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

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

DLR

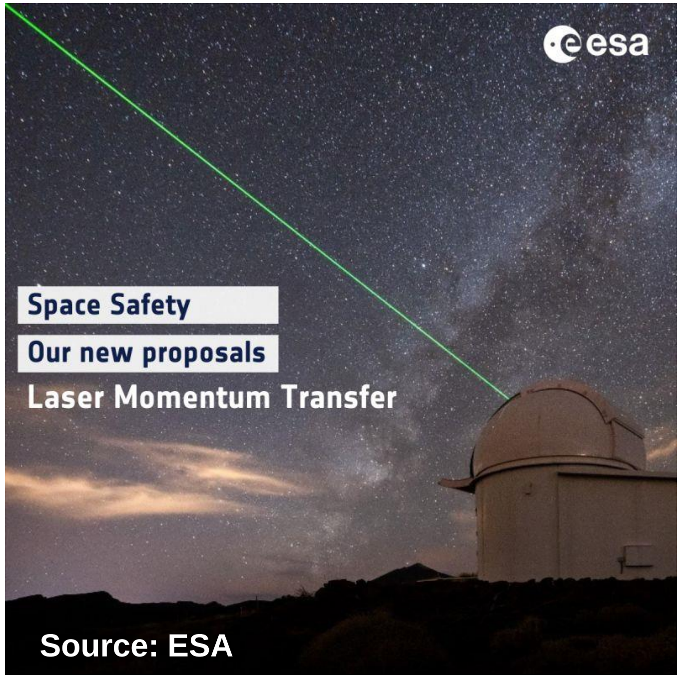
ALGORITHM FOR DETECTING AIRBORNE OBJECTS WITH A THERMAL INFRARED CAMERA TO ENSURE A SAFE OPERATION OF LASER-OPTICAL GROUND STATIONS

DLR / Paul Wagner

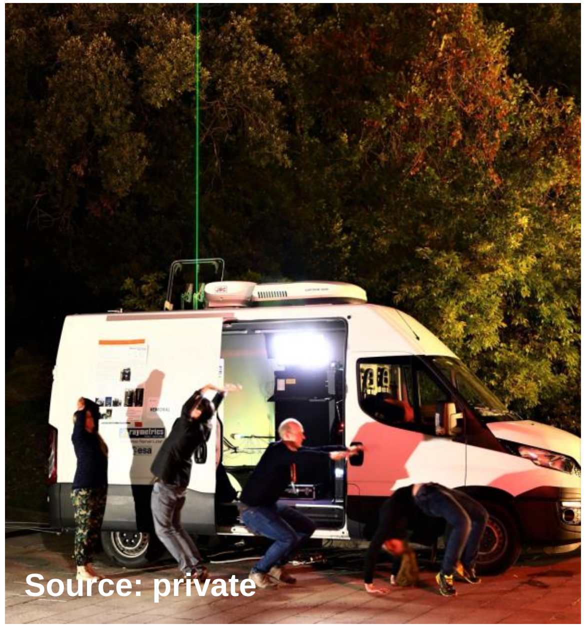
Lasers in public airspace

Satellite/space debris laser ranging

Laser communication



Laser momentum transfer

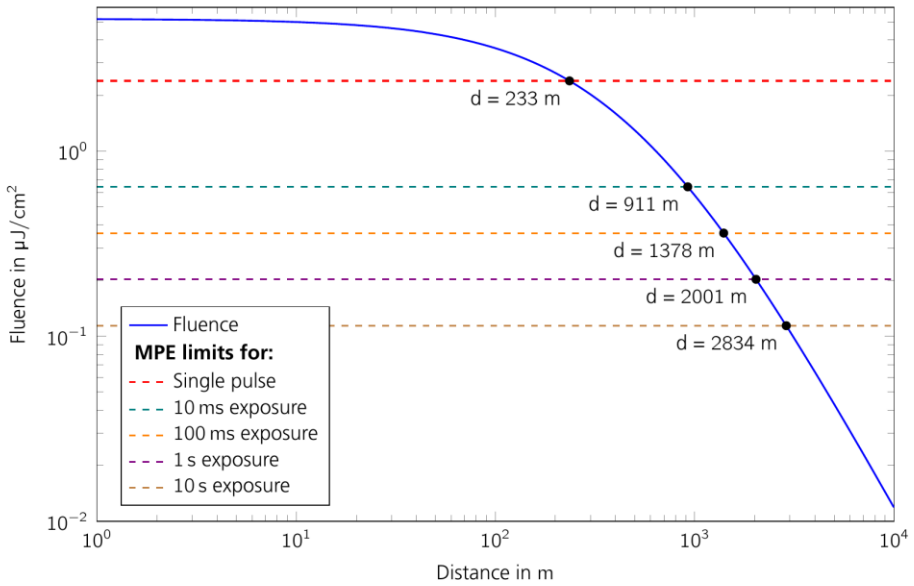


(Atmospheric) LIDAR

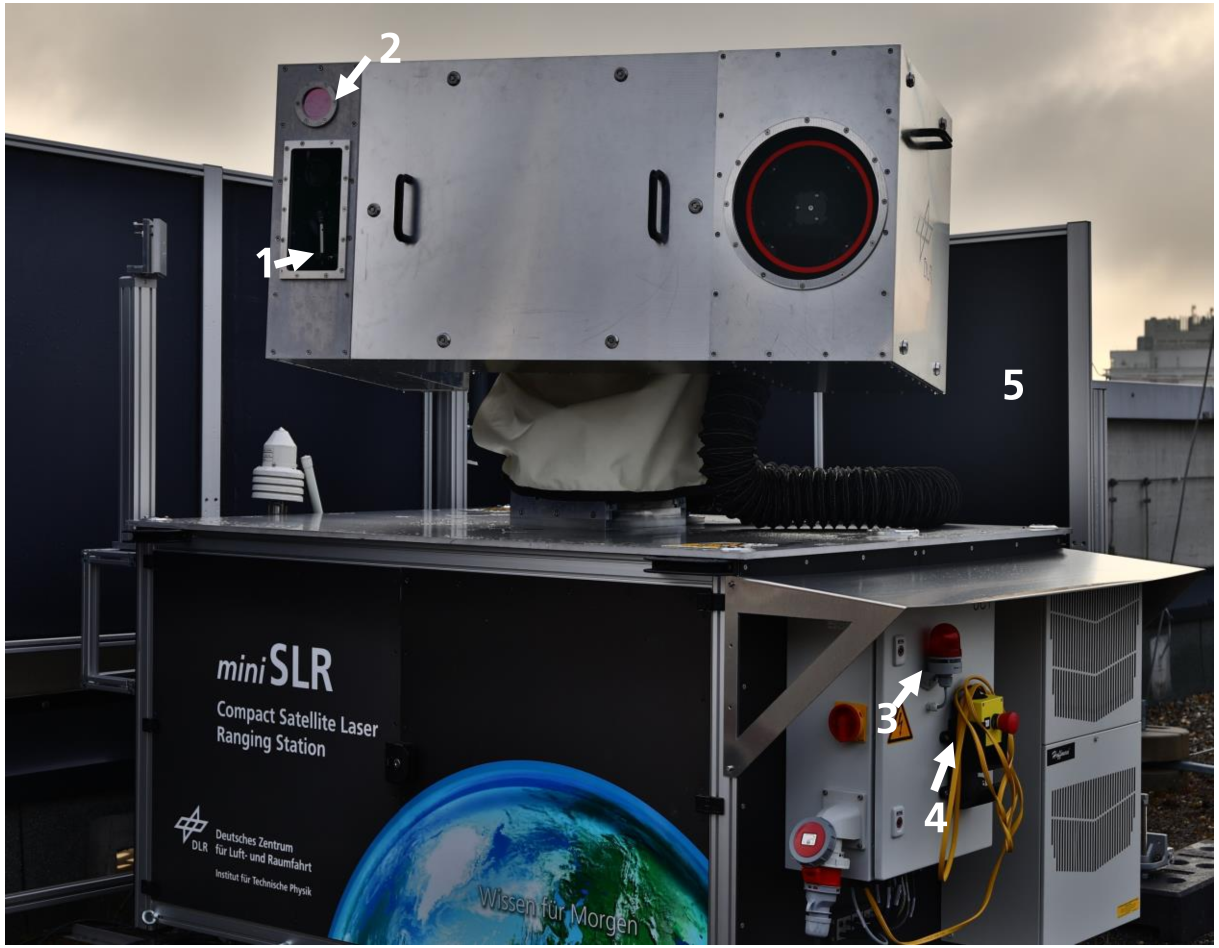
For fun/advertisement…

Laser safety at miniSLR®

Laser parameters miniSLR®	
Wavelength	1064 nm
Pulse energy	85 µJ
Pulse duration	500 ps
Pulse repetition rate	50 kHz
Beam divergence	50 µrad
Beam diameter (transmitter exit)	5 cm



→ Laser safety system needed

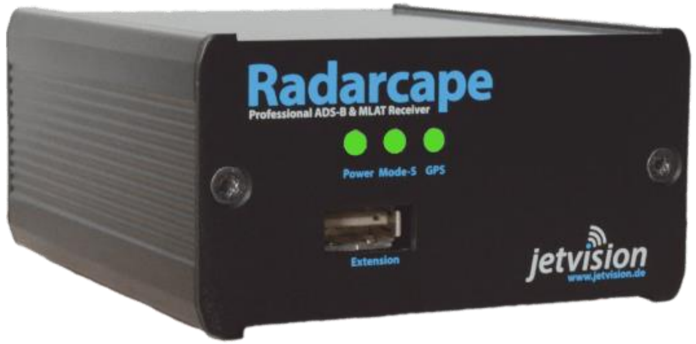


1 = laser transmitter window, 2 = Germanium window of the thermal infrared camera, 3 = laser warning lamp, 4 = emergency stop button (4), and physical laser safety barriers (5).

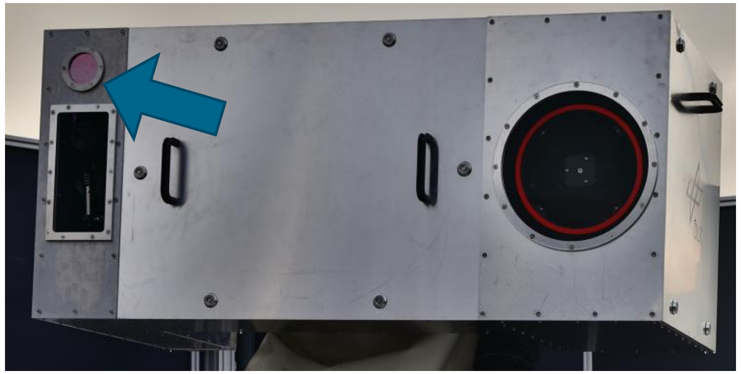
Laser safety at miniSLR®

Radar (as data stream from air traffic control)	ADS-B receiver	Thermal infrared camera

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



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

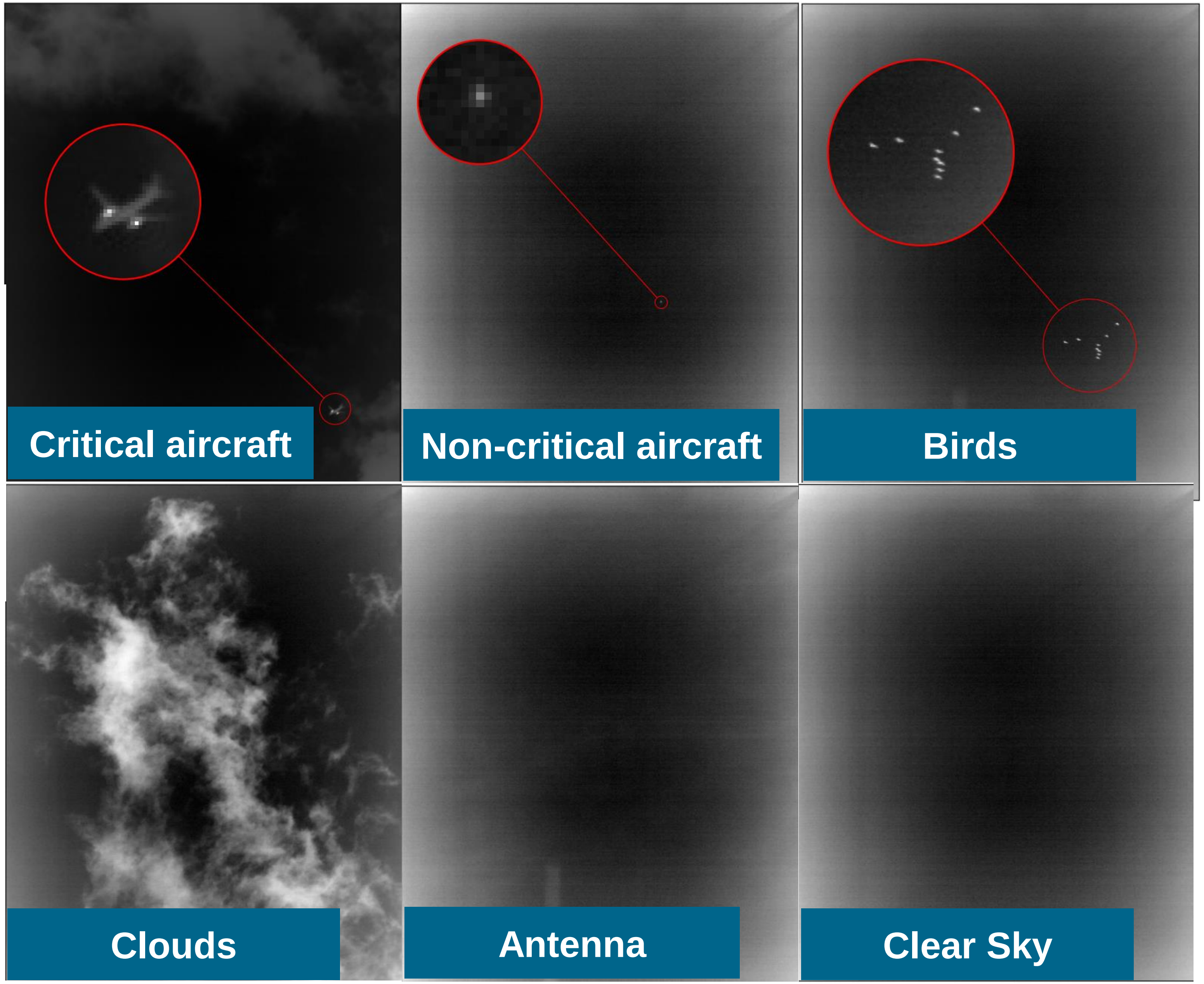


Key task: Reliable detection of aircraft from thermal infrared images.

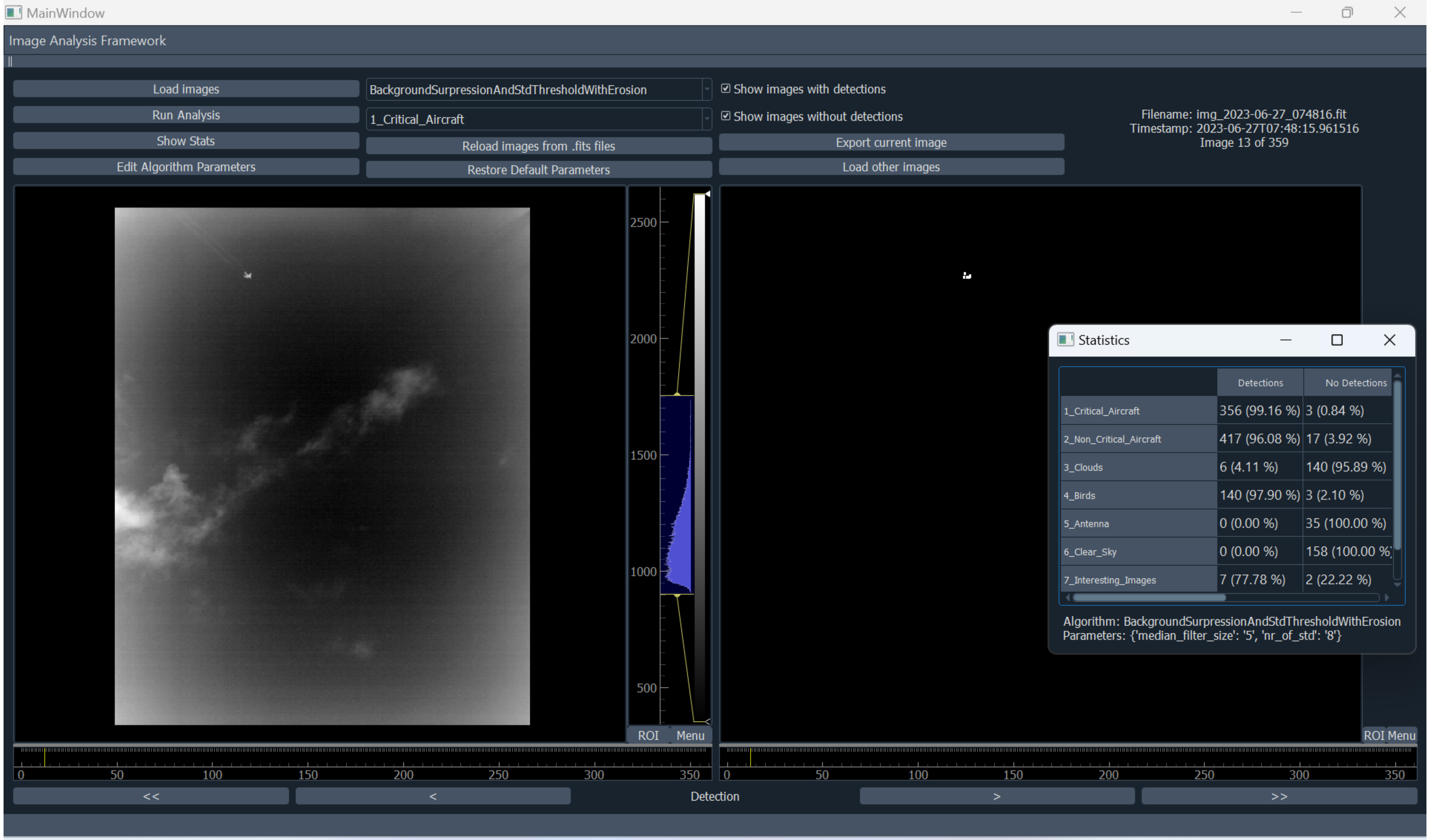
Dataset

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



Simple comparison of different algorithms and parameters…

Results

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

ICSES 2008 International Conference on Signals and Electronic Systems
Kraków, September 14-17, 2008

