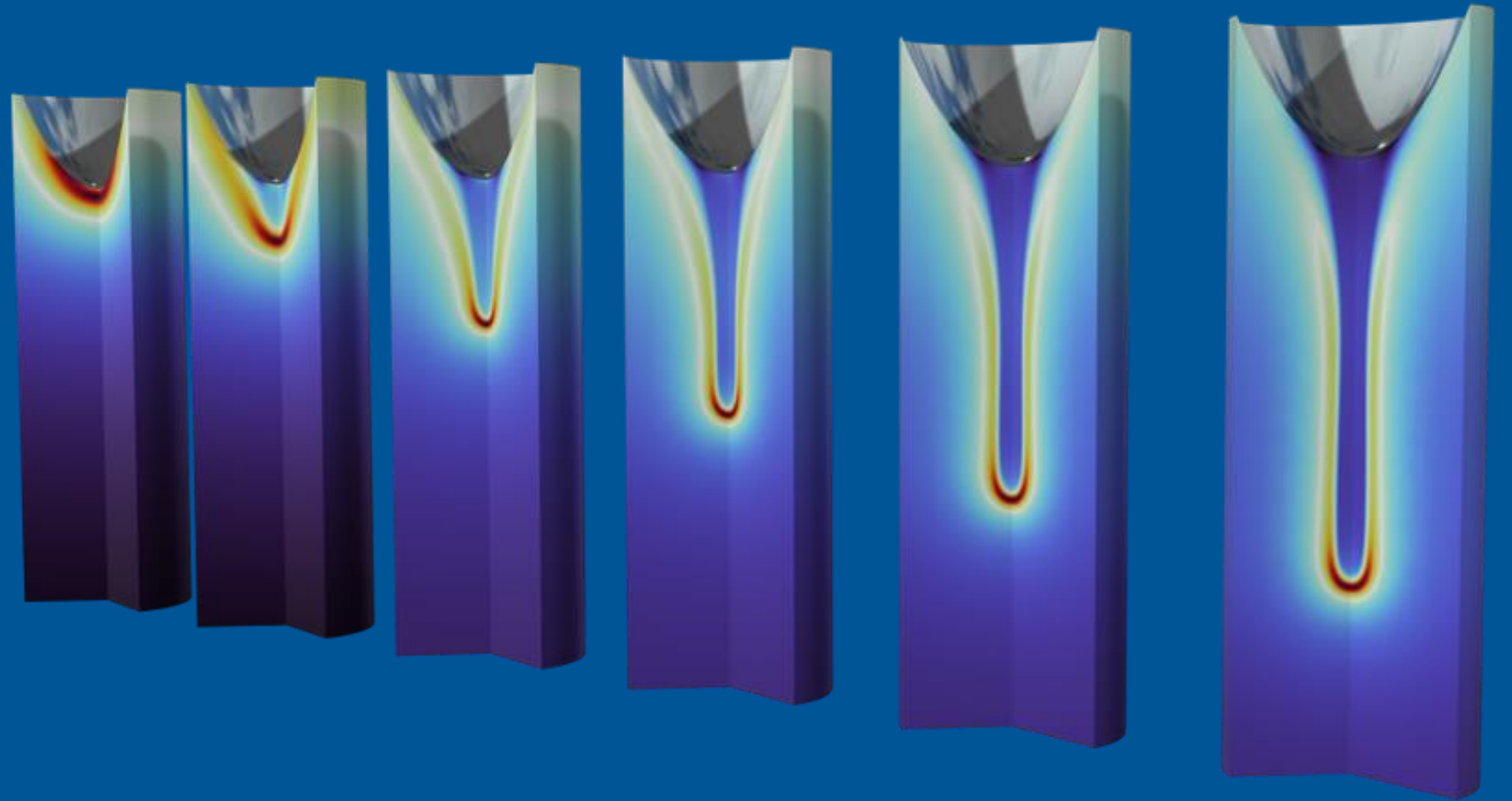


Introduction to Electric Discharge Module



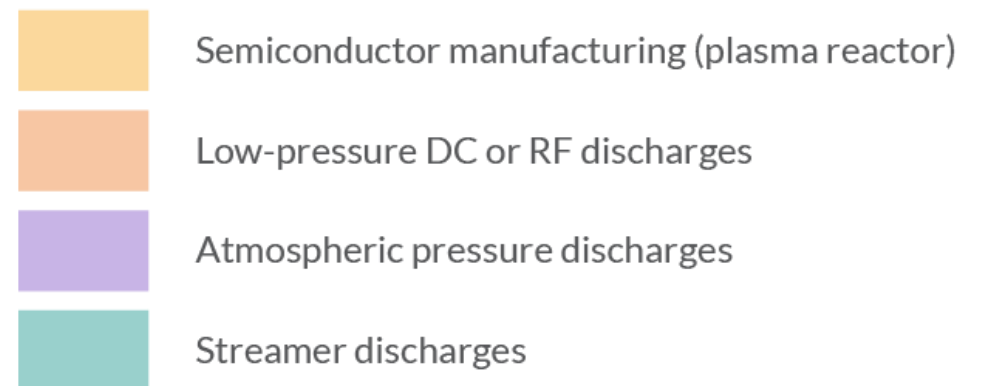
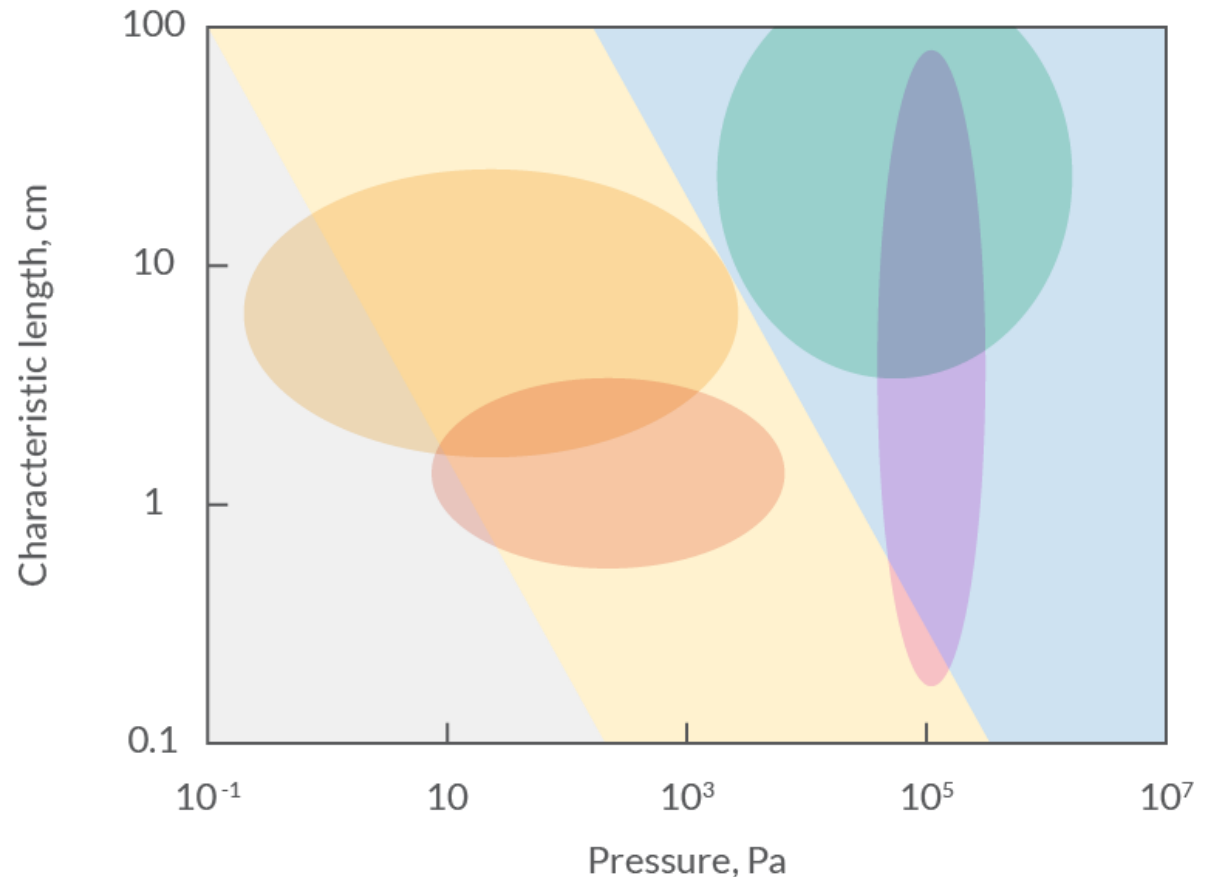
