Integrated simulation solutions for the plasma and transversal physics in electric propulsion systems

Adam Obrusník[1] , Martin Kubečka[2], Petr Zikán[1], Zdeněk Bonaventura[2]

[1]PlasmaSolve Ltd., Brno, Czech Republic
[2]Faculty of Science, Masaryk University, Brno, Czechia

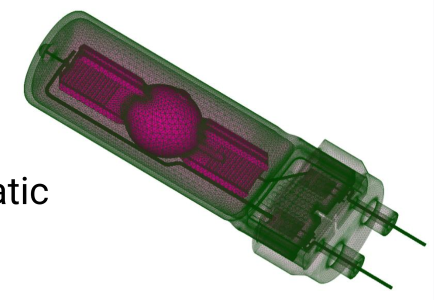
Motivation: from plasma coatings to electric propulsion

Plasma simulations computationally difficult (multiphysics, numerically stiff systems, timescales), possibilities?

a) **In-house codes from scratch** – powerful but difficult to maintain, generalize to other problems or couple to other solvers
b) **Commercial platforms** (COMSOL, TechX USim) – often expensive, closed-source but usually good user support
c) **Open-source solutions –** not common in plasma physics. **Is it feasible to build plasma models using open-source frameworks?**

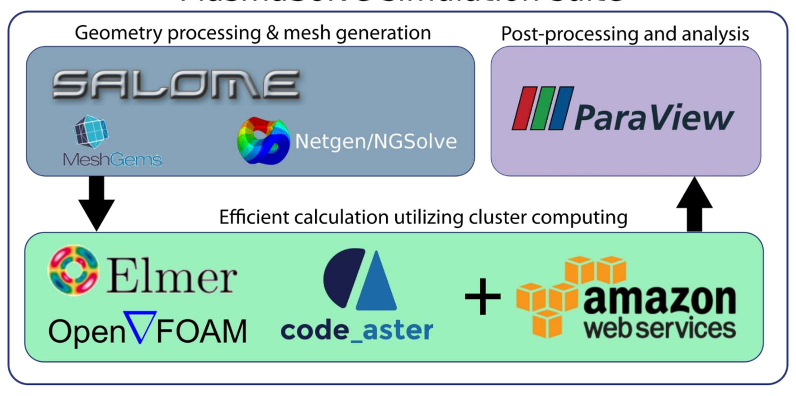
Workflow & Tools

We create a common framework (mostly Python scripts) based on open-source libraries:

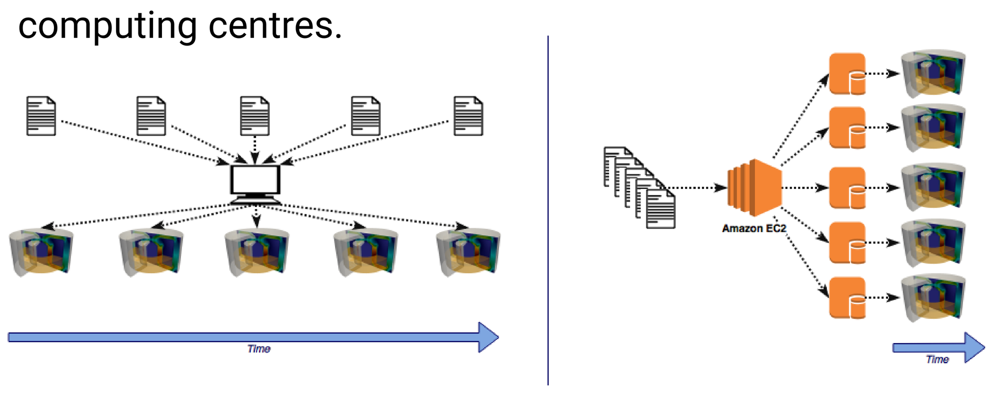


1. **Geometry pre-processing**
   - SALOME Platform
   - **Python API** – programmatic geometry generation
2. **Mesh generation**
   - NETGEN (tetrahedral) or snappyHexMesh (hex) algorithms
3. **Physics solvers**
   - **Elmer FEM** (finite element method)
   - **OpenFOAM FVM** (finite volume method) OpenFOAM-based DSMC solver
4. **Postprocessing**
   - unified .vtu format readable by ParaView

PlasmaSolve simulation suite



Key enabling technology for complex geometries and large studies: Solvers integration with Amazon cloud computing centres.



