Simulating Obscurants Under High Energy Laser Illumination

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Introduction: Here we present a simulation for evaluation of novel obscurant candidates under high-energy laser (HEL) illumination. This approach incorporates thermal modeling into obscurant characterization, allowing for evaluation of the temperature increase of the candidate obscurants as well as temperature induced change in their scattering behavior. For ease of use, we built a custom graphical user interface (GUI) that allows a user to perform this analysis without specialized simulation knowledge. The only inputs required are a CAD file of the obscurant geometry and the material properties. We present simulated results for several scatterers that demonstrate the necessity of a multiphysics simulation approach.

The mitigation of HEL is important for the protection of various assets from an adversarial laser threat. A recent push in obscurant technologies has been the development of novel materials and novel geometries that exhibit customizable spectral features. To properly characterize these obscurants response to HEL illumination, both their electromagnetic and thermal behavior must be accounted for.

Methods: We simulated the electro-thermal response of the candidate scatterers using COMSOL Multiphysics and the Electromagnetic Waves, Frequency Domain and Heat Transfer in Solids interfaces. These two interfaces allow evaluation of the particle's behavior, such as its steady state temperature, for a given intensity illumination. The magnitude of the incident wave was then increased to determine the particle temperature vs intensity (Fig 1). Because the material properties of the obscurant may be temperature dependent, this approach also allows for determination of temperature dependent absorption (ACS), scattering (SCS), and extinction cross sections (ECS) for the obscurant. The equations solved are

Electromagnetics: $\nabla \times \mu_r^{-1}\left(\nabla \times \vec{E}\right) - k_0^2\left(\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0}\right)\vec{E} = 0$

Heat transfer: $\nabla \cdot (-k\nabla T) = Q$

EM Heat source: $Q = \frac{1}{2}Re\left(\vec{J}\cdot\vec{E}^*\right) + \frac{1}{2}Re\left(j\omega\vec{B}\cdot\vec{H}^*\right)$

The electromagnetic setup is similar to a standard scattering simulation, where the obscurant particle is surrounded by a small air domain and perfectly matched layer (PML) and a linearly polarized plane wave is used as a background field. The heat transfer domain was restricted to the particle volume. Heat Flux and Diffuse Surface boundary conditions were applied to the particle surface to account for convective and radiative loss, respectively. In cases of scattering candidates without spherical symmetry, the plane wave angle of incidence and the angle of polarization were swept to obtain maximal, minimal, and angle averaged behavior.

