

National Aeronautics and Space Administration



NASA'S FUTURE EARTH SCIENCE MISSIONS FOR GLOBAL OBSERVATIONS

Dr. Upendra N. Singh

Associate Director, ED, NASA Langley Research Center
February 2, 2015; ISRO, India



The NASA Vision

To improve life here,
To extend life to there,
To find life beyond.

The NASA Mission

To understand and protect our home planet,
To explore the universe and search for life,
To inspire the next generation of explorers
... as only NASA can.



Outline



- **NASA's Current Earth Observation Missions**
- **NASA's Future EO Missions**
- **Enabling Active Optical Remote Sensing Technology Development for Future Space Missions**
 - Risk reduction and technology maturation Programs
 - Techniques
 - Technology development and validation
 - Concept-to-flight approach for maturing the technologies
- **Advancement of technology readiness level (TRL) in relevant environment (CO₂ and Winds as example)**
- **Summary**



Strategy



- **Maintain a balanced program**
- **Advance overall Earth System Science**
- **Deliver societal benefits through Application Development**
- **Develop and demonstrate technologies for next generation of measurements**
- **Provide essential global spaceborne measurements now and in the future supporting science and operations**
- **Complement and coordinate with activities of other agencies and international partners**

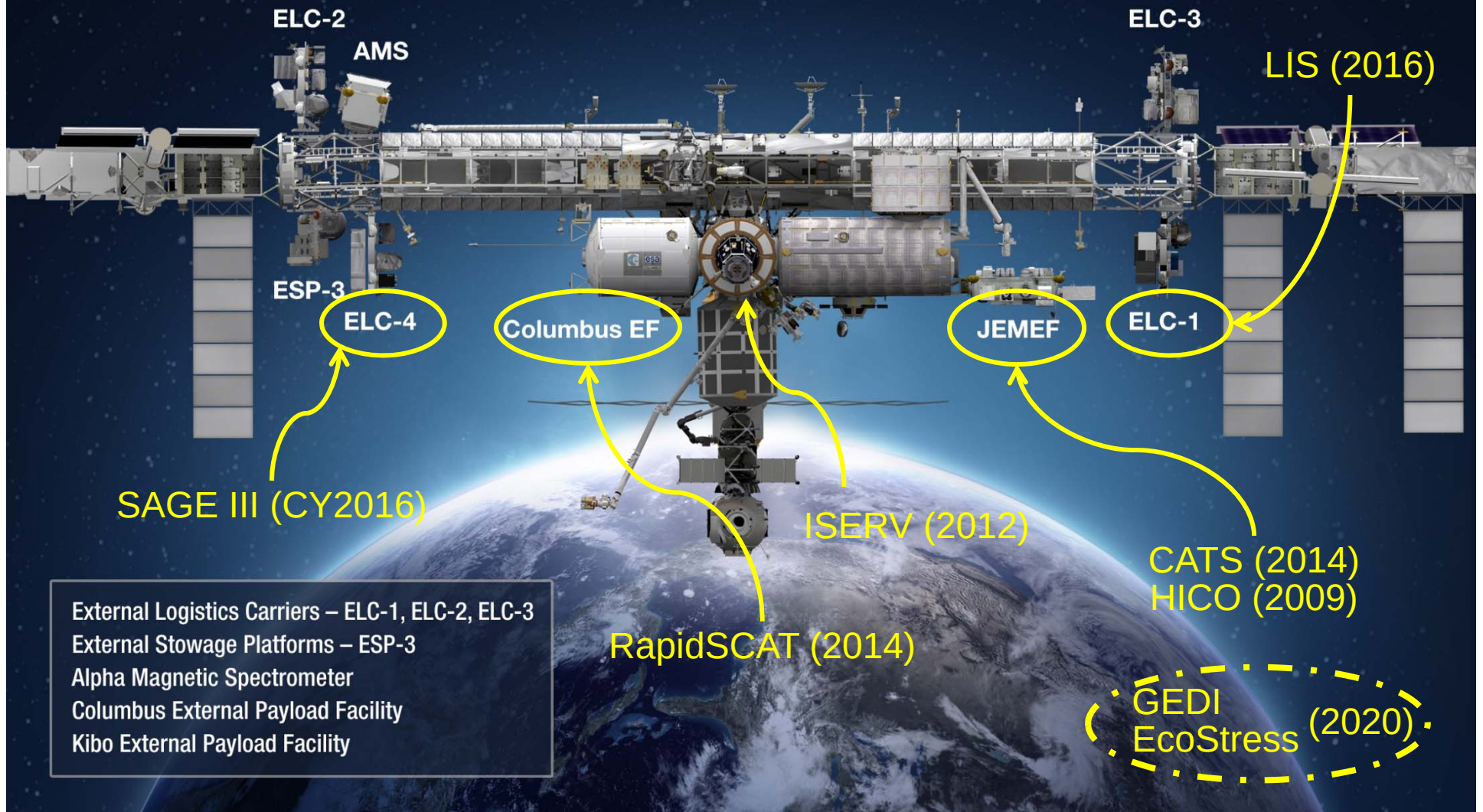


2 ESD-developed EO missions launch in 2014
2 ISS-developed EO instruments in 2014, 1 in 2016
10 more ESD EO launches before 2022



International Space Station

Earth Science Instruments





Active Optical Measurements in the Earth Sciences



Weather

Tropospheric Winds

Atmospheric Temperature
and Water Vapor

Cloud Particle Properties

Cloud System Structure

Storm Cell Properties



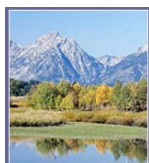
Climate Variability

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

CO₂ & Methane

Trace Gas Sources

Land Cover & Use

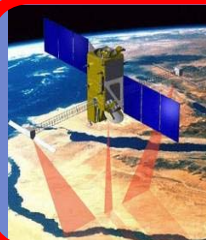
Terrestrial & Marine
Productivity

Doppler Altimetry DIAL Backscatter

NASA Earth Science Decadal Survey Measurements



Soil Moisture
Active
Passive
(**SMAP**)

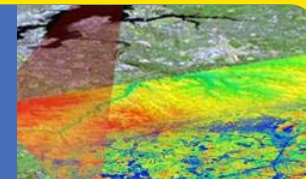


Surface Water
and Ocean
Topography
(**SWOT**)

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

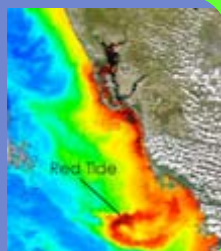


LIDAR Surface
Topography
(**LIST**)



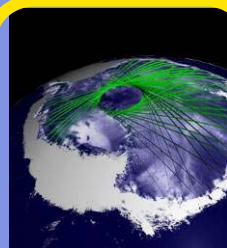
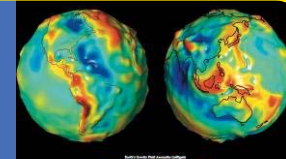
Precipitation and
All-Weather
Temperature and
Humidity (**PATH**)

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



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

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

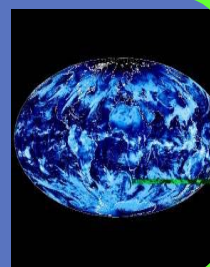


Ice, Cloud, and
land Elevation
Satellite II
(**ICESat-II**)



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

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

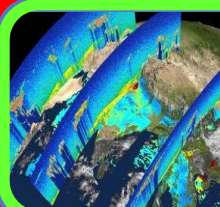


Snow and Cold
Land Processes
(**SCLP**)

Global
Atmospheric
Composition
Mission (**GACM**)



Hyperspectral
Infrared Imager
(**HYSPIRI**)



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



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

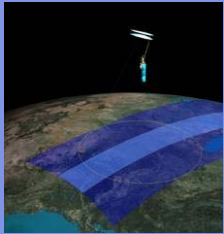
Lasers

Radars

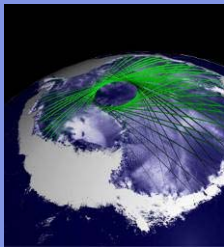
Passive Optics

Passive Microwave

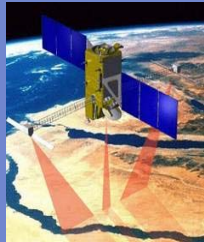
NASA Earth Science Decadal Survey Missions



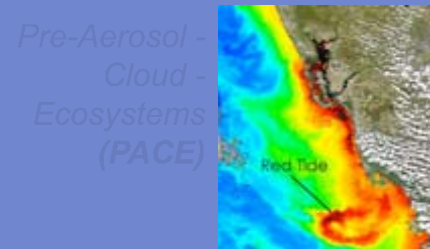
Soil Moisture
Active Sensing
(SMAP)
**1 μm laser
altimeter**



**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)**

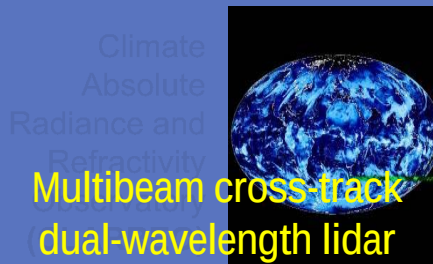
**1.57 or 2.06 μm
column lidar**



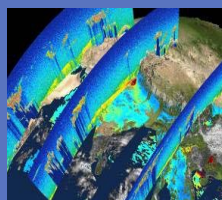
**Geostationary
Coastal and
Pollution
(GEO-CAPE)**



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



**Multibeam cross-track
dual-wavelength lidar**

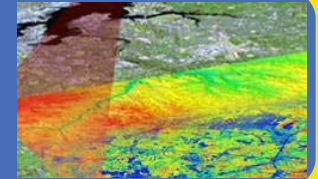


**Aerosol -
Cloud -
Ecosystems
(ACE)**

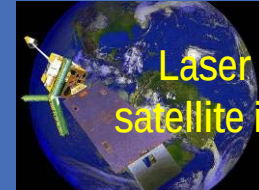
**Mapping laser
altimeter system**



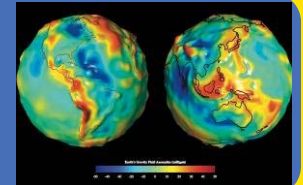
**LIDAR Surface
Topography
(LIST)**



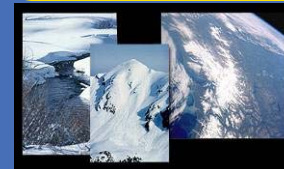
**Laser satellite-to-
satellite interferometer**



