

ELECTRONICS & DEFENSE

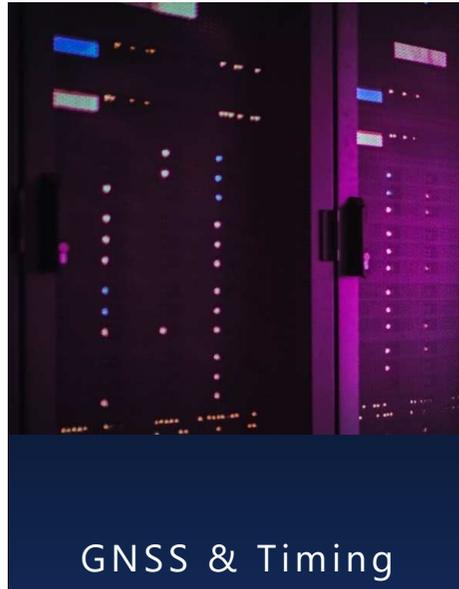
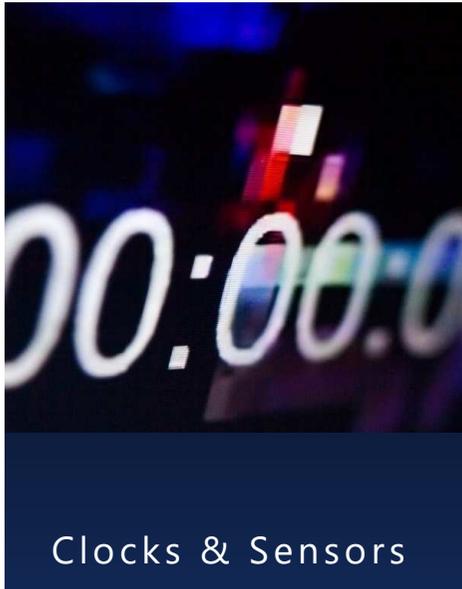
MINIATURE CLOCKS FOR CISELUNAR AND LUNAR APPLICATION

GRÉGORIO MOURA
SAFRAN TIMING TECHNOLOGIES

2ND CISELUNAR PNT WORKSHOP
FEB 13TH 2026

 **SAFRAN**

Safran One PNT – 3 Business Lines



Safran Timing Technologies

at a glance



› **200 employees**

Located in Neuchâtel and Yverdon-Les-Bains , Switzerland



› **35 people in R&D**

To leverage our knowledge



› **30 years experience.**

in Atomics Clocks & high-performance Oscillators



› **World leader**

In Space atomic clocks and High-End MEMS inertial sensors



› **Sole European manufacturer**

for micro atomic clocks, Rubidium technologies and Hydrogen Maser, MEMS Accelerometers



› **Worldwide sales implementation**

To support our customers everywhere



› **4 product lines to serve customers**

Inertial MEMS , Space, Industry & Defense (IND&DEF) and Sciences & Metrology (SCI&ME)



› **A Process industry**

including a 400 m² ISO 8 clean room for space activities and a foundry of 600m² for MEMS

Safran Electronics & Defense / One PNT / Safran Timing Technologies

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The Heartbeat of Galileo



Rubidium Atomic Frequency Standard (RAFS)

- Safran provides the Atomic Physics Package and is responsible for the clock integration with a third party procured EPC
- Next-Gen Developments (RAFS II):
 - Improved short-term stability
 - Frequency jumps removal
 - New Electronic Power Converter (EPC) designed and manufactured by Safran



Passive Hydrogen Maser (PHM)

- Safran provides the Atomic Physics Package and a **Master Oscillator** to Leonardo which is responsible for the clock integration
- Next-Gen Developments (PHM II):
 - New HDO (Hydrogen Dissociation Oscillator) designed and manufactured by Safran
 - Improved C-Field and Thermal Control



Safran Timing Technologies also produces clocks for NavIC (ISRO, India) and QZSS (JAXA, Japan) constellations

C2 - Confidential

SAFRAN Timing Technologies main lunar partners



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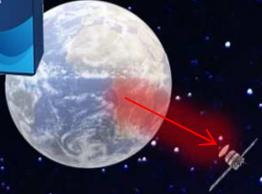
SAFRAN Timing Technologies main lunar partners

Ground Stations
GAHM

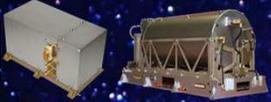


SAFRAN Timing Technologies main lunar partners

Ground Stations
GAHM

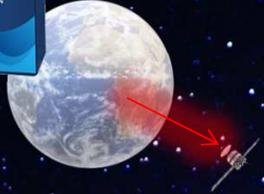


MEO GNSS
RAFS and PHM
MIC-SPA



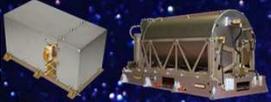
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Ground Stations
GAHM



