Current Status: Lunar Laser Ranging

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3rd Matjiesfontein Workshop: Technical discussions

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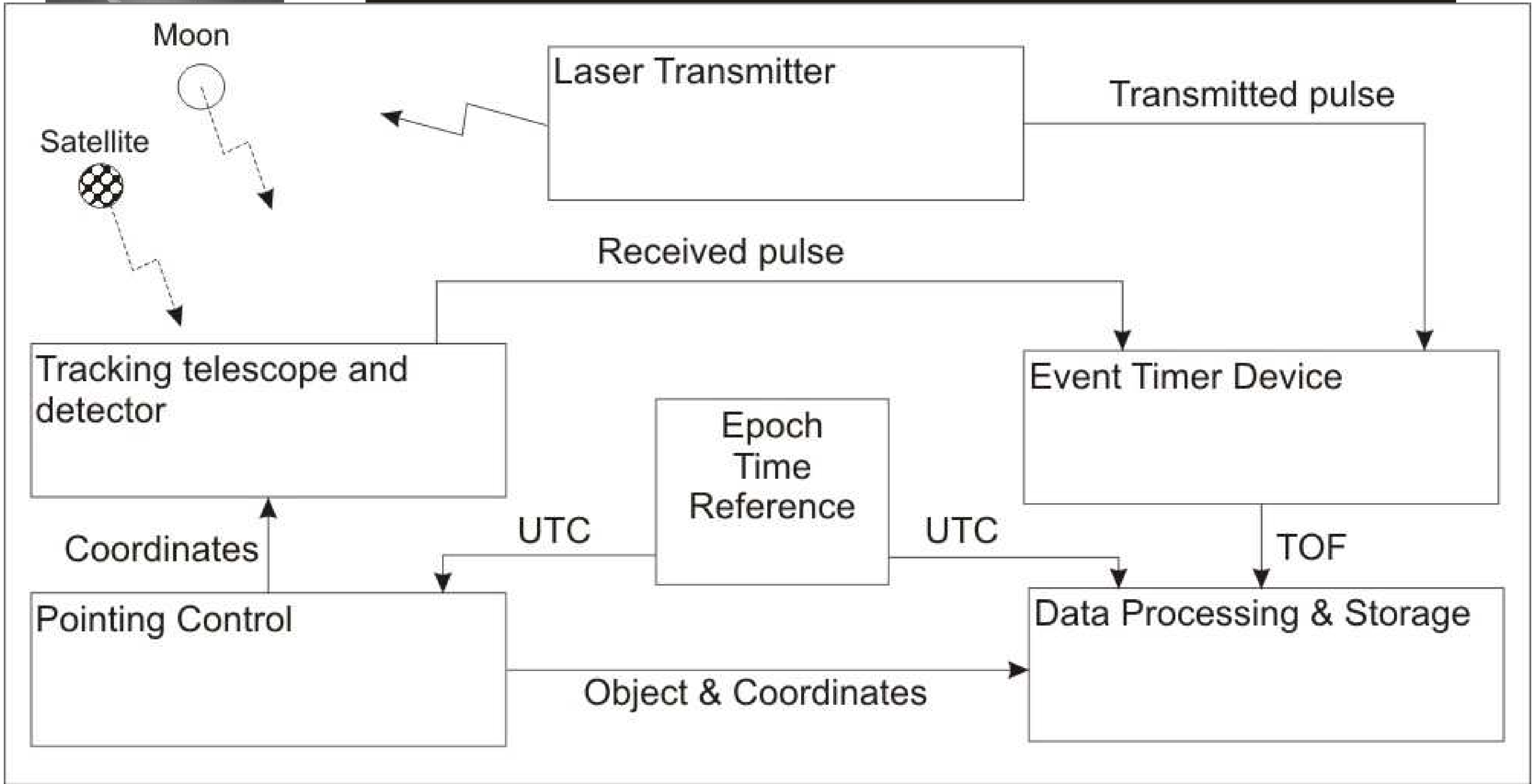
Outline

- Background- Lunar Laser Ranging
- Overall system parameters
- Laser Development and ideas
- Telescope

GOAL: Lunar Laser Ranging



matter?”

- To determine the time dependence of the universal gravitational constant G.

