LUCE: Present status of the ASI-NASA space lidar mission aimed to disclose the secrets on the coupled atmosphere-ocean-land system

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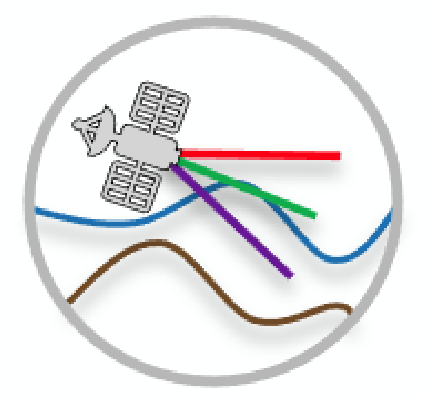
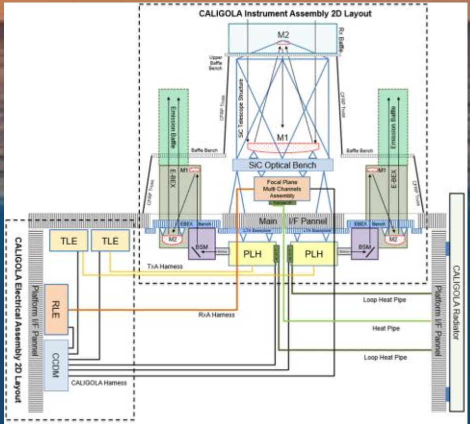
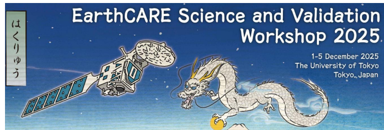




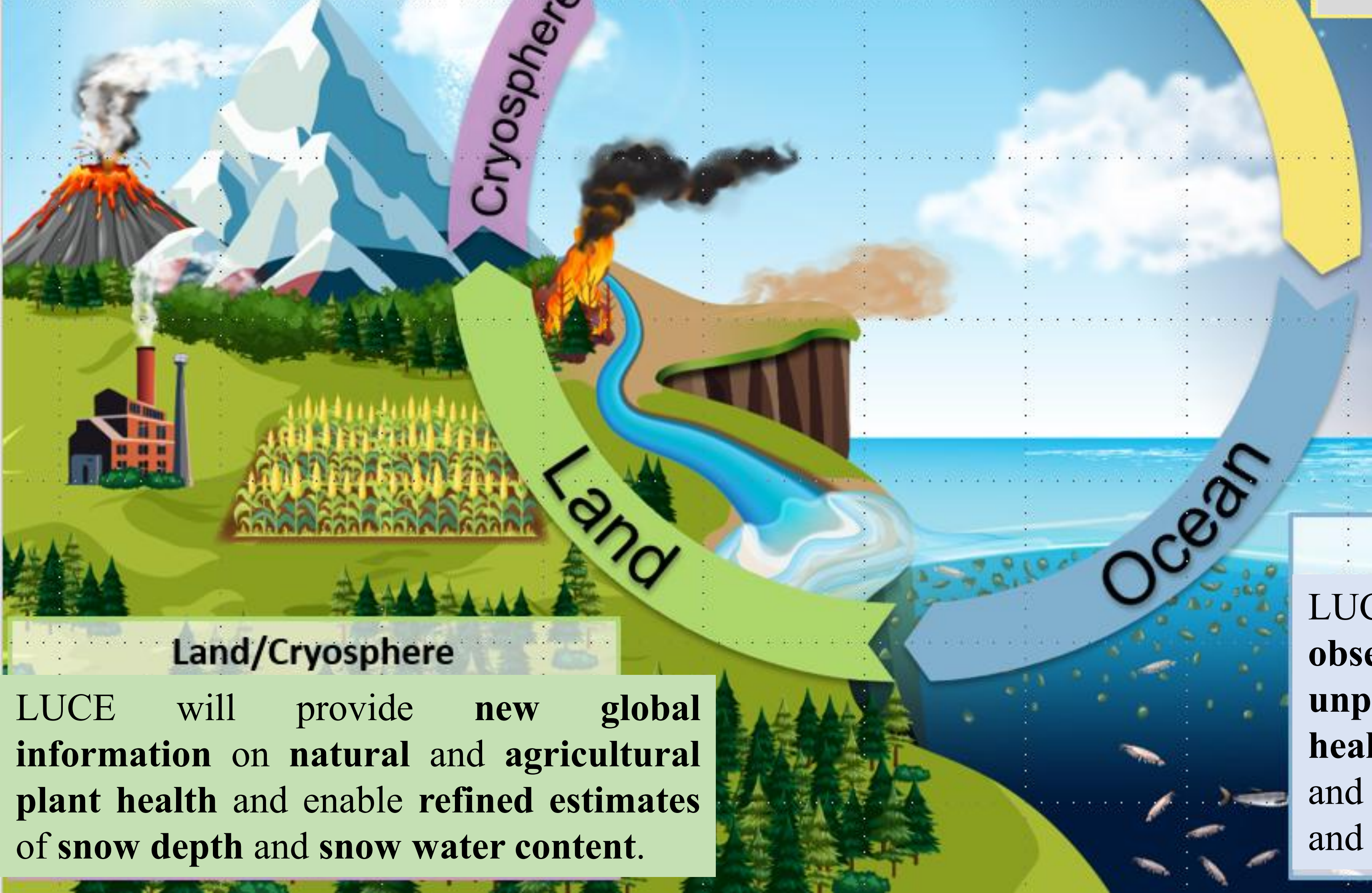
LUCE: Advanced multi-disciplinary space lidar mission for Earth Sciences, primarily focusing on the observation of the atmosphere and oceans, aimed at advancing global knowledge on the coupled atmosphere-ocean-land system.