MEO GNSS

RAFS and PHM
MIC-SPA



LEO PNT Layer
MIRA Space



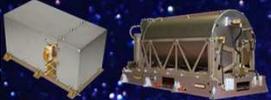
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MIC-SPA



LEO PNT Layer
MIRA Space



- Lockheed Martin is leveraging their GPS domain knowledge in developing a lunar PNT payload with the miniRAFS as the timing source
- The payload is targeting several lunar surface opportunities to provide precision time and ranging data to local users
- Providing a surface-based source of Lunar Coordinated Time is seen as an enabler for lunar exploration and infrastructure

SAFRAN Timing Technologies main lunar partners

Ground Stations
GAHM

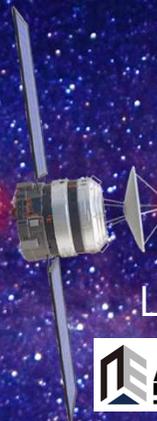


MEO GNSS

RAFS and PHM
MIC-SPA



LEO PNT Layer
MIRA Space



LNSS



- LNSS is GPS-like satellite constellation for the Moon designed by JAXA
- ArkEdge Space has been selected by JAXA to lead the development of advanced lunar navigation technology.
- ArkEdge Space has selected STT clocks for this first stage of this mission.

SAFRAN Timing Technologies main lunar partners

Ground Stations
GAHM



MOONLIGHT



MEO GNSS
RAFS and PHM
MIC-SPA

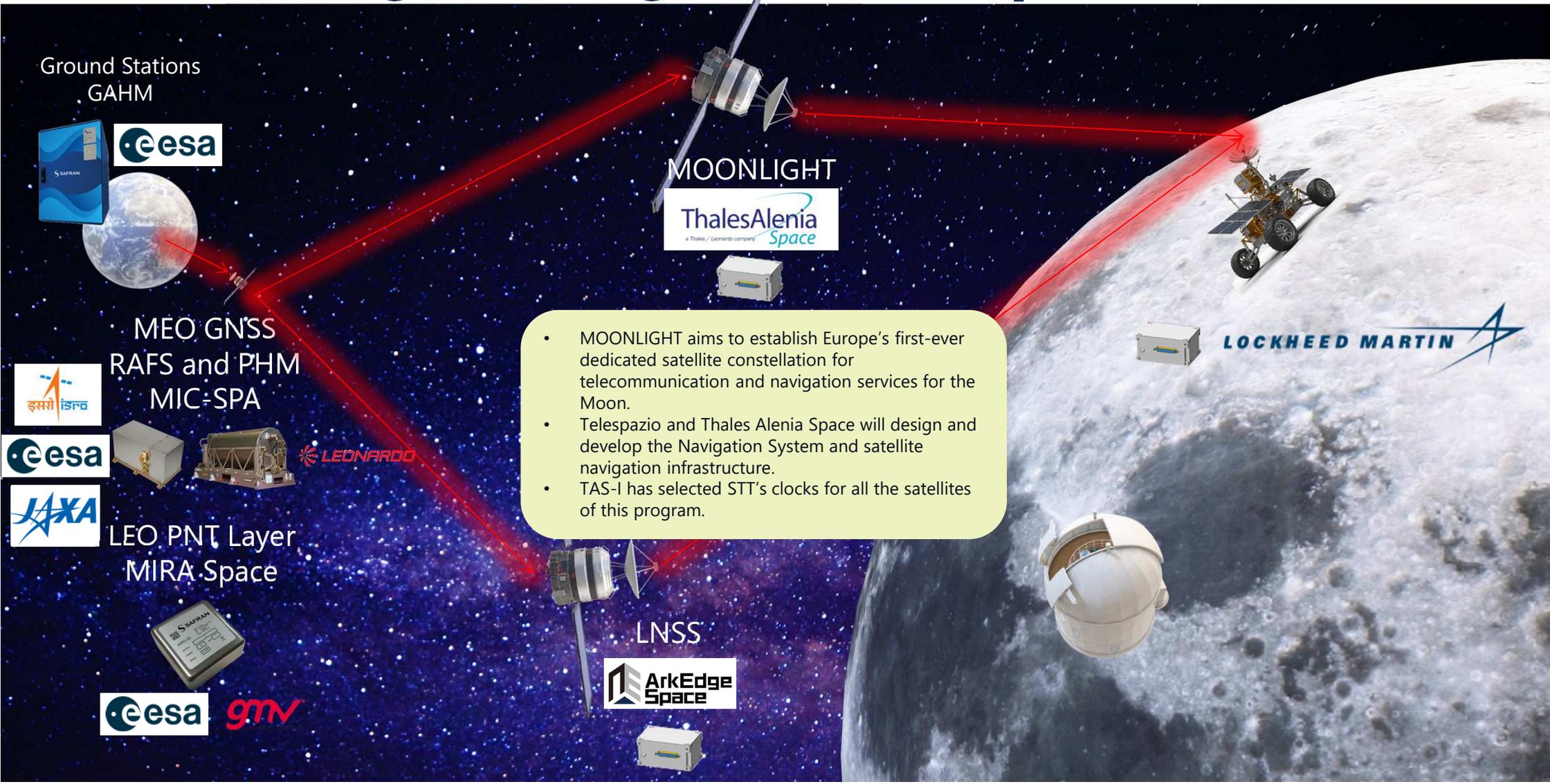


LEO PNT Layer
MIRA Space

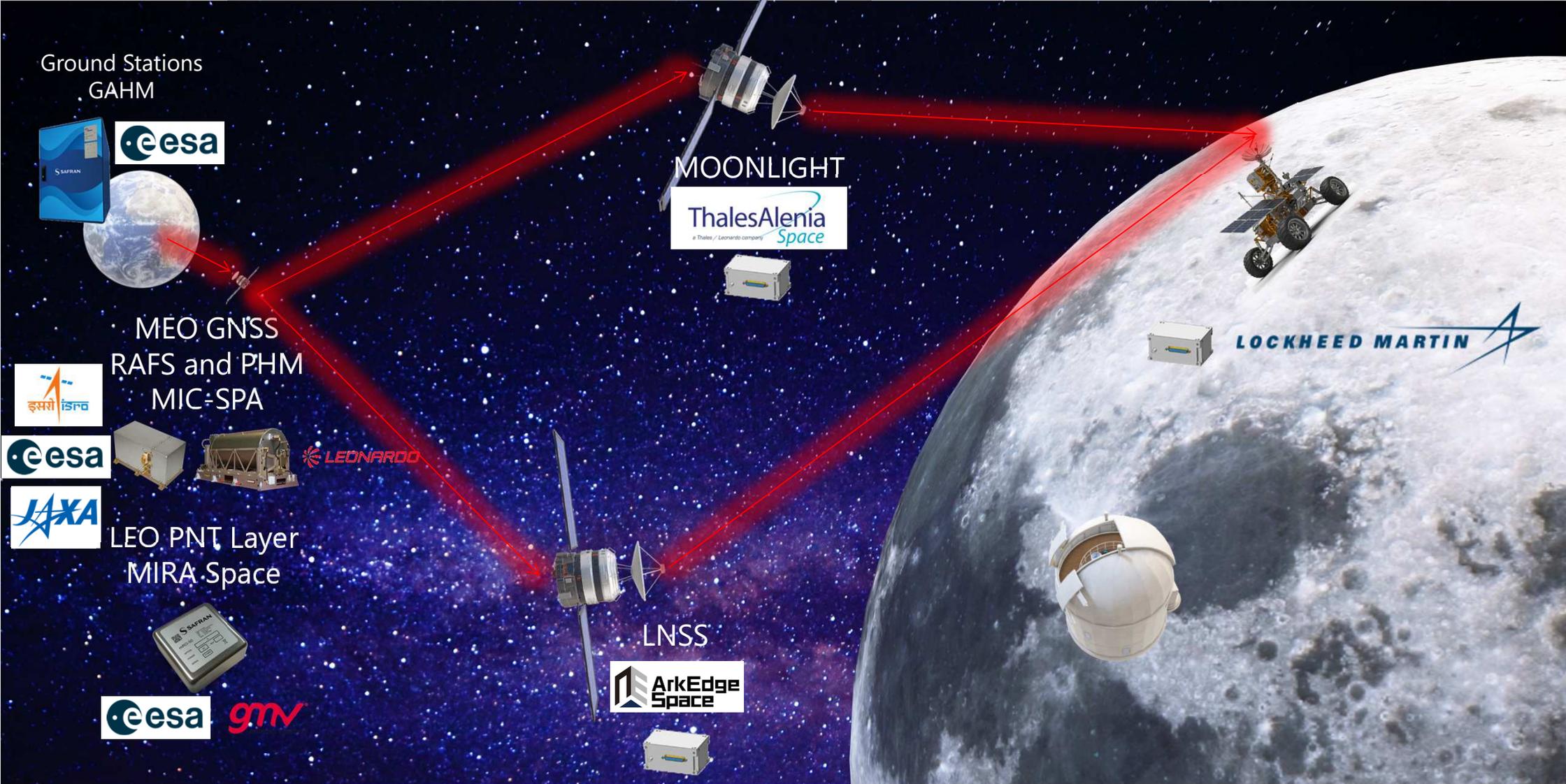


- MOONLIGHT aims to establish Europe's first-ever dedicated satellite constellation for telecommunication and navigation services for the Moon.
- Telespazio and Thales Alenia Space will design and develop the Navigation System and satellite navigation infrastructure.
- TAS-I has selected STT's clocks for all the satellites of this program.

