LaserNetUS – The First Five Years of Scientific Discovery

APS Division of Plasma Physics Annual Meeting

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On behalf of the LaserNetUS facilities and user community

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LaserNetUS

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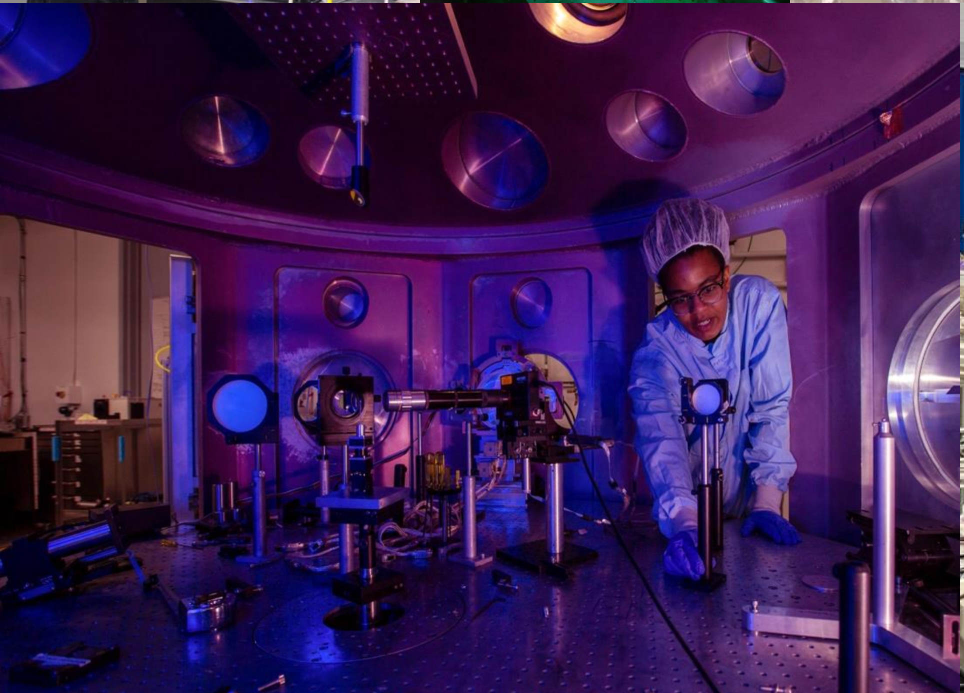


HAMAMATSU

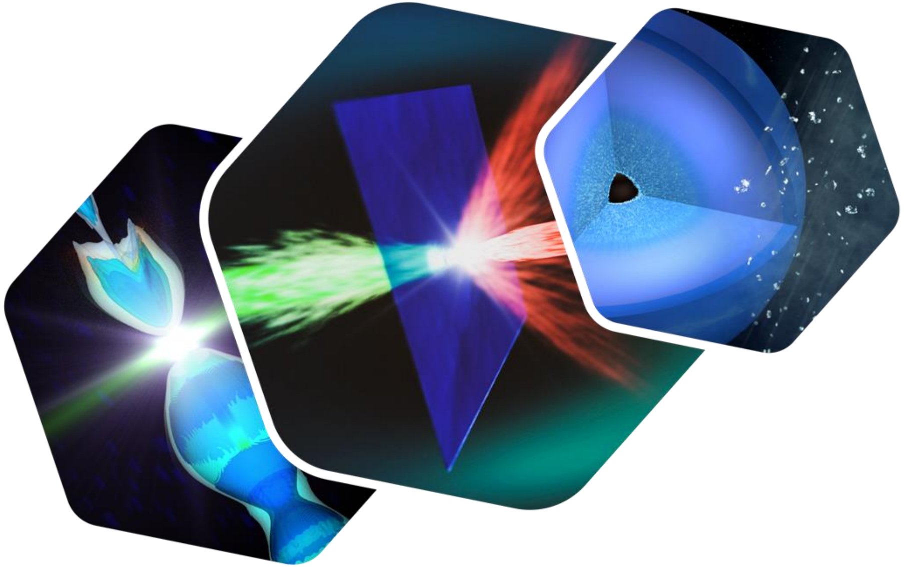

BELLA, LBNL
MEC, SLAC
Aleph, CSU
JLF, LLNL
Phoenix, UCLA
Diocles, UNL
TPW, UT
UMich
ALLS, INRS
Omega, UR
Scarlet, OSU
ILMI, UMD
iFAST, UCF

LaserNetUS

Our Mission

"to advance the frontiers of high-power laser science and applications"

We fulfill this mission by



Supporting cutting edge research with high-power lasers

Providing access to unique facilities and enabling technologies

Fostering collaboration among researchers around the world

Providing training and leadership opportunities for students and early career researchers

Outline

History of high power and high intensity lasers

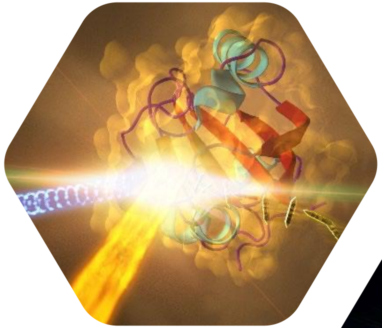
The creation and operation of LaserNetUS

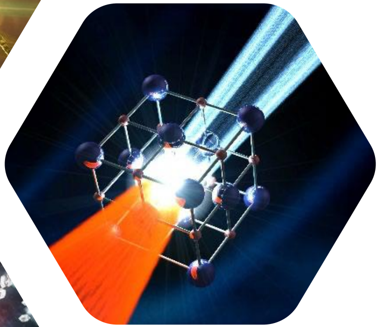
LaserNetUS: 5 years of scientific discovery

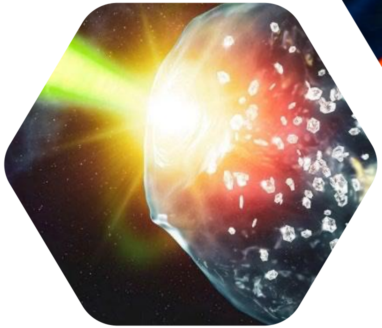
- Secondary sources in underdense plasmas
- Secondary sources in overdense plasmas
- Extreme environments to understand space and fusion plasmas

LaserNetUS: 5 years of community building

High power lasers can







Recreate the conditions at the heart of stars and planets and harness fusion

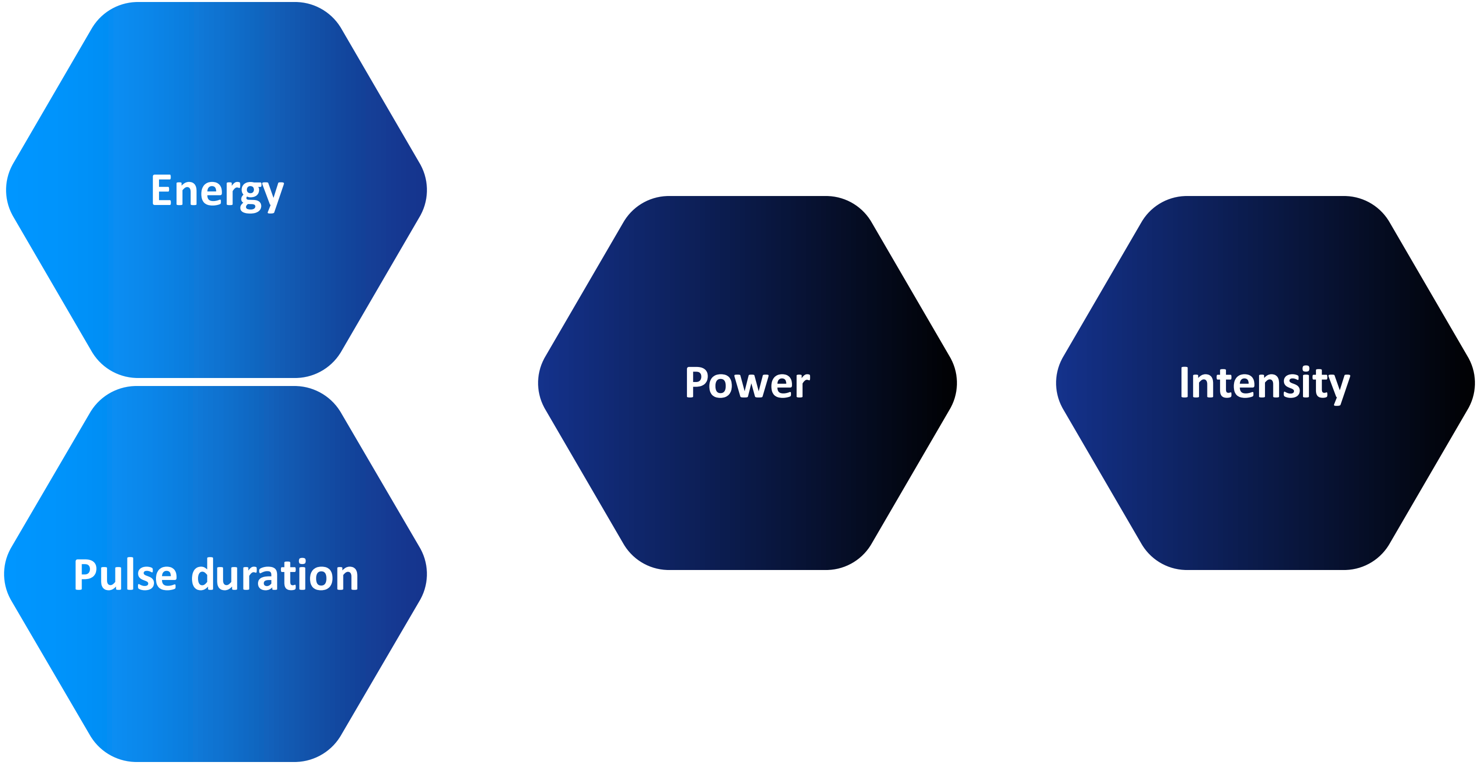
Control and probe chemical reactions

Create matter out of vacuum

Transform materials to gain advanced functionality

Shrink the next generation of particle accelerators

Laser characteristics drive the physics of laser-plasma interactions



Laser characteristics drive the physics of laser-plasma interactions

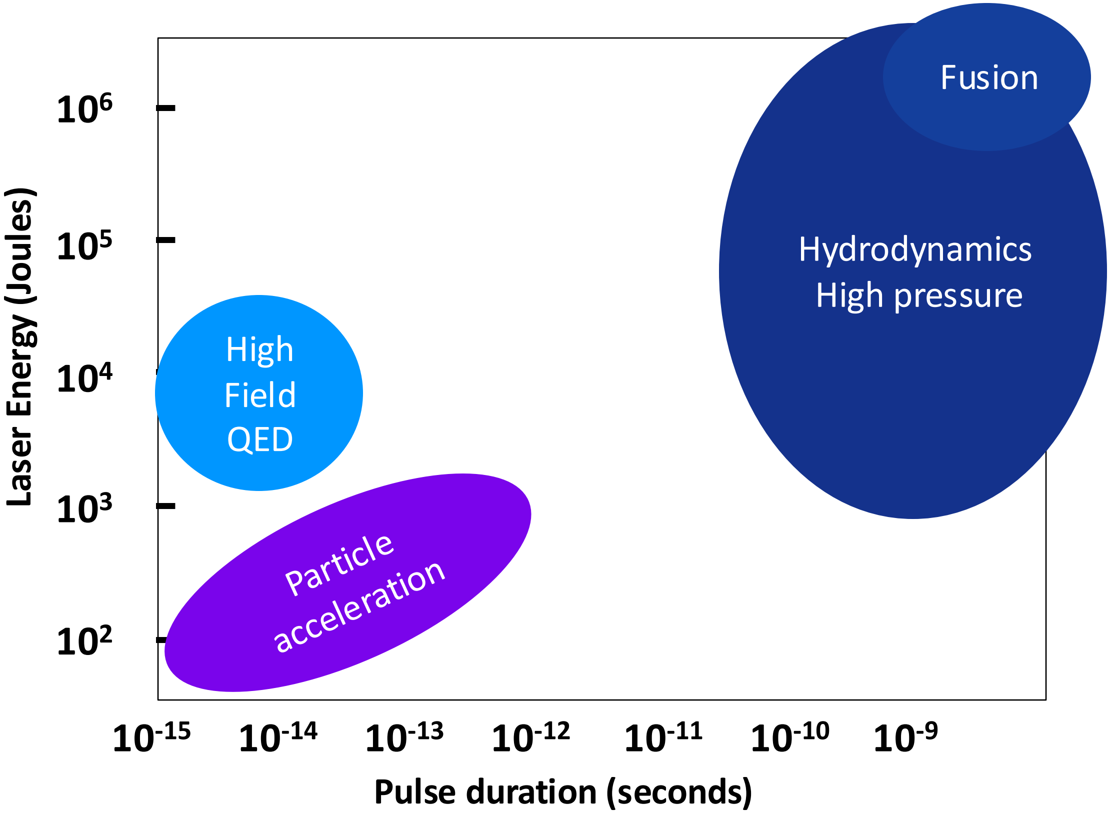
100 TW laser

1 MJ, 10 ns

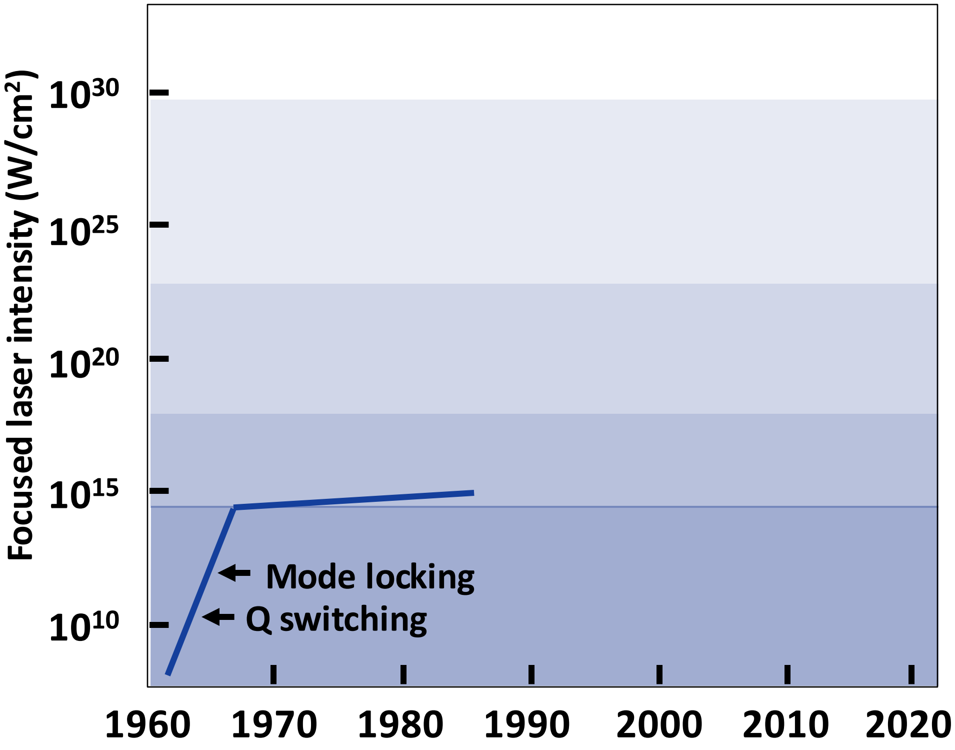
Hydrodynamic effects
Fluid motion

3 J, 30 fs

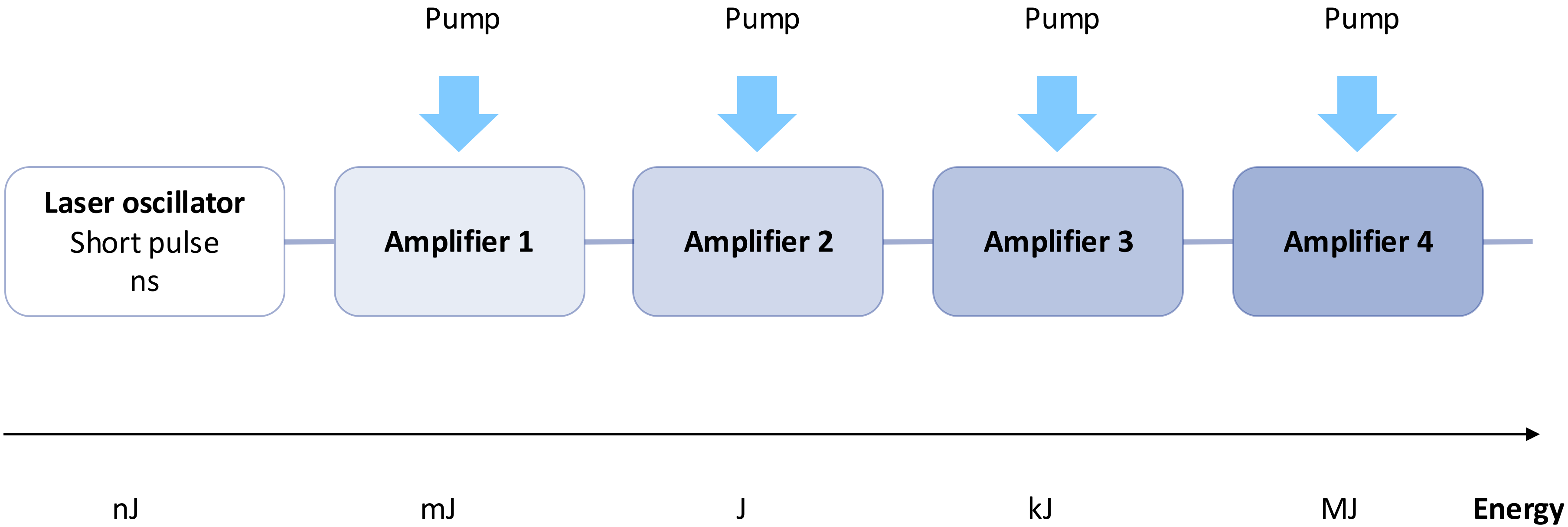
Kinetic effects
Particle motion



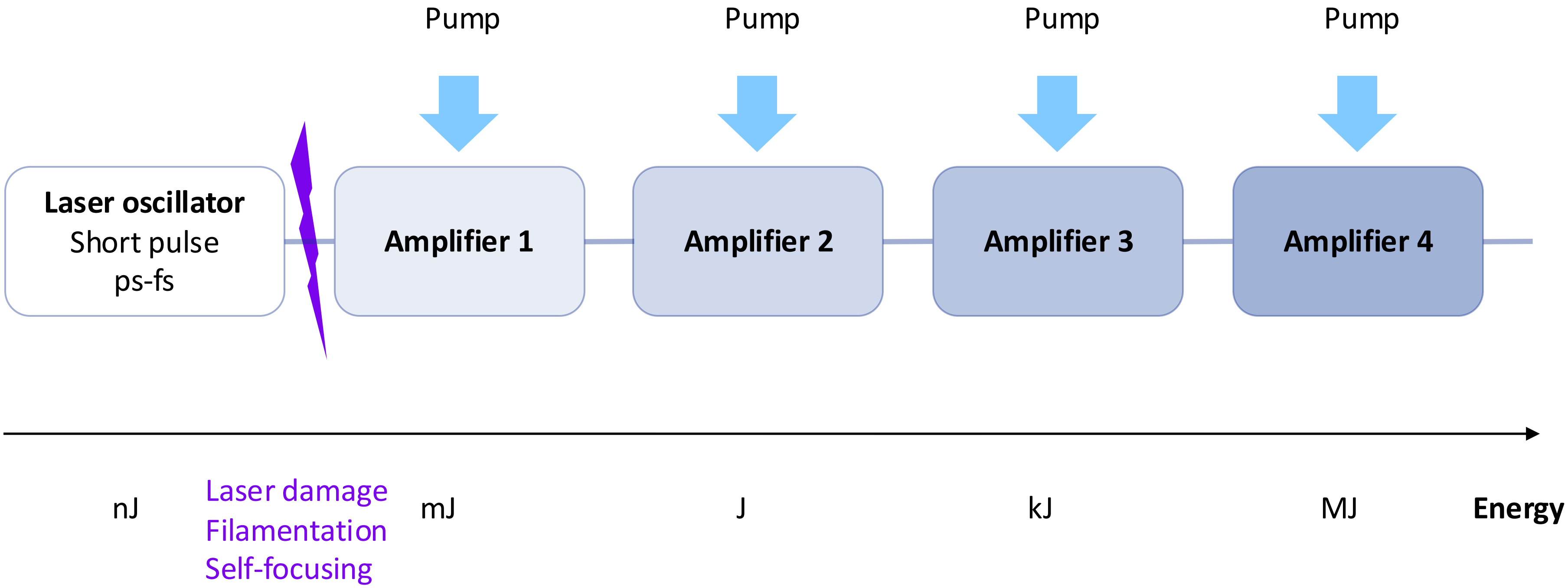
Following the laser invention in 1960, laser intensity rapidly increased but plateaued until the mid 1980s

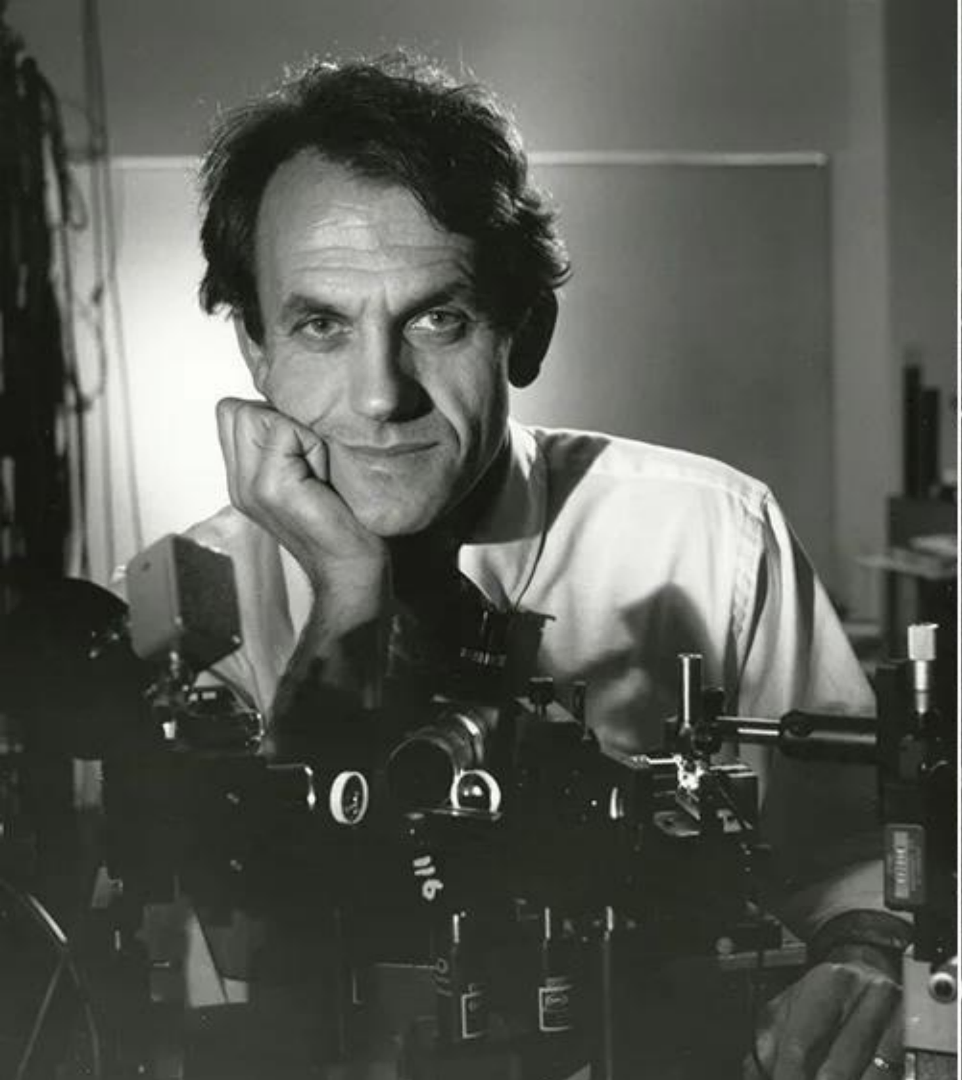


Increasing laser energy can be achieved by successive amplification stages

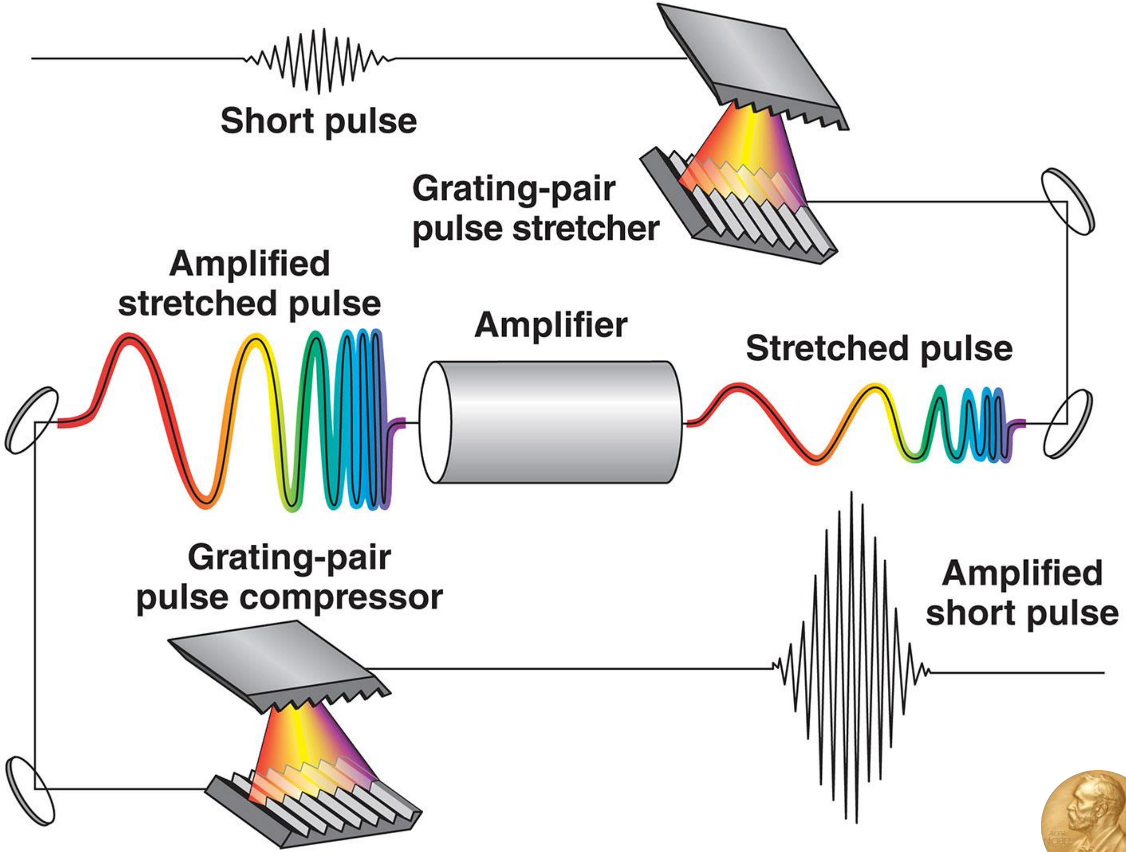


But it does not work for pulses shorter than a few 100 ps





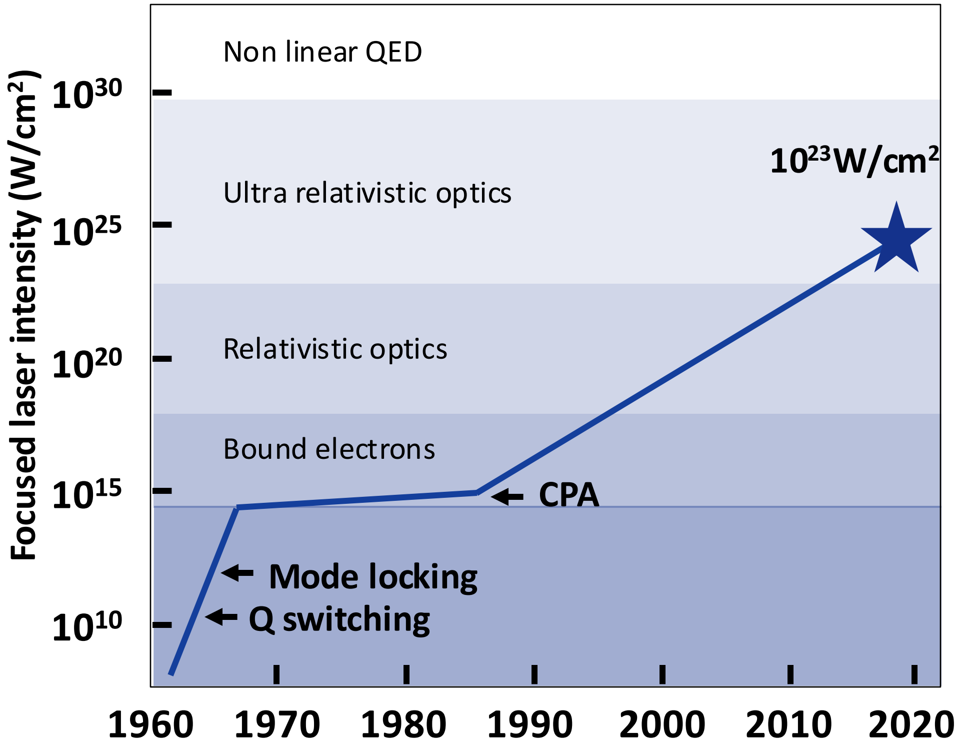

High intensity lasers rely on chirped pulse amplification



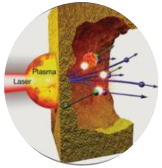
D. Strickland and G. Mourou, Optics Communications 55, 447 (1985)

