Time Transfer between Satellite Laser Ranging Stations via Simultaneous Laser Ranging to the Lunar Reconnaissance Orbiter

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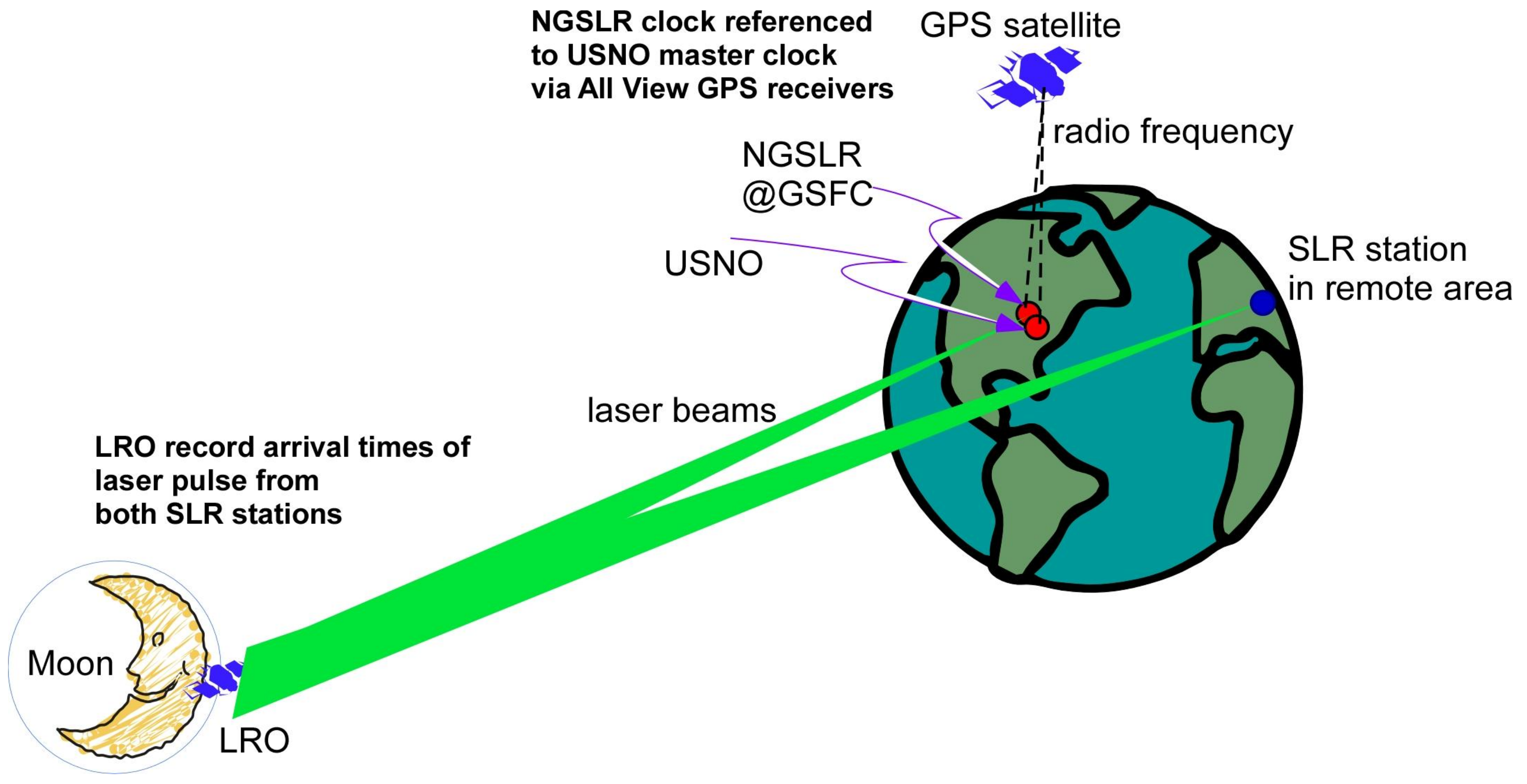
Abstract *A new technique is described to transfer time between distant satellite laser ranging (SLR) stations via simultaneous one-way laser ranging to the Lunar Reconnaissance Orbiter (LRO). All-View GPS receivers and hydrogen maser or cesium clocks are used to establish the epoch time for the SLR station at NASA Goddard Space Flight Center (GSFC) in reference to the USNO master clock. Sub-nanosecond precision and accuracy was achieved in ground validation and calibration tests.*

