Laser Ranging at Planetary Distances From SLR2000

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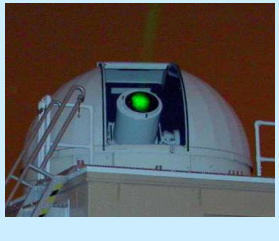
Laser Ranging Workshop
Canberra 2006

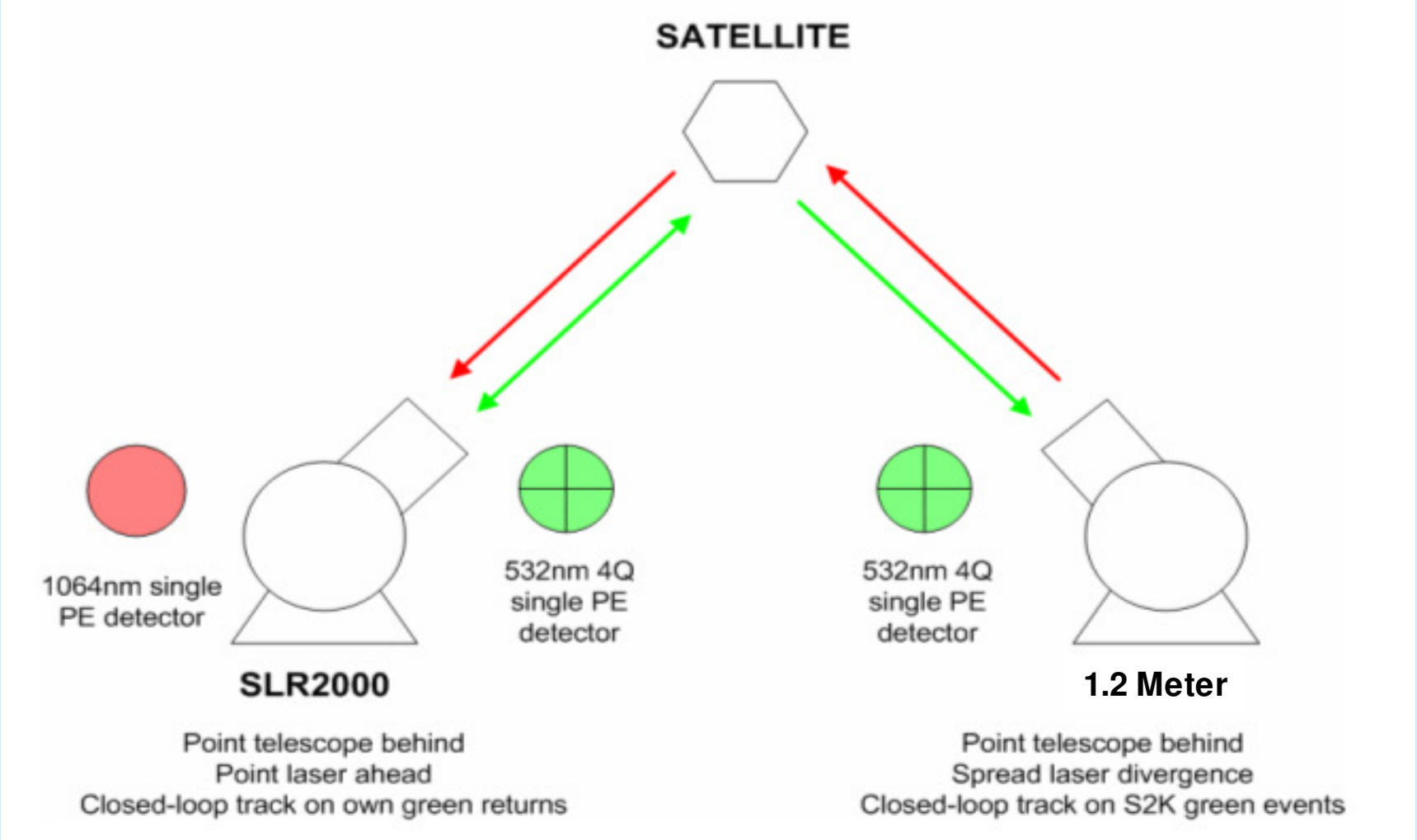


Two Separate Experiments

- **Asynchronous laser transponder (2-way):**
  - Goddard in-house funded R&D effort (2nd 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

