FY21 LaserNetUS Program

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UR/LLE is part of the LaserNetUS Collaborative Network established in 2018 and funded by the Department of Energy (DOE) Fusion Energy Sciences (FES) within the Office of Science. Its mission is to advance and promote intense laser science and applications by providing scientists and students with broad access to unique facilities and enabling technologies, advancing the frontiers of laser-science research, and fostering collaboration among researchers and networks from around the world. During FY21, LaserNetUS consisted of ten institutions including Colorado State University, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory (LLNL), SLAC, The Ohio State University, the University of Michigan, University of Nebraska-Lincoln, Institut National de la Recherche Scientifique, the University of Rochester, and the University of Texas at Austin. Through a coordinated annual call for proposals and an independent proposal review panel (PRP) process, the LaserNetUS network makes available a variety of ultrafast, high-peak-power and high-energy, petawatt-class lasers including LLE's four-beam, high-energy and high-intensity OMEGA EP laser to users who do not have regular access to ultrahigh-intensity lasers.

UR/LLE provides an average of four shot days each year on OMEGA EP to LaserNetUS users. Since 2019, 13 projects have been awarded a total of 15 shot days on OMEGA EP, including seven projects from the first two solicitations for shots in Cycle-1 (2019–2020) and Cycle-2 (2020–2021) and six projects from the third solicitation completed during FY21 for experiments in Cycle-3 (2021–2022). During FY21, a total of 29 target shots were successfully conducted over four shot days for three LaserNetUS projects led by scientists from LLNL, Univeristy of California, San Diego (UCSD), and General Atomics (see Table I below). These experiments involved four graduate students and five postdoctoral researchers. FY21 LaserNetUS user experiments are summarized below.

Table I: One LaserNetUS Cycle-2 project and six LaserNetUS Cycle-3 projects were awarded beam time on OMEGA EP for experiments in FY21–FY22. Three projects (shaded cells) were successfully conducted over four shot days during FY21 and the remaining four Cycle-3 experiments with five approved shot days are scheduled for FY22.

Principal Investigator	Institution	Title	LaserNetUS beam-time cycle
Y.-J. Kim*	LLNL	Extreme Chemistry of Synthetic Uranus	2
K. Matsuo*	UCSD	Laser Ablation and Shock Generation as a Function of Laser Pulse Length at an Intensity of 10^{15} W/cm^2	3
M. J.-E. Manuel	General Atomics	Laboratory Study of Quasi-Parallel Magnetized Collisionless Shocks	3
M. Edwards*	LLNL	Reaching an Electron–Positron Plasma with OMEGA EP	3
G. Righi**	UCSD	Understanding Temperature Dependence of Iron Strength at High Pressure with Ramped Compression on OMEGA EP	3

Table I: One LaserNetUS Cycle-2 project and six LaserNetUS Cycle-3 projects were awarded beam time on OMEGA EP for experiments in FY21–FY22. Three projects (shaded cells) were successfully conducted over four shot days during FY21 and the remaining four Cycle-3 experiments with five approved shot days are scheduled for FY22 (continued).

Principal Investigator	Institution	Title	LaserNetUS beam-time cycle
D. Riley	Queen's University, Belfast, Ireland	Recreating Accretion-Powered X-Ray Astrophysical Sources in the Laboratory	3
S. Zhang*	Princeton University	Study of Particle Acceleration in Magnetic Reconnection Using Laser-Powered Coils	3

*Postdoctoral researcher
**Graduate student

Extreme Chemistry in H:C:N:O Mixtures at the Interior Conditions of Icy Planets

Principal Investigator: Y.-J. Kim (LLNL)
Co-investigators: M. Bethkenhagen (École Normale Supérieure de Lyon, Université Lyon); and F. Coppari, S. Hamel, and M. Millot (LLNL)

Synthetic Uranus is a H:C:N:O mixture having a composition similar to the interior of icy planets such as Uranus and Neptune. The IcyPlanetsDAC-EP-21 Campaign on OMEGA EP under the support of the LaserNetUS Program aims at measuring the microstructure of the H:C:N:O ices with *in-situ* nanosecond x-ray diffraction[1] during dynamic compressions. This work expands on our recent discovery of superionic water ice[1–3] and provides new insights into the chemistry (e.g., new bonding, mixing/demixing, polymerization, and precipitation) at the interior pressure–temperature conditions of the icy planets.

