MISSION REQUIREMENTS DOCUMENT

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This Mission Requirement Document (MRD) is the document which sets the scientific and technological activities required for the design and development of the space Raman lidar system called the CALIGOLA (Cloud and Aerosol Lidar for Global Scale Observations of the Ocean-Land-Atmosphere) Mission. This MRD includes the Level-1 requirements for the mission design which will drive the activities of the CALIGOLA working groups. The MRD provides the description of the scientific objectives of the mission, the identified observables to be measured that address those scientific objectives, and the requirements for these observables.

1. Scientific objectives of the CALIGOLA mission

The CALIGOLA mission will include a dedicated observatory hosting a multi-wavelength elastic-Raman-fluorescence backscatter lidar for atmospheric-ocean-terrestrial measurements. CALIGOLA will improve understanding of the processes that influence climate, weather, and air quality by vertically profiling microphysical and optical properties of clouds and aerosols. The mission also aims to study phytoplankton biomass and zooplankton dynamics and to provide observations of surface vegetation, ice, and snow.

The mission may also include coordinated measurements with the planned elements of NASA's Atmosphere Observing System (AOS) mission. A possible formation flight of these missions is under consideration, at least for a portion of the mission lifetimes. The AOS elements are expected to include a combination of; a doppler radar, a microwave radiometer, a multi-angle polarimeter, and an imaging radiometer. While the mission concept for coordinated measurements will maximize the scientific outcome and impact of the measurements as a result of sensors' synergy, nevertheless even in case of a CALIGOLA-only mission (no-formation flight) all of the objectives below will still be achieved.

1.1 Atmospheric objectives

1.1.1 Aerosol science objectives

1.1.1.1. Provide continuity and improve observations of the vertical distribution of aerosol optical and geometrical properties.
1.1.1.2. Determine the microphysical and dimensional properties of aerosols and particle typing.
1.1.1.3. Improve the characterization of the global-scale distribution and intensity of natural and anthropogenic aerosol sources and sinks.
1.1.1.4. Improve understanding and quantitative characterization of aerosol direct and indirect impacts on the global energy budget and Earth's climate with the aim to reduce an uncertainty of aerosol direct radiative forcing by a factor of 2.
1.1.1.5. Improve an understanding of aerosol-cloud-radiation interactions and their representation in climate and weather models.
1.1.1.6. Improve the representation of aerosol long-wave scattering in regional and global climate models.
1.1.1.7. Refine aerosol radiation closure.
1.1.1.8. Improve the characterization of biological particles from biomass fuels, sulfates, and dust.
1.1.1.9. Improve the characterization of aerosol particle hygroscopic-hydrophobic properties.
1.1.1.10. Improve the characterization of Saharan dust outbreaks and understanding of their role in enhancing or inhibiting cloud formation and precipitation.
1.1.1.11. Improve observations of tropospheric aerosols from volcanic eruptions and predictions of their interaction with air-traffic.
1.1.1.12. Improve observations of stratospheric aerosols from volcanic eruptions and assessments of their role in altering Earth's radiative budget.
1.1.1.13. Improve the characterization of long-range aerosol transport over the Mediterranean Sea and Atlantic Ocean and understanding of its role on air quality worldwide.
1.1.1.14. Improve the characterization of stratospheric clouds and aerosols and understanding of their role in ozone depletion.
1.1.1.15. Improve profiling capabilities of stratospheric and mesospheric temperature and characterization of gravity wave propagation.

1.1.2 Cloud science objectives

1.1.2.1. Improve the characterization of global-scale cloud vertical/horizontal distributions.
1.1.2.2. Improve the characterization of cloud-precipitation interaction mechanisms.
1.1.2.3. Improve the characterization of low and high cloud radiative feedbacks.
1.1.2.4. Improve understanding of deep convection mechanisms and their role in low/high cloud formation.
1.1.2.5. Improve global scale measurements of cloud liquid water and ice content and the characterization of microphysical processes and phase partitioning mechanisms within cold (mixed phase and ice) clouds.

1.1.3 Aerosol-cloud interaction science objectives

1.1.3.1. Improve the characterization of aerosol-cloud interaction mechanisms.
1.1.3.2. Improve the characterization of particle hygroscopicity and aerosols' role in warm and cold cloud formation and development processes and the formation of hydrometeors.

1.1.3.3. Characterize aerosol transport and redistribution mechanisms in the proximity of clouds.

1.1.3.4. Determine atmospheric radiative heating and cooling profiles through observations of aerosol and cloud optical and microphysical properties.

1.1.4 Continuity/synergy with other space missions and international ground networks

1.1.4.1. Provide continuity to CALIOP/ATLID/ALADIN atmospheric measurements.

1.1.4.2. Provide coincident and co-located measurements of CALIGOLA with instruments on-board AOS spacecraft and exploit the synergetic use of data from the missions based on the possibility of formation flight, with CALIGOLA following or preceding AOS spacecraft by a few tens of seconds.

1.1.4.3. Improve the global-scale observation and characterization of aerosol and cloud optical and microphysical properties based on coincident and co-located measurements of CALIGOLA with international ground-based lidar networks such as:
i) “Aerosol, Clouds and Trace Gases Research Infrastructure” (ACTRIS)
ii) “Global Atmosphere Watch (GAW) Aerosol Lidar Observation Network” (GALION)
iii) “Network for the Detection of Atmospheric Composition Change” (NDACC).

1.2 Oceanic objectives

1.2.1. Provide an unprecedented temporal record of vertically-resolved global ocean particulate backscattering and absorption coefficients to allow quantification of phytoplankton carbon biomass, particulate organic carbon standing stocks, phytoplankton pigment absorption, and other Essential Ocean Variables (EOVs).

1.2.2. Provide unprecedented vertically-resolved observations in polar regions of plankton cycles throughout all seasons (including polar night) to improve understand environmental and ecological drivers of these cycles in these climate-sensitive regions.

1.2.3. Provide unprecedented global day and night vertically-resolved observations of ocean animal diel vertical migrations (DMV) during all lunar phases to improve understanding of environmental queues governing DVM behaviours and quantify DVM contributions to midterm ocean carbon sequestration.

1.2.4. Quantify DVM stocks within the upper 20 meters of the ocean surface to provide CALIOP continuity and assessment of long-term DVM trends and implications for fisheries stocks and improve fisheries modelling.

1.2.5. Measure depth-resolved phytoplankton carbon and pigment stocks and integrate these data with coincident surface layer ocean colour data to improve quantification of photic zone phytoplankton biomass and net primary production and enable 4-dimensional reconstruction of these properties across the global ocean.

1.2.6. Provide unprecedented depth-resolved measurements of spectral particulate backscatter and pigment absorption to improve characterization of phytoplankton and particle community composition and size structure.

1.2.7. Provide unprecedented active measurements of chlorophyll fluorescence during day and night to advance understanding of phytoplankton physiology (i.e., ‘health’), improve estimates of net primary production and carbon cycling, and characterize growth-limiting nutrients, thereby linking ocean ecosystems and atmospheric aerosol depositions.

1.2.8. Improve the characterization of phytoplankton seasonal to inter-annual changes to improve understanding of environmental and ecological drivers of these changes and better resolve plankton predator-prey dynamics.

1.2.9. Quantify ocean ecosystem properties in regions and during time periods when persistent cloud cover compromises routine coverage with passive ocean colour sensors.
1.2.10. Provide global, independent assessments of ocean particulate backscatter and absorption within the detection depth of passive ocean color measurements (e.g., PACE) to enable comparison between products, identify biases in ocean colour products, and improve ocean color inversion algorithms.
1.2.11. Provide vertically-resolved measurements of atmospheric aerosols to improve atmospheric correction approaches applied to passive ocean color mission data.
1.2.12. Characterize dissolved organic matter stocks, consequently allowing improved retrieval accuracy of ocean color geophysical products.
1.2.13. Provide vertical profiles of optical properties (spectral backscattering coefficients and absorption coefficients) for model data assimilation.
1.2.14. Contribute to the improvement of the Copernicus Marine Service products.
1.2.15. Improve the characterization of coastal bathymetry and assessments of water quality.

1.3. Synergy with other space missions and international ground networks

1.3.1. Complement ocean color multi-spectral and hyperspectral missions by providing independent retrievals of shared geophysical properties of the upper ocean, with an important advantage of CALIGOLA ocean retrievals being their general immunity to the significant atmospheric correction uncertainties associated with ocean color retrievals.
1.3.2. Provide coincident and co-located measurements from CALIGOLA and those instruments on-board the Sentinel-ocean color missions and PACE.
1.3.3. Improve global characterization of key geophysical Earth system properties by providing CALIGOLA measurements coincident and co-located with international ground-in situ networks such as:
- “Aeronet-OC”
- ARGO Program and in particular its biogeochemical component
- Global Ocean Observing System (GOOS).

1.4 Air-sea interaction science objectives

1.4.1. Improve the characterization of the carbon circulation between ocean and atmosphere.
1.4.2. Improve the characterization of the marine ecosystems impacts on atmospheric aerosol particle load and properties.
1.4.3. Improve the characterization of ocean-biogeochemical aerosol effects on marine cloud radiative properties, lifetime and precipitation.
1.4.4. Improve understanding of ocean ecosystem responses to atmospheric aerosol depositions.

1.5 Terrestrial and cryosphere objectives

1.5.1. Provide accurate, pulse-to-pulse measurements of variability in terrestrial and snow/ice surface elevations at approximately 1 meter resolution to characterize variations in ice and snow levels, terrain elevation, vegetation and forest canopy structure and elevation.
1.5.2. Perform accurate measurements of snow depth and snow water equivalent measurements.
1.5.3. Provide global day and night measurements of chlorophyll fluorescence and ferulic acid compounds to characterize terrestrial plant stress (e.g., light, nutrient, water) to

quantify terrestrial gross primary production and improve understanding and modelling of biotic factors influencing Earths water cycle

A1 L0 Measurement Requirements

The performance requirements below have been defined assuming atmospheric clear-sky conditions, standard thermodynamic and compositional conditions (US Standard Atmosphere, 1976), and standard aerosol optical properties in compliance with the ESA Aerosol Reference Model of the Atmosphere (ARMA, Vaughan et al., 1998). For the ocean simulations we considered case 1 oligotrophic clear water conditions (Morel et al. 2001, Mason et al. 2016, Voss 1992, McClain, 2009). The requirements in this document, if not otherwise specified, shall be interpreted as End Of Life (EOL) and Worst-Case (WC) specifications.

NOTE: The final mission is expected to be comprised of no more than 8 channels (versus the 12 channels listed in this document) with 8 resulting measurements. The selection of the specific channels is TBD.

A1.1 L0 Data Observational Requirements

Measurements of the below listed Products 1-12 must be carried out simultaneously, i.e., for each laser shot when the targeted measurements are possible.

CLG-MRD-1 Product 1

The mission shall measure the co-polarized elastic backscatter signals at 354.7 nm, $P_{355\parallel}(z)$, from the atmosphere, land, and snow-ice surface and ocean subsurface layers.

CLG-MRD-2 Product 2

The mission shall measure the cross-polarized elastic backscatter signals at 354.7 nm, $P_{355}{}^{\perp}(z)$, from the atmosphere, land, and snow-ice surface and ocean subsurface layers.

CLG-MRD-3 Product 3

The mission shall measure the co-polarized elastic backscatter signals at 532 nm, $P_{532\parallel}(z)$, from the atmosphere, land, and snow-ice surface and ocean subsurface layers.

CLG-MRD-4 Product 4

The mission shall measure the cross-polarized elastic backscatter signals at 532 nm, $P_{532}{}^{\perp}(z)$, from the atmosphere, land, and snow-ice surface and ocean subsurface layers.

CLG-MRD-5 Product 5

The mission shall measure the co-polarized elastic backscatter signals at 1064 nm, $P_{1064\parallel}(z)$, from the atmosphere, land, and snow-ice surface and ocean subsurface layers.

CLG-MRD-6 Product 6

The mission shall measure the cross-polarized elastic backscatter signals at 1064 nm, $P_{1064}{}^{\perp}(z)$, from the atmosphere, land, and snow-ice surface and ocean subsurface layers.

