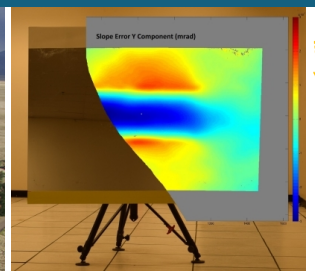
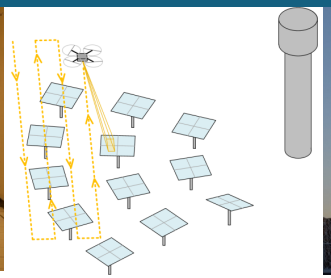
SAND2024-12936C

Sandia National Laboratories

OpenCSP: Collaborative Code and Data for CSP



OPEN CSP

Randy C. Brost, Benjamin Bean, Felicia Brimigion, Margaret Gordon, Evan Harvey, Madeline Hwang, Tristan Larkin, Miranda Mundt, Nicholas Phelps, Braden Smith, and Carly Tanaka-Lubensky

October 11, 2024

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SAND2024-12936C

Overview

- Why OpenCSP?
- OpenCSP Goals
- Example OpenCSP Content
- How to Access OpenCSP
- Conclusion

Concentrating Solar Optics Laboratory (CSOL):

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Dan Small
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NSTTF Team

We thank:

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
SOLAR ENERGY TECHNOLOGIES OFFICE

Sandia National Laboratories | LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Why OpenCSP?

From the United Nations Framework Convention on Climate Change:[1]

"To limit global warming to 1.5°C, greenhouse gas emissions must peak before 2025 at the latest and decline 43% by 2030."

It is now late 2024. If the CSP community is to contribute to meeting this goal, it must proceed with great urgency.

[1] United Nations Framework Convention on Climate Change. The Paris Agreement. https://unfccc.int/process-and-meetings/the-paris-agreement.

https://opencsp.sandia.gov

OpenCSP Goals

1. ***Accelerate*** transfer of state-of-the-art CSP metrology and analysis tools to industry.
2. Provide a collaborative development environment to aid collaborative CSP research.
3. Support CSP education.

- ❖ Remove barriers to access.
- ❖ Make widely available.
- ❖ Provide an effective collaboration environment.

Inspired by other successful open-source collaborative projects:

- Linux
- Pyomo
- OpenCV
- pvlib

OpenCSP Components

- **OpenCSP_Code** Foundation classes for building new code, plus ready-to-run programs, including SOFAST 2.0.
- **OpenCSP_Data** Large data sets to support collaborative research, plus code test data.
- **OpenCSP_Mechanical** Interactive CAD tool for SOFAST layout, plus gallery of CAD models.
- **OpenCSP_Tools** Non-code tools to aid CSP analysis and understanding.
- **OpenCSP_Documents** Supporting OpenCSP and related topics.
- **Web Portal** Welcomes users and developers to OpenCSP.

All under an open-source license allowing unlimited use.

Example OpenCSP Content

OpenCSP Code

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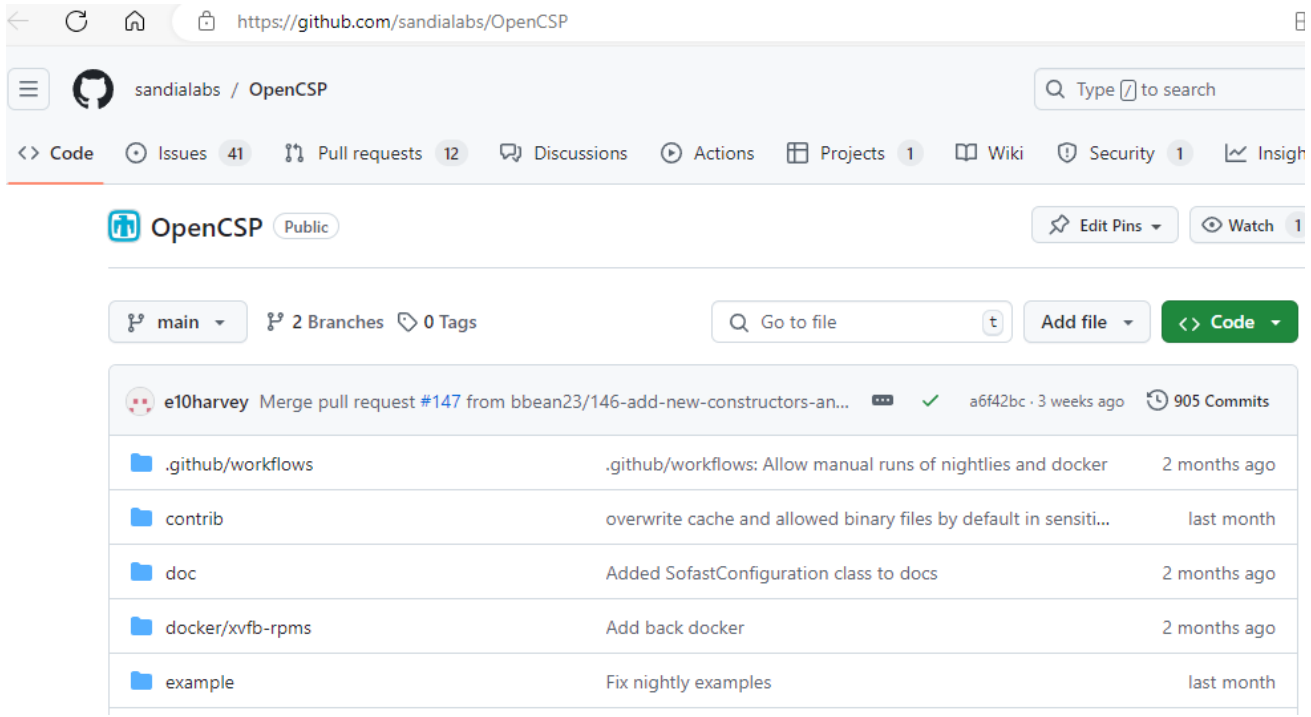
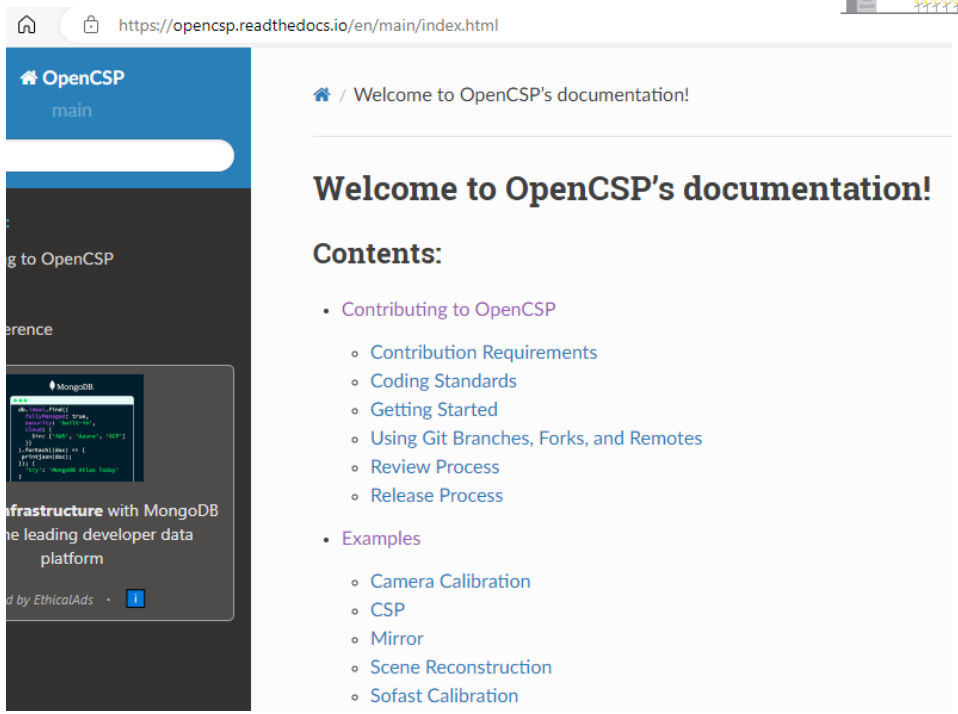
Collaborative Code Development Environment





<u>Description:</u>

The OpenCSP code development environment supports team development of high quality code across institutions.

- Git fork/branch protocol
- Code style standards
- Fast development cycle automated testing
- Detailed overnight automated testing
- Pull request reviews
- Issue tracking/management
- Automatic documentation generation
- Rich set of code examples
- Supplementary documents (Getting started guide,…)

OpenCSP encourages interested developers to join the CSP team.

