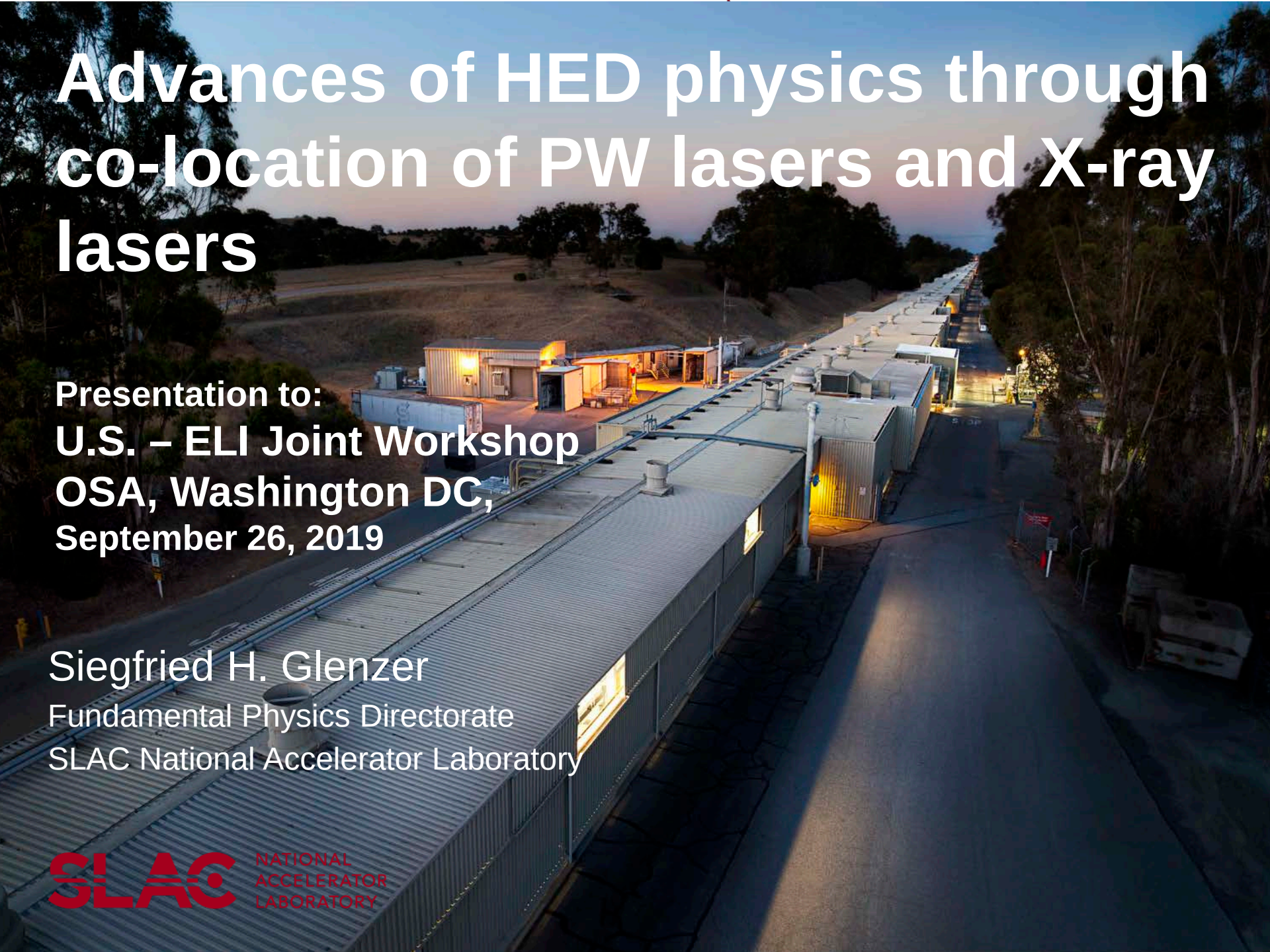
Advances of HED physics through co-location of PW lasers and X-ray lasers



Presentation to:
U.S. – ELI Joint Workshop
OSA, Washington DC,
September 26, 2019

Siegfried H. Glenzer
Fundamental Physics Directorate
SLAC National Accelerator Laboratory

SLAC NATIONAL ACCELERATOR LABORATORY

X-ray lasers probe High Energy Density Plasmas to resolve questions on producing and diagnosing fusion plasmas and their environment

SLAC

- **Validate simulations of the most extreme plasma phenomena**
  - *Particle in Cell (PIC)* simulations predict novel plasma accelerators, instabilities that lead to high-energy cosmic rays
- **Understanding the conditions of burning plasmas**
  - Test *Density Functional Theory (DFT)* for alpha stopping and plasma heating to simulate nuclear burn waves
- **Predict material behavior in extreme fusion plasma environments**
  - Knowledge of inter-atomic potential for *Molecular Dynamics (MD)* modeling of ultrafast behavior/design of new materials

A high-energy, petawatt laser will produce plasmas in support of DOE missions

Basic Plasma Science

Extreme Conditions

Fusion Material Science

Inside of a tokamak

LCLS is essentially a 2-mile long atomic-scale camera with a femtosecond “shutter speed”