CLG-MRD-7 Product 7

The mission shall measure the water (water vapor, liquid water, snow/ice) roto-vibrational Raman signals (at 405 nm TBC, but using a spectral selection device with a large enough spectral width to also include echoes at 407.5 nm from water vapor), $P_{H2O}(z)$, from the atmosphere, ocean, land, and snow-ice surface and the underlying layers (stimulated at 354.7 nm).

CLG-MRD-8 Product 8

The mission shall measure the total fluorescence backscattered signals at 450 nm, $P_{FL,\ 450}(z)$, from the atmosphere, terrestrial vegetation and ocean surface and the underlying layers (stimulated at 354.7 nm).

CLG-MRD-9 Product 9

The mission shall measure the pure rotational Raman backscatter signals, in the Stokes (at 355.7 nm) branch, $P_{ref,S}(z)$, from atmospheric N_2 and O_2 molecules (stimulated at 354.7 nm) and the possible additional detection of water low-frequency vibrational Raman signals from the ocean and snow-ice surface.

CLG-MRD-10 Product 10

The mission shall measure the pure rotational Raman backscatter signals, in the Anti-Stokes branch (at 353.95 nm), $P_{ref,AS}(z)$, from atmospheric N_2 and O_2 molecules (stimulated at 354.7 nm) and the possible additional detection of water low-frequency vibrational Raman signals from the ocean and snow-ice surface.

CLG-MRD-11 Product 11

TO REACH THE BASELINE CONFIGURATION: The mission measures the total fluorescence backscattered signals at 685 nm, $P_{FL,\ 685}(z)$, from the atmosphere, terrestrial vegetation, and the ocean (stimulated at 532 nm).

CLG-MRD-12 Product 12

TO REACH THE BASELINE CONFIGURATION: The mission shall measure the water (water vapor, liquid water, snow/ice) roto-vibrational Raman signals, with center wavelength and bandwidth TBD in the spectral interval 630-680 nm, $P_{H2O,532}(z)$, from the atmosphere, ocean, land, and snow-ice surface (stimulated at 532 nm).

A1.2 L0 DATA Resolution and vertical extent Requirements

CLG-MRD-13 Horizontal resolution for the measurements of the products 1-12

The mission shall acquire measurements of the products 1-12 with a horizontal resolution of 150 m.

CLG-MRD-14 Vertical extent for the measurements of the products 1-12

The mission shall acquire measurements of over the vertical extents given in the table below. All vertical extents are TBC. The altitude boundaries are specified in the following table are approximate and are subject to adjustment such that (1) they fall precisely at range bin boundaries determined by ultimate vertical range binning scheme and (2) the altitude boundaries and vertical range binning scheme are consistent across all channels. Additionally, when vertical range binning schemes differ across channels in an altitude regime, the altitude boundaries shall be adjusted such that the vertical resolutions will evenly divide into one another, ensuring that one could average the finest resolution to the coarsest resolution.

Product	Lower Altitude Limit	Upper Altitude Limit
1: $P_{355\parallel}$	-0.5 km	90km
2: $P_{355\perp}$	-0.5 km	90 km
3: $P_{532\parallel}$	-0.5 km	45 km
4: $P_{532\perp}$	-0.5 km	45 km
5: $P_{1064\parallel}$	-0.5 km	32 km
6: $P_{1064\perp}$	-0.5 km	32 km
7: P_{H2O}	-0.5 km	20 km
8: $P_{FL,\ 450}$	-0.5 km	5 km
9: $P_{ref,S}$	-0.5 km	32 km
10: $P_{ref,AS}$	-0.5 km	32 km
11: $P_{FL,\ 685}$	-0.5 km	5 km
12: $P_{H2O,532}$	-0.3 km	0.09 km

CLG-MRD-15 Vertical resolution for the measurements of the products 1-12

The mission shall downlink measurements at the vertical reporting resolutions given in the table below. All resolutions are TBC.

Altitude range [km]		Vertical resolution (in air) [meters]						
Lower	**Upper**	**Product 1 and 2**	**Product 3 and 4**	**Product 5 and 6**	**Product 9 and 10**	**Product 7**	**Product 12**	**Product 8 and 11**
-0.5	-0.3	30	30	30	60	60		60
-0.3	-0.09	1.25	1.25	30	30	1.25	1.25	1.25
-0.09	0.09	1.25	1.25	30	1.25	1.25	1.25	1.25
0.09	3	3.75	30	30	60	3.75		60
3	20	30	30	30	60	60		60*
20	32	30	30	30	60			
32	45	90	90					
45	90	300						

*Only up to 5 km altitude

A1.3 L0 DATA Performance Requirements

CLG-MRD-16 Dynamic Range

Requirements on the dynamic range of each Product measurement are provided in the following table. The upper end of the dynamic range includes daytime solar background signal in addition to the target atmosphere, ocean, or cryosphere maximum backscatter signal. All values are TBC or TBD.

Product	Minimum	Min Basis	Maximum	Max Basis
1: $P_{355\parallel}$	2.1×10^{-8} km^{-1}sr^{-1}	$\beta_{m\parallel}$(90 km)	2 km^{-1}sr^{-1} or 0.15 sr^{-1}	Strong cloud or 2x margin on snow surface reflection
2: $P_{355\perp}$	2.1×10^{-8} km^{-1}sr^{-1}	$\beta_{m\parallel}$(90 km)	2 km^{-1}sr^{-1} or 0.15 sr^{-1}	Strong cloud or 2x margin on snow surface reflection
3: $P_{532\parallel}$	2.4×10^{-6} km^{-1}sr^{-1}	$\beta_{m\parallel}$(45 km)	5 km^{-1}sr^{-1} or 0.05 sr^{-1}	Strong cloud or 2x margin on ocean surface reflection
4: $P_{532\perp}$	2.4×10^{-6} km^{-1}sr^{-1}	$\beta_{m\parallel}$(45km)	5 km^{-1}sr^{-1} or 0.05 sr^{-1}	Strong cloud or 2x margin on ocean surface reflection
5: $P_{1064\parallel}$	5×10^{-6} km^{-1}sr^{-1}	$\beta_{m\parallel}$(22 km)	2 km^{-1}sr^{-1} or 0.04 sr^{-1}	Strong cloud or 2x margin on ocean surface reflection
6: $P_{1064\perp}$	5×10^{-6} km^{-1}sr^{-1}	$\beta_{m\parallel}$(22 km)	2 km^{-1}sr^{-1} or 0.04 sr^{-1}	Strong cloud or 2x margin on ocean surface reflection
7: P_{H2O}	5×10^{-8} km^{-1}sr^{-1}	$\beta_{H2O\parallel}$(2 km)	TBD	Day Background
8: $P_{FL,\ 450}$	TBD	TBD	TBD	Day Background
9: $P_{ref,S}$	5.1×10^{-7} km^{-1}sr^{-1}	β_{S}(32 km)	TBD	Day Background
10: $P_{ref,AS}$	3.9×10^{-7} km^{-1}sr^{-1}	β_{AS}(32 km)	TBD	Day Background
11: $P_{FL,\ 685}$	4.5×10^{-8} sr^{-1}	0.1 x signal from Chl=0.01mg/m^{-3}	TBD	Day Background
12: $P_{H2O,532}$	TBD	TBD	TBD	Day Background

CLG-MRD-17 Statistical Uncertainty

Requirements on the statistical uncertainty (random uncertainty) of for the measurement products are provided in the following table. All values are TBC.

Product	**Lighting Conditions**	**Target Atmospheric Attenuated Backscatter Coefficient ($km^{-1}sr^{-1}$ unless otherwise noted)**	**Maximum Horizontal Averaging Distance (km)**	**Maximum Vertical Averaging Distance (m)**	**Statistical Uncertainty Requirement (68% confidence level)**
1: $P_{355\parallel}$	Day/Night Albedo = 0.3; SZA = 47-90°	1.2×10^{-4} Molecular backscatter at 30 km	50	200	< 3%
	Day/Night Albedo = 0.3; SZA = 47-90°	2.5×10^{-5} Molecular backscatter at 40 km	50	200	< 7%
	Day/Night Albedo = 0.3; SZA = 47-90°	6.4×10^{-6} Molecular backscatter at 50 km	50	200	< 15%
	Day/Night Albedo = 0.3; SZA = 90°	5.1×10^{-7} Molecular backscatter at 70 km	50	200	< 50%
	Day/Night Albedo = 0.3; SZA = 47°	5.1×10^{-7} Molecular backscatter at 70 km	50	200	< 100%
	Day Albedo = 0.3; SZA = 40°	2.37×10^{-3} Attenuated molecular backscatter at 1 km	50	200	< 1%
	Day Albedo = 1; SZA = 20°	2.0 @ 1 km altitude Strongest cloud backscatter	0.15	5	3.2%
	Day Albedo = 1; SZA = 40°	0.073 sr^{-1} Snow/ice surface reflection	0.15	Column	1.2%
	Day/Night Albedo = 0.06; SZA = 47-90°	Water backscatter at -0.03 km	0.15	5	TBD
	Day/Night Albedo = 0.06; SZA = 47-90°	Water backscatter at -0.08 km	0.15	5	TBD
2: $P_{355\perp}$	Shall satisfy the same statistical uncertainty requirements as the $P_{355\parallel}$ Product when the $P_{355\perp}$ Product receiver channel is illuminated with the same signal and background.				
	Day/Night	2.3×10^{-5}	50	200	< 15%

Product	Lighting Conditions	Target Atmospheric Attenuated Backscatter Coefficient ($km^{-1}sr^{-1}$ unless otherwise noted)	Maximum Horizontal Averaging Distance (km)	Maximum Vertical Averaging Distance (m)	Statistical Uncertainty Requirement (68% confidence level)
	Albedo = 0.3; SZA = 47-90°	Molecular backscatter at 30 km			
3: $P_{532\parallel}$	Day/Night Albedo = 0.3; SZA = 47-90°	$4.9x10^{-6}$ Molecular backscatter at 40 km	50	200	< 40%
	Day/Night Albedo = 0.3; SZA = 90°	$1.3x10^{-6}$ Molecular backscatter at 50 km	50	200	< 60%
	Day/Night Albedo = 0.3; SZA = 47°	$1.3x10^{-6}$ Molecular backscatter at 50 km	50	200	< 100%
	Day Albedo = 0.3; SZA = 47°	1.1×10^{-3} Attenuated molecular backscatter at 1 km	50	200	< 2%
	Day Albedo = 1; SZA = 40°	5 Strongest attenuated cloud backscatter	0.15	5	TBD
	Day Albedo = 0.04; SZA = 40°	0.025 sr^{-1} Ocean surface reflectance	0.15	Column	TBD
	Day/Night Albedo = 0.06; SZA = 47-90°	Water backscatter at -0.03 km	0.15	5	< 60%
	Day/Night Albedo = 0.06; SZA = 47-90°	Water backscatter at -0.05 km	0.15	5	< 80%
4: $P_{532\perp}$	Shall satisfy the same statistical uncertainty requirements as the $P_{532\parallel}$ Product when the $P_{532\perp}$ Product receiver channel is illuminated with the same signal and background.				
5: $P_{1064\parallel}$	Day/Night Albedo = 0.3; SZA = 47-90°	Attenuated molecular backscatter at 20 km	50	200	< 20%
	Day/Night Albedo = 0.3; SZA = 47-90°	Attenuated molecular backscatter at 10 km	50	200	< 10%
	Day Albedo = 0.60; SZA = 40°	10^{-3} Aerosol	50	200	TBD

