



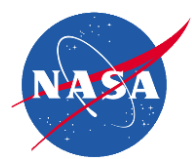
# An Independent Assessment of T2L2 results from the NASA SLR Network

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# Deriving an ILRS Time Synchronization Goal

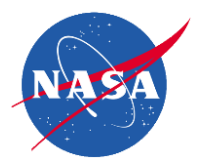
1. GGOS recommends that geodetic networks be accurate at 1 mm and be stable at 1 mm/year [Plag et al. 2009]
2. Based on #1, the ILRS recommends all SLR components be calibrated to sub-mm accuracies [Prochazka 2015]
3. In prior ITRF SLR solutions, only LAGEOS-1 and -2 data were used. LAGEOS has a velocity of  $\sim 3$  mm/1000 ns. A time bias of 100 ns will induce a horizontal station position error up to 0.3 mm
4. Maintaining 100 ns time synchronization will ensure the timing component of a station's systematic error budget is sub-mm level



# MOBLAS 5 Historical Onsite UTC Synchronization

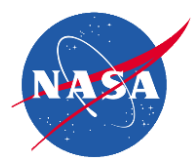


Historically, NASA SLR tried to maintain synch to within 0.5 to 1.0 microseconds of UTC during it timing hardware related technology refreshes. T2L2 was used as an independent assessment technique.



# Why do an T2L2 independent assessment?

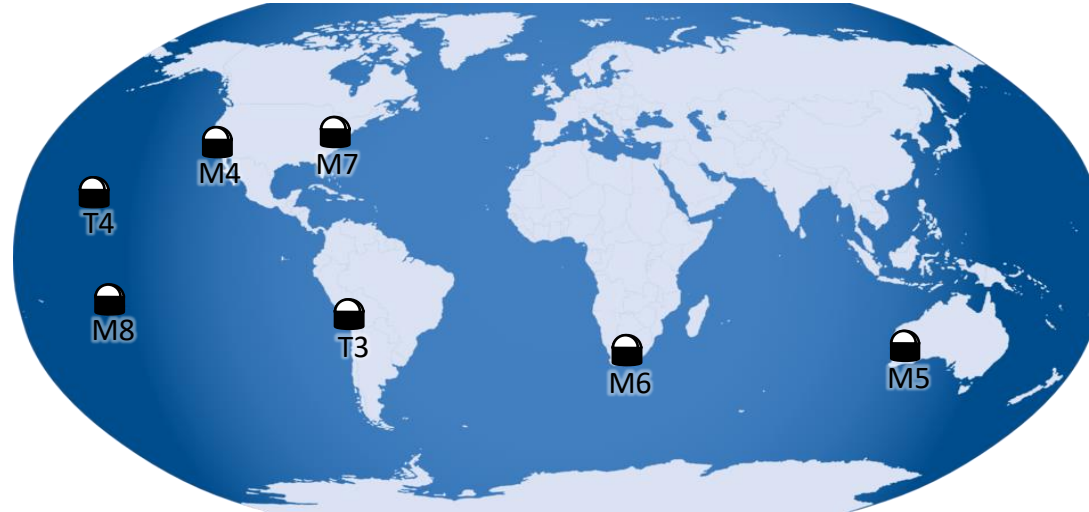
- ◆ The Time Transfer Laser Link (T2L2) experiment monitored ILRS station time biases to an accuracy of  $<15\text{ns}$  [Exertier 2010, Belli et al. 2018].
- ◆ ILRS stations, including the NASA SLR stations, were not achieving the 100 ns recommendation [Belli et al. 2018]
- ◆ Station T2L2 time bias corrections were added to the ILRS Data Handling file for use in the next ITRF2020 solution
- ◆ If possible, always do an independent assessment to ensure the ITRF solutions are as accurate as possible.



# The T2L2 Independent Assessment Technique(s)

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- ◆ Compared T2L2 results to NASA MOBLAS and TLRs onsite timing data
- ◆ Differenced ETM epochs to HP5370 epochs and compared these differences to the T2L2 results
- ◆ Compared T2L2 data to pass-by-pass and aggregate LAGEOS time bias results from Hitotsubashi University daily Multi-Satellite Bias Analysis Reports

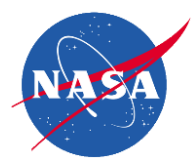


Key	Full Name	Identifiers	Location
M4	MOBLAS-4	7110/MONL	Monument Peak, California, USA
M5	MOBLAS-5	7090/YARL	Yarragadee, Australia
M6	MOBLAS-6	7501/HARL	Hartebeesthoek, South Africa
M7	MOBLAS-7	7105/GODL	Greenbelt, Maryland, USA
M8	MOBLAS-8	7124/THTL	Tahiti, French Polynesia
T3	TLRS-3	7403/AREL	Arequipa, Peru
T4	TLRS-4	7119/HA4T	Haleakala, Hawaii, USA



