SolarPACES 2010

Perpignan, France, September 21-24, 2010

Hazard Analysis and Web-Based Tool for Evaluating Glint and Glare from Solar Collector Systems

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Overview

- Introduction
- Glint and Glare Analysis
- Web-Based Tool
- Summary

Introduction

- **Glint and glare may cause unwanted visual impacts**
  - Glint is momentary flash of light; glare is more continuous source of excessive brightness
  - Visual impacts range from flash blindness to retinal burn

- **Need quantified analysis of glint/glare to reduce uncertainties associated with visual impacts of CSP installations**
  - Industry, military, government agencies (e.g., California Energy Commission, Transportation Research Board)

Examples of Glint/Glare

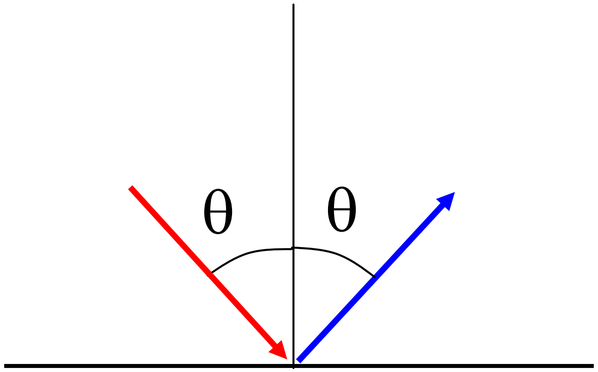
Solar One
(10 MW_e power tower, Daggett, CA)

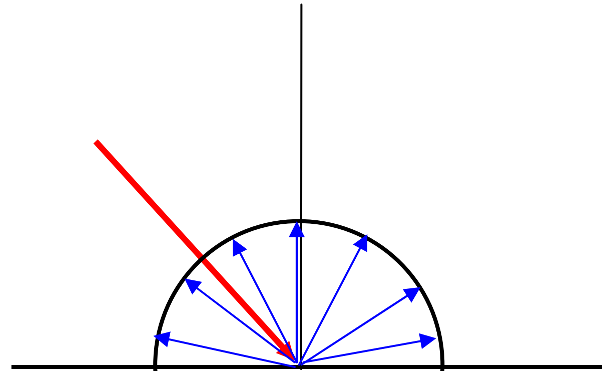
Central Receiver Test Facility
(SNL, NM)

National Solar Thermal Test Facility
(SNL, NM)

Kramer Junction
(150 MW_e parabolic trough, Mojave Desert, CA)

Glare Types





Specular
Reflection

(polished surfaces;
e.g., mirrors)

Diffuse
Reflection

(rough surfaces;
e.g., receivers)

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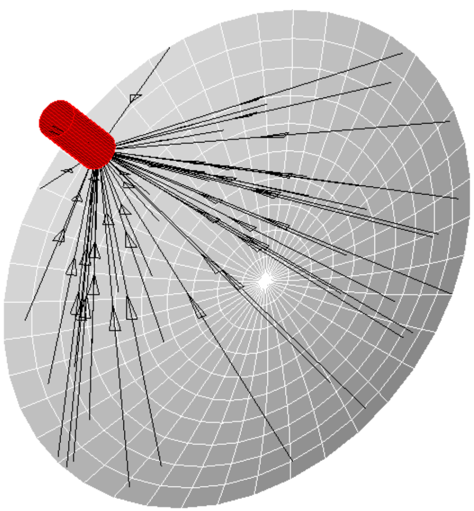
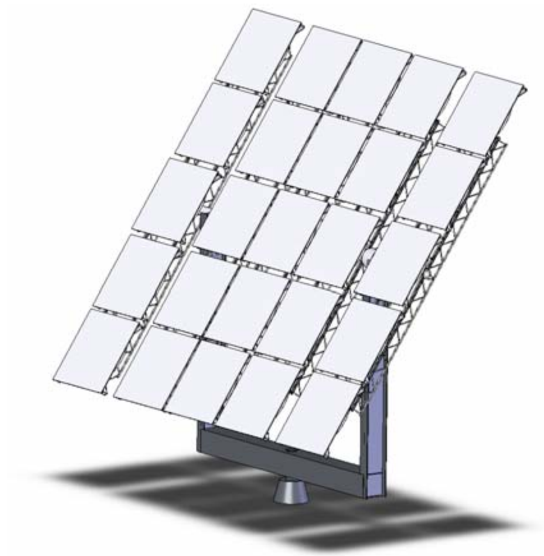
Specular Reflections

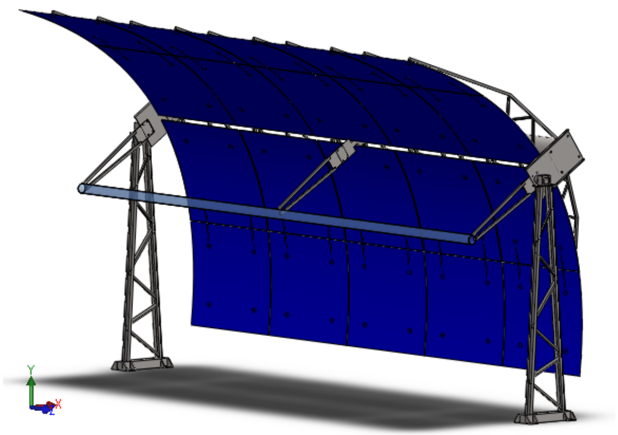
- **Point Focus and Line Focus Collectors**