Laser Ranging: Link and Error budget

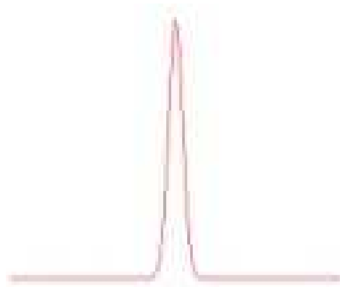
Link Budget from radar equation:

$$N_{pe} = \eta_q E_T \frac{\lambda}{hc} \eta_T G_T \sigma_{Sat} \left(\frac{1}{4\pi R^2}\right)^2 A_T \eta_R T_A^2 T_C^2$$

Transmit and receive-path efficiency

Source of error	RMS Error (ps)	One-way error (mm)
Leading edge variation of laser pulse	2 - 4	0.3 – 0.6
Laser pulse width	10 - 30	1.5 – 4.5
Jitter: Start detector	2 - 5	0.3 – 0.8
Jitter: Return detector	6 - 50	0.9 – 7.5
Time stability of clock	5 – 10	0.7 – 1.5
Calibration	2 - 4	0.3 – 0.6

Differences between SLR and LLR

	SLR	LLR
Measured Signal		
Transmit Signal		
Timing measurement	Interval	Event
Pulse Repetition Frequency	~ 5 Hz	~ 1 kHz

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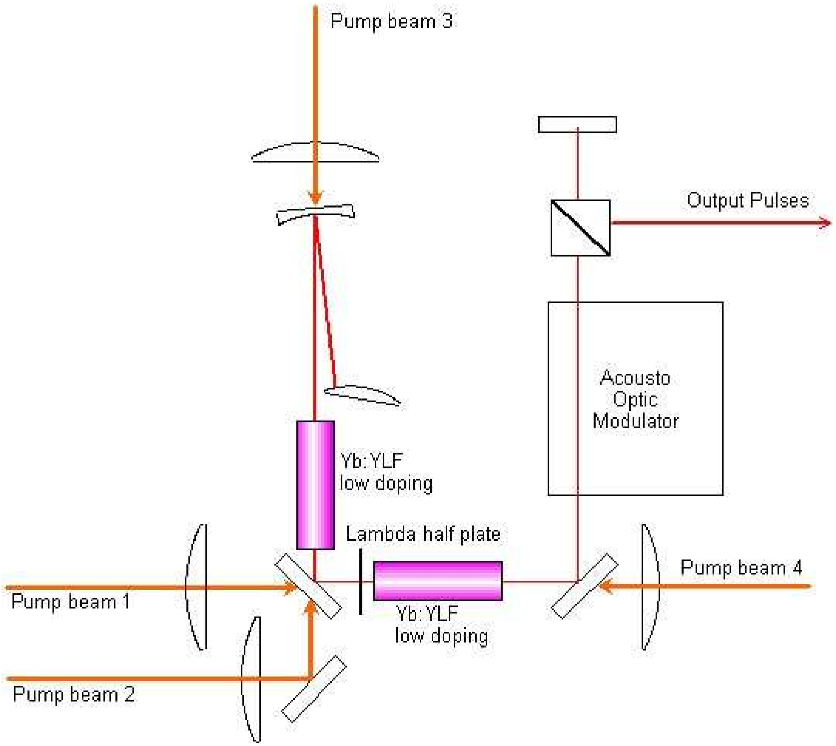
Conceptual Laser Design

For LLR laser we would like:

- ~ 500-540 nm wavelength
- < 50 ps pulse length (FWHM)
- M^2 close to 1
- 200 – 400 mJ per pulse
- Pulse Repetition Rate: up to 1000 Hz

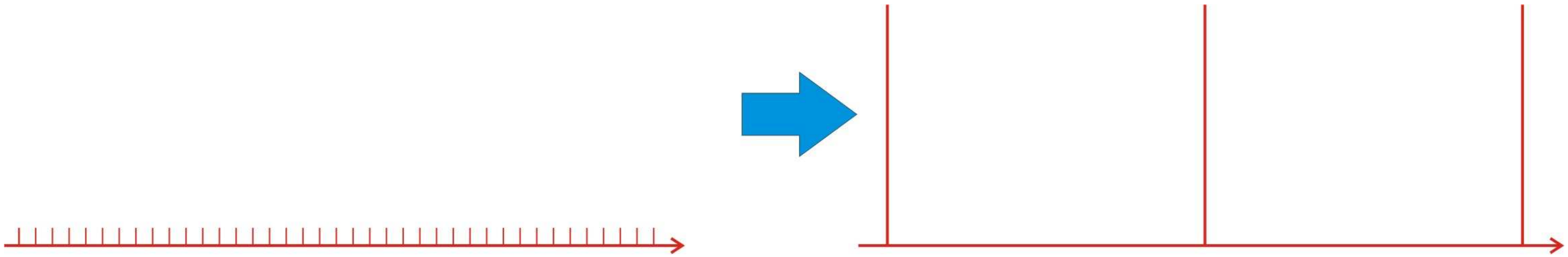


General Q-switched mode-locked parameters:

- Several microjoule per pulse
- Picosecond pulse length regime
- 100's of MHz pulse repetition frequency

Conceptual Laser Design

How do we get from 100's of MHz low-energy to kHz high-energy in mode-locked Q-switched lasers?



