Space Metrology: Laser Stability for the LISA Mission and 3D imaging LiDAR

EPIC Meeting on Photonics for Space: Opening New Horizons at Exail

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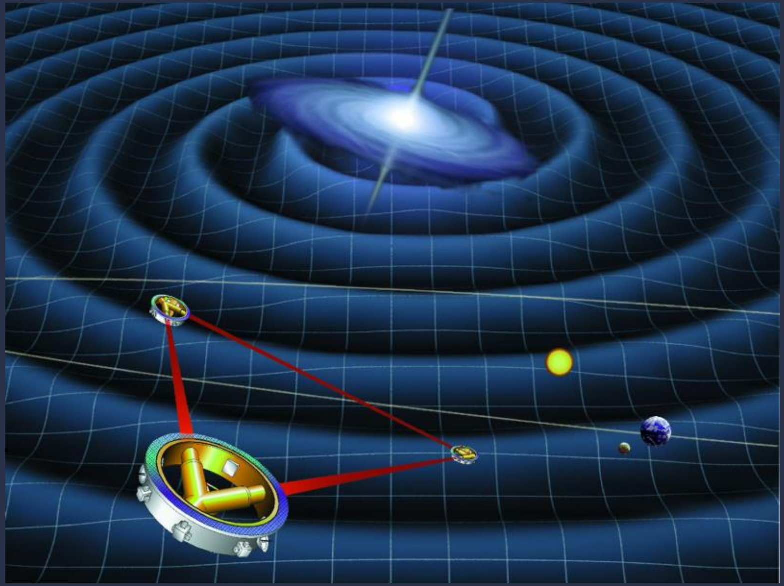

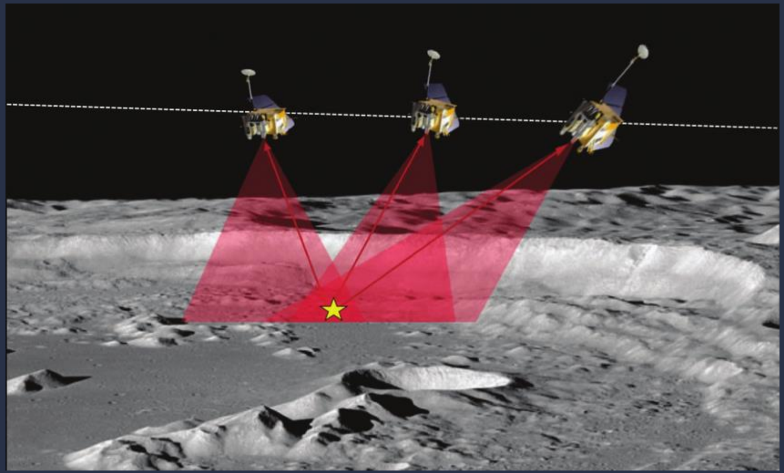

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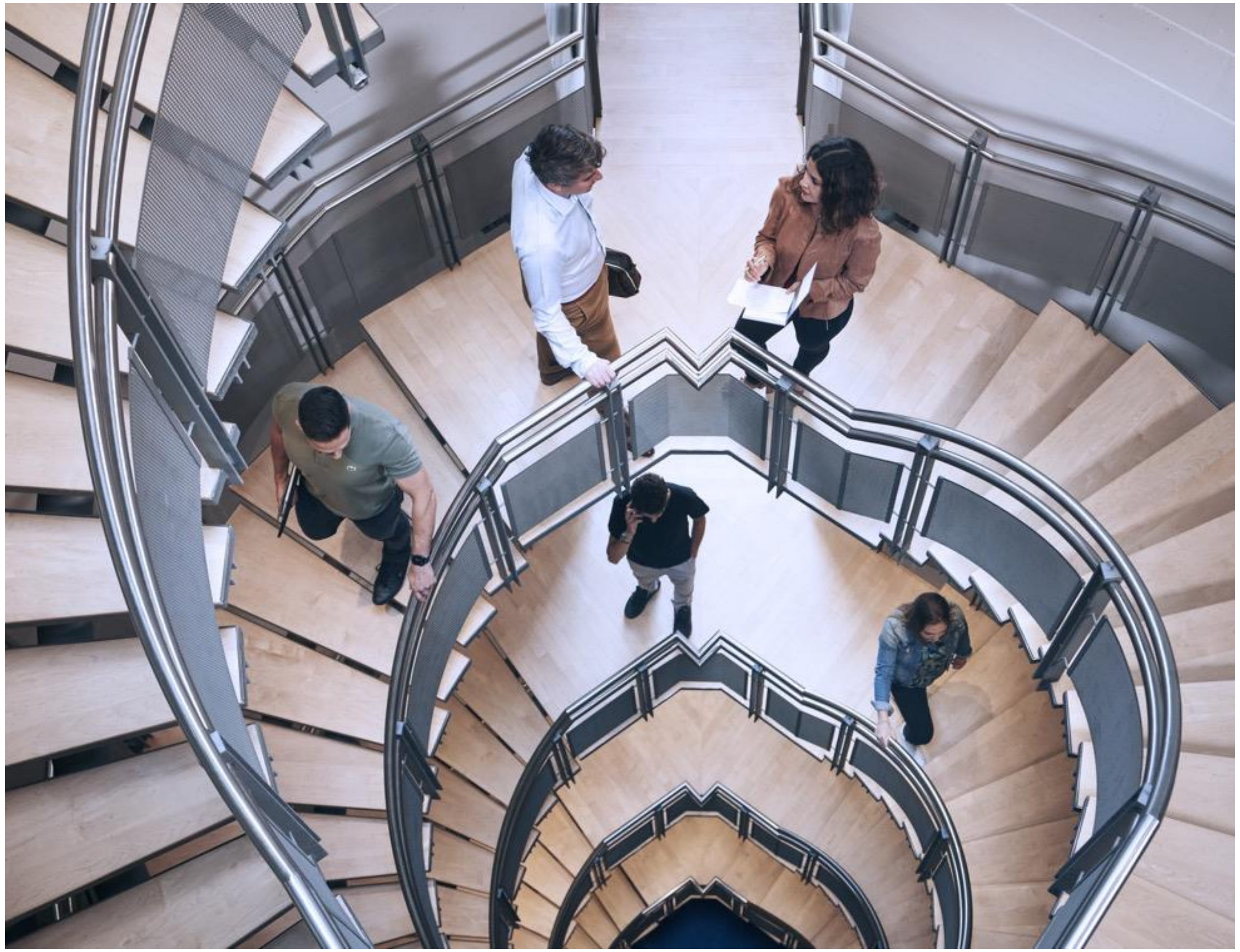
EPIC
EUROPEAN PHOTONICS INDUSTRY CONSORTIUM

CSEM AT A GLANCE

We are a public-private, non-profit, Swiss technology innovation center.

We enable competitiveness through innovation by developing and transferring world-class technologies to industry.

COMBINING EXPERTISE, PASSION, AND DIVERSITY FOR SUCCESS



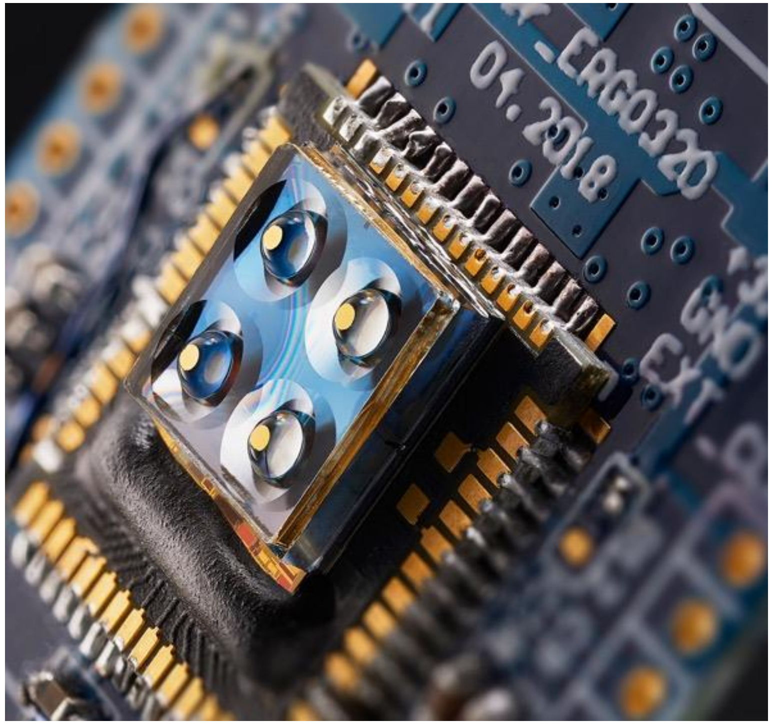
566
EMPLOYEES

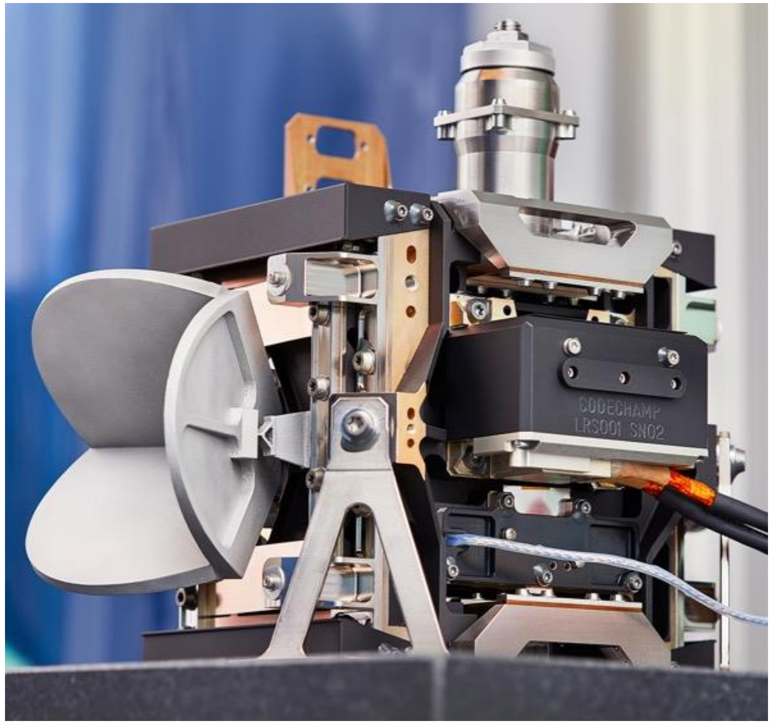
46
NATIONALITIES

35%
PHD

28%
WOMEN

WE SERVE INDUSTRY NEEDS WITH A FOCUS ON DEEP TECH





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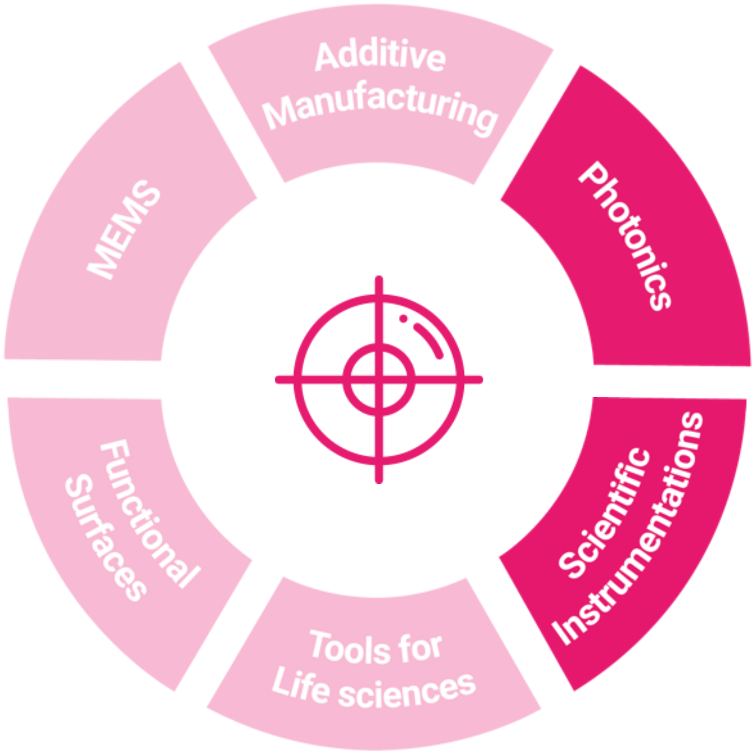
WE FOCUS ON THREE RESEARCH PRIORITIES