LUCE is the **first spaceborne Raman-elastic-fluorescence lidar**, created through an Agenzia Spaziale Italiana (ASI) and National Aeronautics and Space Administration (NASA) partnership.



LUCE SCIENCE OBJECTIVES IN BRIEF

Luce: Multidisciplinary Earth Science



Atmosphere

LUCE will provide **improved vertical profile measurements** of **aerosols** and **clouds** to better understand their roles in **climate**, **weather**, and **air quality**.

Land/Cryosphere

LUCE will provide **new global information** on **natural** and **agricultural plant health** and enable **refined estimates** of **snow depth** and **snow water content**.

Ocean

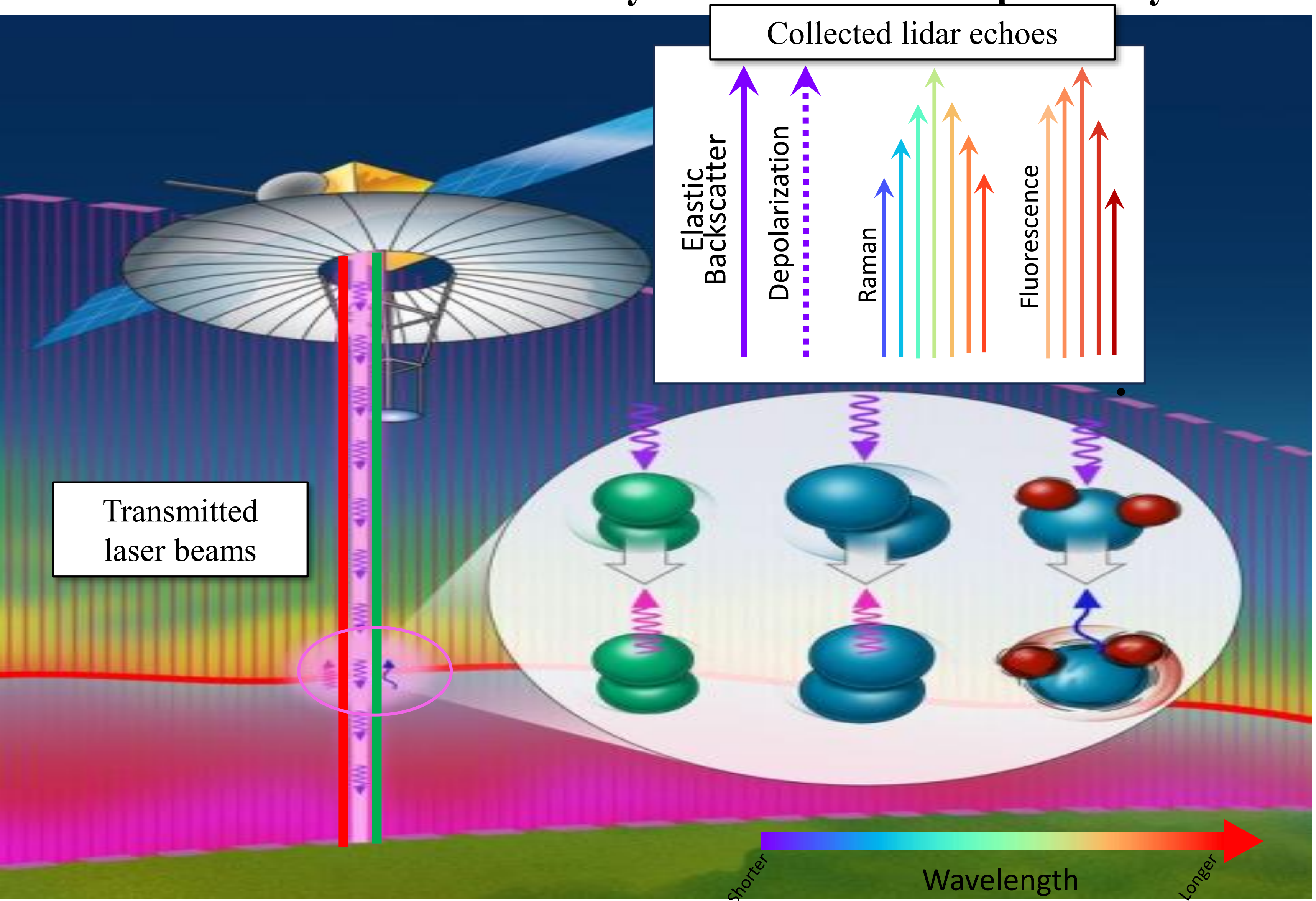
LUCE will provide the **first profile observations** of the **oceans** leading to an **unprecedented characterization** of the **health** and **productivity** of **phytoplankton** and **zooplankton**, their impact on fisheries and the Earth’s carbon cycle.