SIGNALS AND ELECTRONIC SYSTEMS
INTERNATIONAL CONFERENCE

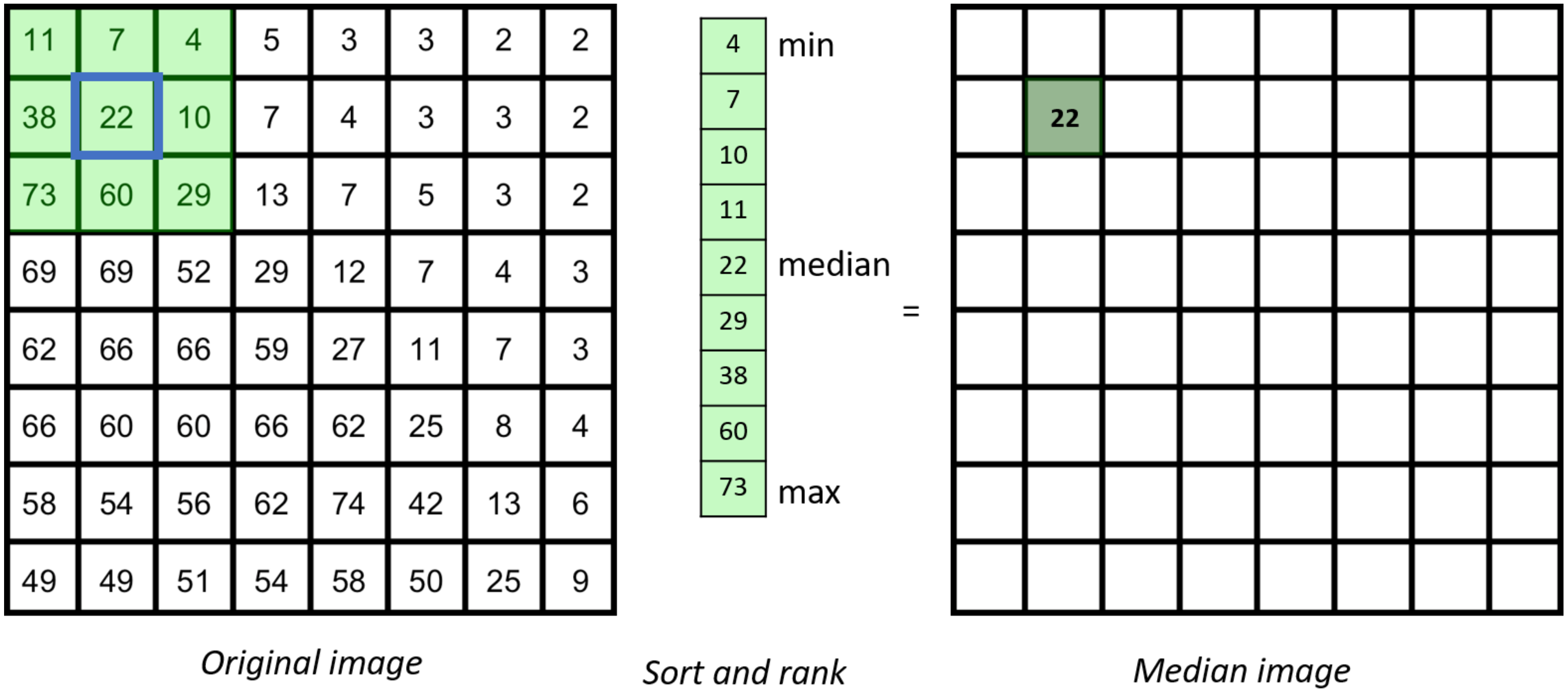
Object detection in grayscale images based on covariance features

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

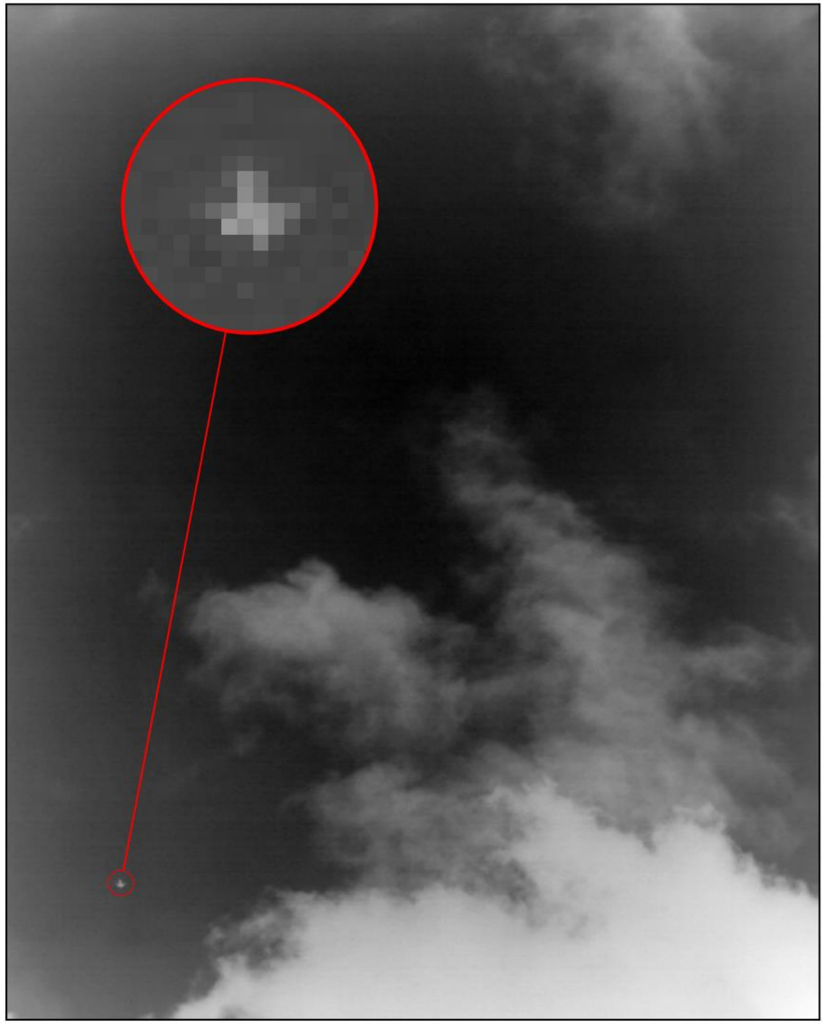
What is a median filter?



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

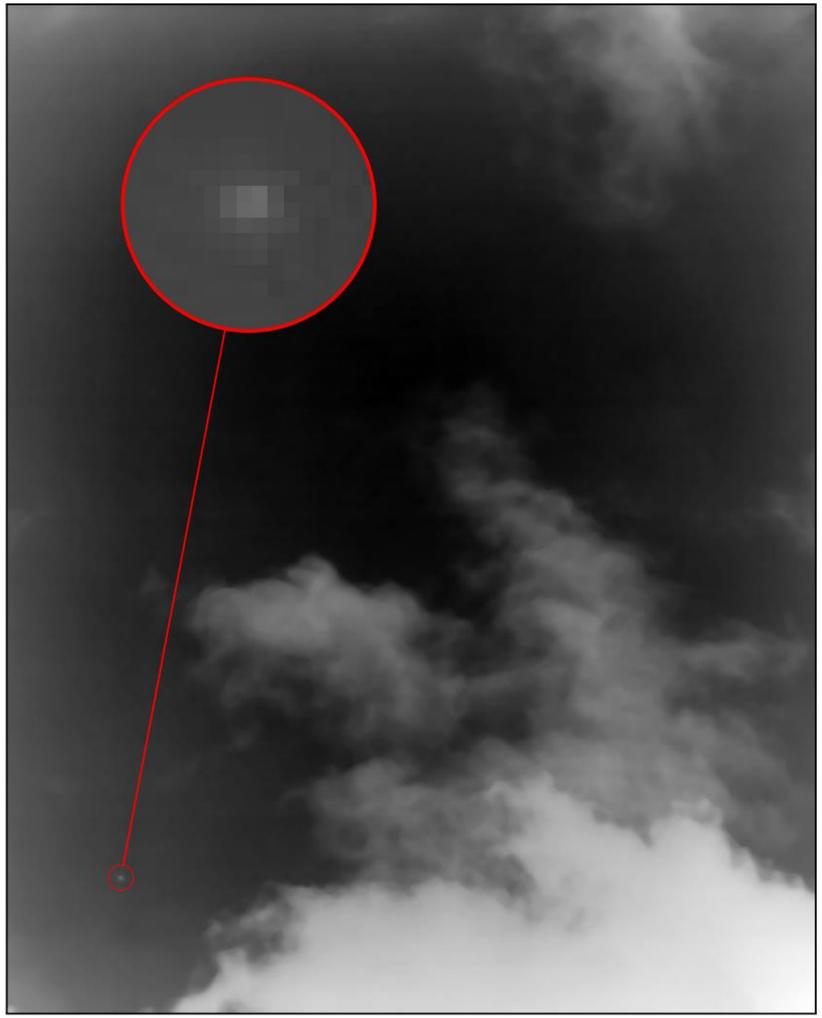
Median filter for noise reduction

Original image



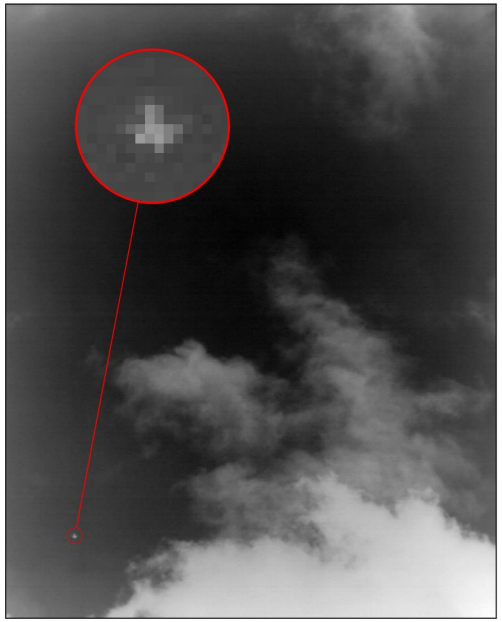
Median-Filter

Image after 5x5 median filtering

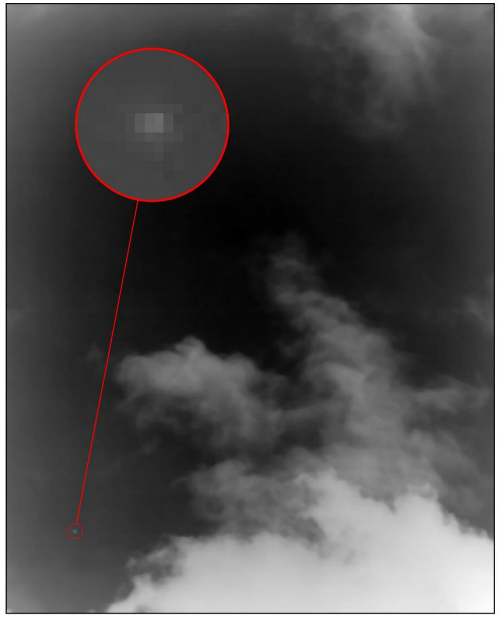


Median filter for background subtraction

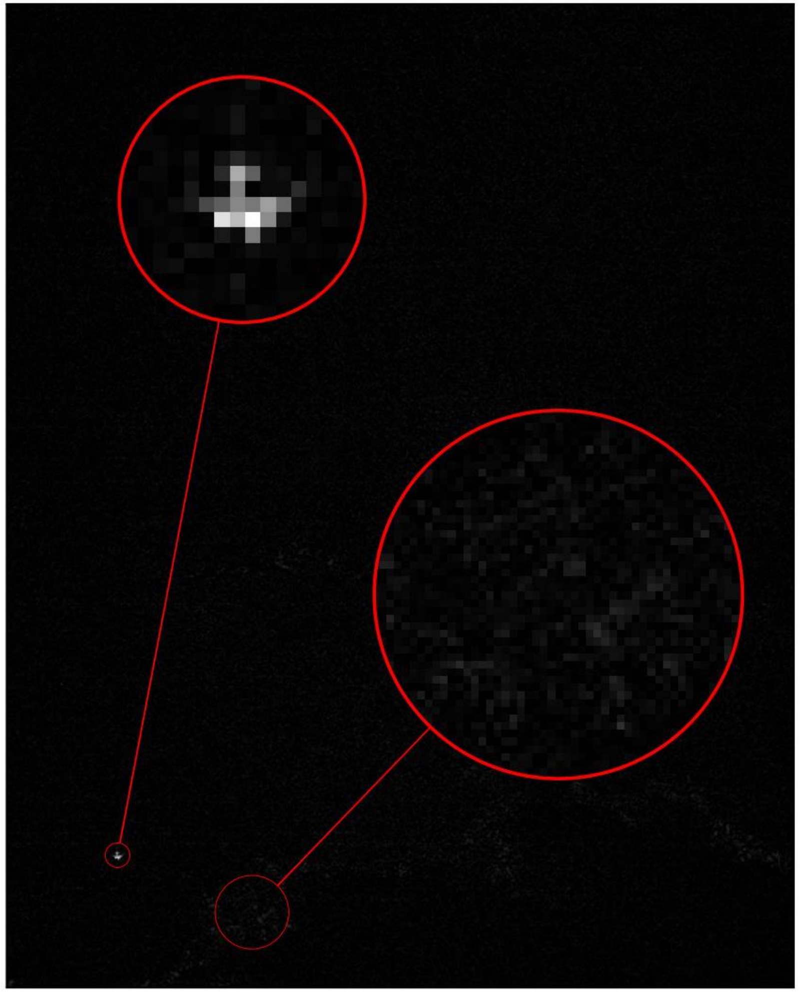
Original image



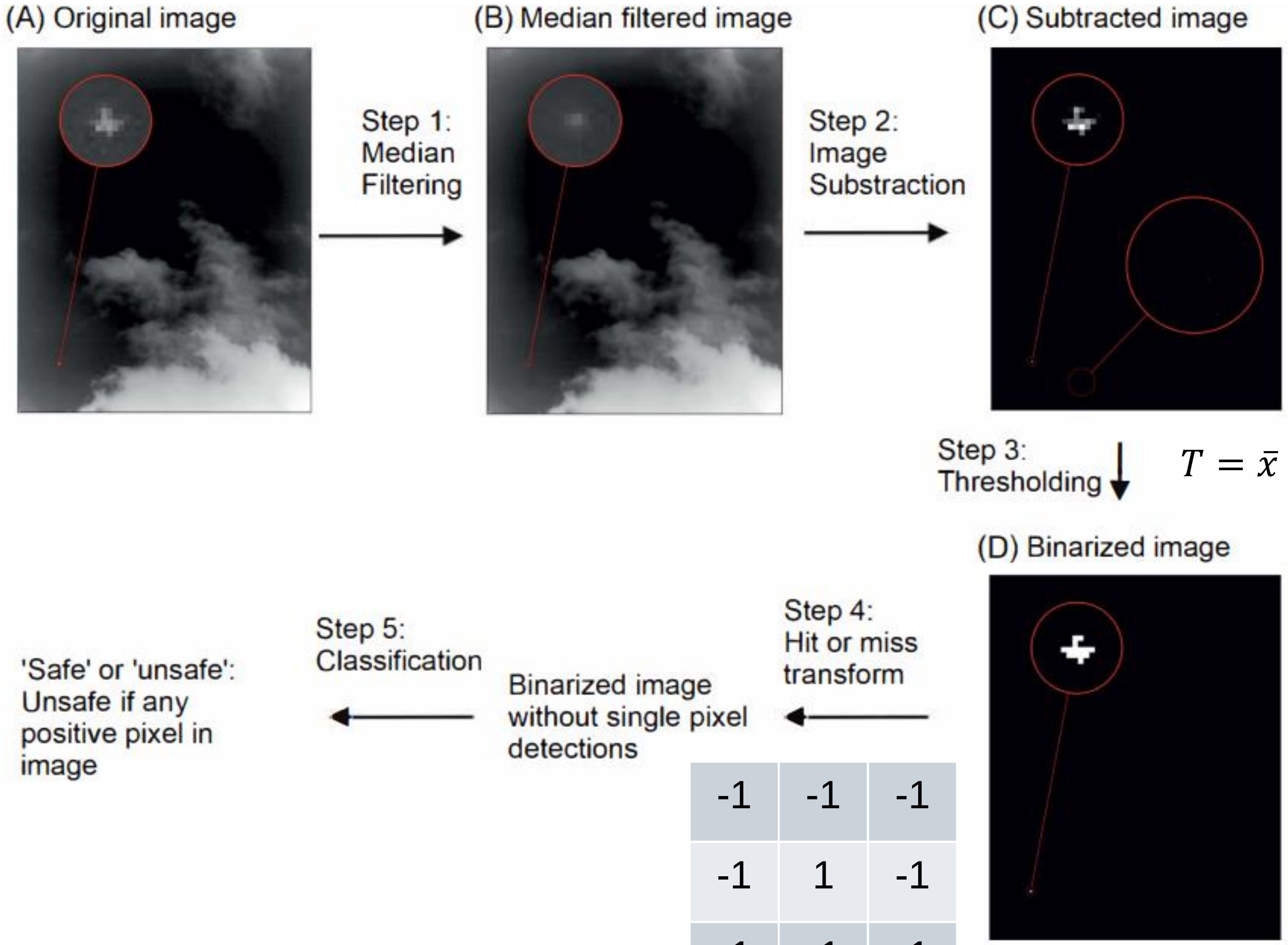
Background



Aircraft (& noise)



Proposed algorithm



$$T = \bar{x} + k\sigma$$

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

Optimization of parameters

Threshold optimization:

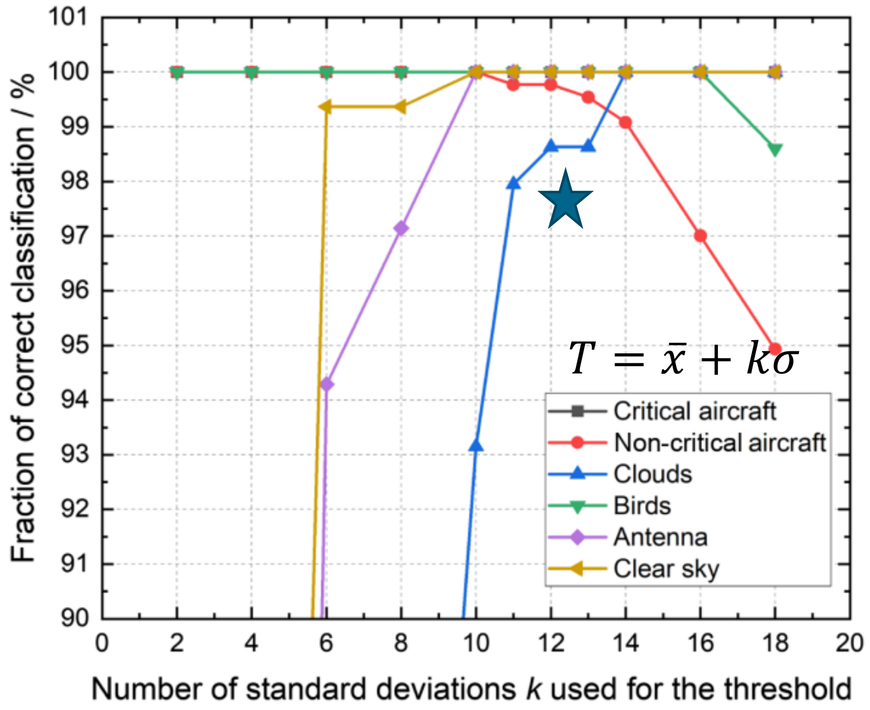


Fig. 4. Fraction of correct classifications as a function ("safe" or "unsafe") of the optimized parameter k for the different image categories.