Seed Laser

Final Output

Steps:

1. Pulse Selection
2. Amplification

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Proposal for new optical subsystem

- Compact, light-weight diode-pumped laser mounted onto telescope
  - Pump diodes separately with light delivered to laser through multi-mode fibres
  - Very good beam quality
  - Own smaller telescope for outgoing beam (e.g. ~40 cm diameter)
  - High-rep-rate operation

- Adaptive optics to reduce laser divergence and field of view independent of seeing conditions.
  - Laser itself creates guide star through time gating to return from higher atmosphere
  - With a 30 cm outgoing beam, a divergence of ~0.5 arcsec could be achieved.
  - This gives a factor 4 improvement compared to 1 arcsec, much more compared to most current systems.
  - The reduced field of view would reduce noise by a similar factor

- Automatic pointing system ensures optimum overlap of laser and telescope field of view.

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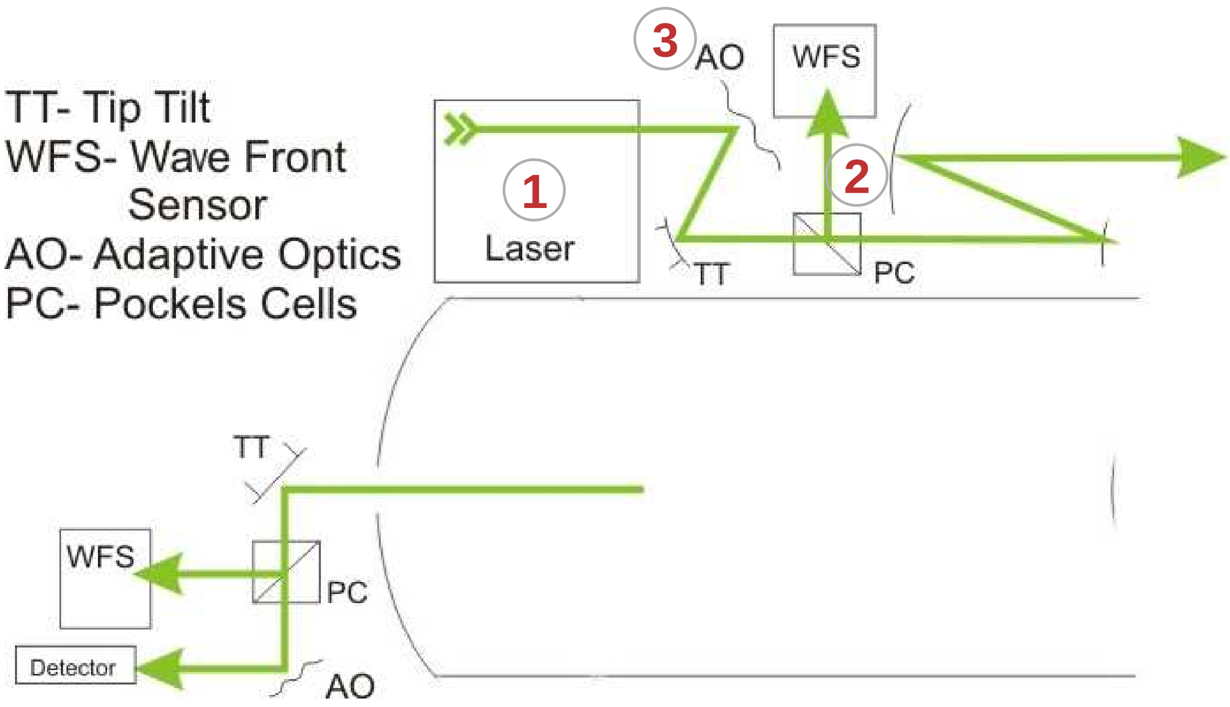
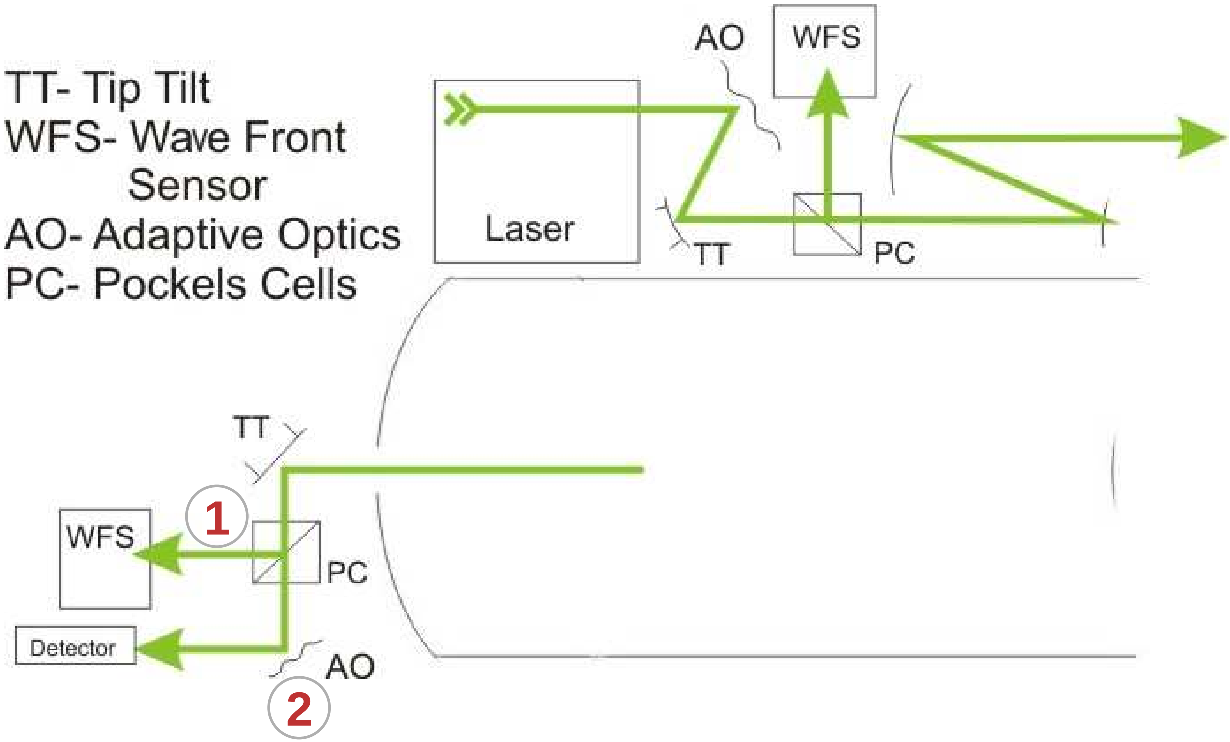
Proposed system: outgoing laser



