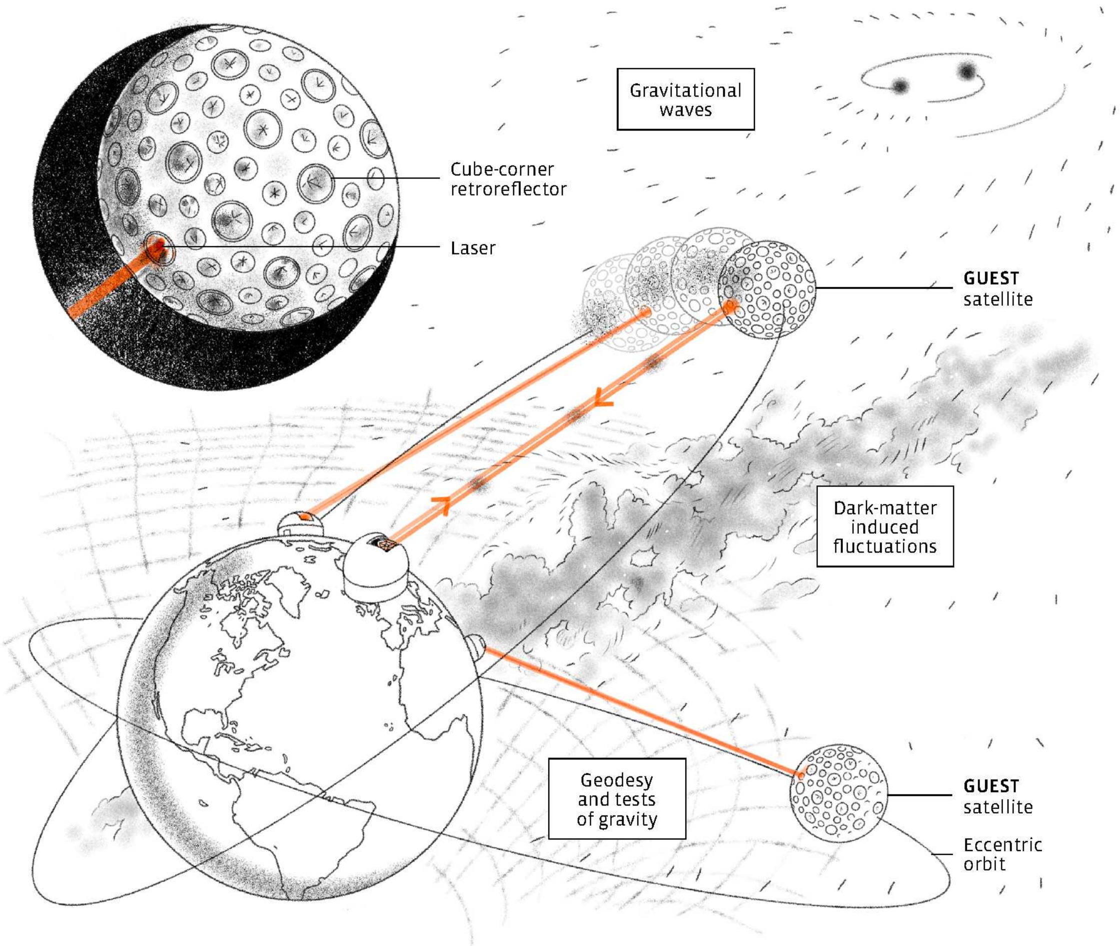


GUEST

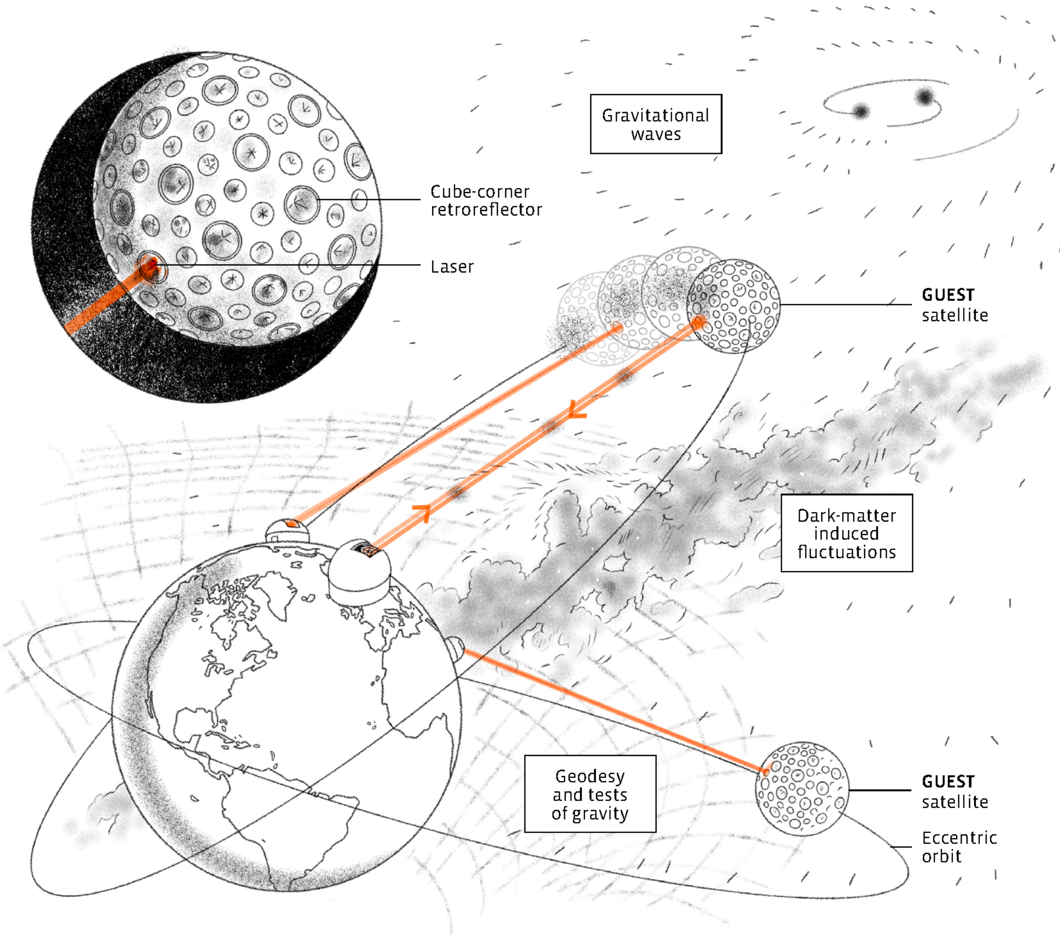
Gravitational Universe Exploration with Satellite Tracking

Lead Proposer: Prof. Diego Blas Temiño, Spain

Proposal in 5 seconds

GUEST

Two satellites laser tracked
at cm accuracy
in orbits $e > 0.6$, $P_b > 1$ day
for more than 10 years.



Mission team (in May 2025)

List of core team members insofar (Country/Full Name/Email/Institution)

Country	Full Name	Email	Institution
Spain	**Diego Blas (Leading Proponent)**	dblas@ifae.es	IFAE/ICREA
	Jorge M. Camalich	jcamalich@iac.es	IAC
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	Javier Rico	jrico@ifae.es	IFAE
	Nanda Rea	rea@ice.csic.es	ICE-CSIC
	Rafael Rebolo	rrl@iac.es	IAC
	Marco Reyes	mreyes@iac.es	IAC
	Carlos Sopuerta	carlos.f.sopuerta@csic.es	ICE-CSIC
	José Rodríguez Pérez	jcrodriguez@transportes.gob.es	IGN
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	Bruno Bertrand	bruno.bertrand@observatory.be	ROB
	Marta Goli	m.goli@oma.be	ROB
	J. Janquart	justin.janquart@observatory.be	UCLouvain/ROB
	Sébastien Le Maistre	sebastien.lemaistre@oma.be	UCLouvain/ROB
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France	Julien Chabé	julien.chabe@geoazur.unice.fr	OCA/GeoAzur
	Clément Courde	courde@geoazur.unice.fr	CNRS/Geoazur
	Aurélien Hees	aurelien.hees@obspm.fr	LTE/OBSPM
	Nicola Tamanini	nicola.tamanini@l2it.in2p3.fr	L2IT-CNRS
	Alice Perego	alice.perego@oca.eu	J L LAGRANGE-OCA
Germany	Mathis Bloßfeld	mathis.blossfeld@tum.de	DGFI-TUM
	Miguel Zumalacárregui	mzuma@aei.mpg.de	MPI Grav. Phys.
Italy	Massimo Bassan,	bassan@roma2.infn.it	Uni. Tor Vergata
	Giada Bargiacchi	Giada.Bargiacchi@lnf.infn.it	LNF-INFN
	Roberto Campagnola	roberto.campagnola@lnf.infn.it	LNF-INFN
	Marco Cinelli	marco.cinelli@inaf.it	IAPS-INAF
	Simone Dell'Agnello	simone.dellagnello@lnf.infn.it	LNF-INFN
	Alessandro Di Marco	alessandro.dimarco1@inaf.it	IAPS-INAF
	David Lucchesi	david.lucchesi@inaf.it	IAPS-INAF
	Marco Lucente	marco.lucente@inaf.it	IAPS-INAF
	Roberto Peron	roberto.peron@inaf.it	IAPS-INAF
	Luca Porcelli	luca.porcelli@lnf.infn.it	LNF-INFN
	Francesco Santoli	francesco.santoli@inaf.it	IAPS-INAF
	Feliciana Sapio	feliciana.sapio@inaf.it	IAPS-INAF
	Alberto Sesana	alberto.sesana@unimib.it	U. Milano
	Massimo Visco	massimo.visco@inaf.it	IAPS-INAF
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Romania	Laurentiu Caramete	lcaramete@spacescience.ro	Institute of Space Science
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United States	Neil Cornish	ncornish@montana.edu	U. Montana
	Joshua W. Foster	jwfoster@fnal.gov	U. Wisconsin

IFAE: Institut de Física d'Altes Energies. **ICREA**: Institució Catalana de Recerca i Estudis Avançats. **ICE**: Instituto de Ciencias del Espacio. **IAC**: Instituto de Astrofísica de Canarias. **IGN**: Instituto Geográfico Nacional. **ROB**: Royal Observatory of Belgium. **OCA**: Observatoire de la Côte d'Azur. **LTE/OBSPM**: Laboratoire Temps Espace, Observatoire de Paris. **L2IT**: Laboratoire des 2 Infinis. **LNF**: Laboratorio Nazionale de Frascati. **IAPS**: Istituto di Astrofisica e Planetologia Spaziali. **PWr**: Wrocław University of Environmental and Life Sciences. **DGFI-TUM**: Deutsches Geodätisches Forschungsinstitut, Technische Universität München.

ILRS people

Science case: 1. Gravitational Waves

Gravitational waves are **new messengers** from the Universe.

- First direct detection in 2015 (Nobel Prize 2017)
- Emitted by all energetic processes, including those unaccessible with electromagnetic waves (black holes, early Universe, dark universe).

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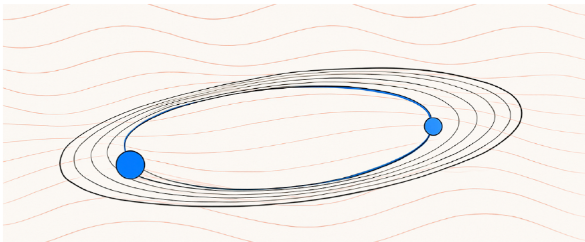
gravitational waves affect
gravitationally bound systems



$$\ddot{r}_i + \frac{GM}{r^3} r_i = \boxed{\frac{1}{2}\ddot{h}_{ij} r^j} + \boxed{f_{\text{ext}}}$$

Newtonian Potential

Perturbing Gravitational Wave

Other forces

If $h \sim \cos(2\pi f t)$ and $r \sim e \cos(2\pi t/P)$
possible resonances at $f=n/P$

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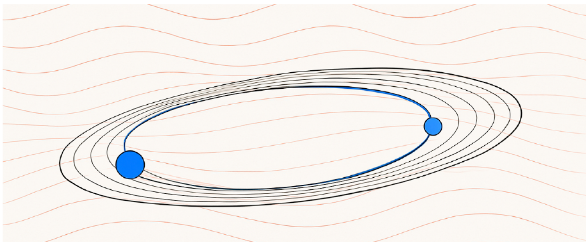