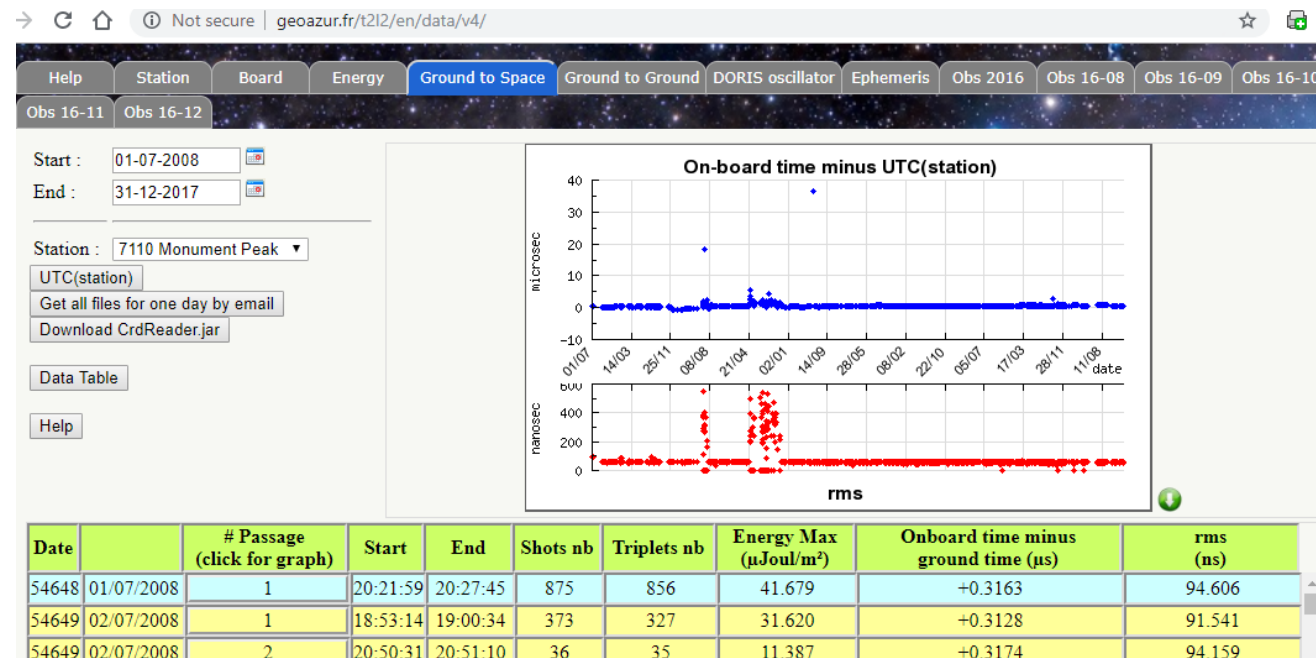
# NASA SLR Major Timing Configuration Changes

Location	Cesium, HP5370, Time Code Generator (TCG)	Rubidium replaced Cesium	Maser replaced Rubidium	Rubidium replaced Maser	Time Code Generator (TCG) Removed	Event Timer replaced HP5370
Monument Peak	Initial	30-Jun-1999	N/A	N/A	13-Jan-2016	29-Mar-2019
Yarragadee	Initial	29-Jun-2000	15-May-2010	20-Feb-2015	4-Mar-2016	11-Sep-2017
Hartebeesthoek	Initial	9-Jun-2000	N/A	N/A	26-Sep-2015	26-Feb-2019
Greenbelt	Initial	23-May-1999	N/A	N/A	25-Jul-2015	27-Jul-2016
Tahiti	Initial	18-Aug-1999	N/A	N/A	24-Jun-2016	N/A
Arequipa	Initial	26-May-2001	N/A	N/A	6-Sep-16	1-May-19
Haleakala	Initial	23-May-1999	N/A	N/A	5-May-16	17-Oct-17



# T2L2 Data Example for Station 7110 (MOBLAS 4)

- ◆ T2L2 results are based on Jason-2 full-rate data, not normal points
- ◆ T2L2 results are available at <http://www.geoazur.fr/t2l2/en/data/v4/>
- ◆ Click the Ground to Space Tab; Enter a start time of 1-Jul-2008 and an end time of 31-Dec-2017; then select a station from the pull down menu. Below is a screen shot of 7110 Monument Peak T2L2 Results