We prepared a liquid H:C:N:O mixture with water, ammonia, and isopropanol and documented its optical property at the ambient condition.[4] For laser-driven dynamic compressions, this mixture was loaded into thin sample chambers fabricated with a chemical-resistive polymer and sealed by ablator and window materials. With excellent laser performance and support, we collected 13 system shots in the two-day allocations. Two OMEGA EP beams were stacked to produce a 20-ns drive, and another two beams were focused on a Cu backlighter for generating a 1-ns x-ray emission. At a steady shock state during a shock-wave reverberation, the x-ray diffraction (XRD) pattern of the mixture was recorded using the powder x-ray diffraction image-plate diagnostic. Doppler velocimetry [velocity interferometer for any reflector (VISAR)] was used to track the free surface velocity of the window, which was compared with hydrodynamic simulations for determining pressure–density–temperature conditions of the samples (see Fig. 1).

The ongoing data analysis on the diffraction patterns, surface velocities, and simulations will be used to improve our understanding of the interior structure of the icy planets.

Successful Platform Development Day for MagCShockPar

Principal Investigators: M. J.-E. Manuel (General Atomics); S. Bolaños, A. Bogale, and F. N. Beg (UCSD); and D. Michta and P. Tzeferacos (University of Rochester)

The formation of unmagnetized collisionless shocks has been extensively studied computationally and through laboratory experiments over the last decade[5,6] to study the microphysics of formation and particle acceleration within these structures. However, many collisionless shocks observed in the universe exist within a background magnetic field, which can affect shock formation and particle acceleration. This LaserNetUS Campaign is the first experiment aimed at extending the previous platform into the magnetized regime in a quasi-parallel configuration on the OMEGA EP laser. In contrast to previous unmagnetized experiments, this campaign implemented a thin laser-driven titanium foil within a magneto-inertial fusion electrical system (MIFEDS) coil to create a cold, dense, magnetized "core" plasma. Then, a fast "beam" plasma using laser-ablated titanium impinges on the core in an asymmetric, collisionless interaction where the B field is parallel to the primary flow direction [see Fig. 2(a)]. The interaction was successfully diagnosed using short-pulse proton imaging on radiochromic film (RCF) and angular filter refractometry (AFR).

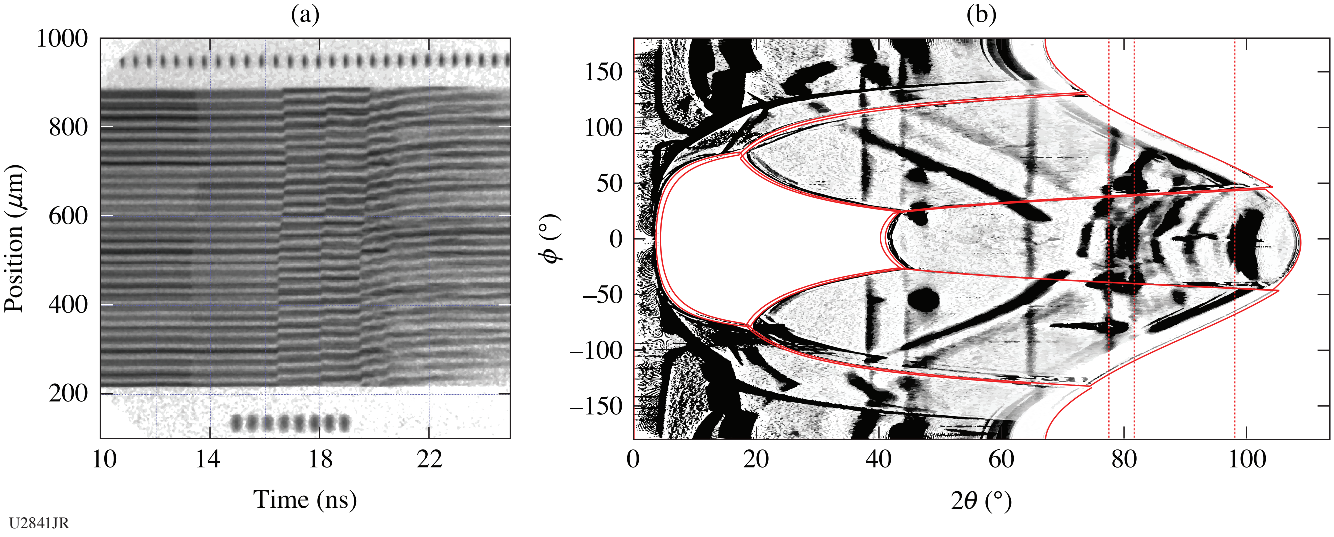

Figure 1
Example of VISAR and XRD data obtained from 50-μm-thick synthetic Uranus mixture at ~280 GPa and ~2300 K on OMEGA EP.

