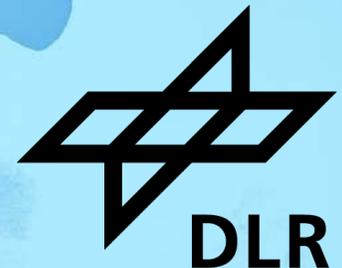


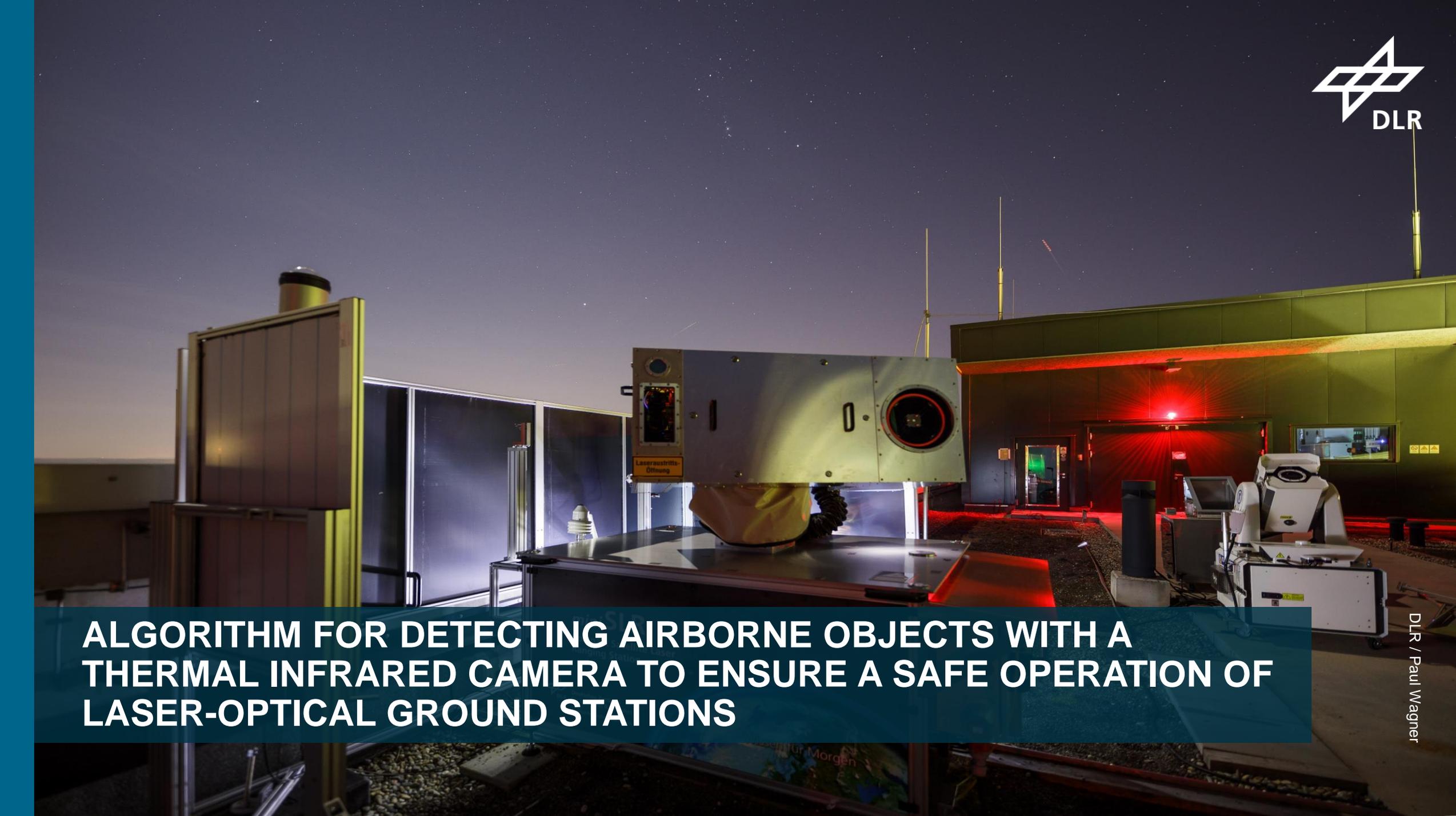
# ALGORITHM FOR DETECTING AIRBORNE OBJECTS WITH A THERMAL INFRARED CAMERA TO ENSURE A SAFE OPERATION OF LASER-OPTICAL GROUND STATIONS

Nils Bartels, Felicitas Niebler, Tristan Meyer, Wolfgang Riede, Thomas Dekorsy

German Aerospace Center (DLR), Institute of Technical Physics, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany

Meeting of the ILRS Networks and Engineering Standing Committee (NESC), January 23<sup>rd</sup>, 2025





**ALGORITHM FOR DETECTING AIRBORNE OBJECTS WITH A THERMAL INFRARED CAMERA TO ENSURE A SAFE OPERATION OF LASER-OPTICAL GROUND STATIONS**

# Lasers in public airspace



Source: DLR

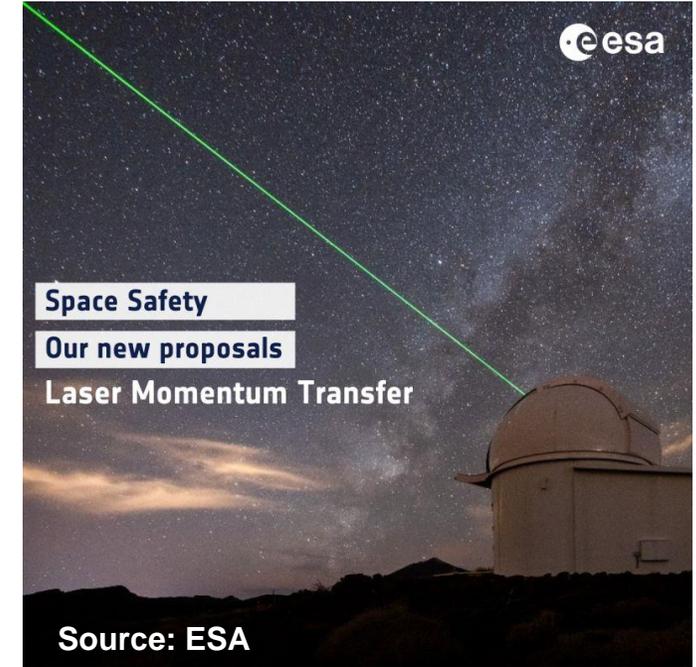


Satellite/space debris laser ranging



Source: DLR

Laser communication



Laser momentum transfer



Source: private

(Atmospheric) LIDAR

Nils Bartels, January 23<sup>rd</sup>, 2025



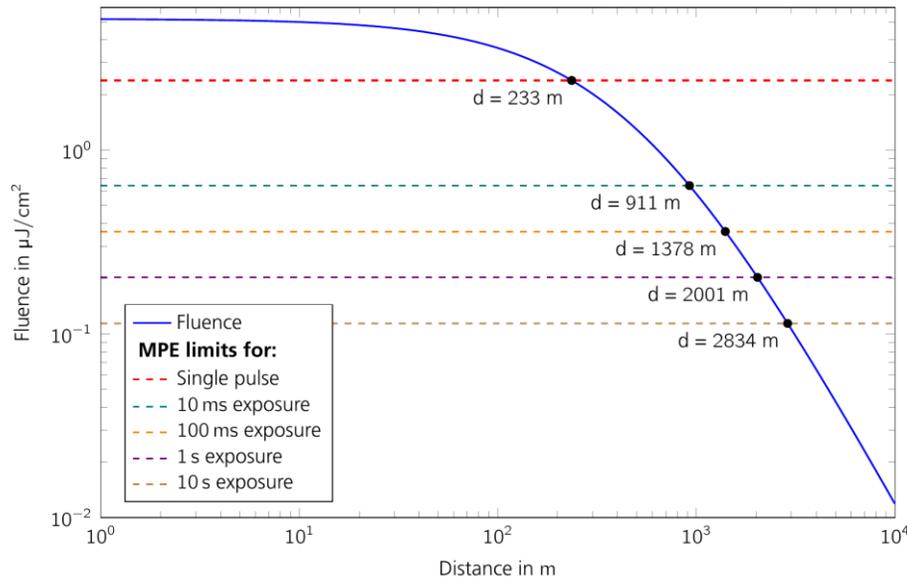
Source: Trumpf

For fun/advertisement...

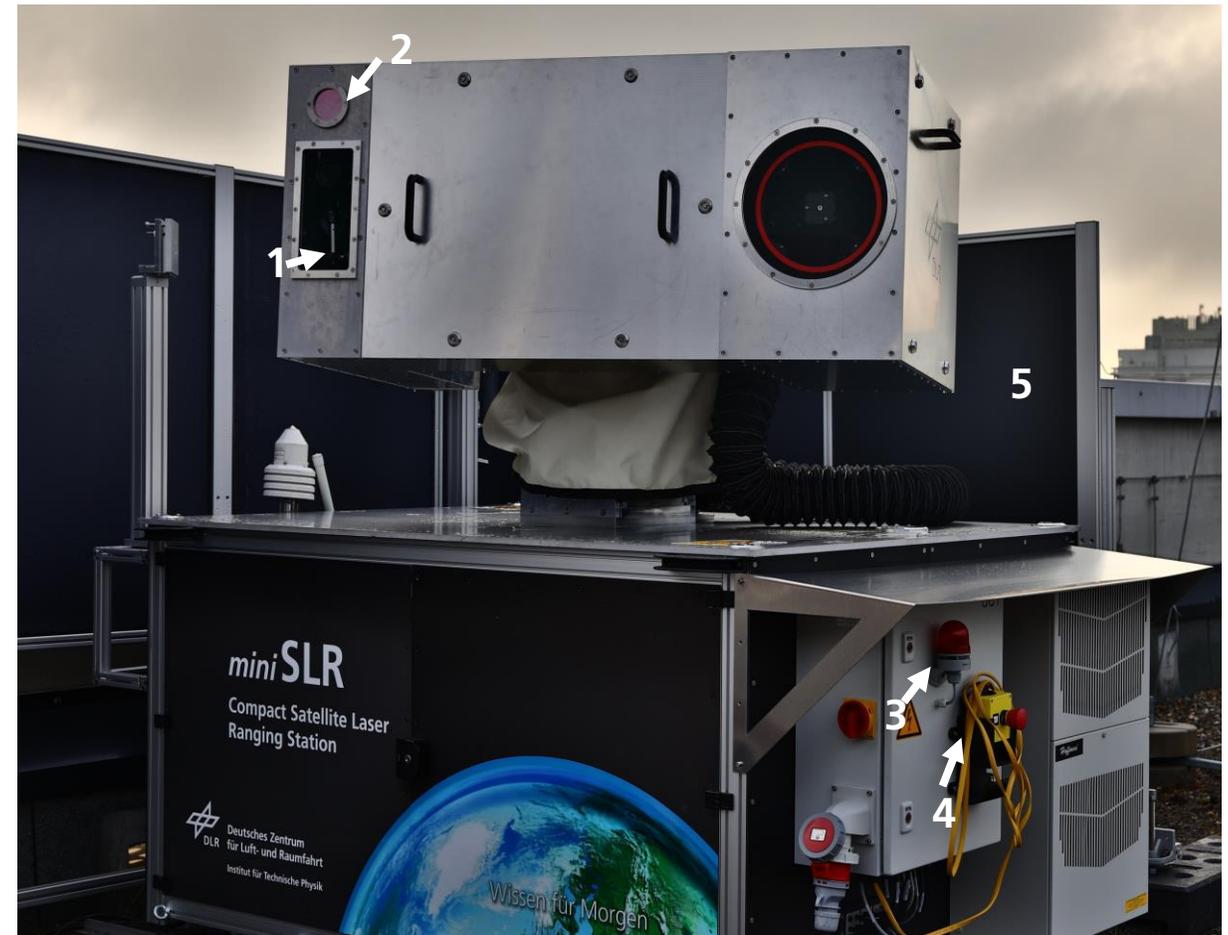
# Laser safety at miniSLR<sup>®</sup>

## Laser parameters miniSLR<sup>®</sup>

Wavelength	1064 nm
Pulse energy	85 $\mu$ J
Pulse duration	500 ps
Pulse repetition rate	50 kHz
Beam divergence	50 $\mu$ rad
Beam diameter (transmitter exit)	5 cm



→ Laser safety system needed



1 = laser transmitter window, 2 = Germanium window of the thermal infrared camera, 3 = laser warning lamp, 4 = emergency stop button (4), and physical laser safety barriers (5).

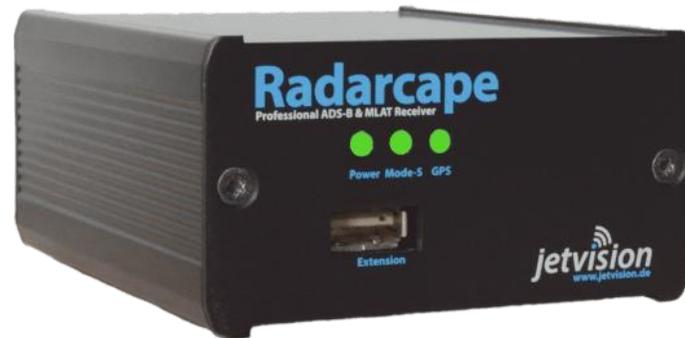
# Laser safety at miniSLR<sup>®</sup>

Radar (as data stream from air traffic control)



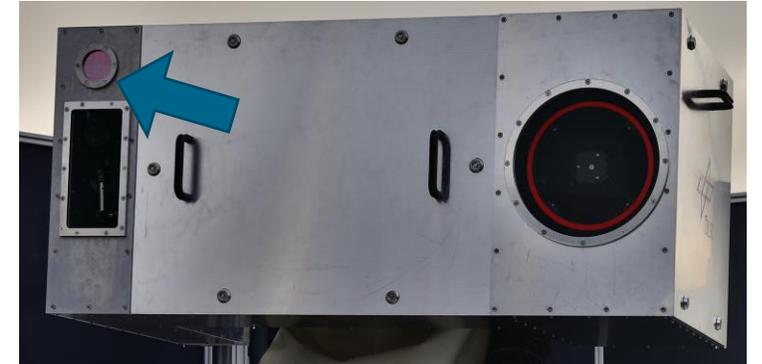
Quelle: <https://www.dfs.de/homepage/de/flugsicherung/betrieb/ortung/>

ADS-B receiver



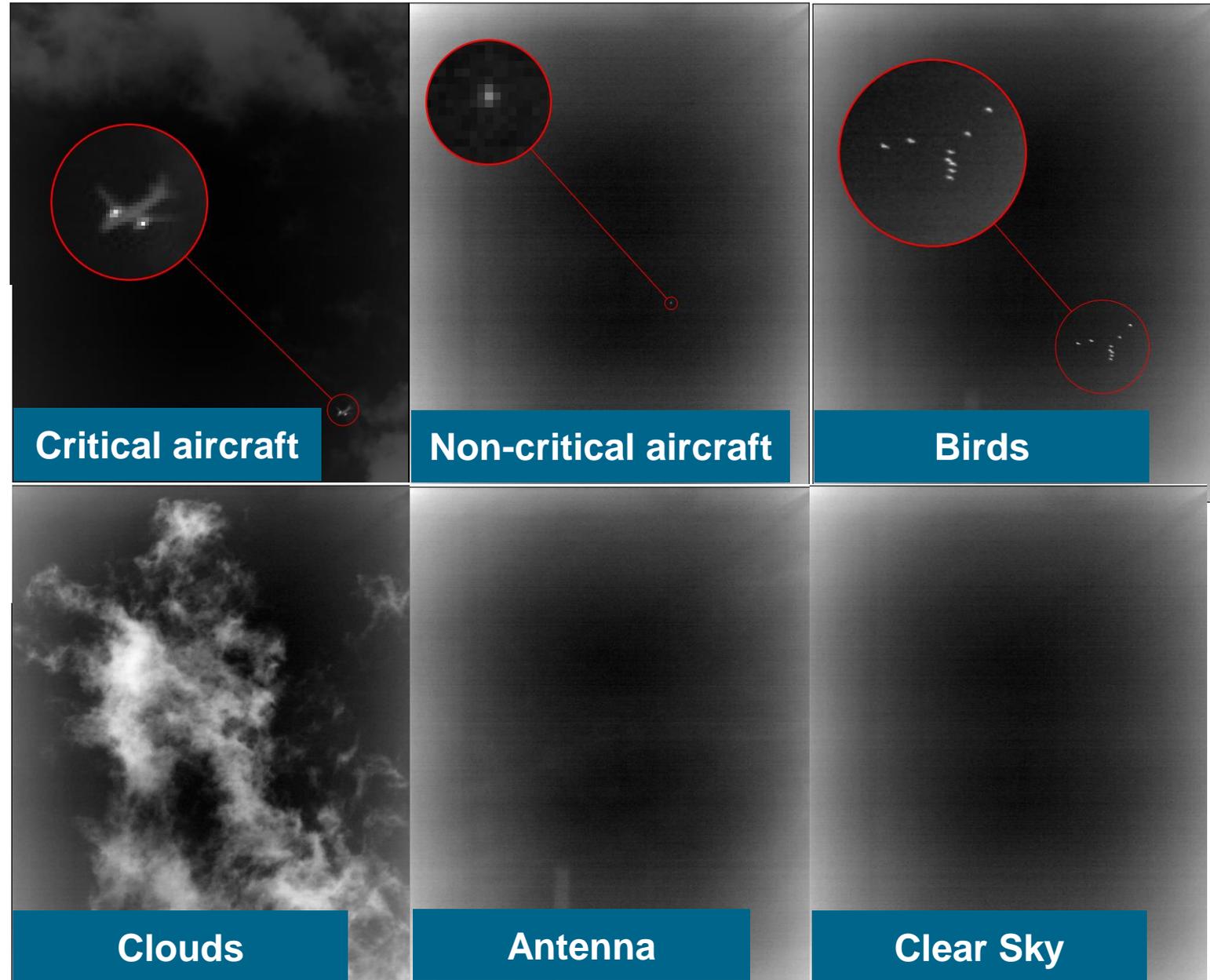
Quelle: <https://radarcape.com/de/ads-b-empfaenger-mlat-radarcape/>

Thermal infrared camera



Key task: Reliable detection of aircraft from thermal infrared images.

