PUFFIN: a New Microsecond, Mega-Ampere Pulser for Magnetized HED Plasma Physics

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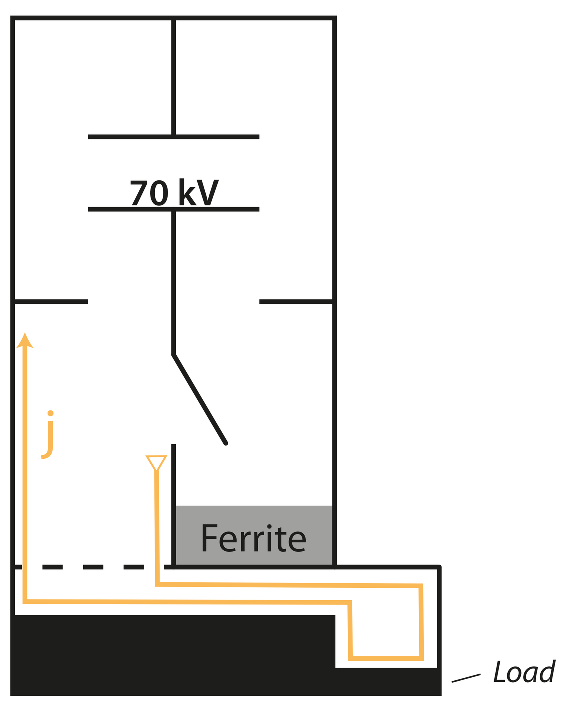
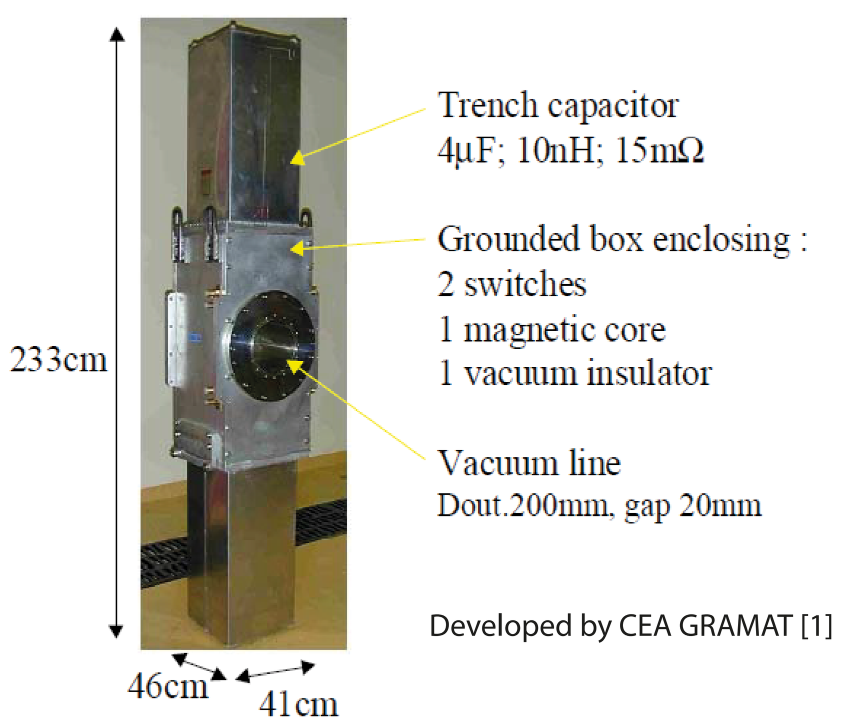
Summary

Many interesting plasma physics phenomena in the universe develop over long time scales. One example is magnetohydrodynamic turbulence, which must be driven over many hydrodynamic time scales to reach the statistical steady state typical of astrophysical plasmas. Existing pulsed-power generators are usually optimised for very fast rise times (~ 100 ns), which can drive the rapid implosions which generate bright x-rays sources. However, for basic plasma physics or laboratory astrophysics studies it is desirable to drive the plasma over longer timescales, and reach a quasi-steady-state. In this poster we discuss the design of PUFFIN, a medium sized pulsed power facility with a 1-2 MA peak current and a 2 μs rise time, based on the LTD-5 modules developed at CEA Gramat. PUFFIN will be constructed at the Plasma Science and Fusion Center at MIT starting in January 2021. It will be a versatile driver of magnetized HED plasmas and will provide a testbed for the development of laser based diagnostics which can then be used on large scale facilities such as OMEGA. Particular research topics of interest include magnetized turblence, magnetic re-connection, and transport and instabilities in magnetised plasmas.

