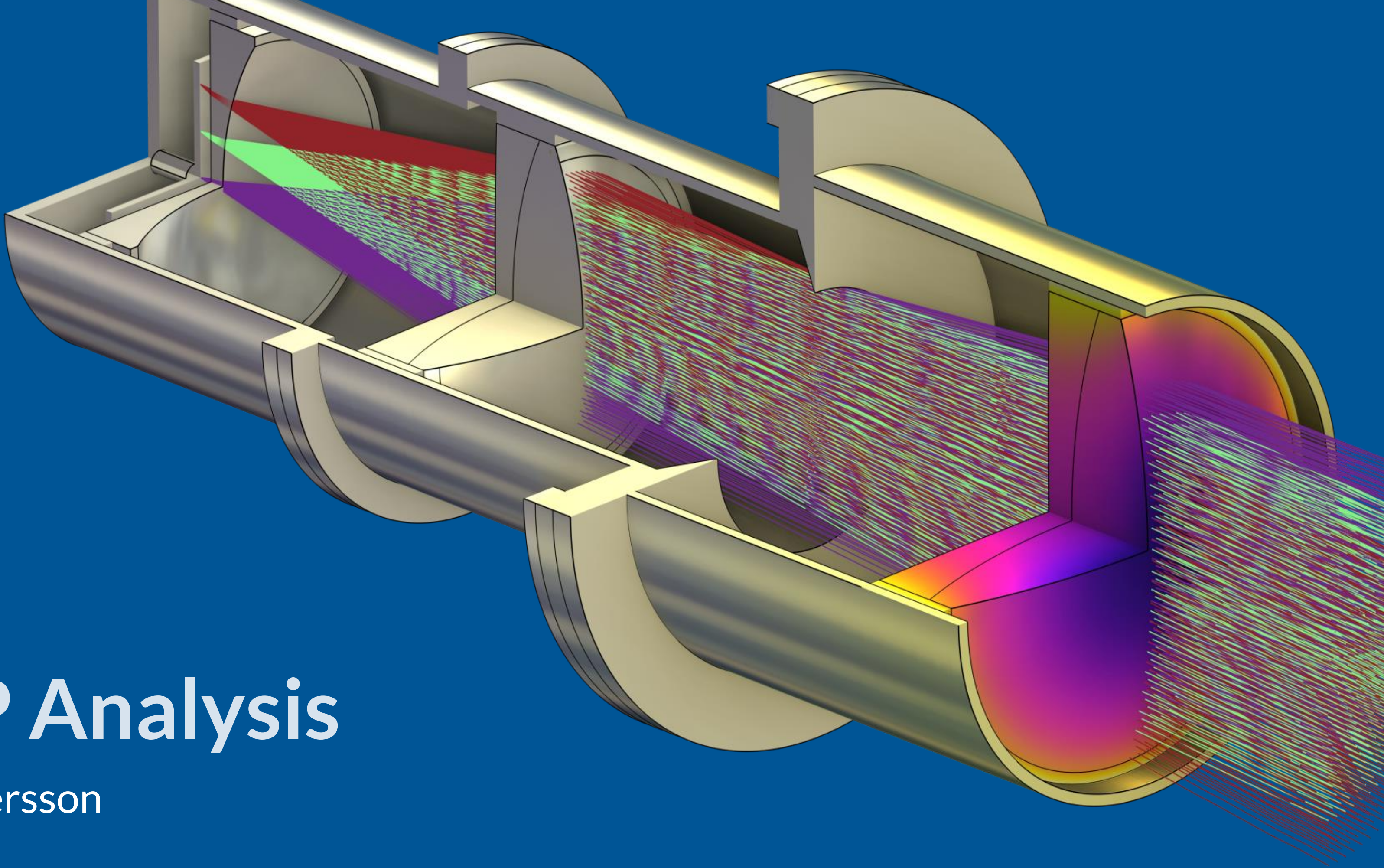
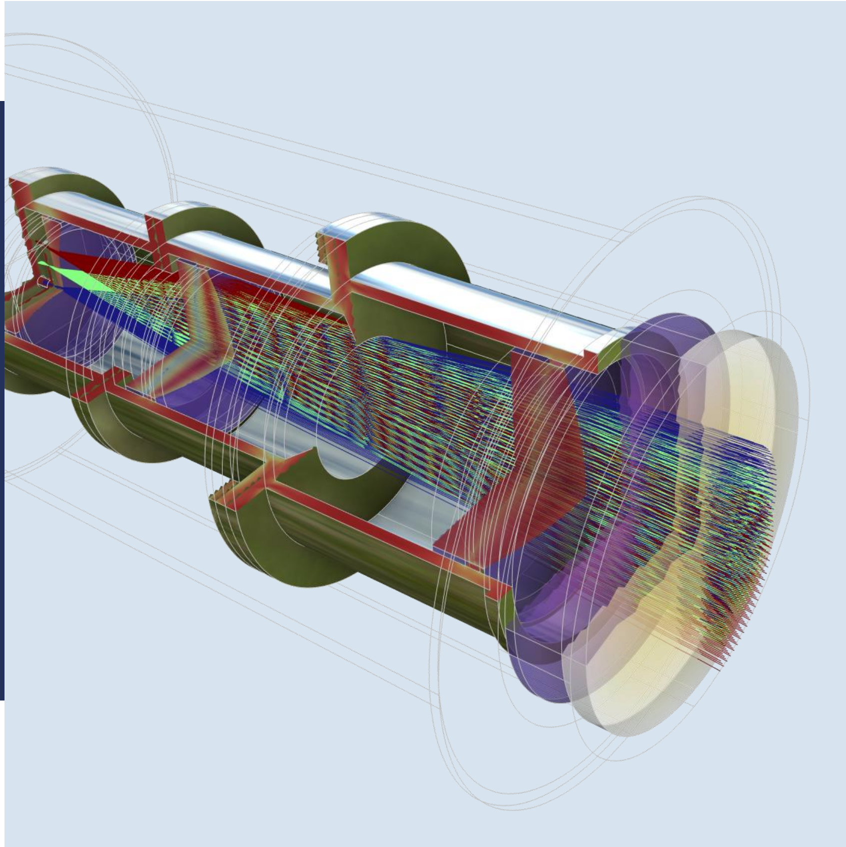


STOP Analysis

Linus Andersson

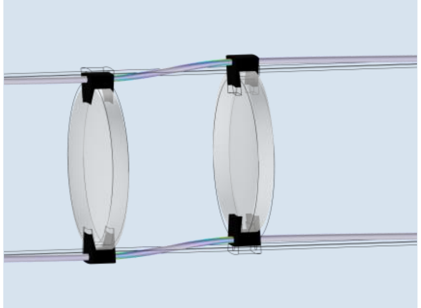
COMSOL



STOP Analysis

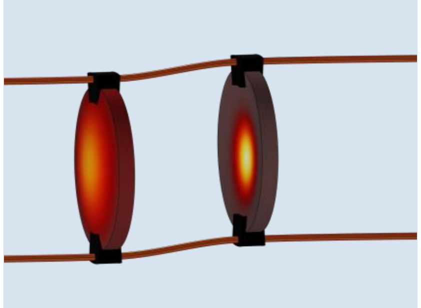
From cellphone cameras to space telescopes, optical systems are regularly subjected to varying temperatures and structural stress. With structural-thermal-optical performance (STOP) analysis, you can find out how these conditions affect their operation. In COMSOL®, all parts of a STOP analysis can be included in a single self-contained model.

