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A SENSITIVITY ANALYSIS OF SOFAST 2.0 ESTIMATION OF MIRROR SLOPE ERRORS

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Renewable Energy Technologies

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AGENDA

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  - OpenCSP
  - SOFAST 2.0
  - Metrology Uncertainty
- Methods
- Results
  - Focal Length Variation
  - Enclosed Energy Variation
  - Surface Slope Deviation Errors
- Discussion

CONCENTRATED SOLAR THERMAL (CST)

- Concentrated Solar Thermal (CST) technologies harness solar power to generate heat and electricity.
- CST has potential for a variety of applications in the energy field.
- The applications of some CST technology rely on optical surfaces called solar collectors.
  - Achieving optimal performance in these technology depends on the quality and design of solar collectors.

OPENCSP

- CSP: Concentrating Solar Power
- OpenCSP is an open-source platform for software and data for applications in optical metrology.
- It is a collaborative project that aims to increase scope and access of optical tools and high-quality data for metrology development and analysis.
- The platform provides a variety of tools to facilitate metrology and analysis of optical surfaces, including solar collectors.
- https://opencsp.sandia.gov

SOFAST 2.0

- SOFAST 2.0 is an OpenCSP tool for mirror characterization.
- It is a deflectometry tool within OpenCSP.
  - Used to assess characteristics of mirror facets.
  - Originally developed at Sandia National Laboratories in 2009 [1].
  - Updated and publicly available as SOFAST 2.0 in 2024 [2].
- It provides a measure of the surface slope and other characteristics of a CSP optic, including mirror facets [3].
  - Surface slope is a critical characteristic of a CSP optical surface, contributing to the performance of solar collector.

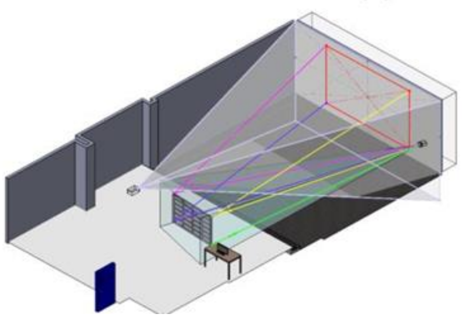
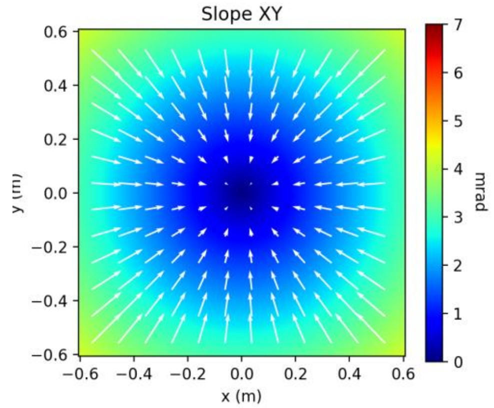


Figure 1, Brost et al. (2025) [2]



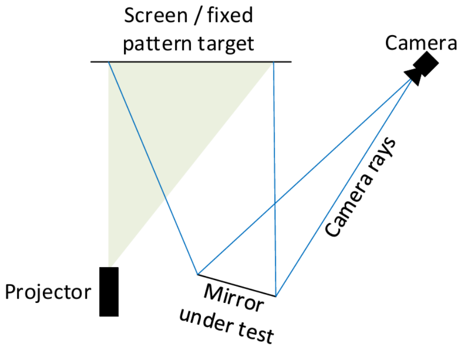
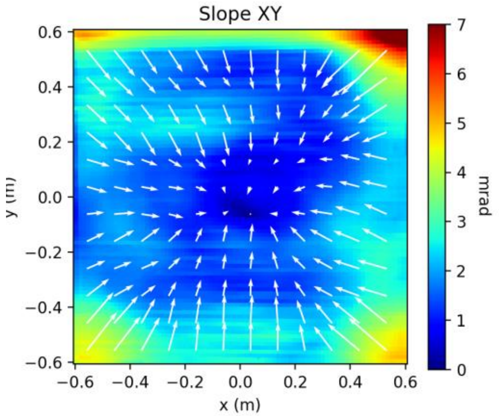
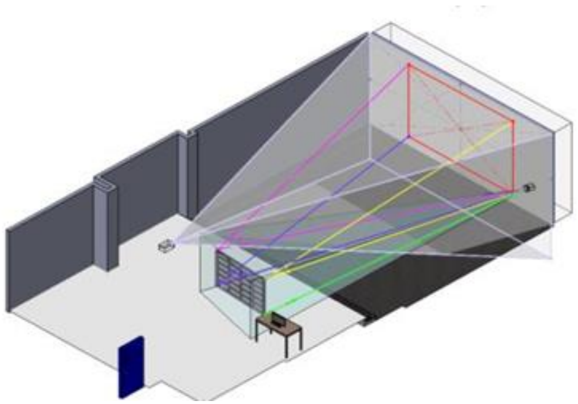