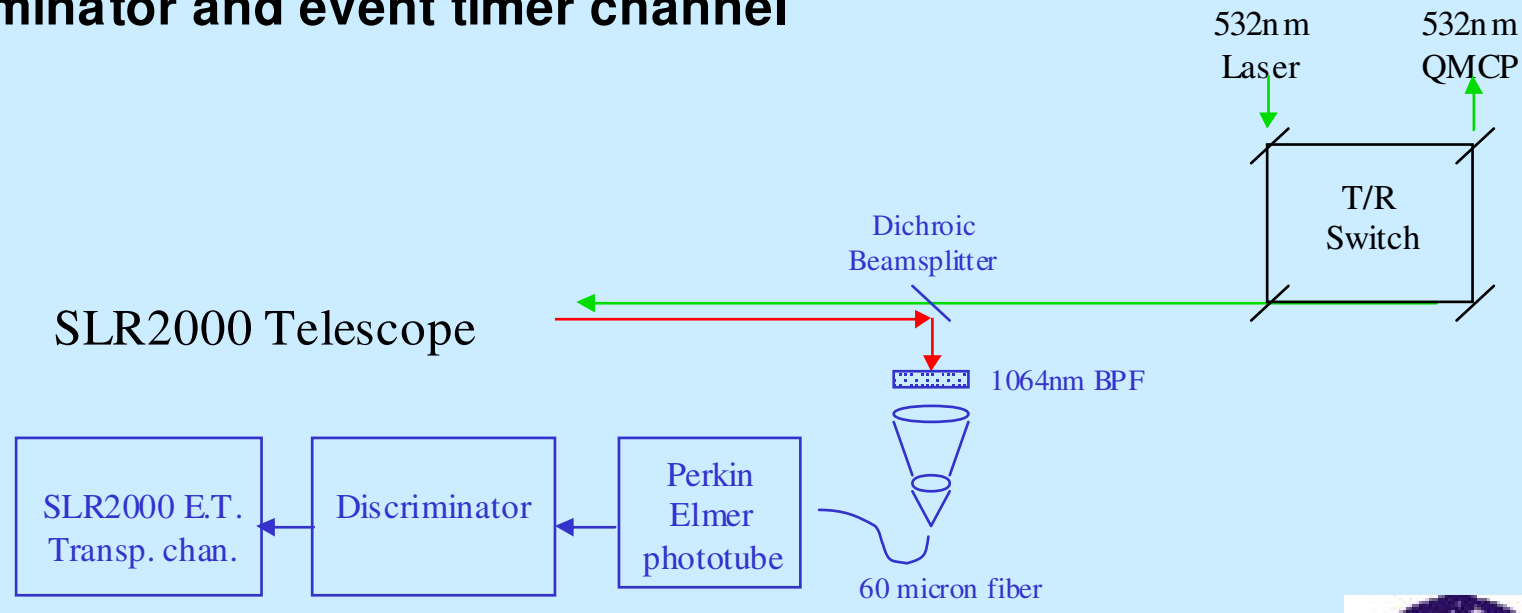


J. Degnan concept

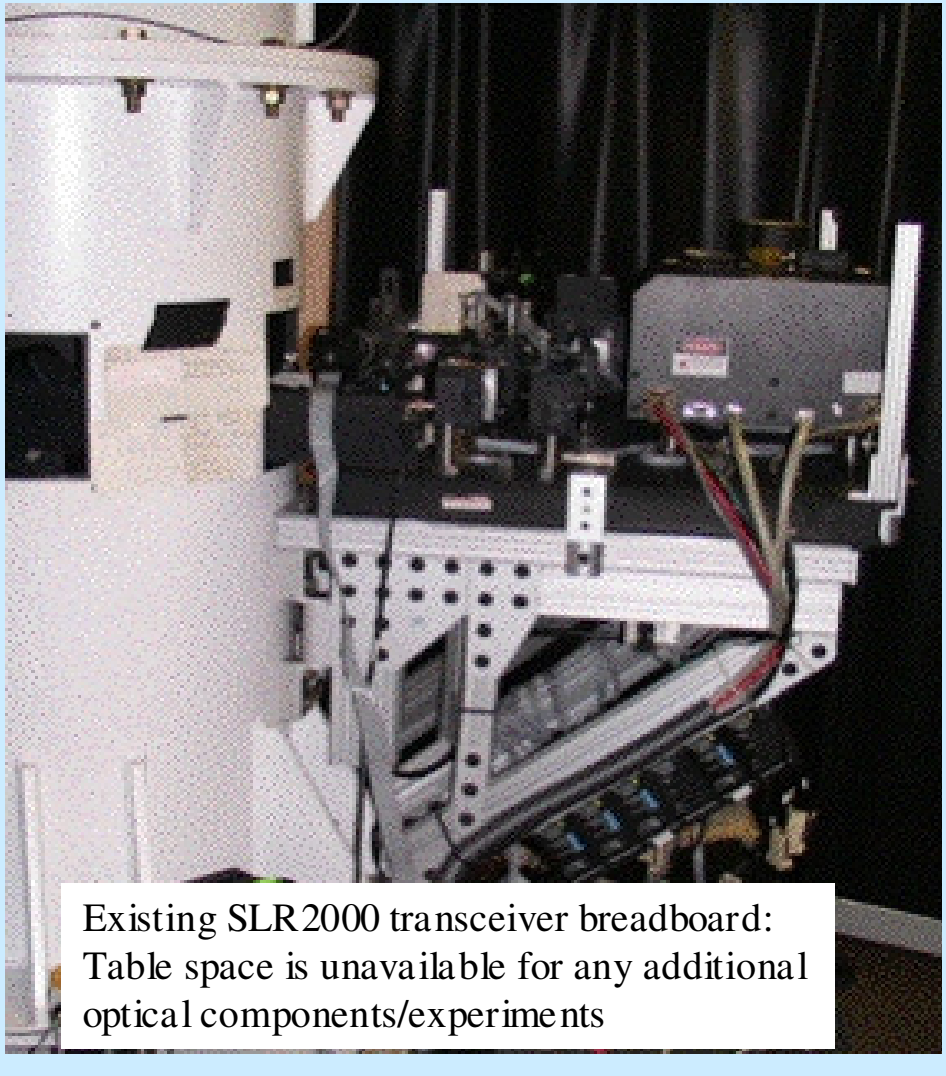
Transponder Upgrades to SLR2000

(Transmit 532/Receive 1064nm)

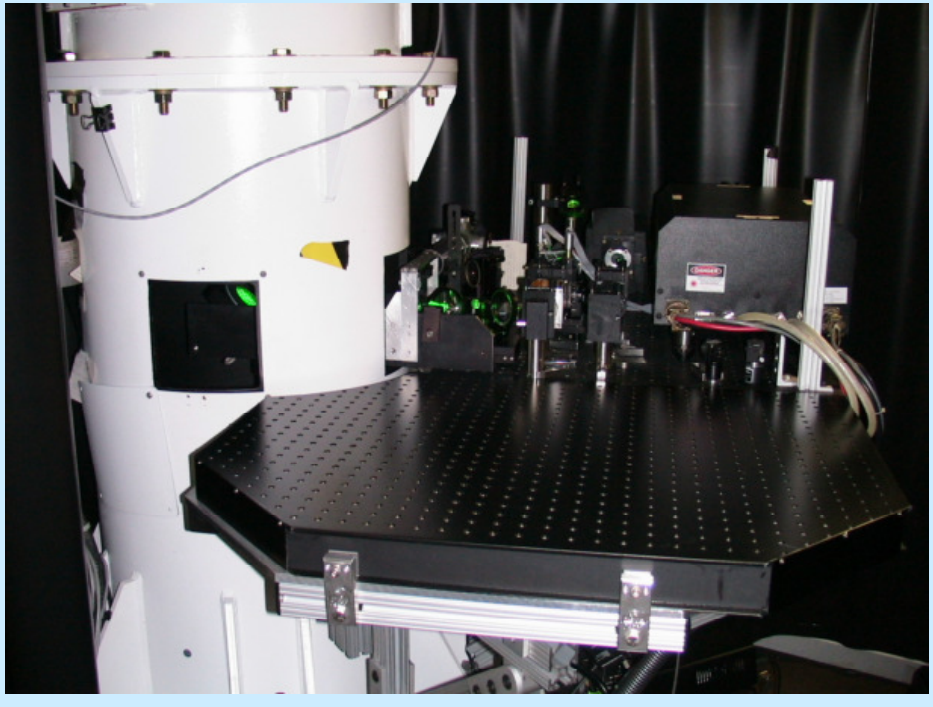
- **Additional 2'x 3' table space (optical breadboard) has been added**
- **Addition of dichroic beam splitter (532/1064nm) for receive channel**
- **Beam reduction optics, narrow BPF, and a fiber optic delivery to the 1064nm photodetector**
- **Perkin Elmer model SPCM-AQR-14 photodetector (QE ~2%)**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



