LA-UR 14-29374

Fusion and Plasma Physics Research at Los Alamos

Don Rej

35th Annual Meeting and Symposium

Fusion Power Associates

Washington, D.C.

December 16-17, 2014

Los Alamos Portfolio

Inertial Confinement Fusion

Magnetic Fusion Energy

High-Energy-Density Laboratory Plasmas

General Plasma Science

Work supported by:

NNSA (Science Campaigns, LDRD, NNSA Labs)

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ITER Organization

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LANL leads a multi-lab team investigating of beryllium ablators for ICF "hot spot" ignition on NIF

Scientific Achievement

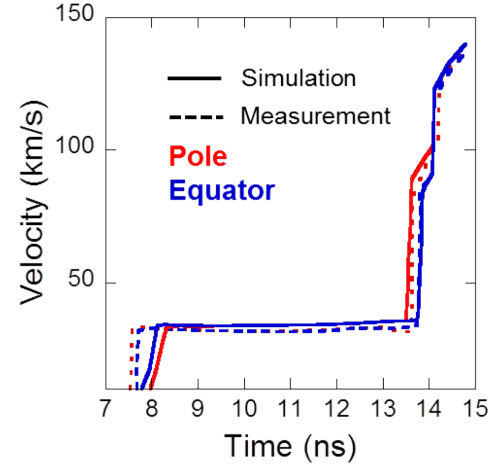
Campaign goal is to determine if Be is a better path forward than plastic (CH) ablators. Initial comparisons between pre- and post-shot simulations for the first keyhole target shot provide insight into the differences between CH and Be capsule performance. ICF Be ablator tests with the first DT layered shot planned for Apr 2015

Significance and Impact

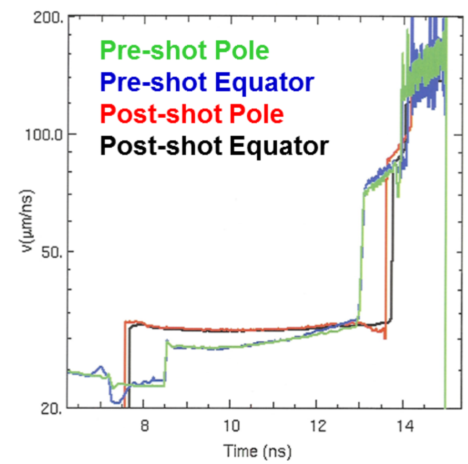
Current implosion simulations for ICF require multipliers to reduce the drive on the capsule to match experimental observations. Keyhole experiments measure the breakout and amplitude for hohlraum driven shocks from which multipliers can be derived. Comparing the coupling multipliers provide a means to compare ablator materials.

Research Details

VISAR measurements (shown on right) show breakout and the velocity of the first two shock for a Be capsule. Top plot shows the match between simulation and experimental data. The bottom shows the comparison of the pre- and post-shot simulations which indicate Be has better coupling in the picket of the laser pulse than CH. This is indicated by the earlier breakout in the post-shot simulations, as well as the higher velocity of the first shock. The coupling in the trough of the laser pulse and second shock are comparable with plastic.



Shock velocity in foot vs time



Top: Comparison between measured and post-shot simulated shock parameters. Bottom: Comparison between pre- and post-shot simulated shock parameters

DT Liquid Layers Will Explore the Physics of Hotspot Formation

Scientific Achievement

Scientists at LANL created a novel technique for forming the DT hot spot in a NIF implosion has been created. High-density carbon (HDC) capsules with DT liquid layers will study the physics of hotspot formation and capsule convergence. Scientists at LLNL have created a novel technique for lining the inside of a NIF capsule with a wetted foam liquid DT layer.

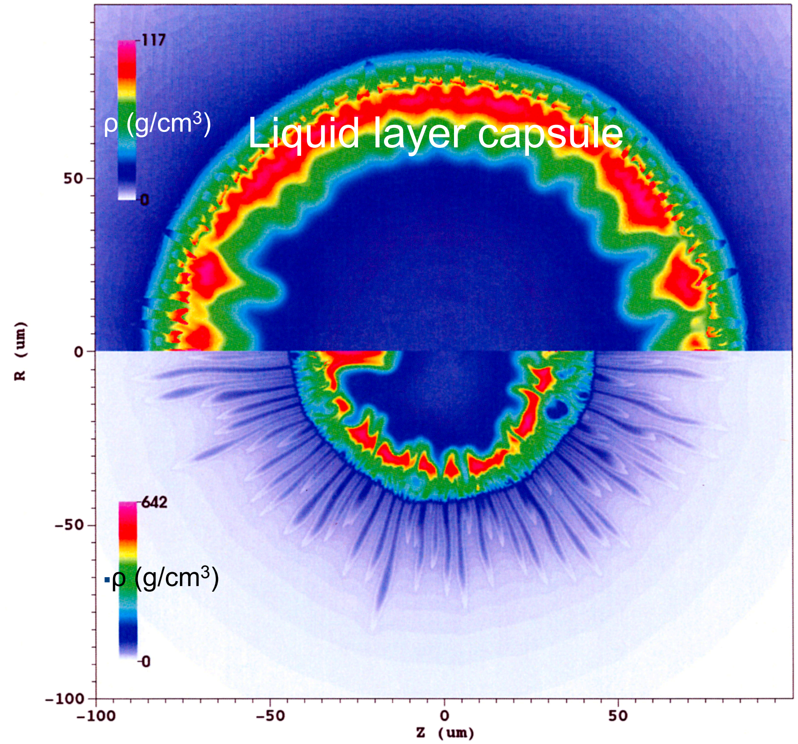
Significance and Impact

Liquid layer capsules form their hotspot from mass originating from the core DT vapor. This process is expected to be more robust than the baseline NIF designs, which form their hotspot from DT mass dynamically ablated from a thin inner ice layer

Research Details

Experiments will test the robustness of the liquid layer hotspot formation method. Liquid layer capsules will be fielded at NIF to measure the hotspot size, neutron yield, ion temperature, reaction duration, and hotspot pressure

1. R.E. Olson and R.J. Leeper, Phys. Plasmas 20, 092705 (2013).
2. J. Biener et al., Nucl. Fusion 52, 062001 (2012).



Ice layer capsule

Reduced instability growth in liquid layer capsules: *Simulation showing the imploded density of a new liquid layer (above) and traditional ice layer (below) capsule, both at the time of peak fusion reaction rate. The liquid layer capsule has converged to a larger final radius, while suppressing capsule hydrodynamic instability growth.*

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Fast imaging of intact and shattered cryogenic neon pellets

Scientific Achievement

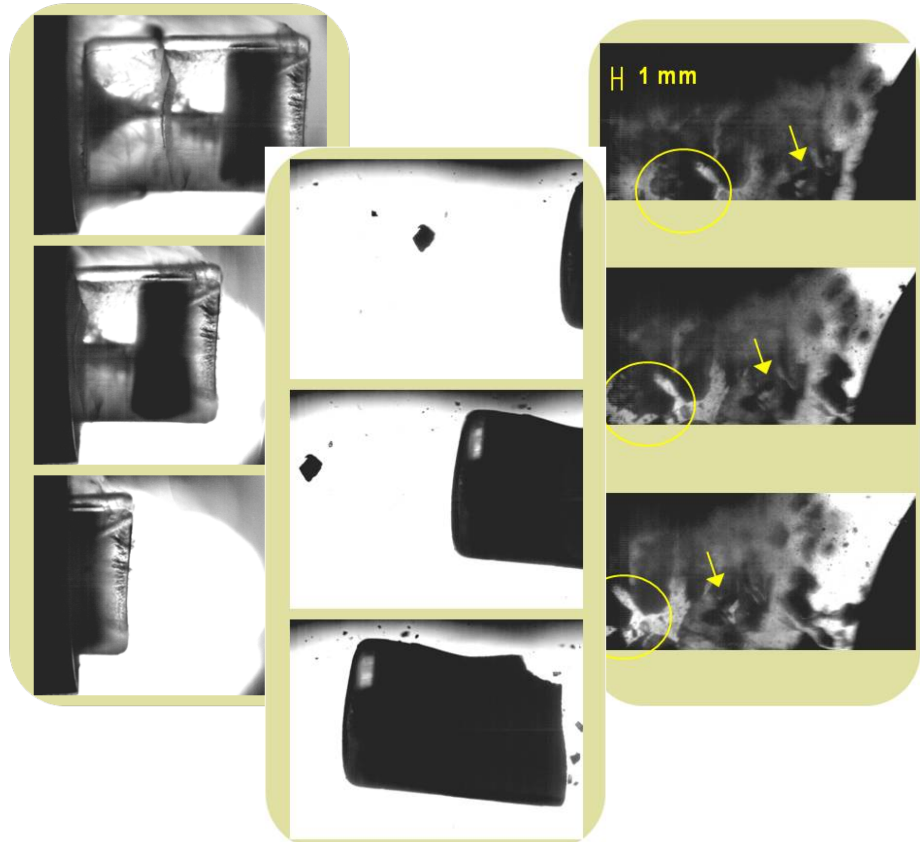
Fast real-time imaging system with fine spatial resolution (less than 100 μm), sub-μs temporal resolution and a frame rate close to 1M frame per second is demonstrated. The technology is now used to characterize intact and shattered cryogenic neon pellets for ITER disruption mitigation.