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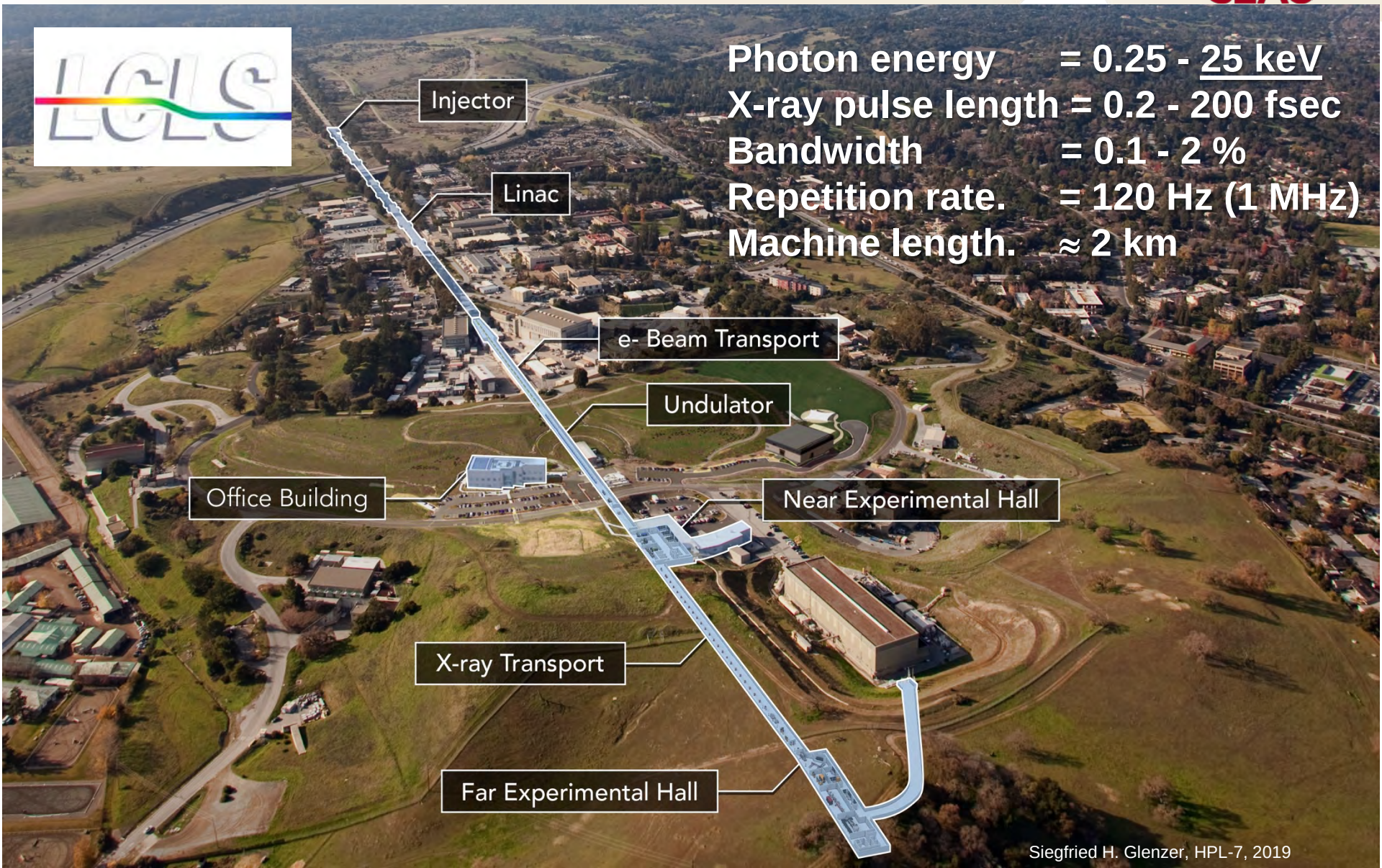

Siegfried H. Glenzer, HPL-7, 2019

LCLS: coherent, extreme brightness x-rays (>10^9 increase over prior sources) resolve collective plasma waves and structures

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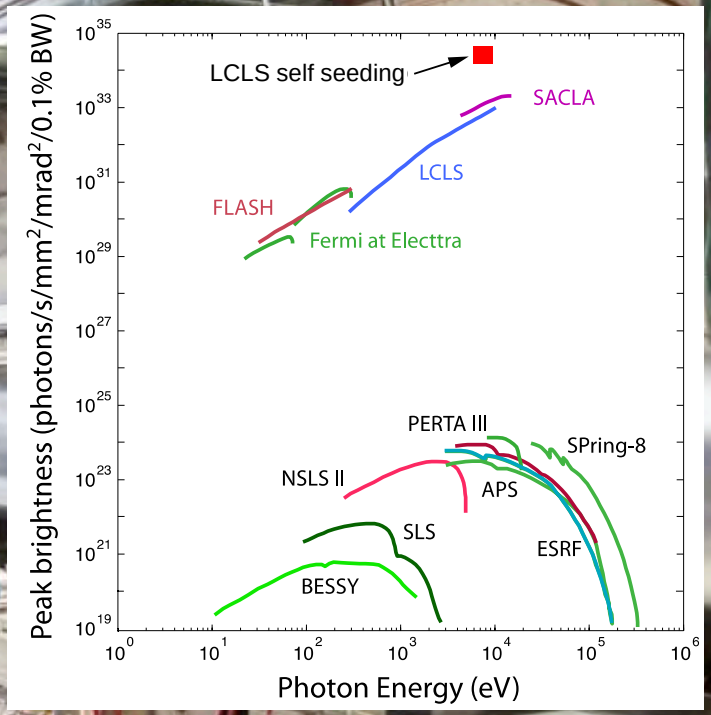