D. Strickland, G. Mourou
Physics Nobel Prize 2018

CPA has enabled the community to reach new intensity frontiers

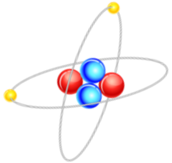


Creating matter out of light



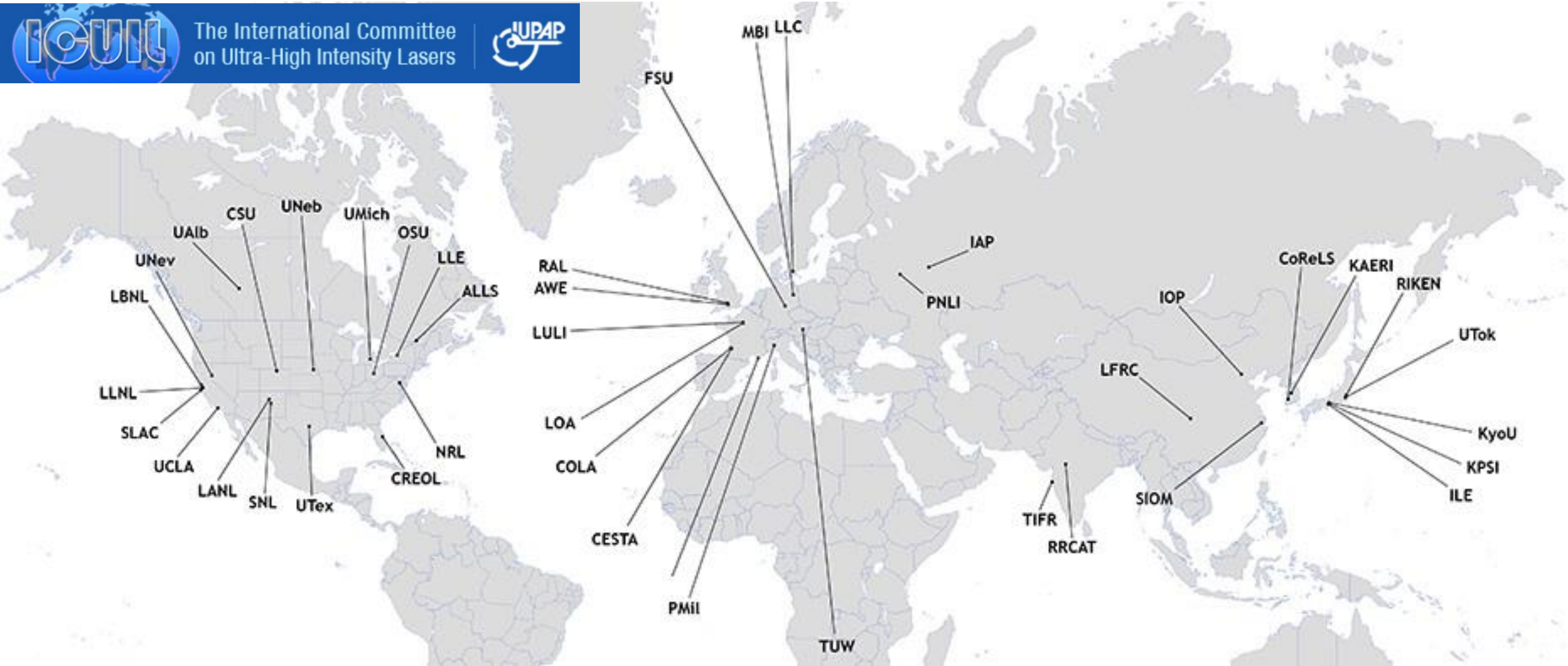
Accelerating ions to relativistic energies

Accelerating electrons to relativistic energies



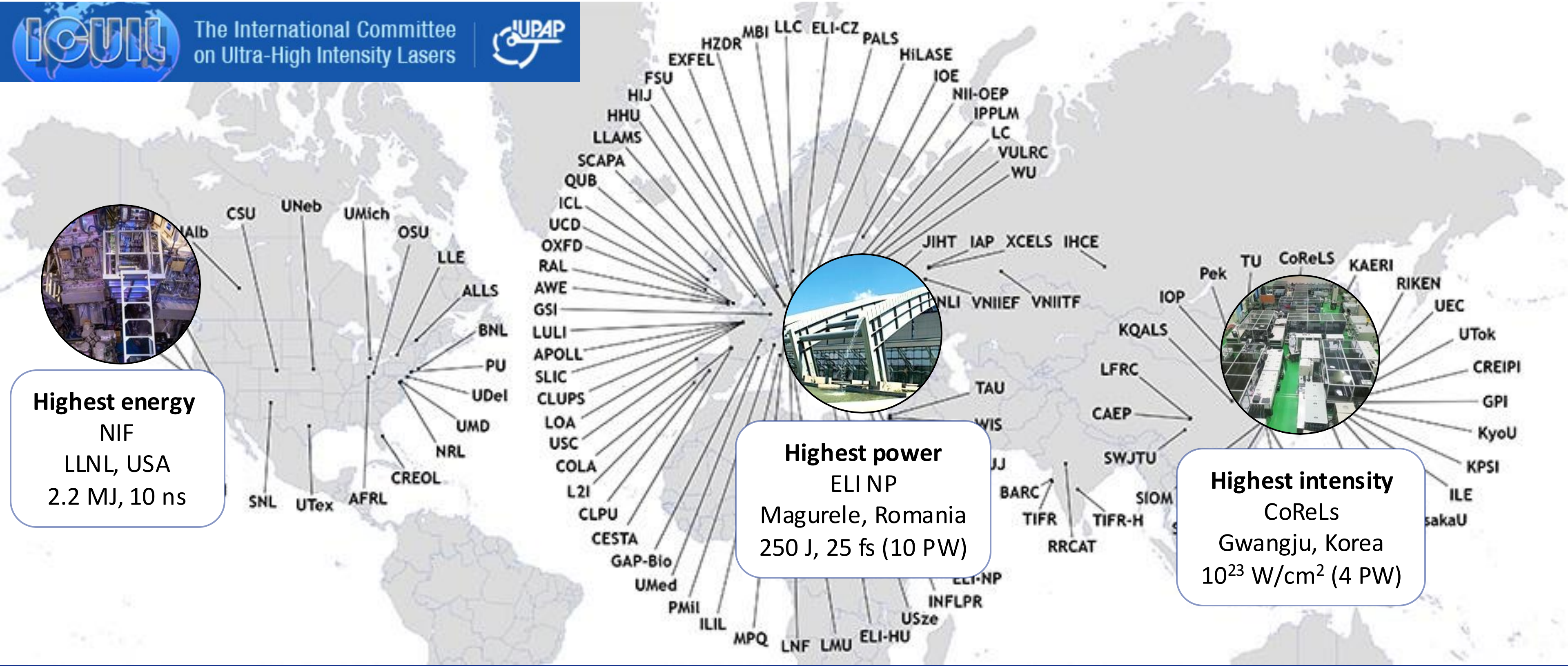
Stripping electrons out of atoms

In 2009, there were few high power lasers in the world



That number increased to about 100 in 2020, but mostly in Europe and Asia

The International Committee on Ultra-High Intensity Lasers

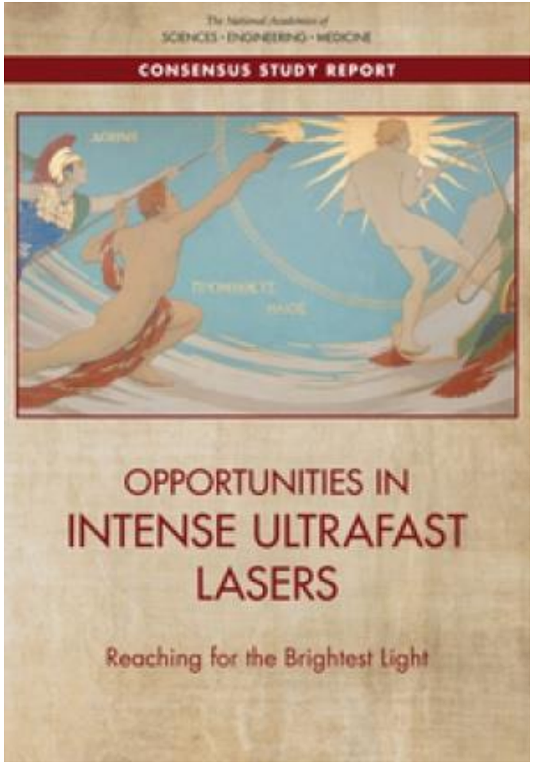


Highest energy
NIF
LLNL, USA
2.2 MJ, 10 ns

Highest power
ELI NP
Magurele, Romania
250 J, 25 fs (10 PW)

Highest intensity
CoReLs
Gwangju, Korea
10^{23} W/cm^2 (4 PW)

A 2018 NAS report made recommendations to revive high intensity laser research in the US



*"In particular, that DOE should **create a broad national network** in coordination with OSTP, DOD, NSF, and others to support science, applications and technology."*

The LaserNetUS network was established on August 20th, 2018

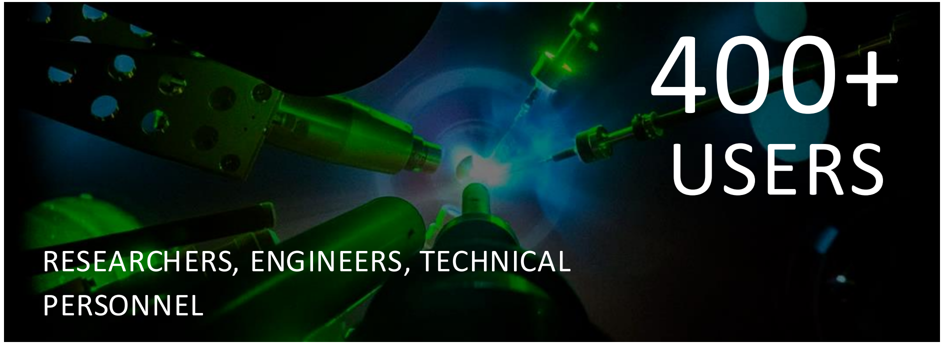
13

HIGH-POWER LASER FACILITIES

ACROSS NORTH AMERICA

140+

EXPERIMENTS



400+

USERS

RESEARCHERS, ENGINEERS, TECHNICAL PERSONNEL

44

PUBLICATIONS

The first five years of LaserNetUS

Scientific Advisory Board forms

Formation of LaserNetUS Committees

2018: first Chair of LaserNetUS

First meeting in Lincoln, NE

2020: LaserNetUS renewed

2023: DE-FOA-0002982: LaserNetUS For Discovery Science And Inertial Fusion Energy

Established by DOE FES 2018

LaserNetUS looks forward

Kramer Akli
DOE FES

New Proposal Review Process

2020: Second Chair of LaserNetUS

2021: LaserNetUS Coordinator

2022: New Chair and Vice-Chair

LaserNetUS has a structure providing broad support for users

US Department of Energy – Office of Fusion Energy Sciences

Chair

Vice Chair

Coordinator

Network Facilities Committee

I-USE

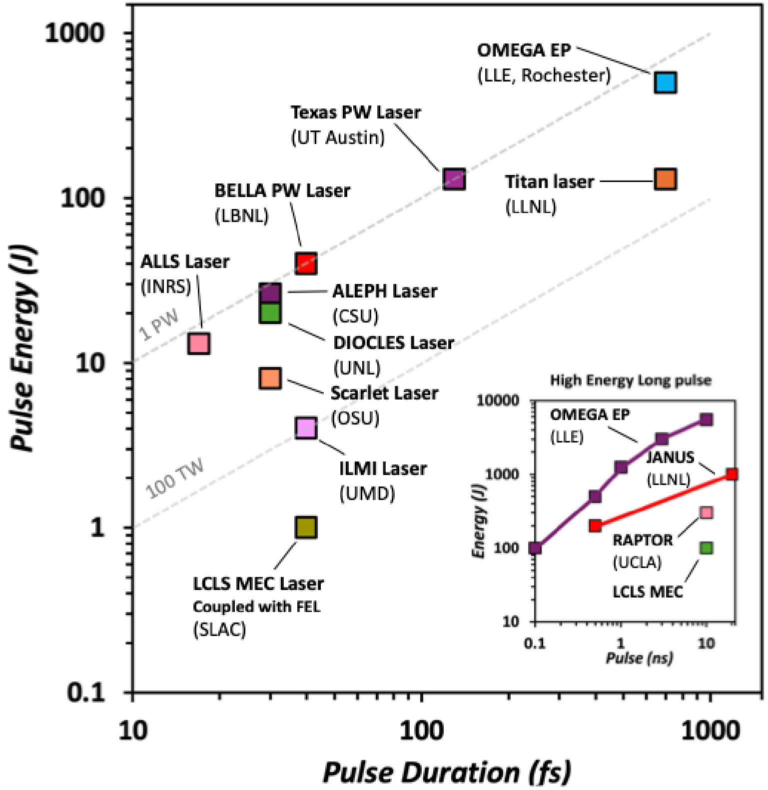
Diagnostics

Simulations

Proposal Review Panel

Scientific Advisory Board

Our capabilities enable science and applications of interest to the DPP community



- High intensity laser pulses at high repetition rate
- High energy (up to kJ) pulses with precision control and flexible configurations
- High repetition rate targetry and diagnostics
- Multiple wavelengths from 0.4 to 2 μm
- High energy x-ray beam synchronized to optical lasers

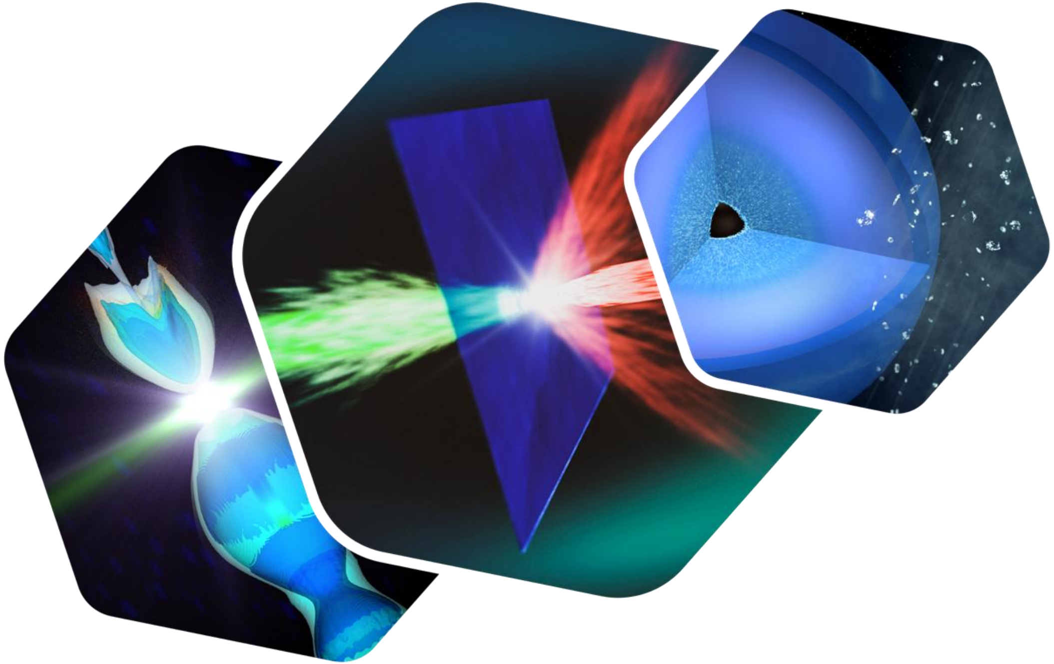
LaserNetUS: Five years of scientific discovery

Secondary sources in underdense plasmas

Secondary sources in overdense plasmas

Extreme environments to understand space and fusion plasmas

LaserNetUS: Five years of scientific discovery



Accelerating electrons to energies and quality only thought possible in conventional particle accelerators

In 1979, John Dawson and his student Toshi Tajima proposed a revolutionary technique to accelerate electrons in plasmas

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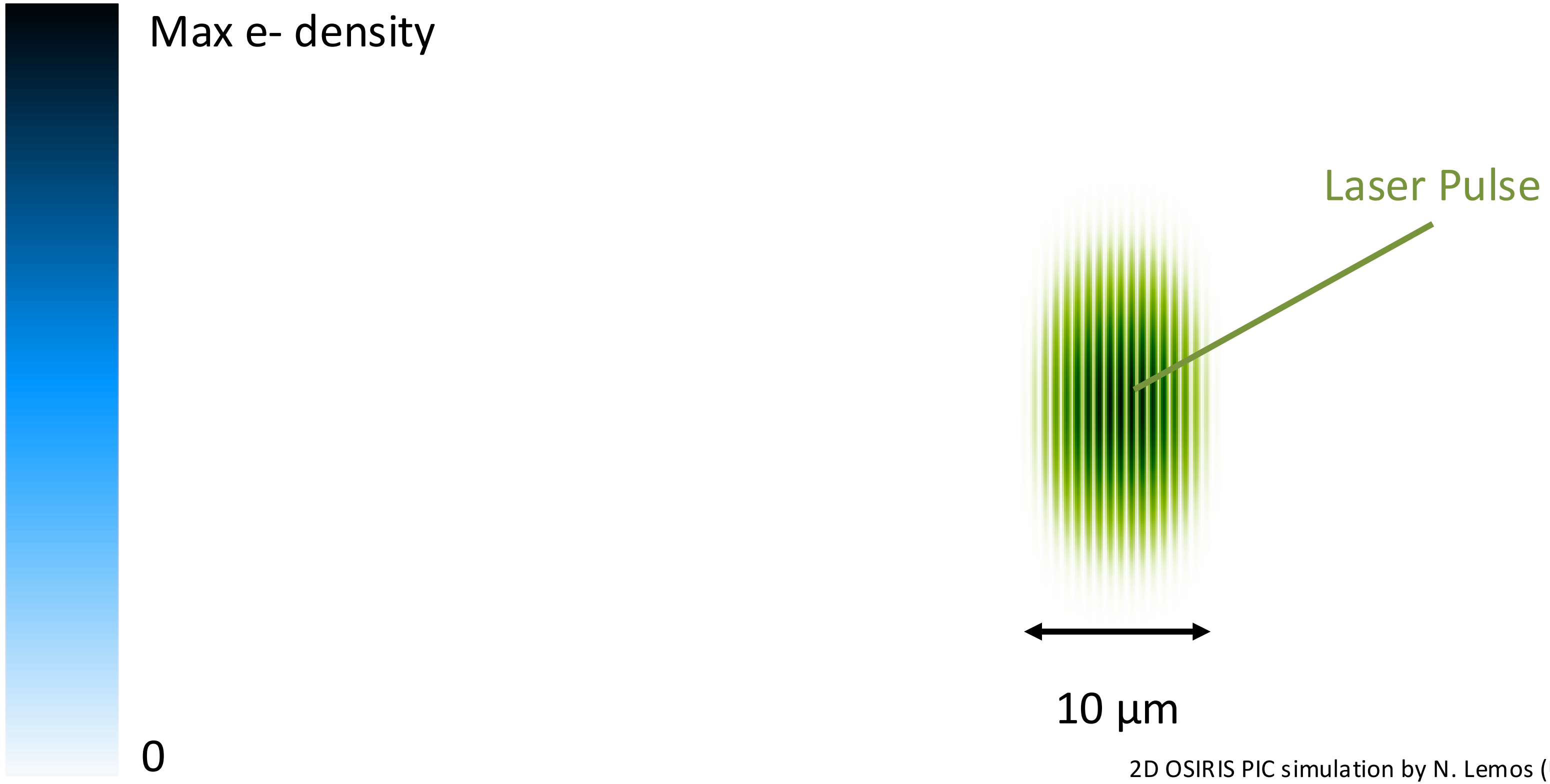
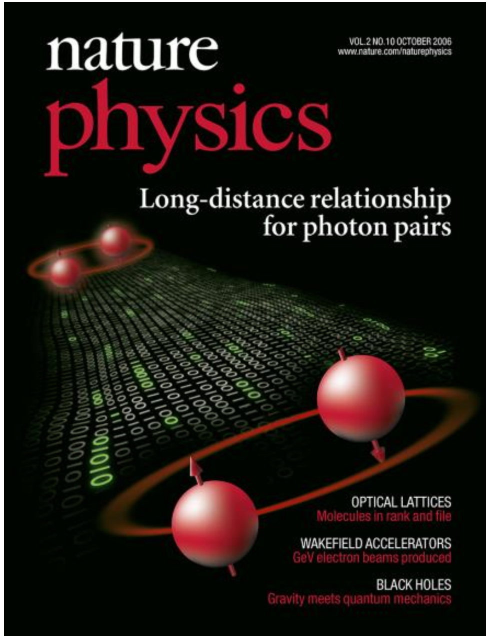


2D OSIRIS PIC simulation by N. Lemos (UCLA/LLNL)

With the advent of CPA lasers, Laser Wakefield Acceleration went on to achieve groundbreaking results

