



Lawrence Livermore National Laboratory (LLNL) pairs multidisciplinary science and engineering with world-class experimental and computing resources to develop technical solutions to the most pressing national security problems of our time.



Livermore's defining responsibility is ensuring the safety, security and reliability of the nation's nuclear deterrent without nuclear testing. As part of the Stockpile Stewardship Program, LLNL researchers are tackling the grand challenge of understanding the scientific details of nuclear weapons performance through nonnuclear tests and experimentally validated computer simulations.

LLNL's national security mission is broader than stockpile stewardship, as dangers from nuclear proliferation and terrorism to energy shortages and climate change threaten both national security and global stability. Livermore's multidisciplinary science and engineering are being applied to achieve breakthroughs for counterterrorism and nonproliferation, defense and intelligence, domestic security and energy and environmental security.

Lawrence Livermore offers fellowship opportunities in the following research areas:

Pulsed power science and engineering

Pulsed power is a critical technology at LLNL, supporting a broad range of applications relating to national security and fundamental science. The pulsed power systems at LLNL range from low-energy ultra-fast pulsers used in diagnostic systems, to explosively-driven flux compression generators, to the 400 million joule pulsed power driver for the National Ignition Facility (NIF) - the world's largest laser system. For more than 50 years LLNL researchers have been actively researching, developing, designing, instrumenting and executing experiments on pulsed power systems for multiple programs to support high-energy-density physics experiments in support of the U.S. nuclear deterrent and other national security missions.

A number of state-of-the-art radiography systems are in development for use at LLNL, in Nevada and other locations in the nuclear weapons complex. These accelerator systems require advanced pulsed-power design, high-voltage engineering, and solid-state pulsed-power design. LLNL researchers are developing high-current (> 80 million amperes) flux compression generators in support of stockpile stewardship, which requires extremely high-current engineering, computational magneto-hydrodynamics (MHD), high-explosive initiation physics and high-voltage switch design. Pulsed-power engineers are also exploring novel applications of

B-fields in high-energy-density physics experiments on NIF using electromagnetic analysis and computational MHD techniques.

Radiation magneto-hydrodynamics/nuclear astrophysics

Livermore physicists are currently studying several challenging problems in astrophysics, such as the effects of magnetic fields and turbulence in star formation, and the slow nucleosynthesis process, or S-process. Livermore physicists are also tackling challenges related to inertial confinement fusion with NIF experiments. Exploration of these multi-physics problems lend an improved understanding of our universe and are also relevant to LLNL's stockpile stewardship mission. To tackle these problems, LLNL physicists are developing validated modeling and simulation tools that accurately capture the relevant physics processes in action.

LLNL researchers are developing numerical methods for solving the equations of radiation-magneto-hydrodynamics (RMHD) in high energy environments for these applications in astrophysics and inertial confinement fusion. Such methods are essential for the investigation of a variety of multi-dimensional, strongly coupled, and highly dynamical astrophysical and fusion systems. Of particular interests are problems associated with the nucleosynthesis of star formation, stellar disruption events, galactic enrichment, black hole accretion disks, and also by problems associated with the chemical and RMHD evolution of the intergalactic medium, the creation of complex molecules, and the formation of molecular clouds and proto-planetary condensation, as well as those for inertial confinement fusion. These problems require high-fidelity, self-consistent, and fully-coupled modeling of a variety of complex physical models encompassing many decades of scale in both time and space. Interests also include development and improvement of advanced numerical methods for RMHD and the challenges introduced by the use of arbitrary Lagrangian-Eulerian (ALE), adaptive mesh refinement (AMR), and adaptive high-order interpolatory representations.

One of our great scientific challenges is understanding how elements form. This process, called nucleosynthesis, occurs at extreme stellar temperatures and pressures, making it difficult to simulate in the laboratory. The conditions produced by NIF experiments, however, are well matched to the conditions that exist in stars in several phases of their evolution, making NIF is an unmatched tool for exploring nuclear physics. For instance, elements heavier than iron are formed either slowly, during the life of a star, or rapidly, during a star's last few seconds. NIF can realistically replicate the hot, dense stellar plasma where both processes occur in nature unlike any other experimental platform.

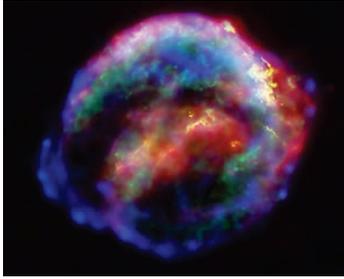


Figure 1: Remains of a supernova, called Kepler's supernova remnant (NASA JPL, <https://www.jpl.nasa.gov/spaceimages/details.php?id=pia06907>). Supernova, as shown here, are a sources of collisionless shocks.

