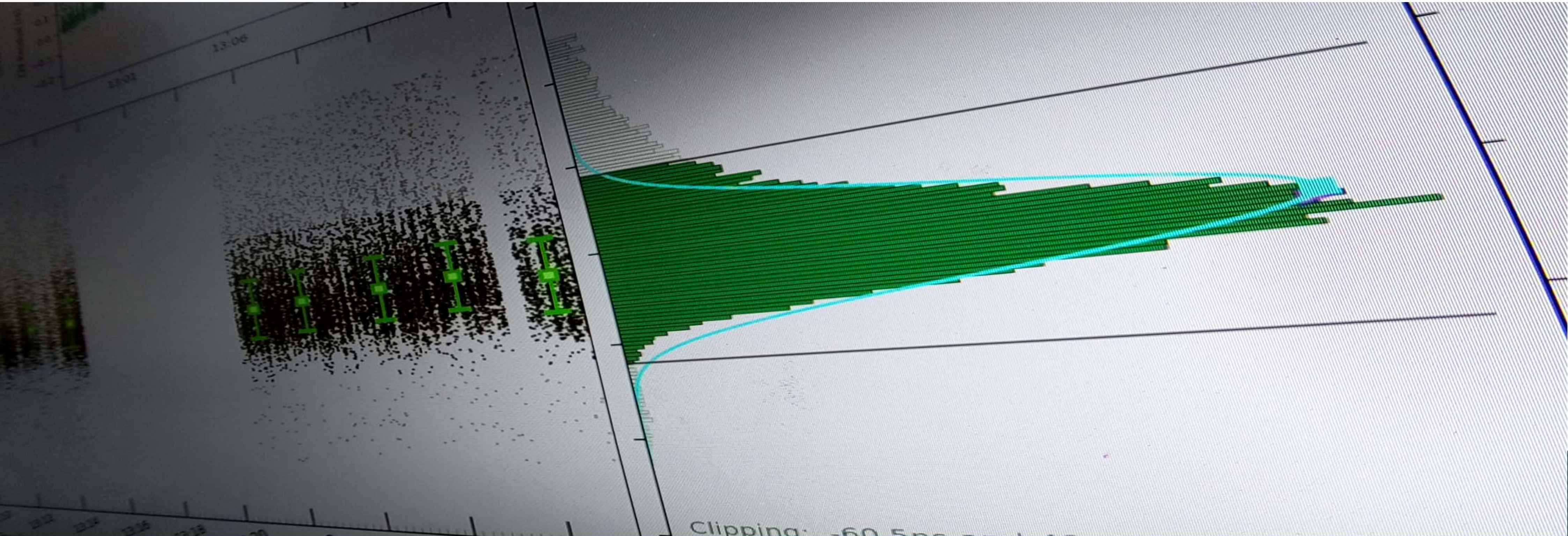

MATTHEW WILKINSON

Advancing Fully Automated SLR Data Reduction

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British Geological Survey

Natural Environment Research Council

INTRODUCTION

Reduction of SLR data, to extract the satellite return measurements from the surrounding noise points and to generate normal points, must be performed following the completion of the satellite pass.

Before this can happen, another calibration measurement to a ground target is made to determine the systems delay and further meteorological readings are recorded.

In place of the observer manually selecting track, an automated process is under development and testing at the SGF, Herstmonceux.

INTRODUCTION

A continuously running, multi-process Python program prepares the necessary calibration, track, prediction, status and meteorological files for each satellite pass.

Data reduction must be able to deal with the different distributions of data, including weaker return signals, intermittent data flows, high background noise levels due to sky brightness and returns that were not detected in real-time.

An autonomous process must also provide visual feedback of the final results for inspection.

WHY AUTOMATE SLR REDUCTION?

Many SLR stations in the ILRS network are partly automated.

There are stations that operate automatic scheduling, automatic searching and automatic track detection. Some operate autonomously, without an observer.

An automated data reduction system needs to be reliable so that ultimately it will be allowed to take the final step of generating normal points and submitting data files.

The SGF is developing an automated reduction process using a Riga A033-ET event timer which is installed in parallel. The SGF, Herstmonceux is a kHz SLR station.

CONTENTS

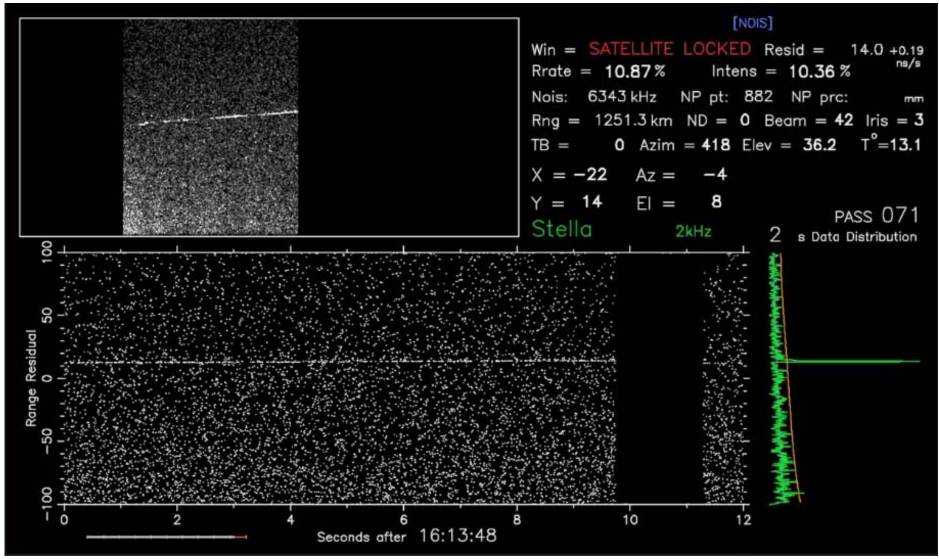
- Automatic SLR Data Reduction
- Track Searching
- Data Clipping by Elevation
- Normal Point Comparison
- Visual Feedback

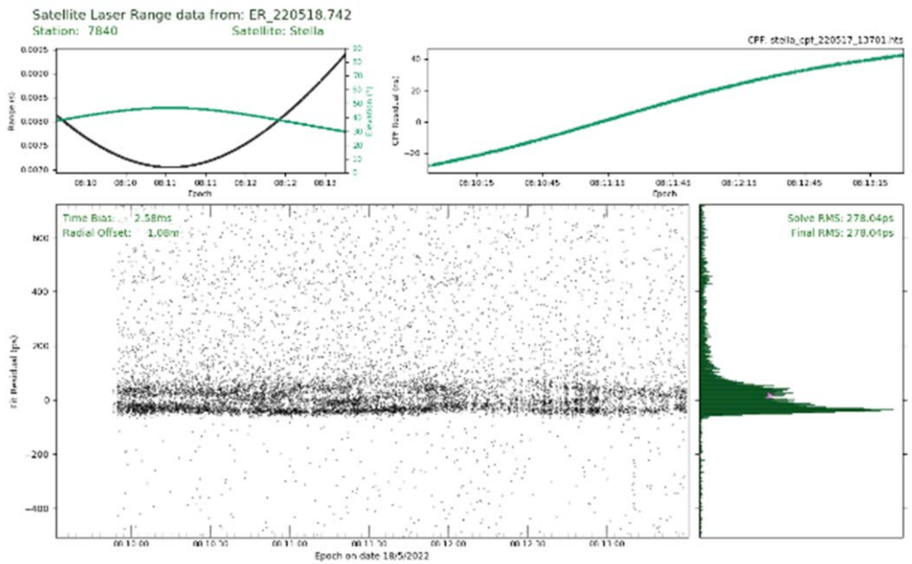
AUTOMATIC DATA REDUCTION

Track is identified in real-time and track ranges are recorded to a file.

orbitNP.py uses these epochs and ranges in an orbit solution and outputs the time bias and radial corrections.

These corrections can then be applied to the whole pass dataset to produce flattened SLR residuals.



