A LUNAR LASER RANGING RETRO-REFLECTOR ARRAY for the 21^{st} CENTURY

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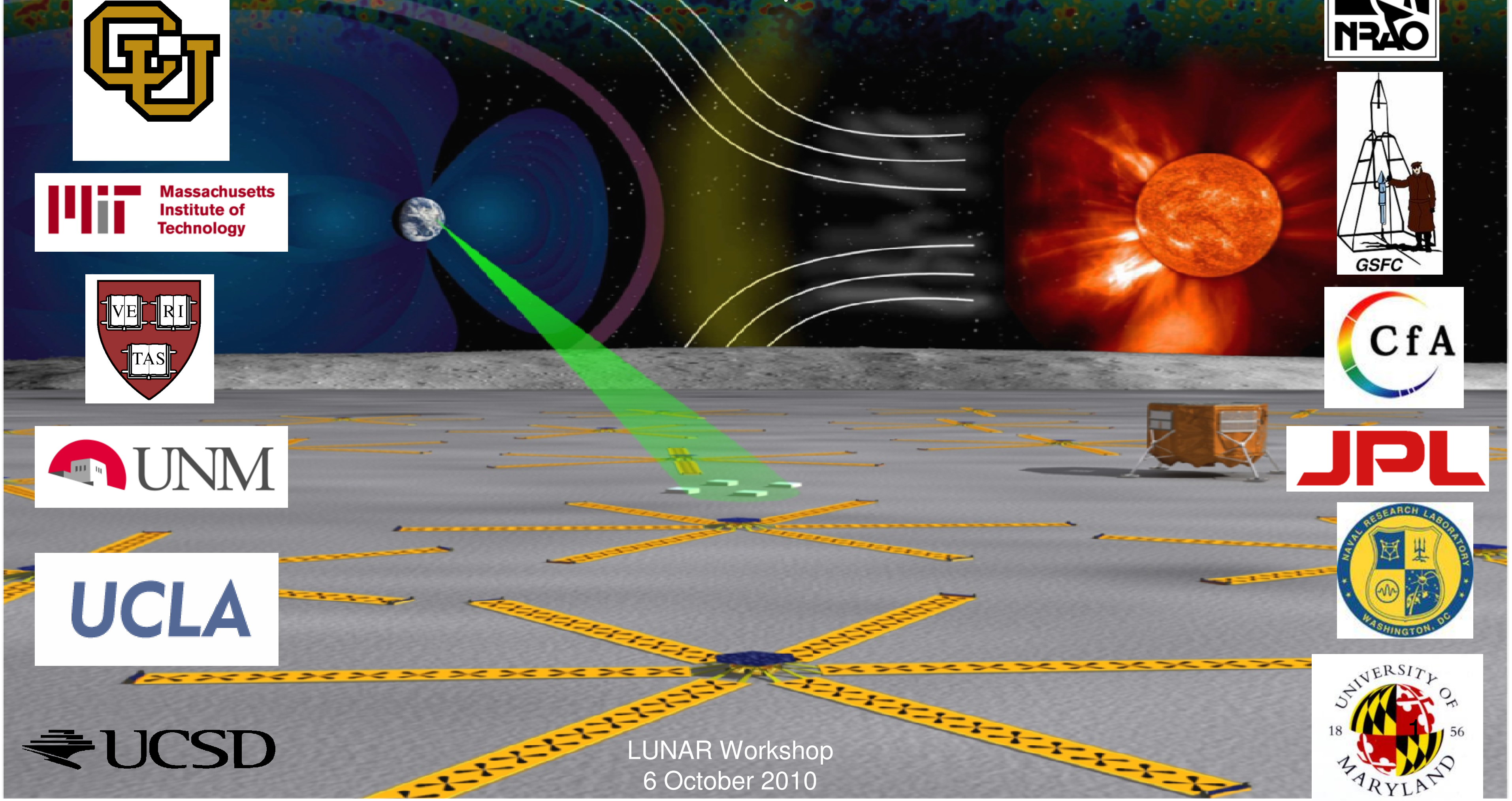
& The LLRRA-21 Teams with the
*L*unar *U*niversity *N*etwork for *A*strophysics *R*esearch
Jack Burns, Director



LUNAR Workshop
6 October 2010

Overview

- Signal Level of the LLRRA-21 Compared to Apollo 15
  - Intuitive Estimate
  - Simulation of Return
    - Thermal Estimation Procedure
    - Simulation Result for Return and Comparison to A15
- Lifetime limitations
  - Three Candidates
    - Electrically Lofted Dust – Perhaps, but No Defendable Model Yet
    - Direct Impacts of Micrometeorites onto Front Face of CCR
    - Secondary Ejecta from Micrometeorites Impacting Regolith
- Ground Station Hardware
  - Requirements
  - Detector
  - Short Pulse Laser
  - Electronics
- ESO

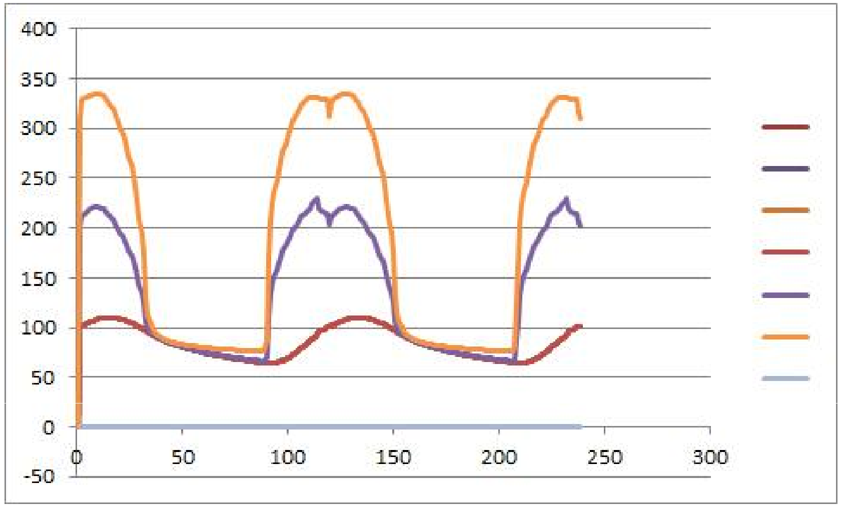
Role of LLRRA-21

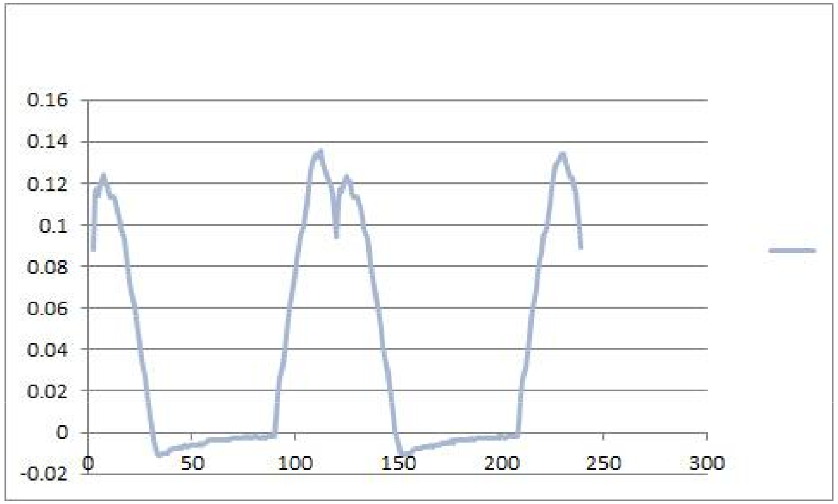
- Future Goal
  - Much Greater Accuracy for Better Science by 200
- Immediate Problem
  - Today, for 1 mm, only APOLLO Can Reach This
  - Only A Few Observations / month
- Immediate Goal
  - ~ 1 mm Precision with a Few Returns
  - With a Return ~ like Apollo 15
  - Multiple Stations, Similar in Capability to McDonald