# Dataset



**Table 3. Number of Images and Targeted Classification of Different Categories in the Generated Dataset**

Category	Number of Images	Target Classification
Critical aircraft	359	Unsafe
Non-critical aircraft	434	Unsafe
Clouds	146	Safe
Birds	143	Unsafe
Antenna	35	Safe
Clear sky	158	Safe
Interesting images	9	Unsafe
Total	1284	-

# Python software with GUI for testing of algorithms



The screenshot displays the 'Image Analysis Framework' GUI. The main window includes a control panel with buttons for 'Load images', 'Run Analysis', 'Show Stats', and 'Edit Algorithm Parameters'. A dropdown menu shows 'BackgroundSupressionAndStdThresholdWithErosion' and '1\_Critical\_Aircraft'. Checkboxes for 'Show images with detections' and 'Show images without detections' are visible. A file information box shows 'Filename: img\_2023-06-27\_074816.fit', 'Timestamp: 2023-06-27T07:48:15.961516', and 'Image 13 of 359'. The main area shows a grayscale image of a cloudy sky with a small aircraft. A vertical plot on the right shows a histogram with a yellow line. A 'Statistics' window is open, displaying a table of detection results.

	Detections	No Detections
1_Critical_Aircraft	356 (99.16 %)	3 (0.84 %)
2_Non_Critical_Aircraft	417 (96.08 %)	17 (3.92 %)
3_Clouds	6 (4.11 %)	140 (95.89 %)
4_Birds	140 (97.90 %)	3 (2.10 %)
5_Antenna	0 (0.00 %)	35 (100.00 %)
6_Clear_Sky	0 (0.00 %)	158 (100.00 %)
7_Interesting_Images	7 (77.78 %)	2 (22.22 %)

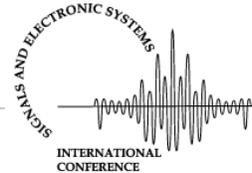
Algorithm: BackgroundSupressionAndStdThresholdWithErosion  
Parameters: {'median\_filter\_size': '5', 'nr\_of\_std': '8'}

# Results



- Different algorithms tested:
  - Laplacian filter with edge detection
  - Canny edge detection
  - **Background subtraction with median filtered image (→ best algorithm)**

ICSES 2008 INTERNATIONAL CONFERENCE ON SIGNALS AND ELECTRONIC SYSTEMS  
KRAKÓW, SEPTEMBER 14-17, 2008



## Object detection in grayscale images based on covariance features

Ints Mednieks  
Institute of Electronics and Computer Science,  
14 Dzerbenes Street, LV1010 Riga, Latvia,  
e-mail: mednieks@edi.lv

Idea came from an article dealing with the detection of artificial objects in processed food via X-ray imaging.

Quelle: <https://doi.org/10.1109/ICSES.2008.4673393>

# What is a median filter?

11	7	4	5	3	3	2	2
38	22	10	7	4	3	3	2
73	60	29	13	7	5	3	2
69	69	52	29	12	7	4	3
62	66	66	59	27	11	7	3
66	60	60	66	62	25	8	4
58	54	56	62	74	42	13	6
49	49	51	54	58	50	25	9

*Original image*

4	min
7	
10	
11	
22	median
29	
38	
60	
73	max

*Sort and rank*

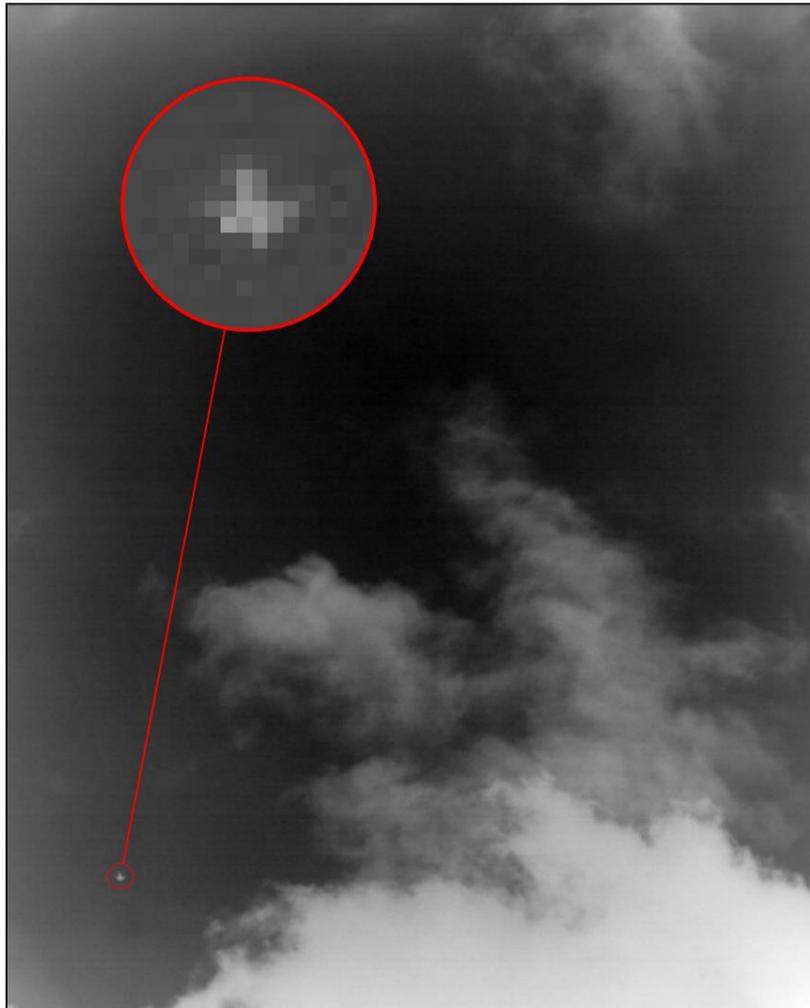
	22						

*Median image*

Quelle: [https://neubias.github.io/training-resources/median\\_filter/index.html](https://neubias.github.io/training-resources/median_filter/index.html)

# Median filter for noise reduction

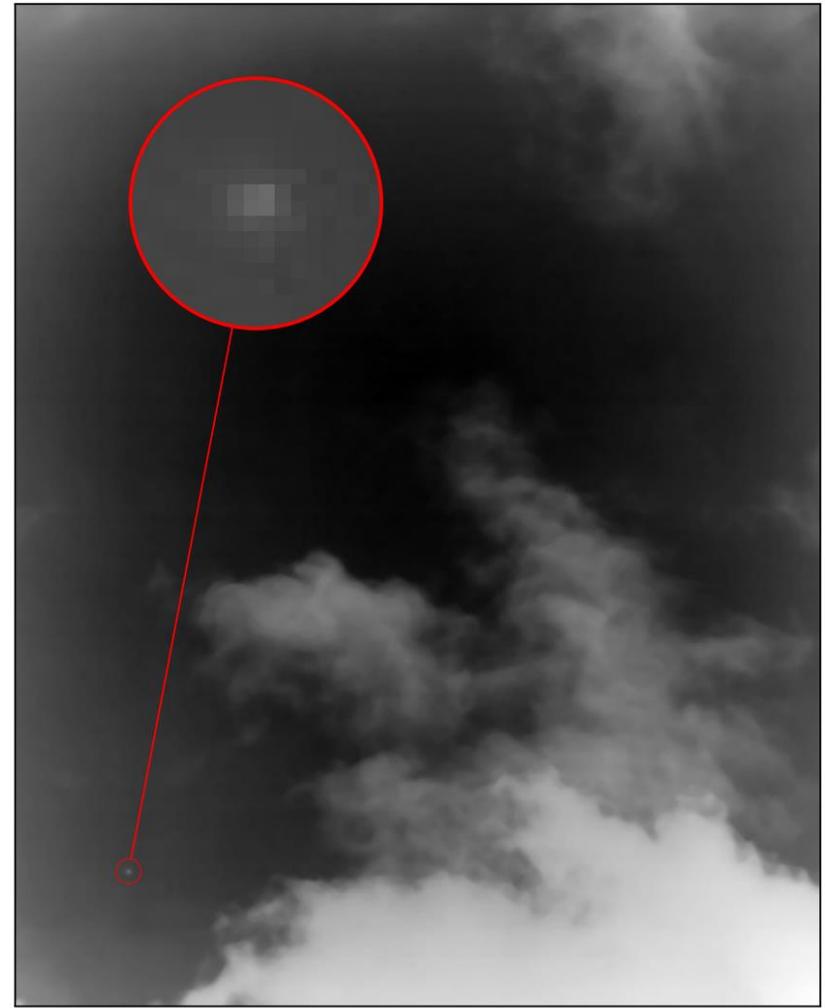
Original image



Median-Filter

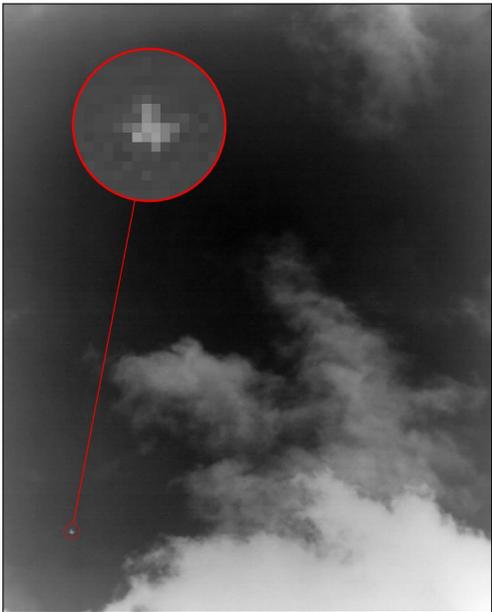


Image after 5x5 median filtering



# Median filter for background subtraction

Original image



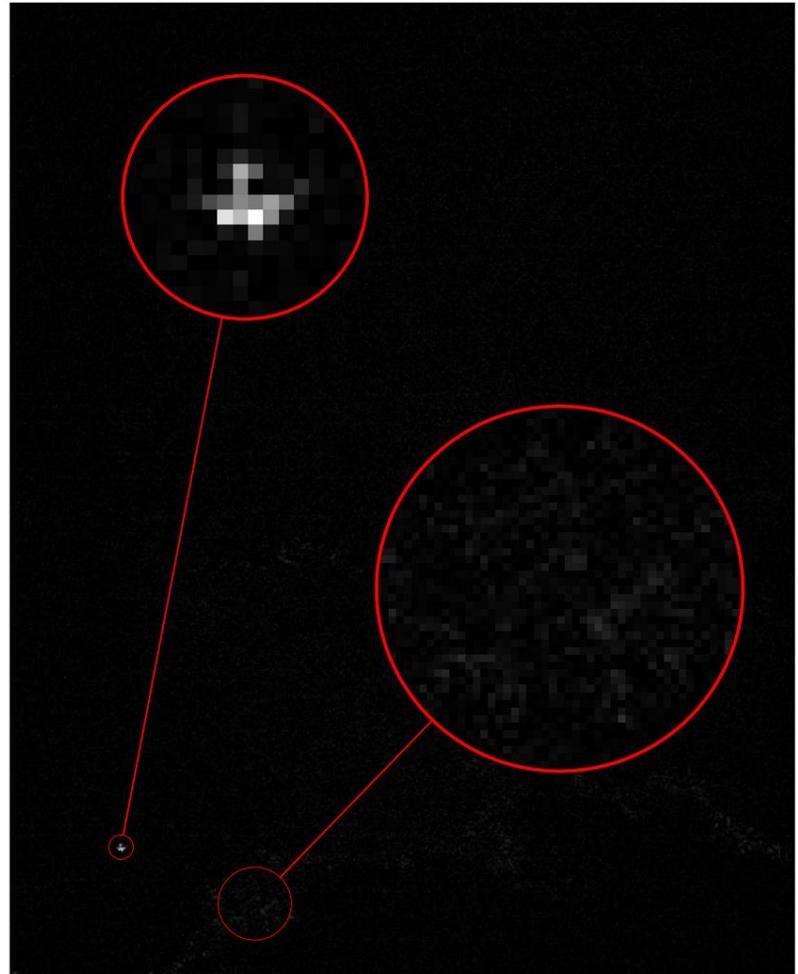
Background



-

=

Aircraft (& noise)

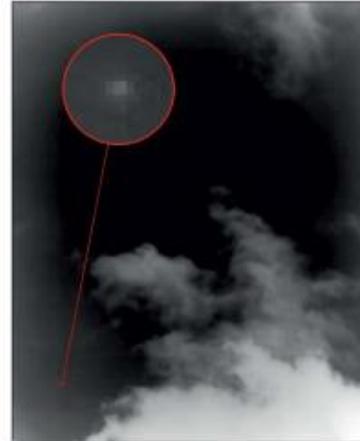


# Proposed algorithm

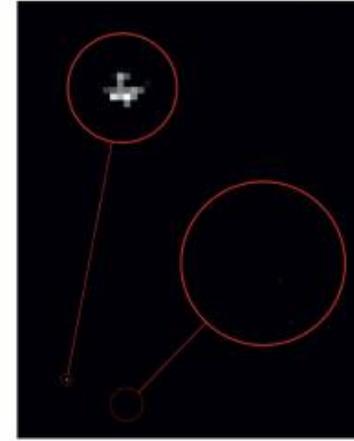
(A) Original image



(B) Median filtered image



(C) Subtracted image



Step 1:  
Median  
Filtering

Step 2:  
Image  
Substraction

Step 3:  
Thresholding  $\downarrow$   $T = \bar{x} + k\sigma$

(D) Binarized image



Step 5:  
Classification

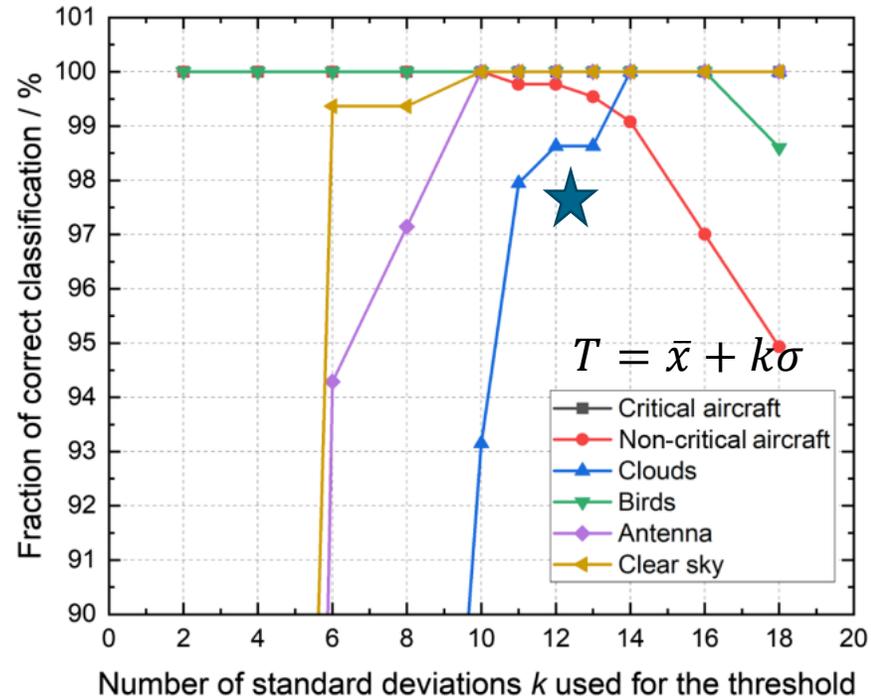
'Safe' or 'unsafe':  
Unsafe if any  
positive pixel in  
image

Step 4:  
Hit or miss  
transform

Binarized image  
without single pixel  
detections

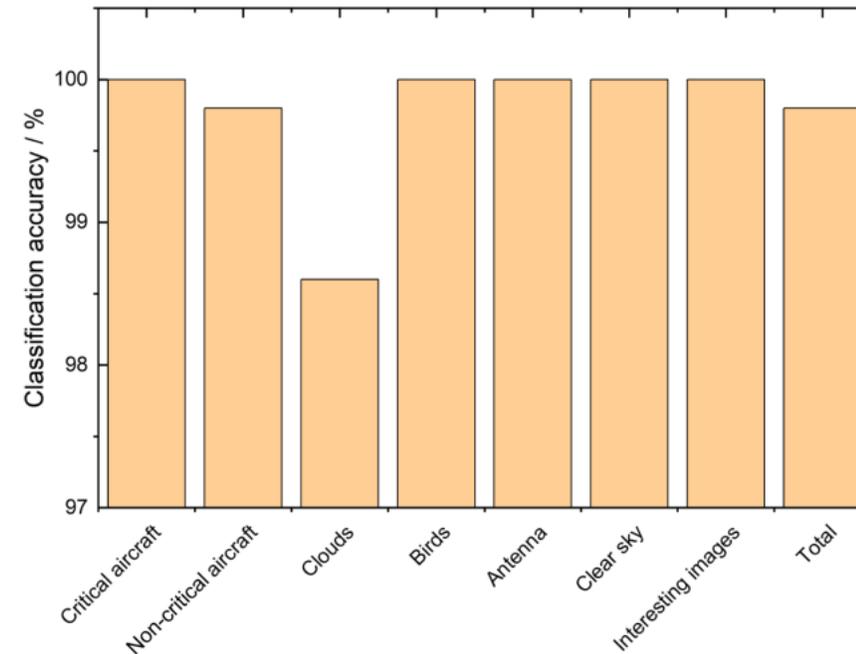
-1	-1	-1
-1	1	-1
-1	-1	-1

## Threshold optimization:



**Fig. 4.** Fraction of correct classifications as a function (“safe” or “unsafe”) of the optimized parameter  $k$  for the different image categories.

