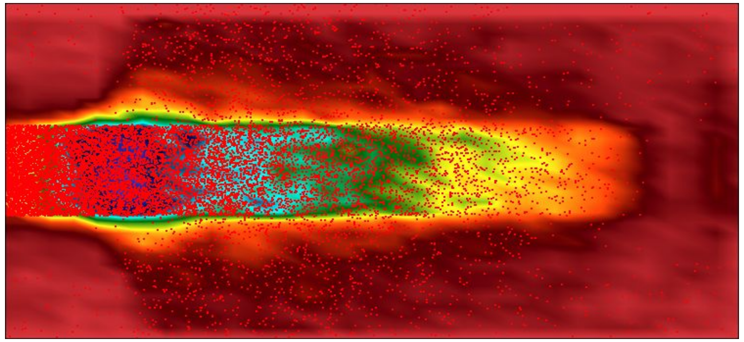
USim for Fluid Plasma

Peter Stoltz, Tech-X Corp.
(and the USim team: Madhu Kundrapu, Jake King, Chrissy Roark)

Tech-X has a fluid plasma tool, USim, that compliments VSim

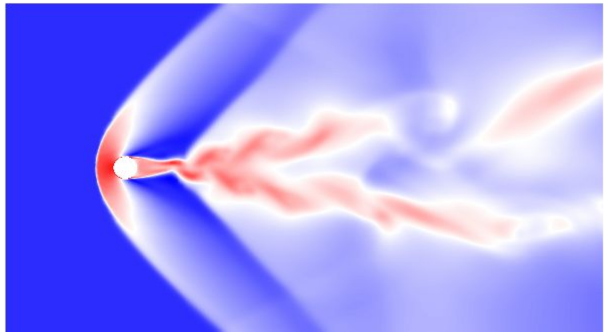
VSim

A finite-difference time-domain (FDTD) and kinetic particle-in-cell (PIC) code



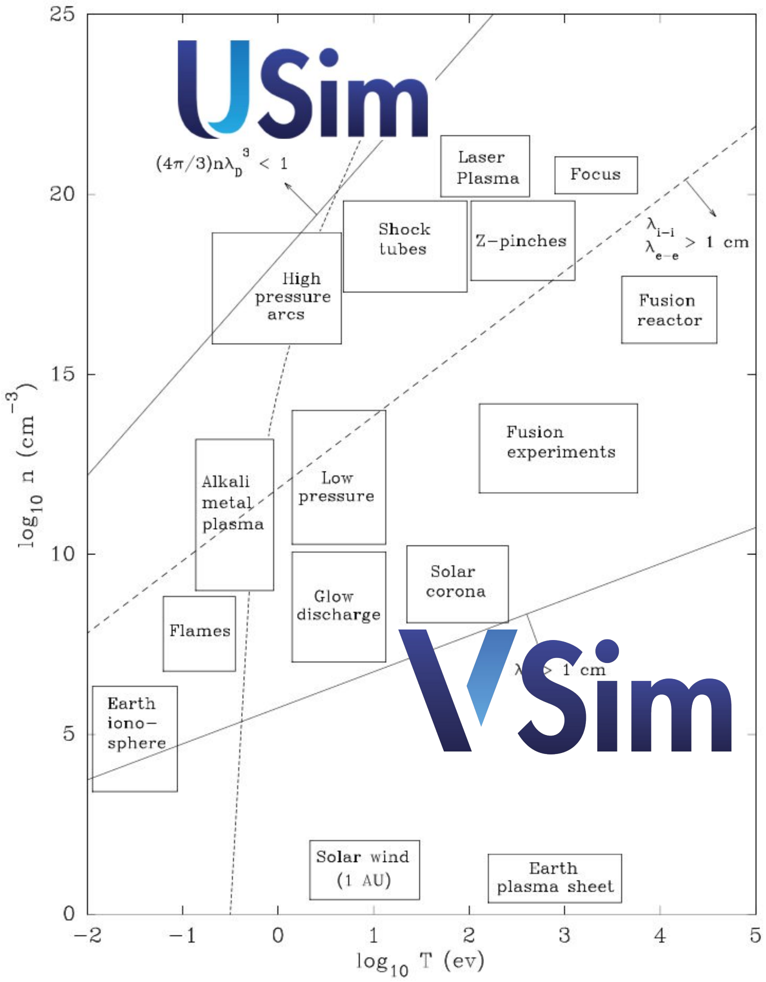
USim

A finite volume time domain (FVTD) code on unstructured meshes, for charged or neutral fluids

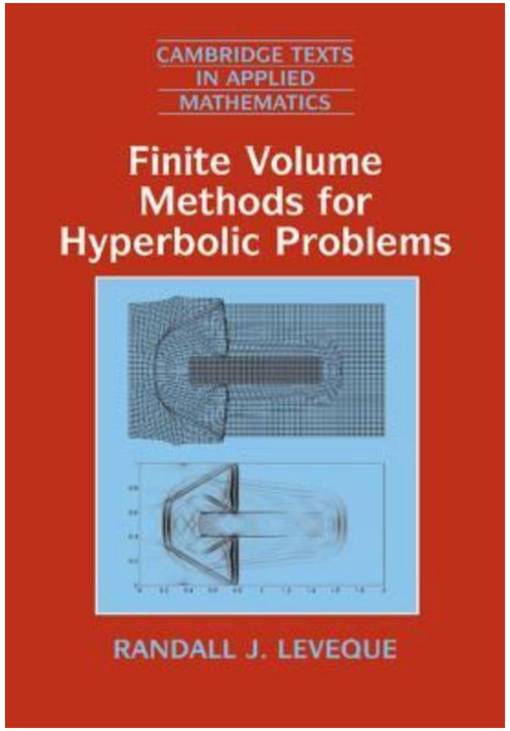


Fluid models can be appropriate for colder, denser plasmas

- Researcher have applied USim to:
    - Z-pinches
    - Dense Plasma Focus
    - Hypersonic vehicles
    - Plasma Arcs

