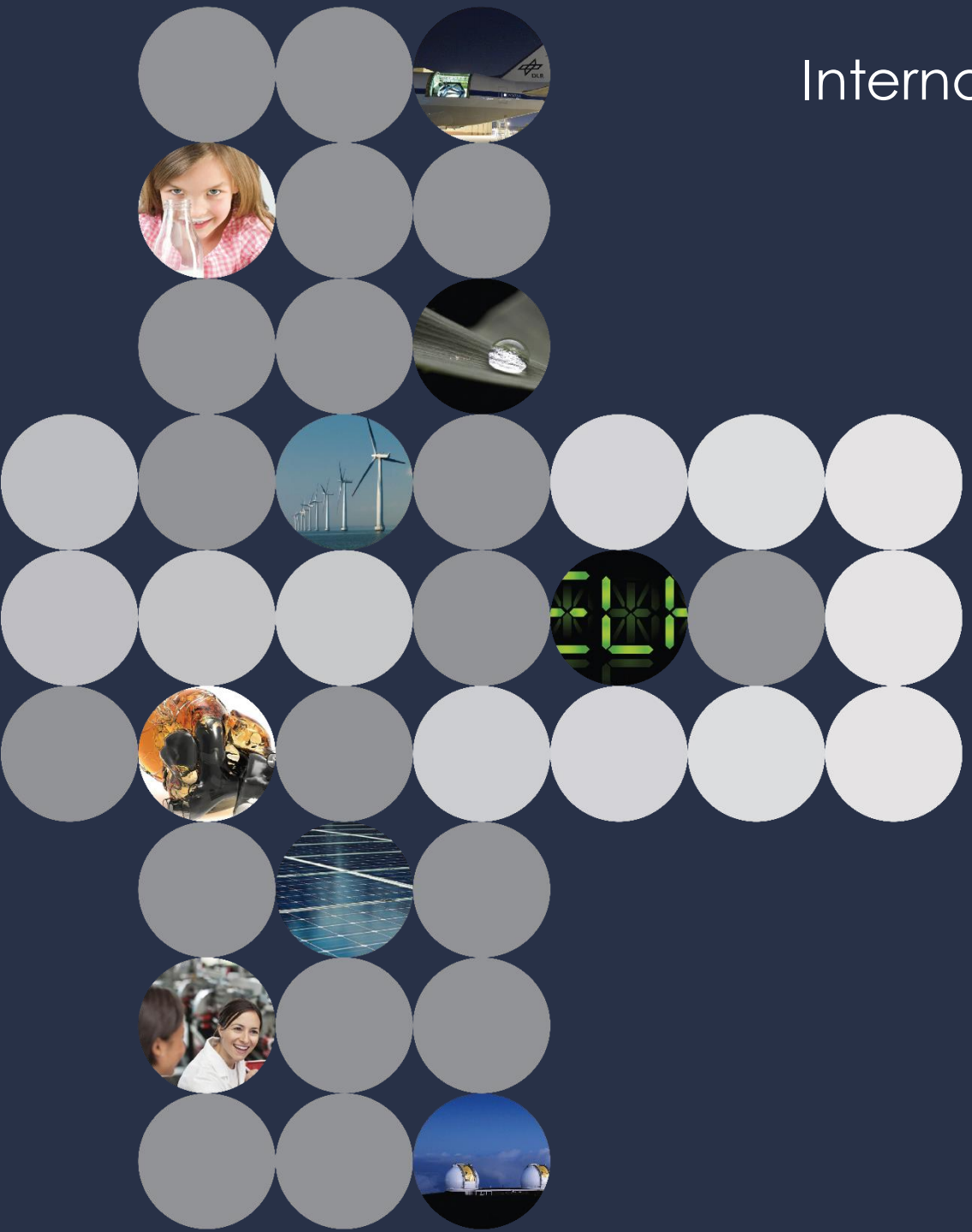

International SPAD Sensor Workshop 2020

LiDARs @ CSEM

SPAD for space
active debris removal and
exploration

Alexandre Pollini, LiDAR activity manager
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Matteo Perenzoni FBK
Christophe Pache CSEM

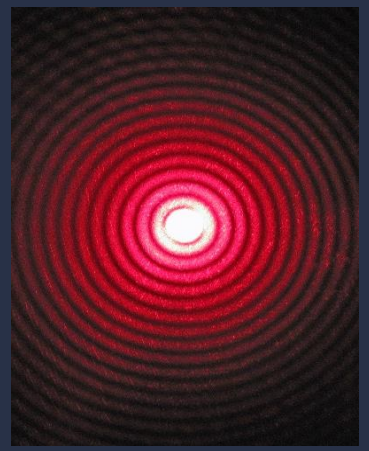
Presentation
outline

CSEM

LiDARs

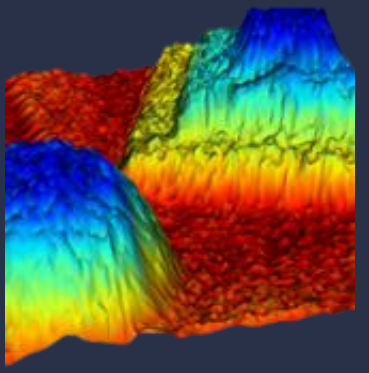
Technology partner

Space heritage



Applications

Solutions



Conclusion

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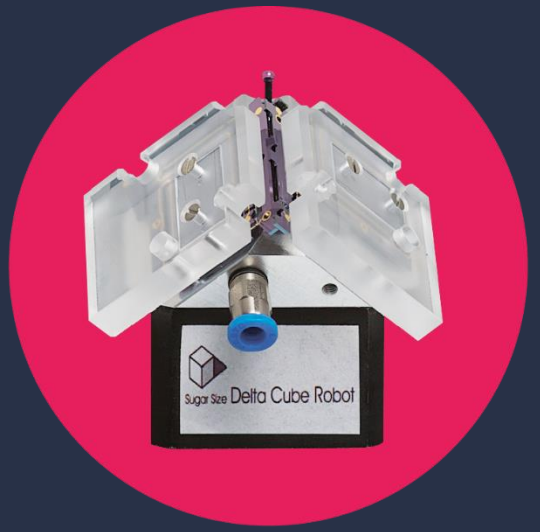
Our **mission**



Development and **transfer of mature technologies** to the industrial sector – in Switzerland, as a priority – in order to reinforce its competitive advantage.

- Cooperation agreements with established companies
- Encouraging the creation of start-ups

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CSEM at a glance

83.0

Turnover
(mio CHF)

