Cielo Integrated Modeling of External Occulters for Exoplanet Missions

SPIE 8127-21

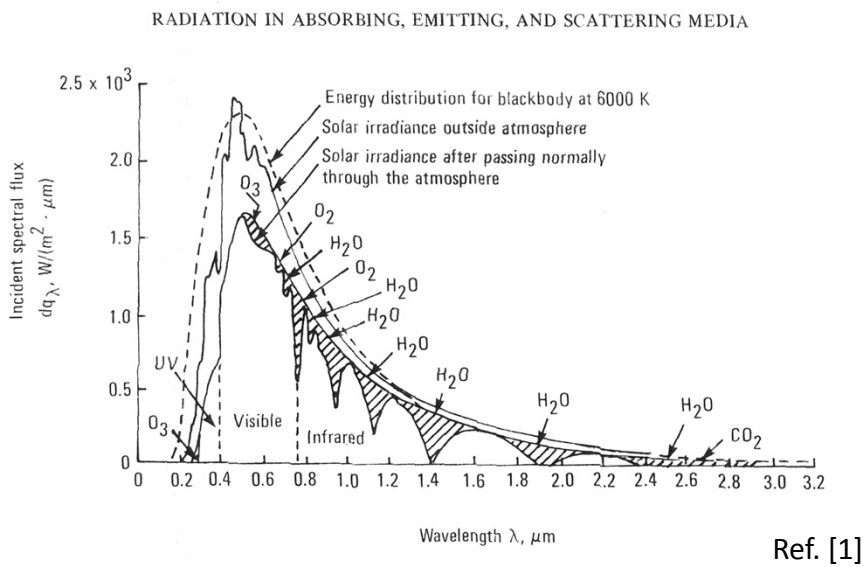
G. Moore, E. Cady, M. Chainyk, A. Kissil, M. Levine
Jet Propulsion Laboratory,
California Institute of Technology

C. Hoff
Cielo Engineering Software, LLC

Thursday, Aug. 25, 2011

Science Objectives

- Search for extra-solar planets in the “habitable zone”
- Reveal the spectral signatures for detection of life supporting atmospheres

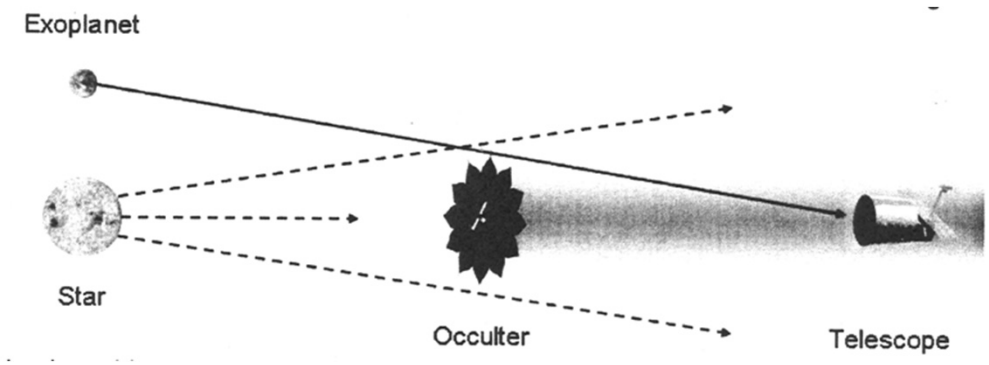


Ref. [1]

- Detector Range of 250nm $\leq \lambda \leq$ 1.0 mm

Functional Challenges

- At visible wavelengths planets are seen by reflected star light
- I-sun/I-planet ~ 10^{10}
- Proximity – at 10 parsecs earth would be only 10 mas from the sun (1parsec=3.26 light years)



Ref. [2]

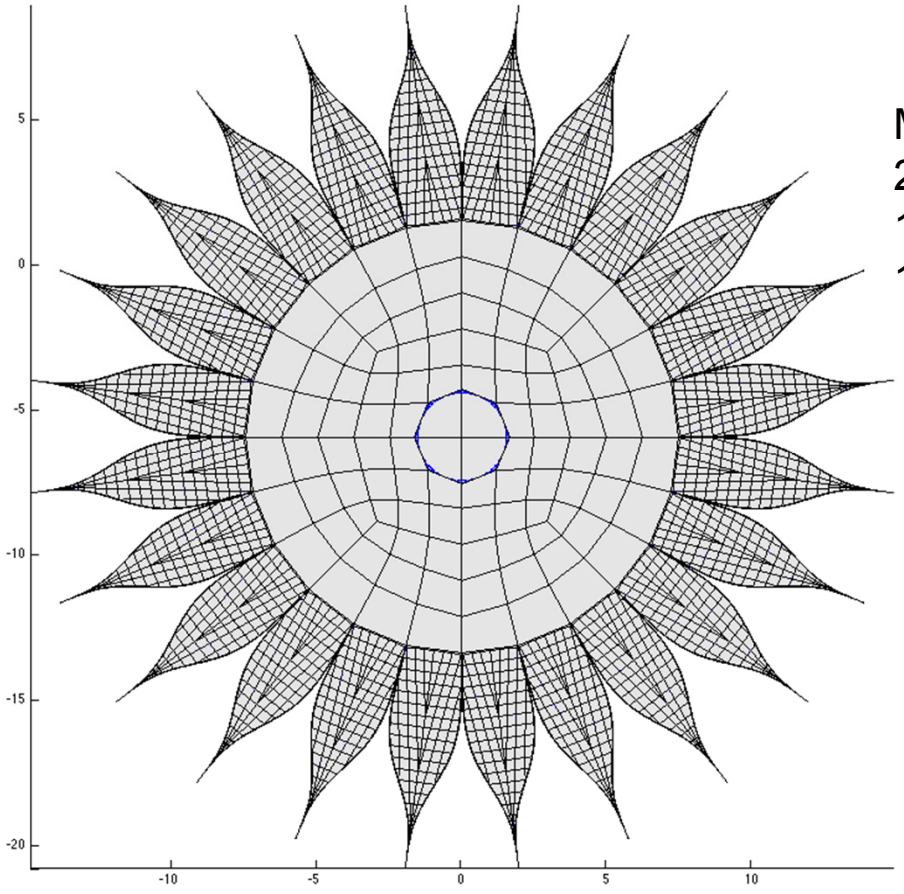
Petal Characterization

- Petal optimized to create a diffraction pattern that produces a high contrast suppression of the on-axis starlight
- Petal operates in the Fresnel (near-field) diffraction regime
- SPIE 2011 References:
  - Conference 8151, Techniques and Instrumentation for Detection of Exoplanets V (Shaklan)
  - Paper 8157-18, “Design, tolerancing, and prototyping of starshades for exoplanet detection and characterization”, Kasdin et al.