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



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



**Coherent and/or direct
detection Doppler wind lidar(s)**



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

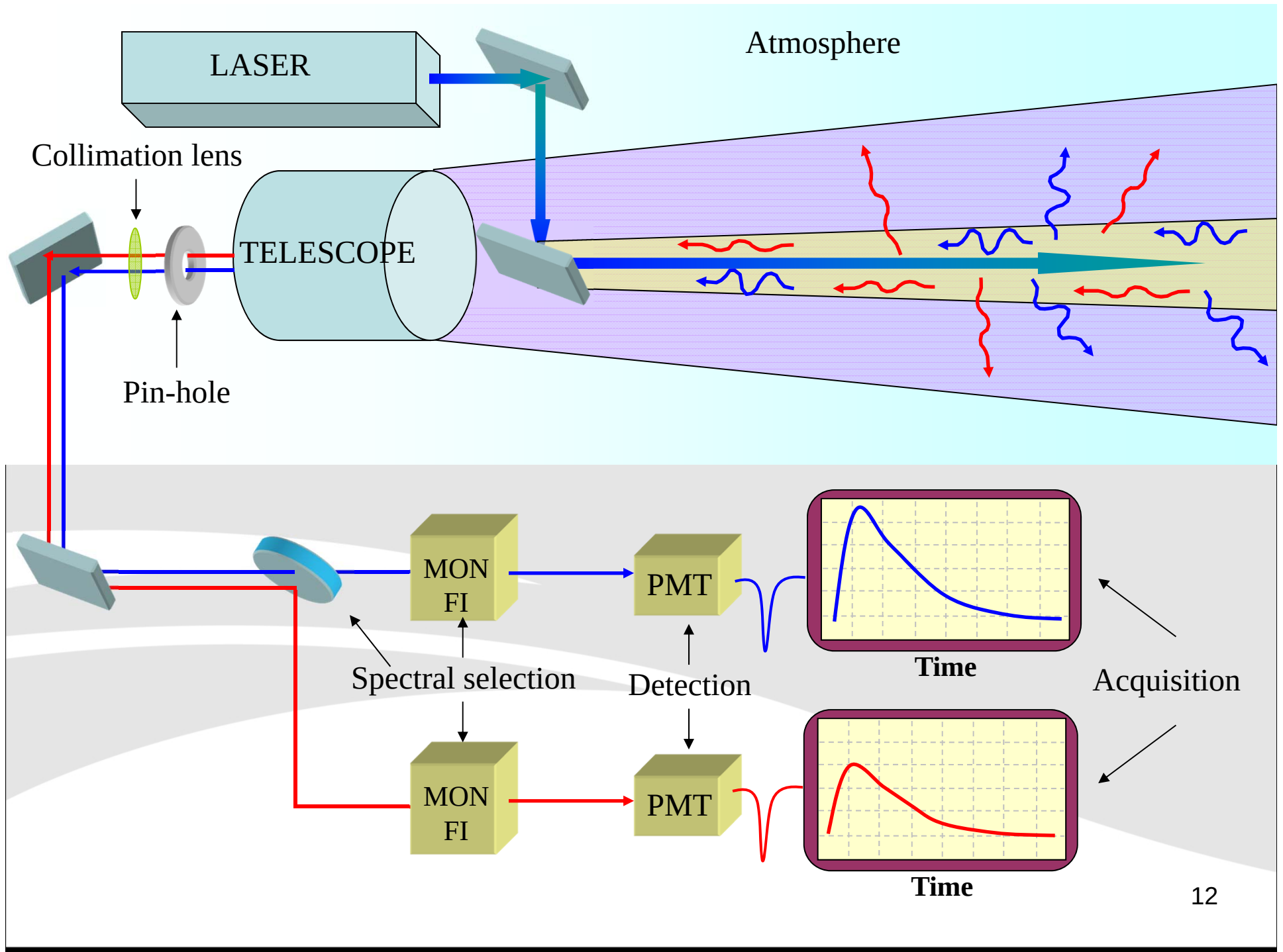
Lasers



LIDAR - Light Detection And Ranging

Lidar is analogous 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

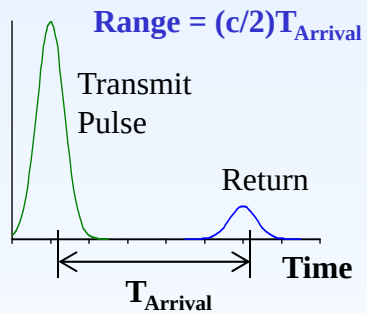




Lasers Enable LIDAR Measurements

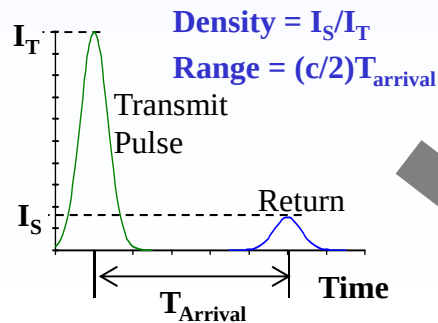
Altimetry Lidar

- Ice Sheet Mass Balance
- Vegetation Canopy
- Land Topography



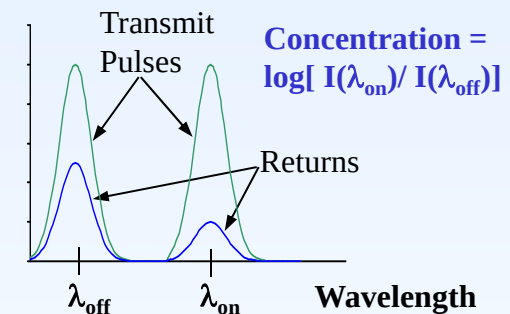
Backscatter Lidar

- Cloud
- Aerosol



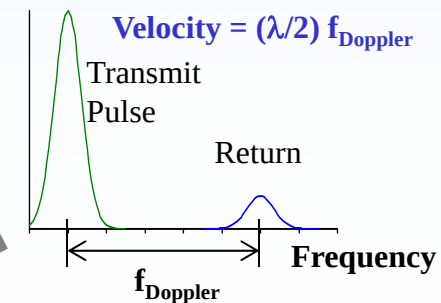
Differential Absorption Lidar (DIAL)

- Ozone
- Carbon Dioxide



Doppler Lidar

- Wind Fields





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
<i>Balkan (Russia)</i>	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 (LaRC-GSFC)

(NASA HQ Funded Directed Program 2001-2010)

2 Lasers, 4 Techniques, 6 Priority Measurements

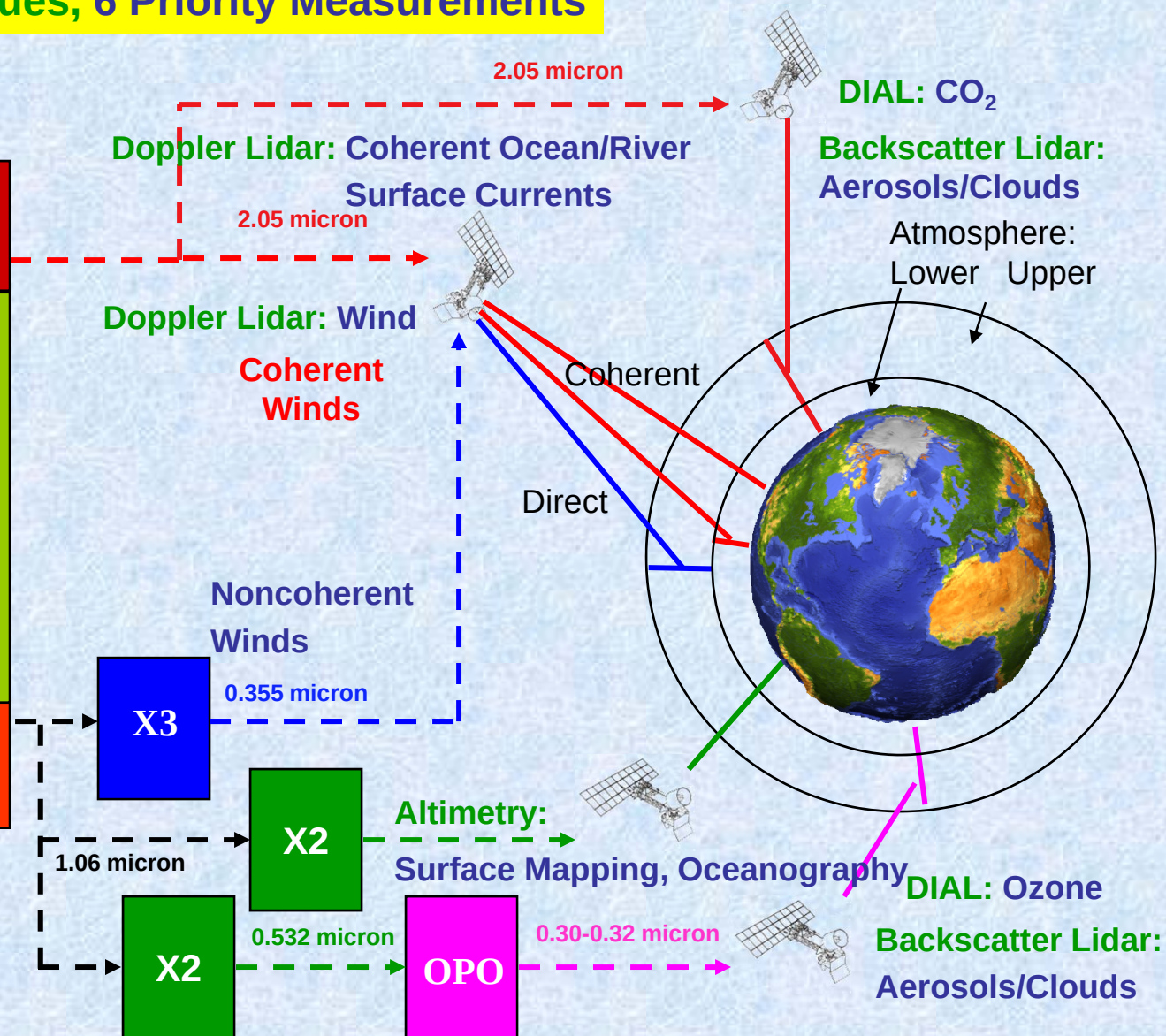
**Pulsed
Laser Development**

2 MICRON

Key Technologies in Common

Laser Diodes
Laser Induced Damage
Frequency Control
Electrical Efficiency
Heat Removal
Ruggedness
Lifetime
Contamination Tolerance

1 MICRON





Summary of Active Optical Measurements



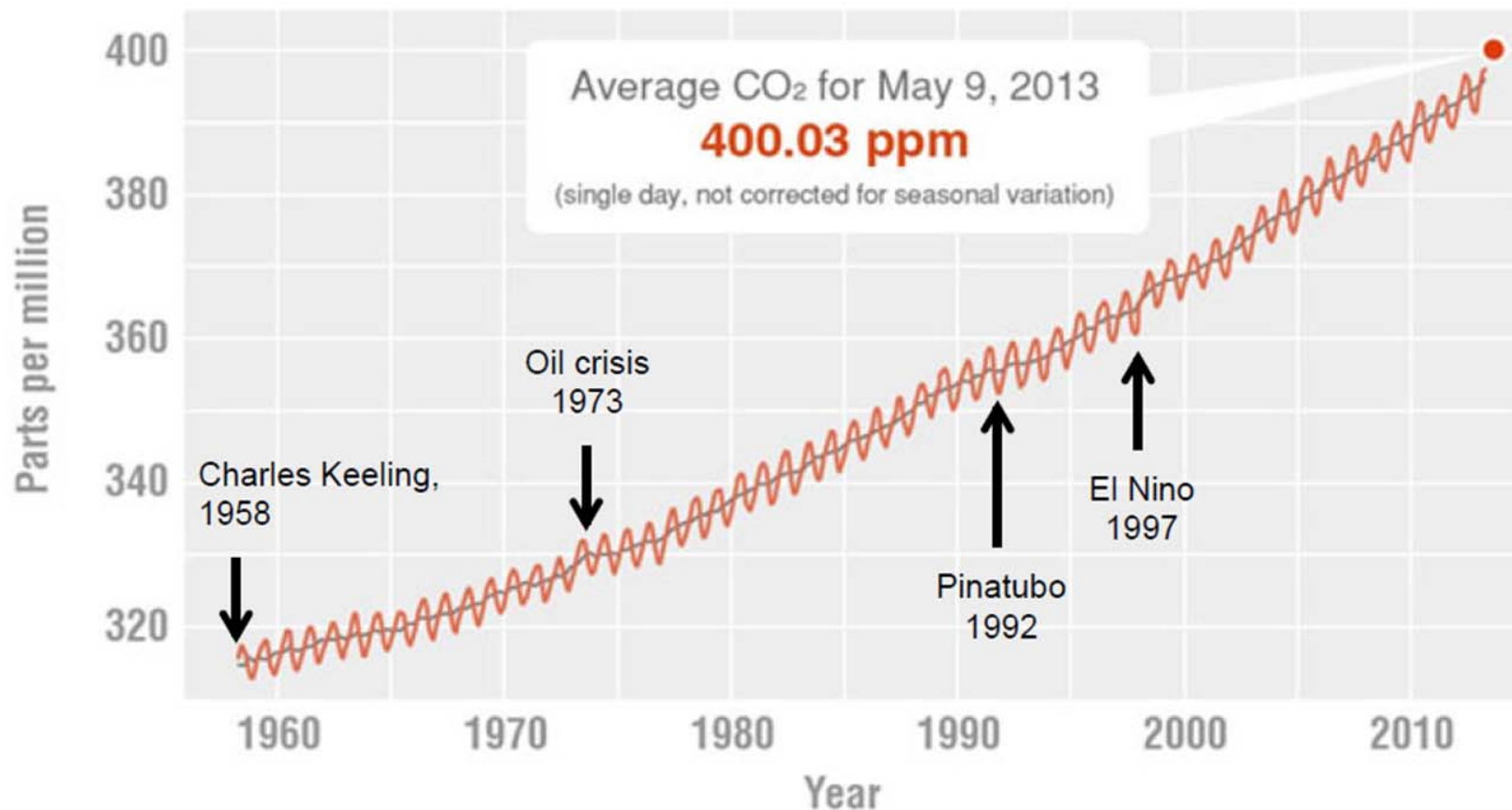
- **Active optical sensing systems offer promising options for several key Earth science measurements that include:**
 - Column CO₂
 - Tropospheric winds
 - Ozone Profiles
 - Water-Vapor Profiles
 - Surface Topography/Vegetation



