Two-color laser ranging with the MLRO system

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Abstract: Preliminary results of two color SLR observations with the MLRO system are described.

Introduction

The Matera Laser Ranging Observatory (MLRO), owned by the Agenzia Spaziale Italiana and located in Matera, Italy, is a state-of-the-art satellite and lunar laser ranging system built by Honeywell Technology Solutions, Inc. A view of the observatory is available in Fig. 1.

A preliminary series of two-color SLR observations at 532 nm and 355 nm wavelengths has been performed in 2002 to support the two-color subsystem final acceptance. This paper outlines the MLRO two color subsystems, describes the data set and discusses the results.

The MLRO two-color subsystems

The MLRO system is described elsewhere in this volume. There are to basic methods of two color ranging that the MLRO employs. These are as follows:

a. Asynchronous (medium bandwidth) two color ranging, which uses two MCP-PMT detectors, both tied to the event timer through discriminators, to independently measure the satellite range using traditional SLR techniques. This method relies upon an average of several individual measurements to form two color normal points over the satellite arc. It assumes that the atmosphere does not change significantly during the short (normal-point) arcs of the pass and that one can acquire a sufficient number of individual measurements in each arc to accurately calculate the atmospheric thickness. This technique's advantages are that it requires less signal to acquire data and the data acquisition is easier since each detector can sample a relatively large angular field-of view. Its weakness is that the individual measurements actually rely upon several independent measurements, each of which contributes error.
b. Synchronous (high-bandwidth) two color ranging which uses a streak camera to directly measure the differential time of flight between two pulses. This method relies on the strength of each individual data point to determine the atmospheric dispersive delay. Since the satellites used must be in low-earth orbit to achieve the signal levels needed, they can contain relatively small arrays and offer reduced contribution to the error of the measurement. This technique's weakness is that it is relatively complex and difficult to achieve.

Table 1 provides insight into the relative expected performance of the two methods of two color ranging and how these compare with single-color performance.

The observations

During the qualification phase, several LEO satellites have been observed using both modes outlined above. The graph in figure 2 describes the amount of single differential delay determinations for each observed satellite, while the graph in figure 3 describes the distribution of differential delay determination as a function of the elevation above the horizon. At this moment, the MLRO is allowed to track targets at an elevation greater than 20 degrees.

As an example, plot in fig. 4 illustrates the observed minus computed (MLRO minus Marini-Murray) differential delay as a function of the time for one selected Ajisai pass observed in asynchronous mode and processed by the system on board software.

Apart from other secondary effects, it's quite evident that all passes show a distinct bias of about 10-20 mm. This apparently means that the MLRO differential delays are somehow larger with respect to the ones determined with the Marini-Murray formula.

This feature does not appear in ground target ranging data. Other than that, software, hardware and procedures have been double checked to make sure that the observed bias is not an artifact of the system.

Discussion

We decided to compare our observational results with the currently used atmospheric refraction models, namely those by Marini-Murray (1973), hereafter MM, and Saastamooinen (1973), the latter eventually coupled with the Mendes (2002) mapping function (hereafter MENDES) as well as with the Ciddor (1996) dispersion formula (hereafter C-MENDES).

Figure 4 shows the accumulated MLRO observed differential delays, plotted together with the respective theoretical differential delays as computed by using the MM and the C-MENDES models.

Finally, Figure 5 shows the difference between the MLRO-observed differential delay and the respective theoretical values by the three models quoted above as a function of the elevation above the horizon.

Conclusions

While those results should be considered as preliminary, it appears that all models considered do not properly compute atmospheric refraction at relatively short wavelengths. That is possibly the reason why the MLRO differential delays (green-UV) are larger than the values obtained by the theoretical models.

The Saastamoinen-Mendes-Ciddor model is the most successful in this regard, showing a bias of about 5 mm with respect to the MLRO results.

Of course, a much larger data set is necessary to corroborate those conclusions.

References:

Marini, J.W. and C.W. Murray (1973). "Correction of laser range tracking data for atmospheric refraction at elevations above 10 degrees." NASA-TM-X-70555, Goddard Space Flight Center, Greenbelt, Md.