Product	Lighting Conditions	Target Atmospheric Attenuated Backscatter Coefficient (km^{-1}sr^{-1} unless otherwise noted)	Maximum Horizontal Averaging Distance (km)	Maximum Vertical Averaging Distance (m)	Statistical Uncertainty Requirement (68% confidence level)
	Day Albedo = 1; SZA = 40°	2 Strong cloud	0.15	5	TBD
	Day Albedo = 0.02-0.08; SZA = 40°	0.021 sr^{-1} Ocean surface reflection	0.15	Column	TBD
6: $P_{1064\perp}$	Shall satisfy the same statistical uncertainty requirements as the $P_{1064\parallel}$ Product when the $P_{1064\perp}$ Product receiver channel is illuminated with the same signal and background.				
7: P_{H2O}	Night	TBD Oligotrophic ocean water Raman backscatter	50	200	TBD
	Day Albedo = 0.3; SZA = 47-90°	TBD Oligotrophic ocean water Raman backscatter	50	200	TBD
	Night	Atmospheric water vapor mixing ratio at 1 km	500	200	< 50%
	Night	Atmospheric water vapor mixing ratio at 2 km	500	200	< 60%
	Night	Atmospheric water vapor mixing ratio at 1 km	500	1,000	< 25%
	Night	Atmospheric water vapor concentration of 9.7×10^{22} /m^3	500	1,000	<30%
8: $P_{FL,\ 450}$	Night	4.80×10^{-9} Aerosol fluorescence target value	500	1000	TBD
9: $P_{ref,S}$	Night	Attenuated rotational Raman backscatter from 30 km	50	200	< 40%
	Day Albedo = 0.3; SZA = 47-90°	Attenuated rotational Raman backscatter from 10 km	50	200	< 20%
10: $P_{ref,AS}$	Night	Attenuated rotational Raman backscatter from 30 km	50	200	< 46%
	Day Albedo = 0.3; SZA = 47-90°	Attenuated rotational Raman backscatter from 10 km	50	200	< 25%

Product	Lighting Conditions	Target Atmospheric Attenuated Backscatter Coefficient ($km^{-1}sr^{-1}$ unless otherwise noted)	Maximum Horizontal Averaging Distance (km)	Maximum Vertical Averaging Distance (m)	Statistical Uncertainty Requirement (68% confidence level)
11: $P_{FL, 685}$	Night	Chl = 0.1 mg m^{-3} , Φ = 2%	50	Column	TBD
	Day Albedo = ocean value; SZA = 47°	Chl = 0.1 mg m^{-3} , Φ = 2%	50	Column	TBD
12: $P_{H2O,532}$	Night	TBDOligotrophic ocean water Raman backscatter	50	Column	TBD
	Day Albedo = ocean value; SZA = 47°	TBD Oligotrophic ocean water Raman backscatter	5	Column	TBD

CLG-MRD-18 Systematic uncertainty

The uncorrectable systematic uncertainty affecting the lidar signal measurements from the atmosphere, ocean, land, and snow-ice surface shall not exceed 5 % (TBC) for each of the Product channels.

NOTE: This requirement will be refined in the future such that it is articulated differently for different Products and signal levels. For the elastic backscatter channels, the requirement should be in the 1-2% regime from the lowest end of the dynamic range up through aerosol and weak cloud signals; at the high end of the dynamic range, i.e., associated with the strongest clouds and surface reflections, it may not be practical to achieve such low systematic errors and we should investigate the impact of greater errors, e.g., 5%. Science assessment will be needed for impact of errors on snow/ice retrievals, the ocean surface reflection constraint for over-ocean optical depth and cloud/aerosol retrieval constraints, and retrievals of cloud properties. For the rotational Raman signals, the error tolerance will likely be as low as practical, e.g., 1 to 2%, over the entire dynamic range of those signals. The water Raman and fluorescence channels will require some analysis to determine how much systematic error that can be tolerated and how the requirement should be stated.

A1.4 Calibration Related Requirements

CLG-MRD-19 System Constant Stability

The System Constants for Products 1 through 12, after applying known corrections for, e.g., gain variability, baseline signal offsets variations, daytime background light, polarization cross-talk, and boresight drift, shall vary by no more than ±1.0% (68% confidence level) (TBC) over 24 hours (TBC) during normal Science Operations, exclusive of changes caused by platform pointing jitter and within 3 hours of startup from a non-operational mode. The System Constant, *K*, is defined by the following link equation.

$$P(r) = \frac{E_L K}{r^2} \beta'(r) + P_S(\mathrm{r}) + P_D(r)$$

where:

- P = Signal measured on a Product Channel (units of digitizer counts)
- r = Line-of-sight range of the measurement from the instrument
- E_L = Energy of the laser pulse emitted from the transmitter
- $\beta'(r)$ = Attenuated backscatter coefficient at range r (units of length^{-1} sr^{-1})
- K = System Constant. Together with laser energy and range, the System Constant is the factor scaling attenuated backscatter to digitizer counts. The System Constant incorporates the effects of the telescope area, optical overlap of the transmitter and receiver field of view, optical throughput of the receiver, quantum efficiency and collection efficiency of the detectors, gains of the detectors and downstream electronics, and other factors in the remote sensing link equation. The System Constant will be estimated from on-orbit Product measurements, and that estimate will be used in retrievals of geophysical observables.
- P_S = Solar background signal
- P_D = Sum of dark current, baseline, and offset signals

CLG-MRD-20 Laser Energy Reporting

The laser pulse energies shall be measured and reported in the downlinked data stream with a precision of ±3% (68% confidence level) (TBC) for each laser shot and each wavelength for laser energies above 5% of the nominal maximum operational energy.

NOTE: This concerns random error in the laser energy measurement. The laser energy values are required to calibrate the measured signal to attenuated backscatter units, and random error in the reported energy value is part of the calibration error budget for compositing attenuated backscatter profiles from the measurement. For all but strong cloud and surface reflection measurements, multiple profiles will be averaged to increase SNR for geophysical retrievals from the attenuated backscatter profiles. Assuming the ±3% specification for single-shot random precision amounts to precisions of ±1% at 1-km horizontal averaging and ±0.5% at 5-km horizontal averaging. Specifying that the relative precision is maintained down to only 5% of the nominal energy value is intended to avoid the requirement of high precision on a near-zero measurement, which is deemed to be impractical.

CLG-MRD-21 Laser Energy Monitor Bias Error Magnitude

The relative bias of the reported laser pulse energy measurements shall be less than ±10% (TBC).

NOTE: For use science calibration purposes, absolute accuracy is irrelevant. The relative bias should be set by the engineering team on the basis of monitoring the health and status of the laser.

CLG-MRD-22 Laser Energy Monitor Bias Error Stability

The relative bias of the laser pulse energy measurements shall be constant within ±0.5% (68% confidence level) (TBC) over time scales of 24 (TBC) hours for each wavelength.

NOTE: the reported laser energies must be consistent over time to enable calibration of the signals.

CLG-MRD-23 Laser Energy Monitor Linearity

The reported laser pulse energy measurements shall be linear to within ±0.5% (TBC) over the dynamic range from the maximum nominal pulse energy to 5% of the maximum nominal pulse energy for each wavelength.

NOTE: the reported laser energies may exhibit a relative bias, but the relative bias must be consistent over the dynamic range of the laser energies to enable accurate calibration of the signals.

CLG-MRD-24 Polarization performance

The Products 1-6 shall exhibit <±1% (68% confidence level) (TBC) bias errors due to polarization artifacts including but not limited to the following: polarization impurity of the transmitter, polarization cross-talk introduced anywhere in the instrument, diattenuation of the polarization components in the receiving optics, and other non-ideal polarization performance of the lidar, after all known corrections are made in post processing of lidar signals.

CLG-MRD-25 Polarization Gain Ratio (PGR) Measurement

The Instrument shall include a means of episodically calibrating the ratios of the parallel Product ($P_{xxx\parallel}$) System Constants to the perpendicular Product ($P_{xxx\perp}$) System Constants. The System Constant ratios are referred to as the Polarization Gain Ratios.

NOTE: PGR calibration can be implemented by optically splitting or polarization scrambling of received backscatter by a known and approximately equal amount between the parallel-polarized and perpendicular polarized optical paths of the relevant Product channels, regardless of polarization state of the incident backscatter.

CLG-MRD-26 Polarization Gain Ratio (PGR) Scheduling

PGR operations shall be conducted on a cadence defined by commands issued from the ground.

NOTE: it is anticipated that PGR operations will be required no more frequently than on a monthly basis; however, there may be periods of intensive PGR operations to characterize on-orbit performance.

CLG-MRD-27 Polarization Gain Ratio (PGR) Accuracy

The Polarization Gain Ratio Measurement shall provide Polarization Gain ratios to within ±2% (95% confidence level) (TBC) accuracy under both nighttime and daytime solar lighting conditions.

CLG-MRD-28 Polarization Gain Ratio (PGR) Duration

The Polarization Gain Ratio Measurement shall require no greater than 5 (TBC) minutes interruption of normal science acquisition mode operations under night lighting conditions and TBD minutes under day lighting conditions.

A2 L2 Measurement Requirements

A2.1 L2 Observational Requirements

In what follows with the term “observables” we intend to represent the geophysical variables (GVs) under investigation.

CLG-MRD-29 Atmospheric observable 1

The mission shall perform measurements of vertical profiles of the atmospheric particle (aerosol/clouds) backscattering coefficient at 354.7 nm, $\beta_{355}(z)$.

CLG-MRD-30 Atmospheric observable 2

The mission shall perform measurements of vertical profiles of the atmospheric particle (aerosol/clouds) backscattering coefficient at 532 nm, $\beta_{532}(z)$.

CLG-MRD-31 Atmospheric observable 3

The mission shall perform measurements of vertical profiles of the atmospheric particle (aerosol/clouds) backscattering coefficient at 1064 nm, $\beta_{1064}(z)$.

CLG-MRD-32 Atmospheric observable 4

The mission shall perform measurements of vertical profiles of the atmospheric particle (aerosol/clouds) extinction coefficient at 354.7 nm, $\alpha_{355}(z)$.

CLG-MRD-33 Atmospheric observable 5

The mission shall perform measurements of vertical profiles of the atmospheric particle (aerosol/clouds) depolarization ratio at 354.7 nm, $\delta_{355}(z)$.

CLG-MRD-34 Atmospheric observable 6

The mission shall perform measurements of vertical profiles of the atmospheric particle (aerosol/clouds) depolarization ratio at 532 nm, $\delta_{532}(z)$.

CLG-MRD-35 Atmospheric observable 7

The mission shall perform measurements of vertical profiles of the atmospheric particle (aerosol/clouds) depolarization ratio at 1064 nm, $\delta_{1064}(z)$.

CLG-MRD-36 Atmospheric observable 8

The mission shall perform measurements of vertical profiles of atmospheric (aerosol) fluorescent coefficient at 450 nm, $\beta_{FL\_AER,\ 450}(z)$.

CLG-MRD-37 Atmospheric observable 9

The mission shall perform measurements of vertical profiles of the atmospheric water vapour mixing ratio, $x_{H2O}(z)$.

CLG-MRD-38 Atmospheric observable 10

The mission shall perform measurements of vertical profiles of the atmospheric temperature, $T(z)$ (only in case the acquisition of the pure-rotational Raman backscatter echoes will be performed based on the exploitation of two channels including temperature sensitive rotational lines).

CLG-MRD-39 Atmospheric observable 11

AVAILABLE IF REACHING THE BASELINE CONFIGURATION: The mission shall perform measurements of vertical profiles of the atmospheric (aerosol) fluorescent coefficient at 685 nm, $\beta_{FL\_AER,\ 685}(z)$.

CLG-MRD-40 Oceanic observable 1

The mission shall perform measurements of vertical profiles of oceanic particulate backscattering coefficients at 354.7 nm from particulate matter suspended in water, including marine phytoplankton, $b_{bp\_355}(z)$.

CLG-MRD-41 Oceanic observable 2

The mission shall perform measurements of vertical profiles of oceanic particulate backscattering coefficients at 532 nm from particulate matter suspended in water, including marine phytoplankton, $b_{bp\_532}(z)$.

CLG-MRD-42 Oceanic observable 3

The mission shall perform measurements of vertical profiles of oceanic particulate depolarization ratios at 354.7 nm from particulate matter suspended in water, including marine phytoplankton, $\delta_{355\_OCE}(z)$.

CLG-MRD-43 Oceanic observable 4

The mission shall perform measurements of vertical profiles of oceanic particulate depolarization ratios at 532 nm from particulate matter suspended in water, including marine phytoplankton, $\delta_{532\_OCE}(z)$.

