Oral contributions

Kondratyev Boris Petrovich
The Vector Approach to the Problem of Physical Libration of the Moon: the Linearized Problem

A flexible and informative vector approach to the problem of physical libration of the rigid Moon has been developed in which three Euler differential equations are supplemented by 12 kinematic ones. A linearized system of equations can be split into an even and odd systems with respect to the reflection in the plane of the lunar equator, and rotational oscillations of the Moon are presented by superposition of librationsin longitude and latitude. The former is described by three equations and consists of unrestricted oscillations with a period of T1 = 2.878 Julian years (amplitude of 1.855'') and forced oscillations with periods of T2 = 27.201 days (15.304''), one stellar year (0.008''), half a year (0.115''), and the third of a year (0.0003'') (five harmonics altogether). A zero frequency solution has also been obtained. The effect of the Sun on these oscillations is two orders of magnitude less than that of the Earth. The libration in latitude is presented by five equations and, although they are perturbed by the Earth, is described by two harmonics of unrestricted oscillations (T5 ~ 74.180 Julian years, T56 ~ 27.347 days) and one harmonic of forced oscillations (T3 = 27.212 days). The motion of the true pole is presented by the same harmonics, with the maximum deviation from the Cassini pole being 45.3''. The fifth (zero) frequency yields a stationary solution with a conic precession of the rotation axis (previously unknown). The third Cassini law has been proved. The amplitudes of unrestricted oscillations have been determined from comparison with observations. Some statements of the previous theory are revised. Poinsot's method is shown to be irrelevant in describing librations of the Moon. The Moon does not have free (Euler) oscillations it has oscillations with a period of T5 ~ 74.180 Julian years rather than T ~ 148.167 Julian years.

Makram Ibrahim
Statistical studies of the calibration of the Helwan-SLR

The paper concerns on the calibration of the Helwan Satellite Laser Ranging station (SLR). The calibration technique, which has been applied at the Helwan station, is explained. The calibration constant of the system produced from the internal calibration is computed and the results are summarized for two different kinds of Photo multiplier (PMT) tubes. The average root mean square values of the calibrations carried out to the Helwan-SLR station during the period from the year 1991 to the year 2008 are computed.

Makram Ibrahim, Khalil I. Khalil, and A. T. Roman
Recent Satellite laser ranging from Helwan-SLR station

The paper concerns on the recent satellite laser ranging from Helwan-SLR station. The updated equipments used for the operation of the Helwan SLR-station are described. The results and the analysis of the data obtained after the use of the cpf-formats are given. The future operation of the Helwan-SLR station is also discussed.

B. P. Kondratyev
The Vector Approach to the Problem of Physical Libration of the Moon: the Linearized Problem

A flexible and informative vector approach to the problem of physical libration of the rigid Moon has been developed in which three Euler differential equations are supplemented by 12 kinematic ones. A linearized system of equations can be split into an even and odd systems with respect to the reflection in the plane of the lunar equator, and rotational oscillations of the Moon are presented by superposition of librations in longitude and latitude. The former is described by three equations and consists of unrestricted oscillations with a period of T1 = 2.878 yr (amplitude of 1.855'') and forced oscillations with periods of T2 =27.201 d (15.304''), one stellar year (0.008''), half a year (0.115''), and the third of a year (0.0003'') (five harmonics altogether). A zero frequency solution has also been obtained. The effect of the Sun on these oscillations is two orders of magnitude less than that of the Earth. The libration in latitude is presented by five equations and, at pertrubations from the Earth, is described by two harmonics of unrestricted oscillations (T5 ~74.180 yr, T6 ~ 27.347 d) and one harmonic of forced oscillations (T3 = 27.212 d). The motion of the true pole is presented by the same harmonics, with the maximum deviation from the Cassini pole being 45.3''. The fifth (zero) frequency yields a stationary solution with a conic precession of the rotation axis (previously unknown). For the ratio ~ 0.2311, the theory gives 0.2319, which confirms the adequacy of the approach. Some statements of the previous theory are revised. Poinsot's method is shown to be irrelevant in describing librations of the Moon. The Moon does not have free (Euler) oscillations it has oscillations with a period of T5 ~ 74.180 yr rather than T ~ 148.167 yr.

Wu Bin,Lin Mingsen,Zhang Zhongping

Global SLR Tracking Support for HY-2 precise orbit determination

Huang C.L.

On the study of the lunar structure interior from integration of the LLR data and gravity data

With the accumulation of more than 40 years LLR data and the improvement of the precision of LLR observations, some lunar physical parameters, such as the physical librations, lunar tides and lunar reference frame, can be retrieved with higher precision. And these parameters provide key information of and constraints on the lunar physics interior. Meanwhile, more and more lunar missions provides us with improved lunar gravity field, like the Chinese C'-E mission, Japanese SELENE mission and the upcoming NASA GRAIL mission. The gravity information of the lunar backside from SELENE mission is the best so far, while the GRAIL will improve again the lunar gravity field model by at least one degree of magnitude. All these gravity field data provide also very important information of the lunar physics interior. It then becomes a challenge, and will be discussed here, how to integrate these two kinds data to study the lunar structure interior.

del Pino, Jorge

Hazards and Risk @ SLR Network, A Preliminary Overview

The March 11 Tohoku-oki quake and the damages suffered by the SLR network in last decade clearly shows that a Risk Mitigation Policy for the SLR network is required. The concepts associated with Hazard Prevention and Risk Management will be introduced and an overview of the most common hazards presented. Some ideas of how to manage future cases will be proposed.

Mathis Bloßfeld, Horst Müller, Detlef Angermann

Benefits of SLR in epoch reference frames

In the actual terrestrial reference frame realizations the station motions are approximated by linear velocities (multi-year reference frames). But this parameterization is not adequate since we know that the stations movements include non-linear parts. One possibility to overcome this lack of modelling is to estimate the station positions more frequent by computing epoch reference frames instead of the conventional multi-year reference frames. SLR is the primary technique to determine the origin together with station coordinates, EOP and gravity field parameters. The transfer of these information from SLR to the other techniques in the combination (GPS, VLBI) is done by tying the techniques with terrestrial difference vectors (local ties) together. The choice of the used local ties are one crucial part of the combination process. In this study we analyze the quality of the datum realization by comparing the gained epoch reference frames with a multi-year solution. Furthermore we discuss the impact of the temporal resolution on the datum realization. The EOP are validated w.r.t. the IERS 08 C04 time series.

C. Schwatke

Automated Data Management of SLR Data and Products at the EUROLAS Data Center (EDC)

Within the ILRS, the EUROLAS Data Center (EDC) at the DGFI operates as ILRS Data Center adjacent to the CDDIS. Over the last years the data volume of SLR observations, predictions and products increased from year to year. An additional hourly and daily data exchange between CDDIS/HTSI and EDC demands an automated system for the management of data. This automated system checks the formats of incoming data (quick-look, full-rate, CRD, CPF). Valid data sets will be distributed via mail (CPF) and published on FTP. The permanent upload of data to the EDC requires also a high available server structure consisting of two servers to minimize the downtime of FTP, web server, etc. The distribution of users to the available services on the servers is realized by using port forwarding of Iptables. This requires an additional timely synchronization between FTP and especially databases for the data management. Furthermore the mailing lists (SLR-Mail, SLR-Report) are automatized by using the open source tool Mailman.

Schlicht A., Schreiber U., Prochazka I.

The European Laser Timing Experiment (ELT) and Data Centre (ELT-DC)

The Atomic Clock Ensemble in Space (ACES) is an ESA mission in fundamental physics, which will establish a very precise time scale in space. The basis of this time scale is an active hydrogen maser for short and medium-term stability and a laser cooled caesium fountain working in microgravity for long-termstability and accuracy. A frequency comparison and distribution package ensures the on-board comparison of these two clocks and distributes the clock signal to a microwave link (MWL), which finally transfers the ACES time scale to Earth. Connected to this mission is a secondary way for time transfer, the European Laser Timing experiment (ELT). It uses a combination of one-way and two-way laser ranging to compare the ACES clocks with ground clocks at SLR stations. Therefore the ACES module mounted on the ISS will carry a retroreflector array and a SPAD detector to time tag laser pulses in ACES time scale. The ELT experiment will allow a space to ground clock comparison with a time stability sigma x(tau = 300 s) = 4 ps, and a ground to ground clock comparison of 6 ps after an ISS pass (300 s of integration time) in common view and 7 ps in non-common view (after a dead time of one orbit cycle). The accuracy for sychnonizing ground clocks will be better than 50 ps. Laser ranging will be performed by the satellite laser ranging (SLR) community. Therefore the support of the International Laser Ranging Service (ILRS) is needed. The ELT-DC has the responsibility to provide the information needed by the SLR stations to track the ACES module, collect the two-way ranging events from the stations and the one-way ranging data from ACES, to combine these data to defined products, to assure the backup of the products, to send raw data and products to the ACES USOC for archiving. As sole interface between ESA and the ILRS the ELT-DC will organize common view campaigns, build up a communication platform, and provide special ranging software to the SLR stations.

