Executive Summary

E. M. Campbell

Director, Laboratory for Laser Energetics

The Laboratory for Laser Energetics (LLE) is primarily funded by the U.S. Department of Energy (DOE) National Nuclear Security Administration's (NNSA's) Office of Experimental Sciences Inertial Confinement Fusion (ICF) Program through a five-year Cooperative Agreement. The fiscal year ending September 2020 (FY20) comprised the second year of LLE work under DOE/NNSA Cooperative Agreement No. DE-NA0003856. The Laboratory's work is also sponsored by the New York State Energy Research Development Authority (NYSERDA) and other federal agencies such as DOE's Office of Science (Fusion Energy Sciences and High Energy Physics) and the National Science Foundation (NSF). This annual report summarizes work conducted at LLE during FY20, including research on the ICF and High-Energy-Density (HED) science campaigns; laser, optical materials, and advanced technology development; operation of the Omega Laser Facility for the ICF and HED Campaigns, the National Laser Users' Facility (NLUF), the Laboratory Basic Science (LBS) Program, and other external users including the newly established LaserNetUS supported by the DOE Office of Fusion Energy Sciences (FES); and programs focusing on the education of high school, undergraduate, and graduate students. Much of the work conducted during FY20 was adapted including virtual participations and remote shot operation for users of the Omega Laser Facility to overcome the challenge of the COVID-19 pandemic.

Inertial Confinement Fusion Research

One of the principal missions of LLE is to conduct research in ICF with an emphasis on supporting the goal of achieving fusion ignition or determining what is needed for this goal at the National Ignition Facility (NIF). This program uses the Omega Laser Facility, the NIF, and the full experimental, theoretical, computational, and engineering resources of the Laboratory. During FY20, despite the challenges brought on by the pandemic (including a two-month shutdown of the Laboratory), 1825 target shots were taken at the Omega Laser Facility (comprised of the 60-beam OMEGA UV laser and the four-beam, high-energy petawatt OMEGA EP laser). The ICF and HED Campaigns accounted for approximately 63% of the facility shots. LLE is the lead laboratory worldwide for the laser-direct-drive approach with research focused on cryogenic implosions on the 60-beam OMEGA laser and on laser–plasma interaction physics of importance to all laser-driven concepts at both the Omega and NIF facilities. LLE has also developed, tested, and constructed a number of diagnostics currently being used at both the Omega Laser Facility and on the NIF. During this past year, progress in the ICF Program continued in three principal areas: ICF cryogenic DT implosion experiments on OMEGA and physics experiments in support of ICF on OMEGA, OMEGA EP, and the NIF; theoretical analysis and design efforts aimed at improving direct-drive–ignition capsule designs and advanced ignition concepts such as magnetized implosion; and the development of diagnostics for experiments on the NIF, OMEGA, and OMEGA EP Laser Systems. This annual report includes the summaries published in the LLE Review (Quarterly Reports) on the LLE research performed during FY20 in these areas.

Twenty-one of the summaries highlighted in the report concern research on various aspects of ICF by LLE scientists and external Omega users including:

- inferring thermal ion temperature and residual kinetic energy from nuclear measurements in ICF implosions;

- understanding low-mode azimuthal drive asymmetry in ICF implosions on the NIF;

- revisiting the late-time growth of single-mode Rayleigh–Taylor instability and the role of vorticity;
- novel hot-spot–ignition designs for ICF with liquid deuterium–tritium (DT) spheres;
- first observation of hot-spot mix in laser-direct-drive ICF;
- probing in-flight shell breakup in DT cryogenic implosions on OMEGA;
- first temperature and velocity measurements of the dense fuel layer in ICF experiments;
- self-radiography of imploded shells on OMEGA based on multi-monochromatic continuum spectral analysis;
- in collaboration with LLNL, principal factors in the performance of indirect-drive laser-fusion experiments;
- in collaboration with LLNL, experiments to explore the influence of pulse shaping on the NIF;
- in collaboration with LLNL, deficiencies in compression and yield in x-ray–driven implosions;
- azimuthal uniformity of cylindrical implosions on OMEGA;
- characterizing laser preheat for laser-driven magnetized liner inertial fusion (MagLIF) using soft x-ray emission;
- constraining physical models at gigabar pressures;
- molecular dynamics simulations revealing hydrogen streaming upon release from polystyrene shocked to ICF conditions;
- direct-drive laser fusion: status, plans, and future;
- direct measurements of DT fuel preheat from hot electrons in direct-drive ICF;
- validating heat-transport models using directly driven spheres on OMEGA;
- magnetic-field generation and its effect on ablative Rayleigh–Taylor instability in diffusive ablation fronts;
- self-consistent theory of the Darrieus–Landau and Rayleigh–Taylor instabilities with self-generated magnetic fields;
- transport coefficients for magnetic-field evolution in inviscid magnetohydrodynamics; and
- hydrodynamic simulations with an improved microphysics model to study the initial plasma formation and laser imprint in dielectric ablator materials for direct-drive implosions.