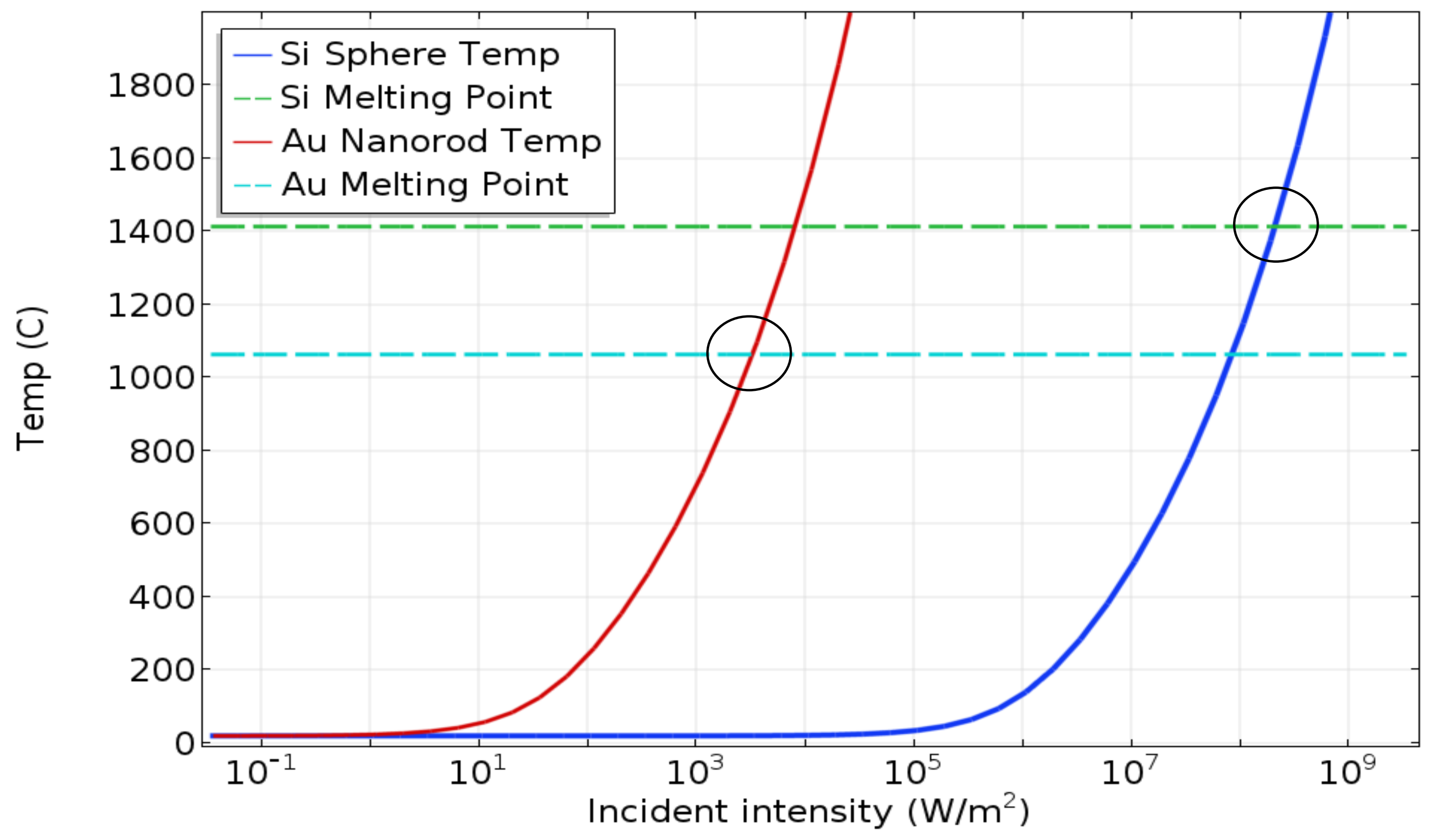
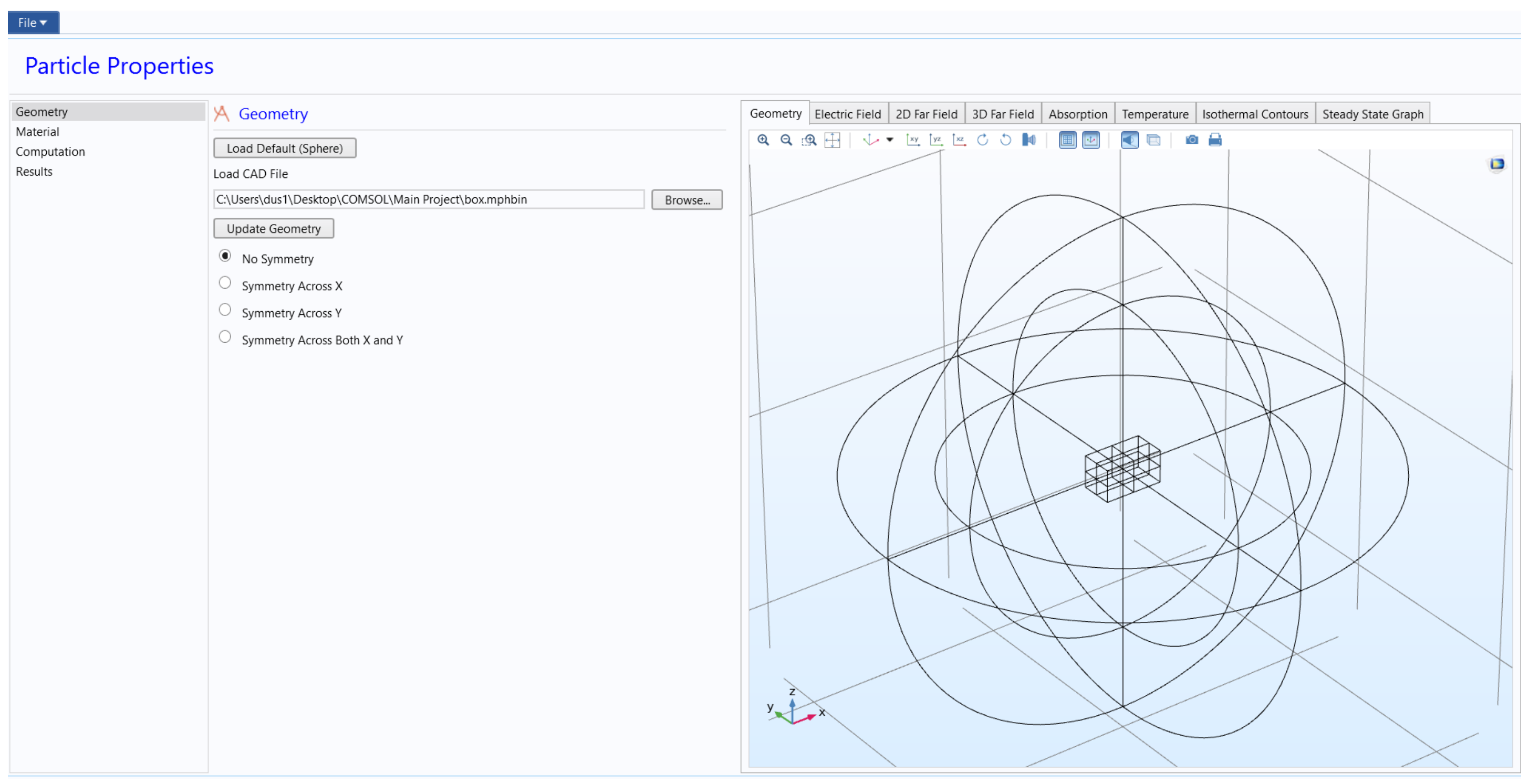