The Technique:

- •Two or more ground stations perform simultaneous one-way laser ranging to LRO
- •Each ground station time-tags its laser emission times to its own time base
- •LRO time-tags all received laser pulses to the on-board clock
- •Radio frequency (RF) tracking provides the spacecraft ephemeris
- •A hydrogen maser or a cesium clock provides a stable time base for each of the ground stations
- •An All-View GPS receiver compares the primary ground station clock to the near-by USNO master clock via the GPS satellites with most of the common view ionosphere effects canceling out
- •Solve for the difference between two ground station epoch times and hence transfer the time from the primary station to the remote station(s)



Principle of Operation:

Light-time of laser pulses from each ground station to LRO:

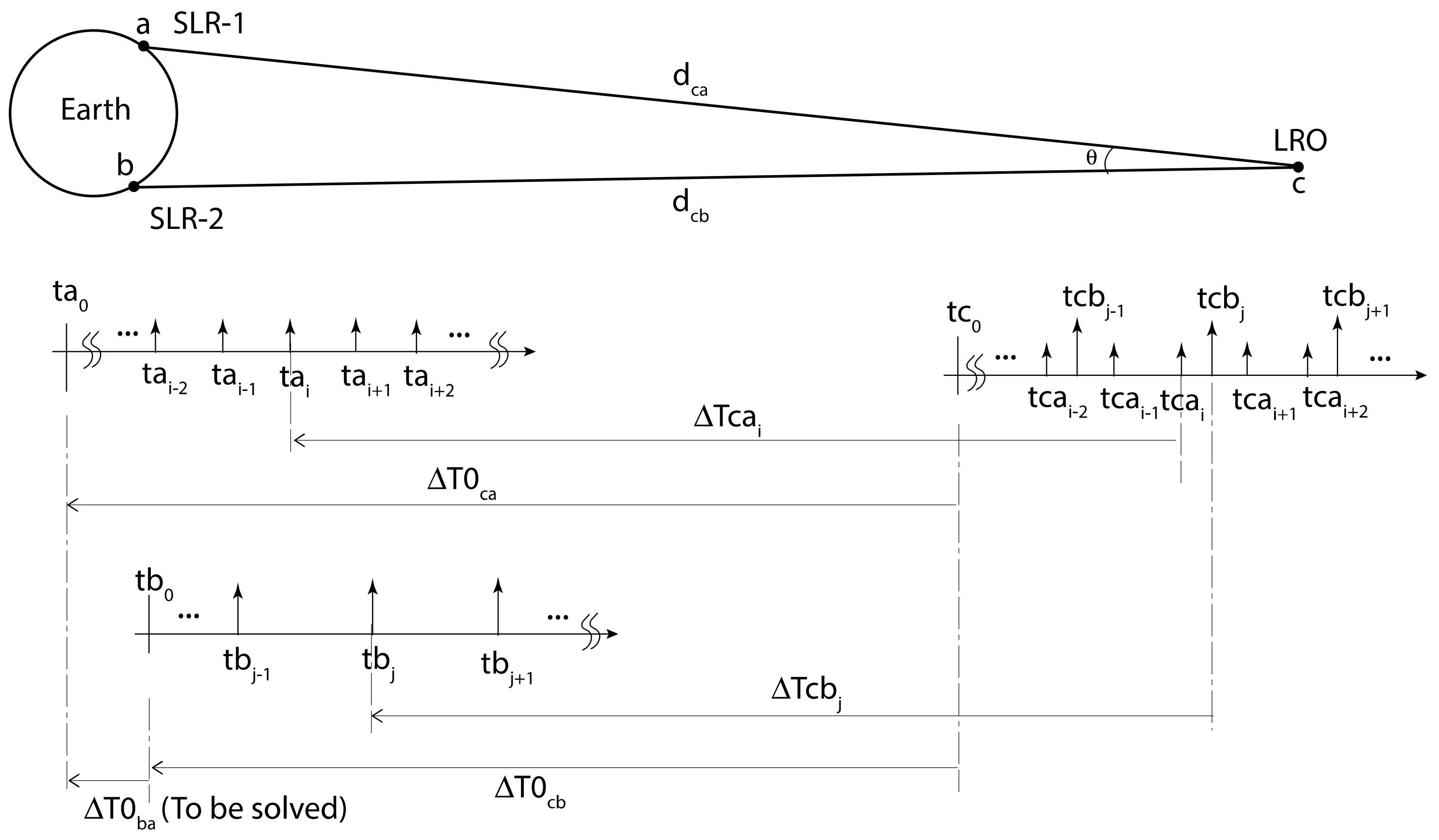
$$t_{Lca}(i) = (tca_i - t_{c0}) - (ta_i - t_{a0}) = (tca_i - ta_i) - (t_{c0} - t_{a0})$$
$$t_{Lcb}(j) = (tcb_j - t_{c0}) - (tb_j - t_{b0}) = (tcb_j - tb_j) - (t_{c0} - t_{b0}) \qquad (1)$$