LCLS operates 24 hours/day with 95% beam availability as an open-access User Facility

Siegfried H. Glenzer, HPL-7, 2019

Matter in extreme conditions (MEC) instrument is supporting the science

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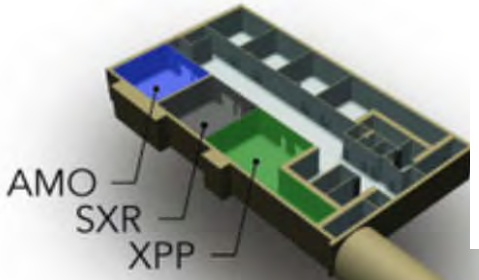
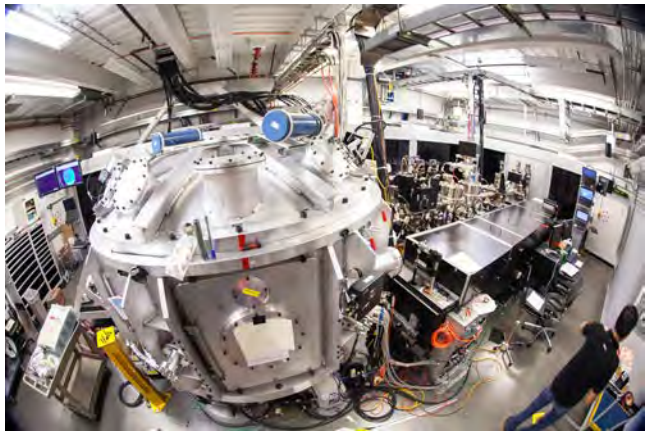
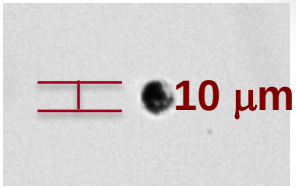


Combined X-ray beam and high-power lasers in large target chamber

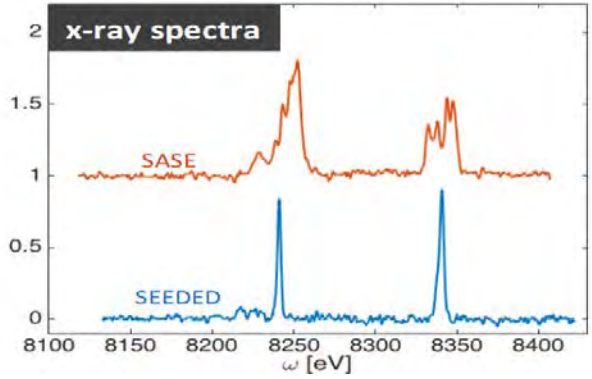




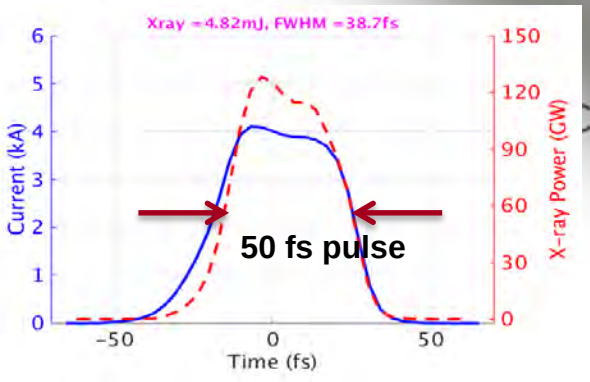
Long pulse and short pulse lasers

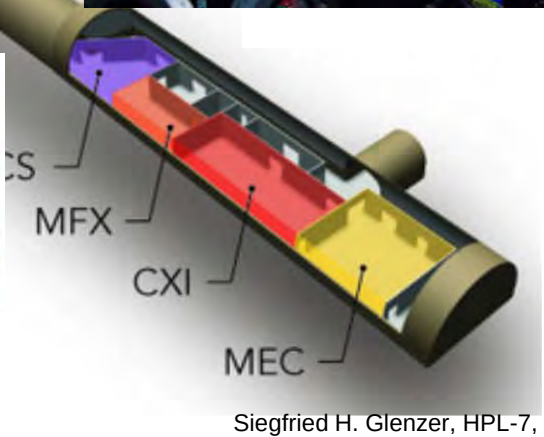
LCLS brings unique capabilities to study high-energy density plasmas

