Exploring the impact of Lunar Dust on Apollo Retroreflector Array LLR Return Rates

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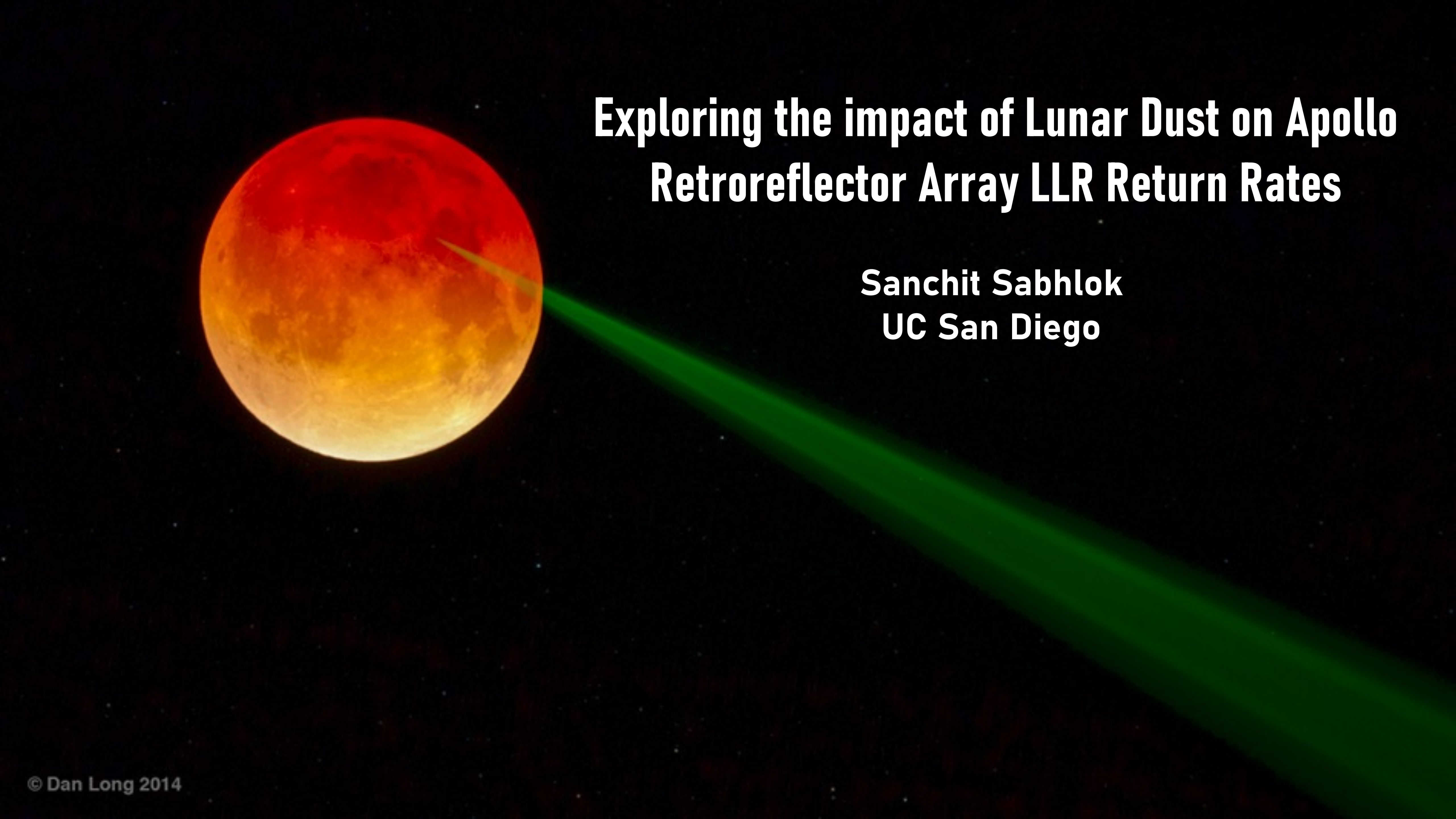

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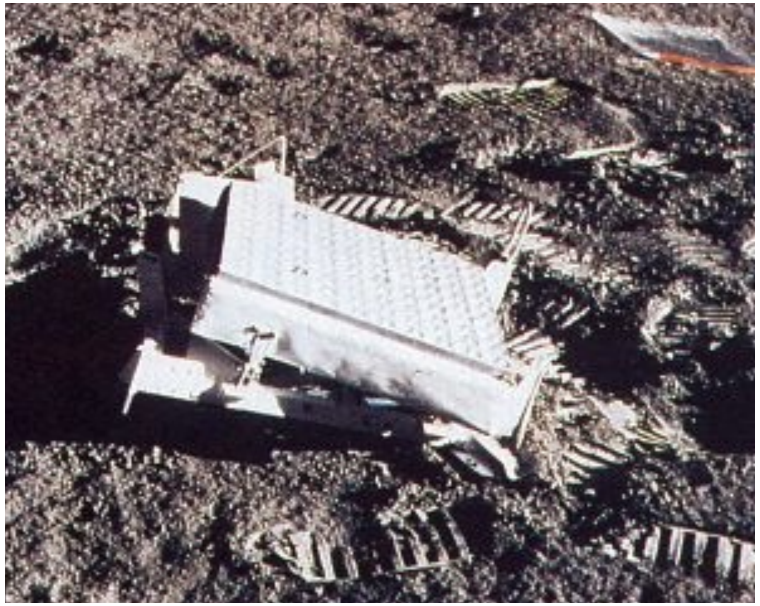
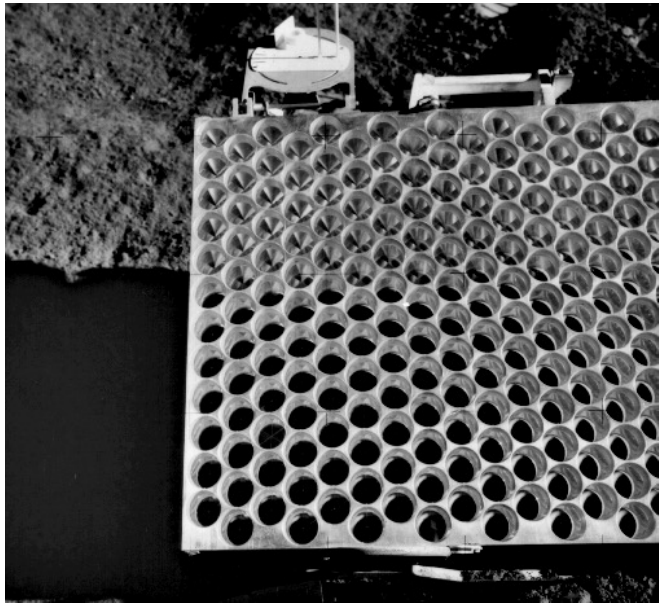
Apollo Retroreflector Arrays

