

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

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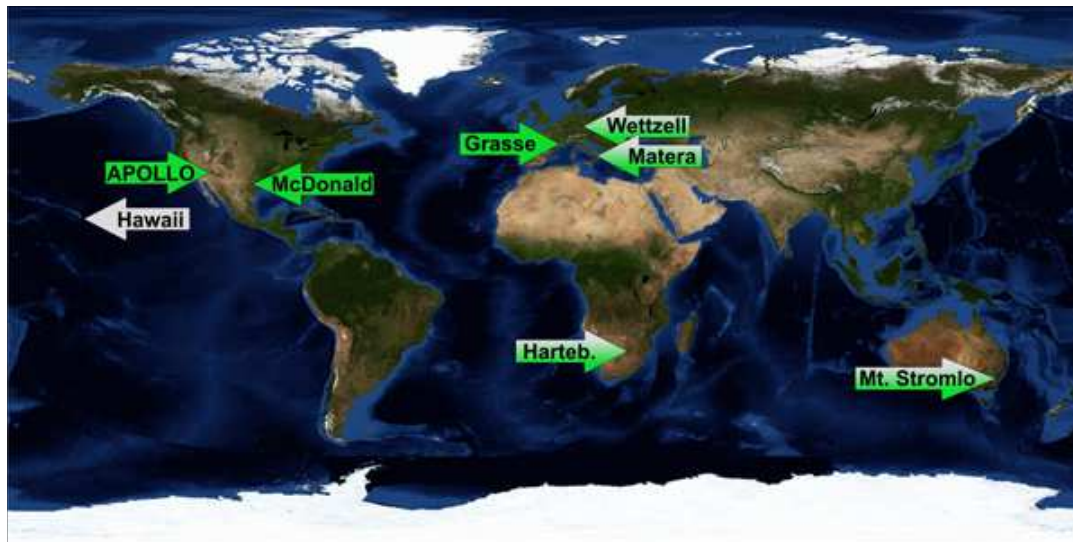
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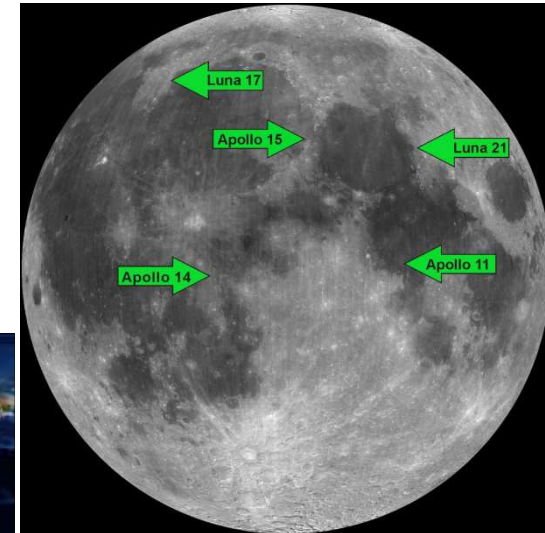
# Introduction

## What is HartRAO-LLR?

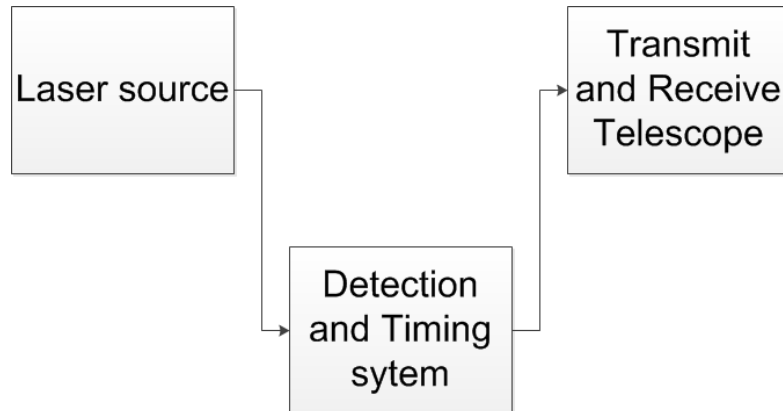
- Hartebeesthoek Radio Astronomy Observatory's Lunar Laser Ranger.
- Lunar Laser Ranging (LLR) is a geodetic technique.



