

*Exceptional service in the national interest*



# CSP Training Module 11: Plant Safety- Glint and Glare Analysis

James E. Pacheco

**Courtesy of Cliff Ho, Sandia National Labs**

Sponsored by College of the Desert  
BrightSource Ivanpah, CA  
September 5 and 6, 2012



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.

# Agenda

- 1. Basic Theory of Operation
- 2. Fuel
- 3. Modeling CSP plants
- 4. Basic construction and Design
- 5. Startup and Shutdown
- 6. Major System Operations
- 7. Plant Operation influences on the grid
- 8. Response to Weather Changes
- 9. Water Chemistry
- 10. Plant Performance Measurements
- 11. Safety Concerns – Glint and Glare

# Introduction

- Multiple agencies are interested in evaluating potential safety impacts from emerging energy technologies
  - Air Force
    - Impact on training missions at Nevada Test and Training Range
  - FAA
  - California Energy Commission
    - Solar power plant Applications for Certification
  - National Academies – Transportation Research Board
    - Synthesis Report on “Investigating Safety Impacts of Energy Technologies on Airports and Aviation”

# Air Force White Papers

- Series of white papers covering renewable energy technologies (PV, CPV, CSP, etc.)
  - Potential impacts include the following:
    - Ground-based and airborne radar interference
    - Radio frequency interference
    - Glare impact on pilots and sensors
    - Infrared emissions (“thermal signature”)
    - Overflight restrictions
    - Sonic overpressure

# Glint and Glare Safety Concerns

- 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<sub>e</sub> power  
tower, Daggett,  
CA)



Central Receiver  
Test Facility  
(SNL, NM)

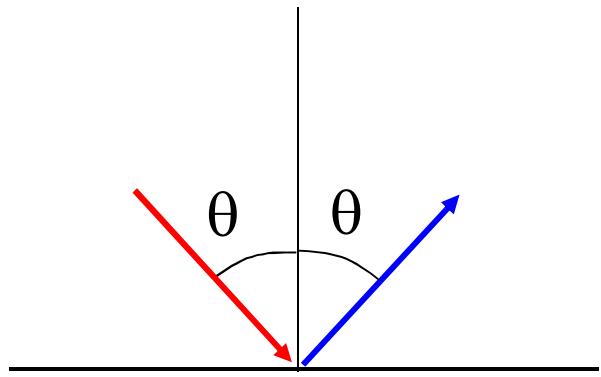


National Solar Thermal Test Facility  
(SNL, NM)



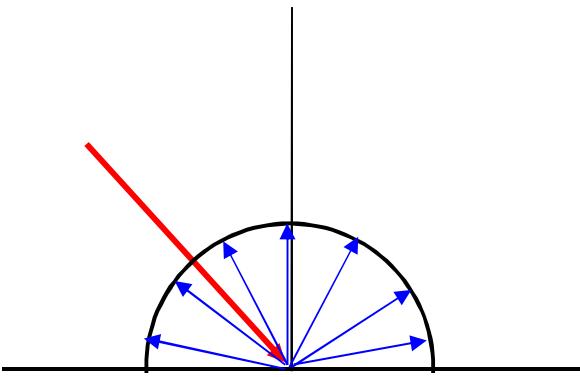
Kramer Junction  
(150 MW<sub>e</sub> parabolic trough, Mojave  
Desert, CA)

# Glare Types



Specular  
Reflection

(polished surfaces;  
e.g., mirrors)



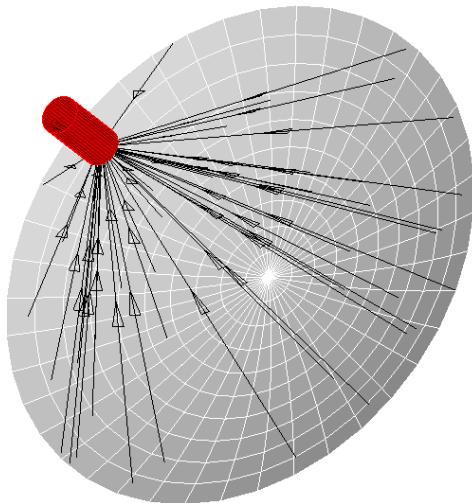
Diffuse  
Reflection

(rough surfaces;  
e.g., receivers)

