SAND2010-4302P

Information Exchange with PWR

June 22, 2010

Sandia Optical Analyses and Testing for Heliostats and Central Receiver Systems

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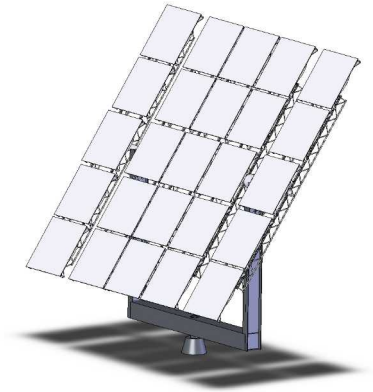
Overview

- Optical Codes
- Analysis of PWR Modules
- Analysis of Gravity Sag
- Analysis of Wind Loading
- Summary

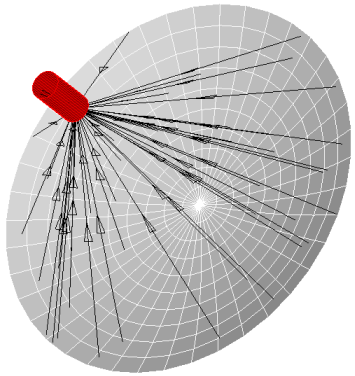
Optical Analysis Codes

Heliostat



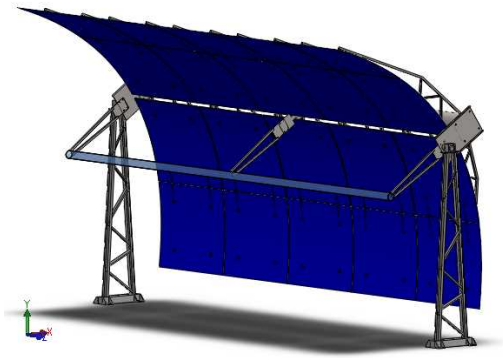
- **MIRVAL**
  - Ray tracing; flux from entire heliostat field; not supported
- **HELIOS**
  - Cone optics; flux from entire heliostat field; not supported
- **DELSOL**
  - Hermite polynomials; flux from entire heliostat field; optimization; energy output
- **ASAP**
  - Commercial ray-tracing code

Dish



- **CIRCE**
  - "Daughter" of HELIOS; cone optics; flux distribution within receiver
- **ASAP**
  - Commercial ray-tracing code

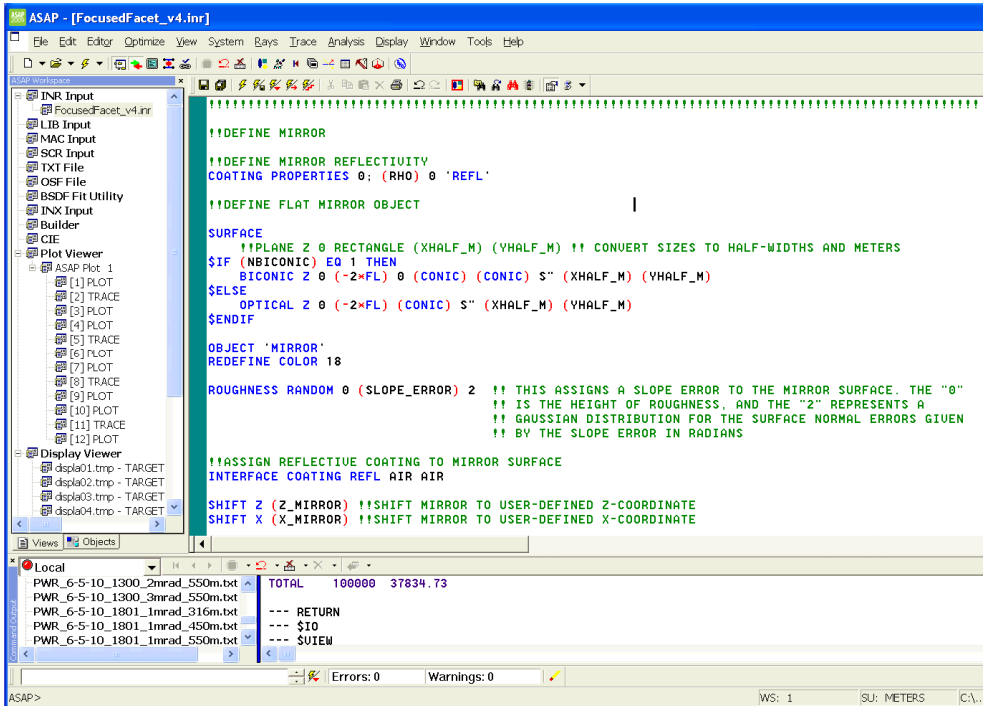
Parabolic Trough

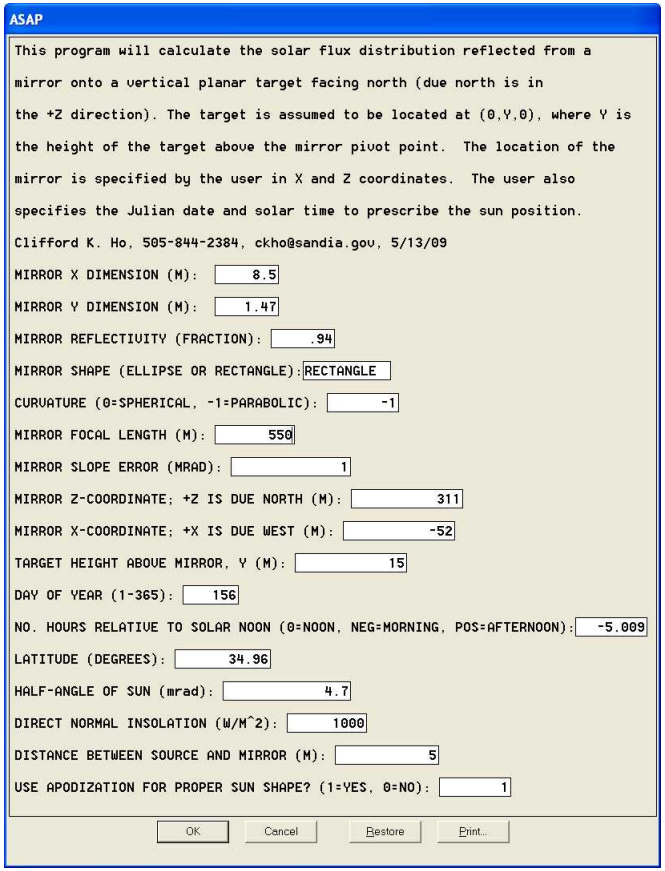


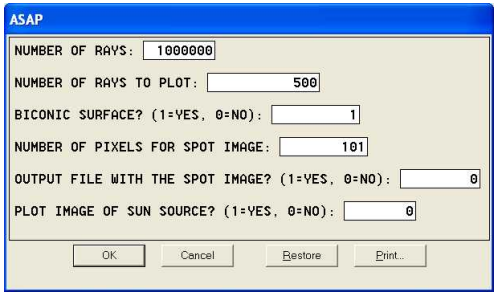
- **TROUGH_HELIOS**
  - Trough version of HELIOS; cone optics
- **ASAP**
  - Commercial ray-tracing code

ASAP Code

- **Primary customer is automotive industry**
- **Powerful scripting interface**
- **CAD import**







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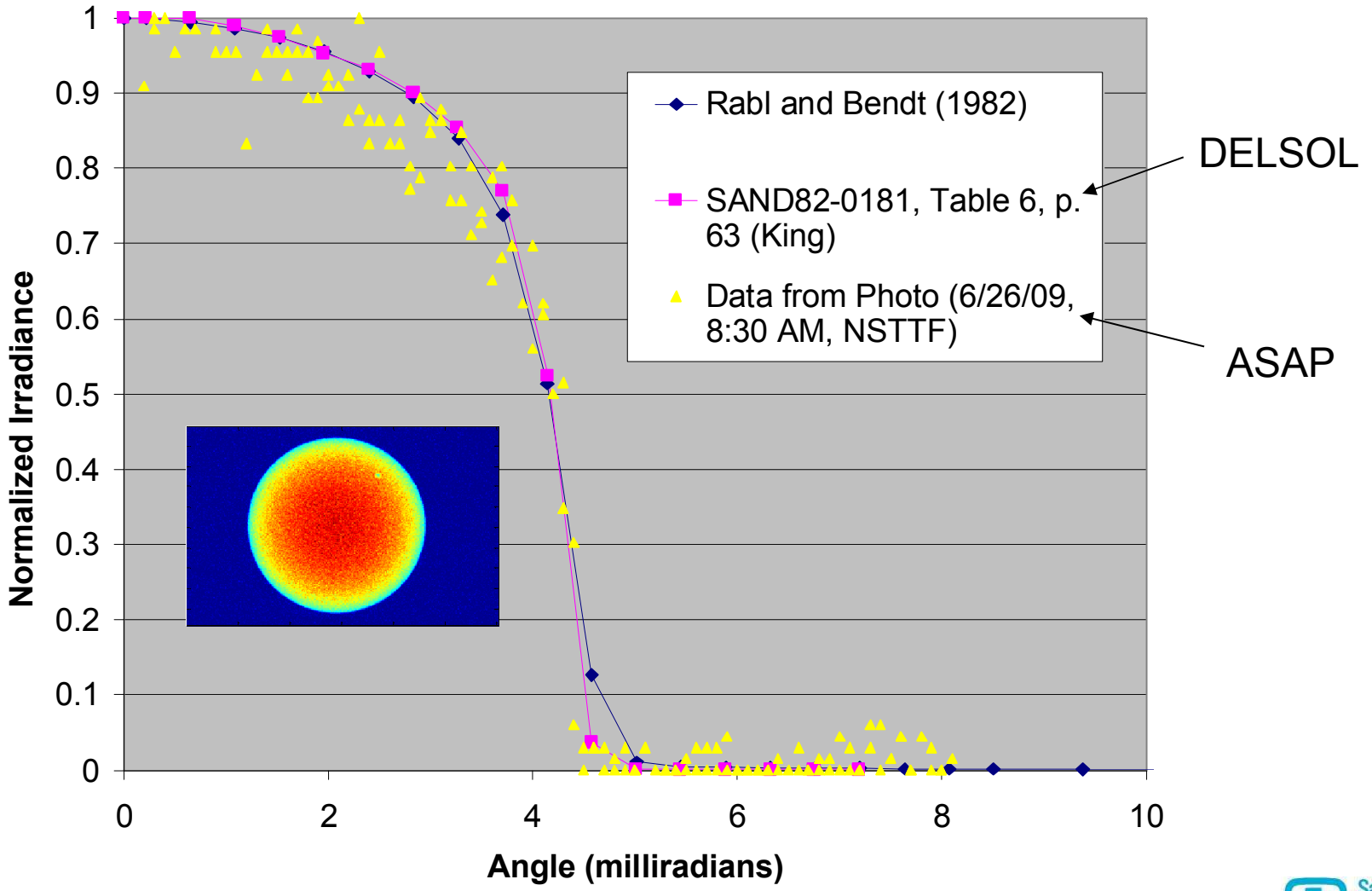
Sun Shape and Apodization