Significance and Impact

Fast imaging systems are essential tools to MFE and understanding of many rapidly changing phenomena around us. We combined the latest high-intensity LED lighting technology, fast optics with a fast CMOS camera to achieve both fine spatial resolution and sub-μs temporal resolution in imaging of intact and shattered frozen neon pellets. A shattered pellet consists of many pieces with a wide spread in sizes (the ratio of the sizes of the largest object (~ 1 cm) to the smallest is more than 100). The results were obtained at low cost using an existing fast camera. The technology can be broadly applied to MFE and other fields when simultaneous imaging of many mm-size and smaller objects are becoming increasingly important.

Research Details

- A backlighting configuration was used with high intensity commercial LED illumination and fast optics.
- Particle distribution obtained from time-resolved movies.
- Velocity distributions of particulates obtained from time-of-flight.



Left: *The motion of a intact pellet upstream of the injector*

Middle: *A pellet downstream of the injector*

Right: *A shattered pellet that is turned into a thick cloud*

Work was led by Los Alamos National Laboratory.

Z. Wang, S. K. Combs, L. R. Baylor, C. R. Foust, M. S. Lyttle, S. J. Meitner and D. A. Rasmussen, *Rev. Sci. Instr., 85*, 11E805 (2014).

New diagnostic to study tokamak plasma disruptions

Scientific Achievement

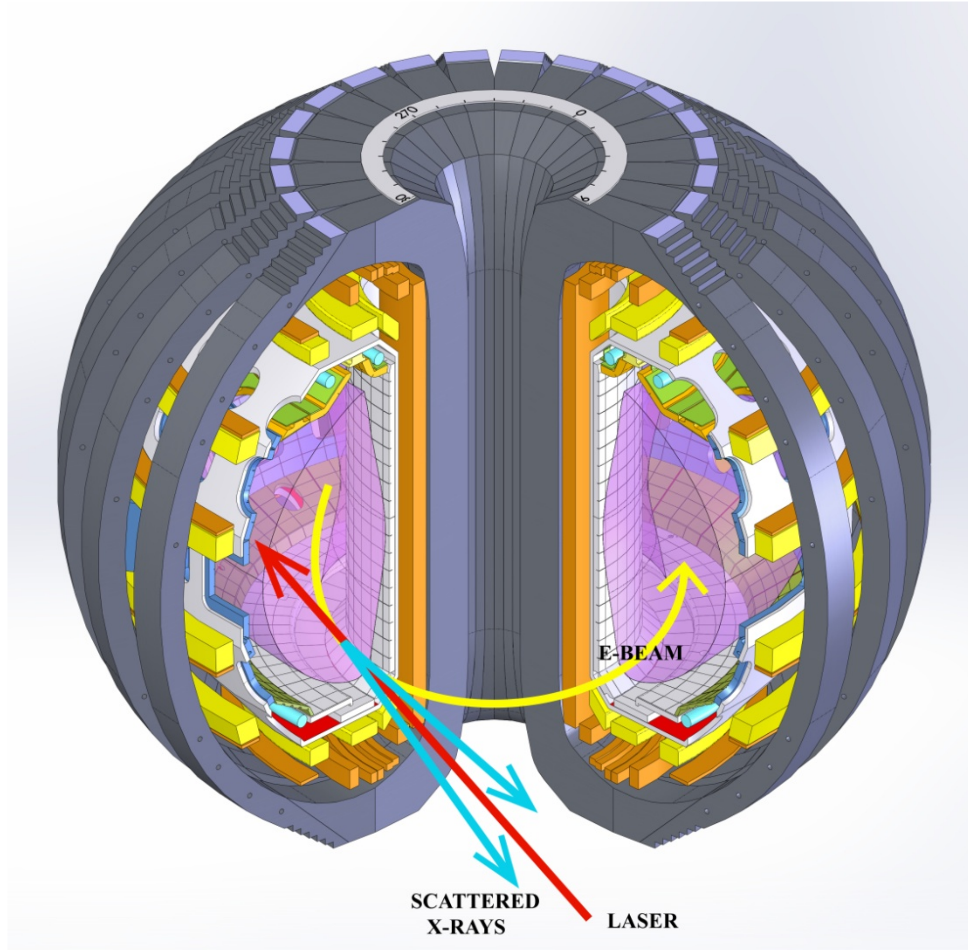
By combining new short pulse laser technology with gated x-ray imagers (developed for NIF), we conclude it will be technically feasible to measure laser inverse Compton scattered light from the core of a tokamak, to enable the in-situ study of relativistic (10's of MeV runaway) electrons.

Significance and Impact

The ability to measure the time-resolved space and energy distribution of runaway electrons in the core of the tokamak during a plasma disruption would greatly aid our understanding of the dynamics of their generation and loss in large tokamaks, better enabling us to design disruption mitigation schemes, which are crucial for the success of ITER.

Research Details

A team of LANL and General Atomics researchers has been formed, to develop a prototype system for the DIII-D tokamak. A design paper was presented at the 2014 High Temperature Plasma Diagnostics Conference in Atlanta.[1]



Up to 700 kA of runaway electrons can be generated in the DIII-D tokamak. A tangentially injected 60 picosecond laser pulse will be sent (head-on) across the e-beam, causing a backward-directed cone of up-shifted scattered light (in the 1-40 keV range) to be emitted. This light can be detected by gated soft x-ray imager technology which LANL originally developed for NIF.

[1] G. A. Wurden, J. A. Oertel, T. E. Evans, "An in-situ runaway electron diagnostic for DIII-D", Rev. Sci. Instr., **85** (11) 11E111 [2014].

W7-X Stellarator International Collaboration

Scientific Achievement

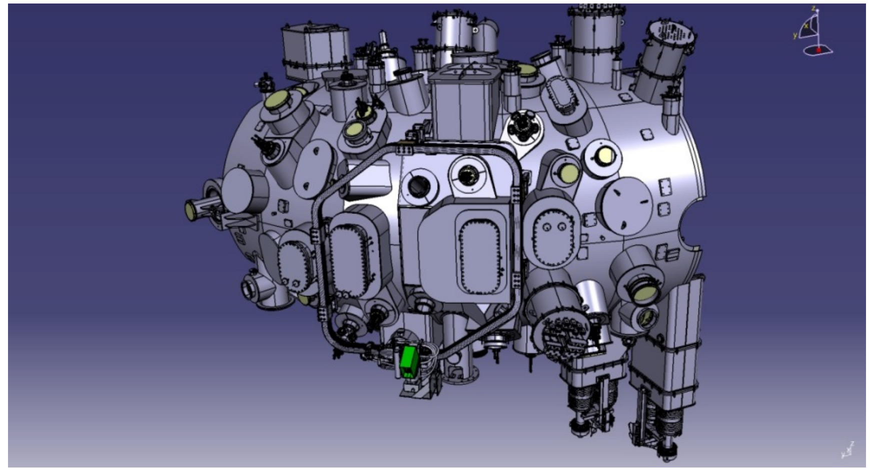
LANL/ORNL/PPPL are partners with the Max Planck Institute in Greifswald, Germany, to study 3D effects and plasma edge interactions in stellarators.

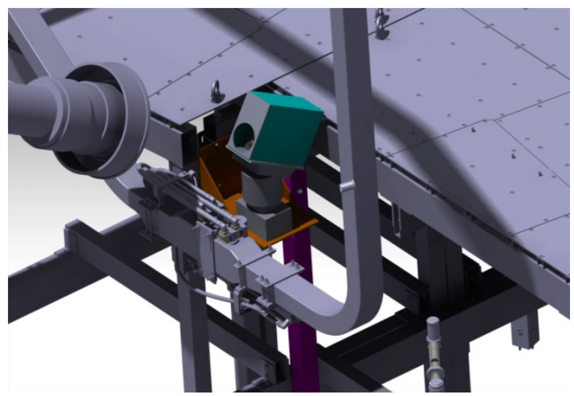
Significance and Impact

The new W7-X experiment (first plasma expected in 2015) is a superconducting long-pulse stellarator, which does not require current drive, and has no plasma disruptions. We are interested in developing stellarators as a potential “backup” to the tokamak approach to fusion energy.

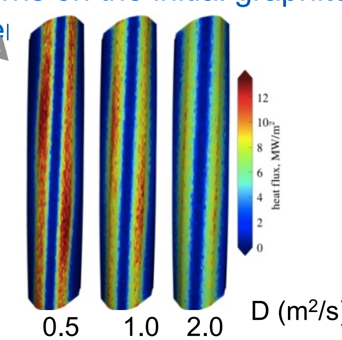
Research Details

- LANL is fielding a high resolution IR camera to view the heat loads on armor tiles during the first operations period
- We are designing another system for the second operations phase (OP1.2) to view into the divertor to diagnose the ORNL “scraper element”, which is the next major American contribution to W7-X.
- We expect to be transitioning from an engineering orientation towards physics campaigns in FY2015.





Cross field diffusion rate visibly affects expected heat load patterns on the initial graphite limite



CATIA drawings of 1/5 of the W7-X vessel, with one of the American magnetic trim coils (odd-shaped hoop), and the LANL high resolution IR camera (green) mounted near it. Also close-up views of the port, trim coil, and camera shield box (aqua) on W7-X the deck structure. The striped heat load patterns for three different plasma diffusivities are calculated on one of five graphite poloidal limiters.

