CURRENT STATUS OF NEXT GENERATION RETROREFLECTOR FOR LUNAR LASER RANGING

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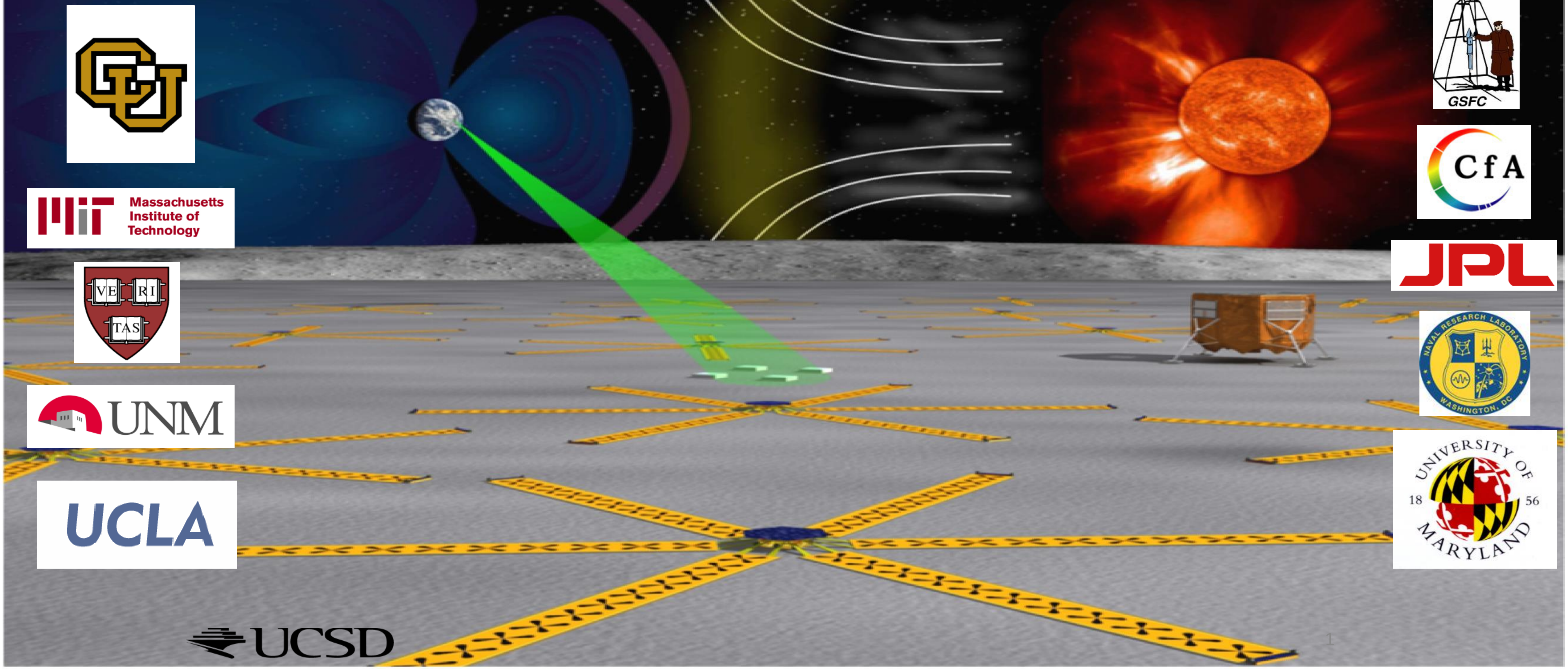
University of Maryland, College Park, MD, USA
NASA Lunar Science Institute, Moffett Field, CA
INFN – LNF, Laboratori Nazionali di Frascati, Italy

& The UMCP and INFN Teams

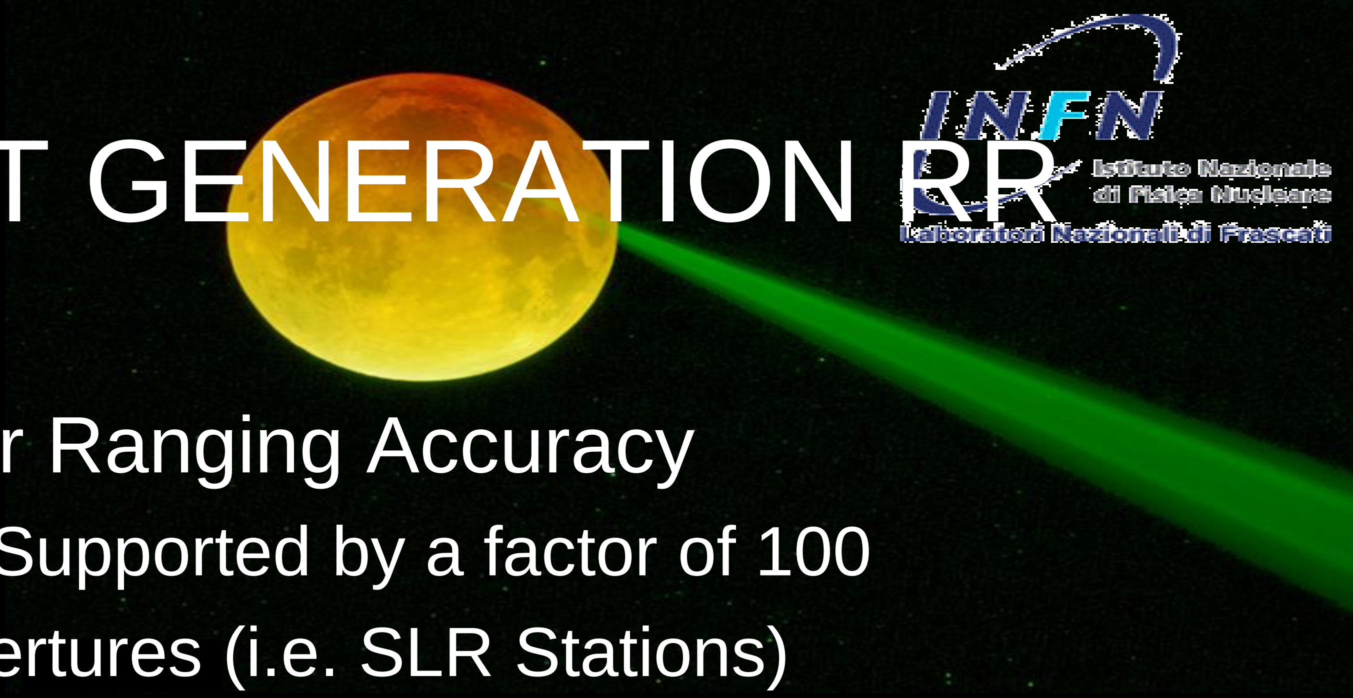


Next Generation Retroreflector Teams

- UMCP Team
  - Douglas Currie
  - Bradford Behr
  - Chensheng Wu
  - Christopher Davis
  - Giovanni Delle Monache
- INFN Team
  - Emanuele Cioccia,
  - Manuele Martinia,
  - Stefania Contessaa,
  - Luca Porcellia,
  - Marco Mastronia,
  - Giovanni Delle Monache,
  - Simone Dell'Agnelloa
  - Douglas Currie

LUNAR SCIENCE OF APOLLO LLR

- Most of the Best Tests of Gravitation and General Relativity
- Deep Interior of the Moon
  - Liquid Core – 2002 – Parameters Confirmed by Rene Weber
  - Currently Collaborating with GRAIL for Surface to Core Physics
- Fundamental Selenodetic Coordinate System
  - Used as Reference for Maps of Other NASA Mission
    - Many other Maps that Need to Be Connected
    - Need More CCRs

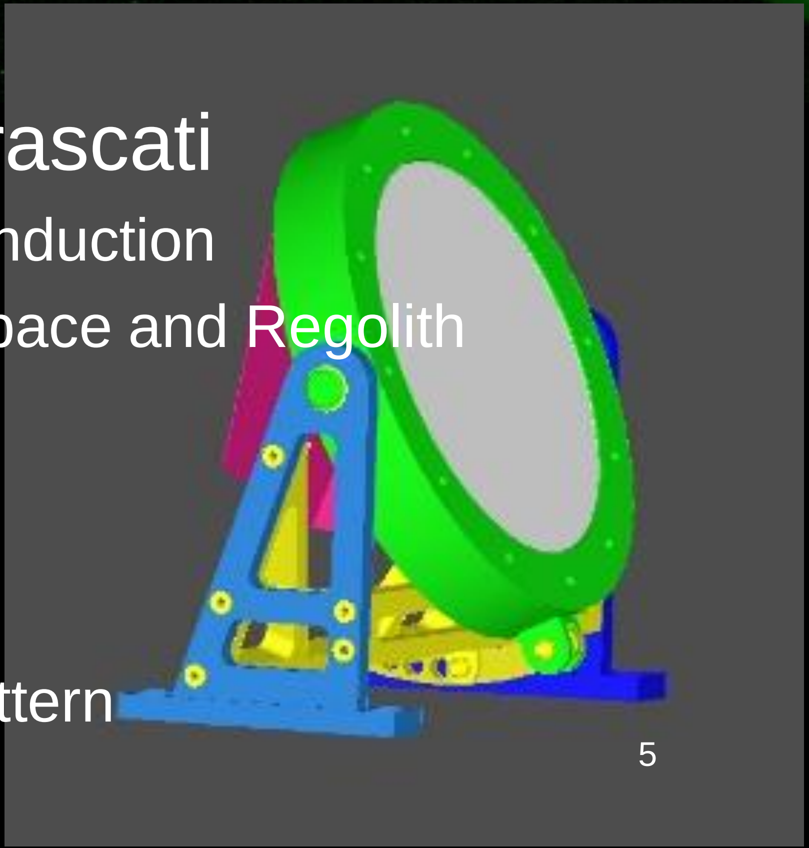


ROLE OF NEXT GENERATION RR

- Will Support Improved Lunar Ranging Accuracy
  - Improved Ranging Accuracy Supported by a factor of 100
  - Allows A Role for Smaller Apertures (i.e. SLR Stations)
- Expect Reflection of Improved Accuracy in Improved Science
  - Gravitation (Address Modifications in G to Explain Dark Matter)
  - General Relativity Tests
  - Addressing Theories of Dark Matter and Perhaps Dark Energy

