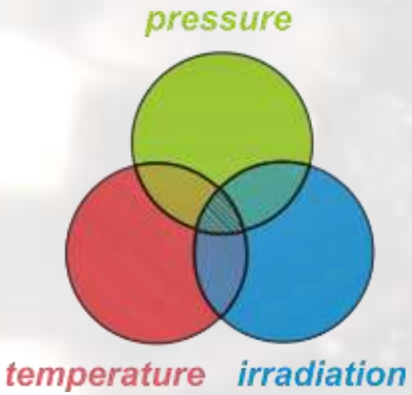
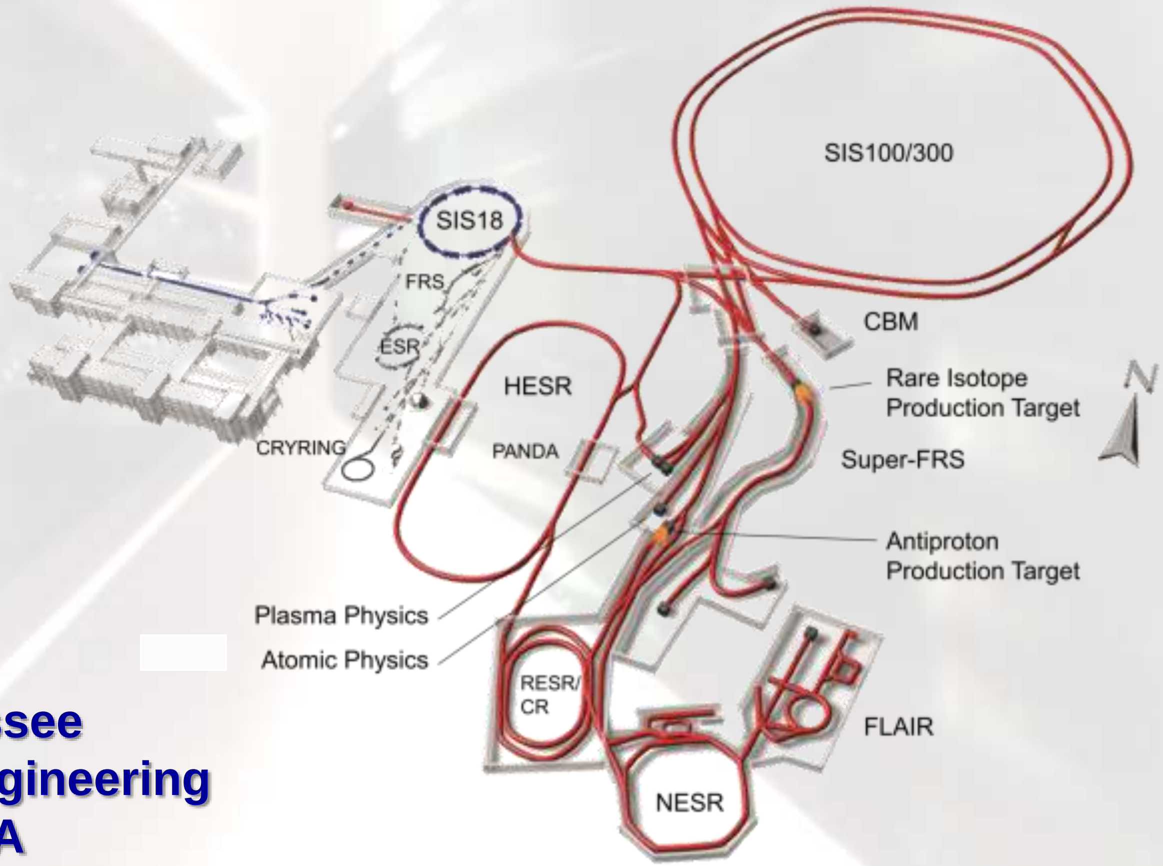
BIO*MAT
Materials Research

