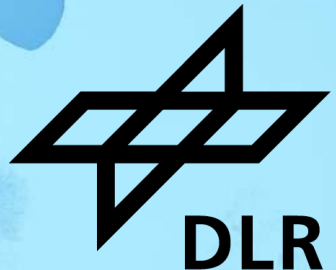


ALGORITHM FOR DETECTING AIRBORNE OBJECTS WITH A THERMAL INFRARED CAMERA TO ENSURE A SAFE OPERATION OF LASER-OPTICAL GROUND STATIONS

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 23rd, 2025



A photograph of a laser-optical ground station at night. In the foreground, a large, silver, box-like thermal infrared camera is mounted on a black table. The camera has a circular lens and a small display. To its left is a tall, narrow, yellowish structure. In the background, a large, dark building with a red-lit entrance is visible. A white robotic arm or camera mount is positioned to the right of the main camera. The sky is dark with some stars visible.

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



Source: private

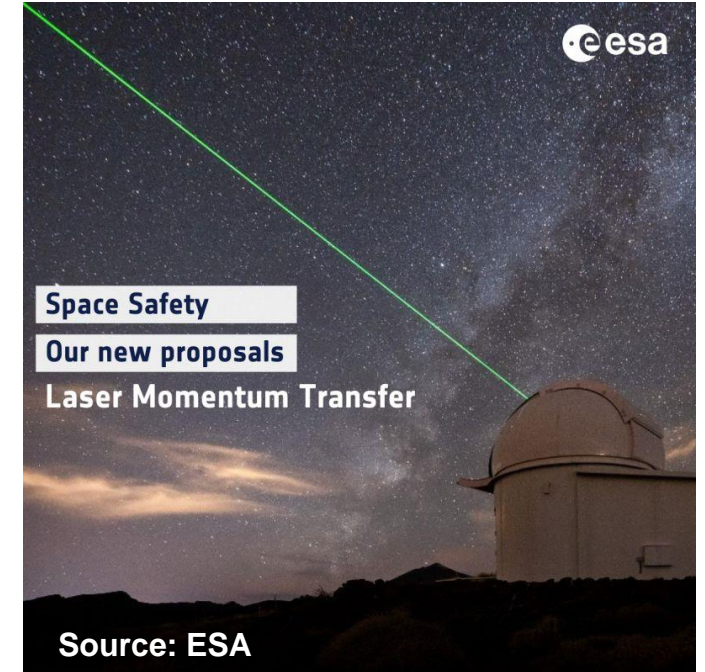
(Atmospheric) LIDAR

Nils Bartels, January 23rd, 2025



Source: Trumpf

For fun/advertisement...



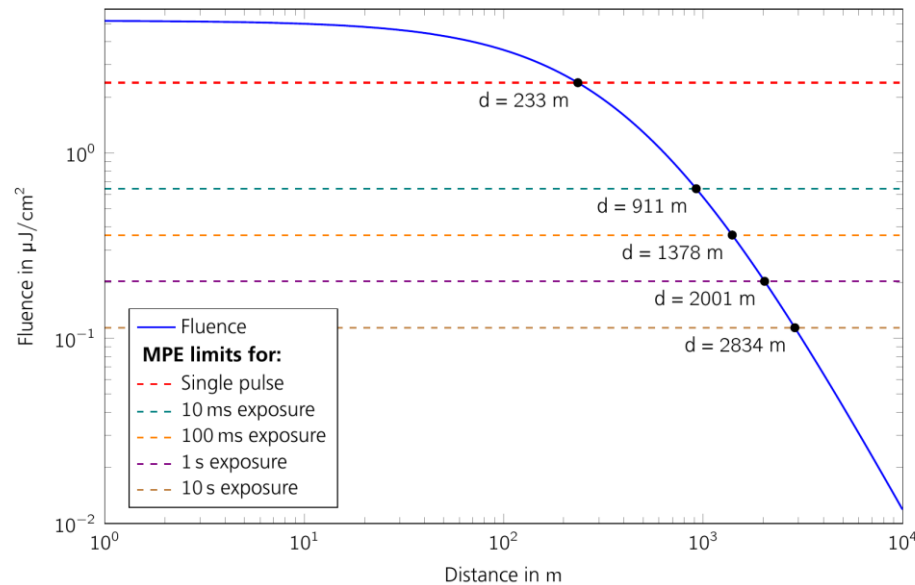
Source: ESA

Laser momentum transfer

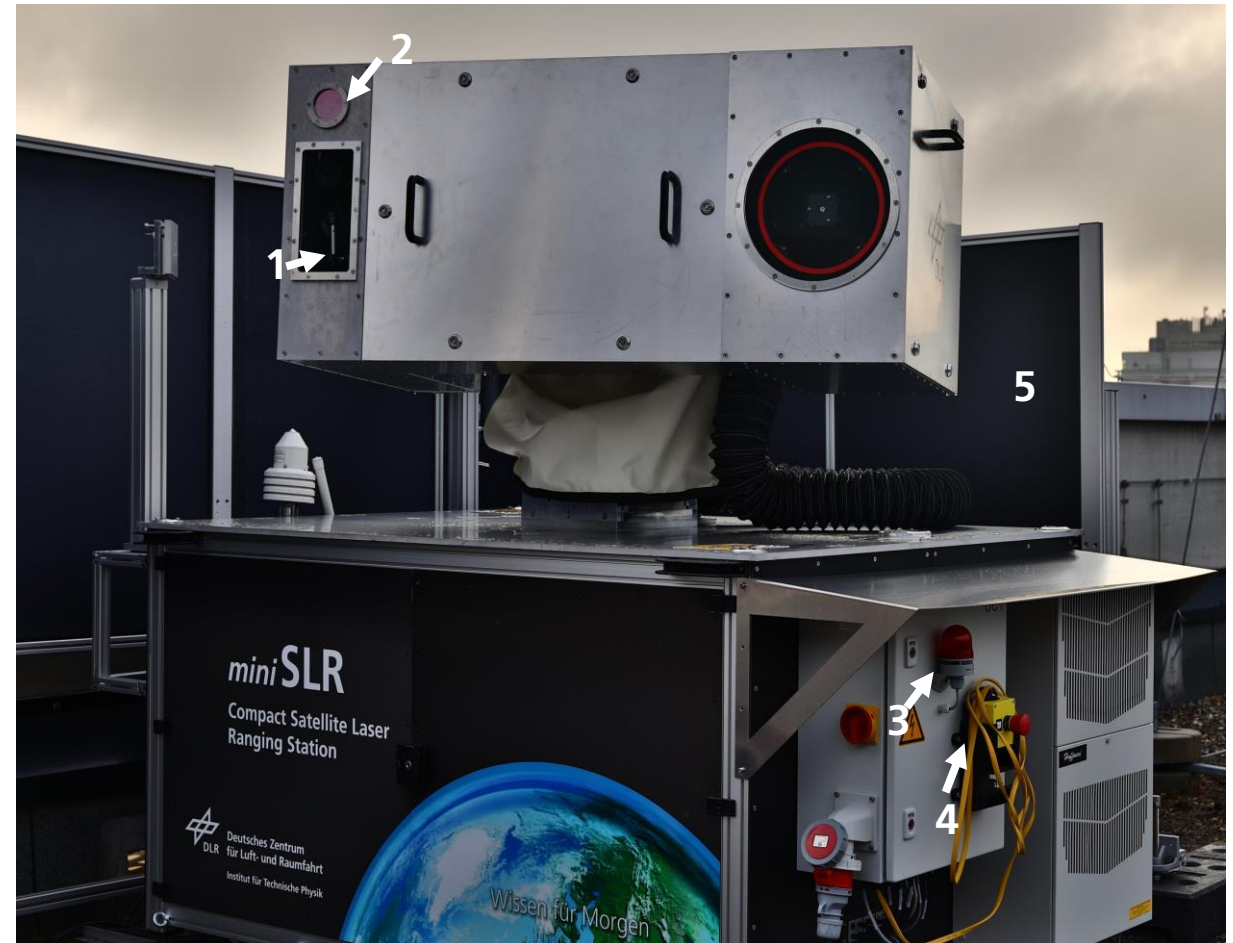
Laser safety at miniSLR[®]

Laser parameters miniSLR[®]

Wavelength	1064 nm
Pulse energy	85 μ J
Pulse duration	500 ps
Pulse repetition rate	50 kHz
Beam divergence	50 μ 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).

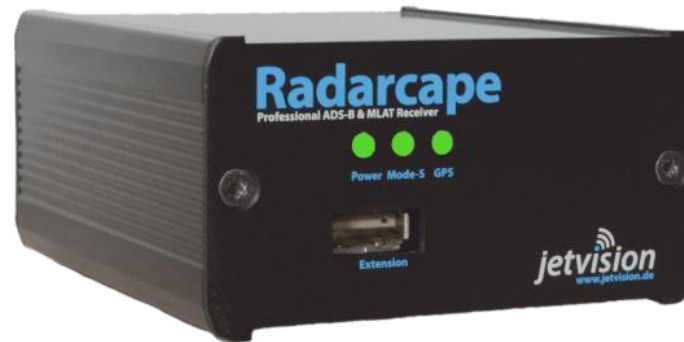
Laser safety at miniSLR®

Radar (as data stream from air traffic control)



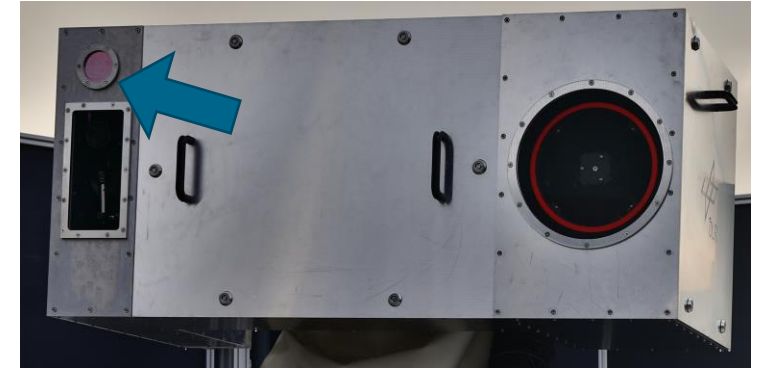
Quelle: <https://www.dfs.de/homepage/de/flugsicherung/betrieb/ortung/>

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

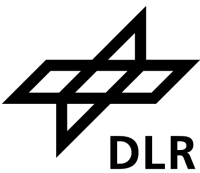
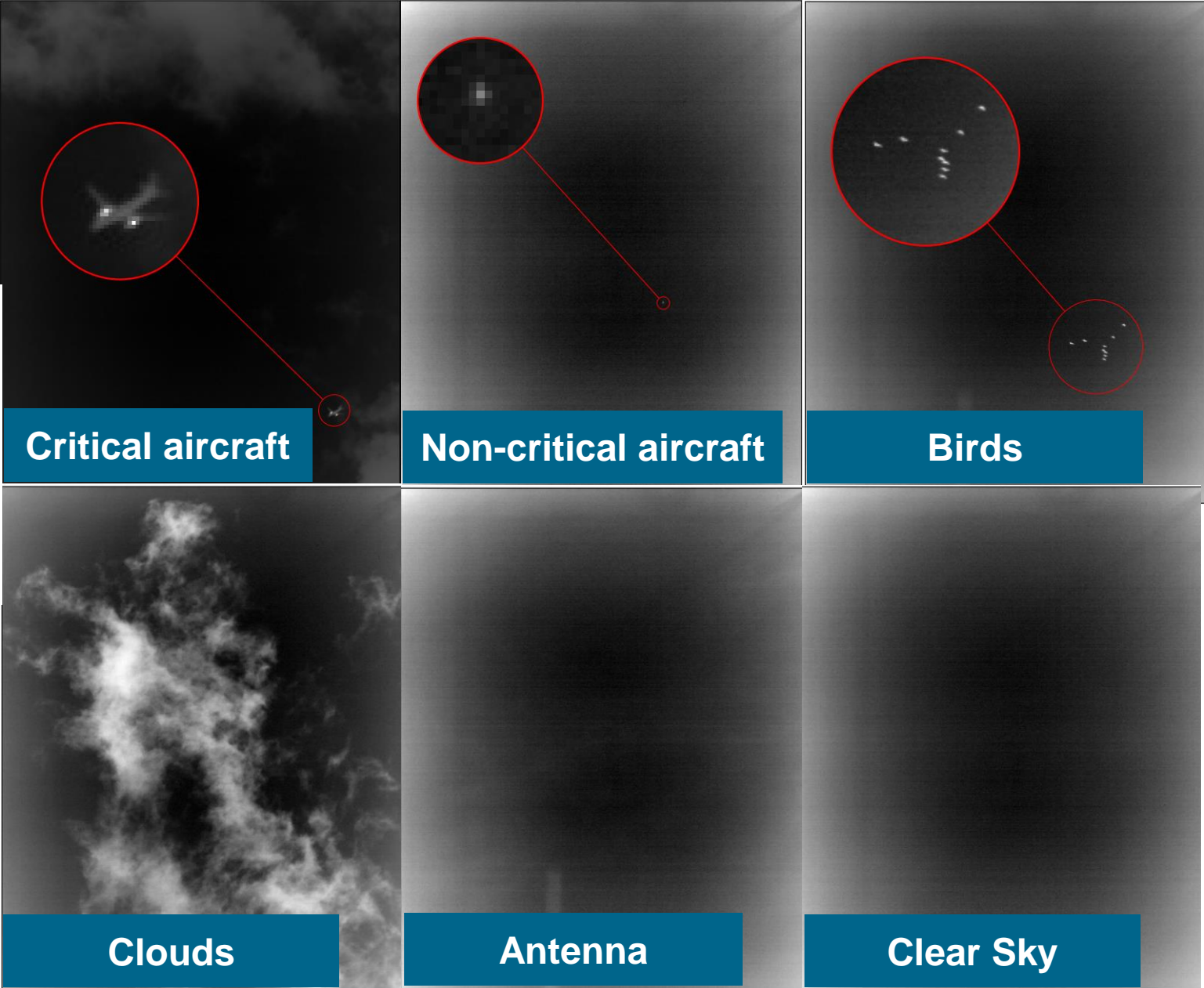
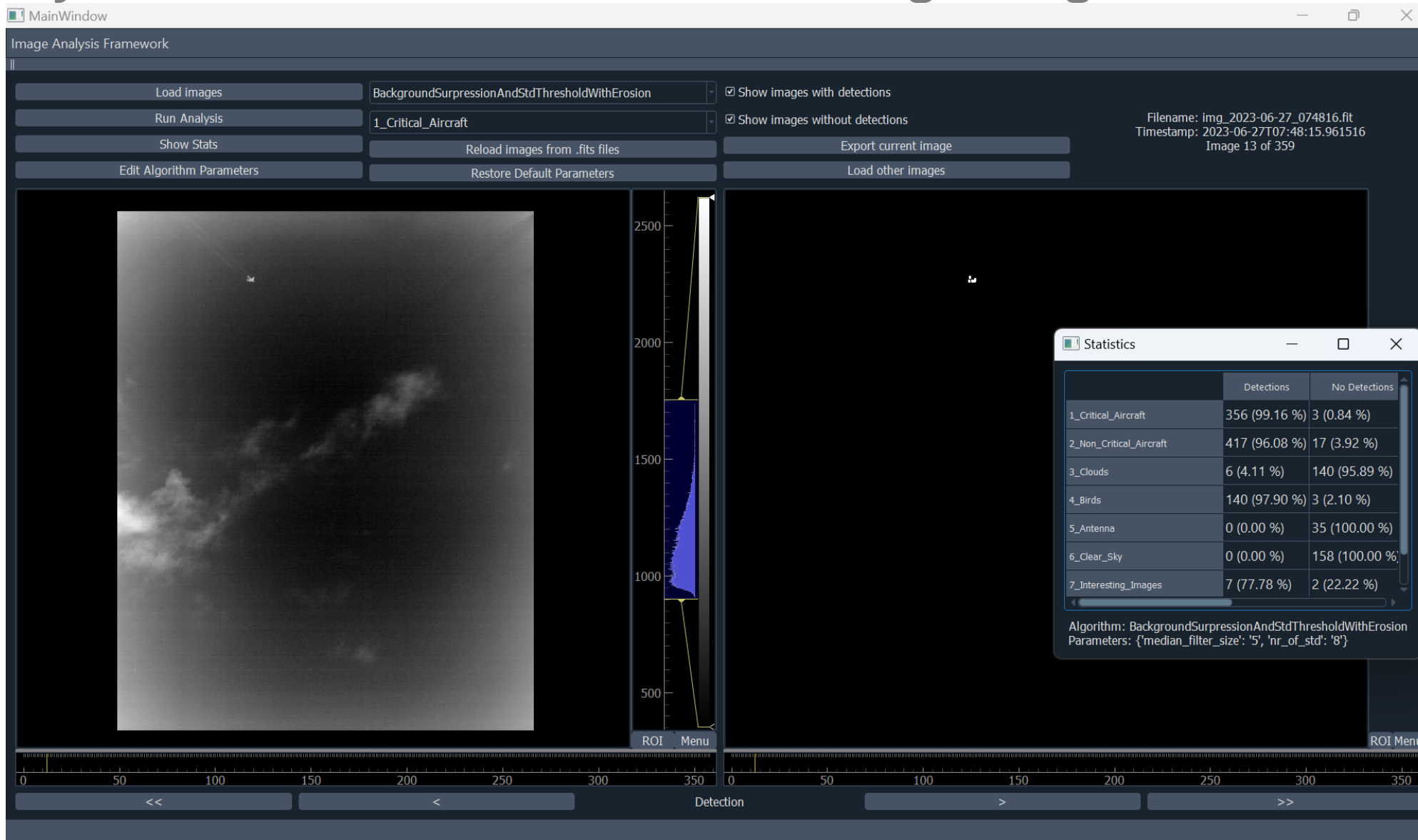