- 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,

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

- Equation 1 becomes,

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

# Returned photons estimation

## Generating data

Beam Diameter Adjustment is Activated

Station: <input type="text" value="HARL"/>	System: <input type="text" value="LLR"/>	Satellite: <input type="text" value="Apollo11"/>
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**Transmitted Data**

Beam Diameter [m]: <input type="text" value="1"/>	Laser Pulse Energy [J]: <input type="text" value="0.1"/>	Pulse Repetition Rate [kHz]: <input type="text" value="0.02"/>
Transmit Optics Efficiency [#]: <input type="text" value="0.4"/>	Beam Pointing Error [μrad]: <input type="text" value="40"/>	Laser Power [W]: <input type="text" value="0.002"/>
Far Field Divergence [mrad]: <input type="text" value="0.677363437799107"/>	Transmitter Gain [#]: <input type="text" value="42470572107265.5"/>	Pulse Duration [FWHM] [ps]: <input type="text" value="80"/>
Wavelength [nm]: <input type="text" value="5.32e-007"/>	Beam Intensity [W/m <sup>2</sup> ]: <input type="text" value="0.00509295817894065"/>	Number of Photons [#]/pulse: <input type="text" value="5.35622198680799e+015"/>

**Visualisation**

Beam Diameter  
 Number of Photons  
 Thermal Turbulence

**Moon Data**

Moon Direction: <input type="text" value="0.940174358815227"/>	Moon's mean anomaly: <input type="text" value="158.8709316"/>	Distance from asc. node: <input type="text" value="321.3715201"/>	Semi-Major Axis: <input type="text"/>
Moon Distance [km]: <input type="text" value="386272.464787044"/>	Moon's mean longitude: <input type="text" value="148.6550615"/>	Sun's mean anomaly: <input type="text" value="139.5155594"/>	Moon's mean elongation: <input type="text" value="85.9349047"/>

**Additional Data**

Receive Aperture [m <sup>2</sup> ]: <input type="text" value="0.714712328691678"/>	Receive Optics Efficiency [#]: <input type="text" value="0.4"/>	<input type="text" value="0"/>
Atmospheric Transmission: <input type="text" value="0.02"/>	Cloud Cover: <input type="text" value="0.1"/>	Satellite Cross-Section [m <sup>2</sup> ]: <input type="text" value="220000000"/>

**Received Data**

Number of Photons [#]/pulse: <input type="text" value="7.09426738269074e-006"/>	Photon Difference [#]: <input type="text" value="5.35622198680799e+015"/>
Number of Photons [#]/minute: <input type="text" value="0.00851312085922889"/>	Slant Range [km]: <input type="text" value="378084.028430674"/>

**Moon Distance Change**

Perigee:  Apogee:

**Current Local Data**

Time: <input type="text" value="13:01:00"/>	Date: <input type="text" value="5/25/2015"/>	Temperature: <input type="text" value="22.6 degC"/>	Pressure: <input type="text" value="869.5 mbar"/>	Humidity: <input type="text"/>	Saturation Vapour Pres.: <input type="text" value="2.743 kPa"/>	Ambient Vapour Pres.: <input type="text" value="1.262 kPa"/>
Julian Day: <input type="text" value="2457167.95902778"/>	Modified Julian Date: <input type="text" value="57167.459027779"/>	Julian Time: <input type="text" value="1.153948228"/>	Wind Speed: <input type="text" value="3.6 m/s - 26-m telese"/>	Wind Direction: <input type="text" value="325 degrees NW"/>	Precipitable Water Vap.: <input type="text" value="18.7 mm (est.)"/>	Dew Point Temperature: <input type="text" value="10.4 degC"/>

