An integrated software based analytical model for the signal path efficiency of the HartRAO lunar laser ranger optical system

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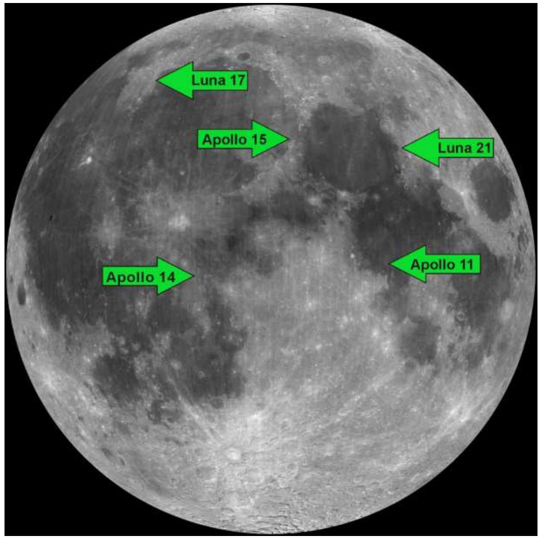
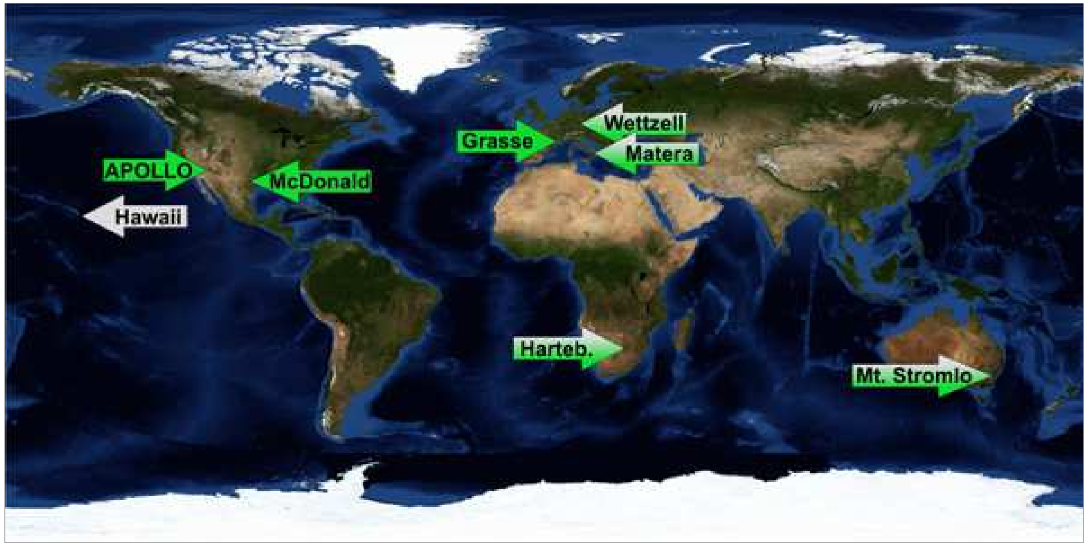
Introduction

What is HartRAO-LLR?

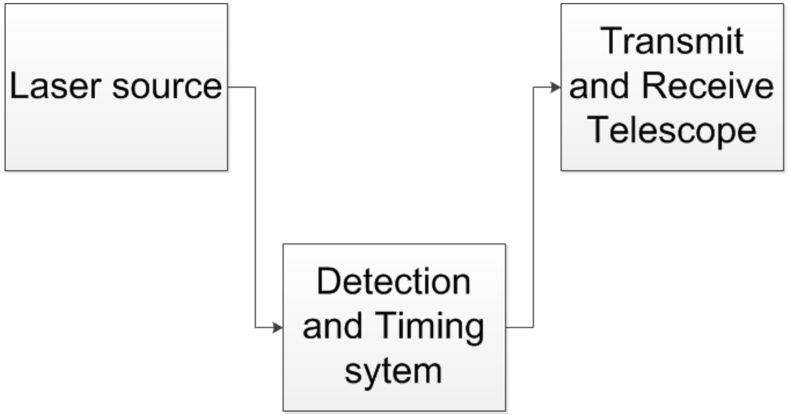
- Hartebeesthoek Radio Astronomy Observatory's Lunar Laser Ranger.
- Lunar Laser Ranging (LLR) is a geodetic technique.