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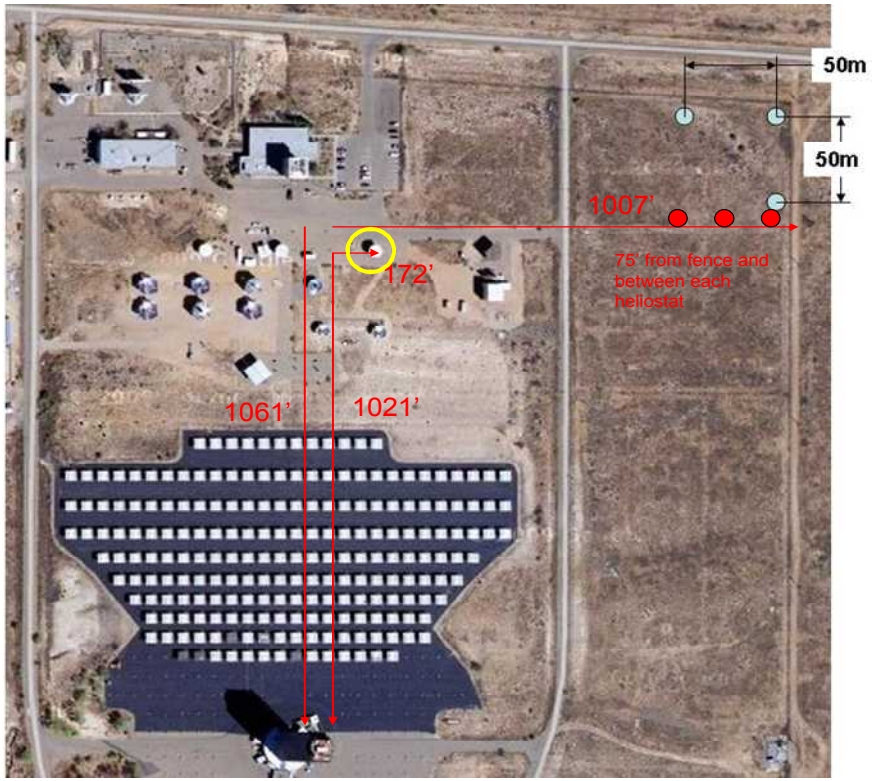
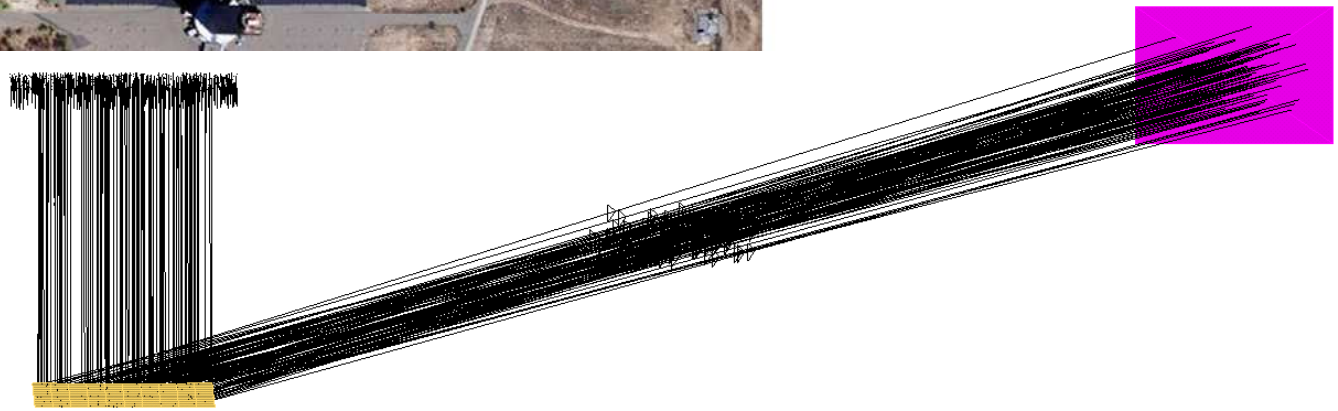
Single Mirror Module

Single Mirror Module



- **June 5, 2010**
  - All day test with single mirror module
  - Compared beam flux distribution with ASAP and DELSOL
    - 8:04 AM, 1:00 PM, and 6:01 PM (MDT)



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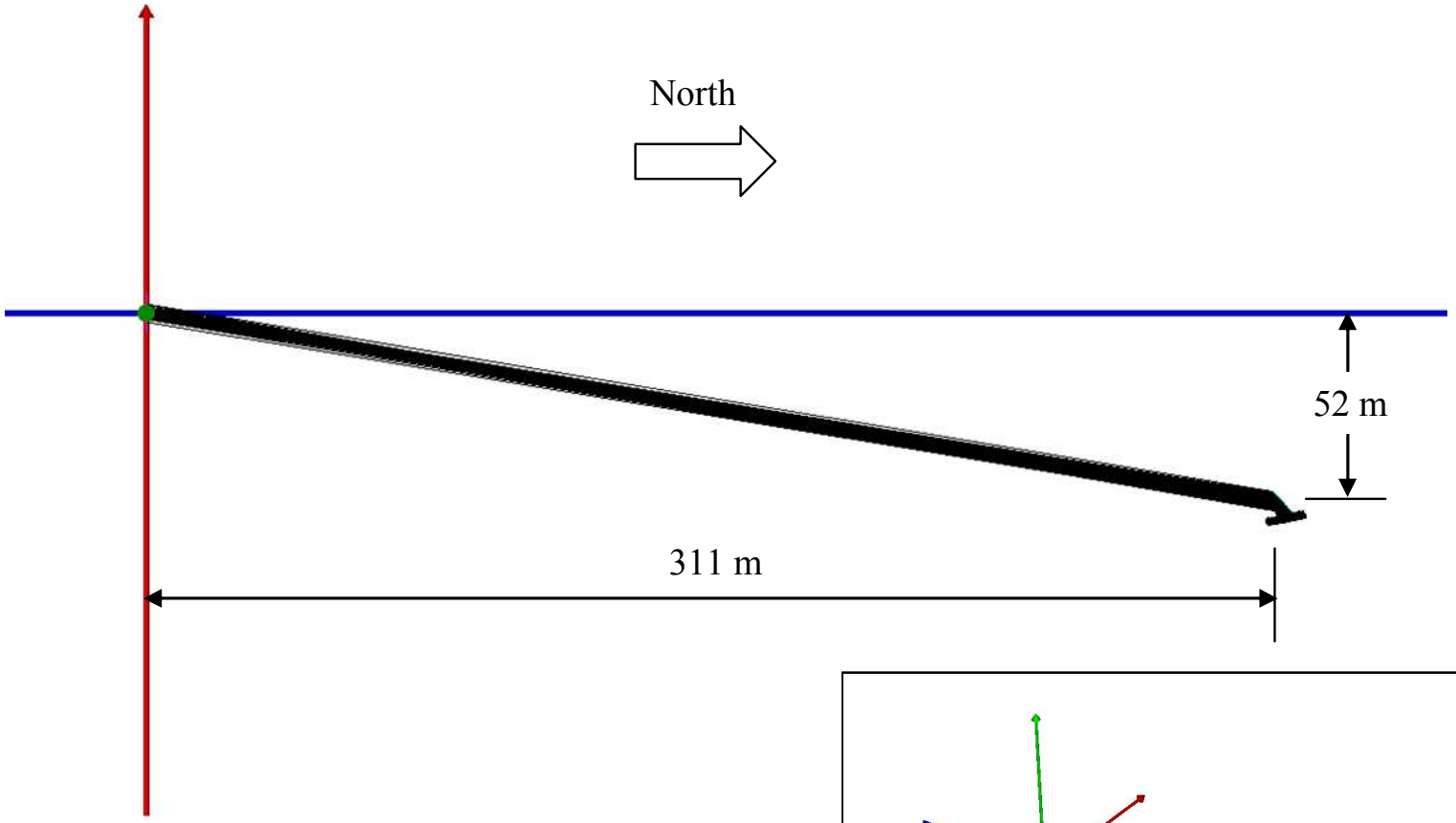
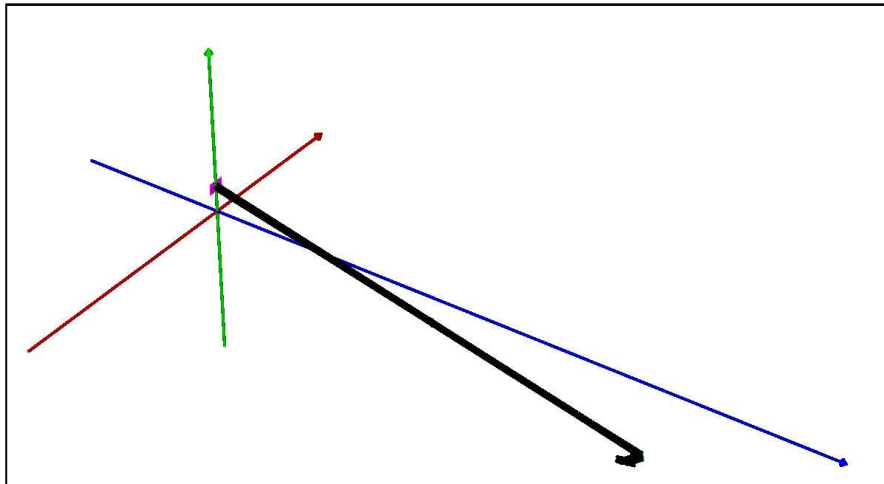
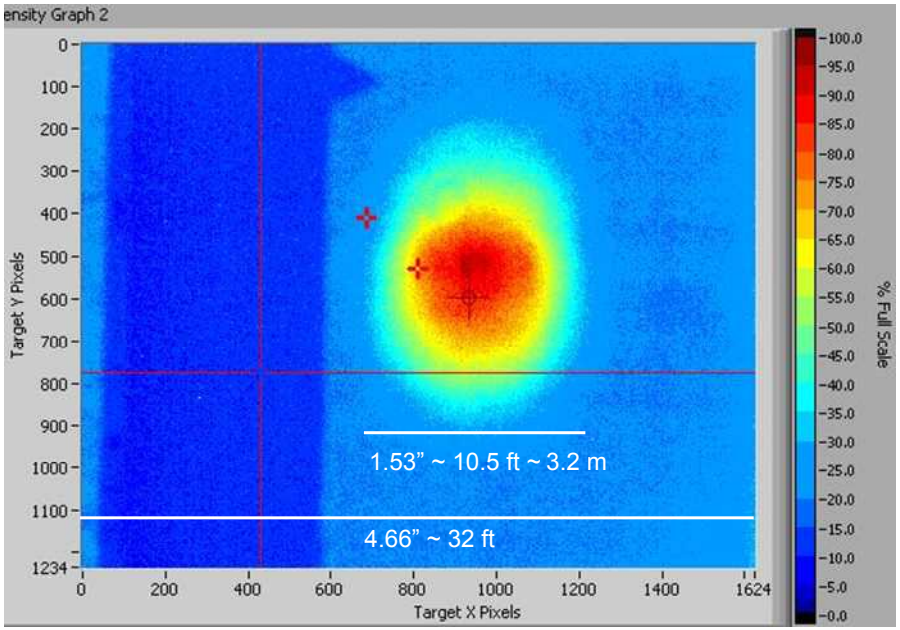
8:04 AM, June 5, 2010



