

# SLR2000: The Path Toward Completion

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Laser Ranging Workshop  
Canberra 2006



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# SLR2000 TEAM

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Susan Valett



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# What's new in 2006

- **SLR2000 development is a high priority for NASA again**
  - We received additional money in 2006.
  - We have been able to add members back to the team.
  
- **Accomplishments in 2006**
  - New higher QE quadrant PMT installed in system.
  - Optical shutter to reduce laser backscatter on detector.
  - Laser beam expander added - used to control divergence.
  - Monitor installed to give confirmation of divergence.
  - Risle prism point-ahead now operational in system.
  - Laser Pulse Repetition Frequency (PRF) control - to avoid fire/return collisions is now installed. Preliminary checkout looks good.
  - New star and sky cameras added to system.
  - Testing with MOBLAS-7 has solved problems & shown good results.



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# SLR2000 Quadrant MCP PMT Replacement

	Photek model #PMT210	Ham. model #R4100U- 74-M004C
MCP stages	2 plates	2 plates
Active diameter	10mm	6mm
Photocathode	S20	GaAsP
Q.E.*	12%	33%
DC current Gain	$1 \times 10^6$	$2.6 \times 10^5$
PMT HV bias	-4700V (nom.)	-2250V (nom.)

\*The relative sensitivity improvement of the Hamamatsu tube over the Photek tube was estimated during an Etalon track to be approximately 5:1. Additional loss in Photek sensitivity is surmised to be due to aging or degradation of the photocathode over many months of SLR operation.



# SLR2000 Optical Shutter

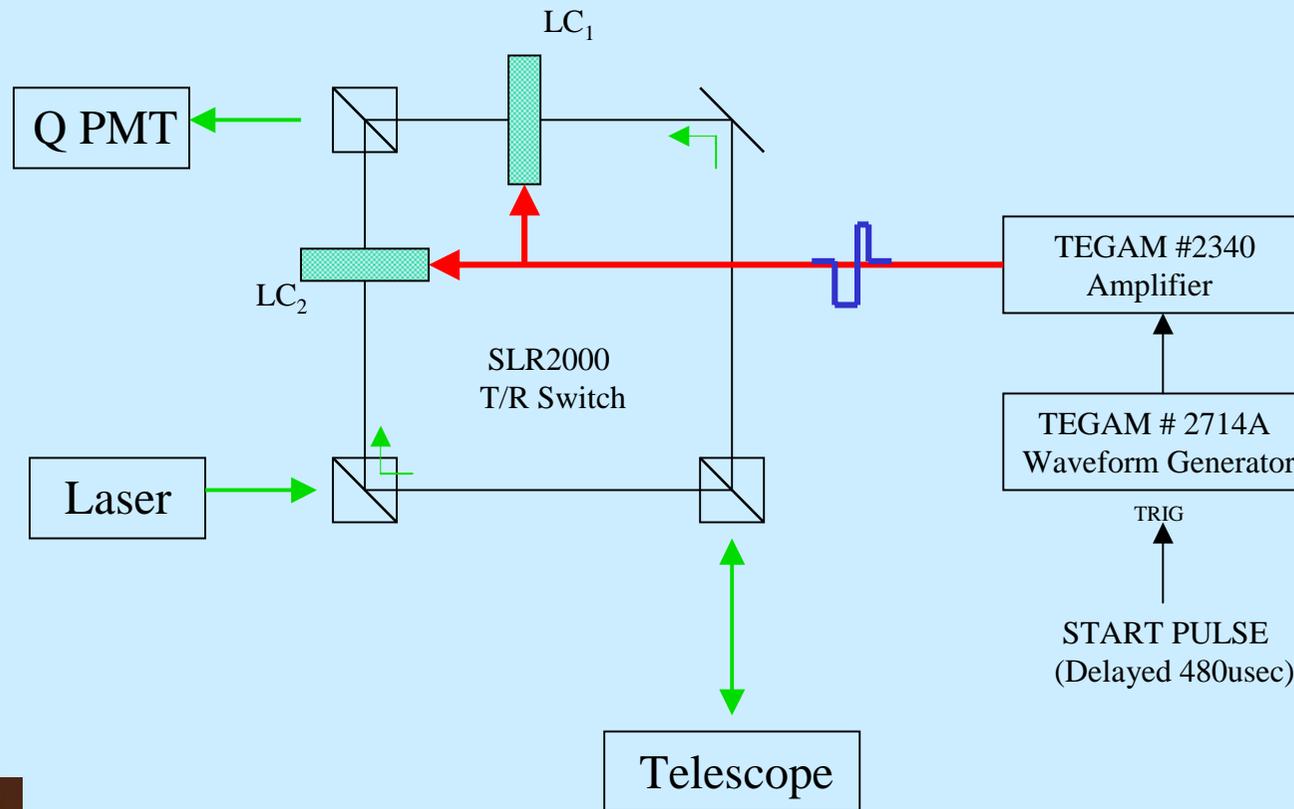
**Problem:** In a single telescope common optics transmit/receive system **the PMT is exposed to a significant amount of laser backscatter** within its FOV as the pulse leaves the system. Even though the PMT is gated off during the laser fire this illumination stresses the PMT photocathode and may shorten its lifetime. Mechanical choppers or shutters were investigated but deemed too problematic for operation at 2 KHz.

