EURISA: Developing a European IMU for Scientific and Commercial Applications

JJ. Bonnefois, P. Cheiney, **L. Dutheil**, L. Ferraioli, R. Fredouille, O. Jolly, N. Kossa, G. Lecamp, S. Masson, JP. Michel, D. Negretto, C. Ollivier, C. Roudier, S. Theil, C. Sieg, E. de Toldi, X. Weilemann

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101004205.

Outline

1. Project Presentation
2. Targeted Missions
3. IMU Main Features & Architecture
4. IMU Inertial Measurements
5. Development Progress

eurisa

Project Presentation

Inertial Measurement Unit (IMU)

Capture the **6-degrees of freedom** in space:

- 3 rotations: **3 gyroscopes** (FOG)
- 3 translations: **3 accelerometers** (ACC)

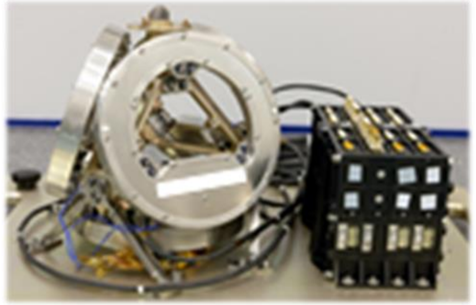
Deliver **navigation** data:

- Sensors thermal behavior known and modeled
- Thermal model integrated
- On-board navigation algorithm: **FPGA**

➢ Navigate in **harsh thermal** and **mechanical** environments

Extending from Astrix Family

2007

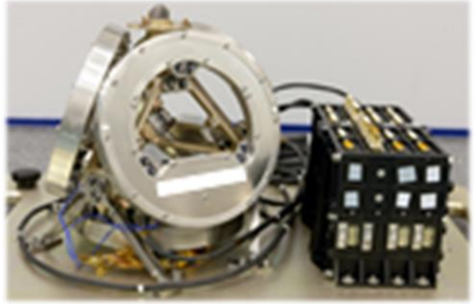


Astrix 200

- Airbus product
- Design and manufacturing of the optical gyroscope
- Tests and validation of sub-systems
- Gyroscope

Extending from Astrix Family

2007



Astrix 200

- Airbus product
- Design and manufacturing of the optical gyroscope
- Tests and validation of sub-systems
- Gyroscope

2017

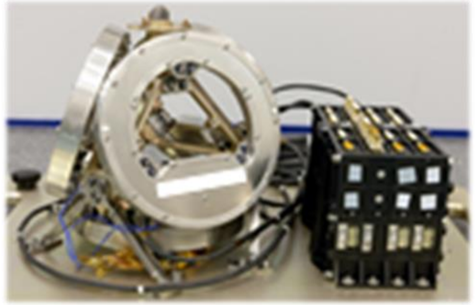
Astrix 1090A

- Airbus product
- Design and manufacturing of the optical gyroscope
- Tests and validation of sub-systems
- Integration of the whole equipment
- Acceptance tests of the equipment
- 6-axis IMU

eurisa

Extending from Astrix Family

2007



Astrix 200

- Airbus product
- Design and manufacturing of the optical gyroscope
- Tests and validation of sub-systems
- Gyroscope

2017

Astrix 1090A

- Airbus product
- Design and manufacturing of the optical gyroscope
- Tests and validation of sub-systems
- Integration of the whole equipment
- Acceptance tests of the equipment
- 6-axis IMU

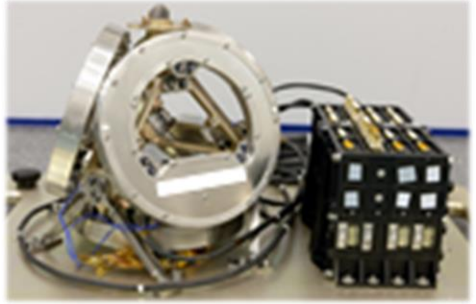
2023

Astrix NS

- **Exail product**
- Design and manufacturing of the optical **gyroscope**
- Tests and validation of sub-systems
- Integration of the whole equipment
- Acceptance tests of the equipment
- Design of the electronic boards
- **Gyroscope**

Extending from Astrix Family

2007



Astrix 200

- Airbus product
- Design and manufacturing of the optical gyroscope
- Tests and validation of sub-systems
- Gyroscope

2017

Astrix 1090A

- Airbus product
- Design and manufacturing of the optical gyroscope
- Tests and validation of sub-systems
- Integration of the whole equipment
- Acceptance tests of the equipment
- 6-axis IMU

2023

Astrix NS

- Exail product
- Design and manufacturing of the optical **gyroscope**
- Tests and validation of sub-systems
- Integration of the whole equipment
- Acceptance tests of the equipment
- Design of the electronic boards
- Gyroscope

2025

- European project lead by Exail
- Integration of the 3 accelerometer channels
- 6-axis integrated IMU

EURISA: a Space European Inertial Measurment Unit

H2020 project supported by the European Union gathering 4 partners:

AIRBUS

- Market Study
- Specifications
- Expertise

DLR — Deutsches Zentrum für Luft- und Raumfahrt — German Aerospace Center

- Algorithm
- Sensor fusion
- Simulation
- Test facilities

ETH zürich

- Accelerometer designed for space electronics

exail

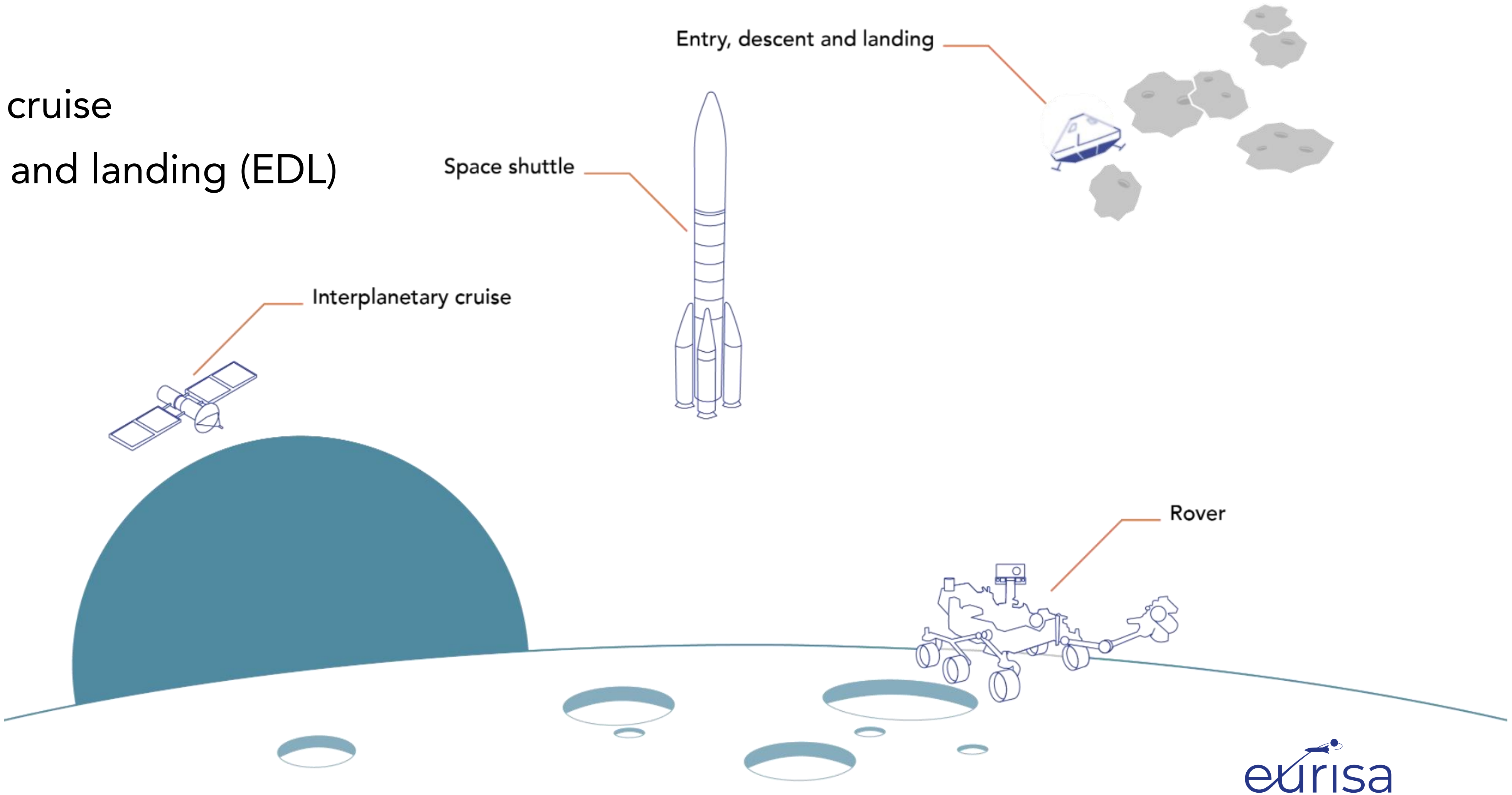
- 3 gyroscopes
- 3 accelerometers
- Electronics
- Algorithms
- Assembly and implementation
- Testing

