ILRS

A LUNAR LASER RANGING RETRO-REFLECTOR ARRAY

Thermal Analysis of

Large Cube Corner Retroreflectors

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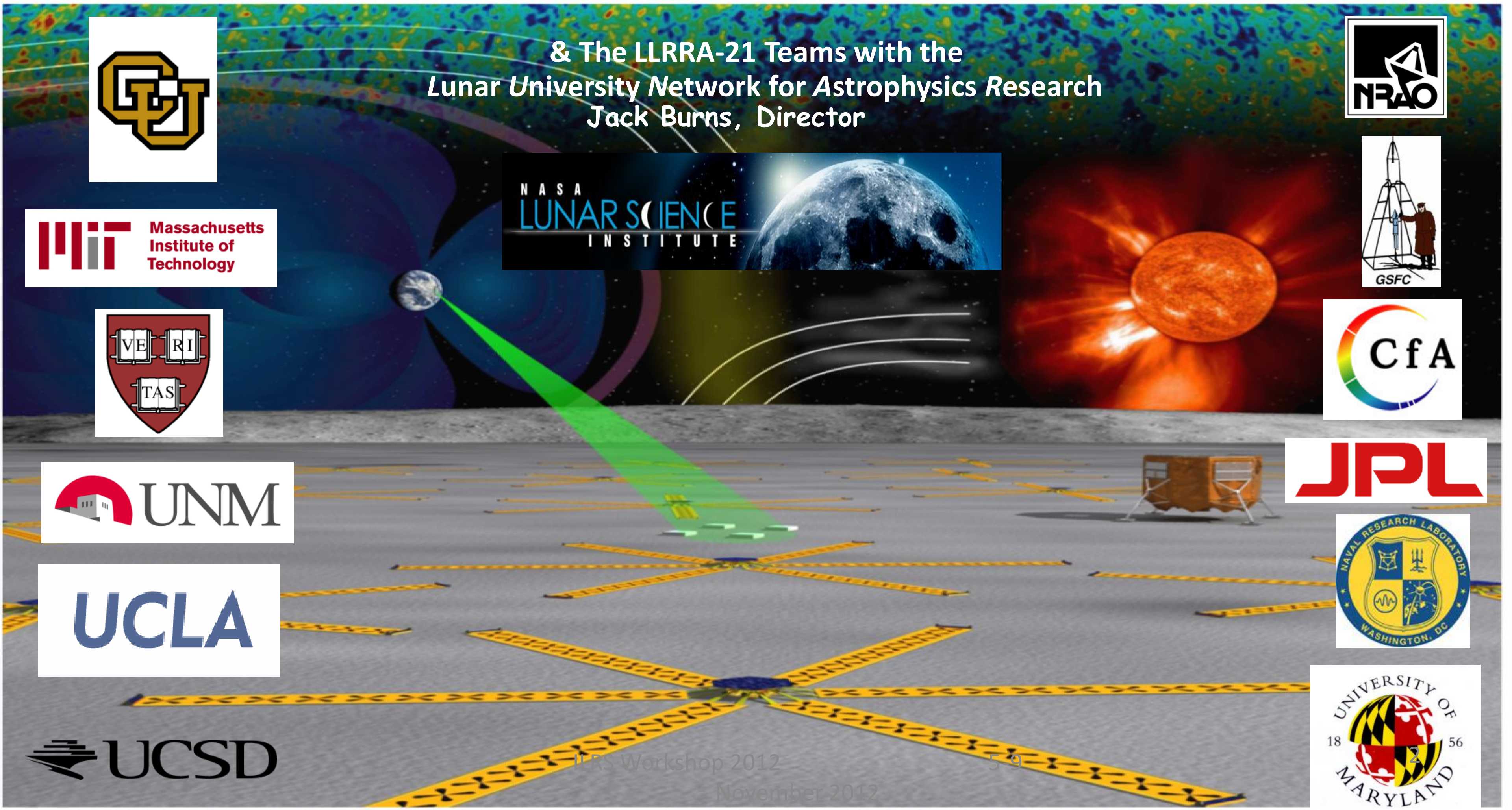
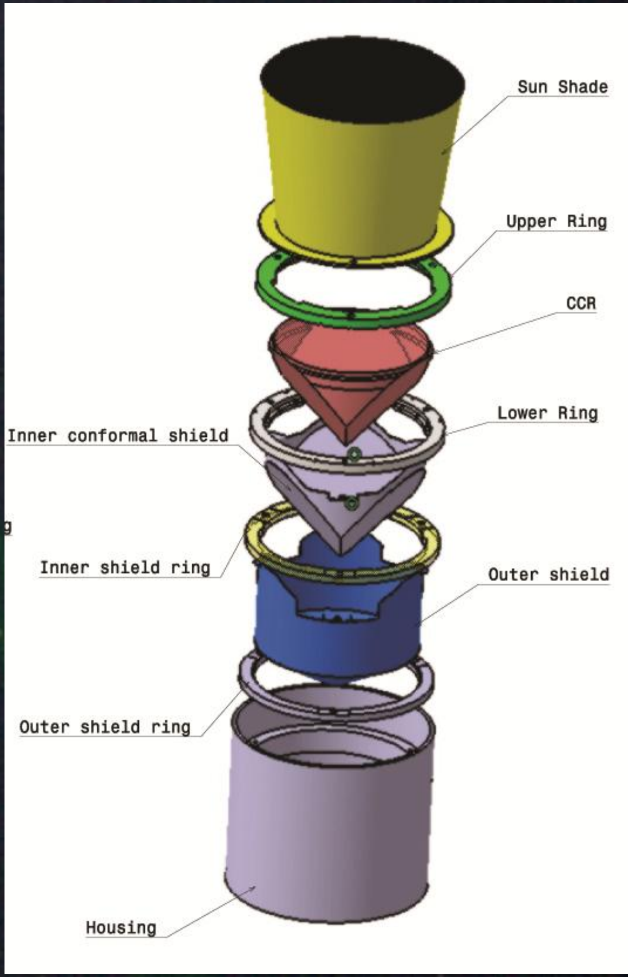


