Category A Letter of Intent

High Energy Density Science Experimental Station

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• Overview of the High Energy Density Science Experimental Station

In this Letter of Intent (LoI) we set out a proposal for an experimental station at the Linac Coherent Light Source (LCLS) that will create a capability to perform High Energy Density Science (HEDS) covering a vast range in the temperature-density phase space. While HED experiments, in which the response of solid material to heating to various degrees of ionization, are performed on existing facilities, the capabilities provided by the x-ray XFEL will remove the temperature and density gradients that presently limit the volume of material that can be studied. Thus, HEDS, which has been slowly developing on x-ray light sources, will burgeon with the advent of the LCLS. For example, experiments on current light sources, where heating and/or perturbing matter is achieved, the light source is the probe and not the pump. We will use the unique x-ray laser-like qualities of the LCLS – short pulse duration, high bunch photon numbers, 120 Hz repetition rates, and photon energy tunability – to make a full range of HEDS experiments possible. As there are no alternatives to this unique x-ray source the research proposed here is dependent on access to the LCLS.

In broad outline it is assumed that the experimental station could be placed in the near hall contingent on the possibility for focusing the LCLS to ~10 micron spot sizes. This is also a consideration for the implementation of interferometers, and monochromators needed for the experiments discussed below. The experimental station would have at least two experimental chambers and would have two optical lasers systems, one would be a short pulse system, ~1 J 50 fs, and the other would be a high-energy laser, >100J, 1 ns. The combination of the LCLS with these optical lasers will open a new frontier in HED research.

The uniqueness of the facility has attracted a substantial number of researchers to a capability that is by definition in its formative stages. This LoI will present the case for research into the two broad areas of which the HED regime is composed, *i.e.*, the Warm Dense Matter (WDM) region and the Hot Dense Matter (HDM) region. They correspond to ideal and highly correlated plasmas, respectively. The case for the uniqueness of the LCLS can be made for each separately. 1) The HDM regime requires the use of x-rays to probe the dense medium, sub-picosecond source to perform the measurements on the timescales of importance to the hot dense systems, and a focusable source to probe the spatial scales of importance. 2) The WDM regime can be created directly by the LCLS or other sources (e.g., laser driven shocks) and can be probed by the LCLS with the requirements of short time duration, intense bursts of x-rays.

Experiment	Brief Description
Warm Dense Matter Creation	Use XFEL to uniformly warm solid density samples
Equation of State Measurements	Heat and probe a solid with an XFEL to provide a diagnostic of material properties
Absorption Spectroscopy	Heat a solid with an optical laser or XFEL and use the XFEL to probe
Shock Phenomena	Create shocks with a high-energy lasers and probe with the XFEL
Surface Studies	Probe ablation/damage process to study structural changes and disintegration processes
XFEL / Gas Interaction	Create exotic, long-lived highly perturbed electron distribution functions in dense plasma
XFEL / Solid Interaction	Use XFEL directly to create extreme states of matter at high temperature and density
Plasma Spectroscopy	Use XFEL as a pump to excite bound-state populations and study radiation redistribution
Diagnostic Development	Develop the XFEL for Thomson scattering, interferometry, and radiographic imaging

Table 1: List of experiments incorporated in the High Energy Density Science experimental station proposal

For this LoI we will schematically indicate the areas of research, representing them as three areas of research covering a wide range of topics from condensed matter physics to plasma science. The experiments will be grouped into three categories, see Table 1: **WDM** regime (WDM creation, Equation of State studies, Absorption spectroscopy, Shock Phenomena, Surface studies); **HDM** regime (gas/XFEL interactions, Focused XFEL/Solid matter interactions, Plasma Spectroscopy); and, **Diagnostic Development** (Thomson scattering, Interferometry, radiographic imaging). More than 60 individuals, who are cited in the proposal along with their areas of expertise, participated in the production of this LoI. Finally, preliminary estimates of the costs associated with creating the experimental station capability are presented.