Figure 1, Smith et al. (2024) [3]



CONSIDERATION OF METROLOGY UNCERTAINTY

- Analysis of SOFAST 2.0 measurement uncertainty is needed.
- Application of SOFAST 2.0 depends on setting up and collecting measurements of the optic surface.
  - Data measurements include a variety of parameters in:
    - Camera Settings
    - Screen Display
    - Spatial Orientation
    - Calibration Settings
    - Facet Characteristics
- **How do errors in these parameters contribute to the SOFAST calculation of mirror characteristics?**



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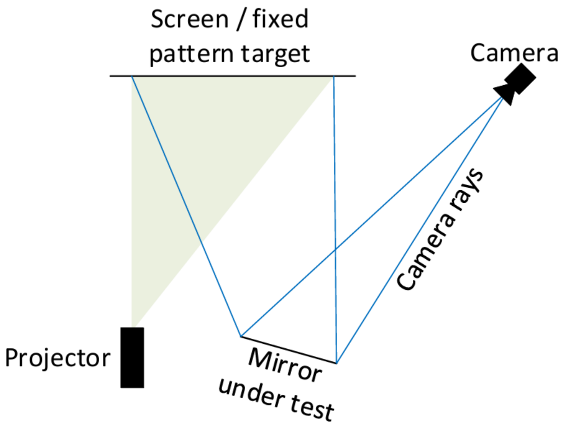
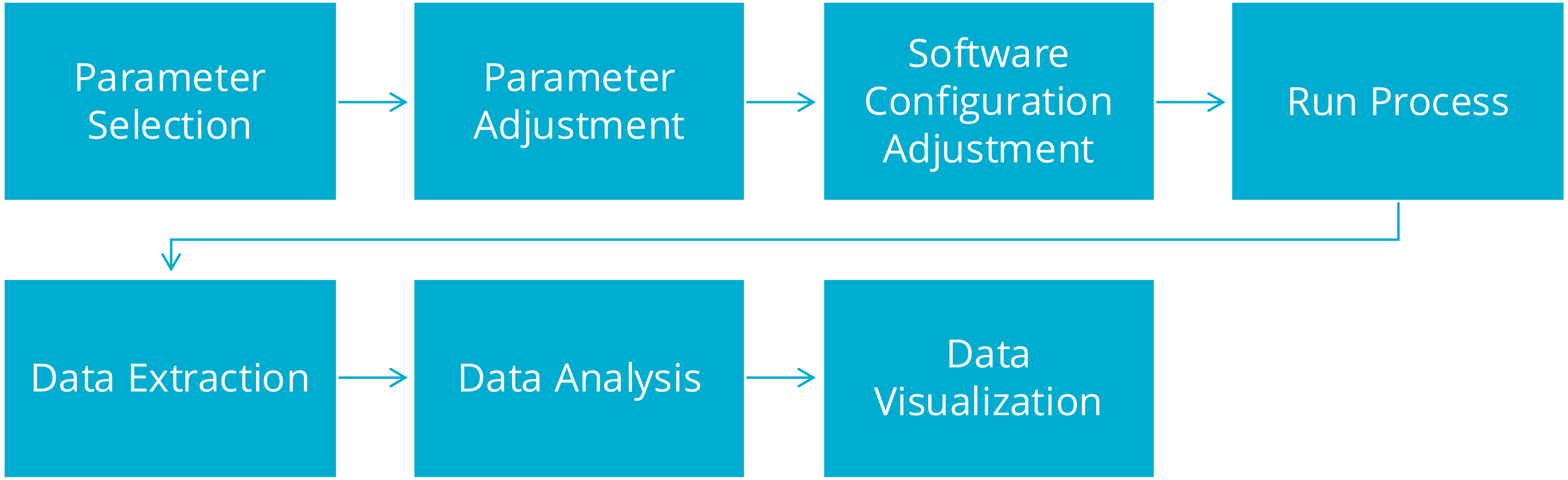


Figure 1, Smith et al. (2024) [3]

METHOD

METHOD

- Develop analysis tool that can:
  - Automate the SOFAST analysis process for a variety of changing parameter conditions.
  - Demonstrate the effects of changing measurements on SOFAST assessment of mirror characteristics.