Apollo 11
100 Corner Cubes

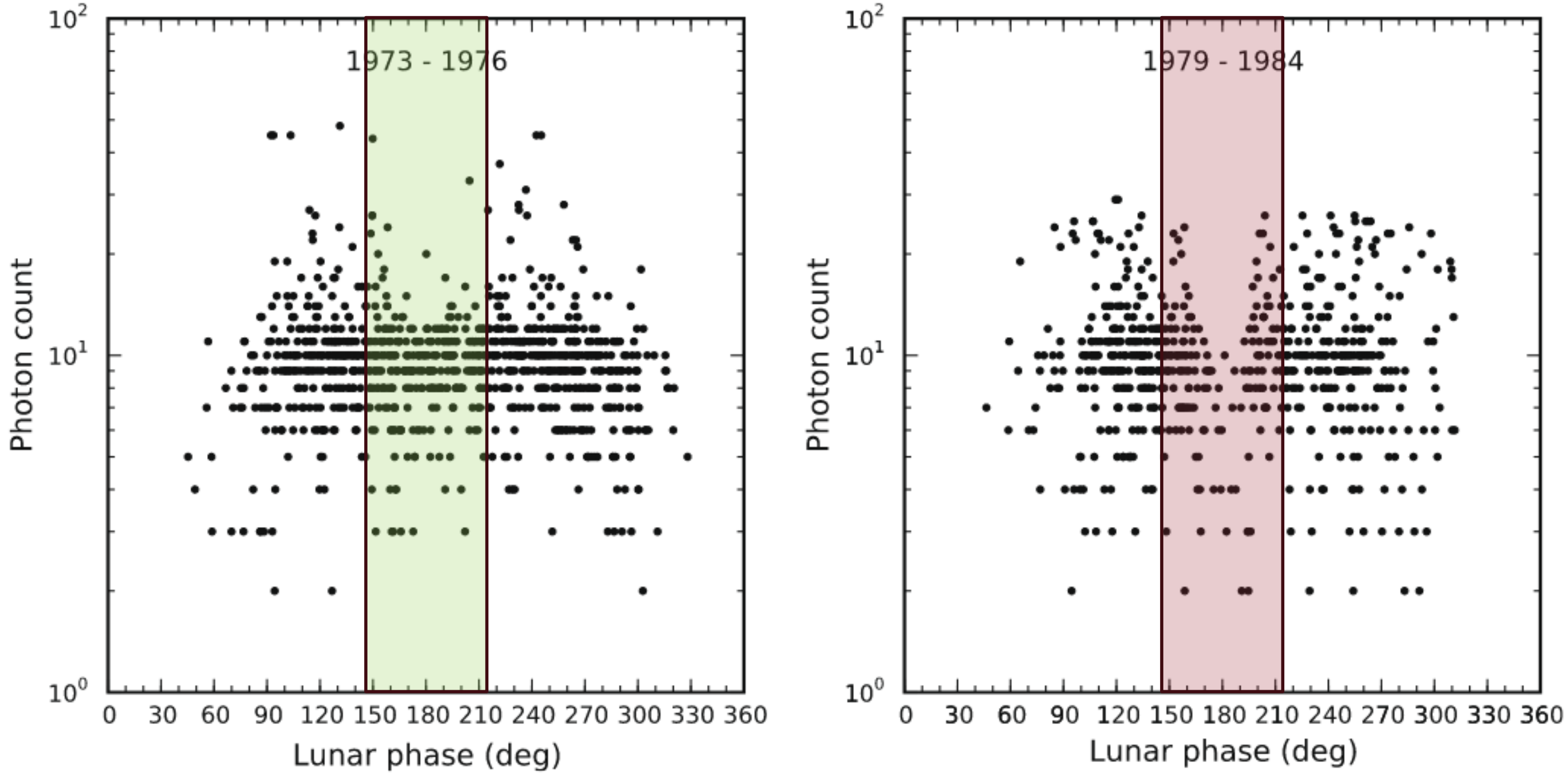


Apollo 14
100 Corner Cubes



Apollo 15
300 Corner Cubes

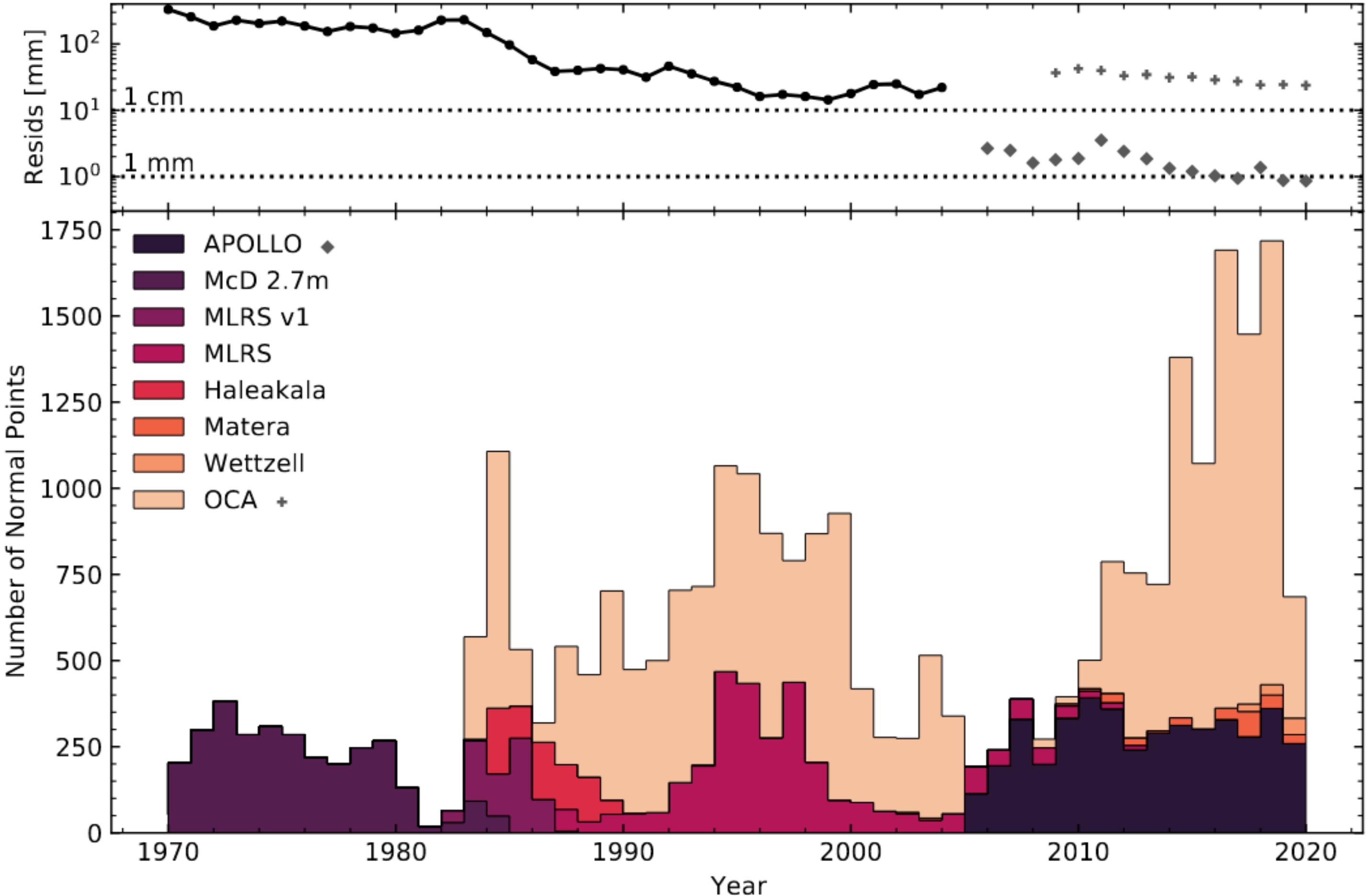
The Origin of the Full Moon Curse