STOP Analysis in COMSOL®



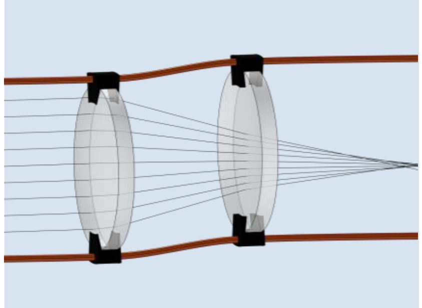
Structural

Model the structural displacements in an optical system.



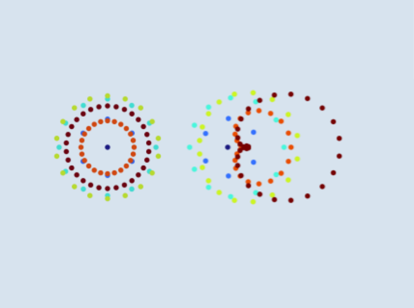
Thermal

Apply a fixed operating temperature or simulate the temperature distribution. Heat sources may include absorption from the beam itself.



Optical

With the local temperature and displacement considered, model how light will propagate through the system.



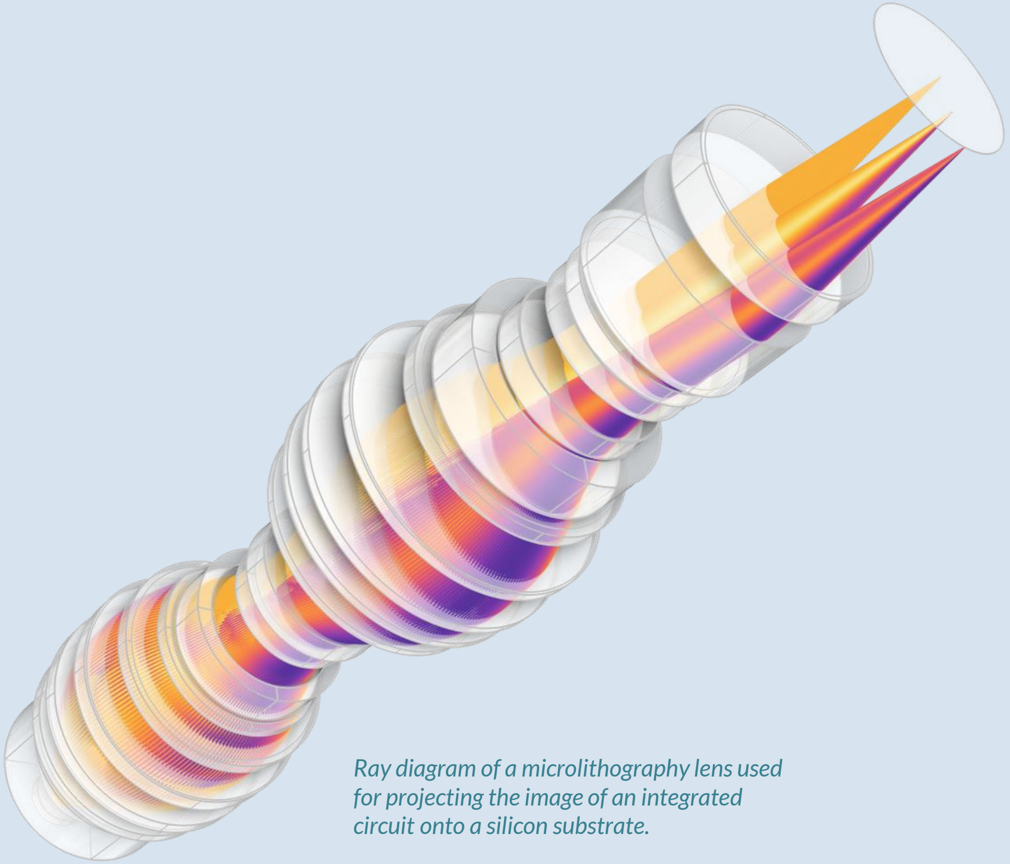
Performance

Evaluate the optical performance under the influence of thermal and structural loads.

OVERVIEW

Geometrical Optics

- Ray tracing in homogeneous and graded media
- Detailed analysis of ray intensity and polarization
- Variety of features for releasing rays and controlling interaction with boundaries
- Functionality for multiscale electromagnetics modeling
- Multiphysics couplings for STOP analysis