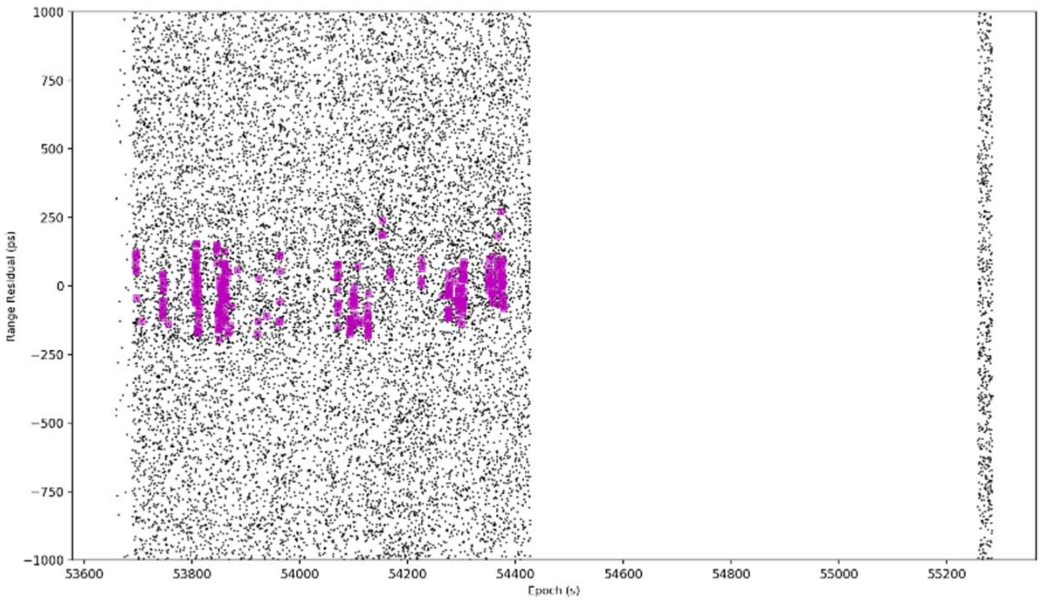


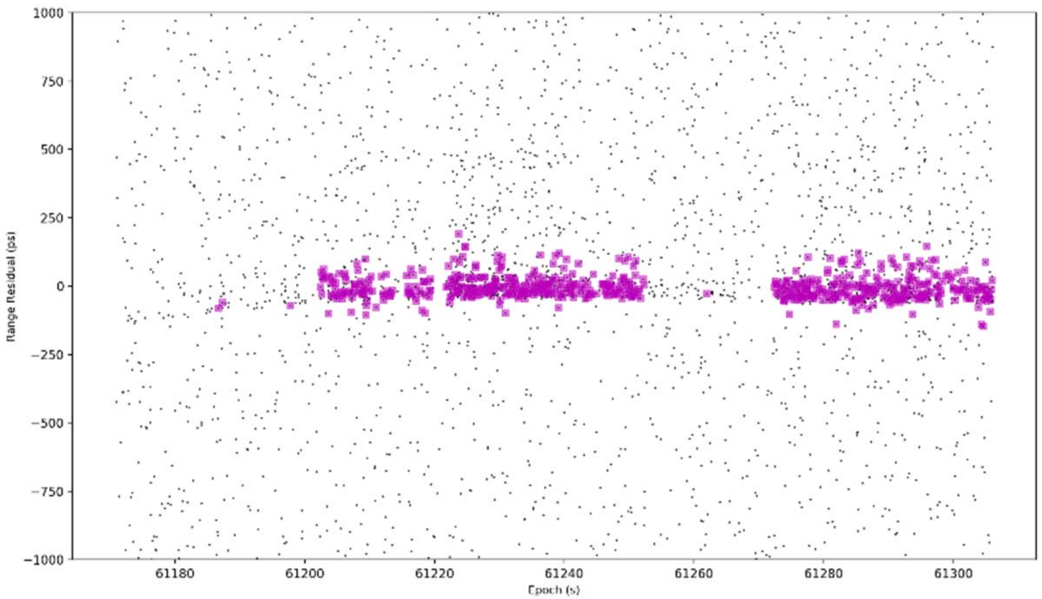
AUTOMATIC DATA REDUCTION

Track is identified in a flattened residual plot by considering relative densities.

For each point, the **interval to the Nth closest point** within a narrow range residual window is calculated. This will be very short for satellite track and longer for random noise.

By incrementally including the next shortest intervals and looking for a marked change in RMS, a cut-off point can be determined, below which is track.





TRACK SEARCHING

The automated reduction process is dependent on the first step of real-time track detection.

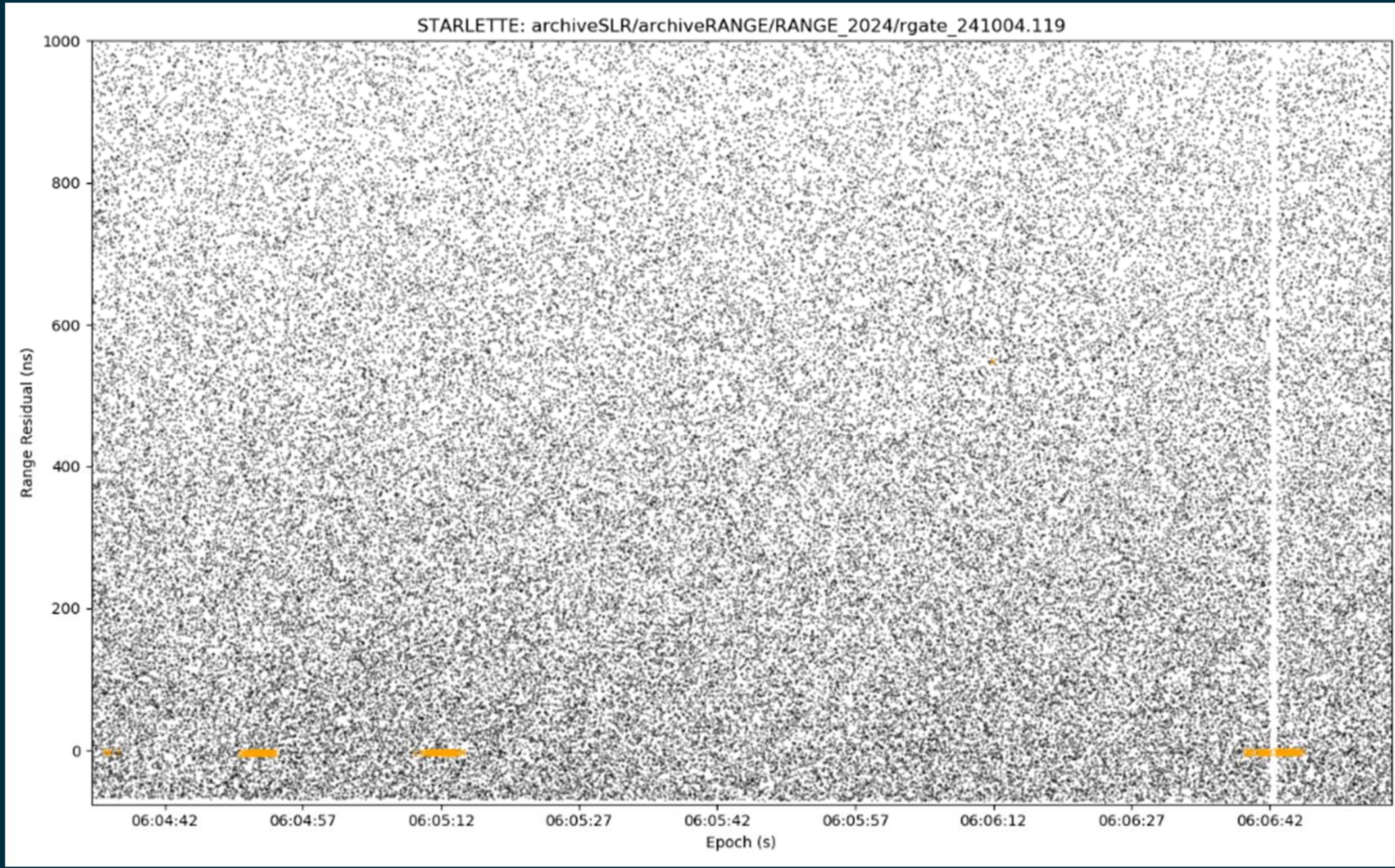
This information, however, might not always be available. The track data could be limited or even corrupted.

Alternatively, the satellite might not have appeared in the displayed range gate.

Before a pass is discarded a search for any track present is needed.