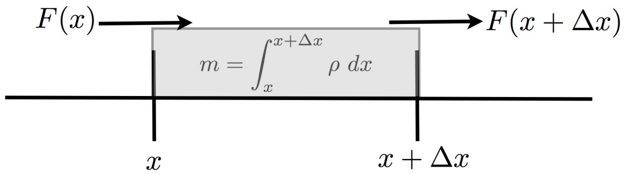


USim solves flux-conservative equation sets using Finite Volume algorithms



Many of the USim algorithms are described in detail in this book

$$\frac{\partial \mathbf{q}}{\partial t} + \nabla \cdot [\mathcal{F}(\mathbf{w})] = 0$$



As an example, Ideal MHD:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot [\rho\, \mathbf{u}] = 0$$

$$\frac{\partial \rho\, \mathbf{u}}{\partial t} + \nabla \cdot \left[\rho\, \mathbf{u}\, \mathbf{u}^T - \mathbf{b}\, \mathbf{b}^T + \mathbb{I}\left(P + \frac{1}{2}\left|\mathbf{b}\right|^2\right)\right] = 0$$

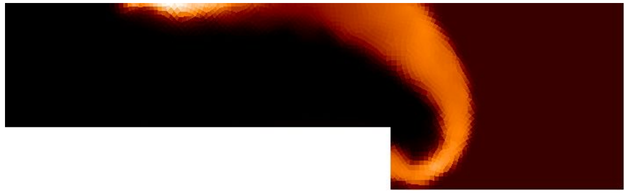
$$\frac{\partial E}{\partial t} + \nabla \cdot [(E+P)\mathbf{u} + \mathbf{e} \times \mathbf{b}] = 0$$

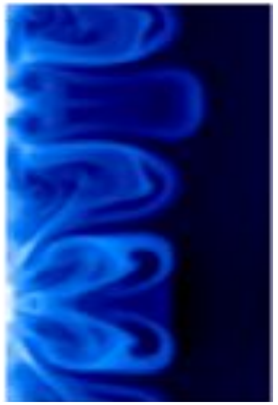
$$\frac{\partial \mathbf{b}^{\text{plasma}}}{\partial t} + \nabla \times \mathbf{e} + \nabla \psi = 0$$

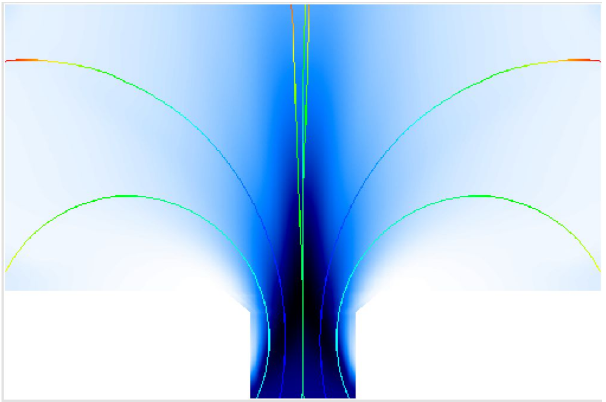
$$\frac{\partial \psi}{\partial t} + \nabla \cdot [c_{\text{fast}}^2\, \mathbf{b}] = 0$$

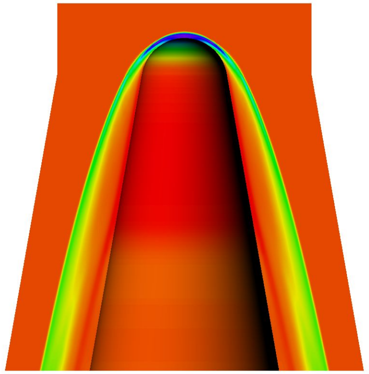
USim supports a variety of well-known fluid models

- Hydrodynamics
  - Euler and Navier-Stokes
- Ideal magnetohydrodynamics
  - one T and two T (usually T_e)
  - one fluid, multiple species
- Hall magnetohydrodynamics
- Two-fluid + Maxwell's equations

