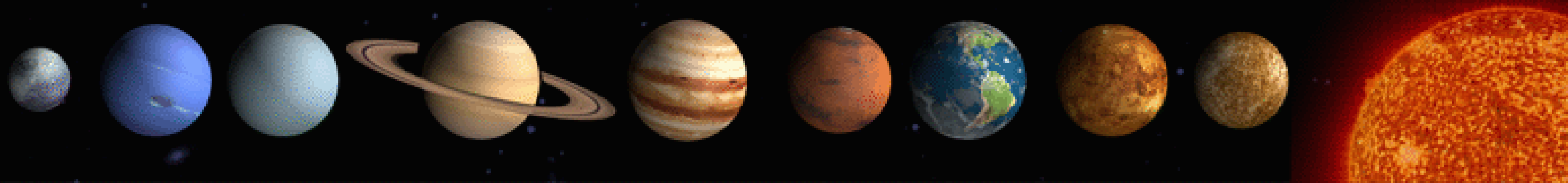
Active NASA Sensors and Instrumentation for Space-based Remote Sensing Applications

Upendra N. Singh
NASA Technical Fellow Sensors/Instrumentation
NASA Engineering and Safety Center
NASA Langley Research Center
Hampton, Virginia 23681, USA
Upendra.N.Singh@nasa.gov



Active Optical Remote Sensing Technologies

AORS Need: National need exists for reliable, efficient, space-capable AORS systems for civilian and defense applications in the area of Earth sciences, planetary exploration, aviation safety, chemical and biological detection, and tactical imaging. Core technology developments for these applications are not addressed by industry suppliers because of limited market.

Unique AORS Capabilities:

- High resolution profiling capability for atmospheric trace species
- High precision tropospheric wind measurements
- Wavelength specificity for chemical and biological detection
- Altimetry for surface mapping, Ocean mixed layers, ice topography

AORS Applications:

- Weather and severe storm prediction (winds, humidity)
- Atmospheric chemistry, climate and radiation (ozone, aerosols, clouds)
- Carbon cycle (CO2, biomass)
- Surface mapping (ocean, land, ice)
- Space science (planetary exploration, space transport, communication)
- Chemical and biological agent detection (Homeland Security, DoD)

Earth Science Measurements

- ***Global tropospheric winds*** *are acknowledged as the greatest unmet observational need for improving global weather forecasts on anything more than an incremental basis, and Doppler lidar is recognized as the only means for acquiring such data with the required precision (1 m/s, 25-100-km horizontal resolution). They can be measured with* ***AORS Doppler techniques.***
- ***High precision profiling of tropospheric*** CO_2 *(0.3% mixing ratio, 2-km vertical scale) is essential to understanding the global carbon cycle, greenhouse warming and the sustainability of life on Earth can only be obtained with the required resolution and precision through the use of AORS techniques (**Differential Absorption Lidar, DIAL**)*
- *Measurement of the global distributions of **tropospheric ozone and aerosols** using a space-based DIAL system will help address the causes and impacts of long-term climate variability and will distinguish natural from human-induced drivers. Precise, high vertical resolution measurements are only available through the use of AORS techniques*
- *AORS is the **only method** for measuring **particle profiles in the oceans' mixed layer**, necessary to understand how oceanic carbon storage and fluxes contribute to the global carbon cycle*
- *AORS DIAL is the **only technique** for **global moisture profiles at high resolution** (0.5 km vertical by 50 km horizontal) in the boundary layer, essentially needed for the understanding of convective processes and severe storm development and to improve our understanding of the global hydrological and energy cycle*
- *AORS backscatter lidar is the **only method** for **high vertical resolution (30 m) measurements of optical properties of clouds and aerosols** including planetary boundary height, cloud base, cloud top, cloud amount, cloud depolarization, and aerosol microphysical properties needed in climate modeling and research*
- ***AORS laser altimetry is only technique*** *for **profiling a surface level changes** of less than 1 cm/year, essential for studying terrestrial land cover vegetation, land surface topography, volcano monitoring, global sea level, and polar ice sheet level changes caused by climatic changes*

Planetary Science Measurements

- *AORS techniques offer versatile planetary surface topography measurements and other planetary surface deformation information with sub-meter vertical accuracy **laser altimetry** to study geological, volcanic, climatic, and tidal effects in planetary bodies including Mars, the Moon, Venus, Titan, and Jupiter's Icy Moons*
- *As with terrestrial applications, AORS **backscatter lidar** is the only method for determining detailed **vertical profiles of the Martian and Jovian atmospheres** including dust storms and surface eddies that can provide information about their aerosol and clouds needed to study the structure, dynamical, and radiative properties of the atmospheres of these planetary bodies*
- *AORS **Doppler wind lidar** is the only technique to study the **three-dimensional dynamical and transport properties,** dust storms, and turbulence in the atmospheres of Mars, Jupiter, Venus, Titan, and other planetary systems that can shed new insight into knowledge about the state of these atmospheres*
- *AORS **surface-based lidar** is ideal for measuring **tropospheric winds** on Mars as a boundary condition in global climate models but also to ensure engineering design safety of next-generation entry, descent, and landing systems.*

Planetary Science Measurements

- ***High power AORS lasers*** *can be used as remote sensing* ***mass spectrometers*** *by performing laser ablation of distant planetary bodies including Jupiter's Icy Moons, as well as direct compositional information about primitive objects including asteroids and cometary nuclei.*
- *AORS* ***DIAL lidar*** *enables measurement of the variability of* ***water vapor, ozone, CO_2, and other trace gas species*** *in planetary atmospheres (e.g., Mars) to study the chemical and radiative properties and obtain information about water and water vapor that are of keen interest as an indispensable ingredient for life*
- ***AORS backscatter lidar*** *in polarimetric mode can be used to detect surface volatile phases as well as to constrain surface particle sizes*
- ***AORS Laser Raman Spectroscopy*** *for detection of organic phases at local and remote scales (e.g., on Mars)*
- ***AORS Tunable Diode Laser sensing for noble gas isotope ratios*** *for studies of sources and sinks of key volatile species on Mars*
- ***AORS lidar spectroscopy for Biogenic Trace Gas sensing*** *(i.e., detection of methane and other species) in the Martian atmosphere*
- ***AORS scanning lidar altimetry*** *as a means of quantifying interannual climate variability on planets such as Mars where meters of precipitation in polar regions has been suggested*