Matouš Lorenc
lorenc@humusoft.cz



Electric Discharge Module

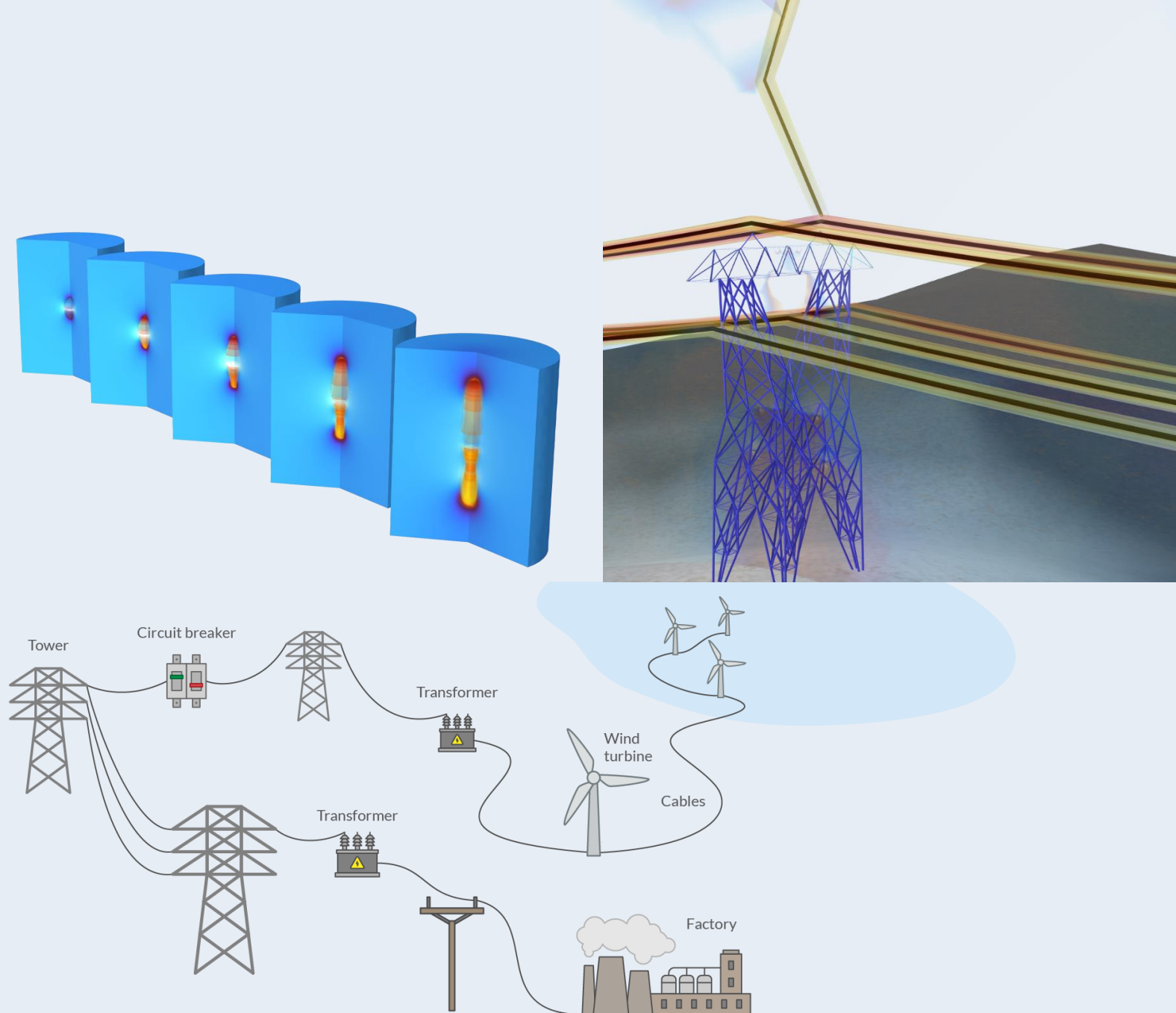
Electric Discharge Module or Plasma Module?

