SAND2011-5665C

5th International Conference on Energy Sustainability & 9th Fuel Cell Science, Engineering and Technology Conference ESFuelCell2011

Washington, DC, Aug. 7 – 10, 2011

Projection of Flat-Plane Fluxmap Images onto Non-Flat Receiver Surfaces

Julius Yellowhair and Chuck Andraka

Concentrating Solar Technologies
Sandia National Laboratories
Albuquerque, NM 87185
jeyello@sandia.gov

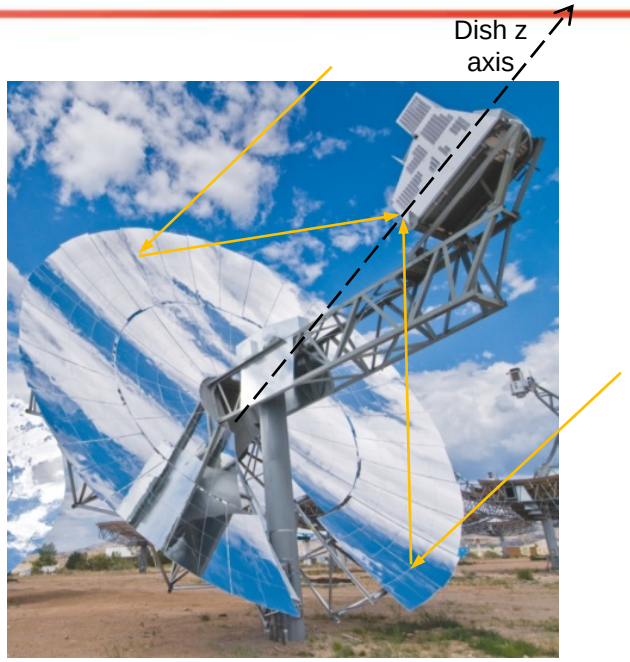
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

Sandia National Laboratories

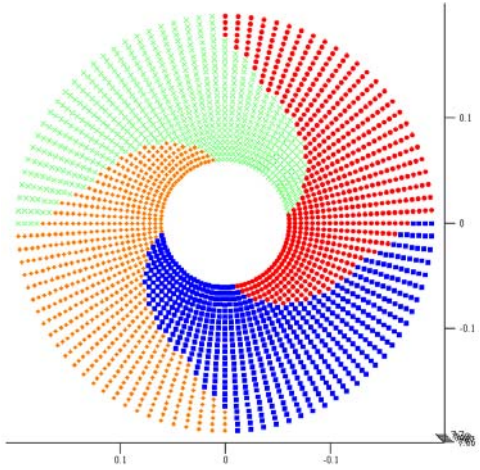
Overview

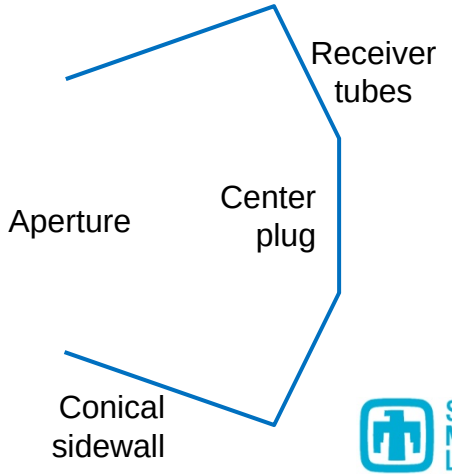
- Background on dish concentrator used & CIRCE2
- Motivation for flat-plane flux projection
- Our flux projection approach
- Flux projection method/development
- Projection of CIRCE2 flux
- Projection of real flux images
- Summary

Background on Dish Concentrator



- **Dish concentrating system**
  - 0.6 focal ratio (f/D), ~20 feet diameter
  - Uses 2 rows of faceted gore-shaped mirrors
  - 4 cylinder Stirling engine
- **Receiver**
  - Tube bundle is divided into 4 quadrants each providing power to a cylinder of the engine
  - Sidewall is conical



