First Laser Ranging Results of the new Potsdam SLR System

L. Grunwaldt, R. Neubert, H. Fischer
GeoForschungsZentrum Potsdam (GFZ), Division 1, Germany
Tel.: (+49)-331-2881733 Fax: (+49)-331-2881732 e-mail: grun@gfz-potsdam.de

K. Salminsh
Astronomical Institute, University of Latvia
Boulevard Rainis 19, Riga, LV-1586 Latvia
e-mail: kalvis@lanet.lv

J. del Pino
CENAIS Santiago de Cuba
Calle #17 e/ 4 y 6, 90400 Santiago de Cuba
e-mail: pino@sssn.ciges.inf.cu

Abstract
After completing the hardware installation and alignment of main optical components, successful laser ranging has been carried out since summer 2001 using the new Potsdam SLR system. The optical system consists of separated transmit and receive telescopes featuring direct drives for the telescope axes and separately driven, servo-controlled telescope housings. For target calibration, a direct optical link between transmit and receive telescope is established. Special emphasis was put on the efficient PC-based remote control of important system components thus allowing for a strict single-observer operation of the system.
Data filtering and management software is built as a client-server database application running under MS-Windows. Data conversion to dedicated formats and data publishing is strongly supported by the internal use of the flexible XML format.
Collocation using both the new and the presently operated SLR system (7836) is under way using different satellites. First results using both a Hamamatsu Hybrid PMT and a Silicon Sensor SPAD as a receiver are reported.

Short System Description
All main components of the station are described in more detail in [1]. Here only a short summary is given (cf. Fig. 1 and Table 1 below):

1. Separate telescopes are used as transmitter and receiver. Both telescopes use direct drives in azimuth and elevation axes.
2. Separately driven housings encapsulate the telescopes. The control is performed by PMAC type (**P**rogrammable **M**ulti **A**xis **C**ontroller) control units in all telescopes which are interfaced to the tracking PC via serial links.
3. All optical subsystems for the transmit and the receive path are located in sealed boxes which are mounted in vertical position to the pillar carrying the telescopes.
4. The laser is an active/active modelocked, frequency-doubled Nd:YAG laser with a diode-pumped oscillator stage and two single-pass amplifiers. Single pulses or pulse groups can be selected by remote control.
5. A hybrid Hamamatsu H 5023 PMT or a Silicon Sensor AD230 APD can be used as receivers.

Figure 1 Transmit and receive telescopes of the new Potsdam SLR station

General	Az-Alt, direct drives, digital servo, separately driven housing
maximum velocity ; acceleration	20°/s ; 4°/s_
pointing precision ; accuracy	< 1“ ; <5“
Transmitting telescope	
General	Coude-Refractor, afocal, achromatic
Entrance Aperture ; Output Aperture	45mm ; 130 mm (Γ= 2.9)
Receiving telescope	
General	Coude-Cassegrain, afocal, plane window on housing
Entrance Aperture ; Output Aperture	440 mm ; 48 mm (Γ=9.12)
Transmitting focal unit	
General	Variable beam expander, guiding system (CCD)
Entrance Aperture ; Output Aperture	11 mm ; 45 mm
Receiving focal unit	
General	Apochromat 100/600 , 2 CCDs, PMT, SPAD
System focal length (incl. receiver telescope)	5.47 m

Laser	
Type	Diode-laser pumped Nd-YAG oscillator, 2 amplifiers (flashlamp-pumped)
Single pulse data	10 mJ @ 532 nm, 50 ps, 10 Hz, up to 10 pulses/shot selectable in semitrain
Electronics	
Time Base	HP58503B GPS receiver
Epoch Timer Resolution	100 ns
Range Gate Resolution	10 ns
Time Interval Counter	SR620

Table 1 Main characteristics of the system

Control System and Software

The measurement cycle is controlled by a single PC communicating via serial as well as GPIB interfaces. The serial interfaces communicate with the telescopes‘ PMAC controllers and the GPS clock while the GPIB bus is used for interfacing all other system components as gate, station clock and time-of-flight counter. Additional tasks which are not time-critical (as control of laser parameters, beam divergency, receiver field of view) are controlled by a separate PC.