Digital Technologies

Precision Manufacturing



Sustainable Energy

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SCIENTIFIC INSTRUMENTATION

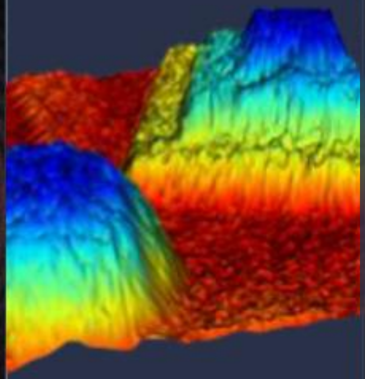
LASERS

Astrocombs

Laser metrology

Environmental testing

LIDARS



Navigation

QUANTUM SENSORS

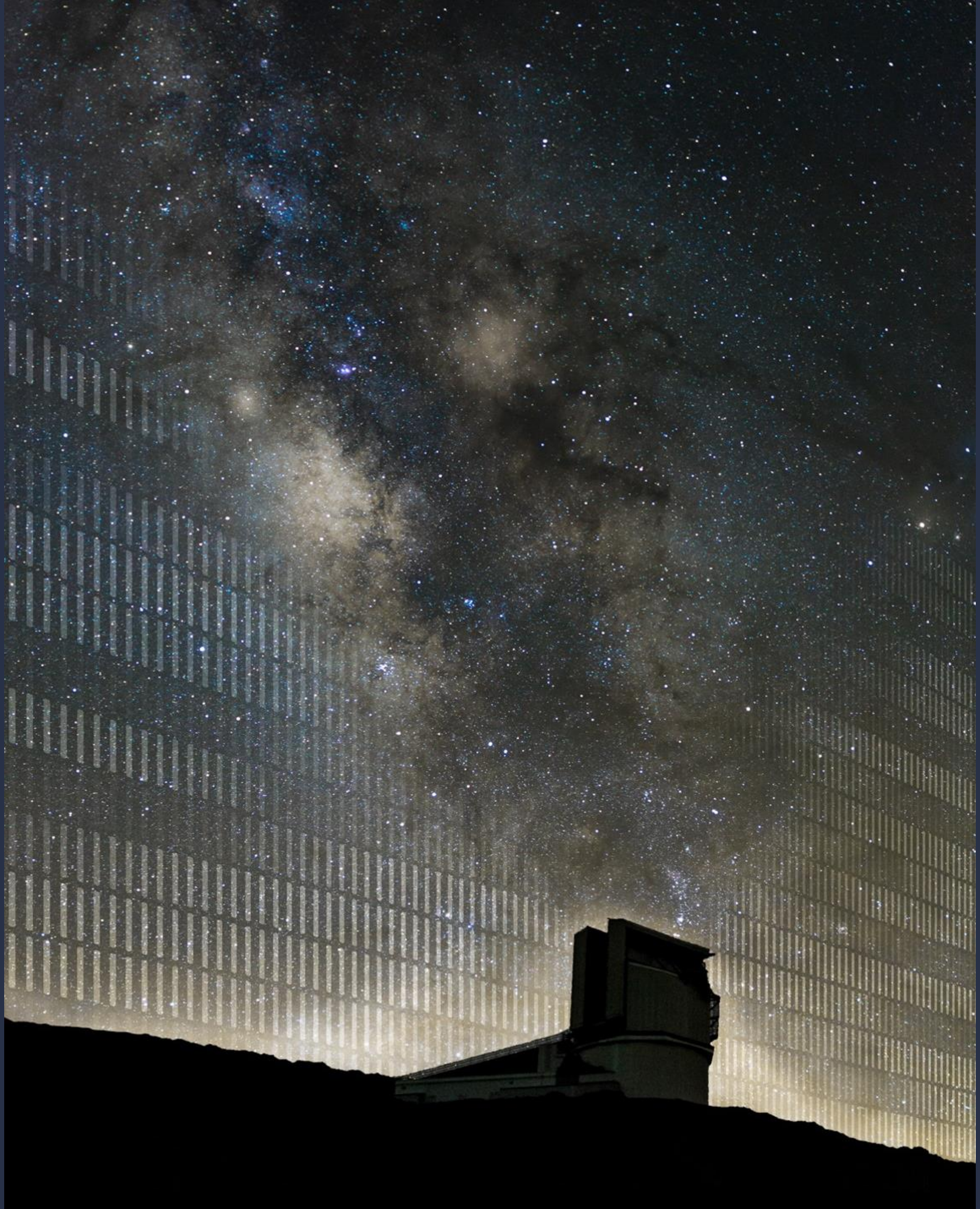
SPACE MECHANISMS

Micro-vibration

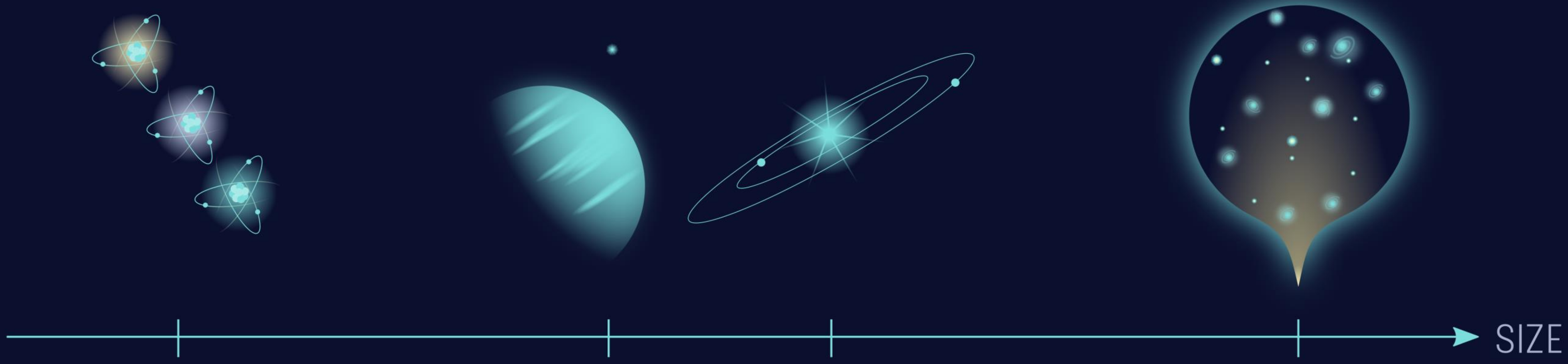
ADDITIVE MANUF

WATCH MECHANISMS

Astrocombs



(extreme precision) ASTRONOMICAL SPECTROSCOPY



fundamental constants variability

exoplanets

characterisation

detection

Universe's accelerating expansion

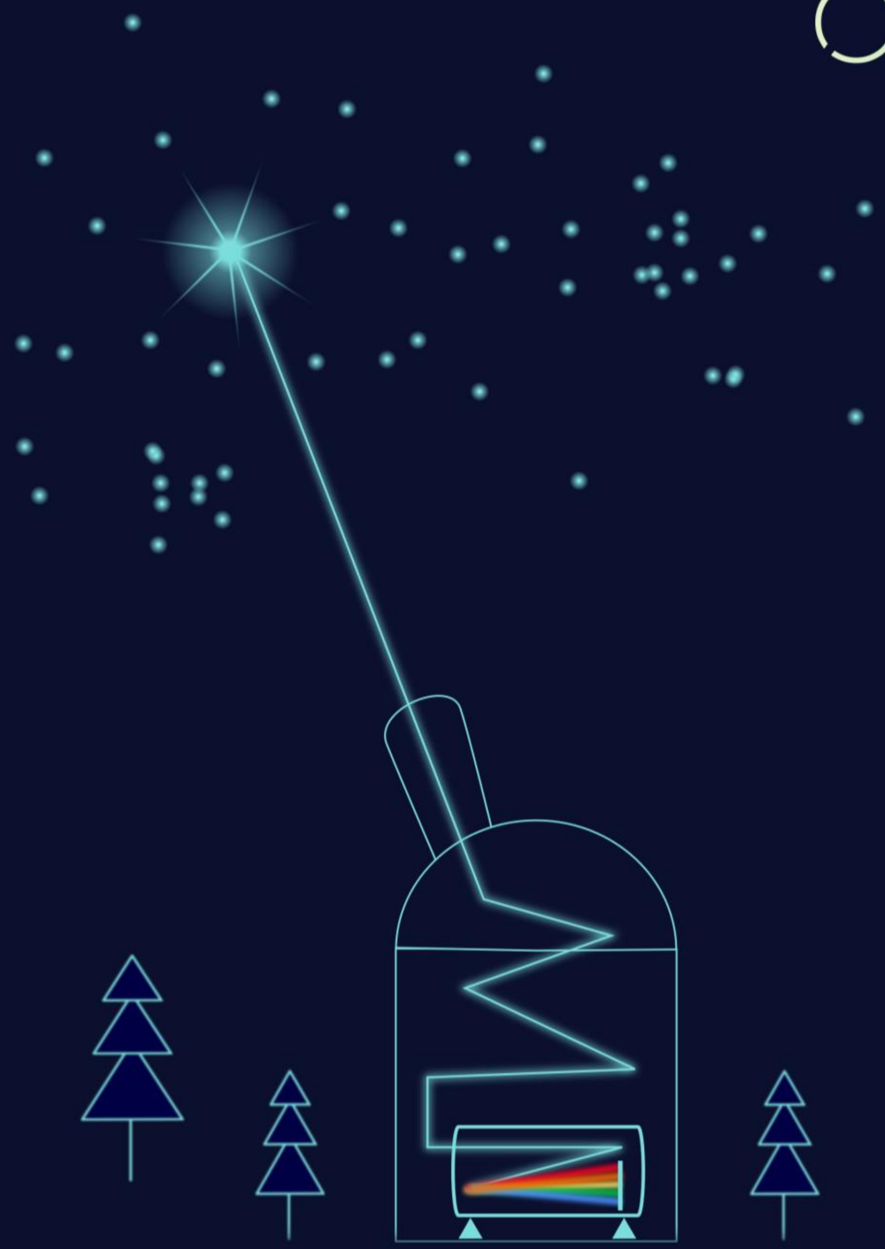
sample questions of a concerned astronomer:

is this constant TRULY constant ?

is there a planet ?
how massive it is ?
is it in the habitable zone ?
Earth 2.0 ???

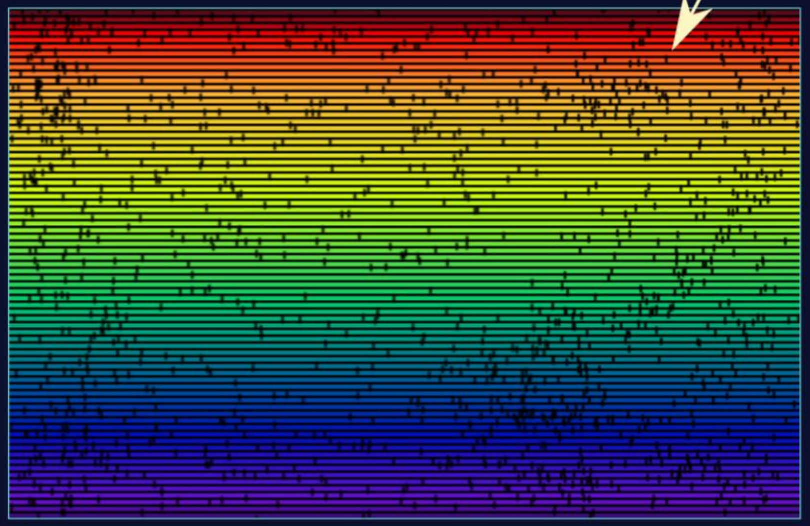
what is going on with the Universe ?
what is this dark stuff ?

OBSERVATIONS



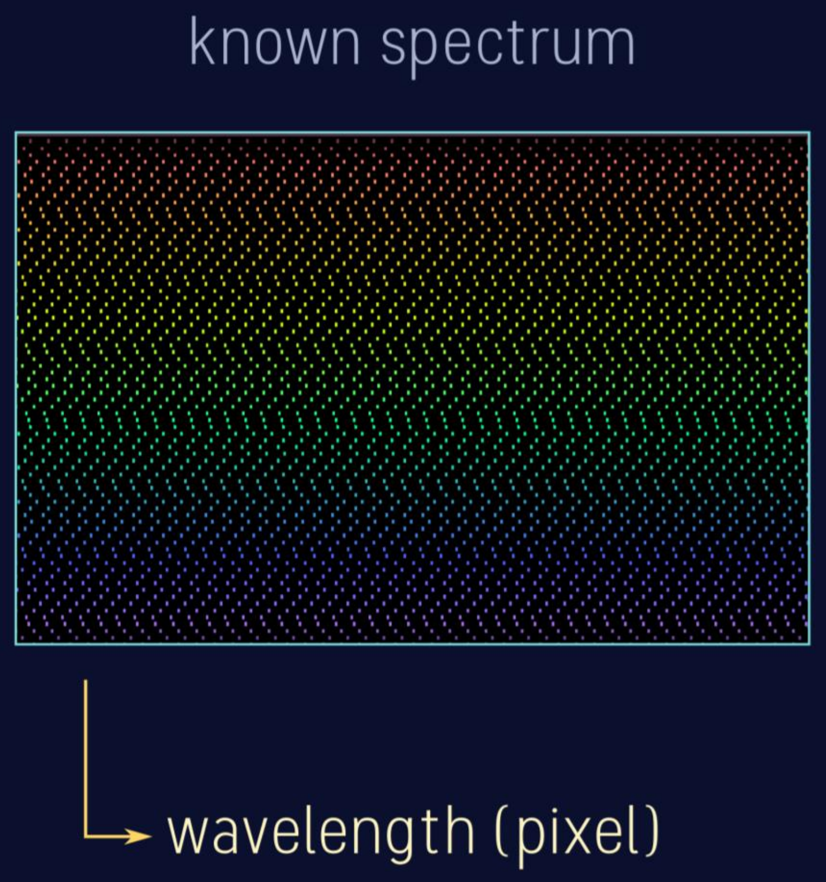
what is the wavelength of this feature ???

unknown spectrum



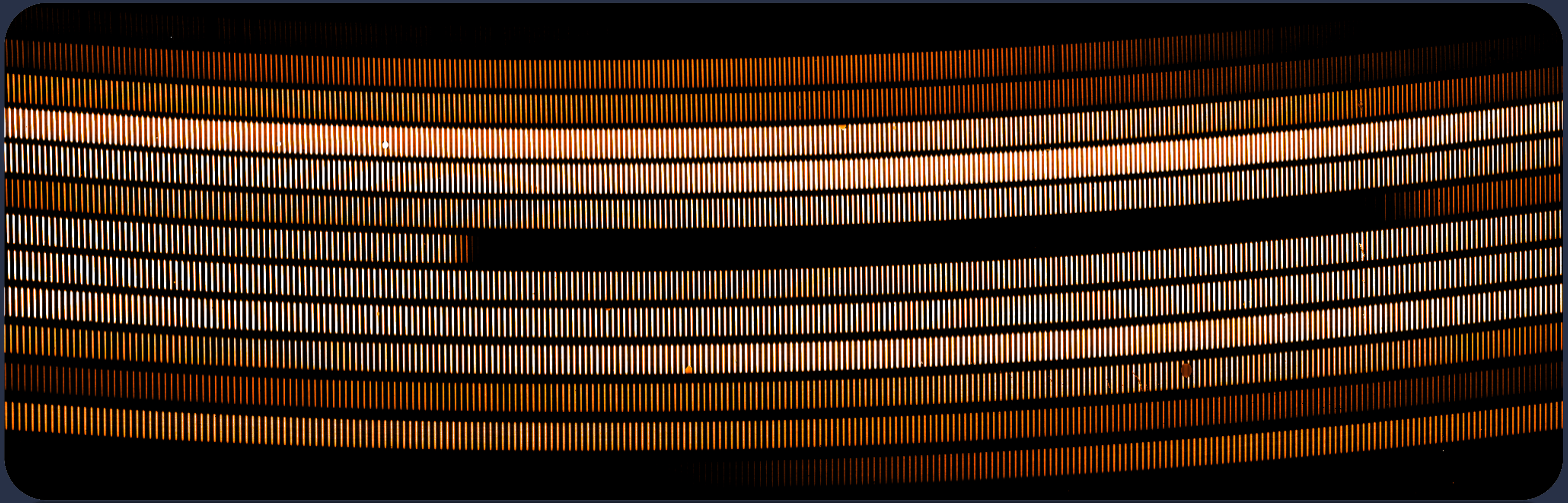
2 axes: echelle grating & cross-disperser (prisms)

WAVELENGTH CALIBRATION



Astrocomb on GIANO-B spectrograph

Prototype demonstration at La Palma (previous project)



