NASA SLR System Characterization
A Case Study using Ground Tests

Van Husson, Christopher Szwec,

Peter Dunn

2023 Virtual International Workshop on Laser Ranging, Oct 16-20

Peraton

System Characterization and Ground Tests

- Pearlman outlined a standard model for SLR stations to characterize their station's performance in his 1984 paper "Laser System Characterization" (Reference: https://ilrs.gsfc.nasa.gov/docs/ilrw05_vol1a.pdf starts on page 66)

- NASA SLR network developed four ground tests, in addition to SLR colocations, to assist in characterizing our ranging accuracies

- Colocation had a specific meaning within the SLR community: Two SLR systems within 60 meters simultaneous ranging to LAGEOS. Colocation was a total system test

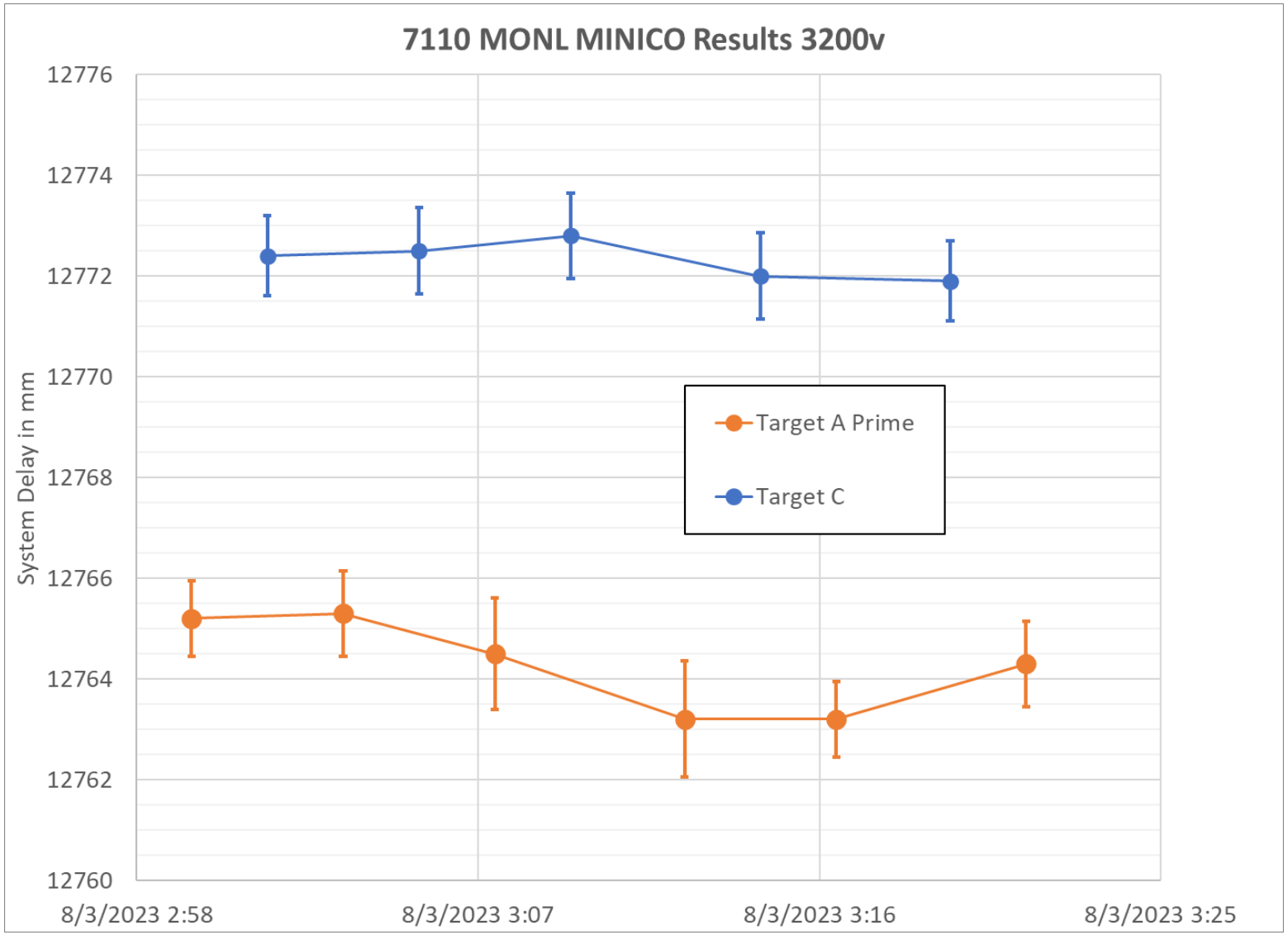
- Without being collocated with another SLR system and without ranging to a satellite, the next best thing to characterize total system performance was to conduct quasi-simultaneous ranging to multi ground targets at different ranges, separated in azimuth. This ground test was aptly named the MINICO, short for MINI-COlocation

NASA SLR Error Budget Contributors

- **Ivan Prochazka presented "ranging machine" error budgets contributors at the 2015 Matera ILRS Technical Workshop (ref: https://cddis.nasa.gov/2015_Technical_Workshop/docs/presentations/6_BIAS_B_pdf/6.4_Prochazka_pres.pdf)**
- **Below are potential error budget contributors. Some contributors can't be characterized via ground tests**

Ranging Machine Error Sources	Other Potential Error Sources
Optics (parallax, ND filters)	Meteorological Sensors
Laser Wavefront (spatial)	Local Atmosphere
System Stability (temporal)	Local Survey (calibration targets, system reference point)
RF Interference/Background Noise	Depth of Calibration Prisms
Receiver (echo signal strength)	Calibration Target Stability
Timing System Non-linearities	System Reference Point Stability
Time (epoch) and Frequency	Satellite Center of Mass Correction