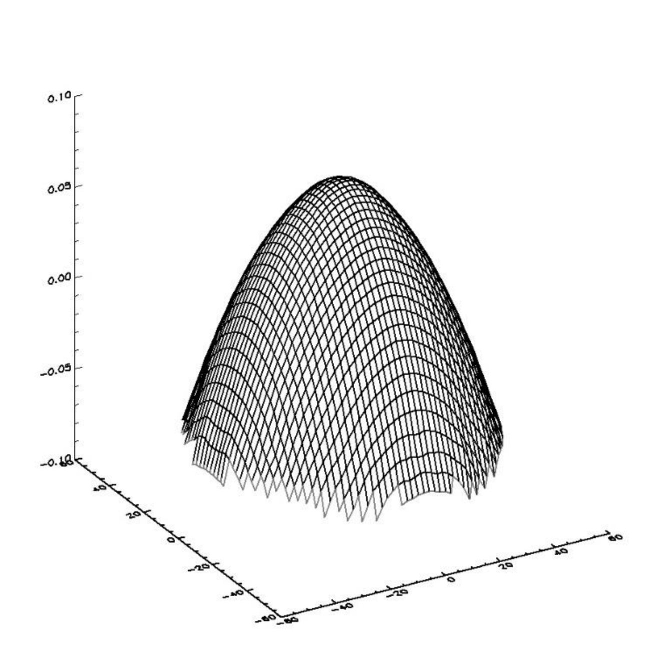
Thermal Simulation

- Heat Load 3D - IDL Program - UMCP
  - Power Dumped in each mm Cube, as a Function of Wavelength
  - Through Changing Angles During a Lunation
- Thermal Desktop – C&R Technologies & Frascati
  - Converts Heat Load to Temperature via Internal Conduction
  - Handles Conductive & Radiation Exchanges with Space and Regolith
  - Through Changing Solar Angles during a Lunation
- TPS – IDL Program - UMCP
  - Converts Temperatures to Refractive Index
  - Creates Output Phases and Far Field Diffraction Pattern



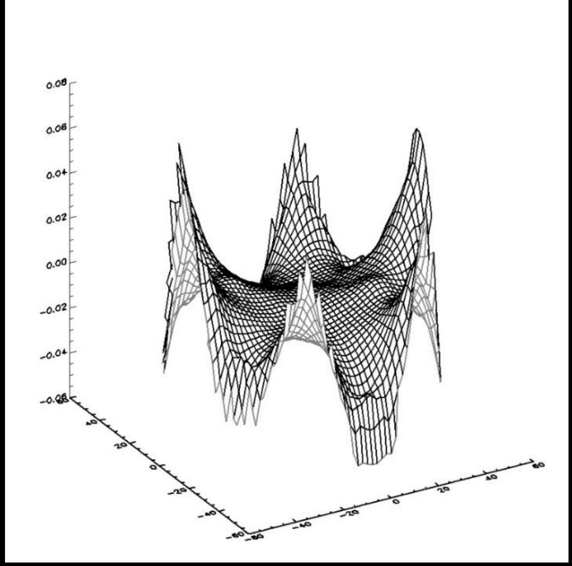
Principal Components of Thermal

- Axial Gradients
  - Results in Spreading of Outgoind Beam
  - Few Tenths of a Degree
  - Controlled by Isolating Rear Face of CCR
  - Low Emissivity Silver Coating at 0.01

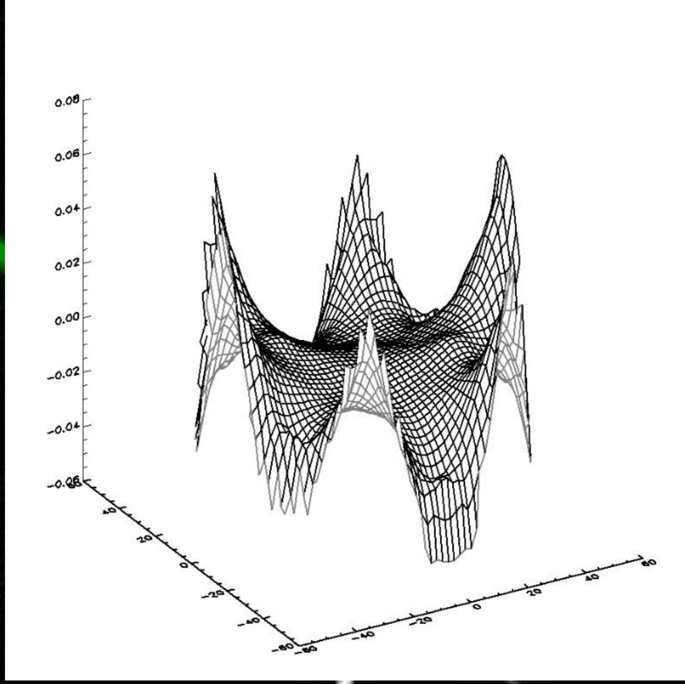


Principal Components of Thermal

- Axial Gradients
  - Results in Spreading of Out-Going Beam
  - Need Few Tenths of a Degree
- Radial Gradients
  - Addressed Near the Front Face of the CCR
  - Conduction and Radiation near the Support Tabs
    - Conduction Controlled by “Wires” with Small Area
    - Radiation Controlled by Low Emissivity Silver Coating Plastic Rings



Principal Components of The



- Axial Gradients
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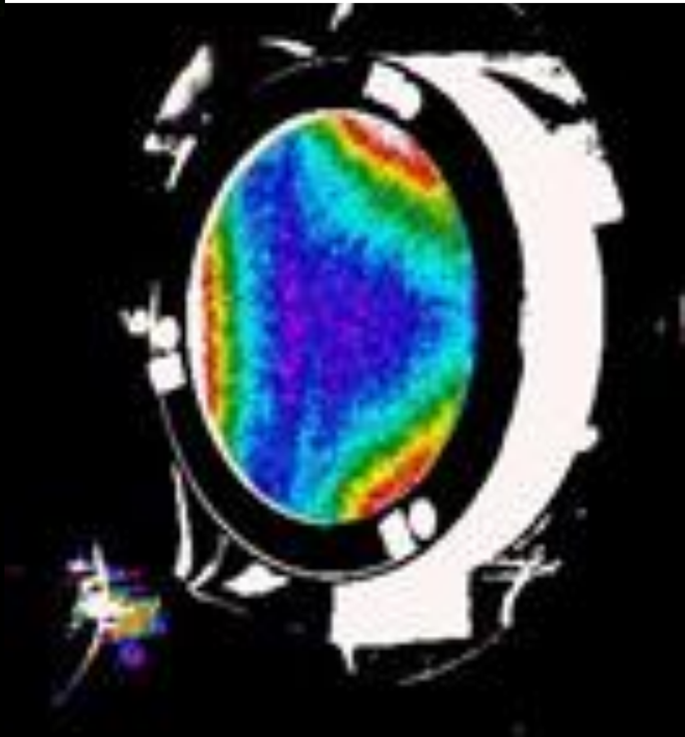
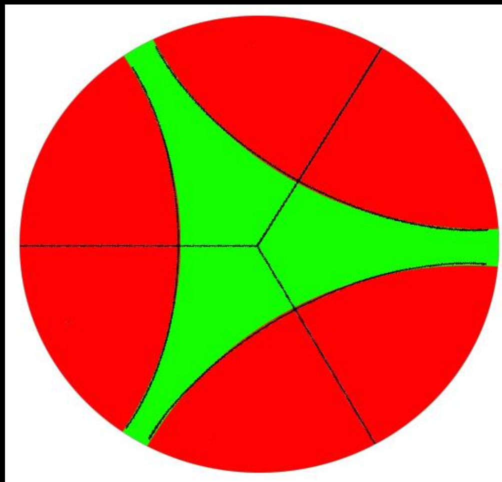
    - Conduction Controlled by “Wires” with Small Area
    - Radiation Controlled by Silver Coating Plastic Rings
- SCF Testing In Frascati has shown
  - Control of Axial Effects
  - Control of Cylinderical Wall Radiation Effects