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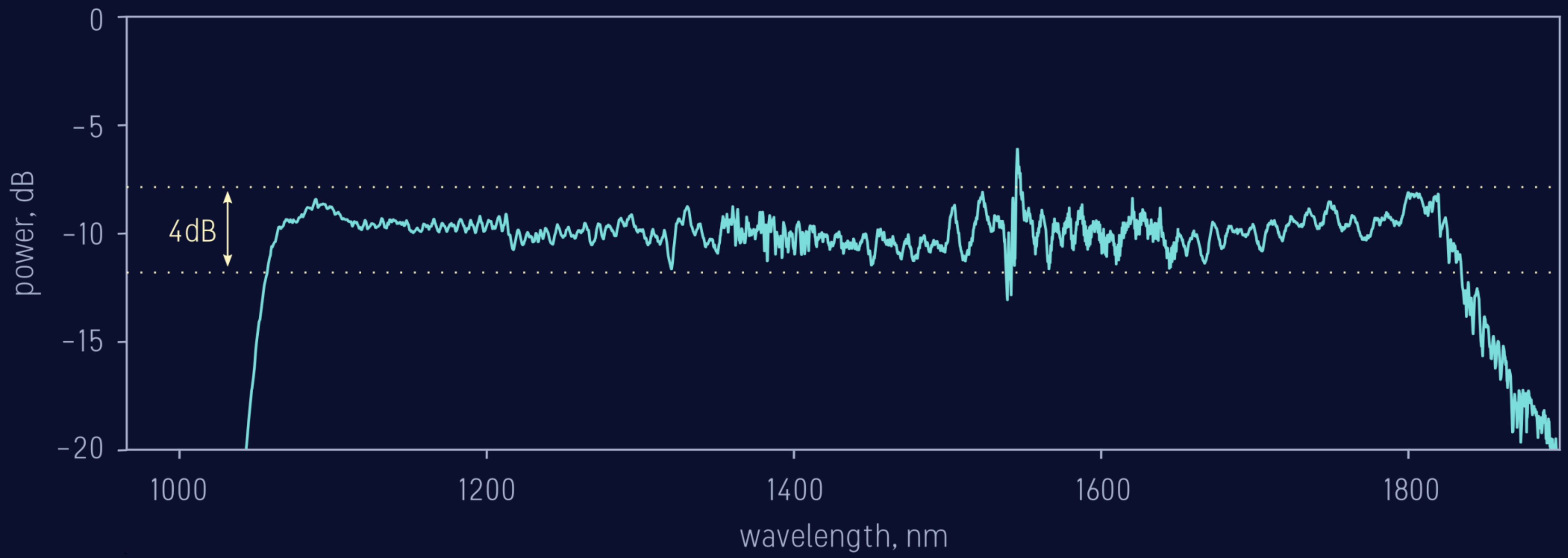
E. Obrzud, M. Rainer, A. Harutyunyan, B. Chazelas, M. Cecconi, A. Ghedina, E. Molinari, S. Kundermann, S. Lecomte, F. Pepe, F. Wildi, F. Bouchy, T. Herr, "Broadband near-infrared astronomical spectrometer calibration and on-sky validation with an electro-optic laser frequency comb," Opt. Express **26,** 34830-34841 (2018);
https://www.osapublishing.org/oe/abstract.cfm?uri=oe-26-26-34830

ASTROCOMB FOR NIRPS



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NIRPS

ASTROCOMB FOR NIRPS

- accuracy: 10^{-12}
- 24h spectral stability: ±8%
- ~7000 calibration lines

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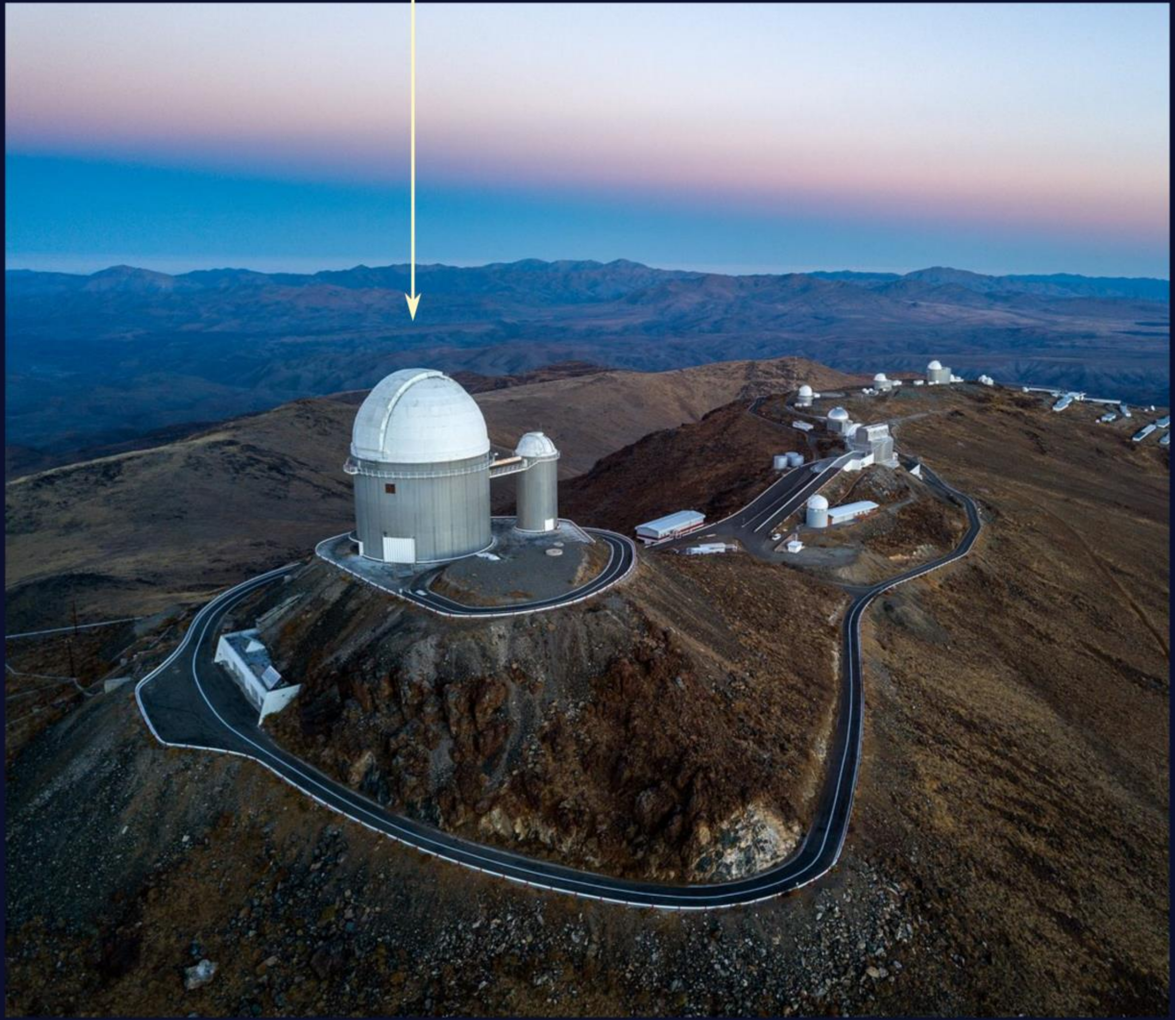
NIRPS
LOOKING FOR BLUE PLANETS AROUND RED STARS

ASTROCOMB FOR NIRPS aka Astrobox

- electro-optic modulation LFC
- 15 GHz line spacing
- 17 GHz tunability
- min. spectral coverage 1150 – 1850nm



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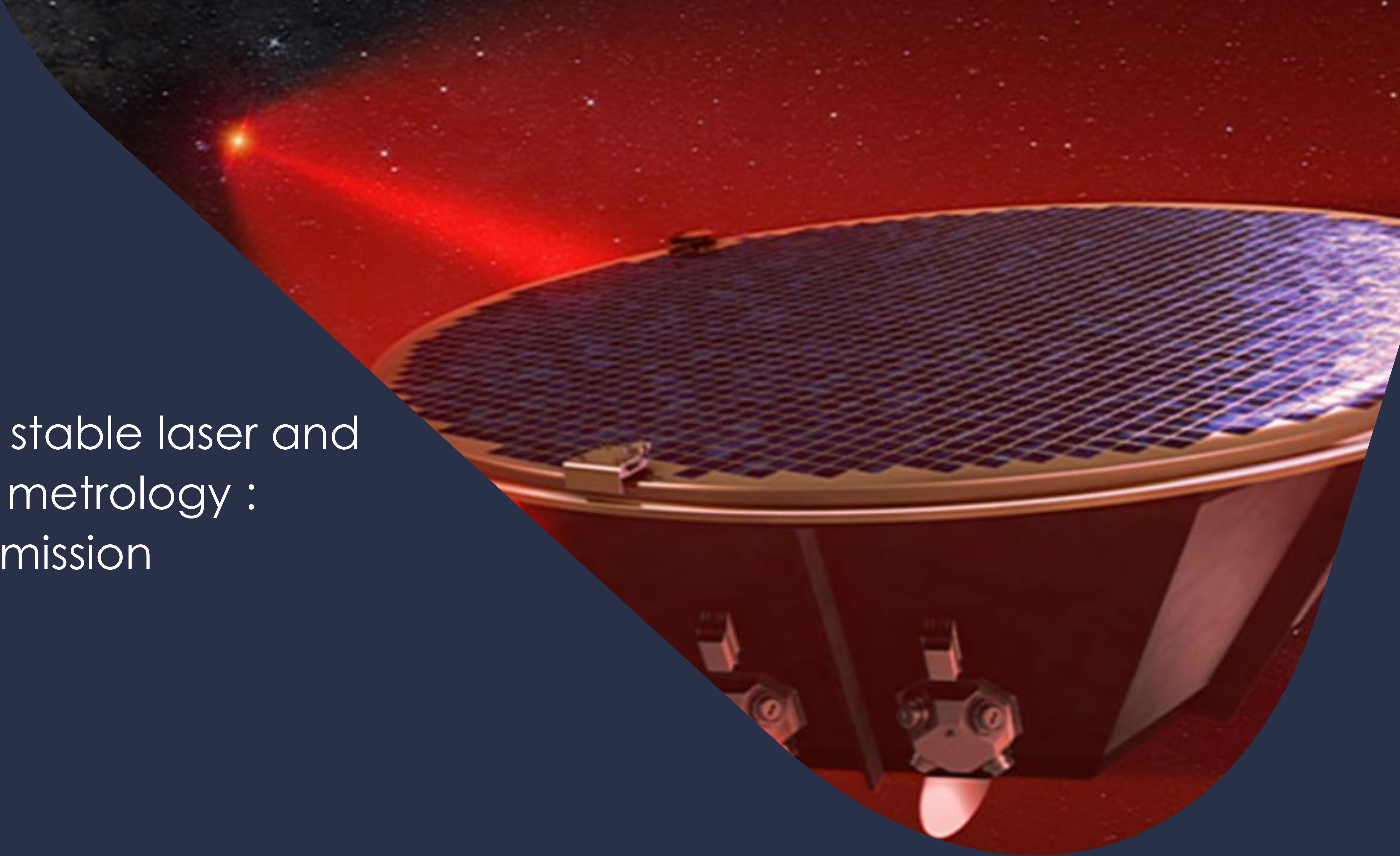
NIRPS
LOOKING FOR BLUE PLANETS AROUND RED STARS

eso.org

Ultra stable laser and their metrology : LISA mission



LISA mission: Laser Interferometer Space Antenna
Gravitational waves detected in space

Ground-based detection : LIGO

- First detection (Sep.14 2015)
- Detection band [10 Hz; 10kHz]

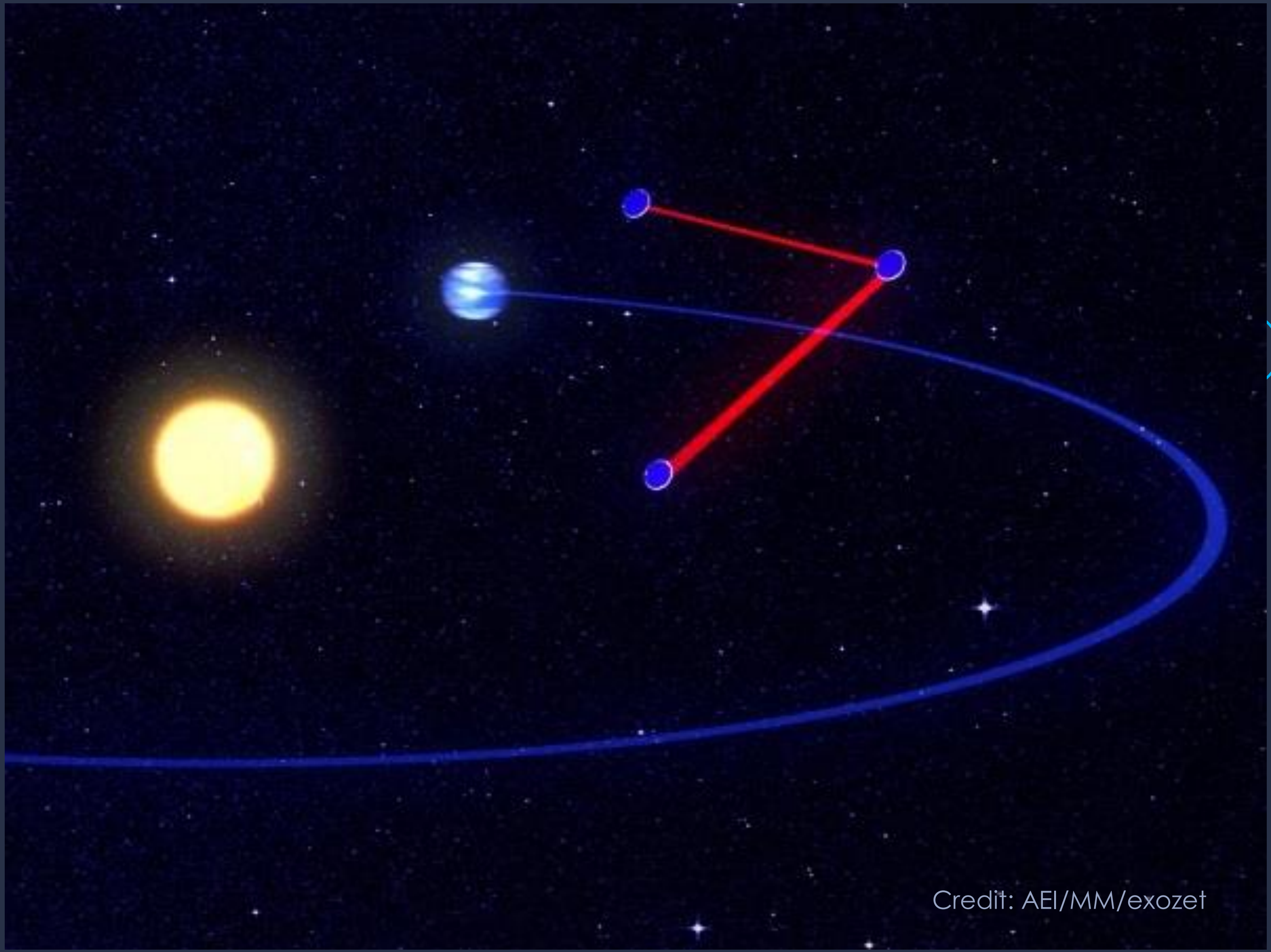
Space-based detection : LISA mission

- Detection band [0.1 mHz; 1Hz]
- Launch, planned in 2034

➢ **Space compatible laser system**

➢ **High performance requirement of laser**

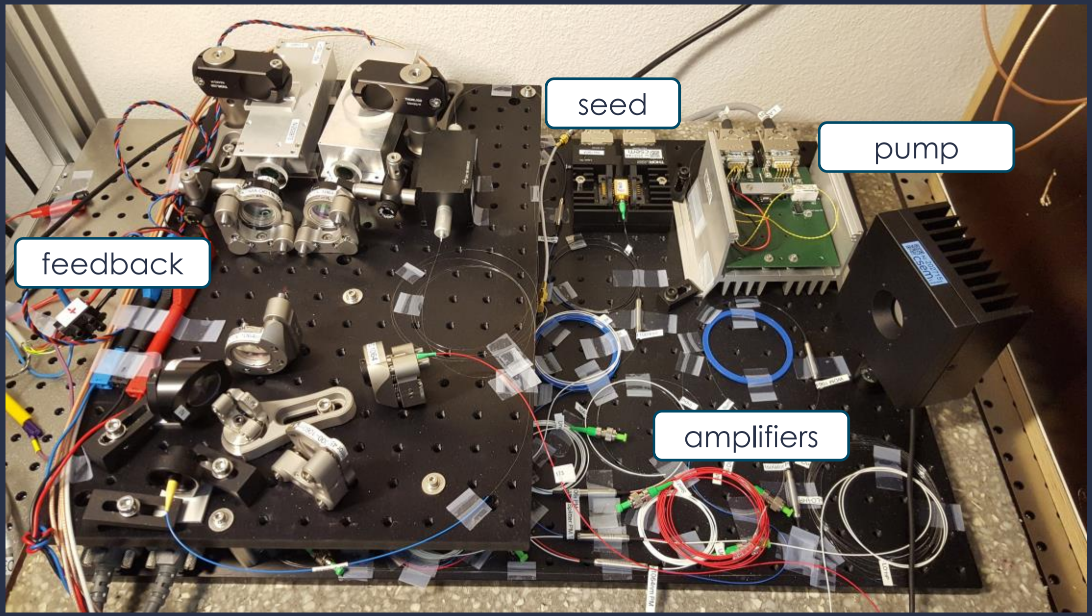
  - 2W at 1064nm
  - Ultra-low Amplitude noise
  - Ultra-low frequency noise
  - Ultra-low sideband phase noise