- The Electric Discharge Module is designed for atmospheric and high-pressure gas discharges, while the Plasma Module focuses on low-pressure gas discharges
- The Electric Discharge Module also enables simulations of discharge and charge transport in liquids and solids, unlike the Plasma Module, which is limited to plasma modeling in gases



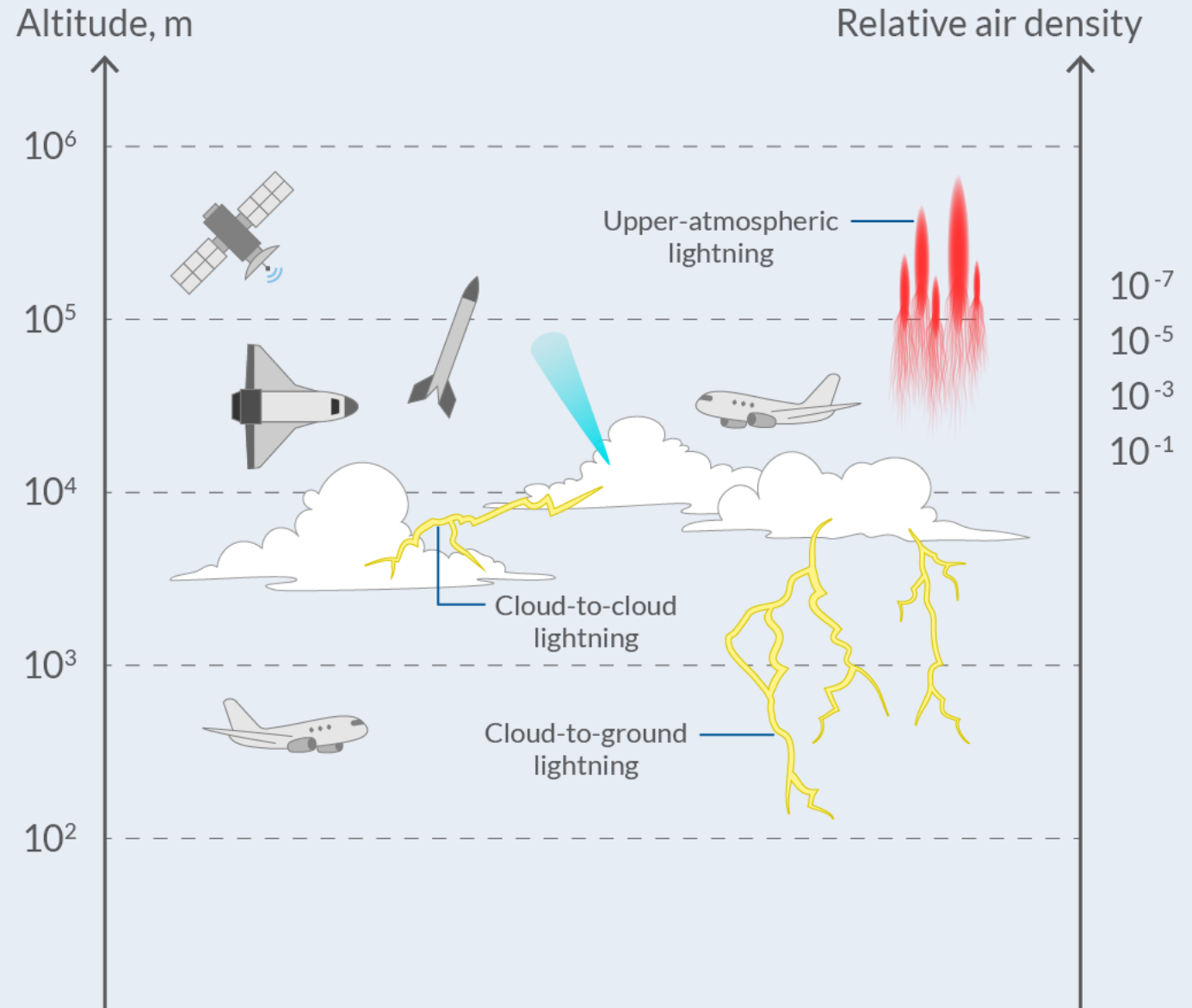
Electrical Insulation in Power Systems

- Internal insulation
 - Transformers
 - Circuit breakers
 - Cables
 - Gas-insulated switchgear (GIS)
- External Insulation
 - Insulators (overhead lines)
 - Bushings
 - Switching overvoltage
 - Lightning overvoltage



Electrical Insulation in Aerospace

- Aerospace vehicles are subject to a variety of electric discharges that can cause electrical insulation failure:
 - Internal discharge such as electric arcs
 - External discharge such as lightning
- The aerospace environment can be extreme, and the discharge is highly dependent on air pressure.
- Sustainable and clean energy drives greater use of composites, making electrical insulation more challenging.
- Simulation is an important tool for understanding and designing new insulation systems before experimentation.