**Solution:** **Develop an optical shutter with adequate switching speed and optical throughput** (See J. Degnan / Kilohertz System Session) and install the liquid crystal (LC) polarizing filters in both legs of the transmit receive switch to reduce laser backscatter by 2 orders of magnitude.



# SLR2000 Optical Shutter

Triggered from the previous laser pulse, the Liquid Crystal shutter ( $LC_1$  &  $LC_2$ ) suppresses laser backscatter into the receive PMT by about 2 orders of magnitude.



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# SLR2000 Variable Beam Expander

**Problem:** Laser transmitter beam divergence cannot be adjusted without de-focusing the common beam expander for the receiver. The resultant FOV change in the receiver adversely effects control of background noise and vastly complicates tracking.

**Solution:** Develop a beam expander mechanism which operates solely on the laser transmit beam (independent of the receive path) and can be focussed to accommodate the 10 to 30 arcsecond (full angle) desired beamwidth. (See J. Degnan / Automation & Software Session). Focus of the beam expander must be under computer control, be repeatable, and provide operator feedback.



# Special Optics Variable Beam Expander

## Variable Beam Expander

### Specifications:

Wavefront Distortion	< 1/4 Wave
Transmission	> 95%
Coating Damage Threshold	100 MW/cm <sup>2</sup>
Useable Spectral Range	450 - 1100 nm

### Features:

- Compatible to Standard Computer Controlled Actuators
- Minimal Internal Focus for High Power Use
- Large Input and Output Apertures
- Replaces Several Fixed Wavelength Devices
- Non-Rotating Lens Elements, Eliminating Beam Wander

532nm

Model	Expansion Range	Max. Input Aperture (mm)	Max. Output Aperture (mm)	O.D. (mm)	Max. length (mm)
56-30-2-8X- $\lambda$	2-8X	10.0	30.0	37.6	167