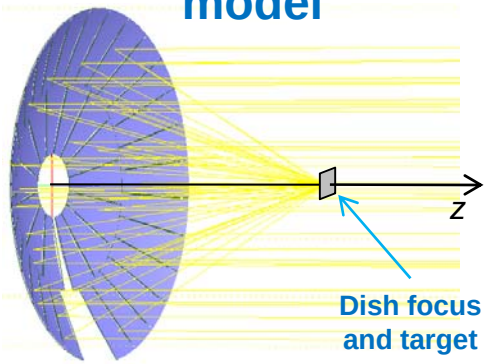


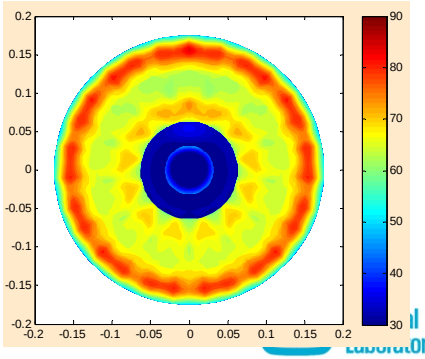
Sandia National Laboratories

Background on CIRCE2

- **Optical performance modeling tool for point-focus concentrators; Runs on DOS**
- **<u>Input</u> (DEKGEN2):**
  - **concentrator & receiver/target geometries**
  - **facet slope errors**
  - **sun shape**
- **Convolves the sun shape with slope errors**
- **<u>Output</u>:**
  - AEETES file (not used; for thermal analysis)
  - Flux file (use Matlab to plot flux map)
  - **Angle binned flux file** (optional feature)

Dish concentrator model





Motivation

- **Flux profiles on the receiver heat tubes need evaluation**
  - Hot spots
  - Flux imbalance

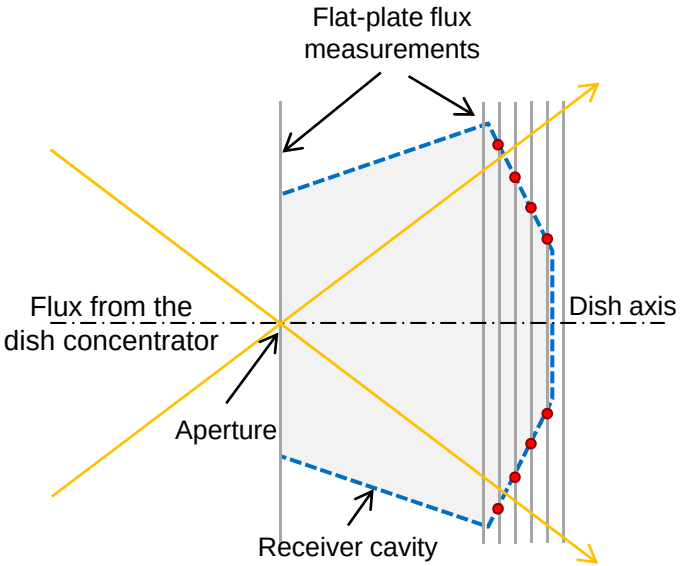
  } Limits system performance and shortens engine life

- **There is no direct way to measure the flux on the heat tubes**

- **Radiosity (flux reflection & re-radiation) limit real flux measurements to flat-plate targets**