OUTLINE

- Objectives of LLRRA-21 Program
- Description of Thermal Simulations
  - Objectives of Thermal Simulations
  - Program Structure
    - Heat Loads from Solar Absorption
    - Thermal Desktop – Orbital Thermal Effects
    - Optical Phase Error Maps & FFDP
    - Results for “Bare” CCR
    - Role of Code V – Offsets and Phases
- Deployment Methods
- Earth-Pointing Procedure
- Flight Possibilities



OBJECTIVES OF LLRRA-21 PROGRAM

- Eliminate the Libration Problem
  - for Apollo Arrays
  - Up to 15 cm Single Photo-Electron Amiguity
- Provide Apollo 15 Return Signal Level
  - Allows for Participation by Multiple Observatories
- Provide for the Possibility for
  - More Frequent Observations
- Provide Three LLRRA-21s
  - To Define Libration Angles
  - For Lunar Physics (for Rotation /Libration Time Series)
  - For General Relativity (for Location of Center of Mass)

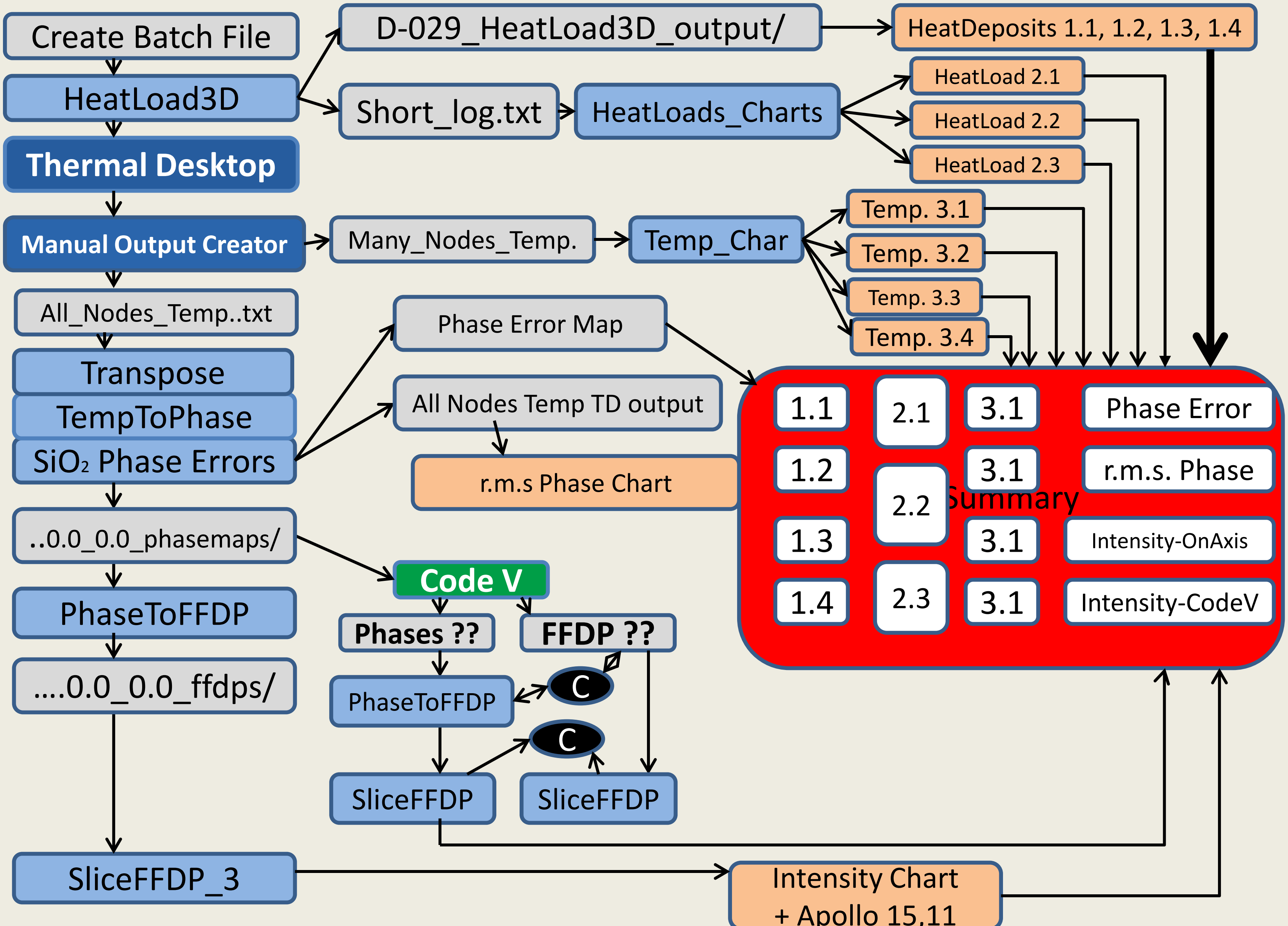
Thermal Simulations Objectives

- Determine Thermal/Optical Effects on CCR
  - due to Solar Absorption
- Optimize Enclosure Parameters
  - Tab Conductivity
  - Emissivity and Absorption of External Surfaces
  - Emissivity and Absorption of Sunshade Interior
  - Emissivity and Absorption of Inner Thermal Shields
- Determine Return Signal Levels to Be Expected
  - As a Function of Time during a Lunation
- Model the Behavior in SCF Enviroment
  - Comparison of Simulation and SCF Performance
- Perhaps Develop a Service to Model Other CCRs

Thermal Simulations Program Structure

- Requires a Sequence of Computer Programs
  - IDL from RSI
    - IDL is Programing Language for Handling Data Arrays
    - Bradford Behr of University of Md is Primary Programmer
  - Thermal Desktop from C&R Technologies
    - Commercial Program (SINDA/FLUINT) for Orbital Thermal
    - Giovanni Delle Monache of INFN-LNF is Primary Programmer
  - Code V from Optical Associates, Inc.
    - Commercial Program for Modeling Optical Systems
    - Alesandro Boni of INFN-LNF is the Primary Programmer