Dish



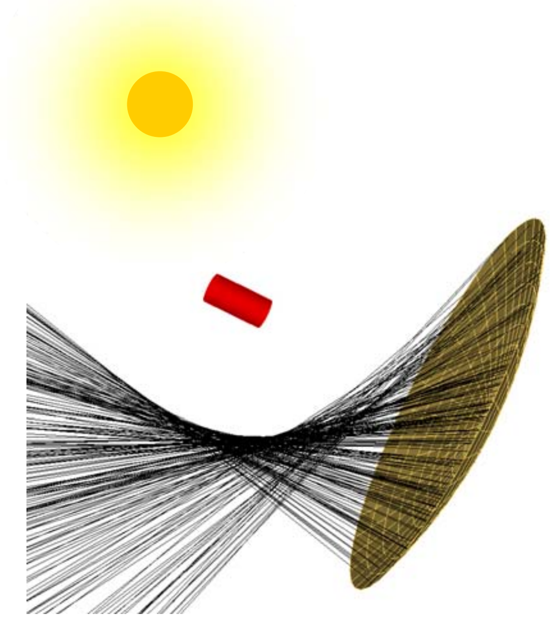
Heliostat



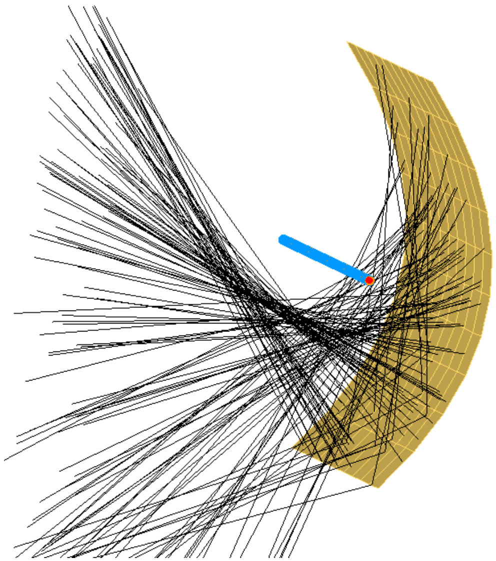
Parabolic Trough

Specular Glare

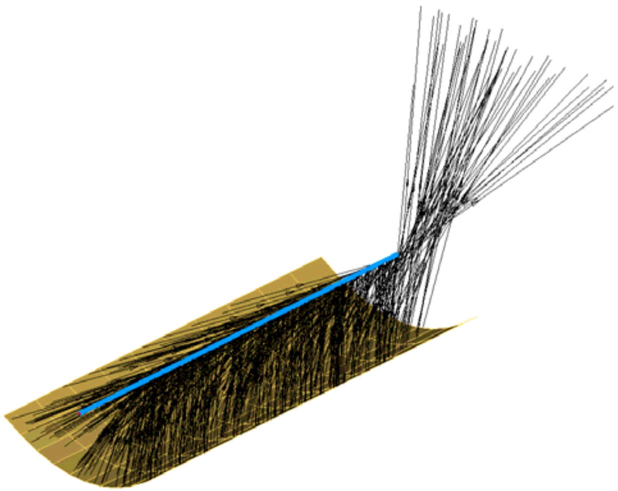
- **Potential for glint and glare from collectors**
  - Off-axis; misalignment; moving to or from stow/standby
  - End-loss and spillage for troughs



Off-axis Dish



Off-axis Trough



End-Loss from Trough

Previous Work

(Pertaining to CSP Glint and Glare)

- **1976-1984: Brumleve, T.D., SAND76-8022 and SAND83-8035**
  - Performed analysis and tests of glare from heliostats and receivers using retinal burn metrics from Sliney and Freasier (1973)
  - Determined exclusion zones and developed beam control strategies

- **2009: Ho, C.K., C.M. Ghanbari, and R.B. Diver, SolarPACES 2009**
  - Developed safety metrics for both retinal burn and temporary flash blindness using data from multiple literature sources

Previous Work (cont.)

(Pertaining to CSP Glint and Glare)

- **2010: Ho, C.K., C.M. Ghanbari, and R.B. Diver, ASME Energy Sustainability Conference**
  - Developed analytical equations to evaluate specular and diffuse glare using retinal burn and temporary flash blindness metrics; performed validation tests
- **2010: Ho, C.K. and S.S. Khalsa (this paper)**
  - Derived explicit equations to determine distances that cause retinal burn and temporary flash blindness for specular glare
  - Introduced web-based tool