Motivation *cont'd*

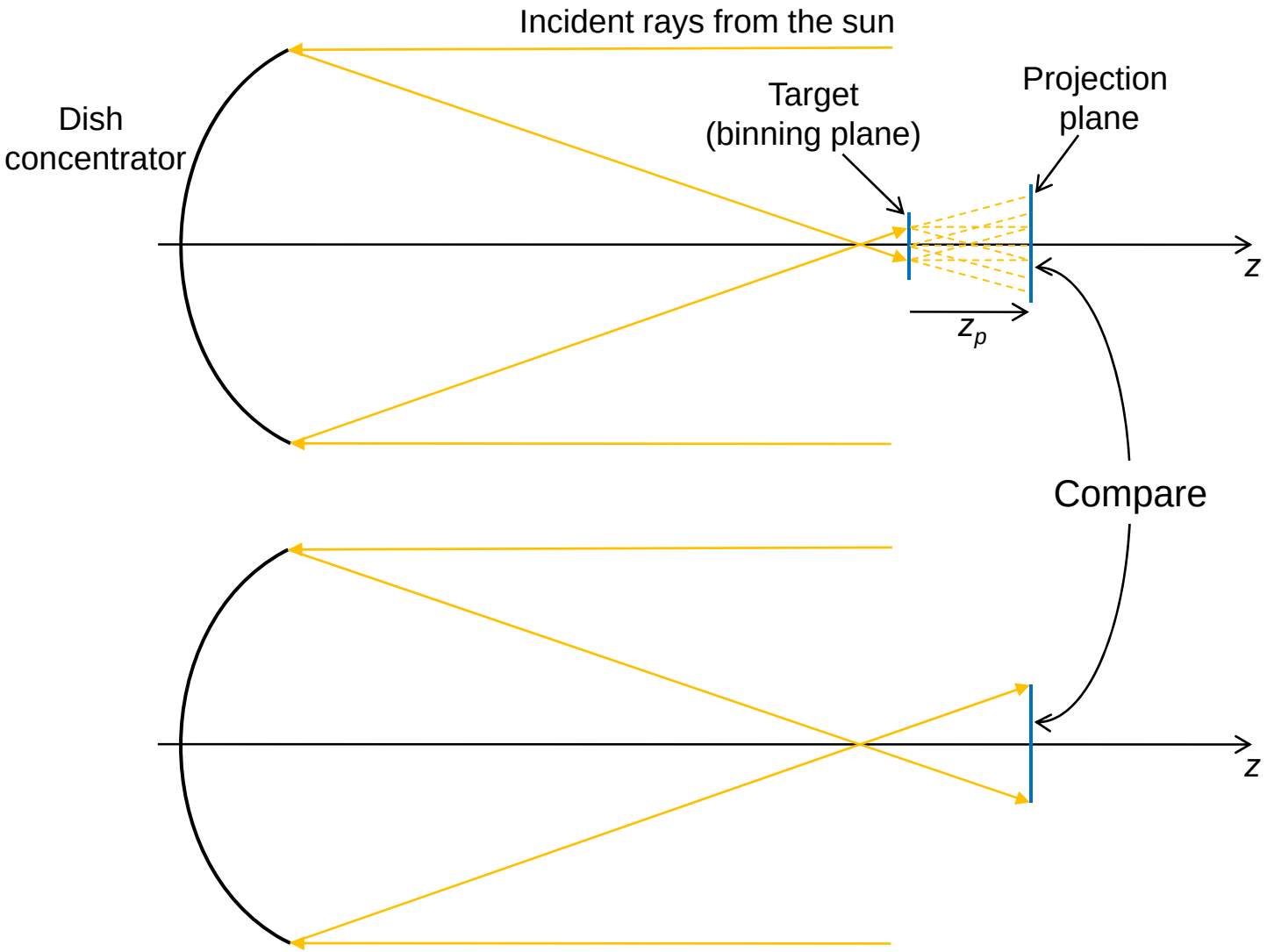
- **Current method uses many flat-plate measurements in the vicinity of the heater head using the Fluxmapper or BCS**
  - Angular flux content gets lost
  - Can potentially hide or accentuate problem areas



- **Our approach is to take one of the flat-plate measurements, partition the flux into angle bins, and project the angle bins**