THE UNIVERSITY of TENNESSEE UT KNOXVILLE

Materials Research at BIOMAT



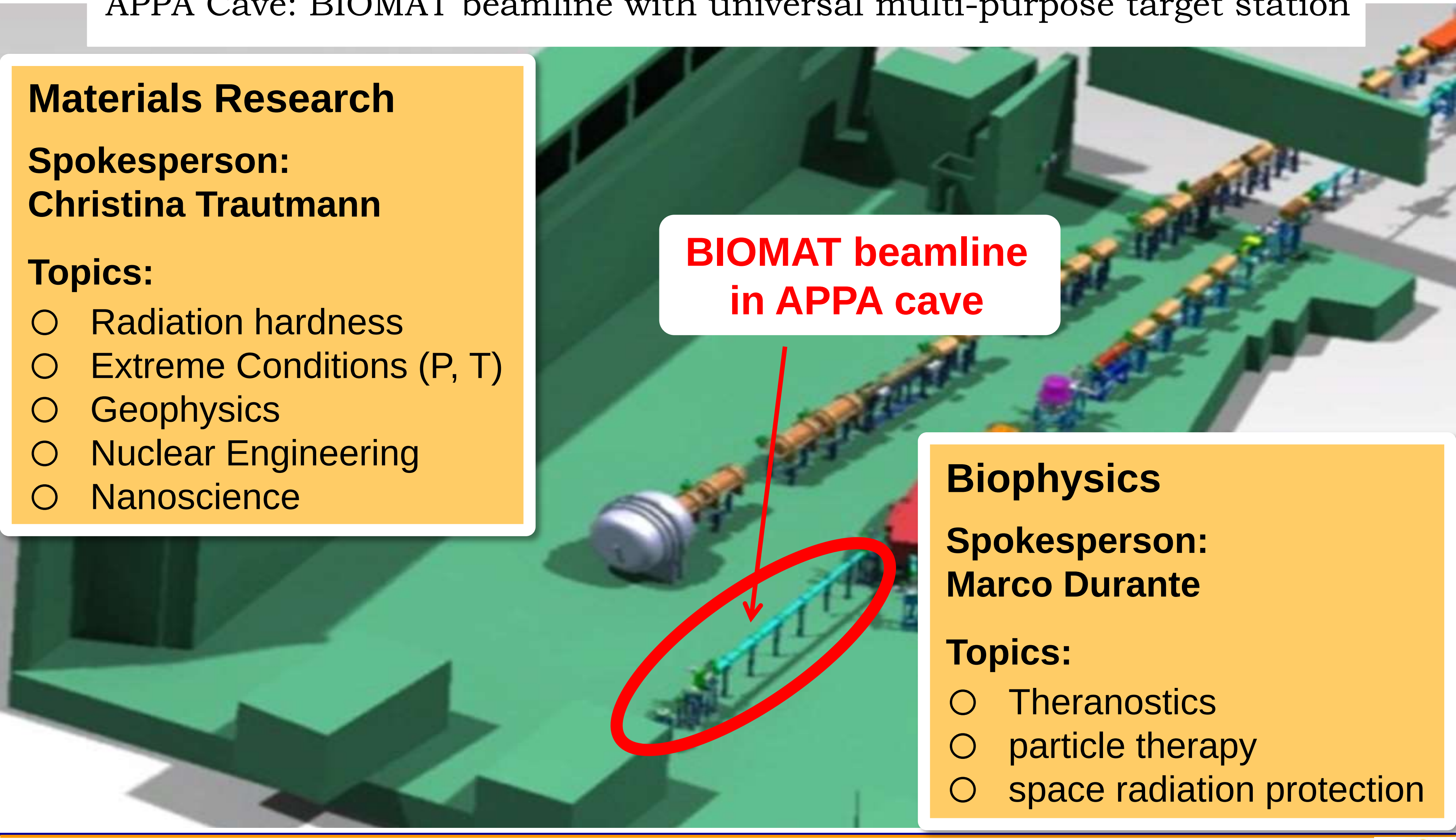


Maik Lang

University of Tennessee
Department of Nuclear Engineering
Knoxville, TN, USA

BIOMAT User Facility

APPA Cave: BIOMAT beamline with universal multi-purpose target station



Materials Research

Spokesperson:
Christina Trautmann

Topics:
- Radiation hardness
- Extreme Conditions (P, T)
- Geophysics
- Nuclear Engineering
- Nanoscience