Figure 1. Steady state temperature of an Au nanorod and 144 nm radius Si sphere under illumination of various intensities. This data suggests that the nanorod will approach its melting point near 0.33 W/cm^2, while the silicon sphere will withstand over 21 kW/cm^2, a difference of approximately five orders of magnitude. For simplicity we have assumed temperature dependent material properties in this figure.

Results: To demonstrate the importance of this multiphysics approach, we simulated the response of two candidate scatterers: a 144 nm Si sphere and a Au cylinder with a length of 150 nm and radius of 10 nm. The dimensions of each particle were chosen to optimize their ECS at 1.064 µm. A purely electromagnetic analysis reveals that the Au nanorod reduces the EM intensity more efficiently, with a ECS/weight of 89.34 m^2/g, whereas the Si sphere is approximately four times smaller at 21.85 m^2/g. Because of the high loss of Au relative to Si, however, we expect the temperature of the Au nanorod to increase much more than in the Si sphere. A thorough multiphysics analysis reveals that the Au nanorod temperature will approach its melting point near 0.33 W/cm^2, whereas the Si sphere will not reach this point until an illumination of over 20 kW/cm^2 (Fig 1). In other words, the Si sphere is expected to survive intensities larger by approximately five orders of magnitude.

Conclusions: We have presented an electro-thermal simulation for the evaluation of obscurant candidates for HEL sensor protection. In particular, we have shown the results of this workflow for two candidate scattering particles, an Au nanorod and a Si sphere. The multiphysics simulation shows that the nanorod temperature will approach its melting point at an intensity level that can be achieved with off-the-shelf lasers, while the Si sphere will still be at room temperature. This demonstrates how both optical and thermal behavior must be incorporated into a multiphysics analysis to properly characterize obscurant performance.