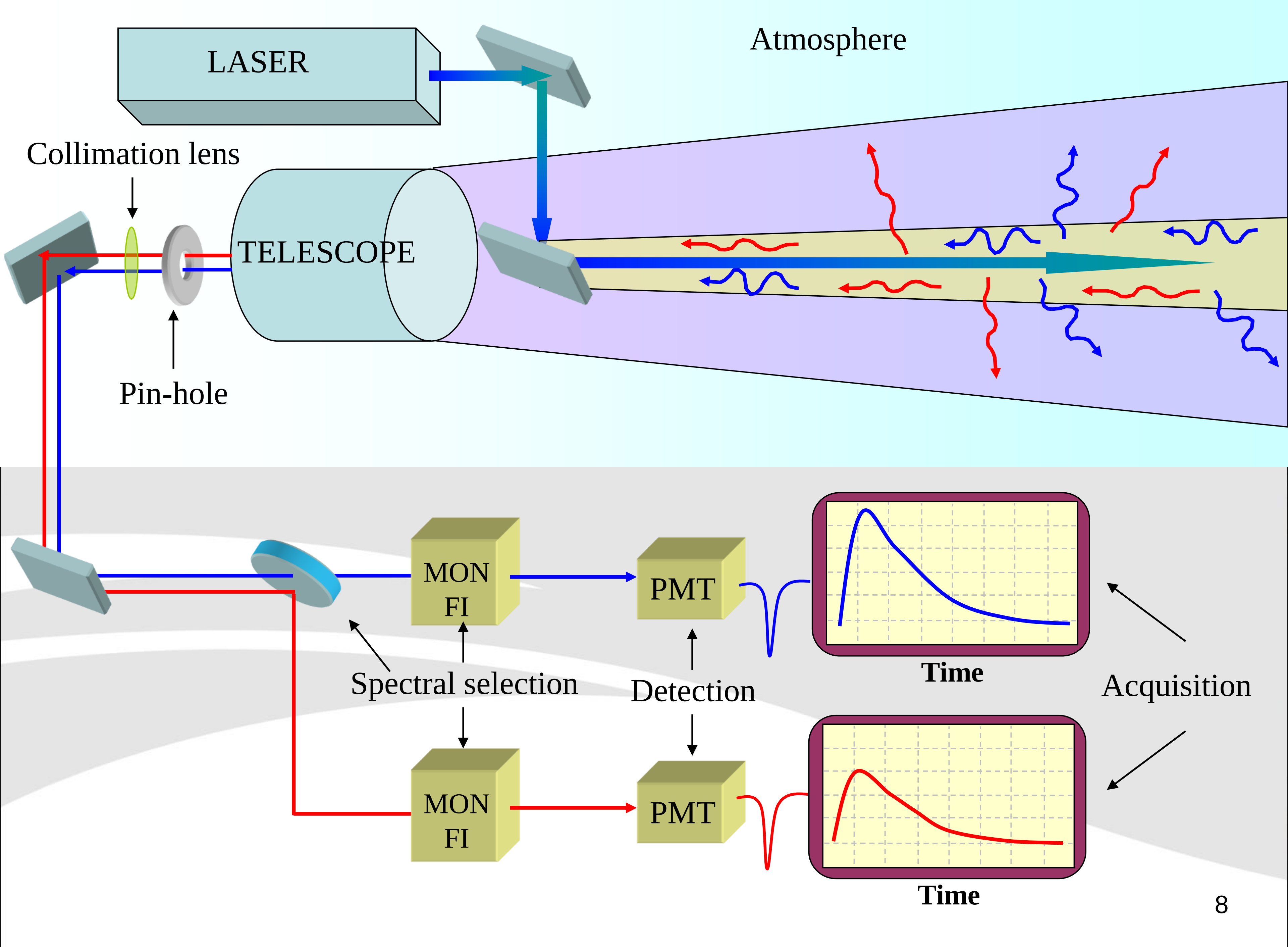
AORS Strategies

- Laser based instruments are applicable to a wide range of Earth Science, Aerospace Technology, Space Science, and Human Exploration and Development of Space Enterprise 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 analogues to Radar, where lightwaves, instead of radiowaves, are sent into the atmosphere and returns are collected which contains the information about the interacting atmospheric constituents, their microphysical properties and profile.

Lidar is an active optical remote sensing technique able to provide measurements with a very high resolution in time and altitude