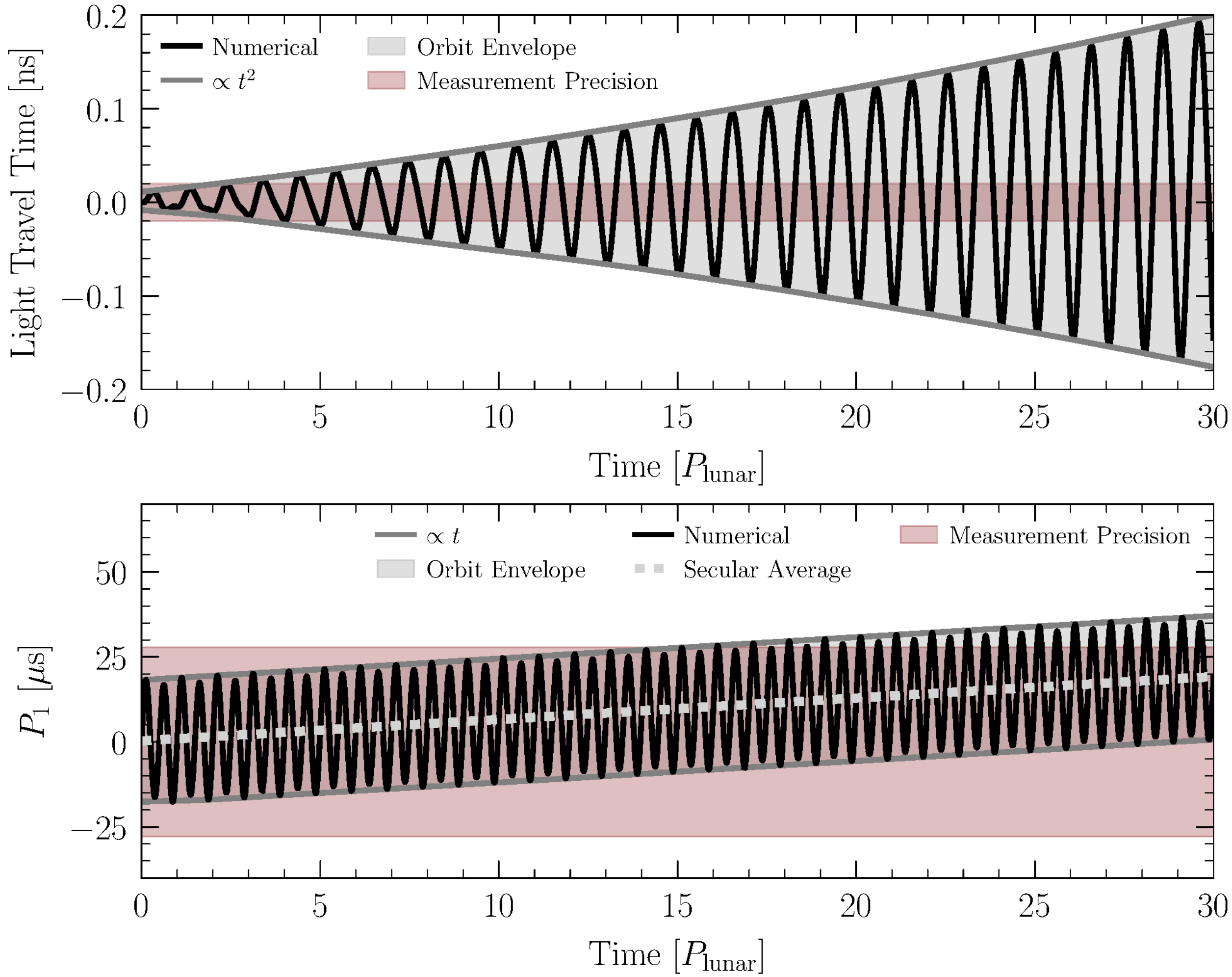

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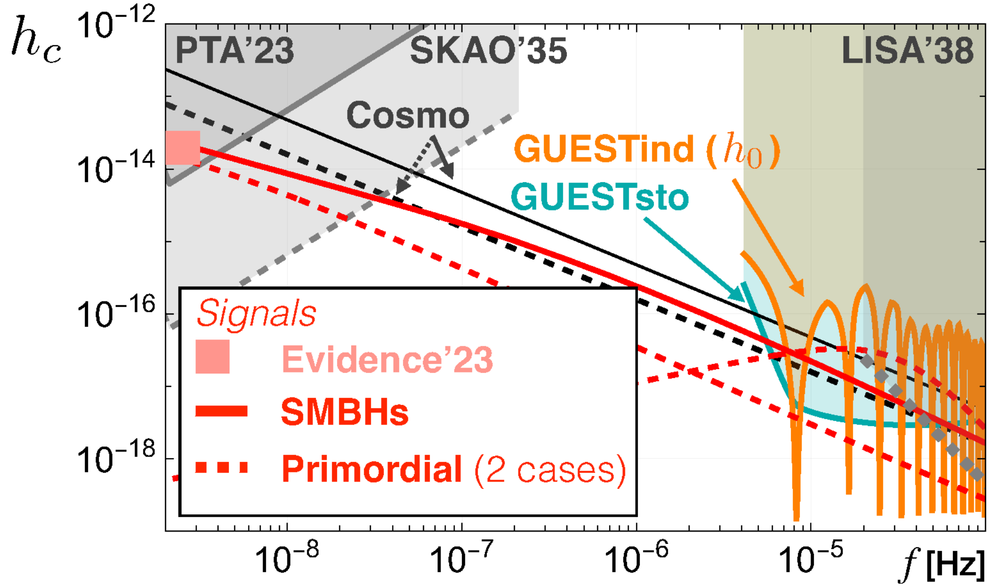
GUEST will/may achieve

- **Detection** of supermassive black holes of masses $10^6\, M_\odot$ (first!) to $10^8\, M_\odot$
- Best sensitivity to relevant **primordial** signals from the Big Bang
- Complementarity to **LISA** and **SKAO** in a small budget and short time scale

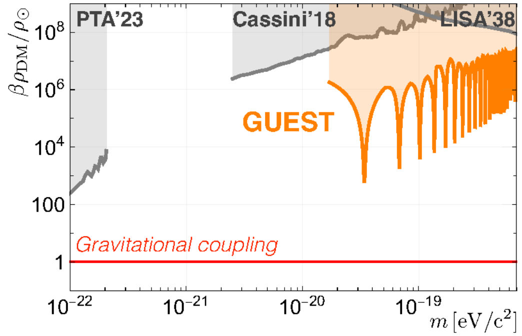


Science case: 2 & 3. Dark matter and geodesy

Dark matter is 5x more abundant than ordinary matter, yet **we ignore its nature**

GUEST will achieve

- Unprecedented sensitivity to large set of unexplored **dark matter models**



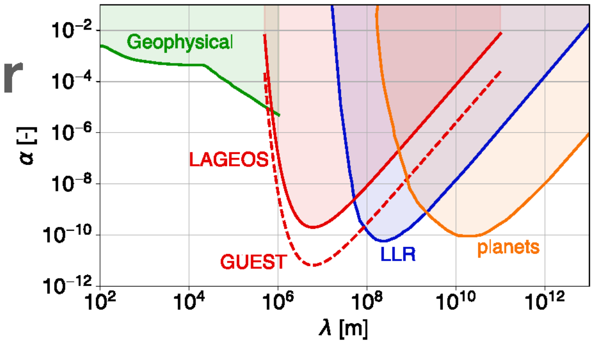
Geodetic products are essential for virtually all modern geospatial and space-based systems (including **space navigation**) and tests of General Relativity

GUEST will achieve

- Better determination of the key **gravitational parameter**

$$GM_{\oplus}$$

- Significant progress on searches for new forces **beyond General Relativity**



Summary

Conceptually simple, **scientifically** rich

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Two satellites laser tracked
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- **SG3**. *Impact in geodesy and tests of general relativity*

Mission concepts

Orbits: **maximize** physics (1) and data taking (2), **minimize** systematics (3), within F3 ESA constraints (4) (e.g. TRL 7) and budget (5), and satisfy ESA **debris** policy (6).

Concept	Perigee altitude	Apogee altitude	e_0	ι	Period
$G\text{-}l_{30}$	6926 km	86700 km	0.75	75 deg	33.8 hours

Reenters in 30 years (6)

v_a (velocity at apogee)	μ_a	v_p (velocity at perigee)	μ_p
≈ 1 km/s	$\approx 6\,\mu$rad	≈ 7.5 km/s	$\approx 50\,\mu$rad

Concept	Perigee altitude	Apogee altitude	Eccentricity	ι	Period
GUEST-h	35993 km	92479 km	0.4	10 deg	51.84 hours

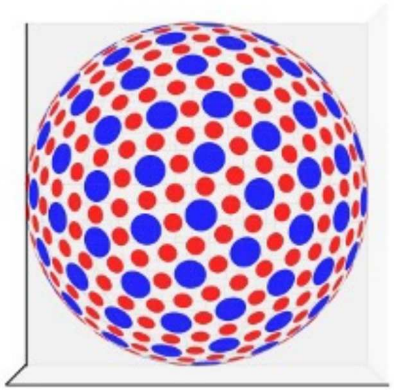
Can stay in orbit for longer as doesn't touch GNSS or GEO belt in 100 years

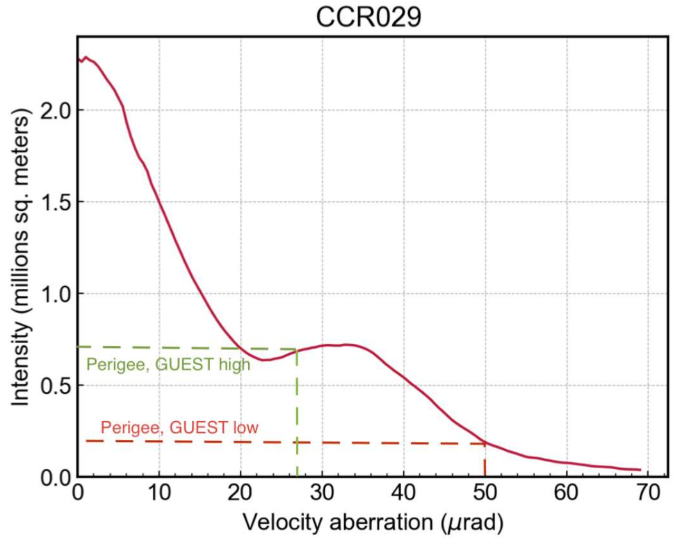
v_a (velocity at apogee)	μ_a	v_p (velocity at perigee)	μ_p
≈ 1 km/s	$\approx 6\,\mu$rad	≈ 4 km/s	$\approx 27\,\mu$rad

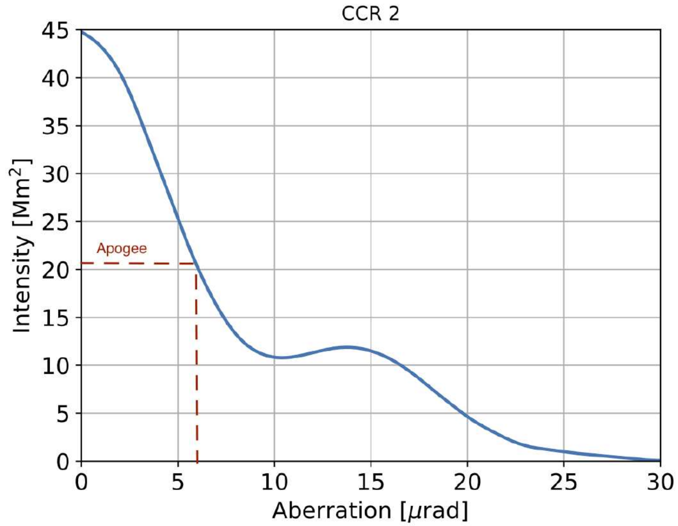
Mission concepts

2 Passive satellites (spheres) that rely only on **CCR** (Cube Corner Retroreflectors)

To beat the ranges of aberration:
two CCRs (1 inch and 2 inches)







∅	weight	∅ CCR1/CCR2	single OCS CCR1 (v_p)/ CCR2 (v_a)	# CCR1/CCR2	OCS range
70 cm	400 kg	1 inch /2 inches	*G-l* $0.2\,\mathrm{M}m^2$ / $21\,\mathrm{M}m^2$	360/120	2-45 $\mathrm{M}m^2$
			G-h $0.7\,\mathrm{M}m^2$ / $21\,\mathrm{M}m^2$	360/120	14-45 $\mathrm{M}m^2$

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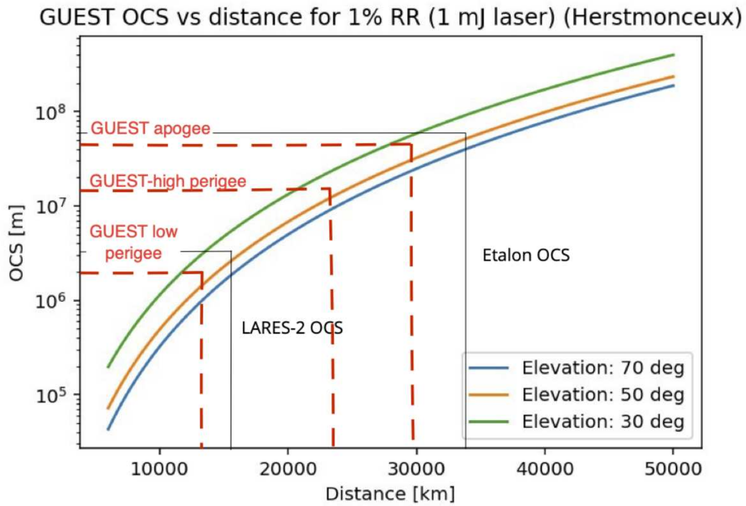
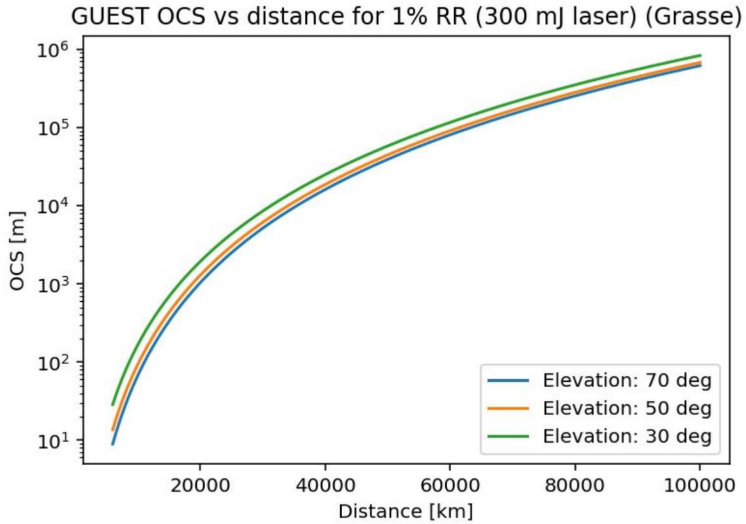




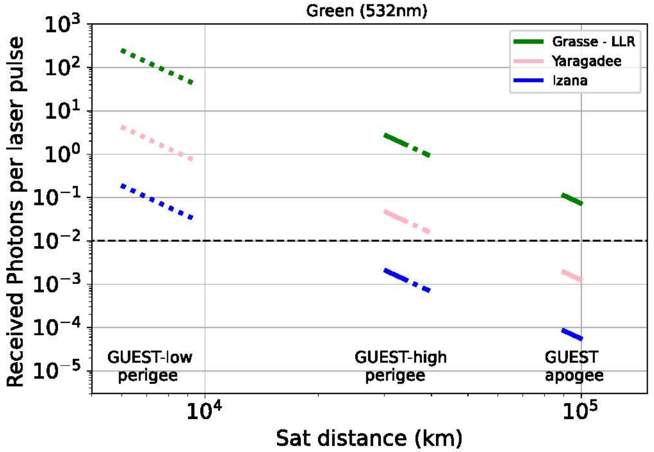
For most of the orbit, tracking is impossible for many ILRS stations today

That may work: we are looking at 10 NPs per orbit (34 h) at cm accuracy*

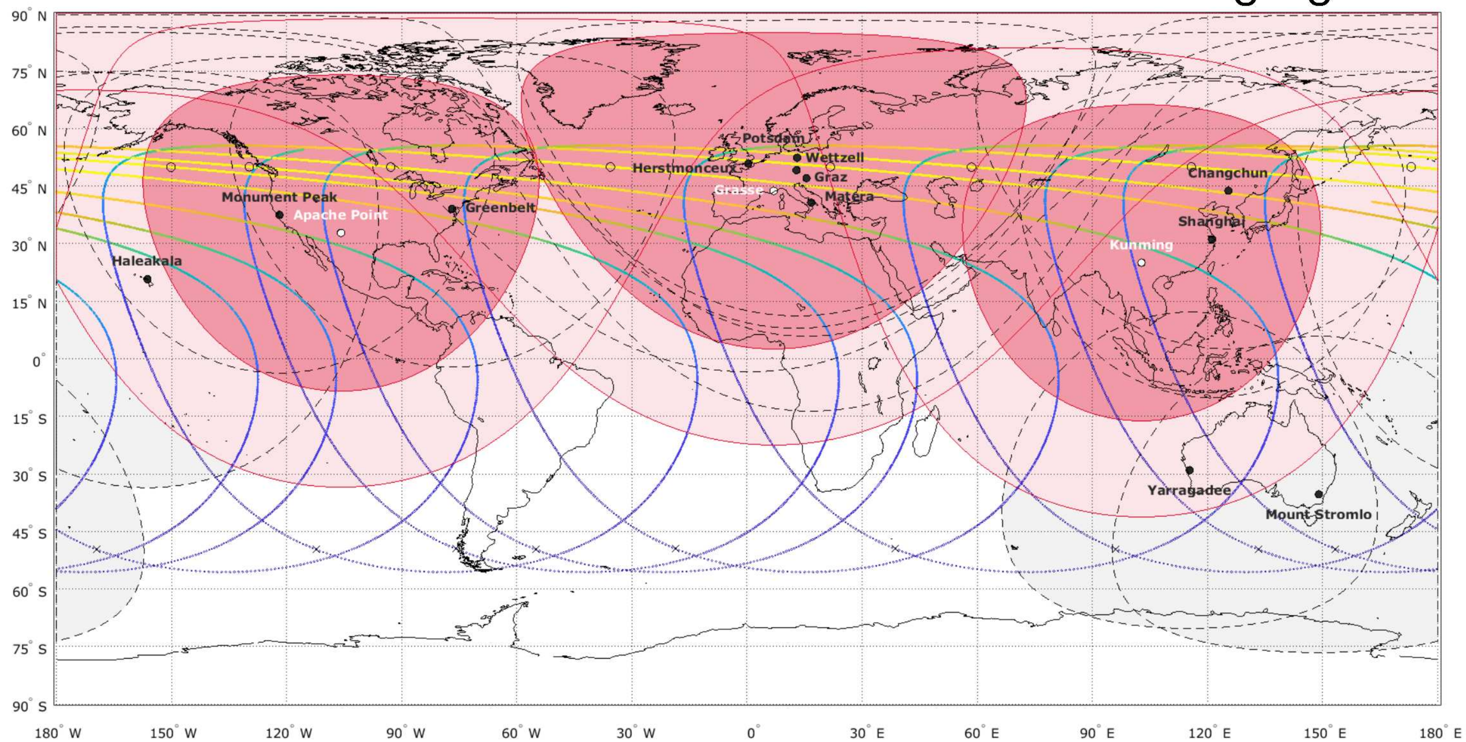
* required distribution of NPs in orbit under study

Mission concepts

Stations



G-I orbit with LLR stations and some SLR stations highlighted



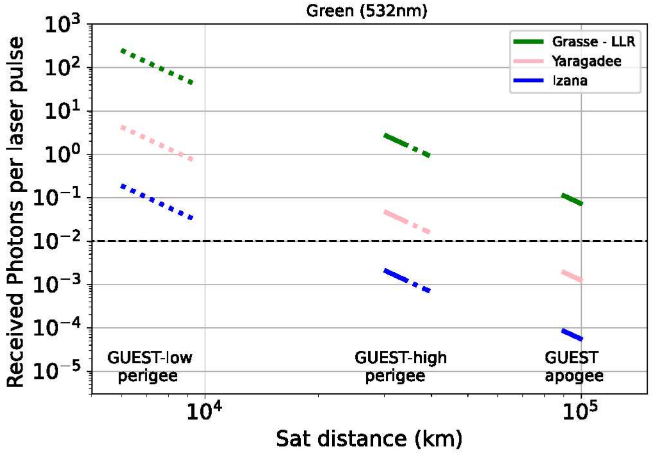
Yellow: apogee; Blue: perigee

How do we guarantee 10 NPs per orbit (34 hours)?

i) Exploring current capacities (discussion with ILRS and stations): it can work. Let’s discuss!