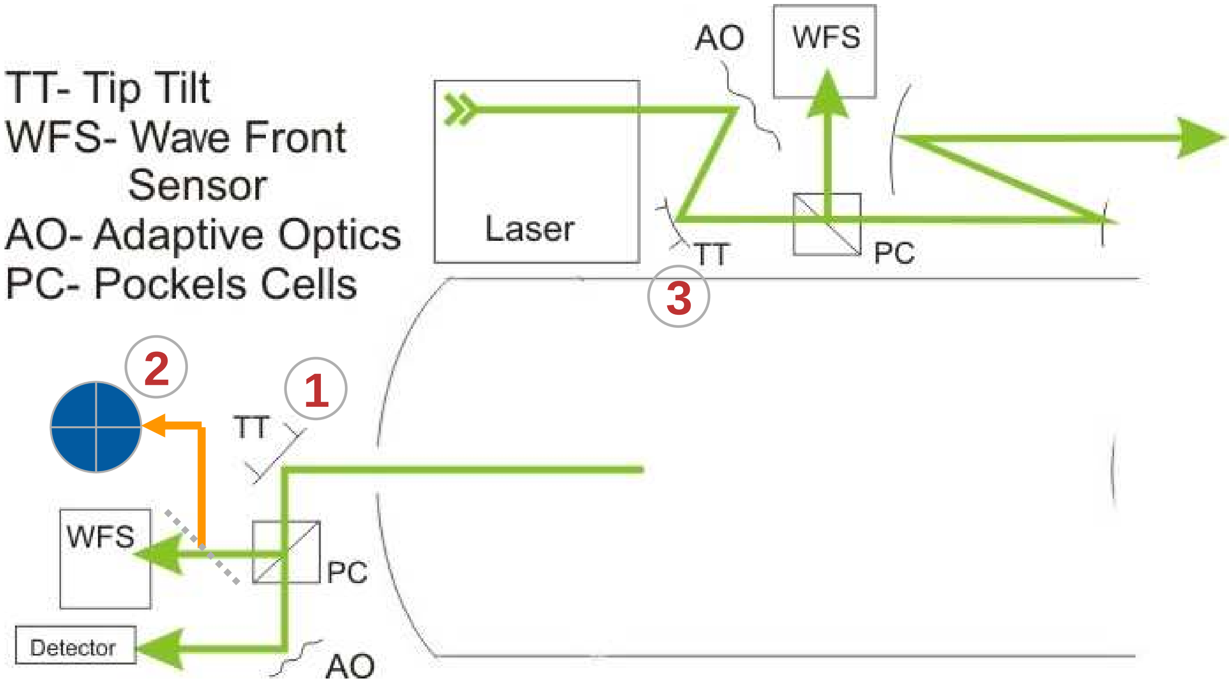
- Laser with good beam quality
- Time-gated detection of wave front through laser telescope
- Adaptive optics to correct laser divergence
- Very low laser divergence
- Factor 3 to 10 improvement of intensity on moon