7110 MONL 03-Aug-2023 MINICO Results
Electronic System Delays



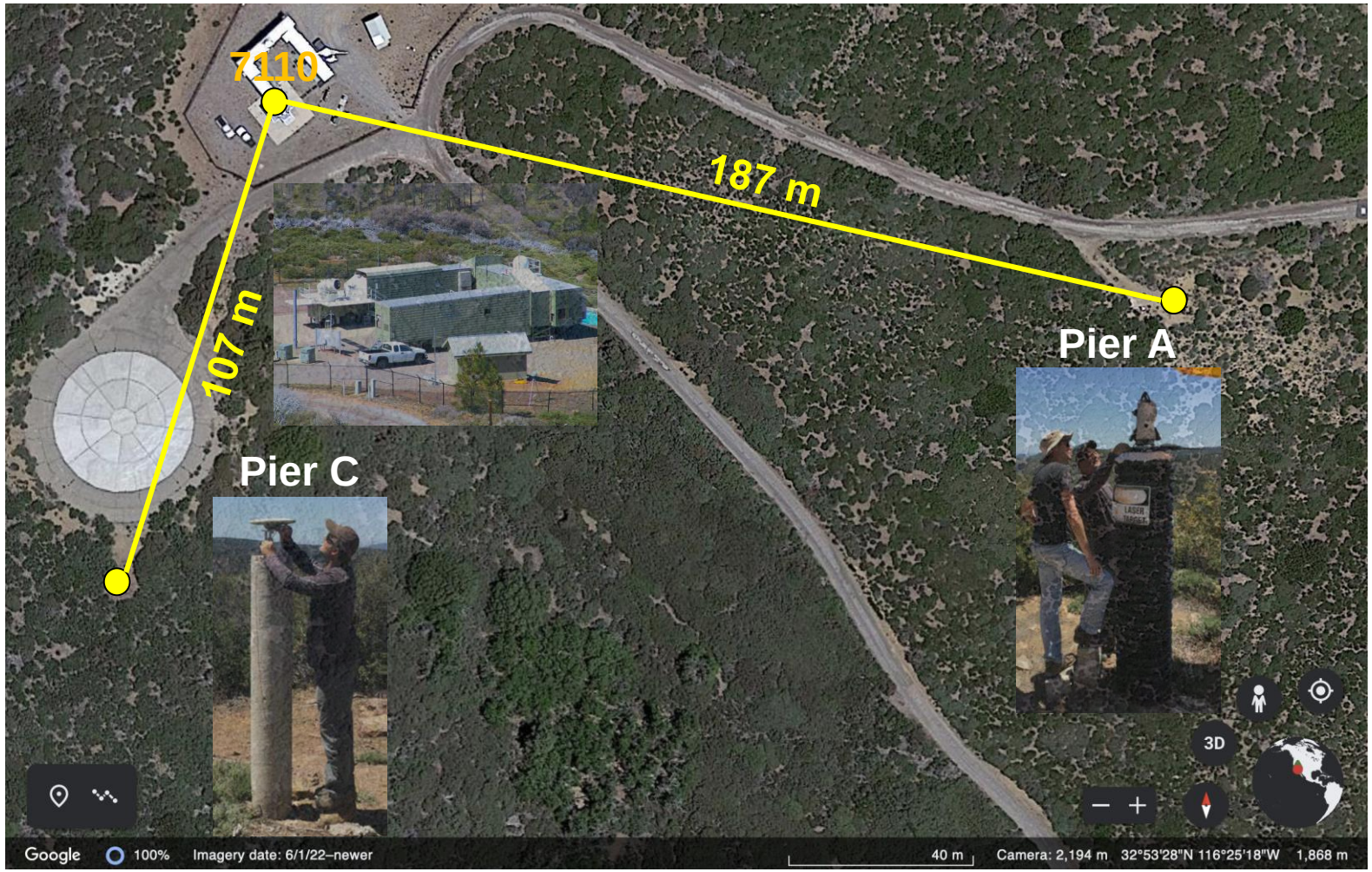
- **The system delay difference between these two targets is -8.0 mm (Target A minus Target C)**
- **Based on the magnitude of these system delay differences, raises two obvious questions**
  1. How repeatability is this -8.0 mm offset?
  2. How accurate are the target distances used in the onsite data reduction?

NASA SLR System Delay Calculation

- **System Delay (ps) = Cal ToF(ps) – Fn * (CalDis + Trans + ND)/(C/2) where**
  - Cal ToF: the measured round-trip Calibration Time of Flight
  - Fn: index of refraction dependent upon laser wavelength and meteorological conditions
  - CalDis: distance to the ground calibration target
  - Trans: Translator correction
  - ND: neutral density filter
  - C: speed of light is mm/ps divided by two (0.299792458/2)

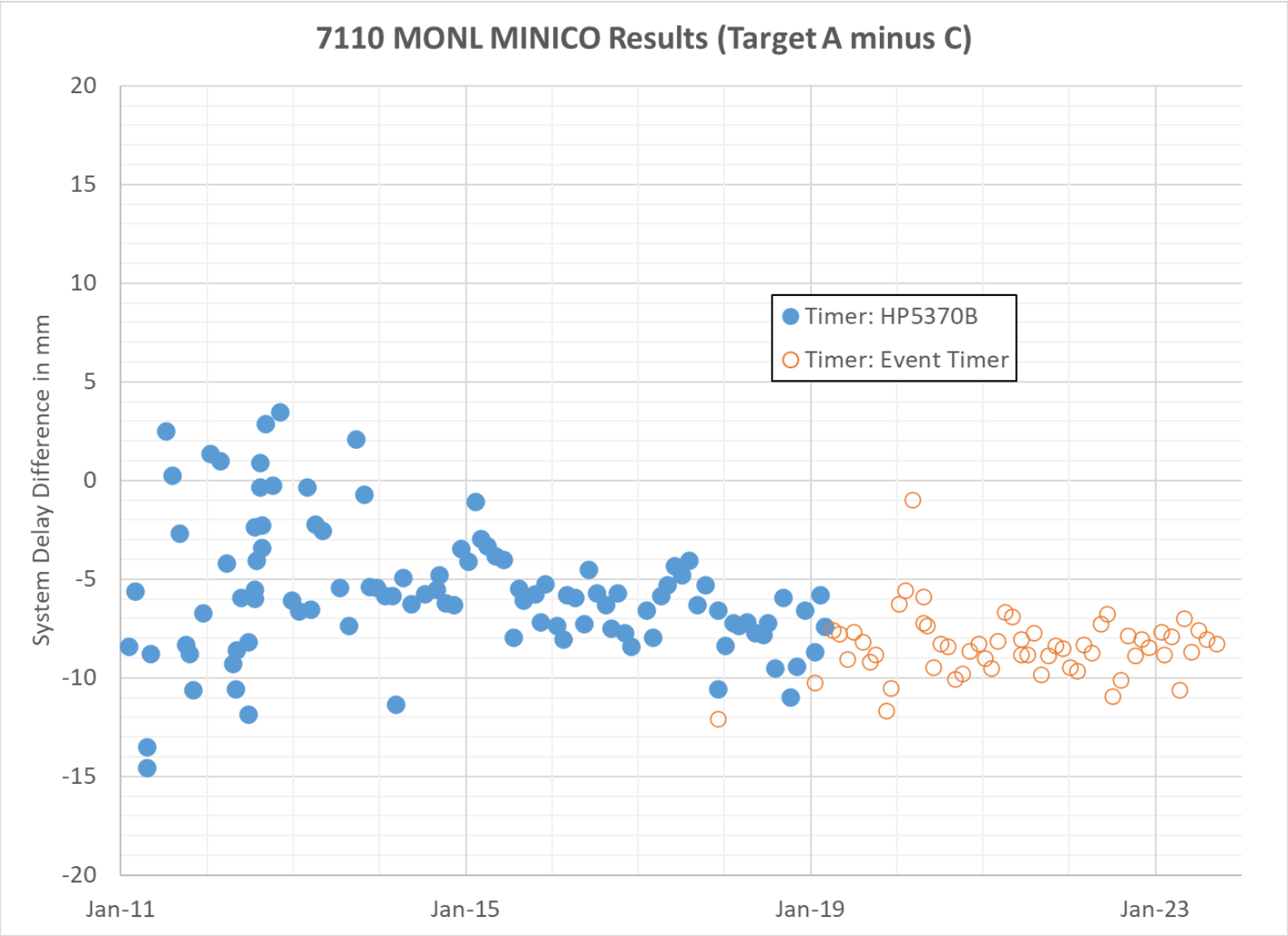
Note: Any errors in the CalDis, Trans or ND will induce a fixed range bias

MOBLAS-4 at 7110 MONL (Monument Peak, California, USA)



