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

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OUTLINE

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- Conclusion

Introduction

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

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

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

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

Methodology

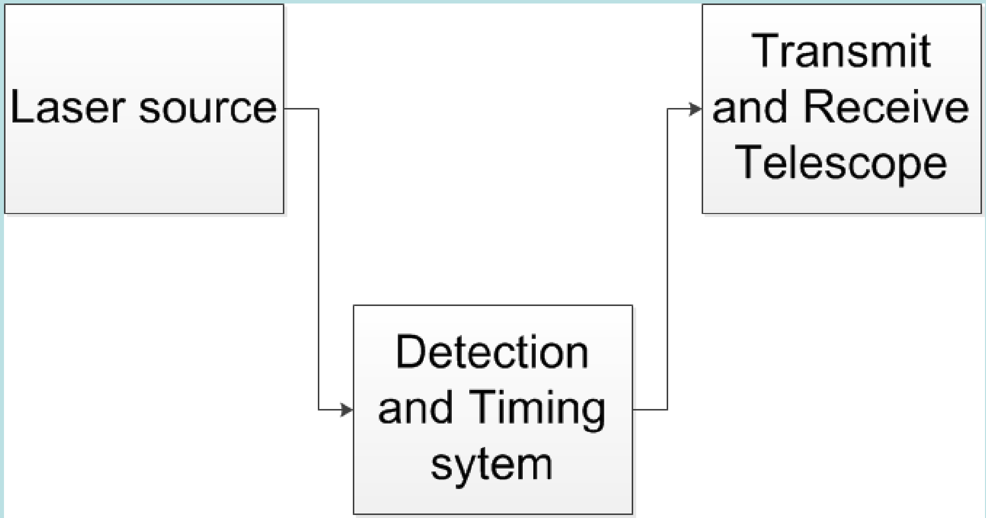

Figure 1: Basic description of the HartRAO LLR laser timing signals for emitted pulse and receive window.

- 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.

Methodology Cont.…

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.

Methodology Cont.…

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HartRAO Hartebeesthoek Radio Astronomy Observatory

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

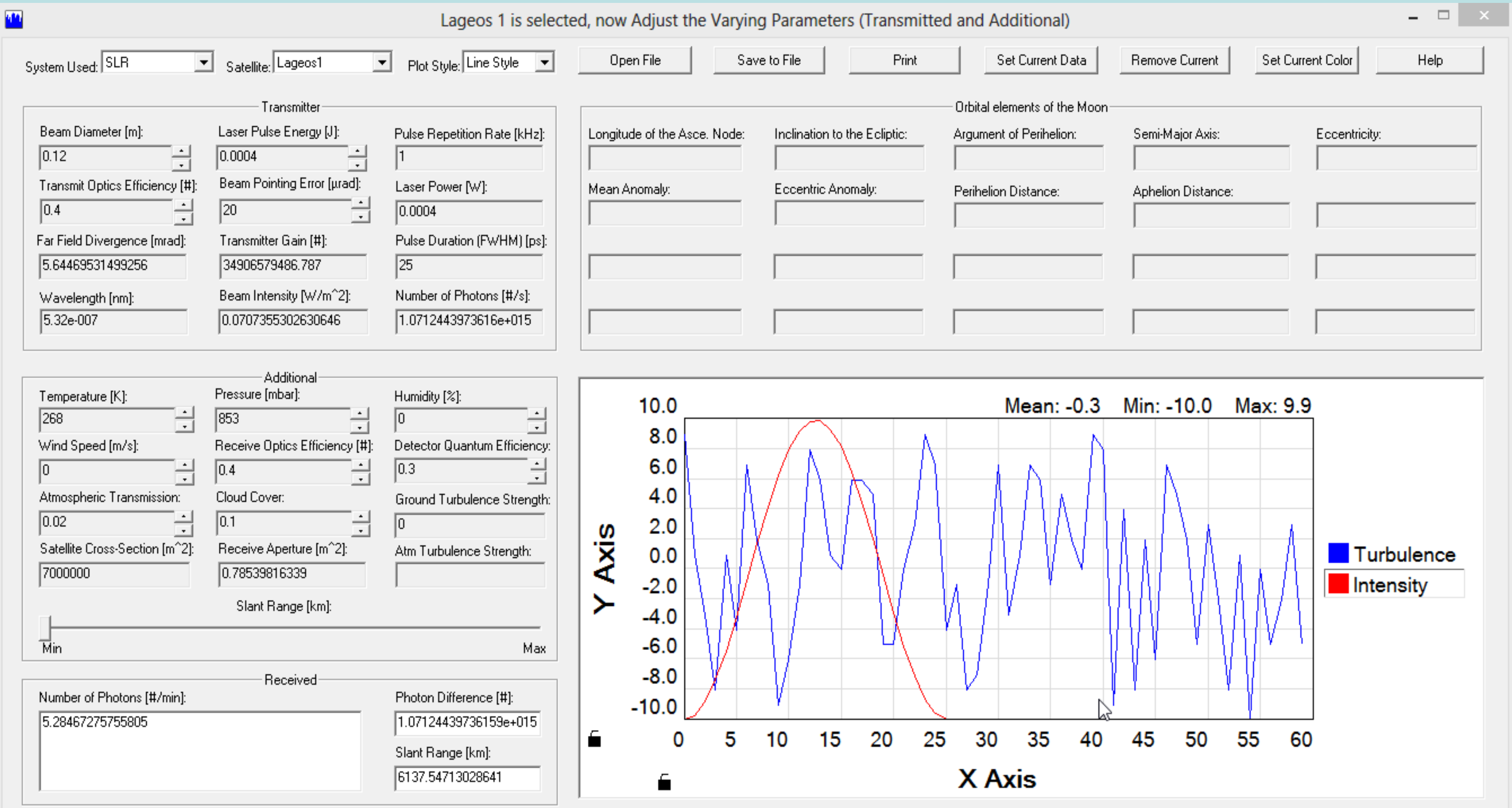

Figure 7: GUI for calculating the estimated number of returned photons under various conditions.