Plasma and Ultrafast Science

The development of a strong, fundamental, both theory and experimental plasma physics and ultrafast science capability, including generation of more powerful, efficient, and compact sources of high-energy photons and directed particle beams as advanced probes, underlies much of ICF and HED science. In this report we present 14 articles that highlight the FY20 laboratory efforts in these areas including:

- dephasingless laser wakefield acceleration enabled by a novel optical technique for spatiotemporal pulse shaping that has potential to accelerate electrons to TeV in a meter-scale plasma;

- three-dimensional calculations of multibeam absolute stimulated Raman scattering (SRS) thresholds that provide explanations for experiments on OMEGA and the NIF;

- a novel high-temperature, efficient Raman amplification scheme for generating high-peak-power laser pulses;

- study of SRS mechanisms and plasma scaling behavior in planar direct-drive experiments on the NIF;

- modeling magnetic confinement of a laser-generated plasma in cylindrical geometry leading to disk-shaped structures;

- anomalous absorption by the two-plasmon–decay (TPD) instability at the quarter-critical density in laser-produced underdense coronas;

- experimental study of the impact of spatiotemporal smoothing on the TPD instability and comparison with simulations;

- a novel vacuum laser acceleration (VLA) of electrons in a dynamic laser pulse utilizing LLE's "flying focus" technique;

- a study of the convective gain and kinetic inflation threshold from SRS driven by a broadband, frequency-modulated laser pulse in an inhomogeneous plasma;

- first measurements of complete electron distribution functions without any assumptions on their shape or the underlying physics that produced them and the resulting non-Maxwellian electron distribution on laser heating;

- nonlinear spatiotemporal control of laser intensity producing an arbitrary trajectory of the intensity peak that can be sustained for large distances compared to the Rayleigh range of the focusing system and its application to generate long plasma channels;

- the discovery of a novel regime of plasma wave excitation and wakefield acceleration that removes the wave-breaking limit, allowing arbitrarily high electric fields; and

- demonstration of axial proton probing of magnetic and electric fields inside laser-driven coils in OMEGA EP experiments that clearly distinguish deflection contributions from electric and magnetic fields.

High-Energy-Density Physics

High-energy-density physics (HEDP) is the study of matter at extreme conditions. The HED condition, often defined by an energy density (in pressure units) in excess of 1 Mbar, not only is foundational for ICF research and national nuclear security, but is also common in the universe, including at the interior of stars, giant planets, and exoplanets, as well as the atmospheres and the vicinity of compact objects such as white dwarfs, neutron stars, and black holes. HED regimes also enable the study of new realms of quantum mater behavior, properties, and phenomena including room-temperature superconductivity at 2.67 Mbar recently demonstrated in laboratory experiments led by UR researchers. HED plasma created by high-power lasers also enables the exploration of new regimes of plasmas mediated by extreme fields and the generation of intense beams of high-energy photons and particles.

LLE plays a major role in the nation's HEDP Program not only through the numerous users' experiments conducted at the Omega Laser Facility but also by HED physics research (experiments, theory, and modeling) carried out by LLE scientists and graduate students. This volume contains summaries of ten of these efforts including:

- first-principles molecular dynamics (MD) calculations of the equation of state (EOS) and shock Hugoniot of various boron phases, strongly indicating differences in the mechanisms of phase transitions in equilibrium and under shock;

- application of thermal density function theory (DFT) to investigate the spectra of a Fe–Zn plasma mixture at extreme densities (250 to 2000 g/cm^3) and temperatures of 50 to 100 eV, accessible by imploding double-shell targets, revealing two new and uniquely extreme atomic physics phenomena: interspecies radiative transition and the breakdown of the dipole-selection rule for radiative transitions in isolated atoms;

- an overview of the x-ray diffraction (XRD) platforms on the NIF and the measurements of the density-pressure EOS and crystal structure of a variety type of materials compressed up to 2 TPa, leading to the discovery of several new phases;

- optimizing deuterated metal foils for the production of a quasi-monoenergetic MeV deuteron beam using the Multi-Terawatt (MTW) laser;

- DFT-based quantum molecular dynamics (QMD) simulations to determine the insulator-to-metal transition boundary in warm dense hydrogen that shows a good agreement with experimental measurements across a wide range of pressure and temperatures;