# NASA SLR Daily Laser Operations Report (LOR)

## ◆ Example of daily LOR Timing Section:

```
TIMING XDD 191003 276
GGG 500 0006 .092
GGG 500 1308 .101
GGG 500 2115 .095
BBB 700 1308 813.25
CCC 1.STA-RB = 0.257 USEC
    2. DAC -19840
END:
```

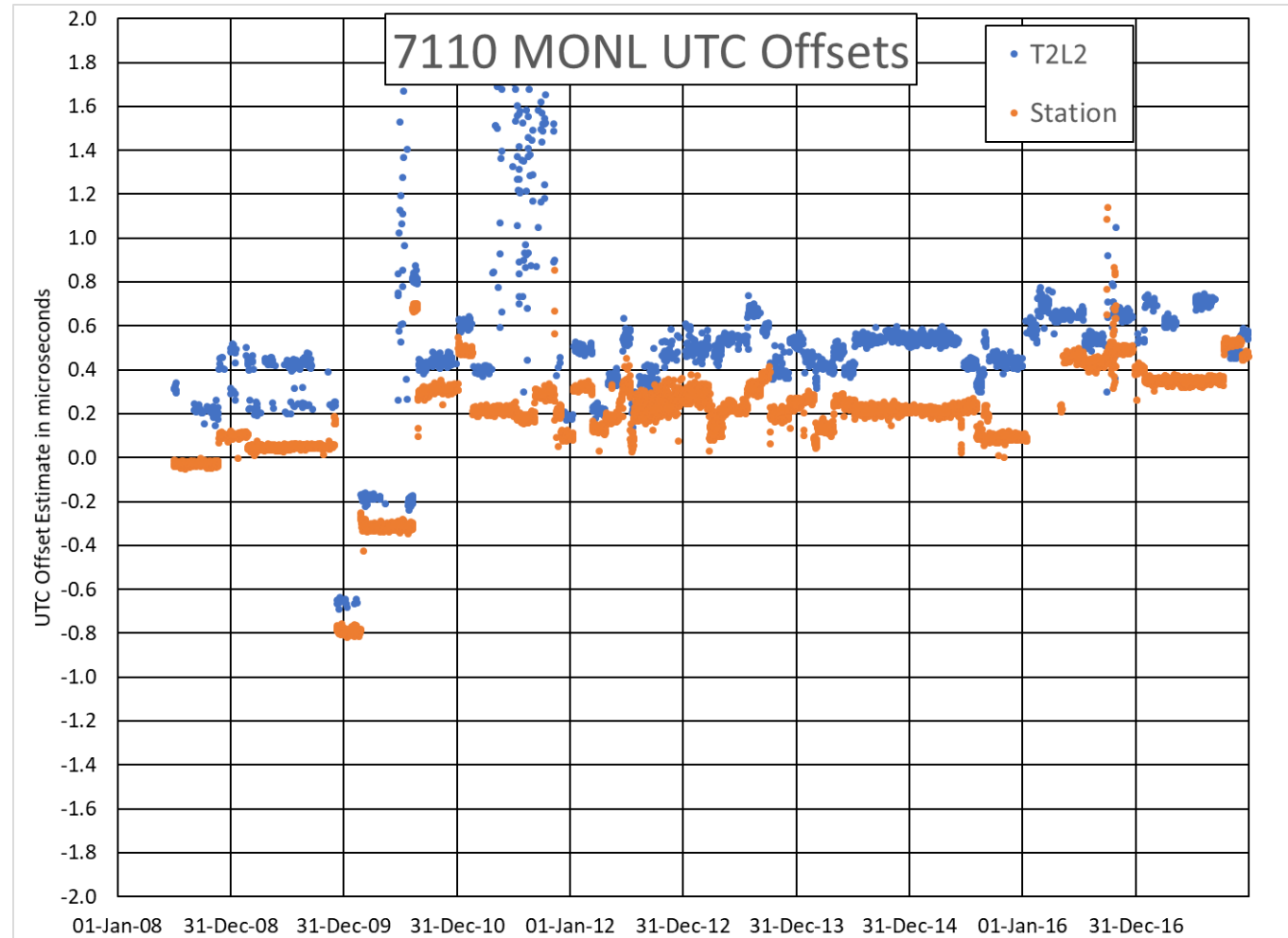
- ◆ XDD is short for MOBLAS 4, XEE is MOBLAS 5, etc...
- ◆ GGG entries are GPS measurements in usecs (Rubidium – UTC)
- ◆ CCC entries are the Station – Rubidium (STA-RB) in usec (1 entry/day)
- ◆ All timing measurements are manually entered into the LOR
- ◆  $UTC\ offset(s) = GPS\ measurement(s) + STA-RB\ measurement$



# MOBLAS 4 Station Timing Example

- ◆ Sta – RB values in the MOBLAS were set to 4 to 8 microseconds (us)
  - 4 us for MOBLAS 4, 5 us for MOBLAS 5, etc.