Classification with optimized threshold:

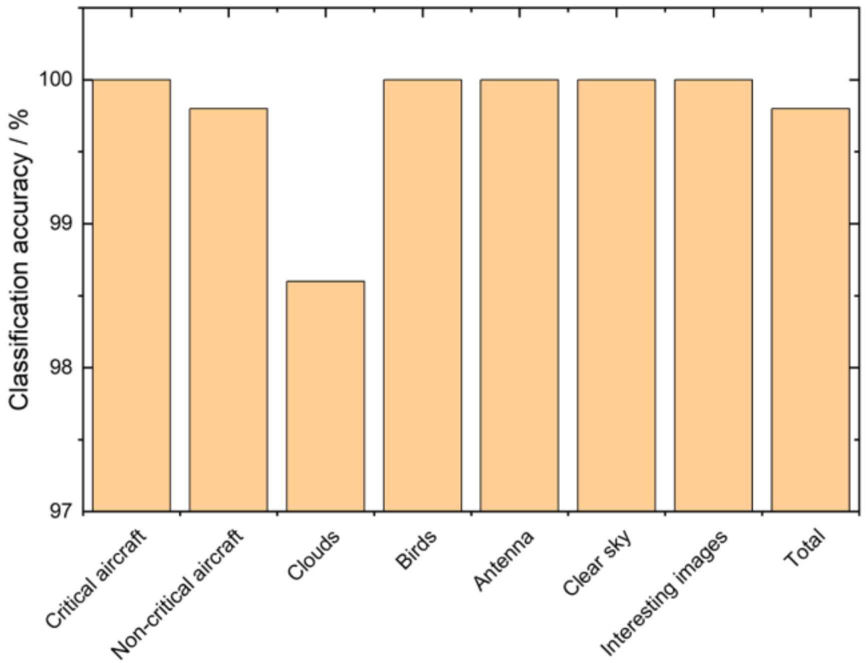
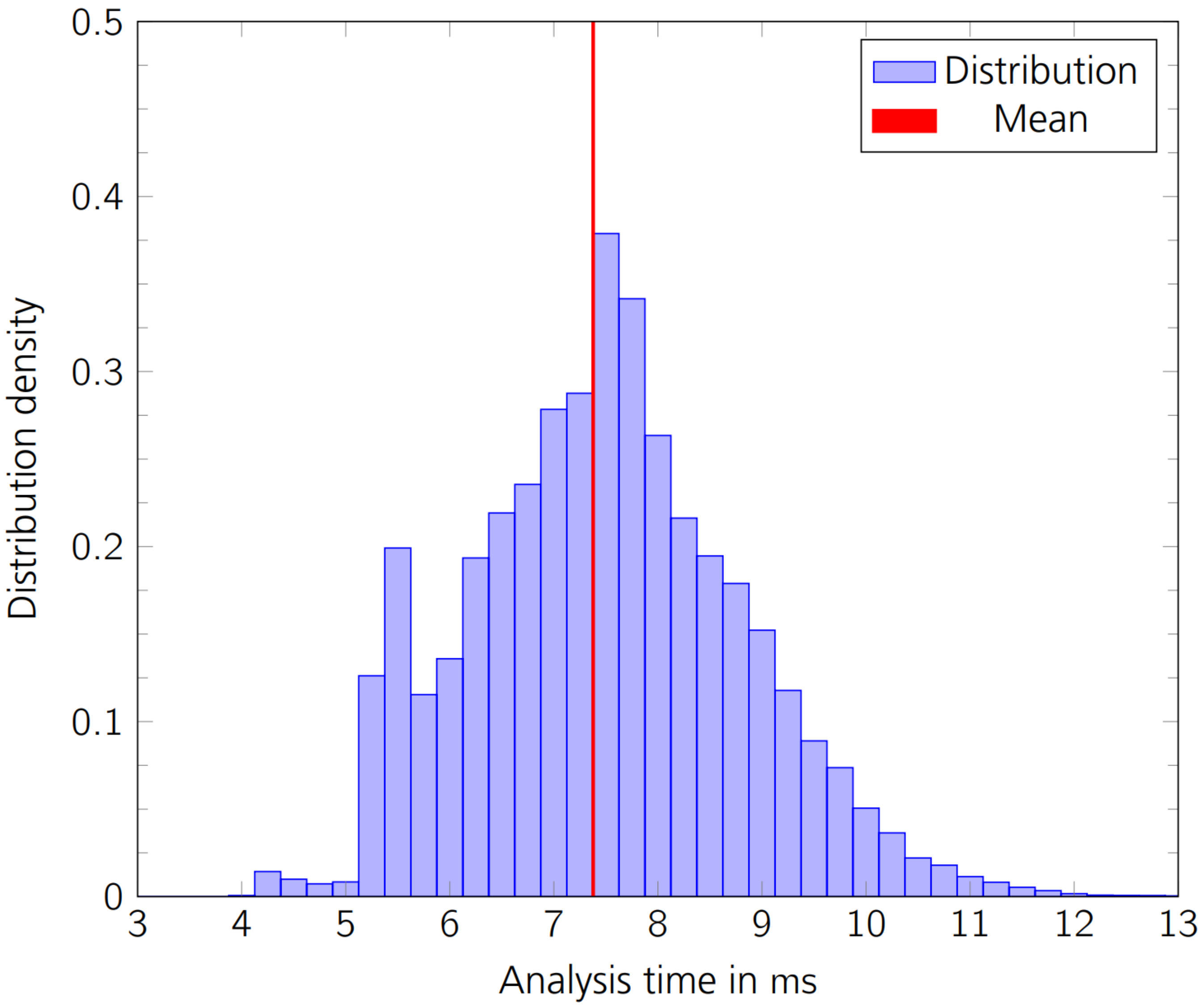


Fig. 5. Results of classification accuracy (safe/unsafe) for the proposed image processing algorithm with $k = 12$.

Speed

- Image analysis takes ~7ms on a standard PC



Limitations of this work

- No helicopters, hot air balloons, gliders in dataset
  $\rightarrow$ 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

6336 Vol. 63, No. 24 / 20 August 2024 / *Applied Optics* **Research Article**

applied optics

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

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

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

- 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**

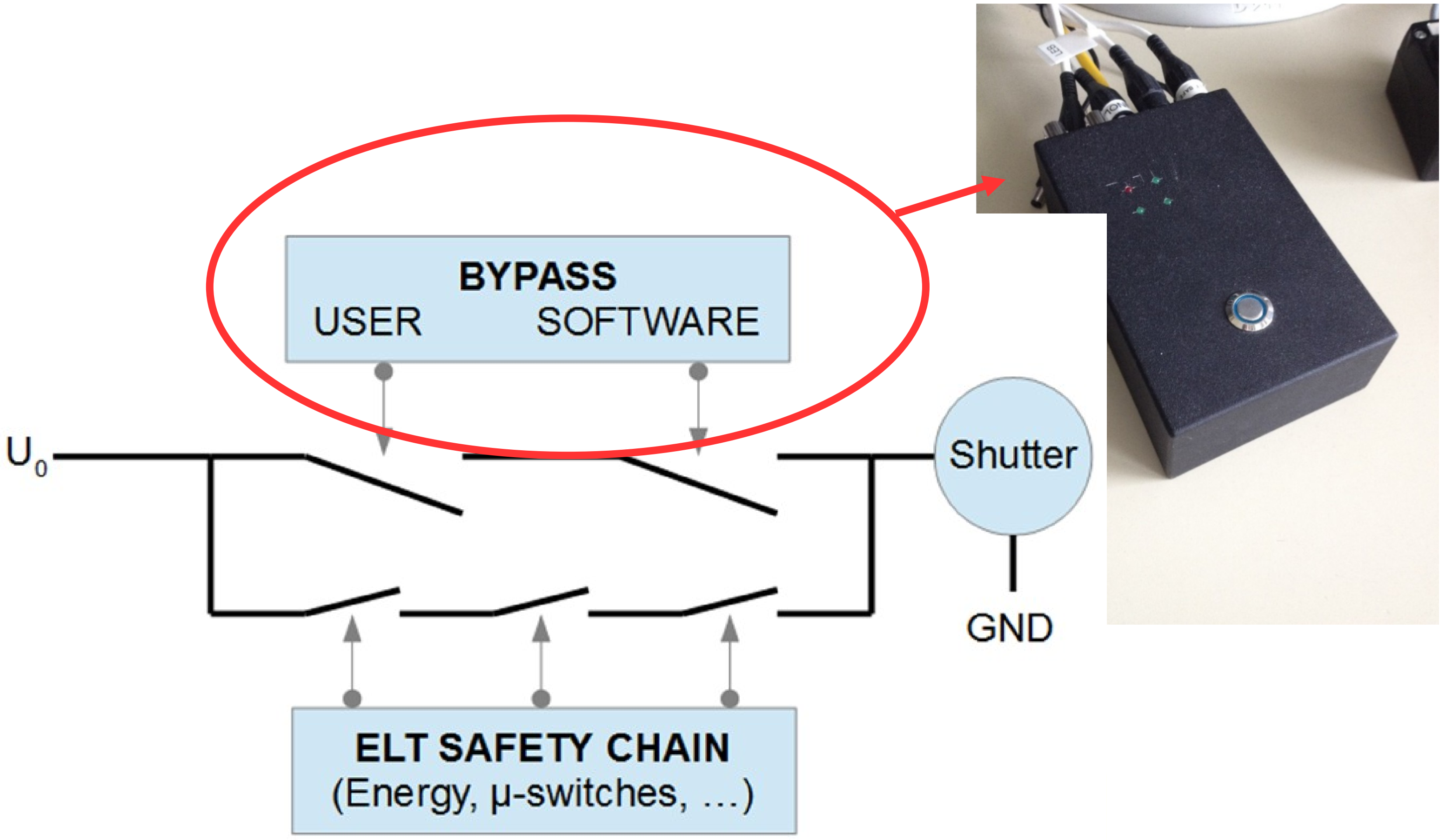
- Short laser pulses with a wavelength of 532 +/-0.1 nm, **capability to hit ELT gate window**.
  The additional header for transponder: offset and drift of the on-board clock

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

- ELT calibration, **Questionnaire for Stations**

- Clocks (H-Maser / Cs / Opt. clocks)

- Ranging data files: full-rate (fr2) and all laser-fire times (ff2)



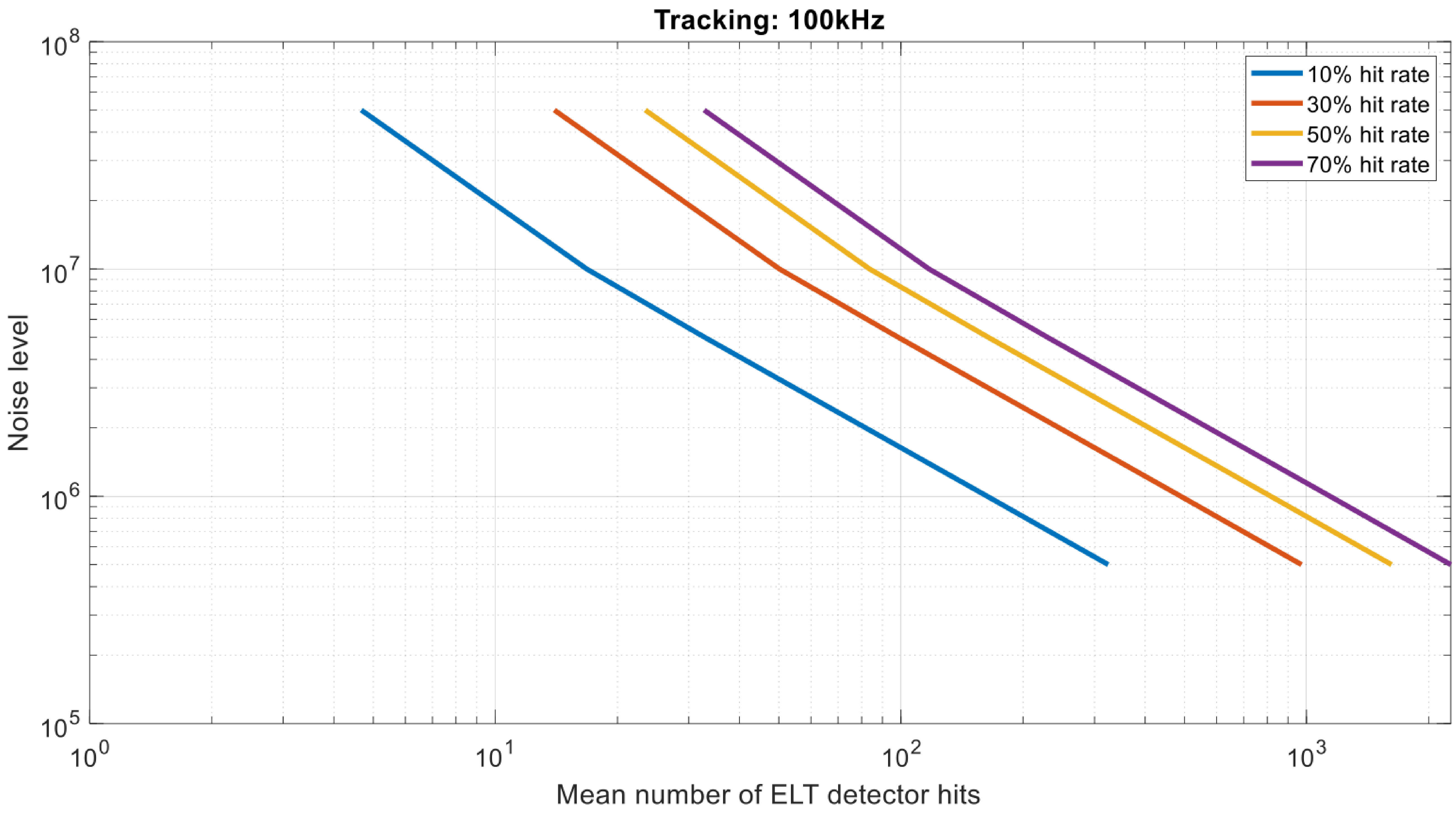
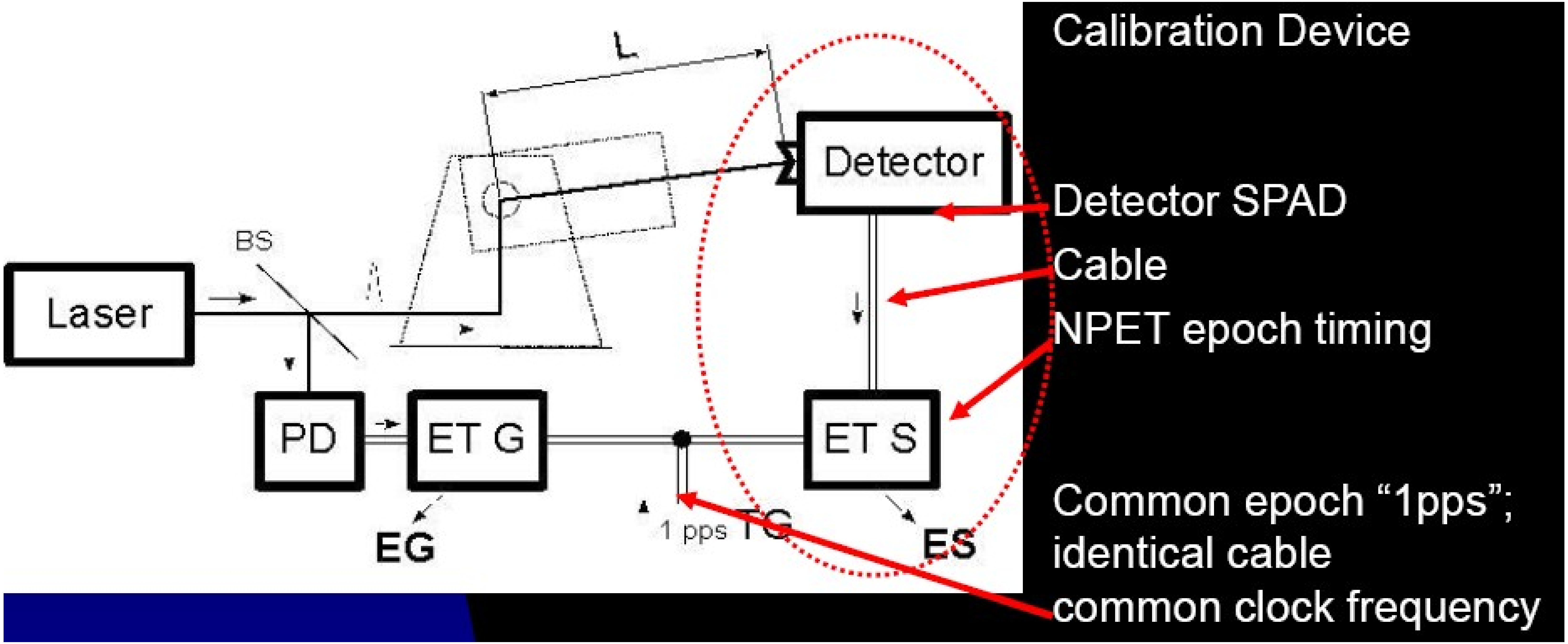
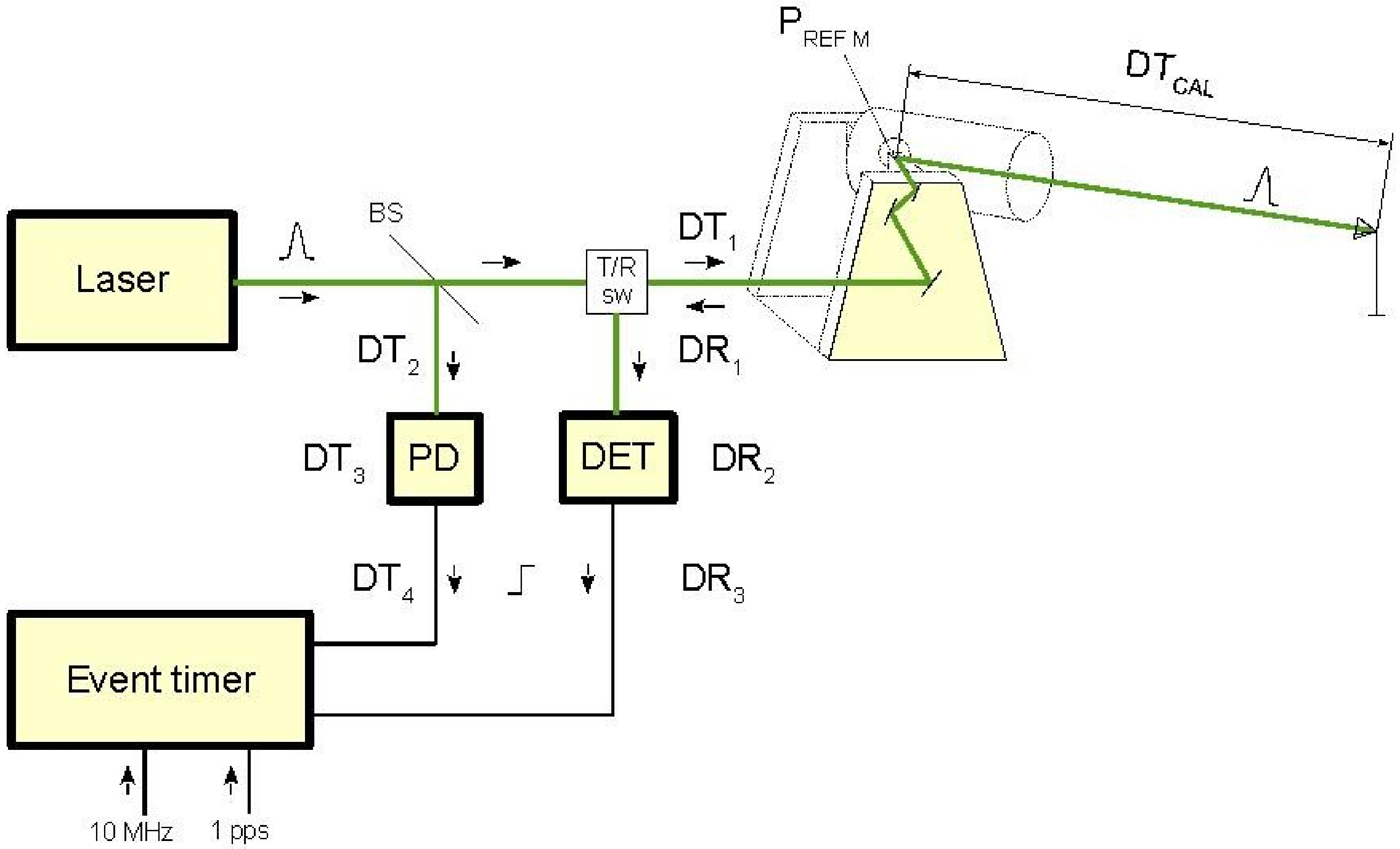