PARAMETER AND SOFAST OUTCOMES CONSIDERED

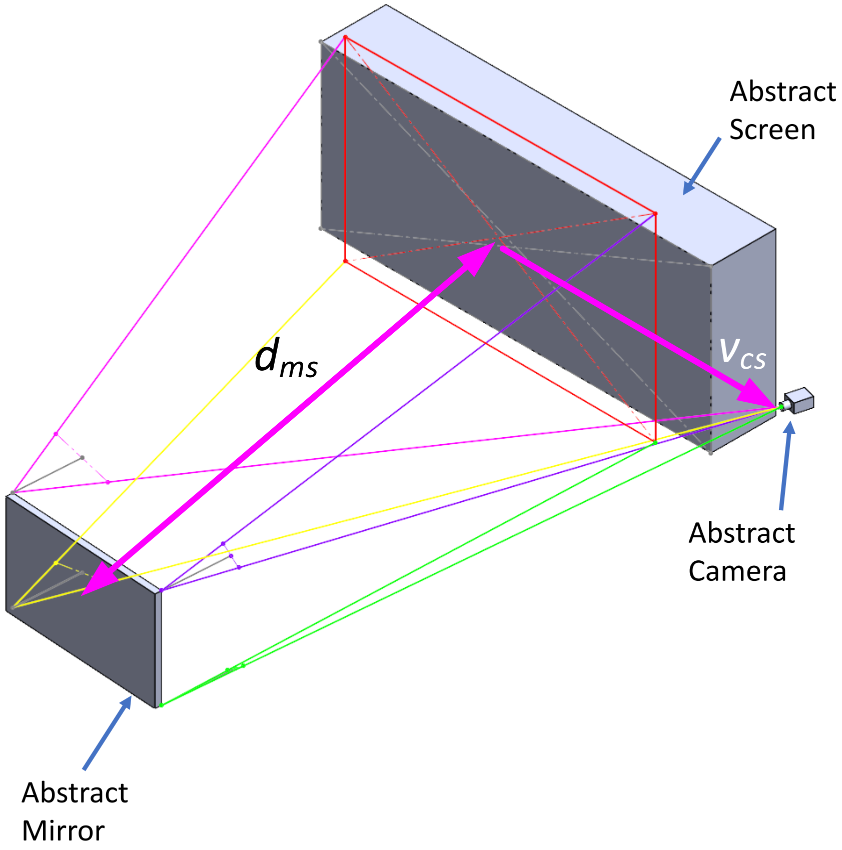
Parameter considered for measure variation (so far)

- optic-to-screen distance : d_{ms}
- camera-to-screen origin position in 3D space:

$$\overrightarrow{v_{cs}} = \begin{bmatrix} v_{cs_x} & v_{cs_y} & v_{cs_z} \end{bmatrix}$$

SOFAST estimated mirror characteristics :