Design Challenges

- Full scale testing cannot be performed
- Occulter in-plane edge local deformations may be restricted to ~10µm mean displacement
- 40m shade plus telescope must be transported, deployed, stationed, and repositioned for observational scenarios
- Variable solar heat loads result in subtle thermal deformations
- Formation flying to maintain a distance between the occulter and telescope around $4x10^4$km $\pm$ a few meters

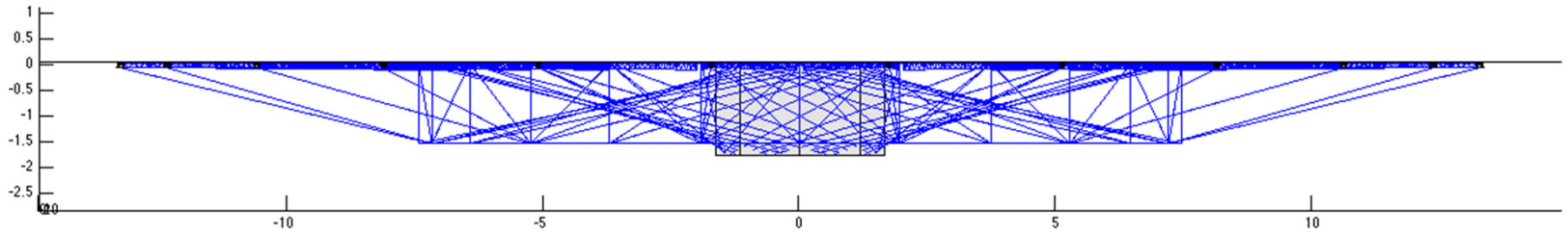
Occulter Plan Form



Model particulars:
210k radiation exchange elements
170k thermal degrees of freedom
1M structural degrees of freedom