Figure 10: Mean number of ELT detector hit for 100 kHz tracking w.r.t. the noise level.

Clock Metrology: ELT calibration



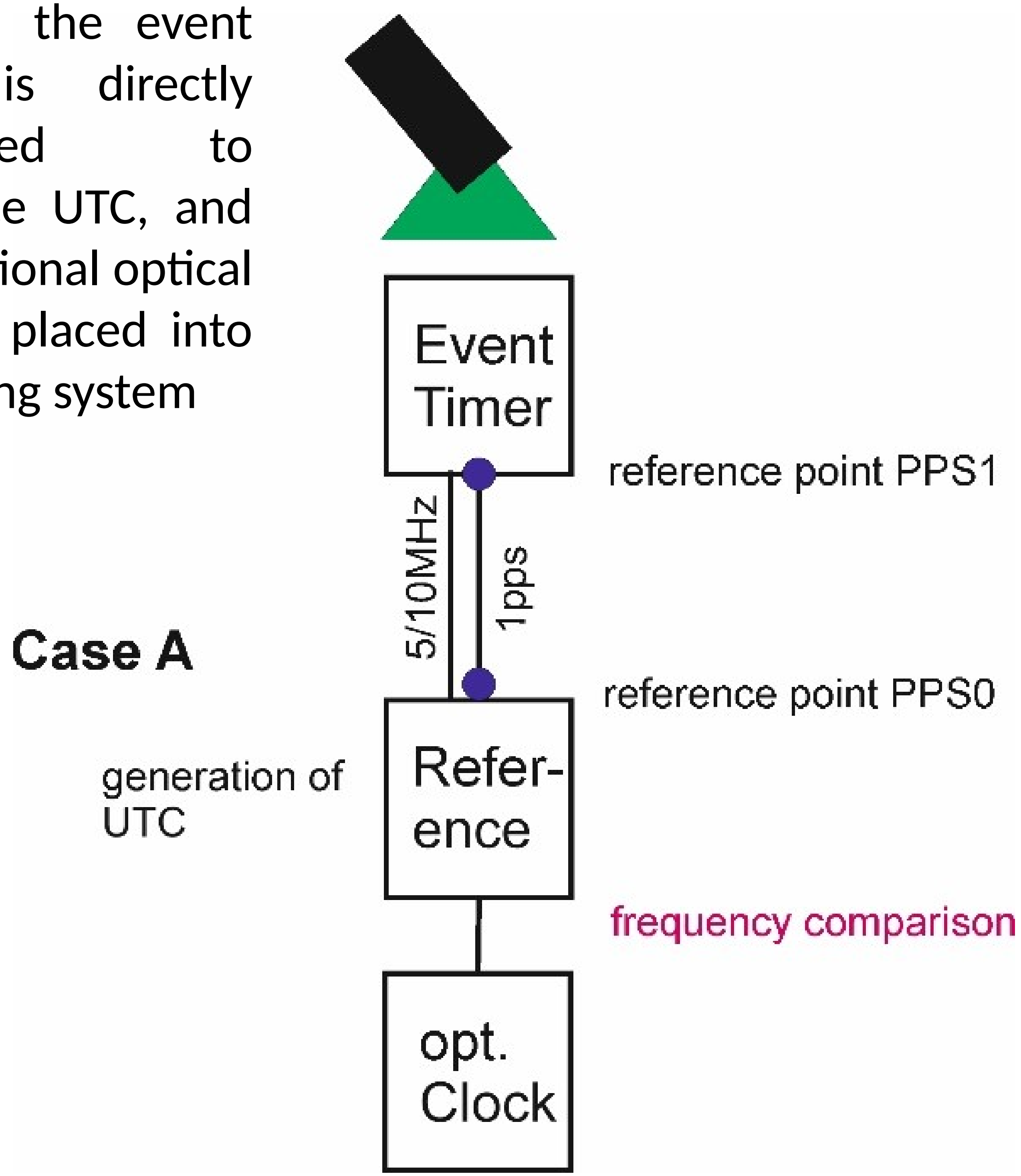
SLR system delays - simplified



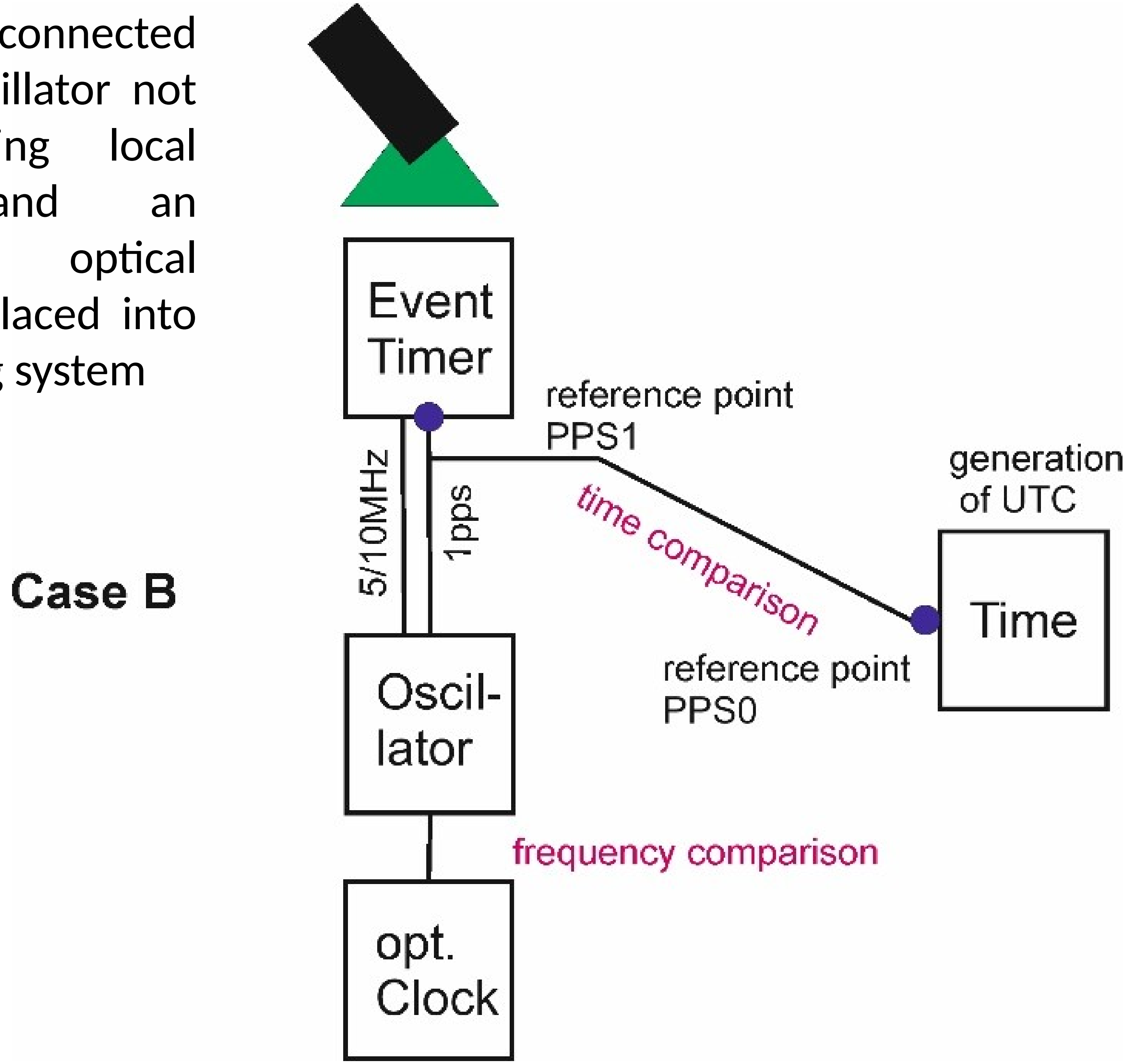
Although the individual contributors *DTi* and *DRi* might be identified and measured (Herstmonceux..) the resulting accuracies of T and R calibration constants would be low using such a measurement scheme.

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



The Correlation Between Geodetic Satellite Passes and positioning quantity for ITRF2020

Alexandre Belli[1], Magda Kuzmicz-Cieslak[2,3], Frank G Lemoine[4] and Keith D Evans[3]

(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

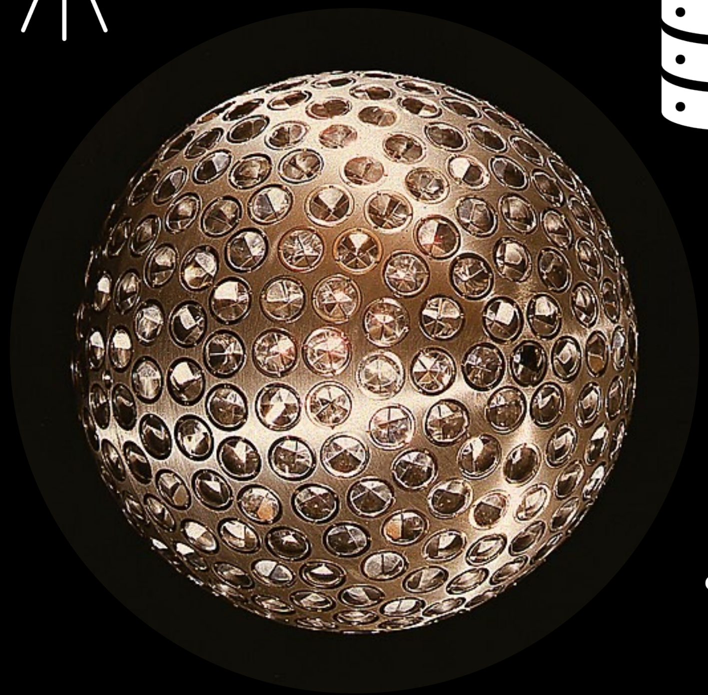
First presented at the AGU2024, modified for NESC

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

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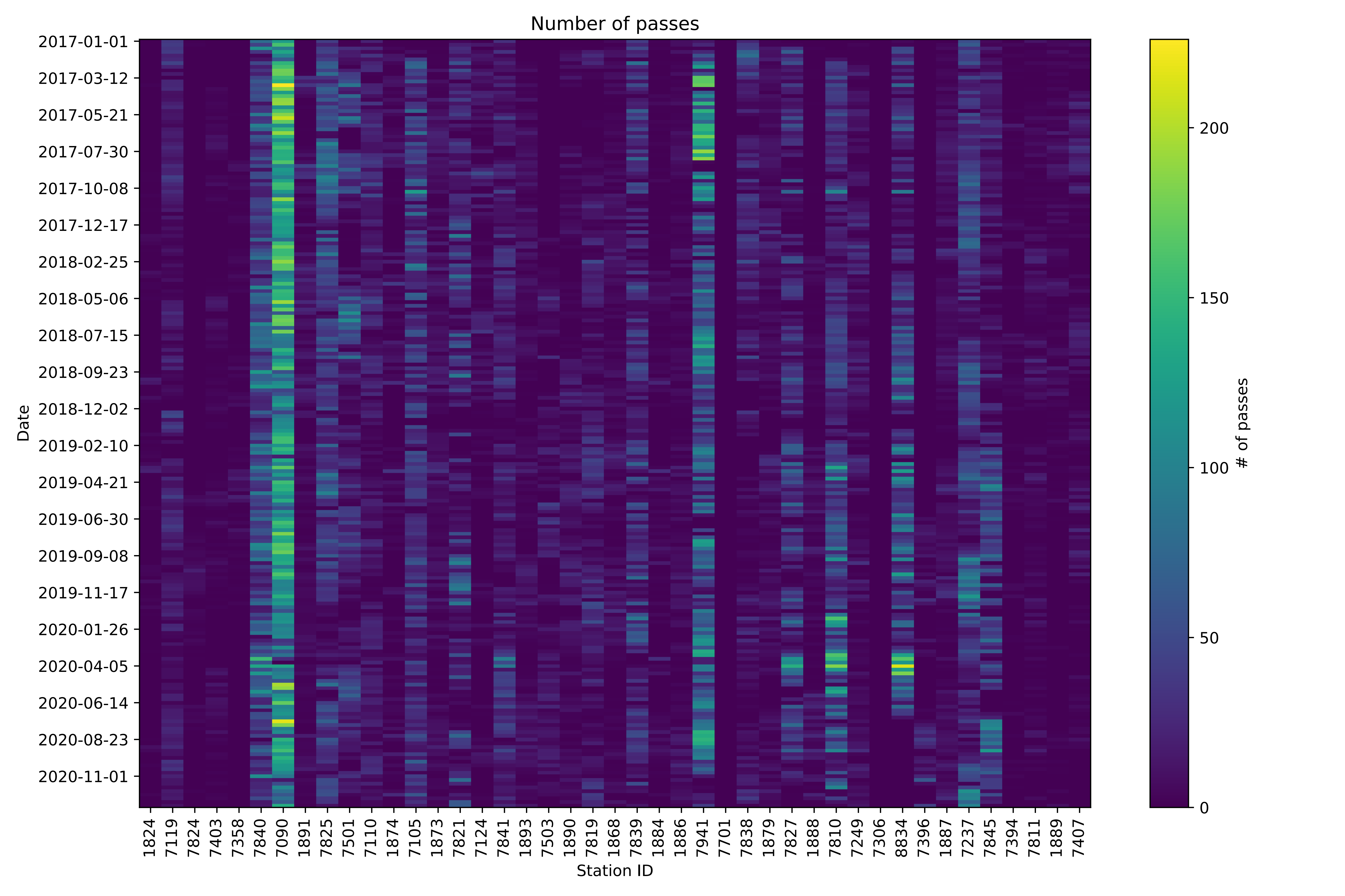
of passes



