Executive Summary

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The fiscal year ending September 2019 (FY19) comprised the first year of Laboratory for Laser Energetics work under the renewal U.S. Department of Energy (DOE) National Nuclear Security Administration's (NNSA's) Office of Experimental Sciences Inertial Confinement Fusion Cooperative Agreement No. DE-NA0003856. The Laboratory's work is also sponsored by the New York State Energy Research Development Authority, and other federal agencies. This annual report summarizes work conducted under the Cooperative Agreement at LLE during FY19 including work on the Inertial Confinement Fusion (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; and programs focusing on the education of high school, undergraduate, and graduate students.

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 ignition 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 FY19, 2320 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 78% 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 Inertial Fusion Research Program continued in three principal areas: ICF experiments and experiments in support of ICF; 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 FY19 in these areas.

Fourteen of the summaries highlighted in the report concern research on ICF including: rarefaction flows and the mitigation of imprint in direct-drive implosions; the use of secondary neutron yields to infer the fuel areal density of magnetized liner inertial fusion; the impact of a non-Maxwellian electron energy distribution function on cross-beam energy transfer (CBET); the inference of electron temperature from x-ray continuum emission for OMEGA direct-drive ICF implosions; the effects of fuel–shell interface instability growth on the performance of room-temperature direct-drive implosions; simulated refraction enhanced x-ray radiography of laser-driven implosions; the effect of CBET on target offset asymmetry in directly driven ICF implosions (see Fig. 1 on p. 128); a wavelength-detuning CBET-mitigation scheme for polar direct drive; the development of a platform for burning-plasma studies using direct-drive double-shell implosions; density measurements of the inner shell release; the role of baroclinicity in the kinetic energy budge; development of an ignition criterion for inertial fusion implosions based on yield amplification from alpha-particle heating; the development of and experiments on a hybrid target design that incorporates both direct- and indirect-drive target designs for mitigating the Rayleigh–Taylor instability; and the development of two modifications to the Guderley solution to the converging shock problem to extend its utility to (1) the addition of an isentropic release wave and (2) fluid partitioning between an electron fluid and an ion fluid.

Plasma and Ultrafast Science

The development of a strong fundamental plasma physics and ultrafast science capability underlies much of ICF and HED science. In this report we present 14 articles that highlight the FY19 laboratory efforts in these areas including: the investigation of the impact of non-Maxwellian electron velocity distribution functions on inferred plasma parameters in collective Thomson scattering; measurements of the heat flux from collective Thomson scattering with non-Maxwellian distribution functions; a review of the laser–plasma interactions enabled by emerging laser and optical technologies; the demonstration of a modified technique for laser-driven magnetic reconnection; the demonstration of a technique to mitigate self-focusing in Thomson-scattering experiments; a report on a numerical study of absolute instability thresholds for stimulated Raman scattering (SRS) and two-plasmon–decay (TPD) instabilities using a broad-bandwidth pump beam; the development of a program that models CBET for the simple case of two intersecting beams; a summary of the investigation of picosecond thermodynamics in a laser-produced plasma using Thomson scattering; efforts to create and control ionization fronts using the flying focus technique; the demonstration that the ionization front produced by a flying focus can upshift the frequency of an ultrashort optical pulse to the extreme ultraviolet over a centimeter of propagation; the measurement of the picosecond evolution of non-Maxwellian electron distribution functions in plasmas generated by the Multi-Terawatt (MTW) laser; a report on the finding that a dynamic instability saturation mechanism allows laser light to be transmitted through coronal plasma even if it surpasses the threshold conditions for SRS (as observed in experiments on the NIF); the development of an experimental platform on the NIF to investigate hot-electron production from laser–plasma instabilities at conditions relevant to direct-drive targets; and the use of 3-D particle-in-cell simulations to investigate the interplay between TPD and SRS at conditions relevant to direct-drive targets.

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 planets such as Earth or Jupiter, stellar interiors, and 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.