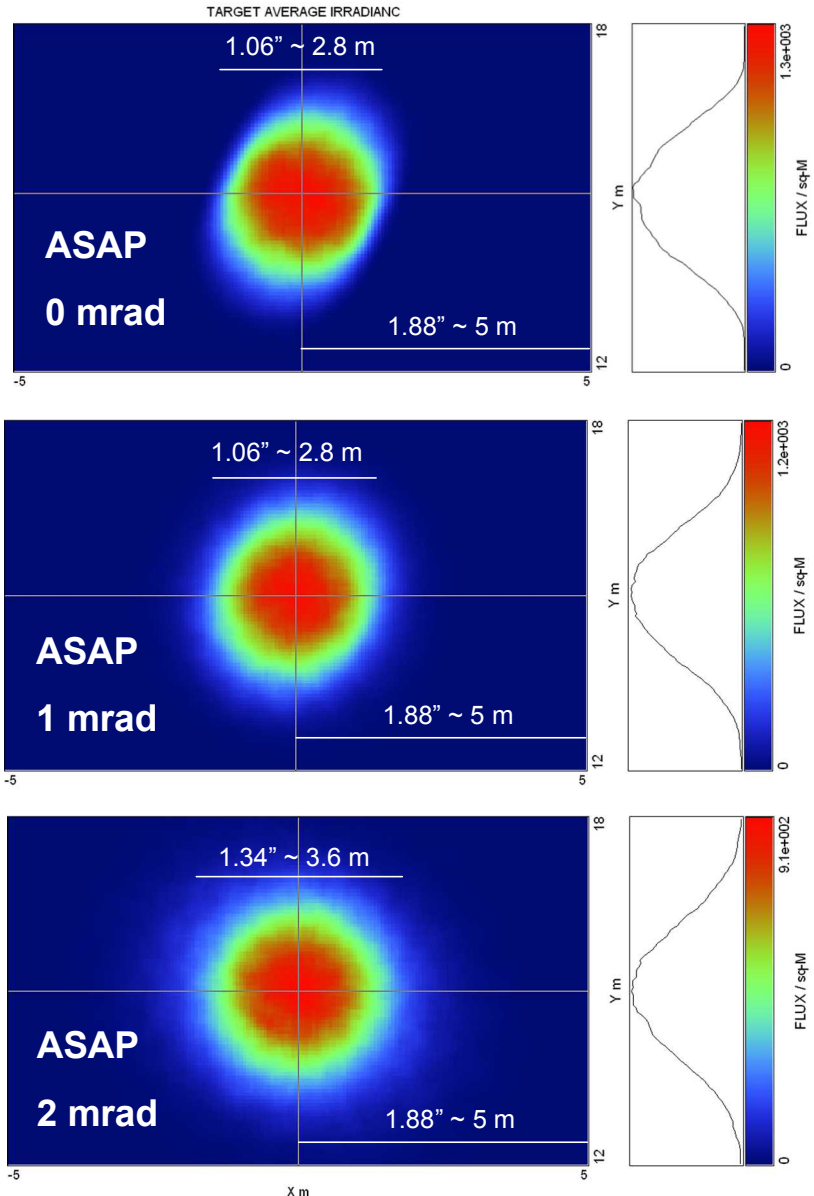


8:04 AM, June 5, 2010

550 m focal length
Slant range to tower = 316 m



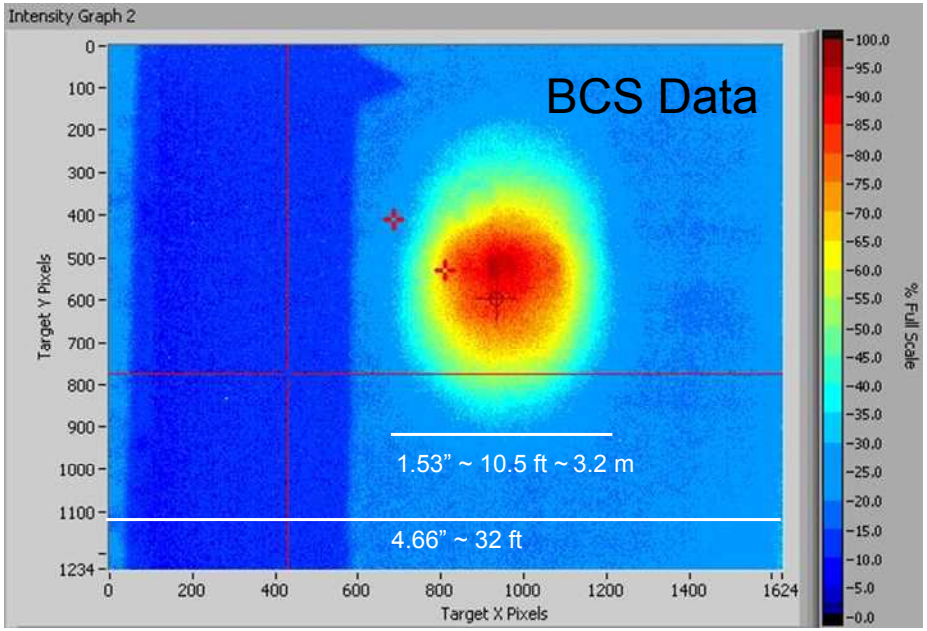
BCS Data



Different RMS slope errors in ASAP

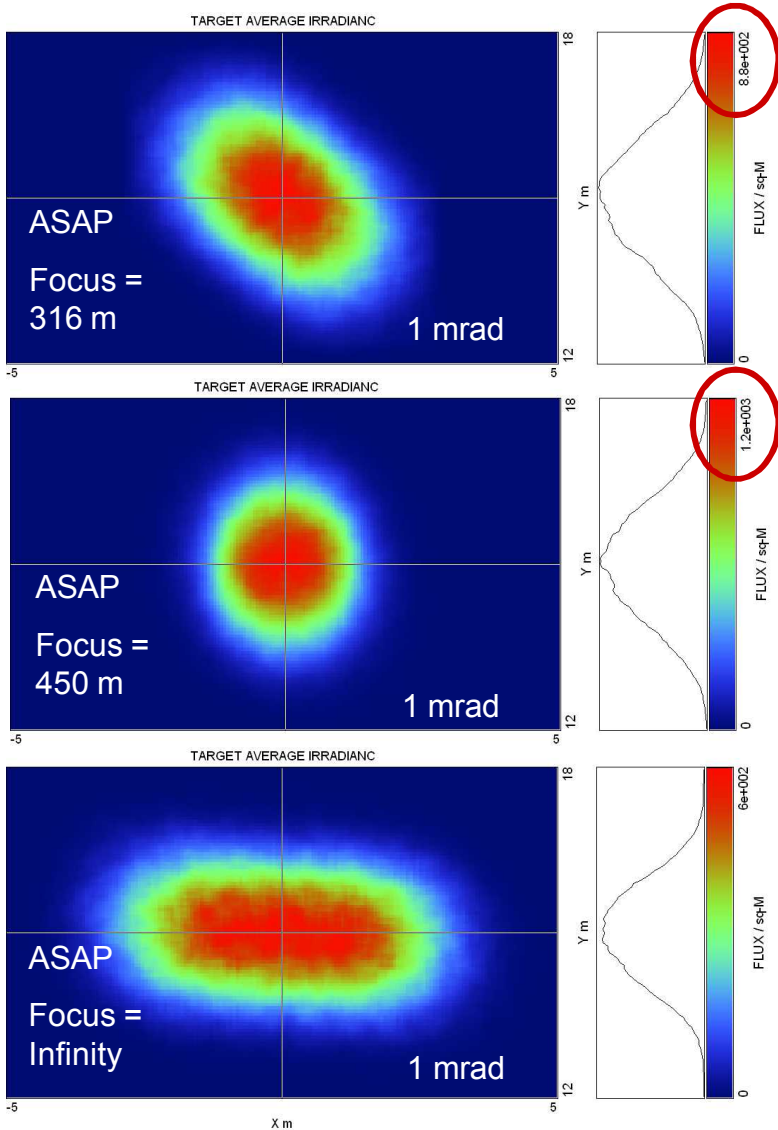
8:04 AM, June 5, 2010

Slant range to tower = 316 m

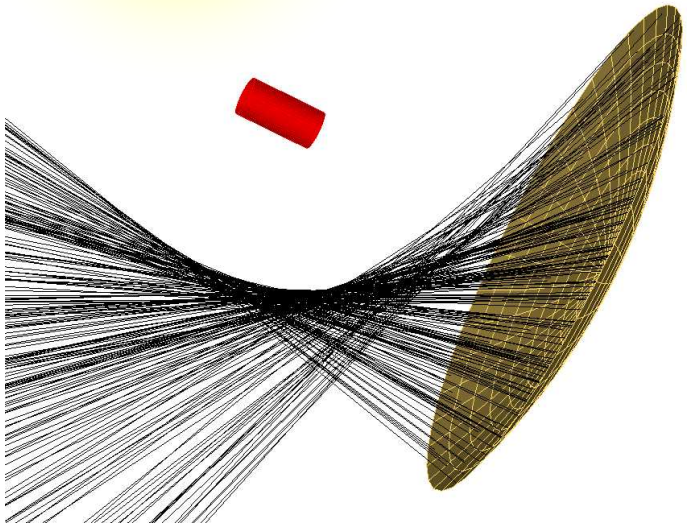


- **Shape of beam when mirror is angled sharply provides indication of true focal length**
- **Peak flux not always highest when focal length equals slant range**