Fine spectral control



Ultra short pulses

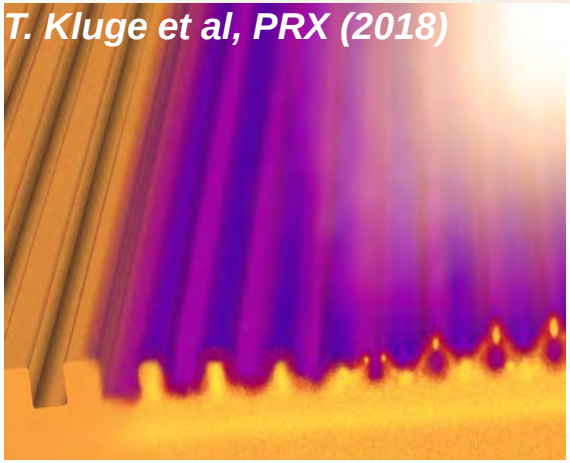




SLAC has delivered a world-leading program in HED science with X-ray lasers

SLAC

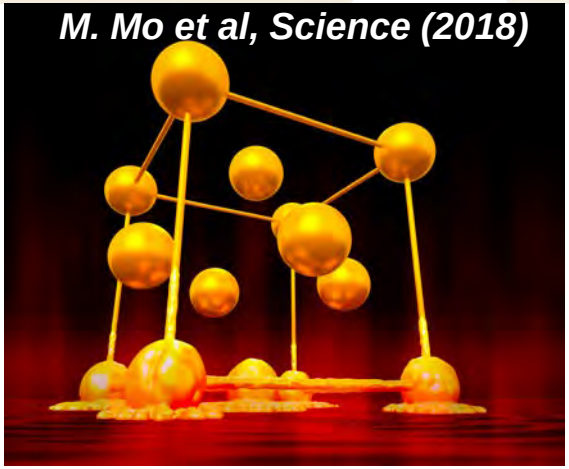
T. Kluge et al, PRX (2018)



Visualizing Nano-plasmas with Small Angle X-ray Scattering (SAXS)

Data validate PIC modeling

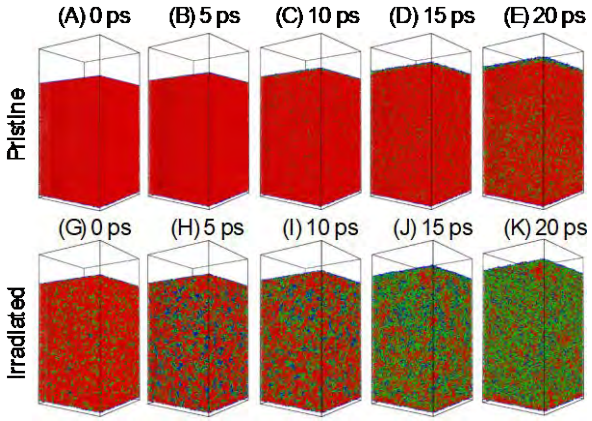
M. Mo et al, Science (2018)



Ultrafast heterogeneous melting

Data demonstrate sensitivity to material defects

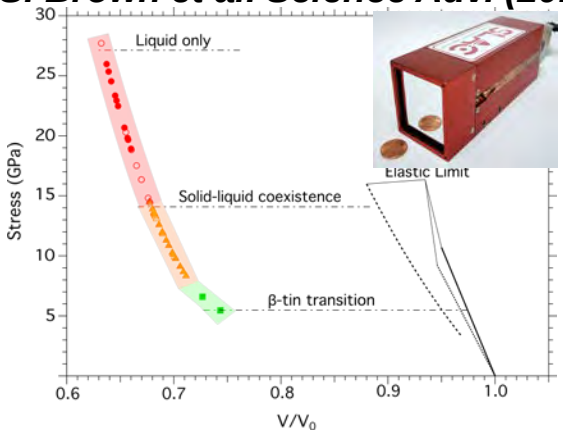
M. Mo et al, Science Adv. (2019)