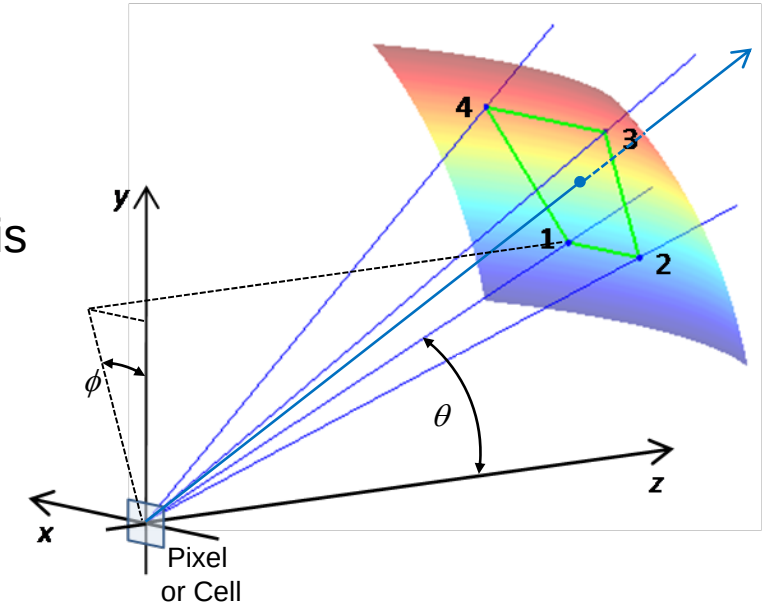
Sandia National Laboratories

Approach



CIRCE2 Flux Angle Binning

- CIRCE2 **solid angle** geometry
  - The solid angle carries flux intensity, I
  - *z*-axis is along the concentrator optical axis
  - ϕ = azimuth angle (0 – 360°)
  - θ = polar angle ($0 < \theta \leq 90°$)



- The **solid angle bin** is bounded by the extents of the **azimuth** ($\Delta\phi$) and **polar** ($\Delta\theta$) angle bands

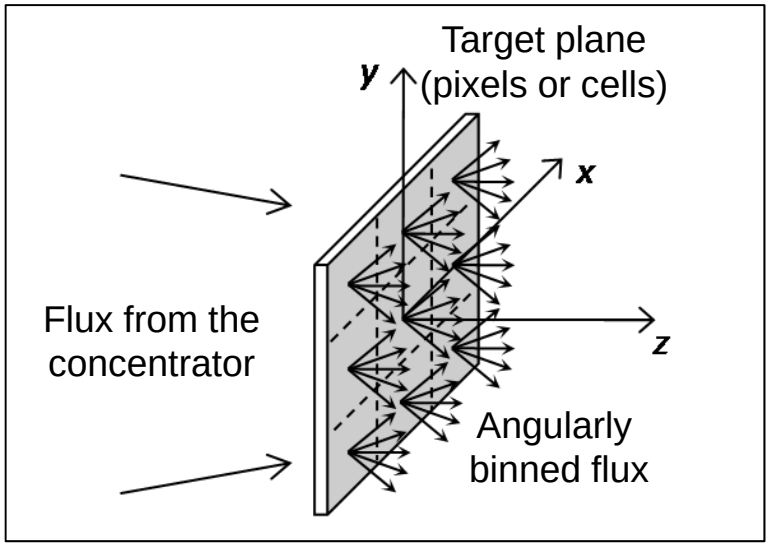
$$\Theta = [(\theta,\phi),(\theta,\phi+\Delta\phi),(\theta+\Delta\theta,\phi+\Delta\phi),(\theta+\Delta\theta,\phi)]$$

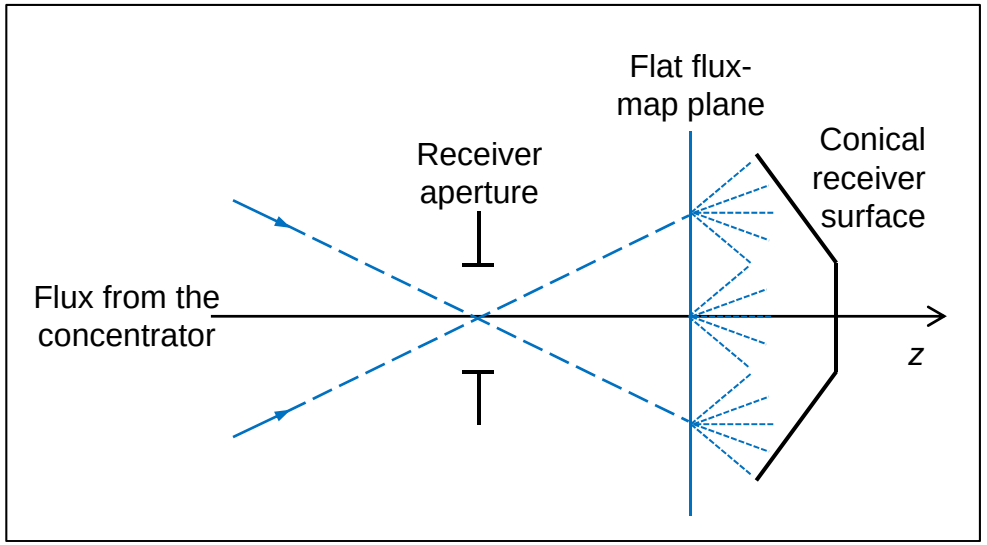
1 2 3 4

- Specify <u>target size (pixels)</u>, <u>polar angle range</u>, <u>number of polar and azimuth angle bins</u>