The difference of the time offset of the two ground stations at LRO:

$$\Delta T0_{ca} = t_{c0} - t_{a0} = (tca_i - ta_i) - t_{Lca}(i)$$
$$\Delta T0_{cb} = t_{c0} - t_{b0} = (tcb_j - tb_j) - t_{Lcb}(j) \qquad (2)$$

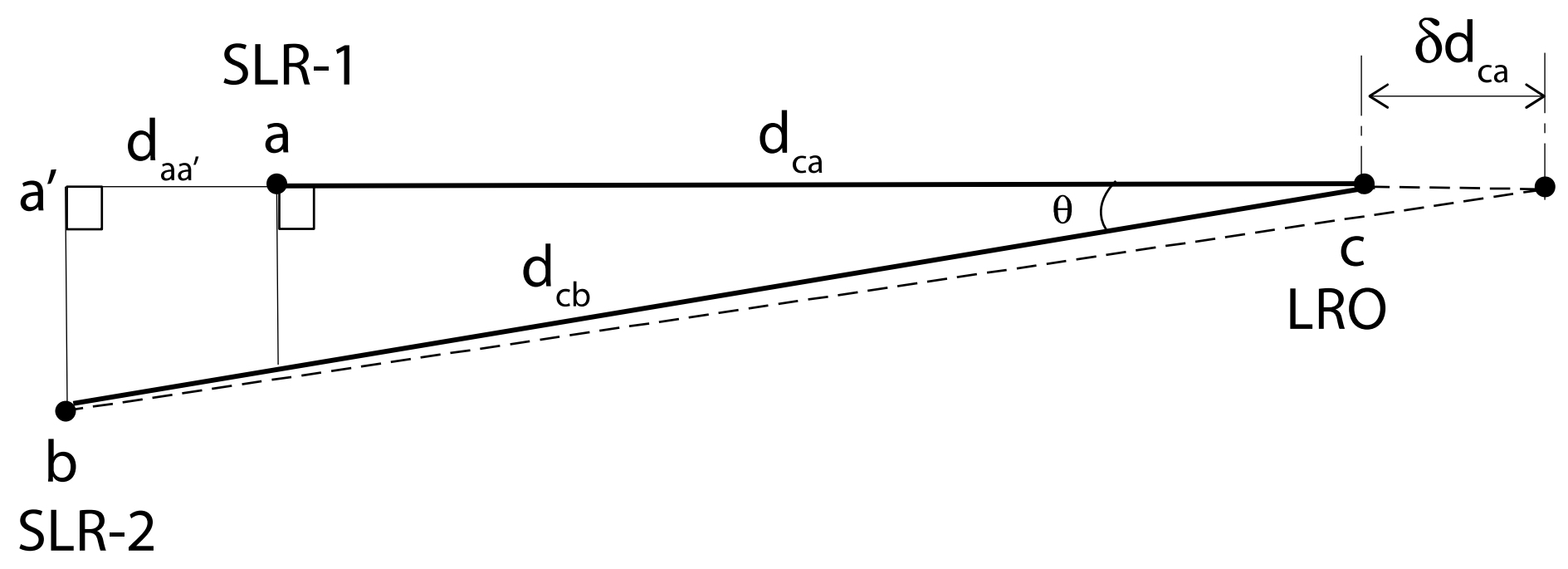
The time difference between the two ground stations can be solved using the light times from orbit determination via RF tracking, i.e. the standard ephemeris of LRO given in the form of polynomials, as

