Presentation to FAA

February 16, 2011

Summary of Impact Analyses of Renewable Energy Technologies on Aviation and Airports

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Overview

- **Introduction**
- **Glint and Glare Analysis**
- **Thermal Signature Analysis**
- **Summary**

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"

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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

Overview

- Introduction
- Glint and Glare Analysis
- Thermal Signature Analysis
- 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)

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Examples of Glint/Glare

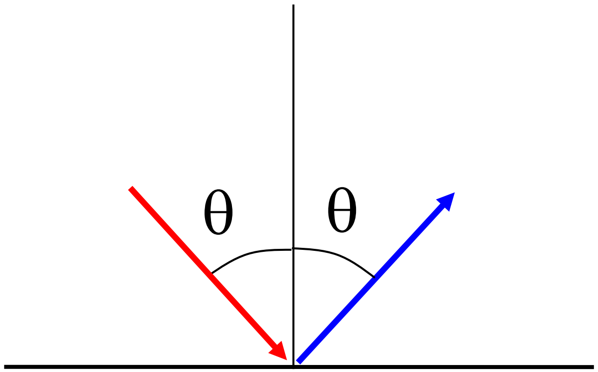
Solar One
(10 MW_e power tower, Daggett, CA)

Central Receiver Test Facility
(SNL, NM)

National Solar Thermal Test Facility
(SNL, NM)

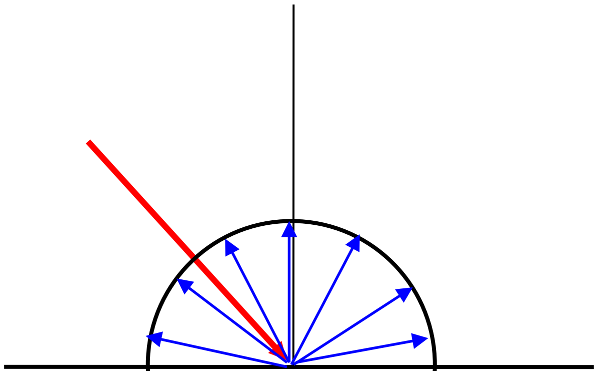
Kramer Junction
(150 MW_e parabolic trough, Mojave Desert, CA)

Glare Types



Specular
Reflection

(polished surfaces;
e.g., mirrors)



Diffuse
Reflection

(rough surfaces;
e.g., receivers)

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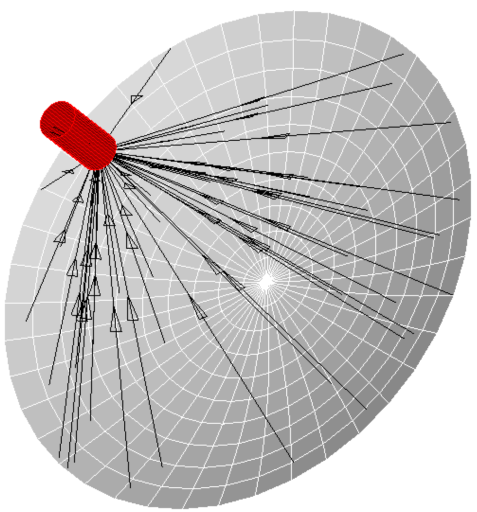
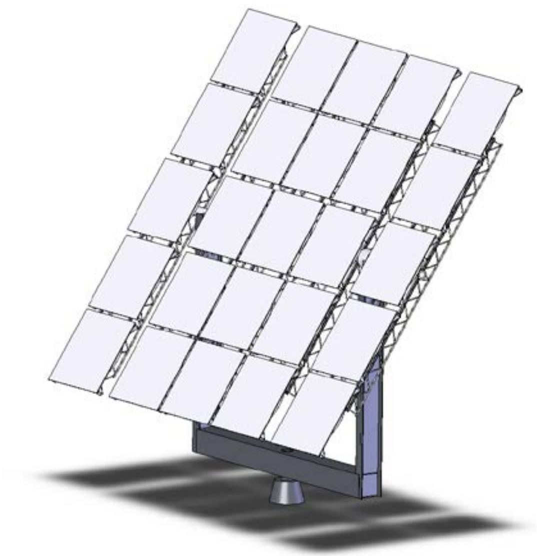
Specular Reflections

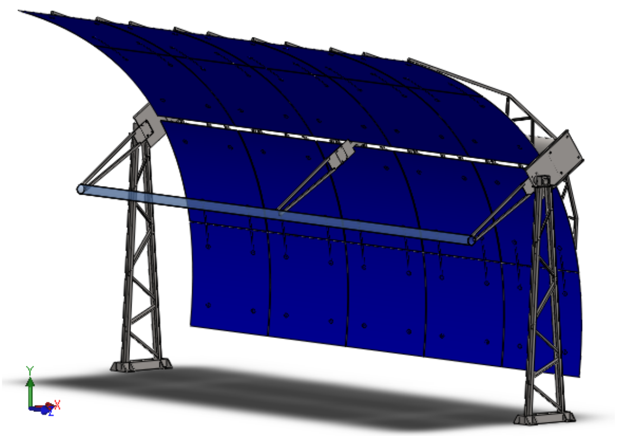
- **Point Focus and Line Focus Collectors**



Dish



Heliostat



Parabolic Trough

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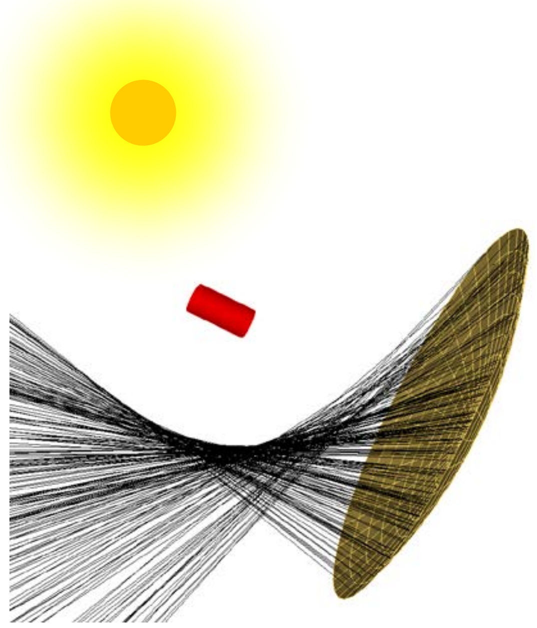
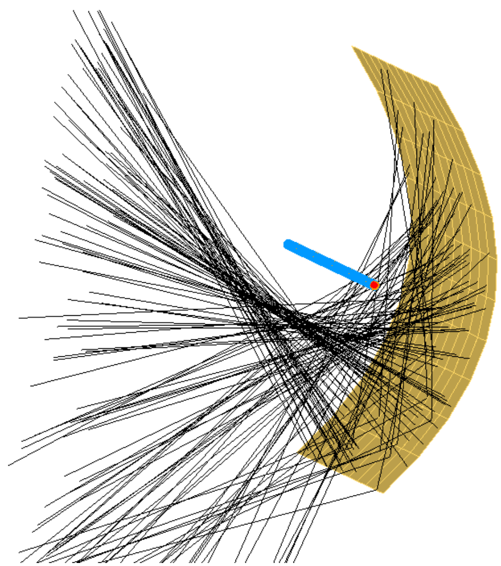
Specular Glare