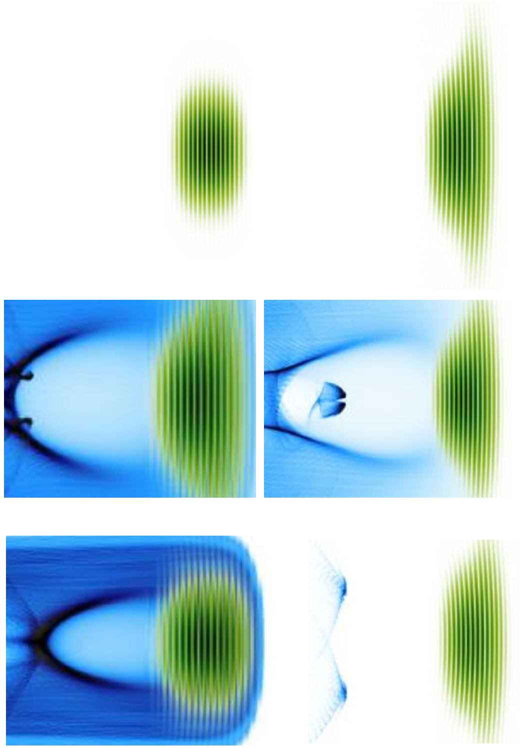
1994
28 MeV electrons

2004
Monoenergetic electrons



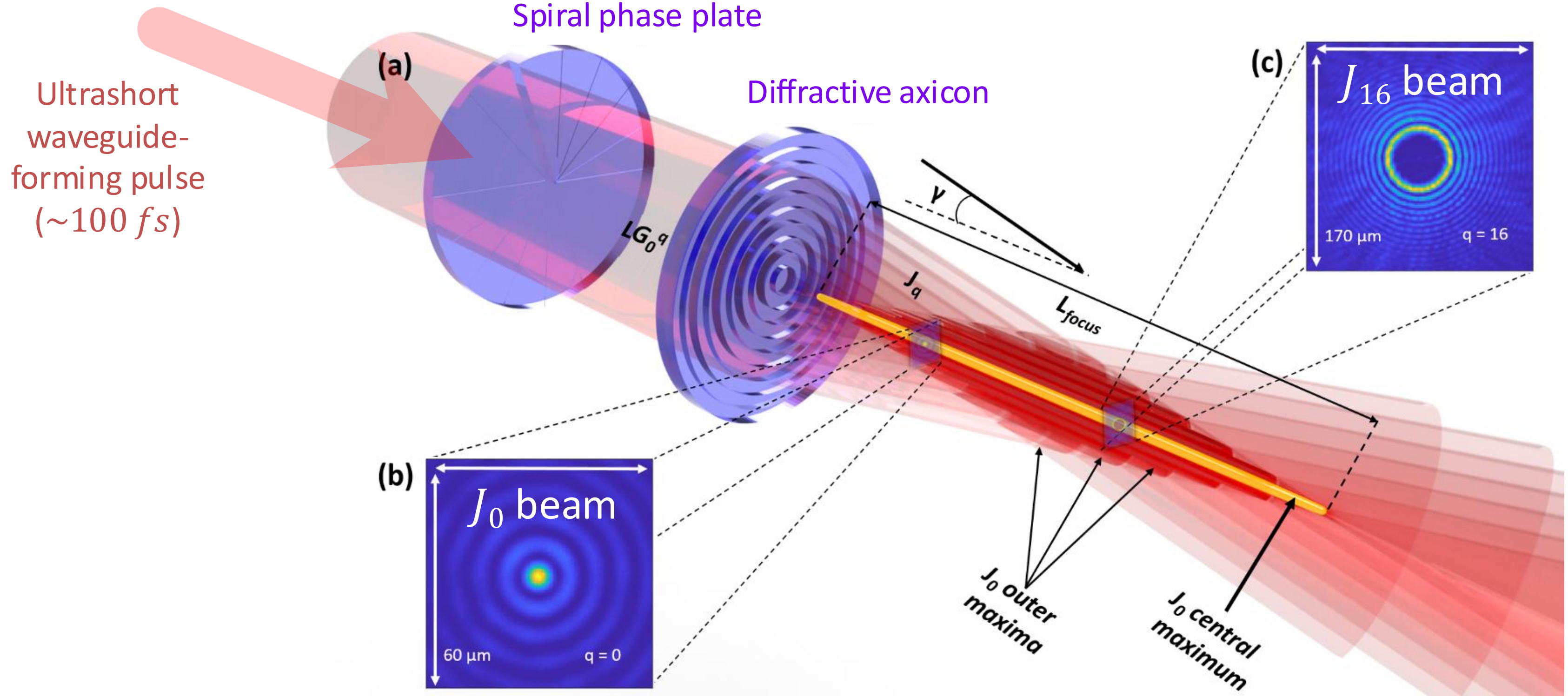
2006
Reaching 1 GeV

To push the energy frontier for applications, several limitations remain



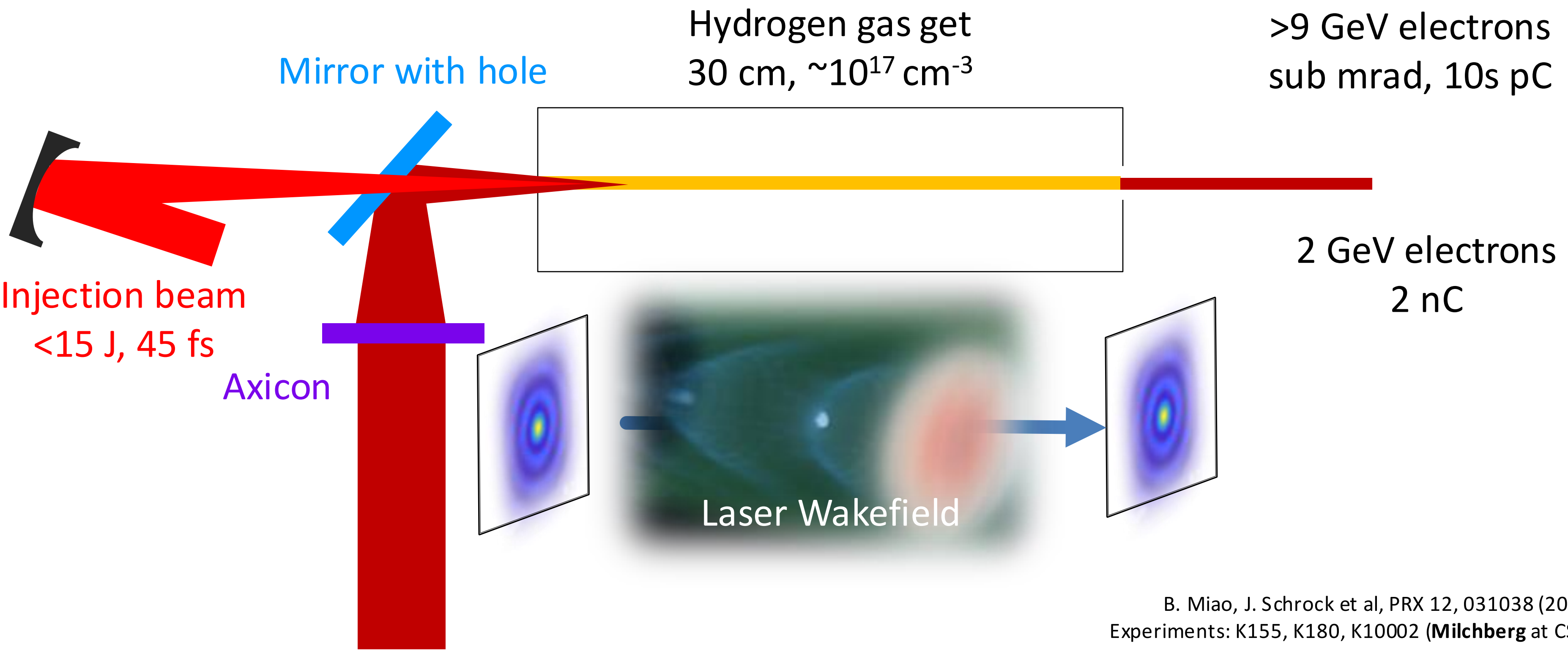
- **Diffraction:** length over which the laser stays focused to maintain sufficient intensity
- **Dephasing:** length over which electrons catch up with the plasma wave
- **Depletion:** length over which the laser has transmitted most of its energy to the plasma wave

A University of Maryland group developed a technique to create plasma waveguides



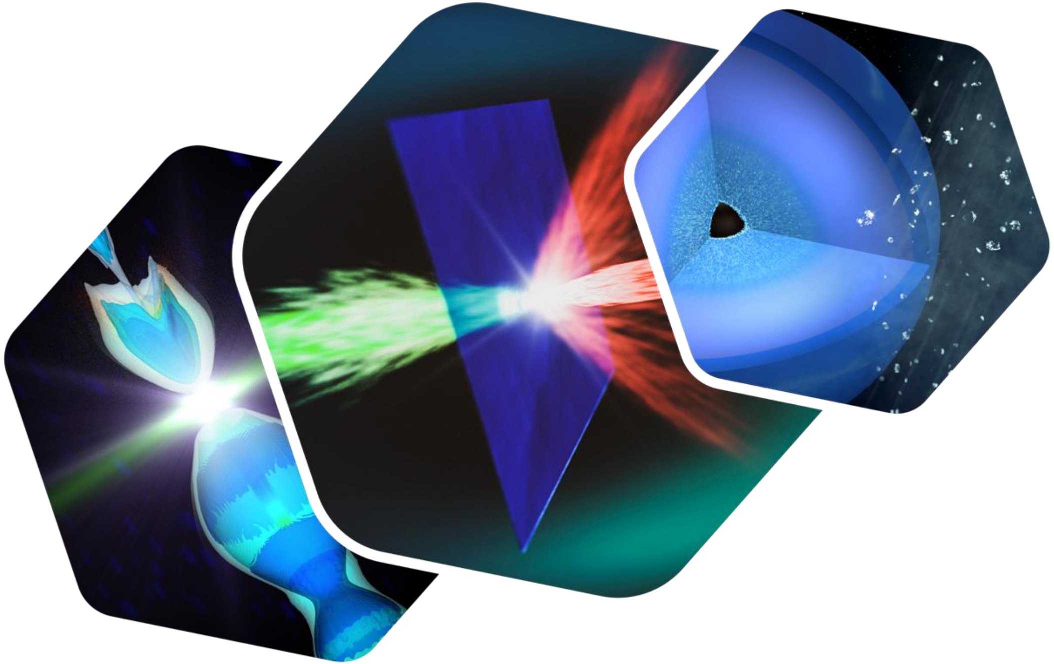
PRL **125**, 074801 (2020); PoP **29**, 073101 (2022); PRX **12**, 031038 (2022); PRL **133**, 053803 (2024)

They took it to LaserNetUS to demonstrate consistent >9 GeV electron acceleration at high repetition rate



B. Miao, J. Schrock et al, PRX 12, 031038 (2022)
Experiments: K155, K180, K10002 (**Milchberg** at CSU)

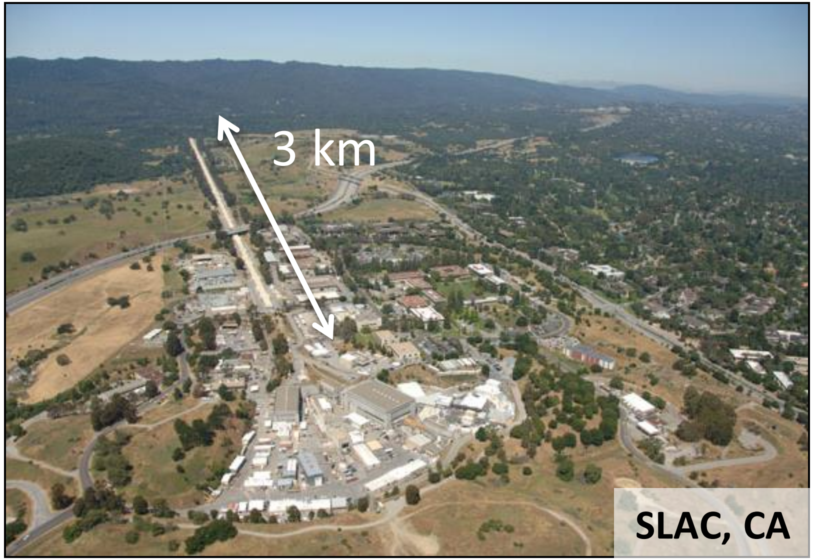
LaserNetUS: Five years of scientific discovery



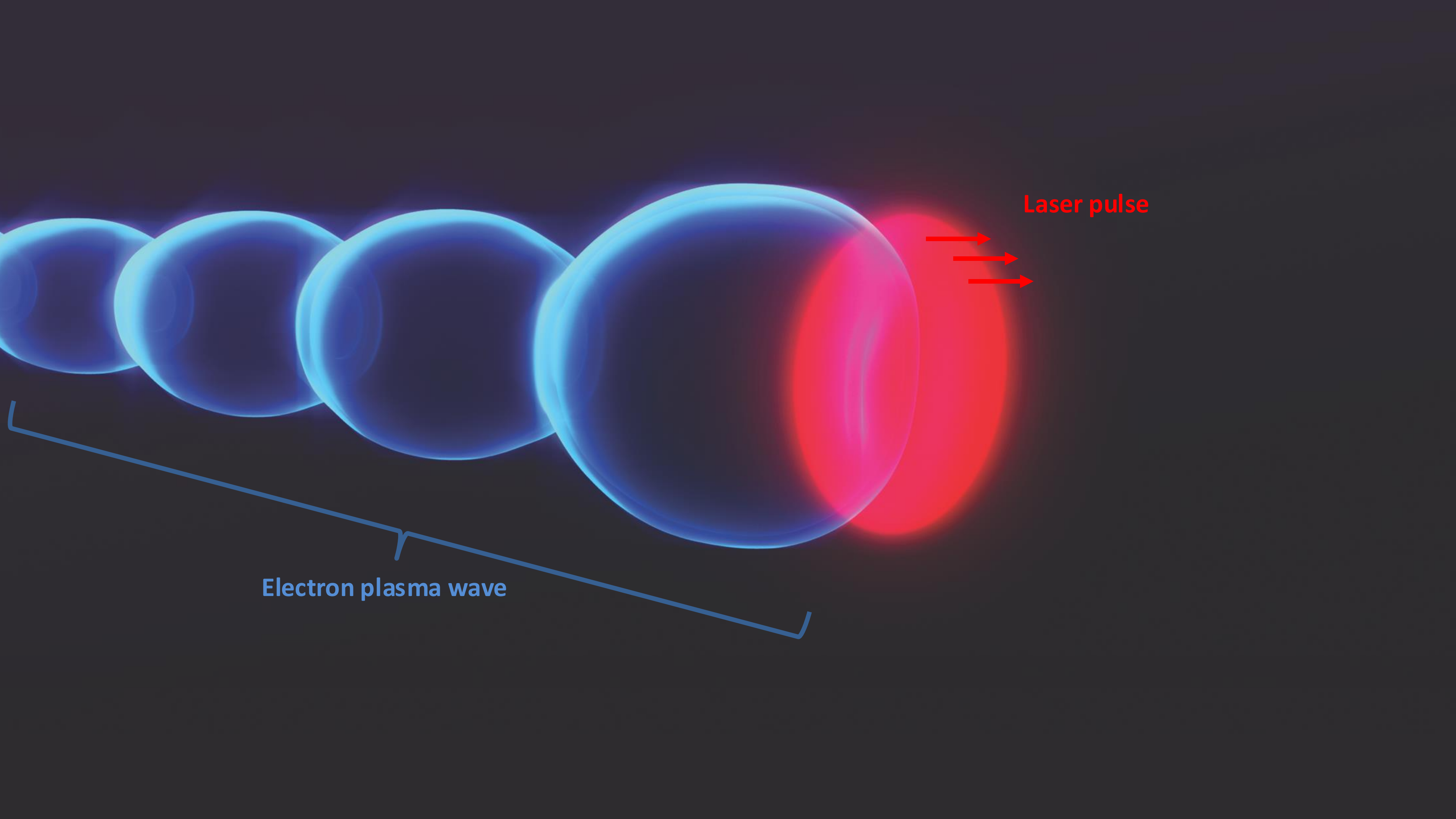
Inventing new x-ray imaging methods with societal impact

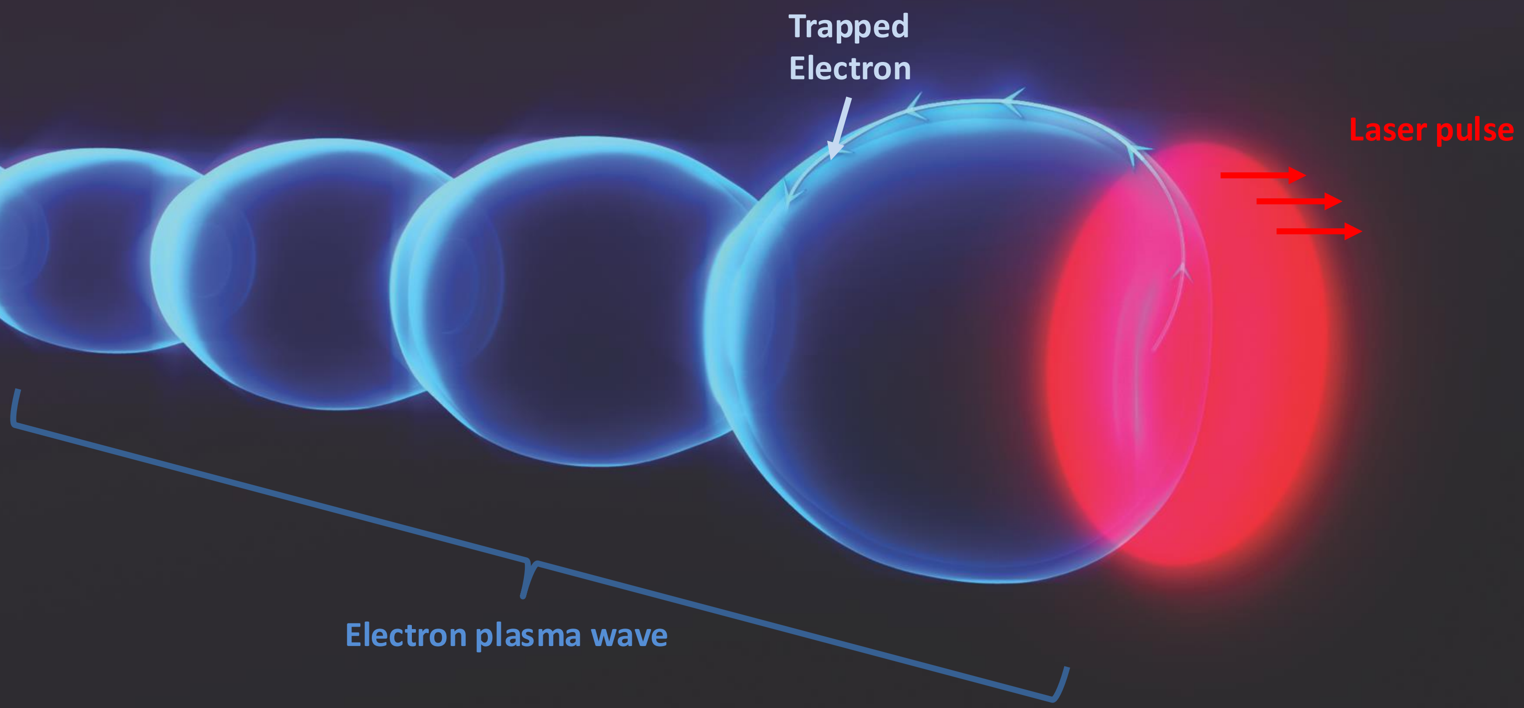
Conventional x-ray light sources are large scale national facilities