The tracking software is running under DOS and makes extensive use of the Norton Commander menu options. A single tracking program with an intuitive graphical user interface covers several options as

- „Standard“ tracking of a single satellite under day- and nighttime conditions
- Dual-satellite tracking for tandem missions as GRACE A/B with optimum distribution of the tracking arcs for both satellites

The observer can perform an online-prefiltering during the pass by narrowing the acceptance window which allows for a reduction of noise points written to the data file. Protection subroutines for sun-avoidance during daylight tracking and handling of high-elevation passes are called automatically in case of respective conditions. In case of passes with very high elevation, the tracking is segmented into two arcs thus avoiding excessively high speed and acceleration of the azimuth drives. For elevations below 20°, a strong neutral density filter is automatically placed into the transmit path in order to avoid unwanted laser illumination of nearby buildings.

Modular programs for defined actions as system calibration and raw data file generation are independent of the tracking program. For system calibration we follow an idea of G. Kirchner (SLR station Graz, Austria): both telescopes are pointed opposite to each other in a way that the (strongly attenuated) laser beam is directly fed into the receiving telescope thus establishing a direct short-way optical link between transmitter and receiver (cf. Fig. 2 and Fig. 3). Like in satellite ranging, both a single pulse and a pulse group can be selected for a calibration run. Data filtering may be performed fully automatic or in a dialog with the operator.

The mount parameters for the telescopes are derived by using a star tracking and processing subroutine which steers both mounts in parallel and this way takes into account the differential deformation of the telescope base due to the unbalanced masses (especially of the receiver).