Yuriy V. Ignatenko, Vladimir M. Tryapitsyn, Andriy A. Makeyev, Igor Yu. Ignatenko

Direction of the Light Deviation Vector during Satellite Laser Ranging

In this article the method of construction of the three-dimensional laser beam deviation vector using satellite laser ranging observations is described. The scheme of deduction of the equation of this vector by its two projections onto the focal plane of a telescope at different instants of time during a satellite pass is stated. Influence of the Earth orbital velocity on the direction of the light deviation 3D-vector is estimated. Solutions are given in the inertial frame with an origin in the solar system mass center. Earth rotation and orbital motion irregularities are taken into account. Observed deviation of light from preset direction is a result of composition of the satellite relative-to-observer velocity, the Earth orbital velocity, and velocity of the luminiferous medium.

Chen Wanzhen,Yang Fumin,Zhang Zhongping,Wang Yuanming,Li Pu

Design of LRA for Compass GEO and IGSO satellites and observations

GEO and IGSO orbital satellites are important parts in the Chinese regional satellite navigation system. All of those satellites will be equipped with LRA designed and manufactured by Shanghai Astronomical Observatory for precision orbital determination. We reported the LRA on Compass MEO orbital satellite at last workshop. This paper presents the characteristics of LRA for Compass GEO and IGSO satellite and the observation of laser ranging by the dedicated Compass SLR system with 1 meter aperture telescope. Considering Compass GEO satellites serving for Chinese region, we adopt a method of inclined installing LRA for increasing LRA reflective area, with normal direction of LRA pointing to the Chinese continent rather than the geocenter. The theoretical calculation and measuring results show that the method is very effective.

Reinhart Neubert, Ludwig Grunwaldt, Christian Schopf, Engelbert Hofbauer, Jost Munder, Mark Herding, Rolf Sand

Single Open Reflector for MEO/GNSS Type Satellites. A Status Report

The status of a project to design, manufacture and test a single open reflector breadboard model is reported. Main advantage of this concept is the absence of any spreading of the return pulses. The practical realization places high challenges on mechanical/thermal design, material selection and manufacturing accuracy. A critical analysis based on numerical calculations and performance simulations is presented.

Liu Chengzhi, Han Xingwei, Fan Cunbo, Zhang Ziang, Song Qingli

Progress in KHz SLR and Daylight tacking at Changchun Station

This paper introduces that Changchun SLR station upgraded the original system. Using independent research software and hardware, Changchun SLR station successfully achieved conventional KHz satellite laser ranging and daytime ranging. It includes kHz laser system, Event Timer, designing nanosecond accuracy of Range Gate Generator with event mode and back-scattering avoiding circuit, developing real-time control software and data pre-processing software. The paper presents the progress in KHz SLR at Changchun station, including ranging to the LEO and HEO satellites at night and daylight tracking. In addition, some new measuring results also showed in this paper. Key words: KHz SLR,Daylight tacking

Li Zhulian,Fu Honglin,Zheng Xiangming, He Shaohui, Xiong Yaoheng,Li Rongwang
Co-optical Path KHz SLR

Hyung-Chul Lim, Eunseo Park, Yoon-Kyung Seo, Seung-Cheol Bang, Seong-Yeol Yu, Jin-Young Lee, Kwang Dong Kim, Jakyoung Nah, Jeong Gyun Jang, Bi-Ho Jang, Jong-Uk Park
Status and Progress of Korean SLR Program, ARGO

KASI (Korea Astronomy and Space Science Institute) has proceeded a governmental program named ARGO (Accurate Ranging system for Geodetic Observation) since 2008 to develop one mobile and one fixed SLR systems, ARGO-M and ARGO-F respectively. ARGO-M, which will be completely developed in 2011, has the separate optical path that employs the 40cm receiving and 10cm transmitting telescopes. The system is a semi-automated and KHz laser ranging system with the single shot range precision of about one centimeter and NP precision better than 5 mm for LAGEOS satellite. ARGO-M is capable of tracking satellites with the laser retro-reflector array in the range of 300 to 25,000 km altitude and will provide 24 hour tracking coverage including daylight tracking. Some essential components effecting on ranging accuracy came from the foreign institutes, which include the timing system, photon detector, laser and optoelectronic controller developed by Graz station in Austria. The CDR (Critical Design Review) of ARGO-M was carried out on March 2011 and it is now in the phase on a fabrication and system integration. ARGO-F, which is equipped with a telescope of 1 m diameter, has the common optical path and its development will actually begin from 2012 after ARGO-M completion. Its basic function is also laser ranging to satellites with the laser retro-reflector array and it can have an additional function such as optical tracking using laser illumination, satellite imaging using an adaptive optics and space debris laser ranging. None of these additional functions are determined yet but KASI is going to make development strategies including these additional functions by 2011. In this study, the status and progress of ARGO-M are discussed and the future plan of ARGO-F is also provided.

Arsov K. Wagner J.
New fpga based SLR controller in Metsähovi

Metsähovi SLR system is currently going through a major renovation. A new 2KHz laser has been bought together with the timing devices, C-SPAD and other necessary electronics. This change from old 1Hz system to our new 2KHz SLR requires improvement in all the hardware and software in Metsähovi accordingly. Since in 2KHz scenario many operations are time critical, and it is difficult for some tasks to be managed in the software, we implemented one new fpga-based SLR controller who is capable of managing all time-critical tasks within the fpga. For this we decided not to design the board from scratch, but to use already available commercial fpga/cpld development boards and to program the desired functionality. Two versions of the controller have been implemented. For one we used the PCI Cyclone II Altera development board and the second light-weight controller uses relatively cheap Altera cpld mounted in a PCI host board. The functionality of both boards is programmed with Verilog hardware language. In this presentation the functionality/performance as well as development strategies will be outlined and explained.

D. Thaller, K. Sosnica, R. Dach, A. Jäggi, G. Beutler, M. Mareyen, B. Richter
GNSS satellites as co-locations for a combined GNSS and SLR analysis

The ILRS stations are tracking GNSS satellites since many years, and SLR range residuals to GPS and GLONASS orbits based on microwave-data are computed routinely at AIUB. The biases seen in the SLR residuals indicate on the one hand inconsistencies between GNSS and SLR terrestrial reference frames (TRF), and errors in the models applied for computing the residuals (e.g., satellite antenna offsets (SAO) for the microwave antennas, offsets for the laser reflector arrays (LRAs), or unmodelled SLR range biases) on the other hand. In order to overcome the above mentioned deficiencies, a combined analysis of microwave and SLR range data to GNSS satellites should be the goal. In such type of analysis, the GNSS satellites are

used as co-location with orbit parameters based on both, i.e., GNSS and SLR data. Local ties are not needed in such an approach so that the networks of GNSS and SLR remain un-distorted. Additionally, the SAO parameters as well as LRA offsets and range biases can be estimated consistently in such an approach. We performed a combined analysis of GNSS microwave and SLR range data with the GPS and GLONASS satellites used as co-location. SLR data to LAGEOS and ETALON are included additionally in order to improve the stability of the SLR station coordinates' estimates. Corrections to the official SAO and LRA values (from file igs05.atx and from ILRS website) will be presented. The question concerning their separability from range bias parameters and TRF scale will be addressed.

Arsov K.

New KHz-capable SLR software in Metsähovi

Metsähovi SLR system is currently going through a major renovation. A new 2KHz laser has been bought together with the timing devices, C-SPAD and other necessary electronics. This change from old 1Hz system to our new 2KHz SLR requires improvement in all the hardware and software in Metsähovi accordingly. Since in 2KHz scenario many operations are time critical, our old 1Hz SLR software was not capable of many tasks, and together with the hardware a decision has been made to write a new operational SLR software. The software is written in C++ by the use of MFC libraries and is fully capable of handling 2KHz scenario. Main objective of this presentation is to give an overview of performance/development, as well to identify all the critical items and their solution. Many test performance will be presented and documented.