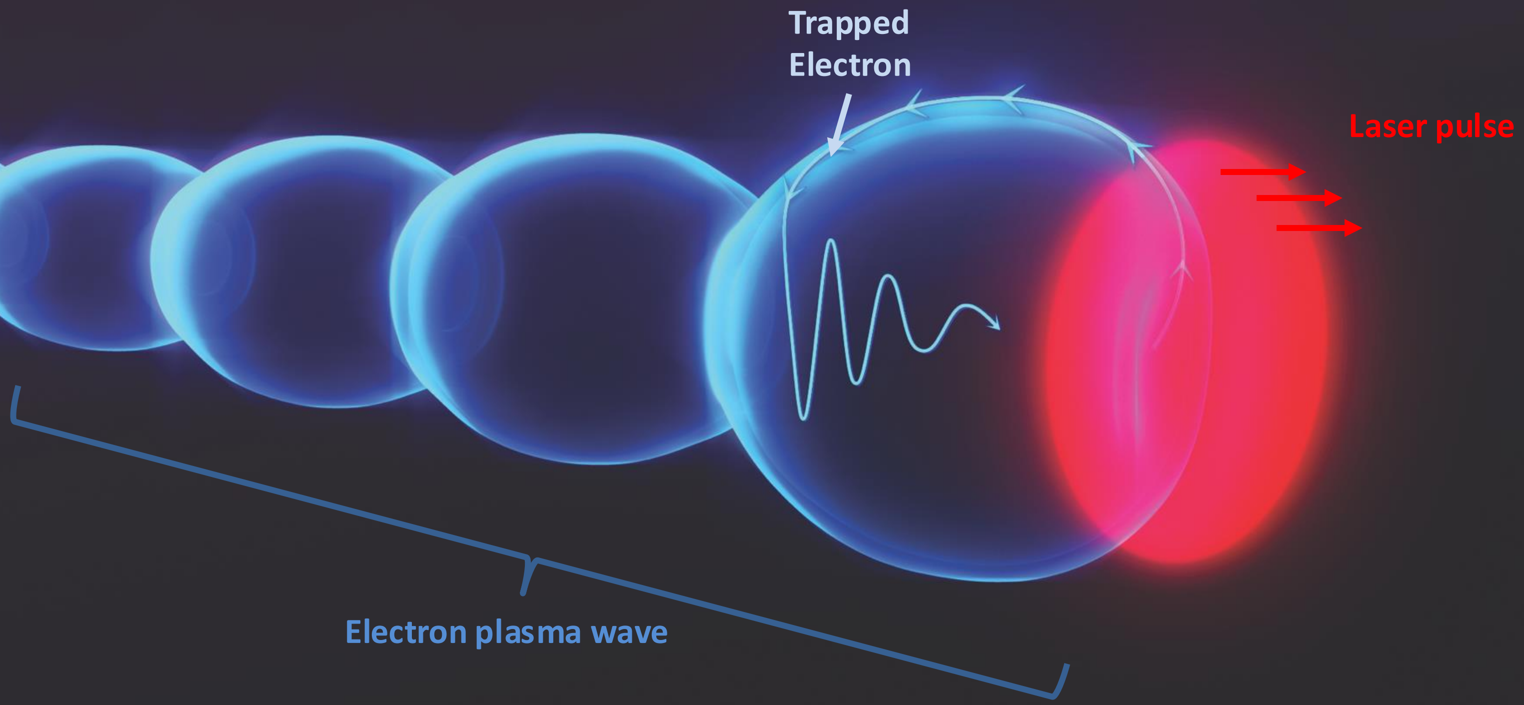
X-ray free electron laser: LCLS

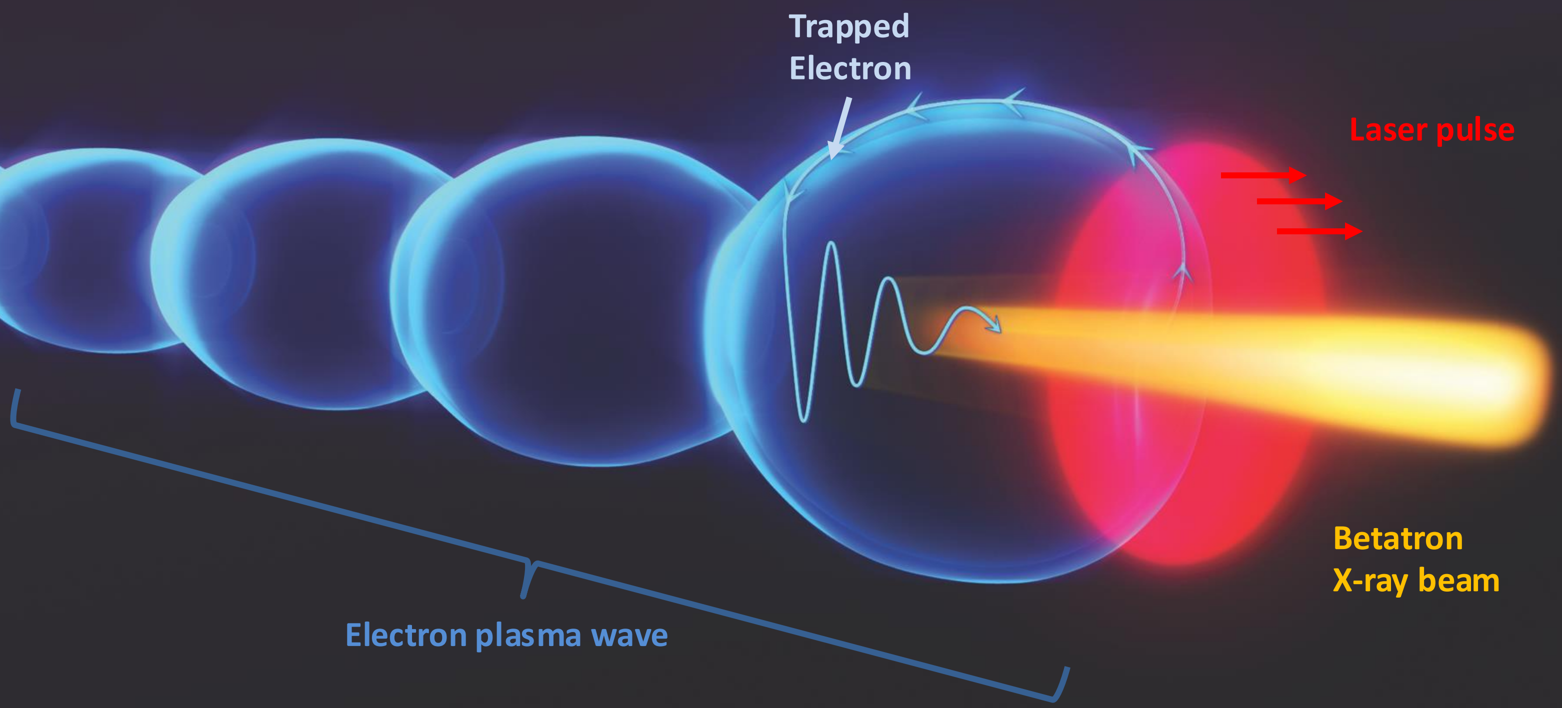


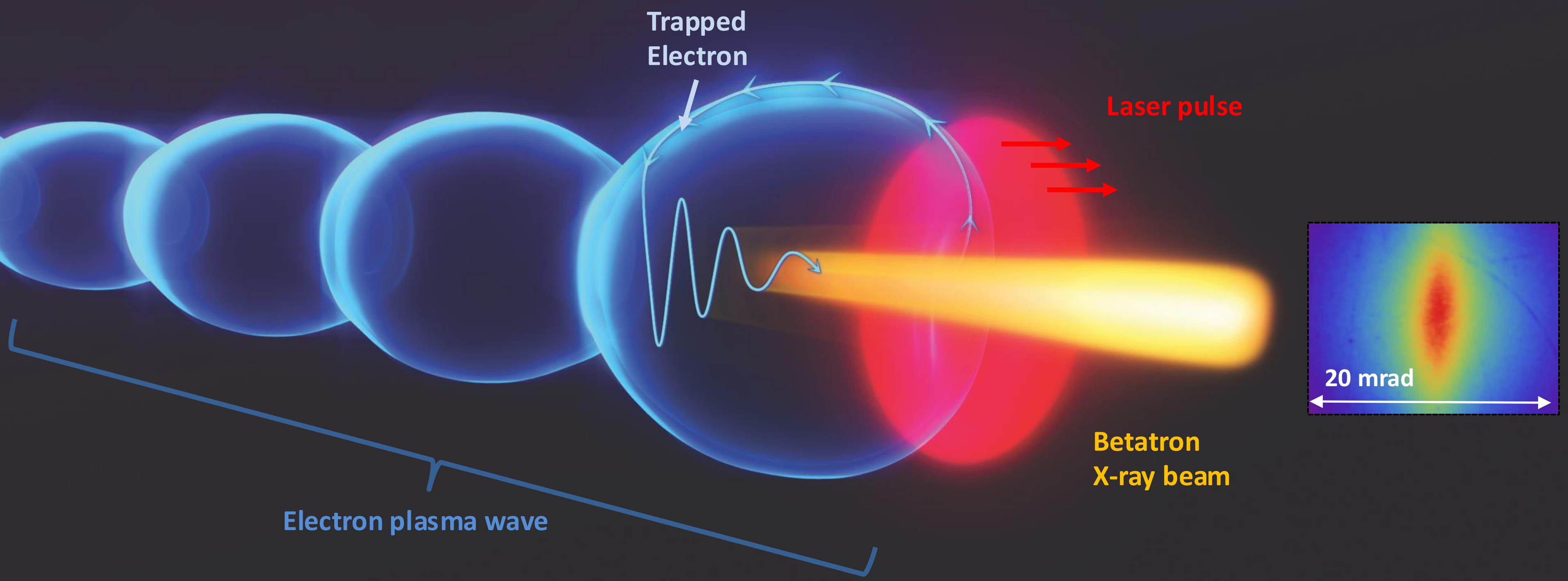
Synchrotron: APS


Laser pulse
Electron plasma wave

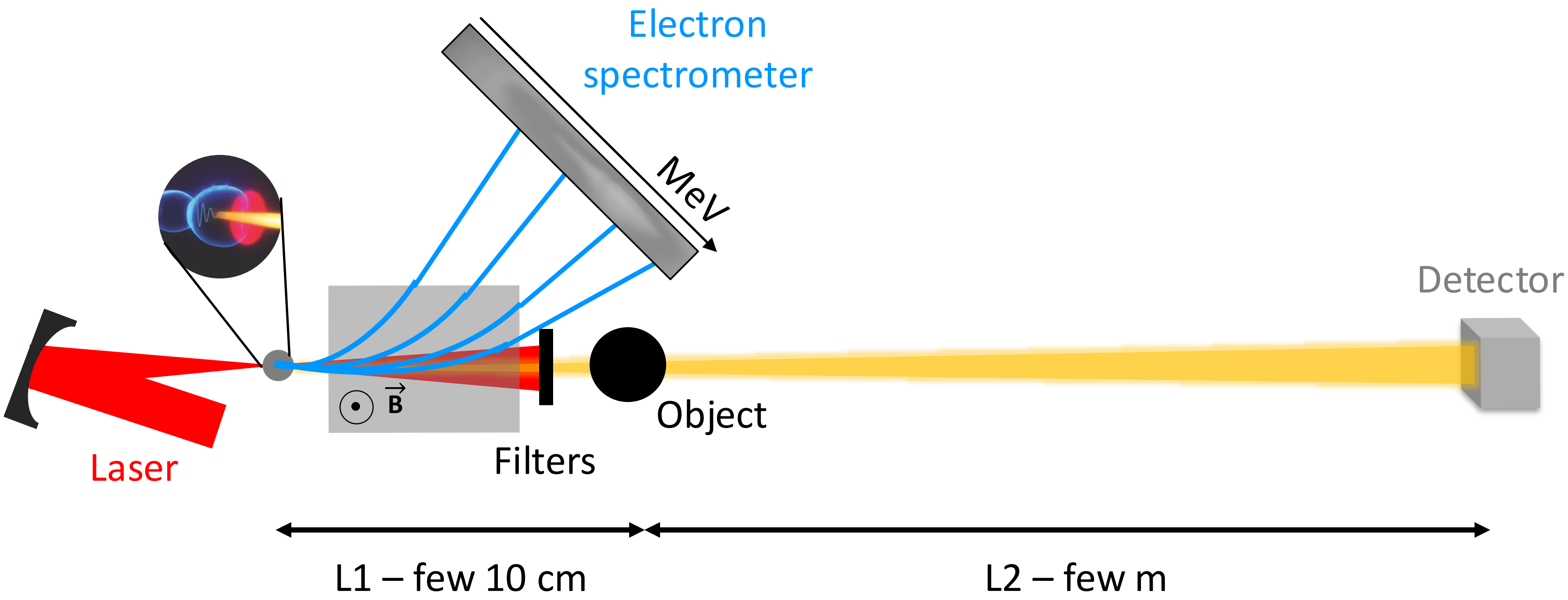

Trapped
Electron
Laser pulse
Electron plasma wave


Trapped
Electron
Laser pulse
Electron plasma wave


Trapped
Electron
Laser pulse
Betatron
X-ray beam
Electron plasma wave

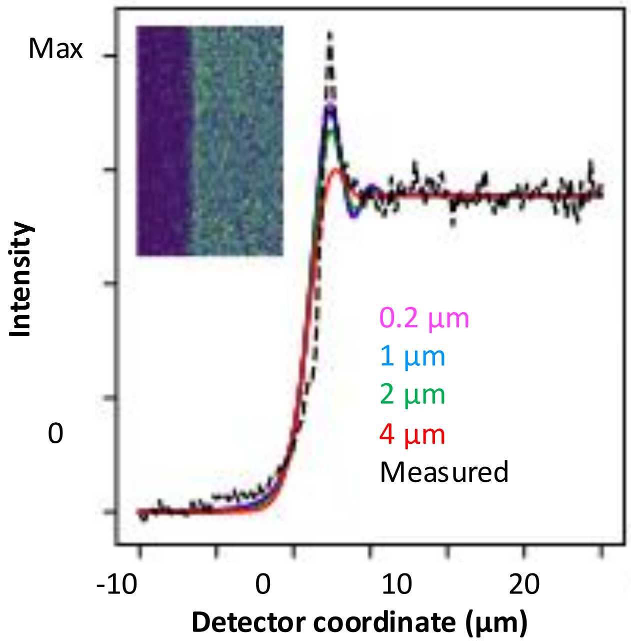

Trapped
Electron
Laser pulse
Betatron
X-ray beam
20 mrad
Electron plasma wave

Betatron x-rays offer a versatile platform for x-ray imaging

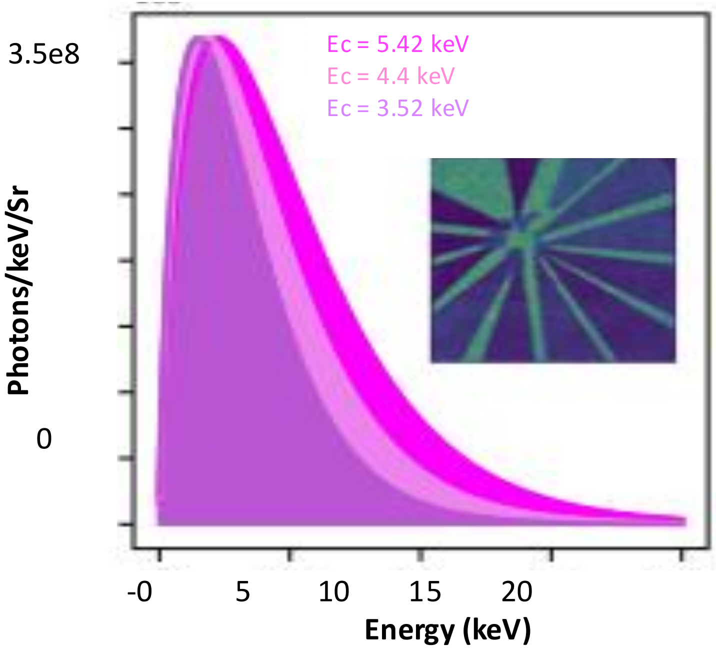


Several LaserNetUS facilities are able to produce bright betatron x-rays for applications

Source Size



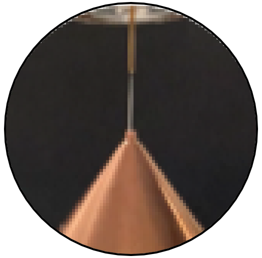
Spectrum

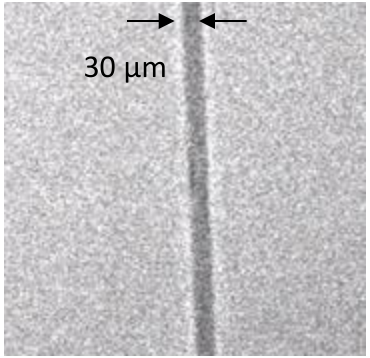


Experiments: K33, K090 (**Kuranz** at LBNL)

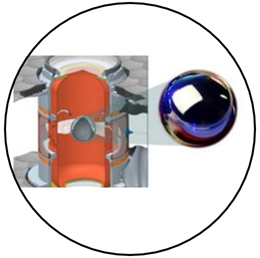
Small source size and keV x-rays enable imaging applications with µm-scale resolution

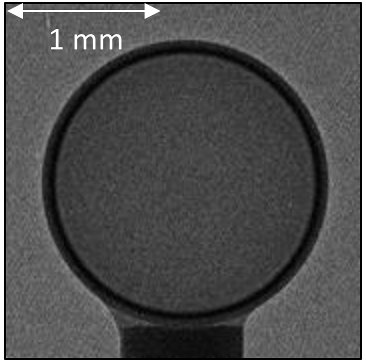
Hydrodynamic shock in a water jet



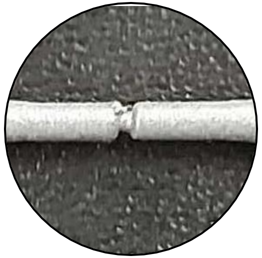


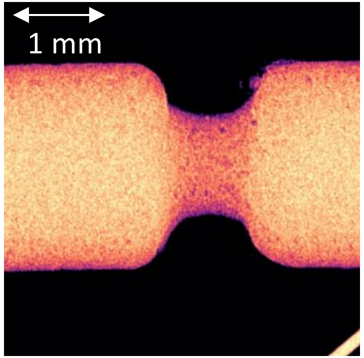
Inertial confinement fusion Targets





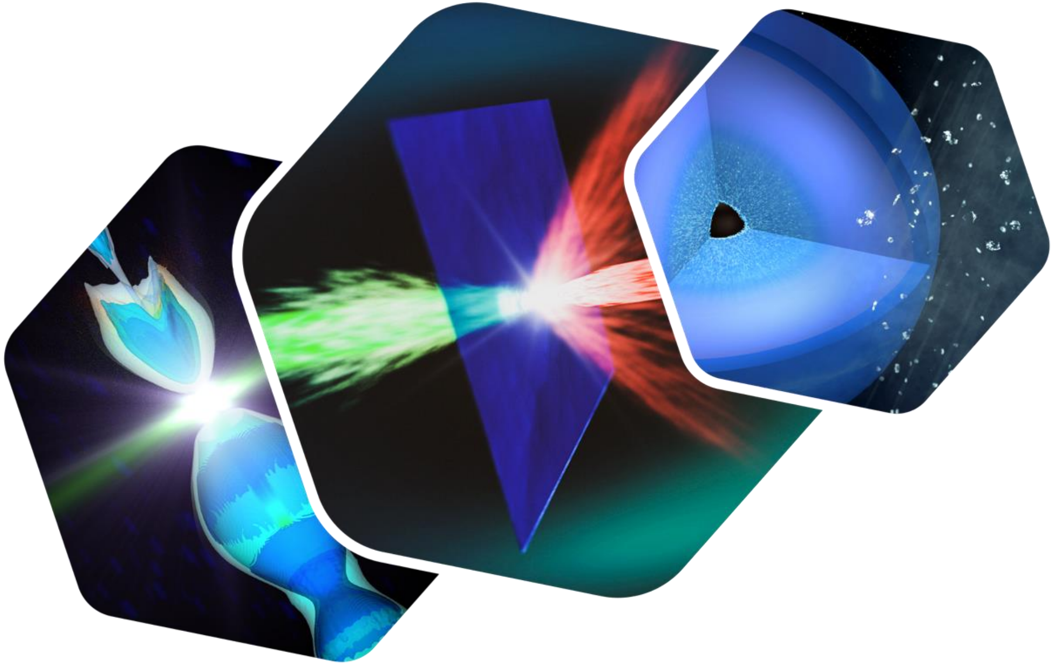
Porosity evolution in additively manufactured Al Alloys





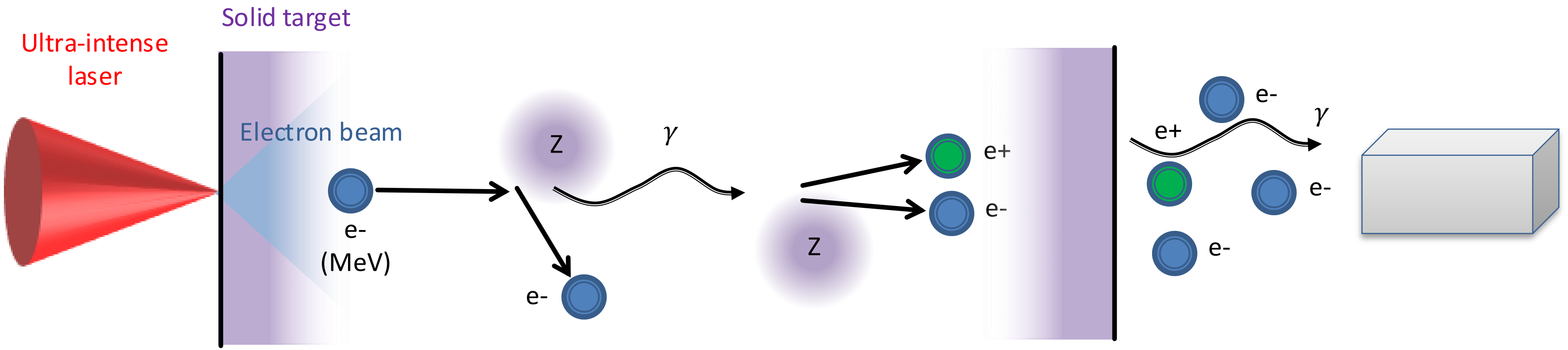
Experiments: K33, K090 (**Kuranz** at LBNL), K136 (**Hussein** at ALLS), K10040 (**Pagano** at ALLS)

LaserNetUS: Five years of scientific discovery



Harnessing solid laser-matter interactions to produce photon sources for radiography

The interaction of high intensity lasers with high-Z solid targets produces MeV photons and electron-positron pairs



Relativistic (hot) electrons: Direct Laser Acceleration

Bremsstrahlung photon production

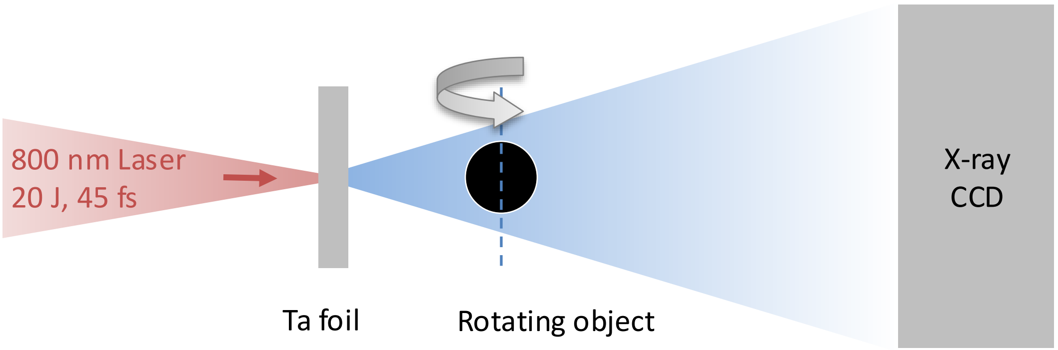
Pair production (Bethe-Heitler)

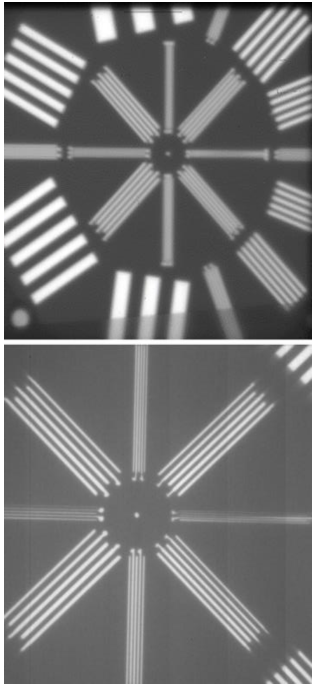
Particle and photon spectrometers

$$e^-_{(\text{high energy})} + Z \rightarrow e^-_{(\text{lower energy})} + Z + \gamma_{(\text{bremsstrahlung})}$$

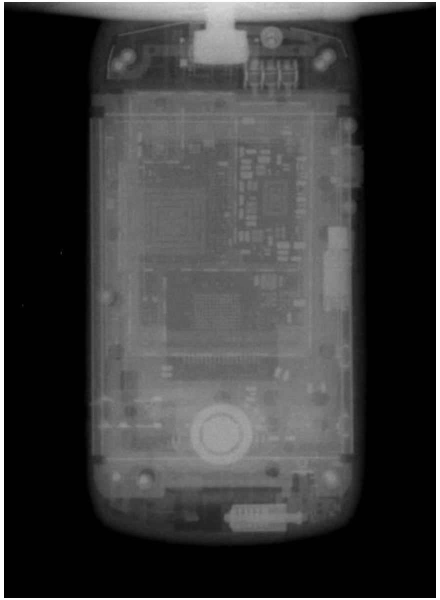
$$\gamma_{(\text{bremsstrahlung})} + Z \rightarrow (e^+ + e^-) + Z$$

Tomographic imaging with an intense gamma-ray source



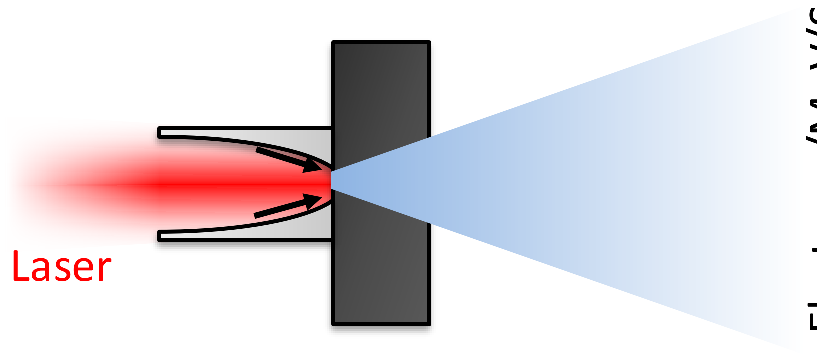


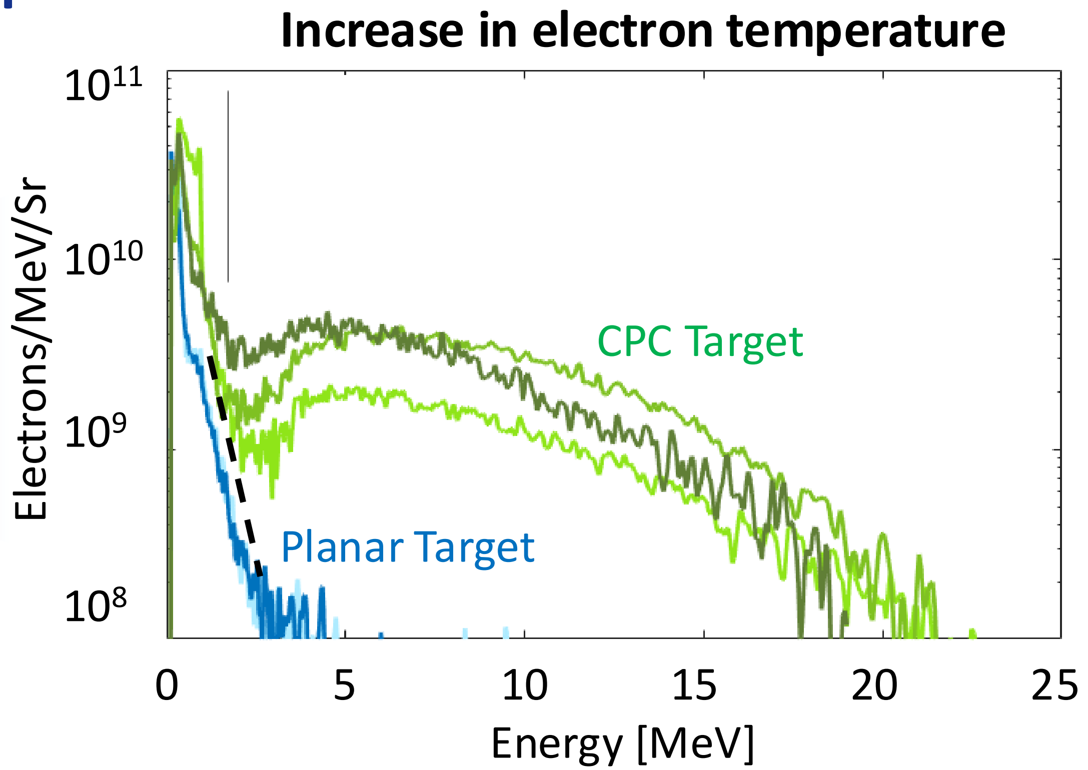
200 µm resolution
Detector limited



Experiments: K06 (**Fernandez** at CSU)

The source can be optimized with target structure to enhance radiographic capabilities



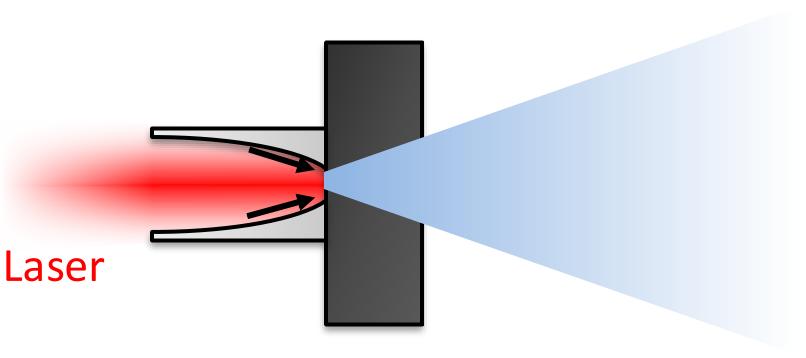


D. Rusby et al, PRE, 103 053207 (2022)
P. King et al, HEDP 100978 (2022)

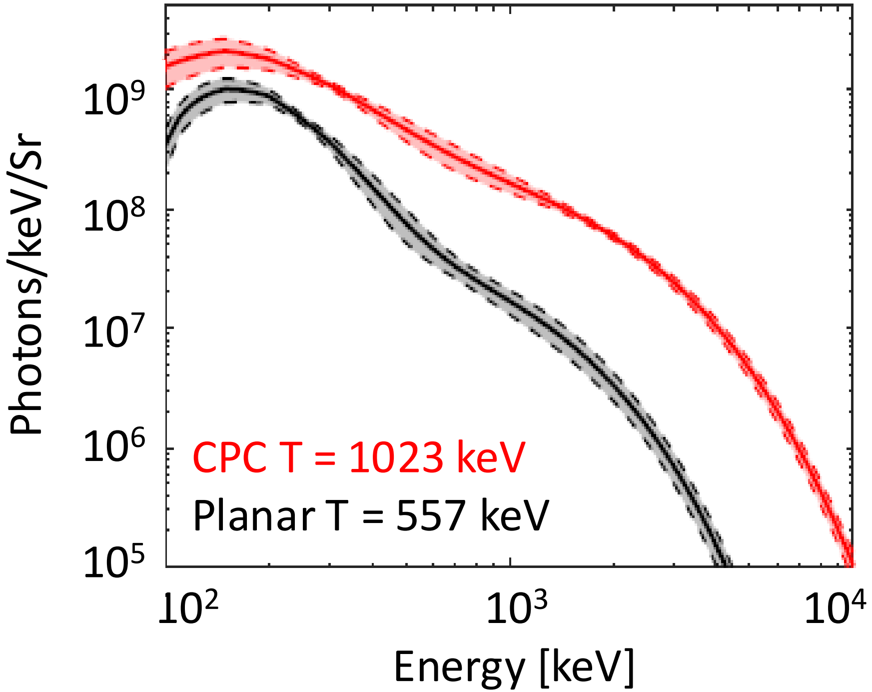
Experiments: K39 (**Mackinnon** at UT), K103 (**Rusby** at UT), K186 (**Aghedo** at LLNL)

The source can be optimized with target structure to enhance radiographic capabilities

Compound **P**arabolic **C**oncentrator



Increase in x-ray temperature



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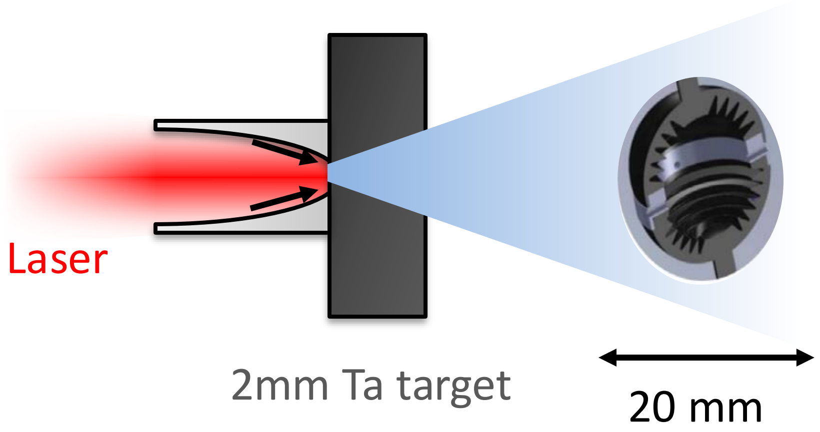
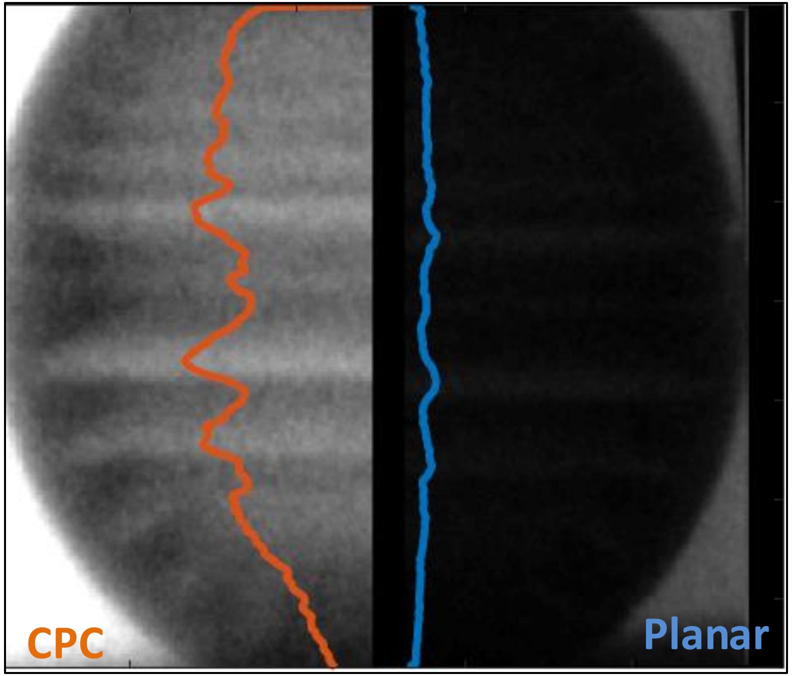
Compound Parabolic Concentrator