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 researchers. This volume contains summaries of four of these efforts including: a collaborative effort involving LLE and the University of Florida demonstrating the equivalence between the three global representations of the free energy [the Karasiev–Sjostrom–Duffy–Trickey (KSDT) representation]; its descendant, the corrected KSDT; and the Gruth–Dornheim–Bonitz parametrization; a review of work to derive new thermodynamic constraints on internal, thermal, and magnetic states of super-Earth (SE) planets ranging in size from 1 to 10 earth masses; a discussion of exchange-correlation thermal effects in shocked deuterium confirming that the crossover between the quantum and classical statistics occurs below a temperature equal to the Fermi temperature (see Fig. 3 on p. 99); and the presentation of a first-principles construction of a high-pressure–temperature phase diagram of silicon up to multi-TPa pressures that revealed new stable phases.

Diagnostic Science and Detectors

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 the joint development a ten-inch-manipulator–based fast-electron spectrometer with multiple viewing angles for experiments at the Omega Laser Facility led by Osaka University and LLE; a report on the joint study by the University of Rochester, Rochester Institute of Technology, Brookhaven National Laboratory, Savannah National Laboratory, Brimrose Technology Corporation, and the Institute of Electron Technology, Poland, of the ultrafast optical properties of single-crystal cadmium magnesium telluride for use in x-ray detectors; a report on the use of a short-pulse laser and precision triggering system to generate a spatiotemporal flat field for a high-speed gated-optical imager used on the OMEGA UV beamlets; a demonstration of the co-timing of the UV and IR beams of the OMEGA EP Laser System with variations less than 20 ps during routine operations; and a report on the fabrication of aluminum–gallium–nitride photodetectors with micrometer-scale length metal–semiconductor–metal structures.

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 six articles on work in this area including: a report on the development of high-efficiency, large-aperture fifth-harmonic generation of 211-nm pulses in ammonium dihydrogen phosphate (ADP) crystals for deep UV Thomson scattering diagnostics performed with LLNL; a study of the interaction of short laser pulses with model contamination microparticles on a high reflector; a review of the current status of chirped-pulse–amplification (CPA) technology and its applications; a summary of heat-flow measurements from surface defects in lithium triborate; an investigation of the role of Urbach tail optical absorption on the subpicosecond laser-induced–damage threshold at 1053 nm in hafnia and silica monolayers; an investigation of mechanisms of laser-induced secondary contamination from metal particles attached on the input surface of optical components; and the demonstration of efficient parametric amplification of broadband spectrally incoherent pulses with applications to the development of a 1% fractional bandwidth laser for improved direct-drive implosions.

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 seven summaries of materials science efforts at LLE: the evaluation of laser-induced–damage threshold in saturated and unsaturated nematic liquid crystals between 600 fs and 1.5 ns at 1053 nm; a report on mechanisms governing laser-induced damage in absorbing glasses under exposure to nanosecond pulses; a review of international efforts to extract tritium from water; measurements of tritium migration in the near surface of stainless-steel 316; a report on the electrochemical synthesis of copper nanoparticles on hydroxyapatite coating for antibacterial implants; a report on silver-hydroxyapatite composite coatings with enhanced antimicrobial activities through heat treatment; a report on a collaborative effort of the University of Rochester, the West Pomeranian University of Technology (Poland), the Institute of Electron Technology (Poland), the University of Iceland, and the Center for Physical Sciences and Technology (Lithuania) to investigate terahertz time-domain spectroscopy of graphene nanoflakes embedded in a polymer matrix; and measurements of the angular dependence of spontaneous Raman scattering in anisotropic crystalline materials using spherical samples.

Laser System Science

Safe, efficient, and effective operation of the Omega Laser Facility at LLE requires a 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 eleven summaries of research and development work carried out at LLE in this area including: the implementation of a wavelength-tunable ultraviolet beam on OMEGA EP (see Fig. 2 on p. 44); the development and construction of a full-beam in-tank (FBIT) diagnostic to characterize the OMEGA focal spots; a comparison of FBIT data with equivalent-target-plane measurements of the OMEGA focal spot; a report on efforts to achieve power imbalance on OMEGA of less than 1% rms; a report on PSOPS, a MATLAB-based semi-analytic model for the OMEGA EP laser to predict system performance; a report on a method for calculating the Raman fluency at the surface of an arbitrary crystal and pump polarization configuration for the purpose of improved understanding of the laser power limitations due to transverse Raman generation and amplification in KDP/DKDP crystals; an investigation of the damage resistance of liquid crystals for OMEGA laser conditions; a study of multilayer glancing-angle deposition on a silica substrate to reduce light scattering on film; the development of a radially nonuniform film-deposition technique to mitigate deformations induced by high-compressive films; the design of a four-mirror image relay for the correction of field-constant coma and field-constant astigmatism; and a description of a process using ellipsometric measurement techniques along with a well-established optical design to create precise index models for improving coating designs.