$$\Delta T0_{ba} = t_{b0} - t_{a0} = \Delta T0_{cb} - \Delta T0_{ca} = \left[(tcb_j - tb_j) - (tca_i - ta_i)\right] - \left[t_{Lcb}(j) - t_{Lca}(i)\right]$$
$$= \Delta Tcb_j - \Delta Tca_i - \left[t_{Lcb}(j) - t_{Lca}(i)\right] \qquad (3)$$



Effect of RF tracking Uncertainty on Time Transfer Accuracy:

The time transfer accuracy is affected mostly by the errors in the difference of the two light times and much less affected by typical uncertainties in LRO orbit determination.



Difference between the two light times

$$\Delta T_{light} = d_{cb} - d_{ca} = (d_{ca} + d_{aa'})\sec\theta - d_{ca} \qquad (4)$$

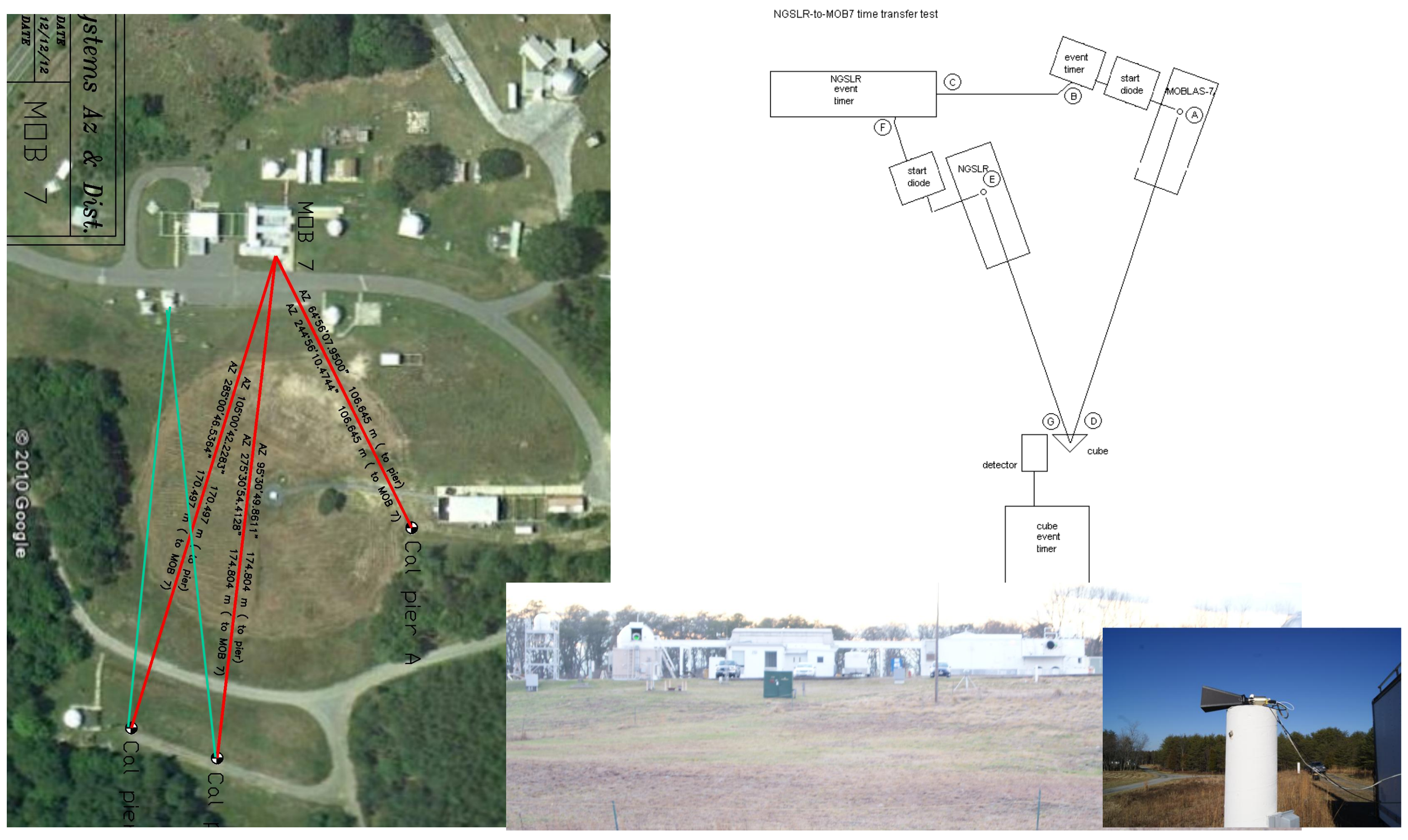
Error resulted from an orbit determination uncertainty