Sandia National Laboratories

CIRCE2 Flux Angle Binning *cont'd*

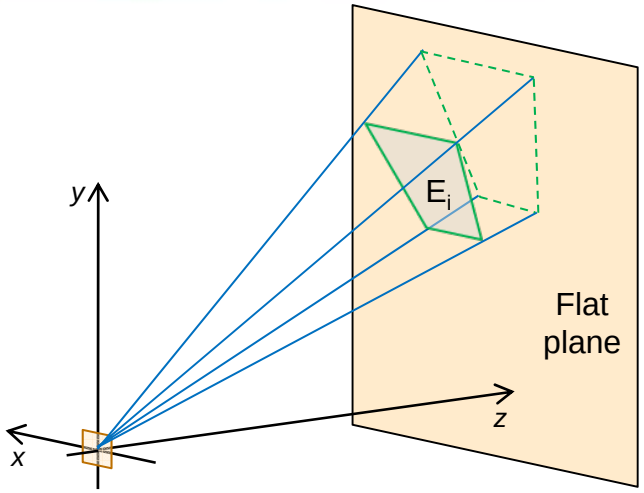




- Conservation of energy (flux) must hold

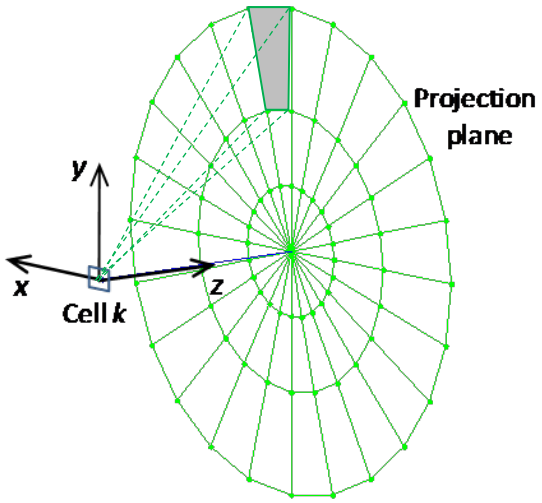
Flux Projection Method

- **Example of a single angle bin mapped to a flat target plane**

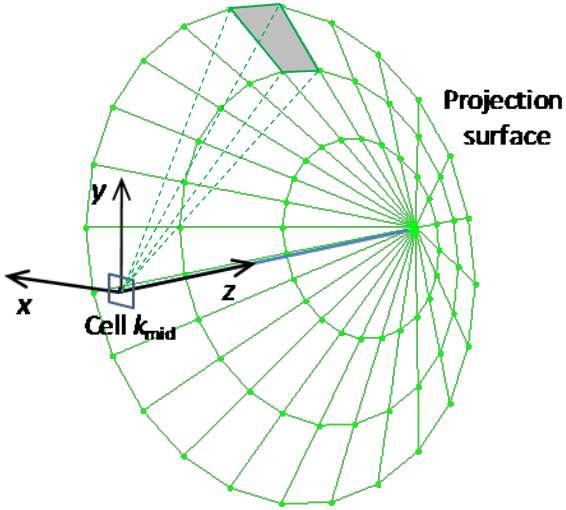


- **Examples of angle bins mapped to a planar and conical surfaces (24 azimuth & 3 polar angle bins)**