Mission concepts

Stations



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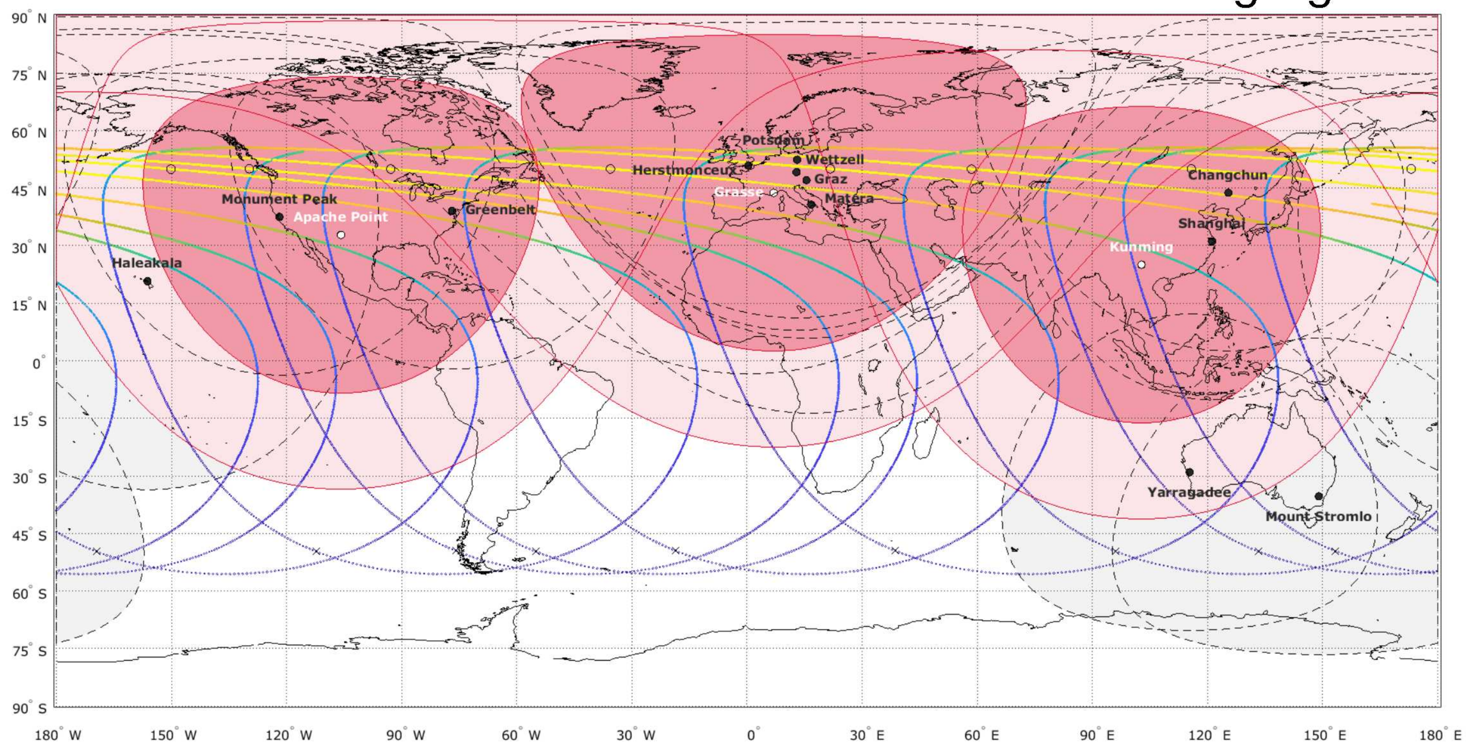

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ii) Upgrading some stations with ESA countries contributions, better if in LLR empty regions.

iii) Beyond this? (EU companies may be funded. Other in-kind data? NASA upgrading stations?

Mission concepts

Stations

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Can it work?

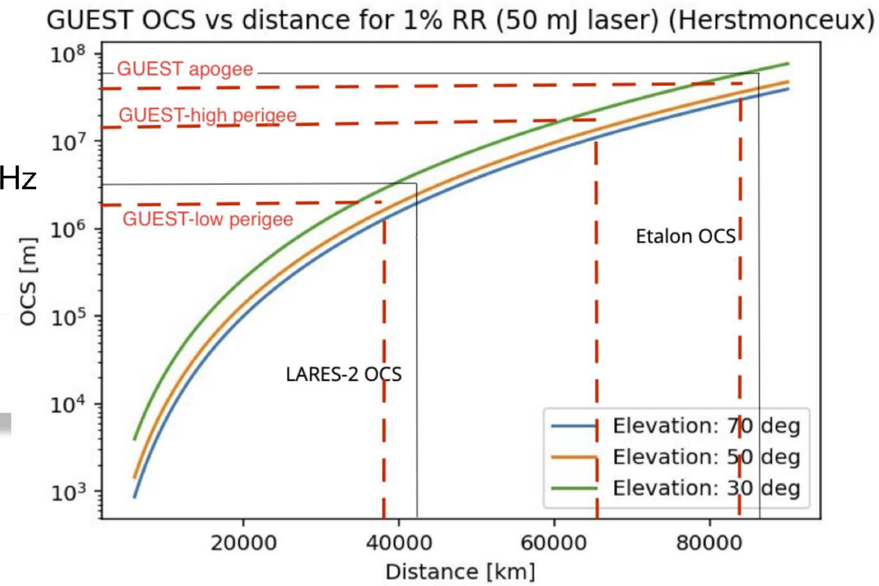
S/C and CCR	Separation Module	Launch	OTV	Ground segment	Total
5 M€	7 M€	75 M€	90 M€	10 M€	~ 190 M€

We have the funds (total budget can be 205 M€) and the plan!

J. Rodríguez, C. Courde, J. Chabé conclusions:

	Possible gains	Cost	Difficulty	
Laser	× 20-50	~ 300 k€	Medium	e.g. 50 mJ, 10 ps, 100 Hz
Detector	A few tens of %	10-40 k€	Medium	High QE detectors
Filters & Optics	A few tens of %	~ 1k€	Low to Medium	Case by case

Invest 500 k€ in 10 -20 stations: 10 M€ to reach



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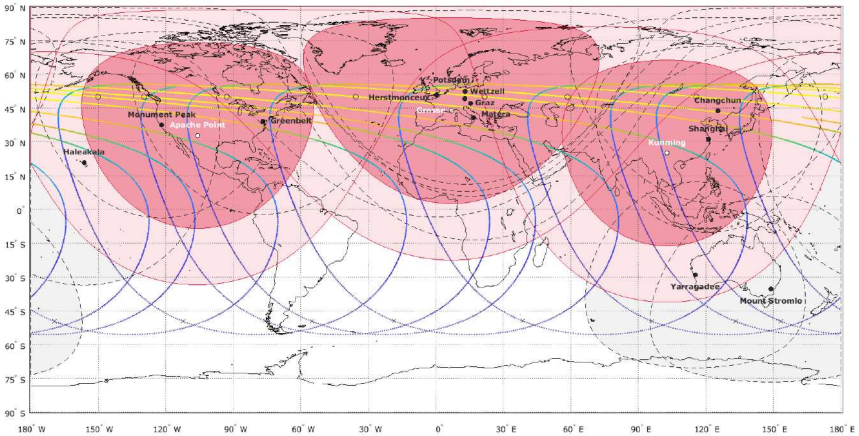
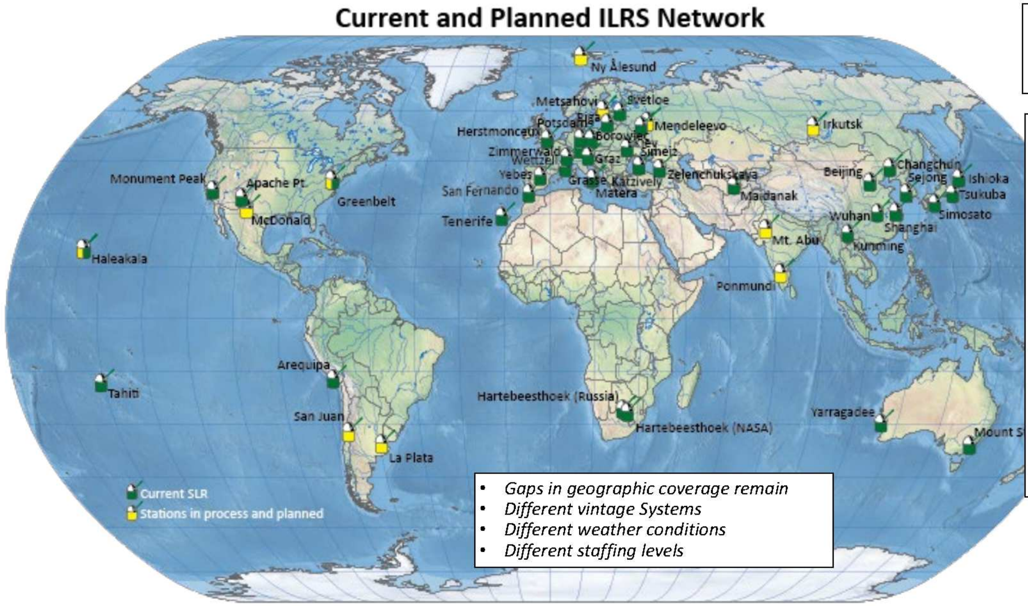


Claudia C. Carabajal, Michael Pearlman 23rd International Workshop on Laser Ranging (IWLR)

ILRS – Network



New Stations (2023-2024)
Yebes, Spain
Ishioka, Japan

Future Stations (2024-2027)
La Plata, Argentina
San Juan, Argentina
Metsähovi, Finland
McDonald, TX, USA
Ny Ålesund, Norway
Mt Abu, India
Ponmundi, India
Irkutsk (Tochka), Russia
Mendeleevo (Tochka), Russia

Other stations are undergoing significant upgrades

Mission concepts

Stations

ii) Upgrading some stations with ESA countries contributions, better if in LLR empty regions.

iii) Beyond this? (EU companies may be funded. Other in-kind data? NASA upgrading stations?

i. Start ups about SLR (eg. UK Lumi Space - Now Foundational Space)

ii. Upgrading other stations with ESA MoU

iii. In-kind from other stations. Other agencies joining?

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10 NPs/34 h at cm accuracy

Tracking challenging for large part of the orbit: **global ILRS** tracking required

Budget and call allow for 10M€ (or more) to **upgrade** stations (or other ideas)

Summary and GUEST in ILRS

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Let's talk! (deadline 21st of April)

i) Support letter from ILRS

ii) Strategies for upgrade (we'll contact all stations from ESA countries + others interested)

iii) More/feedback. Which stations can be upgraded?

iv) Data veto for some time?

Everyone is welcome! (Low entry level)

Budget and call allow for 10M€ (or more) to **upgrade** stations (or other ideas)

INSTITUTO DE ASTROFISICA DE CANARIAS · IAC

ICREA

IFAE — Institut de Física d'Altes Energies

bist

EXCELENCIA SEVERO OCHOA

CERCA

CSIC — Consejo Superior de Investigaciones Científicas

IEEC

IGN CNIG

UCLouvain 600

Royal Observatory of Belgium

GéoAzur — Laboratoire de Recherche Terre - Océan - Espace

cnrs

LAGRANGE

Observatoire de la Côte d'Azur

Université Côte d'Azur

LTE

L2IT

Observatoire de Paris | PSL

INFN LNF

INAF IAPS — Istituto di Astrofisica e Planetologia Spaziali

Università degli Studi di Milano Bicocca

Tor Vergata — Università degli Studi di Roma

TUM — Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)

Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

Institute of Space Science — INFLPR Subsidiary

Université de Genève

University of Cambridge

Wrocław University of Science and Technology

Wisconsin — University of Wisconsin–Madison

University of Montana

Mission concept

Consortium (> 40 core participants)

Leading proposer: D. Blas (Spain) **co-leading:** A. Hees (France)

Working Groups

Scientific Interpretation: Leader A. Jenkins (UK)

+ contributions from

Orbit Determination: Leaders S. Le Maistre (Belgium)

+ contributions from

Signal discrimination from correlations: Leader B. Bertrand (Belgium)

+ contributions from

Visibility and Spacecraft: Leader J. Rodríguez (Spain)

+ contributions from

Industry OHB, Lumi Space, gmv

Risks/Issues

Disposal:

- If disposal required (the mission can last 1M years!): working on it.