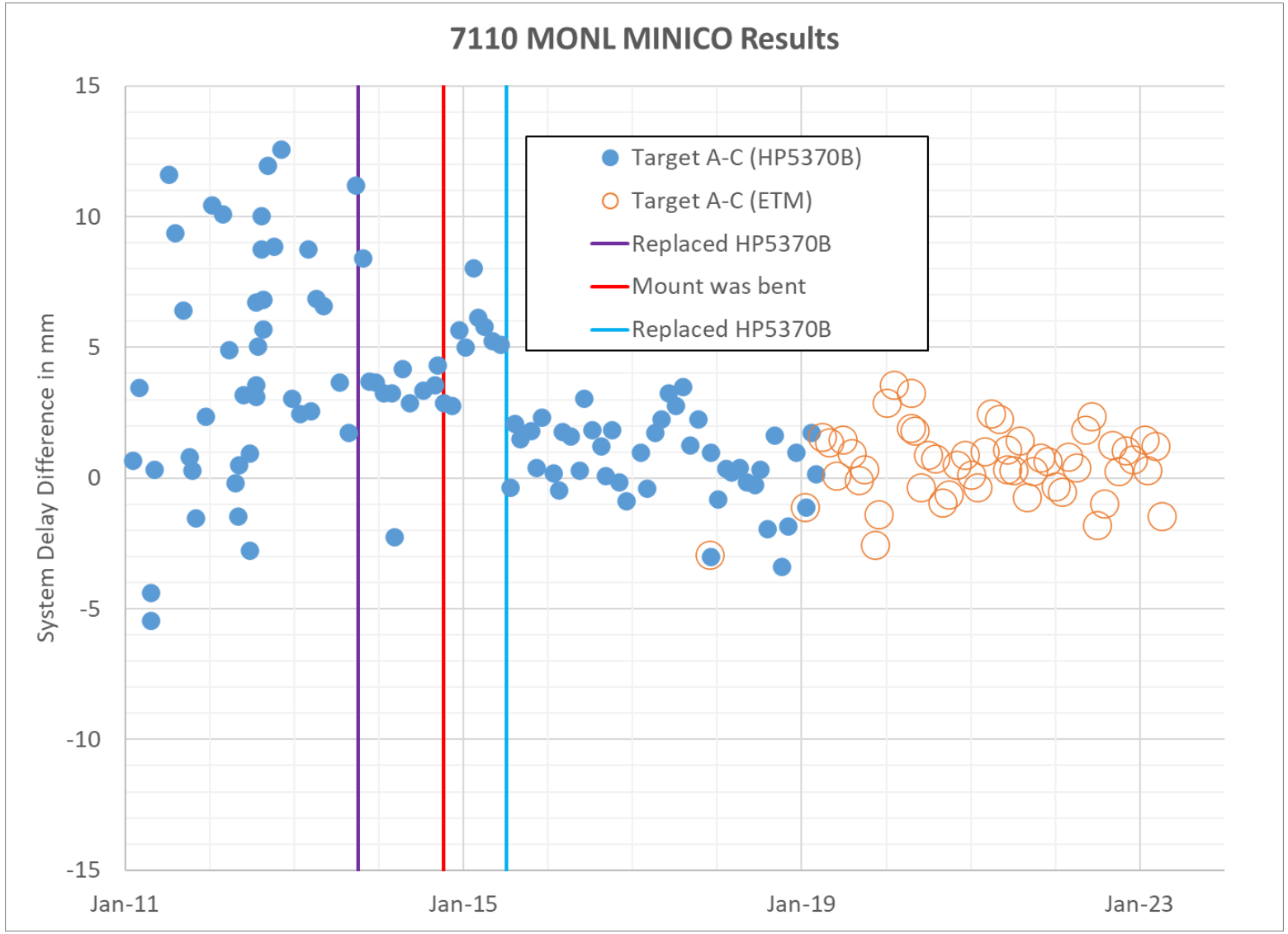
- **MOBLAS-4 has two calibration targets A & C separated by more than 90 degrees. Target A is prime**
- **Another short ground target (<200 meters) to the northwest would be beneficial to detect changes in the system reference point**
- *Pier photos from the May 2018 NGS Monument Peak Local Survey Report (Ref: https://ilrs.gsfc.nasa.gov/docs/2018/Monument_Peak_Report.pdf)*

7110 MONL Aggregate Monthly MINICO Results



- The last three MONL local surveys were June 2003, November 2011 and May 2018
- There was sub-mm changes in the target distances between the 2003 and 2011 surveys
- These are the 7110 MONL MINICO results based on the 2003 survey
- Based on the 2018 survey, there was mm level movement in the SRP and each calibration pier. The net impact on MINICO results was a -9.1 mm offset
- In late 2018, an Eventech Event Timer integrated by Cybiom was installed in parallel with the HP5370B time interval unit. Two simultaneous MINICOs were taken with both devices in parallel, which revealed a 1.5 mm non-linearity in the HP5370B results

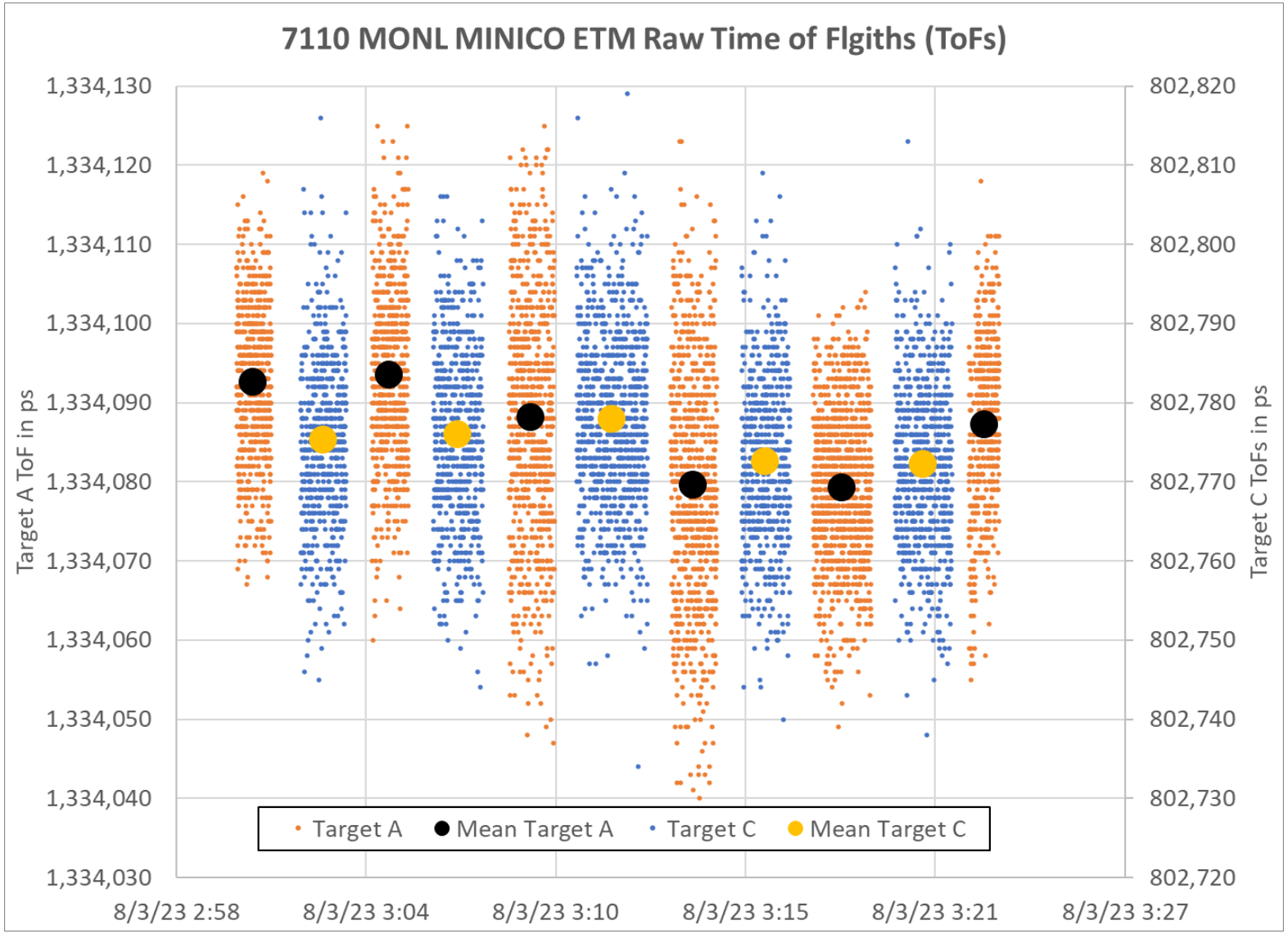
7110 MONL MINICO Results (retroactively applying May 2018 Survey)