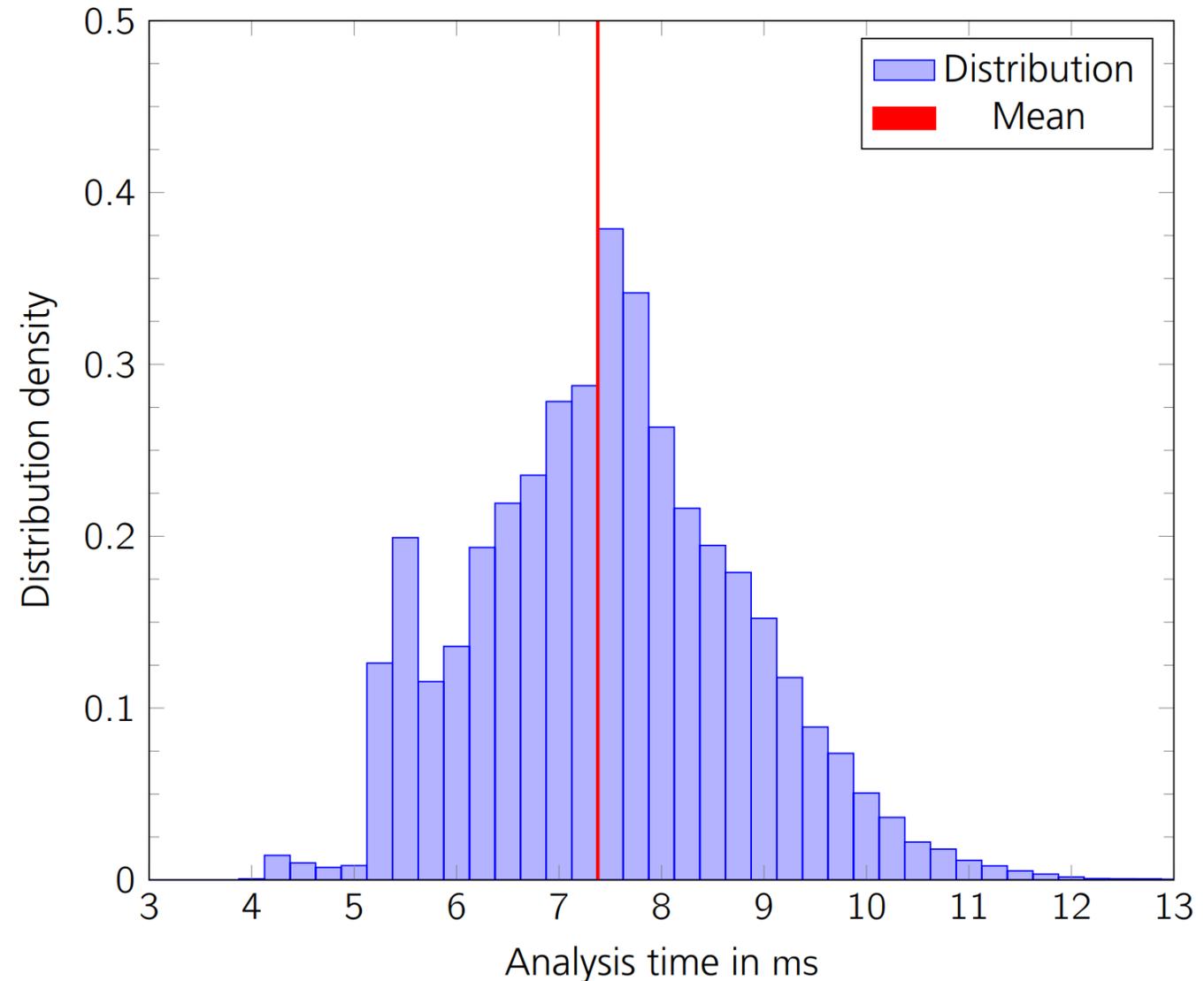
## Classification with optimized threshold:



**Fig. 5.** Results of classification accuracy (safe/unsafe) for the proposed image processing algorithm with  $k = 12$ .

# Speed

- Image analysis takes ~7ms on a standard PC



# Limitations of this work



- No helicopters, hot air balloons, gliders in dataset  
→ detection is likely but untested
- No detection of objects „behind“ clouds
- Detection only works in front of a sky background
- Algorithm only tested at one place (Stuttgart/Germany)

# Further reading



<https://doi.org/10.1364/AO.529222>

## Algorithm for detecting airborne objects with a thermal infrared camera to ensure a safe operation of laser-optical ground stations

JAKOB STEURER,<sup>1</sup> NILS BARTELS,<sup>1,\*</sup>  DANIEL HAMPF,<sup>2</sup> FELICITAS NIEBLER,<sup>1</sup>  
TRISTAN MEYER,<sup>1</sup> WOLFGANG RIEDE,<sup>1</sup> AND THOMAS DEKORSY<sup>1</sup> 

<sup>1</sup>German Aerospace Center (DLR), Institute of Technical Physics, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany

<sup>2</sup>DiGOS Potsdam GmbH, Telegrafenberg 1, 14473 Potsdam, Germany

\*[nils.bartels@dlr.de](mailto:nils.bartels@dlr.de)

Received 6 May 2024; revised 25 July 2024; accepted 26 July 2024; posted 26 July 2024; published 13 August 2024

- Article contains source code (Python) and link to repository with raw images (classified dataset)
- Anyone is free to use the algorithm, feedback or suggestions are appreciated

# **ACES Mission Update: Ground Station Requirements**

**<https://www.asg.ed.tum.de/fesg/european-laser-time-transfer-elt/>**

[elt@sgd.lrg.tum.de](mailto:elt@sgd.lrg.tum.de)

# Clock Metrology: Preparation of ground stations for ELT tracking

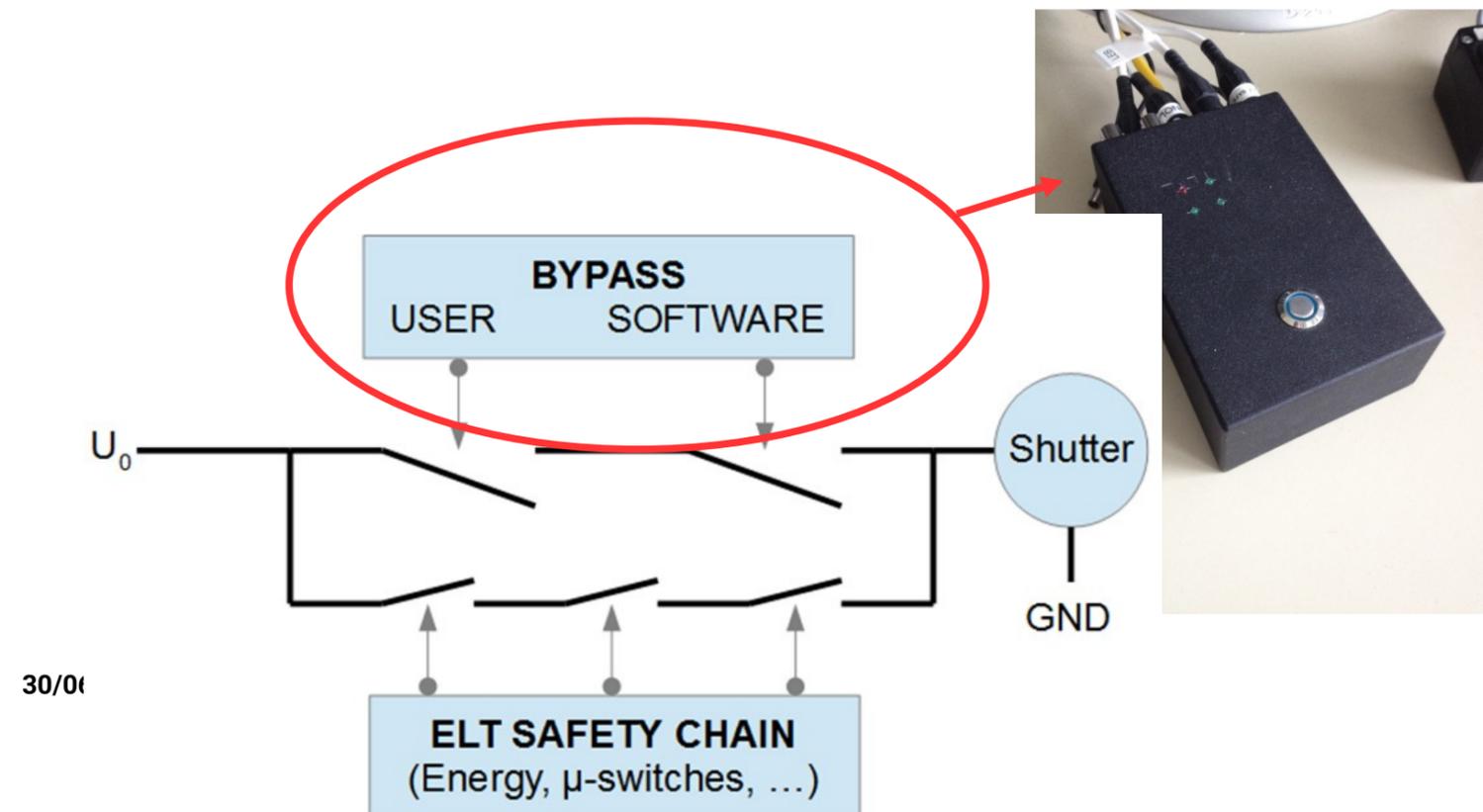


The requirements for participating stations are summarized in the **Technical Note**

- Spreadsheet for Laser Safety ELT, **go/nogo** flag published by EDC - validity 5 minutes
- Stations which non-eye save operation
  - Safe switching between std. **SLR-** and **ELT-mode**
- Short laser pulses with a wavelength of 532 +/-0.1 nm, **capability to hit ELT gate window.**  
The additional header for transponder: offset and drift of the on-board clock

$$t_{UTC(k)} = t_{ACES} + (t_{ACES} - t_0) \cdot 10^{-15} \cdot drift + offset,$$

- ELT calibration, **Questionnaire for Stations**
- Clocks (H-Maser / Cs / Opt. clocks)
- Ranging data files: full-rate (fr2) and all laser-fire times (ff2)



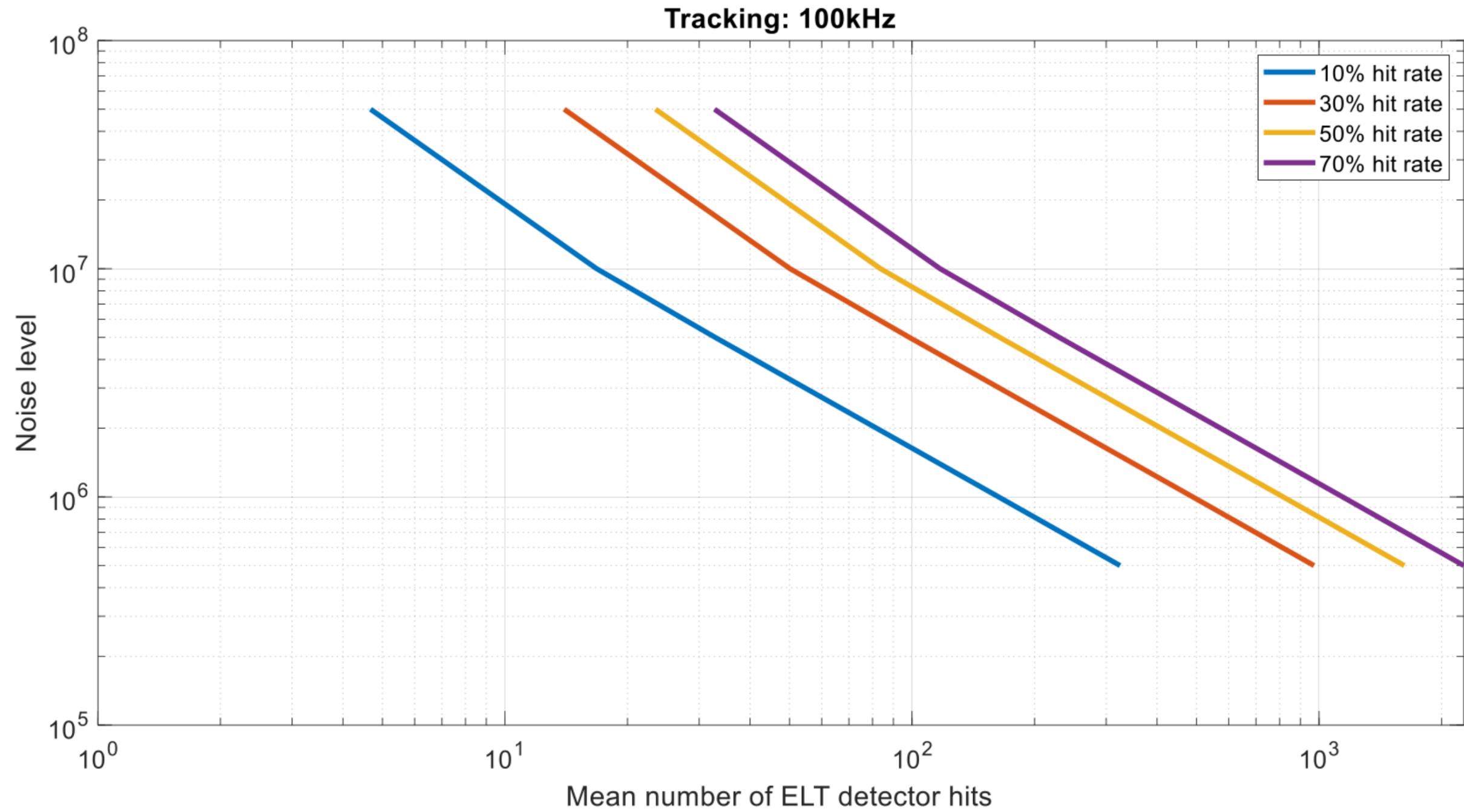
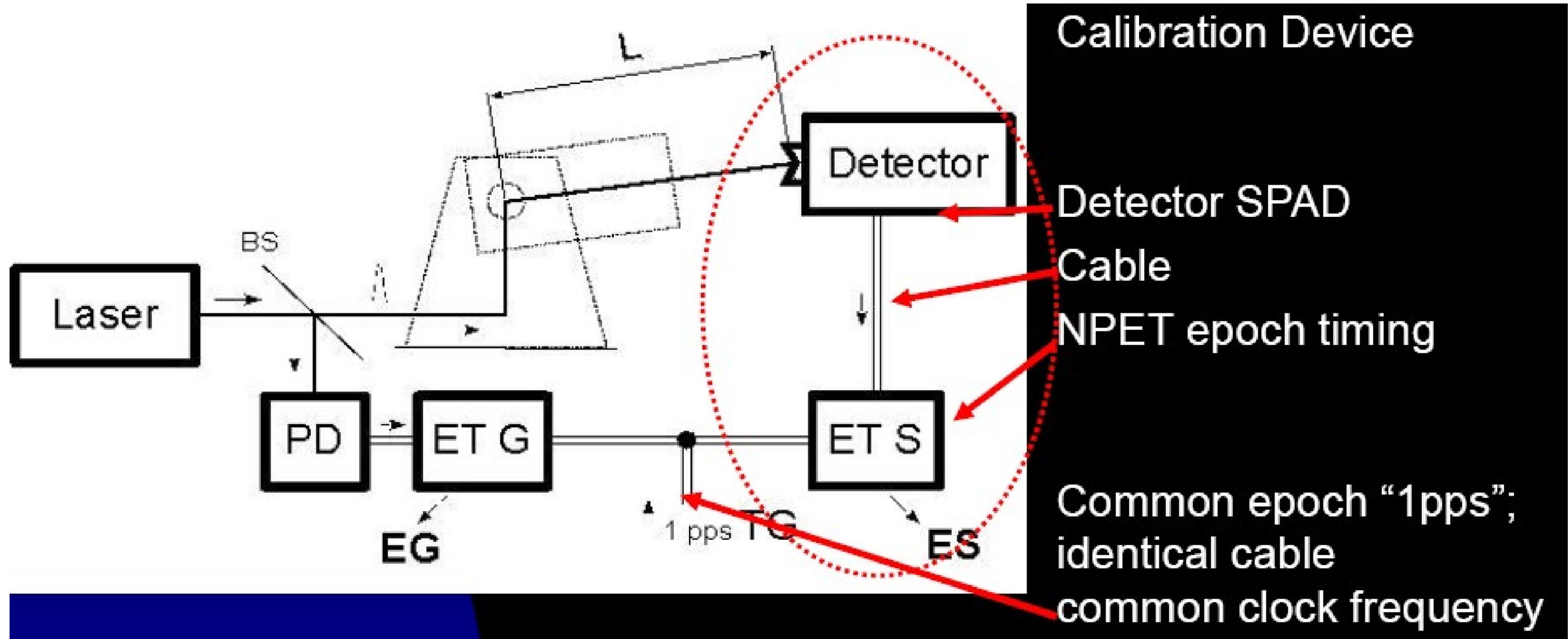
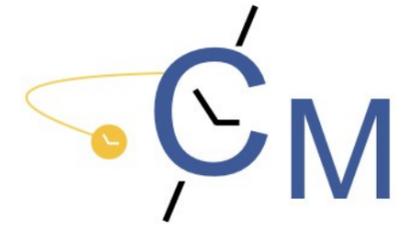
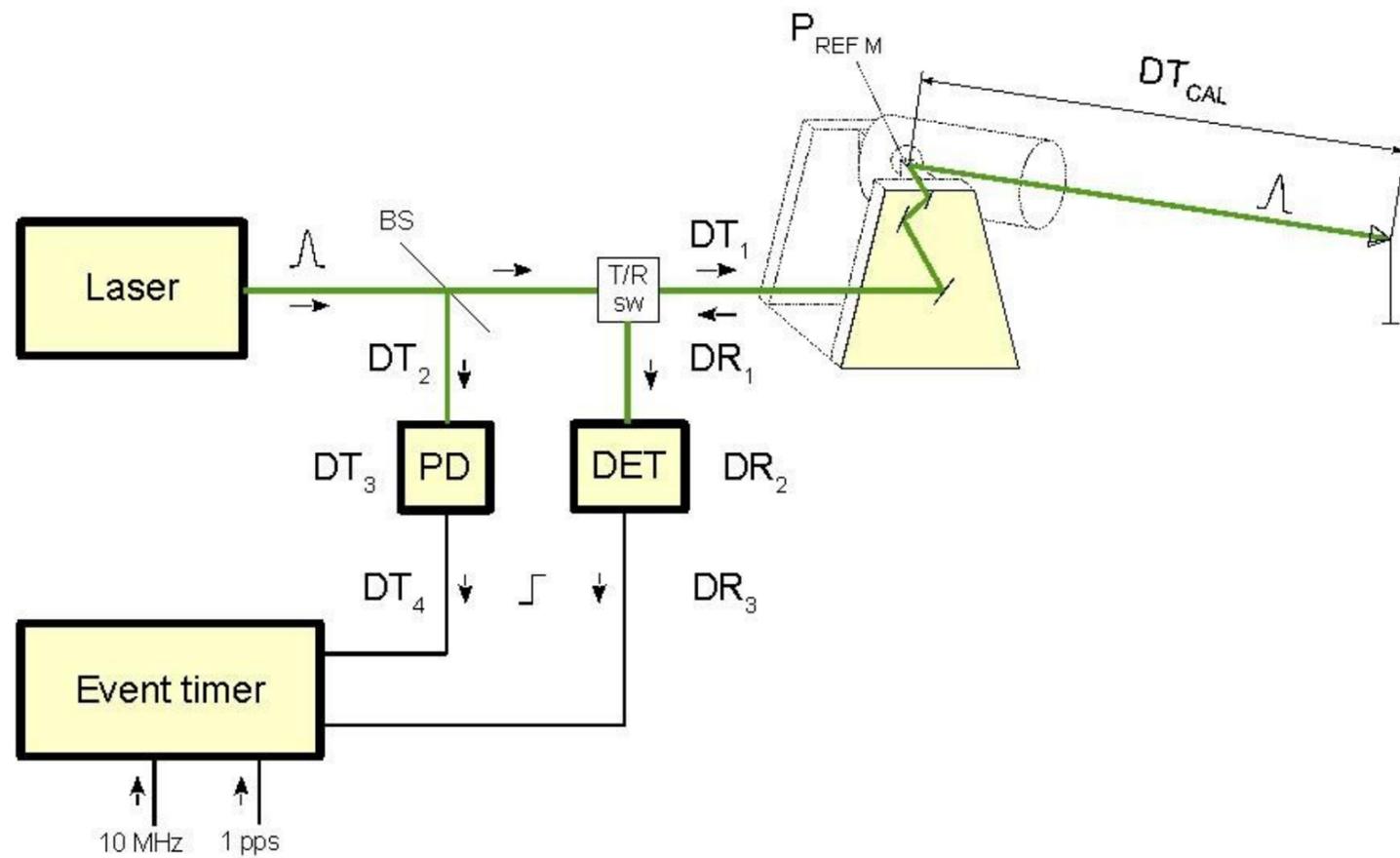


Figure 10: Mean number of ELT detector hit for 100 kHz tracking w.r.t. the noise level.