Mendes, V.B., G. Prates, E.C. Pavlis, D. E. Pavlis, and R.B. Langley (2002). "Improved mapping functions for atmospheric refraction correction in SLR." Geophysical Research Letters, Vol. 29, No. 10, 1414, doi:10.1029/2001GL014394.

Saastamoinen, J. (1973). "Contributions to the theory of atmospheric refraction". In three parts. Bulletin Geodesique, No. 105, pp. 279-298; No. 106, pp. 383-397; No. 107, pp. 13-34.

Ciddor, P.E. (1996). "Refractive index of air: New equations for the visible and near infrared." Applied Optics, Vol. 35, No. 9, pp. 1566-1573.

Figure 1 – View of the Matera Laser Ranging Observatory

Characteristic	Single-Color Ranging	Asynchronous Two Color Ranging	Synchronous Two Color Ranging
Laser Output Energy/ Pulse (estimate)	100 mJ (532nm)	60 mJ (532 nm) 30 mJ (355 nm)	60 mJ (532 nm) 30 mJ (355 nm)
LAGEOS Single-Shot RMS	~ 5mm RMS	~ 1 cm RMS (532 nm) ~ 1 cm RMS (355 nm) *(these numbers may be closer to one color performance)*	N/A
Low-Orbit small array Single-Shot RMS	~ 5mm RMS	~ 5mm RMS (532) ~ 5mm RMS (355 nm)	~ 5mm RMS (532)
Differential Range Precision (single-shot) LAGEOS	N/A	~ 1.5 cm RMS (Best Effort)	N/A
Differential Range Precision (single-shot) Low Orbit, Small Array	N/A	~ 7 mm RMS (Best Effort)	(instrumental precision) + unknown external (satellite and atmosphere) effects (Best Effort)

Table 1 – Comparison of the MLRO features in the various operational modes.

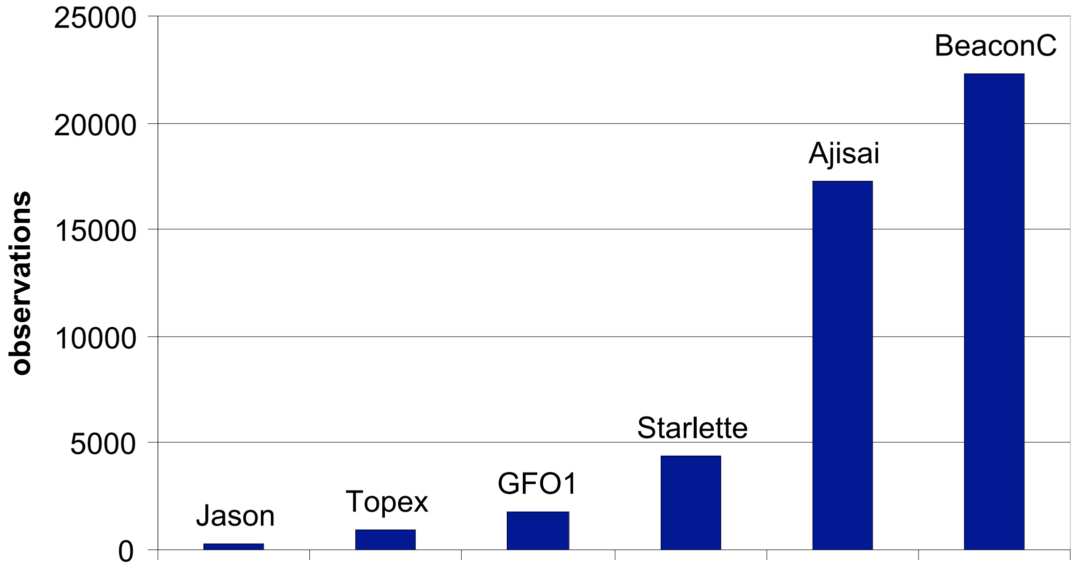

Figure 2 – Number of MLRO full rate differential delay observations per satellite.