Initial results clearly show the formation of field structures due to the presence of both plasmas and the necessity of the parallel background magnetic field to produce the high-frequency filaments observed in the middle image shown in Fig. 2(b). Analysis of both RCF and AFR data is ongoing, and post-shot simulations are presently being done. A follow-up experiment will be proposed to study the temporal evolution of the observed high-frequency filaments and further characterize the plasma conditions in the interaction to compare with simulations and theory.

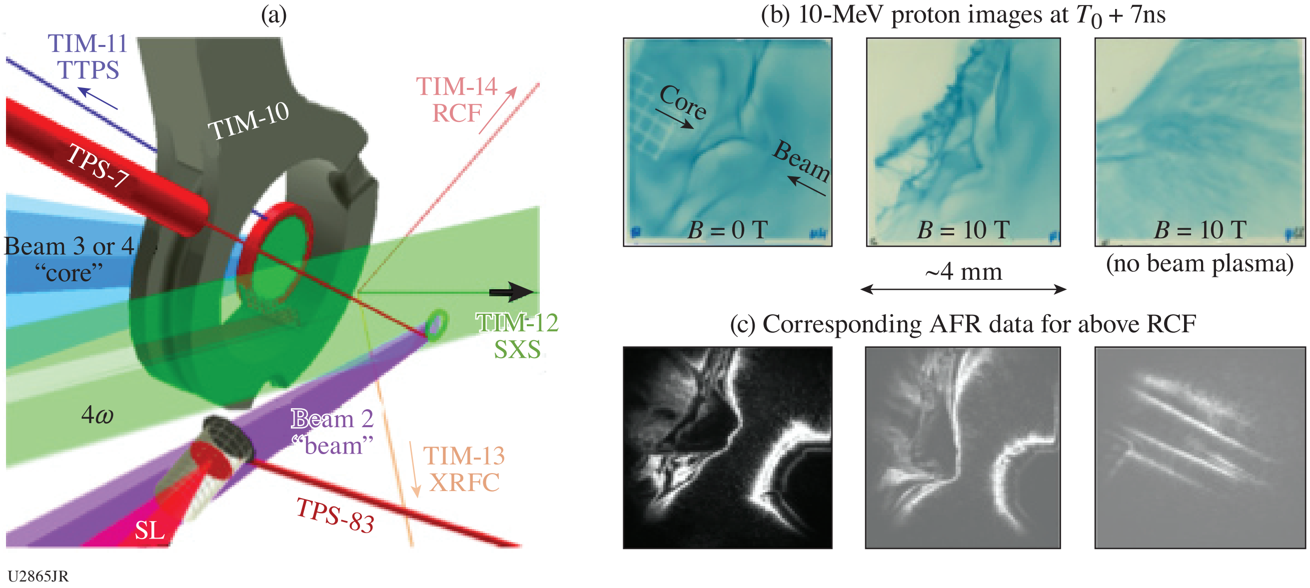

Figure 2
(a) VisRad schematic of the experiment showing beam and diagnostic configurations; (b) 10-MeV proton images from "proof-of-existence" experiments. The B = 0-T image shows that large-scale field structures have formed at the center of the field of view 7 ns after the initial asymmetric interaction (T0). With the B field on, similar bulk features are apparent (shifted down and to the left due to the field), but now high-frequency filaments are clearly visible on the core side of the asymmetric interaction. When only the core plasma is present in the B field, both bulk and high-frequency field structures are gone. (c) The AFR data correspond to the same shots as in (b) with the same spatial scale. TIM: ten-inch manipulator; TPS: Target Positioning System; SXS:streaked x-ray spectrometer; SL: sidelighter.

