Opportunities for U.S.—ELI Collaborations: Laboratory for Laser Energetics Perspective

Proposed EP-OPAL facility

Omega experiment

Dr. Mingsheng Wei
Manager, National Laser Users’ Facility
University of Rochester
Laboratory for Laser Energetics

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The University of Rochester’s Laboratory for Laser Energetics (LLE) is an internationally recognized university-based research center of scale with a focus on national security, fundamental science, laser development, and STEM education.

- **Inertial confinement fusion (ICF)**
  - Experiments, modeling, diagnostics, and innovation

- **High-energy-density physics (HEDP)**
  - $(P, \rho, T)$ of materials of interest to SSP and science (stars, planets, novel materials)

- **Laser technology**
  - Dynamic Compression Sector (DCS) laser

- **Facility operations: 80% of the shots for ICF/HEDP research**

- **Sustain the essential skills and develop future scientists**
  - 500 Ph.D. degrees based on LLE-sponsored and OMEGA-based research

- **OMEGA EP Control Room**

- **LLE-trained national leaders**
  - Charles Verdon
    DOE NNSA Deputy Administrator for Defense Programs
  - David Meyerhofer
    Physics Division Leader
    Los Alamos National Lab
The Omega Laser Facility (the largest lasers in any academic setting worldwide) designed, built and operated by LLE, is a unique national resource, delivering ~2300 shots/year for ICF, HED, and fundamental science research.

**UR/LLE**
- Funded by DOE/NNSA through a cooperative agreement
- Faculty equivalent staff: 121
- Professional staff: 178
- Associated faculty: 25
- Graduate and undergraduate students: 145
  - ~35 students from other universities

**OMEGA Laser System**
- Operating since 1995
- 60 beams, 30 kJ UV on target
- Spherical and cylindrical compression
- 1% to 2% irradiation nonuniformity
- Flexible pulse shaping
- Up to 1500 shots/year

**OMEGA EP Laser System**
- Operating since 2008
- 4 NIF-like beamlines
  - 5-kJ/beam UV (10 ns)
- Two IR beams can be kJ-class petawatt
- IR beam(s) or one tunable UV beam can be coupled to OMEGA
- ~800 shots/year

**>200 diagnostics operated and supported by LLE**
- Combined long- and short-pulse operation
- Versatile experimental capabilities
- Magnetic fields (~50 Tesla)

More than half of Omega shots are for external users from national laboratories and universities including international users.
LLE plays a key role in building the scientific user community through the Omega Laser Facility Users Group (OLUG)—a self-organized group guided by its bylaws

- OLUG represents over 400 scientific users from 55 universities, over 35 centers and national laboratories in 21 different countries on 4 continents
- Annual OLUG workshop with >110 attendees
- Enhances the capabilities of the Omega facilities and user experiences through findings & recommendations
- Offers mentorship and networking for students and postdocs
LLE partners with various institutions to advance science and technology and to expand the community

UR/LLE organizes workshops and meetings (15 in last two years), covering a broad range of topics with international participations:

- Laser operations and safety
- Laser–plasma interactions
- ICF and HED physics
- Relativistic plasmas and high field science
- Equation of state
- Magnetic field in laser plasmas
- Diagnostics
- Target fabrications
- User group and networks
- and more …

We have strong collaborations with institutions from Europe! CEA and CELIA are our international partners.
Innovations in laser science lead to new opportunities in science and applications

Chirped pulse amplification technique was invented at LLE

Figure 1. With the Petawatt laser in the background, Livermore's Michael Perry (left) shows how far the technology has come to UC Berkeley Professor Charles Townes, who co-invented the laser.

LLNL: Lawrence Livermore National Laboratory
LLE is building a prototype system pumped by the Multi-Terawatt laser (MTW-OPAL, 0.5 PW in 15 fs)
- MTW-OPAL demonstrates laser technologies for EP-OPAL and provides a unique mid-scale laser user facility
- Scheduled completion by end of 2019

LLE proposes EP-OPAL: a world-class ultra-intense laser facility with unprecedented capabilities leveraging the existing OMEGA EP infrastructure

EP-OPAL capabilities: Two 25-PW beams + up to 1-TeV electron beam from LWFA

Frontier science topics addressing two NSF Big Ideas:
“Windows on the Universe” and “Quantum Leap”

EP-OPAL directly responds to 2018 National Academy of Sciences study* recommendations:
- Define facilities and laser parameters that will best serve research needs emphasizing parameters beyond the current state of the art
- Plan for at least one large-scale open-access, high-intensity laser facility that leverages other major science infrastructure in the DOE complex

* 2018 National Academy of Sciences report Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light

OPAL: optical parametric amplifier line
NSF: National Science Foundation
LWFA: laser wakefield acceleration
EP-OPAL enables frontier science that could lead to multiple advances worthy of Nobel prizes.