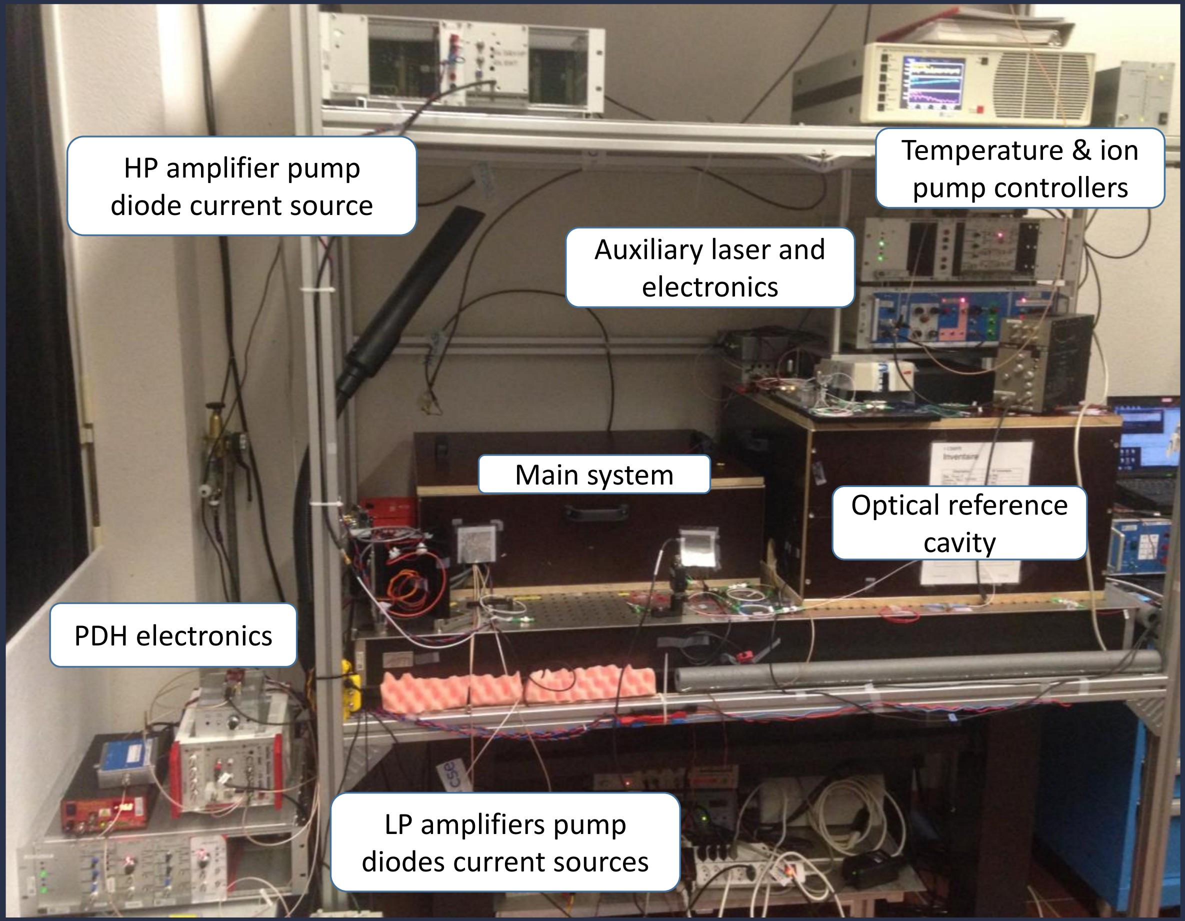


Ultra stable laser and their metrology

Full laser system (space compatible development)

- BB development (2017-2018)
- MOPA architecture
- Ultra low-frequency noise laser stabilized on cavity

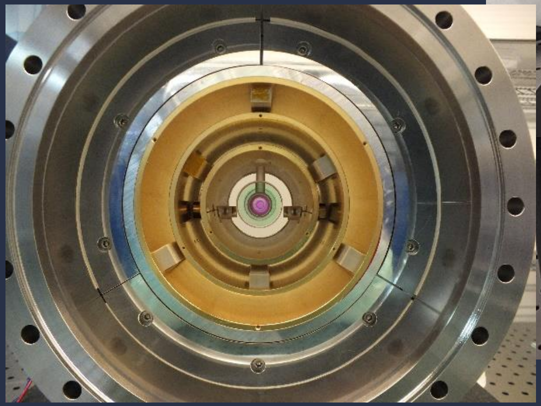


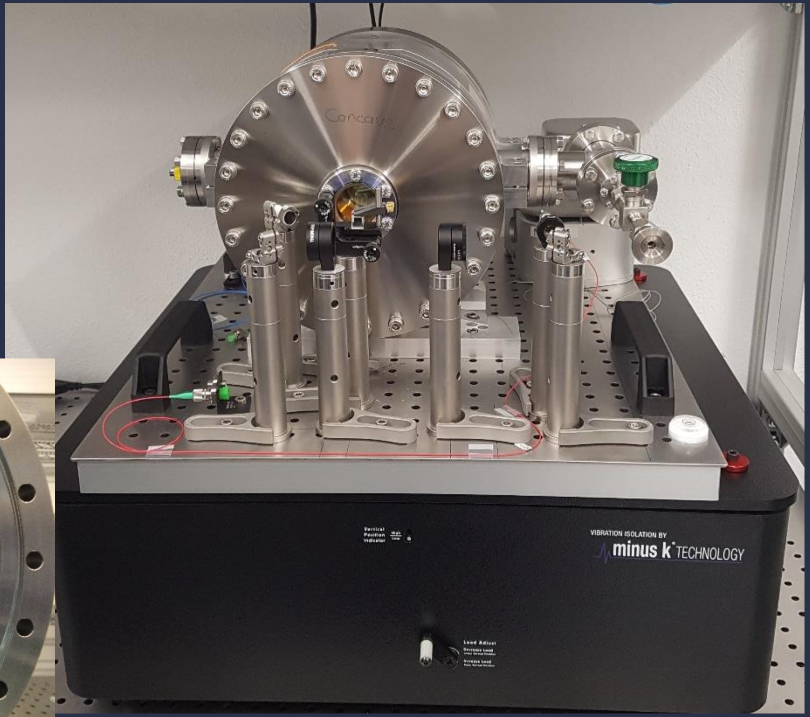


Ultra stable laser and their metrology

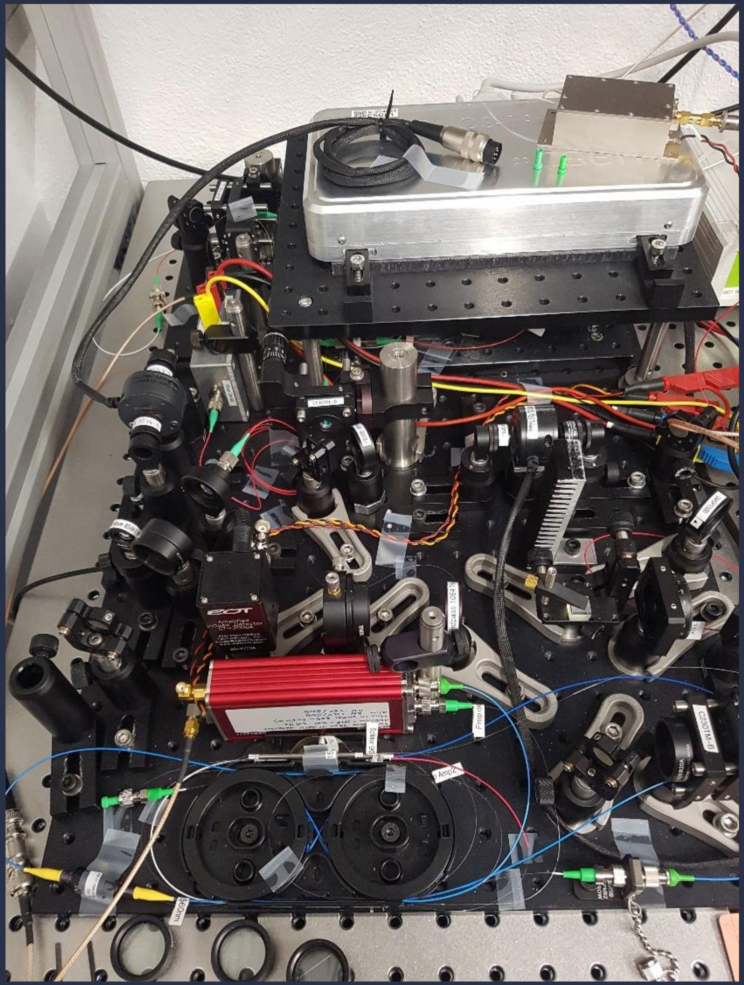
Laser system metrology development

- Dedicated laboratory with high stability (mechanic + thermic)
- Frequency noise measurement from 20 µHz to 10Mhz



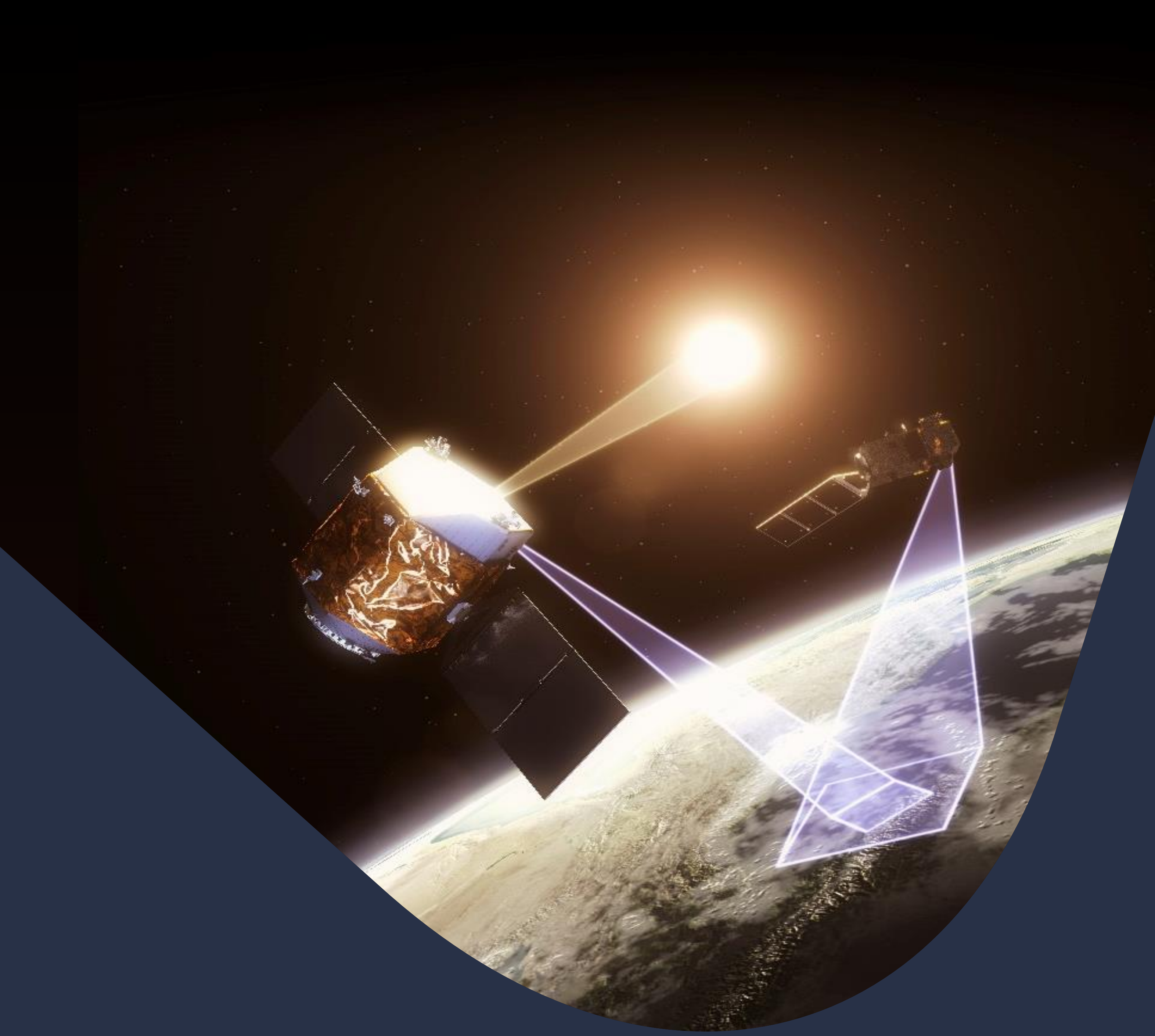


Fabry-Perot cavity in vacuum



Frequency comb & ref. maser

Photodiode metrology: TRUTHS mission



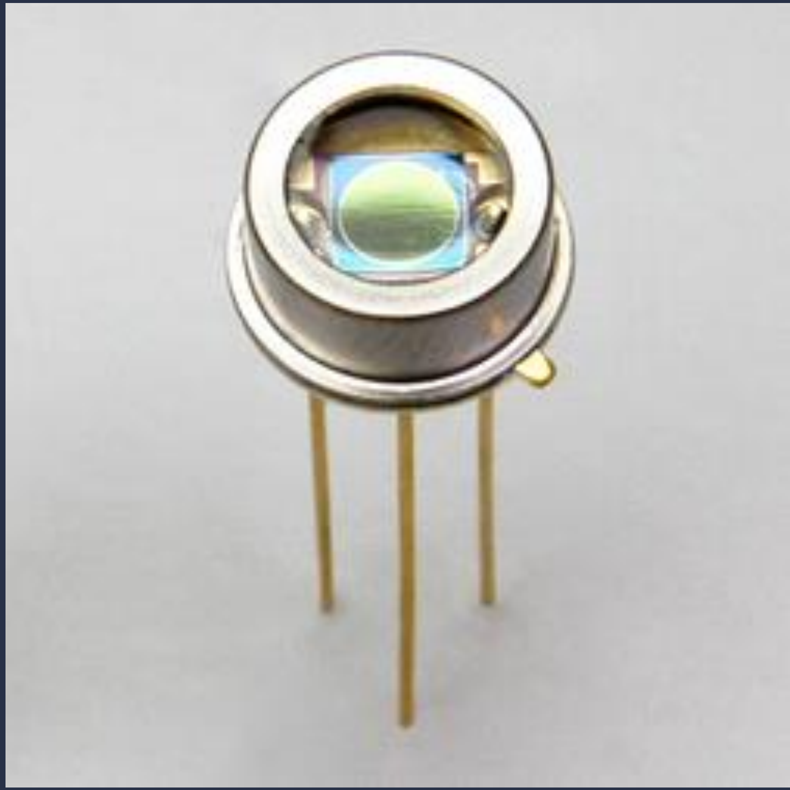
TRUTHS mission
Photodiode metrology

Truths mission :