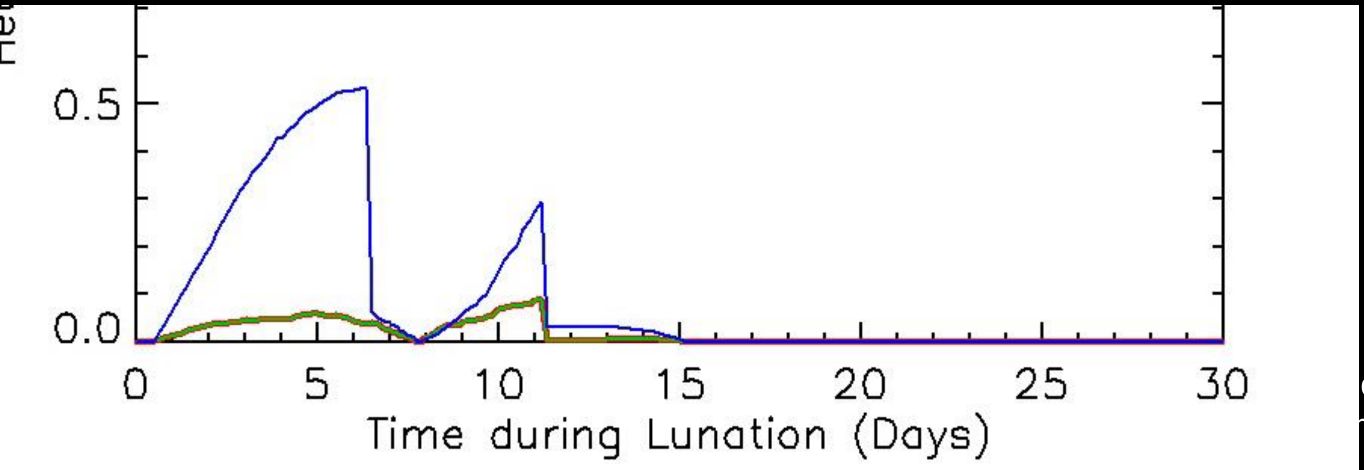
TIR BreakThrough Effects

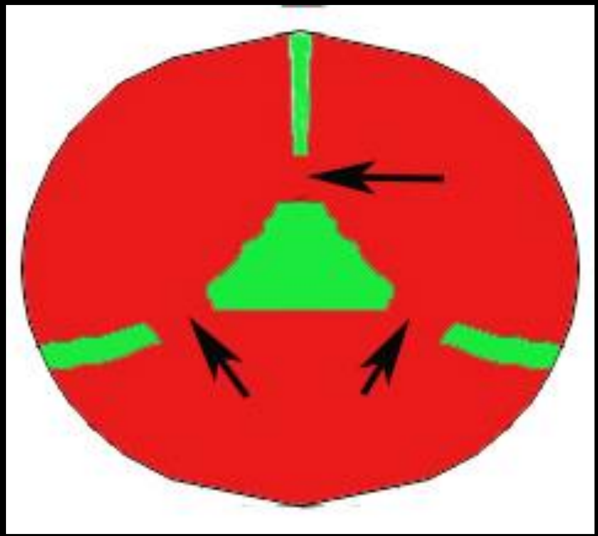
- Analysis of Simulation Results has Pointed to Other Effects
- Classically, We Have Expected for an Uncoated CCR
  - Have TIR Over Useful areas for Rejection of Solar Breakthrough
  - This Assumption has Defined Some our Package Design
- However the Simulations Indicted Energy Passing Through
  - Depositing Additional Solar Energy in the Housing
  - For Unexpected Angles of Incidence of the Sun



TIR BreakThrough Effects

- Deposited Energy Due to TIR Failure
- Throughout the Solar Angles During a Lunation
  - Sunrise through Day 7.5 – Expected Breakthrough
  - Days 7.5 to 9.5 Expected Rejection of Sun by TIR
  - Unexpected Breakthrough of TIR from Day 9.5 to 11.5





THERMAL CONTROL OF HOUSNG

- Thermal Control (Absorption and Emissivity) & Lifetime Issues:
- AZ-93 Inorganic White 0.15±0.02 0.91±0.02
- AZW/LA-II Inorganic White 0.09±0.02 0.91±0.02

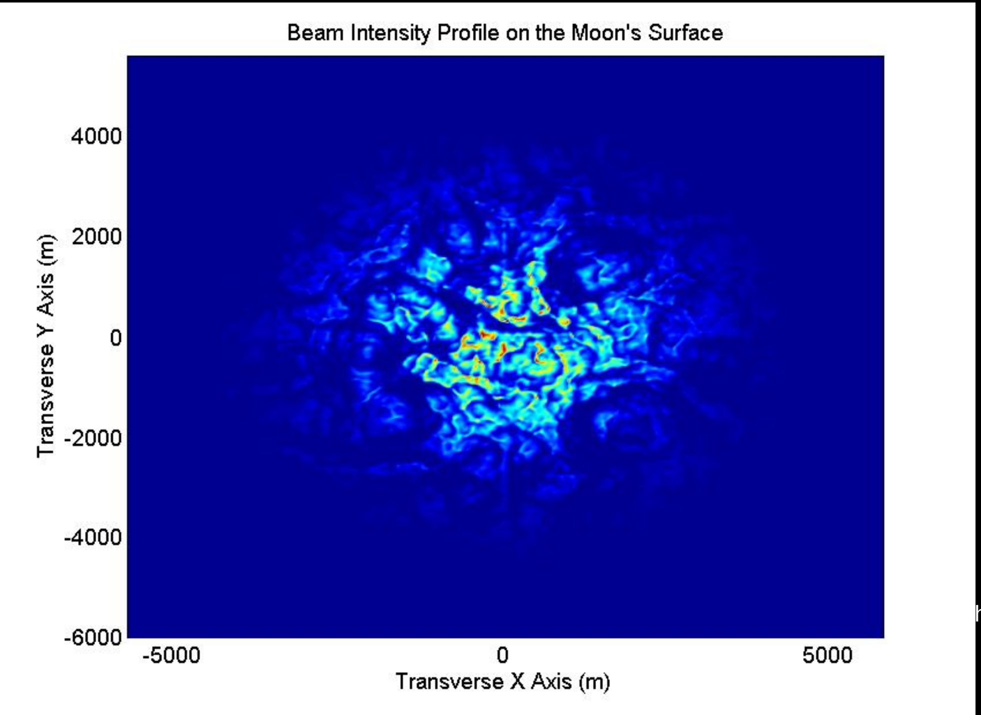
- Interferential CERMET by Consorzio CREO in Italy
- Gold - No Adhesion Layer 0.10 0.88
- Gold – With Adhesion Layer 0.10 0.88
  - Full Temperature Range has been Tested on the B-C Titanium Base
  - Temperature Range on Our Gold/Nickel Base to be Tested at UMCP