**Plot**

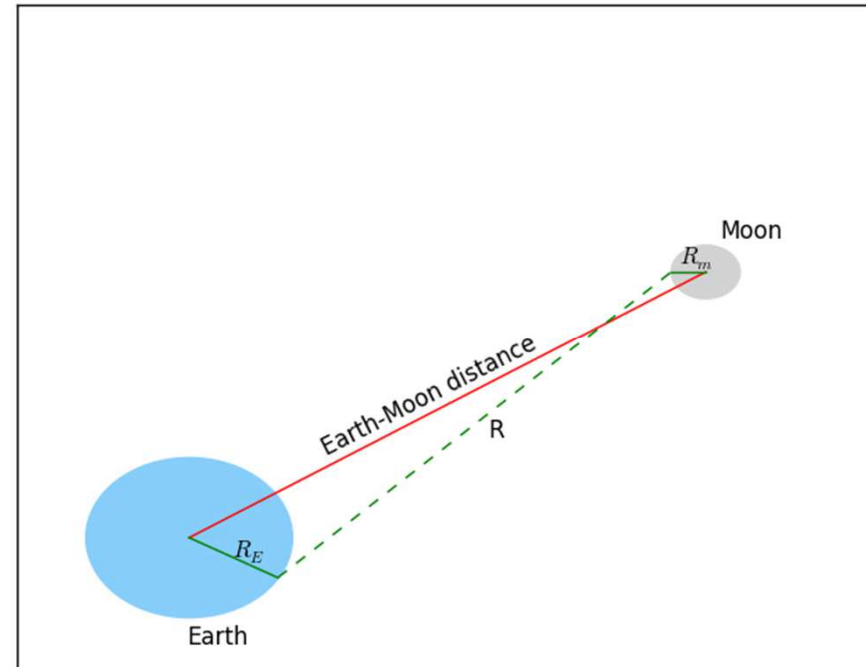
Beam Diameter: 1.0 Irradiance: 0.0 Mean: 10.1 Min: 0.0 Max: 20.0

# 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, $\mu\text{rad}$	<30	<50
Beam Diameter, m	0.2	1.0



## Slant range



## Retroreflectors

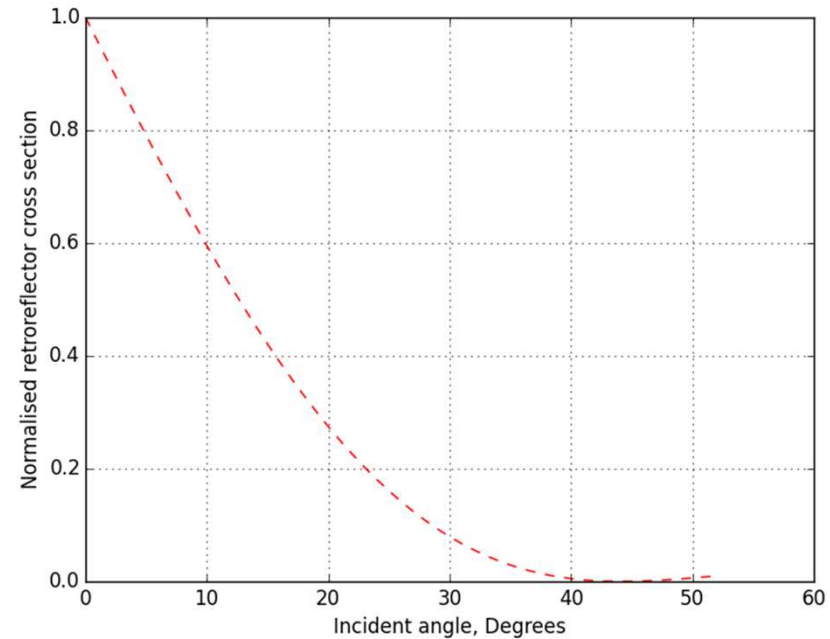
The number of returned photons linearly varies with the lunar reflector cross section. A study on the effective area of the corner cube has revealed that, at arbitrary incident angle, the area is reduced by the factor,

