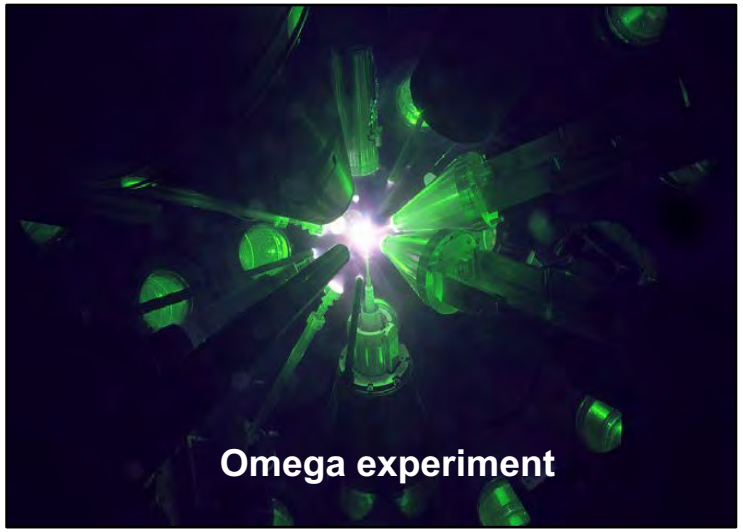
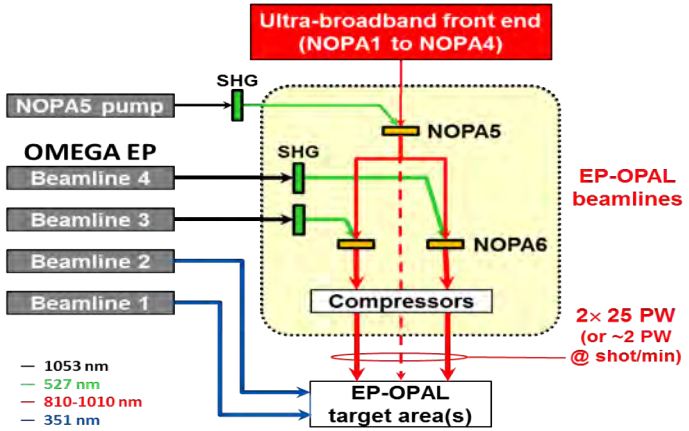
Opportunities for U.S.—ELI Collaborations: Laboratory for Laser Energetics Perspective



Proposed EP-OPAL facility



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

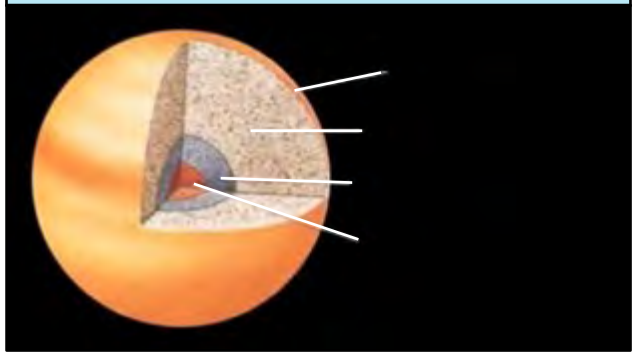
U.S.—ELI Joint Workshop
The Optical Society (OSA)
Washington, D.C.
25 September 2019

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)

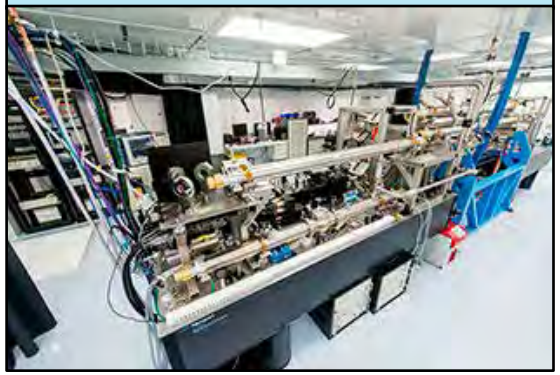
Experiments, modeling, diagnostics, and innovation

High-energy-density physics (HEDP)