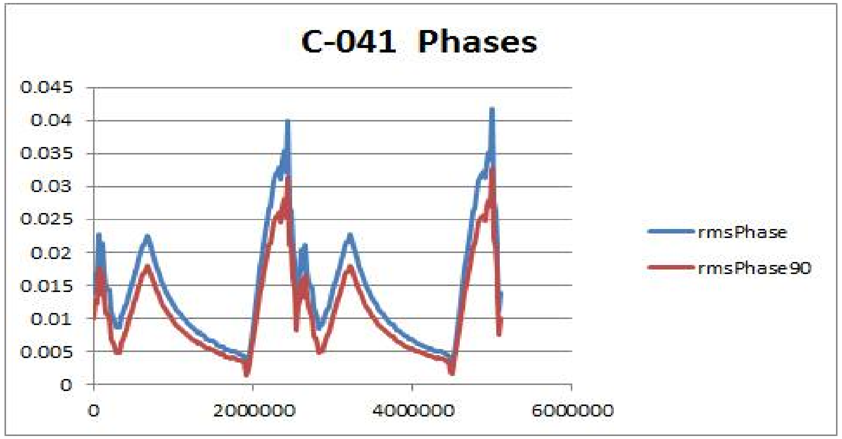
Intuitive Estimate

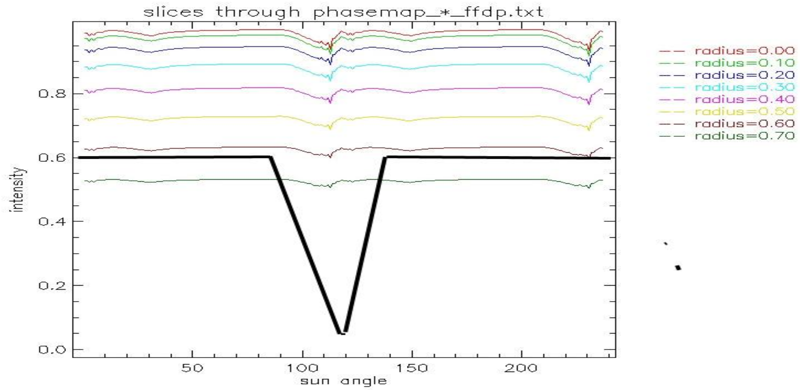
- 100 mm vs. 38.1 mm
  - Fourth Power – on Axis
  - LLRR-21 Stronger by 47 for a Single CCR
- Apollo 15 has 300 CCRs
  - LLRRA-21 Only 14% of A15 Return
- But this Addresses a Brand New A15
  - From Murphy's APOLLO Measurement – 9.6
  - LLRRA-21 Stronger by 20%
- But Need to Address Velocity Aberration

Thermal Analysis









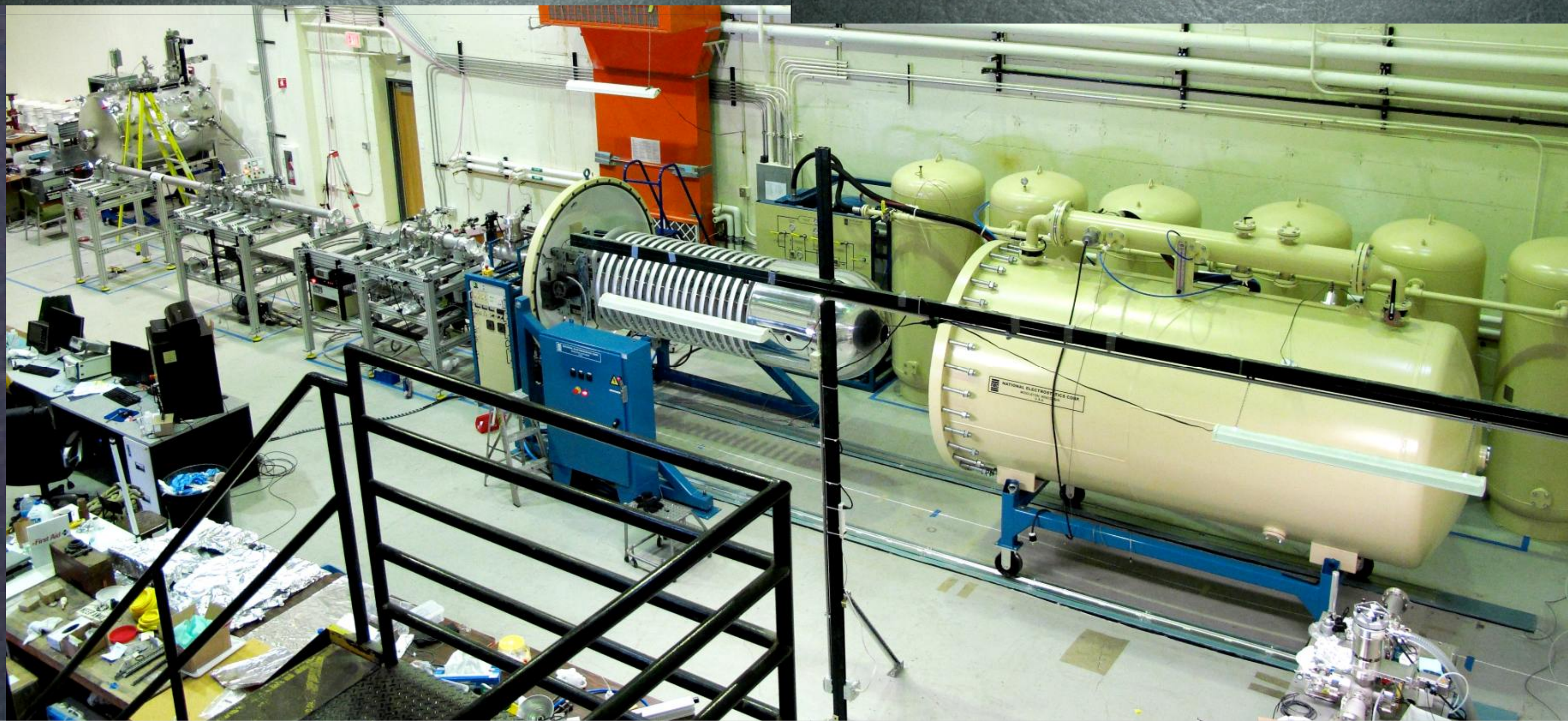
Signal Degradation

- Results from the APOLLO Station
  - Very Significant Reduction in the Signal
  - Overall 10% of expected Return
  - ~1% for the Sun at Zenith
- Must Learn Source to Prevent with LLRA-21
- Candidates for Causing Degradation
  - Lofted Dust
  - Direct Micrometeorite Impact
  - Secondary Ejecta of Micrometeorites Hitting Regolith

