

LUCE: a pioneering elastic-Raman-fluorescence LIDAR

P. Ferrara (1), C. Trigila (1), V. Sacchieri (1), A. Perna (1), G. Landi (1)(2), L. Gentili (1), E. Capuano (1), G.D. Pekala (1), B. Ardini (1)(3), M. Burrelli (1), P. Mosciarello (1), A. Dattoli (1), L. Zerilli (1), A. Cosentino (1),
P. Di Girolamo (4), D. Dionisi (5), R. Santoleri (5), L. Mona (6),
C. A. Hostetler (7), T. J. Thorsen (7), S. Scola (7), K. Daugherty (7),
M. Rinaldi (8), R. Votta (8), F. Tataranni (8), M. Picchiani (8), G. Viavattene (8),
A. Di Ruscio (9), M. Grottadaurea (9), F. Zagami (9).

(1) Leonardo S.p.A, Italy

(2) International PhD Programme, UNESCO Chair “Environment, Resources and Sustainable Development”, Università degli Studi di Napoli “Parthenope”, Napoli, NA, 80143, Italy

(3) Alten Italia, Italy

(4) School of Engineering, University of Basilicata, Italy

(5) Institute of Marine Sciences, Italian National Research Council, Italy

(6) Institute of Methodologies for Environmental Analysis, Italian National Research Council, Italy

(7) NASA Langley Research Center, USA

(8) Italian Space Agency, Italy

(9) TAS-I, Thales Alenia space, Italy

ABSTRACT

LUCE, developed through a co-participation between Agenzia Spaziale Italiana (ASI) and National Aeronautics and Space Administration (NASA), is an advanced multi-disciplinary space mission for Earth Sciences. Leonardo's Space Division (LDO) serves as the prime contractor for the mission's instrument, a pioneering elastic-Raman-fluorescence LIDAR, for the first time in a spaceborne mission.

Exploiting the three emitted wavelengths (ultraviolet, visible, and near-infrared) of an high-energy Nd:YAG laser and a demanding 8-channel receiver, LUCE provides unique information content for the retrieval of atmosphere, ocean, terrestrial and cryosphere geophysical variables. The elastic and depolarized vertical profiles of the backscattered echoes from atmosphere, land, sea surface and its underlying layers, as well as the particle extinction coefficient from aerosols and clouds, will be the primary objectives of the mission. In addition, the measurement of water roto-vibrational Raman signals and the fluorescent scattering measurements will be acquired. The mission has the purpose to provide the international scientific community with an unprecedented dataset of geophysical parameters capable to increase scientific knowledge in the areas of atmospheric, aquatic, terrestrial, cryospheric and hydrological sciences. The mission is planned to be launched at the end of 2034, with an expected lifetime of 3-5 years.

This conference contribution aims at providing an overview of the Instrument objectives and architecture. The Instrument will be able to benefit of the world-class Italian industry expertise in the development of space-qualified power laser sources for Earth Explorer mission LIDARs together with the large technical and scientific knowledge of the national optical industry with their solid experience in the development of sensors, spectrometers, radiometers, imagers and optical devices for space applications. This expertise has been complemented with the deep NASA heritage on detector sensors and relevant electronics.

The industrial team, Leonardo responsible for the design and development of the instrument and TAS-I for the mission and the platform, is currently hired in the phase A/B1 study, while scientific studies are carried by NASA and ASI through a number of Italian research institutions, led by the University of Basilicata.

Keywords: LIDAR, atmosphere, ocean, land, cryosphere, Raman, fluorescence, LASER.

1. INTRODUCTION

LUCE (formerly CALIGOLA) is a next-generation multidisciplinary spaceborne lidar mission developed through a partnership between the Italian Space Agency (ASI) and NASA. The mission is designed to observe the coupled atmosphere-ocean-land system and will be the first spaceborne lidar to combine elastic, Raman, depolarization, and fluorescence measurements within a single instrument.

The mission aims to provide unprecedented global observations of atmospheric aerosols and clouds, ocean ecosystems, terrestrial vegetation, and cryospheric processes. By exploiting laser emissions at 355, 532, and 1064 nm, LUCE will retrieve detailed information on particle backscatter, extinction, depolarization, fluorescence, and other geophysical properties across multiple Earth system compartments.

A key innovation of LUCE is its capability to simultaneously collect eight lidar channels, including polarized elastic returns, Raman signals, water-related Raman measurements, and fluorescence observations at 685 nm. These measurements will enable:

- Characterization and classification of atmospheric aerosols and clouds.
- Monitoring of phytoplankton biomass, productivity, and nutrient stress.
- Assessment of marine biogeochemical processes and the global carbon cycle.
- Observation of vegetation fluorescence and ecosystem health.
- Measurements related to snow, ice, land elevation, and vegetation structure.