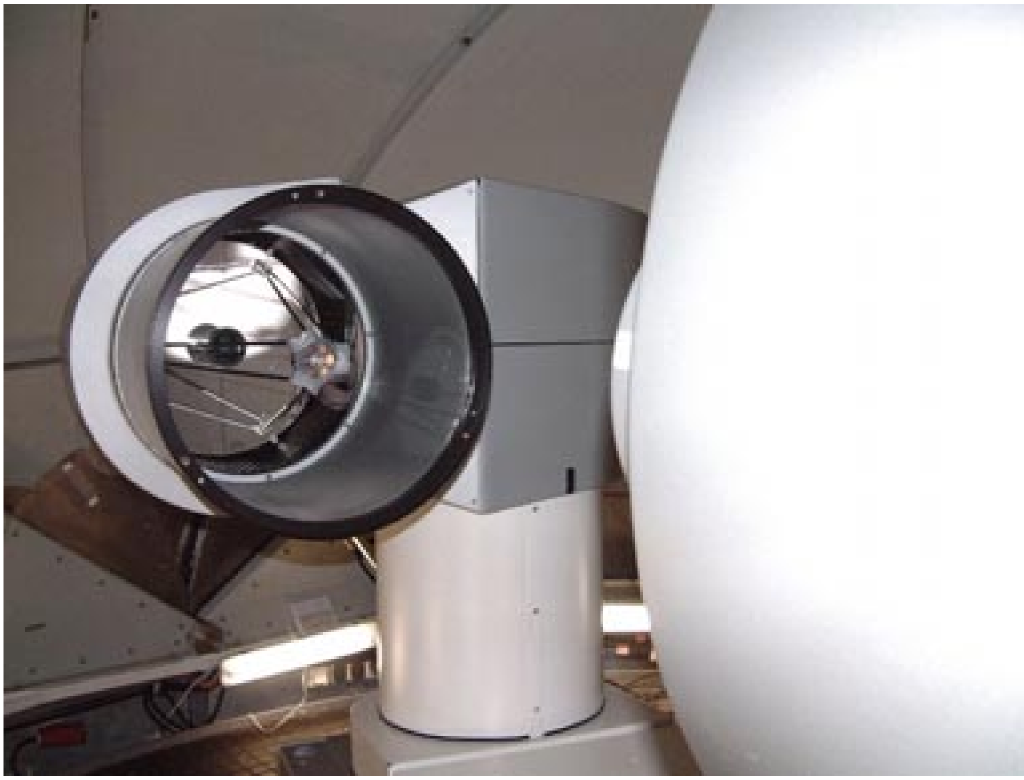

Figure 2 Transmit and receiver telescopes in position for system calibration

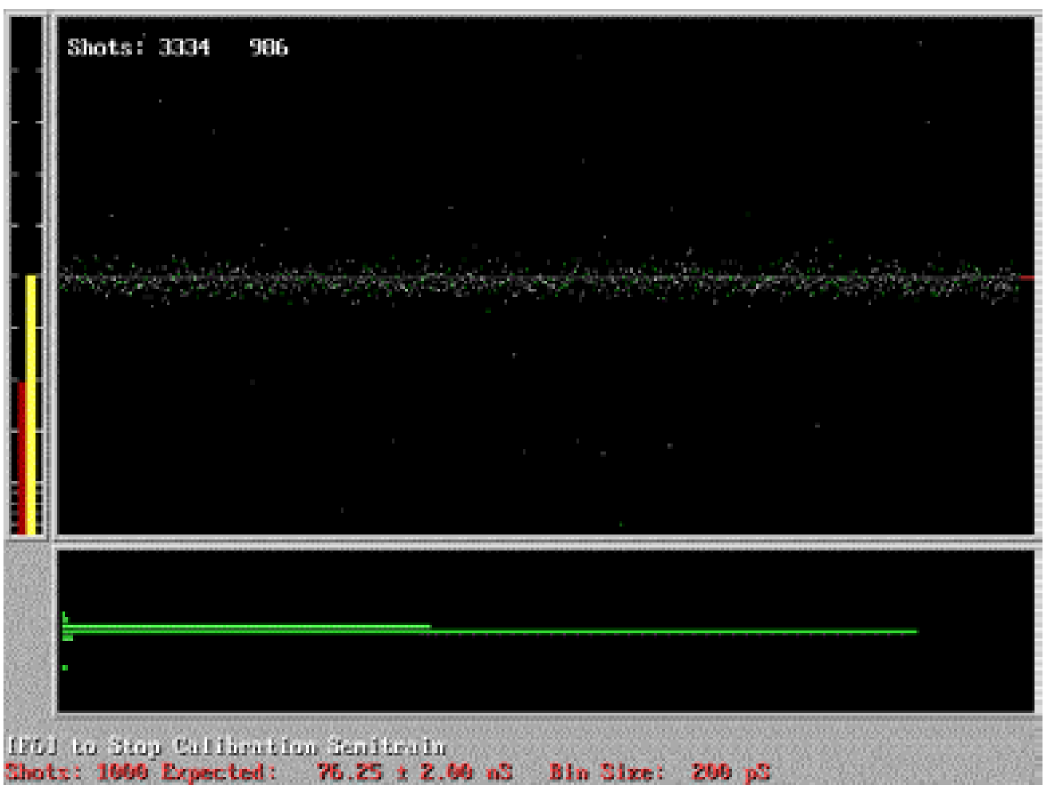

Figure 3 Screen of the tracking PC during a calibration run

Data processing software

All SLR ranging data processing is performed offline on a separate PC running under MS-Windows NT™ to which the raw data from the tracking DOS-PC is transferred to. Fig. 4 shows an example of a LAGEOS pass processing screen in the final step. The SLR data analysis and management software is designed as a client-server application, where the clients are (but not limited to) the 32-bit windows applications, but the data is stored in the Firebird 1.01 relational database which is open source and is freely available on Linux, Windows and many Unix systems. The database can be accessed remotely and the data can also be published directly to the WWW if necessary. The system internally uses an XML (e**X**tendable **M**arkup **L**anguage) based format to handle the increased sophistication of the ranging and associated data. For additional details about the XML based data SLR formats see [2]. The database also supports different kinds of the orbital data (SAO, IRVS, NORAD TLE) and can be extended with new ones if necessary. The system can also import and analyse data from other stations and store them into the database. For the predictions the RGO orbit integrator is used, but it can be replaced by some other system in the future. The database also maintains a data analysis status including information about data transmission to the SLR data centers. The normal points and time biases can be sent to the list of addresses directly from the program without resorting to the external e-mail client.