- This is currently the only LLR in the Southern Hemisphere.

Overview of the HartRAO-LLR system



Measurement challenge

- 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 by calculating the mean number of detected returned photons as,

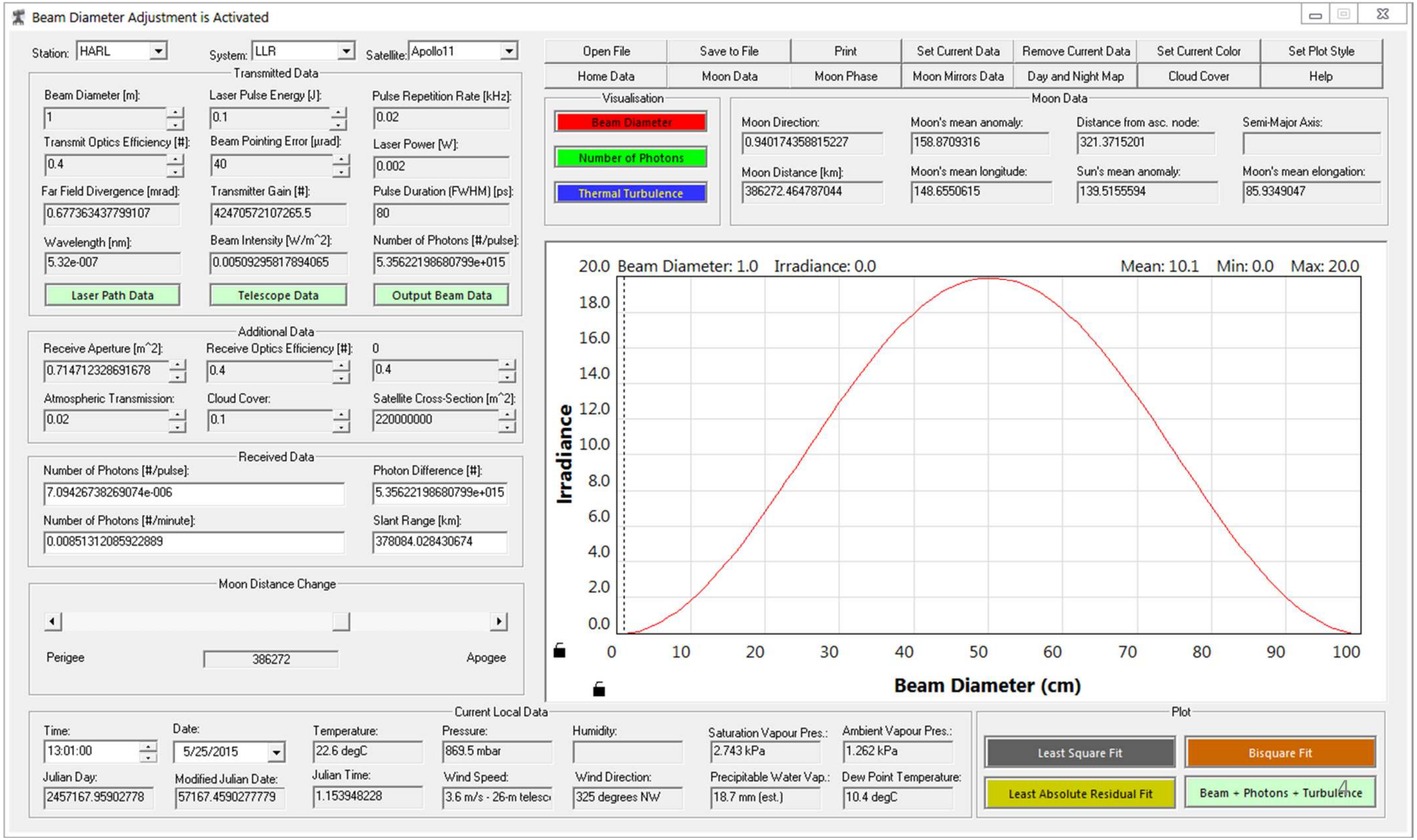
$$n_p = \eta_q \left(E_T \frac{\lambda}{hc}\right) \eta_t G_t \sigma \left(\frac{1}{4\pi R^2}\right)^2 A_r \eta_r T_a^2 T_c^2. \qquad (1)$$