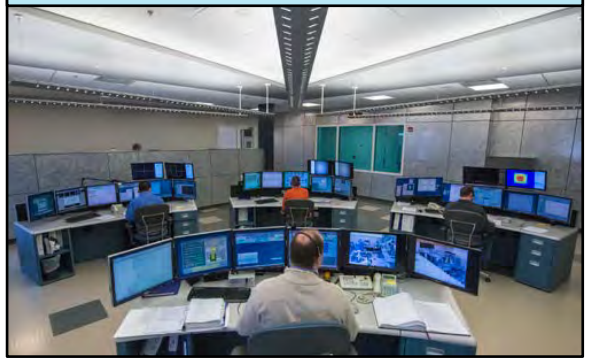
(P, ρ, T) of materials of interest to SSP and science (stars, planets, novel materials)

Laser technology



Dynamic Compression Sector (DCS) laser

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



OMEGA EP Control Room

Sustain the essential skills and develop future scientists

500 Ph.D. degrees based on LLE-sponsored and OMEGA-based research

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

OMEGA EP Laser System

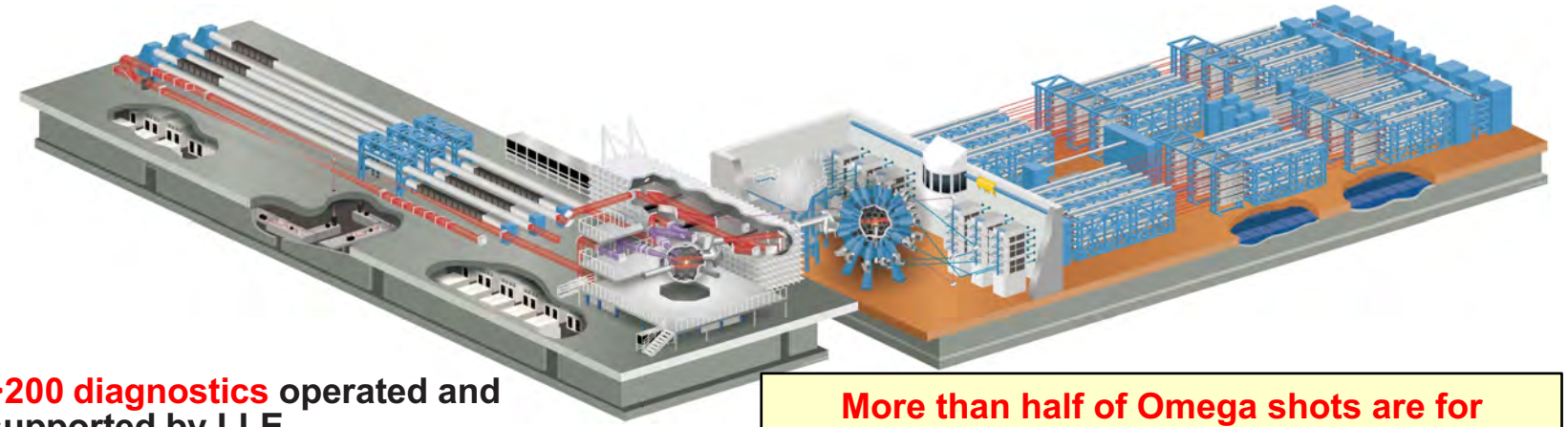
- Operating since 2008
- 4 NIF-like beamlines
  - 5-kJ/beam UV (10 ns)
- Two IR beams can be kJ-class petawatt
- IR beam(s) or one tunable UV beam can be coupled to OMEGA
- ~ 800 shots/year

