NSLS-II Beamline Development Proposal

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Time-resolved X-ray diffraction and spectroscopy under extreme conditions (TEC)

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A. Science Case

Understanding material properties under extreme conditions is central for many fields of science. These include synthesis of new materials with improved properties, energy and defense technologies, reaction chemistry of energetic materials, and environmental and planetary sciences [1, 2]. In spite of numerous recent technological advances, the development of the required *in situ* measurements of material properties under extreme conditions remains a challenging problem. Moreover, the study of physical and chemical phenomena on very short time scales comparable to phase and electronic transitions, heat transport, atomic diffusion, and fast chemical reactions require development of novel time-resolved techniques. Here we address these present and future challenges by proposing to develop and build a beamline at NSLS-II, which would specialize in time-resolved *in situ* measurements of material properties under the extreme conditions of high pressure, temperature, strain rate (P-T-ε), and magnetic field applied continuously or in a pulsed mode. Below we give more detailed account of the scientific problems, which will benefit from the proposed development:

Thermomechanical and electromagnetic extremes:

Shock compression of a precompressed material enables the characterization of thermodynamic states off the principal Hugoniot [3]. Here we proposed to generate table top laser driven high strain-rate compression waves inside samples pre-compressed by a DAC [4, 5] (Fig. 1). This technique allows studying material pre-compressed up to 100 GPa static pressures and creates shock conditions in excess of several tens of GPa (depending on the impedance matching conditions).

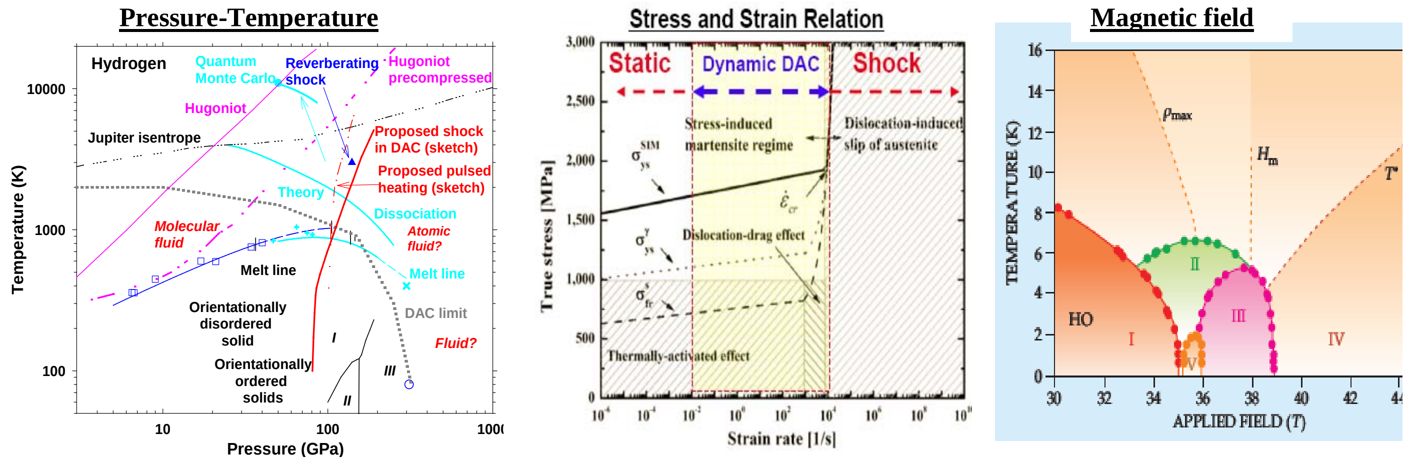

Figure 1. Modern experimental routes to explore materials properties under extremes. Left panel: pressure-temperature phase diagram of hydrogen studied by static and dynamic experiments, and by theoretical calculations. We propose to develop new experimental routes to extreme conditions including the application of laser-induced shocks and pulsed laser heating (red solid and dashed lines) in the DAC, achieving conditions that bridge the gap between static (gray dots) and shock (solid and dashed pink lines for conventional and pre-compressed, respectively) studies. Middle panel: Schematic deformation map of the shape-memory alloys as a function of strain rate [6]. The red-dashed area represents the stress/ strain regime that can be covered using the dynamic DAC [7]. Right panel: magnetic phase diagram of heavy electron compound URu_2Si_2 [8] [Kim *et al.*, 2004]. The subtle energy differences among phases are rearranged by the magnetic field.

Static compression methods applied to many materials are limited to approximately 300 GPa and relatively moderate temperatures (<6000 K using continuous-wave laser heating). *Pulsed laser heating* is a recently developed technique [9-11]. Apart from reaching substantially higher temperatures compared to continuous heating (in excess of 12,000 K as currently reached and measured using ~10 ns laser pulses) (Fig. 1), this technique also holds a promise to overcome the problem of containing and probing chemically reactive and mobile materials (*e.g.*, H_2 [12]). *Pulsed internal* (resistive) heating will allow using a very short duty cycle (comparable to the synchrotron pulse structure) and provides more spatially uniform heating pattern, thus enabling access to a broader P-T domain with sufficiently large for X-ray diffraction and spectroscopy samples.

Use of *mechanically driven dynamic diamond anvil cell* (dDAC) [7] will allow bridging the gap in strain rate between the static and shock compression, because the strain rate range between 10^{-2} and 10^{5} s^{-1} is currently largely unexplored. Modest strain rates in this range may drive a system out of thermodynamic equilibrium, *i.e.*, to a metastable state. Other processes in this regime include phase transformations and chemical reactions, such as the recrystallization and growth in liquid-solid transitions. At these extreme conditions of stress/strain rates, fundamental changes occur in physical properties and chemistry of materials, study of which open new research directions for discoveries and better understanding of new materials, physical and chemical transformation, and dynamic processes during planetary collisions and within planetary interiors.

Studies in *high magnetic fields* can substantially further our understanding of strongly correlated matter exhibiting a wealth of phenomena (Fig. 1), which are intimately related with exotic but technologically significant states of matter such as superconductivity. Here we propose to determine structural information in magnetic fields exceeding 50 Tesla to explore the coupling between the lattice and electronic properties. The current ‘state of the art’ with respect to performing X-ray diffraction measurements in pulsed magnetic fields comprises a 3mm internal diameter split-coil solenoid, providing a millisecond duration 35 Tesla magnet pulse with a 60 degree scattering window. At NSLS-II we will create the unique combination of intense sub-micron spot sizes and ns to μs gate times, which will enable further miniaturization of a pulsed magnet to facilitate higher field production, without being limited by the detrimental effects of loss of field homogeneity and duration. Miniaturization will also enable greater cooling and hence higher repetition rates.

Material properties under static and dynamic thermomechanical and electromagnetic extremes: Knowledge of those is vital for a broad range of applications, such as future fusion power, efficient steam turbines, jet engines, and heat exchangers, fuel-efficient vehicles, and strong wind turbine blades. Better understanding the fundamental chemical and physical processes involved in materials failure is needed in a wide range of the length scales extending from the nano- to macroscale. This can be addressed by direct observations of the material properties at the corresponding length scales. Here we propose to characterize the processes of material failure both on micro- and macroscopic levels by combining different (time-resolved) observations on the same material. First, time-resolved x-ray diffraction and spectroscopy tools will be used to determine possible physical and chemical transformations. Furthermore, we will employ combined ultrafast laser ultrasonics and time-resolved diffraction measurements [13], which provide a unique opportunity to probe the materials elastic and vibrational properties and electron-phonon coupling under extreme *P-T* conditions [14, 15]. Second, the same techniques combined with x-ray imaging can be turned into the observations of the time-dependent strain, plastic deformations, dislocation, voids, and grain boundaries [16]. The high strain-rate conditions will be generated by laser, electromagnetically, and mechanically driven techniques as described above and below.

New materials synthesis: Extreme P-T-ε conditions profoundly alter materials behavior, such as vibrational, electronic, magnetic, structural, mechanical and chemical properties, reactivity, and kinetics. Likewise, applications of large magnetic fields can dramatically alter the mictrostructure, phase composition, and effective solubility of elements [17]. Materials in extreme environments often exhibit optimal properties for technological applications. For example, the highest T_c of 165 K [18] was achieved in cuprate superconductors at high *P*. The paramount challenge is to turn this and other discoveries into new methods of synthesizing practical materials as has been realized, for example, in the case of diamond, which was first synthesized under extreme *P-T* conditions. By advancing our knowledge about the material properties such as the equation of state, kinetic and thermodynamic phase diagram at high P-T-ε conditions, we create a necessary foundation for development of future material synthesis technologies. Here we propose to create a unique access to metastable and kinetically impeded states by controlling the strain rate over a wide range. This will be achieved by applying laser-driven shock [4, 5] as well as ramp and mechanical compression [7] to pre-compressed samples in the DAC. Furthermore, for new materials synthesis we will explore *ultra fast heating* to prevent diffusion [19] (using pulsed laser heating), low-T supercompression [20], and high magnetic fields (in combination with other extremes or alone). In this context, X-ray time-resolved diagnostics (diffraction and spectroscopy) will provide unique insight information about the material's (instantaneous) crystal and local structure, elastic and vibrational properties, spin state, and lattice strain.

Fast reaction chemistry: Chemical reactivity, elemental partitioning and diffusion coefficients change drastically under pressure because of changes in the electronic energies which result in modifications of bonding character. Better understanding of the chemical reactions in the condensed phase is currently required. Almost all industrial and synthetic chemistry occur in the condensed phase. Chemistry in the condensed phase is the basis of life. Condensed phase chemistry is essential to processes in the interiors of terrestrial as well as the giant gas planets. The knowledge of the reaction chemistry of energetic materials at high pressure and temperature is necessary to understand their behavior under impact and detonation conditions. Although this field has blossomed to include a large list of materials and theoretical predictions and calculations (*e.g.*, [21]), what are crucially lacking are details of thermodynamics, reactivity and diffusion.

In general, currently available analytical techniques only provide information about time-averaged properties (Fig. 2), and dynamical information on the microscopic level is missing. Moreover, information about the length scale of these phenomena is very limited. Here we propose to use recently developed x-ray absorption and fluorescence spectroscopies [22, 23] for *in situ* time-resolved chemical mapping of the reaction front. By combining these techniques with x-ray imaging we will be able to characterize the reaction on a variable length scale, which is vital for understanding chemical reaction on both atomic and macroscopic scales. Shock compression and pulsed heating will enable such studies in two modes: "repetitive" (when the results are acquired by averaging time dependences of measured properties over many events), and "single shot" (when all the data is obtained during one path through *P-T* configuration space).

Also, the initial state of the material can be placed, via precompression (preheating may also be used), in the proximity of a phase transition or chemical reaction boundary before shock compression, enabling the observation of phase transition, deformation or chemical dynamics as the material is shock compressed across the boundary. We note that, in cases where shock-induced chemistry or phase transitions do not occur, shock compression obtains equilibrium compressed states over picosecond time scales. When materials undergo structural changes upon compression, shock compression can be used to obtain ultrafast dynamic information from shocked metastable compressed states *en route* through a phase transition or chemistry. Such experiments can provide valuable information on early time states of shocked materials, such as the pre-chemistry shocked Hugoniot of reactive materials, or anomalous transient states preceding phase transitions.

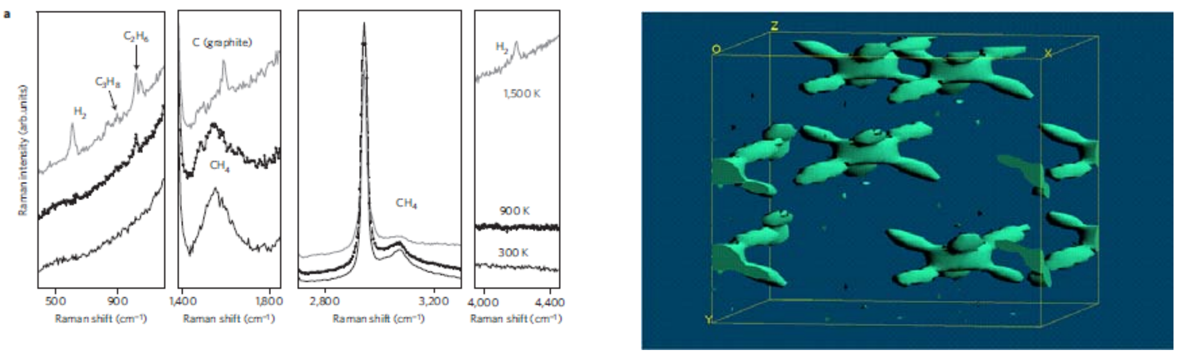

Fig. 2. Examples of recent observations of chemical reactivity in the DAC. Left: Polymerization and dissociation of methane at 5 GPa observed by Raman spectroscopy [24]. Right: Electron density of the synthesized under pressure $Xe(H_2)_7$ molecular crystal calculated from the observed X-ray structure factors (Beever-Lipson maps). It shows the spread of electron density between Xe atoms and in the direction of coordinated H_2 molecules lying within the first coordination sphere of the Xe [25].

