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Magnetized High-Energy-Density Plasma

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Outline

Magnetized Plasmas at the HEDLP ReNeW

- Fusion applications (MTF-MIF; SNL approach)
- Astrophysics
- Other areas

Magnetized Plasmas at the WOPA

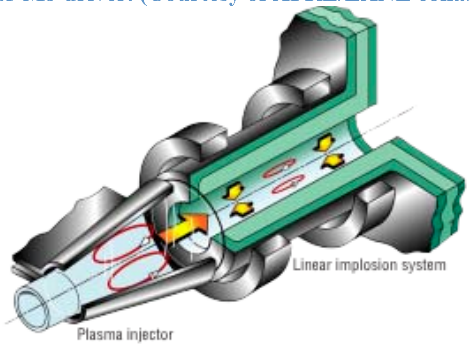
- Reconnection in the dense plasmas

New suggestions

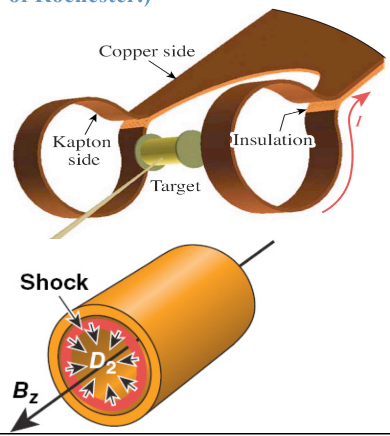
- Random fields for MTF/MIF
- Imitating the accretion discs
- Collisionless shocks in the intersecting jets

Magnetized target fusion

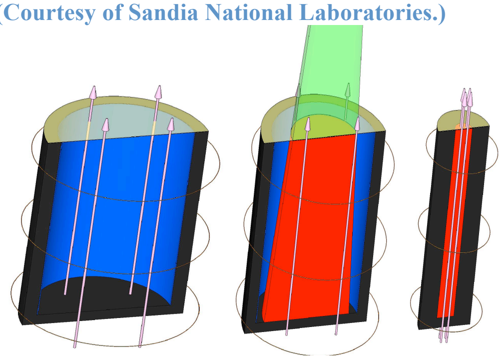
In one realization, a magnetically confined (Field Reversed Configuration) plasma will be compressed in ~10 µs by a solid aluminum shell (liner) using a 12 MA, 4.5 MJ driver. (Courtesy of AFRL/LANL collaboration.)



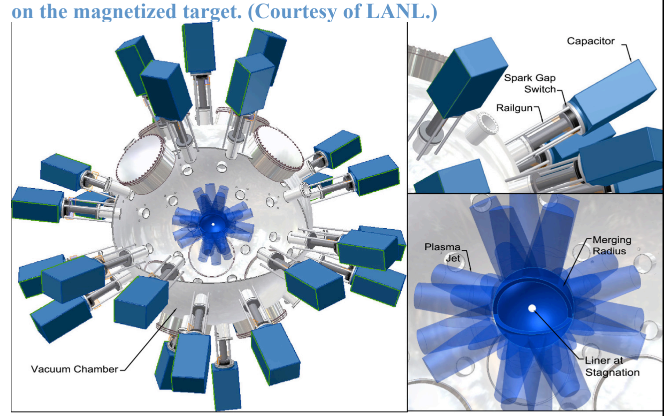
Compression of a shock-heated magnetized cylinder of fusion fuel plasma by a laser in ~ 1 ns. (Courtesy of the LLE, Univ. of Rochester.)



