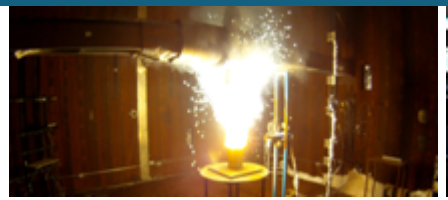
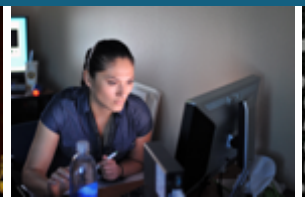
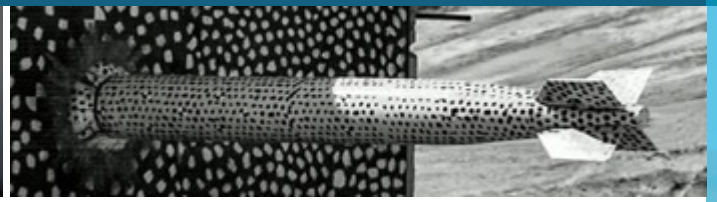
SAND2021-12366PE

Sandia National Laboratories

Current and planned dynamic compression drivers at light sources







PRESENTED BY

Chad McCoy

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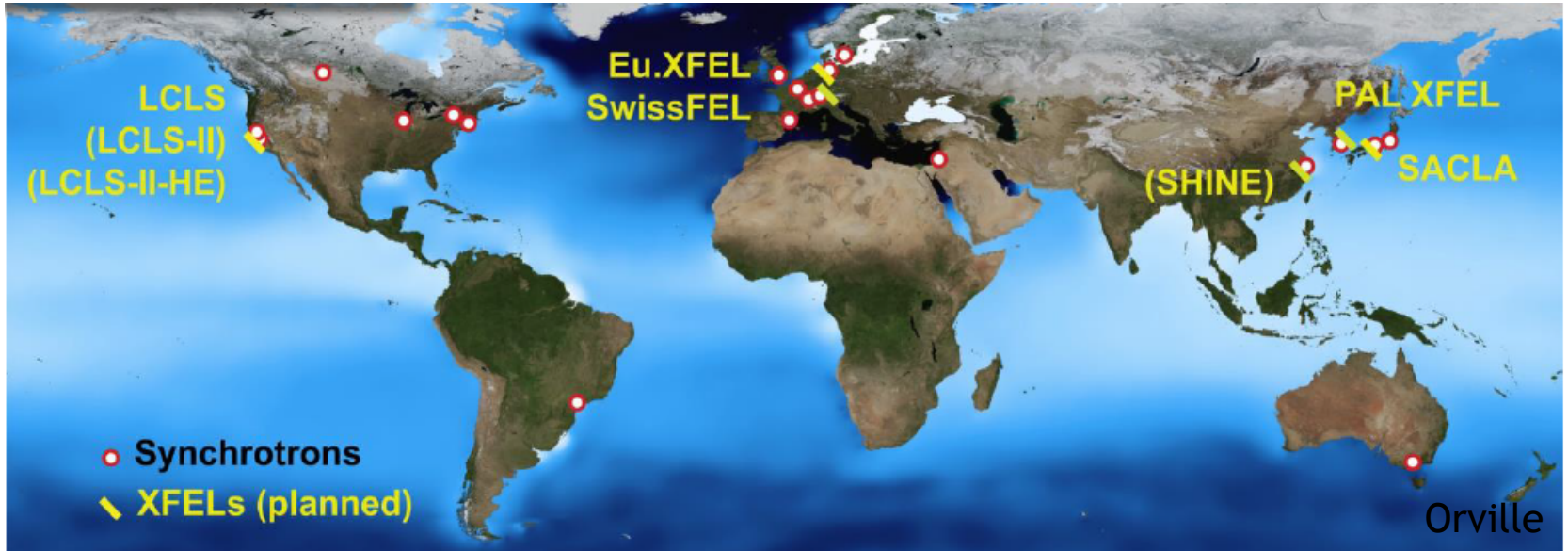
To better understand the fundamental properties of matter we must continue to investigate with greater resolution

Broad range of pure and applied sciences, industry, and defense all utilize x-ray light sources to achieve their missions

44 Synchrotrons operated as large-scale research facilities across the world
- ~20 smaller university-scale facilities in operation

16 XFELs are currently operating for scientific research
- 14 operate for FEL physics or without extensive end-stations for research

13 XFELs currently proposed or under construction



Key to stewarding the nations nuclear deterrent is our understanding of how materials perform at extreme conditions

We perform small-scale experiments with lasers or pulsed power to understand fundamental material properties

Intermediate scale gas gun experiments allow for understanding of mesoscale phenomena of material response, but without the diagnostic access of small-scale experiments

Large-scale explosive experiments enable testing of macroscale properties for realistic geometries

NNSA has been increasingly utilizing light sources in a pump-probe configuration to understand at increasingly finer resolution the controlling phenomena of materials at extreme conditions.