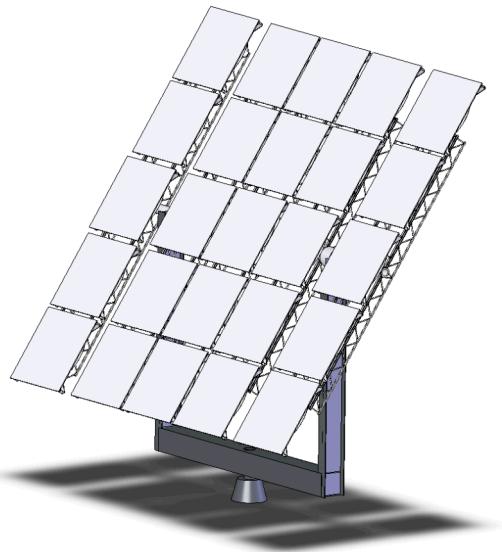


# Specular Reflections

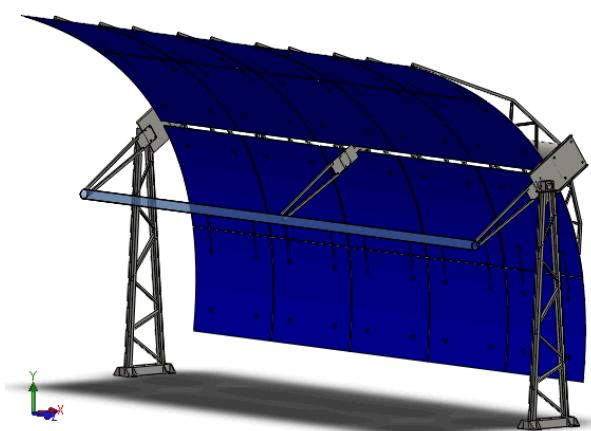
- Point Focus and Line Focus Collectors



Dish



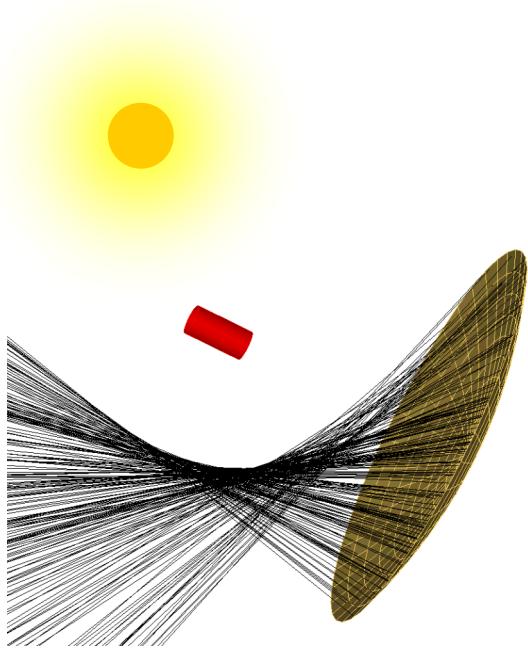
Heliostat



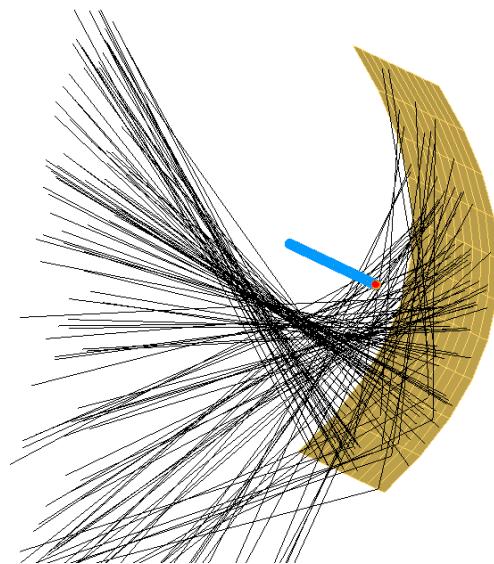
Parabolic Trough

# Specular Glare

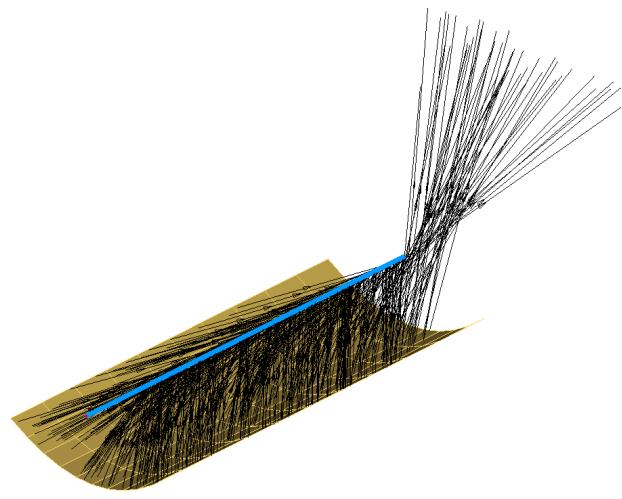
- Potential for glint and glare from collectors
  - Off-axis; misalignment; moving to or from stow/standby
  - End-loss and spillage for troughs



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.)

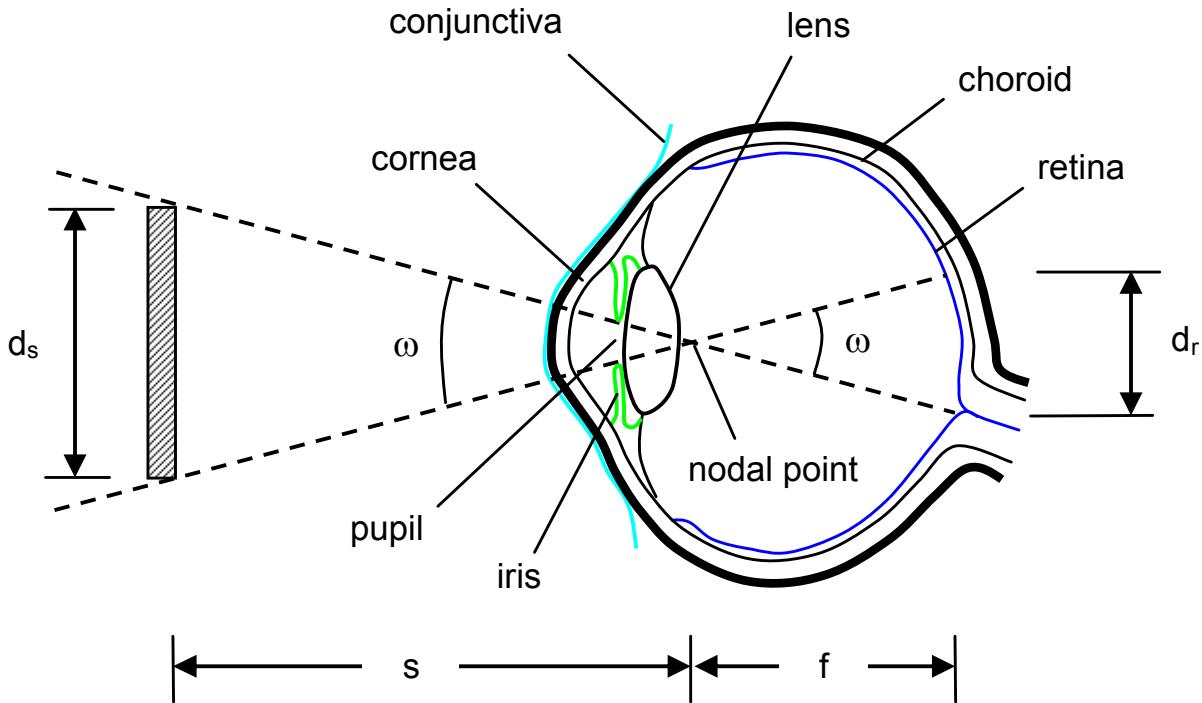
(Pertaining to CSP Glint and Glare)