Creating and probing new quantum states of matter at atomic pressures extends UR leadership in HEDS.

Generating electron-positron plasmas from vacuum and other extreme field effects opens a *Window on the Universe*.

Scaling laser-based particle acceleration enables ~TeV electrons for basic science and applications.

Collaborative effort throughout the research community including engagement in research at ELI facilities will be needed to realize these opportunities.

UR: University of Rochester
ILC: International Linear Collider
EP-OPAL would provide world-leading ultrahigh-peak-power lasers complementary to ELI for breakthrough frontier science

Two Optical Parametric Amplifier Lines (OPAL) would be:
- Pumped to ~ 500 J by an existing EP beamline (kJ, ns) ...
- Compressed to 20 fs to achieve world-leading laser power (25 PW) and intensity (>>10\(^{23}\) W/cm\(^2\))

EP-OPAL facility will include:
- Beam 1: short and long focal length
- Beam 2: short focal length in near copropagating, perpendicular, and near counterpropagating geometry
- Option for 2 PW shot/min operations in each beamline
- Additional existing high energy OMEGA EP long-pulse beams for target preconditioning (351 nm, multi-kJ, ns)

The University will provide a new dedicated building to house the EP-OPAL facility (if awarded) adjacent to the OMEGA EP building.

We will continue to seek input from scientific community to further define the facility system design to achieve the best science!
ELI and LLE have developed strong connections and are discussing the development of multidisciplinary collaborations

- Dr. Jon Zuegel from LLE has served on the Scientific Advisory Committees for ELI-Beamlines and ELI-ALPS

- ELI and LLE Operations staff have made connections through International Laser Operations Workshops (ILOW) and have met bi-annually since 2013
  - ELI-NP and ELI-ALPS groups visited LLE for the 2017 ILOW
  - extensive dialog regarding operational efficiency, effectiveness, and common issues

- Various ELI groups including ELI-ERIC have visited LLE since 2017

- UR/LLE and the Institute of Physics of the Czech Academy of Sciences (FZU, ELI Beamlines) signed a MoU to establish mutually beneficial multidisciplinary collaborations in 2016
  - a new MoU is close to being finalized

- A MoU between UR/LLE and “Horia Hulubei” National Institute of Physics and Nuclear Engineering, Romania is under discussion to establish collaborations centered around ELI-NP
ELI and LLE have developed strong connections and are discussing the development of multidisciplinary collaborations.
There are potential collaboration opportunities on facility operation, laser development, optics, diagnostics, and collaborative scientific research

- Laser facility operation training opportunities at LLE for ELI facilities’ operation teams
- Optical coating for large optics for ELI facilities
  - LLE operates a world-class optical coating facility that develops and produces coatings for research facilities around the world including the National Ignition Facility in the U.S. and Laser Mégajoule in France
- Laser development: optical and optomechanical design; frequency and phase conversion optics (doubling crystal, distributed phase plates); laser diagnostics
- Collaboration on experimental instruments: optical, x-ray, particle, and neutron diagnostics
- Collaborative experiments at ELI and LLE facilities, for example
  - laser wakefield acceleration of electrons and x-ray source generation
  - mega-tesla magnetic field assisted particle and gamma beams from ultra-intense laser interaction with structured targets
- Joint workshops and working group meetings
The new LaserNetUS network provides an excellent basis for developing expertise and collaboration in frontier science using ultra-intense lasers.

- A U.S. DOE research network (established in Aug. 2018), funded by the Office of Fusion Energy Sciences, to give U.S. scientists access to intense laser sources: www.lasernetus.org
  - First beam-time awards in May 2019
  - has expanded to International users from the 2nd LaserNetUS call issued in July 2019
- Ongoing discussions with international institutions and organizations about collaborations
Summary and remarks

• The Omega Laser Facility is a DOE’s workhorse laser user facility for ICF, HED, and fundamental science research
  - high standard in operation
  - strong user culture
  - experiments and research are inherently collaborative

• Technology for high-intensity lasers was invented at LLE and we continue to innovate to define its future
  - the proposed EP-OPAL facility with 2 × 25-PW laser beams will go beyond the current state of the art, complementary to the ELI facilities

• Strong synergies between LLE and ELI on ultraintense lasers and their many applications with prospect breakthrough in frontier science with broad societal impact warrant close collaborations
  - Several opportunities and areas for collaborations have been identified

We welcome collaborations with various ELI institutions in exploring these exciting new frontiers!