Atmospheric CO₂ Increase



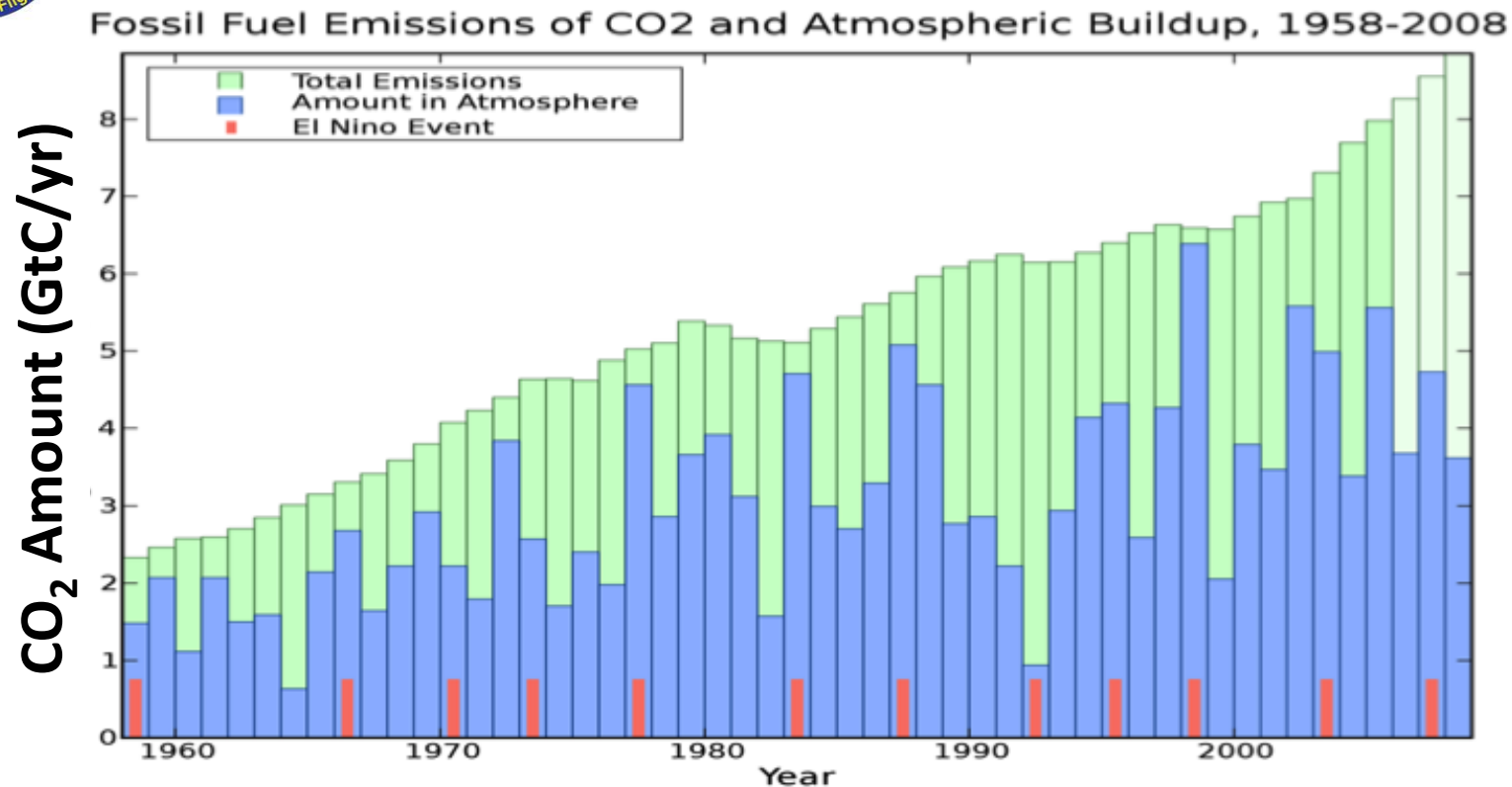
Carbon Dioxide Concentration



Credit: NOAA/Scripps Institution of Oceanography



Missing CO₂ Sink?

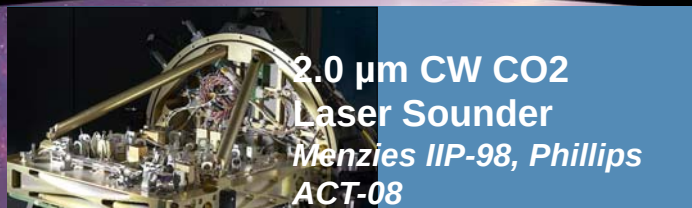


Anthropogenic activities have added >200 Gt C to the atmosphere since 1958

- o less than half of this CO₂ is staying in the atmosphere
- o where are the missing CO₂ sinks?

Toward CO₂ Column Measurements

National Aeronautics and Space Administration



2.0 μm CW CO₂
Laser Sounder
*Menzies IIP-98, Phillips
ACT-08*



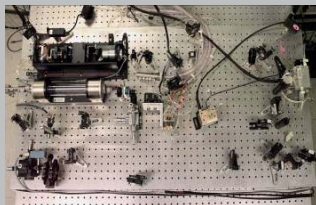
1.6 μm Pulsed CO₂
Laser Sounder
*Abshire ATI-99, IIP-04, IIP-
07*



1.6 μm CW CO₂ Laser
Sounder
Dobbs ACT-08



Broadband Lidar
Heaps IIP-08



2.0 μm Pulsed CO₂
IPDA
Singh IIP-13

Airborne Validations

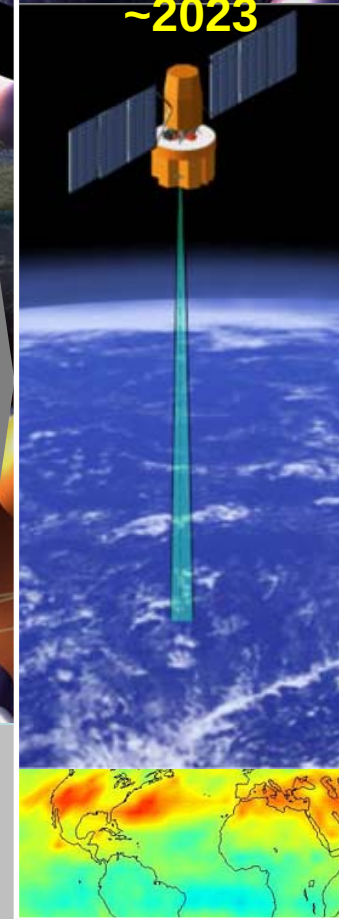
2010 ASCENDS
Science Definition
Airborne Experiments



Ground
Demonstration



ASCENDS
Mission
~2023



Technology Development

Demonstrations / Campaigns

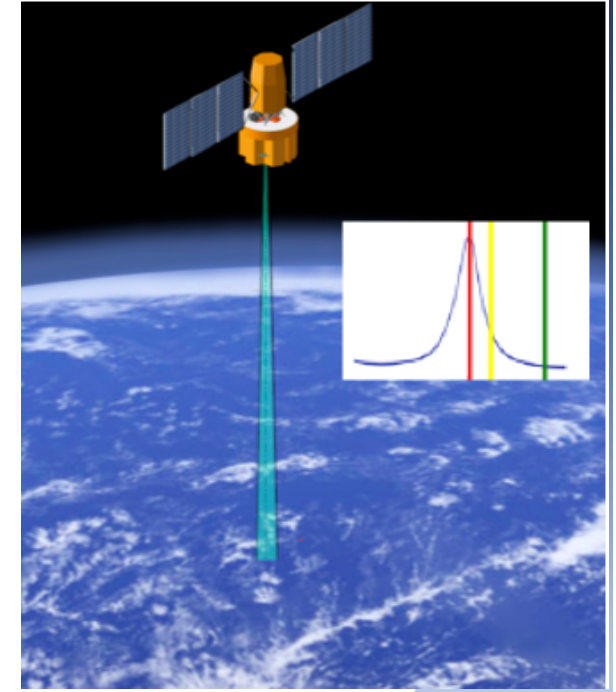
Science Measurements



CO₂ Measurement from Space



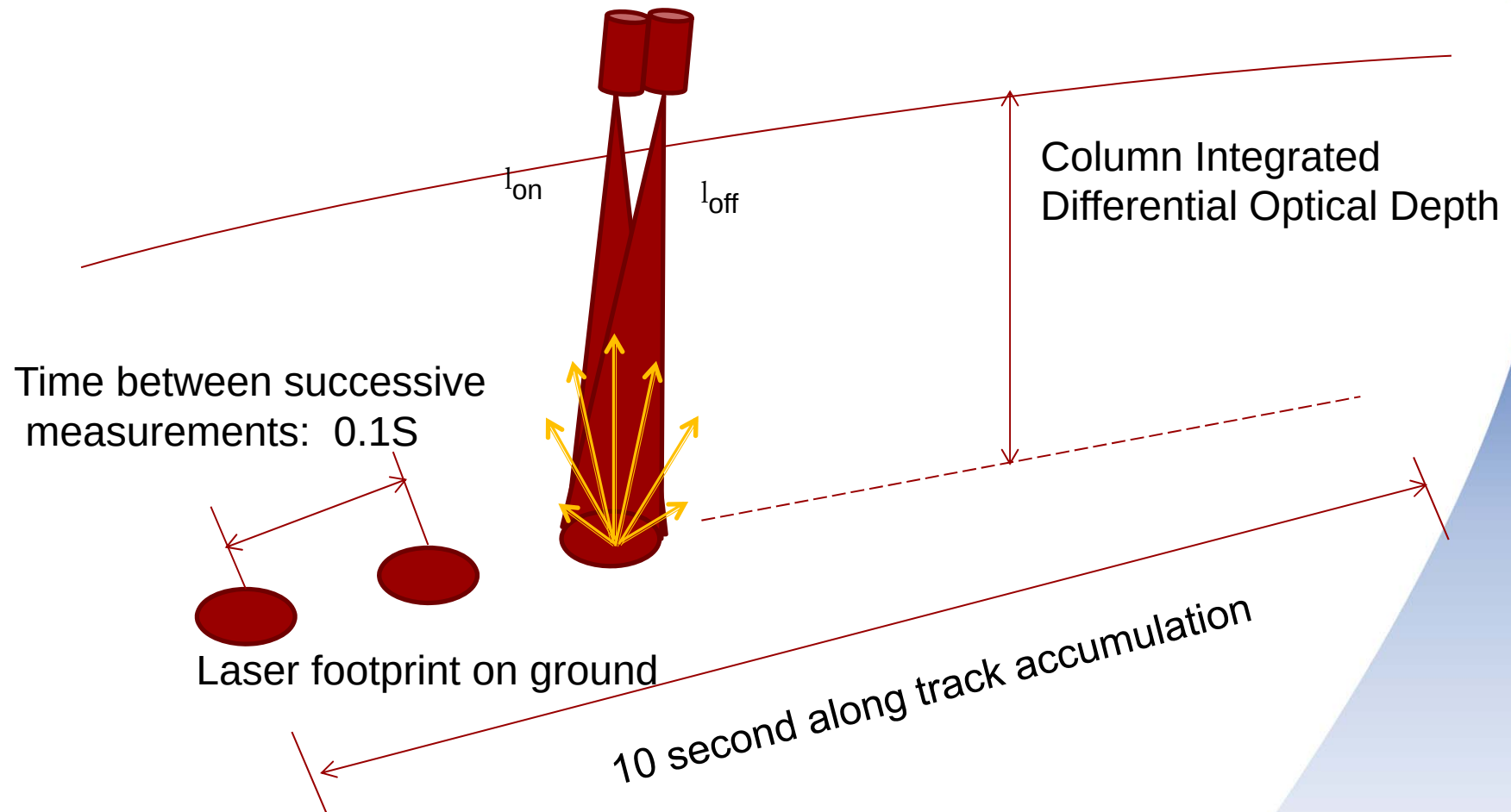
- **Primary goals:**
- **Science Requirement: 1 ppm CO₂ measurement for the column from space**
- **Concept**
- **1.57 μm laser-based integrated path differential absorption for column CO₂**
- **2.053 μm laser-based integrated path differential absorption for column CO₂**
- **Challenge:**