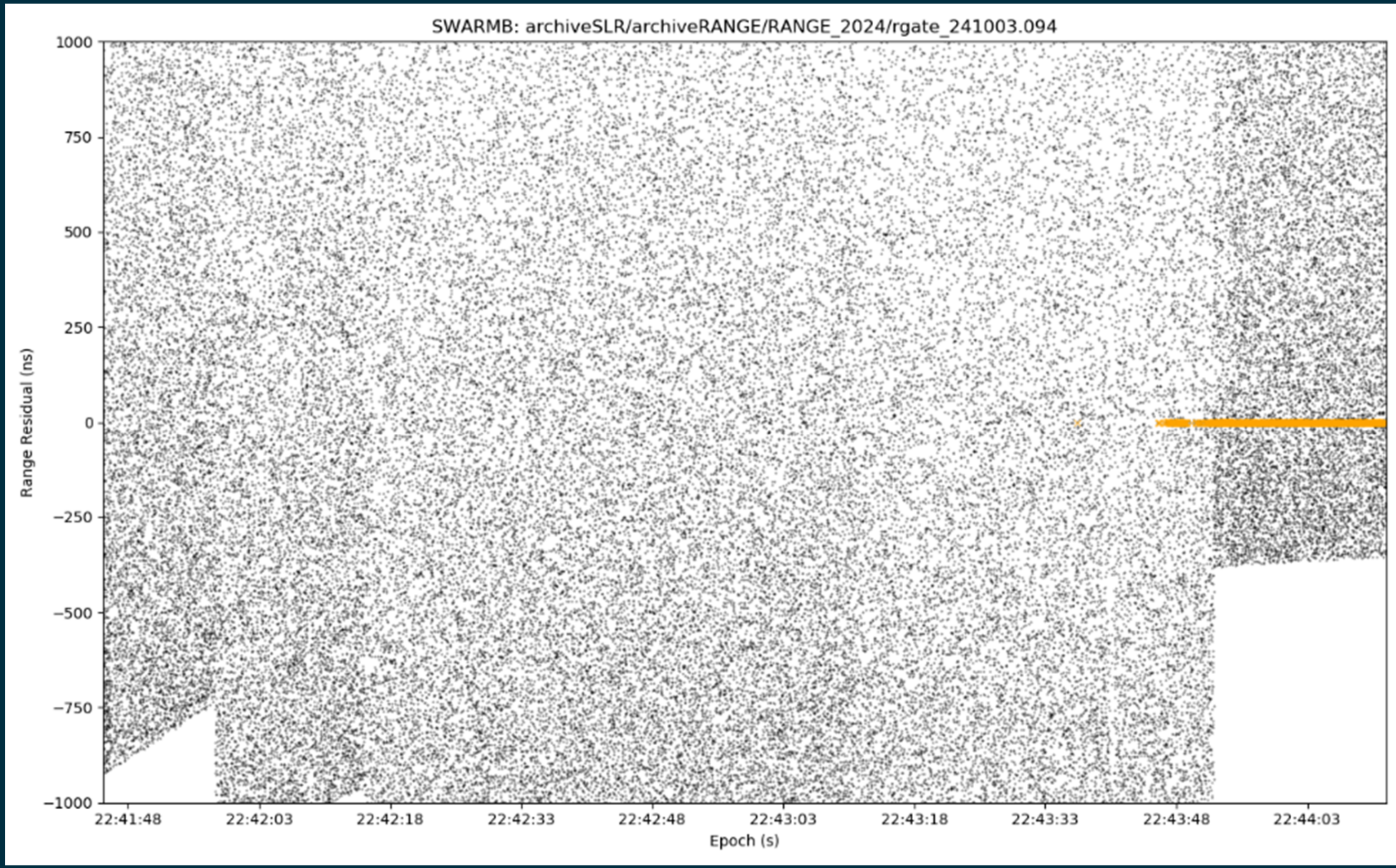
TRACK SEARCHING

Starlette



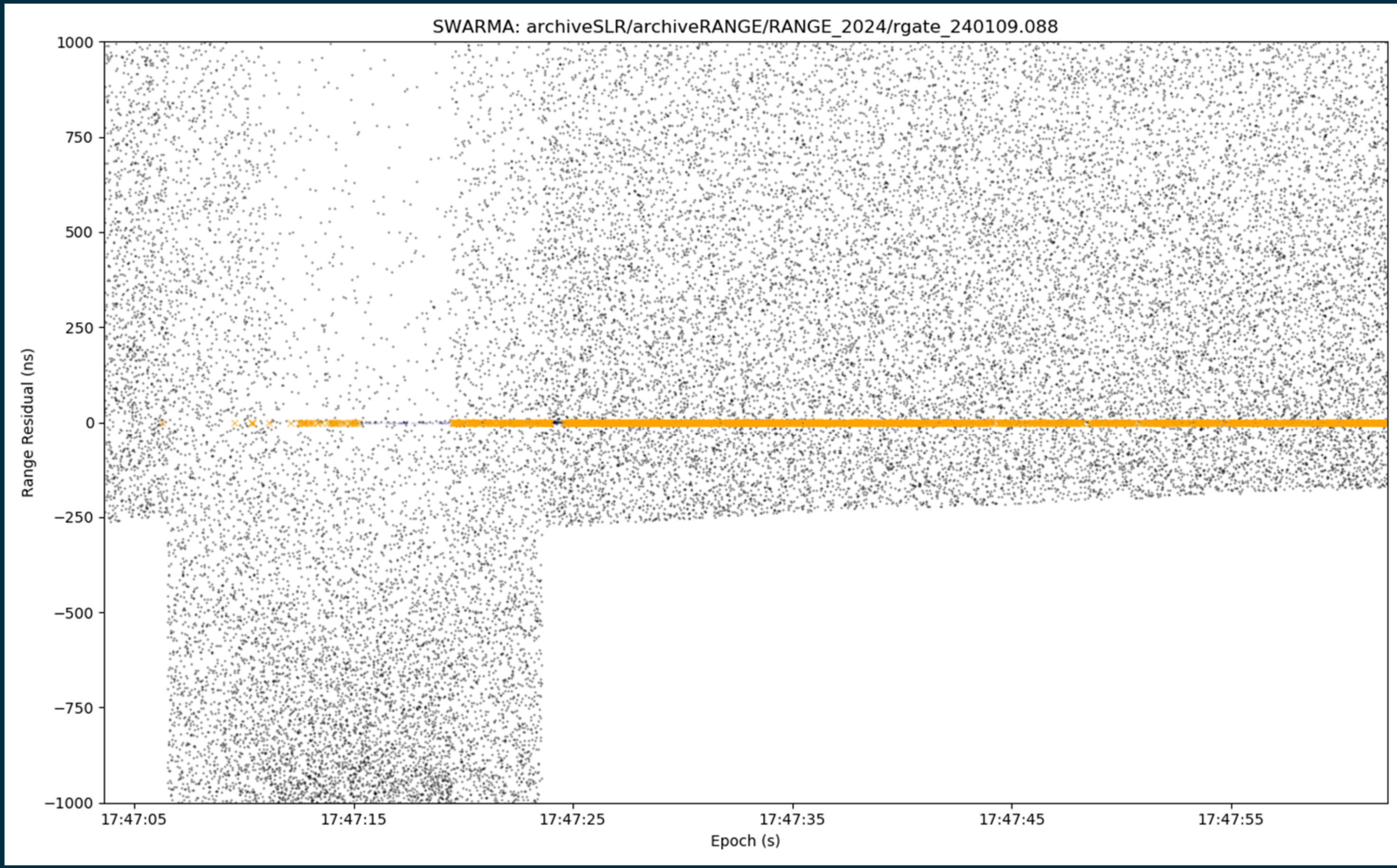
TRACK SEARCHING

Swarm -B



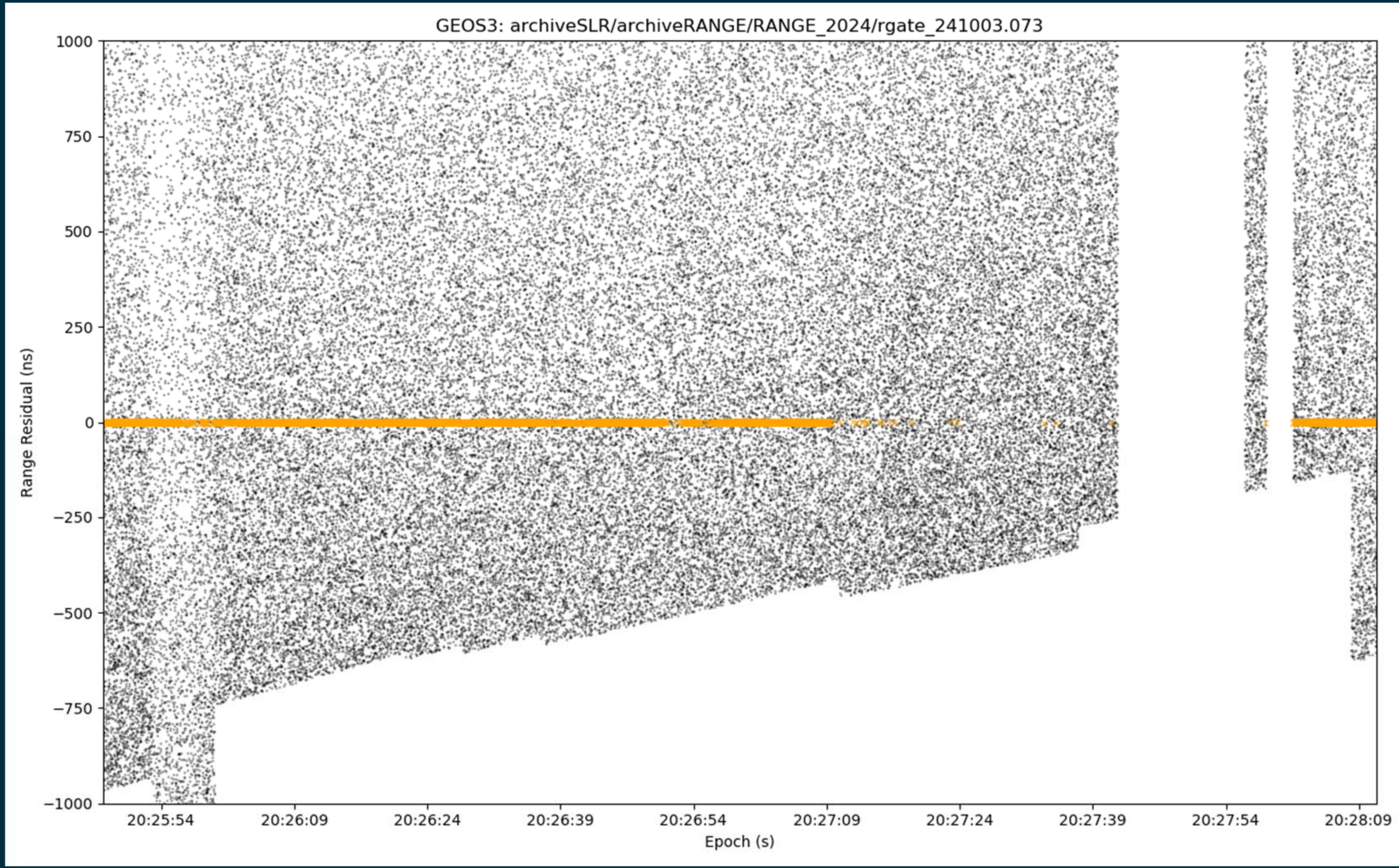
TRACK SEARCHING

Swarm-A



TRACK SEARCHING

GEOS-3



ELEVATION CLIPPING

GNSS satellites carry flat trays of retro-reflectors.

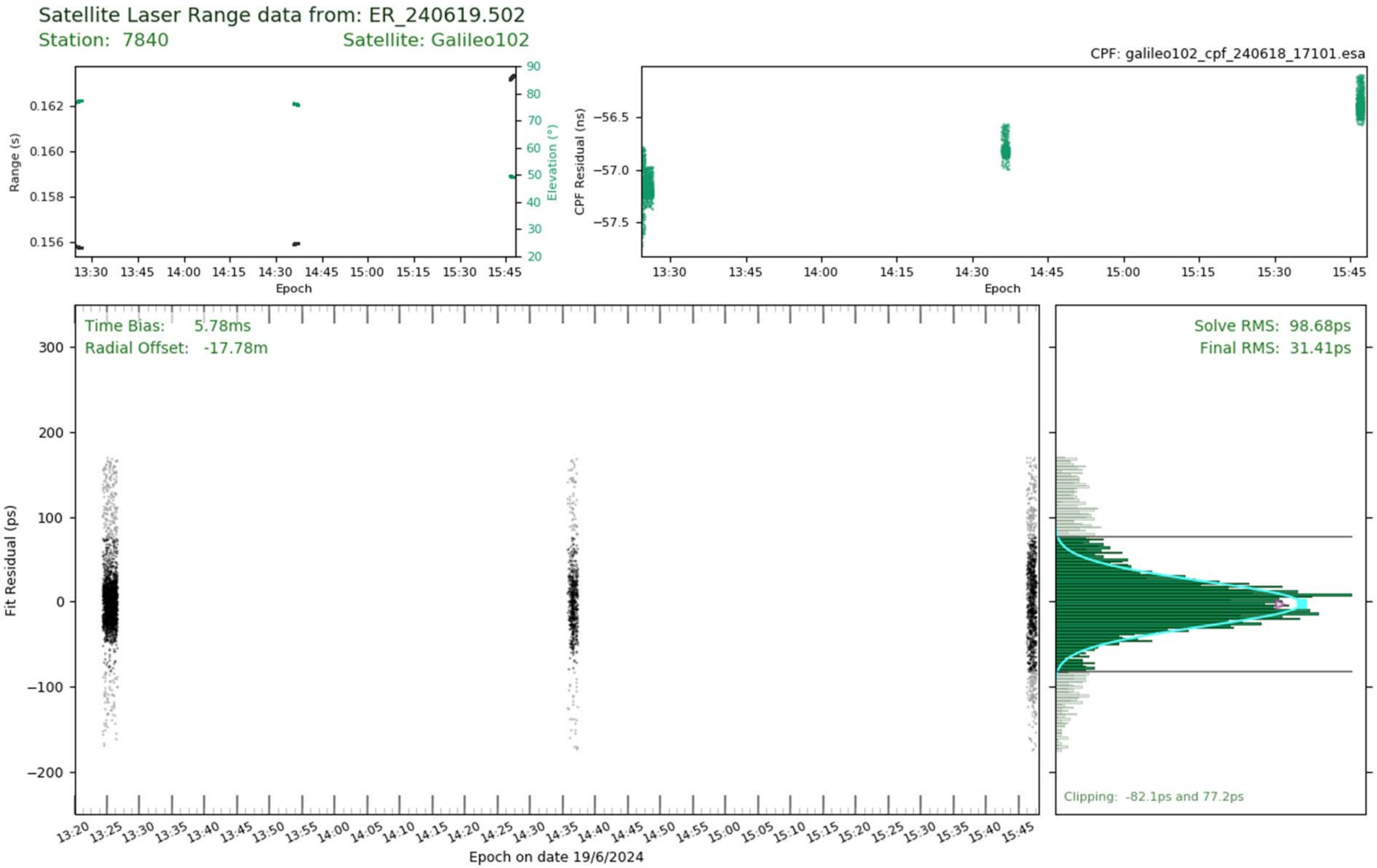
These can contain many corner cubes and therefore take up a large surface area.