Table 3. Number of Images and Targeted Classification of Different Categories in the Generated Dataset

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	–

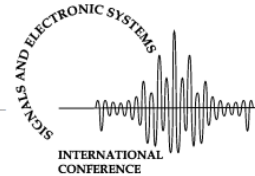


Python software with GUI for testing of algorithms



- 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

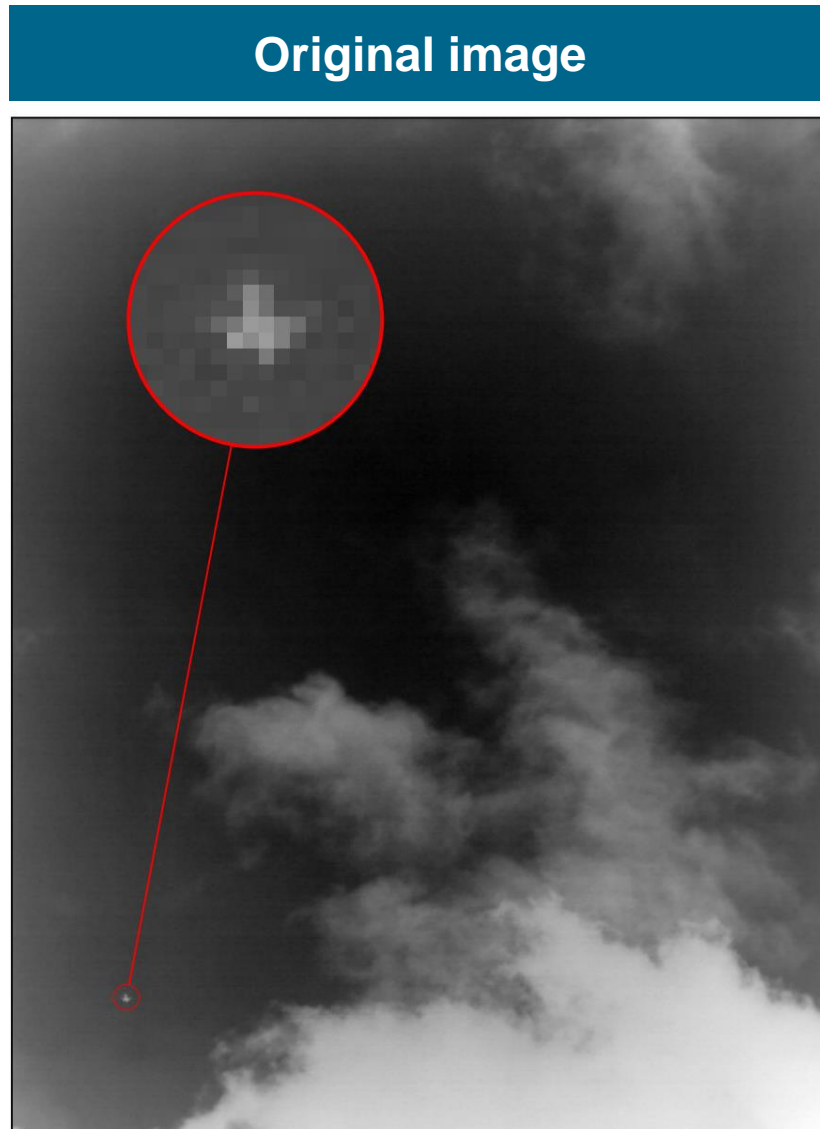
=

	22						

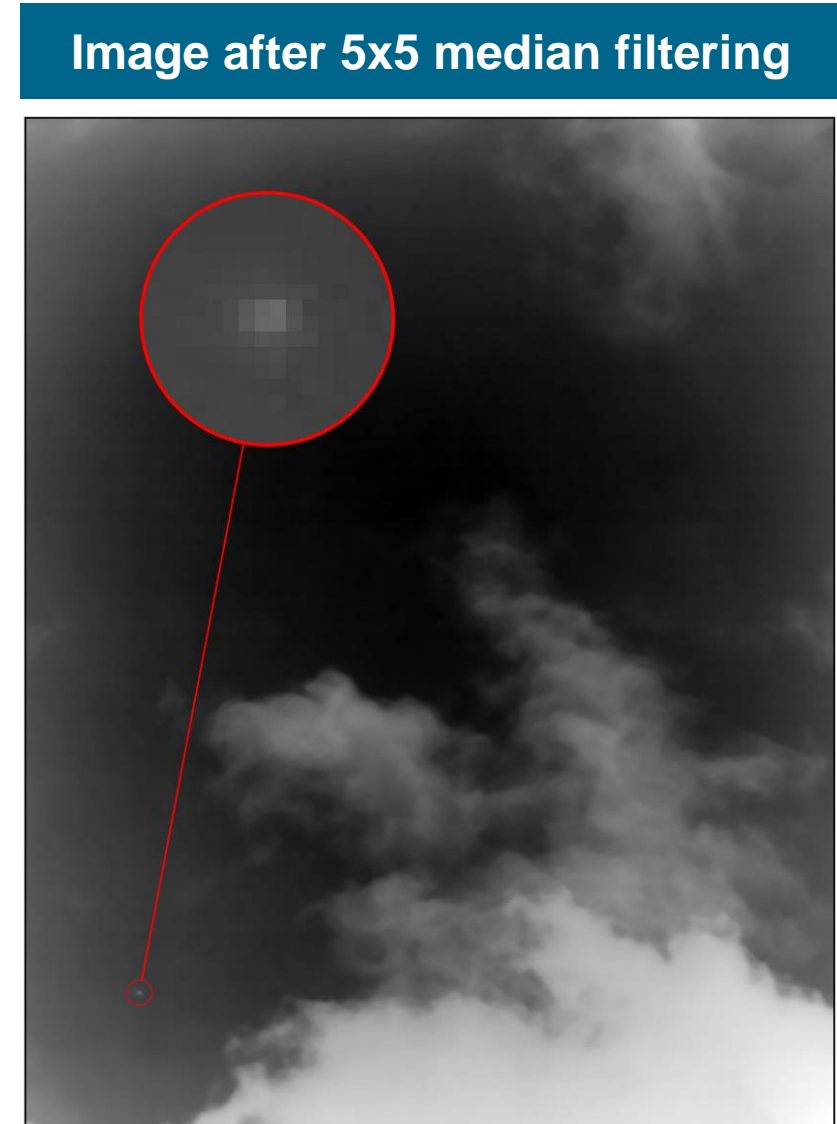
Median image

Quelle: https://neubias.github.io/training-resources/median_filter/index.html

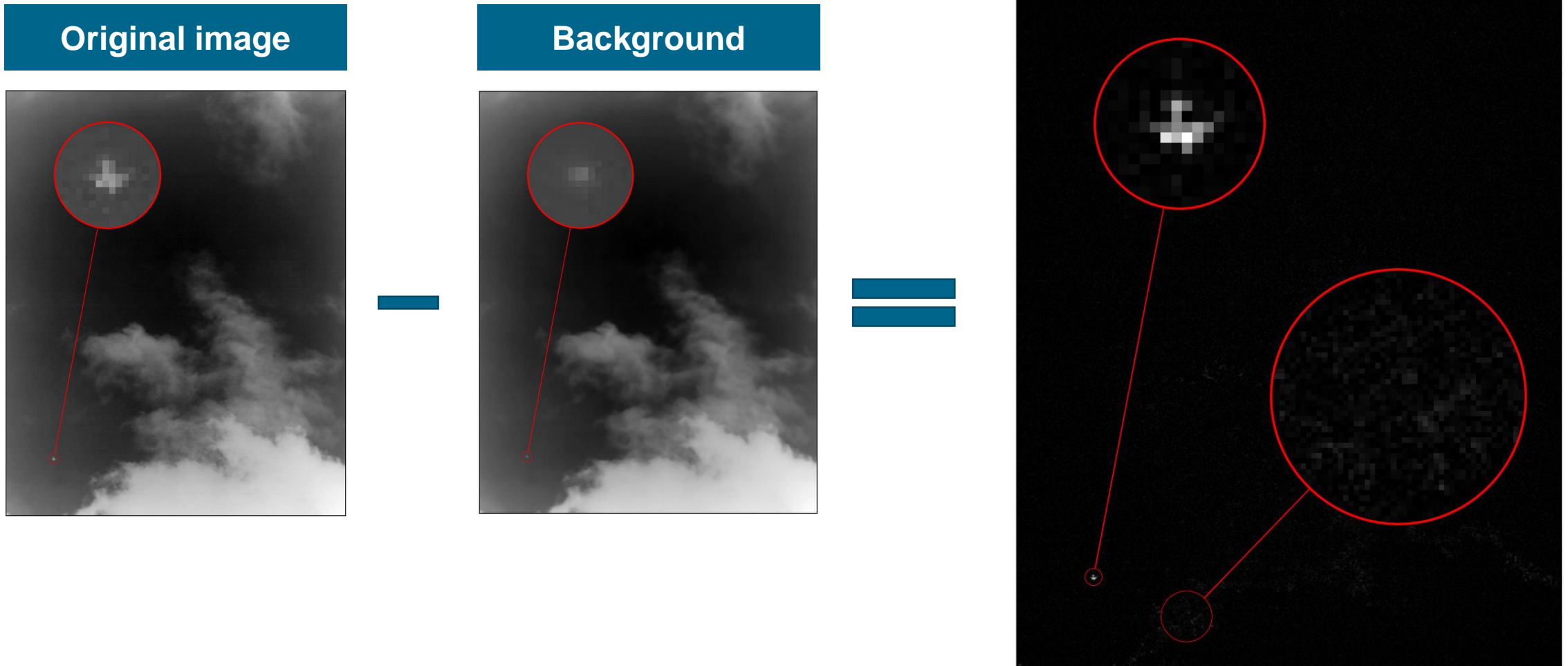
Median filter for noise reduction



Median-Filter



Median filter for background subtraction



Proposed algorithm

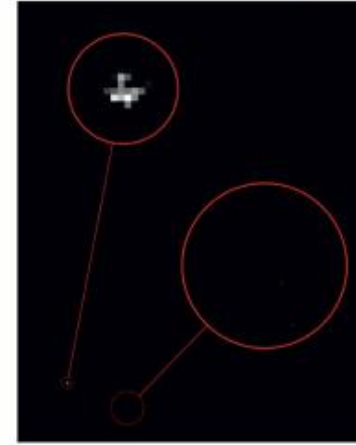
(A) Original image



(B) Median filtered image



(C) Subtracted image



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

(D) Binarized image



Step 4:
Hit or miss
transform

Binarized image
without single pixel
detections

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

Step 5:
Classification

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



Step 1:
Median
Filtering



Step 2:
Image
Substraction



Threshold optimization:

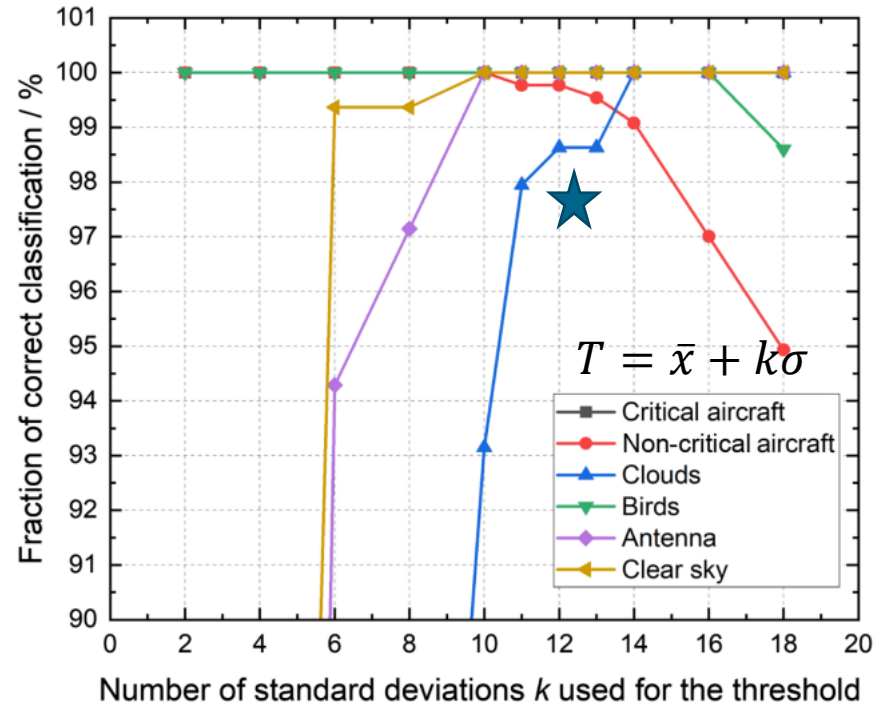


Fig. 4. Fraction of correct classifications as a function (“safe” or “unsafe”) of the optimized parameter k for the different image categories.

Classification with optimized threshold:

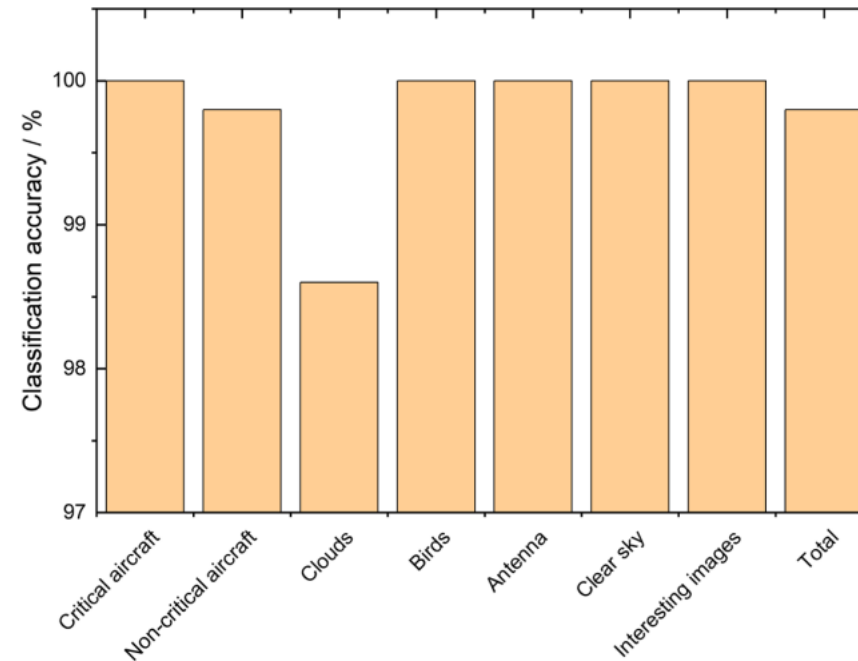
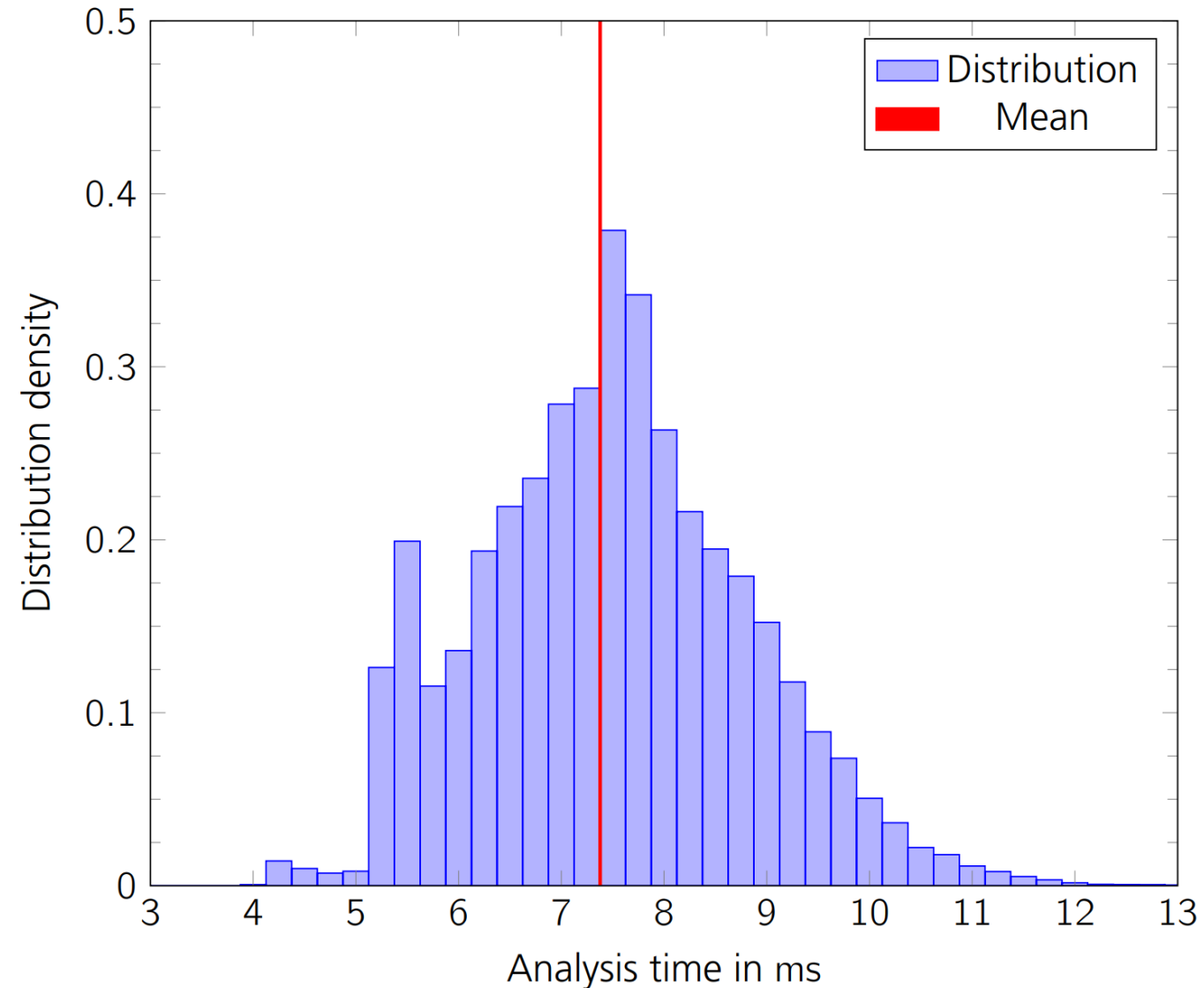


Fig. 5. Results of classification accuracy (safe/unsafe) for the proposed image processing algorithm with $k = 12$.