Existing dynamic drivers include short- and long-pulse lasers, gas guns, pulsed power, and high explosives

- Highest pressure achievable ~500 GPa for shock experiments
- Gas gun and high explosive experiments also regularly conducted at pRad

More energetic drivers are required to study mesoscale phenomena at appropriate length and time scales

The most common dynamic compression drivers at light sources are long-pulse (few-ns) lasers

Operational laser energies all ≤100 J

Synchrotrons:

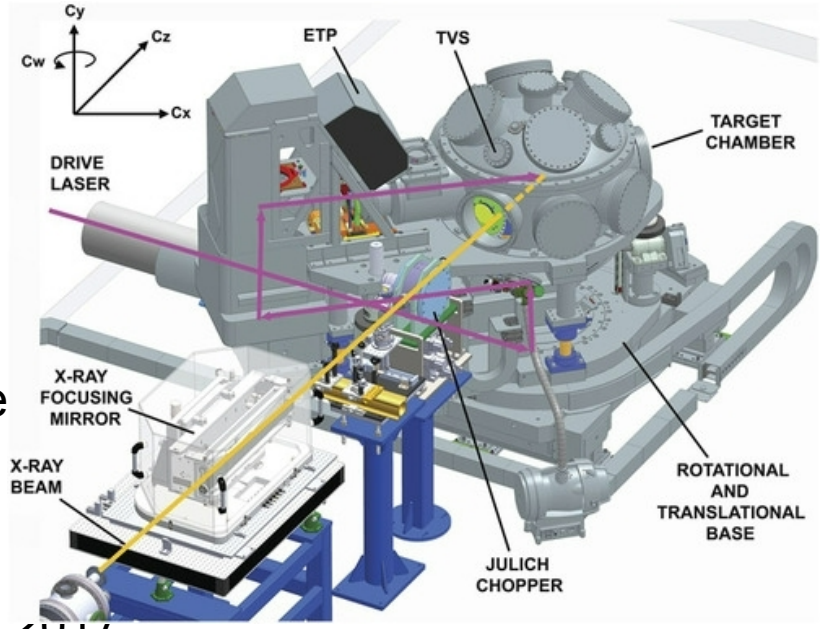
- APS (USA) – DCS operates Laser Shock Facility with 100 J UV laser
- ESRF (France) – HPLF has set up a 100 J UV laser (became operational e
  - Previous experiments conducted with 40 J portable laser

XFELs:

- LCLS (USA) – MEC upgraded to 60 J green laser for shock experiments in 2017
- European XFEL (Germany) – Shock experiments with 80 J green laser started 2019
- SACLA-XFEL (Japan) – Demonstrated capabilities of 60 J green laser (design spec >100 J)

Under development:

- SHINE (China) XFEL – multi-kJ long-pulse laser planned to come online 2025, specific details not provided
- LCLS XFEL – FES MEC upgrade includes ~1 kJ laser
- PETRA-IV Synchrotron (Germany) – Proposal for ~1 kJ long pulse laser



DCS laser shock station*

*[Wang *et al*, RSI 90, 053901 (2019)]

