CALIGOLA: A New Spaceborne Lidar Mission

(**C**loud **A**erosol **Li**dar for **G**lobal scale **O**bservations of the ocean-**L**and-**A**tmosphere system)

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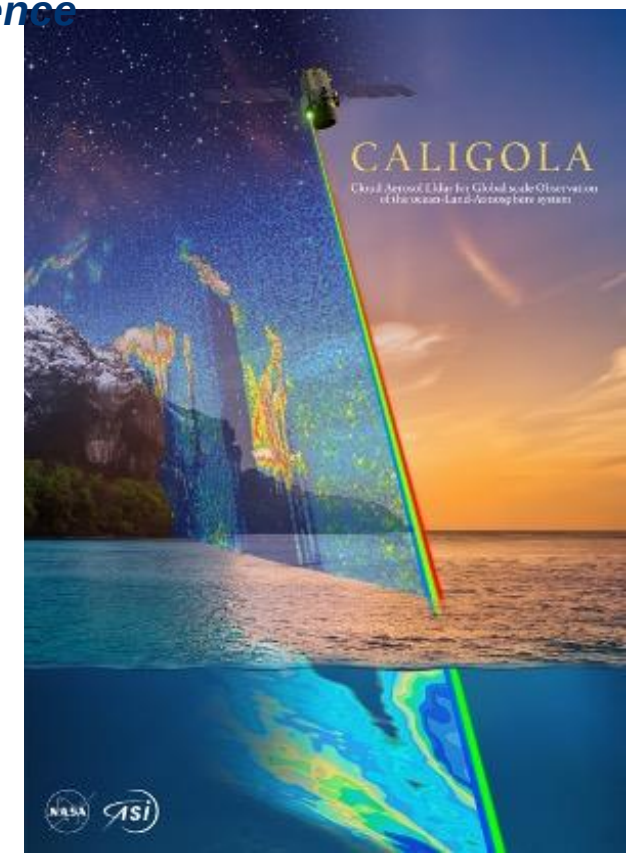
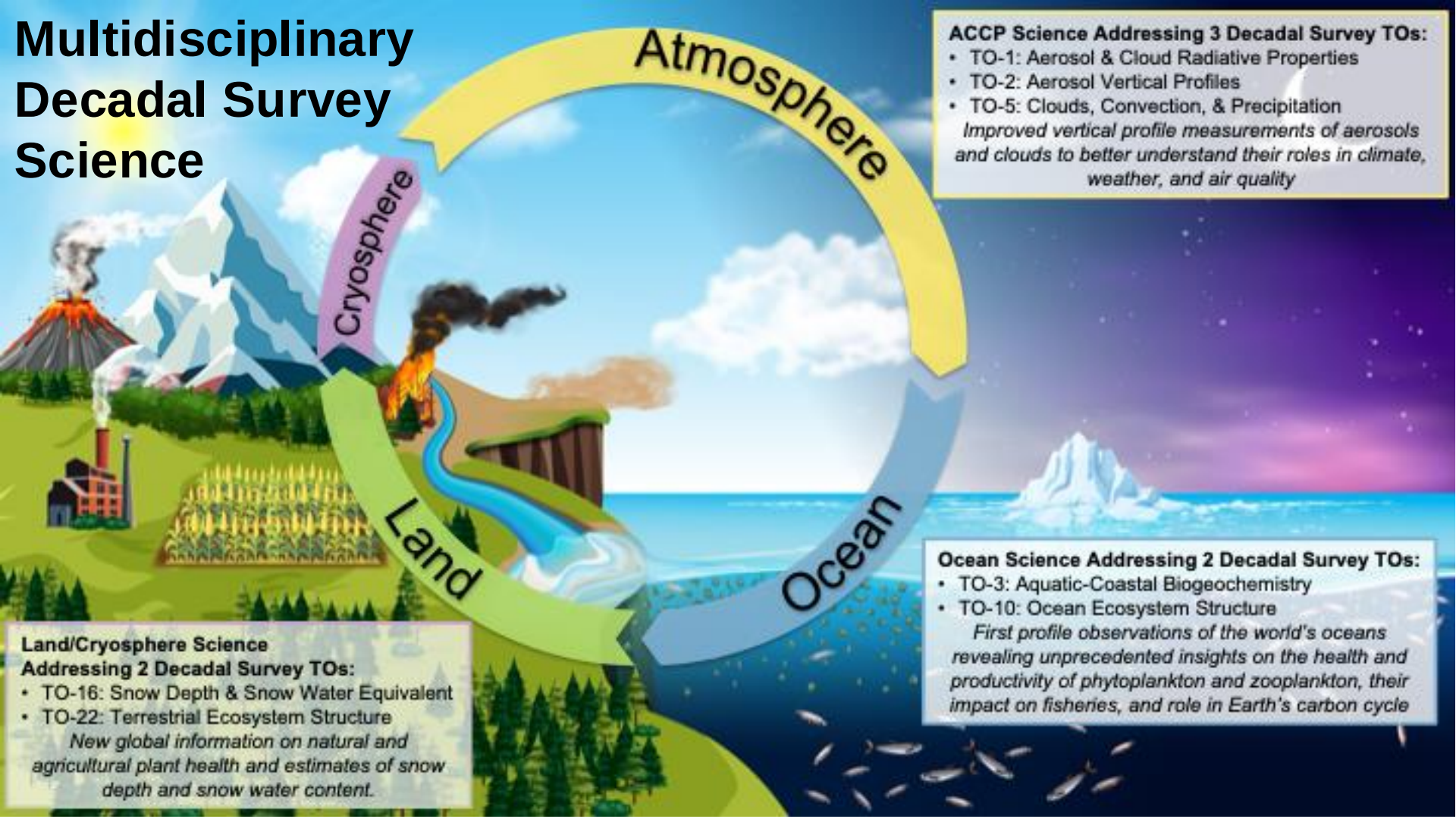
CALIGOLA