Projection onto a planar surface



Projection onto a conical surface



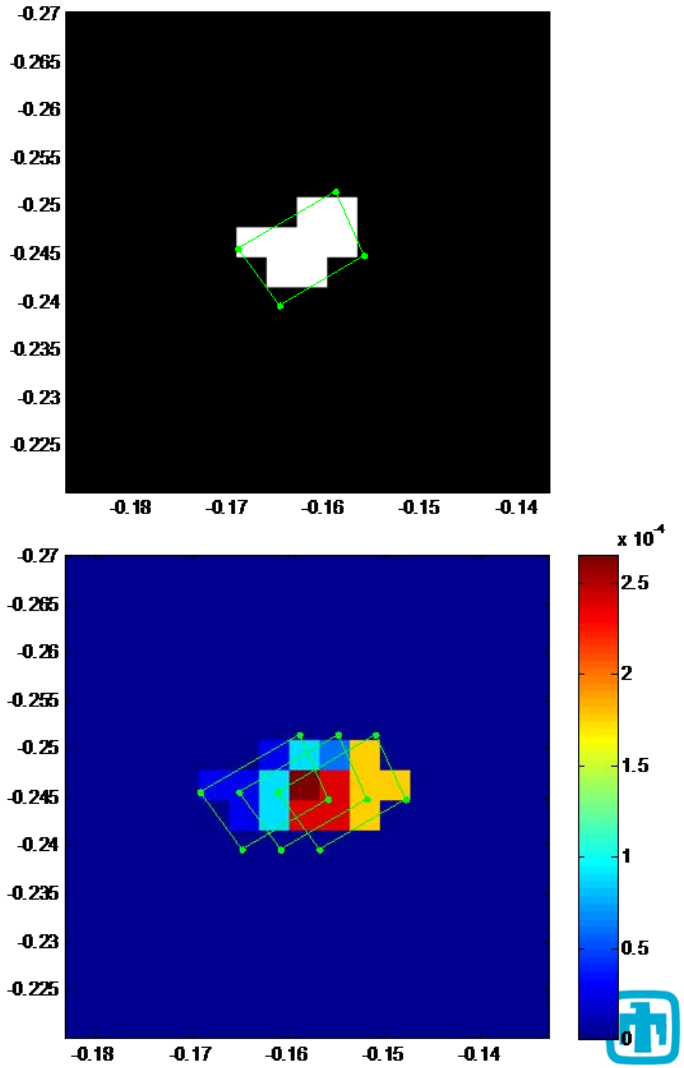
Sandia National Laboratories

Flux Projection Method *cont'd*

- **Projection of an angle bin onto a flat target plane (256 x 256 pixel plane)**
  - Intersecting pixels are 'lit' up

- **Accumulation of the mapped angle bins carrying flux intensity (from 3 consecutive cells)**

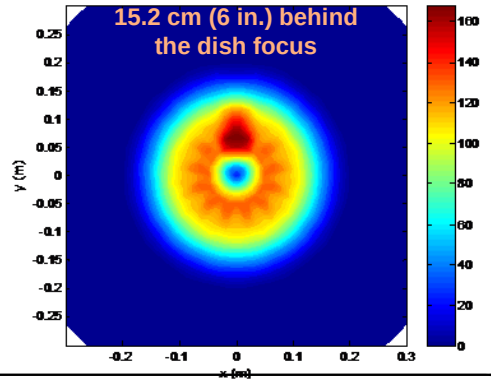
12° x 4° angle bin



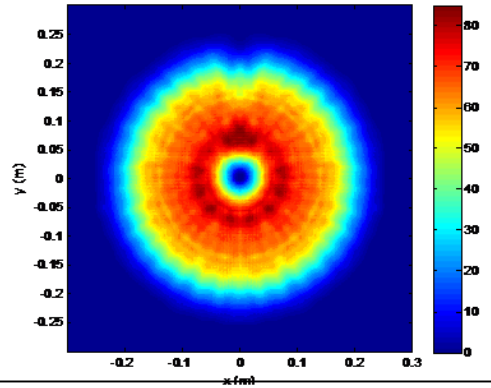
Sandia National Laboratories

Validation of the Flux Projection Method: Flat Projection Plane

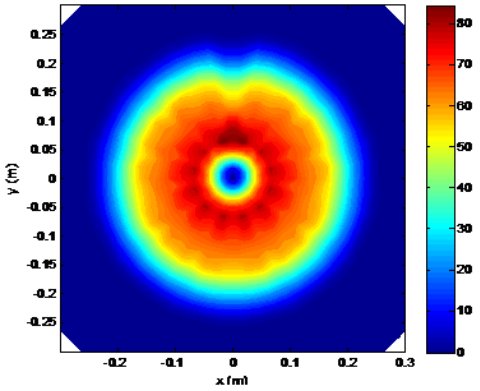
Starting CIRCE2 flux located at 15.2 cm (6 in.) behind the dish focus



Projected flux to a location 20.3 cm (8 in.) behind the dish focus.