DRIVING IDEAS BEHIND THE MISSION

1) exploit all 3 wavelengths (354.7, 532 and 1064 nm) emitted by a **Nd:YAG source**, instead of throwing one or more into the deep space or in a dump.

2) exploit different atmospheric/surface/oceanic, elastic and **anelastic echoes**, stimulated with these **3 wavelengths**.

Physical mechanisms exploited by LUCE



Elastic scattering: change in light's direction with no change in wavelength

Depolarization: change in light's polarization state

Raman scattering: change in light's direction and wavelength

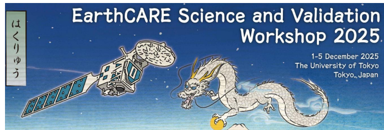
Fluorescence: re-emission of absorbed light

Raman spectrum: wavelength shifts correspond to the roto-vibrational energy level structure of the scattering species → wavelength shifts are **unique fingerprints**

- Possibility to collect backscatter echoes from a specific species of interest

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

- Possibility to identify of the particle type



CHN	Optical receiver band(s)	Stimulating Tx wavelength(s)	Scattering or re-emission mechanism	CHN symbol
I	354.8 nm (‖)	354.8 nm	Co-polarized elastic signal from the atmosphere, the ocean, land, and snow-ice surface and the ocean subsurface layers	$P_{355\parallel}(z)$
II	354.8 nm (⊥)	354.8 nm	Cross-polarized elastic	$P_{355\perp}(z)$
III	532.2 nm (‖)	532.2 nm	Co-polarized elastic	$P_{532\parallel}(z)$
IV	532.2 nm (⊥)	532.2 nm	Cross-polarized elastic	$P_{355\perp}(z)$
V	1064.4 nm	1064.4 nm	Total elastic	$P_{1064}(z)$
VI	402-408 nm	354.8 nm	Water vapor, liquid and ice water roto-vibrational Raman signal from the atmosphere, the ocean, land, and snow-ice surface and the underlying layers	$P_{H2O}(z)$
VII	355.85 nm, 353.95 nm	354.8 nm	Pure rotational Raman (Anti-Stoke and Stokes branches) from atmospheric N_2 and O_2 molecules and water low-freq. vibrational Raman signals from the ocean and snow-ice surface	$P_{ref,S/AS}(z)$
VIII	675-695 nm	354.8 nm, 532.2 nm	Chlorophyll fluorescence	$P_{FL,685}(z)$

Measured geophysical variables

Atmospheric observable 1: Vertical profiles of the atmospheric particle (aerosol/clouds) backscattering coefficient at 354.7 nm, $\beta_{355}(z)$

Atmospheric observable 2: Vertical profiles of the atmospheric particle (aerosol/clouds) backscattering coefficient at 532 nm, $\beta_{532}(z)$

Atmospheric observable 3: Vertical profiles of the atmospheric particle (aerosol/clouds) backscattering coefficient at 1064 nm, $\beta_{1064}(z)$

Atmospheric observable 4: Vertical profiles of the atmospheric particle (aerosol/clouds) extinction coefficient at 354.7 nm, $\alpha_{355}(z)$

Atmospheric observable 5: Vertical profiles of the atmospheric particle (aerosol/clouds) depolarization ratio at 354.7 nm, $\delta_{355}(z)$

Atmospheric observable 6: Vertical profiles of the atmospheric particle (aerosol/clouds) depolarization ratio at 532 nm, $\delta_{532}(z)$

Atmospheric observable 7: Vertical profiles of the atmospheric water vapour mixing ratio, $x_{H2O}(z)$ *(over long horizontal integration paths)*

Atmospheric observable 8: Vertical profiles of the stratospheric and mesospheric temperature, $T(z)$

Atmospheric observable 9: Vertical profiles of the atmospheric (aerosol) fluorescent coefficient at 685 nm, $\beta_{FL\_AER,685}(z)$

Oceanic obs. 1: Vertical profiles of oceanic particulate backscattering coeff. at 354.7 nm from water susp. particulate matter, including marine phytoplankton, $b_{bp\_355}(z)$

Oceanic obs. 2: Vertical profiles of oceanic particulate backscattering coeff. at 532 nm from water susp. particulate matter, including marine phytoplankton, $b_{bp\_532}(z)$

Oceanic obs. 3: Integrated oceanic particulate backscattering coeff. at 354.7 nm from water susp. particulate matter, including marine phytoplankton, $b_{bp\_355}(z)$