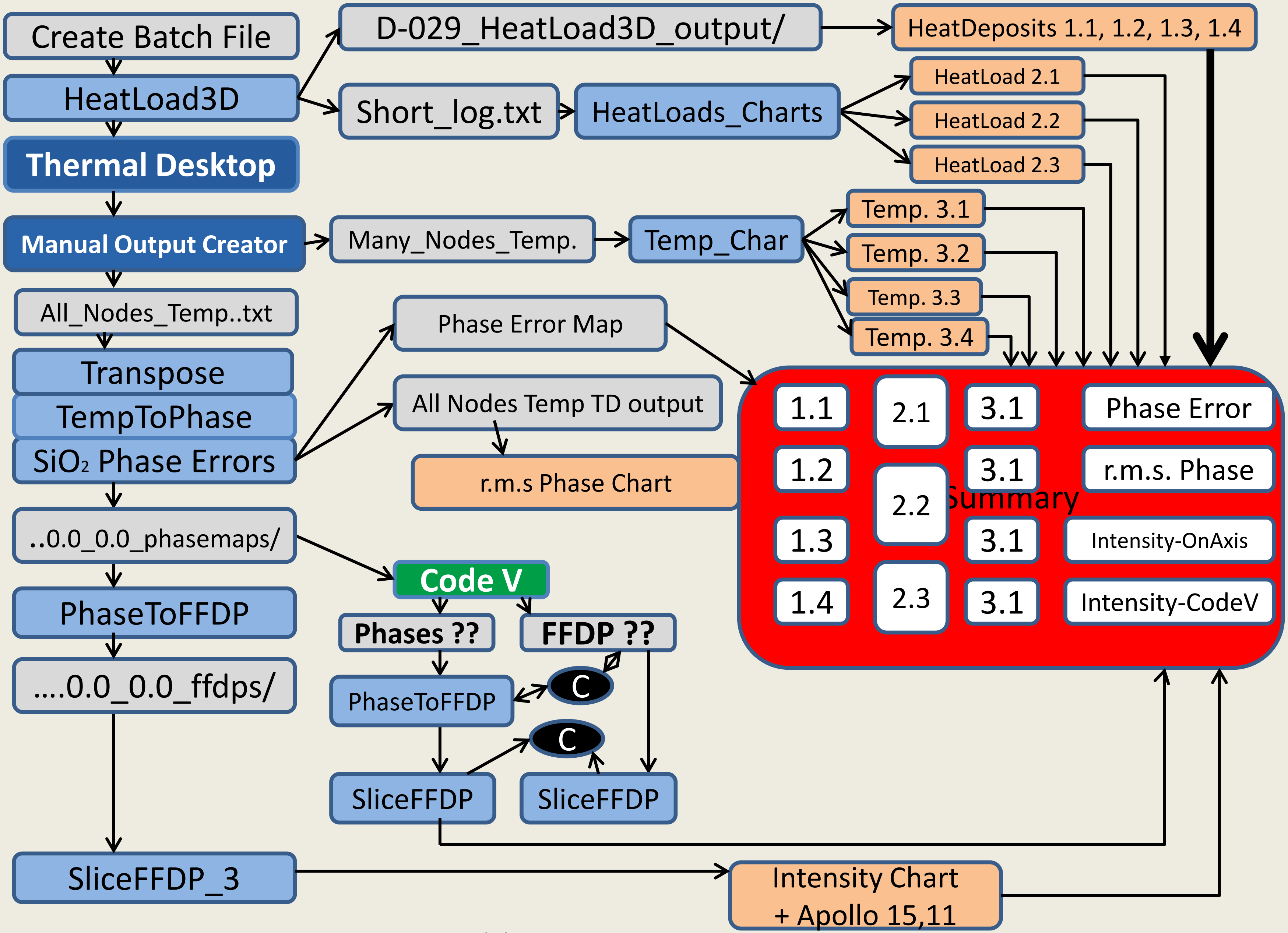
LLRRA-21 Thermal/Optical Simulation



Program Structure
Computation of Heat Loads

- Computes the Deposition of Thermal Energy in CCR
  - Volumetric Effects Due to Solar Radiation Falling on CCR
  - Also Interior of the Sunshade and the Inner Thermal Shield
- Absorption of Fused Silica Depends on Wavelength
  - We Address Absorption of SupraSil 1 or 311 from Hereaus
  - Divide Solar Spectrum into 1 nanometer Wavelength Bands
  - Propagate 1000 Rays for each of the Wavelength Bands
  - In each mm Cube along the Path, Compute Deposited Absorption
  - Propagate Remaining Energy along the Path via Beer's Law
- During Breakthrough - the Failure of TIR