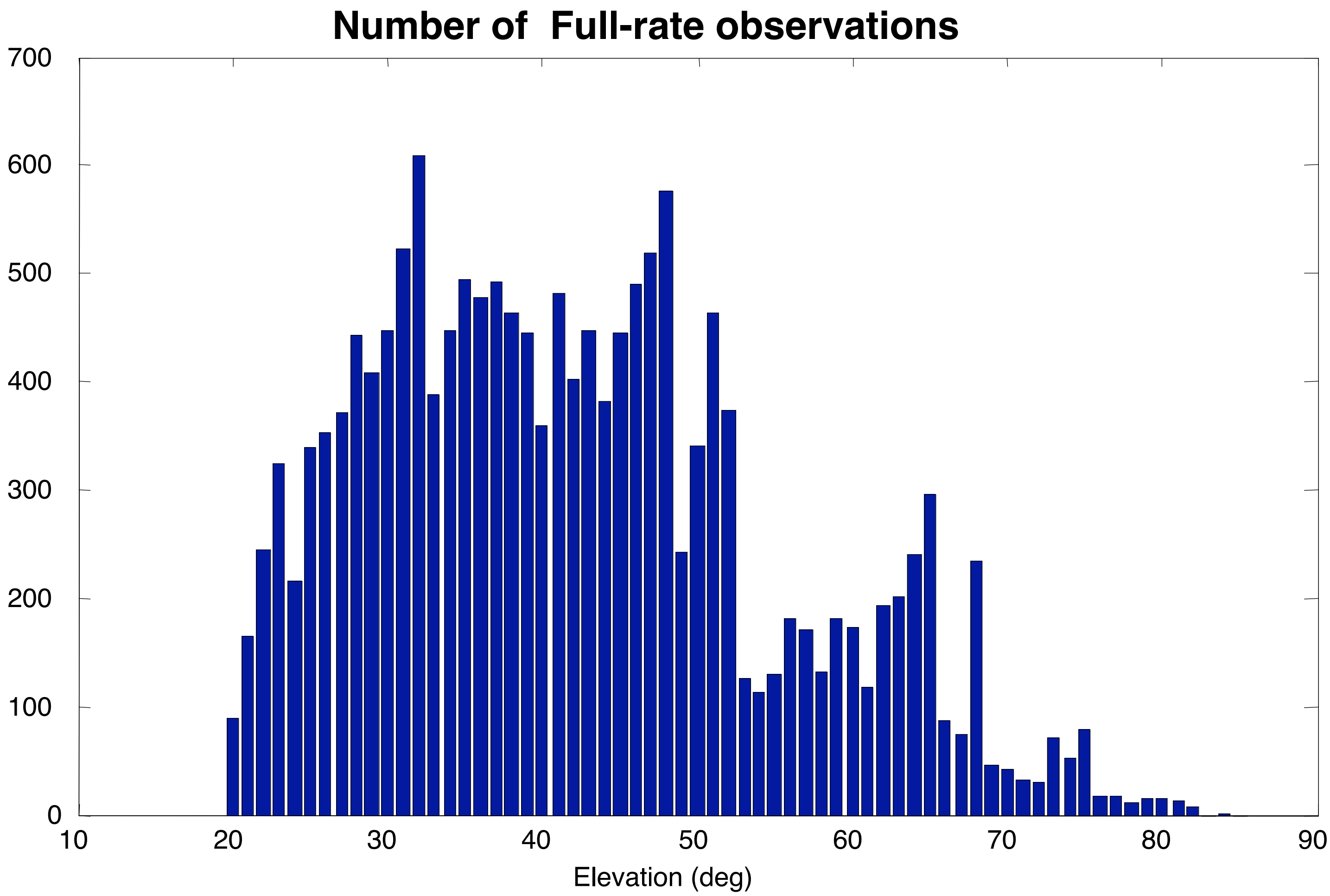

Figure 3 – Accumulated number of full rate differential delay observations as a function of the satellite elevation