- These are the HP5370B and ETM MINICO results retroactively applying the 2018 survey results & removing a 1.5 mm HP5370B non-linearity since July 2015
- The impact of HP5370 non-linearities on the MINICO results prior to July 2015 are unknown
- Below are the MINICO summary statistics since July 2015. The mean values are well within the uncertainty in the survey measurements

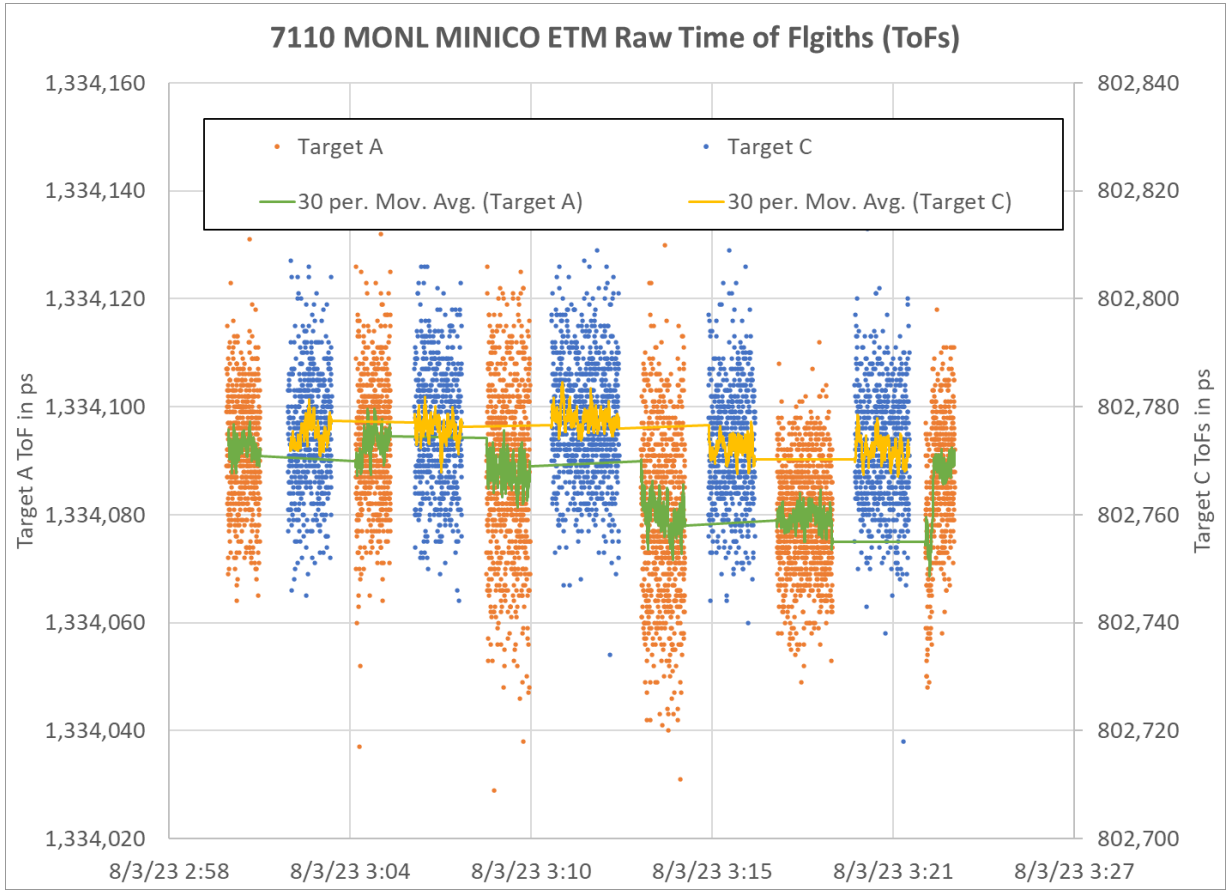
Statistic	ETM	HP5370B
Average Offset in mm	0.58	0.69
Standard Deviation in mm	1.27	1.55

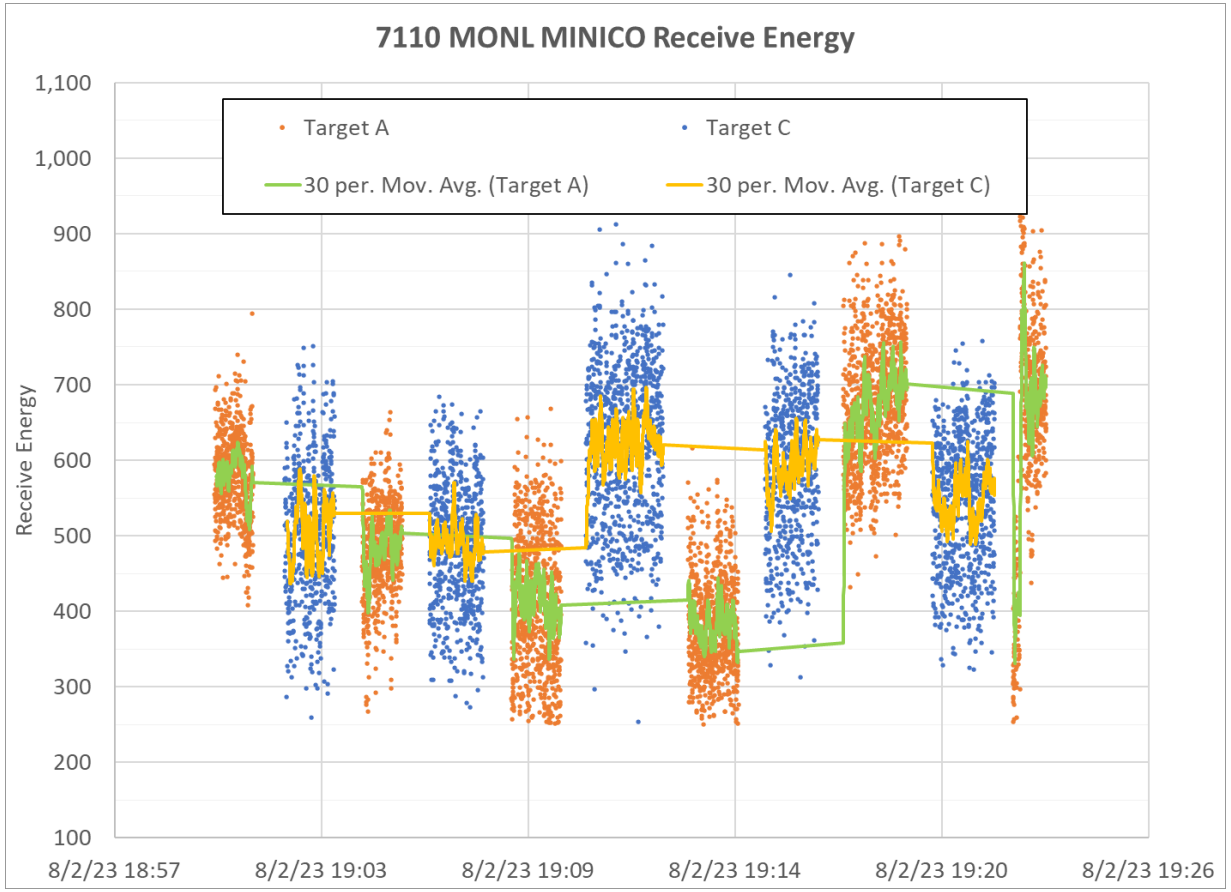
7110 MONL Event Timer Module (ETM) Raw Calibration Time of Flights (ToFs)