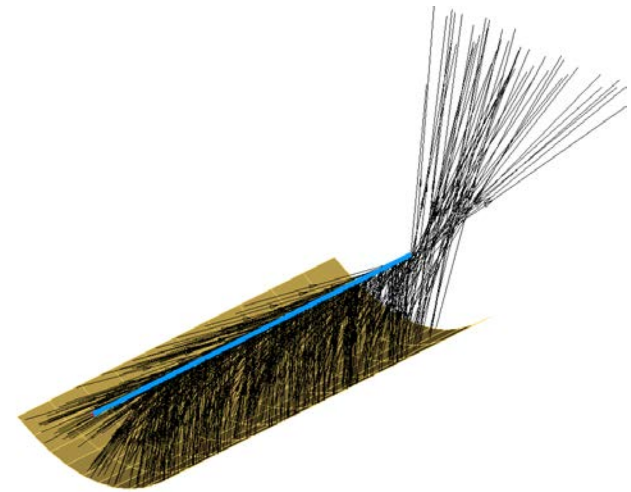
- **Potential for glint and glare from collectors**
  - Off-axis; misalignment; moving to or from stow/standby
  - End-loss and spillage for troughs



Off-axis Dish



Off-axis Trough



End-Loss from Trough

Previous Work

(Pertaining to CSP Glint and Glare)

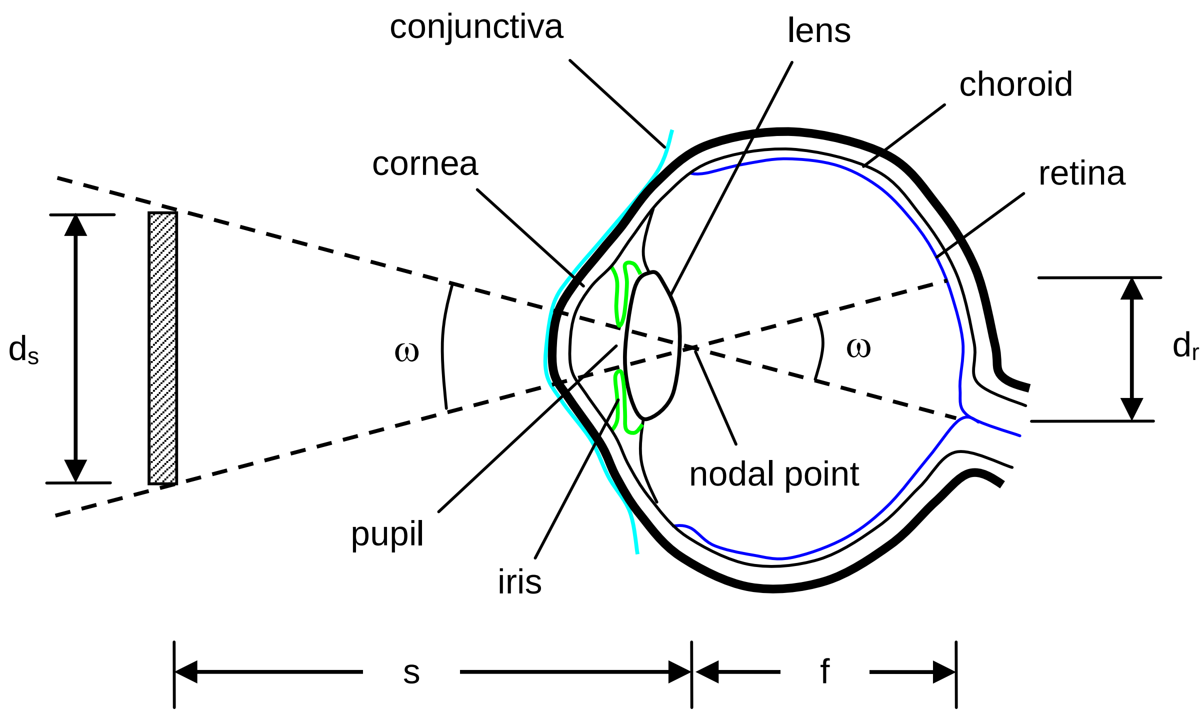
- **1976-1984: Brumleve, T.D., SAND76-8022 and SAND83-8035**
  - Performed analysis and tests of glare from heliostats and receivers using retinal burn metrics from Sliney and Freasier (1973)
  - Determined exclusion zones and developed beam control strategies
- **2009: Ho, C.K., C.M. Ghanbari, and R.B. 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