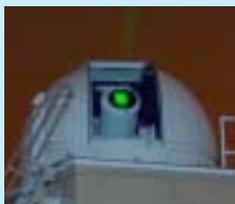
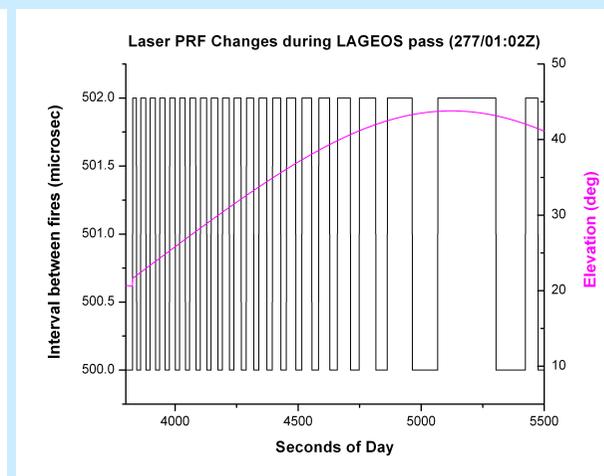
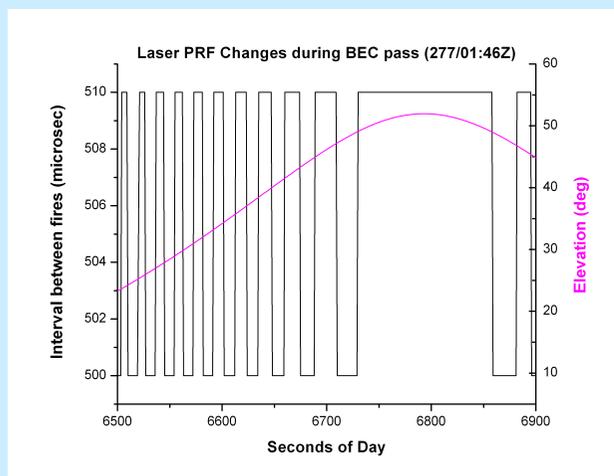


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# Controlling the Laser PRF

- Laser fire rate is modified to keep fires from colliding with returns. (see P. Titterton presentation at 11<sup>th</sup> Workshop in 1998). Needed due to common optics design.
- Only two different fire intervals (rates) needed for given satellite:
  - LEO: 500 and 510 microsec
  - LAGEOS: 500 and 502 microsec
  - HEO: 500 and 501 microsec
- Has been used successfully at S2K with LEO satellite passes.



# New Star Camera

- For Star Calibrations: older EDC camera failed (after ~10 years).
- Santa Barbara Instrument Group ST-402ME CCD imaging camera:
  - 9 microns square - 765 x 510 pixels. Low noise, high QE.
  - USB 2.0 interface - now hosted on Windows XP computer.
  - greatly increases star sensitivity from our old camera (from star magnitude ~3.5 to ~9.0).
- Improves mount model (10/2/2006 RMS=1.6 arcsec) → improved satellite tracking performance.
- Shortens time to perform starcal (from ~1 hour to ~30 mins)



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# New Sky Camera

- For automated cloud cover determination (see A. Mallama's presentation at 12<sup>th</sup> Workshop in 2000).
- Older camera failed (after ~ 5 years of operation and 2 repairs).
- Jenoptik VarioCam infraRed (8 – 13  $\mu\text{m}$ ) camera
- Uncooled sensor with 320 x 240 pixel resolution
- Fire-Wire interface to Windows XP computer



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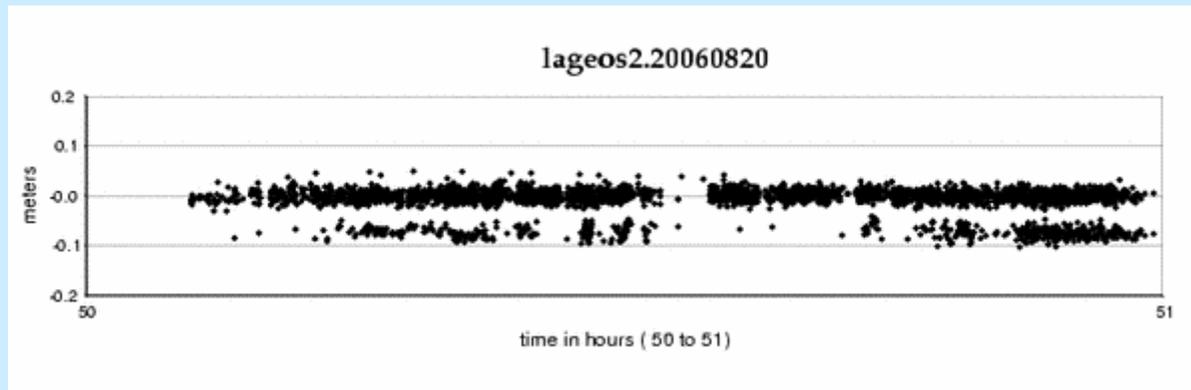