CLG-MRD-44 Oceanic observable 5

The mission shall perform measurements of vertical profiles of oceanic diffuse attenuation coefficients for down-welling irradiance at 354.7 nm from particulate matter suspended in water, including marine phytoplankton, $K_{d\_355}(z)$.

CLG-MRD-45 Oceanic observable 6

The mission shall perform measurements of oceanic dissolved organic matter (DOM) fluorescent coefficient at 450 nm, $\beta_{FL\_CHL,\ 450}(z)$.

CLG-MRD-46 Oceanic observable 7

AVAILABLE IF REACHING THE BASELINE CONFIGURATION: The mission shall perform measurements of vertical profiles of oceanic diffuse attenuation coefficients for down-welling irradiance at 532 nm from particulate matter suspended in water, including marine phytoplankton, $K_{d\_532}(z)$.

CLG-MRD-47 Oceanic observable 8

AVAILABLE IF REACHING THE BASELINE CONFIGURATION: The mission shall perform measurements of phytoplankton chlorophyll fluorescence coefficient at 685 nm, $\beta_{FL\_CHL,\ 685}(z)$, from the upper ocean.

CLG-MRD-48 Cryosphere observable 1

The mission shall perform snow depth and snow water equivalent measurements, *SD, SEW*, at 354.7 and 532 nm.

CLG-MRD-49 Terrestrial observable 1

The mission shall perform measurements of terrestrial plant canopy structure at 354.7, 532 and 1064 nm, TC_{355}, TC_{532} and TC_{1064}, respectively.

CLG-MRD-50 Terrestrial observable 2

AVAILABLE IF REACHING THE BASELINE CONFIGURATION: The mission shall perform measurements of chlorophyll fluorescence coefficients at 685 nm from terrestrial vegetation, $\beta_{FL\_CHL, 685\ surf.\ veg}$.

A2.2 L2 Data Resolution and vertical extent Requirements

CLG-MRD-51 Horizontal resolution for the atmospheric observables 1-12, the oceanic observables 1-8, the terrestrial observables 1 and 2 and the cryosphere observable 1

The mission shall provide measurements of the:

- atmospheric observables 1-12,
- oceanic observables 1-8,
- terrestrial observables 1 and 2, and
- cryosphere observable 1

with a horizontal resolution of 150 m.

CLG-MRD-52 Vertical resolution for the measurements of the atmospheric observables 1 and 5 and the oceanic observables 1 and 3

The mission shall acquire measurements of the atmospheric observables 1 and 5 and the oceanic observables 1 and 3 with an effective vertical resolution of:

- 30 m in the vertical interval -0.5 to -0.25 km,
- 5 m in the vertical interval -0.25 to 3 km,
- 30 m in the vertical interval 3 to 30 km.

CLG-MRD-53 Vertical resolution for the measurements of the atmospheric observables 2 and 6 and the oceanic observables 2 and 4

The mission shall provide measurements of the vertical profiles of atmospheric observables 2 and 6 and the oceanic observables 2 and 4 with an effective vertical resolution of:

- 30 m in the vertical interval -0.5 to -0.25 km,
- 5 m in the vertical interval -0.25 to 0.1 km,
- 30 m in the vertical interval 0.1 to 30 km.

CLG-MRD-54 Vertical resolution for the measurements of the atmospheric observable 3 and 7

The mission shall acquire measurements of the atmospheric observable 3 with an effective vertical resolution of 30 m in the vertical interval 0 to 30 km.

CLG-MRD-55 Vertical resolution for the measurements of the atmospheric observable 4

The mission shall provide measurements of the vertical profiles of atmospheric observable 4 with an effective vertical resolution of:

- 60 m in the vertical interval -0.5 to -0.25 km,
- 30 m in the vertical interval -0.25 to -0.1 km,
- 5 m in the vertical interval -0.1 to 0.1 km,
- 60 m in the vertical interval 0.1 to 30 km.

CLG-MRD-56 Vertical resolution for the measurements of the atmospheric observable 9 and the oceanic observable 6

The mission shall provide measurements of the vertical profiles of atmospheric observable 9 and the oceanic observable 6 with an effective vertical resolution of:

- 60 m in the vertical interval -0.5 to -0.25 km,
- 5 m in the vertical interval -0.25 to 0.1 km,
- 50 m in the vertical interval 0.1 to 5 km.

CLG-MRD-57 Vertical resolution for the measurements of the atmospheric observables 9 and 12, the oceanic observables 6 and 8 and the terrestrial observable 1

The mission shall provide measurements of the vertical profiles of atmospheric observable 9 and 12, the oceanic observable 6 and 8 and the terrestrial observable 1 and the oceanic observable 6 with an effective vertical resolution of:

- 60 m in the vertical interval -0.5 to -0.25 km,
- 5 m in the vertical interval -0.25 to 0.1 km,
- 60 m in the vertical interval 0.1 to 5 km.

CLG-MRD-58 Vertical resolution for the measurements of the atmospheric observable 10

The mission shall acquire measurements of the atmospheric observable 10 with an effective vertical resolution of 3-500 m in the vertical interval 0 to 2 km.

CLG-MRD-59 Vertical resolution for the measurements of the oceanic observables 5 and 7

The mission shall acquire measurements of the atmospheric oceanic observables 5 and 7 with an effective vertical resolution of:

- 60 m in the vertical interval -0.5 to -0.25,
- 5 m in the vertical interval -0.25 to 0 km.

CLG-MRD-60 Vertical resolution for the measurements of the cryospheric observable 1 and the terrestrial observable 2

The mission shall acquire measurements of the cryospheric observable 1 and the terrestrial observable 2 with an effective vertical resolution of 5 m in the vertical interval -0.25 to 0 km.

CLG-MRD-61 Vertical extent for the atmospheric observables 1-12, the oceanic observables 1-8, the terrestrial observables 1 and 2 and the cryosphere observable 1

The mission shall provide measurements of:

- the atmospheric observables 1, 2, 4-7 and the oceanic variables 1-4 over the vertical interval -0.5 to 30 km,
- the atmospheric observables 3 and 7 over the vertical interval 0 to 30 km,
- the atmospheric observables 9 and 12 and the oceanic variables 5-8 over the vertical interval 0 to 5 km,

A2.3 L2 DATA Expected Performance

NOTE: This section indicates the expected statistical and systematic uncertainties of the Level-2 geophysical variables that will be derived from the L0 Measurement Products. These uncertainties assume a particular algorithm for the retrieval of each geophysical variable, and those algorithms are applicable for representative geophysical scenes but not necessarily all geophysical scenes. As such, the table represents a list of expectations, not a list of requirements.

CLG-MRD-0055 Statistical uncertainty (RMS) and Systematic uncertainty (BIAS) affecting the measurements of the atmospheric-oceanic-terrestrial observables (considering a vertical resolution of Δz=200 m and a horizontal resolution of Δh= 50 km in the atmosphere and a vertical resolution of Δz=5 m and a horizontal resolution of Δh= 50 km in the water, unless differently specified)

Geophysical variable	Vertical interval [km]	Portion of orbit	Statistical uncertainty (RMS) [% unless differently specified]	Systematic uncertainty (BIAS) [%]
Atmospheric observable 1, $\beta_{355}(z)$	-0.5 to 30	night/day	< 8	< 5-10
Atmospheric observable 2, $\beta_{532}(z)$	-0.5 to 30	night/day	< 15	< 5-10
Atmospheric observable 3, $\beta_{1064}(z)$	-0.5 to 30	night/day	< 50	< 5-10
Atmospheric observable 4, $\alpha_{355}(z)$	-0.5 to 1	night/day	< 100	< 5-10
Atmospheric observable 5, $\delta_{355}(z)$	-0.5 to 10	night/day	< 30	< 5-10
Atmospheric observable 6, $\delta_{532}(z)$	-0.5 to 10	night/day	< 50	< 5-10
Atmospheric observable 7, $\delta_{1064}(z)$	-0.5 to 10	night/day	< 70	< 5-10
Atmospheric observable 8, $\beta_{FL\ AER,\ 450}(z)$	-0.5 to 5	night	< 100	< 5-10
Atmospheric observable 9, $x_{H2O}(z)$ Δz=500, Δh= 1000 km	-0.5 to 2	night	< 40	< 5-10
Atmospheric observable 10, T(z)	-0.5 to 2	night/day	TBD	< 1 K
Atmospheric observable 11, $\beta_{FL\ AER,\ 685}(z)$	-0.5 to 5	night	< 100	< 5-10
Oceanic observable 1, $b_{bp\_355}(z)$	-0.5 to 0	night/day	TBD	TBD
Oceanic observable 2, $b_{bp\_532}(z)$	-0.5 to 0	night/day	TBD	TBD
Oceanic observable 3, $\delta_{355\_OCE}(z)$	-0.5 to 0	night/day	TBD	TBD
Oceanic observable 4, $\delta_{532\_OCE}(z)$	-0.5 to 0	night/day	TBD	TBD
Oceanic observable 5, $K_{d\_355}(z)$	-0.5 to 0	night/day	TBD	TBD
Oceanic observable 6, $\beta_{FL\ CHL,\ 450}(z)$	-0.5 to 0	night	TBD	TBD
Oceanic observable 7, $K_{d\_532}(z)$	-0.5 to 0	night/day	TBD	TBD
Oceanic observable 8, $\beta_{FL\ CHL,\ 685}(z)$	-0.5 to 0	night	TBD	TBD
Cryosphere observable 1, *SD, SEW*	surface	night/day	TBD	TBD
Terrestrial observable 1, TC_{355}, TC_{532}, TC_{1064}	surface	night/day	TBD	TBD

Terrestrial observable 2 $\beta_{FL\_CHL,\ 685\ surf.\ veg}$	surface	night/day	TBD	TBD

A3. Design Requirements

CLG-MRD-62 Pointing inclination

The CALIGOLA satellite will be tilted along-track with respect to the Nadir of an angle of 12-14 (TBC) degrees to reduce specular reflection from the sea surface and artifacts in subsurface signals caused by the response to that reflection.

CLG-MRD-63 In-flight alignment correction

The mission shall guarantee a system for transmitter-receiver co-alignment to within 1 μrad (TBC)

A4. Mission Requirements

CLG-MRD-64 In-orbit lifetime

The CALIGOLA mission shall be designed for a duration in-orbit of 3 years, extendable to 5, after IOC excluding the decommissioning phase.

CLG-MRD-65 Propellent Requirement

The CALIGOLA mission shall have enough propellant to support an on-orbit lifetime of at least 5 years after completion of the IOC.

CLG-MRD-66 In-orbit commissioning phase

The CALIGOLA mission In Orbit Commissioning (IOC) phase duration shall be ≤ 6 (TBC) months after launch.

CLG-MRD-67 LIDAR Data Latency

The CALIGOLA mission shall make L0 data products available within 4 hours (TBC) from the acquisition.

CLG-MRD-68 Mission orbit

The CALIGOLA mission orbit shall be a sun-synchronous low Earth orbit with an altitude of 450 ± 20 km (TBC).

CLG-MRD-69 Crossing time - Science Node Accuracy

he CALIGOLA satellite shall operate on a SSO with an LTDN at 13:30 +/- 15 min (TBC).

CLG-MRD-70 Alternative Mission orbits

The CALIGOLA System shall be able consider also dawn-dusk SSO low Earth orbit with an altitude between 400Km and 500Km during design phase up to SRR.

CLG-MRD-71 FOV Geolocation

Knowledge of the lidar FOV footprint at Mean Sea Level (MSL) shall be derivable to an accuracy of ±TBD m in the along-track and cross-track directions.

CLG-MRD-72 Pointing Control

The spacecraft pointing shall be controlled to TBD arcsec.

CLG-MRD-73 Pointing Stability

Pointing jitter on time scales of <TBD s shall be < 0.017°/s.

NOTE: jitter in pointing will cause the lidar backscatter to be misaligned from the receiver FOV. Presumably, the instrument will incorporate an active, near-real-time boresighting system that aligns the transmitted laser beam to the FOV of the receiver. That system can account for a steady-state rotation of the spacecraft as it progresses around the orbit, but cannot account for jitter on time scales shorter than the update time of the laser-to-receiver pointing control system. This specification is to put a bound on that shorter time scale jitter such that the System Constant Stability error associated with jitter is within the allocated budget.