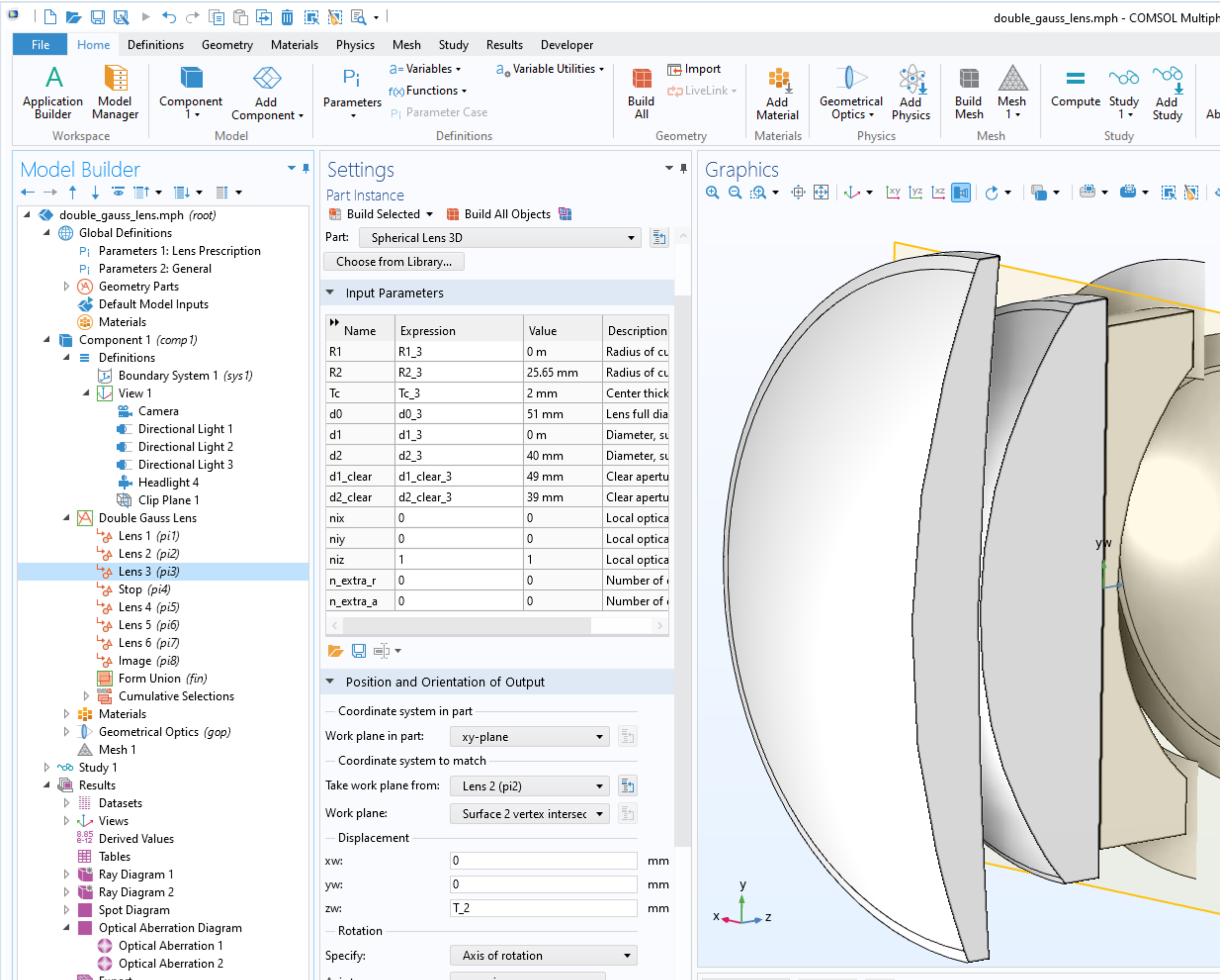
Ray diagram of a microlithography lens used for projecting the image of an integrated circuit onto a silicon substrate.

Ray Optics Module Part Library

The Ray Optics Module Part Library contains parameterized geometry parts for optical systems:

- Apertures and obstructions
- Aspheric, cylindrical, doublet, triplet, and spherical lenses
- Beam splitters and prisms
- Mirrors and reflectors

The parts include predefined selections for convenient set up of boundary conditions



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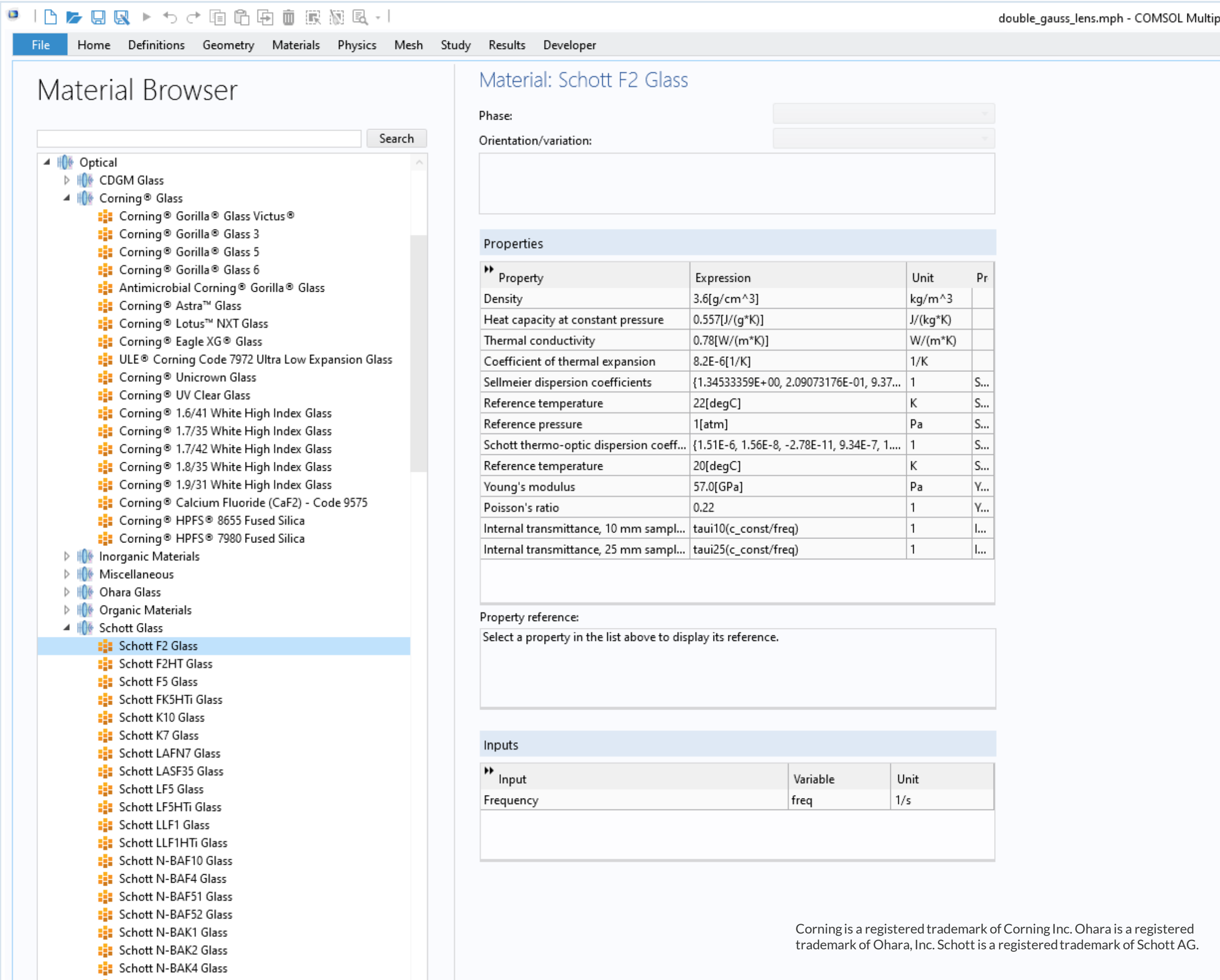
Optical Material Library

The Optical Material Library has more than 1200 materials, e.g., optical adhesives, antireflective coating materials, glasses, and more.

Glasses in the Optical material library include structural and thermal properties as well as temperature-dependent refractive index and dispersion models.



