# THERMAL ANALYSIS OF APOLLO 11 RETROREFLECTOR


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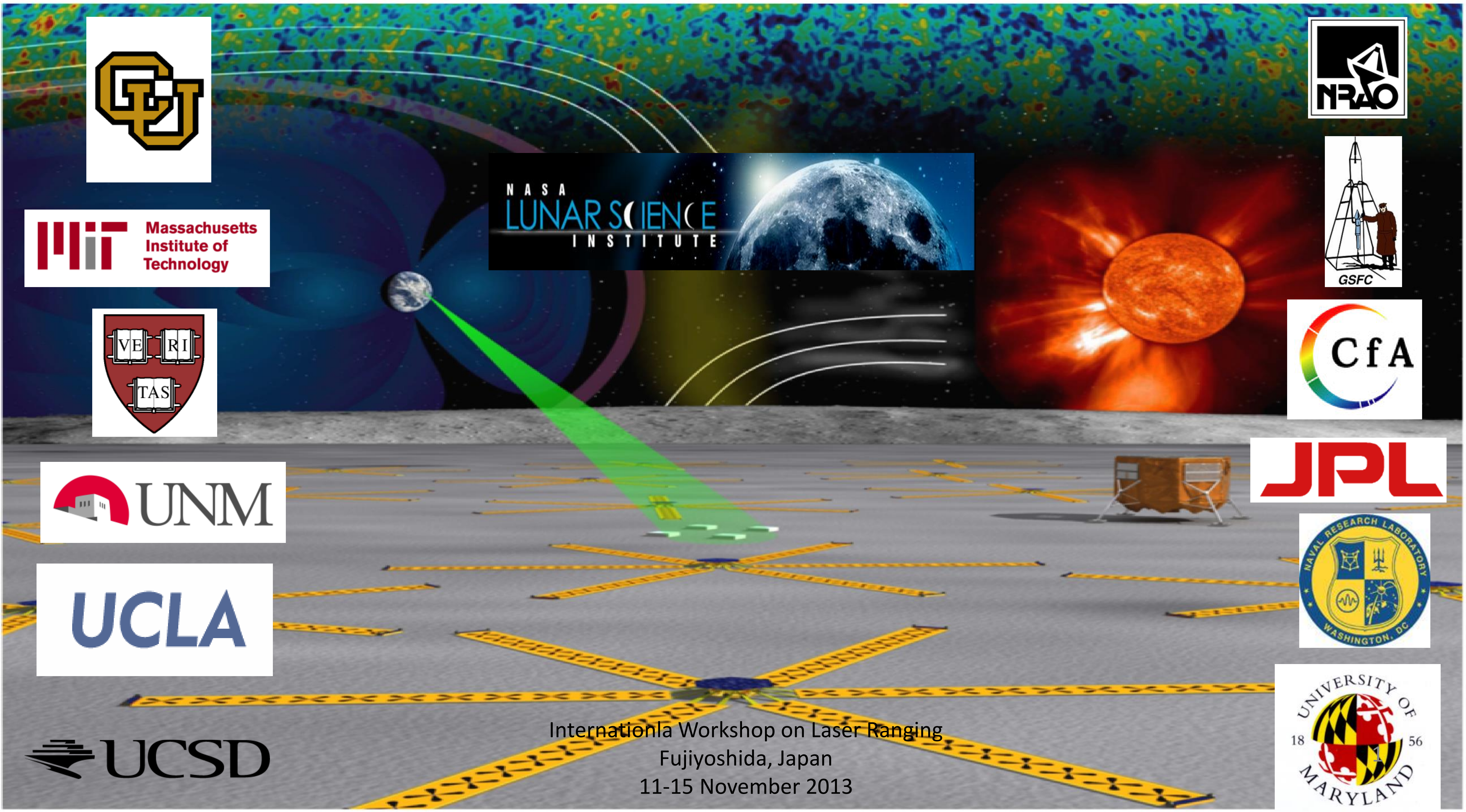
NASA Lunar Science Institute, Moffett Field, CA
INFN – LNF, Laboratori Nazionali di Frascati, Italy

**& The LLRRA-21 Teams with the**

***L**unar **U**niversity **N**etwork for **A**strophysics **R**esearch*

*Jack Burns, Director*

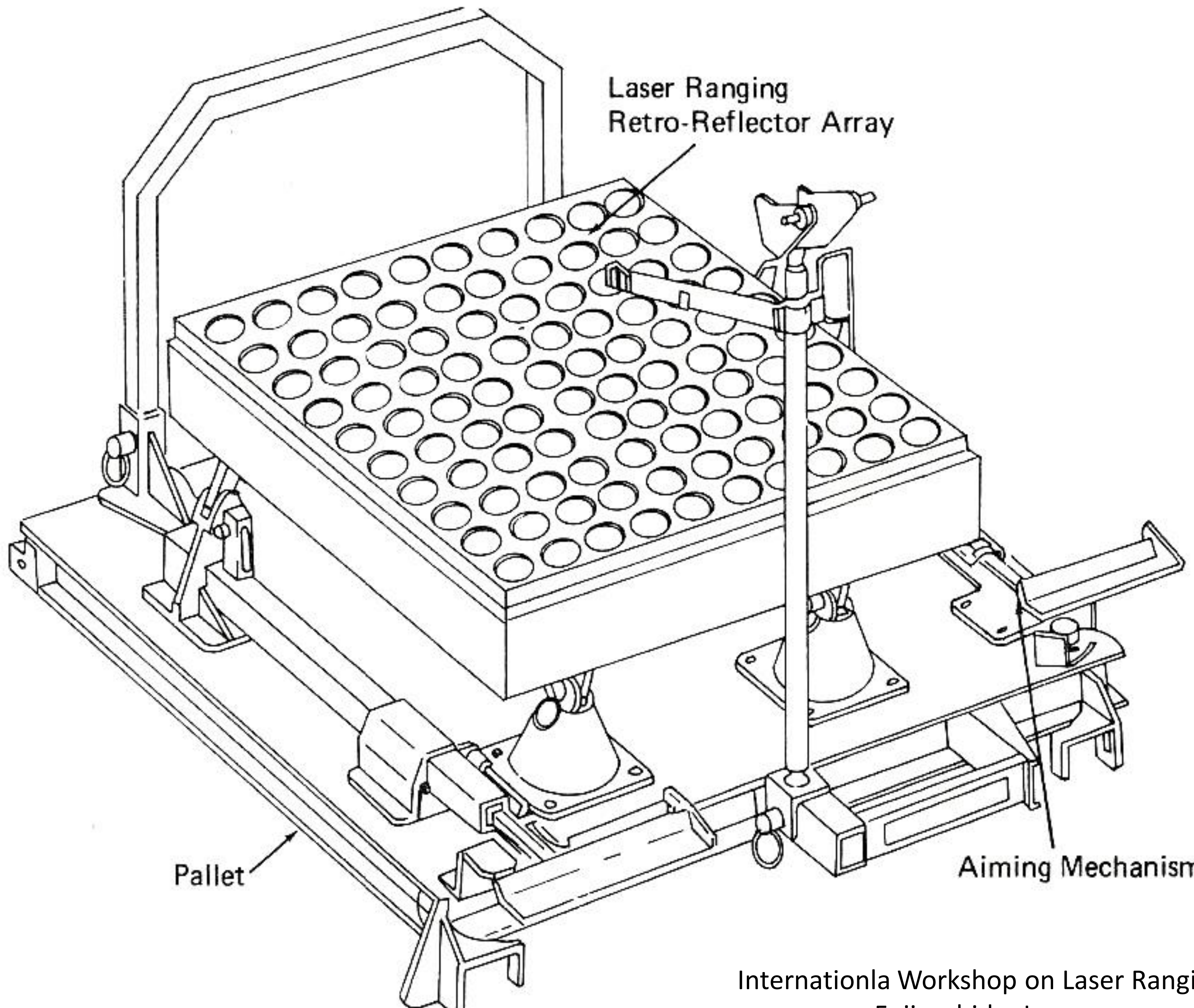



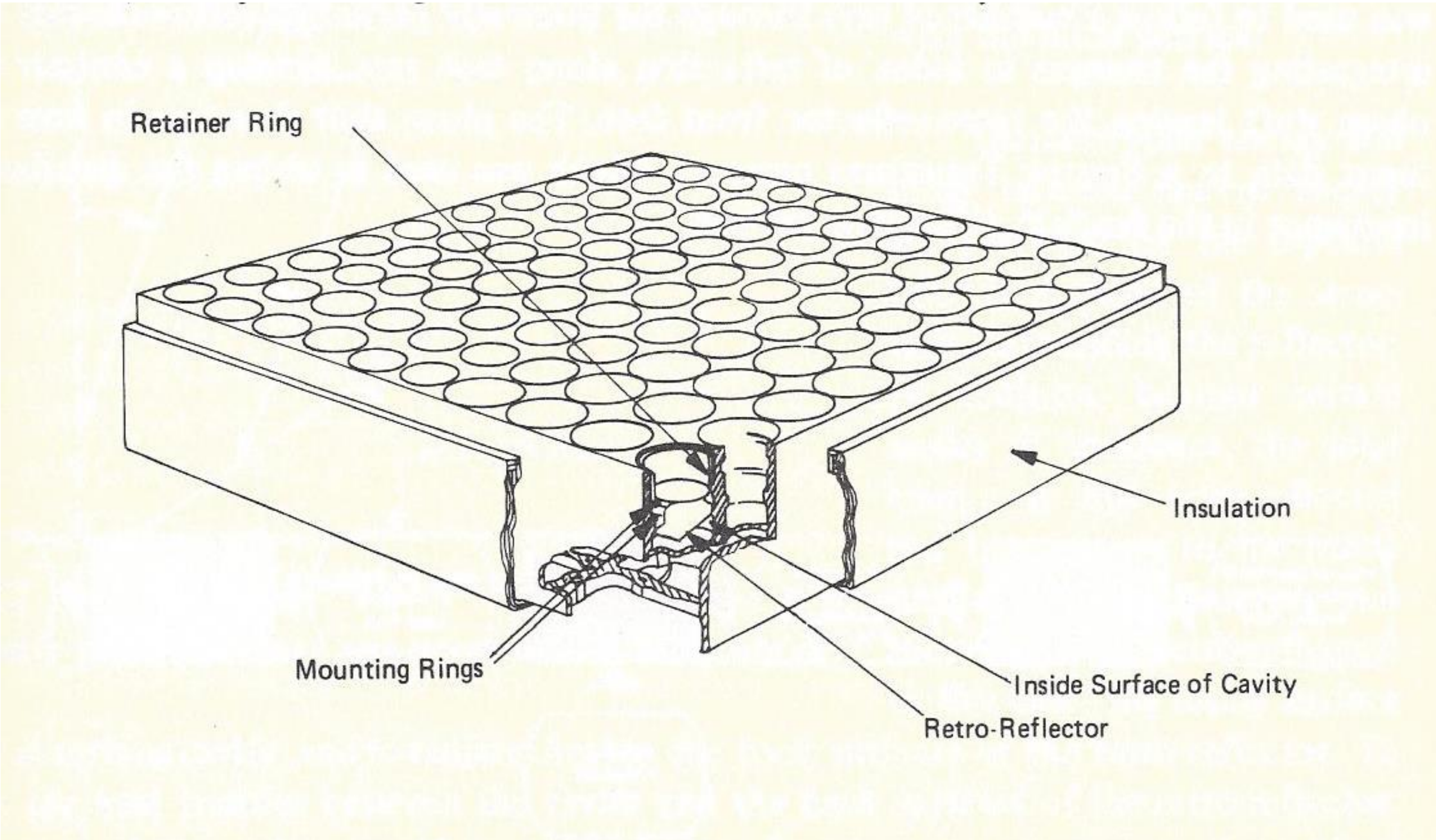
# OBJECTIVES

- Apollo Retroreflector Arrays – Apollo 11
  - Past and Current Performance
    - Lunar Night, Lunar Day and Lunar Eclipse
    - Role of “Dust”
  - Simulation Approach for this Discussion
    - Simulation of  Radiation  and Conduction
    - Solar Illumination, Interaction with Regolith and Internal
  - Structural Simulation has Three Domains
    - Solar Effects – Internal Absorption in CCR – IDL  -  UoM
    - Environmental Thermal Effects – Thermal Desktop – Giovanni
    - Optical Analysis of Thermal Effects – IDL – UoM
- Address Physical Principles not  Structure of Simulation
  - Initially Developed for the LLRRA-21 for  Delivery to the Moon
  - Also Applicable to CCR Arrays in Orbit

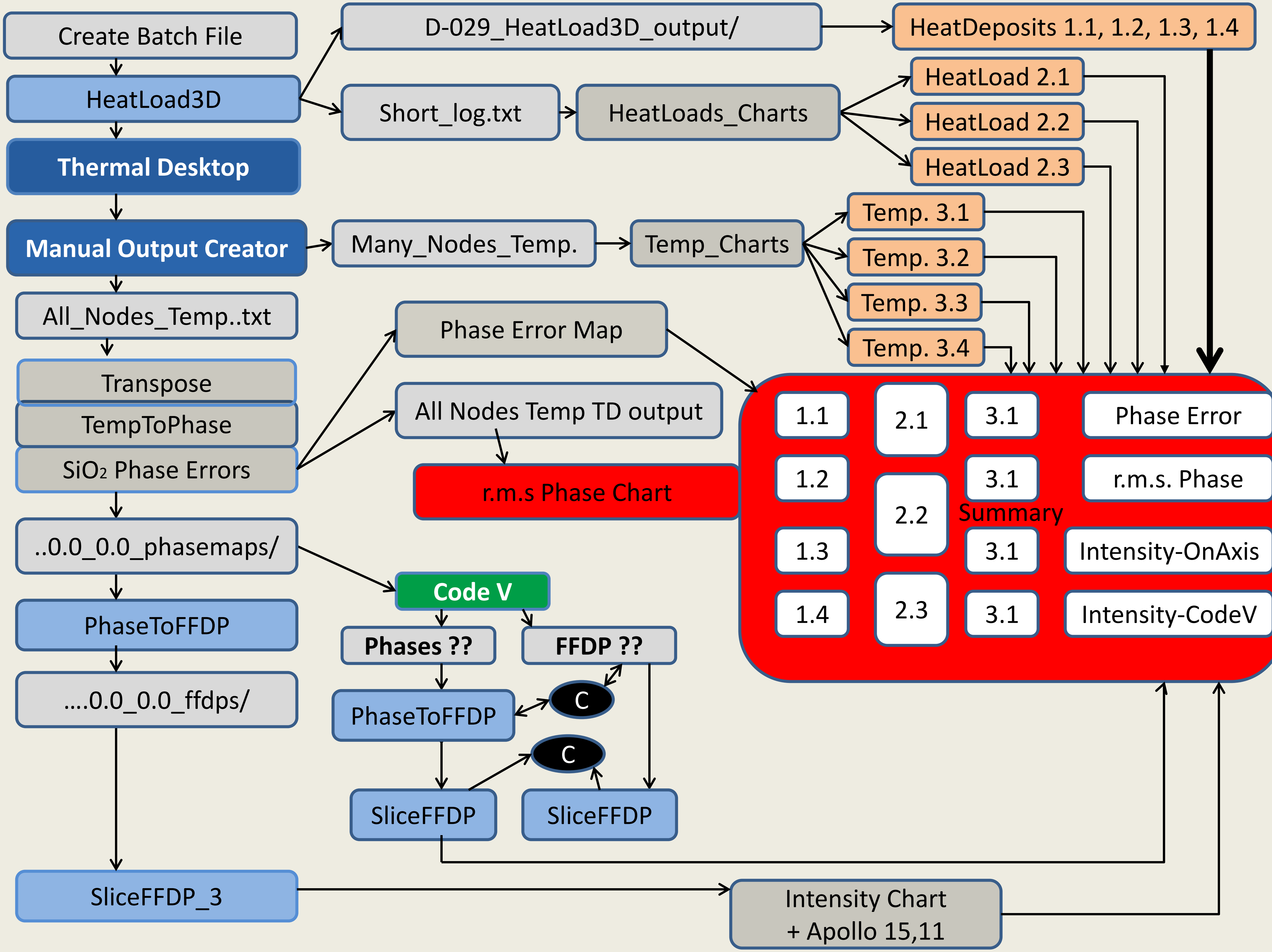
# OBJECTIVES

- Highlight Critical Issues for LLRRA-21
  - Assure High Initial Performance
  - Effect of Long Term Weathering over 40 Years
- Stimulate Suggestions
  - Of Missing Elements that are Important
    - Especially Issues that have Arisen in Other CCR Systems
    - To be Considered for Future Implementation
- Provide Options for Use of Simulation Programs
  - By Other Groups
  - Especially for Satellite CCR Systems
  - For Apollo, Thermal Problems Reduce Signal >50%

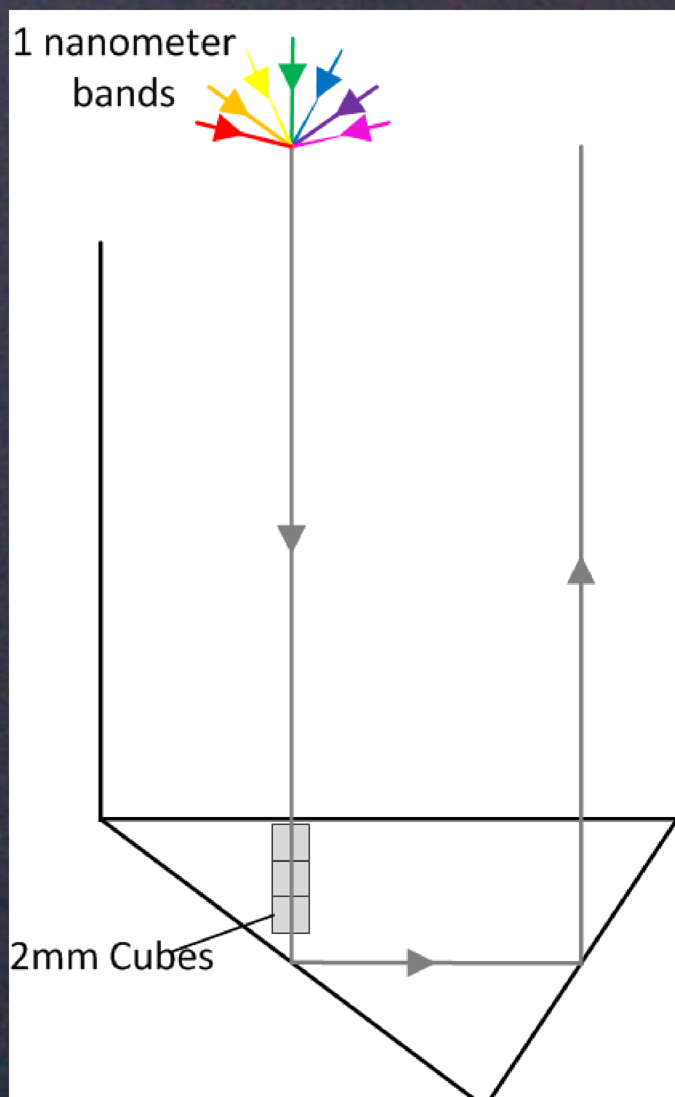

Laser Ranging
Retro-Reflector Array
Pallet
Aiming Mechanism


Retainer Ring
Insulation
Mounting Rings
Inside Surface of Cavity
Retro-Reflector

# LLRRA-21 Thermal/Optical Simulation

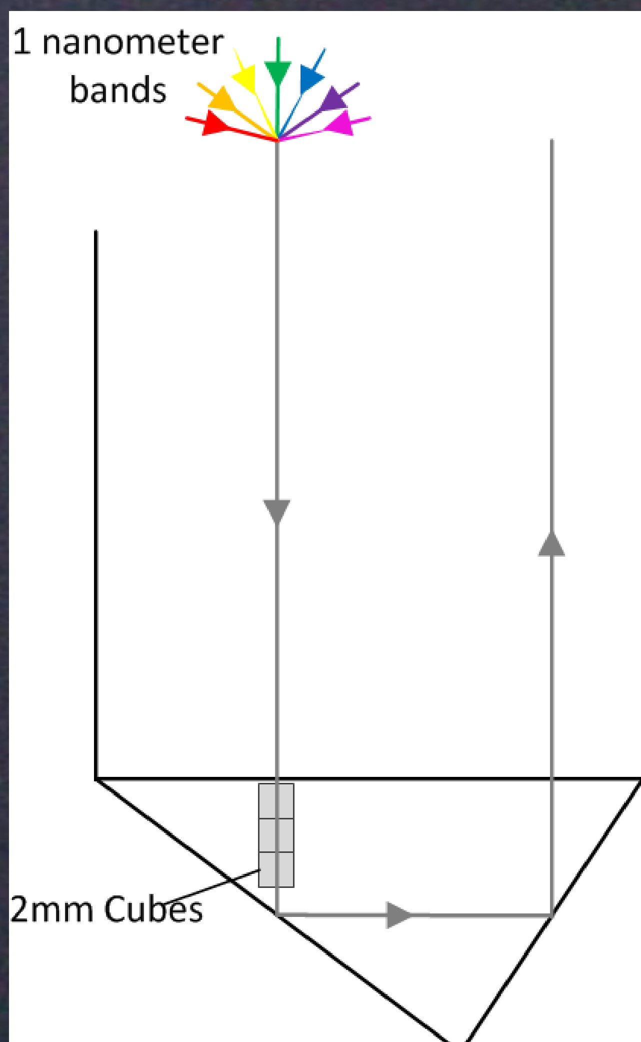


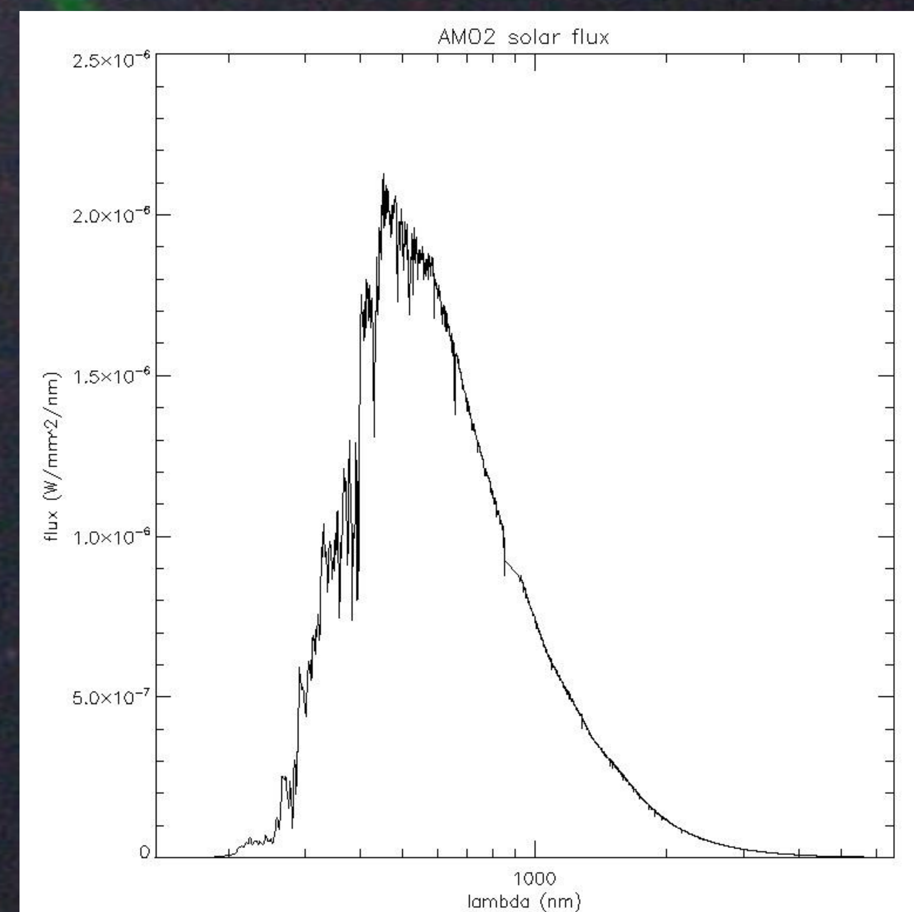
# RAY PROPOGATION OF SOLAR INPUT



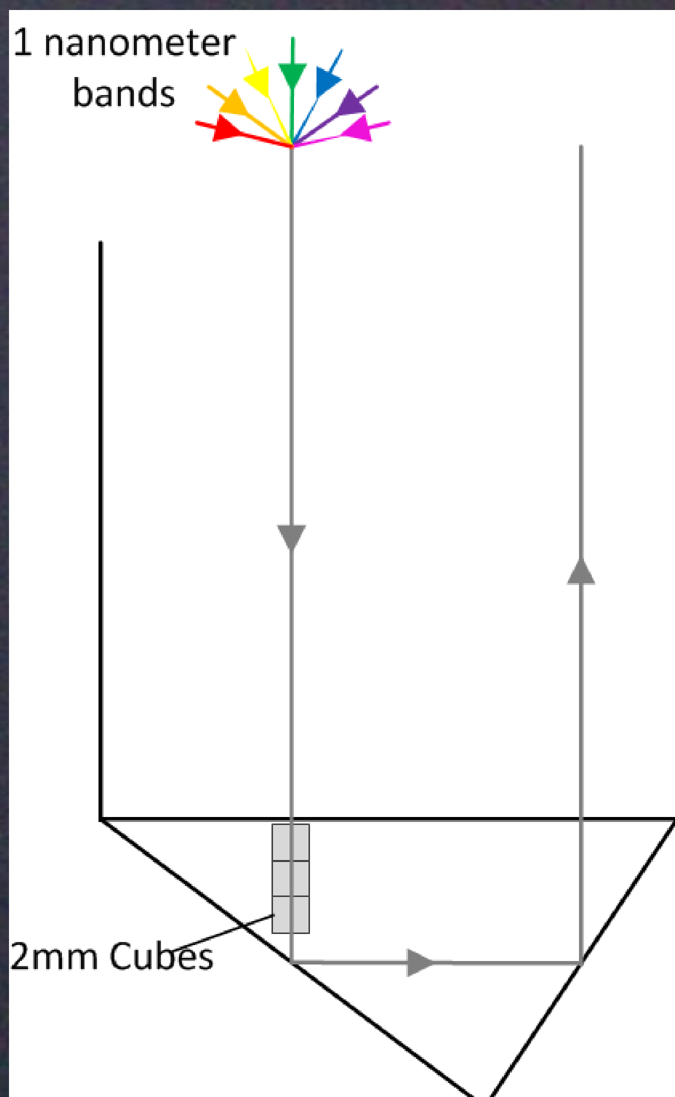

- For a "Perfect" CCR
  - Metal Coating
    - Tight Return Beam
    - Unacceptable Solar Heating
- Total Internal Reflection
  - No Coating on Back Faces
    - No Back Face Absorption
    - Less Tight Beam
    - TIR Breakthrough for Some Angles
- Solar Absorption
  - Spatial Variation of Heat Loads
    - Absorption in CCR
    - Depends on Solar Spectrum
    - Depends on SiO2 Absorption

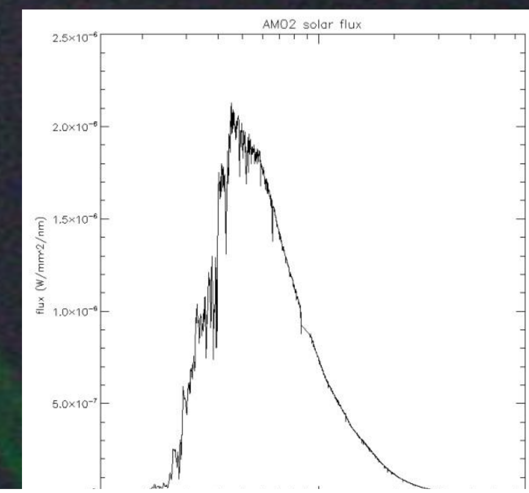
# RAY PROPOGATION OF SOLAR INPUT
# SOLAR SPECTRUM