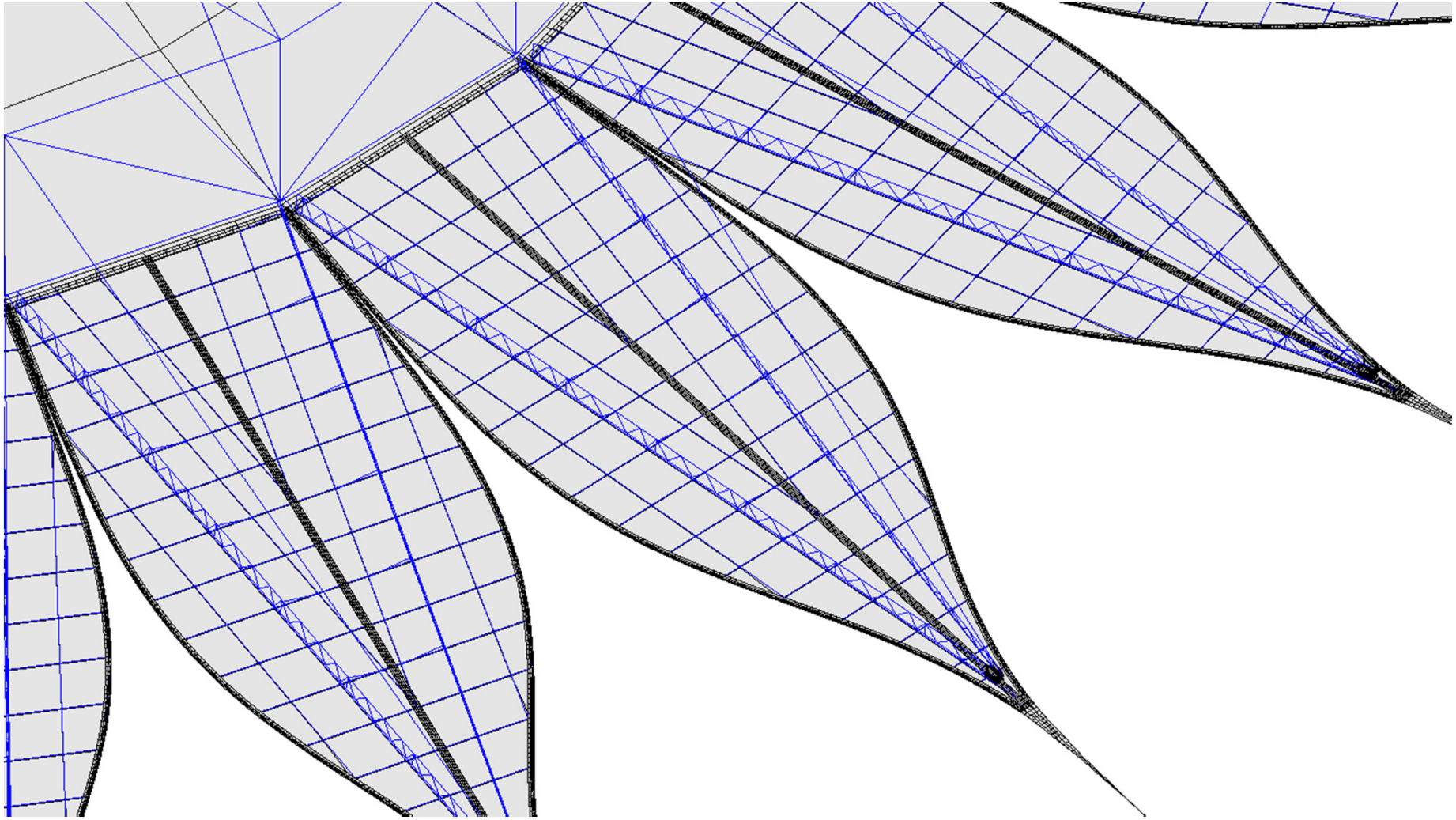
6

Occulter Side On



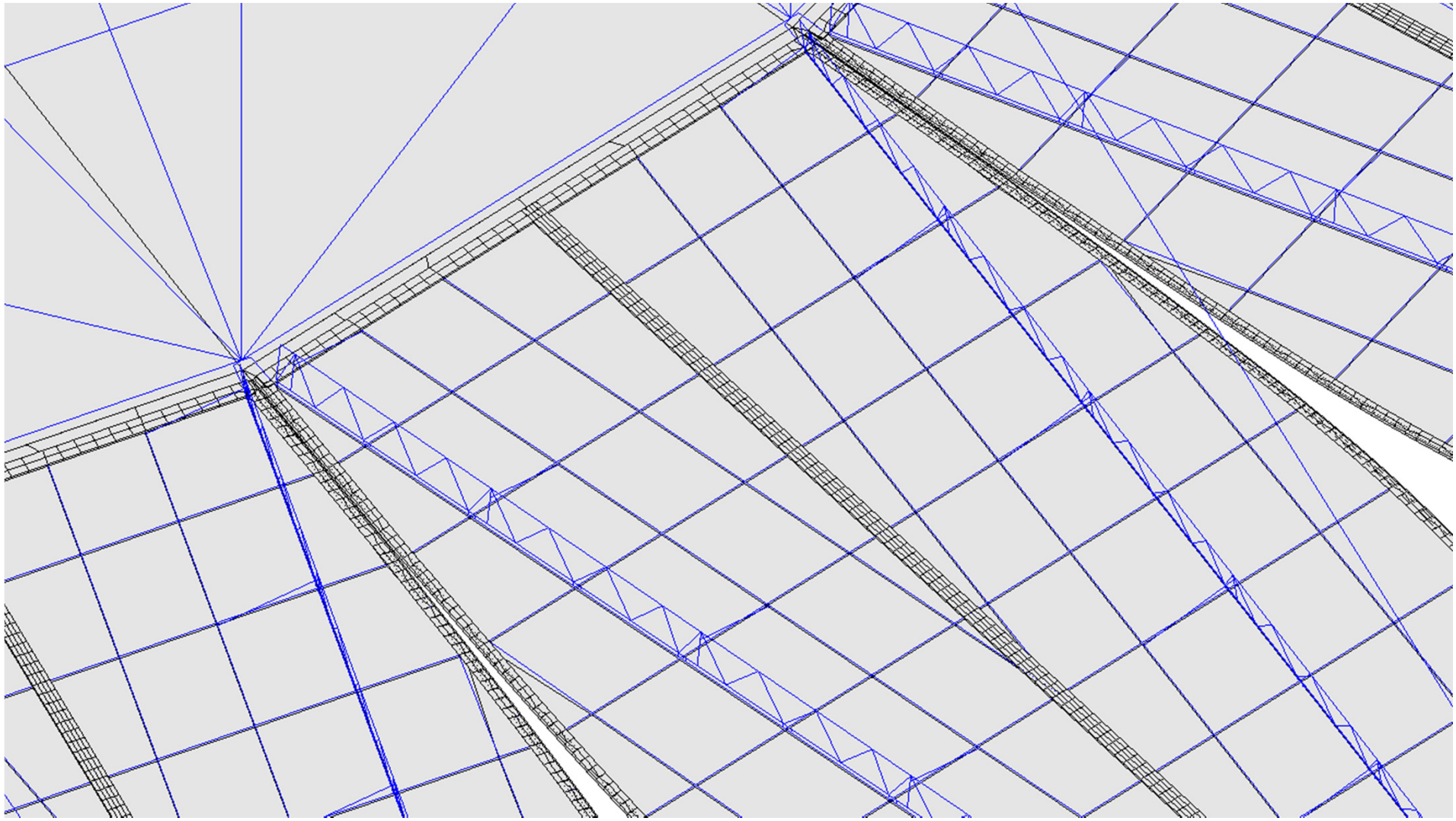
7

Petal Details



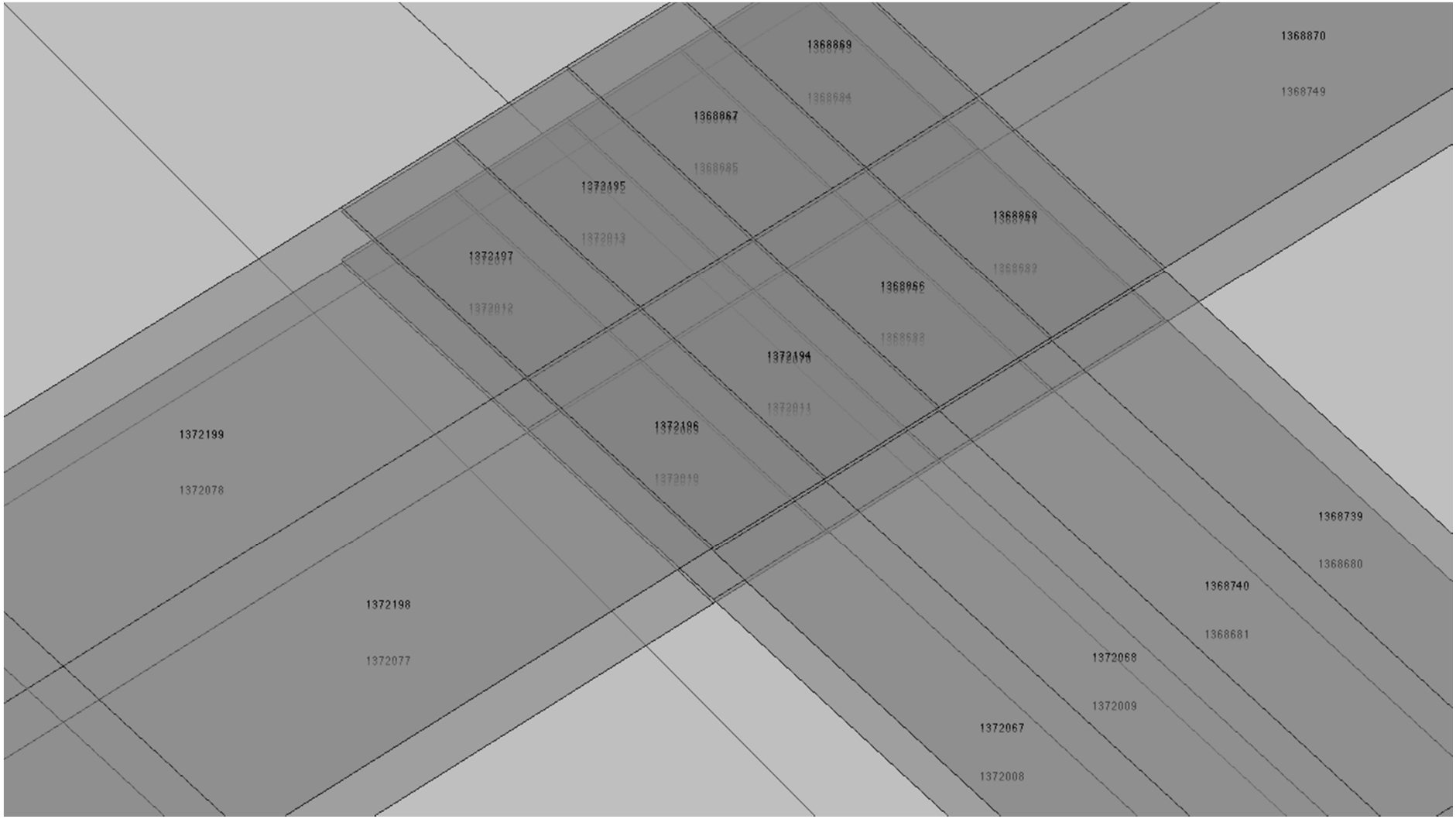
8

… And More Detail



9

… And More

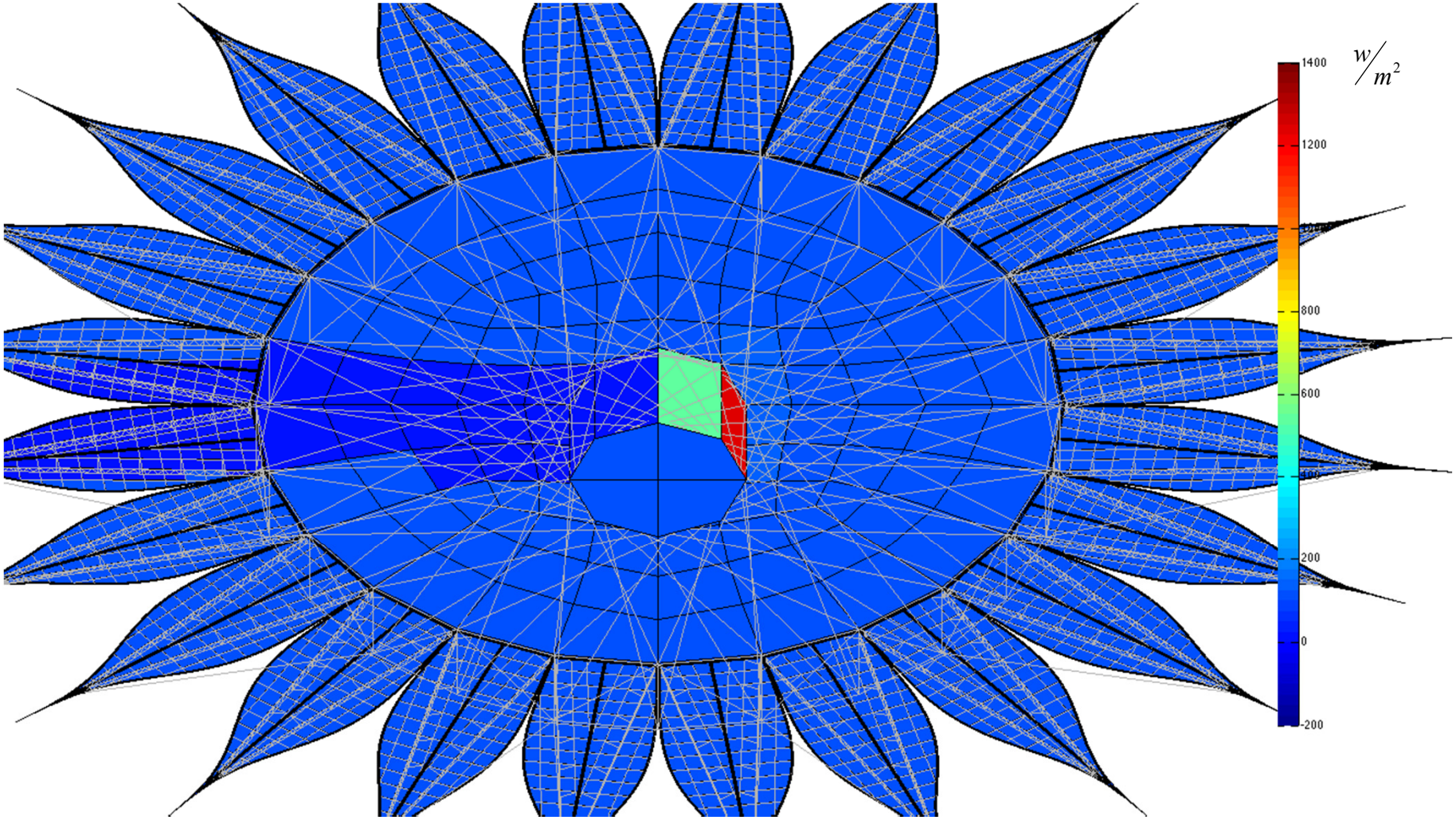

1368869
1368870
1368749
1368867
1372195
1372197
1368868
1368956
1372194
1372199
1372078
1372196
1368739
1368680
1368740
1372198
1372077
1368681
1372068
1372009
1372067
1372008

10

What Cielo Does:

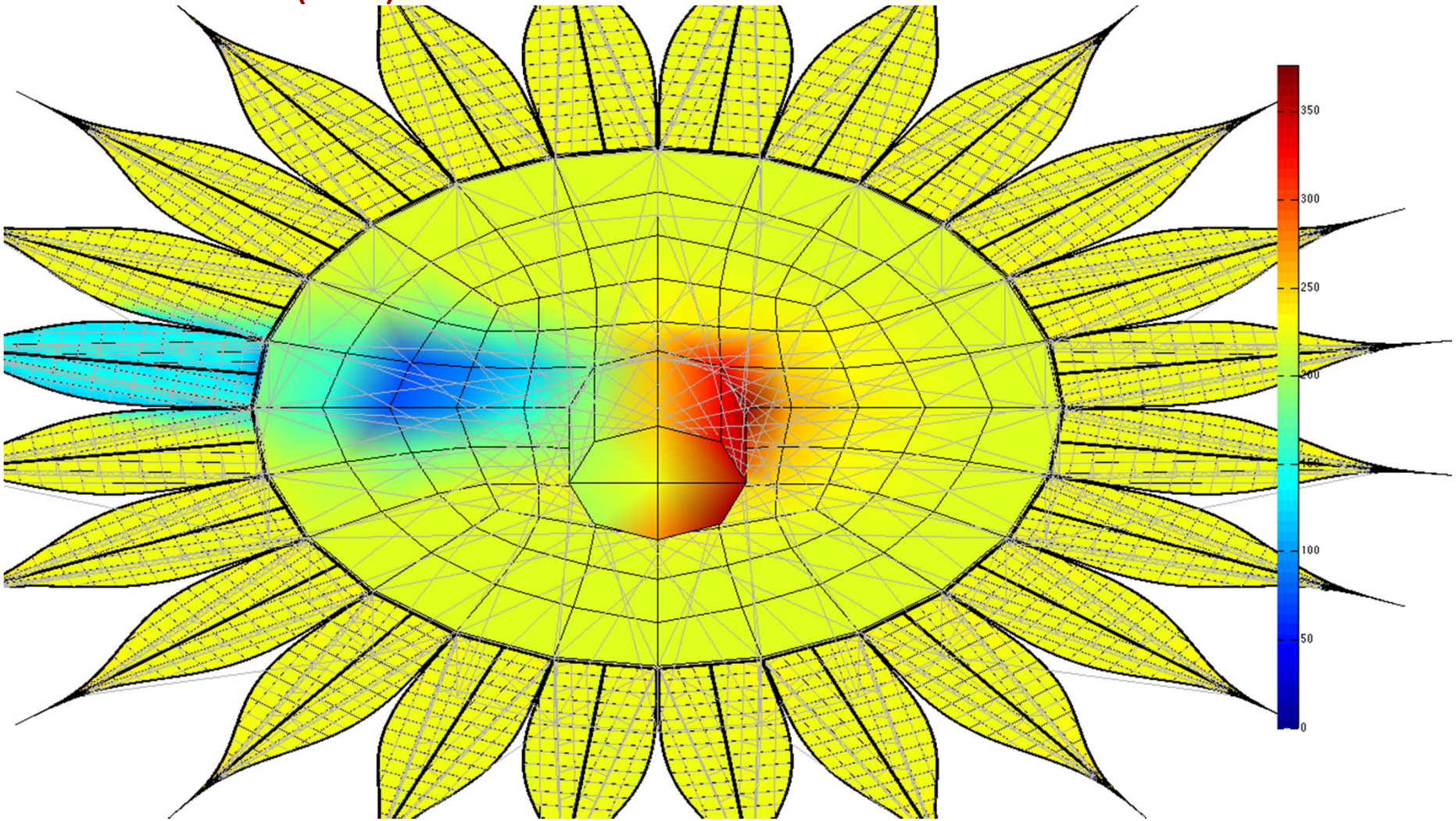
- High performance, high accuracy solution to the STOP (structural/thermal/optical) modeling problem
- Approach based on:
  - Single, common, model with thermal, structural, and optical “attributes”
  - MATLAB-hosted client for external routine integration, “in the loop” optical analysis
  - Parallel remote server for cpu-intensive tasks (e.g., radiation heat transfer solutions)
- Benefits:
  - Accuracy
  - No results mapping
  - Greatly accelerated throughput
  - Enables rapid variational studies, data mining, etc.