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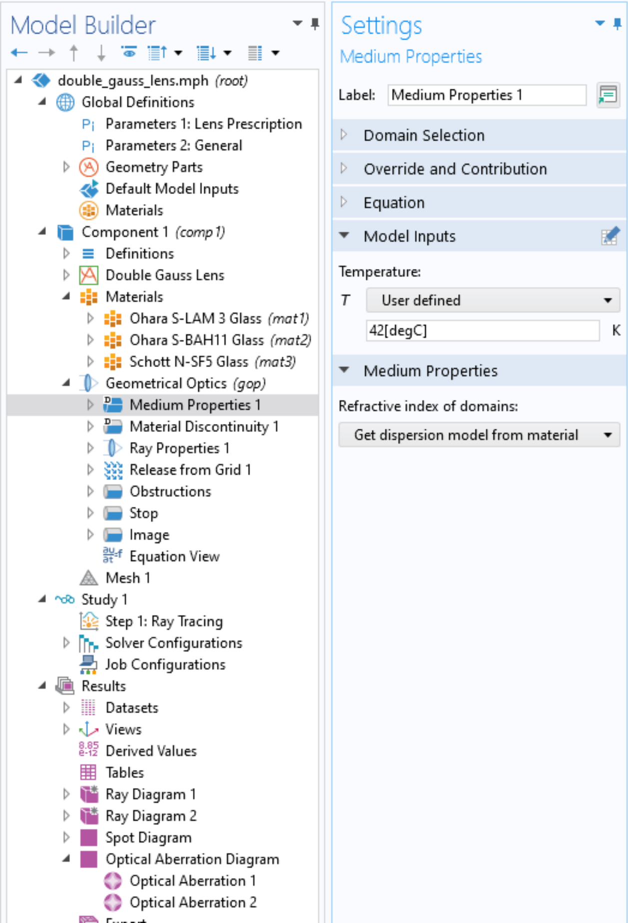
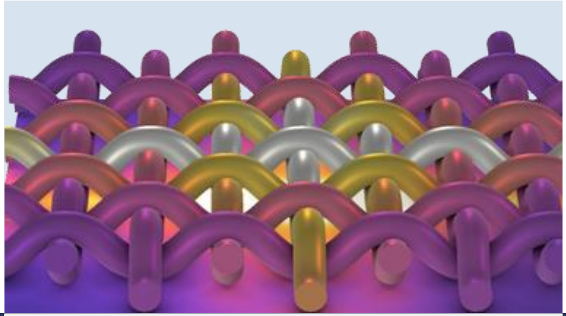


Temperature Dependency

- To use a temperature-dependent refractive index from a glass in the Model Library at a fixed temperature, simply enter the temperature. The dispersion relation from the material will control both the wavelength dependence and the temperature dependence of the refractive index.
- To use your own material data, pick from a list of dispersion types, enter the refractive index as an arbitrary function of the temperature, or interpolate from a text file with refractive index versus temperature data.
- In a STOP analysis, the modeled local temperature will automatically be fed into the dispersion relation.

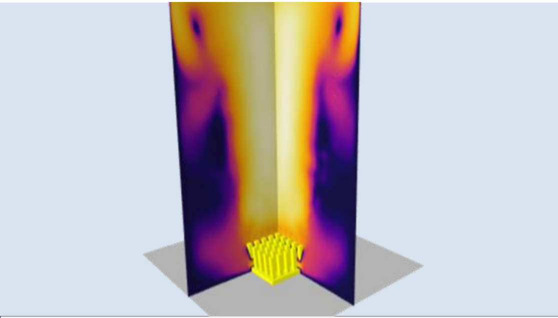
OVERVIEW

Heat Transfer Functionality



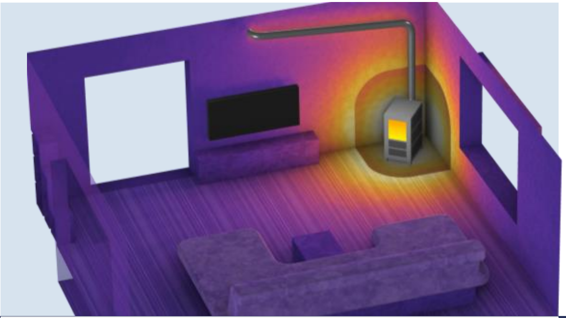
Conduction

- Isotropic, anisotropic, linear, and nonlinear thermal conductivity
- Thermal contact
- Thin layers



Convection

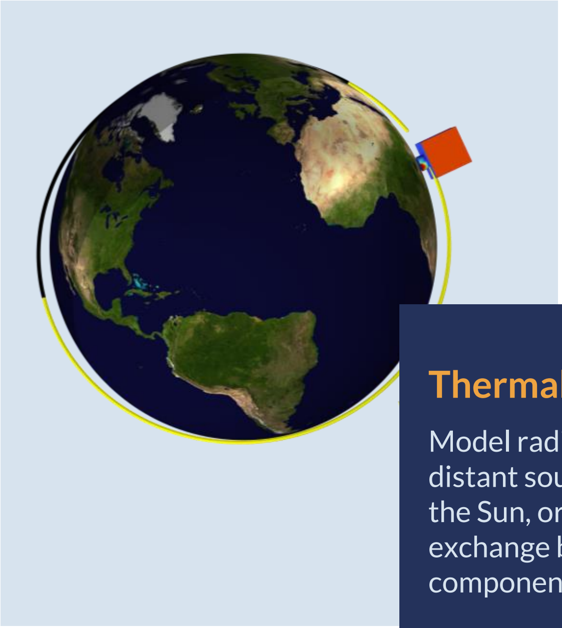
- Free and forced convection
- Laminar and turbulent flow
- Effective material properties