Melting below T_{melt} in radiation-damaged W

Data validate MD modeling

E. McBride et al, Nature Physics (2019)
S. Brown et al. Science Adv. (2019)



Silicon failure in extreme conditions

Data indicate phase transition below elastic limit

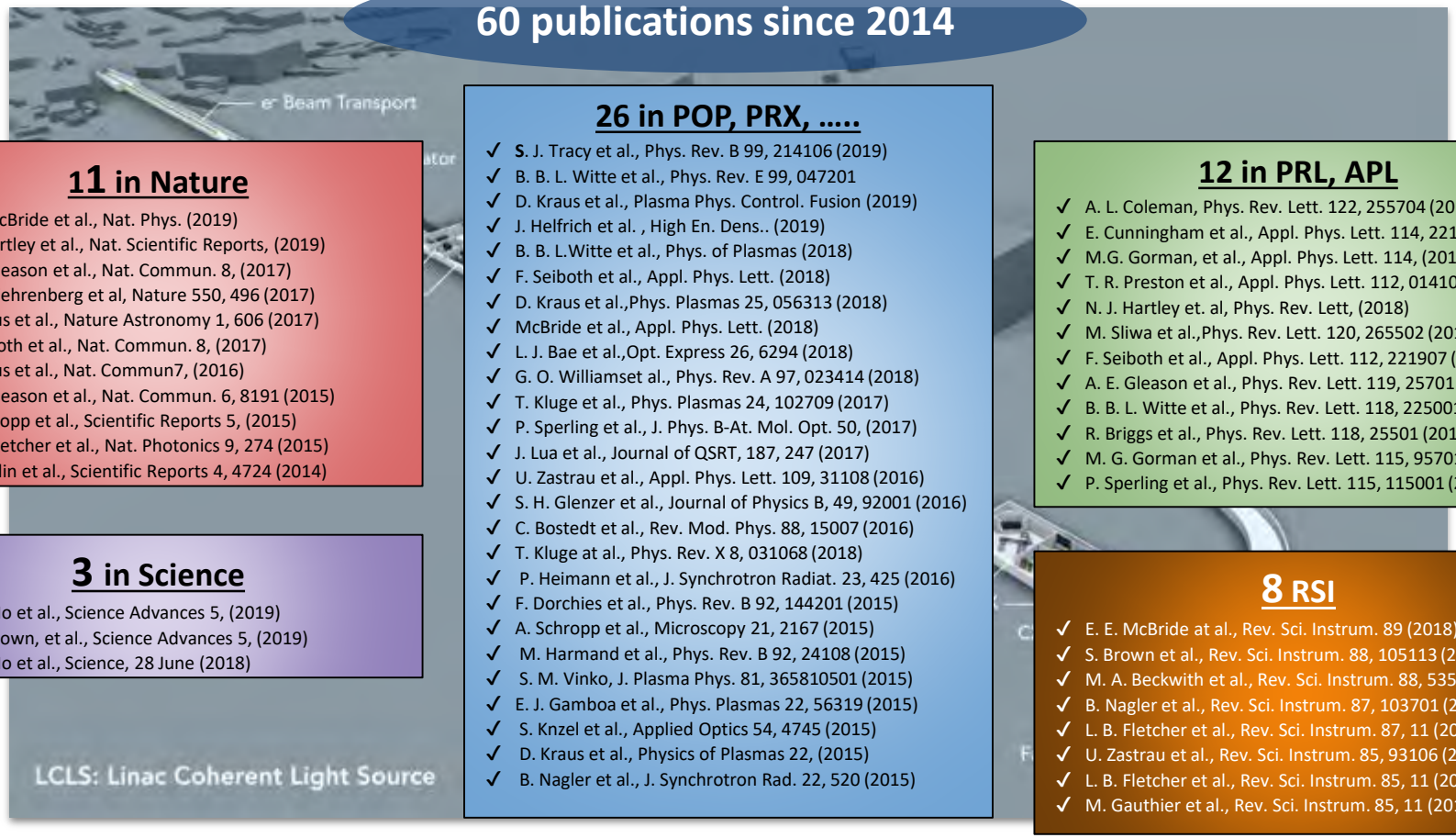
Beginning of 2020, LCLS-II will provide a major leap in performance both in high energy and multi-bunch trains greatly benefitting this research

Siegfried H. Glenzer, HPL-7, 2019

LLNL and SLAC are leading the publication list in HED science with X-ray Lasers

SLAC

60 publications since 2014



11 in Nature

- ✓ **E**. E. McBride et al., Nat. Phys. (2019)
- ✓ N. J.Hartley et al., Nat. Scientific Reports, (2019)
- ✓ A. E. Gleason et al., Nat. Commun. 8, (2017)
- ✓ C. E. Wehrenberg et al, Nature 550, 496 (2017)
- ✓ D. Kraus et al., Nature Astronomy 1, 606 (2017)
- ✓ F. Seiboth et al., Nat. Commun. 8, (2017)
- ✓ D. Kraus et al., Nat. Commun7, (2016)
- ✓ A. E. Gleason et al., Nat. Commun. 6, 8191 (2015)
- ✓ A. Schropp et al., Scientific Reports 5, (2015)
- ✓ L. B. Fletcher et al., Nat. Photonics 9, 274 (2015)
- ✓ J. Gaudin et al., Scientific Reports 4, 4724 (2014)

3 in Science

- ✓ M.Z. Mo et al., Science Advances 5, (2019)
- ✓ S. B. Brown, et al., Science Advances 5, (2019)
- ✓ M.Z. Mo et al., Science, 28 June (2018)

26 in POP, PRX, …..

- ✓ **S**. J. Tracy et al., Phys. Rev. B 99, 214106 (2019)
- ✓ B. B. L. Witte et al., Phys. Rev. E 99, 047201
- ✓ D. Kraus et al., Plasma Phys. Control. Fusion (2019)
- ✓ J. Helfrich et al. , High En. Dens.. (2019)
- ✓ B. B. L.Witte et al., Phys. of Plasmas (2018)
- ✓ F. Seiboth et al., Appl. Phys. Lett. (2018)
- ✓ D. Kraus et al.,Phys. Plasmas 25, 056313 (2018)
- ✓ McBride et al., Appl. Phys. Lett. (2018)
- ✓ L. J. Bae et al.,Opt. Express 26, 6294 (2018)
- ✓ G. O. Williamset al., Phys. Rev. A 97, 023414 (2018)
- ✓ T. Kluge et al., Phys. Plasmas 24, 102709 (2017)
- ✓ P. Sperling et al., J. Phys. B-At. Mol. Opt. 50, (2017)
- ✓ J. Lua et al., Journal of QSRT, 187, 247 (2017)
- ✓ U. Zastrau et al., Appl. Phys. Lett. 109, 31108 (2016)
- ✓ S. H. Glenzer et al., Journal of Physics B, 49, 92001 (2016)
- ✓ C. Bostedt et al., Rev. Mod. Phys. 88, 15007 (2016)
- ✓ T. Kluge at al., Phys. Rev. X 8, 031068 (2018)
- ✓ P. Heimann et al., J. Synchrotron Radiat. 23, 425 (2016)
- ✓ F. Dorchies et al., Phys. Rev. B 92, 144201 (2015)
- ✓ A. Schropp et al., Microscopy 21, 2167 (2015)
- ✓ M. Harmand et al., Phys. Rev. B 92, 24108 (2015)
- ✓ S. M. Vinko, J. Plasma Phys. 81, 365810501 (2015)
- ✓ E. J. Gamboa et al., Phys. Plasmas 22, 56319 (2015)
- ✓ S. Knzel et al., Applied Optics 54, 4745 (2015)
- ✓ D. Kraus et al., Physics of Plasmas 22, (2015)
- ✓ B. Nagler et al., J. Synchrotron Rad. 22, 520 (2015)