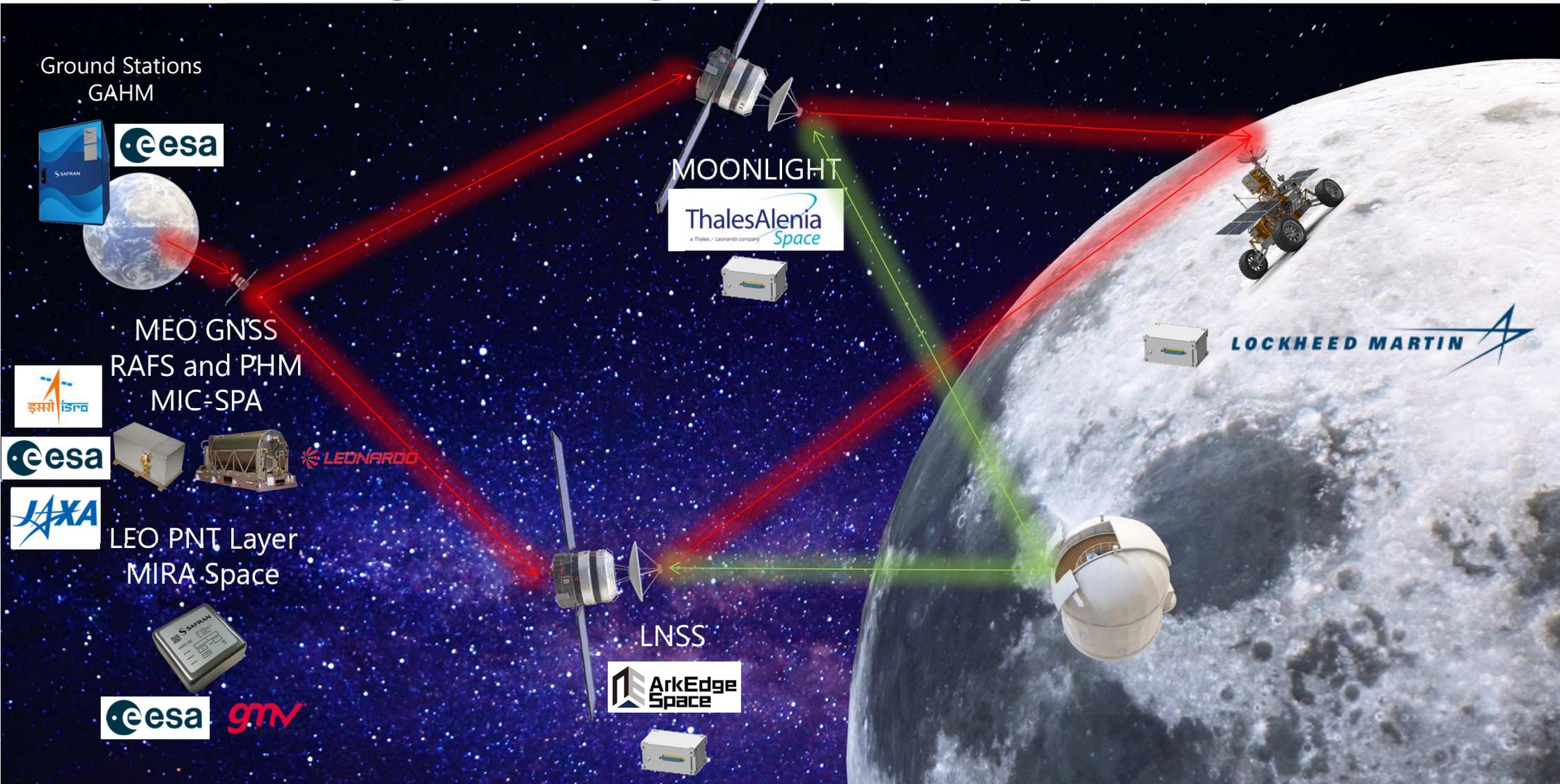
LNSS



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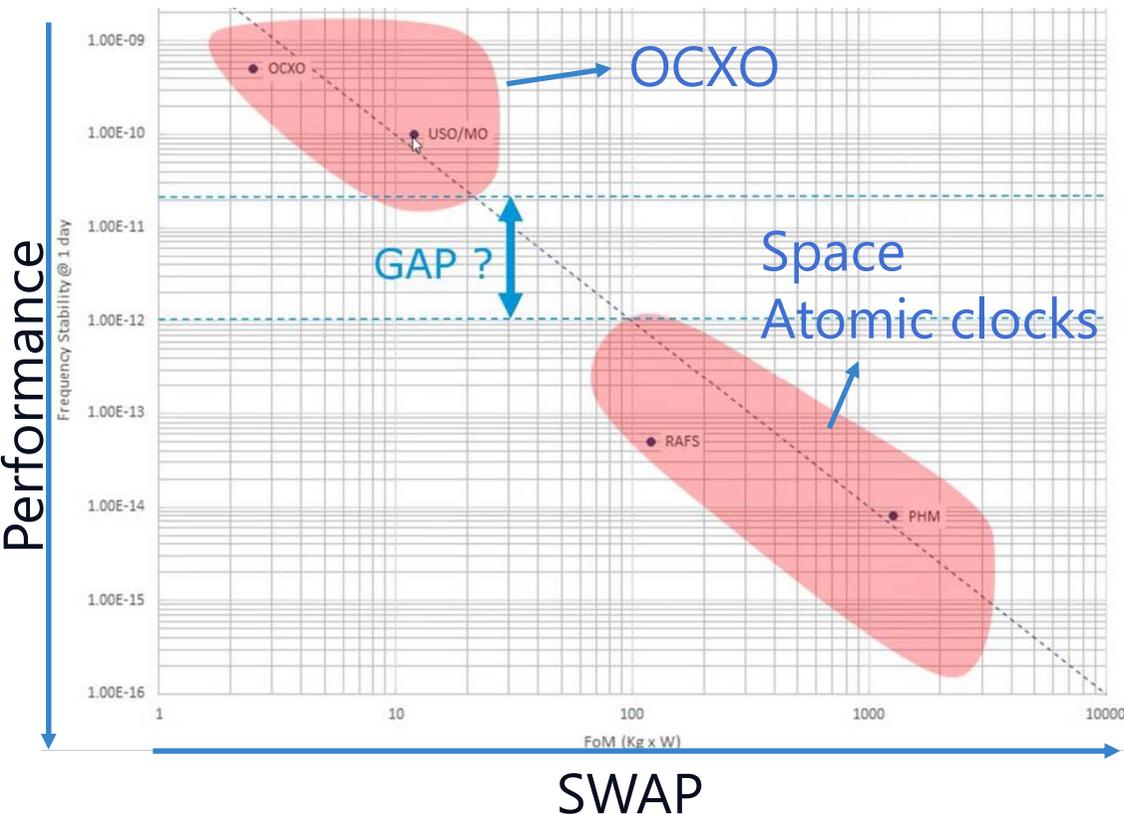


SAFRAN Timing Technologies main lunar partners