Occulter at 5 deg Grazing Angle to Sun
Heat Flux Loading Steady-State



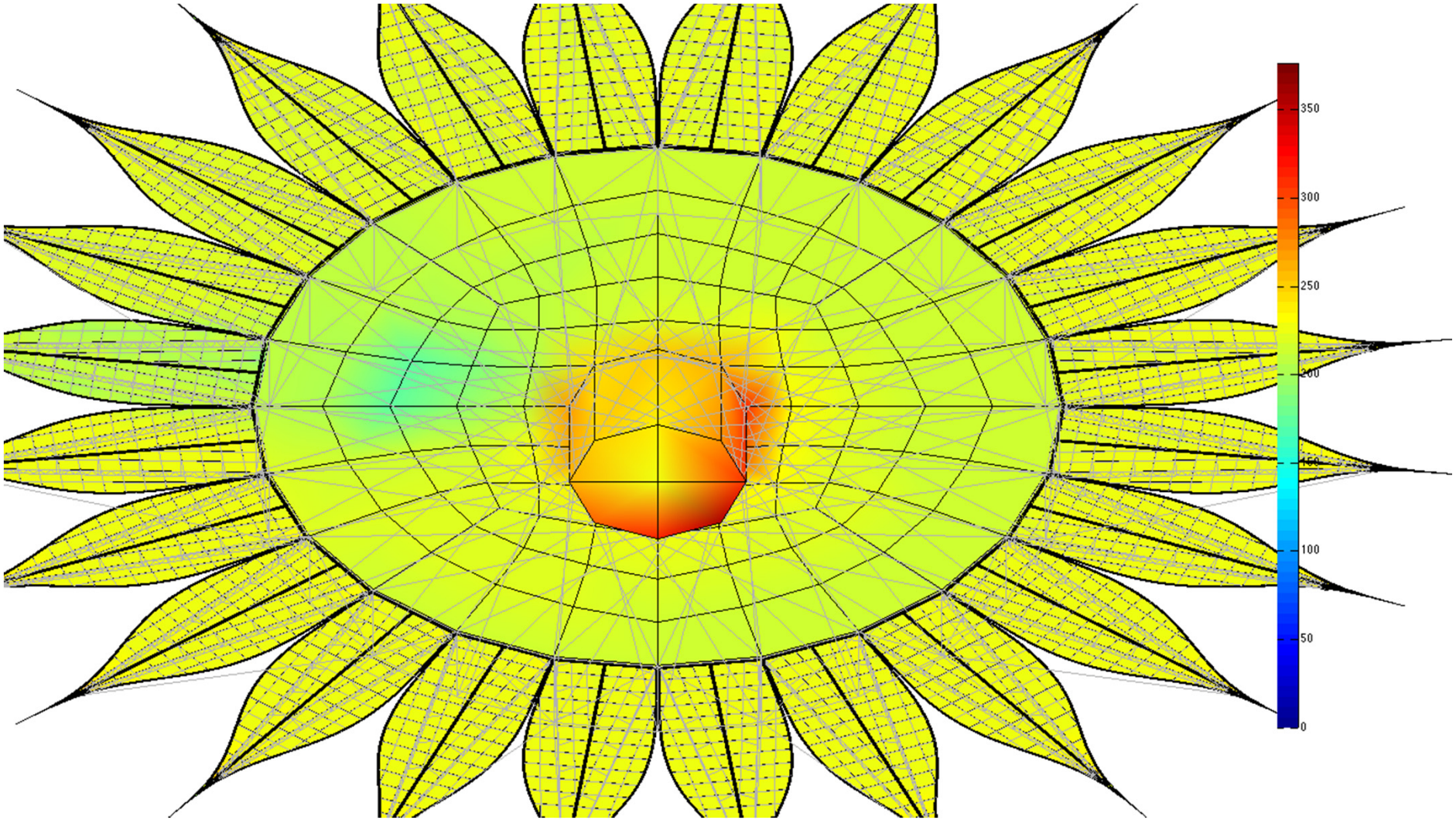
12

Occulter at 5 deg Grazing Angle to Sun Steady-State Temperature Solution (° K)