Biophysics

Spokesperson:
Marco Durante

Topics:
- Theranostics
- particle therapy
- space radiation protection

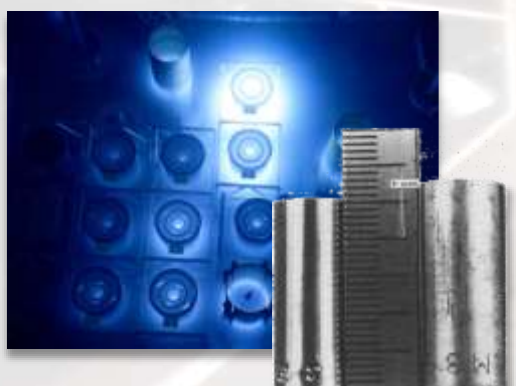
Heavy Ions & Materials Research

GEOSCIENCE

Fission-Track Dating

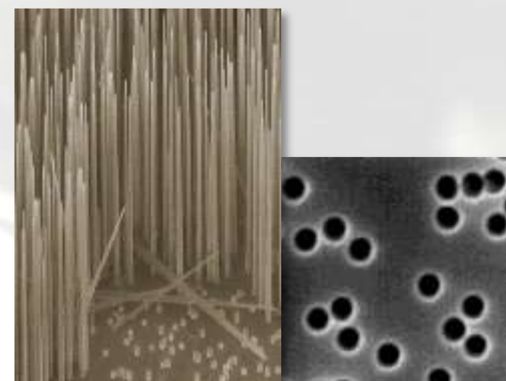
ACCELERATOR TECHNOLOGY

Degradation of Components



NUCLEAR ENGINEERING

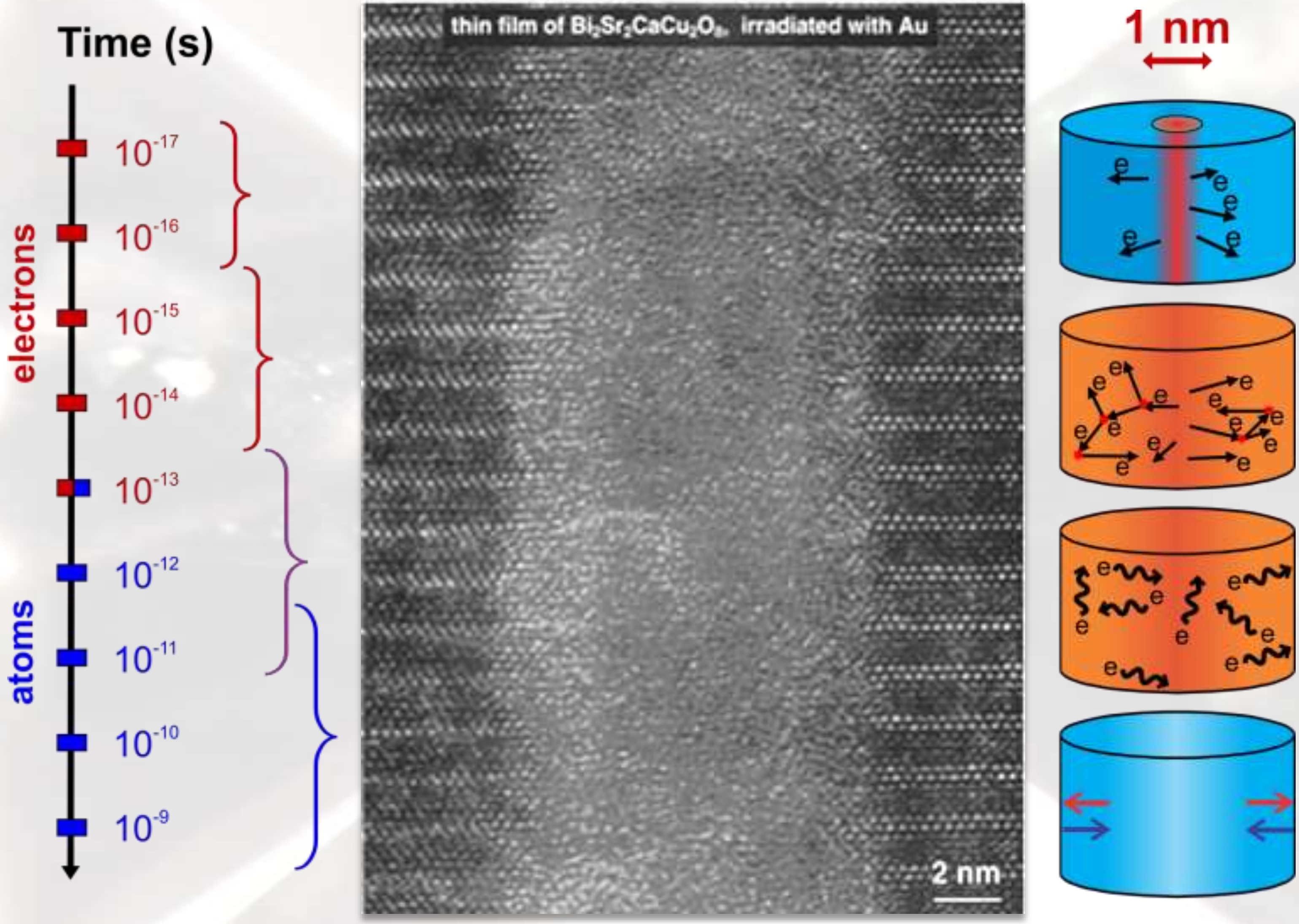
Radiation Damage



ION-BEAM APPLICATIONS

Nano-Structuring