Parallel heat flux & flow acceleration in open field line plasmas with magnetic trapping

Scientific Achievement

Marginal collisionality in scrape-off layer produces exotic parallel transport. Particle's mean-free-path is only a fraction (λ_{mfp}/L~0.2) of, or comparable to, the system gradient length scale

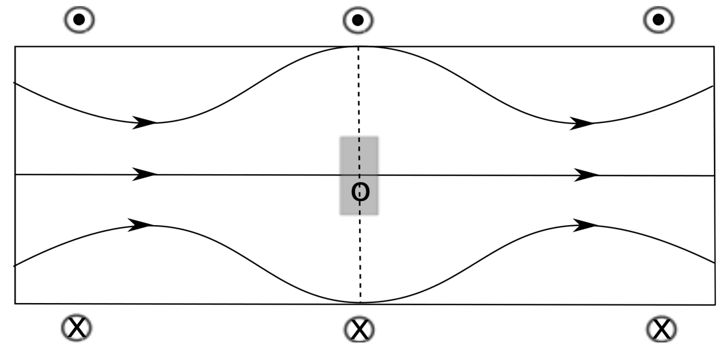
Significance and Impact

Effects of magnetic and electrostatic trapping must be included. Prediction of ion heat flux by Braginskii is in the wrong direction, requiring a better way to solve tail distribution than Chapman-Enskog.

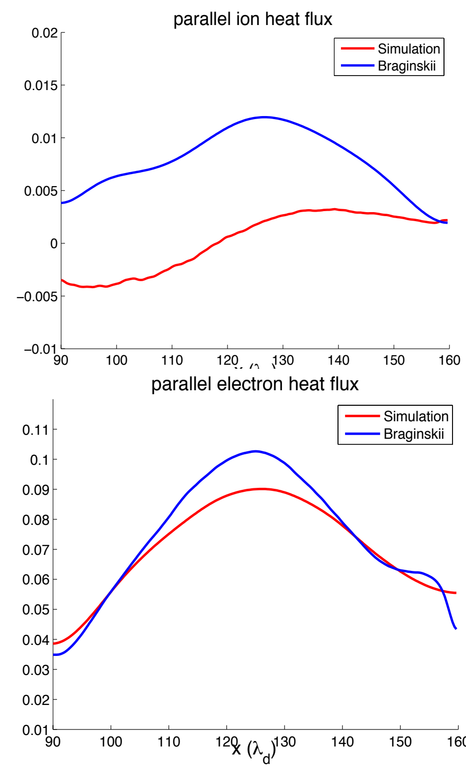
Research Details

- Magnetic field strength modulation in a tokamak scrape-off layer (SOL) provides both flux expansion next to the divertor plates and magnetic trapping in a large portion of the SOL.
- Kinetic simulation of a magnetic mirror-expander suggests the Braginskii's closure is problematic, particularly for ions.

Z. Guo, X. Tang, C. McDevitt, Physic of Plasmas 21, 102512 (2014)



Simulation setup. The magnetic field configuration is controlled by the currents in the three surrounding coils.



Anomalous heat flux (normalized to $n_0 v_0 T_s$) in the magnetic mirror-expander

Turbulence-Driven Bootstrap Current in Low-Collisionality Tokamaks

Scientific Achievement

A novel mechanism through which a bootstrap current may be driven even in a collisionless plasma.

Significance and Impact

Bootstrap current is essential for achieving an economical steady-state tokamak -- Arises from a collisional equilibrium between trapped and passing particles Turbulent transport can significantly modify the magnitude and profile of tokamak bootstrap current.

Research Details

Resonant scattering of electrons by drift wave microturbulence provides an additional means of determining the equilibrium between trapped and passing electrons and thus driving a bootstrap current

Employing a linearized Fokker-Planck collision operator, the plasma current in the presence of both collisions and resonant electron scattering is computed, allowing for the relative strength of these two mechanisms to be quantified as a function of collisionality and fluctuation amplitude.

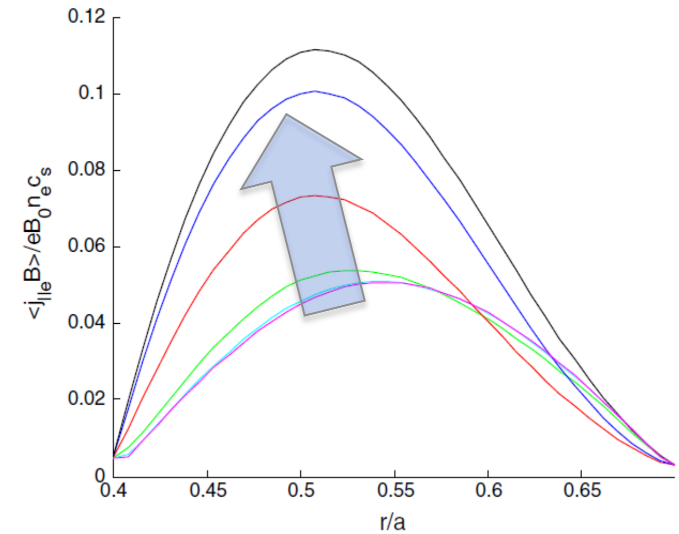


FIG. 4 (color online). The radial profile of the electron current for: no turbulence (magenta line), $\nu_e^* = 10^{-1}$ (cyan line), $\nu_e^* = 10^{-2}$ (green line), $\nu_e^* = 10^{-3}$ (red line), $\nu_e^* = 10^{-4}$ (blue line), and $\nu_e^* = 0$ (black line). The amplitude of the turbulent fluctuations was assumed to be $\langle|e\delta\phi/T|\rangle \approx 5 \times 10^{-3}$.

McDevitt, Tang, & Guo, PRL 111, 205002 (2013)

Tearing Mode Analysis and Momentum Transport

Scientific Achievement

- New method for calculating tearing mode inner layer profiles with various tearing layer physics (based on variational principles with Pade' approximants) developed and benchmarked with known results
- Forces and torques on layers of driven tearing modes

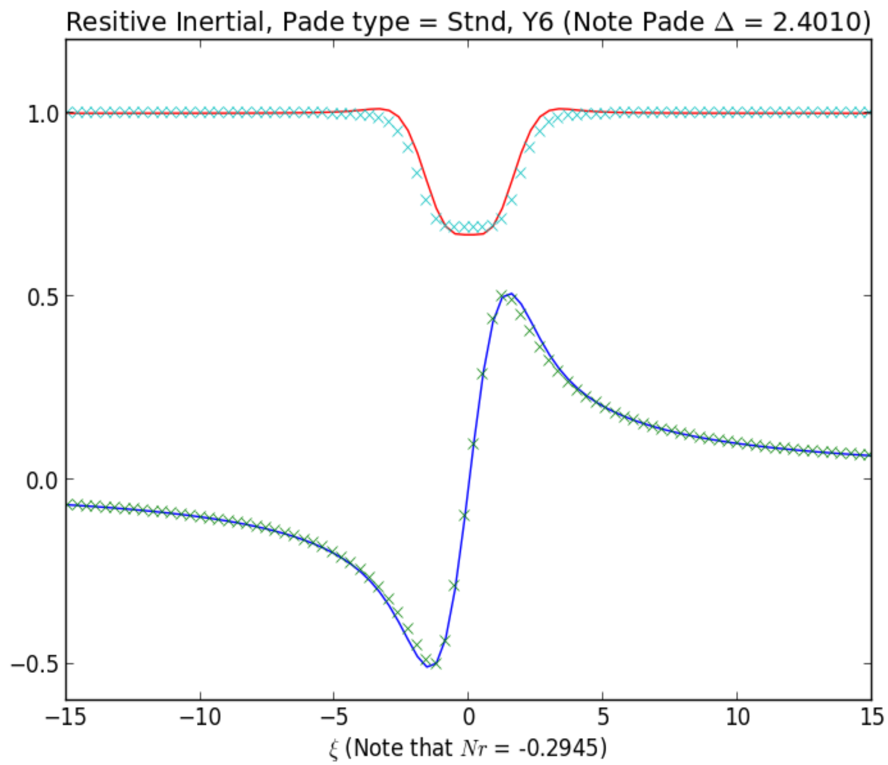
Significance and Impact

- Allows simple treatment of tearing layers with physical effects such as rotation shear, pressure, diamagnetic effects, non-constant-psi.
- Calculates forces on tearing layers and torques across layers, to be used with neoclassical toroidal viscosity (NTV) for momentum transport calculations

Research Details

- Expresses tearing mode eigenfunction in Pade' approximant form and minimizes a variational principle for the layer.
- Calculates forces on a tearing layer (Maxwell force) in the presence of velocity shear, in various regimes of the tearing mode. Major contributions to momentum transport in toroidal devices

A.J. Cole and J. M. Finn, *Phys. Plasmas* March 2014, Vol.21
A.J. Cole, J. M. Finn, C. C. Hegna, and P. W. Terry, in final preparation for submission to Phys. Plasmas.



Pade' approximants: even and odd parts of the streamfunction f calculated numerically and by Pade' approximants with tearing layer variational principle.