- implementation of thermal hybrid exchange-correlation density functional providing significant improvements for the description of warm dense matter;

- first-time experimental measurements of the EOS of CO_2 shock compressed to 1 TPa on OMEGA, revealing a rich and complex phase diagram that cannot be described by current models;

- measurements of the principal Hugoniot and sound speed of shock-compressed silicon to 2100 GPa, showing changes in physical properties of HED materials coincident with an increase in ionic coordination and ionization of the $3s^2$ electrons predicted by the DFT-based QMD simulations;

- systematic studies of effects of thermal excitations on the electronic properties of sodium electride under high pressure using the DFT-based molecular dynamics and electro-optical calculations; and

- a comprehensive study of the EOS of boron carbide constrained by theoretical calculations and shock experiments resulting in new EOS models available for use in hydrodynamic simulations.

Diagnostic Development

The continued development of state-of-the-art diagnostic instrumentation is required to conduct experiments in support of the national ICF and HED Programs. In this volume, we present seven summaries on research and development projects in this area including:

- a report on a suite of six neutron time-of-flight (nTOF) detectors on OMEGA to measure the primary DT neutron energy spectrum along multiple quasi-orthogonal lines-of-sight in direct-drive ICF cryogenic target implosion experiments providing critical information of hot-spot flow velocity for the first time;

- a design for a free-space, image-relay optical time domain reflectometer to measure fiber-optic time delays at ICF-relevant wavelengths to within 2 ps;

- a report describing soft x-ray spectrum unfold of K-edge–filtered x-ray diode arrays using cubic-spline interpolation that provides an analytical way of solving for the temporally and spectrally resolved x-ray flux with no free parameters or assumptions about the geometry or material of the emitting plasma;

- a joint study optimizing a short-pulse, laser-driven silicon He_α soft x-ray backlighter for radiography of ICF layered DT implosions at the Omega Laser Facility led by LLE in collaboration with the Technical University of Darmstadt;

- a report on the development of, along with the results from, the use of Fresnel zone plates (FZP's) for high-resolution (micron-scale) x-ray radiography experiments on the OMEGA and OMEGA EP Laser Systems;

- development of a novel photomultiplier tube (PMT) nTOF detector without use of a scintillator for accurate measurement of the neutron energy and hot-spot flow velocity in high-yield DT implosions on OMEGA; and

- a report describing a generalized forward-fit analysis method for neutron detectors with energy-dependent instrument response functions (IRF's), which are most essential for the analysis of nuclear states with smaller widths.

Laser System Science

Safe, efficient, and effective operation of the Omega Laser Facility requires a dedicated team of scientists and engineers with a high level of expertise in solving the various challenges presented by the operation of ultrahigh-power laser systems at their performance limits. In this volume we present a summary of research and development work carried out at LLE reporting on the optical characterization of the OMEGA beam profile at full energy at target chamber center using the new full-beam-in-tank diagnostic that is capable of accurate measurements of the beam-to-beam focal-spot variation in target-plane fluence. Results show the ability of the OMEGA Laser System to provide uniform fluence profiles that are consistent across all 60 beams in the laser, critical for high-performance ICF implosions.

Laser Technology and Development

In addition to advanced diagnostic development, the ICF and HED experimental programs require continuous laser technology development. This annual report contains three articles on work in this area including:

- a study examining the limits on the gas-filled hollow-core fiber (HCF) energy scaling and the new method to overcome gas ionization limitations with divided-pulse nonlinear compression, which is important for the development of ultrafast (~10-fs) high-average power lasers;

- a report describing the framework to support optical parametric amplifier (OPA) simulations using normalized equations and the modeling study of OPA operation with spectrally incoherent signals for the development of high-energy broadband UV lasers; and

- a series of investigations and comparisons of the laser-induced–damage threshold in single-layer optical films measured at different testing facilities.

Optical Materials Science

A strong materials science effort is required to realize the required laser and instrumentation objectives for ICF and HED research. This report includes the following six summaries of materials science efforts at LLE:

- a report on the development of an optical component such as a reflective radial echelon via electron-beam vapor deposition of a silicon-dioxide thin film onto a substrate through a mask to form a phase-stepped reflected wavefront for use in a chromatic flying focus;

- a study of damage mechanisms in multilayer dielectric gratings at different laser pulse durations (0.6 and 10 ps at 1053 nm) to inform the design and fabrication of the next-generation gratings with a significantly higher damage threshold;

- development of high laser-induced–damage threshold glassy liquid crystal materials for large-aperture polarization control and beam-smoothing optics that could replace current low-molar-mass liquid crystal devices on the OMEGA Laser System as well as offering the potential for use in other ICF-class laser systems in future upgrades;

- a study of morphologies and underlying mechanisms of laser-induced damage (LID) by model contamination particles on a high reflector showing that the contamination microparticles can be a potent precursor for optical damage with short pulses, causing damage initiation far below the pristine LID threshold, and thereby exposing optics to the potential for damage growth;

- a novel experimental design that enabled the determination of the Raman polarizability tensor in the optically anisotropic crystal potassium dihydrogen phosphate (KDP) and its deuterated analog (DKDP); and

- a report on the results of a long-term monitoring of the damage performance of multilayer dielectric grating samples positioned inside the OMEGA EP grating compressor vacuum chamber during normal operation with various pulse durations (0.7 to 100 ps).