Targeted Missions

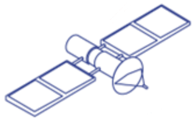
eurisa

Targeted Missions

- Space shuttle
- Interplanetary cruise
- Entry, descent and landing (EDL)
- Rover

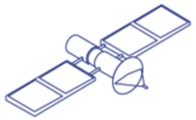


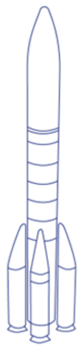
Mission Specificities



Applications	Interplanetary cruise
Typical Missions	◦ Carrier module, ◦ In-orbit rendezvous ◦ Missions at Lagrange point
Mission Specificities	◦ Long-term stability ◦ Sensitivity
Technical Requirements	◦ FOG/ACC noise ◦ FOG/ACC dead zone ◦ ACC bias and stability

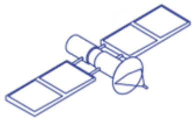
Mission Specificities

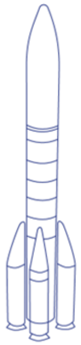
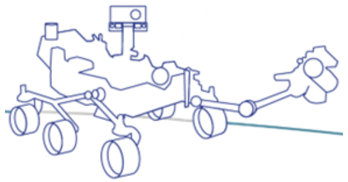




Applications	Interplanetary cruise	EDL and Launchers
Typical Missions	◦ Carrier module, ◦ In-orbit rendezvous ◦ Missions at Lagrange point	◦ Moon landing ◦ Mars Robotic Exploration, ExoMars Descent Module
Mission Specificities	◦ Long-term stability ◦ Sensitivity	◦ Harsh mechanical/thermal environment
Technical Requirements	◦ FOG/ACC noise ◦ FOG/ACC dead zone ◦ ACC bias and stability	◦ FOG/ACC performance ranges ◦ FOG/ACC scale factor misalignments

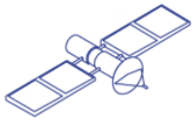
Mission Specificities

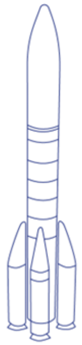


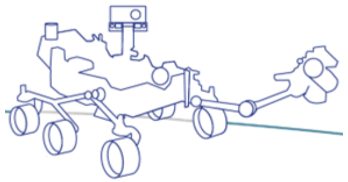



Applications	Interplanetary cruise	EDL and Launchers	Rover
Typical Missions	○ Carrier module, ○ In-orbit rendezvous ○ Missions at Lagrange point	○ Moon landing ○ Mars Robotic Exploration, ExoMars Descent Module	○ Lunar programs/missions, MMX ○ Mars Robotic Exploration
Mission Specificities	○ Long-term stability ○ Sensitivity	○ Harsh mechanical/thermal environment	○ Electrical and space efficiencies
Technical Requirements	○ FOG/ACC noise ○ FOG/ACC dead zone ○ ACC bias and stability	○ FOG/ACC performance ranges ○ FOG/ACC scale factor misalignments	○ System mechanical footprint ○ Power consumption

Mission Requirements







Sensors		Interplanetary cruise	EDL and Launchers	Rover
FOG	Range	$\pm 10\ °/s$ (sat. $> 500°/s$)	$\pm 100\ °/s$ (sat. $> 800°/s$)	$\pm 10\ °/s$ (sat. $> 500°/s$)
	Bias	$0.15\ °/h$	$0.15\ °/h$	$0.5\ °/h$
	Scale F^{or}	300 ppm	50 ppm	1,000 ppm
ACC	Range	$\pm 0.1\ \mathbf{g}$ (sat. $\pm 0.5\ \mathbf{g}$)	$\pm 12\ \mathbf{g}$ (sat. $\pm 20\ \mathbf{g}$)	$\pm 1\ \mathbf{g}$ (sat. $\pm 3\ \mathbf{g}$)
	Bias	$50\ \mu\mathbf{g}$	$300\ \mu\mathbf{g}$	$500\ \mu\mathbf{g}$
	Scale F^{or}	500 ppm	150 ppm	1,000 ppm
Sampling Rate		≤ 20 Hz	≤ 100 Hz	≤ 10 Hz
Mechanical Environment		$\leq 0.1\ \mathbf{g}$ [0 , 1 kHz]	$11\ \mathbf{g}_{\mathbf{RMS}}$ [0 , 10 kHz]	$\leq 0.1\ \mathbf{g}$ [0 , 1 kHz]