Control of linear modes in cylindrical resistive MHD with a resistive wall

Scientific Achievement

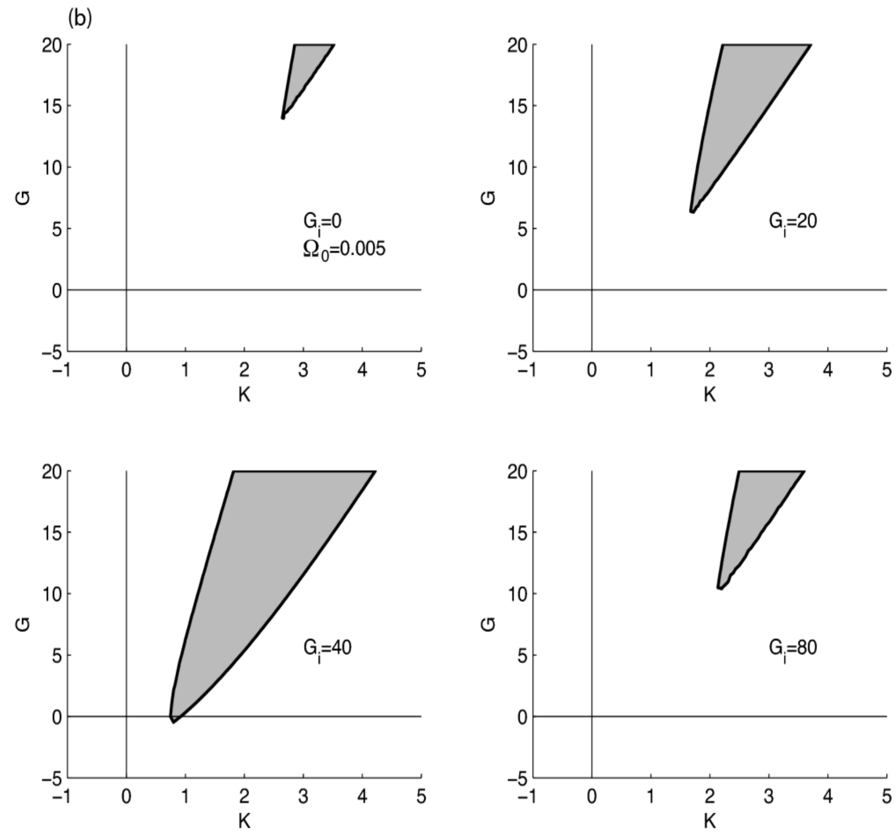
Control of MHD modes in a cylindrical model for a tokamak based on normal and tangential magnetic field sensing.

Significance and Impact

Showed that feedback based on normal plus tangential sensors can stabilize up to the ideal plasma – ideal wall limit. Optimum stability is achieved by using complex gain.

Research Details

Above the resistive plasma - ideal wall limit, plasma rotation is destabilizing and the optimum feedback uses complex gain (phase shift of control coils) to cancel the effect of the plasma rotation.



Stability zones based on the real parts of the gains G and K (normal and tangential). The stable region is maximized when the imaginary G gain balances the effect of the plasma rotation.

J. Finn's contribution to this work was performed at Los Alamos National Laboratory.

Control of linear modes in cylindrical resistive magnetohydrodynamics with a resistive wall, plasma rotation, and complex gain', D. P. Brennan and J. M. Finn, *Phys. Plasmas* **21** , 102507 (2014).

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Deuterium Retention, Thermal Conductivity, and Yield Strength of Plasma Treated Tungsten with and without Ion Irradiation Damage

Scientific Achievement

Radiation induced defects are found to enhance H-D isotope exchange efficiency; increase yield strength and hardness; and decrease thermal conductivity of first wall candidate material W.

Significance and Impact

The nano-scale characterization techniques are developed to study deuterium retention, thermal conductivity, and hardness of plasma exposed tungsten with and without prior ion irradiation damage.

Research Details

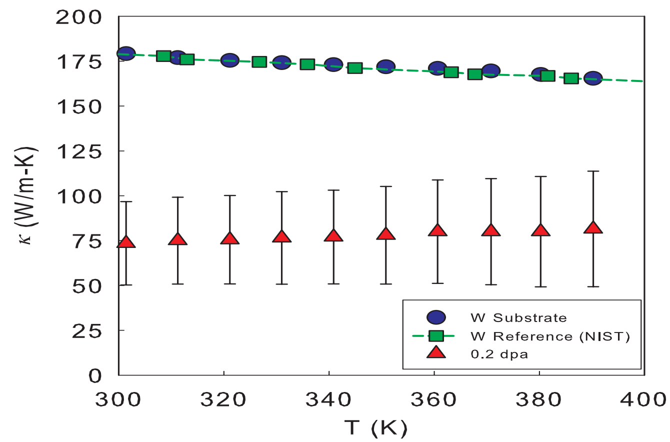
- Nuclear reaction analysis, D(^{3}He,p)^{4}He, was applied to measure deuterium depth profiles in W several microns below the surface. Ion damage was found to increase deuterium trapping sites and also promote H-D isotope exchange efficiency.
- 3-ω method was developed to measure thermal conductivity of the ion irradiated surface layer (~ 500 nm) on bulk W coupon. Conductivity was found to decrease from ~180 to ~75 (W/m-K) after a very modest damage of only 0.2 displacements per atom (dpa).
- Spherical nanoindentation combined with EBSD and SEM images was developed to measure stress-strain responses of individual grains in ion irradiated W (irradiation depth ~ 500 nm). Average yield strength increases in W from 2.8 to 7.7 GPa after 1 dpa damage.

J.L. Barton et al. J. Nuclear Materials, 438 (2013) s1183

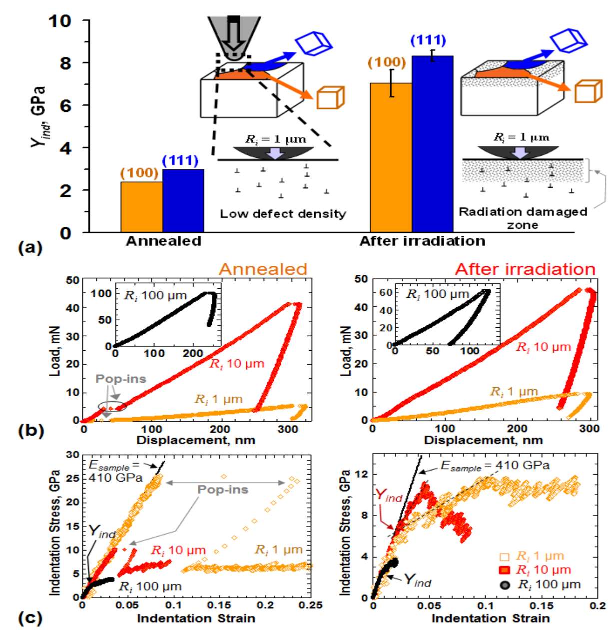
E. Dechaumphai et al. J. Nucl. Mater. 455 (2014) 56

S. Pathak et al. submitted to APL

3-ω thermal conductivity



Spherical Nanoindentation



Metallic Glass Nanostructures Exhibit Enhanced Radiation Damage Tolerance

Scientific Achievement

Mechanical testing of metallic glass nanostructures shows that helium irradiation actually enhances ductility with no sacrifice in strength.

Significance and Impact

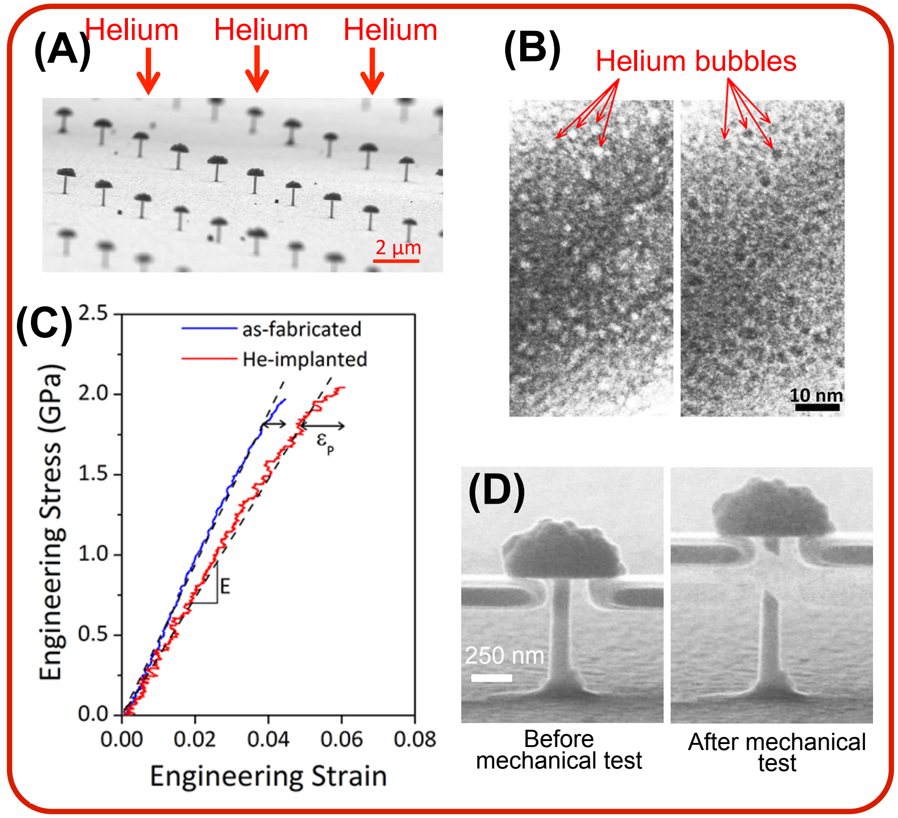
This study reveals an improvement in the mechanical properties of $Ni_{73}P_{27}$ metallic glass upon high levels of helium implantation, which suggests that metallic glasses may be well-suited for irradiation-intensive applications, such as nuclear reactors.