LTD5 Modules

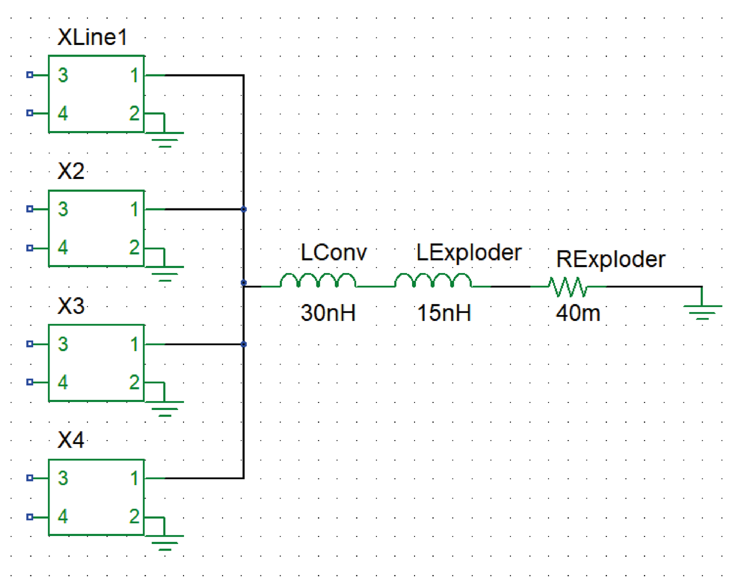


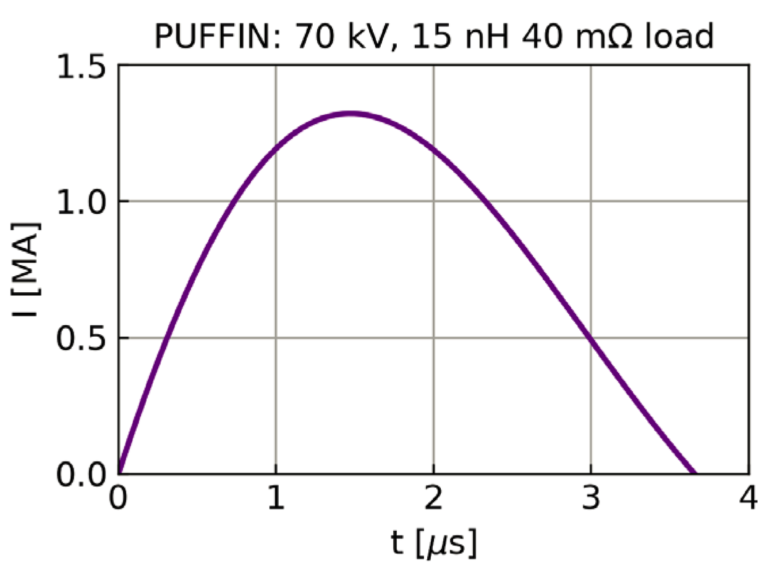


Developed by CEA GRAMAT [1]

- Capacitors charged to 70 kV
- Ferrite cores pre-magnetized to inductively choke short-circuit path
- Low inductance multi-channel switches are triggered and close
- Capacitors discharge into vacuum coaxial transmission line, through load and back to ground