Daniel Kucharski, Georg Kirchner, Toshimichi Otsubo, Franz Koidl, Mihoko Kobayashi

Spin of Ajisai: influence of Solar Irradiation on the spin period and precession of the spin axis measured by the Graz 2kHz SLR system

Using Graz 2 kHz SLR data of more than 5 years we calculated spin period of Ajisai with an accuracy of 84 µs (0.0042%). The spin period is increasing, following an exponential trend: T = 1.9028 • Exp(0.014859 • (Year - 2003.0)) [s]. This slow down is mainly caused by gravitational and magnetic fields of the Earth. The high accuracy of the spin period determination allows detection of small perturbations of the spin period caused by non-gravitational effects related to the solar energy flux to which the satellite is exposed. The high repetition rate of the laser makes it possible to determine the epoch time when the laser is pointing directly between two corner cube reflector rings of the satellite. Identification of many such events during a few (up to 3) consecutive passes allows to state the satellite orientation in the inertial frame. From 6 years of 2 kHz SLR data delivered 331 orientation values which clearly show precession of the spin axis with a period of 117 days. Accurate measurements of Ajisai's spin parameters are necessary for the envisaged laser time transfer via Ajisai mirrors.

Daniel Kucharski, Georg Kirchner, Hyung-Chul Lim, Franz Koidl

BLITS: spin parameters and its optical response measured by the Graz 2kHz SLR system

The nanosatellite BLITS (Ball Lens In The Space) is the first object designed as a passive, spherical retroreflector of the Luneburg type, dedicated for Satellite Laser Ranging. The 2 kHz SLR station Graz measures spin parameters of this satellite, providing information about the rotational dynamics of the body. The measurements obtained during the period from September 26, 2009 to November 24, 2010 show a significant change of the spin configuration. The spin axis was dynamically precessing since the launch and currently is sinus-like behaving between coordinates RA 120°...150°, Dec 30°...60° (J2000 inertial reference frame). The angle between the symmetry axis and the spin axis of BLITS is not constant, but is decreasing since the launch, while its spin period is rather stable with a mean value of 5.613 s (clockwise rotation). The satellite was dynamically changing its attitude during the first three months after deployment after this time the spin parameters are relatively stable. The successful application of the spherical retroreflector satellite concept allows recommending this solution for active satellites like GOCE, GRACE and CHAMP. Using a spherical reflector, instead of a classical CCR array, would provide more accurate and stable center of mass correction – at sub-mm level, instead of > 5 mm variations of classical retro-reflector arrays – and a wider incident angle between the laser beam and a nadir direction for which the SLR measurements can be obtained.

Krasinsky G.A.,Prokhorenko S.O., Yagudina E.I.

New version of EPM –ERA Lunar theory

The numerical lunar theory EPM –ERA has been constructed in IAA RAS .The dynamical model of the Moon motion has been constructed by simultaneous numerical integration of the equations of orbital and rotational motions of the Moon, major planets, five biggest asteroids. Potential of the Moon is calculated up to 4-th order of zonal index, that of the Earth includes the 2-th order harmonics C20 and C22. Tidal perturbations in the lunar orbital motion caused by tidal dissipation on the Earth's body is computed by the model with a constant lag. The effects of the elasticity of the lunar body have been also taken into account. New version of EPM-ERA Lunar theory was corrected by improved model of dissipative effect of the lunar rotation by integration orbital and rotational motions with retarded argument. The comparison of the improved dynamical model with 17315 LLR data from 1970 till March 2011 has been made. The LLR-observations were also processing with three versions of DE ephemeredes and with INPOP10 French ephemeris.

Randall L. Ricklefs

ILRS Standardization of Hardware, Software, and Procedures: Extending the Range

Over the years, the ILRS has established and refined standards for station performance. However, standardization of hardware, software, and procedures appropriate for ILRS stations and operations, analysis, and data centers has been spotty. Advantages and disadvantages of standardization are explored. Finally, a proposal is made to augment the current performance-based standards with a standard station reference design and additional software as a way to facilitate new station construction.

Polac Team/ SYRTE / Observatoire de Paris, INPOP Team / IMCCE / Observatoire de Paris and MeO Station / GeoAzur / Observatoire de la Côte d'Azur

Lunar Laser Ranging: Two Tools for assisting observers

These two tools intends to help the LLR observers. The first one gives the predictions of topocentric and geocentric coordinates of lunar targets (as retro-reflectors or craters) and allows to determinate in which direction the laser has to be positioned for reaching a target on the Moon. The second one gives the differences between the observations and the computations of the round trip times of laser pulses between a terrestrial station and a lunar retro-reflector. These residuals allow the user to have a validation of his LLR observations. This tool can be used in the observatories already operational for the laser lunar ranging but it is aimed more particularly at the new teams who begin to carry out LLR observations.

D. G. Currie, S. Dell'Agnello & G. O. Delle Monache

Lunar Laser Ranging Retroreflector for the 21st Century

After forty years, because of the lunar librations, the existing Apollo retroreflector arrays contribute significant fraction of the limiting errors in the range measurements. The University of Maryland, as the Principal Investigator for the original Apollo arrays, is now proposing a new approach to the Lunar Laser CCR array technology. The investigation of this new technology, with Professor Currie as Principal Investigator, is currently being supported by two NASA programs and, in part, also by INLN/LNF in Frascati, Italy. Thus after the proposed installation on the next Lunar landing, either robotic or manned, the new arrays will support ranging observations that are a factor 100 more accurate than the current Apollo LLRRAs, from the centimeter level to the tens of microns level. In the design of the new retroreflectors, there are three major challenges, fabrication, thermal and emplacement on the lunar surface. These will be described and the methods to mitigate these problems will be explained. Finally, near term flight opportunities to carry the LLRRRA-21 to the moon will be discussed.

D. G. Currie

Ground Stations for the Next Generation Lunar Retroreflectors

The next generation lunar retroreflectors will supply the capability for greatly improved single photo-electron ranging accuracy. In principle, there are three deployment methods for the “Lunar Laser Ranging Retroreflector for the 21st Century” that have the possibility of 2 mm, 200 micron and 30 microns. We will address the relation between the required aperture, laser power and pulse length in order to obtain a given number of photo-electrons for a normal point. Then we will address the timing requirements, and the required laser pulse length, timing circuits and most important, the detector performance. The required offset pointing will be discussed. Finally, the combination of the timing and the signal level will be addressed with respect to obtaining the normal point accuracy commensurate with the next generation retroreflector capabilities.

D. G. Currie

A New Approach for the Spin Axis to Determine LAGEOS

The Thermal Thrust, defined by orientation of the axis of rotation LAGEOS, is a significant contributor to the measurement the Lenses Thirring Effect and other effects in General Relativity. However, this has been difficult to determine. For the first decade or so, theoretical models were used. At the University of Maryland, I proposed that observations were conducted by Fresnel Photometry. That is, detected of the Fresnel reflections of the solar radiation from the front faces of the individual CCRs. These measurements were then analyzed giving an experimentally measured value of the spin axis orientation. This technique is still the only one that has produced the orientation. This was developed in an analytic/phenomenological theory based on the fast rotation theory by Nacho Andres. To date, the rotation rate of LAGEOS Has slowed so this Fresnel Reflection technique is no longer feasible. I will present a new procedure that will deal with the collection of observations of LAGEOS. This technique, denoted as the “Pocket Photometry” approach will allow the determination of the orientation for the slowly rotating LAGEOS. Data will be presented to demonstrate the validity of this approach.

Evan Hoffman, HTSI, Randall Ricklefs, The University of Texas / Center for Space Research

Controlling Laser Ranging with RTAI-based Real-Time Linux

Currently, many laser ranging systems, such as NASA's MOBLAS systems and the McDonald Laser Ranging Station (MLRS), use proprietary Unix-like real-time operating systems for time-sensitive ranging control software. Such OS's are expensive to maintain and often carry a risk of vendor lock-in. We outline a method of controlling an SLR system using the Linux operating system with the RealTime Application Interface (RTAI) hard real time extension. Linux provides a wide variety of software packages that have low operating cost, are under active development, and are open source. Two flavors of Linux are discussed: Arch Linux and CentOS. Both of these flavors have strengths and weaknesses when being used in a real time environment. Choosing which real time scheduler to use is important for programming considerations. Our approach uses the LXRT scheduler which allows real time control in user mode. We show effective control of an LR system using modest hardware. The current status of conversions of the Goddard Geophysical and Astronomical Observatory (GGAO) 48” telescope and (MLRS) is presented.