Electric Discharge Processes

Charge

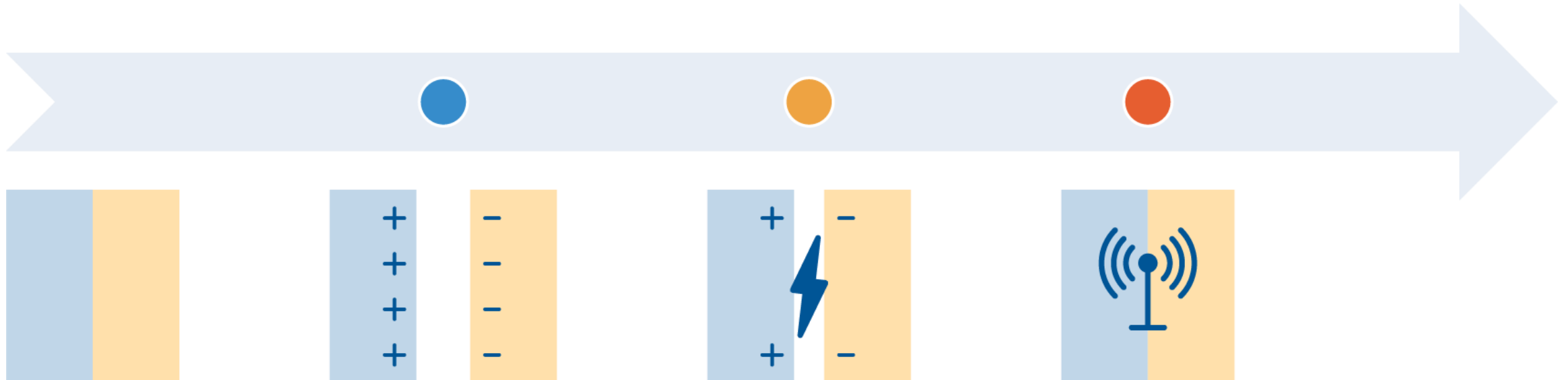
- Charge generation:
 - Charge separation
 - External charging
- Charge accumulation

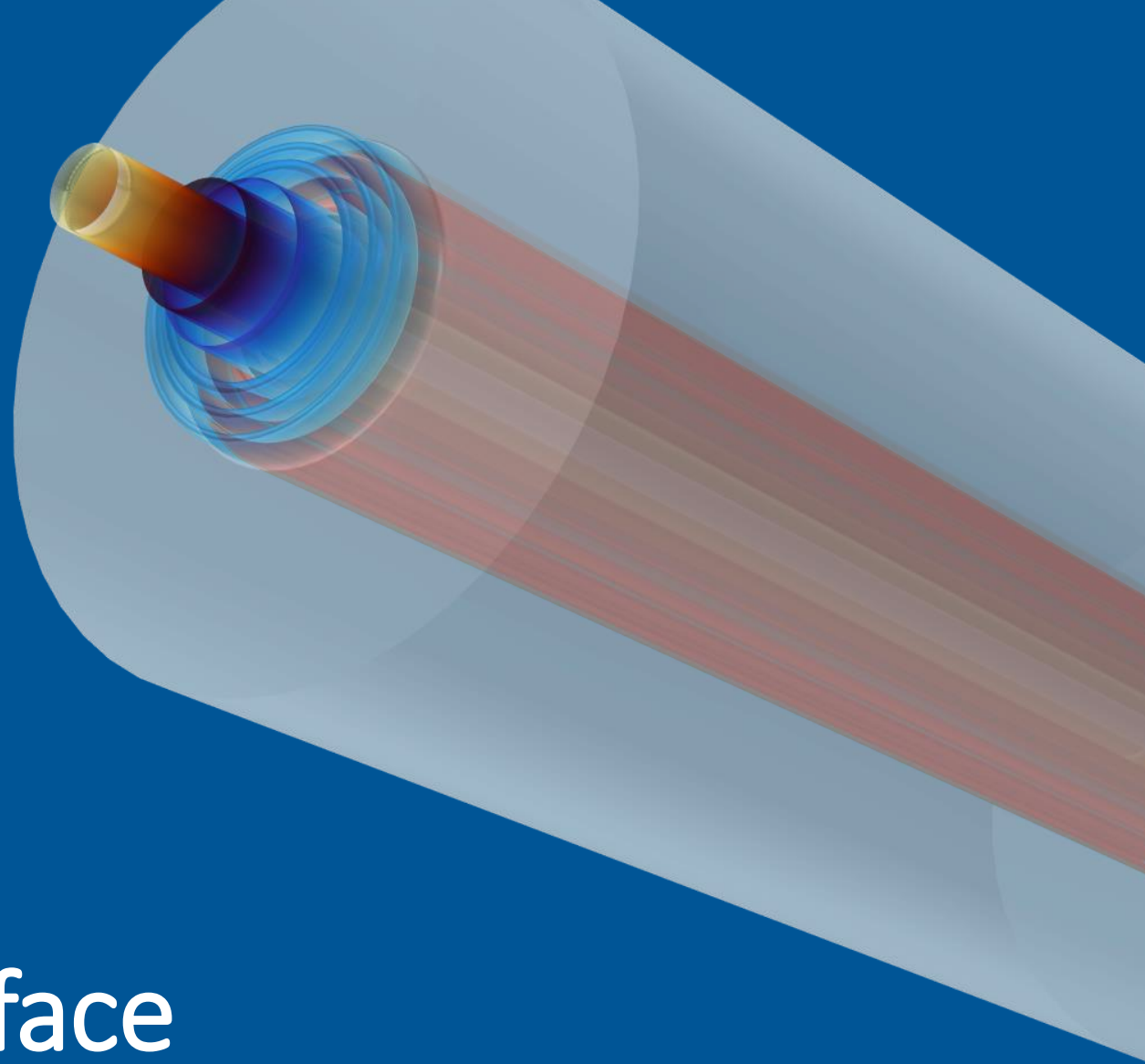
Discharge

- Charge relaxation
- Electric discharge:
 - Conductor–conductor
 - Insulator–conductor

After Discharge

- Direct effects
- Indirect effects:
 - Electric field coupling
 - Magnetic field coupling