Laser	Measurement	Current capability	Needed Capability
1.57μm Pulsed	CO ₂	.025 mJ@ 10kHz	4 mJ @ 10 kHz
1.57 μm CW	CO ₂	5W	20-40 W
2.05 μm Pulsed	CO ₂	100/40 mJ @10Hz	50/15/5 mJ@ 50Hz



Principle of IPDA Measurement Using Surface Targets



Transmit and receive near nadir-pointing laser beams with on and off-line wavelength channels

- Ground surface reflection (land and sea)
- Measure difference in integrated path absorption at these two wavelengths



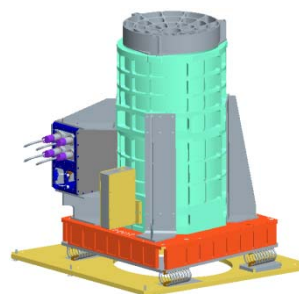
Development of a Double-Pulsed 2-micron Direct Detection IPDA Lidar for CO₂ Column Measurement from Airborne Platform



PI: Upendra N. Singh, NASA LaRC

Objective

- Develop, integrate and demonstrate a 2-micron pulsed Integrated Path Differential Absorption Lidar (IPDA) instrument CO₂ Column Measurement from Airborne platform
- Conduct ground validation test to demonstrate CO₂ retrieval
- Conduct engineering test flights to demonstrate CO₂ retrieval from UC-12 aircraft
- Conduct post flight data analysis for the purpose of evaluation of CO₂ measurement capability



Mobile and Airborne 2μm IPDA LIDAR system

Approach:

- Repurpose existing hardware including previously developed transmitter, receiver and data acquisition system
- Complete fabrication of transmitter, wavelength control and receiver units assembly
- Integrate existing and to be developed subsystems into a complete breadboard lidar system
- Fabricate a mechanical structure and integrate completed subsystem

Key Milestones

- | | |
|--|-------|
| • Design of laser transmitter assembly | 10/12 |
| • Design, manufacture and assembly of receiver | 04/13 |
| • Integrate subsystems into breadboard lidar system | 06/13 |
| • Conduct ground test of the integrated lidar assembly | 07/13 |
| • Integrate lidar system on UC-12 aircraft | 11/13 |
| • Conduct post flight data analysis | 09/14 |

Co-Is/Partners: Jirong Yu, Mulugeta Petros, Syed Ismail, NASA LaRC

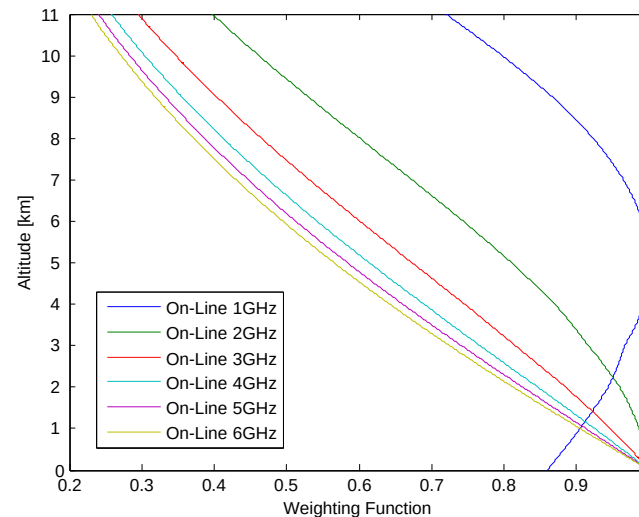
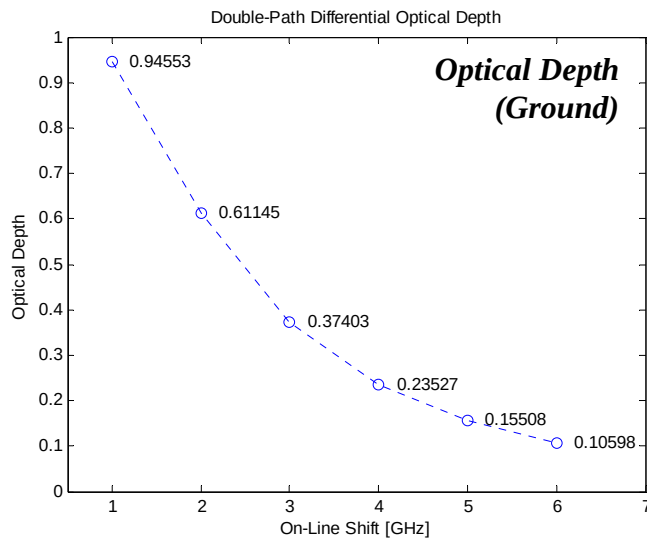
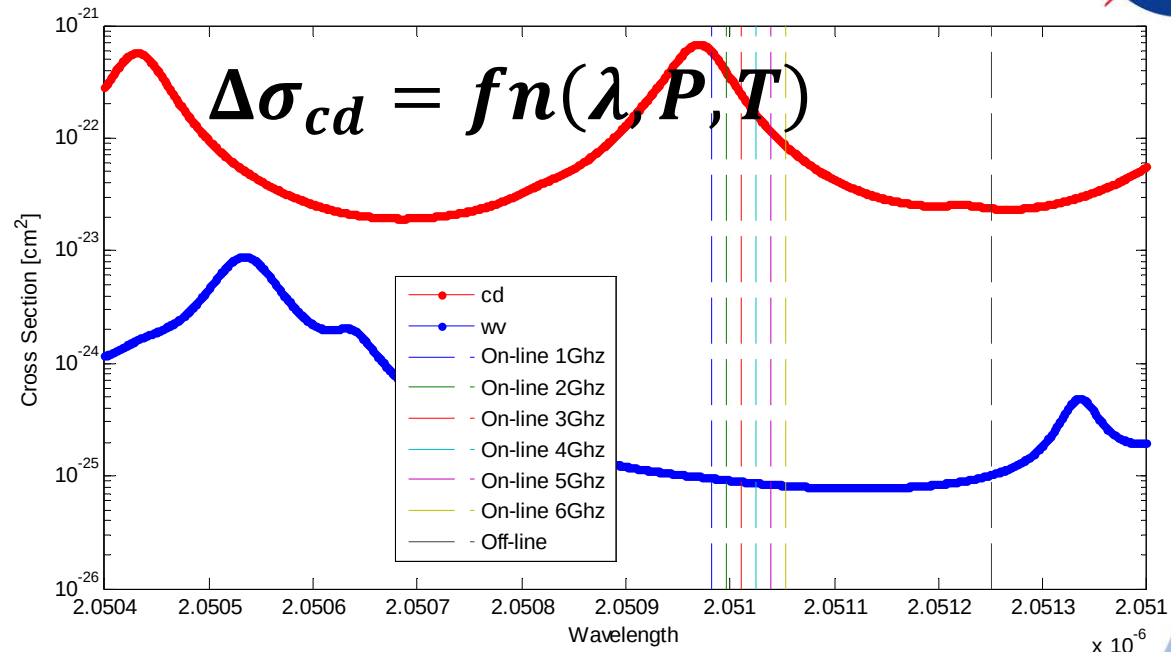
TRL_{in} = 3 TRL_{out} = 5 (AIRCRAFT)



Spectroscopy



- Standard models are used for estimating optical depth, return pulse strength, SNR and errors for any operating condition.
- Modeling and meteorological data are used for XCO₂ derivation.