Oceanic obs. 4: Integrated oceanic particulate backscattering coeff. at 532 nm from water susp. particulate matter, including marine phytoplankton, $b_{bp\_532}(z)$

Oceanic obs. 5: Vertical profiles of oceanic particulate depol. ratio at 354.7 nm from water suspended particulate matter, including marine phytoplankton, $\delta_{355\_OCE}(z)$

Oceanic obs. 6: Vertical profiles of oceanic particulate depol. ratio at 532 nm from water suspended particulate matter, including marine phytoplankton, $\delta_{532\_OCE}(z)$

Oceanic obs. 7: Vertical prof. of oceanic diffuse atten. coeff. for downwell. irrad. at 354.7 nm from water susp. particulate matter, incl. marine phytoplankton, $K_{d\_355}(z)$

Oceanic obs. 8: Vertical profiles of diffuse attenuation at 405 nm, , $K_{d\_405}(z)$

Oceanic observable 9: Vertical profiles of phytoplankton chlorophyll fluorescence coefficient at 685 nm from the upper ocean, $\beta_{FL\_CHL,685}(z)$

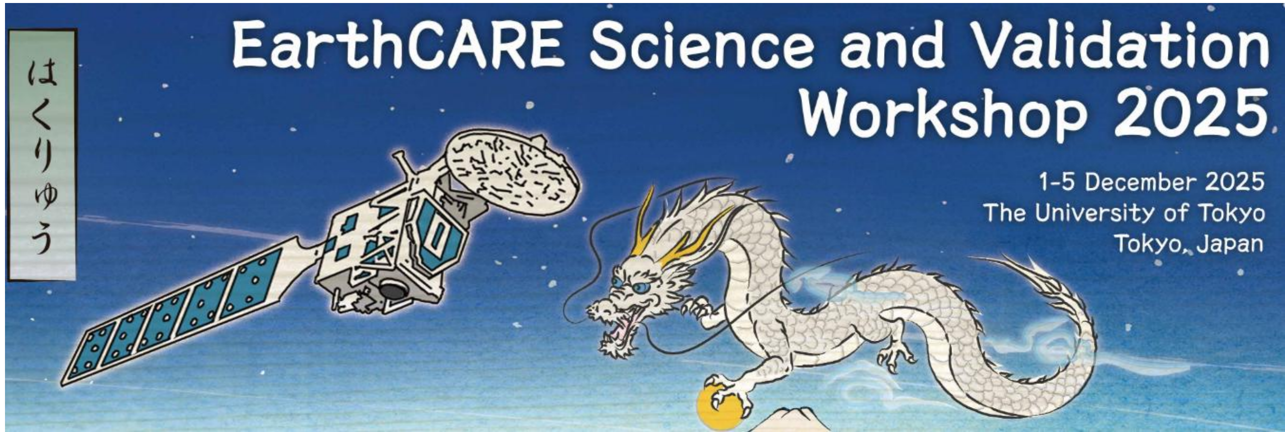
Cryosphere observable 1: Snow water equivalent measurements, SD, SEW

Terrestrial observable 1: Terrestrial plant canopy structure at 354.7, 532 and 1064 nm.

Terrestrial observable 2: Chlorophyll fluorescence coefficients at 685 nm from terrestrial vegetation, $\beta_{FL\_CHL,685}(z)$

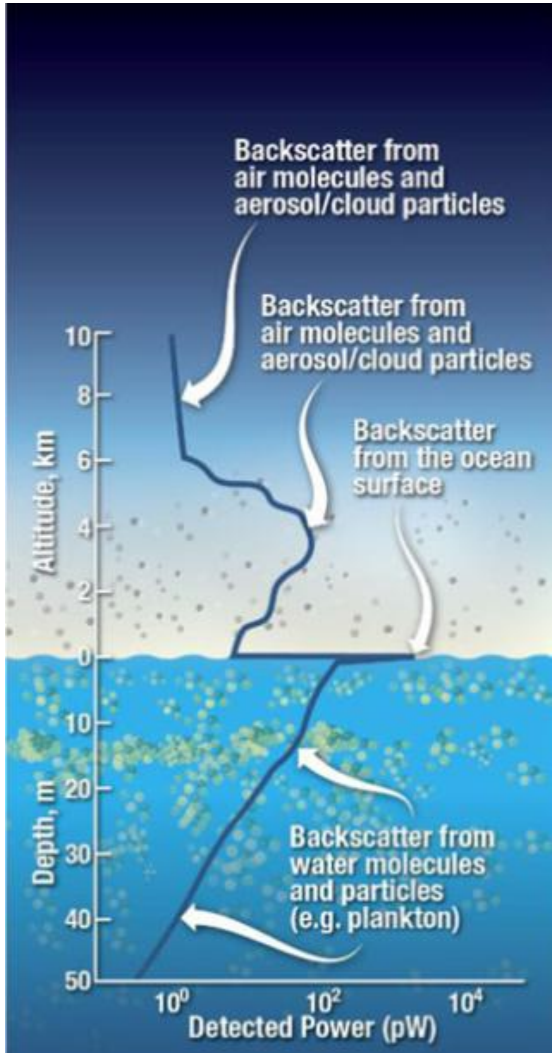
9 Atmospheric observables
9 Oceanic observables
2 Terrestrial observables
1 Cryosphere observable