ESA UNCLASSIFIED – Releasable to the Public

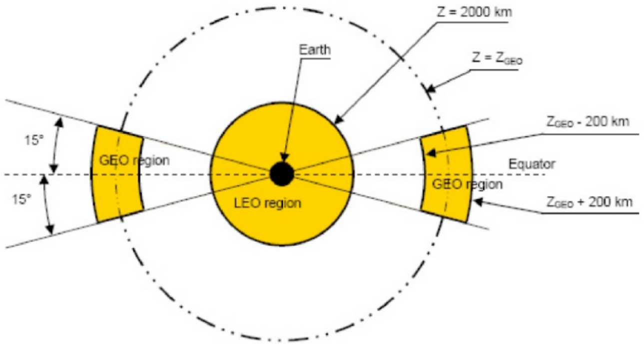
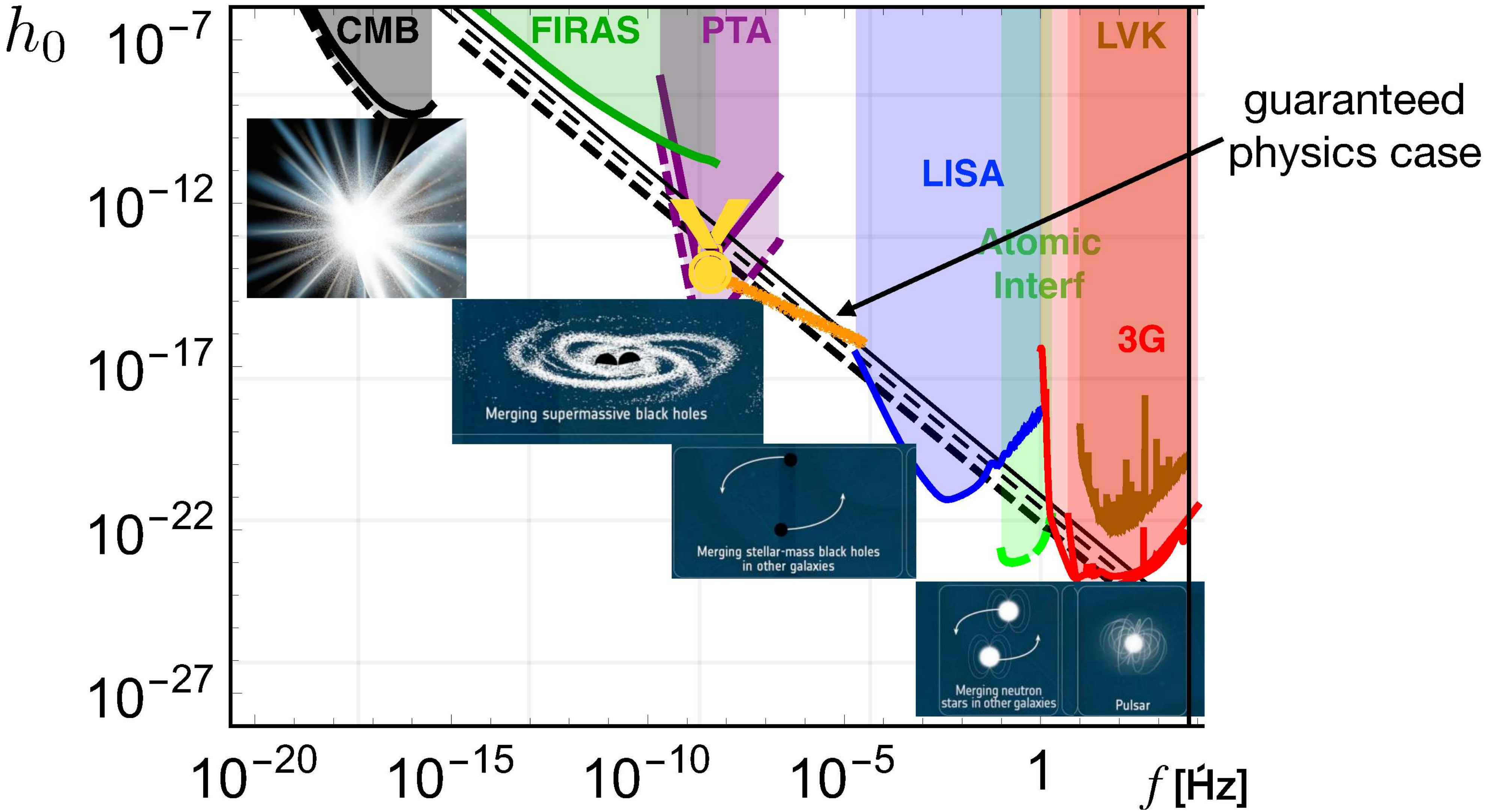


Figure 8: LEO and GEO protected regions [6].

- This can be done. The problem are GNSS

GWs searches ca. 2040

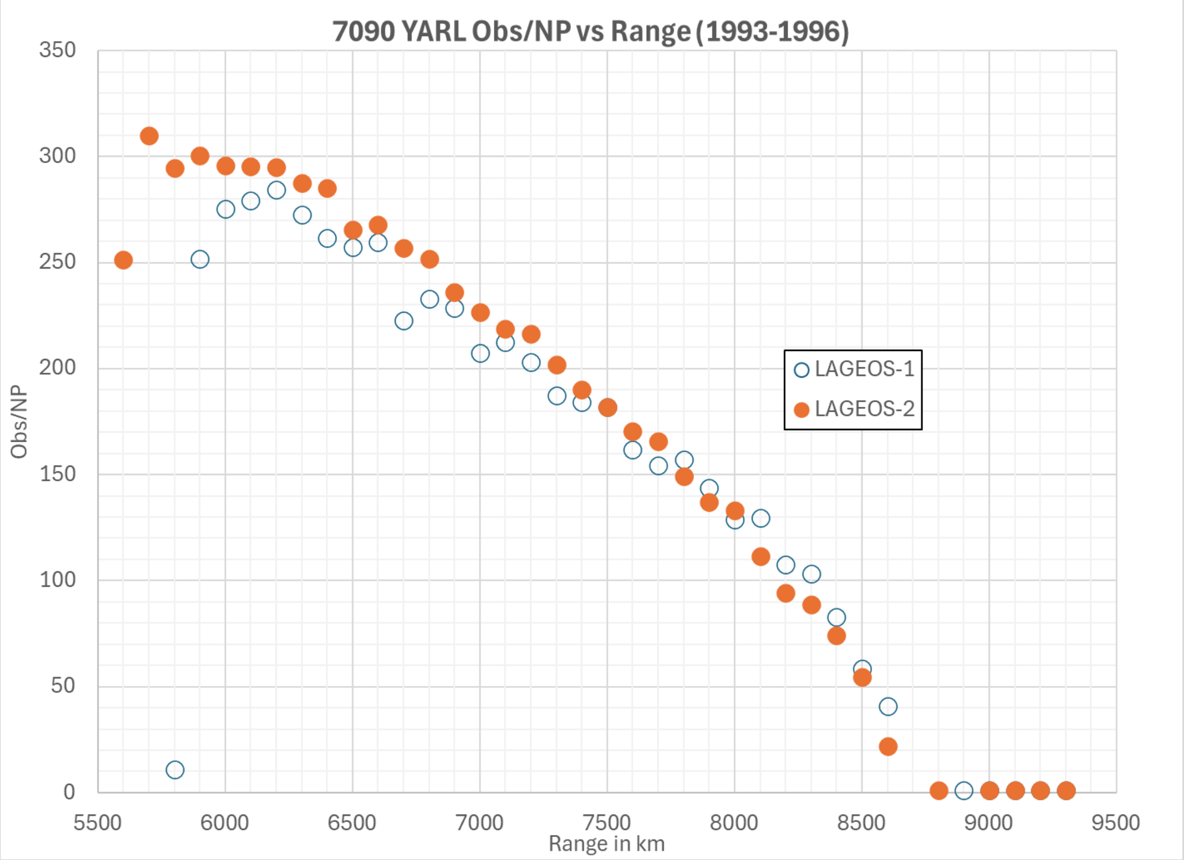


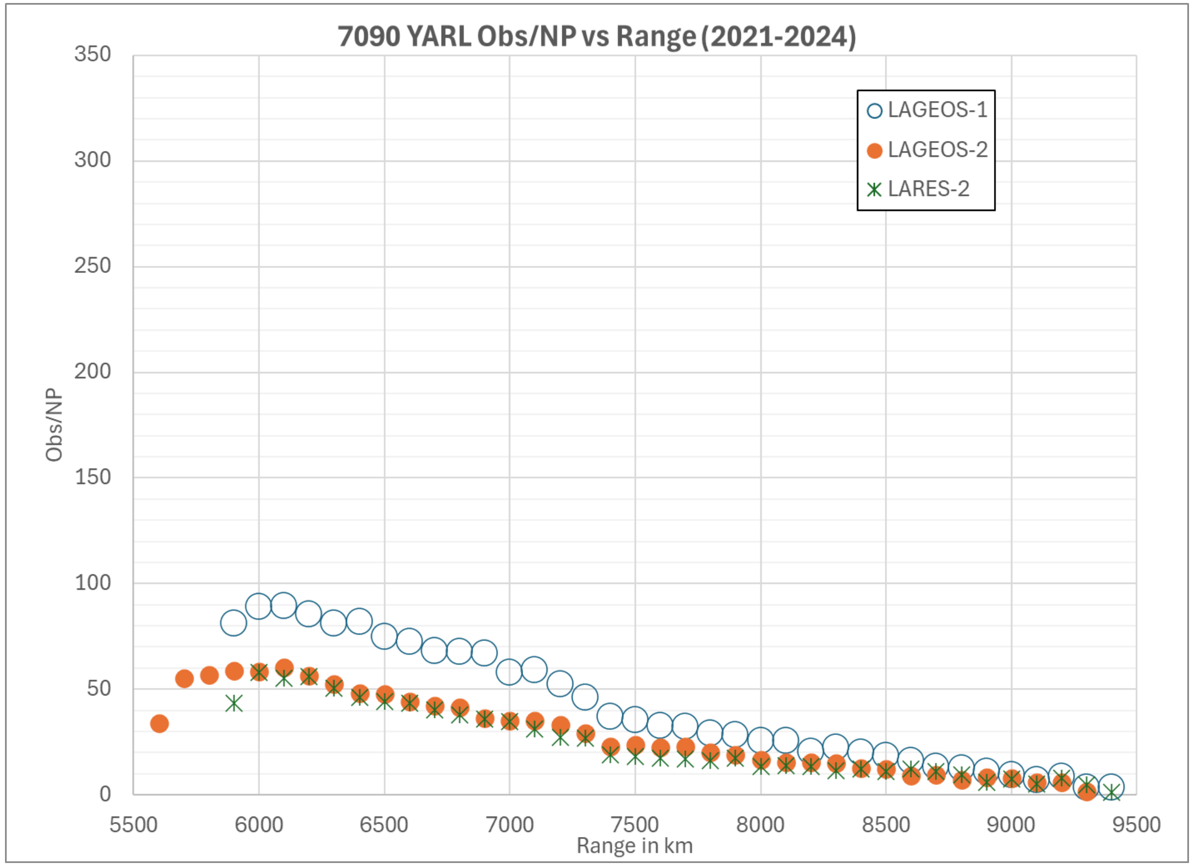
Medium Earth Orbit (LAGEOS-1, LAGEOS-2, LARES-2) Signal Strength Investigation (1993-1996 to 2021-2024)

NESC

Van Husson

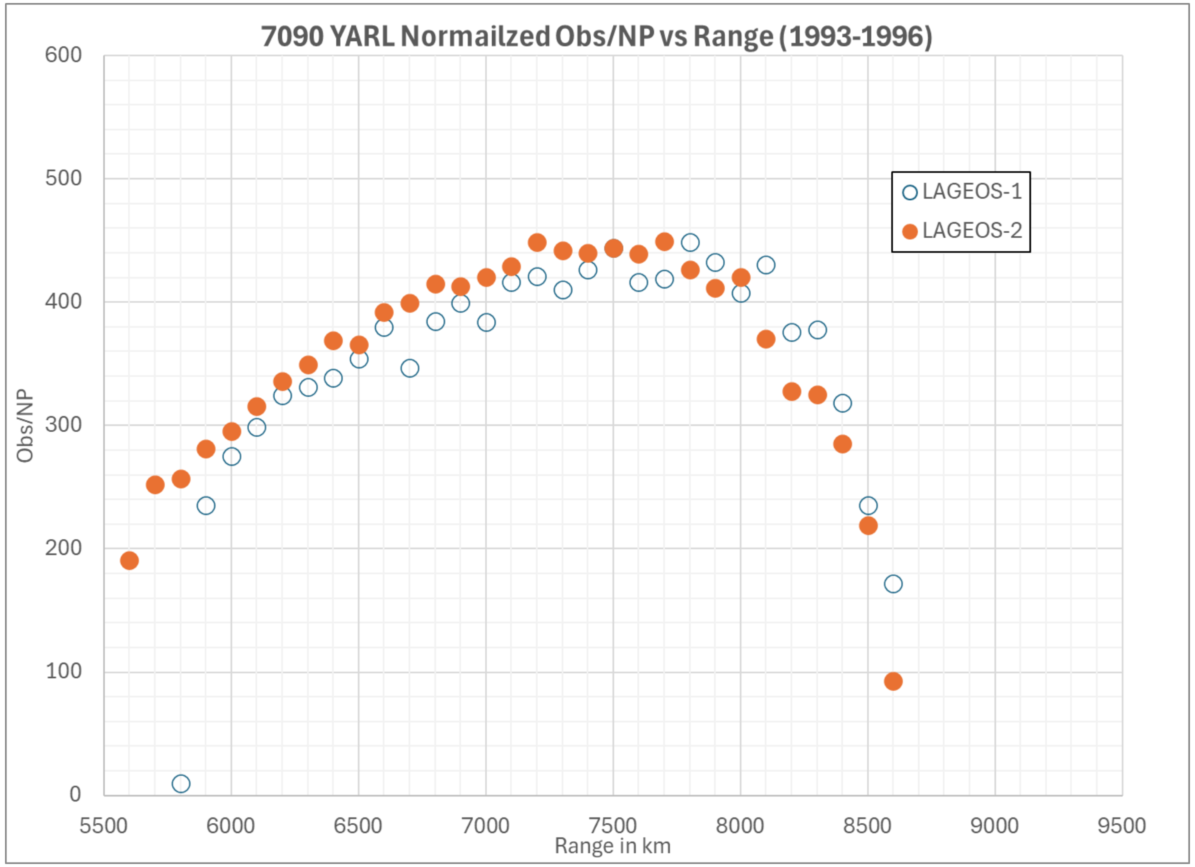
7090 YARL LAGEOS-1, LAGEOS-2, and LARES-2 Data Yield Comparisons

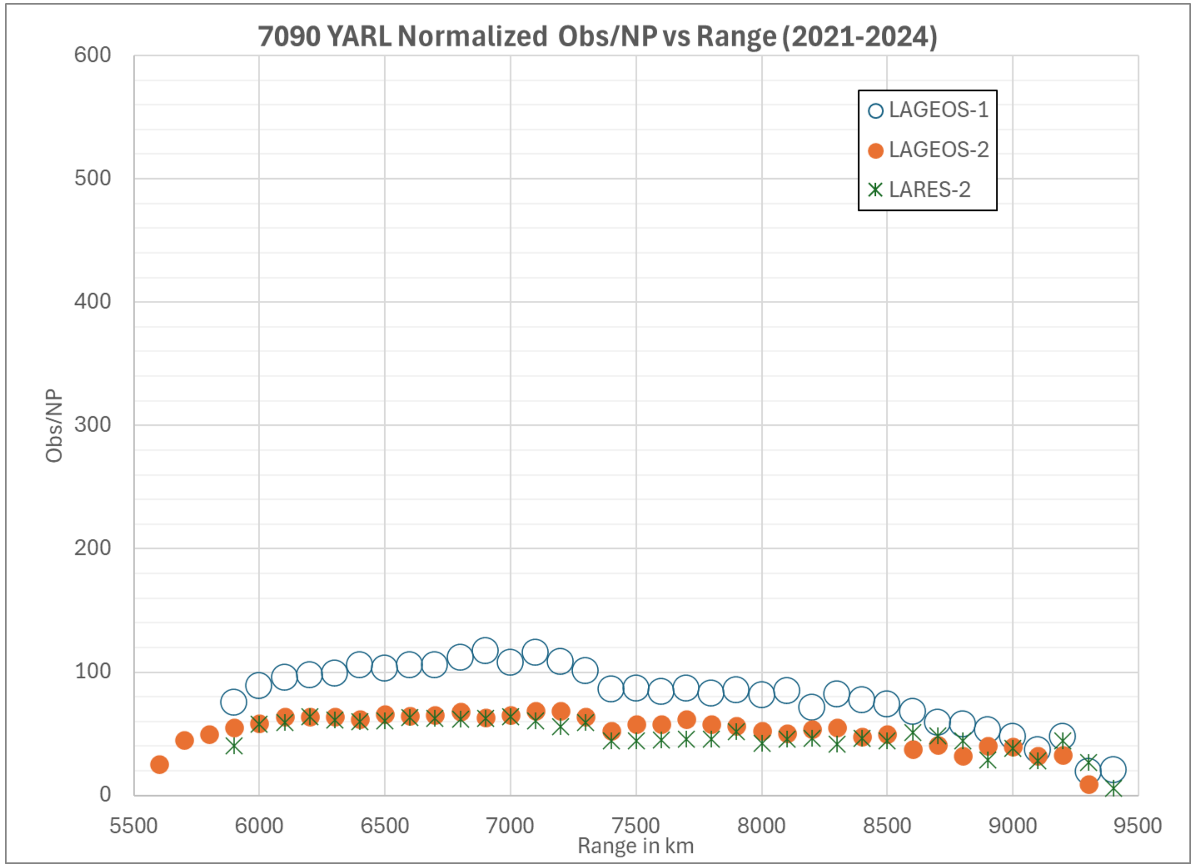




- **Post Event Timer, the NASA MOBLAS laser repetition rate has increased from 5 to 10 Hz dependent upon the range (5 or 10 Hz at <7500 km, 5 Hz > 7500 km) installation, there is a noticeable reduction in the number of observation per NP bin due to several reasons**
  - Pass interleaving
  - Degradation in satellite signal strengths
  - Degradation in the detector, optics, and pointing