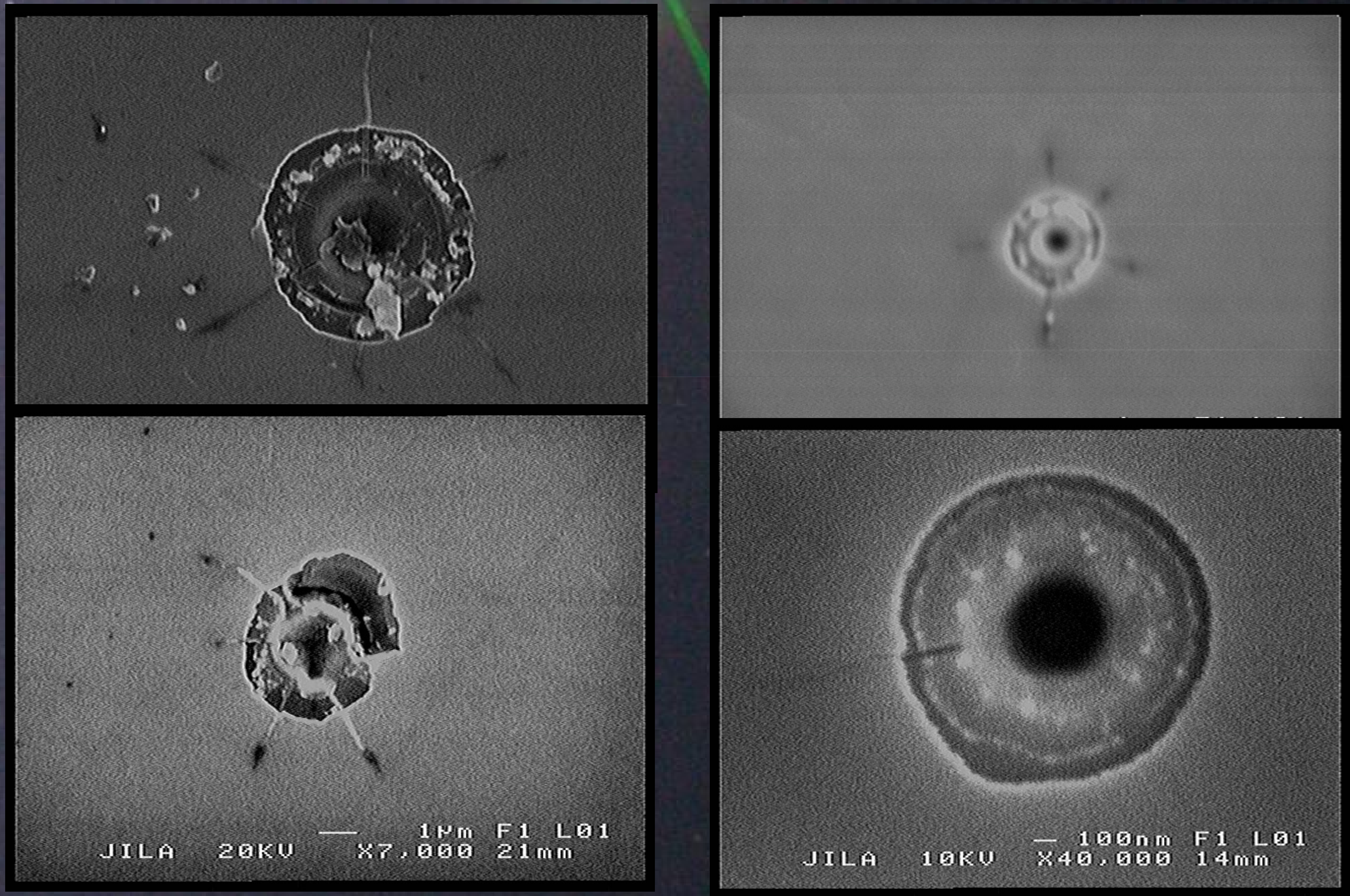
Direct impact

- Dust accelartyor
  - Description
  - Layout from CCLDAS
  - Photograph
- Observations
  - Few thousand impacts
- SEM
  - Images of Individual Damage Craters

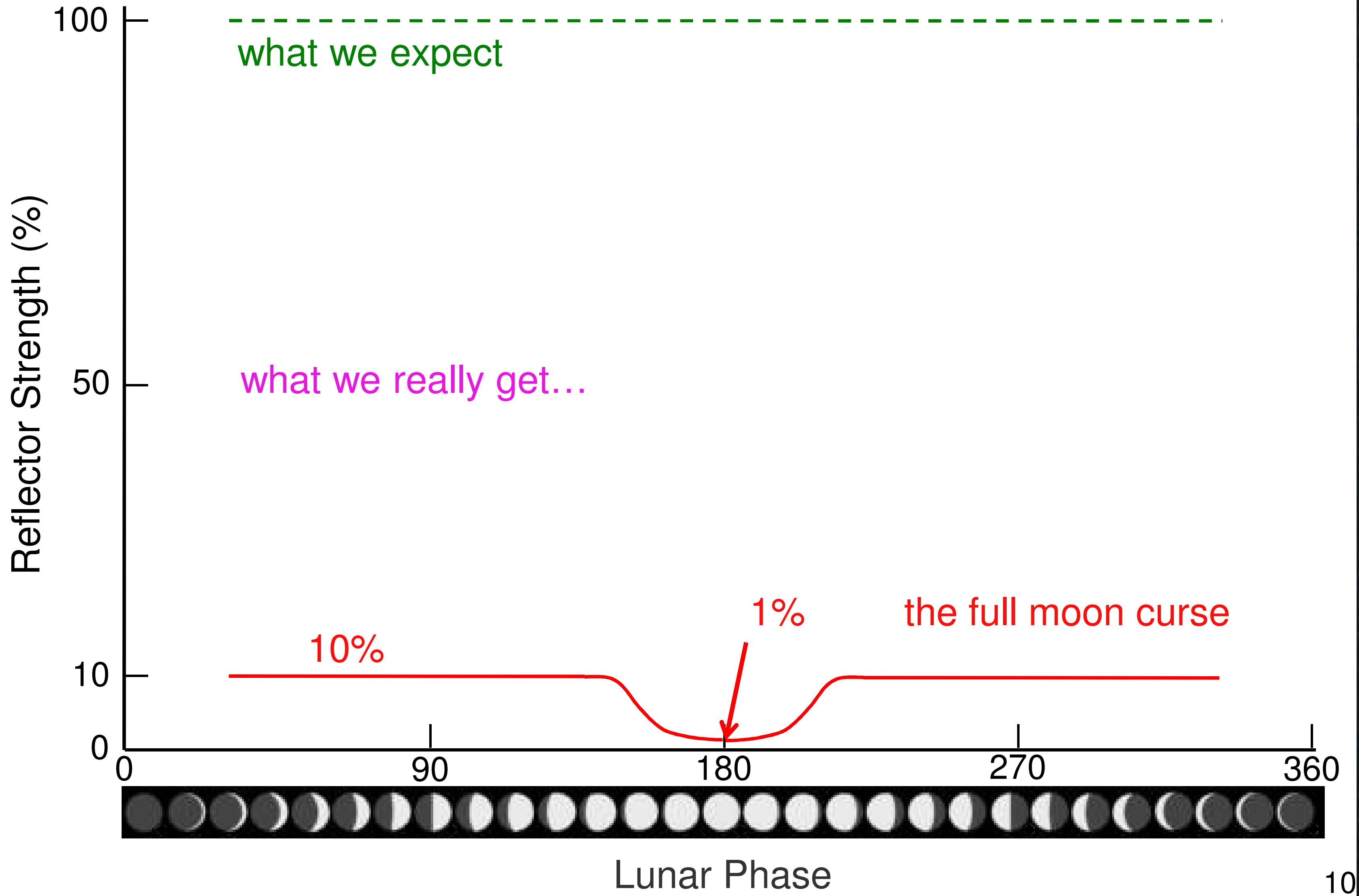
Dust Accelerator
University of Colorado
Fused Silica Witness Plates