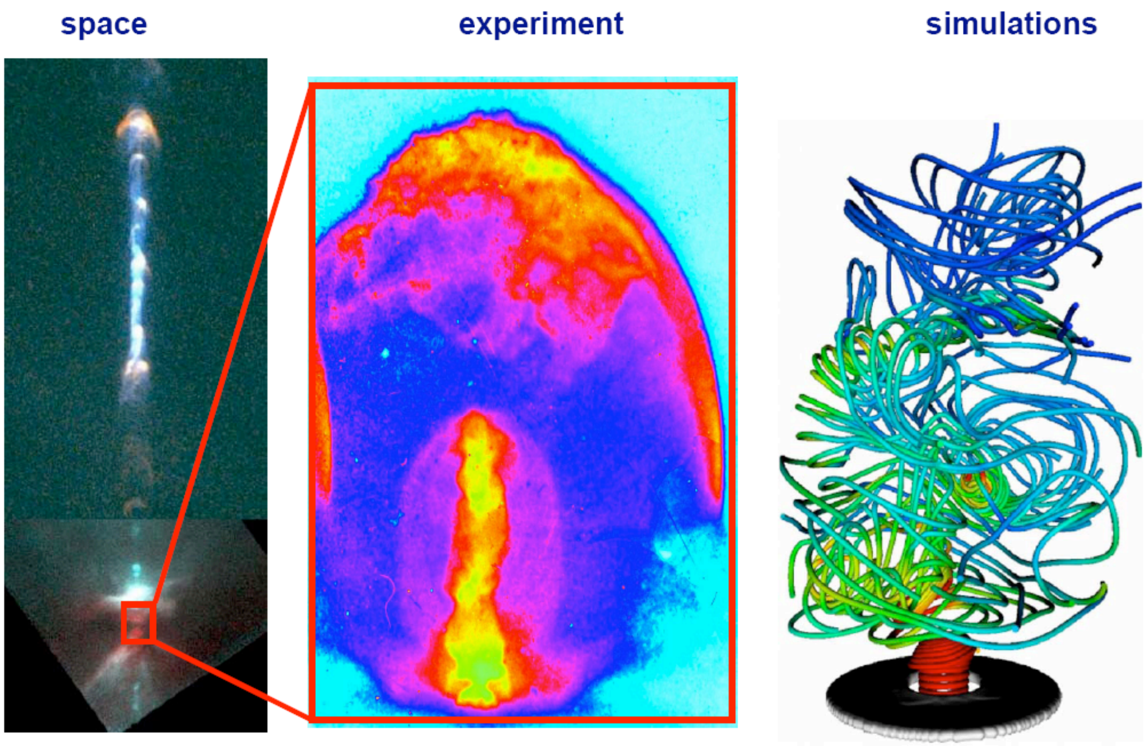
A (blue) gas-filled beryllium cylinder (black) is compressed by a ~ 25 MA, ~100 ns current pulse. The initial target plasma (red) is generated by a ~ 1 ns laser. (Courtesy of Sandia National Laboratories.)



Formation of a plasma liner in ~ 1 µs by multiple individual cold dense plasma jets inside a 2.7 m diameter sphere. The liner implodes on the magnetized target. (Courtesy of LANL.)



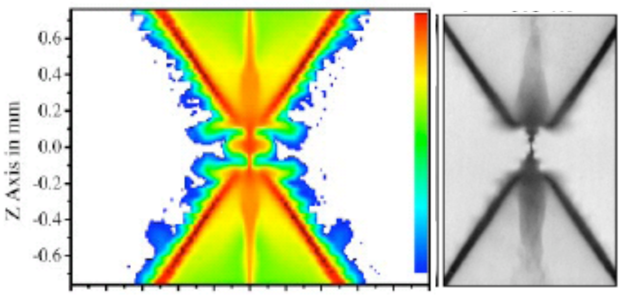
Astrophysical aspects



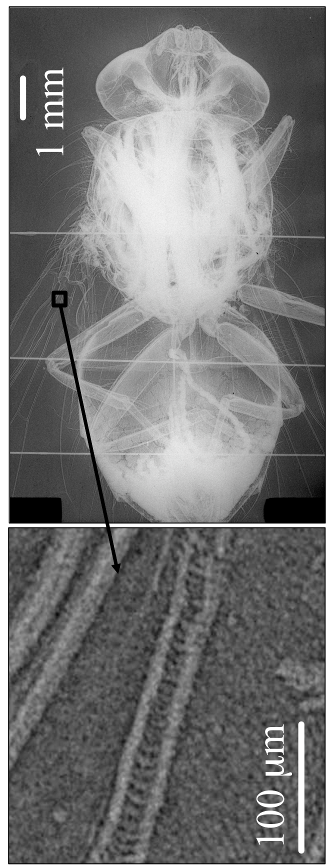
Scaled experiments (center) combined with high performance computer simulations that include magnetic field evolution (right) aid in understanding the nature of launch regions of astrophysical jets (left), which are too small to be clearly observed. Although the Solar system size launching region of jets from young stars is represented by just 2 cm in the experiment, the physics at work is thought to be the same.