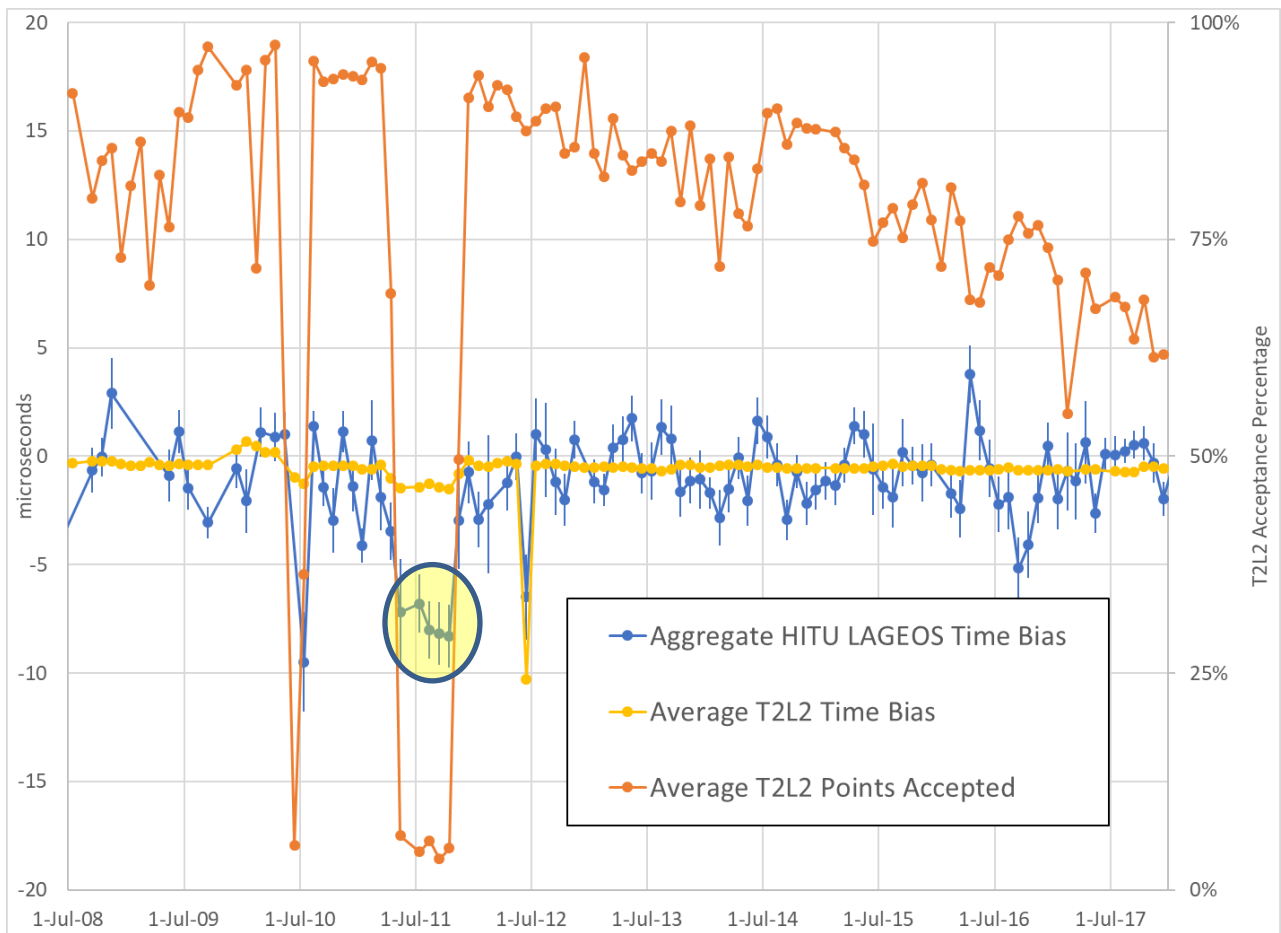
STA	Date and time	RB-UTC (us)	STA-RB (us)	STA-UTC (us)
MOBLAS 4	3/9/2009 19:07	-3.933	3.99	0.057
MOBLAS 4	3/10/2009 10:10	-3.943	3.99	0.047
MOBLAS 4	3/10/2009 16:29	-3.944	3.99	0.046
MOBLAS 4	3/10/2009 19:07	-3.933	3.99	0.057
MOBLAS 4	3/11/2009 11:00	-3.956	3.99	0.034
MOBLAS 4	3/11/2009 14:52	-3.939	3.99	0.051
MOBLAS 4	3/11/2009 18:35	-3.935	3.99	0.055
MOBLAS 4	3/12/2009 11:04	-3.952	3.99	0.038
MOBLAS 4	3/12/2009 15:00	-3.934	3.99	0.056
MOBLAS 4	3/12/2009 19:08	-3.934	3.99	0.056
MOBLAS 4	3/13/2009 10:40	-3.948	3.99	0.042
MOBLAS 4	3/13/2009 15:02	-3.934	3.99	0.056
MOBLAS 4	3/13/2009 19:01	-3.937	3.99	0.053