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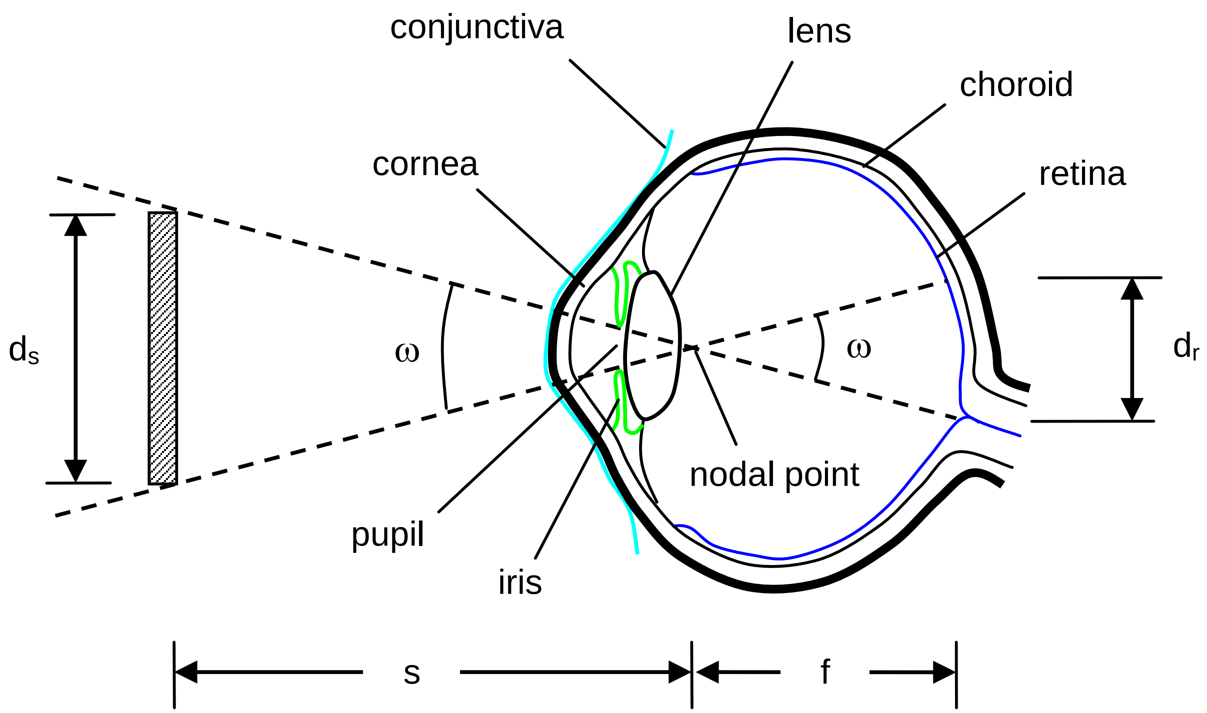
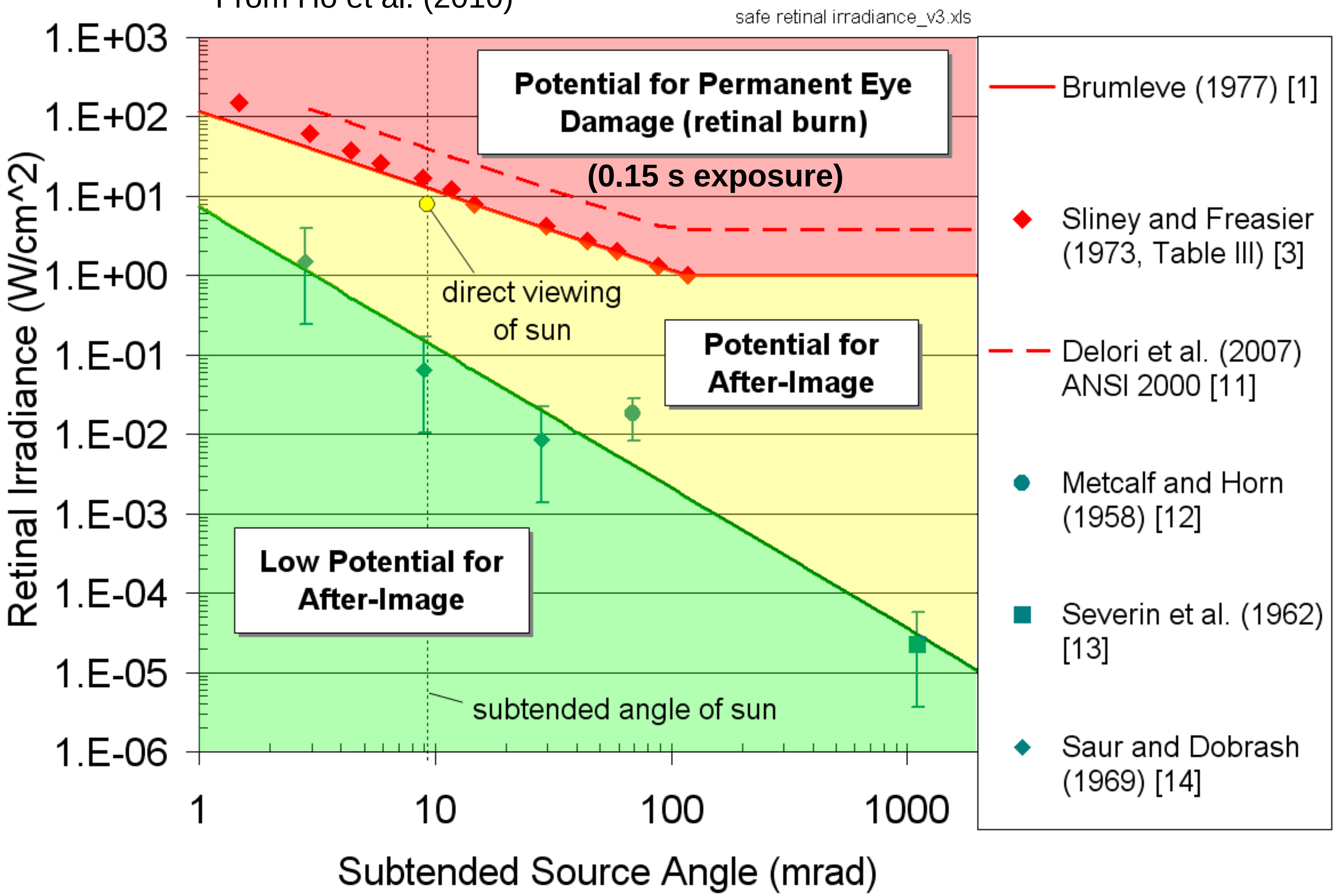
Retinal Irradiance



