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A Flux Mapping Method for Central Receiver Systems

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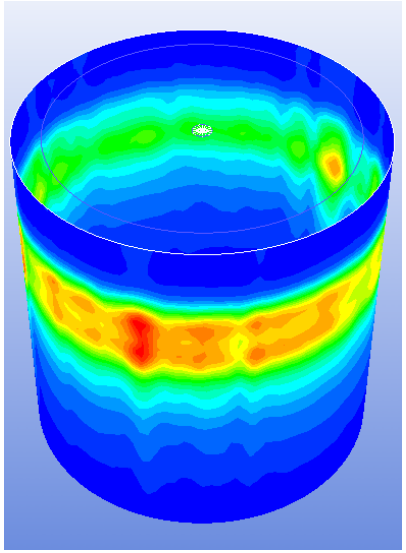
Overview

- Introduction
- PHLUX Method
- Testing and Validation
- Web-Based PHLUX Tool
- Summary

Introduction

- **Need tools for industry and R&D to characterize concentrated solar flux on receiver**
  - Monitor receiver performance
  - Assess heliostat tracking
  - Improve designs

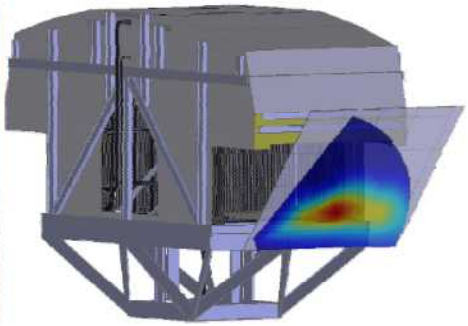
Receiver testing at the National Solar Thermal Test Facility at Sandia National Laboratories

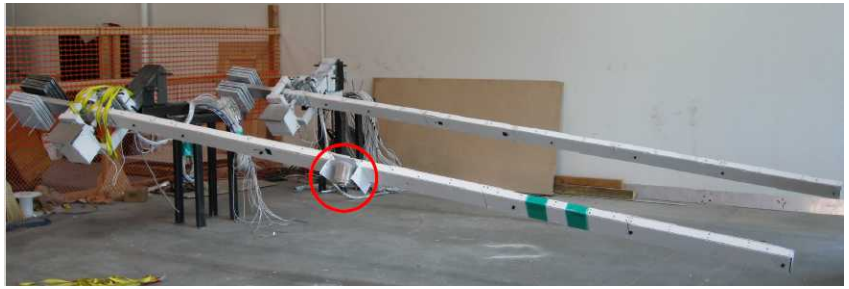


Simulated flux on a cylindrical receiver

Background

- **Existing methods can be costly and difficult to implement**
  - Flux gauges, mechanical wands, or costly infrared cameras
  - Scaling digital images with known power
    - Complex for non-planar surfaces or when spillage occurs





from Yogev et al., eSolar (SolarPACES 2009)

Projecting a beam from a heliostat onto the face of the tower

Objective

- **Develop accurate flux-mapping tool that is less expensive and simpler than existing methods**
- **PHLUX Method**
  - Photographic Flux Mapping Tools

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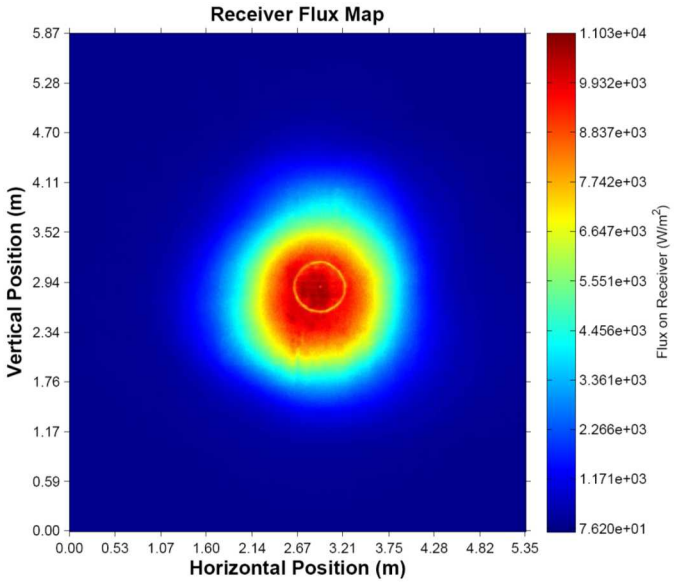
PHLUX Method