2- μm IPDA Lidar Schematic



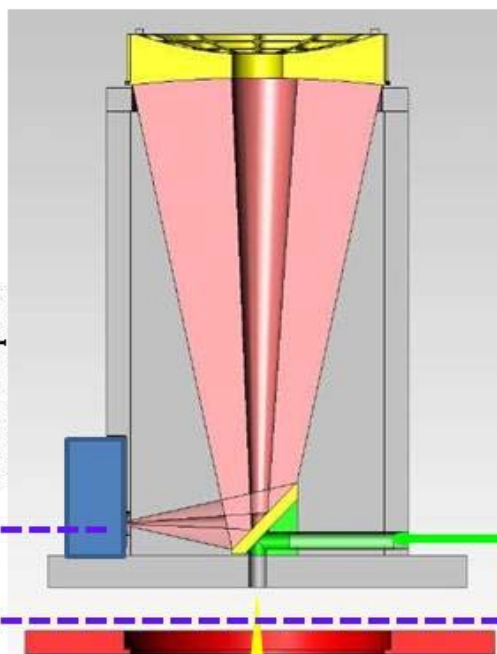
Data Acquisition & Display

Data Acquisition,
Processing,
and Display

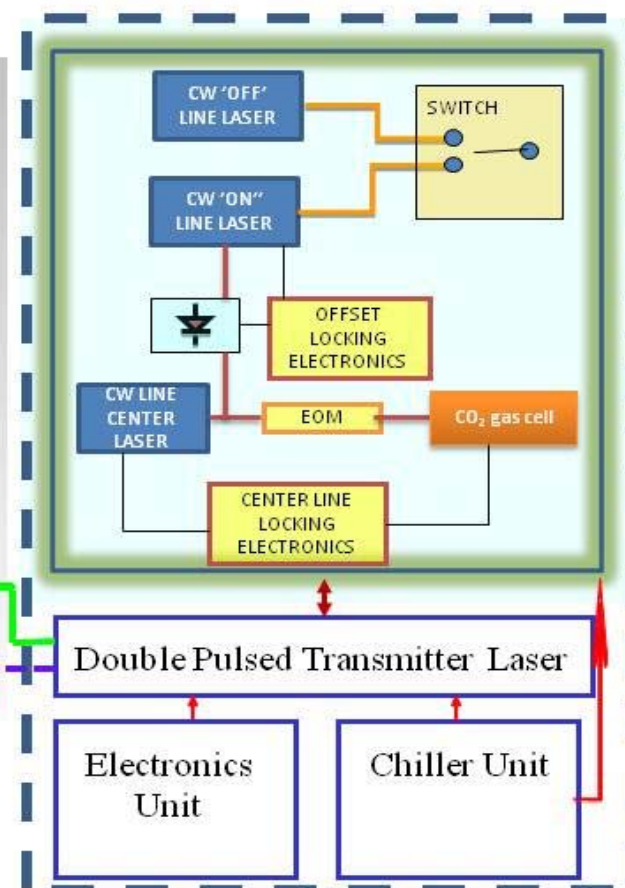


Telescope & Receiver

Receiver Optics

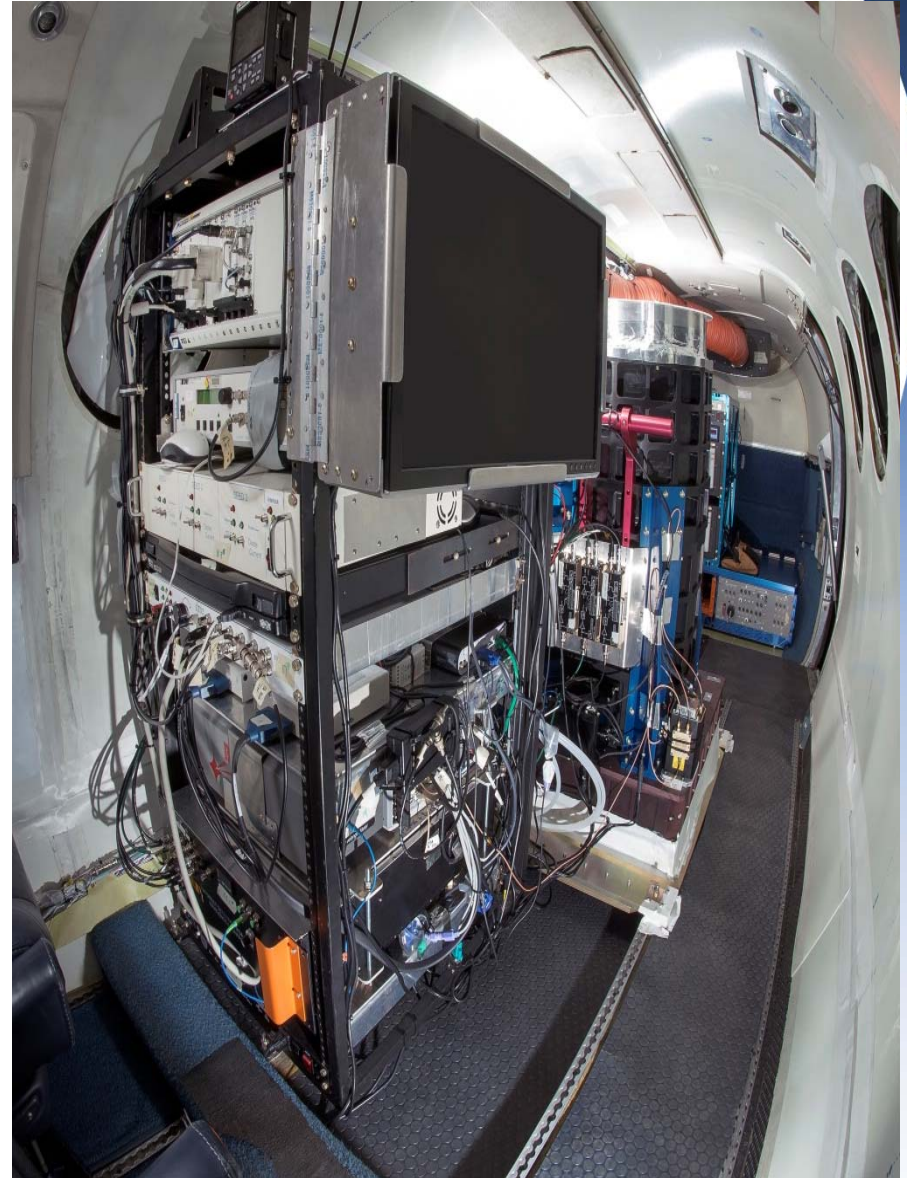


Transmitter





Aircraft Configuration: Instrument

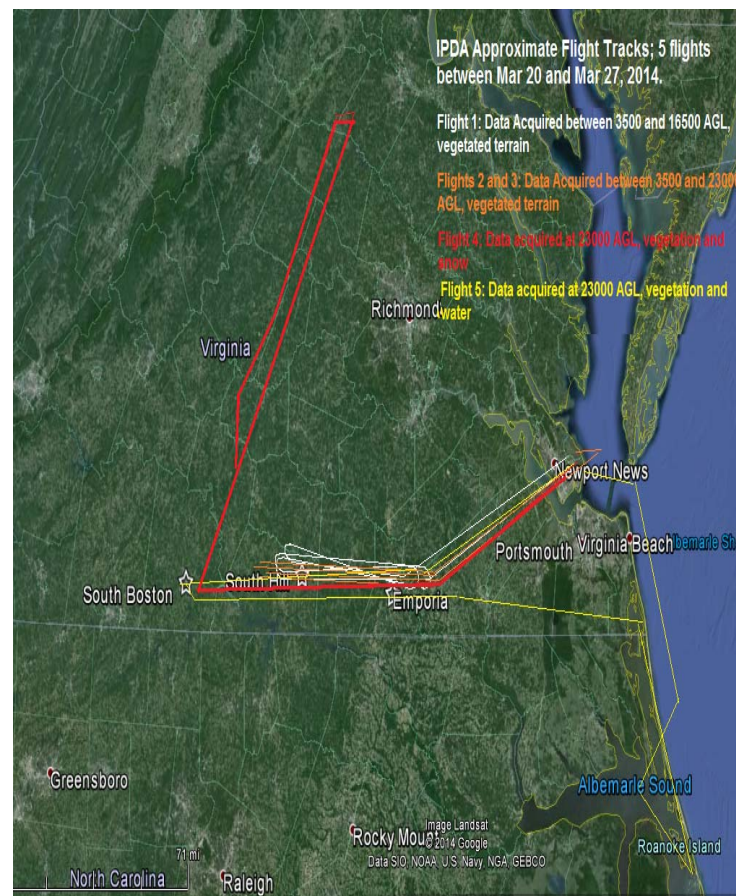




10 Flights in March & April 2014



Date	Purpose	Duration	Location
March 20	Instrument Check Flight	2.1 hr	VA
March 21	Engineering	2.7 hr	VA
March 24	Engineering	3.0 hr	VA
March 27	Early morning	3.0 hr	VA
March 27	Mid-afternoon	2.5 hr	VA
March 31	Inland-Sea	2.5 hr	VA, NC
April 02	Power Station	2.4 hr	NC
April 05	With NOAA	3.7 hr	NJ
April 06	Power Station	3.0 hr	NC
April 10	Late afternoon	2.3 hr	VA



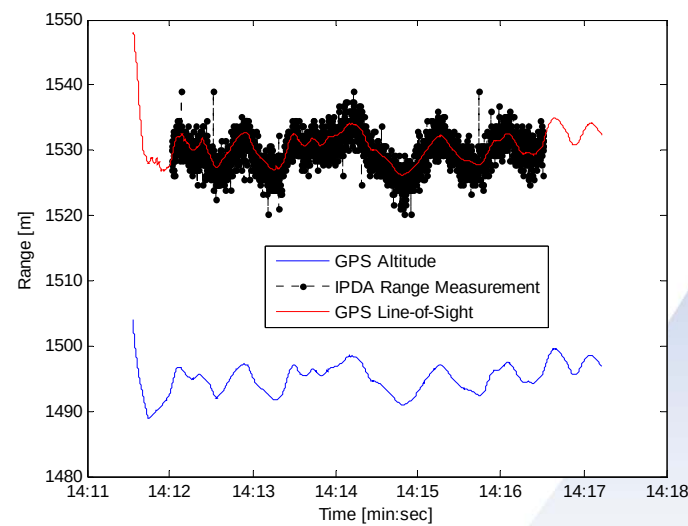
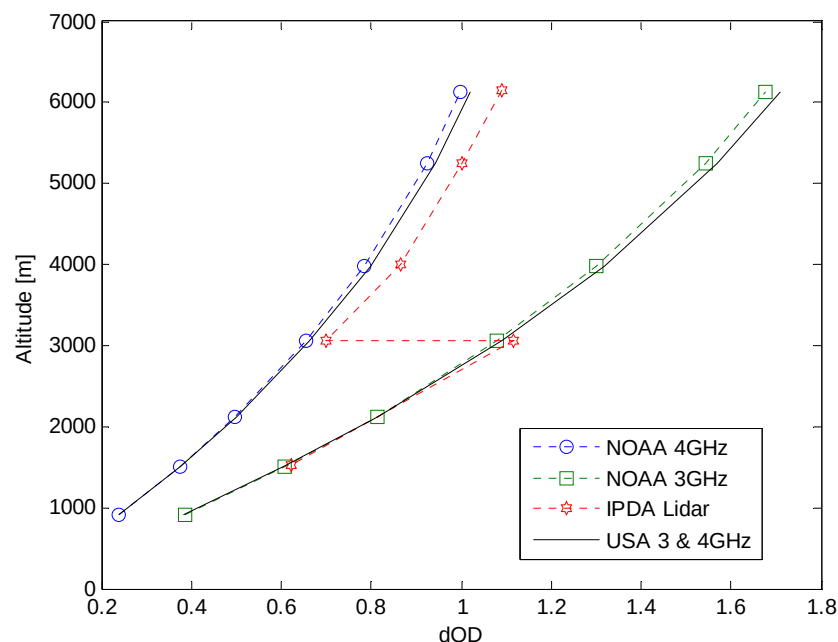
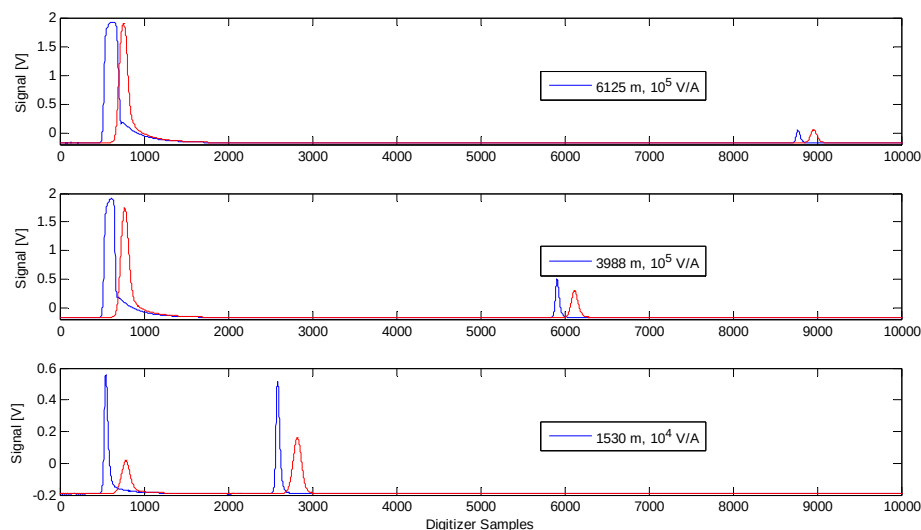
- Aircraft had temperature, pressure, humidity sensors, LiCor and GPS
- Some of the flights were supported by balloon launches



IPDA Airborne Testing: Sample Return Signals



- NOAA air sampling and IPDA lidar optical depth comparison.
- Return signal samples from different altitudes up to 6km.
- IPDA range measurements compared to on-board GPS.



