Lidar concepts for space applications

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TAS-I Torino main studies on altimeters:

- ATLID (Atmospheric LIDar): measurement of vertical profiles of the physical aerosols parameters, altitude of the highest cloud top
- A-SCOPE (Advanced Space Carbon and Climate Observation of Planet Earth): measurement of column averaged dry air CO_2 mixing ratio
- Laser occultation: limb sounding observations in the SWIR spectral range (2 μm ÷ 2.5 μm) to measure the absorption spectral lines of a number of trace gases
- Laser altimeter: altimetry in different application domains

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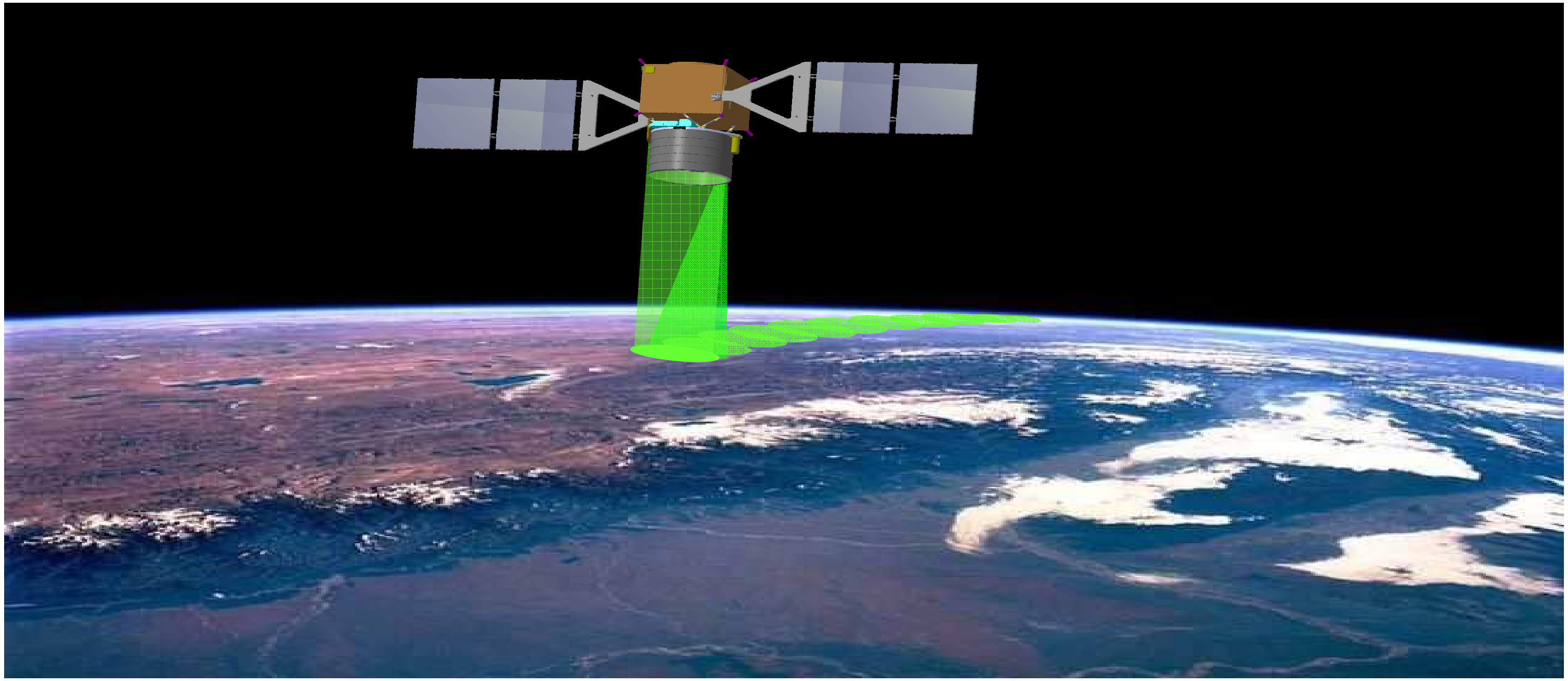
Laser altimeter study



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Applications required

4 different domains are targeted: for each of them a list of innovative applications is defined, based on scientific needs for the future

-Cryosphere sea ice land ice land	- Land Topography digital terrain modelling land surface parameterization natural hazards
- Ocean open ocean costal and shallow seas polar seas other applications	- Biosphere vegetation and canopy

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Comparison of Altimetry Methods

- Full-Waveform
- Multi-kHz
- Pseudo Random Noise (PRN)

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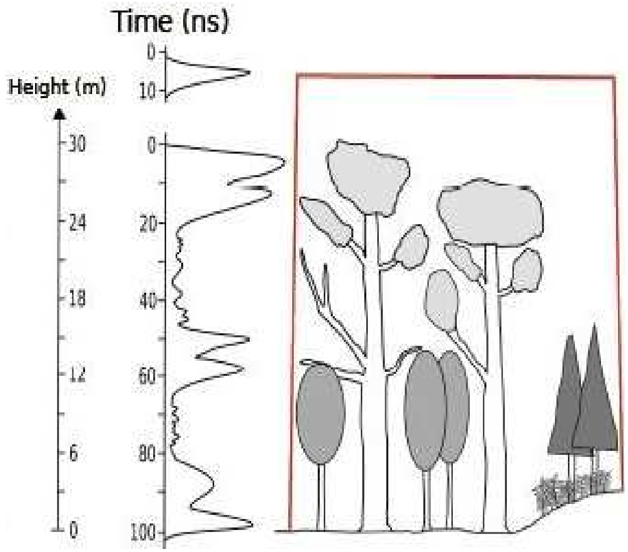
Full Waveform Altimetry Principle

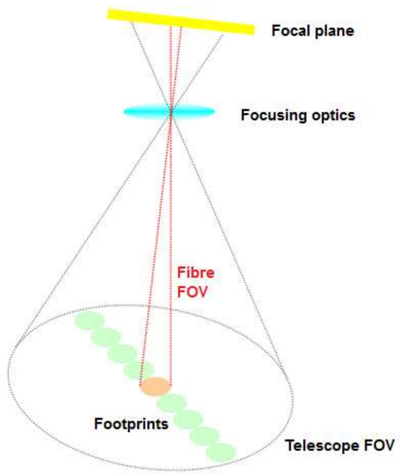


Pros

- High information contents
- Proven technology

Cons

- High power requirements
- Lower spatial resolution - limited by eye safety
- Difficult for multi-beam from satellite
- Laser lifetime issues