Proposed system: receiving



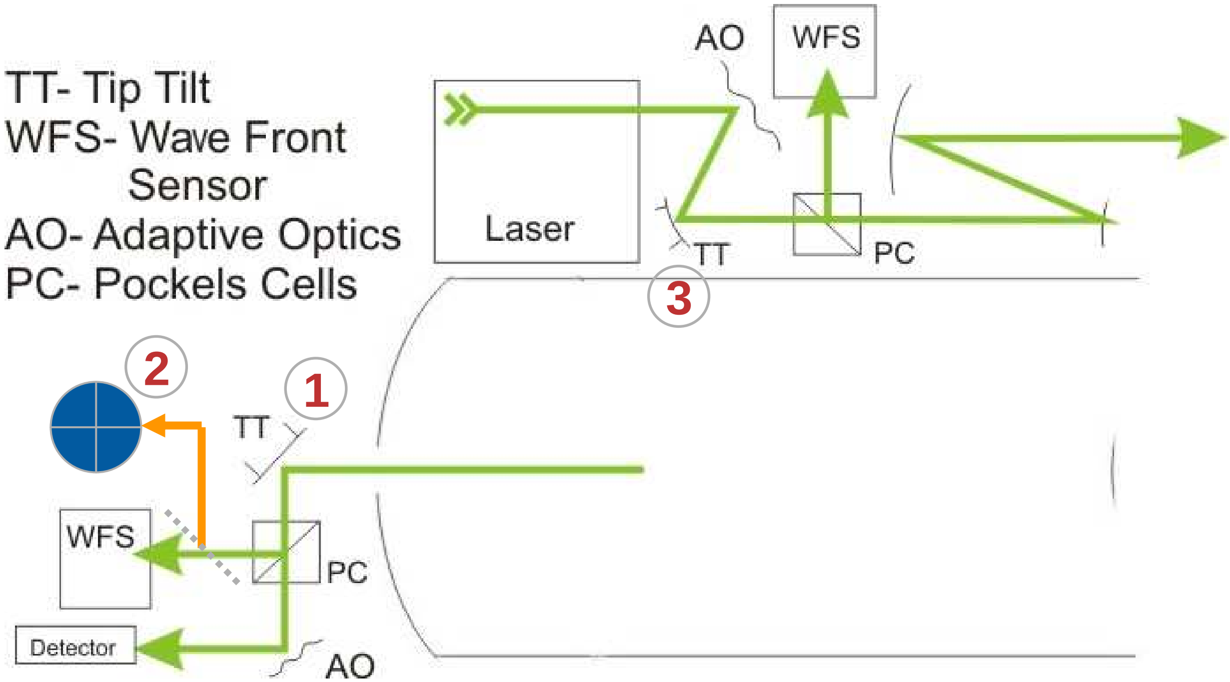
- Time-gated detection of wave front through main telescope
- Adaptive optics to improve receiving resolution
- Can significantly reduce field of view
- Factor 3 to 10 reduction of noise