The instrument is based on a high-energy Nd:YAG laser transmitter and a 1 meter aperture telescope, providing highly sensitive measurements from the ocean subsurface to the upper atmosphere. The system is designed to sample signals over a very large dynamic range and deliver a comprehensive suite of Level-1, Level-2, and Level-3 data products for scientific research and operational applications.

LUCE data products will support atmospheric and oceanographic studies, climate research, environmental monitoring, and numerical forecasting systems. To enable near-real-time applications, calibrated Level-1B measurements and selected higher-level products are planned to be available within approximately three hours of acquisition.

Overall, LUCE represents a major advancement in spaceborne lidar remote sensing, offering a unique capability to simultaneously investigate atmospheric composition, cloud and aerosol properties, ocean biology, vegetation status, and cryospheric variables. The mission is expected to significantly improve understanding of Earth-system processes and their interactions while providing valuable datasets for climate, environmental, and operational applications.

The LUCE mission builds on Italy's strong heritage in space lidar technologies and optical instrumentation. The Italian space industry has extensive experience in developing space-qualified high-power laser sources, sensors, spectrometers, radiometers, imagers, and other optical systems for Earth observation missions. This expertise is complemented by NASA's long-standing experience in detector technologies and associated electronics. The mission responds to the growing interest in active Earth observation systems, which can provide highly accurate measurements of atmospheric, land, and ocean geophysical properties, including parameters that cannot be adequately observed by passive sensors. LUCE also benefits from a strong scientific foundation, combining the expertise of Italian research institutions in lidar remote sensing with NASA's scientific and technological support. This international collaboration aims to advance the understanding of Earth system processes through innovative spaceborne lidar observations.

The mission is currently undergoing Phase A/B1 studies. The payload feasibility assessment is being conducted by Leonardo S.p.A. under contract from ASI, while platform studies are led by Thales Alenia Space. Scientific support activities are coordinated by the University of Basilicata together with several national research institutions. In parallel, NASA Langley Research Center is contributing to the mission definition and to the development of the receiver detection chain and data transmission capabilities.

2. INSTRUMENT CONCEPT

The LUCE payload is based on a state-of-the-art Nd:YAG laser capable of simultaneously transmitting three wavelengths: 355 nm (UV), 532 nm (Visible), 1064 nm (Near Infrared). The system collects atmospheric, terrestrial, and oceanic returns through eight dedicated receiver channels that measure at different wavelengths elastic backscatter, depolarization coefficient, nitrogen and oxygen rotational Raman scattering, water vapor rotational-vibrational Raman scattering, Fluorescence emissions. This architecture provides a unique measurement capability never previously implemented in a spaceborne lidar mission. One of LUCE's most innovative features is the introduction of Raman and fluorescence lidar measurements from space. Unlike Differential Absorption Lidar (DIAL) techniques, Raman observations allow retrieval of atmospheric properties using a less complex transmitter architecture while still providing valuable information on water vapor and atmospheric composition. Moreover fluorescence observations open new possibilities for characterization of organic aerosols, detection of biological activity in oceans, assessment of vegetation condition and productivity, investigation of cloud-aerosol interactions.

Table 1. LUCE physical measurement channels compared with previous LIDAR instruments.

Measured parameter	CALIPSO (Calip) 2006-2013	AEOLUS (Aladin) 2018-2023	EarthCARE (Atlid) Launch 2024	Luca/ CALIGOLA
$\beta_{355}(z)$		X	X	X
$\beta_{532}(z)$	X			X
$\beta_{1064}(z)$	X			X
$\alpha_{355}(z)$		X	X	X
$\delta_{355}(z)$			X	X
$\delta_{532}(z)$	X			X
$\beta_{FL685}(z)$				X
$\beta_{H2O}(z)$				X

Transmitted wavelengths	Receiver Wavelengths [nm]				
	Parallel elastic backscatter	Perpendicular elastic backscatter	N ₂ +O ₂ rotational Raman backscatter	H ₂ O 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:
A Atmosphere
O Ocean
L Land
C Cryosphere

Figure 1. LUCE physical measurement vs transmitted wavelengths and channel usage.

The mission is planned for a sun-synchronous polar orbit at approximately 450-480 km altitude, providing global coverage with a repeat cycle of about 16 days. Its observation geometry is optimized to maximize measurement accuracy over both land and ocean surfaces. A representation of the transmitted and acquired geometry is visible on the following figure.

Considering an emission repetition rate of about 50 Hz, the total amount of scientific data acquired by the eight measurement channels is in the order of 3.7 Tbit for day thanks to a sophisticated sampling rate optimization strategy.