Florent Deleflie (IMCCE / Observatoire de Paris, GRGS), Jean-Michel Lemoine CNES/DTP, GRGS Gilles Metris, and François Barlier (Geoazur / Observatoire de la Côte d’Azur,GRGS)

Assessment on the non gravitational forces acting on the Lageos satellites

The Lageos and Lageos II satellite motions have been at the origin of a relevant literature, developing various models accounting for non-gravitational forces. In this paper, some past results are recalled, and then extended toward recent observations to show which changes can now be observed, in relation with the time evolution of the satellite spin. We then analyze the long-term evolution of the Lageos satellite orbits, tracked by the Satellite Laser Ranging network over more than 20 years. The level of residuals enables to show very small perturbations in the orbit, that can be reasonably attributed to non- gravitational effects. These perturbations are displayed through time series of empirical residual accelerations, linked to the non-gravitational effects. We then discuss the impact on the determination of the gravity field coefficients of degree 2.

Zhang Zhongping, Yang Fumin, Zhang Haifeng, Meng Wendong,Chen Juping, Chen Wenzhen, Wu Zhibo

The achievements of the dedicated Compass SLR system with 1m aperture telescope: GEO satellite daylight tracking and laser time transfer (LTT)

Since 2008, Shanghai Observatory began to construct the dedicated SLR system with 1 meter aperture telescope for tracking Chinese Compass satellite from 2,000km to 4,000km with the precision of 2cm. Now the dedicated SLR system has the ability to routinely track Compass satellites at the night and daytime. This paper presents the achievements and measuring results of the SLR system: daylight tracking Compass GEO/IGSO satellites and the LTT experiments with improved LTT payload onboard IGSO satellite.

Jong Uk Park, Hyung-Chul Lim, Sungki Cho and Jae-Cheol Yoon

The Contribution of Korean Side to the International Laser Ranging Service

Korean SLR program, ARGO, started from 2008 to install the 40cm transportable SLR system (ARGO-M)and 1 meter fixed SLR system (ARGO-F). ARGO-M had been passed the Critical Design Review in Mar.

2011 and just started to fabricate all the sub systems. KOMPSAT-5 will be the first satellite in Korean space missions which is equipped with Laser Retro Reflector Array and scehduled to launch at the second half of this year. Korea Astronomy and Space Science Institute (KASI) has the plan to install one GGOS core site (fundamental station) outside Korea, which is consist of GNSS, Geodetic VLBI, DORIS and SLR systems in near future. In addition, KASI has the capability to host the Data Center and Analysis Center of ILRS for the international community. In this presentation, we will give the information about the current status and future plan of each program.

Takahide MIZUNO, Hirokazu IKEDA, Kousuke KAWAHARA

Development of pulse detection IC for LIDAR on planetary lander

In recent years, LIDAR has been used for a remote sensing, an obstacle avoidance system of a planetary lander. Especially, a wide dynamic range is necessary for applications of a planetary lander. For instance, the asteroid sample return mission "Hayabusa" required 60 dB as for the dynamic range of the receiving system, because it was necessary to measure the distance of 50 m-50 km. In addition, an obstacle avoidance system needs a ranging resolution more than 10 cm. For the planetary lander, ISAS/JAXA is developing a customized IC for a LIDAR reception. This report introduces an outline of the customized IC and reports the evaluation experiment of prototype LIDARX03.

Shinichi Nakamura, Ryo Nakamura, Takahiro Inoue, Hiroyuki Noda, and Motohisa Kishimoto

Comparative verification of return rate on GNSS LRA

Recently, GNSS mounted LRA for precise orbit determination, precise clock estimation, and precise orbit validation. As regional navigation satellite, JAXA has launched QZS-1 on September 2010. JAXA confirmed the performance (return rate) of LRA on QZS-1 as initial check out. Moreover, we are interested in other GNSS LRA since there are some kind of GNSS LRA, for example, non coated or coated CCR. We focused on the performance (return rate) for each CCR. At this workshop, we will report performance of each GNSS LRA, which based on actual tracking through ILRS network.

Speaker Vedin Vadim, co-autors: Artyukh Yu., Bespal'ko V., Boole E.

Event Timer A033-ET: Curent State and Typical Performance Characteristics

The A033-ET has been developed as an advanced version of the model A032-ET that is well known in SLR community. As annonced at the previous ILRS Workshop, the A033-ET is commercially available from 2010, and up to now 10 units of this device have been manufactured and carefully tested. Consequently, sufficient statistics have been accumulated to specify the A033-ET typical performance characteristics more reliably than those at the development stage. The main results of experimental testing of the A033-ET parameters (both conventionally considered and new ones) are presented in this report. These results allow to suppose that the A033-ET could be basic measurement instrument for the most of ground-based SLR stations that provide both routine and KHz SLR.

Speaker Boole Eugene, co-autors: Artyukh Yu., Bespal'ko V., Stepin V., Stepin D., Vedin V.

Main Directions of Riga Event Timer Development and Current Results

It seems that the present-day high-performance event timers (including Riga Event Timers) already offer resolution and measurement speeed that are quite enough for SLR applications. Taking that into account, currently we focus our research activity on the compact design and advancing of other important performance characteristics of Riga Event Timers, such as their reliability, friendliness, hardware simplicity, and affordable price. In this report we present the current results of such activity and suppose that the next model of Event Timer could be offered already in the nearest future to cover a wider range of applications (including airborne ones).

Toshimichi Otsubo, Mihoko Kobayashi

New performance assessment for laser ranging stations

The performance of laser ranging stations in the world is assessed using a new concept "hit rate", which is the ratio of the actual data acquisition with respect to the possible opportunity. We provide station-by-station "hit rate" statistics from a number of different aspects, such as day/night, sunlit/umbra, elevation angle, etc.

Toshimichi Otsubo, Hiroo Kunimori, Hirotomo Noda, Hideo Hanada, Hiroshi Araki

Simulation of optical response for next-generation single-reflector LLR targets

Diffraction pattern is the key to design an efficient reflector for laser ranging. We numerically simulate it assuming a single, large-size retroreflector placed on the Moon, which suggests an asymmetric dihedral angle offset will be effective for future LLR targets.

Martin Ploner, Adrian Jaeggi, Johannes Utzinger

Skyguide and Flarm - 2 in-sky-laser-safety systems used at Zimmerwald

At the observatory Zimmerwald SLR measurements are performed in case of good weather conditions 24 hours per day. Most of the time the system is running in automatic mode without any interaction of an operator. Because of the little distance to the airport of Bern aeroplanes are flying sometimes in very low altitude over the station. During the flyover the SLR measurements have to be suspended automatically due to safety reasons. For this task two independent systems are installed. On the one hand the station computer is permanently connected to the air traffic control (Skyguide), on the other hand a traffic and collision-warning system (Flarm) is used. At first both systems will be introduced, afterwards the implementation in our SLR software will be presented. Depending on the weather conditions the lecture will end with an online demonstration of both systems.

Yin Zhiqiang, Han Yanben, R.Podesta, Liu Weidong, A. Pacheco, A.Ester

The SLR monitoring crustal movement in South America

In South America, there are several SLR stations. One of them is SLR station co-operated between German and Chile in Concepción City, and the equipment number is 7405 in the ILRS network. Northeast of the 7405 about 700 km, where is the Observatory of San Juan University of Argentina, there is another joint establishment of the SLR station by National Astronomical Observatories of China and San Juan University, and its number is 7406 in the ILRS network. The magnitude 8.8 earthquake struck near Maule of Chile on Feb. 27, 2010. It caused the movement of the entire city of Concepción by ~3-meter to the west, major damage and a tsunami near the epicenter at the same time. SLR-7405 (phi =-36°.843, lambda =-73°.025) is about 80km from epicenter (phi =-36 °.122, lambda =-72°.898) of Chile Ms8.8 earthquake, it was struck by the major earthquake and was fully operational again near May 2010. SLR-7406 (phi =-31°.509, lambda =-68°.623) is about 650km from the epicenter, its observation was not interrupted by the earthquake. The distance between SLR-7405 and SLR-7406 is about 716km. Combining the observations of these two SLR stations with global SLR observations, we calculate the geocentric coordinates of the two stations based on ITRF2000. The results show that the coordinates of the two stations have changed by varying degrees. SLR-7405 moved substantially towards the southwest with displacements of about 3.11, 0.52 and 0.49 m in X, Y, Z directions the corresponding displacements for SLR-7406 are about 0.02, 0.03 and 0.02 m, respectively. This solution, as an independent result derived from SLR observations, could provide an essential external check for other positioning techniques such as GPS. This work was supported by the Foundation of International Science and Technology Cooperation (2009DFB00130, 2010DFB53100), the External Cooperation Program of the Chinese Academy of Sciences (GJHZ200813).