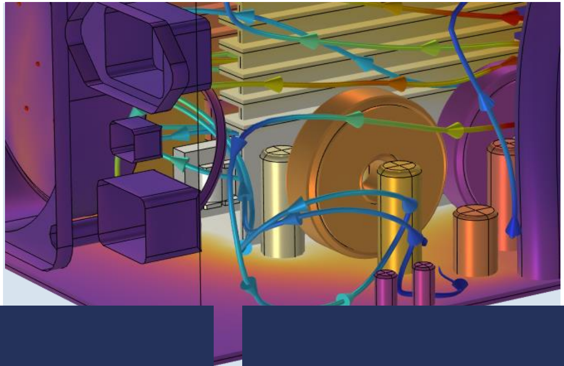


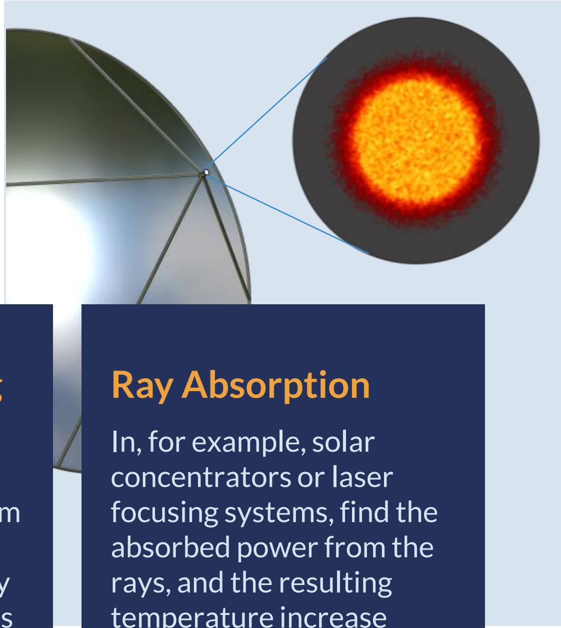
Radiation

- Surface-to-ambient and surface-to-surface radiation
- External radiation sources
- Radiation in participating media

Heat Transfer Modeling in Ray Optics







Thermal Radiation

Model radiation from distant sources, such as the Sun, or radiative heat exchange between optical components

Convective Cooling

Model passive or active convective cooling, removing excess heat from the optical system, including its power supply and connected electronics

Ray Absorption

In, for example, solar concentrators or laser focusing systems, find the absorbed power from the rays, and the resulting temperature increase

EXAMPLE

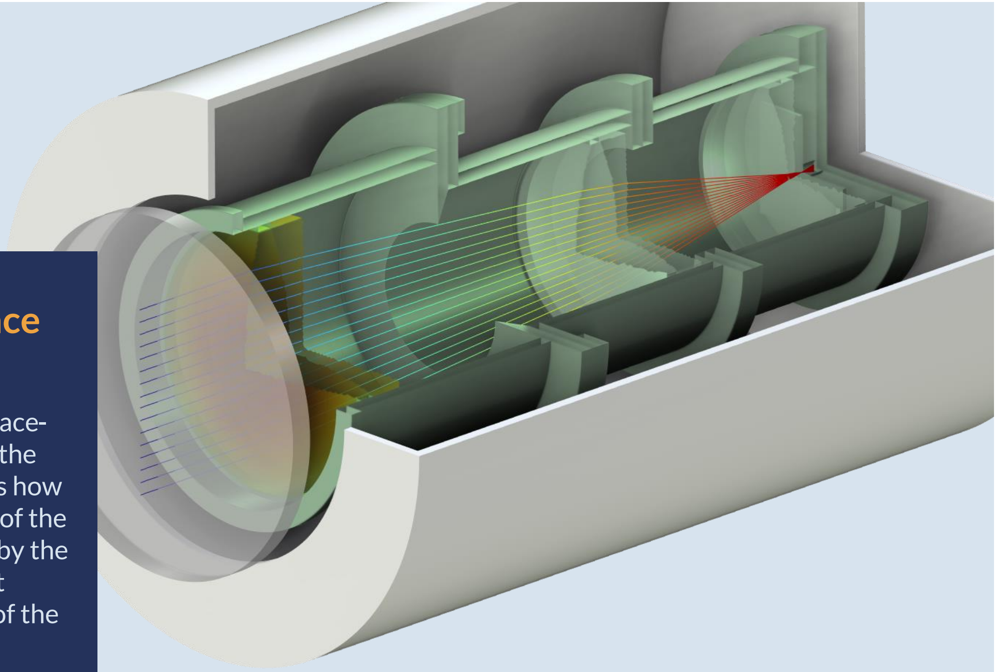
Radiative Heat Transfer in a Lens System

Lens Assembly in Thermal Shroud

This Petzval lens assembly is placed in a thermal shroud at a constant low temperature, inside a vacuum chamber. Heat radiating in through the thermal window primarily affects the first lens.

Surface-to-Surface Radiation

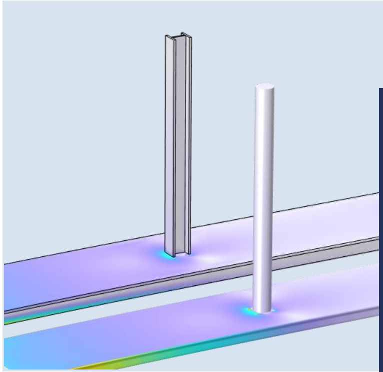
The model features surface-to-surface radiation for the heat transfer, and shows how the location and quality of the focal point are affected by the temperature-dependent glass refractive indices of the glasses.



Ray diagram and temperature distribution in the lenses and the surrounding barrel.

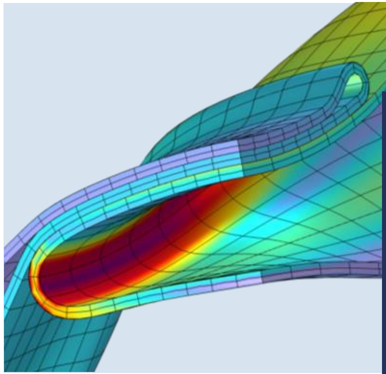
OVERVIEW

Structural Mechanics Functionality



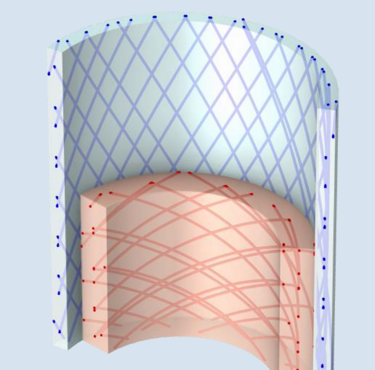
Formulations

Combine solids, single and layered shells, plates, membranes, beams, pipes, trusses, and wires.



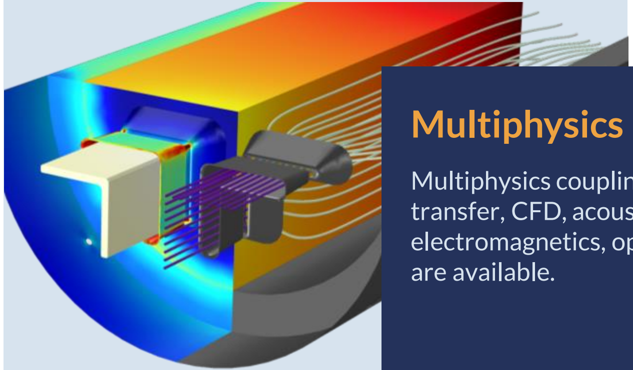
Analysis Types

Run stationary, transient, and frequency response analyses, as well as specialized analyses such as mechanical contact, buckling, and fatigue.