- **In this test, the temporal variations in the raw calibration ToFs are target dependent [10 to 20 ps/1.5 to 3 mm]. The question is why?**

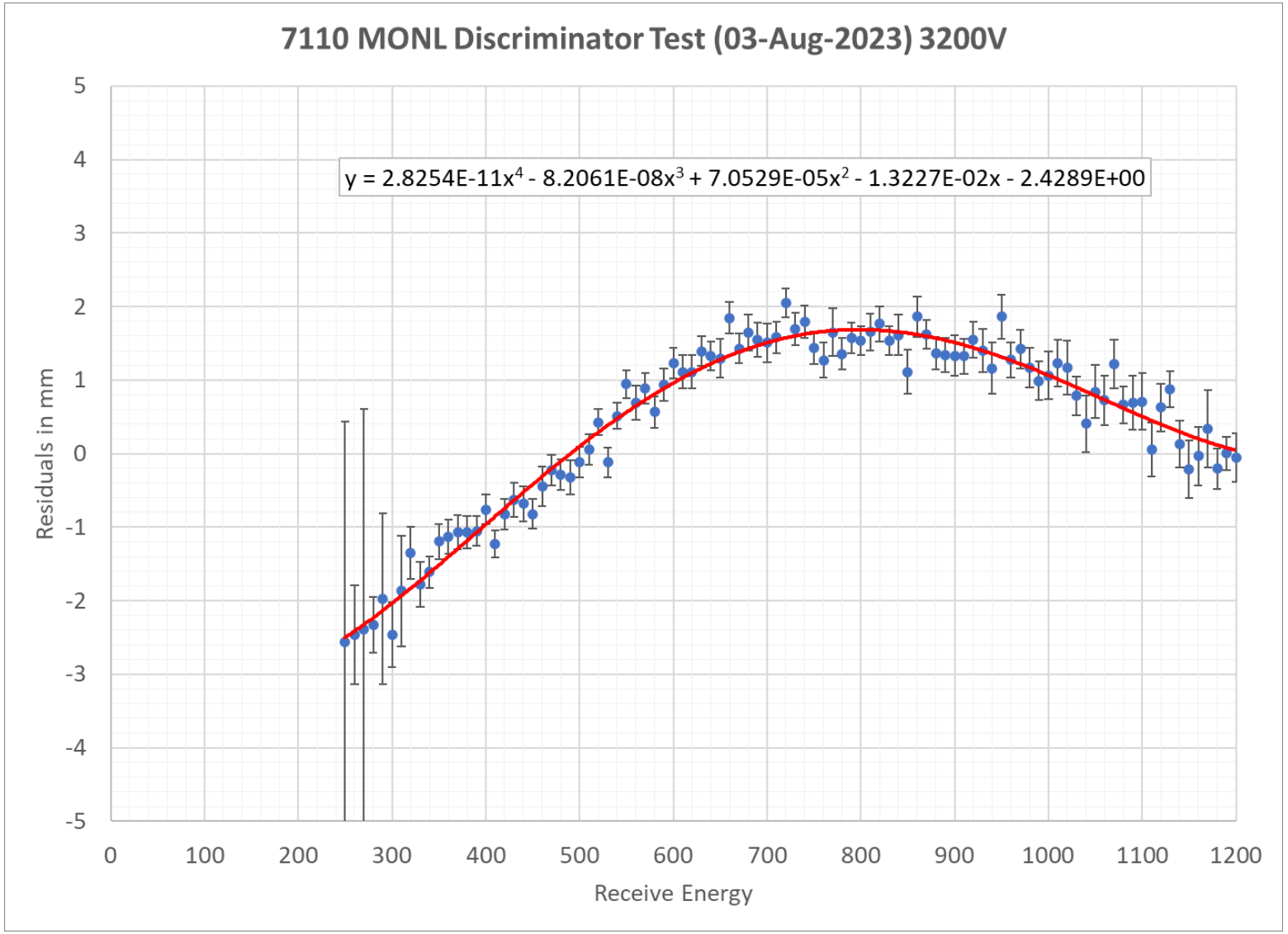
7110 MONL 03-Aug-2023 MINICO Results
ToFs and Receive Energy