Target Engineering and Research

The development and microfabrication of precise targets for Omega Laser Facility experiments requires significant effort by LLE including the projects outlined in the following areas: the comparison of shadowgraphy and x-ray phase-contrast methods for the characterization of DT ice layers in ICF fusion targets; a report on the prediction of deuterium–tritium ice-layer uniformity in direct-drive ICF target capsules; a report on measurements of a pressure–composition–temperature (PCT) phase diagram for palladium hydride and palladium deuteride at low temperatures; and a comparison of hydrogen absorption for different samples of stainless-steel with Al_2O_3 coatings.

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 Facility shots are allocated by programs following NNSA guidance.

During FY19, the Omega Laser Facility conducted 1489 target shots on OMEGA and 831 target shots on OMEGA EP for a total of 2320 target shots. OMEGA had an experimental effectiveness of 96.6%, while OMEGA EP recorded an experimental effectiveness of 94.3%. OMEGA EP was operated extensively in FY19 for a variety of user experiments. Per the guidance provided by DOE/NNSA, the facility provided target shots for the ICF, HED, NLUF, and LBS programs (see Fig. 1 below). The ICF and HED programs received 78 % of the facility shots in FY19 conducted by scientists from Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Sandia National Laboratories (SNL), Naval Research Laboratory (NRL), and LLE. The facility also provided a small number of shots (~3% in FY19) for Commissariat à l'énergie atomique et aux energies (CEA), Centre Lasers Intenses et Applications (CELIA)/University of Bordeaux, and Rutherford Appleton Laboratory/York University (RAL/York). Approximately 57% of the facility time was allocated for experiments led by external users.

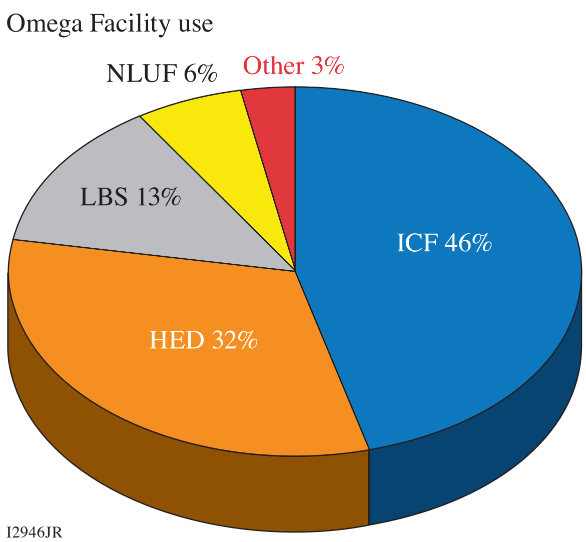

Figure 1
Omega Laser Facility use by program in FY19.

National Laser Users' Facility and External Users' Programs

The 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; and (2) the LBS Program for basic science experiments conducted by the NNSA ICF laboratories and Office of Science laboratories. In FY19, the Fundamental Science Program obtained a total of 416 target shots (289 for LBS, 127 for NLUF) that accounted for 18% of the 2320 overall Omega Laser Facility shots. The relative lower fraction of the Fundamental Science shots in FY19 is due to the postponed NLUF Solicitation for the 2019 and 2020 period that resulted in no new NLUF projects. Some of the shot time reserved for the NLUF allocation in FY19 was redistributed to LBS, ICF, and HED. Eight collaborative teams participating in the NLUF Program with the Omega Laser Facility shot allocation from the FY17–FY18 awards obtained a total of 127 shots.