CASTLE Simulations



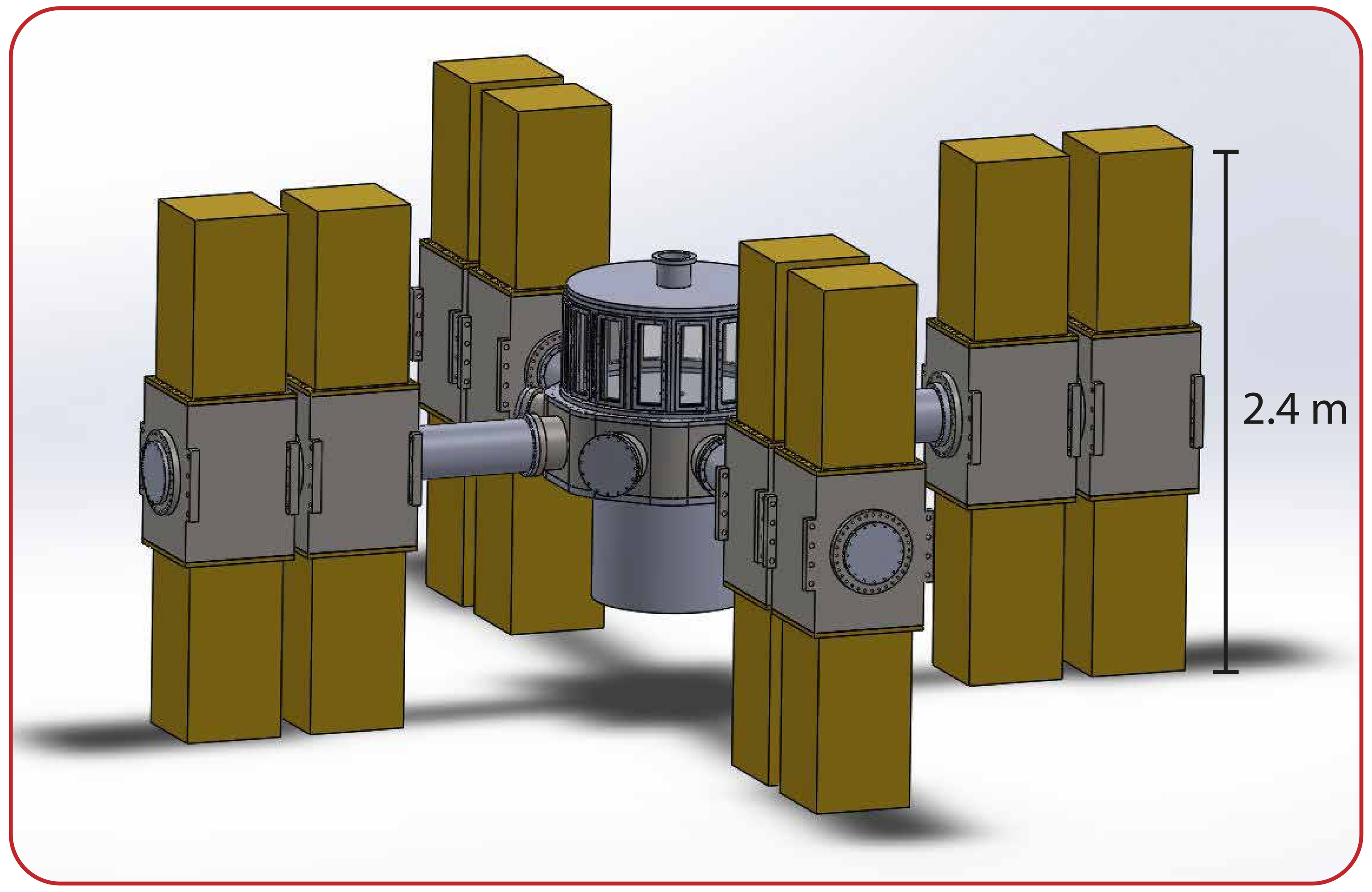


- Four lines of two modules each merge in convolute
- Example load: overmassed exploding cylindrical wire array, treated as a constant inductance
- Use a resistive load to damp voltage reversals