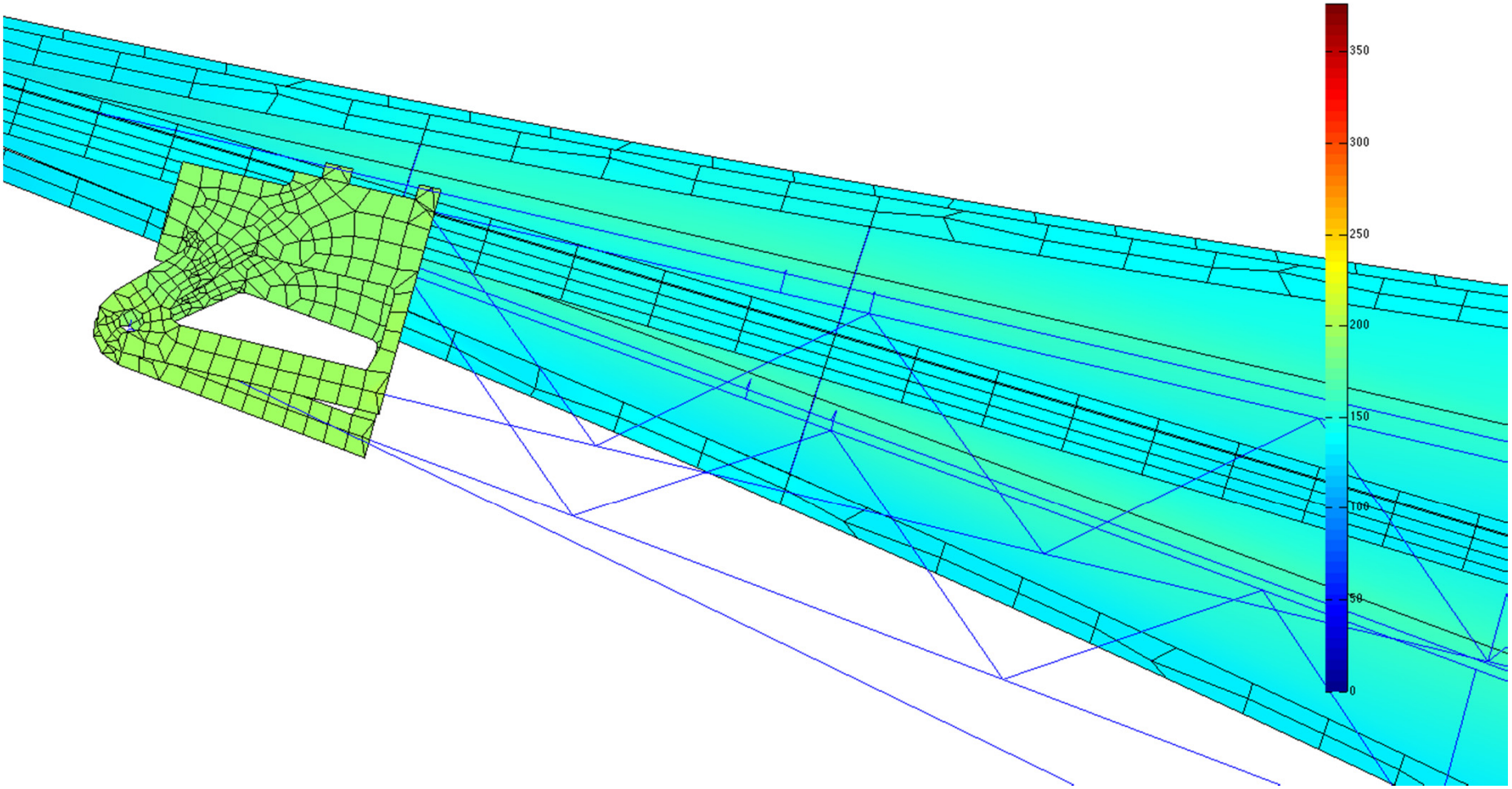
13

Occulter at 5-deg Grazing Angle to Sun Rotating Simulation – 1 Revolution per 30 Minutes



