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Dual laser system for the HartRAO Lunar Laser Ranger: design, configuration and expected performance

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HartRAO has been planning and developing a Lunar Laser Ranger (LLR) for the past 10 years. This system will also be used for Satellite Laser Ranging during available operational time. We already have a 1 m optical telescope as well as a functional control room. We are now at the stage of procuring the remaining hardware components and implementing these according to the overall system design. The laser system for this LLR has been designed in collaboration with and procured via the NASA laser ranging network contractor, Cybioms Corporation. The system consists of 2 lasers: one providing high-power green pulses at 20 Hz for lunar capability and another delivering low power green pulses at 1 kHz for satellite capability. These lasers have recently arrived in South Africa. An overview of the laser system configuration and design as well as anticipated performance is presented.

The development of the Lunar Laser Ranger (LLR) at the Hartebeesthoek Radio Astronomy Observatory (HartRAO) is progressing well. During the system design phase attention was given to incorporate ideas that worked at other laser ranging stations, as well as avoid designs and implementations that proved to be problematic [1, 2].

The LLR system will be utilised for ranging to the Moon (which orbits at ~ 350 000 km) when possible, and as a Satellite Laser Ranger (SLR) to orbits at ~ 500 to 22 000 km during available system time. It ranges by transmitting short laser pulses to an array of corner cube reflectors and detecting the reflected light signal. Both the pulse transmit and receive times are accurately logged at picosecond level to determine the effective distance the laser light travelled. The expected number of returned laser photons n_p are given by the modified radar equation from [3] as

$$n_p = \eta_q \left(E_T \frac{\lambda}{hc}\right) \eta_t G_t \sigma \left(\frac{1}{4\pi R^2}\right)^2 A_r \eta_r T_a^2 T_c^2, \qquad (1)$$

with η_q the quantum detector efficiency, E_T the outgoing laser energy per pulse, λ the laser wavelength, η_t the transmit optics efficiency, G_t the transmitter gain, σ the reflector optical cross-sectional area, R the range, A_r the effective area of the receiving telescope aperture, η_r is the receive optics efficiency, T_a the one-way atmospheric transmission and T_c is the cirrus cloud cover. The main factor that influences the number of return photons n_p adversely is the distance R, since it results in a quadratic decrease in the photon density for each of the transmit and return paths due to divergence (the R^{-4} in Equation 1). By changing the laser energy per pulse E_T one adjusts the operational parameters in terms of the efficient range of the system. Since the Moon is in an orbit about 2 orders of magnitude further than the average satellite, the laser energy per pulse needs to be much higher than for satellites. Minimising the beam divergence of the laser is of utmost importance since it will ensure a higher photon density at the reflector, which will increase the number of expected return photons.

The huge difference in the pulse energies required for ranging to satellites or to the Moon necessitates having a dedicated laser for each type of target. Utilising a fairly high-power laser operating at 532 nm (the atmosphere is near transparent at this wavelength) we can expect a faint return pulse that can be detected using a 1 m optical telescope. Since the Moon is 2 orders of magnitude further away than satellites, we effectively need to increase the energy per pulse by a factor of 10^8, which is not possible with existing technology. Therefore we have to utilize a laser with the highest 532 nm pulse energy available and decrease the divergence of this laser, as well as settle for single-photon returns. The design specifications for the SLR and LLR lasers are listed in Table 1.

Table 1: *Design specifications for the SLR and LLR lasers*

Param.	Energy / pulse (mJ)ᵃ	Pulse Duration (ps)ᵇ	Peak Power (GW)	Pulse Rep Rate (Hz)	Diverg. (")	Beam diameter (mm)	Pointing Stability (")
SLR Laser	0.45 ± 0.8%	25 ± 2	0.018	1 000	< 330	3	< 6
LLR Laser	100 ± 1.0%	80 ± 3	1.250	10 or 20	< 100	12	< 10

a) At 532 nm b) At 1064 nm

Since the single ranging system will have 2 lasers, the lasers need to be configured to make use of the same optical path to the telescope – the Coudé path. A special beam combining and beam matching optical setup will be utilised to ensure that beams are perfectly aligned with each other before entering the Coudé path. The Coudé path is designed to ensure minimal loss of laser photons. At the telescope, laser pulses for the SLR will be routed via a side-refractor on the telescope tube, whereas the LLR laser pulses will be routed to the main telescope 1 m aperture; here the transmit and receive paths will be split by a rotating mirror assembly. The different paths are to cater for the difference in distance to the objects, and to ensure minimal beam divergence for LLR operation.

The 2 lasers required have been under development in collaboration with Cybioms Corporation (the NASA laser ranging contractors) for the past few years and have recently been completed. The complete laser systems have just arrived at HartRAO (Figure 1) and will be commissioned during October 2014. Some performance specifications, are listed in Table 2.

Figure 1: *SLR laser head and power supply (left) and LLR laser head (right). The LLR Laser has an additional power supply and 2 water coolers which are not included in the image.*

Table 2: *Current known parameters for the SLR and LLR lasers*

Parameter	Energy / pulse (mJ)ᵃ	Pulse Duration (ps)ᵇ	Peak Power (GW)	Pulse Rep. Rate (Hz)	Beam diam. (mm)
SLR Laser	0.51 ± 0.6%	22.5	0.023	1 000	3
LLR Laser	110 ± 0.9%	83.0	1.325	20	12

a) At 532 nm b) At 1064 nm

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References

1. Combrinck, L and Botha, R. (2013). Challenges and progress with the development of a lunar laser ranger for South Africa. *ILRS, 11-15 November*, 13-0504. Available at: http://cddis.gsfc.nasa.gov/
2. Botha, R and Combrinck L (2013). System design of the South African Lunar Laser Ranger. *ILRS, 11-15 November*, 13-Po45. Available at: http://cddis.gsfc.nasa.gov/
3. Degnan J. J. (1993). *Millimeter accuracy Satellite Laser Ranging*. Contributions of Space Geodesy to Geodynamics: Technology DOI: 10.1029/GD025p0133