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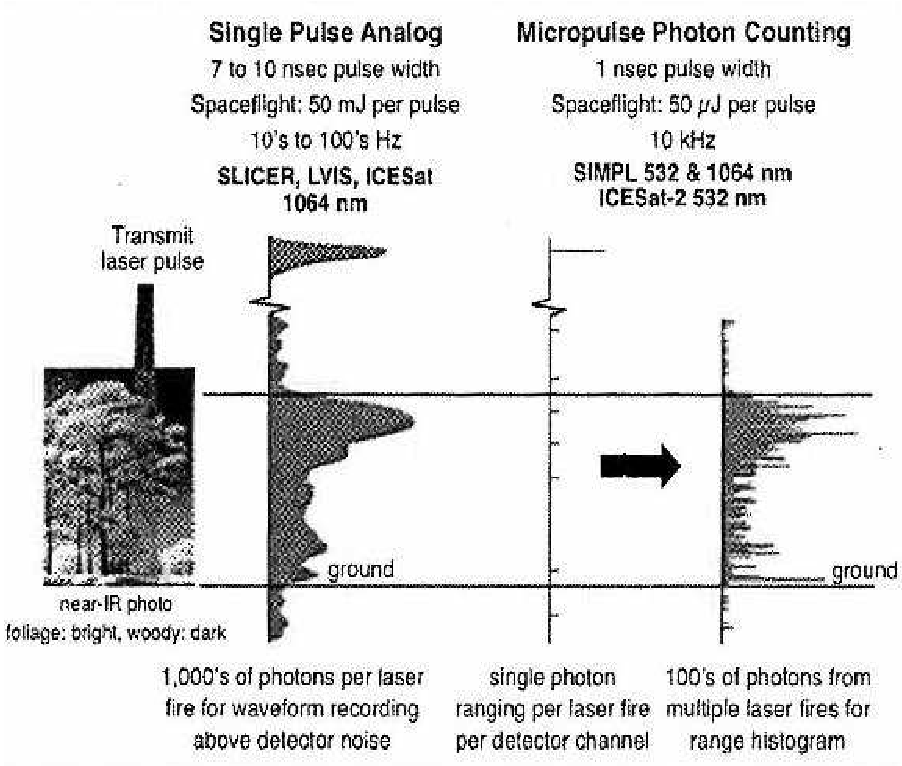
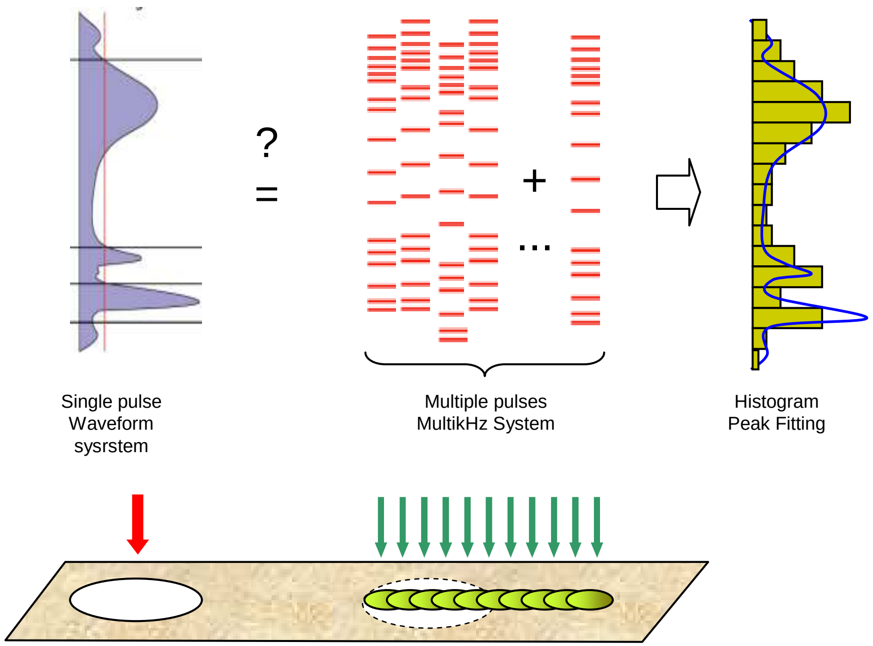
Photon Counting Altimetry Principle





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Photon Counting Altimetry Pros & Cons

Pros

- High spatial resolution (eye-safe) and range resolution
- Suitable for multi-beam systems
- lower laser power, smaller impacts on emission optics
- Higher laser efficiency (high Pulse Repetition Rate)
- All digital processing (high speed, lower power)

Cons

- Limited to visible wavelengths mostly, Photon Counting is difficult in the IR
- Need to build statistics for analyses of foliage
- Narrow-band filtering required to reduce background (solar)
- On-board processing to reduce the data output

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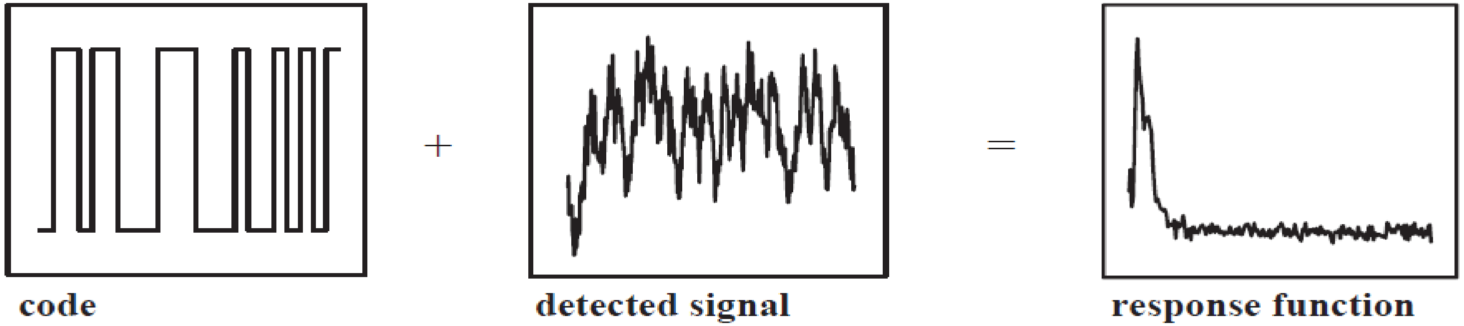
PRN Altimetry Principle



Pros

- Low peak laser power – Continuous Wave and quasi Continuous Wave possible (fiber)
- Easy implementation using telecom components
- Suitable to bodies without atmosphere

Cons

- SNR (range accuracy) more sensitive to presence of scatterers above the surface (clouds, aerosols, vegetation) than Time Of Flight
- Longer integration time may be required (lower spatial resolution)

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Comparison of Methods

	Units	Photon Counting Altimetry	Full Waveform Altimetry	PRN Laser Altimetry
Wavelengths	[nm]	532	1064/532	1550/1064
Pulse width	[ns]	< 1 ns	(5 – 10) ns	trains of pulses (5-10 ns per bin)
Energy (order of magnitude)	[J]	10 µJ	10-100 mJ	CW, few W
Information				
-range	-	yes	yes	yes
-elevation variation	-	yes	yes	yes
-reflectance	-	no	yes	no
Spot size	[m]	5	25	(5-10)
Waveform reconstruction	-	yes	yes	yes

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Performance Model structure

1: General Input Data

↓

2: Instrument Design Parameters

↓

3: Atmospheric parameters

↓

4: Return signal waveform simulation

↓

5: Return signal waveform processing

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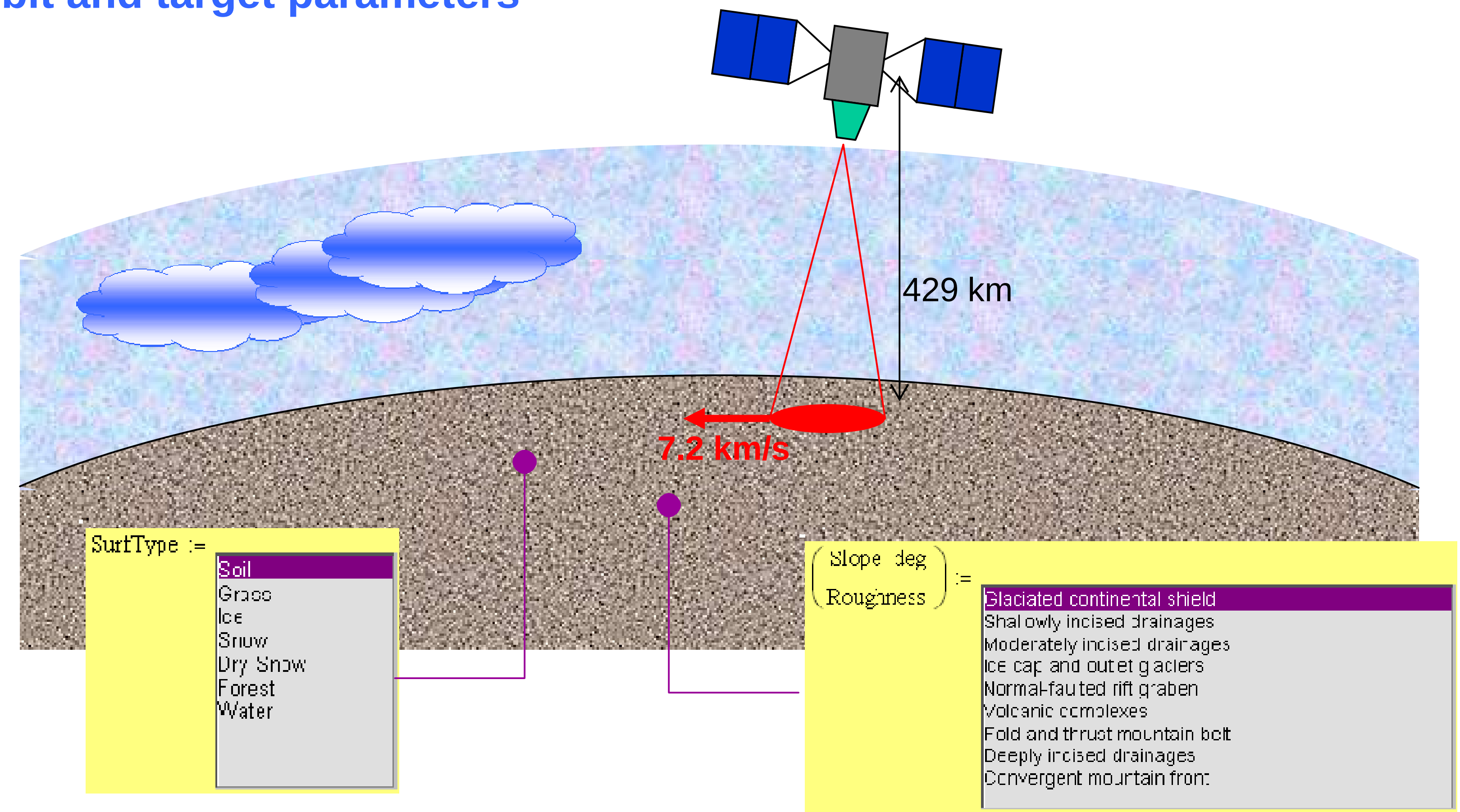
General Input Data