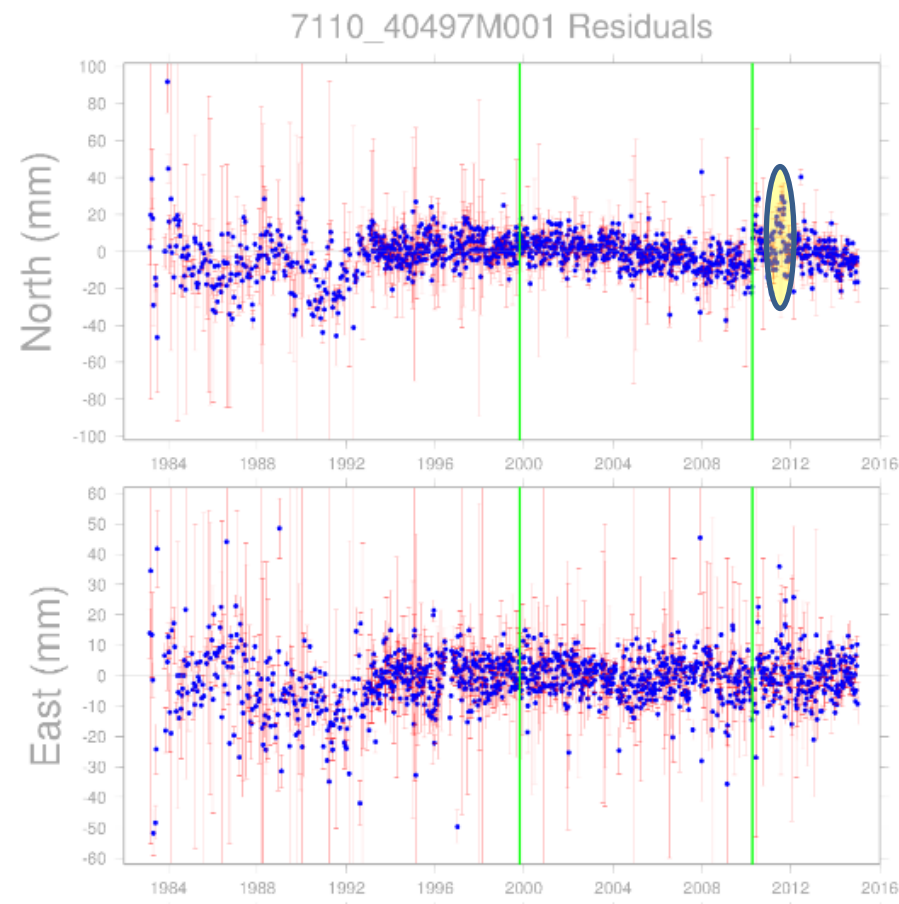
General agreement between the 2 datasets to better than 0.4 microseconds, except for some noisy periods of T2L2 results in 2010 and 2011 requiring further investigation.