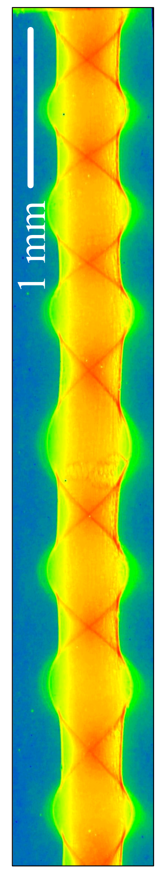
Other applications

EOS with magnetically-driven flyers, Pulsed radiation sources, ...
An example of an exciting table-top experiment: an X-pinch



Left – A slice through a 3D simulation of an imploding X-pinch reveals the formation of a narrow column of plasma at the cross-point. Right - A flash of X-ray from one X-pinch is used to capture the moment when the centre of a second X-pinch collapses to a few microns.





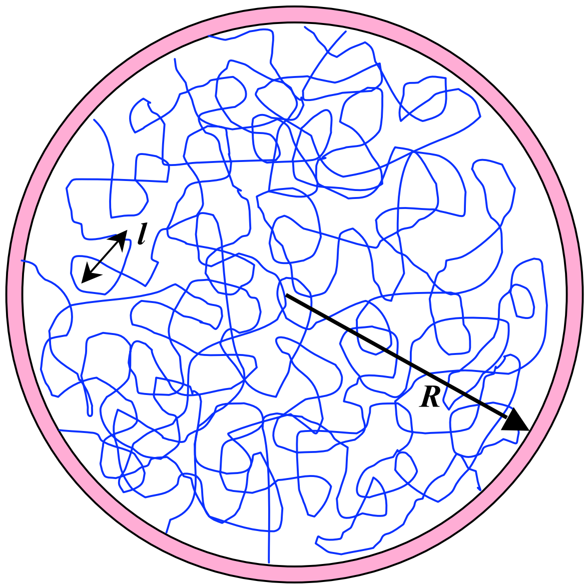
The common house fly as seen using the high resolution afforded by the microscopic X-ray source of an X-pinch. The fast duration also allows the X-pinch to image rapidly evolving plasma experiments such as this exploding pair of twisted wires. (Courtesy of Cornell University.)

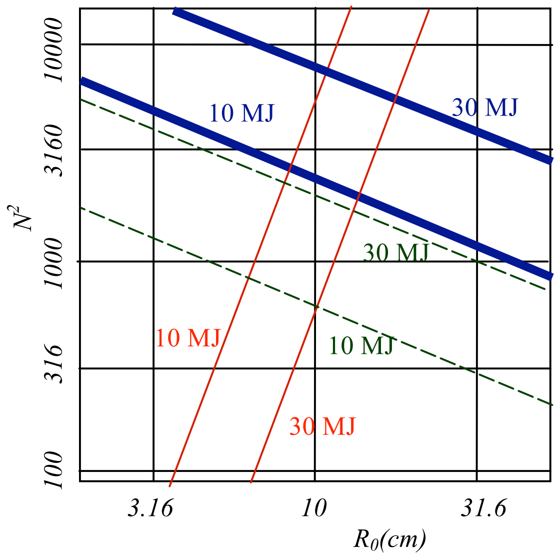
Magnetized HEDLP at WOPA

Significant interest in using the HEDLP experimental platforms to study two problems:

- Magnetic reconnection in the high-beta, non-ideal plasmas
- Collisionless shocks in an initially un-magnetized plasma