Orbit and target parameters



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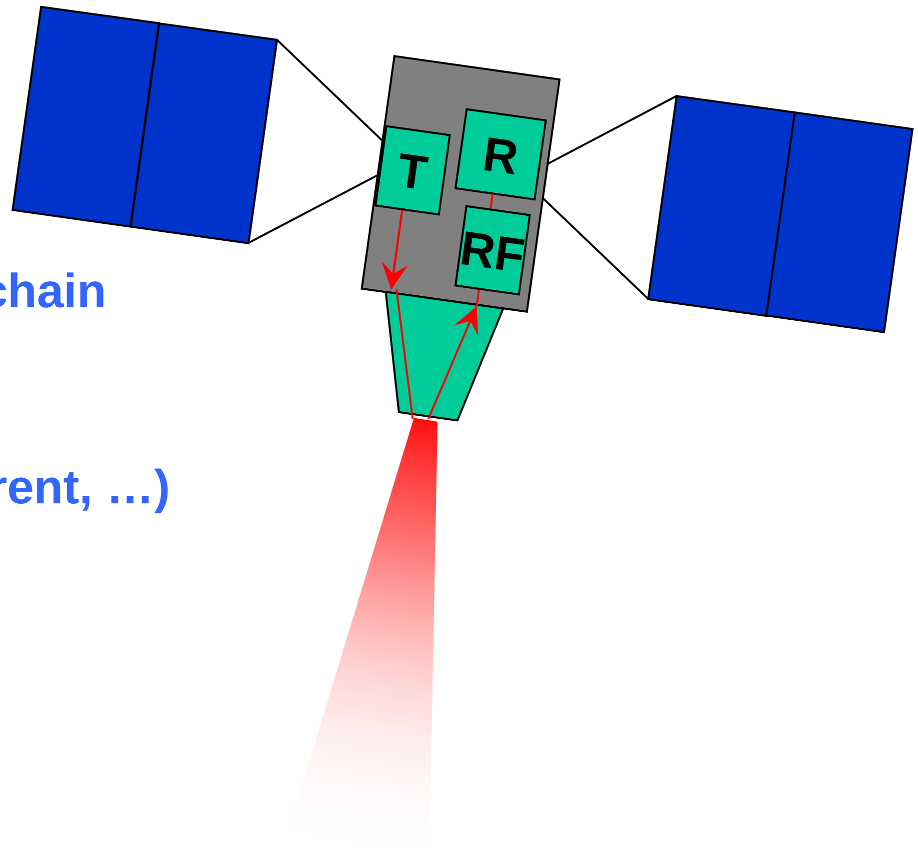
Instrument Design Parameter

- Beam parameters
- Spectral profile
- Transmitting and receiving chain
- Filtering
- Detector (QE, gain, dark current, …)



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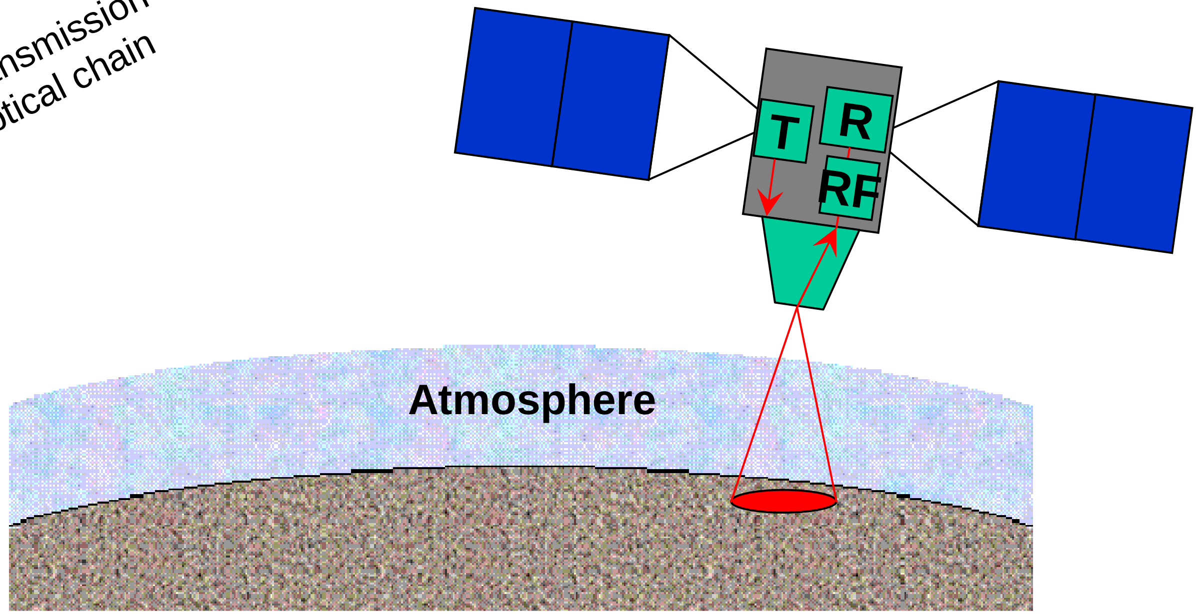
Return power: the lidar equation

$$P_R = P_T \cdot \varepsilon_T \cdot \varepsilon_R \cdot \varepsilon_{RF} \cdot L^2_{Atm,tot} \cdot \frac{\rho_S \cdot A_R}{\pi \cdot R^2}$$

- P_R, P_T: Received and transmitted power
- $\varepsilon_T \cdot \varepsilon_R \cdot \varepsilon_{RF}$: Transmission coefficients optical chain
- $L^2_{Atm,tot}$: Total atmospheric transmission
- ρ_S: soil albedo
- A_R: Receiving telescope area
- R: distance