Material Models

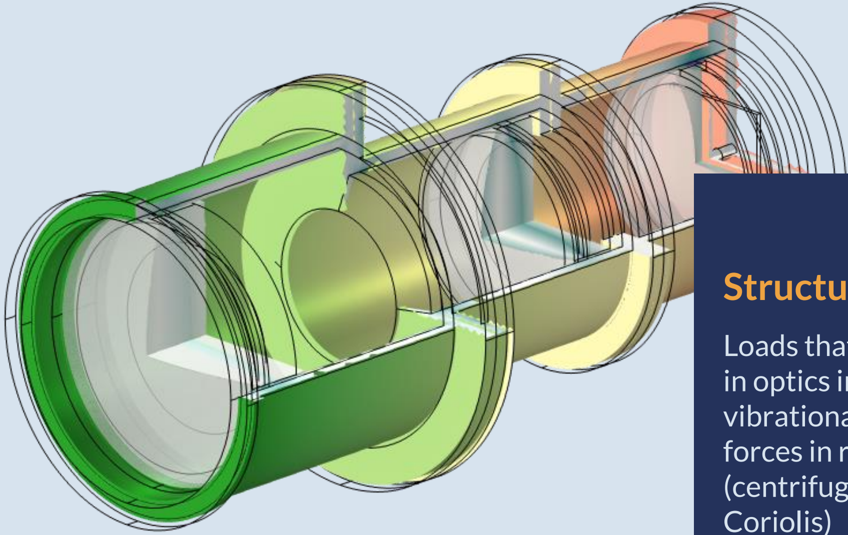
Choose from a wide variety of elastic, viscoelastic, hyperelastic, elastoplastic, and composite material models. Materials can be spatially varying, anisotropic, and dependent on other variables.



Multiphysics

Multiphysics couplings with heat transfer, CFD, acoustics, electromagnetics, optics, and more are available.

Structural Mechanics Modeling in Optics



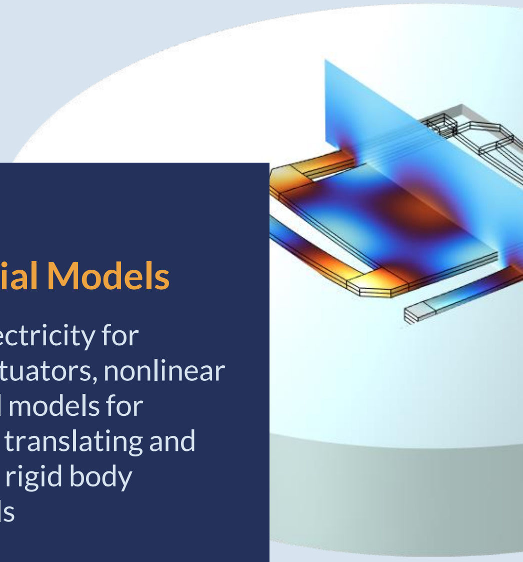
Displacements and stresses in a Petzval lens with hyperelastic supports.

Structural Loads

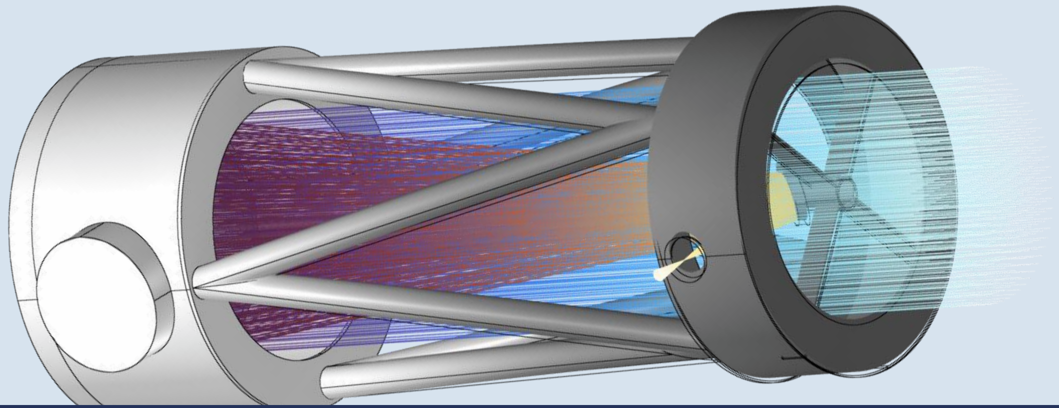
Loads that are often useful in optics include gravity, vibrational loads, and forces in rotating frames (centrifugal, Euler, Coriolis)

Material Models

Piezoelectricity for microactuators, nonlinear material models for mounts, translating and rotating rigid body materials

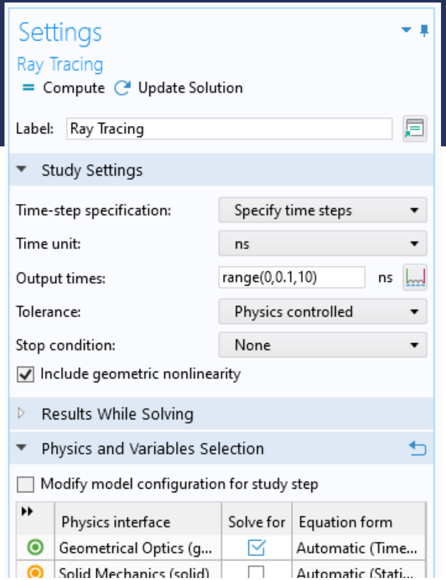


Vibrating micromirror with prestress and viscous damping.

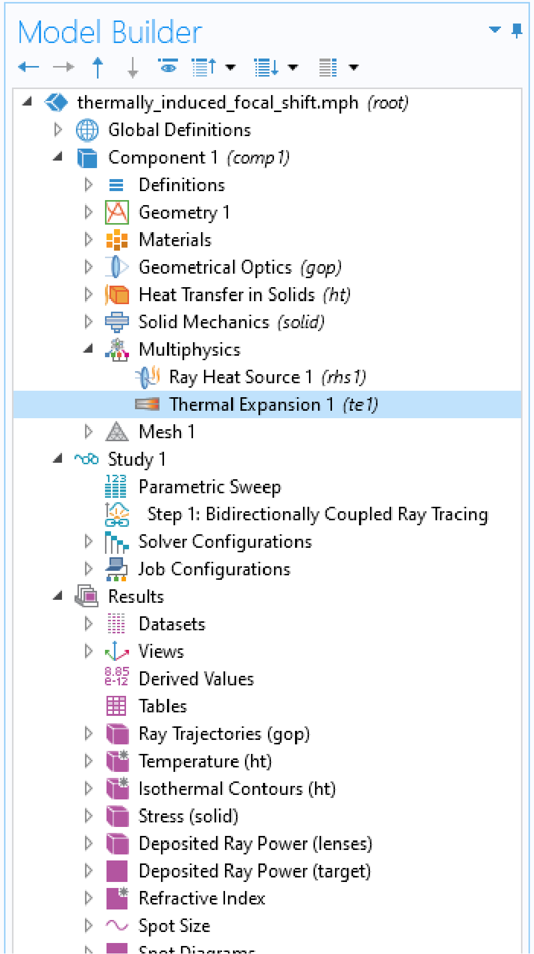


EXAMPLE

Gravitational Analysis of a Telescope



In this model of a Newtonian telescope, a structural mechanics study computes the deformations under gravity. The *Include geometric nonlinearity* check box in the subsequent ray tracing study ensures that it is run in the deformed geometry.