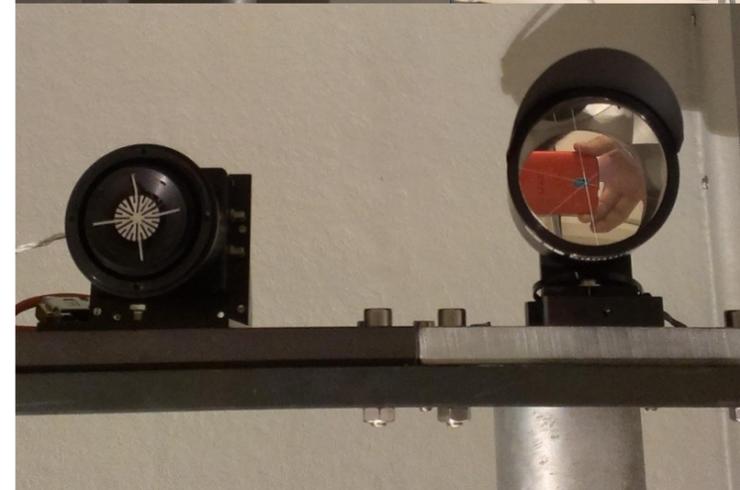
# Clock Metrology: ELT calibration



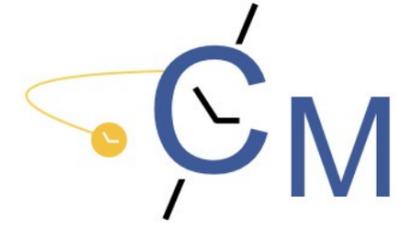
# SLR system delays - simplified



Although the individual contributors  $DT_i$  and  $DR_i$  might be identified and measured (Herstmonceux..) the resulting accuracies of T and R calibration constants would be low using such a measurement scheme.

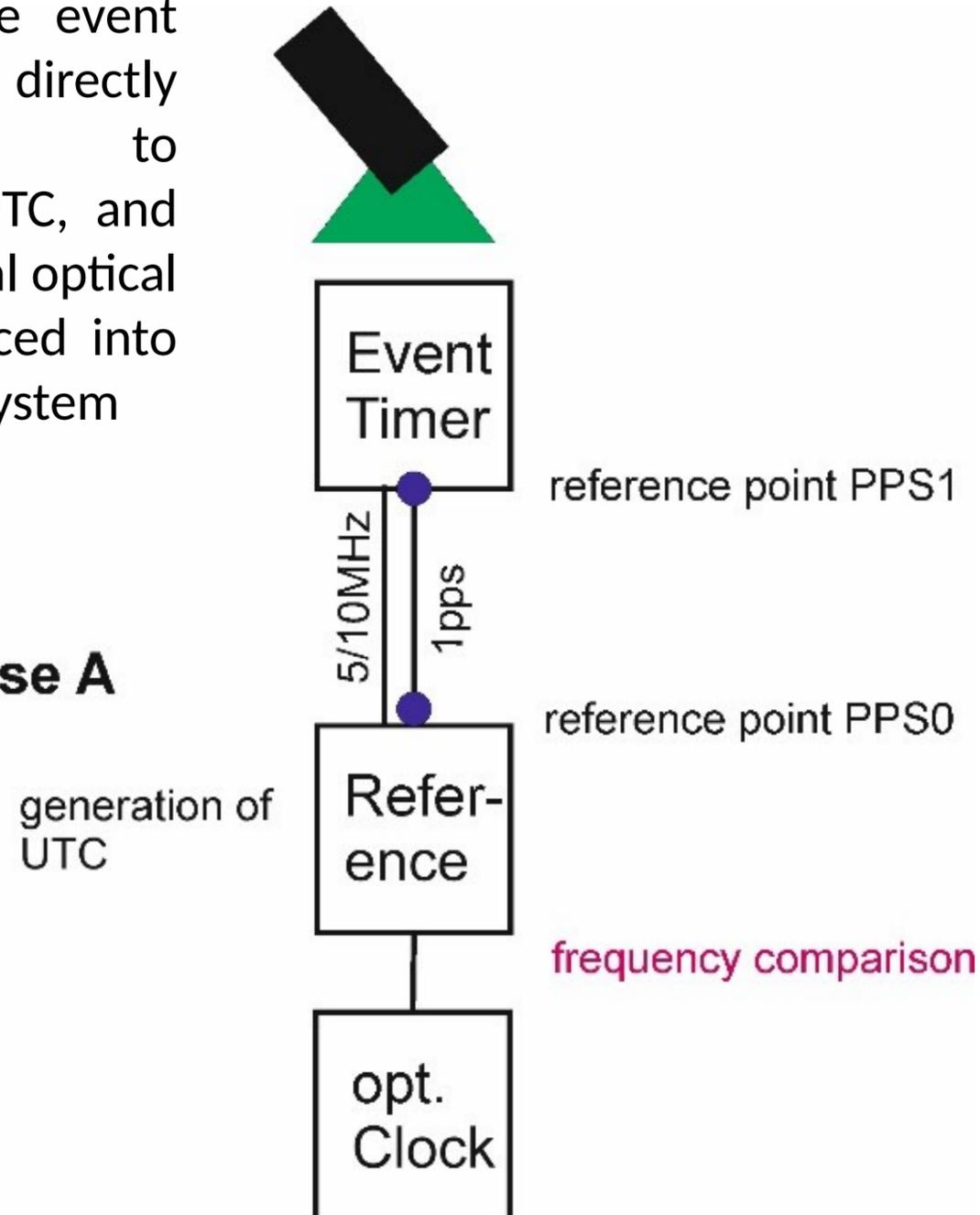


# Clock Status Files



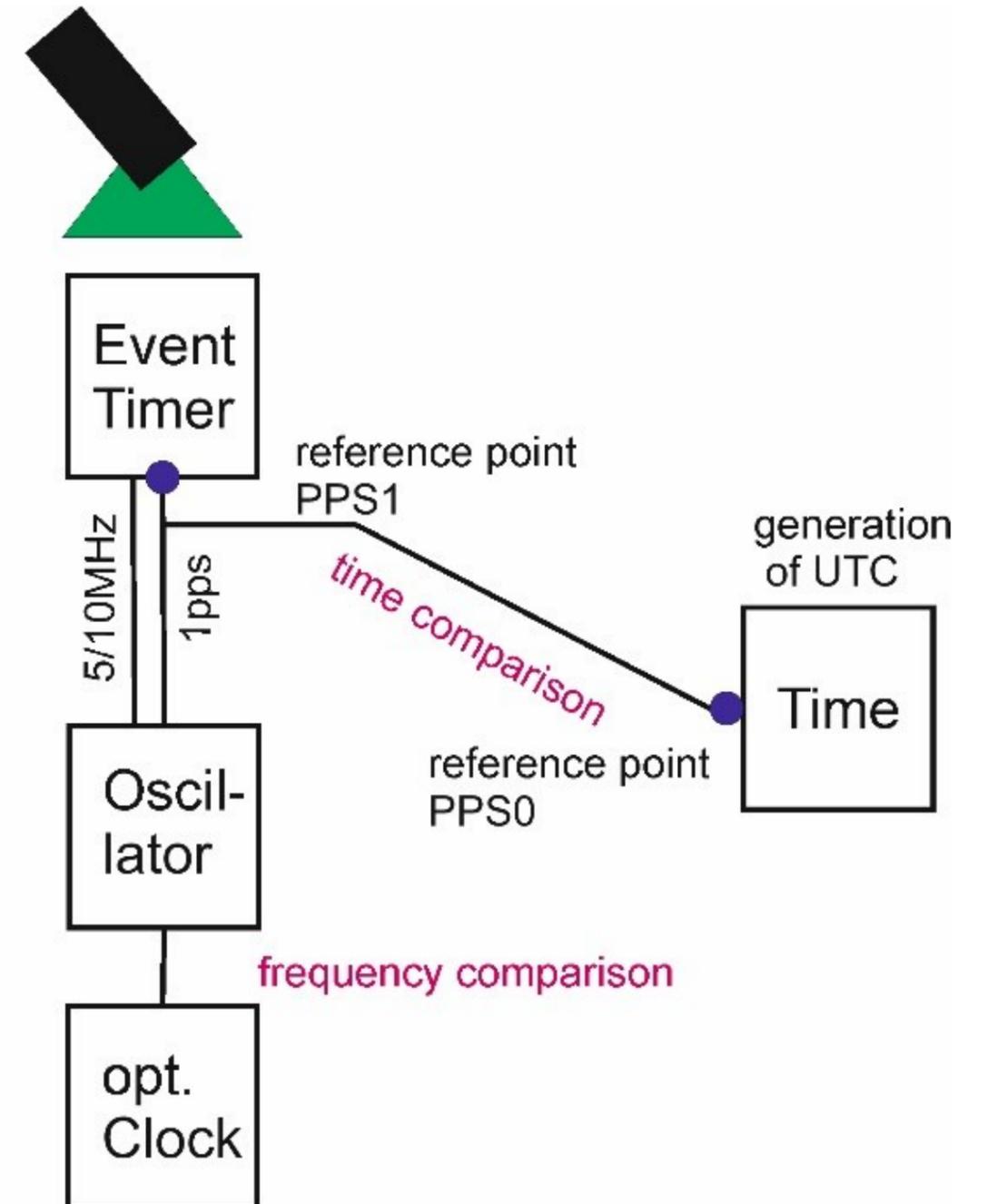
Case A: the event timer is directly connected to reference UTC, and an additional optical clock is placed into the timing system

**Case A**



Case B: the event timer is connected to an oscillator not representing local UTC, and an additional optical clock is placed into the timing system

**Case B**





# The Correlation Between Geodetic Satellite Passes and positioning quantity for ITRF2020

Alexandre Belli<sup>1</sup>, Magda Kuzmicz-Cieslak<sup>2,3</sup>, Frank G Lemoine<sup>4</sup> and Keith D Evans<sup>3</sup>

*(1) Science Systems and Applications, Inc. (SSAI), Lanham, MD, United States,*

*(2) Joint Center for Earth Systems Technology, Baltimore, United States,*

*(3) University of Maryland Baltimore County, GESTAR II, Baltimore, MD, United States,*

*(4) NASA Goddard Space Flight Center, Geodesy and Geophysics Laboratory, Greenbelt, MD, United States*

First presented at the AGU2024, modified for NESC  
January 23<sup>rd</sup>, 2025

# Context



## SLR Stations

43 stations (not observing all the satellites)



## LASER DATA

Number of passes for the 4 satellites weekly generated by the ILRS NASA/UMBC-JCET AC, for each observing stations



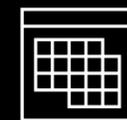
## ITRF2020 DATA

ITRF time series of station residuals (N,E,U) from <https://itrf.ign.fr/en/solutions/itrf2020>



## SATELLITES

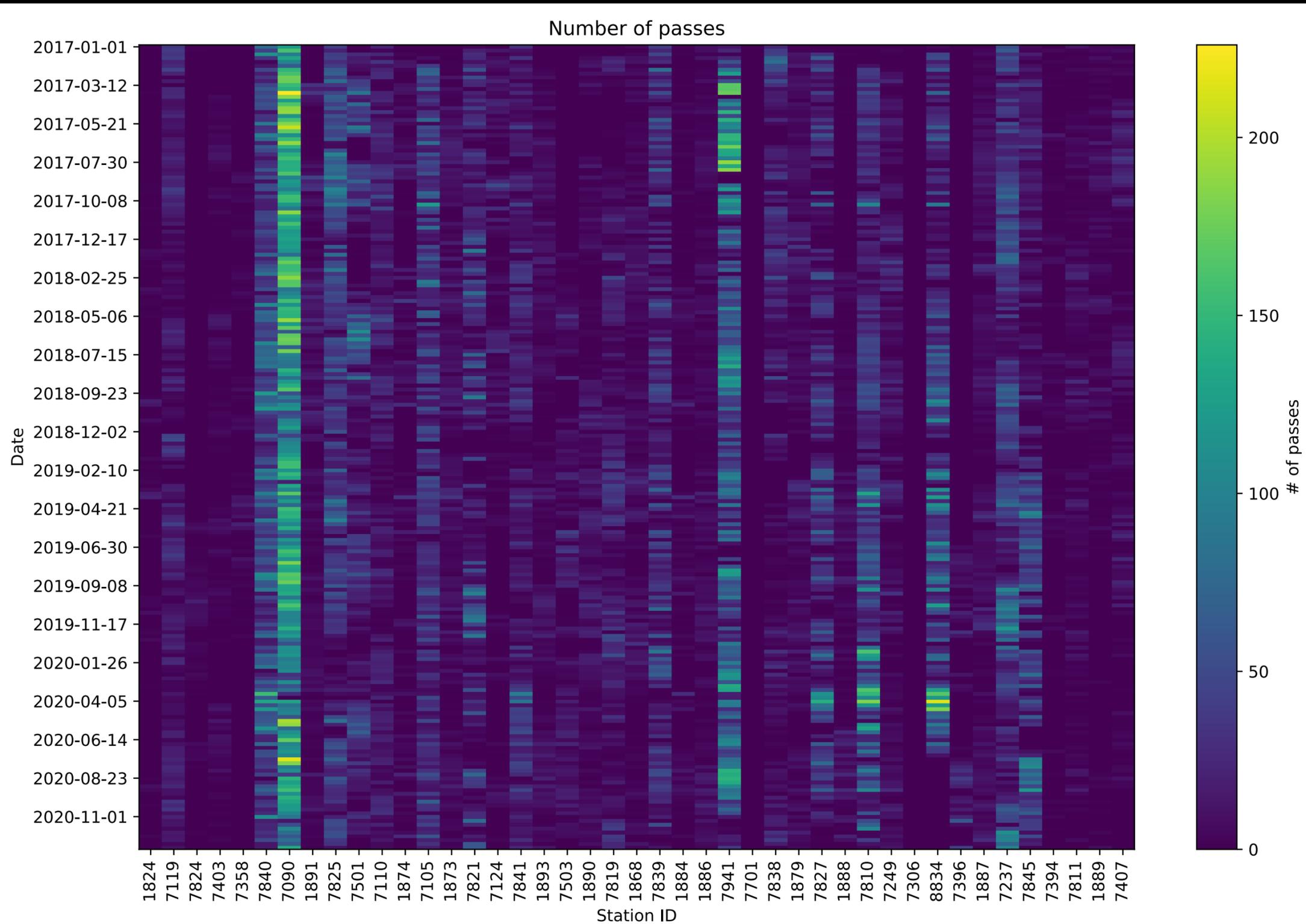
LAGEOS 1 and 2, ETALON 1 and 2



## TIMEFRAME

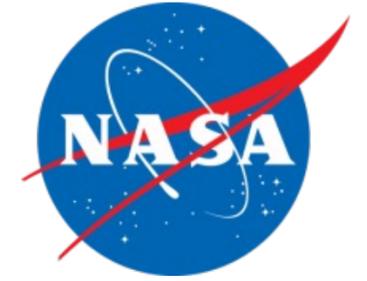
From January 2017 to December 2020  
Weekly data