  - The Energy is Deposited in the Inner Thermal Shield
- Compute Absorption and Reflection in Sunshade
  - Interior Only
  - Taking into Account the Angles in the Steps

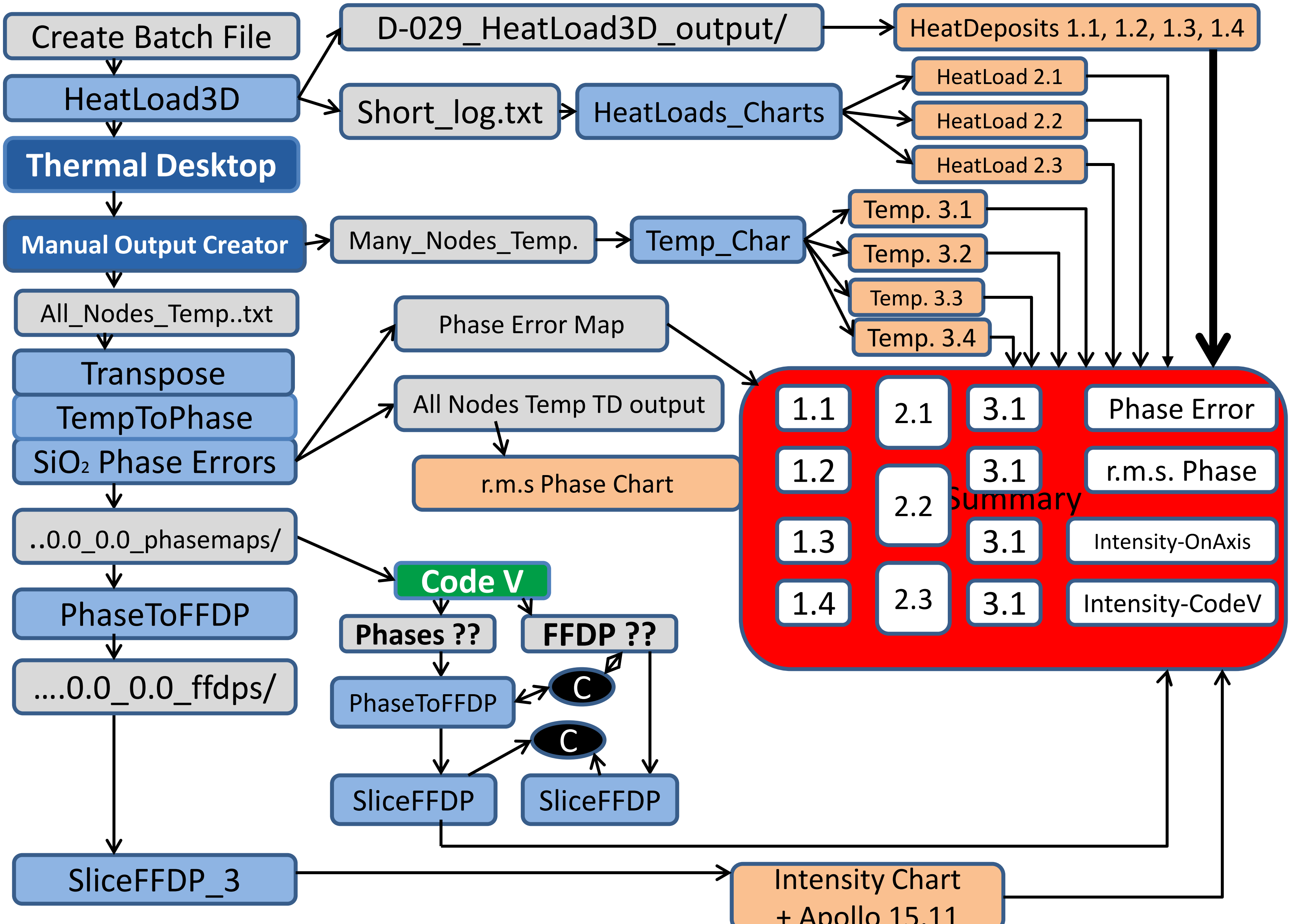
LLRRA-21 Thermal/Optical Simulation



Thermal Simulations
Program Structure
Heat Loads to Temperature Distribution

- This is Performed by Thermal Desktop
- Inputs to Program are:
  - Heat Loads from HeatLoad3D (IDL)
  - Solar Input due to Absorption on the Exterior of Package
  - Accounts for Changing Sun Angle through a Lunation
  - Temperature Evolution of Radiation from the Regolith
- Radiation of exterior and CCR top Space
- Heat Exchange among the Various Components
- Finally Results in a 3D temperature Distribution in CCR