SLR returns can come from any of the cubes. When the retro-reflector array is observed at a non-incident angle there is a spread in range.

This means a higher RMS range distribution at lower elevations.

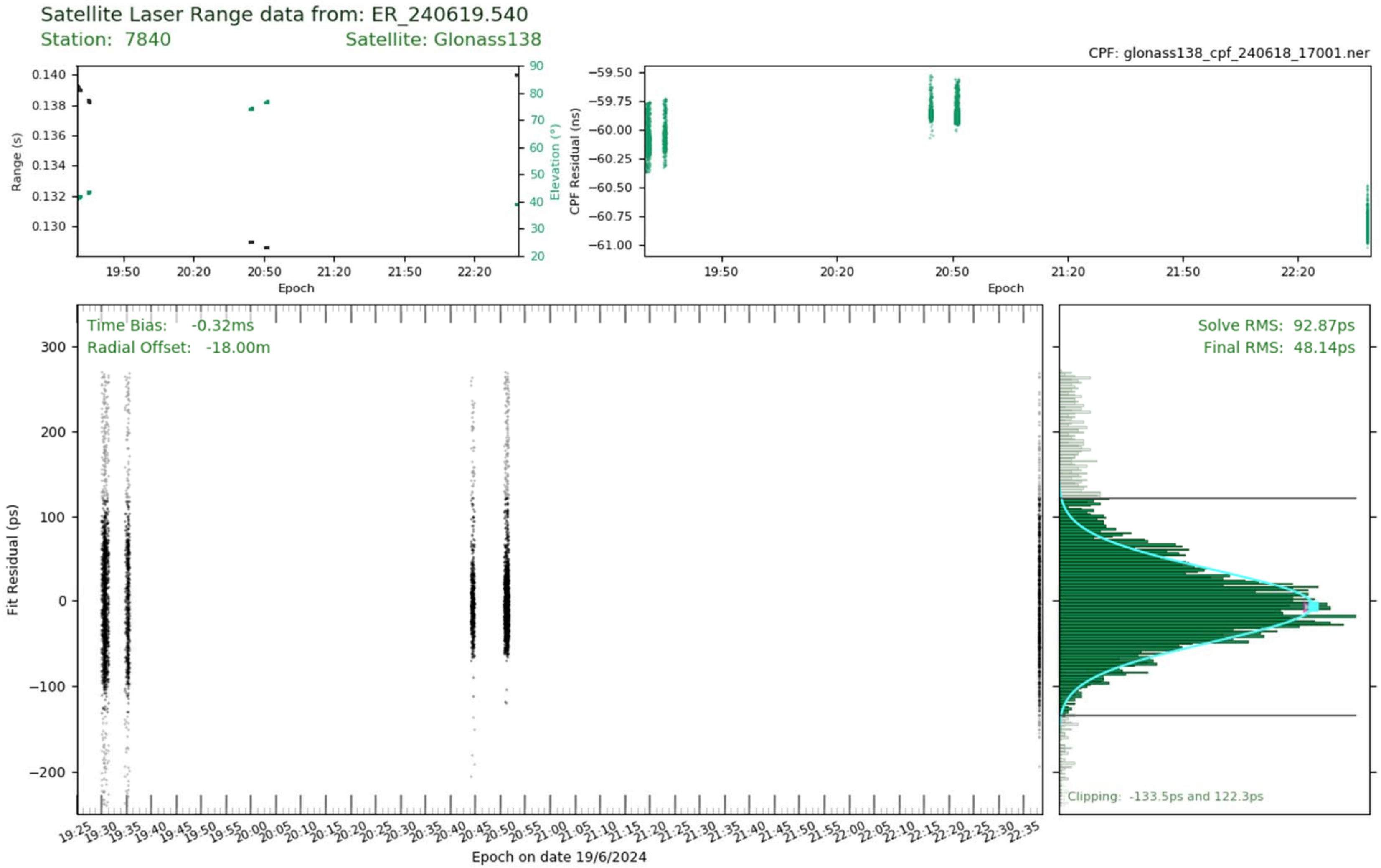
ELEVATION CLIPPING

Galileo 102



ELEVATION CLIPPING

Glonass 138



ELEVATION CLIPPING

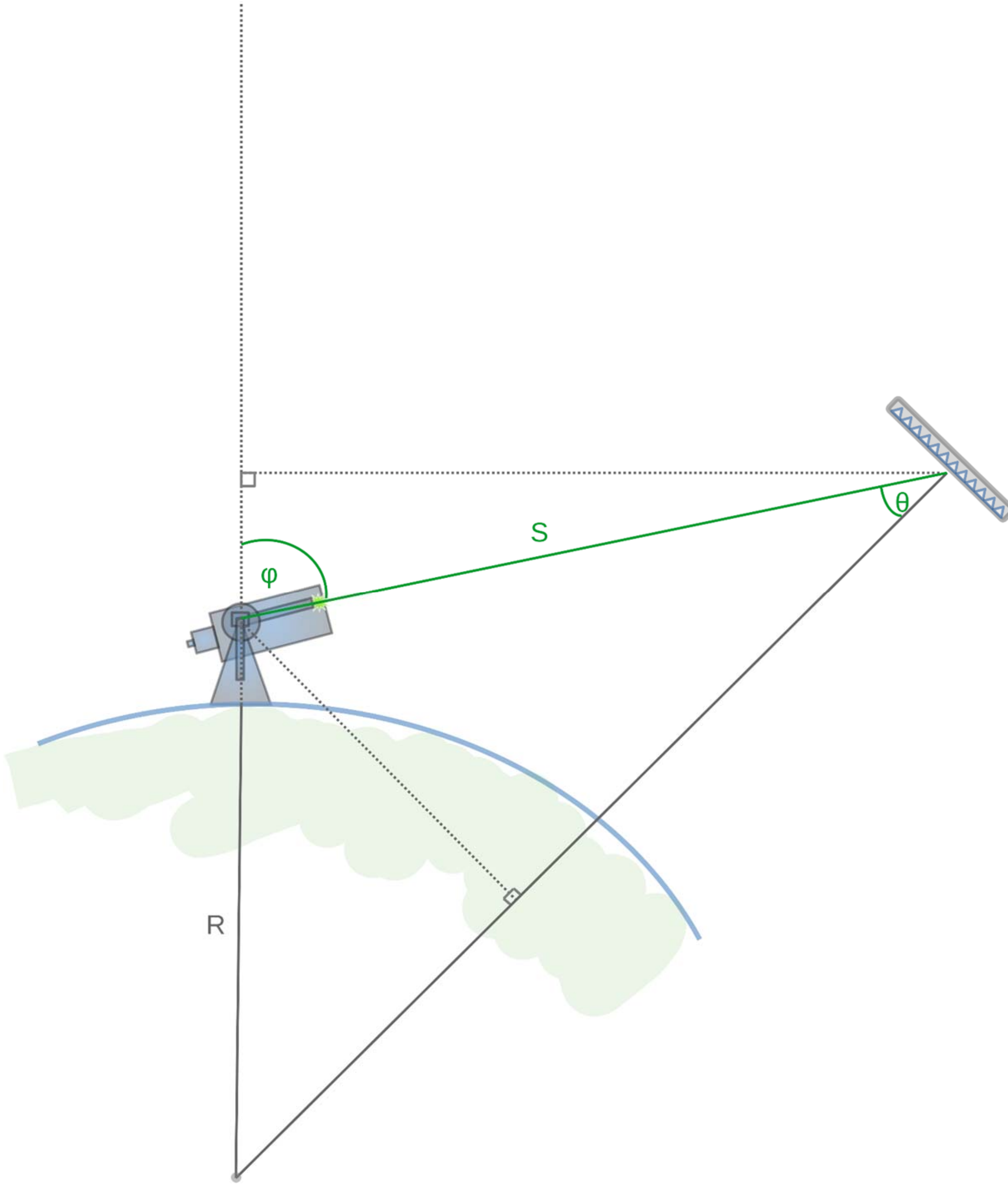
This variation in RMS is due to the angle at which the retro-reflector array is observed.

At lower elevations, the array is tilted and retro-reflectors are visible at different ranges.

The incidence angle can be calculated as:

$$\theta = arcsin\left(\frac{R}{S} sin\left(arctan\left(\frac{Ssin(\varphi)}{R + Scos(\varphi)}\right)\right)\right)$$