- Absolute radiometer
- Hyperspectral imaging spectrometer
- On-board calibration system

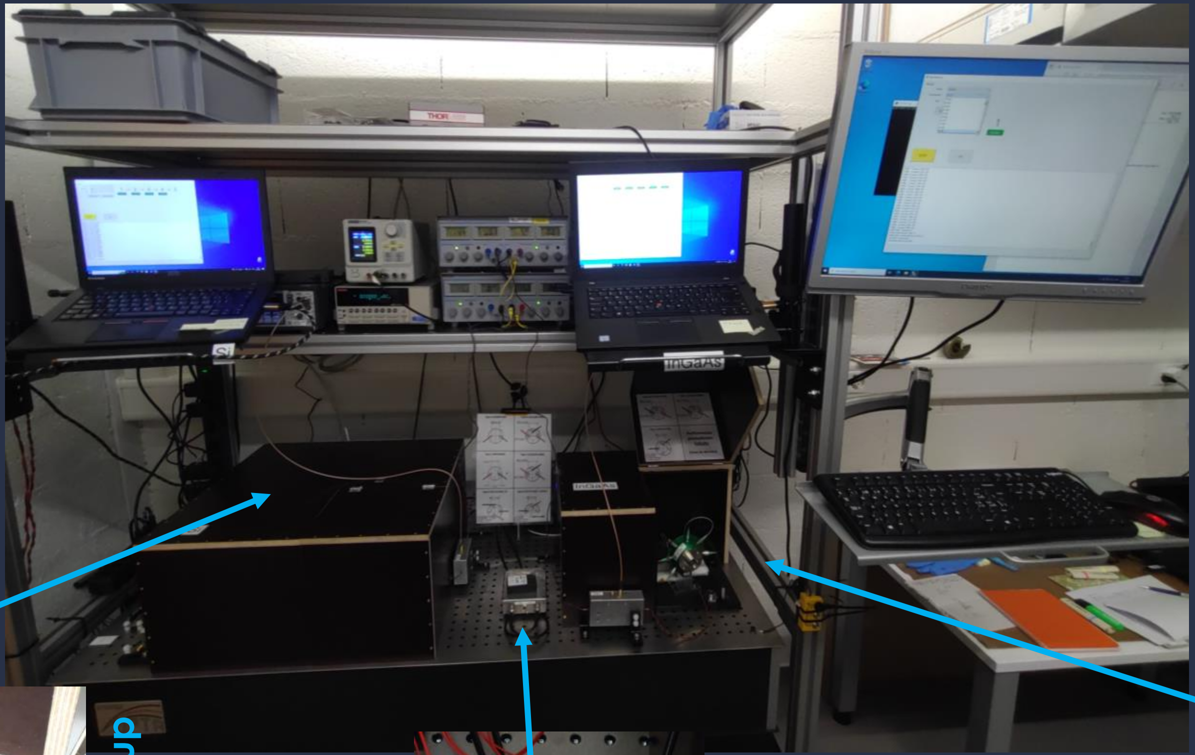
CSEM contribution

- Performance measurement of photodiode (for calibration system)
- Environmental test of the photodiode
- More than 100 PD testes before and after environmental test

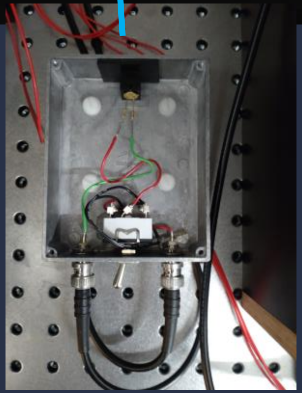


TRUTHS mission
Photodiode metrology

Development and automatization of two test benches

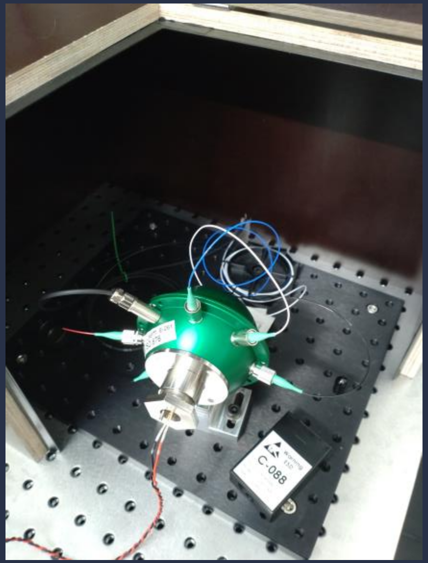


Si performance setup



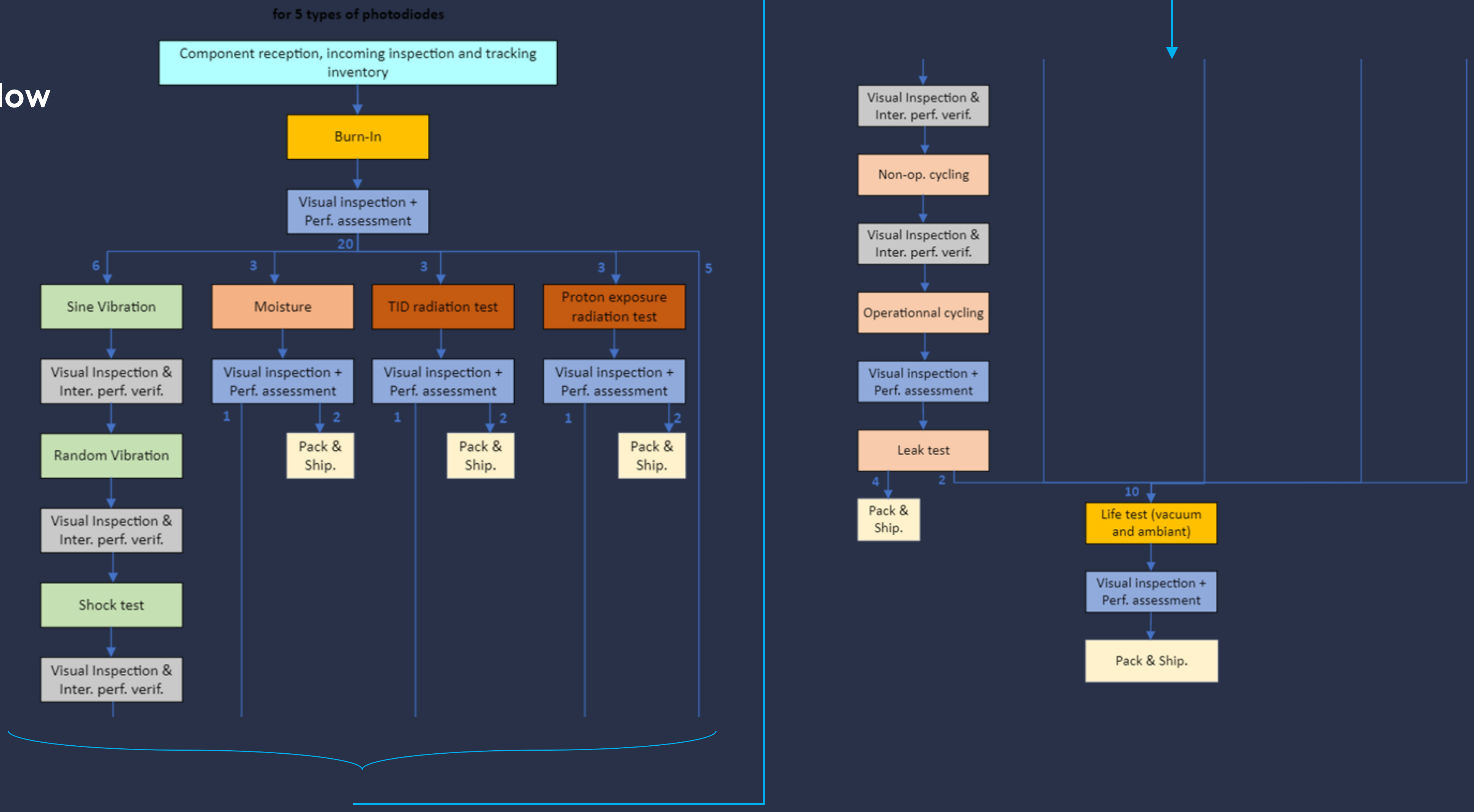
Dark current setup

InGaAs performance setup



TRUTHS mission
Photodiode metrology

Environmental test flow



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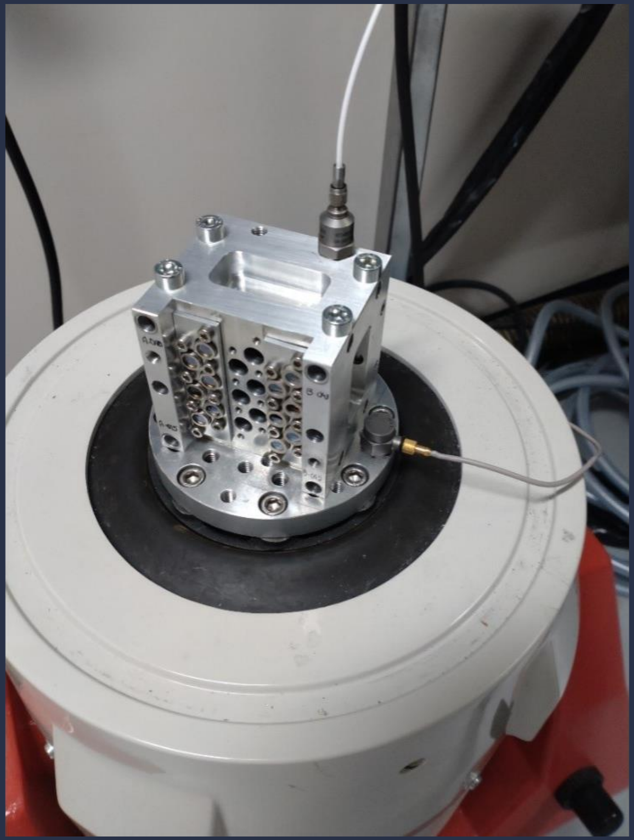
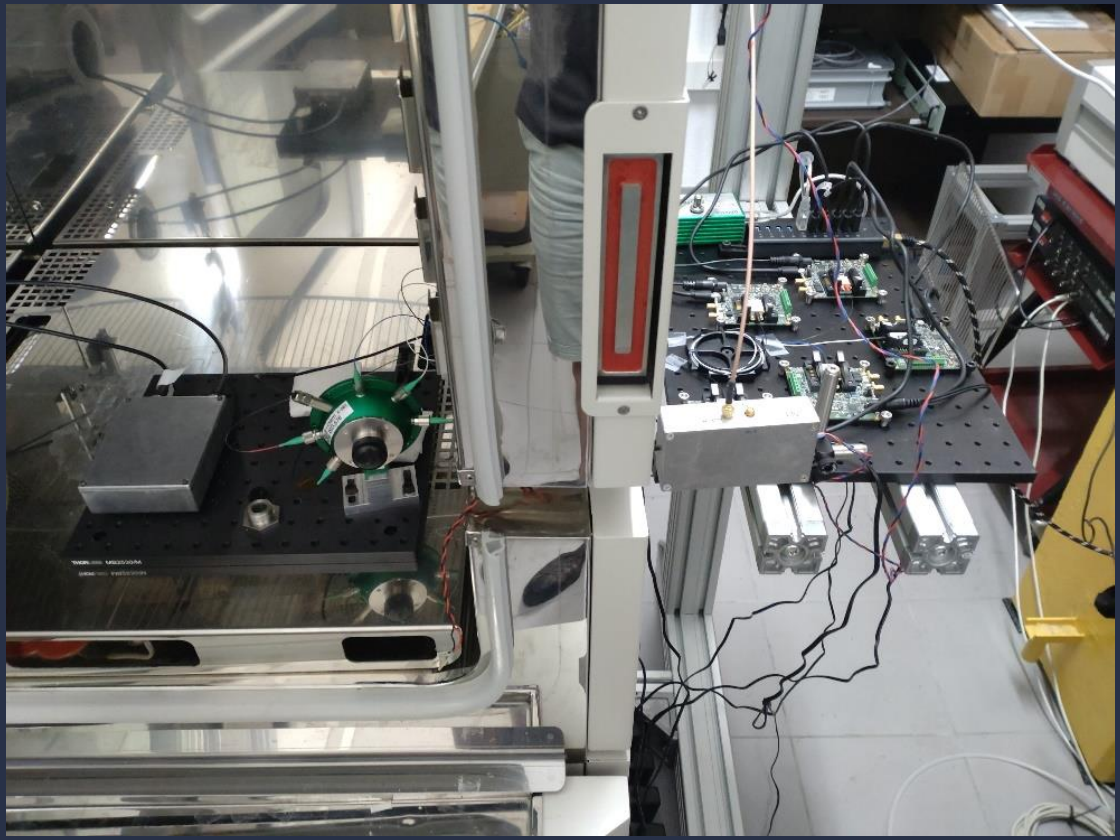
TRUTHS mission
Photodiode metrology