Ivan Prochazka1, Jan Kodet1, Josef Blazej1, Petr Panek2

New technologies for sub – millimeter laser ranging

We are presenting the work progress and recent results in a development and construction of new technologies for sub – millimeter laser ranging and picosecond accuracy laser time transfer. The key hardware components: the Start detector and discriminator, the echo signal detector, the timing device and signal cablings were studied in detail. The new devices have been designed, built and tested in our lab. To minimize the systematic errors the photon counting approach has been selected. The ranging chain has been designed and optimized with a goal of single shot resolution of several millimeters and sub-millimeter normal points and overall system stability. The Start detector & discriminator are constructed as a single device to optimize their matching and maintain stability. The NPET timing system based on surface acoustic wave interpolator has a resolution of 800 fs and 4 fs long term stability. The echo detector is based on innovated SPAD detector optimized for high repetition Gate rate and minimal dark count rate. Both the detectors output signals have ultrafast slew rates < 200 ps / 1V. In connection to the 6 GHz bandwidth of the timing system inputs these fast slew rates improves the timing and temperature stability along with the RF interference immunity. The new low temperature drift signal cables have been selected, tested and used. The new hardware was tested in indoor calibration experiments. We have achieved the single shot resolution of 3 mm rms. The temperature and temporal stability of the individual components is excellent. The drift is typically below 200fs / K for each contributor. The overall temperature drift of the entire laser ranging chain is below 500 fs/ K. The long term stability of the ground target calibration is better than +/- 800 fs within 3 days. During this period the environment temperature changed by more than 4 degrees Celsius. In the sense of time deviation Tdev the stability of 300 fs was achieved. The presented components will enable to carry out laser ranging with sub-millimeter normal points stability and reproducibility. The accuracy of the “ranging machine” based on these devices will reach sub-mm values, as well. The concept and construction will be presented along with the achieved devices parameters.

K.Salminsh

A Second Look at Engineering Data Files

Engineering Data File(EDF) were proposed some time ago by the ILRS working group “Networks and Engineering” as an additional tool for for the station data quality control but due to the various reasons didn’t get widely used in SLR community. After introducing the Common Ranging Data(CRD) format which incorporated many of the EDF features it’s now an open question about EDF usage and it’s future. This paper compares both formats and discusses EDF future prospects including possible format changes and other scenarios.

R. Koenig, Y. Moon, L. Grunwaldt

On the Calibration of TanDEM-X Precise Baselines via SLR

The TanDEM-X mission strives for the generation of a digital elevation model of the Earth from SAR measurements taken by the TerraSAR-X and TanDEM-X satellites. As a requirement to achieve height accuracies of a few meters, the baseline between the two satellites needs to be known with millimeter accuracy. The baseline is operationally derived solely from the GPS measurements of the geodetic grade IGOR receivers onboard both satellites. Quality assessment is possible via comparison of results by independent solutions within GFZ and from outside institutions. It was foreseen from the beginning of the mission to also validate the GPS based baselines via SLR. As SLR data are sparse in time and space, they may not be used in operational baseline generation. However as the SLR technique may provide range measurements with millimeter accuracy, they may advantageously be used for validation of the GPS based baseline. With the newly developped hopping technique at Herstmonceux, a method to interleavingly range to both satellites without loss of time, and in use also at Potsdam, a means of measuring the differential motion of the two satellites is available. The approach for the baseline validation is described and results are given.

Liu Weidong et al.

Current situation and future of cooperative San Juan SLR station between Chinese-Argentinean

Liu Weidong1, Wang Hongqi1, Han Yanben1, Yin Zhiqiang1, Tian Lili1, Wang Zheng1, Zhao You1, Li Jinzeng1, Huang Dongping1, Wang Rui1, R.Podesta2, A. Pacheco2, A.Ester2, E. Actis2 1. National Astronomical Observatories, Chinese Academy of Sciences, Beijing, China, 2.Observatorio Astronomico Felix Aguilar, San Juan Uni., Argentina Email: wdliu@nao.cas.cn Add: National Astronomical Observatories, Chinese Academy of Sciences, 20A Datun Road, Chaoyang District, Beijing, China.
Abstract: The SLR-7406 station, which is established by the National Astronomical Observatories (NAOC) of Chinese Academy of Sciences (CAS) and the National University of San Juan (UNSJ) of Argentina, is unceasingly working in San Juan of Argentina. Its observations in 2009 keep the good status still, but the instrument met some problems of electric power, malfunction and weather in 2010. At present, the SLR is being upgraded for functions of kHz tracking and ranging operations into the daylight hours. The upgrade will be completed in the end of 2011 or the beginning of 2012. The situations of SLR-7406 will be introduced in the paper.

Mykhaylo Medvedsky

Ukrainian SLR network: corrent status and future

Ukrainian SLR network includes 4 stations. This is the next stations: Kiev, Lviv, Simeiz, Kazivili. Only 3 of them were in operating mode during 2010. We had some problems with hardware. All of our station had similar problems: not so good precision.

S. Dell'Agnello, G. O. Delle Monache, D. G. Currie, R. Vittori, C. Cantone, M. Garattini, A. Boni, M. Martini, C. Lops, N. Intaglietta, R. Tauraso, D. A. Arnold, M. R. Pearlman, G. Bianco et al

ETRUSCO-2: an ASI-INFN Project of Development and SCF-Test of GNSS Retroreflector Arrays (GRA) for Galileo and the GPS-3

With the INFN experiment "ETRUSCO (Extra Terrestrial Ranging to Unified Satellite COnstellations)" we used a new experimental apparatus, the "Satellite/lunar laser ranging Characterization Facility" (SCF) to characterize and model the detailed thermal behavior and the optical performance of LAGEOS and of cube corner GNSS Retroreflector Arrays (GRA) see [1], the SCF-Test. Our key experimental innovation is the concurrent measurement and modeling of the optical far field diffraction pattern (FFDP) and the temperature distribution of the SLR retroreflector payload under thermal conditions produced with a close-match solar simulator. The apparatus includes infrared cameras for non-invasive thermometry, thermal control and real-time movement of the payload to experimentally simulate satellite orientation on orbit with respect to both solar illumination and laser interrogation beams. These unique capabilities provide experimental validation of the space segment for SLR and lunar laser ranging (LLR). Evolutions or refinements of the SCF-Test and its key performance indicators (KPIs) are foreseen and will be outlined here. Uncoated retroreflectors with proper mounting can minimize thermal degradation and significantly increase the optical performance, and as such, are emerging as the recommended design for modern GNSS satellites. The COMPASS-M1, GLONASS-115 GNSS satellites use uncoated cubes. They provide better efficiency than those on GPS and GIOVE, including better daylight ranging performance. However, these retroreflectors were not characterized in the laboratory under space conditions prior to launch, so we have no basis to evaluate how well they were optimized for future GNSS satellites. SCF-Testing, under a non-disclosure agreement between INFN-LNF and the European Space Agency (ESA), of prototype uncoated cubes for the first four Galileo satellites to be launched (named "IOV", In-Orbit Validation satellites) is a major step forward. ESA has been requested the permission to present a selection of the results of the IOV SCF-Test. An SCF-Test performed on a LAGEOS engineering model retroreflector array provided by NASA, showed the good space performance on what is now a reference ILRS payload standard. The IOV and LAGEOS measurements demonstrated the effectiveness of the SCF-Test as an LRA diagnostic, optimization and validation tool in use by NASA, ESA and ASI. Keywords: LAGEOS, SLR, new space test, hollow retroreflectors. Corresponding author: Claudio Cantone, E-mail: Claudio.Cantone@lnf.infn.it, Phone: +39-06-94032730, Fax: +39-06-94032475 [1] Dell'Agnello, S., et al, Creation of the new industry-standard space test of laser retroreflectors for he GNSS, Adv. in Space Res. 47 (2011), 822-842. Full author list: S. Dell'Agnello1, G. O. Delle Monache1, D. G. Currie2, R. Vittori3, C. Cantone1, M. Garattini1, A. Boni1, M. Martini1, C. Lops1, N. Intaglietta1, R. Tauraso4, D. A. Arnold5, M. R. Pearlman5, G. Bianco6, S. Zerbini7, M. Maiello1, S. Berardi1, M. Tibuzzi1, J. F. McGarry8, C. Sciarretta6, V. Luceri6, T. W. Zagwodzki8 1 Laboratori Nazionali di Frascati (LNF) dell'INFN, Frascati (Rome), Italy 2 University of Maryland (UMD), College Park, MD, USA, 3 Aeronautica Militare Italiana (AMI) and Agenzia Spaziale Italiana (ASI), Rome, Italy 4 University of Rome "Tor Vergata" and INFN-LNF, Rome, Italy 5 Harvard-Smithsonian Center for Astrophysics (CfA), Cambridge, MA, USA 6 ASI, Centro di Geodesia Spaziale "G. Colombo" (ASI-CGS), Matera, Italy 7 University of Bologna, Bologna, Italy 8 NASA, Goddard Space Flight Center (GSCF), Greenbelt, MD, USA