CLG-MRD-74 Science Acquisition Duty Cycle

The Mission shall operate in science acquisition mode for at least 90% (TBC) of the available mission life.

CLG-MRD-75 Science Data Availability

The Mission shall acquire, store, downlink, distribute, and archive at least 90% (TBC) of all science and ancillary data that are available for collection by the mission.

CLG-MRD-76 Science Data Availability

The Mission shall be made available L1, L2 and L3 data produced by either ASI or NASA shall to each party within 24 hours of their creation.

CLG-MRD-77 Open Source Science

Public release of L1 and L2 data shall conform to the NASA SPD-41a policy on Open Source Science (September 26, 2022).

NOTE: applicable only to NASA responsibilities for data availability and distribution.

CLG-MRD-78 NSN Communications

The CALIGOLA mission shall use the NASA Near Space Network (NSN).

CLG-MRD-79 Laser Source

The CALIGOLA laser source shall be designed considering spectral and energy characteristics compatible with the observational objectives. Specifically, the solid-state source must be able to simultaneously emit three distinct wavelengths in the IR, VIS and UV.

NOTE: The laser power is maximized for the 355-nm transmission as the backscatter signals excited by it are reference signals for many measurements. The 532- and 1064-nm laser emissions are also transmitted into the Earth's atmosphere to generate backscatter signals, unlike the AFO TXA for which those beams are blocked.

CLG-MRD-80 Spacecraft Autonomous Normal Operations

The CALIGOLA mission shall be able to operate autonomously for at least 5 days, once all the time tagged commands have been uploaded, and without requiring any additional ground commanding.

CLG-MRD-81 Space Segment Reliability

The CALIGOLA Satellite (Platform plus Payload assembly) shall be designed to have a reliability better than 0.75 (TBC) at the end of the nominal lifetime.

CLG-MRD-82 Spacecraft Autonomous Survival Capability

The CALIGOLA Space Segment shall be able to survive autonomously, i.e. without ground commanding, for at least 30 days.

CLG-MRD-83 SPF

The CALIGOLA Space Segment shall be designed such that any credible Single Point Failure (SPF) is avoided.

CLG-MRD-84 Combination Of Two Independent Failures

The CALIGOLA System shall be designed such that no combination of two independent satellite failures or operator errors have catastrophic consequences.

CLG-MRD-85 Ground Segment Availability – End to End

The CALIGOLA System shall operate in compliance with the specifications with an End-to-end availability of the Ground Segment higher than 99.5% per month, to be evaluated during Operating Qualification and in the Operative Phase.

CLG-MRD-86 Software patching

The CALIGOLA System shall support post-launch modifications of all on-board software, including patching of programmed Memory.

CLG-MRD-87 Safe Mode

The CALIGOLA System design shall provide a safe-hold mode providing thermal stability and positive power/energy budget for essential loads and communications.

CLG-MRD-88 Ground Segment Life Extendibility

The CALIGOLA System design shall allow to extend the usable life of the ground segment beyond its design life.

CLG-MRD-89 Disaster risk avoidance

The CALIGOLA Ground Segment shall guarantee the reliability and the disaster risk avoidance for the mission vital data (e.g. data redundancy of the archives in different sites).

CLG-MRD-90 High TRL

The mission should be able to be realized (flight model) capitalizing subsystems already developed for space applications with at least a TRL level greater or equal to 6 (TBC) by mission PDR.

CLG-MRD-91 Launcher compatibility baseline

The CALIGOLA System configuration and design shall be compatible with VEGA-C, as baseline.

CLG-MRD-92 Launcher compatibility backup solution

The CALIGOLA System shall be compatible with multiple launchers (i.e. Falcon 9), agreed with ASI, and considered as a backup launcher solution during design phase up to CDR.

CLG-MRD-93 LIDAR Heat Transfer Accommodation

The CALIGOLA Platform shall accommodate up to [TBD] W of heat transfer from the LIDAR Payload.

CLG-MRD-94 LIDAR Mass Accommodation

The CALIGOLA Platform shall accommodate up to 810Kg (TBC) of mass of LIDAR payload.

CLG-MRD-95 LIDAR Power Supply

The CALIGOLA Platform shall support LIDAR payload with required electrical power not less than 940W average (TBC).

CLG-MRD-96 Cleanroom Requirements

The CALIGOLA System shall employ cleanrooms certified to better than or equal to [Class 7] (TBC) per ISO 14644-1.

CLG-MRD-97 Parameters in Flight

The CALIGOLA System shall allow in-flight changes to flight software parameters via ground command without requiring flight software modification.

CLG-MRD-98 System performance monitoring

The CALIGOLA System shall measure continuously the overall system performances including, at least:

- Discovered Non-Compliances / Software Problem Reports statistics.
- System Maintenance statistics activities.
- Acquired data vs planned acquisitions statistics.
- Ground Stations Download activities statistics (completed download at ground station, outages, missing passess, etc.).
- Data processing time performance and volume performances statistics (total processed data volume, mean processing time per product, etc.).
- Users access statistics.
- Data distribution statistics.

Note: Detailed list of system performances to monitor will be defined during design phase.

CLG-MRD-99 Disposal/Decommissioning Phase.

The CALIGOLA System shall ensure decommissioning phase is able to complete no later than 6 months after the end of the Science Phase.

CLG-MRD-100 Mission Phases

The CALIGOLA System shall progress through the following phases:

- Phase A – Feasibility Study
- Phase B – Preliminary Definition
- Phase C – Detailed Definition
- Phase D – Production/Ground Qualification testing and on-ground calibration

- Phase E1 – LEOP, Flight Qualification / Commissioning and Calibration phase
- Phase E2 – Science Phase / Routine Operations
- Phase F – Disposal.

CLG-MRD-101 LIDAR Data Volume

The CALIGOLA System shall be designed to handle not less than 6.4Tbits (TBC) of science data per day from the LIDAR Instrument.

CLG-MRD-102 LIDAR Launch Date

The CALIGOLA System shall use reuse-elements so as to guarantee a launch date compatible with the 2030-2031 timeframe.

CLG-MRD-103 Telemetry and Command Data Link

The CALIGOLA System shall provide telemetry and telecommand (TT&C) links between the Ground Segment and the Space Segment.

CLG-MRD-104 Downlink Data Rate

The CALIGOLA System shall guarantee a gross downlink rate of at least 500Mbps in X-Band single channel.

Note: It would be desirable to have higher downlink speeds, considering both X-band or Ka-band, given the expected data volume for the mission.

CLG-MRD-105 On-Board Data Compression

The CALIGOLA Platform shall provide the ability to run a compression algorithm to reduce the volume of data to be downlinked. (TBC)

CLG-MRD-106 Encrypted Commands

The CALIGOLA System shall be able to use encryption algorithm for commands sent from ground to space.

CLG-MRD-107 Simultaneous Use of Communications Links

The CALIGOLA Platform shall allow simultaneous operation of low data rate link, for telemetry and telecommand (TT&C), and high data rate link, for payload data.

CLG-MRD-108 Reed Solomon Errors Correction Code

The CALIGOLA System shall be able to use at least Reed-Solomon error correction codes in the communications between the Ground Segment and the Space Segment.

CLG-MRD-109 On-board data storage

The CALIGOLA Platform shall provide sufficient on-board data storage to store the LIDAR data and ancillary data between the acquisition and the downlink and handle contingencies (i.e., ground station temporary unavailability) according to selected mission profiles.

CLG-MRD-110 Allow Acquisition while Downlinking

The CALIGOLA Platform shall allow the continuous acquisition of new scientific data while simultaneously downlinking payload data and ancillary data.

A4.1 Ground Segment Requirements

CLG-MRD-111 Geographically Distributed Ground Segment

The CALIGOLA Ground Segment shall be designed with an architecture distributed between Italy and the United States of America.

CLG-MRD-112 Data and Products Exchange between ASI and NASA

The CALIGOLA Ground Segment shall be able to manage the exchange of Level 0 data and higher Level data products between ASI and NASA ground segment components.

CLG-MRD-113 Detector Subsystem telemetry from ASI to NASA

The CALIGOLA Ground Segment shall be able to collect and send all necessary telemetry data to NASA to perform status verification and health check of the Detector Subsystem.

CLG-MRD-114 Detector subsystem procedures and SW patches

The CALIGOLA Ground Segment shall be able to ingest and uplink NASA parameter changes, commands, and software updates and patches for the Detector Subsystem.

CLG-MRD-115 System architecture based on services

The CALIGOLA Ground Segment shall be structured implementing at least the following main on-ground functionalities as independent common services:

- flight dynamics FDS,
- spacecraft and payload planner;
- satellite control center;
- data and products archive and catalogue;

- processing system;
- high level products generator;
- CALVAL activities;
- mission management;
- quality control management;
- performances monitoring system;
- gate of auxiliary data;
- multivariate statistic performances and usage report system;
- user profile management;
- user Identity and Access Management;

Each independent service listed above shall be designed and developed with a specific interface described in a dedicated ICD so that it could be replaced by ASI with a CFI, without affecting the other services. Standard interfaces shall be defined for each common service.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-116 Micro-services approach of GS common services design

The CALIGOLA Ground Segment shall be defined using microservices approach for Ground Segment related functionalities implementation.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-117 Re-use and upgrade of Italian Multi-Mission Ground Segment

The CALIGOLA Ground Segment shall consider the incorporation (re-use and/or upgrade) of Italian Government owned resources/infrastructures where appropriate; the standard for selection of a resource/infrastructure will be cost-effectiveness, including avoidance of development risk.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-118 Re-use of Italian Multi-Mission Users Ground Segment

The CALIGOLA Ground Segment development shall re-use and/or upgrade the user ground segment of the Multi-mission Italian ground segments (PRISMA and/or PLATiNO missions).

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-119 Cloud Based Architecture

The CALIGOLA Ground Segment Architecture shall be based on IaaS cloud technologies.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-120 Avoid Vendors Lock-In

The CALIGOLA Ground Segment shall be designed and implemented in order to prevent any HW or SW vendors lock-in.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-121 ASI private cloud infrastructure

The CALIGOLA Ground Segment shall be installed in Italy in an ASI private cloud-based infrastructure (TBC), considering only Infrastructure as a Service (IaaS) services available.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-122 ASI private cloud infrastructure backup site

The CALIGOLA Ground Segment shall be designed to take advantage of the ASI cloud-based private backup site, associated with the primary site of ASI private cloud infrastructure located in a geographically distinct site, for backup and disaster recovery activities and to increase the availability of critical services. (TBC).

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-123 Ground Segment Scalability

The CALIGOLA Ground Segment shall be scalable and expandable in terms of:

- Functions (in order to add new functionalities without architecture changes);
- Performance (in order to provide services in decreased times);
- Load capabilities (in order to increase the amount of data volume processed);

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-124 Ground Segment Algorithms Flexibility

The CALIGOLA Ground Segment shall be designed to allow:

- Update to the processing algorithms without impacting the system architecture;
- Coexistence of different version of the data products from alternative processing algorithms in the catalogue and in the data archive;
- Addition of new processing steps and related processing levels without impacting the system architecture;

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-125 Maximization of Ground Segment level of automation

The CALIGOLA Ground Segment shall be designed to maximize the level of automation and the capability to perform operations in an autonomous way in order to reduce operational costs and maximize system reliability.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-126 Minimization of operational costs

The CALIGOLA Ground Segment shall be designed in order to minimize the operational costs by adopting the principles of operations engineering and ILS & OPS optimizations from the earliest stages of system design.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-127 Ground Segment Operations

The CALIGOLA Ground Segment shall be operated in premises agreed with the Italian Space Agency.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-128 NASA Near Space Network (NSN) services

The CALIGOLA Ground Segment shall be able to handle communication links with the spacecraft via the NASA's Near Space Network (NSN) services, providing at least, the following services:

- Reserve a ground station using the interface provided by NSN;
- Handle Telemetry/Telecommands session with the satellite through the NSN ground stations;
- Doppler and Ranging measurements if needed;
- Download scientific data through NSN ground station;
- Handle test and verification activities (i.e. RFCT compatibility test).