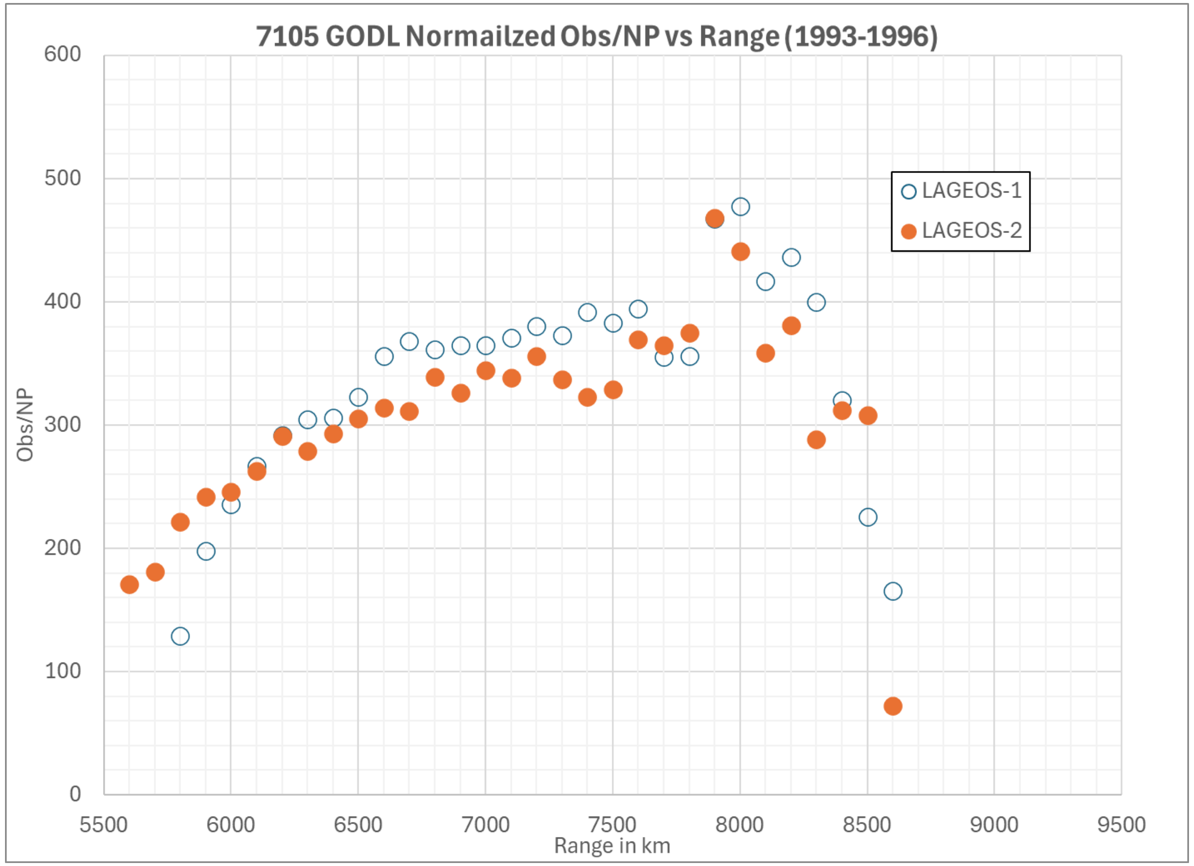
7090 YARL LAGEOS-1, LAGEOS-2, and LARES-2 Data Yield Comparisons

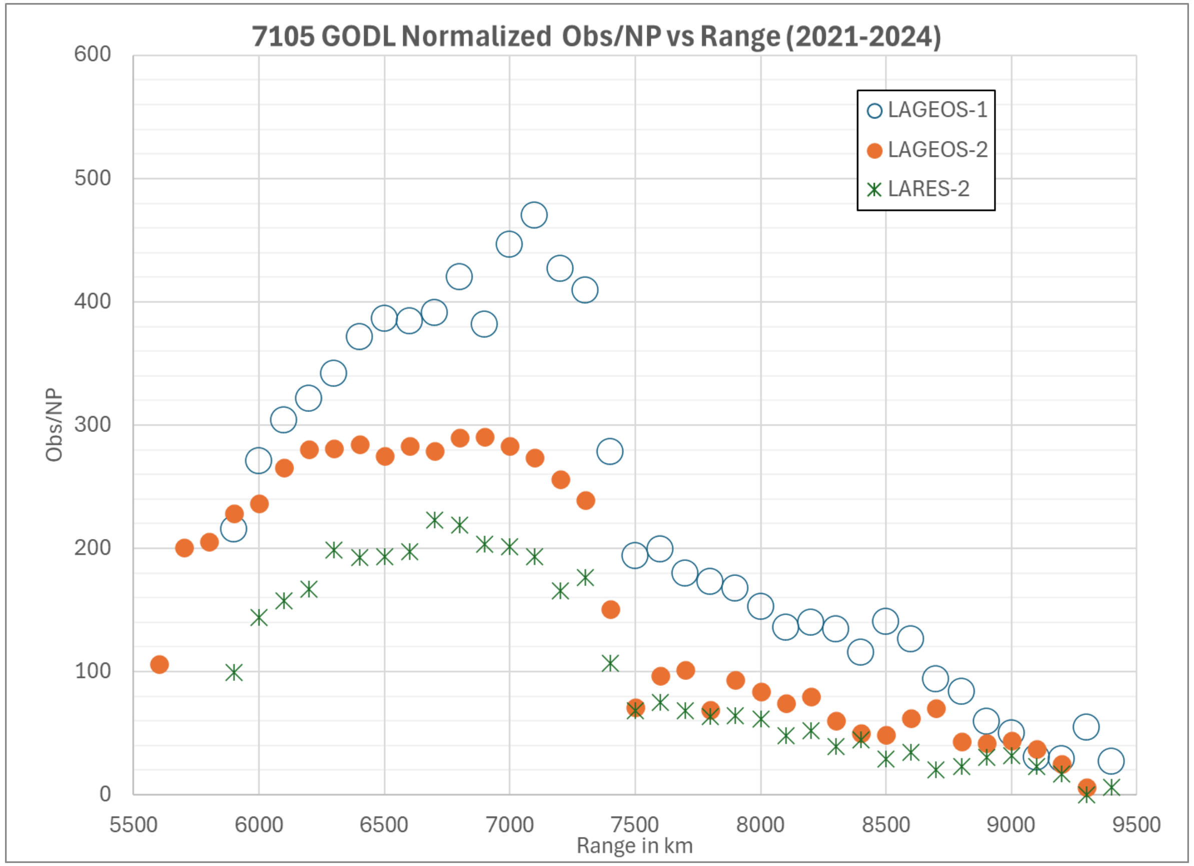




- **The observation count on this and the next set of slides are normalized based on a range of 6000 km (1/(Range^4))**

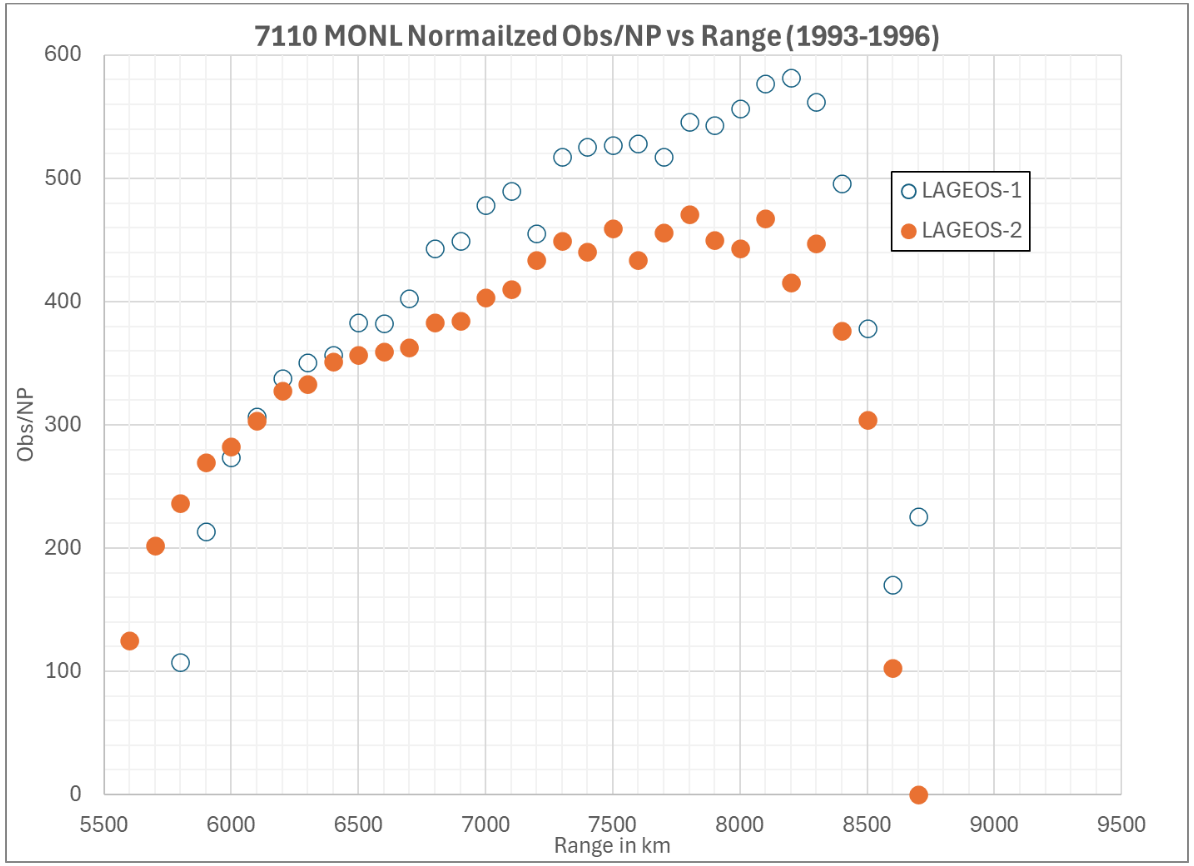
7105 GODL LAGEOS-1, LAGEOS-2, and LARES-2 Data Yield Comparisons

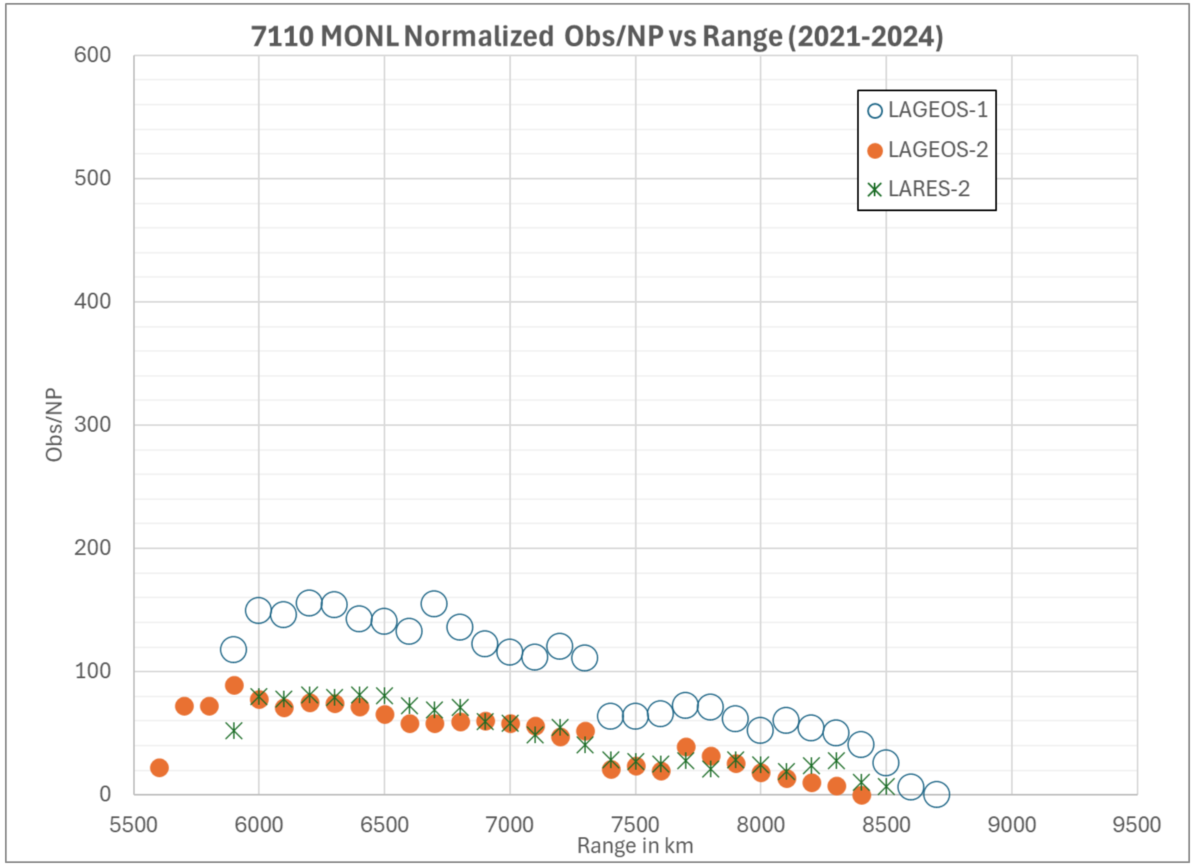




- ❑ **On the right chart there is a clear distinction around 7400 km when the laser is switched from 10 to 5 Hz**