<u>Status:</u> Operational.

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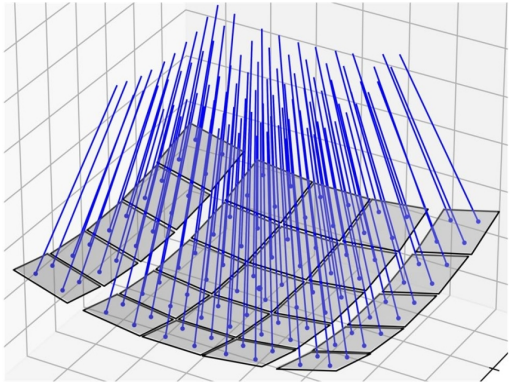
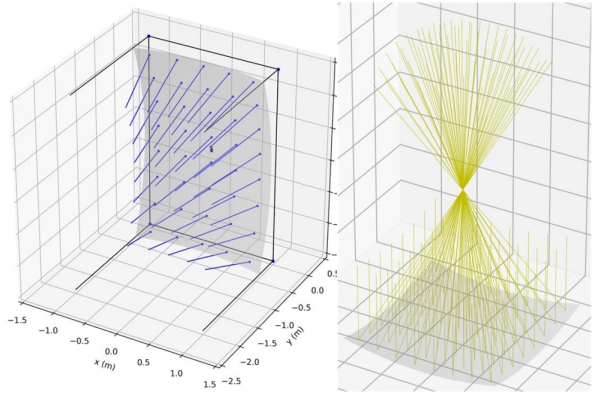
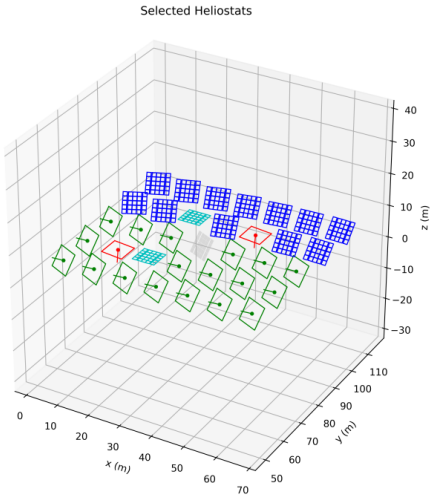
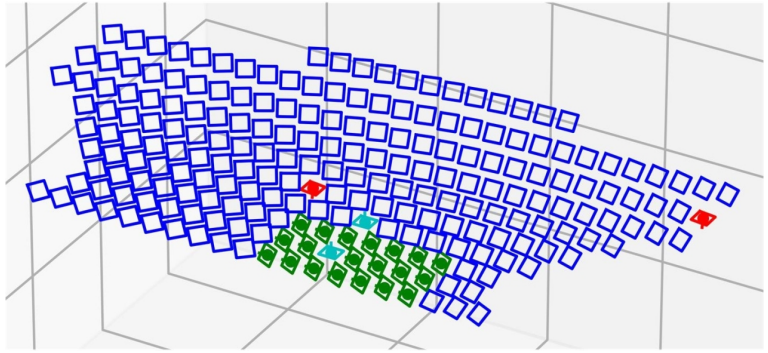
Foundation Classes









Description:

General-purpose representation of collector objects:

Mirror → Facet → FacetEnsemble → Heliostat → SolarField

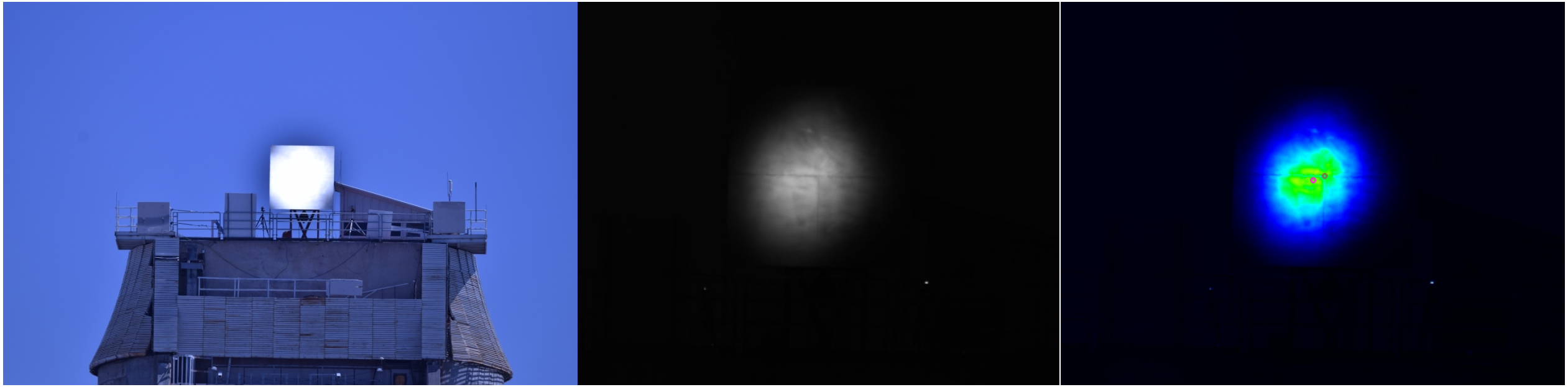
These offer a variety of supporting functions.

Utility examples: Ray tracing, video handling.

Status: Operational, extensions welcome.

Mirrors may be defined by analytic functions, measured data, or a combination of both.

SpotAnalysis



Description:
Generalized analysis of a beam of light on an optical target.

Examples:

- Beam Characterization System (BCS).
- Returned-spot analysis.
- Laser measurement methods.

Status: Functional, still in development.

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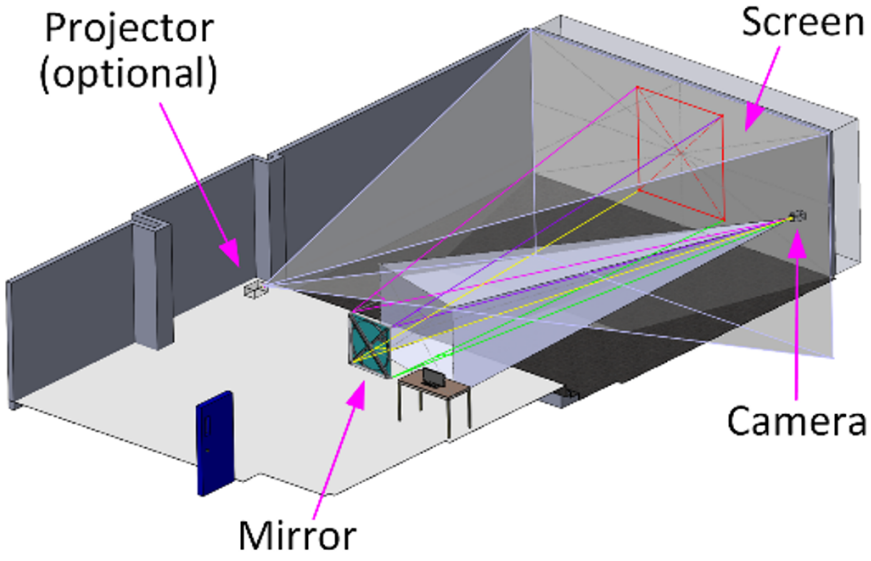
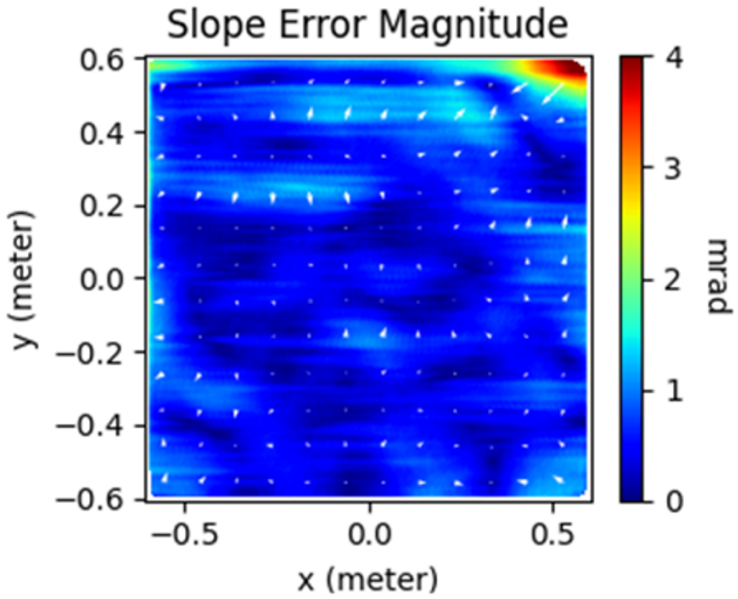
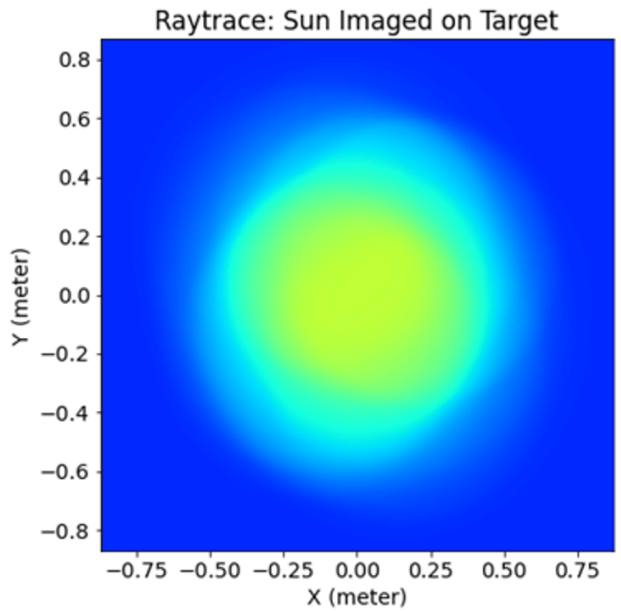
SOFAST 2.0