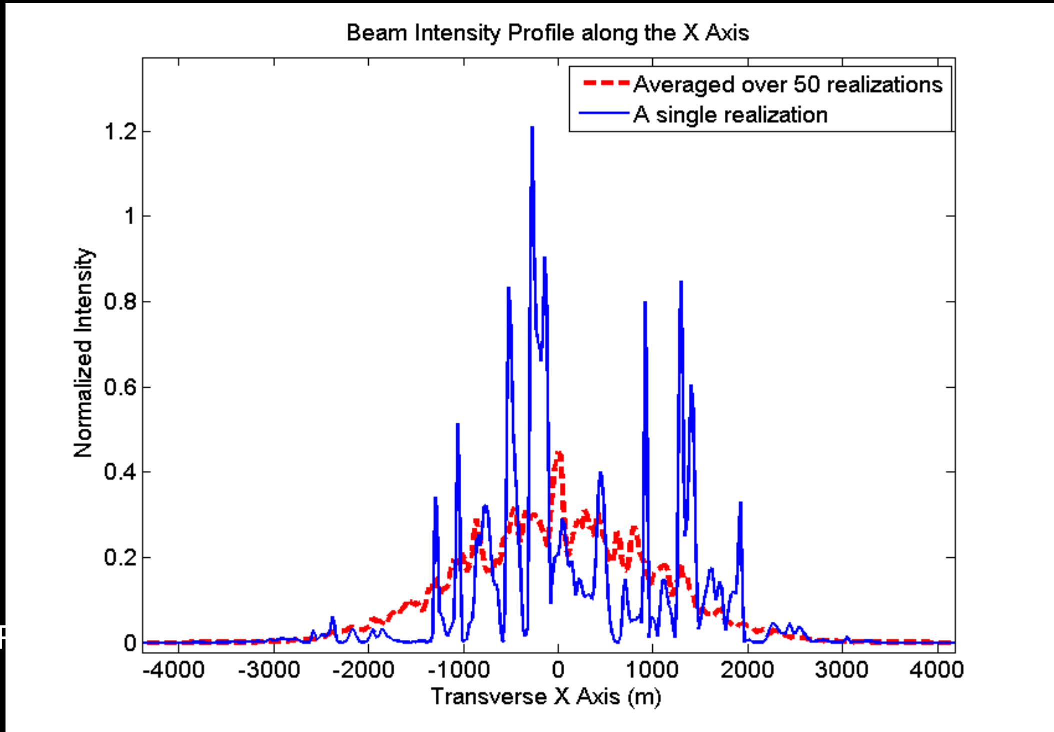
ATMOSPHERIC EFFECTS

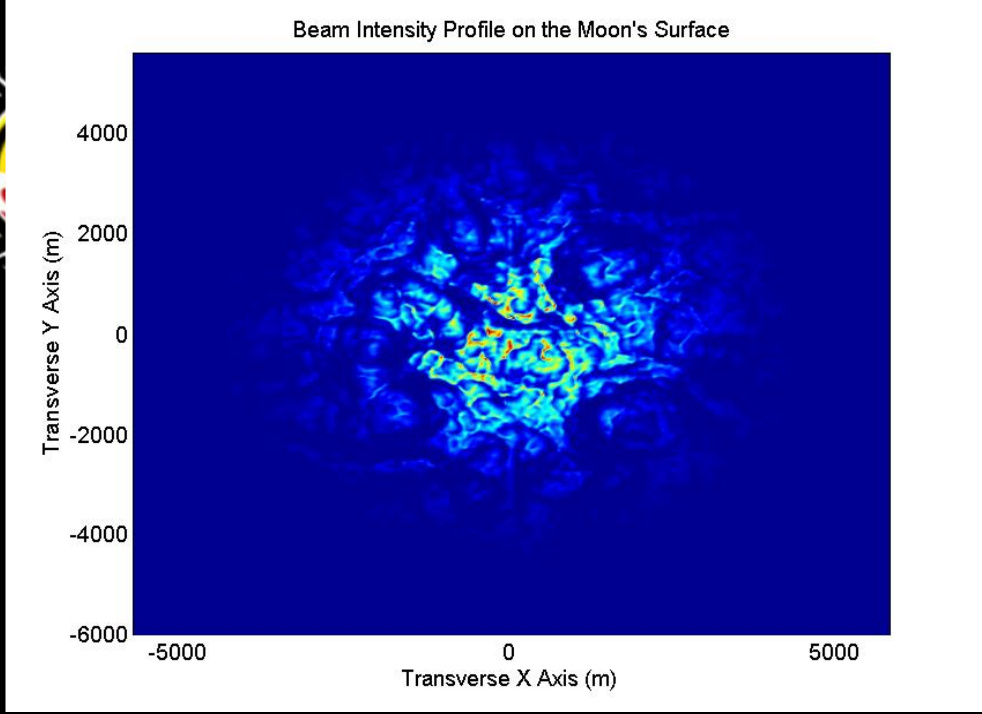
- Addressing Effect of Atmosphere on Multiple Returns
- Multiple Return Bias Range Determination
  - Especially at the Millimeter Level
- Analysis by Chensheng Wu, Post-Doc at UMCP
- Using GLAD Software
- Vertical Turbulence Profiles
  - Measured at SALT Telescope & Gemini South Telescope Sites
  - Hufnagel-Hill Vertical Turbulence Profile of Cn2

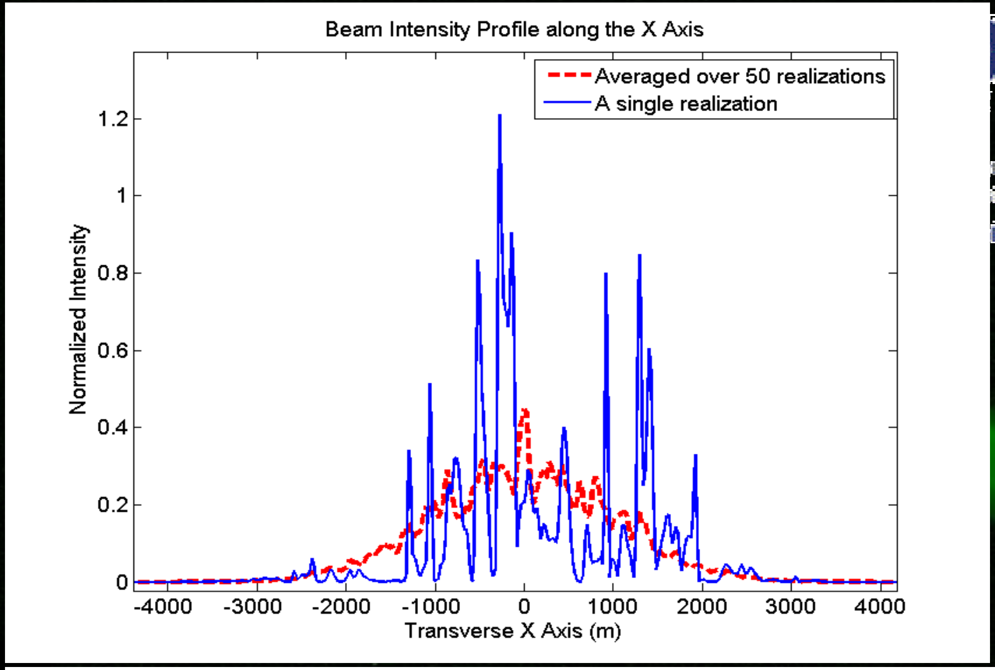
Atmospheric Effects at the Moon

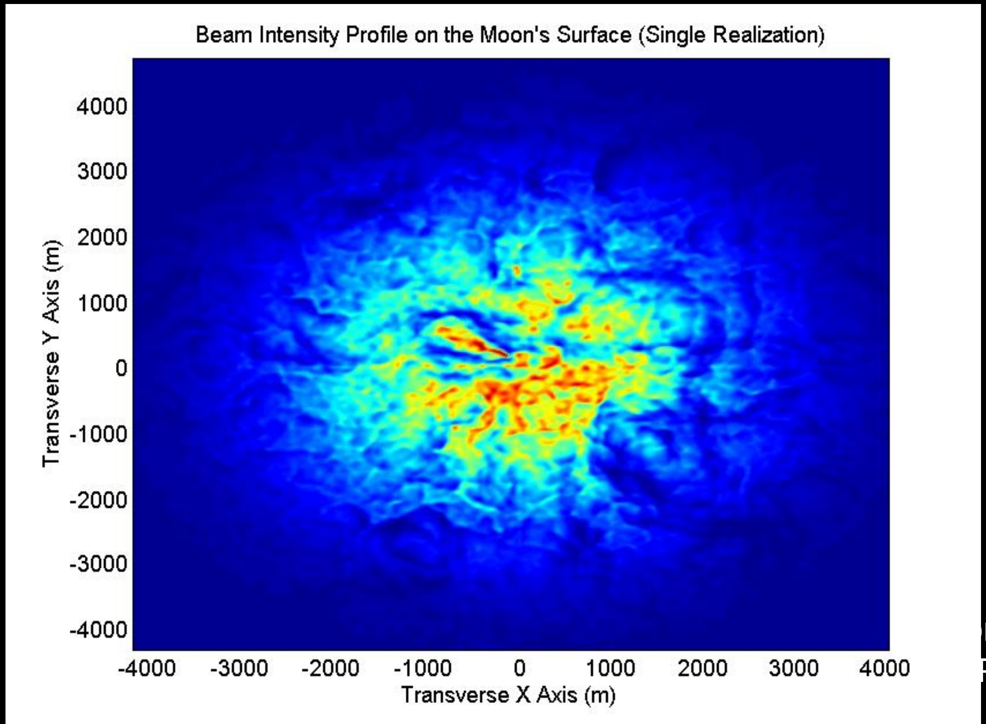
- Measured Cn2 Profilers at Existing Astronomical Sites
  - MASS-DIMM Cn2 Profile at SALT
  - GMS Cn2 Profile at Gemini South