CLG-MRD-129 Catalogue Browsing

The CALIGOLA Ground Segment shall provide to the users the capability to browse the catalog of all acquired data and generated products of the mission.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-130 LIDAR data rolling archive.

The CALIGOLA Ground Segment shall be able to catalogue and store, in a local rolling archive, all generated LIDAR related products.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-131 The rolling archive minimum capacity.

The CALIGOLA Ground Segment shall be able to keep online all processed LIDAR data acquired at least in the last 180 (TBC) days, with a configurable retention/deletion policy.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-132 Product Catalogue Search Function.

The CALIGOLA Ground Segment shall provide a function to allow registered users to search for available LIDAR products and download related metadata. The search criteria shall include at least: area of interest, acquisition time window, product level.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-133 Products Distribution

The CALIGOLA Ground Segment shall be able to distribute to all users all the generated LIDAR products.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-134 Products Delivery to the External Product Distribution System

The CALIGOLA Ground Segment shall be able to delivery all the CALIGOLA products to an external products delivery system (eg. MADS and DAAC).

CLG-MRD-135 Product Download Function.

The CALIGOLA Ground Segment shall provide a function to allow registered users to search for available LIDAR products and download them if already available in the rolling archive or after submitting reprocessing request.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-136 HMI and Machine to Machine (M2M) access.

The CALIGOLA Ground Segment shall provide users and mission manager with remote access via both HMI and M2M interfaces for:

- catalog browser and query;
- search and download available LIDAR products;
- reprocessing of rolled-out products;
- functions for user’s management (mission manager only).

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-137 LTDP Archive.

The CALIGOLA Ground Segment shall be able to save all LIDAR RAW data and related ancillary and support data, in a low latency Long-Term Data Preservation archive for at least 10 years (TBC) after the end of the mission.

Note: The specific implementation of LTDP shall be agreed with ASI with the possibility to use the multi-mission LTDP service provided by other ASI project (i.e. MADS).

CLG-MRD-138 Users authentication, authorization and management.

The CALIGOLA Ground Segment shall implement user authentication, authorization and management, based on the most popular standards, at the state of the art, in order to:

- allow the users to register the system in order to access to CALIGOLA mission data;
- allow the users authentication and authorization to be managed through the ASI-MADS (Multi Mission Data Access System) (TBC);
- allow the users authentication by using their SPID or eIDAS accounts (TBC);

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-139 CRUD functionality on user profiles database.

The CALIGOLA Ground Segment shall provide the mission manager of CRUD (create-read-update-delete) functionality on the user profile database (including the bulk mode).

Note: a secure connection with an adequate level of encryption via VPN is assumed. This requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-140 Reports Generation.

The CALIGOLA Ground Segment shall produce, on-demand and periodically, reports and multiparameter statistics useful to manage the system and the mission, including at least:

- The current coverage of totally acquired LIDAR data per geographic area
- The most requested geographical areas by the users;
- Generic statistics about performed acquisitions;
- Generic statistics about users' requests;
- System performances;

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-141 Ground Segment General Activities.

The CALIGOLA Ground Segment shall be designed in order to perform, automatically or manually assisted, at least the following general activities:

- Spacecraft control operations during contacts
- Stations keeping operations
- Doppler and ranging measurements
- Platform telemetry control and health check
- LIDAR instrument telemetry control and health check
- Manage onboard SW and parameter update operations (platform, LIDAR instrument)
- Manage upload of time-tagged LIDAR instrument commands
- Satellite maintenance
- Satellite FDS related activities
- LIDAR acquisition planning definition activities
- ACQ plan generation and on-board upload
- Satellite CAM related operations
- Acquisition of LIDAR scientific data and Auxiliary data from ground station

- Generation of all LIDAR related products (processing software as CFI)
- Generation of all LIDAR calibration parameters.
- Ground segment maintenance and logistic operations
- Ground segment operation for calibration activities of LIDAR instrument
- Manage onboard SW and parameters update (LIDAR instruments)
- Interaction with LIDAR instrument design authority for solving issues.
- Generate Ground Stations pass-plan
- Booking of TM/TC and Scientific-Data download passages on NSN (if necessary)
- Interaction between ASI and NASA ground segment components to exchange telemetry data and products.
- Perform activities needed for formation flying operations

Note: Specific analysis, tradeoff and use cases definition has to be defined in order to details each of foreseen activities.

CLG-MRD-142 Reprocessing Capabilities

The CALIGOLA Ground Segment shall provide to the registered users any requested LIDAR products even if they are not present into rolling archive by using a reprocessing function.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment. The limits to reprocessing requests shall be studied and defined during the feasibility analysis phase.

CLG-MRD-143 Bulk Reprocessing Capabilities

The CALIGOLA Ground Segment shall be able to provide bulk reprocess of LIDAR data in rolling archive for major update of processing algorithms or calibration parameters.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-144 Ground Segment Design Lifetime.

The CALIGOLA Ground Segment must be designed considering a duration of at least 10 years, starting from the end of the commissioning phase.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-145 Restrict Access to System Resources.

The CALIGOLA Ground Segment resources (physical and logical) shall be granted only to authorized personnel.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-146 ICT security measures

The CALIGOLA Ground Segment shall implement minimum ICT security measures at advanced level, according to AGID guidelines, in order to counteract the most frequent cyberattacks.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-147 Cyber security policies and procedures

The CALIGOLA Ground Segment shall implement cybersecurity procedures and policies.

CLG-MRD-148 Cyber security monitoring

The CALIGOLA Ground Segment shall monitor assets, vulnerabilities/patching, cyber risks and incidents.

CLG-MRD-149 Cyber security incidents and risks

The CALIGOLA Ground Segment shall implement specific procedures for incidents handling and cyber risk reduction.

CLG-MRD-150 Supply chain security

The CALIGOLA Ground Segment shall monitor the cyber risks up to the supply chain.

CLG-MRD-151 Supply chain security rules

The CALIGOLA Ground Segment shall implement rules for software developing and testing related to cyber security (rif. LINEE GUIDA DI SICUREZZA NELLO SVILUPPO DELLE APPLICAZIONI, V1 del 21/11/2017).

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-152 Ground segment monitoring

The CALIGOLA Ground Segment shall monitor each of its subsystem/function/service/failures measuring the performance of efficiency and effectiveness.

CLG-MRD-153 Collaboration Platform

The CALIGOLA Ground Segment shall provide a Collaboration Platform in order to allow scientists to work together and collaborate on the development of algorithms and prototypes for processing CALIGOLA data. The platform shall allow at least:

- sharing documents;
- sharing test data sets;
- sharing and running prototypes on shared virtual machines;
- access management and control.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-154 Outreach

The CALIGOLA System shall be advertised to reach general and specific targets of audience, providing information about the mission status (with website, workshop, brochures etc.), promoting educational activities and identifying a logo with a mission name.

A4.2 Regulations and Policies Requirements

CLG-MRD-155 Comply with Deorbit Guidelines

The CALIGOLA System development and operation shall ensure that the mission has the capability to comply with international guidelines, ECSS-U-AS-10C, Rev. 1 Space Debris Mitigation: Clarifications to ISO 24113:2019, in safely de-orbiting the Space Segment for disposal following decommissioning.

CLG-MRD-156 Comply with International Laws and Regulations on RF emitters

The CALIGOLA System design, development and operations shall comply with all applicable licensing regulations (e.g., ITU).

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

CLG-MRD-157 Comply with Export Control Regulations

The CALIGOLA System development and deployment shall comply with all Italian / US and international export control regulations.

CLG-MRD-158 Comply with GDPR regulations

The CALIGOLA Ground Segment development, and operations shall comply with GDPR regulations (EU) 2016/679.

Note: this requirement applies only to the Italian component of the entire CALIGOLA ground segment.

A5. Science Tracebility Flow

SCIENCE TRACEBILITY FLOW

1.1 Atmospheric objectives

1.1.1 Aerosol science objectives

Obj. Nr.	Scientific objectives	Observables	Horiz. res. Δh (km)	Vert. Res. Δz (m)	Vert. Extent (km)	Stat. Error (%)	BIAS (%)	AOS
1.1.1.1.	Provide continuity and improve observations of the vertical distribution of aerosol optical and geometrical properties (with the aim to reduce an uncertainty of aerosol direct radiative forcing by a factor of 2).	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	MRP
1.1.1.2.	Determine the microphysical and dimensional properties of aerosols and particle typing.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$, $\beta_{FL\_AER, 450}(z)$, $\beta_{FL\_AER, 685}(z)$, $\beta_{FL\_AER, 735}(z)$	10-50	30	0 to 30	10 to 20 %	3-5 %	MRP
1.1.1.3.	Improve the characterization of the global-scale distribution and intensity of natural and anthropogenic aerosol sources and sinks.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$, $\beta_{FL\_AER, 450}(z)$, $\beta_{FL\_AER, 685}(z)$, $\beta_{FL\_AER, 735}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	MRP
1.1.1.4.	Improve understanding and quantitative characterization of aerosol direct and indirect impacts on the global energy budget and Earth's climate.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	DR MRP
1.1.1.5.	Improve an understanding of aerosol-cloud-radiation interactions and their representation in climate and weather models.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$	10-50	30	0 to 20	10 to 40 %	3-5 %	DR MRP
1.1.1.6.	Improve the representation of aerosol long-wave scattering in regional and global climate models.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	MRP
1.1.1.7.	Refine aerosol radiation closure (radiation closure within 5 Wm^{-2} for a 50 km^2 snapshot).	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$	10-50	30	0 to 30	10 to 20 %	3-5 %	MRP
1.1.1.8.	Improve the characterization of biological particles from biomass fuels, sulfates, and dust.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$, $\beta_{FL\_AER, 450}(z)$, $\beta_{FL\_AER, 685}(z)$, $\beta_{FL\_AER, 735}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	MRP
1.1.1.9.	Improve the characterization of aerosol particle hygroscopic-hydrophobic properties.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$, $x_{H2O}(z)$	10-50	30	0 to 20	10 to 40 %	3-5 %	MRP
1.1.1.10.	Improve the characterization of Saharan dust outbreaks and understanding of their role in enhancing or inhibiting cloud formation and precipitation.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$, $x_{H2O}(z)$	10-50	30	0 to 20	10 to 40 %	3-5 %	DR MRP

SCIENCE TRACEBILITY FLOW

1.1.1 Aerosol science objectives (cont.)

Obj. Nr.	Scientific objectives	Observables	Horiz. res. Δh (km)	Vert. Res. Δz (m)	Vert. Extent (km)	Stat. Error (%)	BIAS (%)	AOS
1.1.1.11.	Improve observations of tropospheric aerosols from volcanic eruptions and predictions of their interaction with air -traffic.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	MRP
1.1.1.12.	Improve observations of stratospheric aerosols from volcanic eruptions and assessments of their role in altering Earth's radiative budget.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$, $\beta_{FL\_AER, 450}(z)$, $\beta_{FL\_AER, 685}(z)$, $\beta_{FL\_AER, 735}(z)$	10-50	30 (0-30 km), 90 (30-45 km)	0 to 45	10 to 40 %	3-5 %	MRP
1.1.1.13.	Improve the characterization of long -range aerosol transport over the Mediterranean Sea and Atlantic Ocean and understanding of its role on air quality worldwide.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$, $\beta_{FL\_AER, 450}(z)$, $\beta_{FL\_AER, 685}(z)$, $\beta_{FL\_AER, 735}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	MRP
1.1.1.14.	Improve the characterization of stratospheric clouds and aerosols and understanding of their role in ozone depletion.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$	10-50	30 (0-30 km), 90 (30-45 km)	0 to 45	10 to 40 %	3-5 %	DR MRP
1.1.1.15.	Improve profiling capabilities of stratospheric and mesospheric temperature and characterization of gravity wave propagation.	$T(z)$	10-50	30 (0-30 km), 90 (30-45 km)	0 to 90	10 to 40 %	3-5 %	MR