# # of passes



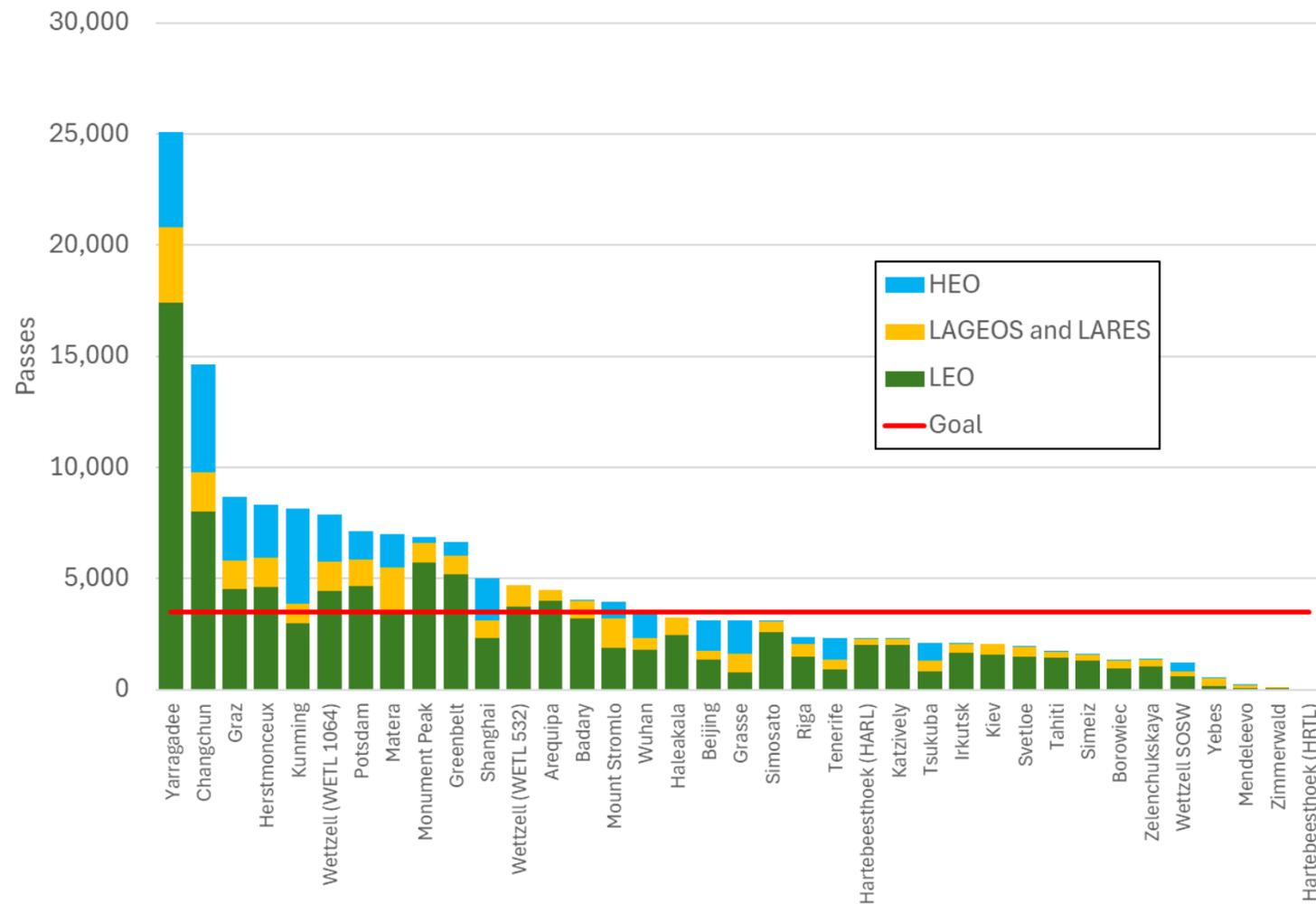


# ILRS 2024 Pass Totals

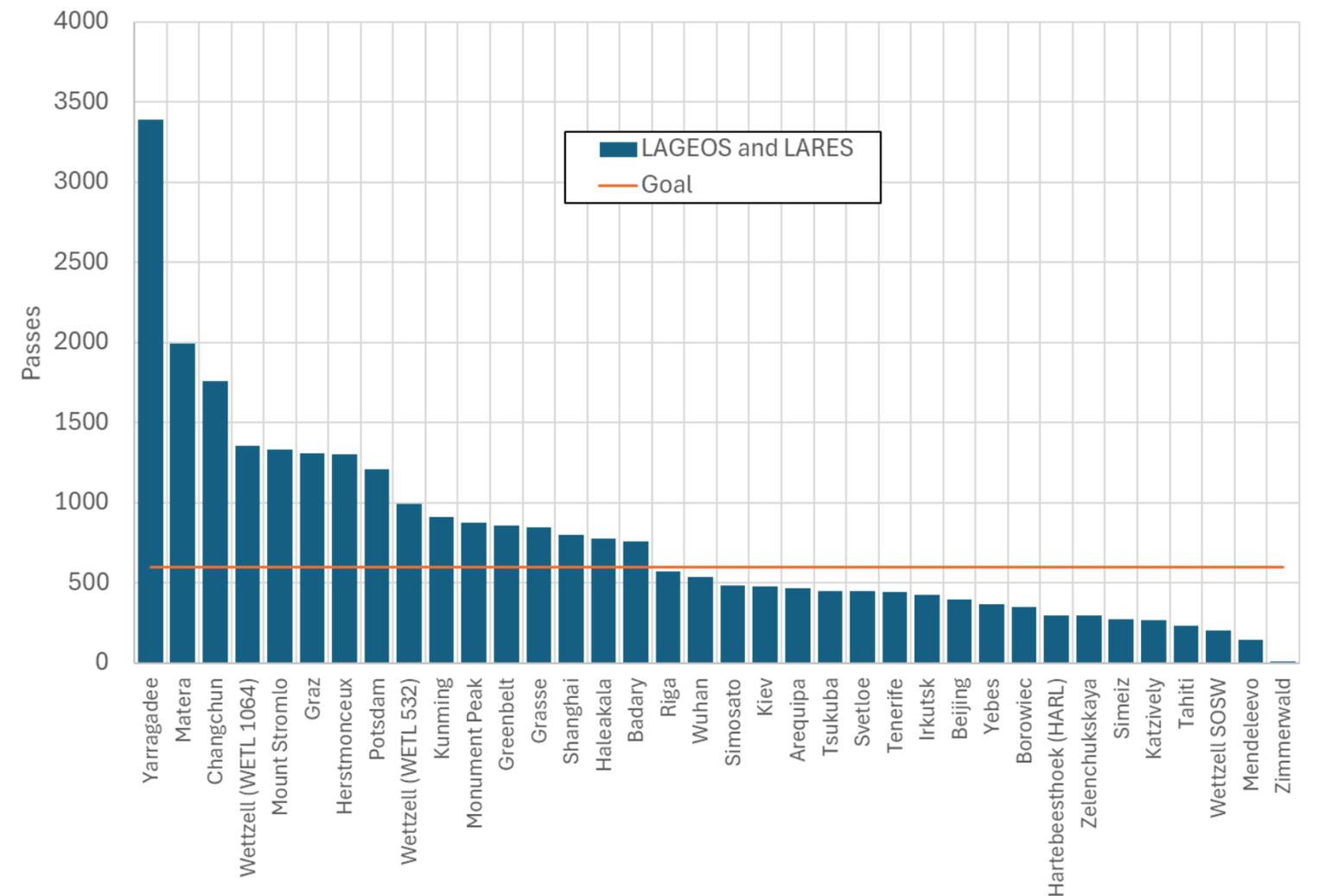


Courtesy of Van Husson

2024 ILRS Tracking Performance



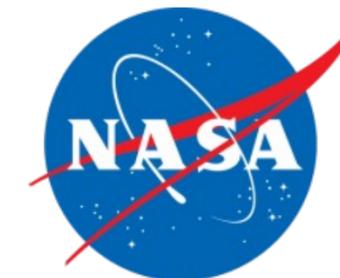
2024 ILRS LAGEOS and LARES Tracking Performance



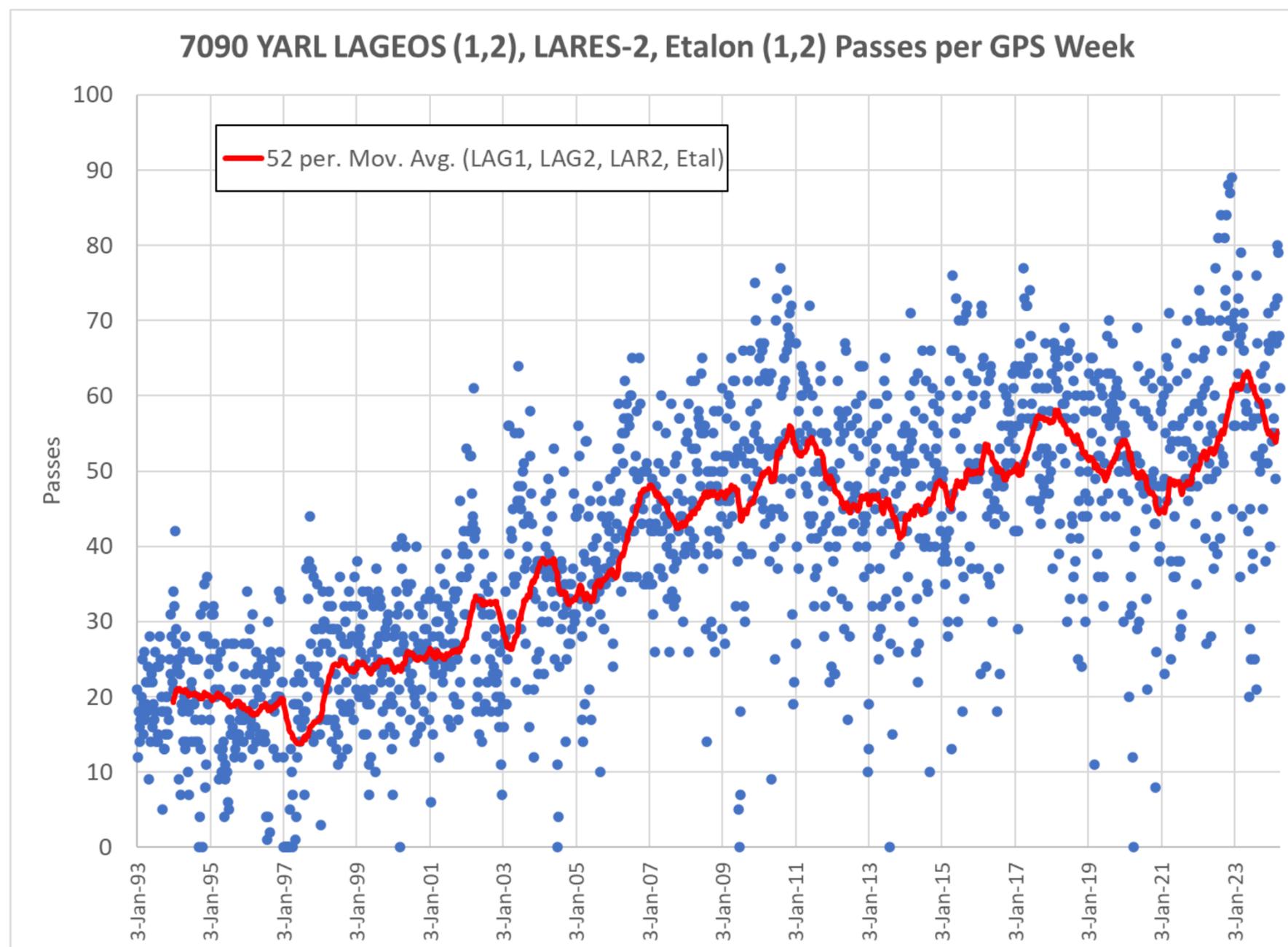
Fourteen different stations met the 3500 pass requirement while fifteen different stations met the LAGEOS/LARES 600 pass requirement. Note: Wetzell (8834) tracked LEO and LAGEOS simultaneously in dual wavelengths, but not HEOs.



# 7090 YARL LAGEOS (1,2), LARES-2, and Etalon passes per GPS Week



Courtesy of Van Husson

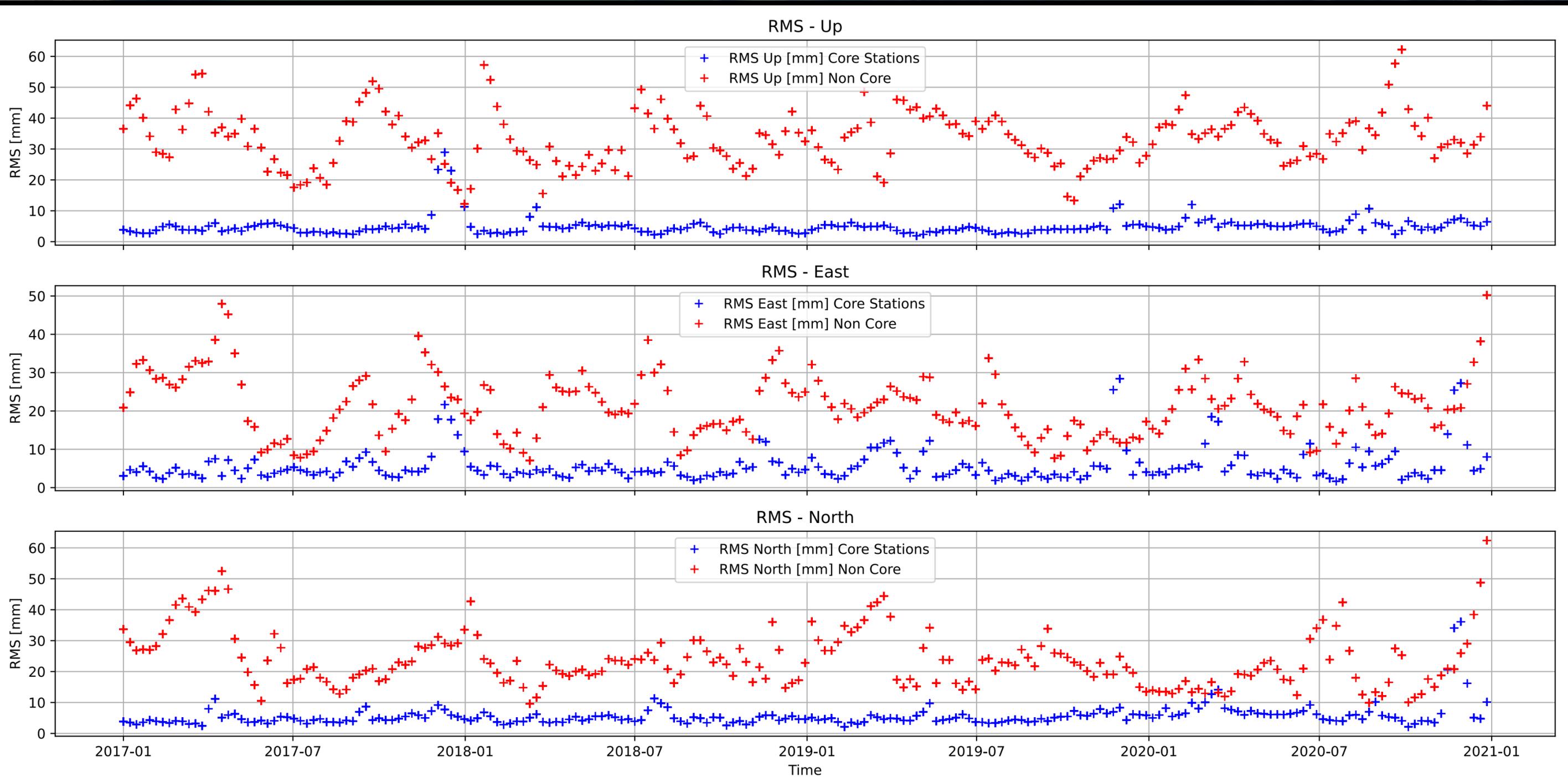


□ The weekly 7090 pass totals do not include LARES, a LEO satellite

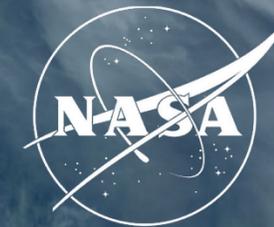
# ITRF2020 residuals for core stations



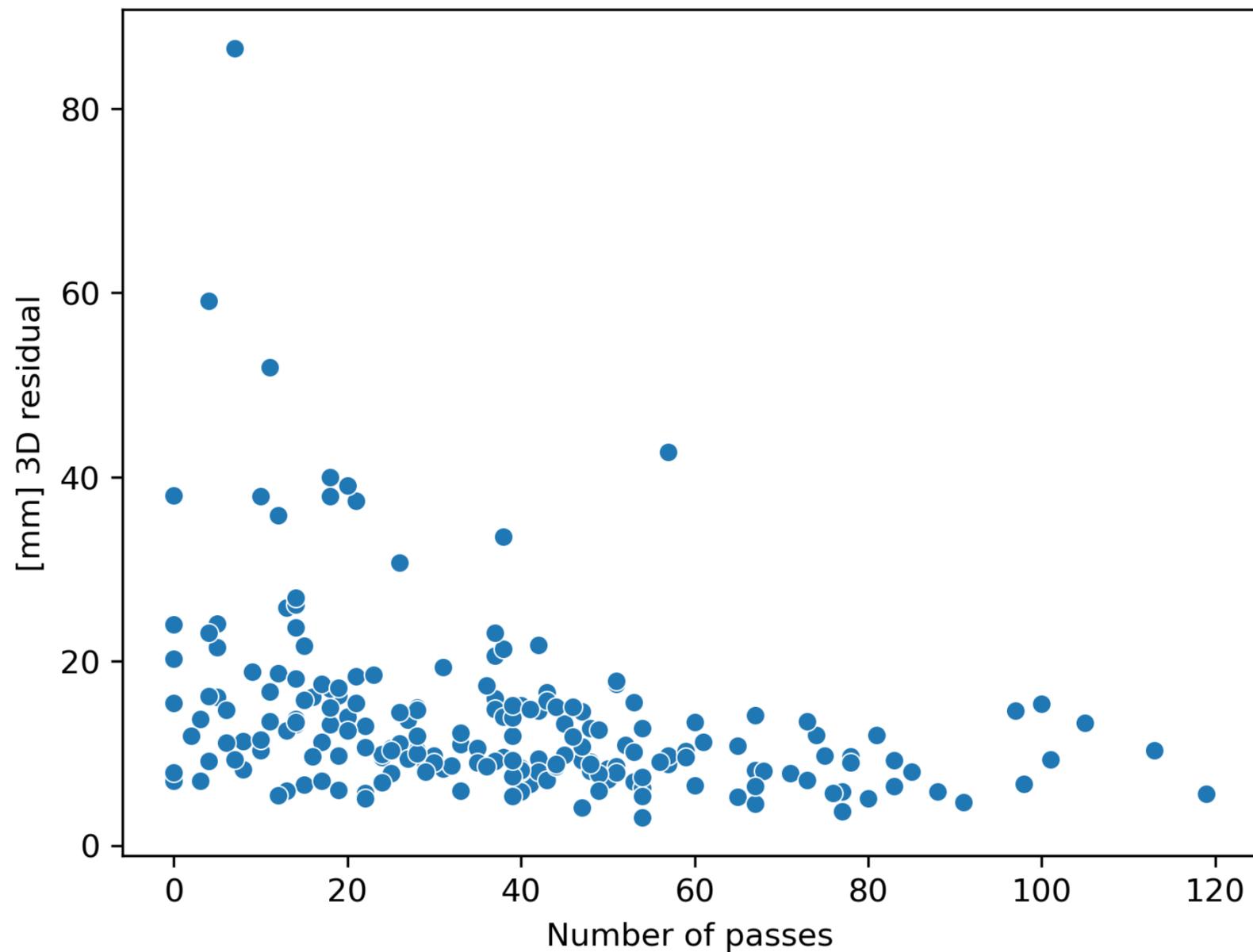
Core Stations = ['7080', '7090', '7105', '7109', '7110', '7119', '7210', '7810', '7825', '7827', '7832', '7835', '7836', '7838', '7839', '7840', '7849', '7941', '8834']