21 Total observables with 8 chns



Vertical resolution and extent for the different signals

Reference	Range (km)		Description	Vertical resolution (in air) [m]					
	Upper	Lower		Para-Perp 355nm	Para-Perp 532nm	Total 1064nm	Rotational Raman	Water Raman	Fluore-scence
MSL	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
AGL	0.20	-0.05	Snow & vegetation (land-only)	1.25				1.25	1.25



Extended vertical regions

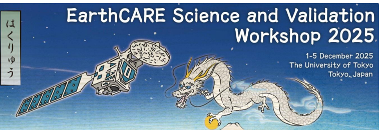
-0.5 km ≤ z ≤ 90 km

Variable vertical resolutions

1.25 m ≤ Δz ≤ 360 m

Dynamic Range

Product	Minimum	Maximum
1: $P_{355\parallel}$	2.1×10^{-8} km^{-1}sr^{-1}	3.0 km^{-1}sr^{-1} and 0.095 sr^{-1}
2: $P_{355\perp}$	2.1×10^{-8} km^{-1}sr^{-1}	3.0 km^{-1}sr^{-1} and 0.095 sr^{-1}
3: $P_{532\parallel}$	2.4×10^{-6} km^{-1}sr^{-1}	4.2 km^{-1}sr^{-1} and 0.015 sr^{-1}
4: $P_{532\perp}$	2.4×10^{-6} km^{-1}sr^{-1}	4.2 km^{-1}sr^{-1} and 0.015 sr^{-1}
5: P_{1064}	5.5×10^{-5} km^{-1}sr^{-1}	2.0 km^{-1}sr^{-1} and 0.019 sr^{-1}
7: P_{ref}	1.1×10^{-7} km^{-1}sr^{-1}	2.0×10^{-5} km^{-1}sr^{-1}