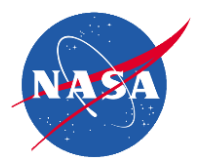
# 7110 T2L2 Results vs HITU LAGEOS Time Biases



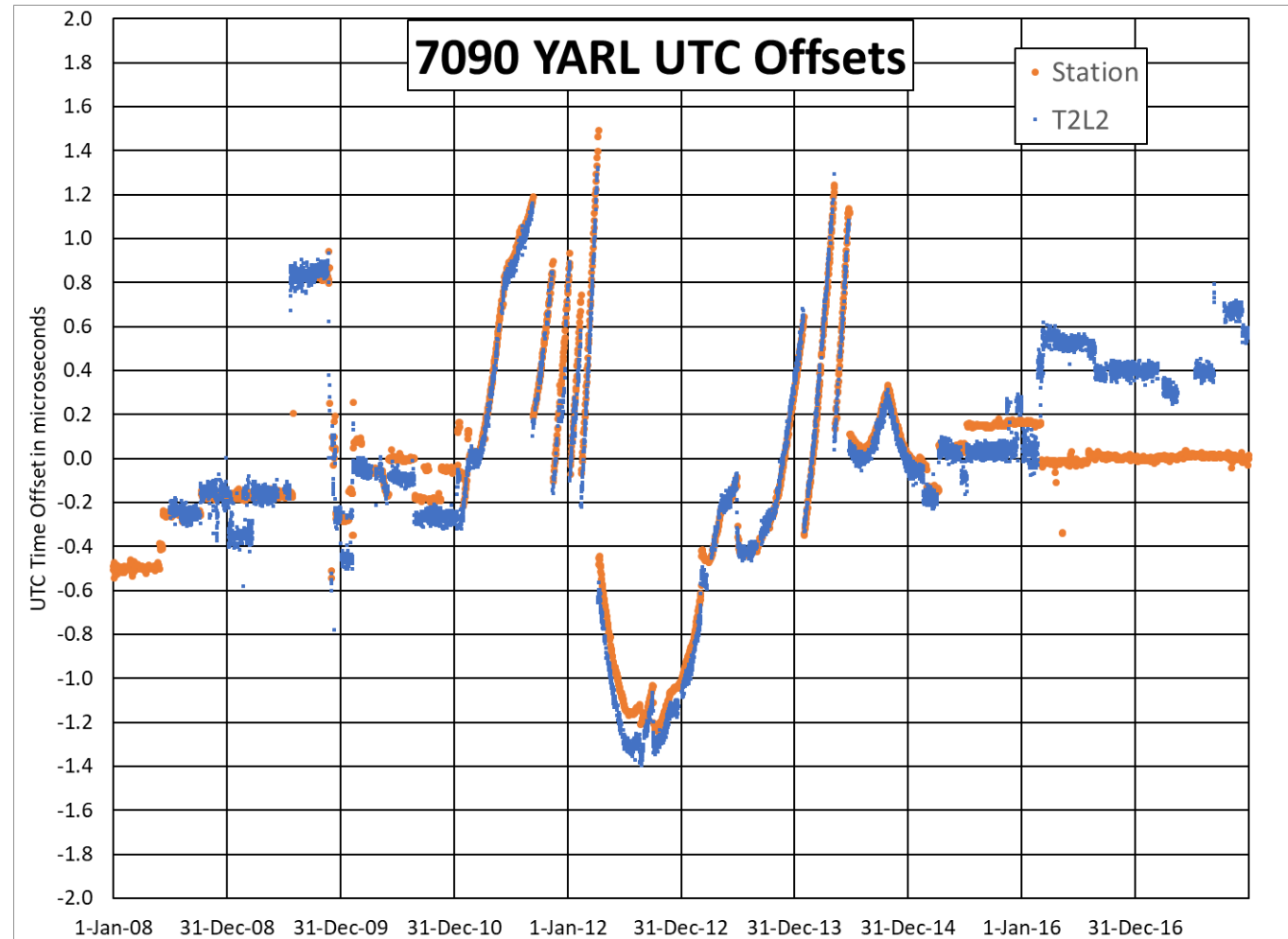
### 7110 Weekly ITRF2014 Residuals



For several consecutive months in 2011, there was a ~8 microsecond TB that T2L2 underestimated when most T2L2 points were rejected. The unmodeled 8 microsecond TB impacted the computed 7110 North component.



# NASA SLR UTC Offsets (MOBLAS 5)



Agreement between the 2 datasets to better than 200 nanoseconds until 4-Mar-2016 when the station's time code generator was removed.