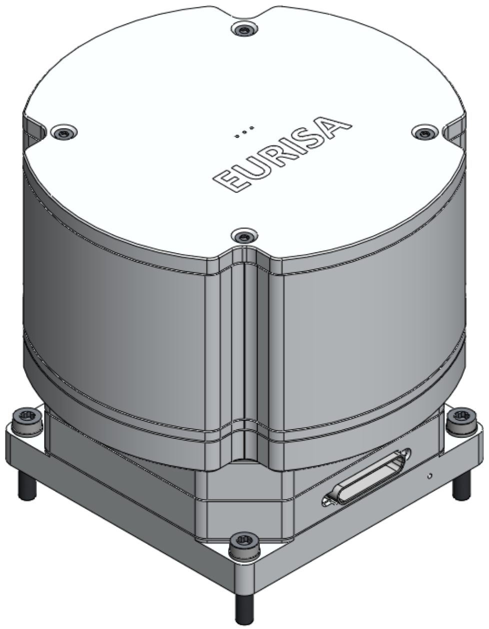
IMU Main Features

eurisa

Inheritance of Astrix Family and Pioneers

Small volume and low power

- 2 liter (½ gallon)
- < 2 kg (4 lbs)
- 12 W

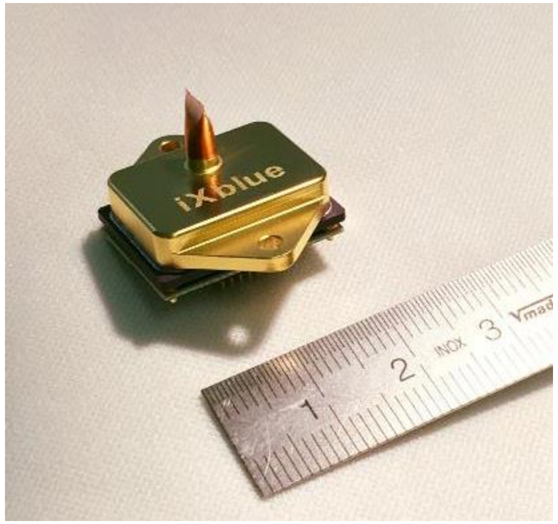


Fast

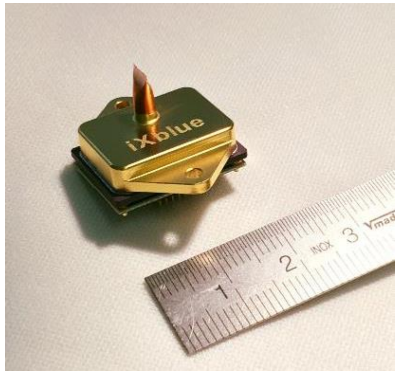
- > 1 kHz internal bandwidth
- Data rate up to 500 Hz
- Accurate data in less than 1 s

Durability

- GEO 15 years + EOR (LEO compatible also)
- 800 FITS target for GEO 15 years + EOR (FIDES 2009)



Inheritance of Astrix Family and Pioneers



Electronics

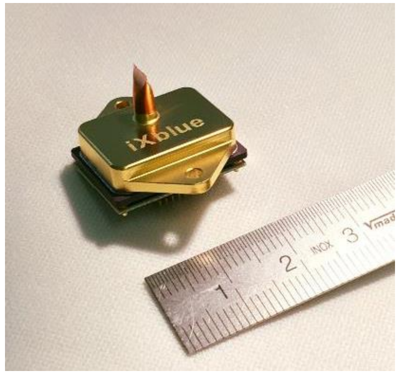
Inheritage

- FPGA based
- Design rules
- Reduction of the number of components

Innovation

- ITAR free
- Space ACC
- Exail smallest ACC

Inheritance of Astrix Family and Pioneers



Electronics

Inheritage

- FPGA based
- Design rules
- Reduction of the number of components

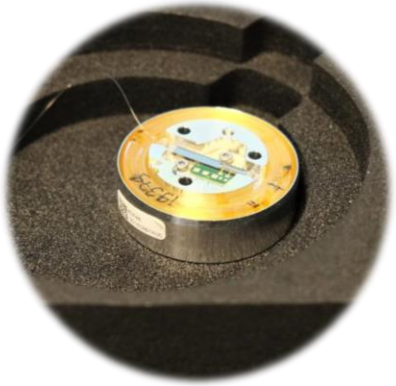
Innovation

- ITAR free
- Space ACC
- Exail smallest ACC

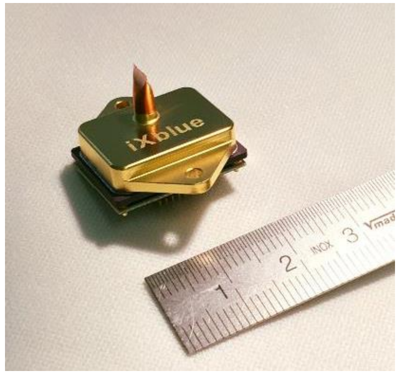
Optics

Inheritage

- Homemade optical parts manufacturing (rad-hard fiber, modulators)
- Compact optical components



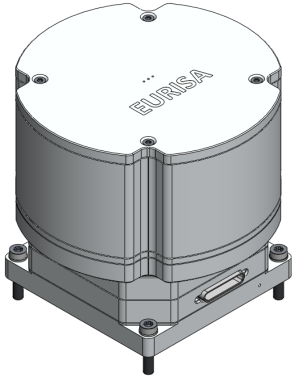
Inheritance of Astrix Family and Pioneers



Optics

Inheritance

- Homemade optical parts manufacturing (rad-hard fiber, modulators)
- Compact optical components



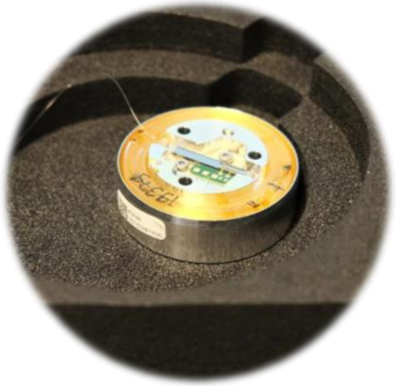
Electronics

Inheritage

- FPGA based
- Design rules
- Reduction of the number of components

Innovation

- ITAR free
- Space ACC
- Exail smallest ACC



Mechanics

Inheritage

- Symmetrical pyramid
- Compact magnetic shield

Innovation

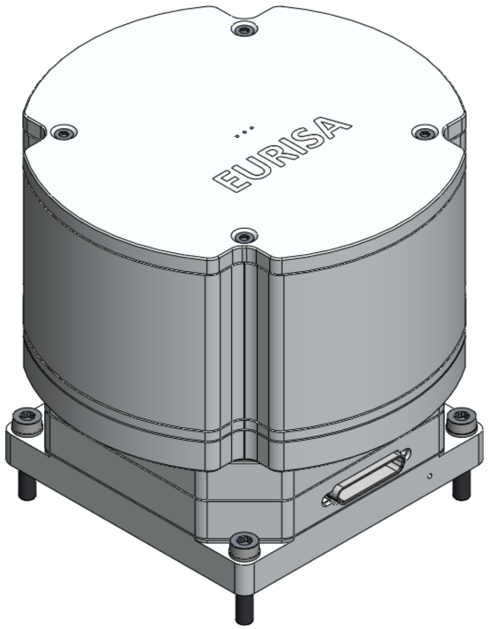
- Includes 3 ACC channels
- Compact design
- **Harsh environment compatible**

eurisa

Inheritance of Astrix Family and Pioneers

Small volume and low power

- 2 liter (½ gallon)
- < 2 kg (4 lbs)
- 12 W



Fast

- > 1 kHz internal bandwidth
- Data rate up to 500 Hz
- Accurate data in less than 1 s

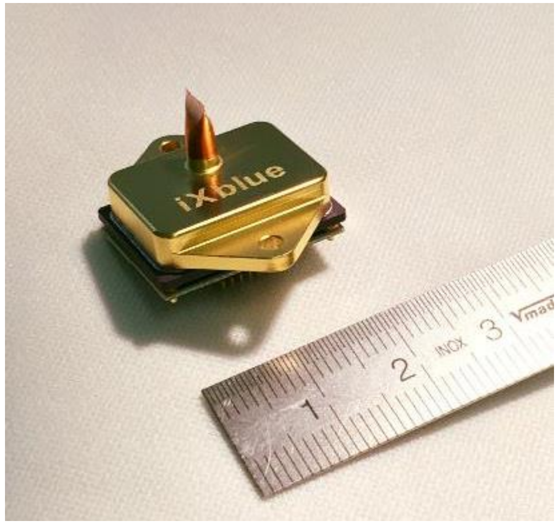
Durability

- GEO 15 years + EOR (LEO compatible also)
- 800 FITS target for GEO 15 years + EOR (FIDES 2009)