Geo- and planetary sciences: These disciplines require detailed knowledge the physical and chemical processes which occur on both the micro- and macro- scales. Since access to decisive *in situ* diagnostics at relevant *P-T* conditions is challenging most of our current understanding is based on the results of indirect and/or *ex situ* measurements. Accordingly, new insights into the processes that govern planetary interiors requires a meaningful comparison of the relevant materials properties under actual below-ground conditions associated with the planetary observations (*e.g.*, seismic) and the results of theoretical calculations. Here we propose to aggressively exploit the enhanced beam focusing and brilliance of the proposed NSLS-II beamline to tackle these problems by using measurements with unrivaled previously length and time resolution in unexplored previously *P-T-ε* space (Fig. 1), as described briefly above and further elucidated below using several examples:

<u>Equations of state of fluids and fluid-fluid transitions.</u> This knowledge is vital for understanding of the structure, dynamics, and chemical compositions of planetary interiors. Of particular examples include the formation of the planet through meteorite impacts in the early stage of the Earth's history where melts' presence was dominant (*e.g.*, [26]). The shock wave generated by meteorite impacts creates extreme *P-T-ε* conditions in a short time (less than seconds), dramatically altering materials properties such as the occurrence of melts and transport of heat. Characterization of the EoS of fluids and solids under dynamic extremes similar to meteorite impacts is thus critical. The EoS information of fluids and solids is also needed to understand how the planetary interiors evolved through time as they are present in the deep interiors of the planets which can be deciphered through studying their EoS.

Critical point measurements are fundamental components of any equation of state model. In the planetary sciences, the location of the critical point in geologic materials has implications for the global effects of planetary impact since most of the impactor and some fraction of the target will vaporize upon release from the shocked state [27]; impact-produced vapor contributes to atmospheric loss [27] and climate change (*e.g.*, [28]) following large impact events. Measurements along release isentropes after Mbar shock compression is the only the technique available to constrain the critical points of many materials. Time-resolved diffraction and spectroscopy [29] techniques proposed here will create unique opportunities to study fluid's EoS, including the dynamical behavior in laser driven compression experiments. Furthermore, these techniques will be combined with ultrafast laser ultrasonics measurements of materials sound velocities [14, 30], which provides a robust method for measurements of EoS at high *P-T* conditions in both solids and liquids (*e.g*., [31]).

Melting curves of planetary materials. Knowledge of melting curves of planetary materials is needed to understand the temperature distributions (*e.g*., geotherm), thermal history, and dynamic convections of planetary interiors including rocky and icy planets. Particularly, the Earth's outer core is mainly made of liquid Fe-Ni alloy with approximately 10 wt% light elements, whereas liquid silicates are expected to occur as a result of decompression melting and/or addition of volatiles in the deep Earth. Knowledge of the melting curves of Fe-Ni-light element system can in turn help address how the outer core circulates and how the magnetic fields are generated in the core. Unambiguous detection of melting currently presents a great challenge [32, 33]. Observation of a diffuse ring in X-ray diffraction has been proven to be one of the most reliable methods to detect melting [34]. Newly developed flat top laser heating technique [35] allows making the heating conditions more stable thereby improving the quality of the diffraction patterns at high temperatures including that for the molten state. Further improvements of the laser heating technique will extend the available *P-T* range, which is currently limited because of very tight geometrical constrains inside the DAC cavity. Use of pulsed laser and internal resistive heating combined with time-resolved X-ray diffraction and spectroscopy [36] will allow probing Earth's and planetary materials (Fe-Ni alloys, silicates, H_2, He, and planetary ices) at much higher *P-T* conditions compatible to the planetary interiors.

Transport properties. Viscosity, thermal conductivity, diffusion are central for understanding of the planetary mantle dynamics, thermal history and balance, magnetic field generation, and planetary history. Measurements of the transport properties *in situ* under the relevant *P-T* conditions require time-resolve probe of materials properties (*e.g*., lattice parameters), sample position, and chemical distribution. These will be studied here using highly temporally and spatially resolved x-ray diffraction, spectroscopy, and imaging synchronized with pulsed laser techniques used both to initiate the processes under study and to generate the high temperatures of interest.

Bonding, electronic, and spin properties and redox and valence state. Those are crucial for understanding of the planetary composition, magnetic field generation, and planetary thermal balance. Knowledge of electronic bonding characters of the planetary materials under extreme *P-T-ε* can significantly affect our understanding of the seismic, geodynamic, and geochemical observations of the deep Earth. For example, electronic spin-pairing transitions of iron in the lower-mantle ferropericlase and perovskite have been observed to affect their elastic, thermodynamic, electrical, thermal, and rheological properties under relevant lower-mantle pressures [37]. These electronic transitions typically occur in the femto-second time period and requires time-resolved techniques to decipher their microscopic origins. Time-resolved x-ray diffraction and spectroscopy measurements through the spin transition will be uniquely combined at the proposed beamline with laser and resistive internal pulsed heating, laser ultrasonics [14], and thermal conductivity measurements using time-domain thermoreflectance technique [38] (the latter is also applicable for the *Transport property* section).

Chemical reactivity of volatiles and on the mineral interfaces. Volatiles play important role in the evolution and dynamics of Earth and planets. There is a range of unsolved problems involving degassing in the early planetary history, volatile recycle in the subduction zone, and storage of volatiles in the deep Earth. In particular, the effects of H_2O and CO_2 on melting, rheological and physical properties, and transport properties, hold the key to understanding the composition and thermal structure of the planetary interior, planetary volcanism, volatile recycling in the interior, fluid-mineral interaction. In order to quantify these effects, we must understand the fundamental physical and chemical properties of H- and C-bearing compounds at high pressure and temperature and their stability fields in the subduction zone and the Earth's deep interior. The proposed beamline will provide new capability to investigate hydrogen and carbon solubility in minerals, chemical reactivity of volatiles, and surface chemistry. In particular, high-resolution imaging with a tightly focused beam will allow direct production of 3D images of samples at high pressure and temperature, providing insight into fluid migration network, permeability, and connectivity.

Environmental Science and Energy Sustainability: The sequestration of carbon from the anthropogenic CO_2 emissions associated with fossil fuel utilization, represents a major programmatic thrust of the U.S. Department of Energy. A detailed elucidation of fundamental chemical/geochemical reaction mechanisms, and the stability of the product phases observed in both "above-ground" mineral sequestration and "below-ground" geological sequestration is essential to the development of viable processes for carbon mitigation. *In situ* observations under the pressure, temperature and activities present during sequestration are of special interest, since they are in principle devoid of artifacts associated with sample manipulations and quenching effects typically encountered in the conventional bench scale approach using, *e.g.*, autoclaves. When CO_2 is injected into the subsurface reservoirs, it is subject to extreme pressure-temperature conditions, *i.e.*, pressures up to a few hundred bars and temperatures of tens of Celsius along typical geothermal gradients. In the subsurface of the earth, CO_2 can exist as a dissolved component in water/brine as well as in gaseous and liquid phases, and in the supercritical state. While laboratory experiments have observed a series of reaction products between the injected CO_2 and surrounding minerals, *in situ* experimental observations of the kinetics of the reactions remain to be further understood. The injection of the CO_2 into the subsurface reservoirs creates physical and chemical conditions away from equilibrium. Understanding such transient non-eqilibrium phenomena and mechanical instabilities requires *in situ* identification of the reactions and physical, chemical, and transport properties at various pressure, temperature, stress/strain rate, and time conditions. To address these issues, we propose to use the dynamic diamond anvil cell and the time-resolved Raman and synchrotron-based spectroscopies (X-ray fluorescence, X-ray absorption, inelastic X-ray scattering spectroscopies) to study the kinetics and reaction products of CO_2-brine-minerals (*e.g.*, [7]). We shall also investigate key below-ground brine-mineral reactions using a recently developed moissanite-window microreactor which enables *in situ*, spectroscopic investigations at *constant reactant activity* in the pressure and temperature range from ambient conditions to 400 °C and 310 bar, respectively [39]. While the latter system has to date allowed a study of dissolution and carbonation kinetics in the temporal regime from 100-105 seconds, the proposed beamline will provide access to processes on much shorter time scales needed to elucidate the early stages (nucleation kinetics) of key mineral reactions.

Another viable large-scale carbon sequestration option is based on ex-situ (above-ground) mineral sequestration. The latter is based on an artificially accelerated version of "natural weathering" in which ubiquitous serpentine minerals with composition $Mg_3Si_2O_5(OH)_4$ react exothermically with CO_2 to form a mineral carbonate ($MgCO_3$), silica (SiO_2) and water (H_2O). In the optimal process a mild carbonic acid solution (T~100 ^oC, P_{CO2} ~ 150 atm) is used to simultaneously dissolve the Mg mineral feedstock and precipitate carbonate. Several "bottlenecks" preclude the scale-up of the existing process to the industrial scale: (1) the serpentine feedstock mineral must first be ground (~100 μm), and then partially dehydroxylated via (costly) prolonged direct heating to 600 ^oC in order to induce reactivity, presumably by improving the dissolution kinetics in the aqueous process. (2) Rapid incongruous dissolution leads to a build-up of silica on the mineral feedstock grains inhibiting further reaction. Variations of the solution chemistry are being explored to cope with the latter issue. As to the heat treatment, a novel approach has recently been developed based on the explosive release of the high H_2O content (~13% by weight) in the feedstock via rapid heating (e.g., a "popcorn" effect). Heating rates of ~10,000 ^oC/sec, with a subsequent hold time of several seconds at T~1000^oC produce complete dehydroxylation. The resulting "flashed" product is highly reactive and has been shown to carbonate as readily as samples produced using the far more expensive long-time, low-temperature approach. The new beamline will be used to elucidate the mineral decomposition mechanism in this highly non-equilibrium approach. This new insight and detailed mechanistic understanding will allow further cost-optimization, paving the way to scale-up and near-term deployment at the industrial scale, and a viable carbon sequestration technology.

B. Beamline Concept & Feasibility

The principally new approaches for the proposed new beamline, which have not yet been used before in the synchrotron static and dynamic studies, include:

(i) combination of several x-ray techniques (diffraction, spectroscopy, 2d and 3d imaging microscopy), pulsed-laser driven and mechanical actuator (dDAC) compression, pulsed laser heating, pulsed internal heating, high magnetic fields and fast optical diagnostics of the sample properties in a pump-probe mode;

(ii) time-domain measurements to access the time-scales of micro- and macro processes in the materials under extremes; this includes chemical reactions, diffusions, phase equilibria, heat fluxes, strain rates, etc.
(iii) variable length scale measurements allowing to connect materials properties on different length scales. Of particular interest is the study of heterogeneous structures, such as chemically reacted or incompletely phase transformed samples in the DAC, dynamically stressed samples, samples with grain sizes comparable to the spot size, superconductors in magnetic fields.

Due to a unique combination of tightly focused beams with very high brilliance (exceeding any other available synchrotron sources below 20 keV) we will enable new ultrafast (ps to ms) time-resolved capabilities for x-ray diagnostics, which will be combined with each other continuous and pulsed laser tools. This will make the proposed beamline totally unique and competitive to other existing and currently developing facilities including those in Japan and Europe.

Although the proposed beamline is not a part of a suite of beamlines for high pressure research, it is favorable if it would be positioned in close proximity to other high-pressure beamlines, because of a possibility to share the auxiliary resources (e.g., sample preparation and diagnostic areas, off-line techniques) more time- and space efficiently. Moreover, we anticipate that the proposed here beamline will be complementary to others in capabilities (*e.g.*, in x-ray source flux).

X-ray source: IVU, or U22 high beta undulator for maximum flux (see Fig. 3 for beamline layout). We will be using tapered undulator configuration for optimizing the parameter of the beam for white (pink), and monochromatic applications (see below).

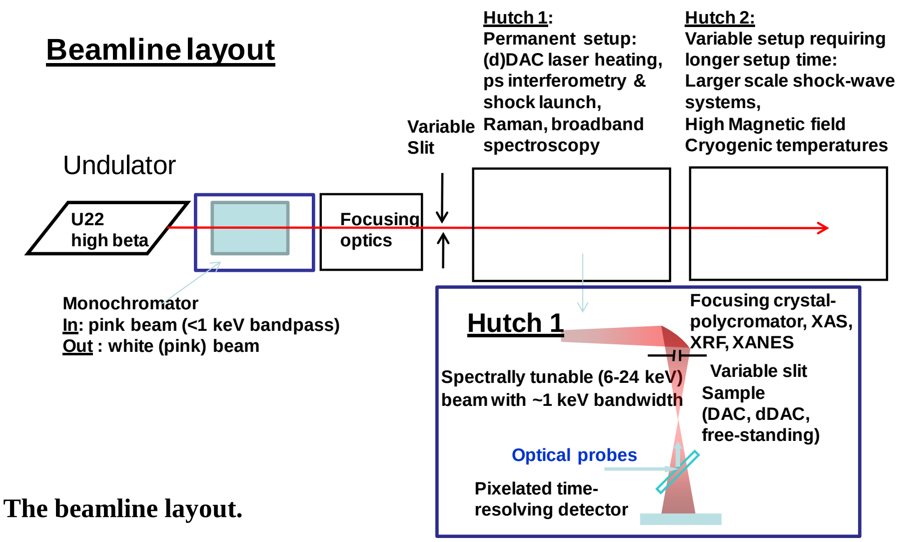

Figure 3. The beamline layout.

Energy range: we are going to have interchangeable options for pink and monochromatic beams in the range of 5-40 keV. The choice of the x-ray energy and undulator settings will be based on the requirements of conducted experiments according to the selected techniques: spectroscopy, diffraction, ultrafast imaging and their combination.