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

Active Sensing is a Multi-Enterprise Need

Clouds/Aerosols

Tropospheric Winds

Ozone

Carbon Dioxide

Biomass Burning

Water Vapor

Surface Mapping

Laser Altimetry

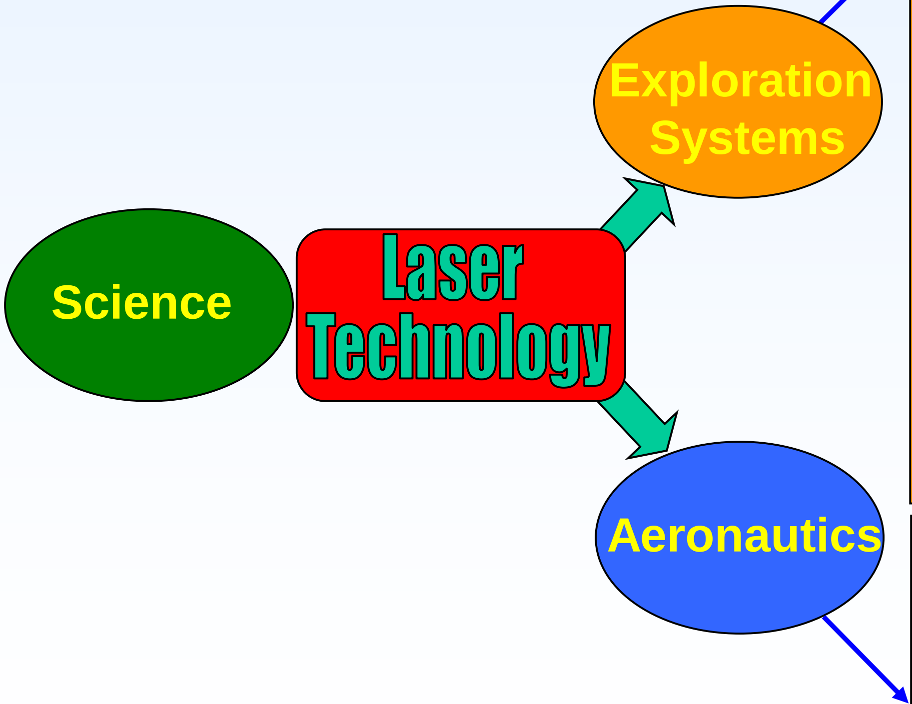
Oceanography

Surface Topography

Molecular Species

(H_2O, CO_2, Methane)

NASA Enterprises Needs



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

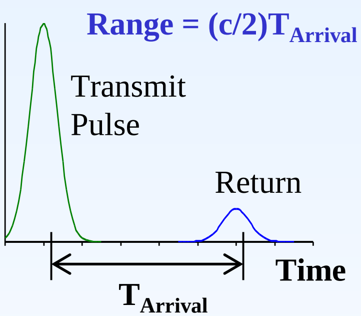
Turbulence detection

Wind shear detection

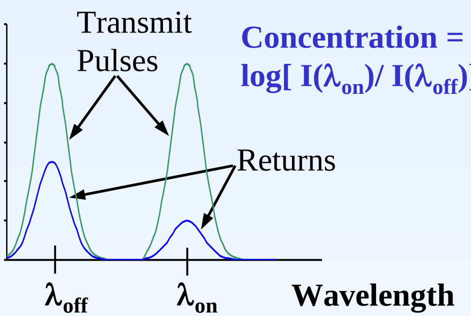
Wake vortices

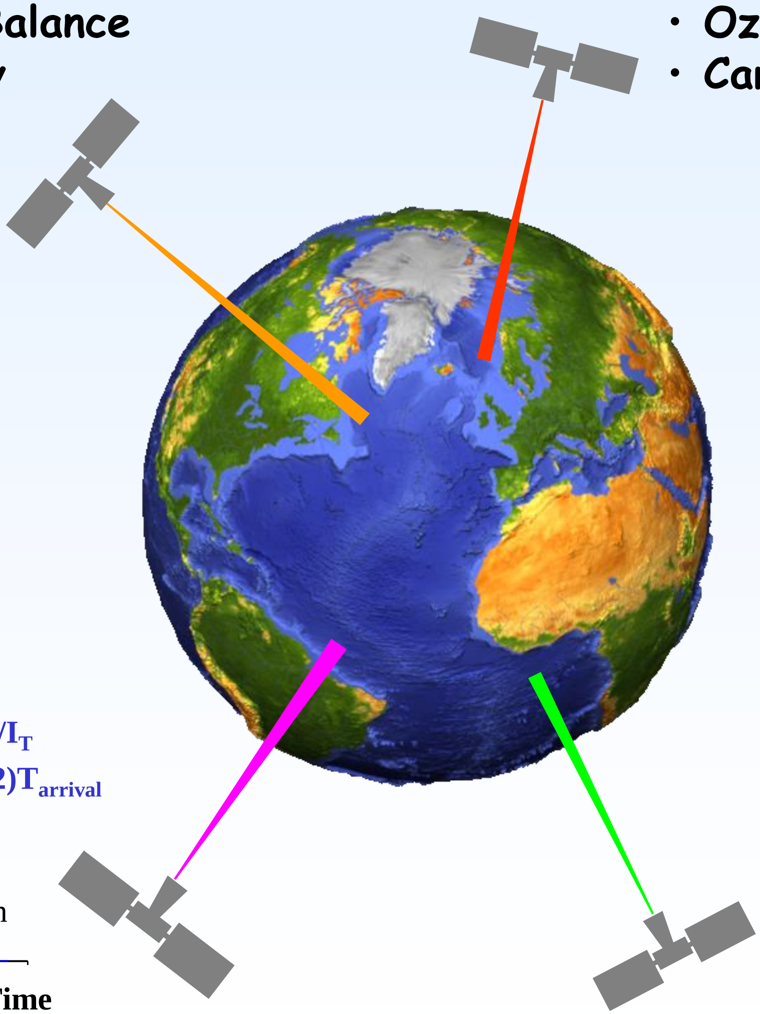
Lidar Techniques

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

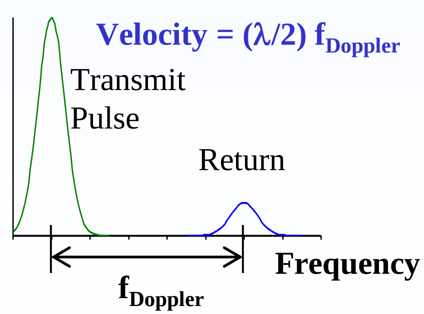


Differential Absorption Lidar (DIAL)
- Ozone
- Carbon Dioxide

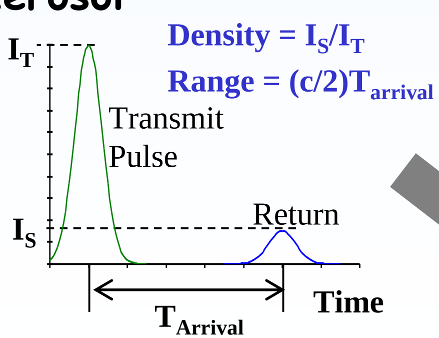




Doppler Lidar
- Wind Fields



Backscatter Lidar
- Cloud
- Aerosol



Earth Sciences Application Foci

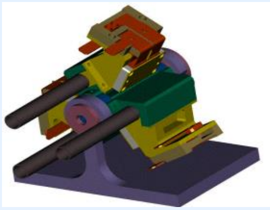
Key Priority Measurements for Earth Science