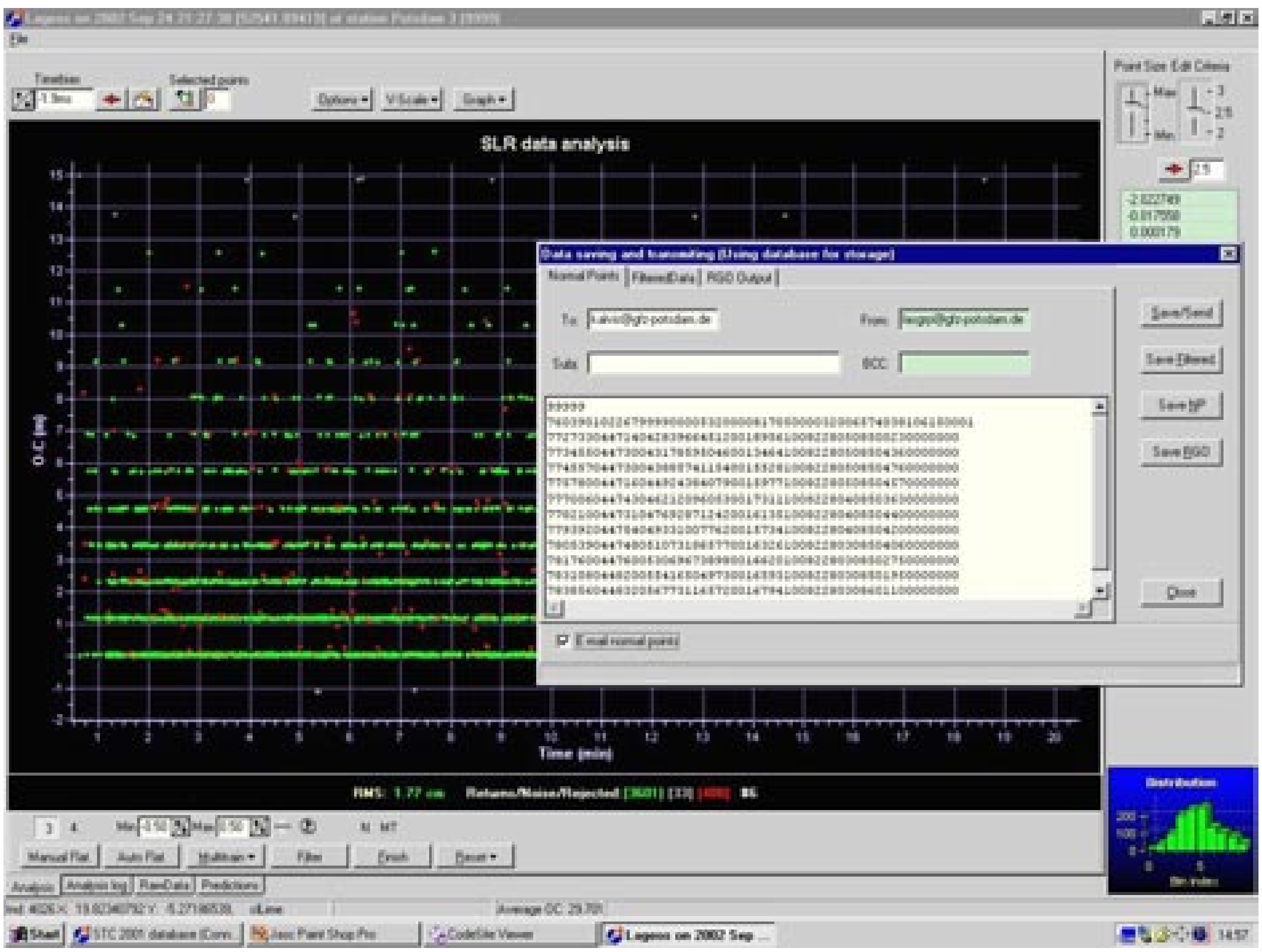

Figure 4 **Final screen of LAGEOS pass processing (3601 „good returns“) with the Normal Points ready to be sent on mouse-click**

System Status

First successful satellite laser rangings were performed in July / August 2001. Ranging to all SLR targets between the orbits of CHAMP / GRACE and Etalon has been obtained since that time. Under optimum sky conditions, the average return rate for a typical LAGEOS pass amounts to about 30 - 40% using laser semitrain and the Hamamatsu PMT as receiver. Applying strict single-photoelectron conditions, the single shot accuracy is in the order of 10 mm for target calibration and satellite targets with negligible signature as CHAMP, ERS-2 and GFO-1, and ~15-18 mm for LAGEOS. These values are practically identical for both the PMT and the (non-compensated) 230 µm AD230 SPAD (Silicon Sensor, Inc.) and are consistent with both the laser pulse width and the detector parameters.

Several satellite passes were obtained in parallel with the presently operational system (station 7836) in order to look for a possible systematic range bias with respect to the GPS-derived preliminary station coordinates. A possible systematic offset of approximately 3-4 cm between both systems appears to be present; the source of this bias is presently under investigation by means of a dedicated geodetic survey campaign.