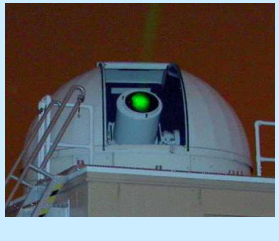
Changes at SLR2000 for Transponder



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.



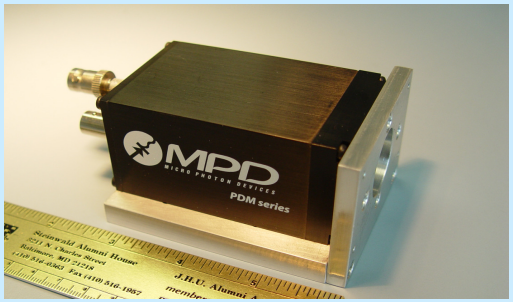
New instrumentation at S2K

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

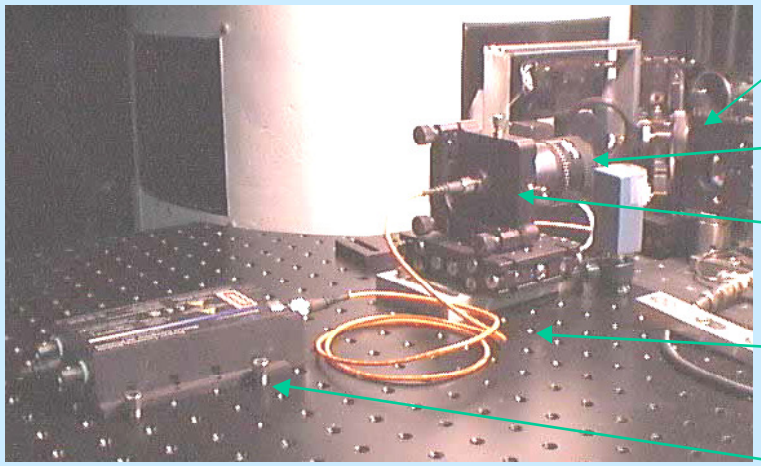
4 x

- Micro-Photon Devices PDM ("all 532nm" transponder-future):
  - Superior timing jitter: <50 psec.
  - Negligible PDE @ 1064 nm
  - ~40% PDE @ 532 nm