Signal Deficit around Full Moon from McDonald Observatory 2.7 m Smith Telescope (Murphy+ 2010)

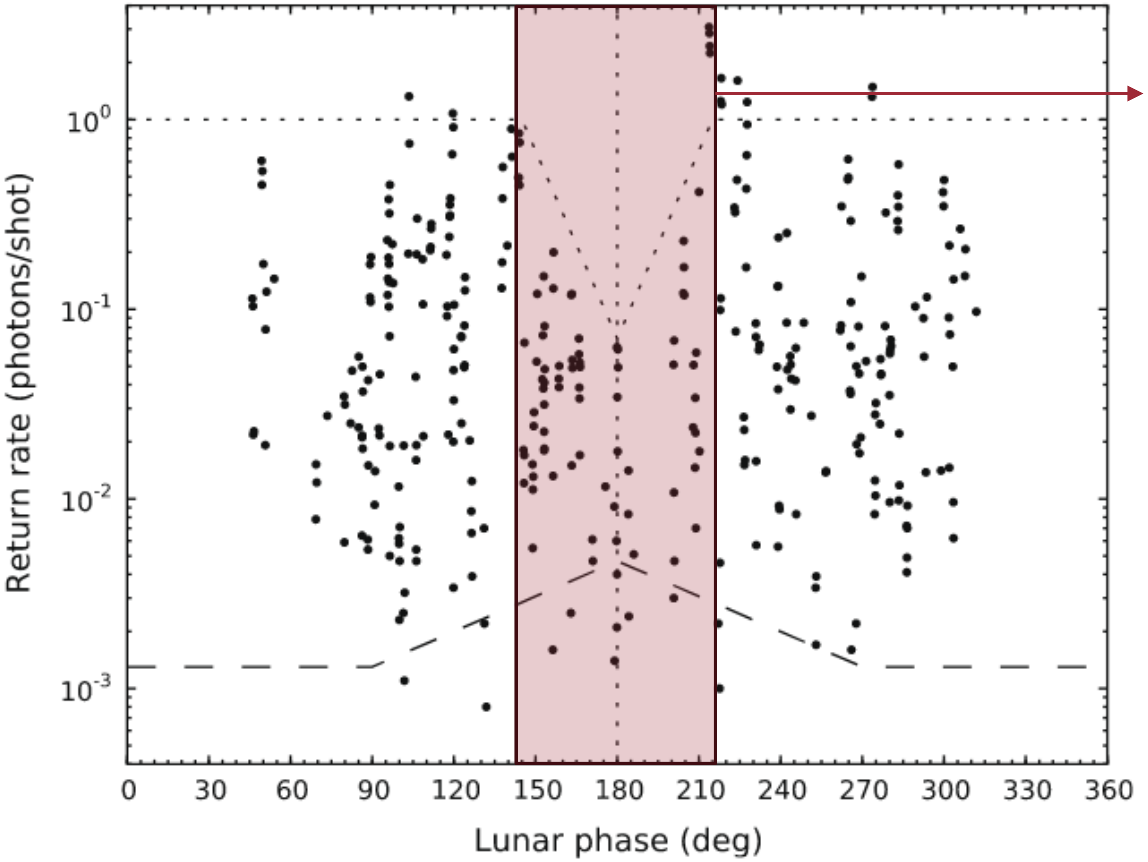
APOLLO

Apache Point Observatory Lunar Laser-ranging Operation (APOLLO) has been on sky since 2005



APOLLO Normal Points (Battat+ 2023)