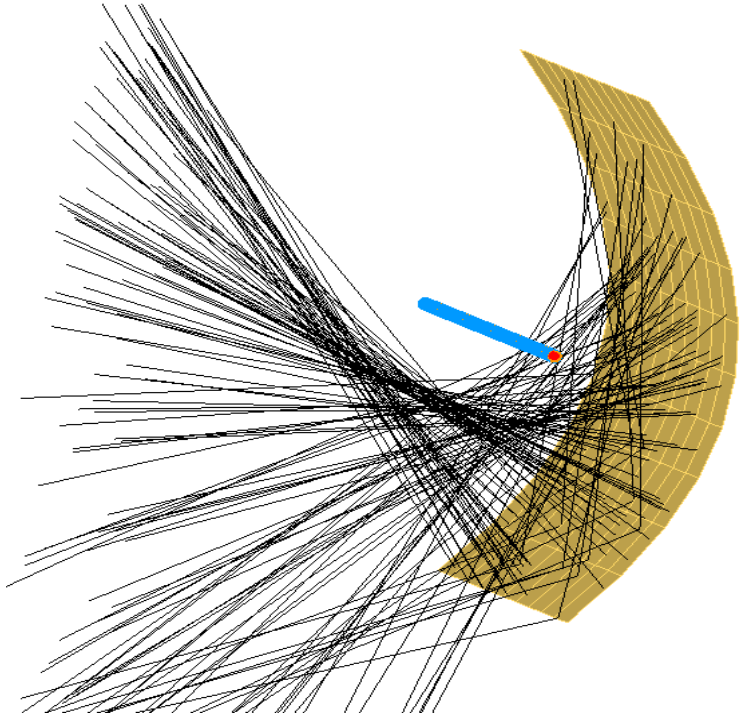
Different focal lengths in ASAP



Optical Aberrations

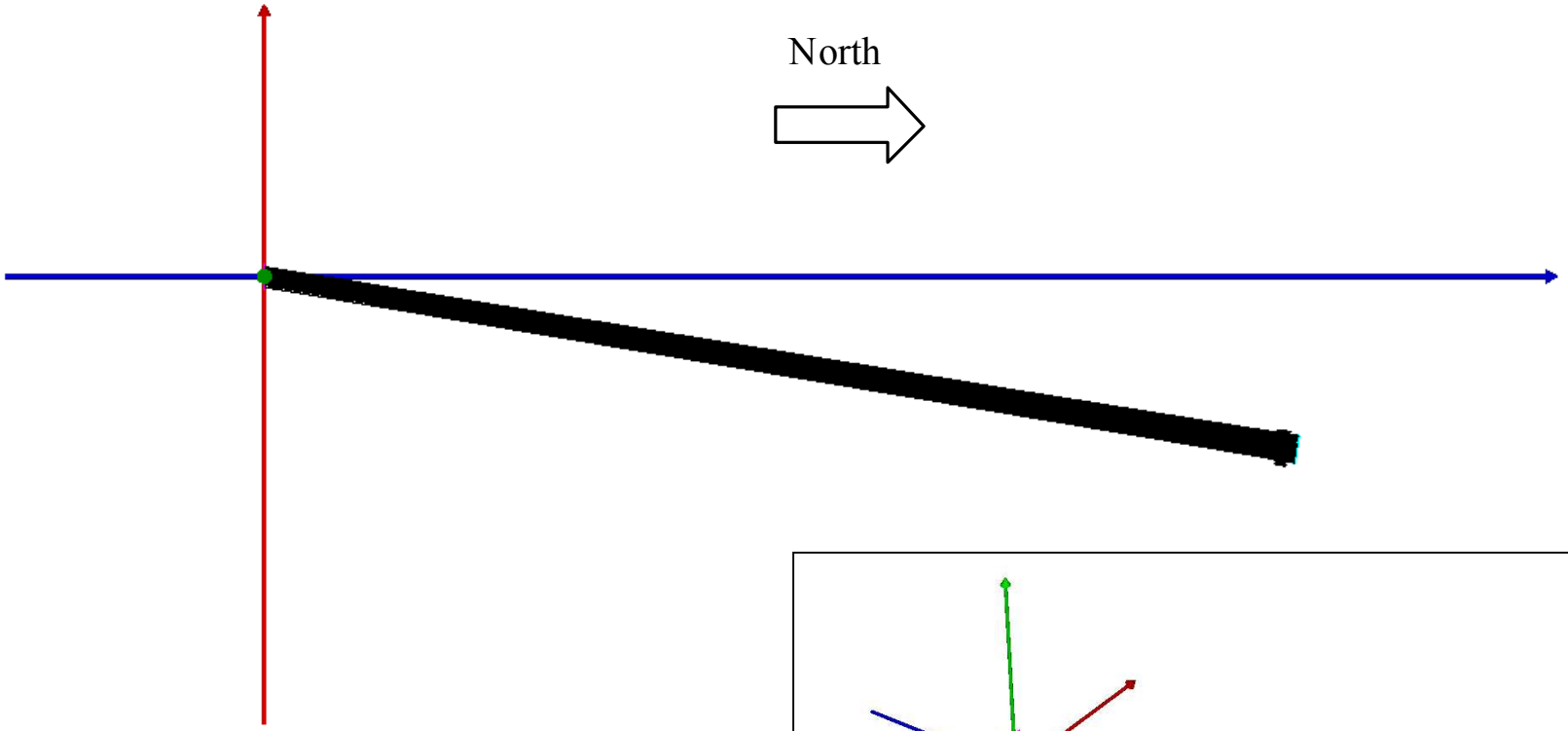


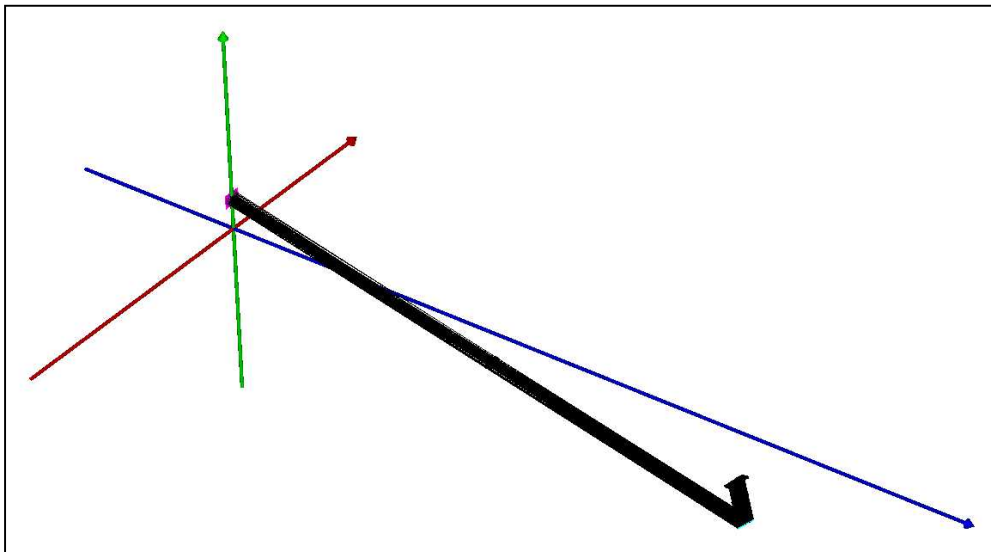
Off-axis Dish



Off-axis Trough

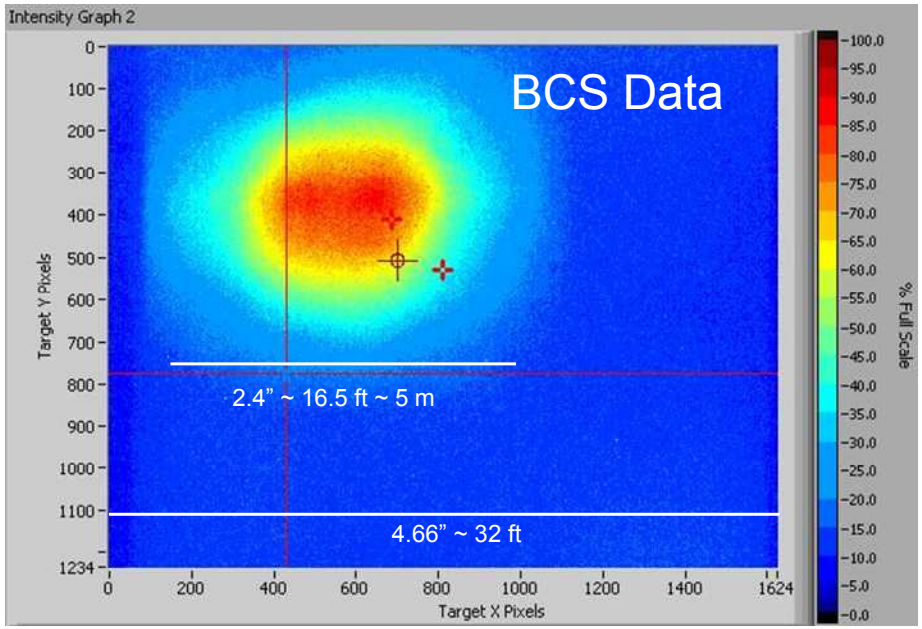
1:00 PM, June 5, 2010





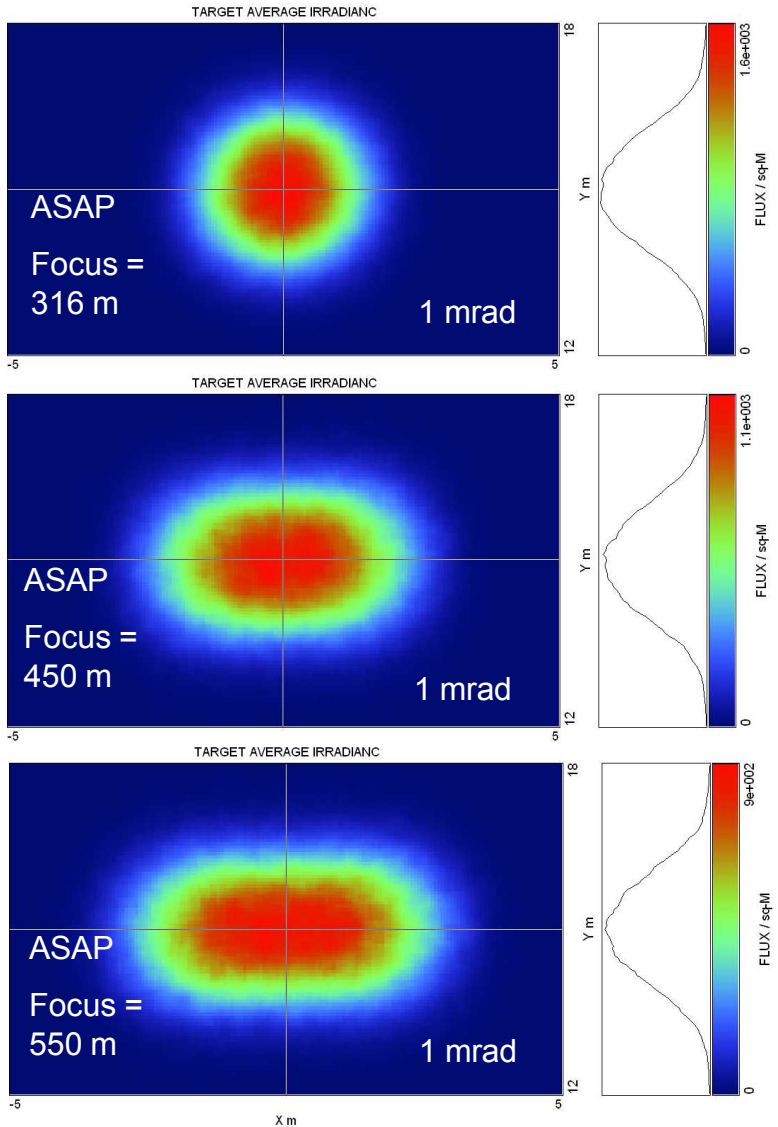
1:00 PM, June 5, 2010

Slant range to tower = 316 m

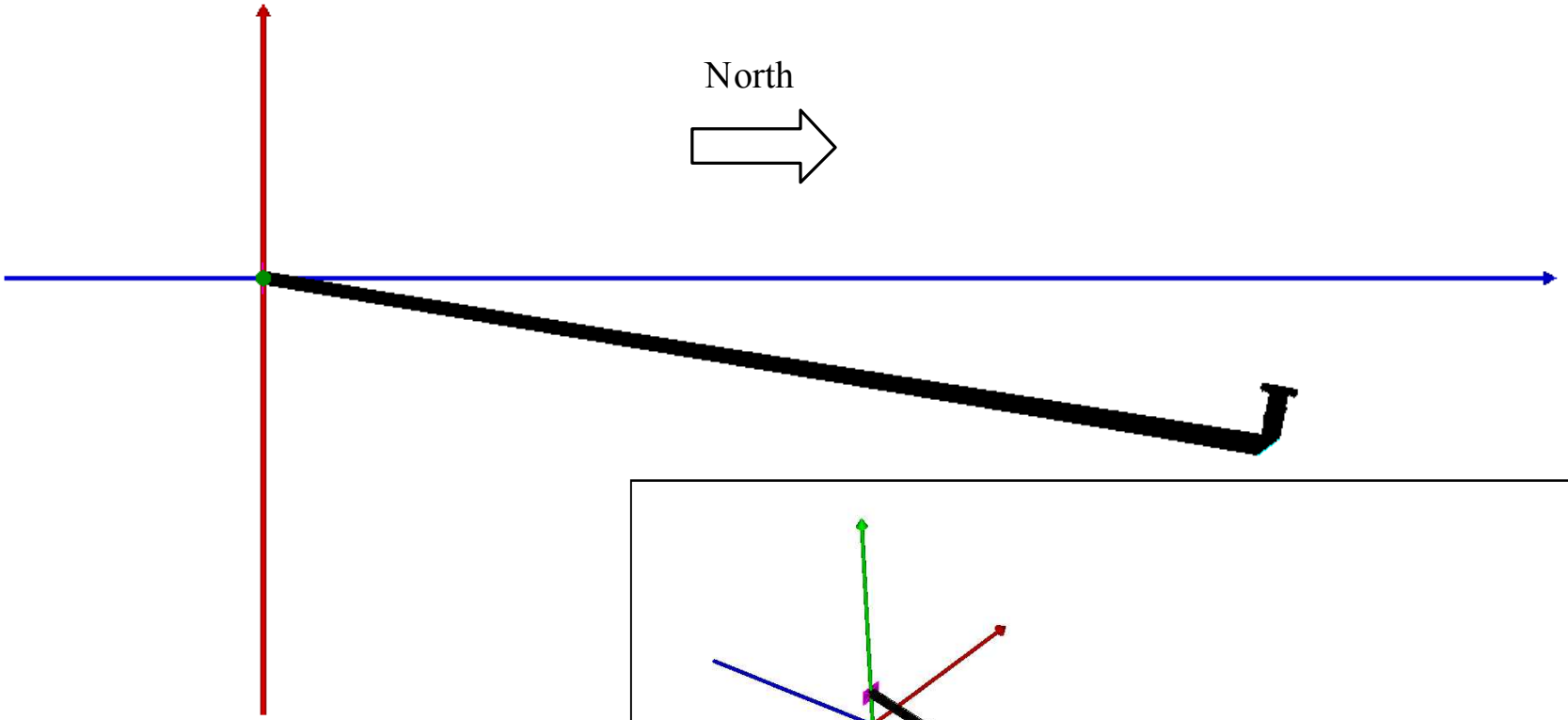