- 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
  - Derived explicit equations to determine distances that cause retinal burn and temporary flash blindness for specular glare
  - Introduced web-based tool

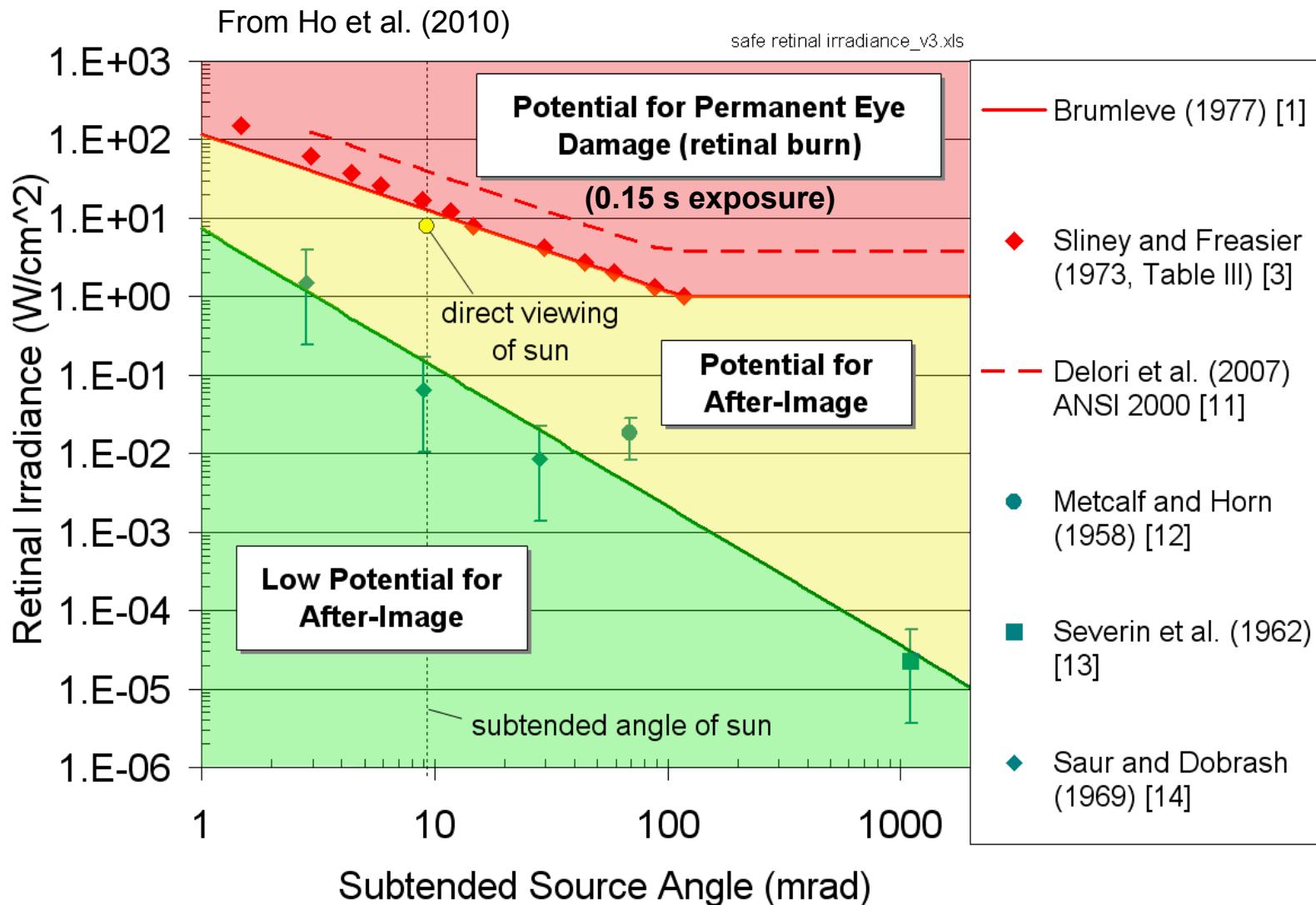
# Glare Analysis

# 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

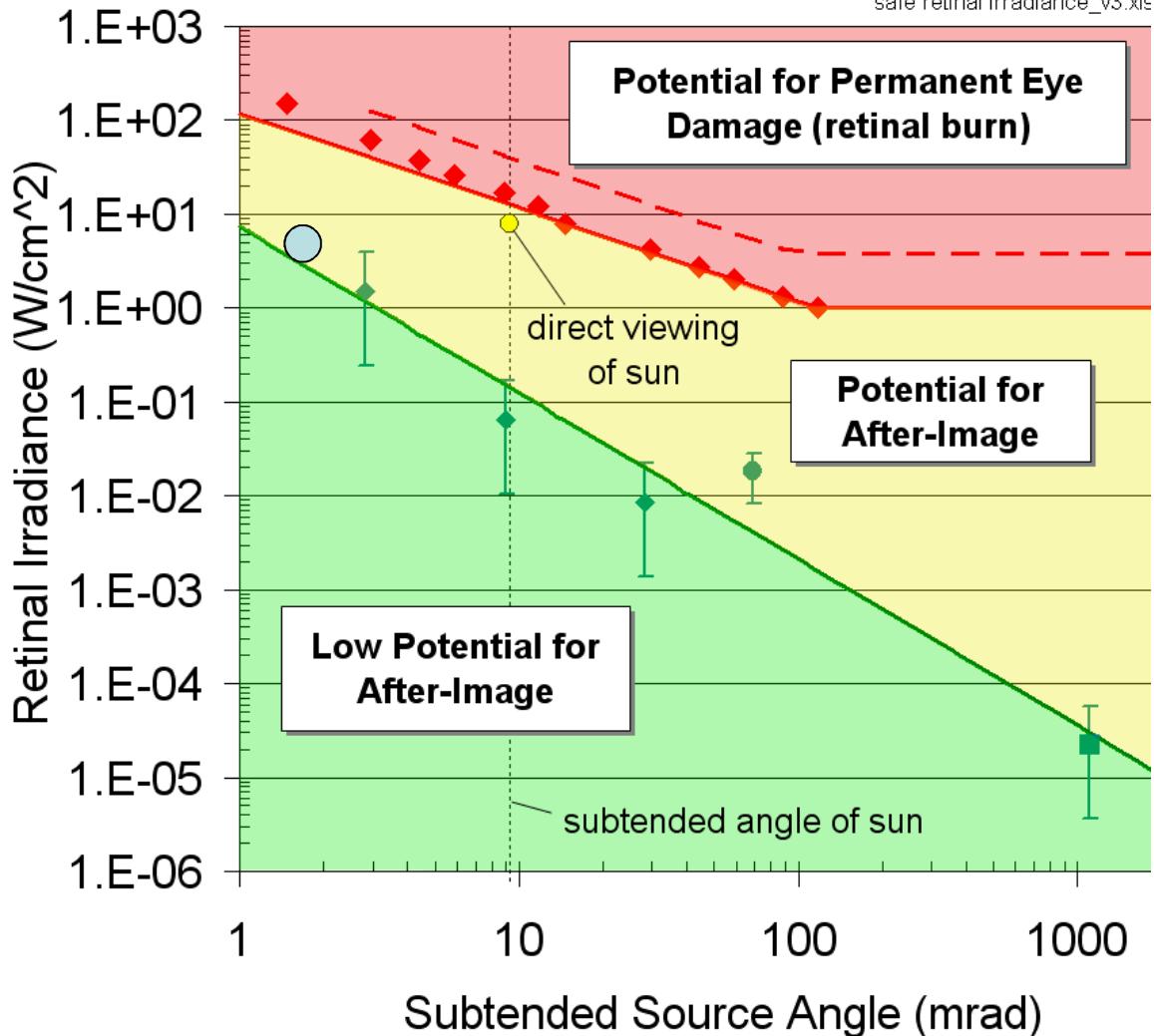


# Analysis Steps

(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

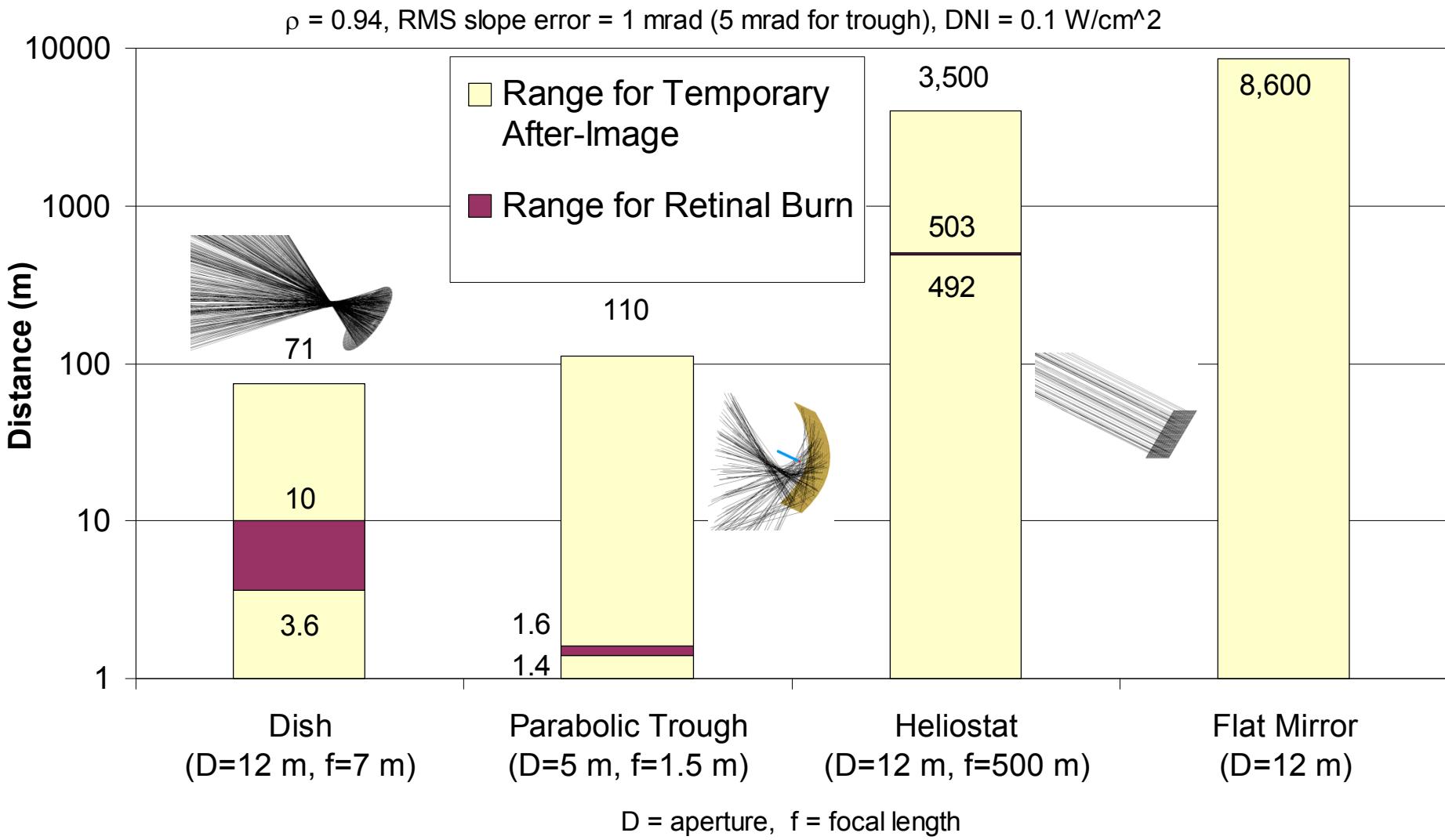
focal length = 7 m

50 m viewing  
distance

○ ⇒ Retinal irradiance  
= 5 W/cm<sup>2</sup>

⇒ Subtended source  
angle = 1.8 mrad

# Distances for Retinal Burn and Temporary After-Image



# Glare Web Tool

# PHLUX Web Tool

## Photographic Flux Tools for Solar Glare and Flux Mapping

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

File Edit View History Bookmarks Tools Help