- Equation 1 becomes,

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

Returned photons estimation

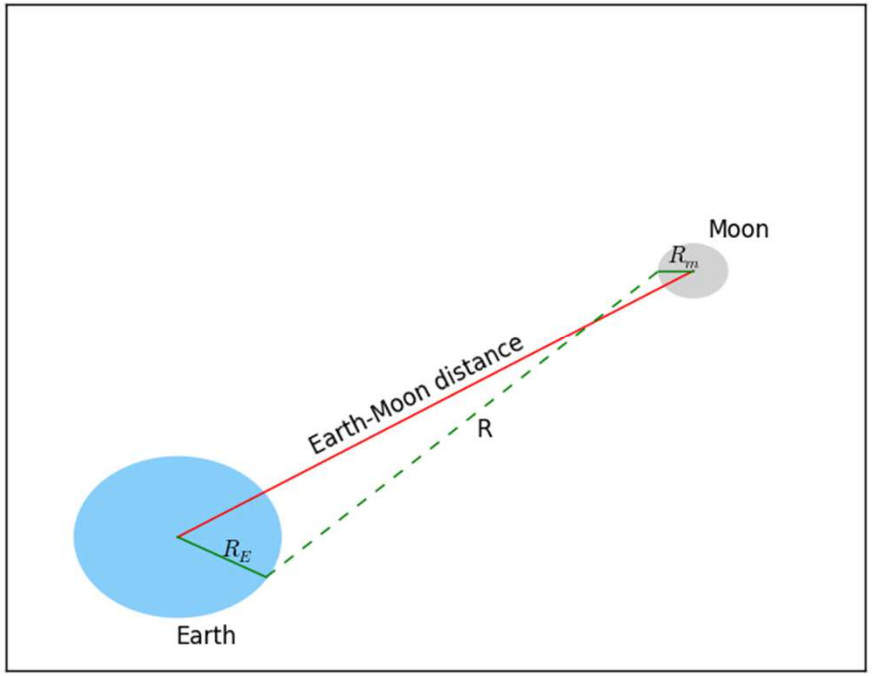
Generating data



Simulations and analysis

Laser Specifications	SLR	LLR
Output Energy, mJ	0.5	120
Repetition rate, Hz	1000	20
Beam Diameter, mm	~3	~12
Pointing stability, µrad	<30	<50
Beam Diameter, m	0.2	1.0

Slant range



Retroreflectors

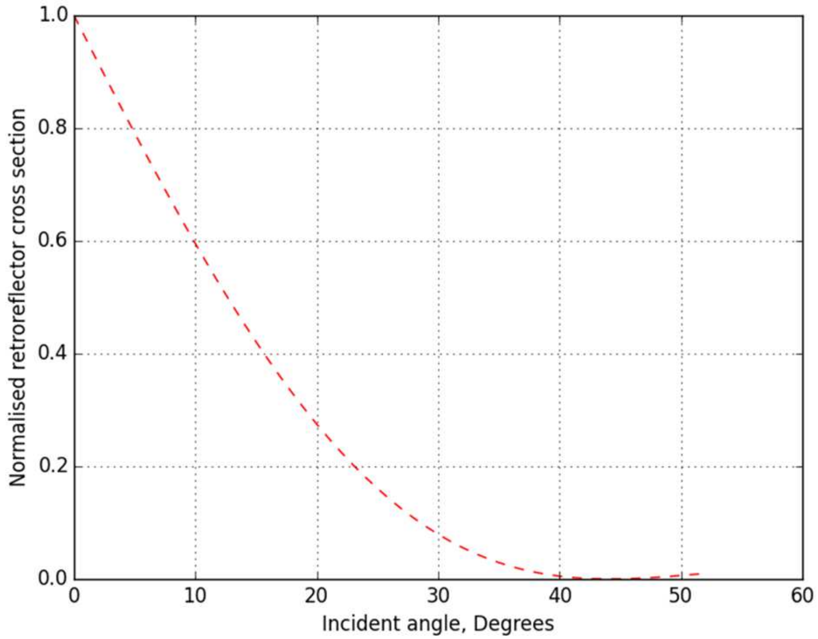
The number of returned photons linearly varies with the lunar reflector cross section. A study on the effective area of the corner cube has revealed that, at arbitrary incident angle, the area is reduced by the factor,