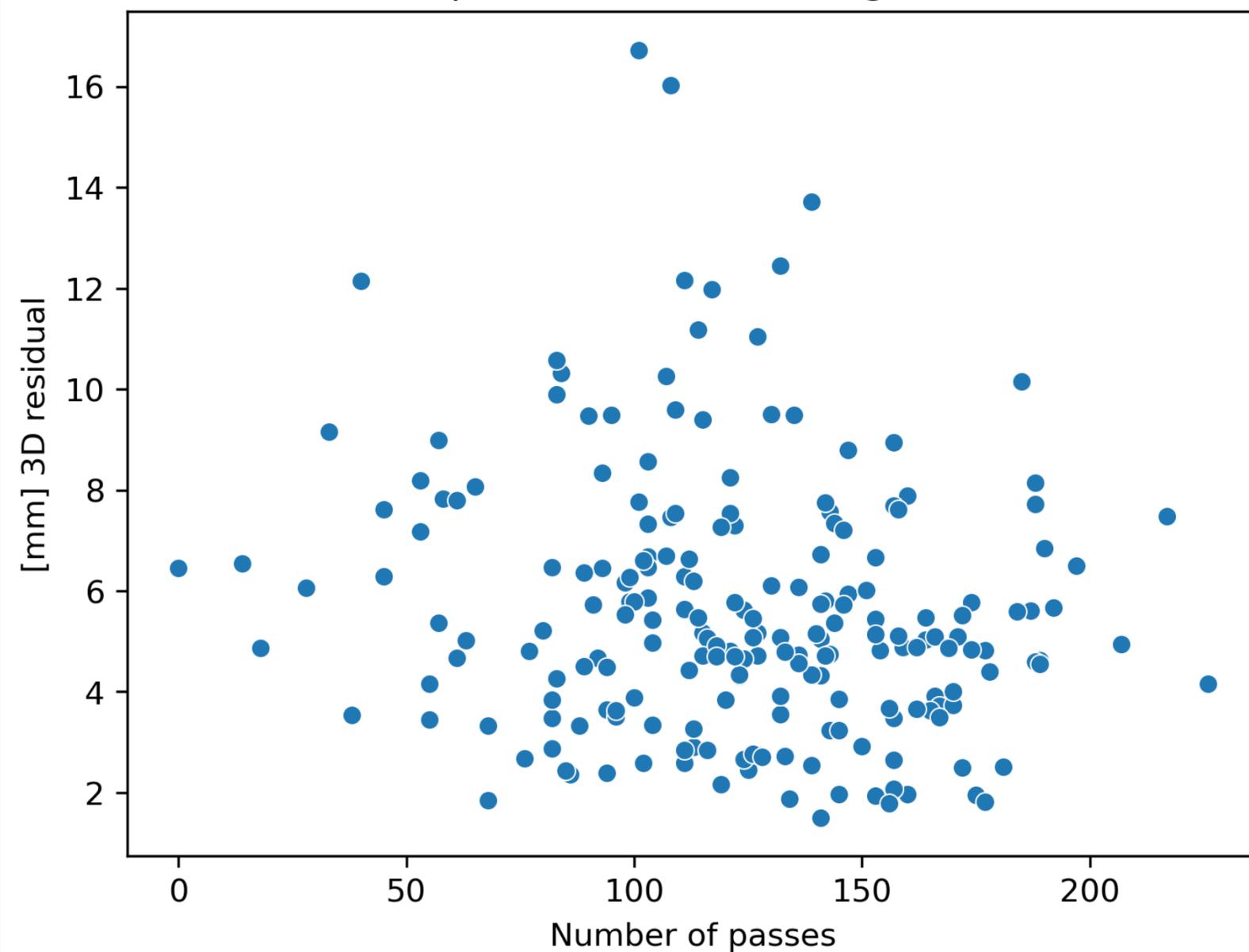
# Results 1 – One station (1/2)



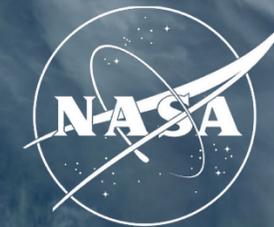
# passes for 7237 Changchun



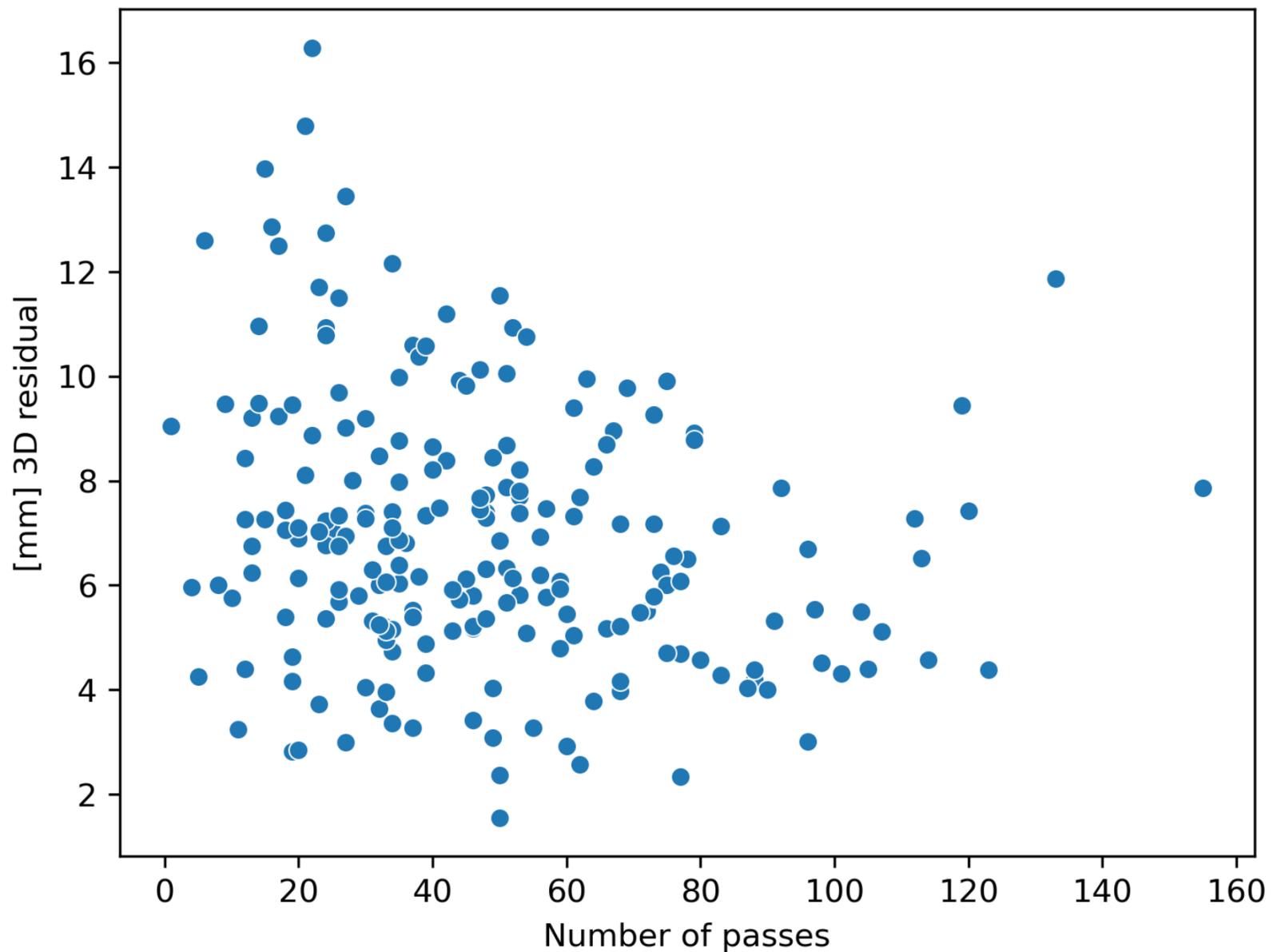
# passes for 7090 Yarragadee



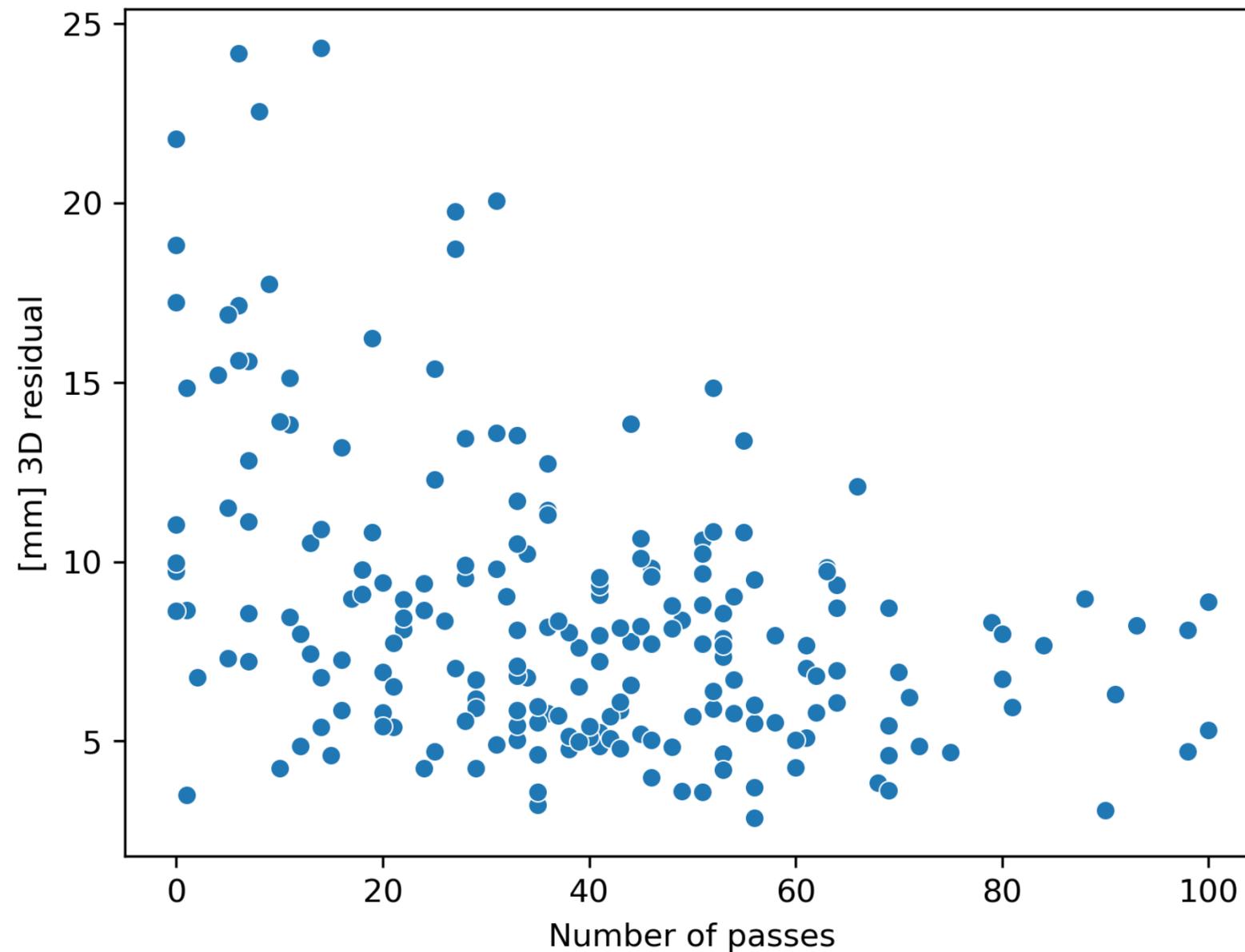
# Results 1 – One station (2/2)