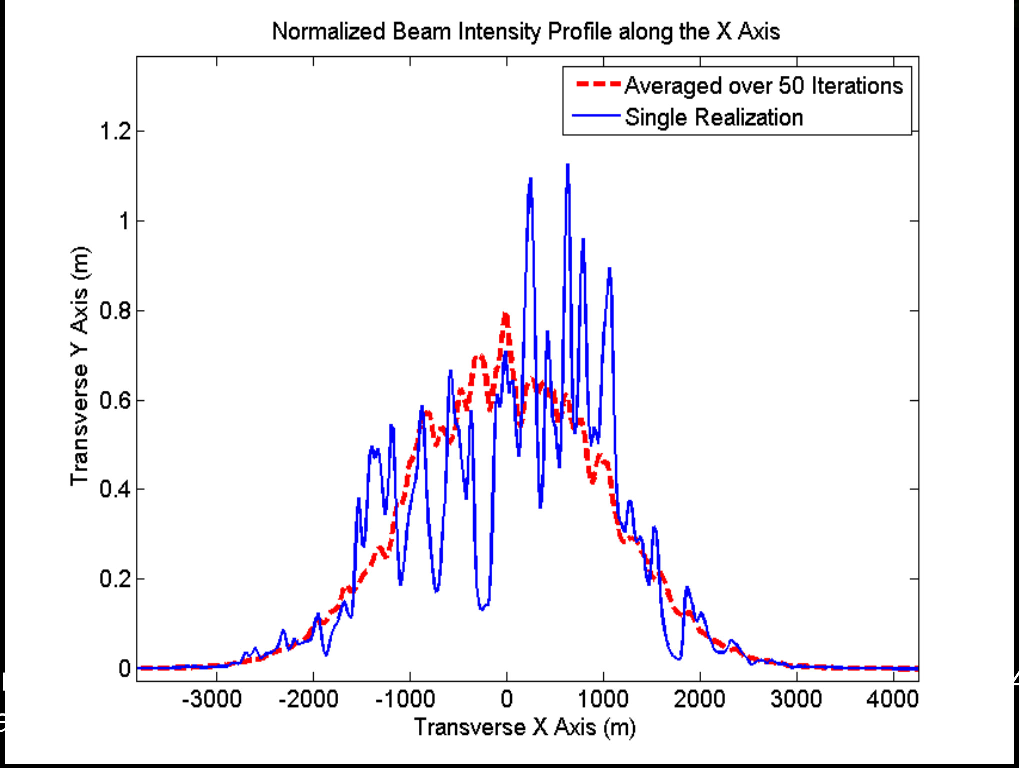


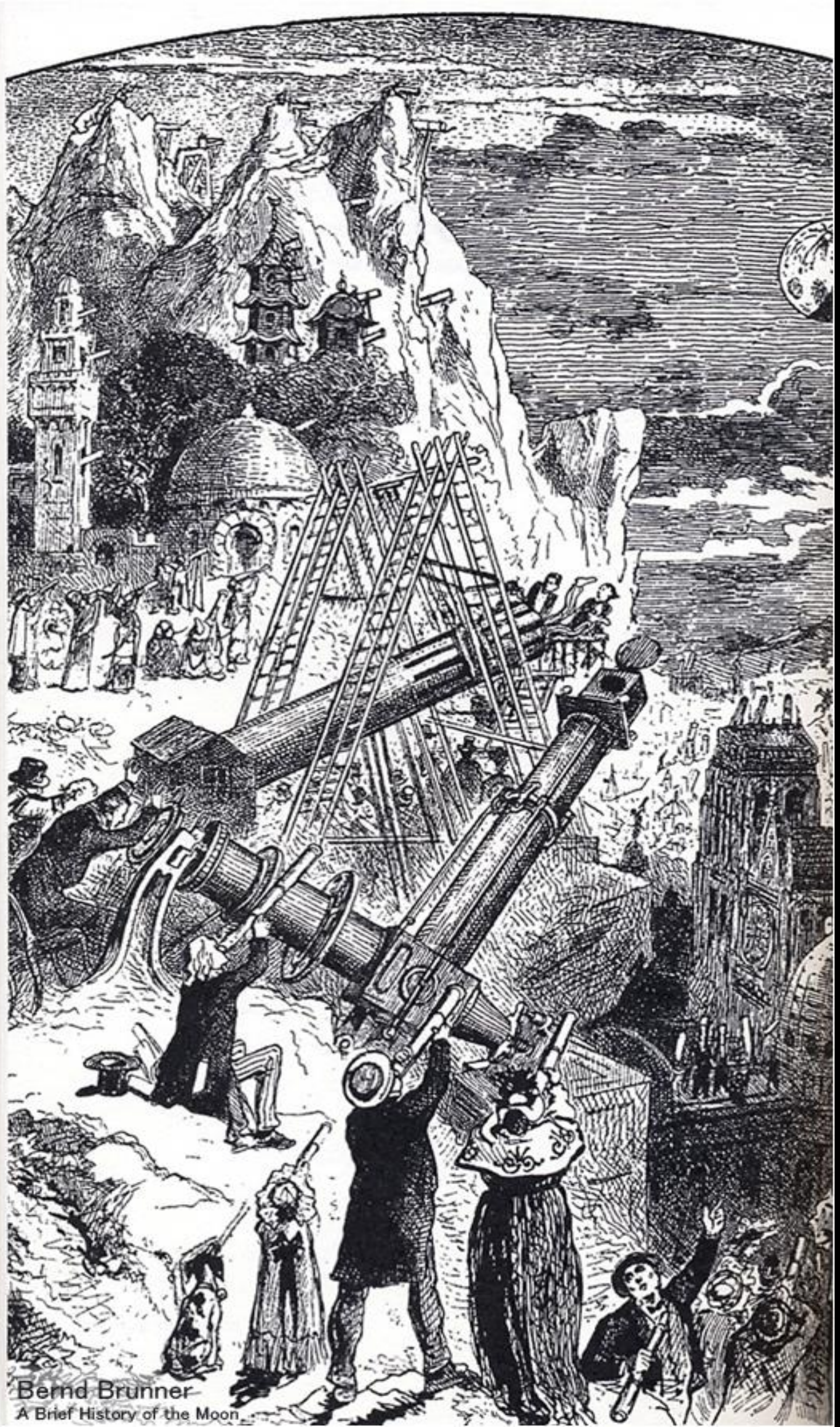



Beam Intensity Profile on the Moon's Surface
Transverse Y Axis (m)
4000
2000
0
-2000
-4000
-6000
-5000
0
5000
Transverse X Axis (m)


Beam Intensity Profile along the X Axis
Averaged over 50 realizations
A single realization
Normalized Intensity
1.2
1
0.8
0.6
0.4
0.2
0
-4000
-3000
-2000
-1000
0
1000
2000
3000
4000
Transverse X Axis (m)


Beam Intensity Profile on the Moon's Surface (Single Realization)
Transverse Y Axis (m)
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-4000
-3000
-2000
-1000
0
1000
2000
3000
4000
Transverse X Axis (m)


Normalized Beam Intensity Profile along the X Axis
Averaged over 50 Iterations
Single Realization
Transverse Y Axis (m)
1.2
1
0.8
0.6
0.4
0.2
0
-3000
-2000
-1000
0
1000
2000
3000
4000
Transverse X Axis (m)



Thank You!

any

Questions?

or

Comments?