Proposed system: pointing and alignment



- Tip-tilt mirror to actively fine-adjust pointing to retro-reflector
- Time-gated detection of laser direction from atmospheric far-field scattering
- Tip-tilt mirror to adjust laser pointing to main telescope
- Always perfect alignment of laser beam to main telescope

Proposed Optical Subsystem: Telescope, Laser and Adaptive optics



- Tip-tilt mirror to actively fine-adjust pointing to retro-reflector
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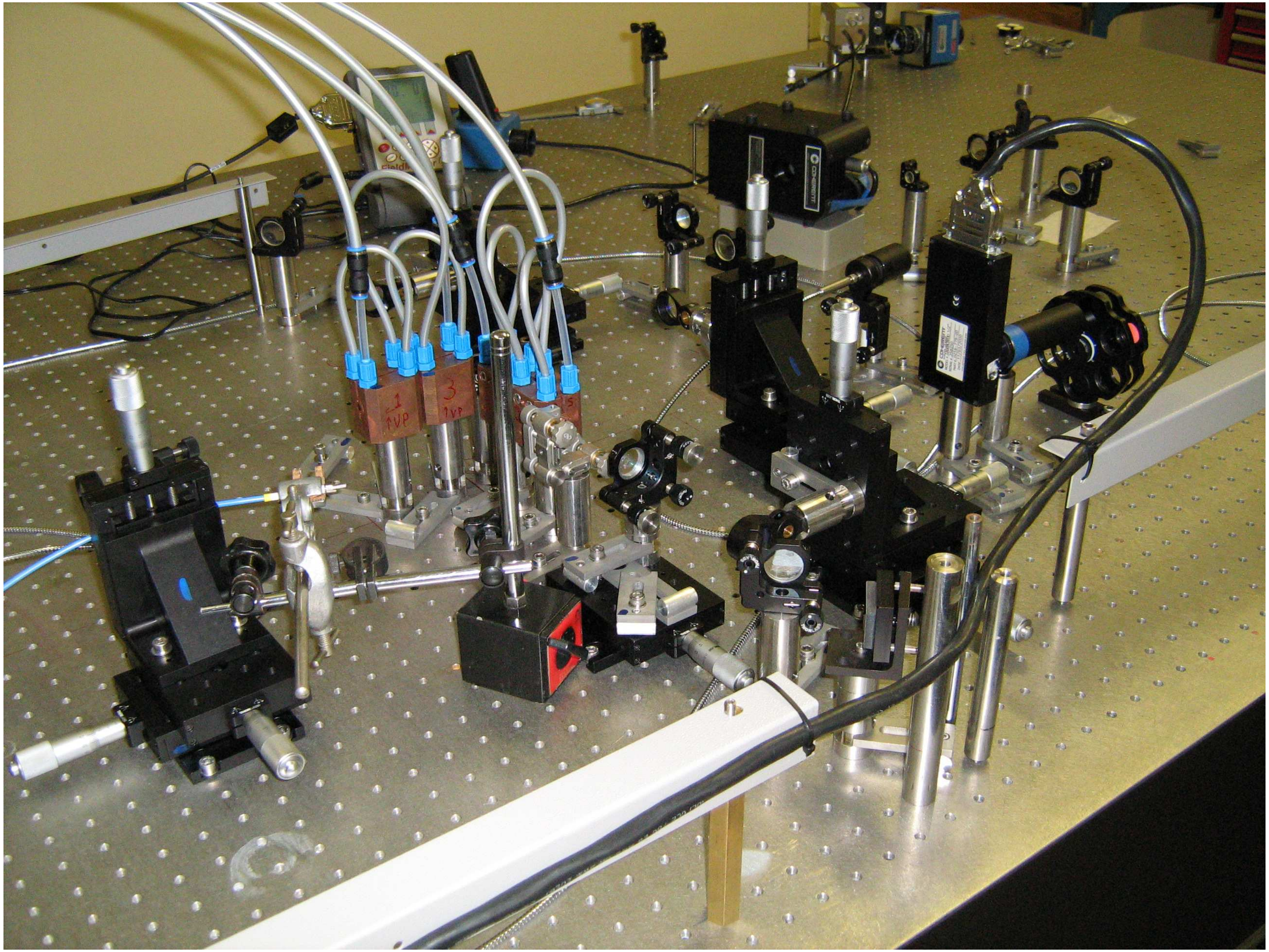
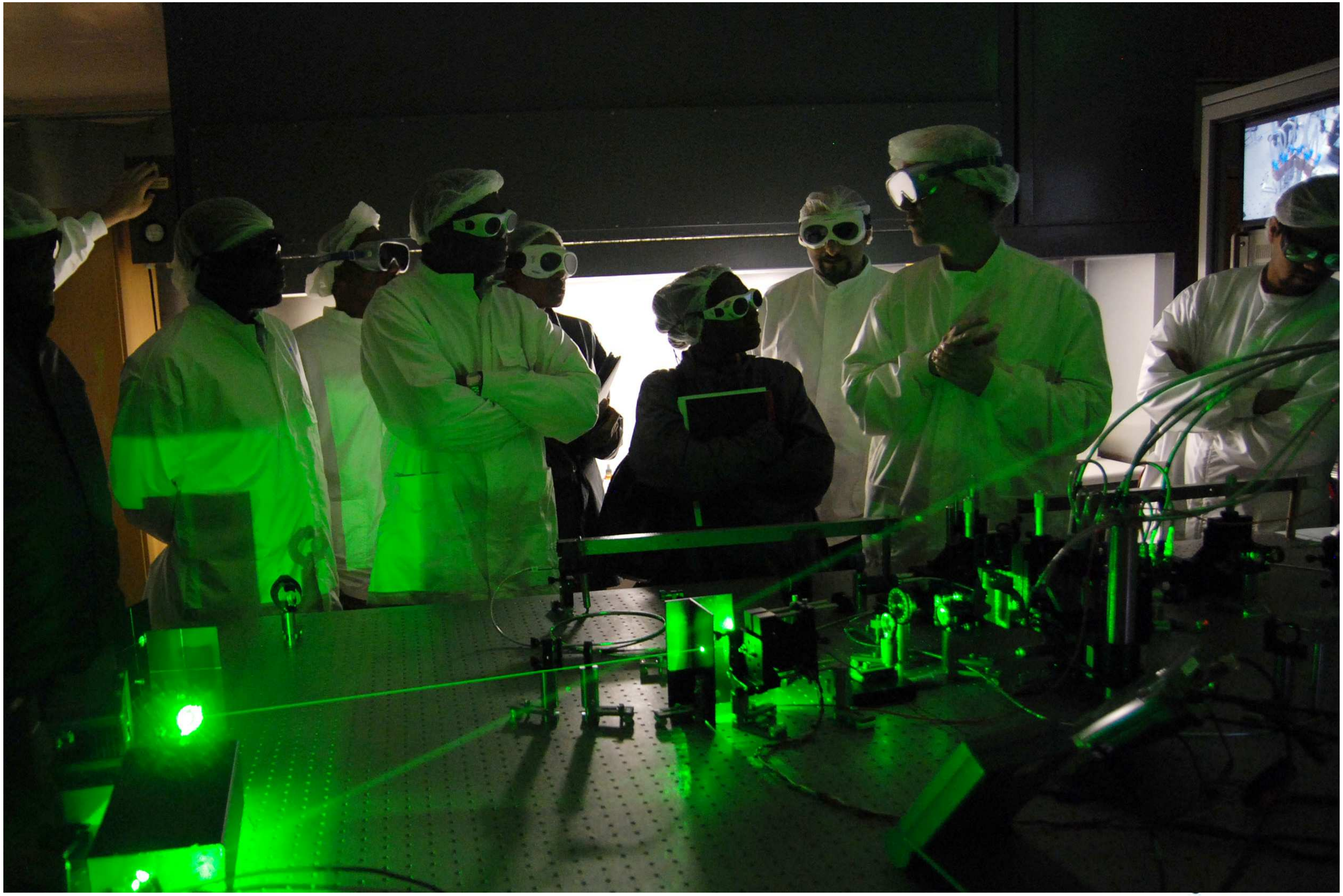
Conclusion