sanda.gov https://share.sandia.gov/glare/

Sandia National Laboratories https://share.sandia.gov/glare/ Employee Locator | Index | Site Map

About | Mission Areas | Newsroom | Careers | Doing Business | Education | Contact Us

**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.

**Contacts:**

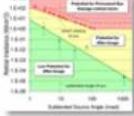
Clifford K. Ho  
[ckho@sandia.gov](mailto:ckho@sandia.gov)  
(505) 844-2384

Siri Sahib S. Khalsa  
[sskhals@sandia.gov](mailto:sskhals@sandia.gov)  
(505) 844-1229

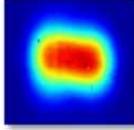
**Empirical Glare Analysis**  
Upload Glare Photos



**Analytical Glare Analysis**



**Flux Mapping Analysis**  
Upload Receiver Photos



©2010 Sandia Corporation | Questions and Comments | Privacy and Security | News release RSS feed

Done

# Empirical Analysis



Images are uploaded with relevant information

Digital photographs are taken of the glare

Empirical Analysis - Mozilla Firefox

File Edit View History Bookmarks Tools Help

sandia.gov https://share.sandia.gov/glare

Empirical Analysis

Analysis Title:

Reflection Raw Image:

Sun Raw Image:

Reflection Image Filter Factor:

Sun Image Filter Factor:

DNI (W/m<sup>2</sup>):

Number of Points for Irradiance Plots:

Analyze

Done

# Selection Tools

Empirical Analysis - Mozilla Firefox

File Edit View History Bookmarks Tools Help

sandia.gov https://share.sandia.gov/glare/cgi-bin/upload.cgi

Empirical Analysis

## Uploading Images... Done!

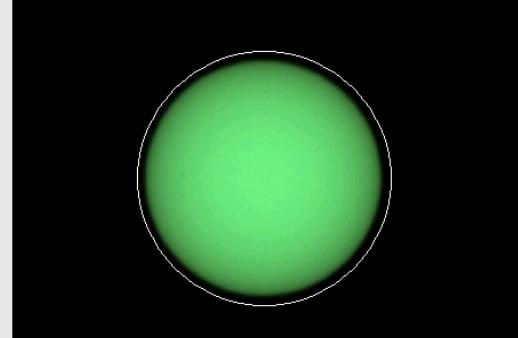
### Sun Image

Ellipse Definition

Axis 1, Point 1, x (pixels):	1276	Axis 1, Point 1, y (pixels):	920
Axis 1, Point 2, x (pixels):	1523	Axis 1, Point 2, y (pixels):	1187
Axis 2 Length (pixels):	364	<input type="button" value="Done"/>	