- Cloud/Aerosols
- Tropospheric Winds
- Tropospheric Ozone
- Carbon Cycle (CO_2, Biomass)
- Surface Mapping
- Oceanography

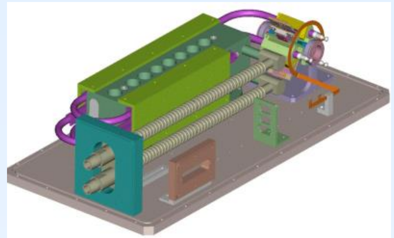
Pulsed Lidar Space Missions: History

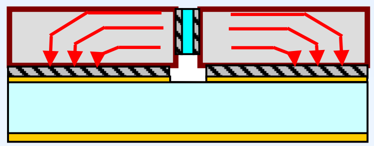
Mission	Date	Purpose	Status	Laser Issues
Apollo 15, 16, 17	1971-2	Ranging, Moon	Success	
MOLA I	1992	Ranging, Mars	S/C Lost	Contamination
Clementine	1994	Ranging, Moon	Success	
LITE	1994	Profiling	Success	Energy Decline
Balkan (Russia)	1995	Profiling	Success	
NEAR	1996	Ranging	Success	
SLA-01	1996	Ranging, Shuttle	Success	
MOLA II	1996	Ranging	Success	Laser diode bar dropouts
SLA-02	1997	Success	Success	
MPL/DS2	1999	Ranging	S/C Lost	
VCL	2000	Ranging	Cancelled	Cost, schedule over-runs
SPARCLE/EO-2	2001	Profiling, Shuttle	Cancelled	
ICEsat/GLAS	2002	Ranging+Profiling	Operational	Laser Anomalies
DAWN LA	2004	Ranging	Cancelled	Cost
Messenger/MLA	2004	Profiling, Mercury	En Route	Cost, schedule over-runs
Calipso	2005	Profiling		Schedule over-runs
ADM (ESA)	2007	Wind Demo.		Delayed (was 2006)
LOLA/LRO	2008	Altimeter, Moon		
Mars Smart Lander	2009	Ranging, Mars		

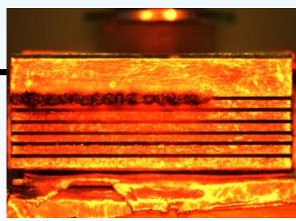
Laser Risk Reduction Program (LRRP)

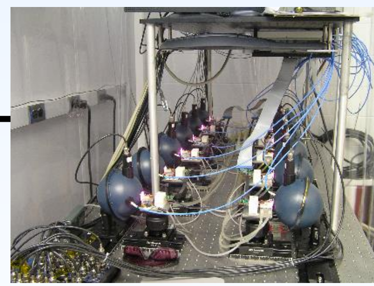


Products









Approach & Partners

Upendra N. Singh, LaRC and William S. Heaps, GSFC – Co-PI

This is a joint LaRC-GSFC program. The primary output product is knowledge that will reduce risk of future NASA laser/lidar space missions. Investigations are primarily performed at the two Centers, with frequent inter-Center communication, collaboration, and review. Numerous partnerships with other agencies, academia, and industry have been initiated and are ongoing.

Description and Objectives

The objective is to reduce the risk of failure in future NASA laser/lidar space missions. Laboratory experiments will be conducted to gain understanding and demonstrate advancement of the high-energy, 2-micron laser; the laser diode arrays that pump the pulsed laser; wavelength conversion technologies to permit O_3 measurement; detector and receiver technologies; and lifetime effects from contamination, radiation, etc.

Schedule & Deliverables

The LRRP began in FY02. It has already assisted the GLAS and CALIPSO lidar missions, and a RTF activity. Elements of LRRP should be continued since the knowledge is vital to the success of future multi-$100M missions.