- Random fields for MTF-MIF





N=R/l

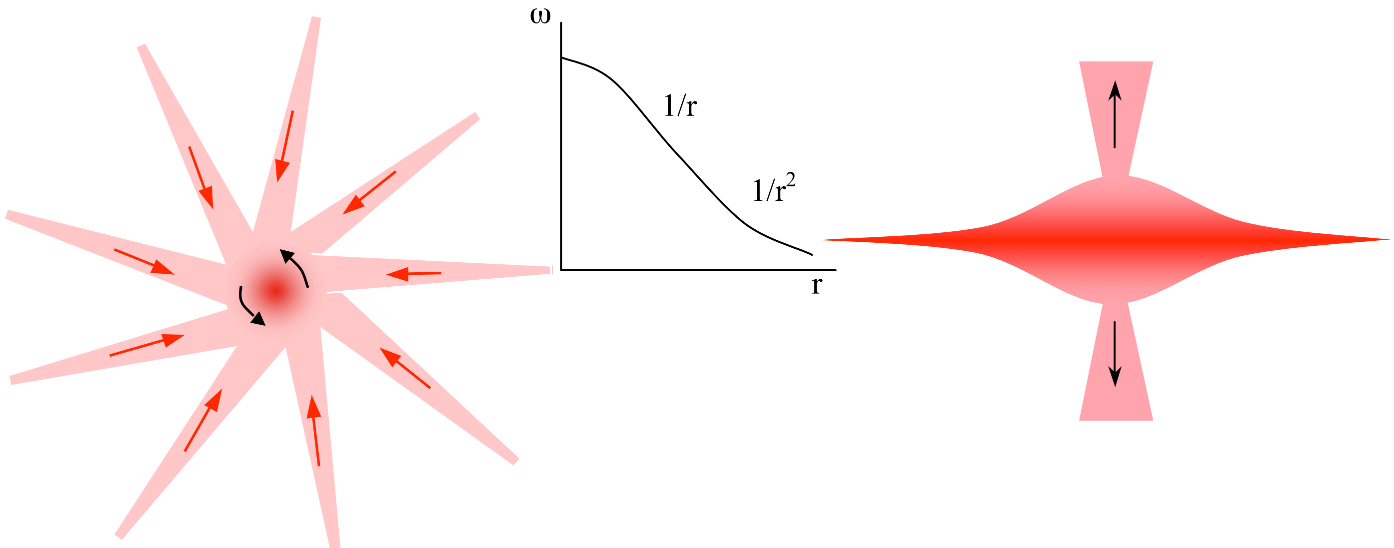
It turns out that, with a properly chosen spatial scale of random field variation, one can provide conditions for a good heat confinement.

Possible scenario: injecting multiple magnetized plasma bunches towards the center of the chamber, to form the target; after that launch a plasma liner (or the other type of the liner)

(D.D. Ryutov. "Adiabatic compression of a dense plasma "mixed" with random magnetic field". Fusion Science and Technology, **56**, 1489-1494, November 2009)

Simulating the astrophysical accretion discs

An array of plasma jets would allow one to imitate the formation of a differentially rotating disc



Top view	Side view

A planar array of jets forms a rotating disk in the zone of their merger. One can expect formation of outflow in the direction perpendicular to the plane of the figure. Each jet originates from a target irradiated by a laser beam (targets and beams are not shown). In the case shown, 9 beams would be used. In order to produce rotation, the center line of each jet is offset with respect to the center of the merger.

Jets with the divergence angle of 20 and less degrees have been produced in a number of experiments

C.D. Gregory et al, PPCF, **50**, 124039 (2008): ~ 0.1-1 kJ, v~300 km/s, *D*~300 μm

J.M. Foster et al, ApJ, 634, L77 (2005): 1 kJ, v~10 km/s, *D*~100 μm

V. Tikhonchuk et al, PPCF, 50, 124056 (2008): ~ 0.1 kJ, v~ 500 km/s, *D*~100 μm

B. Loupias et al, J.of Phys., 112, 042022 (2008): ~ 0.3 kJ, v~ 150 km/s,
D~100 μm

An example of possible plasma parameters for an array of 9 jets forming a 3 mm diameter disc

Plasma parameters in the central part of the disc:

n=10^{22} cm^{-3}; T=100 eV; disc radius r=1.5 mm; disc thickness 3mm; rotation velocity at the periphery v_{rot}=$3 \cdot 10^{7}$ cm/s

Plasma parameters in the outflow:

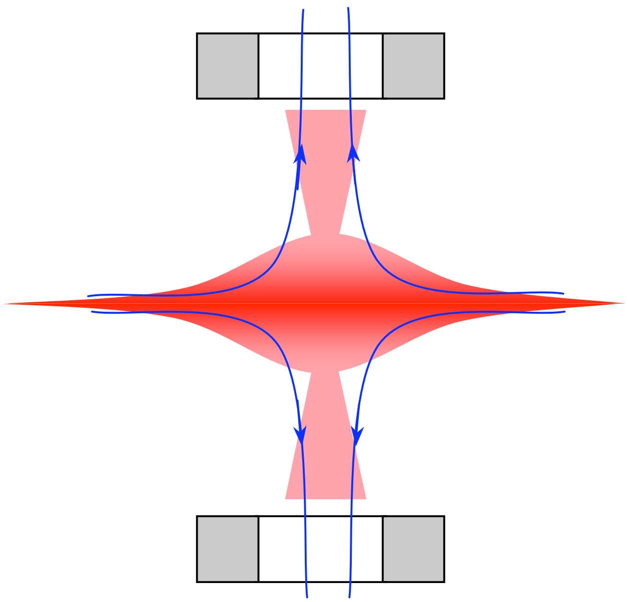
n_{jet}=10^{22} cm^{-3}; T_{jet}=100 eV; minimum radius r_{jet}=1.5 mm; vertical velocity v_{jet}=$5 \cdot 10^{7}$ cm/s