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

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,

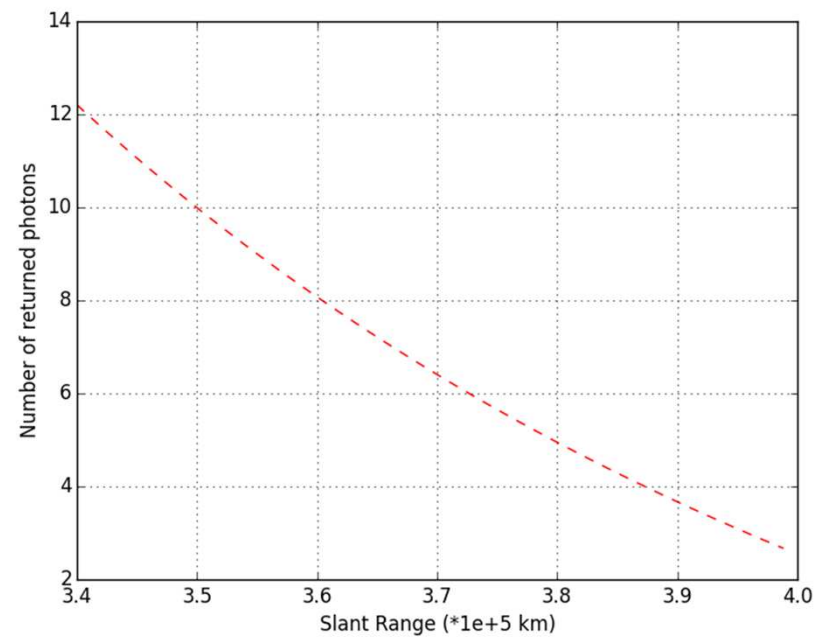
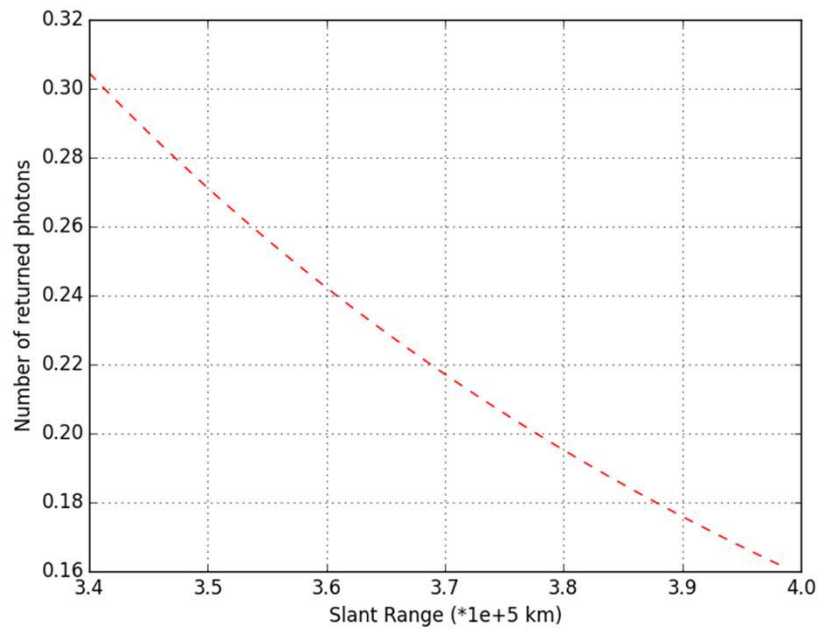
$$\sigma_{eff}(\theta_{inc}) = \eta^2(\theta_{inc}) \frac{\pi^3 \rho D^4}{4\lambda^2}$$