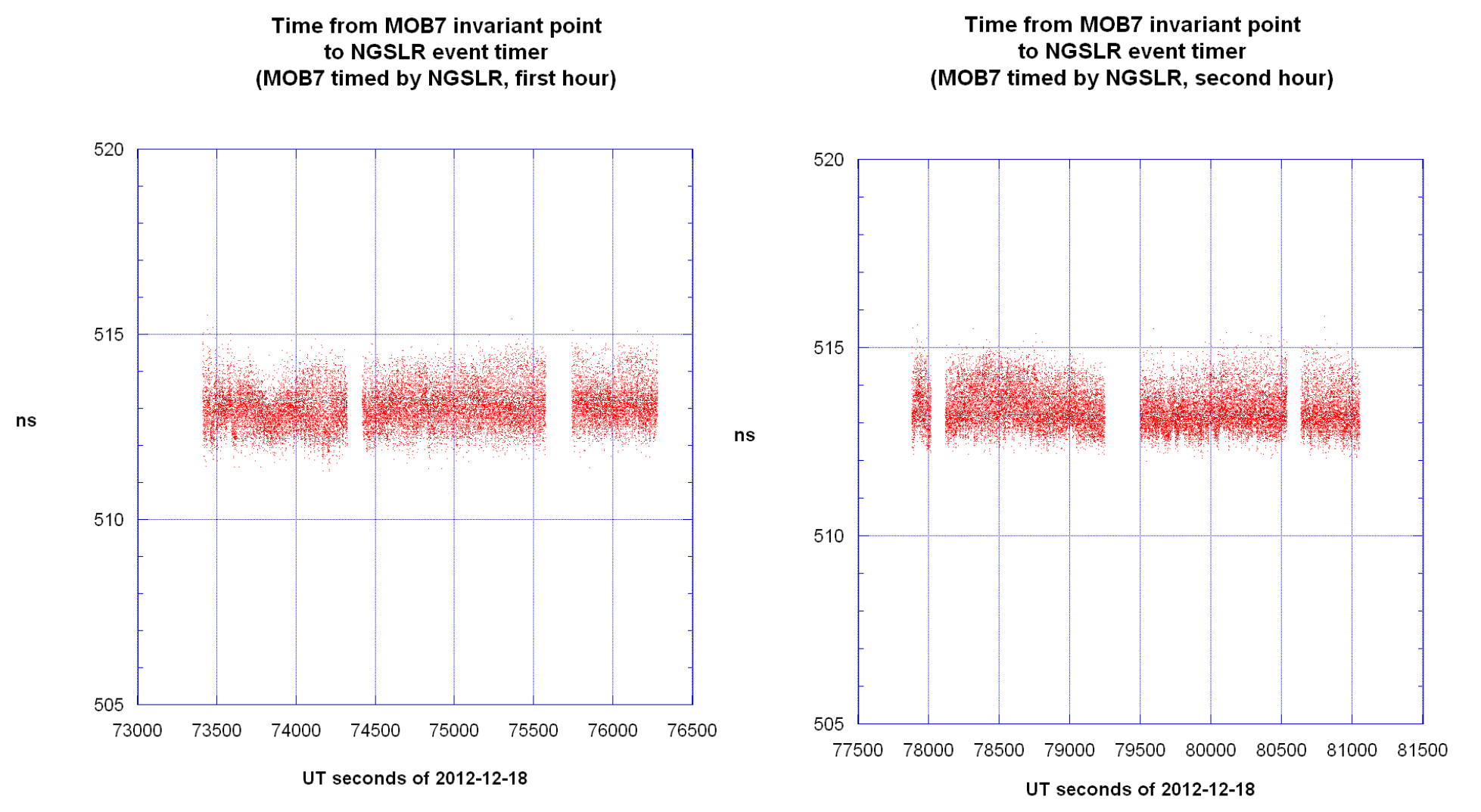
$$\delta_{LT} \approx (\sec\theta - 1)\delta d_{ca} = \left(\frac{1}{2}\theta^2 + \frac{5}{24}\theta^4 + \dots\right)\delta d_{ca} \approx \frac{1}{2}\theta^2\delta d_{ca} \qquad (5)$$