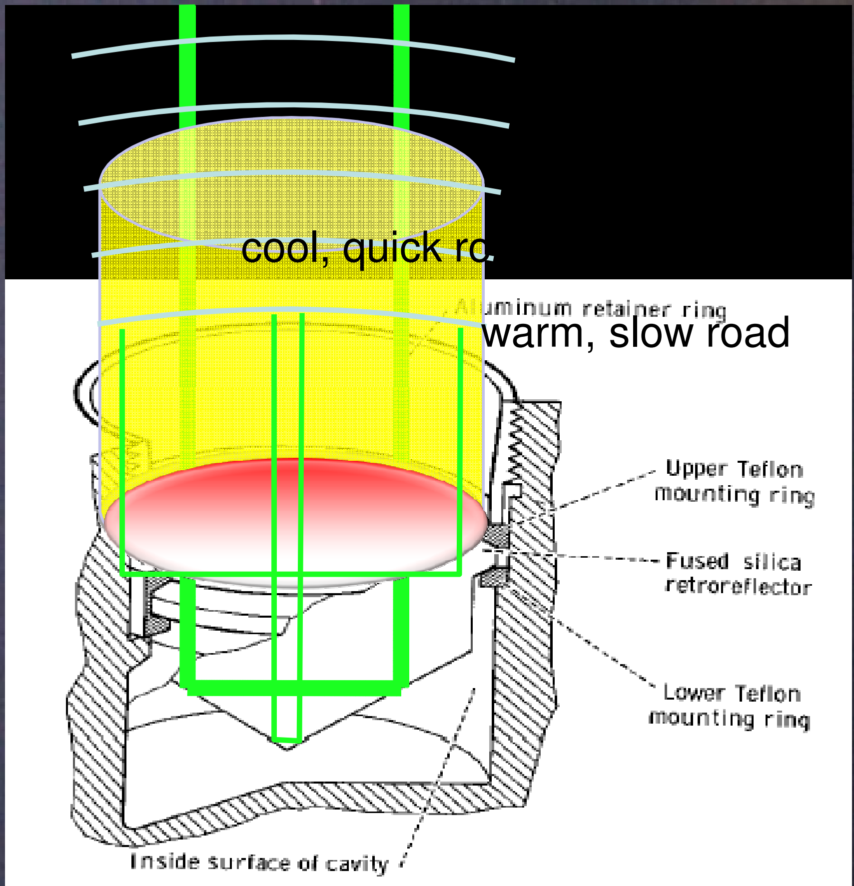
SEM Images of Dust Impacts



Reflector Degradation

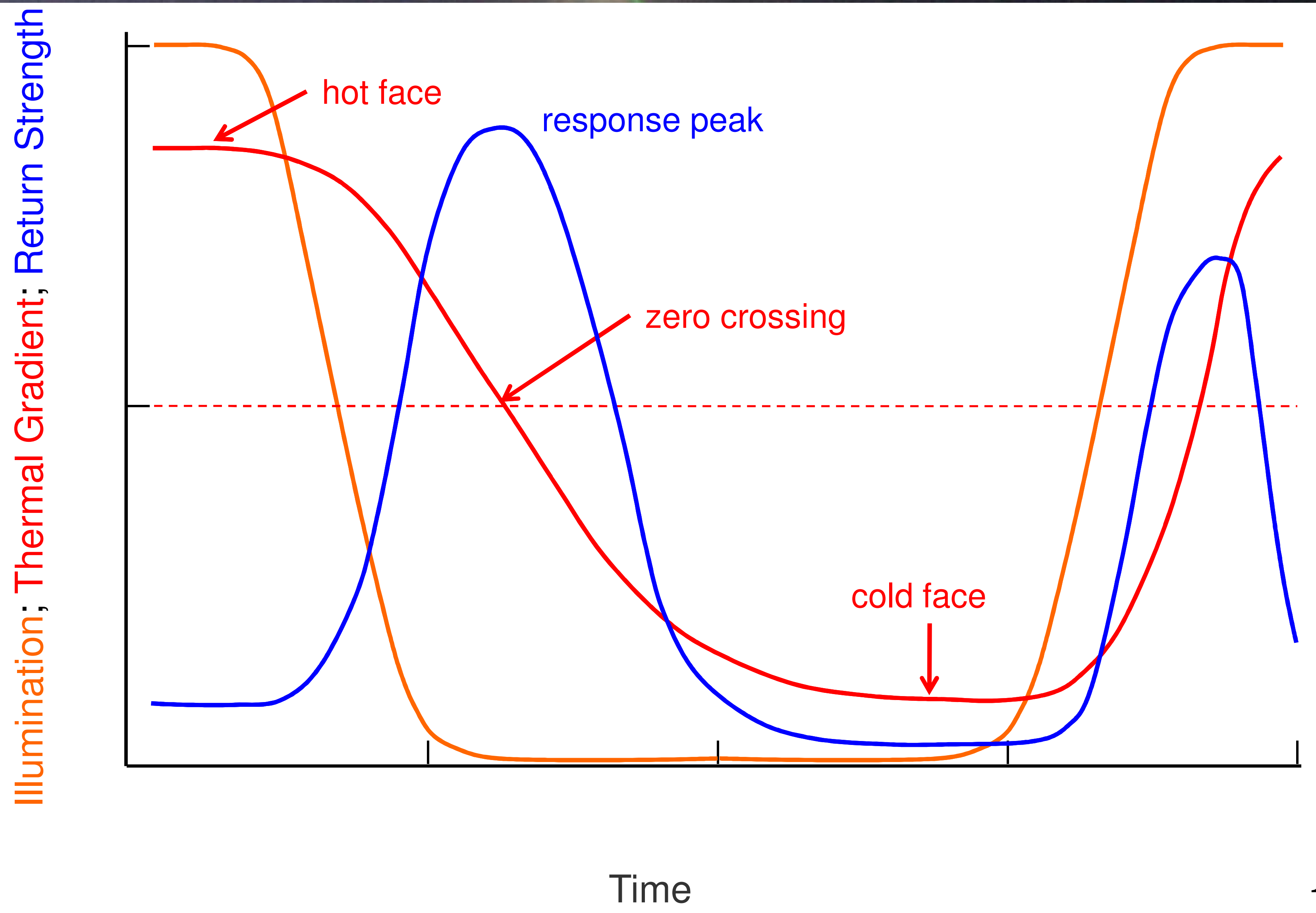


What's Wrong?

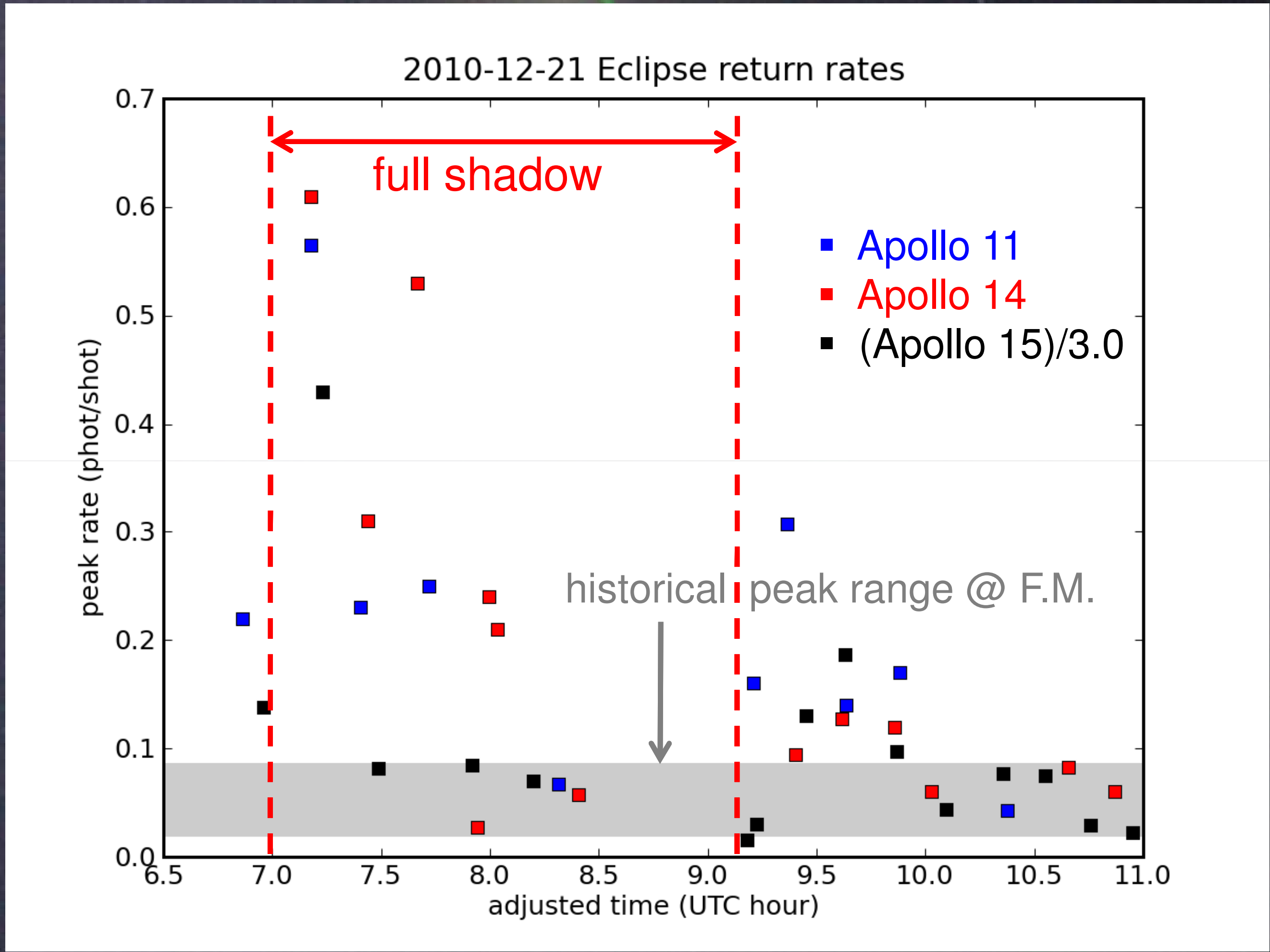


- The full-moon deficit, together with normal eclipse behavior, gives us the best clues:
  - thermal nature
  - absorbing solar flux
- Most likely: dust
  - Obviously could explain overall deficit (10%)
- Full moon effect then due to solar heating of dust
  - sun comes straight down tube at full moon
  - makes front hotter than vertex of corner cube, leading to divergence of exit beam
  - only takes 4℃ (7℉) gradient to introduce 10× reduction