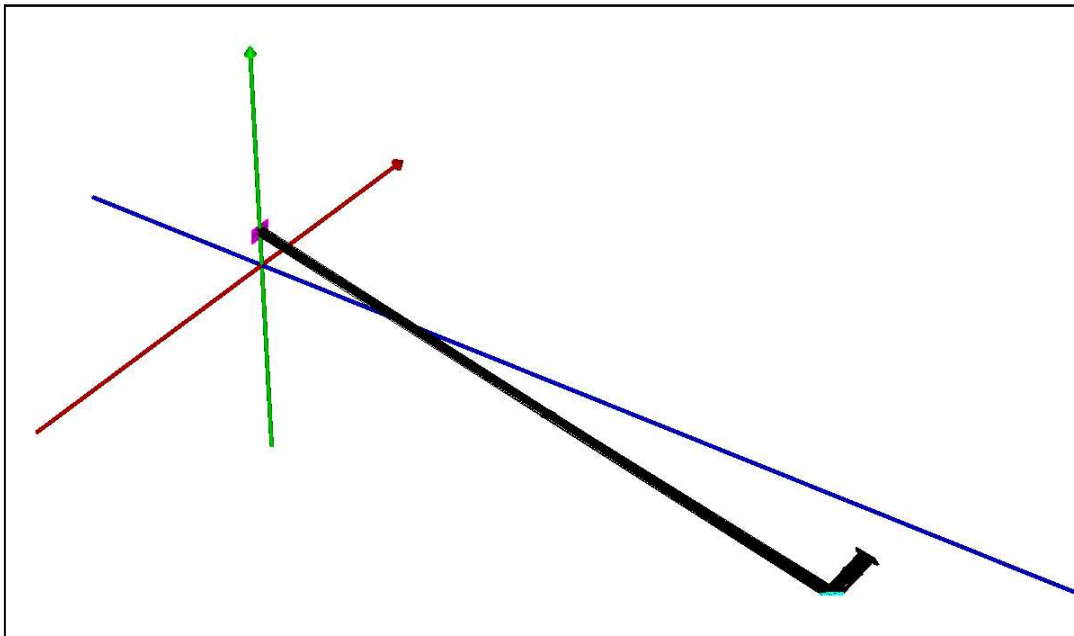
- **Actual focal length of modules appears to be less than 550 m**
  - Consistent with module profiles shown in June 10 peer-review presentation (slides 52 and 53)

Different focal lengths in ASAP



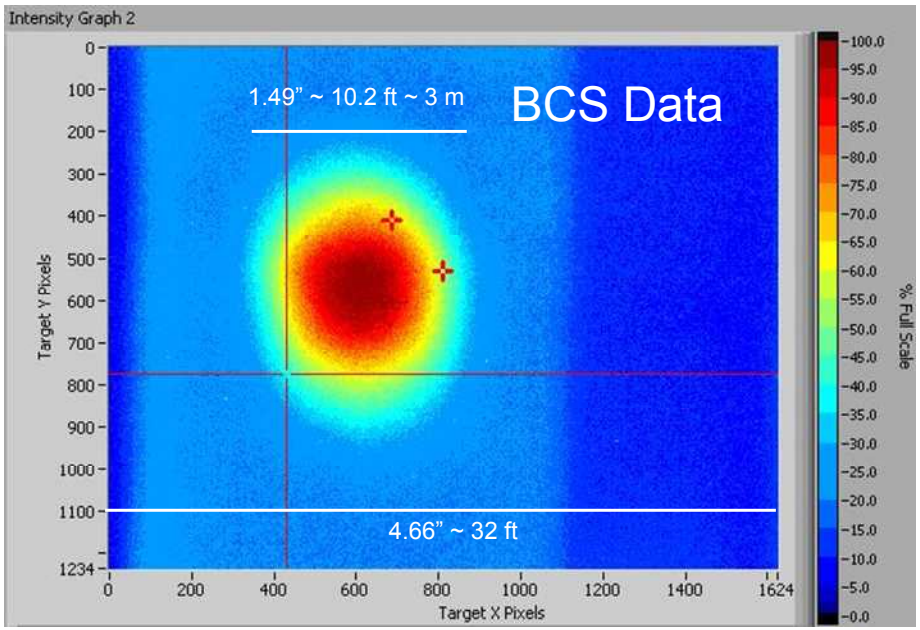
6:01 PM, June 5, 2010



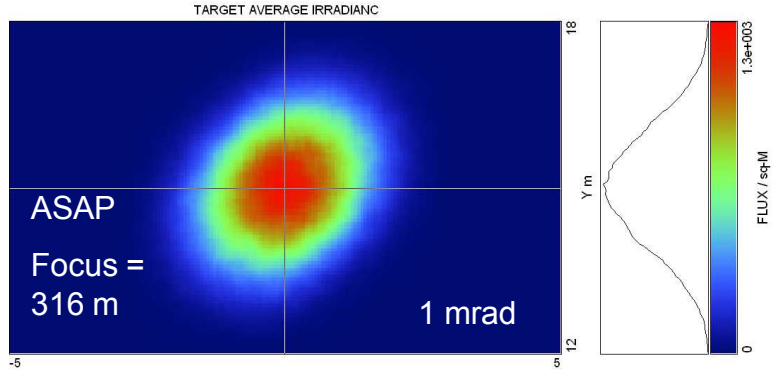


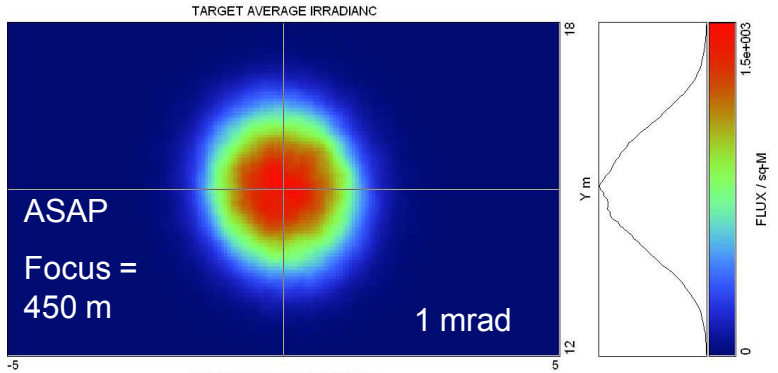
6:01 PM, June 5, 2010

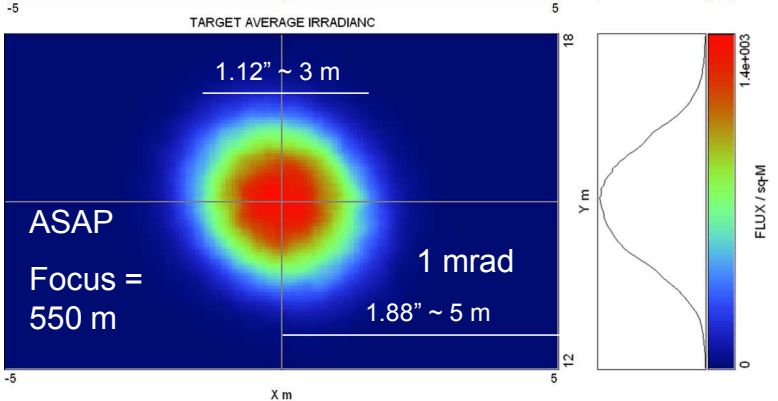