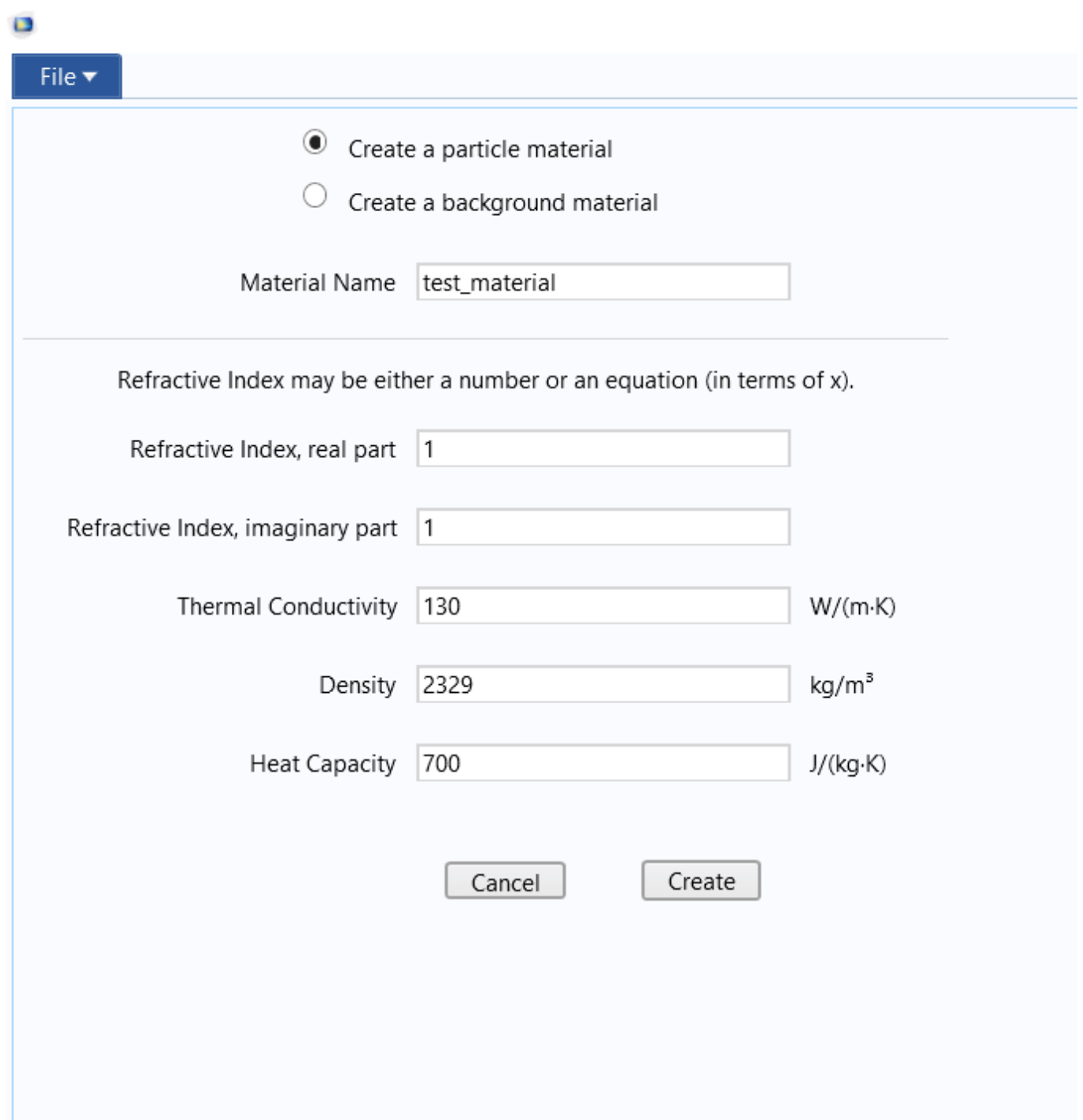
Application: We built an interface that allows any user to easily test a variety of shapes and materials to obtain different results. The GUI separates the problem into Geometry, Material, Computation, and Results. Figure 2 shows the various options for the user in the Geometry tab, including the possibility of importing their own CAD file for use. The Material tab allows the user to choose materials for the particle and outside domain. The Computation and Results tab give the user options for performing their study and how they want to view the results, like changing the angle of incidence.



Load CAD File: C:\Users\dus1\Desktop\COMSOL\Main Project\box.mphbin

● No Symmetry
○ Symmetry Across X
○ Symmetry Across Y
○ Symmetry Across Both X and Y

Figure 2. A rectangular prism is imported into the geometry instead of the default sphere.