Speed

- Image analysis takes ~7ms on a standard PC

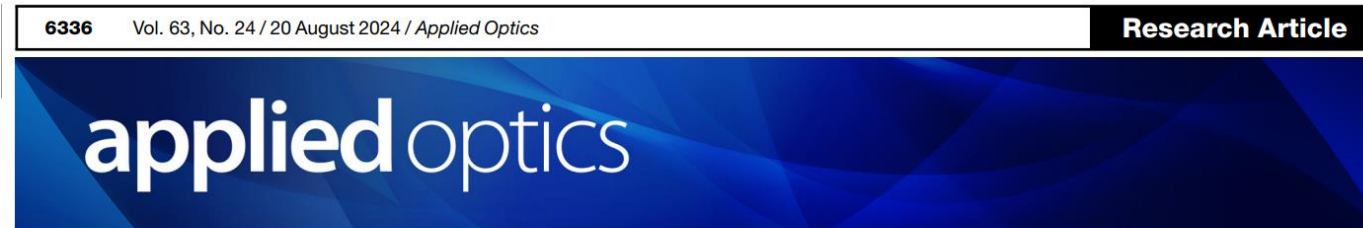


Limitations of this work



- 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

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TRISTAN MEYER,¹ WOLFGANG RIEDE,¹ AND THOMAS DEKORSY¹

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

²DiGOS Potsdam GmbH, Telegrafenberg 1, 14473 Potsdam, Germany

*nils.bartels@dlr.de

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

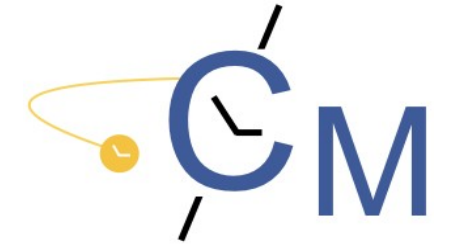
- Article contains source code (Python) and link to repository with raw images (classified dataset)
- Anyone is free to use the algorithm, feedback or suggestions are appreciated

ACES Mission Update: Ground Station Requirements

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

elt@sgd.lrg.tum.de

Clock Metrology: Preparation of ground stations for ELT tracking

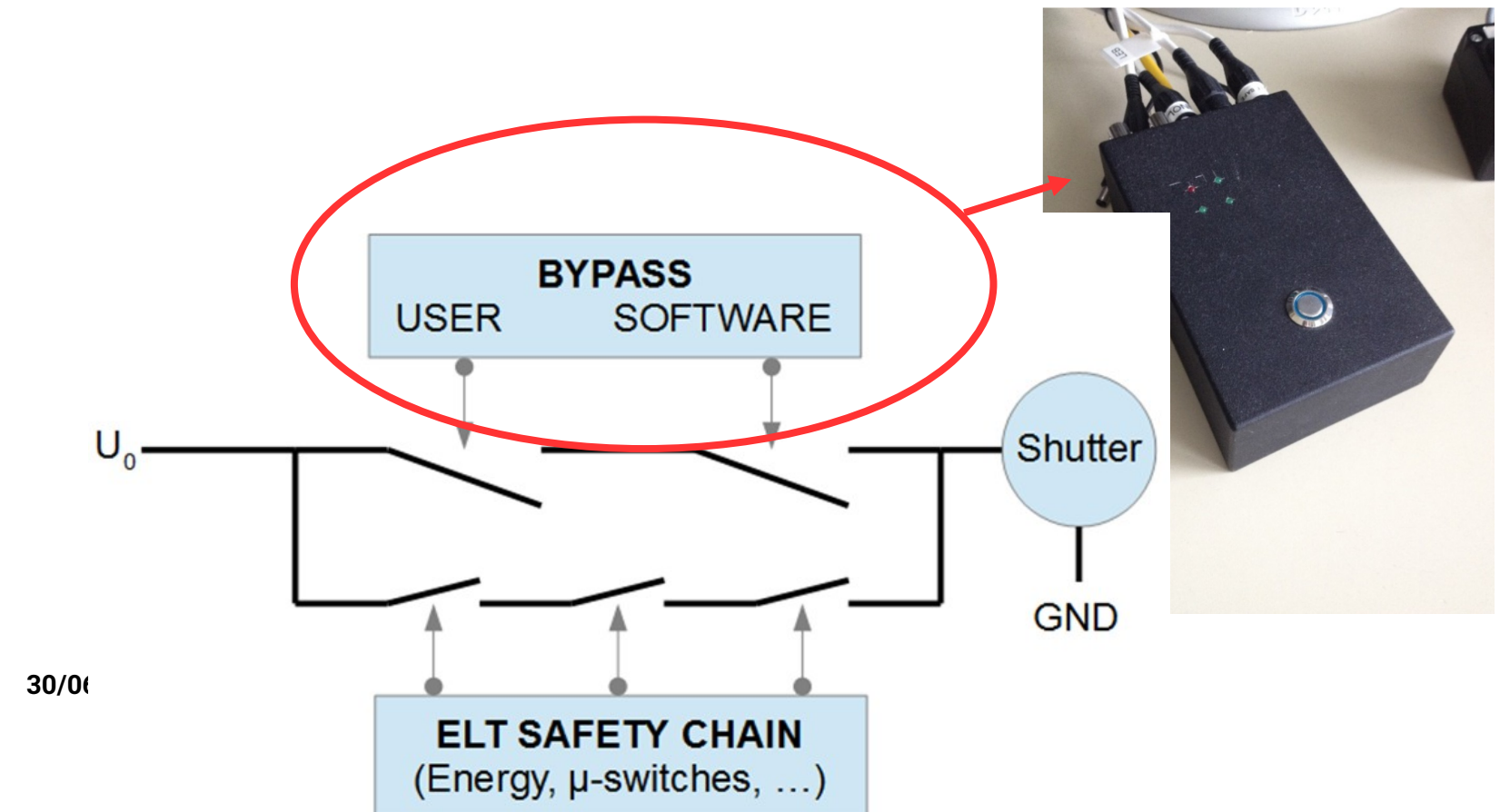


The requirements for participating stations are summarized in the **Technical Note**

- 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)



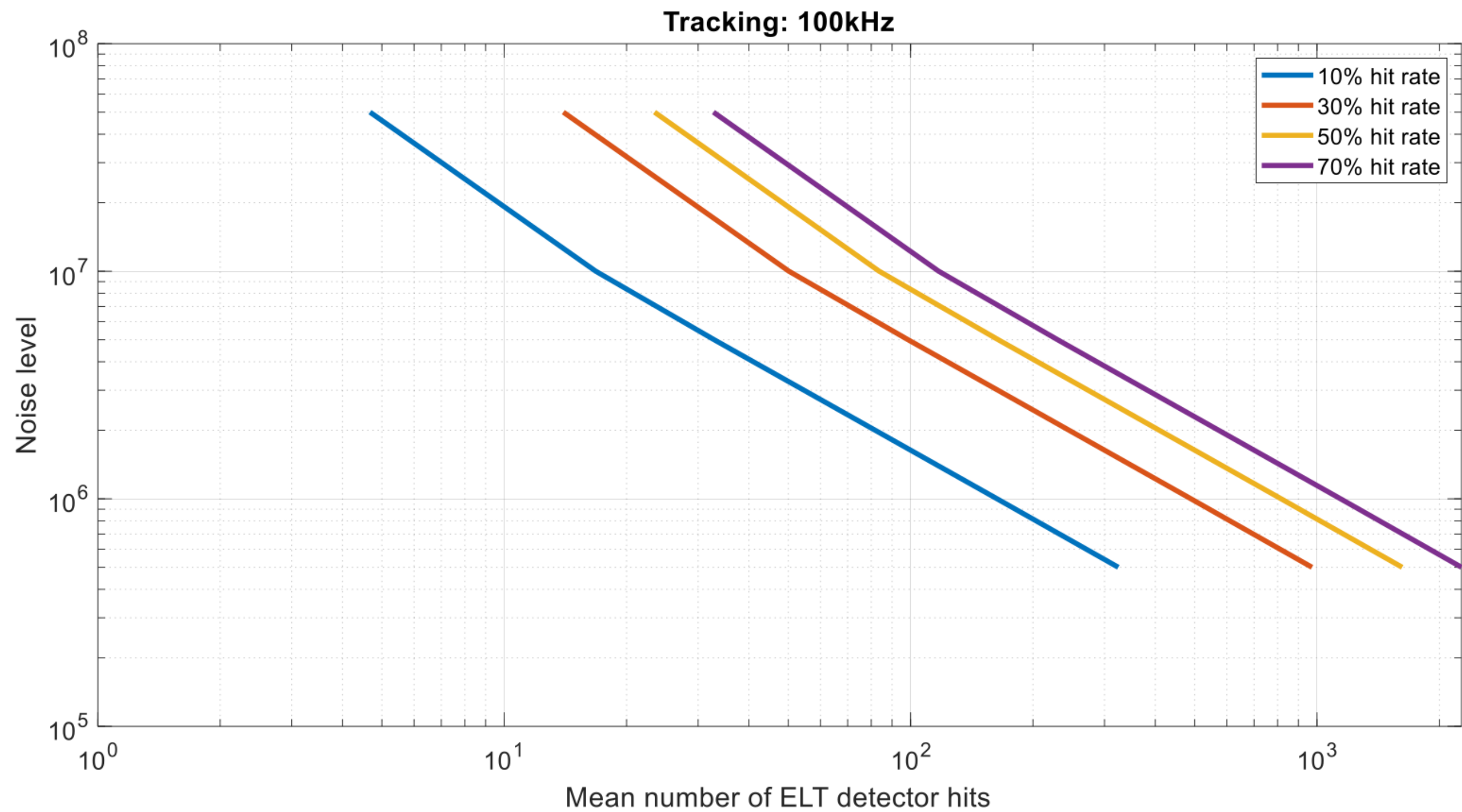
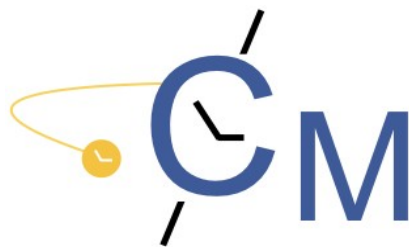
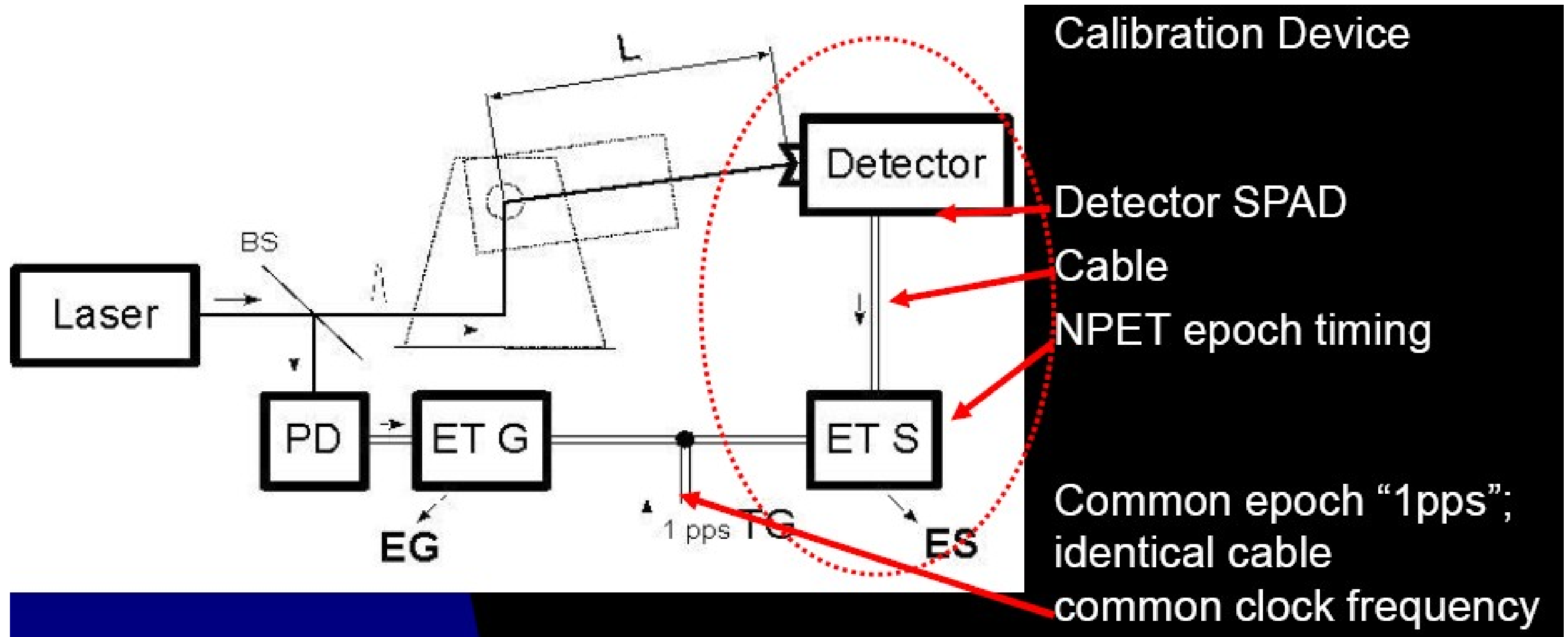
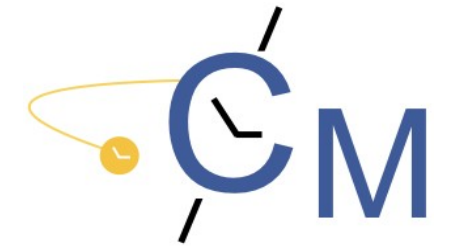
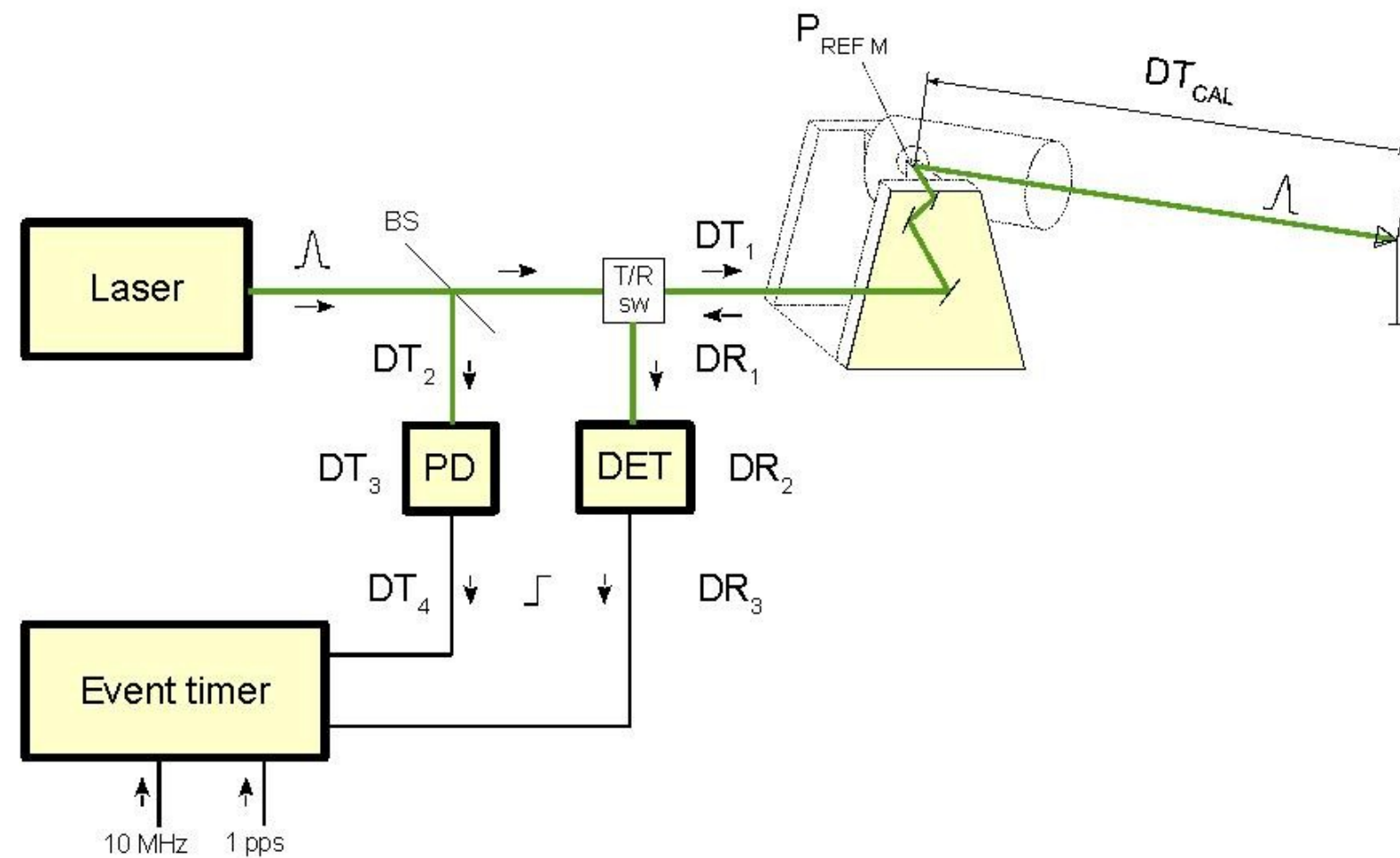