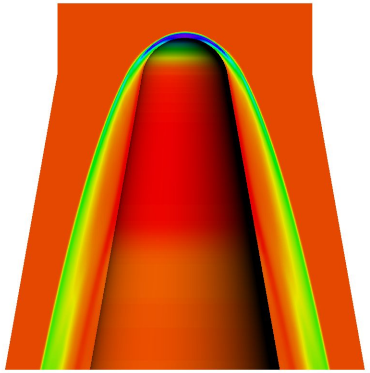

Dense Plasma Focus

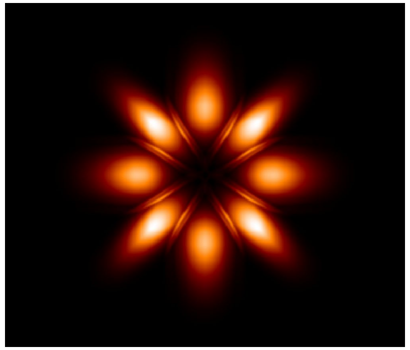

Z-Pinch


Magnetic Nozzles


Re-Entry Vehicles

USim has packages oriented towards specific plasma research areas



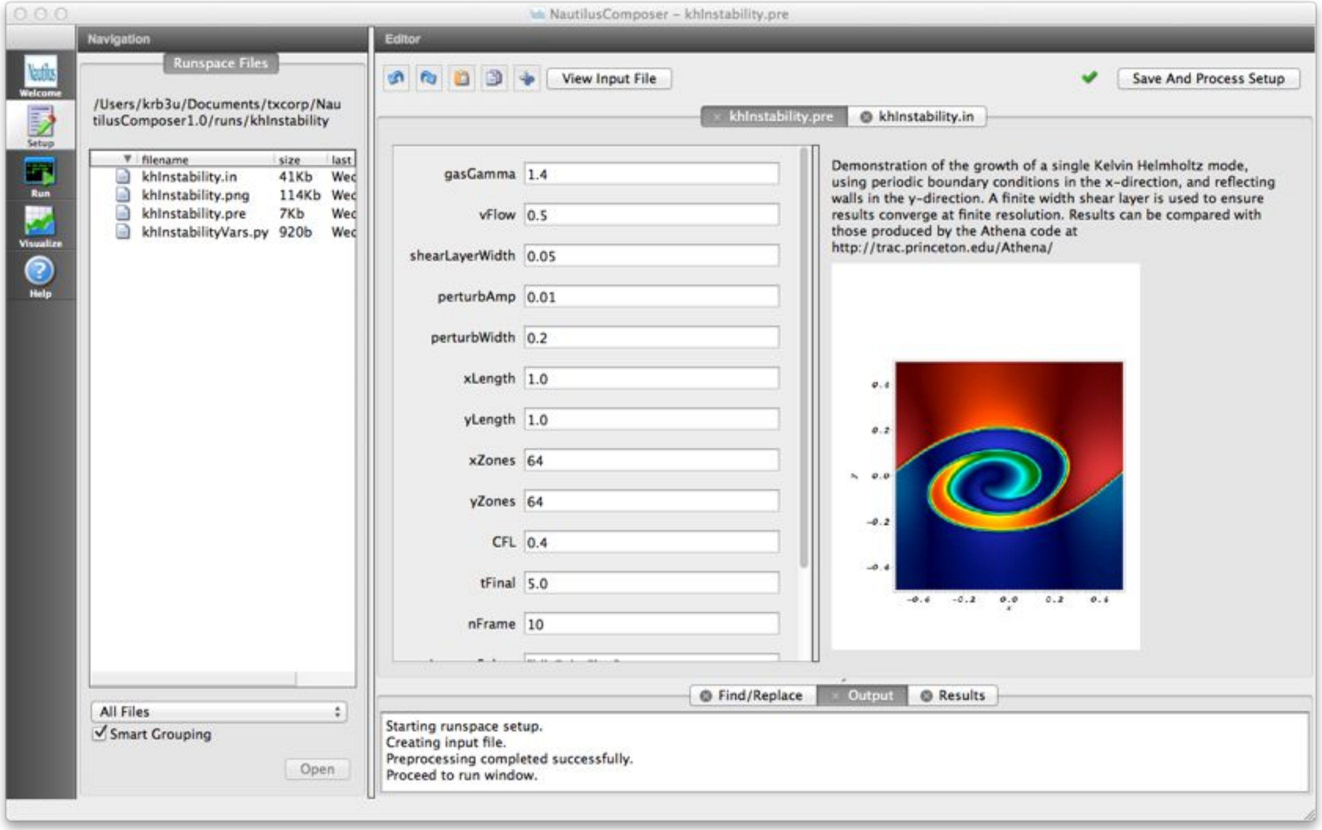


USim HYPERSONICS

USim HIGH ENERGY DENSITY PLASMAS

USim BASE

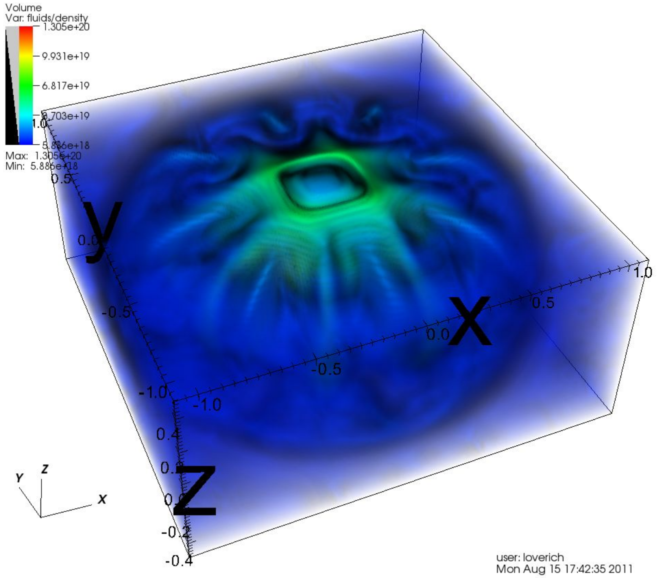
USim has a Composer-based interface, so users of other Tech-X tools will come up to speed quickly



- USimComposer provides:
  - Key parameter interface for simulation control
  - Built-in validation of simulation design
  - Visualization and analysis of simulation data

- Each USim package (Base, Hypersonics and HEDP) has a range of examples available

2013: Researchers at LANL featured USim results in a PRL on jet merger

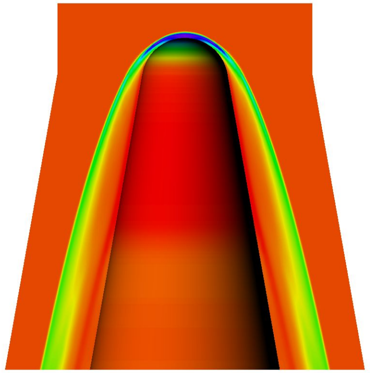


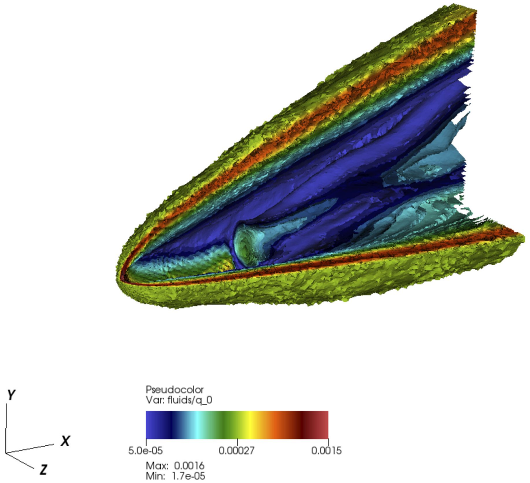
PRL **111,** 085003 (2013) PHYSICAL REVIEW LETTERS week ending 23 AUGUST 2013

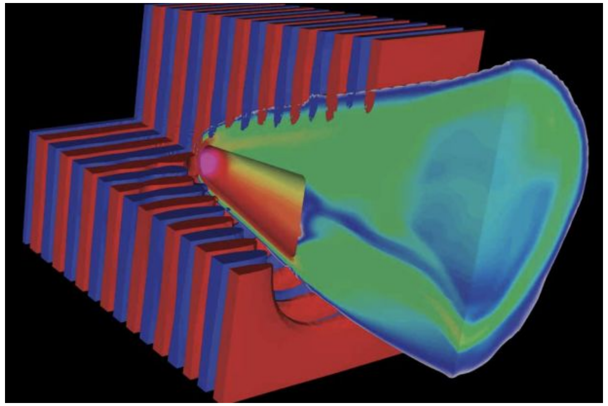
Experimental Characterization of the Stagnation Layer between Two Obliquely Merging Supersonic Plasma Jets