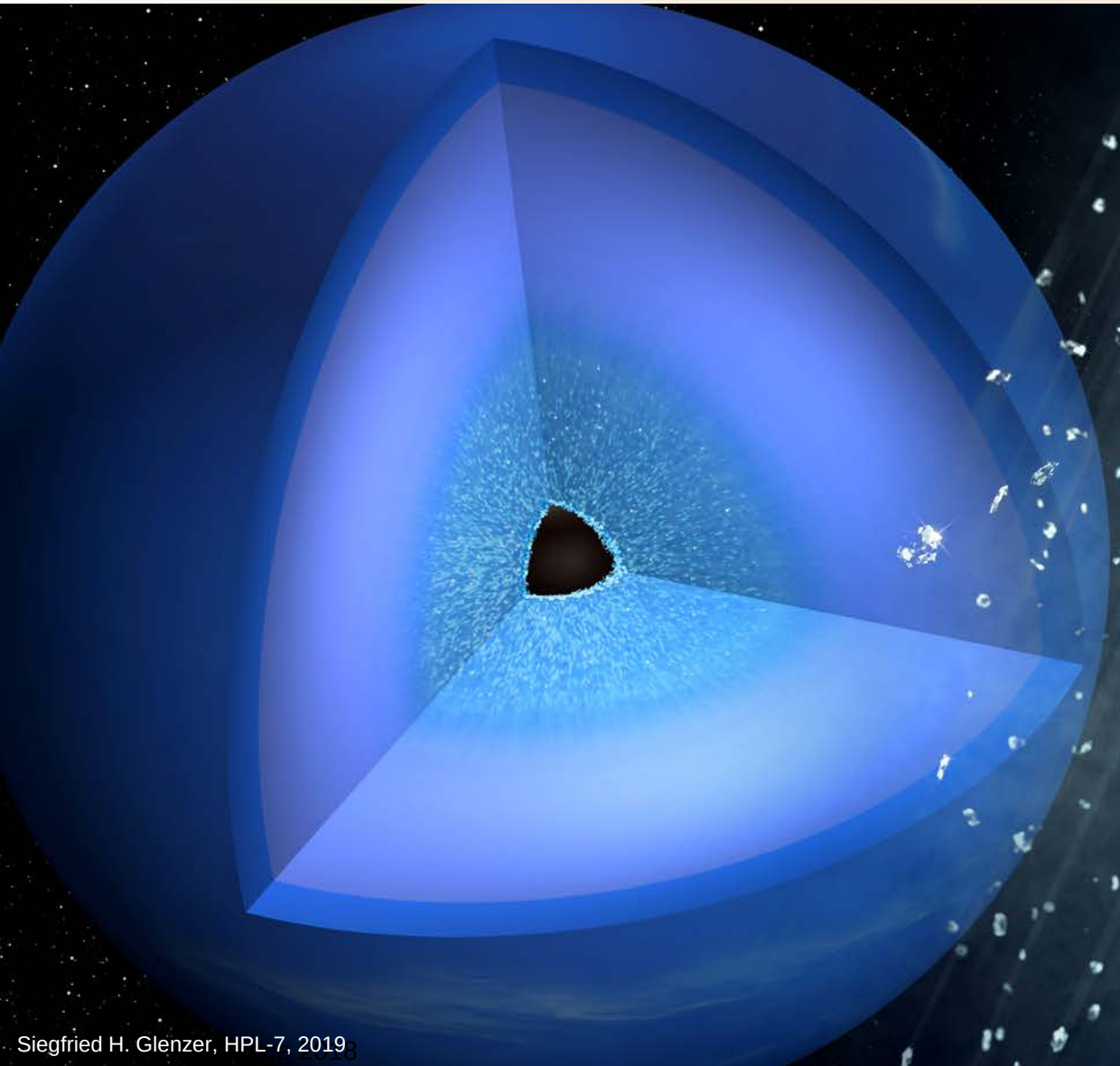
12 in PRL, APL

- ✓ A. L. Coleman, Phys. Rev. Lett. 122, 255704 (2019)
- ✓ E. Cunningham et al., Appl. Phys. Lett. 114, 221106 (2019)
- ✓ M.G. Gorman, et al., Appl. Phys. Lett. 114, (2019)
- ✓ T. R. Preston et al., Appl. Phys. Lett. 112, 014101 (2019)
- ✓ N. J. Hartley et. al, Phys. Rev. Lett, (2018)
- ✓ M. Sliwa et al.,Phys. Rev. Lett. 120, 265502 (2018)
- ✓ F. Seiboth et al., Appl. Phys. Lett. 112, 221907 (2018)
- ✓ A. E. Gleason et al., Phys. Rev. Lett. 119, 25701 (2017)
- ✓ B. B. L. Witte et al., Phys. Rev. Lett. 118, 225001 (2017)
- ✓ R. Briggs et al., Phys. Rev. Lett. 118, 25501 (2017)
- ✓ M. G. Gorman et al., Phys. Rev. Lett. 115, 95701 (2015)
- ✓ P. Sperling et al., Phys. Rev. Lett. 115, 115001 (2015)