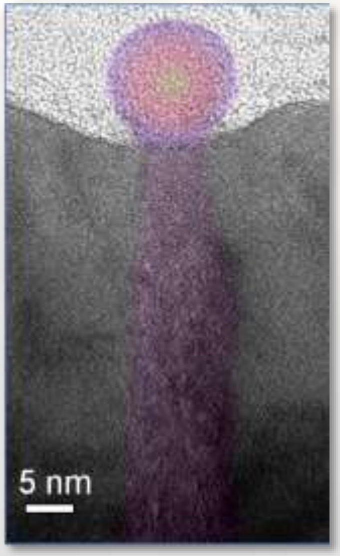
Swift Heavy Ion Interaction in Matter

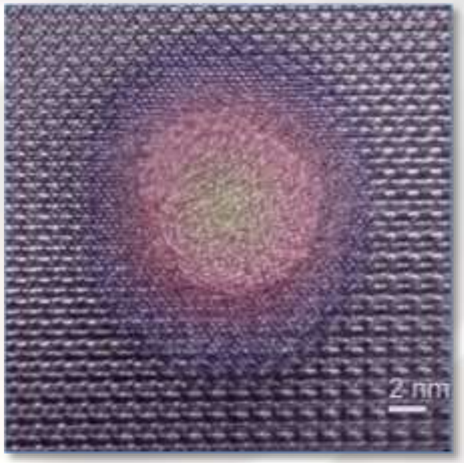


Swift Heavy Ion Interaction in Matter

Ion-Beam Properties:

- Very high electronic energy losses: up to 50 keV/nm
- Short interaction times: ~10^{-15} seconds
- Small interaction volume: ~10 nm diameter
- Extreme energy densities: several eV/atom
- Melting, rapid quenching, shock-wave formation