During the second and third quarters of FY19, NNSA and the Office of Science jointly completed a funding opportunity announcement, review, and selection process for NLUF experiments to be conducted at the Omega Laser Facility during FY20 and FY21. After the panel review, NNSA selected 11 proposals for funding and Omega shot allocation with a total of 22.5 and 23.5 shot days for experiments in FY20 and FY21, respectively. Following NNSA's guidance, LLE made a one-time additional open-call late in FY19 to receive Omega Laser Facility time proposals for Academic and Industrial Basic Science (AIBS) experiments in order to fulfill the remaining NLUF shot allocation in FY20–FY21. Based on the merit review committee's recommendation, ten new projects were selected with a total of 11 and 10 shot days for AIBS experiments in FY20 and FY21, respectively. Table I (on p. 243) shows the list of NLUF grant projects and AIBS beam-time awards approved for Omega shot allocations in FY20–FY21.

A critical part of the NLUF program 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 more than 60 graduate students from 18 universities involved in the external user-led research programs supported by NLUF/LBS and/or with experiments conducted at the Omega Laser Facility (see Table II on p. 244).

In FY19, a total of 25 LBS projects were allocated a total of 275 shot days for experiments at the Omega Laser Facility, which included five additional projects selected from the FY19 LBS proposals based on their ranking to back-fill some of the NLUF allocations. A total of 289 target shots were conducted for the LBS experiments led by scientists from LLNL, LANL, LLE, SLAC, and Princeton Plasma Physics Laboratory (see Table III, p. 257).

During FY19, LLE issued a solicitation for LBS proposals for beam time in FY20. A total of 36 proposals were submitted, requesting a total of 57.5 shot days, exceeding the LBS allocation by 274%. After review, 22 projects were selected and allocated a total of 21.5 shot days for experiments at the Omega Laser Facility in FY20 as shown in Table IV on p. 258.

In FY19, the Omega Laser Facility was also used for several campaigns (a total of 78 target shots) led by teams from the CEA and CELIA at the University of Bordeaux, France and the joint RAL/University of York of the United Kingdom. These externally funded experiments were conducted at the facility on the basis of special agreements put in place by the UR/LLE and participating institutions with the endorsement of NNSA.

Omega Laser Facility Users Group

The Eleventh Omega Laser Facility Users Group (OLUG) Workshop was held at LLE on 24–26 April 2019. It was attended by 110 researchers, including scientists, postdoctoral fellows (postdocs), and students (Fig. 1, p. 172). The attendees represented institutions from four countries, including the U.S., Canada, U.K., and France. As has been the case for previous workshops, postdocs and students received travel support to attend the workshop from DOE/NNSA. The Workshop program included the presentations of invited science talks from five newly funded NNSA Centers; the NNSA perspective presented by Dr. Sarah Wilk, Deputy Director of NNSA's Office of Experimental Sciences; a facility update and progress on OLUG Recommendations; a summary of the OLUG Executive Committee election results; evening tutorials on "Non-Standard Targets" by LLE scientists and engineers; summaries of the EP-OPAL Workshop and MTW-OPAL; an update on the American Physical Society–Division of Plasma Physics (APS–DPP's) Community Planning Process by Carolyn Kuranz; panel discussions on OLUG Findings and Recommendations; young researcher panel discussions; and three poster sessions comprising a total of 68 posters of which 44 were presented by graduate students, postdocs, and undergraduate students. During the workshop, LLE staff also organized tours of the Omega Laser Facility.

Education and Outreach

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 FY19 including:

1. High School Program

LLE holds 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. Three hundred and ninety-one students from 55 high schools have participated in the program, among which 137 are female. A total of 39 students, including Simon 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. One hundred and fifty-five students from this program have obtained 190 advanced degrees to date.

2. Undergraduate Student Program

During 2019, LLE employed 54 undergraduate students from the University of Rochester as well as 13 co-op college students from Rochester Institute of Technology, Monroe Community College, and Finger Lakes Community College. Additionally LLE also funded 23 students (and their six faculty advisors) from SUNY Geneseo and Houghton College to conduct research in Physics and Engineering. One of the highlights of LLE's undergraduate student programs in 2019 was the *APS Leroy Apker Award*—an Undergraduate Physics Achievement Award—to *Katelyn Cook*, a recent alumna of LLE's undergraduate student programs, for her outstanding research into measuring low-energy nuclear cross sections using ICF while a student at Houghton College in collaboration with LLE and SUNY Geneseo. Only two awards are made each year, including one to a student from a non-Ph.D. granting institution. After graduating from Houghton in May 2019, Katelyn went on to do nuclear physics research as a Summer Research Assistant at LLNL. She is now a graduate student at Florida State University, pursuing experimental nuclear physics and high-energy-density physics as the focus of her Ph.D. research.

