Laser Ranging at Planetary Distances
From SLR2000

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Two Separate Experiments

- **Asynchronous laser transponder (2-way):**
  - Goddard in-house funded R&D effort (2\textsuperscript{nd} year of 2-year effort): Phil Dabney, PI.
  - Goals are:
    (i) to demonstrate acquisition and tracking using single-photon detection, and
    (ii) recover range and time bias using 2-way transponder data.

- **Laser ranging to LRO (1-way):**
  - Part of LRO mission.
  - Operational experiment Fall 2008 through January 2010.
  - Purpose is to provide laser ranges at rate of one per second with precision of < 10 cm.
Overview of Asynchronous Transponder Experiment

J. Degnan concept

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Transponder Upgrades to SLR2000
(Transmit 532/Receive 1064nm)

• Additional 2’x 3’ table space (optical breadboard) has been added
• Addition of dichroic beam splitter (532/1064nm) for receive channel
• Beam reduction optics, narrow BPF, and a fiber optic delivery to the 1064nm photodetector
• Perkin Elmer model SPCM-AQR-14 photodetector (QE ~2%)
• Additional discriminator and event timer channel

SLR2000 Telescope

532nm Laser  532nm QMCP

T/R Switch

Dichroic Beamsplitter

1064nm BPF

60 micron fiber

Perkin Elmer phototube

Discriminator

Changes at SLR2000 for Transponder

Existing SLR2000 transceiver breadboard:
Table space is unavailable for any additional optical components/experiments

Additional transceiver breadboard is contour-cut to fit mount and allow walkway clearance.
New instrumentation at S2K

Single Photon Counting Modules (SPCM):
- Perkin Elmer SPCM-ACQ(4):
  - Up to 4 channels (spares + possible NIR quadrant implementation).
  - <500 psec jitter (<250 psec is optional)
  - ~2% photon detection efficiency (PDE) @ 1064 nm
  - ~45% PDE @ 532 nm
- Micro-Photon Devices PDM (“all 532nm” transponder-future):
  - Superior timing jitter: <50 psec.
  - Negligible PDE @ 1064 nm
  - ~40% PDE @ 532 nm
New instrumentation at S2K

- Photo of S2K transponder station receiver channel:
  - Dichroic Beam-splitter (Harmonic)
  - 5 x Beam Expander
  - 8 mm fl fiber optic collimator
  - Fiber optic feed to detector(s).
  - SPCM detector

- Transponder station SPCM Input to S2K Event Timer.

- Transponder terminal (1.2 m SLR) clock reference input to S2K Event Timer.

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Transponder Upgrades to 1.2m Telescope
(Receive 532/Transmit 1064nm)

• Quadrant detector (Hamamatsu metal channel dynode) ungated single photon detection of SLR2000 returns
• Four channel discriminator and four Event Timer channels
• Continuum Inlite Il-50 laser operating at 1064nm
• BPF for 532nm and 1064 blocking filter
• Aperture share Transmit/Receive
Experiment Approach

- Demonstrate closed loop tracking at 1.2 meter telescope on SLR2000 green returns.

- Ensure knowledge of true clock offsets with cable between systems.

- Introduce biases and frequency offsets at 1.2 meter telescope clock using programmable delay generator.

- Solve for ranges and time biases and verify using known satellite orbits and known clock offsets.
Data Analysis: 2-Way Asynchronous Transponder

\[
\begin{align*}
Su + Rp &= Tu - (R-Rp) = p_1 + p_2 t - p_3 - p_4 t - p_5 t^2 \\
Sd - Rp &= Td + (R-Rp) = p_1 + p_2 t + p_3 + p_4 t + p_5 t^2
\end{align*}
\]

Where:
- \( Su \) = transmit time (S2K)
- \( Sd \) = receive time (S2K)
- \( Tu \) = receive time (1.2m)
- \( Td \) = transmit time (1.2m)

And interpolate to set \( Tu = Td \)