43

Nationalities

437

Persons

43

New ventures

175

Industrial clients

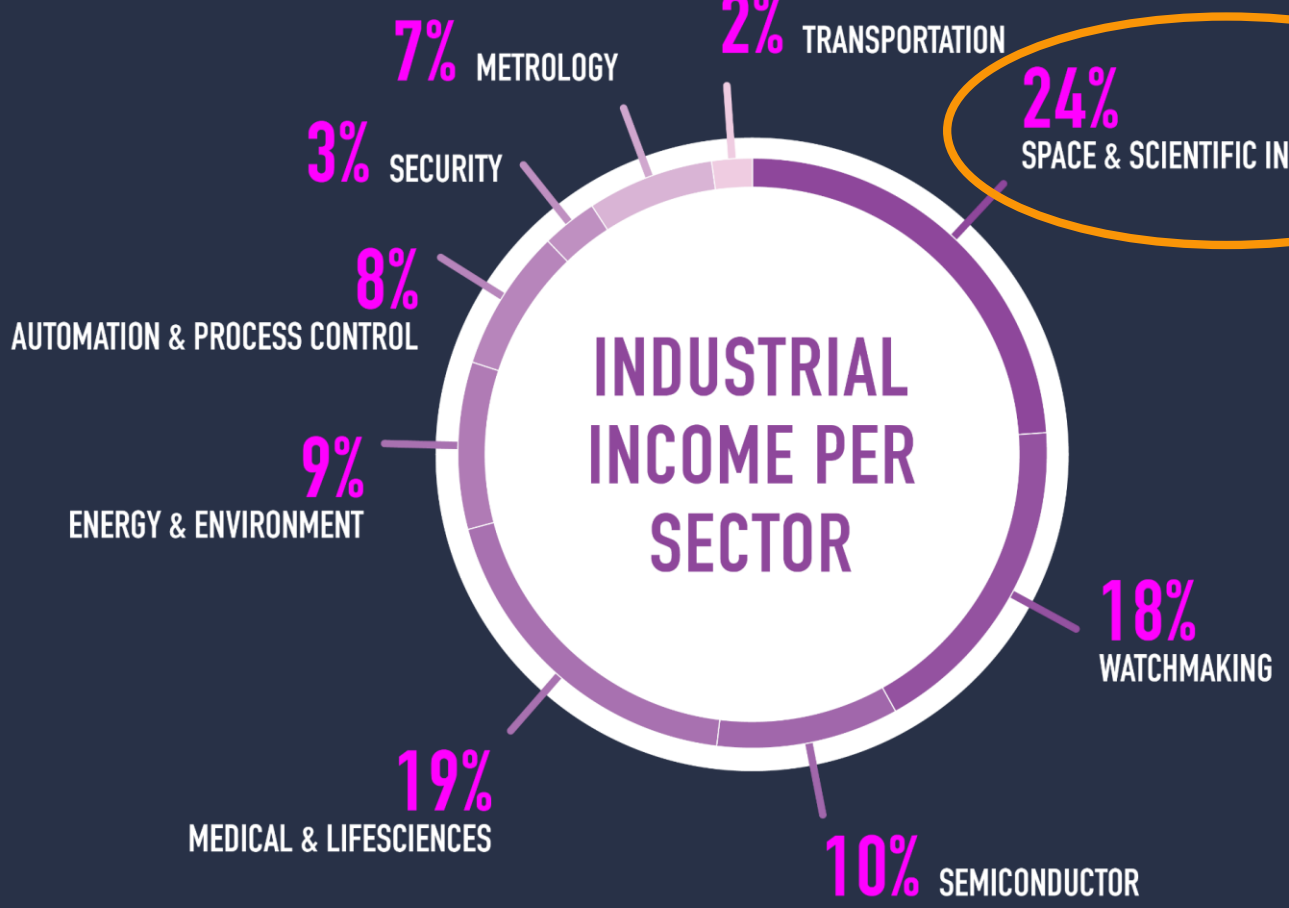
203

Patent families

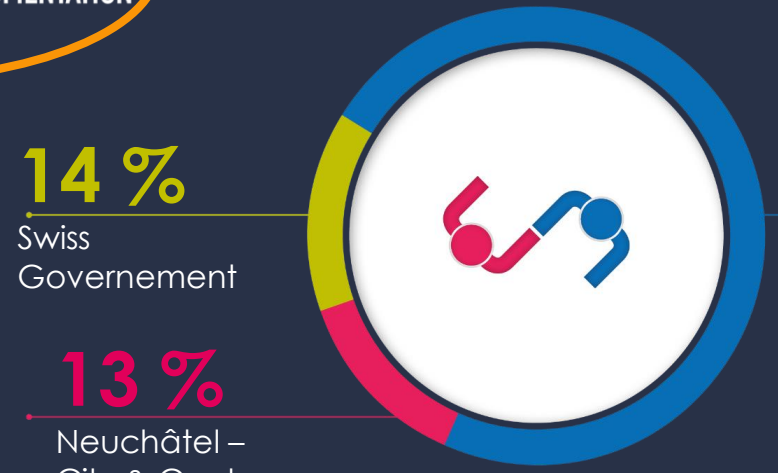
64

European
projects

Markets and shareholding



public-private



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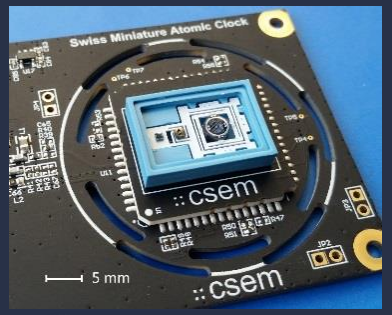
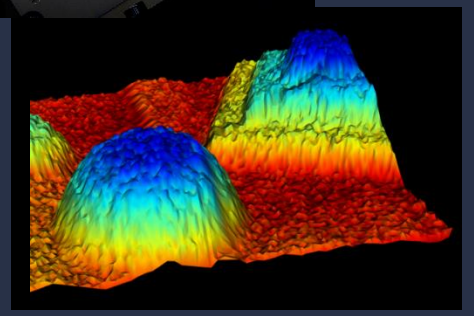
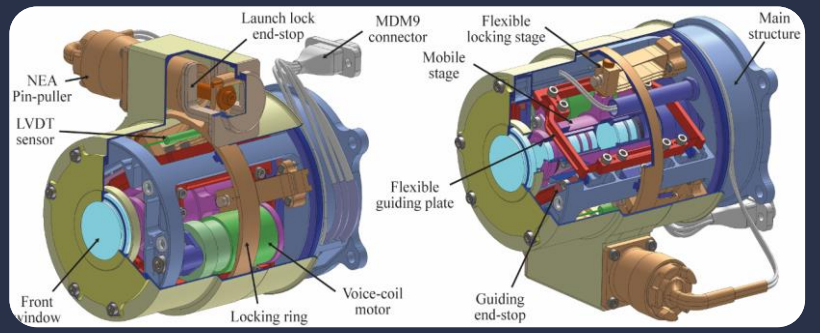
Scientific Instrumentation, Systems

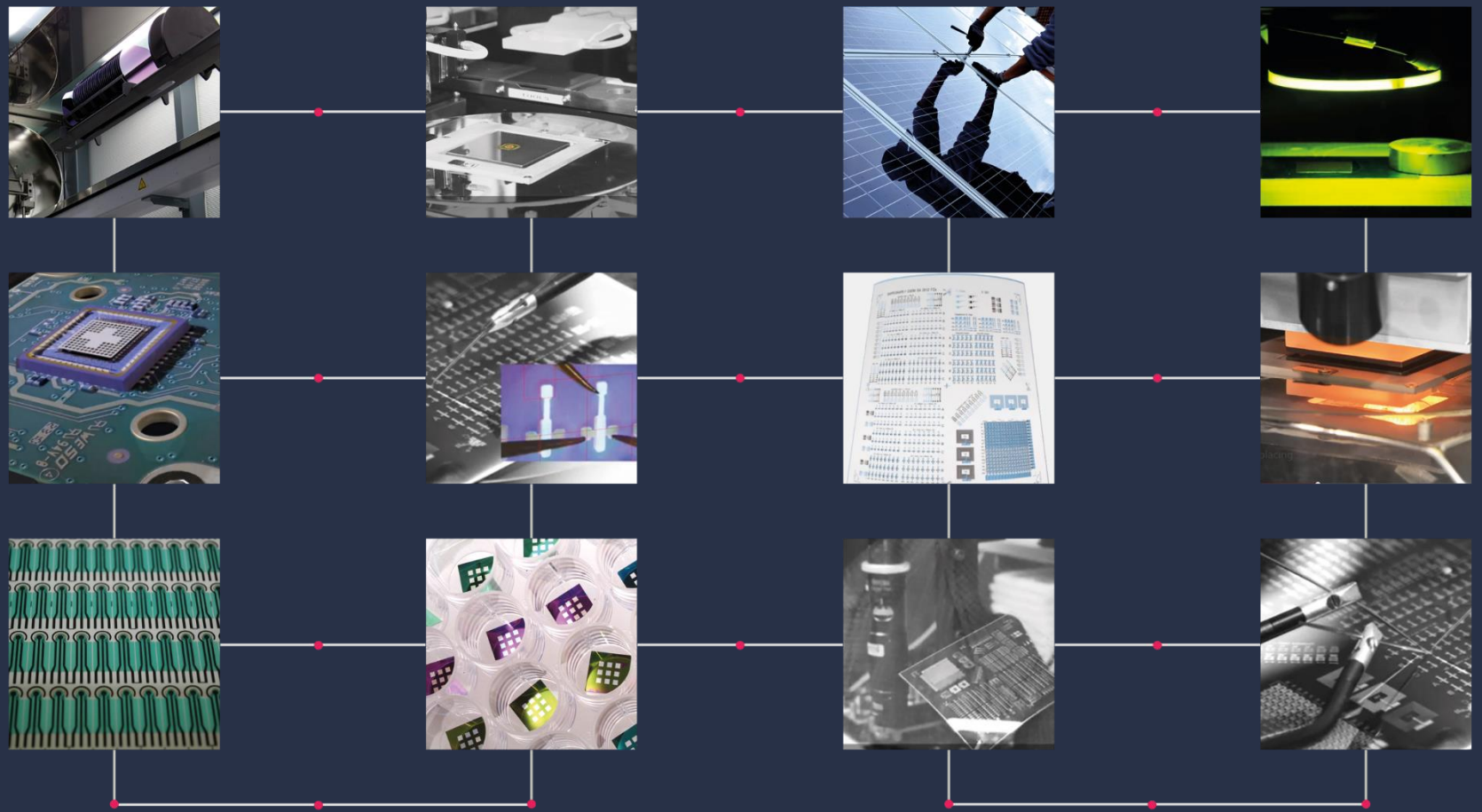
- Precision mechanisms
- Quantum devices
- Stabilized lasers
- AM
- LiDARs







Pillars of our success : technology and system integration



Technology

Integration

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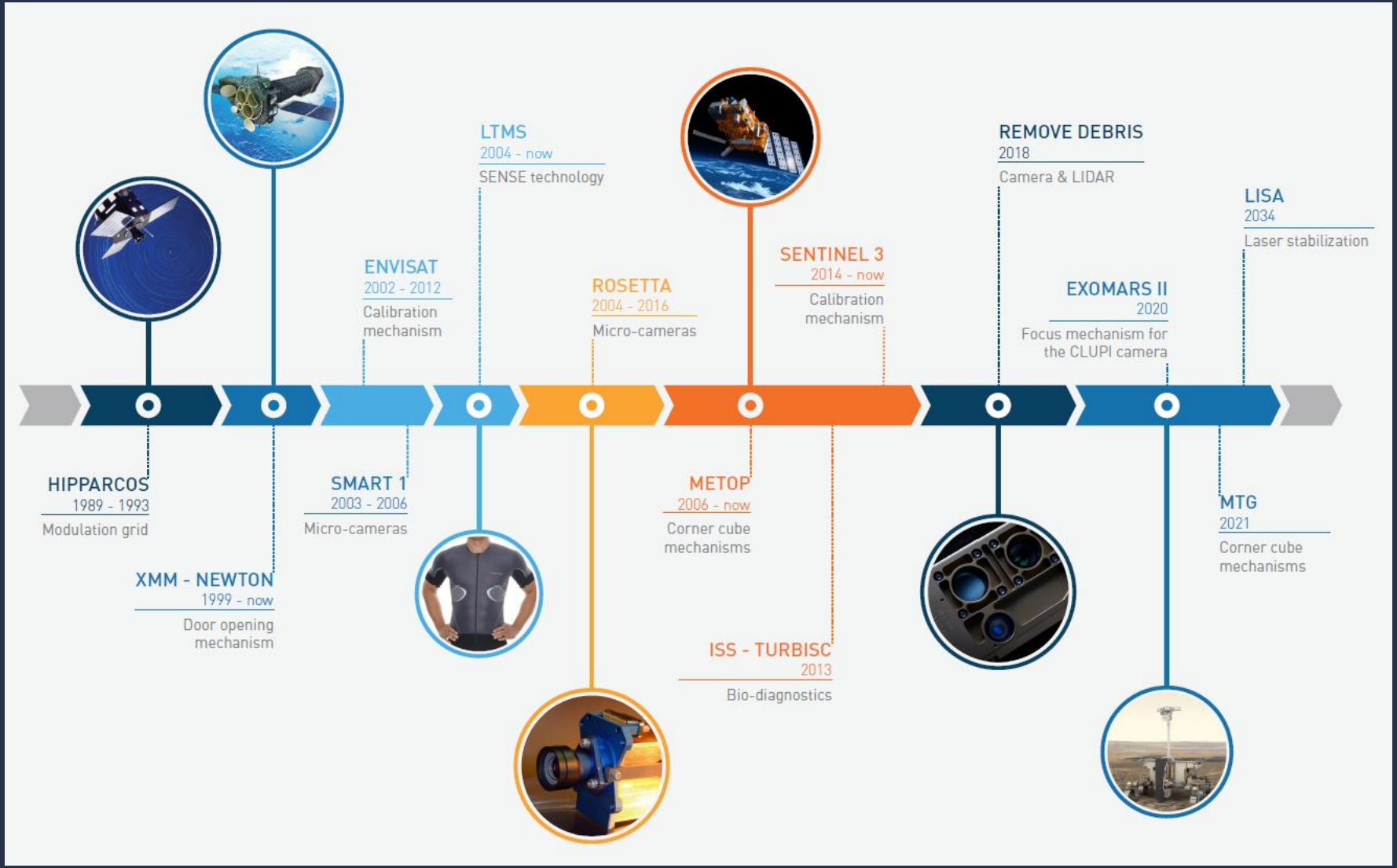
Space heritage