E. C. Merritt,[1,2] A. L. Moser,[1] S. C. Hsu,[1,*] J. Loverich,[3] and M. Gilmore[2]
[1]*Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*
[2]*University of New Mexico, Albuquerque, New Mexico 87131, USA*
[3]*Tech-X Corporation, Boulder, Colorado 80303, USA*

2015: Tech-X and GWU researchers used USim to test blackout mitigation models for the Air Force







JOURNAL OF SPACECRAFT AND ROCKETS 2015

Modeling Radio Communication Blackout and Blackout Mitigation in Hypersonic Vehicles

Madhusudhan Kundrapu,* John Loverich,† Kristian Beckwith,‡ and Peter Stoltz§
Tech-X Corporation, Boulder, Colorado 80303
and
Alexey Shashurin¶ and Michael Keidar**
The George Washington University, Washington, D.C. 20052

Tech-X

SIMULATIONS EMPOWERING INNOVATION

TWSS 2020

2020: Tech-X, Sandia, and VTU researchers determined how real EOS affects HED simulation

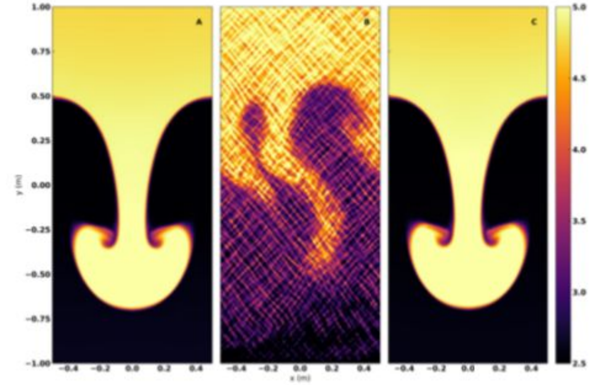


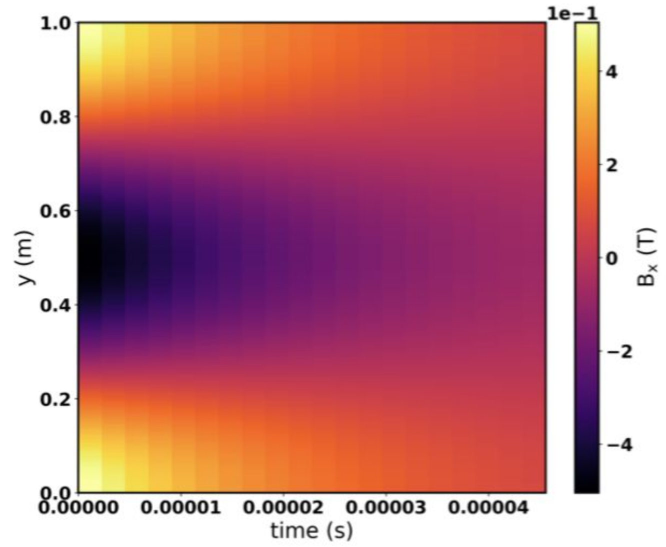
Figure 10: The final density state in kg/m^3 ($t = 27.5\ ms$) of the 2D MRT instability growth of density in kg/m^3 for the (A) ideal-gas EOS, (B) the SESAME-5760 EOS using the cell-centered EOS evaluation algorithm, and (C) the SESAME 5760-EOS using the interface EOS evaluation algorithm.

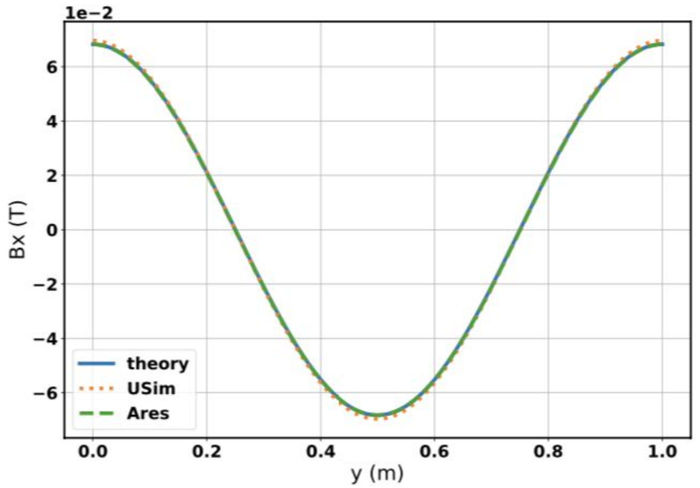
902 IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL. 48, NO. 4, APRIL 2020

Multidimensional Tests of a Finite-Volume Solver for MHD With a Real-Gas Equation of State

Jacob R. King, Robert Masti, Bhuvana Srinivasan, and Kris Beckwith

Coming soon in 2020: VTU, LLNL, and Tech-X researchers examine ETI with USim

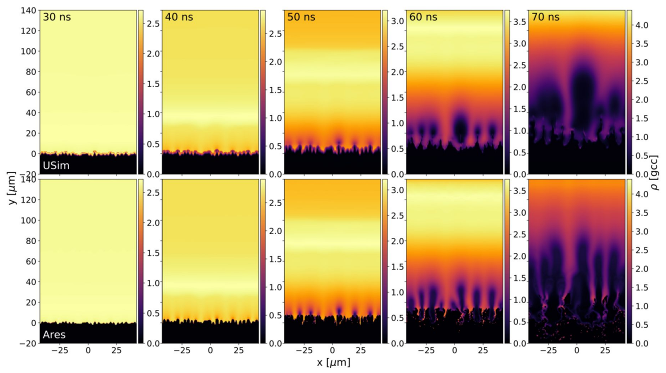


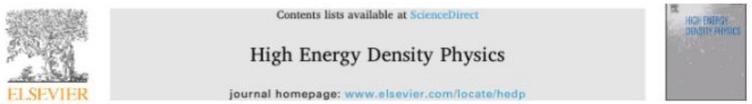


EOS-SESAME 5761; ρ=0.167 kg/m^3; T=300 K; η=1.396 mΩ-m

USIM

ARES




Contents lists available at ScienceDirect
High Energy Density Physics
journal homepage: www.elsevier.com/locate/hedp
ELSEVIER