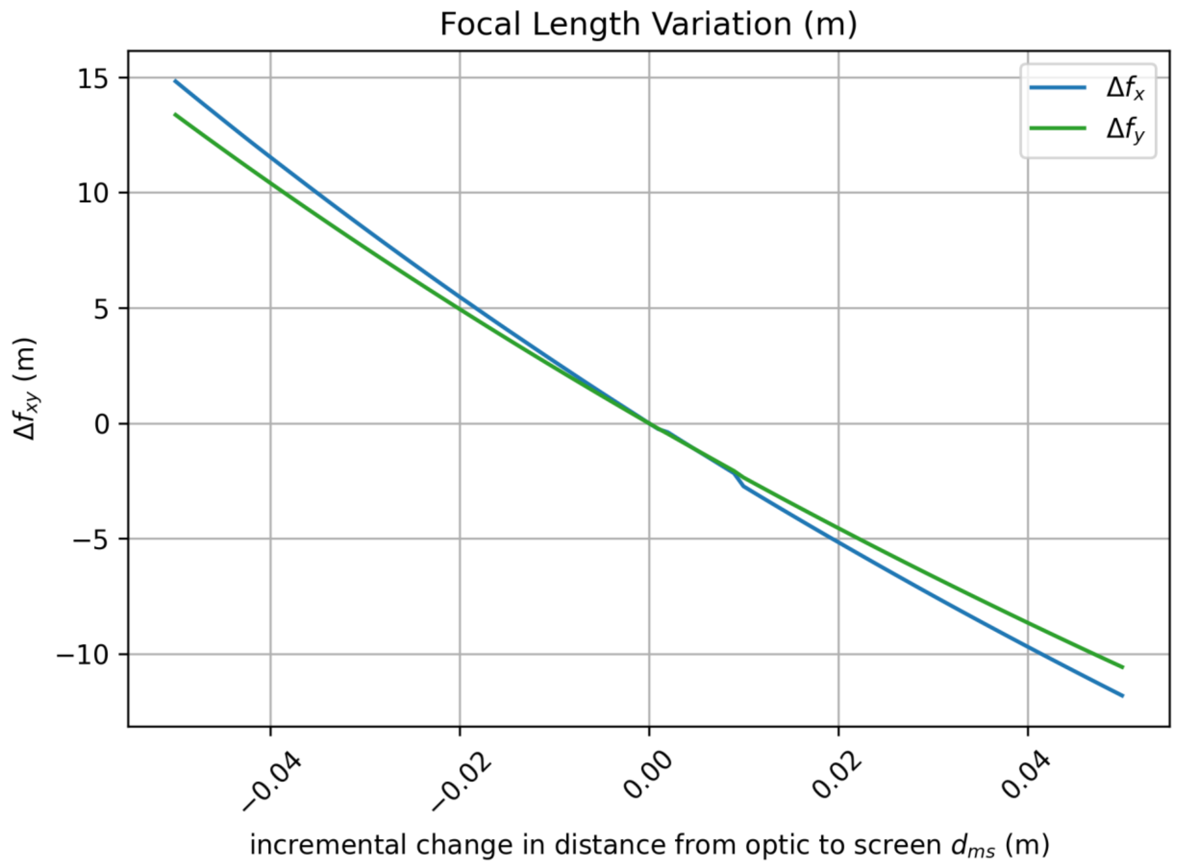
- Mirror Focal Length in X and Y directions
- Enclosed Energy
- Difference in Surface Slope Deviation
  - RMSE
  - More in the future…



Modified from Brost et al. (2024) [4]