Figure 10: Mean number of ELT detector hit for 100 kHz tracking w.r.t. the noise level.

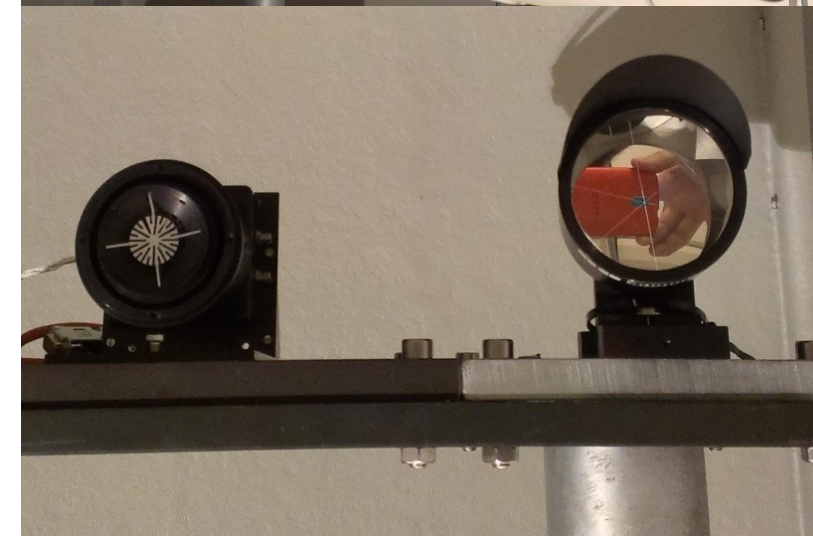
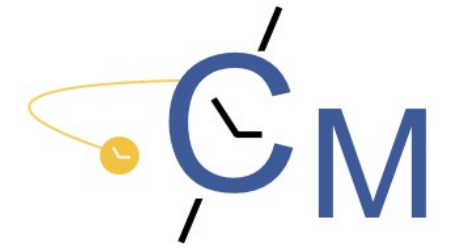
Clock Metrology: ELT calibration



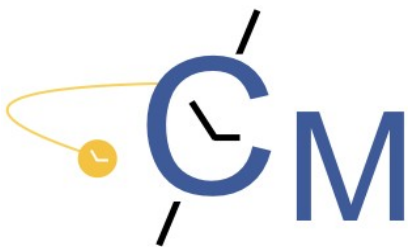
SLR system delays - simplified



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.

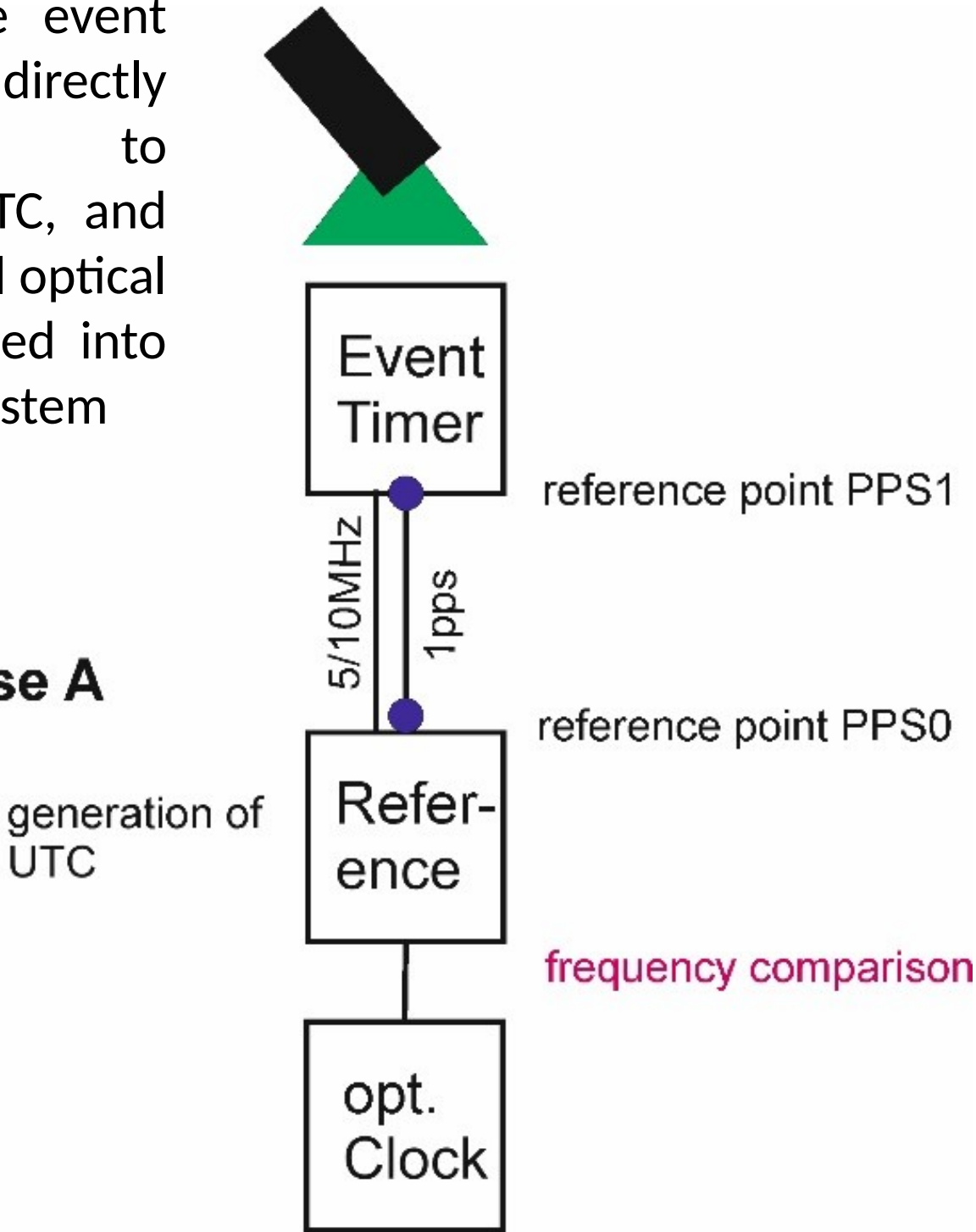


Clock Status Files



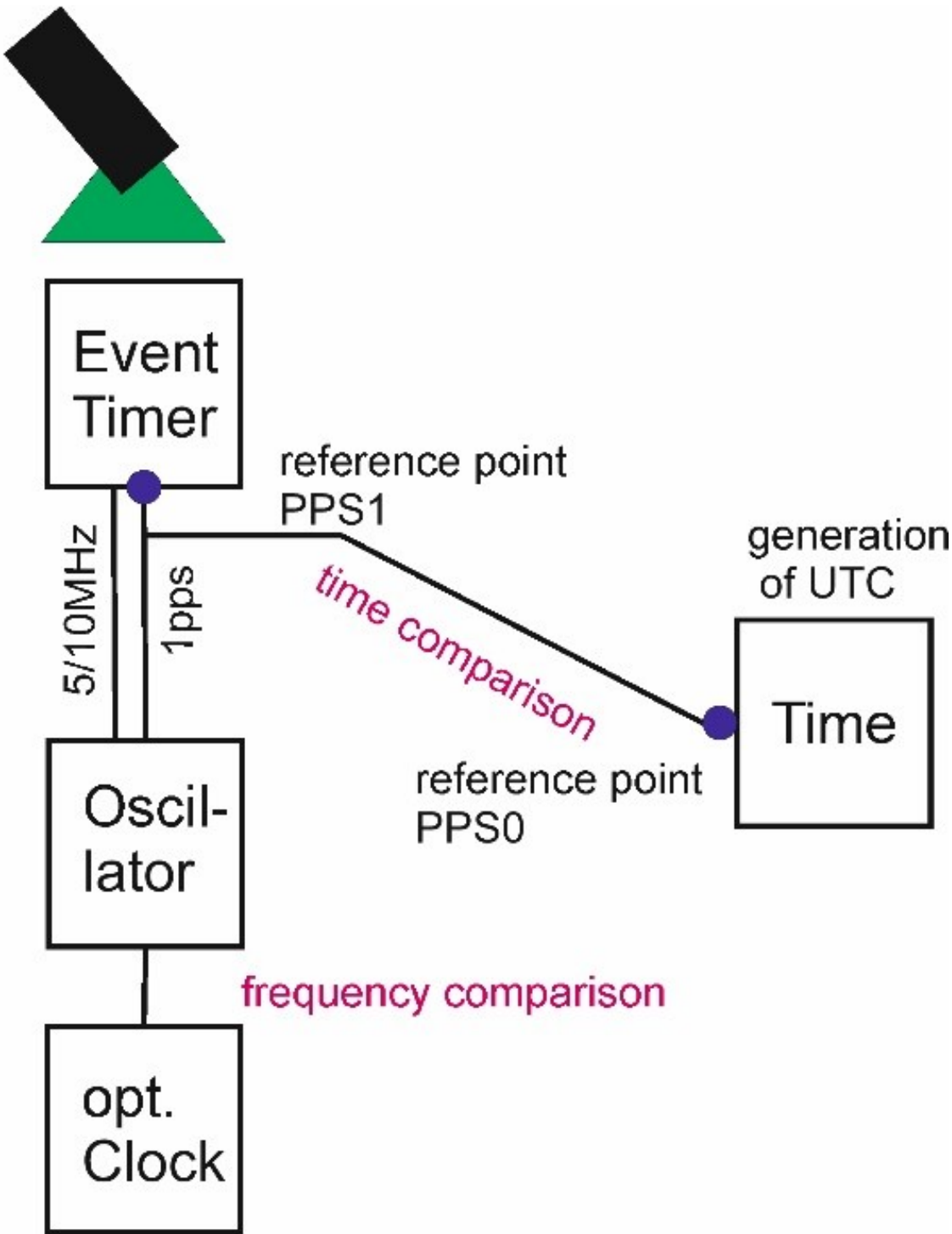
Case A: the event timer is directly connected to reference UTC, and an additional optical clock is placed into the timing system

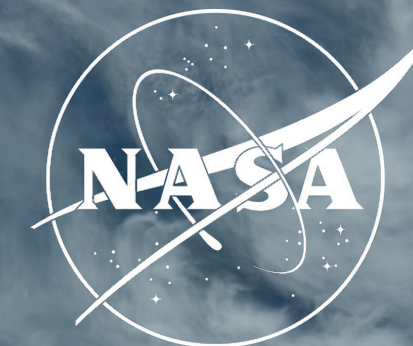
Case A



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 Belli¹, Magda Kuzmich-Cieslak^{2,3}, Frank G Lemoine⁴ and Keith D Evans³

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

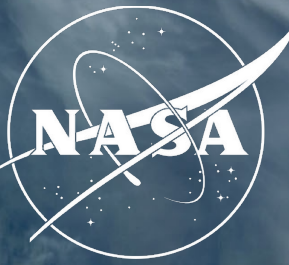
(2) Joint Center for Earth Systems Technology, Baltimore, United States,

(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

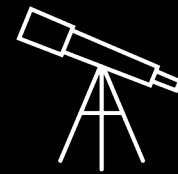
First presented at the AGU2024, modified for NESC
January 23rd, 2025

Context



SLR Stations

43 stations (not observing all the satellites)

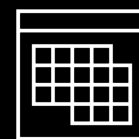
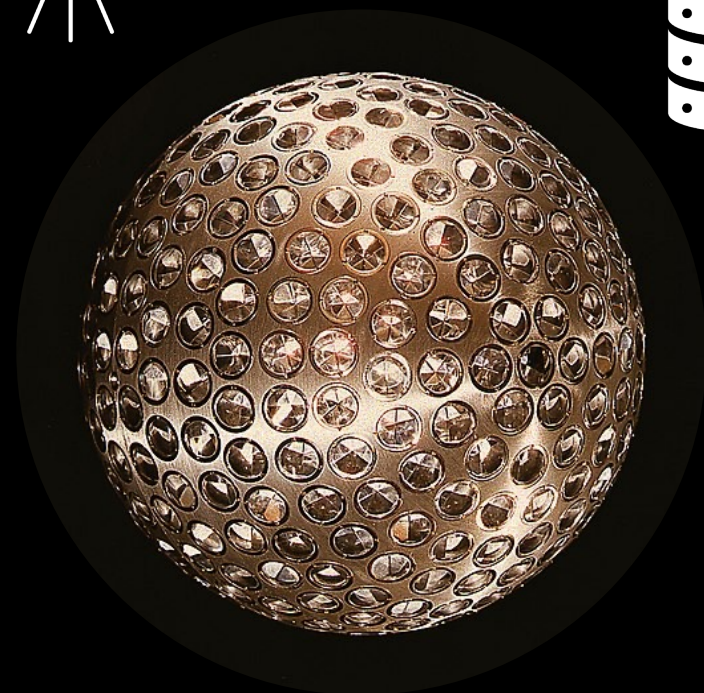