Full moon deficit seen by APOLLO



Reduced Return Rates when close to Full Moon

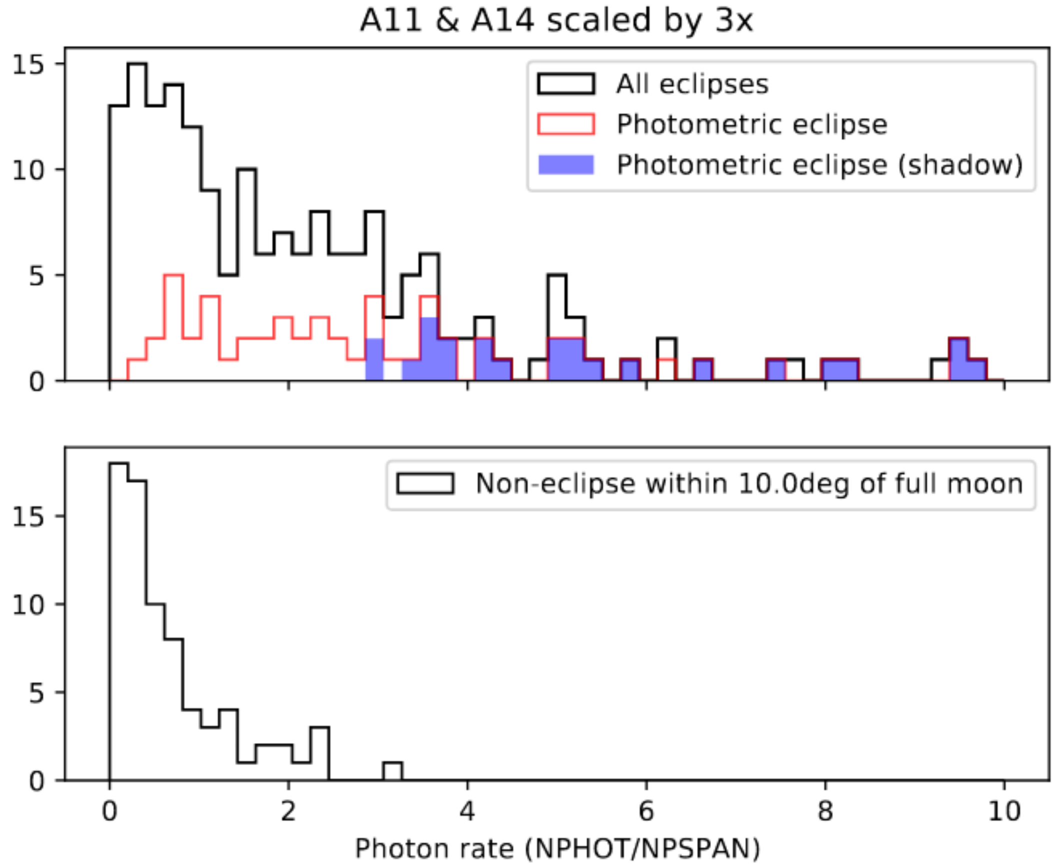
APOLLO Return Rate deficit (Murphy+ 2010)

Signal recovers during Lunar Eclipse

Laser Ranging Return rates tend to rebound during an eclipse

APOLLO has observed this rebound repeatedly since 2010

This gives a timescale against which thermal effects can be compared



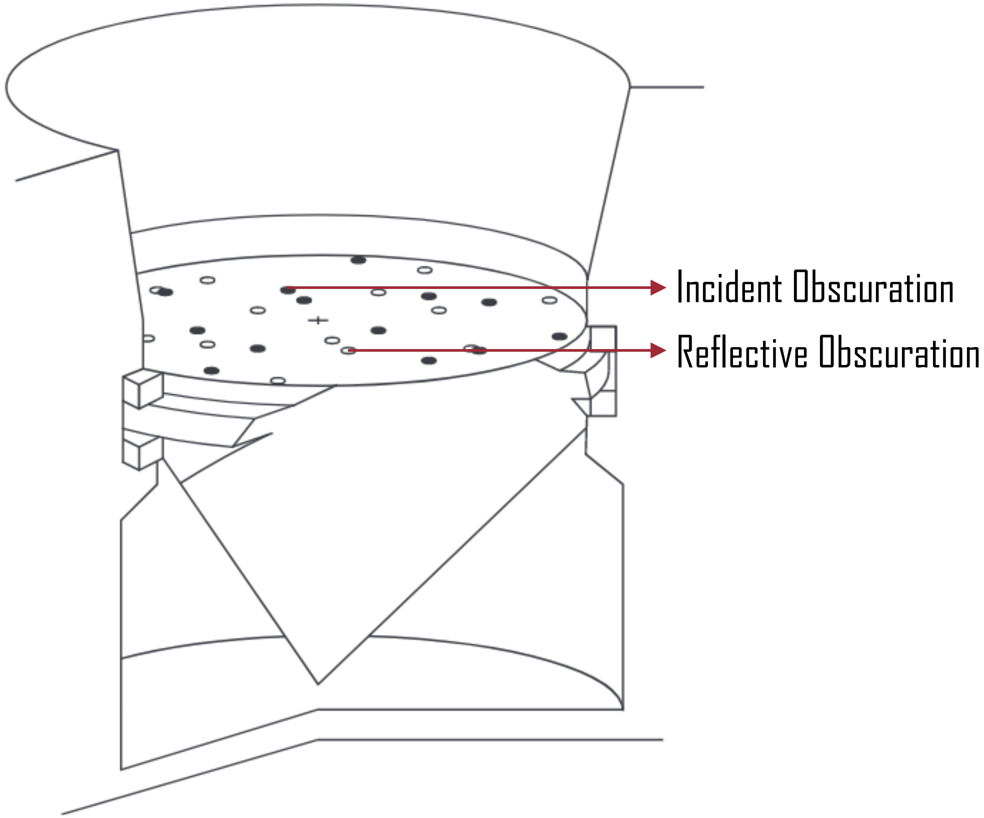
Enhanced Return Rates during Eclipses (Sabhlok+ 2023 (in prep))

Dust obscuration on Corner cubes

Dust obscuration on the corner cube surfaces can set up thermal gradients.