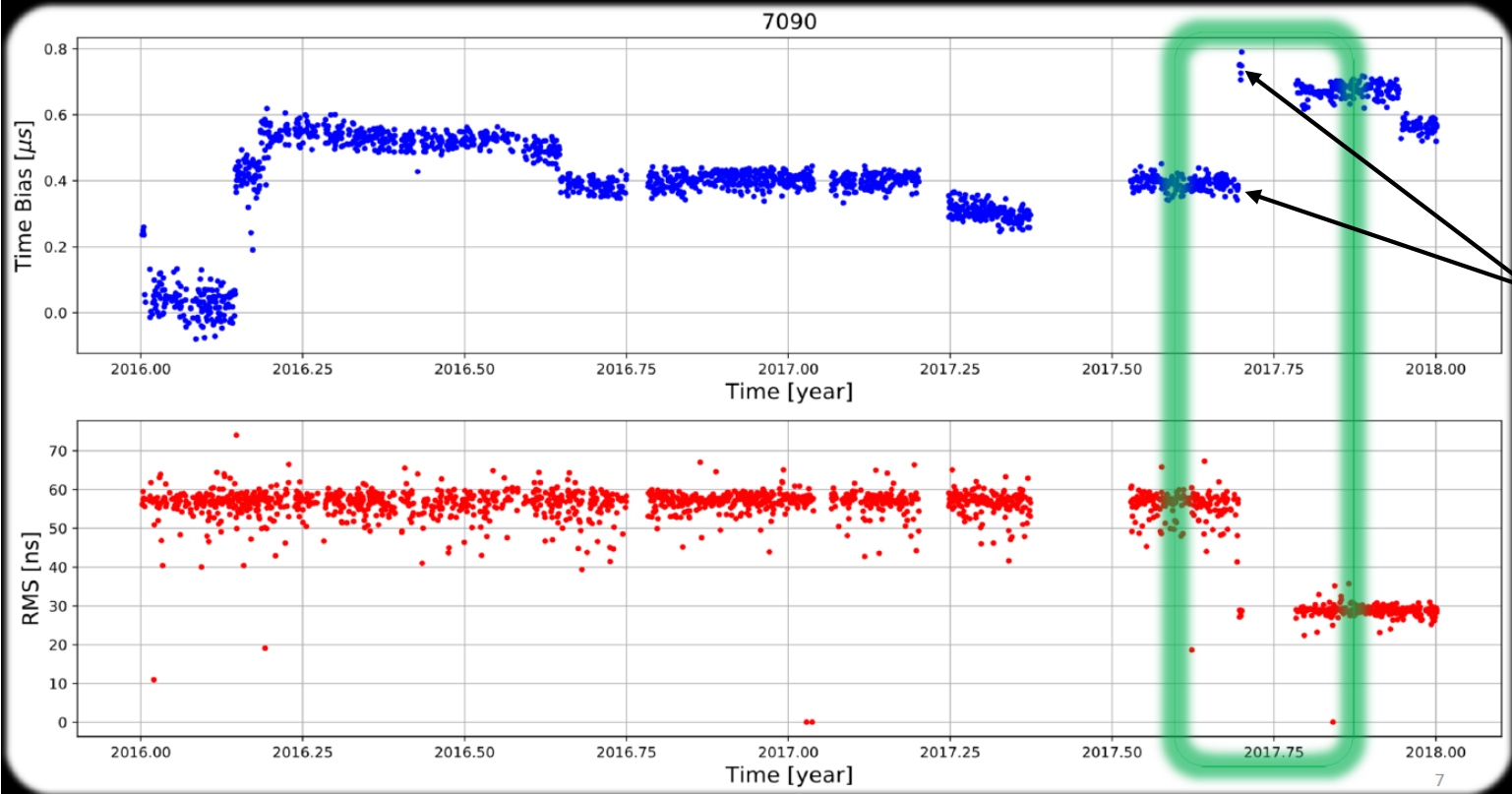


# MOBLAS 5 Event Timer UTC Offset Validation



Slide 7 from Belli et al. 2018 presentation from 21<sup>st</sup> Laser Workshop

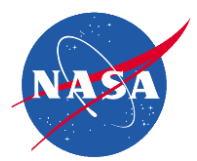
*Yarragadee Moblas-5: E.T. changed 9/11/2017*