Applications/Mission

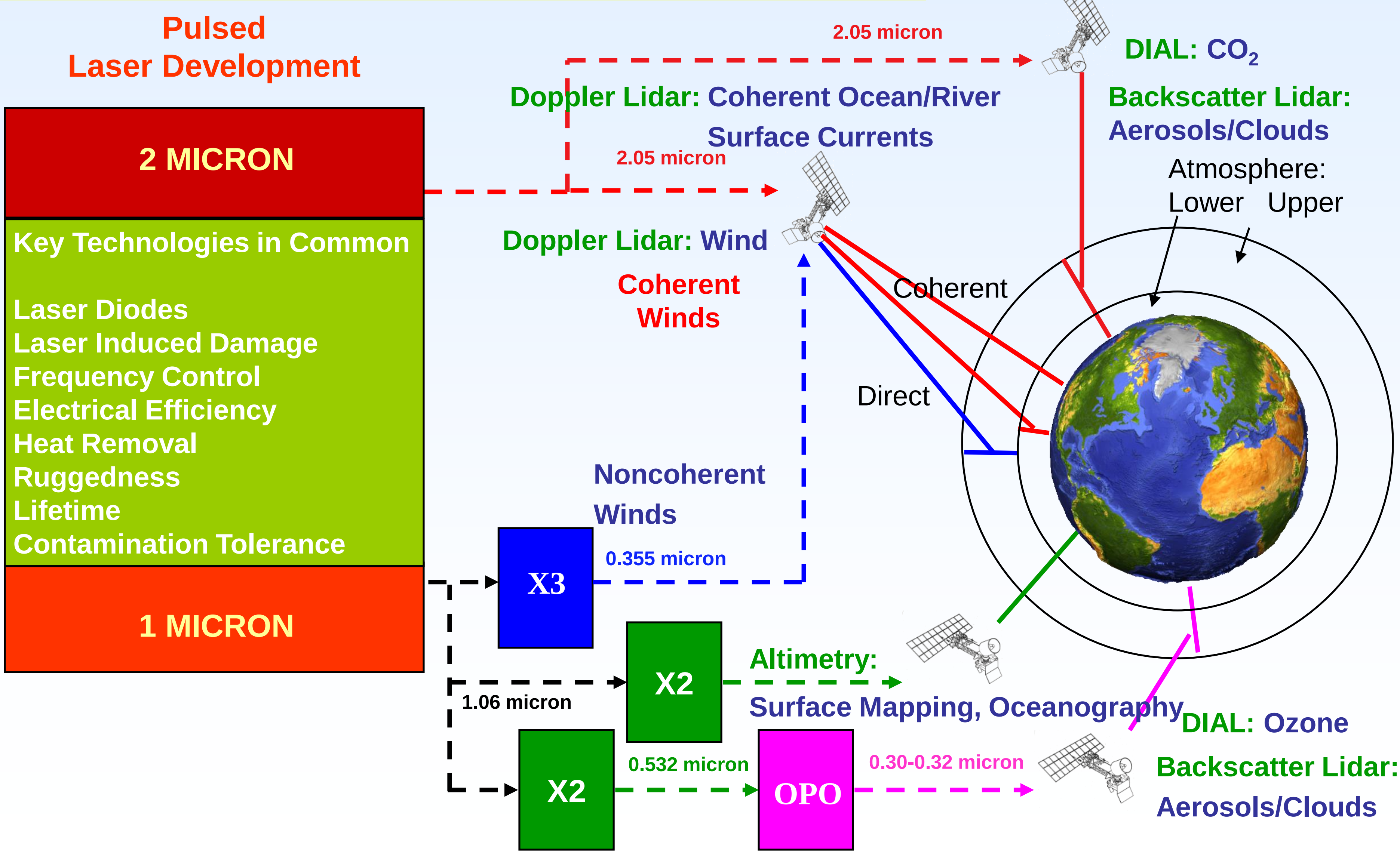
Global tropospheric wind profile measurements
Global CO_2 profile measurements
Global O_3 profile measurements
Global aerosol measurements
Global cloud measurements
Mars exploration

Laser Risk Reduction Program (LaRC-GSFC)

(NASA HQ Funded Directed Program 2001-2010 - $70M)

Principal Investigators: Upendra N. Singh, LaRC and William S. Heaps, GSFC

2 Lasers, 4 Techniques, 6 Priority Measurements



Laser Transmitter Testbeds

2 μ Test Bed
1 μ Test Bed

→ **Knowledge**

Contamination Tolerance
Now: 50, A/10
Goal: Better Tolerance

Laser Induced Damage
Now: 15 J/cm^2 for 5 nsec
Goal: 60 J/cm^2 for 5 nsec

Ruggedness
Now: 1 min @ 10G
Goal: 1 min @ 15 G

Lifetime
Now: 850? M shots
Goal: 2 G shots

Heat Removal
Now: 110 Watts
Goal: 300 Watts

Frequency Control
Now: < .25 pm
Goal: < .005 pm

Electrical Efficiency
Now: 3-4%
Goal: 6%

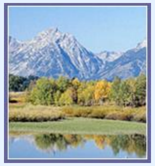
Active Optical Measurements in the Earth Sciences

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

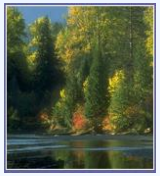
- Land Surface Topography
- Surface Deformation
- Terrestrial Reference Frame

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

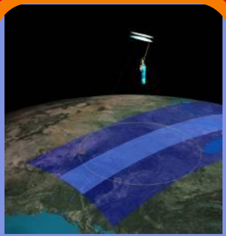


Carbon Cycle & Ecosystems

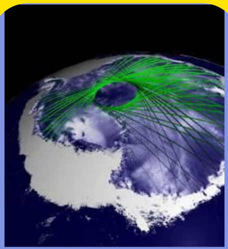
- Biomass
- Vegetation Canopy
- Fuel Quality & Quantity
- CO_2 & Methane
- Trace Gas Sources
- Land Cover & Use
- Terrestrial & Marine Productivity

Doppler Altimetry DIAL Backscatter

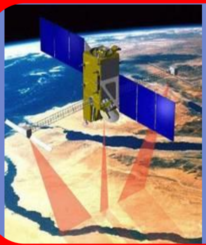
NASA Earth Science Decadal Survey Measurements



Soil Moisture Active Passive **(SMAP)**

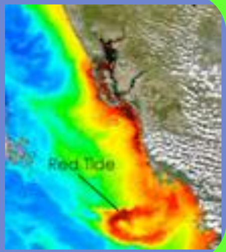


Ice, Cloud,and land Elevation Satellite II **(ICESat-II)**



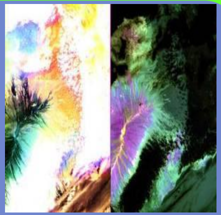
Surface Water and Ocean Topography **(SWOT)**

Pre-Aerosol - Cloud - Ecosystems ***(PACE)***



Active Sensing of CO2 Emissions **(ASCENDS)**

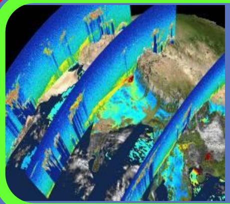
Hyperspectral Infrared Imager **(HYSPIRI)**