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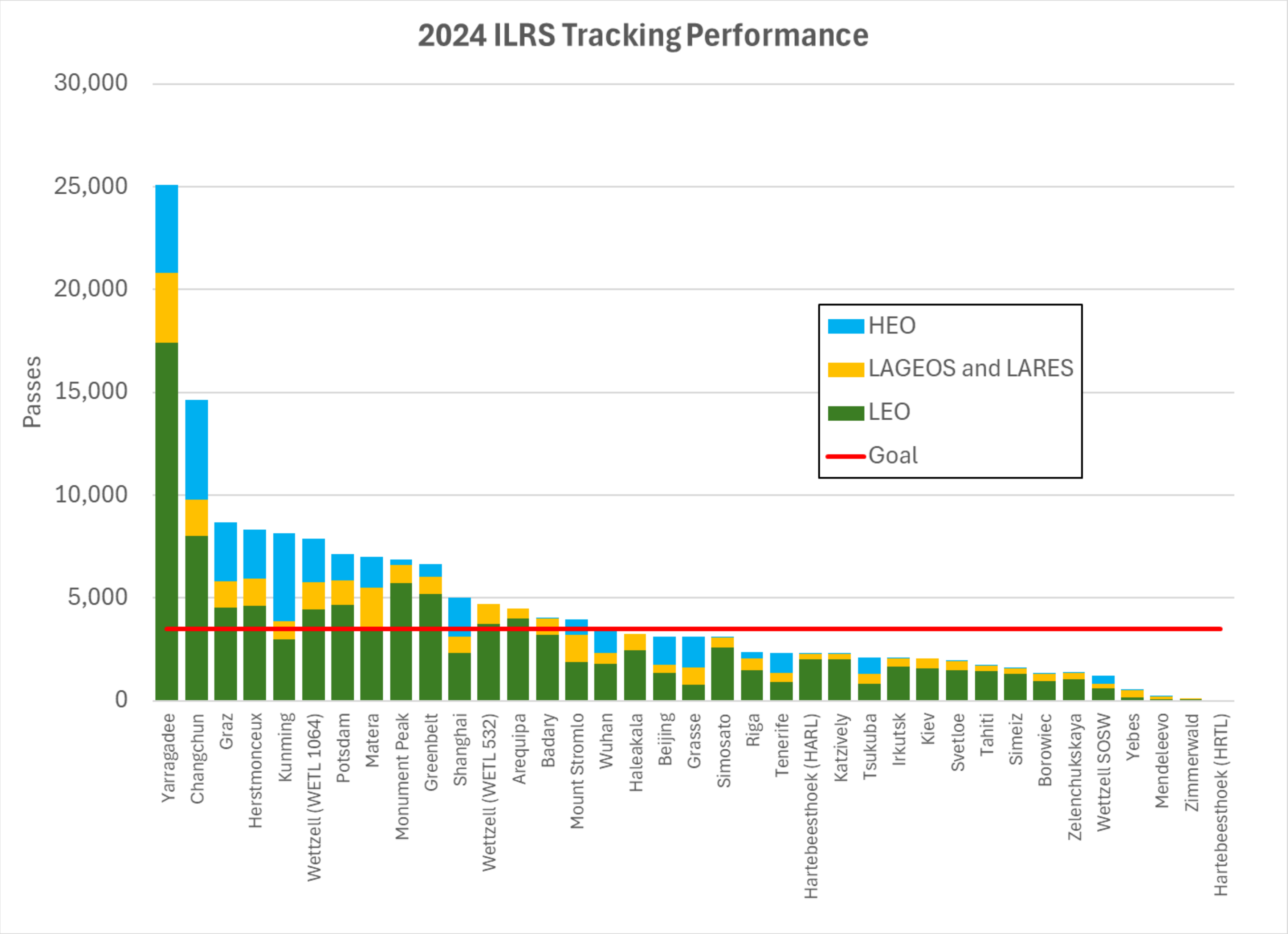
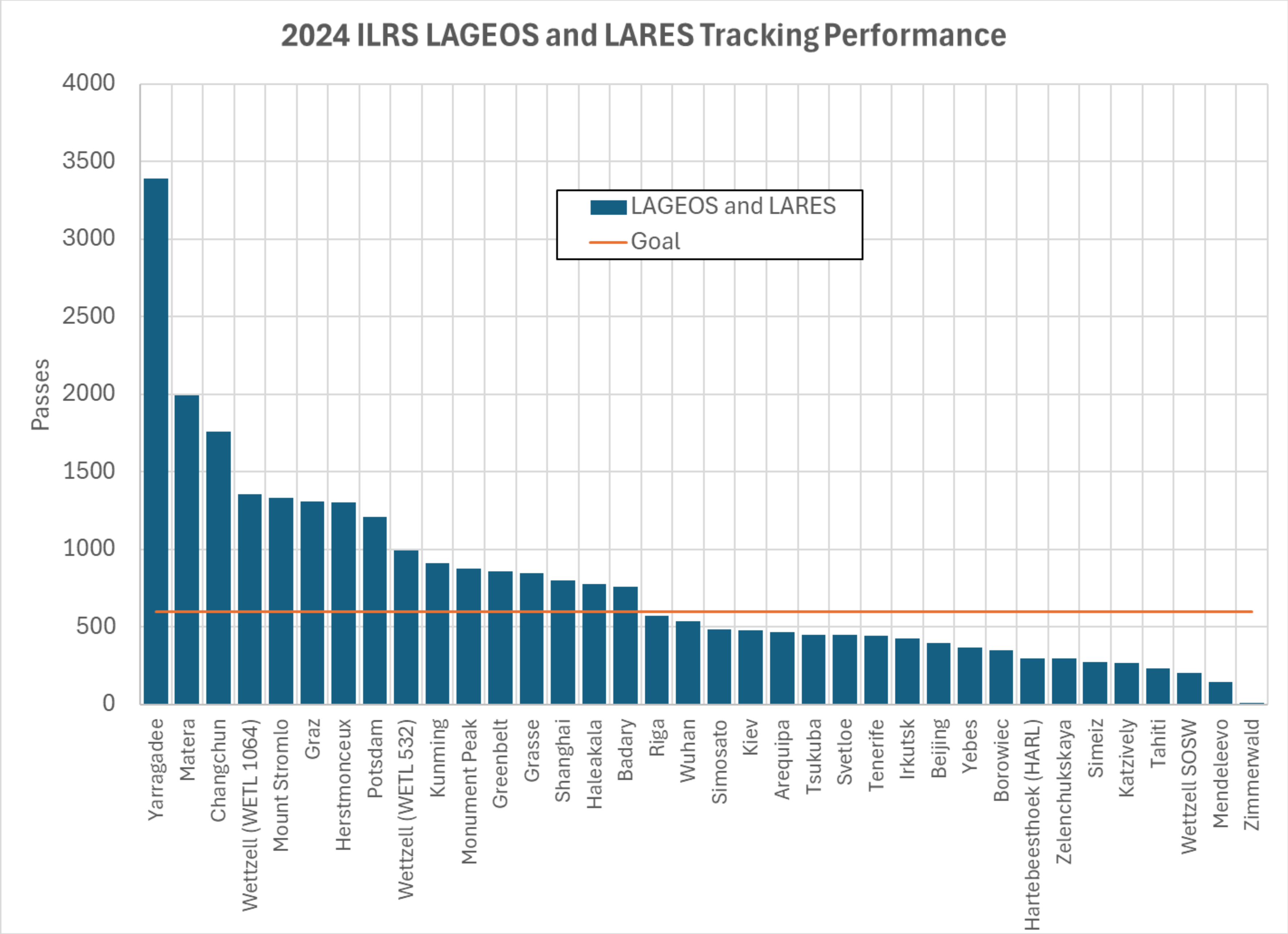
ILRS 2024 Pass Totals

Courtesy of Van Husson

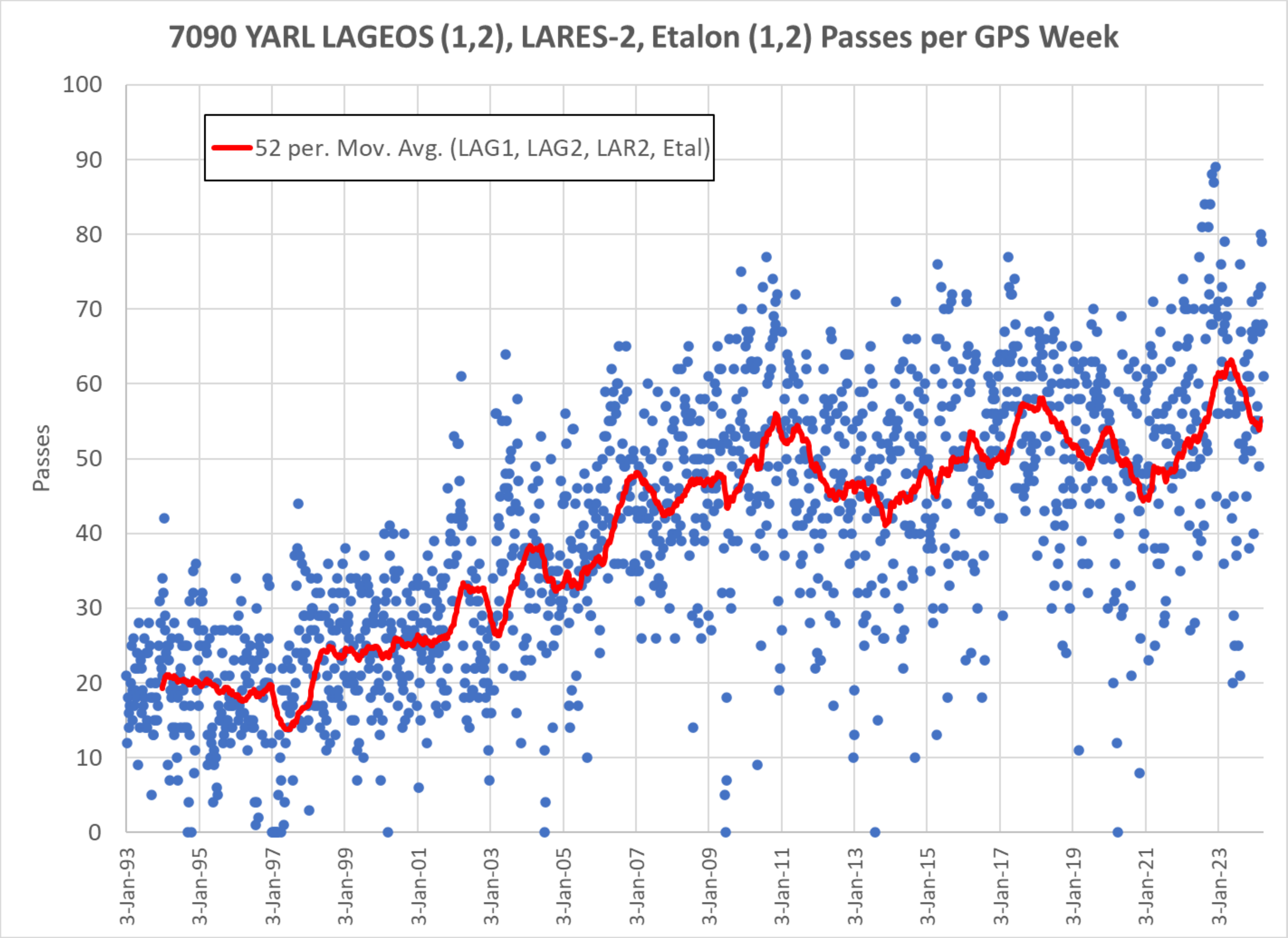




- **Fourteen different stations met the 3500 pass requirement while fifteen different stations met the LAGEOS/LARES 600 pass requirement. Note: Wetzell (8834) tracked LEO and LAGEOS simultaneously in dual wavelengths, but not HEOs.**

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

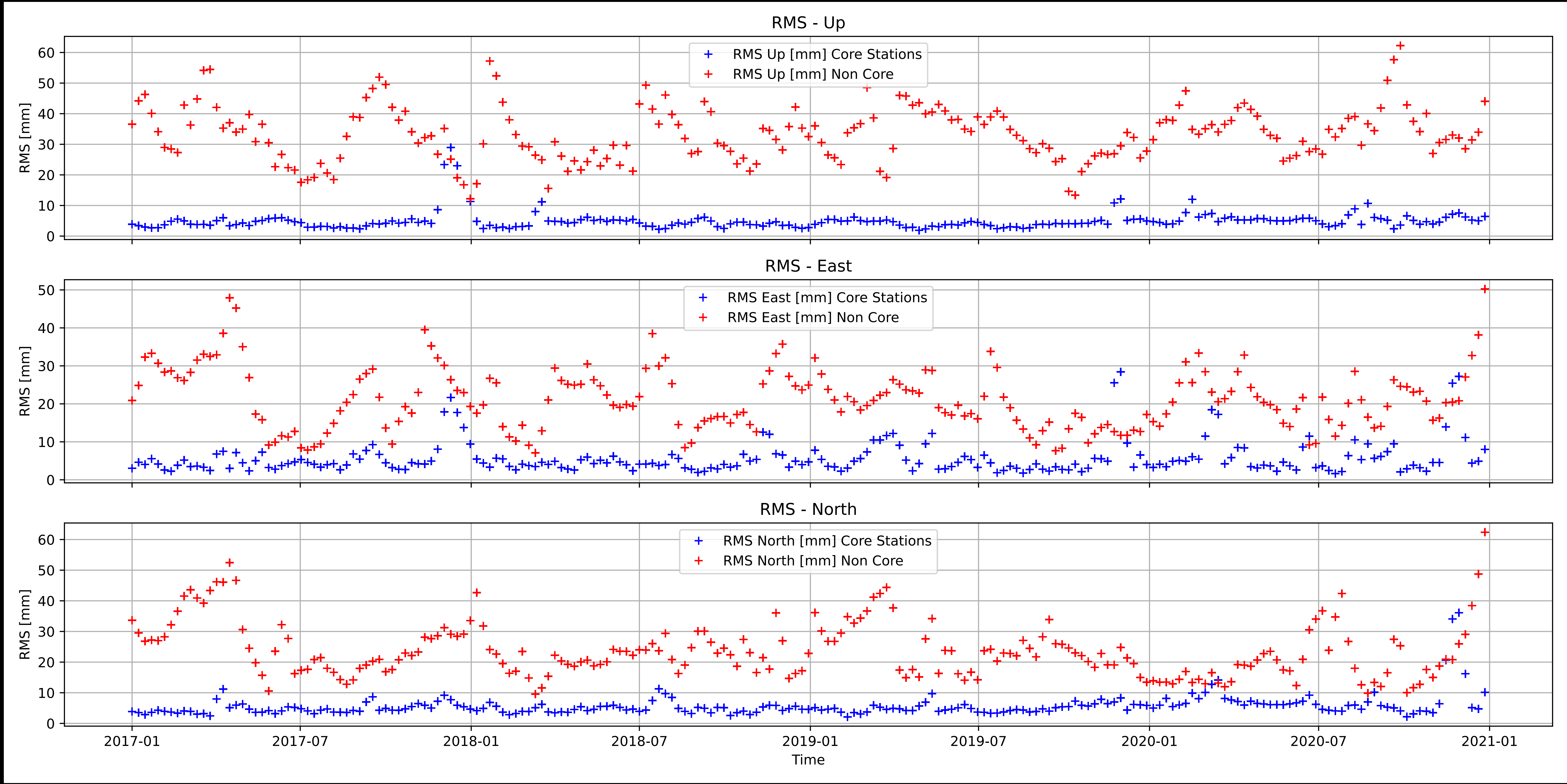
Courtesy of Van Husson



- 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']