Mini-RAFS – Motivation

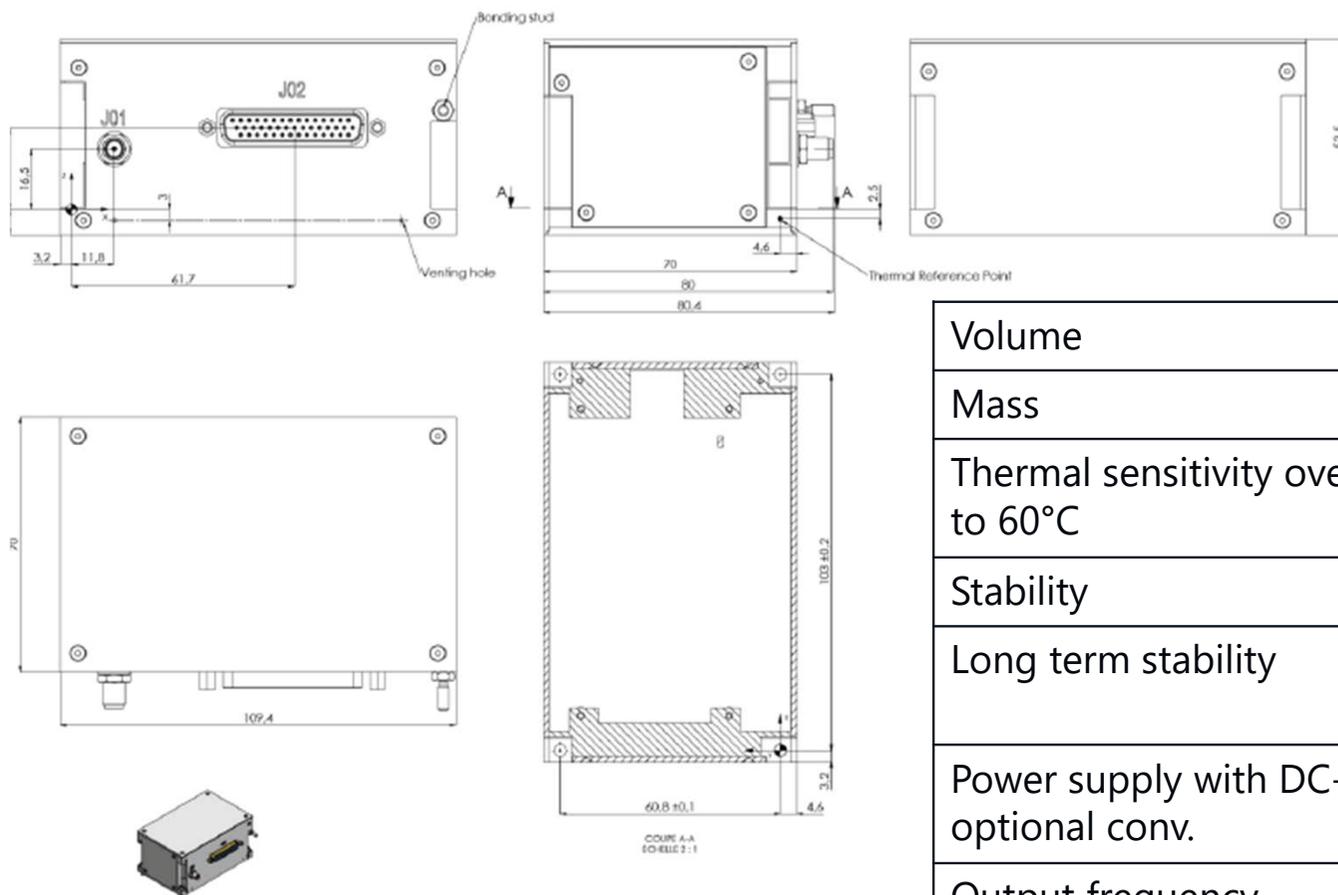
- **Objective:** to offer the optimal trade-off between high performance and low SWaP.