Cross-Code verification and sensitivity analysis to effectively model the electrothermal instability

R. L. Masti[a,b], C. L. Ellison[b], J. R. King[c], P. H. Stoltz[c], B. Srinivasan[a,*]

[a] *Virginia Polytechnic Institute and State University, Blacksburg, VA 24060, USA*
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[c] *Tech-X Corporation, 5621 Arapahoe Ave., Boulder, CO 80303, USA*

In publication

Naval Research Laboratory is investigating charged particle acceleration in DPFs

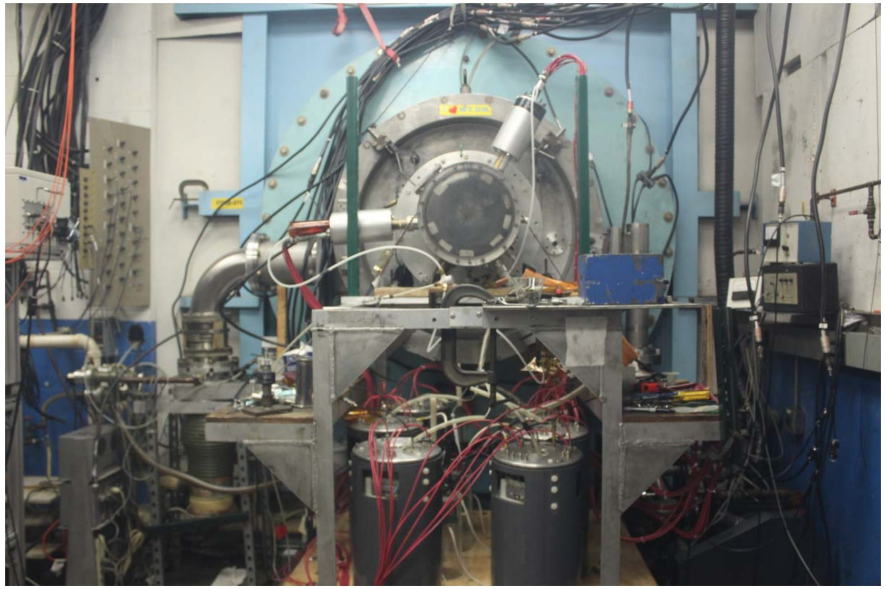
- High-inductance Hawk pulsed power generator at NRL is being used to drive a dense plasma focus (DPF) load

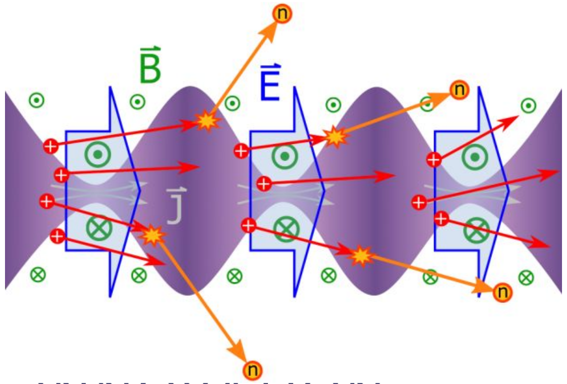
- Suite of diagnostics is in development to diagnose implosion, possible electric field generation, charged particle acceleration, and neutron production

- Tech-X partnered with NRL and Michigan State through an ONR-funded effort to provide modeling support

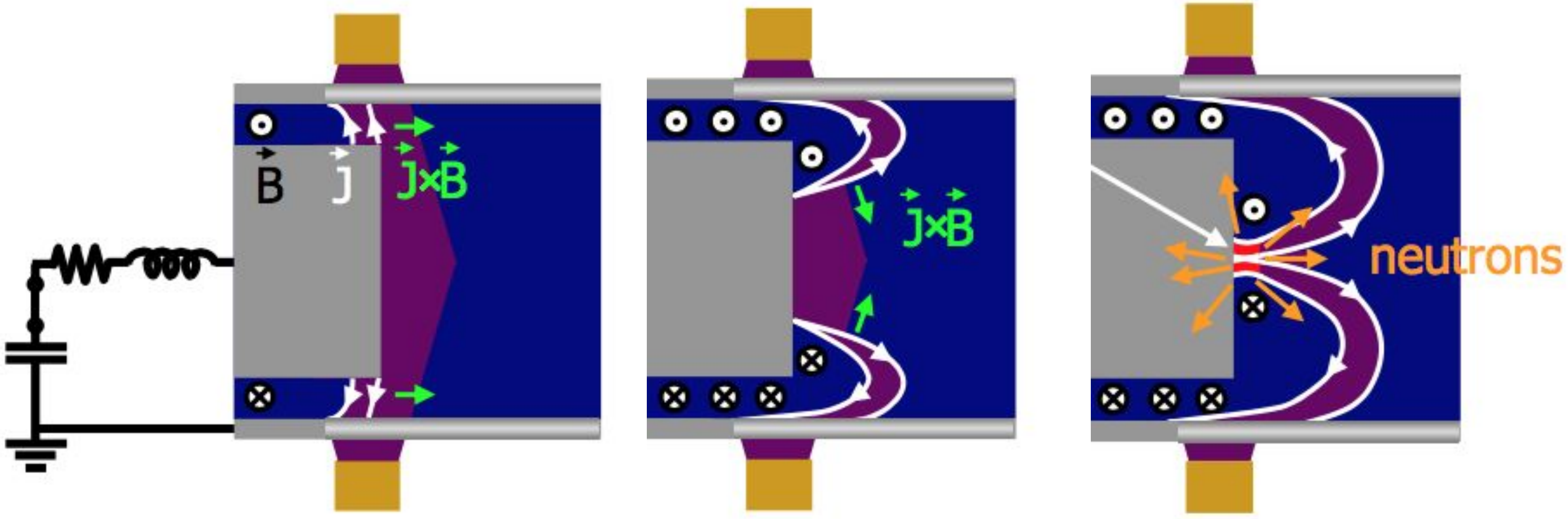
- Collaborators: Stuart Jackson, Joe Schumer, John Giuliani, Joey Engelbrecht, Ian Rittersdorf, Steve Richardson, John Luginsland