This material is based upon work supported by the Department of Energy (DOE), National Nuclear Security Administration under Award Number DE-NA0003842 and by the DOE Office of Science, Fusion Energy Sciences under Contract No. DE-SC0021061: the LaserNetUS initiative at the Omega Laser Facility.

Plasma Ablation and Shock Generation Using the Omega Laser Facility

Principal Investigators: K. Matsuo, E. Hahn, T. Cordova, M. Bailly-Grandvaux, R. E. Turner, J. E. Garay, and F. N. Beg (UCSD); and T. Joshi and R. B. Spielman (LLE)

X-ray–induced thermomechanical shock (TMS) is a major risk for electronics operating outside the Earth's atmosphere. Therefore, direct measurements using x rays to drive TMS are of significant interest; however, experimental platforms with high-enough x-ray flux are presently limited. Alternatively, careful implementation of high laser flux and fluence can be substituted to drive target ablation and the production of TMS at the relevant multi-Mbar levels. The major factors influencing the efficient coupling of the laser energy to the target are presently being investigated to reveal key aspects of the underlying physics of plasma blowoff as a function of the laser pulse length. We carried out extensive radiation-hydrodynamic modeling to facilitate an experimental design utilizing the OMEGA EP laser.

A schematic of the experiment and representative data from the critical diagnostics are shown in Fig. 3. Importantly, each experimental configuration maintained a constant laser intensity of 6 × 10^{14} W/cm^2. From analytical scaling, the ablation