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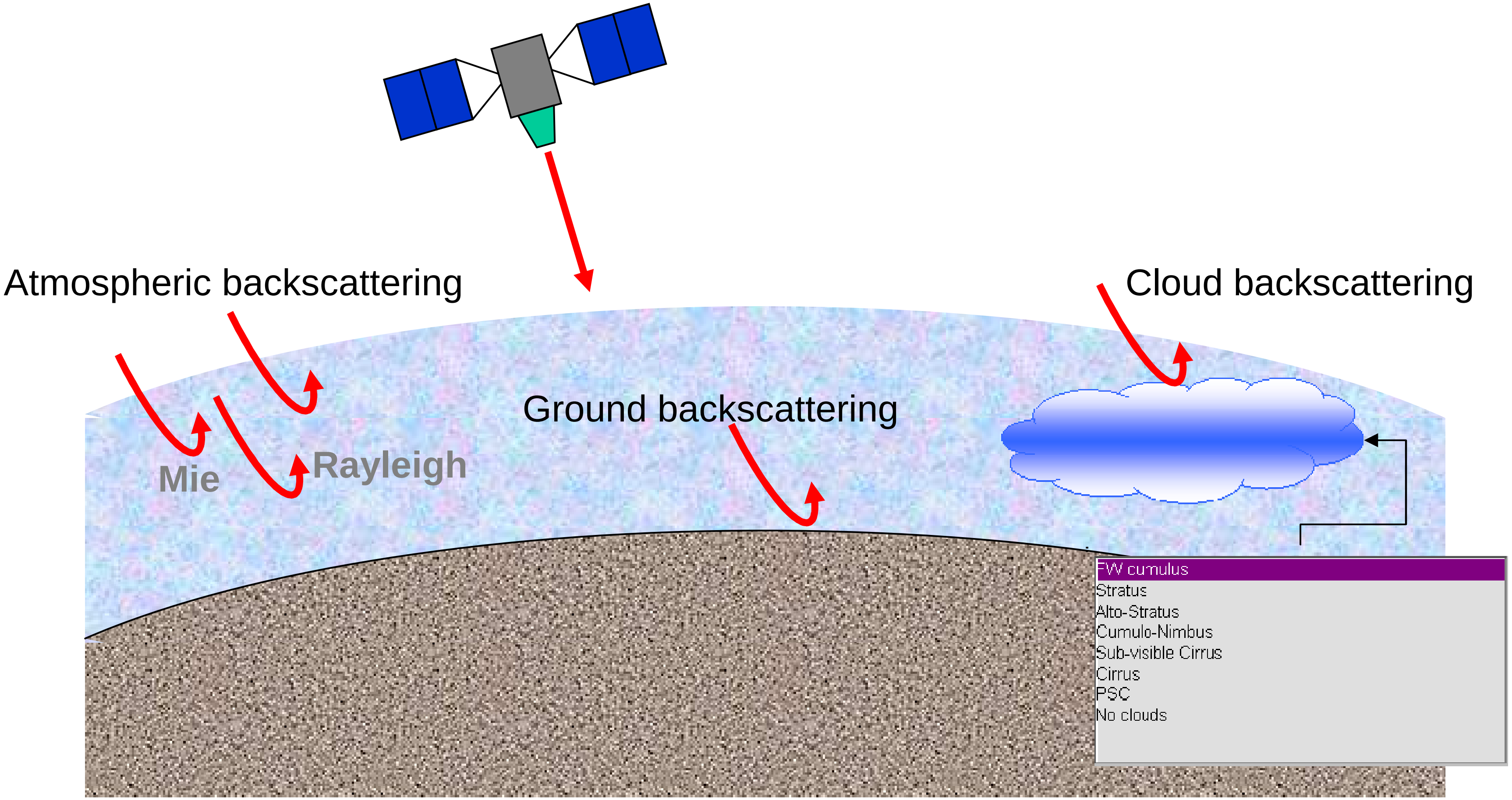
Background radiation

Signal backscattered radiation (with signal extinction)



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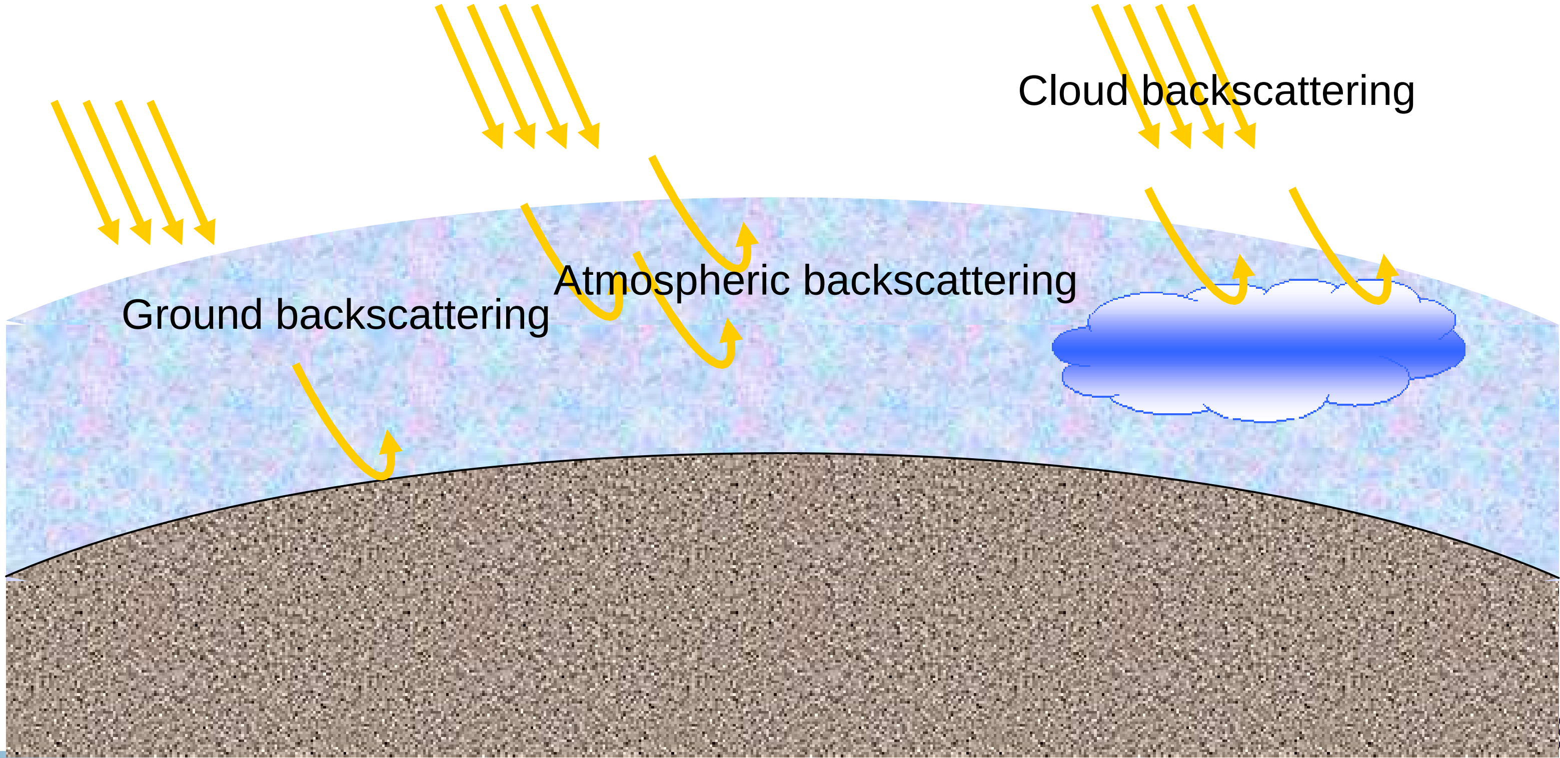
Background radiation