Geostationary Coastal and Air Pollution Events **(GEO-CAPE)**

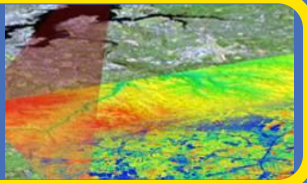
Deformation, Ecosystem Structure and Dynamics of Ice (Radar) **(DESDynI -R)**

Climate Absolute Radiance and Refractivity Observatory **(CLARREO)**



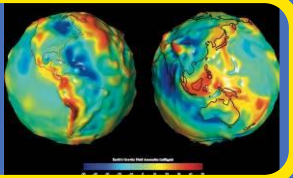
Aerosol - Cloud - Ecosystems **(ACE)**

LIDAR Surface Topography **(LIST)**



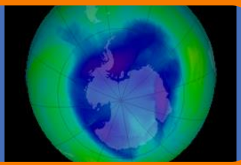
Precipitation and All-Weather Temperature and Humidity **(PATH)**

Gravity Recovery and Climate Experiment - II **(GRACE - II)**



Snow and Cold Land Processes **(SCLP)**

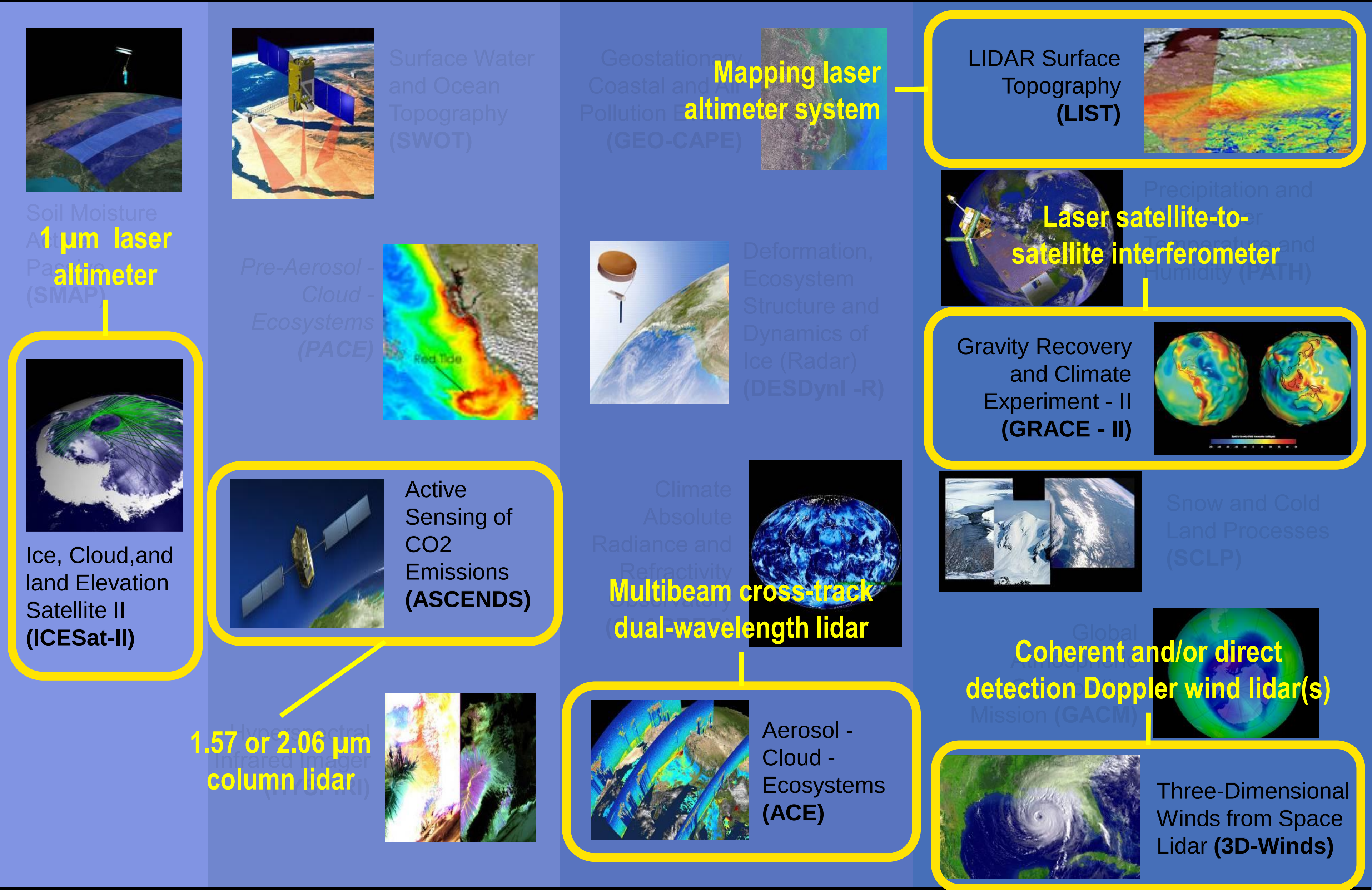
Global Atmospheric Composition Mission **(GACM)**