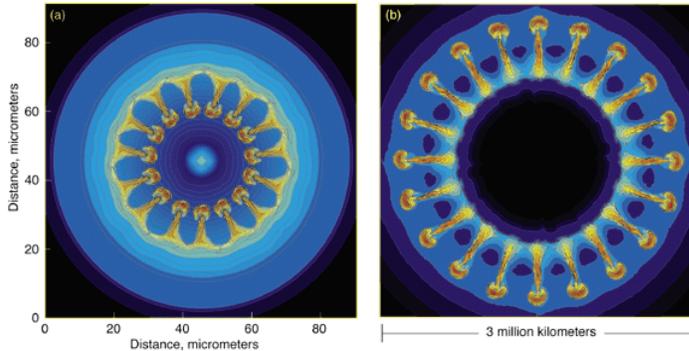


Figure 2: Striking similarities exist between hydrodynamic instabilities in (a) inertial confinement fusion capsule implosions and (b) core-collapse supernova explosions. [Image (a) is from Sakagami and Nishihara, *Physics of Fluids B2*, 2715 (1990); image (b) is from Hachisu et al. *Astrophysical Journal* 368, L27 (1991).]

LLNL researchers have also explored the feasibility of using NIF to study relativistic and non-relativistic collisionless shocks in the laboratory, and to study the scalability and relevance of such laboratory experiments to astrophysical shocks. Collisionless plasmas have highly important astrophysical implications, particularly with plasma instabilities, the creation of pervasive (cosmological) magnetic fields, and (supernova) shock transitions into thin plasmas. Collisionless shock modeling and simulation capabilities are also important for capturing the effect of high altitude nuclear explosions (HANE). In particular, studies suggest sensitivity of electronic infrastructure to some types of electromagnetic pulse (EMP), and other types of EMP have the potential to threaten power distribution systems or even satellite function.

The main challenge of creating collisionless shocks using lasers, and studying their structure and evolution, is the small spatial scale and short duration of laser-created plasmas. To be collisionless, the plasma must have long coulomb mean-free-paths compared to the plasma scale height, requiring low density and high temperature. Yet it must also have collisionless mean-free-paths (related to the plasma skin depth and gyroradii) short compared to the plasma size in order to form a shock, requiring high density and strong magnetic fields. These two requirements are often in conflict. Even when they are not, the small space-and-time domain of laser-created plasmas means that the collisionless shock can only exist for a brief time and propagate a short distance before these conditions are violated, making the detection and diagnosis of the shock extremely difficult and challenging.

Atomic physics and visible/UV/x-ray spectroscopy

Detailed atomic physics modeling of complex ions directly impacts our understanding of complicated plasmas, from stellar objects to Inertial Confinement Fusion (ICF) hohlraums. Atomic physics work can loosely be broken into local thermodynamic equilibrium (LTE) and non-local thermodynamic equilibrium (NLTE) studies.

For LTE studies, in which system populations can be described with statistics, LLNL researchers are exploiting exascale computing capabilities by writing new opacity codes with much more detailed atomic energy levels and physics. These codes are used to solve outstanding questions in astrophysics, such as radiation transport in the sun and the iron opacity problem. The latter refers to the result of recent experiments at the Sandia Z machine that measure an iron opacity that can explain radiation transport in the sun but is completely outside the error bars of the best current opacity models.

For NLTE studies, system populations and resulting X-ray spectra are determined by solving rate equations between millions of levels. Getting the NLTE physics right is crucial to developing a predictive hohlraum model for ICF experiments, in particular the region where laser energy is converted to x-ray energy. LLNL researchers are developing techniques to incorporate best NLTE models into in-line models in radiation-hydrodynamic codes, and they are taking high quality experimental data across a spectrum of plasma conditions. New analysis techniques involving genetic algorithms and other sophisticated methods are being applied to benchmark the atomic physics codes to this data.

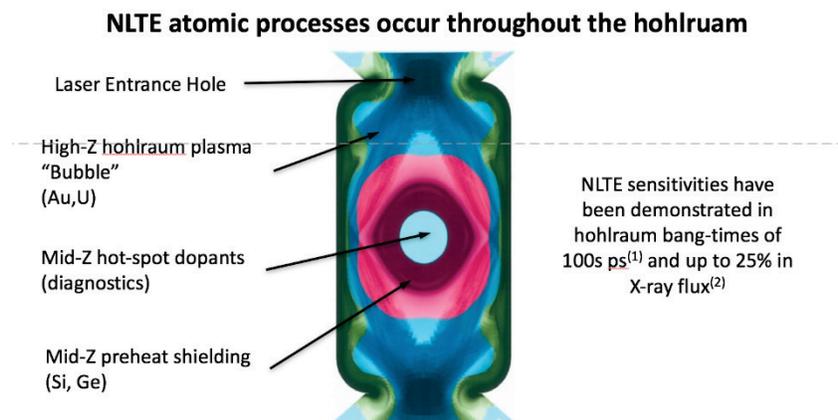


Figure 3

NLTE physics determines radiative properties in HED plasma

Dynamic materials/shock physics

The fundamental properties of materials under extreme conditions is of particular interest in the area of dynamic materials and shock physics. LLNL researchers are investigating high-pressure response of materials, kinetics of phase transitions and plasticity, dynamic response of heterogeneous media, architected structures, and additively manufactured material structure.