Glare Analysis

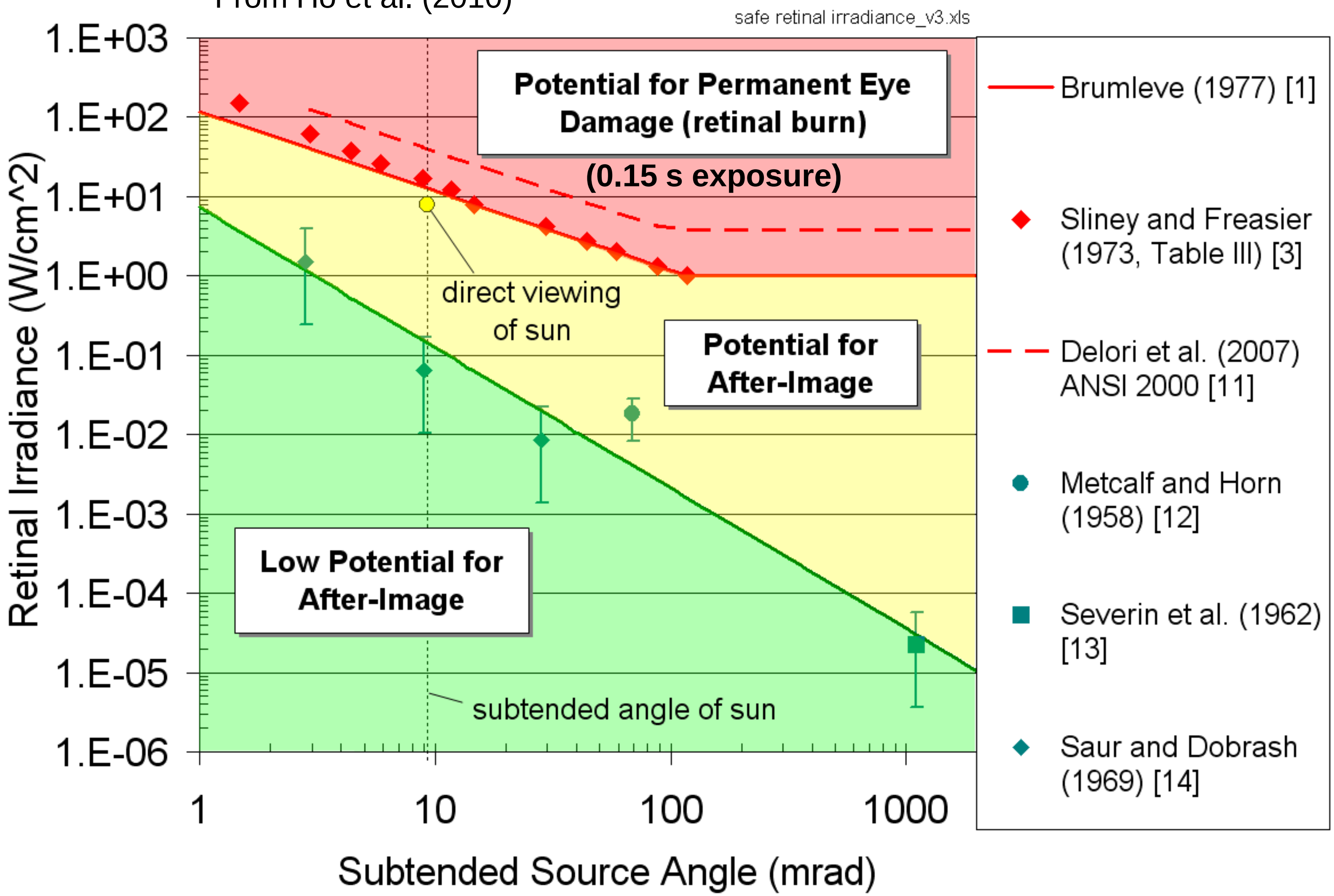
Retinal Irradiance



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

Potential Impacts

From Ho et al. (2010)



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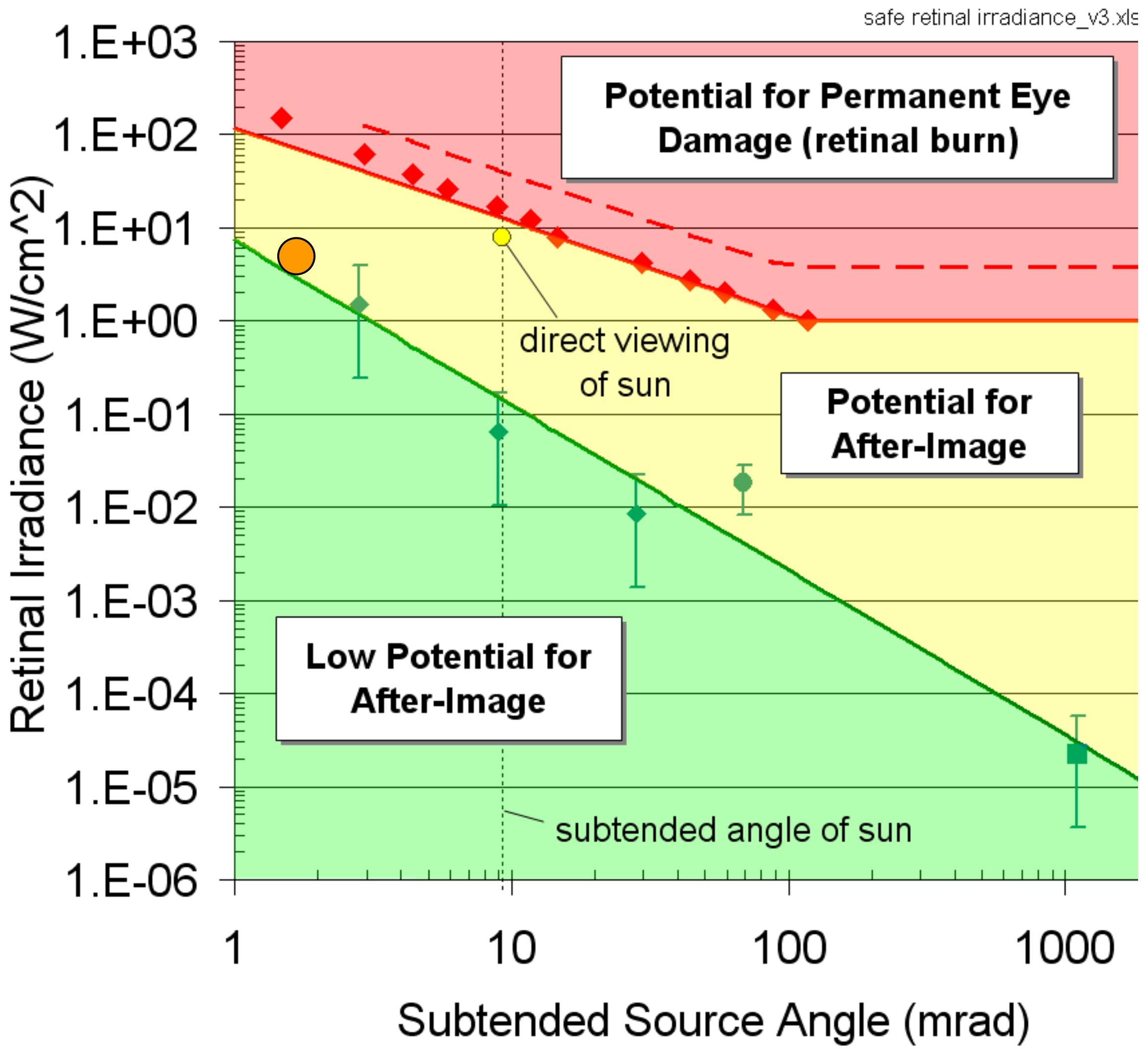
Analysis Steps
(from ASME ES2010 paper)