Research Details

- $Ni_{73}P_{27}$ metallic glass nanostructures were fabricated and implanted with helium to create a uniform helium concentration throughout the sample volume
- Transmission electron microscope imaging reveals the presence of ~2 nm helium bubbles as a result of the helium implantation
- Tension testing on helium-implanted and as-fabricated nanostructures shows that helium implantation increases ductility by a factor of two with no sacrifice in strength

R. Liontas, X. W. Gu, E. Fu, Y. Wang, N. Li, N. Mara, and J. R. Greer, "Effects of Helium Implantation on the Tensile Properties and Microstructure of $Ni_{73}P_{27}$ Metallic Glass Nanostructures", Nano *Lett. 14* (2014) 5176-5183

Work was performed at Los Alamos National Laboratory with the Danfysik Ion Implanter and at the California Institute of Technology.



(A) Array of "mushroom-shaped" metallic glass nanostructures with the vertical direction of helium implantation indicated

(B) Helium bubbles resulting from the helium implantation

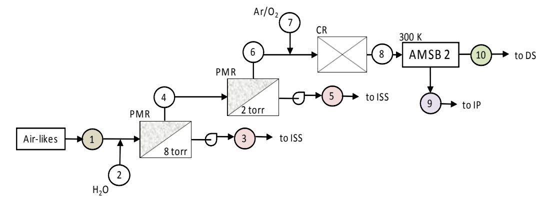
(C) Mechanical data from representative as-fabricated and helium-implanted samples

(D) Typical sample images before and after tension testing

Fuel Cycle R&D

Scientific Achievement

LANL Chemical Diagnosis and Engineering Group has developed a hydrogen processing laboratory (HPL) capability to act as a surrogate for tritium fuel cycle research and development. The capability initially supported the successful conceptual design of the Tritium Exhaust Process (TEP) for the ITER program through the US-IPO.



Process flow diagram example for TEP, ITER

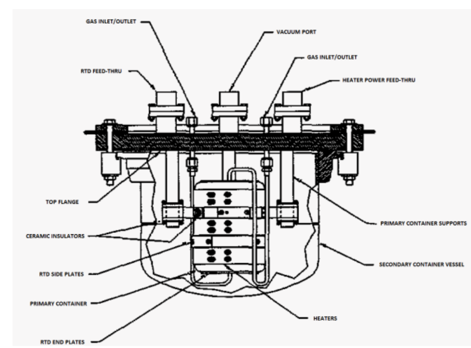
Significance and Impact

HPL capability can support all aspects of a tritium fuel cycle such as impurity separation, isotope separation, and storage and delivery systems designs. Use of hydrogen as a surrogate allows verification processes without the added cost/risk associated with a nuclear facility.

Hydrogen Processing Lab

Research Details

- HPL was recently supported by FES to upgrade hardware and software data collection system, allowing greater reliability with a modern computerized system.
- Current work on the HPL is supporting uranium storage bed design for ITER-IO.
- Later in FY15, team will begin an assessment of historical data collected from the TSTA facility at LANL. TSTA ceased operations in the 1990's; however, there still exist a great deal of data that will be useful to the fusion science community in the performance and design of tritium handling systems



Self-assaying Tritium Accountability and Containment unit for ITER (STACI)

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FINAL FRCHX MAGNETIZED TARGET FUSION EXPERIMENTS

Scientific Achievement

A high density Field Reversed Configuration (FRC) plasma was produced at the Air Force Research Laboratory (AFRL), translated into a metal liner, and cylindrically compressed by liner implosion more than a factor of 10x in radius.

Significance and Impact

Magneto-inertial fusion is a pulsed approach to fusion, combining features of inertial compression with magnetic insulation. Demonstration of successful compression of a magnetized target plasma to kilovolt conditions is a necessary & key physics step.

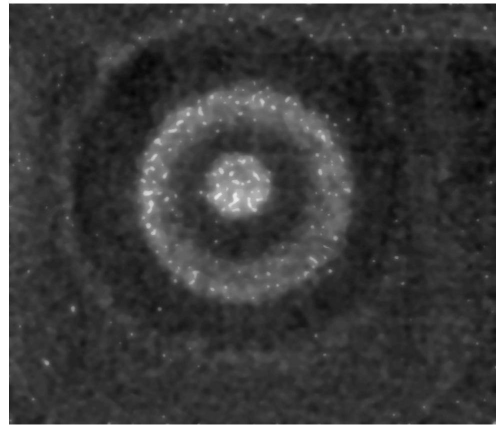
Research Details

LANL, AFRL, UNM, and UNR researchers built the FRCHX compression experiment and conducted a series of experiments to prepare for integrated plasma compression shots.[1,2]

A final compression test was conducted in Oct. 2013. Soft x-ray images showed the FRC was compressed to < 0.5 cm diameter (~10 x compression), but the plasma was cold (~ 300 eV based on neutron yield). This was the highest density FRC plasma ever created.

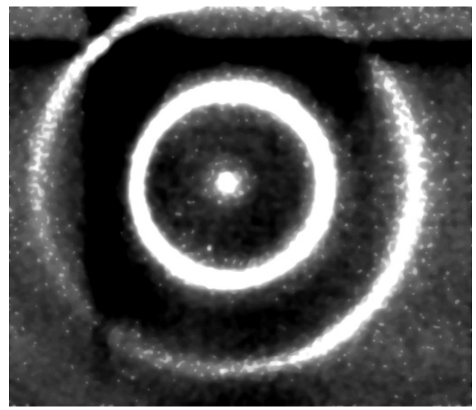
We learned that a plasma target lifetime equal to the compression timescale, is inadequate. The plasma temperature did not increase until the final stage of the compression, because initial compressive heating was too weak (relatively) until the last few microseconds.

Axial soft x-ray images during FRCHX compression shot



Frame 4 @13.8 μsec.

Plasma has entered the imploding liner. The first circle is the FRC direct image. The second ring of light is a wall reflection on the quartz tube closer to the x-ray pinhole camera. This also provides information on the length of the FRC.



Frame 9 @23.8 μsec.

Near time of stagnation (peak compression). Object size is at or below the diagnostic resolution limit (0.5 cm). The FRC is also shorter in length, as expected. However, light levels were much dimmer than expected.

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Laboratory investigation of magnetized collisionless shocks

Scientific Achievement

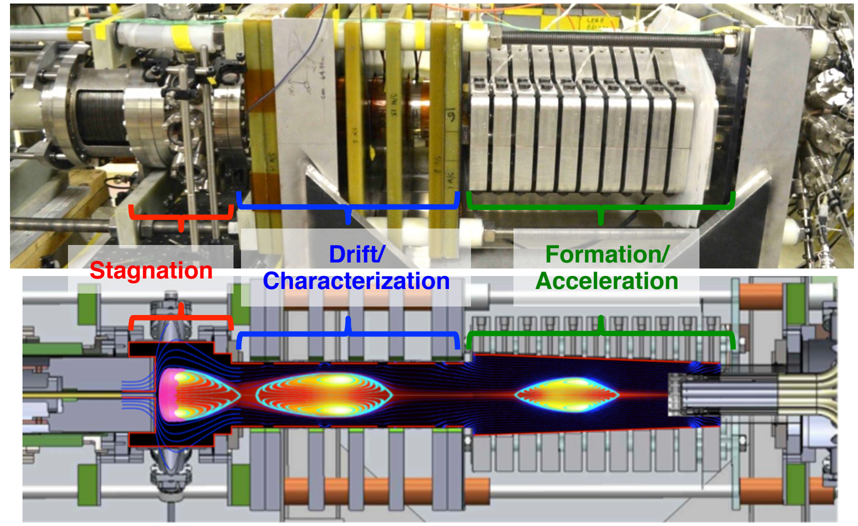
We are studying the physics of magnetized collisionless shocks in cosmically relevant dimensionless parameter regimes. Variable plasma Mach number, collisionality, and stagnation geometry allow for sub and super-critical shocks at perpendicular, parallel, and oblique magnetic field angle.

Significance and Impact

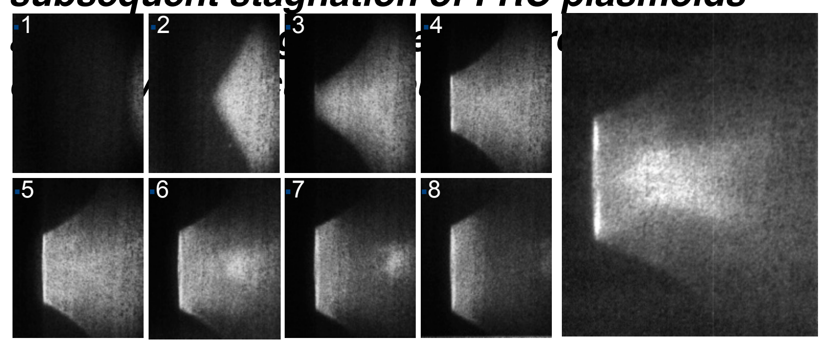
Magnetized collisionless shocks are common throughout the cosmos, but differ fundamentally from hydrodynamic shocks. They exhibit transition length and time scales much shorter than can arise due to Coulomb collisions and are thought to generate non-thermal distributions that can accelerate particles to cosmic-ray energies. Creation of these conditions in the laboratory has historically proven elusive.