- Tech-X simulation effort led by Christine Roark





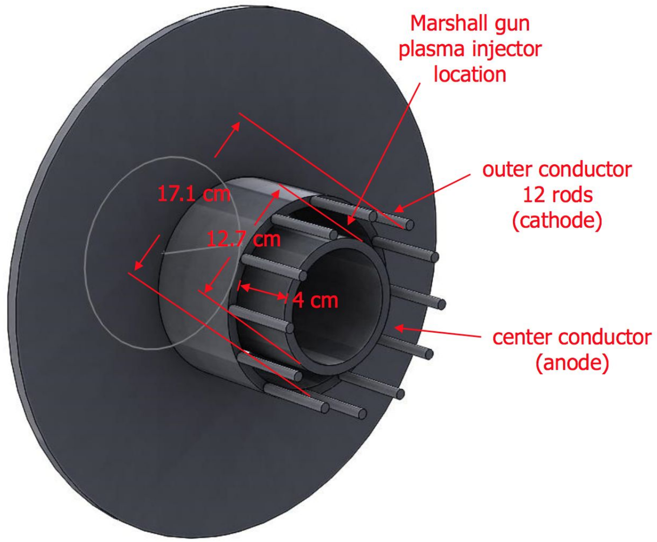
DPFs are simple and compact sources of neutrons

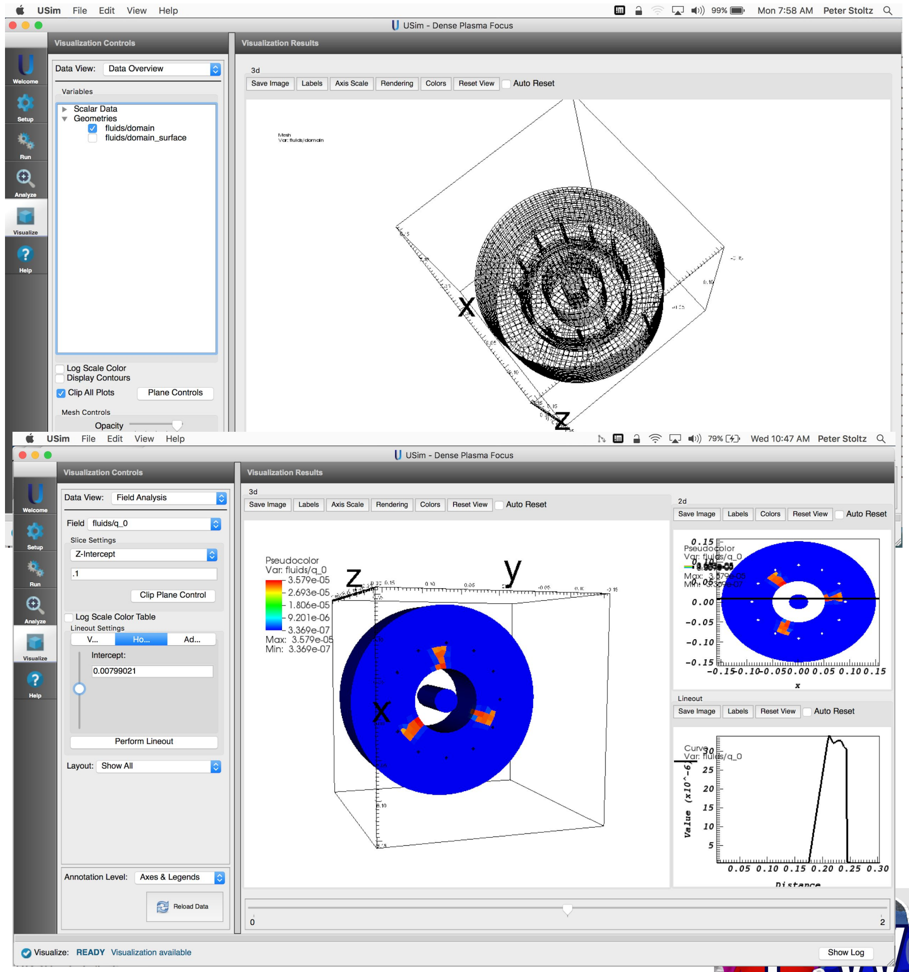


Axial Phase Radial Phase Pinch

- Neutron production regularly exceeds the values estimated from simple thermal calculations