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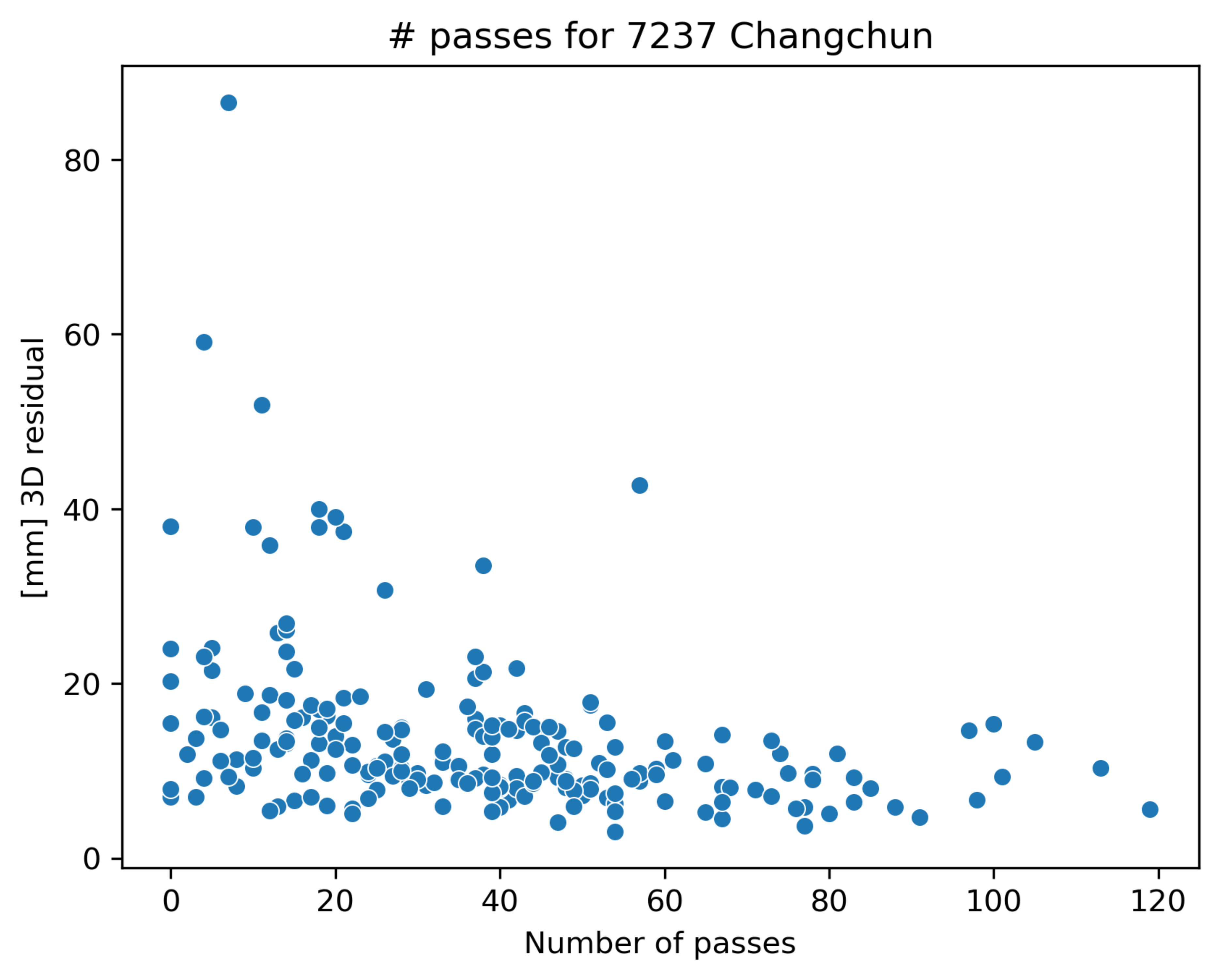
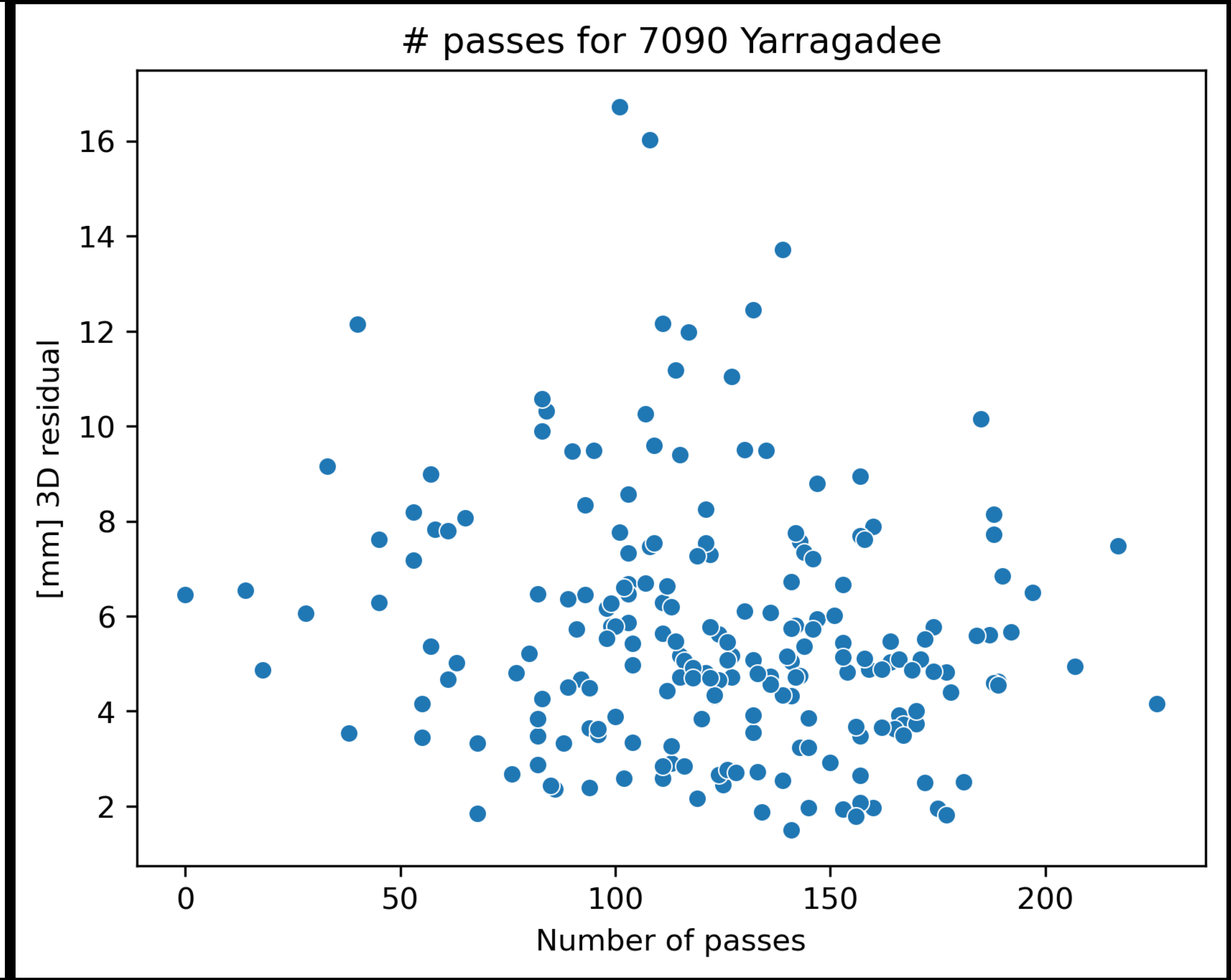
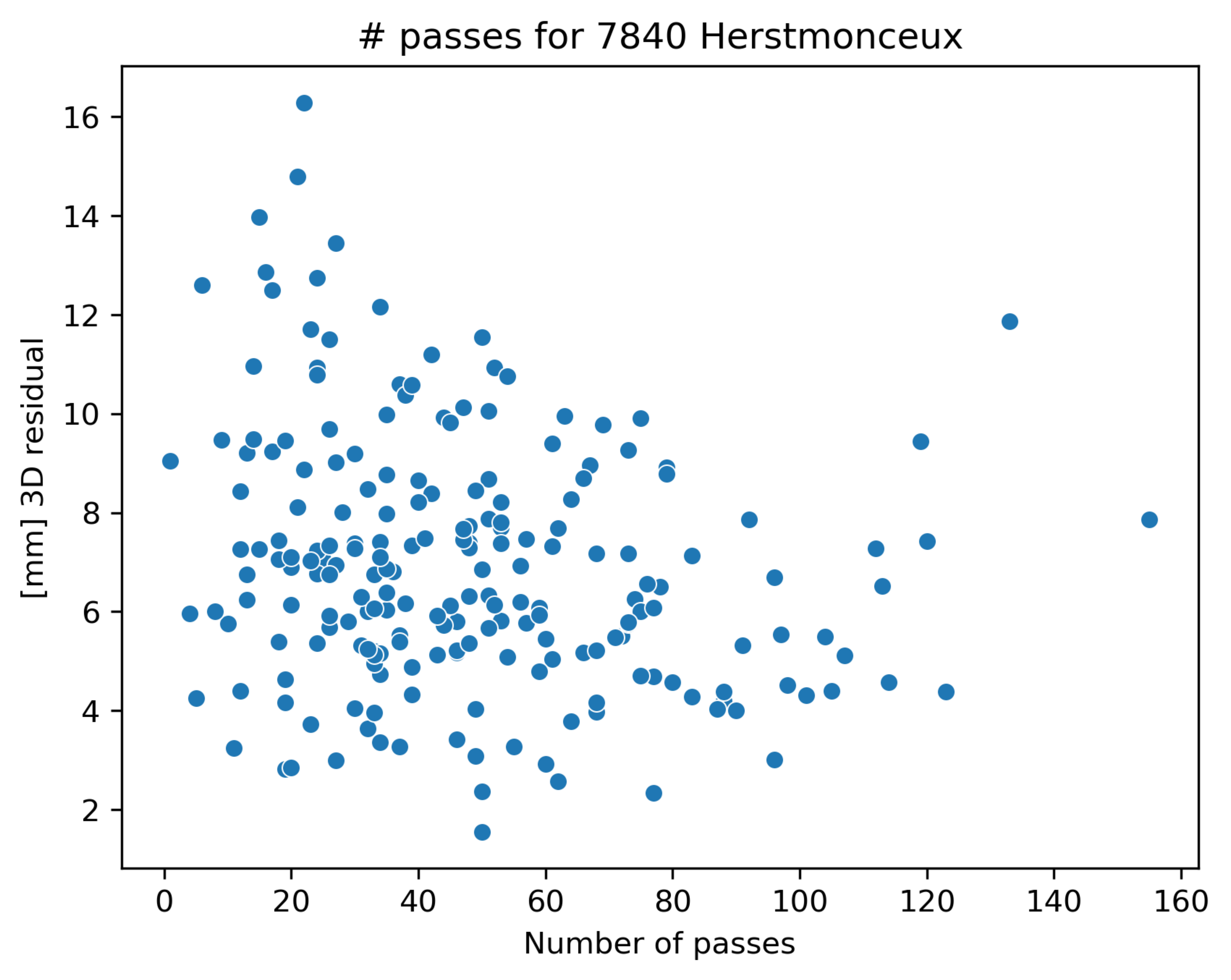
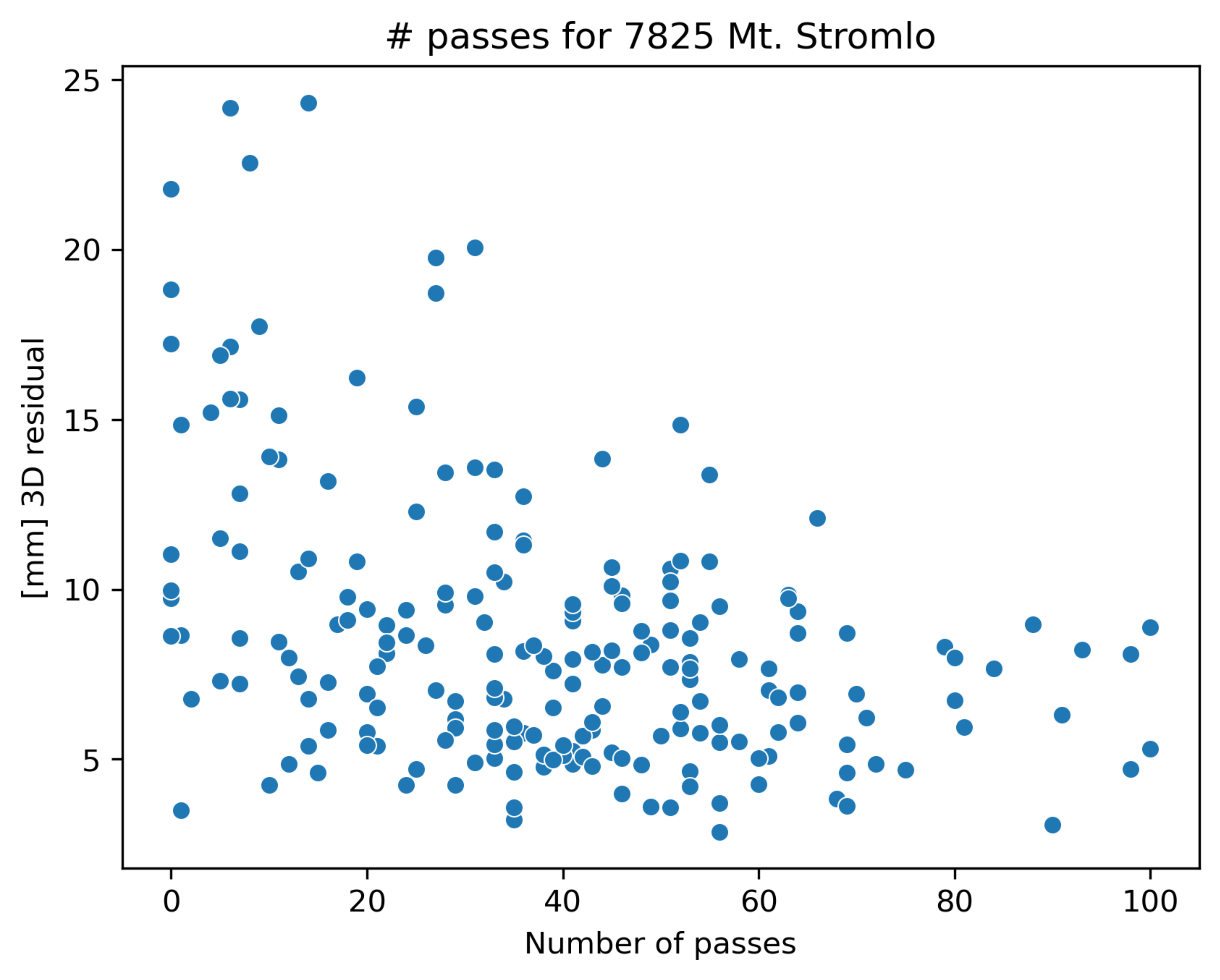
Results 1 – One station (1/2)