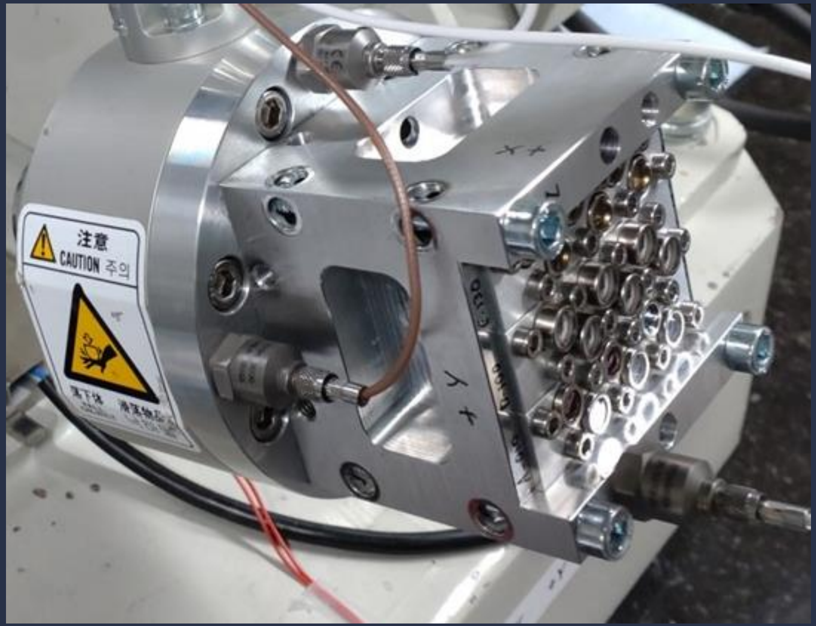


Vibration test (inhouse)

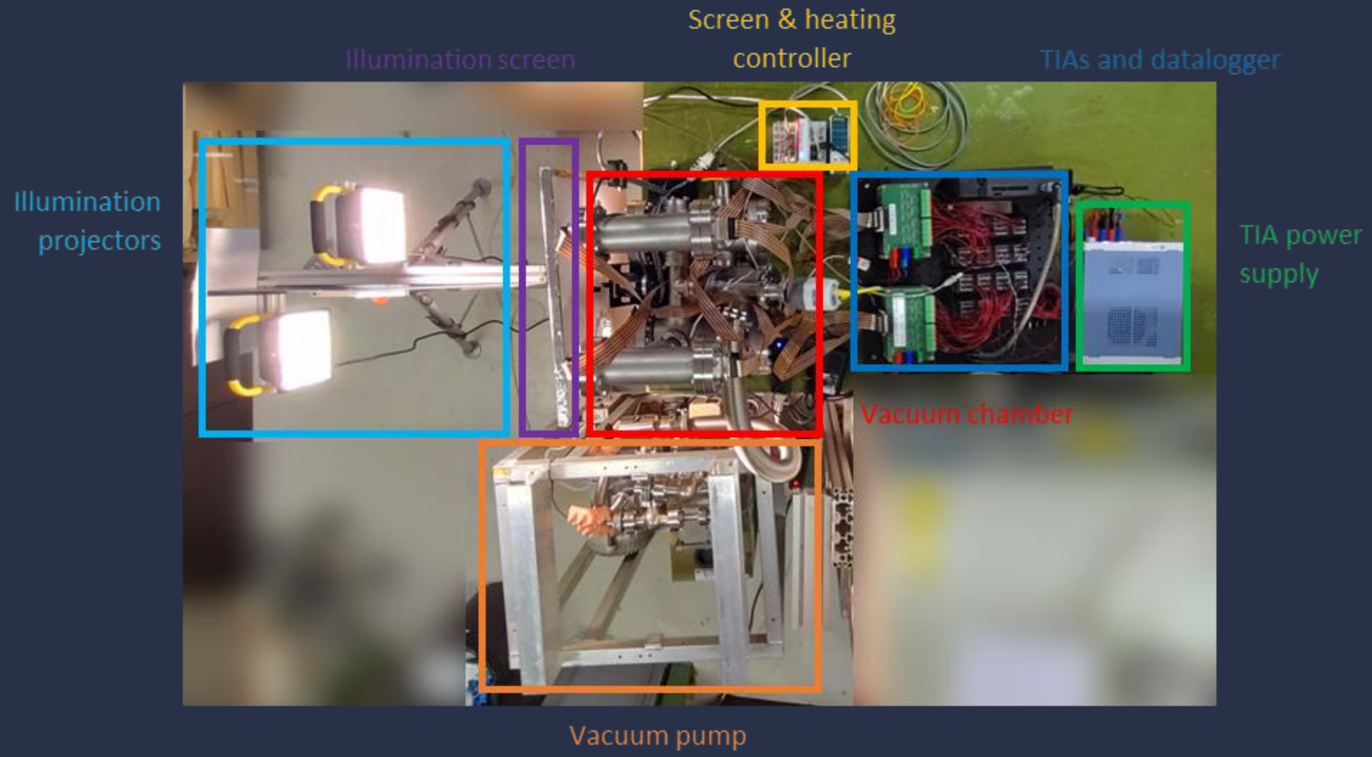


Thermal test and thermal cycling (inhouse)

TRUTHS mission
Photodiode metrology



Shock test (inhouse)



Lifetime test under vacuum (inhouse)

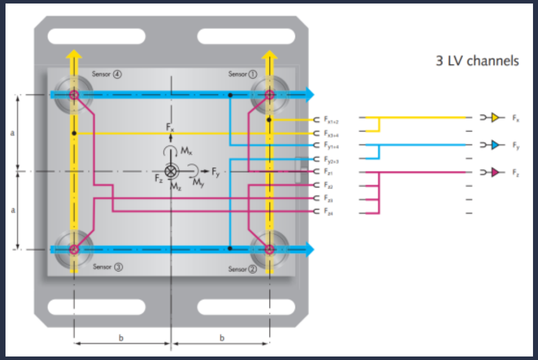
System's modelling
& identification

from mechanics to control

In-house µ-Vibration characterisation facility

Features

- Multicomponent dynamometer (6DoF).
- mN resolution, 1st eigenmode > 2kHz.
- Frequency range: 5 - 1000 Hz.
- Decoupled from environment.



430mm x 430mm x 81mm

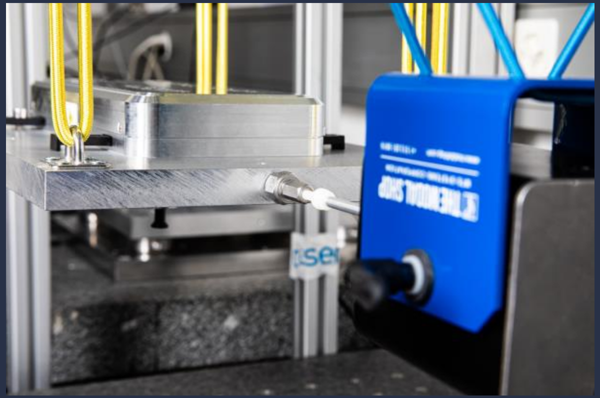
Applications

- µ-vib characterization for active components.
- Spectral analysis of exported forces.
- Sensor characterization with injected vibrations.

In-house µ-Vibration characterisation facility

Features

- Miniature modal shaker as excitation.
- Wide range of accelerometers: from µg resolution to 5 g amplitude.
- Frequency range: 0.1 - 2000 Hz.
- Decoupled from environment.



Applications

- Performance assessment of sensitive equipment under µ-vibration.
- Phase noise or frequency stability analysis under µ-vibration.

Flash lidar

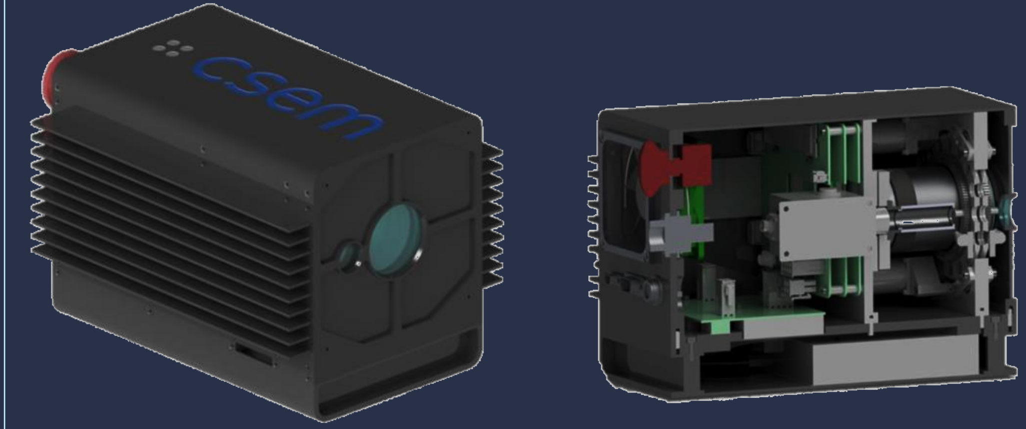
CSEM's developments & positioning

Flash lidar

CSEM's developments & positioning

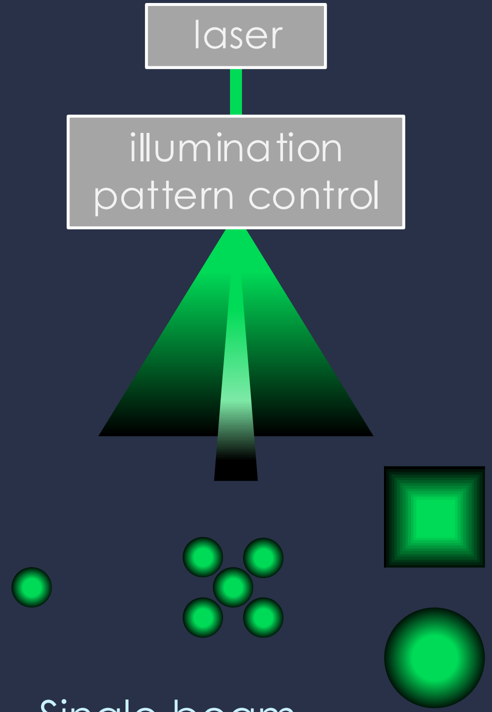
Flash lidar

System design



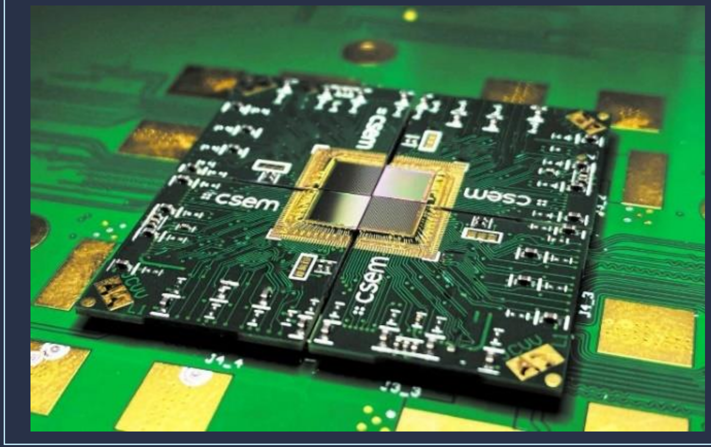
Time-gating & multiple echoes

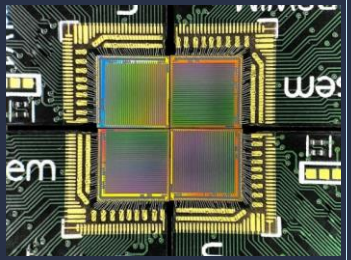
Illumination pattern control



- Single beam
- Multiple beams
- Large field-of-view

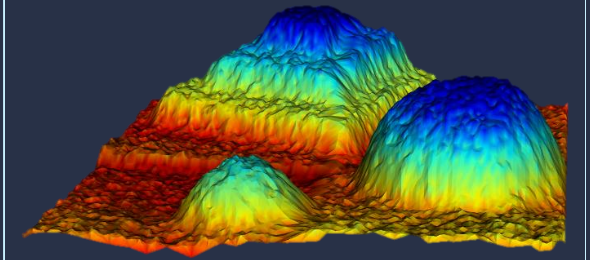
Focal plane: time-of-flight detectors





FONDAZIONE BRUNO KESSLER

Processing



Current specifications

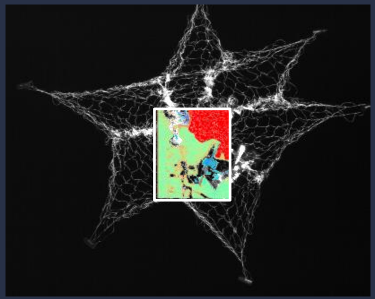
Specifications	AIRSWIM	RemoveDebris
Application	Bathymetry	Space (rendezvous)
Architecture	d-TOF	i-TOF
Laser	Pulsed, Class 4, λ = 532 nm	Laser diode, Class 4, λ = 808 nm, cw mod.
Sensor resolution	128 x 128 2023: 256 x 256 or 512 x 512	120 x 160
Precision	< 5 cm at 100 m in air	< 10 cm at 60 m
FOV [°]	5 - 20	20
Size [cm³]	20 x 17 x 19	10 x 10 x 15
Weight [kg]	6.5	< 2
Power consumption [W]	< 55	15
Frame rate [Hz]	> 4 (target: 10)	20

AIRSWIM

Remove Debris

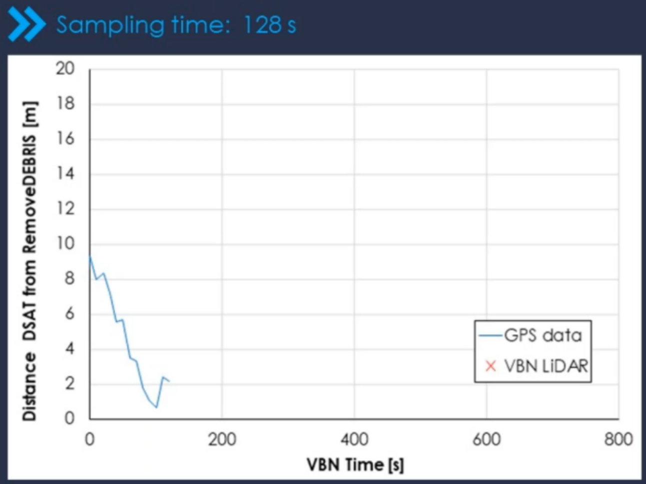
Space Applications

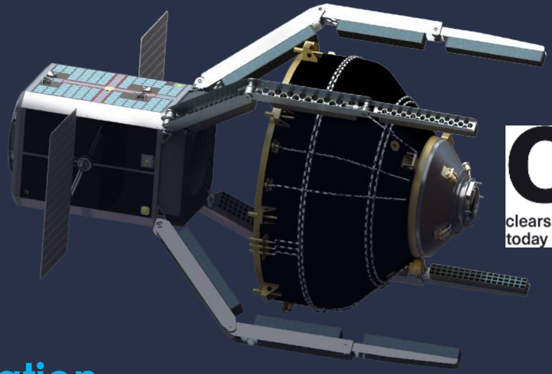
Debris removal missions – New Space



- **RemoveDEBRIS**
  - Launch with SpaceX in April 2018
  - NET and VBN in-orbit experiments
  - Mission end April 2019