Upcoming (2020) support for:

Microsoft Azure, Google Cloud, IBM Cloud, ORACLE CLOUD

Cutting edge IT makes our software truly multi-platform – **supporting Windows 10, Linux and Mac systems**

Bottomline

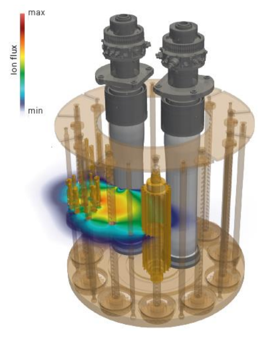
What are **the pros and cons of building** a plasma model code **on open-source**?

+
- Superior performance and scaling
- Provide a framework for implementing any PDE or Lagrangian solver
- No node/core license locking
- Possible to couple different codes seamlessly

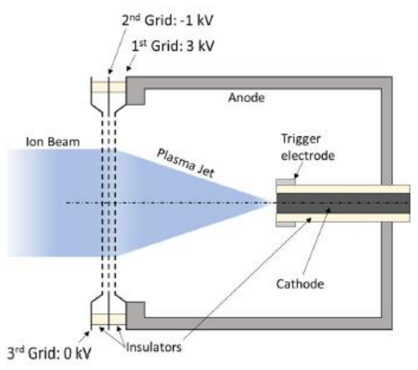
–
- Very poor documentation - the source code is your only reference
- Steeper learning curve

Hydrodynamic plasma models

Laboratory problem
- Plasma discharge propagation in complex discharge chambers
- Vacuum arc, HiPIMS magnetron



Use in electric propulsion
- Simulation of secondary plasma jets in vacuum arc thrusters.
- Interaction of plasma jet with grids and spacecraft



[Kohlbeck et al. J. Appl. Phys. 125, 220902 (2019)]

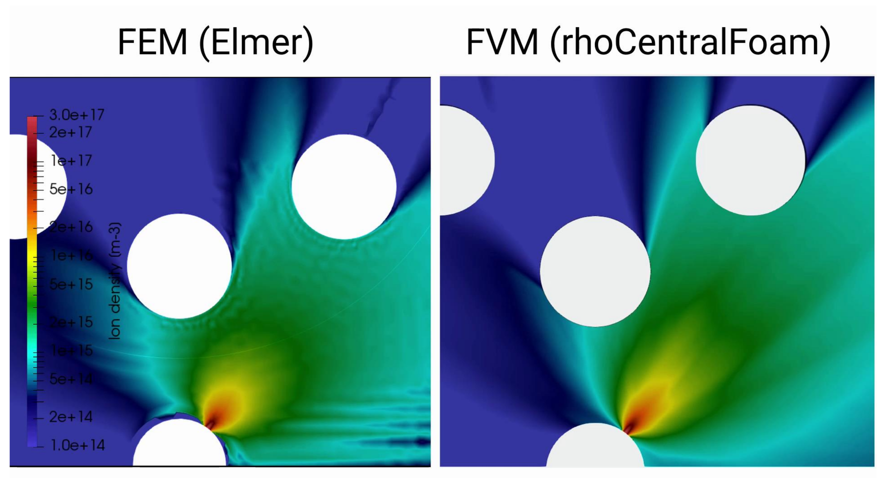
Easily modifiable model equations

$$\frac{\partial \rho_i}{\partial t} + \nabla\cdot(\rho_i \mathbf{u}) = 0 \qquad \mathbf{u} = \mathbf{u}_i - \mathbf{u}_e$$