Slant range to tower = 316 m



Different focal lengths in ASAP

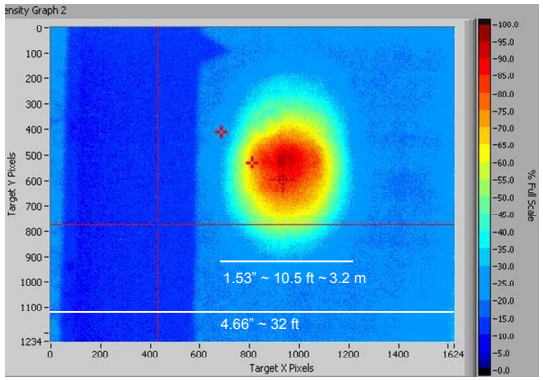




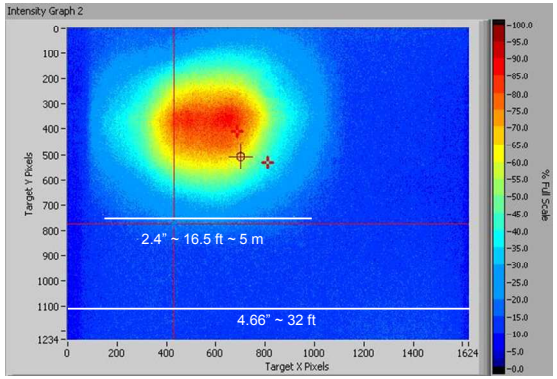


Comparison of Peak Fluxes

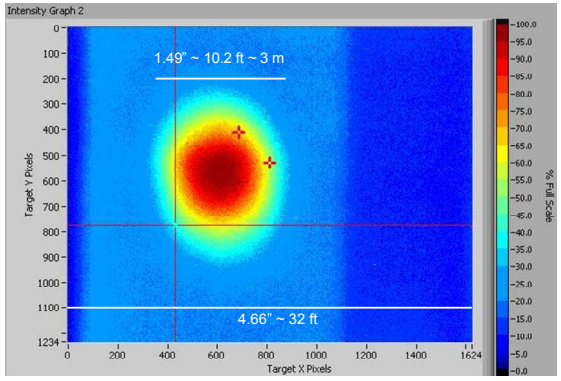
8:04 am
DNI=850 W/m^2



1:00 PM
DNI=990 W/m^2



6:01 PM
850 W/m^2



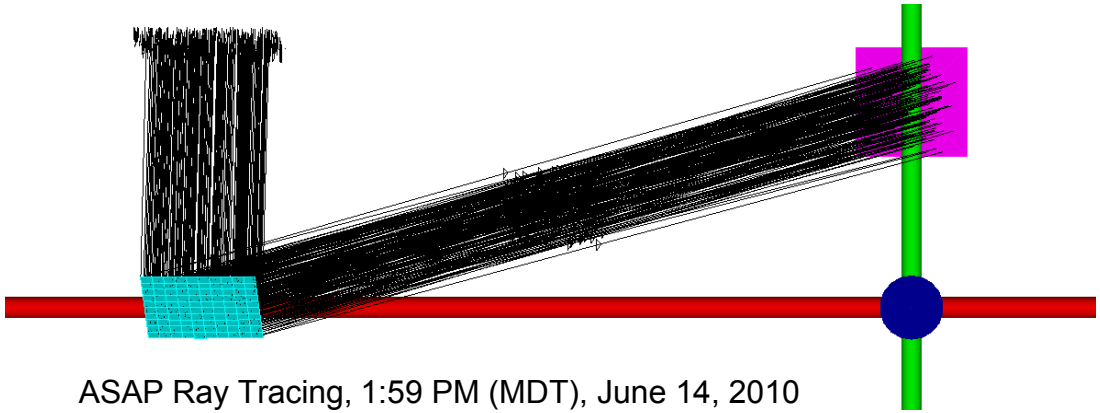
- BCS images all taken with same f-stop (f/8)
  - Measured peak fluxes appears consistent with predictions

