Session Summaries

SESSION SUMMARIES

On the last day of the conference, each of the session chairman were asked to summarize, in vu-graph form, major conclusions or observations distilled from the individual talks within their sessions. These vu-graphs are reproduced in the following pages (with some minor editing on my part to improve clarity and eliminate duplication) along with comments made by workshop participants following the formal presentation by the session chairman. I have made no attempt in this record to identify the source of individual comments.

John Degnan

SCIENTIFIC APPLICATIONS AND MEASUREMENTS REQUIREMENTS

Bob Schutz/Richard Eanes

The science applications of SLR were summarized as follows:

Mean Gravity Field

Gravity field improvements - GEM-T3, TIG2, GRIM

Gravity Field Fluctuations/Variability

Longterm J_2
18.6 year tide
seasonal correlation with atmosphere

Terrestrial Reference Frame/Earth Orientation

- Polar Motion
  - 0.5 milliarcsecond routine accuracy on X and Y for 3 day values
  - 1 day series available
- Rapid Service UT1
  - Possible use of ETALON to extend to higher frequencies
- Motion of network relative to center of mass of Earth/oceans/atmosphere
  - RMS 1 cm in X,Y; 3 cm in Z
- Relative Station Positions
  - Best: 0.5 cm
  - Typical: 1-2 cm
- Relative Motion
  - Horizontal velocities: 1 to 10 mm/yr for 40 or 50 sites
  - Vertical motions: Available for the "best-behaved sites"

Ocean Surface Study with SLR tracked altimetric satellites

ERS-1 orbits controlled by laser tracking

Time Transfer

Preliminary LASSO results from Grasse and MLRS < 100 ps

SCIENCE GOALS AND REQUIREMENTS

GOALS	REQUIREMENTS
Mean Gravity Field 2 cm LAGEOS <10 cm TOPEX,AJISAI, STARLETTE	Better control of systematic error Better global coverage Satellite campaigns Altimetric satellite tracking
Gravity Field Variations	Continued operations by stable network Multiple targets
Earth Orientation	Continued operations by core network Better coverage of sidereal day Multiple targets
Terrestrial Reference Frame	Continued operations by core network Subcentimeter control of systematics Better Southern Hemisphere coverage
Ocean Topography	More ERS-1 coverage Good TOPEX support
Time Transfer	More attempts with Meteor-P2 Wider participation CRL,OGO

COMMENTS

(1) The breadth of SLR applications is not adequately known in the scientific community.

(2) It is essential that instrumental errors in SLR be minimized at a small level because the scientific analyses based on SLR could be either misled or limited by such systematics.

(3) The global SLR community needs to assist all participants to reach a uniform level of performance and a common operational view.

(4) Developments in two color techniques are important, but the competitiveness, and perhaps survival, of SLR will not be accomplished solely on those efforts. We, as a community, must find the right balance between new developments and conducting operations, i.e. regular and high quality tracking.

(5) SLR should play to its strengths, e.g. gravity and vertical positioning.

(6) The community should establish ties to Global Change.

(7) Carroll Alley reminded the group that lunar ranging was developed to support relativistic and fundamental physics studies whereas the present program appears to be tightly tied to Earth science.

TIMELY ISSUES
Andrew Sinclair

SATELLITE SIGNATURE

Issue has been raised previously
Subject is controversial
Effects of signature have been clearly established by two papers
Signature primarily affects single photon systems
Has consequences for data screening and center-of-mass computations

DATA SCREENING

Simple 3 sigma screening not adequate for skew data
Two methods
- adaptive median filtering
- determine bias of mean from peak

Tasks
- write up details
- develop subroutine for assessment
- CSTG Working Group to consider extra information in data format

MISSION PLANNING

Interleaving of passes

LASER TECHNOLOGY
Helena Jelinkova

LASER TRANSMITTER SUMMARY

Wavelength	0.53 μm (1.06 μm) Nd:YAG
Length of pulses	30 psec to 400 psec
Energy	20 mJ to 300 mJ
Repetition Rate	2 to 10 Hz
Maintenance	1 alignment/pass to 1 alignment/0.5 year (Improving)

GOALS AND ISSUES

Multipulse Transmitter (to maximize energy usage)

- Semitrain
- Full train

Multiwavelength Transmitters

- Doubled and third harmonic
- Stokes and Anti-stokes
- New Active Materials

10 picosecond pulses compression by

- Brillouin + Raman
- Raman
- Negative Feedback
- Colliding Pulse Method

Space use of Diode-pumped lasers

- High efficiency
- Long life

COMMENTS

Billion shot flashlamps have been demonstrated but lamp failure is catastrophic whereas diode arrays degrade.

