From Atom to Universe

High Pressure Physics Research

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Materials Deformation

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Expertise

- High Pressure Rock Deformation

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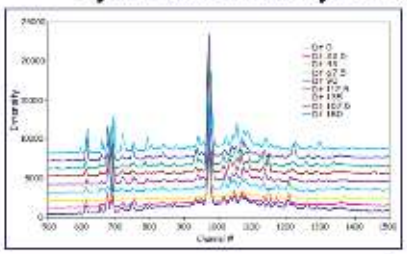
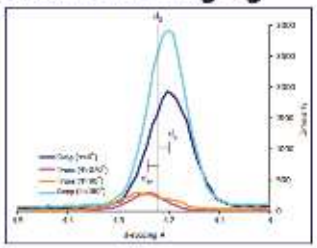
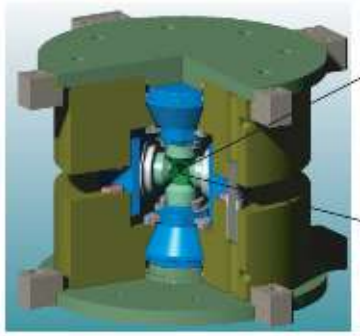
High Pressure studies of Deformation and the Acoustoelastic effect

Synchrotron X-ray diffraction and imaging

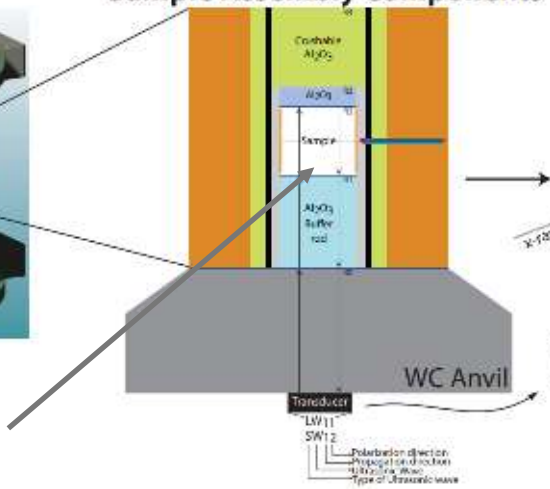


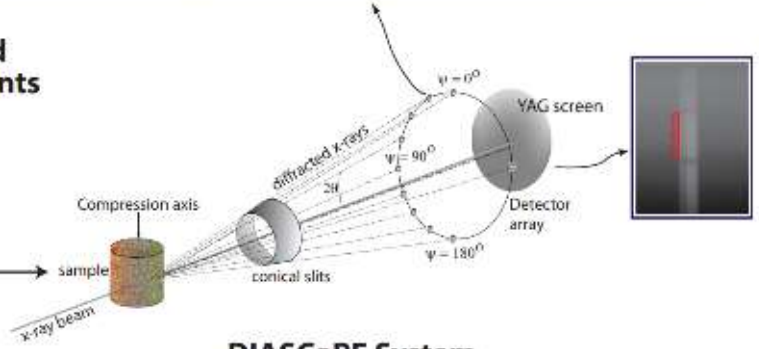


D-DIA module

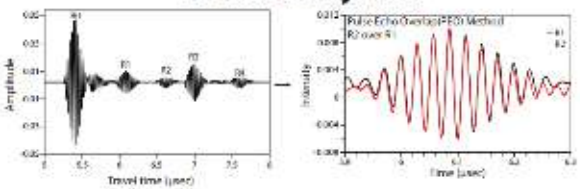


Ultrasonic D-DIA Modified Sample Assembly Components



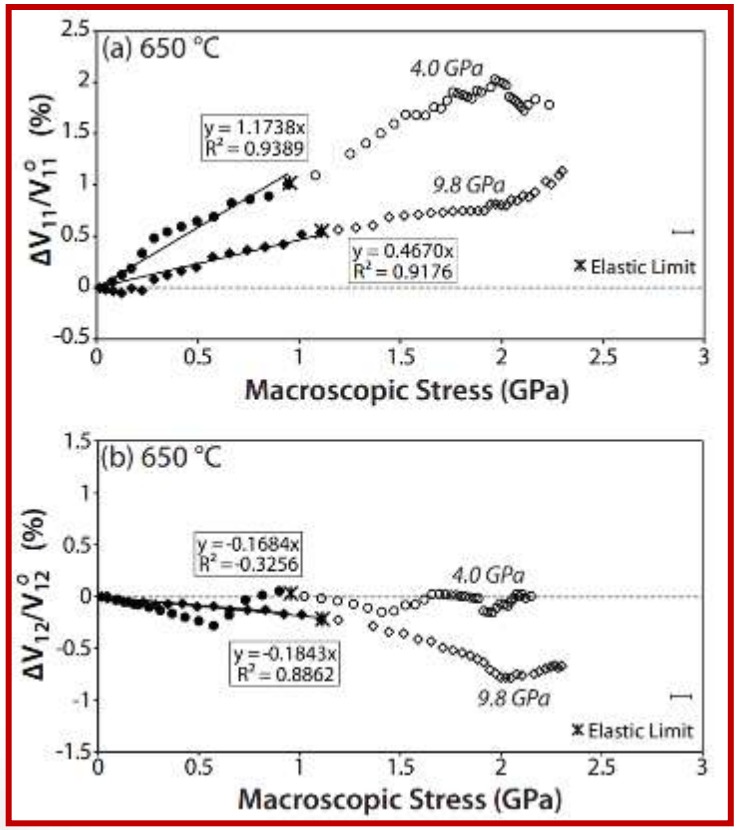


DIASCoPE System



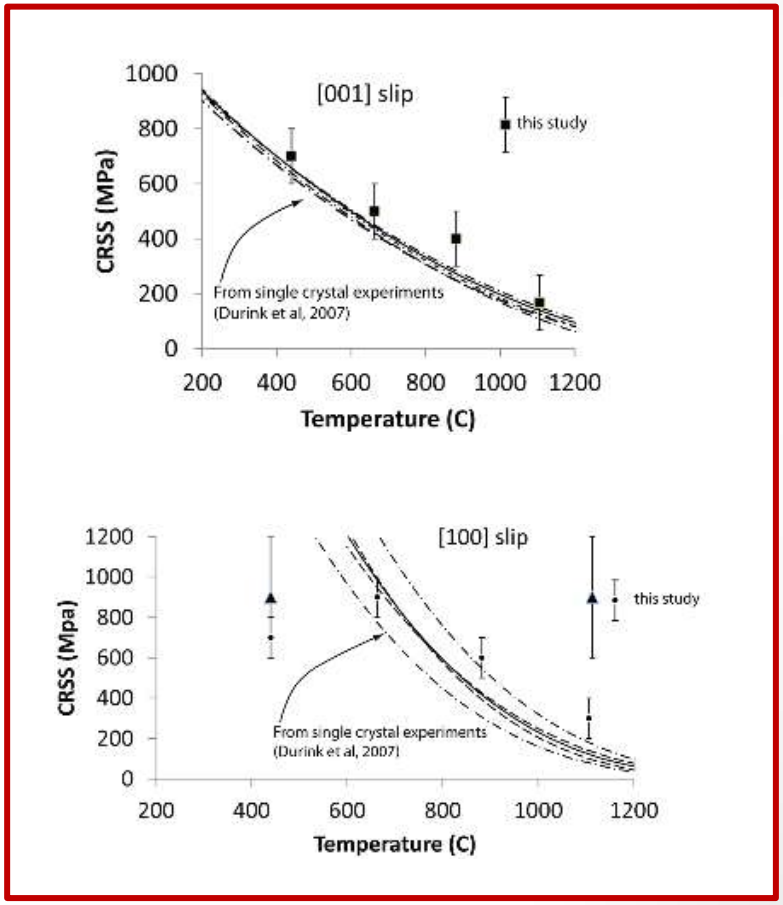
High Pressure studies of Deformation and the Acoustoelastic effect

Compression- and shear-wave velocities are a function of compressive stress



(Traylor, Whitaker & Burnley, in prep)

Details of multiple slip systems derived from a single multi step experiment



(Burnley & Kaboli, 2019)

Theoretical and Computational

Condensed Matter and Materials Physics

Dr. Changfeng Chen
Department of Physics and Astronomy
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Expertise