Enhanced x-ray radiography



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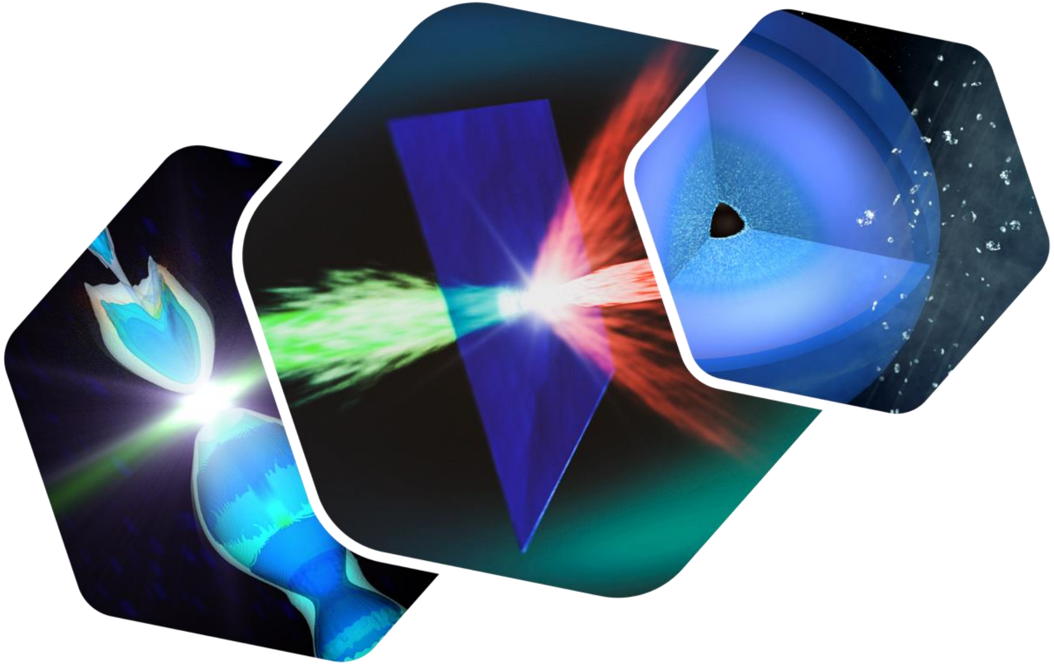
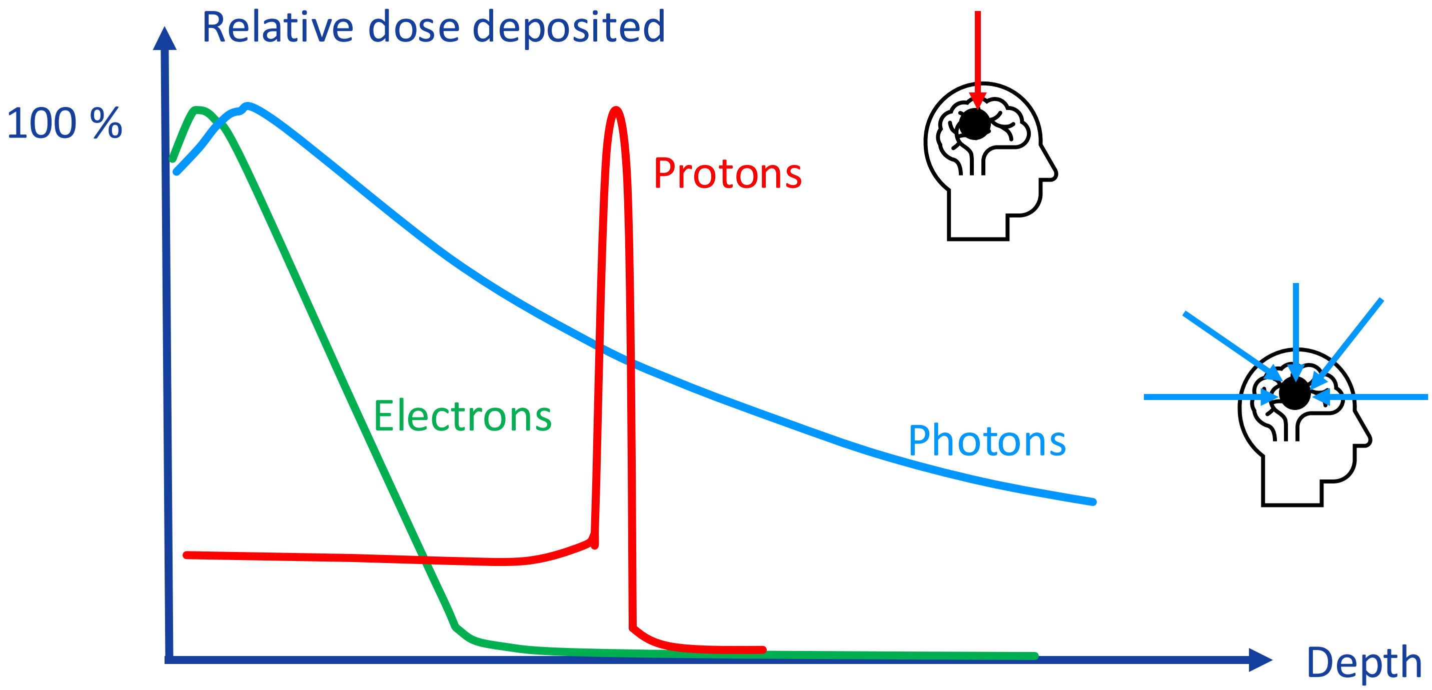
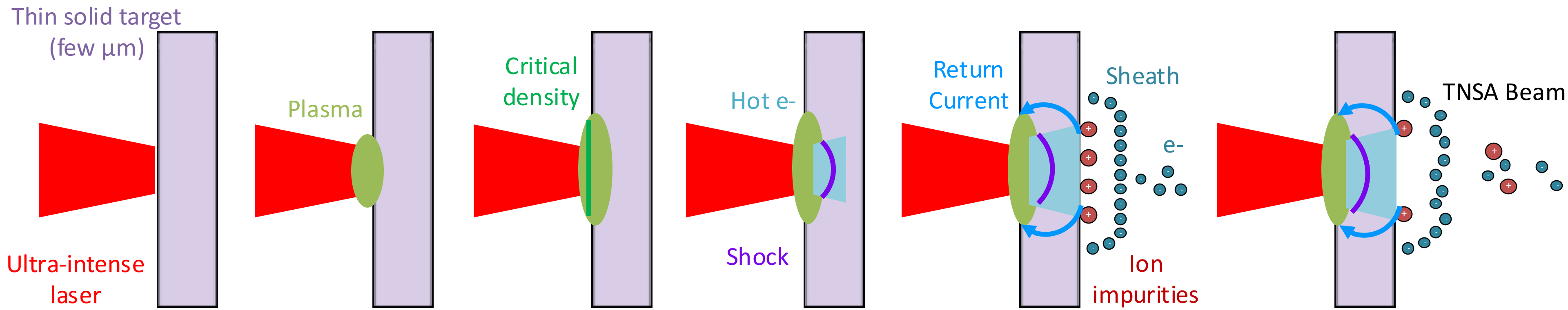


Protons changing the way we understand biology and treat cancer

Proton therapy treats cancer at reduced healthy tissue damage compared to other types of radiation

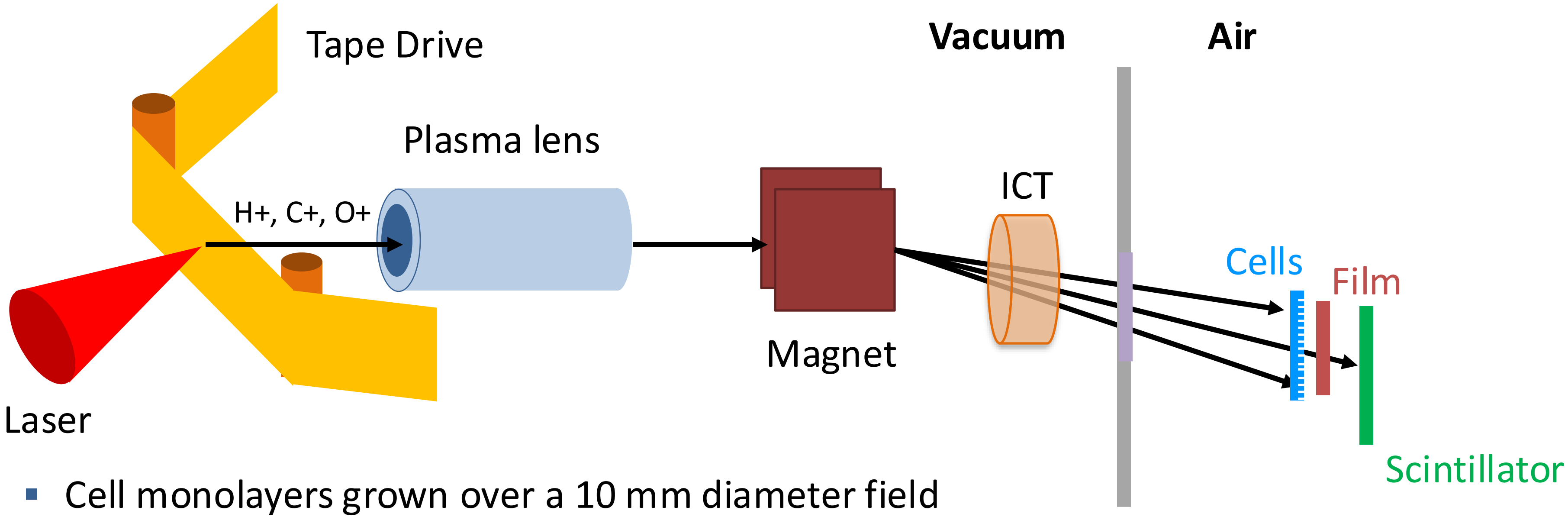


High Intensity Lasers Accelerate Protons via Target Normal Sheath Acceleration



The biological effects of these particles is still relatively unknown

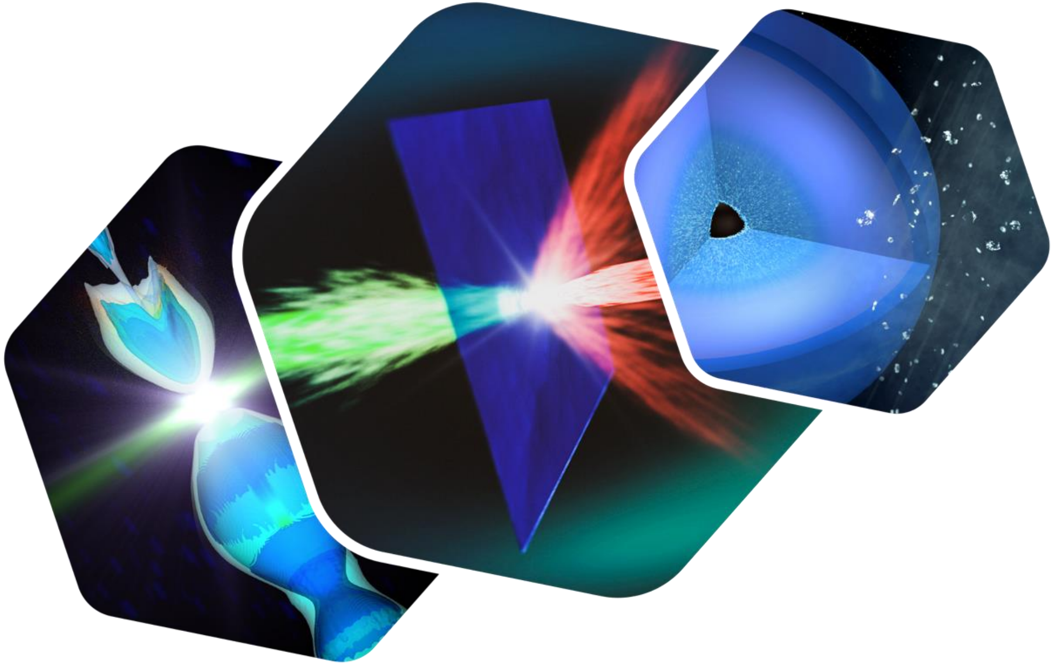
A new platform for ultra-high dose rate radiobiological research



- Cell monolayers grown over a 10 mm diameter field
- Exposed to clinically relevant proton doses 7 - 35 Gy
- Ultra-high instantaneous dose rates of 10^7 Gy/s.

Experiments: K110, K163 (**Snijders** at LBNL)
J. Bin et al, Scientific Reports, 12, 1484 (2022)

LaserNetUS: Five years of scientific discovery



Harnessing nuclear reactions to produce neutron sources for fusion and material science

Sources of neutrons are used for fusion and materials studies

Reactors

ILL Reactor
10^{15} neutrons/s/cm^2

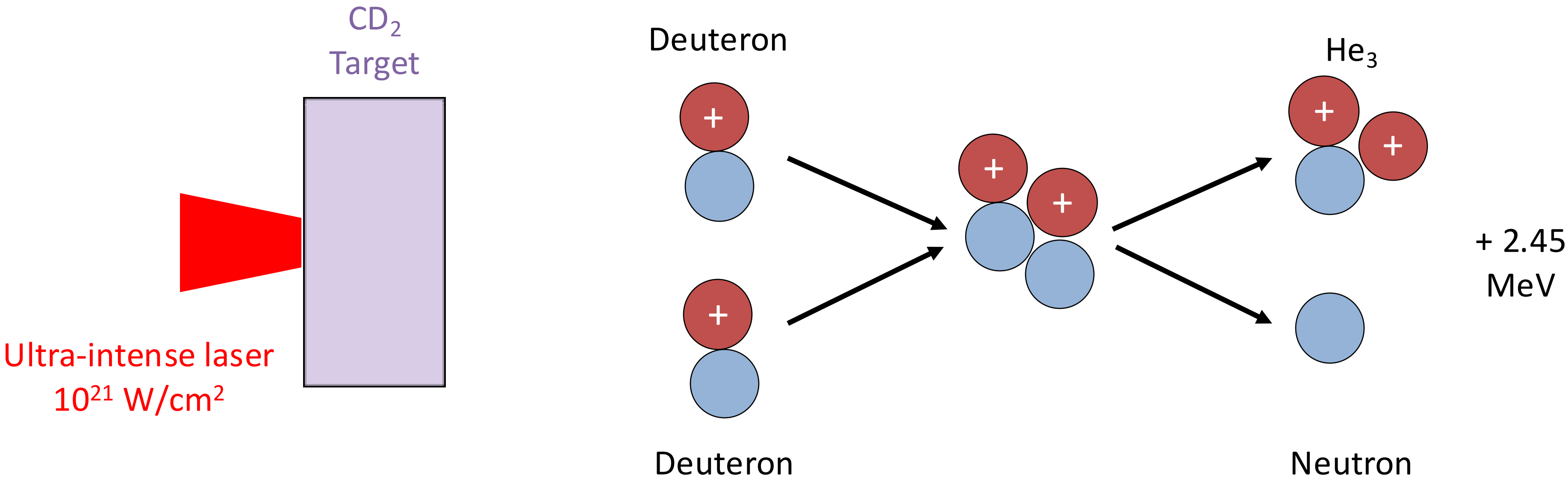
Accelerators

ONRL spallation source
10^{16} neutrons/s/cm^2

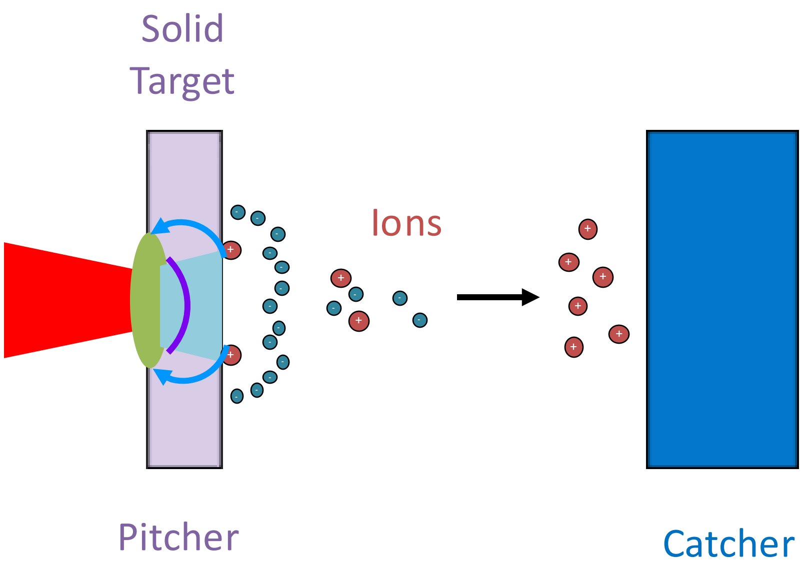
Laser-driven fusion

National Ignition Facility
$>10^{27}$ neutrons/s/cm^2

High intensity laser-plasma interactions create an ideal fusion environment to produce neutrons



Neutrons can also be produced indirectly



Proton – Boron

$H + {}^{11}B \longrightarrow 3He + 8.7\ MeV$

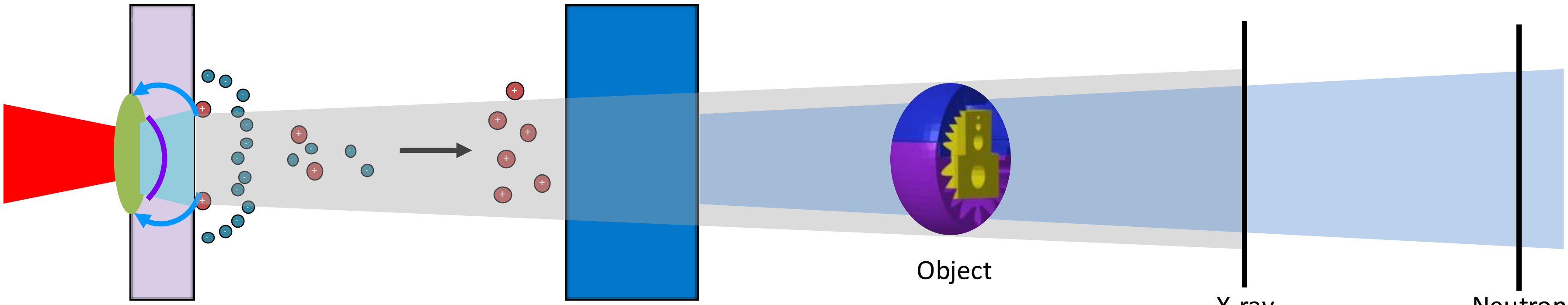
Deuteron – Lithium

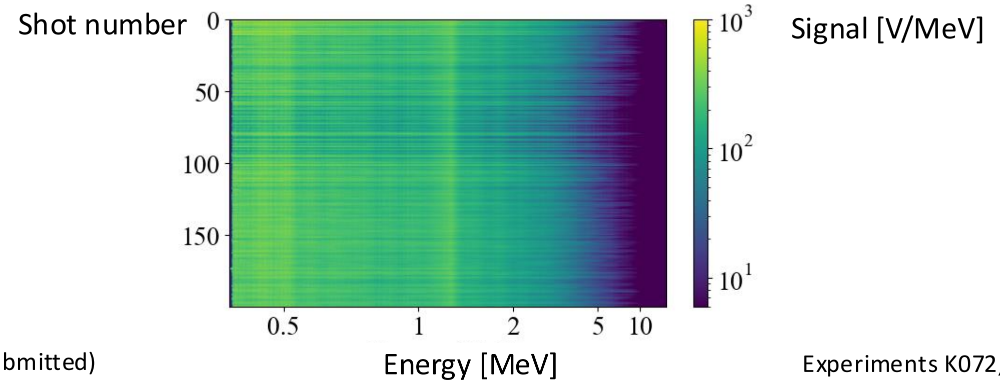
${}^{7}Li + D \longrightarrow {}^{8}Be \longrightarrow {}^{7}Be + n$

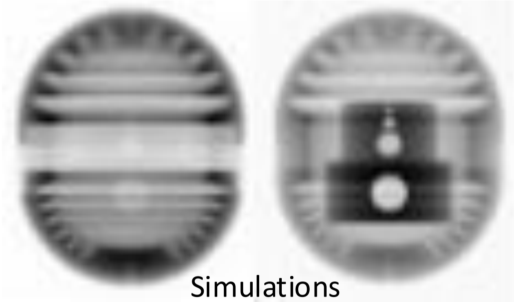
$D + D \longrightarrow {}^{3}He + n$

$D + D \longrightarrow H + n + H + n$

Neutrons from high intensity lasers enable multi-modal radiography



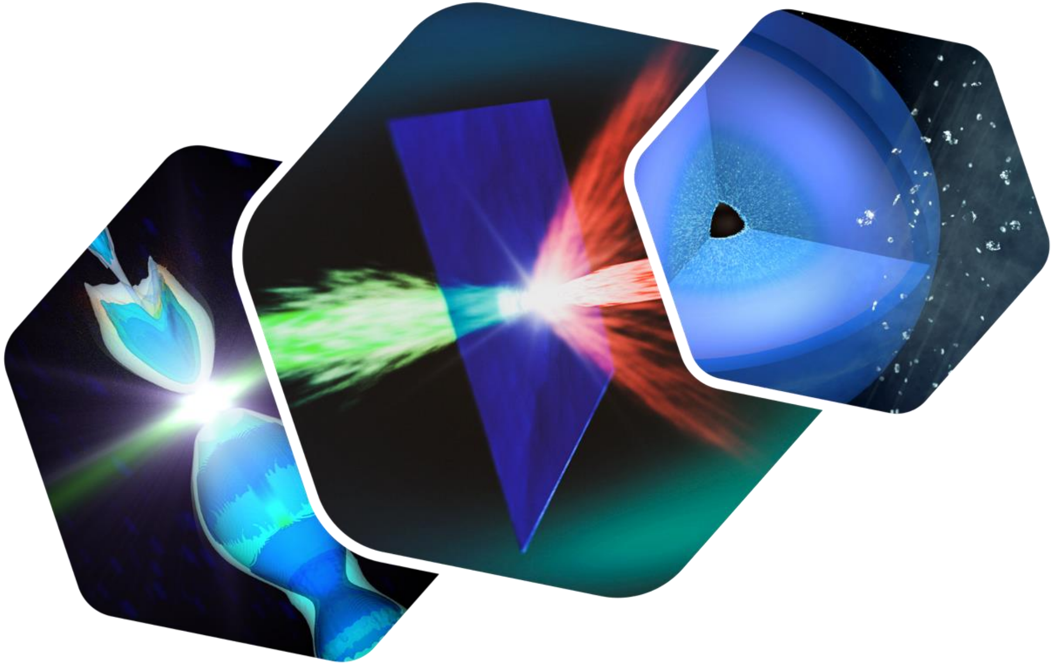




F. Treffert et. al, RSI (submitted)

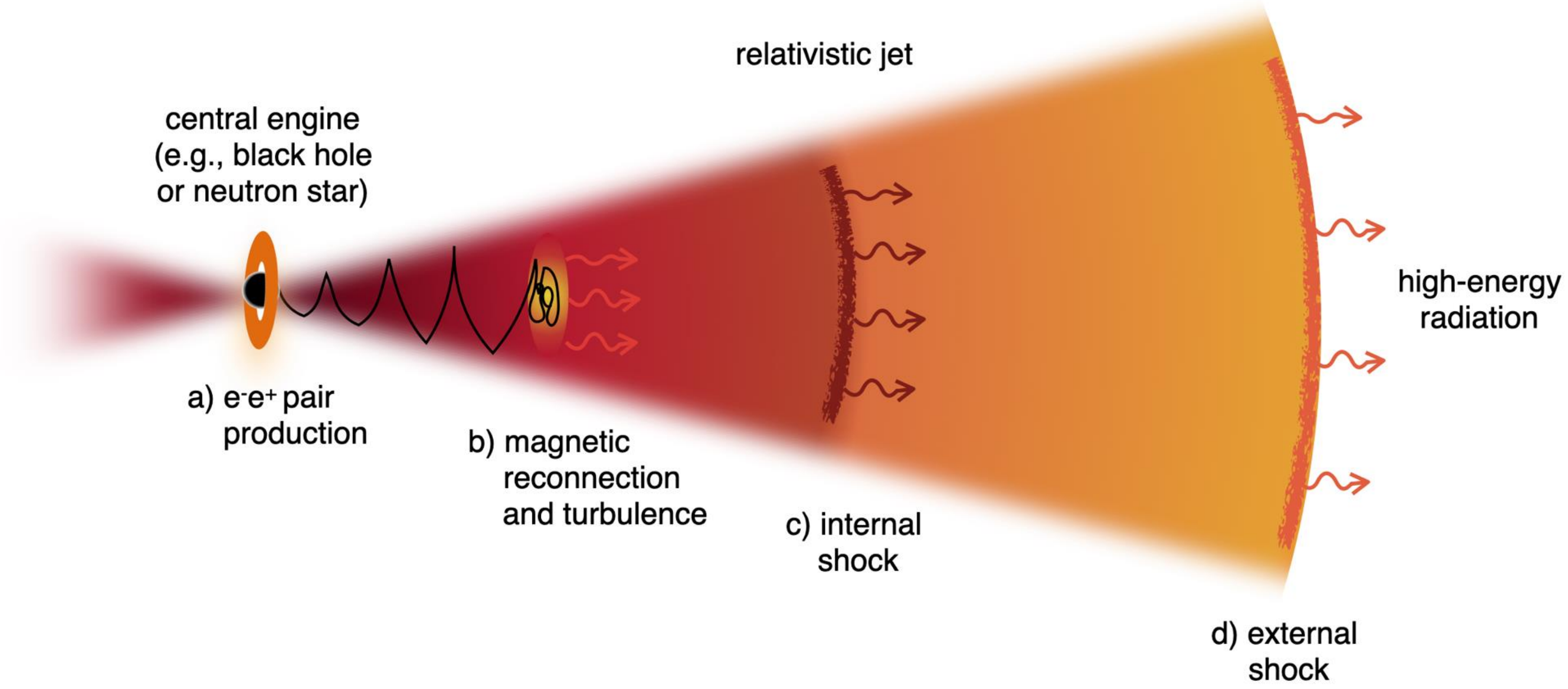
Experiments K072, K168 (**Treffert** at CSU), K10055 (**Williams/Treffert** at CSU)

LaserNetUS: Five years of scientific discovery



Elucidating energy partition in astrophysical environments

Energy partition in astrophysical objects is complex and difficult to reproduce in the laboratory



Chen and Fiuza, POP, 30 020601 (2023)

Collisionless shocks are a source of

Magnetic field amplification

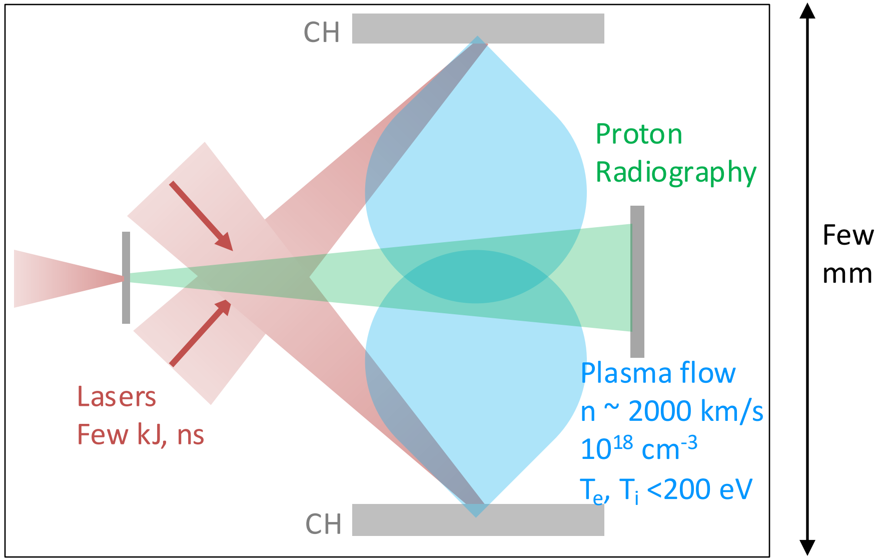
Particle acceleration (cosmic rays)