• Overview of High Energy Density Science Experiments

High Energy Density Science on the LCLS covers an extremely large range in temperature-density phase space, see Figure 1 as an example. To generate the full range of conditions indicates that a number of sources will be employed, from ~100 fs duration short pulse optical lasers, to the ~100 fs duration LCLS, to ~ 1 ns duration long pulse high-energy optical lasers. For these HED systems the LCLS will provide unique capability as a probe, and/or pump, and/or a generator. The time duration of the experiments vary from a few picoseconds for systems where the primary timescales are limited by sub-picosecond phenomena, to a few nanosecond where either shocks or larger volumetric hot dense plasma will be studied. Further, the duty cycle of the experiments also varies widely with the high-energy laser having repetition rates at the highest output energy of >10 minutes, while the short pulse laser will have repetition rate commensurate with the LCLS. Inherent in this diversity is the need for multiple experimental setups, within the HEDS experimental station capability, that could operate in tandem.

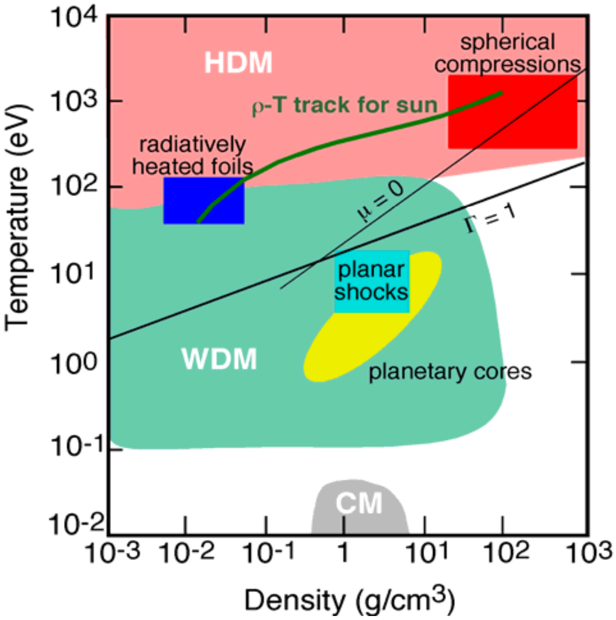

Figure 1: The temperature-density phase diagram for hydrogen shows the relevant regimes of Hot Dense Matter (HDM) and Warm Dense Matter (WDM). The regime where the standard weakly coupled plasma descriptions breakdown, is the region below the Γ = 1 curve˜ The region where degeneracy will become important is to the right of the line where the chemical potential μ = 0. The HDM regime is relevant to laser/solid plasma interactions, x-radiatively heated foils, ICF science, and astrophysical plasmas. The WDM region is relevant to solid matter heated to and above the Fermi energies, to planar shocks, planetary cores, and all plasma generation devices that start from solid density. For reference we label the condensed matter phase by CM. Note that each atomic element has a distinct phase diagram of this type.

• Experiments on LCLS in the WDM regime

With a short duration pulse containing a substantial number of high energy photons one can generate solid matter at temperatures of ~ 10 eV, *i.e.*, warm dense matter. The interest in the warm dense matter regime arises because in dense plasmas the atoms and/or ions will start to behave in a manner that is intrinsically coupled to the plasma. That is, the plasma starts to exhibit long- and short-range order due to the correlating effects of the atoms/ions. This intriguing regime where the plasma can no longer be considered a thermal bath and the atoms are no longer well described by their isolated atom behavior provides a tremendous challenge to researchers. In the limit of dense cool plasmas one obviously arrives at the threshold of condensed matter. Here the problem has changed from a perturbative approach to ground-state methods where complete renormalization of the atom/ion and its environment is essential.

From the perspective of plasma studies the defining quantity is the coupling parameter Γ, *i.e.*, the ratio of the inter-atomic potential energy to the thermal energy given by the equation:

$$\Gamma = \frac{Z^2 e^2}{r_0 kT} \quad \text{with } r_0 = \left(\frac{3Z}{4\pi n_e}\right)^{1/3}$$

where Z is the ion charge and r_o is the interparticle spacing given in terms of the electron density n_e. The regions of interest span the density-temperature phase space going from modestly coupled ($\Gamma \leq 1$) to strongly coupled ($\Gamma > 1$), while bridging the transition regimes between solid to liquid to plasma.