Solar backscattered radiation

$$P_B = P_{B,Surf} + P_{B,Atm}$$



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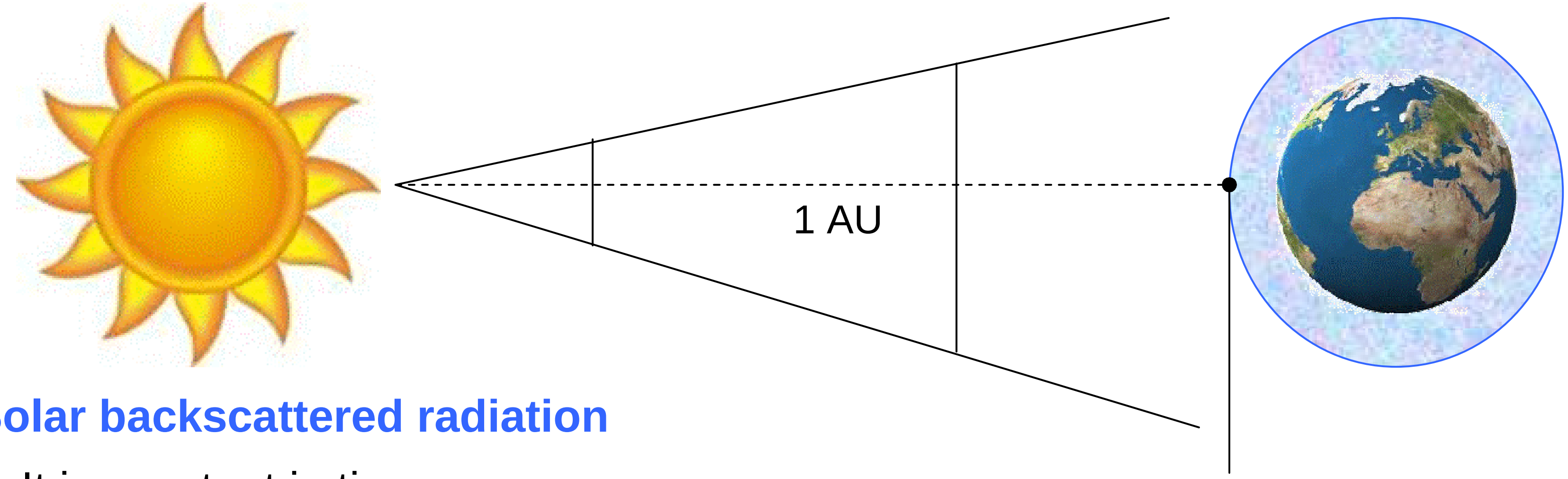
Background radiation

Wehrli model

Wehrli model (1985) gives Sun irradiance at 1 AU (Earth), outside atmosphere.



Solar backscattered radiation

- It is constant in time
- Requires narrow (detector) FOV
- Requires high spectral resolution filter
- Observations with high Sun aspect angle preferable

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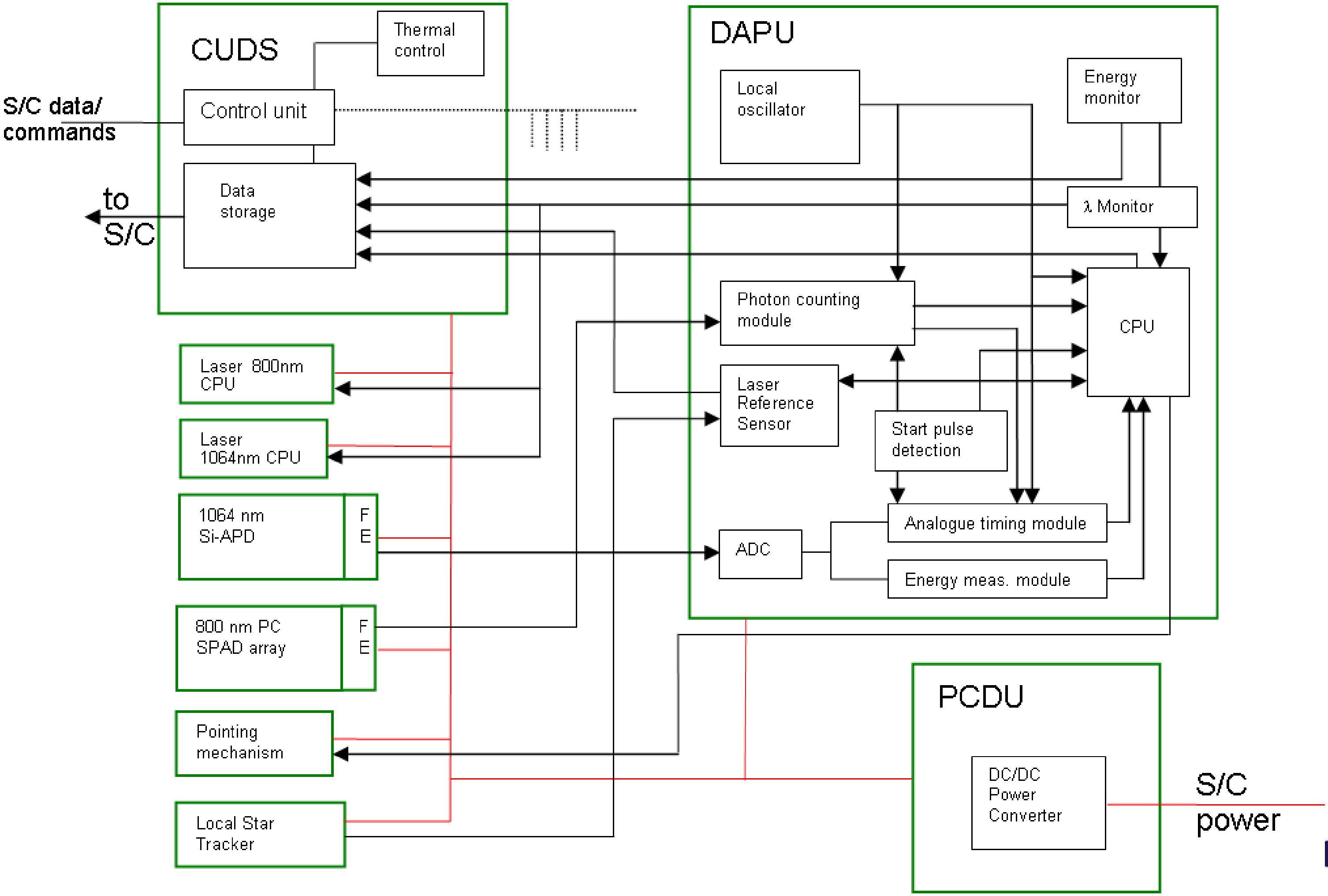
Avionic functional scheme

CUDS : Control Unit and Data Storage
DAPU : Data Acquisition and Processing Unit
PCDU: Power Control and Distribution Unit



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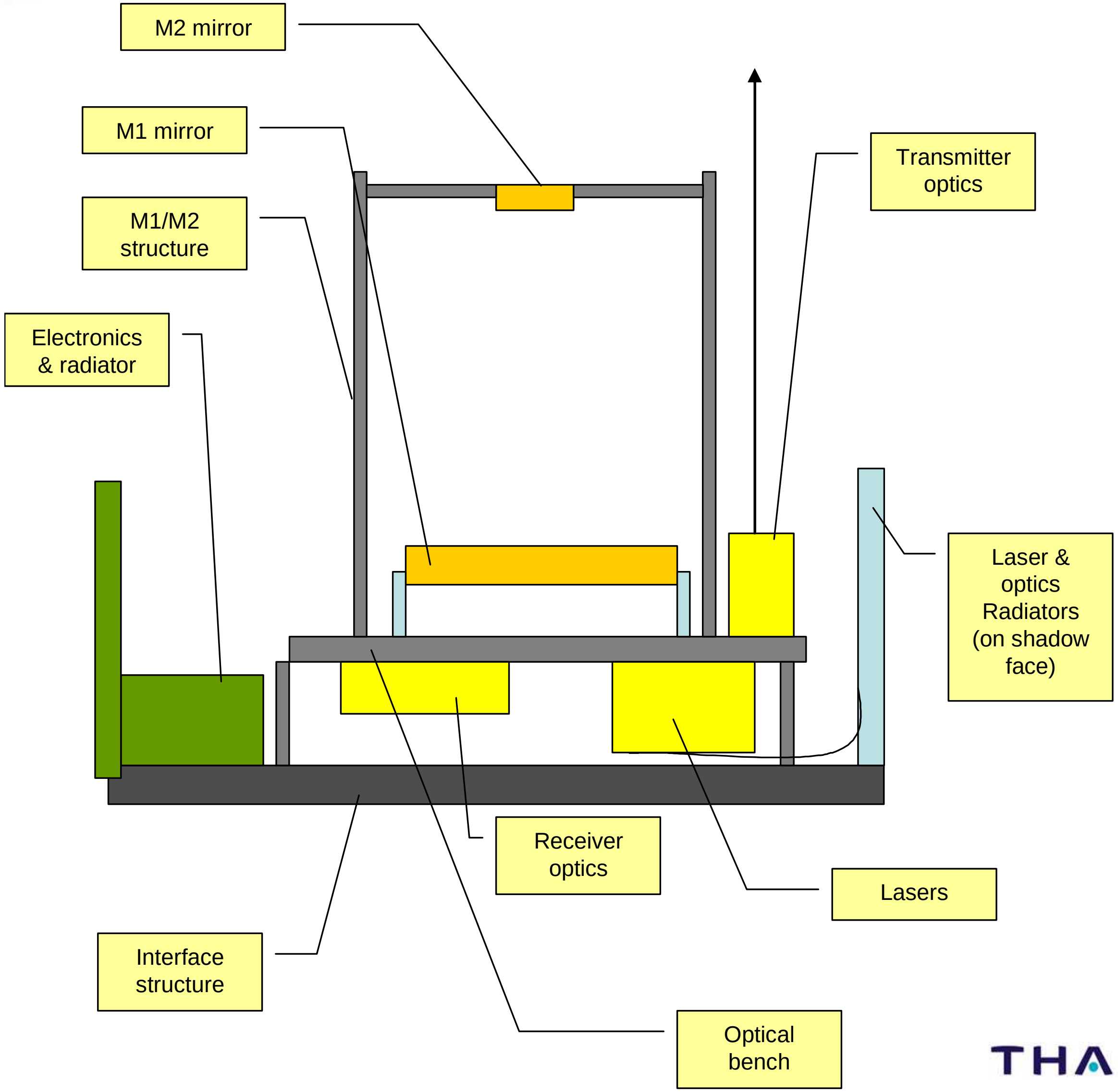
Guidelines for Opto-mechanical and thermal architecture