LLRRA-21 Thermal/Optical Simulation

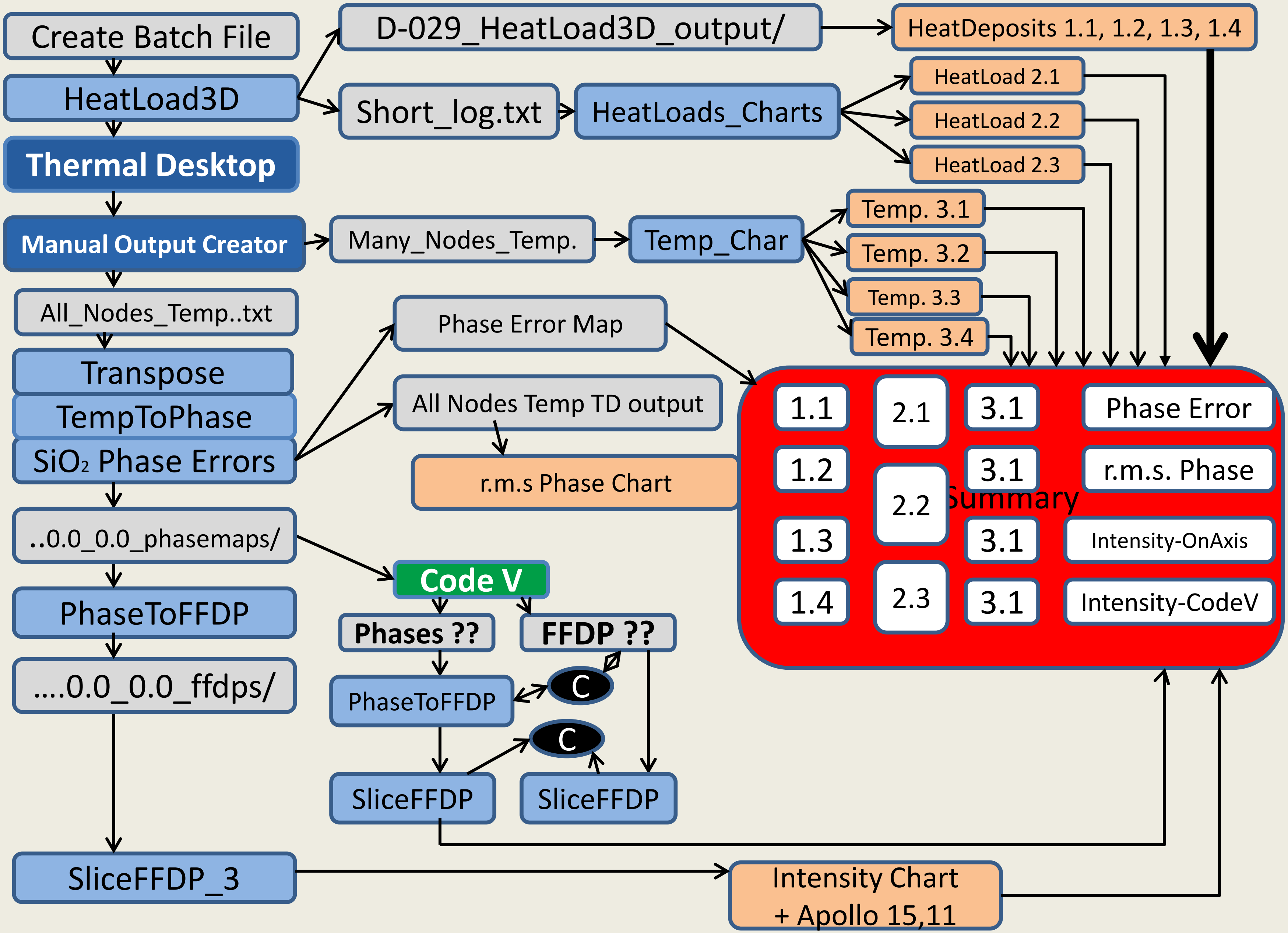


Program Structure

Temperature Distribution to Phase Error Map

- Convert from Thermal Desktop Mesh to IDL Mesh
- Trace 1000 rays through the CCR with all Reflections
- At each mm Cube in the CCR along the Ray Path
  - Convert the Temperature of the mm Cube to an
  - Index of Refraction then to a Phase Delay
- Sum of Phase Delays along Each Ray
  - Results in a 2D Array of Phase Error at the Output Face
- Integrate a Typical Phase Error Map that:
  - Contains Variation of index of Refraction of the Material
  - Contains Angle Errors due to Manufacturing
- Fourier Transform of the Phase Error Map for FFDP

LLRRA-21 Thermal/Optical Simulation



Thermal Simulations Program Structure Code V for FFDP

- IDL/Thermal Desktop Addresses the Case of
  - Zero Offset Angles
  - No Phase Shift from TIR of Back Face Reflection
  - Ideal for Understanding and Optimizing Thermal
- Code V Addresses the Additional Effects of:
  - Non-Zero Offset Angles
  - Phase Shifts due to TIR