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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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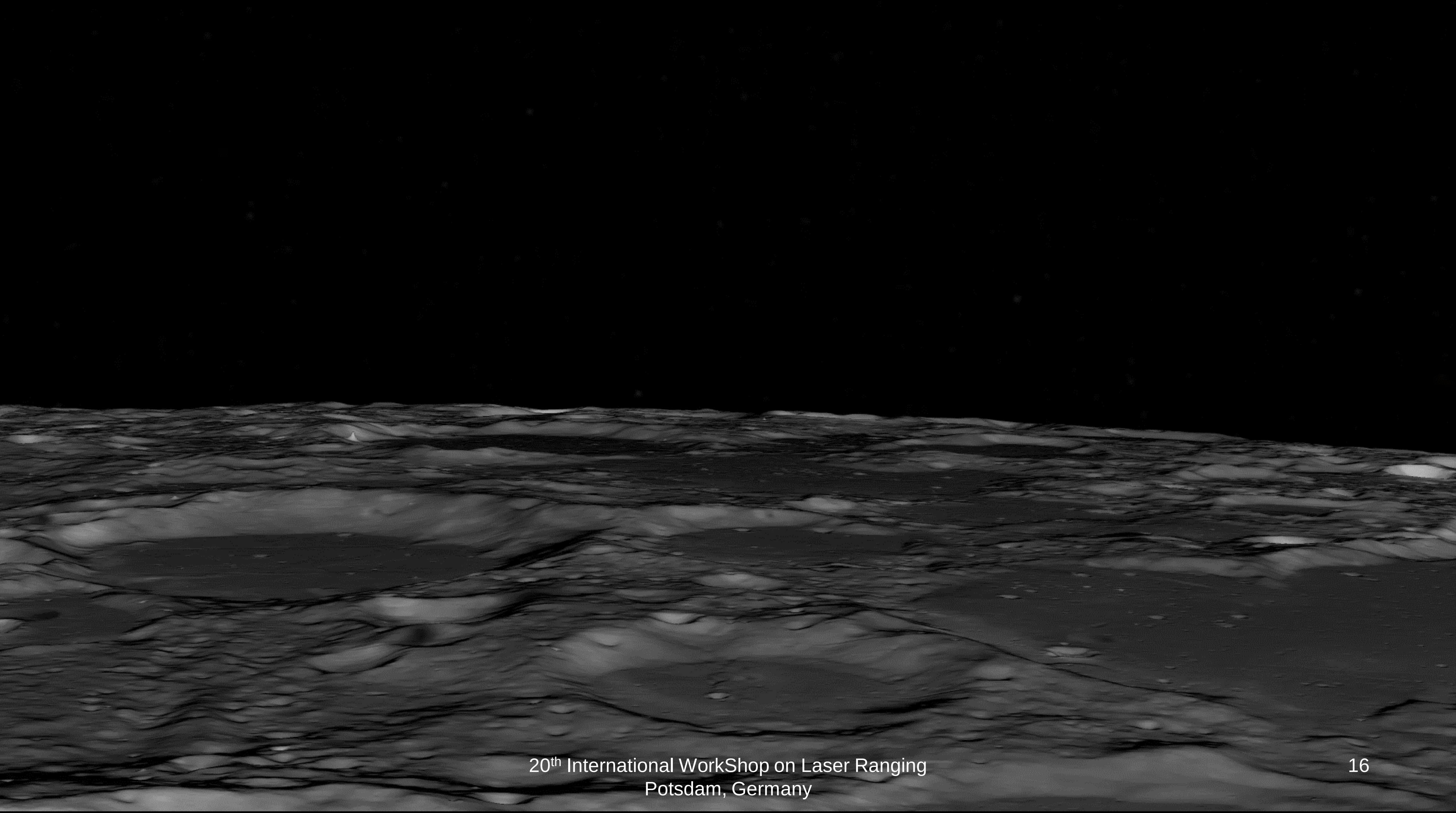
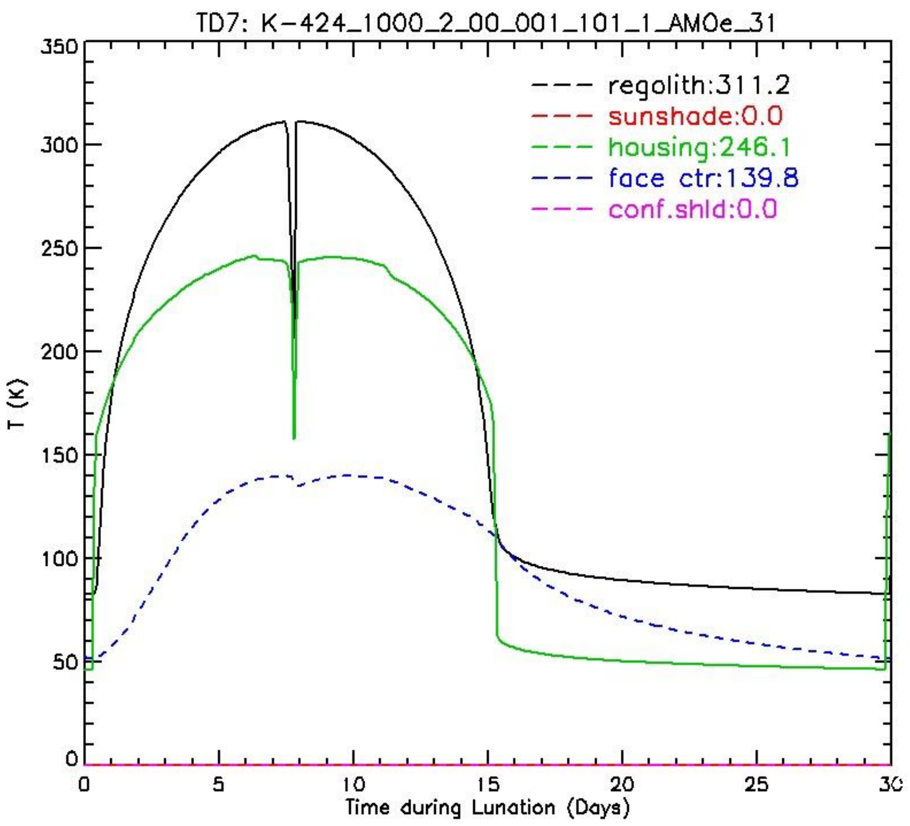
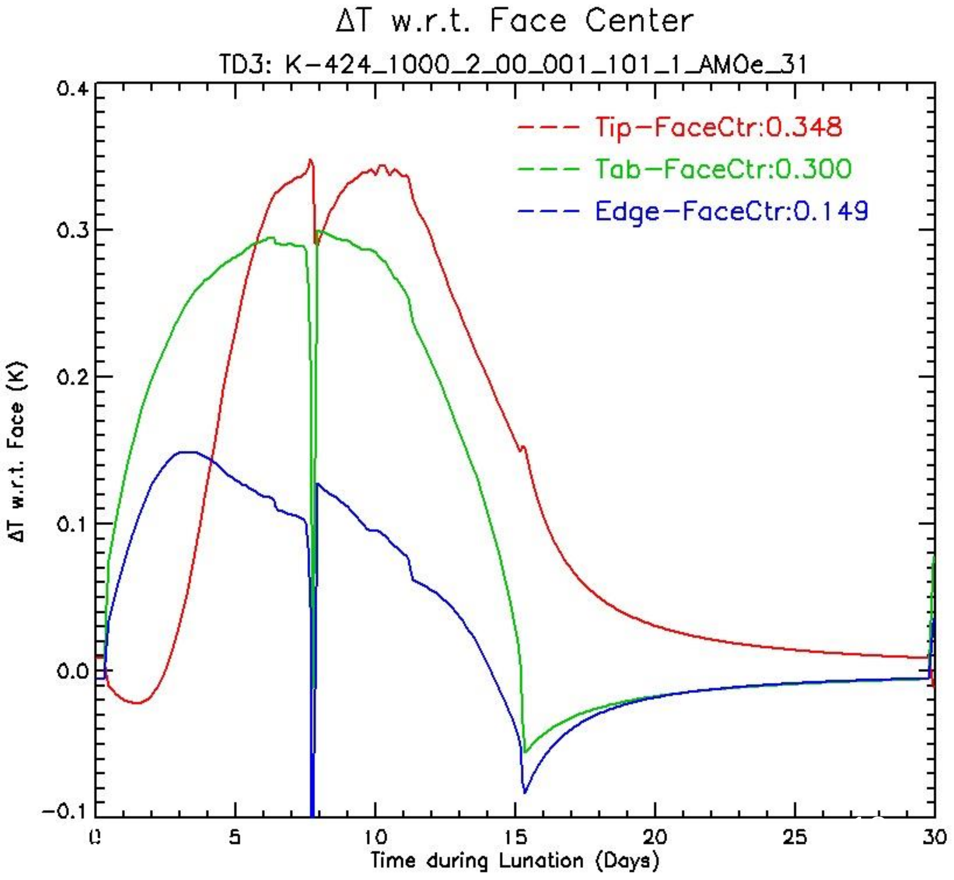