Tech-X and NRL researchers simulate Hawk in 3D with an ideal MHD model





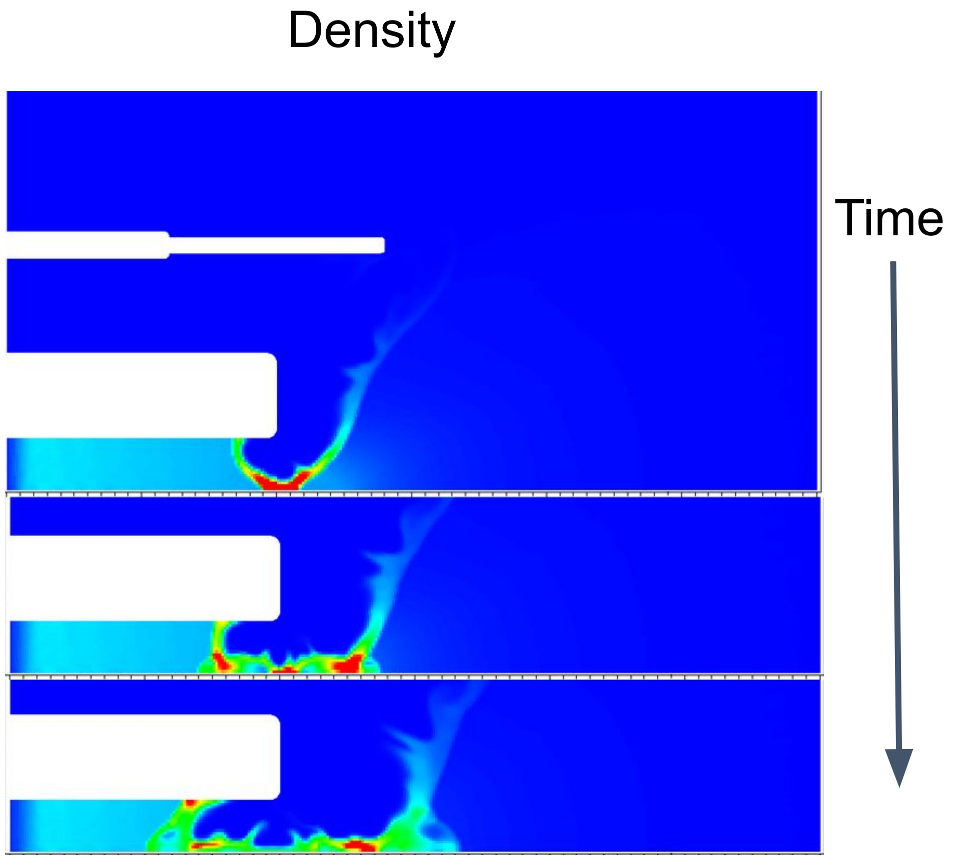
- USim can create its own meshes or import meshes in many popular formats including gmsh and Cubit

- We performed these simulation on 48 cores in ½ day

USim results allow researchers to see the density evolution and plasma pinch

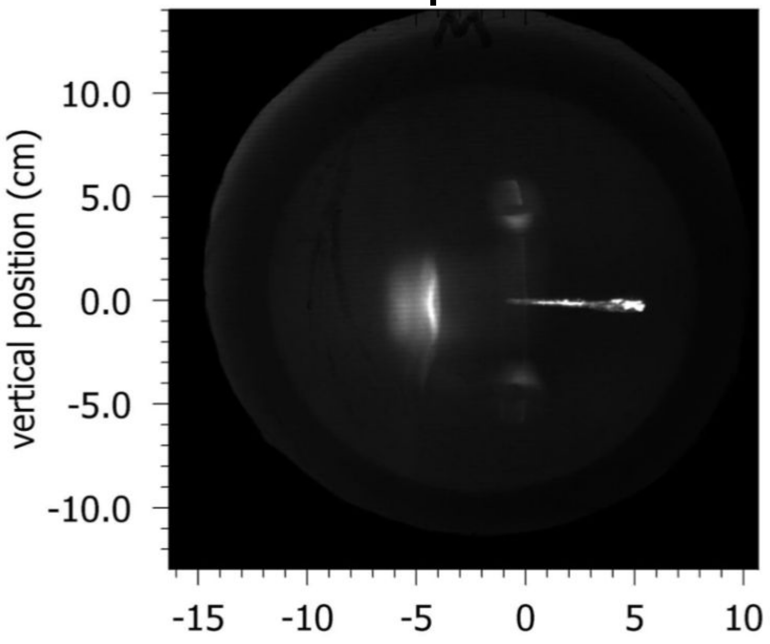
- By tracking the density (and temperature) as a function of time, one can estimate optical emission or neutron yield

- This allows researchers to compare USim results with experiment



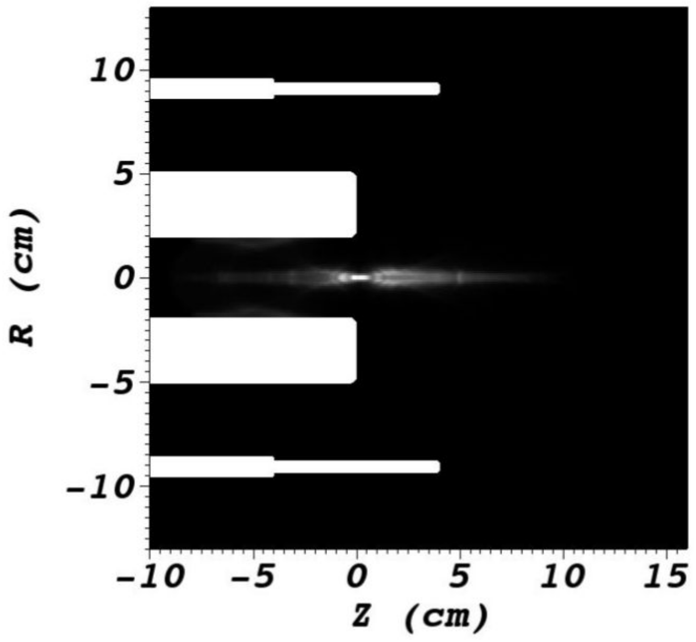
USim can simulate optical emission for comparison with experimental diagnostics

NRL Experiment



Measured x-ray pinhole imaging

USim



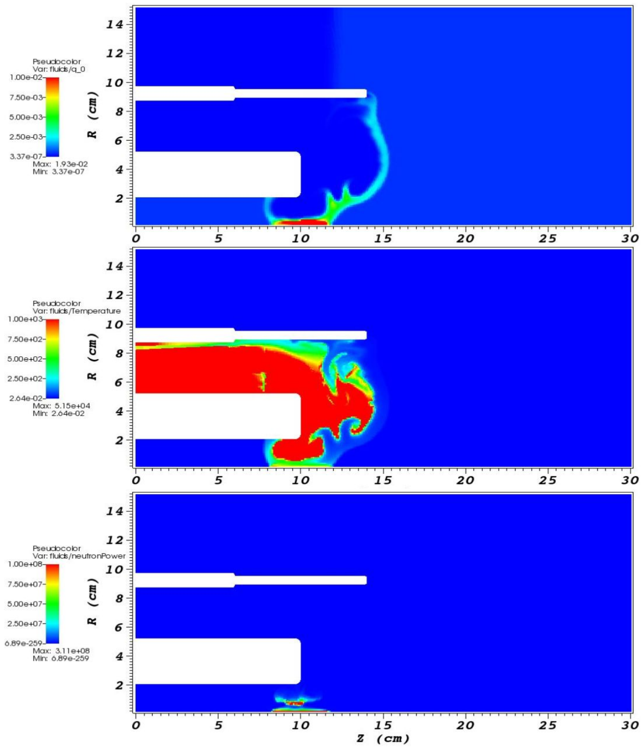
Time-integrated simulated emission

USim can simulate neutron production, another important diagnostic in the HEDP community