- **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

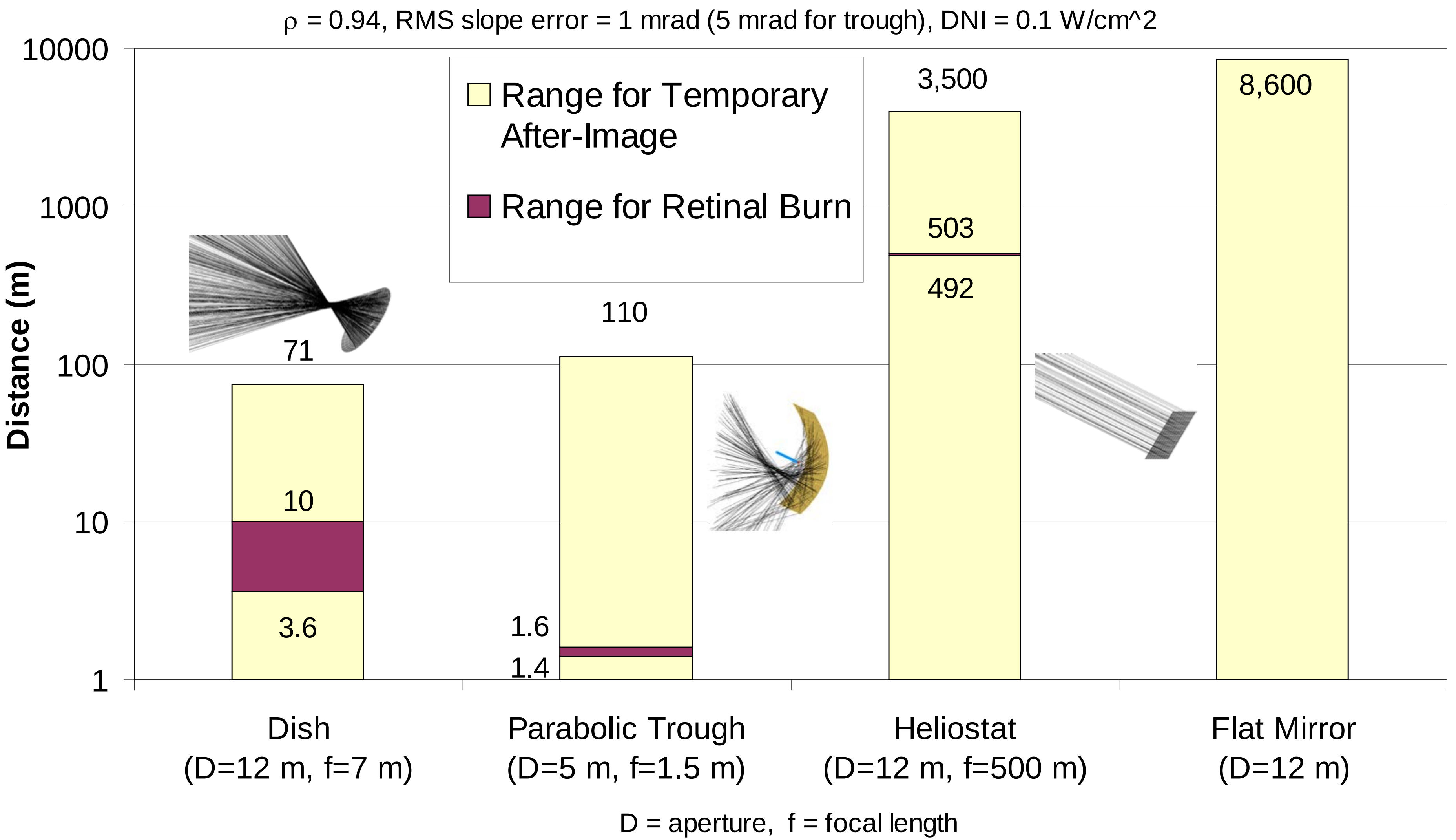
focal length = 7 m

50 m viewing distance

⇒ Retinal irradiance = 5 W/cm^2

⇒ Subtended source angle = 1.8 mrad

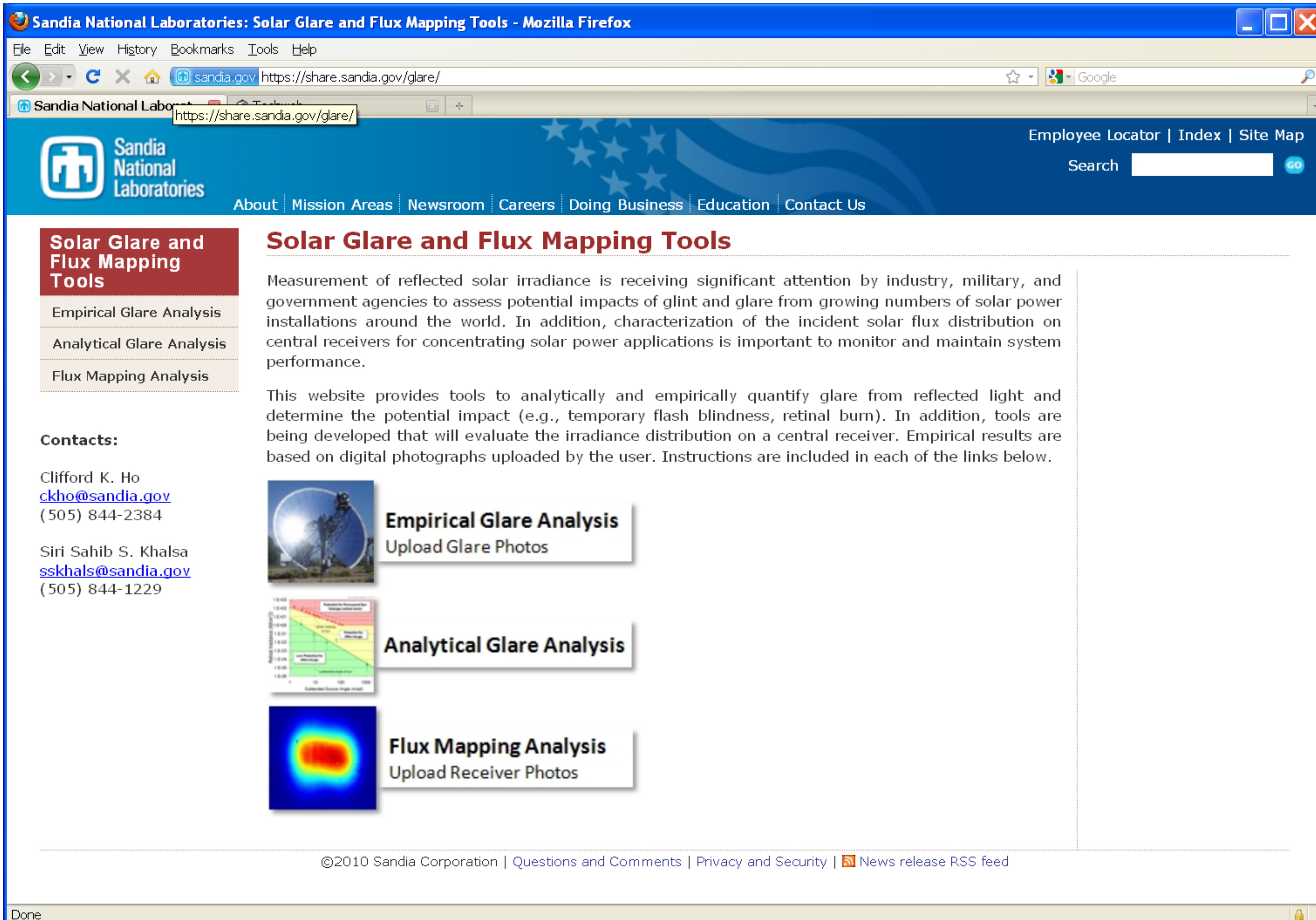
Distances for Retinal Burn and Temporary After-Image