LASER DATA

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>



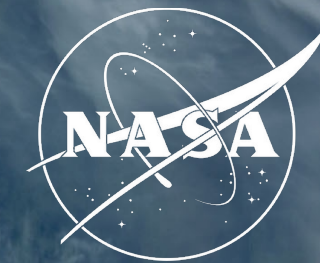
SATELLITES

LAGEOS 1 and 2, ETALON 1 and 2

TIMEFRAME

From January 2017 to December 2020
Weekly data

of passes



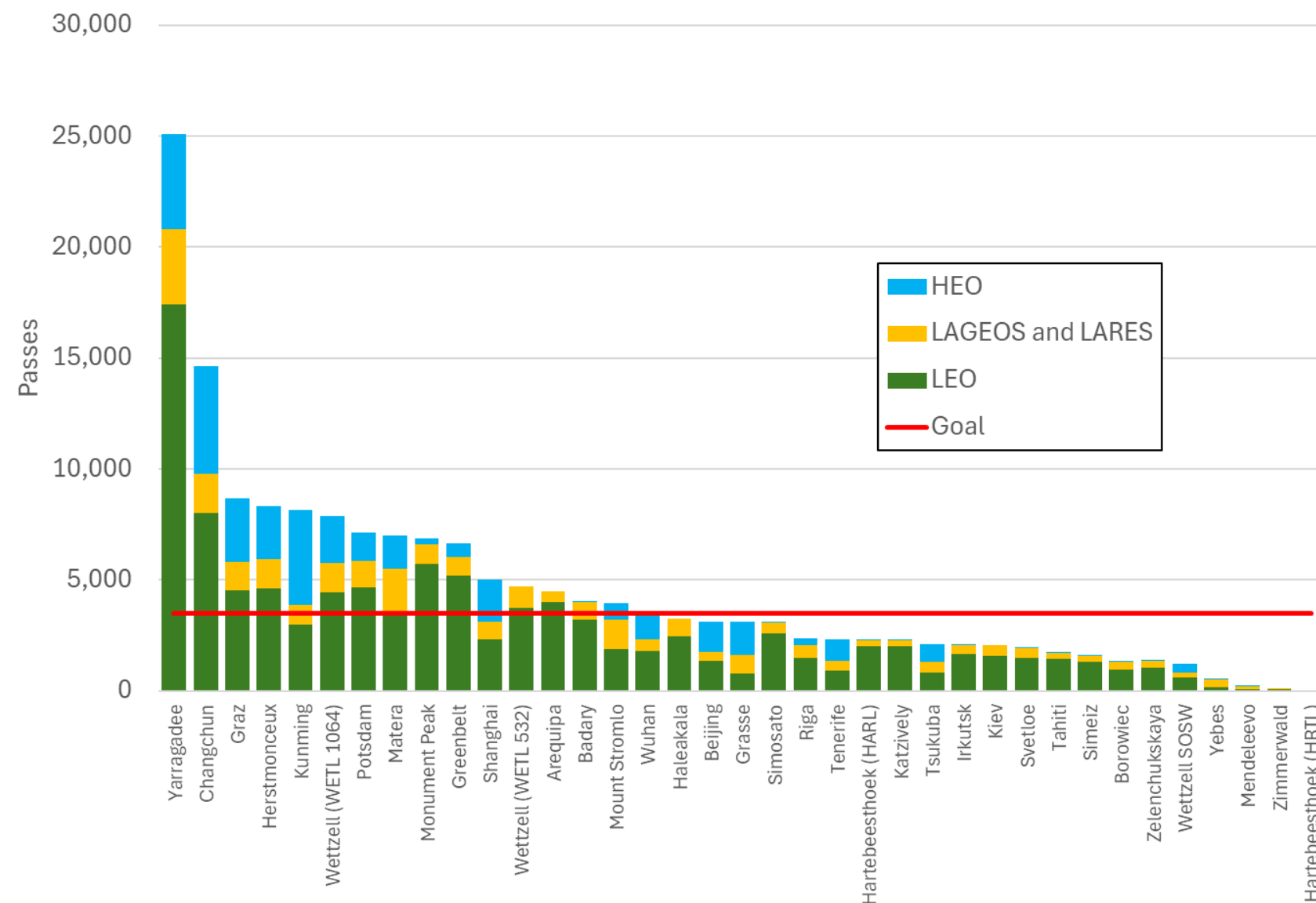


ILRS 2024 Pass Totals

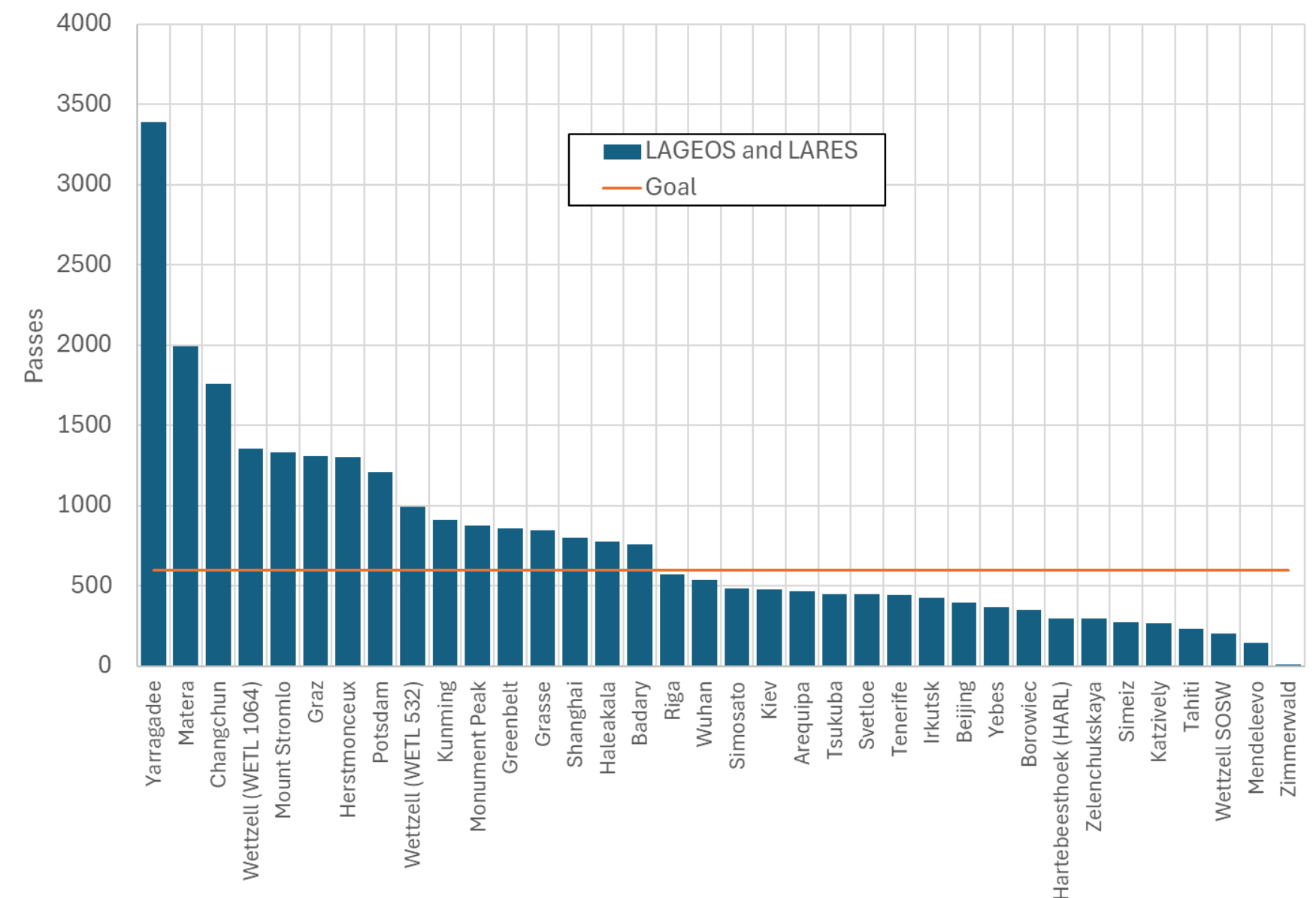
Courtesy of Van Husson



2024 ILRS Tracking Performance



2024 ILRS LAGEOS and LARES Tracking Performance

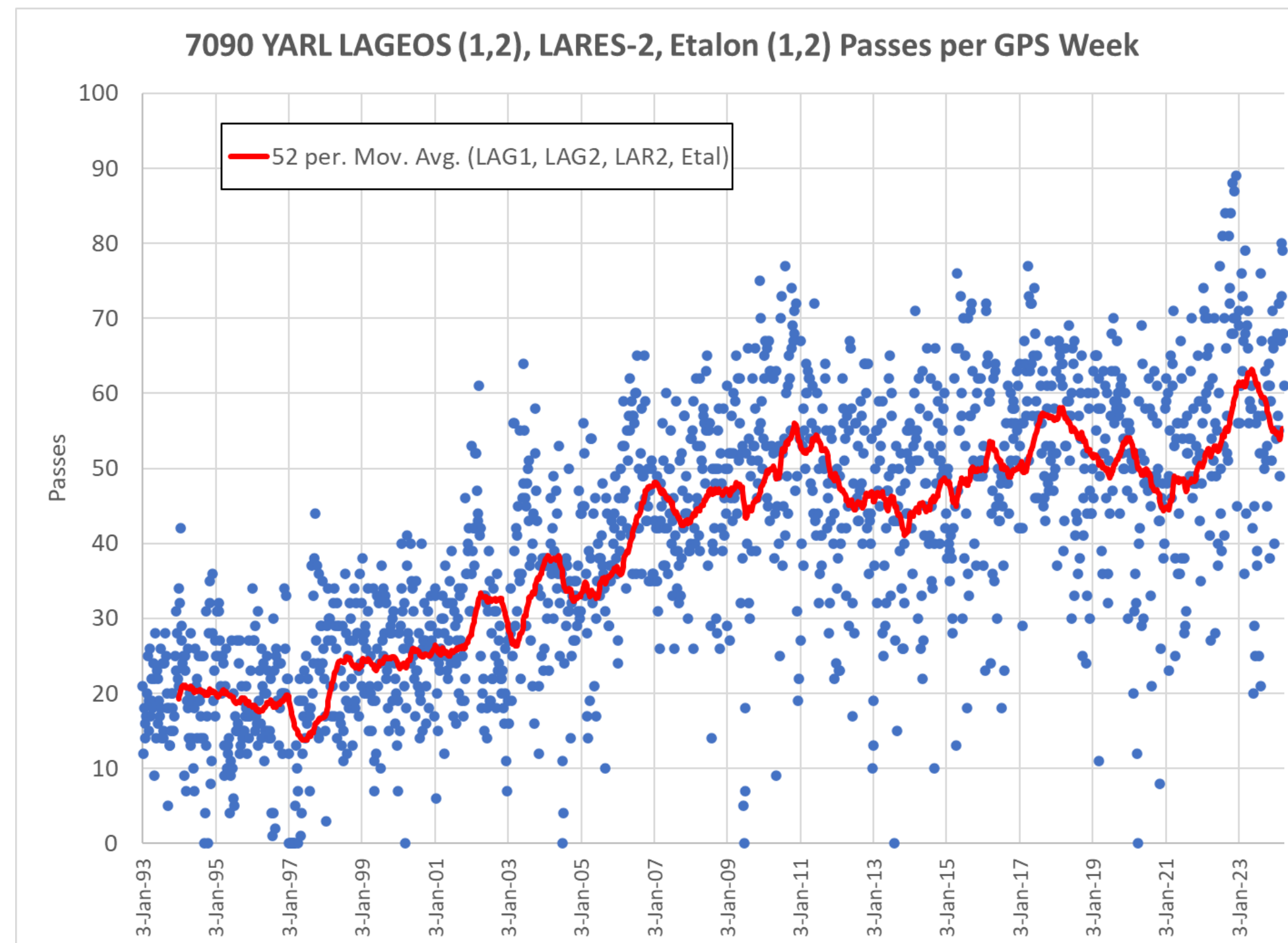
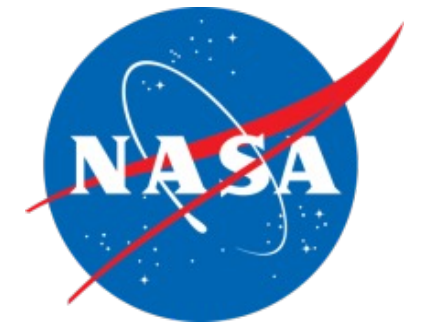


❑ Fourteen different stations met the 3500 pass requirement while fifteen different stations met the LAGEOS/LARES 600 pass requirement. Note: Wetzell (8834) tracked LEO and LAGEOS simultaneously in dual wavelengths, but not HEOs.



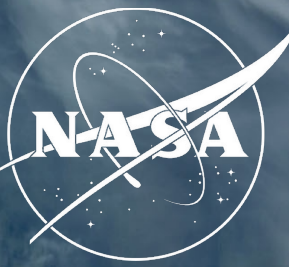
7090 YARL LAGEOS (1,2), LARES-2, and Etalon passes per GPS Week