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

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

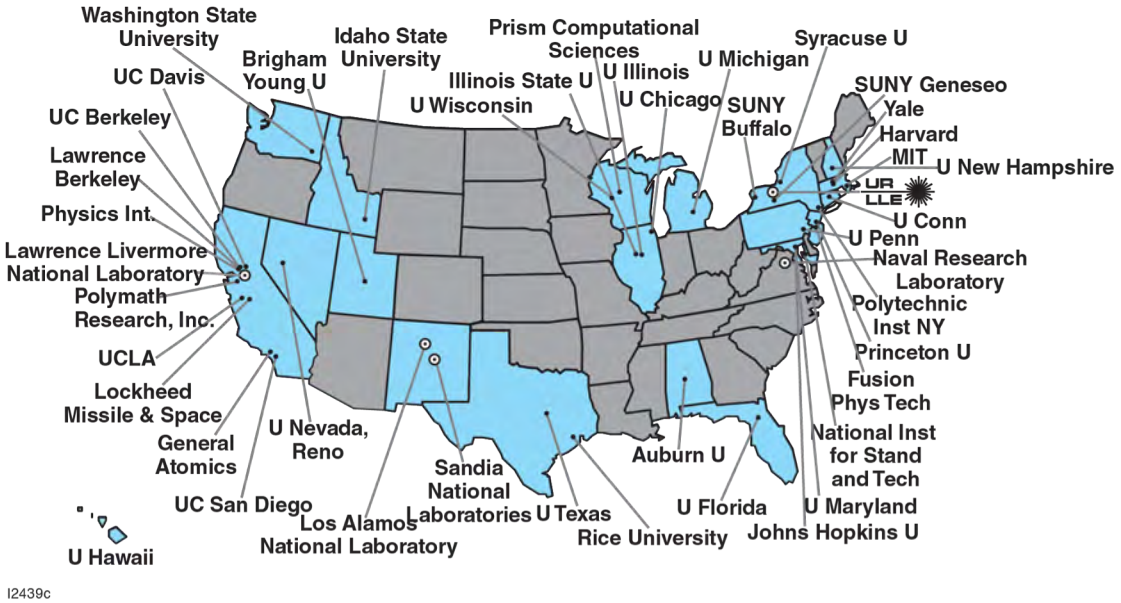


- >200 diagnostics operated and supported by LLE
- Combined long- and short-pulse operation
- Versatile experimental capabilities
- Magnetic fields (~50 Tesla)

More than half of Omega shots are for external users from national laboratories and universities including international users.

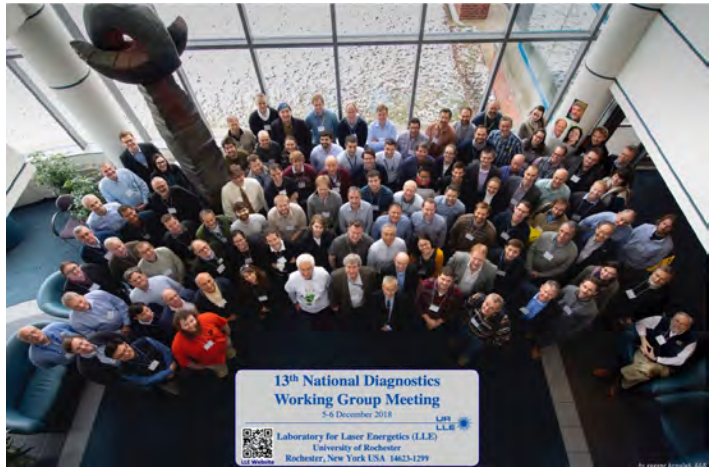
DOE: Department of Energy
NNSA: National Nuclear Security Administration
NIF: National Ignition Facility

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

First Petawatt at LLNL

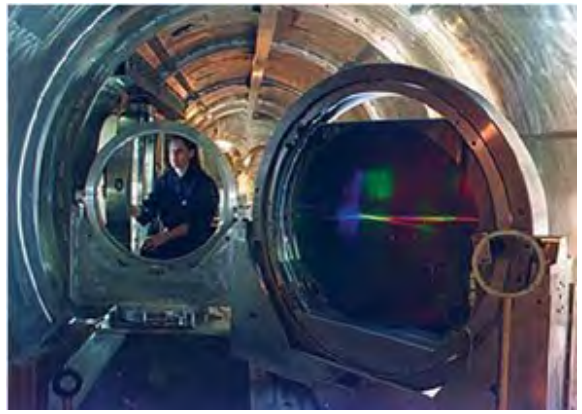


Figure 1. With the Petawatt laser in the background, Livermore's Michael Perry (left) shows how far the technology has come to UC Berkeley Professor Charles Townes, who co-invented the laser.