- Novel states of matter: topological insulators and semimetals
- Superior bonding structures: superhard and supertough materials
- Intriguing quantum phenomena: superconductivity and magnetism
- Extreme mechanics: stress responses to complex large strains
- Ultimate thermodynamics: materials inside Earth and other planets

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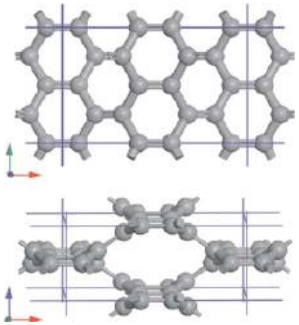
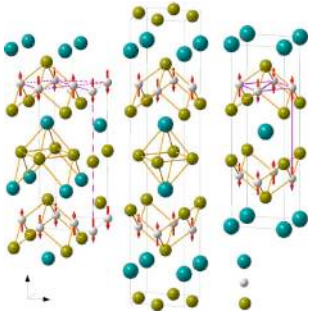
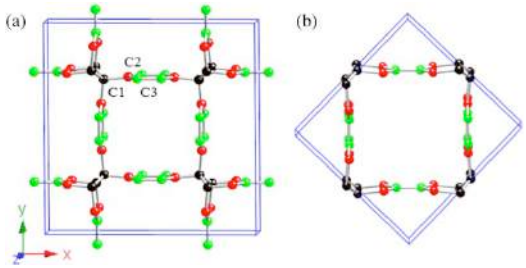


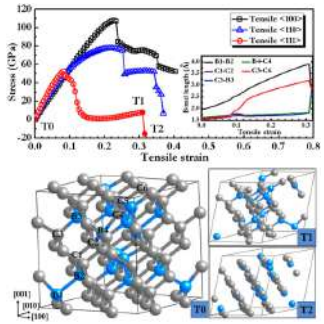
Nodal-ring Dirac semimetal states identified in bco-C_{16} crystal [Wang, Weng, Nie, Fang, Kawazoe, Chen, ***Phys. Rev. Lett.*** 116, 195501 (2016)].



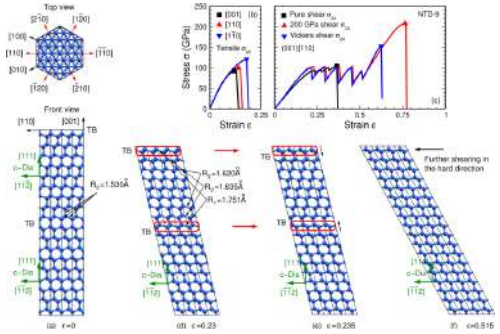
Magnetic Dirac materials $CaMnBi_2$ and $SrMnBi_2$ [Zhang, et al., ***Nature Commun.*** 7, 13833 (2016)].



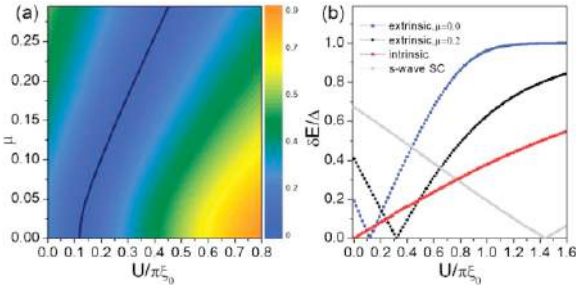
Nodal-net Dirac semimetal states in a graphene network structure [Wang, Nie, Weng, Kawazoe, Chen, ***Phys. Rev. Lett.*** 120, 026402 (2018)].



Superhard B_3C in diamond structure [Zhang, et al., ***Phys. Rev. Lett.*** 114, 015502 (2015)].



Extreme mechanics of nanotwinned diamond [Li, Sun, Chen, ***Phys. Rev. Lett.*** 117, 116103 (2016)].



Kondo physics in 2D topological superconductors [Wang, et al., ***Phys. Rev. Lett.*** 122, 087001 (2019)].

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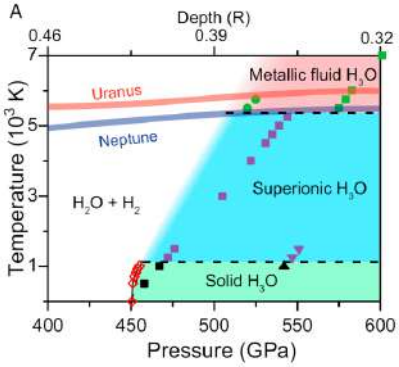
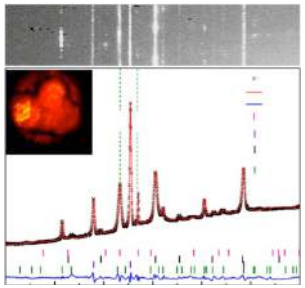
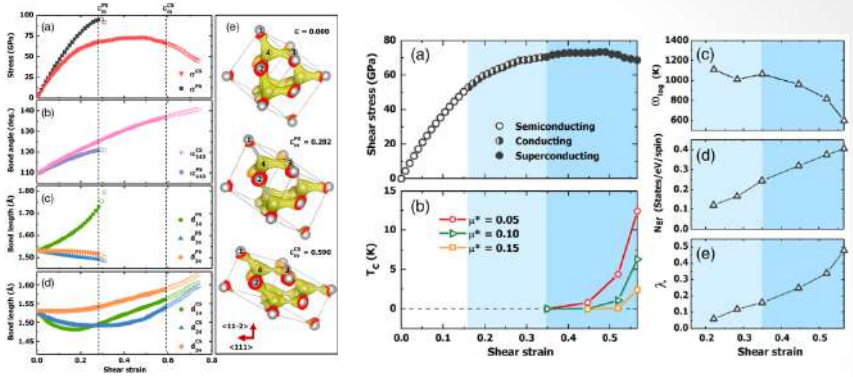
Helium-bearing compound FeO_2He predicted to stabilize at deep-Earth conditions [Zhang, et al., ***Phys. Rev. Lett.*** 121, 255703 (2018)].



Prediction of novel H_3O and implications for the magnetic fields of Uranus and Neptune [Huang, et al., ***Proc. Natl. Acad. Sci.*** 117, 5638 (2020)].



Pressure-stabilized divalent ozonide CaO_3 and its impact on Earth's oxygen cycles [Wang, et al., ***Nature Commun.*** 11, 4702 (2020)].



Metallization and superconductivity in diamond [Liu, et al., ***Phys. Rev. Lett.*** 123, 195504 (2019); ***Phys. Rev. Lett.*** 124, 147001 (2020)].

Further Reading (selected papers by Chen Group, 2015-2020)

Anomalous Stress Response of Ultrahard WB_n Compounds, Li, Zhou, Zheng, Ma, Chen, ***Phys. Rev. Lett.*** 115, 185502 (2015).

Ultralow-Frequency Collective Compression Mode and Strong Interlayer Coupling in Multilayer Black Phosphorus, Dong, et al., ***Phys. Rev. Lett.*** 116, 087401 (2016).

Extraordinary Indentation Strain Stiffening Produces Superhard Tungsten Nitrides, Lu, Li, Ma, Chen, ***Phys. Rev. Lett.*** 119, 115503 (2017).

Xenon iron oxides predicted as potential Xe hosts in Earth's lower mantle, Peng, Song, Liu, Li, Miao, Chen, Ma, ***Nature Commun.*** 11, 5227 (2020).