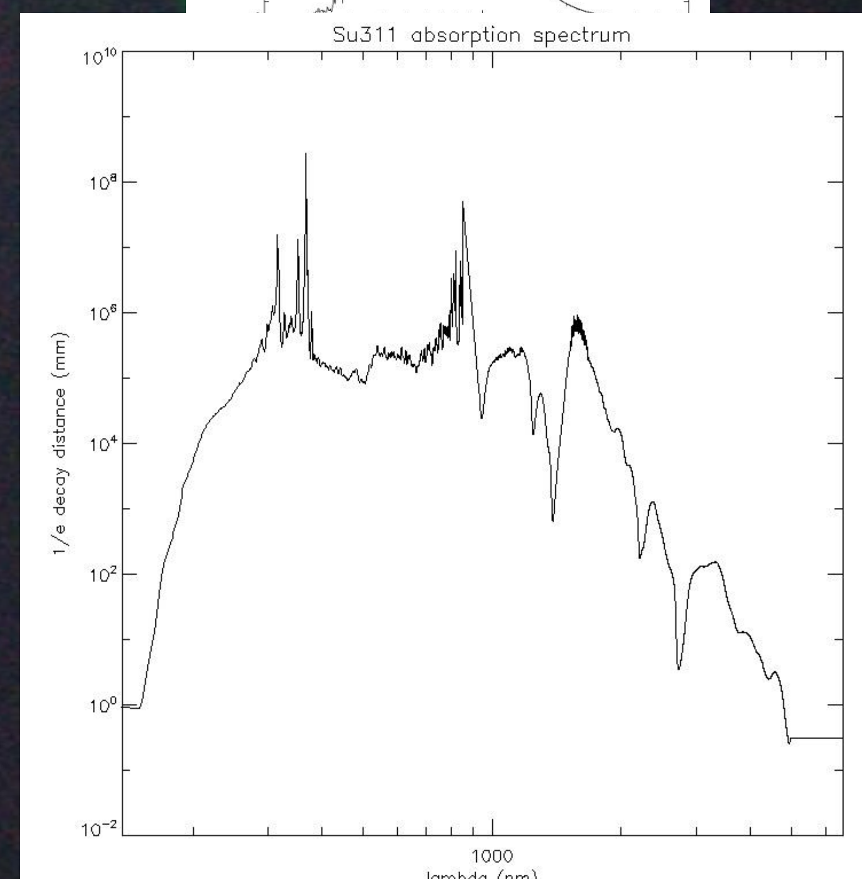


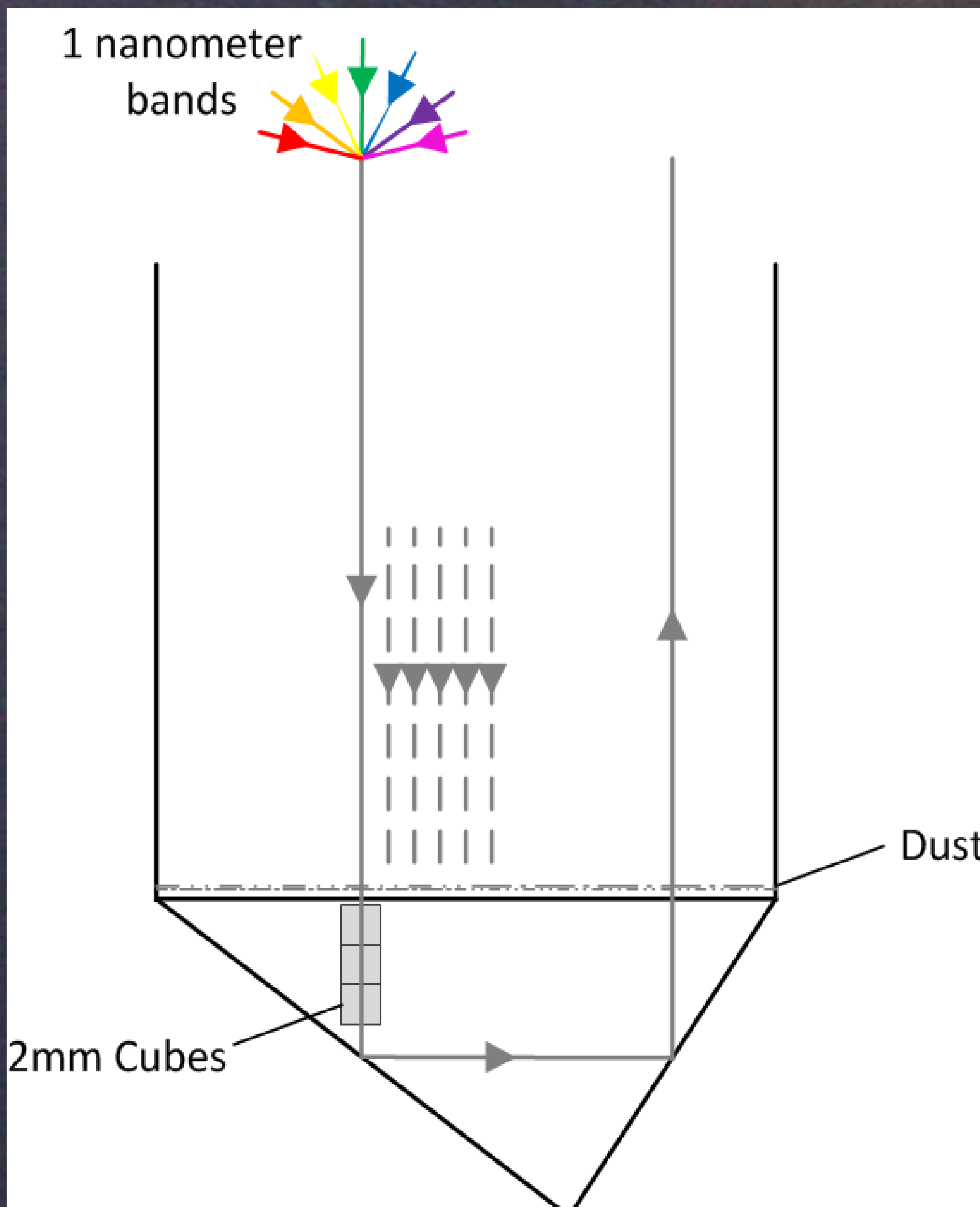
# RAY PROPOGATION OF SOLAR INPUT FUSED SILICA ABSORPTION



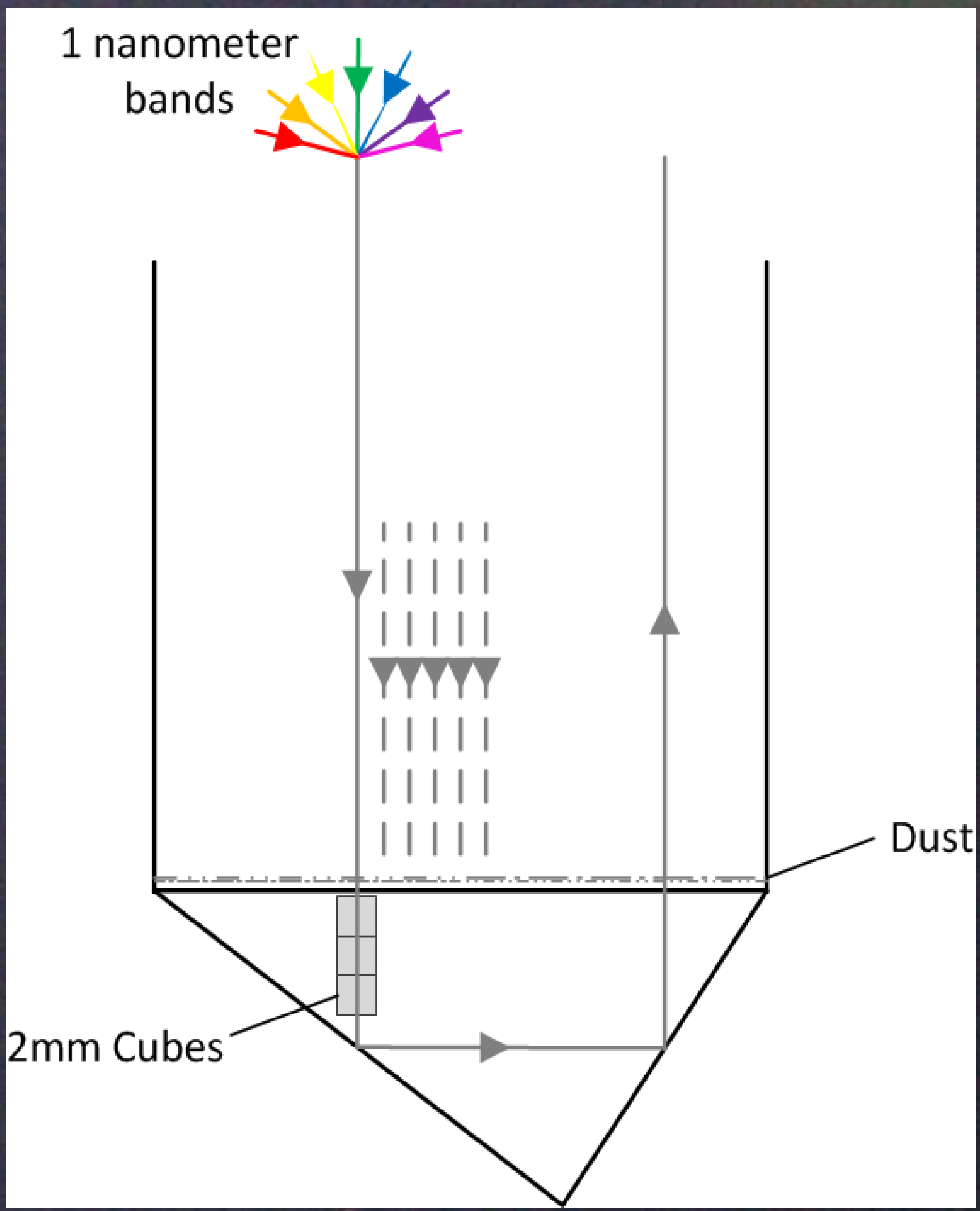



# RAY PROPOGATION OF SOLAR INPUT MULTIPULE RAYS



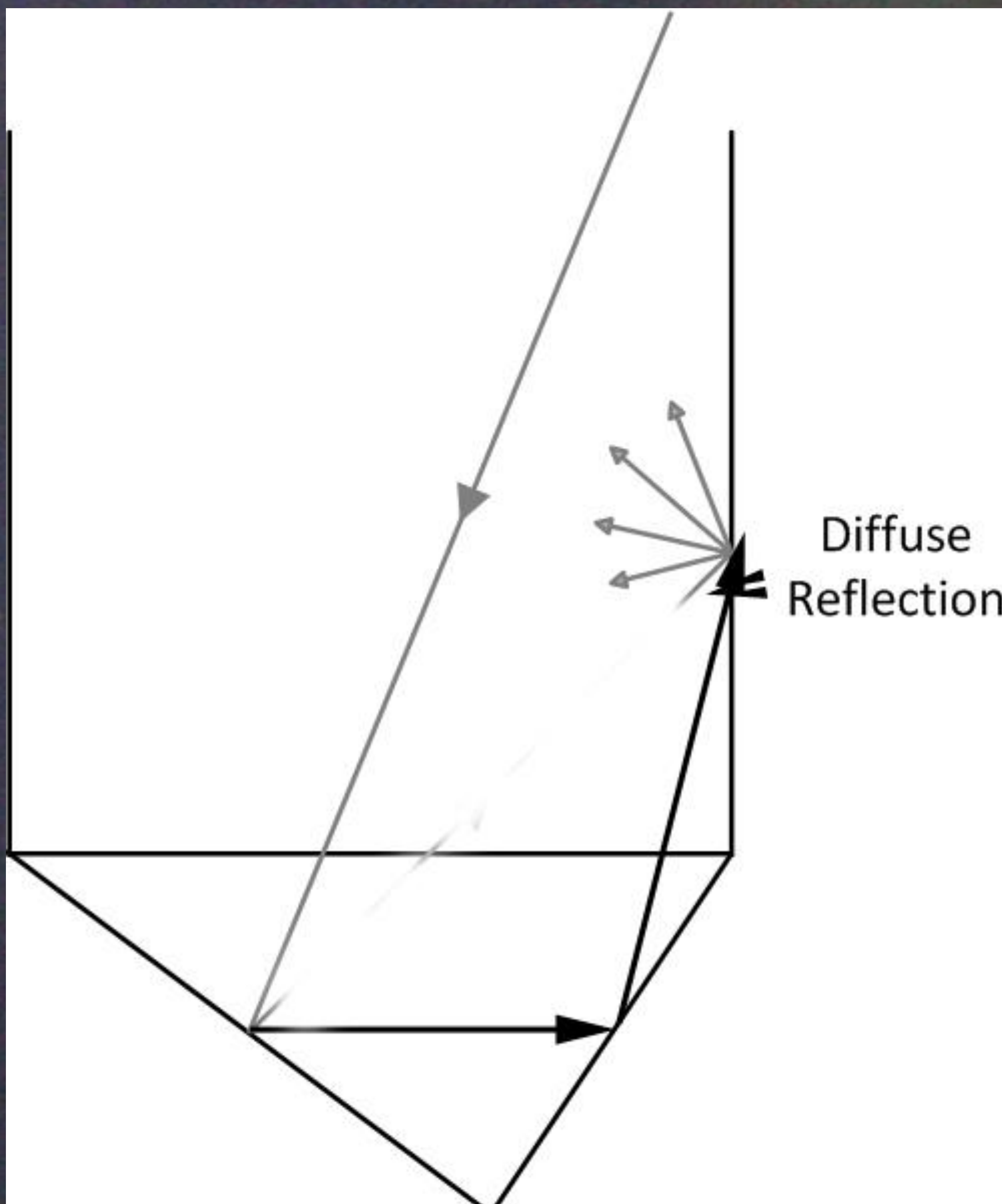

- Previously a Single Ray
- Now propagate Many Rays
  - Currently 1000
- Rectangular Grid
- Each Ray Creates:
  - Independent Heat Load
  - In each 2 mm Cube
  - Propagates Rest of Energy

# RAY PROPOGATION OF SOLAR INPUT DUST LAYER ON CCR



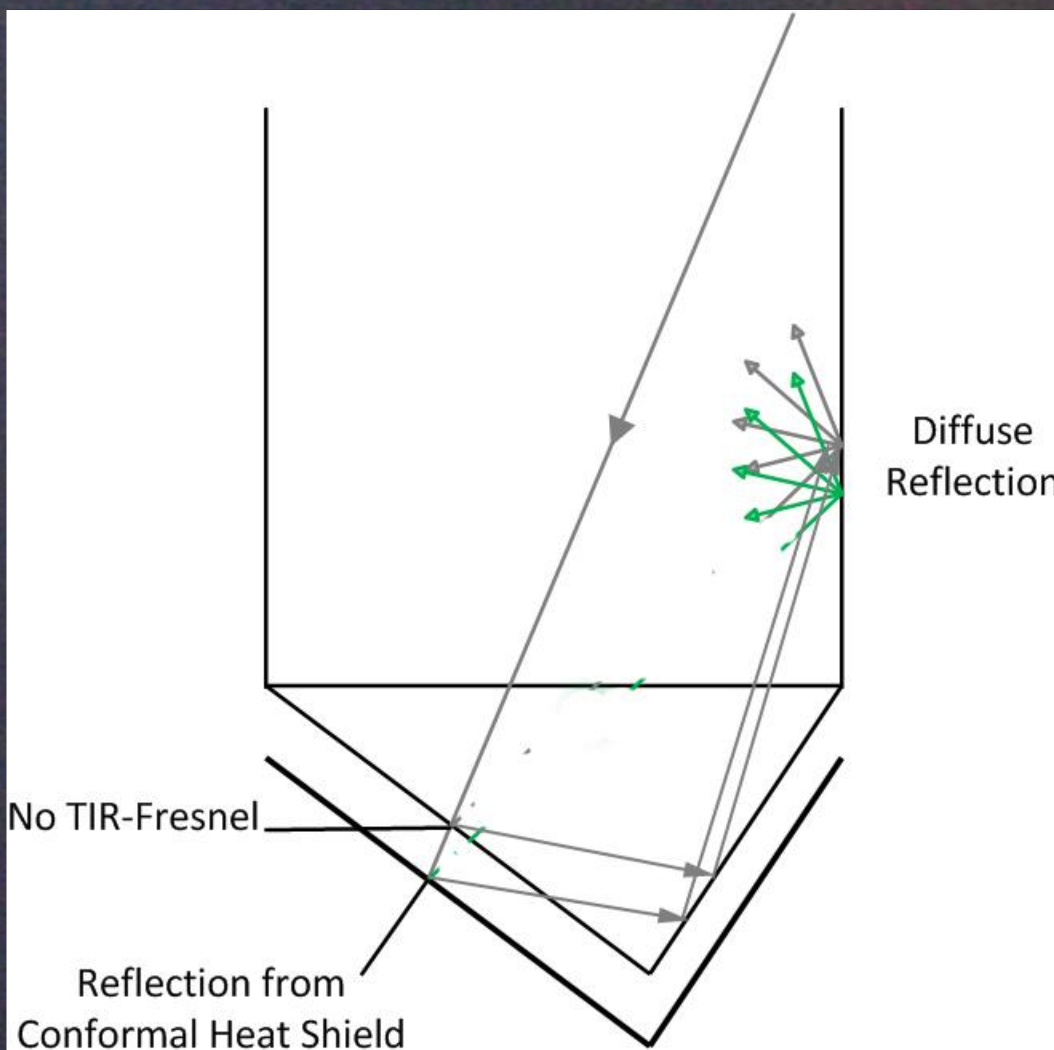

- Add Dust Layer on Front
  - Blocks Input and Output
  - Night Observations
    - Compare with Theory
    - ~ 67% Coverage
- Optical Properties
  - 95% Absorption in Visible
- Thermal Properties
  - 85% Emissivity

# OFF AXIS SOLAR ILLUMINATION



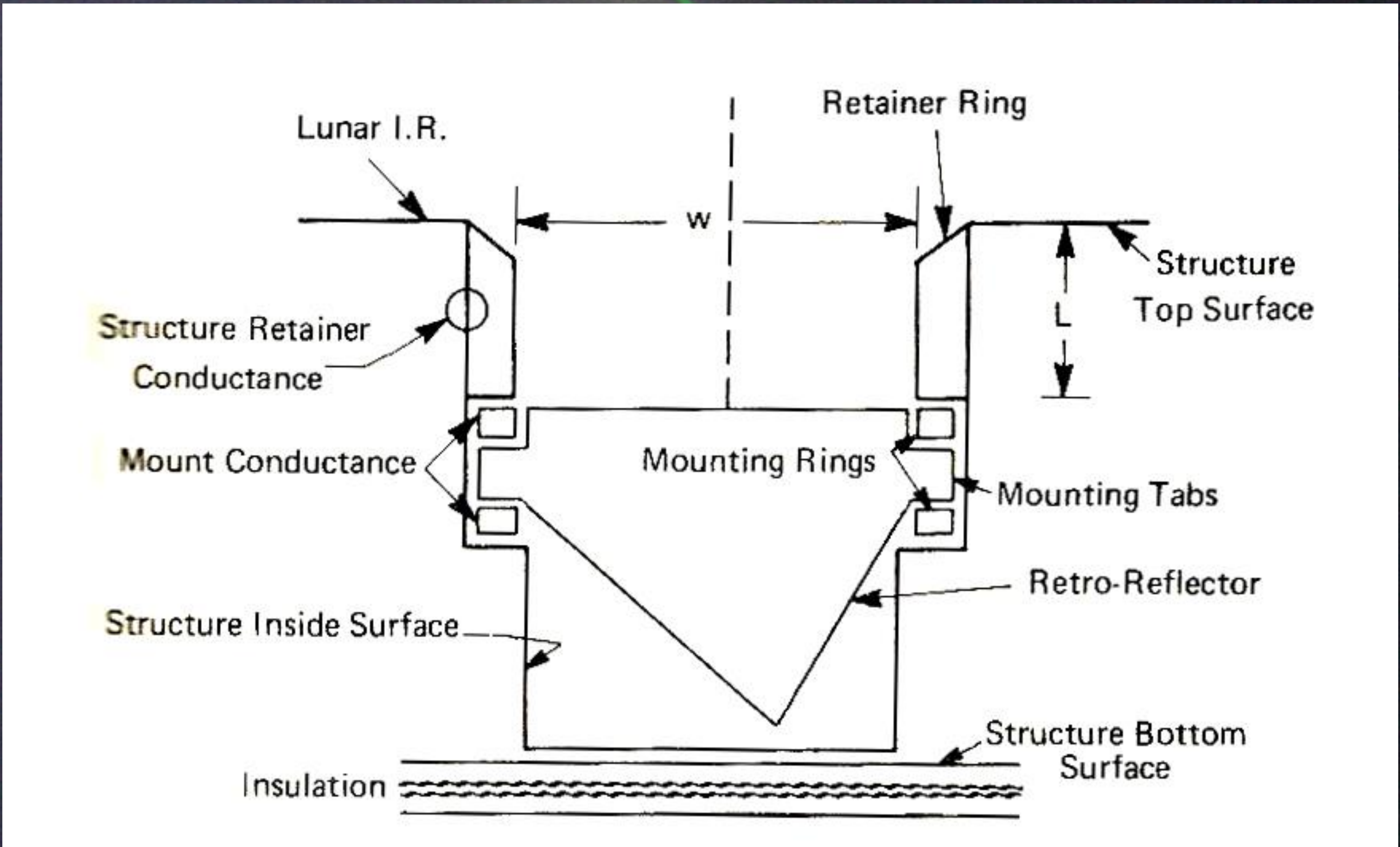

- Incoming Ray Exits
  - With Lateral Offset
  - Some Exiting Rays Hit Wall
    - Heat Absorption in Wall
    - Diffuse Reflection from Wall

# OFF AXIS SOLAR ILLUMINATION

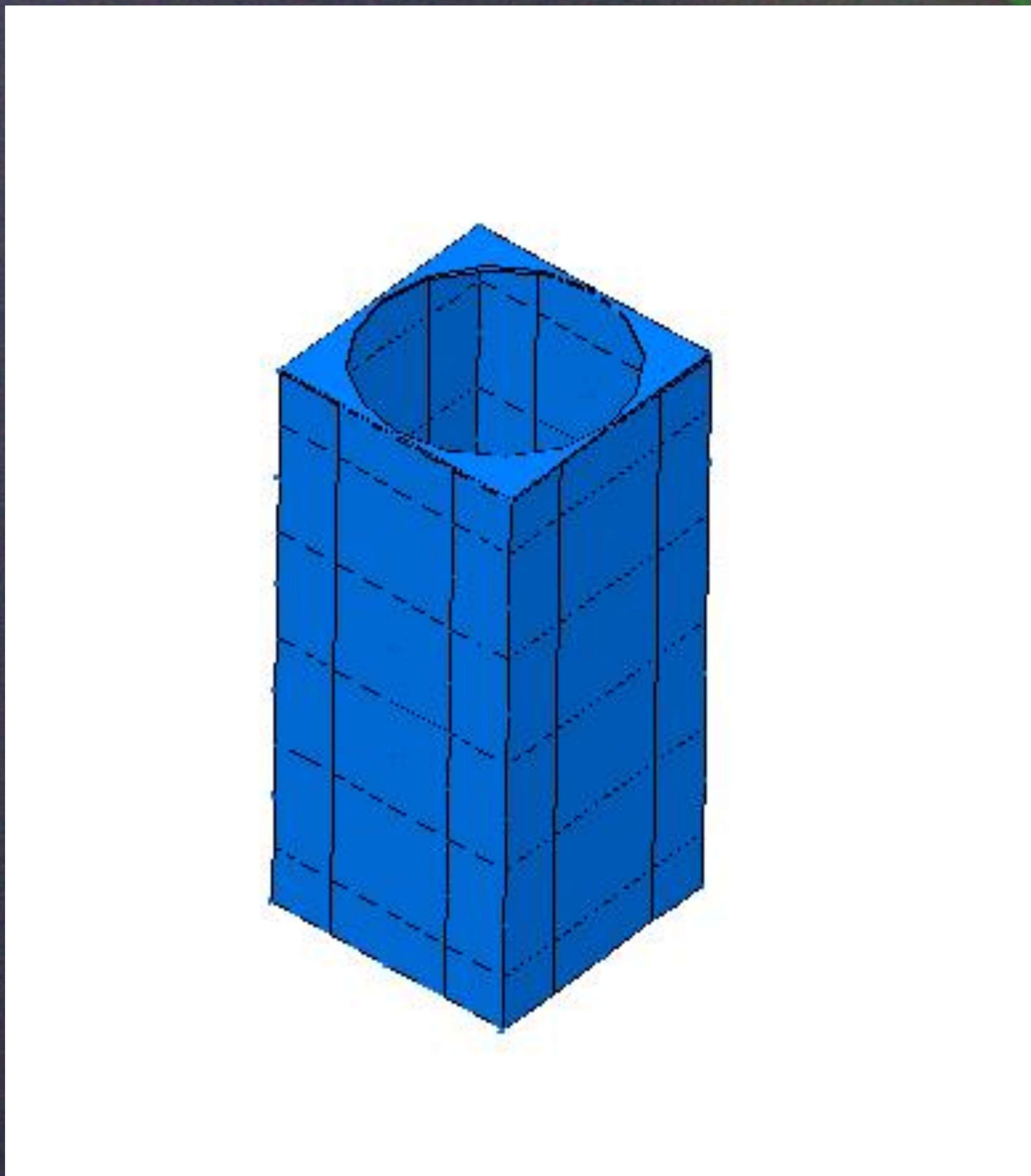



- For Some Sun Angles
  - TIR is Violated
- Portion is Fresnel Reflected
- Portion is Absorbed
  - Behind CCR in Pocket
- Portion Leaves Pocket
  - Conformal Thermal Shield
  - Cylindrical Pocket