Energy exchange between particles

Plasma flows sweep through interstellar media and can be reproduced with lasers

Bow shock in the Orion Nebula

Experiment using the OMEGA-EP Laser

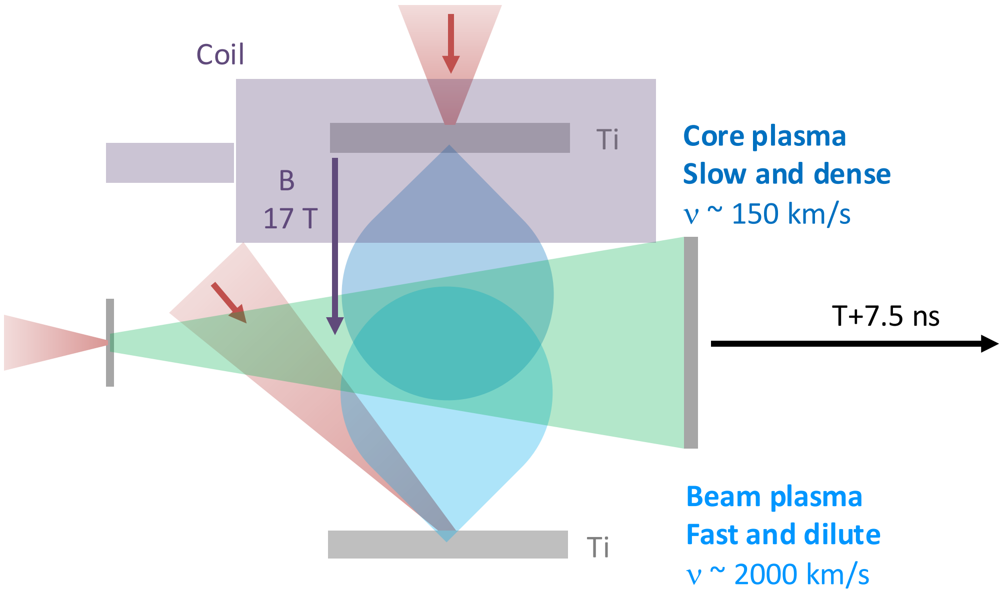


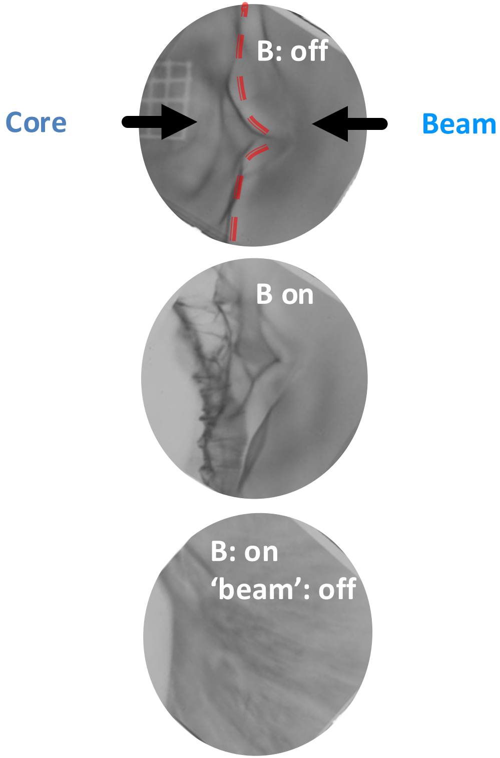
Magnetization parameter

$$\sigma \sim B^2/4\pi m_i n_i v^2$$

C. Huntington *et al.*, Nat. Phys (2015)
F. Fiuza *et al.*, Nat. Phys (2020)

Conditions can be tailored for quasi-parallel collisionless shocks and high Alfven numbers relevant to young Supernova remnants

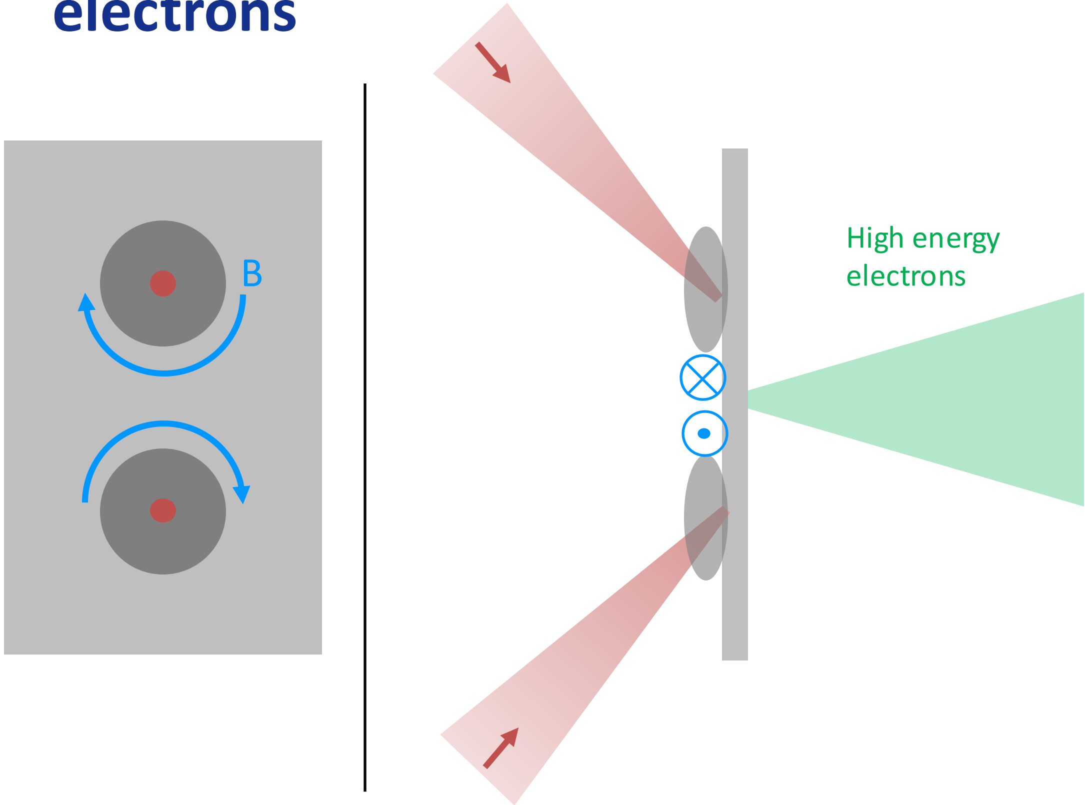


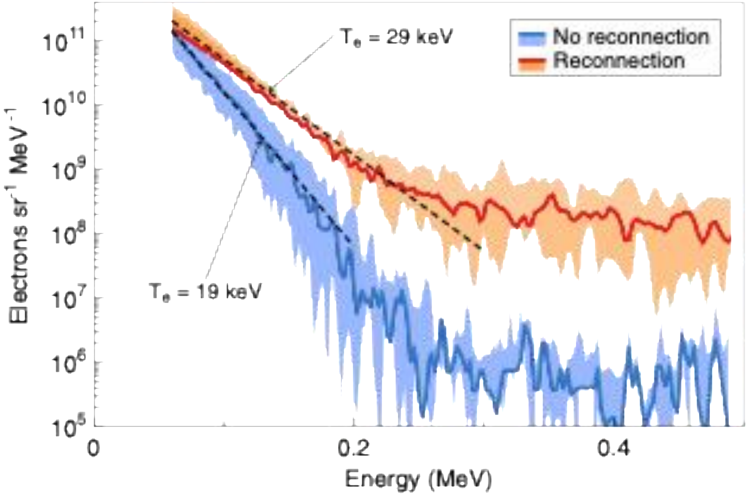


S. Bolaños *et al.*, Phys. Rev. E **110**, L033201 (2024)

Experiment: K129, K200 (**Manuel** at UR/LLE)

Magnetic reconnection at merging is a source of high energy electrons

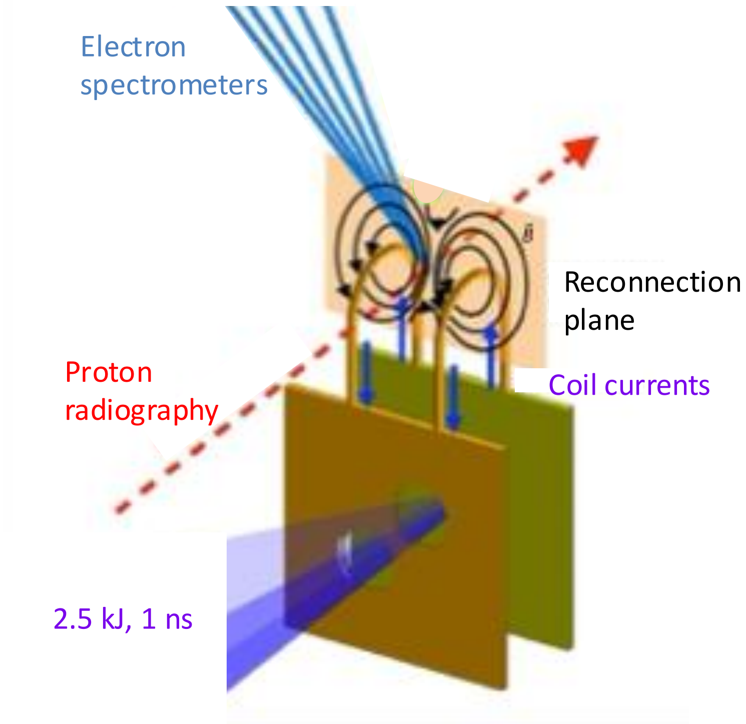




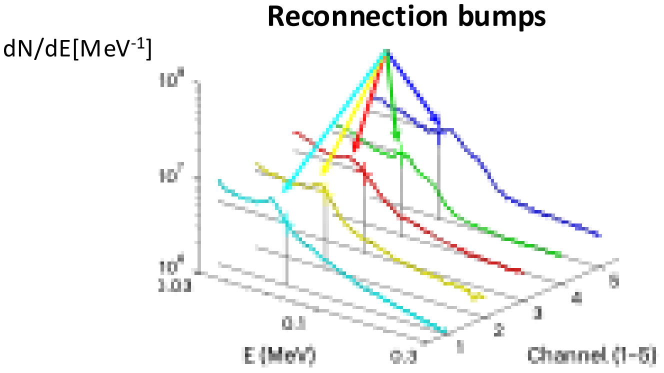
G. Fiksel, *et al.*, J. Plasma Phys., 87, 905870411 (2021)

Experiment: K068 (**Fox** at UR/LLE)

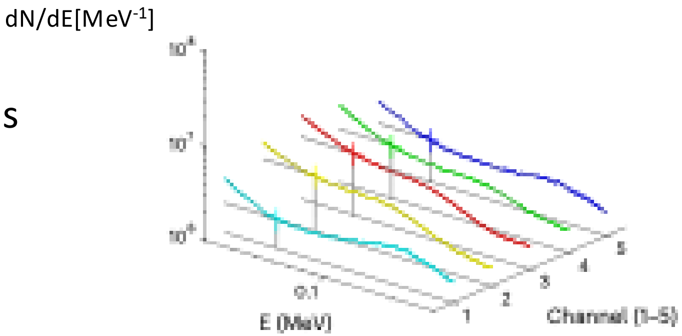
Magnetic reconnection at merging is a source of high energy electrons



Coils



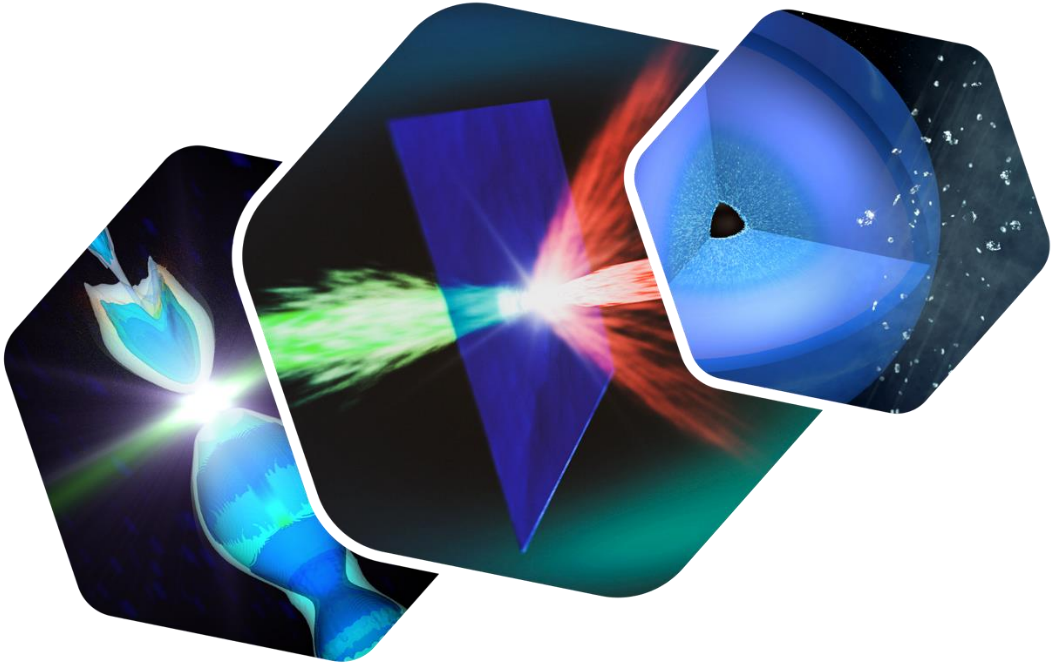
No coils



A. Chien, *et al.*, Nature Physics, 19, 254 (2023)

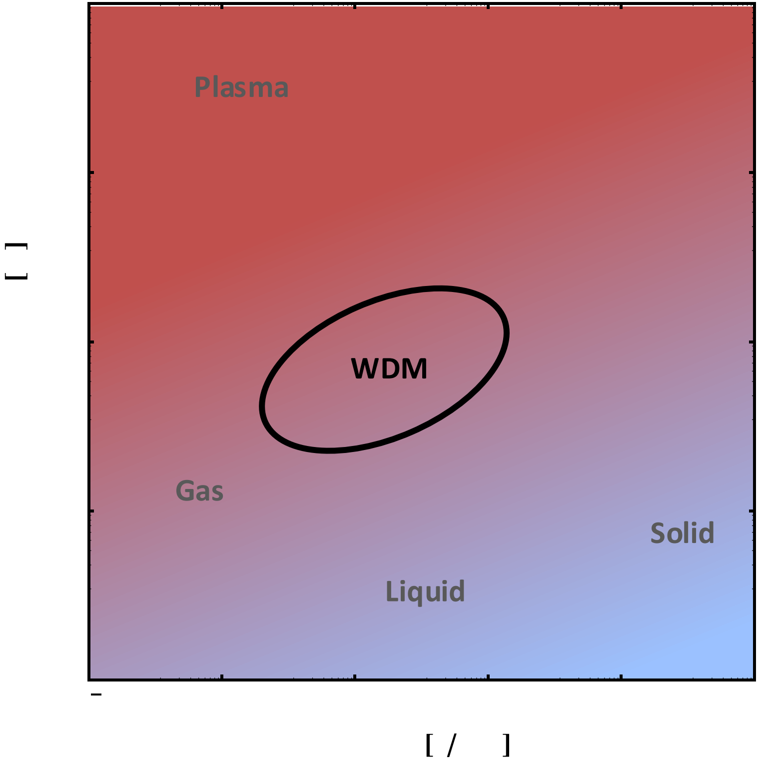
Experiments: K065, K141, K042 (**Gao** at UR/LLE and LLNL)

LaserNetUS: Five years of scientific discovery

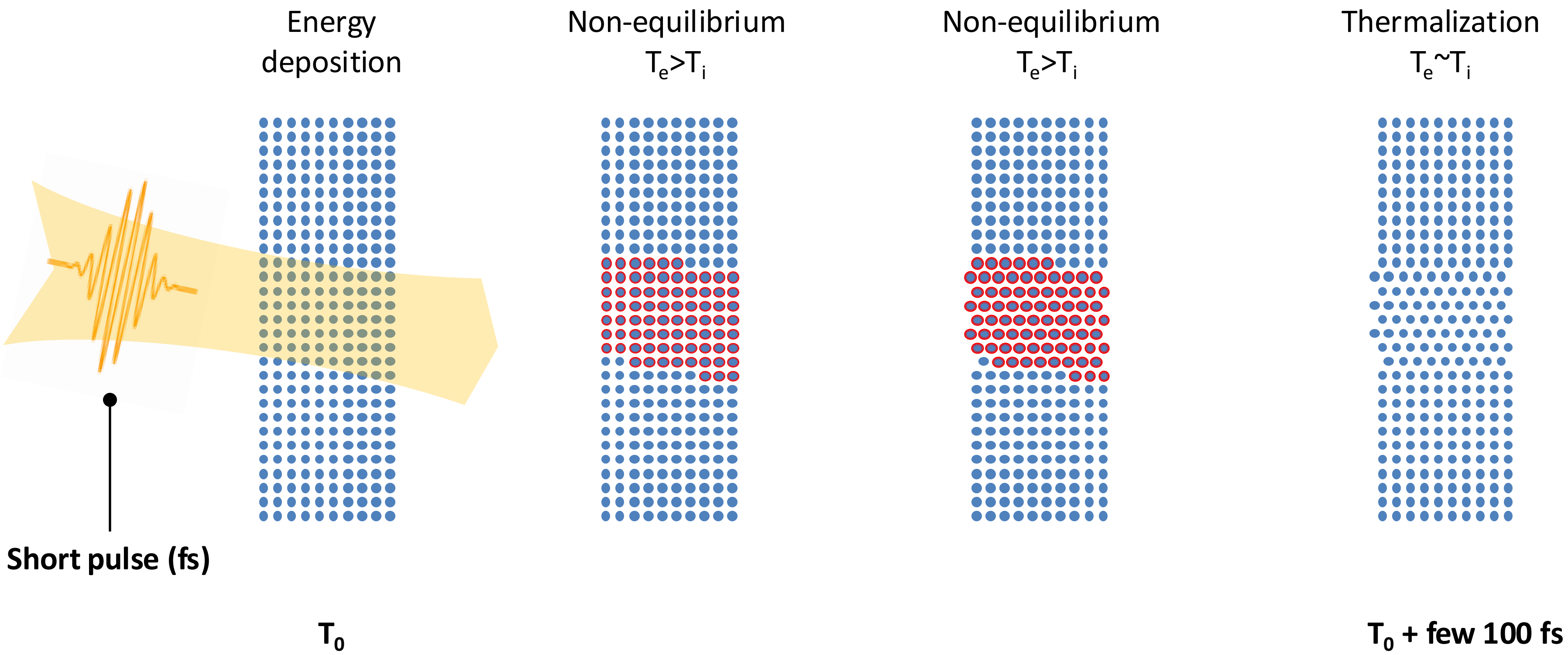


Creating and diagnosing warm dense matter with high fidelity

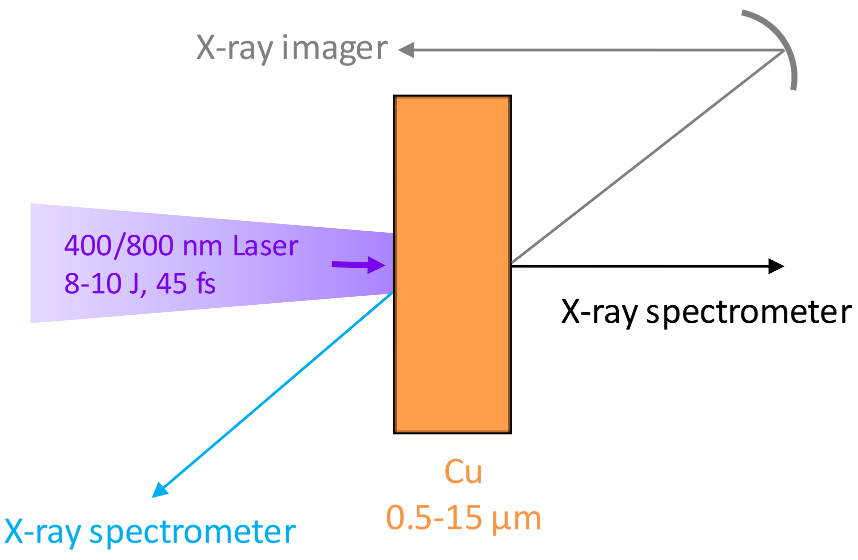
Warm dense matter is ubiquitous in astrophysical, fusion and industrial plasmas

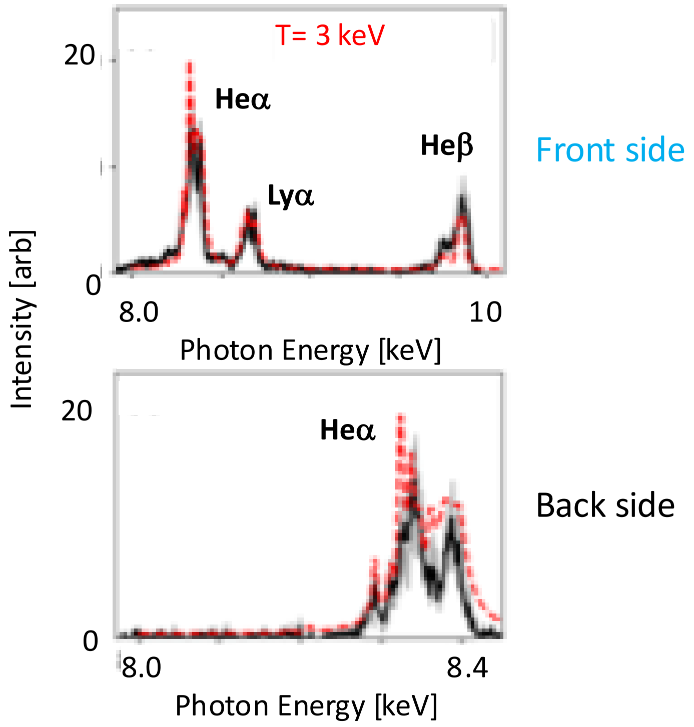


It is difficult to create in the laboratory, and high intensity lasers can rapidly produce and diagnose warm dense matter



First demonstration of µm-scale, solid density keV plasmas with x-ray spectroscopy

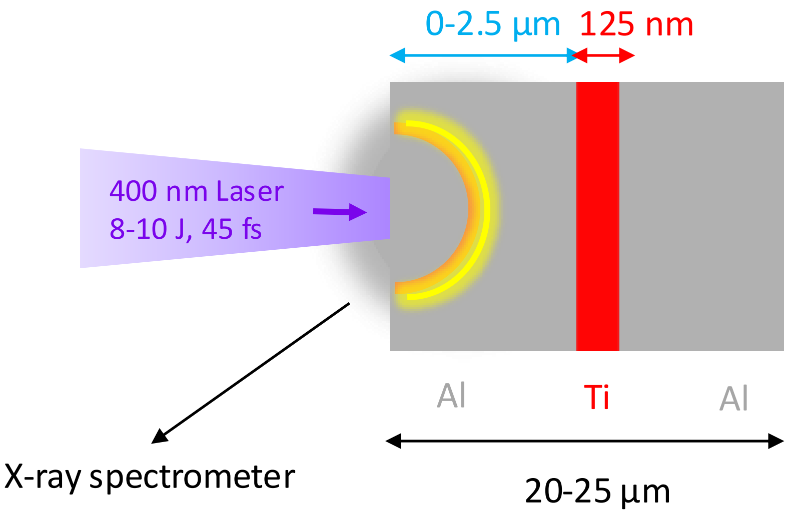


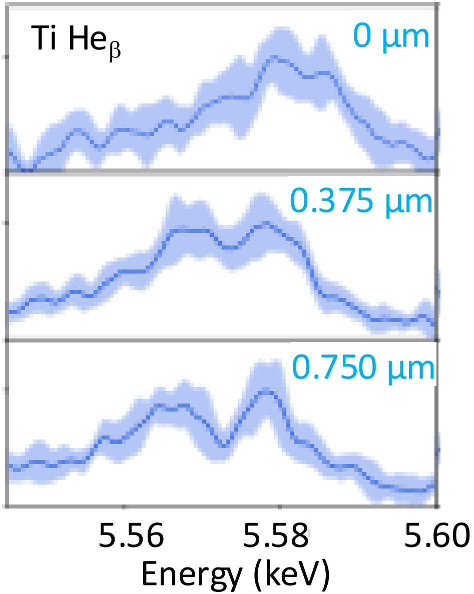


N.F. Beier *et al.*, PRL, 129, 135001 (2022)

Experiments: K079 (**Hussein** at CSU)

Ion-electron equilibration was studied by measuring x-ray emission line shapes in solid density plasma