Monochromator: we will be combining white/pink (for energy-dispersive spectroscopy and ultrafast scattering studies), and monochromatic (*e.g.*, for diffraction) operation. For this we choose a cryogenic Si monochromator with changeable crystals of different cuts (111, 311). For the white/pink beam operation the monocromator will be removed from the beam.

Focusing optics: x-ray beam will be first focused (using double focusing technique) on the intermediate adjustable aperture, which determines the beam spot dimensions. The ultimate spot dimensions (at the sample) can be varied between 0.2 and 5 μm by adjusting the size of the intermediate aperture.

Experimental hutches: we propose to build two hutches for most efficient operation and easy switch between different experimental tasks.

The first hutch will have permanent x-ray and optical laser/spectroscopy equipment. The x-ray beam will be refocused into the sample using a bent crystal (horizontally) and K-B mirror (vertically). The X-ray time-resolved spectroscopy (XAS, EXAFS, XANES) measurements will be performed in the energy dispersive mode [23]. A variable slit positioned behind the bent Si crystal will determine the bandwidth of the pink beam used in spectroscopy /diffraction experiments. A dedicated (pulsed) laser heating/(pulsed) optical spectroscopy/laser ultrasonics/ps interferometry/shock compression system will be a permanent part of this setup. This setup will be designed and optimized for operation with DAC, but low-pressure vessels, and free-standing samples can also be studied including the levitation methods. The experimental table in this hutch can be moved away to install a vacuum pipe to path the beam to the second hutch.

The second hutch will have variable equipment for various experiments requiring longer setup time and unique tools. Those include diffraction and spectroscopy under conditions of high magnetic field, low temperature (combined with DAC if needed), larger scale laser driven shocks, cryogenic experiments, and other not yet identified experiments under extremes.

The x-ray detectors will include area pixilated fast detectors such as Pilatus. In the case of spectroscopy applications, when one direction corresponds to spectral direction, the second dimension can be used to disperse the signal in time. In this case a streak camera will be employed in most fast time-resolved experiments. For imaging application we will be using fast CCD detectors including gated intensified CCD detectors [16].

Below is the summary of the x-ray and laser techniques, which will be used at the proposed beamline:

Main x-ray techniques: micro-XRD and SAXS, XAS, XFS, XES, x-ray Raman.

On-line optical: laser heating, laser driven compression, broadband optical, Raman, Coherent Antistokes Raman, fluorescence spectroscopies, ultrafast laser ultrasonics, pulsed ultrafast laser interferometry.

Regime: pulse and static

Sample: single crystal, poly-crystalline, nano-sized, non-crystalline (amorphous solid and fluids)

High-pressure techniques: static and dynamic diamond-anvil cell, laser driven shocks and ramp compression, high and low T, static and pulse magnetic field

High pressure lab: sample preparation and off-line diagnostic.

C. Required Technical Advances

The performance level of the proposed beamline is directly related to the following technical capabilities which are currently being developed or already developed.

Dynamic DAC: The dDAC uses piezoelectric actuators to control the stress rate of the sample, and has reached to compression (strain rates) of up to 500 GPa/s (0.16 s^{-1}) for a metal up to 50 GPa [7] (Figure 1). The potential of the dDAC technique, including various modulation modes and strain and repetition rates, remains largely explored, however, because of the limited attempts in its use [40, 41]. The strain rate can be increased by developing stronger confining gaskets and more powerful piezoelectric actuators (currently available commercially), whereas repetition rates and modulation modes can be improved using a variety of source generators. These variations will allow P-T-ε extremes to be more applicable to probing materials properties, *e.g.*, for metals in the regime of thermally-activated effect, dislocation-drag effect, stress-induced effect, to dislocation-induced slip (Figure 1).

Pulsed laser and external heating: Pulsed laser heating [11] allows much more stable in time operation at much higher temperatures because of substantially reduced averaged power compared to the continuous operation. The use of very short laser pulses (~10 ns) allows reaching very high instantaneous temperatures (>1 eV) in the DAC, but the diagnostics (*e.g.*, x-ray) of materials under such conditions remains a problem because of extremely small amount of materials (<1 μm in thickness) which can be heated during a short laser pulse. This will be circumvented by the use of ultra-bright and very tightly focused x-ray source of NSLS-II as proposed here, enabling measurements in eV temperature and 100 GPa pressure ranges (Fig. 3). Recently we have developed a microsecond (μs) pulsed laser heating technique using an electrically modulated fiber laser [36]. X-ray diffraction and finite element calculations show uniform heating conditions (tested to 60 GPa and 3500 K). This opens the possibility of performing a variety of measurements as a function of temperature.

The technique of internal resistive heating (*e.g.*, [42]) has been limited in pressure due to difficulties in handling of the micro-wires of ~μm in dimensions. Here we will use advance micro- fabrication techniques (e.g., recently acquired by Carnegie FIB) to build the necessary for this technique micro- circuits (Fig. 4). Furthermore, we will be using advantages of reduced averaged power of a pulsed heating and more uniform heat deposition (compared to the laser heating) to reach ultrahigh *P-T* conditions with a very high repetition rate. This will enable time-resolved diffraction and spectroscopy measurements with ns time resolution.

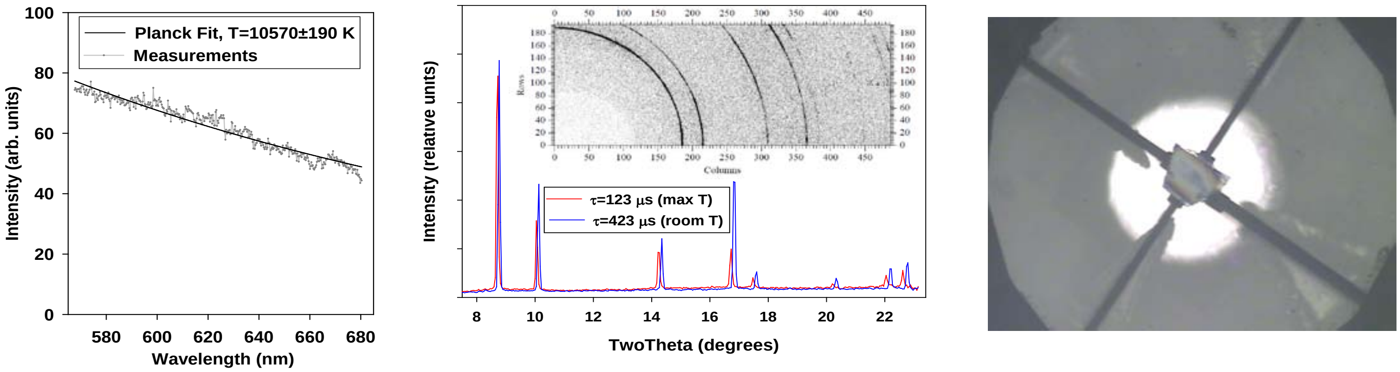

Figure 4. Left panel: Example of the incandescent spectrum measured in the DAC at 124 GPa with 10 ns temporal resolution. Middle panel: Representative x-ray diffraction patterns of platinum sample in the DAC at the nominal pressure of 38 GPa for the experiments with 80 μs long laser pulses. Blue solid line – the pattern measured (using a Pilatus detector) at the delay time well outside the laser pulse duration; the diffraction peak positions are indistinguishable from those for the pattern obtained at room temperature with the laser power off. Red solid line- the pattern collected at the delay time corresponding to the largest thermal expansion and hence the largest bulk sample temperature. The inset shows the diffraction image corresponding to the pattern measured from the hot sample (red curve). Right panel: electrical contacts prepared by FIB.

Laser driven compression (including shock) in the DAC [4, 5]. To initiate shock compression of the sample, a sub-ns duration pump pulse with ps duration initial rise time is focused to a spot size with some 10s of μm FWHM intensity diameter at the diamond interface of a ~μm thick aluminum layer which partially coats one culet of one diamond in the DAC (Fig. 5). Plasma expansion of the ablated aluminum layer drives a shock wave into the precompressed sample.

The shock and particle velocities are measured via interferometry using a pair of broadband linearly chirped probe pulses (with the same spectral characteristics as the pump) separated in time by 10 ps – a method that is the ultrafast analog to the velocity interferometry system for any reflector (VISAR) used to characterize shock waves on longer time scales. The probe pulses are chirped to provide a sub-ns window with <10 ps intrinsic time resolution. Time resolution is obtained by spectrally resolving the probe, whose wavelength is linearly correlated with time over the probe pulse duration.

The surface of the sample on the probe side is imaged at an imaging spectrometer with the probe and pump profiles centered on the spectrometer slit. The pump is focused with a relatively high numerical aperture onto the ablator. The experiment obtains both the shock and particle velocities for optically transparent samples. This enables full characterization of the pressure and density of the shocked state in a single shot.

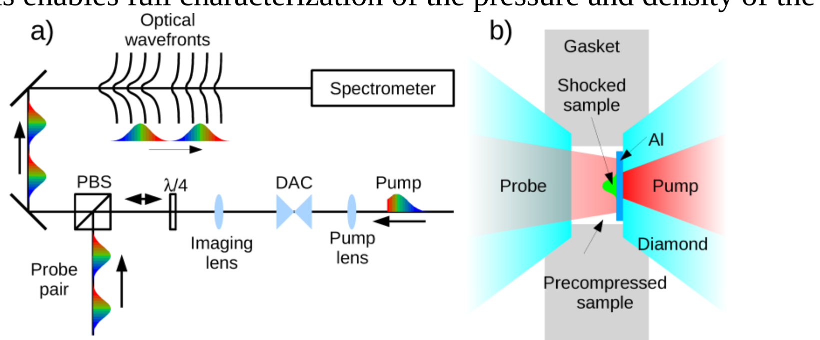

Fig. 5. The experimental setup, a) shows the optical setup external to the DAC. Although the probe pulses are shown as separated for the purpose of illustration, they overlap temporally. b) shows a close up of a cross section of the DAC, where precompressed sample is shocked via ablation of a ~1 μm aluminum layer on the culet of the right side diamond. PBS is a polarizing beam splitter.

D. User Community and Demands

The proposed beamline design comprises two most popular for the high-pressure community x-ray techniques which are currently at the very high demand: diffraction and spectroscopy in the laser heated DAC (GSECARS and HPCAT at APS) and energy dispersive x-ray absorption spectroscopy (ID 24 ESRF). These techniques will be substantially enhanced by the use of the light source of NSLS-II, which is at least two orders of magnitude brighter than any other currently available one. This will allow very rapid measurements enabling time resolved measurements at a very short time scale comparable to transport phenomena such as heat transfer, diffusion, re-crystallization, strain wave propagation, etc. Moreover, the proposed beamline will have new unique capabilities related to the combined use of x-ray techniques and pulsed laser probes in the pump-probe mode.

On June 15, 2010 with the financial help of NSLS and COMPRES, a workshop "Time-resolved X-ray diffraction and spectroscopy under extreme conditions" was held at NSLS organized by the BAT members V. Prakapenka and A. Goncharov. The workshop was devoted to discussion of new opportunities related to the construction of NSLS-II for study of materials under extremes. Based on the discussions, the workshop identified the scientific challenges in the field and suggested the experimental techniques, which are most suitable for the proposed beamline and are best matching for the NSLS-II source properties.

In the Appendix I, we list potential users and supporters of the beamline proposed.

E. Proposal Team Expertise and Experience

Proposal Team member	***Expertise and experience***
Alexander Goncharov	Optical spectroscopy; Pulsed laser techniques; Optical instruments; High Pressure Techniques; Laser heating; X-ray probes; Condensed Matter Physics
Vitali Prakapenka	Synchrotron x-ray techniques at extreme conditions, On-line laser heating and optical spectroscopy, High pressure techniques, Applied crystallography
Mark Rivers	Design and construction of X-ray optics, Synchrotron sources, High Pressure Techniques, X-Ray probes, Geosciences
Kanani K. M. Lee	Diamond-anvil cell techniques with laser and external heating combined with x-ray diffraction. Mineral physics, Earth and planetary interiors
Michael R. Armstrong	Ultrafast time-domain & nonlinear spectroscopy; Optical instrument & high power/ short pulse laser design; THz acoustics; Time resolved electron imaging /diffraction.
Sarah T. Stewart	Shock compression of natural materials; EOS; dynamic strength; planetary collisions; simulations of hypervelocity collisions
Jung-Fu Lin	Diamond anvil cell techniques with laser and external heating combined with X-ray spectroscopies. Mineral physics and planetary interiors
Maddury S. Somayazulu	Synchrotron x-ray techniques, High pressure – High temperature chemistry, Optical spectroscopy, Molecular dynamics simulations, Stress-Strain behavior
Evan Reed	Quantum and classical atomistic calculations of materials at extreme conditions including high pressures, temperatures, field strengths, and strain rates; Multi-scale modeling of shock and quasi-isentropic compression of materials
Yingwei Fei	High pressure techniques, Electron microscopy and microprobes, X-ray synchrotron probes, Mineral physics, Earth and planetary interiors
Andrew V.G. Chizmeshya	High-pressure/high-temperature hydrothermal moissanite-cell technology and techniques; Condensed matter, liquid and gas-phase *ab initio* simulations; Chemistry under extreme temperature - pressure conditions; X-ray synchrotron
James A. Hawreliak	Shock-wave compression methods, Laser techniques, X-ray diffraction of shocked materials, Atomic, nuclear and solid-state physics
Evan H. Abramson	Transient optical techniques, thermodynamics and transport properties of fluids, measurement of viscosity, thermal diffusivity and acoustics in the DAC
Ross McDonald	High (pulsed) magnetic fields, GHz-frequency complex-conductivity technique, High-pressure techniques, Magnetotransport (Hall and Shubnikov-de Haas effects), Clear room, Correlated electron systems in high magnetic fields
Pavel Zinin	Ultrafast laser ultrasonics, Brillouin and Raman spectroscopy, High-pressure techniques, Ultrahard materials,
Viktor Struzhkin	X-ray spectroscopy, Electromagnetic probes, High-pressure techniques, High-temperature superconductivity, Materials science, Solid State Physics
Raymond Jeanloz	High-pressure techniques, Dynamic compression techniques, Mineral physics, Earth and planetary interiors, Materials science
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CDAC- the Carnegie/DOE Alliance Center
EFree - a DOE-funded Energy Frontier Research Center (EFRC)
DCO **–** Deep Carbon Observatory, sponsored by The Alfred P. Sloan Foundation