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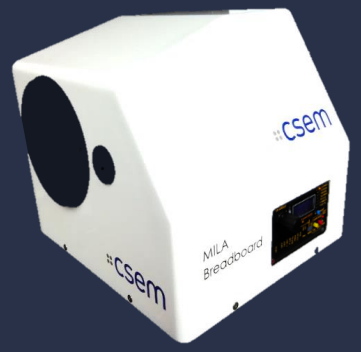
LiDARs

Space developments

MILA	CECILE	MILEB	RemoveDebris
			
ESA funded			EU-funded
dTOF TRL4	Compressive Sensing TRL3	dTOF TRL5	Flight model

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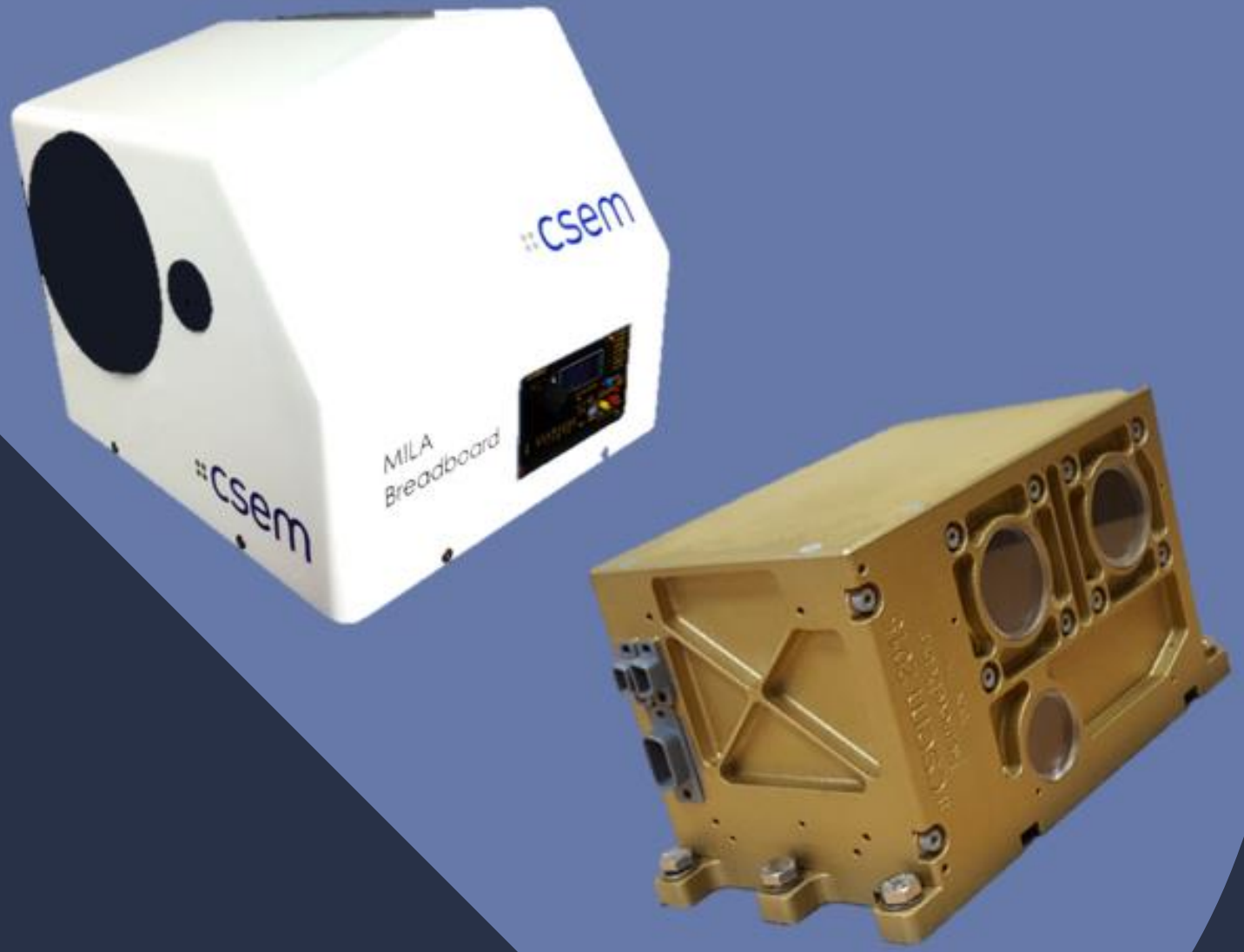
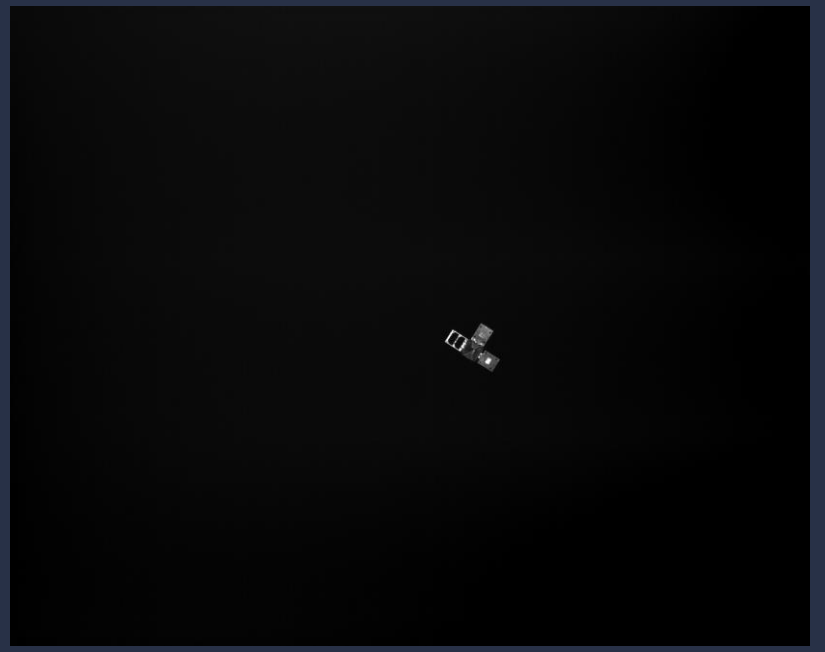
Applications



Space application: rendezvous

- E.g. Debris removal, satellite refuelling
- Limited processing ressources on-board
- High image **sparsity**
- Background changes
  (eclipse, no eclipse, Earth in background)
- Trajectory: complex
- SWaP: 10x10x10 cm^3, <2 kg, 5W
- 2 phases:



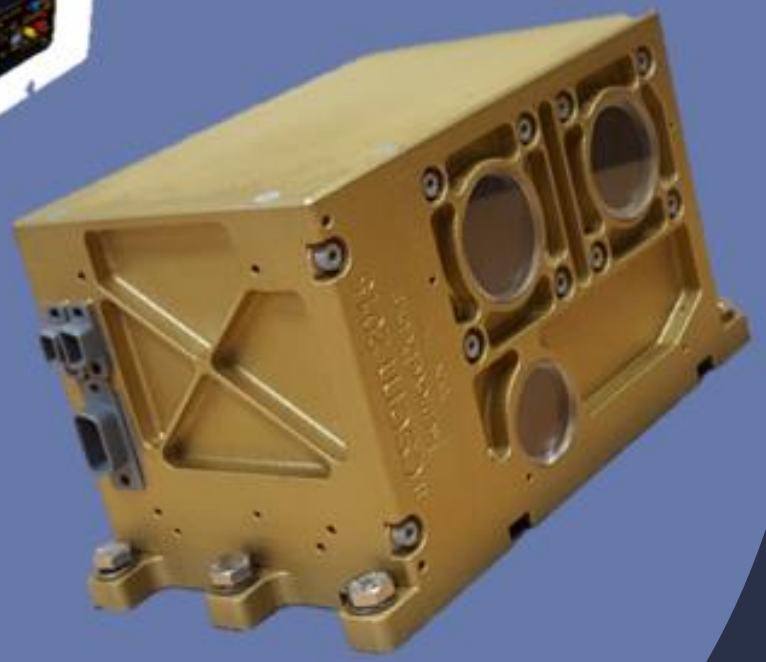
Distance Satellite - Target	**> 200m**	**< 200 m**
Relative Velocity	A few m/s	0 m/s
Main function	Distance measurement	Real-time profilling Identification
Accuracy	1 m	5 cm
Measurement rate	10 Hz	1 Hz
FOV	< 1°	> 20°