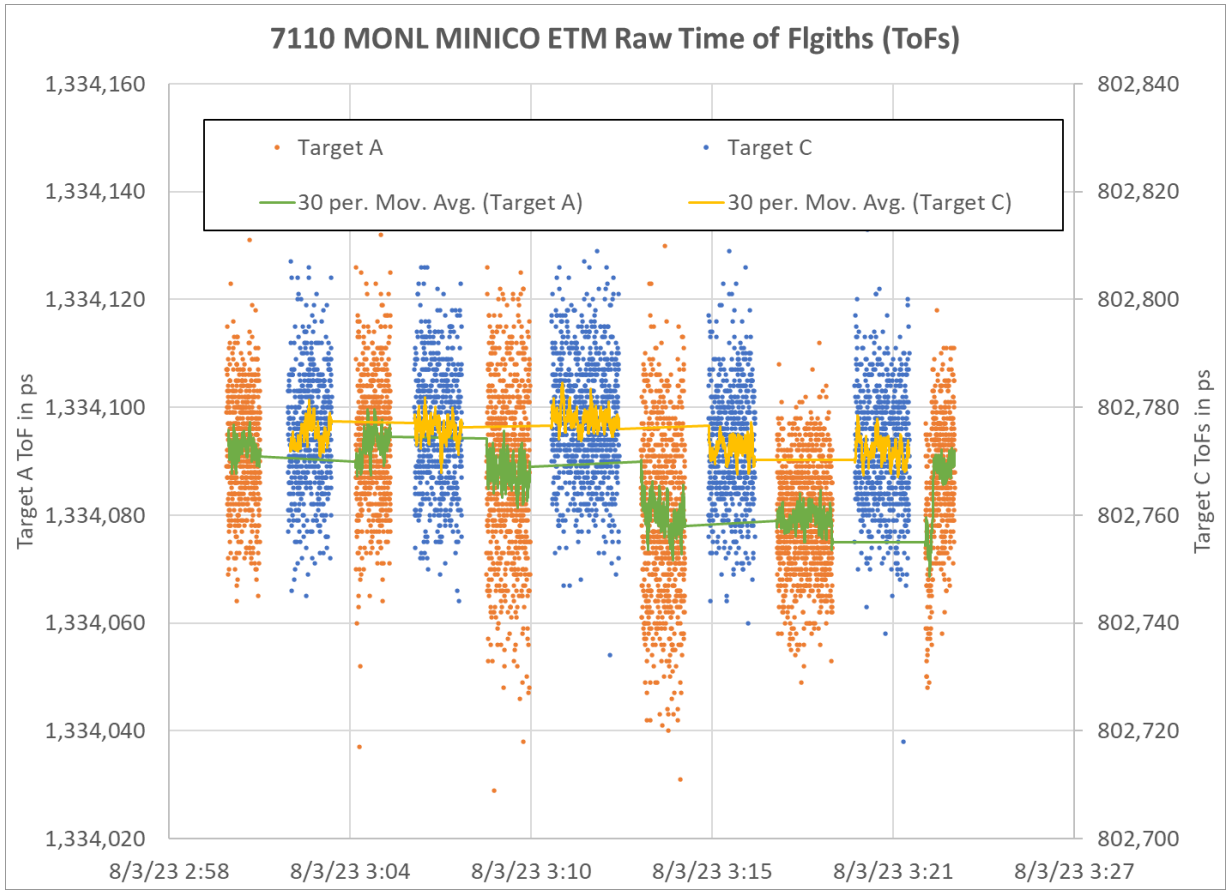
- ❑ **Left chart: Raw ToFs vs time (GMT); Right chart: Receive Energy vs time (local)**
- ❑ **Sunset in Monument Peak on 03-Aug-2023 is 19:45 local time. 7110 MONL MINICOs are taken during the day**

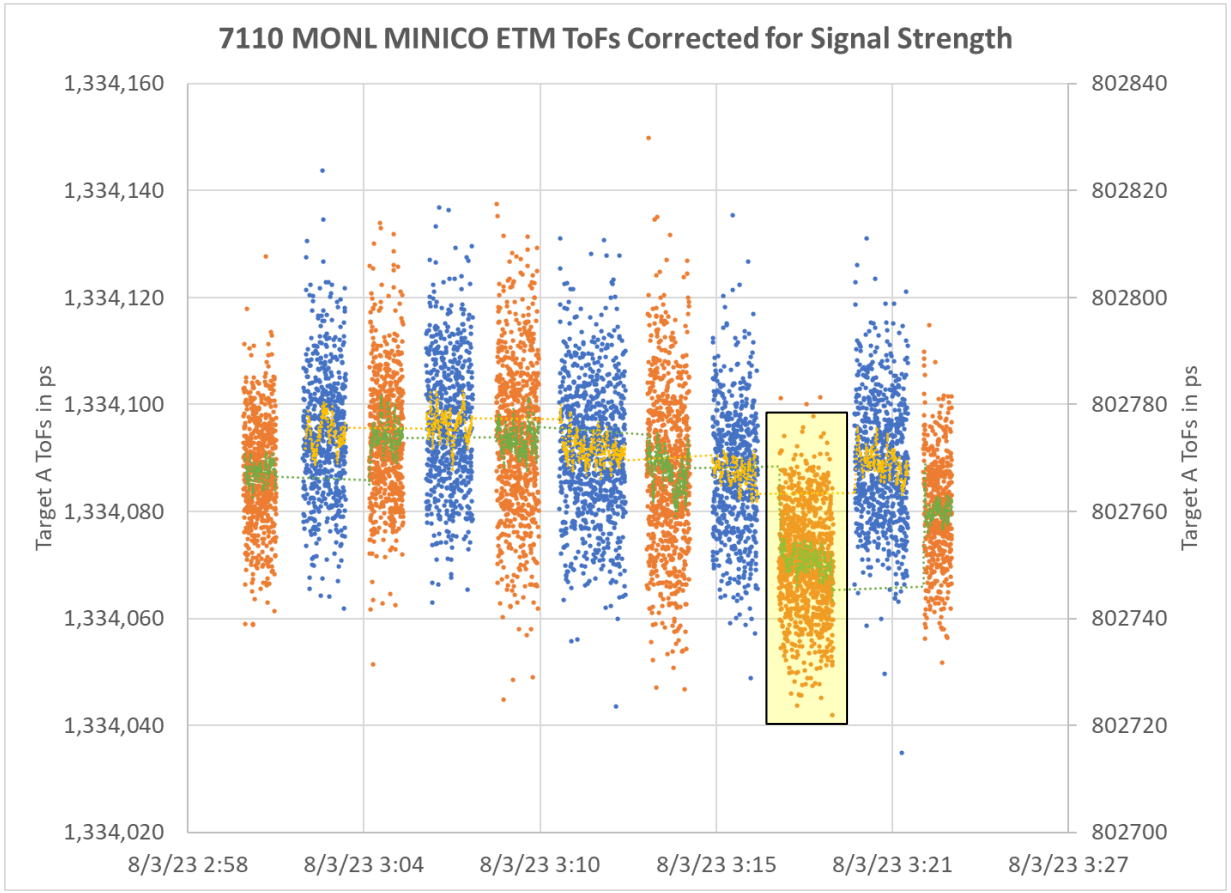
7110 MONL 03-August-2023 Discriminator Test



- A 4th order polynomial fit to receive energies in the range 250 to 1200. This timewalk correction was applied to the raw MINICO ToFs