Extreme conditions include material response when subjected to one or more of the following: high-pressure (> 100 kilobar), high-temperature (near melt or at ICF conditions), or high-strain-rate (>10⁴ per second).

The goal of this research is to develop predictive material-response models based on closely integrated experiment and theory for materials under dynamic loading conditions. For model validation and physics insight, experimental investigations of the static and dynamic properties of materials under conditions of high-pressure, high-temperature, high-strain and/or high-strain-rate are of particular significance. Interests include the development and application of methodologies to investigate detailed dynamics and evolution of materials under dynamic loading conditions using novel time-resolved diagnostics and high-fidelity control of the drive conditions.

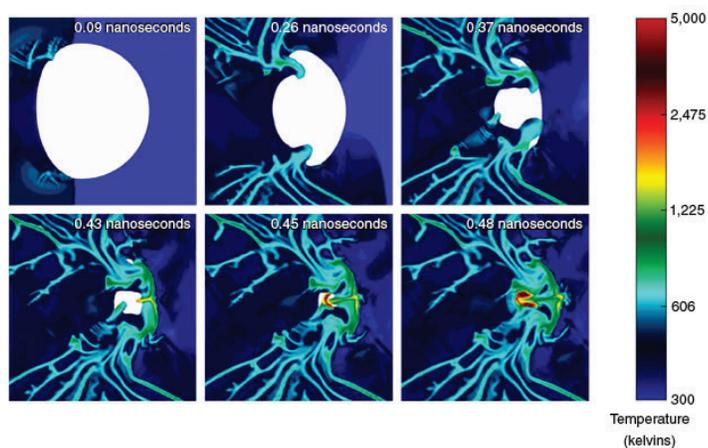


Figure 4: A multiphysics finite-element simulation provides a detailed view of an evolving microscopic pore in the energetic material HMX as the pore is hit by a shock wave and collapses. The evolution illustrates interaction between mechanical deformation (strength) kinetics that result in the shear localizations and chemical kinetics through induced temperature heterogeneity. (Colors indicate temperature.)

<http://aip.scitation.org/doi/10.1063/1.4918538>

Kinetics research is particularly important to the development of predictive material response models at LLNL. A team of LLNL researchers is tackling a long-standing gap in understanding of dynamic materials processes relevant to stockpile stewardship related to phase transformation in materials. How does a material “know” to change phase once it is shocked? How fast or slow does that phase transformation process proceed, and why? And, if experimental measurements are made during this process, how can we definitively extract information about the phase transition kinetics? The LLNL Phase Transition Kinetics team has developed a general theory for nonequilibrium phase transitions based upon an established approach known as “phase field.” Phase field models are mesoscopic in their description of a mixed-phase system and the interface that spatially separates phases. As the phase transition proceeds, heat is transported across the interface and the material volume and sound speed change tremendously. It is in this scenario that the hydrodynamics is perturbed and becomes strongly coupled to the details of the phase transition.

In addition, LLNL investigates the dynamic response of both aging and newly-manufactured materials. This area may connect back into kinetics through the influence of material microstructure on response, whether through nucleation kinetics or other mechanisms.

Interest also exists in materials with engineered intermediate length scales, such as additively manufactured lattice structures or explosive materials with controlled porosity distributions. There are opportunities at LLNL to explore and develop understanding of the dynamic response of such materials.

Accelerator design

Particle accelerators are a fundamental tool of modern science for advancing high-energy and nuclear physics, understanding the workings of stars, and creating new elements. The machines produce high electric fields that accelerate particles for use in applications such as cancer radiotherapy, nondestructive evaluation, industrial processing, and biomedical research, as well as Stockpile Stewardship. Linear induction accelerators are high current particle accelerators developed at LLNL. The flash x-ray (FXR) accelerator located at site 300 is used as a radiography diagnostic for dynamic experiments. This machine has been operating for 35 years and has been continuously upgraded. The most recent upgrade to the machine added the capability of two-pulse radiography.

LLNL is designing next generation accelerators for flash radiography. These accelerators will be powered by solid-state pulsed power in order to provide a user-programmable pulse train of X-rays. LLNL physicists are using end to end simulations to predict the beam performance. LLNL is currently seeking engineers and physicists for multidisciplinary teams to design, prototype, and build these next generation accelerators.

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