Exploration

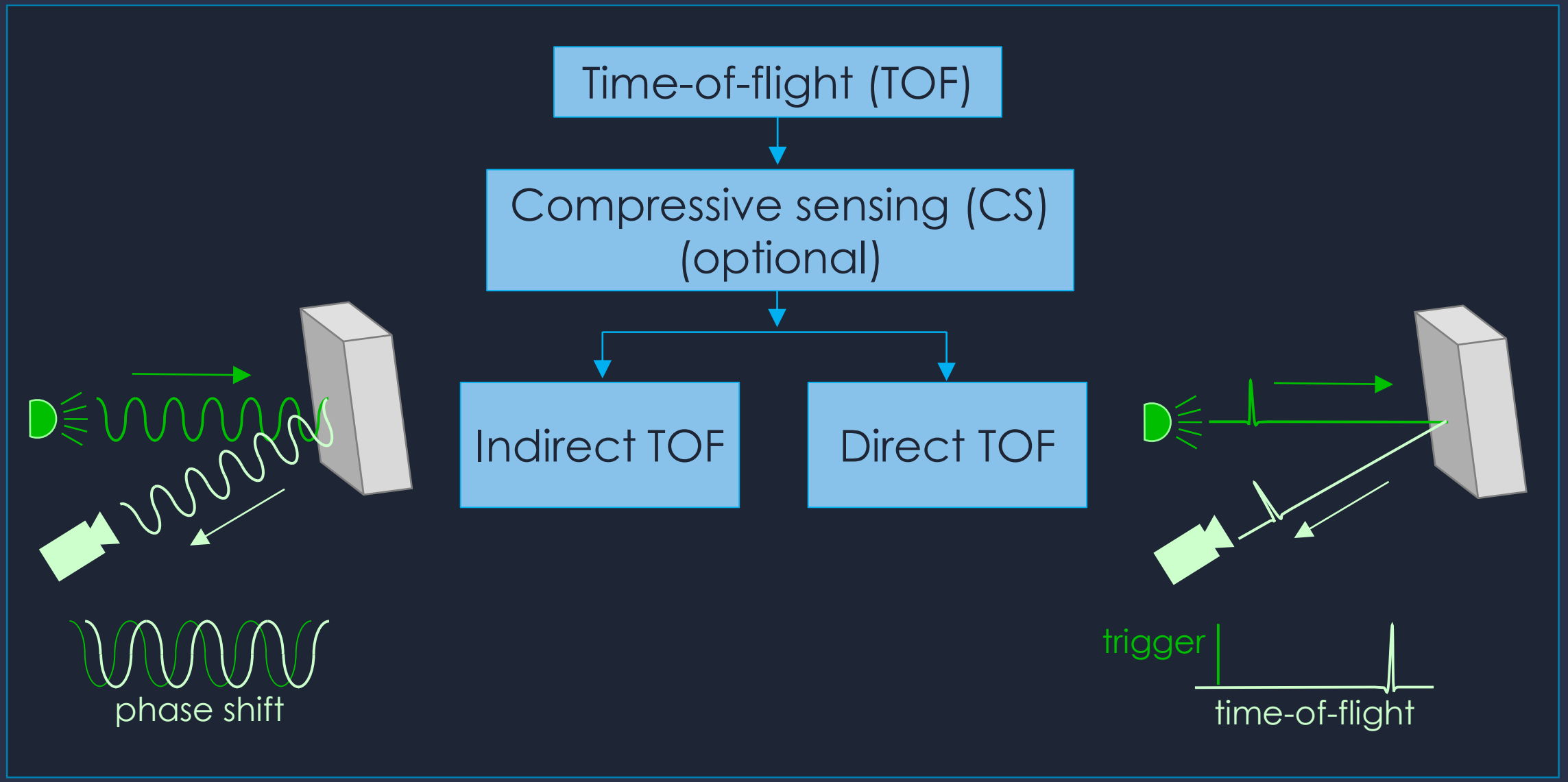
- E.g. landing on asteroids/Mars
- Limited processing ressources on-board
- Low image sparsity
- Background can be chosen
- Trajectory: linear
- SWaP: 20x20x20 cm3, <6 kg, 50W
- 3 phases:

Distance Satellite - Target	> 1000 m	500-1000 m	< 500 m
Relative Velocity	65 m/s	30 m/s	1 m/s
Main function	Distance measurement	Relative Attitude	Mapping Hazards detection
Accuracy	1 m	10 cm	5 cm
Measurement rate	10 Hz	1 Hz	1 Hz
FOV	< 1°		> 20°

Technology ingredients

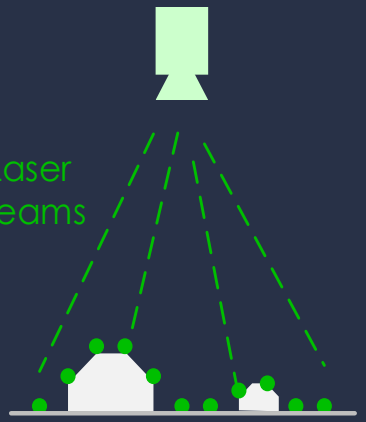


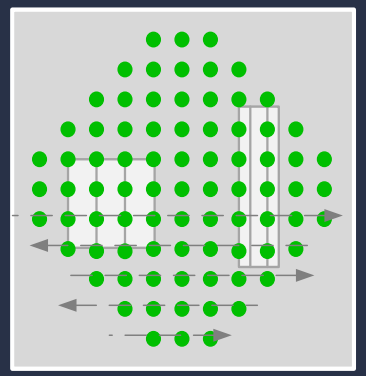
Indirect and direct time-of-flight



Speciality: Flash imaging LiDAR architecture

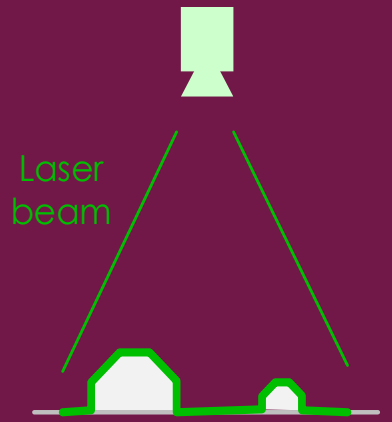
Scanning LiDAR

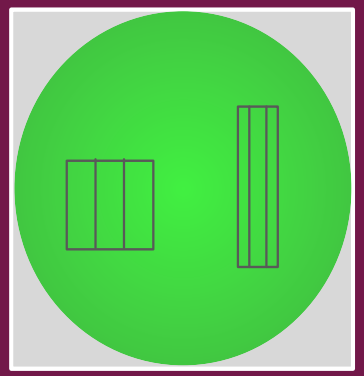




raster scan

Flash LiDAR





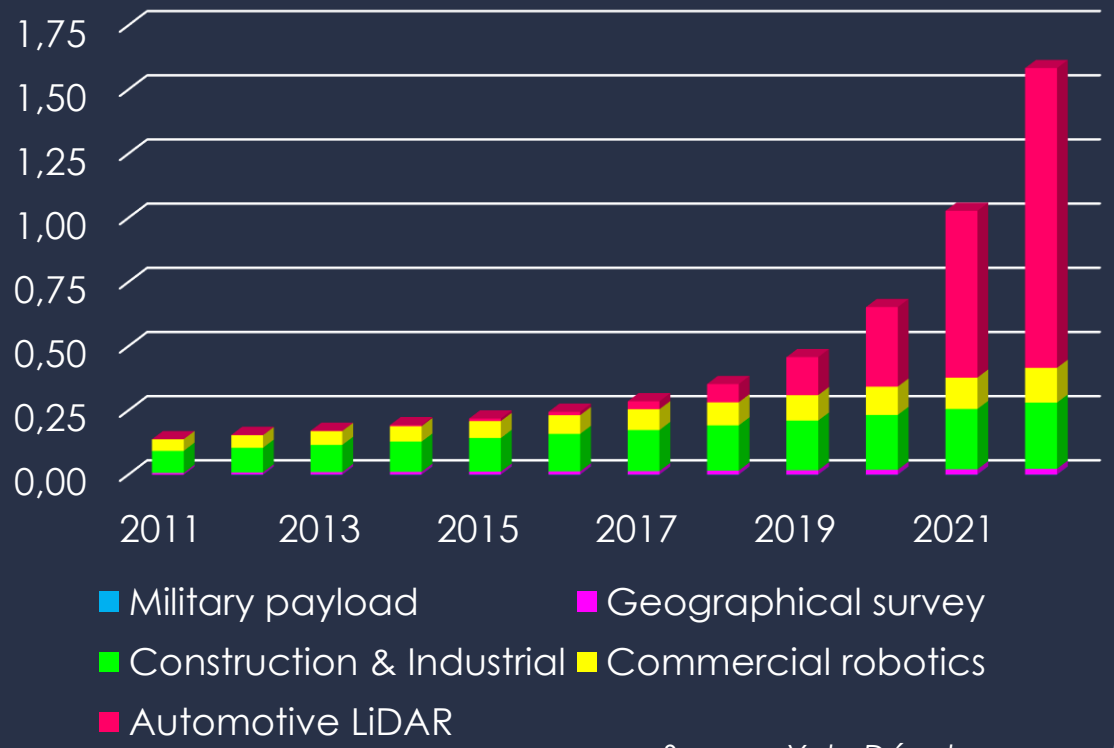
single snapshot

- Towards all solid-state
  - **Simplicity**: better integration, low cost
  - **Reliabiliy**: longer product lifetime
  - **Image quality**:
    robust against motion blur and vibrations
  - **High resolution**:
    diffraction-limited,
    not limited by scanning mechanism precision

Technology trend

- Towards **miniaturisation**
- **Automotive** market defines benchmarks
  1. All solid-state
  2. Low-cost
- Unmanned vehicles increase demand for LiDAR

LiDAR volume forecast in M units



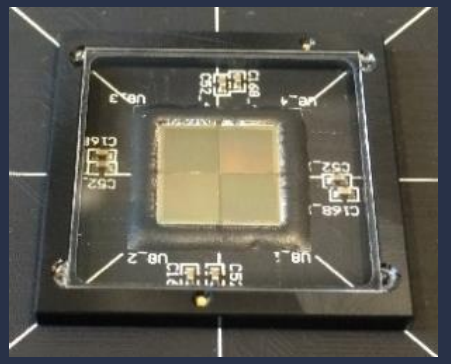
Source: Yole Développement

Automotive LiDAR architectures

Technology	direct TOF	FMCW		
Wavelength	800-900 nm	1500 nm		
Laser	VCSEL	pulsed solid-state	cw	
Detector	SPAD	SiPM	InGaAs	APD
Scanning	mechanical	MEMS	Flash / multi-beams	OPA