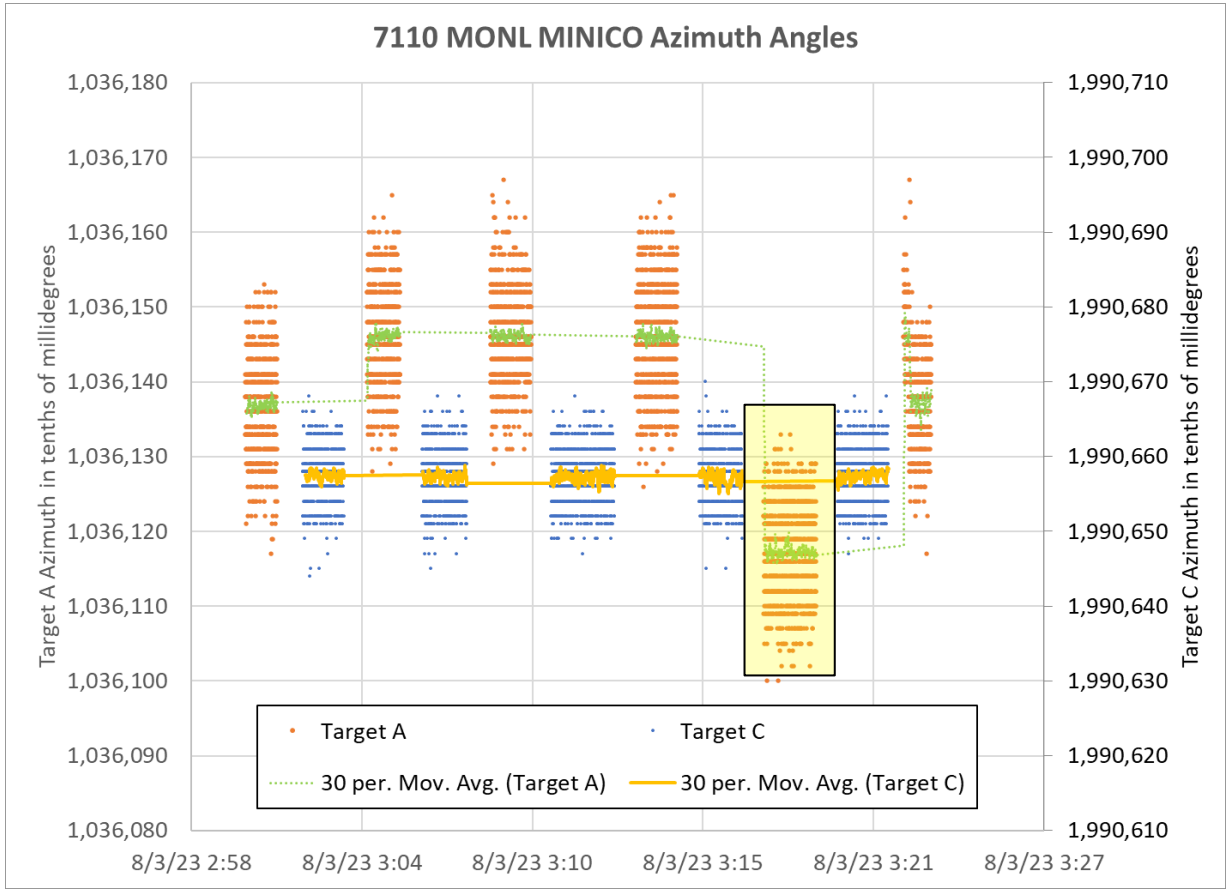
7110 MONL 03-August-2023 MINICO Results ToFs and Receive Energy

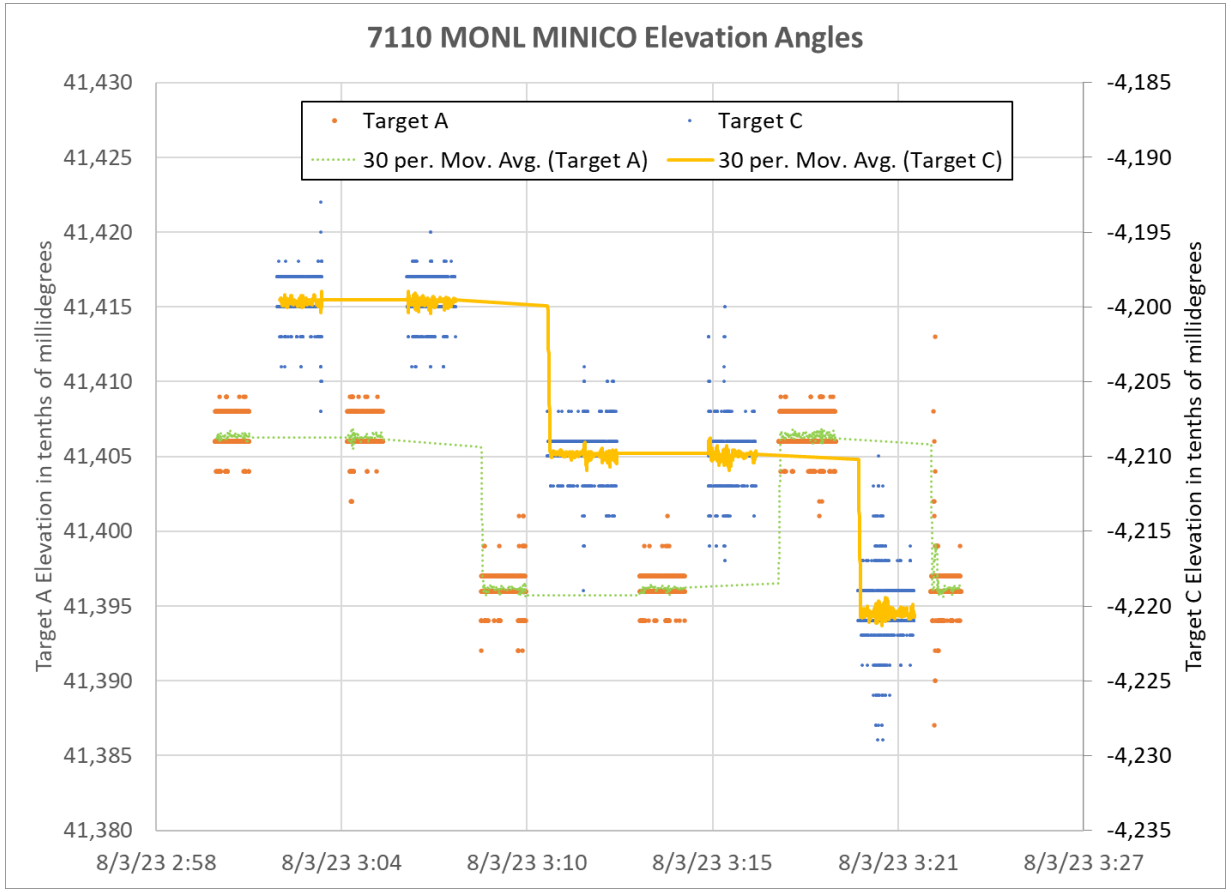




- ❑ **Left chart: Raw ToFs (i.e. no signal strength correction);**
- ❑ **Right chart: ToFs corrected for signal strength, What other systematic error(s) could still be contributing?**