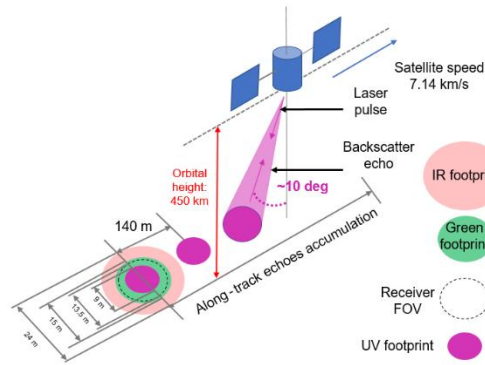


Figure 2. LUCE observational characteristics.

3. INSTRUMENT ARCHITECTURE OVERVIEW

The LUCE instrument is designed as an integrated payload-platform system that minimizes mass, volume, and interface complexity while ensuring efficient accommodation within the spacecraft. The architecture consists of two main segments: the Laser Optical Head (LOH), mounted on the spacecraft top deck and containing all optical subsystems, and a distributed Electrical Assembly located within the spacecraft platform. The baseline configuration was selected following trade-off analyses against major spaceborne lidar missions.

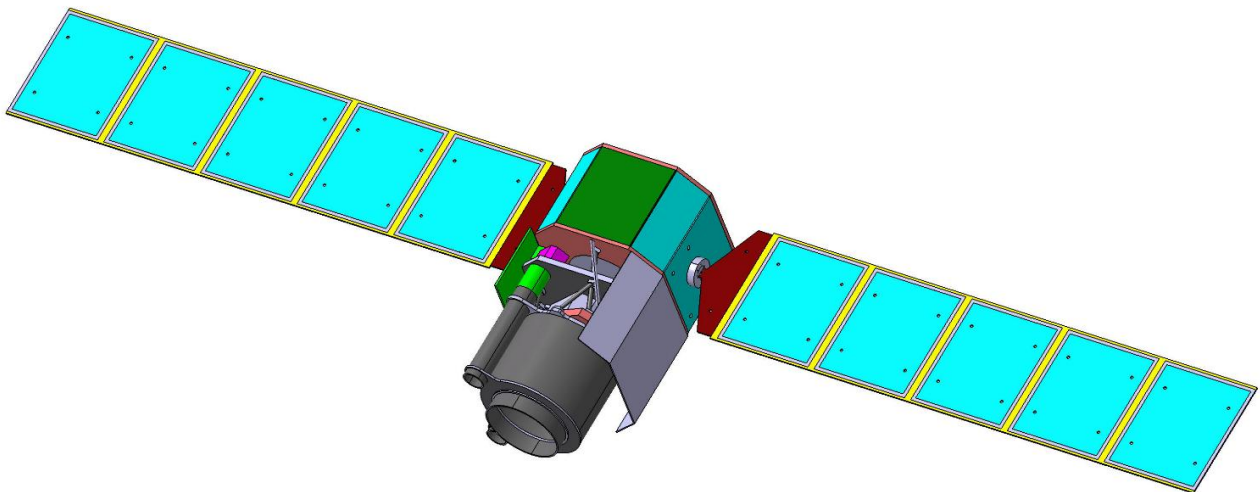


Figure 3. LUCE Instrument and radiators preliminary accommodation on platform.

3.1 Optical Head Configuration

LUCE adopts a bi-static lidar architecture, with physically separated transmitter and receiver optical paths. Although less compact than a monostatic solution, this configuration offers improved reliability, maintainability, and true transmitter redundancy while reducing critical single-point failures. The LOH is mounted through an isostatic bipod system that isolates it from platform distortions and preserves structural stability. The optical head integrates the Receiver Assembly (RxA) and the Transmitter Assembly (TxA) on a common optical bench, enabling independent subsystem optimization while maintaining precise optical co-registration.

The RxA is based on a 1 m-class telescope developed with a full silicon carbide (SiC) architecture to meet the demanding signal-to-noise requirements of aerosol, cloud, Raman, water-vapour and fluorescence measurements.

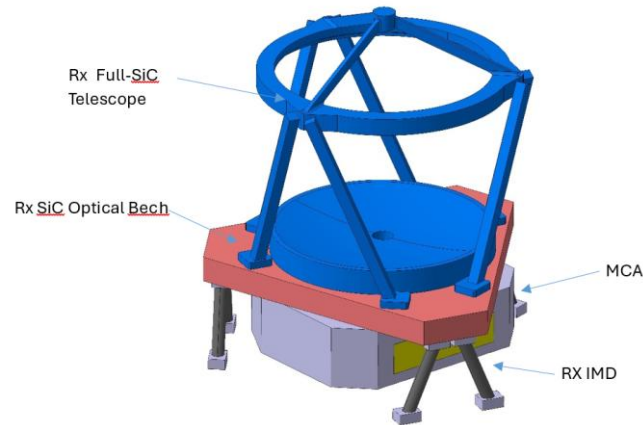


Figure 4. LUCE RxA layout.