Courtesy of Van Husson

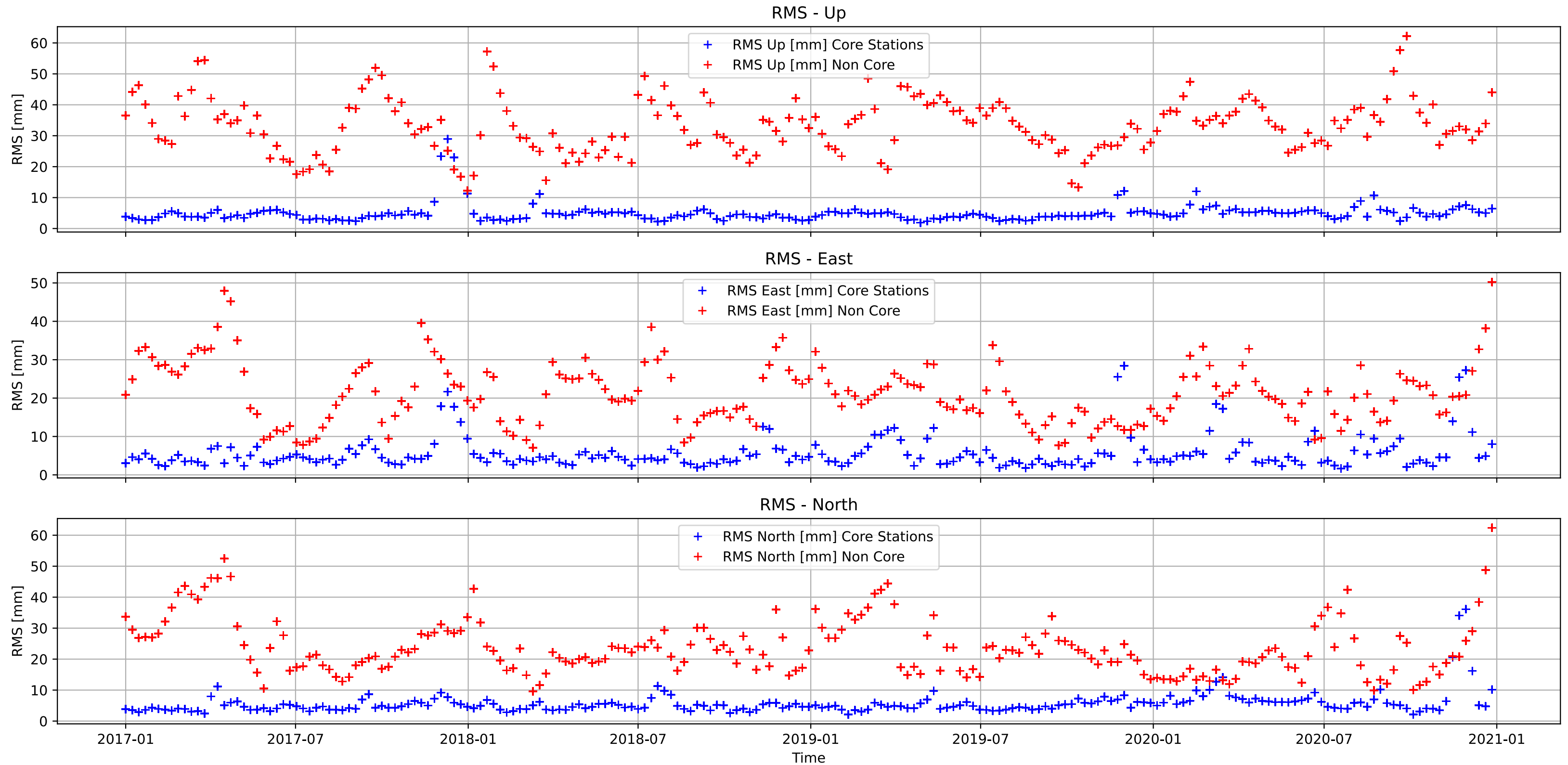


❑ The weekly 7090 pass totals do not include LARES, a LEO satellite

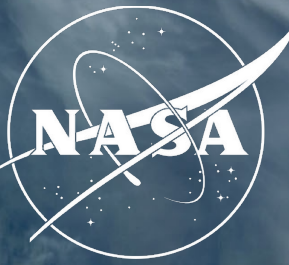
ITRF2020 residuals for core stations



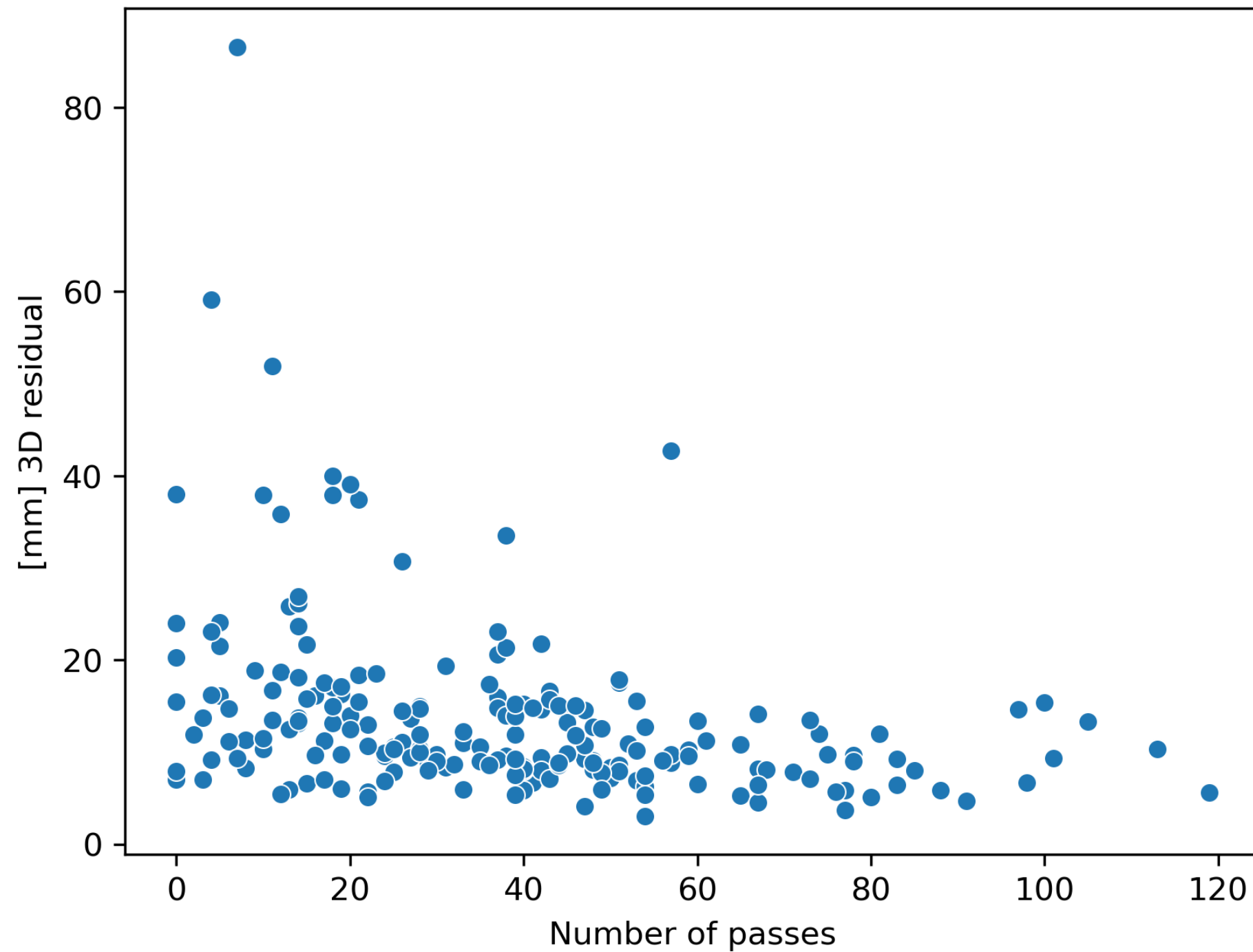
Core Stations = ['7080', '7090', '7105', '7109', '7110', '7119', '7210', '7810', '7825', '7827', '7832', '7835', '7836', '7838', '7839', '7840', '7849', '7941', '8834']



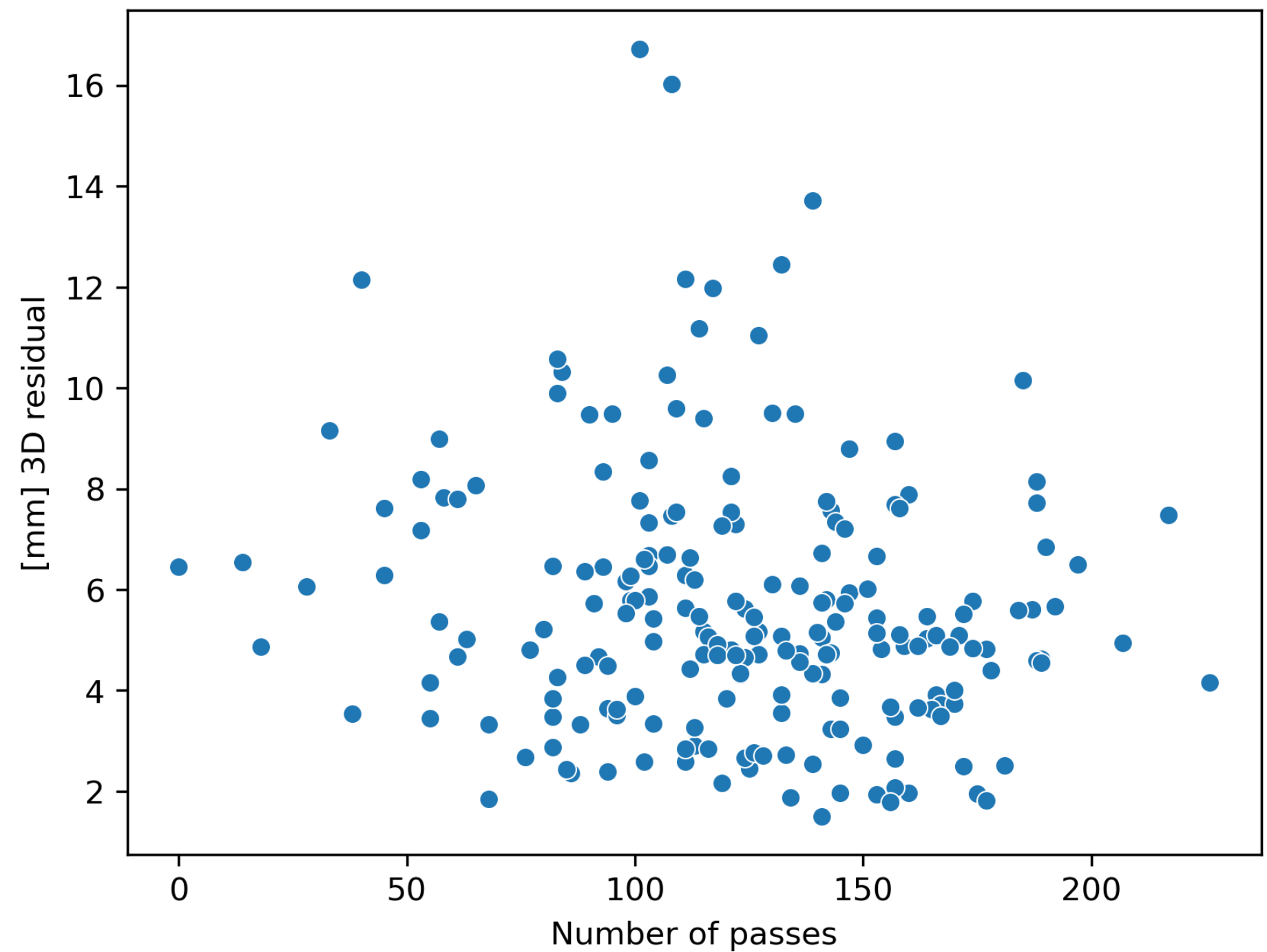
Results 1 – One station (1/2)



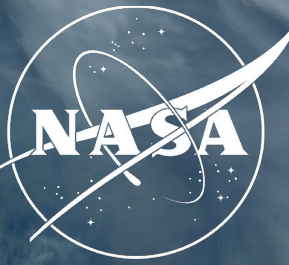
passes for 7237 Changchun



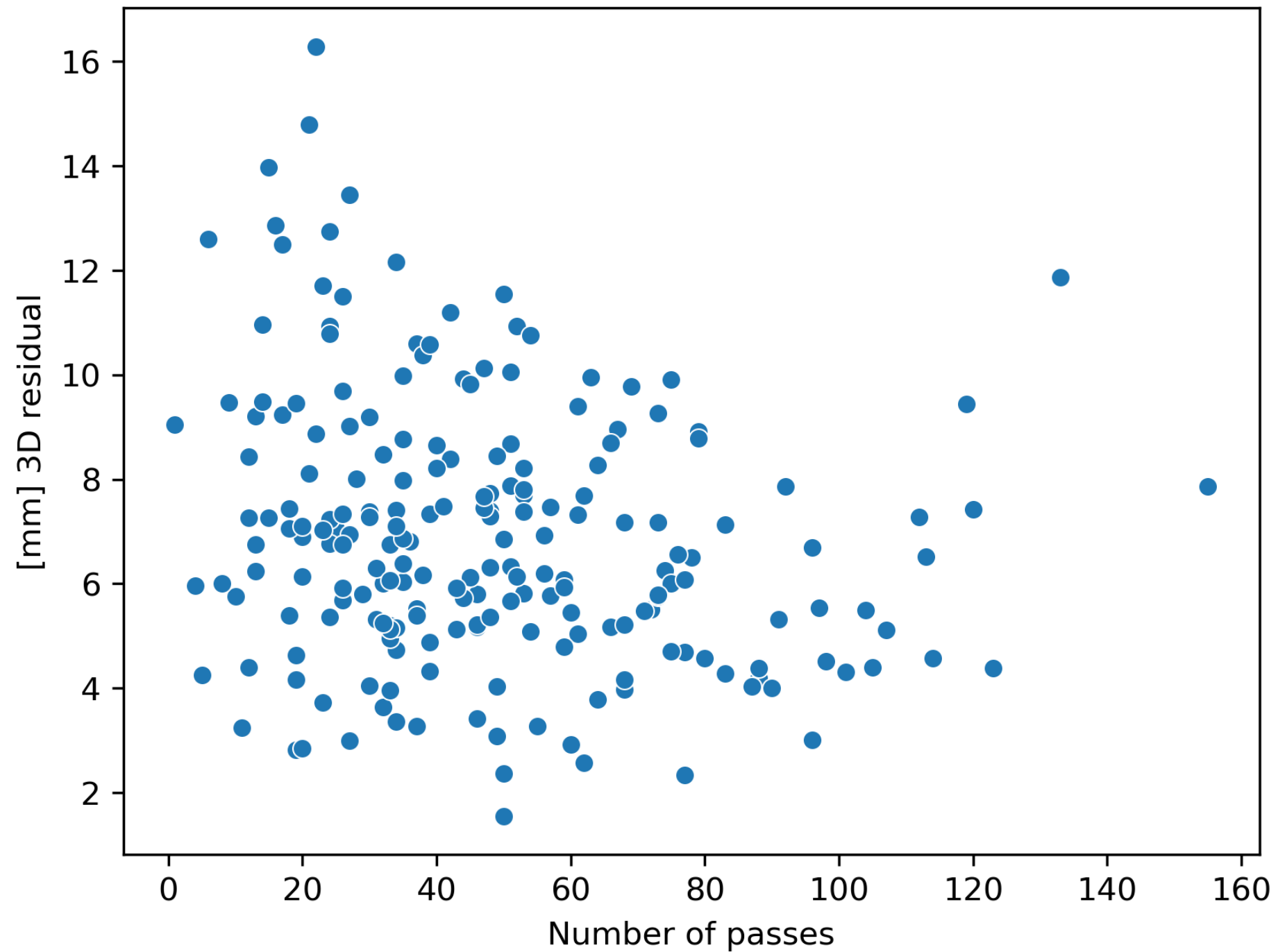
passes for 7090 Yarragadee



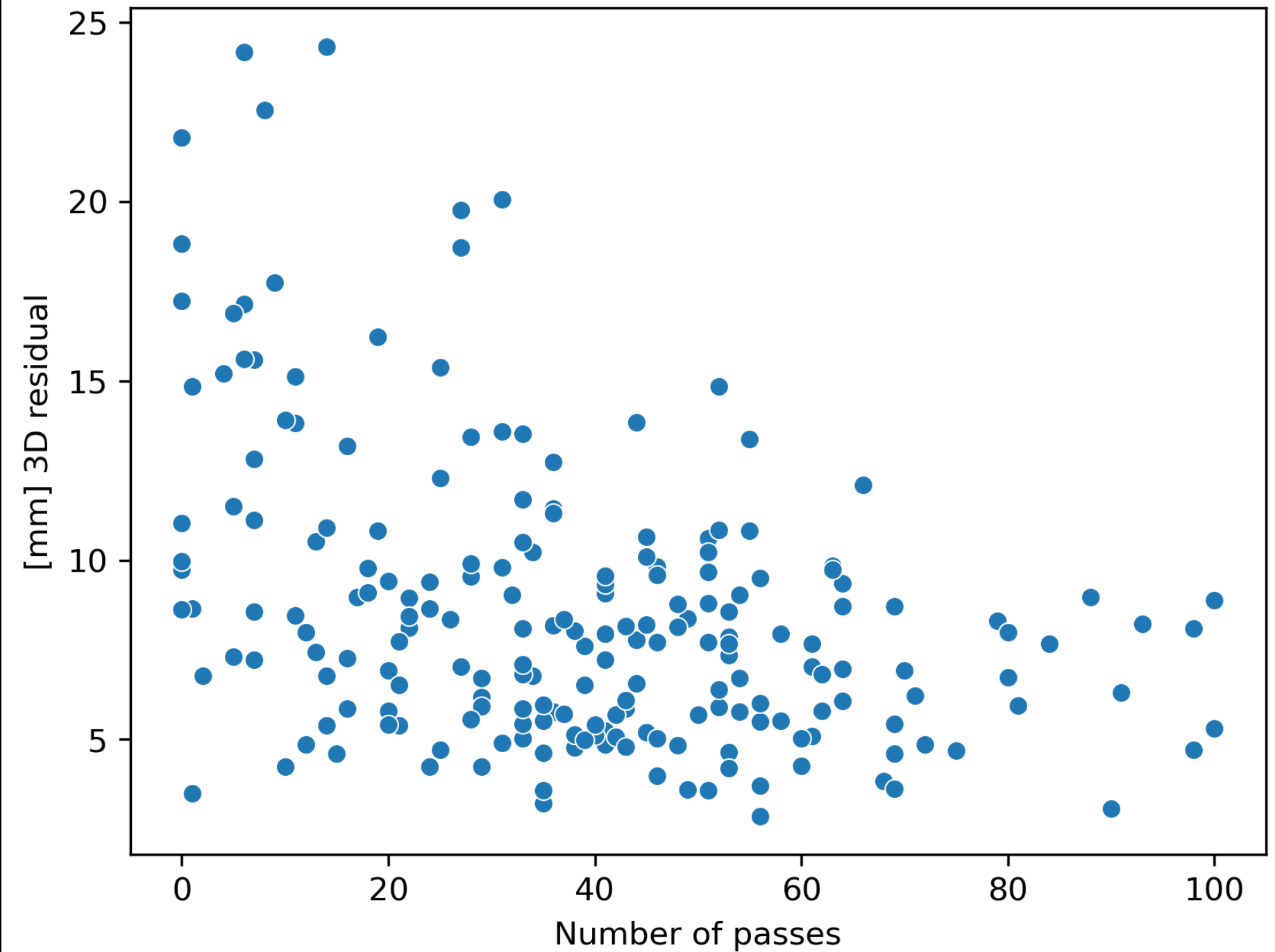
Results 1 – One station (2/2)



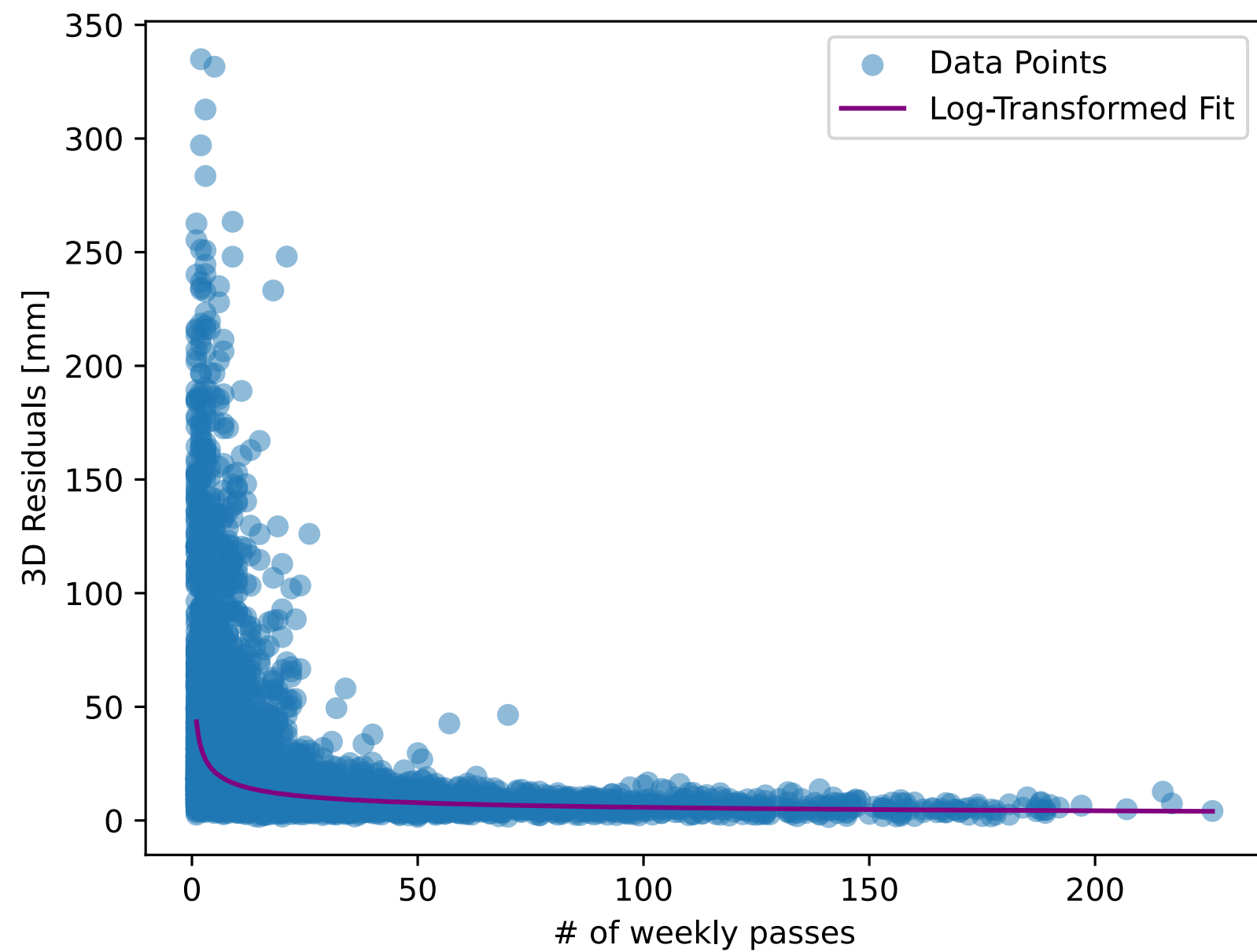
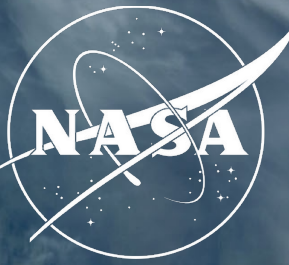
passes for 7840 Herstmonceux