Performance

	FOG	ACC
Dynamic range	$\pm 800\ °/s$	$\pm 12\ \mathbf{g}$
Bias stability over 1h (steady temperature)	10 ppm	$20\ \mu\mathbf{g}$
Scale factor stability (all effects)	300 ppm	150 ppm
Angular|Velocity Random Walk (ARW|VRW)	$0.0025\ °/\sqrt{h}$	$4\ \frac{mm/s}{\sqrt{h}}$

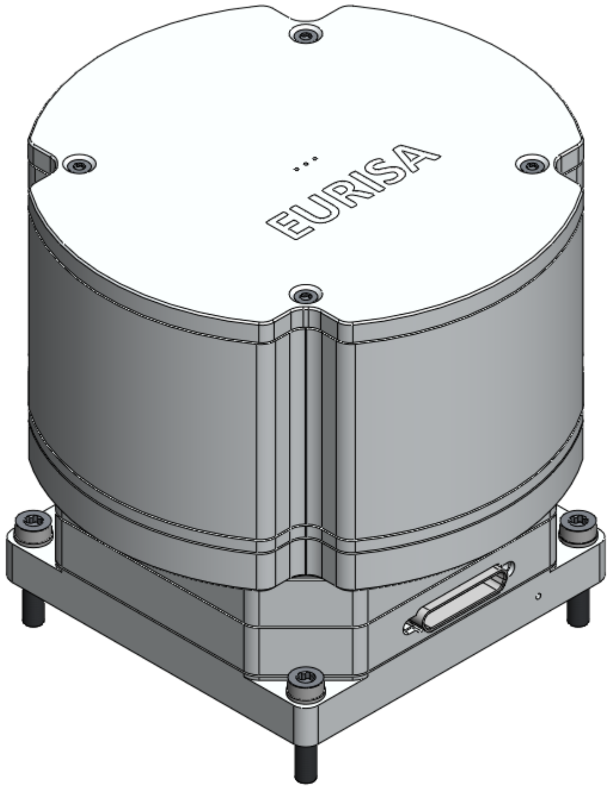
No other noise contributors for FOG technology like AWN, flicker noise…



eurisa

IMU Architecture

IMU Architecture



IMU Architecture

3 FOG + 3 ACC mounted on a solid **pyramid**:

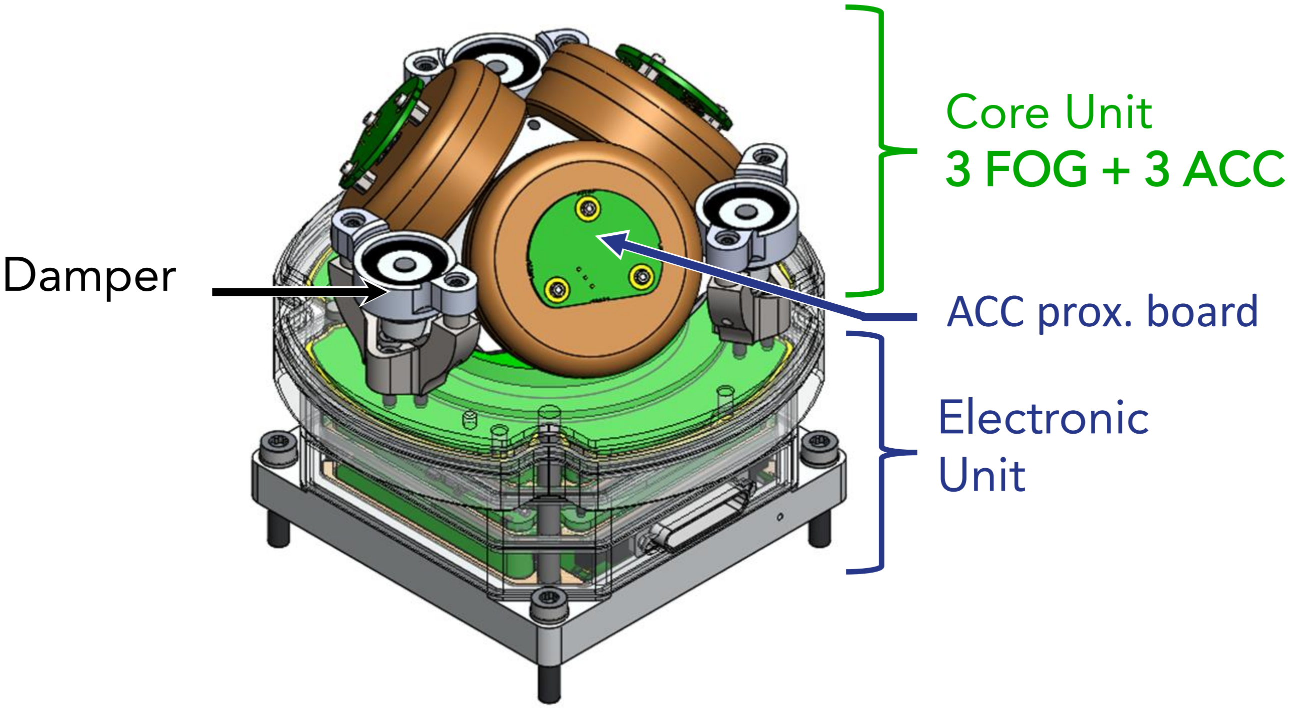
- Robust **Orthogonality, Harmonization**
- Low **deformation** in harsh environment

Damped pyramid:

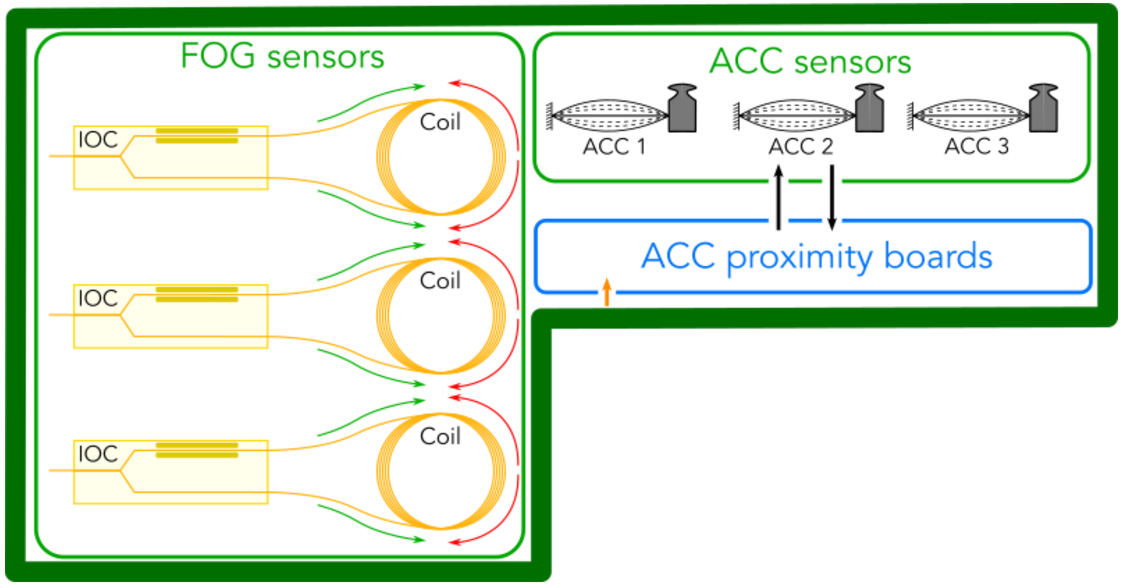
- Safe for **severe** mechanical environment