Omega Laser Facility Operations

Under the facility governance plan implemented in FY08 to formalize the scheduling of the Omega Laser Facility as an NNSA User Facility in support of the science-based Stockpile Stewardship Program, Omega Laser Facility shots are allocated by programs (ICF, HED, NLUF, LBS) following NNSA guidance.

During FY20, the Omega Laser Facility conducted 1033 target shots on OMEGA and 792 target shots on OMEGA EP for a total of 1825 target shots (see Fig. 1 below for the use by various programs). OMEGA had an experimental effectiveness of 95.7%, while OMEGA EP recorded an experimental effectiveness of 95.8%. The ICF and HED Programs received 63% of the facility shots in FY20 conducted by scientists from Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Sandia National Laboratories (SNL), the Naval Research Laboratory (NRL), and LLE. About 9% of the facility shots were for the laser system calibration led by LLE. The NLUF and LBS Programs described below conducted ~23% of the facility shots. The facility also delivered 70 shots (~4% of the total) for the newly established LaserNetUS Program and 21 shots (1% of the total) for the joint Rutherford Appleton Laboratory/York University (RAL/York) team and the LANL Laboratory Directed Research & Development (LDRD) Program. Approximately 52% of the facility time was used for experiments led by external users.

It should be noted as mentioned above that during the third quarter of FY20, the Omega Laser Facility was in safe stand-down for eight weeks, with additional weeks of recovery activities due to the COVID-19 pandemic and associated state regulations. As a result, almost a quarter of the FY20 approved shot days were delayed into FY21. One highlight was the implementation of the Omega remote PI shot operation developed by LLE during the safe stand-down period, which is a new protocol enabling users

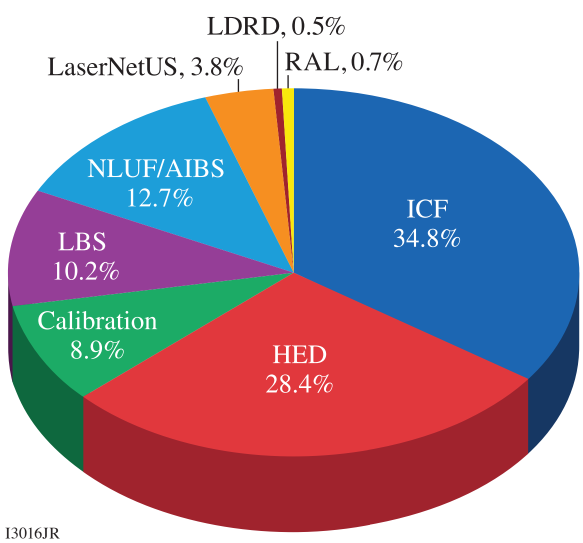

Figure 1
Omega Laser Facility use by program in FY20.

to safely and effectively conduct Omega experiments via remote access. The remote PI system has been used on all production OMEGA and OMEGA EP target shots since 3 June 2020. Neither the effectiveness nor the availability of these target shots have been compromised by remote PI operations. Description of the "remotePI" protocol and the shot operation statistics can be found in a feature article on the LLE website under "LLE Today/Around the Lab."

National Laser Users' Facility and External Users' Programs

The NNSA-supported Fundamental Science Program at the Omega Laser Facility is also allotted target shots, with projects selected through open-call and peer-reviewed processes. The program has two distinct components: (1) the NLUF Program awarded to individual principal investigators (PI's) on a two-year cycle with the associated Omega Laser Facility time for experiments led by U.S. academia and business [note: a special one-time Academic and Industrial Basic Science (AIBS) program was created to provide shot opportunities in FY20–FY21 with beam time from the unassigned NLUF allocation]; and (2) the LBS Program with annual beam-time awards for basic science experiments conducted by the NNSA laboratories and Office of Science laboratories.

FY20 was the first year of a two-year period of performance for 11 NLUF grant projects and 10 AIBS beam-time awards with Omega shot allocations (see Table I on p. 221). A total of 232 target shots were delivered for 15 NLUF/AIBS projects that accounted ~13% of the 1825 overall Omega Laser Facility shots.