- **PHLUX Tool consist of:**
  - A digital SLR camera
    - Photo of the sun
      - Scaling (size, power)
    - Photo of the desired image
  - Algorithms/Software
    - Determines length scales and angles
    - Processes irradiance distributions of the receiver



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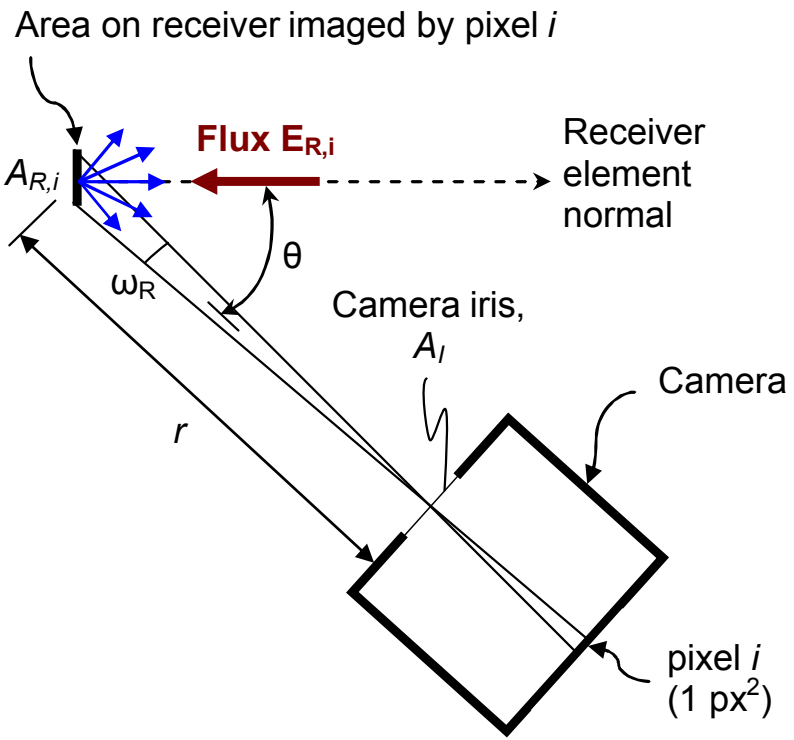
PHLUX Theory

- **Assumes a diffuse (Lambertian) receiver**
- **Each pixel value of the camera corresponds to an elemental receiver irradiance**
- **Sun image is used to scale size and power for irradiance calculations**
- **Paper contains rigorous derivation**



PHLUX Theory

Pixel value

DNI value at time sun image was recorded

Average pixel value in sun image

$$E_{R,i} = \frac{V_{CCD,i} E_{DNI}}{\rho_{R,i} \tan^2(\gamma/2)} \frac{\pi r_{sun\_pixels}^2}{\sum_{sun} V_{CCD\_sun,i}}$$