SiC was selected for its low mass, high stiffness, excellent thermal conductivity, thermo-elastic stability, and proven space heritage. Compared with conventional Zerodur/CFRP solutions, the full-SiC design significantly reduces mass while improving thermal-mechanical uniformity and stability. The receiver assembly includes a SiC primary mirror, a SiC secondary mirror with a lightweight metering structure, a SiC optical bench, and the Multichannel Assembly (MCA).

The multichannel receiver simultaneously detects elastic, Raman, polarization-sensitive, water-vapour and fluorescence lidar returns through eight dedicated channels. Precise spectral separation is achieved using cascaded dichroic beam splitters, narrow-band optical filters, and polarization splitters. Photomultiplier tubes (PMTs) are used for the UV and visible channels, while the infrared channel employs an avalanche photodiode (APD).

The detector architecture developed by NASA Langley Research Center has been designed to satisfy stringent mission requirements. The system emphasizes high technology maturity, large dynamic range, high radiometric accuracy, high measurement precision, simplified and common architecture across channels. The System includes the detectors (PMTs and APD), and the related electronics necessary for signal processing and power supply.

On the other hand, the transmitter generates high-energy laser pulses at UV, visible, and infrared wavelengths and comprises four main units: the Power Laser Head (PLH), Emission Beam Expanders (EBEX), Beam Steering Mechanisms (BSM), and Transmitter Laser Electronics (TLE). To reduce mass concentration and thermal loads within the optical head, the driving electronics are accommodated separately inside the spacecraft platform. One of the principal design challenges is the simultaneous management and alignment of three high-power laser beams along the same optical path while maintaining stability and efficiency throughout the mission lifetime.

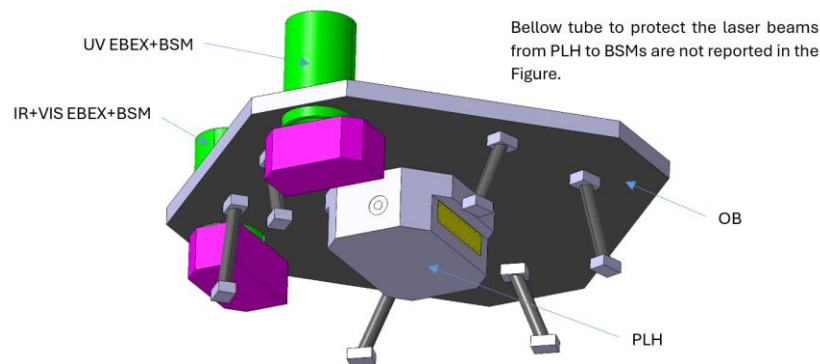


Figure 5. Transmitter Assembly Layout.

Thermal stability is a key design driver for LUCE. The thermal control concept relies on dedicated spacecraft-mounted radiators connected to the payload through controlled thermal interfaces. Because of the high power dissipation of the laser subsystem, Loop Heat Pipes (LHPs) are used for the Power Laser Head, while conventional heat pipes are adopted for lower-power electronics. Separate radiators are allocated to transmitter and receiver sections. The receiver and MCA are thermally isolated from the platform through titanium bipod interfaces, minimizing conductive heat transfer and preserving optical alignment and radiometric stability.

The mechanical design follows a stiffness-driven approach aimed at ensuring launch survivability and maintaining optical co-alignment throughout the mission. The architecture employs isostatic bipod interfaces, lightweight high-stiffness structures, material homogeneity within the telescope assembly, and thermal decoupling between optical and electronic subsystems. Preliminary analyses indicate compliance with typical launcher dynamic requirements.

3.2 Baseline Configuration

The selected LUCE architecture combines a bi-static lidar concept, a full-SiC receiving telescope, a multichannel receiver, isostatic mechanical interfaces, and a Loop Heat Pipe-based thermal control system. This configuration provides the best balance between scientific performance, mass efficiency, thermo-elastic stability, manufacturability, and mission reliability while leveraging the heritage of previous European and international spaceborne lidar missions.



Figure 6. LUCE Optical Head current configuration mounted on platform

4. CONCLUSION

LUCE represents a major step forward in spaceborne active remote sensing. By combining a three-wavelength laser transmitter, eight-channel receiver architecture, Raman and fluorescence capabilities, and contributions from leading Italian and American institutions, the mission will provide an unprecedented view of the Earth system. Its measurements are expected to significantly advance scientific understanding of atmospheric processes, marine ecosystems, terrestrial vegetation, and cryospheric dynamics, while establishing a new reference standard for future space lidar missions.

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