Description:

Measures maps of mirror optical slope.

- High-resolution fringe (projector) or medium-resolution fixed (daylight) modes.
- Variety of analytic outputs (absolute slope, slope deviation, curvature, comparison, ensquared energy,…).
- Built-in ray-tracing analysis.
- High speed.
- Script or GUI control.
- Flexible for a variety of environments.

Status: Operational.

See posters:
- SOFAST 2.0
- Hybrid Deflectometry

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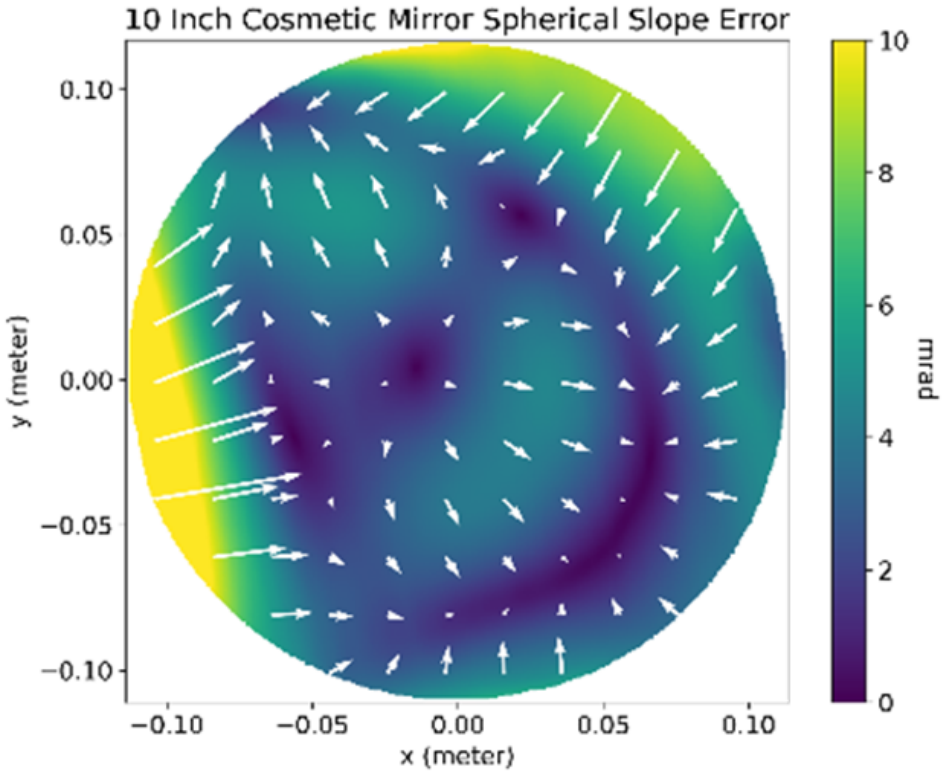
Laptop SOFAST



Description:
SOFAST 2.0 can run on many laptops, using built-in screen and camera.

Readily accessible, great for CSP education.

Status: Operational, but not documented.

See posters:
- SOFAST 2.0
- Hybrid Deflectometry

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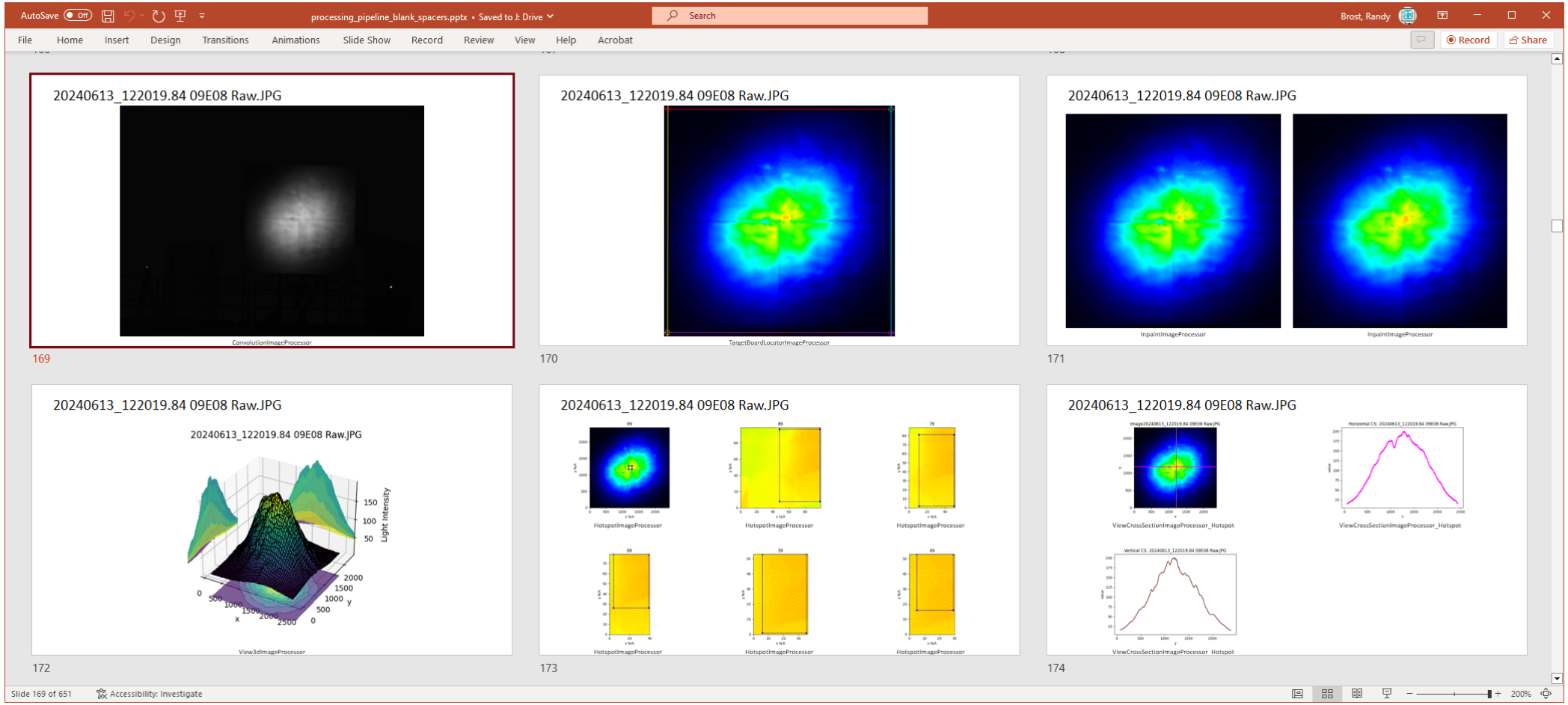
PowerPoint Slide Generation



Description:

- Automatic rendering of analysis in PowerPoint.
- Above excerpt from automatically-generated presentation with 651 slides.

Status: Operational.

