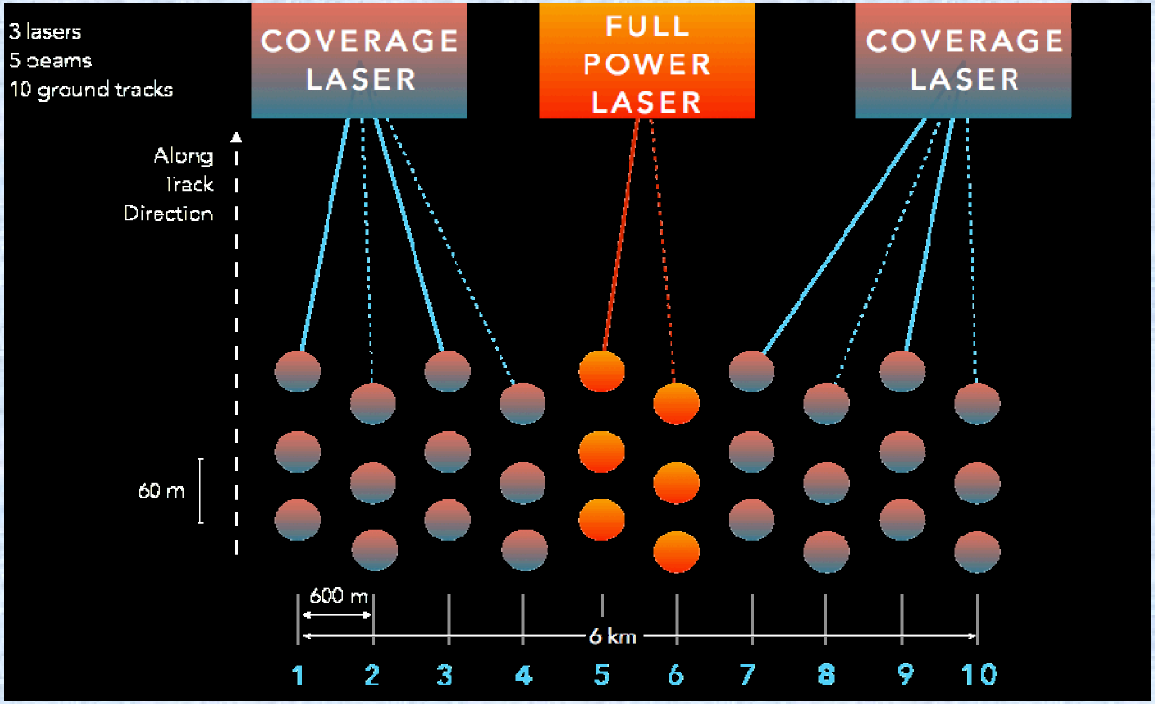
ICESat-2

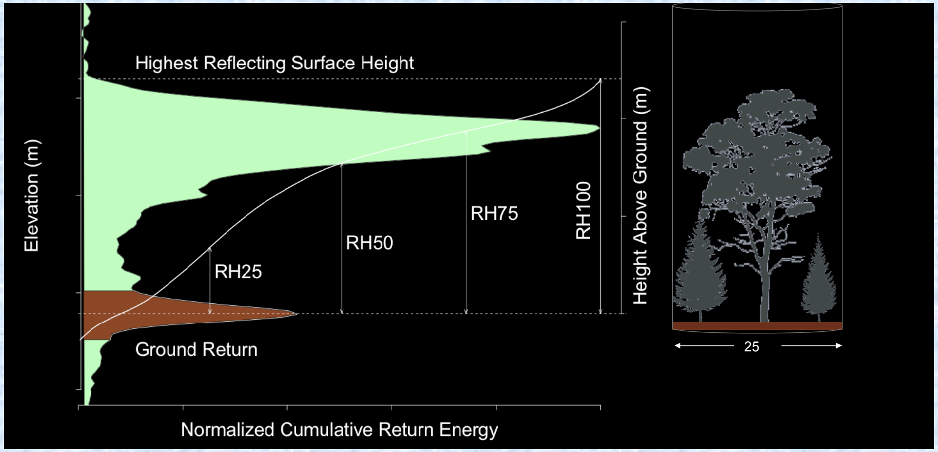
- Scheduled for launch in 2019
- Near-polar orbit, ~500 km altitude
- 92-degree inclination (max latitudes of +/- 88 degrees)
- Year-round operation planned



Advanced Topographic Laser Altimeter System (ATLAS)

- Six beams, 532 nm (green)
- Single laser fires 10K shots per second, split into 6 beams
- Spots on surface 17 m in diameter, 70 cm separation
- Photon-counting detectors
- Beam pairs allow direct local slope determination





NASA's Global Ecosystem Dynamics Investigation (GEDI) is a full waveform lidar system that will launch to the International Space Station in late 2018.

GEDI's 3 lasers will return 10 tracks of ~25 m waveform samples, providing ~15 billion surface structure observations

Conclusions

- Active optical remote sensing is making significant contributions to NASA's Earth Science, Planetary Science and being targeted for future Mars and Lunar explorations space-based observations
- The integration of active optical remote sensing with other observing approaches is providing new knowledge in a broad set of disciplines.
- An Agency level active optical strategy effort will align NASA efforts for Science, Exploration and Aeronautics
- Industry, academia, OGA and international partners are key contributors in advancing the active optical capability
- Active optical remote sensing can be expected to play an increasing role in the future and will benefit from investments in lidar technology by NASA and our industry, interagency and international partners

- Questions?