Results

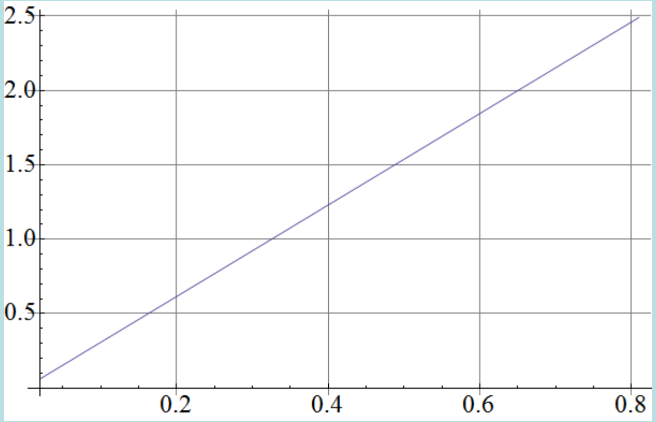

Figure 3: Received photons per minute vs. varying atmospheric transmission.

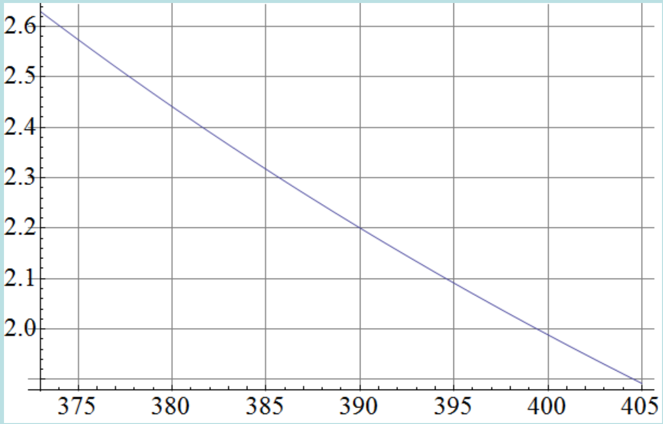

Figure 4: Received photons per minute vs. the slant range (x 10^3 km).

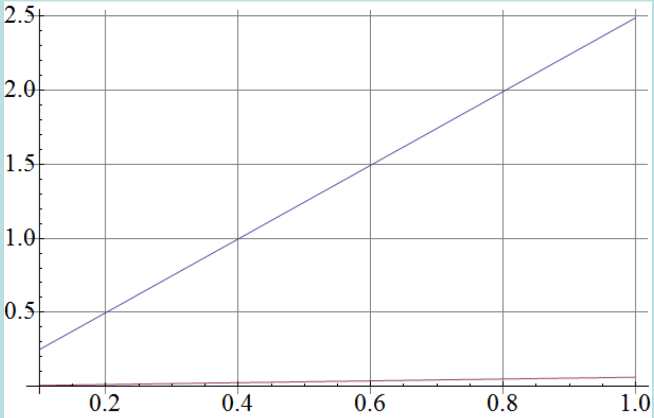

Figure 5: Received photons per minute vs. cirrus cloud transmission, for atm. transmission at min. (red) and max (blue).

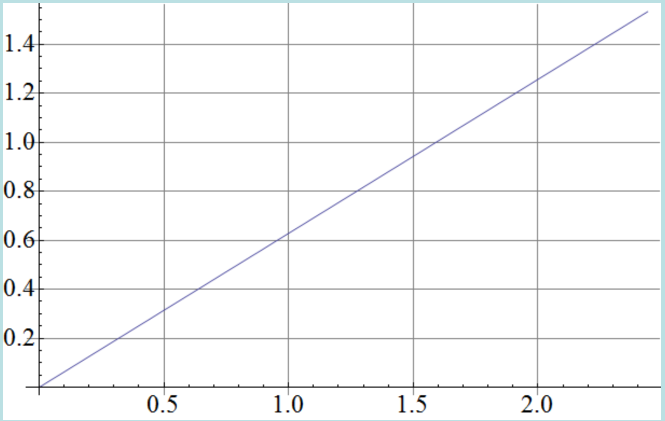

Figure 8: Received photons per minute vs. fixed system parameters (C_{system} x 10^{35}).

Analysis and Discussion Cont.….

- 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).

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

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

Conclusion

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.

Acknowledgements

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References

Combrinck, L. and Botha, R. (2013), *Challenges and progress with the development of a Lunar Laser Ranger for South Africa, 18th* ILRS proc.

Degnan J. J. (1993), *Millimeter accuracy Satellite Laser Ranging*.

Ndlovu S. C. and Chetty, N. (2014), *Analysis of the fluctuations of a laser beam due to thermal turbulence*, CEJP.

Questions

Thank you very much for your time