BRINGING IT TOGETHER

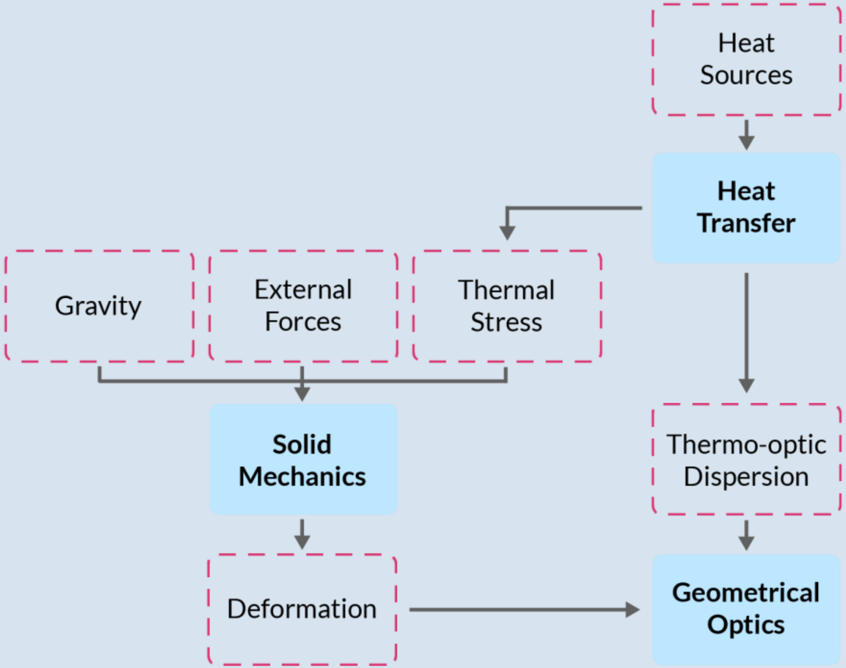
Thermal Expansion

Thermal expansion is readily available as a multiphysics coupling. The glasses in the Optical material library include thermal expansion coefficients, and many of them also come with complete elastic and thermal material properties.

BRINGING IT TOGETHER

STOP Analysis

The flowchart shows how the structural and thermal effects come together and affect the rays in a one-way coupled STOP analysis.



BRINGING IT TOGETHER

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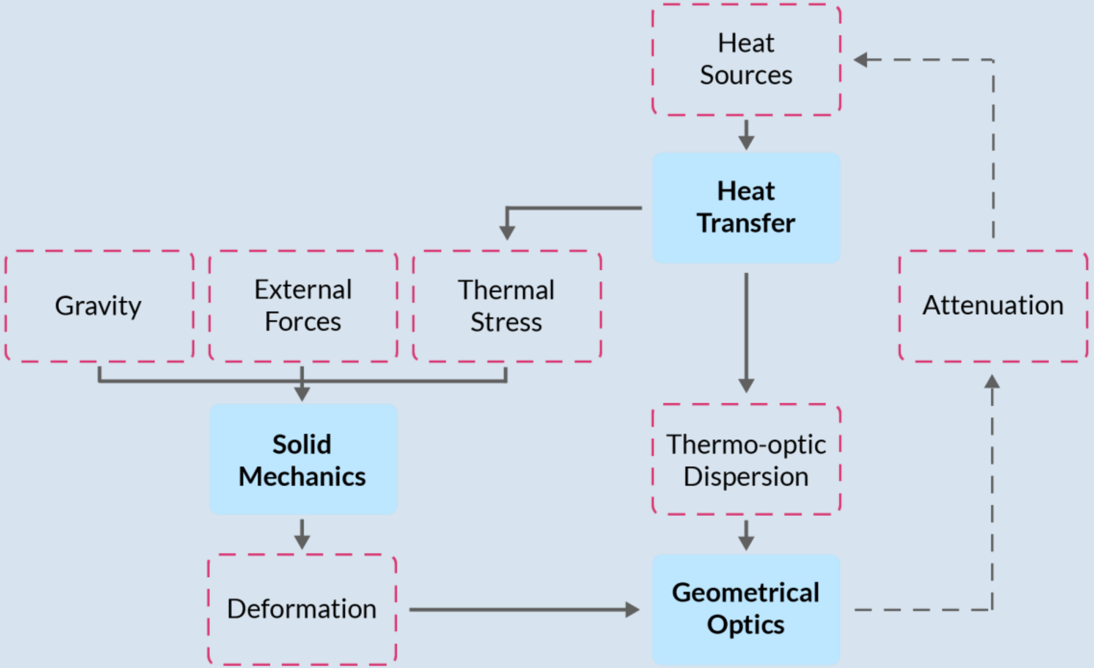
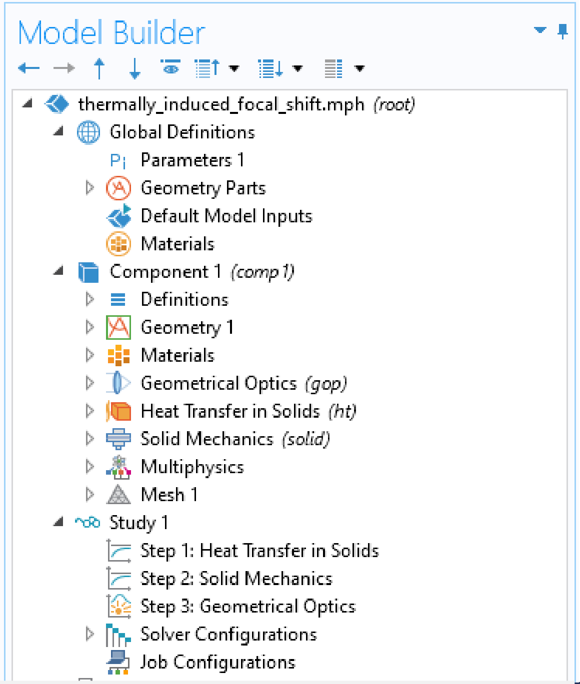
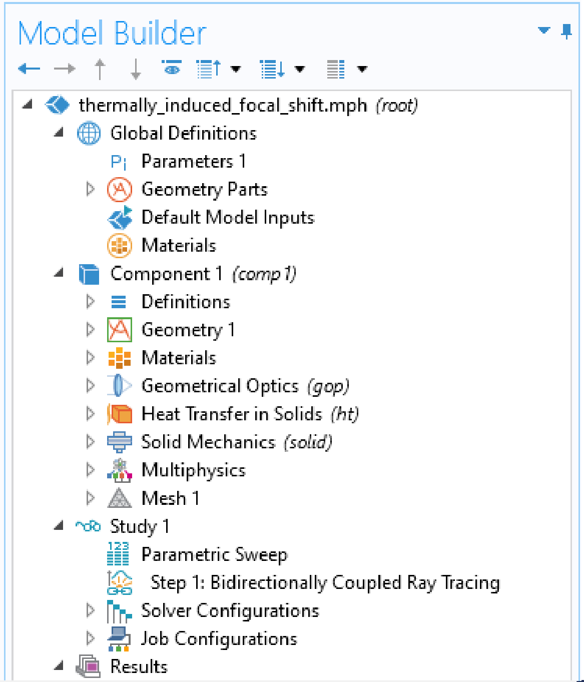