OpenCSP Mechanical

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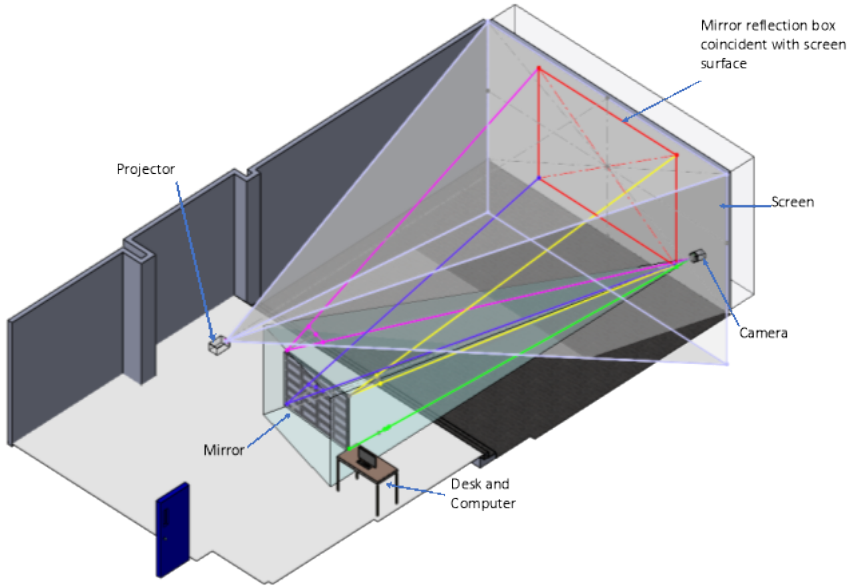
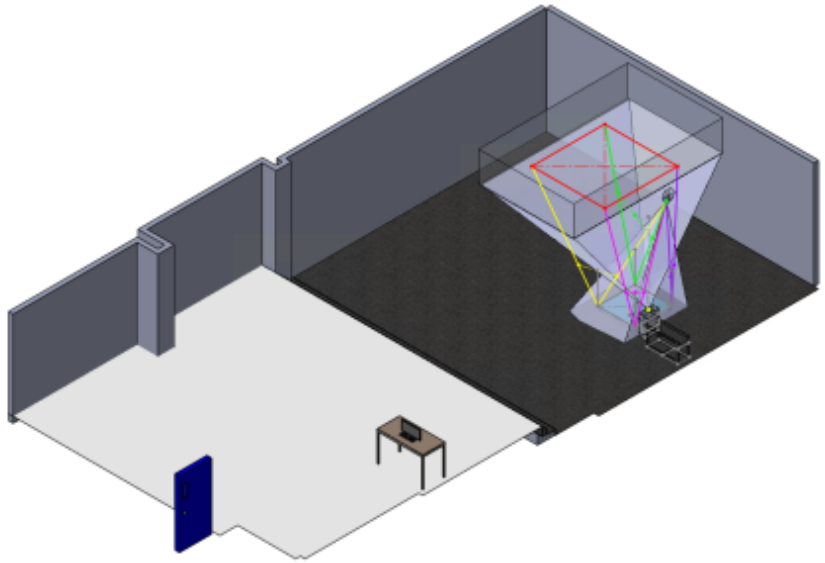
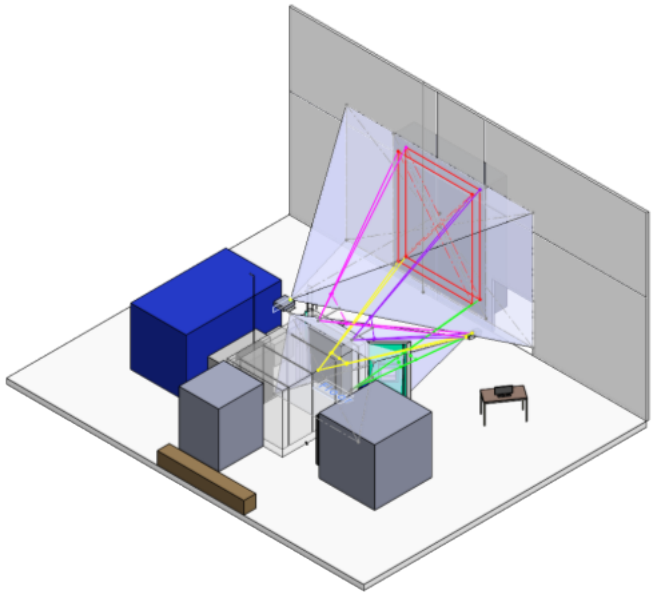
SOFAST CAD Layout Tool



Landscape



FaceUp



CFV Labs

Description:

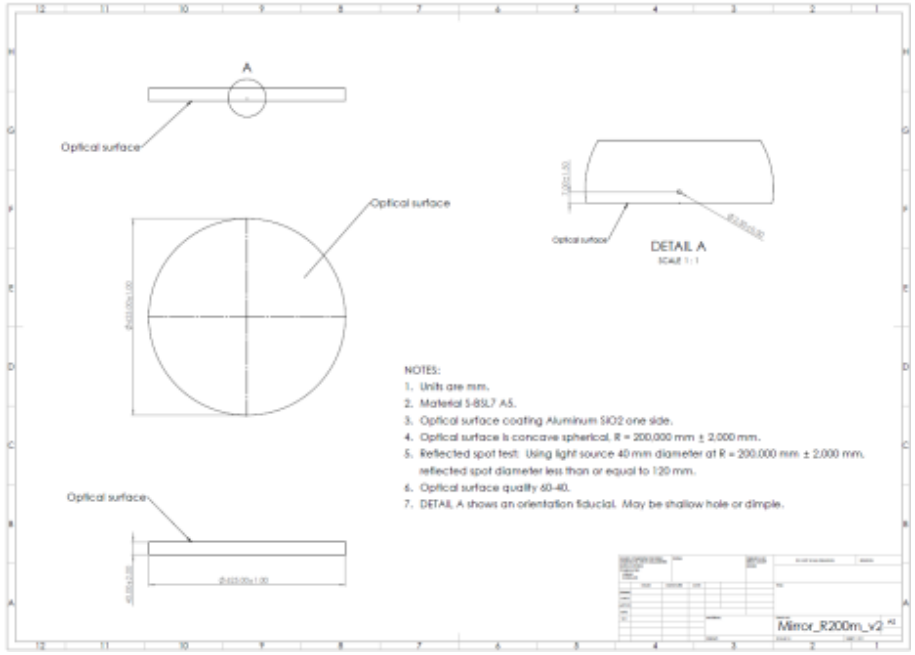
An interactive SolidWorks tool for designing a SOFAST layout.

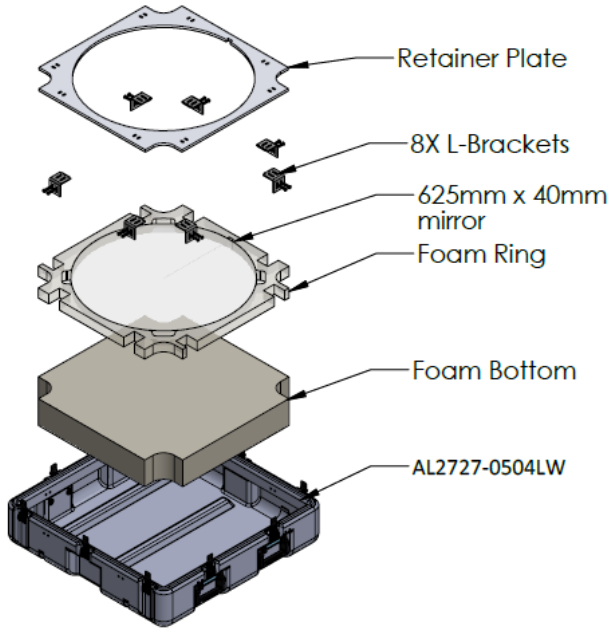
- Automatic reflection construction
- Visualization of optical constraints

It has been successfully used to design several challenging SOFAST installations.

Status: Operational.

High-Precision Calibration Mirror Design





Description:

A high-precision reference mirror for cross-checking complex metrology systems.

- High dimensional stability.
- Manufactured using optical imaging methods.
- Very high accuracy (evaluation still in progress).
- Custom-designed case for both transport and use.
- Complete design and vendor information.

Status: Operational.