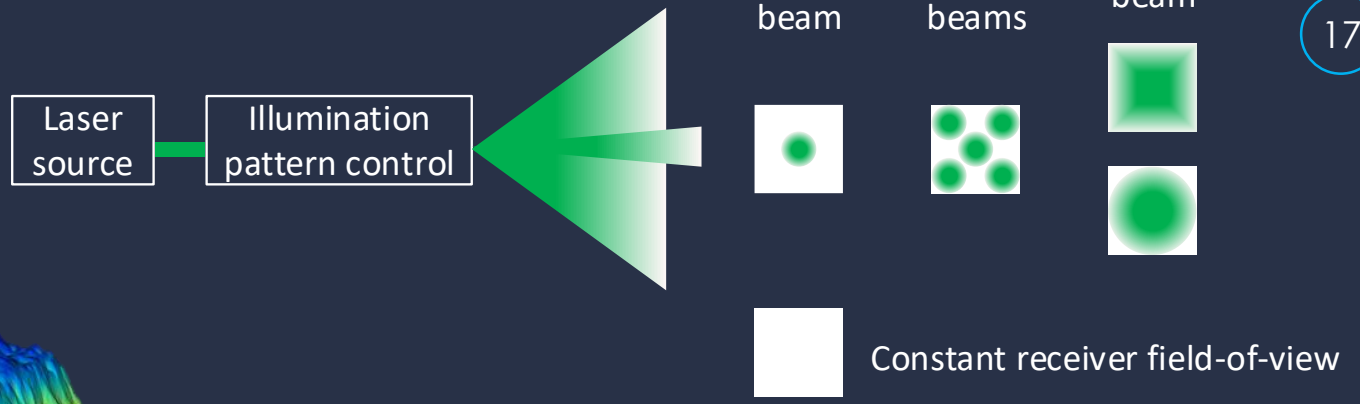
Versatile hybrid flash imaging LiDAR

- 2D Time-Of-Flight detector

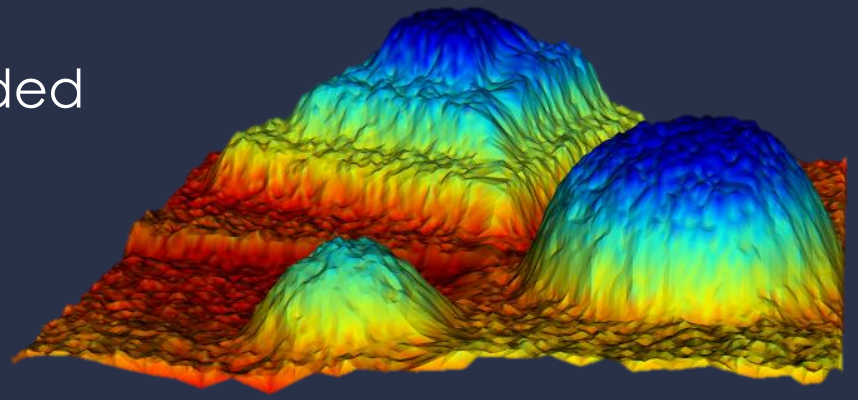


Focal plane array
(e.g. 4x detectors)

- Illumination pattern control



- Raw data embedded edge processing



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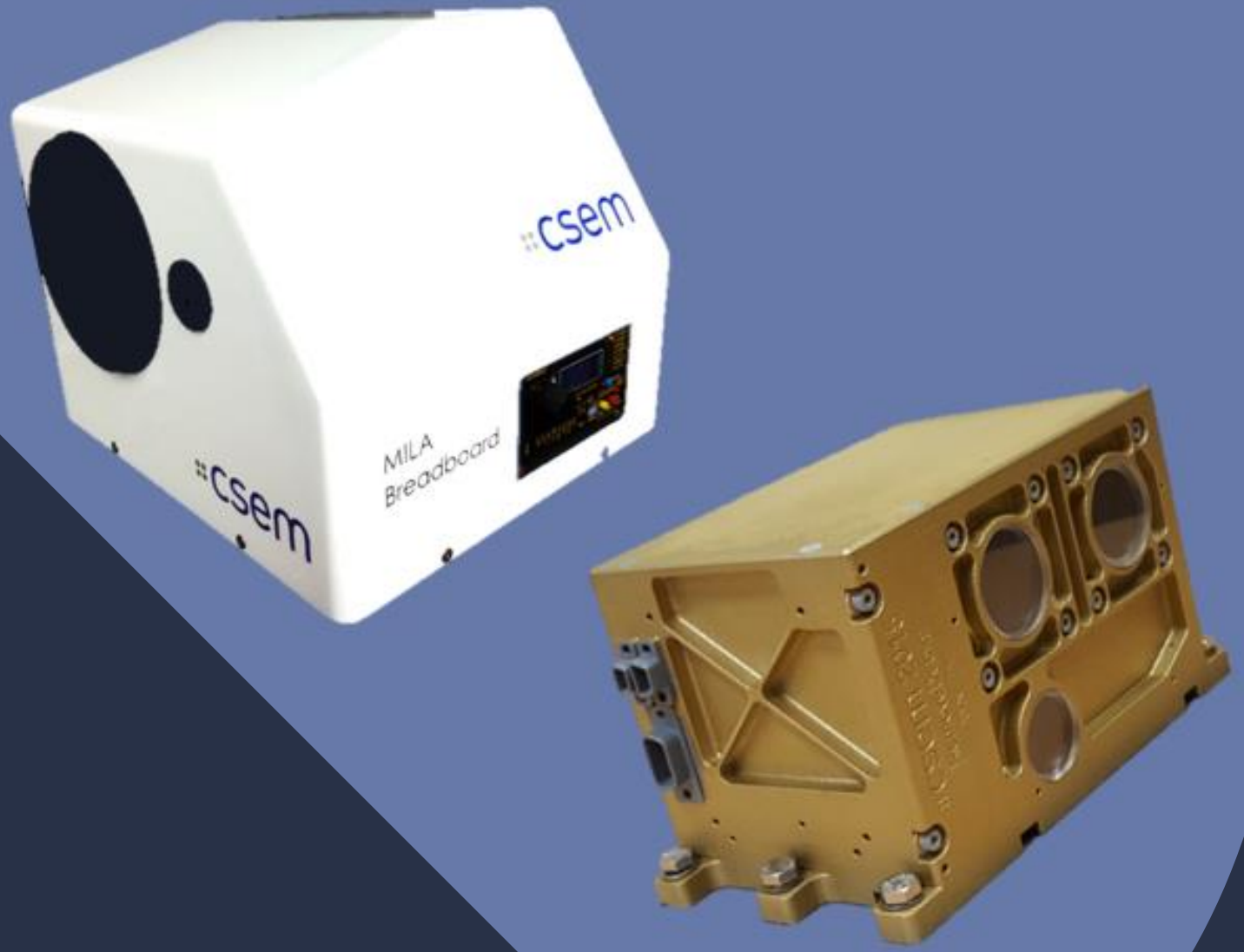
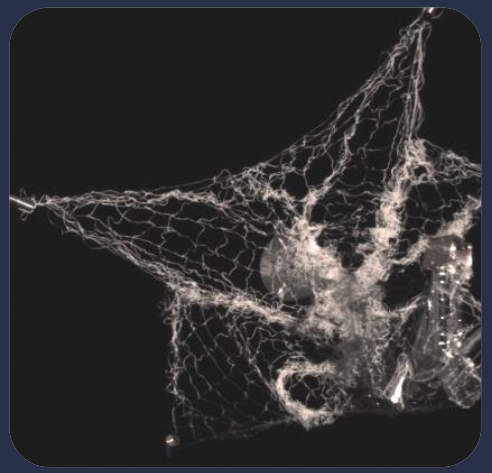
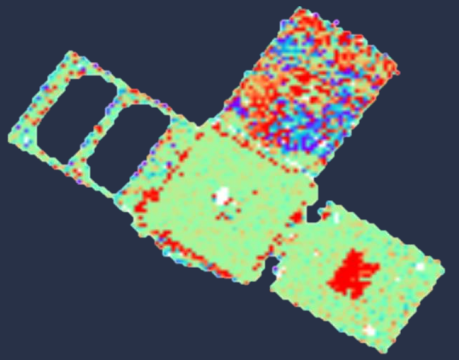
Solution for Rendezvous



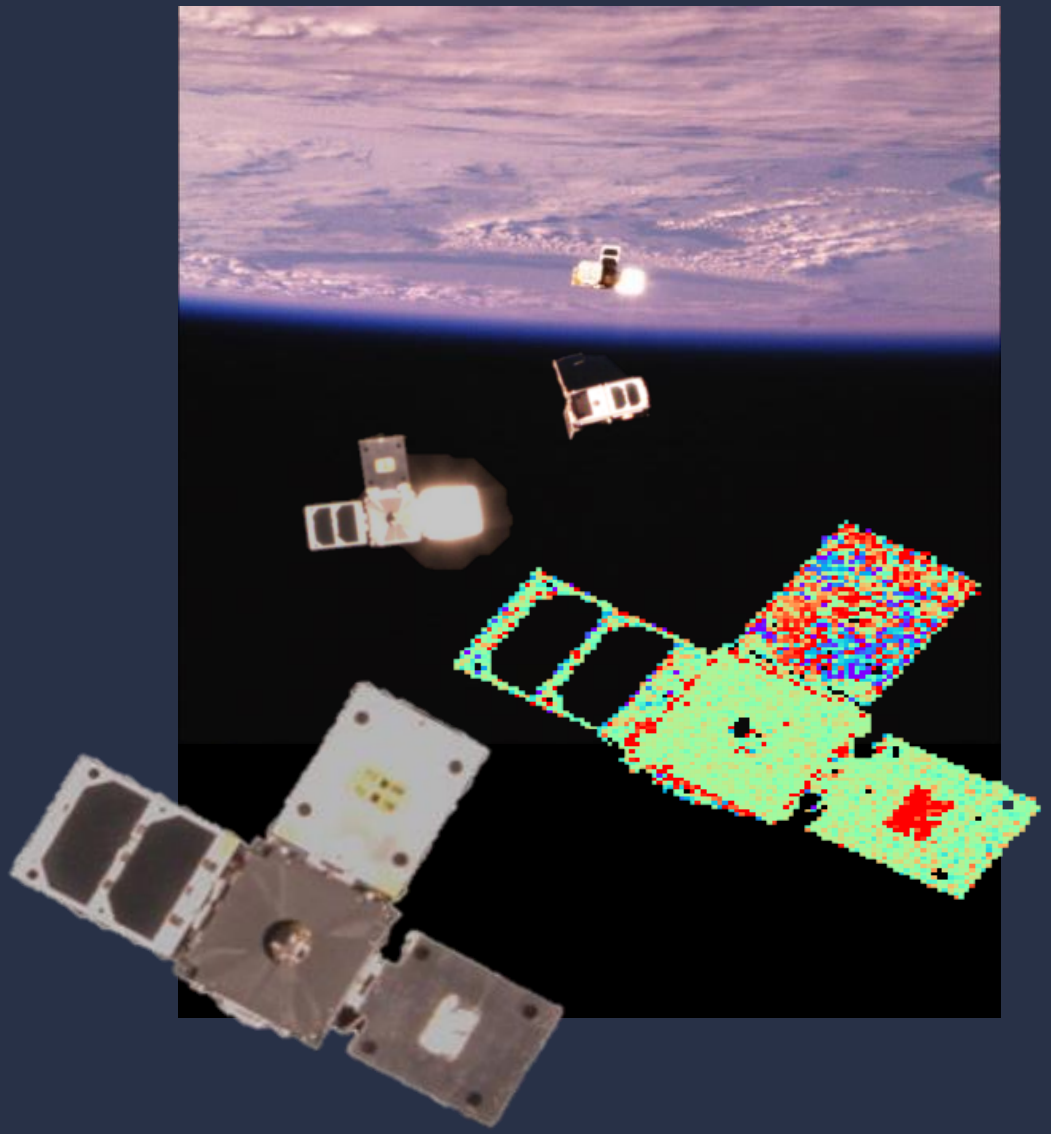
RemoveDebris

- A low-cost Active Debris Removal mission (EC)
- Launch with SpaceX 2 April 2018
- ISS tethering Dragon Capture 4 April 2018
- Released in space from ISS 20 June 2018
- Commissioning in-orbit June-August 2018
- Experiments: net, visual-based navigation, harpoon
- Mission end March 2019