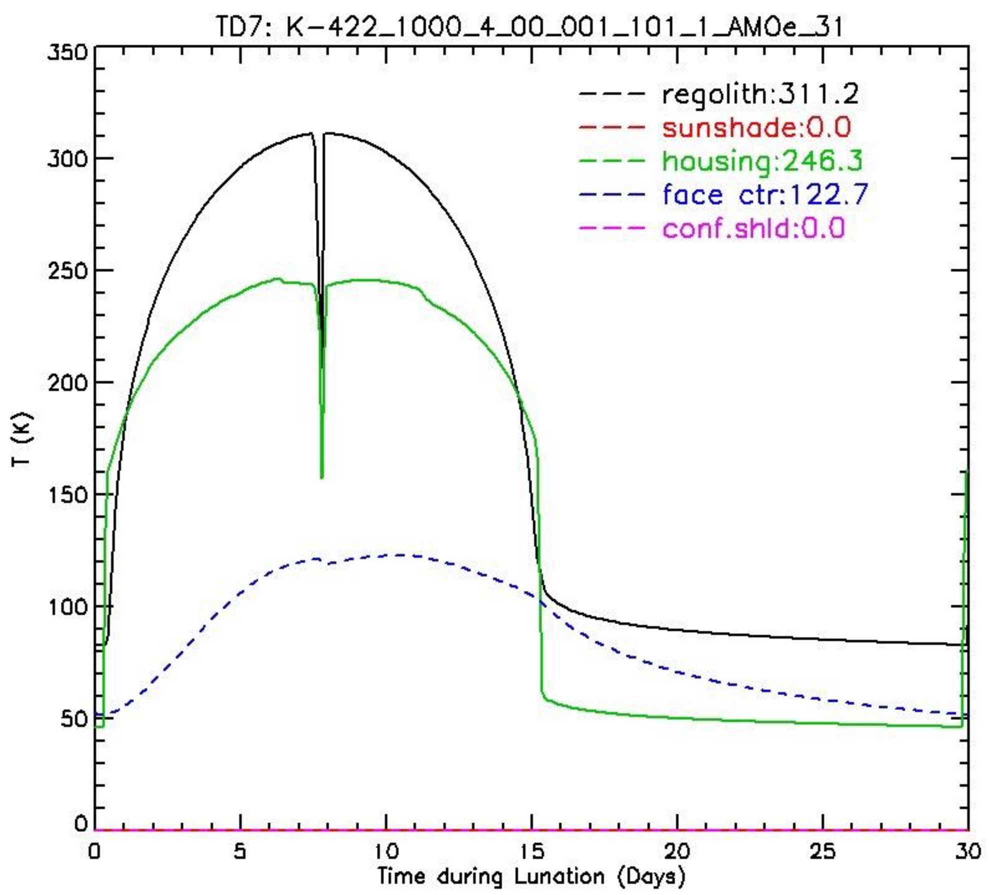
BACKUP SLIDES

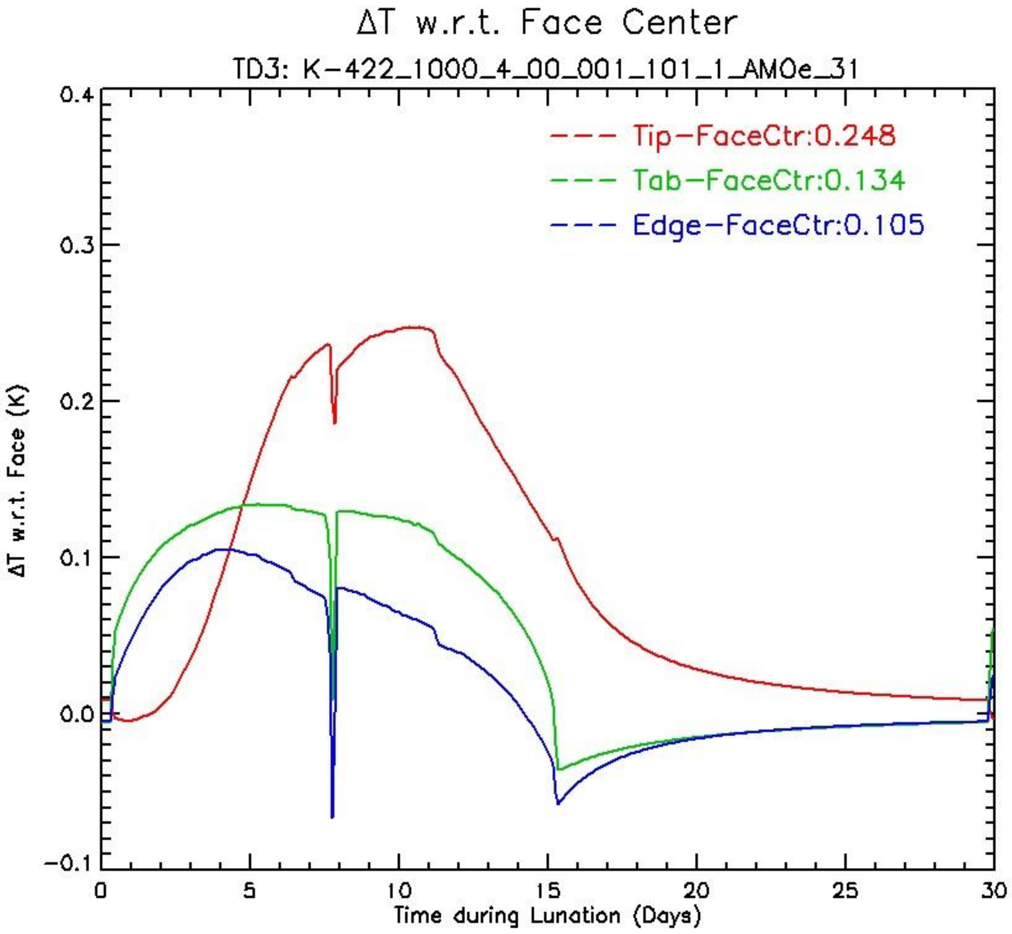
Example: K-424 - 75% Maximum Loss of Signal



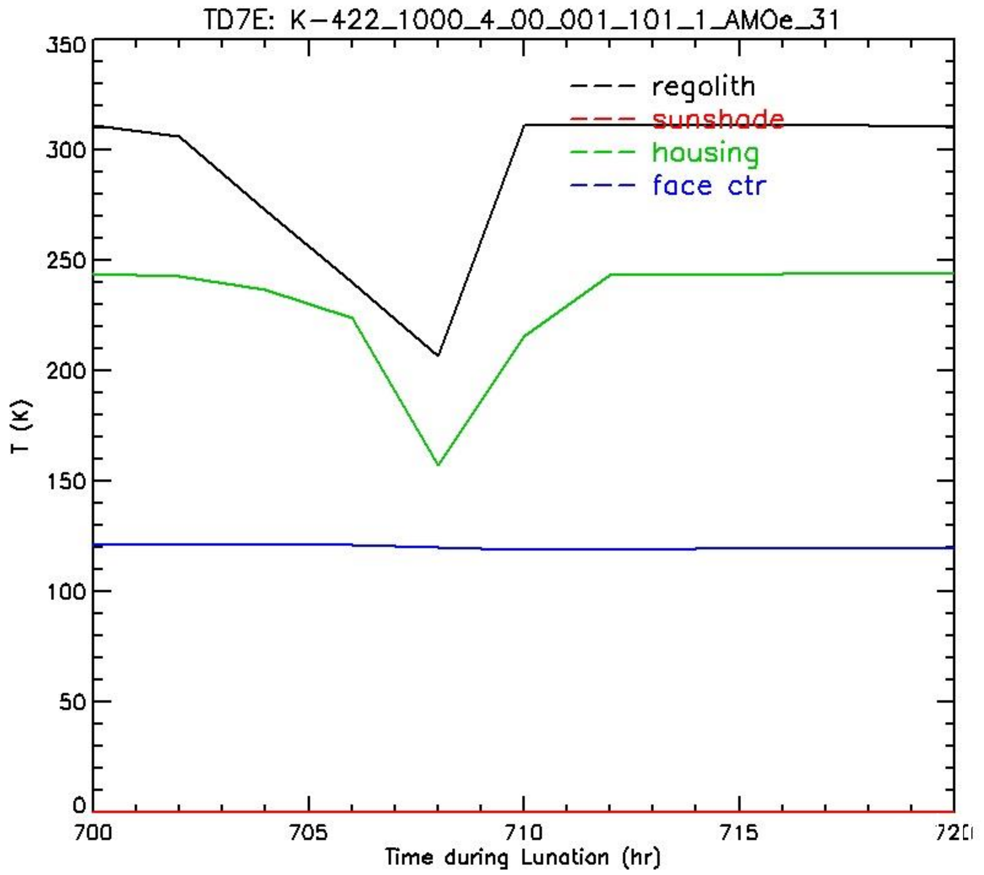


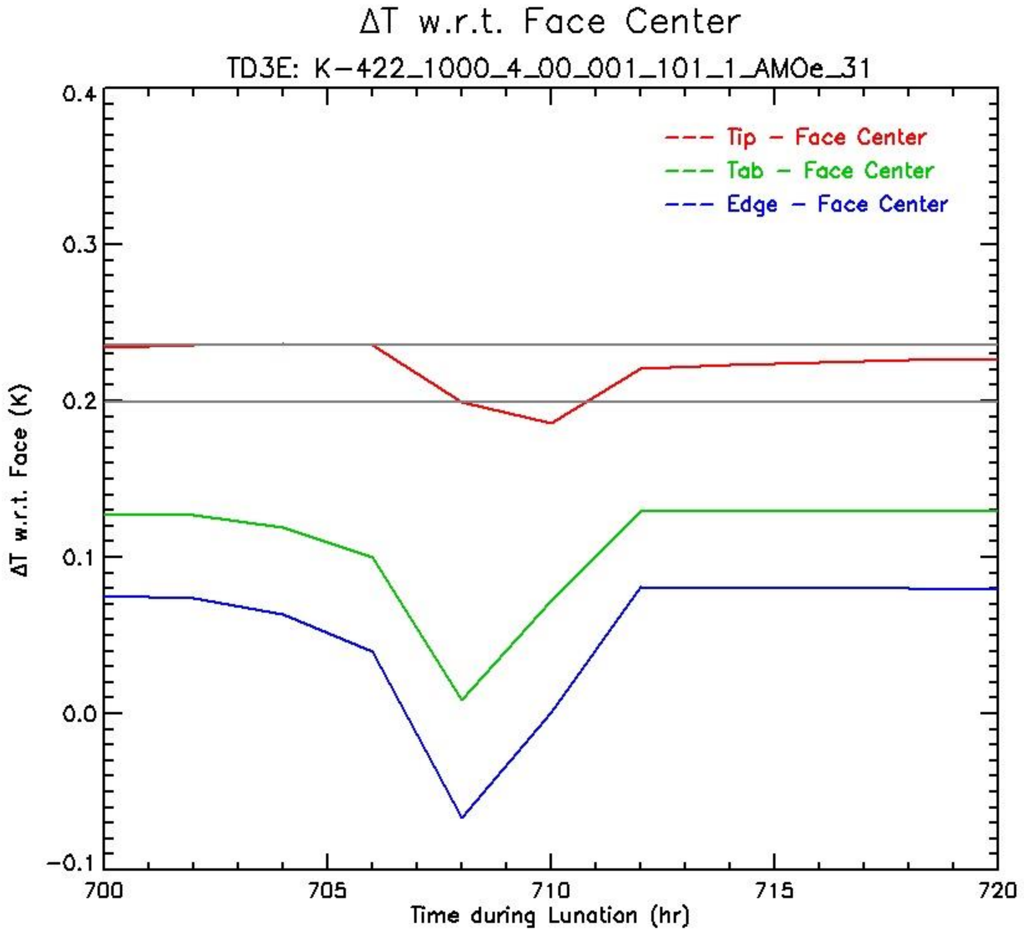
Example: K-422 - 25% Maximum Loss of Signal