Electric Discharge Interface

Gas/Liquid/Dielectric Discharges

- Define your medium:
 - Model atmospheric and high-pressure gas discharges using fluid and local field approximations
 - Model liquid dielectrics, such as transformer oil
 - Model solid dielectrics, such as a polyethylene layer
- Solve transport equations for electrons, positive ions, and negative ions
- Incorporate processes like impact ionization, attachment, and recombination

streamer_in_transformer_oil.mph - COMSOL Multiphysics

File Home Definitions Geometry Sketch Materials Physics Mesh Study Results Developer

Application Builder Model Manager Component 1 Add Component 1 Parameters Variables Functions Equation Contributions Build All Import LiveLink Add Material Electric Discharge Add Physics

Workspace Model Definitions Geometry Materials Physics

Model Builder

streamer_in_transformer_oil.mph

- Global Definitions
- Component 1
 - Definitions
 - Geometry 1
 - Materials
 - Electric Discharge
 - Liquid 1
 - Initial Values 1
 - Insulation 1
 - Electrode 1
 - Electrode 2
 - Axial Symmetry 1
 - Mesh 1
 - Study 1
 - Step 1: Time Dependent
 - Solver Configurations
 - Results
 - Datasets
 - Derived Values
 - Tables
 - Color Tables
 - 2D Plot Group 1
 - 1D Plot Group 2
 - 1D Plot Group 3
 - Export
 - Reports

Settings

Liquid

Constitutive Relation D-E

Dielectric model:

Relative permittivity: ϵ_r From material

Transport Properties

Transport mechanisms

- Electric field drift
- Magnetic field drift
- Convection
- Diffusion

Drift

Electron mobility: μ_e From material

Positive ion mobility: μ_p From material

Negative ion mobility: μ_n From material

Reactions

Field ionization

Number density of ionizable species: n_{ioni} From material

Molecular separation distance: a From material

Effective electron mass: m^* From material

Ionization potential: φ_{Δ} From material

Parameter: φ_{γ} From material

Attachment

Attachment time constant:

Graphics

Space Charge Density and Electric Field

Time=90 ns

Surface: Space charge density

mm

Messages Progress Log

Photoionization

- Photoionization plays a critical role in positive electric discharges
- The built-in photoionization model is based on the radiative transfer method, enabling efficient computation of the photoionization rate
- Up to seven exponential terms are available to approximate the photoionization process

The screenshot displays the COMSOL Multiphysics software interface. The top menu bar includes File, Home, Definitions, Geometry, Sketch, Materials, Physics, Mesh, Study, Results, and Developer. The main workspace is divided into several panels:

- Model Builder:** Shows a tree view of the model structure. The 'Photoionization 1' component is selected under 'Electric Discharge' > 'Gas 1'.
- Settings:** Displays the configuration for 'Photoionization 1'.
 - Domain Selection:** (Collapsed)
 - Override and Contribution:** (Collapsed)
 - Equation:** (Collapsed)
 - Photoionization:**
 - Number of exponential terms: $N = 3$
 - Element order: Linear
 - Partial pressure: $P_p = 150$ [Torr] Pa
 - Quenching pressure: $P_q = 30$ [Torr] Pa
 - Efficiency: $\frac{\xi \nu}{\xi \nu_i} = 0.06$
 - Fitting parameter: $A_1 = 2e-4$ [(cm*Torr)⁻²] s⁴/kg²
 - Fitting parameter: $\lambda_1 = 0.055$ [1/(cm*Torr)] s²/kg
 - Fitting parameter: $A_2 = 5e-3$ [(cm*Torr)⁻²] s⁴/kg²
 - Fitting parameter: $\lambda_2 = 0.15$ [1/(cm*Torr)] s²/kg
 - Fitting parameter: $A_3 = 1$ [(cm*Torr)⁻²] s⁴/kg²
 - Fitting parameter: $\lambda_3 = 1$ [1/(cm*Torr)] s²/kg
- Graphics:** Shows a 2D plot of the 'Photoionization Rate' at 'Time=23 ns'. The plot has a vertical axis labeled 'cm' ranging from 0.17 to 0.35 and a horizontal axis ranging from -0.04 to 0.0. A color bar on the right indicates the rate values, with a peak in the center.
- Messages:** A panel at the bottom right for displaying progress and logs.

DEMO: Corona Discharge

- Corona discharge between two wires with high voltage difference
- Electrons and ions are generated in the process
- Resulting in electrohydrodynamic force

The screenshot displays the COMSOL Multiphysics software interface. The top menu bar includes File, Home, Definitions, Geometry, Sketch, Materials, Physics, Mesh, Study, Results, and Developer. The main workspace is divided into several sections:

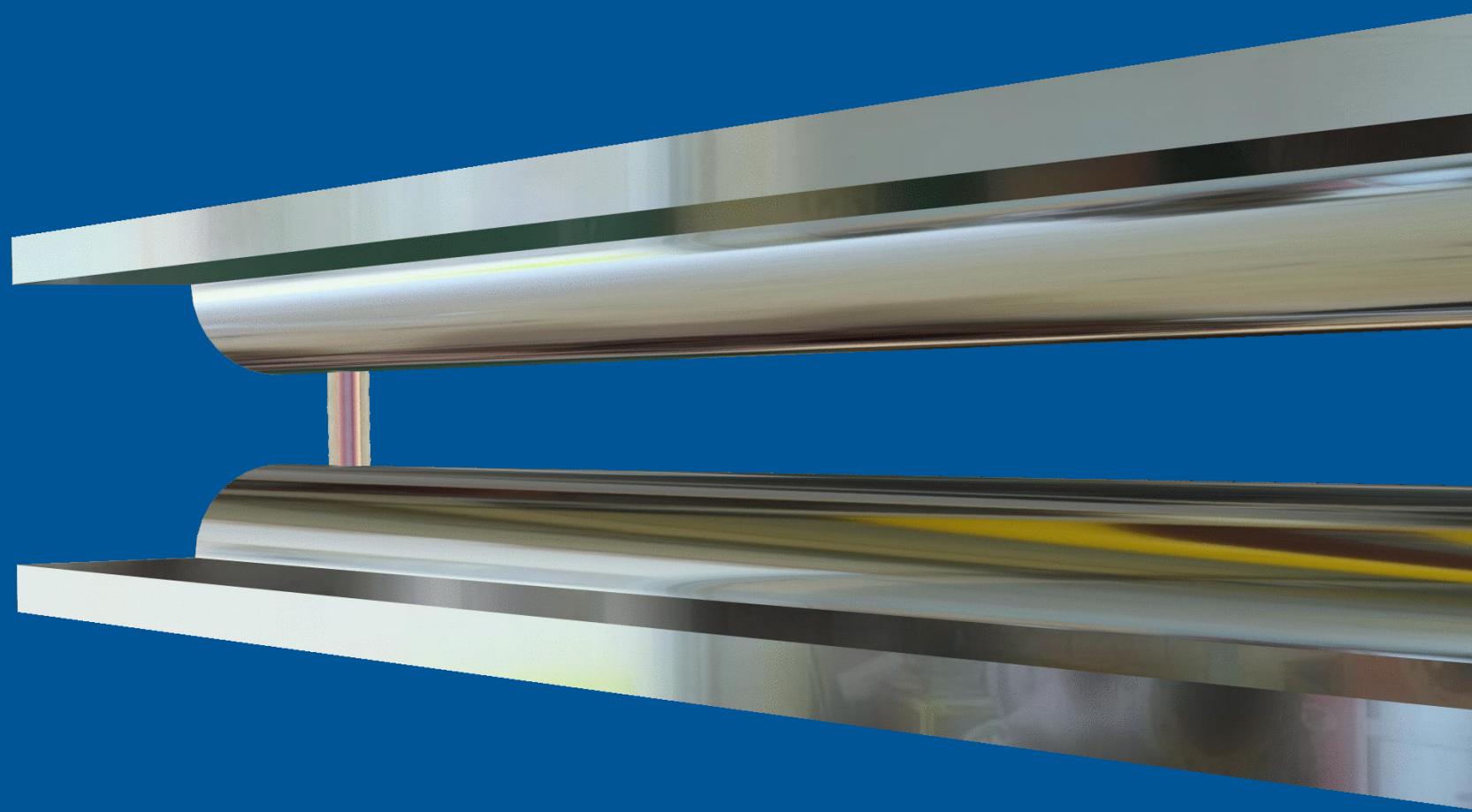
- Workspace:** Application Builder, Model Manager.
- Model:** Component 1, Add Component.
- Definitions:** Parameters, a=, a, f00, Δu, Pi.
- Geometry:** Build All.
- Materials:** Add Material.
- Physics:** Select Physics Interface, Add Physics, Add Mathematics.

The **Model Builder** panel shows a tree view of the model structure:

- corona_discharge_empty.mph (root)
 - Global Definitions
 - Parameters 1
 - Default Model Inputs
 - Materials
 - Component 1 (comp1)
 - Definitions
 - Geometry 1** (selected)
 - Materials
 - Mesh 1
 - Study 1
 - Results

The **Settings** panel for **Geometry 1** is visible on the right:

- Geometry:** Build All
- Label:** Geometry 1
- Units:**
 - Scale values when changing units
 - Length unit: cm
 - Angular unit: Degrees
- Constraints and Dimensions:**
 - Use constraints and dimensions: Off
- Advanced:**
 - Default repair tolerance: Automatic
 - Build new operations automatically
 - Build automatically when leaving geometry



Arc Discharge Interface

Arc Discharge Interface(s)

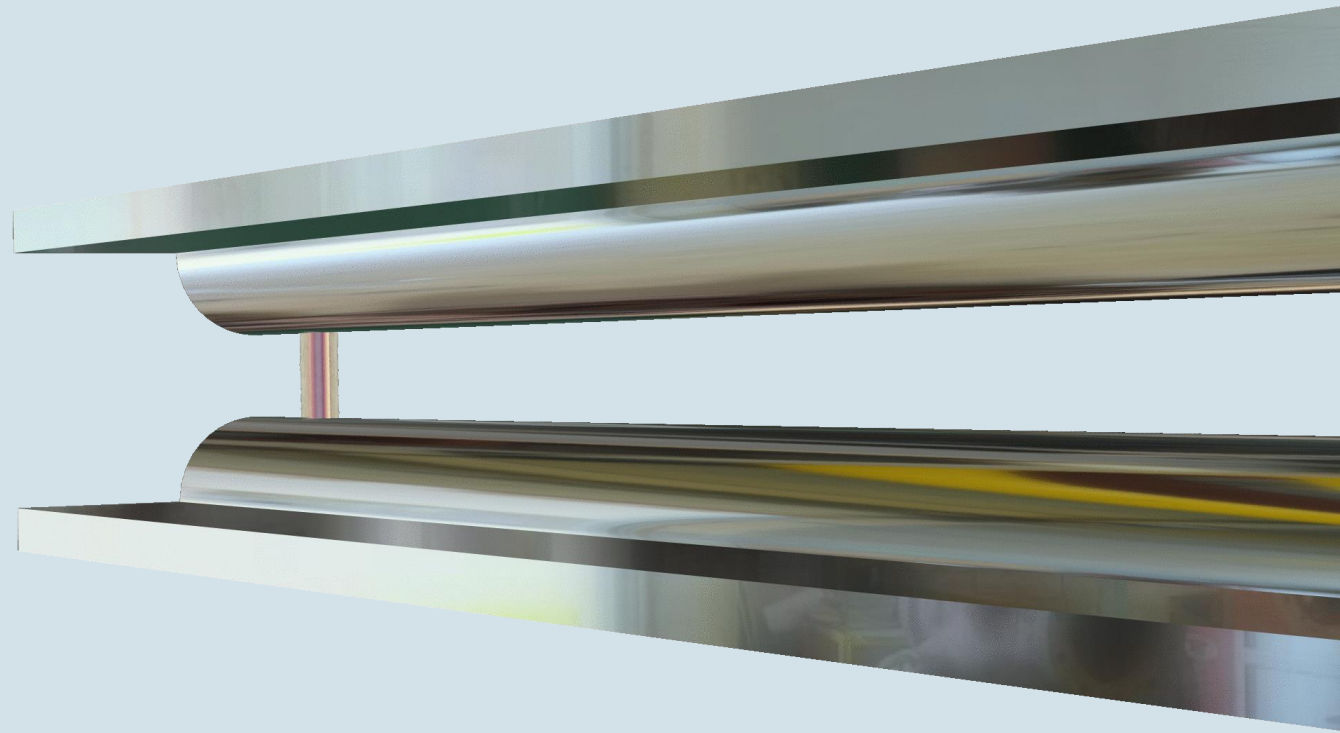
- Dedicated multiphysics interface for modeling high-temperature arc discharges
- Coupled physics interfaces:
 - Magnetic and Electric Fields
 - Heat Transfer in Fluids
 - Laminar Flow
- Multiphysics couplings:
 - Magnetohydrodynamics
 - Equilibrium Discharge Heat Source
 - Nonisothermal Flow