Dust coverage will also obscure the incident and reflected radiation.

We can convert the corner cube temperature profile into a Far Field Diffraction pattern (FFDP) (Goodrow & Murphy 2014)

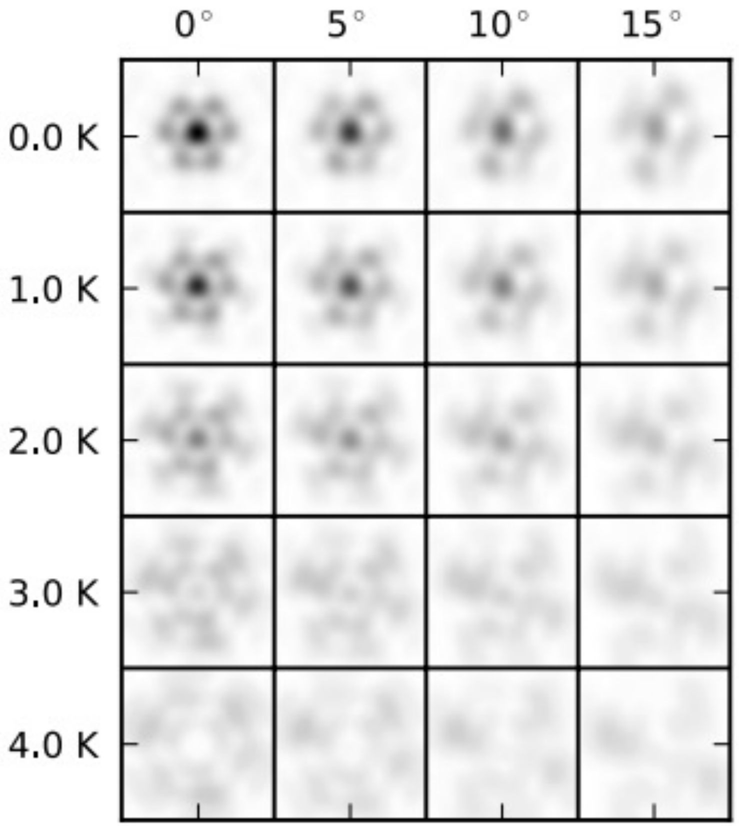


Dust Obscuration on Corner Cubes (Murphy+ 2014)

Thermal gradients impact return rates

Thermal gradients in the Corner Cube can decrease the intensity of Far Field Diffraction Pattern central maximum.

These gradients can be axial, radial or a combination of the two.



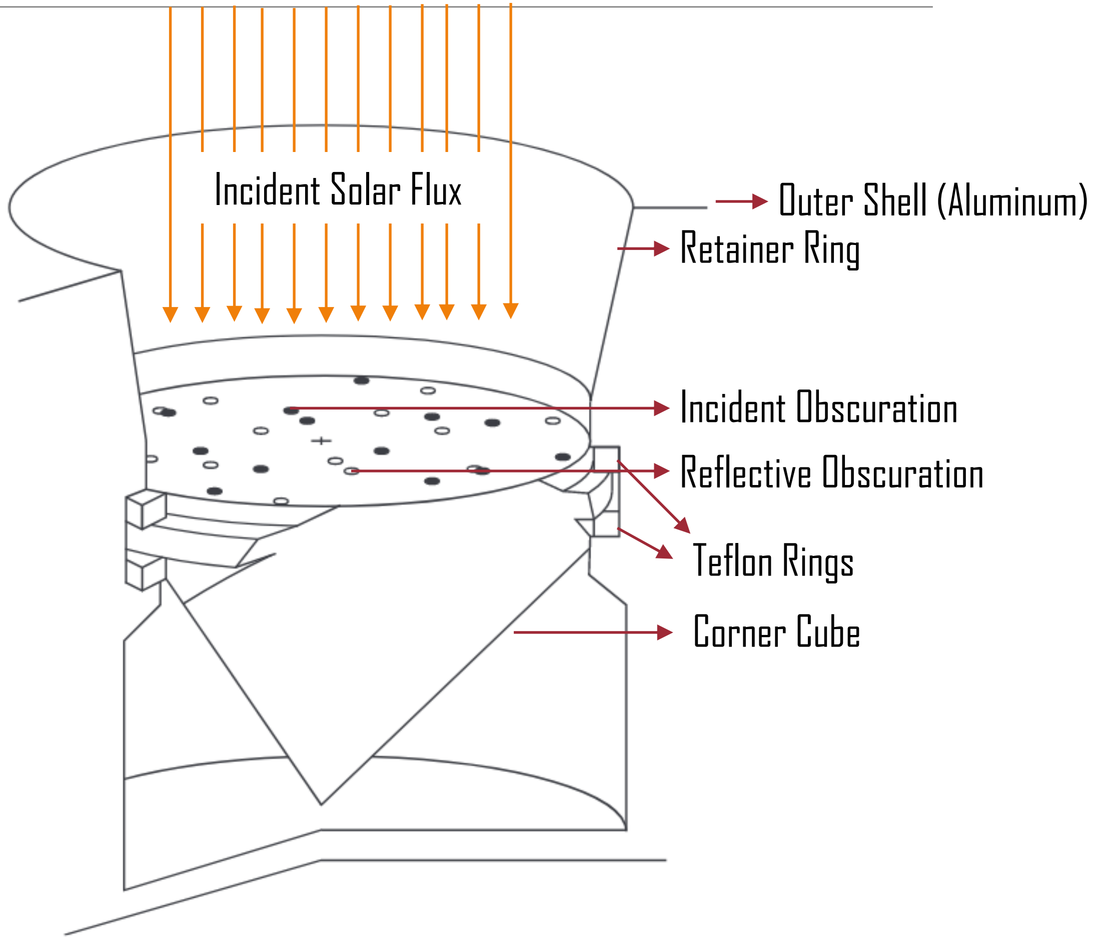
Effects of axial thermal gradient on Far Field Diffraction Pattern (Goodrow and Murphy 2012)

Thermal Simulations

We use in house code written in C to simulate the heat transfer in a dust obscured Corner Cube.