Typical optical elements position tolerances for a space optical system: 10-100μm

The temperature variation that causes such length variation of a 10cm Al bar corresponds to 4C – 40C → careful thermal control is required



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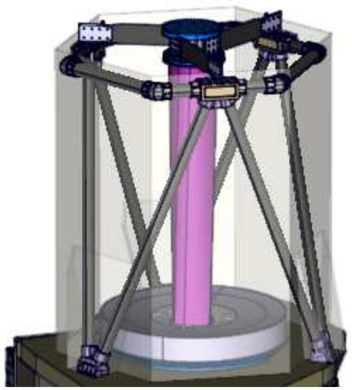
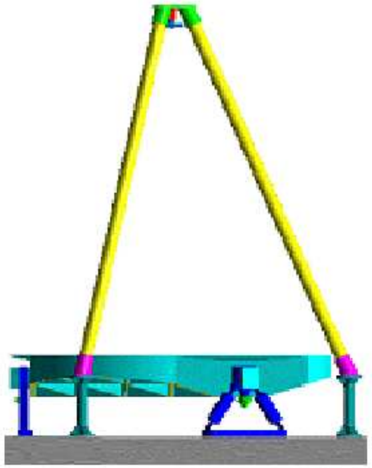
Telescope

- 1m class telescope → low weight, stable materials and optimized thermal control.
- Examples of possible choices: M1 Zerodur mirror, ceramic or invar (or other low Coefficient of Thermal Expansion material) M2 supporting structure
- M2 supporting structure geometry: truss, central mast or tripods type
- The M1 mirror can be interfaced with optical bench through invar mounts.



Ceramic Trusses M1/M2 structure



Tripods M1/M2 structure

Central Mast M1/M2 structure

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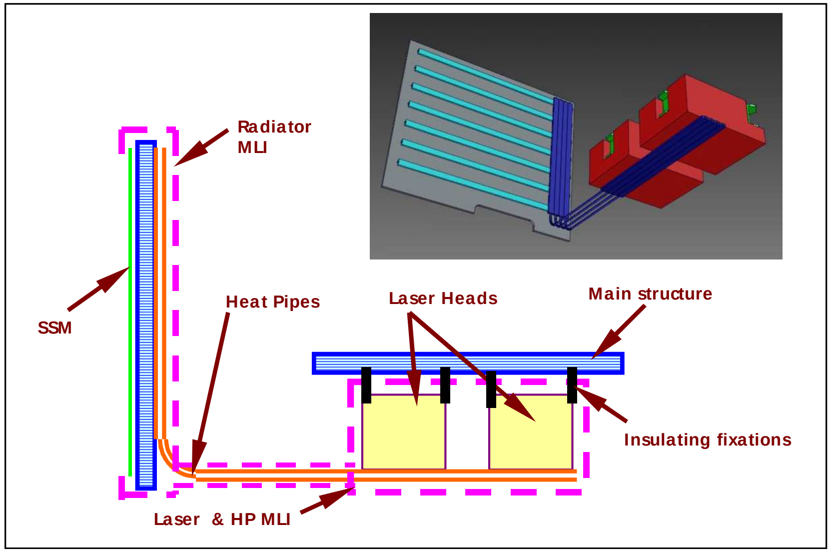
Thermal control

- Provides a homogeneous and stable environment to the telescope cavity
- MLI blankets for radiative insulation from the environment,
- Low conductive fixations for the mirrors
- Proper heating regulation concept.
- Ensure the rejection of the large dissipation at the laser head levels. Shadow face needed
- Use of heat pipes
- A first option uses conventional two-directional L-shaped heat pipes, which are connected on one end to the laser cold plate and on the other end to the radiator heat pipes
- Dissipating 150W of a laser head will require about 1 m² radiator



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Examples of budgets

Mass budget: 700kg

Power budget: depending on selected laser concept

	Power [W]
with Alexandrite Laser	380
with the possible future evolution of Alexandrite Laser	360
with OPO source at 800 nm	650
with Nd:YAG 532 nm laser	770

Data rate budget

Total data per second	25	Mbps
Total data per second (compressed)	10	Mbps
Total data per day	860	Gb
Mean ground contact time	427	s
N. of contacts per day	10	
Total contact time per day	4270	s
Mean accumulated data between downloads	86	Gb
Mean required data rate capacity	0.2	Gbps
Maximum time without contacts	28500	s
Maximum accumulated data	280	Gb
Maximum data rate to ground	0.660	Gbps

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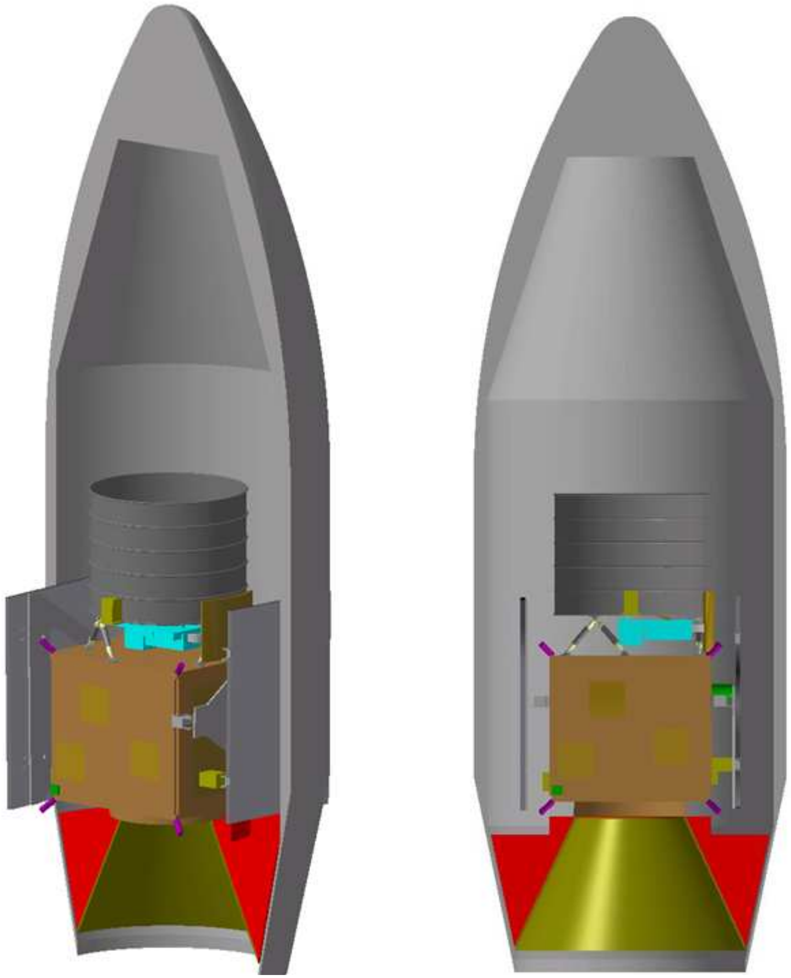
Example of lidar S/C view beneath Vega Fairing