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Electronic and Magnetic Properties at High Pressure

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Expertise:

- Experimental high pressure measurements
- Magnetism
- Superconductivity

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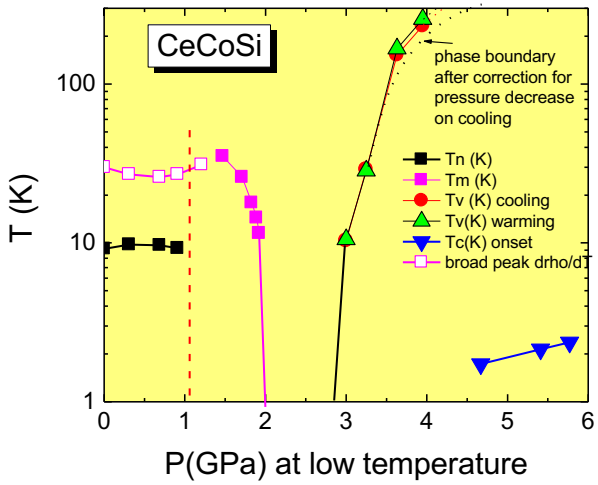
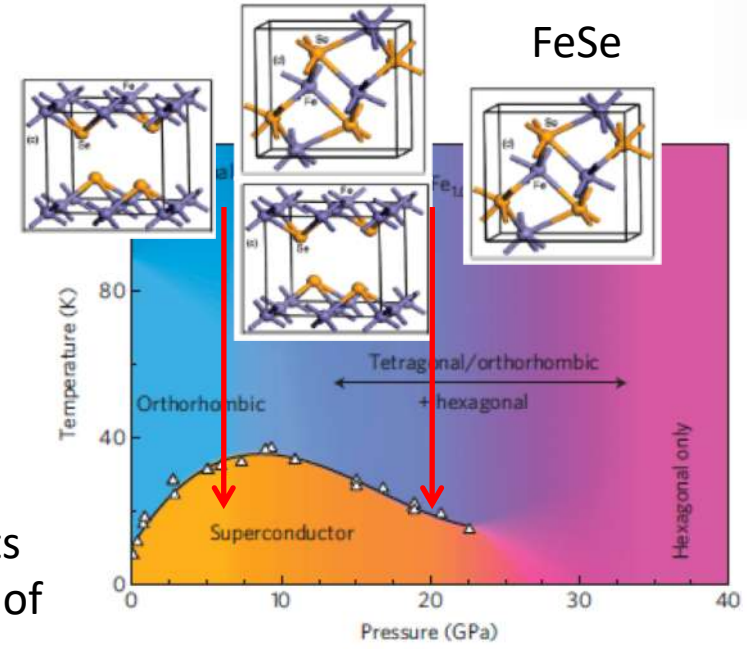
Superconductivity

Quantum Design PPMS at UNLV

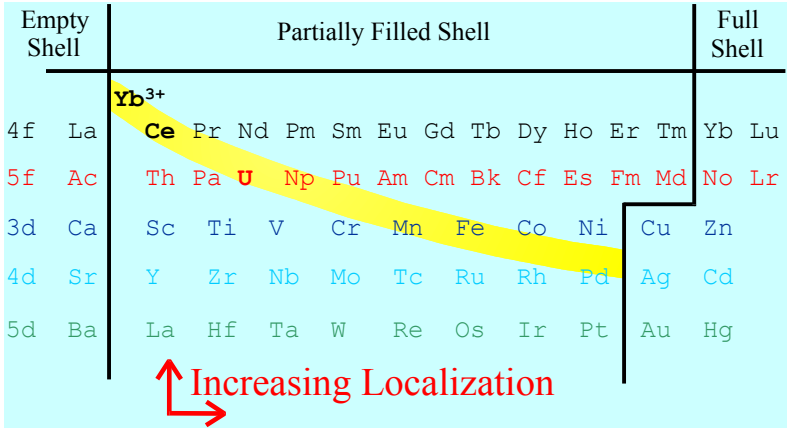
- Measurements from 0.3 K to 400 K
  - Heat capacity, electric and thermal transport, and AC/DC magnetization
- Pressure cells to measure electrical properties (clamp to 3 GPa and diamond anvil cell to >100 GPa)





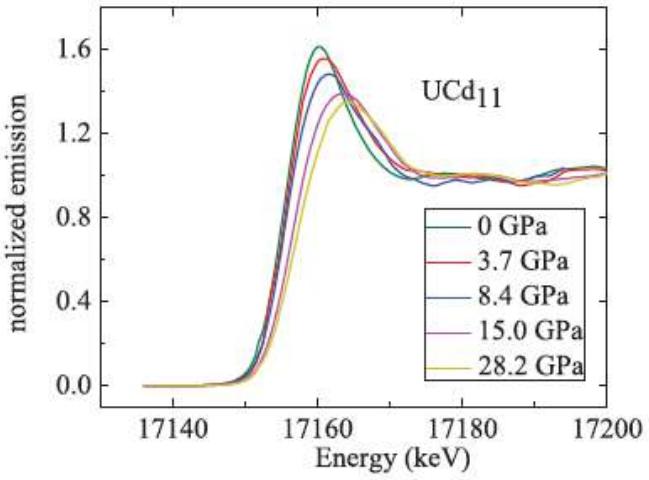
Addition of high pressure synchrotron experiments (diffraction and X-ray absorption) allows mapping of complex superconducting phase diagrams

Correlated-Electron Systems

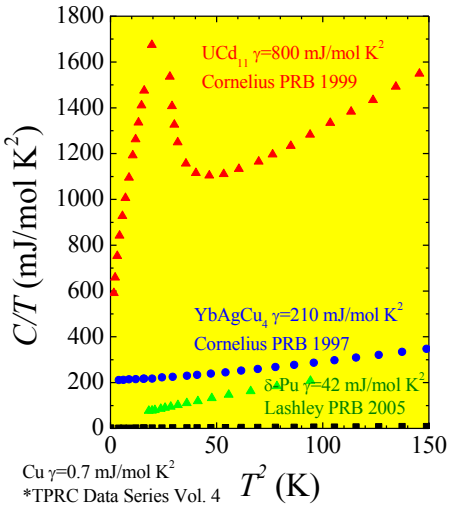


Modified periodic table

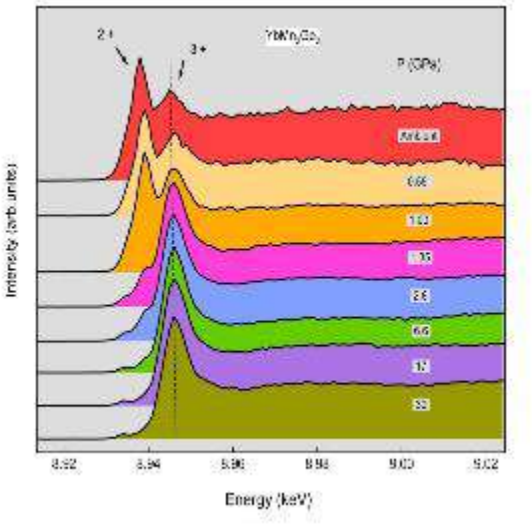
- Going from localized to delocalized electrons one often finds strong electron-electron correlations
- Correlated electron systems can yield interesting behavior: fluctuating valence, superconductivity, non-Fermi liquid, heavy fermion and many more



f-electron delocalization
X-ray absorption



Heavy fermions
Heat Capacity

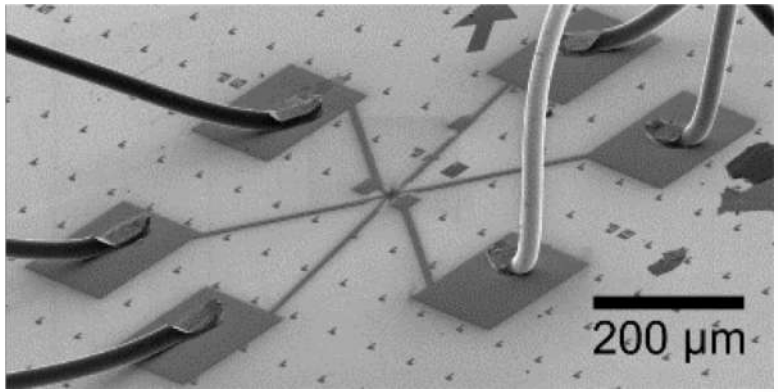


Fluctuating valence
X-ray fluorescence

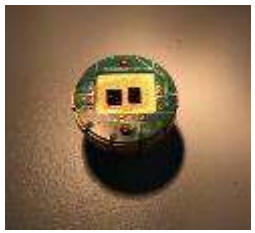
Island – Quantum computing, quantum sensing

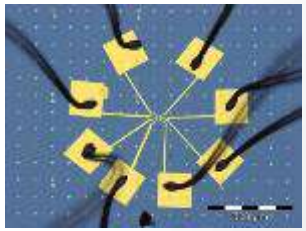
Areas of Research

- Nanotechnology, device physics
- Photodetection and quantum sensing
- Quantum computing, topological qubits
- Non-equilibrium, driven systems
- Superconductivity, proximity effects
- Low dimensional materials