Advancing Earth System Science

- CALIGOLA is an **interdisciplinary Earth Sciences mission** significantly advancing global knowledge on the coupled atmosphere-ocean-land system.
- **First spaceborne Raman-elastic-fluorescence lidar** enabled through a partnership between ASI and NASA.
- Provides **improved vertical profile measurements** of atmospheric particles (aerosols) and clouds to better understand their roles in climate, weather, and air quality.
- Provides the **first profile observations of the world's oceans** revealing unprecedented insights on the health and productivity of phytoplankton and zooplankton, their impact on fisheries, and role in Earth's carbon cycle.
- Offers **new land measurement capabilities** on natural and agricultural plant health and refined estimates of snow depth and snow water content.



Multidisciplinary Decadal Survey Science



ACCP Science Addressing 3 Decadal Survey TOs:

- TO-1: Aerosol & Cloud Radiative Properties
- TO-2: Aerosol Vertical Profiles
- TO-5: Clouds, Convection, & Precipitation

Improved vertical profile measurements of aerosols and clouds to better understand their roles in climate, weather, and air quality

Land/Cryosphere Science Addressing 2 Decadal Survey TOs:

- TO-16: Snow Depth & Snow Water Equivalent
- TO-22: Terrestrial Ecosystem Structure

New global information on natural and agricultural plant health and estimates of snow depth and snow water content.

Ocean Science Addressing 2 Decadal Survey TOs:

- TO-3: Aquatic-Coastal Biogeochemistry
- TO-10: Ocean Ecosystem Structure

First profile observations of the world's oceans revealing unprecedented insights on the health and productivity of phytoplankton and zooplankton, their impact on fisheries, and role in Earth's carbon cycle

Measurement Capabilities Beyond CALIPSO

- Improved calibrated profile measurements of attenuated backscatter for day/night conditions.
- Improved daytime sensitivity (SNR) to identify aerosol layers missed by CALIPSO.
- Finer vertical/horizontal resolution in lower atmosphere to better characterize aerosols near the surface and to determine microphysical properties of liquid water clouds.
- Improved ability to characterize aerosol typing for air quality assessments and better capability to discriminate between aerosol and clouds.
- Wider detector dynamic range capable of quantifying backscatter from liquid clouds and ocean surface reflectance to support more accurate estimates of integrated aerosol optical properties.