$$\eta(\theta_{inc}) = \frac{2}{\pi}\left(\sin^{-1}\mu - \sqrt{2}\tan\theta_{ref}\right)\cos\theta_{inc}$$

where $\mu = \sqrt{1-\tan^2\theta_{ref}}$

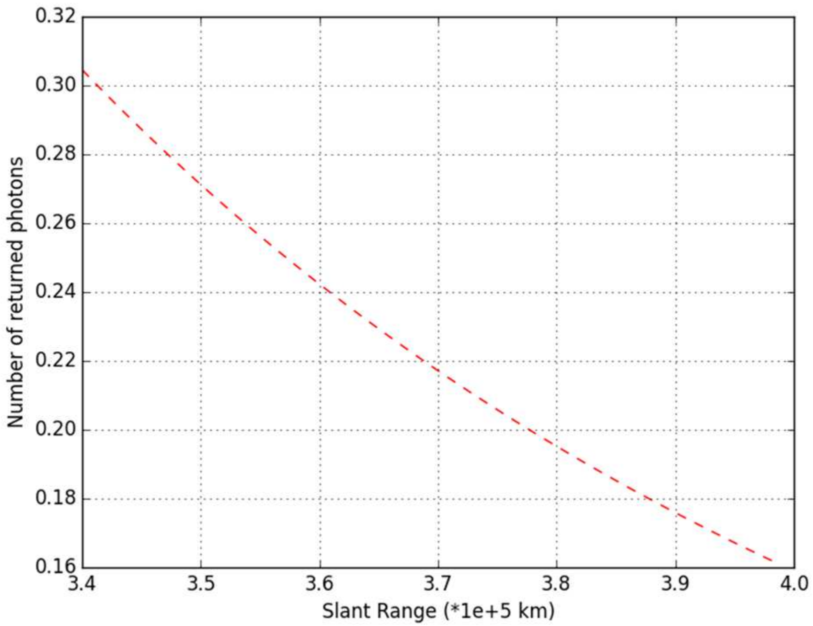
The peak optical cross-section in the centre of the reflected lobe decreases as the incident angle increases,

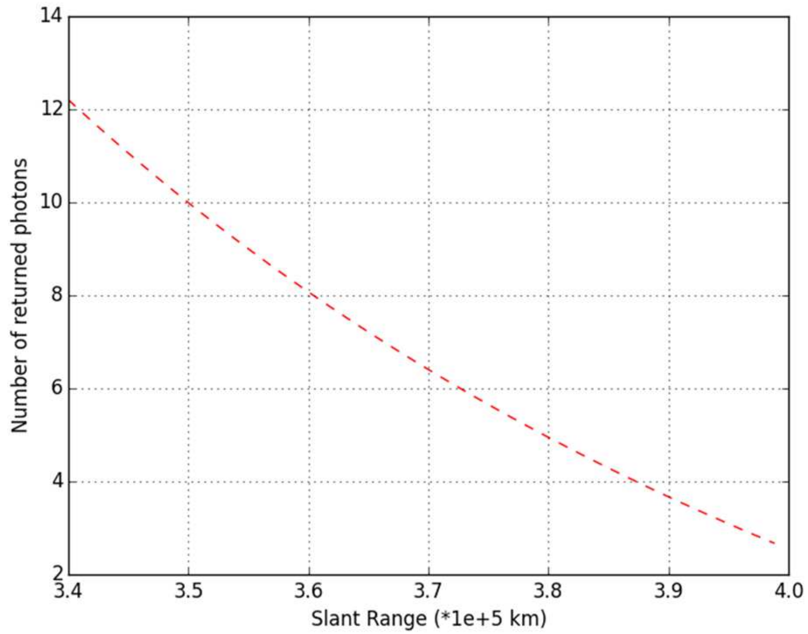
$$\sigma_{eff}\left(\theta_{inc}\right) = \eta^2\left(\theta_{inc}\right)\frac{\pi^3\rho D^4}{4\lambda^2}$$