Measurement Tools

Image Measurement



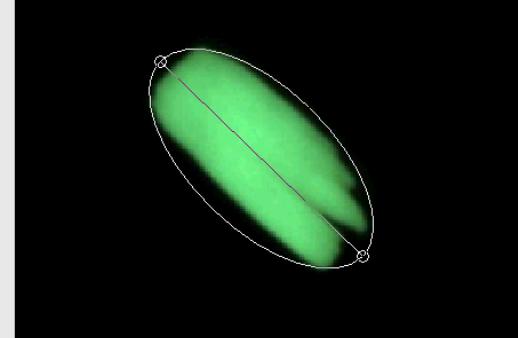
### Reflection Image

Ellipse Definition

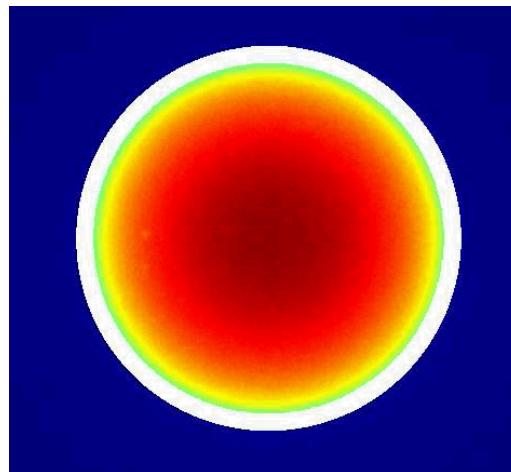
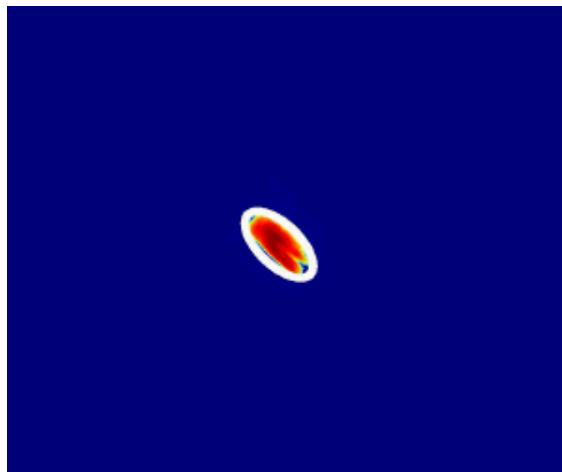
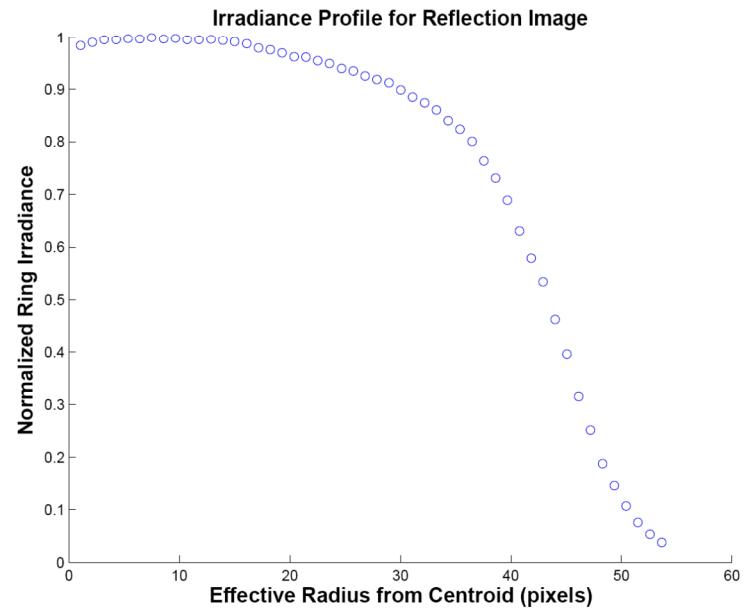
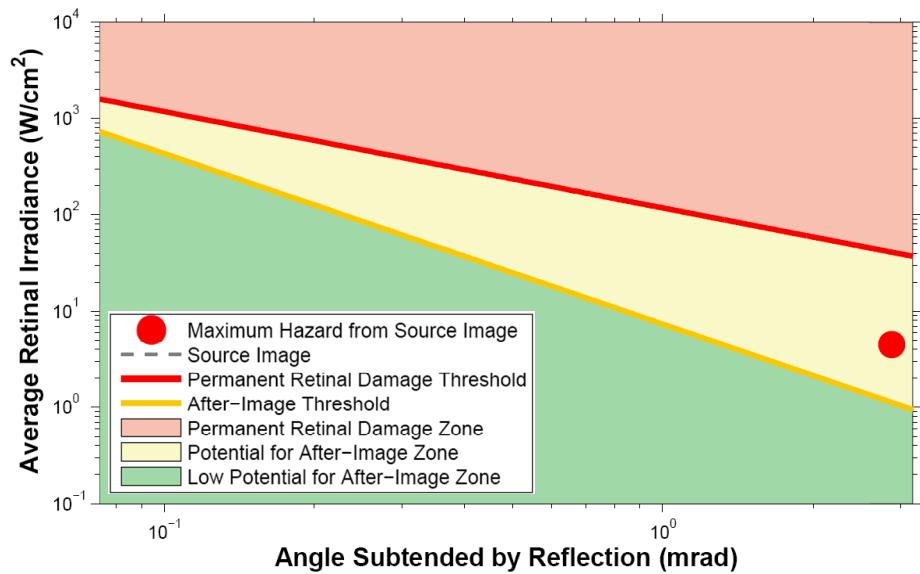
Axis 1, Point 1, x (pixels):	1487	Axis 1, Point 1, y (pixels):	974
Axis 1, Point 2, x (pixels):	1593	Axis 1, Point 2, y (pixels):	1075
Axis 2 Length (pixels):	73	<input type="button" value="Done"/>	