# APOLLO 11 CONFIGURATION

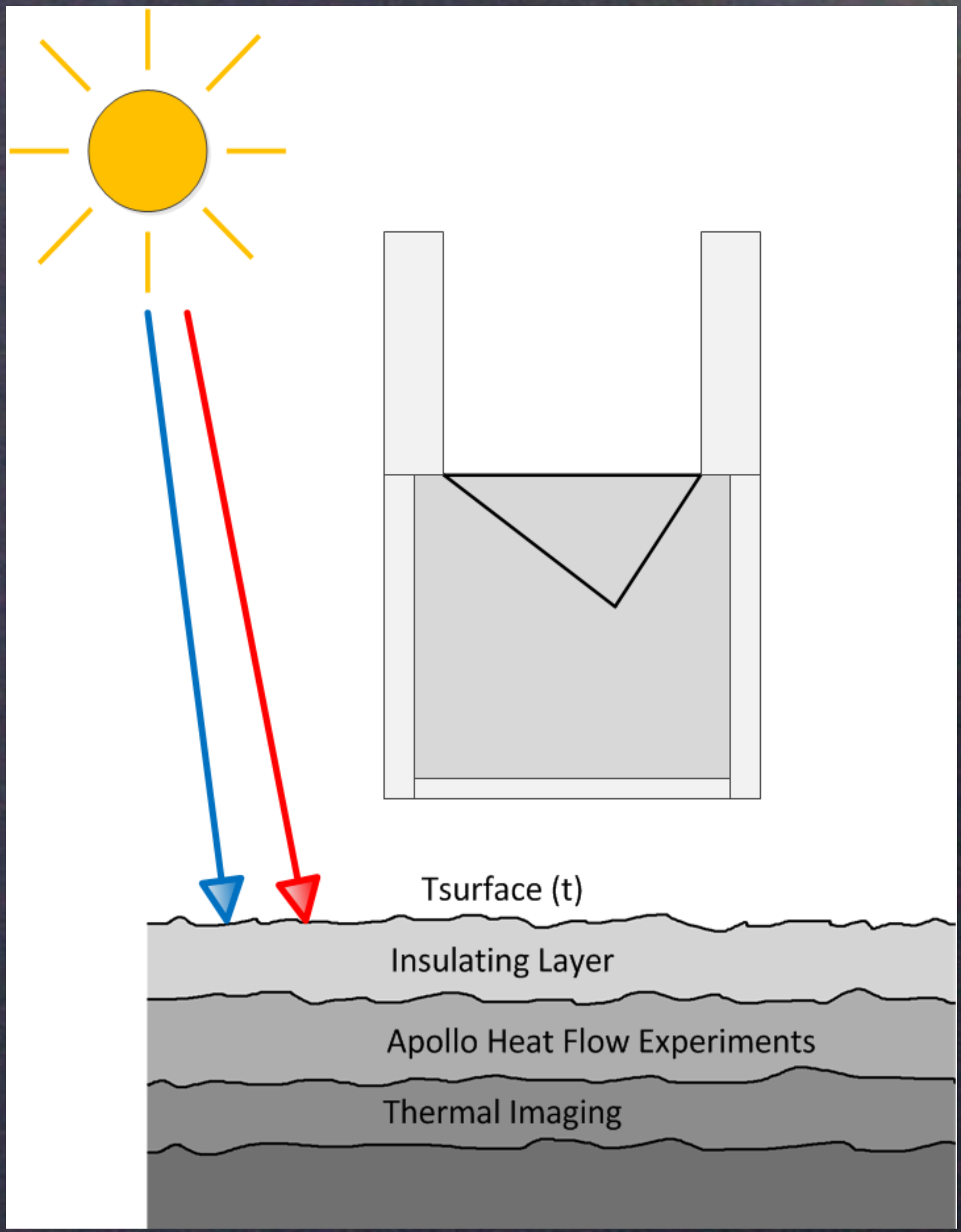


# THERMAL MODEL



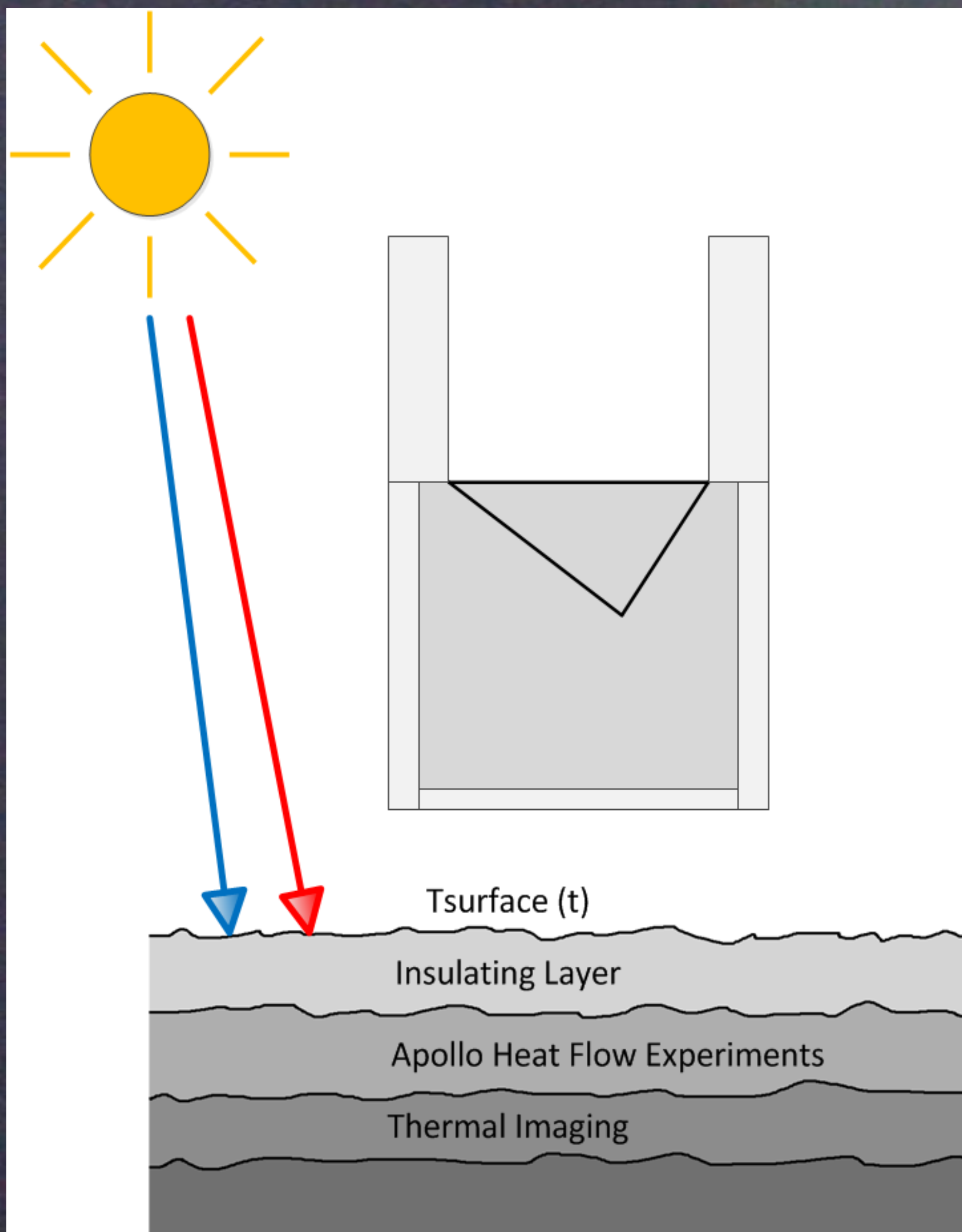
– Thermal Desktop
  - C&R Technologies
– AutoCAD Model
– AutoMesh
  - Creates Nodes
  - According to Complexity
– Properties for Model
  - Physical Material Properties
  - Measured and Estimated by ADL
  - Effects of 45 years Exposure
  - Guesses
  - ~30 Relevant Parameters

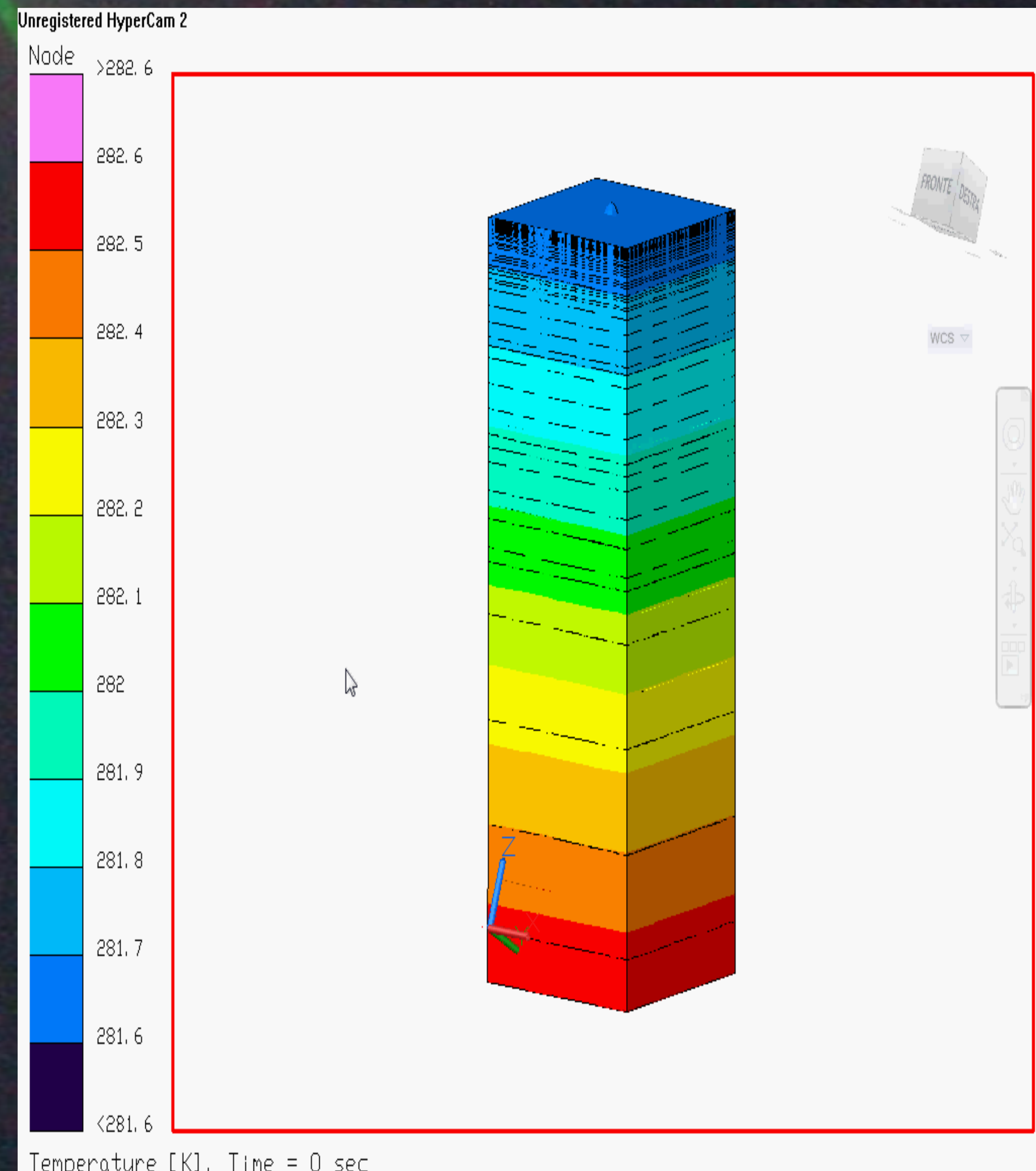
# SOLAR ILLUMINATION ON REGOLITH



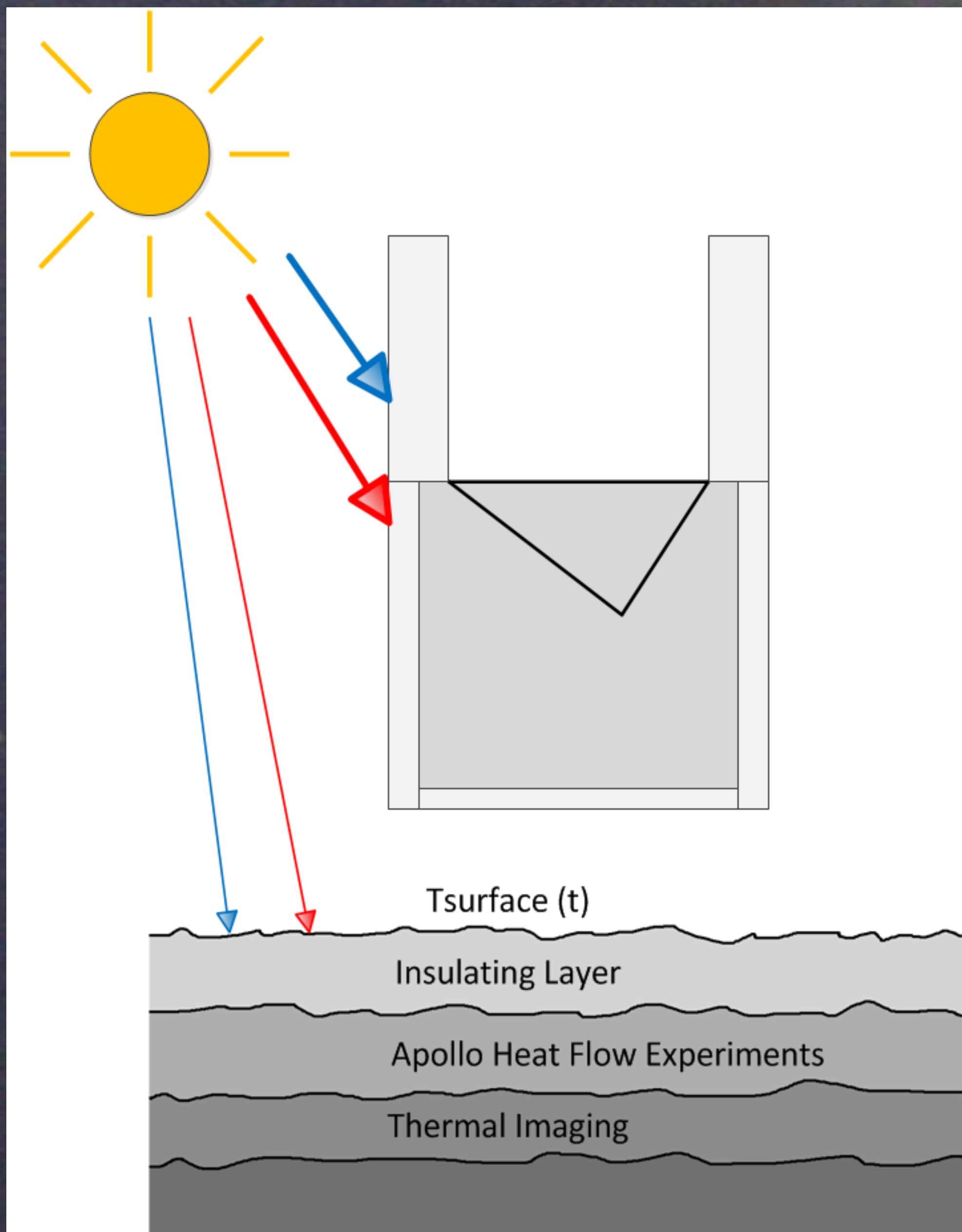

- Need Regolith Temperature
  - Changes During a Lunation
  - Change During an Eclipse
- Different Layers have:
  - Different Heat Conduction
  - Different Heat Capacity
  - Different Density
- Data to Model Behavior
  - From Apollo Heat Flow Exp.
  - From Thermal Imaging of Surface

# SOLAR ILLUMINATION ON REGOLITH



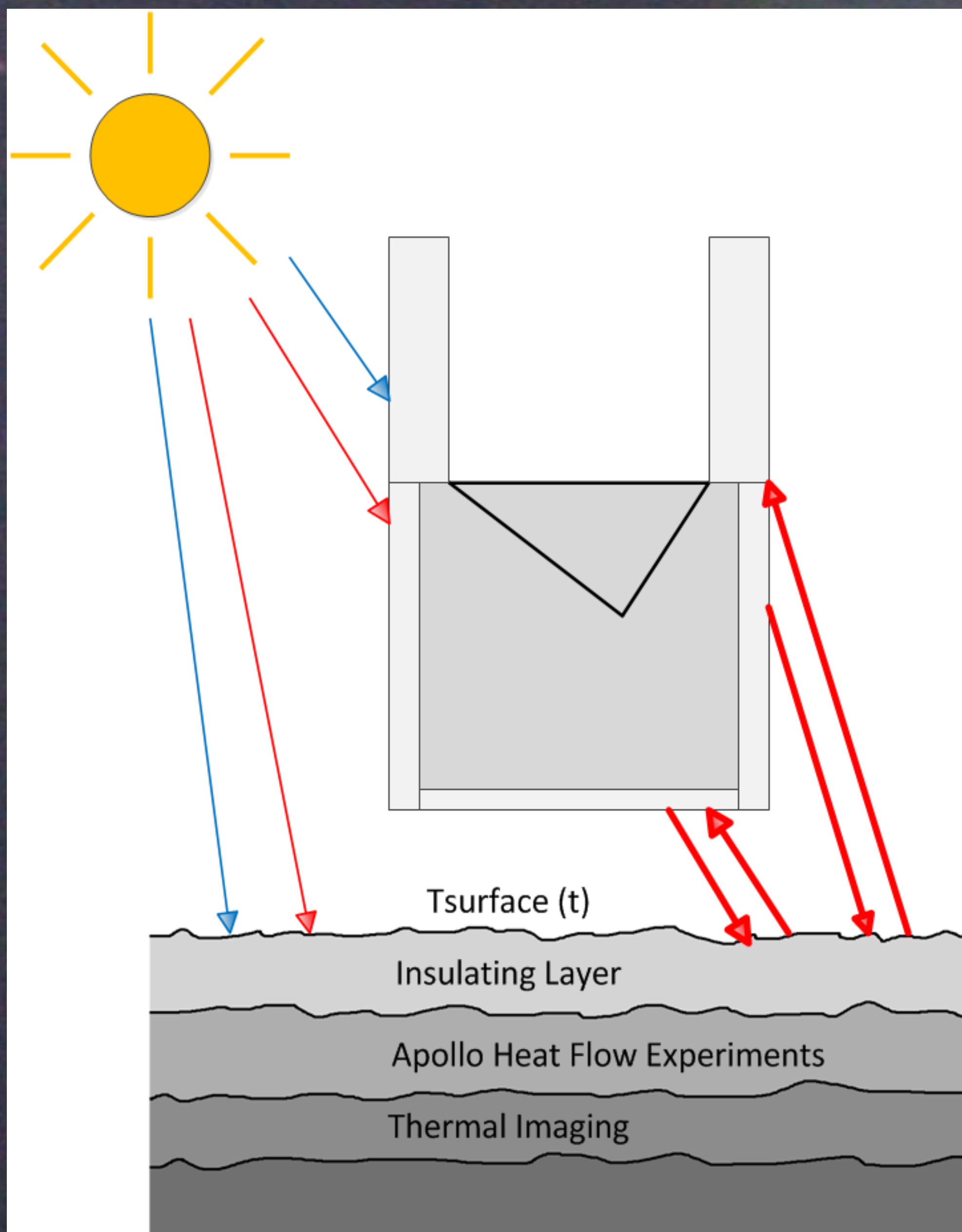



# SOLAR ILLUMINATION ON EXTERIOR



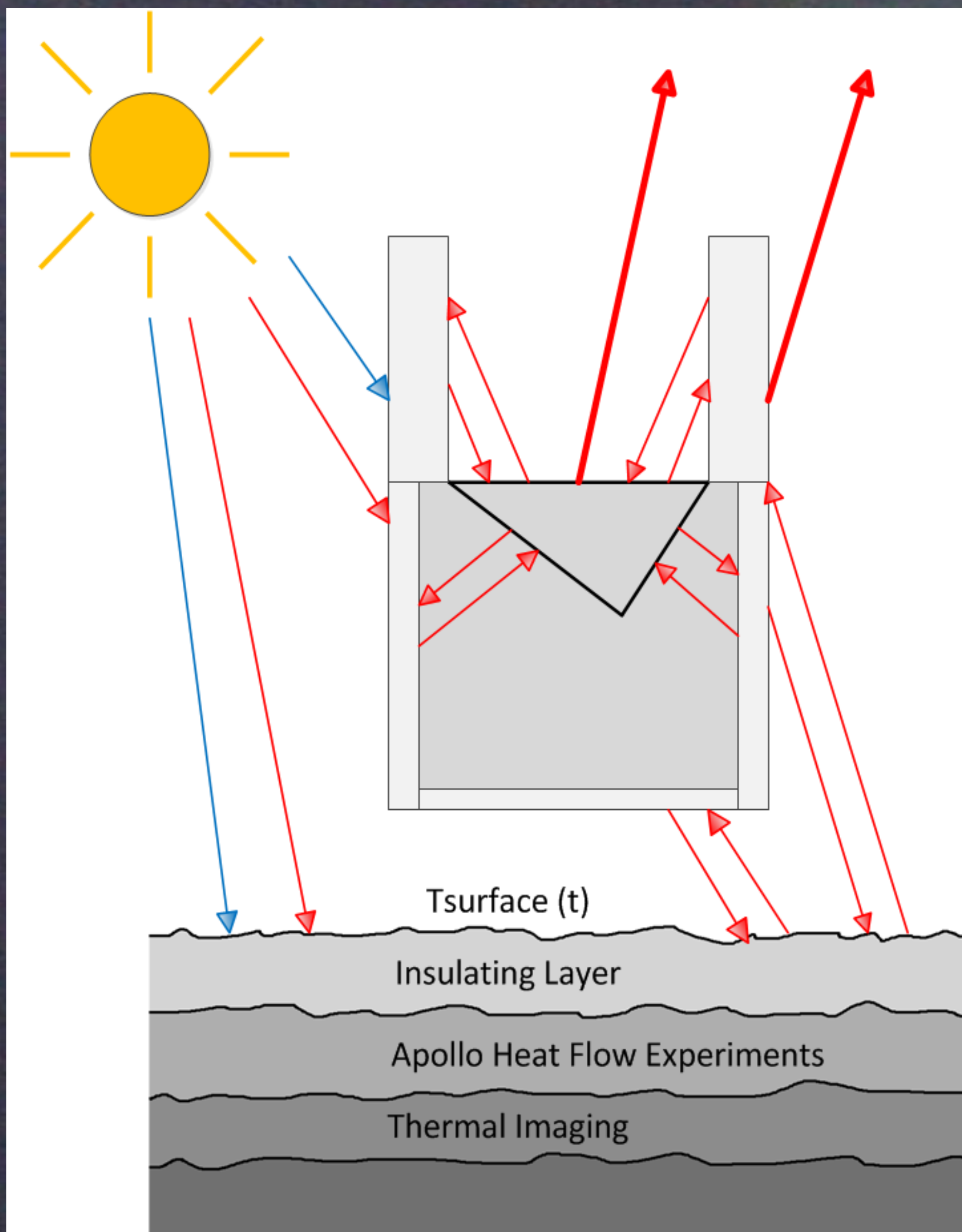

- Properties of External
  - Visible - Absorption
  - Infrared – Emissivity & Abs.
- Sources of Data
  - University of Maryland
  - Arthur D. Little Report
  - Effects of Weathering
- Estimates
  - Many Runs to Compare

# HOUSING INTERACTION WITH REGOLITH



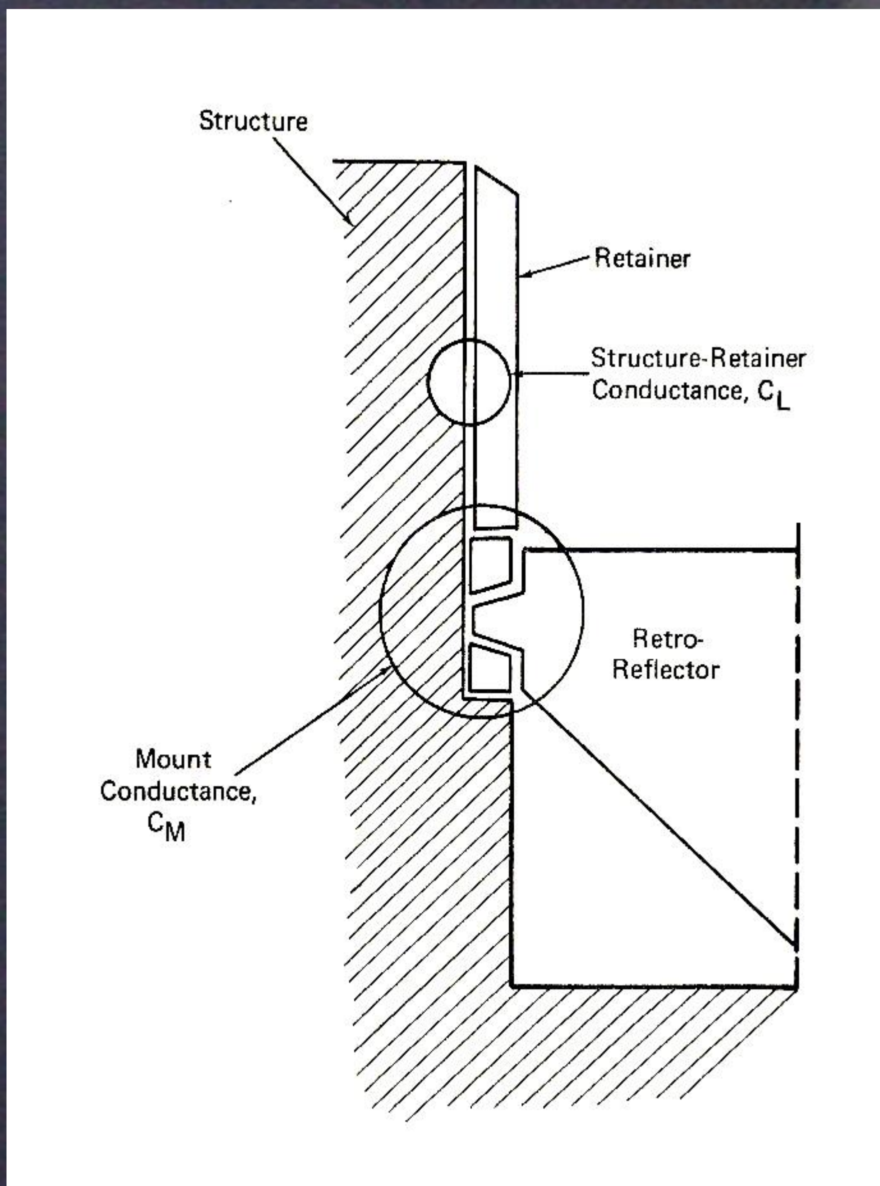

- Heat Exchanges via Radiation
  - Two Way Effects
  - Changes over Lunation
  - Changes over Eclipse
- Different Temperatures of
  - Sides of Housing
  - Bottom of Housing

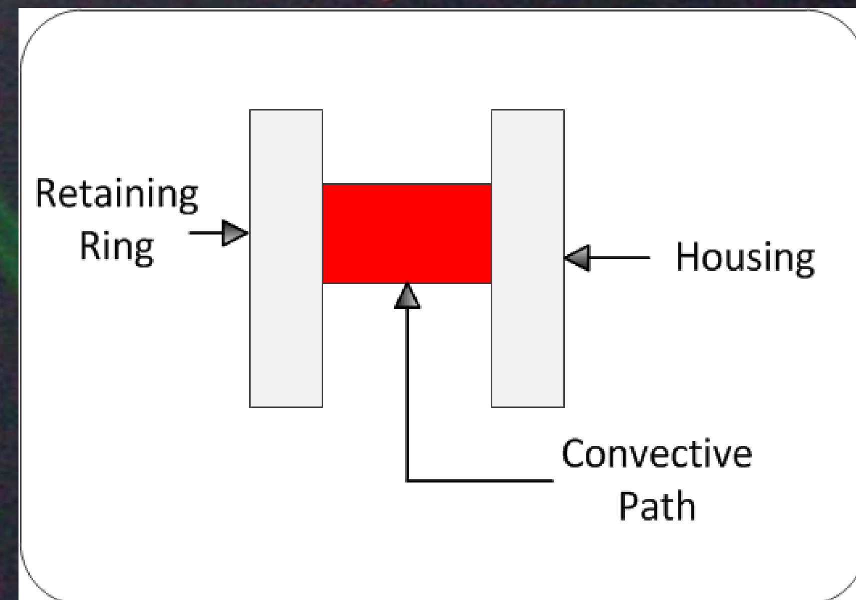
# RADIATION EXCHANGE WITH RETAINER RADIATION TO SPACE

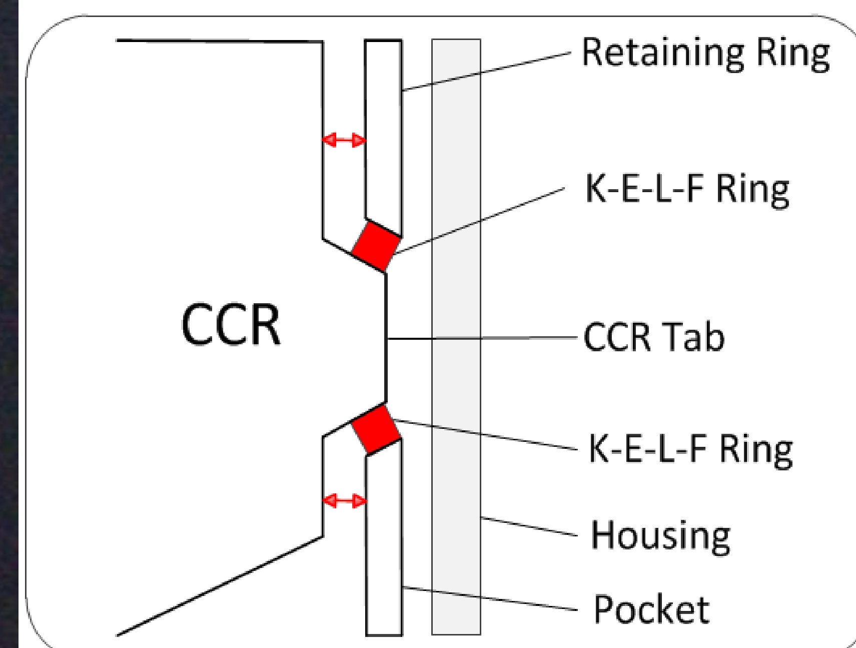



- Interior of Retainer Ring
  - CCR to Retainer Ring
  - Radiation Exchange
- Emission to Space from
  - CCR Front Face
  - Exterior Surface of Housing
  - Interior of Retainer Ring