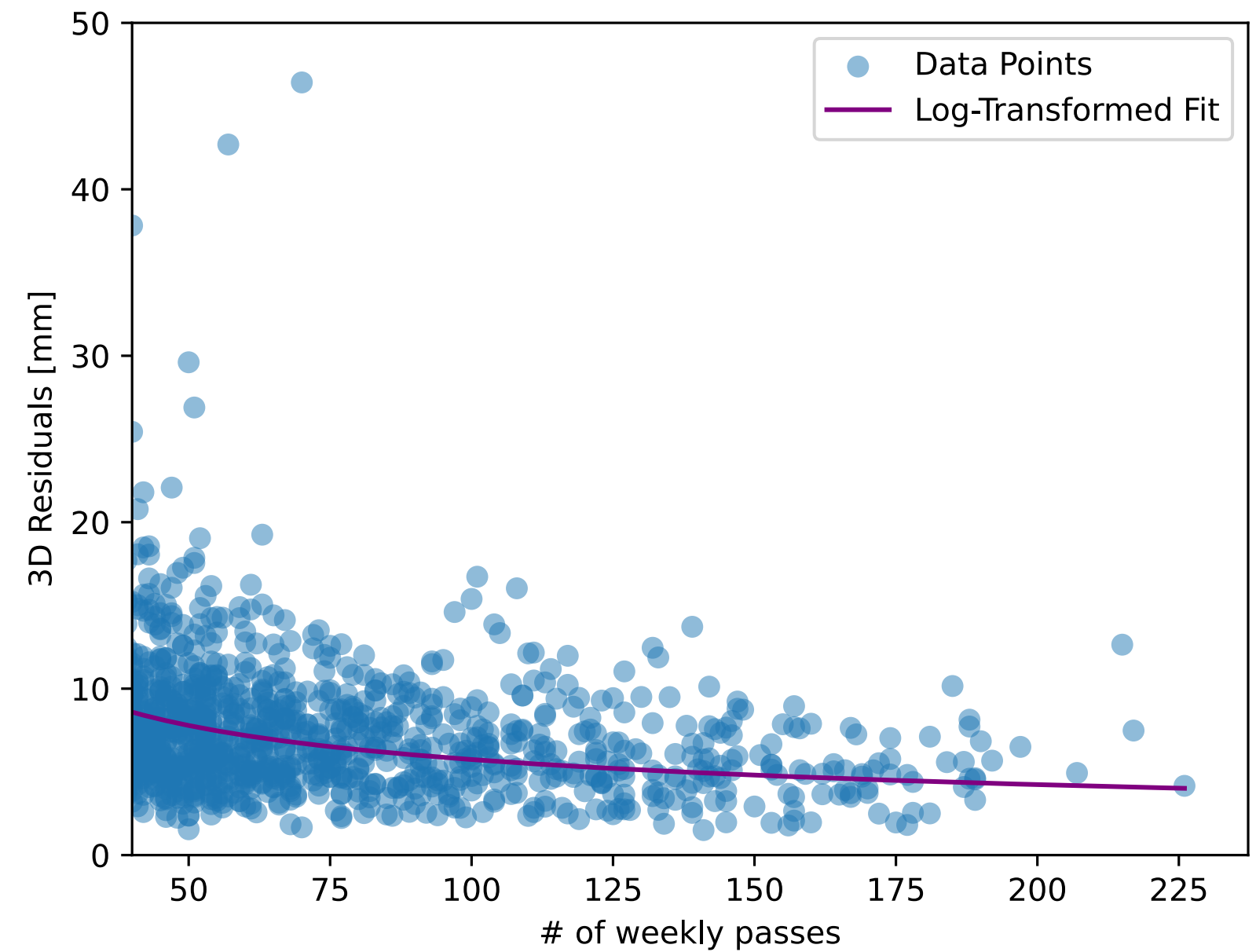
passes for 7825 Mt. Stromlo



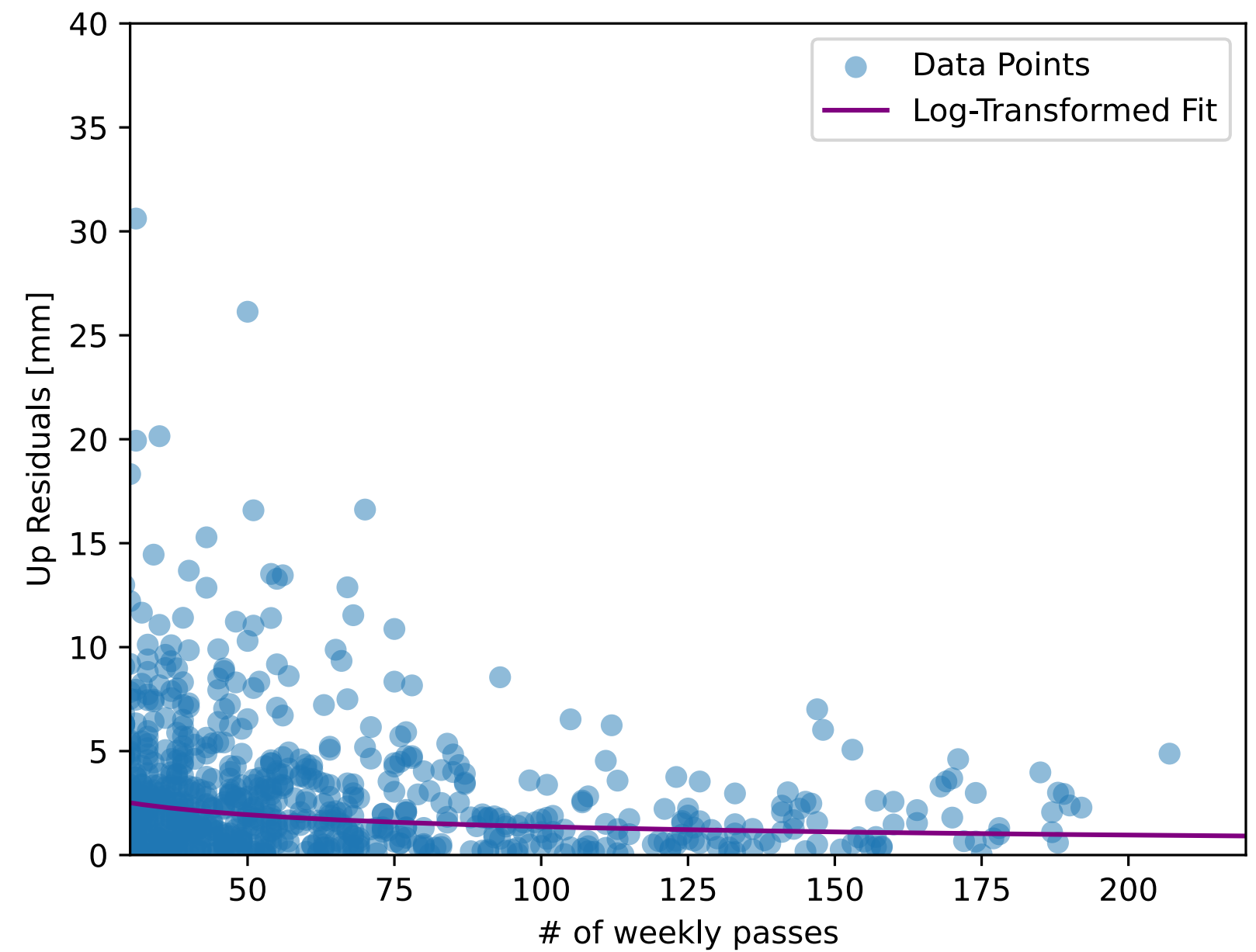
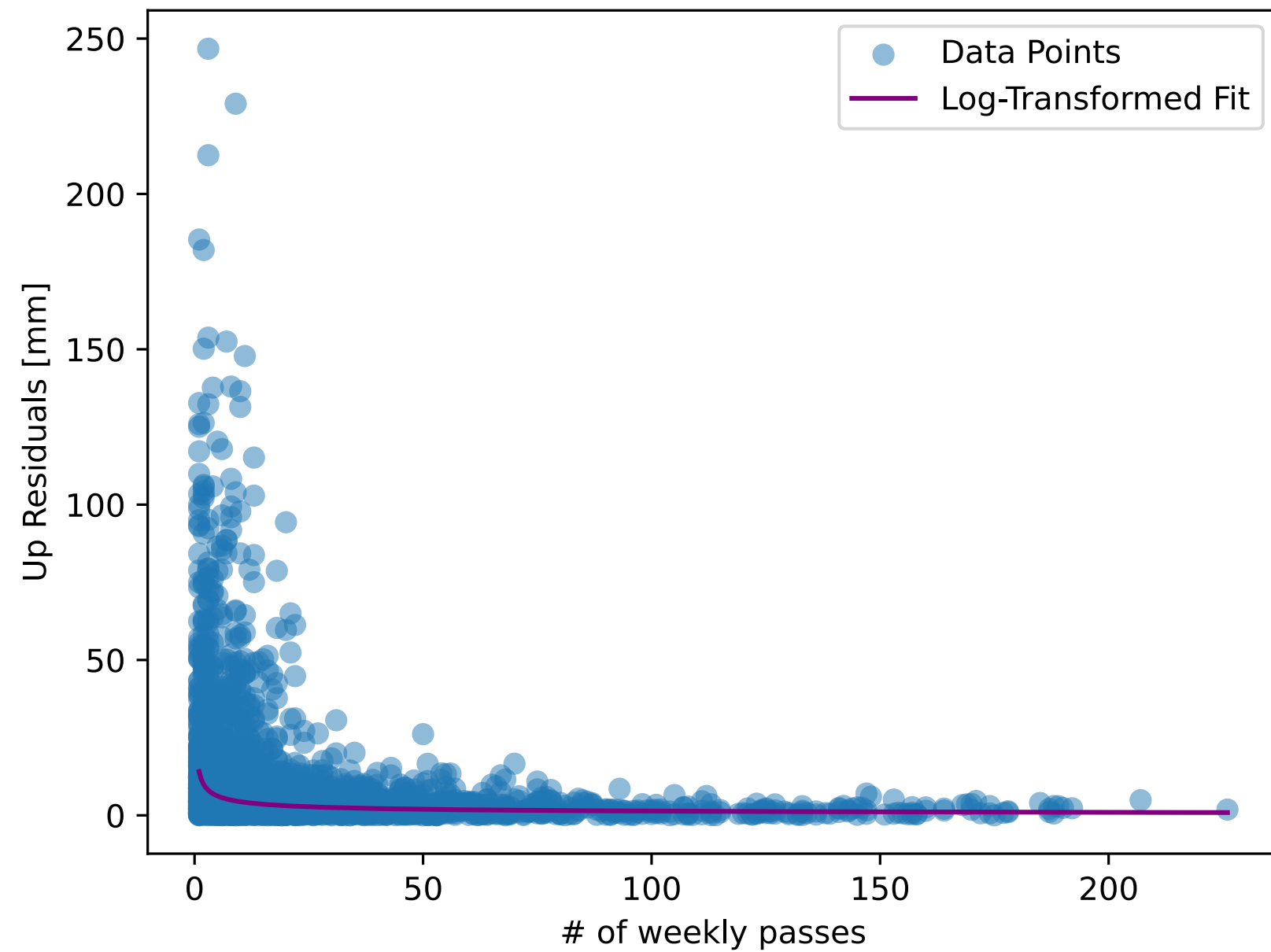
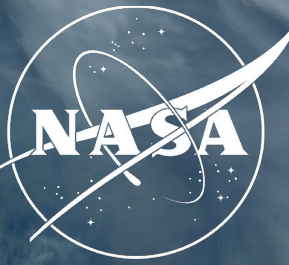
Results 2 – all stations