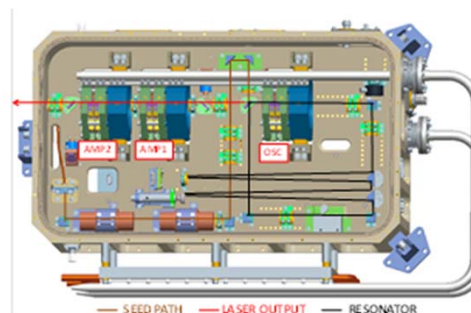


Triple-Pulsed 2- μm Direct Detection Airborne Lidar for Simultaneous and Independent CO_2 and H_2O Column Measurement

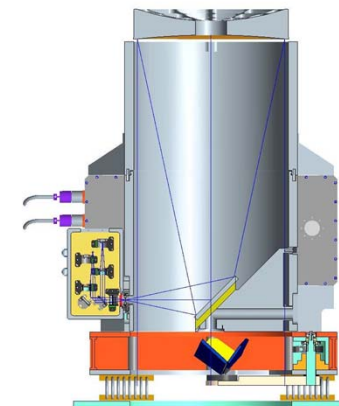
PI: Upendra Singh, NASA LaRC



- Demonstrate and validate simultaneous and independent measurement of the weighted-average column dry-air mixing ratios of carbon dioxide (XCO_2) and water vapor (XH_2O) from an airborne platform
- Design and fabricate a space-qualifiable, fully conductively-cooled, triple-pulsed, 2- μm laser transmitter
- Design and develop wavelength control system for rapid and fine tuning of the three sensing lines of the $\text{CO}_2/\text{H}_2\text{O}$ Integrated Path Differential Absorption (IPDA) lidar
- Integrate laser transmitter with receiver to develop the triple-pulsed 2- μm direct detection IPDA lidar
- Conduct extensive ground and airborne column $\text{CO}_2/\text{H}_2\text{O}$ measurement and validate with *in-situ* sensors



An example of space-qualifiable, fully conductively-cooled 2- μm laser packaging from ACT 11



Integrated 2- μm $\text{CO}_2/\text{H}_2\text{O}$ Airborne packaged IPDA Lidar

- Team with industry to utilize extensive space-flight laser development expertise to build a unique triple-pulsed 2- μm laser
- Develop a novel, lightweight, frequency agile, wavelength tuning and locking system for triple-pulsed IPDA Operation
- Integrate state-of-the-art laser transmitter to the existing and upgraded receiver system and strengthen for stable flight operation
- Conduct initial ground testing and validation of the IPDA lidar from a mobile lidar trailer
- Conduct extensive ground and airborne column $\text{CO}_2/\text{H}_2\text{O}$ measurement and validate with in-situ sensors

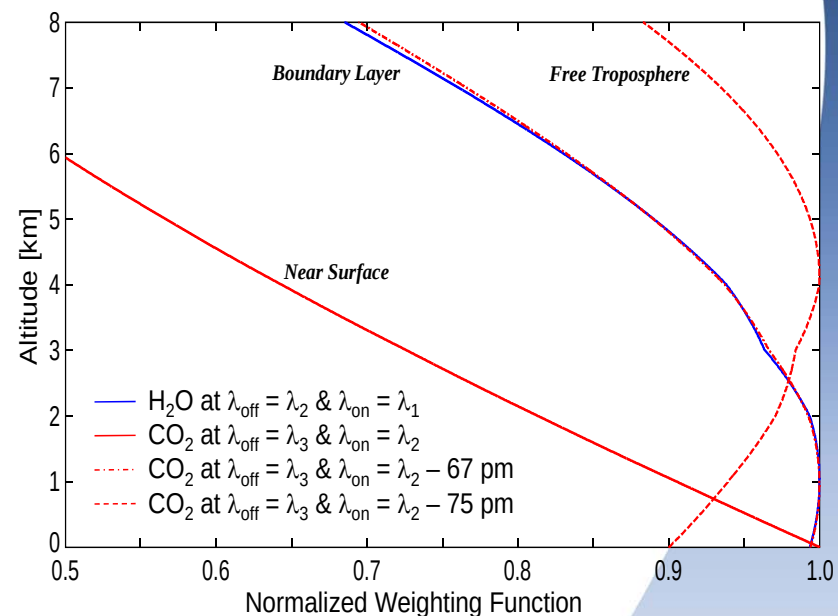
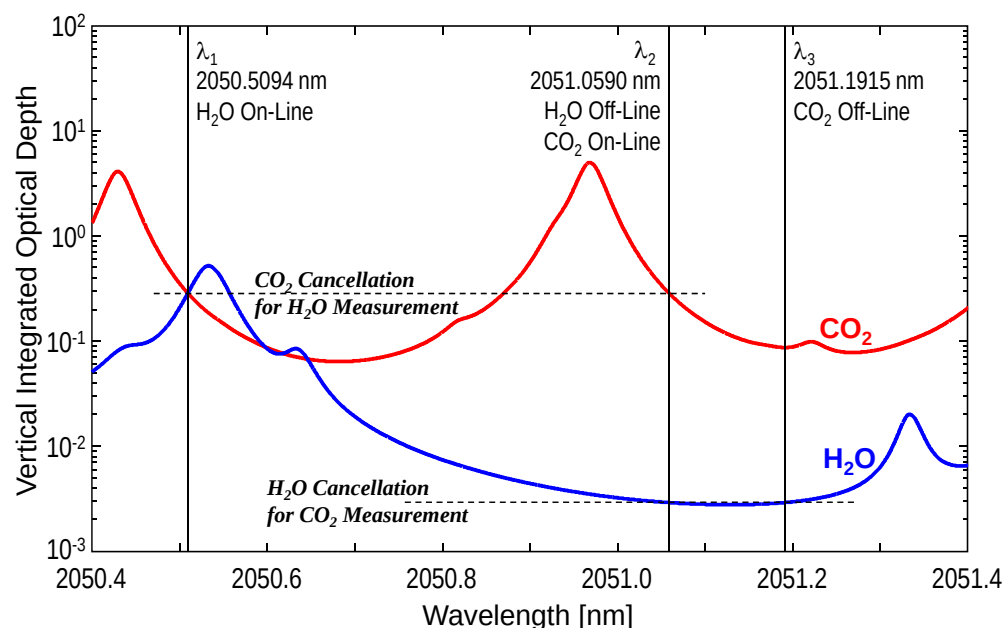
Co-Is/Partners: Ken Davis, Penn State Univ; Jirong Yu, Mulugeta Petros, LaRC;

- | | |
|--|-------|
| • Complete the preliminary triple pulse laser optical, mechanical, thermal and structure design and analysis | 12/14 |
| • Complete laser wavelength control unit design | 2/15 |
| • Complete laser transmitter design, and mechanical lidar system design | 05/15 |
| • Complete fabrication and testing of laser transmitter and wavelength control unit | 12/15 |
| • Integrate laser transmitter with wavelength control unit | 04/16 |
| • Complete lidar instrument integration, and ground test | 08/16 |
| • Conclude $\text{CO}_2/\text{H}_2\text{O}$ airborne lidar demonstration | 06/17 |

$\text{TRL}_{\text{in}} = 3$ $\text{TRL}_{\text{out}} = 5$



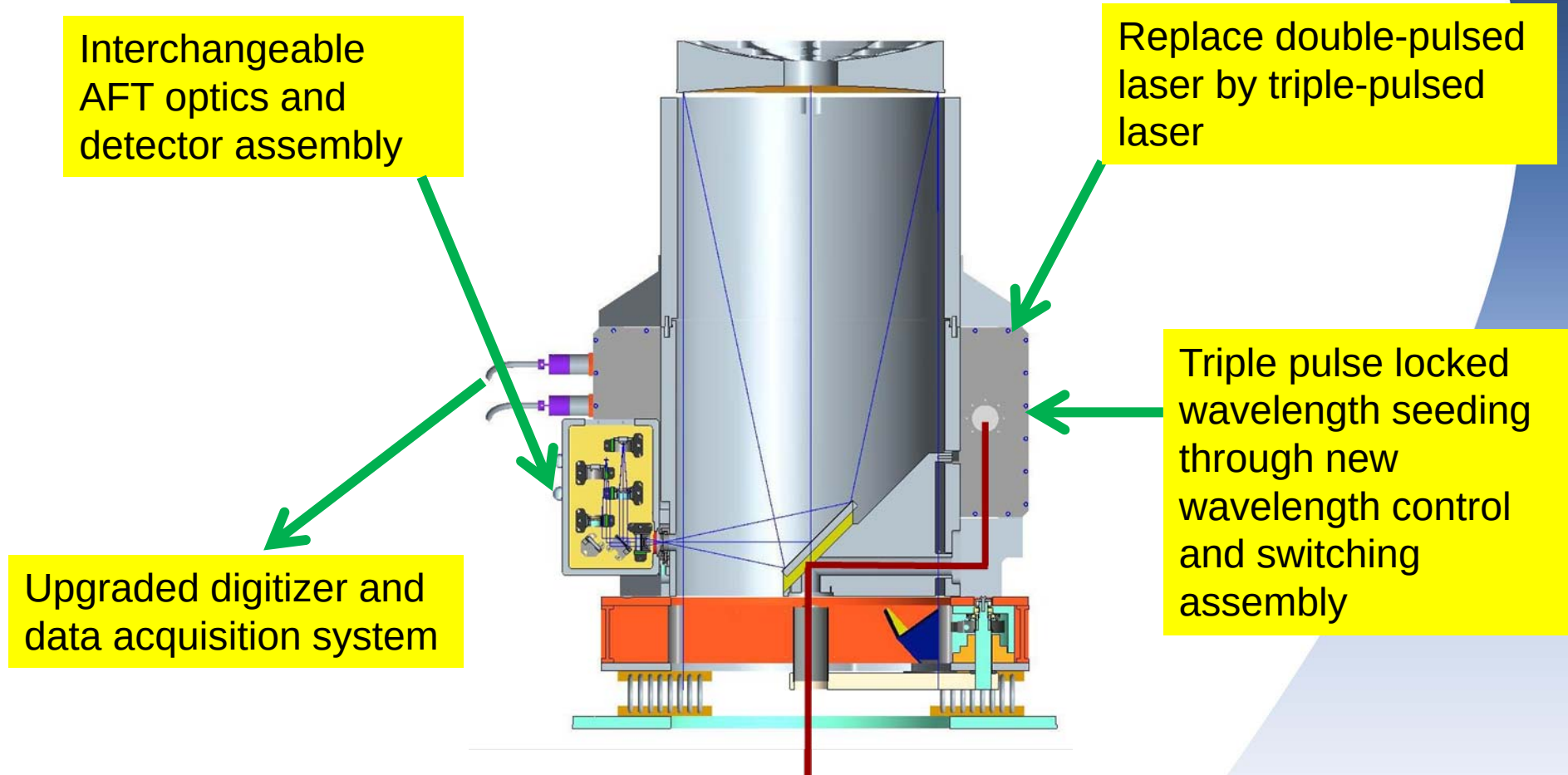
Triple-Pulsed 2- μm IPDA Airborne Lidar Simulation - CO_2 and H_2O Optical Depth



A novel measurement approach – the use of a single lidar instrument to measure two species, simultaneously and independently by using three different wavelengths



Key Component Development and Integration to the Existing IPDA Lidar System





Triple-Pulse Laser Transmitter



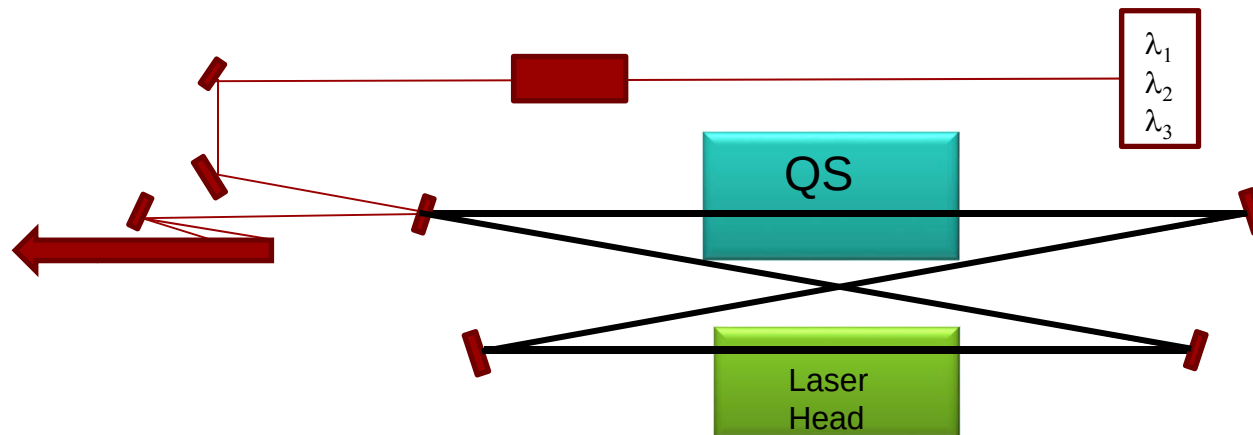
Seed Laser	Wavelength Control	Oscillator	Laser Output	IPDA Transmitter
Solid State Laser CTI Fiber Laser AdValue Semiconductor Laser JPL	- Designed to inject 3 wavelengths from a single laser - Novel Electro-optics modulators and fiber filters based design - Eliminates 90W of power and 30lbs	- In-house laser development - Conductive cooling - Slab architecture - End-pump 5ms pumping at 50 Hz - Innovative thermal design - Compact laser system	$\lambda_1 = 50$ mJ $\lambda_2 = 15$ mJ $\lambda_3 = 5$ mJ	Beam Expander Divergence 0.1mrad Steering Optics



Transmitter Design



Item	Parameter	Rationale
Laser Enclosure	Blue laser 6"x26"x11"	compatibility
Laser Configuration	Oscillator + Amplifier	
Output Reflectivity	70%	
size	2x2x15	Heat extraction
Pump configuration	End pump	Higher efficiency





Wavelength Control



OBJECTIVE: Generate three distinct wavelengths, with respect to a CO₂ absorption center-line locked wavelength.