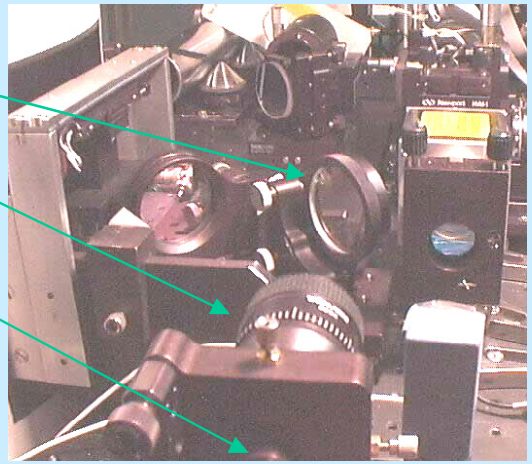


New instrumentation at S2K

- **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

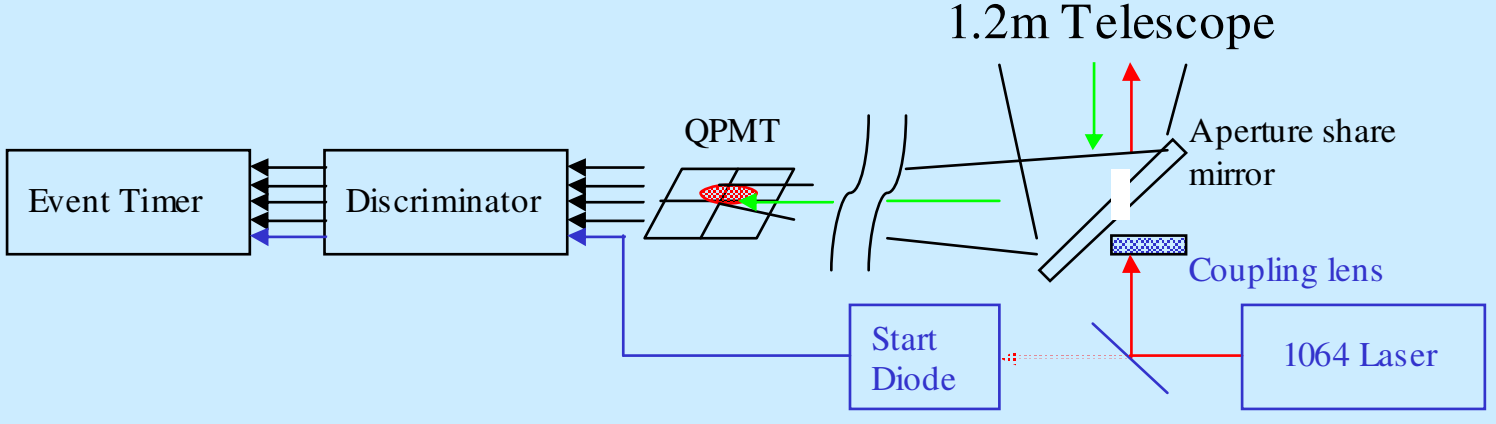


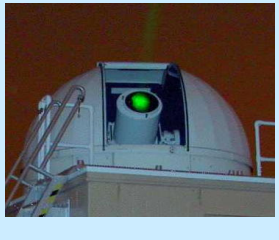
- **Transponder station SPCM Input to S2K Event Timer.**
- **Transponder terminal (1.2 m SLR) clock reference input to S2K Event Timer.**

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 II-50 laser operating at 1064nm**
- **BPF for 532nm and 1064 blocking filter**
- **Aperture share Transmit/Receive**