In the figure below we show the region of the temperature-density plane where WDM and HDM studies are important for hydrogen. WDM is the region where the theoretical uncertainties are largest because the standard theoretical approaches fail and experiments are exceedingly difficult. The difficulty arises theoretically from the fact that this is a regime where the usual perturbation expansions in small parameters used in plasma phase theories are no longer valid. Further, there becomes an increased importance on density-dependent effects, *e.g.*, pressure ionization, as the surroundings starts to impinge on the internal structure of the ion or atom. Experimentally the study of warm dense matter is difficult, as the isolation of samples in this regime is complicated. The warm dense matter regime plays an important role in the evolution of all plasmas generated from solid material as *every* -*T* path from solid to plasma will lead through this region yet trying to isolate warm dense matter remains a major challenge since it is generally a transient and inhomogeneous state.

• The study of **WDM creation,** although of great interest witnessed by the literature on strongly coupled plasmas, there has seen little progress in understanding warm dense matter.[1] The interest generated in laboratory experiments is mirrored in the astrophysical literature where the warm dense matter is found in the cores of large planets and brown dwarfs.[2,3,4,5,6]. The experimental concept is straightforward, but the impact will be vast, as the data obtained in the generation of the warm dense matter along an isochore, *i.e.*, a track of constant density, with subsequent probing along the release isentrope, *i.e.*, a track of constant entropy, will be unique and critically important for progress in the field. We will heat a sample uniformly as the LCLS at 1 Å can volumetrically heat a sample via photo-absorption. Calculations indicate that 10 µm x10µm x100 µm of Al can be heated to 10 eV in this manner. Here one would strive to determine the evolution of the system from strongly non-thermal non-equilibrium to an equilibrium state while determining the spatial uniformity.

• Equation of State measurements (EOS) of matter at high pressure (exceeding >1 Mbar) are fundamental to numerous applications in astrophysics, geophysics, high-pressure science, plasma physics, laboratory laser experiments, inertial confinement fusion, and related fields. Experimentally accessing these material states offers opportunities to study phase transitions in solids near the critical point, strong coupling effects in dense plasmas, and transport properties at high densities and temperatures. However, even in the most studied materials one finds that in the WDM regime there are significant differences between models. Since the EOS relates temperature, volume, and pressure an EOS measurement requires determining two of the three state variables independently. The experiments envisioned would build on WDM creation techniques and LCLS probing to provide measures of the pressure-density-temperature relationship defining the EOS.

• Absorption Spectroscopy using the LCLS can serve as a probe of material dynamics of WDM or the interatomic dynamics of shocked materials. By closely examining the structure of the spectrum in the vicinity of an absorption edge, information about local electronic and atomic structure can be extracted. The absorption spectrum very close to an edge yields information on the local bonding properties, ionization and chemical environment of a particular element. Further above the edge, small oscillatory modulations due to interference from photoelectron scattering gives information on the short range nuclear order near the absorbing atom. Forays into the realm of time-resolved spectroscopy have recently approached the ultrafast time-scale [7, 8]. Although alternate short time-duration sources and fast detectors suited for x-ray absorption are under development, scientific progress in this area will be greatly advanced by high peak brightness of the LCLS.

• Shock Studies using the LCLS in tandem with a high-energy laser will allow one to measure EOS in a complementary manner to the direct x-ray heating techniques. The shock technique can sample the Hugoniot, the locus of points in pressure-density-temperature phase space accessible by single shocks, which for these experiments will be in excess of 1 Mbar. Here we will augment the usual measurements by providing faster time resolutions and smaller spatial scale probing than will be possible elsewhere. The possibility to probe the microscopic state of the shock front, i.e., measuring the local temperature, composition and ionization state will provide critical new capability to the understanding of matter in these extreme conditions. The connection between the strong shocks described here and the warm dense matter regime is very strong. As a example, the highest compression that can be achieved by single shock in solid H_2 is approximately 4-fold, which gives a density of 0.3 g/cc. However, the pressure (and temperature) can be varied by many orders of magnitude by changing the energy of the driver. Thus, the shock is essentially heating the sample isochorically with a large degree of tunability in the pressure. Further, higher densities can be accessed with multiple shocks.