- Upsizing of current technology will not allow millimeter level accuracy
- A new laser design for better beam quality is necessary
- A novel 'dual-telescope' system is a feasible option
- Adaptive optics will correct for transmit and receive path efficiencies by lowering final beam divergence
- Automatic alignment and pointing control will significantly reduce system errors and increase accuracy

Laser Development



Laser demonstration



Telescope: as large as possible!

- 1m + Primary mirror diameter
- Astronomical / military grade mirror
- Accurate pointing to about 3 arcseconds

We do laser ranging systems redesign rather than upscaling of typical current design:

- Introduce new technologies (laser type, processing techniques etc)
- Expect factor 100 better data because of this

Telescope: We have a donor!

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The telescope: 1m **Schmidt-Cassegrain**

The Telescope II

Timeline of telescope within project

	Year two thousand and														
	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
LLR Concept Development	■	■	■	■											
Design specifications		■	■	■	■	■	■								
Laser Research and design		■	■	■	■	■									
Laser prototype						■	■								
Packaged Laser							■	■							
Telescope parameters			■	■											
Acquire telescope			■	■	■										
Telescope Refurbishment					■	■	■								
Mount and test laser on telescope								■	■	■					
Electronics Development						■	■	■	■	■	■	■			
Software development			■	■	■	■	■	■	■	■	■	■	■		
Systems Integration											■	■	■		
System Testing												■	■		
System relocation to Matjiesfontein													■	■	
Final testing, start of operations														■	■

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Telescope initial timeline

	2007						2008											
	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Final donation documentation etc	■	■	■	■	■	■												
Planning for refurbishments					■	■	■	■	■	■	■	■						
Packing, shipping								■	■									
Installing in new building												■	■					
Initial investigation into state of equipment													■	■	■			
Refurbishment															■	■	■	■
Electronic systems																		
Testing of refurbishment																		

Requirements: Telescope Refurbishments

- Large closed brick building with large door- to move outside for tests
- Proper tracks- 6.5 tonnes and proper trolley cradle
- Pit between tracks within the building (nice to have)
- Extra area in building to work, set up lasers and electronics, PC's etc
- 3 phase electricity (low kW though)
- Near HartRAO and CSIR
- Semi clean room conditions
- Proper access control

Envisaged Role of host institution, collaboration

- Provide building + space for refurbishment, initial tests
- Help with required changes to the structure
- Very good link to start student projects from:
  - electronics
  - physics
  - computer science

Option 1- Failed

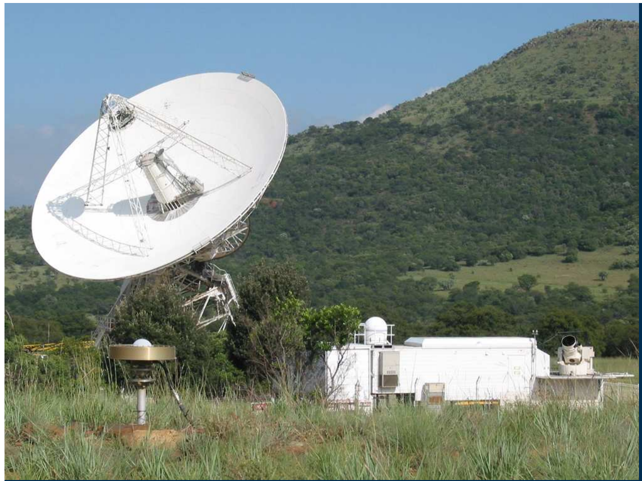
Option 1- Failed

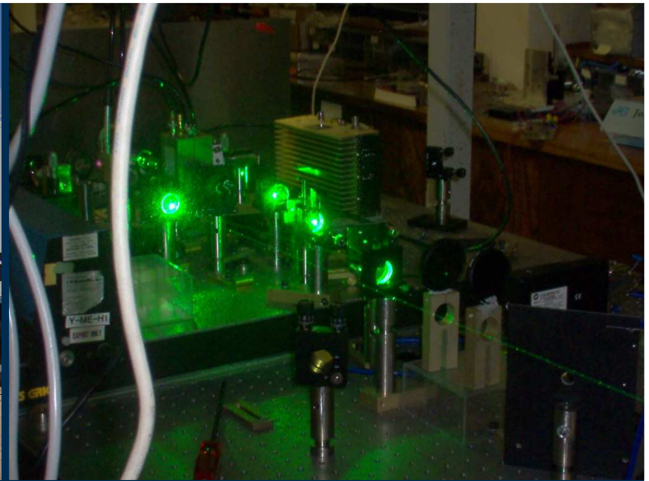
Conclusion

- Upsizing of current technology will not allow millimeter level accuracy
- A new design for laser ranging is necessary
- 1m Telescope acquired from OCA, arrived in SA 2008
- Initial refurbishments about 2 – 3 years
- This is a long-term multi-partner project on international level
- Operational 2014 (?) at Matjiesfontein

Latest ideas

- Get most of the equipment as standard 'off-the-shelf'- helps in both availability of *parts* and *support*
- Plug-and-play approach for the whole system as far as possible
- Laser- copy the OCA design, implement dual laser system later on
- Labview for system control (Win-blows / li-nots?)





Thank you

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