A critical part of the NLUF and LaserNetUS programs is the education and training of graduate students in plasma and HED physics. In addition, graduate students can also access the Omega Laser Facility for shots through their collaborations with national laboratories and LLE. There were about 60 graduate students from 18 universities involved in the external user-led research programs with experiments conducted at the Omega Laser Facility (see Table II on p. 222).

In FY20, 21 LBS projects were allocated a total of 21.5 shot days for experiments at the Omega Laser Facility. A total of 186 target shots (~10% of the total) were conducted for 16 LBS projects led by scientists from LLNL, LANL, LLE, Lawrence Berkeley National Laboratory, SLAC, and Princeton Plasma Physics Laboratory (PPPL) (see Table I, p. 263). Six FY20 LBS projects are postponed with shots to be conducted in FY21.

During FY20, LLE issued a solicitation for LBS proposal for beam time in FY21. A total of 36 proposals were submitted, requesting a total of 56 shot days, exceeding the LBS allocation by 260%. After review, 22 projects were selected and allocated a total of 22.5 shot days (including one additional day from the contingency pool) for experiments at the Omega Laser Facility in FY21 as shown in Table II on p. 264.

Since 2019, the Omega Laser Facility, specifically the OMEGA EP Laser, has been part of the FES-supported LaserNetUS network consisting of nine high-intensity laser facilities in the U.S. and one in Canada. Through a coordinated 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. During FY20, seven LaserNetUS projects (see Table I on p. 288) were awarded a total of eight shot days on OMEGA EP for experiments in FY20 and FY21. A total of 70 target shots were successfully conducted in FY20 for six LaserNetUS projects led by scientists from Johns Hopkins University, LLNL, PPPL, Princeton University, and the University of California, San Diego.

In FY20, the Omega Laser Facility was also used for two campaigns (a total of 21 target shots), one for the joint RAL/University of York of the United Kingdom and one for the LANL LDRD program. These externally funded experiments were conducted at the facility on the basis of special agreements put in place by UR/LLE and participating institutions with the endorsement of NNSA.

Omega Laser Facility Users Group

LLE hosted a virtual meeting for the Omega Laser Facility Users Group (OLUG) focusing on the development of Findings and Recommendations (F&R's) from 23–25 September 2020 (two hours each day). It was attended by more than 90 participants including scientists, postdoctoral fellows (postdocs), and students from 27 institutions (Fig. 1 on p. 215). The virtual meeting program included the NNSA perspective presented by A. Satsangi from NNSA's Office of Experimental Sciences; two facility presentations: "Omega Facility Updates" presented by S. F. B. Morse and "Omega RemotePI Operation," presented by G. Pien; and the "Omega Basic Science User Program Update" by M. S. Wei. Over three days of the meeting, OLUG members discussed and developed a list of 23 new F&R's to further improve facility capabilities and user experiences.

Education

As a major university participant in the National ICF Program as part of the NNSA's science-based Stockpile Stewardship Program, education continues to be an important mission for LLE. The Laboratory's education programs cover the range from high school to graduate education. This report provides a summary of LLE's main activities on education in FY20 including:

1. Summer High School Research Program

Since 1989, LLE has held an annual Summer High School Research Program for Rochester-area high school students who have just completed their junior year. The eight-week program provides an exceptional opportunity for highly motivated students to experience scientific research in a realistic environment. Unfortunately, the 2020 full program was cancelled due to the COVID-19 pandemic. Although there were no new high school students, several prior year program participants returned to work (virtually) in the summer of 2020 and continued their research projects under the guidance of their LLE advisors.

Three hundred and ninety-one students from 55 high schools have participated in the program to date, among which 137 are female. A total of 39 students, including S. Narang from the 2019 summer program, have become Scholars in the prestigious Regeneron Science Talent Search for the research projects they carried out at LLE. H. Berger and S. Narang from the 2019 summer program won gold and bronze medals, respectively, in the InspoScience Research and Innovation Competition (North America's Continental Science Fair) in 2020.

2. Undergraduate Student Program

During FY20, LLE employed 36 undergraduate students from the University of Rochester and 12 co-op college students from Rochester Institute of Technology, Monroe Community College, and Finger Lakes Community College. The research activities carried out by the undergraduate and co-op students at LLE in 2020 were performed virtually. LLE also funded 20 students (and their six faculty advisors) from SUNY Geneseo and Houghton College to conduct research in Physics and Engineering.