Research Details

- Improved FRC formation has resulted in higher Mach numbers and lower collisionality then previously possible.
- First experimental measurements of highly supersonic magnetized stagnating flows in dimensionless parameter regimes similar to Earth's bow shock.
- First data with novel pulsed polarimetry technique to simultaneously measure f_e (provides n_e, T_e) and **B•k** optically within plasma (R. Smith, Univ. Washington).
- Distinct differences seen in structure, density, and ramp between collisional and collisionless stagnation.
- Observed collisionless density enhancement much greater than collisional/hydrodynamic shocks ($\rho_1 \approx 10\ \rho_o$).



The Magnetized Shock Experiment (MSX) produces shocks through acceleration and subsequent stagnation of FRC plasmoids



A range of visible emission structures are observed during stagnation. (Hadland camera provided by DOE 2010 ARRA stimulus funding)

This work was performed at Los Alamos National Laboratory

T.E. Weber, T.P. Intrator, *Rev. Sci. Instr.*, 85, 043501 (2014).

T.E. Weber,T.P. Intrator, R.J. Smith, et al., to be submitted to *Phys. Plasmas* (2014).

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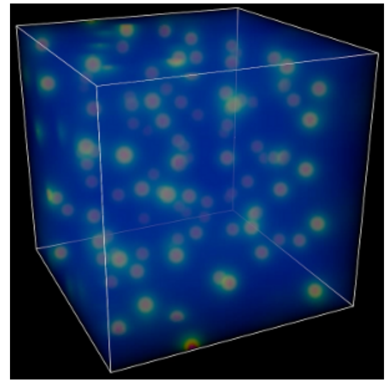
Fast and accurate quantum molecular dynamics of dense plasmas across temperature regimes

Scientific Achievement

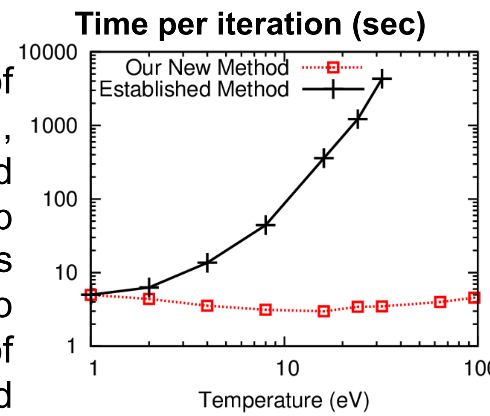
Our new simulation method that allows accurate ab-initio simulations of dense plasmas spanning from low temperature (e.g., liquid metal) to high temperature (e.g., ICF plasma) conditions. This method is significantly less computationally expensive and provides the same accuracy as the established approaches.

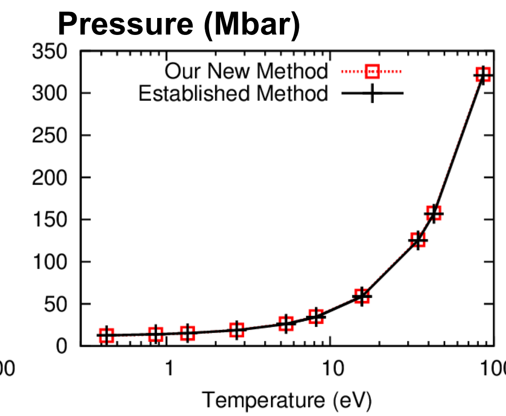


Total electron density of a warm dense plasma of carbon at density 5.7 g/cc and temperature 8.6 eV. Conduction electrons are in blue, tightly bound electrons to nuclei are in red and yellow.

Significance and Impact

A significant challenge HEDP is the determination of the fundamental properties of plasmas (e.g., equation of state, transport properties). Accurate and wide ranging simulations of such plasmas have up to now been severely restricted due to the enormous computational expense of established ab-initio methods. Our method allows for characterization of HEDP systems over much broader temperature and density regimes than previously accessible.





(Left panel) Prohibitive temperature scaling of established methods is shown, whereas our method extends to all temperatures without increased cost.

(Right panel) Pressure results for deuterium at 4 g/cc show excellent agreement between the computationally expensive established methods and our new fast and accurate method.

Research Details

- Quantum molecular dynamics is used to determine system properties.
- Approach replaces expensive wave-function based-calculations by a true density functional approach.

Work was performed at Los Alamos National Laboratory.

T. Sjostrom and J. Daligault, Phys. Rev. Lett. 113, 155006 (2014)

U.S. DEPARTMENT OF ENERGY | Office of Science

Los Alamos NATIONAL LABORATORY EST. 1943

Large scale kinetic plasma simulation of laser-speckle interaction in nonlinear optical systems as a platform for study of self-organization phenomena

Scientific Achievement

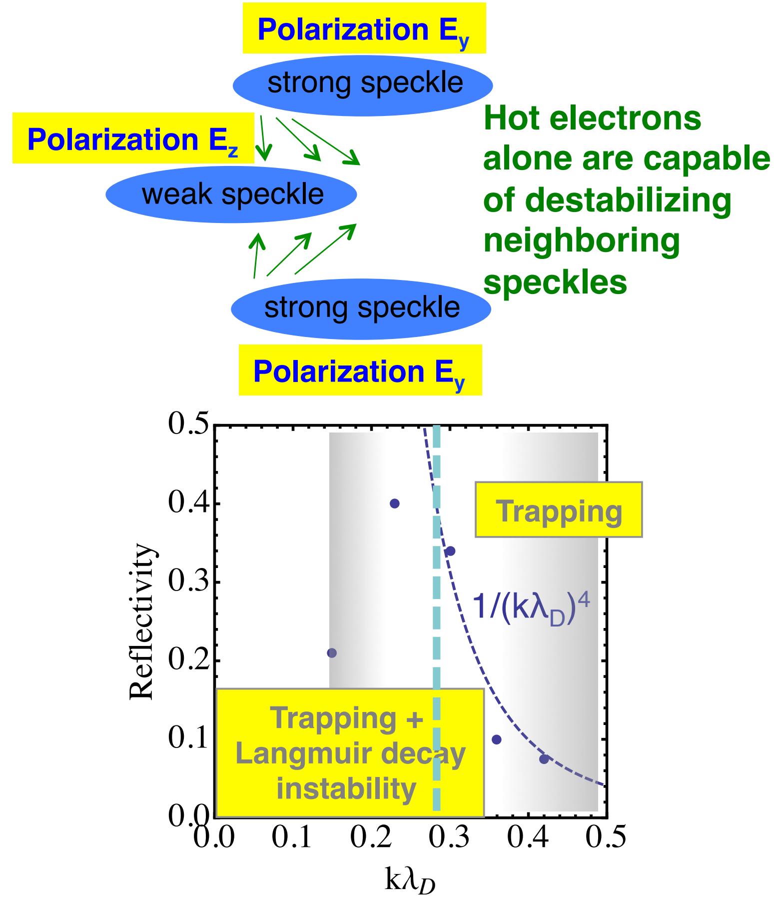
With Petaflop-class supercomputers and state-of-the-art first-principles computer simulations, scientists at LANL advanced the understanding of how laser speckles in a large laser beam, as in HEDP experiments at the Omega and NIF facilities, exhibit self-organization in Stimulated Raman Scattering (SRS)

Significance and Impact

Our project supports the understanding of the nonlinear optics and self-organization of laser-plasma systems and enabled a critical assessment of a novel means of controlling SRS in the nonlinear, kinetic regime

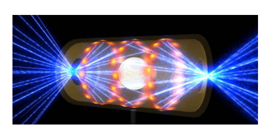
Research Details

- Aggregates of laser speckles exhibit *emergent behavior* through an exchange of particles and seed waves. An intense speckle “de-stabilizes” its neighboring speckles, resulting in enhanced emission of particles and waves from these speckles back to the original speckle, thus affecting its behavior nonlinearly and nonlocally
- Speckle self-organization in 3D ensembles of speckles has been found to be robust – consistent with recent experimental results



Self-organization in SRS: *(Upper panel) Large-scale 3D simulations show robust coupling among speckles (Lower panel) SRS reflectivity decreases with increasing wavenumber $k\lambda_D$ because Landau damping increases and speckle coupling decreases (hot electron flux reduces and SRS sidescatter angle decreases). The speckle coupling determines the greatest SRS risk to be when $k\lambda_D$ ~ 0.2 to 0.3*

Yin et al., Phys. Plasmas **20**, 012702 (2013);
Yin, et al., Physics of Plasmas **21**, 092707 (2014);
B. Albright, L. Yin, B. Afeyan, Phys. Rev. Lett. **113**, 045002 (2014) .



Los Alamos NATIONAL LABORATORY

Exploring the Theoretical Similarities between Quark-Gluon Plasmas and Warm Dense Matter

Scientific Achievement

- The most precise molecular dynamics (MD) simulation of transport coefficients (η*) plasma in the Γ ~ 1-10 regime. We constructed a semi-analytic theory that describes MD data in this regime (See Fig. 1)
- We evaluate the stopping power dE/dx of electron-positron and quark-gluon plasmas for heavy fermions, employing novel field-theoretic techniques and the stress-energy tensor of the plasma (See Fig. 2)

Significance and Impact

Our project advances the understanding of warm dense matter (WDM) in the coupling regime the Γ ~ few. Wide range of applications – from imploding ICF capsules to the core of Jovian planets and quark-gluon plasmas (QGPs). Leverages the close connection between strongly-coupled electron-ion and quark-gluon plasmas.