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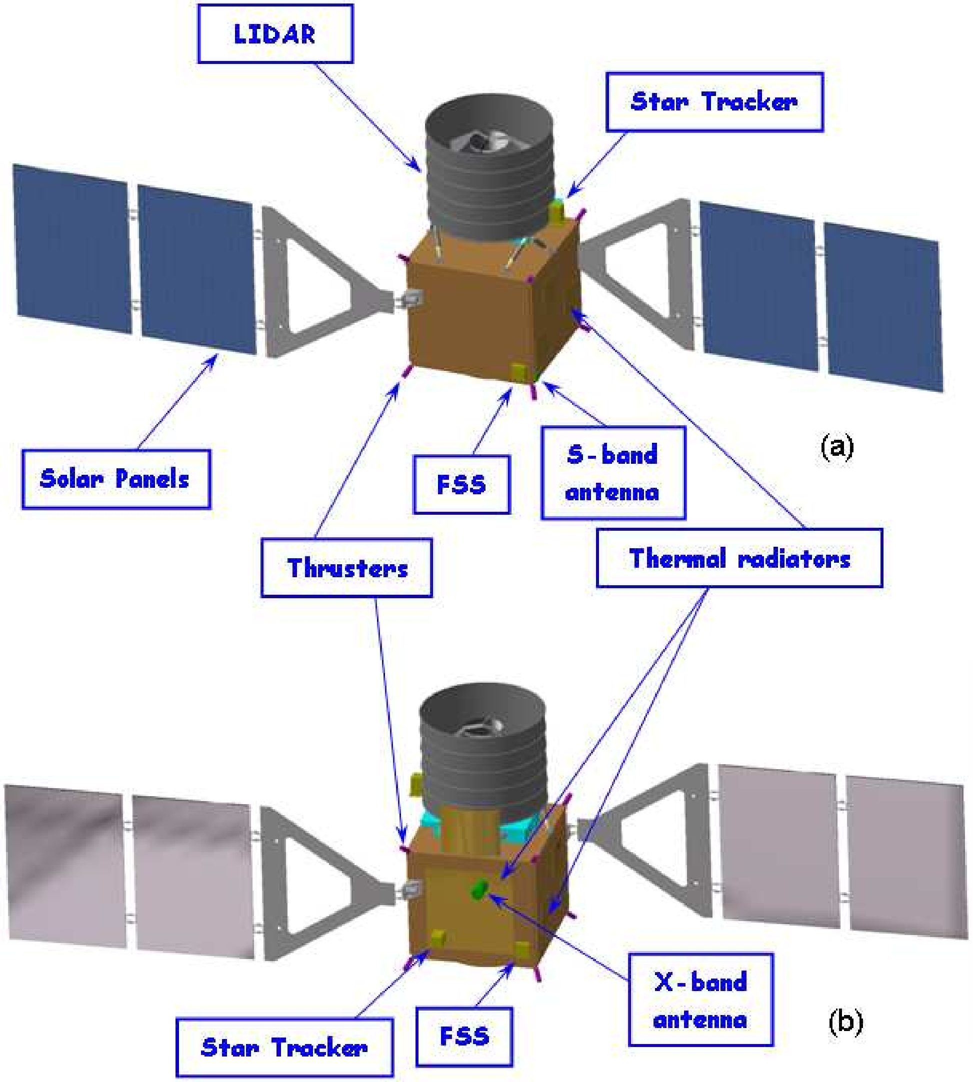
Example of lidar S/C sun and anti-sun views



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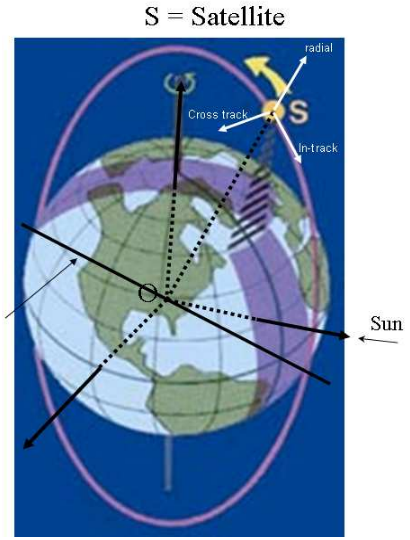
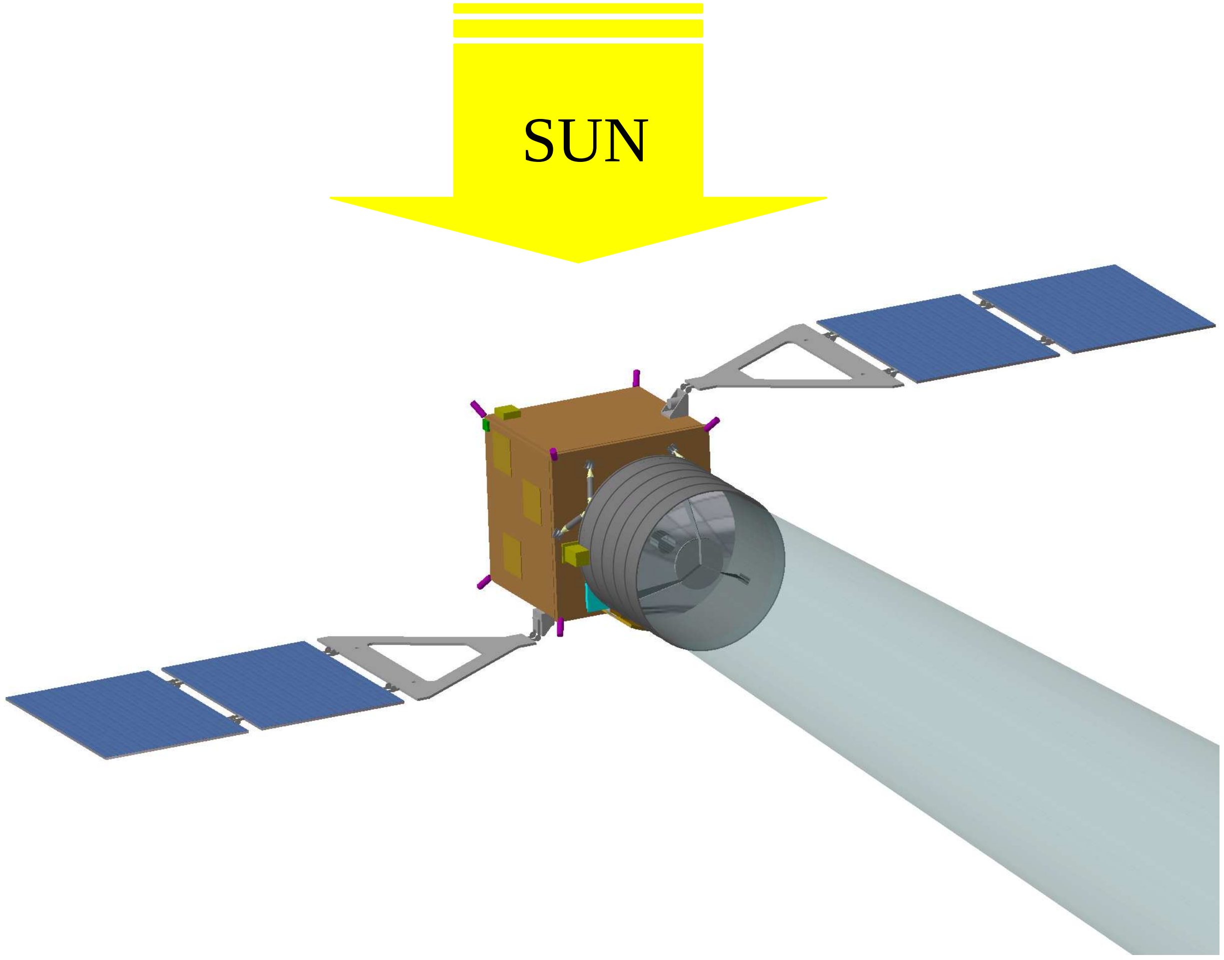
Example of lidar S/C operational view