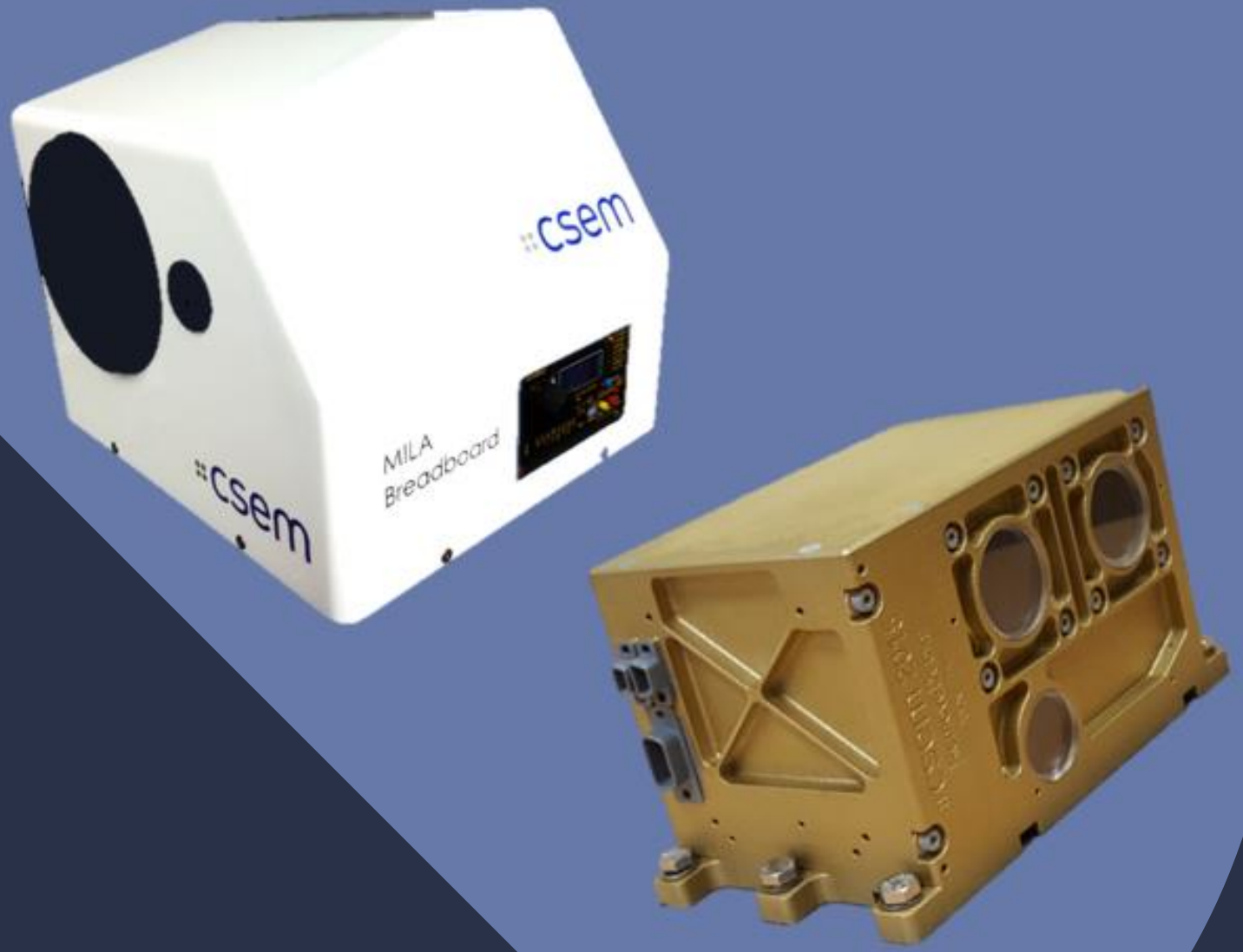




1. iTOF architecture
2. Parameters programmed several days in advance
3. Relative positioning debris-chaser to favor standard cameras



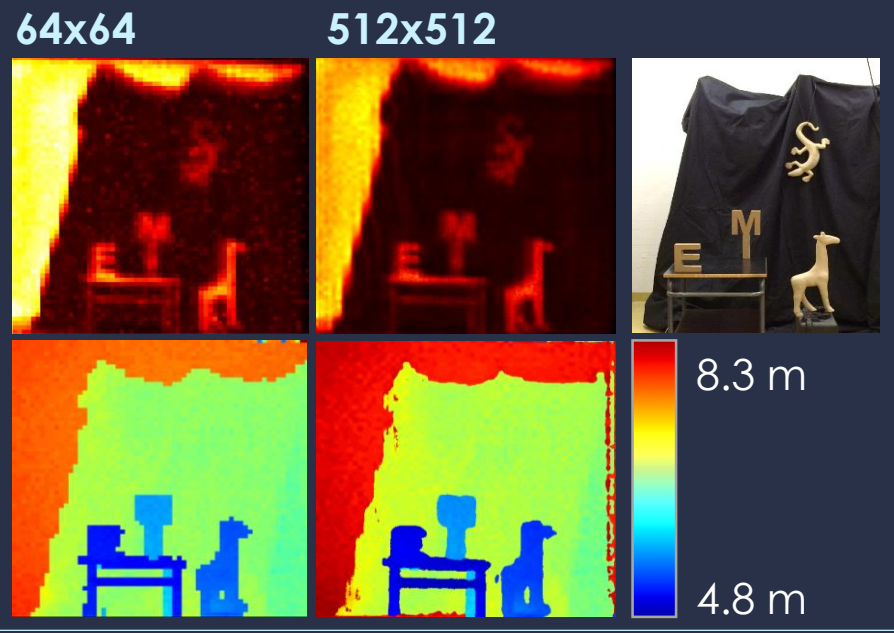
Compressive sensing



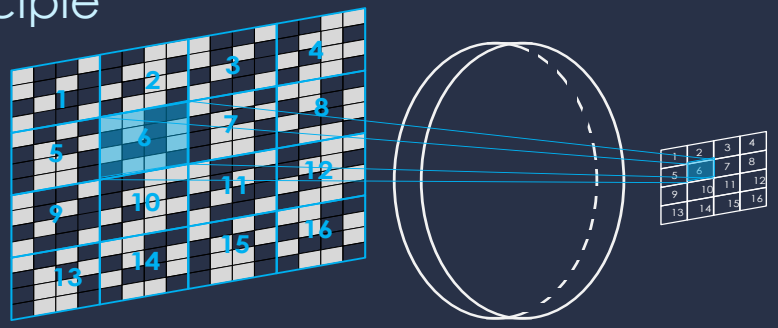
Flash Imaging LIDAR Compressive sensing

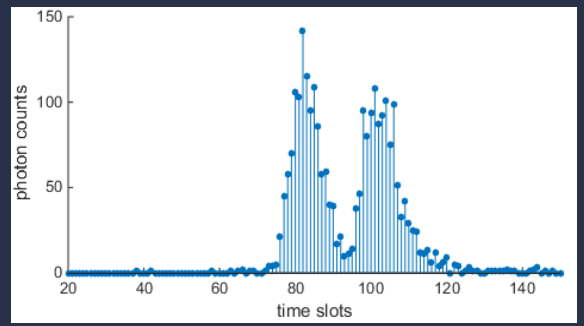
- Gain = Spatial resolution increase
- Cost =
  Increased complexity and
  power consumption

Results



Principle





N independent CS reconstructions

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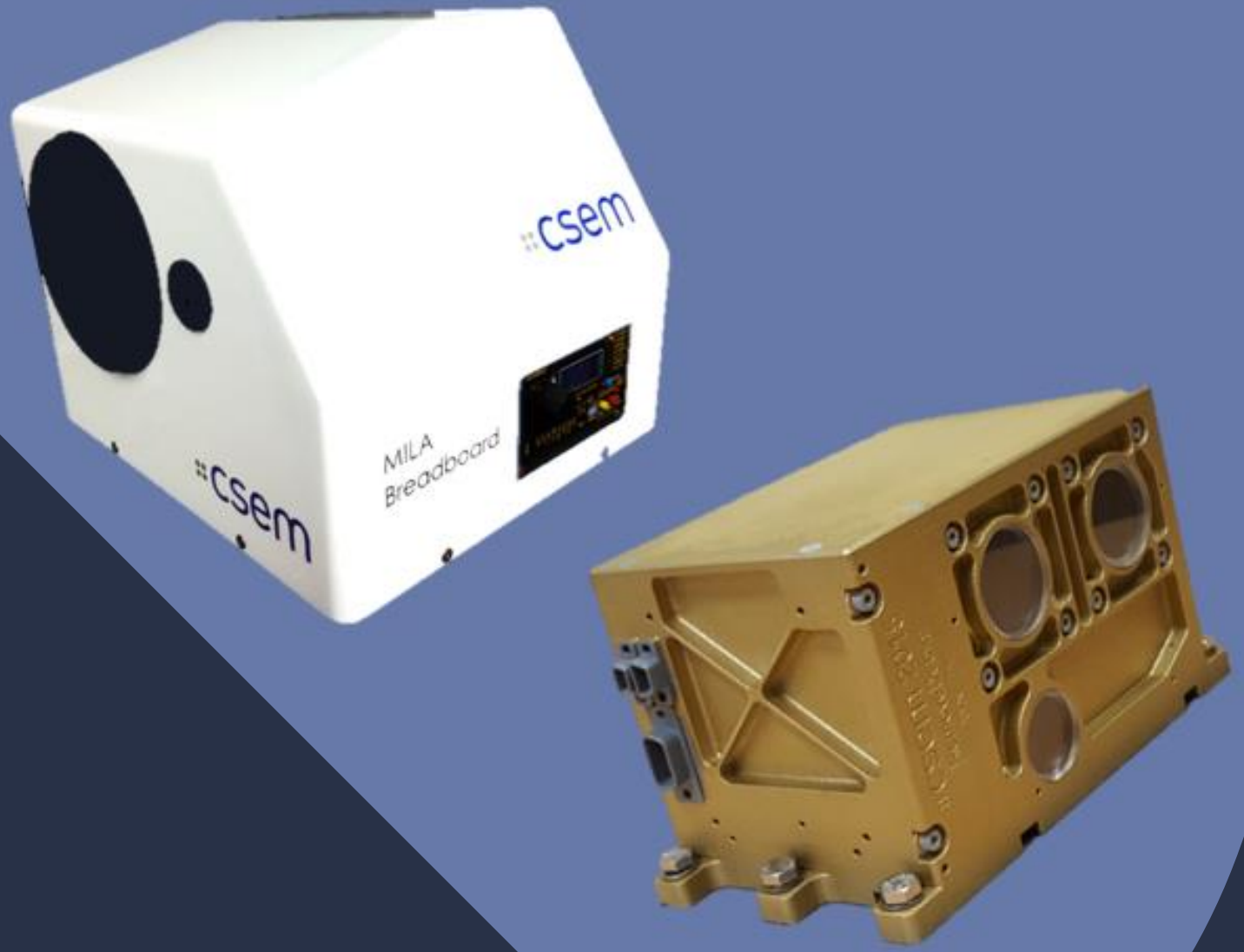
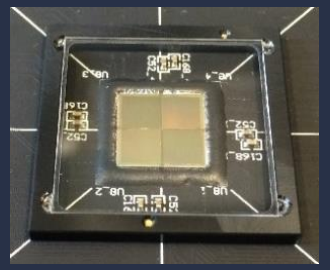
Solution for Exploration