• Surface Studies using either a short pulse optical laser or the LCLS directly can create novel state of matter that can be probed by the short pulse x-rays of the LCLS. The interaction of intense x-rays with matter differs from conventional laser-matter interaction as one will be able for the first time, to excite directly deep lying electron states in the atomic time scale. The high photon density is expected to lead to new kinds of matter excitations such as collective motion of inner atom shells [9] or nonlinear processes due to interactions of highly excited states. Further, the role of non-thermal phenomena such as Coulomb explosions, photo-induced bond breaking and ionization excited by multi-high-energy-photon absorption can be studied for the first time. Since the goal here is to study the processes modifying the irradiated surfaces, time dependent reflectivity measurements, time and wavelength dependent fluorescence measurements, energy and mass spectra of the ejecta, and photoelectron spectroscopy will be employed.

• Experiments on LCLS in the HDM regime

The great interest in the high temperature dense plasma regime arises with the ability of the LCSL to probe plasmas at electron densities in excess of 10^{21} cm^{-3}. In any experiment where a high intensity, *e.g.*, I ≥ 10^{12} W/cm^2, laser irradiates a solid target there will be a region of the solid that is hot and near solid densities. Lasers with wavelengths > 0.25 μm do not directly heat the solid as they cannot propagate beyond the critical electron density, n_{cr},

$$n_{cr} \square 10^{29}\mathrm{cm}^{-3} / \lambda^2(\text{Å}).$$

However, heat flow from the surface efficiently generates the hot dense medium. On the one hand, the spectroscopic information derived from these plasmas provides diagnostic information about the plasma itself, while on the other hand, we can use spectroscopy to understand the mechanisms at play in the creation of the plasma and the interaction of the atoms/ions with the plasma in which they are embedded. Here the LCLS will provide two related and intriguing capabilities. First, there is the possibility to perform *in situ* diagnostics of the dense high temperature matter, e.g., probing via Thomson scattering on near solid-density plasmas becomes a reality. Second, we can explore laser pump-probe techniques for high-density plasmas that have been used in much lower densities plasmas and neutral gases to measure line shapes, observe radiation redistribution, and determine the kinetics processes.

The mechanisms involved in the formation of a plasma, and the details of the atomic kinetics can be illuminated by using a laser as a pump to selectively populate levels thus providing a redistribution of the emitted radiation. In a particularly intriguing possibility, one will be able to study the formation of plasma x-ray lasers that currently depend on kinetics processes. Thus, one could disentangle the plasma production from the inversion-forming processes that lead to the x-ray lasing. Numerous aspects of plasma spectroscopy have been severely constrained by a lack of data. The LCLS will provide a major step forward in the development of our understanding of intrinsic line shape formation, level shifts, radiation transfer, and detailed kinetics processes.

XFEL-gas interactions is built on two unique properties of the intense x-ray source: the ability to photoionize gas and create an electron distribution function (EDF) with sharp energy distribution defined by ionization stages, and the small value of the ponderomotive potential compared to optical lasers at the same intensity. The latter allows creation of the plasma with high degree of spatial uniformity, free of parametric instabilities and sources of super-energetic particles. Thus, for the first time one can engineer hot uniform plasmas with prescribed EDFs over a wide range of conditions. In the proposed experiment, the gas will be both irradiated and probed (via Thomson scattering) by the same LCLS beam Thomson scattering (TS) measurements are used to determine plasma parameters and details of the EDF. They will provide a proof-of-principle for x-ray TS (see Diagnostic Development below) and will enable further developments and applications of this powerful diagnostic. The anisotropy of EDF in photoionized gases gives rise to unique plasma physics processes, such as electrostatic two-stream instability, Weibel instability, magnetic field generation, and terahertz radiation emission. Measurements of the magnetic field and of the emitted radiation will provide additional detailed diagnostics of these plasmas.

• **XFEL-solid interactions** have a strong precedent in the long history of the use of high-power laser beams to generate high energy density matter in the laboratory. An outstanding application is inertial confinement fusion. In this context, it is of interest to use short-wavelength laser light to couple efficiently to the solid. The plasma generated by the LCLS will be unique as one can expect primary photo-electrons to have energies ~ 10 KeV, while simple estimates using Spitzer formulas indicate that free electrons thermalize within 10 fs, while excited bound states live longer, and ions equilibrate only after 1 ps. However, more detailed studies indicate that the electron distributions stay non-thermal for substantially longer, which will be monitored via the emission spectra observing the effects on the line shapes, line shifts and ionization potential depression. Optical probing of x-ray heated non-conducting material via reflection and transmission will be used to characterize the time dependent evolution of the electron relaxation.