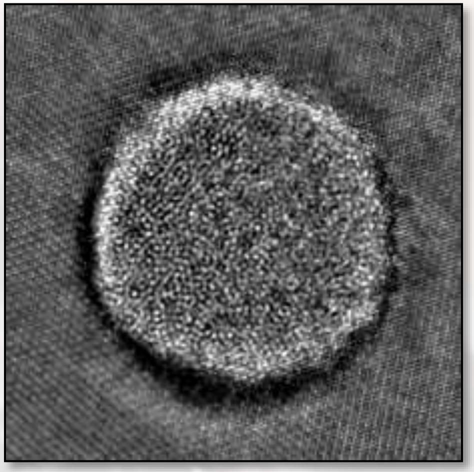




Open Questions:

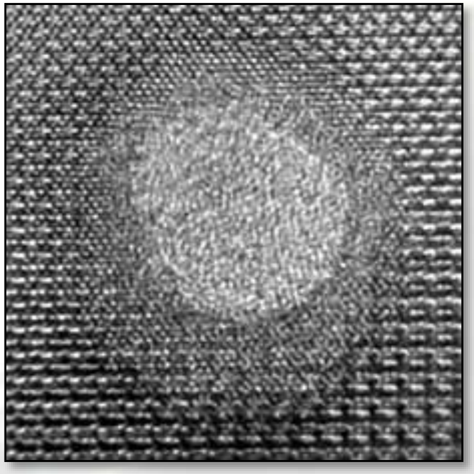
- Energy transfer from electrons to lattice
- Material's dependence
- Ion velocity and charge state
- *In situ* recrystallization and damage recovery