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SCF-Test of the NASA-GSFC "LAGEOS Sector" and of a Hollow Retroreflector

With the INFN experiment "ETRUSCO (Extra Terrestrial Ranging to Unified Satellite COnstellations)" we used the "Satellite/lunar laser ranging Characterization Facility" (SCF, [1]) located at INFN-LNF in Frascati, Italy, to characterize and model the detailed thermal behavior and the optical performance of LAGEOS and of a prototype hollow cube corner retroreflector. Our key experimental innovation is the concurrent measurement and modeling of the optical far field diffraction pattern (FFDP) and the temperature distribution of the retroreflector payload under thermal conditions produced with a close-match solar simulator. The apparatus includes infrared cameras for non-invasive thermometry, thermal control and payload movement in front of the solar, infrared and laser interrogation windows of the SCF. These unique capabilities provide experimental validation of the space segment for Satellite and lunar laser ranging (SLR/LLR). Uncoated solid retroreflectors are deployed in what are now reference IRLS payload standards for SLR and LLR: LAGEOS and Apollo, respectively. Uncoated retroreflector with properly insulated mounting can minimize thermal degradation and significantly increase the optical performance, and as such, are emerging as the recommended design for modern GNSS satellites [1]. We report the results of an extensive, first-ever SCF-Test program performed on a LAGEOS engineering model retroreflector array provided by NASA (the "LAGEOS Sector"), which showed a good space performance. The LAGEOS sector measurements demonstrated the effectiveness of the SCF-Test as an SLR/LLR diagnostic, optimization and validation tool in use by NASA, ESA and ASI. These results form a database of measured thermal and optical key performance indicators (KPIs), which can then be used to improve the precise orbit determination of LAGEOS, for the benefit of all its important science applications. We also report the first-ever SCF-Test of a prototype hollow retroreflector provided by NASA, which showed an acceptable performance in the tested temperature range. These unprecedented results are relevant as a starting point for the development and validation of compact and (potentially) lightweight arrays of hollow laser retroreflectors with the size and the optical specifications to be selectively chosen depending on the specific space mission. Among these, is the development of hollow retroreflectors of large, or very large size now under consideration for LLR applications. Keywords: LAGEOS, hollow laser retroreflector, SLR, new space test. Corresponding author: Alessandro Boni, E-mail: Alessandro.Boni@lnf.infn.it, Phone: +39-06-94032741, Fax: +39-06-94032475 [1] Dell'Agnello, S., et al, Creation of the new industry-standard space test of laser retroreflectors for he GNSS, Adv. in Space Res. 47 (2011), 822-842.

R. March, G. Bellettini, R. Tauraso, S. Dell'Agnello

Constraining spacetime torsion with Lunar Laser Ranging, Mercury Radar Ranging, LAGEOS, next lunar surface missions and BepiColombo

We present the results of a search for new gravitational physics phenomena in terms of a specific theory with several unknown parameters that can be constrained by the experimental data from a variety of past, present and future space missions. We report experimental limits on parameters of the Riemann-Cartan theory of General Relativity (GR) with non-vanishing spacetime torsion. Starting from the parametrized torsion framework of Mao, Tegmark, Guth and Cabi [1], we have computed the secular corrections to the perihelion advance and to the orbital geodetic precession (GP) of a satellite, due to space-time torsion, under the assumption of slow motion in a spherically symmetric, weak field and considering autoparallel trajectories. We used two stalwarts of the experimental foundations of GR, the Moon geodetic precession measured by lunar laser ranging (LLR) and Mercury's perihelion advance measured by planetary radar ranging, to constrain linear combinations of the metric torsion parameters [2]. Exploiting the above LLR limits, we set also further (although less stringent) constraints on the frame-dragging torsion parameters using the LAGEOS data [3]. The LAGEOS constraints are complementary with those that can be set by Gravity Probe B [1], with the notable exception that the latter is more suitably designed to separate the frame-dragging torsion parameters from the metric torsion parameters. In the future more stringent limits can be set by: the continuing LLR of Apollo and Lunokhod Mercury's radar ranging data accumulated since 1990 by proposed lunar surface missions that will deploy new LLR payloads. The GP plays a special role because it can be measured using three very different instrumental techniques: LLR, Gravity Probe B gyroscopes and future BepiColombo's radio science. Around 2020, BepiColombo, an approved ESA Cornerstone mission to Mercury can improve the test of the perihelion advance and provide independent measurement of the GP (20"/cy vs 2"/cy for the Moon). Keywords: Riemann-Cartan spacetime, torsion, autoparallel trajectories, geodetic precession, perihelion advance, LLR, SLR, planetary radar ranging, LAGEOS, Gravity Probe B. Corresponding author: Simone Dell'Agnello, E-mail address: Simone.DellAgnello@lnf.infn.it, Phone: +39-06-94032730, Fax: +39-06-94032475 [1] Constraining torsion with Gravity Probe B, Y. Mao, M. Tegmark, A.H. Guth, S. Cabi, Phys. Rev. D 76, 1550 (2007). [2] Constraining spacetime torsion with the Moon and Mercury, R. March, G. Bellettini, R. Tauraso, S. Dell'Agnello, arXiv:1101.2789v2 [gr-qc], accepted for publication in Physical Review D. [3] Constraining spacetime torsion with LAGEOS, R. March, G. Bellettini, R. Tauraso, S. Dell'Agnello, arXiv:1101.2791v2 [gr-qc].

I. Ciufolini, A. Paolozzi, E. Pavlis, R. Koenig, J. Ries, R. Matzner, D. Arnold, R. Neubert, H. Neumayer, D. Rubincam, G. Sindoni, V. Slabinski, C. Paris, M. Ramiconi, D. Spano and C. Vendittozzi

LARES Laser Relativity Satellite

The LARES space experiment, by the Italian Space Agency (ASI), is based on the launch of a new laser ranged satellite, called LARES (LAser RElativity Satellite), planned at the end of 2011 using the new launch vehicle VEGA (provided by ESA). LARES will have an altitude of about 1450 km, orbital inclination of about 71.5 degrees and nearly zero eccentricity. The LARES satellite, combined with the satellites LAGEOS (launched by NASA) and LAGEOS 2 (built by ASI and launched by NASA and ASI) and using GRACE (a NASA and DLR mission) gravity field models, will allow a measurement of Earth's gravitomagnetic field and of the Lense-Thirring effect with an accuracy of a few percent. After a description of the LARES experiment and of its scientific goals, we describe some engineering aspects of the LARES mission.

Ben Greene, Craig Smith, Jizhang Sang [EOS] and Nasr A. Al-Sahhaf [KACST],
Atmospheric Refraction Correction Using Multiple Wavelength Laser Ranging

Multiple wavelength ranging has long been proposed as one means of verification of the refraction correction applied to precision laser range measurements. Early schemes seeking to determine a two-color range difference on a shot-by-shot basis were shown to be impractical by 1990. In 1986 [Laser Workshop: Greene & Herring] it was proposed that ranging normal point differences be used to determine the range diffrence in different wavelengths. Since then it has proven impossible to achieve individual normal point formal errors and true bias both below 3 ps rms as required for practical application. A new tracking configuration is proposed to achieve the required performance using existing technology already operational at some SLR sites.