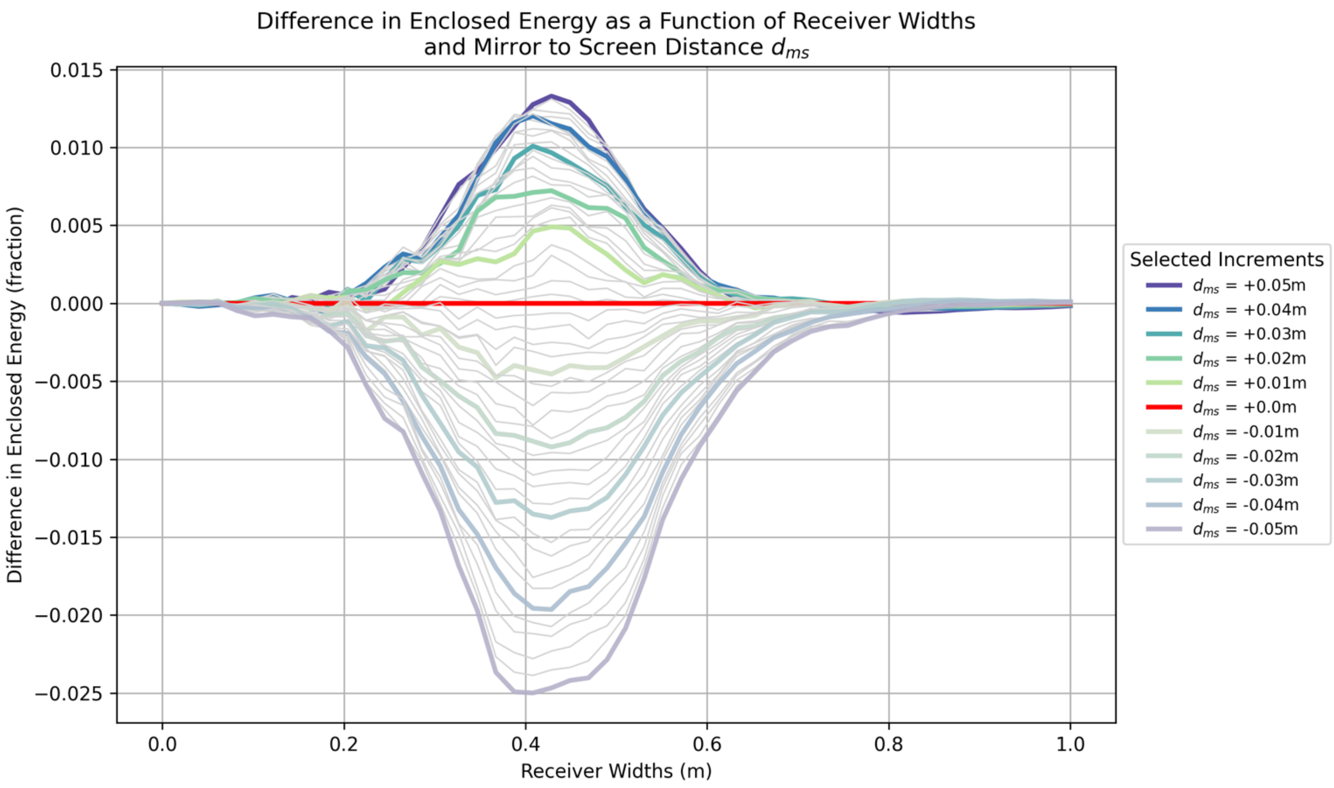
RESULTS

HOW DOES CHANGE IN DISTANCE FROM MIRROR TO OPTIC SCREEN CONTRIBUTE TO FOCAL LENGTH VARIATION?



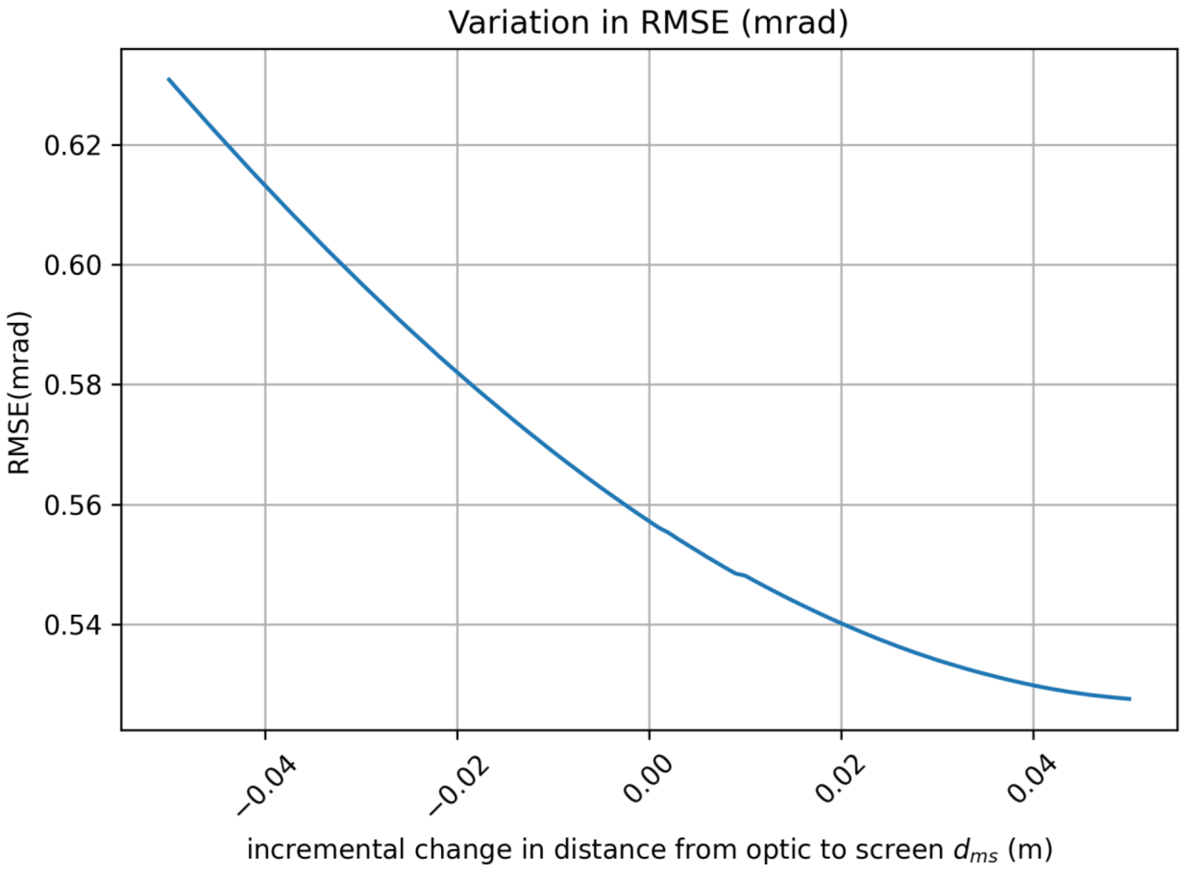
- Focal length is the distance between the mirror and the focus point of the light.
- One of the outputs of SOFAST slope analysis.
- Discrepancies in measuring distance from projector screen of ±0.05 m result in variation in output focal length from -10 to 15 m.
- While widely used, focal length is not the most important measure of optical performance. For shallow optics such as heliostat mirrors, it can also be misleading.
- Slope deviation and enclosed energy are much more important metrics.