• **Plasma spectroscopy** is concerned with the measurements of the kinetic rates or the populations. However, a major impediment has been the inability to probe *in situ* HDM plasmas. Further, the population kinetics of highly stripped ions that occur in HDM plasmas is difficult due to the large number of states that must be considered in a model and the detail to which one must incorporate these states. The situation is made more difficult due to the fact that these plasmas tend to have rapid time evolution and large spatial gradients.[10] The initial goal for the LCLS experiments will be to create a plasma using a high-energy laser and then with the LCLS selectively pump a single line transition. Variations on the idea of pumping individual transitions in high energy density plasma include the selective pumping of the wings of a line transition to observe redistribution within the line profile and pumping of selected transitions to attempt to understand the inversion mechanisms for the production of x-ray lasers.

• Diagnostic Development for High Energy Density Science

• **Thomson scattering** provides an *in situ* measurement of the temperature, density, velocity, charge state, and collective behavior of a plasma. Indeed, the Thomson scattering diagnostic is directly related to the dynamic structure factor, $S(k,\omega)$ (where hk and hω are the momentum and energy transfer from photon to the electron, respectively),of the plasma and thus provides insight into the theoretical predictions of the constituent particle velocity distribution functions predicted by different theories. It is fair to say that in recent years each effort at diagnosing a higher density plasma, *i.e.*, higher than 10^{20} cm^{-3}, using Thomson scattering has led to new and important discoveries. These experiments have, of course, been few since the constraints on the experiments are substantial. Here we believe that the next generation sources will provide a major advance in diagnosing dense plasmas, particularly in the WDM regime. The advantage of Thomson scattering using the LCLS as a probe versus a conventional optical laser is three fold. First, the short wavelength increases the critical density to which the probe beam can reach. Secondly, the susceptibility of the probe beam to refraction effects is reduced making the probe focus location more reliable, particularly in the steep density gradients close to the target surface in a laser produced plasma from a solid target. Lastly, the tunable phone energy from LCLS makes it possible to select a wavelength so $S(k,\omega)$ is optimized for the desired diagnoses. However, the preconditions for the interpretation of the scattering data is that there is a valid theoretical model for the $S(k,\omega)$ in the high density regime, and this in itself will be a challenge. The tunable nature of the x-ray source, the high energy, bandwidth, the short pulse duration and, importantly, the very high peak photon flux makes the LCLS the only source that can address the Thomson scattering of high-density transient plasmas.

- **Interferometry** has been demonstrated with long wavelength plasma x-ray lasers employing a wide range of techniques from Mach-Zehnder, Michelson, Lloyd's mirrors, and Fresnel bi-mirrors. The other major difference in using interferometers is the intrinsic requirement on beam coherence, either temporal or spatial. Michelson or Mach-Zehnder instruments do not require any coherence. However, for Lloyd's mirror or Fresnel bi-mirror the useful field of view is limited by the transverse coherence length. The full transverse coherence of the LCLS opens the possibility to use these two last techniques that are technically simpler. Further, these latter two interferometers work in grazing incidence enabling one to use the same interferometer over a wide wavelength range. The short wavelength and short pulse length of the LCLS will enable interferometric studies of denser plasmas at higher time resolution than currently possible with plasma x-ray lasers.
- **Radiography** will be developed as a complement to interferometry, which cannot give a fully two-dimensional image of the plasma. Indeed, for interferometry the spatial resolution is quite high along the fringes but is about 10 times smaller in the perpendicular direction. This might make the interferometry inappropriate for probing small-scale structures that would arise from hydrodynamic or laser induced parametric instabilities. X-ray laser radiography has been used for measurement of hydrodynamic instabilities growing in thin foils. With the short pulse LCLS this type of experiments will be easily reproduced and extended to high time resolution and denser and longer plasmas than has been previously possible.