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Education and Training:

Moscow Institute for Physics and Technology,	Physics	M.S., B.A.	1979
Institute of Spectroscopy, Russian Academy of Sciences,	Physics	Ph.D	1983

Research and Professional Experience:

2005- present: Senior Staff Scientist, Geophysical Laboratory, CIW
2002- 2005: Staff Scientist, Lawrence Livermore National Laboratory
1999-2002: Research Scientist, Geophysical Laboratory, CIW
1995-1999: Senior Research Associate, Geophysical Laboratory, CIW
1993-1995: Carnegie Fellow, Geophysical Laboratory, CIW
1992-1993: A. von Humboldt Fellow, Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany
1989-1991: Senior Research Scientist, Institute of Crystallography, Russian Academy of Sciences, Moscow, Russia
1982-1989: Research Fellow, Institute of Crystallography, Academy of Sciences, Moscow, Russia

Selected Publications:

Tang, Y., A. F. Goncharov, V. V. Struzhkin, R. J. Hemley, & M. Ouyang (2010). Spin of Semiconductor Quantum Dots under Hydrostatic Pressure, *Nano Lett.* **10**, 358–362.
Somayazulu, M., P. Dera, A. F. Goncharov, S. A. Gramsch, P. Liermann, W. Yang, Z. Liu, H.-K. Mao, R. J. Hemley. "Pressure-induced bonding and compound formation in xenon–hydrogen solids" *Nature Chemistry*, **2**, 50 - 53 (2010).
Kolesnikov, A., V. G. Kutcherov, A. F. Goncharov. "Dissociation and polymerization of methane under upper mantle conditions: implication for an abiotic origin of petroleum". *Nature Geoscience*, **2**, 566-570 (2009).
Goncharov, A. F., Montoya, J. A., Subramanian, N., Struzhkin, V. V., Kolesnikov, A., Somayazulu, M., Hemley, R. J. "Laser heating in diamond anvil cells: Developments in pulsed and continuous techniques." *J. Synchrotron Rad*. **16** (2009) 769–772.
Goncharov, A. F., B, D. Haugen, V. V. Struzhkin, P. Beck, S. D. Jacobsen, "Radiative Conductivity and Oxidation State of Iron in the Earth's Lower Mantle", *Nature*, **456**, 231-234 (2008).
Crowhurst, J. C., J. M. Brown, A. F. Goncharov, S. D. Jacobsen. "Elasticity of (Mg,Fe)O Through the Spin Transition of Iron in the Lower Mantle" *Science* **319,** 451-453 (2008).
Beck, P., A. F. Goncharov, V.V. Struzhkin, B. Militzer, H.-K. Mao, R.J. Hemley, "Measurement of thermal diffusivity at high pressure using a transient heating technique" *Appl. Phys. Lett*. **91,** 181914-(1-3) (2007).
Goncharov, A. F., V. V. Struzhkin, and S. D. Jacobsen. "Reduced radiative conductivity of low-spin (Mg,Fe)O in the lower mantle." *Science,* **312**, 1205-1208 (2006).

Honors :

Lawrence Livermore National Laboratory Associate Director (CMS) Award, 2005.
Research Fellowship of the *Alexander von Humboldt Foundation*, 1992-1993.
Annual European High Pressure Research Group Award, 1991.

Synergistic Activities:

Symposium Organizer, AGU 2007 Fall Meeting.
COMPRES Workshop Organizer "Current vision and prospects for establishing of the high-pressure scale at high temperature", Washington D.C., January 26-28. 2007.
Symposium Organizer, MRS 2006 Fall Meeting.
Member for NSLS X-17 DAC Management team (COMPES).

Vitali B. Prakapenka
Center for Advanced Radiation Sources, The University of Chicago
5640 South Ellis Avenue, Chicago, IL 60637

Professional Experience

2006-present	**Senior Research Associate**, Center for Advanced Radiation Sources, University of Chicago
2003-2006	**Beamline Scientist**, Center for Advanced Radiation Sources, University of Chicago
2001-2003	**Research Associate**, Center for Advanced Radiation Sources, University of Chicago
2000-2001	**Guest Researcher**, Institute of Earth Sciences, Uppsala University, Sweden
1998-2002	**Principal Research Scientist**, Advanced Materials Research Laboratory, Gomel State University, Belarus
1997-1998	**Senior Research Scientist**, Advanced Materials Research Laboratory, Gomel State University, Belarus
1994-1997	**Research Scientist,** Advanced Materials Research Laboratory, Gomel State University, Belarus
1994	**Research Scientist,** Department of Solid State Physics at the Moscow Engineering Physics Institute (Technical University), Russia
1990-1993	**Post-graduate student**, Department of Solid State Physics at the Moscow Engineering Physics Institute (Technical University), Russia
1989-1990	**Probation-teacher**, Department of Solid State Physics at the Moscow Engineering Physics Institute (Technical University), Russia

Education

1989	**M.Sc.** Department of Solid State Physics at the Moscow Engineering Physics Institute (Technical University), Russia
1996	**Ph.D.** in Solids State Physics, Moscow Engineering Physics Institute (Technical University), Russia

Most Relevant Publications

1. Prakapenka, V. B., A. Kubo, A. Kuznetsov, A. Laskin, O. Shkurikhin, P. Dera, M.L. Rivers, & S.R. Sutton. Advanced flat top laser heating system for high pressure research at GSECARS: application to the melting behavior of germanium. High Pressure Research, 28 (3), 225, 2008.
2. Dubrovinsky L, N. Dubrovinskaia, O. Narygina, I. Kantor, A. Kuznetzov, V.B. Prakapenka, L. Vitos, B. Johansson, A.S. Mikhaylushkin, S.I. Simak, and I.A. Abrikosov. Body-Centered Cubic Iron-Nickel Alloy in Earth's Core, Science, 316(5833), 1880, 2007.
3. Komabayashi, T., Y. Fei, Y. Meng, and V. Prakapenka, In-situ x-ray diffraction measurements of the γ-ε transition boundary of iron in an internally-heated diamond anvil cell, Earth Planet. Sci. Lett., 282, 252, 2009.
4. Martin, C. D., Y. Meng, V. Prakapenka, and J. B. Parise, Gasketing optimized for large sample volume in the diamond anvil cell: first application to $MgGeO_3$ and implications for structural systematics of the perovskite to post-perovskite transition, J. Appl. Cryst.,41, 38 2008.
5. Catalli, K., S.-H. Shim, and V.B. Prakapenka. Thickness and Clapeyron slope of the post-perovskite boundary. Nature, 462, 782-785. 2009
6. Lin, J. F., G. Vankó, S. D. Jacobsen, V. Iota, V. V. Struzhkin, V. Prakapenka, A. Kuznetsov, and C. S. Yoo, Spin transition zone in Earth's lower mantle, Science, 317, 1740, 2007.

Synergistic Activities

- Develop state-of-the-art research techniques available to a broad user community
- Promote collaborative research by facilitating access to the instrumentation
- Train students and scientists from universities, national laboratories and industry in the use of synchrotron measurement techniques and analysis methods

Name: Mark L. Rivers

Education:

University of California Berkeley	PhD, Geology and Geophysics, 1985
Harvard College	A.B summa cum laude, Geological Sciences, 1976

Research Experience:

1993-present	Co-direct the design and construction of the GeoSoilEnviroCARS sector at the Advanced Photon Source. Experimental capabilities include high-pressure diffraction, x-ray microprobe and x-ray absorption spectroscopy.
2001-present	Senior Scientist, Department of the Geophysical Sciences and Center for Advanced Radiation Sources, The University of Chicago.
1989-present	Associate Director, Center for Advanced Radiation Sources, The University of Chicago
1988-2001	Senior Research Associate, Department of the Geophysical Sciences, The University of Chicago.
1984-1988	Research Associate, Department of the Geophysical Sciences, The University of Chicago.
1984-1993	Designed, constructed, and operated a synchrotron x-ray fluorescence microprobe at the National Synchrotron Light Source. Conducted research on trace element geochemistry of minerals, melt and fluid inclusions.

Professional Societies:

American Geophysical Union

Professional Activities:

Member of COMPRES Facilities Committee. 2002-present, Chair 2003-present.

Member of United States National Committee for Crystallography. 1997-1999

Member, NSF Proposal Review Panel, Earth Sciences Instrumentation and Facilities Program, 1994-1997

Member of APS User's Organization Steering Committee. 1992-1995,2003-present. Chair 2003-2004.

Develop national synchrotron user facilities for earth science research.

Develop beamline controls and data analysis software that are widely used at x-ray synchrotrons around the world (see http://cars.uchicago.edu/software).

Awards:

R&D 100 Award for X-ray Microprobe/Microscope, Co-winner (1989)

Selected Publications:

J.R. Royer, E.I. Corwin, A. Flior, M.L. Cordero, M. Rivers, P. Eng, H.M. Jaeger, "Formation of granular jets observed by high-speed x-ray radiography," Nature Phys. 1 (2), November, 164-167 (2005).

D. Wildenschild, J.W. Hopmans, M.L. Rivers, A.J.R. Kent, "Quantitative Analysis of Flow Processes in a Sand Using Synchrotron-Based X-ray Microtomography," Vadose Zone J. 4, 112-126 (2005).

M.L. Rivers, Y. Wang, T. Uchida, "Microtomography at GeoSoilEnviroCARS," Proceedings of SPIE : Developments in X-Ray Tomography IV, Ulrich Bonse, eds., 5535, SPIE (2004), 783 - 791.

Y. Wang, Y., G. Shen and M. L. Rivers (2002), High Pressure Research at Third Generation Synchrotron Sources, in Third Generation Hard X-ray Synchrotron Radiation Sources, D. M. Mills ed, Wiley, 203-236.

Sham, T. K. and M. L. Rivers (2002). A brief overview of synchrotron radiation. In Reviews in Mineralogy & Geochemistry: Applications of Synchrotron Radiation in Low-Temperature & Environmental Science, Mineralogical Society of America, Vol 49, 117-147.

L. Bai, D.R. Baker, M.L. Rivers, "Experimental study of bubble growth in Stromboli basalt melts at 1 atm," Earth Planet Sci. Lett. 267 (3-4), 533-547 (2008). DOI: 10.1016/j.epsl.2007.11.063

P. Eng, M. Newville, M. Rivers, S.R. Sutton, "Dynamically figured Kirkpatrick Baez x-ray micro-focusing optics," X-ray Microfocussing: Applications and Technique, I. McNulty, eds., SPIE, (1998), 145 - 155.

Kirk G. Scheckel, Rebecca Hamon, Laurence Jassogne, Mark Rivers, Enzo Lombi, "Synchrotron X-ray absorption-edge computed microtomography imaging of thallium compartmentalization in Iberis intermedia," Plant Soil 290 (1-2), 51-60 (2007). DOI: 10.1007/s11104-006-9102-7

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Education

1999-2003	**Ph.D., Geophysics** University of California, Berkeley Thesis advisor: Raymond Jeanloz Thesis: Exploring planetary interiors: Experiments at extreme conditions
1995-1999	**BS, Physics, *Cum Laude*** University of San Francisco

Appointments

July 2008 - present	**Assistant Professor** Yale University, Department of Geology & Geophysics
January 2006 - June 2008	**Assistant Professor** New Mexico State University, Department of Physics
January 2004 - December 2005	**O. K. Earl Postdoctoral Fellow** California Institute of Technology, Geological & Planetary Sciences

Selected Awards and Honors

2010	University of San Francisco's Arthur Furst Award
2005-2008	Alexander von Humboldt Summer Fellow, Bayerisches Geoinstitut
2004-2005	O. K. Earl Postdoctoral Fellow, California Institute of Technology
2000-2003	National Science Foundation Graduate Research Fellow

Selected Publications

Y. Al-Khatatbeh, K. K. M. Lee and B. Kiefer, "Phase relations and hardness trends of ZrO_2 phases at high pressure," *PRB*, 81, 214102 (2010).

Y. Al-Khatatbeh, K. K. M. Lee and B. Kiefer, "High-pressure behavior of TiO_2 as determined by experiment and theory," *PRB*, 79, 134114 (2009).

R. Jeanloz, P. M. Celliers, G. W. Collins, J. H. Eggert, K. K. M. Lee, R. S. McWilliams, S. Brygoo, P. Loubeyre, "Achieving novel states through shock-wave loading of pre-compressed samples, *PNAS,* doi/10.1073/pnas.0608170104 (2007).