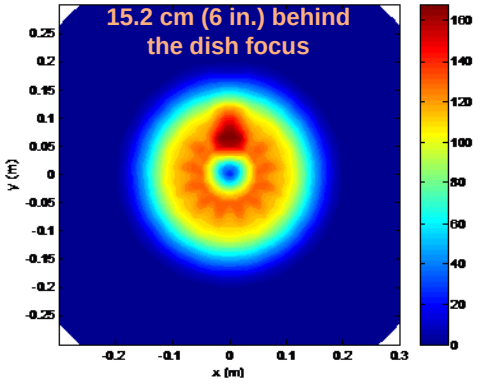
CIRCE2 flux at the projection plane (for comparison to projected flux)



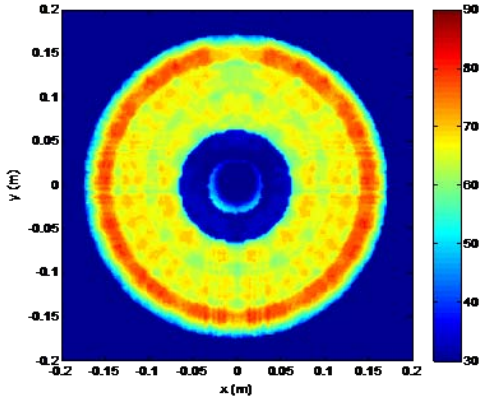
Sandia National Laboratories

Validation of the Flux Projection Method: Conical Receiver Projection

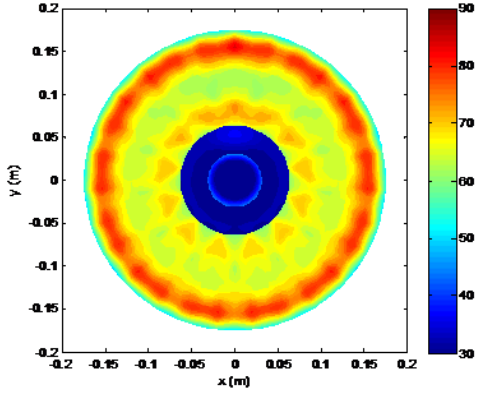
Starting CIRCE2 flux located at 15.2 cm (6 in.) behind the dish focus



Projected flux onto the conical receiver.



CIRCE2 flux on the same receiver geometry (for comparison to the projected flux)



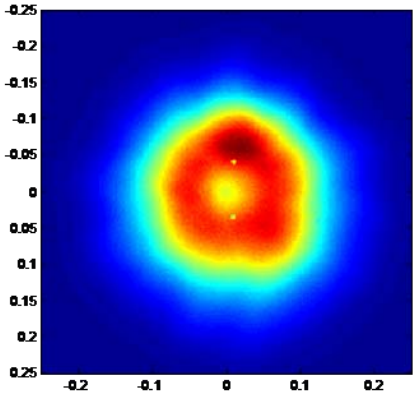
- We desire the flux on the non-flat receiver cone and parts, based on actual (measured) data rather than CIRCE (ideal) data

Sandia National Laboratories

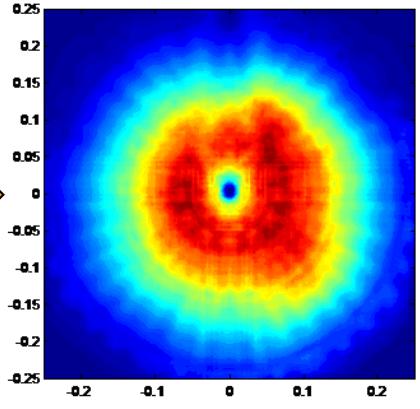
Projection of Real Flux onto Flat Plate Targets