Three-Dimensional Winds from Space Lidar **(3D-Winds)**

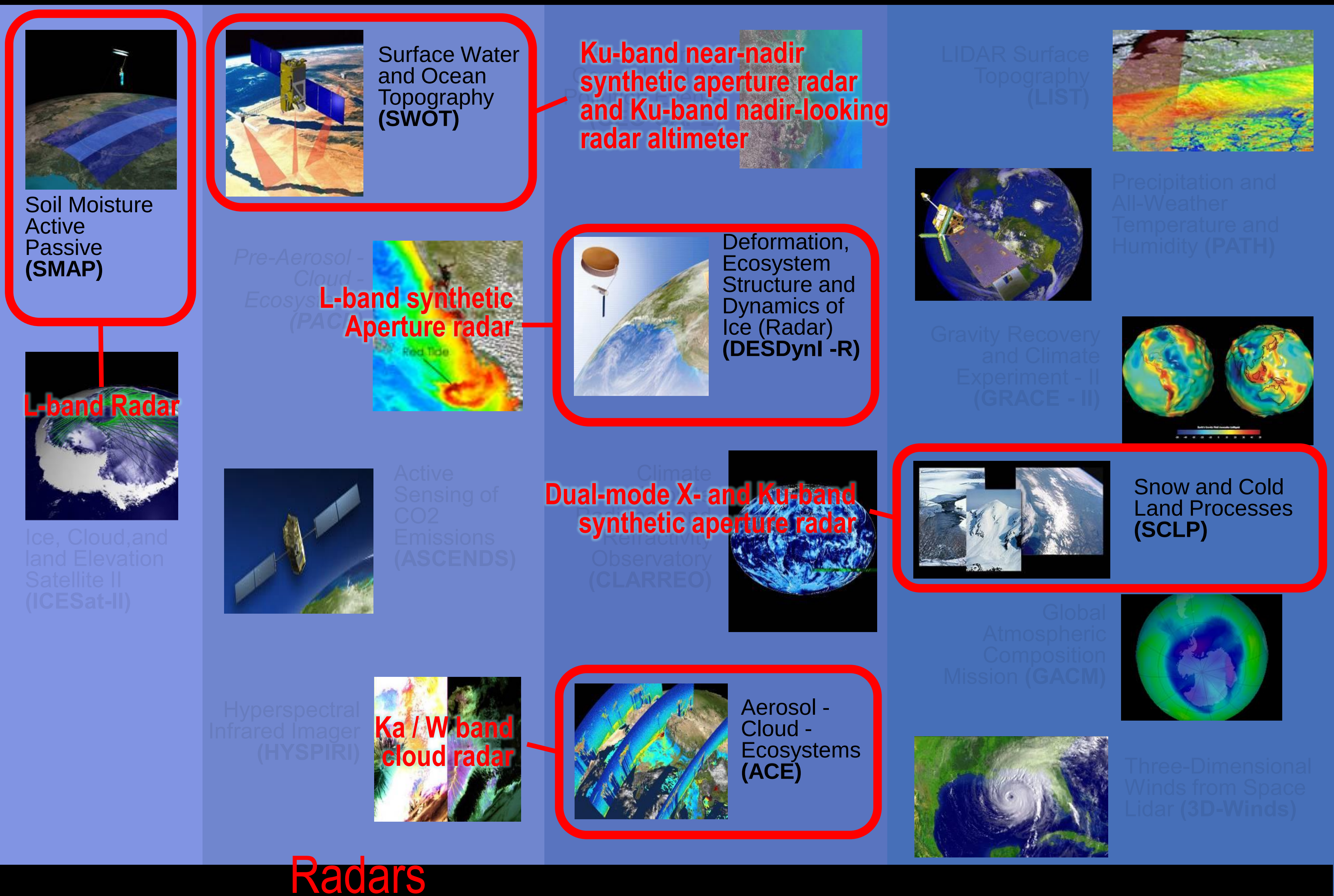
Lasers | Radars | Passive Optics | Passive Microwave