3. 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-two faculty members with primary appointments with six of the University of Rochester's academic departments collaborate with LLE scientists and engineers. In addition, 14 scientists and engineers at LLE hold secondary faculty appointments with the University at five different academic departments. In FY19, a total of 80 University of Rochester graduate students were involved in research projects at LLE. LLE directly sponsored 51 students pursuing Ph.D. degrees via the NNSA-supported Frank Horton Fellowship Program, among which ten are new Horton fellows (see Table I, p. xv). 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 fabrication 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 FY19, 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, Stony Brook University, the University of New Mexico, and Oxford University. These programs involve a total of approximately 18 graduate students, 5 postdoctoral researchers, and 11 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 and LBS experiments, or through their collaborations with LLE and national labs. Sixty-one graduate students from 19 universities were involved in these external user-led research programs with the experiments conducted at the Omega Laser Facility in FY19 as described above.

During FY19, 16 Omega graduate students (seven from the University of Rochester and nine from other academic institutions) successfully completed their thesis research and obtained Ph.D. degrees. Table II (p. xviii) lists their name, university, and destination after graduation. Six students (~40% of the total) have joined national laboratories and leading industries for national security, six have stayed in universities, and four work in the private sector. It is expected that a similar number of Ph.D. degrees will be awarded in FY20.

Table I: Recipients of the University of Rochester Frank Horton Fellowship Program at LLE in FY19.

Student Name	Dept.	Faculty Advisor	LLE Advisor	Research Area	Notes
J. Baltazar	ME	S. P. Regan	R. C. Shah	ICF implosion physics	New
Z. Barfield	PA	D. H. Froula		Lateral transport with and without magnetic fields	New
D. Bassler	CH	W. U. Schröder	W. T. Shmayda	Effect of surface chemistry and electronic structure of atomic layer deposition deposits on the tritium inventory of stainless steel	
D. Bishel	PA	G. W. Collins	P. M. Nilson	Mapping the atomic physics of complex ions with detailed nonlocal thermodynamic equilibrium spectroscopy	New
G. Bruhaug	ME	G. W. Collins	H. G. Rinderknecht and M. S. Wei	Advanced x-ray particle sources for HED and ICF diagnostic applications	New
S. Cao	ME	C. Ren		Large-scale fluid and kinetic simulation study of laser–plasma instabilities and hot-electron generation in shock ignition	
D. A. Chin	PA	G. W. Collins	P. M. Nilson and J. R. Rygg	Exploring planetary building blocks through x-ray absorption spectroscopy	NNSA Stewardship Science Graduate Fellow since June 2019
A. R. Christopherson	ME	R. Betti		Theory of alpha heating, burning plasmas, and ignition in inertially confined plasmas	Defending in early 2020
L. Crandall	PA	G. W. Collins	J. R. Rygg	Equation of state of planetary fluids	
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
A. Debrecht	PA	A. Frank		Radiation magnetohydrody-namics of exoplanet winds and evaporation	
M. Evans	PA	P.-A. Gourdain		Experimental studies of ablation in magnetic anvil cells	
C. Fagan	CH	W. U. Schröder	W. Shmayda	The role of surface chemistry and microstructure on the retention of tritium in structural metals	

Table I: Recipients of the University of Rochester Frank Horton Fellowship Program at LLE in FY19 (continued).