Density

Temperature

Neutron Power Density

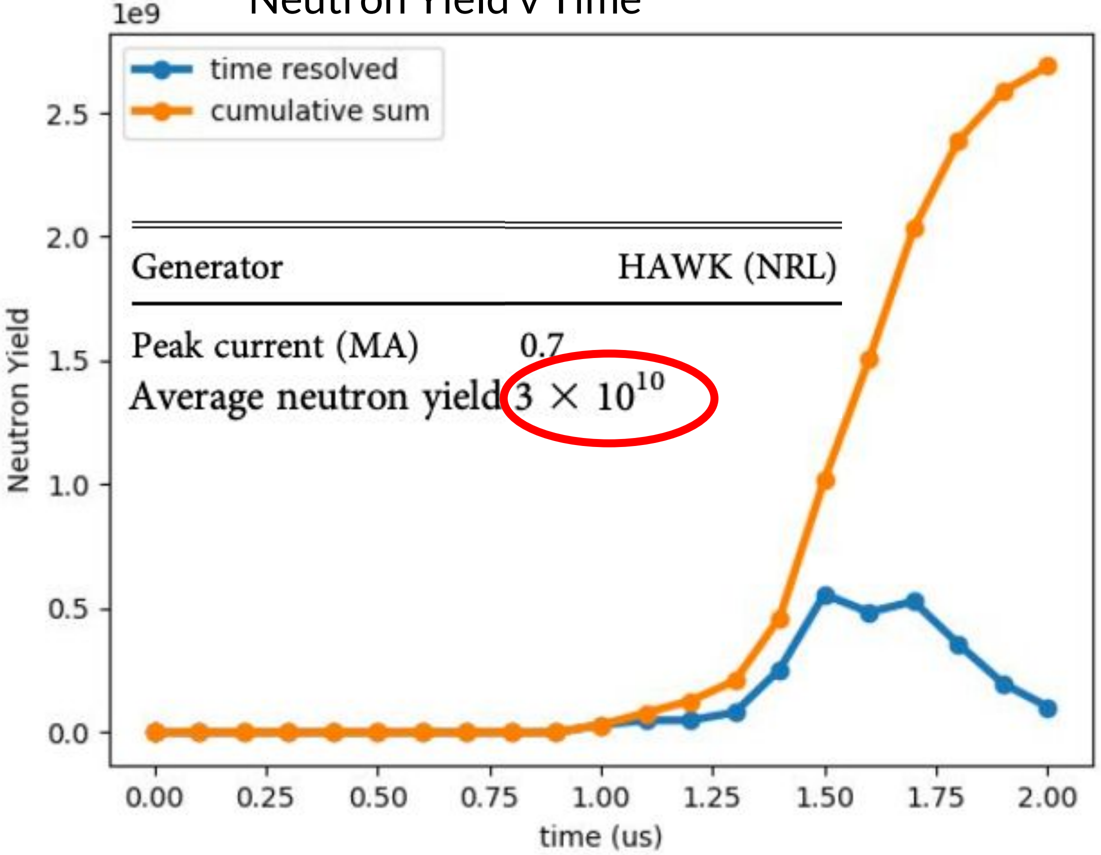


Red = 10^{24} m^{-3}

Red > 1 keV
(~5 keV in pinch)

Red = 10^{8} W/m^{-3}

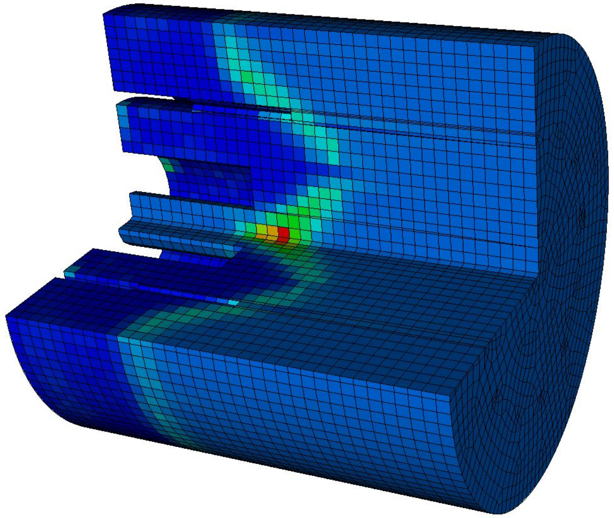
Neutron Yield v Time



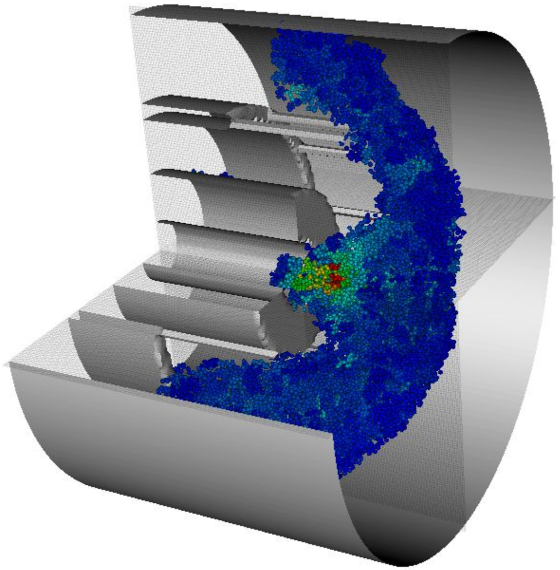
- But! Experimentalists believe thermal yields are typically ~10% of the total for most DPFs!

The future: leverage the power of both Tech-X plasma modeling codes!

USim (Fluid)



VSim (Kinetic)



Thanks for listening!

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