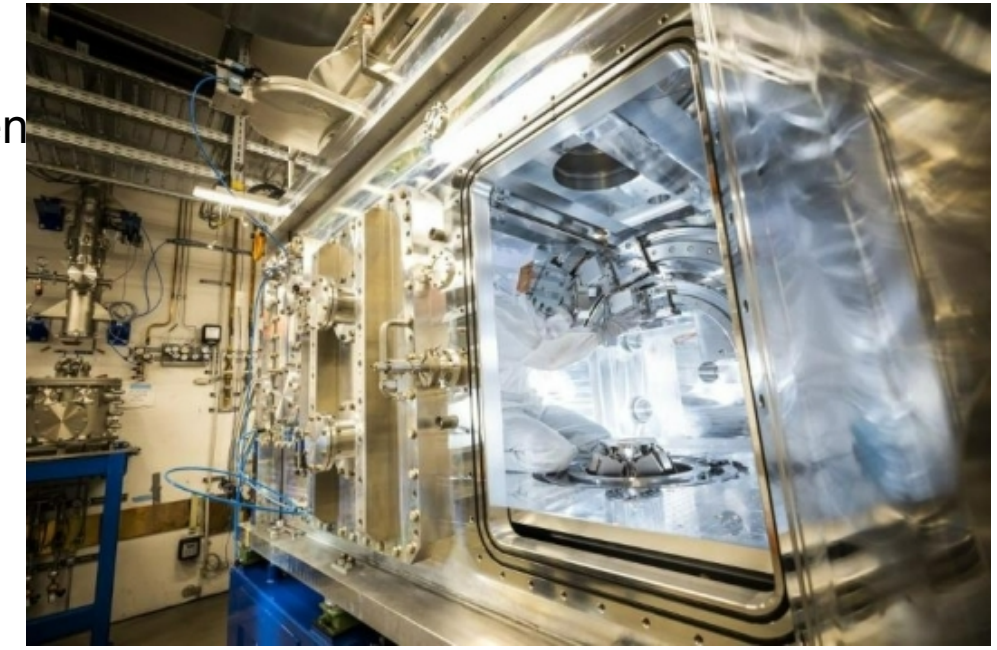
To reach extreme plasma P-T conditions, short-pulse multi-TW class lasers are operational at XFELs

Operational:

- LCLS-MEC (USA) – 25 TW peak power; 1J, 40 fs pulse length
- European XFEL (Germany) – 2 short-pulse lasers; XFEL pump-probe (operational) and High-intensity under construction
  - Pump-probe laser – 6 TW peak power; up to 100 mJ, 15 fs pulse length
  - High-intensity laser – 400 TW peak power; 4-10 J, <25 fs pulse length
- SACLA (Japan) – 600 TW; 18 J, 30 fs pulse length
- PAL-XFEL (South Korea) – TW-class; tens of mJ, ~30-50 fs pulse length

Under development:

- SHINE (China) – 100 PW peak power; 1500 J, 15 fs pulse len
- LCLS – FES upgrade inclused ~1 PW laser



Installation of the HED instrument at European XFEL ©*European XFEL*

Planar shock experiments have been carried out with gas guns at synchrotron facilities

Gas guns have been fielded at the Diamond Light Source (UK), ESRF (France), and APS (USA)

Diamond – Single-stage light gas gun experiments up to 600 m/s

ESRF – Single-stage gas gun experiments up to 1 km/s; two stage experiments up to 4.7 km/s

DCS-APS – Single-stage, powder, and two-stage guns available

- Can achieve velocities up to ~6 km/s with variety of
- Max achievable pressure on two-stage gun: ~350 G

Setup of gas gun on ID19 at ESRF.
Credit ESRF

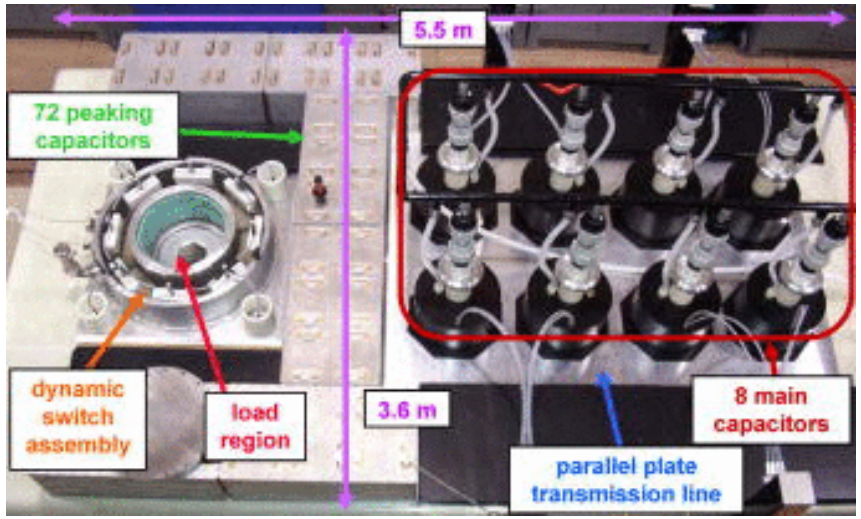
Pulsed power experiments use portable accelerators to study dynamics of wire explosions and magnetic properties

No permanent pulsed power capabilities have been installed at light sources

Compact, portable systems have been fielded at ESRF and SACLA

Pulsed power capabilities have been used to test exploding wires or structural changes due to intense magnetic fields

- No experiments using pulsed power to dynamically compress solids have been paired to light sources
- Future plans to field SNL Veloce generator at APS