Glare Web Tool

PHLUX Web Tool

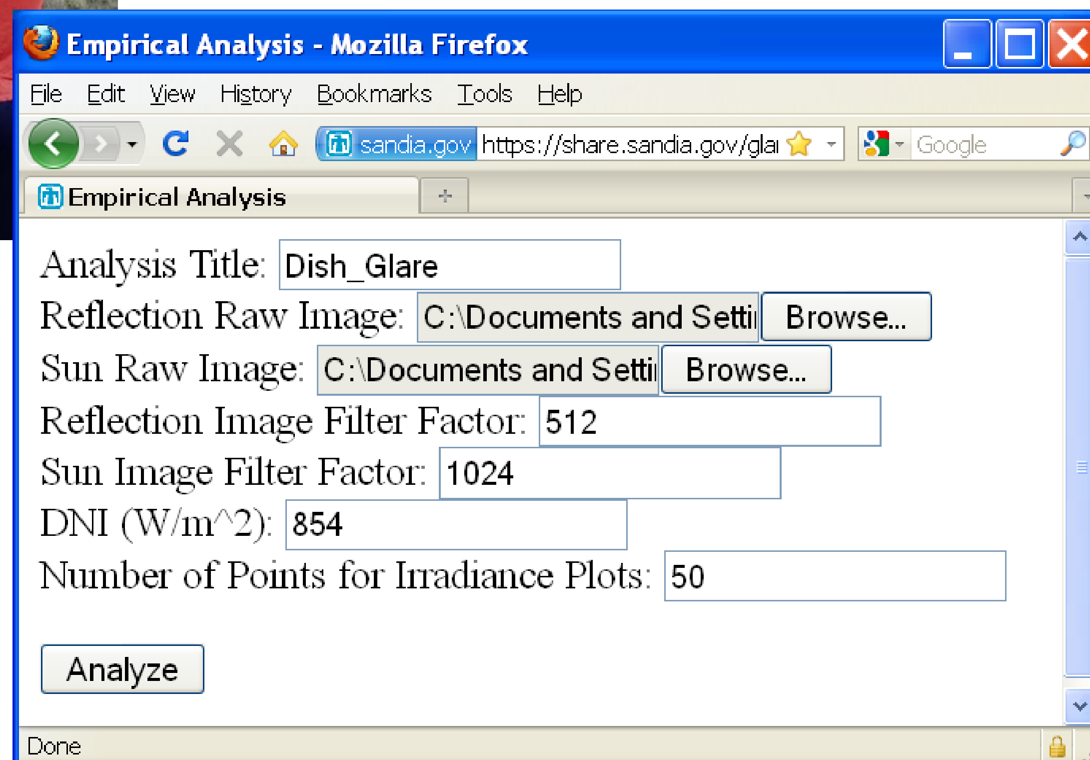
Photographic Flux Tools for Solar Glare and Flux Mapping