Non equilibrium plasma

$n_e \sim 1 \times 10^{24}$ cm^{-3}

$T_e \sim 1$ keV

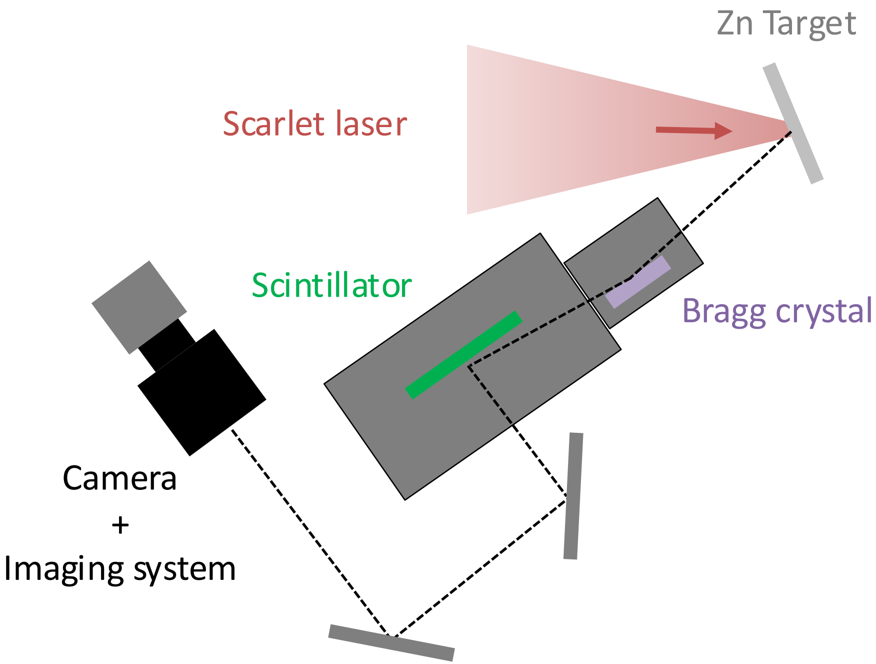
T_i <750 eV

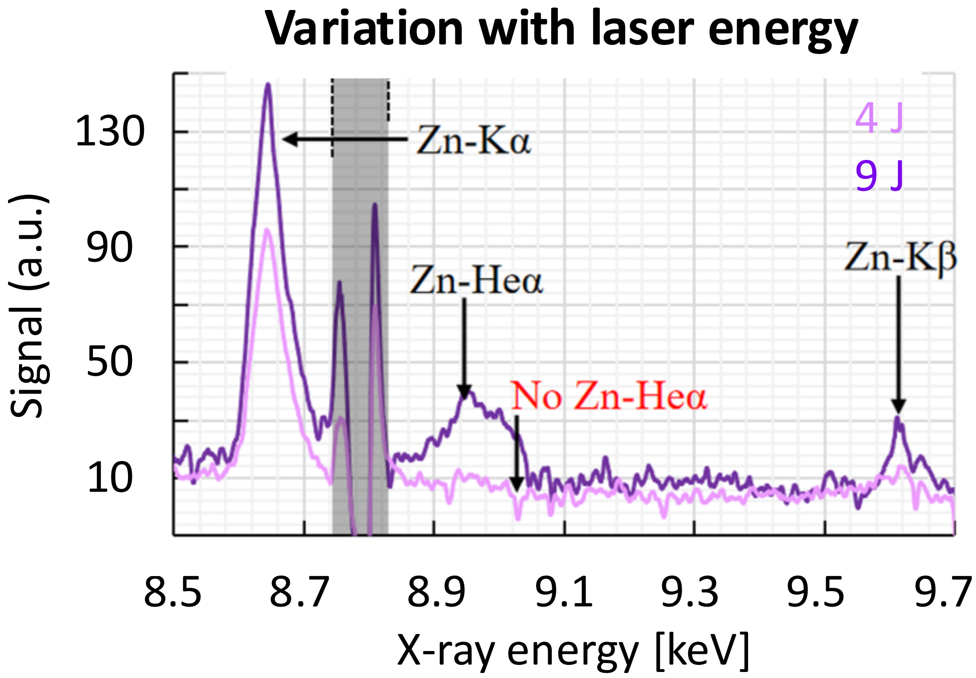
B.F. Kraus *et al.*, PRL, 127, 205001 (2021)

B.F. Kraus *et al.*, RSI, 92, 033525 (2021)

Experiments: K43, K109, K197 (**Kraus** at CSU)

Such precise measurements rely on novel x-ray spectrometers developed by our users

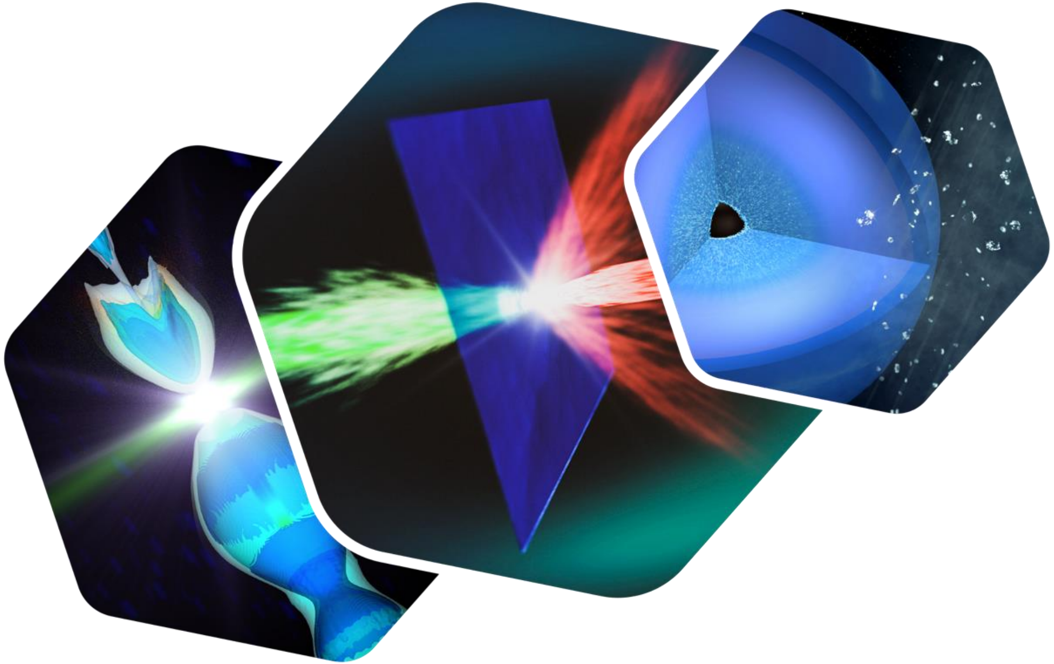




G. Zeraouli et al, RSI, 95, 073102 (2024)

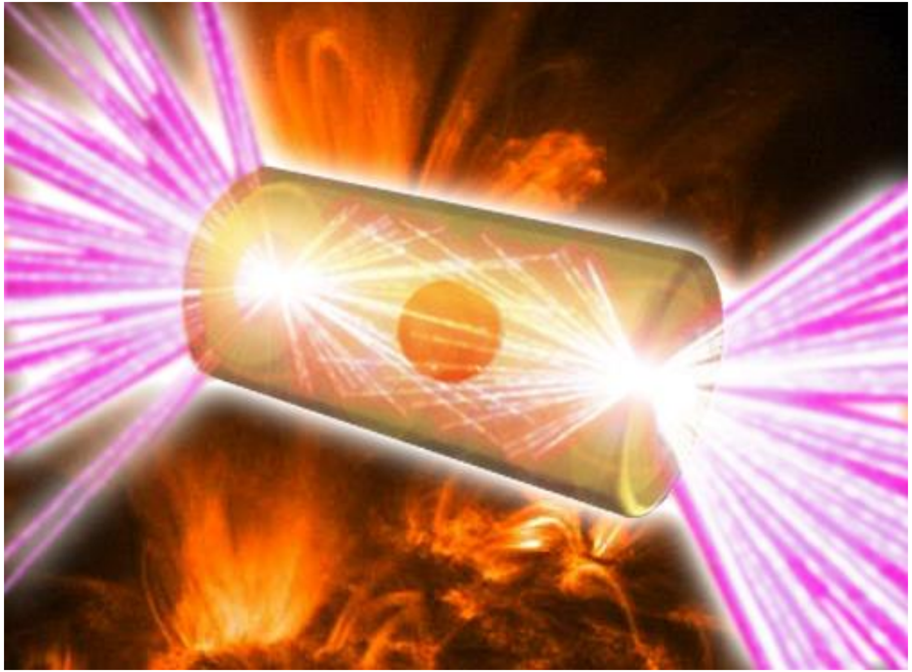
Experiments: K175 (**Zeraouli** at OSU and at LLNL)

LaserNetUS: Five years of scientific discovery



Accessing matter under extreme states of compression relevant for planetary interiors

Planetary science and inertial confinement fusion require understanding materials at extreme states of compression

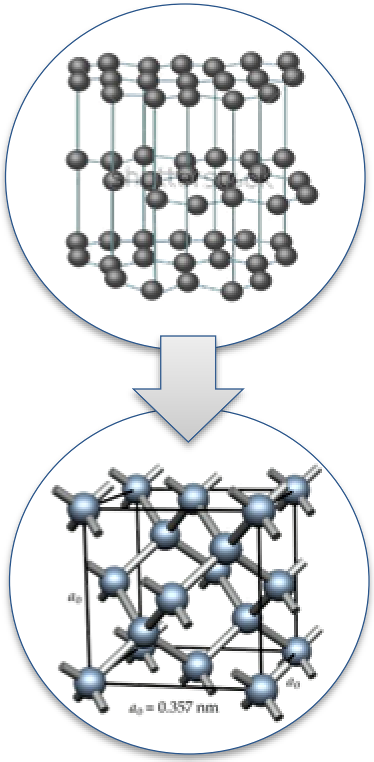


Material properties can fundamentally change at high pressures

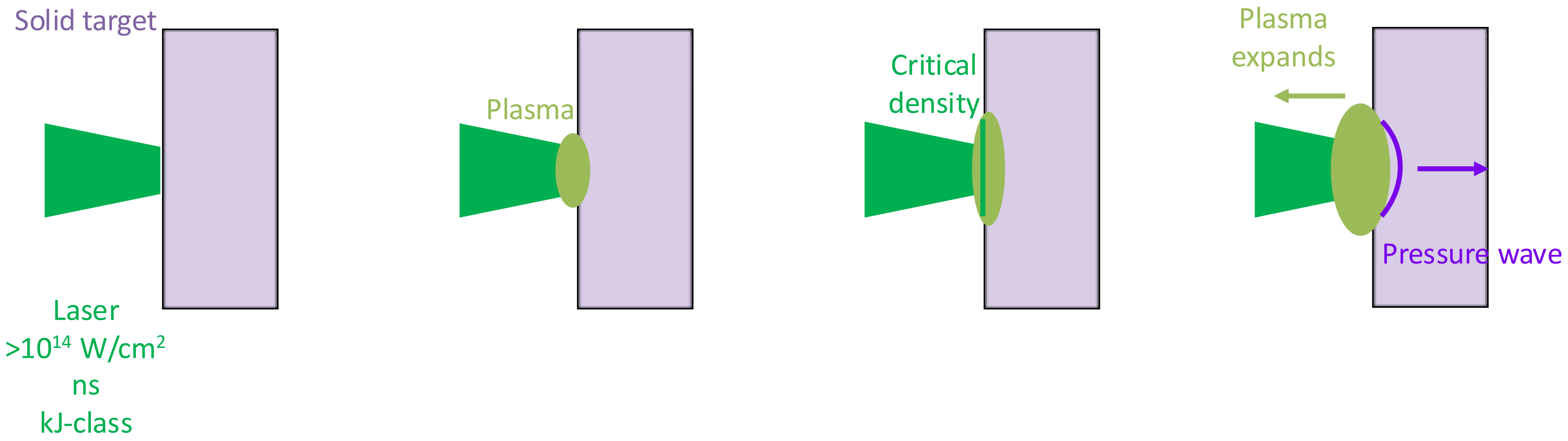
1 Atmosphere = 1 bar

Bottom of the ocean = 1000 bar

Center of the Earth = 3,600,000 bar = 3.6 Mbar



High power lasers can compress matter to Mbar pressures



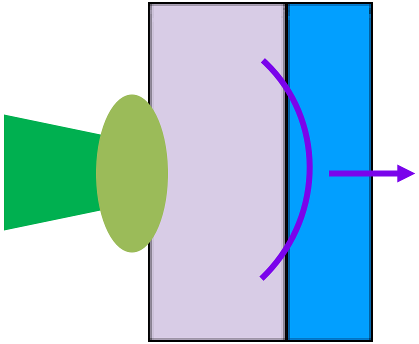
Energy transferred to target

Hot electrons transfer their energy to material
Coronal plasma forms

Laser energy primarily absorbed through IB collisions

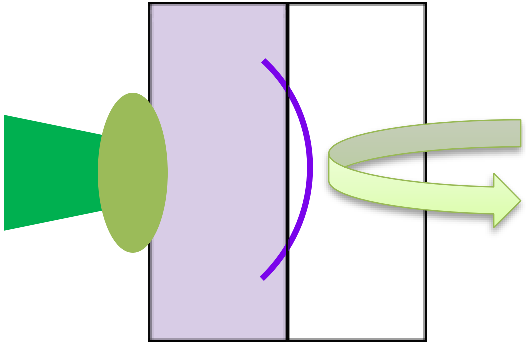
Plasma expands from target, pressure wave in opposite direction
"Rocket effect"

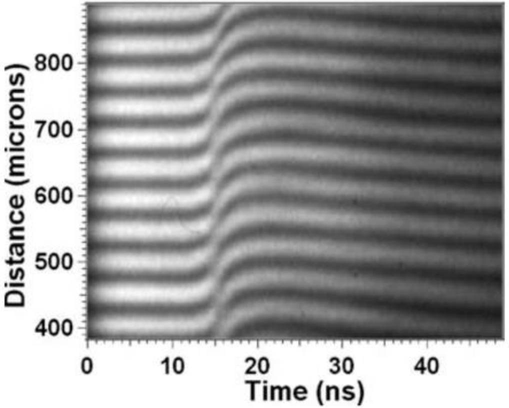
Laser-driven pressure waves can compress samples and be measured with shock velocimetry



Ablator Sample

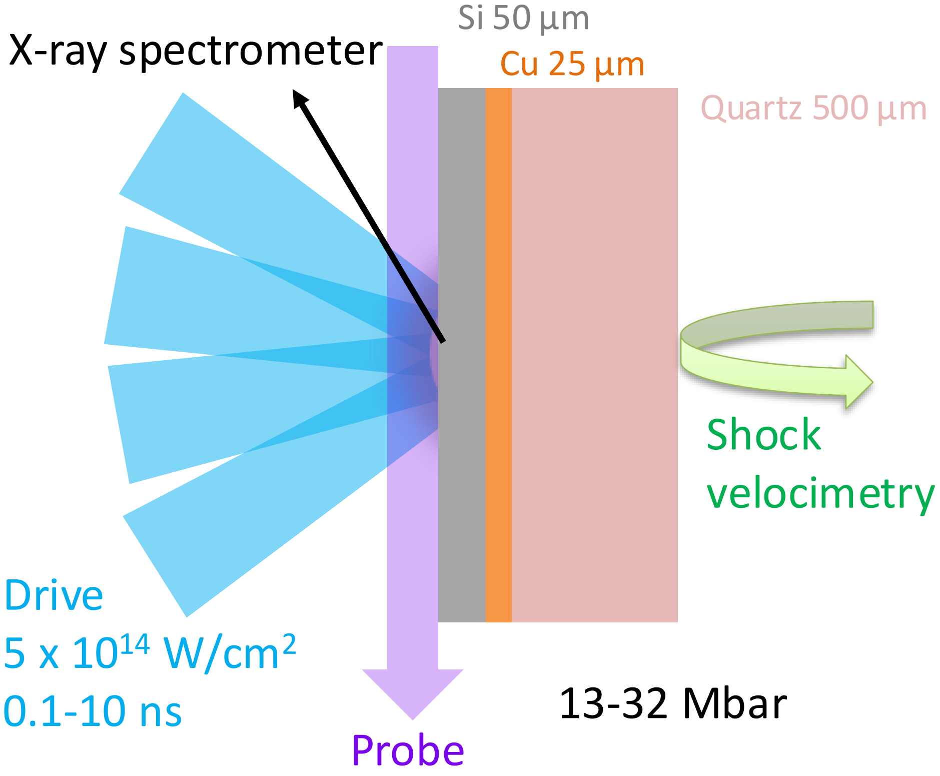
Transparent material
eg. quartz

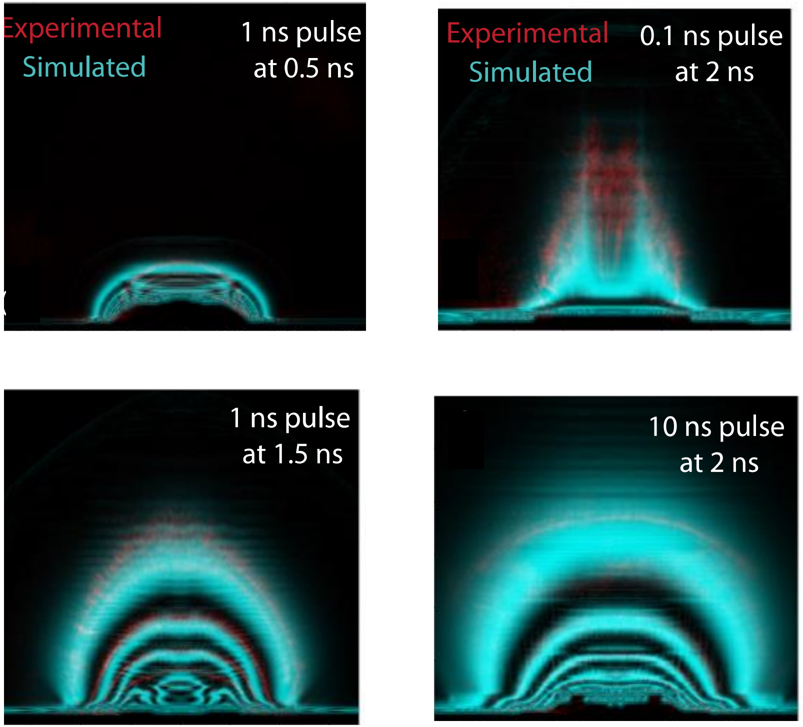




Shock
velocimetry

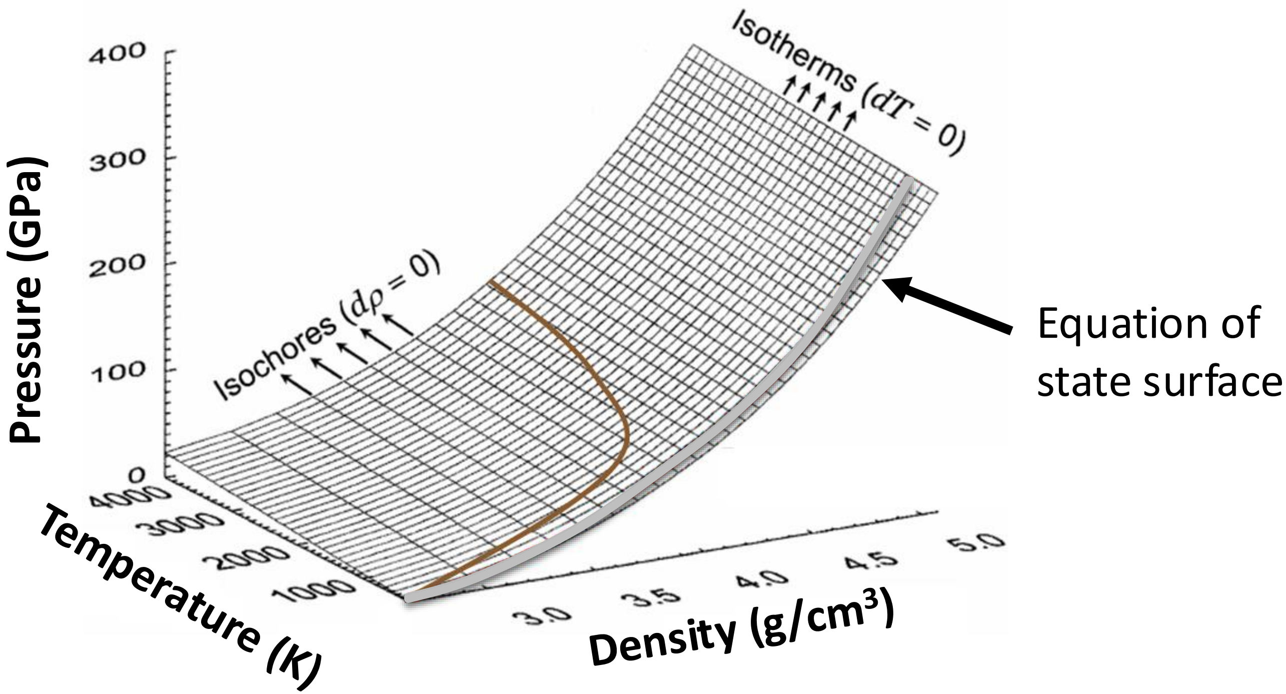
LaserNetUS experiments have investigated the influence of pulse duration on ablation pressure at constant intensity





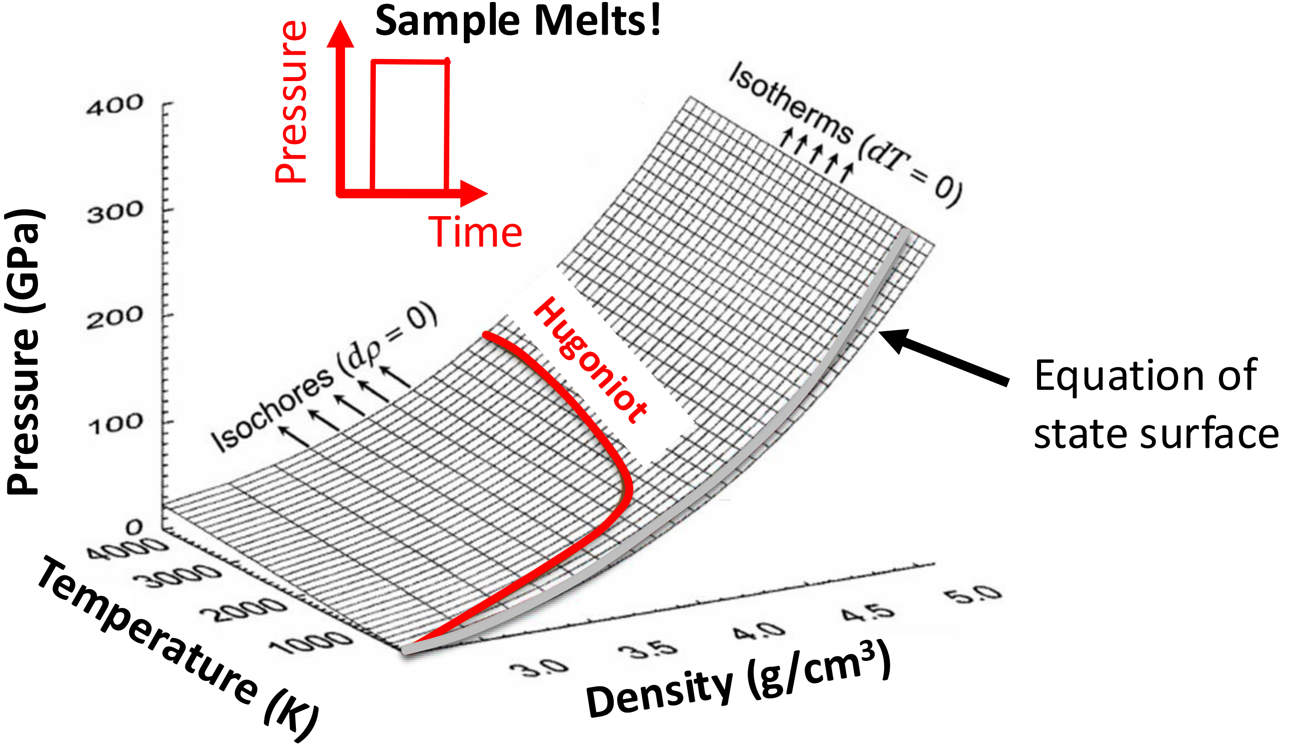
M. Bailly-Grandvaux, *et al.*, PRR, 033053 (2024)
Experiments: K120 (**Matsuo** at UR/LLE)

Thermodynamic compression space can be explored by varying the temporal shape of the laser driver



Thermodynamic compression space can be explored by varying the temporal shape of the laser driver

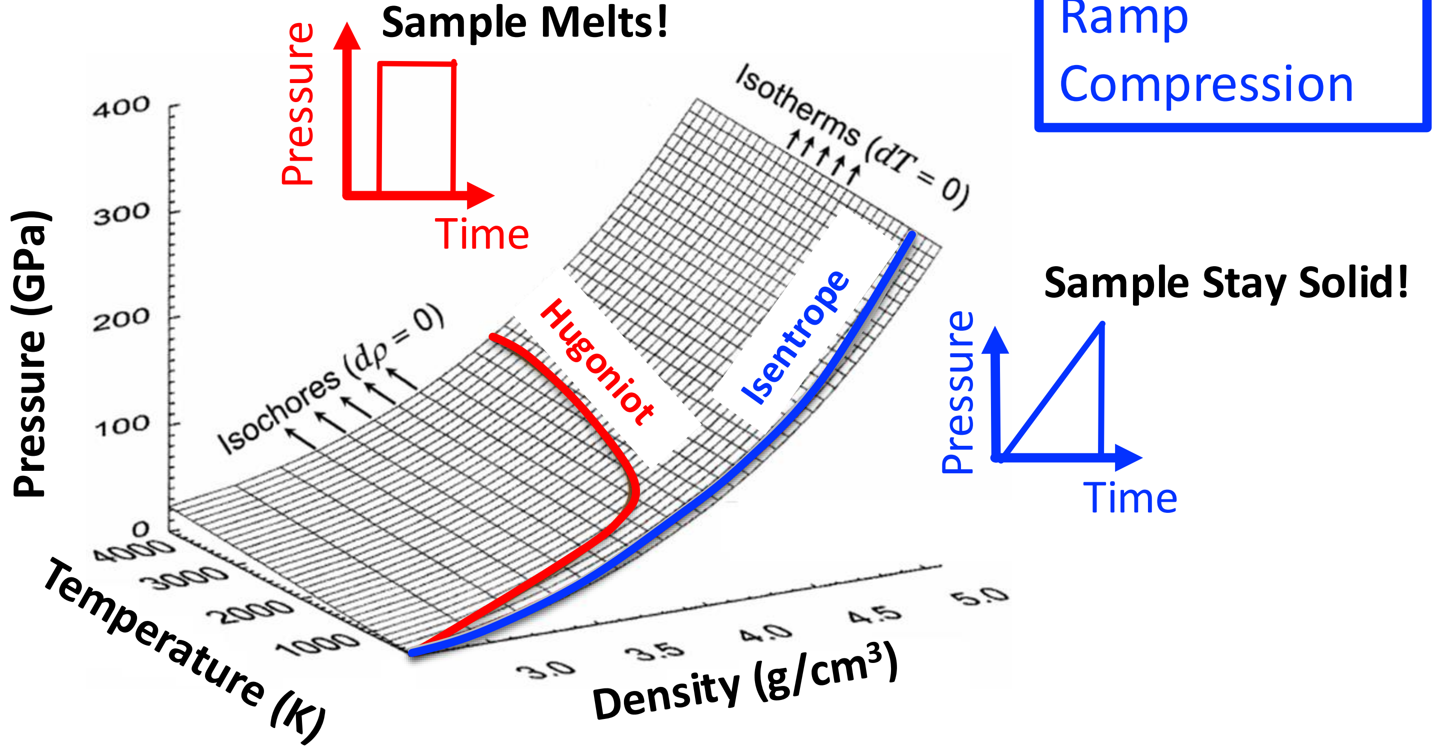
Shock Compression



Thermodynamic compression space can be explored by varying the temporal shape of the laser driver