- Mini-RAFS vs. OCXO benefits:
 - Order of magnitude in lower frequency drift
 - Better holdover , accuracy & retrace performance
 - Improved temperature coefficient and radiation resistance
- Mini-RAFS vs. RAFS/Maser benefits:
 - Order of magnitude in Size, Weight and Power Consumption

- **Mini-RAFS does not aim at replacing any technology but rather addressing new markets/usages which require optimized SWaP/performance compromises.**

Mini-RAFS – Main Requirements



Volume	0.41 l
Mass	0.548kg
Thermal sensitivity over -20°C to 60°C	$< 2 \times 10^{-12} / ^\circ\text{C}$
Stability	$< 3 \times 10^{-13} / 1000\text{sec}$
Long term stability	$< 3 \times 10^{-11} / \text{month}$ $< 1 \times 10^{-9}$ over 10 years
Power supply with DC-DC optional conv.	compatible with 50V power bus
Output frequency	10MHz

RAFS vs mini-RAFS



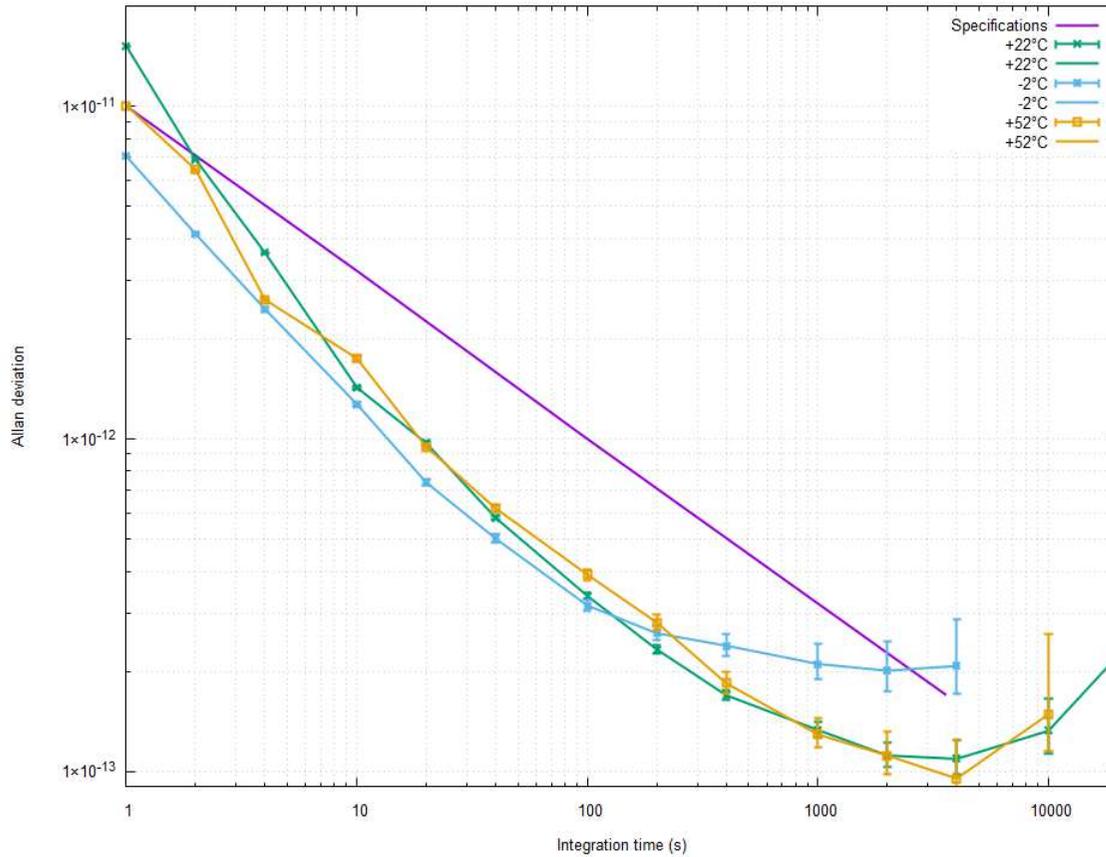
RAFS



MiniRAFS

Flight Heritage	More than 100 units flying on Galileo, DFH , GAIA, IRNSS	None yet
Qualifications status	Various qualification programs	Ongoing Qualification program
Radiation Tolerance	> 12 years MEO orbit with < 3mm sat shielding	> 12 years MEO within additional shielding 2mm + 1.7-2.4mm sat shielding
Weight / Warm-up Power / Bus	< 3.5Kg / < 65W , 27-42V bus or 50V bus , DC-DC converter included	< 0.548 Kg / < 15W +16V-18V & +4V-+5V external supply
Drift / year	< 1 E-10 / year	< 2 E-10 / year
Temperature sensitivity / range	< 1 E-13 / °C from -15°C to + 15°C (qualifications up to 20°C)	< 1 E-12 /°C from -15°C to +55°C (qualification / acceptance -20 to +60°C)

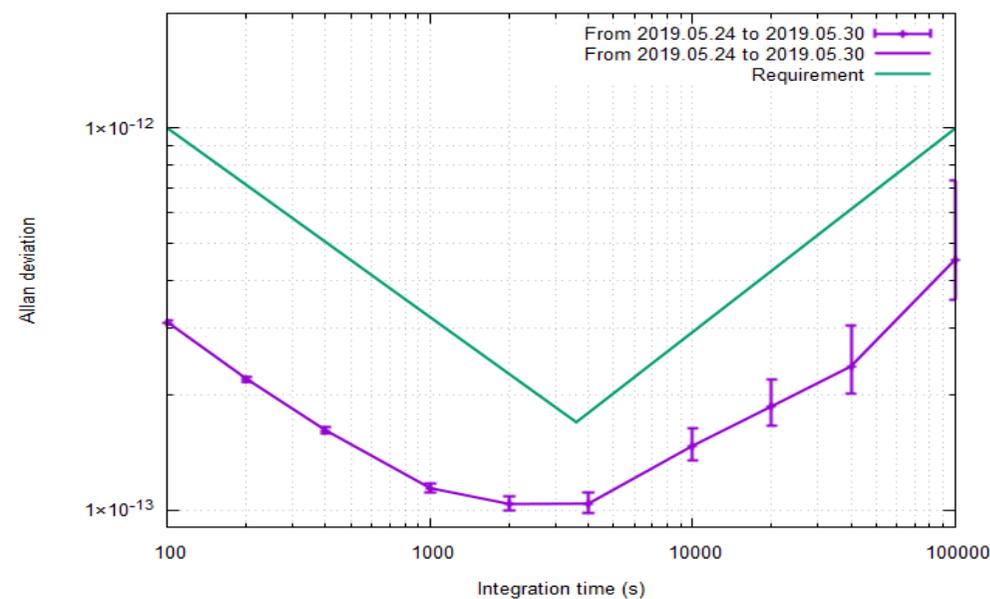
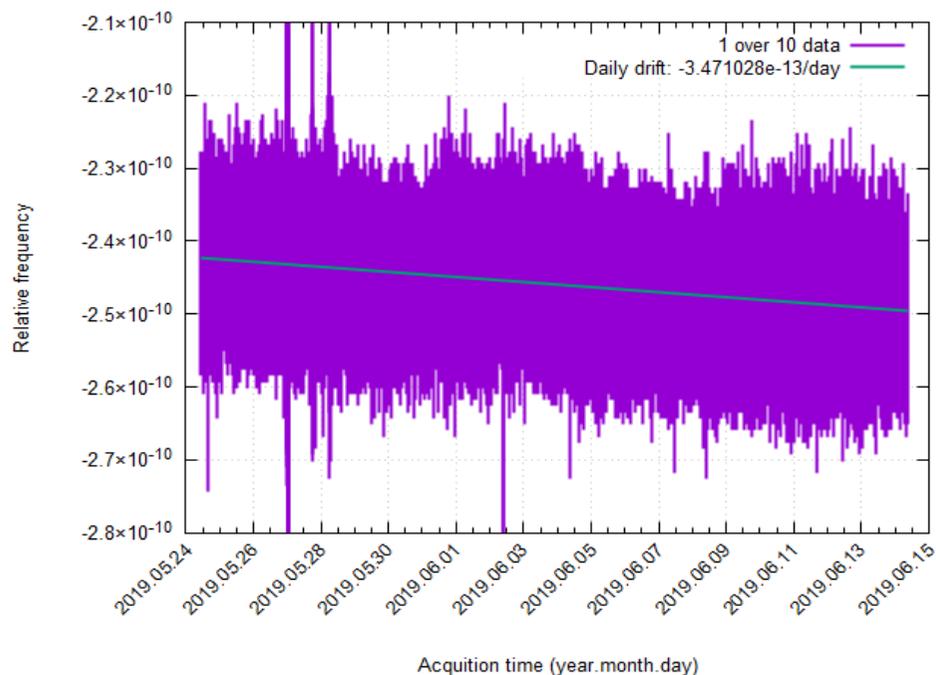
Frequency stability