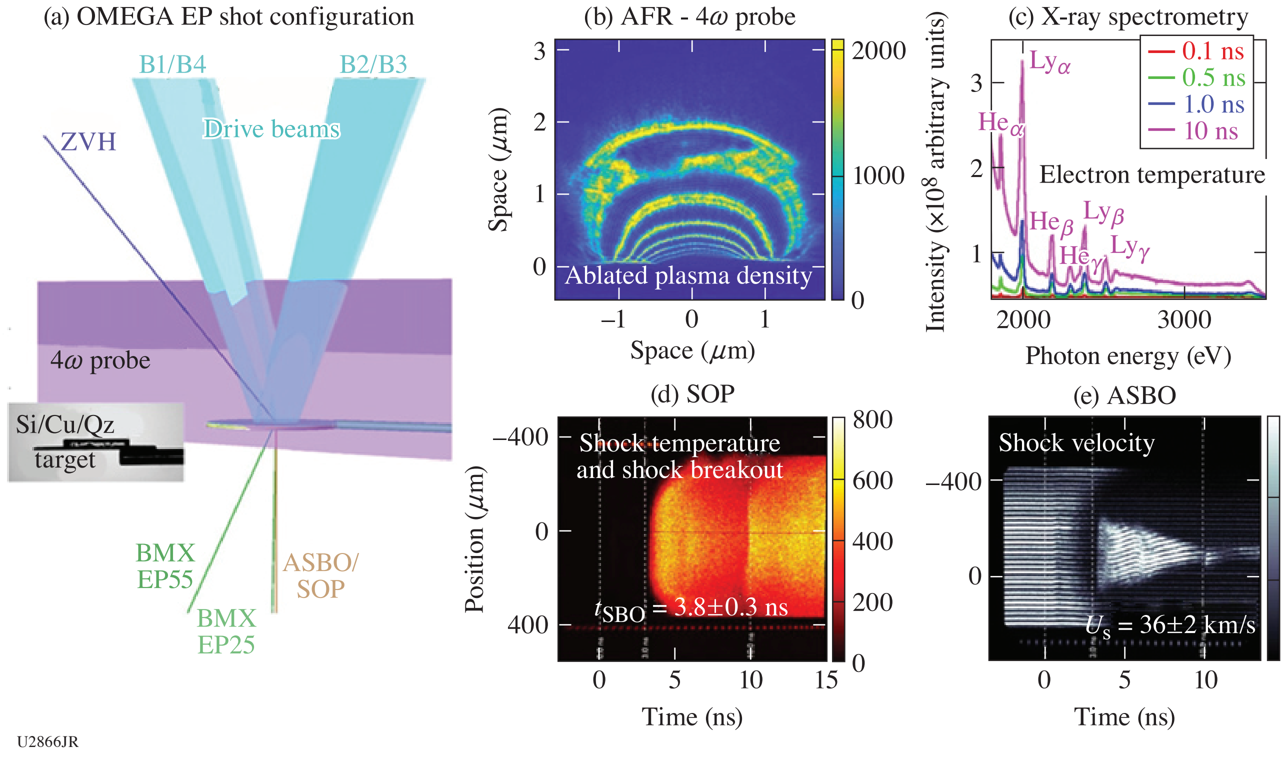

Figure 3
(a) Defense Threat Reduction Agency (DTRA) OMEGA EP experimental configuration. There was a systematic investigation of ablation physics and thermo-mechanical shock propagation at an intensity of ~10^{15} W/cm^2 as a function of the laser pulse length. The targets consisted of three layers: (Si/Cu/Qz). (b) An angular filter refractometry (AFR) diagnostic used the 4ω probe to measure the density of the ablated plasma. (c) Time-integrated x-ray spectrometry can provide an inferred electron temperature using the K-shell line ratio of Ly_γ to He_γ. (d) Streaked optical pyrometry (SOP) can measure shock-breakout times and the internal temperature of the quartz. (e) The active shock break-out (ASBO) diagnostic measures the timing and, therefore, the velocity of the decaying shock wave. ZVH: zinc Von Hamas; BMX: bremsstrahling MeV x-ray spectrometer.

pressure is proportional to the instantaneous intensity to the power ~2/3 and independent of the pulse length.[7] However, radiation-hydrodynamic modeling suggests a complex interplay between the pulse length and the ablation pressure as it translates to a TMS wave traveling through the multilayer target, further motivating a study of laser pulse length (100 ps, 500 ps, 1 ns, 10 ns) on the physics of plasma blowoff and strong shock generation. We performed ten shots in total, including two shots at 10-ns pulse duration, four shots at 1-ns pulse duration, two shots at 0.5-ns pulse duration, and two shots at 0.1-ns pulse duration. As shown in Fig. 3, the targets, fabricated at UCSD, consisted of three layers: single crystalline nominally undoped silicon, polycrystalline copper, and crystalline SiO_2 quartz (Si/Cu/Qz).

In these experiments, the measured ablation-front temperature is ~500 eV [Fig. 3(b), analyzing relative line intensities], independent of the pulse duration. Yet, the investigation of ablation temperature from the sole effect of pulse duration requires an experiment at constant laser fluence (planned next year) to complement the present study at constant intensity. Ablation density is indirectly inferred from the AFR diagnostic through a comparison with synthetic AFR images post-processed from the radiation-hydrodynamic simulations. The resulting TMS propagation into the dense target is measured in the quartz witness layer using ASBO (shock velocity) and SOP (shock temperature) diagnostics. For the longest pulse length (10 ns), the measured shock velocity is ~35 km/s (~22 Mbar), in agreement with the analytical scaling laws after considering the shock impedance matching of the Si/Cu/SiO_2 layers. Interestingly, the measured shock velocity for the shortest pulse (0.1 ns) is ~3 km/s (<1 Mbar), marking a significant decrease in the shock pressure for subnanosecond pulses. This trend is also observed in the 0.5-ns and 1-ns pulse lengths, signaling that the supported shock pressure is proportional to the pulse duration and that shock-decay effects (rarefaction, dispersion, reflection/transmission) are not insignificant. Evidence of such multiwave features can be distinctly identified in the 10-ns pulse data [Figs. 3(d) and 3(e)], marking recognizable shock and release waves as they traverse the sample and enabling a direct measurement of the contribution thereof. These results clearly demonstrate that the laser pulse length plays a pivotal role in plasma ablation and strong-shock generation. Next, new scaling laws will be established using the experimental data for the ablation pressure's dependence on pulse length. The physics of laser coupling is different between the shortest pulse duration (0.1 ns) and the longest pulse duration (10 ns), which is likely the cause of discrepancy between the *FLASH* simulations and the experimental data observed in these cases. We will include a modified laser absorption model in *FLASH* that has been designed for short pulses and that we believe will better reproduce the experimental results for 0.1-ns pulse duration. A similar investigation is being sought for the 10-ns pulse, where the laser interaction with the longer ablated plasma in front of the ablator may also sensibly affect the laser coupling computed by *FLASH*. This endeavor will certainly benefit the community, maturing the models used in radiation-hydrodynamic simulations for subnanosecond or multinanosecond laser interactions with a solid target.

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