Credit NASA

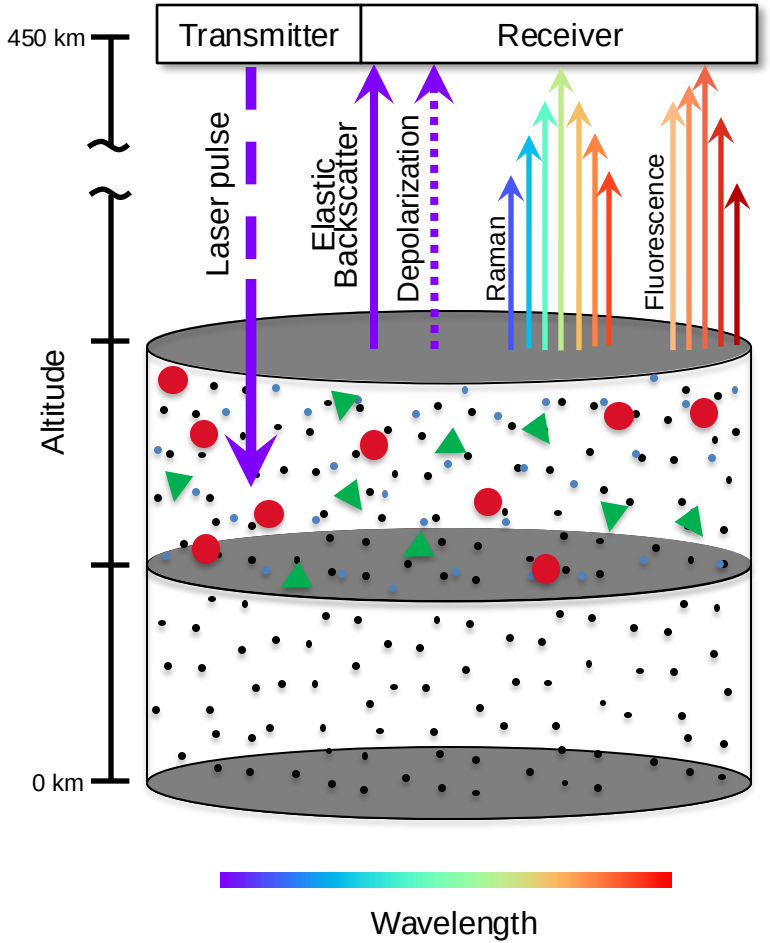
Physics Exploited by CALIGOLA

Elastic scattering: change in light's direction

Depolarization: change in light's polarization state

Raman scattering: change in light's direction *and* an exchange of energy

Fluorescence: emission of light that has been absorbed



Raman spectrum: wavelength shifts correspond to the vibrational-rotational energy level structure of the scatterer
→ **unique fingerprint**

- Allows one to collect backscatter from a specific species of interest

Fluorescence spectrum: specific to a species, only some species fluoresce
→ **unique fingerprint**

- Identifier of the type particle in the volume

CALIGOLA

A multi-wavelength elastic-Raman-fluorescence backscatter lidar

8 receiver channels
- Multiple channels often used to derive a single geophysical quantity

3 wavelength laser

Transmitted wavelengths	Receiver Wavelengths [nm]				
	Parallel elastic backscatter	Perpendicular elastic backscatter	N_2+O_2 rotational Raman backscatter	H_2O rotational-vibrational Raman backscatter	Fluorescence
355 nm	355 nm A O L C	355 nm A O L C	353.95 nm + 355.7 nm A	405 nm A O L C	685 nm A O L
532 nm	532 nm A O L	532 nm A O L			
1064 nm	1064 nm A L				

Channel Usage:
Atmosphere
Ocean Land
Cryosphere

Elastic backscatter with polarization sensitivity
- Foundational to nearly all types of retrievals

Raman backscatter
- Atmosphere (N_2+O_2) & ocean (H_2O) calibration
- Water vapor retrievals

Fluorescence
- indicator of organic matter (e.g. biological aerosols, chlorophyll)

Heritage measurements
- CALIOP on CALIPSO (2006 – 2023)
- ATLID on EarthCARE (2024 – 2027+)

CALIGOLA's first-ever measurements
- Relatively weak signals that are stimulated more effectively by shorter wavelengths (i.e. 355nm)

Preliminary Lidar Characteristics

- Transmission wavelengths: 354.76, 532, 1064 nm
- Average pulse energy: 151, 44, 156 mJ
- Pulse repetition rate: 51 Hz, ~150 m between shots
- Receiver sampling rate: 120 MHz
- Telescope diameter: 1 m
- Field of View: 30 µrad; 10 m footprint at sfc
- Off-nadir point angle: 10-12 deg
- Mean orbit altitude: 455 - 481 km (equator - pole)
- Equatorial Cross time: 1:30 pm/am (descending orbit)
- 8 Detector channels Raman, elastic and fluorescence
- Data volume ~4 Tbits/day
- Data access NASA and ASI data facilities
- Launch (TBD) mid 2032