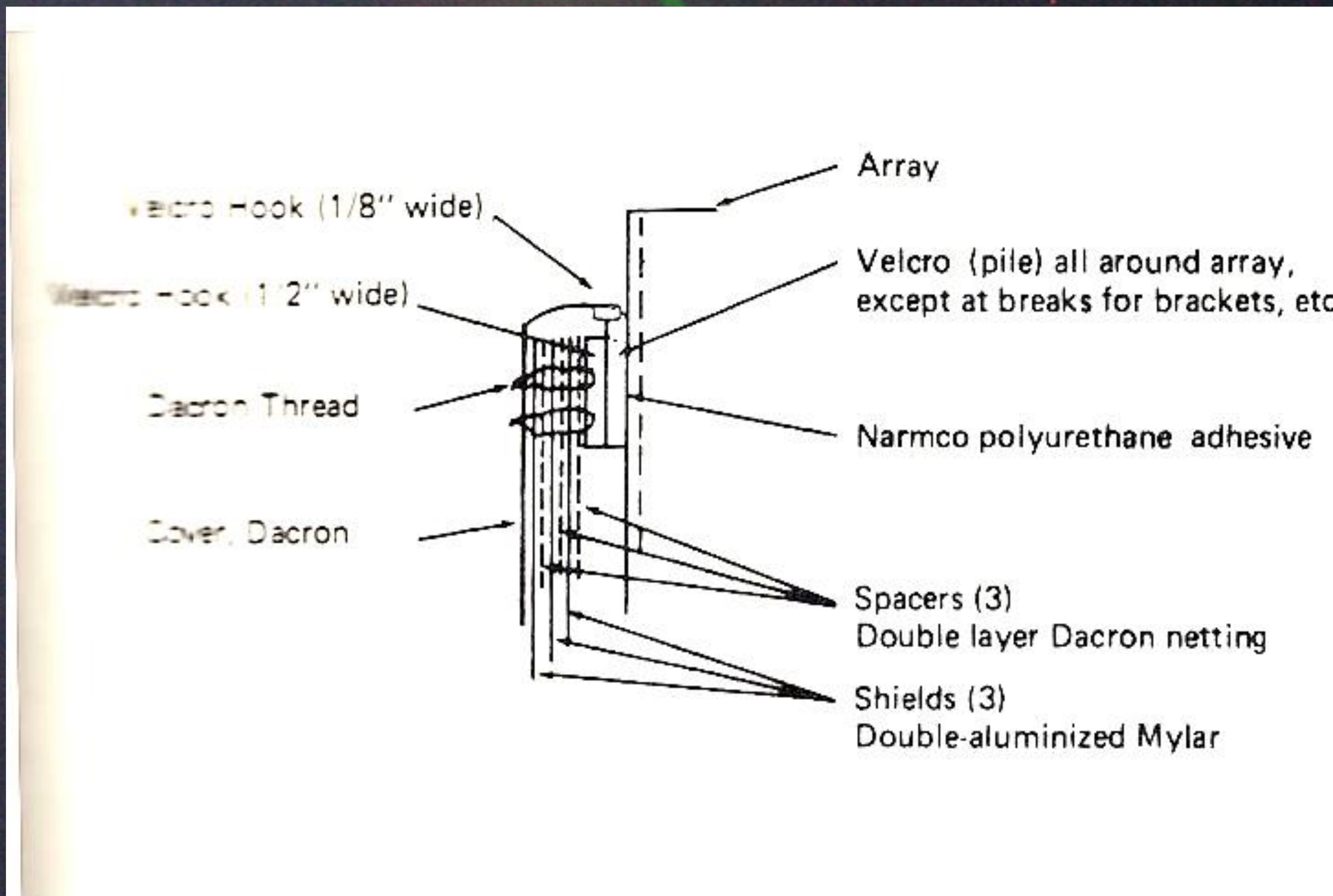
# PRIMARY CONDUCTION PATHS



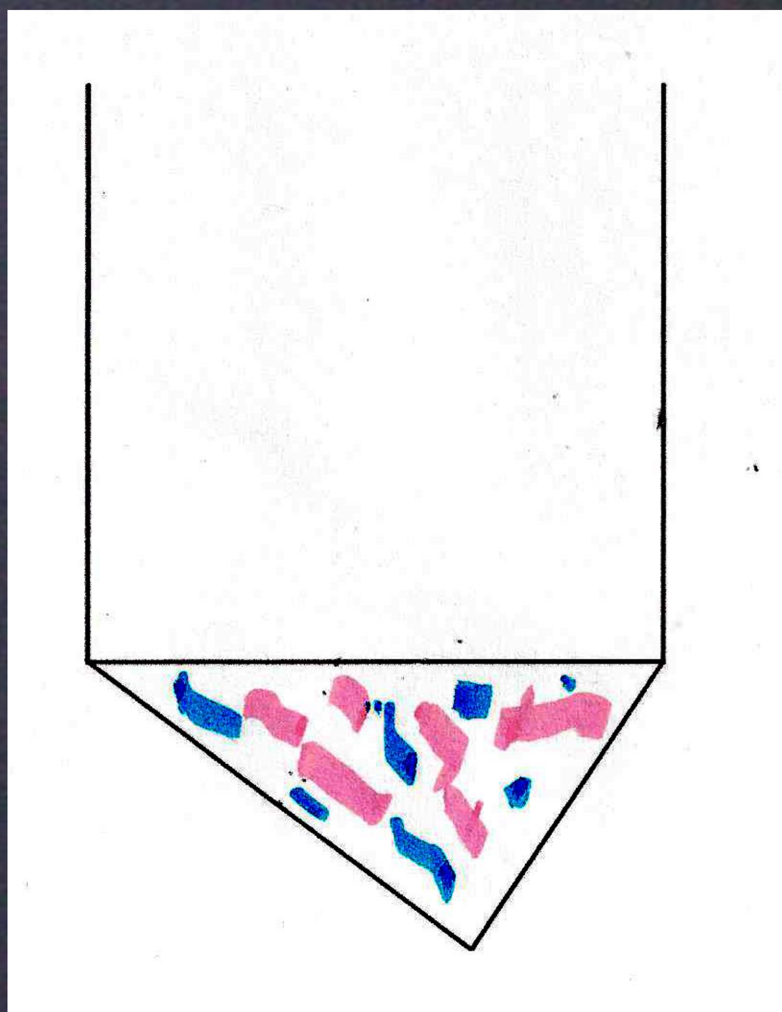



# EXTERIOR OF PANEL

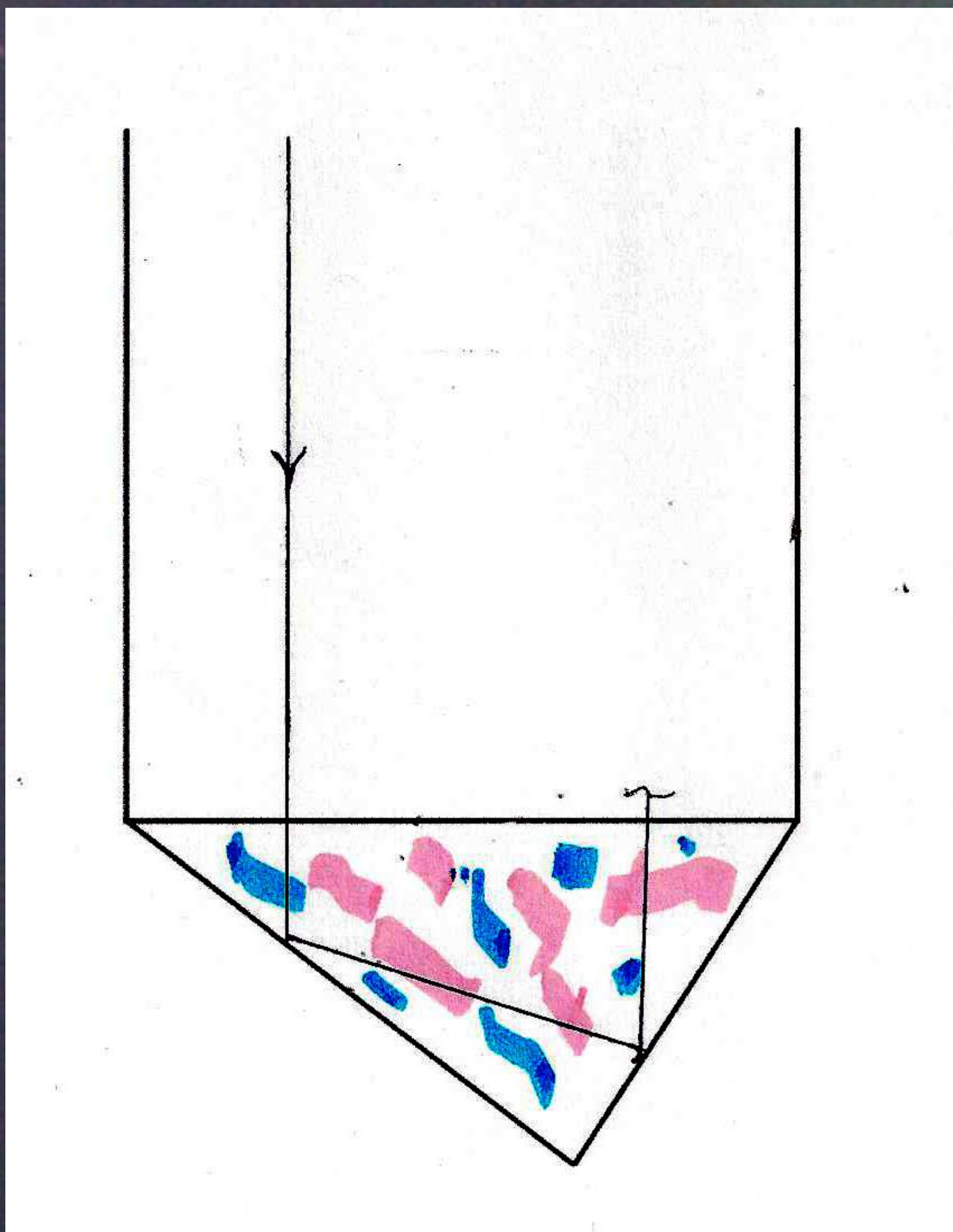


# INTERNAL 3D TEMPERATURE DISTRIBUTION



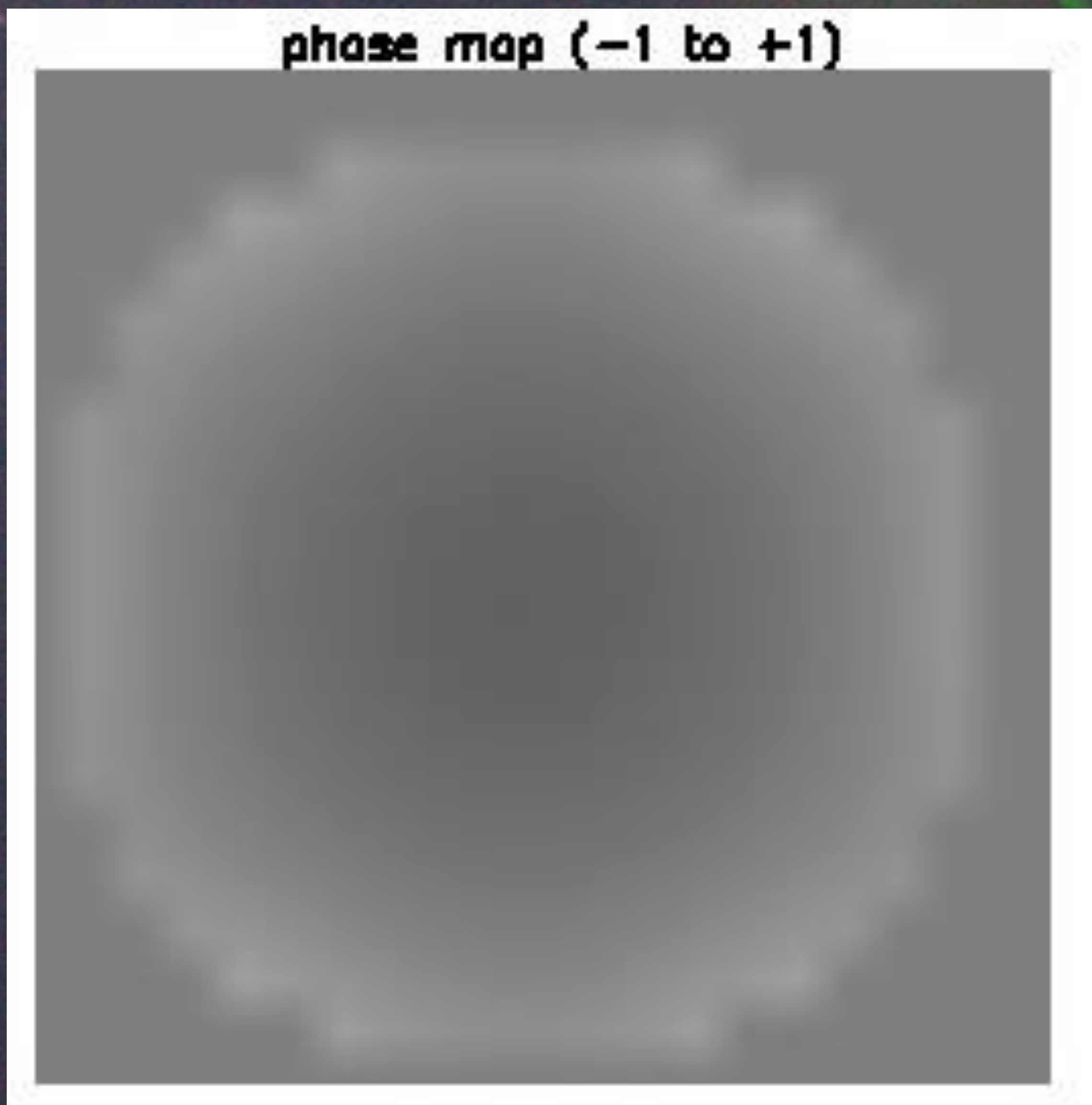
- Using the Listed Inputs
- Run Thermal Desktop
- This Results in
  - 3D Temperature Distribution
  - In the CCR Interior
- Temperatures of Other Elements
  - Not Currently of Primary Interest

# RAY SAMPLING OF 3D TEMPERATURE



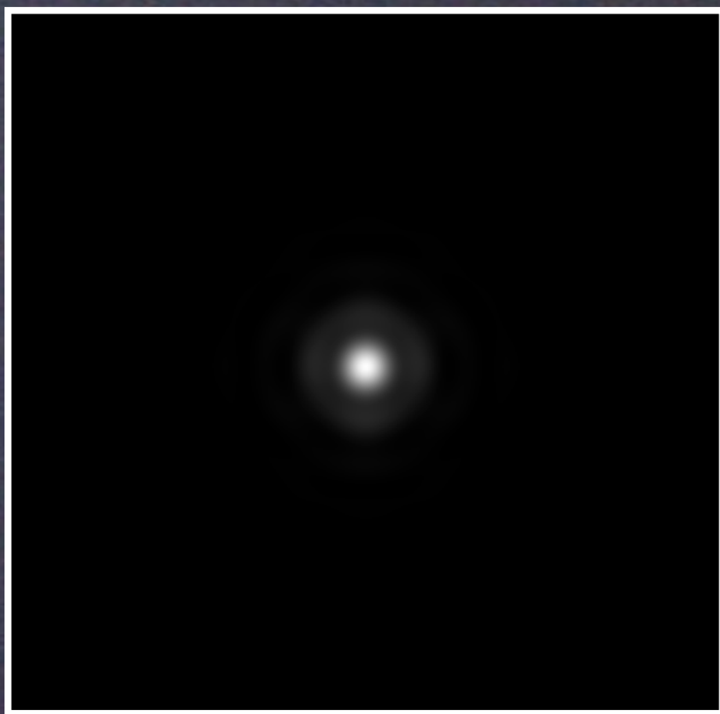
- Laser Ray Enters CCR
- Encounters Different Ts
- Converts to Phase dn/dT
- Determines Integral Phase
- Produces Phase Error Map
- Repeat for 1,000 Rays

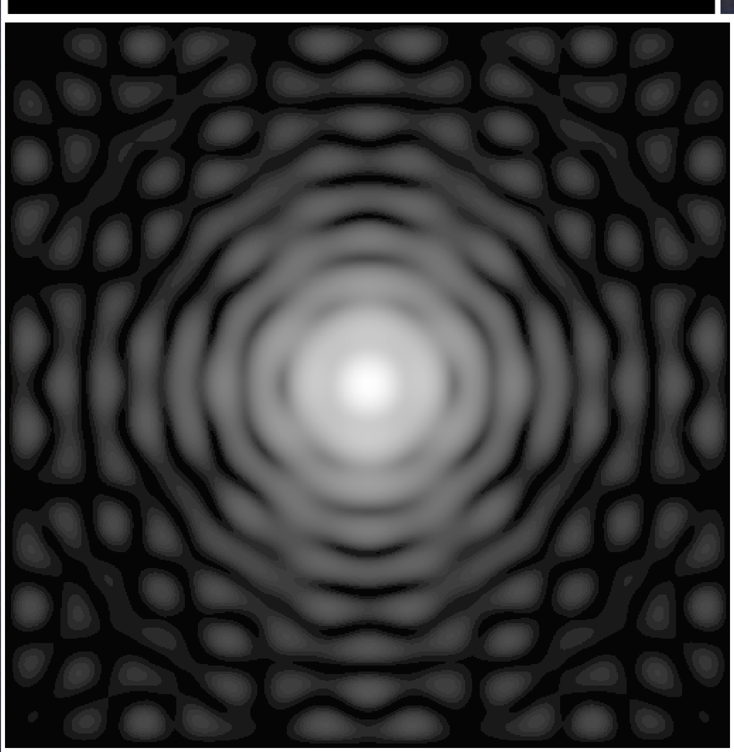
# 2D PHASE ERROR MAP

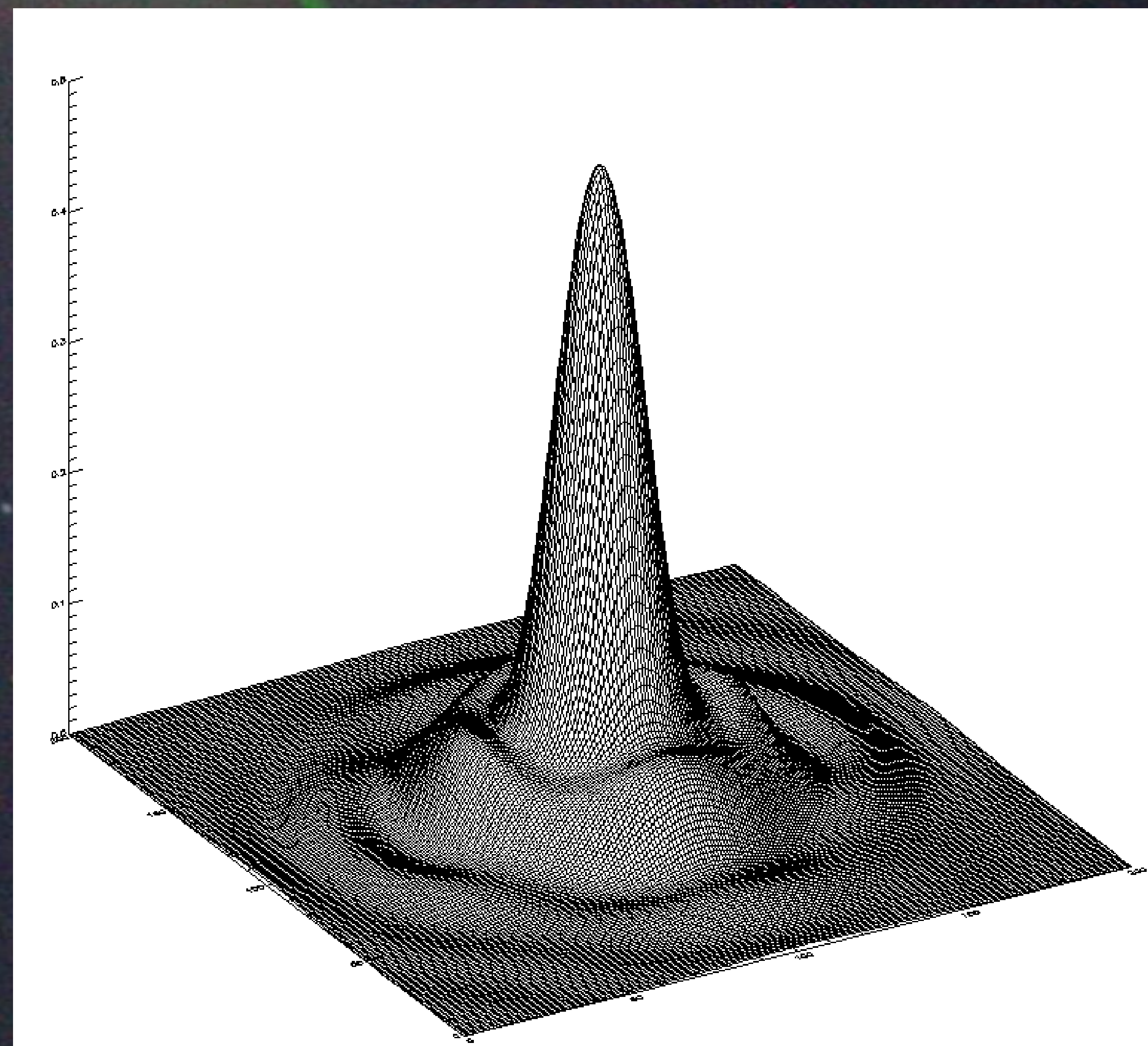



- Change of Phase
  - At Each Point

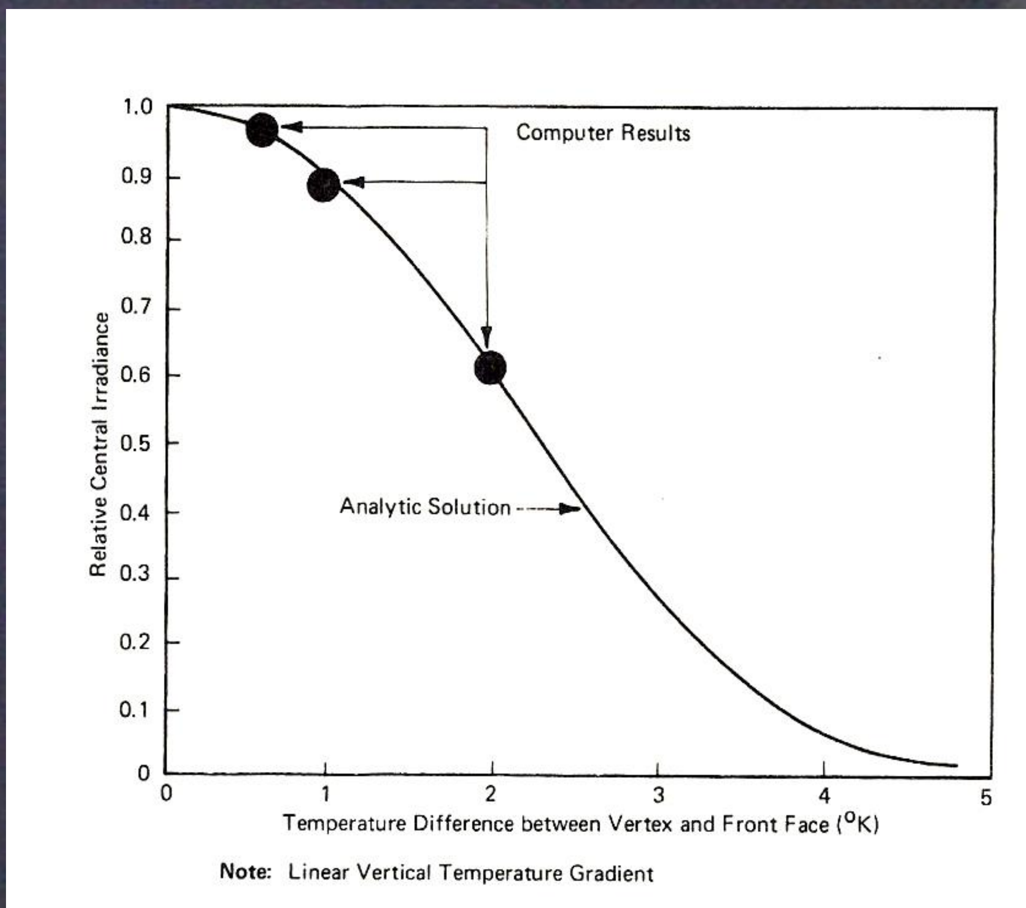
# FAR FIELD DIFFRACTION PATTERN





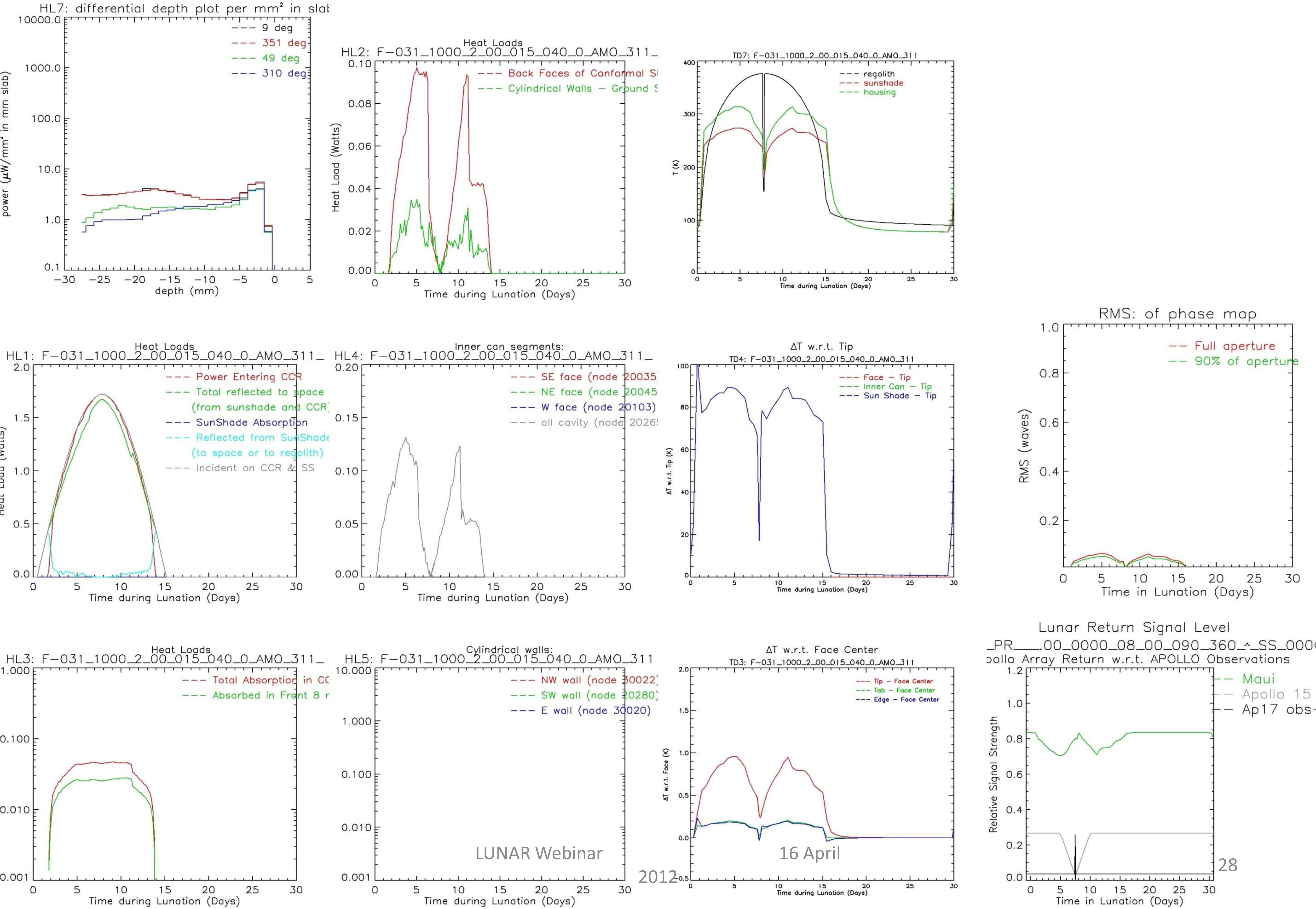


# AXIAL TEMPERATURE EFFECT




- Sample of Results
- Effect of Axial Gradient
  - From 1968 Analysis
  - 80% Return at 1 Degree
  - Neglects Radial Effects
- Confirmed by Later Analysis
  - E.g., Tom Murphy Recent Paper