- **Need to calculate**
  - Power entering eye
    - Function of irradiance at the cornea (front of eye)
  - Subtended angle of glint/glare source

Potential Impacts

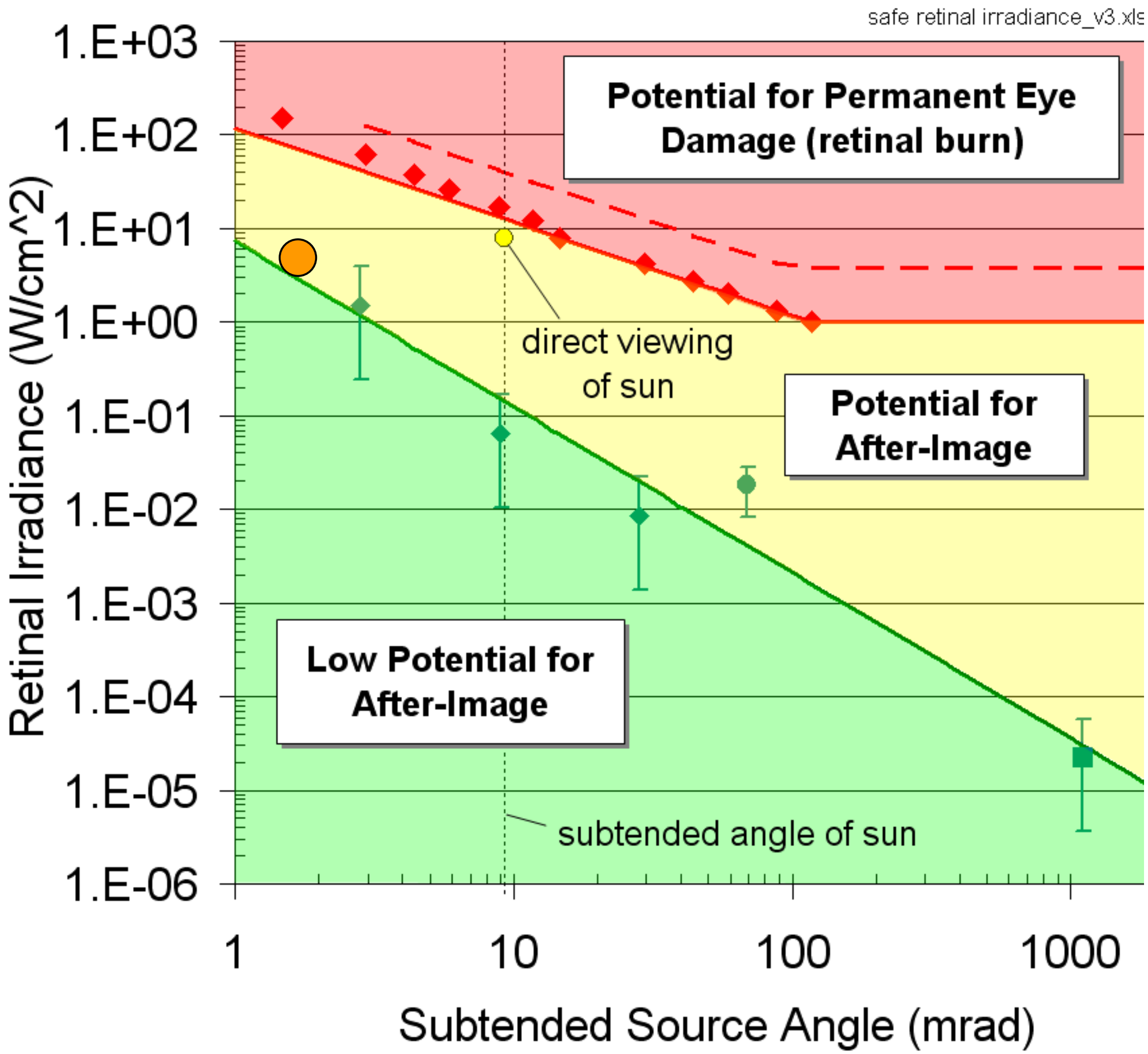
From Ho et al. (2010)



Analysis Steps
(from ASME ES2010 paper)

- **Calculate retinal irradiance using equations in paper for specular or diffuse reflections**
  - Collector optical properties, DNI, pupil diameter
- **Calculate subtended angle using equations in paper**
  - For diffuse reflections, source is given by size of receiver or reflecting source
  - For specular reflections, use equations
- **Identify potential impact using plot of retinal irradiance vs. subtended source angle**