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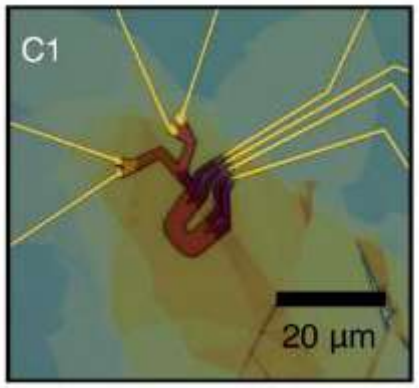
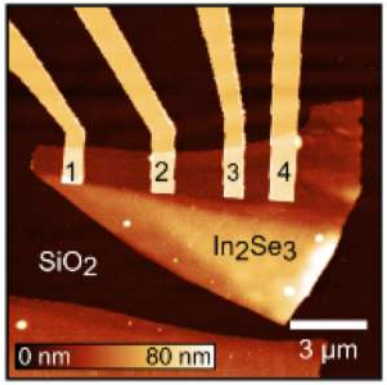
Island – Quantum computing, quantum sensing

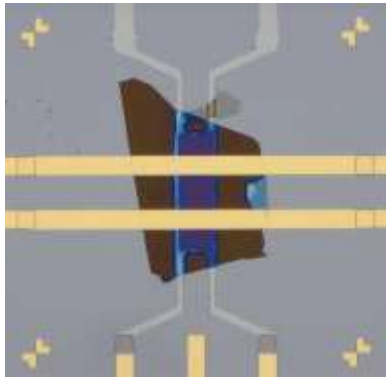
Quantum computing: Topological phases for fault-tolerant, universal quantum computing.

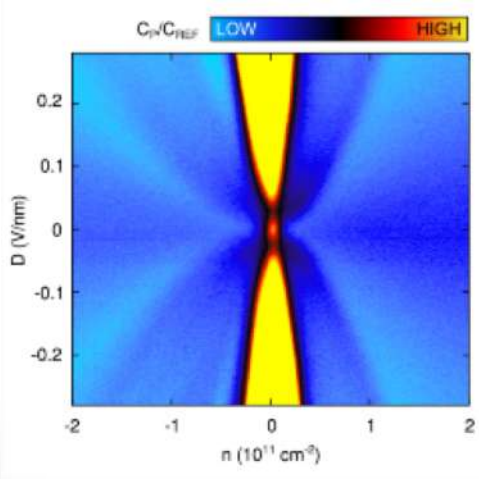
Industry-disruptive photodetectors: Ultra-sensitive phototransistors designed with 2D materials and heterostructures.

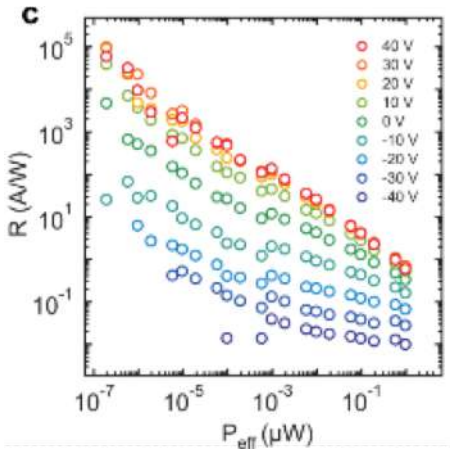
Transient phases of driven systems: Non-equilibrium response of pumped nanomaterials below the diffraction limit.

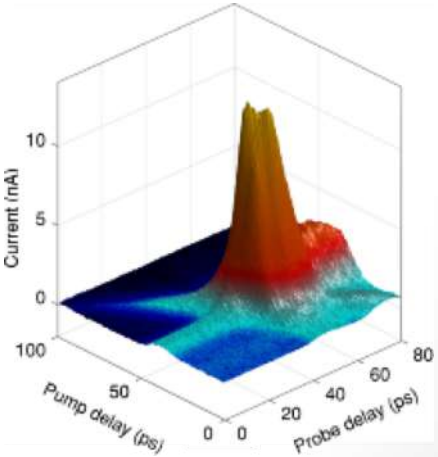












Island, J. O., et al. *Nature* **571** (2019): 85–89.

Island, J. O., et al. *Nano Letters* **15** (2015): 7853-7858.

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Island – Quantum computing, quantum sensing

Journal publications

Spin-orbit-driven band inversion in bilayer graphene by van der Waals proximity effect
J. O. Island, X. Cui, C. Lewandowski, J. Y. Khoo, E. M. Spanton, H. Zhou, D. Rhodes, J. C. Hone, T. Taniguchi, K. Watanabe, L. S. Levitov, M. P. Zaletel, A. F. Young, *Nature* **571**, 85-89 (2019). (arXiv)

Enhanced superconductivity in atomically thin TaS2
E. Navarro-Moratalla*, J. O. Island*, S. Manas-Valero, E. Pinilla-Cienfuegos, A. Castellanos- Gomez, J. Quereda, G. Rubio-Bollinger, L. Chirolli, J. A. Silva-Guillη, N. Agrat, G.A. Steele, F. Guinea, H.S.J. van der Zant, E. Coronado, *Nature Communications* **15**, 7853 (2016). (arXiv)

Proximity-induced Shiba states in a molecular junction
J. O. Island, R. Gaudenzi, J. de Bruijckere, E. Burzuri, C. Franco, M. Mas-Torrent, C. Rovira, J. Veciana, T. M. Klapwijk, R. Aguado, H. S .J. van der Zant, *Physical Review Letters* **118**, 117001 (2017). (arXiv)

TiS3 transistors with tailored morphology and electrical properties
J. O. Island, M. Barawi, R. Biele, A. Almazan, J.M. Clamagirand, J.R. Ares, C. Sanchez, H.S.J. van der Zant, J.V. Alvarez, R. D'Agosta, I. J. Ferrer, A. Castellanos-Gomez, *Advanced Materials* **27**, 2595 (2015). (arXiv)

Environmental instability of few-layer black phosphorus
J. O. Island, G.A. Steele, H.S.J. van der Zant, and A. Castellanos-Gomez, *2D Materials* **2**, 011002 (2015). (arXiv)

Ultrahigh photoresponse of few-layer TiS3 nanoribbon transistors
J. O. Island, M. Buscema, M. Barawi, J.M. Clamagirand, J.R. Ares, C. Sanchez, I.J. Ferrer, G.A. Steele, H.S.J van der Zant, and A. Castellanos-Gomez, *Advanced Optical Materials* **2**, 641 (2014). (arXiv)

Gate controlled photocurrent generation mechanisms in high-gain In2Se3 phototransistors
J. O. Island*, S.I. Blanter*, M. Buscema, H.S.J. van der Zant, and A. Castellanos-Gomez, *Nano Letters* **15**, 7853 (2015). (arXiv)

Precise and reversible band gap tuning in single-layer MoSe2 by uniaxial strain
J. O. Island, A. Kuc, E.H. Diependaal, H.S.J. van der Zant, T. Heine, and A. Castellanos- Gomez, *Nanoscale* **8**, 2589 (2016). (arXiv)

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Research in Condensed Matter Theory

Tao Pang

Department of Physics and Astronomy

University of Nevada, Las Vegas

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Research Methods and Materials Systems

- Analytical Approach

  Quantum Hall effect; quantum transport phenomena, superconductor-insulator transitions; vibrational modes in glasses; and slow light in cold atoms.