SYSTEM GEOMETRY AND ORBIT SELECTION

Sun-syncronous polar orbit

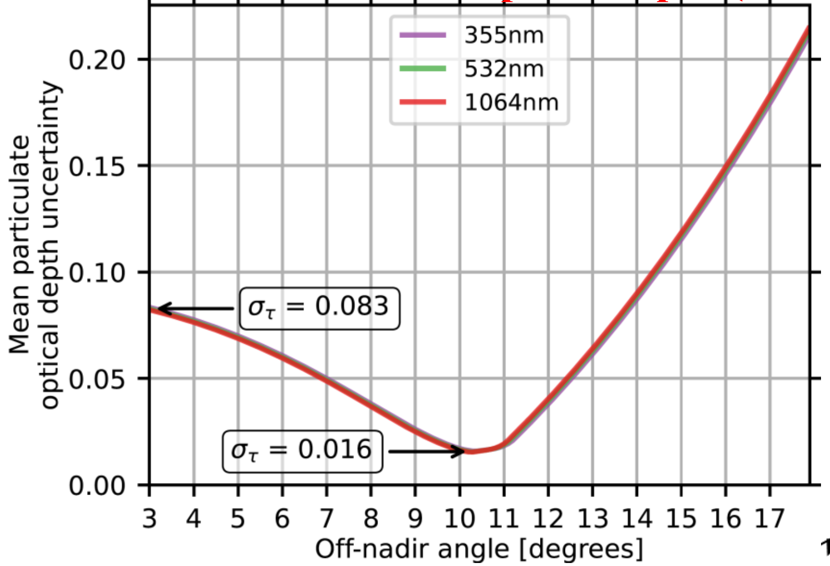
Orbit height: 450 km

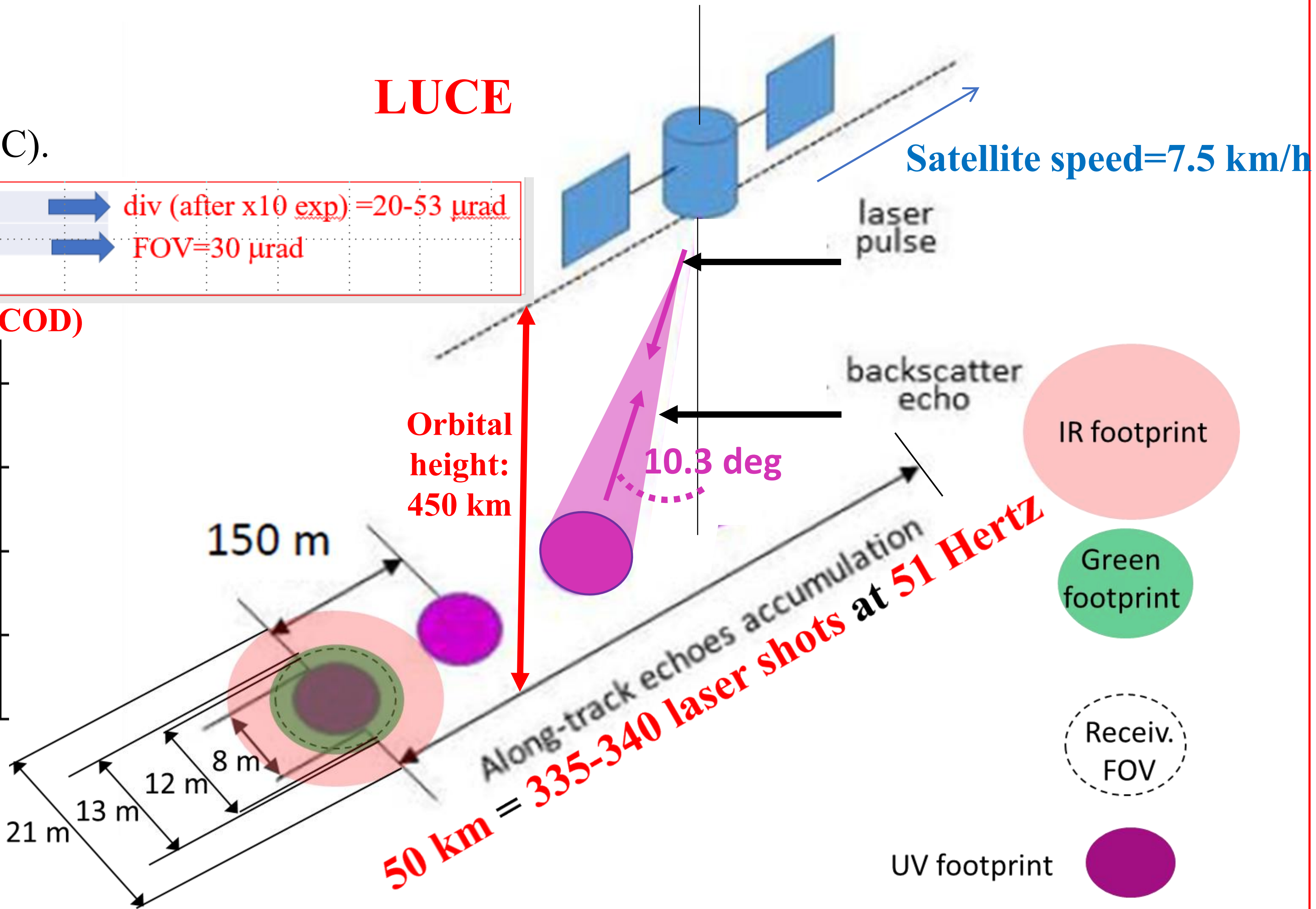
Continous observations with duty cycle close to 90%.

450 ± 20 km (TBC)
Ascending mode preference (TDC).
Crossing time:13:30 hrs +/- 15min (TBC).

Output beam divergence	0.2-0.53 mrad full angle	→ div (after x10 exp) =20-53 µrad
Pointing jitter	< 0.02 mrad	→ FOV=30 µrad
Beam expander x 10		

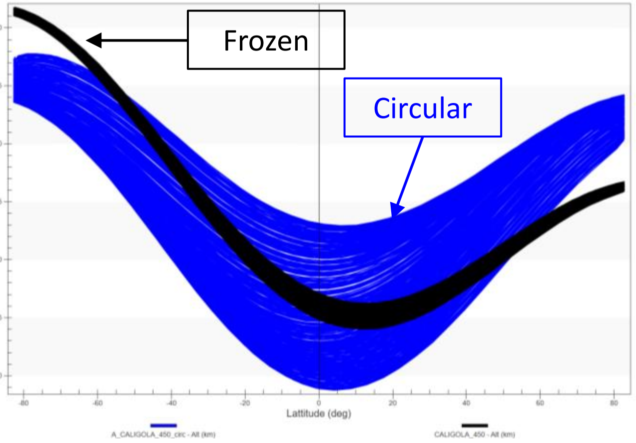
Ocean surface derived optical depth (ODCOD)