Comparison to Safety Metrics



$\rho = 0.94$

RMS slope error = 1 mrad

aperture = 12 m

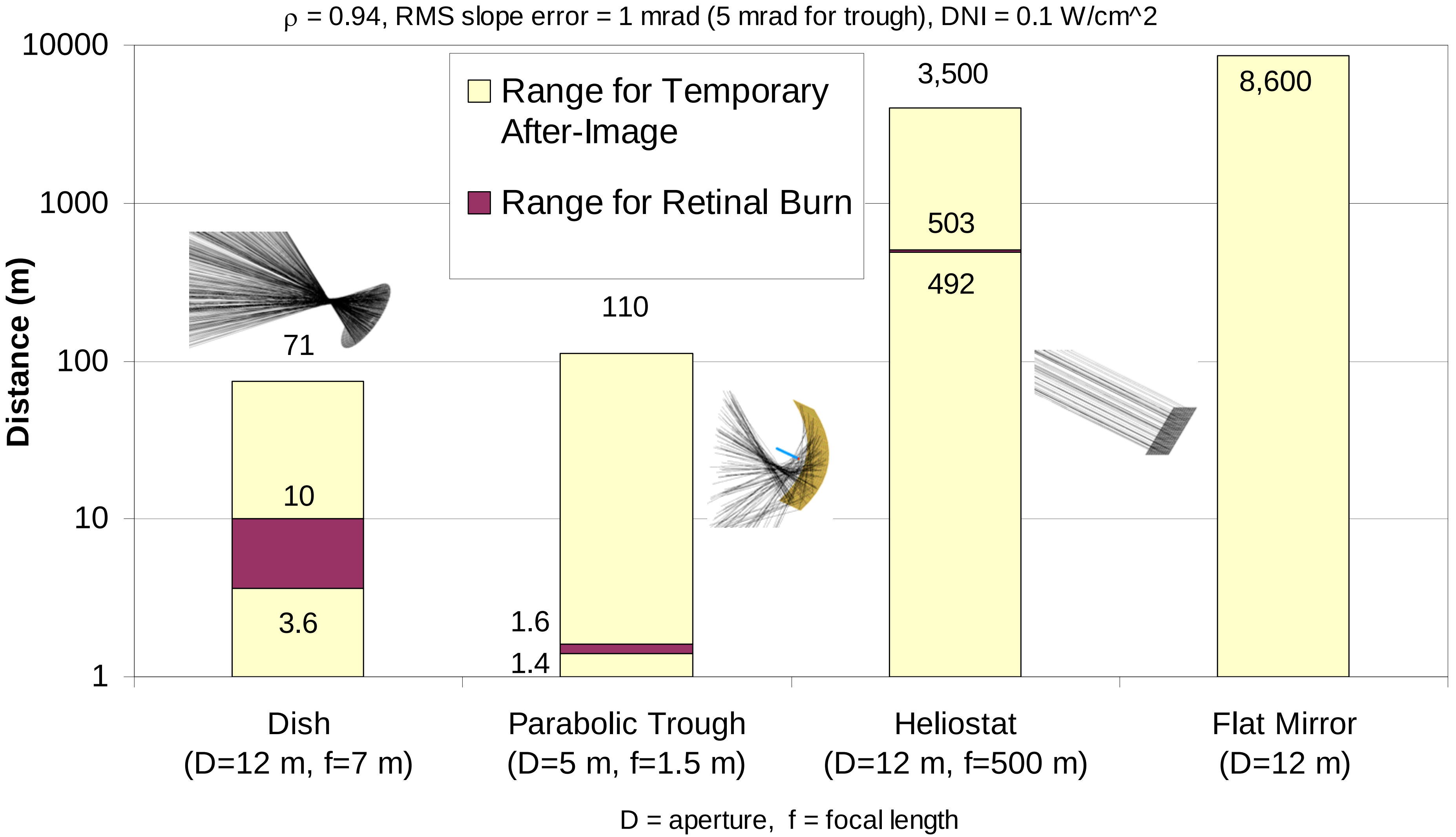
focal length = 7 m

50 m viewing distance

$\Rightarrow$ Retinal irradiance = 5 W/cm^2

$\Rightarrow$ Subtended source angle = 1.8 mrad

Distances for Retinal Burn and Temporary After-Image



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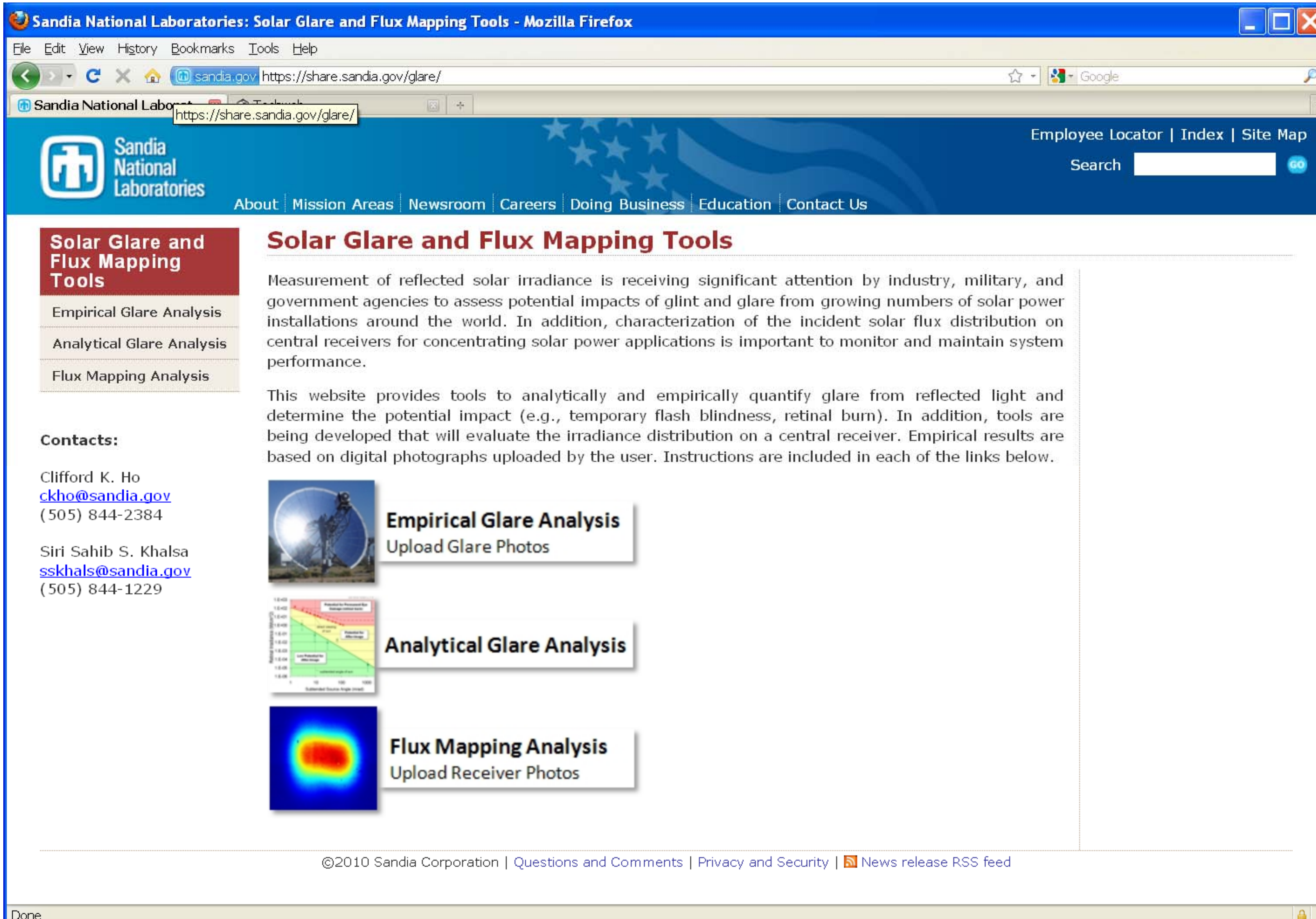
Phlux Tools Website

Photographic Flux Tools for Solar Glare and Flux Mapping



Sandia National Laboratories: Solar Glare and Flux Mapping Tools - Mozilla Firefox

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Solar Glare and Flux Mapping Tools

- Empirical Glare Analysis
- Analytical Glare Analysis
- Flux Mapping Analysis

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Solar Glare and Flux Mapping Tools