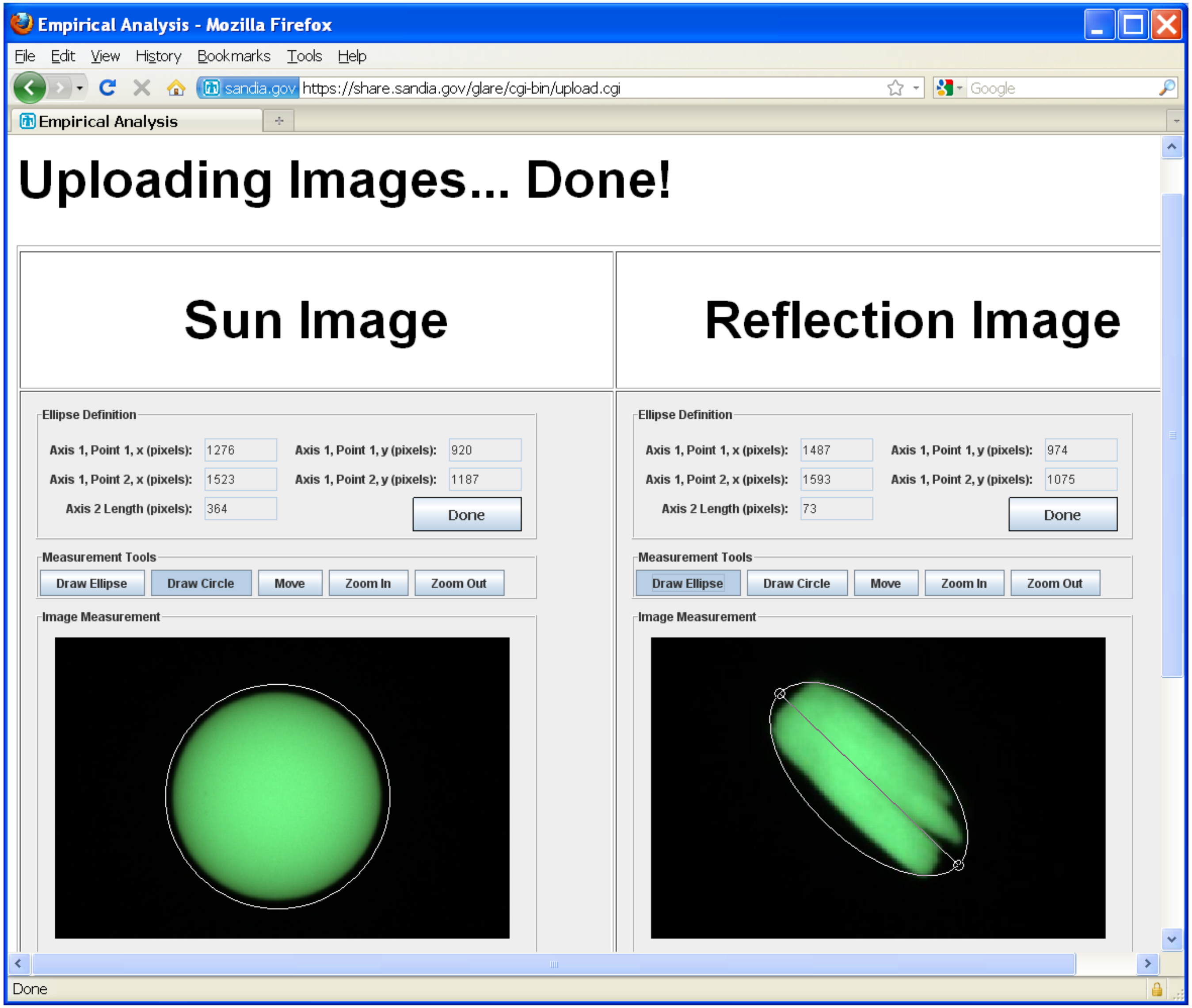
Empirical Analysis

Digital photographs are taken of the glare

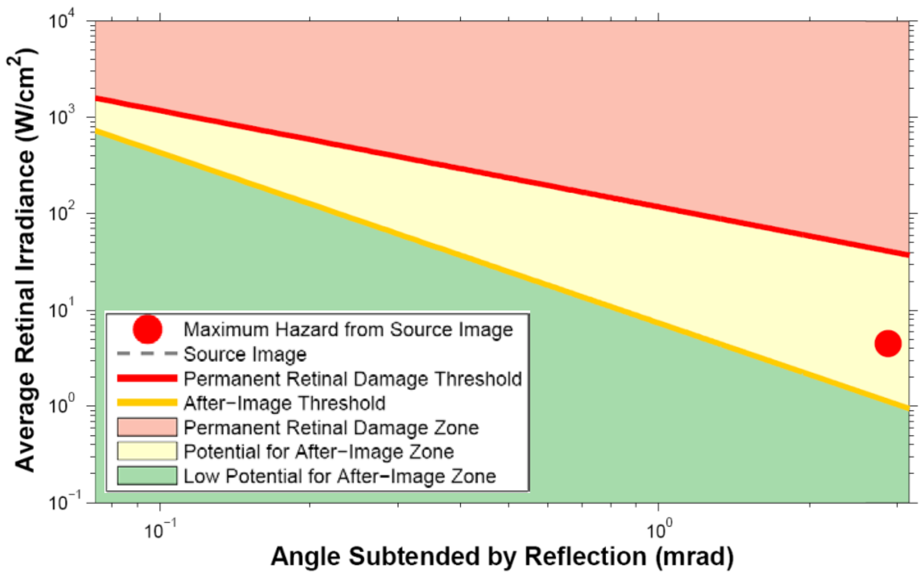
Images are uploaded
with relevant information



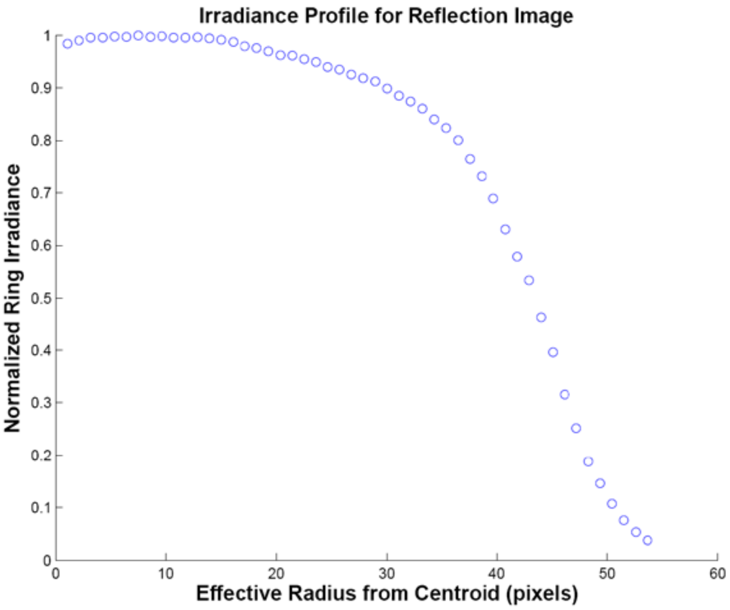
Selection Tools



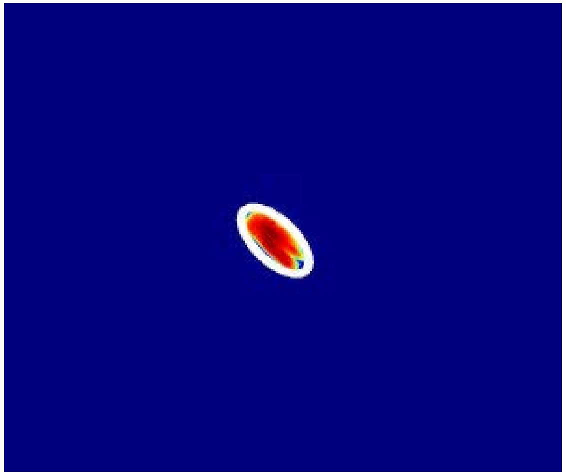
Output

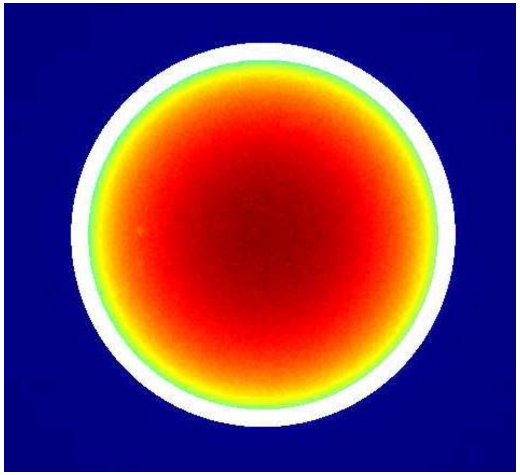


Average Retinal Irradiance (W/cm^2)
Angle Subtended by Reflection (mrad)
Maximum Hazard from Source Image
Source Image
Permanent Retinal Damage Threshold
After−Image Threshold
Permanent Retinal Damage Zone
Potential for After−Image Zone
Low Potential for After−Image Zone



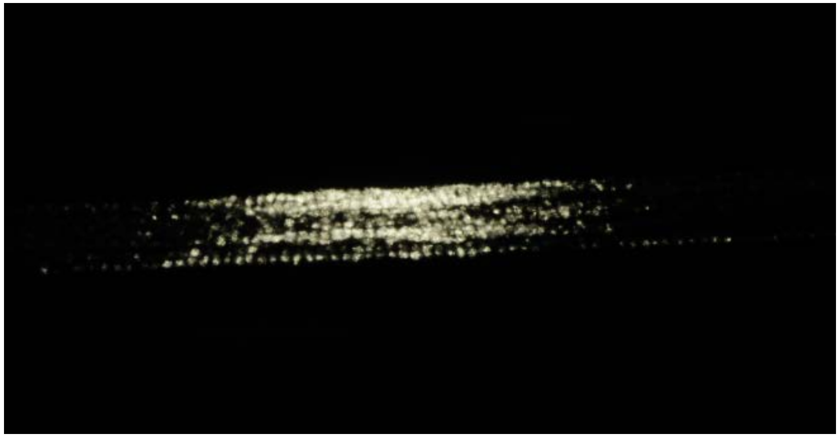
Irradiance Profile for Reflection Image
Normalized Ring Irradiance
Effective Radius from Centroid (pixels)