We consider the conduction between corner cube, Teflon rings, retainer ring and the larger shell

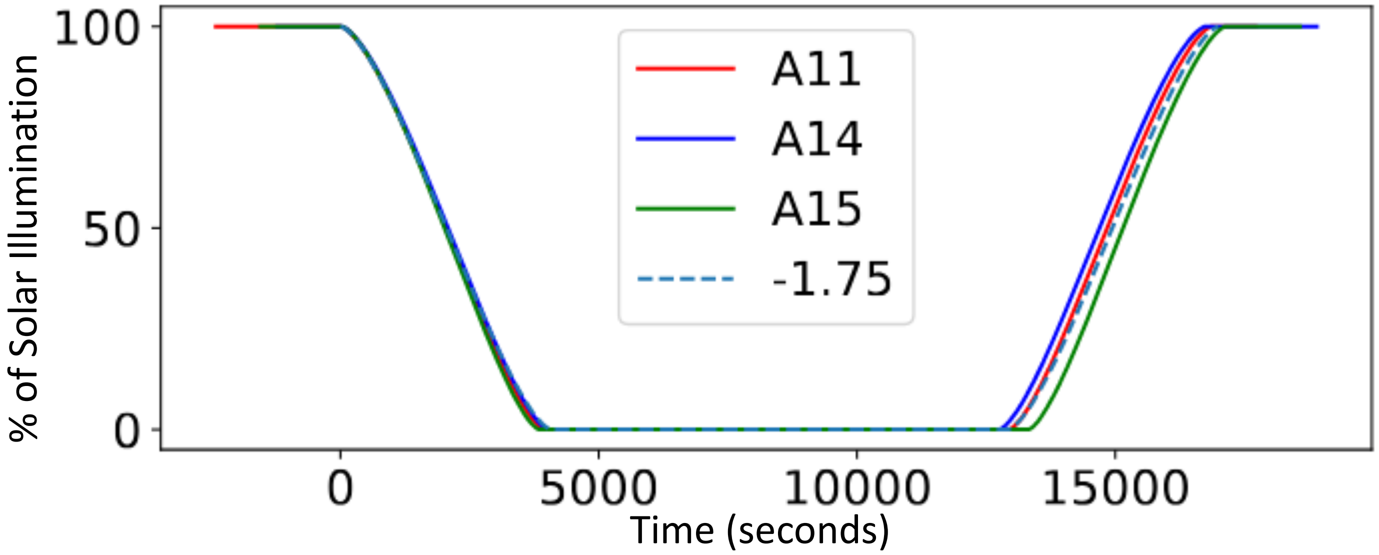
Radiative heat transfer is treated analytically for all surfaces in the geometry.

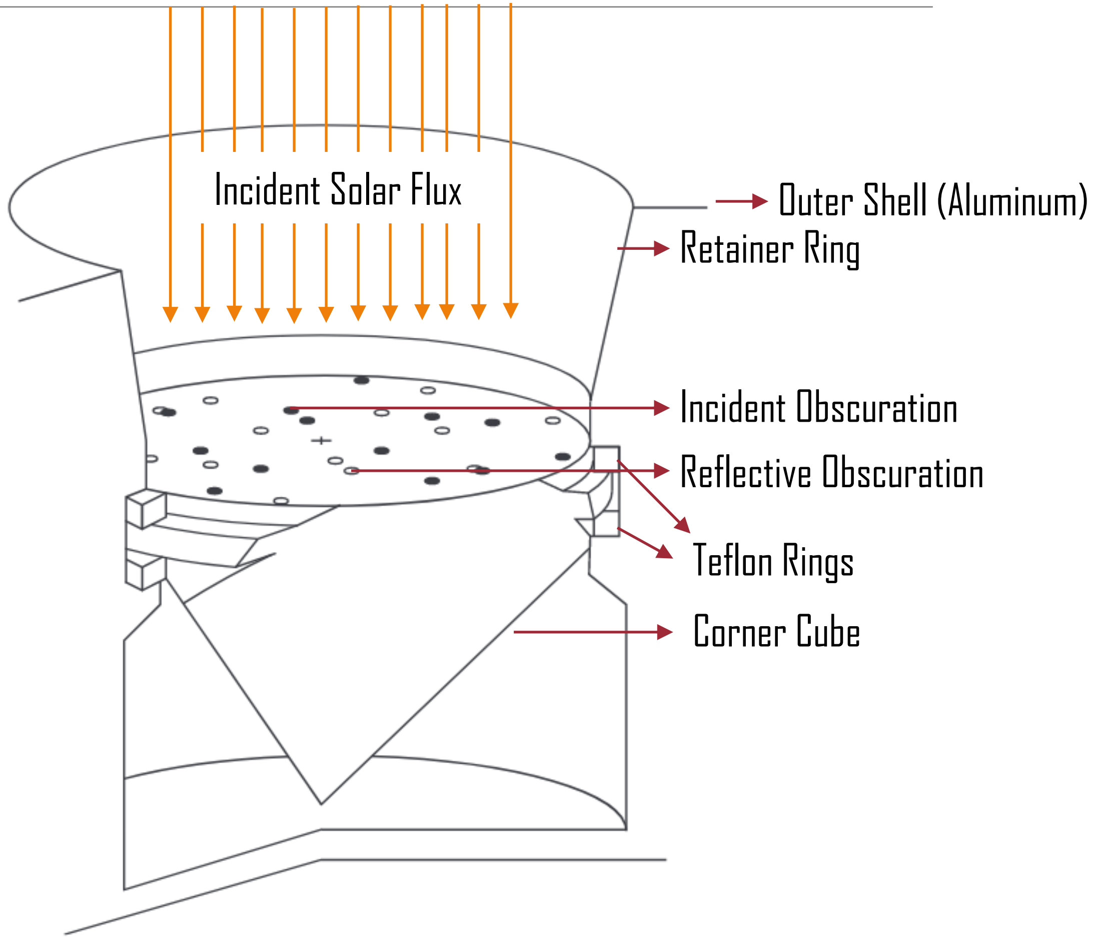


Simulation Setup

First Equilibrate to Full Moon Steady State.

Then apply transient solar flux during an eclipse





Thermal Simulation Objectives

We compare steady state solutions for full moon conditions and compare FFDP to an isothermal corner cube.