Personnel:

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Roles

Here we separate the group of participant in the HEDS experimental station plan into the broad categories associated with the nine areas to be explored in HEDS. That is, Warm Dense Matter Creation, Equation of State Measurements, Absorption Spectroscopy, Shock Phenomena, Surface Studies, XFEL / Gas Interaction, XFEL / Solid Interaction, Plasma Spectroscopy, Diagnostic Development.

Experiment	Participants
Warm Dense Matter Creation	R. Lee, H.-K. Chung, S. Glenzer, G. Gregori, S. Moon, O. Landen. K. Widmann, P. Young, M. Murillo, J. Benage, P. Heiman, A. Lindenberg, A. Correa, R. Falcone, W. Nellis, W. Rozmus, A. Ng, T, Ao, J. Wark, J. Sheppard, R. Redmer, D. Schneider, F. Rosmej
Equation of State Measurements	R. Lee, K. Budil, G. Collins, S. Glenzer, G. Gregori, M. Koenig, A. Bennuzi-Mounaix A. Nelson, O. Landen, K. Widmann, W. Nellis, A. Ng, P. Young, J, Benage, M. Taccetti, S. Rose, D. Schneider
Absorption Spectroscopy	P. Heimann, S. Johnson, S. Tzortzakis, S.Bastiani-Ceccoti, C. Chenais-Popovics, P. Audebert, F. Rosmej, R. Lee, R. Falcone, R. Schuch, A. Lindenberg, M. Fajardo, D. Chambers, J. Wark, S. Rose
Shock Phenomena	G. Collins, C.-S. Yoo, K. Budil, M. Koenig, A. Bennuzi-Mounaix, S. Clark, P. Heimann, R. Jeanloz, P. Alivisatos, R. Falcone, W. Nellis, A. Ng, T. Ao
Surface Studies	T. E. Glover, J, Kuba, A. Nelson, A. Andrejczuk1, J. B. Pelka, J. Krzywinski, R. Sobierajski, K. Sokolowski-Tinten, L. Juha, M. Bittner, J. Krasna
XFEL / Gas Interaction	R. London, S. Hau-Riege, P. Young, H. K. Chung, W. Rozmus, R. Fedosejev, H. Baldis, V. N. Shlyaptsev, T. Ditmire, H. Fiedorowicz, M. Fajardo, A. Bartnik, F. Dorchies, J.-C. Gauthier, P. Audebert, V. Bychenkov, D. van der Spoel, M. Bergh, C. Caleman, T. Möller, T. Tschentscher, H. Merdji
XFEL / Solid Interaction	R. Lee, K. Budil, H.-K. Chung, J, Dunn, S. Glenzer, S. Hau-Riege, R. London, H. Fiedorowicz, A. Bartnik, M. Bittner, J. Krasna, V. Letal, K. Rohlena, K. Eidmann, D. Chambers, N. Woolsey, A. Andrejczuk, J.B. Pelka, J. Krzywinski, R. Sobierajski, F. Dorchies, J.-C. Gauthier, M. Fajardo, J.M Dias, N. Lopes, G. Figueira, K. Sokolowski-Tinten, M. Bergh, C. Caleman, T. Tschentscher
Plasma Spectroscopy	D. Riley, F. Y. Khattak, E. Förster, F. Dorchies, J.-C. Gauthier, S. Tzortzakis, S.Bastiani-Ceccoti, C. Chenais-Popovics, P. Audebert, S. Rose, J. Wark, N. Woolsey, R. Schuch, K. Eidmann, F. Rosmej, S. Ferri, R. Lee,
Diagnostic Development	R. Bionta, H. Baldis, P. Heimann, H. Padmore, H. Merdji, P. Zeitoun, J. Seely, E. Förster

• Budgetary Requirements

We based the following budgetary requirement on several assumptions about the capabilities provided by the LCLS facility:

- Incident intensity monitor on a pulse-to-pulse basis
- Spectral properties monitor on a pulse-to-pulse basis
- Measurement of the time delay, i.e., jitter, between the XFEL and short pulse laser on a pulse-to-pulse basis. The temporal resolution should be comparable to the pulse length of the XFEL.
- Monitors to determine the spatial overlap of the XFEL and the short pulse laser pulse
- Tunability of the XFEL energy over a range of about 10% with accuracy to within the 0.1% bandwidth
- Focusing of XFEL down to 10 micron focus (higher performance optics to achieve ~ 0.1 µm minimum spot to be implemented in target chamber)
- Capability to phase lock experiment to RF clock of the LCLS
- A mechanism for isolating harmonics of the XFEL (e.g., a monochromator)