LLNL: Lawrence Livermore National Laboratory

LLE continues to play a central role in defining the future of the high-intensity lasers

- **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"

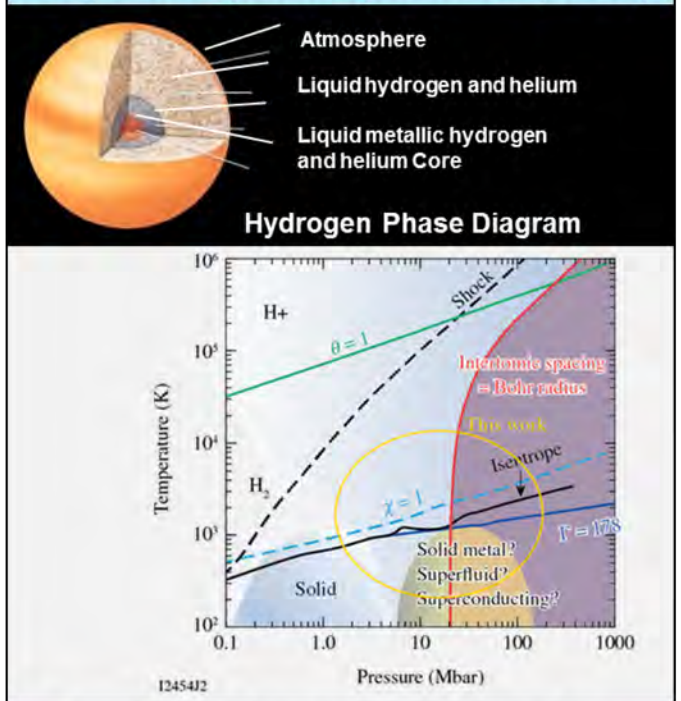
- **EP-OPAL directly responds to 2018 National Academy of Sciences study* recommendations:**
  - ***Define facilities and laser parameters that will best serve research needs emphasizing parameters beyond the current state of the art***
  - ***Plan for at least one large-scale open-access, high-intensity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

OPAL: optical parametric amplifier line
NSF: National Science Foundation
LWFA: laser wakefield acceleration

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

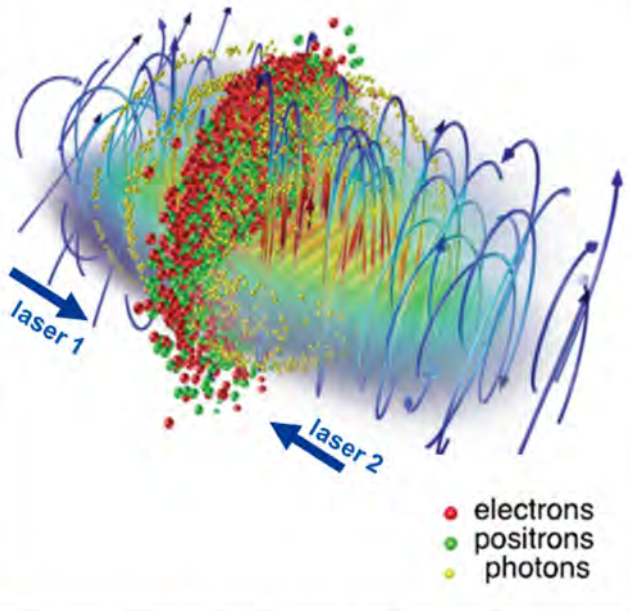
EP-OPAL enables frontier science that could lead to multiple advances worthy of Nobel prizes

High-Energy-Density Science (HEDS)



