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VARIABLE LINK EQUATION PARAMETERS AND EXPECTED PHOTON RETURNS FOR THE HARTRAO LUNAR LASER RANGER

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- Introduction
- Methodology
- Results
- Analysis and Discussion
- Conclusion





- The HartRAO Lunar Laser Ranger (LLR) system requires a state-ofthe-art software tool.
- The existing link budget equation estimates the number of returned photons.
- It calculates the mean number of returned photons,

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

 In this work, we focus on the effects of the three variable link budget parameters,

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





- Thermal and density fluctuations are major limiting factors.
- Other effects are introduced by the LLR system itself.
- This causes the laser to propagate through different media and thus, introduces time delays that can affect the range measured.



Figure 1: Basic description of the HartRAO LLR laser timing signals for emitted pulse and receive window.







Figure 2: The ex-OCA 1 m telescope installed on its foundation at HartRAO and the new assembly of the DC motor to control the objective lens of the beam expander.





 Development of an advanced mathematical tool, utilising C++ code, to estimate the number of received photons.

Lageos 1 is selected, now Adjust the Varying Parameters (Transmitted and Additional) -			
System Used: SLR 🔹 Satellite: Lageos1 💌 Plot Style: Line Style 💌	Open File Save to File Print Set Current Data Remove Current Set Current Color Help		
Transmitter Beam Diameter [m]: Laser Pulse Energy [J]: Pulse Repetition Rate [kHz]: 0.12 • 0.0004 1 Transmit Optics Efficiency [#]: Beam Pointing Error [#rad]: Laser Power [W]: 0.0004 0.4 • 20 • 0.0004 1 Far Field Divergence [mrad]: Transmitter Gain [#]: Pulse Duration (FWHM) [ps]: 5.64469531499256 34906579486.787 25 Wavelength [nm]: Beam Intensity [W/m^2]: Number of Photons [#/s]: 5.32e-007 0.0707355302630646 1.0712443973616e+015	Urbital elements of the Moon Longitude of the Asce. Node: Inclination to the Ecliptic: Argument of Perihelion: Semi-Major Axis: Eccentricity: Mean Anomaly: Eccentric Anomaly: Perihelion Distance: Aphelion Distance: Image: Comparison of the Asceler of Comparison of Comparis		
Additional Temperature [K]: Pressure [mbar]: Humidity [%]: 268 - 853 - Wind Speed [m/s]: Receive Optics Efficiency (#): Detector Quantum Efficiency: 0 - 0.4 - Atmospheric Transmission: Cloud Cover: Ground Turbulence Strength: 0.02 - 0.1 - Satellite Cross-Section [m^2]: Receive Aperture [m^2]: Atm Turbulence Strength: 7000000 0.78539816339 Atm Turbulence Strength: Slant Range [km]: Min Max Received Photon Difference [#]: 1.07124439736159e+015 Slant Range [km]: Slant Range [km]: Slant Range [km]:	$\left[\begin{array}{c} 10.0 \\ 8.0 \\ 6.0 \\ 4.0 \\ 2.0 \\ -2.0 \\ -2.0 \\ -3.0 \\ -6.0 \\ -8.0 \\ -10.0 \\ -1$		
6137.54713028641	🖌 🖌 X Axis		

Figure 7: GUI for calculating the estimated number of returned photons under various conditions.







Figure 3: Received photons per minute vs. varying atmospheric transmission.



Figure 5: Received photons per minute vs. cirrus cloud transmission, for atm. transmission at min. (red) and max (blue).



Figure 4: Received photons per minute vs. the slant range (x 10^3 km).



Figure 8: Received photons per minute vs. fixed system parameters ($C_{system} \times 10^{35}$).



- The slant range, R is one of the biggest influences on the number of received photons.
- The maximum number of returned photons also depends on "better" atmospheric conditions (Table 1).

Parameter	Worst value	Optimal value
Laser pulse energy (mJ)	100	110
Transmit optics efficiency	0.4	0.9
Slant range (km)	405000	378084
Detector quantum eff.	0.4	0.7
Receive optics eff.	0.4	0.9
Atmospheric transmission	0.02	0.81
Cirrus transmission	0.1	1
Returned photons/min	0.003	15

Table 1: The relationship between varying parameters and number of photons.





In conclusion, expansion of the existing link equation is required in order to consider those time delays (that affects the range) and other factors, which can be caused by the detection system as the photons are transmitted and received through the LLR signal path. This will help improve the system signal-to-noise ratio, thus ensuring more photon returns for the HartRAO LLR.





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Questions

Thank you very much for your time