VBN experiment data





clearspace today

- **ADRIOS**
  - Launch: 2026
  - **Further miniaturisation**
  - **Embedded processing**, i.e. system-on-chip

Confirmed potential for **future commercialisation** (in-orbit maneuvers)

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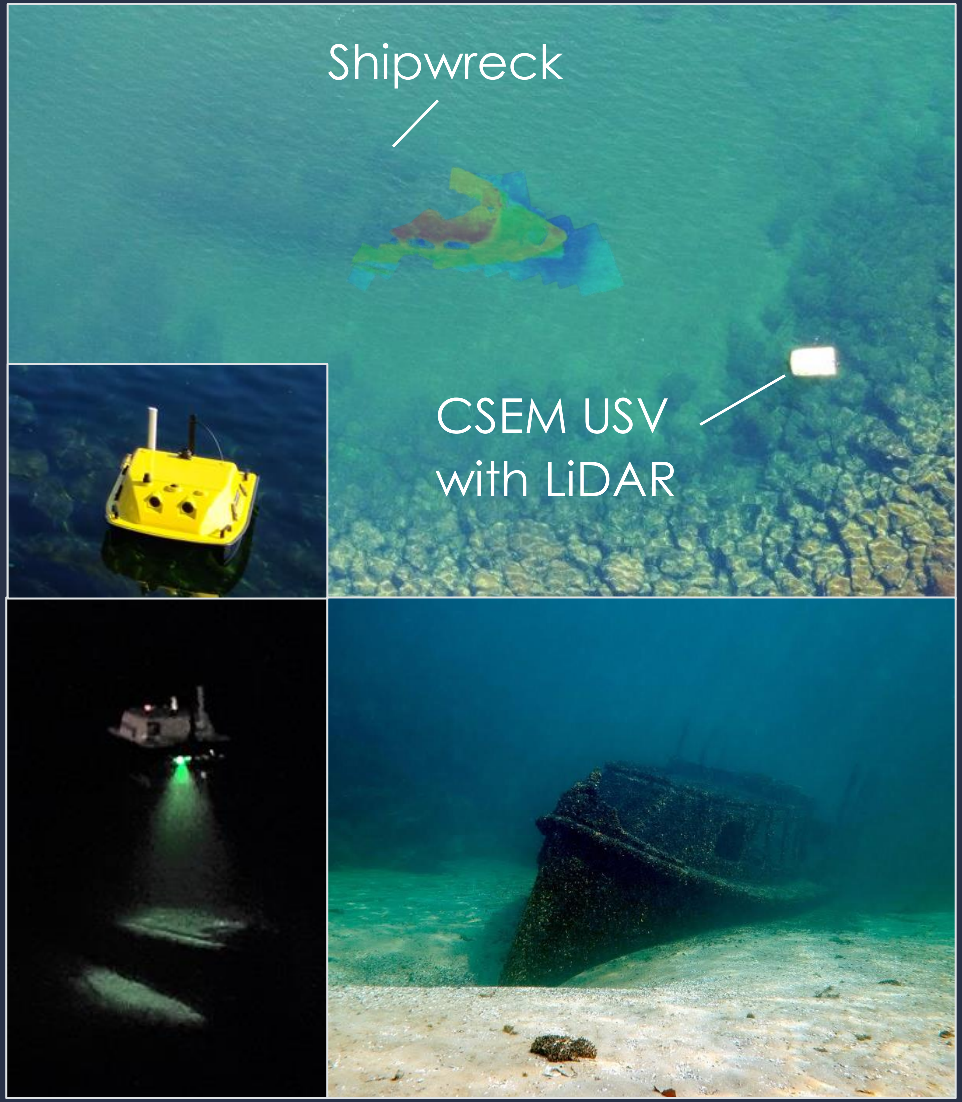
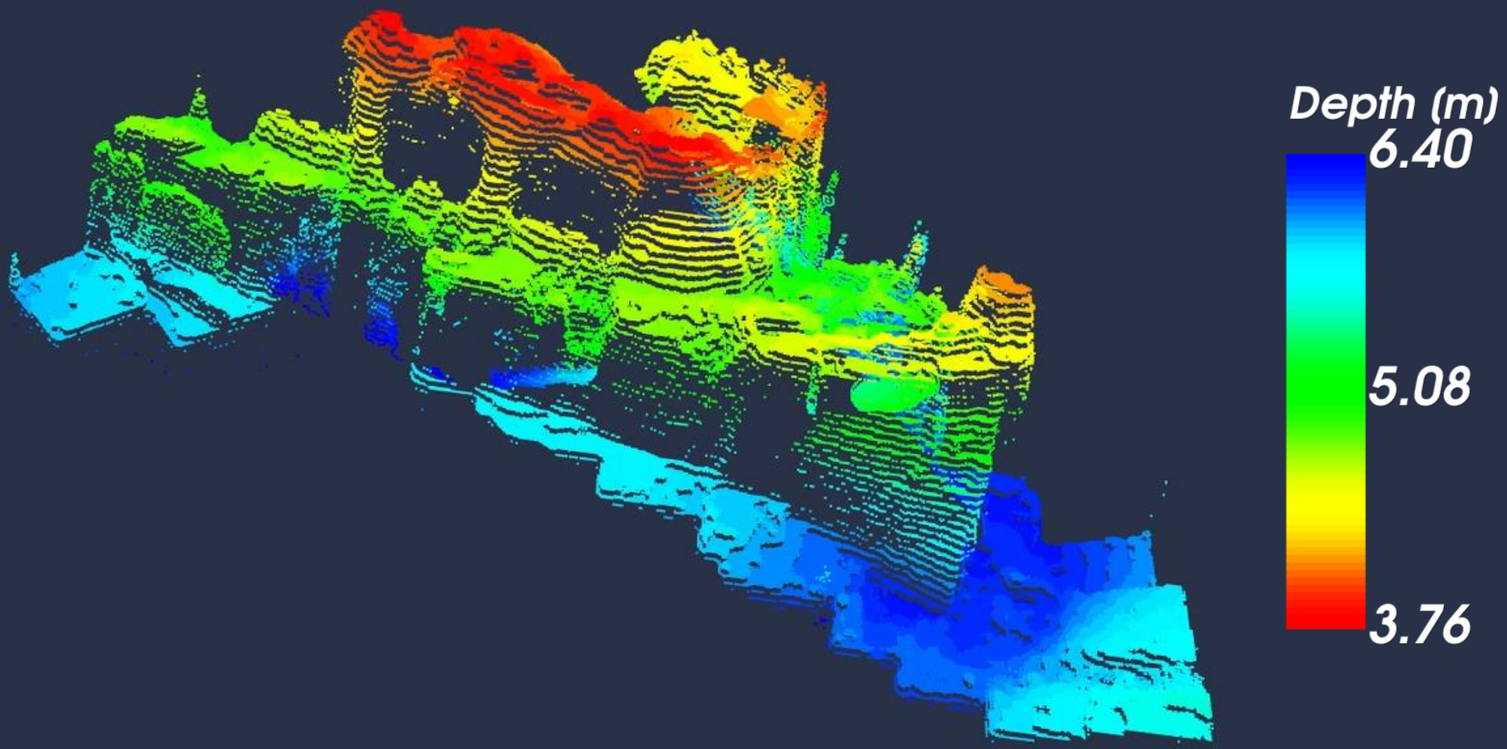
Bathymetric Applications

Demonstration from unmanned surface vehicle (USV)





Conclusions and outlook

- **Metrology** for laser sources & optical systems
- System-level testing: **space environment** & micro-vibrations
- Flash **lidar**

➢ *Push the performances to new paradigms*

Thank you for your attention!

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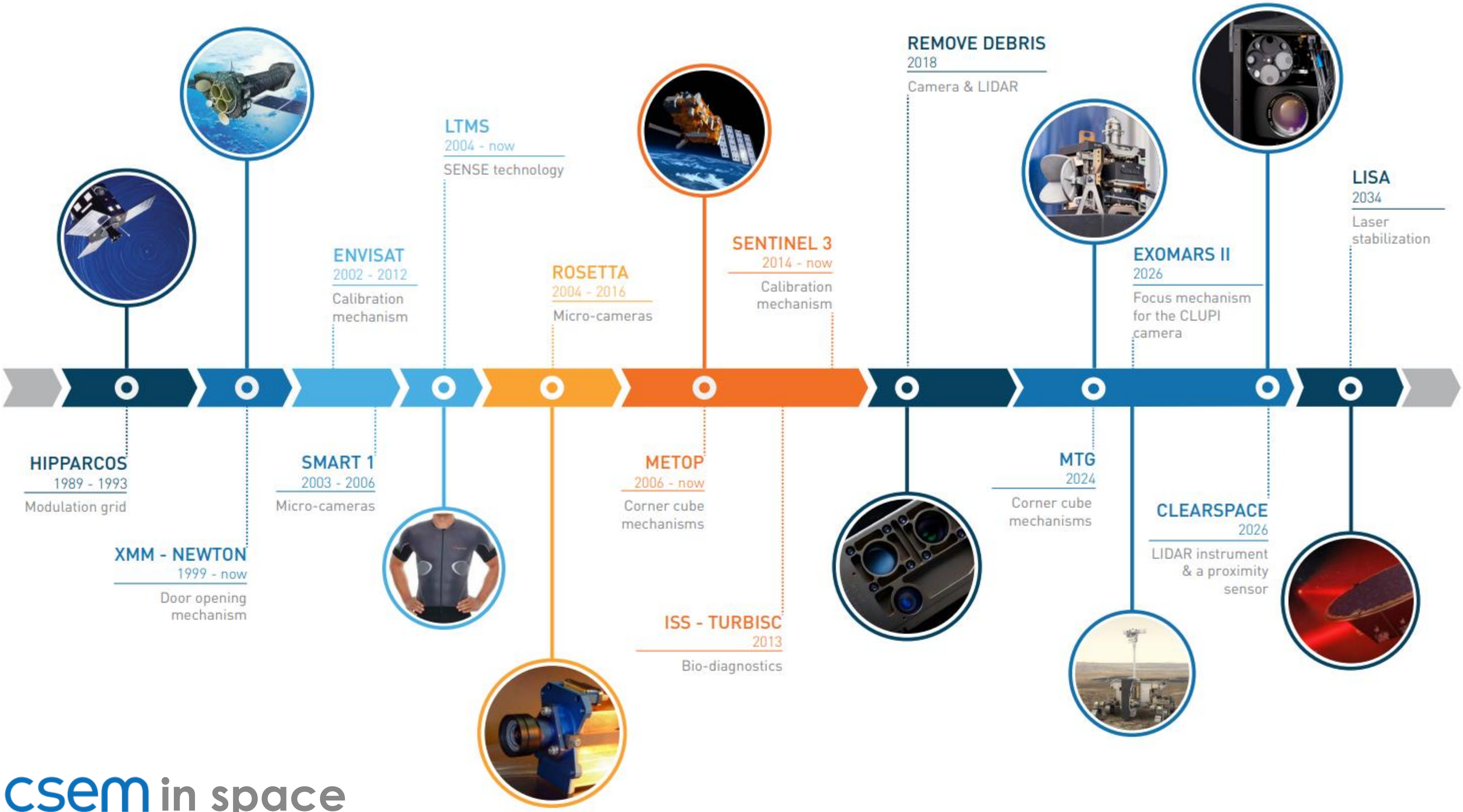
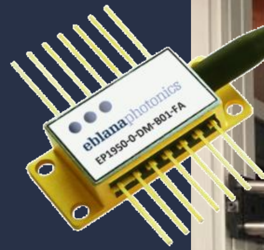
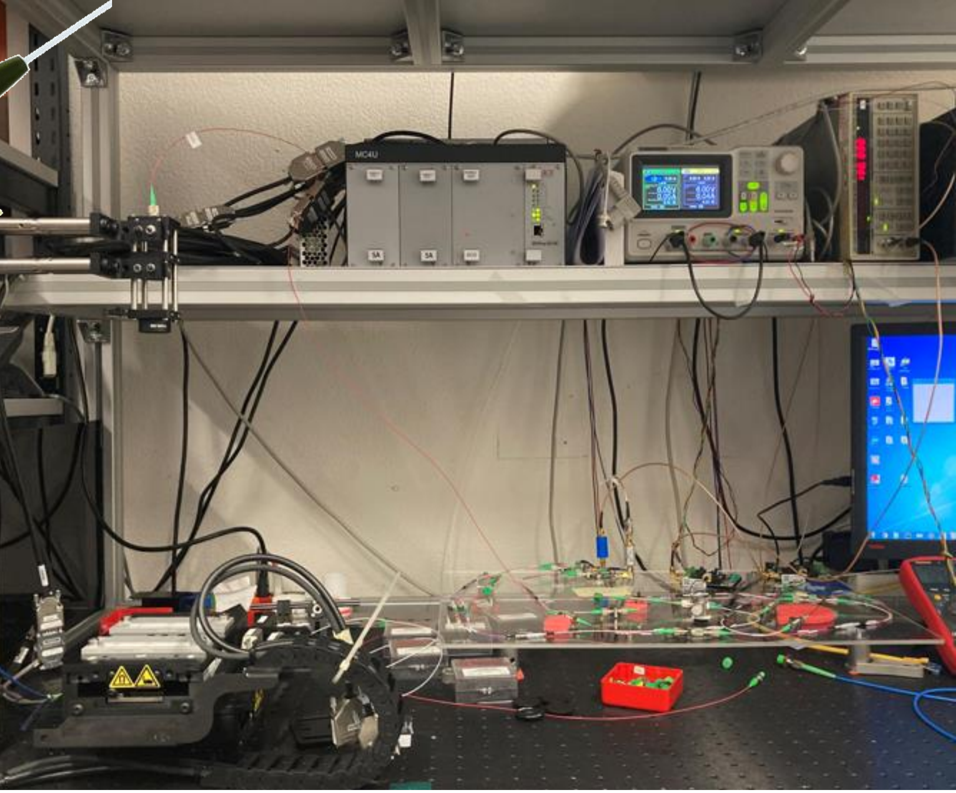