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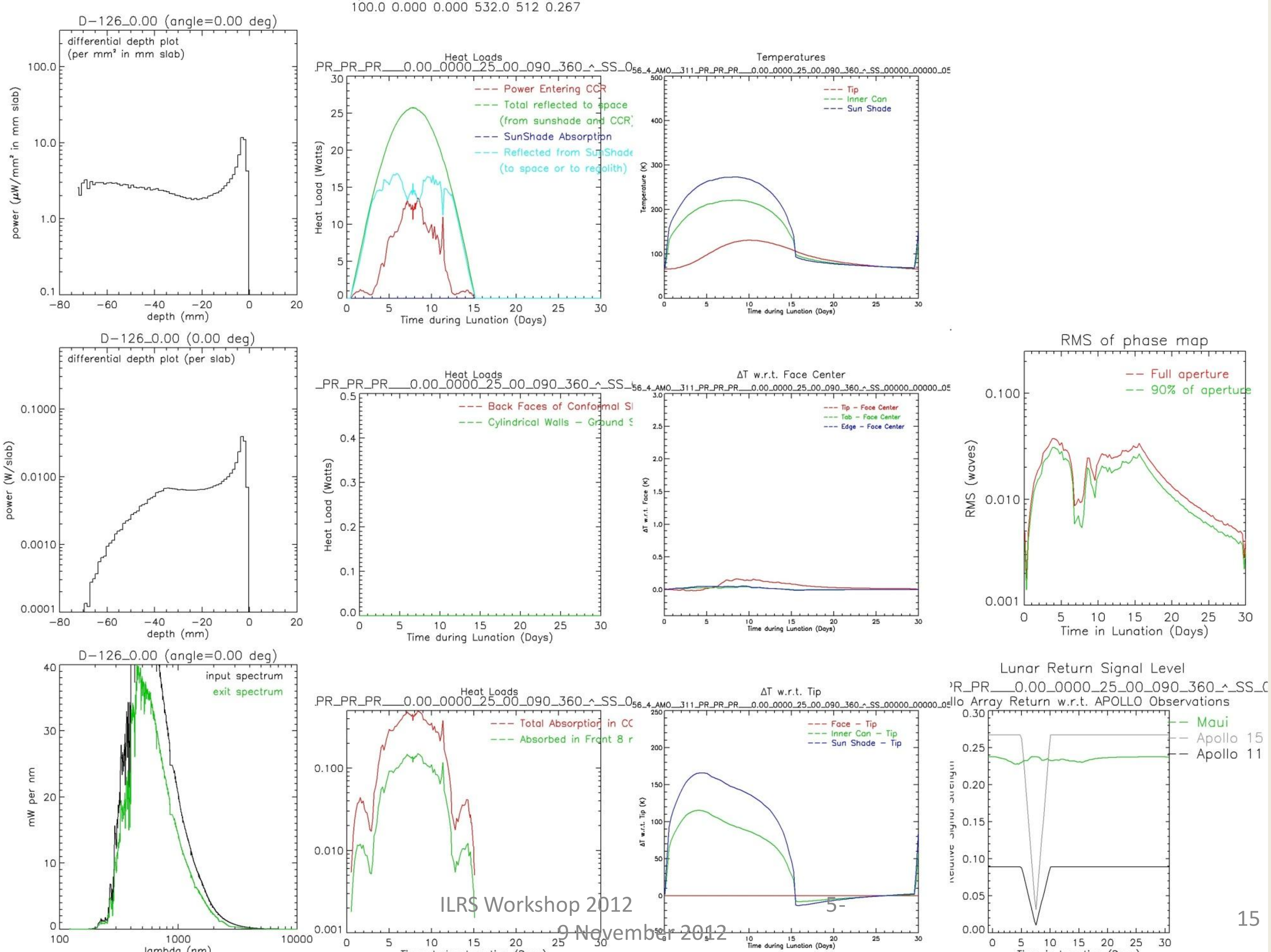