K. K. M. Lee, L. R. Benedetti, R. Jeanloz, P. M. Celliers, J. H. Eggert, D. G. Hicks, S. J. Moon, A. Mackinnon, L. B. DaSilva, D. K. Bradley, W. Unites, G. W. Collins, E. Henry, M. Koenig, A. Benuzzi-Mounaix, J. Pasley, D. Neely, "Forming conducting water: Implications for magnetic field generation in Icy Giant planets," *J. Chem. Phys.,* 125, 014701, doi: 10.1063/1.2207618 (2006).

P. Loubeyre, P. M. Celliers, D. G. Hicks, E. Henry, A. Dewaele, J. Pasley, J. H. Eggert, M. Koenig, F. Occelli, K. K. M. Lee, R. Jeanloz, D. Neely, A. Benuzzi-Mounaix, D. Bradley, M. Bastea, S. Moon and G.W. Collins, "Coupling static and dynamic compressions: First measurements in dense hydrogen," *High Press. Res.*, 24(1), 25 (2004).

P. M. Celliers, G. W. Collins, D. G. Hicks, M. Koenig, E. Henry, A. Benuzzi-Mounaix, D. Batani, D. K. Bradley, L. B. DaSilva, R. J. Wallace, S. J. Moon, J. H. Eggert, K. K. M. Lee, L. R. Benedetti, R. Jeanloz, I. Masclet, N. Dague, B. Marchet, M. Rabec Le Gloahec, Ch. Reverdin, J. Pasley, O. Willi, D. Neely and C. Danson, "Electronic conduction in shock-compressed water," *Phys. Plasmas*, 11(8), L41 (2004).

Michael Armstrong
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(a) Professional Preparation

New Mexico State University	Physics	BA, 1993
University of Rochester	Physics	PhD, 2001
LLNL (post-doc)	Physics	2004-2007

(b) Appointments

2007-present; Physicist, flexible term, LLNL

(c) Awards

National Academy of Sciences Postdoctoral Research Associateship
Materials and Manufacturing Ontario Industrial fellowship
R&D 100 award, 2008
Nano 50 award, 2008

(d) Selected publications

M. R. Armstrong, J. C. Crowhurst, S. Bastea, J. M. Zaug, "Ultrafast observation of shock states in a precompressed material," under review, *J. Appl Phys*, (2010)

M. R. Armstrong, E. J. Reed, K. Y. Kim, J. H. Glownia, W. M. Howard, J. C. Roberts, and E. Piner, "Observation of THz radiation coherently generated by acoustic waves," *Nature Physics* ***5*** *285* (2009)

Judy S. Kim, Thomas LaGrange, Bryan W. Reed, Mitra L. Taheri, Michael R. Armstrong, Wayne E. King, Nigel D. Browning, and Geoffrey H. Campbell, "Imaging of Transient Structures Using Nanosecond in Situ TEM," *Science* **321** 1472 (2008)

M. R. Armstrong, J. C. Crowhurst, E. J. Reed, and J. M. Zaug, "Ultrafast high strain rate acoustic wave measurements at high static pressure in a diamond anvil cell," *APL* **92** 101930 (2008)

M. R. Armstrong, N. D. Browning, B. W. Reed, and B. R. Torralva, "Prospects for Electron Imaging with Ultrafast Time Resolution", *Appl Phys Lett* **90** 114101 (2007)

M. R. Armstrong, K. Boyden, C. G. Brown, G. H. Campbell, J. D. Colvin, W. J. DeHope, A. M. Frank, D. J. Gibson, F. V. Hartemann, J. S. Kim, W. E. King, T. LaGrange, B. J. Pyke, B. W. Reed, M. D. Shirk, R. M. Shuttlesworth, B. C. Stuart, B. W. Reed,, and N. D. Browning, "Practical considerations for high spatial and temporal resolution dynamic transmission electron microscopy", *Ultramicroscopy* **107**, 356 (2007)

M. R. Armstrong, J.P. Ogilvie, M. L. Cowan, A. M. Nagy, and R. J. D. Miller, "Observation of the cascaded atomic-to-global length scales driving protein motion" *PNAS* **100**, 4990 (2003)

M. R. Armstrong, P. Plachta, E. A. Ponomarev and R. J. D. Miller, "Versatile 7 fs optical parametric generation and compression using adaptive optics", *Opt. Lett.* **26**, 1152 (2001)

Sarah T. Stewart **Biographical Sketch**
Department of Earth and Planetary Sciences sstewart@eps.harvard.edu
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Scientific Background and Experience

Dr. Stewart is a specialist in shock physics studies of natural materials and numerical studies of planetary collisions with over 14 years of experience. In 2004, she established the Shock Compression Laboratory at Harvard that focuses on Earth and planetary science topics. Previous work includes determining the criteria for shock-induced melting and vaporization of water ice and development of a new multi-phase equation of state model for water for use in hydrocodes. Current research includes experimental programs on shock temperature, hydrated minerals, and the thermodynamics of shocked mixtures. Stewart also leads development of numerical techniques for simulations of impact events. Current work includes improving rheological models in the CTH shock code for simulations of large cratering and giant impact events. General interests include the evolution, physical properties, and internal structure of planets.

Dr. Stewart received an A.B. in Astronomy & Astrophysics and Physics from Harvard (1995) and a Ph.D. in Planetary Sciences (minor Astrophysics) from Caltech (2002). Dr. Stewart is a recipient of a Presidential Early Career Award for Scientists and Engineers and the Harold C. Urey Prize.

Professional Positions

John L. Loeb Associate Professor of the Natural Sciences, Harvard University	2009-present
Assistant Professor of Planetary Science, Harvard University	2003-2009
G. K. Gilbert Postdoctoral Fellow, Carnegie Institution of Washington	2002-2003

Selected Publications (PDFs available on web site)

1. Louzada, K. L., S. T. Stewart, B. P. Weiss, J. Gattacceca, N. S. Bezaeva, Shock and static pressure demagnetization of pyrrhotite and implications for the Martian crust, *Earth and Planetary Science Letters*, **290**, 90-101, doi:10.1016/j.epsl.2009.12.006, 2010.
2. Kraus R. G., S. T. Stewart, A. Seifter, A. W. Obst, Shock and Post-Shock Temperatures in an Ice-Quartz Mixture: Implications for Melting During Planetary Impact Events, *Earth and Planetary Science Letters*, **289**, 162-170, doi:10.1016/j.epsl.2009.11.002, 2010.
3. Stewart, S. T., A. Seifter, and A. W. Obst, Shocked H_2O Ice: Thermal Emission Measurements and the Criteria for Phase Changes during Impact Events, *Geophysical Research Letters*, **35**, L23203, doi:10.1029/2008GL035947, 2008.
4. Yoshimura, Y., S. T. Stewart, H.-k. Mao, and R. J. Hemley, *In situ* Raman spectroscopy of low-temperature/high-pressure transformations of H_2O, *J. Chem. Phys.*, **126**, 174505, doi:10.1063/1.2720830, 2007.
5. Stewart, S.T., G.B. Kennedy, L.E. Senft, M.R. Furlanetto, A.W. Obst, J.R. Payton, A. Seifter. Post-Shock Temperature and Free Surface Velocity Measurements of Basalt. In *Shock Compression of Condensed Matter-2005*, pp. 1484-1487, Eds. M.D. Furnish et al., AIP, 2006.
6. Seifter, A., S.T. Stewart, M.R. Furlanetto, G.B. Kennedy, J.R. Payton, A.W. Obst. Post-Shock Temperature Measurements of Aluminum. In *Shock Compression of Condensed Matter-2005*, pp. 139-142, Eds. M.D. Furnish, et al. AIP, 2006.
7. Yoshimura, Y., S. T. Stewart, M. Somayazulu, H-K Mao, R. J. Hemley. High-pressure x-ray diffraction and Raman spectroscopy of ice VIII, *J. Chemical Physics*, **124**, 024502, doi: 10.1063/1.2140277, 2006.
8. Stewart, S.T., T.J. Ahrens. Shock Properties of H_2O ice, *J. Geophysical Research*, **110**, E03055, doi: 10.1029/2004JE002305, 2005.
9. Stewart, S.T., T.J. Ahrens. A New H_2O Hugoniot: Implications for Planetary Impact Events. In *Shock Compression of Condensed Matter-2003*, pp. 1478-1483, Eds. M.D. Furnish, et al., AIP, 2004.
10. Stewart, S.T., T.J. Ahrens. Shock Hugoniot of H_2O ice, *Geophysical Research Letters*, **30** (6), 1332, doi: 10.1029/2002GL016789, 2003.

Biographical Sketch
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The University of Texas at Austin, 1 University Station C1100, Austin, TX 78712
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Education and Training:

2002 Ph.D., Geophysical Sciences, The University of Chicago, Chicago, Illinois, USA

1994 M.S., Earth Sciences, National Cheng-Kung University, Taiwan
1992 B.S., Earth Sciences, National Cheng-Kung University, Taiwan

Research and Professional Experience:

2008-present Assistant Professor in high-pressure mineral physics, Department of Geological Sciences, the University of Texas at Austin; research interests include properties of planetary interiors, high-pressure mineral physics and condensed matter physics, optical and synchrotron X-ray spectroscopies.

2005-2008 Lawrence Livermore Fellow, Lawrence Livermore National Laboratory; hosted by H Division, Physics and Advanced Technology (PAT); research topics include properties of the 3*d* and *f*-band metals and compounds, liquids and glasses under extreme environments.

2003-2005 Research Scientist, Carnegie/DOE Alliance Center (CDAC), Geophysical Laboratory, Carnegie Institution of Washington; a Center funded by National Nuclear Security Administration (NNSA) to advance the science for stewardship applications.

2002-2003 Carnegie Postdoctoral Fellow, Geophysical Laboratory, Carnegie Institution of Washington

1997-2002 Research and Teaching Assistant, The University of Chicago

Relevant Publications:

Lin, J. F., H. C. Watson, G. Vankó, E. E. Alp, V. B. Prakapenka, P. Dera, V. V. Struzhkin, A. Kubo, J. Zhao, C. McCammon, W. J. Evans, Intermediate-spin ferrous iron in lowermost mantle post-perovskite and perovskite, *Nature Geoscience*, 1, 688-691, 2008.

Lin, J. F., G. Vankó, S. D. Jacobsen, V. Iota-Herbei, V. V. Struzhkin, V. B. Prakapenka, A. Kuznetsov, and C. S.Yoo, Spin transition zone in Earth's lower mantle, *Science* **317**, 1740-1743, 2007.

Lin, J. F., H. Fukui, T. Okuchi, Y. Q. Cai, N. Hiraoka, C. S. Yoo, A. Trave, P. Eng, M. Y. Hu, P. Chow, Electronic bonding transition in compressed SiO_2 glass, *Phys. Rev. B*, 75, 012201, 2007.

Lin, J. F., E. Gregoryanz, V. V. Struzhkin, M. Somayazulu, H. K. Mao, and R. J. Hemley**,** Melting behavior of H_2O at high pressures and temperatures, *Geophys. Res. Lett.*, 32, L11306, doi:10.1029/2005GL022499, 2005.

Lin, J. F., V. V. Struzhkin, S. D. Jacobsen, M. Hu, P. Chow, J. Kung, H. Liu, H. K. Mao, and R. J. Hemley, Spin transition of iron in magnesiowüstite in Earth's lower mantle, *Nature,* 436, 377-380, 2005.

Lin, J. F., W. Sturhahn, J. Zhao, G. Shen, H. K. Mao, and R. J. Hemley, Sound velocities of hot dense iron: Birch's law revisited, *Science* **308**, 1892-1894, 2005.

Lin, J. F., W. Sturhahn, J. Zhao, G. Shen, H. K. Mao, and R. J. Hemley, Sound velocities of hot dense iron: Birch's law revisited, *Science* **308**, 1892-1894, 2005.

Synergistic Activities:

Member of the **C**arnegie/**DOE** Alliance Center, EFree (**E**nergy **F**rontier **R**esearch under **E**xtreme **E**nvironments), and COMPRES (**CO**nsortium for **M**aterials **P**roperties **R**esearch in **E**arth **S**ciences), **Ce**nter for **F**rontiers of **S**ubsurface **E**nergy **S**ecurity (**CFSES**), American Geophysical Union, American Physical Society, Mineralogical Society of America.

Maddury S. Somayazulu

Maddury Somayazulu is currently the CDAC research scientist overseeing the CDAC facilities at Geophysical Laboratory, Carnegie Institution of Washington. In addition to managing the laboratory facilities, he has the responsibility of coordinating with all diamond cell users within CDAC. He therefore involved with a number of research groups helping them design experiments at the synchrotron and neutron beamlines at APS, NSLS, ALS and SNS. In addition to this, he drives his own research in high pressure-high temperature xenon chemistry and also hydrogen storage in molecular materials. He was one of the key personnel entrusted with the responsibility of setting up the HPCAT beamlines at APS and was involved with the setting up of FOE optics, branching monochromator, ID stations and the BM stations. Prior to this he held a joint appointment with the materials research center (MRSEC) of ASU and the Geophysical Laboratory which involved setting up the first laser heating facility for conducting *in-situ* high pressure-high temperature chemical synthesis research.