- We now use CIRCE2's angle binning information to project real flux-maps onto a flat projection plane
- Spatial scaling of the real flux-map is corrected by the known spacing of two fiducial points on the flat-plate target
- Intensity scaling is corrected by matching the integrated flux-map image to the integrated CIRCE2 flux-map

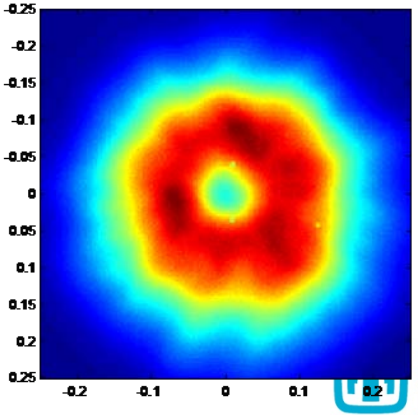
Fluxmapper image - starting flux (6 in. behind the dish focus)



Projected flux onto a flat plane surface



Fluxmapper image at the projection plane location for comparison

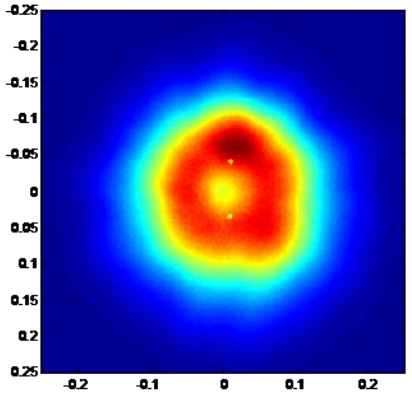


Sandia National Laboratories

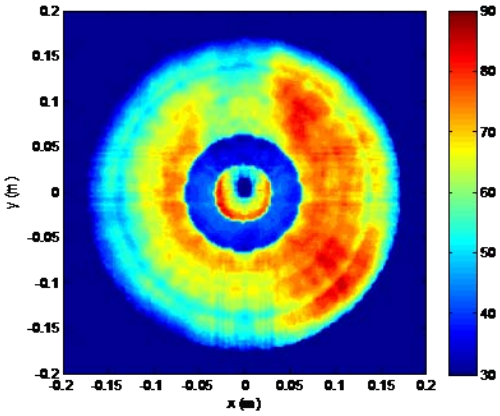
Projection of Real Flux onto Receiver Surface

- **We use CIRCE2's angle binning information again to project real flux-maps**
- **Projected on the same receiver geometry used before**

Fluxmapper image - starting flux (6 in. behind the dish focus)



Projected flux onto the conical receiver surface



Sandia National Laboratories

Summary

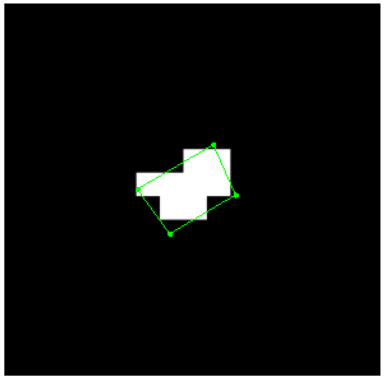
- There is a need to accurately evaluate the flux (from as-built dishes) on the non-flat receiver surfaces
- There is no direct way to measure flux on receivers
- Radiosity concerns limit the fluxmapping to flat-plate target measurements
- We introduced & demonstrated a method the projects flat-plane flux images onto non-flat surfaces

Questions?

- **Contact information:**
  - Julius Yellowhair (jeyello@sandia.gov)
    - Sandia National Laboratories
    - (505) 844-3029
  - Chuck Andraka (ceandra@sandia.gov)
    - Sandia National Laboratories
    - (505) 844-8573

Sandia National Laboratories

Discussion



- **Flux mapping errors**
  - Pixilation – causes multiple effects (e.g. speckle and streaks in the projected images)
  - Flux “leakage” – combines with others to form hot spots
  - Area of mapped angle bin – causes artificial changes to mapped irradiances
- **Use a flat target closer to receiver surface for binning to reduce projection errors**

Future Work

- **Potential improvements**
  - Ratio the irradiance between shared pixels
  - Improvement to mapping of angle bins onto curved surfaces