Study Setup



One-Way Coupled STOP Analysis

With the temperatures affecting the deformations, and both temperatures and deformations influencing the ray paths, you can solve for the different physics interfaces one at a time.



STOP Analysis with Ray Heating

The dedicated *Bidirectionally Coupled Ray Tracing* study type, along with the *Ray Heat Source* feature, will automatically follow the iteration scheme in the previous slide.

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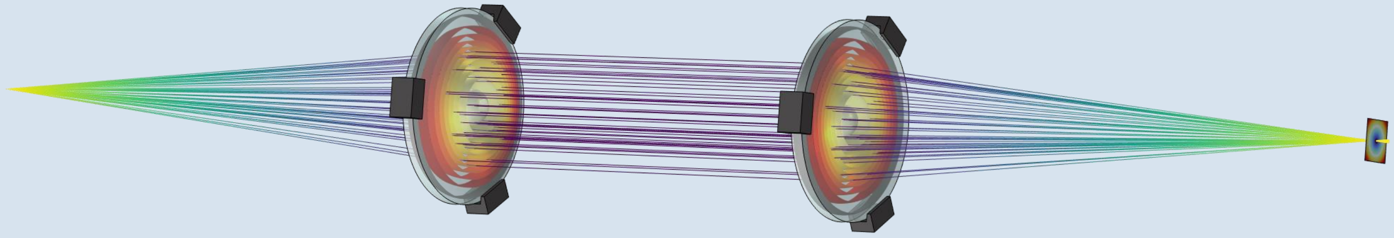
DEMO

Thermally Induced Focal Shift

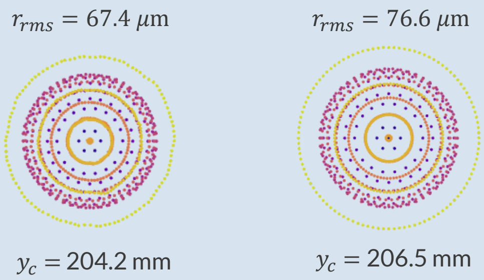


Double Lens System

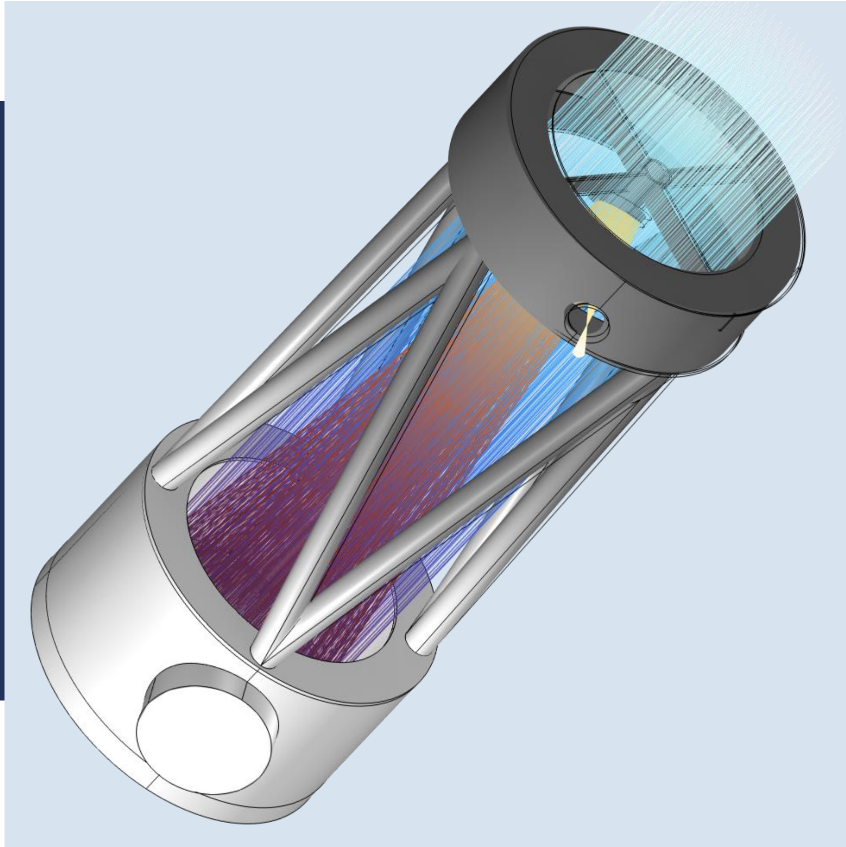
In this demo model, a high-powered laser is sent through two lenses, focusing after the second one. The laser is strong enough to significantly heat up the lenses.

STOP Analysis

Use a bidirectionally coupled ray tracing study to see how the heat absorption changes the refractive index and deforms the lenses, thereby affecting the ray paths.



Spot diagram, focal coordinates, and RMS radius of an undeformed (left) and deformed (right) system.



SUMMARY

Advantages

COMSOL Multiphysics® has unique capabilities for modeling all aspects of STOP analysis in a single software environment. A meshed formulation in lenses allows for continuously varying refractive indices, while a mesh-free formulation in air and vacuum makes it trivial to include the effects of structural deformations on the ray paths. Extensive libraries of optical components and materials with temperature and dispersion relations make setting up a model robust and convenient.

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CONCLUDING REMARKS

STOP Analysis in COMSOL®

The COMSOL® software features a wide range of capabilities for modeling ray optics, heat transfer, structural mechanics, and the interaction between them. It provides unique functionality for fully self-consistent STOP analysis.