Education and Training:

Mysore University	Physics, Chemistry and Mathematics	B. Sc., 1979
University of Hyderabad	Physics	M. Sc., 1981
Bombay University	Physics	Ph.D., 1991

Professional Experience:

2005-present: CDAC Research Scientist, Geophysical Laboratory, Washington DC
2000-05: Beamline Scientist, HPCAT, Carnegie Institution of Washington
1998-2000: CSSS/MRSEC Research Associate Professor, Arizona State University
1997-98: Joint Carnegie Fellow and ASU Fellow, Arizona State University
1996-97: Scientist F, Bhabha Atomic Research Center, Bombay, India
1994-96: Post-doctoral fellow, Geophysical Laboratory, Washington DC
1990-94: Scientist E, Bhabha Atomic Research Center, Bombay, India
1986-90: Scientist D, Bhabha Atomic Research Center, Bombay, India
1982-86: Scientist C, Bhabha Atomic Research Center, Bombay, India

Honors and fellowships:

1997-98: Carnegie fellow
Elected Life Member, Indian Instrumentation Society
Life Member, Indian Physical Society
Ferroelectrics Award, Ravishankar University, 1991
Young Physicist Award, Indian Physics Society, 1990

Selected Publications

Maddury Somayazulu, Przemyslaw Dera, Alexander F. Goncharov, Stephen A. Gramsch, Peter Liermann, Wenge Yang, Zhenxian Liu, Ho-kwang Mao&Russell J. Hemley. Pressure-induced bonding and compound formation in xenon–hydrogen solids. *Nature Chemistry*, **2**, 50-53 (2010).

Ahart, M.; **Somayazulu, M**.; Cohen, R. E.; Ganesh, P.; Dera, P.; Mao, H.-k.; Hemley, R. J.; Ren, Y.; Liermann, P.; Wu, Z., Origin of morphotropic phase boundaries in ferroelectrics. *Nature* 451, (7178), 545-548 (2008)

Chellappa, R. S.; Chandra, D**.; Somayazulu, M**.; Gramsch, S. A.; Hemley, R. J., Pressure-Induced Phase Transitions in LiNH2. *J. Phys. Chem B* 111, (36), 10785-10789 (2007)

Degtyareva O, Gregoryanz E, **Somayazulu M**, Dera P, Mao HK, and Hemley RJ, Novel Chain Structures in Group VI elements, Nature Materials, **4**, 152 (2005).

Gregorayanz E, Sanloup C, **Somayazulu M**, Badro J, Fiquet G, Mao HK and Hemley RJ, Synthesis and Characterization of a binary Noble metal Nitride, Nature Materials, **3**, 294 (2004).

Somayazulu M, Madduri A, Goncharov AF, Tschauner O, McMillan PF, Mao HK and Hemley RJ, Novel Broken Symmetry phase from N_2O at high pressures and high temperatures, Phys. Rev. Lett., **87**, 135504 (2001).

Somayazulu MS, Finger LW, Hemley RJ and Mao HK, High-pressure Compounds in methane-hydrogen mixtures, Science, **271**, 1400 (1996).

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Education and Postdoctoral Experience

2004-2007: E. O. Lawrence Postdoc Fellow, Lawrence Livermore National Laboratory.
2003-2004: Postdoc, Physics Department, Massachusetts Institute of Technology.
Ph.D., Physics, Massachusetts Institute of Technology, 2003.
B.S., Applied Physics, California Institute of Technology, 1998.

Professional Experience

2009-present: Assistant Professor, Department of Materials Science and Engineering, Stanford University.
2007-2009: Staff Scientist, Physical and Life Sciences Directorate, Lawrence Livermore National Laboratory.

Historical research interests

- Quantum and classical atomistic calculations of materials at extreme conditions including high pressures, temperatures, field strengths, and strain rates.
- Multi-scale modeling of shock and quasi-isentropic compression of materials, including ultrafast chemistry in energetic materials, high-pressure phase transformations in piezoelectrics.
- THz frequency acoustic waves, THz radiation generation in materials, electrical diagnostics of ultrafast processes

Selected relevant publications

1. N. Goldman, E. J. Reed, I.-F. W. Kuo, "**Synthesis of pre-biotic molecules in shocked astrophysical ices**," Nature Chemistry**,** in press.
2. E. J. Reed, "**Atomic transformation pathways from THz radiation generated by shock-induced phase transformations**," Phys. Rev. B 81, 144123 (2010).
3. M. R. Manaa, E. J. Reed, L. E. Fried, N. Goldman, "**Nitrogen-Rich Heterocycles as Reactivity Retardants in Shocked Insensitive Explosives**," Journal of the American Chemical Society 131, 5483 (2009).
4. M. R. Armstrong, E. J. Reed, K. Kim, J. H Glownia, E. Piner, J. Roberts, W. M. Howard, "**Observation of THz radiation coherently generated by strain waves**," Nature Physics 5, 285 (2009).
5. E. J. Reed, M. R. Manaa, L. E. Fried, K. Glaesemann, J. D. Joannopoulos, "**A transient semi-metallic layer in detonating nitromethane**," Nature Physics 4, 72 (2008).
6. E. J. Reed, M. R. Armstrong, K. Kim, J. H. Glownia, "**Atomic-scale time and space resolution of THz frequency acoustic waves**," Phys. Rev. Lett. 101, 014302 (2008).
7. E. J. Reed, L. E. Fried, J. D. Joannopoulos, "**A method for tractable dynamical studies of single and double shock compression**," Phys. Rev. Lett. 90, 235503 (2003).
8. E. J. Reed, J.D. Joannopoulos , and L. E. Fried, "**Electronic excitations in shocked nitromethane**," Phys. Rev. B, 62, p. 16500-16509 (2000).

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Education and Training:

Zhejiang University, Geochemistry, China, B.S. 1982
City University of New York, Earth and Environment Sciences, Ph.D. 1989
Geophysical Lab, Carnegie Institution of Washington, Postdoctoral Fellow 1989-91

Research and Professional Experience:

1996-present: Senior Scientific Staff, Geophysical Lab, Carnegie Institution
1991-96: Associate Staff, Geophysical Lab, Carnegie Institution of Washington

Selected Publications (140 publications since 1986) :

Mohanty P., Y. Fei and K. Landskron, *High Pressure Research, 29*, 754-763, 2009.

Fei, Y., A. Ricolleau, M. Frank, K. Mibe, G. Shen, V. Prakapenka, *Proc. Natl. Acad. Sci. USA*, *104*, 9182-9186 doi: 10.1073/pnas.0609013104, 2007.

Lee, S. K., K. Mibe, Y. Fei, G. D. Cody, and B. O. Mysen, *Phys. Rev. Lett. 94*, 165507, 2005.

Fei, Y., J. Li, K. Hirose, W. Minarik, J. V. Orman, C. Sanloup, W. van Westrenen, T. Komabayashi, K. Funakoshi, *Phys. Earth Planet Inter*., 143/144, 516-526, 2004.

Rama Murthy, V., W. van Westrenen, and Y. Fei, *Nature*, *423*, 163-165, 2003.

Synergistic Activities:

DOE, NASA, NSF proposal review panels; AGU mineral and rock physics committee (2000-2002); Spring AGU meeting program committee (2000-2003); NSF COMRES facility committee (2002-2006); Associate editor, *American Mineralogists* (2000-2004); Associate editor, *Journal of Geophysical Research* (2001-2010); Chair, International Professionals for the Advancement of Chinese Earth Sciences (IPACES) (2006-2007)

Honors and Fellowships:

2010 Fellow of the American Geophysical Union; 2000 Crosby Visiting Lectureship, Massachusetts Institute of Technology (MIT); 1999 Mineralogical Society of America Award; 1992-1996 Norton Senior Fellow; 1990 Hou Defeng Medal, Chinese Academy of Sciences; 1989 Distinguished Scholar Dissertation Award, City Univ. New York; Mineralogical Society of America, Life Fellow

Supervised Posdoctoral Fellows and Research Associates (past 5 years):

Sung-Keun Lee (*Seoul National University*), Shantanu Keshav (*Bayerisches Geoinstitut*), Haemeyong Jung (*Seoul National University*), Alexandre Corgne (*Macquarie University*), Jennifer Jackson (*California Institute of Technology*), Liz Cottrell (*Smithsonian Institution*), Mathieu Roskosz (*Université des Sciences et Technologies de Lille*), Heather Watson (*Lawrence Livermore National Lab*), Angele Ricolleau (*GL*), Li Zhang (*GL*), Tetsuya Komabayashi (*Tokyo Institute of Technology*), Zhiguo Liu (*Harbin Institute of Technology*), Anat Shahar (*Geophysical Laboratory*), Konstantin Litasov (Tohoko University), Angele Ricolleau (*Institut de Minéralogie et de Physique des Milieux Condensés*), Chris Seagle, Valerie Hillgren.

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PROFESSIONAL PREPARATION

Institution	Major/Area	Degree and Year
University of Toronto (Canada)	Physics	B.Sc. 1985
Queen's University (Canada)	Physics	Physics M.Sc. 1988
Queen's University (Canada)	Physics	Physics Ph.D. 1992

APPOINTMENTS (Arizona State University)

2006-present	*Associate Professor*, Department of Chemistry and Biochemistry
2006-present	*Affiliated Associate Professor*, Department of Physics and Biochemistry
2001-2006	*Associate Research Scientist*, Center for Solid State Science
2001-present	*Affiliated Associate Professor*, Science and Engineering of Materials Graduate Program
1998-2001	*Academic Associate & Manager*, Goldwater Materials Visualization Facility
1996-1998	*Education Coordinator*, Materials Research Science & Engineering Center
1994-1996	*Faculty Research Associate*, Department of Chemistry and Biochemistry

PUBLICATIONS RELATED TO PROPOSAL

1. "*Carbon Sequestration via Aqueous Olivine Mineral Carbonation: Role of Passivating Layer Formation*" Bearat, Hamdallah; McKelvy, Michael J.; Chizmeshya, Andrew V. G.; Gormley, Deirdre; Nunez, Ryan; Carpenter, R. W.; Squires, Kyle; Wolf, George H. *Environmental Science & Technology* **40**(15), 4802-4808 (2006).
2. "*Externally controlled pressure and temperature microreactor for in situ x-ray diffraction, visual and spectroscopic reaction investigations under supercritical and subcritical conditions*". Diefenbacher,J.; McKelvy, M.; Chizmeshya, A.V. G.; Wolf, G.H. *Review of Scientific Instruments*, **76**(1), 15103-15110 (2005).
3. "*In Situ Observation of CO_2 Sequestration Reactions Using a Novel Microreaction System*". Wolf, George H.; Chizmeshya, Andrew V. G.; Diefenbacher, Jason; McKelvy, Michael J. *Environmental Science and Technology*, **38**(3), 932-936 (2004).
4. "*Exploration of the Role of Heat Activation in Enhancing Serpentine Carbon Sequestration Reactions*". McKelvy, M.J.; Chizmeshya, A.V.G.; Diefenbacher, J.; Bearat, H.; Wolf, G.H. *Environmental Science and Technology* , **38**(24), 6897-6903 (2004).
5. "*The Nanoscale Mechanism for San Carlos Olivine Carbonation*". Kim, Y.-C.; Nunez, R; Carpenter, R.W.; Chizmeshya, A.V.G.; McKelvy, M.J. *Microscopy and Microanalysis* , **11**(S02), 1530-1532 (2005).

OTHER SIGNIFICANT RECENT PUBLICATIONS

1. "Ether-like Si-Ge hydrides for Applications in Synthesis of Nanostructured Semiconductors and Dielectrics", Jesse B. Tice, Change Weng, John Tolle, Vijay R. D'Costa, Rachna Singh, Jose Menendez, John Kouvetakis and Andrew V.G. Chizmeshya, *Dalton Transactions*, (34), 6773-6782 (2009).
2. "*Lamellar reaction phenomena: from intercalation to nanomaterials formation*" McKelvy, Michael J.; Sharma, Renu; Chizmeshya,
Andrew V. G. *Journal of Physics and Chemistry of Solids*, **67**(5-6), 888-895 (2006).
3. "*Thermoelastic and Optical Properties of Thick Boride Templates on Silicon for Nitride Integration Applications*" Roucka, R.; D'Costa, V. R.; An, Y.-J.; Canonico, M.; Kouvetakis, J.; Menendez, J.; Chizmeshya, A. V. G. *Chemistry of Materials*, **20**(4), 1431-1442 (2008).
4. "Synthesis of Butane-Like SiGe Hydrides: Enabling Precursors for CVD of Ge-Rich Semiconductors" A.V.G. Chizmeshya, C.J. Ritter, C.-W.Hu, J. Tolle, R.A. Nieman, I. S.T. Tsong and J. Kouvetakis, *J. Am. Chem. Soc.* **128**(21), 6919-6930 (2006).
5. "Low-temperature pathways to Ge-rich $Si_{1-x}Ge_x$ alloys via single-source hydride chemistry" C.-W. Hu, J. Menéndez, I.S.T. Tsong, J. Tolle, A.V.G. Chizmeshya, C. Ritter, and J. Kouvetakis, *Appl. Phys. Lett.* **87**, 181903 (2005).

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Professional Preparation

University of Alberta	Engineering Physics	BSc 1996
University of California, Berkeley	Nuclear Engineering	MSc 1998
University of Oxford	Atomic and Laser Physics	D.Phil 2004
Post-doc, University of Oxford	Atomic and Laser Physics	2002 – 2005
Post-doc, LLNL	NIF / CMLES	2005-2008

Employment History

Physicist, Condense Matter and Material Division (Nov 2008 – present)
Supervisor : Gilbert Colins, Bruce Remington, Hector Lorenzana. Role : Develop ultrafast x-ray diagnostics from probing material response to dynamic loading

Post-doc, Condense Matter and Material Division / NIF (May 2005 – Nov 2008)
Supervisor: Hector Lorenzana, Bruce Remington. Role : Lead dynamic material science experiments at large scale laser facilities

Post-doc, Clarendon Laboratory, University of Oxford (March 2002 – March 2005)
Supervisor : Justin Wark Role : Lead laser based experiments to study HED phenomena.