Shock Compression

Ramp Compression

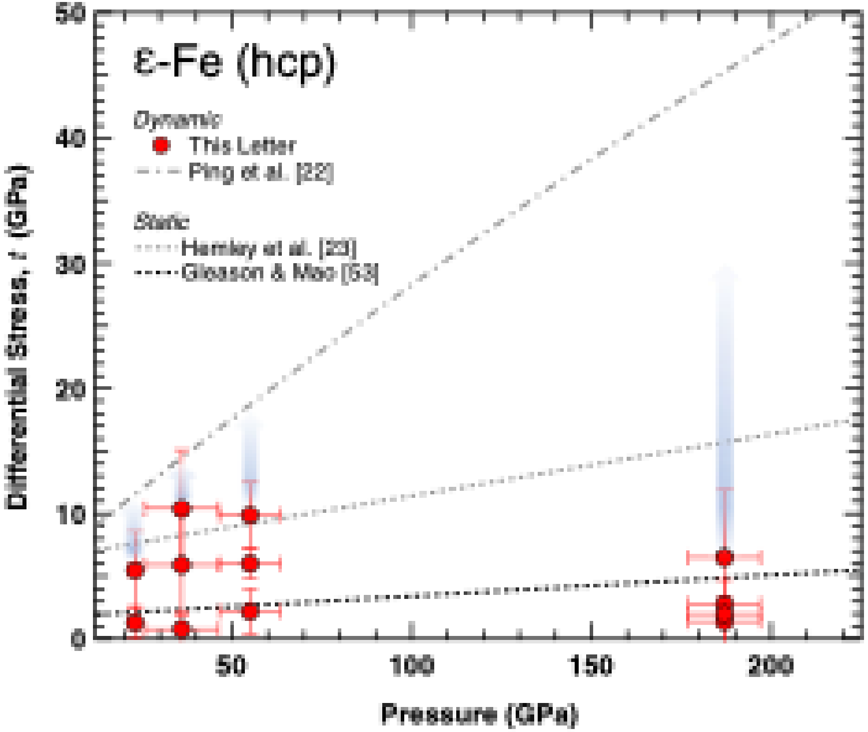


Ramp compression helps understand mechanical properties of solid materials under extreme conditions

Deformation under compression changes the atomic lattice arrangement of materials

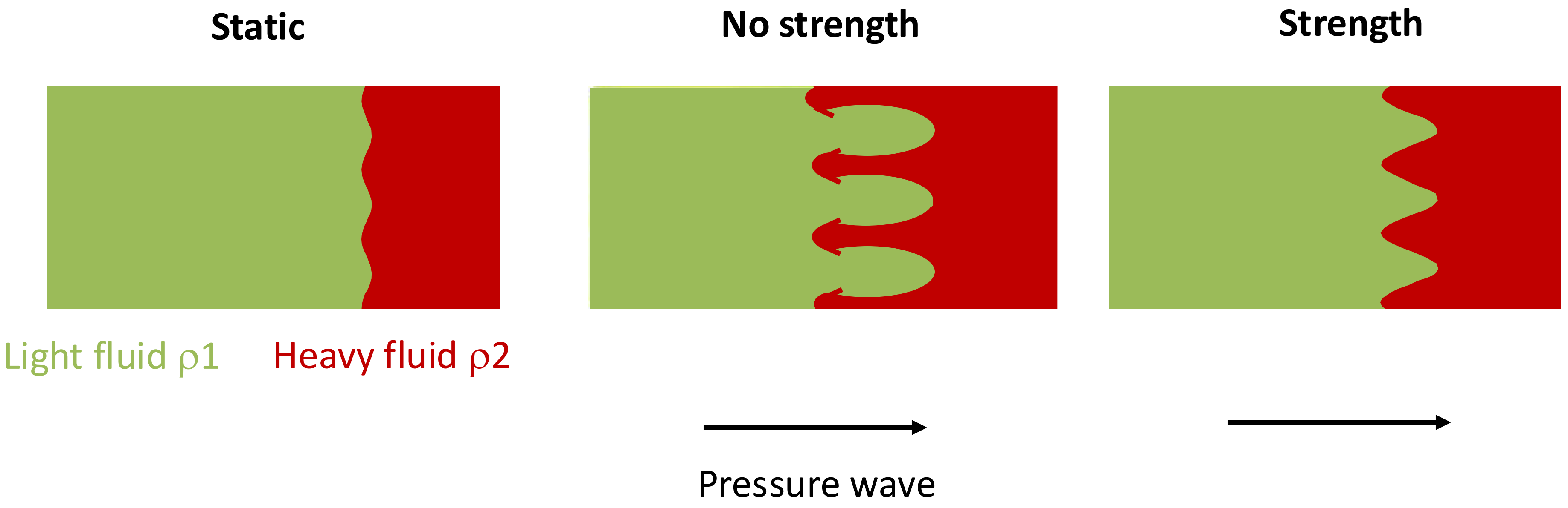
This microscopic change in lattice structure can impact macroscopic properties

One of these properties is strength, or resistance to deformation from an applied stress

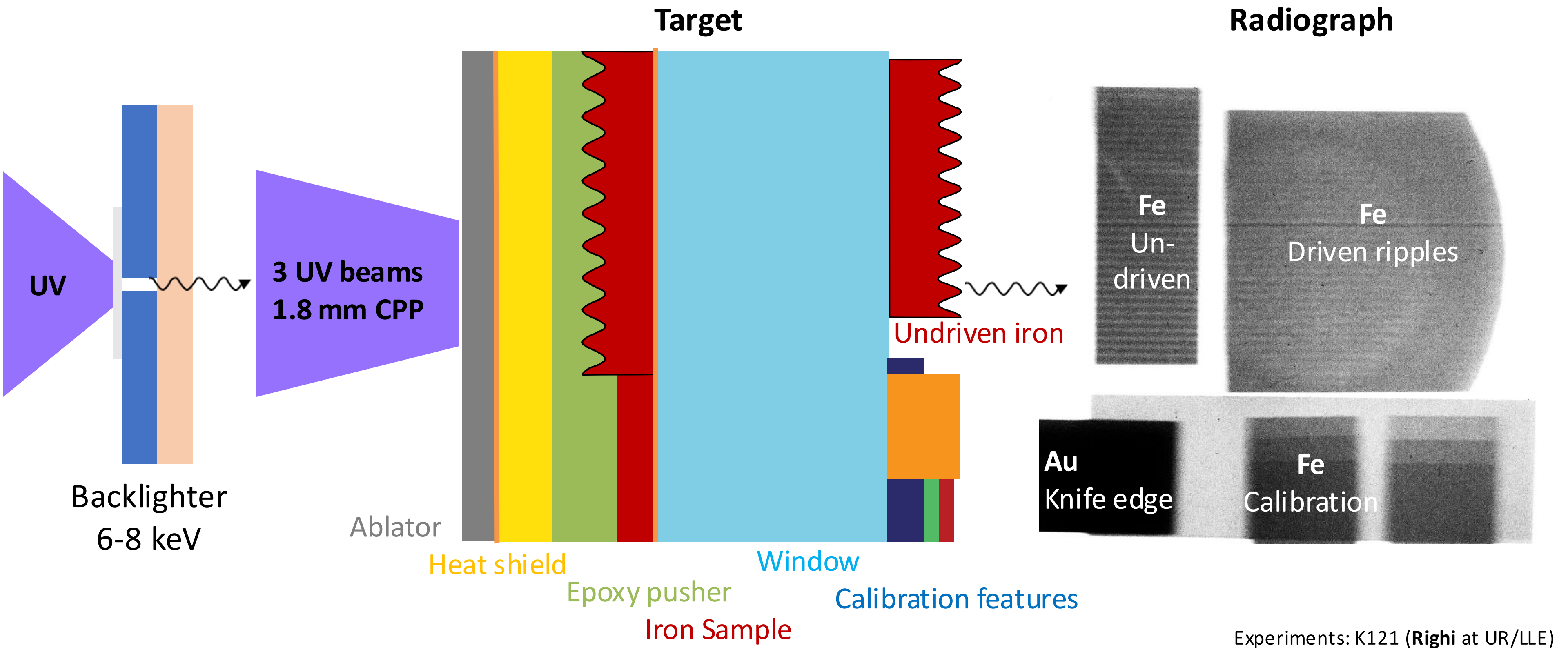


S. Hammel et al, PRL, 127, 205501 (2021)

Among several techniques previously used, the Rayleigh-Taylor instability growth can determine the strength of iron



A LaserNetUS experiment is looking at the RT growth in iron under various ramp compression/strength conditions

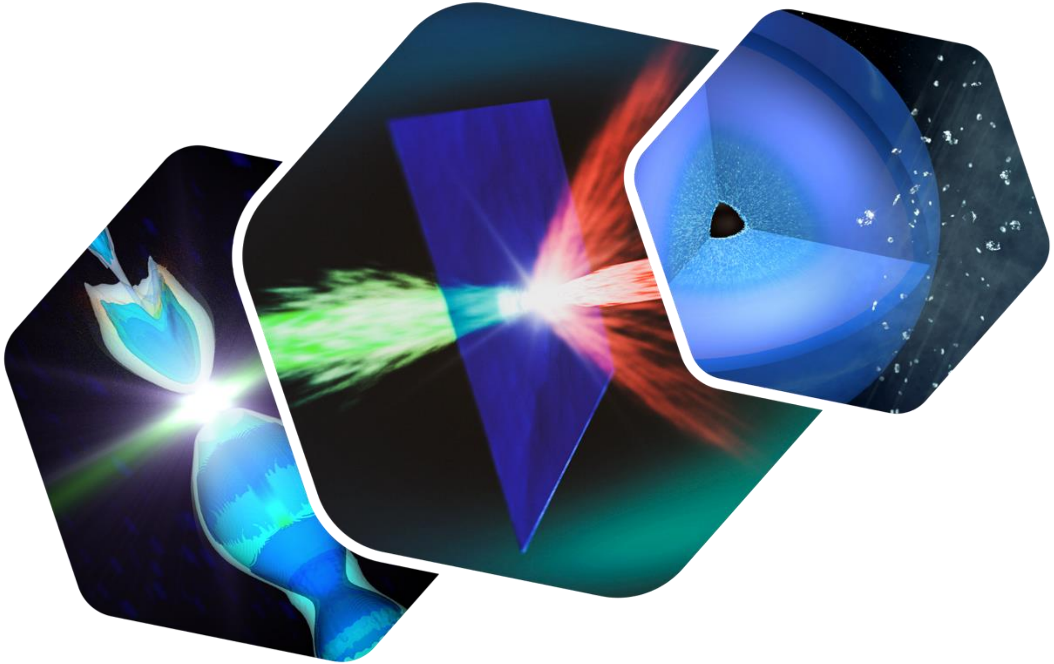


Experiments: K121 (**Righi** at UR/LLE)

Our scientific journey ends with many other achievements

K16	Development of plasma mirrors for PW lasers (**D. Schumacher** at LBNL)
K164	Imaging tin droplets with betatron x-rays (**A. Diallo** at LBNL)
K104	Real time measurements of focal spot intensity (**W. Hill** at OSU)
K146, K063	Effect of pulse shaping on particle acceleration (**D. Mariscal** at CSU)
K107, K218	Proton transport in warm dense matter (**S. Malko** at CSU)
K162	Laser contrast enhancement **(S. Steinke** at UT Austin)
K050, K159	Optimization of MeV x-rays (**J. Strehlow** at UT Austin)
K10060	Interaction of mid-IR laser pulses with plasma (**E. Chowdurry** at UCF)
K172	Edge illumination imaging of Si-Based electrodes (**S. Cipiccia** at ALLS)
K139	Betatron streaking for diagnosing LWFA electrons (**Y. Ma** at ALLS)
K157	Formation of metallic hydrogen in hydrocarbons (**N. Hartley** at SLAC)

LaserNetUS: Community building and outreach



Growing a vibrant, thriving, diverse and inclusive community

HOW TO GET ACCESS TO

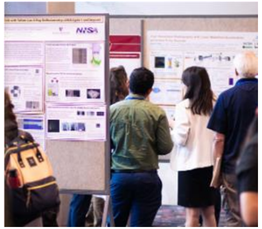
LASERNETUS

We have an annual call for proposals and it just opened

Cycle 7 Call for proposals	October 4th 2024
LaserNetUS Open Office Hours	October 16th - November 27th 2024 (Wed. 10-11 AM PT)
Proposal Writing Workshop	October 23rd 2024
LaserNetUS Townhall	November 14th 2024
Deadline for Proposal Submission	December 16th 2024
Proposal Review	January 16th 2025 to February 17th 2025
Technical Feasibility Review	February 14th 2025 to March 11th 2025
Award Letters Sent	Late March
Experiment Dates	September 2025 to August 2026

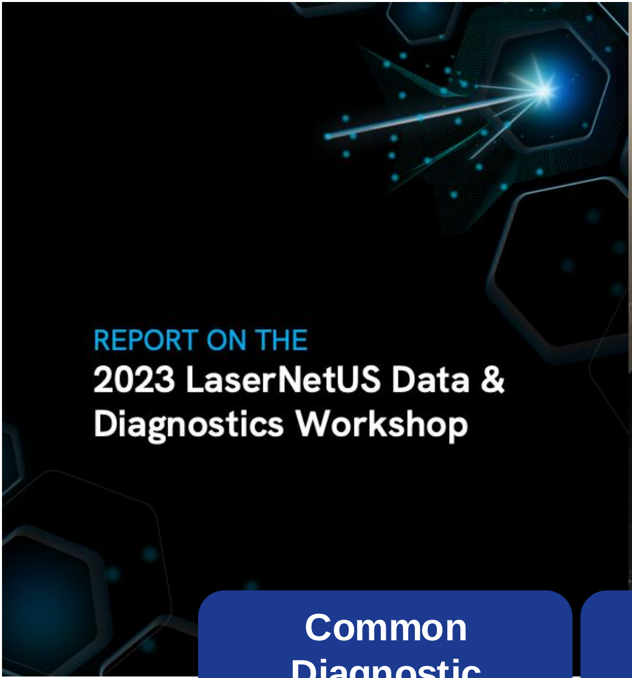
https://lasernetus.org/proposal

Users showcase their research at our annual meeting



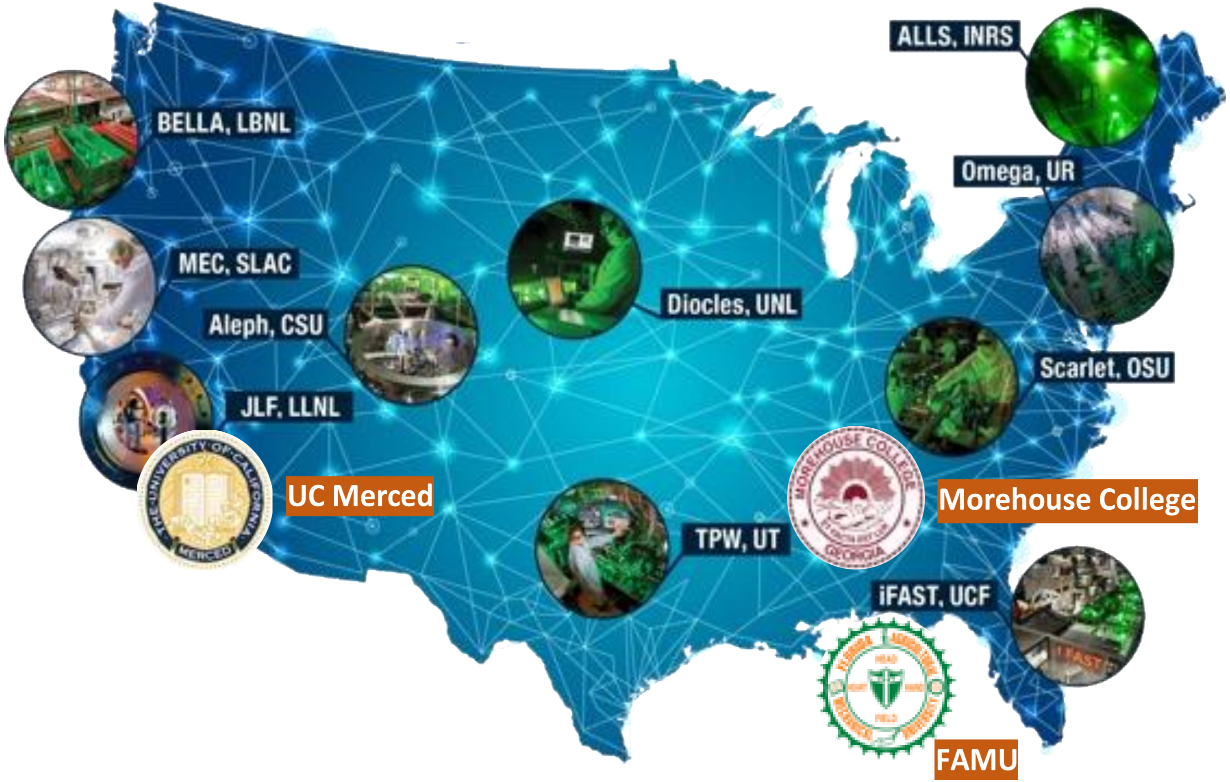
- The 2024 annual meeting was held in Austin, TX, July 16-18.
- 150+ attendees with over 50% students and postdocs
- Exhibitors from national labs or private industry
- LaserNetUS provided support for 62 students and postdocs

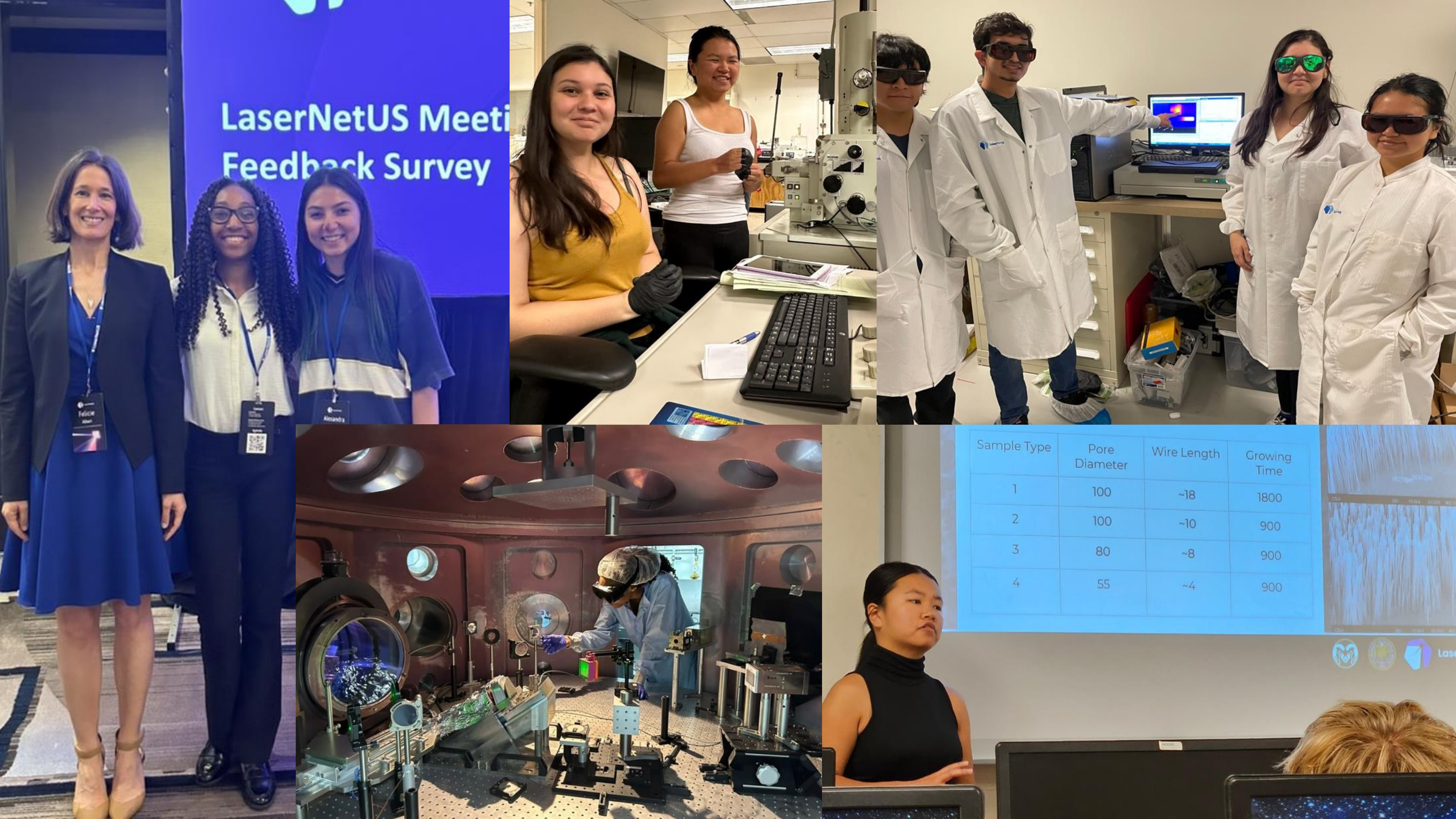
The LaserNetUS Diagnostics Committee coordinates efforts and needs across the network



- Common Diagnostic Program
- High Repetition Rate Diagnostics
- Diagnostics for New Generation of Facilities
- Data Collection and Processing Tools

REaching a New Energy sciences Workforce (RENEW) at LaserNetUS




LaserNetUS Meeti
Feedback Survey
Sample Type
Pore Diameter
Wire Length
Growing Time
1 100 ~18 1800
2 100 ~10 900
3 80 ~8 900
4 55 ~4 900

LaserNetUS

LASERNETUS STUDENT AMBASSADOR PROGRAM

Apply by: October 11, 2024

Are you a U.S.-based graduate student who collaborated on a LaserNetUS experiment? Apply now to become a student ambassador and showcase your research!

Program Highlights:

- ✔ Enhance Your Presentation Skills
- ✔ Expand Your Network
- ✔ 1-Year Term
- ✔ Travel Support for Conferences

Contact Us
info@lasernetus.org

Visit Our Website
lasernetus.org

Outline

History of high power and high intensity lasers

The creation and operation of LaserNetUS

LaserNetUS: 5 years of scientific discovery

- Secondary sources in underdense plasmas
- Secondary sources in overdense plasmas
- Extreme environments to understand space and fusion plasmas

LaserNetUS: 5 years of community building

Where we would like to be in five years

- Augmented capabilities
- Users from new institutions
- Users from new fields
- Grow relationships with industry
- Many more students from LaserNetUS

Acknowledgments

User input
Amina Hussein (U. Alberta)
Mathieu Bailly-Grandvaux (UCSD)
Simon Bolaños (UCSD)
Antoine Snijders (LBNL/LLNL)
Matthew Selwood (LLNL)
Franziska Treffert (LLNL)
Dean Rusby (LLNL)
Gaia Righi (LLNL)
Hye-Sook Park (LLNL)
Isabella Pagano (UT Austin)
Nicholas Hartley (SLAC)
Will Fox (PPPL)
Frances Kraus (PPPL)
Ghassan Zeraouli (CSU)
June Wicks (John Hopkins)

Network Facilities Committee
Mingsheng Wei (LLE)
François Légaré (INRS)
Douglass Schumacher (OSU)
Jorge Rocca (CSU)
Lieselotte Obst-Huebl (LBNL)
Cameron Geddes (LBNL)
Gilliss Dyer (SLAC)
Simon Vallieres (INRS)
Li Fang (UCF)
Mike Chini (OSU)
Howard Milchberg (UMD)
Christoph Niemann (UCLA)
Sandi Bruce (UT Austin)
Todd Ditmire (UT Austin)
Sallee Klein (U. Michigan)
Carolyn Kuranz (U. Michigan)
Chandra Curry (SLAC)

I-USE
Elizabeth Grace (LLNL)
Matthew Hill (LLNL)
Mathieu Bailly-Grandvaux (UCSD)
Quynh Nguyen (SLAC)

Diagnostics
Christine Mariscal (GA)
Sophia Malko (PPPL)
Franziska Treffert (LLNL)
Valeria Ospina (Focused Energy)
Frances Kraus (PPPL)
Dean Rusby (LLNL)
Christopher McGuffey (GA)
Maxence Gauthier (SLAC)
David Garand (Sydor)
Pia Valdivia (UCSD)

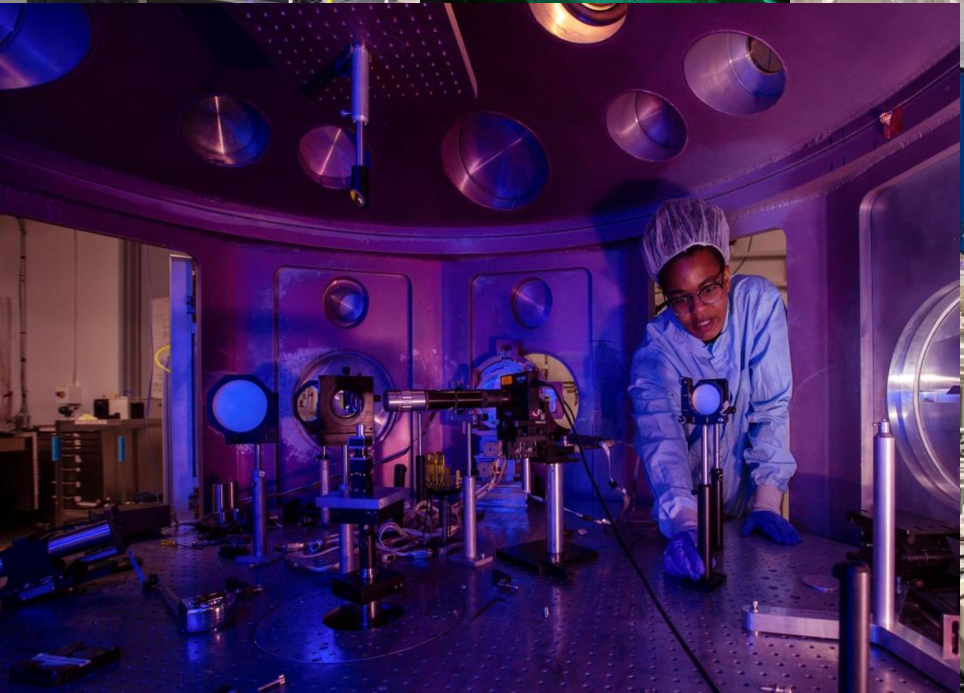
Simulations
Petros Tzeferacos (U. Rochester)
Igor Golovkin (Prism)

SAB
Roger Falcone (UC Berkeley)
Roman Hvezda (ELI Beamlines)
Pravesh Patel (Focused Energy)
Eva Kostadinova (Auburn U.)
Kevin Fournier (LLNL)
Derek Schaeffer (UCLA)
Andrea Kritcher (LLNL)

PRP Chairs
Matthew Edwards (Stanford U.)
Arianna Gleason (SLAC)
Tammy Ma (LLNL)








LaserNetUS

LaserNetUS Annual Meeting
July 8-10th 2025

LaserNetUS at DPP 2024
Oct 7-11th 2024

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