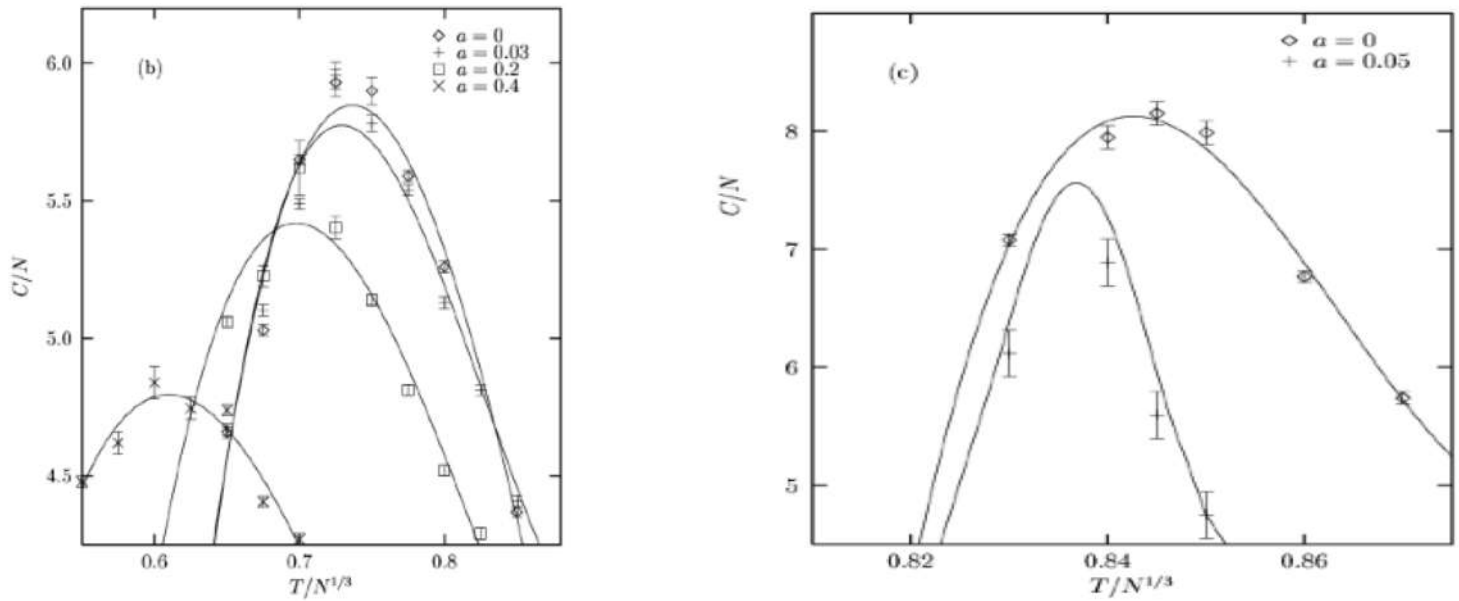
- Diffusion Quantum Monte Carlo Simulation

  Negative donor centers in semiconductors; hydrogen molecules in confinement; ionic hydrogen clusters; and helium clusters with modified interactions.

- Path Integral Quantum Monte Carlo Simulation

  Bosons trapped in potential wells in one dimension or two dimensions; Bose-Einstein condensation of cold atoms; and asymmetric distributions of Bose-Einstein condensates of boson mixtures.

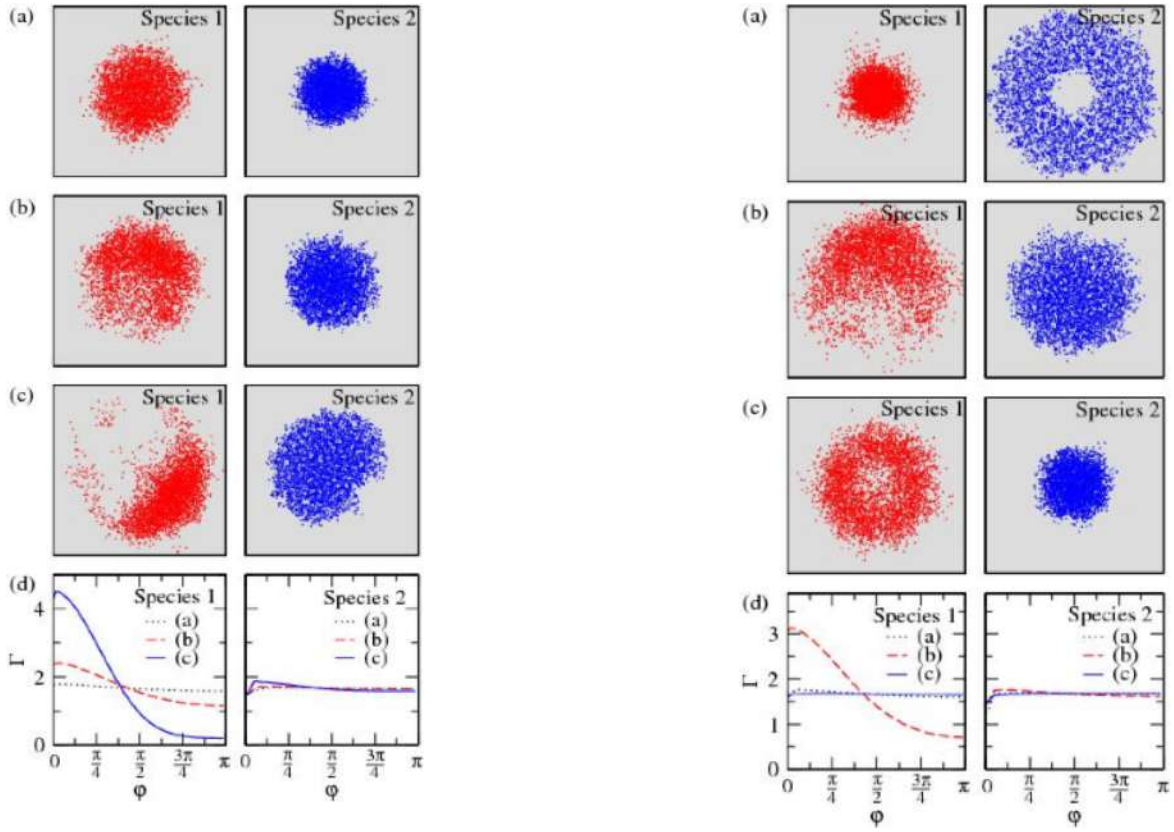
An example: Specific Heat of Bose-Einstein Condensates



The BEC transition temperature changes with the cluster size (100 atoms on the left and 1000 atoms on the right) and the hard-sphere diameter.

S. Pearson, T. Pang, and C. Chen, Phys. Rev. A **58**, 4796 (1998).

Another Example: Asymmetry of the Mixed Condensates:



Asymmetric distributions of two Bose-Einstein condensates in the same trap with different cluster parameters.

H. Ma and T. Pang, Phys. Rev. A **70**, 063606 (2004).

Novel Chemistry Using Highly Ionizing Radiation

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Email: michael.Pravica@unlv.edu

Expertise:

- *Useful Hard X-ray photochemistry*
- High pressure
- Spectroscopy
- *Ion Beam Nuclear Transmutation Doping*