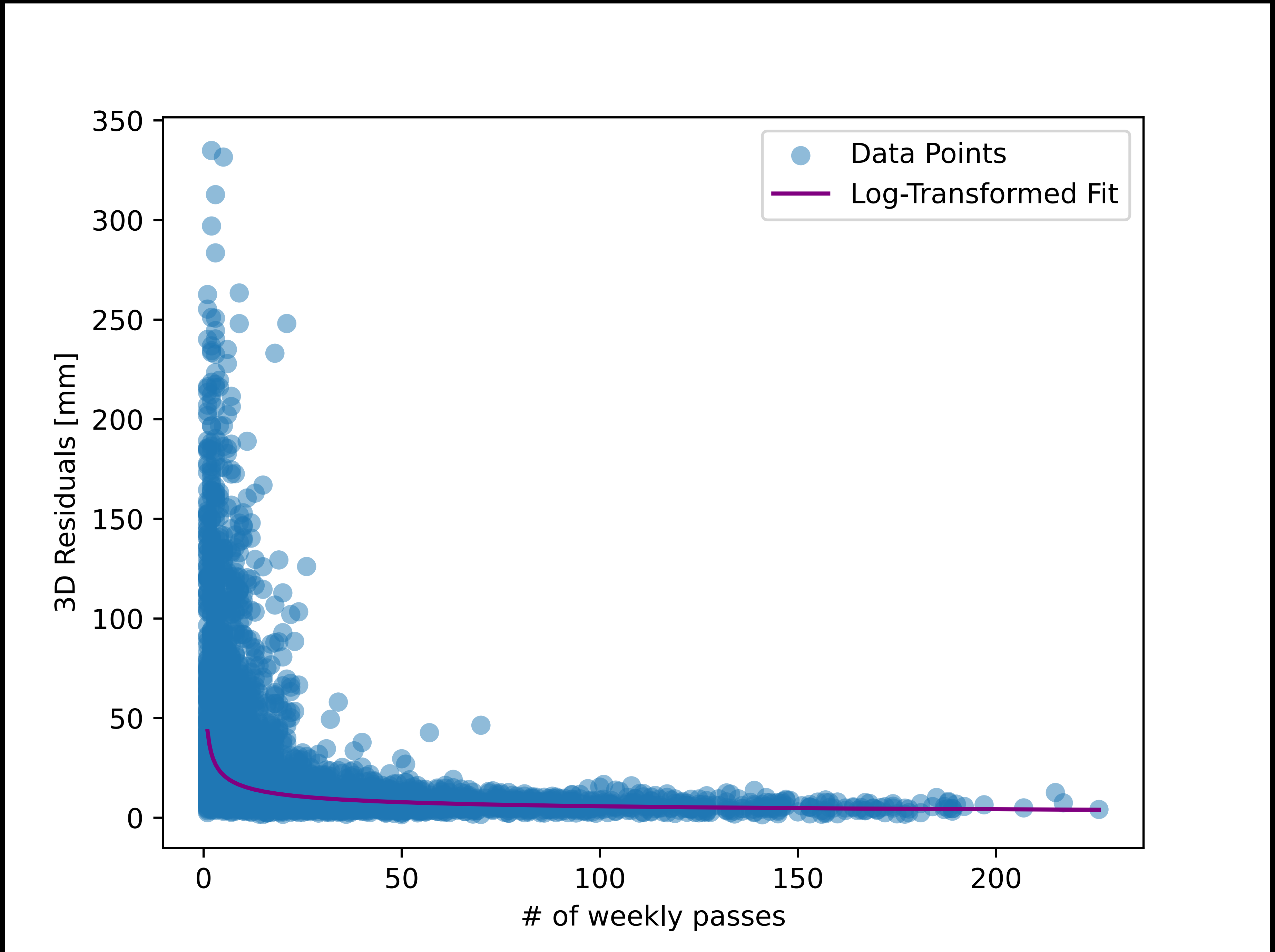


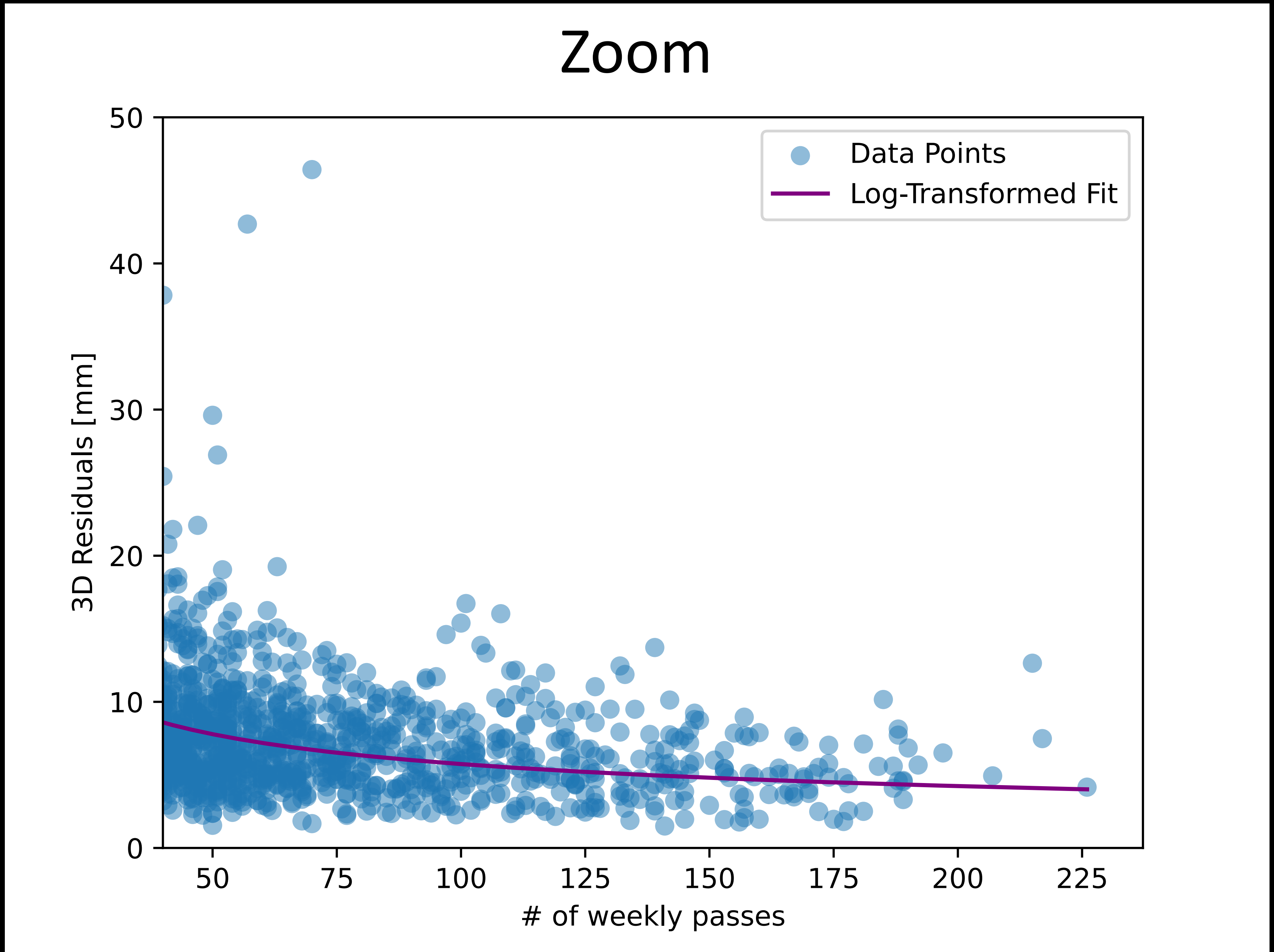
Results 1 – One station (2/2)





Results 2 – all stations





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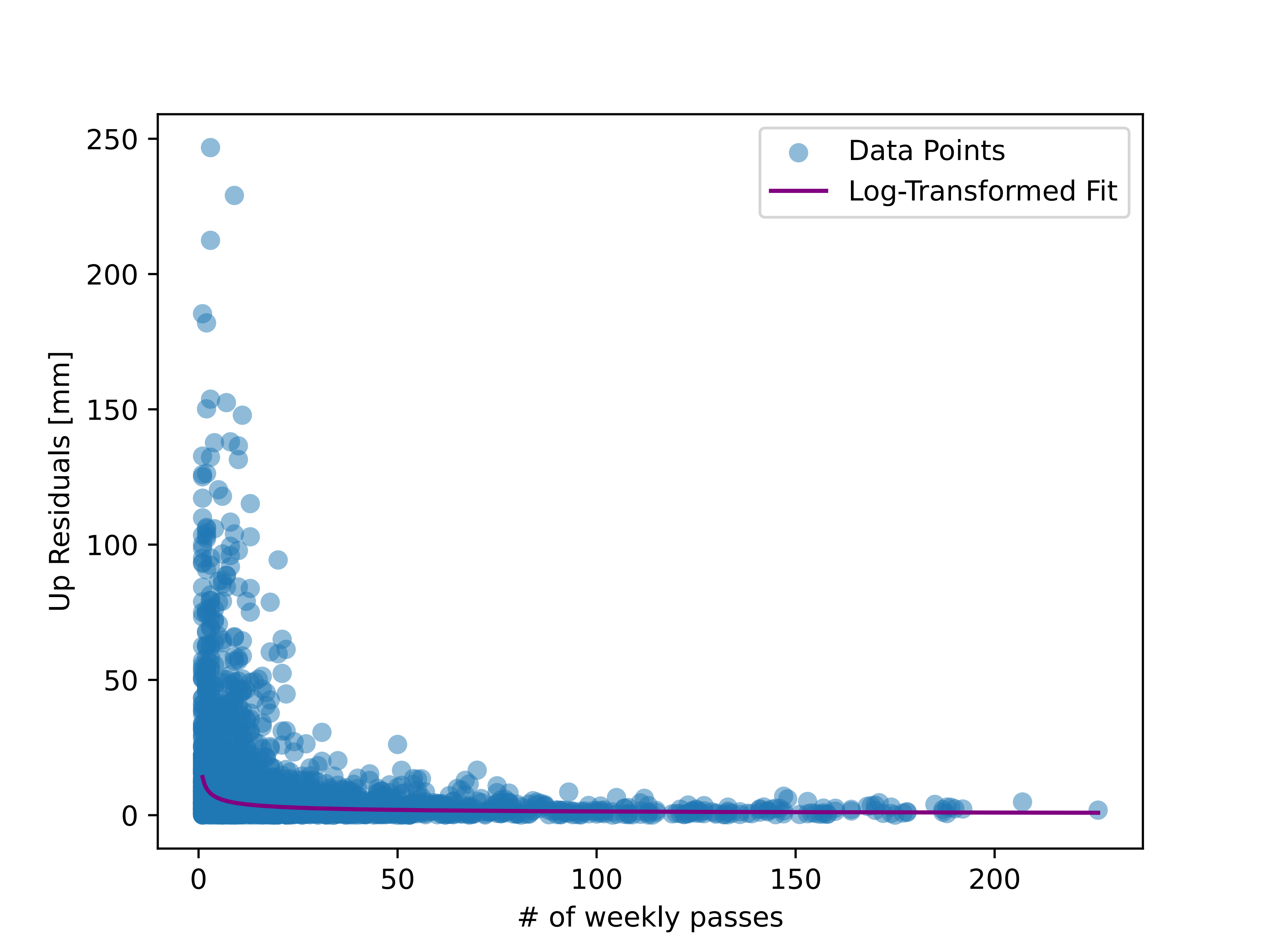
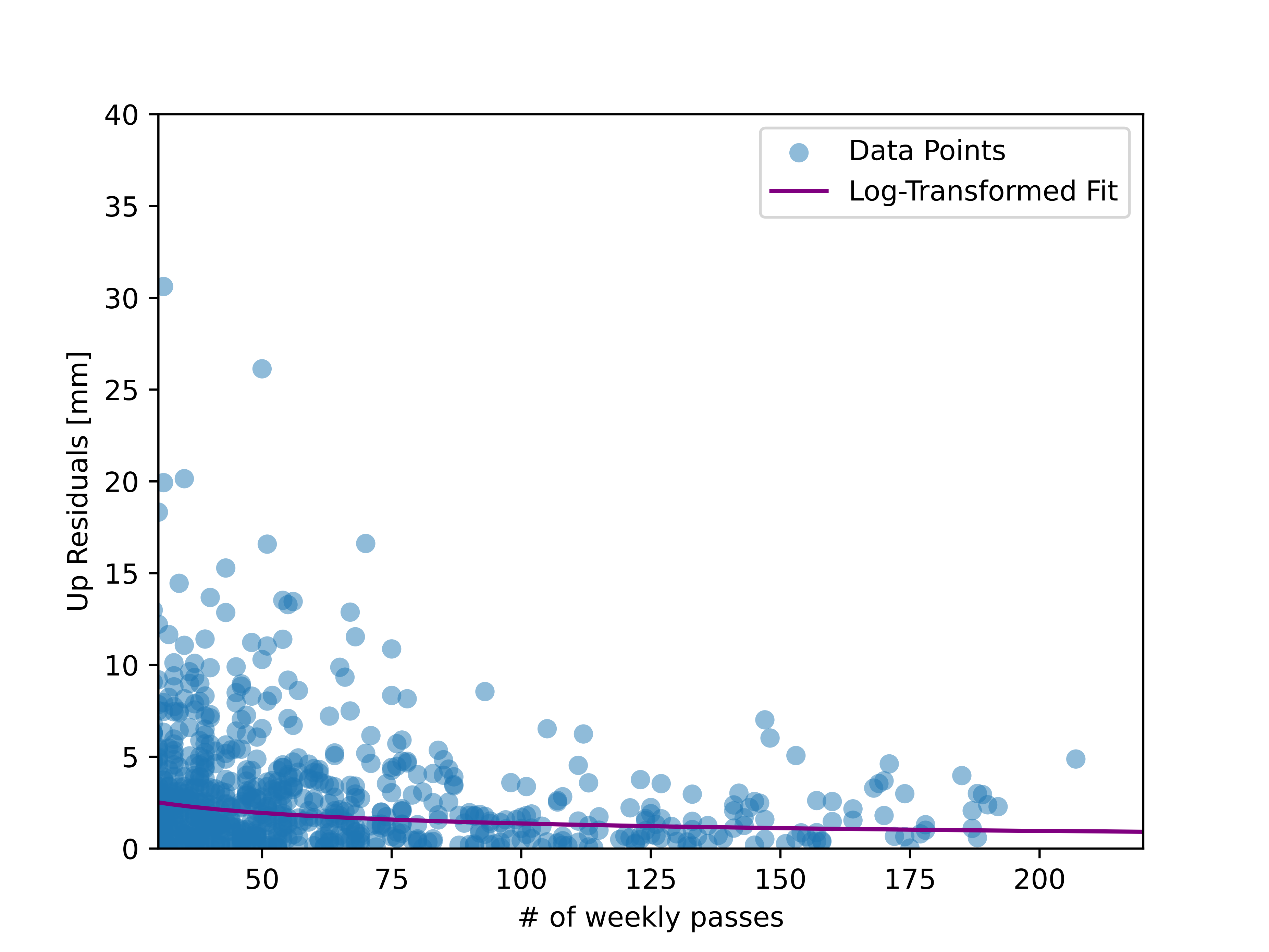
Results 2 – all stations (Up coordinate)





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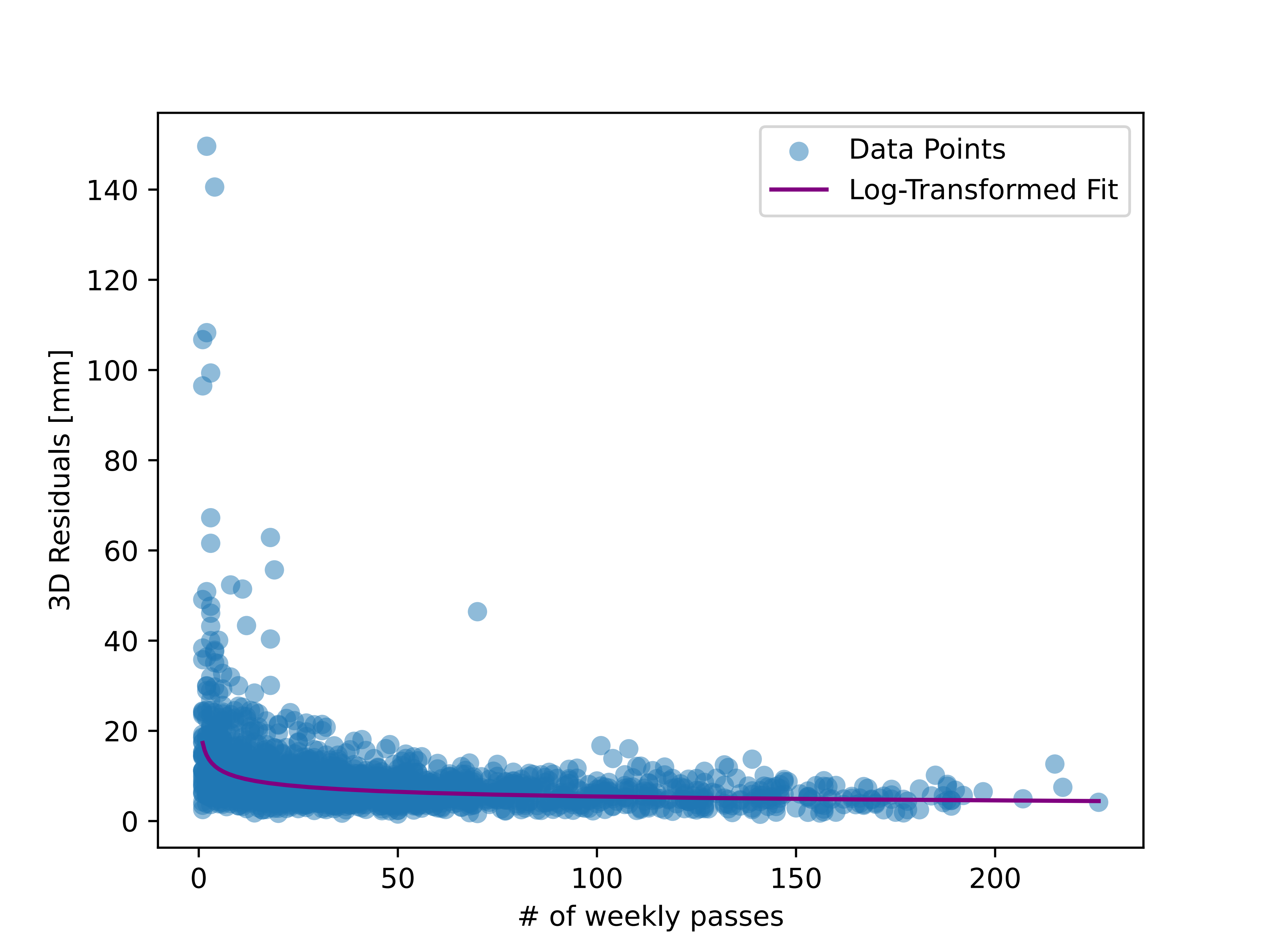
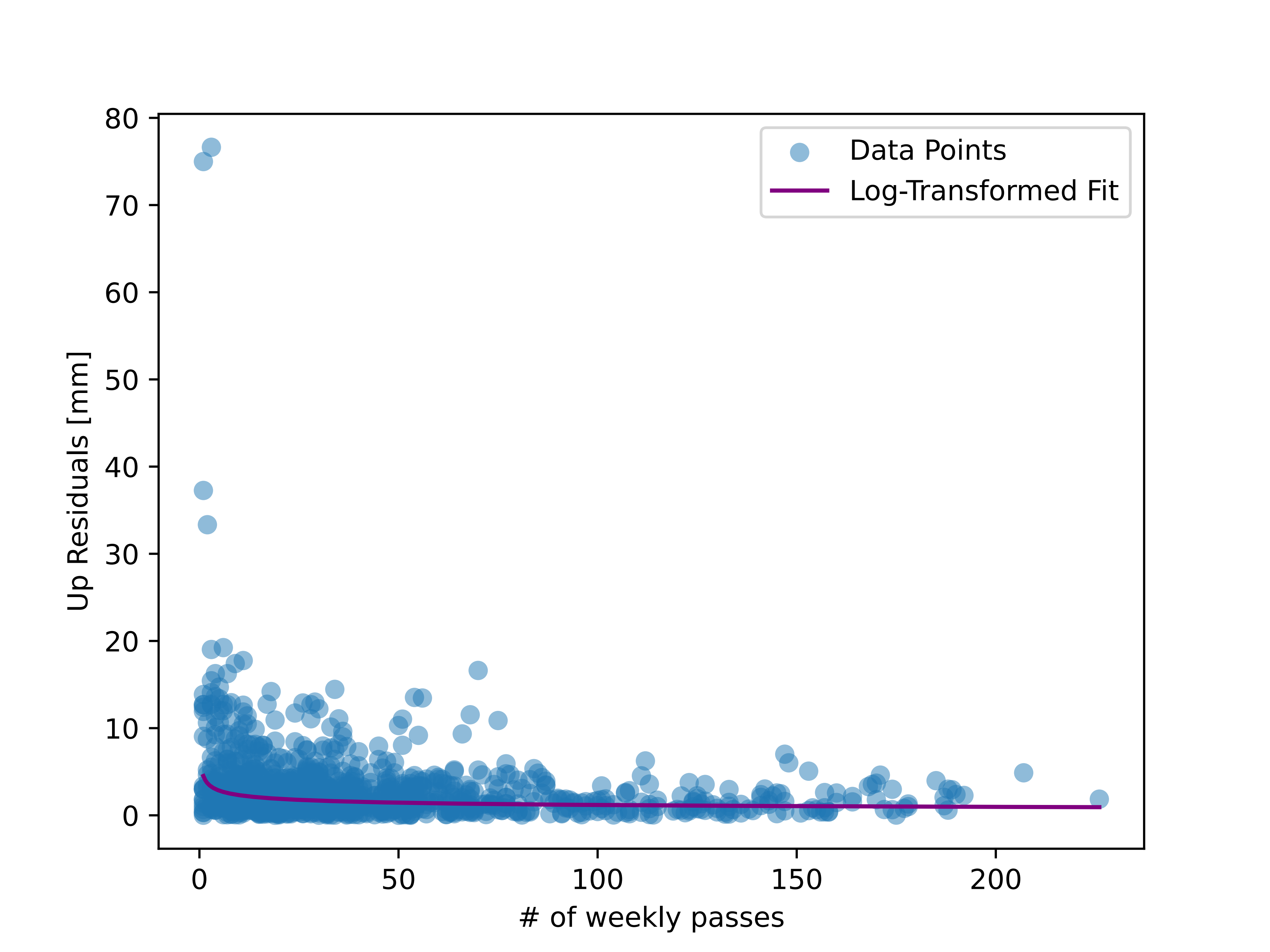
Results 2 – Core Stations (3d and up coordinate)