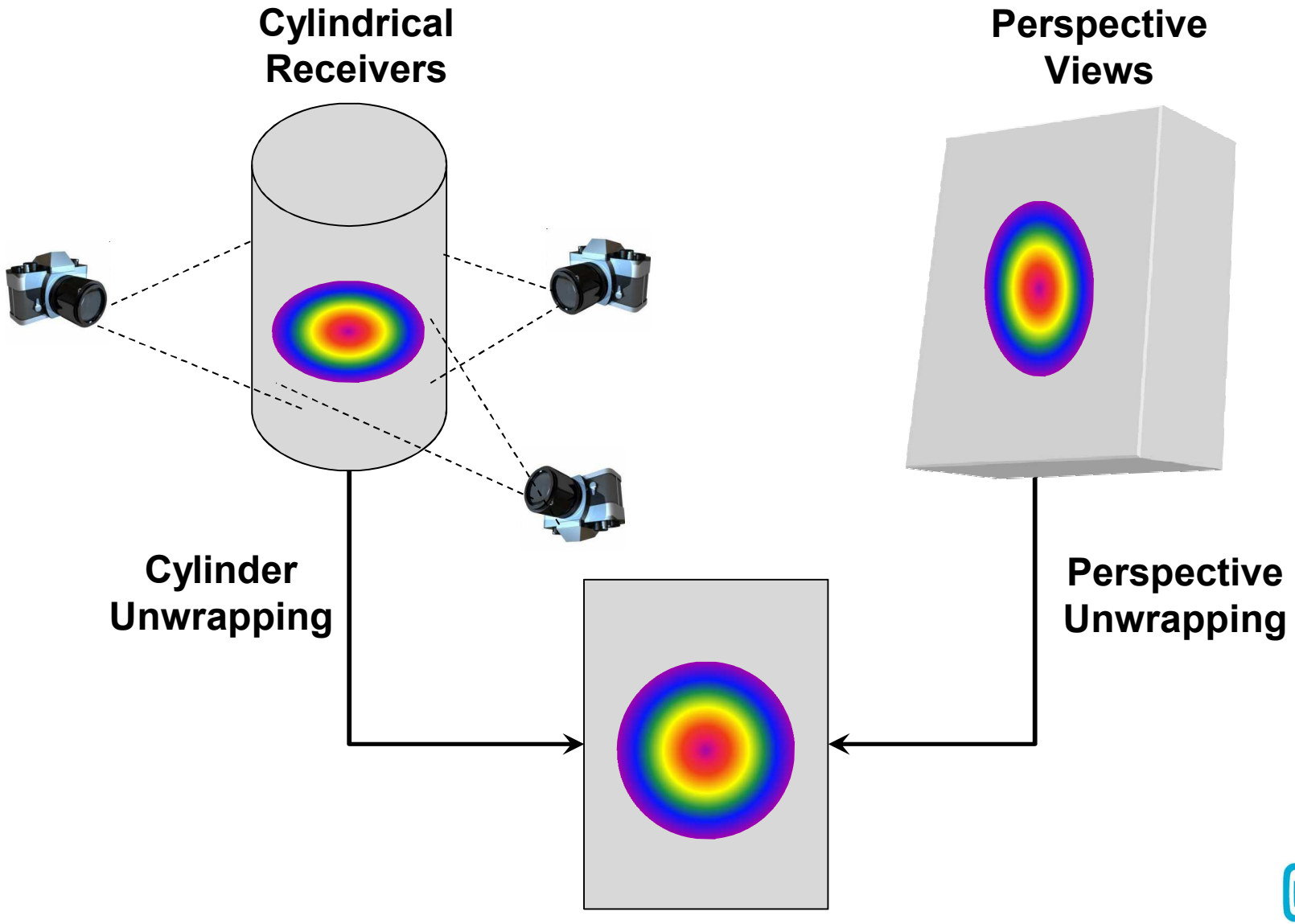
Receiver irradiance corresponding to each pixel value

Reflectivity of receiver element corresponding to pixel *i**

Subtended angle of the sun (~9.3 mrad)

*Paper describes methods to determine an effective reflectivity or a reflectivity map using digital images

Additional Considerations



PHLUX Procedure

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Testing and Validation

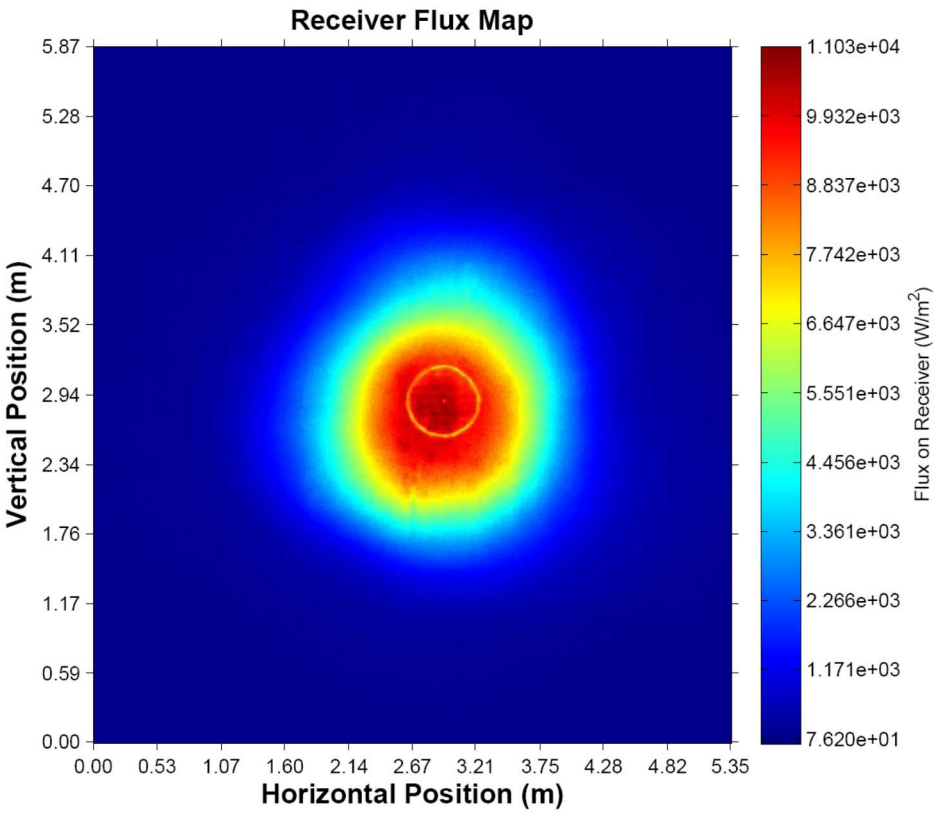
- **Applied PHLUX method to heliostat beams projected onto face of tower**
  - National Solar Thermal Test Facility, Sandia National Labs, Albuquerque, NM