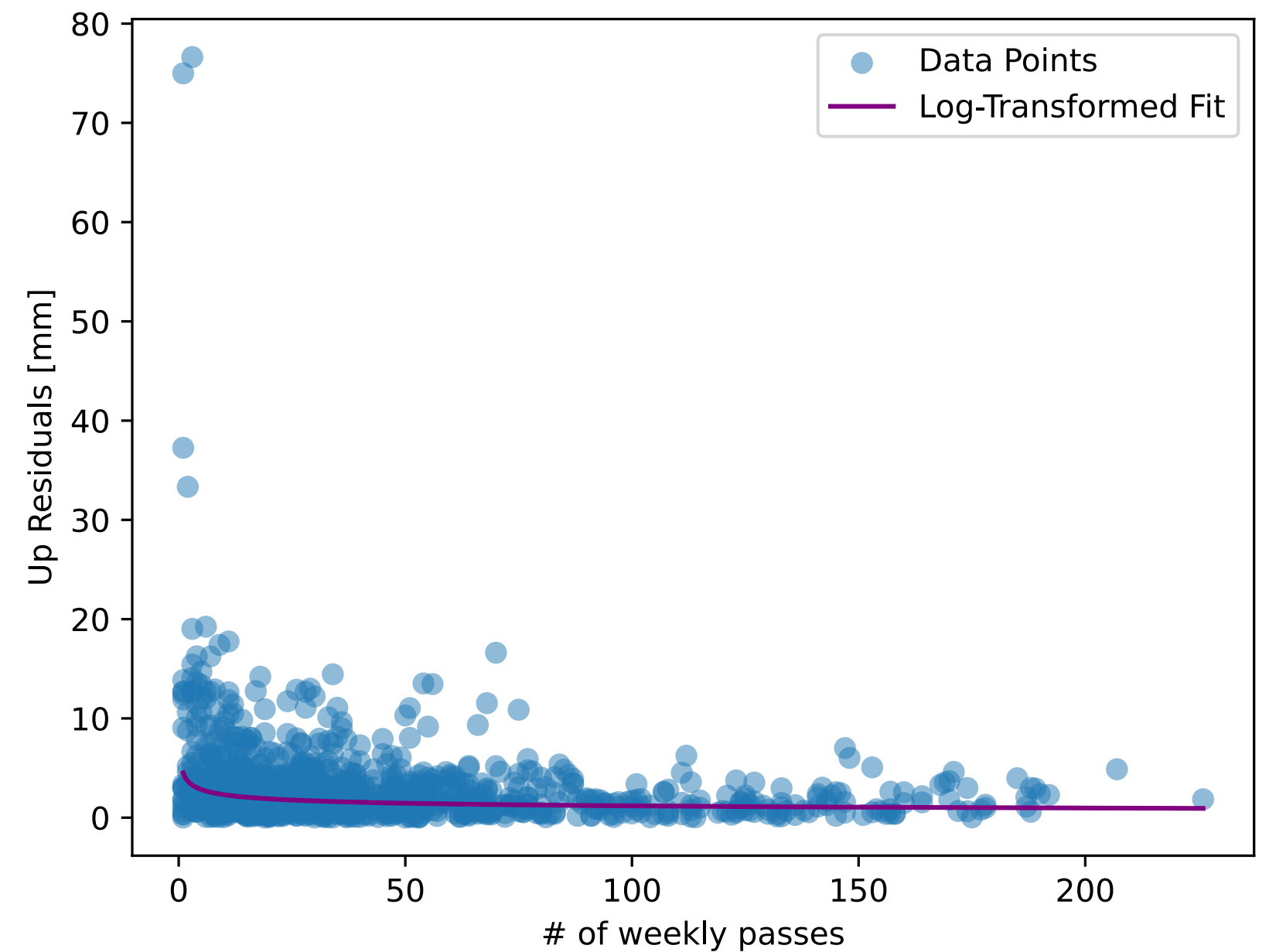
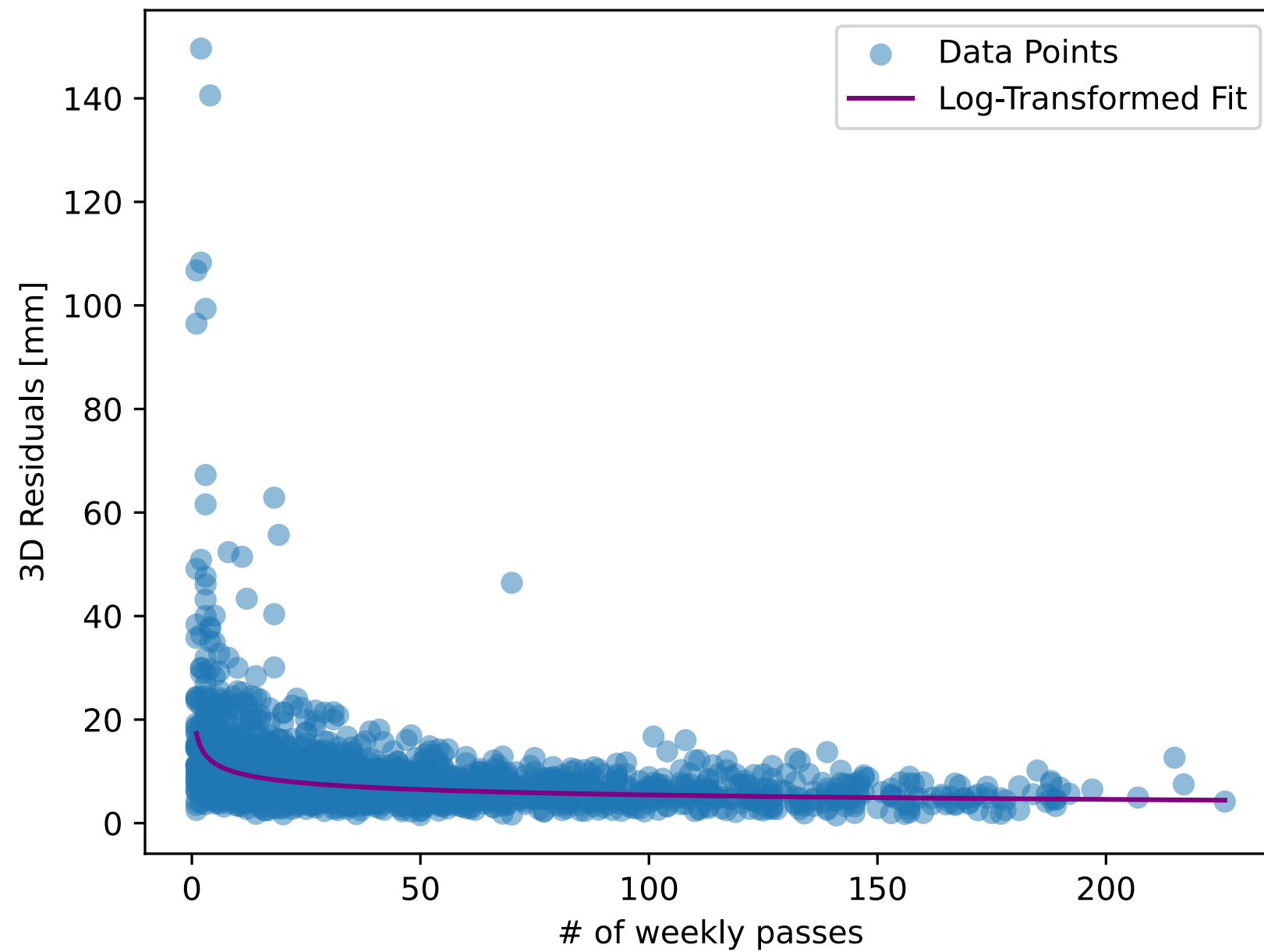
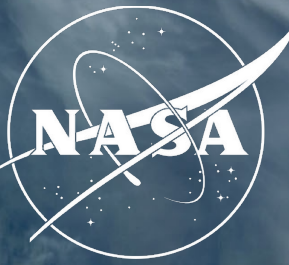
Zoom



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

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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

NETWORK PERFORMANCE BASED ON LAGEOS 1 & 2

Information available for 2010 and beyond

Satellite

Lageos2 ▾

Start (YYYY-MM-DD):

2024-01-01

End (YYYY-MM-DD):

2025-12-31

Minimumn elevation [°]

30 ▾

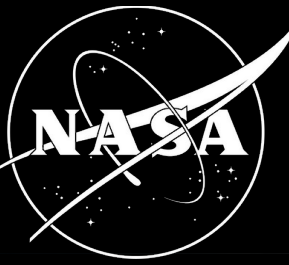
STATIONS ☐ Select All

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

- ☐ 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

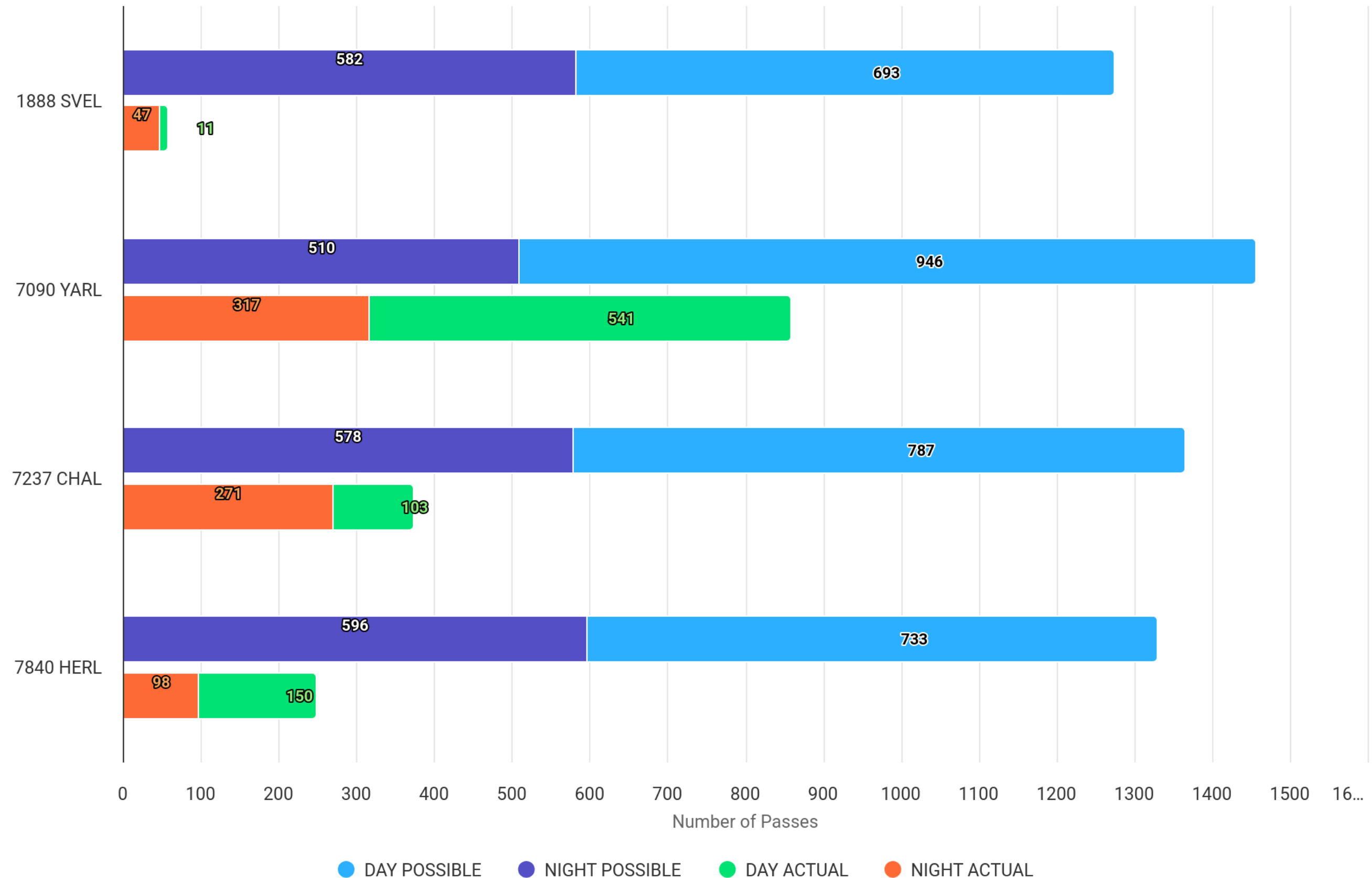
Submit

Is it feasible?

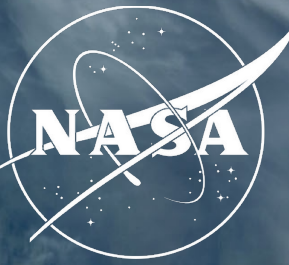


DAY vs NIGHT & ACTUAL vs POSSIBLE PASSES for LAGEOS2

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



Future Work



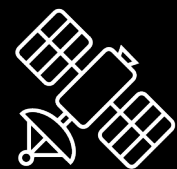
Impact of the number of passes on the EOP, Gravity Coeff, LOD...



Impact of the number of passes on the Origin and Scale



ITRF2020 extension



Consider the impact of LARES-2



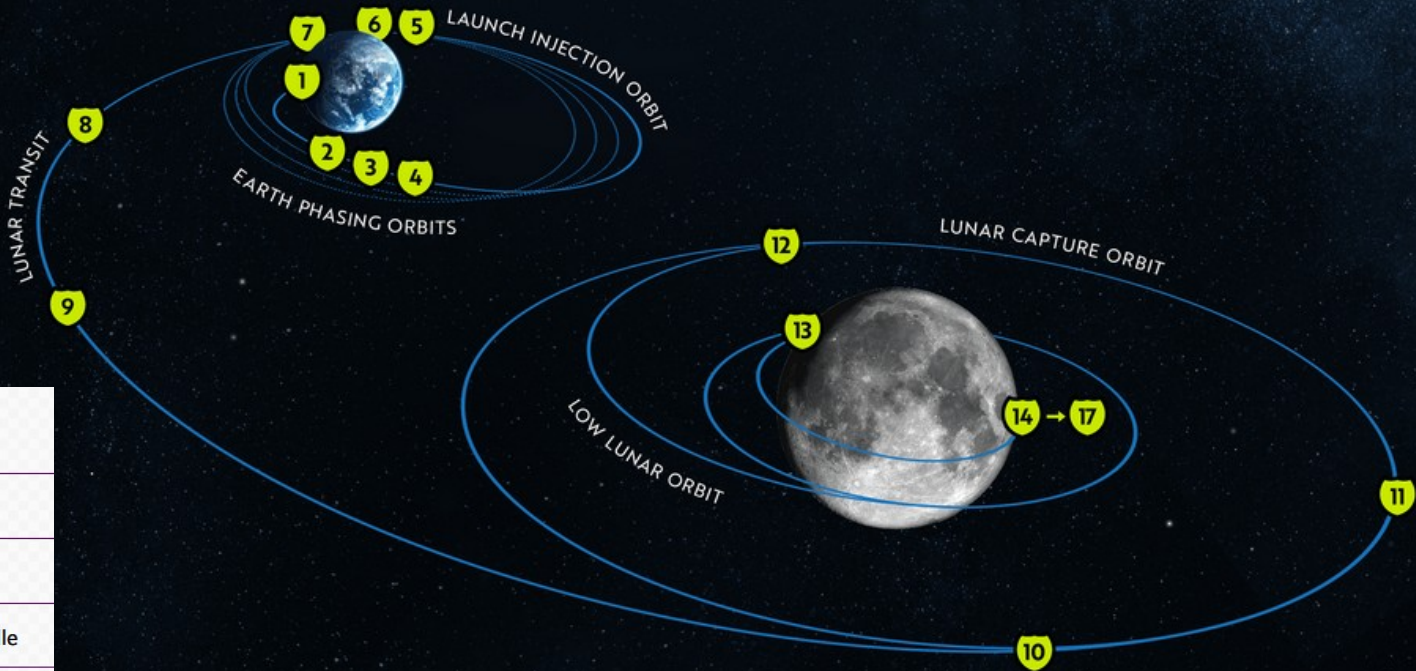
NESC - ILRS

news



NGLR : heading for the Moon

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

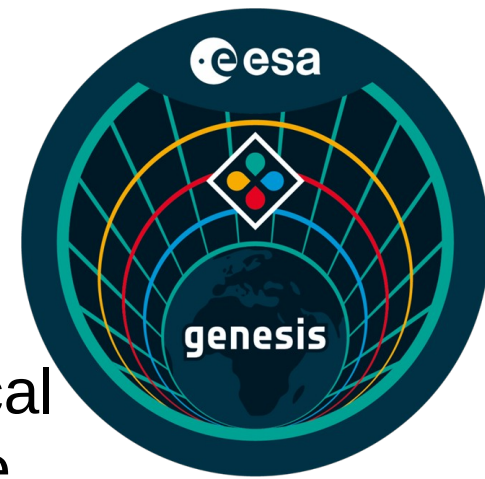


Launch Date: January 15, 2025
Landing Date: March 2, 2025
Landing Time: TBA
Landing Site: Mare Crisium near Mons Latreille

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



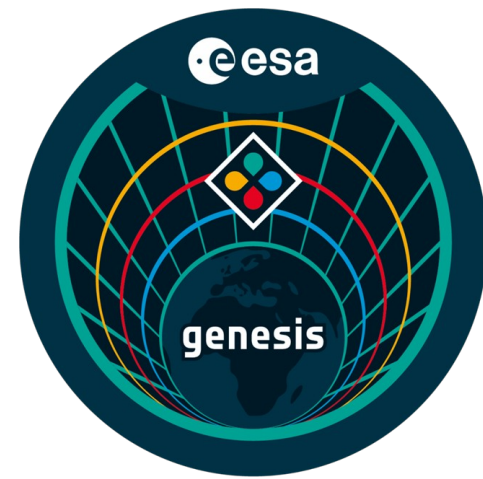
GENESIS



- 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 3Mm2 to 7 Mm2
 - January 2025: ILRS recommendation to ESA for the 7Mm2 option



GENESIS



- 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 2nd 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.

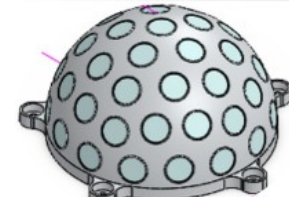
Do ESA and ILRS endorse LaRCo @ Frascati?



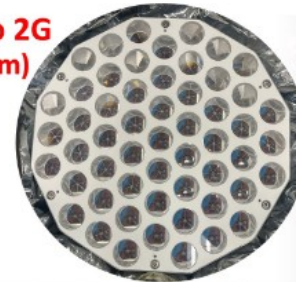
LARES-2 (~6k km)



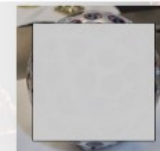
Genesis (~6k km)



Galileo 2G (~23k km)



COSMO-SkyMed Second Generation (~600 km)

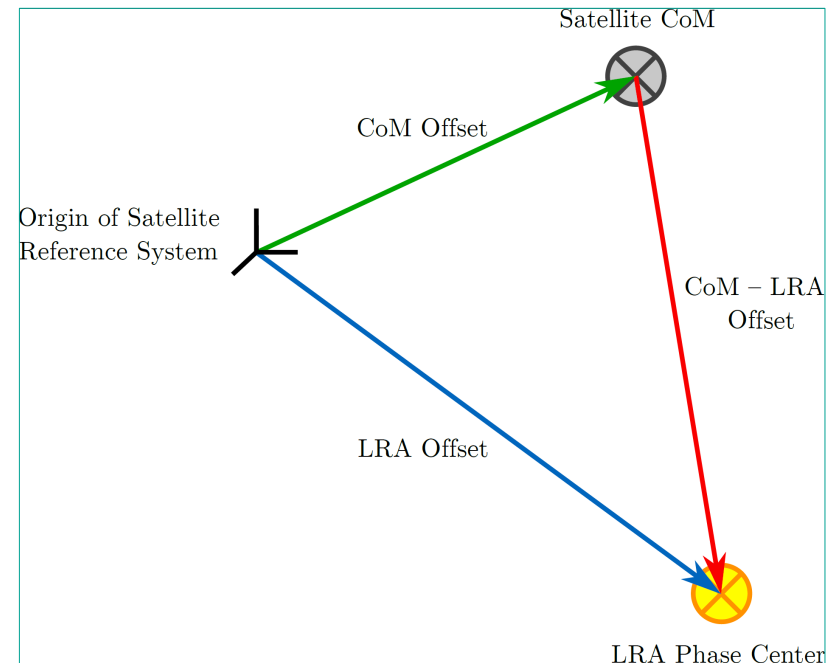




Measuring the Laser ranging correction with level of accuracy required by Genesis

- 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