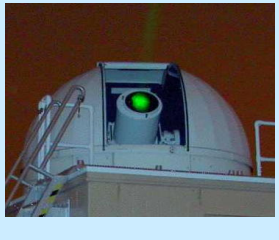
Experiment Approach

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

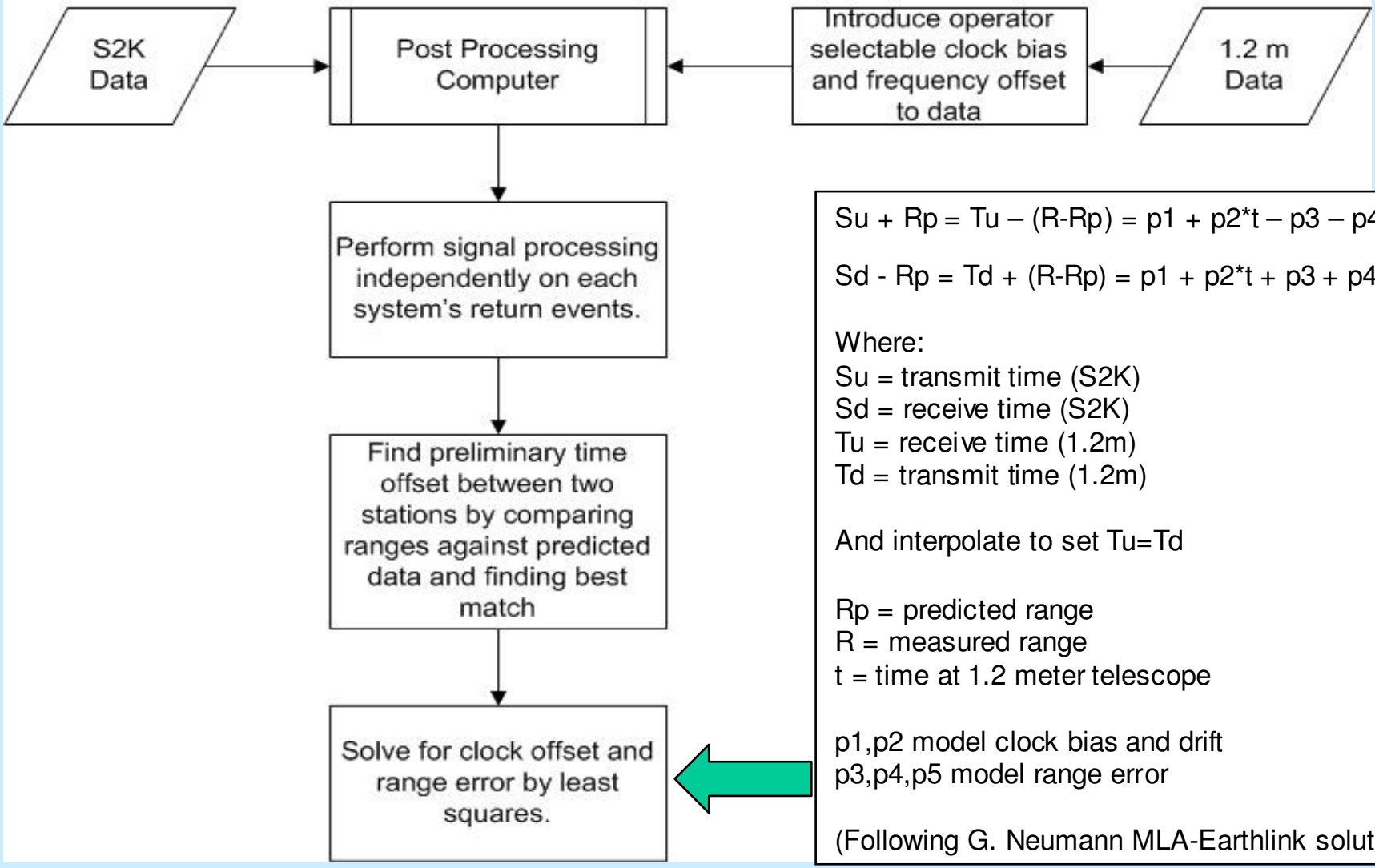
- Ensure knowledge of true clock offsets with cable between systems.

- 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



$Su + Rp = Tu - (R-Rp) = p1 + p2*t - p3 - p4*t - p5*t^2$

$Sd - Rp = Td + (R-Rp) = p1 + p2*t + p3 + p4*t + p5*t^2$

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

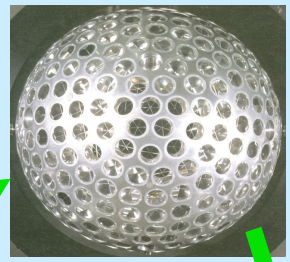
And interpolate to set Tu=Td

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

p1,p2 model clock bias and drift
p3,p4,p5 model range error

(Following G. Neumann MLA-Earthlink solution)