Derived parameters:

Plasma kinematic viscosity ν~60 cm^2/s; Reynolds number $Re \equiv r v_{rot}/\nu$~50000

In astrophysical case, the plasma is collisional due to its very large length-scale (~ 1 parsec for Young Stellar Outflows). Plasma parameters in the typical Herbig-Haro object: r_{jet}=$3 \cdot 10^{17}$ cm; v_{jet}=$2 \cdot 10^{7}$ cm/s; T_{jet}~ 20 eV; n_{jet}=10-100 cm^{-3}; $Re \equiv r_{jet}\, v_{jet}/\nu \sim 10^{3} - 3 \cdot 10^{4}$

Impose a weak cusp magnetic field to see a conversion of the poloidal field into toroidal field by the differential rotation



Magnetic diffusivity for the aforementioned plasma parameters:

D_{magn}~4000 cm^2/s

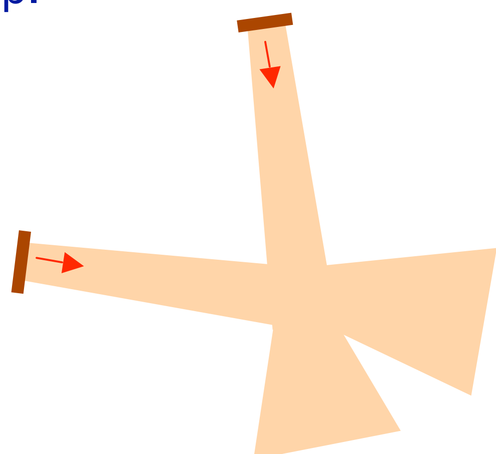
Magnetic Reynolds number:

$Re_m \equiv r v_{rot}/D_{magn} \sim 1000$

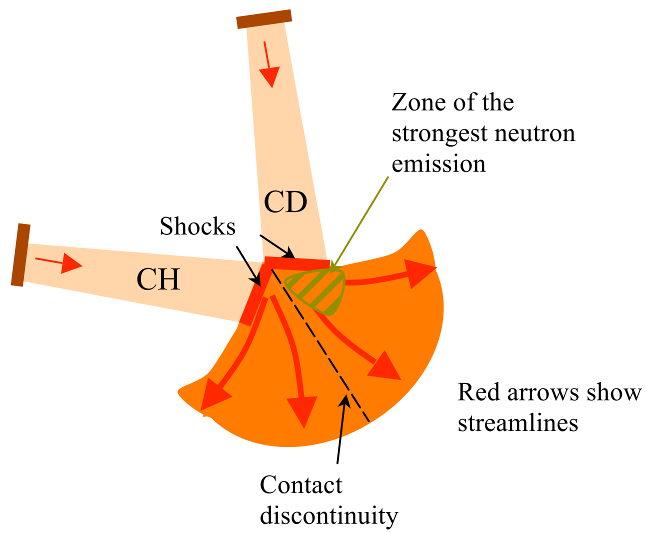
See description of suitable coils in:
O.V. Gotchev, J.P. Knauer, P.Y. Chang et al.
"Seeding magnetic fields for laser-driven flux compression in high-energy-density plasmas",
Rev. Sci. Instrum. **80**, 043504 (2009)

A collisionless shock experiment with two intersecting jets

The idea: choose the size l of the intersection zone so as to satisfy the condition $l^* << l << \lambda$, where l^* is the expected collisionless shock thickness and λ is the ion m.f.p.



No collisionless shocks: only a minor angular broadening of the jets exiting the interaction area



Strong collisionless interaction: a very different picture; at high-enough ion energies, significant neutron emission from a deuterated jet (note that only one jet is deuterated)

A NIF-scale driver is desirable to satisfy the condition $l^* << l << \lambda$ by a large margin

Summary

The field of the magnetized HEDP experiences a rapid growth, a large influx of the new ideas, and continuing development of the new experimental techniques