On-board electronics:

- On-board system-tailored **thermal model**
- **Coning-sculling** compensation
- **Integrated navigation** algorithms



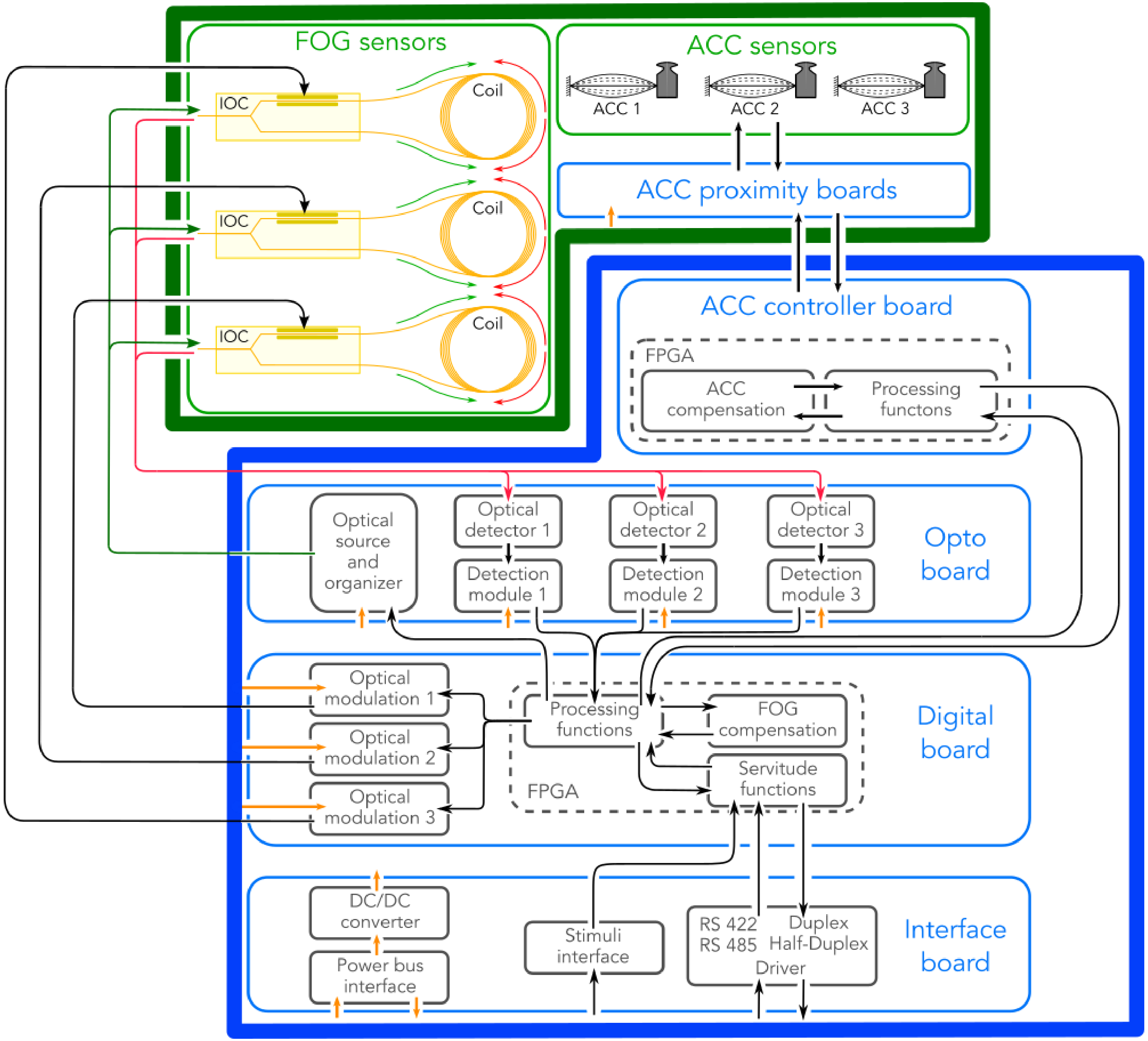
IMU Architecture



IMU Architecture

Digital board integrates on-board IMU intelligence:

- **Sensor Dynamic** compensation
- **Coning-Sculling** compensation
- **Lever Arm** compensation