EPOCH AND EVENT TIMING
Ben Greene

SUMMARY

Streak cameras presently at 2 psec; future resolution and accuracy = 0.5 psec

Electronic timing systems presently at 3 psec; future 1 psec resolution and accuracy

Both technologies are approximating useful levels for 5 mm two color ranging

COMMENTS

General agreement on first bullet

Disagreement on second bullet although new technologies (e.g. GaAs) are becoming available

There has been insufficient vision on the part of the funding agencies in developing this technology

DETECTOR TECHNOLOGY
Thomas Varghese

SUMMARY

High speed single photoelectron detectors (SPADS)

High speed, low jitter microchannel plate photomultipliers (230 psec) benefit from effects

Streak cameras represent the leading edge of high accuracy

COMMENTS

SPADs are useful for lunar ranging

Subcentimeter level ranging has been established on a global level and we are approaching millimeter accuracies

CALIBRATION TECHNIQUES/TARGETS
Jean Gaignebet

SUMMARY

Recommended formation of a study group for the design of improved laser retroreflector arrays. G. Lund offered to chair.

There is a need to monitor and keep records on individual SLR stations and configurations.

An interesting corner cube design based on the Fizeau effect was presented by V. Shargorodsky of Russia.

MULTIWAVELENGTH RANGING/STREAK CAMERAS
Karel Hamal

EXPECTED GOALS	ACHIEVED
Optimum wavelength pair	Preliminary
Two Color Ranging MCP	Not yet
MCP	Some progress
SPAD	single color
Streak Camera	
Optimum Satellite & Fizeau Cubes	Promising
Figure of Merit	Controversial
Laser	Stokes/Antistokes Cr:LiSAF

COMMENTS

Raman systems will never have high figure of merit; frequency shift is relatively small.

A Fizeau target is already in a 620 Km orbit. V. Shargorodsky will send the satellite orbit parameters by telex to the Smithsonian Astrophysical Observatory.

Russians will fly a new target at 1000 Km altitude by the end of the year. Only one cube (Fizeau) is visible at a time.

SLR DATA ANALYSIS/MODEL ERRORS

Ron Kolenkiewicz, Richard Eanes

Dynamic, Semi-dynamic, and Geometric Analyses
Orbital models and nonconservative forces

With increased data precision, the effect of time-varying gravity on the satellites is important, and the tracking site motions due to ocean and atmospheric loading needs to be considered.

Geopotential at the one to two level still exist for LAGEOS. More high quality data should improve this below one cm - especially at new sites or recently improved sites.

Systematic errors in the data due to satellite signature and calibration errors must be reduced to less than one cm.

A large non-gravitational signal affecting the LAGEOS eccentricity and perigee at the few meter level has been detected by the analysis groups at GSFC and UT/CSR. The effect was especially large in 1989 and 1991. The current models that explain the along -track or "drag" acceleration on LAGEOS do not explain the eccentricity anomaly. We need a physical explanation for the once per revolution accelerations on LAGEOS.

An attempt should be made to improve the atmospheric correction for single wavelength SLR by means of acoustic and/or lidar sounding of the atmospheric temperature profile.

There is a need for improved second generation SLR satellites with much more stable and deterministic center-of-mass corrections.

With the increased altitude and number of geodetic satellites (e.g., ETALONS and LAGEOS II), the use of geometric analysis to obtain geophysical parameters should be utilized.

Partly random seasonal fluctuations in the mass distribution of the atmosphere limit our ability to ever completely eliminate gravitational model error. Rather we must consider the error as an opportunity and track the fluctuations over time.

Obtaining successful results for the variations of the vertical component of station positions requires that biases in the SLR data be controlled much better than they have in the recent past. Solutions for range bias show some interesting regionally correlated signals that are evidence of either height variations or of some other model defect that is unknown. However, there are also large sudden changes in the biases that are certainly due to problems at the stations.

OPERATIONAL SOFTWARE DEVELOPMENTS
Georg Kirchner

Software developments are freely exchanged between groups.

Community relies on exchanges, standardized formats, etc.

Conclusions from the Splinter Meeting:

> Transputer-based SLR control system has no disadvantages (according to the engineer who built it)
>
> Stations should transmit full rate data by E-mail in compressed form
>
> The community should investigate possible standardization of SLR operating and control systems.

LUNAR LASER RANGING
Christian Veillet

The loss of Haleakala to the LLR community is "very unfortunate".

There are presently only two regularly working lunar stations (CERGA and MLRS).

LLR needs lots of observations in order to adequately support the science.

LLR is important to lunar studies and fundamental physics.

LLR pushes individual station performance to the limit.

LLR stations could range to cubes in lunar orbit.

FIXED STATION UPGRADES/DEVELOPMENTS
John Degnan

There appear to be at least two hardware configurations capable of subcentimeter range accuracy:

150 psec pulse, MCP/PMT, and constant fraction discriminator

35 psec pulse, SPAD

There is a continued international interest in SLR as evidenced by the development of new stations and continued upgrades of established stations

There is a new emphasis on higher degree of automation to drive down operational costs.

Countries continue to sponsor stations outside their national borders (e.g., Poland in Tunisia) which will help to provide better global coverage.

MOBILE SYSTEM UPGRADES/DEVELOPMENTS

Erik Vermaat

Highly transportable systems are now demonstrating the same state-of-the-art quality as larger stations (< 10 mm)

Mobile stations typically operate in the single or few photoelectron regime

Mobile stations are becoming more miniaturized as evidenced by the latest system, the French Transportable Laser System (FTLRS).

Automation is a major driver in reducing costs.

Levels of standardization is a key issue.