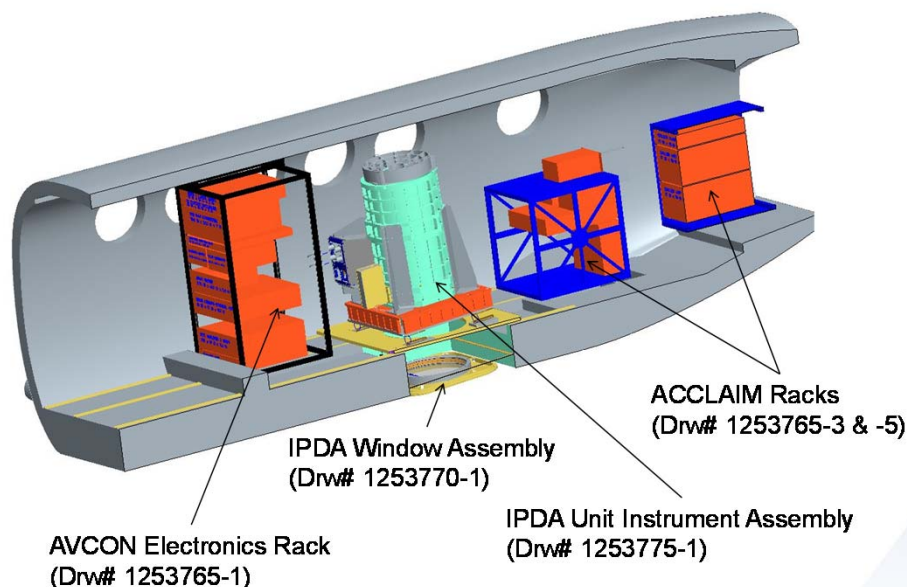
1. Characterize three different seed laser technologies, Solid-State laser, Fiber laser and Semi-conductor laser and compare the suitability for the system with respect to :
 - a) Output power
 - b) Single frequency operation
 - c) Short/long term wavelength stability
 - d) Tuning range
 - e) Tuning speed
 - f) CO₂ absorption center-line locking suitability
 - g) Power consumption and
 - h) Volume and weight
2. The best laser will be locked to the CO₂ line
3. The three wavelengths will be generated as side band using Electro-optic modulators and fiber filters



CO₂/H₂O IPDA Lidar Airborne Integration



- Triple-pulsed CO₂/H₂O IPDA will be designed for integration into a small research aircraft, such as the NASA B-200
- Integration update includes mechanical design, fabrication, assembly, testing and verification of the IPDA system performance with respect to flight requirements and aircraft loading profiles, and laser safety
- Mass, size, and power will be reduced from the existing IPDA system, thus updating the requirement will require minimal qualification for flight, vibration and load requirements – mainly updates





2- μm CO₂ IPDA Path to Space



Table 1. Comparison of CO₂ state-of-the-art 2- μm current and proposed technology with space requirement

	Current Technology	Proposed Technology	Projected Space Requirement [2]
	Laser Transmitter		
	Single Laser	Single Laser	Two Lasers
	Liquid-Cooled, Airborne laser Double-Pulse	Conductively-Cooled Space Qualifiable laser Triple-Pulse	Column CO ₂ Space Mission Single-Pulse
Technology			
Technique			
Laser Wavelength (μm)	2.051	2.051	2.051
Pulse Energy (mJ) 1 st /2 nd /3 rd Pulse	100/30 Double Pulse	50/15/5 Triple Pulse	40/5 Single Pulse
Pulse Repetition Rate (PRF)	10	50	50
Power (W)	1.3	3.5	2.25
Pulse Width FWHM (ns)	200	30-100	50
Optical to Optical Efficiency (%)	4.0	5.0	5.0
Wall Plug Efficiency (%)	1.44	2.1	>2.0
Delay between pulses (200 μsec)	200	200	250+/-25
Transverse/Longitudinal Modes	TEM ₀₀ /Single Mode	TEM ₀₀ /Single Mode	TEM ₀₀ /Single Mode
Pulse Spectral Width FWHM (MHz)	2.2	4-14	> 60
Beam Quality (M ²)	2	2	< 2
Frequency Control Accuracy (MHz)	0.3	0.3	0.2
Seeding Success Rate /Spectral Purity (%)	>99/99.9	>99/99.9	>99/99.9
	Detector		
	InGaAs	HgCdTe	N/A
	Pin photodiode	eAPD	APD
	68	80	75
	---	1.1	1.5
	200	8	100



Motivation for 2-Micron Laser/Lidar Development

NRC Recommended “3-D Winds” Mission



NRC Decadal Survey

EARTH SCIENCE AND APPLICATIONS FROM SPACE

NATIONAL IMPERATIVES FOR THE NEXT DECADE AND BEYOND

Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future

Space Studies Board

Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS

Washington, D.C.

www.nap.edu

2007

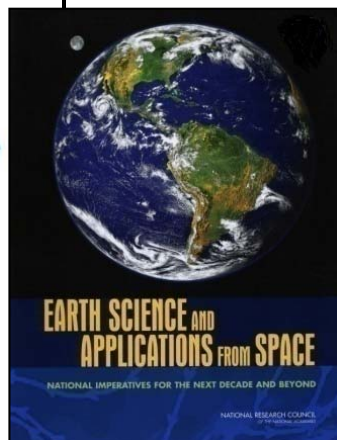


TABLE ES.2 Launch, Orbit, and Instrument Specifications for Missions Recommended to NASA

Decadal Survey Mission	Mission Description	Orbit ^a	Instruments	Rough Cost Estimate (FY 06 \$million)
2010-2013				
CLARREO (NASA portion)	Solar and Earth radiation; spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally resolved Interferometer	200
SMAP	Global Winds 9 Societal Benefits			
ICESat-II				
DESDynI				
2013-2016				
HyspIRI	Human Health			✓
ASCENDS	Earthquake Early Warning			
SWOT	Improved Weather Prediction			✓#1
GEO-CAPE	Sea-Level Rise			
ACE	Climate Prediction			
2016-2020				
LIST	Freshwater Availability			
PATH	Ecosystem Services			
GRACE-II	Air Quality			✓
SCLP	Snow accumulation for freshwater availability	LEO, SSO	Ku- and X-band radars K- and Ka-band radiometers	500
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	600
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	650



Global Tropospheric Wind Measurement



- **Requirement: 3-D global wind measurement under a variety of aerosol loading conditions**
- **Concept**
 - **Hybrid Doppler Wind Lidar operating at 2 μ m and 355 nm (NASA)**
 - 2 μ m system to measure winds in lower troposphere
 - 355 nm system to measure winds in upper tropo/stratosphere
 - **GrAOWL 532 nm system to measure winds from 2-telescope look (Ball)**
- **Challenge:**

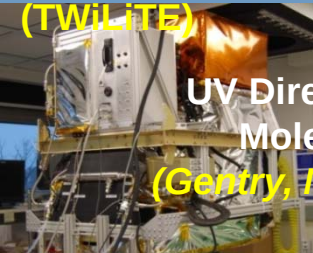
Laser	Measurement	Current Capability	Needed Capability
2 μ m pulsed	Doppler from aerosols	250mJ @ 10Hz	250mJ @ 5Hz
355 nm pulsed	Doppler from molecules	50mJ @ 200Hz	350mJ @100Hz

Toward Global Wind Measurements

National Aeronautics and Space Administration



Tropospheric Wind Lidar Technology Experiment (TWiLITE)



UV Direct Detection
Molecular Winds
(Gentry, NASA GSFC)

2008 Ground Comparison Singh, LaRC

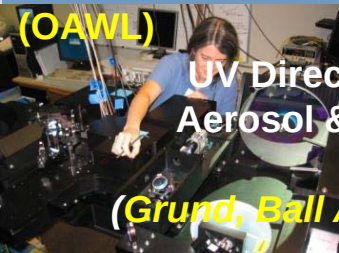


Doppler Aerosol Wind Lidar (DAWN)



2.0 μ m Coherent
Doppler
Aerosol Winds
(Singh/Kavaya, NASA LaRC)

Optical Autocovariance Wind Lidar (OAWL)



UV Direct Detection
Aerosol & Molecular
Winds
(Grund, Ball Aerospace)

2011 Ground Comparison with NOAA mini-MOPA



Integrated
onto ER-2
in 2009

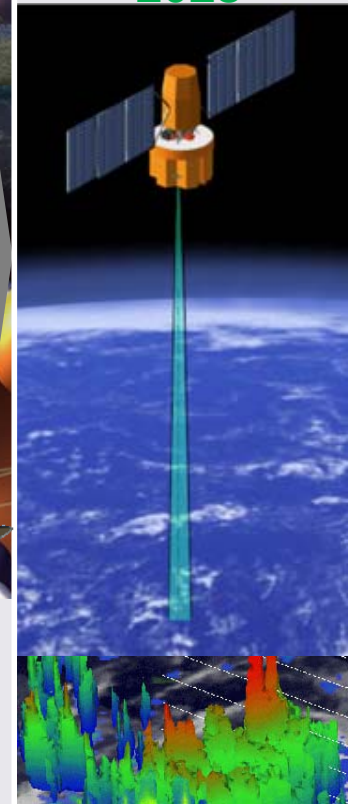


Integrated
onto DC-8
in 2010
(GRIP Campaign)