Awards

Directorate Award, 2007

Publications (Selected)

Yaakobi, B., T. R. Boehly, T. C. Sangster, D. D. Meyerhofer, B. A. Remington, P. G. Allen, S. M. Pollaine, H. E. Lorenzana, K. T. Lorenz and J. A. Hawreliak (2008). "Extended x-ray absorption fine structure measurements of quasi-isentropically compressed vanadium targets on the OMEGA laser." Physics of Plasmas **15**: 062703.

Grant, C. D., J. C. Crowhurst, T. Arsenlis, E. M. Bringa, Y. M. Wang, J. A. Hawreliak, P. J. Pauzauskie and S. M. Clark (2009). "X-ray diffraction of electrodeposited nanocrystalline nickel under high pressure." Journal of Applied Physics **105**: 084311.

Kimminau, G., B. Nagler, A. Higginbotham, W. J. Murphy, N. Park, J. Hawreliak, K. Kadau, T. C. Germann, E. M. Bringa and D. H. Kalantar (2008). "Simulating picosecond x-ray diffraction from shocked crystals using post-processing molecular dynamics calculations." Journal of Physics: Condensed Matter **20**(50): 0953-8984.

Lorenzana, H. E., J. F. Belak, K. S. Bradley, E. M. Bringa, K. S. Budil, J. U. Cazamias, B. El-Dasher, J. A. Hawreliak, J. Hessler and K. Kadau (2008). "Shocked materials at the intersection of experiment and simulation." Scientific Modeling and Simulation **15**(1): 159-186.

Hawreliak, J. A., D. H. Kalantar, J. S. Stölken, B. A. Remington, H. E. Lorenzana and J. S. Wark (2008). "High-pressure nanocrystalline structure of a shock-compressed single crystal of iron." Physical Review B **78**: 22.

Hawreliak, J; Lorenzana, HE; Remington, BA, et al. "Nanosecond x-Ray diffraction from polycrystalline and amorphous materials in a pinhole camera geometry suitable for laser shock compression experiments", Rev. Sci. Instrum., 78 (2007).

Hawreliak, J; Colvin, J; Eggert, J, et al. "Modeling planetary interiors in laser based experiments using shockless compression", Astrophys. Space Sci., 307, 285-289 (2007).

Kalantar, DH; Collins, GW; Colvin, JD, et al. "In situ diffraction measurements of lattice response due to shock loading, including direct observation of the alpha-epsilon phase transition in iron", Int. J. Impact Eng., **33**, 343-352 (2006).

Hawreliak, J; Colvin, JD; Eggert, JH, et al. "Analysis of the x-ray diffraction signal for the alpha-epsilon transition in shock-compressed iron: Simulation and experiment", Phys. Rev. B **74**, (2006).

Bringa, M; Rosolankova, K; Rudd, RE, et al. "Shock deformation of face-centred-cubic metals on subnanosecond timescales", Nat. Mater., **5**, 805-809, (2006).

Kalantar, D. H., J. F. Belak, G. W. Collins, J. D. Colvin, H. M. Davies, J. H. Eggert, T. C. Germann, J. Hawreliak, B. L. Holian, K. Kadau, P. S. Lomdahl, H. E. Lorenzana, M. A. Meyers, K. Rosolankova, M. S. Schneider, J. Sheppard, J. S. Stolken and J. S. Wark (2005). "Direct Observation of the alpha-epsilon Transition in Shock-Compressed Iron via Nanosecond X-Ray Diffraction." Physical Review Letters **95**(7): 075502.

Rosolankova, K; Wark, JS; Bringa, EM, et al. "Measuring stacking fault densities in shock-compressed FCC crystals using in situ x-ray diffraction", J. Phys.-Condens. Mat., **18**, 6749-6757 (2006).

EVAN HOUGHTON ABRAMSON

EDUCATIONAL BACKGROUND

Reed College	B.A.	1975-79
Massachusetts Institute of Technology	Ph.D.	1979-85

EMPLOYMENT RECORD

University of Leiden	Associate Scientist	1985-87
University of Washington	Research Associate and Lecturer	1988-90
University of Washington	Research Assistant Professor	1991-93
Brookhaven National Laboratory	Associate Scientist	1994-95
University of Washington	Research Assistant Professor	1996-98
University of Washington	Research Associate Professor	1998-present

A FEW PUBLICATIONS

"The Thermal Diffusivity of Water at High Pressures and Temperatures", E.H. Abramson, J.M. Brown and L.J. Slutsky, J. Chem. Phys. **115**, 10461-3 (2001)

"Equation of State of Water Based on Speeds of Sound Measured in the Diamond- Anvil Cell", E.H. Abramson and J.M. Brown, Geochimica et Cosmochimica Acta, **68**, 1827-35 (2004)

"Viscosity of Water Measured to Pressures of 6 GPa and Temperatures of 300°C", E.H. Abramson, Phys. Rev. E, **76**, 051203-1-6 (2007)

"Viscosity of Nitrogen Measured to Pressures of 7 GPa and Temperatures of 573K", E.H. Abramson and H. West-Foyle, Phys. Rev. E, **77**, 041202-1-5 (2008)

"Viscosity of Carbon Dioxide Measured to a Pressure of 8 GPa and Temperature of 673K", E.H. Abramson, Phys. Rev. E, 80, 021201-1-3 (2009)

STATEMENT OF RESEARCH GOALS

Despite the many possible applications, little information is available concerning the thermodynamic properties of fluids above pressures of ~1 GPa (10 kbar) and practically no information on their chemical transport properties (*i.e.*, chemical diffusivity, thermal diffusivity, shear viscosity). For the most part, this situation is a result of the lack of techniques suitable to the exigencies of the high-pressure, diamond-anvil cell and also to the necessity, for all but a very few fluids, of working at elevated temperatures.

Our group has pioneered the application of optical techniques to the measurement both of speed of sound (a thermodynamic function) and thermal diffusivity within the diamond-anvil cell. Current efforts are directed to the measurement of viscosities of simple fluids of importance both in the planetary sciences and explosives engineering.

Bio – Ross D. McDonald

Ross McDonald joined the National High Magnetic Field Lab as a postdoc at Los Alamos in 2001. During his postdoctoral appointment and subsequent staff position, commencing 2004, he has developed new instrumentation for conducting GHz-frequency complex-conductivity experiments in millisecond duration pulsed magnetic fields. His current position involves extending the application of this technique to higher intensity and shorter duration magnetic fields, for example, the 300 Tesla, microsecond duration, single turn magnet system. His expertise includes a wide variety of experimental techniques primarily make measurements of correlated electron systems in high magnetic fields. These measurements include: EPR measurements of quantum magnet systems, GHz frequency conductivity of organic molecular metals, angle dependent torque magnetization used to map the Fermiology of exotic superconductors and shape-memory alloys, the temperature and magnetic field dependence of structural and ordering phase transitions in *f*-electron elements (Ce and Pu), the upper critical field and Fermiology of high T_C and Heavy Fermion superconductors and non-linear electrodynamics and narrow band noise of charge density wave materials. During his time at Los Alamos, Ross has written over forty articles in peer-reviewed journals, been invited to speak at ten international conferences and written two book chapters and one patent.

Scientific expertise

- GHz-frequency magneto-spectroscopy: resonant cavity techniques in pulsed and DC fields.
- Magnetometry: Torque magnetometry, including measurements of phase transitions and de Haas-van Alphen oscillations in pulsed and DC fields.
- MHz-frequency contactless conductivity techniques: using perturbation of a tunnel-diode oscillator driven tank circuit to measure changes in skin and penetration depths.
- Optical spectroscopy: Raman and Fourier transform spectroscopy from FIR to visible frequencies, including the use of synchrotron radiation sources.
- High-pressure techniques, including optical measurements in diamond anvil cells.
- Cryogenics: expertise with He^3, He^4 and dilution refrigerator systems.
- Magnetotransport: including measurements of both Hall and Shubnikov-de Haas effects.
- Clean room experience: semiconductor device fabrication and radiation worker including experience working with actinides.

Prizes, Honours and Patents

- Best poster award at the 2005 LANL, Materials Science division review.
- 1^{st} place "For Outstanding Post-Doc Oral Presentation in Materials Science" at the 2003 Los Alamos National Laboratory - University of New Mexico Scientific Careers Symposium.
- A CASE studentship award from Oxford Instruments for the duration of graduate research at Oxford University
- The Dean's commendation during the final year as an undergraduate at Exeter University
- 'Photonic Band Gap Resonator' **R.D. McDonald** and J.Singleton, US Patent application 104809-2004-0744 (2006)

Bibliographical Sketch

Pavel V. Zinin

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Education:

Combined B.S. and M.S. degree in Physics. M. V. Lomonosov, Moscow State University, Moscow, Russia	1980
Ph.D., Moscow Institute of Physics and Technology, Moscow, Russia	1987

Professional Experience:

Associate Researcher, Assistant Researcher, University of Hawaii, Honolulu, USA	1998-present
Research Fellow, University of Oxford, Oxford, UK.	1995 – 1997
Alexander von Humboldt Research Fellow, Bremen University, Bremen, Germany	1993-1994
Research Scientist, Assistant Researcher, Institute of Chemical Physics, Russian Academy of Sciences, Moscow, Russia	1987-1993
Post-graduate student, Moscow Institute of Physics and Technology, Moscow, Russia	1983 – 1987
Assistant Researcher, Research Engineer. Scientific. Research Institute for Biological Testing of Chemical Compounds, Moscow, Russia	1980 – 1983

Professional Societies:

Member, American Geological Union	2006-present
Member, American Physical Society	2002-present

Honors and Awards:

Alexander von Humboldt Foundation Fellowship	1993, 2006

Publications Relevant to this Proposal

1. N. Chigarev, P. Zinin, L.C. Ming, G Amulele, A. Bulou, V. Gusev. "Laser generation and detection of longitudinal and shear acoustic waves in a diamond anvil cell", *Appl. Phys. Lett.* **93**(18) 181905 (2008).
2. N. Chigarev, P. Zinin, D. Mounier, A. Bulou, L. C. Ming, T. Acosta and V. Gusev, “Analysis of ultrasonic echoes induced by pulsed laser action on iron film in a diamond anvil cell”, *High Pres. Res.* **30**(1), 78–82 (2010).
3. P. V. Zinin, N. Chigarev, D. Mounier, A. Bulou, L. C. Ming, T. Acosta, V. Gusev, “Evaluation of elastic properties of iron in diamond anvil cell by laser ultrasonics technique”, *J. Phys.*: *Conf. Ser.* **215**(1) 012053 (2010).
4. S. Berezina, P. V. Zinin, D. Schneider, D. Fei, and D. A. Rebinsky. “Combining Brillouin spectroscopy and laser-SAW technique for elastic property characterization of thick DLC films”. *Ultrasonics.* **43(**2) 87 – 93 (2004).
5. M. G. Beghi, A. G. Every, and P. V. Zinin. “Brillouin Scattering Measurement of SAW Velocities for Determining Near-Surface Elastic Properties”, in T. Kundu ed., *Ultrasonic Nondestructive Evaluation: Engineering and Biological Material Characterization*. CRC Press, Boca Raton, chapter 10, 581-651 (2004)
6. P. V. Zinin, and M. H. Manghnani. “Elasticity Characterization of Covalent (B-C-N) Hard Materials and Films by Brillouin scattering” in B. Raj, G. Amarendra and M. H. Manghnani eds. *Recent Advances in Materials Characterization*. CRC Press, London, 184-225. (2007).

Viktor V. Struzhkin

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University Education: Ph. D. Institute for High Pressure Physics, Russian Academy of Science, 1991, M. A., B. A., Moscow Institute for Physics and Technology, 1980

Professional Experience: 2003-present : Senior Staff member**,** Geophysical Laboratory (GL), Carnegie Institution of Washington (CIW); 2000-2003:Associate Staff, GL, CIW; 1996-2000: Senior Research Associate, GL, CIW; 1994-1996: Research Associate, GL, CIW;1991-1993: DAAD and Max Planck Gesellschaft Fellow, Max Planck Institute für Festkörperforshung, Stuttgart, Germany; 1980-2000: Staff Scientist, Institute for High Pressure Physics, Russian Academy of Science.

Honors and Fellowships: 2003- Mentor Recognition, Siemens Foundation Reward; 1993-1994 Member of the Scientific Board of the Institute for High Pressure Physics, Russian Academy of Sciences; 1991-DAAD Fellow, MPI, Stuttgart; 1993-Max-Planck Geselschaft Fellow, MPI, Stuttgart

***Selected Publications Relevant to Proposed Research (130 total)*:**

Struzhkin, V. V., A. F. Goncharov, R. Caracas, H. K. Mao, and R. J. Hemley, Synchrotron infrared spectroscopy of the pressure-induced insulator-metal transitions in glassy As_2S_3 and As_2Se_3, *Phys. Rev. B 77*, 165133, 2008.