Preliminary Testing Performed: Receive-Only Transponder Simulation



MOBLAS-7

SLR2000

transmit

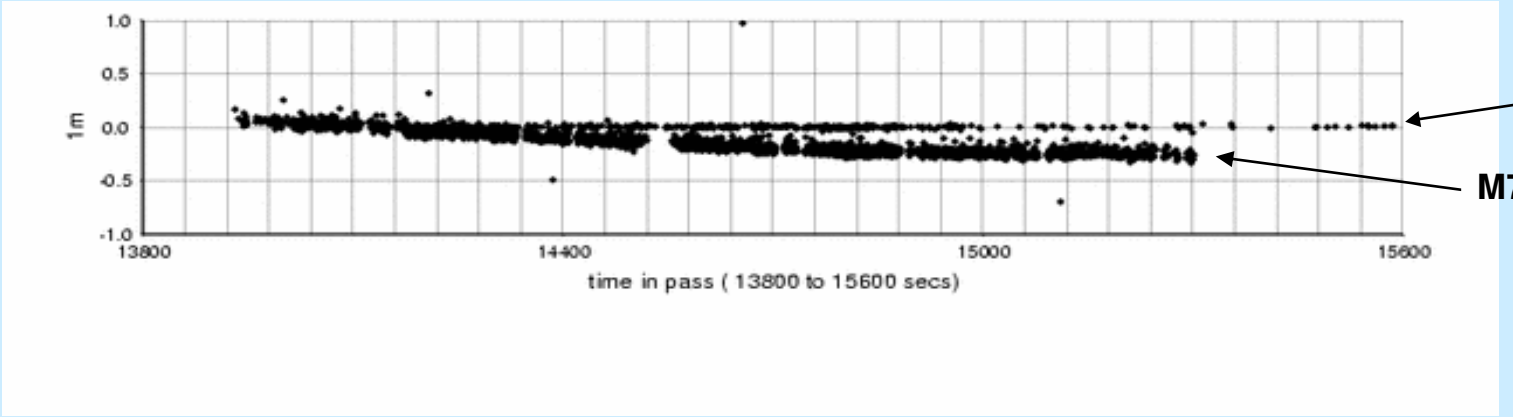
timing signal

receive

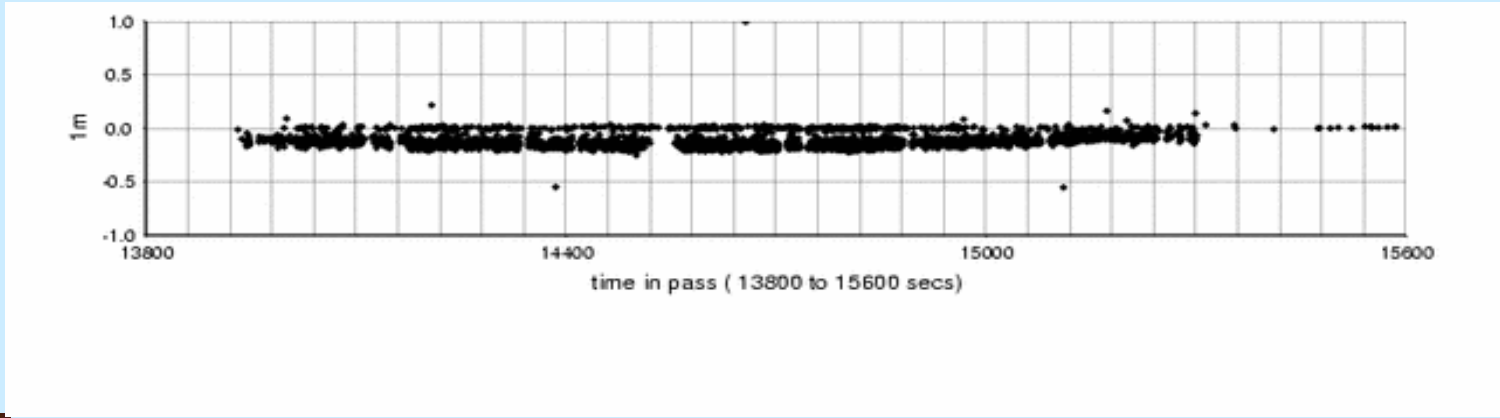
receive

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

A priori fit includes position error



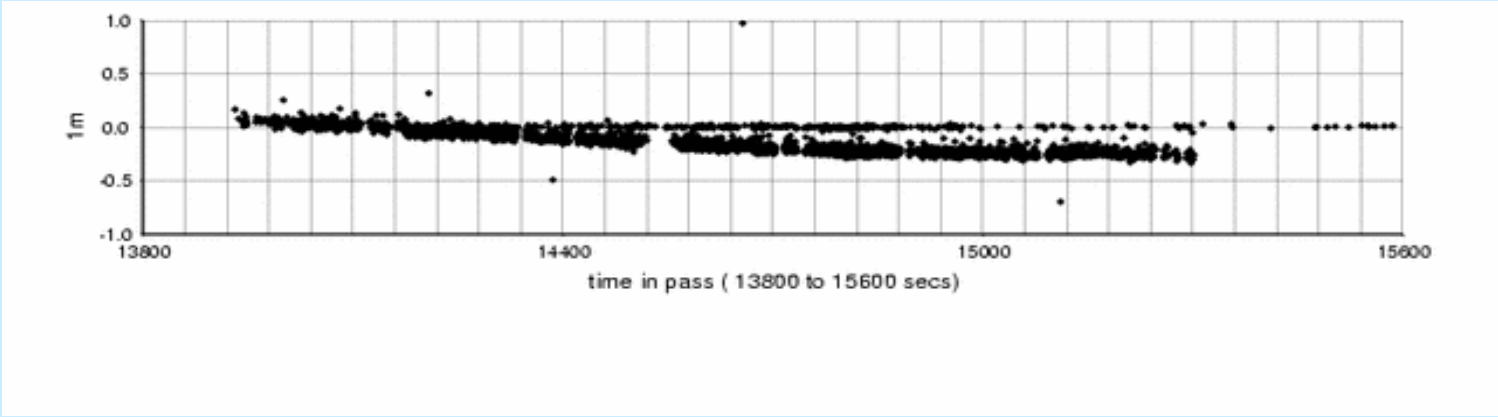
Estimate clock bias 0.2 msec: absorbs position error and improves fit