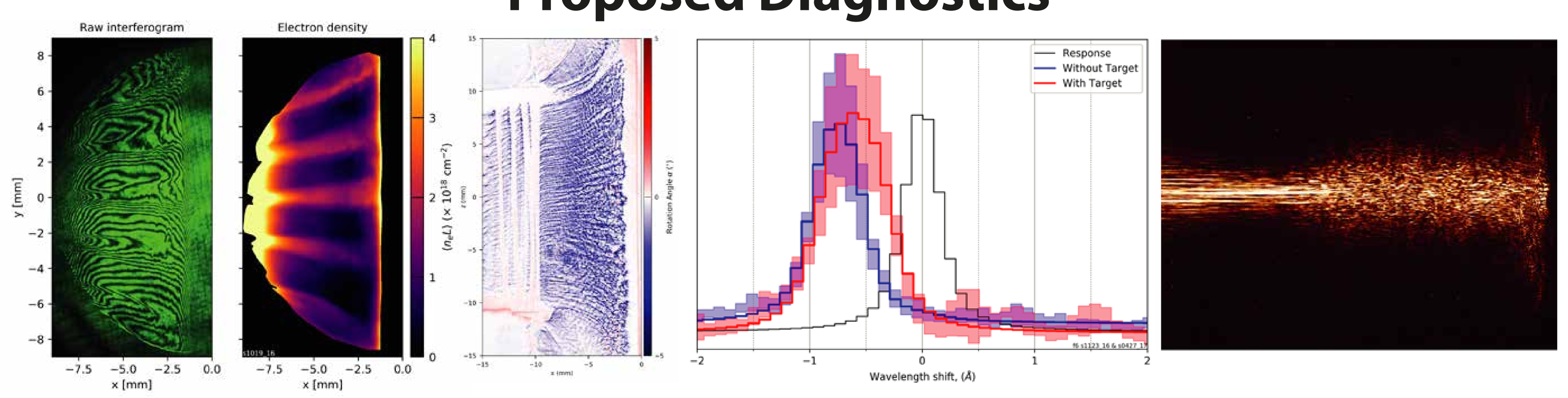
Research Goals

With a drive time much longer than the magneto-hydrodynamic time-scales, plasmas are in a quasi-steady state. We will study fundamental processes in magnetized HED plasmas, including:

- **Magnetic Reconnection:**
  - Growth and kink instability of plasmoids
  - Effects of strong radiative cooling
  - Sheared flows and Kelvin Helmholtz Instabilities
- **Magnetized Turbulence:**
  - Test key components of modern theories, such as critical balance
  - Study transition from MHD to kinetic regimes below the ion skin depth
  - Partition of energy between the electrons and ion
- **Magnetized Heat Transport**
  - Nernst effect in $\beta\sim1$, $\omega\tau_e\sim1$ plasmas
  - Effects of magnetized turbulence on heat transport