R = Earth's radius
S = Satellite range
φ = Zenith angle



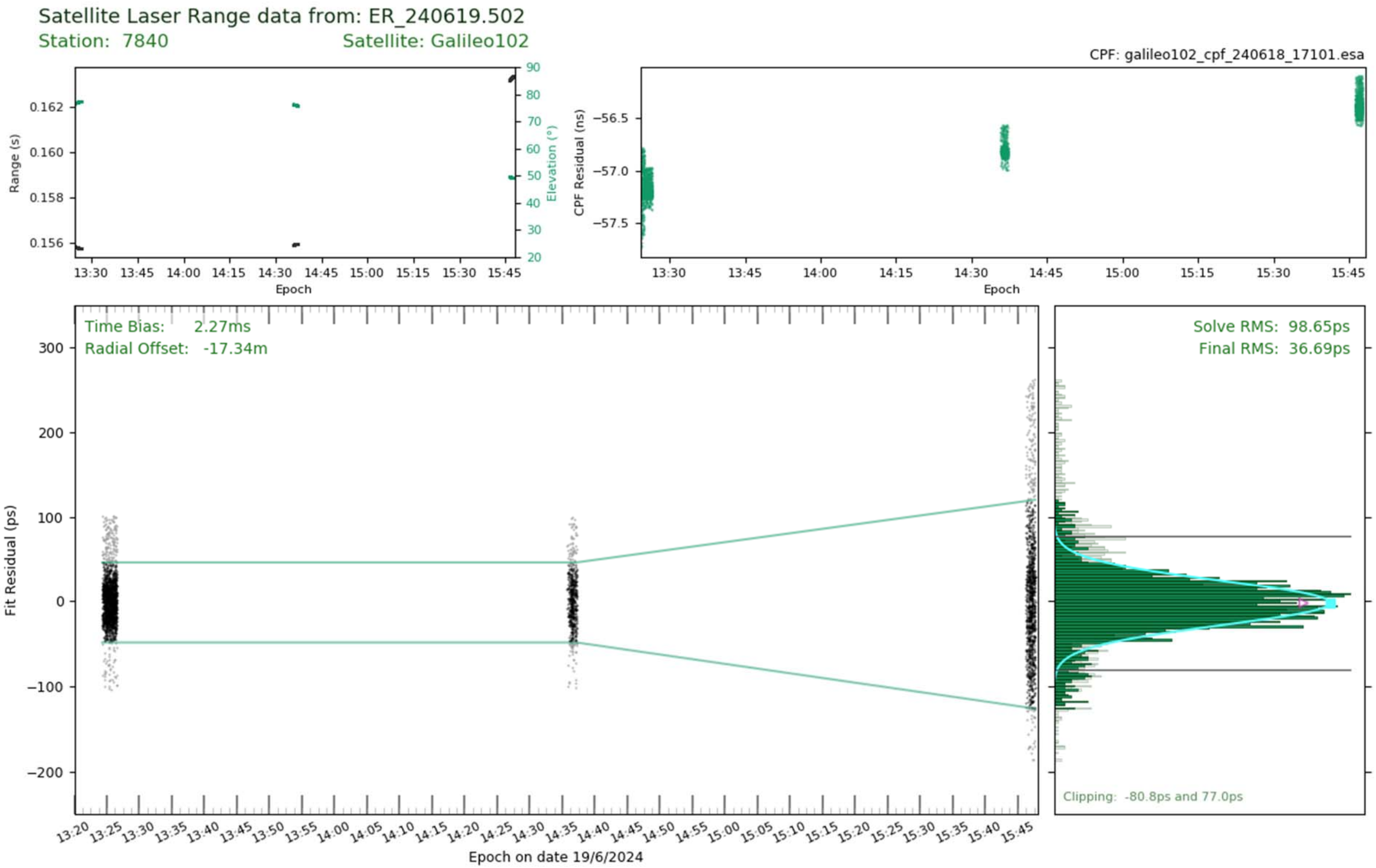
ELEVATION CLIPPING

The clipping is then scaled by sinθ.

This results in wider clipping at lower elevations.

This is now included in orbitNP.py.

Galileo 102



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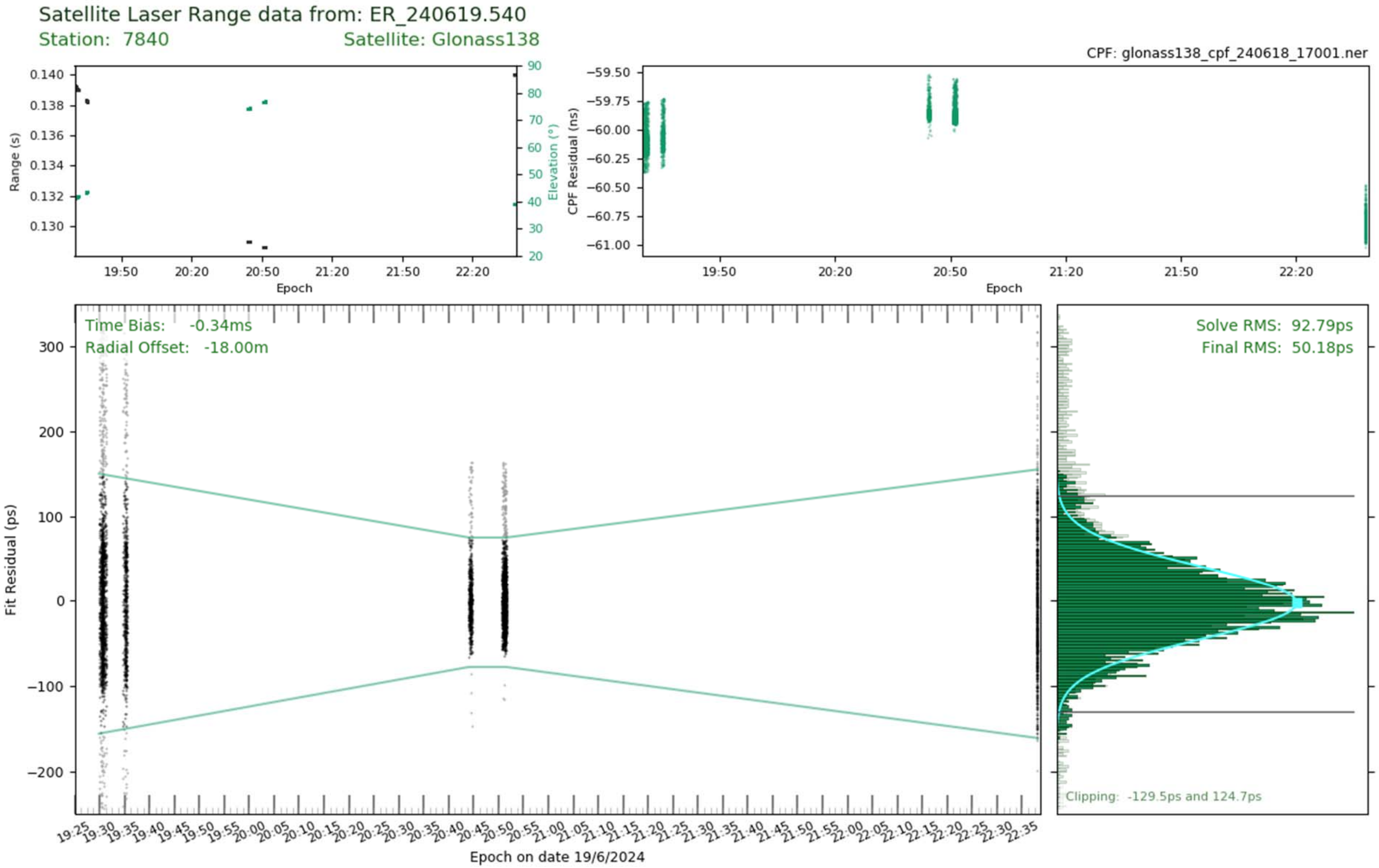


NORMAL POINT COMPARISON

The automated reduction process was developed using a A033-ET Riga event timer.

This is installed in parallel to the HxET timer, which uses Thales Dassault timing modules.

The final normal points generated by the automated process need to closely match those from HxET.

NORMAL POINT COMPARISON

The epochs should match.

An epoch correction is made to refer the recording of the detection of the laser fire to the moment the pulse passes the telescope axes invariant point.

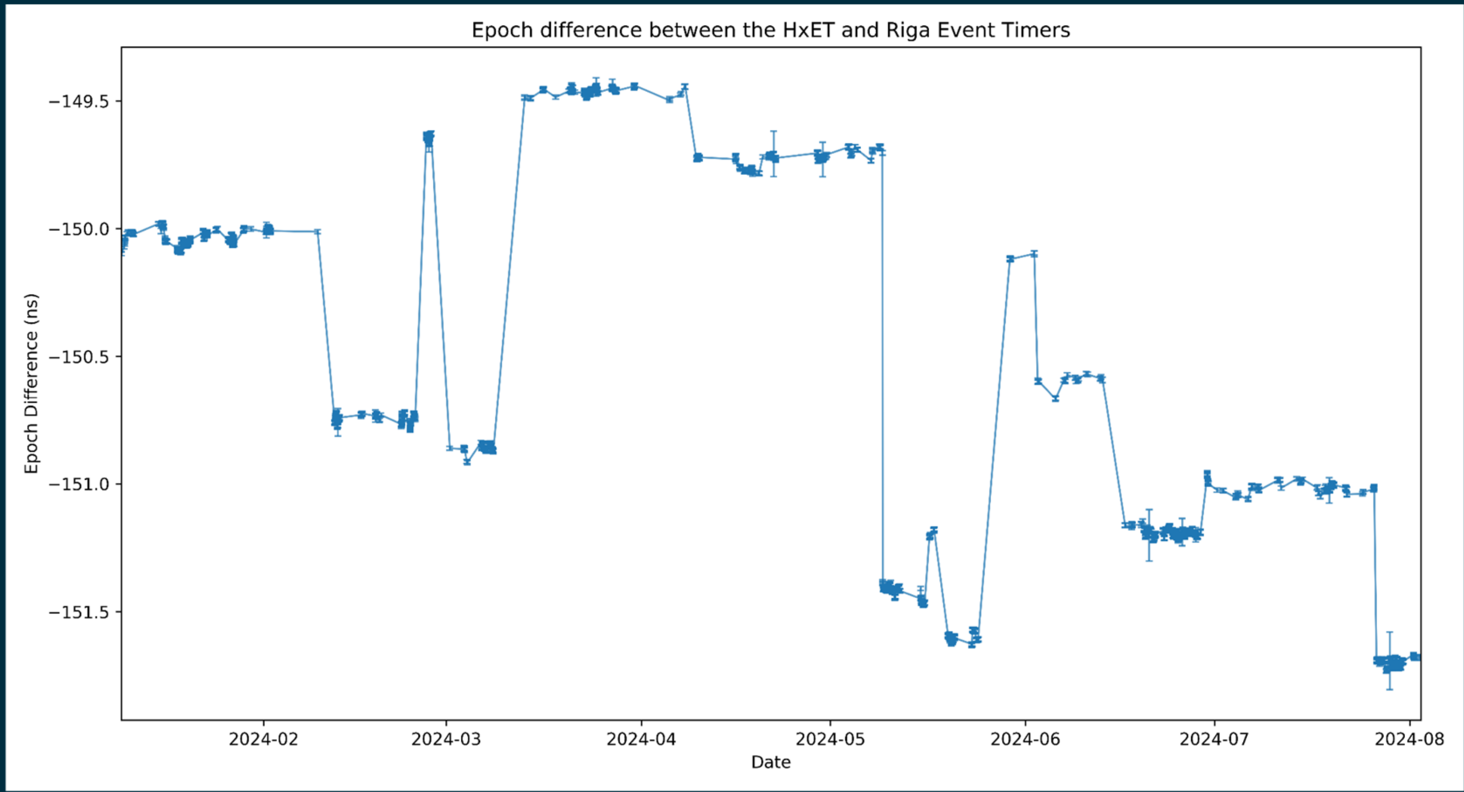
The correction is calculated by measuring cable delays, tracing the optical path and estimating electronic delays.

The corrections are different for each timer, but the corrected epochs should match.

NORMAL POINT COMPARISON

By comparing the recorded epochs from the different timers for a series of passes, it was found that the estimated correction for the Riga timer had an error of -150ns.