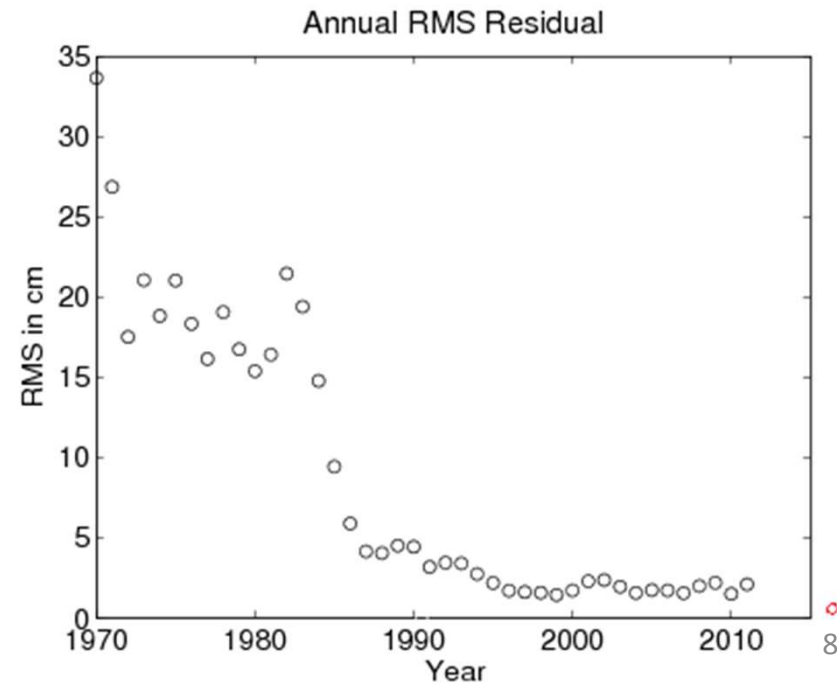
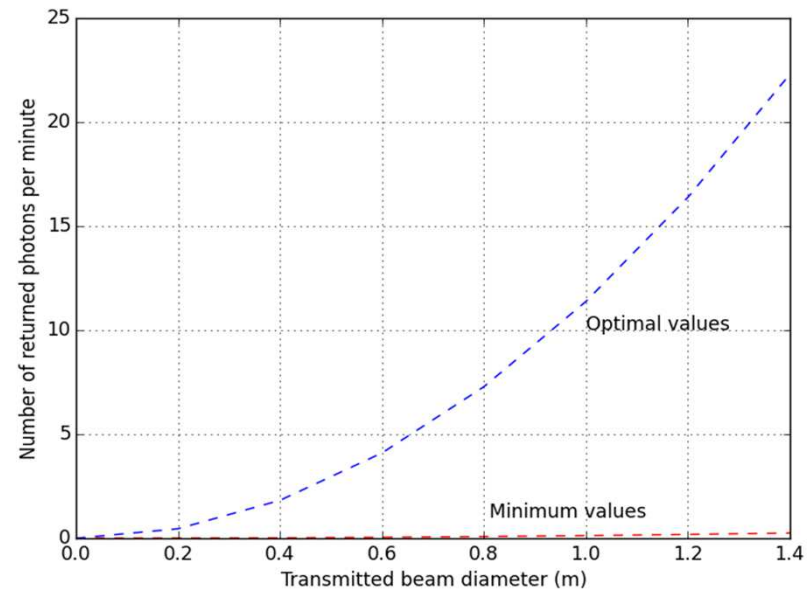
# Results and discussion

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



## 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
<b>Returned photons/minute</b>	<b>0.003</b>	<b>12</b>





## 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.

# Siyabonga (Thank you).



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