Measurement Tools

Image Measurement

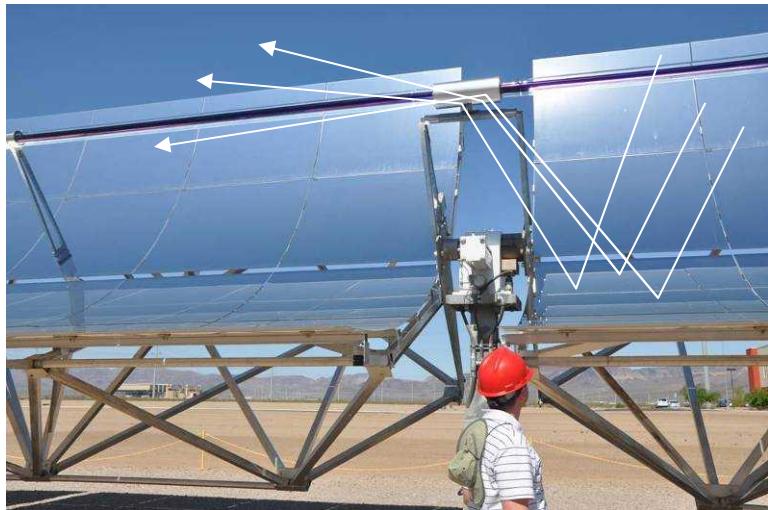
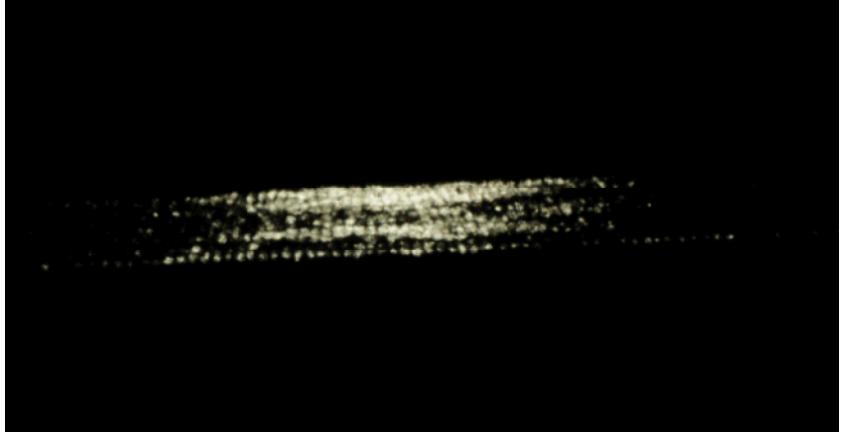


# Output



# Recent Examples of Glare from CSP Facilities

# Concentrated Glare from Troughs



# Nevada Solar One



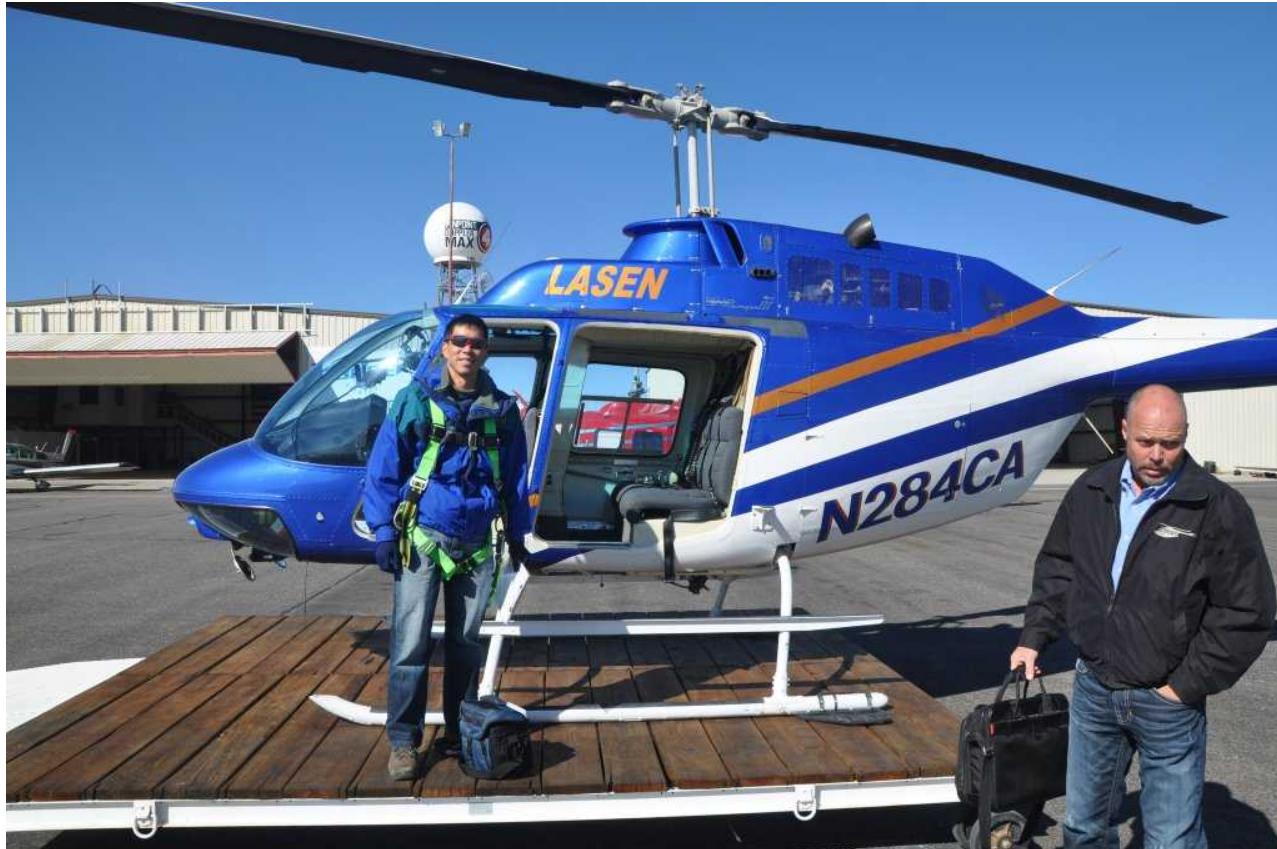
Drive-by video of Nevada Solar One Glare, Boulder City, NV (6/29/10, noon)