F-031_1000_2_00_015_040_0_AMO_311_S6_G1_PR___.00_0000_08_00_090_360_^_SS_00000_99999_05_95_01_MLI_090-360_G_^_MAT
HL run on Oct 24 2013, TD run on Oct 25 2013, TPS run on Nov 07 2013
-38 27.53 1000 2 0.40 00 015 040 0 1 2 6 12 4 1 8
no DWG info
38.0 0.000 0.000 532.0 512 0.267



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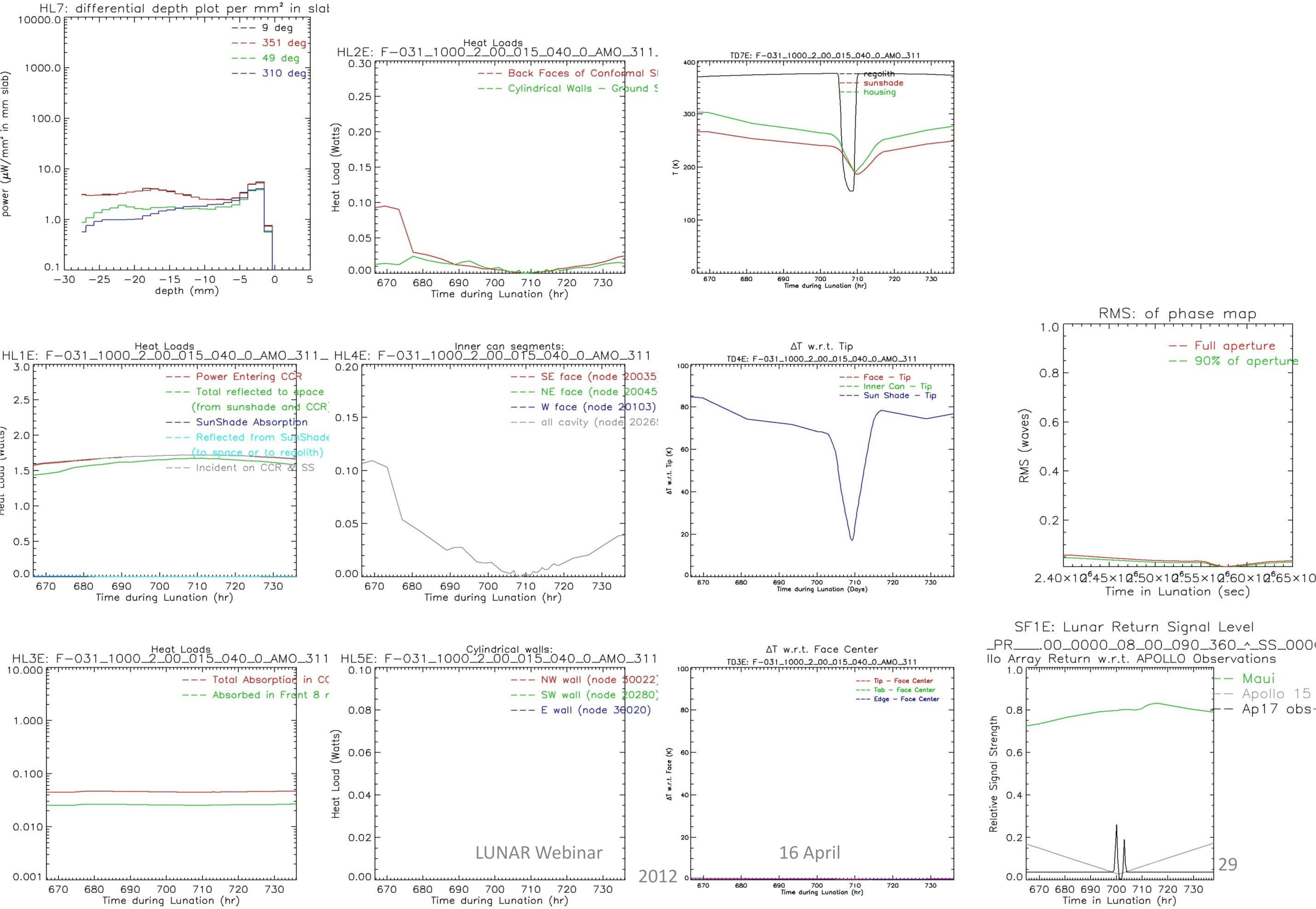

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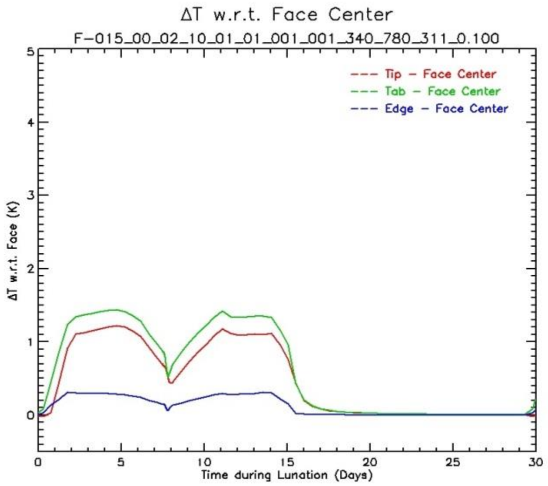


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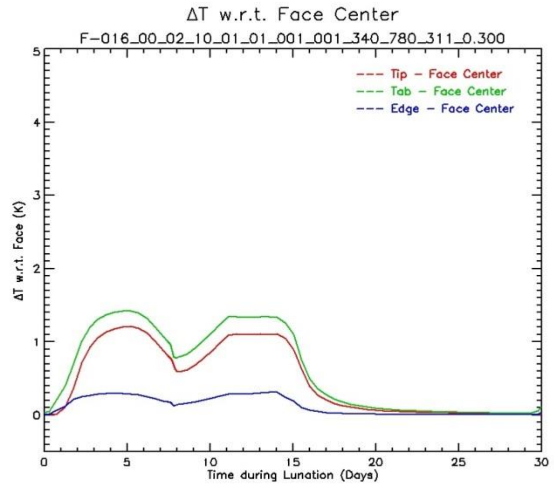


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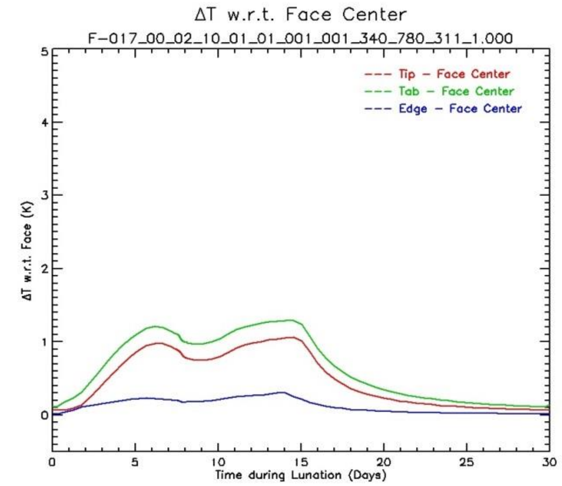


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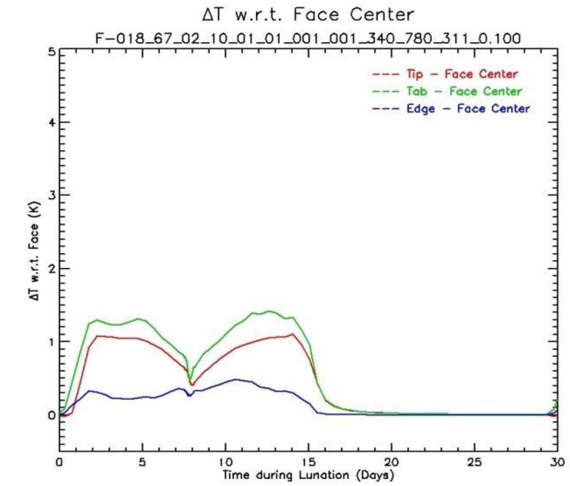


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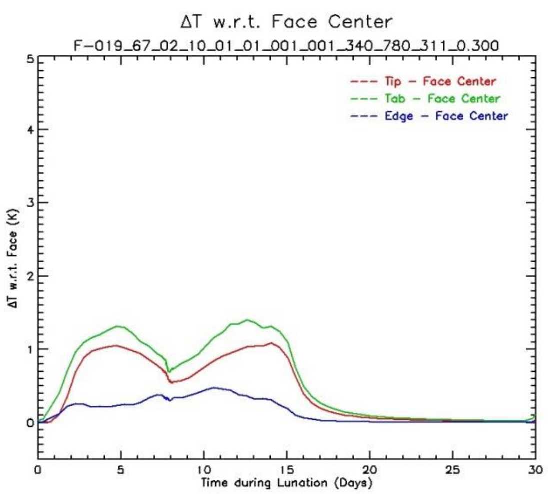


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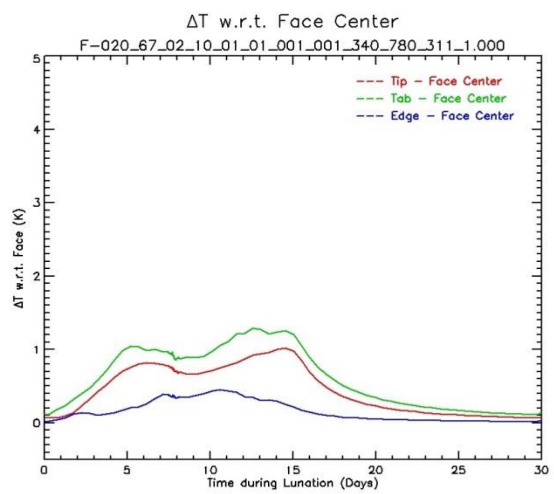


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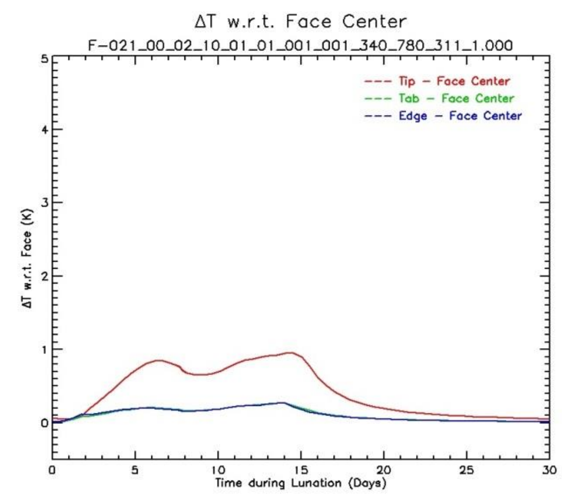


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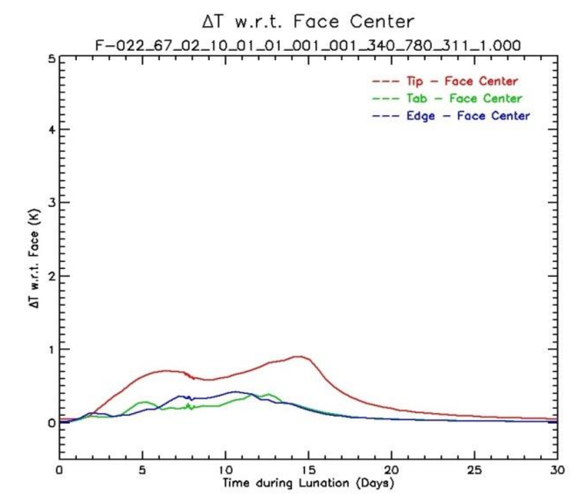


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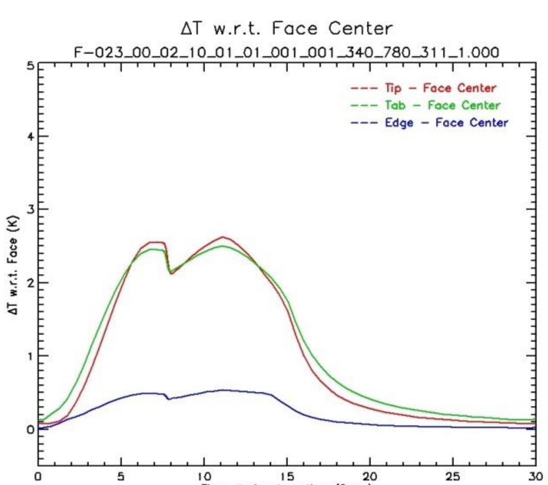


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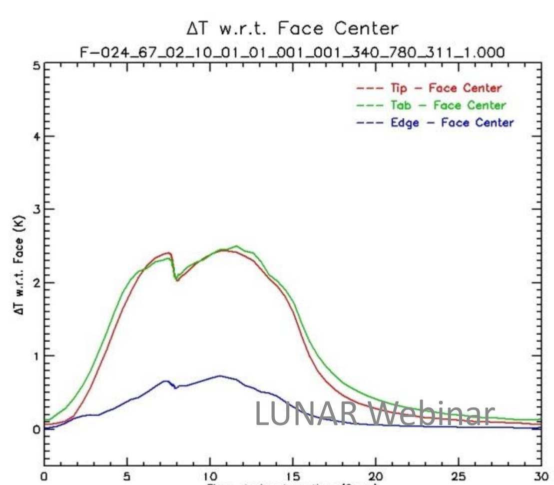
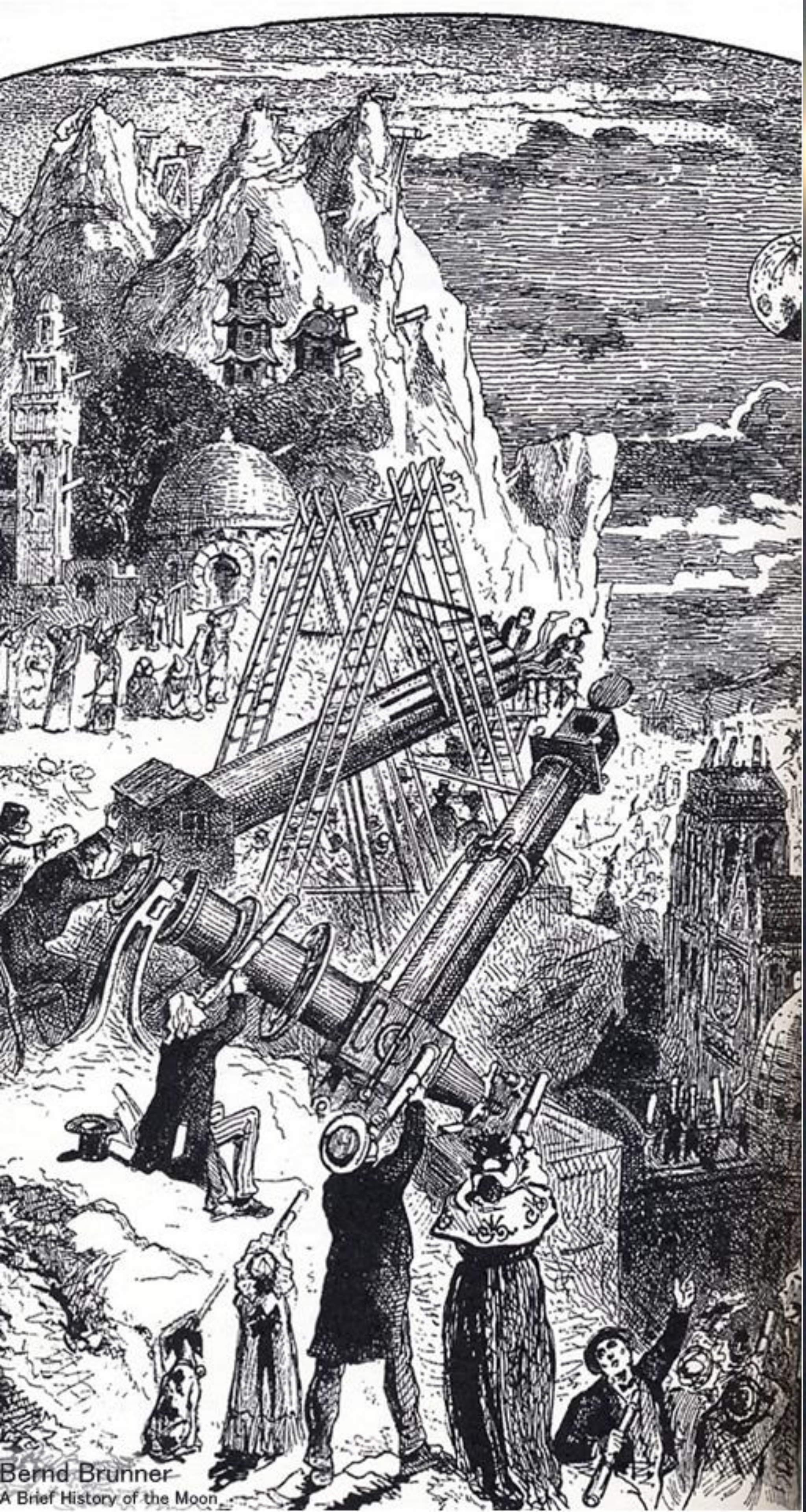


# STATUS AND FUTURE

- Current Results for Apollo 11 Array
  - Tab Conductance most Important
  - Reasonable Agreement with ADL
  - Eclipse  Difficult
- Coatings/Parameter Variation
  - About 25 that are Relevant
- Future Directions
  - Temperature Variation of Index of Refraction i.e. dn/dT(T)
  - Eclipse – Matching Model to Observations
  - Solar Radiation into Cylindrical Pocket

# CONCLUSIONS

- Even For Small CCRs,
  - Thermal Effects can
  - Greatly Reduce Return Signal
- Optical/Thermal/Optical Modeling
  - Detailed Simulations are Necessary
  - To Achieve “Theoretical” Performance
  - Choosing Optimal Design Parameters




# Thank You!

any

## Questions?

or

## Comments?

.

with

Special Acknowledgements

to

NASA Lunar Science Sorties Opportunities

NASA Lunar Science Institute

Italian Space Agency

INFN-LNF, Frascati

LSSO Team

&

LUNAR Team

.

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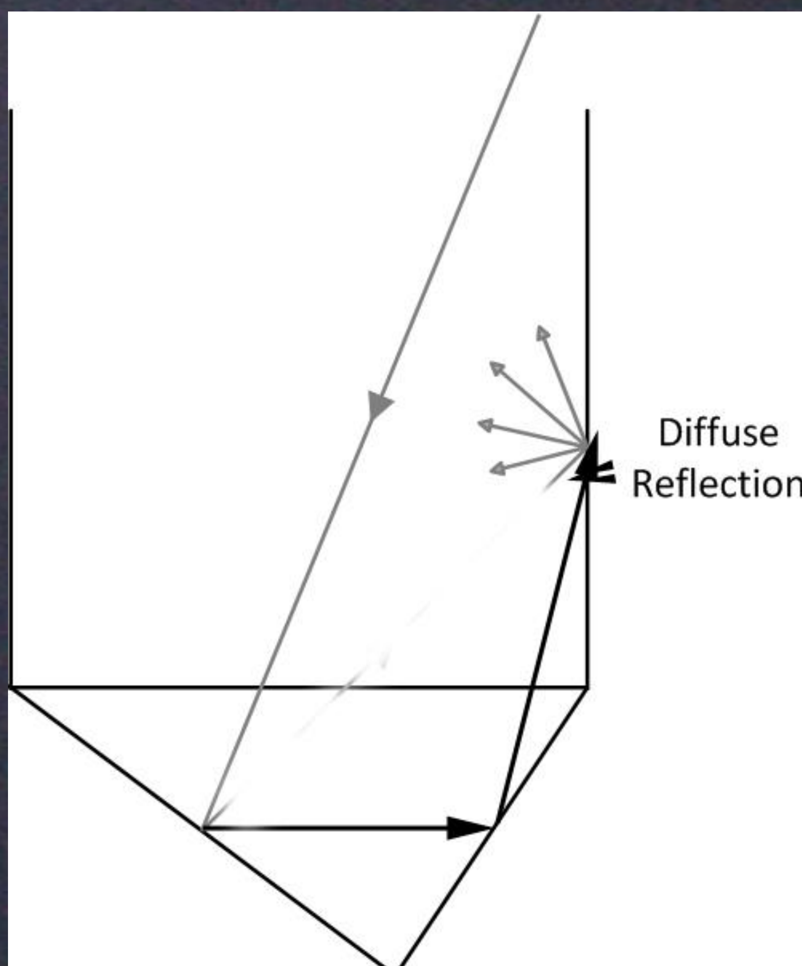
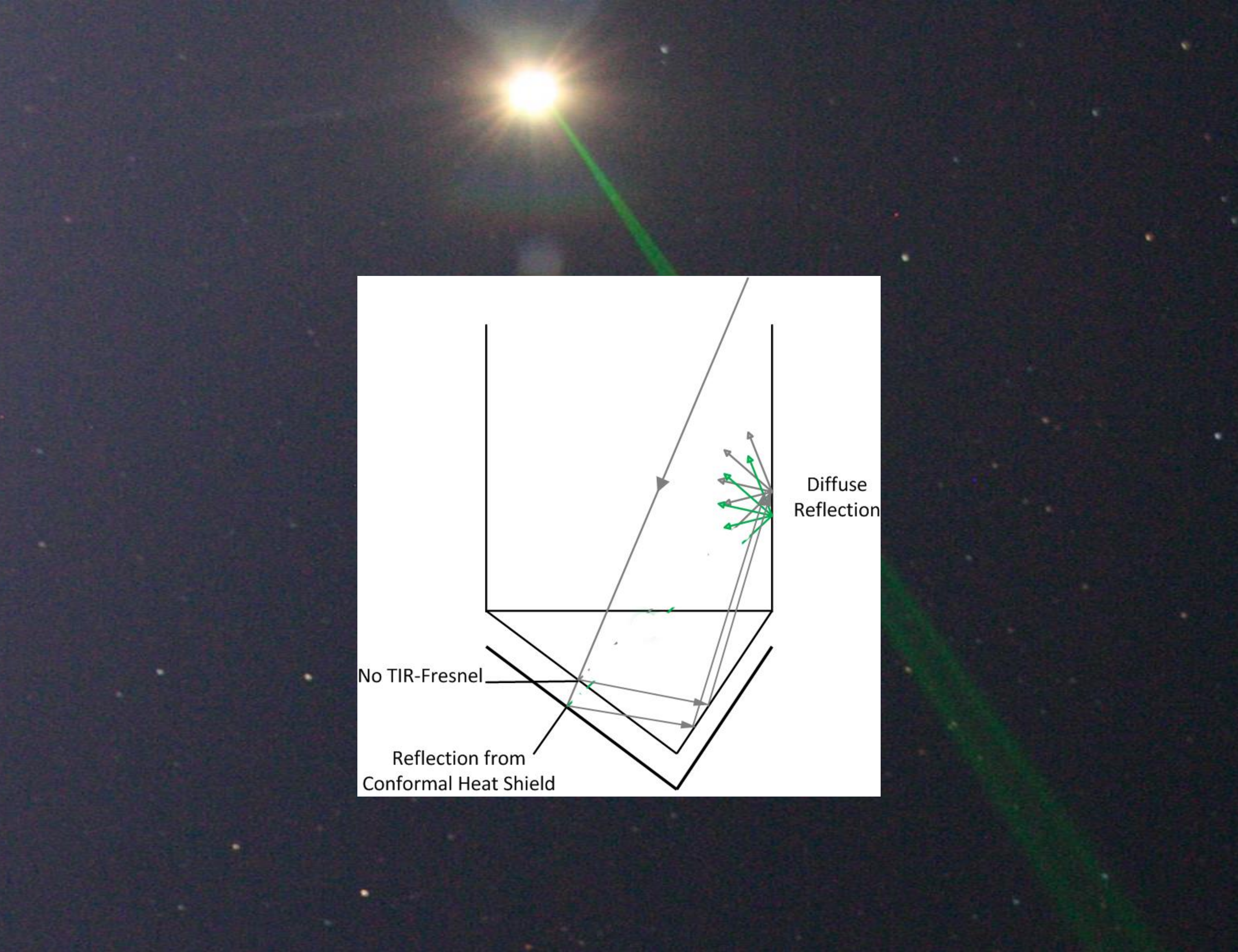
# OFF AXIS SOLAR ILLUMINATION