# Testing with MOB-7

- Using MOB-7 fires – S2K receiving only
  - Cables run from MOB-7 to S2K Event Timer for Start and Stop
  - S2K quadrant detector also receiving
- Identified and resolved many issues with software and hardware:
  - Software timing errors
  - Data precision
  - Logging dropouts (understood but not yet resolved)
- Used to verify receiver software and electronics performance as well as tracking performance:
  - System tracking is very good – hands off with 80 microradian FOV.
  - Full rate RMS is comparable to MOB-7's (M7's Start & Stop).
  - Return rate for LAGEOS is ~ 5x higher at S2K as M7 (as theory indicates).



# SLR2000 Data Quality – compares well to MOB-7



M7 data from MRT

M7 start/stop recorded  
at SLR2000

## LAGEOS RMS (mm)

MOBLAS-7 Start/Stop via cable: 10

SLR2000 quadrant detector: 25 – 40

## ERS-2/ENVISAT RMS (mm)

SLR2000 quadrant detector: 20 – 25

## GLONASS-87 RMS (mm)

MOBLAS-7 Start/Stop via cable: 15

SLR2000 quadrant detector: 35 - 45

## ETALON RMS (mm)

SLR2000 quadrant detector: 50 – 60

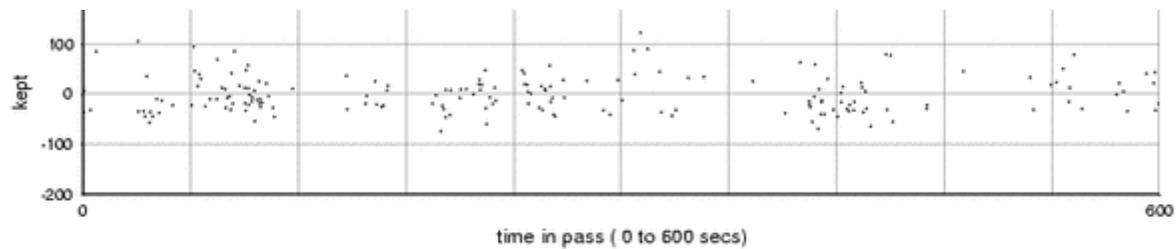
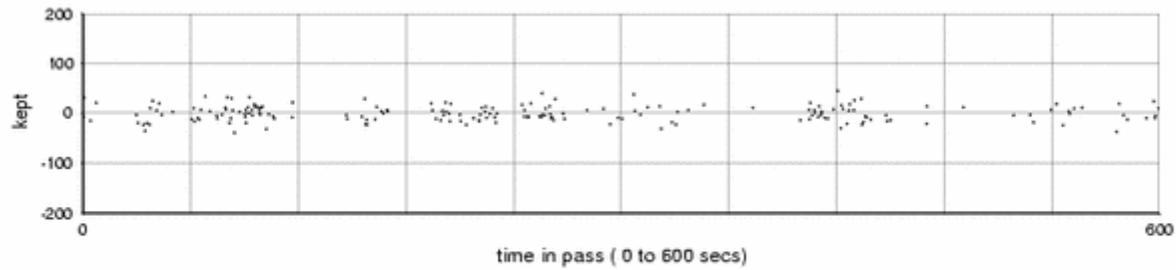
SLR2000 uses  
threshold  
discriminator and  
MOBLAS pulse returns  
are short pulse but  
multi-photon.