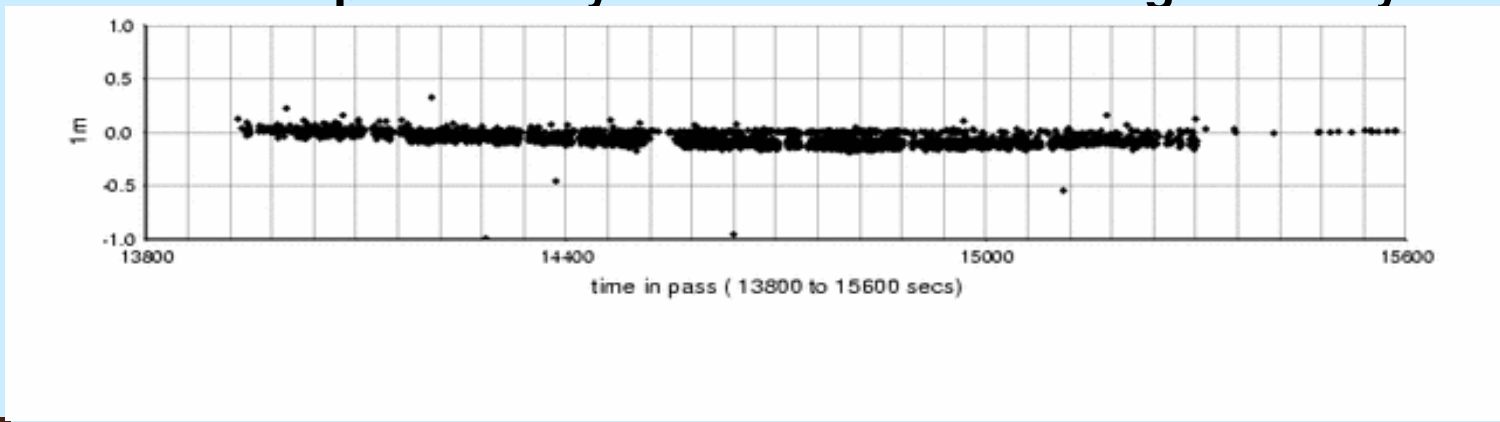
MOB7 Xmit & Rcv defines the orbit along the zero line

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

A priori fit includes position error

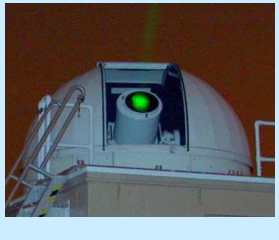


Estimate relative position by 60 cm : fit reduced significantly



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).**
- **Laser safety radar dedicated to SLR2000.**
- **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.**