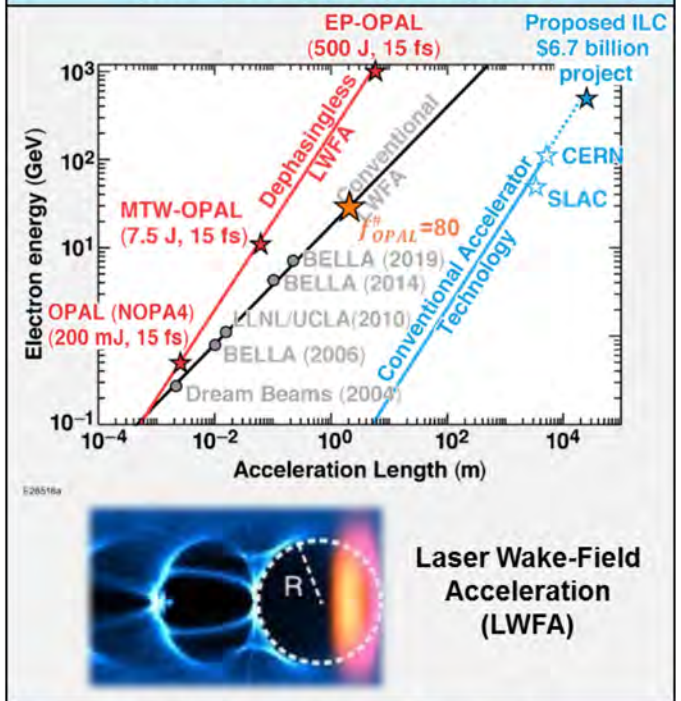
Creating and probing new quantum states of matter at atomic pressures extends UR leadership in HEDS

Quantum Science with Extreme Fields



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

Relativistic particle beams



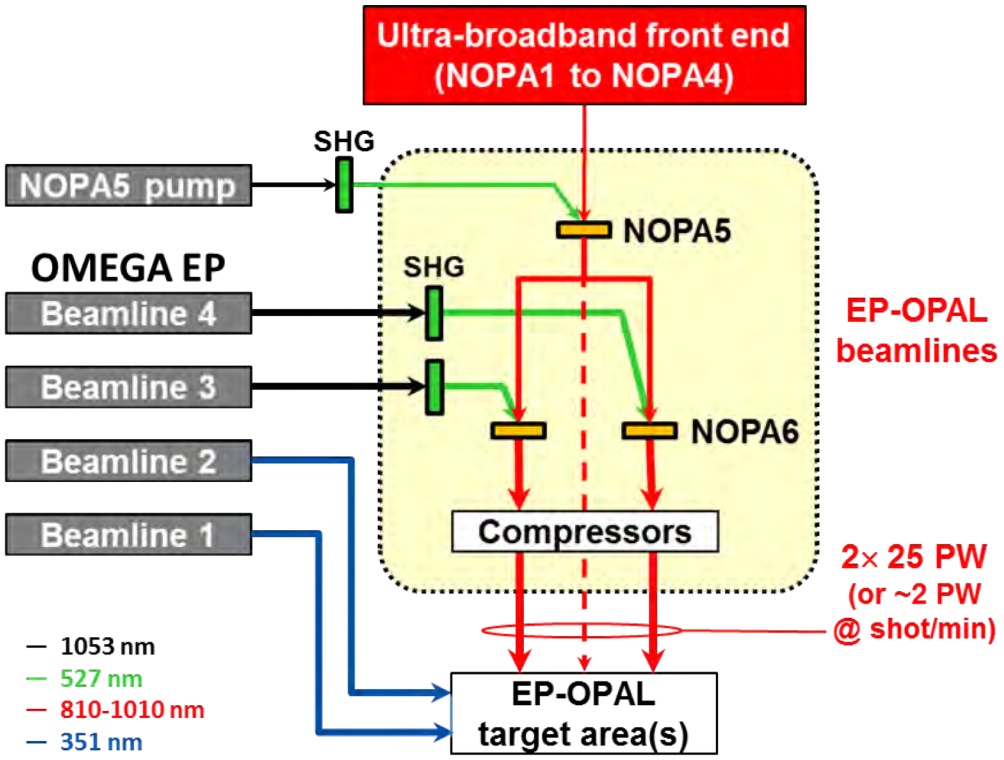
Scaling laser-based particle acceleration enables ~TeV electrons for basic science and applications

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

EP-OPAL facility schematic



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.