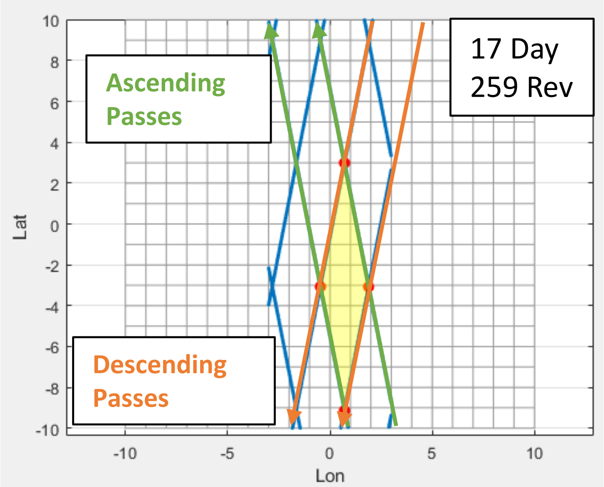


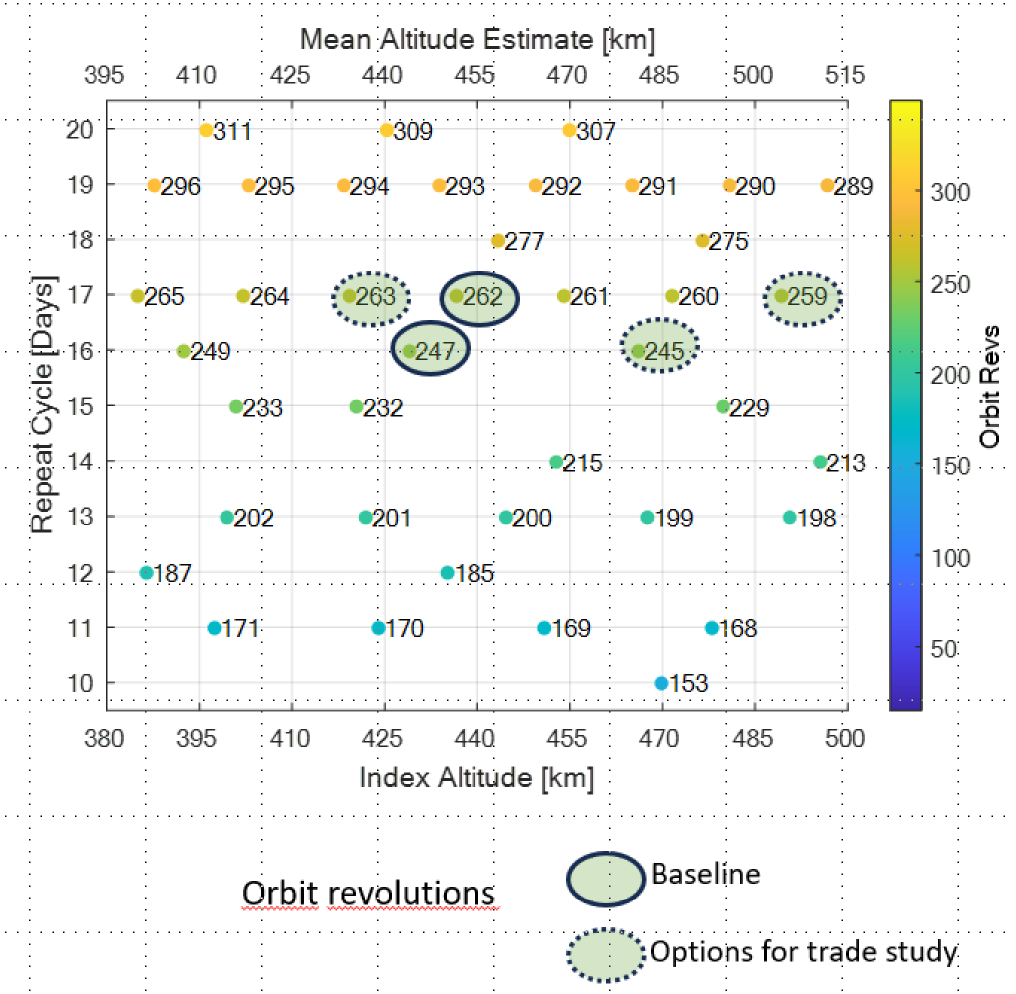


Orbit Selection

- **Frozen orbit, instead of circular,** with a **repeat ground track** because this translates into **less variation in orbit altitude** (more consistent SNR).







- **Repeat cycle ≥ 14 days**
  all 1-degree grid box contain at least 1 observation

- **No repeat cycle** in phase the **lunar cycle (**14-15 day) as this might have unintended sampling consequences
- **Suggested repeat cycle of 16 or 17 days**

Atmospheric simulation results

Two simulators were developed, one by NASA and one by UNIBAS-ISMAR to assess the performance of LUCE