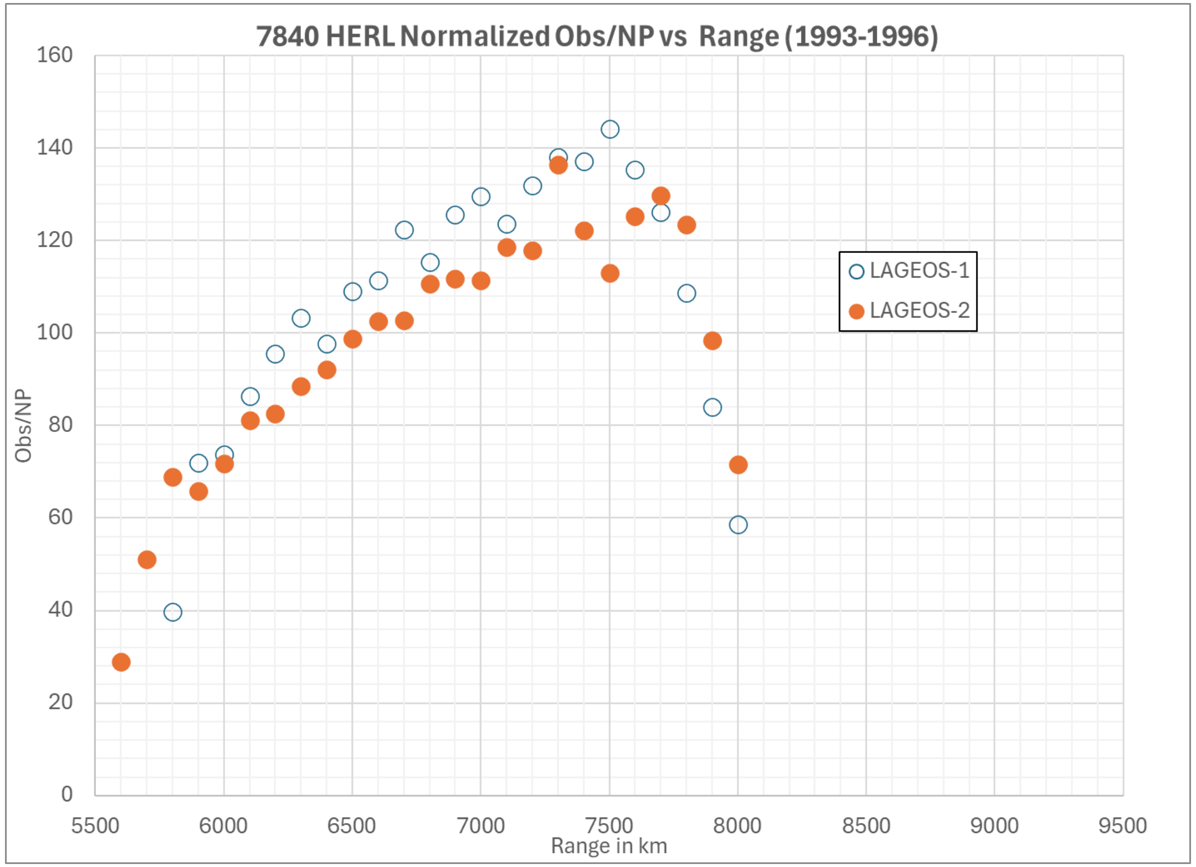
7110 MONL LAGEOS-1, LAGEOS-2, and LARES-2 Data Yield Comparisons

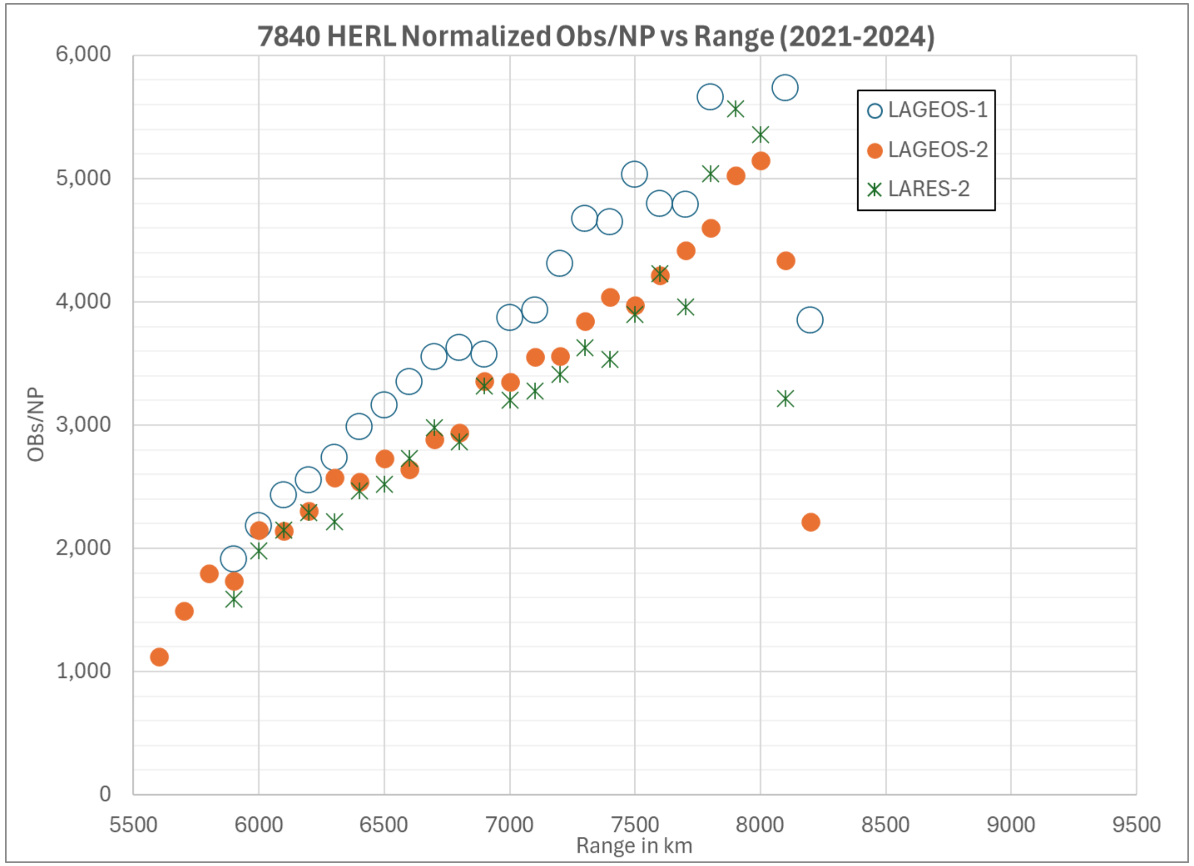




- On the right chart there is a clear distinction around 7400 km when the laser is switched from 10 to 5 Hz
- Do the recent trends indicate a degradation in system performance; weaker returns from the satellite and/or change in operating hours?

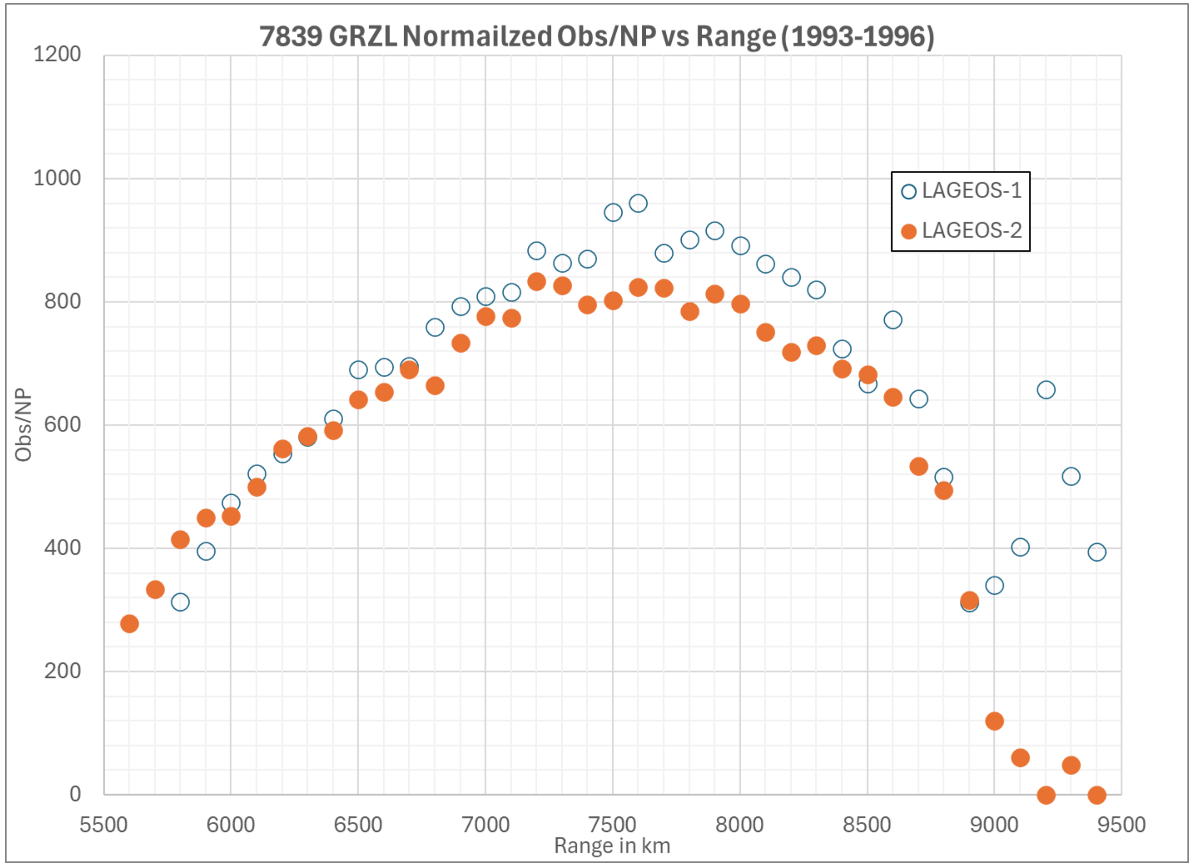
7840 HERL LAGEOS-1, LAGEOS-2, and LARES-2 Data Yield Comparisons

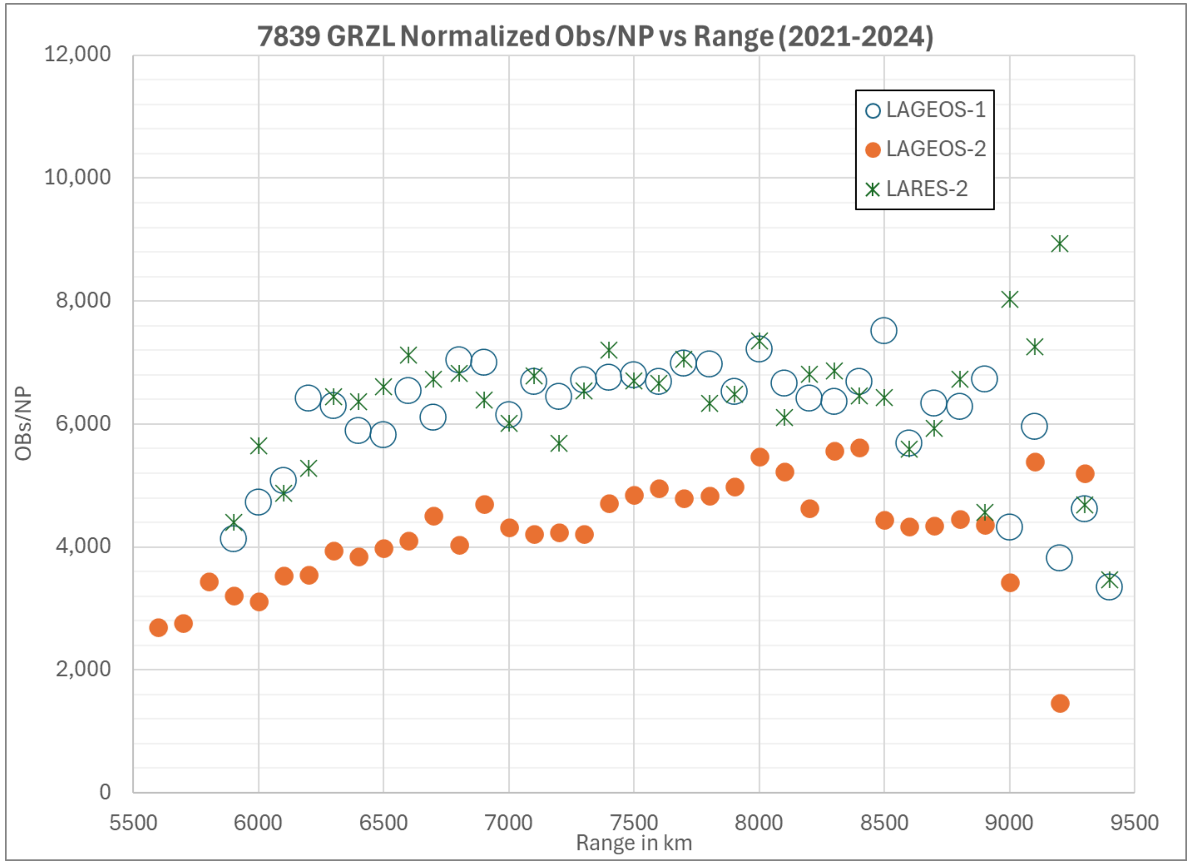




- ❑ **HERL is a single photon system**
- ❑ **In both time periods, LAGEOS-2 signals appear weaker to LAGEOS-1**

7839 GRZL LAGEOS-1, LAGEOS-2, and LARES-2 Data Yield Comparisons





- Graz is multi-photon system and implemented a LAGEOS 20 mm LE filter in March 2008
- A 20 mm LE filter is also applied to LARES-2. LARES-2 LE return rates are like LAGEOS-1, but not LAGEOS-2

Conclusions/Questions

- The trends in Obs/NP per Range are station dependent. The recent trends in 7090 and 7110 may indicate a decline in system performance
- Currently, LAGEOS-2 return signals appear weaker relative to LAGEOS-1 for all stations. Does this indicate anything about the quality and long-term performance of the LAGEOS-2 retroreflectors?
- The LARES-2 LE returns from Graz are just as strong as LAGEOS-1
- Do these trends indicate a possible long-term change in the Center of Mass (CoM) Corrections for any of these systems?
- Is the CoM on these MEO targets range dependent based on the ranging machine configuration?

Attitude Estimation Experiment Using HTV-X

JAXA Shinichi Nakamura

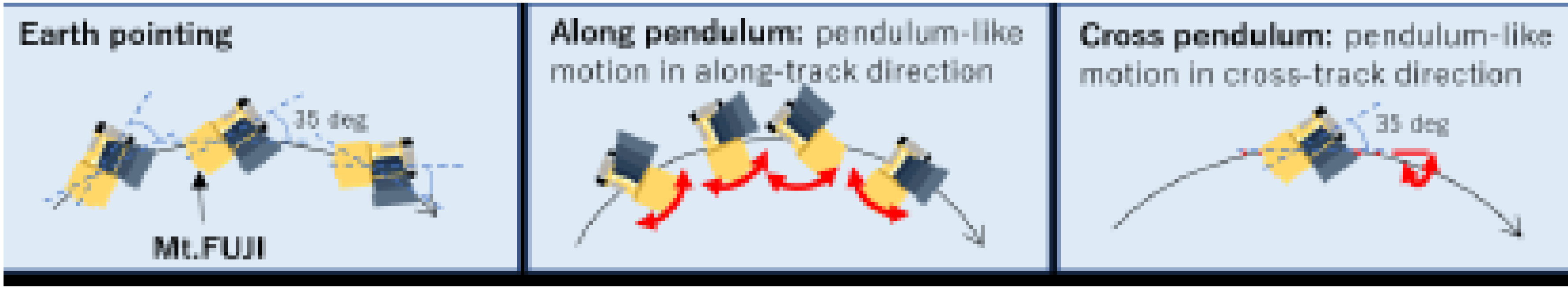
SLR stations

This experiment has already received approval by the ILRS MWG.