To fly on the WB-57
in October 2011

3D-Winds Decadal Survey Mission 2025



Technology Development

Demonstrations / Campaigns

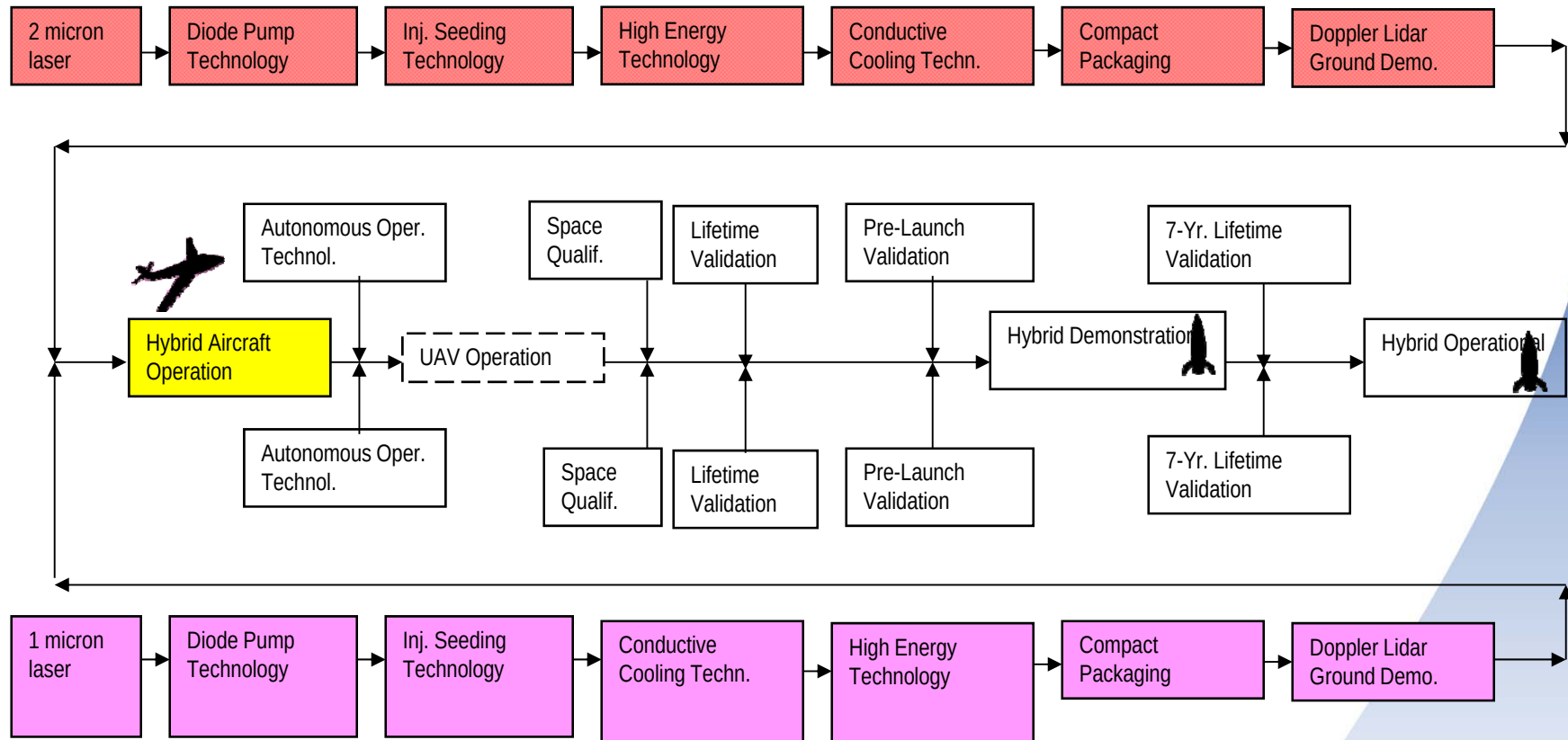
Science Measurements



Space-Based Doppler Wind Lidar Roadmap



2-Micron Coherent Doppler Lidar



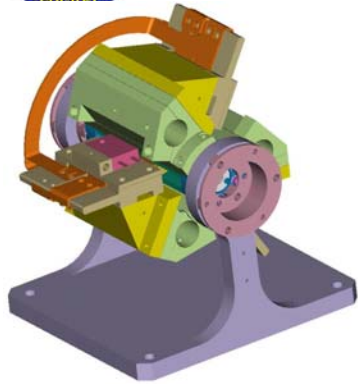
0.355-Micron Direct Doppler Lidar

Global Winds Roadmap Via Hybrid Doppler Lidar

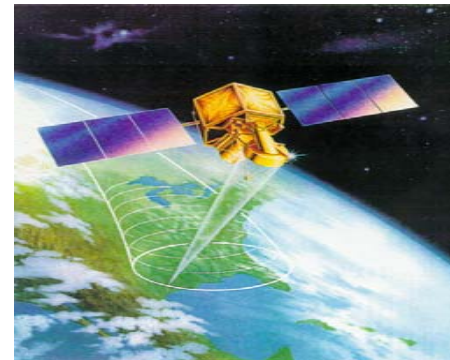


Technology Maturation Example

A fully conductively cooled 2-micron solid-state pulsed laser has been demonstrated to enable 3-D Winds from a space platform



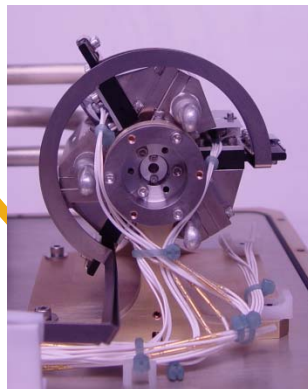
Analysis &
Design



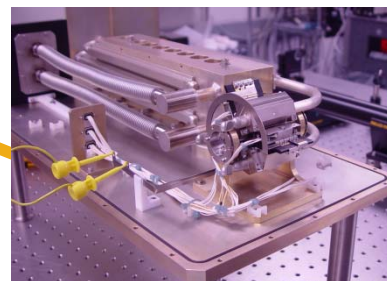
Space Qualifiable
Design



Quantum Mechanical
Modeling



Fabrication



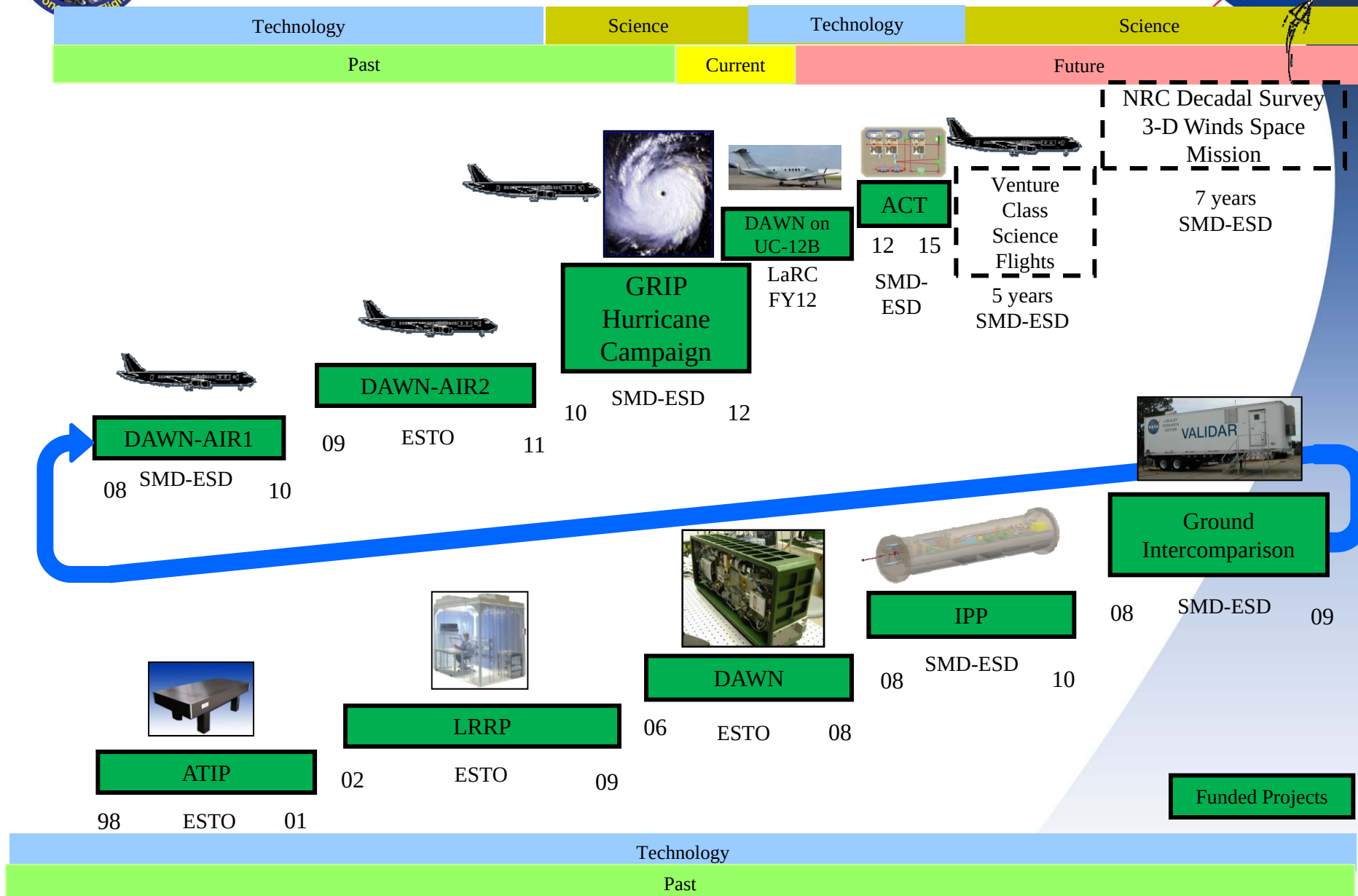
System Integration



Testing and Model
Verification



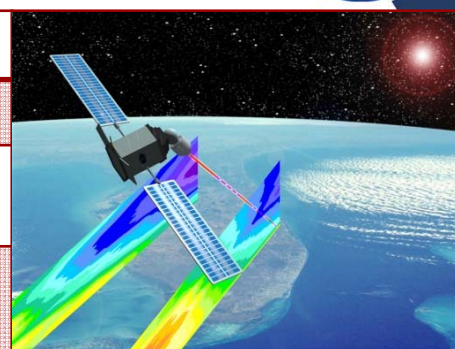
Roadmap to 3-D Winds Space Mission at NASA Langley





Advancements Dramatically Lower Risk of Winds Space Mission



Past		Today	
525 km		400 km	
12 cross-track positions		2 cross-track positions	
1 shot measurement		Multiple shot accumulation	
Continuously rotating 1.5 m telescope		4 stationary 0.5 m telescopes	
Single coherent Doppler lidar		Dual coherent & direct hybrid Doppler lidar	
Gas laser		Solid-state eyesafe laser	
20 mJ 2-micron solid state energy		1200 mJ 2-micron solid state energy	
Space required energy = 20 J		Space required energy = 0.25 J	Conductively Cooled Laser
Energy deficit = 1,000			Energy surplus = 5

➤ From a 20-J, 10-Hz gas laser with 1.5-m diameter rotating telescope, to a 0.25-J, 10-Hz solid-state eyesafe laser with non-moving 0.5-m telescopes!



Summary



- NASA Earth Science maintains a balanced program
- 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 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

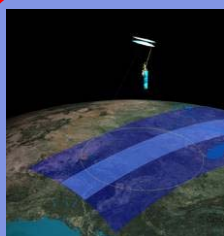
Thanks for your Kind Attention!



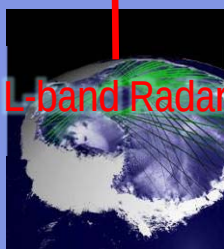
Questions?



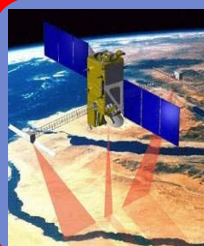
NASA Earth Science Decadal Survey Missions



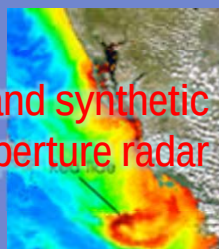
Soil Moisture
Active
Passive
(SMAP)



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



Surface Water
and Ocean
Topography
(SWOT)



L-band synthetic
Aperture radar



Active
Sensing of
CO2
Emissions
(ASCENDS)



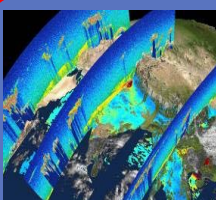
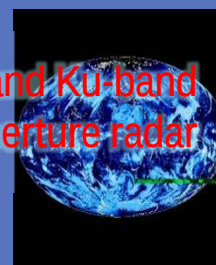
Ka / W band
cloud radar

Ku-band near-nadir
synthetic aperture radar
and Ku-band nadir-looking
radar altimeter



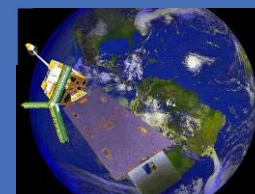
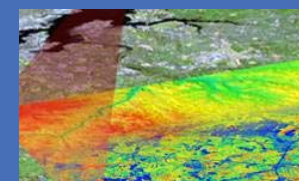
Deformation,
Ecosystem
Structure and
Dynamics of
Ice (Radar)
(DESDynI -R)

Dual-mode X- and Ku-band
synthetic aperture radar



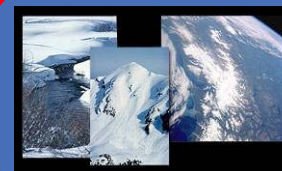
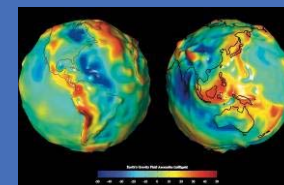
Aerosol -
Cloud -
Ecosystems
(ACE)

LIDAR Surface
Topography
(LIST)



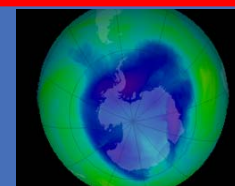
Precipitation and
All-Weather
Temperature and
Humidity (PATH)

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)

Radars