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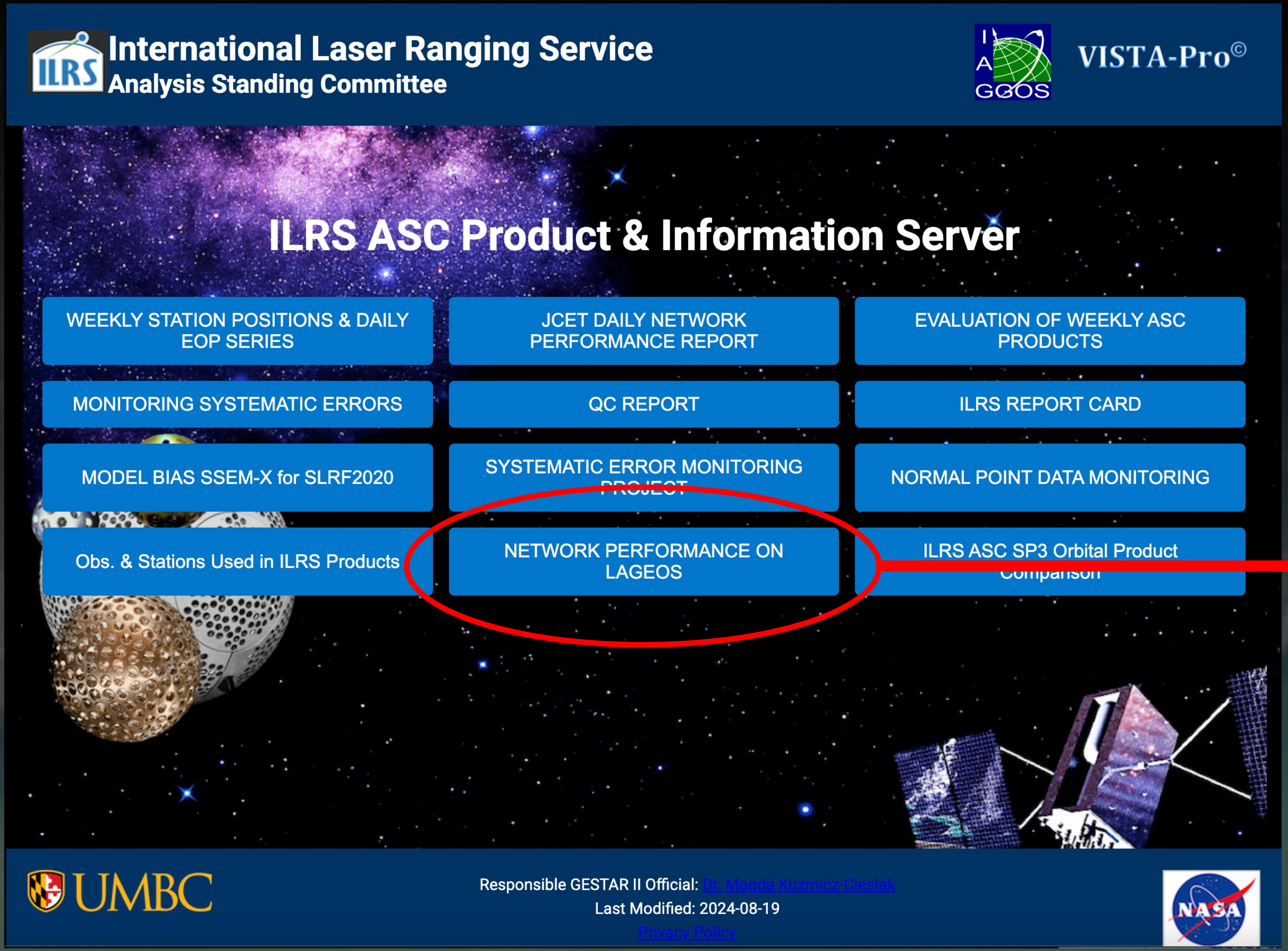
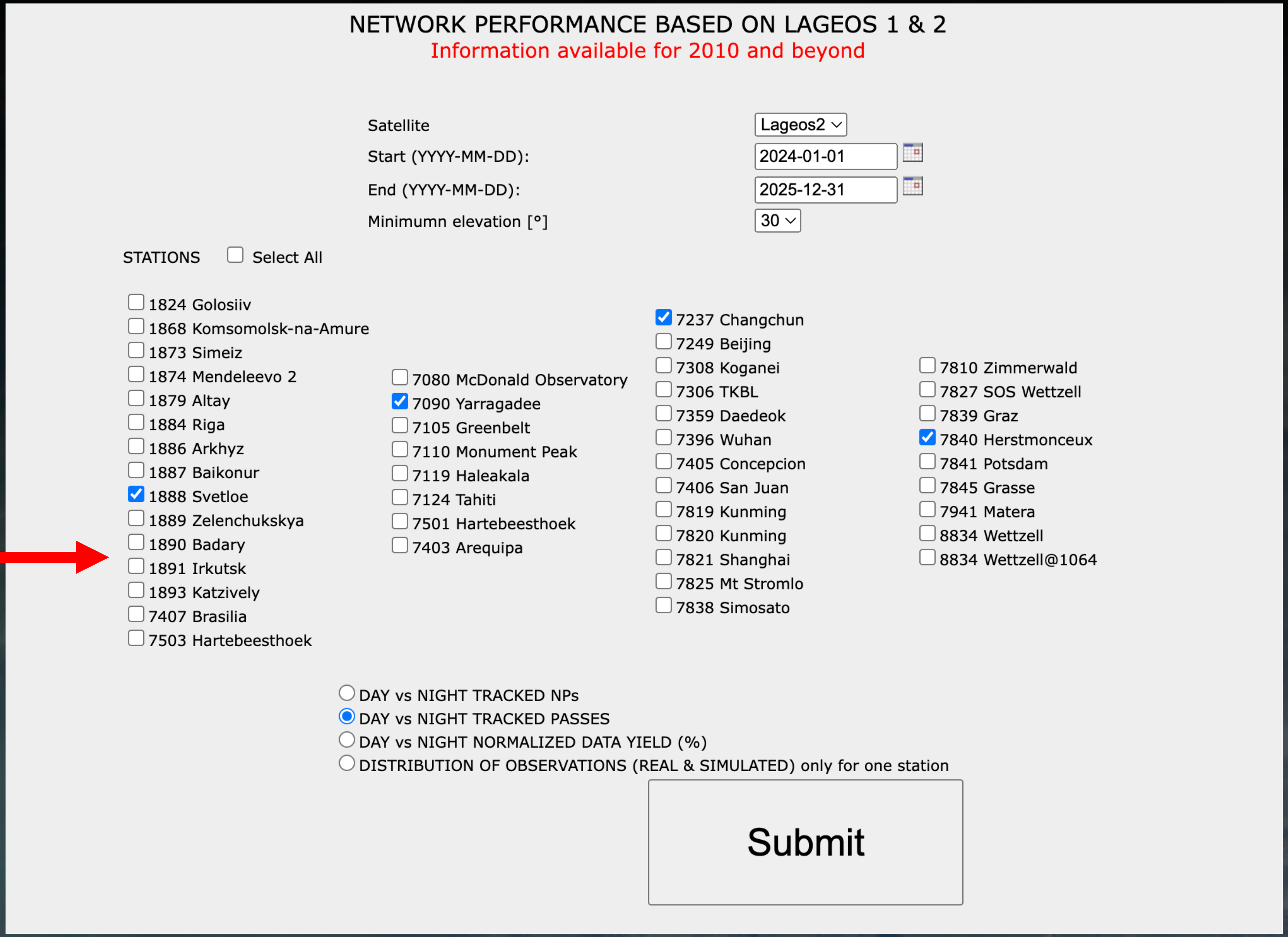
Is it feasible?

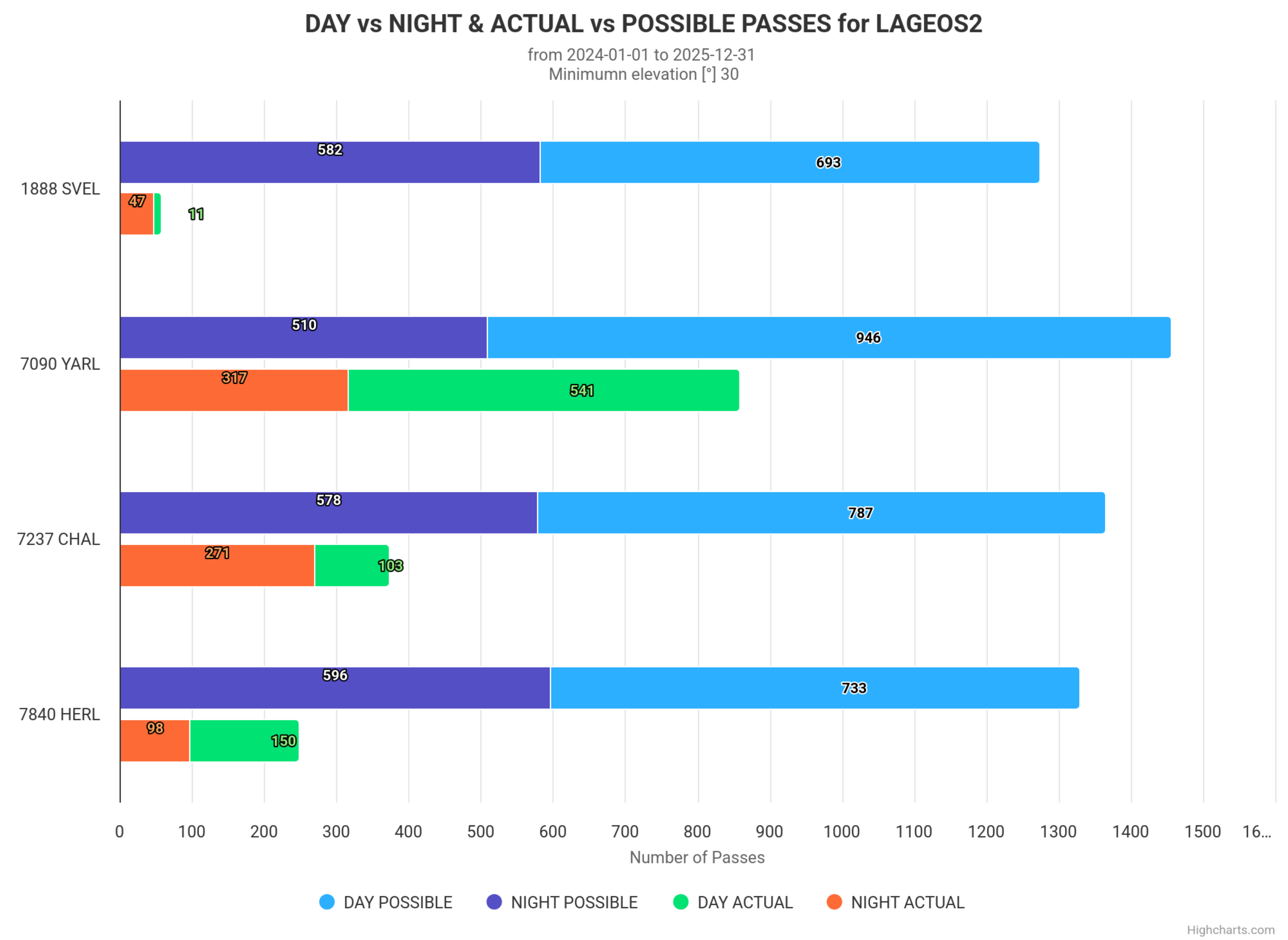
https://geodesy.jcet.umbc.edu/ILRS_AWG_MONITORING/

Is it feasible?





Is it feasible?



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

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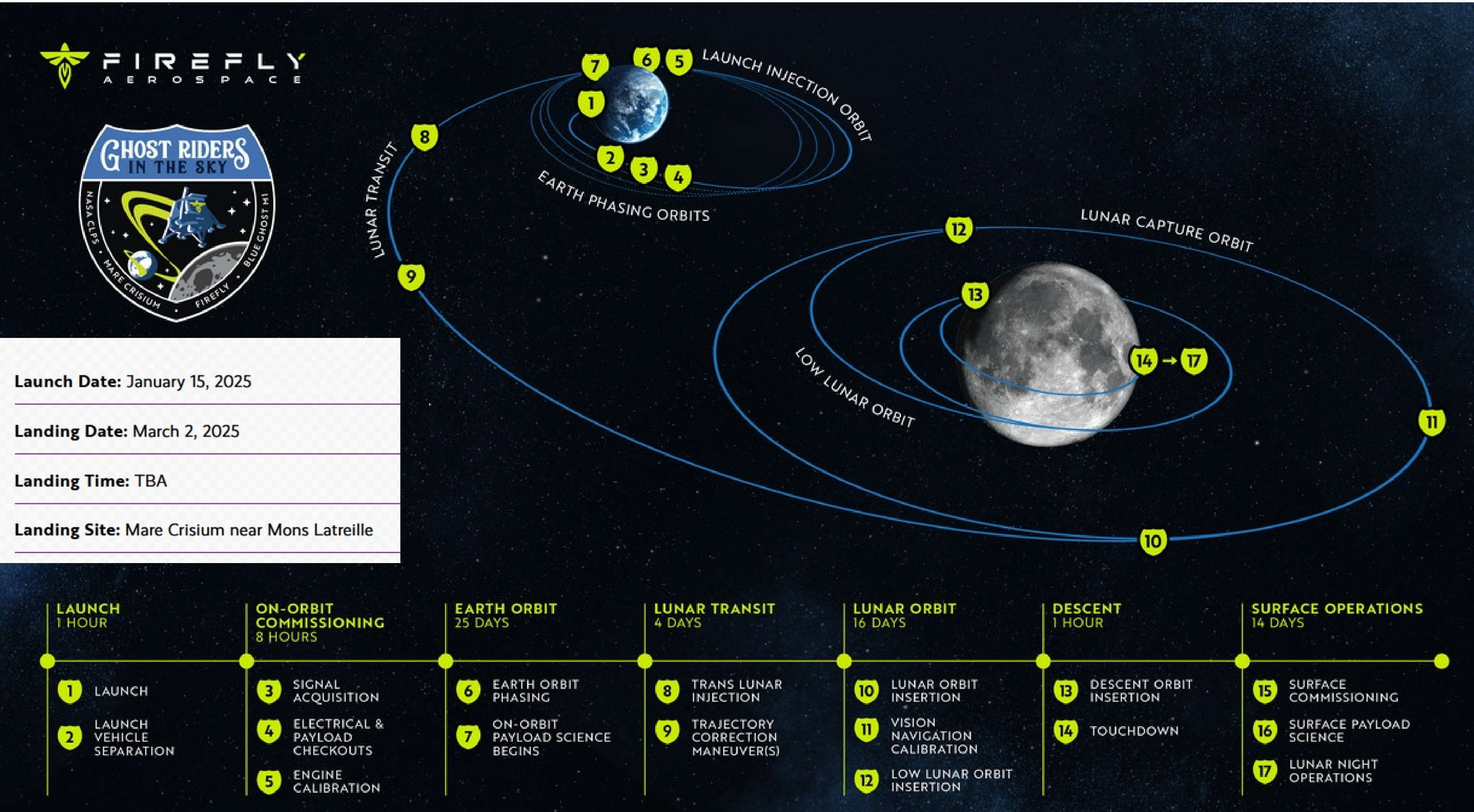
NESC - ILRS

news

NGLR : heading for the Moon

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



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 recommandation 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.

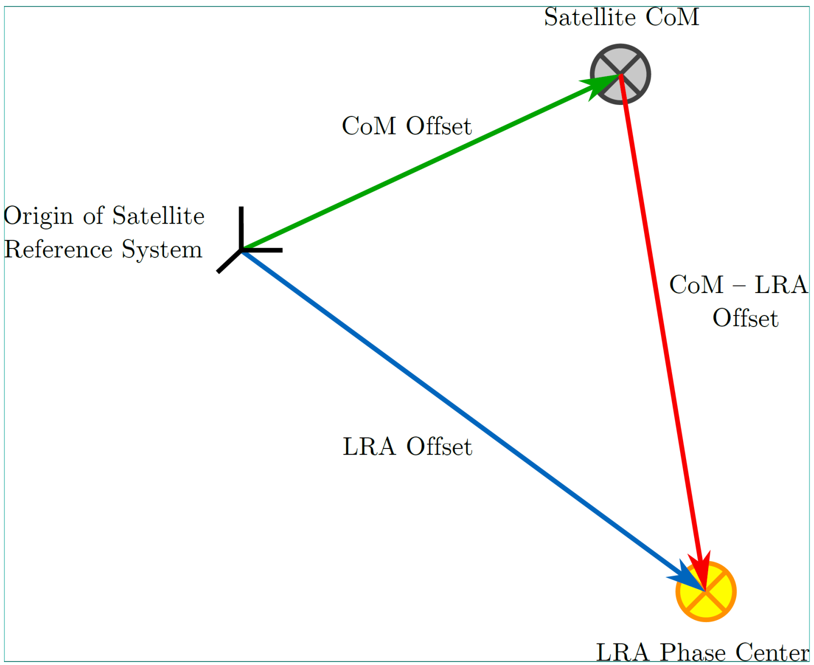
- At INFN-Frascati we have a suited Clean Room, the
  SCF_lab2, already co-funded by ASI & INFN.

Do ESA and ILRS endorse LaRCo @ Frascati?

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