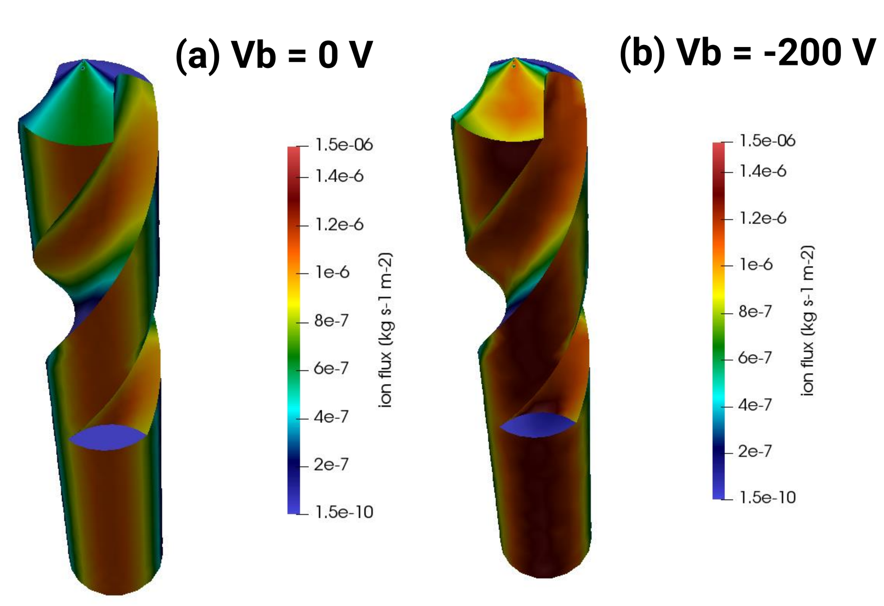
$$\rho_i\left(\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}\cdot\nabla)\mathbf{u}\right) = -\nabla(P_i + P_e) + \mathbf{j}\times\mathbf{B} + e n_i\left(1 - \exp\left(\frac{eV}{kT_e}\right)\right)\mathbf{E}$$

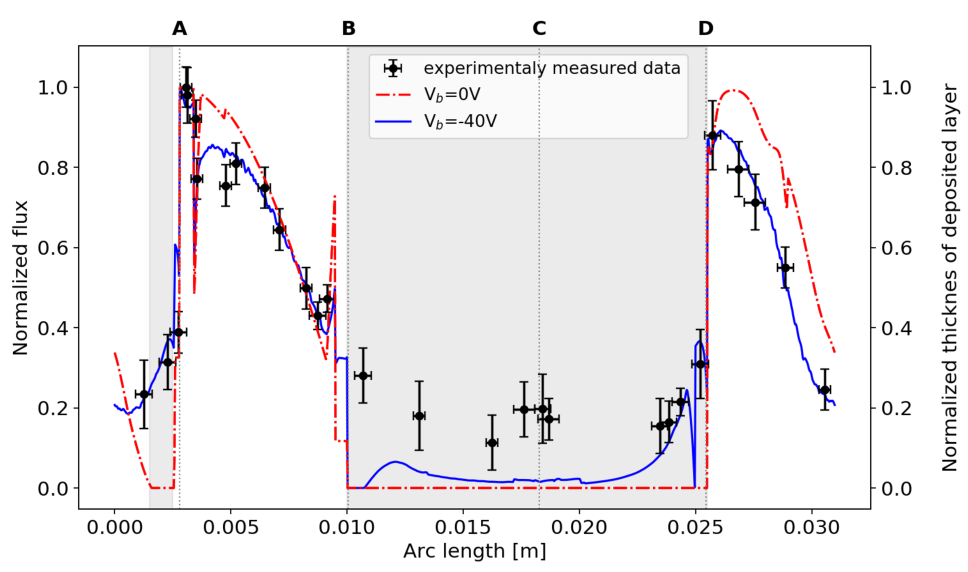
$$\Delta V = \frac{n_i}{\varepsilon_0}\left(1 - \exp\left(\frac{eV}{kT_e}\right)\right) \qquad \nabla\times\mathbf{B} = \mathbf{j} \qquad \nabla\cdot\mathbf{B} = 0$$

- Numerically **stiff Euler equation** difficult to solve using FEM, **Maxwell equations** difficult to solve with FVM => **effective MPI-level solver coupling**



- **3D real-geometry simulations** are possible



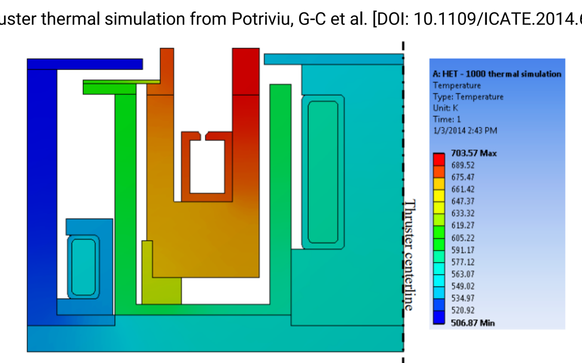


Advanced thermal balance models

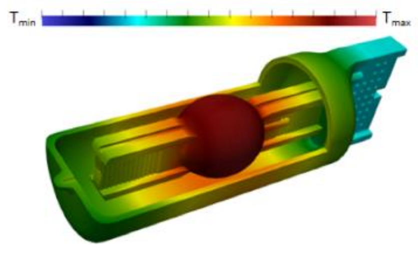
Laboratory problem:
- Thermal balance in ion sources, plasma lamps and other plasma-based devices.