Dandan Mao, David D. Rowlands, Jan F. McGarry, Maria T. Zuber, David E. Smith, Mark H. Torrence, Gregory A. Neumann, Erwan M. Mazarico,James Golder, Xiaoli Sun, Thomas W. Zagwodzki, John F. Cavanaugh
Laser Ranging Experiment on Lunar Reconnaissance Orbiter: Timing Determination and Orbit Constraints

Accurate ranges from Earth to the Lunar Reconnaissance Orbiter (LRO) spacecraft Laser Ranging (LR) system supplement the precision orbit determination (POD) of LRO. LRO is tracked by ten LR stations from the International Laser Ranging Service (ILRS), using H-maser, GPS-steered Rb, and standard Cs oscillators as reference clocks. The LR system routinely makes one-way range measurements via laser time-of-flight from Earth to LRO.Uplink photons are received by a telescope mounted on the high-gain antenna of LRO , transferred through a fiber optic cable to a Lunar Orbiter Laser Altimeter (LOLA) detector, and timed-tagged with respect to the spacecraft clock. The range from the LR Earth stations to LRO is derived from paired outgoing and received times. Accurate ranges can only be obtained after solving for both the spacecraft and ground station clock errors and removing temperature effects. The drift rate and aging rate of the LRO clock are calculated from data provided by the primary LR station, NASA's Next Generation Satellite Laser Ranging System (NGSLR) in Greenbelt, Maryland. The results confirm the LRO clock oscillator mid to long term stability measured during ground testing. These rates also agree well with those determined through POD. 10 cm- level LR observations are implemented in the POD procedure to form strong orbit constraints. We process the whole LRO mission with the radiometric and LR data, and estimate the impact of the LR data on the orbit reconstruction and accuracy.

Wu Bin, Lin Mingsen, Zhang Zhongping
Global SLR Tracking Support for HY-2 Satellite Precise Orbit Determination

The HY-2 Satellite,which will be launched in July 2011,is the first satellite with the microwave altimeter for State Oceanic Administration in China, remote sensing systems for the oceanic environmental monitoring and related scientific researches. For the application of the microwave altimeter measurement, the precise orbit determination (POD) of the satellite is a key support. For the POD of HY-2 satellite, it is equipped with Laser Retro Reflector Array (LRA), Doppler Orbitograph and Radio-positioning Integrated by Satellite (DORIS), Global positioning System (GPS). This paper introduces the method of POD of HY-2 satellite and call for ILRS to organize International Laser Ranging Tracking Network to observe the satellite, which is very important for environment monitoring and scientific research.

Peter Dunn and Mark Torrence
Measures of Network Performance

The ILRS web-site contains several pages which allow the user to monitor the performance of a station in the SLR network. The Global Report Card Tables provide quantitative and qualitative measures of the data collected and a consensus of the results from each Analysis Center can be used to identify lapses in performance at a station. Displays of meteorological data, calibration characteristics and observation precision can be inspected to help isolate aberrations which could adversely affect performance. An alternative view of a station’s behavior can also be found in the position time series determined by the Analysis Centers. The effects of systematic range or epoch time bias in the observations are visible in apparent latitude, longitude and height variations. The strong sensitivity of height determinations to range bias leads us to focus on that component in our analysis. We present a comparison between performance assessments from each of the Analysis Centers and provide examples of station position variations which can be system related or geophysically driven.

Matthew Wilkinson, Toby Shoobridge
Polarisation at SGF, Herstmonceux

An increasing need for laser ranging support of challenging missions, including the rising number of high-orbiting GNSS satellites, makes it essential that the throughput of each SLR system is fully optimised. To better understand potential losses in the SGF optical system, a series of experiments were designed and undertaken firstly explain certain observed phenomena during routine observing and secondly to increase the transmit and receive optical throughput. As a result of these experiments the dichroic filter, internal to the SLR telescope, was found to be performing well below specifications. A standard set-up was designed in the 2kHz laser bed to test all mirrors for their reflective properties and sensitivity to polarisation orientation. Working with a UK optics company a series of dichroic designs were tested and a dichroic was purchased with the required high transmission at 532nm and near-insensitivity to polarisation. This led to an improvement of more than 100% in satellite return signal at the Herstmonceux station and also, it is predicted, at the Graz station, when it later upgraded to a similar mirror.
The five mirrors in the coude chain underwent the same standard test in the kHz laser bed to determine their reflective-variability with polarisation orientation. The mirrors are of various ages and in various states of degradation. Only the newest of the mirrors showed near 100% reflectivity at all polarisations while other mirrors were found to reflect only 90-95% of the light at certain polarisations and also to partially depolarise the beam. Mirror 2 was found to convert the reflected beam to circular polarisation at certain orientations. An investigation into the emitted beam polarisation with respect to the telescope led to the discovery that the orientation moved with azimuth and elevation. This variation was modelled and can now be predicted in software as a function of telescope orientation. An upgrade in the laser bed is envisaged using a rotating half-wave plate that would control the emitted polarisation to a fixed value. Future tests to link return signal and incident polarisation at the satellite retro-reflector target are proposed.

V. Luceri, G. Bianco, C. Sciarretta
Improving ILRS products after an in-depth characterization of station biases

to be submitted asap...

Mark Davis
GNSS array performance prediction using ZEMAX

The uncoated cube corner performance is predicted at the nominal working and extreme incident angles using the ZEMAX optical design software.
The permutation of cube corner specification is explored and cross compared and validated with previous results. The result is a recommendation for designs which will be best for daytime SLR operations.

Graham Appleby, Vincenza Luceri and Toshimichi Otsubo
Improvements in Understanding Systematic Effects in Laser Ranging Observations

The laser ranging technique has the potential to make extremely precise measurements to retro-reflector clusters on orbiting satellites, with normal-point range precision at a level of 1mm for the best tracking stations of the ILRS. To realise a similar level of measurement accuracy to the mass-centres of the satellites and ultimately, through orbital analyses, in the determination of the origin and scale of the ITRF, requires accurate models for two key elements of the technique referring the range measurements to the centres of mass of the geodetic satellites and accurate determination of potential non-linearity in the time-of-flight measurements. Otsubo and Appleby previously published tracking-system-dependent centres-of-mass (CoM) corrections for the LAGEOS and ETALON satellites, which they found to vary across the ILRS network by up to 1 cm and 5 cm respectively. This work has been extended here to develop tables of CoM corrections, with reasonable error bounds, for each of the ILRS tracking stations and which take account of hardware and operational changes as the individual stations seek to improve their measurement precision. Work carried out previously into measurement and mitigation of non-linearity present in some time-of-flight devices highlighted both the magnitude of the effect which can reach 20mm and the potential of using newer, highly-accurate devices to post-calibrate historical laser data. We discuss case studies from a number of ILRS stations and highlight the improvements that can be achieved. However, earlier expectations that this work could be applied to carry out similar absolute calibration of the ten or so mainly European ILRS systems that have used similar electronic devices proved to be too optimistic, but the work does serve as an indication of the magnitude of this source of potential systematic effects.

Michael Pearlman, Erricos Pavlis, Zuheir Altamini, and Carey Noll

The Global Geodetic Observing System: Space Geodesy Networks for the Future

ABSTRACT BODY: Ground-based networks of co-located space geodetic techniques (VLBI, SLR, GNSS, DORIS) are the basis for the development and maintenance of the International Terrestrial Reference Frame (ITRF), which is our metric of reference for measurements of global change. The Global Geodetic Observing System (GGOS) of the International Association of Geodesy (IAG) has established a task to develop a strategy to design, integrate and maintain the fundamental geodetic network and supporting infrastructure in a sustainable way to satisfy the long-term requirements for the reference frame. The GGOS goal is an origin definition at 1 mm or better and a temporal stability on the order of 0.1 mm/y, with similar numbers for the scale and orientation components. These goals are based on scientific requirements to address sea level rise with confidence, but other applications are not far behind. Recent studies including one by the US National Research Council has strongly stated the need and the urgency for the fundamental space geodesy network. Simulations are underway to examining accuracies for origin, scale and orientation of the resulting ITRF based on various network designs and system performance to determine the optimal global network to achieve this goal. To date these simulations indicate that 24 – 32 co-located stations are adequate to define the reference frame and a more dense GNSS and DORIS network will be required to distribute the reference frame to users anywhere on Earth. Stations in the new global network will require geologically stable sites with good weather, established infrastructure, and local support and personnel. GGOS will seek groups that are interested in participation. GGOS intends to issues a Call for Participation of groups that would like to contribute in the network implementation and operation. Some examples of integrated stations currently in operation or under development will be presented. We will examine necessary conditions and challenges in designing a co-location station.