Analysis and plot  
from Peter Dunn



# SLR2000 RECEIVING FROM GLONASS87 Aug 22

MOB7/MOB7 15mm MOB7/SLR2000 35mm

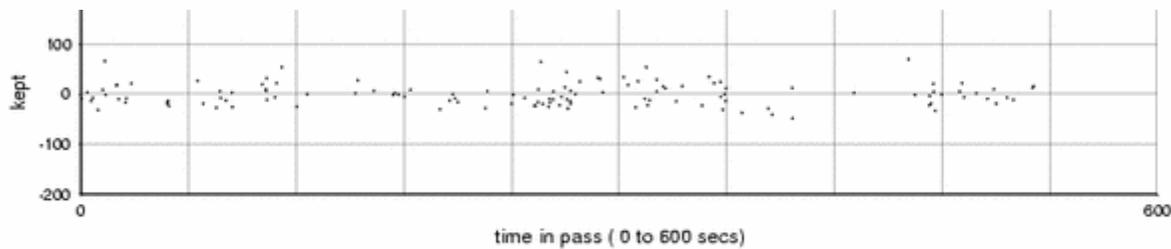
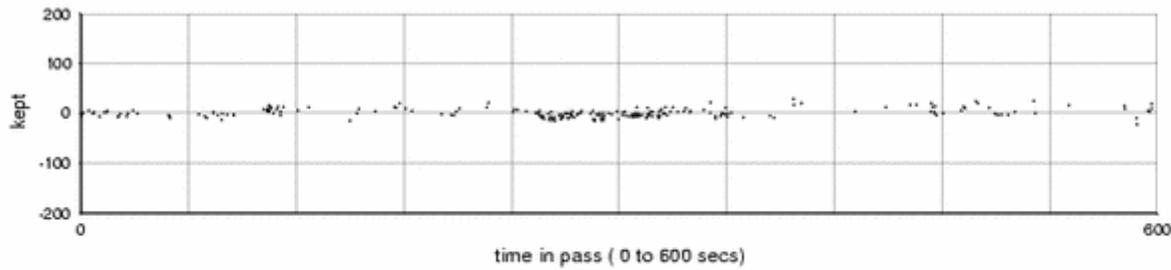


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# SLR2000 RECEIVING FROM LAGEOS2 Aug 22