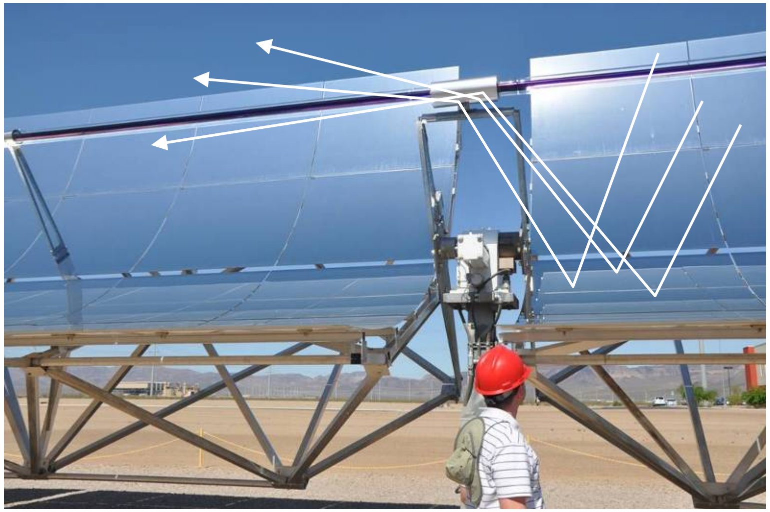




Recent Examples of Glare from CSP Facilities

Concentrated Glare from Troughs





Nevada Solar One

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

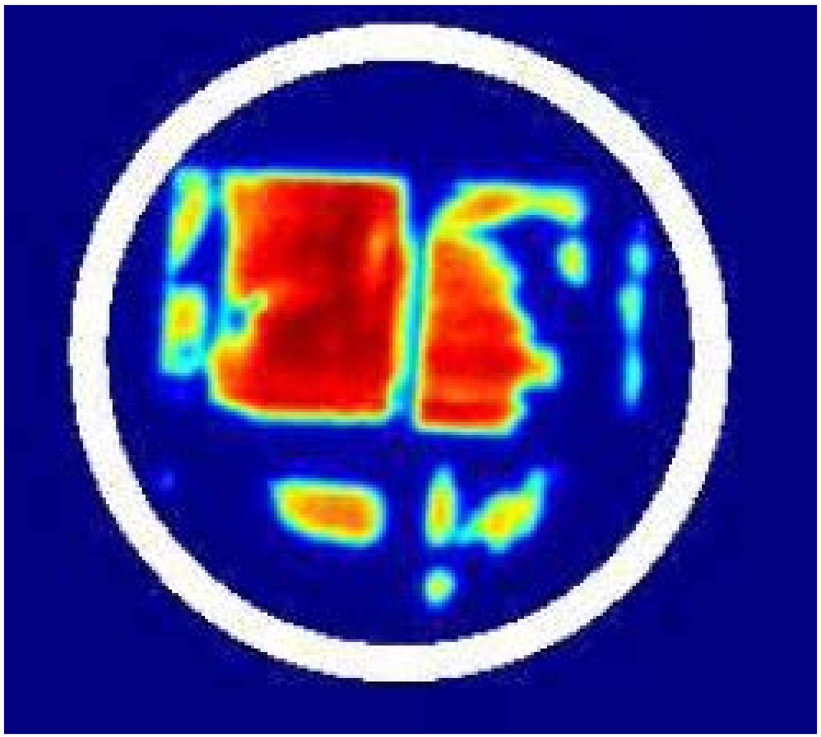
Kramer Junction

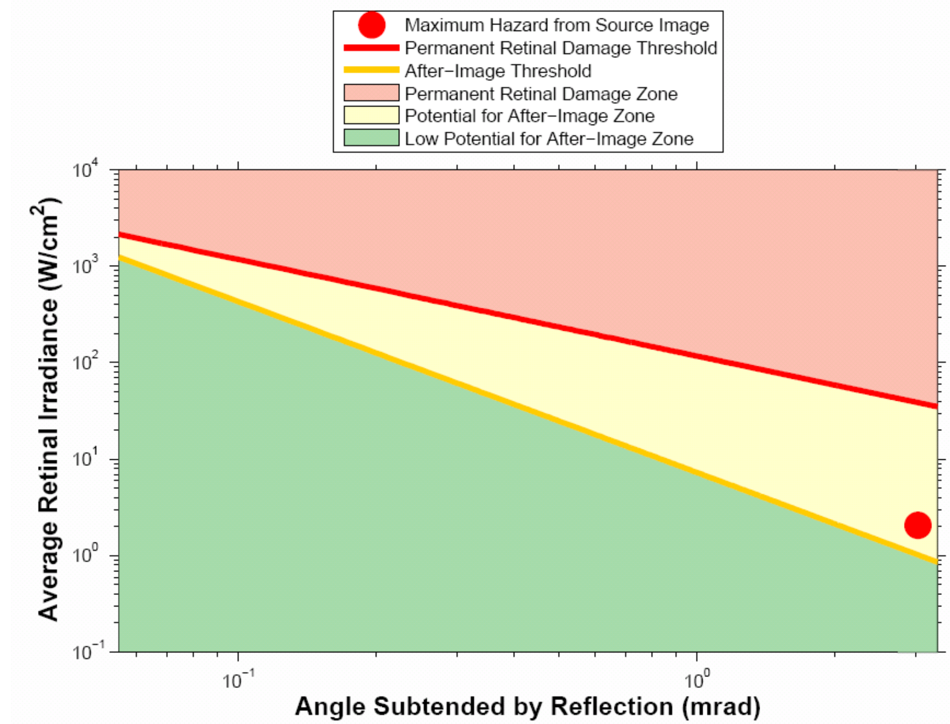
Air Force Flyovers (F-16 and C-12) of Kramer Junction Parabolic Trough Plant in 2010 (CA)

Helicopter Flyover of NSTTF

November 10, 2010

Glare Analysis





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Infrared Emissions

- **Heated objects can emit infrared radiation that may interfere with infrared sensors**