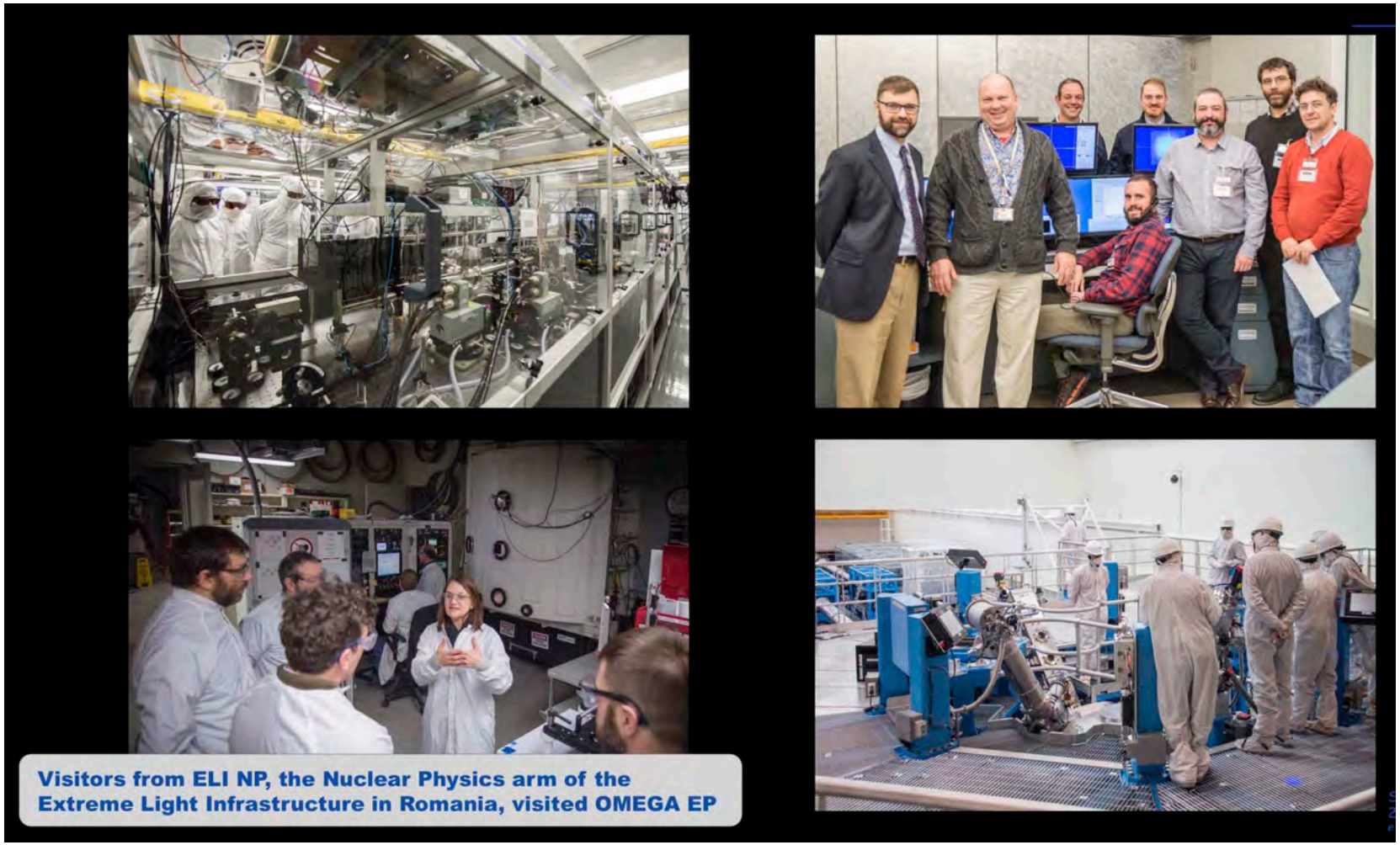
We will continue to seek input from scientific community to further define the facility system design to achieve the best science!