The pointing stability of the two independent telescopes meets our expectations. Applying the improved star calibration routines with both telescopes moving simultaneously, a pointing accuracy of better than 5" can be regularly achieved (cf. Fig. 4). The mount error models for the receive and for the transmit telescope have to be adjusted in a slightly different manner: while 17 parameters appear to be sufficient for the transmitter, the receiver requires a 20 parameter model taking into account several higher harmonics of the telescope base distortion during the rotation in azimuth. This is not unexpected because the unbalanced masses of the receiver telescope are much higher than those of the transmitter.

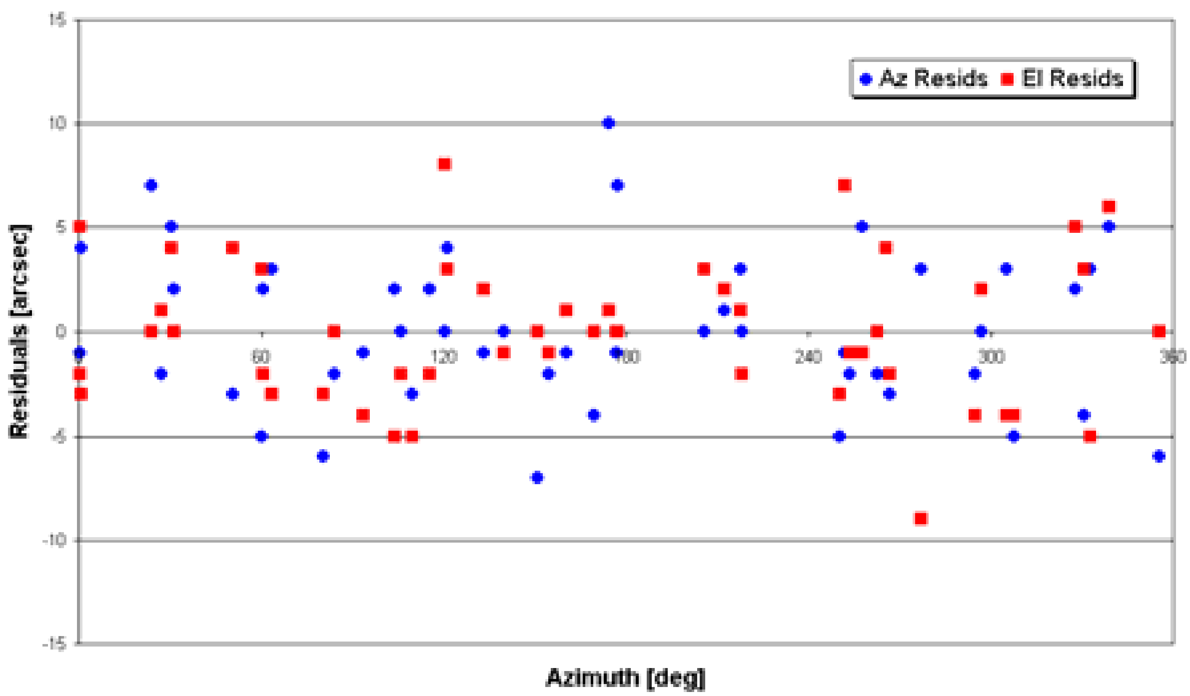

Figure 5 **Residuals in azimuth and elevation for a field of 50 stars as measured by the transmitter telescope, RMS ~3.5 arcsec for both axes (using 17 model parameters)**

A remaining stability problem is caused by effects of thermal distortion of the joint steel base for both telescopes after opening the dome. The slight temperature difference between the upper side of the basement (facing the open sky) and the lower side (facing the large concrete pillar) takes a certain time to even up. For that period, an additional differential bending between both telescopes takes place which amounts up to ~10 arcsec. This was proven independently by star field calibration and an inclinometer put on the telescope base close to the receiver telescope. An improved thermal insolation of the steel base should eliminate this problem to a large degree.

Presently (October 2002) station operations are limited to night and twilight passes until a narrowband daylight filter is inserted into the receiver path (expected end of 2002). The full system is presently undergoing the final commissioning and is expected to start nominal operations within the ILRS network not later than January 2003. After a few weeks of parallel operation, the present SLR system 7836 will be taken out of service.

Reference

[1] R.Neubert, L.Grunwaldt, H.Fischer:
The New SLR Station of GFZ Potsdam :A Status Report
Proceedings of the 12th International Workshop on Laser Ranging, Matera, 2000

[2] K.Salminsh:
XML Applications in SLR
Proceedings of the 13th International Workshop on Laser Ranging, Washington, 2002