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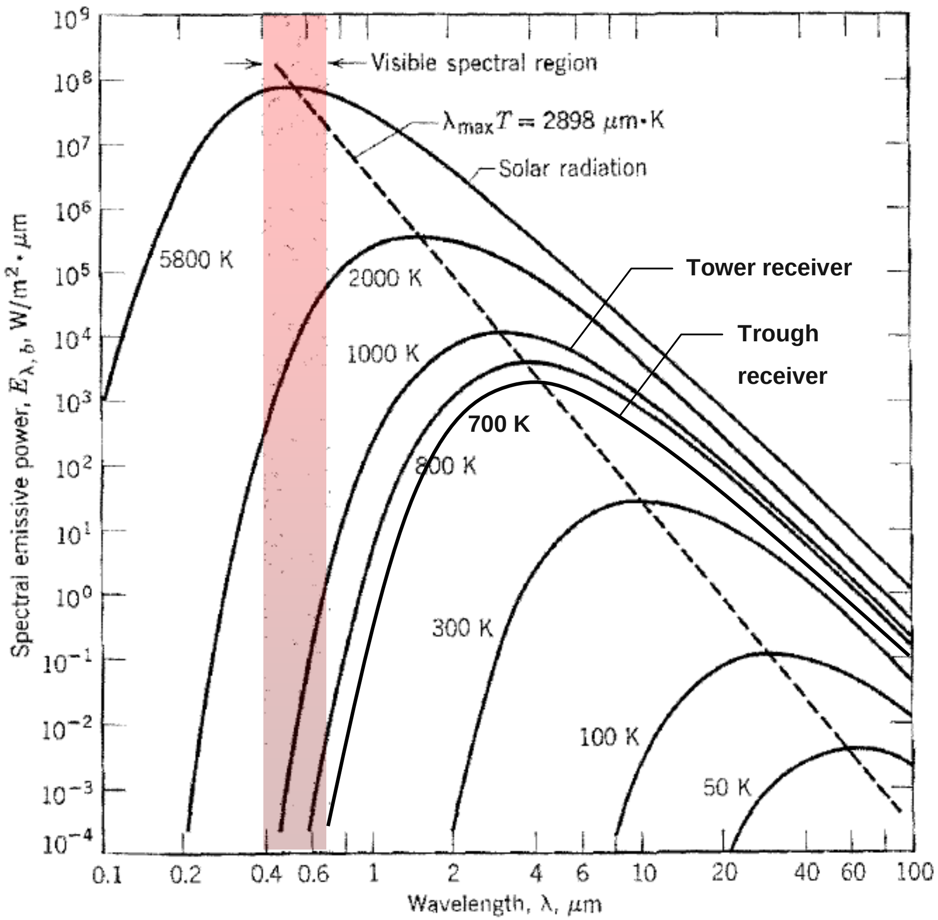
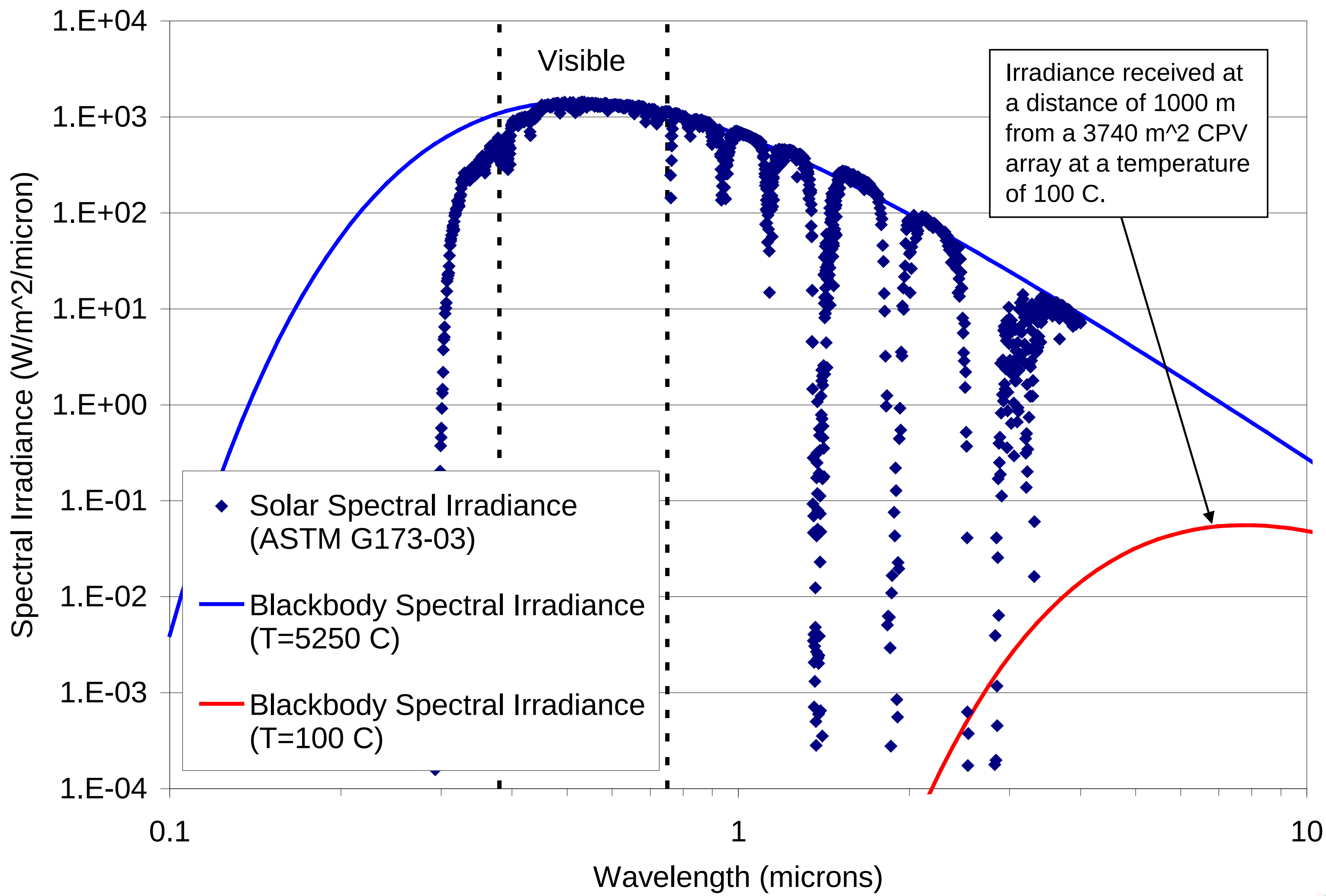
Spectral Emissive Power



Spectral blackbody emissive power as a function of wavelength and temperature (adapted from Incropera and DeWitt, 1985).

Example of Irradiance Received from Hot Photovoltaic Array



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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
  - Models have been validated with test data
  - Web tool has been developed

- **Infrared emissions from heated objects can interfere with infrared sensors**
  - Provide quantification of spectral irradiance for different technologies
    - Temperature and time dependent (e.g., cooling of tower receiver)

Summary

- **Identification and quantification of potential impacts will help agencies to develop appropriate mitigations, measures, and/or requirements**
  - California Energy Commission
  - Air Force
  - FAA
  - National Academies – Transportation Research Board