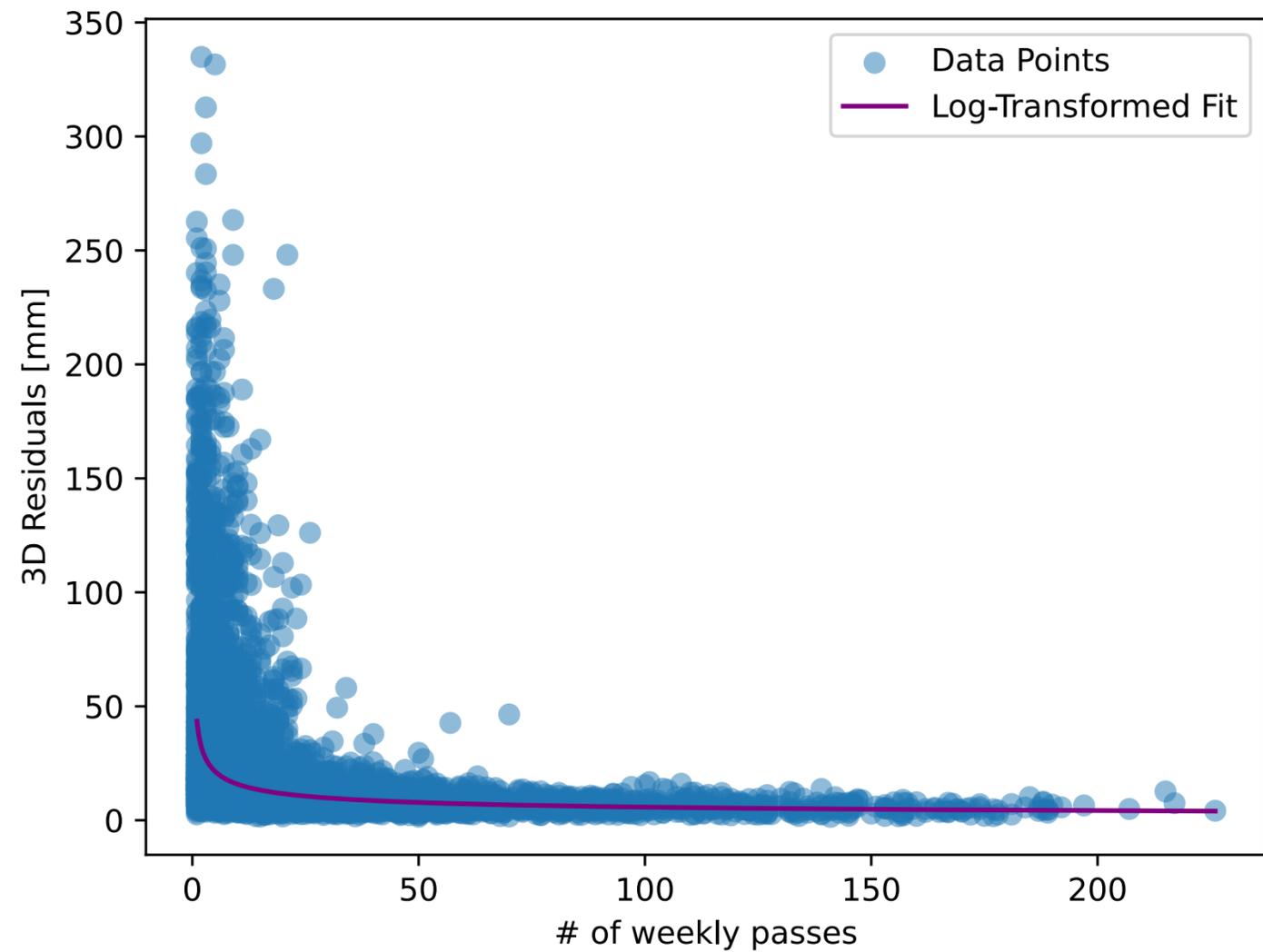
# passes for 7840 Herstmonceux



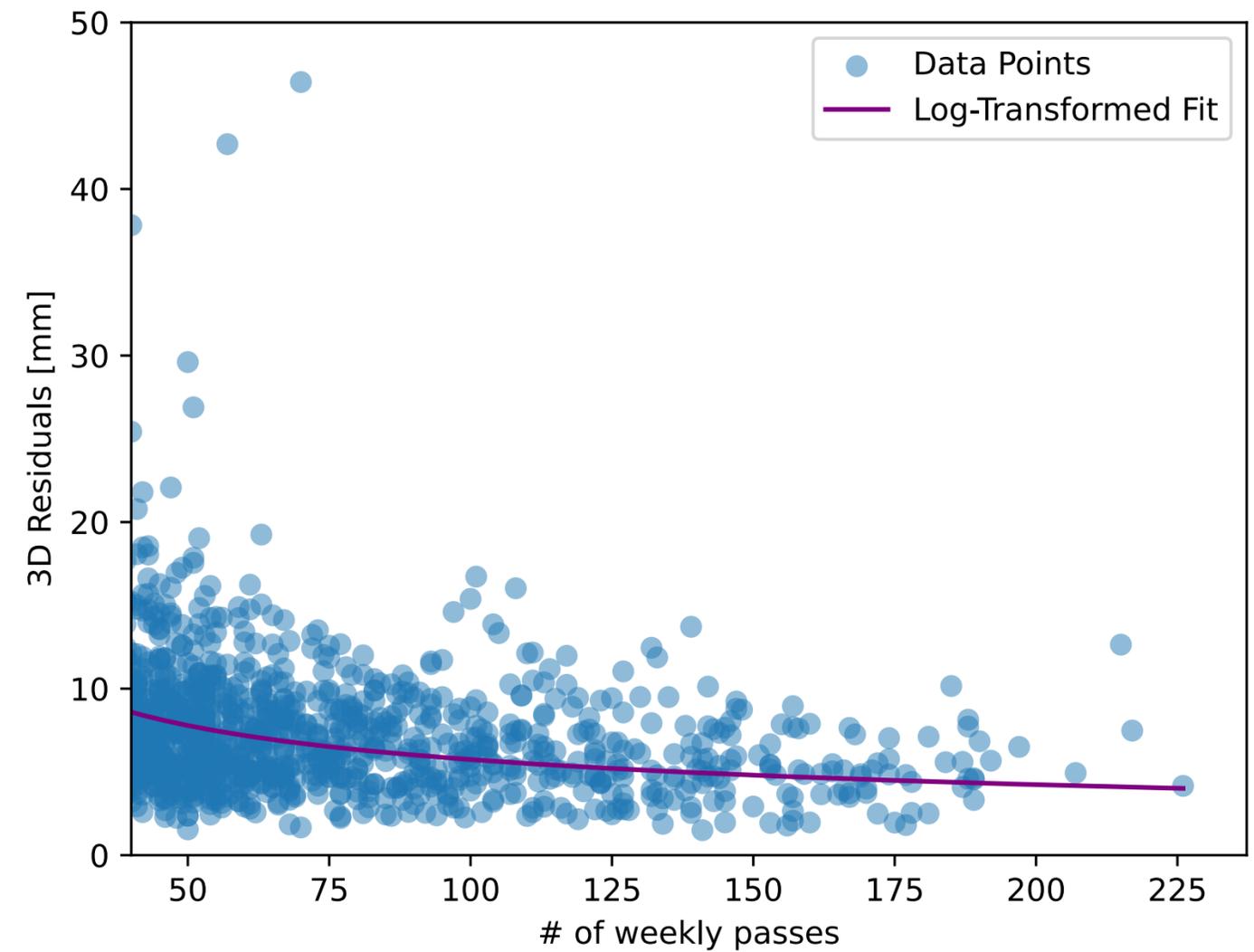
# passes for 7825 Mt. Stromlo



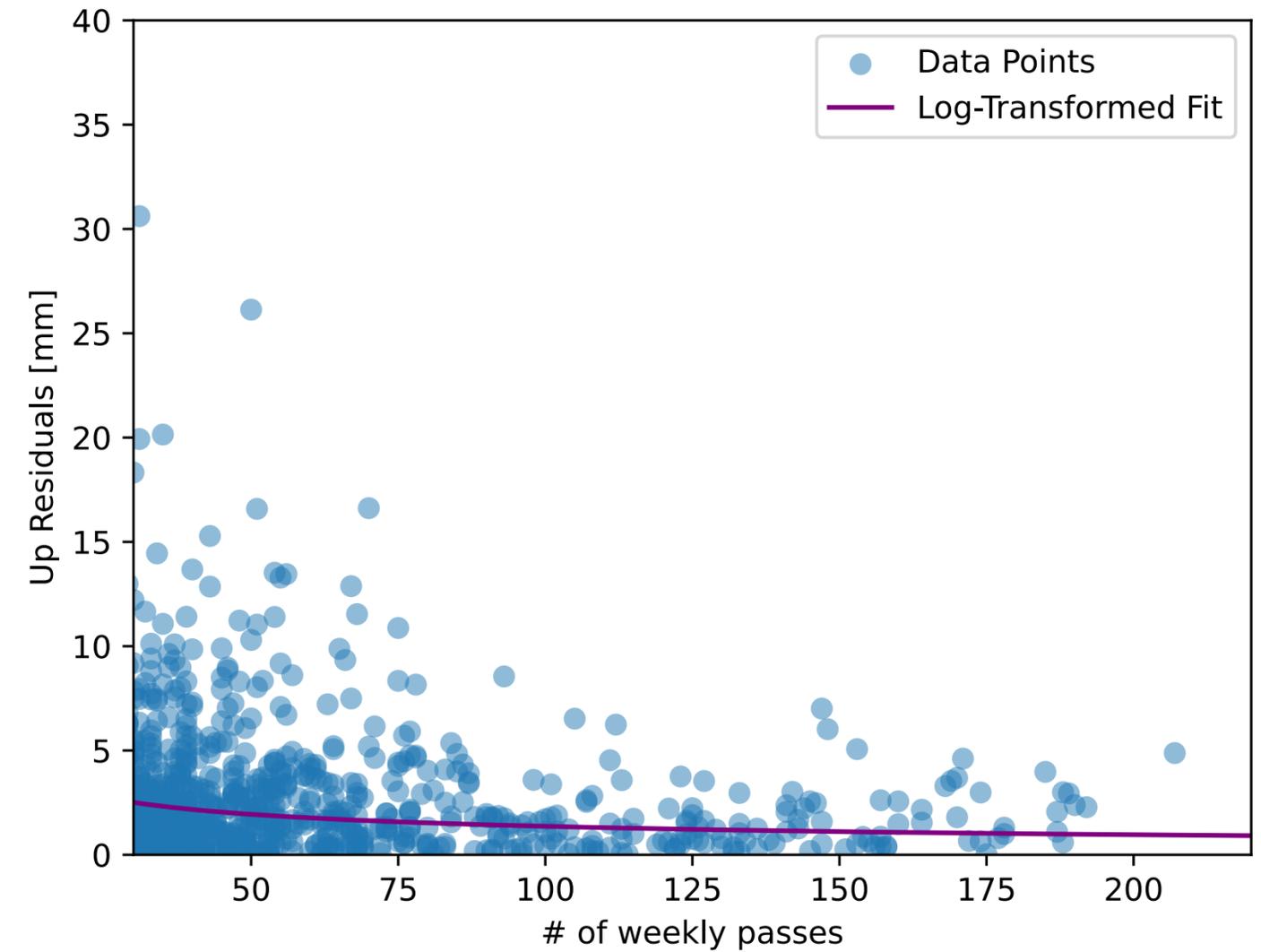
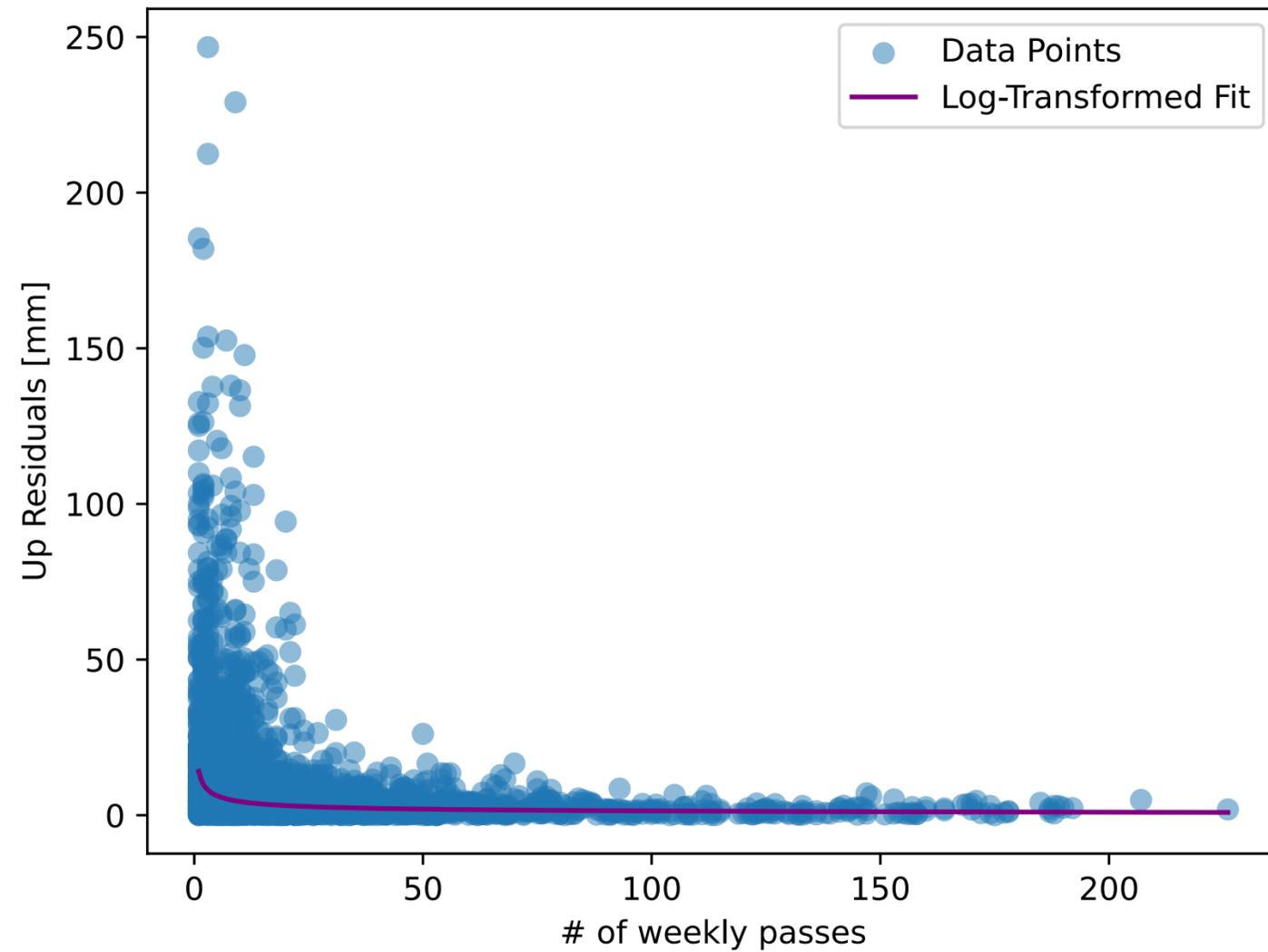
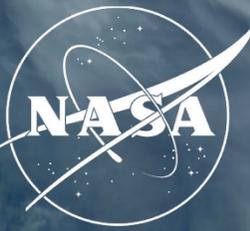
# Results 2 – all stations



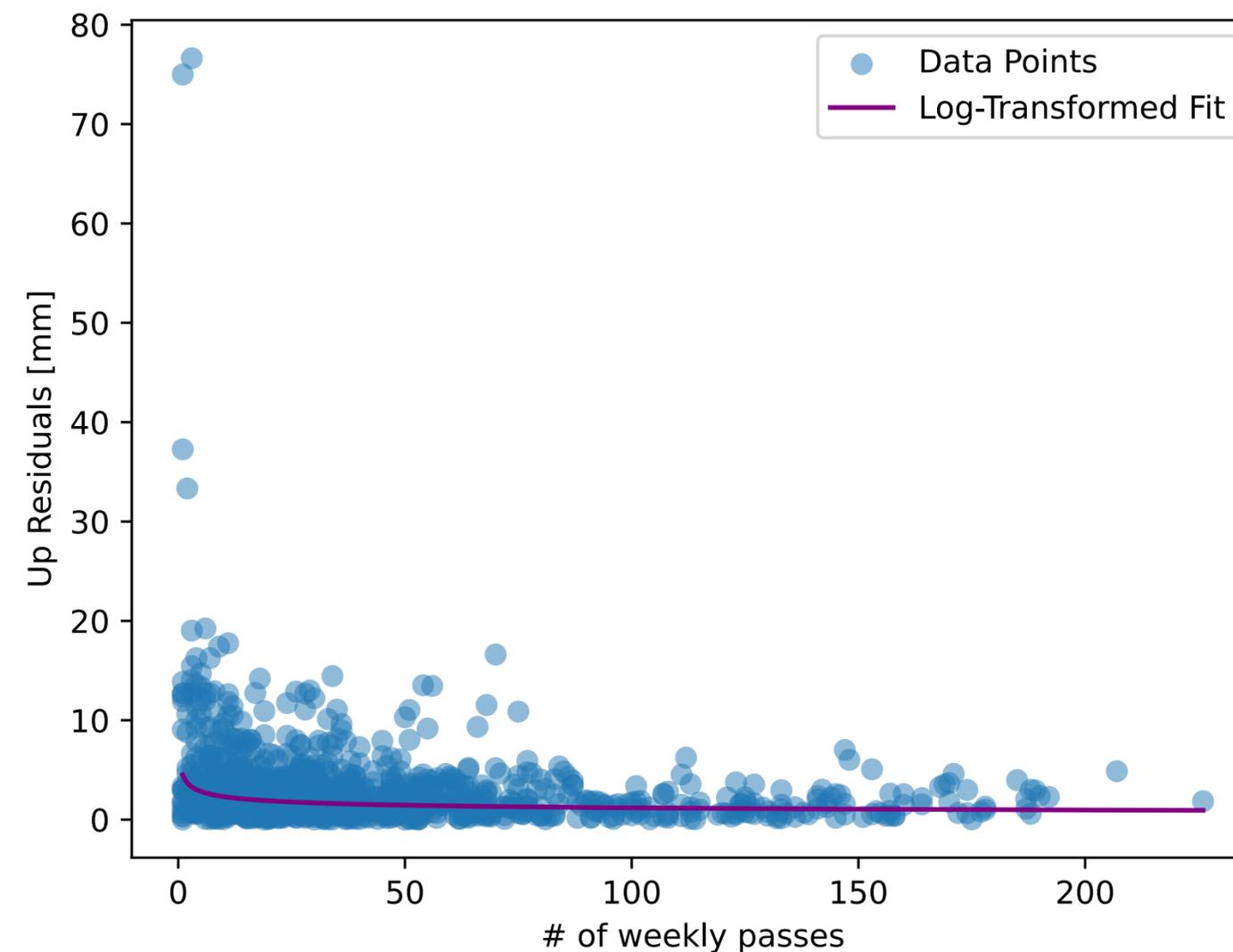
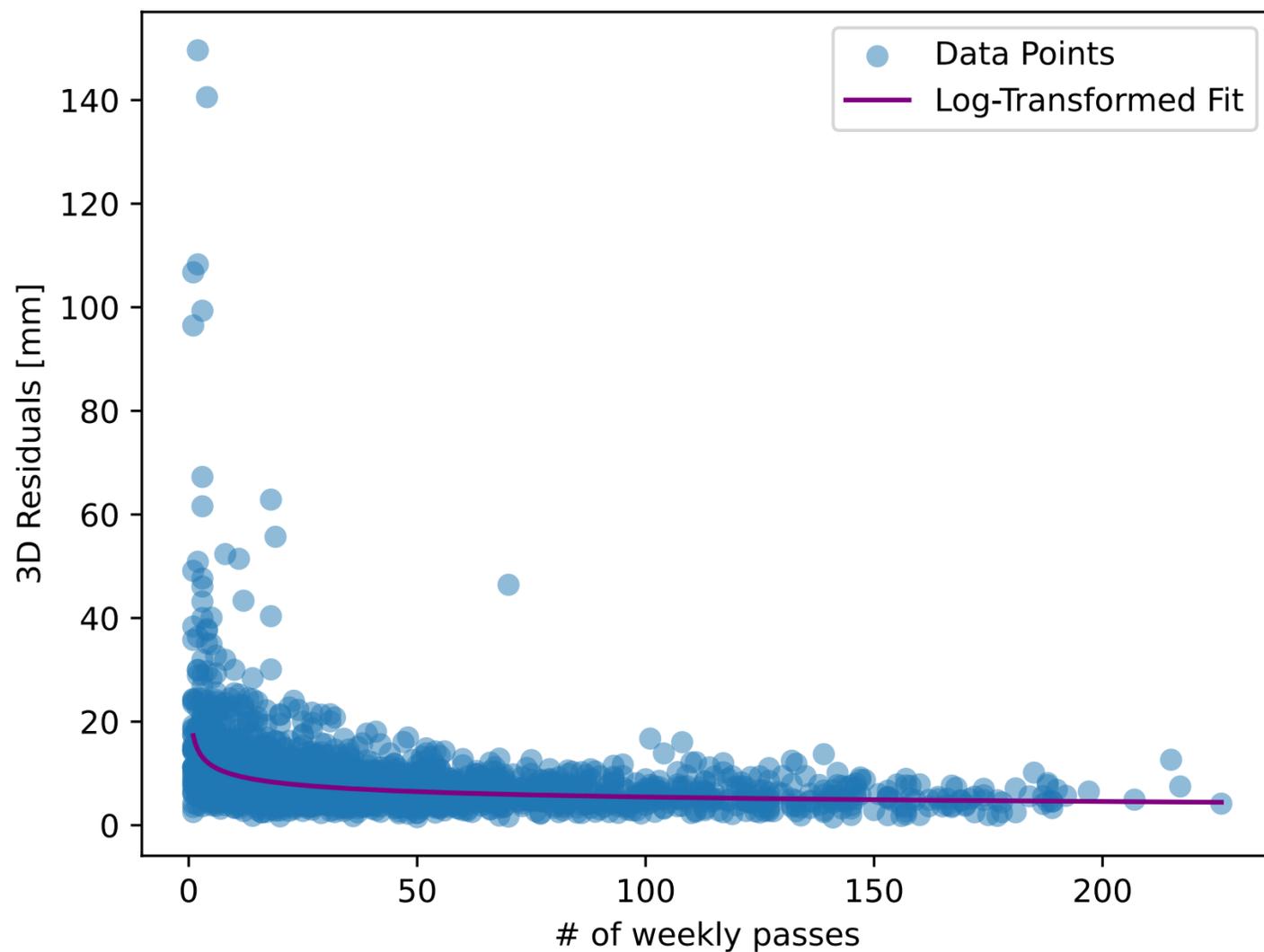
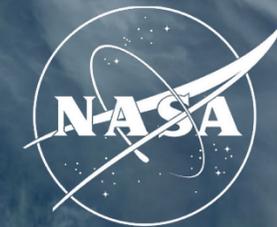
## Zoom



# Results 2 – all stations (Up coordinate)



# Results 2 – Core Stations (3d and up coordinate)



## ILRS ASC Product & Information Server

WEEKLY STATION POSITIONS & DAILY  
EOP SERIES

JCET DAILY NETWORK  
PERFORMANCE REPORT

EVALUATION OF WEEKLY ASC  
PRODUCTS

MONITORING SYSTEMATIC ERRORS

QC REPORT

ILRS REPORT CARD

MODEL BIAS SSEM-X for SLRF2020

SYSTEMATIC ERROR MONITORING  
PROJECT

NORMAL POINT DATA MONITORING

Obs. & Stations Used in ILRS Products

NETWORK PERFORMANCE ON  
LAGEOS

ILRS ASC SP3 Orbital Product  
Comparison

[Dr. Magda Kuzmicz-Cieslak](#)

## ILRS ASC Product & Information Server

WEEKLY STATION POSITIONS & DAILY EOP SERIES	JCET DAILY NETWORK PERFORMANCE REPORT	EVALUATION OF WEEKLY ASC PRODUCTS
MONITORING SYSTEMATIC ERRORS	QC REPORT	ILRS REPORT CARD
MODEL BIAS SSEM-X for SLRF2020	SYSTEMATIC ERROR MONITORING PROJECT	NORMAL POINT DATA MONITORING
Obs. & Stations Used in ILRS Products	<b>NETWORK PERFORMANCE ON LAGEOS</b>	ILRS ASC SP3 Orbital Product Comparison