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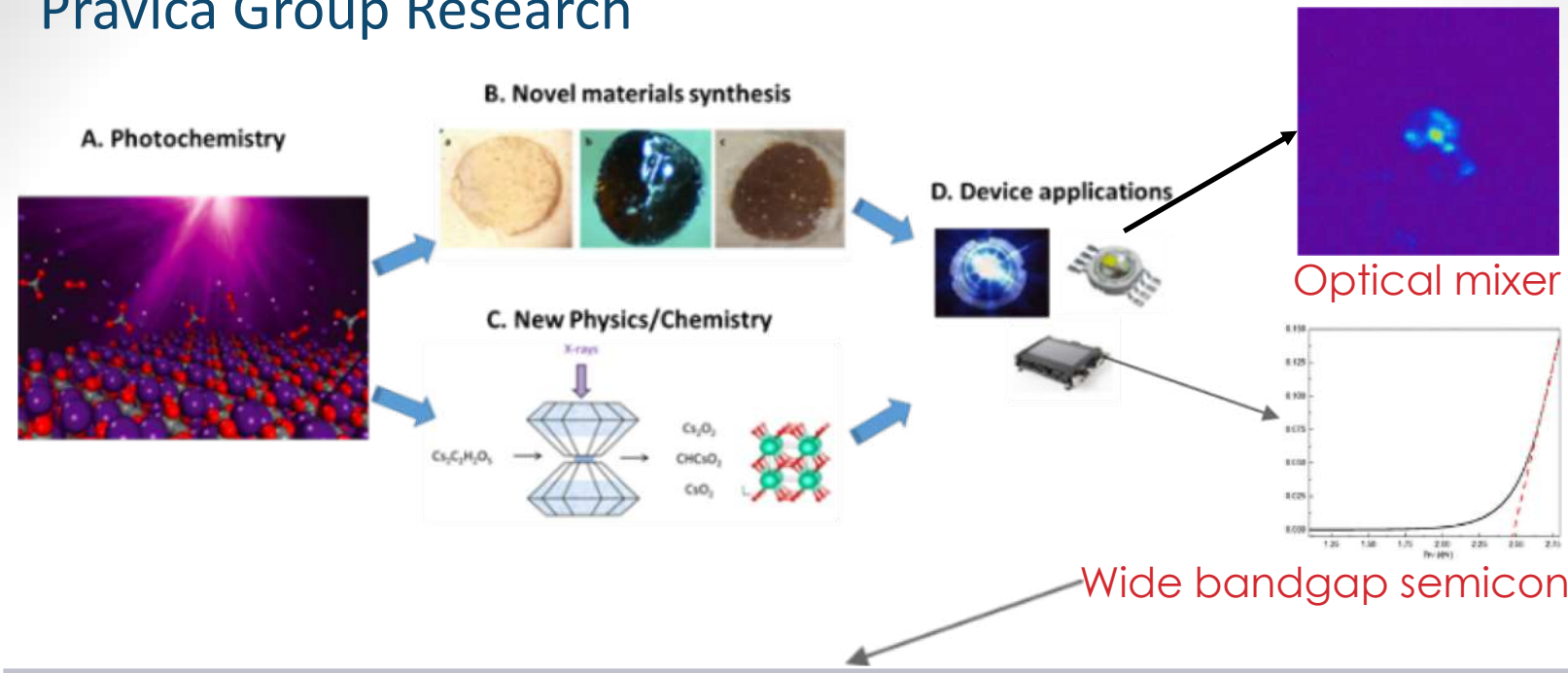
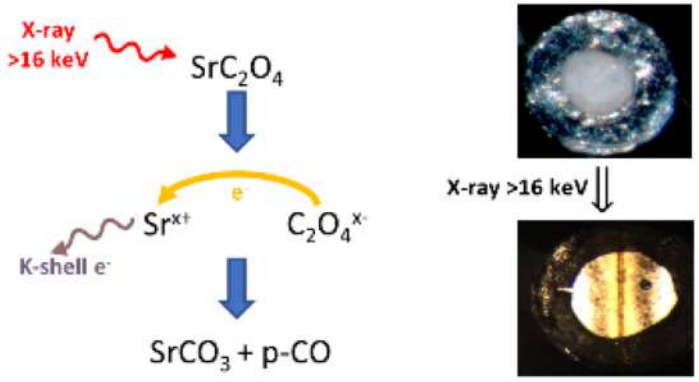
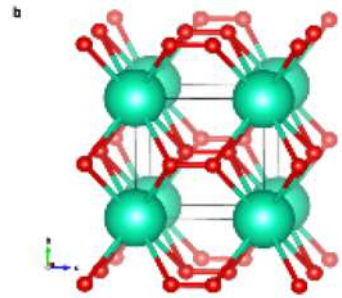
Pravica Group Research



Radiation-hardened sensors/direct energy conversion devices for EXTREME CONDITIONS
or tuned solar materials

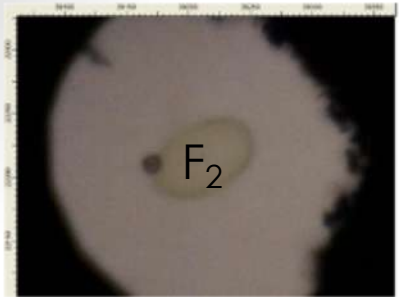
Useful hard x-ray photochemistry

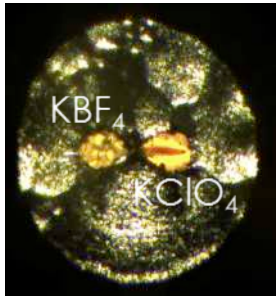




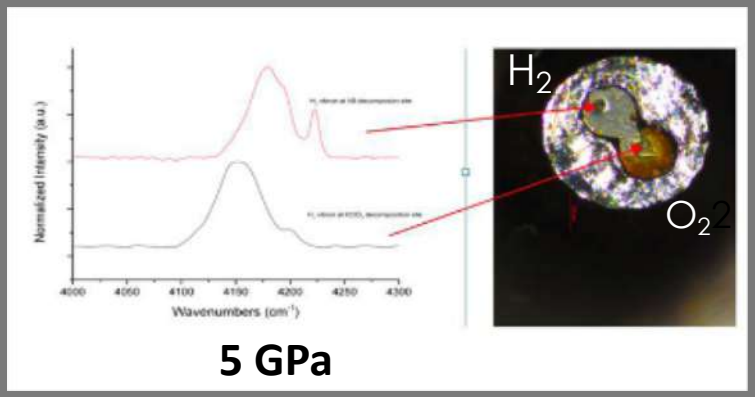
Novel structures of known materials produced With hard x-rays and high pressure (e.g. CsO_2)

High Pressure Fluorine Chemistry





$$2F_2 + O_2 \xrightarrow{h\nu} 2OF_2 \ @\ 3\ GPa$$



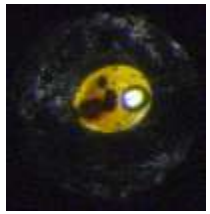
5 GPa

Molecular mixtures at high pressure

Inner shell chemistry at high pressure

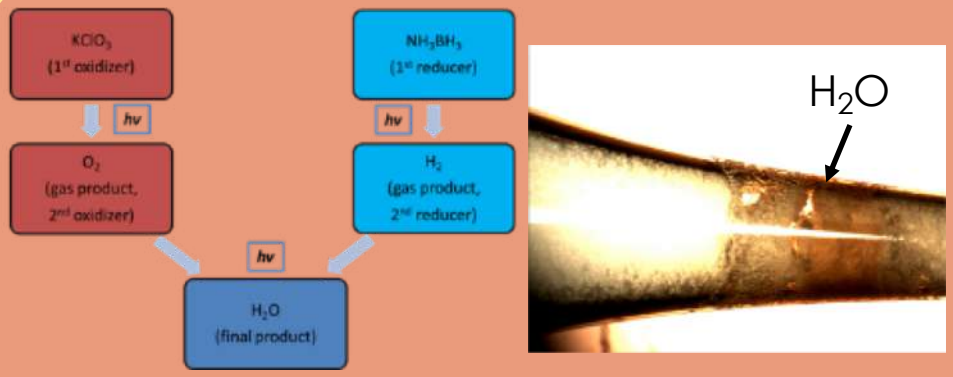
$XeF_2 \xrightarrow{h\nu} Xe + F_2$ (*in situ* x-ray fluorination)

$HgF_2 + F_2 \xrightarrow{h\nu} HgF_4$



UV-irradiation produced N_2 bubble

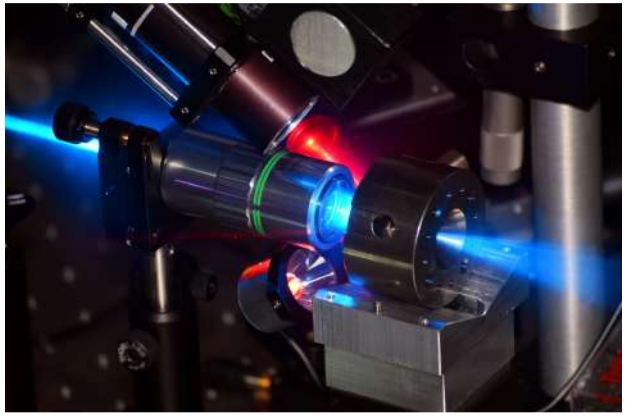
UV irradiation facility



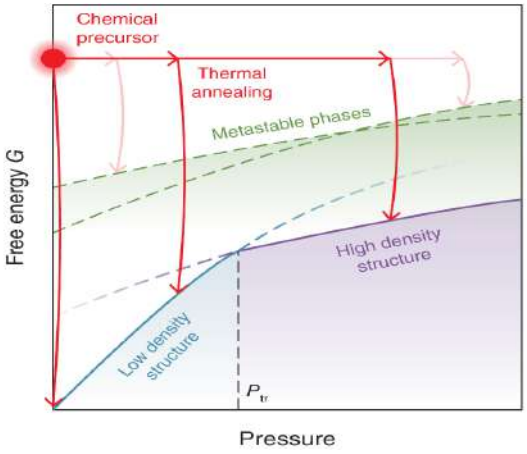
X-ray induced combustion

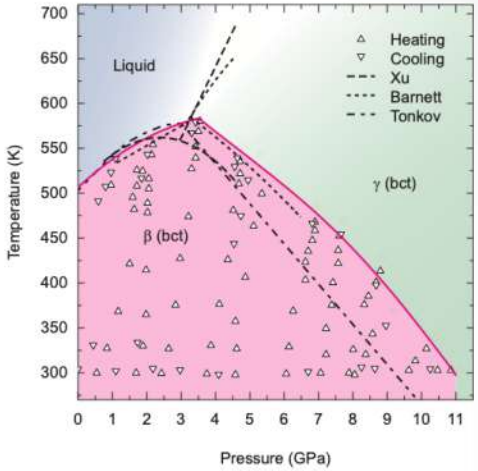
Large Volume Press
For pressure-induced chemistry