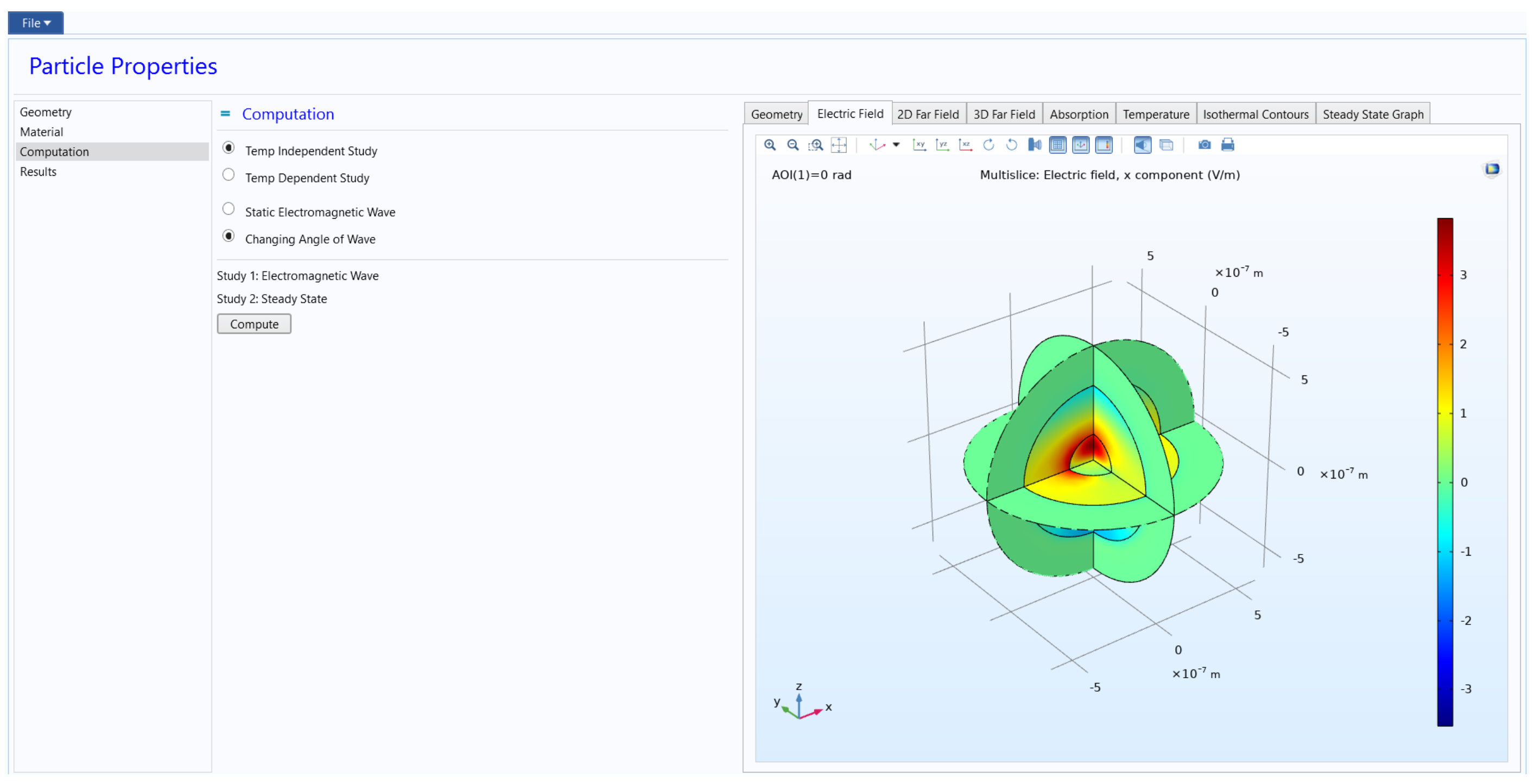
● Create a particle material
○ Create a background material

Material Name: test_material

Refractive Index may be either a number or an equation (in terms of x).

Refractive Index, real part: 1
Refractive Index, imaginary part: 1
Thermal Conductivity: 130 W/(m·K)
Density: 2329 kg/m^3
Heat Capacity: 700 J/(kg·K)

Figure 3. The pop-up menu for creating custom materials.



● Temp Independent Study
○ Temp Dependent Study

○ Static Electromagnetic Wave
● Changing Angle of Wave

Study 1: Electromagnetic Wave
Study 2: Steady State

Figure 4. The Computation tab, along with one of the electric field graph resulting from the simulation.

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