1.1.2 Cloud science objectives

Obj. Nr.	Scientific objectives	Observables	Horiz. res. Δh (km)	Vert. Res. Δz (m)	Vert. Extent (km)	Stat. Error (%)	BIAS (%)	AOS
1.1.2.1.	Improve the characterization of global-scale cloud vertical/horizontal distributions.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	DR MR P
1.1.2.2.	Improve the characterization of cloud-precipitation interaction mechanisms.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$, $\beta_{FL\_AER, 450}(z)$, $\beta_{FL\_AER, 685}(z)$, $\beta_{FL\_AER, 735}(z)$	10-50	30	0 to 30	10 to 20 %	3-5 %	DR MR P
1.1.2.3.	Improve the characterization of low and high cloud radiative feedbacks.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$, $\beta_{FL\_AER, 450}(z)$, $\beta_{FL\_AER, 685}(z)$, $\beta_{FL\_AER, 735}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	DR MR P
1.1.2.4.	Improve understanding of deep convection mechanisms and their role in low/high cloud formation.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	DR MR P
1.1.2.5.	Improve the characterization of vertical motion within clouds.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$	10-50	30	0 to 20	10 to 40 %	3-5 %	DR MR P
1.1.2.6.	Improve global scale measurements of cloud liquid water and ice content and the characterization of microphysical processes and phase partitioning mechanisms within cold (mixed phase and ice) clouds.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	DR MR P

1.1.3 Aerosol-cloud interaction science objectives

Obj. Nr.	Scientific objectives	Observables	Horiz. res. Δh (km)	Vert. Res. Δz (m)	Vert. Extent (km)	Stat. Error (%)	BIAS (%)	AOS
1.1.3.1.	Improve the characterization of aerosol-cloud interaction mechanisms.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	DR MR P
1.1.3.2.	Improve the characterization of particle hygroscopicity and aerosols' role in warm and cold cloud formation and development processes and the formation of hydrometeors.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$, $\beta_{FL\_AER, 450}(z)$, $\beta_{FL\_AER, 685}(z)$, $\beta_{FL\_AER, 735}(z)$	10-50	30	0 to 30	10 to 20 %	3-5 %	DR MR P
1.1.3.3.	Characterize aerosol transport and redistribution mechanisms in the proximity of clouds.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$, $\beta_{FL\_AER, 450}(z)$, $\beta_{FL\_AER, 685}(z)$, $\beta_{FL\_AER, 735}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	DR MR P
1.1.3.4.	Determine atmospheric radiative heating and cooling profiles through observations of aerosol and cloud optical and microphysical properties.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	DR MR P

SCIENCE TRACEBILITY FLOW

1.1.4 Continuity/synergy with other space missions and international ground networks

Obj. Nr.	Scientific objectives	Observables	Horiz. res. Δh (km)	Vert. Res. Δz (m)	Vert. Extent (km)	Stat. Error (%)	BIAS (%)	AOS
1.1.4.1.	Provide continuity to CALIOP/ATLID/ALADIN atmospheric measurements.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	/
1.1.4.2.	Provide coincident and co-located measurements of CALIGOLA with instruments on-board of AOS-Sky and exploit the synergetic use of data from the two missions based on consideration of a formation flight, with CALIGOLA following or preceding AOS-Sky by a few tens of seconds.	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$, $\beta_{FL\_AER, 450}(z)$, $\beta_{FL\_AER, 685}(z)$, $\beta_{FL\_AER, 735}(z)$	10-50	30 (0-30 km), 90 (30-45 km)	0 to 45	10 to 40 %	3-5 %	
1.1.4.3.	Improve the global-scale observation and characterization of aerosol and cloud optical and microphysical properties based on coincident and co-located measurements of CALIGOLA with international ground-based lidar networks such as: i) "Aerosol, Clouds and Trace Gases Research Infrastructure" (ACTRIS) ii) "Global Atmosphere Watch (GAW) Aerosol Lidar Observation Network" (GALION) iii) "Network for the Detection of Atmospheric Composition Change" (NDACC).	$\beta_{355}(z)$, $\beta_{532}(z)$, $\beta_{1064}(z)$, $\alpha_{355}(z)$, $\alpha_{532}(z)$, $\delta_{355}(z)$, $\delta_{532}(z)$, $\delta_{1064}(z)$, $\beta_{FL\_AER, 450}(z)$, $\beta_{FL\_AER, 685}(z)$, $\beta_{FL\_AER, 735}(z)$	10-50	30	0 to 30	10 to 40 %	3-5 %	

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Appendix

This section documents the lidar and geophysical variable assumptions underlying the statistical uncertainty figures provided in the table "L0 DATA Performance Requirements" (CLG-MRD-17).

The following lidar parameters have been assumed for the purpose of deriving the requirements listed in CLG-MRD-17. These parameters are believed to be accurate as of this writing (Feb. 25, 2024) but are assumptions that are subject to change. Some figures, in particular the laser pulse energies, may need to be revised to reflect end of life values. All parameters are intended to reflect end of life values.

Transmitted wavelengths	λ_{Tx}	354.71 nm	532.07 nm	1,064.14 nm
Pulse energy	E_p	151 mJ	44 mJ	156 mJ
Pulse repetition rate	PRF	51 Hz		
Telescope primary diameter	D_T	1 m		
Clear aperture ratio	CAR	0.86*		
Field of view FW	FOV	30 µrad		
Telescope blur circle FWHM	-	6 µrad		
Boresight misalignment	-	1 µrad		
Transmitter output divergence 1/e^2 FW	-	20 µrad	33 µrad	53 µrad
Laser temporal FWHM	-	25 ns	UNK	UNK
Laser spectral width FWHM	-	20 pm	30 pm	60 pm
Mission orbit altitude	L	450 km		
Transmit optics transmittance	η_{Tx}	0.93	0.93	0.93
Field stop transmittance	η_{FS}	0.97	0.78	0.46
Off-nadir pointing angle	$\theta_{ON,0}$	12°		

Table 1. Lidar parameters that are not specific to each receiving channel

Received wavelengths (λ_{Rx})	Receive optics transmittance (η_{Rx})		Photon detection efficiency (PDE)	Excess noise factor (ENF)	Dark count rate (DCR)	Telescope reflectivity (R_T)	Effective bandpass ($\Delta\lambda$)
	∥	⊥					
353.85 nm	0.67		0.39 (1)	1.5 (1)	200 Hz (1)	0.90	0.50 nm
354.71 nm	0.61	0.59	0.39 (1)	1.5 (1)	200 Hz (1)	0.90	0.1 nm (coupled with an etalon Δλ= 25 pm

355.75 nm	0.67		0.39 (1)	1.5 (1)	200 Hz (1)	0.90	0.50 nm
402-407.5 nm	0.67		0.36 (1)	1.5 (1)	200 Hz (1)	0.88	5.5 nm
450-460 nm	0.72		0.29 (1)	1.5 (1)	200 Hz (1)	0.86	10 nm
532.07 nm	0.61	0.59	0.16 (2)	1.5 (2)	10 kHz (2)	0.83	0.1 nm (coupled with an etalon Δλ= 40 pm
640-660 nm	0.60		0.14 (2)	1.5 (2)	10 kHz (2)	0.84	20 nm
675-695 nm	0.60		0.12 (2)	1.5 (2)	10 kHz (2)	0.84	20 nm
1,064.14 nm	0.80	0.73	0.35 (3)	2.7 (3)	40 MHz (3)	0.88	0.4 nm

Table 2. Lidar parameters that are specific to each receiving channel. Detector assumptions:
(1) Hamamatsu R9880-210 UBA photomultiplier
(2) Hamamatsu R9880-20 ERMA photomultiplier
(3) Excelitas C30606 Si avalanche photodiode. Estimated end of life APD primary dark count current from Sun et al, 2022 (ICESat: 4.1 pA/7 year [observed] × 5 year/1.5 krad [ray trace analysis] × 3 krad (Si) [CALIGOLA 3 year dose] = 6 pA) assumed.
No etalons are assumed, only interference filters. Elastic scatter channels are bolded.

Assume that the temperature and pressure linewidth broadening and laser pulse spectrum are insignificant relative to the width of the filter passbands such that the spectral overlap of the backscatter is near unity for all channels. This assumption will need to be revisited if etalons are introduced. For the atmosphere, the co-polarized or cross-polarized backscatter signal, in rate of photoelectrons, can be expressed as

$$S = PDE(\lambda_{Rx}) \frac{E_p}{hc/\lambda_{Rx}} R_T \eta_{Rx} \eta_{Tx} \eta_{FS} \beta_\pi(z, \lambda_{Tx}) \exp\left(-\int_0^{r(z)} [\alpha(z, \lambda_{Tx}) + \alpha(z, \lambda_{Rx})] dr\right) CAR \frac{\pi (D_T/2)^2}{r(z)^2} \frac{c}{2}$$

β_π is the co-polarized or cross-polarized backscatter coefficient in the scatter volume and α are the extinction coefficients. Both are functions of altitude (scatter volume composition) and wavelength. $r(z)$ is the range to a scatter volume at altitude z. All other variables are as defined and specified in Table 1 and Table 2 above. The transmit and receive wavelengths may differ (e.g., Raman, fluorescence), so may experience a different extinction through the intervening medium. $r(z)$ can be found from geometry assuming an Earth radius (R_E) that is constant between nadir pierce point and laser pierce point. R_E is assumed to be equal to Earth's mean radius (6371 km) here.

$$r(z) = (R_E + L)\left(\cos\theta_{ON} - \sqrt{\left(\frac{R_E + z}{R_E + L}\right)^2 - \sin^2\theta_{ON}}\right)$$

$$\theta_{ON}(z) = \arcsin\left(\frac{R_E + L}{R_E + z} \sin\theta_{ON,0}\right)$$

To first order, $r(z) \approx (L - z)/\cos\theta_{ON}$ and $dr \approx -dz/\cos\theta_{ON}$. The range to the surface and off-nadir angle at the surface for the 450 km altitude and 12° initial off-nadir pointing angle configuration for Earth's mean radius are 460.79 km and 12.86°, respectively. The total solar background (sum of parallel and perpendicular polarization channels), in rate of photoelectrons, can be expressed as

$$B = PDE(\lambda_{Rx}) \frac{L_{\lambda_{Rx}}}{hc/\lambda_{Rx}} R_T \eta_{Rx} CAR (\pi D_T\, FOV/4)^2$$

For the elastic scatter channels, which include a polarizer, the background is approximately half the total. The PDE is assumed to be approximately constant across the passband. $L_{\lambda_{Rx}}$ is the upwelling spectral radiance, which can be found from

$$L_{\lambda_{Rx}} = E_{\lambda_{Rx}} \frac{R_e(\lambda_{Rx})}{\pi} \cos(\theta_{SZA})$$

$R_e(\lambda_{Rx})$ is the nondimensional, normalized top of atmosphere (TOA) reflectance, $E_{\lambda_{Rx}}$ is the total TOA spectral irradiance transmitted through the filter passband, and θ_{SZA} is the solar zenith angle at the laser pierce point. The nondimensional, normalized reflectance is equal to the albedo for surfaces that exhibit Lambertian reflectance. Here, square passbands will be assumed that are centered on the wavelengths of each respective channel. Solar irradiance comes from a high spectral resolution solar irradiance atlas produced by Chance and Kurucz, 2005.

Received wavelengths (λ_{Rx})	Effective bandpass ($\Delta\lambda$)	Mean TOA solar spectral irradiance W/m^2/nm	TOA solar irradiance ($E_{\lambda_{Rx}}$) W/m^2
353.95 nm	0.50 nm	1.16	0.58
354.71 nm	0.25 nm	1.19	0.30
355.70 nm	0.50 nm	1.03	0.52
402-407.5 nm	5.5 nm	1.70	9.36
450-460 nm	10 nm	2.07	20.7
532.07 nm	0.25 nm	1.98	0.50
640-660 nm	20 nm	1.57	31.4
675-695 nm	20 nm	1.50	30.0
1,064.14 nm	0.50 nm	0.64	0.32

Table 3. Solar irradiance integrated over passbands defined above for each receiving channel. Elastic scatter channels are bolded.