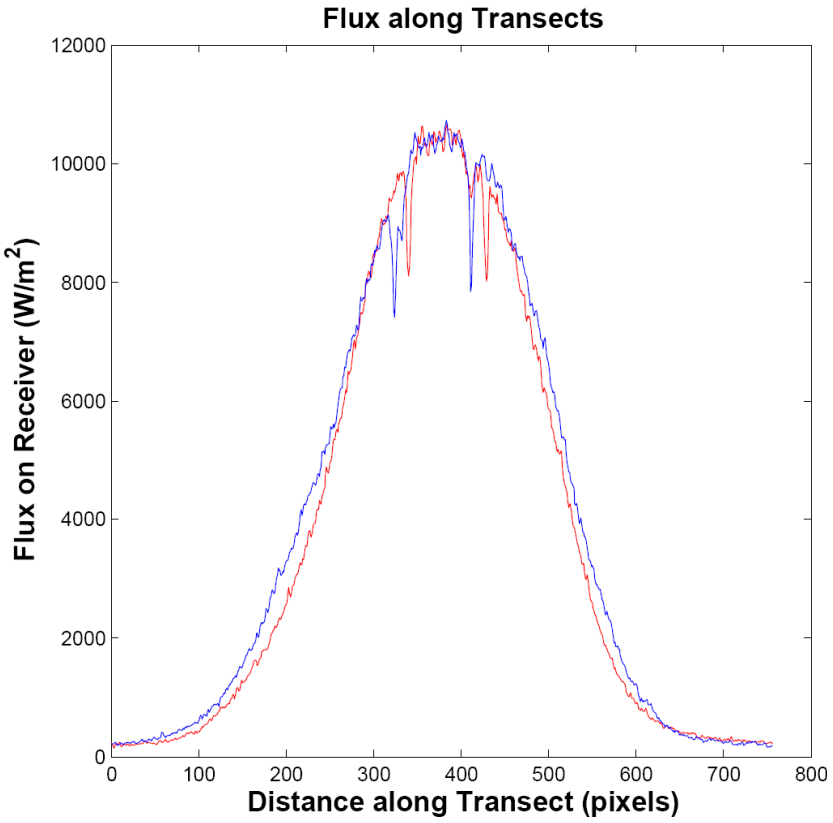
Receiver and Sun Images

Image of beam on tower

Image of sun

PHLUX Map





- **Peak flux using PHLUX method was within 2% of that measured by flux gauge**
- **Additional tests using multiple heliostats showed that the PHLUX method yielded results that were within 10% of that measured by flux gauge**

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PS10 (Spain)

- **PHLUX method was applied during tour of PS10 in Spain**
  - PHLUX-calculated irradiance on receiver was within the range measured by their sensors