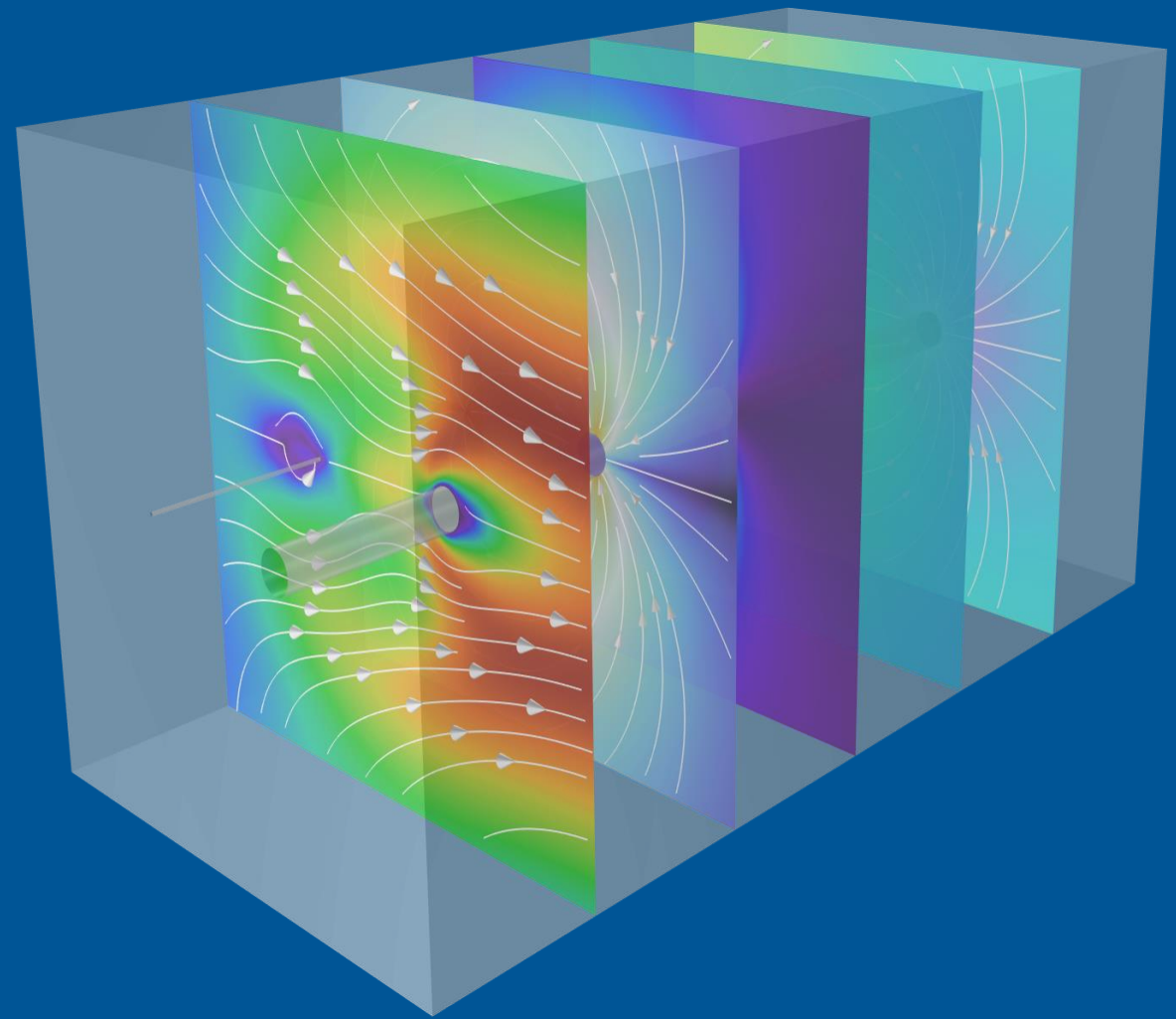
The screenshot displays the COMSOL Multiphysics software interface for a model named "transient_arc_3d.mph". The top menu bar includes File, Home, Definitions, Geometry, Materials, Physics, Mesh, Study, Results, and Developer. The main workspace is divided into several panels:

- Model Builder:** Shows a tree view of the model structure. The "Magnetohydrodynamics 1" interface is selected and highlighted in blue. Other visible components include "Equilibrium Discharge Heat Source 1", "Mesh 1", "Study 1", and "Results".
- Settings:** Displays the configuration for the "Magnetohydrodynamics 1" interface. The "Label" is "Magnetohydrodynamics 1" and the "Name" is "mhd1". Under the "Coupled Interfaces" section, the "Electromagnetic" coupling is set to "Magnetic and Electric Fields" and the "Fluid flow" coupling is set to "Laminar Flow". In the "Coupling Settings" section, both "Include Lorentz force" and "Include electromotive force" are checked.
- Graphics:** Shows a 3D visualization of the model at "Time=4 ms". The model is a rectangular block with a white top surface and a dark purple bottom surface. A coordinate system (x, y, z) is visible at the bottom left of the graphics area.
- Messages/Progress/Log:** Located at the bottom of the interface, currently empty.