We then run this equilibrated corner cube through a lunar eclipse, matching observed parameters for the April 2014 lunar eclipse for which we have ranging observations.

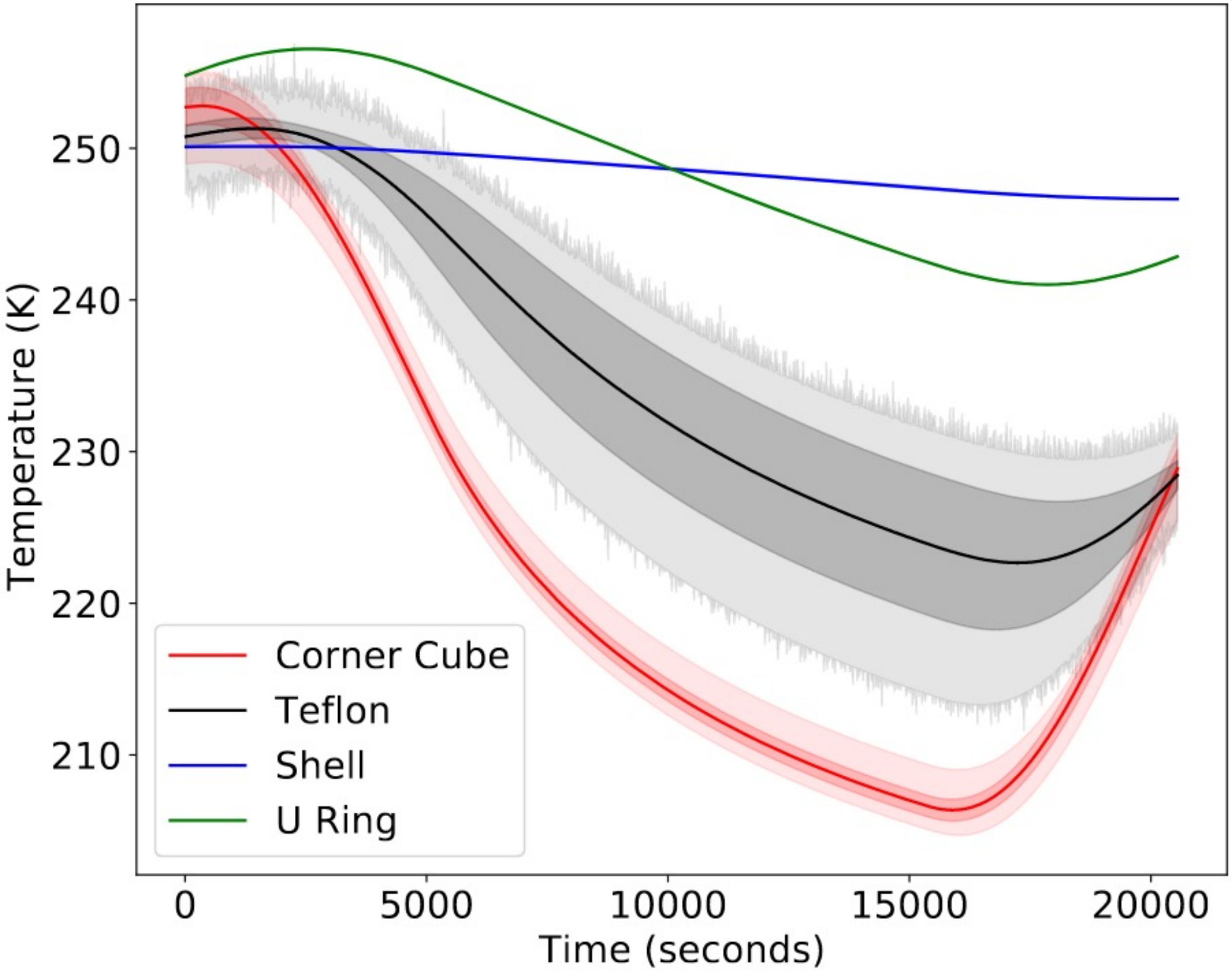
We convert the thermal profile of the Corner cube into a FFDP as a function of time, and compare this to our observed return rates during the eclipse.