3. Broad Exposure to Science and Technology Student and Teacher Research Program

During FY20, LLE initiated a new research and education program called BEST (Broad Exposure to Science and Technology), which was formed and led by T. J. Kessler, LLE's Diversity Officer. This program aims to involve high school teachers and undergraduate and high school students from underrepresented groups in various aspects of science and technology that support LLE's laser science and applications research. This broad exposure to science and technology will help inspire and guide students from underrepresented groups in their pursuit of STEM fields and encourage them to explore the next generation of related jobs and careers. Teacher participation will equip them with knowledge and experience that can be brought back to their schools to enhance science and technology curricula. The research experience for this new pilot BEST program will start in summer 2021.

4. Graduate Student Programs

Graduate students are using the Omega Laser Facility as well as other LLE facilities for ICF and HEDP research and technology development activities. These students are making significant contributions to LLE's research program. Twenty-five faculty members with primary appointments with eight of the University of Rochester's academic departments collaborate with LLE scientists and engineers. In addition, 17 scientists and engineers at LLE hold secondary faculty appointments with the University at five different academic departments. In FY20, a total of 80 UR graduate students were involved in research projects at LLE. LLE directly sponsored 60 students pursuing Ph.D. degrees via the NNSA-supported Frank Horton Fellowship Program, among which 13 are new Horton Fellows starting from September 2020 (see Table I). Their research includes theoretical and experimental plasma physics, HED physics, x-ray and atomic physics, nuclear fusion, material properties under extreme pressure, ultrafast optoelectronics, high-power laser development and applications, nonlinear optics, optical materials and optical fabrica-

Table I: University of Rochester Frank Horton Fellowship Program at LLE in FY20.

Student Name	Dept.	Faculty Advisor	LLE Advisor	Research Area	Notes
M. V. Ambat	ME	D. H. Froula		Dephasing laser wakefield accelerator	New
V. Anand	PA	J. Carroll-Nellenback		The role of exoplanetary magnetic fields in atmospheric evolution and habitability	New
D. Bassler	CH	W. U. Schroeder	W. T. Shmayda	The effect of surface chemistry and electronic structure of atomic layer deposition deposits on the tritium inventory of stainless steel	
J. Baltazar	ME	S. P. Regan	R. C. Shah	ICF implosion physics	
Z. Barfield	PA	D. H. Froula		Lateral transport with and without magnetic fields	
D. Bishel	PA	G. W. Collins	P. M. Nilson	Mapping the atomic physics of complex ions with detailed nonlocal thermodynamic equilibrium (NLTE) spectroscopy	
G. Bruhaug	ME	G. W. Collins	J. R. Rygg/ H. G. Rinderknecht/ M. S. Wei	Advanced x-ray particle sources for HED and ICF diagnostic applications	
S. Cao	ME	C. Ren		Large-scale fluid and kinetic simulation study of laser–plasma instabilities and hot-electron generation in shock ignition	
A. R. Christopherson	ME	R. Betti		Theory of alpha heating, burning plasmas, and ignition in inertially confined plasmas	Defended Ph.D. Thesis in Aug. 2020 (now Staff Scientist at LLNL)
K. Churnetski	ME	S. P. Regan	W. Theobald	Three-dimensional analysis of the time-gated x-ray emission from the hot spot of DT cryogenic implosions in the polar-direct-drive configuration on OMEGA	New
L. Crandall	PA	G. W. Collins	J. R. Rygg	Equation of state of planetary fluids	

Table I: University of Rochester Frank Horton Fellowship Program at LLE in FY20 (continued).

Student Name	Dept.	Faculty Advisor	LLE Advisor	Research Area	Notes
A. Davies	PA	D. H. Froula	D. Haberberger	Investigation of collisional electron plasma waves and picosecond thermodynamics in a laser-produced plasma using Thomson-scattering spectroscopy	Defended Ph.D. thesis in Nov. 2019 (now a Sr. Optical/ Laser Engineer at Spectra-Physics)
A. Debrecht	PA	A. Frank		Radiation MHD of exoplanet winds and evaporation	
R. Dent	CH	A. Shestopalov	S. Demos	Optimization of coating properties and processing steps in optical grating manufacturing for high-intensity laser applications	New
Y. Ding	ME	R. Betti		First-principles investigations on the transport properties of high-energy-density plasmas	Defended Ph.D. thesis in Dec. 2020 (now at Amazon Web Services)
M. Evans	PA	P.-A. Gourdain		Experimental studies of ablation in magnetic anvil cells	
C. Fagan	CH	W. U. Schroder	W. T. Shmayda	The role of surface chemistry and microstructure on the retention of tritium in structural metals	
P. Franke	PAS	D. H. Froula		Measuring the dynamics of electron plasma waves with Thomson scattering	
J. M. García-Figueroa	CHE	D. R. Harding		Controlling the hydrogen content, surface roughness, and other properties of plastic targets using an electron-cyclotron-resonance microwave chemical-vapor–deposition process	
M. Ghosh	CH	P. Huo	S. X. Hu	Understanding the chemistry of hydrocarbons and other materials under high pressure	
M. K. Ginnane	ME	G. W. Collins	J. R. Rygg	Study behavior of materials at high pressure	
X. Gong	ME	G. W. Collins	J. R. Rygg	Structure and electronic properties of sodium and potassium at high pressure	

Table I: University of Rochester Frank Horton Fellowship Program at LLE in FY20 (continued).