Research Details

We employ state-of-the art analytic and numerical simulation techniques to describe plasma response

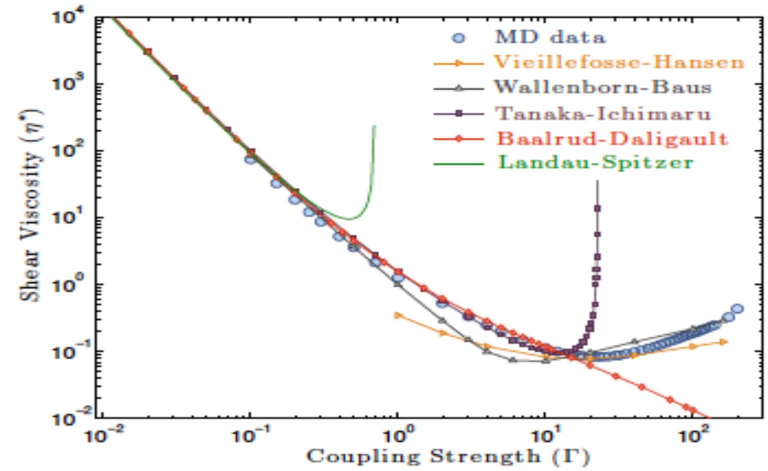


Figure 1. Comparison of MD results for the shear viscosity coeffcient with corrected Landau-Spitzer prediction, the theory of Vieillefosse-Hansen, the kinetic theories of Wallenborn-Baus and of Tanaka-Ichimaru, and the effective potential theory of Baalrud-Daligault.

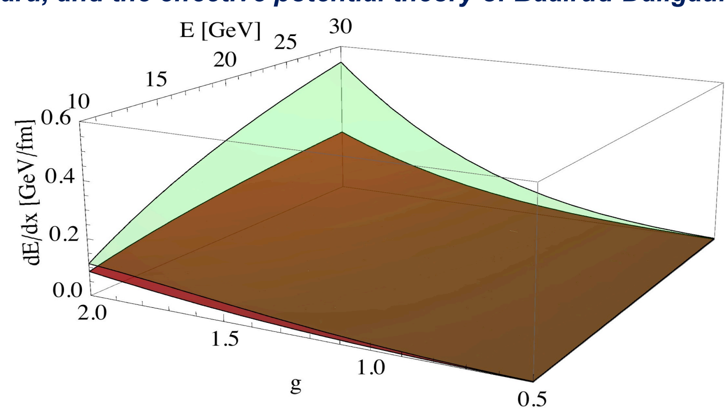
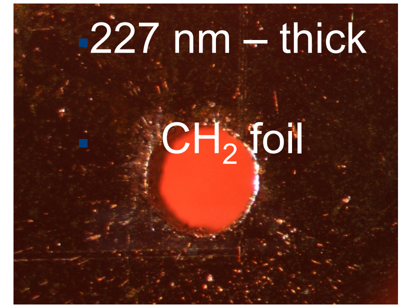


Figure 2. A three-dimensional representation of collisional energy loss for charm (green surface) and bottom (red surface) versus energy E and coupling g. We have chosen M_c = 1.5 GeV and M_b = 4.5 GeV, respectively, a constant temperature T = 250 MeV and N_F = 3 as typical for many phenomenological applications.

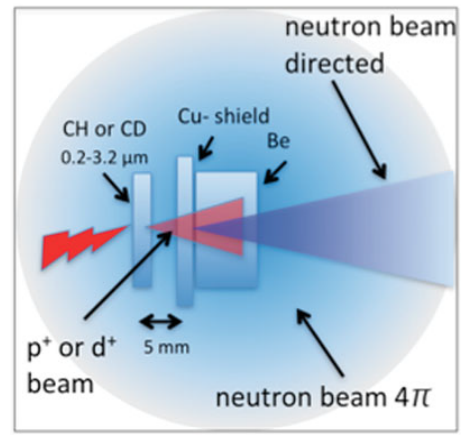
S.D. Baalrud and J. Daligault, Phys. Plasmas 21, 055707 (2014)
J. Daligault, K.O. Rasmussen, S.D. Baalrud, Phys. Rev. E 90, 033105 (2014)
R. B. Neufeld, I. Vitev and H. Xing, Phys. Rev. D 89 (2014) 096003;
J. Huang, Z.-B. Kang, I. Vitev, Phys. Lett. B726 (2013) 251-25.

Record laser-driven neutron-beam generation promises to enable important applications & scientific capabilities



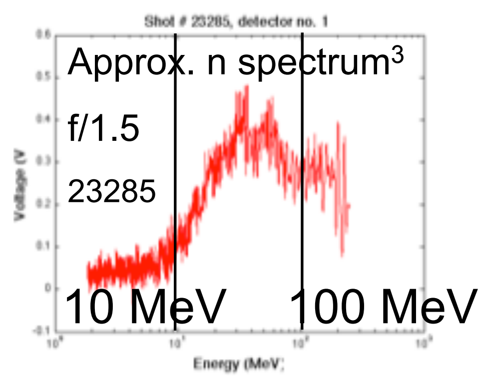
Scientific Achievement

- Novel ion-acceleration mechanism Break-out Afterburner (BOA)[1], discovered computationally at LANL, leads to record proton energies and conversion efficiency[2] demonstration with 150 TW sub-ps laser at LANL Trident facility
- Use of BOA-generated deuterium beams & Be converter leads to record neutron generation[3] : > 10^{10} neutrons in ~ 1 sterad, in ~ 1ns bunch, energies up to 150 MeV.



Significance and Impact

- Bright, safer neutron source enables new applications, e.g.:
- Detect shielded nuclear material in single shot (high throughput)
- Transient material damage study (> 100 n/mm^2/ns @ 1 cm away)
- Radiography, temperature probe via NRS, astro-relevant nuclear physics …



Research Details

- BOA operates in novel regime of relativistic transparency first observed[4] @ Trident -> volumetric interaction of laser with dense, relativistic plasma (γ_e~ 50)
- Laser target is ~ 250-650 nm thick free standing deuterated plastic foil
- Laser pulse: intensity ~ 3-10 x 10^{20} W/cm^2, ~ 0.6 ps, 1μm, ~ 80 J
- Already used to detect and differentiate depleted and enriched U samples

[1] Yin et al., Phys. Plasmas **14,** 056706 (2007);
[2] Hegelich et al., PRL Subm. (2014);
[3] Roth et al., PRL **110**, 044802 (2013); D. Jung et al., Phys. Plasmas **20**, 056706 (2013); highlighted in Nature, APS, Physics World, LANL press release 6/4/2013 & others
[4] Palaniyappan et al., Nature Physics **8**, 763 (2012)

Los Alamos Portfolio

Inertial Confinement Fusion

Magnetic Fusion Energy

High-Energy-Density Laboratory Plasmas

General Plasma Science

Work supported by:

NNSA (Science Campaigns, LDRD, NNSA Labs)

DOE Office of Science (FES)

ITER Organization

Fast Magnetic Reconnection with Large Guide Fields

Scientific Achievement

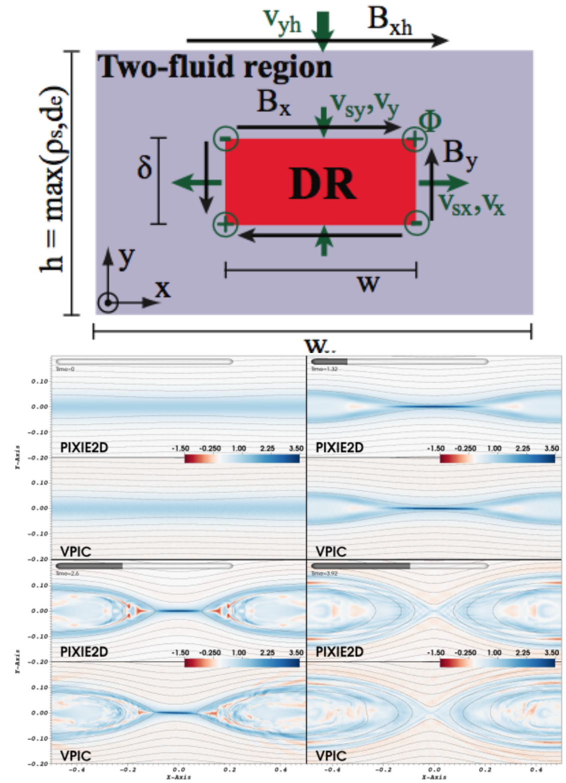
We have developed a fluid model and a corresponding analytical theory predicting that 2D magnetic reconnection with large guide fields is fast, i.e., occurs at a few percent of the Alfvènic rate regardless of the system size, collisional dissipation levels, and presence of fast dispersive waves, in agreement with kinetic simulations.

Significance and Impact

This resolves a long-standing disagreement between fluid and kinetic simulations and disproves a popular paradigm that fast dispersive waves are required for fast reconnection. Our fluid model can accurately describe magnetic reconnection in solar corona and magnetic confinement devices at a greatly reduced computational cost.