Cartoon of Expectations



Preliminary Eclipse Results



robust recovery initially, then down, and brief resurgence once light returns

LLRRA-21 PACKAGE

Sun/Dust-Shade

- Sun/Dust-Shade
  - Thermal – Blocks Sunlight
  - Dust – Blocks Dust Flux
  - Micrometeorite – Blocks Dust Impacts
- Reduces open aperture
  - Access is Reduced by a factor of 200
- Performance
  - Good Thermal Performance
  - Only One Impact/Century
  - Dust at less than 1% /40 years

LUNAR SURFACE EMPLACEMENT

- CCR Optical Performance at Sub-Micron
  - Want to Assure as Much of This as Possible
- We Have Sufficiently Strong Return
- Emplacement Issues - Diurnal Heating of Regolith
  - ~ 400 Microns of Lunar Day/Night Vertical Motion
- Solutions – Dual Approach for Risk Reduction
  - Drill to Stable Layer and Anchor CCR to This Level
    - ~ one meter – Apollo Mission Performed Deeper Drilling
    - ~ 0.03 microns of motion at this depth
  - Stabilize the Temperature Surrounding the CCR
    - Multi Layer Insulation Thermal Blanket – 4 meters diameter
    - Support Rod Sees a Constant Temperature Environment

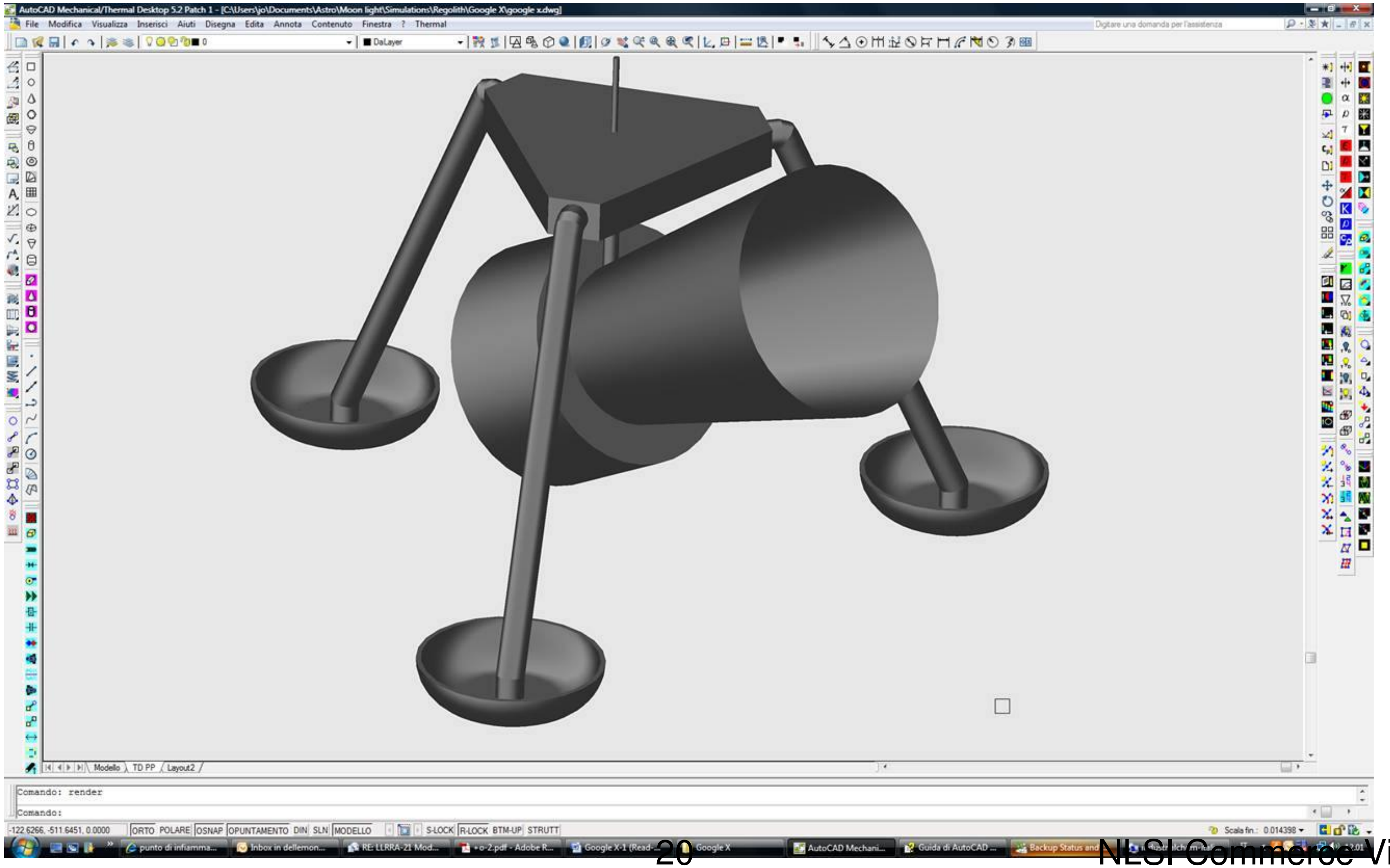
ROBOTIC DEPLOYMENT

- Deployment Methods
  - Lander Mounting
    - Few Millimeters
    - Thermal Expansion of Lander during Lunation
  - Surface Deployment
    - Sub-Millimeter
    - Regolith Expansion during Lunation
  - Anchored Deployment
    - Tens of Microns

SURFACE DEPLOYMENT

- Issues
  - – CCR Should Point Toward Earth "Center"
  - – Maintain Clocking Angle to Handle Sun Break-through
  - – Handle Longitudinal (toward earth) Tilt of Surface
  - – Handle Azimuthal Tilt of Surface
- Requirements
  - – Self Orienting Procedure to Keep Clocking Angle
  - – Longitudinal (Elevation) Self Orientation
  - – Azimuth Angle Adjusted by Arm
    - Calibrated by Goniometer (Sun Dial)