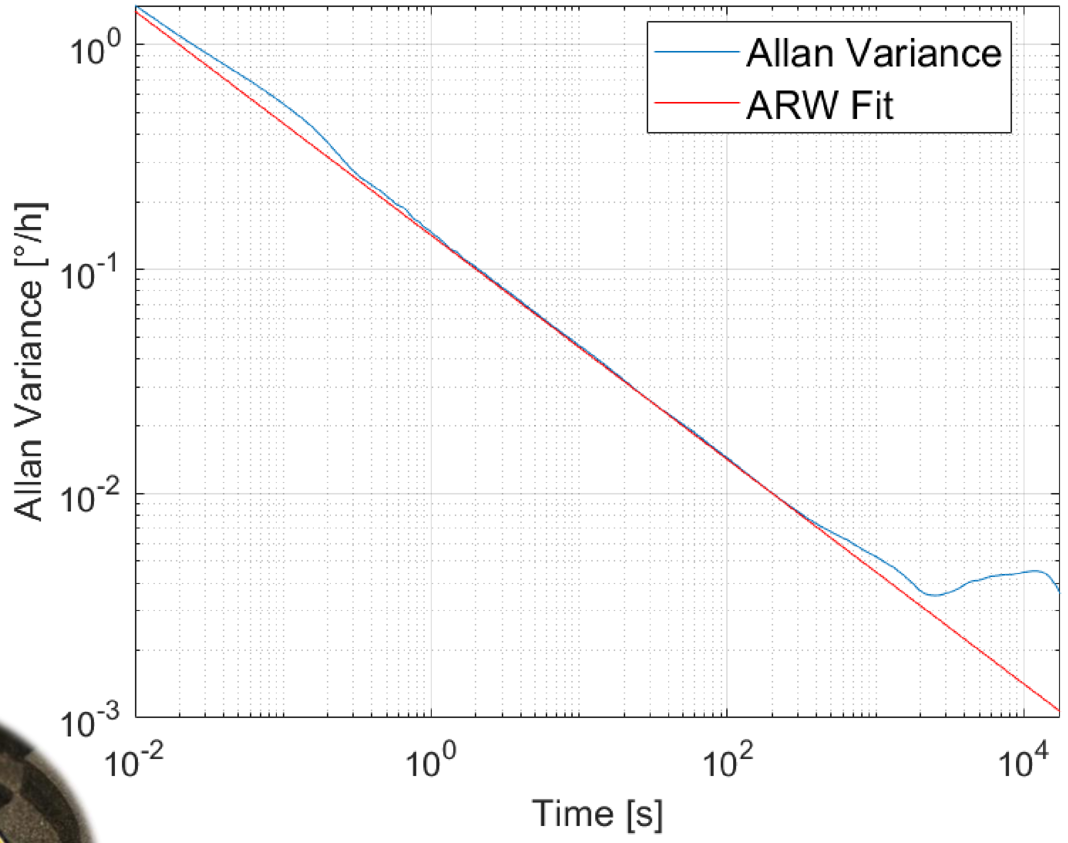
IMU Inertial Measurements

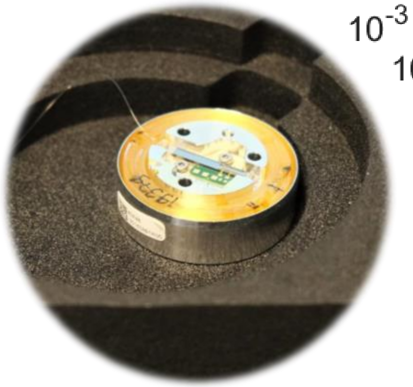
FOG Noise Performance Allan Variance

ARW below $\mathbf{0.0025\ ^{\circ}/\sqrt{h}}$ on all the bandwidth

- No quantization
- No other noise contributors (ARW, RRW)
- Engineering model's **ARW** measurement $\mathbf{0.00231\ ^{\circ}/\sqrt{h}}$
- Stable in the $[\mathbf{-15; 55}]\mathbf{^{\circ}C}$ $([5; 131]^{\circ}\mathrm{F})$

Power spectral density confirms the noise **flatness** over the **full-frequency** range





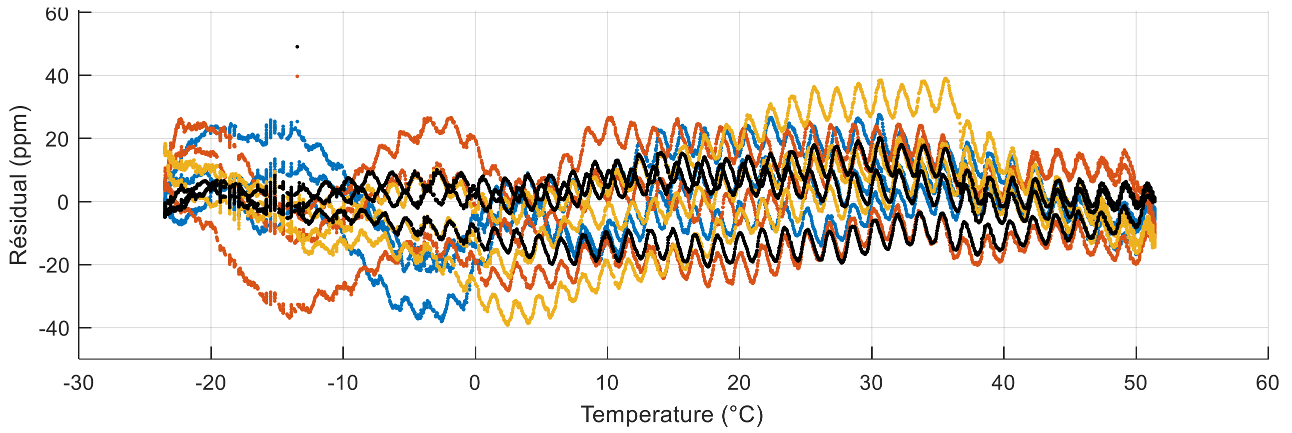
eurisa

FOG Thermal Modeling

Inheritance from the development of **Astrix NS,** all systems:

- Are individually calibrated in temperaure using thermal profiles
- Embed and run their **individually-tailored** thermal compensation model

Modelled IMU: Scale factor residual below 50 ppm



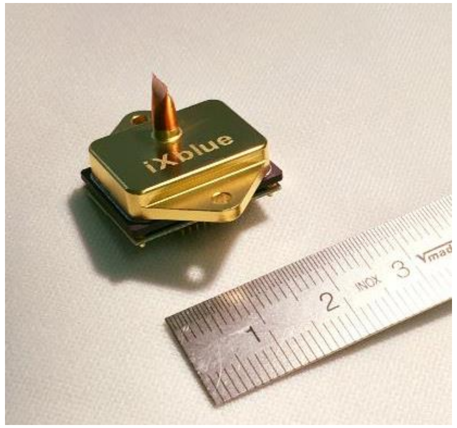
Scale factor residual after thermal modeling on Astrix NS

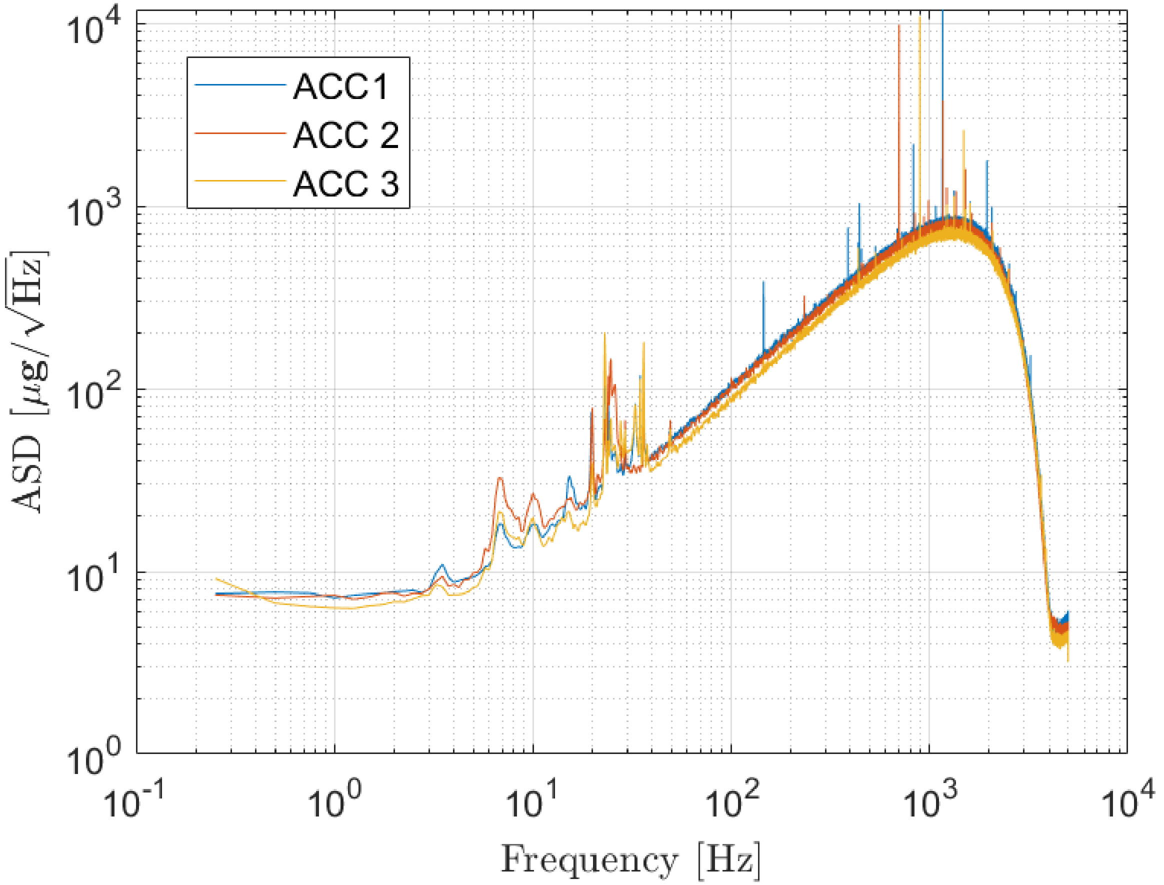
Thermal chamber on **3-axis rotating** table