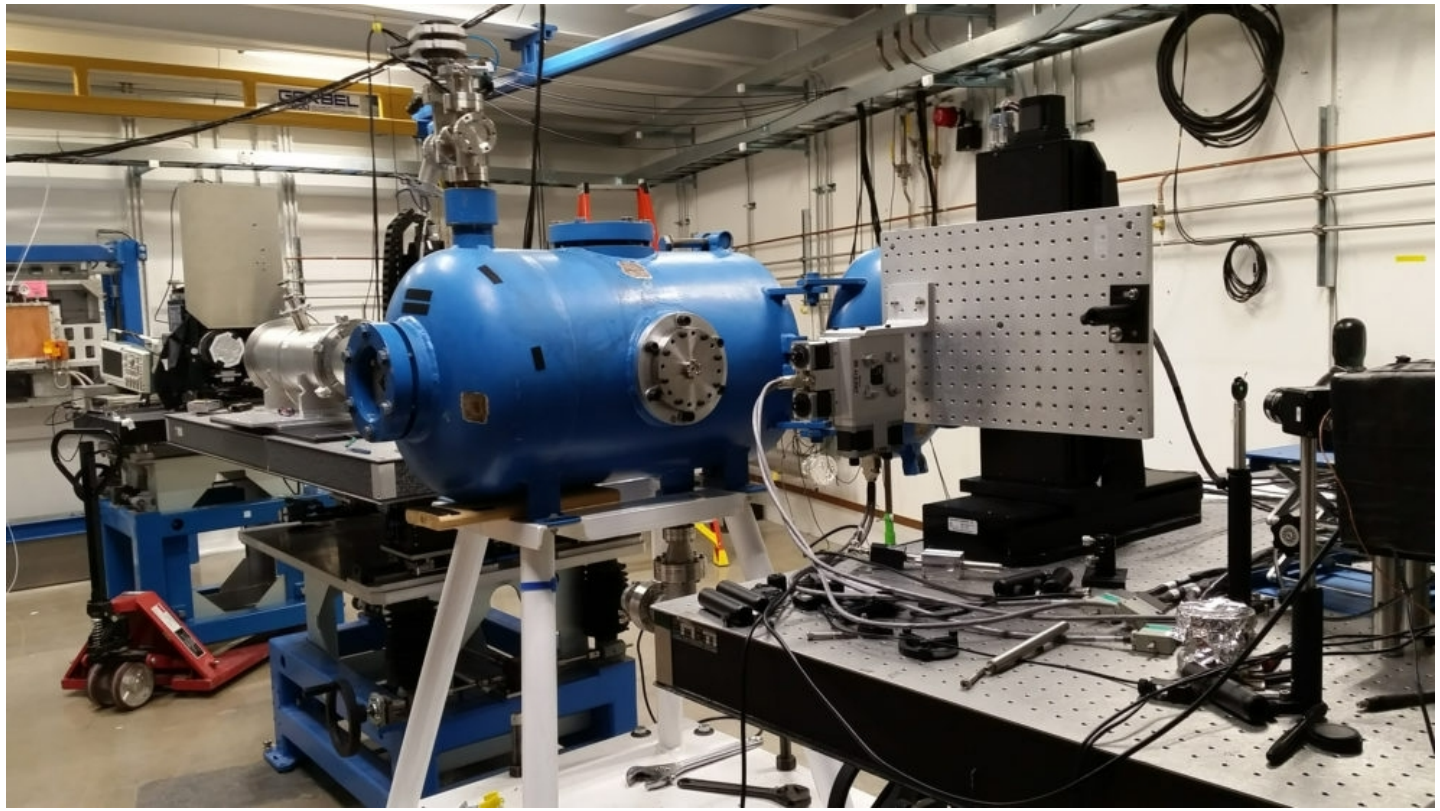


Veloce is a compact pulsed power generator capable of ramp-compressing large samples to 12 GPa [Ao *et al*, RSI **79**, 013903 (2008)]

Detonation chambers predate other drivers at light sources to study properties of high explosives

Detonation chambers have been fielded at synchrotron sources since 2000

- Currently fielded at SSRC (Russia), DCS-APS (USA), and ESRF (France)



Detonation tank at DCS special purpose experiment hutch. *Credit DCS/WSU*

Summary

Capability	Light source	Location
Long-pulse laser	Both	US, France, Germany, Japan
Short-pulse laser	XFELs	US, Germany, Japan, South Korea
Pulsed power	Both	France, Japan
Gas guns	Synchrotrons	US, France
Detonation chamber	Synchrotrons	US, Russia, France