Data Downlink Vertical Resolution

Referenced to Mean Sea Level (MSL)

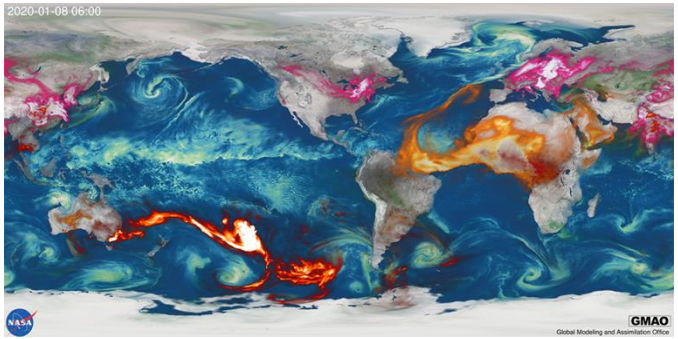
Altitude range [km MSL]		Description	Vertical resolution (in air) [m]					
Upper	Lower		Para-Perp 355nm	Para-Perp 532nm	Total 1064nm	Rotational Raman	Water Raman	Fluore-scence
90	45	Stratosphere & mesosphere	360					
45	32	Elastic calibration	180	180				
32	20	Stratosphere	90	90	180	180	360	
20	8	Troposphere	30	30	30	30	120	120
8	5	Liquid clouds, coarse resolution	7.5	30	30	30	120	120
5	0.20	Liquid clouds, fine resolution	3.75	30	30	30	120	120
0.20	-0.25	Ocean & ocean surface	1.25	1.25	30	1.25	1.25	1.25
-0.25	-0.50	Atmosphere below MSL	30	30	30	30	120	120

Referenced to Above Ground Level (AGL)

Altitude range (km)		Description	Vertical resolution (in air) [m]		
Upper	Lower		Para-Perp 355nm	Water Raman	Fluore-scence
0.20	-0.05	Snow & vegetation (land-only)	1.25	1.25	1.25

Applications of Science for Societal Benefit

- **Weather Forecasting** by observing cloud distributions & properties to improve retrievals and model assimilation
- **Water Resource Management** by providing satellite-based snow depth/water equivalent estimates in high terrain
- **Climate Modeling** by providing measurements of aerosol, cloud and biological processes improving climate prediction
- **Air Quality** through more precise measurements of aerosols to better forecast impacts on human health
- **Disaster Monitoring** by rapidly conveying observations and predictions of volcanic plumes and wildfire smoke



Summary

- **CALIGOLA** is an exciting **new spaceborne Raman/elastic/fluorescence lidar** mission that seeks to provide profile measurements on aerosols, clouds, marine biology as well as new information on vegetation stress and snowpack needed to advance an understanding of the coupled Earth System.
- **Strong partnership between ASI and NASA**.
  - ASI: spacecraft, launch vehicle, laser, optics, ground segment and science
  - NASA: detector system, downlink support, science
- **Completed Mission Concept Study** (September 2024)
  - NASA intends to support a passive measurement mission and active cloud measurement system to fly with CALIGOLA. Details are still under development.

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Backup slides

Evaluating Elastic Channels SNR

- AOS Target is daytime SNR = CALIOP nighttime SNR
  - Satisfying this depends on the variability/magnitude of the daytime background
- SNR of new (subscript "n") lidar relative to CALIOP (subscript "c") nighttime SNR:

SNR to CALIPSO at night

$$= \frac{\sqrt{\frac{P_n}{P_c}\frac{A_n^2}{A_c^2}\frac{QE_n}{QE_c}\frac{\eta_n}{\eta_c}\frac{R_c^2}{R_n^2}\frac{\phi_n^2}{\phi_c^2}}}{\sqrt{1 + BSR_c\frac{\mu_n}{\mu_c}\frac{P_c}{P_n}\frac{r_n}{r_c}\frac{B_n}{B_c}\frac{f_n^2}{f_c^2}\frac{R_n^2}{R_c^2}\frac{\phi_c^2}{\phi_n^2}}}$$

  - **Black: lidar instrument parameters (laser power, rep. rate, telescope size, detector efficiency, etc…)**
  - **Purple: Orbit parameters (altitude, crossing time)**
  - **Red: CALIOP-observed background-to-signal ratio (i.e. scene brightness)**