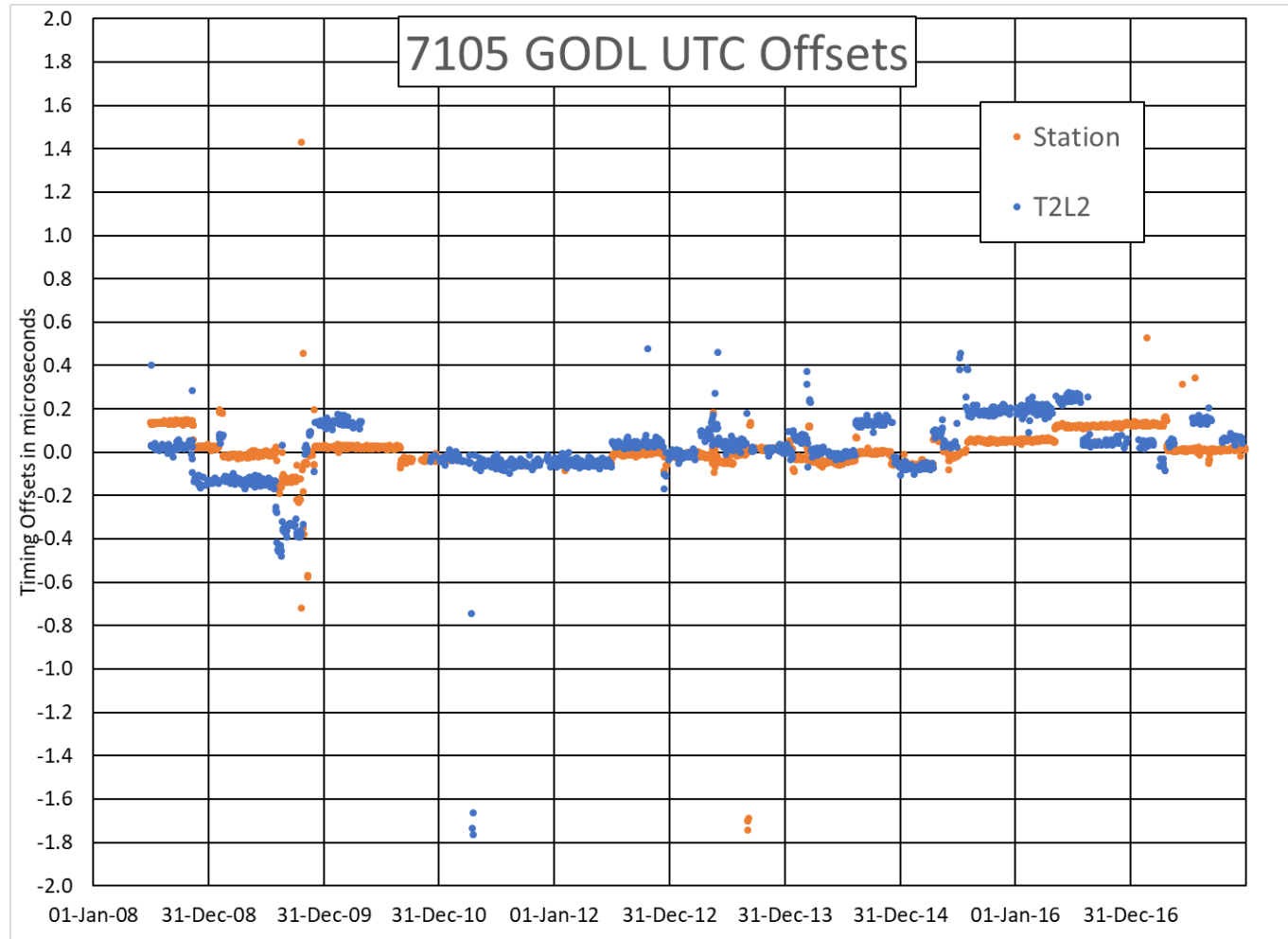
Analysis of MOBLAS 5 Timing Data using onsite Log files [HP 5370 And Event Timer (E.T.)]

Date	E.T. - HP5370 Timetags (us)	Comment
12-Sep-17	0.364	Post E.T. Operational
9-Sep-17	0.364	Pre E.T. Operational

Analysis of NASA SLR onsite log files confirmed the ~.360 microsecond jump in time observed by T2L2 when the E.T. was installed.



# NASA SLR UTC Offsets (MOBLAS 7)



Agreement between the 2 datasets to better than 250 nanoseconds.



# Summary and Conclusions

- ◆ In general, good agreement to better than 400 nanosecond (ns) when comparing T2L2 to NASA SLR timing data.
- ◆ Few hundred ns jumps in the T2L2 results require further investigation to determine the root cause.
- ◆ T2L2 results are accurate: Can detect ns level jumps in station time
- ◆ Only found one issue in the T2L2 results in MOBILAS 4 (7110) when the T2L2 points accepted were very low (i.e. less than 20%)
- ◆ Achieving time synchronization of 100 ns is challenging, but we believe is achievable





# Next Steps

- ◆ Determine the feasibility of achieving NASA SLR station time synchronization to within 100 ns of UTC
- ◆ Investigate the feasibility of automating the timing section of the LOR
- ◆ Encourage our stations to update their station history log when there are timing equipment irregularities or timing related configuration changes