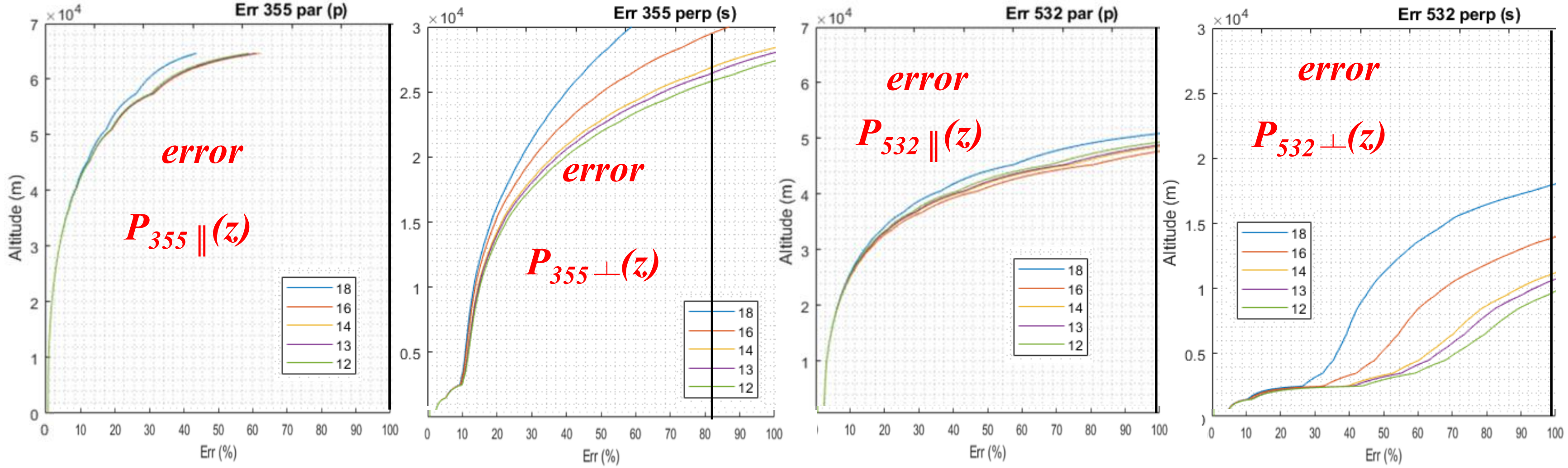
Solar background contribution has been properly accounted for

Atmospheric comp. & thermodyn. properties: US Standard model

Aerosol model: ARMA

FOV = 30µrad

Low-Earth sun-synchronous orbit with equatorial overpasses at different local times (00:00-12:00, 01:00- 13:00, 02:00- 14:00, 04:00- 16:00, 06:00- 18:00)



Statistical Uncertainty affecting

$P_{355\parallel}(z)$ < 5 % up to 30 km

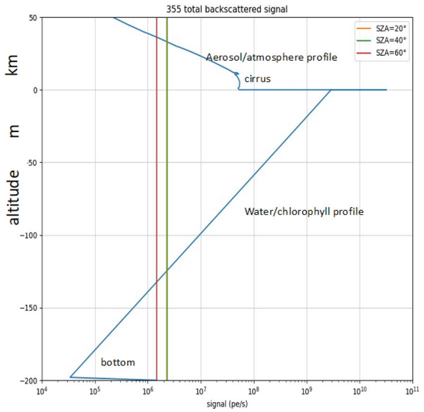
$P_{355\perp}(z)$ < 40 % up to 20 km

$P_{532\parallel}(z)$ < 15 % up to 30 km

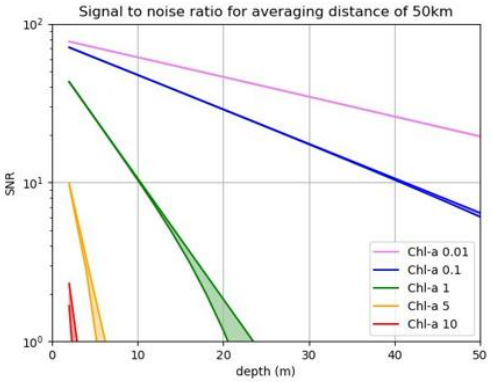
$P_{532\perp}(z)$ < 80 % up to 10 km

A sampling with a horizontal resolution of 50 km (corresponding to a signal averaging over 335 single-shot echoes at 50 Hertz, considering a satellite speed of 7.5 km/h) and a vertical resolution of 200 m (dwell time = 1.33 usec) was considered.

First results of simulated oceanic lidar signals



Column integrated chlorophyll fluorescence SNR for 50 km of horizontal averaging



EarthCARE Science and Validation Workshop 2025

The **Italian Space Agency** (ASI), in partnership with **NASA,** is developing a **space lidar system** based on the **Raman-elastic-fluorescence techniques** for **Earth observation**, with the goal to launch the mission in the **time window 2034-2035**, with an expected lifetime of **3-5 years**.

A **Phase A study**, commissioned by the **Italian Space Agency** to **Leonardo S.p.A.** and focusing of the **technological feasibility** of the **lidar payload**, was carried out starting in **October 2022** and was **bridged** in March 2025 into a **Phase A/B1 study**.

Phase A/B1 activities for the **platform** and the **end-to-end system**, commissioned by the **Italian Space Agency** to **Thales Alenia Space**, were also started in **March 2025**.

In **December 2024 NASA LaRC** started a **Phase A/formulation study** finalized to the preparation for a **System Requirements Review** for the **development** of the **detection system** and **sampling chain** and the implementation **of data downlink capabilities**, with a commitment in the mission guarantted until **September 2026**.

The **Italian Space Agency** is also supporting the **Italian Science community** involved in the LUCE mission through the funding a **dedicated Science project** with the main goal of consolidating/reinforcing the Italian science community supporting the mission, with the involvement of scientists from a variety of scientific international institutions.