We are seeking collaborators to analyze data together.
I want to enjoy this experiment not just as JAXA research, but together with SLR colleagues.

JAXA will release information necessary for estimating angular velocity in orbit in advance.
We will also publish details online beforehand regarding the rotational motion applied to HTV-X during its flight over SLR stations.
Data acquired by SLR is available from CDDIS and EDC.

Note
HTV-X is a cargo resupply spacecraft developed by JAXA for the ISS.
https://humans-in-space.jaxa.jp/en/htv-x/
It is currently docked to the ISS.
Around March, it will be undocked from the ISS.
After that, HTV-X will behave like a satellite.
At that time, I requested that HTV-X perform an artificial rotational motion.
What I want to emphasize is that precise angular velocity data is transmitted from HTV-X via telemetry.
By comparing this with angular velocity calculated from data acquired by SLR stations, I believe we can contribute to improving SLR analysis technology.

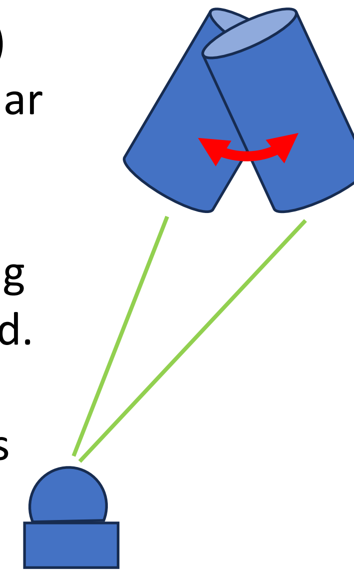


We have designed three flight modes.

(1) Earth-Pointing   The spacecraft will fly with its SLR reflector (Mt. FUJI) pointed toward Earth. We expect to obtain SLR observation data similar to that from standard ILRS satellites.

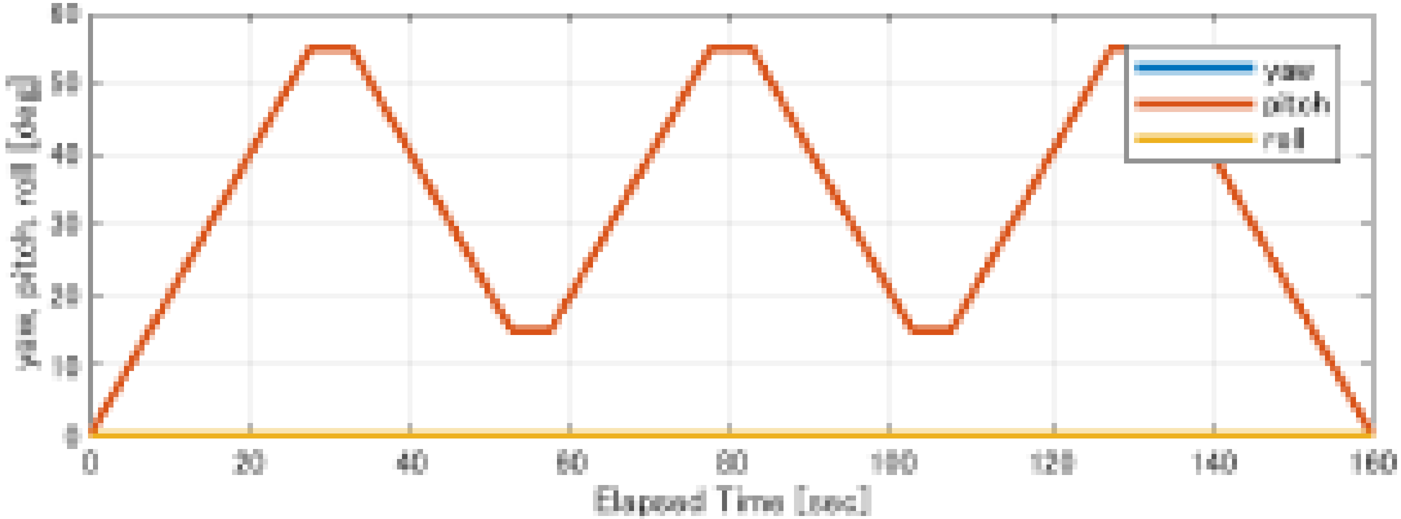
(2) Along Motion   The HTV-X will perform pendulum motion in the Along direction. We are looking forward to seeing what data can be acquired.

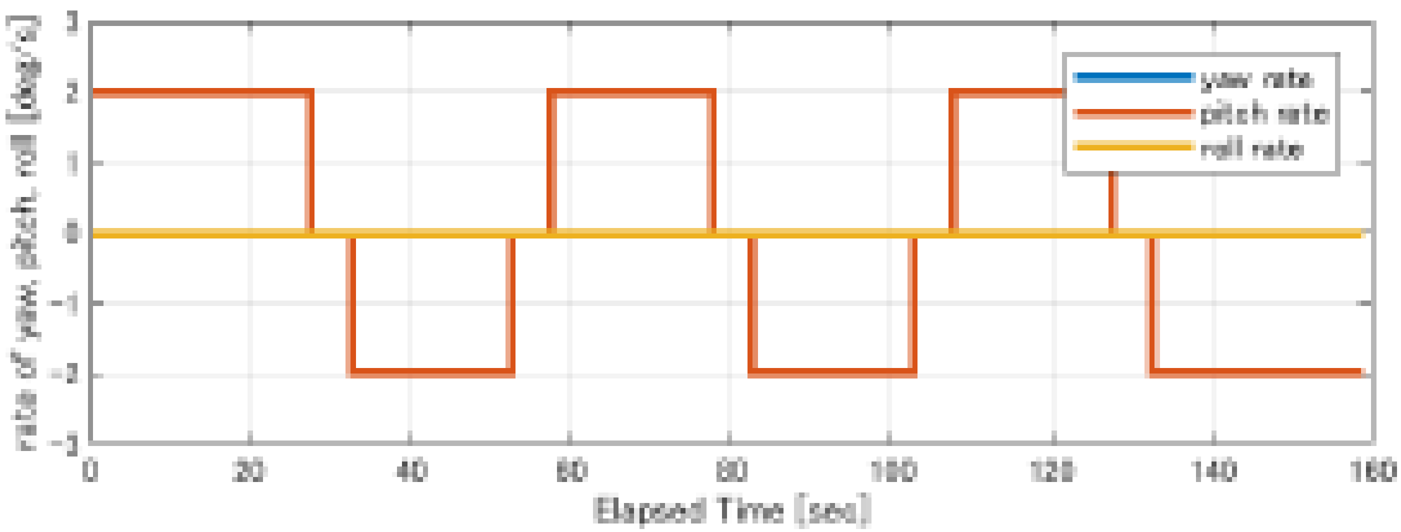
(3) Cross Motion   The HTV-X will perform pendulum motion in the Cross direction.



What kind of observational data will we obtain?

For Example of Along pendulum motion





Experiment Procedure

(1) Data Acquisition

・JAXA will distribute the HTV-X CPF.

・SLR stations should observe HTV-X and upload CRDs to CDDIS and EDC.

(2) Analysis

・JAXA will publish in advance on the web which paths HTV-X will fly and in which flight modes.

・Those interested in this research should download the CRD and perform analysis.

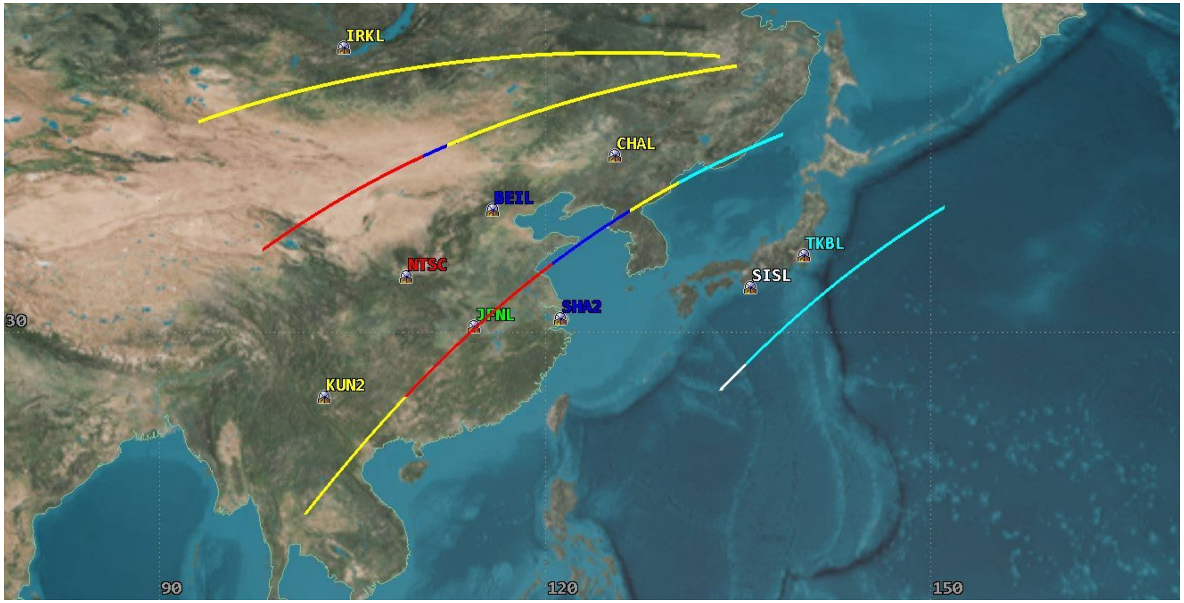
・Notify JAXA of the analysis results.

・JAXA will compare these results with telemetry received from HTV-X and share the findings.

Please understand that we cannot disclose the raw telemetry data from HTV-X itself.

・Finally, let's collaborate to complete a paper together.

There are constraints.
For this experiment only, HTV-X will point Mt. FUJI toward Earth.
Therefore, even if SLR is performed according to CPF, no Return will be obtained.
A large amount of fuel is required to swing HTV-X.
Therefore, we decided to swing HTV-X only over the dense SLR station area.
We plan to conduct this experiment in the dense SLR station area of Asia.



We selected observation paths for HTV-X that can be observed by two or more SLR stations.

Although Europe has a dense network of SLR stations, GPS jamming occurs there, so we abandoned conducting the experiment over Europe.

I have a request for everyone.

Today, I've only provided an overview to pique your interest.
Detailed information (HTV-X dimensions and experiment pass times) will be shared separately via email or our website.

If you are interested in this experiment,please contact us at:
nakamura.shinichi@jaxa.jp
hamada.kiyoshi@jaxa.jp
matsumoto.takehiro@jaxa.jp

After this meeting, I will share my presentation materials.
If you know anyone around you who might be interested in this experiment, please let them know.

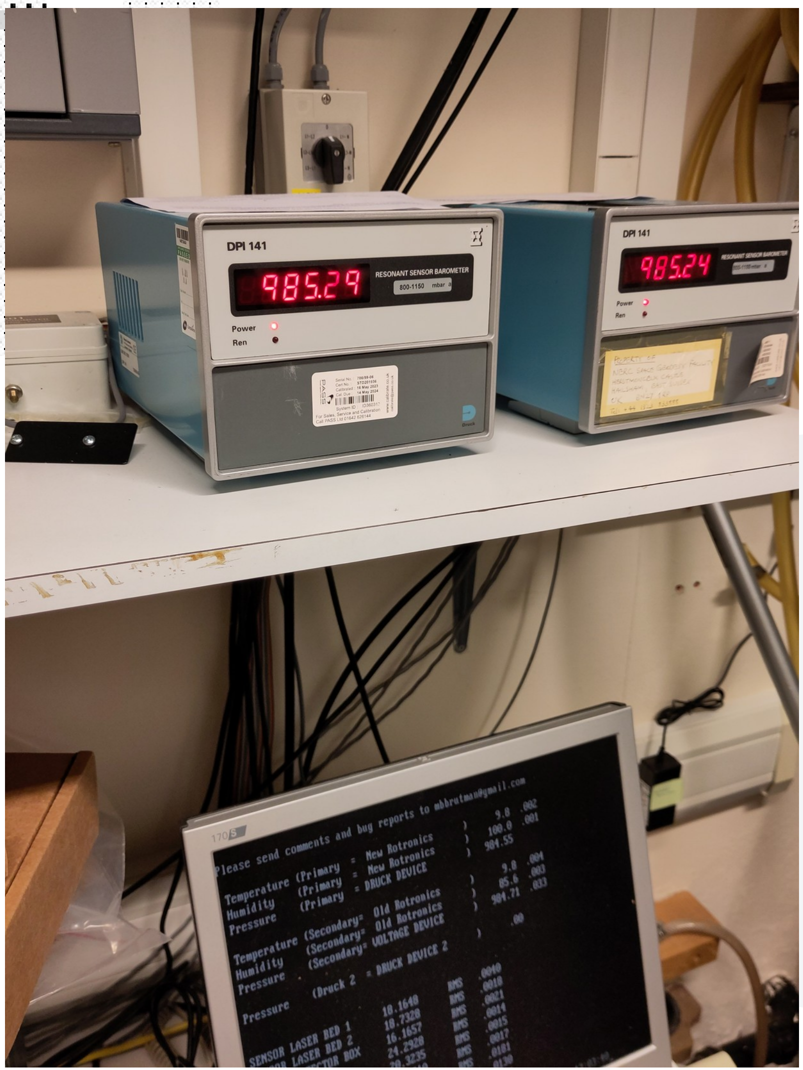
Let's prove together that SLR technology is important not only for POD but also for pose estimation.

Thank You ! By Shinichi

Measuring Pressure at the SGF, Herstmonceux

Matthew Wilkinson
ILRS Networks & Engineering SC

19/02/26



Druck DPI 141

Pair of barometers sit side by side on a shelf in the SGF laser room.

These have been operating for over 25 years.

They were each separately sent away and calibrated in the last 5 years without any issues.

There is a small offset between them within the specified accuracy of 0.15 mbar.

A pressure correction of 0.72 mbar is made to refer the readings to the centre of the SLR telescope height.

Druck DPI 141

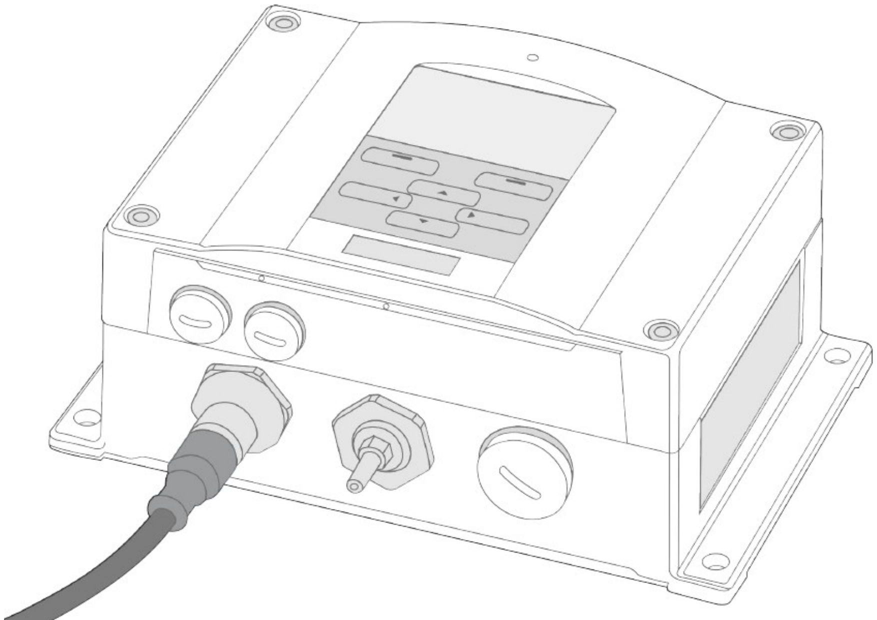
The 2 barometers are pretty old.