EFFECT ON ENCLOSED ENERGY?



- Enclosed energy quantifies the reflected sunlight concentrated on the receiver aperture.
- One of the outputs of SOFAST slope analysis.
- Increased enclosed energy suggest improved mirror quality and more efficient solar concentration.
- Discrepancies in measuring distance from projector screen of ±0.05 m result in variation in output enclosed energy when receiver width is between 0.3 m to 0.5 m

EFFECT ON SURFACE SLOPE DEVIATION?



- How far does the surface slope of mirror of interest deviate from the ideal mirror?
- Root Mean Square Error (RMSE):

$$\sqrt{\frac{\Sigma y_i - \hat{y}_i{}^2}{n}}$$

- Change in RMSE is likely associated with the true focal length of the physical mirror rather than the ideal focal length in the reference.
  - This nonintuitive relationship emphasizes importance of being cautious in interpreting these plots.

DISCUSSION

SUMMARY

- SOFAST 2.0 is a software that uses deflectometry process to provides assessment of CSP optic characteristics.
- An uncertainty analysis would provide further insight into software's robustness against measurement errors in application.
- We have an analysis tool under development that will provide a sensitivity analysis of SOFAST input parameters on the estimation of various mirror performance measures, including:
  - Focal length
  - Enclosed energy
  - Surface slope deviation errors
- Future directions:
  - Additional analysis: More parameters, additional aspects (ground truth, …).
  - Automatic analysis of different SOFAST configurations.

REFERENCES

[1] C. E. Andraka, et al. Rapid reflective facet characterization using fringe reflection techniques. ASME 2009 3rd International Conference on Energy Sustainability, Volume 2, January 2009, https://doi.org/10.1115/es2009-90163.

[2] R. C. Brost, B. Smith, F. Brimigion, B. Bean, and A. Evans. SOFAST 2.0: Open-Source Deflectometry for CSP. SolarPACES Conference Proceedings. 3, November 2025. https://doi.org/10.52825/solarpaces.v3i.2369

[3] B. J. Smith, R. C. Brost, and B. G. Bean. SOFAST 2.0 User Guide and Technical Description, Document Version 1.0. Sandia National Laboratories Report SAND2024-10936, August 2024. https://doi.org/10.2172/2636931

[4] F. M. Brimigion and R. C. Brost. SOFAST CAD Layout Tool Overview and User Guide, Document Version 1.0. Sandia National Laboratories Report SAND2024-10380, August 2024. https://doi.org/10.2172/2429907

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THANK YOU

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