Measurement of reflected solar irradiance is receiving significant attention by industry, military, and government agencies to assess potential impacts of glint and glare from growing numbers of solar power installations around the world. In addition, characterization of the incident solar flux distribution on central receivers for concentrating solar power applications is important to monitor and maintain system performance.

This website provides tools to analytically and empirically quantify glare from reflected light and determine the potential impact (e.g., temporary flash blindness, retinal burn). In addition, tools are being developed that will evaluate the irradiance distribution on a central receiver. Empirical results are based on digital photographs uploaded by the user. Instructions are included in each of the links below.

Empirical Glare Analysis
Upload Glare Photos

Analytical Glare Analysis

Flux Mapping Analysis
Upload Receiver Photos

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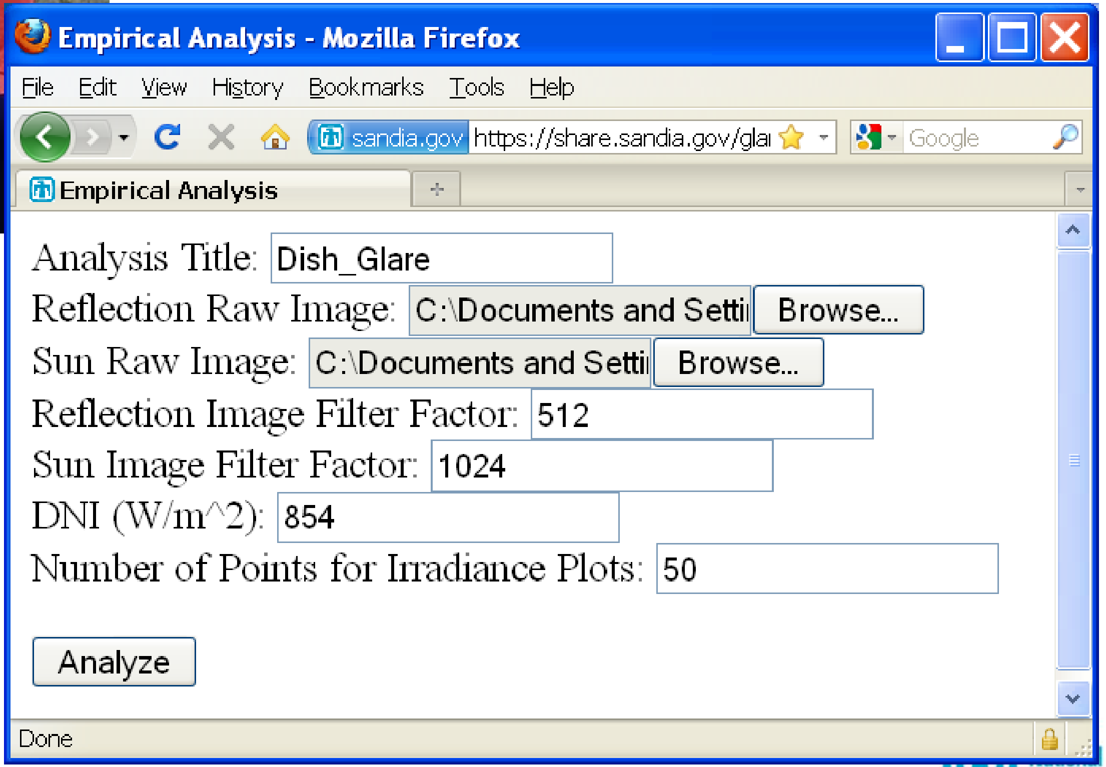
Done