Below we separate the requirements into the categories: 1) Target chamber and Optical Components, 2) Optical Lasers; and, 3) Experiment Specific Equipment. Note that this is a synthesis of the nine experimental requirements

• Target Chamber and Optical Components

• Target chambers with vacuum pumping: 2 x $125,000	$250,000
• Target alignment and rastering capability with real time viewing of the target. In-vacuum translational 3-axis manipulator for foils with an alignment precision of 5 µm.	$60,000
• Sample transfer device without the need to break vacuum.	$20,000

• Collection optics to record incident and scattered spectrum simultaneously to deconvolve the scattered spectrum composed of: X-ray mirrors, crystals, and spectrometers	$460,000
• Beam splitting and delay optics:	$120,000
• Attenuators (10^{-4}):	$50,000
• Fast shutter:	$120,000
• Optical laser energy diagnostics for energy transmitted, the energy scattered, and the energy reflected:	$20,000
• Optical laser beam transport:	$50,000

• Visible Lasers

- Short Pulse Laser

A short pulse laser with 100 fs pulse length and $\geq$ 100 mJ in a high contrast pulse synchronized to the LCLS operating at 120 Hz. Initially a system capable of producing 100 mJ pulses with a pulse length comparable to that of the XFEL would be useful; but, for plasma production ~ 1 J will be necessary. This will be used for: Plasma production; Foil heating, Fourier Domain Interferometry; and Thomson Scattering ($n_e \leq 10^{22}$ cm^{-3}).

.... for > 150 mJ; $650,000

.... for > 1 J; $1,650,000

- High-Energy Laser:

High energy laser for shock generation and plasma production will be required. The system would have dual beam capability for plasma production, for colliding shock measurements, and higher energy continuous spectral absorption source production. The minimum energy per beam would be on the order of 100 Joules (with maximum 1 kJ) at wavelengths of ~ 500nm. It would be possible to use the beams independently: Detailed design study must be performed on energy requirements, a broad estimate derived from discussion with a vendor and individuals at LLNL indicated the cost:

.... for 200 J; $3,000,000

.... for1 kJ; ~$10,000,000

• Experimental Specific Equipment

• Pulsed gas jet capable of operation at 10 Hz with a backing pressure of several 10's of atmospheres:	$30,000
• Pin diodes and CCDs with various filters for EUV, XUV, X radiation monitoring:	$100,000
• High efficiency XUV and X-ray spectrometers with resolving power of 10^4 (with capability for 10^5 for certain experiments) to be coupled to a streak camera and/or CCD:	x-ray; $200,000 XUV with data readout; $320,000
• X-ray / XUV streak camera with better than 200 fs temporal resolution with a temporal range up to the picosecond time-scale: developmental cost for first one:	to improve on current technology; $600,000 to develop new higher repetition rate camera; $1,000,000
• X-ray / XUV streak camera with ~2-5 ps temporal resolution with a temporal range up to the nanosecond time-scale:	$200,000
• Monochromator for X-ray Thomson scattering and optical pumping experiments:	$100,000
• A hemispherical electron analyzer to measure the electron energy per pulse:	$230,000
• TOF mass- and electron-spectrometers:	$200,000
• Fourier domain interferometric arrangement, including beam splitting, Michelson interferometer, the pulse recombining in a UV spectrometer with a CCD detection system.	$160,000
• CCD detector for diffraction experiment: (cost of development in LoI submitted by H. Padmore)	~$1,000,000
• Visar system to optically monitor shock breakout:	$150,000
• Optical Streak Cameras for temperature measurements on shocks: 2 x $250,000	$500,000
• Optical imager gated for spatially monitor WDM production: 2 x $80,000	$160,000
• Gated X-ray imager: 2 x $80,000	$160,000
• Sample fabrication equipment:	$100,000
• Harmonic generation setup – XUV and Visible relay optics, filters, XUV gratings:	$75,000

• References:

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