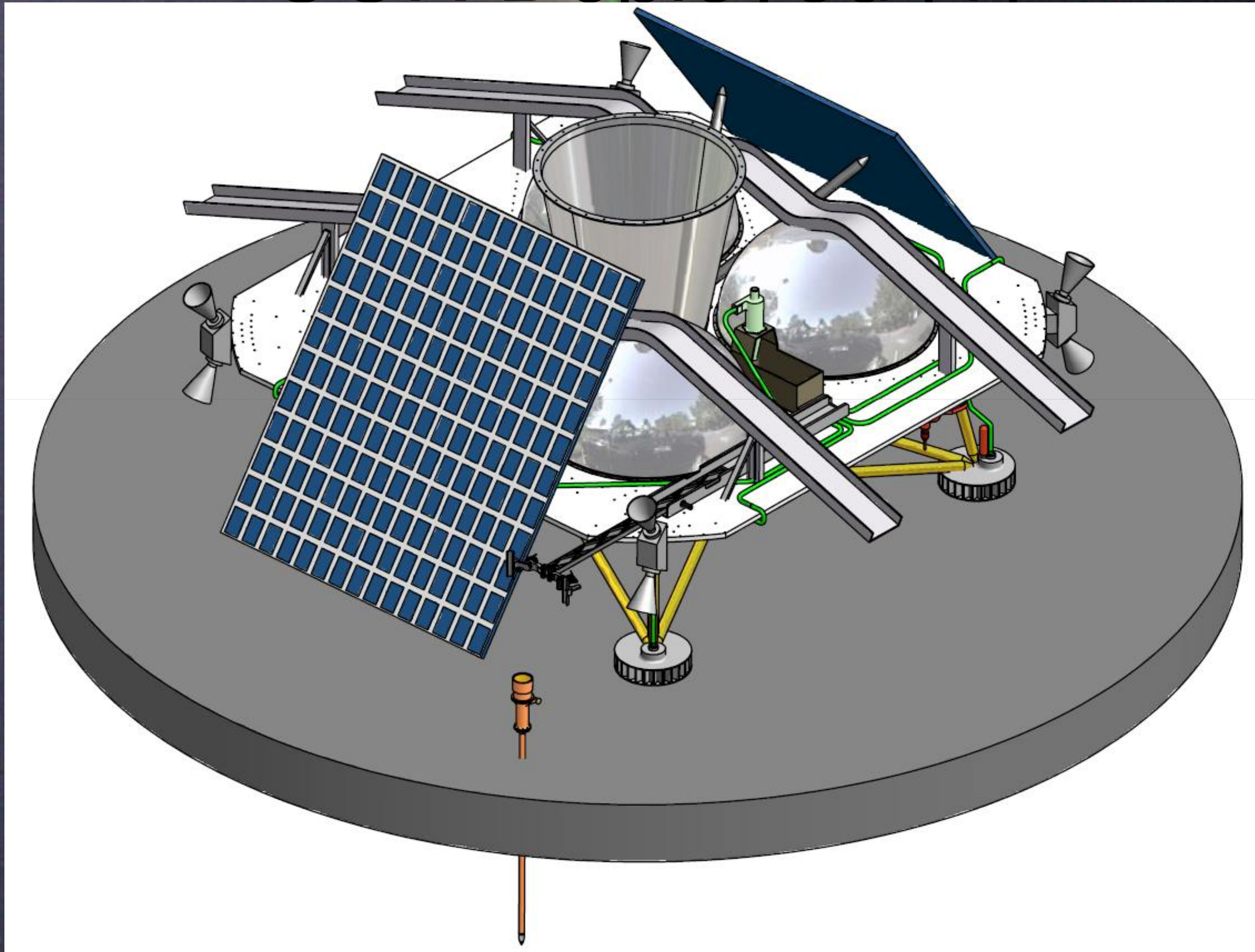
ROBOTIC DEPLOYMENT
Surface Deployment



ANCHORED DEPLOYMENT

PNEUMATIC PROBOSCIS SYSTEM
Chris Zacny – Honeybee, Inc.

CCR Deployed [1]



Emplacement Accuracies

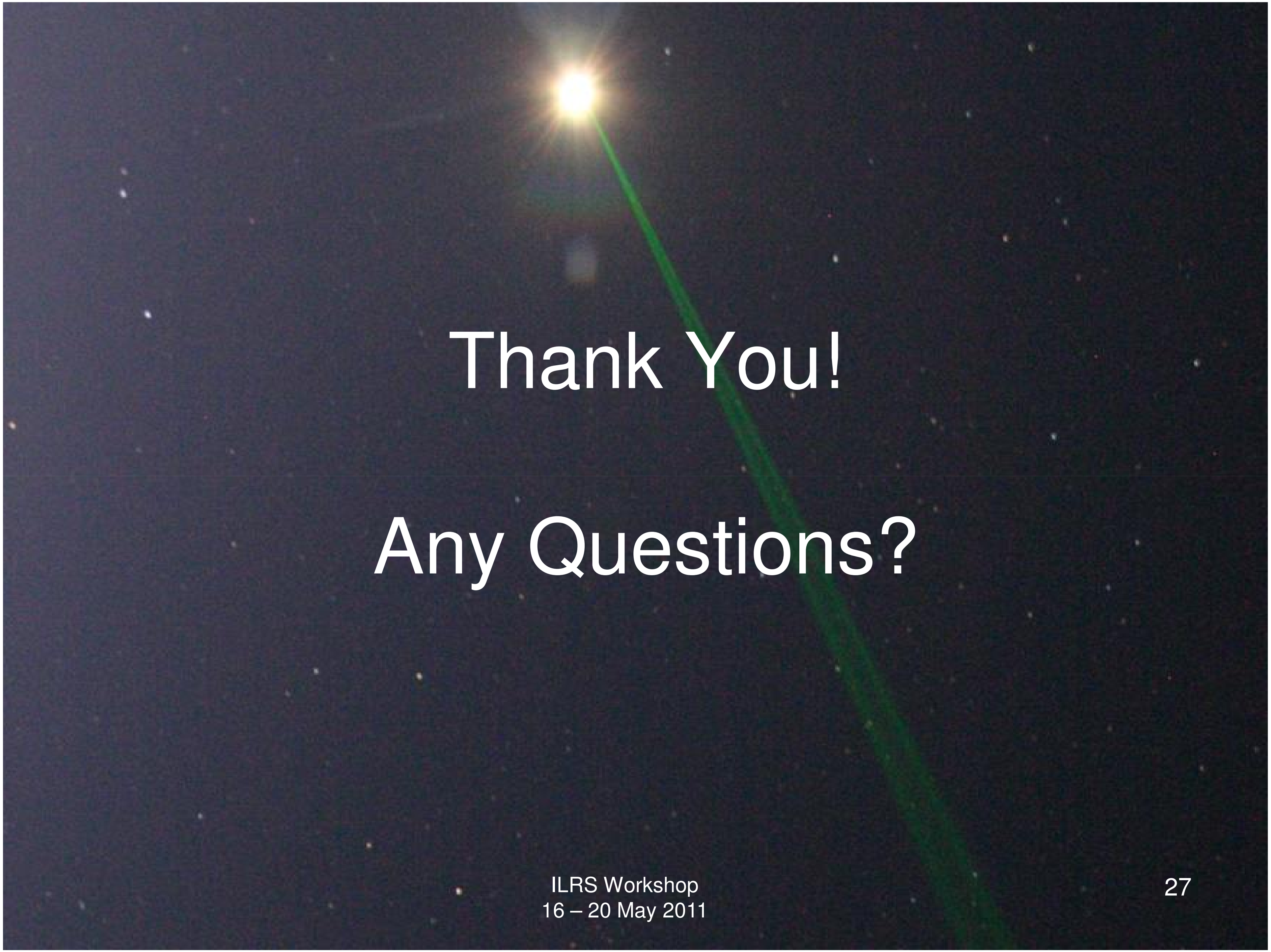
- Mounted on the Lander
  - 1-2 mm single shot accuracy
    - 7-15 ps
    - Google Lunar X Prize Teams
- Placed on the Lunar Surface
  - Fractional mm single shot accuracy
    - 4 ps
    - Google Lunar X Prize Teams
- Anchored in the Deep Regolith
  - Better than 100 microns
    - <0.7 ps
    - Astrobotics/Honeybee for Google Lunar X Prize

PREMER STATION CHALLENGES

- Performance Requirements
  - To take Advantage of LLRRA-21
  - Addressing Sub-Millimeter Ranging
- Basis for Requirements
  - Background on Requirements
- Components
  - Existing
  - Commercial

PREIMER STATION CHALLENGES

- Telescope
- Detector
- Laser
- Timing electronics
- Clock (Frequency Standard)
- Metrology for Weather
- Gravimeter
- Site Location
- Installation



Thank You!

Any Questions?