OpenCSP Tools

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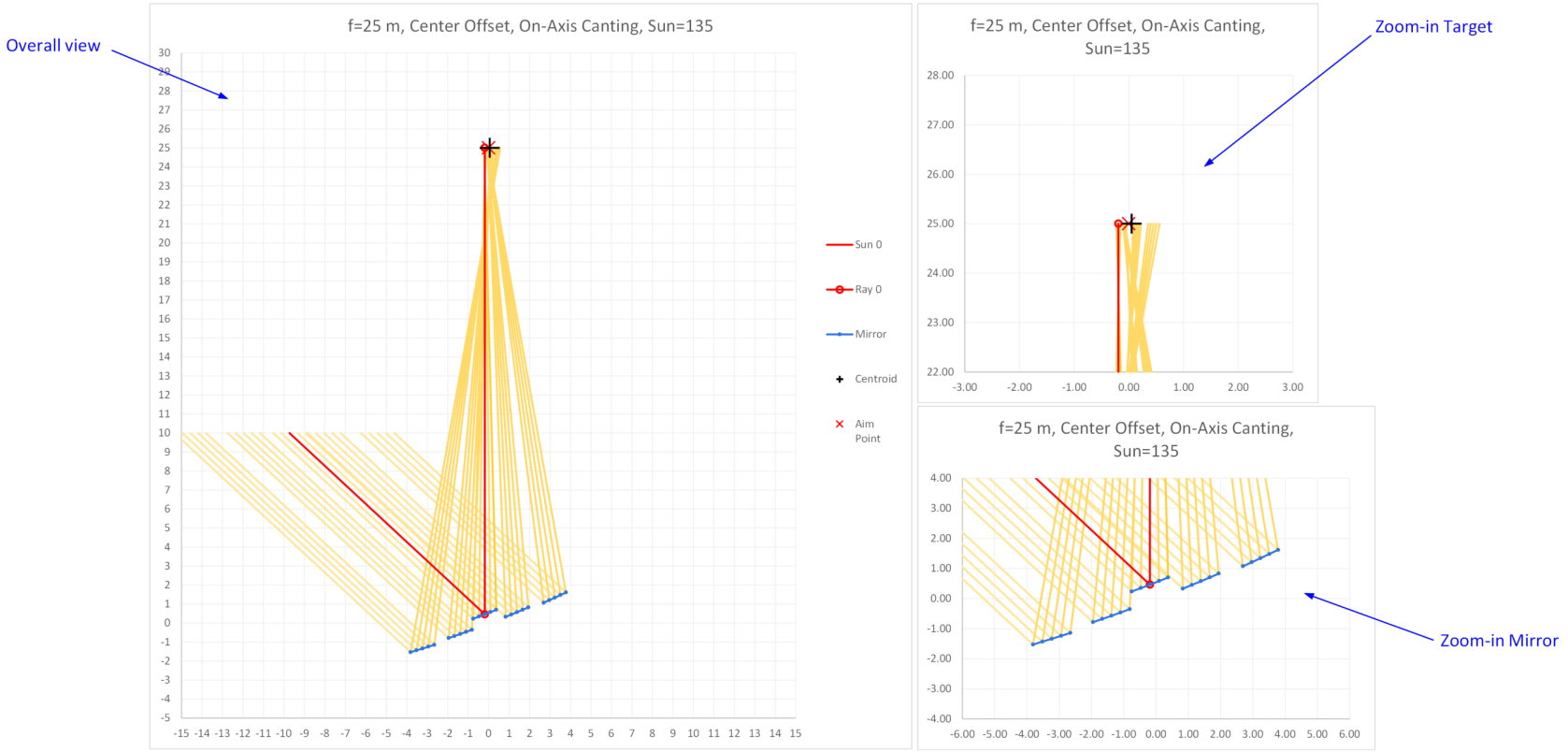
Interactive 2-d Ray Trace



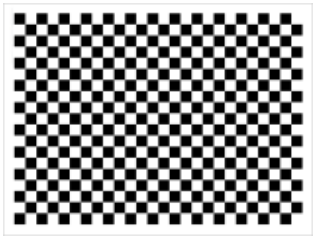
Sun is modeled as a point source. Sun shape not included.

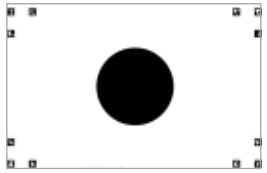
Description:

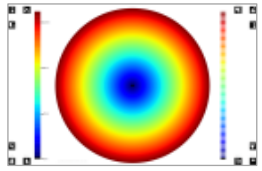
- Simple interactive tool for visualizing concentrating reflections in 2-d.
- Varying mirror design or sun angle produces instant visualization of reflected beam.
- An ordinary Excel spreadsheet with no macros.
- Great for interactive study and CSP education.

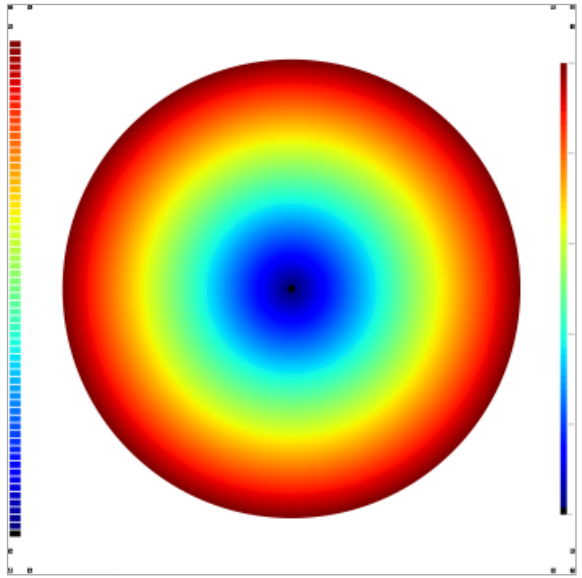
Status: Operational.

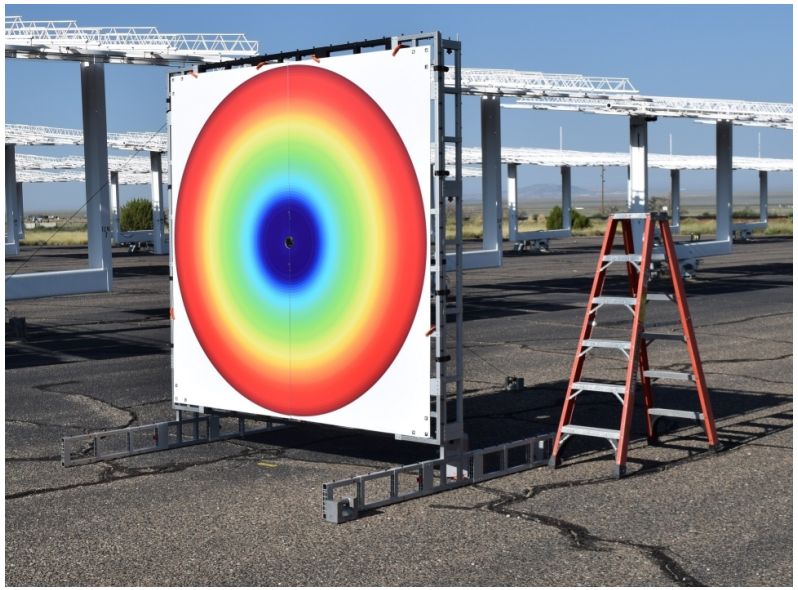
Optical Targets











Description:

- Optical targets to support various metrology tests.
- Both manual and computer-generated examples.

Status: Operational.