The extinction coefficient in the atmosphere is the sum of the extinction from Rayleigh scattering by air and absorption from ozone. Temperature dependent ozone absorption cross sections come from A. Serdyuchenko et al, 2011 and Rayleigh extinction is from A. Bucholtz, 1995. Ozone cross sections are reported for a temperature of 240 K, which is the temperature at the altitude where the ozone concentration is highest. Absorption from other species are not considered but are not expected to contribute significant additional extinction. Temperature, density, and ozone and water vapor concentration come from the US Standard Atmosphere, 1976. The Cabannes line and N_2, O_2 and H_2O vapor Raman differential cross sections come from U. Wandinger, 2006.

	40 km	30 km	10 km	1 km	0 km
Total density, $\rho_V(\Sigma)$	8.31×10^{22} /m^3	3.83×10^{23} /m^3	8.60×10^{24} /m^3	2.31×10^{25} /m^3	2.55×10^{25} /m^3
N_2 density, $\rho_V(N_2)$	6.49×10^{22} /m^3	2.99×10^{23} /m^3	6.72×10^{24} /m^3	1.81×10^{25} /m^3	1.99×10^{25} /m^3
O_2 density, $\rho_V(O_2)$	1.74×10^{22} /m^3	8.00×10^{22} /m^3	1.79×10^{24} /m^3	4.83×10^{24} /m^3	5.33×10^{24} /m^3

H_2O vapor density, $\rho_V(H_2O)$	4.18×10^{17} /m³	1.81×10^{18} /m³	6.02×10^{20} /m³	1.40×10^{23} /m³	1.97×10^{23} /m³
Overlying total column, $\rho_A(\Sigma)$	6.29×10^{26} /m²	2.59×10^{27} /m²	5.67×10^{28} /m²	1.91×10^{29} /m²	2.16×10^{29} /m²
Overlying O_3 column, $\rho_A(O_3)$	2.90×10^{21} /m²	1.73×10^{22} /m²	8.61×10^{22} /m²	9.22×10^{22} /m²	9.29×10^{22} /m²

Table 4. Major species densities and column densities

Received wavelengths	O_3 absorption cross section, $\sigma(O_3)$ m²/mol @ 240 K	Rayleigh scattering cross section, $\sigma(\Sigma)$ m²/mol
353.95 nm	5.33×10^{-27}	2.79×10^{-30}
354.71 nm	4.75×10^{-27}	2.76×10^{-30}
355.70 nm	4.62×10^{-27}	2.73×10^{-30}
402-407.5 nm	1.43×10^{-27}	1.59×10^{-30}
450-460 nm	2.31×10^{-26}	9.81×10^{-31}
532.07 nm	2.74×10^{-25}	5.16×10^{-31}
640-660 nm	2.45×10^{-25}	2.28×10^{-31}
675-695 nm	1.21×10^{-25}	1.85×10^{-31}
1,064.14 nm	8.57×10^{-29}	3.12×10^{-32}

Table 5. Values represent averages across each respective passband. Elastic scatter channels are bolded.

Received wavelengths	$\frac{d\sigma_R}{d\Omega}(N_2)$ @ 288 K m²/sr	$\frac{d\sigma_R}{d\Omega}(O_2)$ @ 288 K m²/sr	$\frac{d\sigma_R}{d\Omega}(H_2O)$ @ 300 K m²/sr
353.95 nm (AS PRR)	1.12×10^{-33}	2.49×10^{-33}	-
355.70 nm (S PRR)	1.41×10^{-33}	3.53×10^{-33}	-
402-407.5 nm (VRR)	-	-	7.5×10^{-34}

Table 6. Total rotational Raman differential cross sections in the backscatter direction for N_2, O_2 and vibrational-rotational Raman differential cross section for H_2O (vapor) for lines contained within each respective passband. H_2O includes the Q-branch and all rotational lines.

Received wavelengths	$\frac{d\sigma_C}{d\Omega}(N_2)$ m²/sr	$\frac{d\sigma_C}{d\Omega}(O_2)$ m²/sr
354.71 nm	3.14×10^{-31}	2.67×10^{-31}
532.07 nm	6.20×10^{-32}	5.27×10^{-32}

1064.14 nm	3.88×10^{-33}	3.29×10^{-33}

Table 7. Total Cabannes/Rayleigh differential cross sections in backscatter direction for each elastically scattered wavelength.

In general, the two way transmittance from the lidar to the scatter volume can be closely approximated as

$$T^2 = \exp\left(-[\rho_A(\Sigma)\sigma(\Sigma) + \rho_A(O_3)\sigma(O_3)](\lambda_{Tx}) - [\rho_A(\Sigma)\sigma(\Sigma) + \rho_A(O_3)\sigma(O_3)](\lambda_{Rx})\right)^{1/\cos\theta_{ON}}$$

Using the appropriate scattering and absorbing cross sections for each channel according to the stimulating and emitting wavelengths, we have for the two-way transmittance to scattering volumes at each altitude.

	T^2				
Received wavelengths	40 km	30 km	10 km	1 km	0 km
353.95 nm	0.996	0.985	0.724	0.338	0.293
354.71 nm	0.996	0.985	0.726	0.340	0.295
355.70 nm	0.996	0.985	0.727	0.342	0.297
402-407.5 nm	0.997	0.988	0.777	0.427	0.382
450-460 nm	0.998	0.990	0.803	0.480	0.437
532.07 nm	0.998	0.988	0.898	0.776	0.756
640-660 nm	0.998	0.989	0.915	0.823	0.808
675-695 nm (1)	0.998	0.990	0.834	0.556	0.516
675-695 nm (2)	0.998	0.991	0.927	0.840	0.825
1,064.14 nm	1.000	1.000	0.996	0.988	0.986

Table 8. Two way transmittances for each channel. Transmittance for the 675-695 nm channel are reported for both the 354.7 nm (1) and 532 nm (2) emissions.

The backscatter coefficient for each channel is the differential cross section multiplied by the density of the scattering species.

N_2+O_2 Cabannes: $$\beta_{\pi,C} = \rho_V(N_2)\frac{d\sigma_C}{d\Omega}(N_2) + \rho_V(O_2)\frac{d\sigma_C}{d\Omega}(O_2)$$

N_2+O_2 Raman: $$\beta_{\pi,R} = \rho_V(N_2)\frac{d\sigma_R}{d\Omega}(N_2) + \rho_V(O_2)\frac{d\sigma_R}{d\Omega}(O_2)$$

H_2O Raman: $$\beta_{\pi,R} = \rho_V(H_2O)\frac{d\sigma_R}{d\Omega}(H_2O)$$

	β_π, /m/sr				
Received wavelengths	40 km	30 km	10 km	1 km	0 km
353.95 nm	1.16×10^{-10}	5.34×10^{-10}	1.20×10^{-8}	3.23×10^{-8}	3.53×10^{-8}
354.71 nm	2.50×10^{-8}	1.15×10^{-7}	2.59×10^{-6}	6.97×10^{-6}	7.64×10^{-6}

355.70 nm	1.53×10^{-10}	7.04×10^{-10}	1.58×10^{-8}	4.26×10^{-8}	4.65×10^{-8}
402-407.5 nm	3.14×10^{-16}	1.36×10^{-15}	4.52×10^{-13}	1.05×10^{-10}	1.48×10^{-10}
450-460 nm	0	0	0	1.0×10^{-11}	0
532.07 nm	4.94×10^{-9}	2.28×10^{-8}	5.11×10^{-7}	1.38×10^{-6}	1.51×10^{-6}
640-660 nm	TBD	TBD	TBD	TBD	TBD
675-695 nm (1) 675-695 nm (2)	TBD TBD	TBD TBD	TBD TBD	TBD TBD	TBD TBD
1,064.14 nm	3.09×10^{-10}	1.42×10^{-9}	3.20×10^{-8}	8.61×10^{-8}	9.44×10^{-8}

Table 9. Backscatter coefficients (pre-attenuated) for each channel.

The aerosol fluorescence backscatter coefficient assumption for 450-460 nm derives from measurements reported in I. Veselovskii 2020 and J. Reichardt 2023 scaled to a 10 nm passband width and assumes a zero extinction layer centered at 1 km altitude. Below are backscatter signals in each channel expressed in photoelectron rates.

	Backscatter signal, PE/s				
Received wavelengths	40 km	30 km	10 km	1 km	0 km
353.95 nm	3,791	16,445	247,106	298,470	281,691
354.71 nm	721,705	3,131,780	47,179,400	57,202,300	54,201,200
355.70 nm	5,023	21,787	328,450	400,026	377,935
402-407.5 nm	0.01	0.04	10.305	1,266	1,587
450-460 nm	0	0	0	128.9	0
532.07 nm	18,973	82,420	1,532,380	3,429,130	3,642,750
640-660 nm	TBD	TBD	TBD	TBD	TBD
675-695 nm (1) 675-695 nm (2)	TBD TBD	TBD TBD	TBD TBD	TBD TBD	TBD TBD
1,064.14 nm	14,274	62,631	1,276,890	3,275,430	3,568,200

Table 10. Backscatter signal and solar background for each channel.

For surfaces, a more appropriate figure from which to derive SNR is the integral number of photoelectrons reflected from the surface. For this, the following expression applies.

$$S_{(\rho/\Omega)} = PDE(\lambda_{Rx})\frac{E_p}{hc/\lambda_{Rx}} R_T \eta_{Rx}\eta_{Tx}\eta_{FS}\left(\frac{\rho}{\Omega}\right)\exp\left(-2\int_0^{r(z)} \alpha(z,\lambda_{Tx})dr\right) CAR\,\frac{\pi(D_T/2)^2}{r(z)^2}$$

$\frac{\rho}{\Omega}$ is the reflectivity of the surface. For ocean surfaces with a 6 m/s surface wind speed and the 12° off-nadir pointing angle, the reflectivity is approximately 0.025 /sr for all three transmitted wavelengths.

Solar background levels shown below are for a unity nondimensional, normalized TOA reflectance.

	Solar background, PE/s		
Received wavelengths	$SZA = 60°$ PE/s	$SZA = 40°$ PE/s	$SZA = 20°$ PE/s
353.95 nm	1.847×10^{7}	2.829×10^{7}	3.471×10^{7}
354.71 nm	4.215×10^{6}	6.458×10^{6}	7.921×10^{6}
355.70 nm	1.664×10^{7}	2.549×10^{7}	3.127×10^{7}
402-407.5 nm	3.076×10^{8}	4.713×10^{8}	5.781×10^{8}
450-460 nm	6.470×10^{8}	9.912×10^{8}	1.216×10^{9}
532.07 nm	3.987×10^{6}	6.108×10^{6}	7.493×10^{6}
640-660 nm	5.509×10^{8}	8.440×10^{8}	1.035×10^{9}
675-695 nm	4.754×10^{8}	7.284×10^{8}	8.935×10^{8}
1,064.14 nm	1.464×10^{7}	2.244×10^{7}	2.752×10^{7}

Table 11. Solar background signals, accounting for presence of polarizer (multiplied by 1/2 if present, 1 if not). Only the elastic channels (bolded) have polarizers. These are for a unity nondimensional, normalized TOA reflectance. Values in the table are TBC.

The signal to noise ratio can be written as follows, where S is the backscatter signal and B is the solar background, both expressed in photoelectron rates (PE/s).

$$SNR = \frac{S\Delta t}{\sqrt{}}0.95$$

The extra factor of 0.95 accounts for the degradation by electronic noise and is conservative, i.e., signals are always used at the lower end of the useable dynamic range of an electronic gain channel. Δt is the total averaging time corresponding to the desired vertical (V) and horizontal (H) averaging scales. For the atmosphere,

$$\Delta t = \lfloor PRF(H/v_g) \rfloor 2V|dr/dz|/c$$

$\lfloor \quad \rfloor$ indicates floor (round to next lowest integer). $|dr/dz|$ is the absolute value of the differential increment in range for a differential increment in altitude and converts the vertical resolution specification to a range resolution. It is approximately 1.0257 m/m near the surface for this pointing geometry. v_g is the satellite's velocity along the ground which, for a sun synchronous orbit, can be approximated as

$$v_g \cong \frac{1.27198 \cdot 10^{14}\ \mathrm{m}^{5/2}\mathrm{s}^{-1}}{(R_E + L)^{3/2}}$$

For the orbit considered here, the velocity is 7,140 m/s. For a 51 Hz repetition rate, the footprints are spaced by 140 m on the ground.