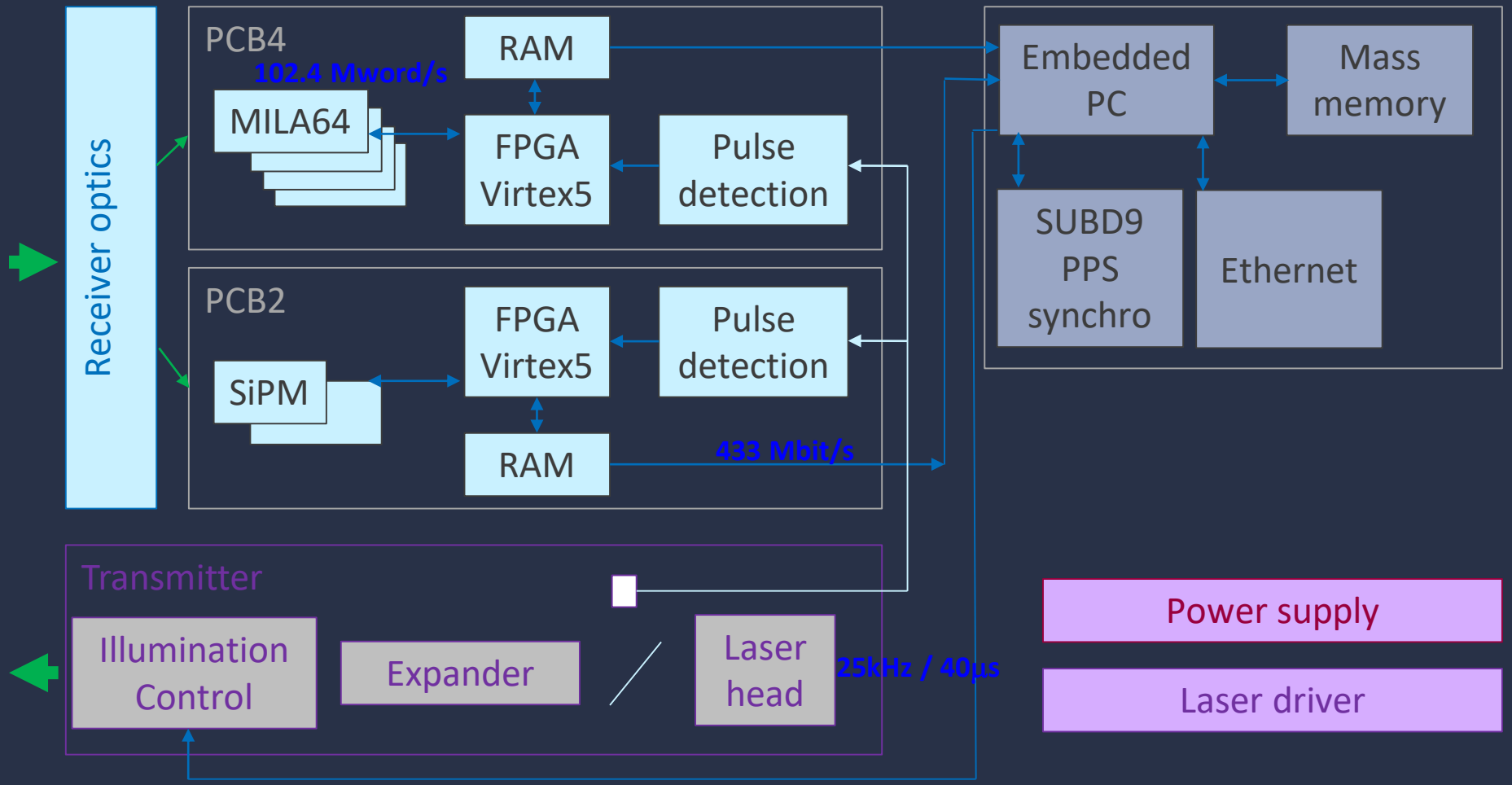
MILA



MILA64

Design: Fondazione Bruno Kessler / IRIS

64x64 pixels, 8 spads/pixel (1Gph/s), dSiPM, 1 16 bits TDC/pixel, correlation fct.



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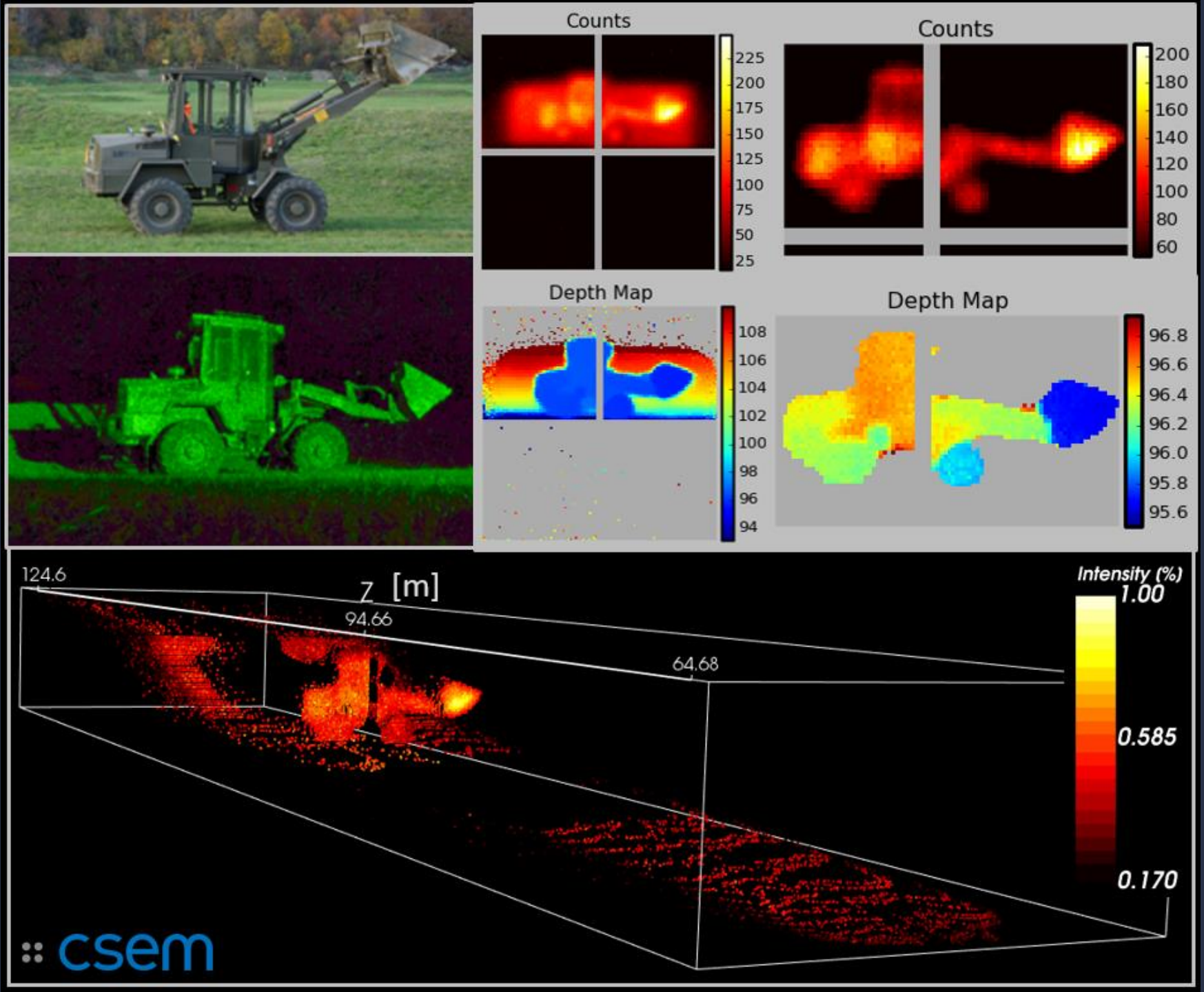
Demonstration at 100 m



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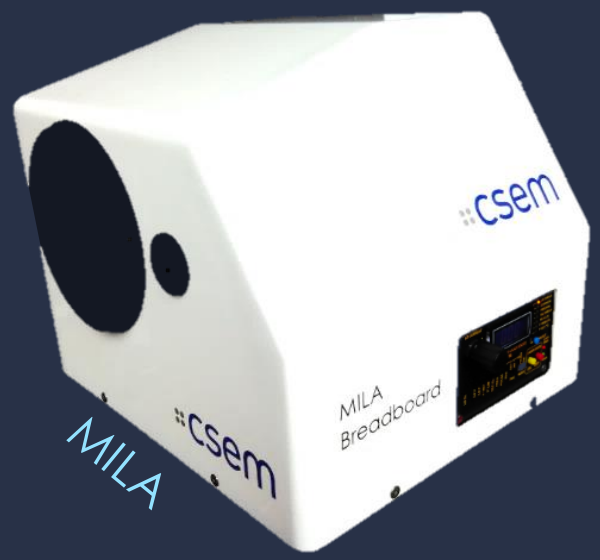
FONDAZIONE BRUNO KESSLER