Results and discussion

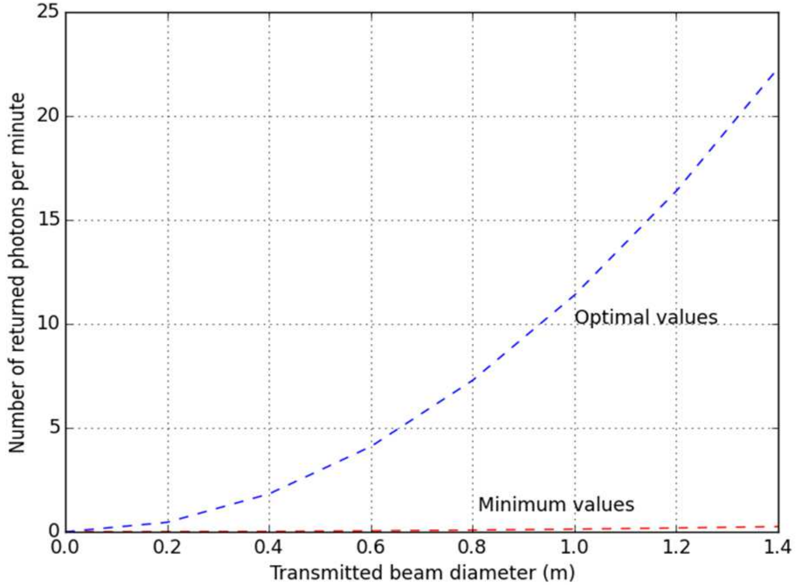
$$n_p \propto \left(\frac{\mathrm{T_a T_c}}{R^2}\right)^2$$

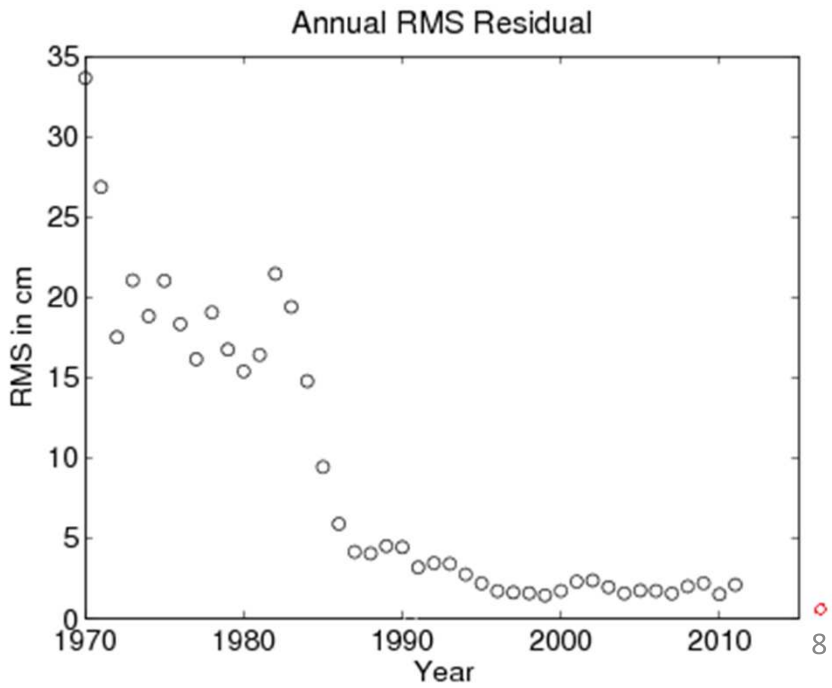




Returned photons

Parameter	Min value	Max value
Transmit optics efficiency	0.4	0.9
Slant range (km)	399929	347929
Detector quantum efficiency	0.4	0.7
Receive optics efficiency	0.4	0.9
Atmospheric transmission	0.02	0.81
Cirrus transmission (Cloud cover)	0.1	1
Returned photons/minute	0.003	12





Conclusion

- We have successfully developed an integrated software model that will enable optimal signal path efficiency for the HartRAO's LLR system.
- Our estimated signal return rate is a true reflection of the LLR photons returns.

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Siyabonga (Thank you).

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