Predicted Peak Flux (suns) 550 m focal length		
Time	**ASAP**	**DELSOL***
8:04 AM	**1.2**	**1.1**
1:00 PM	**1.0**	**0.89**
6:01 PM	**1.4**	**1.2**

*Included atmospheric attenuation (0.963)

Four Modules

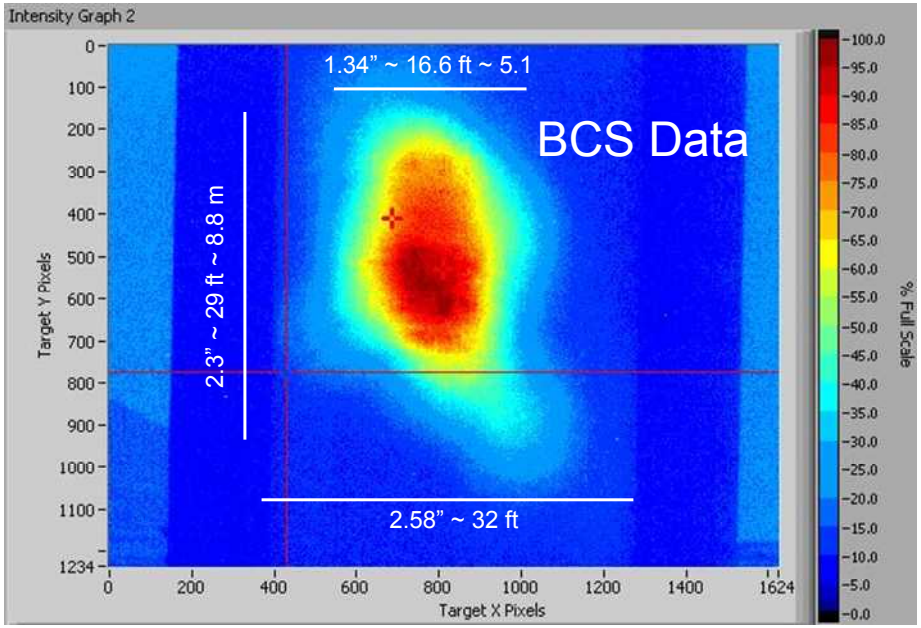
June 14, 2010



ASAP Ray Tracing, 1:59 PM (MDT), June 14, 2010

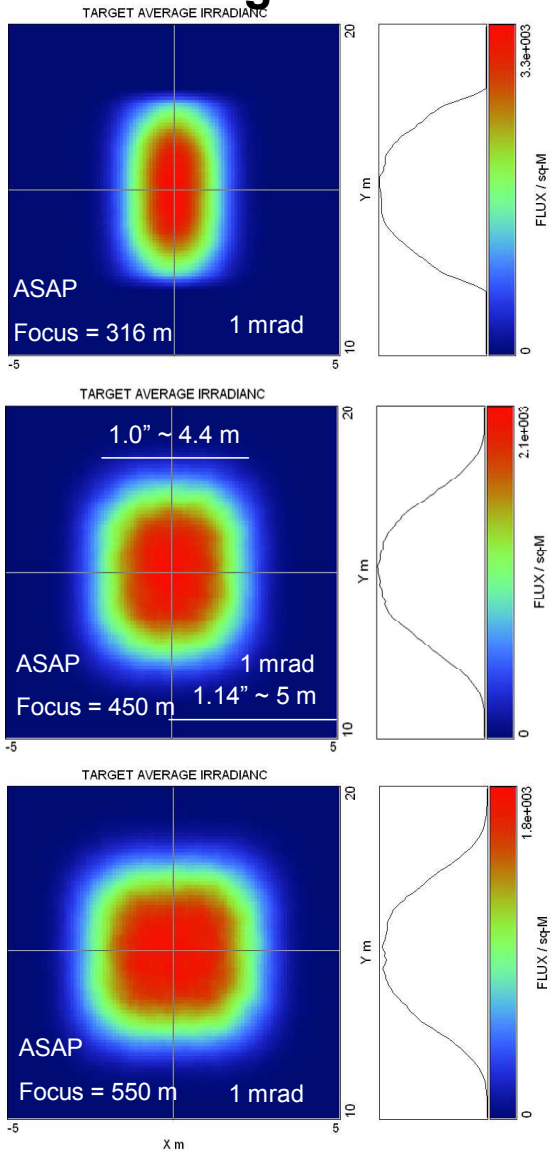
1:59 PM (MDT), June 14, 2010

Slant range to tower = 316 m



BCS Data, 1:59 PM (MDT), June 14, 2010 (F/10)

Different focal lengths in ASAP



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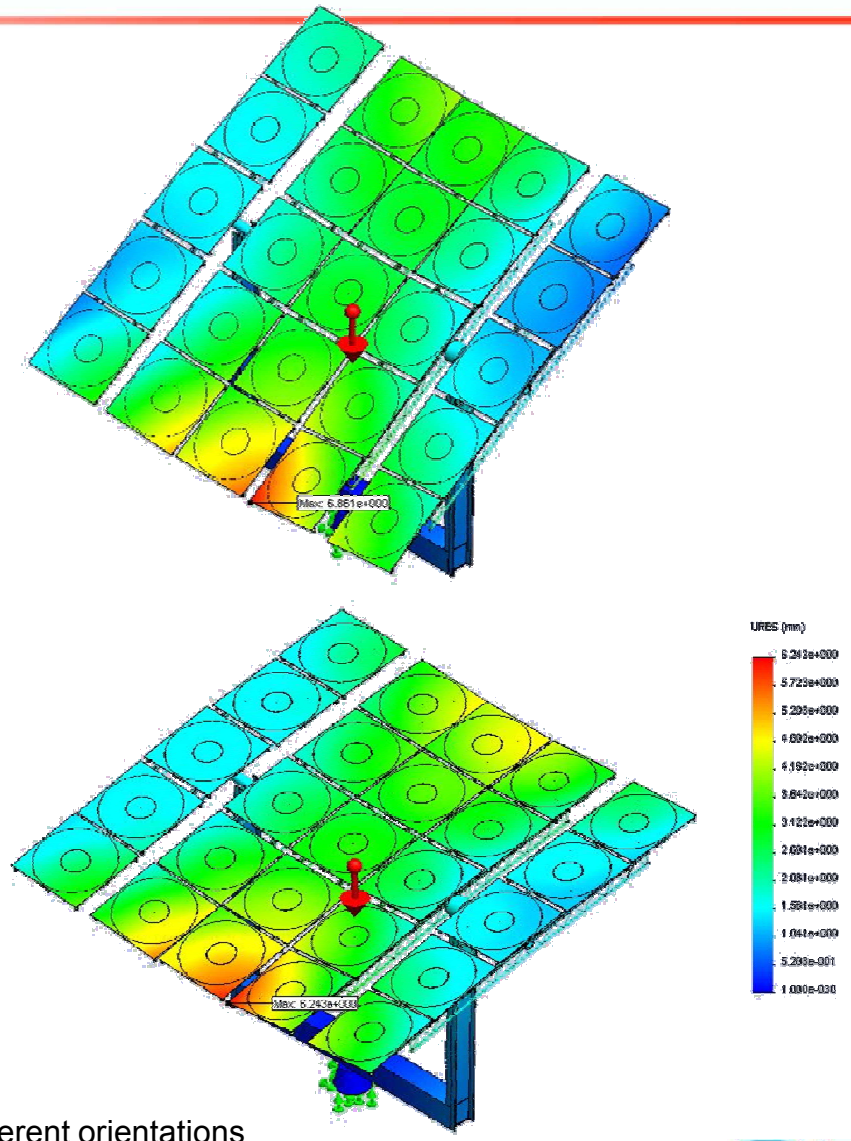
Gravity Sag

- **Integrate deformed shapes from gravity loads into ray-tracing analysis**
  - Sun shape and limb darkening
  - Slope errors at multiple scales
    - Small-scale distortions
    - Larger-scale errors from loads