e.g., $\theta < 0.033\,rad$, an orbit position estimation error of $\delta d_{ca} = 10\ m$ will result in a differential light path length error of $\delta DL = 0.006\ m$, or 0.02 ns.

Verification and Validation with Ground Targets:

Two tests performed with three ground targets in an LRO like configuration at NASA GSFC and the results agreed to within 0.3 ns.



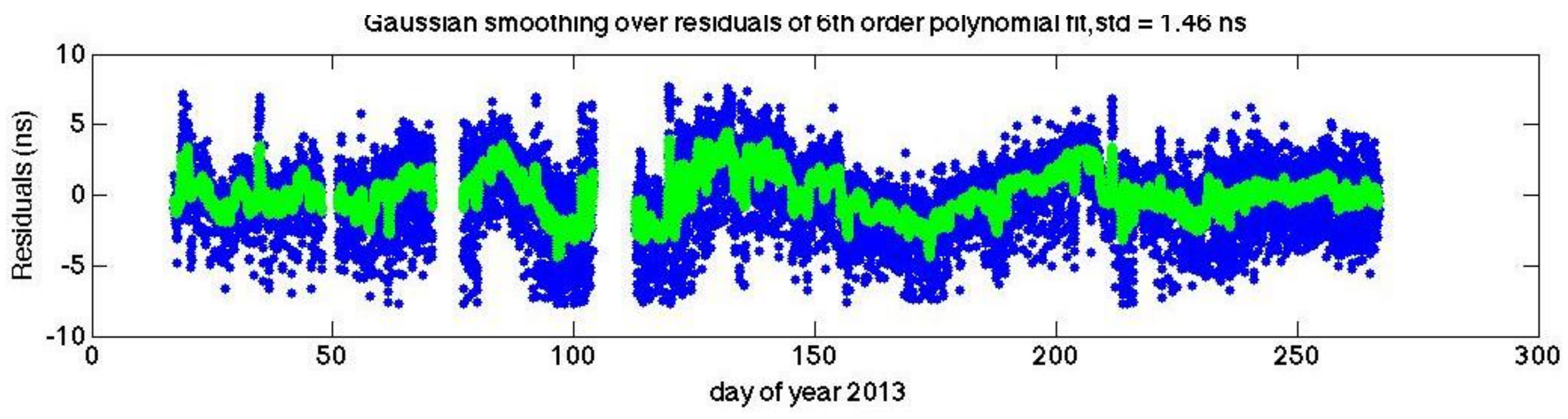


Pier_C
Test 1, 11-30-2011:
M7-IP to s2k event timer = 513.27 ns
Test 2: 12-28-2012:
M7-IP to s2k event timer = 513.00 ns

Pier_B
Test 1, 2012-12-18
M7-IP to s2k event timer = 513.296 ns

Monitoring the Station Time with an All-View GPS Receiver:

Station time is monitored at the Next Generation Satellite Laser Ranging (NGSLR) at NASA GSFC with an absolute accuracy of ~1ns, sub-nanosecond resolution, and a stability mainly governed by the station clock, 4e-15 for the hydrogen maser and 1e-13 for the cesium clock source.



Random walk of the hydrogen maser time at NGSLR over 8 months after removing a polynomial fit, mostly a constant offset and a linear frequency aging trend.

Work in Progress:

- Time transfer tests between NGSLR and MOBLAS-7 at NASA GSFC.
- Time transfer tests between NGSLR in Greenbelt, Maryland to the McDonald Laser Ranging Station (MLRS) in Ft. Davis, Texas, or other remote SLR stations.