Research Details

- The fluid equations evolve plasma flow vorticity and magnetic flux and include electron diamagnetic effects (sound Larmor radius ρ_s), electron inertia (skin depth d_e), as well as plasma resistivity and electron viscosity.
- The analytical theory relates the reconnection rate E_z, the kinetic length scales ρ_s and d_e, and a geometry of the diffusion region (where magnetic field decouples from plasma flow).



(Upper panel) Structure of the diffusion region in 2D magnetic reconnection. Electron and ion motions uncouple in purple (two-fluid) region, magnetic field uncouples from plasma motion in red (dissipation) region. (Lower panel) Plasma current profiles (color map) and magnetic fluxes (contours) from fluid (PIXIE2D) and kinetic (VPIC) simulations for Harris-sheet reconnection problem.

Work performed at Los Alamos National Laboratory.

A.Stanier, A.N.Simakov, L.Chacon, W.Daughton, submitted to *Physics of Plasmas (2014)*.

Dynamics of Interacting Magnetic Flux Ropes

Scientific Achievement

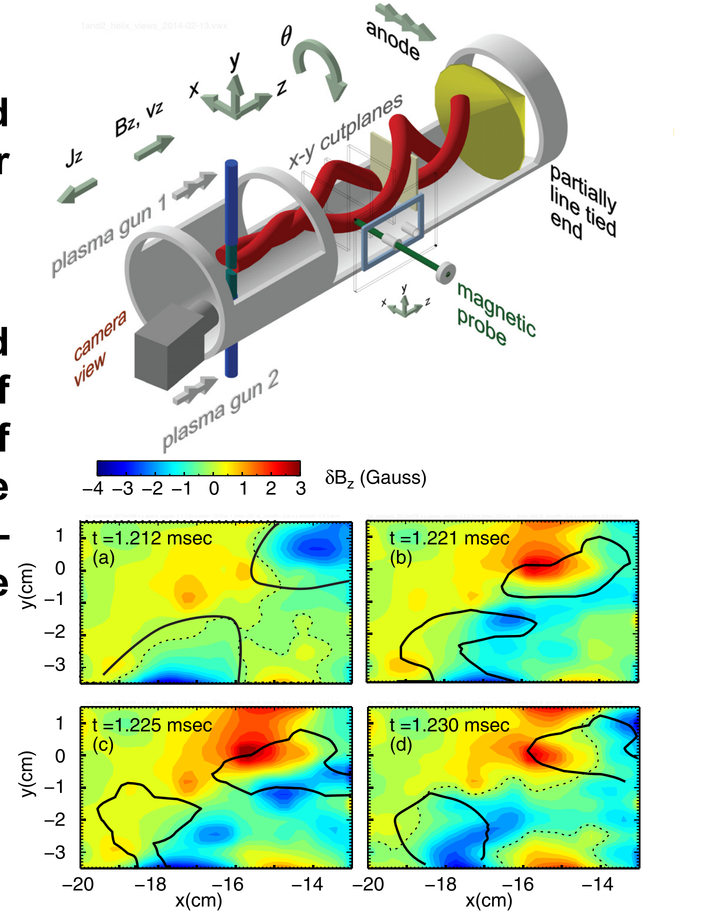
Demonstration that interacting magnetic flux ropes can lead to the generation of magnetic fields driven by the ion shear flow in the interaction region

Significance and Impact

Flux ropes are ubiquitous magnetic structures in space and astrophysical plasmas. It is well known that the interaction of flux ropes can give to reconnection and dissipation of magnetic field. However, this experiment showed that the interaction can also give rise to magnetic field generation – with a specific pattern that may be observable in future spacecraft observations.

Research Details

- **Ion and electron flows along with magnetic field were measured over a 3D volume**
- **Structure of each flux rope was characterized by a generalized screw pinch equilibrium**
- **Simple model developed to explain the generation of magnetic field due to the flux rope interaction**



RSX Experiment: Schematic of the Reconnection Scaling Experiment (RSX) and measured magnetic field pattern generated due to flux rope interaction.

T.P. Intrator, L. Dorf, X. Sun, Y. Feng, J. Sears and T. Weber, Physics of Plasmas 21, 042109, 2014

Discovery Plasma Science Using Merging Supersonic Plasma Jets

Scientific Achievement

Head-on-merging plasma jets (of an argon/impurity mixture) have provided fundamental time- and space-resolved data on plasma collisionality, ionization time scales, shock formation, and interfacial instability evolution.

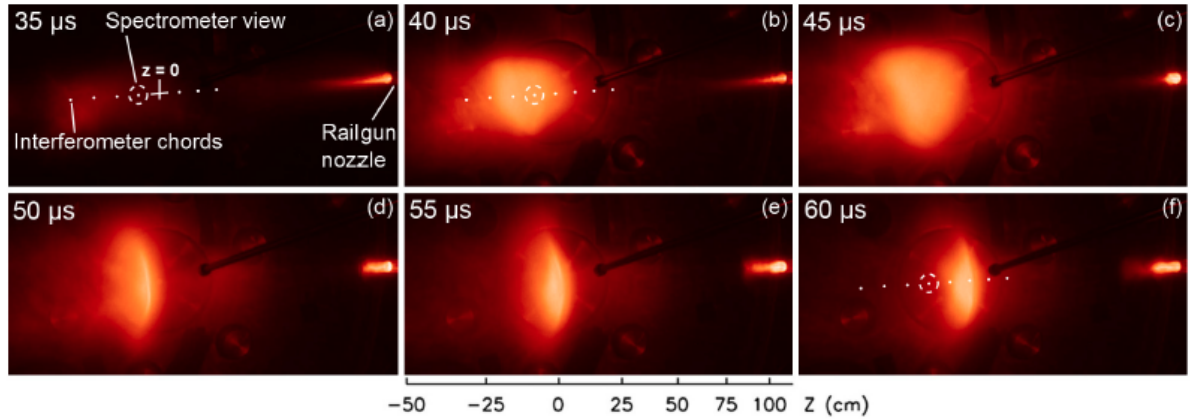
Significanceand Impact

Data are uniquely valuable for validating plasma-collisionality, ionization, shock-handling, and viscosity models that are used in computer-code calculations of plasma-astrophysics phenomena or HEDLP/ICF experiments, especially in the presence of complex plasma equation of state.

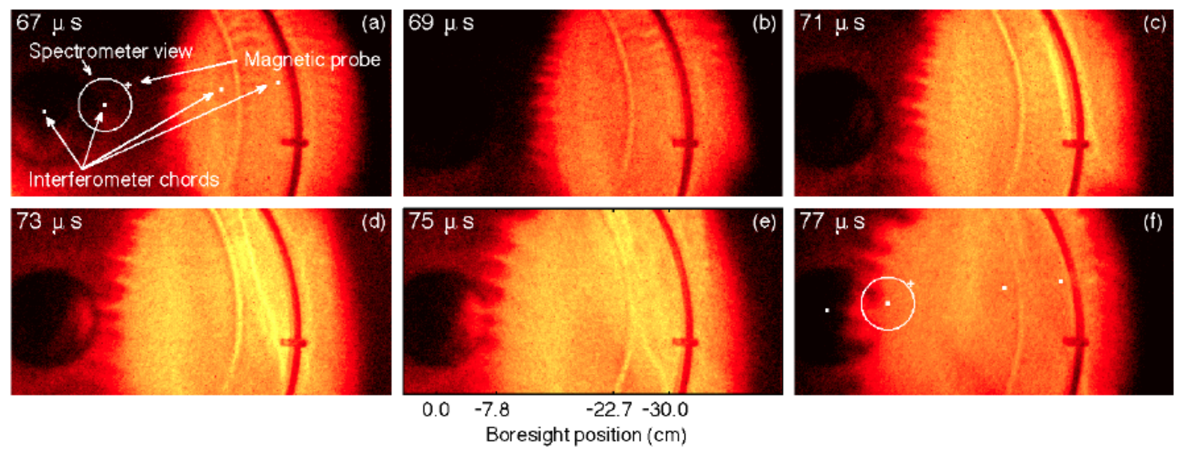
Research Details

Observation of ionization-mediated transition from collisionless inter-penetration to collisional stagnation.[1]

Observation of Rayleigh-Taylor instability evolution toward longer wavelengths in a plasma regime expected to provide magnetic and viscous stabilization.[2]



Fast-camera images (from separate shots) of head-on-merging supersonic plasma jets progressing from (a) interpenetration to (b) rising ionization level to collisional stagnation (c–d) to collisional shock formation (e–f). Plasma jets propagate from left and right, respectively, and interact just to the left of center.[1]



Fast-camera images (from a single shot) of a plasma jet (bright region, incoming from right) colliding with a stagnated plasma (dark region, left) embedded within an applied B-field (portions of in-chamber Helmholtz coils are visible). Fingers evolve toward longer wavelengths at decelerating interface, consistent with Rayleigh-Taylor instability evolution in the presence of magnetic and/or viscous stabilization.[2]

[1] **A. L. Moser & S. C. Hsu, invited talk at the 56th APS-DPP meeting; http://arxiv.org/abs/1405.2286.**

[2] **C. S. Adams, A. L. Moser, and S. C. Hsu, to be submitted to Phys. Rev. Lett. (2014).**

Research supported by the LANL LDRD program; experimental facility constructed under sponsorship from DOE FES.

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