Diffuse
Reflection
No TIR-Fresnel
Reflection from
Conformal Heat Shield

# OFF AXIS SOLAR ILLUMINATION

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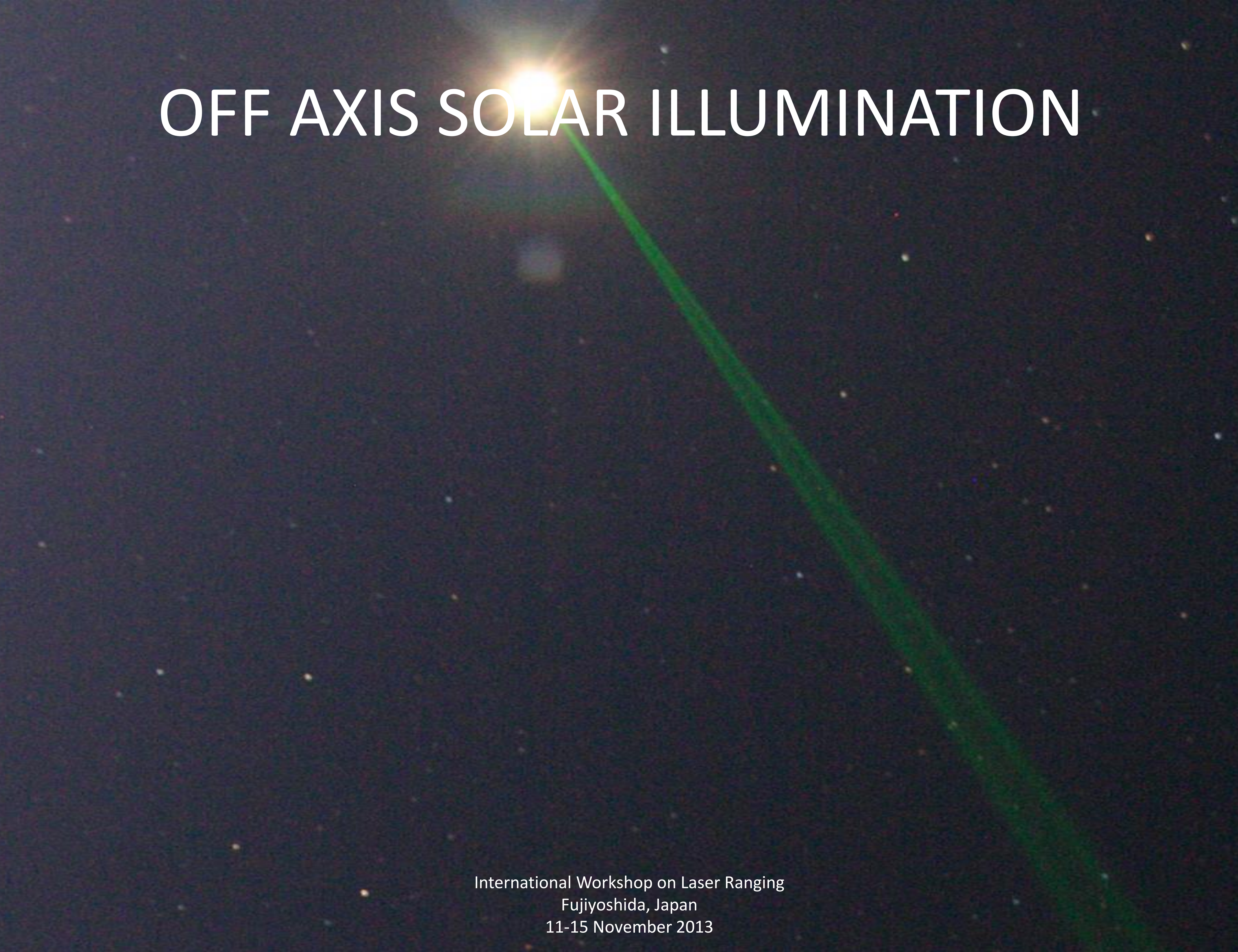
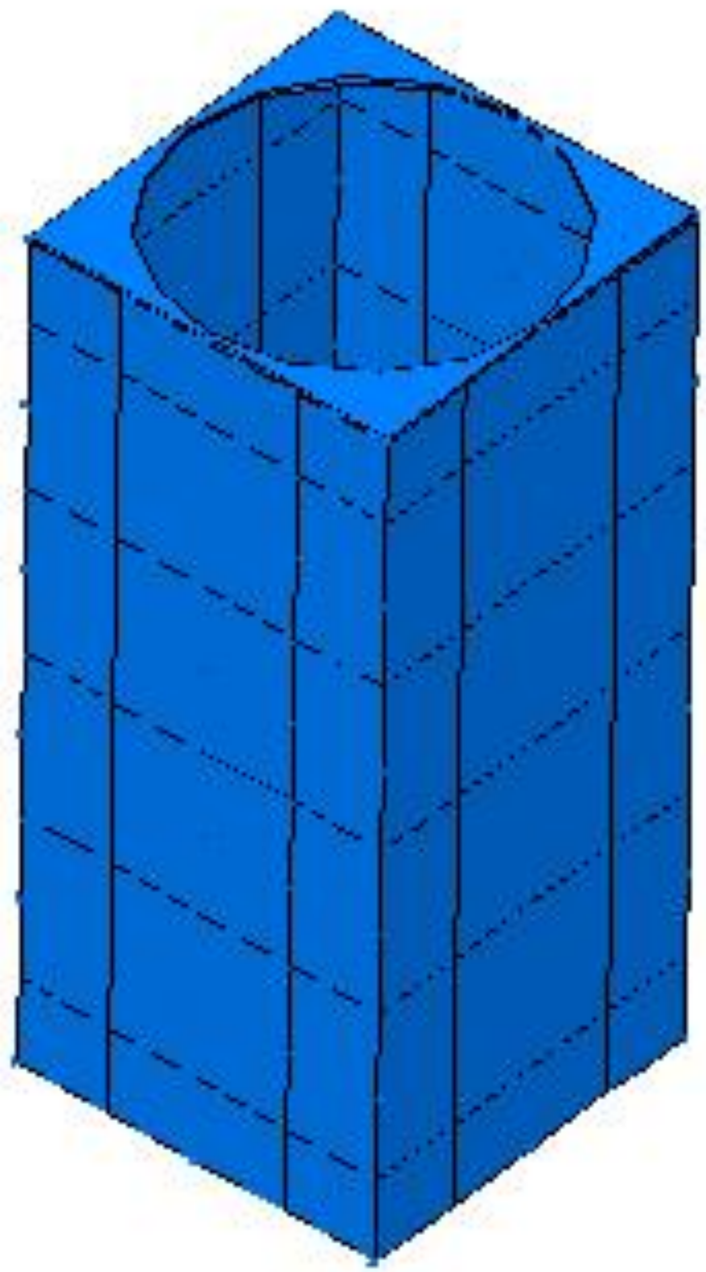
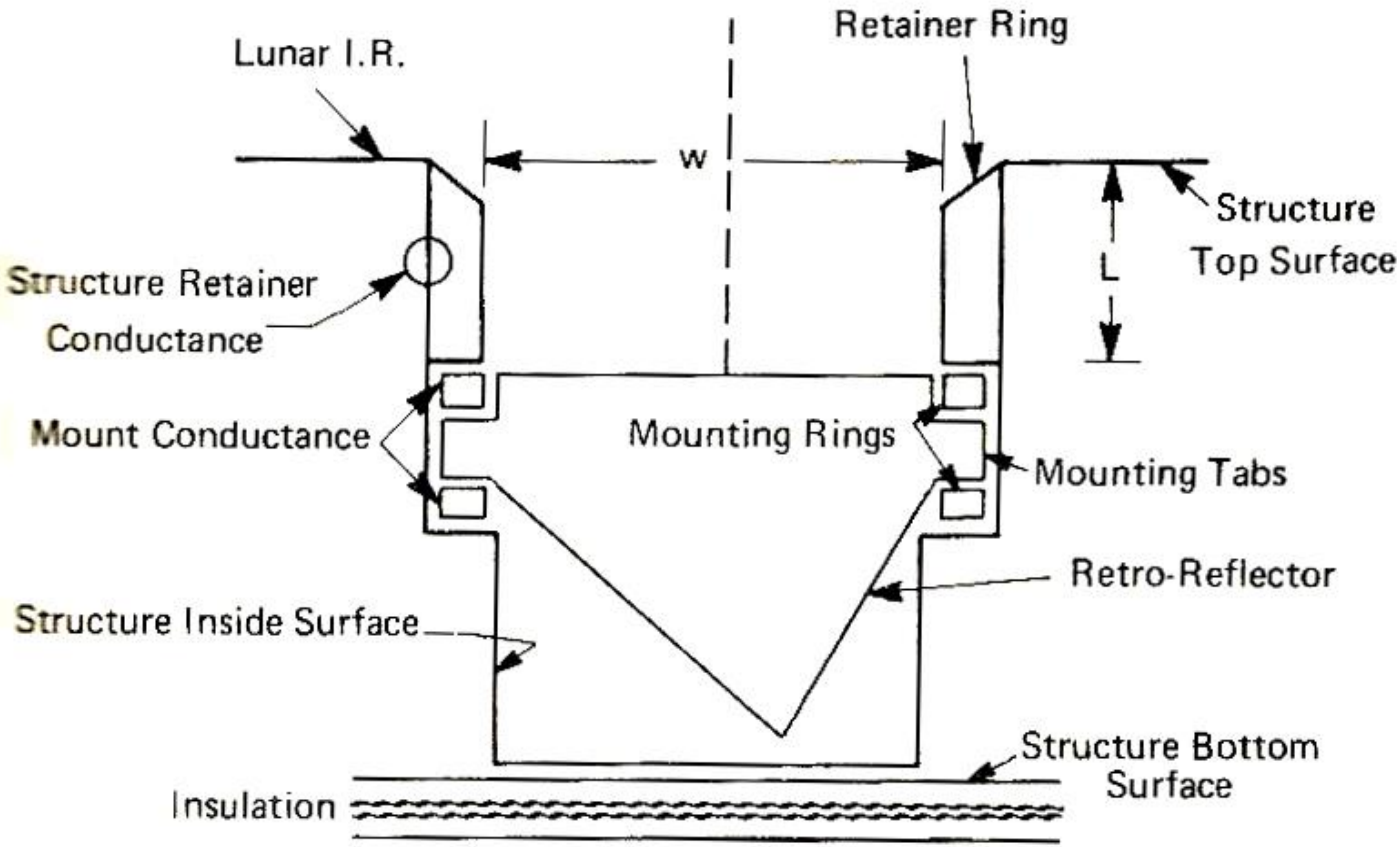
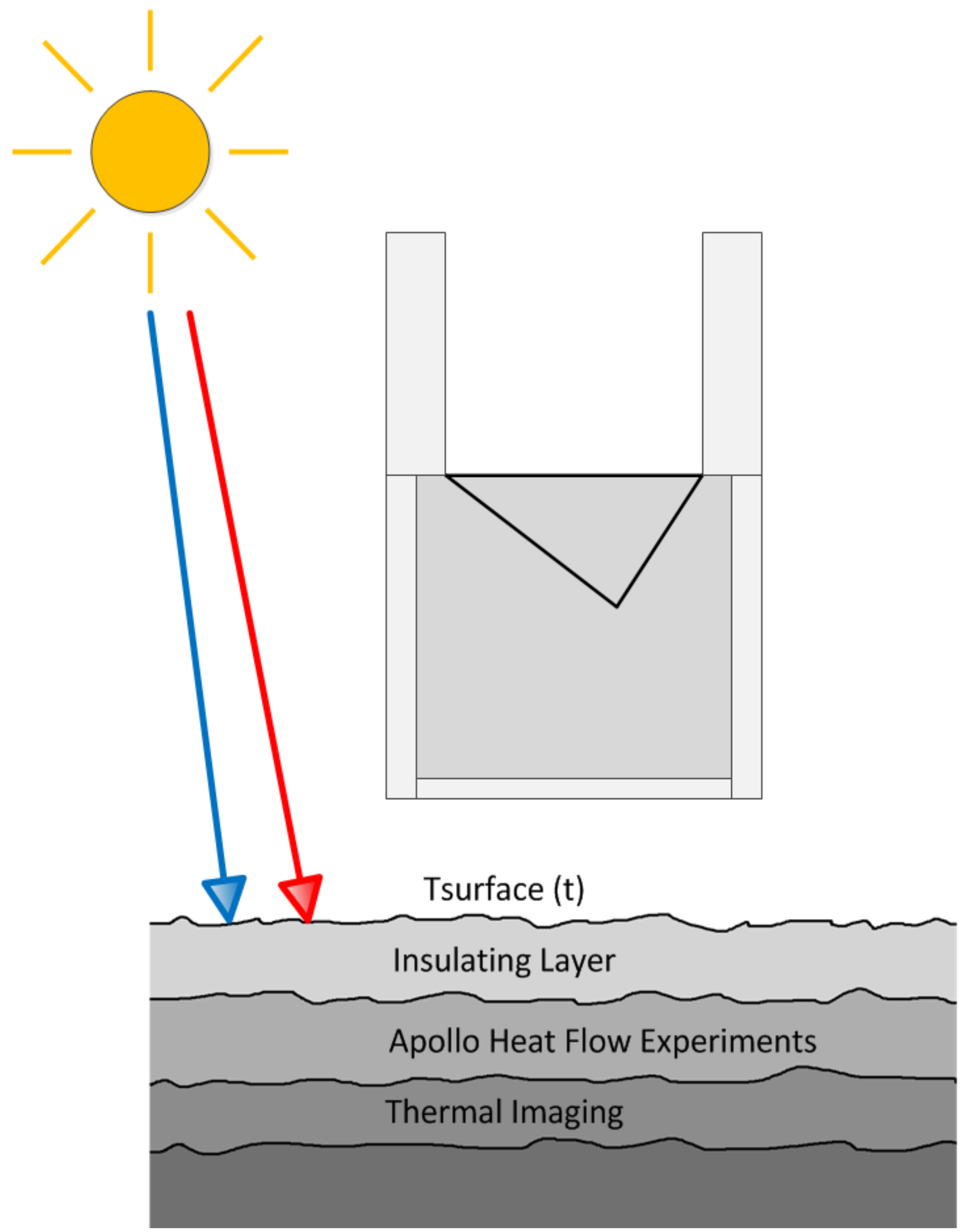


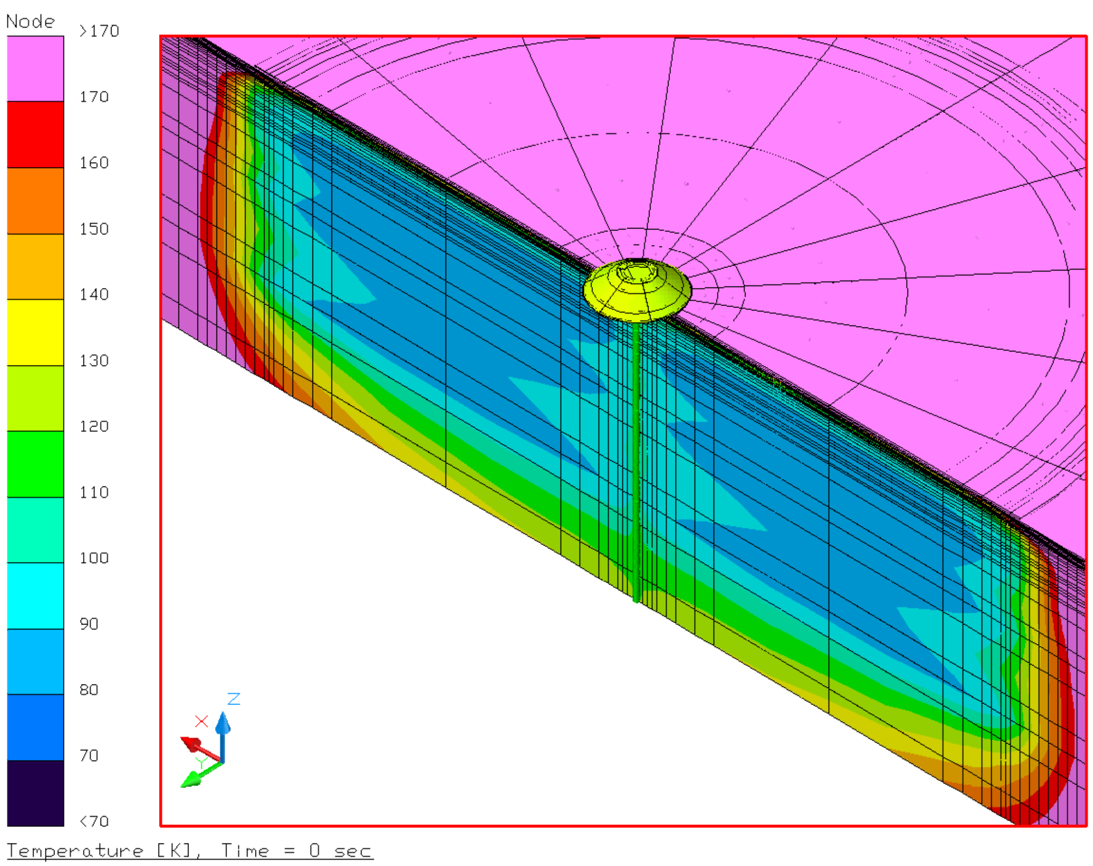


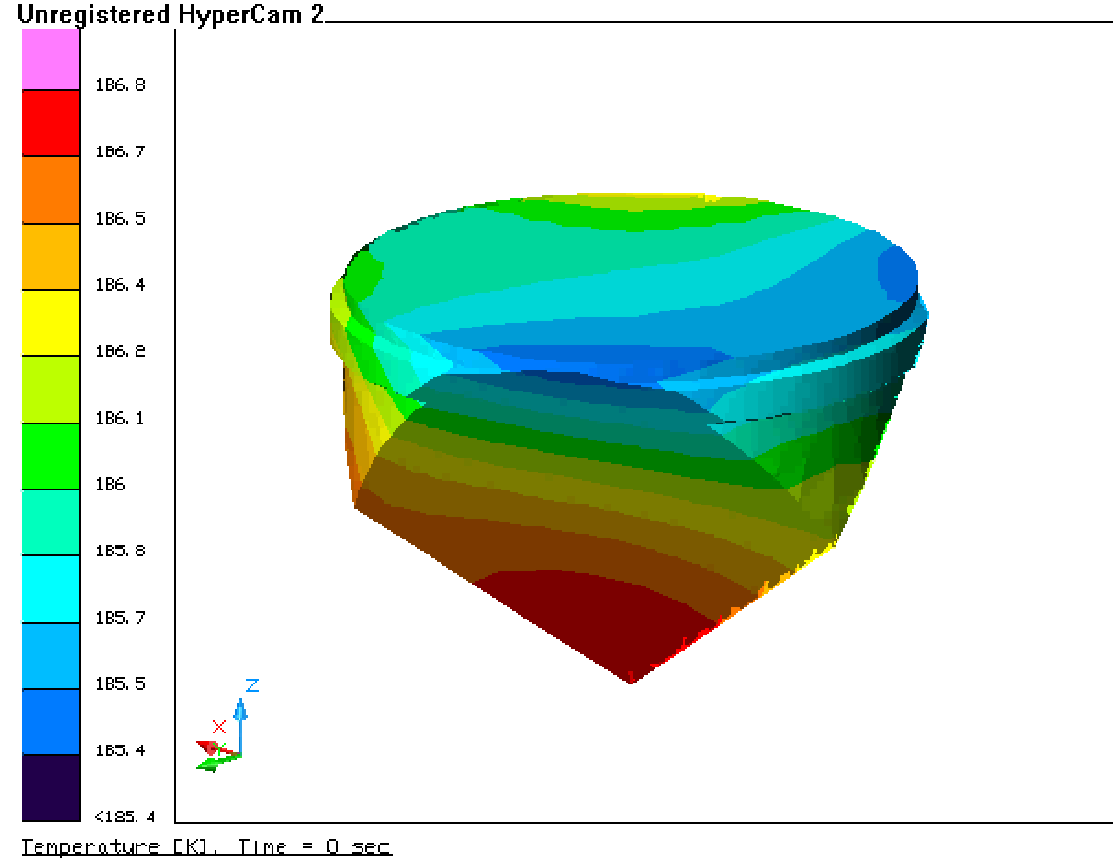


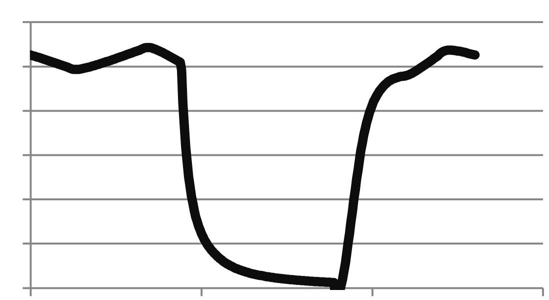
Lunar I.R.
Retainer Ring
w
Structure
Top Surface
L
Structure Retainer
Conductance
Mount Conductance
Mounting Rings
Mounting Tabs
Retro-Reflector
Structure Inside Surface
Structure Bottom
Surface
Insulation