However, this value was inconsistent, over time.

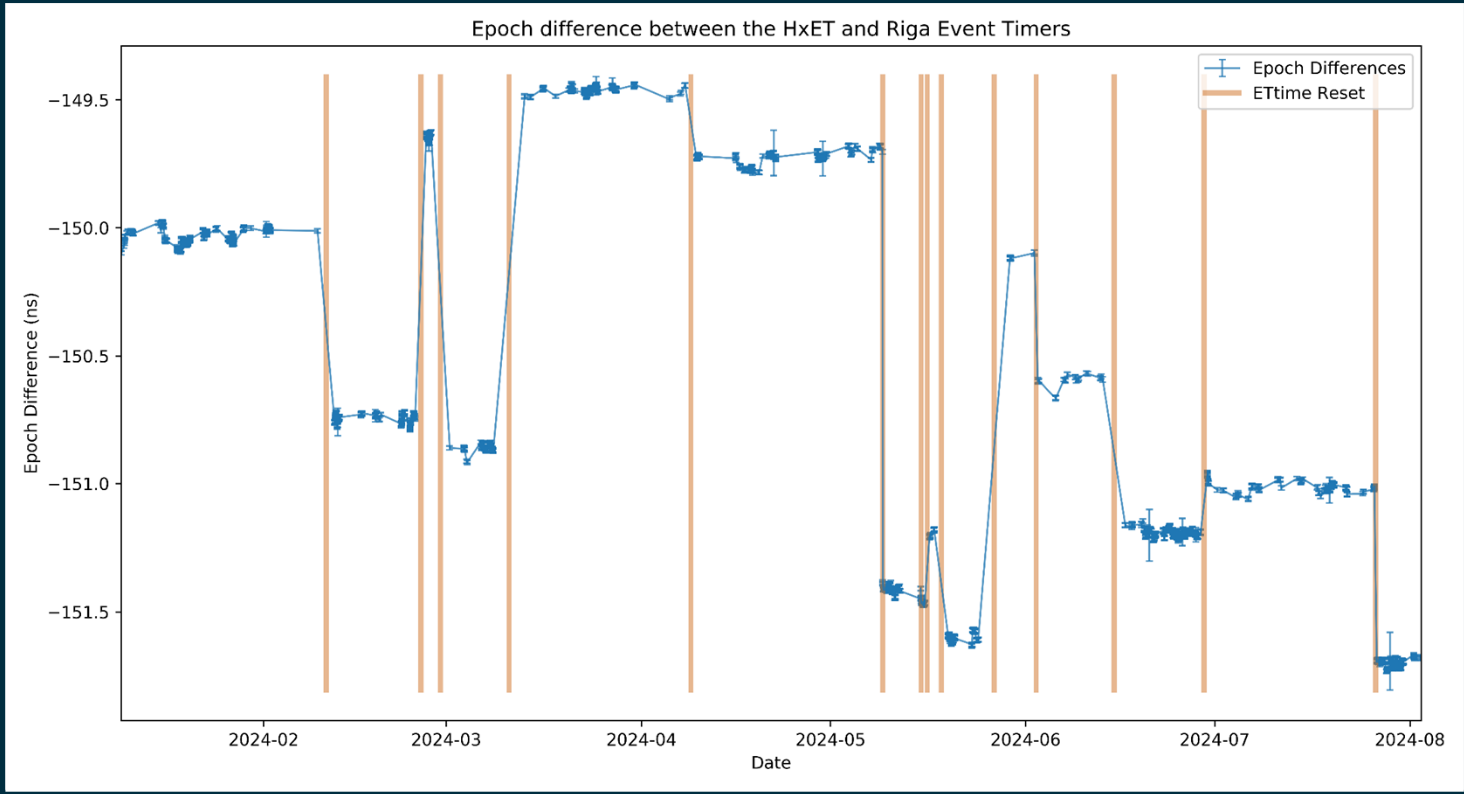


NORMAL POINT COMPARISON

The plot shows the differences in epochs recorded by the two timers, including RMS errorbars.

Some large jumps can be seen during 2024.

These were found to coincide with resets of the HxET timer.



NORMAL POINT COMPARISON

The ranges should match.

It is not straight forward to compare normal points because if they have different epochs then the range will also be different.

V. Husson has developed a method of matching epochs in the full-rate data and removing the residual from the range and applying the normal point residual.

NORMAL POINT COMPARISON

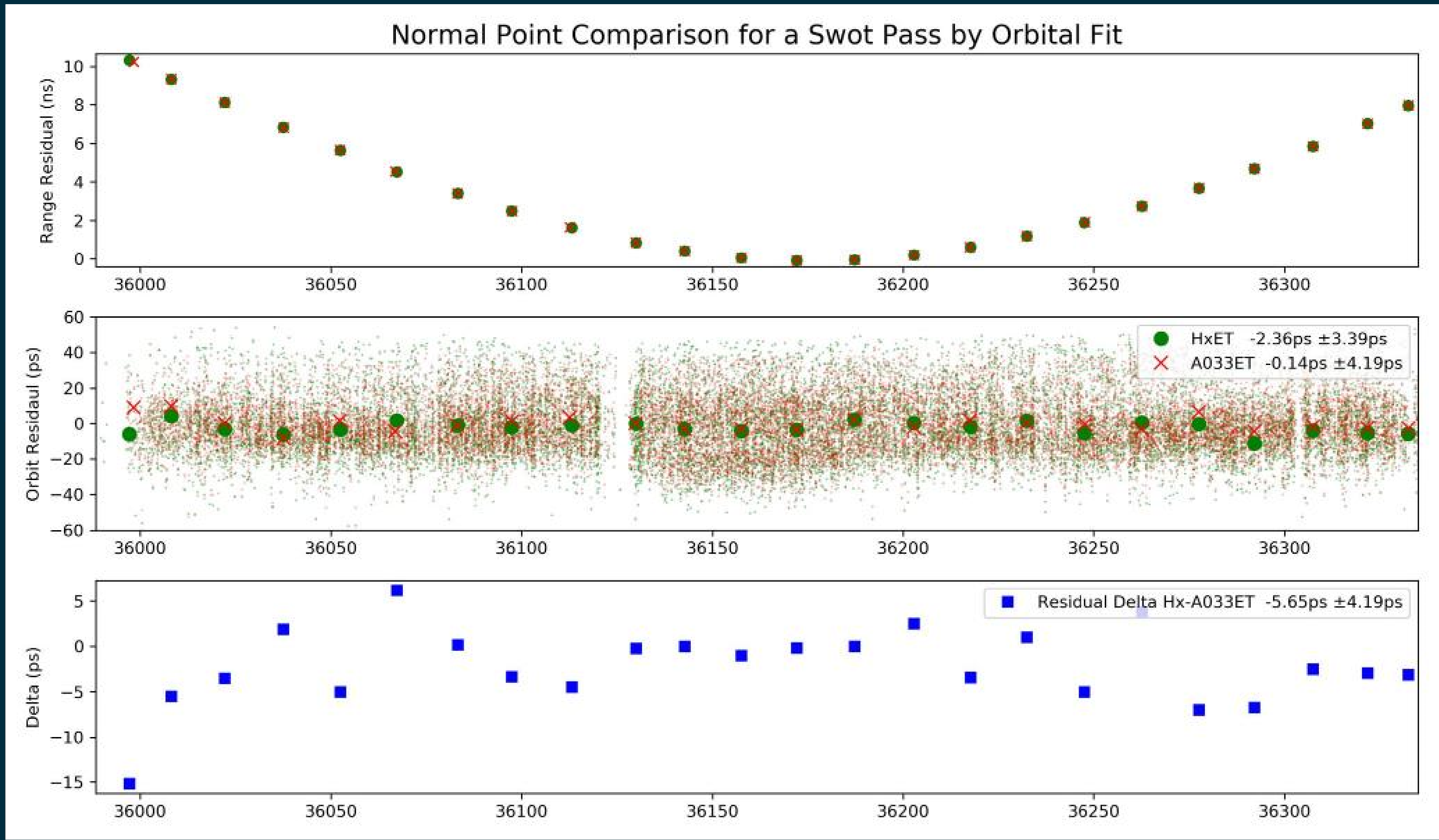
Alternatively, the normal points can be flattened together and compared.

First, the ranges in the normal points and full-rate data are compared to a reference orbit CPF and the residuals are plotted.

Then, these residuals must then be flattened, either by polynomial or by orbit correction.