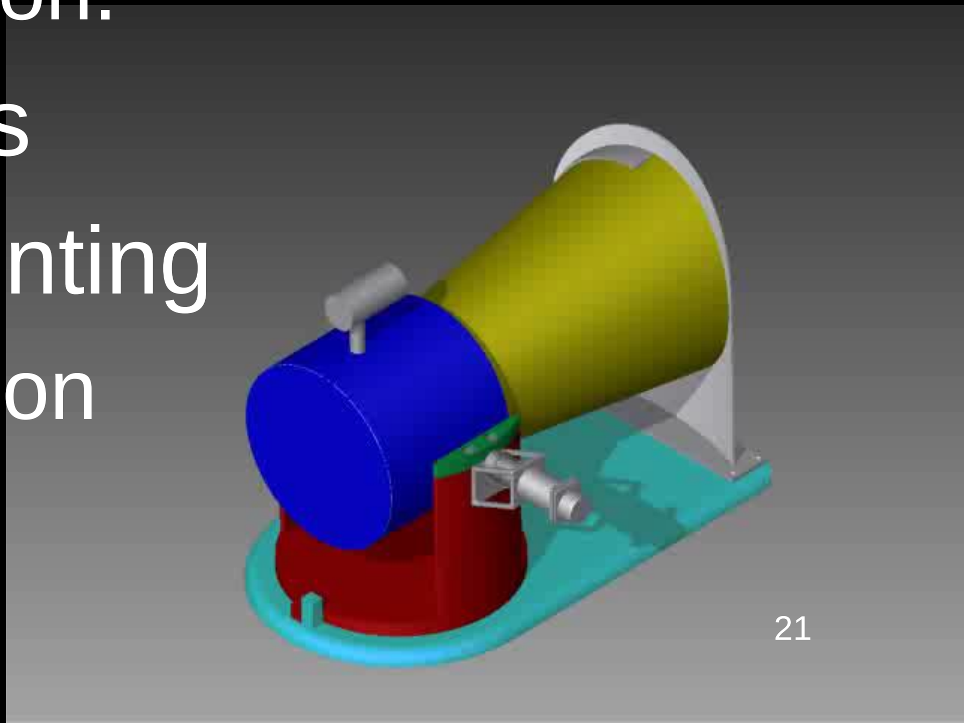
Eclipse Example: K-422 - 25% Maximum Loss of Signal



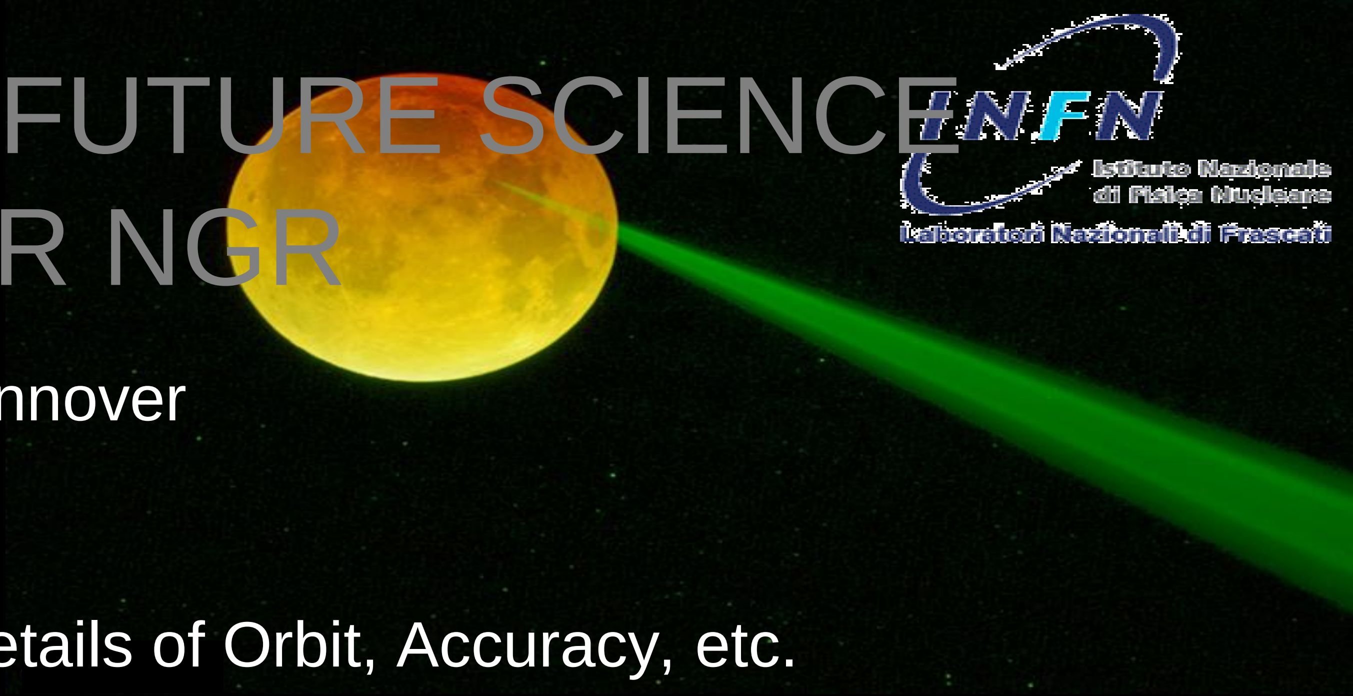


Future Plans for Pointed System

- Current NGR Design Relies upon the Lander
  - Achieving the Specified Azimuthal Orientation and
  - Landing on a Relatively Level Region.
- “Pointed” System Addresses This
- Actively Provides the Correct Pointing
  - Then Locks Down for Rest of Mission



SIMULATIONS FUTURE SCIENCE FOR NGR



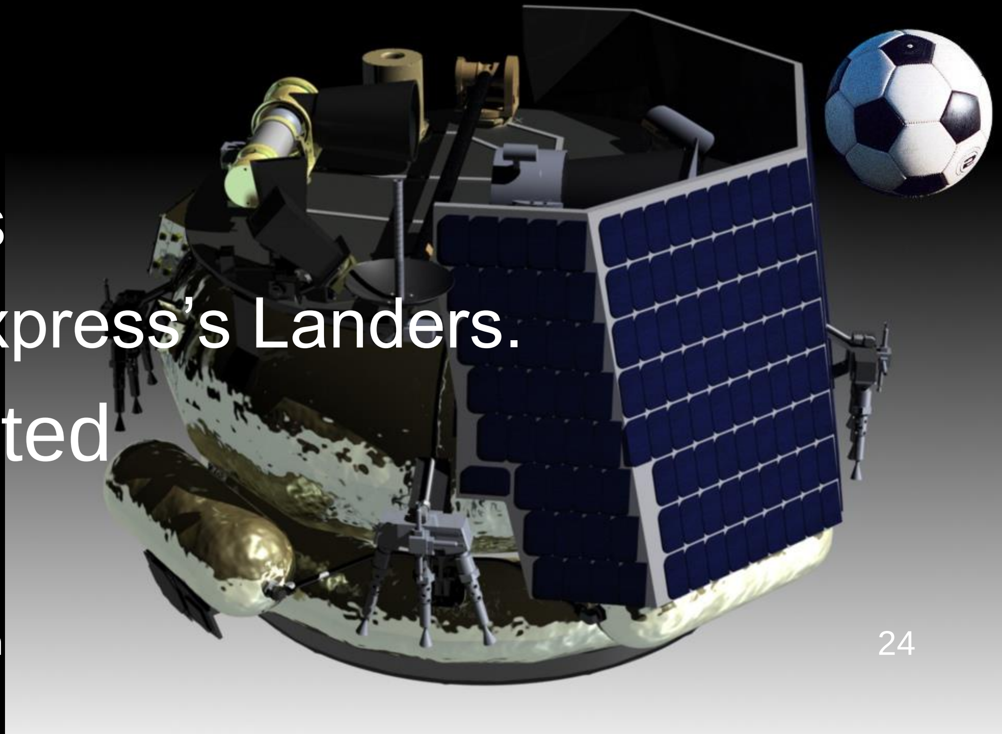
- Collaboration with University of Hannover
  - Jürgen Mueller
  - Franz Hofmann
- Software Program Incorporating Details of Orbit, Accuracy, etc.
- The Effects of the Operational Aspects on Improved Accuracy
  - Effect of an Increased Number of Ground Stations
  - Effect of Limited Operational Conditions (Day/Night, Bright/Dark Moon)
  - Effect of Degradation due to Marginal NGR Design and/or Aging on Lunar Surface
  - Role of Limited Ranging Opportunities
- Criterial is Improvement in Various Science Parameters
  - Typically a factor of 50 by 2030

GRAVITATIONAL & GR SCIENCE

- LLR Currently Provides our Best Tests of:
  - **The Strong Equivalence Principle (SEP)**
  - **Time Rate-of-Change of *G***
  - **Inverse Square Law, Deviation of 1/r**
  - **Weak Equivalence Principle (WEP)**
  - **Gravito-Magnetism**

AGREEMENT FOR NGR DEPLOYMENT

- In Frascati, Italy at the Last Meeting of the ILRS
- An Agreement was Signed with Moon Express by
  - University of Maryland, College Park, USA
  - INFN-LNF of Frascati, Italy
- For the Deployment
  - Of our Next Generation Retroreflectors
  - On the First of Four Flights of Moon Express's Landers.
- First of these Deployments is Expected
  - In the Second Half of 2017.



FUTURE PLANS FOR ANCHORED DEPLOYMENT

- Challenges due to Wide Temperature Variations
  - Temperature Changes from Lunar Day (320K) to Night (70K)
  - For NGR mounted on a Lander,
  - Implies that there is a Vertical Motion of 1 to a few Millimeters,
  - Depending on the Lander Design.
- To address this, an "Anchored" Deployment has been Investigated
- One Meter Down in Regolith, Practically No Change in Temperature
  - and
- A Conceptual Design for Such a System has been Developed.