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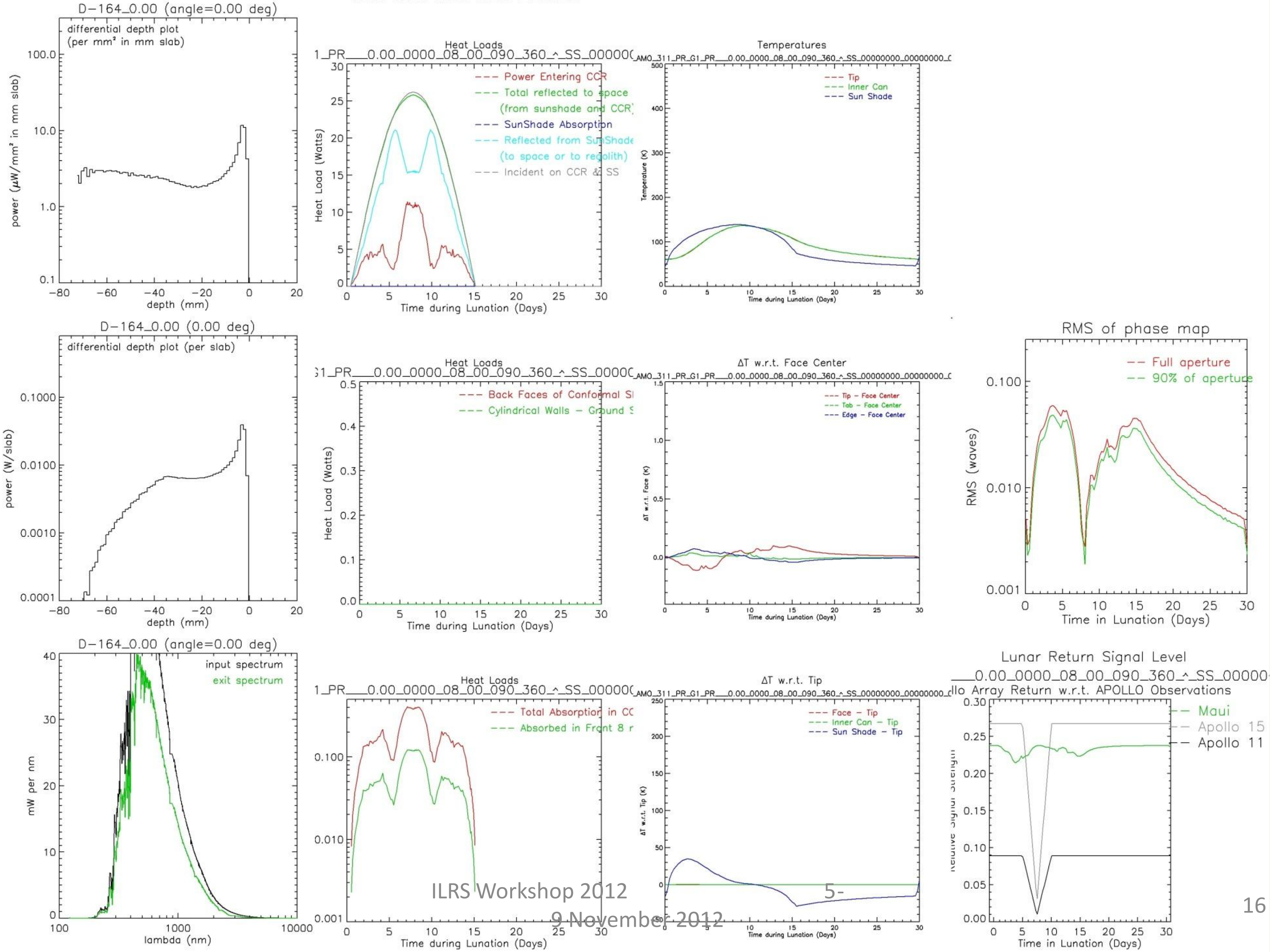


Deployment Methods

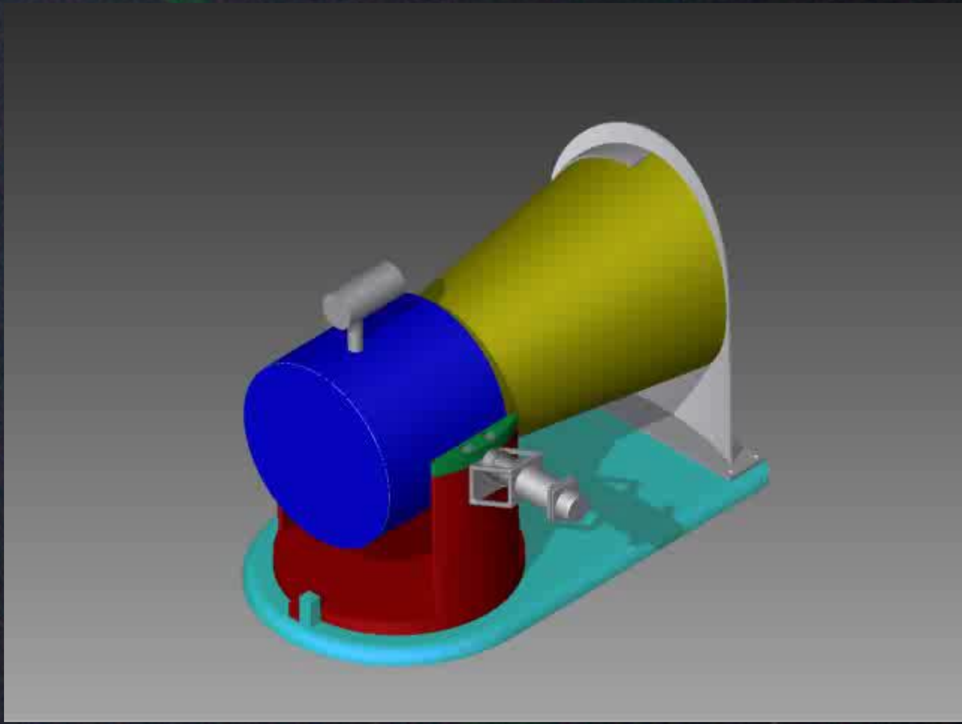
- Lander – Mounted on Instrument Platform
  - Minimizes interface Issues
  - Supports 1-3 cm Single Shot Ranging
    - Motion due to Day/Night Temperature Range
- Surface – Support Placed on Regolith
  - Requires an Arm for Deployment
  - Supports 1 mm Single Shot Ranging
- Anchored – Fixed to Regolith at ~ 1 meter
  - Requires Pneumatic drilling (HoneyBee)
  - Supports < 0.1 mm Single Shot Ranging

Deployments and Flights for LLRRA-21

- Three Methods for Lunar Deployment
  - Lander Deployment Would Support
    - Easiest
    - Day/Night Thermal Motion 1-2 cm
  - Surface Deployment Would Support
    - Needs Arm
    - Day/Night Thermal Motion 1-2 mm
  - Sub-Surface Anchored Deployment Would Support
    - Needs Pneumatic Drilling (Honeybee)
    - Day/Night Thermal Motion < 100 microns
- Possible Flights Currently being Investigated
  - Moon Express – a Google Lunar X Prize Team
  - ESA Lunar Lander – Under Consideration by Ministerial Council