Gravity-induced deformation of NSTTF heliostat in different orientations

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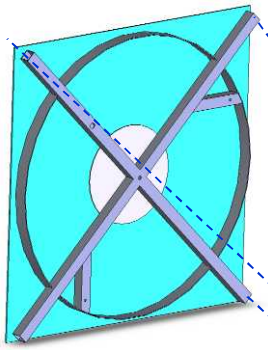
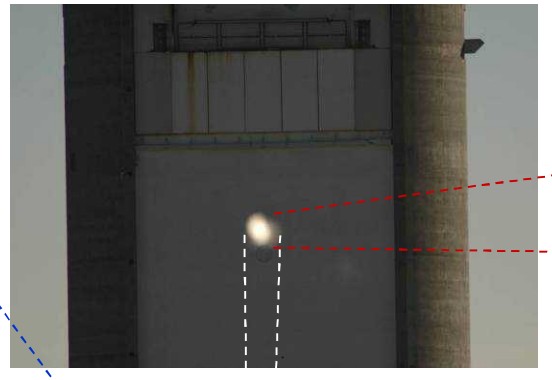
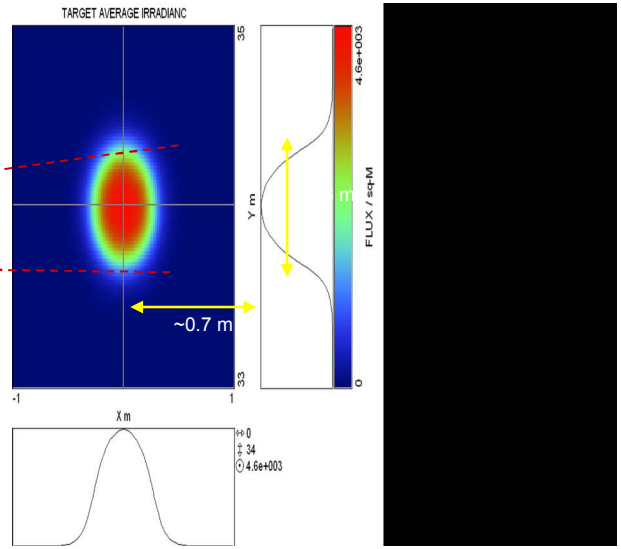
Single Facet Testing for Model Validation



Test



Model



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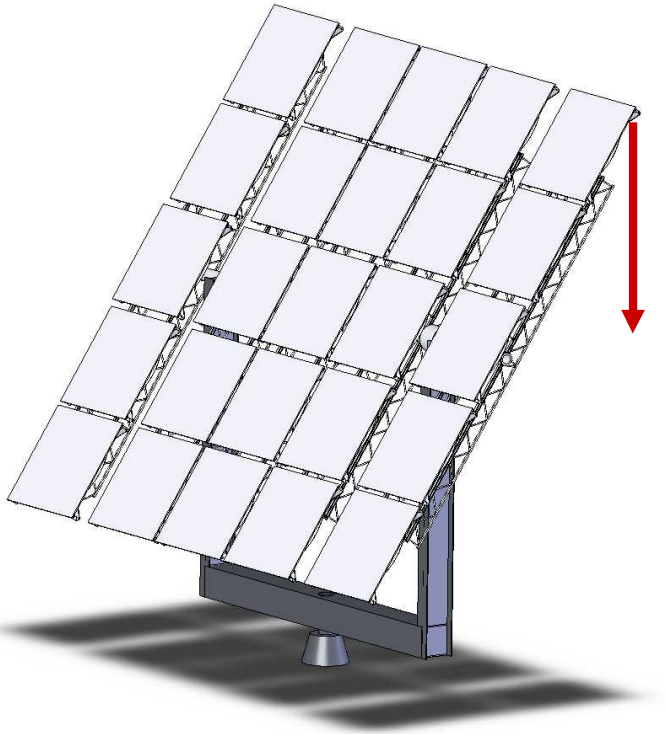
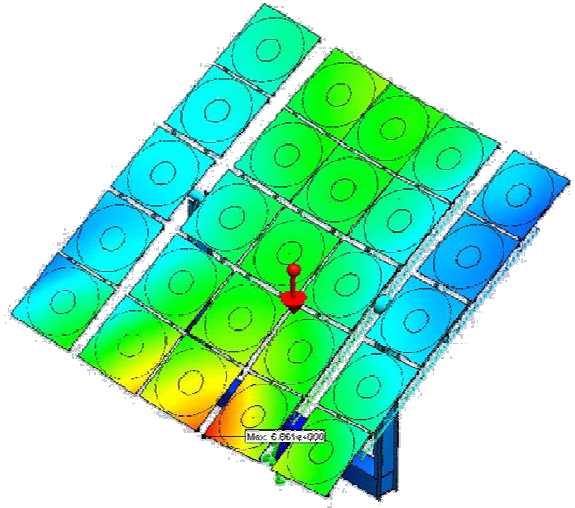
Static Loading Test



- **Hang weights from heliostats in different orientations**
  - Measure displacements and compare to models



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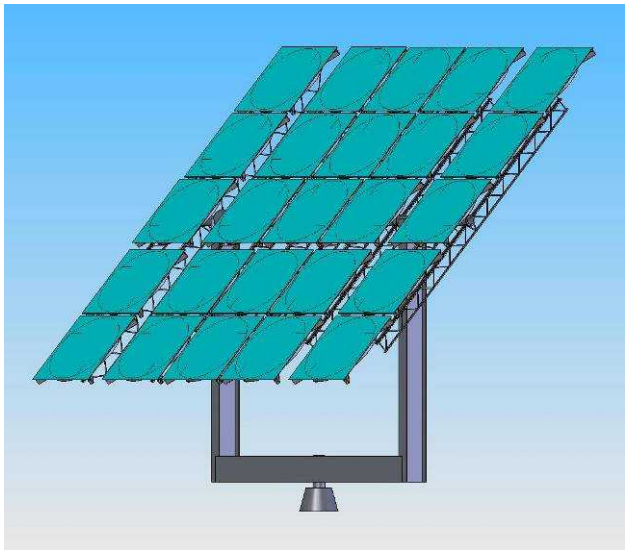
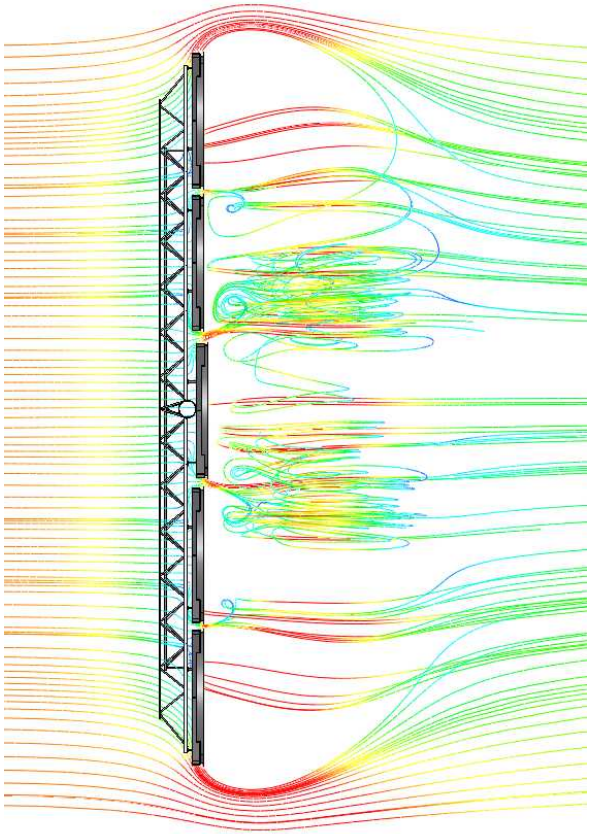
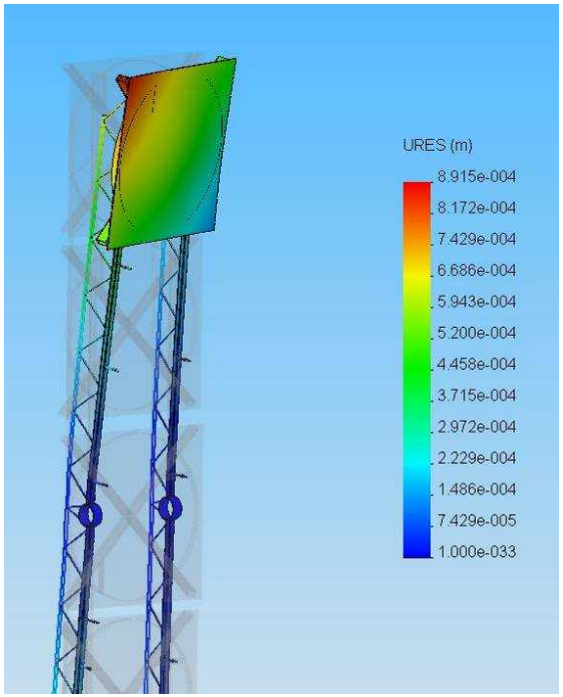
Static Wind Loading



3D Solidworks model of heliostat at Sandia



CFD simulations of flow over heliostat



FEA analysis of loads on facet

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Dynamic Analysis

- **Plan to do modal testing of NSTTF heliostats this summer**
  - Instrument heliostat with accelerometers, strain gauges
  - Validate models through modal analysis
- **Instrument numerous heliostats at NSTTF for dynamic wind-response tests**
  - Accelerometers, strain gauges, pressure sensors
  - Record environmental variables (wind speed direction, temperature, etc.)
  - Glean information regarding field response (e.g., interior vs. perimeter)
  - Apply methods and analyses to other heliostat fields

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Summary

- **Sandia has several optical and system performance codes to analyze heliostats and central receivers**
  - DELSOL, ASAP, HELIOS, MIRVAL
  - Incorporating FEA and CFD into optical analysis
- **Testing to validate models**
  - Static loading
    - Individual facets or heliostats
  - Dynamic testing
    - Modal testing and analysis of entire heliostat
    - Instrumentation of heliostats for dynamic wind analysis