NOPA: noncollinear optical parametric amplification

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



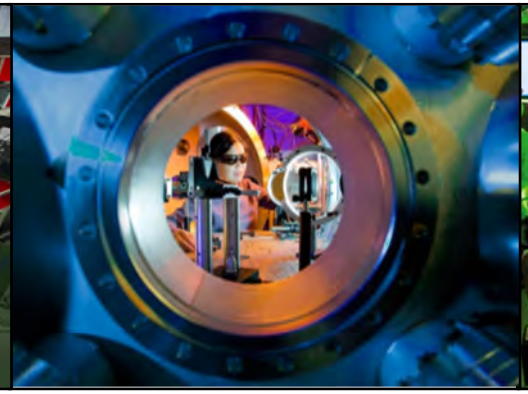
There are potential collaboration opportunities on facility operation, laser development, optics, diagnostics, and collaborative scientific research

- 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

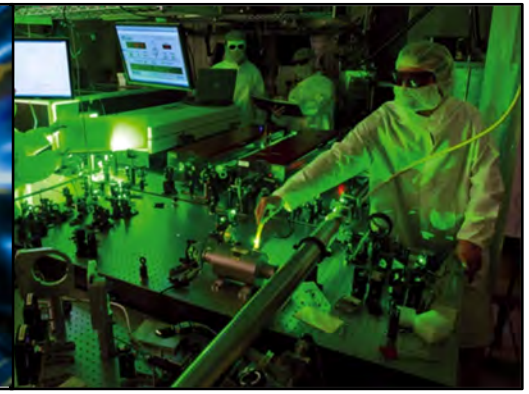
The new LaserNetUS network provides an excellent basis for developing expertise and collaboration in frontier science using ultra-intense lasers

Colorado State University
Advanced Beam Laboratory: Petawatt Laser

Lawrence Berkeley National Laboratory
Berkeley Lab Laser Accelerator (BELLA) Center

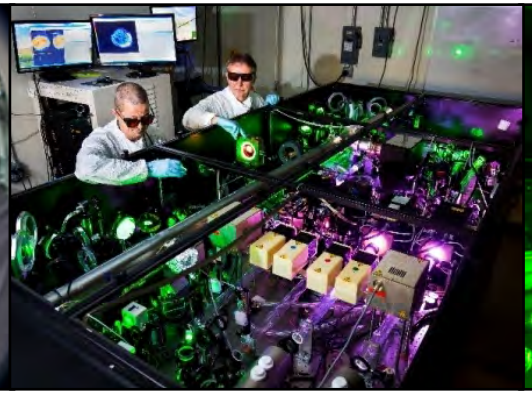


Lawrence Livermore National Laboratory
Jupiter Laser Facility

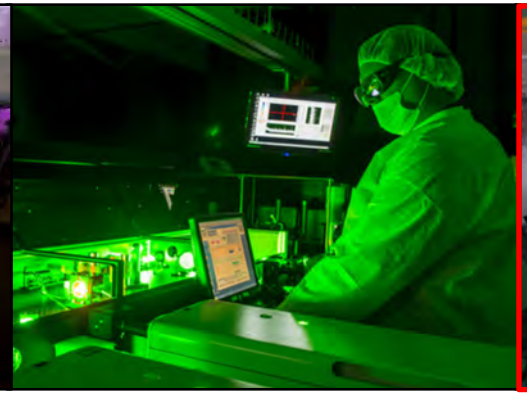


Ohio State University
Scarlet Laser Facility

SLAC National Accelerator Laboratory
Matter in Extreme Conditions (MEC) Laser Facility

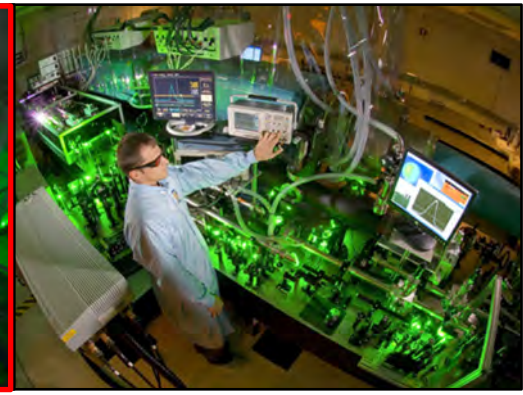


University of Michigan
Center for Ultrafast Optical Science: HERCULES



University of Nebraska - Lincoln
Extreme Light Laboratory

University of Rochester
Laboratory for Laser Energetics: OMEGA EP



University of Texas - Austin
Center for High Energy Density Science:
Texas Petawatt Laser

- **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!