OpenCSP Data

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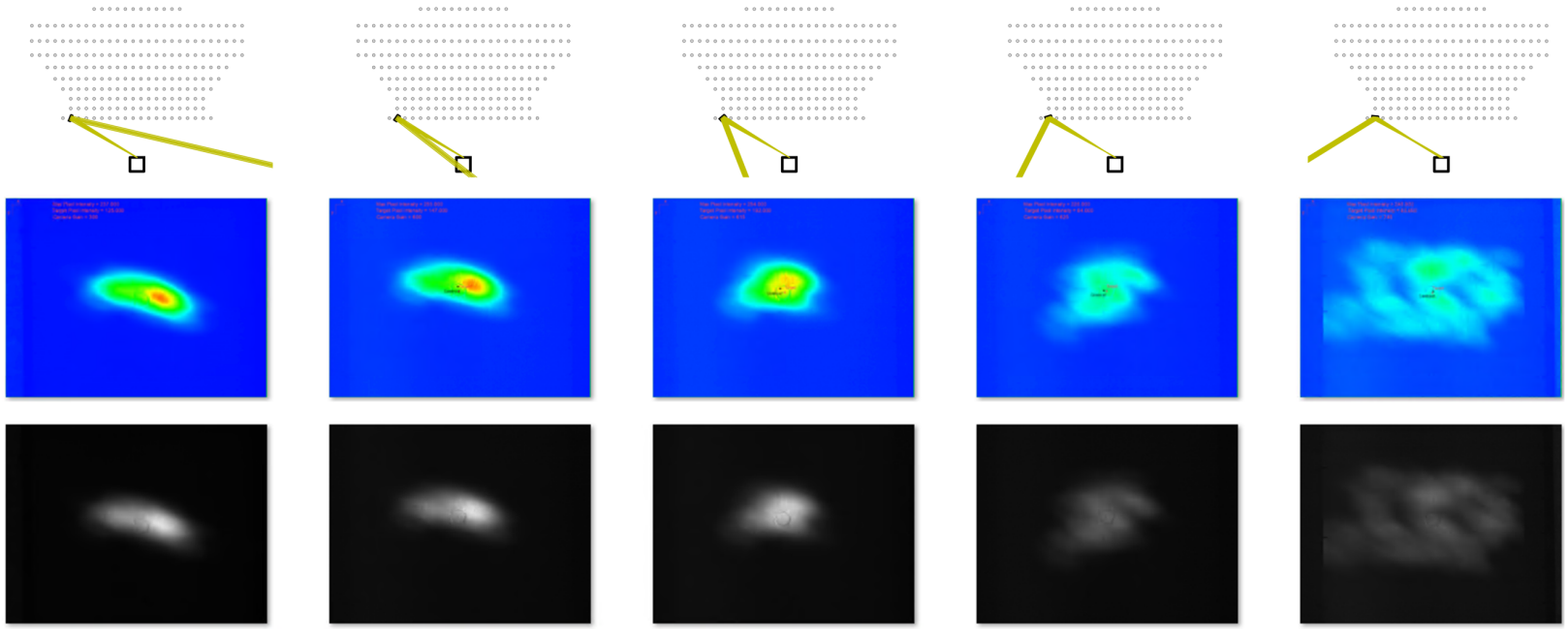
BCS Data: Beam Shape Variation Across Time



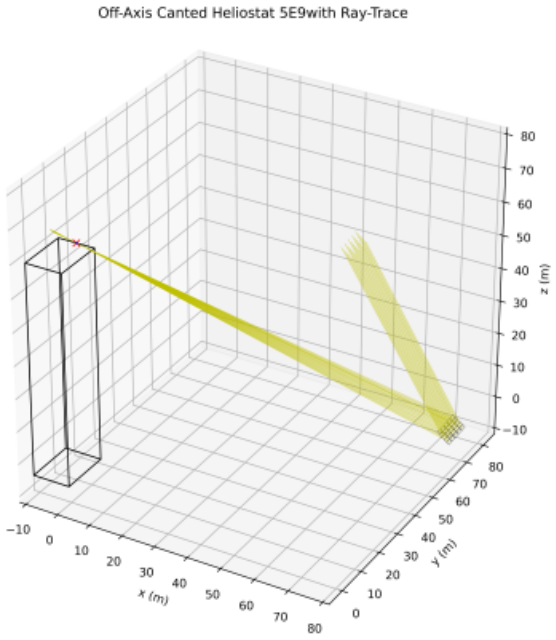
Description:

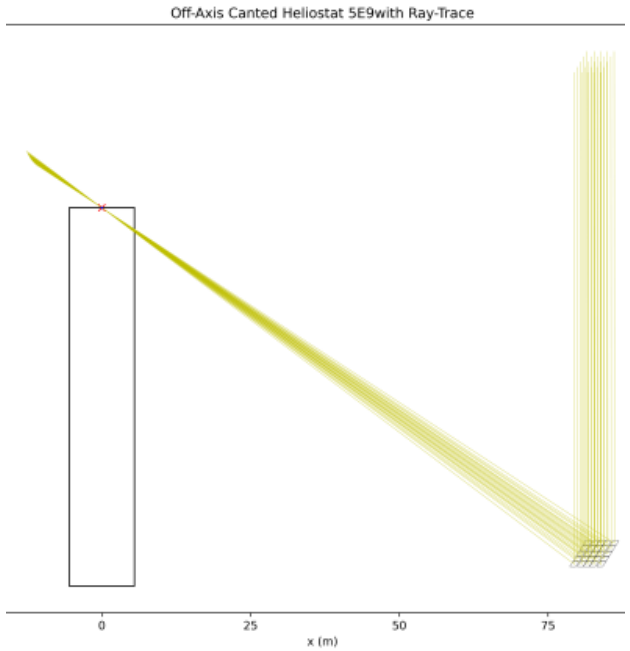
- Over 100,000 Beam Characterization System (BCS) images collected at the Sandia heliostat field.
- Captured from near-sunrise to near-sunset.
- Multiple days spanning the solar year.
- Images show stark variation in beam shape that can occur as sun incidence angle changes.

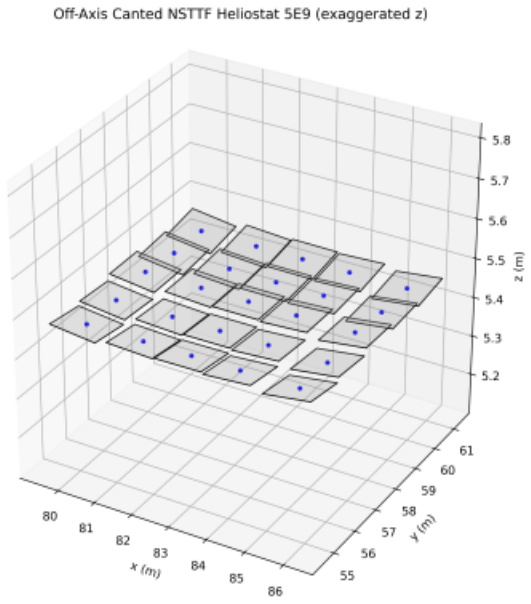
Status: Posted and documented.

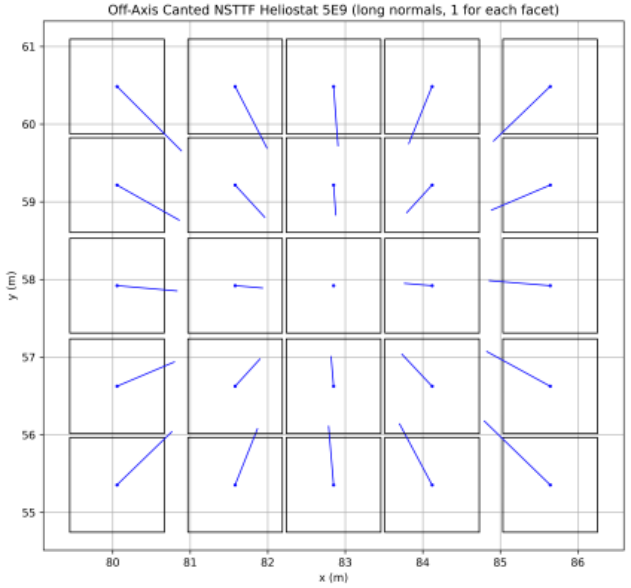
https://opencsp.sandia.gov

Sandia Heliostat Canting Prescriptions









Description:

- Sandia heliostats have 25 facets each.
- To maximize solar flux during tests, set to *off-axis* canting prescription.
- Different from simpler *on-axis* canting prescription often assumed.

Status:

- Data for 9 key heliostats posted.
- Remaining field, and on-axis prescriptions for comparison anticipated soon.

OpenCSP Documents

https://opencsp.sandia.gov

OpenCSP Documents

Current:

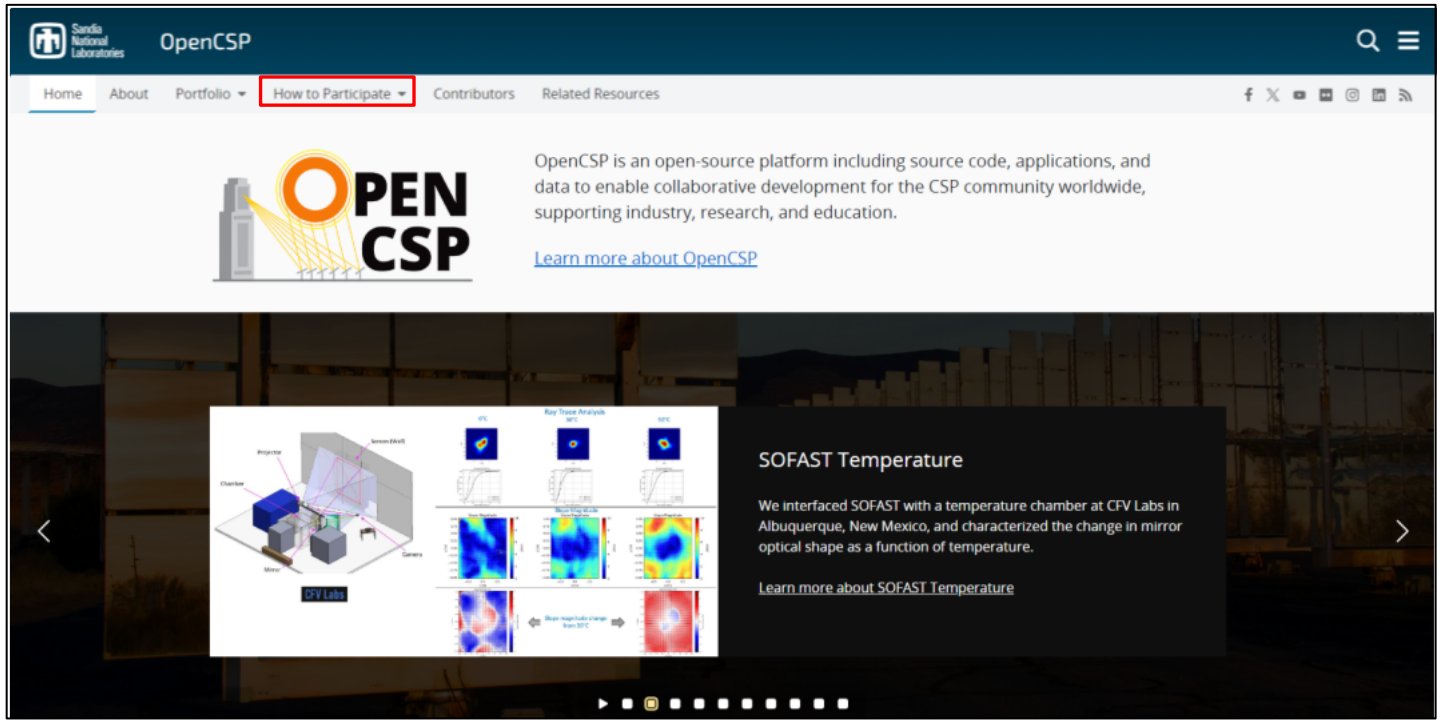
- OpenCSP Getting Started Guide
- OpenCSP Contributor's Guide
- OpenCSP Code Documentation
- OpenCSP Base Classes and Ray Tracing
- OpenCSP Portfolio
- SOFAST 2.0 User Guide and Technical Description
- OpenCSP Deflectometry Technical Description
- Scene Reconstruction User Guide
- OpenCSP Camera Calibration
- SOFAST CAD Layout Tool Overview and User Guide
- NSTTF Technical Information for OpenCSP

ByDate:

- Optical Effects of Temperature Change for Heliostat Mirrors
- High-Speed UAV Assessment of Heliostat Fields
- Interactive CAD Layout of Reflection-Based Mirror Metrology Systems
- Distortion Effects in CSP Mirror Reflections
- Challenges and Solutions in Heliostat Optical Metrology
- Interactive Heliostat 2-d Ray Trace Tool
- Equinox Data Set Analysis
- Dual-Image Color Normalization to Enable High-Performance Concentrating Solar Optical Metrology
- Revisiting the BCS, a Measurement System for Characterizing the Optics of Solar Collectors

How to Access OpenCSP

OpenCSP Website: https://opencsp.sandia.gov



See:
How to Participate → Access OpenCSP
How to Participate → Contribute OpenCSP

- **Code:**
  https://github.com/sandialabs/OpenCSP
  Documentation: https://opencsp.readthedocs.io/en/main/index.html
  Class Overview: https://github.com/sandialabs/OpenCSP/blob/main/doc/source/example/csp/base_classes_and_ray_trace.ipynb
- **Non-Code (OpenCSP Mechanical, Tools, Data, Documents):**
  https://sandia-csp.app.box.com/s/iftmhdkhgjnmfgefsfmkid011dtv8n3g

https://opencsp.sandia.gov

Thanks

We thank those who helped improve OpenCSP!

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
SOLAR ENERGY TECHNOLOGIES OFFICE

Sandia National Laboratories LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

CFV Labs

Cosmo optics
Precision Photonics Artisans

CASETECH
Custom Case Solutions
A Woman Owned - Small Business

Heliogen

SolarDynamics

Planet A Energy

Australian National University

THE UNIVERSITY OF NEW MEXICO

ProjectorScreen.com

Billboards etc

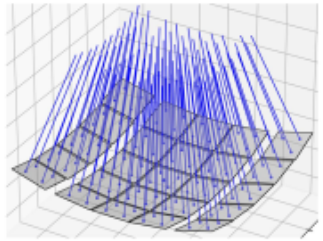
ARI GRAPHIX & SIGNS
a division of Albuquerque Reprographics

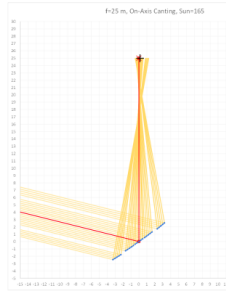
DRAPER®

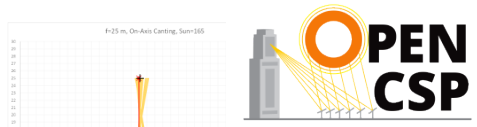
OpenCV

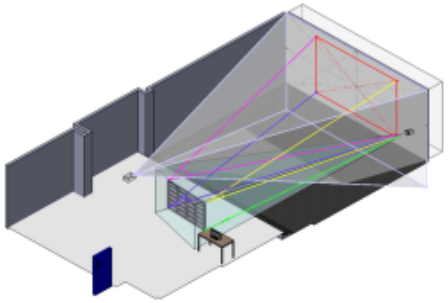
https://opencsp.sandia.gov

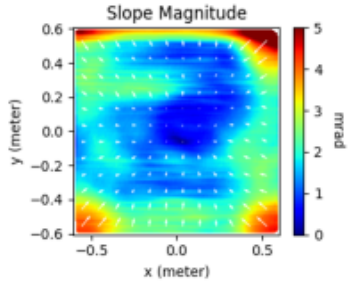
Conclusion

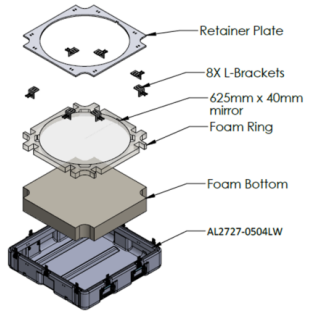


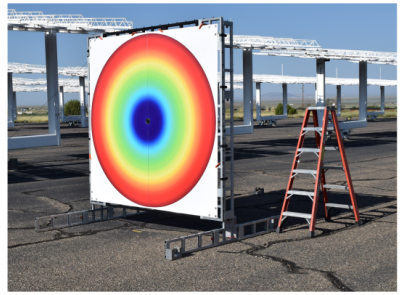


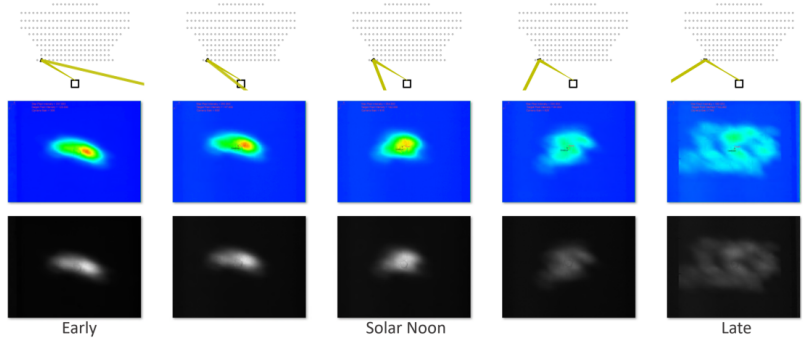












OpenCSP is:

- An effective team code development environment.
- A rich set of CSP code building blocks.
- Ready-to-run apps, including SOFAST 2.0 deflectometry.
- SOFAST CAD layout tool, plus metrology component models.
- Research data: BCS data, heliostat prescriptions, flight data.*
- A work in progress – rough drafts to polished products.

To access or contribute: https://opencsp.sandia.gov

We hope you will find it useful, and we hope you will join us!

This is just the beginning…

* Flight data is pending upload.