Dector

- 10 ps
  - 1 – 5 – 200
- Therefore laser at 5 ps
  - Commerically available
- Electronics ok
- Atm
  - Absolute microbarometers 40 microns
    - Vertical
  - Model of atm
    - Murphy data
    -

ESO

- History of ESO
- We need southern hemisphere
- Need premier station
- Collaboration
- La silla as a site

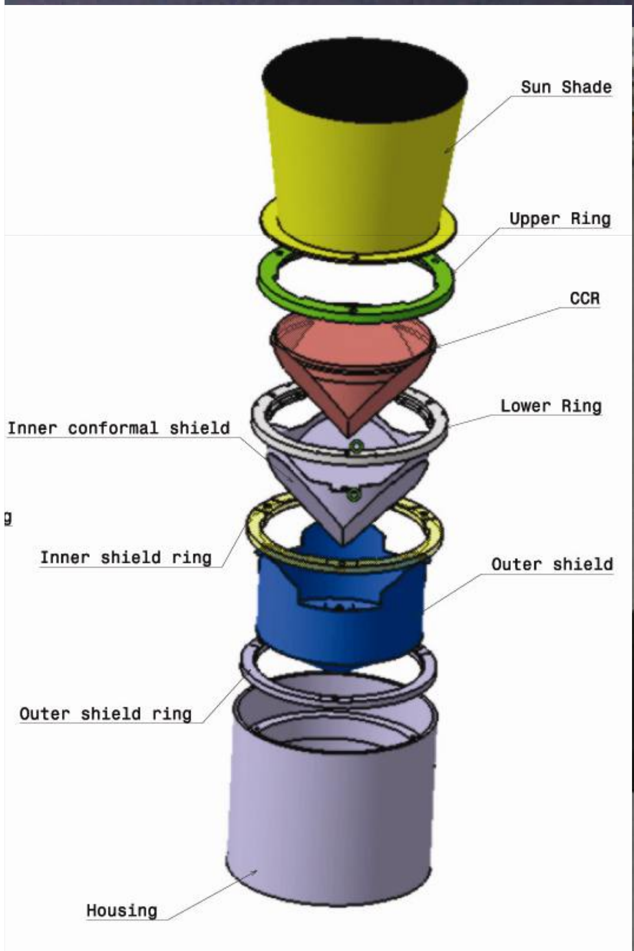
Why Laser Ranging

- Exquisitely precise range
- Sensitive to many parameters
  - Relativity
  - Geo-Physics
  - Seleno-Physics
- Satellite Ranging,
  - esp LAGEOS, but also other satellites
  - Gravity Field, Crustal properties, etc, etc.

University of Maryland, College Park

Lunar Laser Ranging Array for the 21st Century

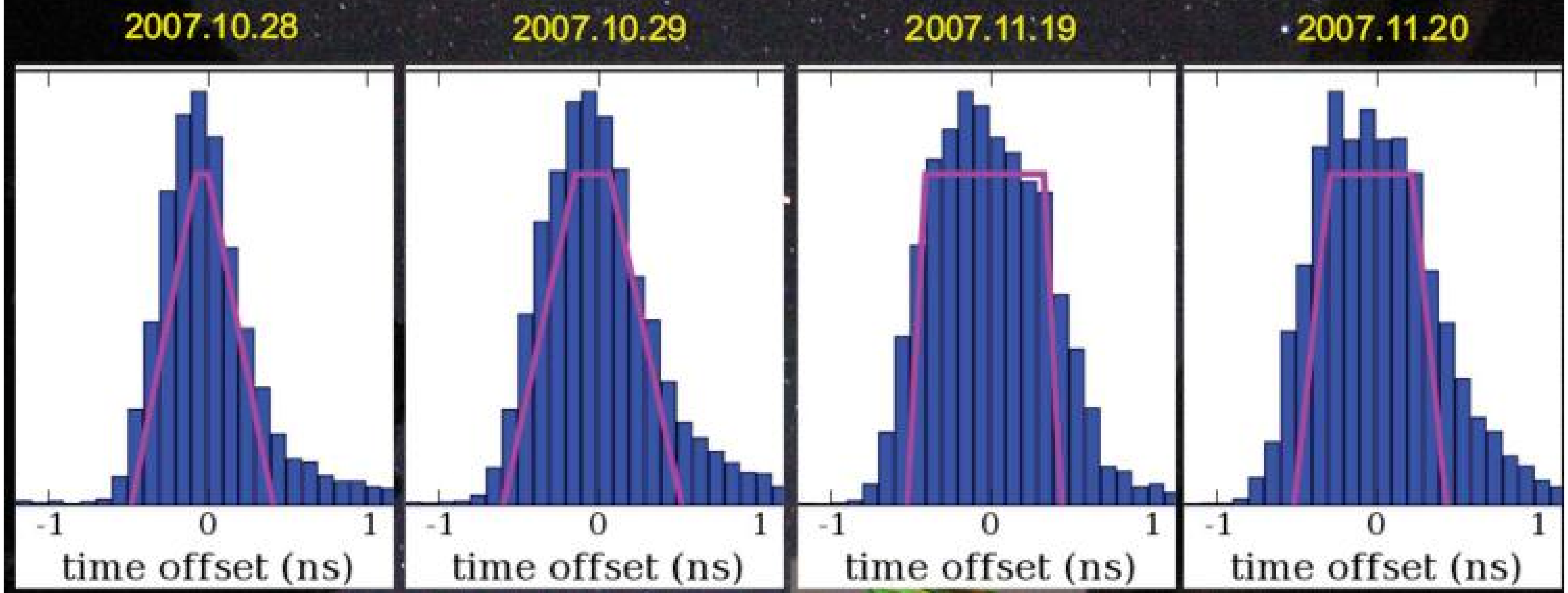
Nominal Package



LIBRATION PROBLEMS

- Why is there a Problem with the Apollo Arrays
  - Libration in Both Axis of 8 degrees
  - Apollo Arrays are Tilted by the Lunar Librations
  - CCR in Corner is Further Away by Several Centimeters
  - Even Short Laser Pulse is Spread
  - Results in a Range Uncertainty by ~2 cm
  - APOLLO Station of Tom Murphy UCSD
    - Thousands of Returns per Normal Point
    - Root N to Get Range to 1 – 2 millimeters
    - Needs Large Telescope
    - Hard to get Daily Coverage

Sensing Array Size and Orientation



LLRRA-21 PROGRAM

- Solid 100 mm Cube Corner Reflector
- 40 Year Heritage, 6.5 TRL
- Program
  - Phase I
    - Surface Emplacement
    - Supports Sub Millimeter Single PhotoElectron Ranging
    - 2012 – 1013
  - Phase II
    - Anchored Emplacement
    - Supports Ranging at less than 100 microns
    - 2016 or Later

CHALLENGES for SOLID CCR

- Fabrication of the CCR to Required Tolerances
- Sufficient Return for Reasonable Operation
  - Ideal Case for Link Equation
- Thermal Distortion of Optical Performance
  - Absorption of Solar Radiation within the CCR
  - Mount Conductance - Between Housing and CCR Tab
  - Pocket Radiation - IR Heat Exchange with Housing
  - Solar Breakthrough - Due to Failure of TIR
- Stability of Lunar Surface Emplacement
  - Problem of Regolith Heating and Expansion
  - Drilling to Stable Layer for CCR Support
  - Thermal Blanket to Isolate Support
  - Housing Design to Minimize Thermal Expansion

CCR FABRICATION CHALLENGE

- CCR Fabrication Using SupraSil 1 Completed
- Specifications / Actual
  - Clear Aperture Diameter - 100 mm / 100 mm
  - Mechanical Configuration - Expansion of Our APOLLO
  - Wave Front Error - 0.25 / 0.15 [$\lambda/6.7$]
  - Offset Angles
    - Specification
      - **0.00", 0.00", 0.00" +/-0.20"**
    - Fabricated
      - **0.18", 0.15", 0.07"**
- Flight Qualified
  - with Certification