A.L.Sokolov, M.A.Sadovnikov, V.D.Shargorodsky, V.P.Vasiliev

Far-field diffraction pattern analysis of cube corner reflectors

One of the most effective ways to modify and optimize the cube corner retroreflector (CCR) far-field diffraction pattern (FFDP) is to control the phase shifts of vector E orthogonal components introduced by coating on the CCR reflecting surfaces.
One way to modify the FFDP is applying various kinds of coating on the reflecting surface. In addition to traditional cases of metallic coating and total internal reflection, various dielectric interference coatings have been investigated, providing smooth variation of the phase shift and thus controlling the angular width and shape of the pattern. Due to redistribution of power in the reflected beam from center to periphery, the CCR with non-metallic coatings forms a more favorable FFDP for the GLONASS system then metal-coated CCR. The best pattern occurs in case of phase shift close to zero: there is a peripheral ring of intensity consisting of six spots at the nearly optimum angular distance, angular distance without a central spot.
Another way to optimize the pattern is to make a gradient coating on the CCR input face and to apply a metal coating on the reflecting surfaces. Instead of the Airy diffraction pattern several rings are then observed the brightest ring is at a distance almost optimum for the GLONASS system.

V.P. Vasiliev,V.D. Shargorodskiy, N.N. Parkhomenko

BLITS: The first autonomous zero-signature satellite in orbit

The BLITS satellite has been designed as an experimental zero-signature SLR target, providing target error value of less than 0.1 mm. It is 17-cm-diameter glass ball lens made of two different types of glass and partly covered by a metal coating, so that it in fact a retroreflector with a cross-section of about 105 sq m at a wavelength of 532 nm, an access solid angle of about 2.
The satellite was launched into a circular 835-km-high orbit September 21, 2009, and since then most of the global SLR network stations provide regular ranging data confirming the basic design parameters. The satellite spin period is about 5.6 sec, and remains constant during the 20 months of operation.
A modified version of this satellite is under design, to be launched into a higher orbit where the atmosphere drag is much less than at the present orbit height.

V.L. Moshkov, M.A. Sadovnikov, A.A. Fedotov and V.D. Shargorodsky

Experimental Laser System for Monitoring of GLONASS Time/Frequency Synchronization

A laser-based system is presented for high-accuracy comparison of GLONASS on-board and on-ground clocks, as well as for mutual synchronization of on-ground clocks located at distant points of territory. The system operation principle is based on comparison of two-way time-of-flight measurement data attained by satellite laser ranging (SLR) of the GLONASS spacecraft equipped with optical retroreflrctor arrays, and data of one-way laser measurements using on-board photoreceivers. Methods and parameters are presented of on-board and on-ground equipment calibration, as well as a measurement data processing algorithm providing simultaneous operation of multiple laser stations observing the GLONASS spacecraft. The expected measurement accuracy is also evaluated.

V.P.Vasiliev, V.D. Shargorodsky, V.B.Burmistrov, N.N. Parkhomenko

Russian Laser Ranging Network: current status and perspectives

The Russian Laser Ranging Network includes 4 stations participating in the ILRS operation: three of them are within the Russian territory – the Altay Optical and Laser Center, the station near Komsomolsk-on-Amur, and the station in the Northern Caucasus – while the fourth is on the Baikonur launching site, in Kazakhstan. It is intended to create three SLR/VLBI collocation points – in the Northern Caucasus, near Irkutsk, and near St. Petersburg. It is also planned to create two stations outside the Russian Federation, using serially produced compact SLR systems inter-state agreements are currently in preparation with Israel, Chile, and SAR. A distributed control network is now under development, providing centralized control of operation of all Russian SLR stations. The control center should provide tracking planning and spacecraft orbit predictions, SLR network monitoring, and measurement date collection.

Stanislaw Schillak

The estimation of the SLR data by analysis centers and possibility of closely cooperation between stations and analysts

The paper presents the list of parameters which can be used to estimation of the quality of the SLR data for each station: long term stability (range bias variation), RMS of fit and stability of station coordinates. The results of the determination of these parameters in the long term period (from 1994 up to 2008) for the select few stations are presented in the five years blocks. Some examples of time series are added. The current control of the one or two parameters in the graphic form for each station month by month can to help in the fast information for sites and analysts about data problem. The author propose control of N, E, U components in the one month periods for all stations. GPS coordinates transmitted to the SLR reference point for the same epochs can be added. Signal to station can be send if the new point or points statistically differs from the current population of this site. This method enable not only control of each station but also permits to find very quickly the source of bias and estimation of the effect of the new equipment and methods on site, also new analysis models and parameters. Generally, we have information about current quality of the SLR data and how far we are from magic 1 mm.

Georg Kirchner, Franz Koidl

Measuring sub-mm range differences caused by polarization effects

Linearly polarized laser light reflected by uncoated retro-reflectors on fast moving satellites shows slightly different delays, depending on the angle between polarization plane and the satellite' s orbital velocity vector. Although the effect is small – in the [sub-]millimetre range - it can be measured, and should be corrected at the stations alternatively, the laser polarization can be changed from linear to circular with a simple lambda/4 plate.

Georg Kirchner, Franz Koidl, Farhat Iqbal

Graz 10 kHz SLR

With a few modifications, we are upgrading the Graz 2 kHz SLR system to 10 kHz repetition rate. The High-Q-Laser was slightly modified, to deliver not only the standard 'strong'2 kHz / 400 µJ pulses, but also additional 'weak' 80 µJ pulses between, for a total repetition rate of up to 10 kHz. While our standard Daussault-based event timer – which is limited to 2.5 kHz maximum – receives only the 'strong' laser start pulses and their returns, the full 10 kHz start and stop pulses are timed with a Riga ET.

Mark Davis, Ray Burris, Linda Thomas

Divergence Estimation procedures

An expermental procedure to measure beam divergence at the stations is presented. This utilized the ratio of beam sizes on satellites with known cross section. Extrapolation to common metrics describing beam shape is discussed.

M. Schmidt, N. Graf, H. Huber,R. Kelnberger, J. Aus der Au

High-energy picosecond laser systems between 10 Hz and 2 kHz for next-generation laser ranging

We will present our latest high-pulse-energy picosecond laser platform ranging from 1.5 mJ at 2 kHz and 3 mJ at 1 kHz up to 1 Joule at 10 Hz at a wavelength of 1 µm.
The application of high-energy picosecond laser systems is well established in satellite geodesy. While the high energies ensure that high earth orbiting satellites can in principle be measured, the low repetition rates of these systems require rather long acquisition times to ensure good signal-to-noise ratio. In addition, more and more stations move from night-time observation only to both night- and daylight observation to increase the number of satellite passes/observations. However, daylight heavily increases background noise, requiring even longer observation times.
While high energy is necessary to reach the high earth orbiting satellites (or even the moon), low earth orbiting satellites can be measured with reduced energy, allowing in principle for higher repetition and therefore also higher data rates; this leads to a drastically improved accuracy for precise orbit determination. To improve the results significantly both for low AND high earth orbiting satellites, a versatile and stable high-energy picosecond laser platform is needed that can be easily upgraded to different operation modes. Our flexible design – based on the field-proven High Q Laser picoREGEN series - allows for more than 3 mJ at 1 kHz and 1.5 mJ at 2 kHz in the infrared wavelength region around 1064-nm. This corresponds to up to 1.2 mJ at 1 kHz and 0.7 mJ at 2 kHz in the Green wavelength range, respectively. For even higher energies, we use either lamp- or diode-pumped booster modules based on the monolithic SpitLight SLM series from Innolas Laser. With such a combination, we are able to produce pulse energies of more than 1 J at 10 Hz. In a next step, we aim at pulse energies in the tens of mJ at 1 kHz.