NASA Earth Science Decadal Survey Missions

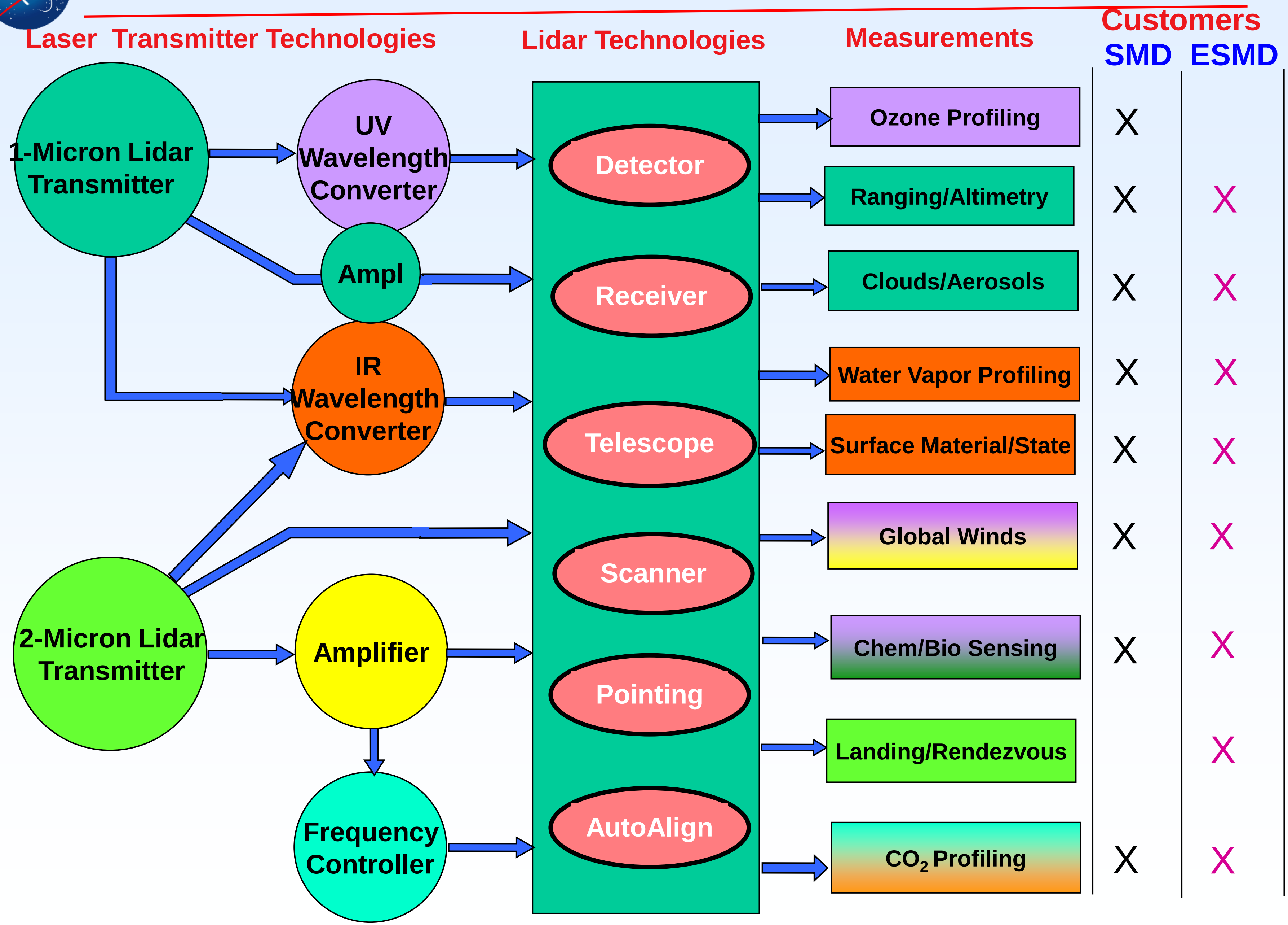


Lasers

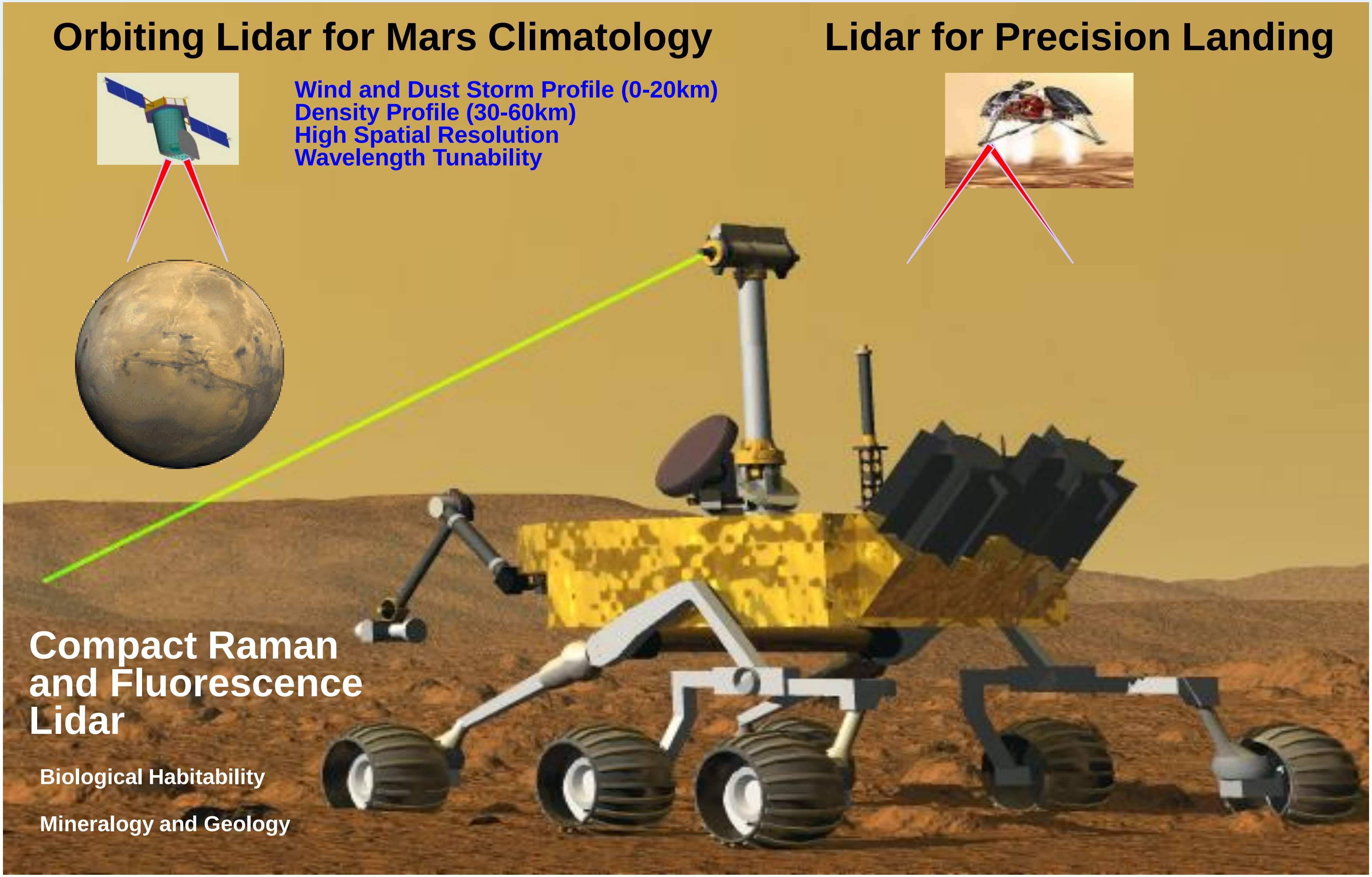
NASA Earth Science Decadal Survey Missions



Enabling Technology Elements



Lidar Remote Sensing for Mars



Summary

- ➢Enabling technology development and extensive risk reduction program is a key for NASA's Space-based mission success
- ➢Active optical remote sensing is a key technology for NASA's Earth and Planetary Science Programs through surface-, aircraft-, and space-based observations
- ➢There are still significant technology challenges for space-based active optical systems
  - Most prominent is the requirement for higher power systems
  - Second is the requirement for higher efficiency
    - Drives all platforms issues: thermal, power, mass,
    - Makes sharing platforms very difficult
  - Third is damage, contamination and degradation resistance
    - Coatings, materials, contamination control and lifetime
    - Optical damage and power scaling

Questions?