BACKUP SLIDES

Legal Notice

UFACET Flight Data

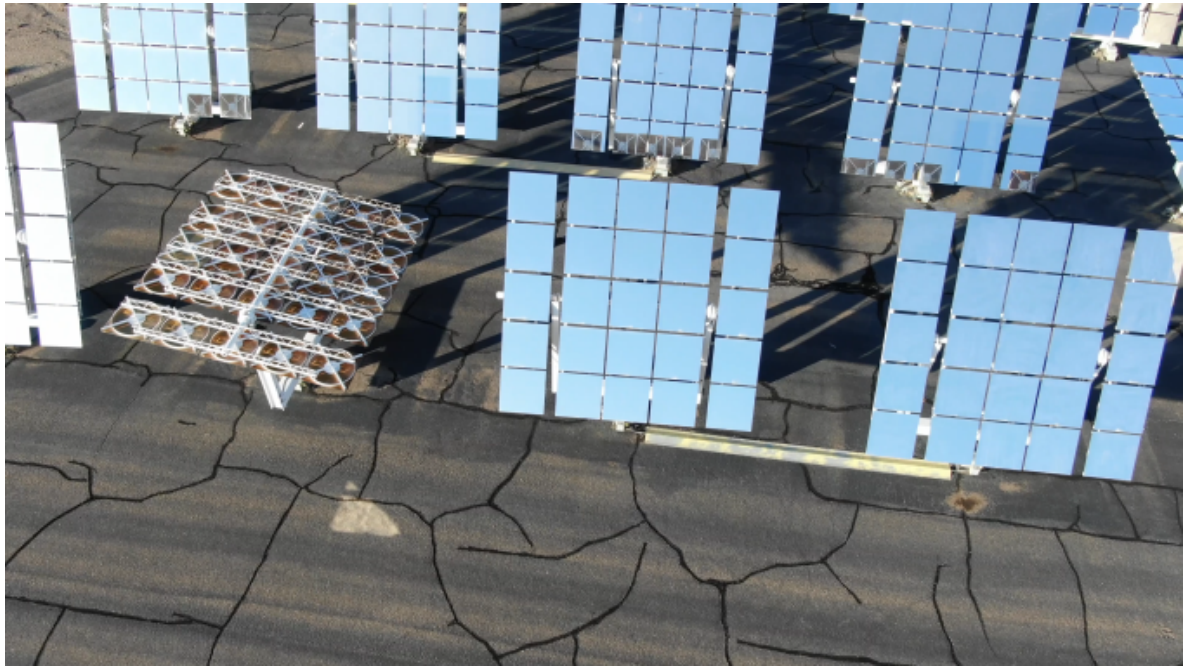
UFACET Flight Plan

Waypoint	x (m)	y (m)	z (m)	z_AHL (m)	longitude (deg)	latitude (deg)	heading (deg)	gimbal pitch (deg)
1	-94.657	34.061	11.837	10	-106.5106455	34.96258255	345.42335	70.5
2	-126.138	155.122	11.755	10	-106.5109912	34.9636721	345.42335	70.5
3	-119.485	174.267	11.997	10	-106.5109182	34.9638444	347.0548	70.5
4	-87.209	33.853	11.999	10	-106.5105637	34.96258068	347.0548	70.5
5	-78.886	33.828	12.181	10	-106.5104723	34.96258046	347.805854	70.5
6	-109.231	174.25	12.222	10	-106.5108056	34.96384425	347.805854	70.5
7	-98.957	174.33	12.448	10	-106.5106927	34.96384497	348.618071	70.5
8	-70.647	33.701	12.362	10	-106.5103818	34.96257931	348.618071	70.5
9	-62.552	33.662	12.539	10	-106.5102929	34.96257896	349.499281	70.5
10	-88.621	174.306	12.674	10	-106.5105792	34.96384476	349.499281	70.5
11	-78.243	174.276	12.902	10	-106.5104653	34.96384448	350.449611	70.5
12	-54.562	33.526	12.713	10	-106.5102052	34.96257773	350.449611	70.5
13	-46.752	33.484	12.884	10	-106.5101194	34.96257735	351.494226	70.5
14	-67.818	174.337	13.131	10	-106.5103508	34.96384503	351.494226	70.5
15	-57.328	174.287	13.36	10	-106.5102356	34.96384458	352.624427	70.5
16	-39.097	33.448	13.052	10	-106.5100354	34.96257703	352.624427	70.5
17	-31.602	33.329	13.216	10	-106.5099531	34.96257596	353.852737	70.5

⋮

(See “UFACET Flight Planner” slide.)

UFACET Flight Video



Click on picture to play video.

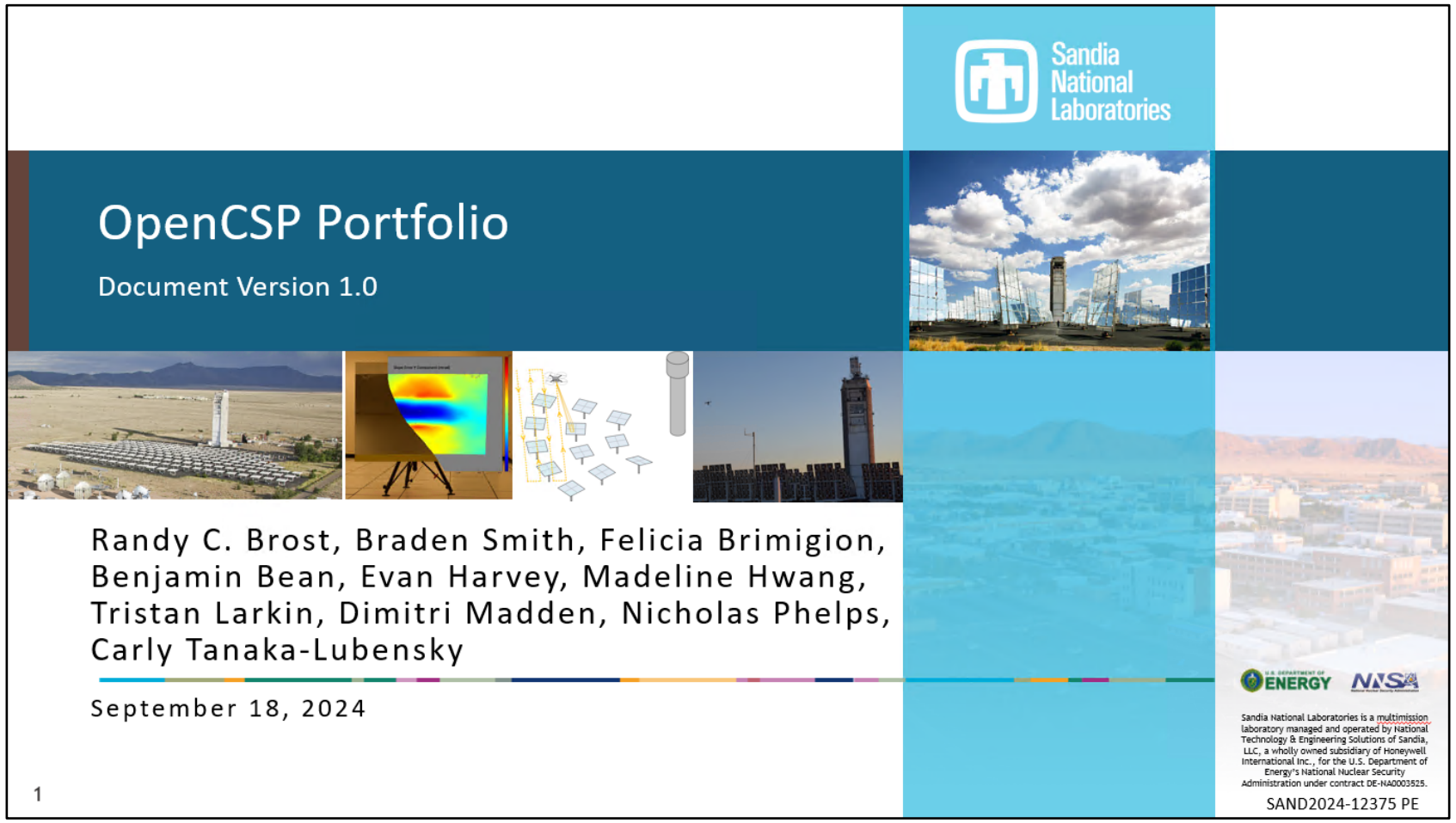
Description:

The UFACET system is designed to fly a scanning passes over a heliostat field, to obtain a video of heliostats with the backs of preceding heliostats seen in reflection, sweeping across. OpenCSP_Code contains related code implementations, and OpenCSP_Data contains related data, including flight plans, captured videos, flight logs, and other data.

Status: Code in rough prototype state. Data in review for posting.

https://opencsp.sandia.gov

OpenCSP Portfolio



Description:

Catalog of OpenCSP items, and pointers to where to find them in OpenCSP.
Designed to support browsing.

Status: Posted.

Sandia NSTTF Technical Information

Description:

Information useful for working with OpenCSP data and collaborating with the Sandia. Basic information about the site, tower, heliostats, heliostat field, and more.

Status: Posted.