	Allan deviation	Time error (ns)
@sec	MiniRb	MiniRb
1	1,0E-11	0,0100
10	2,0E-12	0,0200
30	7,0E-13	0,0210
100	4,0E-13	0,0400
300	2,5E-13	0,0750
500	1,5E-13	0,0750
1 000	1,3E-13	0,1300
6 000	1,3E-13	0,7800
10 000	1,5E-13	1,5000
30 000	2,0E-13	6,0000
33 000	2,2E-13	7,2600
50 000	2,8E-13	14,0000
100 000	6,0E-13	60,0000

Source: Robust Miniaturised Timing Sources, ESA Contract

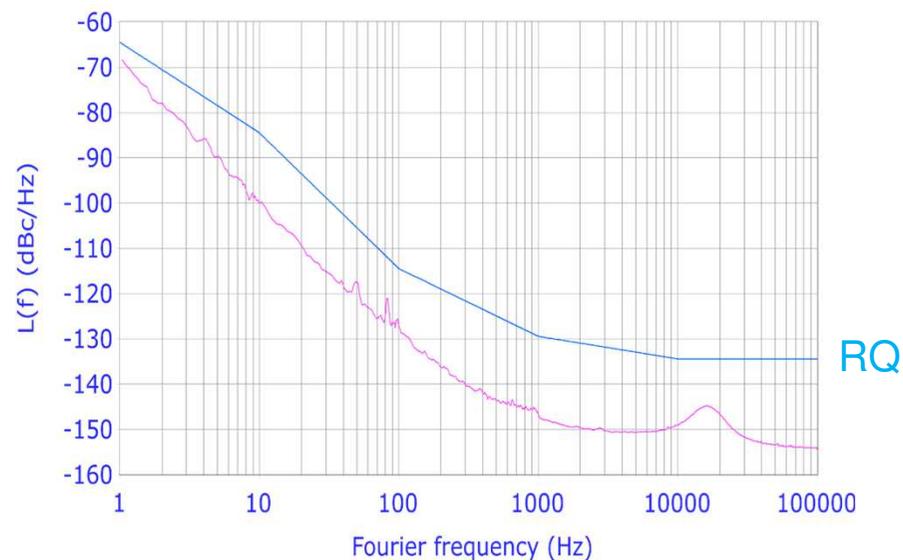
Daily drift



A drift of $-3.4 \times 10^{-13} / \text{day}$ (RQ: $\pm 1 \times 10^{-12} / \text{day}$) has been measured over 22 days which leads to $-1.1 \times 10^{-11} / \text{month}$ (RQ: $\pm 2 \times 10^{-11} / \text{month}$)

Source: Robust Miniaturised Timing Sources, ESA Contract

Phase noise



	Values		Requirements	Remark		
Phase Noise @60MHz	1Hz	-68 dBc/Hz	-64 dBc/Hz	@10 MHz equivalent (not measured)	1Hz	-83.5 dBc/Hz
	10Hz	-100 dBc/Hz	-84 dBc/Hz		10Hz	-115.5 dBc/Hz
	100Hz	-133 dBc/Hz	-129 dBc/Hz		100Hz	-148.5 dBc/Hz
	1kHz	-147 dBc/Hz	-134 dBc/Hz		1kHz	-162.5 dBc/Hz
	10kHz	-149 dBc/Hz	-135 dBc/Hz		10kHz	-164.5 dBc/Hz
	100KHz	-154 dBc/Hz	-135 dBc/Hz		100KHz	-169.5 dBc/Hz

Conclusion

- **Preliminary tests demonstrate the relevance of this new product and its suitability for lunar-specific use cases.**

- **STT provides an optimal balance between performance and SWaP for an industrial-grade product, based on a strong heritage and proven space-grade industrialization expertise that meets demanding standards**

- **miniRAFS is paving the way to other technologies for lunar application such as:**
 - **RAFS, PHM**
 - **Mercury Ion Clock**
 - **Other microwave and optical clocks**

- **miniRAFS also targets other uses cases such as aeronautical usages.**



Thank you for your attention

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The background features a dark blue space filled with stars. In the foreground, a glowing blue globe is partially visible. A complex network of thin blue lines connects various nodes, some of which are highlighted in yellow. A bright blue light source is positioned behind the globe, creating a lens flare effect. The text "POWERED BY TRUST" is centered in white, bold, uppercase letters, flanked by two horizontal white bars.

**POWERED
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