8 RSI

- ✓ E. E. McBride at al., Rev. Sci. Instrum. 89 (2018)
- ✓ S. Brown et al., Rev. Sci. Instrum. 88, 105113 (2017)
- ✓ M. A. Beckwith et al., Rev. Sci. Instrum. 88, 53501 (2017)
- ✓ B. Nagler et al., Rev. Sci. Instrum. 87, 103701 (2016)
- ✓ L. B. Fletcher et al., Rev. Sci. Instrum. 87, 11 (2016)
- ✓ U. Zastrau et al., Rev. Sci. Instrum. 85, 93106 (2014)
- ✓ L. B. Fletcher et al., Rev. Sci. Instrum. 85, 11 (2014)
- ✓ M. Gauthier et al., Rev. Sci. Instrum. 85, 11 (2014)

Studies of Matter in Extreme Conditions have received wide public attention



Iliana Bazar, National Geographic, October 2019

CNN

Siegfried H. Glenzer, HPL-7, 2019

SLAC HED is bringing the HED community to MEC and LCLS

- >100 attendees
- 40% students/postdocs
- 15 Universities
- 5 National Labs
- 8 Company Sponsors
- Reports J. Syn. Rad., Pow. Diff.
- Present MEC experiments

7TH HIGH-POWER LASER WORKSHOP

September 26-27, 2019
SLAC National Accelerator Laboratory
Menlo Park, CA

The 7th HPL workshop will be held co-jointly with the general LCLS users meeting to discuss recent progress in the field of high-energy density physics enabled by the Matter in Extreme Conditions instrument at LCLS. During the first day of the workshop the attendees are encouraged to take part in the general LCLS users meeting and further have technical sessions related to LCLS-II and the MEC instrument. The second day of the workshop is dedicated to presentations of recent experimental results from MEC users during Run 17 and a poster session to encourage discussion and exchange of future ideas in our field. The goal is to discuss the scientific opportunities at the MEC instrument, propose future standard configurations, and provide time to discuss important physics proposals and experimental needs for cutting-edge high-energy density physics at LCLS.

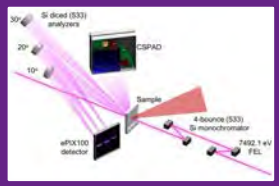
The workshop will provide opportunities for presentations by students and postdocs. Sponsor exhibits will be on display throughout the duration of the workshop.

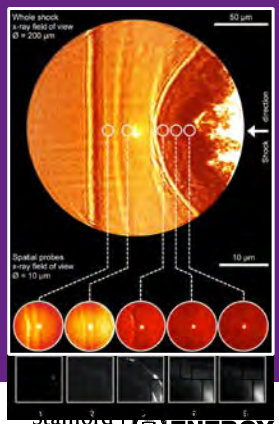
Organizers:
Cindy Bolme, Los Alamos National Laboratory
Gilliss Dyer, SLAC National Accelerator Laboratory
Siegfried Glenzer, SLAC National Accelerator Laboratory

Important Dates:
Poster abstracts due by: September 2, 2019
PDF of final poster due by: September 28, 2019
Registration deadline: September 18, 2019

Deadline for applications for student/postdoc support: August 23, 2019

conf-slac.stanford.edu/hpl-2019





SLAC NATIONAL ACCELERATOR LABORATORY

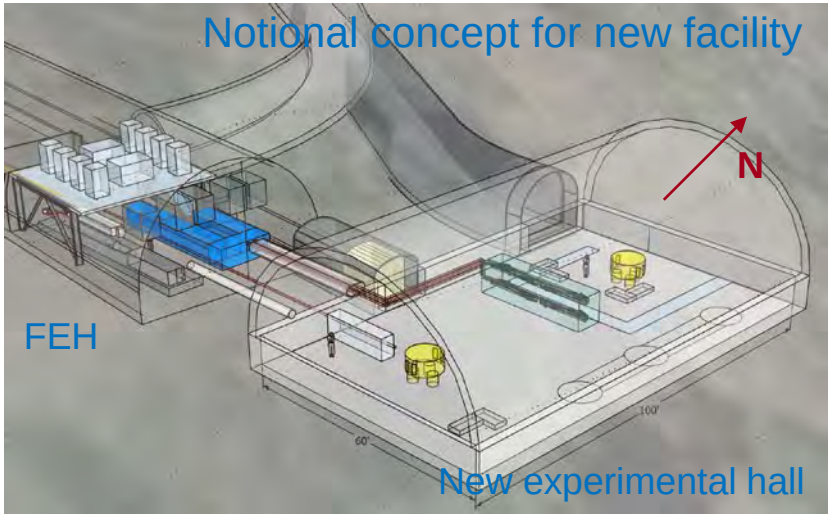
Stanford University | ENERGY

We are planning the next MEC user meeting, *HPL-VII,* September 2019

Siegfried H. Glenzer, HPL-7, 2019

Proposal to upgrade MEC for leadership in HEDS science with X-ray Free Electron Lasers