Student Name	Dept.	Faculty Advisor	LLE Advisor	Research Area	Notes
V. Gopalaswamy	ME	R. Betti		Statistical analysis of OMEGA direct-drive cryogenic DT implosions	
S. Gupta	OPT	P. S. Carney	M. D. Wittman	Quantitative confocal phase imaging for the inspection of target capsules	New
A. M. Hansen	PA	D. H. Froula		Electron plasma wave dynamics	
B. J. Henderson	PA	G. W. Collins	J. R. Rygg	Broadband reflectivity of shock compressed materials	
J. Hinz	PA	G. Ghoshal	V. V. Karasiev	Developing accurate free-energy density functionals via machine learning for warm dense matter simulations	
R. Holcomb	OPT	J. Bromage		Machine-learning optimization of nonlinear compression for high-average-power femto-second lasers	New
M. Huff	PA	G. W. Collins	J. R. Rygg	Sound-speed measurements on shocked material	
G. W. Jenkins	OPT	J. Bromage		Broadband seed generation and amplification at high average power	
M. Jeske	CH	M. Anthamatten	D. R. Harding	Direct laser writing of high-resolution shape memory networks for mechanical interlocking	New
R. Jia	CH	A. Shestopalov	S. G. Demos	Laser damage and chemical passivation of optical surfaces modified with organic molecules	
A. Kish	PA	A. B. Sefkow		Computational plasma physics, development of hybrid methods	
M. Lavell	ME	A. B. Sefkow		The physics of magnetic-flux compression and electron thermal transport in converging magnetized plasma	New
L. S. Leal	PA	R. Betti	A. V. Maximov	Modeling laser-generated plasmas in megagauss external magnetic fields	
A. Lees	PA	H. Aluie	R. Betti	Hydrodynamic instability control in a converging geometry	
O. M. Mannion	PA	S. P. Regan	C. J. Forrest	Measurements of the bulk fluid motion in direct-drive experiments	

Table I: University of Rochester Frank Horton Fellowship Program at LLE in FY20 (continued).

Student Name	Dept.	Faculty Advisor	LLE Advisor	Research Area	Notes
M. McKie	PA	D. H. Froula		Wave breaking of electron plasma waves as it applies to hot-electron generation and laser-plasma amplifiers	New
B. McLellan	PA	P. W. Milonni	S. Zhang	Theoretical study of structural transformation, transition pathways, and optical properties of crystals and amorphous solids under pressure	New
A. L. Milder	PA	D. H. Froula		Measurement of electron distribution function using collective Thomson scattering	
S. C. Miller	ME	V. N. Goncharov	P. B. Radha	Fine Atwood number effects on deceleration phase instability in room-temperature direct-drive implosions	
Z. L. Mohamed	PA	D. H. Froula	J. P. Knauer	Gamma emission from fusion reactions	
K. L. Nguyen	PA	D. H. Froula	J. P. Palastro	Application of the flying focus to nonlinear optical and plasma-based applications using a combination of theoretical and computational techniques	
H. Pantell	PA	G. W. Collins	M. Zaghoo	Thermodynamic and mass transport properties of silicate at extreme conditions	
H. Pasan	PA	R. Dias	G. W. Collins	Novel hydrogen rich materials at HED conditions: route to “hot” superconductivity	New
D. Patel	ME	R. Betti	V. N. Goncharov	Hybrid direct–indirect drive for ICF	
R. Paul	ME	S. X. Hu		*Ab-initio* construction of high-pressure phase diagrams of materials	
D. Ramsey	PA	D. H. Froula	J. P. Palastro	Acceleration and radiation from a flying focus	
J. J. Ruby	PA	G. W. Collins	J. R. Rygg	Understanding the thermodynamics of spherically imploding shocks	
A. Schwemmlein	PA	W. U. Schroeder	J. P. Knauer	Thermonuclear fusion and breakup reaction between light nuclei	

Table I: University of Rochester Frank Horton Fellowship Program at LLE in FY20 (continued).