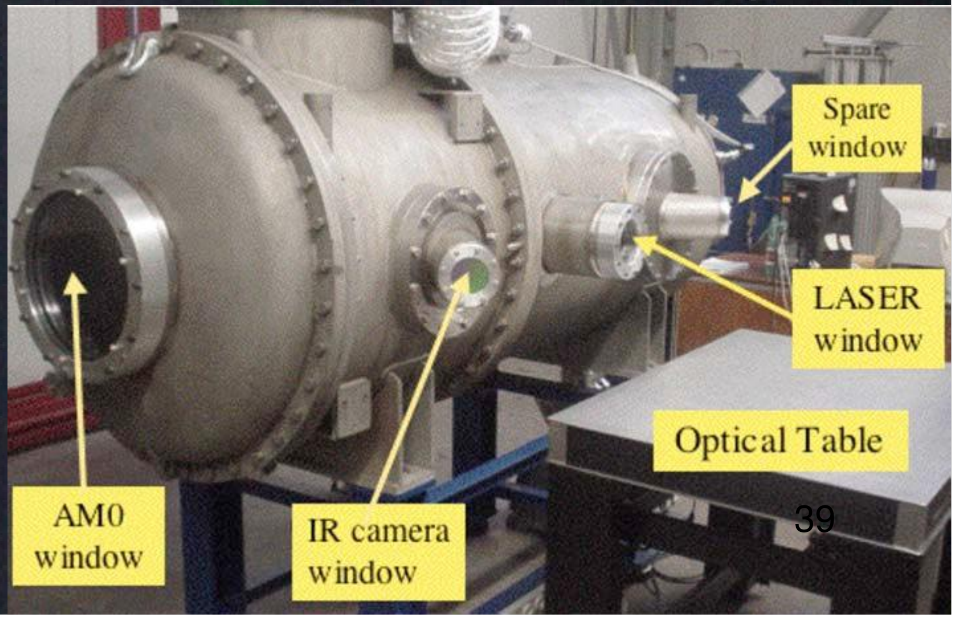
THERMAL ANALYSIS – THEORETICAL
Solar Absorption within CCR

- Solar Heat Deposition in Fused Silica
  - Solar Spectrum – AMO-2
  - Absorption Data for SupraSil 1/311
  - Compute Decay Distance for Each Wavelength
  - Compute Heat Deposition at Each Point
    - Beer's Law
  - Thermal Modeling Addresses:
    - Internal Heat Transport and Fluxes
    - Radiation from CCR to Space
    - Radiation Exchange with Internal Pocket Surroundings
    - Mount Conduction into the Support Tabs

LLRRA-21 PACKAGE

CURRENT STATUS

- Preliminary Definition of Overall Package
- Completed Preliminary Simulations
  - LSSO – Lunar Science Surface Opportunities
  - Thermal (CCR, Regolith, Housing), Optical
- Completed Phase I Thermal Vacuum Tests
  - Solar Absorption Effects on CCR
  - CCR Time Constants –
    - IR Camera – Front Face
    - Thermocouples – Volume
    - Preliminary Optical FFDP

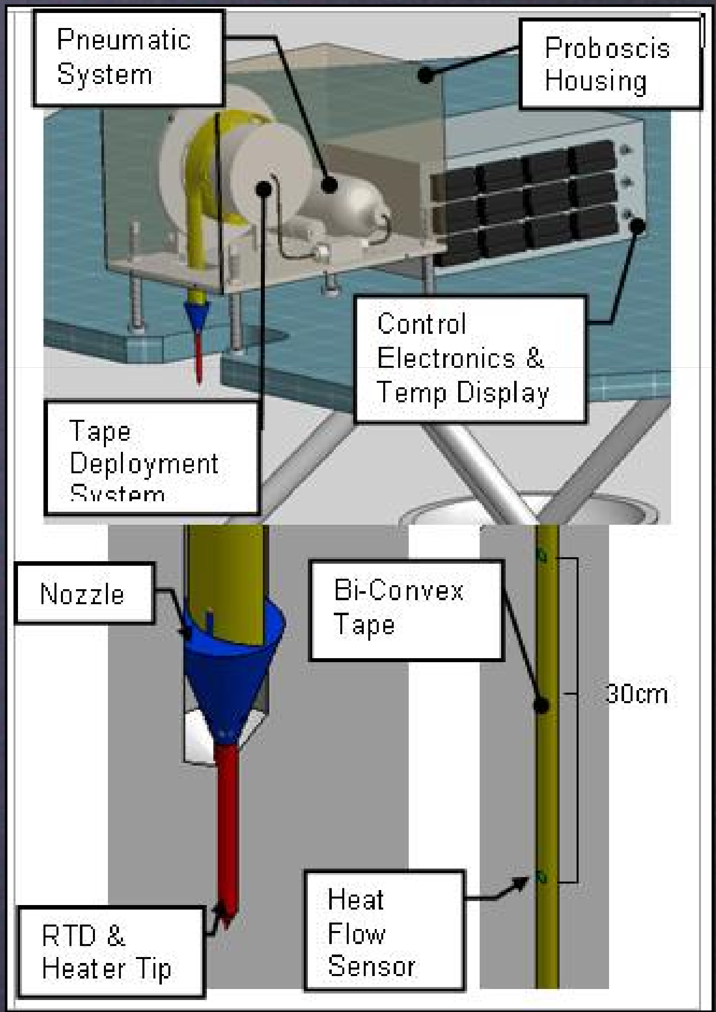


ROBOTIC DEPLOYMENT

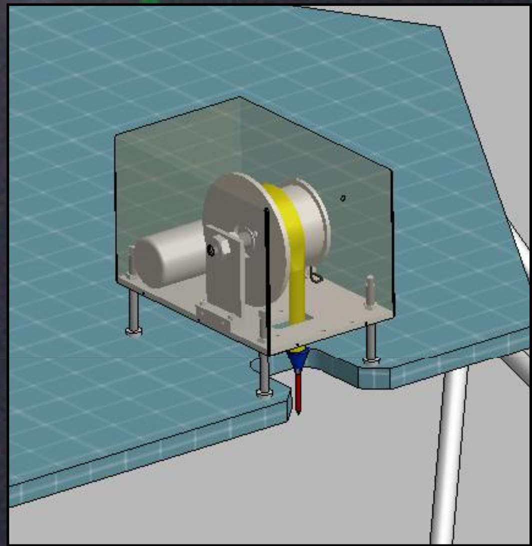
- Candidate Flight Opportunities
  - Google X Prize
    - Astrobotics - Gump
    - Moon Express – Roberts
  - Lunette – Discovery Mission Proposal
    - Backup Retroreflector Package
  - ILN
    - Future NASA Possibility

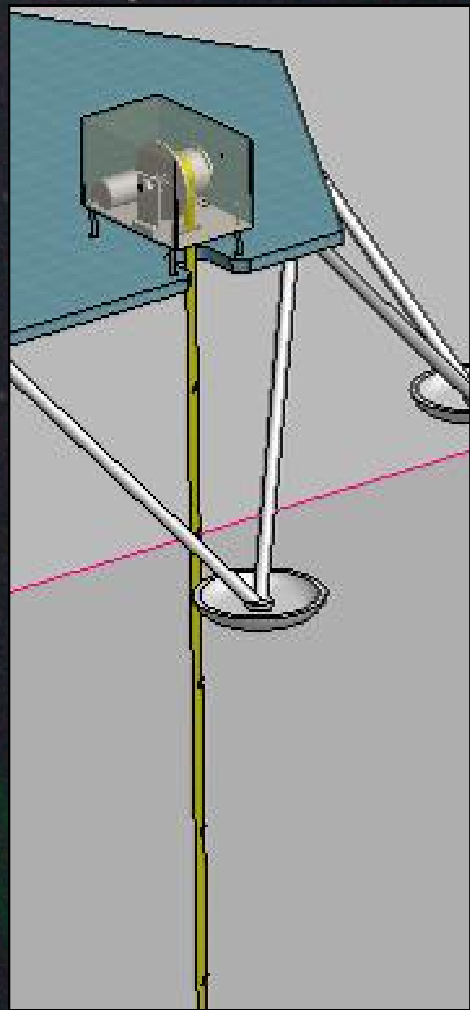
PNEUMATIC PROBOSCIS SYSTEM

Components



Deployment





SIGNAL STRENGTH

- **70 % Stronger than Current Apollo 15 signal level**
  - **At end of first decade 70% or 50% stronger than Apollo 15**
- Simulated Pattern
- 180 million square meters
- Relative to current A15
  - Down by 5.2 w.r.t. A11
  - No dust
    - Up by 9.6
  - Overall – stronger by 1.7
- If Apollo dust is due launch – cover
- If Apollo dust is due to deposit
  - At least a decade
  - But better
    - Sun shade
    - Dust mitigator
- APOLLO gets thousands of returns in 5 minutes on Apollo 15 almost every night
  - 3.6 meter therefore smaller telescopes can work
  - At 1,000 returns on 3.6 meter, one should get 80 returns on 1 meter and 25 returns on 0.6 m