MOB7/MOB7 10mm MOB7/SLR2000 28mm

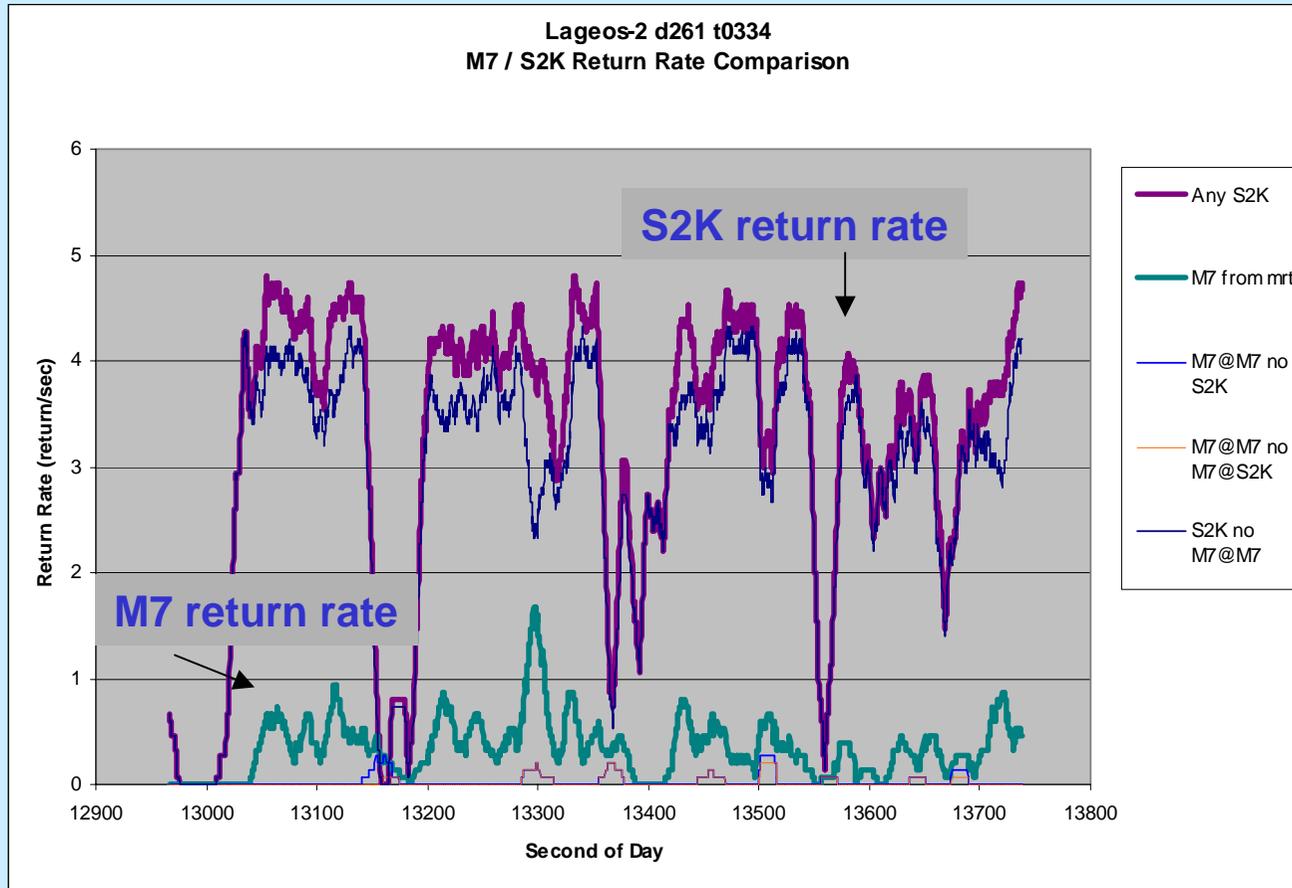


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# LAGEOS Return Rate Comparison: S2K to M7

## M7 firing – S2K returns in quadrant PMT



S2K return rate  
is  $\sim 5x >$  M7's

Data dropouts  
are logging  
problem –  
being worked.

Plot from Bart Clarke



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# SLR2000 Future Verification Issues

- **Laser transmitter beam width to be externally monitored** via beam profile imager before it leaves the transceiver table. This will assure the proper beam divergence is used in tracking.
- **Transmitter point ahead (via Risley Prisms) to be verified** in star camera on night time visual satellite tracks with laser firing into a cube corner mounted at the end of the telescope. The star camera (and receive optics) will track the visual pass while the cube corner will project the actual laser beam point ahead angle back to the camera.
- Proper boresighting and uniform quadrant response in the stop detector is critical. **The current technique of balancing noise counts of all 4 quadrants while tracking a star will be reevaluated.**



# Summary

- SLR2000 has made significant progress in 2006 thanks to additional resources
- Testing with MOBILAS-7 has shown that SLR2000's
  - tracking performance is good (at few arcsec level absolute),
  - performance of receive electronics and software is good (comparable to MOB-7 at 1cm RMS on LAGEOS).
- Milestones for 2006:
  - Complete closed loop tracking,
  - Track LAGEOS with 2khz eyesafe laser.
- Milestones for 2007:
  - Track GNSS satellites,
  - Finish system checkout and ensure system is operationally robust with good data quality and quantity.