- Expanded facility east of LCLS for new lasers, multiple shielded target areas
- MEC Upgrade
  - **PW Laser**
    - 10^{18} Pa light pressure
  - **Compression Laser:**
    - 10^{12} Pa material pressure
- Strongly supported by HEDS community:
  - NAS study, High Power Laser and Brightest Light Initiative Workshop
- Ensure preeminence in the field of HED

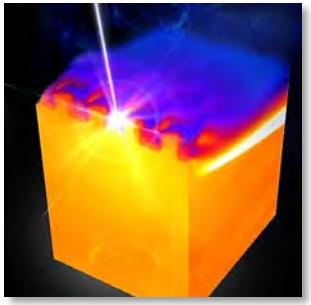


Nobel laureate Donna Strickland visiting MEC at LCLS

Project will position LCLS beyond any other XFEL in HEDS science capability.

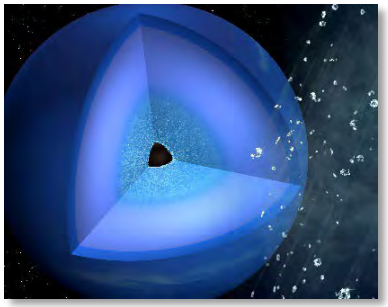
The Laser specs for the MEC upgrade are driven by the scientific missions within DOE

- **PW Laser: 150J, 150 fs, 1 μm, 10 Hz**
- 10^{18} Pa light pressure, Bright ion beams, Collision-less shocks
  - Compared to international competition
    - 10x higher repetition rate
    - 6x higher energy
    - 2x higher power



Producing bright sources of ions, neutrons and magnetic fields for fusion material science

- **Compression Laser: 1 kJ, 20 ns, 0.35 μm, shot/minute**
  - 10^{12} Pa material pressure, Ablator physics, Unearthly materials
  - Compared to international competition
    - 10x higher energy at shot/minute
    - 2x higher energy at 10 Hz



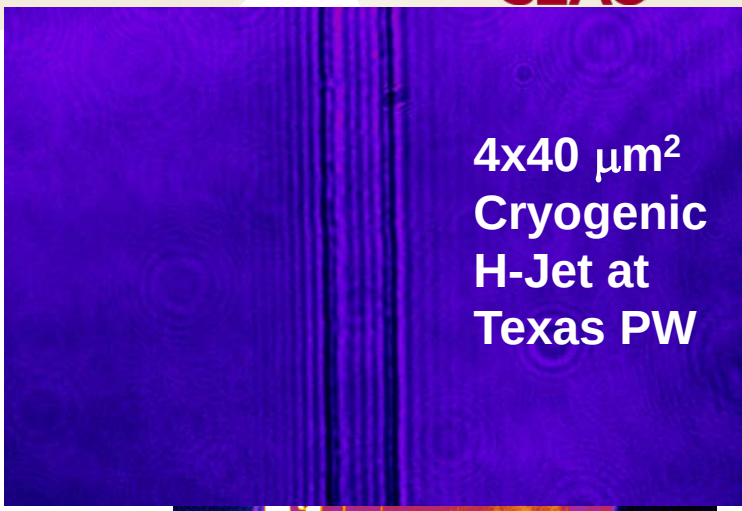
Producing extreme material states through near isentropic compression

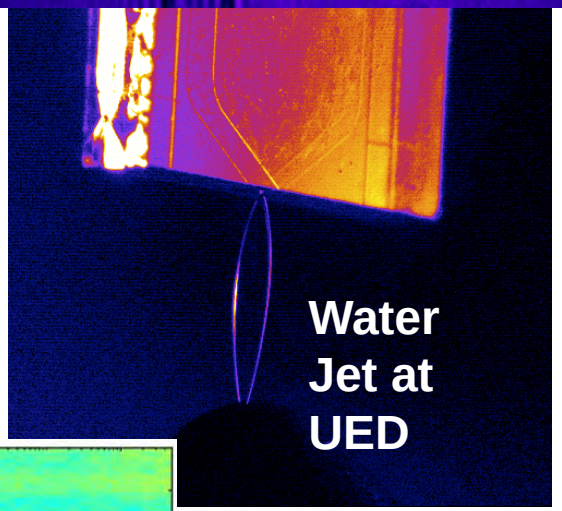
These lasers provide unparalleled capabilities to access and probe new states of matter

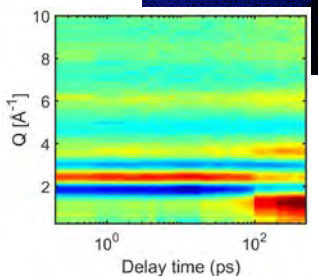
Opportunities for U.S. – ELI joint projects

SLAC

- **Develop ultra-bright, high-energy radiation sources for pump-probe experiments**
  - **Radiation damage cascades**
  - **Neutrons, Protons, heavy ions**
- **Develop high rep rate target delivery systems for high-intensity lasers**
  - **Liquid jets/Cryogenic jets**
- **Machine learning techniques for analysis of large data sets**
  - **We have begun delivering > 1 million shots in laser experiments**
- **High-repetition rate X-ray detectors**







360 Hz data