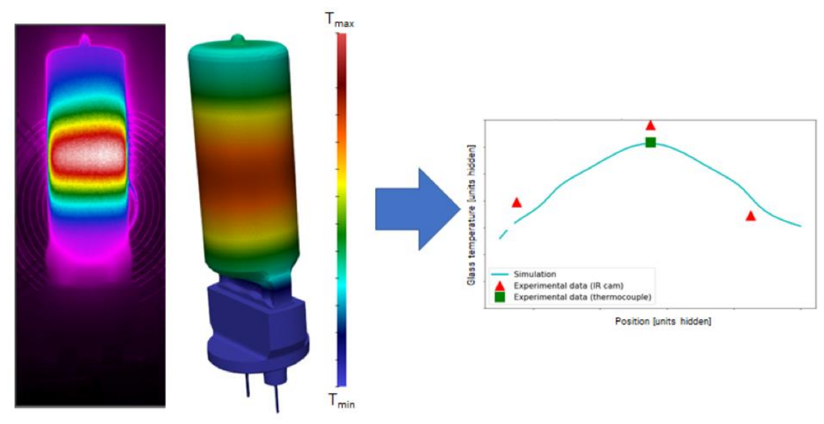
Use in electric propulsion
- Thermal balance in thrusters and ion engines

HET-1000 Thruster thermal simulation from Potriviu, G-C et al. [DOI: 10.1109/ICATE.2014.6972683]



Thermal balance model
- Radiation through optically thin media (vacuum) and thick media (plasma)
- **Coupling to plasma** simulation interfaces
- **CAD-to-simulation** approach (STEP files as input), **3D simulations easy**

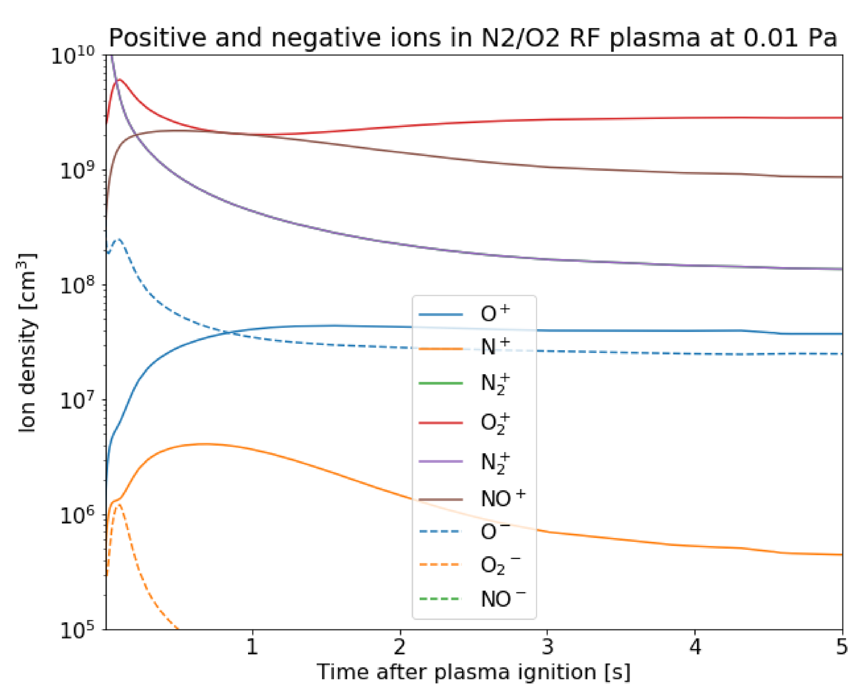




Global plasma models for alternative fuels

Laboratory problem
- Predicting plasma kinetics in various mixtures – N_2, O_2, H_2O, Ar, Xe, Kr, H_2, …
- Global model with user-friendly editing of model equations and coefficients

Use in electric propulsion
- Global modeling of electric propulsion ionizers with alternative fuels, **including air-breathing thruster or CO2 thruster kinetics simulation**



Contact info:

Masaryk University, Brno CZ
adam.obrusnik@gmail.com
https://physics.muni.cz/kfe
+420 776 185 170

PlasmaSolve company, Brno CZ
obrusnik@plasmasolve.com
https://plasmasolve.com