Salamat Group – Collaboration with MSTS

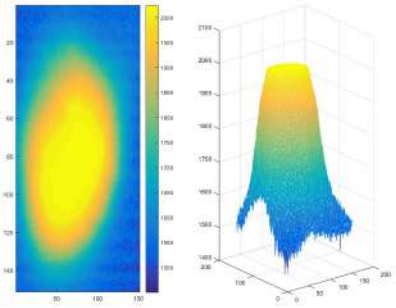


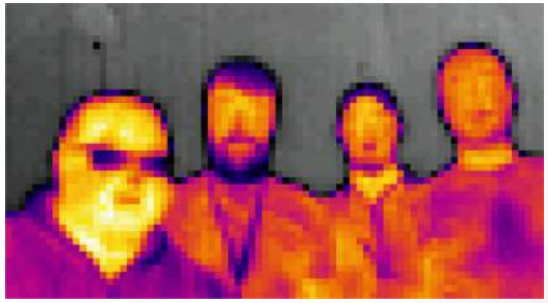
Metrology – accurate mapping of P, V, T





High temperature modelling – understanding emissivity under extreme conditions





Los Alamos NATIONAL LABORATORY

MSTS MISSION SUPPORT AND TEST SERVICES LLC

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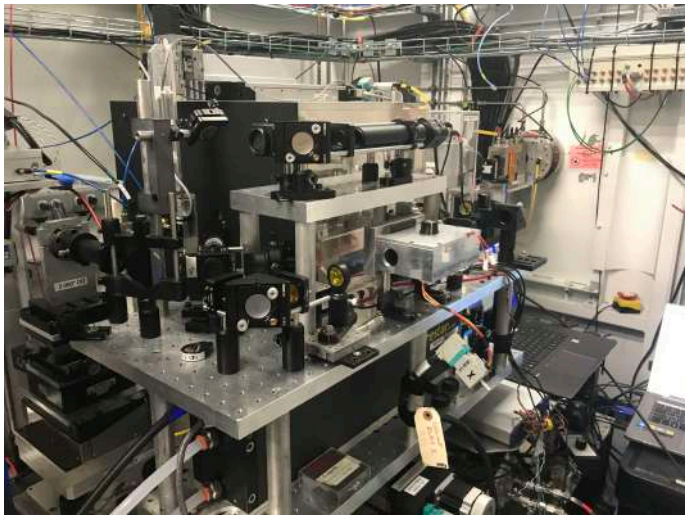
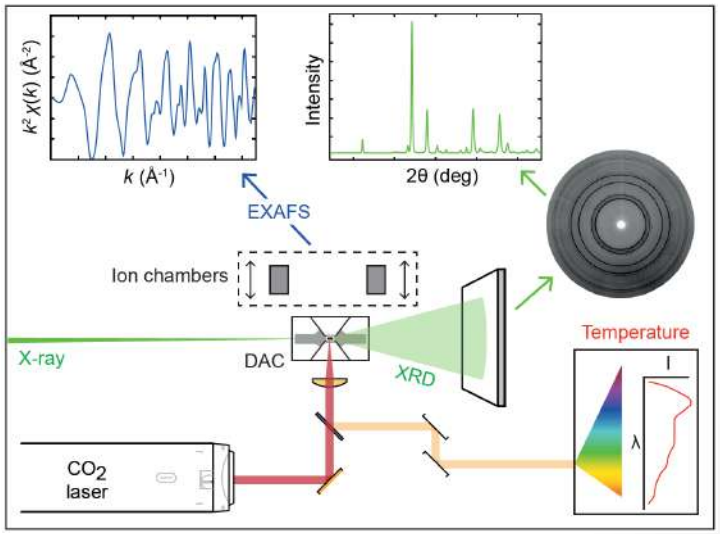
Warm dense matter – probed using EXAFS

- Development of a CO_2 laser heating
- Direct heating of non-metallic systems in a DAC
- First HTHP EXAFS measurements of insulators

- In situ and post heating measurements
- Determining absolute temperature from X-ray spectroscopy





Publications

(1) D. Smith, D. Sneed, N. Dasenbrock-Gammon, E. Snider, G. A. Smith, C. Childs, J. S. Pigott, N. Velisavljevic, C. Park, K. V. Lawler, R. P Dias, A. Salamat*, Anomalous Conductivity in the Rutile Structure Driven by Local Disorder The Journal of Physical Chemistry Letters 10 18 5351-5356 (2019)

(2) J. Kearney M. Grauzinyte D. Smith A. Gulans D. Sneed C. Childs, J. Hinton C. Park J. S. Smith, E. Kim, S. D. S. Fitch, A. L. Hector, C. J. Pickard J. A. Flores-Livas, A. Salamat*, Pressure tuneable visible range band gap in the ionic spinel tin nitride Angewandte Chemie International Edition, 57, 11623-11628 (2018)

(3) C. Childs, K. V. Lawler, A. L. Hector, S. Petitgirard, O. Noked, J. S. Smith, D. Daisenberger, L. Bezacier, M. Jura, C. J Pickard, A. Salamat*, Covalency is Frustrating: $La_2Sn_2O_7$ and the Nature of Bonding in Pyrochlores under High Pressure Temperature Conditions Inorganic chemistry, 57, 15051-15061, (2018)

(4) D. Smith, K. V. Lawler, M. Martinez-Canales, A. W. Daykin, Z. Fussell, G. A. Smith, C. Childs, J. S. Smith, C. J. Pickard, and A. Salamat*, Postaragonite phases of $CaCO_3$ at lower mantle pressures Physical Review M 2, 013605 (2018)

(5) D. Smith, J. S. Smith, C. Childs, E. Rod, R. Hrubiak, G. Shen, A. Salamat*, A CO_2 laser heating system for in situ high pressure-temperature experiments at HPCAT Review of Scientific Instruments 89, 083901 (2018)

(6) R. Briggs, D. Daisenberger, O. T. Lord, A. Salamat, E. Bailey, M. J. Walter, P. F. McMillan*, High-pressure melting behavior of tin up to 105 GPa Physical Review B 95, 054102 (2017)

(7) M. Zaghoo, A. Salamat, I. F. Silvera*, A first order phase transition to metallic hydrogen. Physical Review B 93, 155128 (2016)

(8) A. Salamat*, R. Fischer, R. Briggs, M. I. McMahon, S. Petitgirard, In situ synchrotron X-ray diffraction in the laser heated diamond anvil cell: melting phenomena and synthesis of new materials. Coordination Chemistry Reviews 277-278, 15 (2014)

Google Scholar: Ashkan Salamat

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Explore New Physics Beyond the Standard Model

Dr. Yan Zhou
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Expertise

- Precision measurements
- Quantum information processing
- Cold and ultracold molecules
- High-resolution spectroscopy

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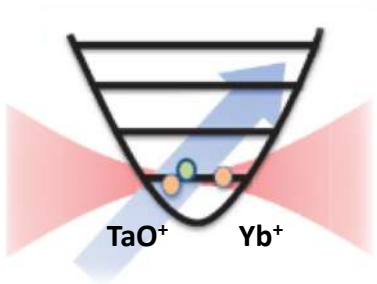
Exploring new phyiscs beyond the Standard Model using ultracold molecular ions and highly-charged ions

Trap

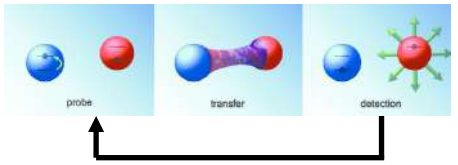
Nature, 417, 709 (2002)