\( Rp \) = predicted range
\( R \) = measured range
\( t \) = time at 1.2 meter telescope

\( p_1, p_2 \) model clock bias and drift
\( p_3, p_4, p_5 \) model range error

(Following G. Neumann MLA-Earthlink solution)
Preliminary Testing Performed: Receive-Only Transponder Simulation

MOBLAS-7 transmit

MOBLAS-7 receive

SLR2000 receive

timing signal
Effect of estimated parameters on Lageos2 residuals from SLR2000 and MOB7 on September 22, 2006

A priori fit includes position error

Estimate clock bias 0.2 msec: absorbs position error and improves fit

MOB7 Xmit & Rcv defines the orbit along the zero line
Effect of estimated parameters on Lageos2 residuals from SLR2000 and MOB7 on September 22, 2006

A priori fit includes position error

Estimate relative position by 60 cm: fit reduced significantly
Status & Timeline for Asynchronous Transponder

- 1.2 meter telescope hardware & software mods completed
- Modifications at SLR2000 nearing completion
- Both systems have tracked green returns from MOBLAS-7
- Demonstration of closed-loop tracking at 1.2 meter: fall 2006
- Two-way ranging with both systems begins: early 2007
- First data analysis: Spring 2007
- Experiment completed: Fall 2007
LRO-LR Objectives

- Use an Earth-to-LRO laser link to achieve the mission precision orbit determination requirement.

- Simulations of the first 3 months of the LRO mission, and experience at Mars, suggest the addition of a precision range to the S-band tracking and inclusion of LOLA altimeter data can provide an improved model of the gravity field adequate for LRO orbit reconstruction.

Measurement Requirements

- Provide relative range measurements to LRO spacecraft at <10-cm precision, at 1 Hz.

- Maintain range stability to ±1 m over 1 hour.
Changes to SLR2000 for LRO-LR

- New 28Hz diode pumped Nd:YAG master oscillator power amplifier laser:
  - up to 50 mJ per pulse at 532nm
  - 6-8 nsec pulse
  - turn-key system - projected lifetime of > 1 year of continuous use.
- Additional optical table space added for laser.
- Removable kinematic mirror mount added to launch LRO transmit beam, and ensure easy transition between SLR and LRO lasers.
- Aircraft radar added to system (due to non-eyesafe laser).
Software changes for LRO-LR & Transponder

- Predictions for transponder targets is being added (Ricklefs / Rowlands)

- Increased # digits in recording of laser fire time (LSB now = 1 psec)

- Parameters and code to ensure the transition between SLR and LRO is transparent to operator:
  - Point-ahead for LRO and behind for SLR
  - Log all fires for LRO, only returns for SLR
  - Control laser fire via RGG for LRO, control PRF for SLR
  - Turn off signal processing and searching for LRO
  - Ensure clouds do not cause software to change target from LRO

- Changes required for Transponder and SLR to co-exist:
  - Added flags and Sitefile parameters for different wavelengths
  - Added separate data path for transponder events
Benefits of Transponder Experiments to SLR

- Modifications to SLR2000 has added diagnostic capability to help resolve SLR system problems.

- Funded 2 shift single operator available in 2009 for SLR (~ one hour between LRO passes).

- Additional funding for making SLR2000 operational, and a critical set of spares.

- High energy 532nm laser capable of demonstrating HEO tracking (until we can purchase new laser for SLR).


- Demonstrated tracking capability which opens the door for future work.

- Proven system that can track Earth Science and Planetary targets.
Summary

- Transponder experiments will extend capabilities of SLR2000 and demonstrate the system’s ability to do planetary ranging.

- Earth orbiting SLR and planetary transponder ranging can co-exist and transitioning between the two will be seamless.

- In-house Transponder experiment will complete in late 2007. LRO-LR experiment will run from Fall 2008 through 2009.

- SLR2000 completion will not be impacted by transponder work and SLR tracking to earth orbiting satellites will continue throughout 2007, 2008, 2009.