Student Name	Dept.	Faculty Advisor	LLE Advisor	Research Area	Notes
T. Simpson	PA	D. H. Froula	J. P. Palastro	Predicting and understanding performance of cryogenic implosions and their extrapolation to NIF energies	New
Z. Sprowal	PA	G. W. Collins		EOS of hydrogen and hydrogen-helium for planetary interior models	
G. Tabak	PA	G. W. Collins/ J. R. Rygg	M. Zaghoo	Study of pre-compressed materials using shock compression	
M. Wang	CHE	D. R. Harding		Use of two-photon polymerization to “write” millimeter-size structures with micron resolution	
C. Williams	PA	J. Davies	R. Betti	The formation of magnetized collisionless shocks	New
J.-C. Yang	CHE	M. Anthamatten	D. R. Harding	Crystallization in shape-memory polymer networks	
J. Young	PA	P.-A. Gourdain		Laser-triggered X pinches on MTW	
D. Zhao	ME	H. Aluie	R. Betti	Multi-scale energy pathways in Rayleigh–Taylor instability flows	Defended Ph.D. thesis in Apr. 2020 (postdoc at Shanghai Jiao Tong Univ.)
H. Zhou	PA	E. Blackman		New perspectives on mean-field theories of astrophysical dynamos and accretion disks	Defended Ph.D. thesis in Aug. 2020 (postdoc at Nordic Institute of Theoretical Physics)
Y. Zou	PA	A. Frank		Common envelope evolution: HEDP studies of gravitational wave merger properties. the role of EOS and radiation transport	

ME: Mechanical Engineering; PA: Physics and Astronomy; CH: Chemistry; CHE: Chemical Engineering;
OPT: Institute of Optics.

tion technology, and target fabrication. A total of about 300 UR graduate students have completed their Ph.D. thesis research work supported by LLE since 1970. Many of LLE's alumni now fill responsible positions at the national laboratories, industry, academia, and government.

In FY20, LLE also directly funded research programs that involve graduate students and postdoctoral researchers within the Massachusetts Institute of Technology Plasma Science and Fusion Center, the University of Michigan, the University of Nebraska-Lincoln, the University of Nevada at Reno, and Oxford University. These programs involve a total of approximately 15 graduate students, 5 postdoctoral researchers, and 10 faculty members.

In addition, the Omega Laser Facility has significantly facilitated the education and training of more than 200 graduate students and postdoctoral researchers in the HEDP and ICF science areas from other universities through their participation in the NLUF, LBS, and/or LaserNetUS experiments, or through their collaborations with LLE and national labs. Sixty graduate students (including these 15 mentioned above) from 18 universities were involved in these external user-led research programs with the experiments conducted at the Omega Laser Facility in FY20.

Thirteen graduate students, including five from the University of Rochester (see Table I) and eight from other academic institutions [see Table II of the **National Laser Users' Facility Program** (p. 222)] have successfully completed their thesis research and obtained Ph.D. degrees during the last 15 months (from October 2019 to December 2020). Table II lists their name, university, and destination after graduation. Five of them (~40% of the total) have joined national laboratories, four have stayed in universities, and four work in the private sector. We expect that six UR/LLE Horton Ph.D. students will be graduating over the next six to nine months and all are pursuing employment at the NNSA National Laboratories including J. J. Ruby who received the prestigious Lawrence Fellowship from LLNL. He is the first University of Rochester graduate to receive this fellowship.

Table II: Thirteen students completed their Ph.D. theses from October 2019 to December 2020.

Name	Institution	Destination After Obtaining Ph.D. Degree
A. R. Christopherson	University of Rochester	LLNL (Scientist)
A. S. Davies	University of Rochester	Topcon Healthcare Solution (Sr. Scientist)
D. Zhao	University of Rochester	Shanghai Jiao Tong University (postdoc)
H. Zhou	University of Rochester	Nordic Institute of Theoretical Physics (postdoc)
Y. H. Ding	University of Rochester	Amazon Web Services
J. Matteucci	Princeton University	Freelancer
K. D. Meaney	University of New Mexico	LANL (Scientist)
J. Levesque	University of Michigan	LANL (postdoc)
G. Perez-Callejo	Oxford University	CELIA, University of Bordeaux (postdoc)
Y. Lu	Rice University	University of Rochester (postdoc in Tzeferacos' Group)
S. Zhang	University of California, San Diego	Princeton University (postdoc in Ji's Group)
D. T. Cliche	University of Nevada, Reno	LLNL (postdoc)
D. Mayes	University of Nevada, Reno	NNSA's Center of Excellence for Astrophysical Plasma Properties (stationed at SNL)