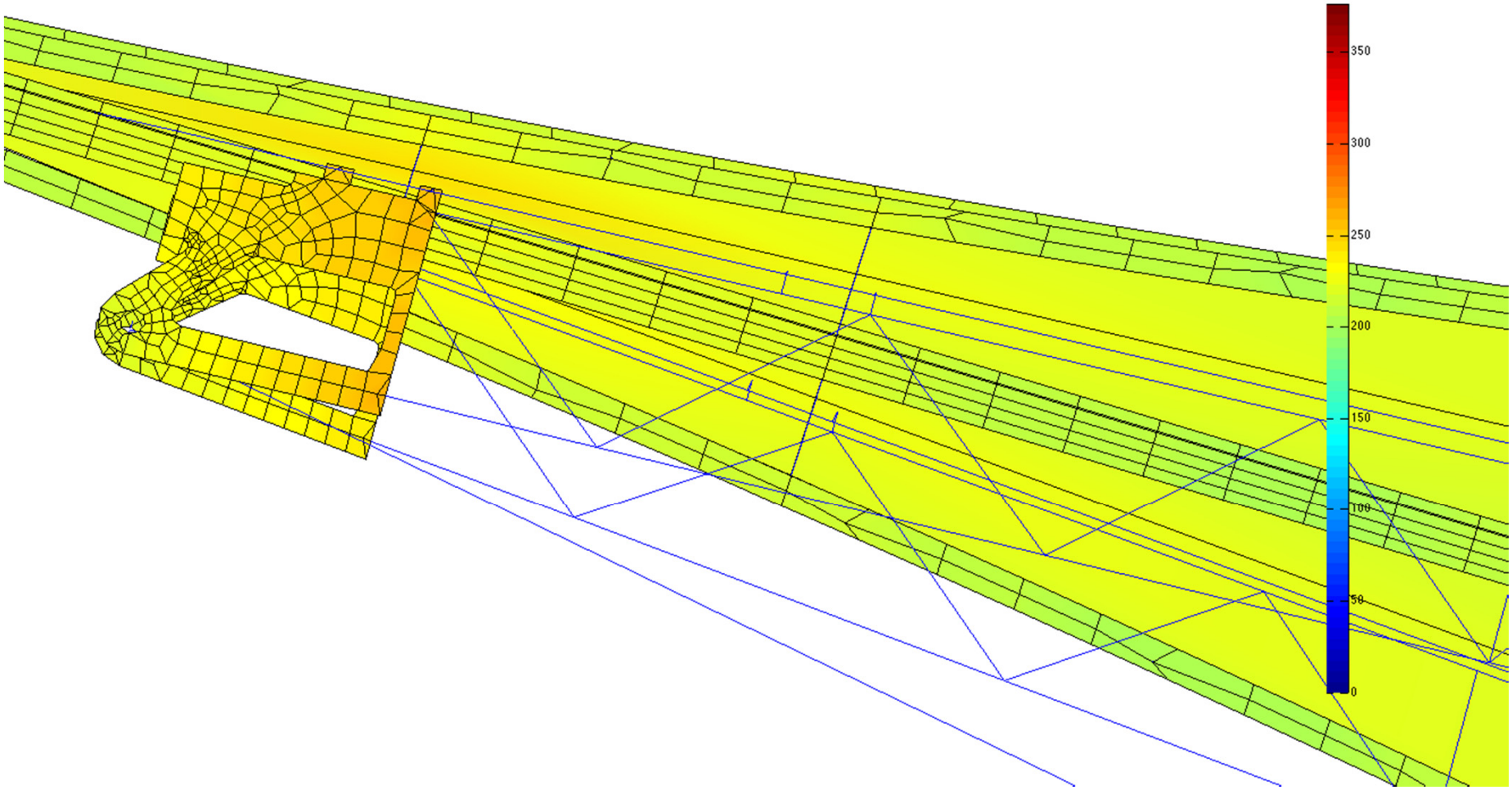
14

Temperature Solution Details



15

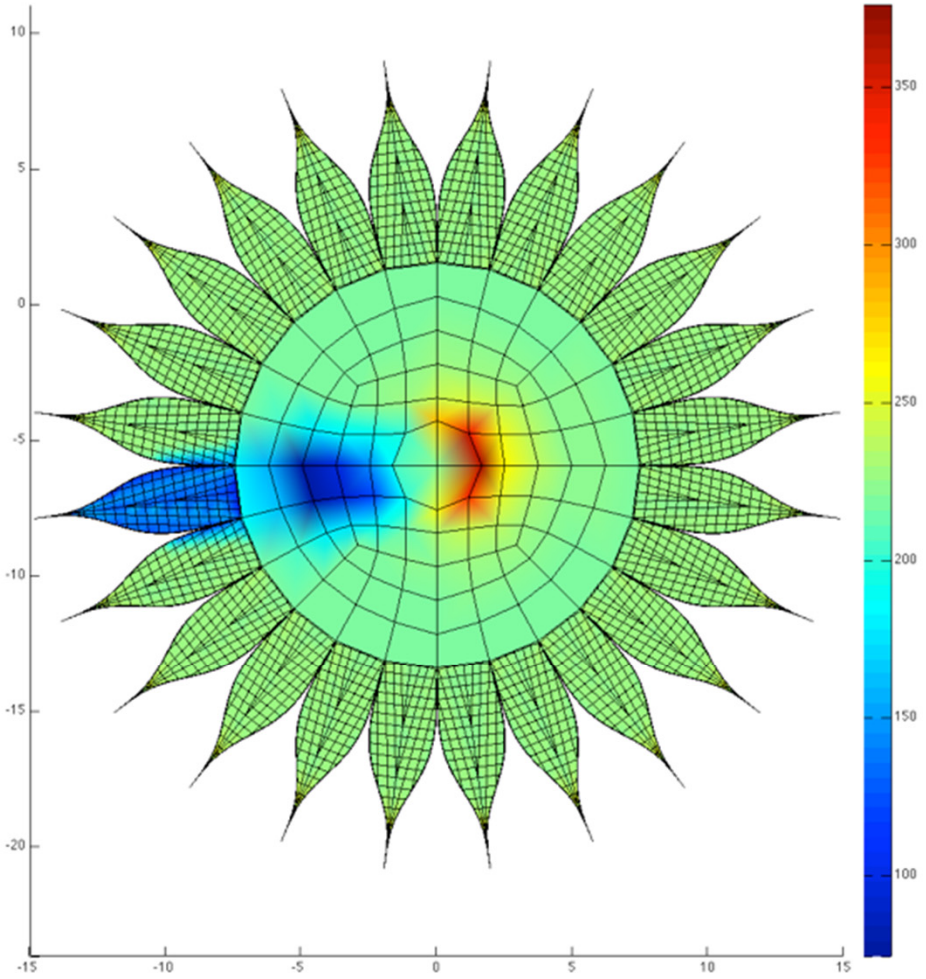
Temperature Solution During Rotation



16

Steady-state Heat Transfer Solutions:

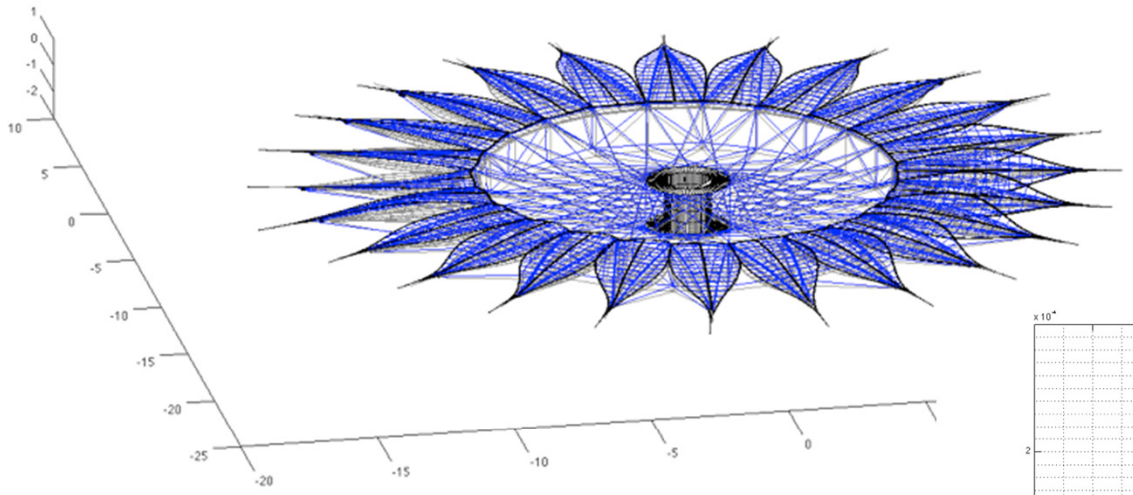
5° sun illumination angle, analysis of full occulter,
tmin/tmax = 74.36/375.93 ° K

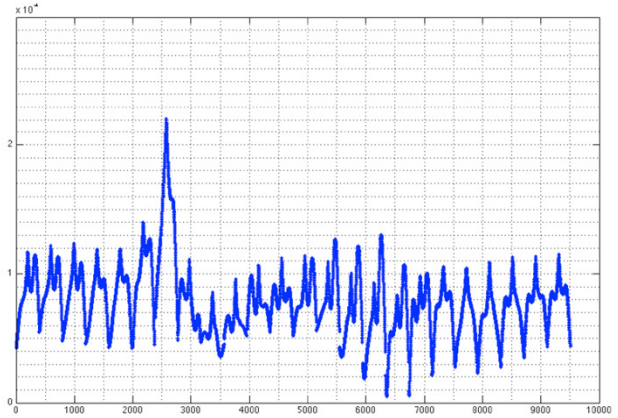


Steady-State Thermal Deformations:

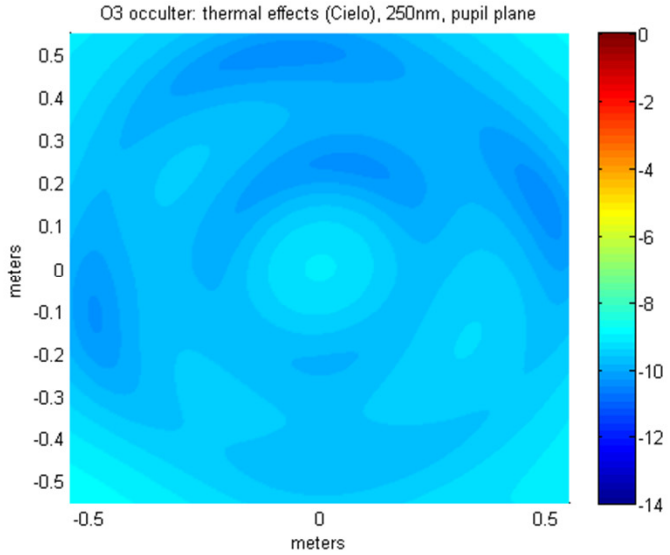
Thermal deformations: min/max = -1.115e-3 / 1.021e-3