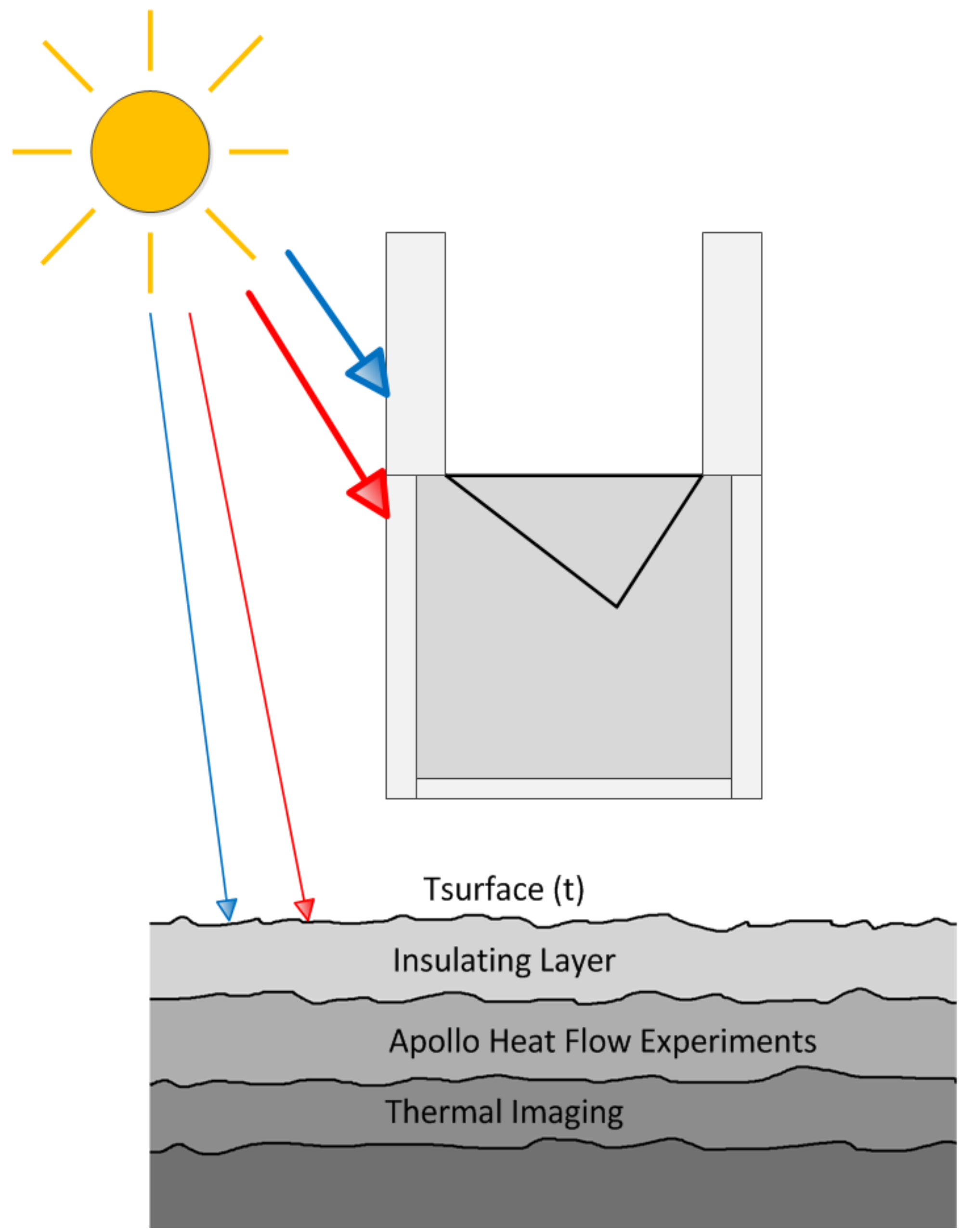

Tsurface (t)
Insulating Layer
Apollo Heat Flow Experiments
Thermal Imaging

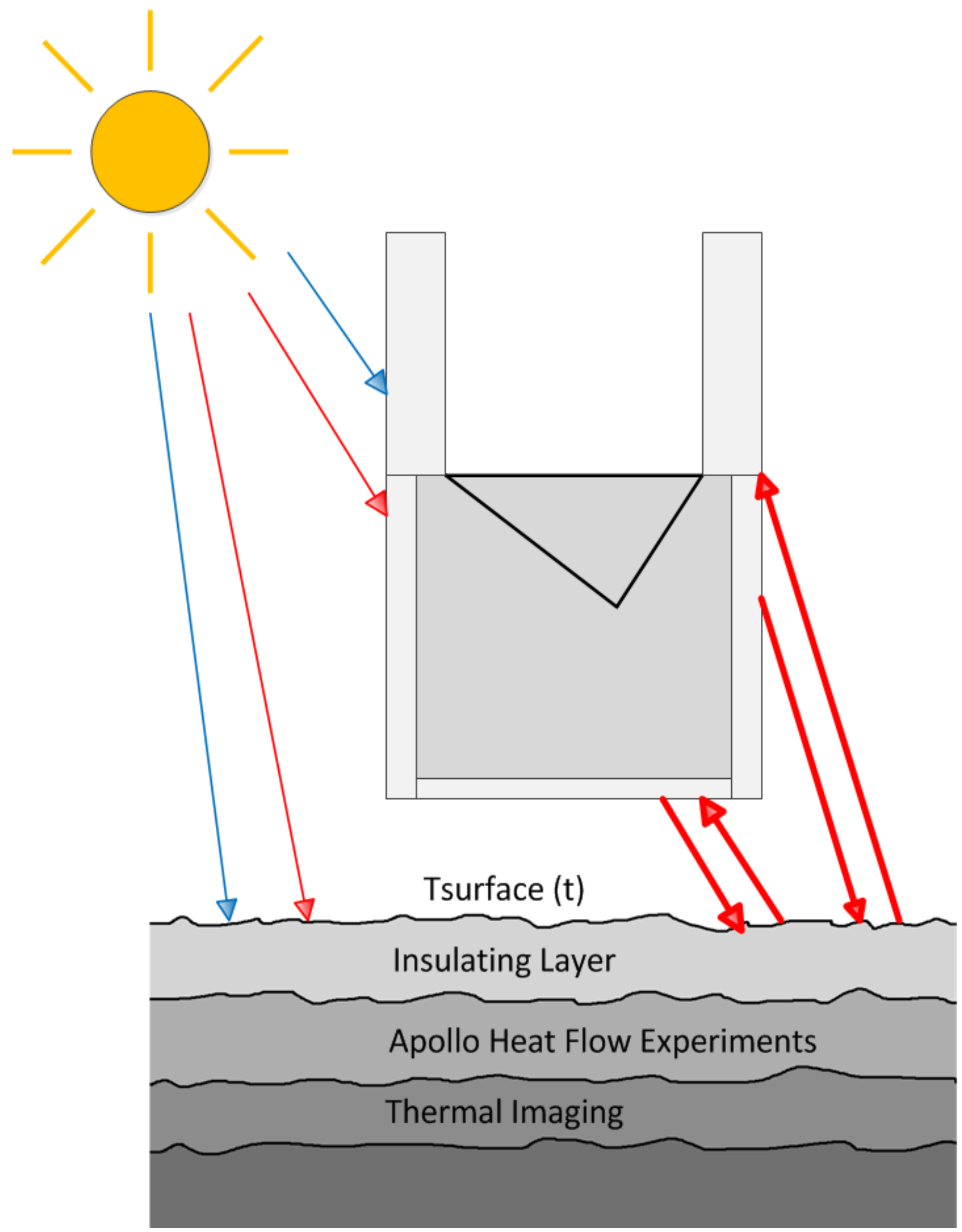
Unregistered HyperCam 2



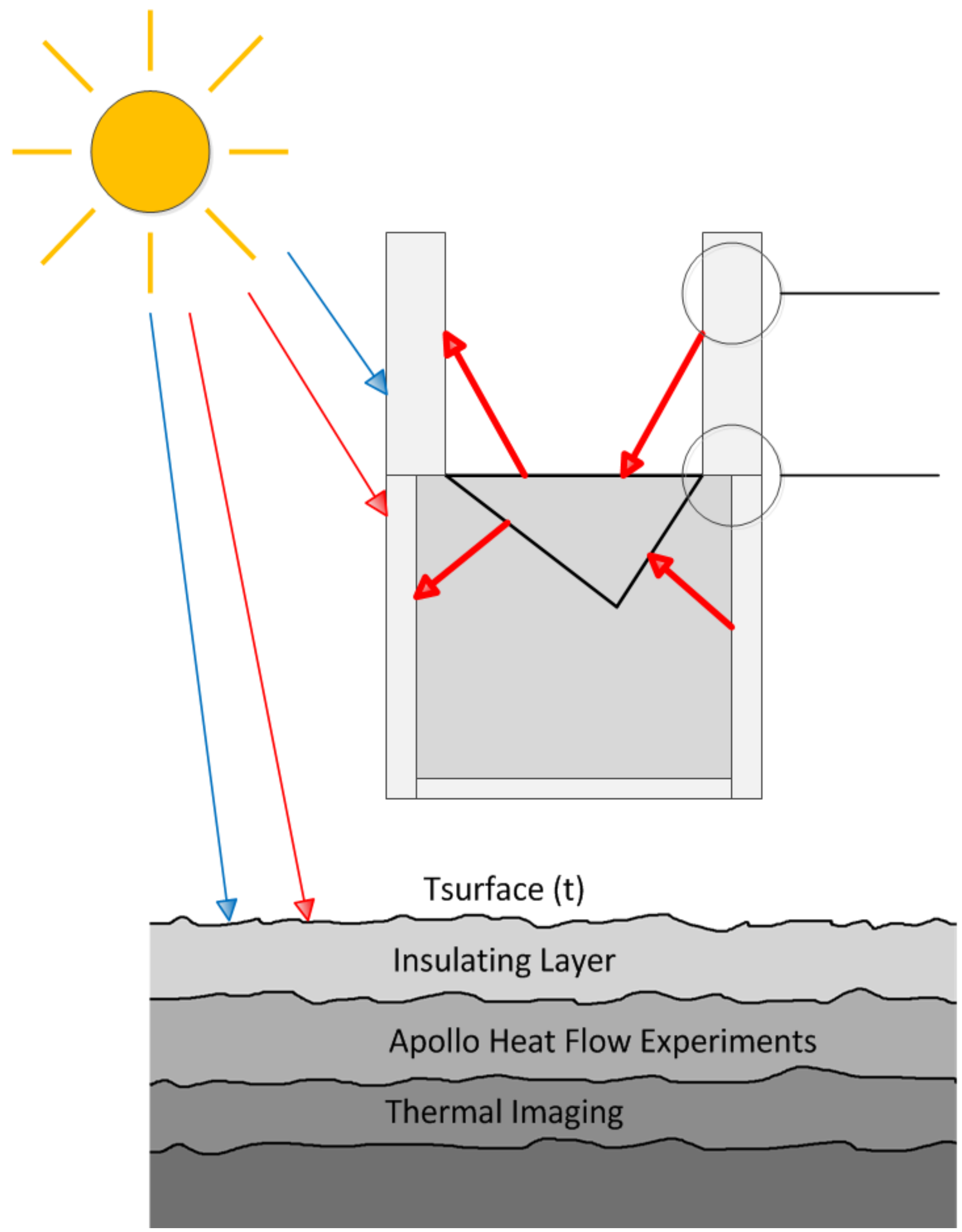



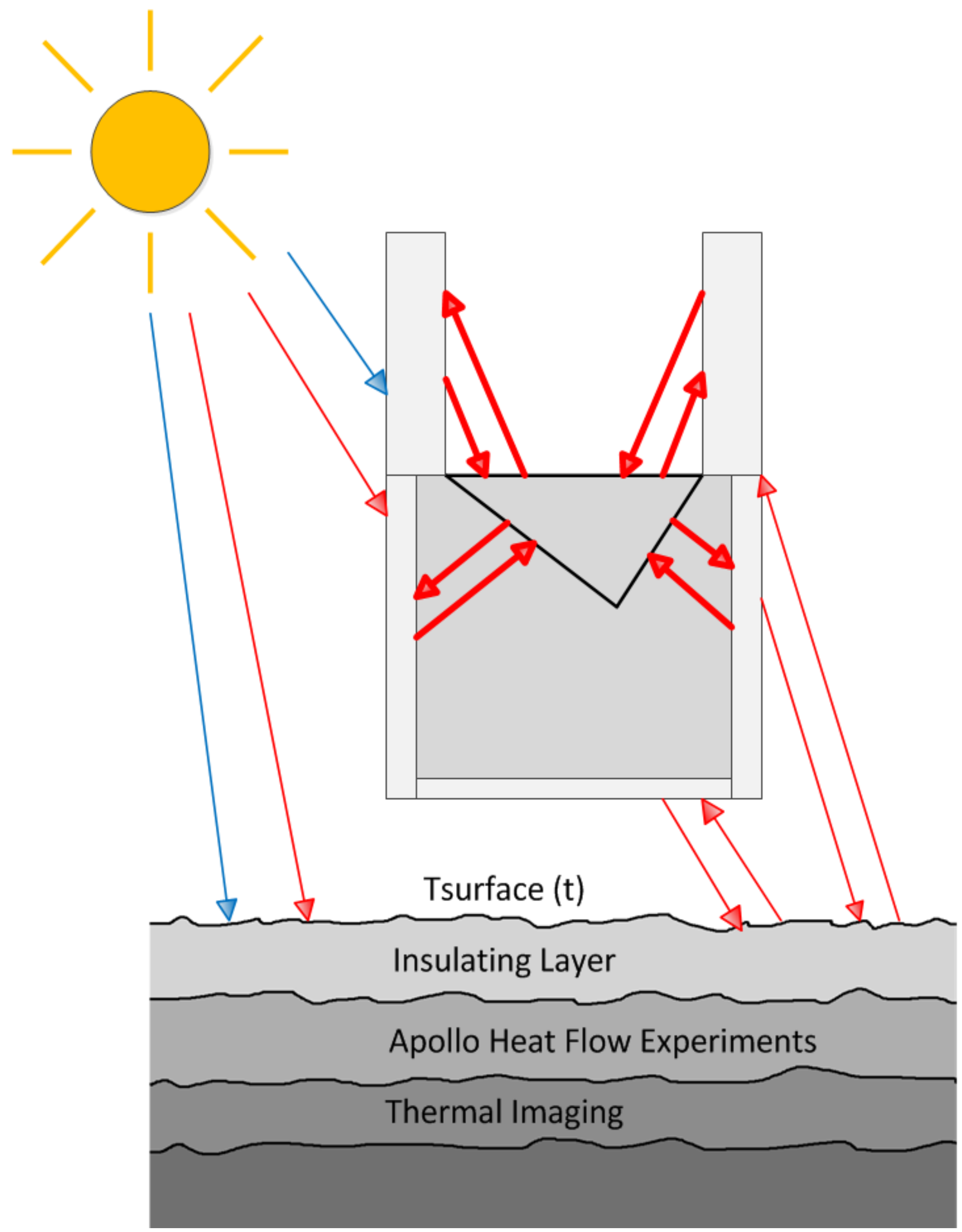

Tsurface (t)
Insulating Layer
Apollo Heat Flow Experiments
Thermal Imaging



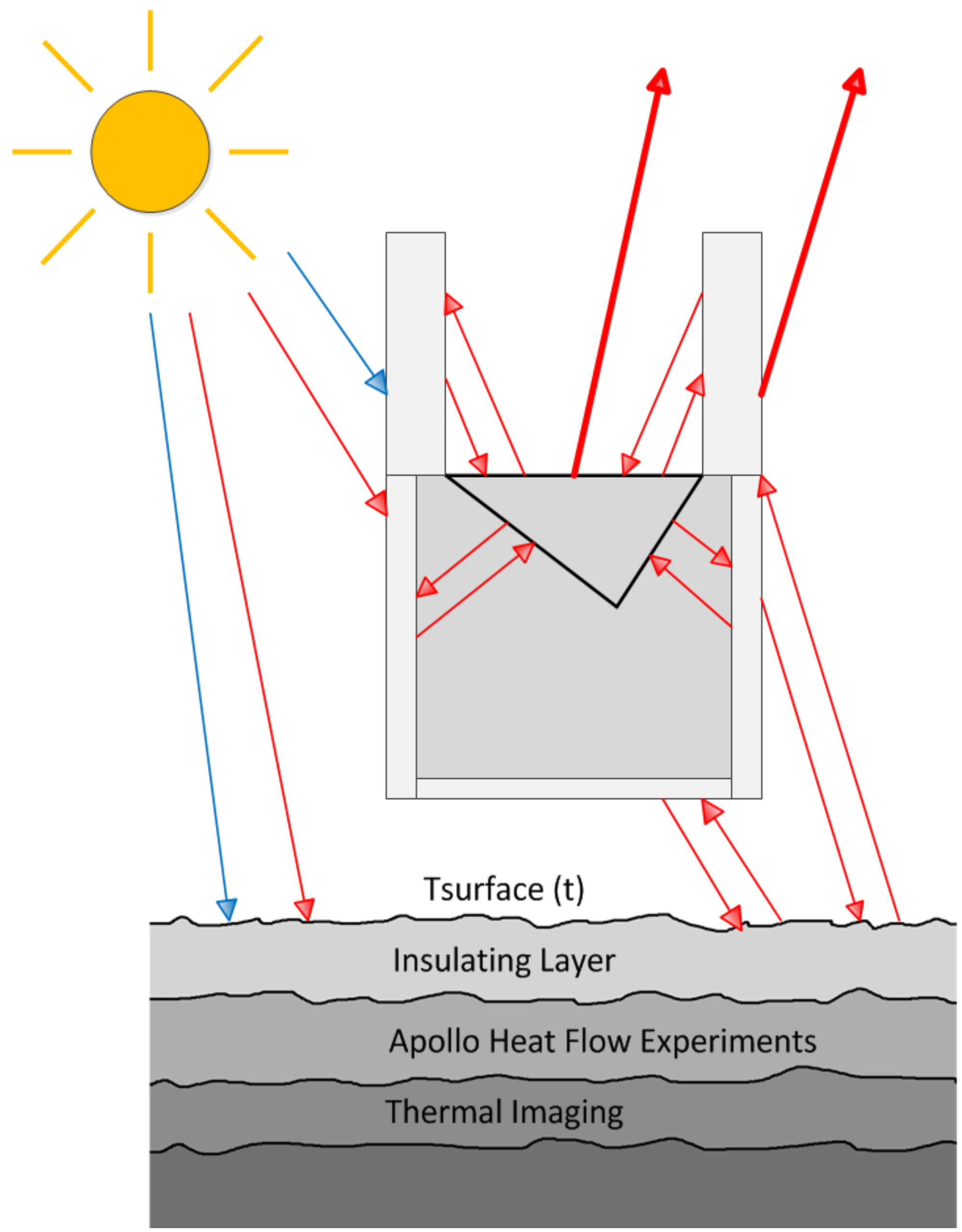
Tsurface (t)
Insulating Layer
Apollo Heat Flow Experiments
Thermal Imaging



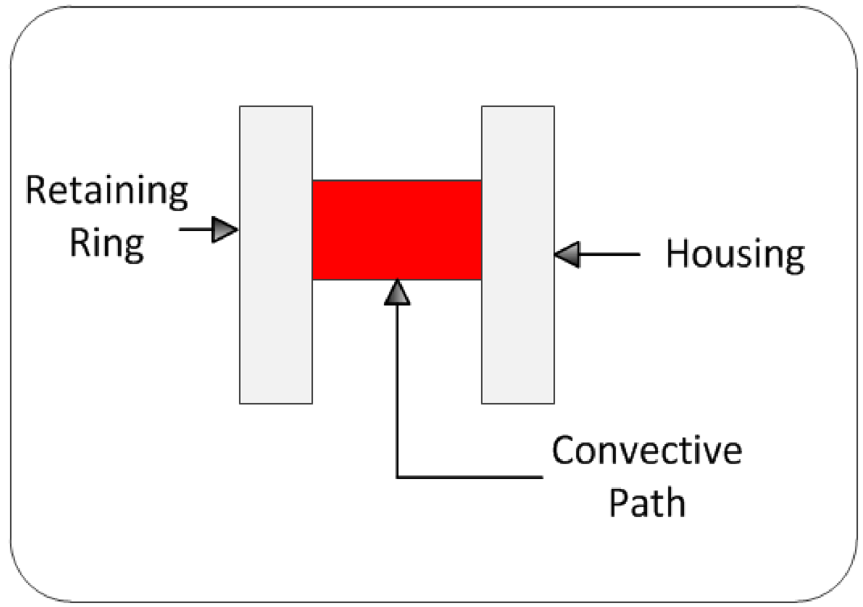
Tsurface (t)
Insulating Layer
Apollo Heat Flow Experiments
Thermal Imaging

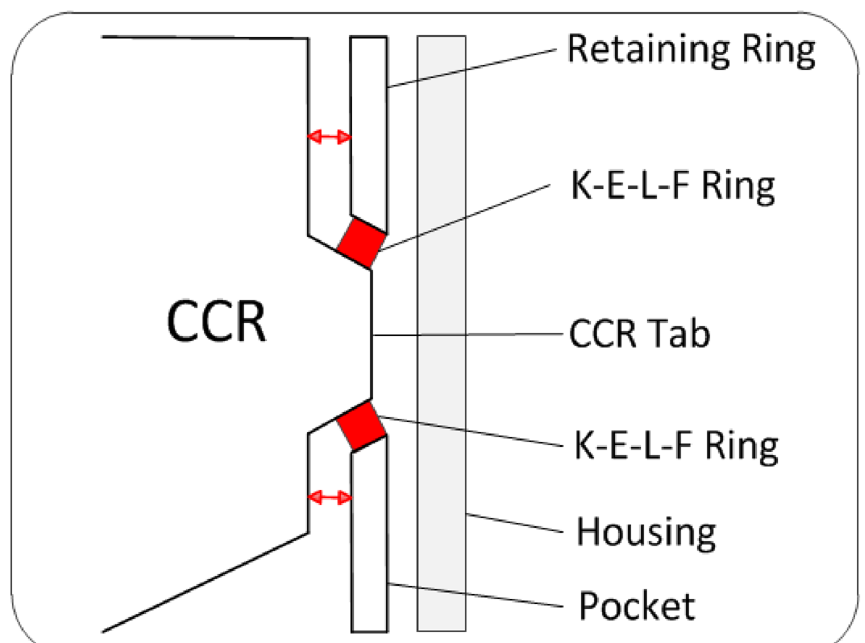


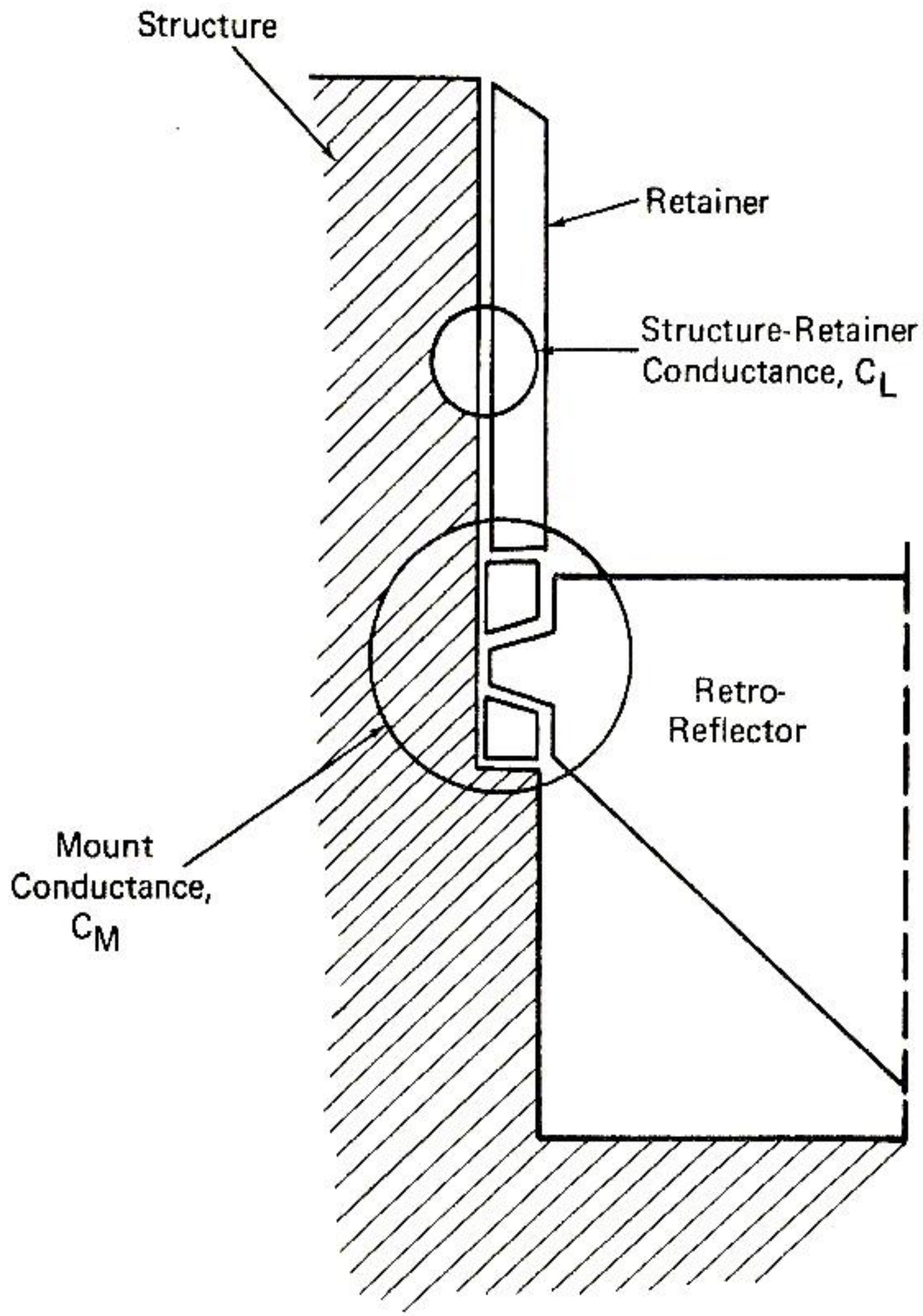
Tsurface (t)
Insulating Layer
Apollo Heat Flow Experiments
Thermal Imaging



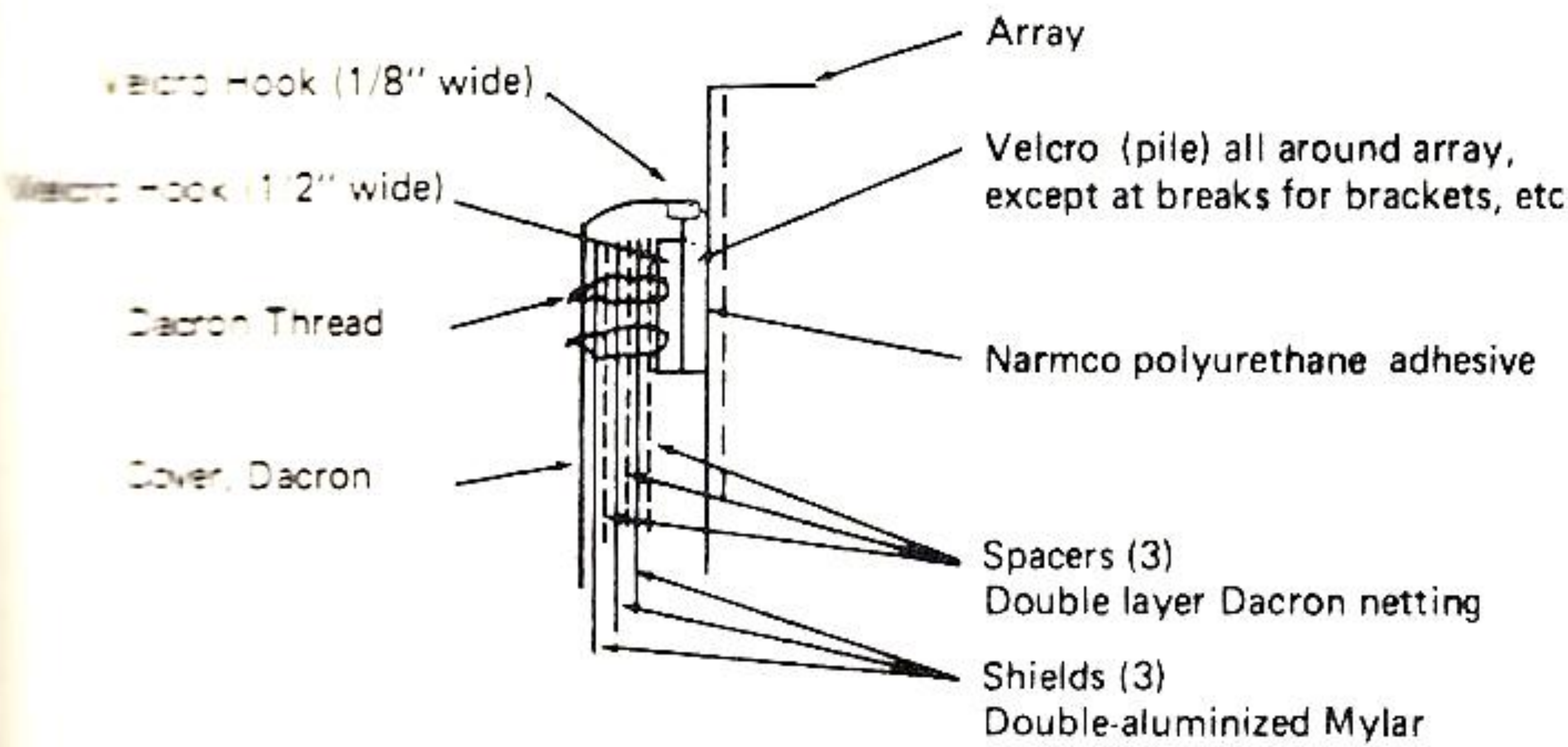
Tsurface (t)
Insulating Layer
Apollo Heat Flow Experiments
Thermal Imaging


Retaining Ring
Housing
Convective Path

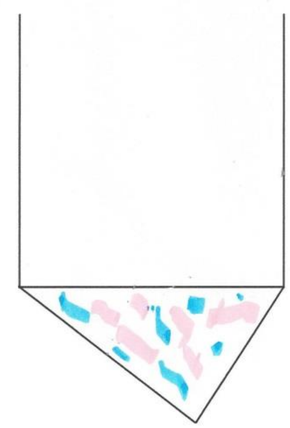

Retaining Ring
K-E-L-F Ring
CCR
CCR Tab
K-E-L-F Ring
Housing
Pocket

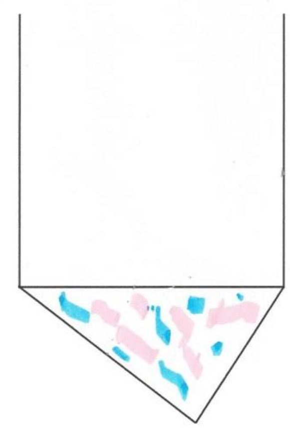


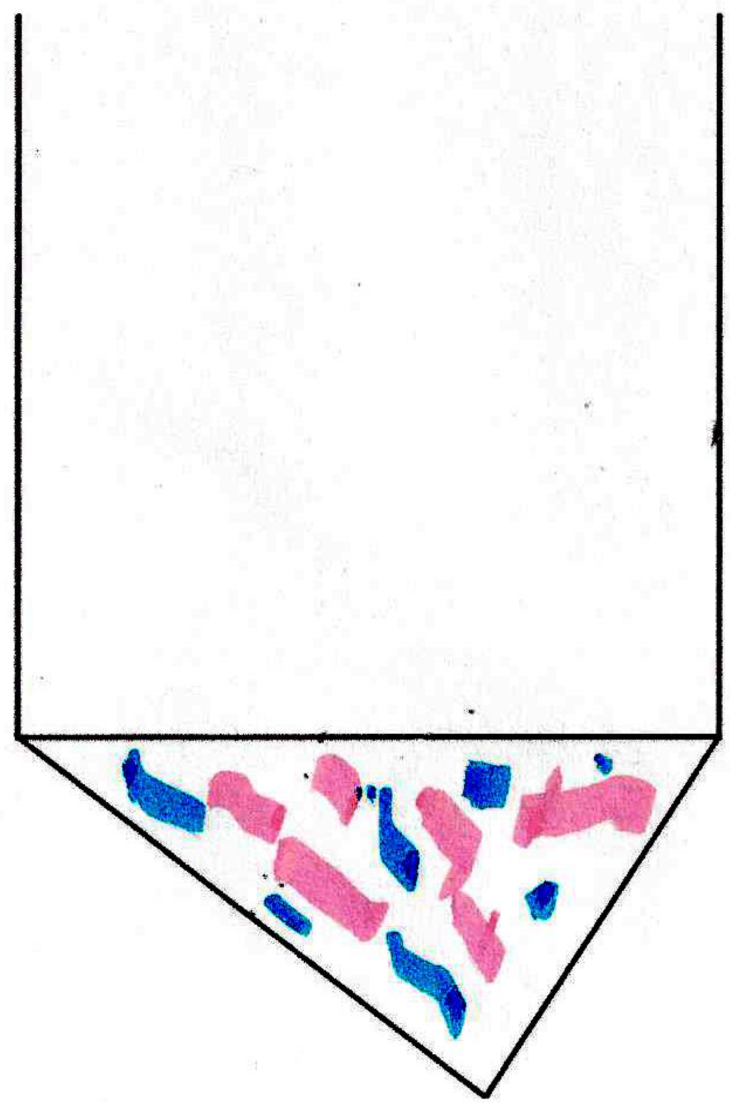
Structure
Retainer
Structure-Retainer
Conductance, $C_L$
Retro-
Reflector
Mount
Conductance,
$C_M$

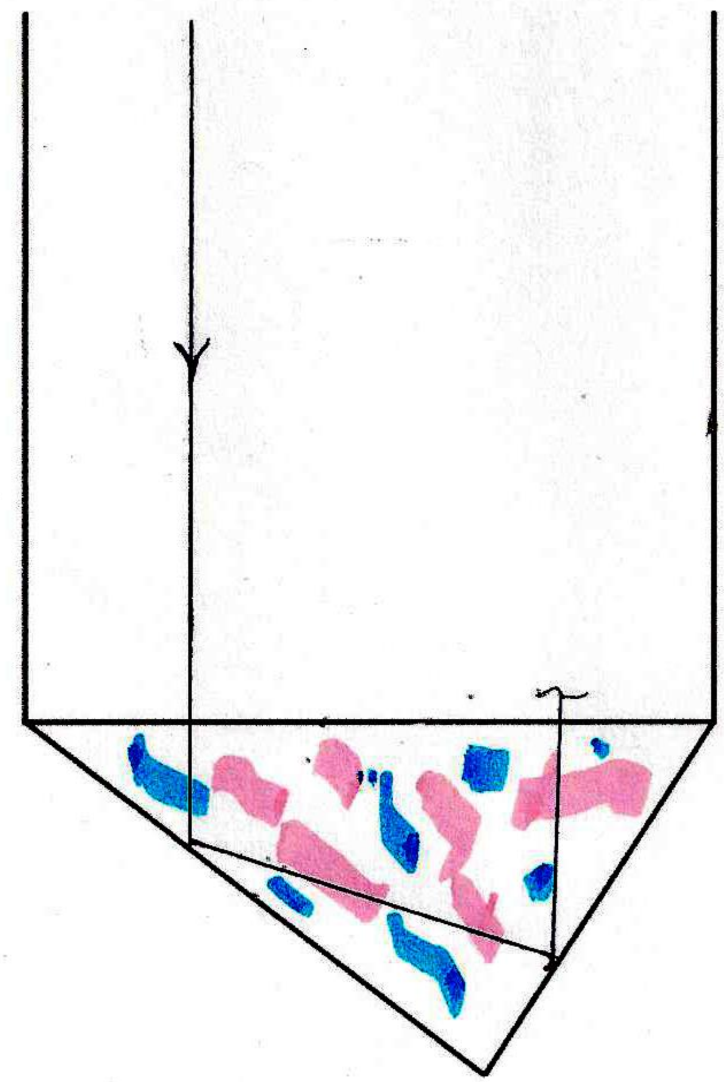


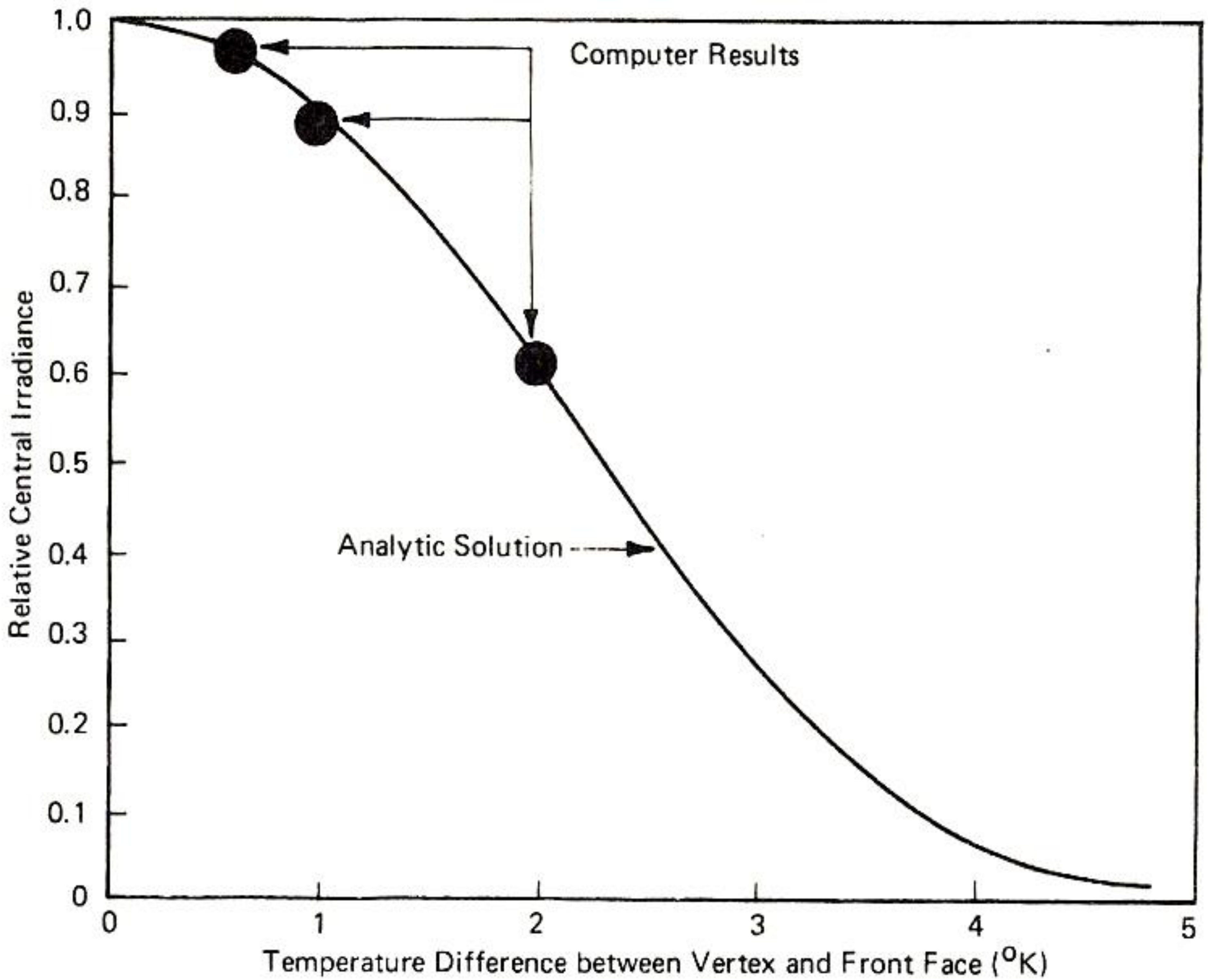
Hook (1/8" wide)
2" wide)
Thread
Dacron
Array
Velcro (pile) all around array,
except at breaks for brackets, etc
Narmco polyurethane adhesive
Spacers (3)
Double layer Dacron netting
Shields (3)
Double-aluminized Mylar