Results: Temperatures

We show temperatures extracted from the Eclipse Simulation

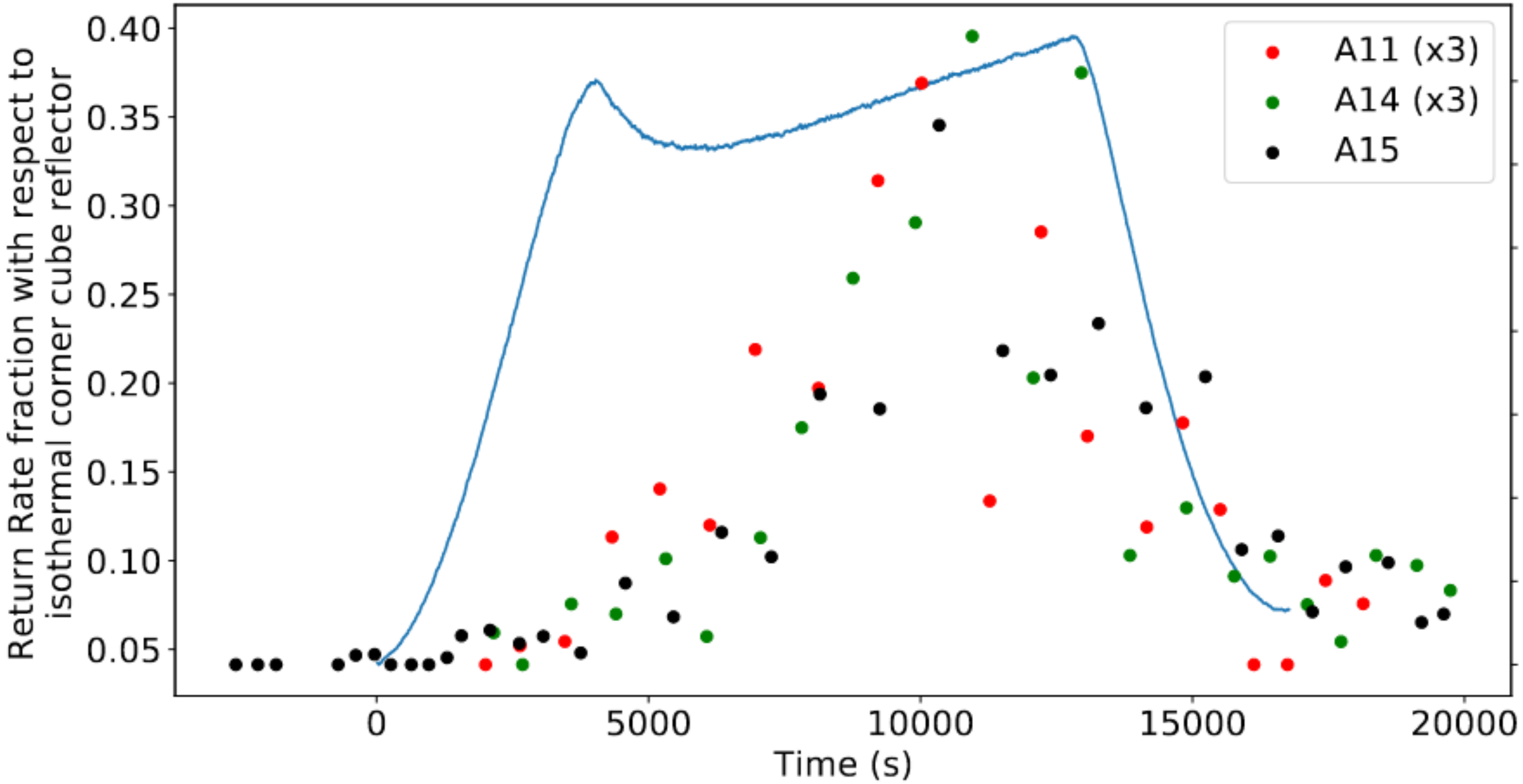
Our best results give us a dust obscuration factor of ~ 0.65

This compares well with our estimates from steady state thermal modelling and link budget calculations



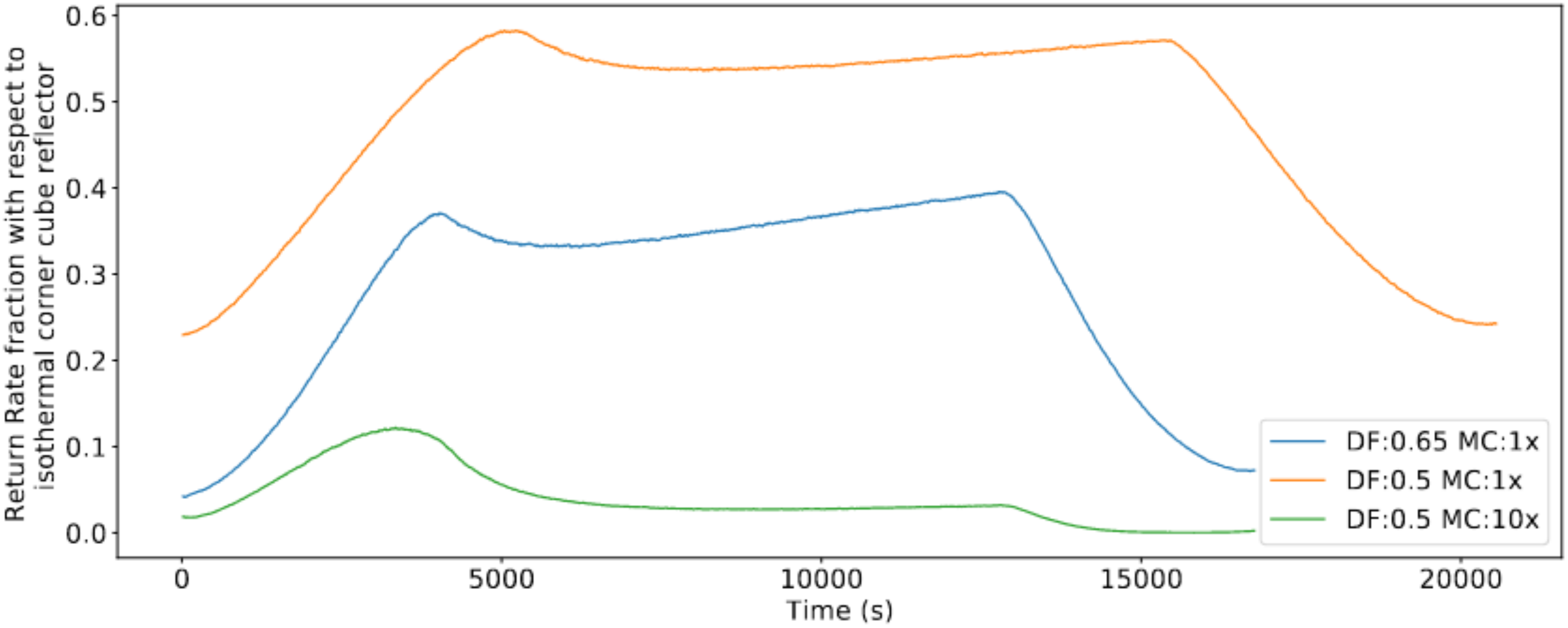
Temperatures during Eclipse (Sabhlok+ 2023 (in prep))

Results: Expected vs. Actual Return Rates



Return Rates during the 2014 Eclipse (Sabhlok+ 2023 (in prep))

Impact of changing parameters



Comparisons of changing parameters on the Eclipse run (Sabhlok+ 2023 (in prep))

Caveats

Our goals here are not to derive the exact coverage or fine tune the exact lunar dust model.

We have only considered a single corner cube instead of the full array.

Our treatment of lunar dust does not involve modelling, only the obscuration and thermal properties.

Conclusions

We investigate role of dust obscuration in LLR return rate deficit near Full Moon.

Steady state and Eclipse thermal simulations suggest a lunar dust obscuration factor of ~ 0.65

We find reasonable agreement between our simulation and the observed return rates for the April 2014 lunar eclipse.