S/C in sun synchronous orbit

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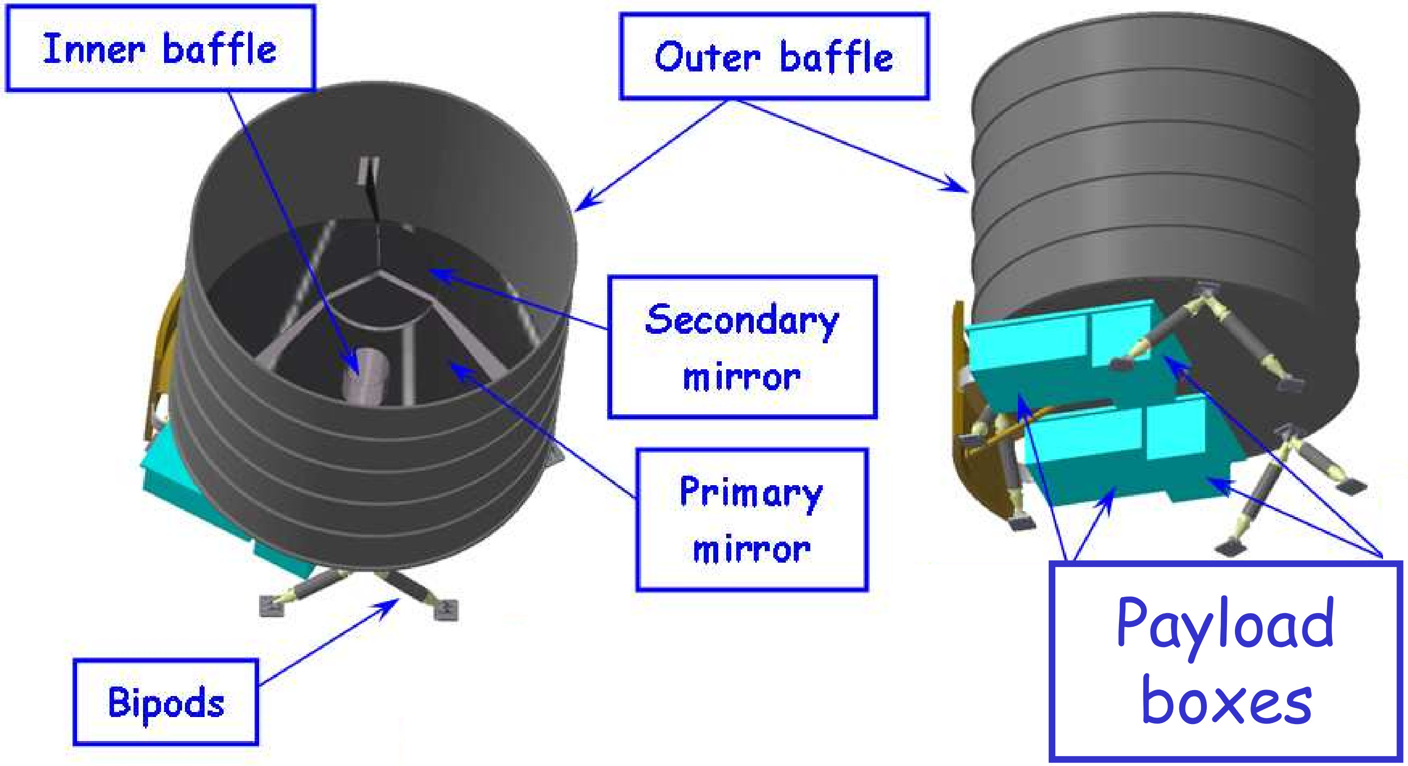
Example of lidar Payload



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Space altimeters

Instrument	Acronyms
GLAS (ICESat)	Geoscience Laser Altimeter System
DESDynI	Deformation, Ecosystem Structure and Dynamics of Ice
ATLAS (ICESat 2)	Advanced Topographic Laser Altimeter System
MOLA	Mars Orbiter Laser Altimeter
MLA	Messenger Laser Altimeter
NLR	NEAR Laser Ranging System
LOLA	Lunar Orbiter Laser Altimeter
BELA	BEpicolombo Laser Altimeter

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Laser Altimeters Assessment

Instrument	Unit	GLAS	DESDynI	ATLAS	MOLA	MLA	BELA	NLR	LOLA
Destination		Earth	Earth	Earth	Mars	Mercury	Mercury	Moon	Moon
Launched/Stopped		2003/2009	2021	2016	1997/2001	2011	2020	1996/1997	2009
Length of service	yr.	3	3 - 5	3 - 5	4	1	1	1	< 1
Along-track separation (*)	m	170	30	0.7	300	100 - 300	-	5	50
Vertical accuracy	m	0.03/0.30	1	0.03/0.30	meter level	-	10	6	0.1(precision)
Vertical resolution	cm	15	7.5-15	15	37.5	15	189	30	7.5
Instrument power consumption	W	330	336	-	34	-	43	16.5	34
Instrument dimensions	mm^3	1100x1400 x1100	-	-	-	300x300 x300	580x260 x200	375x216 x229	-
Instrument mass	kg	300	225	-	26	7.4	11	5	12.6
Data throughput	bps	450 K	4.8M/ <0.8M>	-	620	2.4 K	1130	6.4 to 51	-

(*): Along track – successive ground spots shift

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Parameter	Unit	GLAS	DES DynI	ATLAS	MOLA	MLA	BELA	NLR	LOLA
Active medium		Nd:YAG	-	Cr.Nd:YAG (Yb:YAG + Nd:YVO_4)	Nd:YAG	Cr:Nd:YAG	Cr:Nd:YAG	Cr:Nd:YAG	Cr:Nd:YAG
Laser configuration		O+2xA	-	O + A	O+2xA	O+ A	O+A	-	2xO one redundant
Mode of operation		Pass Q-sw	-	Pass Q-sw	Q-sw	Pass Q-sw	Pass Q-sw	Q-sw	Q-sw
Pump Diode		-	-	CW Pump	AlGaAs	GaInAsP	GaAs	-	-
Wavelengths	nm	1064 (532)	1064	532	1064	1064	1064	1064	1064
Laser mode		-	TEM_{00}	TEM_{00}	-	TEM_{00}	-	TEM_{00}	-
Pulse rate	Hz	40	240	10000	10	8	10	1/8, 1, 2, 8	28
Pulse width	ns	5 (6)	9	< 1.5	10	6	3.4	15	6 (+/-2)
Pulse energy	mJ	75 (35)	-	2 mJ @1064	42	20	50	15	2.7
Average power	W	3 (1.4)	-	0.3mW @1064	0.420	0.160	0.500	0.120	0.0756
Full divergence	μrad	110	-	-	370	80	25	235	100
Beam expansion		-	-	-	-	15	20	9.3	18
Spot on ground	m	70	25	10	160	~20 – 1200	50	11.8	5
Laser power consumption	W	-	65	-	-	8.7	-		

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Laser Altimeters Assessment

Instrument	Unit	GLAS	DESDynI	ATLAS	MOLA	MLA	BELA	NLR	LOLA
Telescope type		-	-	-	-	Four 115mm separate lenses	-	Dall_ Kirkham	Refractive
Telescope diameter	mm	1000	1000 - 1500	1000	500	4x115	125	88.9	140
Focal length	m	3.9	-	3.7	-	-	1.250	-	0.5
FOV	μrad	500 (160)	-	-	850	400	200	3000	400
Filter bandwidth	nm	0.8 (0.03)	-	0.03	2	0.7	0.42	7	0.8
Detector		Si APD (Si G-APD)	-	PMT	Si APD	Si APD	Si APD	Hybrid Si APD	APD
Detector QE		0.3 (0.6)	-	-	-	-	-	-	0.4
Sampling rate	samples /s	1 G	1-2 G	-	100 M	1 G	80 M	500 M	-
Time resolution	ns	1	<1	0.1	2.5	<1	12.5	2	0.5

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