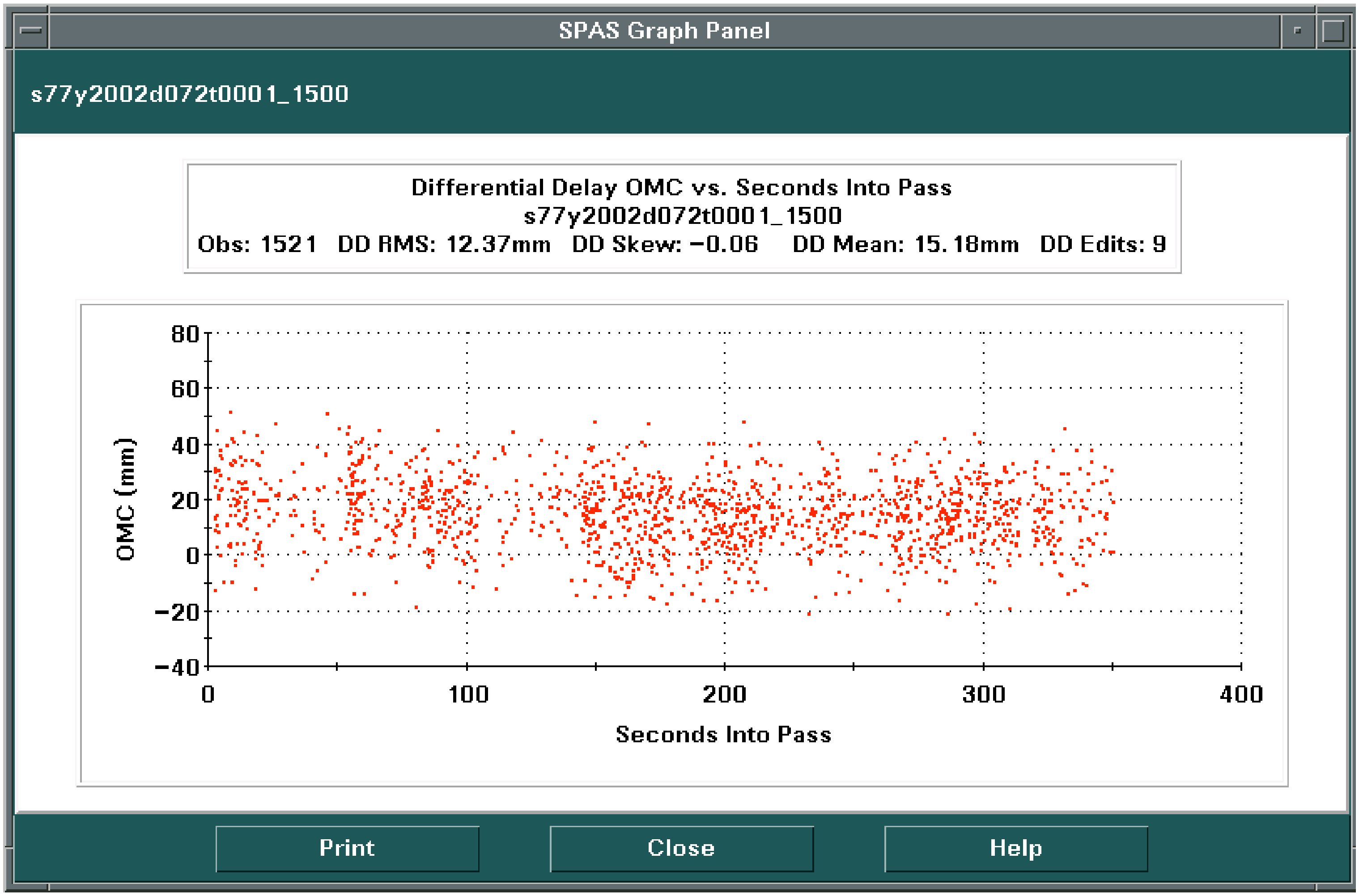

Figure 4 – Green-UV differential delays observed by MLRO

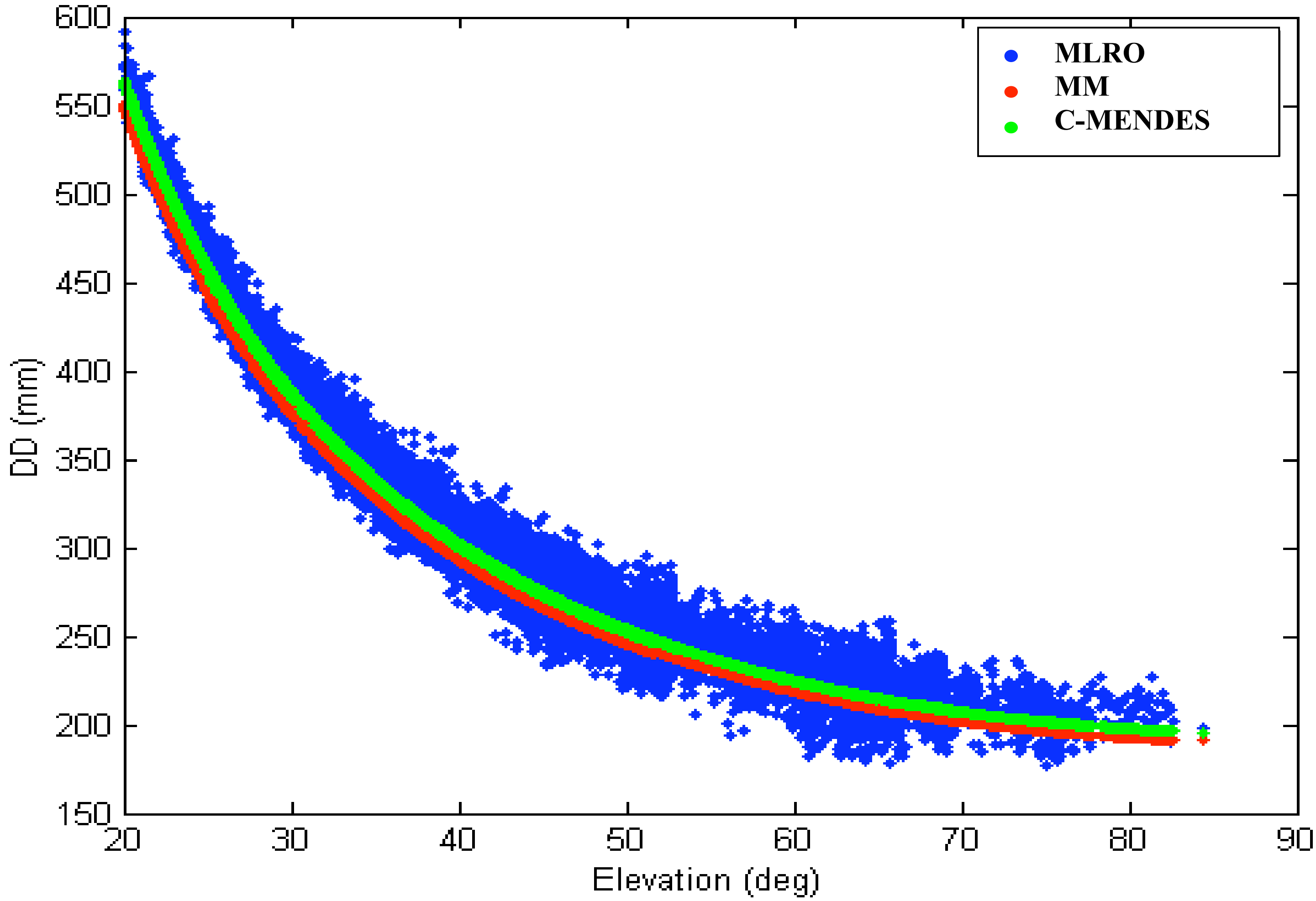

Figure 5 – MLRO determined differential delay compare with MM and SMC (C-Mendes)

Figure 6 – Difference of theoretical models with respect to the MLRO observed differential delays as a funtion of the elevation