Sympathetic cooling

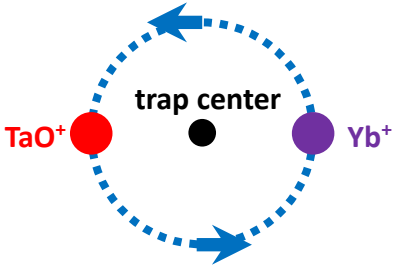


State readout & control

Quantum Logic scheme



Bias E-field

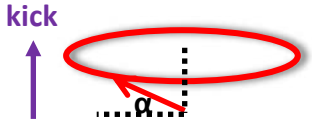


~10 V/cm at 5 MHz

Bias B-field

$$H_{Zeeman} = m_F \mu_B B_{rot}$$

$$H_{Berry} = m_F \omega_{rot} \langle \alpha \rangle$$



Universal platform

- $^{232}ThF^+$ for eEDM
- $^{229}ThF^+$ for NMQM
- $^{181}TaO^+$ for NMQM
- $^{179}HfO^+$ for NSD-PV
- All can be for Axion

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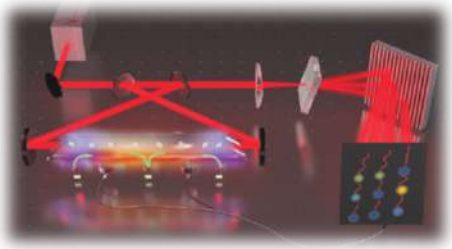
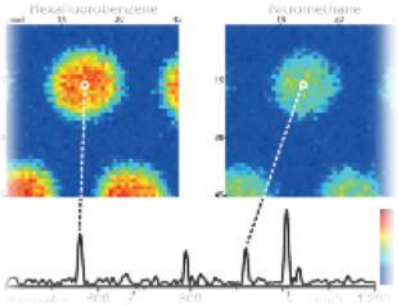
New technology and new applications based on optical frequency comb

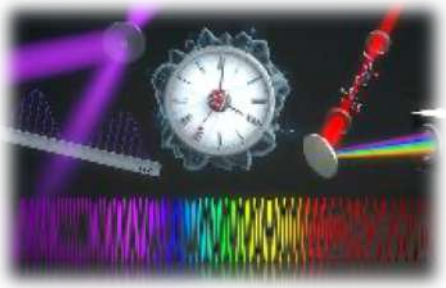
high resolution spectroscopy



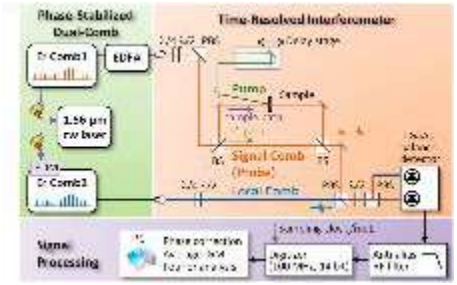
nonlinear spectroscopy

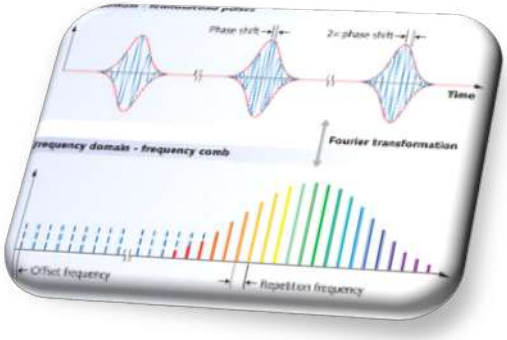


Atomic clock

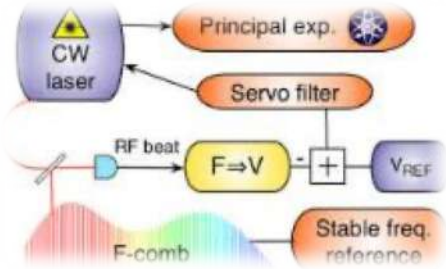


ultrafast spectroscopy

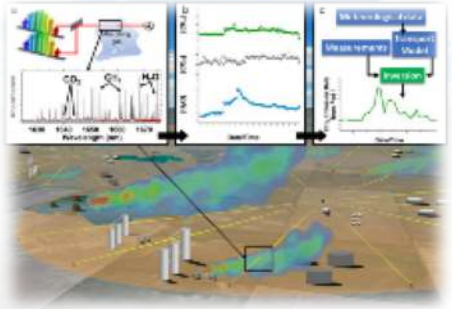




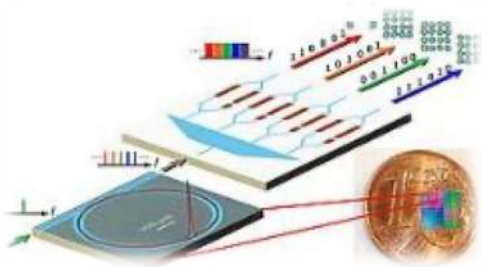
Laser stabilization



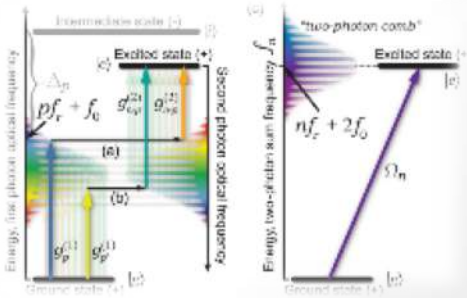
Tracing detection



Communication

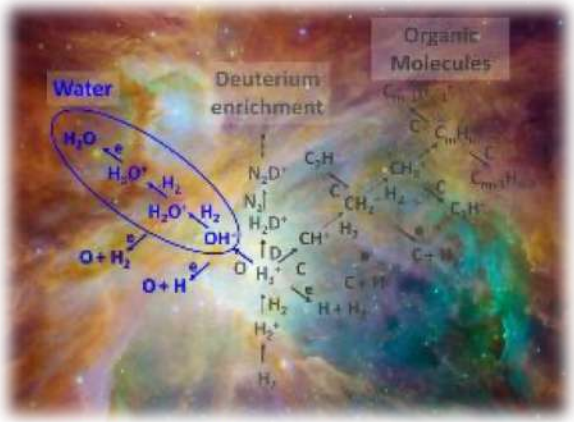


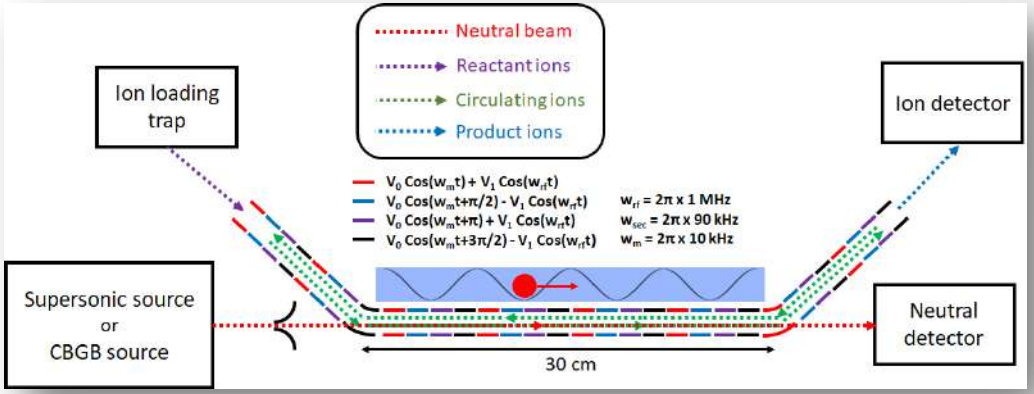
Laser cooling



Figures are from multiple references

Revealing mechanisms of universe evolutions by studying cold ion-radical reactions





- Chain reactions
- Radiative association
- Tunneling resonances
- Collisional resonances
- Discrepancies of reaction dynamics between chemical physics labs and astronomical observatories

Parameters	Expected specifications
Interaction arm length	30 cm
Ion beam velocity	0-1000 m/s
Collision energy range	<0.1 meV to >100 meV
Energy resolution	<0.1 meV
Effective reaction duration	1 s
Detection sensitivity	1×10^{-16} $cm^{-3}s^{-1}$

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