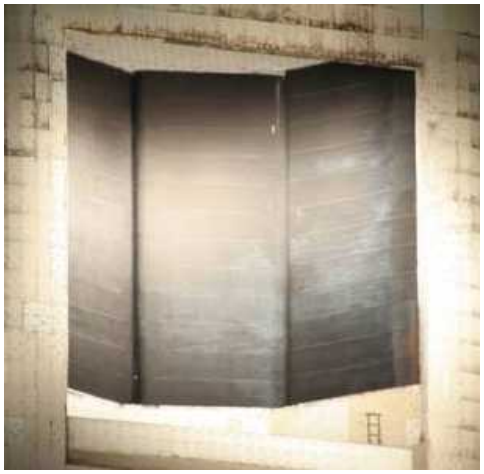
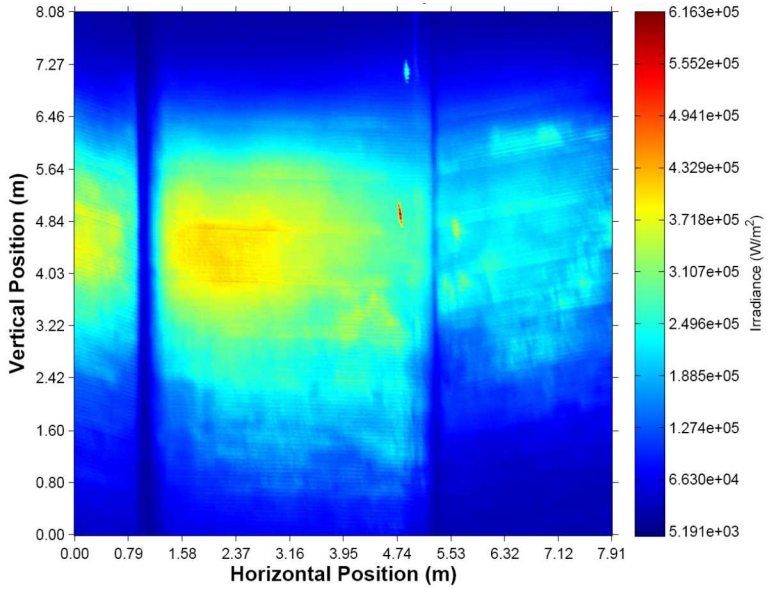


Photo from David Gill



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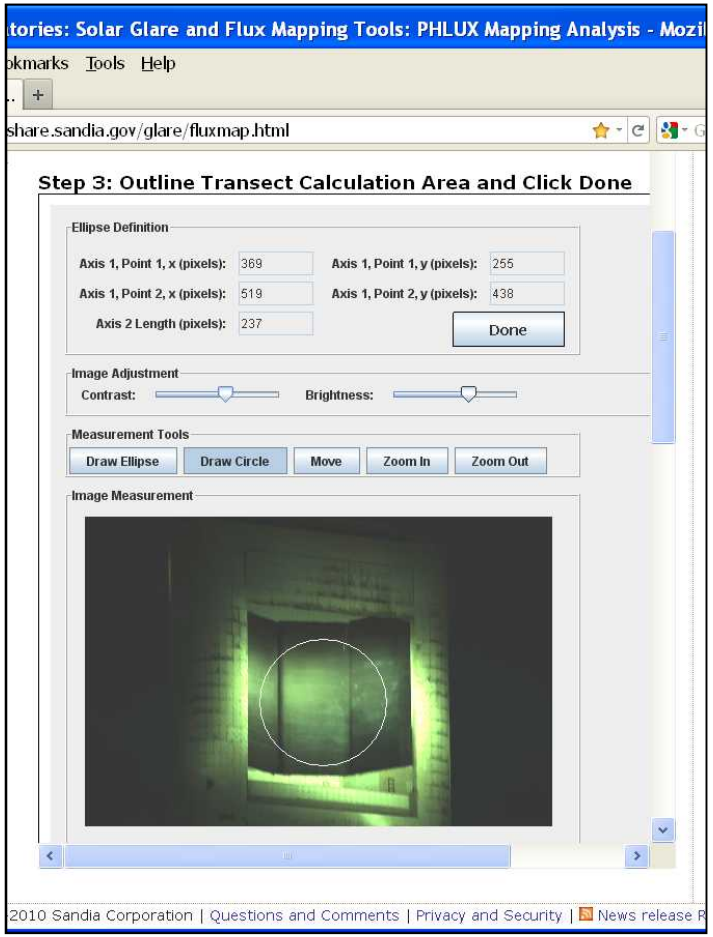
Web-Based PHLUX Tool



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Summary

- **PHLUX method provides simple and inexpensive flux mapping tool**
  - Only requires digital camera and reflectivity of receiver
  - Uses image of sun (and DNI) to scale power and size
  - Can be applied to arbitrary geometry
- **PHLUX method validated with testing**
- **Web-based tool developed**

Next Steps

- **Continue testing PHLUX method**
  - Evaluate impact of camera settings and filters
  - Evaluate impact of different receiver geometries
- **Resolve security issues for website before public release**
- **Demonstrate calculation of reflectivity map for receivers with non-uniform reflectivity**
- **Develop stand-alone software for PHLUX method**
  - Apply to video camera recordings