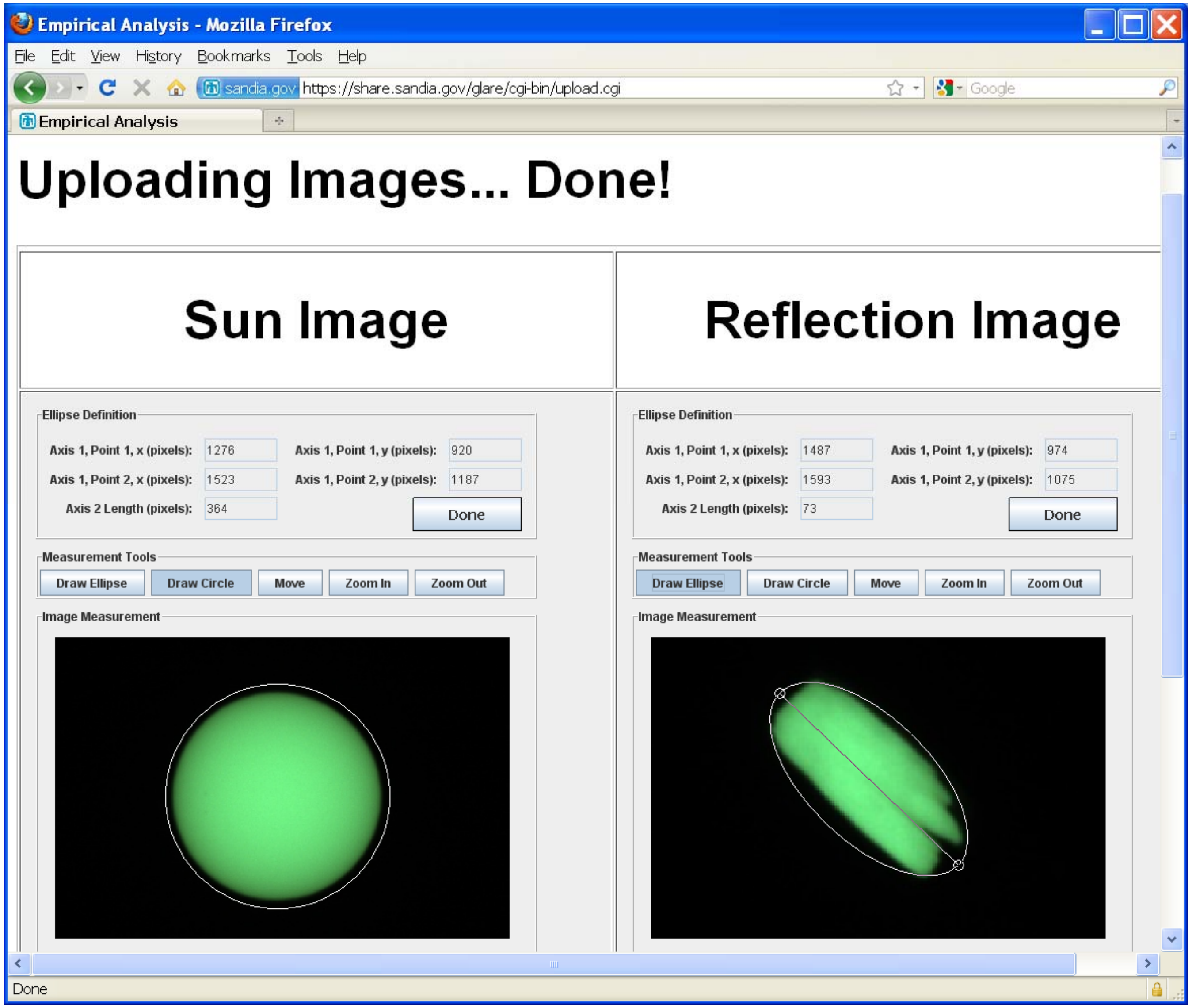
Empirical Analysis

Digital photographs are taken of the glare

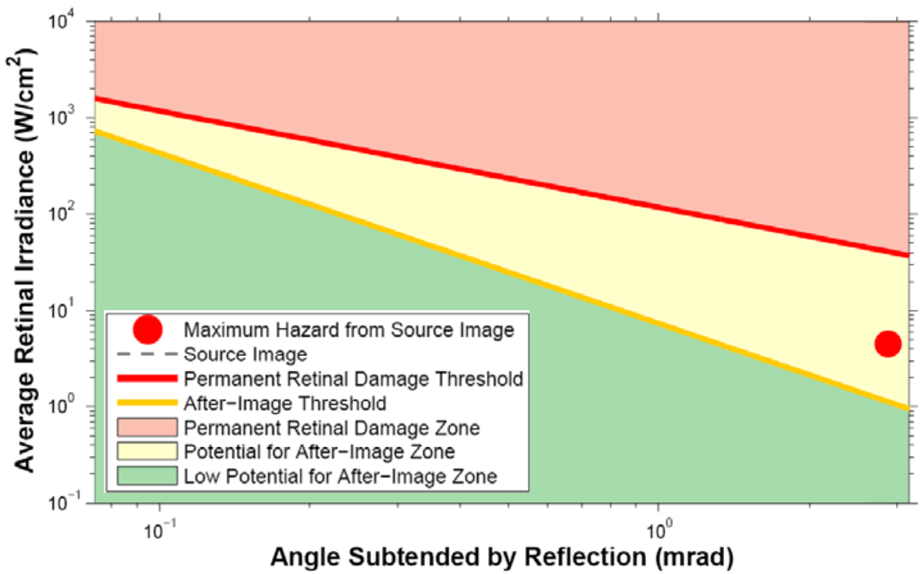
Images are uploaded
with relevant information



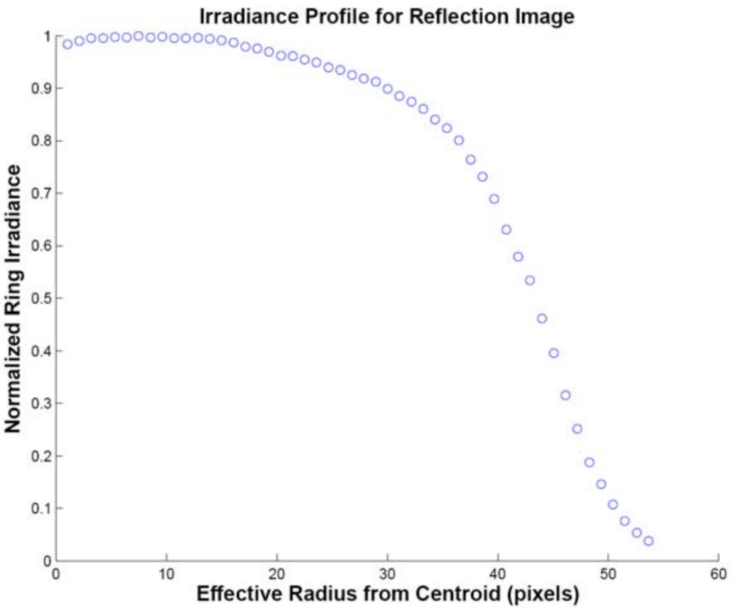
Selection Tools



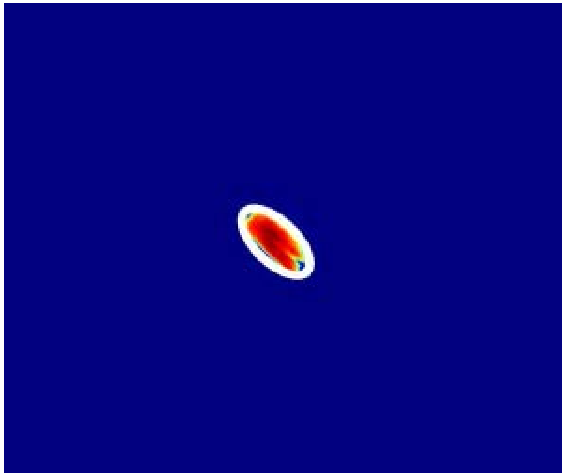
Output

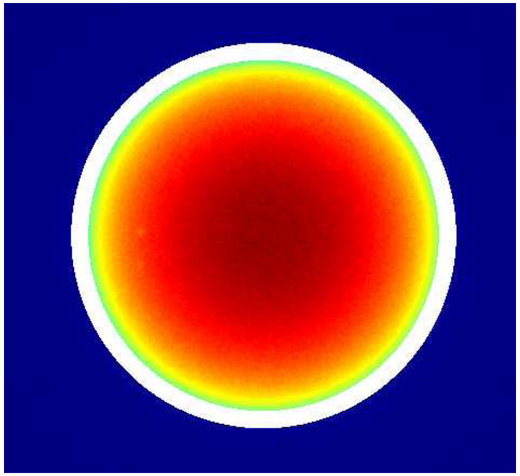


Average Retinal Irradiance (W/cm^2)
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-1}
10^0
Angle Subtended by Reflection (mrad)
Maximum Hazard from Source Image
Source Image
Permanent Retinal Damage Threshold
After−Image Threshold
Permanent Retinal Damage Zone
Potential for After−Image Zone
Low Potential for After−Image Zone



Irradiance Profile for Reflection Image
Normalized Ring Irradiance
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50
60
Effective Radius from Centroid (pixels)





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Summary

- **Glint and Glare can cause unwanted visual impacts**
- **Analytical models and safety metrics have been developed to quantify glint and glare**
  - Specular reflections
    - Point-focus and line-focus
  - Diffuse reflections
  - Models have been validated with test data
- **Web tool has been developed**

Ongoing Work

- **Reduce uncertainties associated with glint/glare for safe and expedient permitting of solar power systems**
  - California Energy Commission
  - Military (Air Force)
  - Industry
  - Transportation Research Board
    - Synthesis Report on “Investigating Safety Impacts of Energy Technologies on Airports and Aviation”