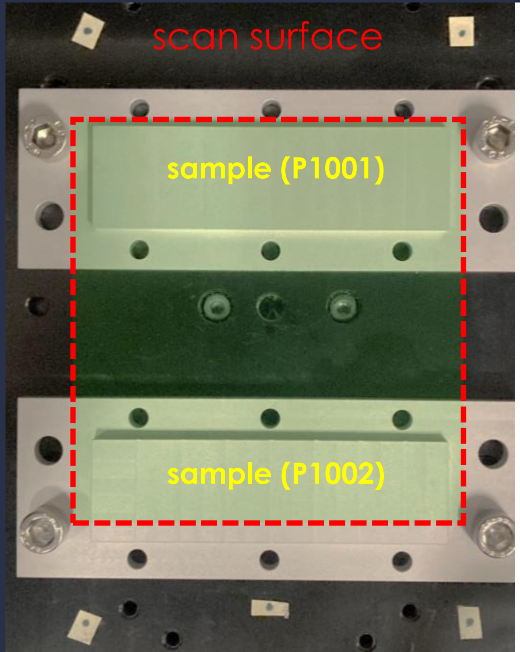
csem in space

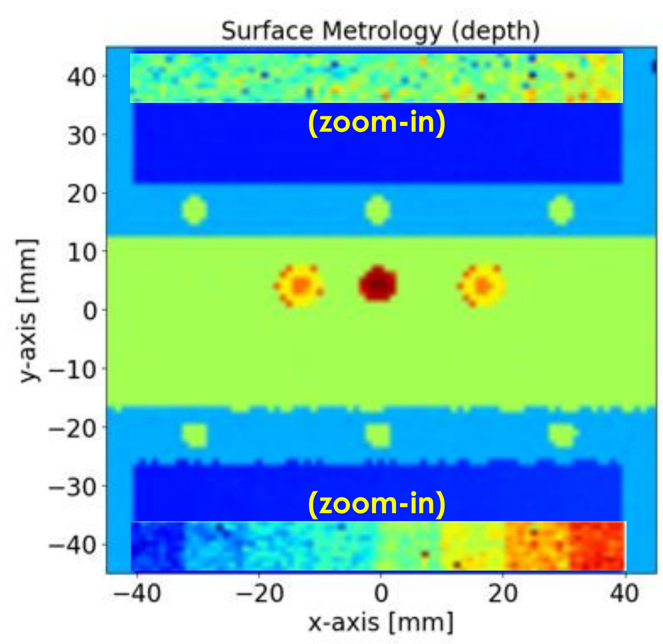
Outlook: FMCW LiDAR

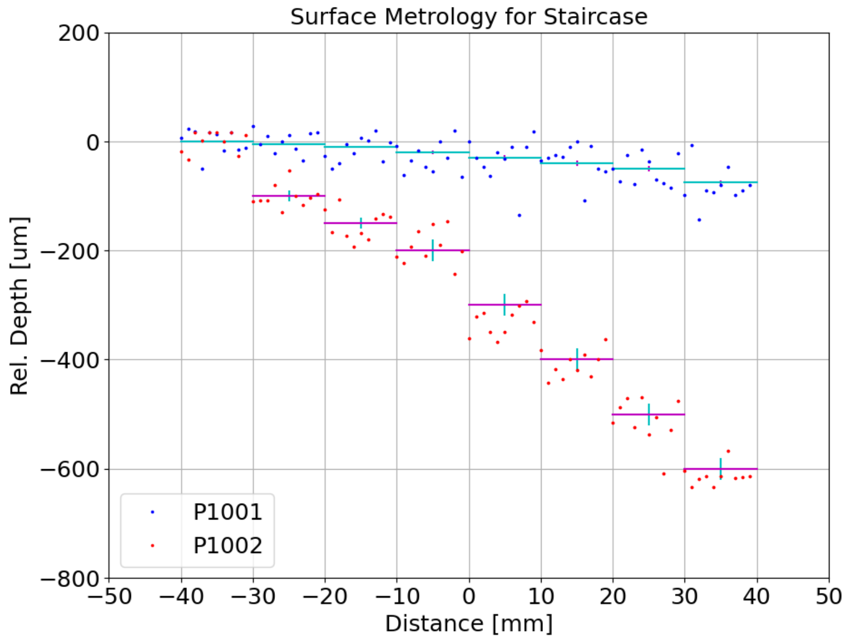
- Point-wise acquisition: 10 - 30 µm beam dia.
- Measuring rate in the kHz range
- Axial precision: < 50 µm



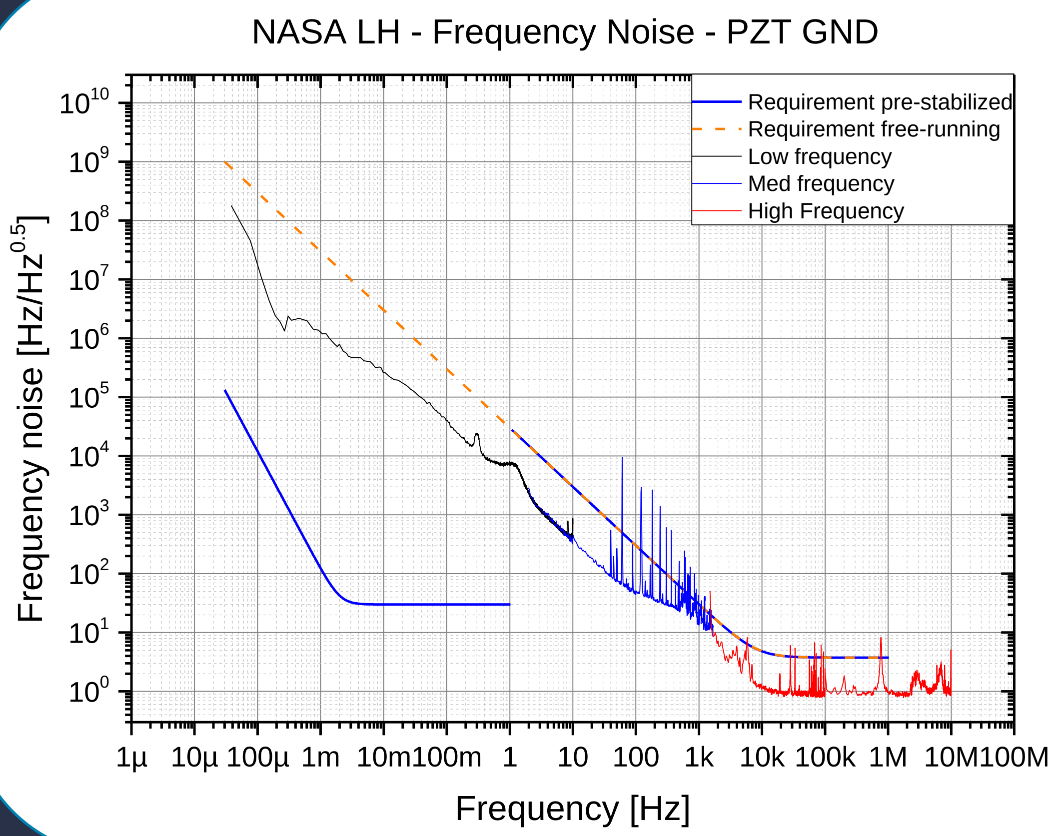


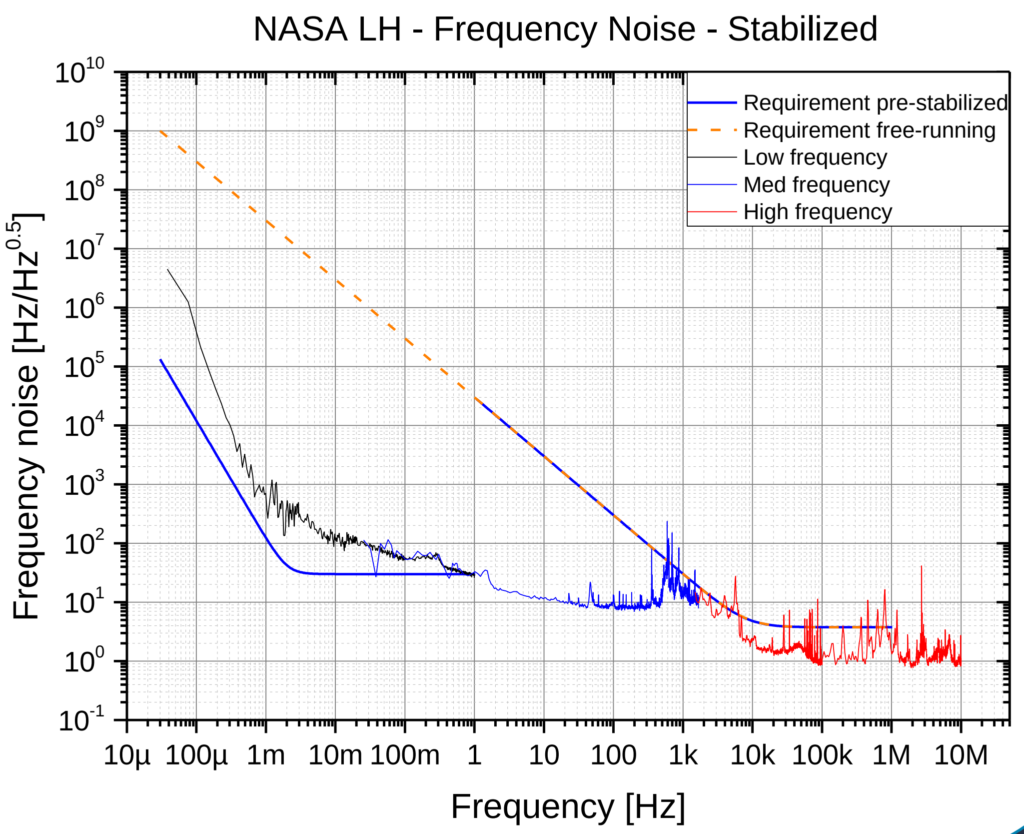






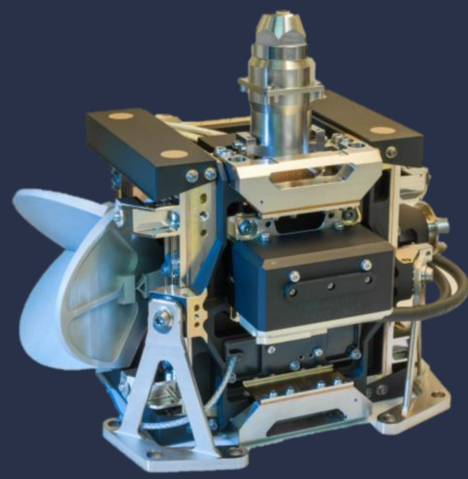
Frequency noise



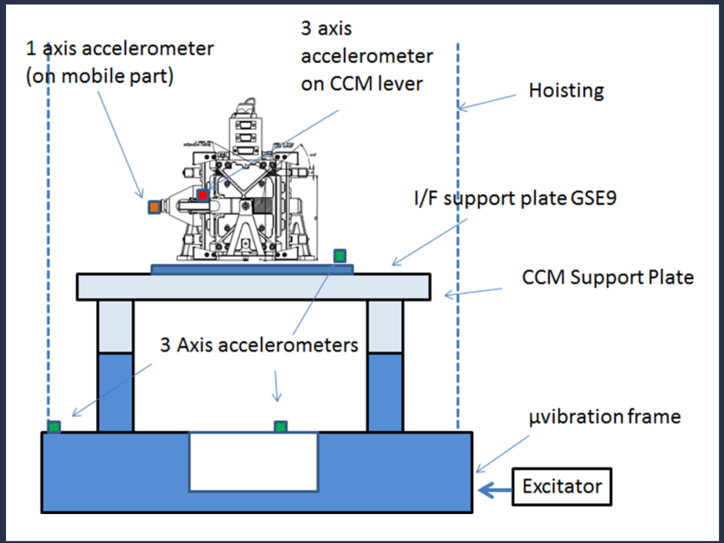


Measurement not limited by the reference setup

System modelling, identification and verification

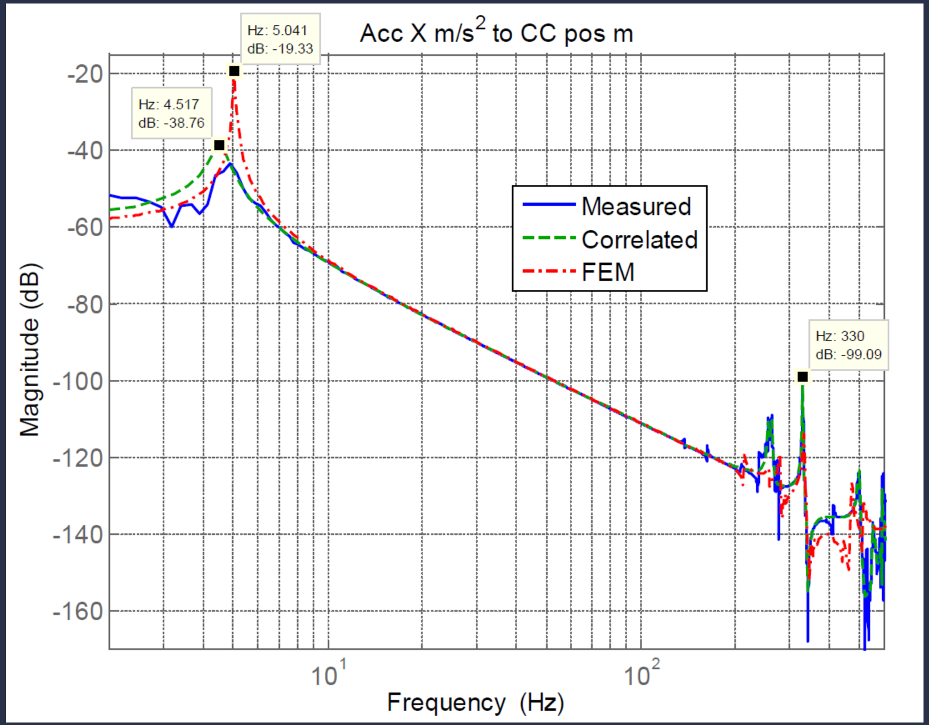


1 - Characterisation



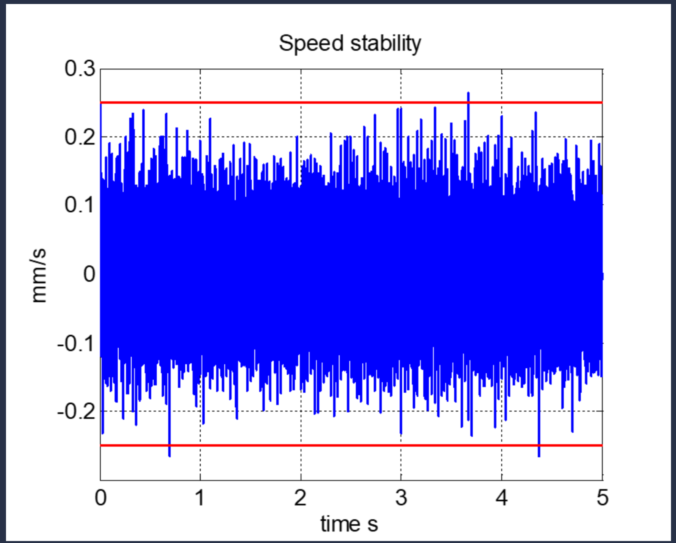
- Disturbances injection and measurements
- Definition of optimal sensors locations

2 - Analysis and correlation



- Measurements vs Finite Element Model
- Model adaptation & correlation

3 - Verification



- Performances assessment
- Performances improvement (control-loop re-tuning)

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