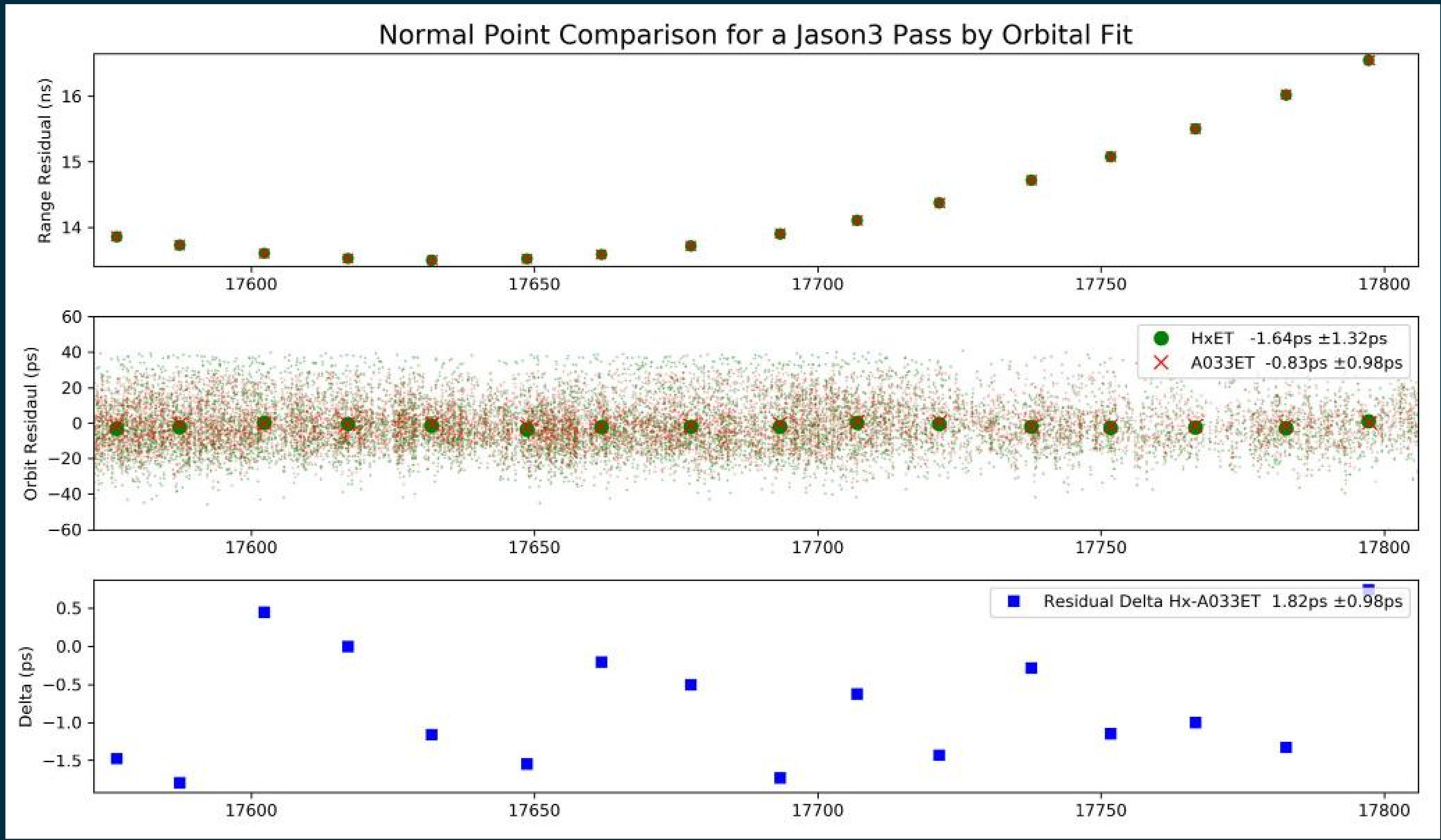
NORMAL POINT COMPARISON

SWOT



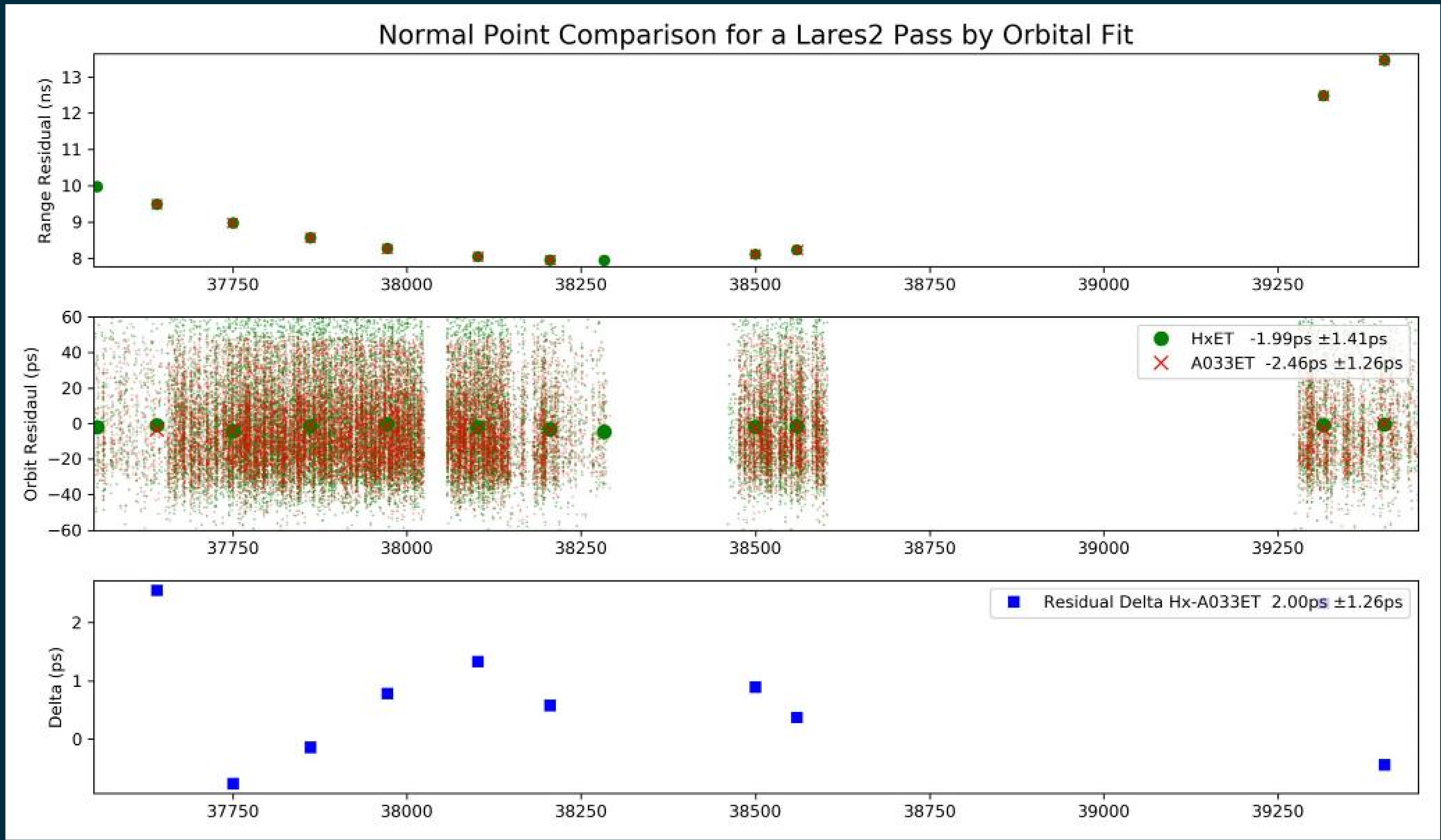
NORMAL POINT COMPARISON

Jason-3



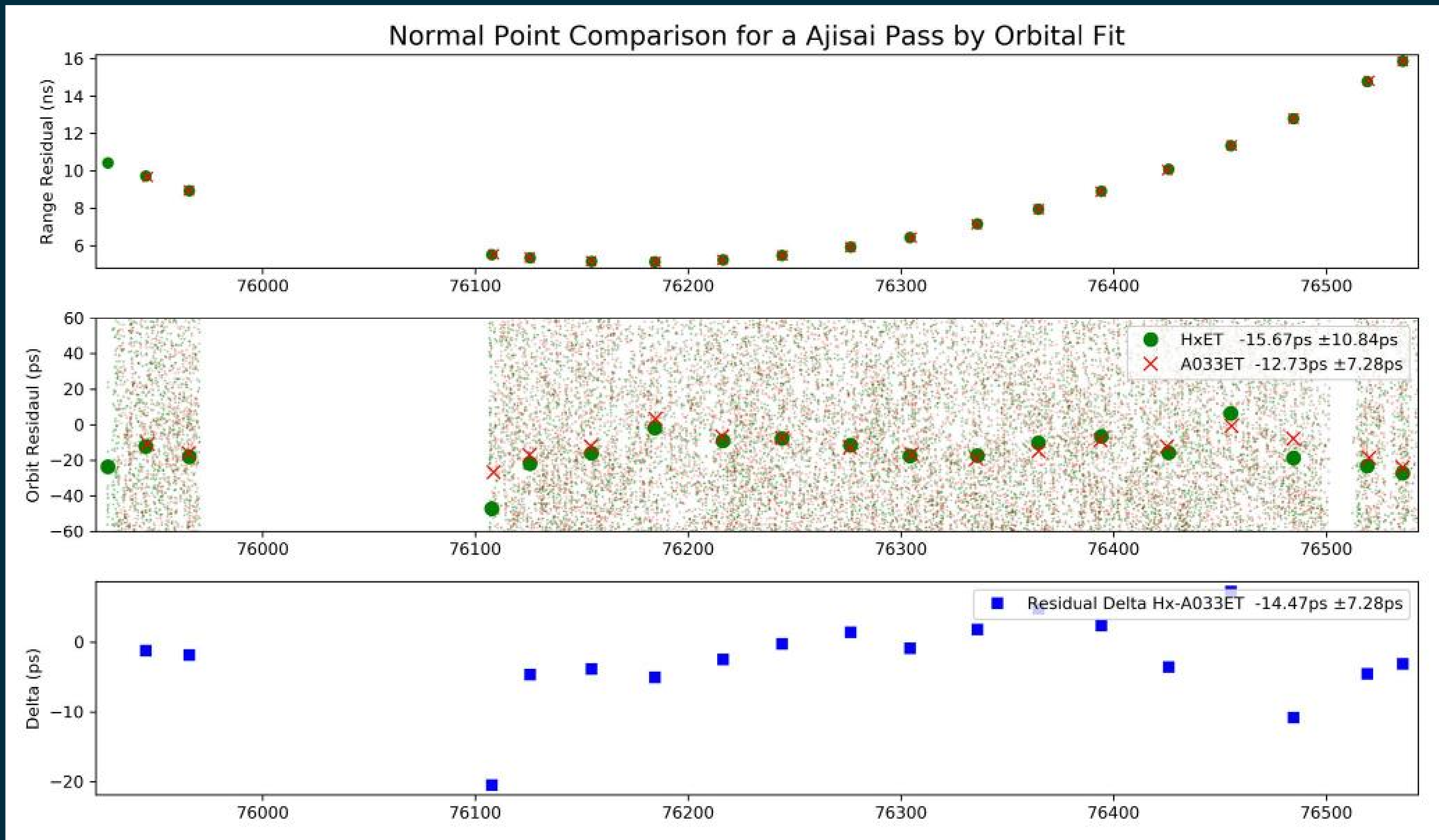
NORMAL POINT COMPARISON

Lares 2



NORMAL POINT COMPARISON

Ajisai

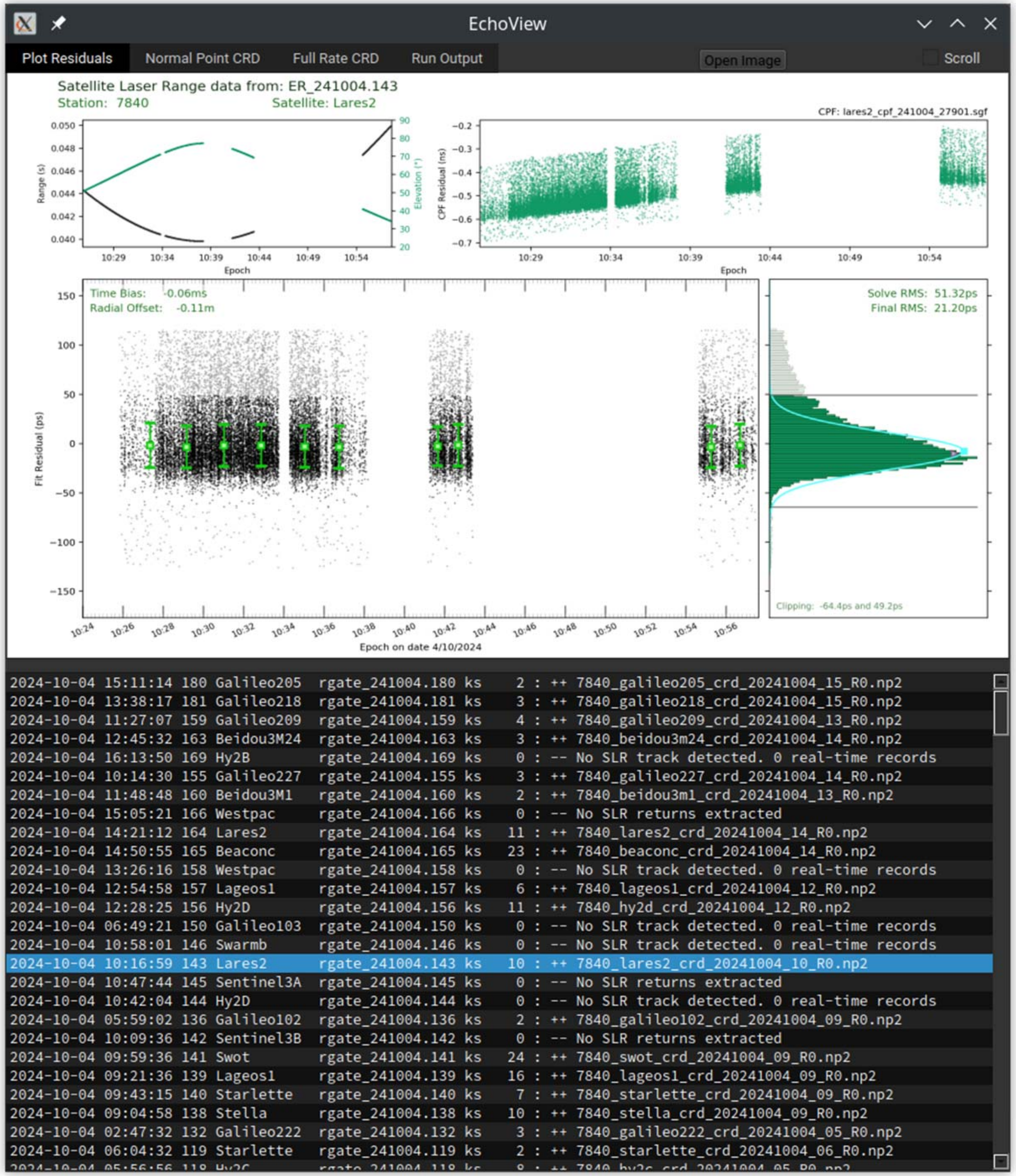


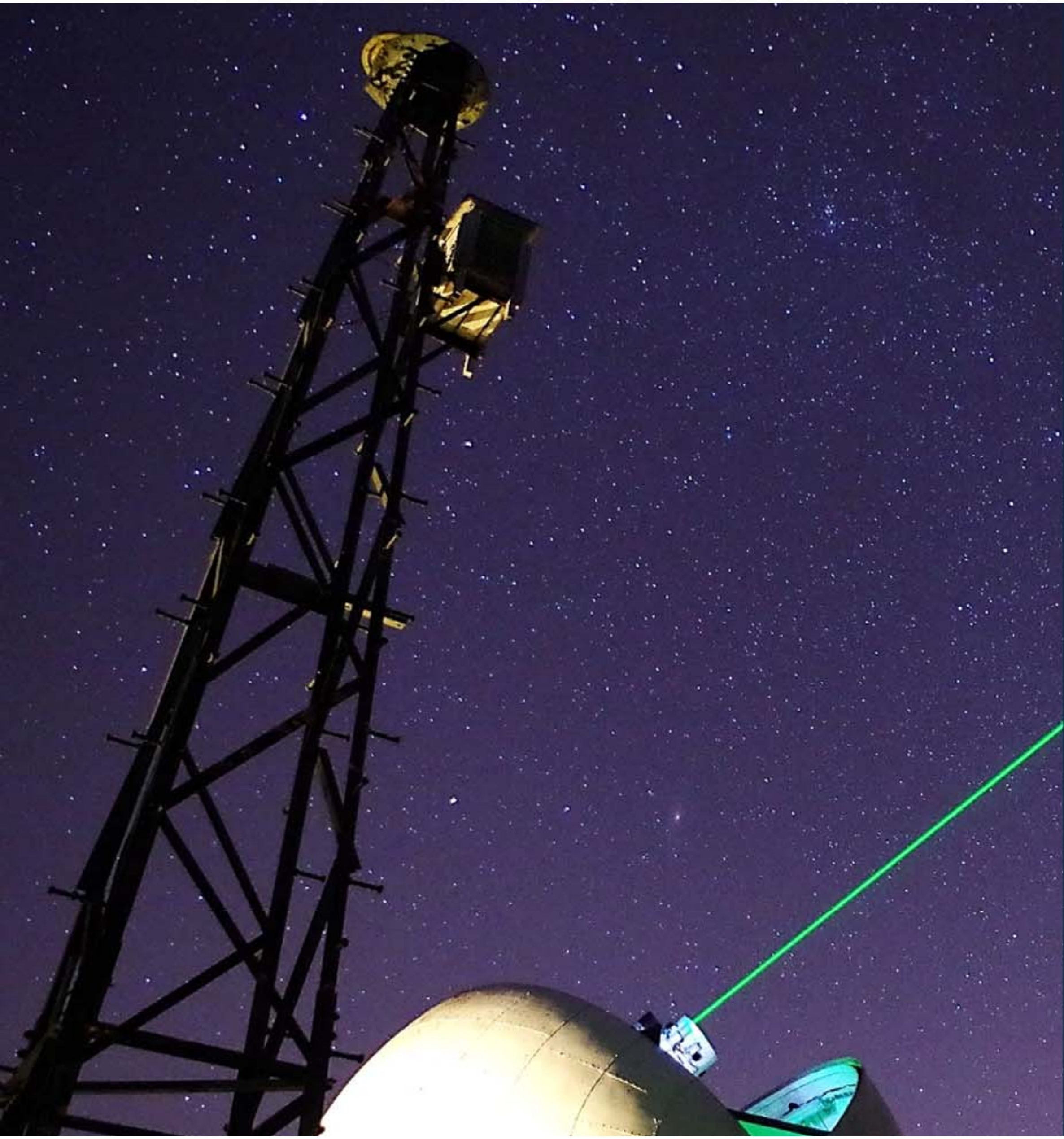
VIEWING THE RESULTS

An interactive application to monitor the output plots and data files was developed.

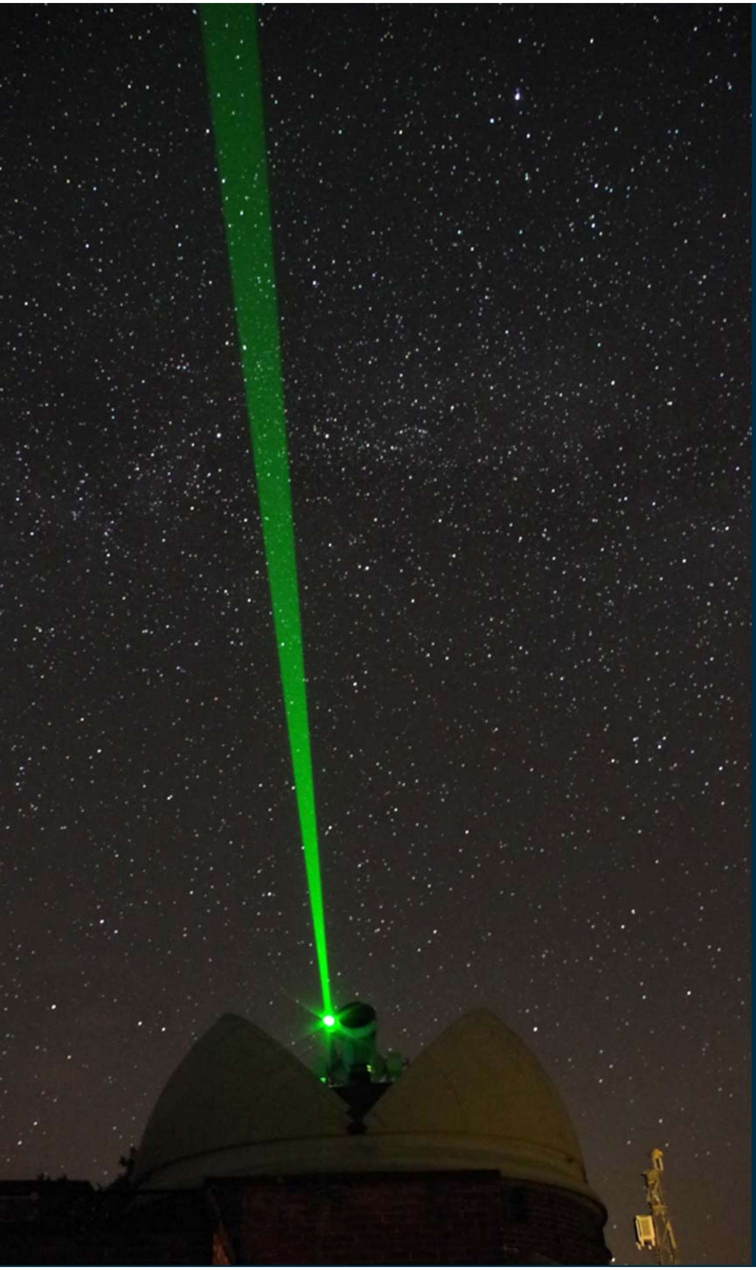
The application updates with the latest reduction results showing the output plot.

The normal point and full-rate files are also made available along with a record of the process output.





Conclusions



CONCLUSIONS

- Automatic reduction of passes is achievable for the majority and possibly for all SLR passes.
- Real-time track detection can be replaced by track searching initiate the flattening of SLR track.
- GNSS satellites exhibit greater residual scatter at lower elevations. Clipping must therefore be elevation dependent.
- Normal points from the two SGF timers and reduction methods were compared by flattening the residuals using a polynomial and orbit correction.
- Automatically generated normal points show agreement to a few millimetres.

British Geological Survey

THANK YOU

Any questions?