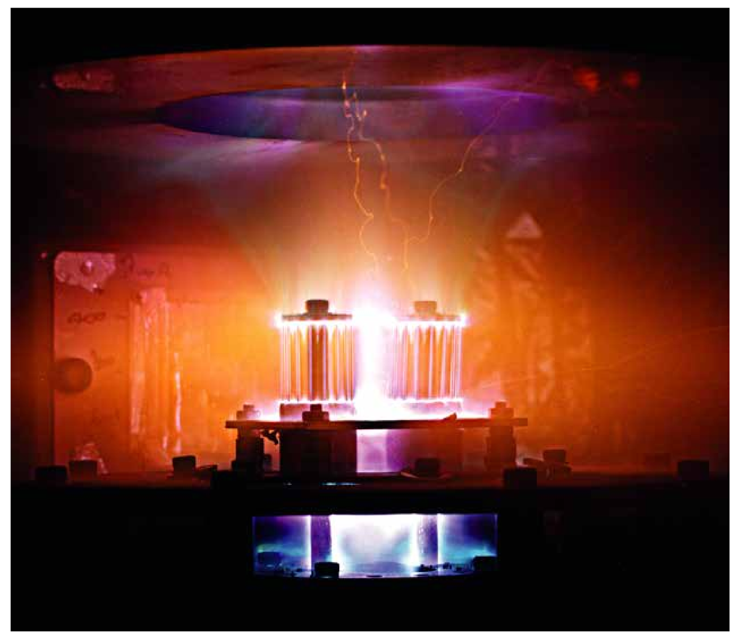


Proposed Diagnostics

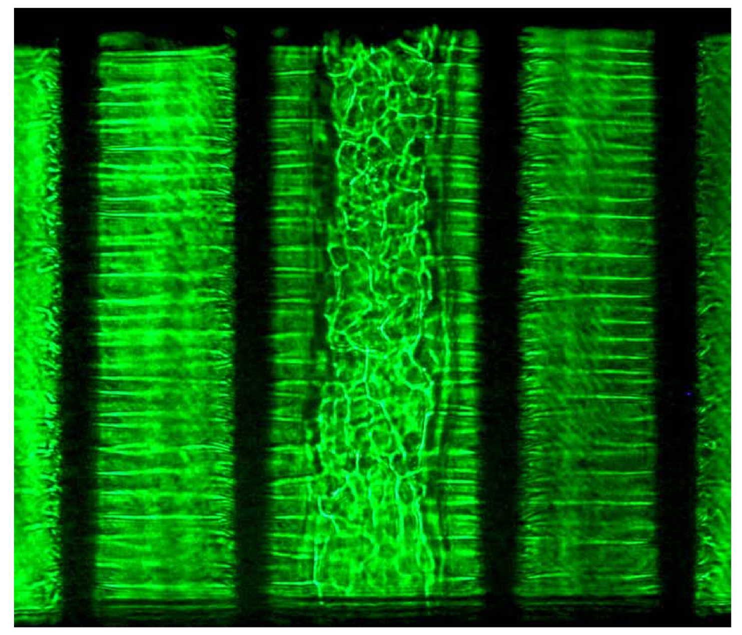


- **Dynamics:** High-speed self-emission imaging, 12 frames: >5 ns exposure, >20 ns interframe
- **Electron Density:** Laser imaging interferometry at multiple times: 1064 nm, 532 nm and 355 nm
- **Magnetic Field:** Faraday Rotation Imaging at 1064 nm, with inline interferometry
- Thomson scattering in the collective regime:
  - Ion acoustic feature gives **electron and ion temperatures, drift velocity, flow velocity**
  - Electron plasma waves give **electron temperature and density**
- **Electron Density Fluctuations:** Imaging Refractometry and Shadowgraphy at 1064 nm
  - See poster by Stefano Merlini CP15.00007, paper https://arxiv.org/abs/2007.04682

Laboratory Astrophysics Driven by Pulsed Power



Long exposure image of a pulsed-power driven reconnection platform, used to study plasmoids, radiative cooling effects and flux pile-up [3-4].

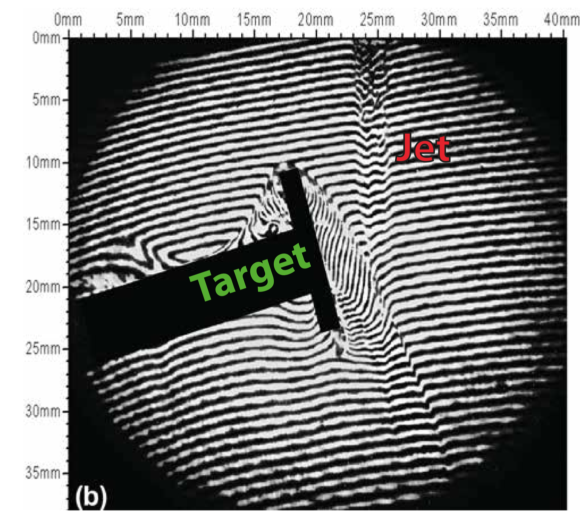


Laser shadowgraphy image of a long-lived turbulent column of carbon plasma, produced inside an over-massed imploding cylindrical wire array.

- Pulsed-power creates inherently magnetized plasmas close to equipartition: the magnetic, thermal and kinetic pressures are all roughly equally, relevant to many astrophysical plasmas.
- Long drive times from microsecond pulses produce plasmas in a quasi-steady-state: we can study the development of plasma processes independently of the changing drive strength.

Conical Wire Array Experiments on OEDIPE

- OEDIPE: Two LTD5 stages in parallel, now disassembled
- 950 kA peak current,1.2 μs rise time
- Load: A conical wire array driving a jet which interacts with an inclined target [2]
- Jet length ~100 mm, diameter ~15 mm, speed 90 km/s
- Demonstration of long drive pulsers for laboratory astro-physics.



Hands on Training for Students

- Practical training of students in pulsed-power engineering and laser-based diagnostic techniques is a key goal for PUFFIN.
- We will involve undergraduates through UROP program and MIT's Summer Research Program, which supports students from historically under-represented groups.
- PUFFIN complements the HED accelerator run by Petrasso's HED Group at PSFC, which is used for nuclear diagnostic development.

References

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[2] Plouhinec, D. et al. Plasma Astrophysical Jets Produced by a 1 microsecond Pulsed Power Driver. IEEE Transactions on Plasma Science 42, 2666 (2014).
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