# Kramer Junction



Air Force Flyovers (F-16 and C-12) of Kramer Junction Parabolic Trough Plant in 2010 (CA)

# Helicopter Flyover of NSTTF



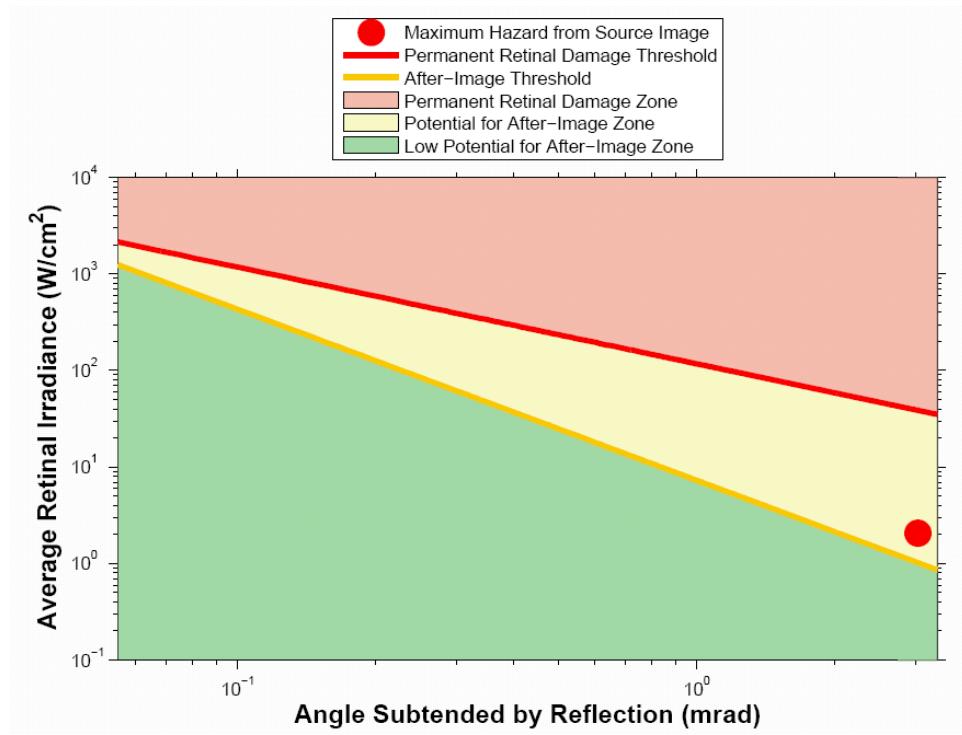
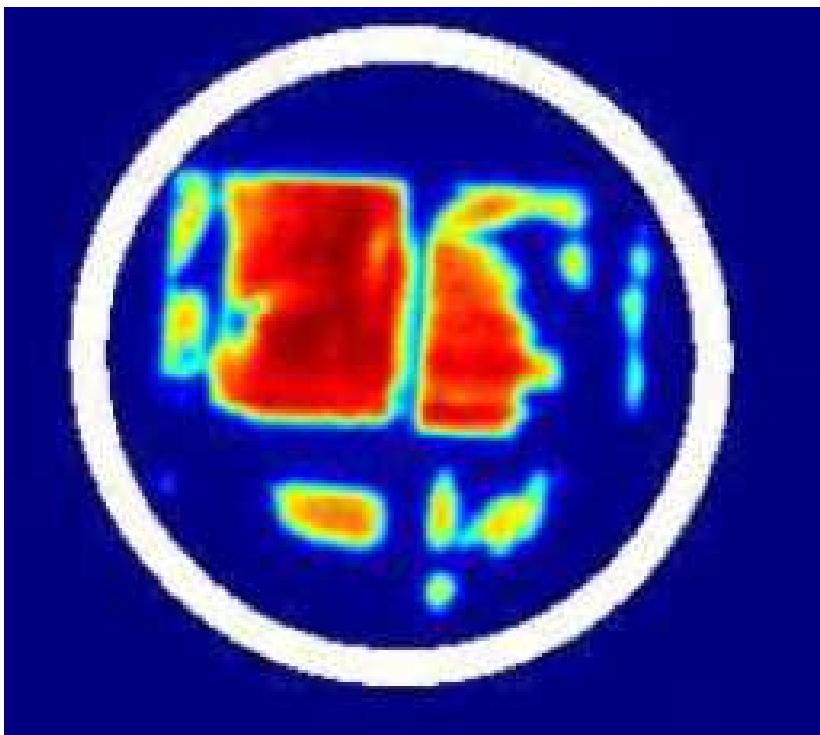
November 10, 2010







# Glare Analysis



# Summary

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