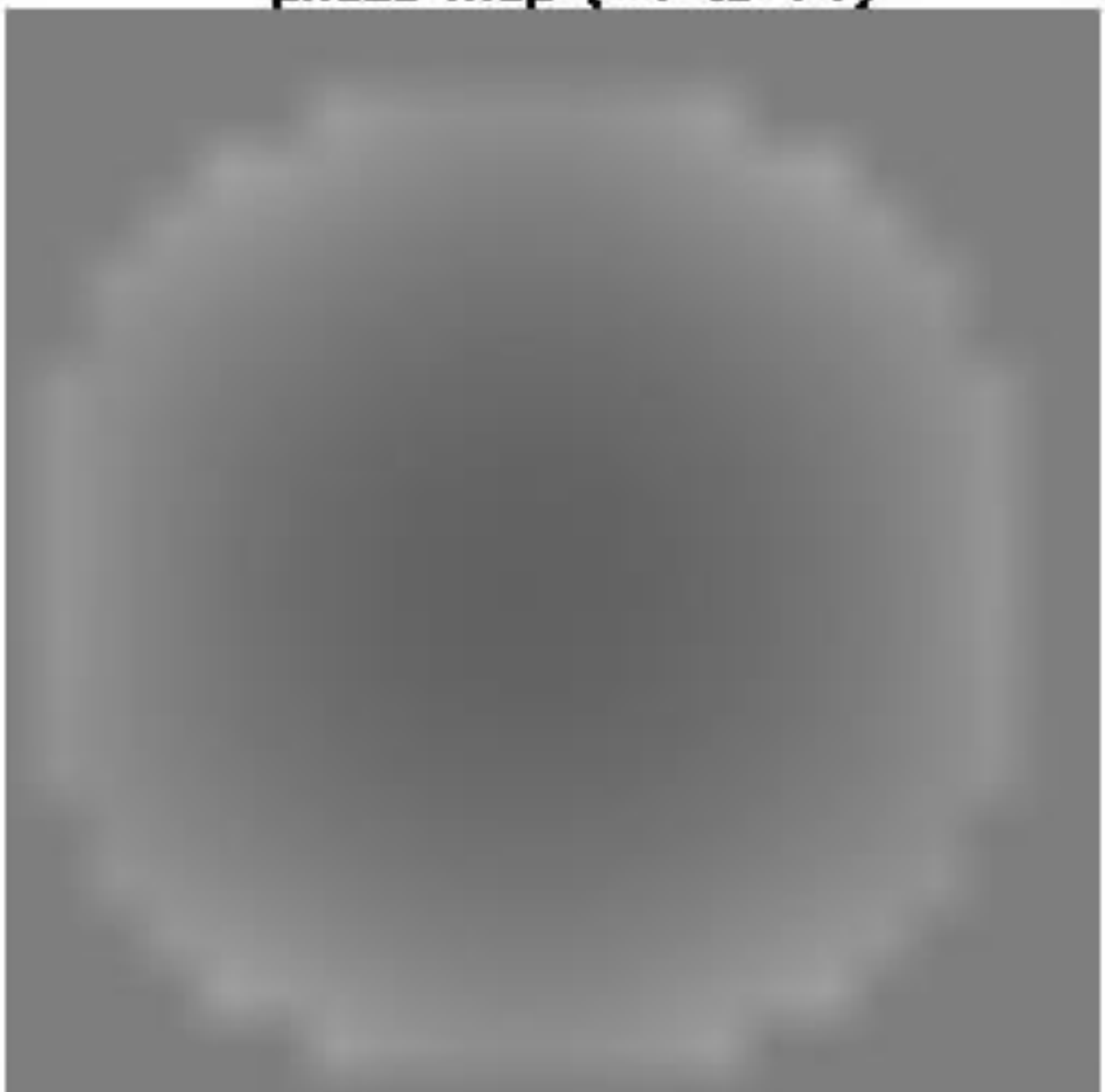


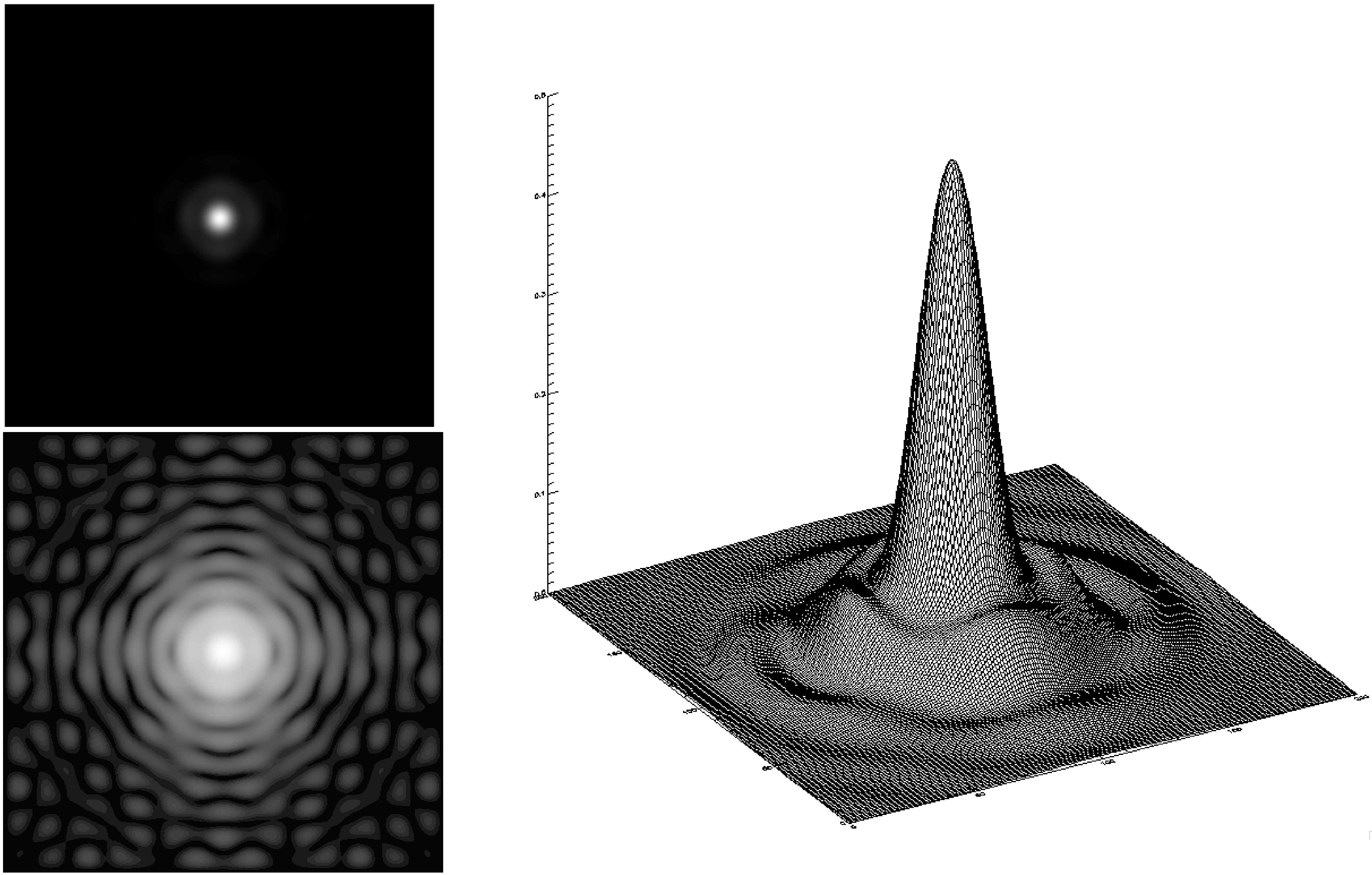







**Note:** Linear Vertical Temperature Gradient phase map (-1 to +1)





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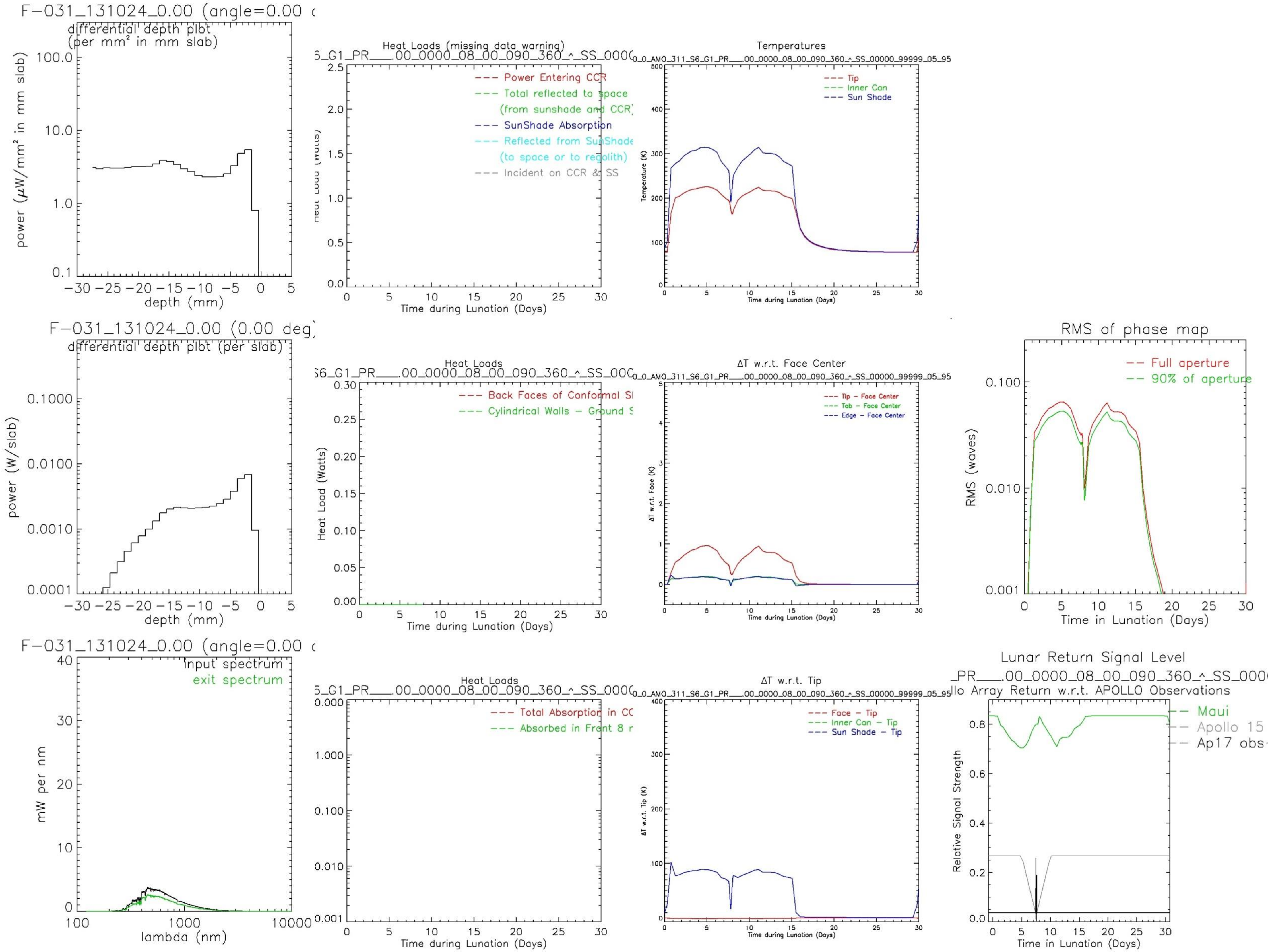
HL run on Oct 24 2013, TD run on Oct 25 2013, TPS run on Oct 30 2013
-38 27.53 1000 2 0.40 00 015 040 0 1 2 6 12 4 1 8
no DWG info
38.0 0.000 0.000 532.0 512 0.267



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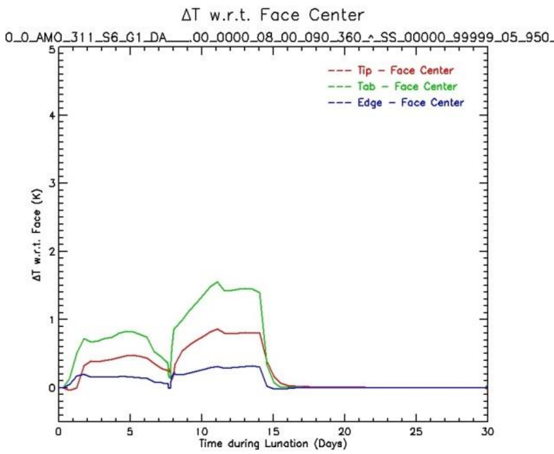


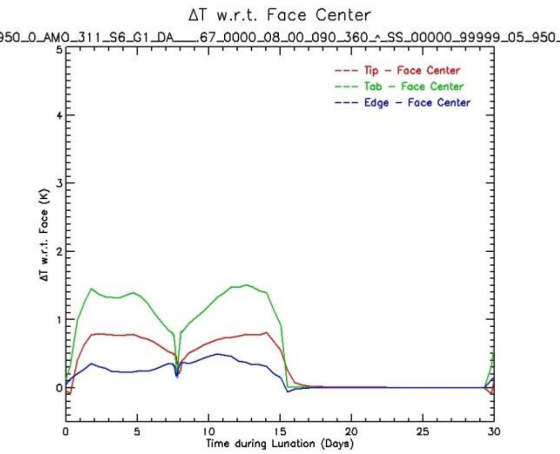


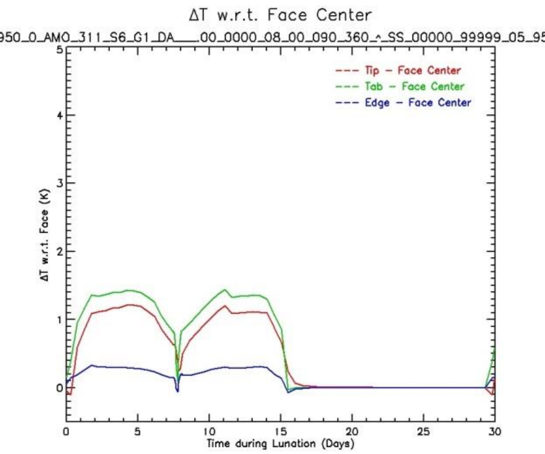


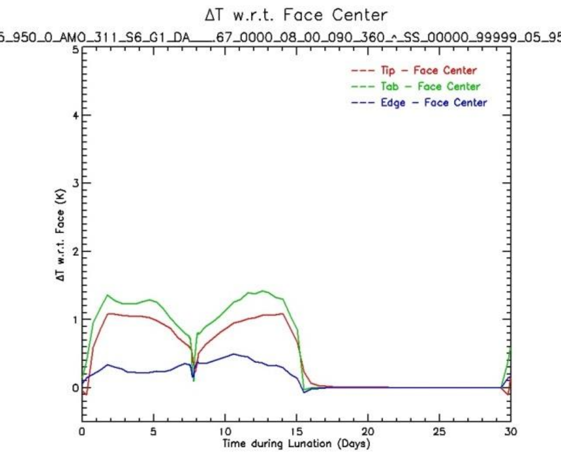


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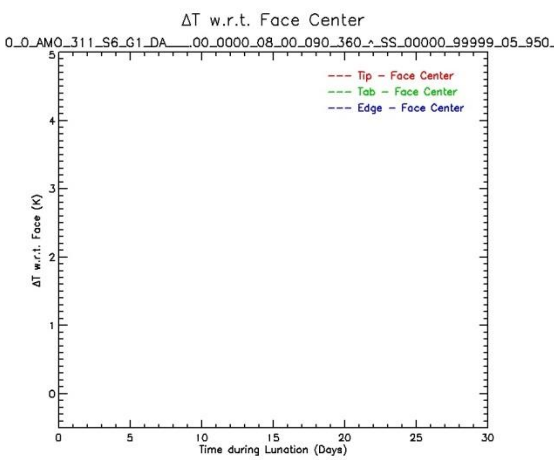


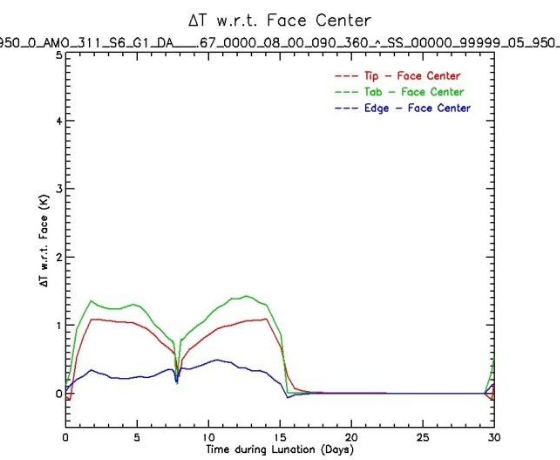


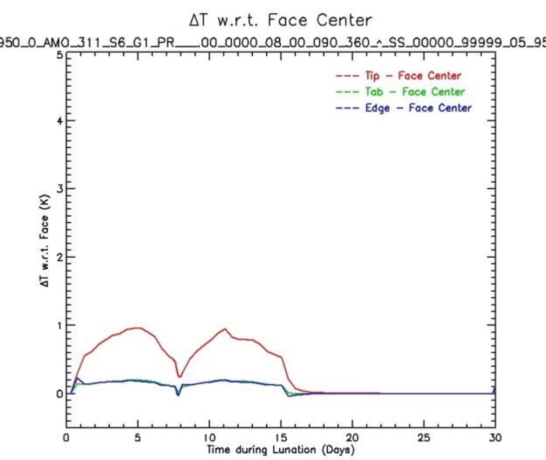


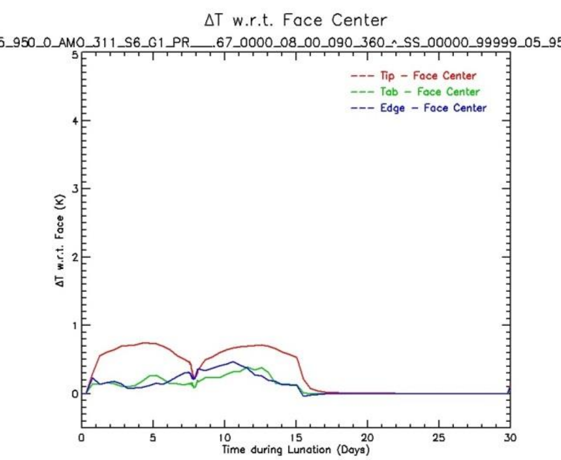


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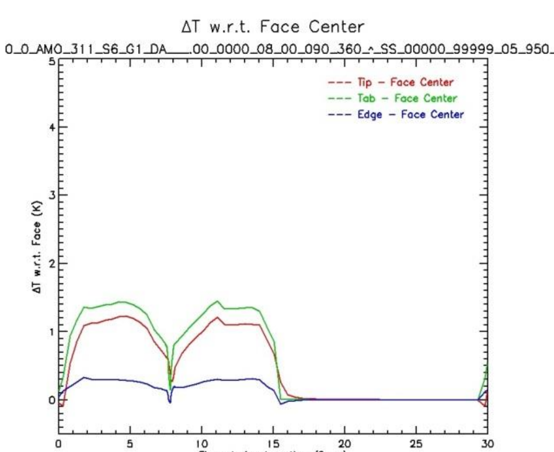


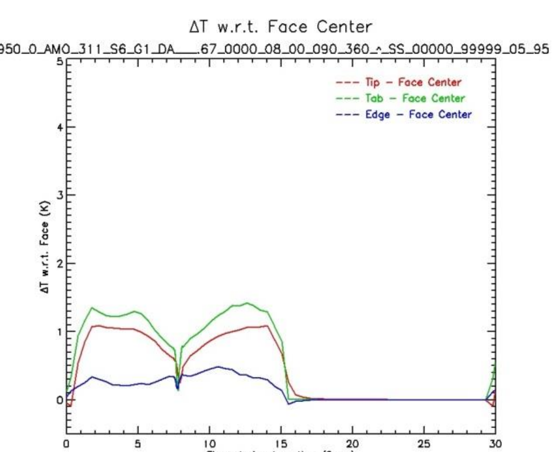

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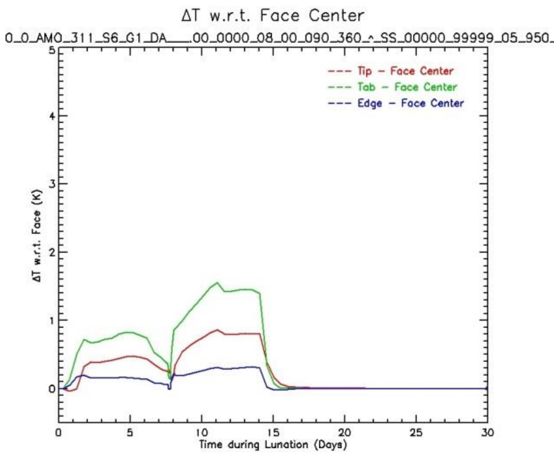


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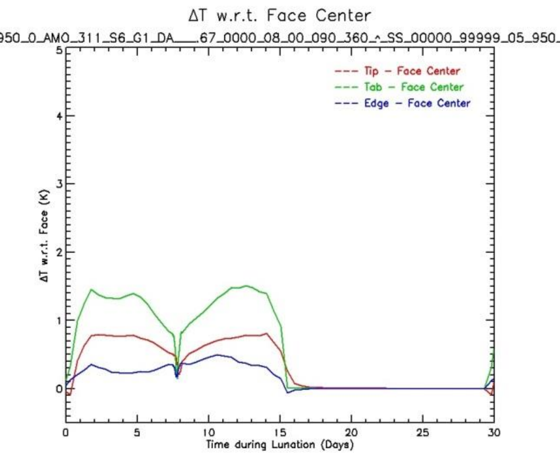


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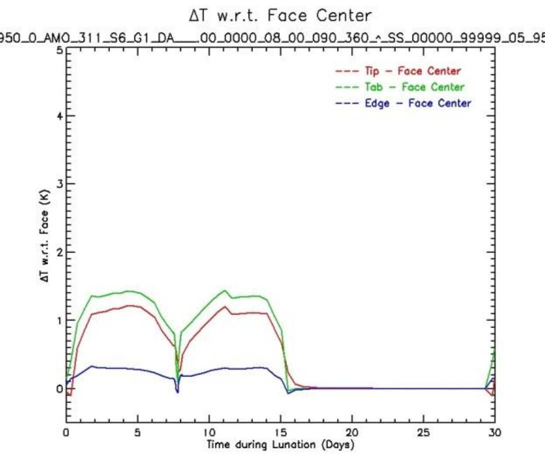


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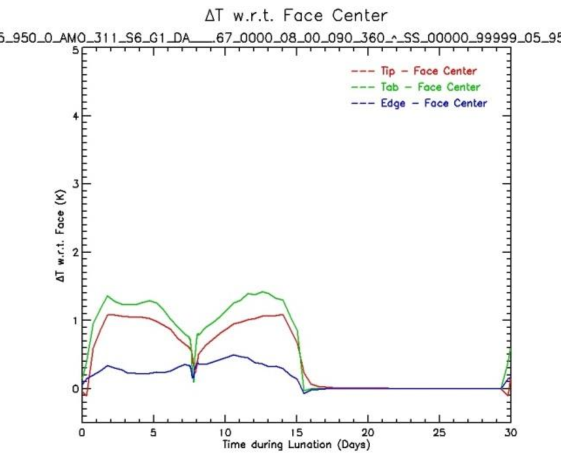


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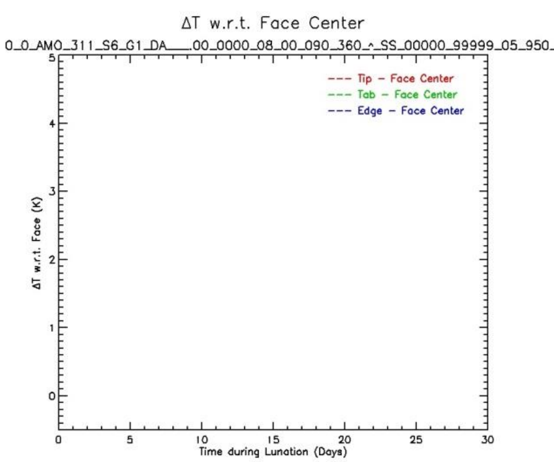


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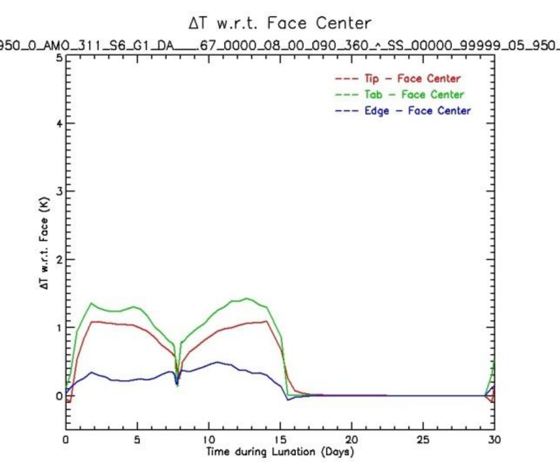


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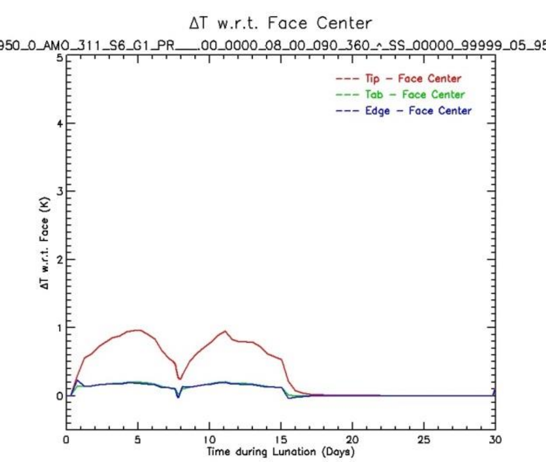


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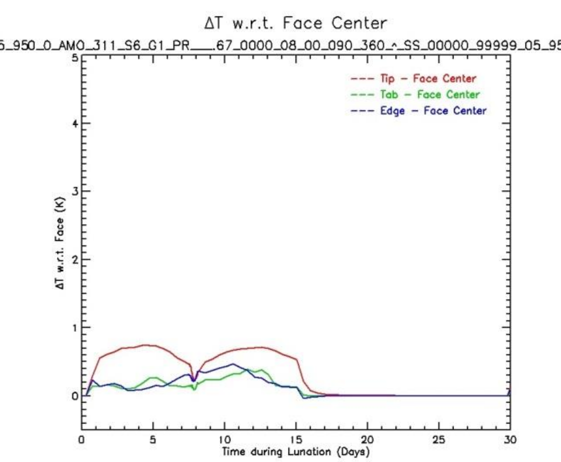


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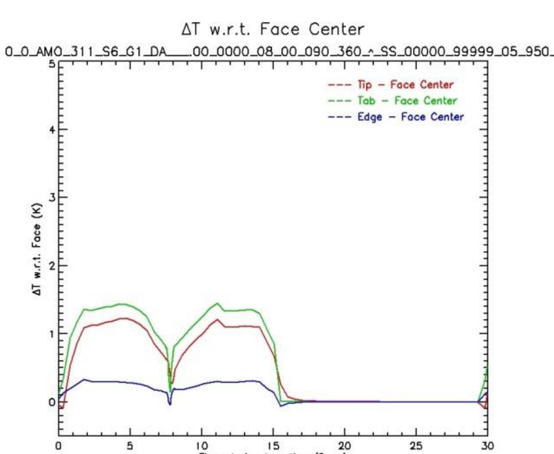


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