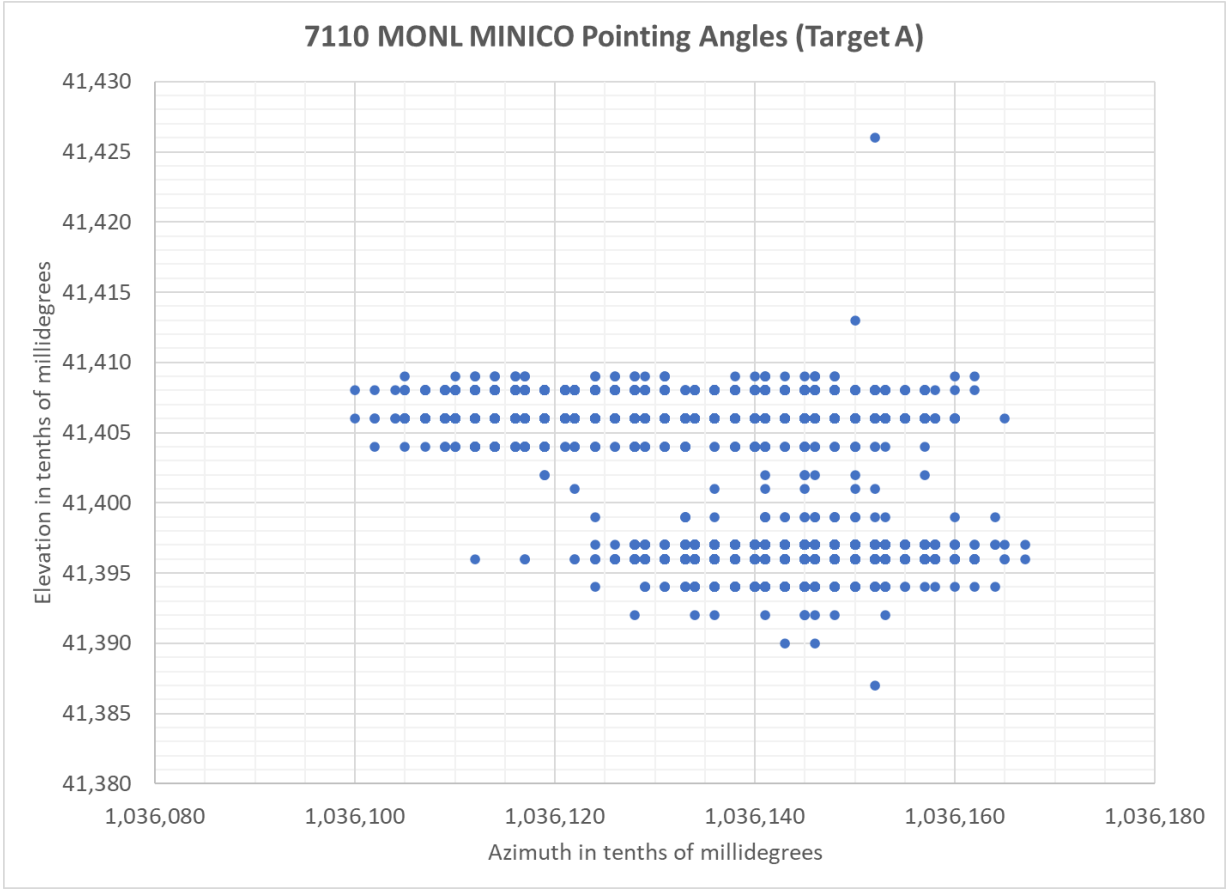
7110 MONL 03-August-2023 MINICO Results Pointing Angles

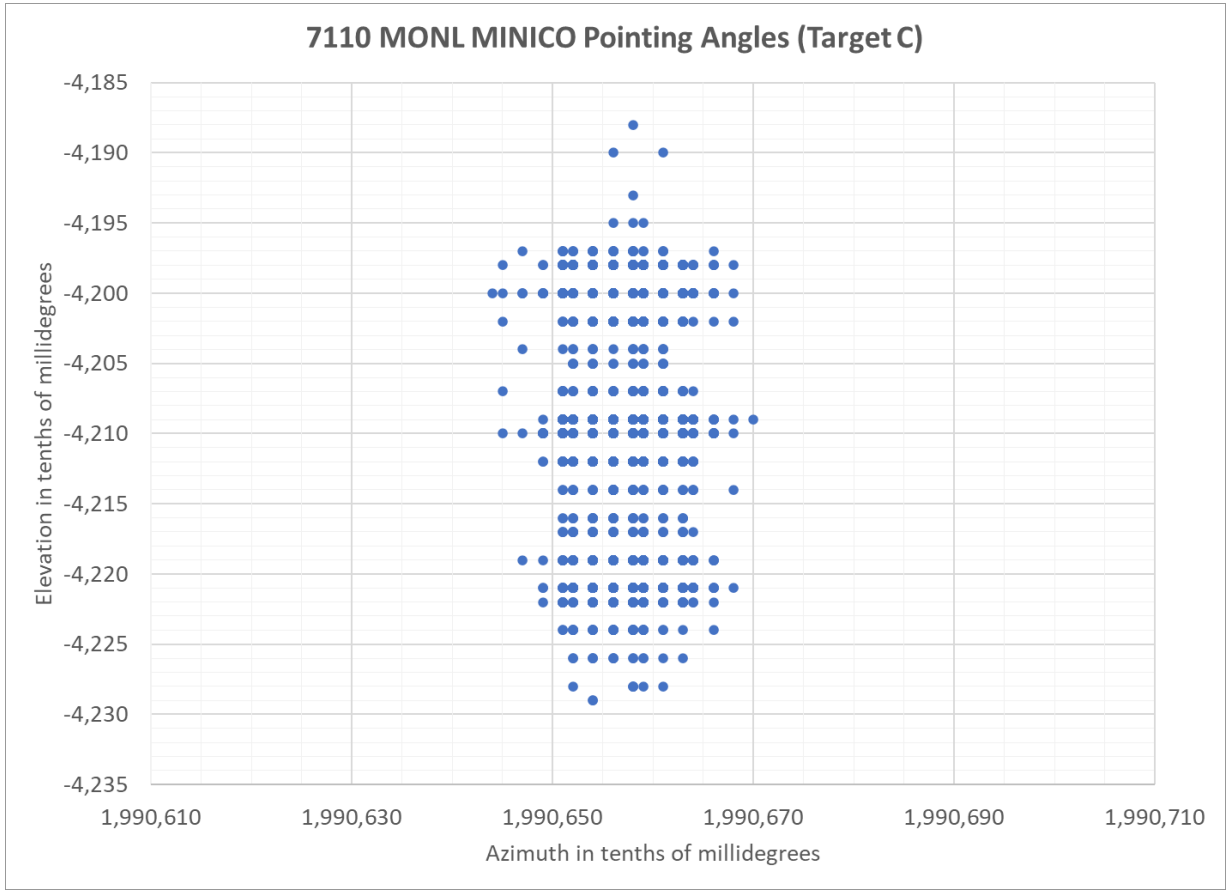




- ❑ **Left Chart: Azimuth pointing angle time series; Right Chart: Elevation pointing angle time series**
- ❑ **There are spatial differences in the pointing angles which coupled with the results from the previous slide indicate up to 3 mm differences in the laser wavefront as a function of pointing angle**

7110 MONL 03-August-2023 MINICO Results
Target Pointing Angles





- Left Chart: Target A pointing angles
- Right Chart: Target C pointing angles

7110 MONL Error Sources Quantified based on Ground Test Results

Error Source	Measurements based on Ground Test results
Laser Wavefront (spatial)	Up to 3 mm
System Stability (temporal)	Up to 3 mm (spatial and signal strength variations contribute)
Receiver (echo signal strength)	4 mm peak-to-peak in the ‘linear’ region
Timing System Non-linearities	HP5370B (since July 2015): 1.5mm; Event Timer: 0mm
Target Distance Stability	<1.5 mm since July 2015
Target Distance (Accuracy)	Primary Target: 5.7mm; Backup Target: 3.4mm

Summary/Recommendations

❑ Summary

- ➢ Before May 2018, there was substantial evidence from the MINICO results that another local survey was needed

❑ Recommendations

- ➢ Peraton to investigate the feasibility of placing a prism at the end of the telescope and use that as the primary NASA SLR calibration target
- ➢ Have NASA SLR re-initiate the monthly cube map ground test to detect laser wavefront errors
- ➢ Have NASA SLR stations take two MINICOs per month, one at night and one during the day