Modeling Arc Discharge

- A magnetohydrodynamics approach is used to describe the discharge as a single fluid with one temperature
- Couplings between electromagnetics and fluid flow: Lorentz force and electromotive force
- Couplings between electromagnetics and heat transfer include enthalpy transport, Joule heating, and radiation loss

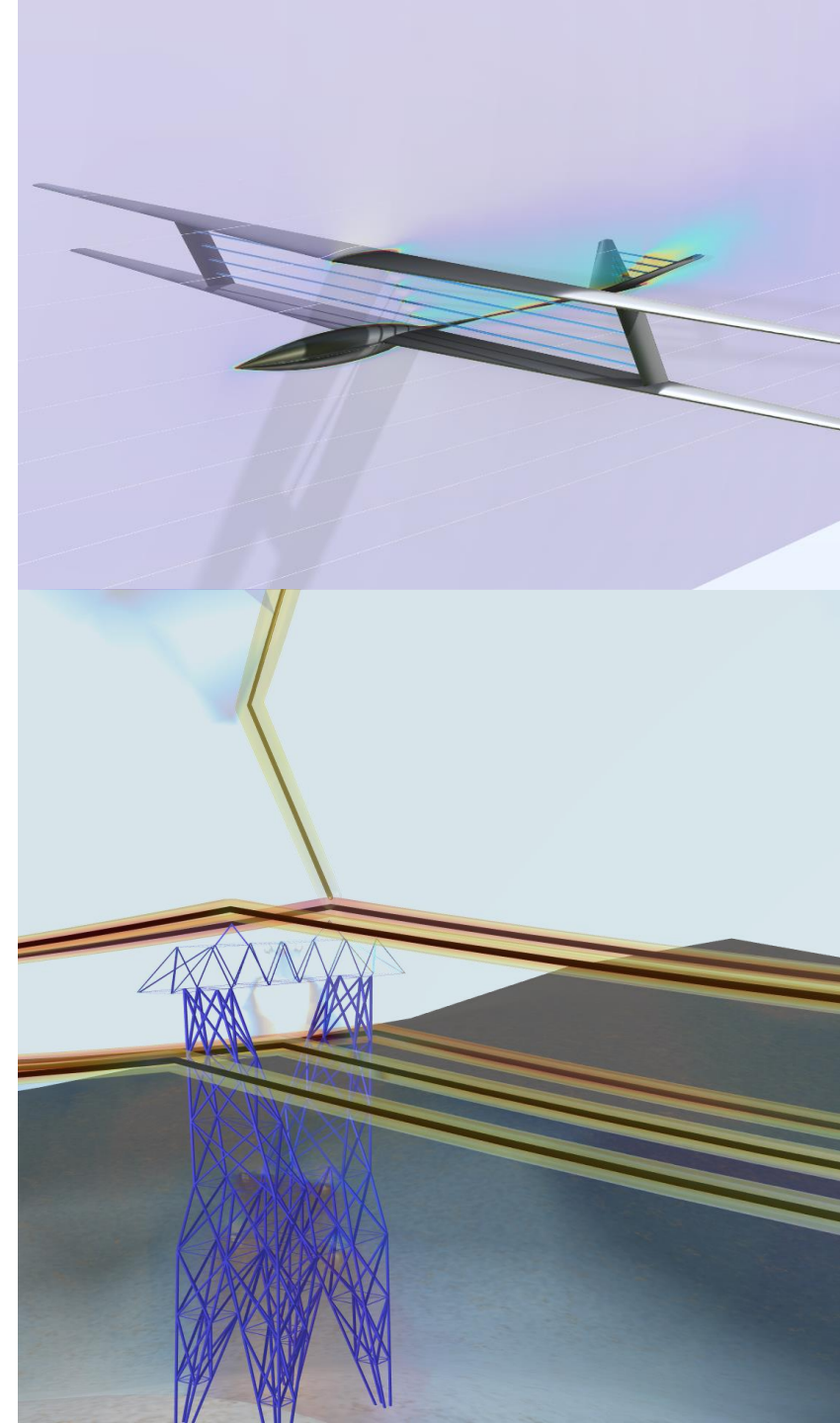




Discharge-Induced Effects

Discharge-Induced Effects

- Lightning-Induced Voltage
 - Simulate lightning-induced electromagnetic pulses and design lightning-proof electrical components, equipment, and systems
- Discharge-Induced Multiphysics Effects
 - Seamlessly integrate with other COMSOL products, including those for electromagnetics, structural mechanics, fluid flow, and heat transfer



DEMO: Ionic Wind

- Applying the electrohydrodynamic force on the surrounding air driving the airflow
- Applications
 - Propulsion systems
 - Cooling of electronics

corona_discharge.mph - COMSOL Multiphysics (Trial version)

File Home Definitions Geometry Sketch Materials Physics Mesh Study Results Developer **Current Discharge**

Plot Plot In Plot Add Plot

Line Graph Table Graph Mesh Color Expression Filter Graph Marker More Plots More Attributes Image Animation

Point Graph Line Segments Annotation Histogram

Global

Attributes Export

Model Builder

Type filter text

- corona_discharge.mph (root)
 - Global Definitions
 - Parameters 1
 - Default Model Inputs
 - Materials
 - Component 1 (comp1)
 - Study 1
 - Results
 - Datasets
 - Views
 - Derived Values
 - Tables
 - Color Tables
 - Space Charge Density
 - Current Discharge
 - Global 1
 - Export
 - Reports

Settings

Global

Plot

Label: Global 1

Data

Dataset: From parent

y-Axis Data

Expression	Unit	Description
edis.I0_0	uA	Terminal current

Expression:

Description:

Title

x-Axis Data

Parameter:

Parameter value

Graphics

Terminal current (uA)

3.5
3
2.5
2
1.5
1
0.5
0

0

Messages

1.46