We only have two barometers at the SGF and they are of the same make and model.

And they are located inside the SGF building, inside an air conditioned room.

Vaisala BAROCAP® Digital Barometer

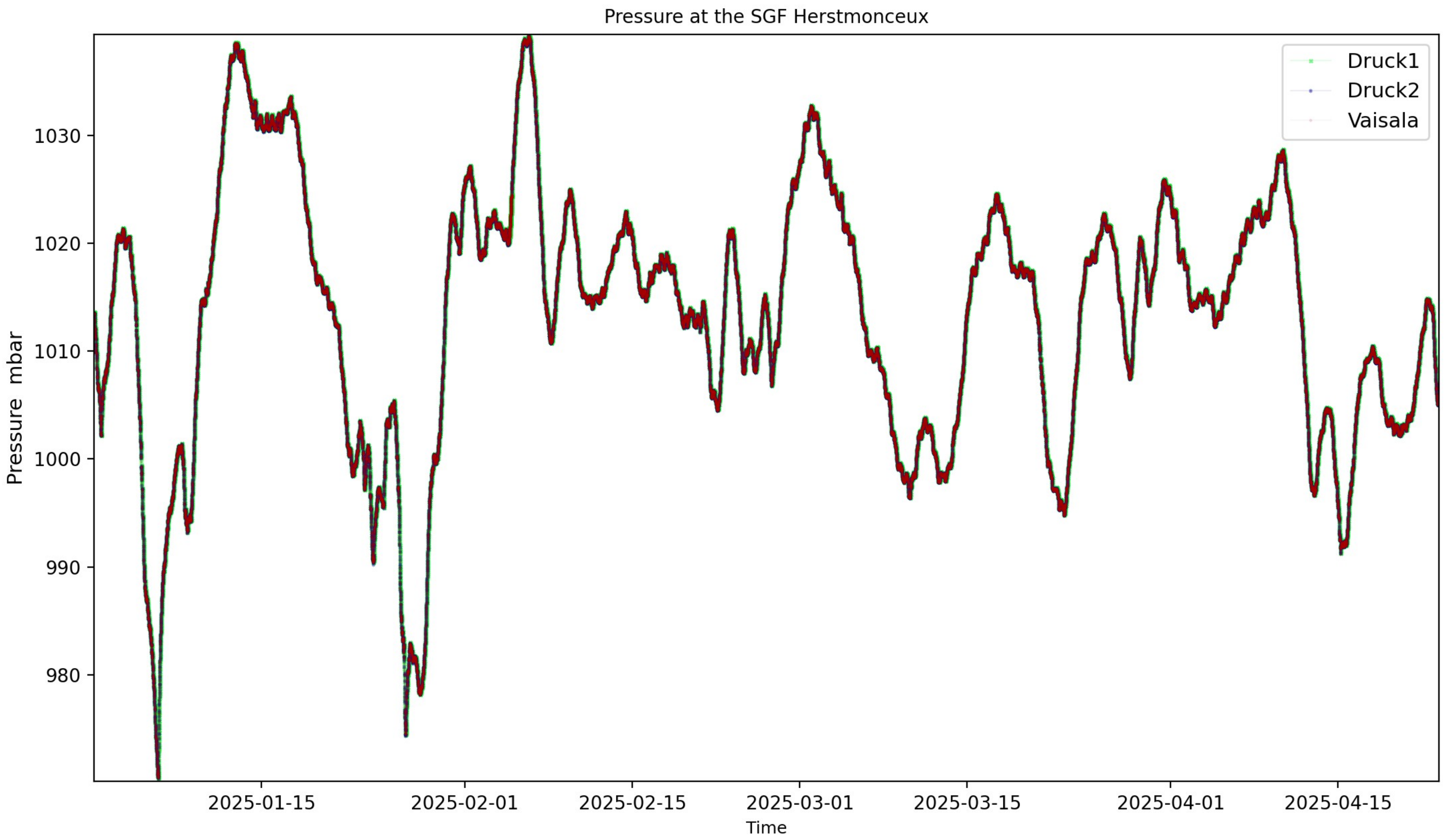
PTB330

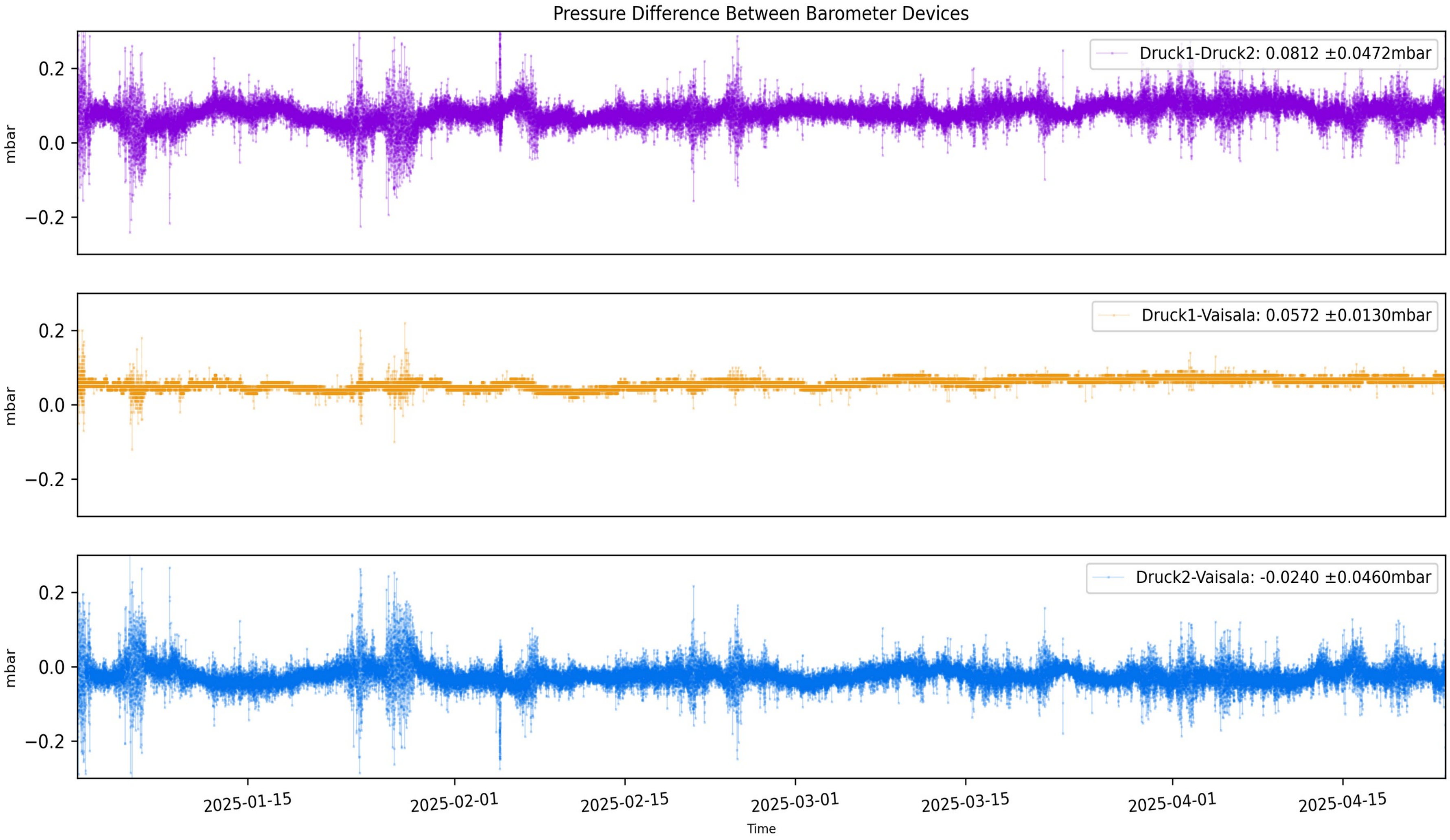


Vaisala PTB330

To strengthen our pressure measurements, a new high accuracy barometer was purchased from Vaisala.

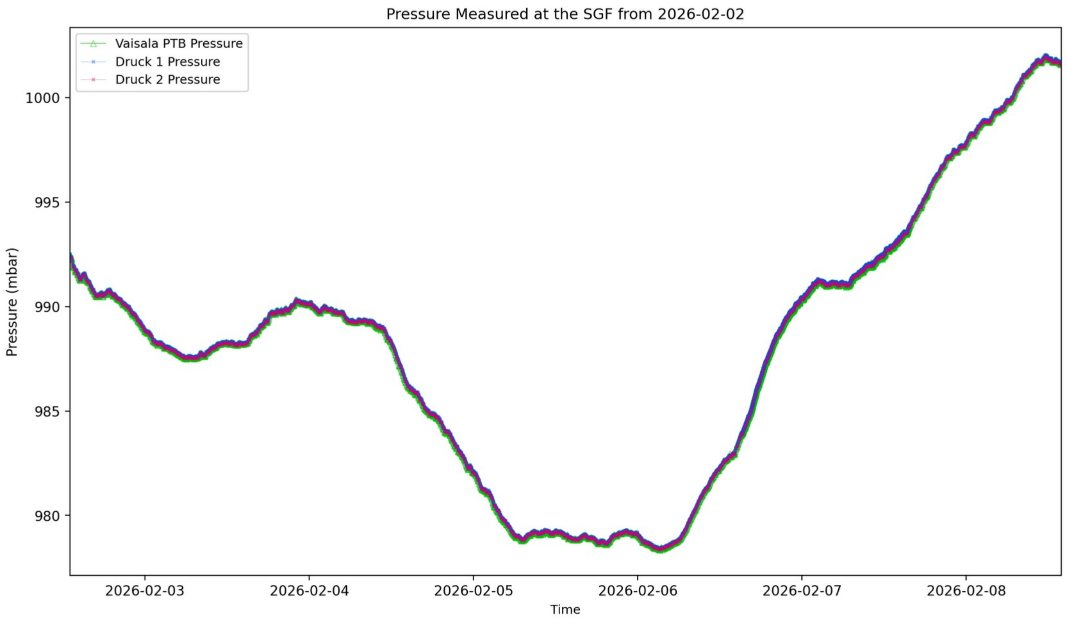
This was installed next to the two Druck barometers and showed very good agreement

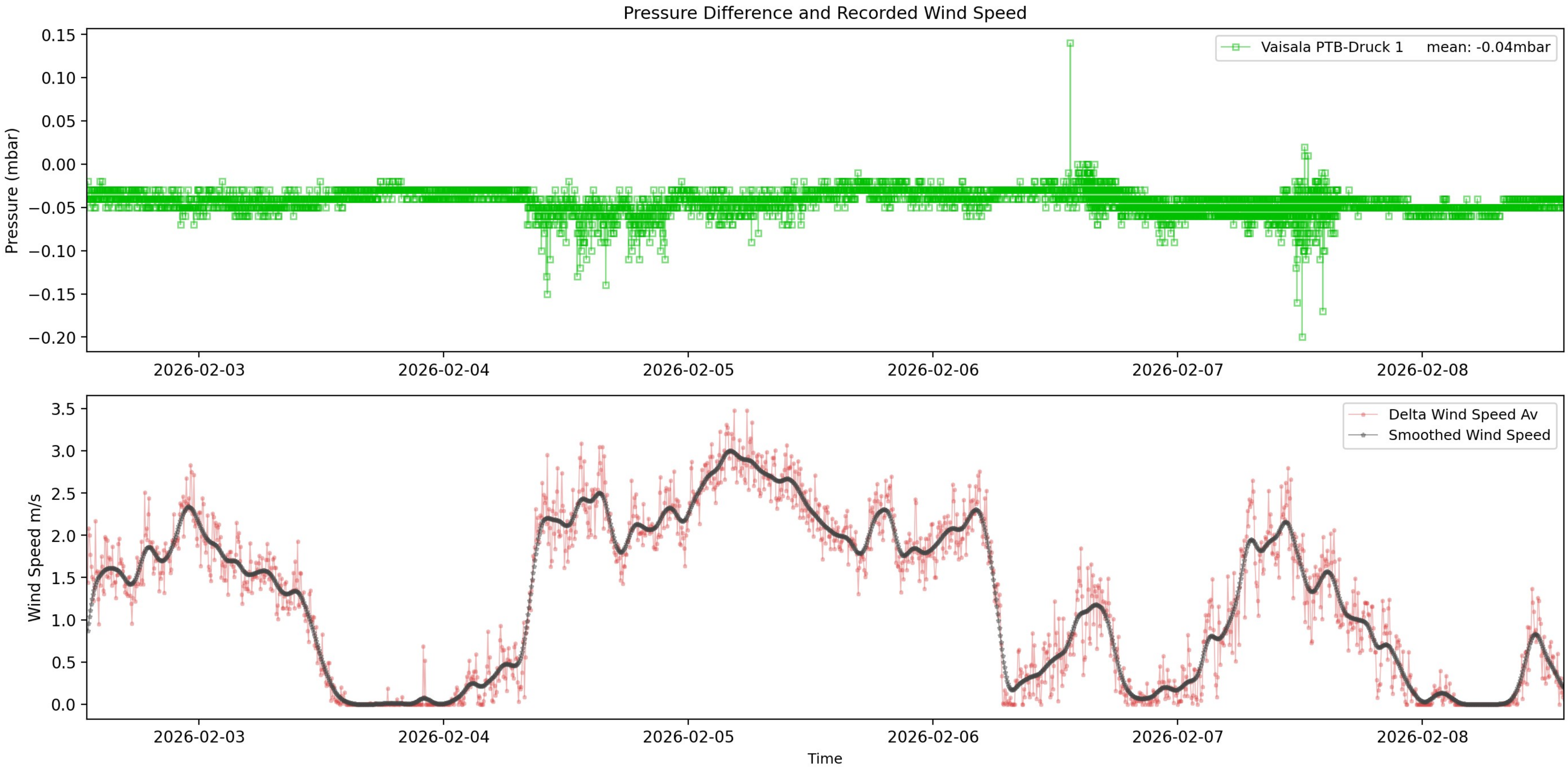

Pressure at the SGF Herstmonceux
Druck1
Druck2
Vaisala
Pressure mbar
1030
1020
1010
1000
990
980
2025-01-15
2025-02-01
2025-02-15
2025-03-01
2025-03-15
2025-04-01
2025-04-15
Time


Pressure Difference Between Barometer Devices
Druck1-Druck2: 0.0812 ±0.0472mbar
Druck1-Vaisala: 0.0572 ±0.0130mbar
Druck2-Vaisala: -0.0240 ±0.0460mbar
mbar
0.2
0.0
−0.2
2025-01-15
2025-02-01
2025-02-15
2025-03-01
2025-03-15
2025-04-01
2025-04-15
Time

Vaisala PTB330

In 2026, the Vaisala PTB330 was installed in the SLR dome at the height of the telescope.





Pressure Difference and Recorded Wind Speed
Vaisala PTB-Druck 1 mean: -0.04mbar
Pressure (mbar)
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
2026-02-03
2026-02-04
2026-02-05
2026-02-06
2026-02-07
2026-02-08
Delta Wind Speed Av
Smoothed Wind Speed
Wind Speed m/s
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2026-02-03
2026-02-04
2026-02-05
2026-02-06
2026-02-07
2026-02-08
Time