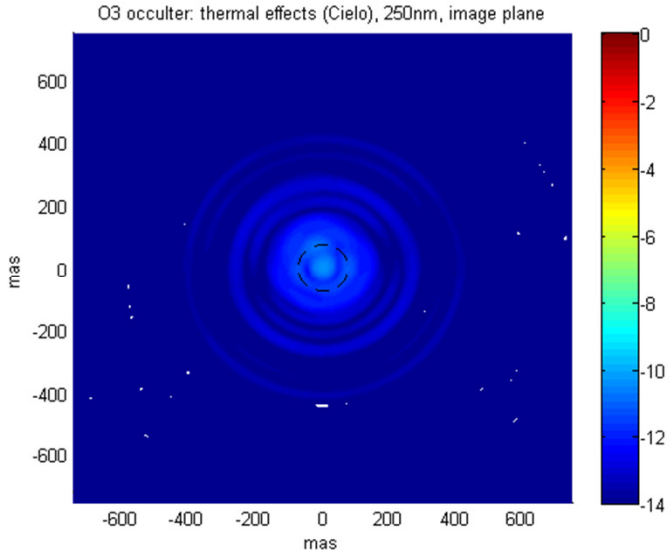
stress-free temperature = 23° C

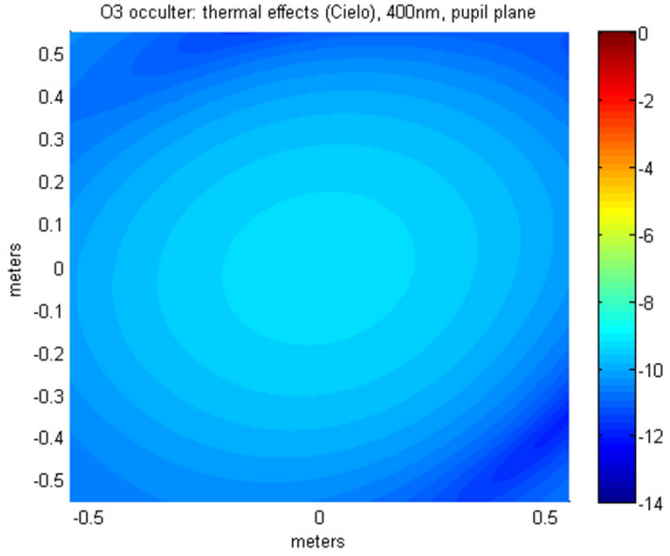


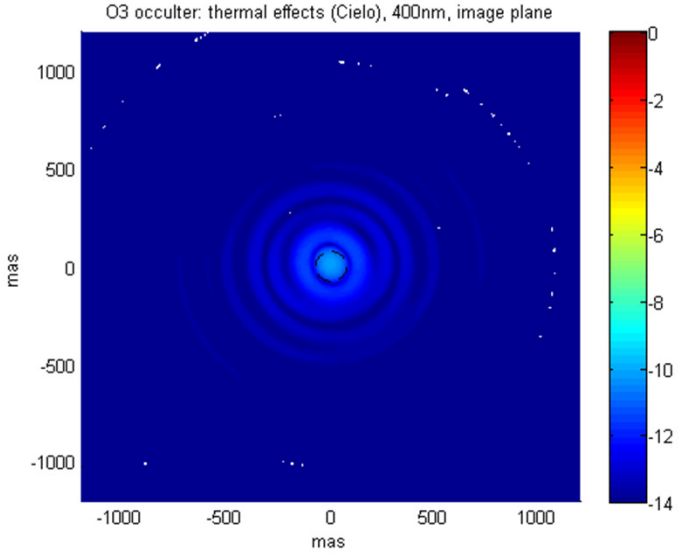


Pupil/Image Plane Intensities:





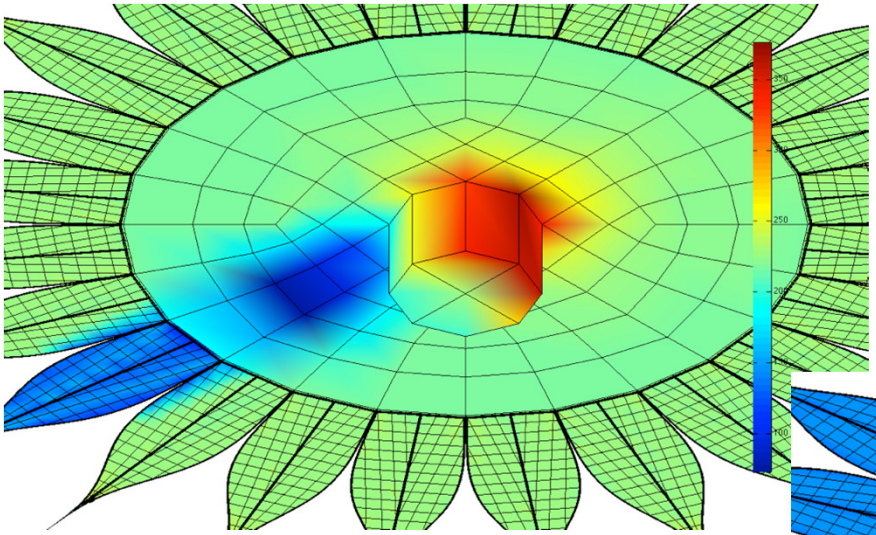




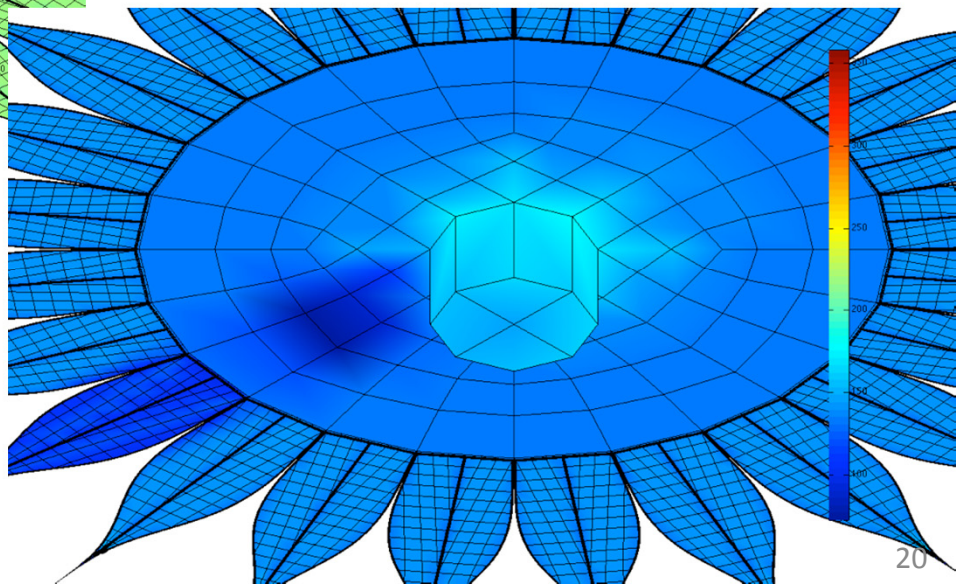
Transient Cooling:

Turn off the sun, investigate star shade “time constant”:

t=0:



t=3600 sec.:



Other Current, Planned Studies:

- Varying sun illumination angles
  - Steady- state thermal/structural/optical analyses throughout range of expected angles
- Starshade angular velocities
  - Investigate effects of thermal transient “equilibrium”, anomaly detection, etc.
- Detailed postprocessing studies
  - Average batten temperatures
  - Thermal “time constants”
  - Continued correlation with COTS tools, performance metrics generation
  - Closed-loop analysis, optimization studies

Acknowledgements, References

Support of the Jet Propulsion Laboratory and the Exoplanet Exploration Office is gratefully acknowledged.

[1] Siegel & Howell. “Thermal Radiation Heat Transfer” 2nd Edition

[2] “New Worlds Observer Optical Performance”, A. Lo, T. Glassman, C. Lillie, Proc. of SPIE Vol. 6687, 668716, (2007)