Beck, P., A. F. Goncharov, V. V. Struzhkin, B. Militzer, H. K. Mao, and R. J. Hemley, Measurement of thermal diffusivity at high pressure using a transient heating technique, *Appl. Phys. Lett. 91*, 181914, 2007.

Goncharov A. F; Haugen B. D; Struzhkin V. V; Beck P; Jacobsen S. D., Radiative conductivity in the Earth's lower mantle, *Nature 456*:231-4, 2008.

Hemley, R. J., V. V. Struzhkin, and R. E. Cohen, Theory and practice – Measuring high-pressure electronic and magnetic properties, in *Treatise on Geophysics, Vol. 2: Mineral Physics,* A. M. Dziewonski and B. A. Romanowicz, eds., pp. 293-337, Elsevier, Amsterdam, 2007.

Lin, J. F., V. Struzhkin, S. D. Jacobsen, M. Y. Hu, P. Chow, J. Kung, H. Liu, H. K. Mao, and R. J. Hemley, Spin transition of iron in magnesiowüstite in Earth's lower mantle, *Nature*, **436**, 377-380 (2005).

Goncharov, A. F., V. V. Struzhkin, S. D. Jacobsen, Reduced Radiative Conductivity of Low-Spin (Mg,Fe)O in the Lower Mantle, Science **312**, 1205 (2006)

Struzhkin, V. V., R. J. Hemley and H.-K. Mao, "New condensed matter probes for diamond anvil cell technology", J. Phys.: Condens. Matter 16 (2004) S1071–S1086.

Struzhkin, V. V., M. I. Eremets, W. Gan, H. K. Mao, and R. J. Hemley, Superconductivity in dense lithium, *Science* **298**, 1213-1215, 2002.

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EDUCATION and POSITIONS HELD

B.A., Amherst College, 1975; Ph.D. (Geology, Geophysics), California Institute of Technology, 1979
Assistant Professor, Harvard University, 1979-81
Member, Materials Research Laboratory and Center for Earth & Planetary Physics, Harvard University, 1979-81
Assistant-Associate Professor, University of California, Berkeley, 1982-85
Professor of Earth and Planetary Science, University of California, Berkeley, 1985- ; Astronomy, 1998-
Executive Director, Miller Institute for Basic Research in Science, UC Berkeley, 1998-03

Selected AWARDS, HONORS and FELLOWSHIPS

Sloan Foundation Fellowship (physics), 1981-85; Presidential Young Investigator Award, National Science Foundation, 1984; Macelwane Award, American Geophysical Union, 1984; Sherman Fairchild Distinguished Scholar, California Institute of Technology, 1988; MSA Award, Mineralogical Society of America, 1988; J. D. and C. T. MacArthur Foundation Prize Fellowship, 1988; First Francis Birch Lecture, American Geophysical Union, 1988; Eyring Distinguished Lecturer in Chemistry, Arizona State University, 1989; Hudnall Lecturer, University of Chicago, 1990; Abelson Lecture, Carnegie Institution of Washington, 1994; University Guest Professor, Jilin University, and Academica Sinica, Inst. Geophysics, Beijing, 1994; Emilio Segré Distinguished Lectures in Physics, Tel Aviv University, 1995; Crafoord Symposium Lecture, Royal Swedish Academy of Sciences, 1998; National Associate, National Academies, 2001; Highly Cited Researcher, Institute for Scientific Information, 2002; J. Tuzo Wilson Lecture, University of Toronto, 2002; University Guest Professor, Harbin Institute of Technology, 2005; ZGC Forum, Chinese Academy of Sciences and Chinese Physical Society, 2005; William Smith Lecture, The Geological Society (London), 2005; American Institute of Physics 75th Anniversary Speaker, 2006; Hans Bethe Award, Federation of American Scientists, 2008; *PNAS* Cozzarelli Prize for best publication in Physical and Mathematical Sciences, National Academy of Sciences, 2009; Leo Szilard Award, American Physical Society, 2009; Capital Science Lecture, Carnegie Institution of Washington, 2010.

Fellow: American Academy of Arts and Sciences; American Association for the Advancement of Science; American Geophysical Union; American Physical Society. Member: National Academy of Sciences.

PROFESSIONAL EXPERIENCE (Partial Listing; current activities underlined)

Advisor, American Scientist, 1993-01; National Geographic, 1995- ; Physics Today, 1996-

American Association for the Advancement of Science Nuclear Weapons Complex Assessment Committee, 2006-07.

American Geophysical Union Tectonophysics Program Chair, 1983; *J. Geophysical Research* Associate Editor, 1983-86; Mineral & Rock Physics Committee, 1983-88, 1998-02 (Chair, 1998-00); *Rev. Geophysics* Committee, 1987 (Chair), 1990; Lehmann Medal Committee (Chair), 1996-97; Bowie Medal Committee, 2000-02.

American Physical Society, Shock Compression Fellows and Science Award Committees, 2002-04.

Department of Energy, Basic Energy Sciences Earth Science Advisory Council, 1997-04; Subcritical Experiment Evaluation Committee (Chair), 1998-99; Senior Advisor to the Under-Secretary, 1999-2000; National Nuclear Security Administration Advisory Committee (Defense Programs Lead), 2001-03; Executive Committee, High Energy Density Laboratory Physics Workshop, 2009-10; Senior Advisor to the Secretary, 2009.

International Association of Seismology and Physics of the Earth's Interior (IASPEI) Executive Committee, 1995-2000.

NASA Planetary Geology & Geophysics Management Operations Working Group, 1987-94 (Chair, 1989-91); Solid Earth and Natural Hazards Program Steering Committee, 2000-03.

National Academy of Sciences, National Research Council Physics and Chemistry of Earth Materials Committee, 1986-88; Steering Committee, Solid-Earth Sciences: A Critical Assessment, 1988-93; Board on Earth Sciences and Resources, 1997-02 (Chair, 1999-02); Basic Research Opportunities in Earth Sciences Committee, 1998-00; Committee on Technical Issues Related to Ratification of the Comprehensive Nuclear Test Ban Treaty, 2000-02; Committee on International Security and Arms Control, 2002- (Chair, 2005-); Committee on Effects of a Nuclear Earth-Penetrator Weapon, 2004; Search Committee for Science and Technology Adviser to the Secretary of State, 2006-07; Committee to Review and Update *Technical Issues Related to Ratification of the CTBT*, 2009-

National Science Foundation Earth Sciences Proposal Review Panel, 1987-91; Earth Sci. Presidential Young Investigator (PYI) Panel, 1988; Continental Dynamics Review Panel, 1988-91; Graduate Research Fellowship Panel, 1997-99; Geosciences Directorate Advisory Committee, 2005-07 (EAR Sub-committee Chair, 2005-07; IF Program Committee of Visitors Chair, 2007).

PUBLICATIONS in 2007-10

Jeanloz, R., Celliers, P. M., Collins, G. W., Eggert, J. H., Lee, K. K. M., McWilliams, R. S., Brygoo, S., and Loubeyre, P., 2007, Achieving high-density states through shock-wave loading of pre-compressed samples, *Proc. National Acad. Sci.*, 104, 10.1073/pnas.0608170104.

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Education:

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Experience:

Staff (1972-present), Geophysical Laboratory, CIW
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Current Synergetic Activities:

2009-present, Director of Energy Frontier Research in Extreme environments (EFree) Center, DOE
2007-present, Director of High Pressure Synergitic Center at APS (HPSynC), Argonne National Lab.
2005-present, Chair of Advisory Committee, Institute of Earth Sciences, Academia Sinica, Republic of China
2005-present, Einstein Professor of the Chinese Academy of Sciences, China
2003-present, Co-PI of the high-pressure instrument at Spallation Neutron Source (SNAP), Oak Ridge National Laboratory, TN
2003-present, Co-PI of Carnegie/DOE Alliance Center (CDAC)
2001-present, Visiting Professor, Department of Geophysical Sciences and James Franck Institute, University of Chicago
1998-present, Director of High Pressure Collaborative Access Team (HPCAT) at Advanced Photon Source, Argonne National Laboratory

Elected Memberships and Fellowships:

Member of National Academy of Science, U.S.A. 1993 -
Member of Academia Sinica, Republic of China, 1994 -
Foreign Member of Chinese Academy of Sciences, People's Republic of China, 1996 -
Foreign Member of the Royal Society of London, 2008 -
Fellow of American Physical Society
Fellow of American Geophysical Union
Fellow of Geochemical Society
Fellow of European Association for Geochemistry
Fellow of Mineralogical Society of America.

Major Awards:

Inge Lehmann Medal, 2007, American Geophysical Union
Balzan Prize, 2005, Balzan Foundation, Italy and Switzerland
Gregori Aminoff Prize in Crystallography, 2005, Royal Swedish Academy of Science
Roebling Medal, 2005, Mineralogical Society of America
Arthur L. Day Prize and Lectureship, 1990, National Academy of Science, USA
P. W. Bridgman Gold Medal Award, 1989, International Association for the Advancement of High Pressure Science and Technology (AIRAPT).
MSA Award, 1979, Mineralogical Society of America

Research Areas

High pressure science and technology with applications to physics, chemistry, Earth, planetary, and materials sciences.

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Education:

B.A.	Carleton College	1979	Chemistry
M.S.	Johns Hopkins University	1986	Chemistry
Ph.D.	Johns Hopkins University	1986	Chemistry

Research and Professional Employment:

2000-present	Adjunct Professor FSU
summer 2003	Visiting Professorship, ISSP, University of Tokyo
1994-present	Staff, National High Magnetic Field Laboratory, extreme conditions research
1989-1993	Staff, DuPont Experimental Station, Wilmington, DE, superconductors and films
1986-1989	Postdoctoral Fellow, IBM T.J. Watson, semiconductor and superconductors, IBM Outstanding Technical Achievement Award (1990)

Publications:

Selected publications related to the project:

1. D. Graf, R. Stillwell, T.P. Murphy, J-H. Park, M. Kano, E.C. Palm, P. Schlottmann, J. Bourg, K.N. Collar, J.C. Cooley, J.C. Lashley, J. Willit, & S.W. Tozer, Fermi surface of alpha-uranium at ambient pressure, PRB Rapid Commun., 80 241101 (2009).
2. Purcell, K.M.; Graf, D.; Kano, M.; Bourg, J.; Palm, E.C.; Murphy, T.; McDonald, R.; Mielke, C.H.; Altarawneh, M.M.; Petrovic, C.; Hu, R.; Ebihara, T.; Cooley, J.; Schlottmann, P. and Tozer, S.W., Pressure evolution of a field-induced Fermi surface reconstruction and of the Néel critical field in CeIn3, Phys. PRB, 79, 214428 (2009).
3. "Magnetic-Field-Induced Lattice Anomaly inside the Superconducting State of $CeCoIn_5$: Anisotropic Evidence of the Possible Fulde-Ferrell-Larkin-Ovchnnikov State", V.F. Correa, T.P. Murphy, C. Martin, K.M. Purcell, E.C. Palm, G.M. Schmiedeshoff, J.C. Cooley, and S.W. Tozer, Phys. Rev. Lett., 98, 87001 (2007).
4. "Evidence for the Fulde-Ferrell-Larkin-Ovchinnikov state in $CeCoIn_5$ from penetration depth measurements", C. Martin, C.C. Agosta, S.W. Tozer, H.A. Radovan, E.C. Palm, T.P. Murphy, and J.L. Sarrao, Phys. Rev B, 71, 020503(R) (2005).
5. "Magnetic enhancement of superconductivity from electron spin domains", H.A. Radovan, N.A. Fortune, T.P. Murphy, S.T. Hannahs, E.C. Palm, S.W. Tozer, and D. Hall, *Nature*, **425**, 51 (2003).
6. "Vortex dynamics in heavy fermion $CeCoIn_5$", H.A. Radovan, T.P. Murphy, E.C. Palm, S.W. Tozer, and D. Hall, and J.L. Sarrao, *Journal of Low Temperature Physics*, **133**, 377 (2003).
7. "Anomalous Superconductivity and field induced magnetism in $CeCoIn_5$", T.P. Murphy, Donavan Hall, E.C. Palm, S.W. Tozer, C. Petrovic, Z. Fisk, R. Goodrich, P.G. Pagliuso, J.L. Sarrao and J.D. Thompson, *Phys. Rev. B*, **65**, 100514 (2002).
8. "Miniature diamond-anvil cell for electrical transport measurements in high magnetic fields", S.W. Tozer, *Rev. Sci. Instr*., **64**, 2607 (1993).
9. "Measurement of Anisotropic Resistivity and Hall Constant for Single-Crystal $YBa_2Cu_3O_{7-x}$", S.W. Tozer, A.W. Kleinsasser, T. Penney, D. Kaiser, F. Holtzberg, *Phys. Rev. Lett*., **59**, 1768-1771 (1987).

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June 20, 2010

Dear Alex,

As President of COMPRES, I am writing to strongly endorse your proposal for a beamline for time-resolved studies at extreme conditions at the NSLS II synchrotron. This would represent a new set of experimental opportunities and scientific questions that can be probed at high pressures and temperatures. Your beamline would be a unique asset for the high-pressure community.

I wish you best of luck in your efforts to develop time-resolved X-ray studies at NSLS II. I further thank you and your writing team for all the work you have done on behalf of the high-pressure community.

Sincerely

Jay D Bass
President, Consortium of Materials Properties Research in Earth Sciences (COMPRES)
Ralph E Grim Professor of Geophysics
Professor of Materials Sciences and Engineering
University of Illinois, Urbana-Champaign

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