Pointing Requirements

- Need to Point to Center of Libration Pattern
  - About +/- 1 degree
- Landers Lack this Accuracy in Landing Orientation
- LLRRA-21 Needs an Automatic Pointing System
- CMOS Camera for Alignment
- Needs Only a Start Pulse
- Operational Sequence
  - Point to Zenith
  - Take a Camera Exposure
  - Fit Earth Image (On-Board)
  - If Missing -Search off Zenith
- Lock Brakes

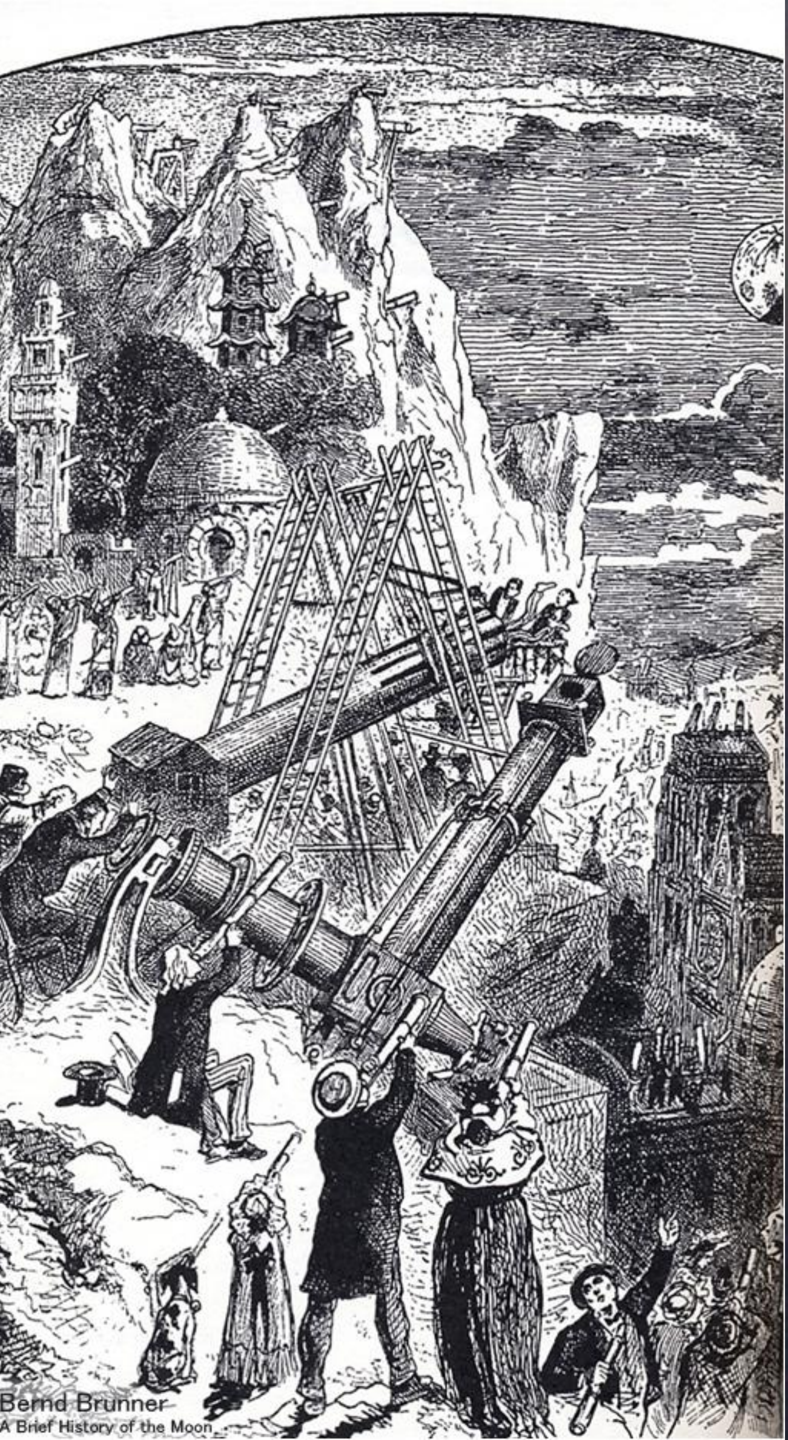


INTERNATIONAL COLLABORATIONS

- INFN-LNF and the University of Maryland
- Recently Signed Agreement between
  - Japan Aerospace Exploration Agency (JAXA)
  - National Astronomical Observatory of Japan (NAOJ)
  - INFN-LNF at Frascati and the
  - University of Maryland
- Current Discussions with
  - European Space Agency
  - Their Lunar Lander

New Science for LLRRA-21

- Ranging Accuracy Improve by factor of 10 to 100
- Enable Multiple Stations to Join Ranging Team
- Evaluate Theories that Address QM-GR Problem
  - Evaluate Alternative Relativity Theories
  - Strong Equivalence Principle - SEP
  - Change of Gravitational "Constant"
  - Temporal (<<1%) and Spatial
- Lunar Physics
  - Core Mantle Properties
  - Inner Solid Core



INFN

Thank You!

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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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