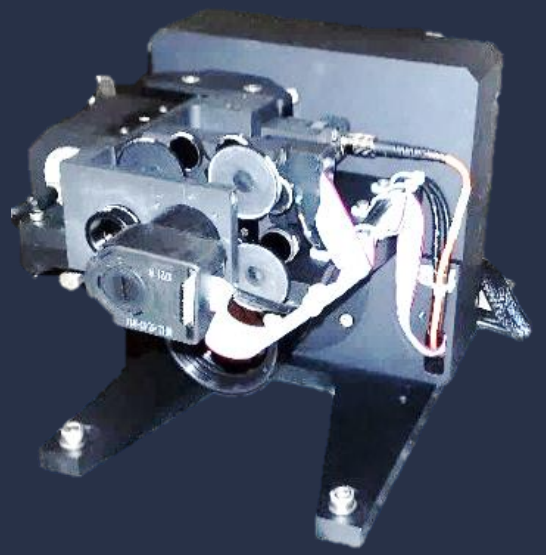
System specifications

Architecture	d-TOF/SPC (VIS, green)
Application (space)	Exploration
Focal Plane resolution	128 x 128
Technology Readiness Level	4
3 operation modes	Altimeter, Attitude meter, 3D imager
Precision (in air)	< 5 cm at 1100 m (altimeter) at 200 m (3D imager)
Dynamic range	distance: 40 dB intensity: 8 dB
FOV	5.8°
Size [cm^3]	25 x 31 x 24 17 x 17 x 20 (MILABIS)
Mass [kg]	< 8
Power consumption [W]	60
Frame rate [Hz]	8 (20)



MILA

MILABIS



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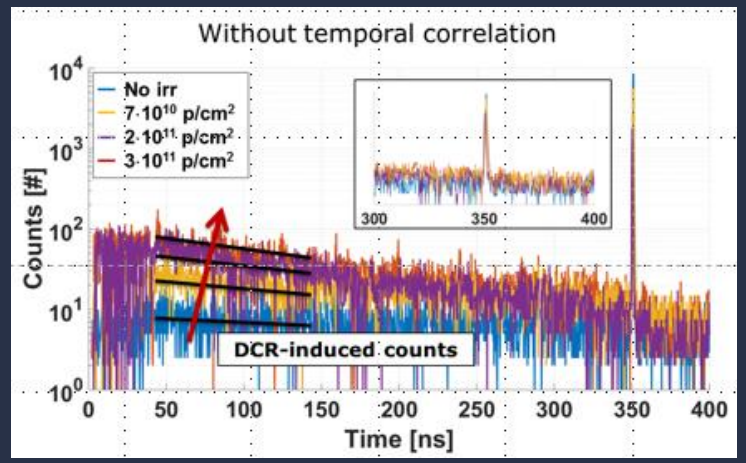
MILA project results

	Requirements			MILA Breadboard		
	Altimeter	Attitude	Imaging	Altimeter	Attitude	Imaging
Max range	> 2 km		< 1 km	1.1 km		300 m
Min range	7 m		5 m	6 m		6 m
Ranging accuracy	1 m		0.05 m	< 0.05		< 0.05
Horizontal resolution	-		0.2 m	-		0.24 m
Target Area	-		10-100 m			
Attitude measurement	-	10°	-		10°	
Measurement rate	< 2 Hz		< 2 Hz		1.5	
Velocity	< 65 m/s		< 31.5 m/s			
Pulses/measurement	> 200		< 250	compliant		compliant
FOV	1-2°		< 19°	compliant		compliant

Most tests successful except for:

- Spatial resolution at 300 m distance: required < 20 cm, measured 23.73 cm
- Dynamic imaging: saturation impacted measurements → lack of DoF to adjust operation settings (e.g. laser power, SPAD sensitivity)
- Sensitivity to ambient sunlight

Radiation



- Irradiation increases DCR and afterpulsing, and shift breakdown voltage
- The sensors are fully operational after irradiation
- Architectural robustness (number of photons discrimination)

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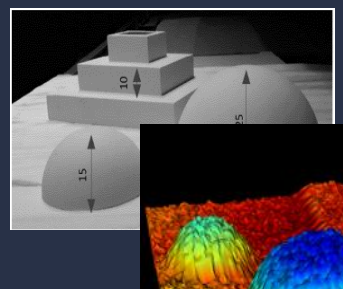
Current developments

- System level (CSEM)
  - On optics: single Fresnel abandonned, more traditional optical elements implemented
  - On detector control: rush current limited electronically and gating
- Detector (FBK)
  - Higher spatial resolution: 512x512 minimum
  - New resolution + TDC depth + keep same image rate → challenge on data rate
  - Higher DoF on link budget by adjustable sensitivity
  - Correlation (MILA) + Radiation hardness by design
  - ROI according to operation mode

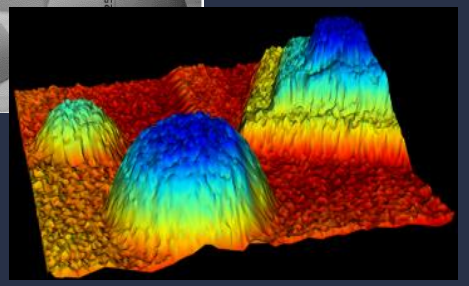
Turn-key developments for challenging applications

Atmospheric measures

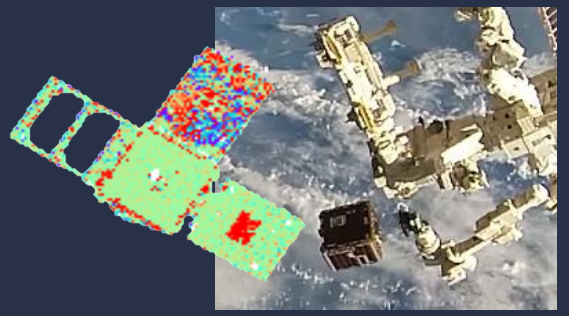


Flight altitude 12 km

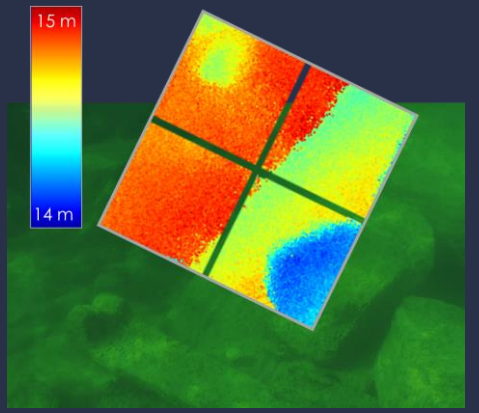
Space navigation (landing)



Space Rendezvous
(RemoveDebris mission)



Bathymetry



Geodesy

Poor weather navigation

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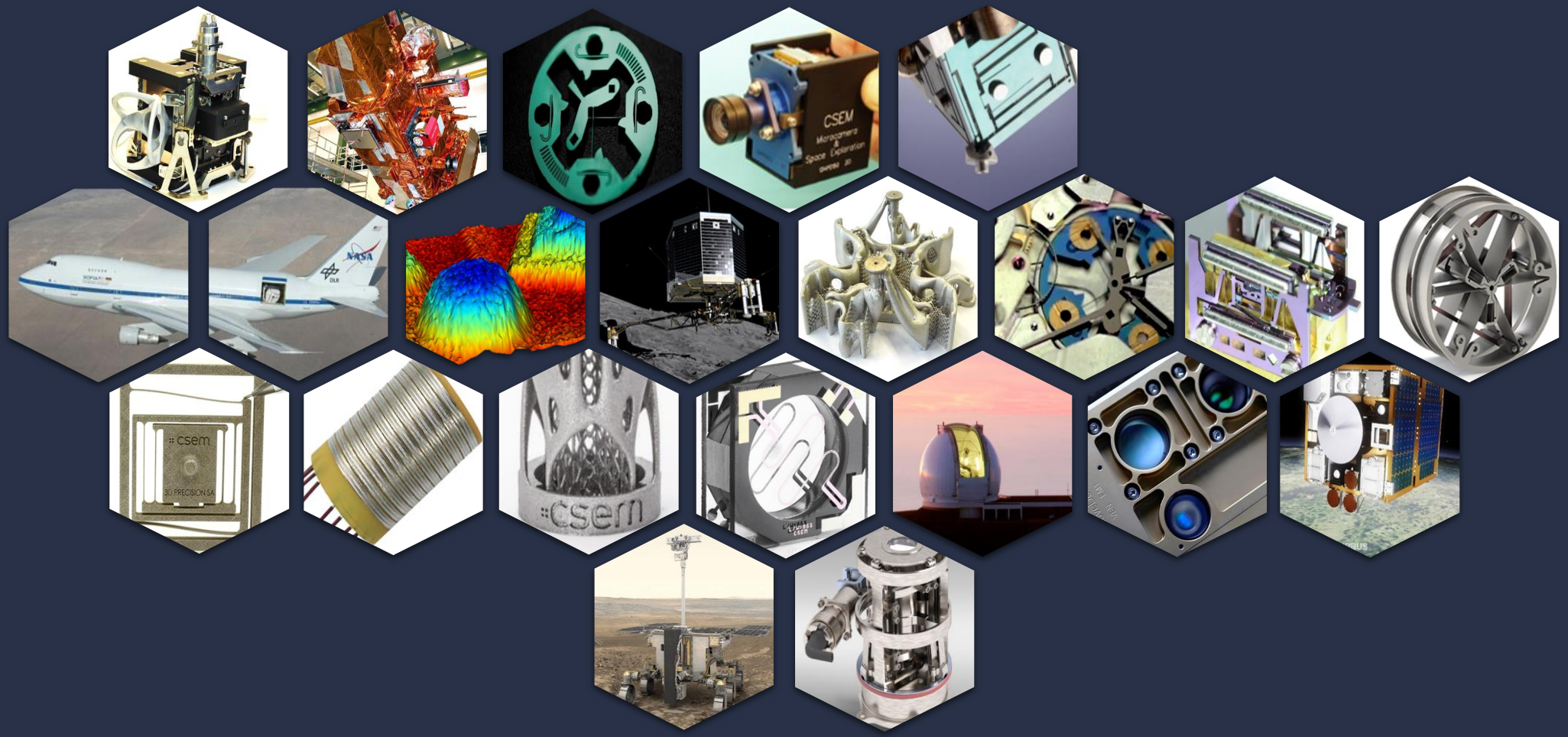
THANK YOU FOR YOUR ATTENTION!

www.csem.ch/Instrumentation



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