Student Name	Dept.	Faculty Advisor	LLE Advisor	Research Area	Notes
P. Franke	PA	D. H. Froula		Measuring the dynamics of electron plasma waves with Thomson scattering	
J. M. Garcia-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	
V. Gopalaswamy	ME	R. Betti		Statistical analysis of OMEGA direct-drive cryogenic DT implosions	
A. Hansen	PA	D. H. Froula		Electron plasma wave dynamics	
R. J. Henchen	ME	D. H. Froula		Hydrodynamic gradients in underdense plasmas	Defended Ph.D. thesis in Dec. 2018 (now a Scientist at Harris Corp.)
B. J. Henderson	PA	G. W. Collins	J. R. Rygg	Broadband reflectivity of shock-compressed materials	
J. Hinz	PA	G. Ghoshal	V. Karasiev	Developing accurate free-energy density functionals via machine learning for warm-dense-matter simulations	
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	
R. Jia	CH	A. Shestopalov	S. G. Demos	Laser damage and chemical passivation of optical surfaces modified with organic molecules	New
A. Kish	PA	A. B. Sefkow		Computational plasma physics, development of hybrid methods	New
L. Leal	PA	R. Betti	A. V. Maximov	Modeling laser-generated plasmas in megagauss external magnetic fields	New

Table I: Recipients of the University of Rochester Frank Horton Fellowship Program at LLE in FY19 (continued).

Student Name	Dept.	Faculty Advisor	LLE Advisor	Research Area	Notes
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	
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	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	New
J. J. Ruby IV	PA	G. W. Collins	J. R. Rygg	Understanding the thermodynamics of spherically imploding shocks	
E. M. Schiesser	OPT	J. Rolland	S.-W. Bahk	Applying nonsymmetric aberration theory to create scalable, compact beamlines	Defended Ph.D. thesis in Sep. 2019
A. Schwemmlein	PA	W. U. Schröder	J. P. Knauer	Thermonuclear fusion and breakup reaction between light nuclei	
Z. Sprowal	PA	G. W. Collins		Equation of state of hydrogen and hydrogen–helium for planetary interior models	
G. Tabak	PA	G. W. Collins and J. R. Rygg	M. Zaghoo	Study of precompressed materials using shock compression	

Table I: Recipients of the University of Rochester Frank Horton Fellowship Program at LLE in FY19 (continued).

Student Name	Dept.	Faculty Advisor	LLE Advisor	Research Area	Notes
M. Wang	CHE	D. R. Harding		Use of two-photon polymerization to "write" millimeter-size structures with micron resolution	
K. M. Woo	PA	R. Betti		Three-dimensional ablative Rayleigh–Taylor instability	Defended Ph.D. thesis in April 2019
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	New
D. Zhao	ME	H. Aluie		Multi-scale energy pathways in Rayleigh–Taylor instability flows	
Y. Zhao	MS	W. R. Donaldson		Investigation of the material properties of GaN/AlGaN ultrafast UV photodetectors	Defended Ph.D. thesis in March 2019
H. Zhou	PA	E. Blackman		New developments in mean field electrodynamics and measurable implications for magnetic-field amplification in turbulent, sheared, rotating flows of astrophysical rotators	
Y. Zou	PA	A. Frank		Common envelope evolution: HEDP studies of gravitational wave-merger properties. The role of equation of state and radiation transport	

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

Table II: Sixteen LLE students who obtained their Ph.D. degrees during FY19.

Name	Institution	Destination after obtaining Ph.D.
E. Schiesser	UR	Synopsys' Optical Solution Group
J. Woo	UR	UR/LLE
Y. Zhao	UR	SLD Laser
R. Henchen	UR	Harris Corp. Space and Intelligence Division
Z. Chen	UR	CITA National Postdoc Fellow at the University of Alberta, Canada
D. N. Polsin	UR	UR/LLE
D. Saulnier	UR	UR Institute of Optics
H. Sio	Massachusetts Institute of Technology	LLNL (2019 Lawrence Fellow finalist)
A. Rasmus	University of Michigan	LANL
L. Elgin	University of Michigan	Sandia National Laboratories
A. Hussein	University of Michigan	University of California, Irvine (UC President Postdoc Fellowship)
P. Kordell	University of Michigan	Northrup Grumman
R. Hua	University of California, San Diego	Canon Medical Research USA
J. Trela	University of Bordeaux, France	CEA, France
A. Bott	Oxford University (UK)	Oxford University (now at Princeton University)
C. Holcomb	Princeton University	The Esteé Lauder Companies