### NETWORK PERFORMANCE BASED ON LAGEOS 1 & 2 Information available for 2010 and beyond

Satellite:

Start (YYYY-MM-DD):

End (YYYY-MM-DD):

Minimumn elevation [°]:

STATIONS  Select All

- |   |   |   |
|---|---|---|
| <input type="checkbox"/> 1824 Golosiiv            | <input type="checkbox"/> 7080 McDonald Observatory  | <input checked="" type="checkbox"/> 7237 Changchun    |
| <input type="checkbox"/> 1868 Komsomolsk-na-Amure | <input checked="" type="checkbox"/> 7090 Yarragadee | <input type="checkbox"/> 7249 Beijing                 |
| <input type="checkbox"/> 1873 Simeiz              | <input type="checkbox"/> 7105 Greenbelt             | <input type="checkbox"/> 7308 Koganei                 |
| <input type="checkbox"/> 1874 Mendeleevo 2        | <input type="checkbox"/> 7110 Monument Peak         | <input type="checkbox"/> 7306 TKBL                    |
| <input type="checkbox"/> 1879 Altay               | <input type="checkbox"/> 7119 Haleakala             | <input type="checkbox"/> 7359 Daedeok                 |
| <input type="checkbox"/> 1884 Riga                | <input type="checkbox"/> 7124 Tahiti                | <input type="checkbox"/> 7396 Wuhan                   |
| <input type="checkbox"/> 1886 Arkhyz              | <input type="checkbox"/> 7501 Hartebeesthoek        | <input type="checkbox"/> 7405 Concepcion              |
| <input type="checkbox"/> 1887 Baikonur            | <input type="checkbox"/> 7403 Arequipa              | <input type="checkbox"/> 7406 San Juan                |
| <input checked="" type="checkbox"/> 1888 Svetloe  |   | <input type="checkbox"/> 7819 Kunming                 |
| <input type="checkbox"/> 1889 Zelenchukskya       |   | <input type="checkbox"/> 7820 Kunming                 |
| <input type="checkbox"/> 1890 Badary              |   | <input type="checkbox"/> 7821 Shanghai                |
| <input type="checkbox"/> 1891 Irkutsk             |   | <input type="checkbox"/> 7825 Mt Stromlo              |
| <input type="checkbox"/> 1893 Katzively           |   | <input type="checkbox"/> 7838 Simosato                |
| <input type="checkbox"/> 7407 Brasilia            |   | <input type="checkbox"/> 7810 Zimmerwald              |
| <input type="checkbox"/> 7503 Hartebeesthoek      |   | <input type="checkbox"/> 7827 SOS Wettzell            |
|   |   | <input type="checkbox"/> 7839 Graz                    |
|   |   | <input checked="" type="checkbox"/> 7840 Herstmonceux |
|   |   | <input type="checkbox"/> 7841 Potsdam                 |
|   |   | <input type="checkbox"/> 7845 Grasse                  |
|   |   | <input type="checkbox"/> 7941 Matera                  |
|   |   | <input type="checkbox"/> 8834 Wettzell                |
|   |   | <input type="checkbox"/> 8834 Wettzell@1064           |

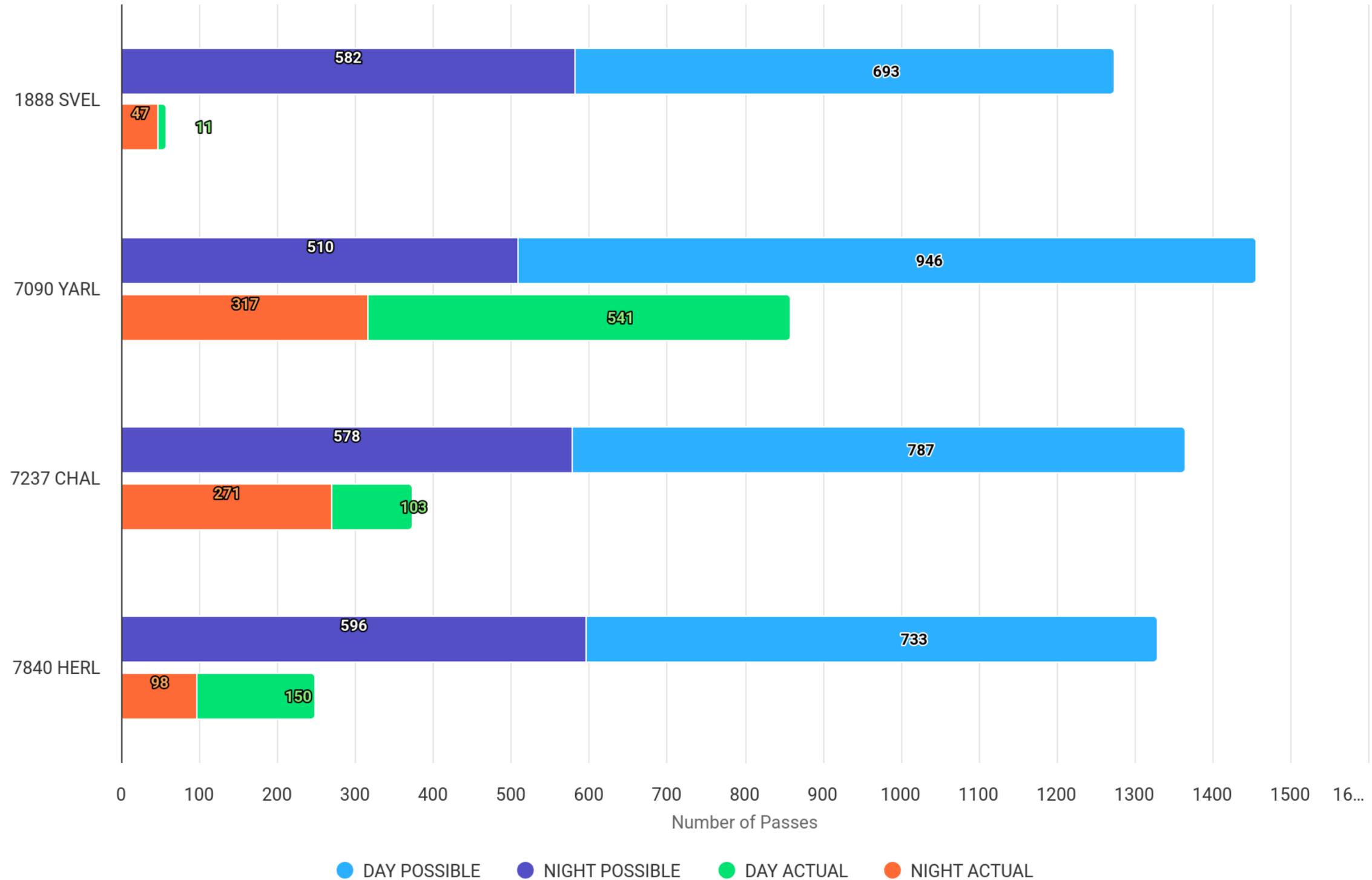
- DAY vs NIGHT TRACKED NPs
- DAY vs NIGHT TRACKED PASSES
- DAY vs NIGHT NORMALIZED DATA YIELD (%)
- DISTRIBUTION OF OBSERVATIONS (REAL & SIMULATED) only for one station

Submit

# Is it feasible?

## DAY vs NIGHT & ACTUAL vs POSSIBLE PASSES for LAGEOS2

from 2024-01-01 to 2025-12-31  
Minimumn elevation [°] 30



# Future Work



Impact of the number of passes on the EOP, Gravity Coeff, LOD...



Impact of the number of passes on the Origin and Scale



ITRF2020 extension



Consider the impact of LARES-2

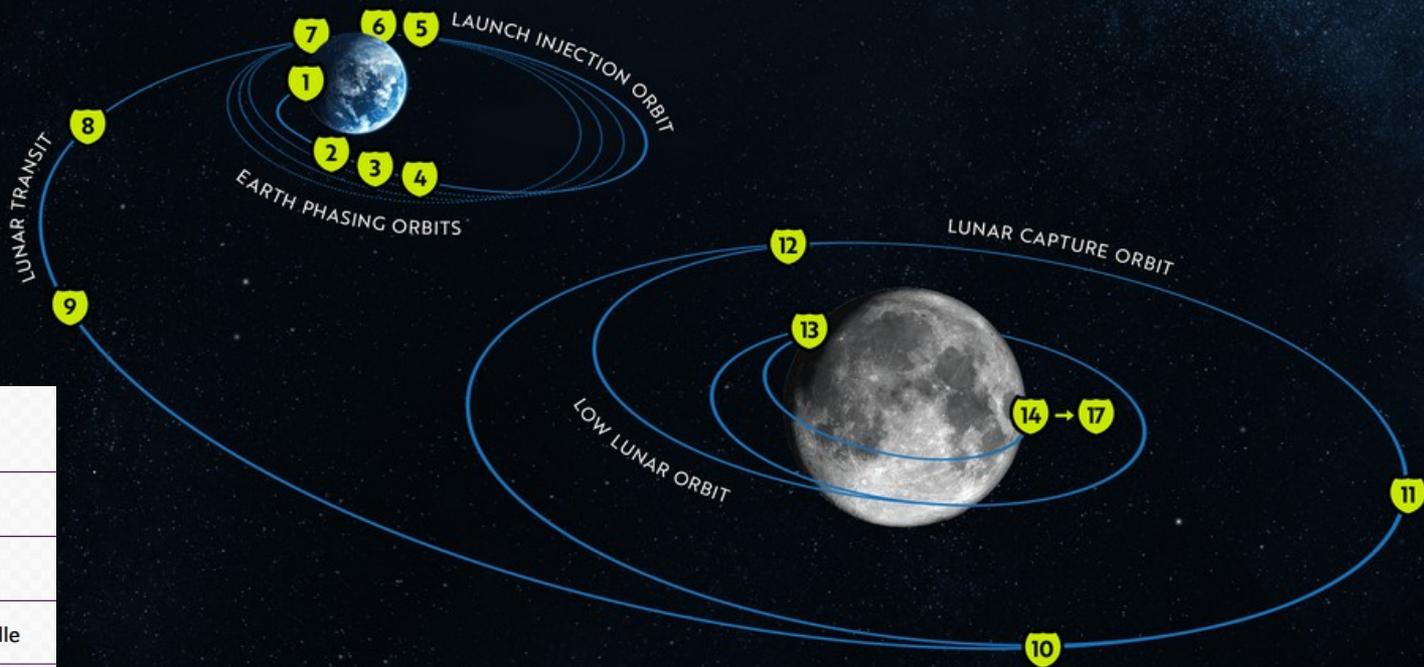


# NESEC - ILRS

**news**

# NGLR : heading for the Moon

- <https://fireflyspace.com/missions/blue-ghost-mission-1/>



**Launch Date:** January 15, 2025

**Landing Date:** March 2, 2025

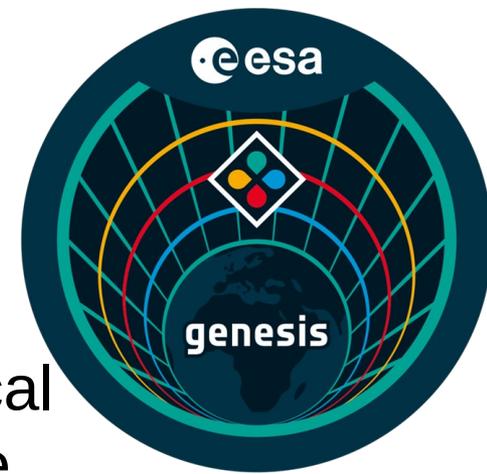
**Landing Time:** TBA

**Landing Site:** Mare Crisium near Mons Latreille

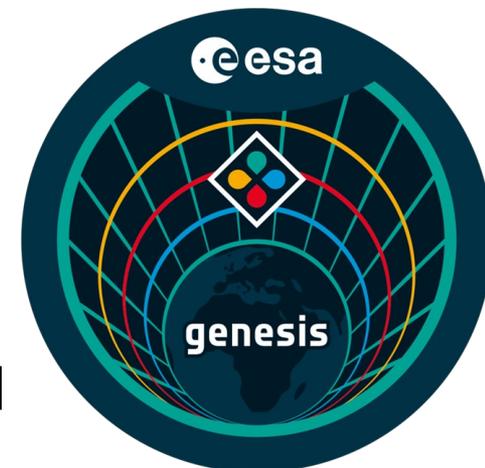
LAUNCH 1 HOUR	ON-ORBIT COMMISSIONING 8 HOURS	EARTH ORBIT 25 DAYS	LUNAR TRANSIT 4 DAYS	LUNAR ORBIT 16 DAYS	DESCENT 1 HOUR	SURFACE OPERATIONS 14 DAYS
1 LAUNCH	3 SIGNAL ACQUISITION	6 EARTH ORBIT PHASING	8 TRANS LUNAR INJECTION	10 LUNAR ORBIT INSERTION	13 DESCENT ORBIT INSERTION	15 SURFACE COMMISSIONING
2 LAUNCH VEHICLE SEPARATION	4 ELECTRICAL & PAYLOAD CHECKOUTS	7 ON-ORBIT PAYLOAD SCIENCE BEGINS	9 TRAJECTORY CORRECTION MANEUVER(S)	11 VISION NAVIGATION CALIBRATION	14 TOUCHDOWN	16 SURFACE PAYLOAD SCIENCE
	5 ENGINE CALIBRATION			12 LOW LUNAR ORBIT INSERTION		17 LUNAR NIGHT OPERATIONS



# GENESIS



- Discussion in progress with ESA
  - September 2024: MSC notices a critical point in the requirements regarding the OCS
  - October 2024: Analysis from Mathis regarding the impact on the network ; outputs of the IWLR discussion sent to ESA
  - November-December 2024: Discussion & simulation from Simone to increase the GENESIS OCS baseline of 3Mm<sup>2</sup> to 7 Mm<sup>2</sup>
  - January 2025: ILRS recommendation to ESA for the 7Mm<sup>2</sup> option



- Perspectives:
  - Laser Range correction facility in INFN  
=> see the proposal from Simone  
« LaRCO »
  - Open discussion on: Measuring the  
Laser ranging correction with level of  
accuracy required by Genesis

## LaRCo (Laser Range Correction)

For hemi/spheres: **Genesis** (ESA), **LARES-2** (ASI),  
**COSMO-SkyMed** Second Generation (CSG, ASI) ...

For flat LRAs: **Galileo** 2<sup>nd</sup> Generation (G2G, ESA),  
**Moonlight** (LCNS, ESA) ...

Endorsement needed to get the support for LaRCo by ASI and its  
ILRS station, the Matera Laser Ranging Observatory (MLRO)

INFN – Frascati National Labs (INFN-LNF)

SCF\_Lab Research Group

<http://www.lnf.infn.it/esperimenti/etrusco/>

Via E. Fermi 54, Frascati (Rome), 00044 – Italy



## What Next? **LaRCo = Laser Range Correction**

- Unique, innovative ASI & INFN-LNF facility to measure in the lab the "laser range correction".
- The ultimate laser ranging calibration, relating geometrical centers of LRA spheres / circles ...  
... to the measured laser time-of-flight (ToF), to reach/break the barrier of 1 mm accuracy.
- LaRCo done twice in 60 years of laser ranging, for LAGEOS-1/2 in 1974/1994. Now only calculated.
- At INFN-Frascati we have a suited Clean Room, the SCF\_lab2, already co-funded by ASI & INFN.

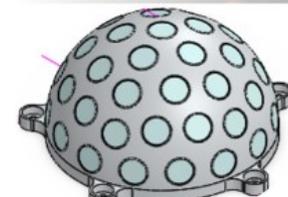
**Do ESA and ILRS endorse LaRCo @ Frascati?**



**LARES-2 (~6k km)**



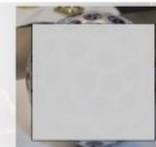
**Genesis (~6k km)**



**Galileo 2G (~23k km)**



**COSMO-SkyMed Second Generation (~600 km)**

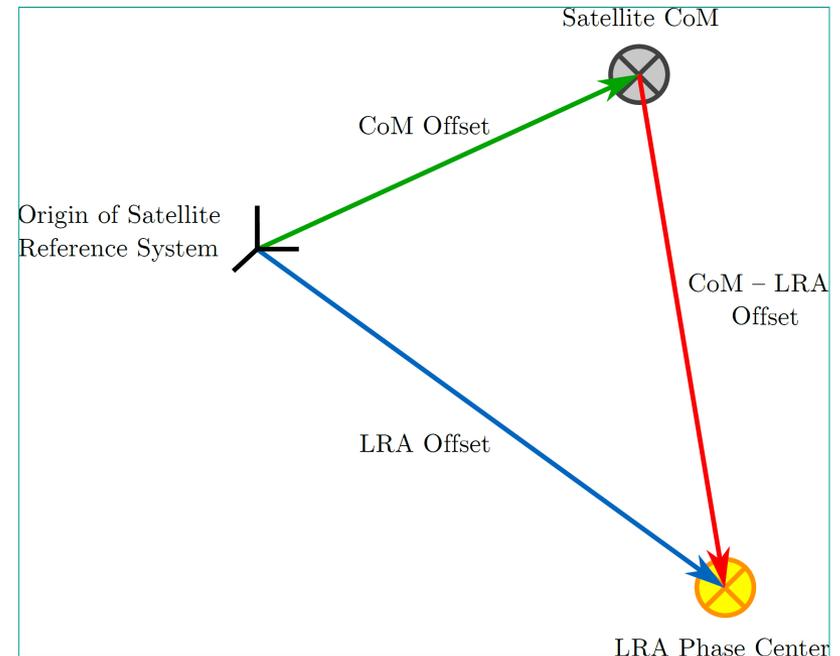




# Measuring the Laser ranging correction with level of accuracy required by Genesis

- Measure/calibrate the optical center of the LRR
  - w.r.t. the center of mass of the LRR
  - w.r.t. the other technics
  - w.r.t. the center of mass of the satellite after all the integration
- Important:
  - Origin of the SRF must be known better than 1mm
  - Satellite CoM must be known better than 1mm
  - LRA optical phase center must be known better than 1mm

→ All points should be calibrated on the fully mounted/equipped satellite, preferably with electronic devices switched on!



Zeitlhöfler, 2019