ACC Noise Performance: Amplitude Spectrum Density (ASD)

ASD match 8 μg/√Hz at 3Hz

In-run stability < 10 μg





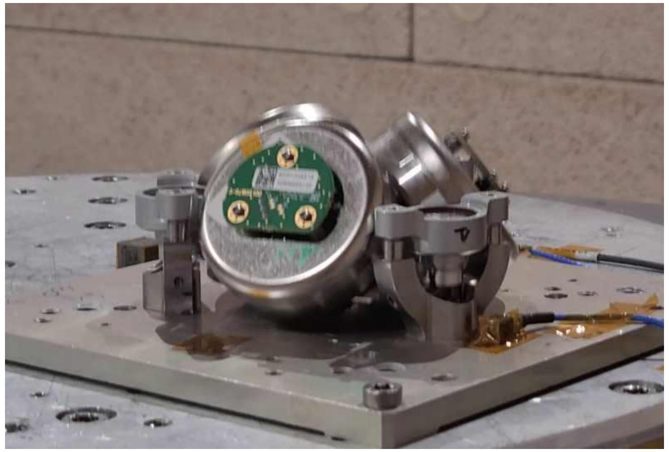
Development Progress

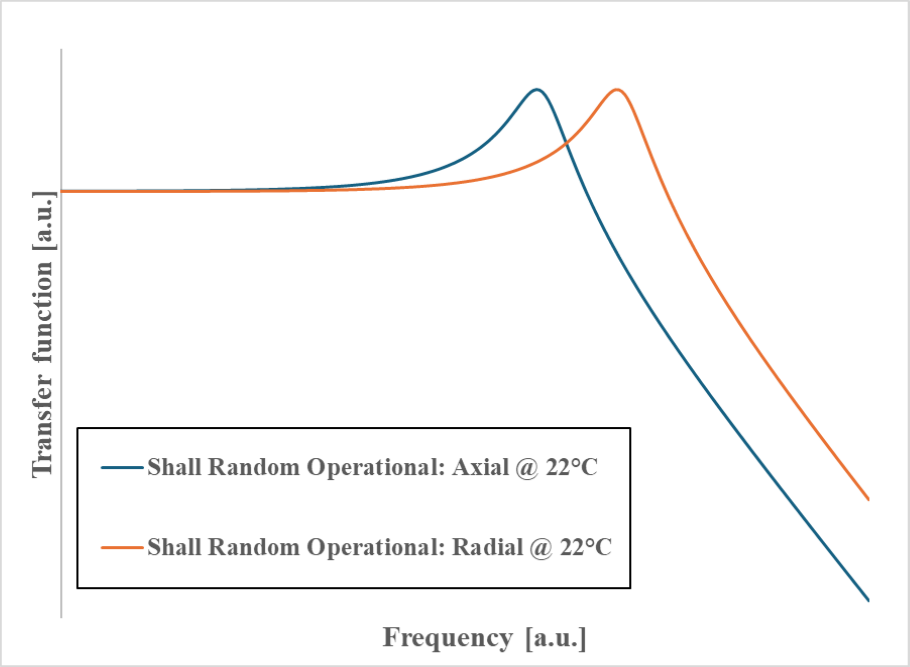
eurisa

Environmental Tests

Dampers' Validation:

- Quality factor
- Resonance frequency
- Maximum displacement
- Sensor survival

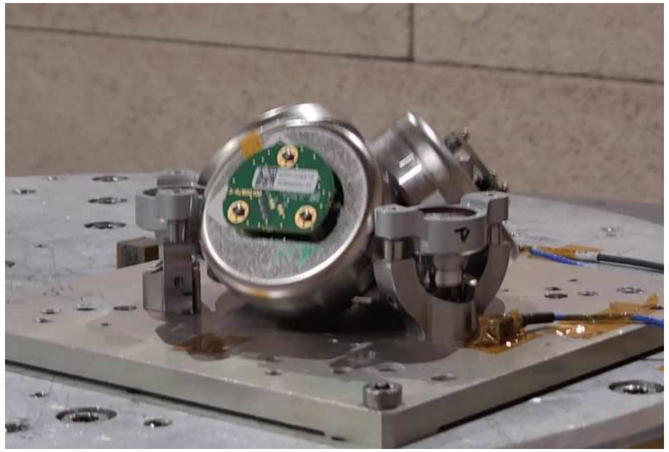


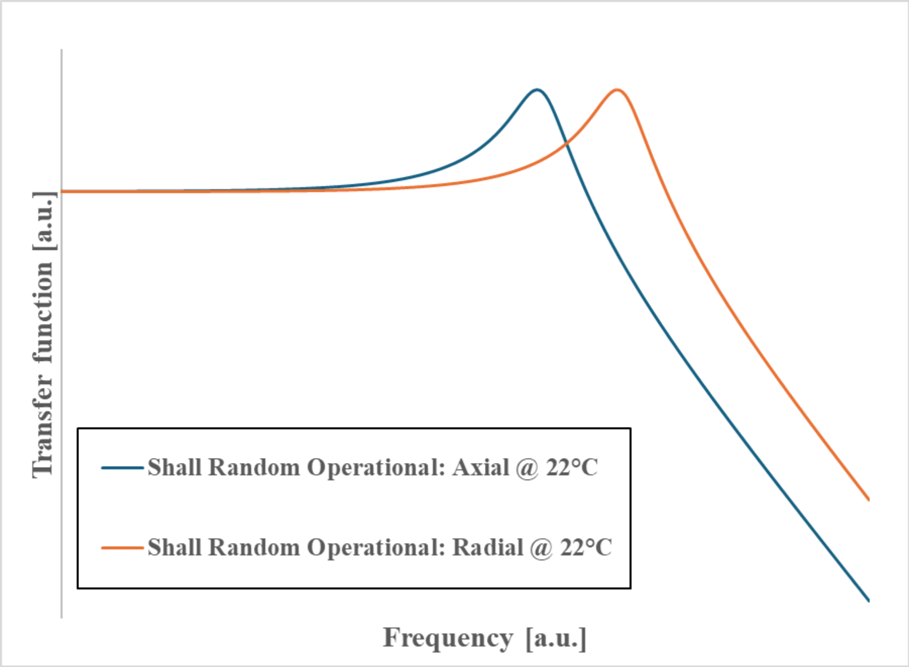


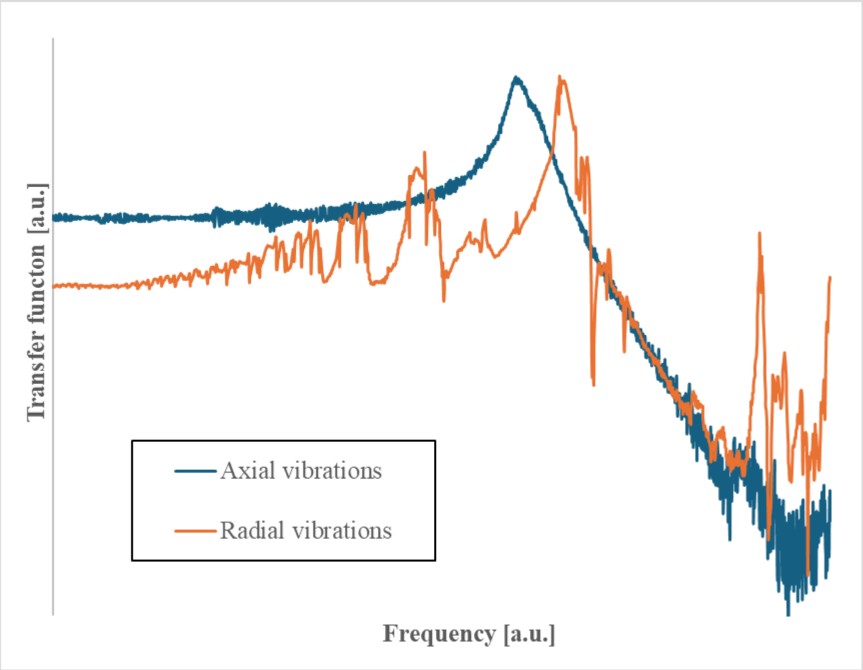
Environmental Tests

Dampers' Validation:

- Quality factor
- Resonance frequency
- Maximum displacement
- Sensor survival



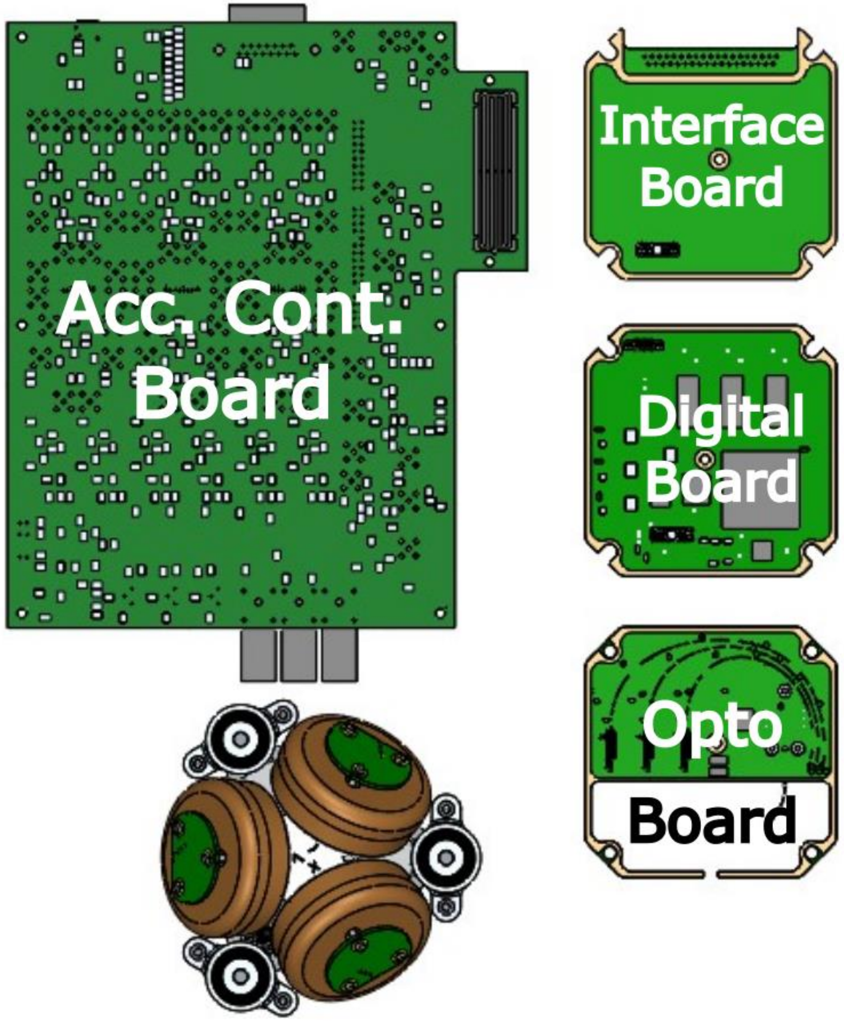




Currently

Building a **flat IMU** (complete IMU out of housing):

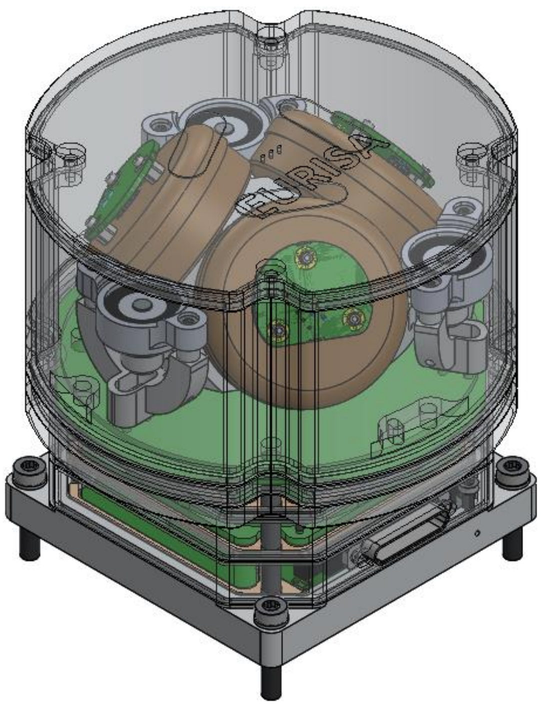
- Inject VHDL code (FPGA)
- Test communication protocols
- Thermal modeling
- First inertial performance tests



New design of the ACC controller board and build the **first EM** for exhaustive testing.

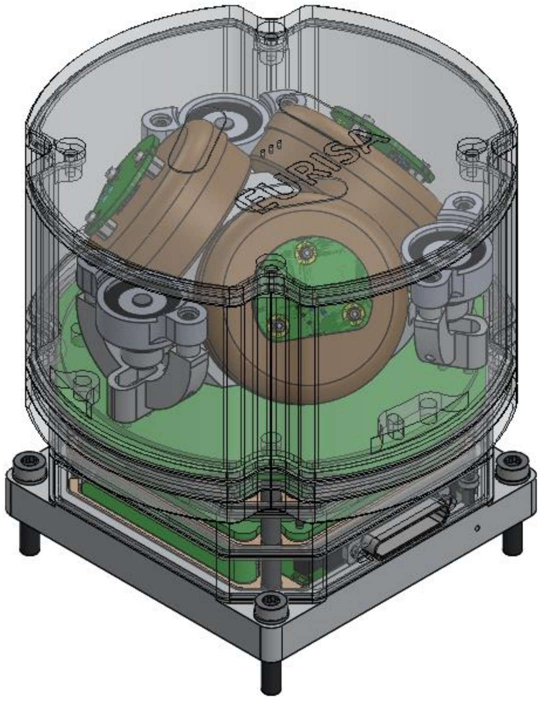
When ?!

- First EM available in 2025 and fully tested in late 2025 in the scope of the H2020 project.
- FM available following qualification (crucial qualification heritage from Astrix NS) in the coming years.



When ?!

- First EM available in 2025 and fully tested in late 2025 in the scope of the H2020 project.
- FM available following qualification (crucial qualification heritage from Astrix NS) in the coming years.



Exail thanks its partner in the EURISA project Airbus DS, DLR and ETHZ, the European Union.

Thank you for your attention

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 101004205.

eurisa