Swift Heavy Ion Tracks



$Gd_2Ti_2O_7$
2.2-GeV ^{197}Au
40 keV/nm; RT

changing
composition

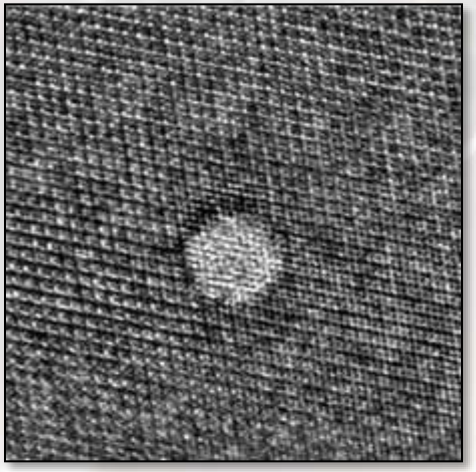


$Gd_2Ti_1O_5$
2.2-GeV ^{197}Au
40 keV/nm; RT

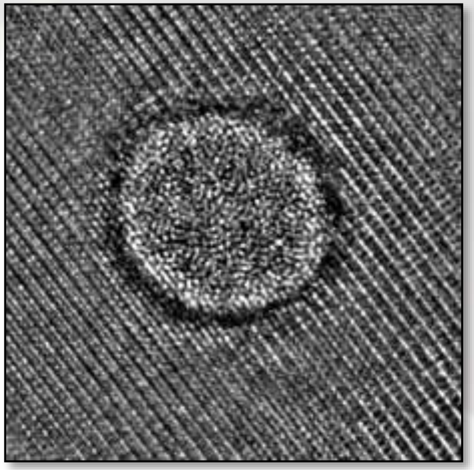
decreasing
energy density

decreasing
temperature

J. Zhang, M. Lang, M. Toulemonde, R. Devanathan, R.C. Ewing, W.J. Weber, *J. Mater. Res.* (2010).



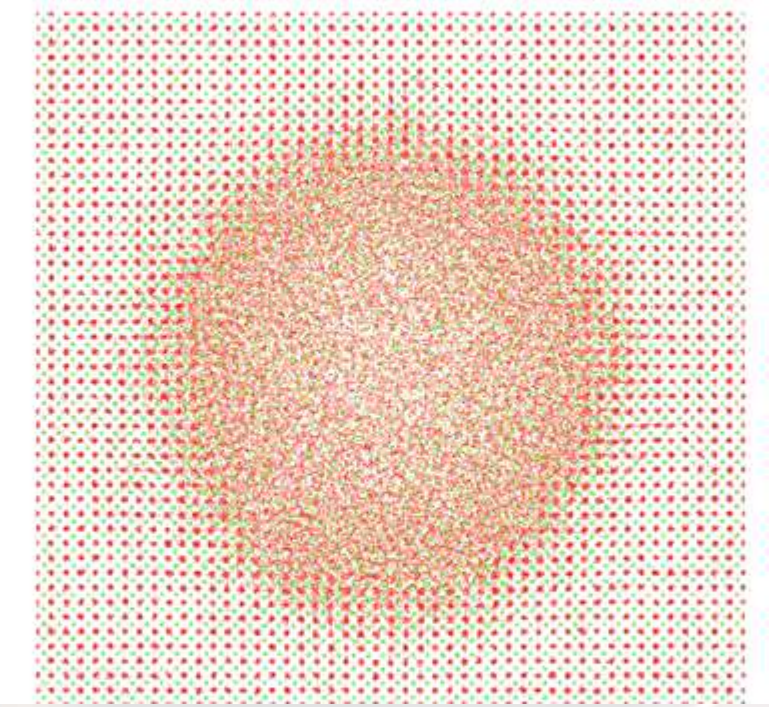
$Gd_2Ti_2O_7$
1.1-GeV ^{101}Ru
20 keV/nm; RT



$Gd_2Ti_2O_7$
2.2-GeV ^{197}Au
40 keV/nm; **8 K**

5 nm

Nanoscale Phase Transformations



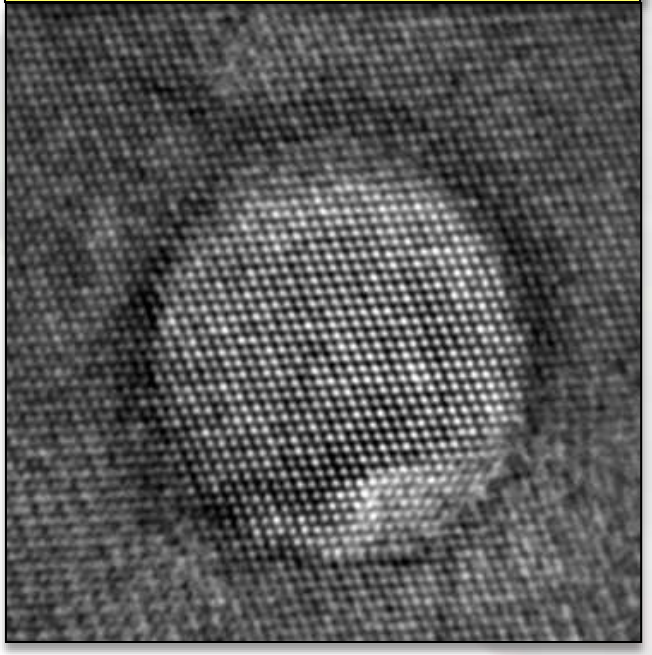
Thermal-Spike based MD-Simulation

J.W. Wang, M. Lang, R.C. Ewing. U. Becker,
J. Phys.: Condens. Matter. (2013)

Energy dissipation within GeV ion path

→ melting + damage recovery
→ recrystallization
→ concentric damage zones

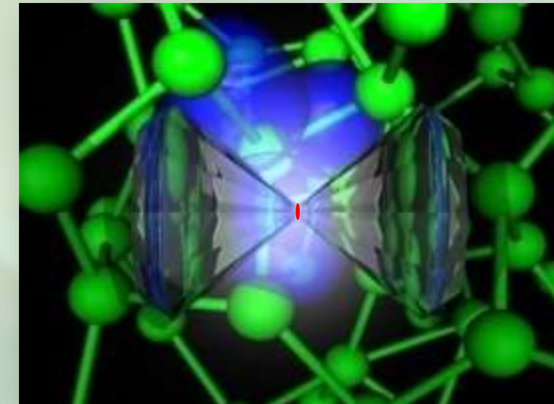
$Gd_2Zr_2O_7$ - 30-GeV C_{60} cluster



Materials under Extreme Conditions

DAC

P **~ 1 Mbar**

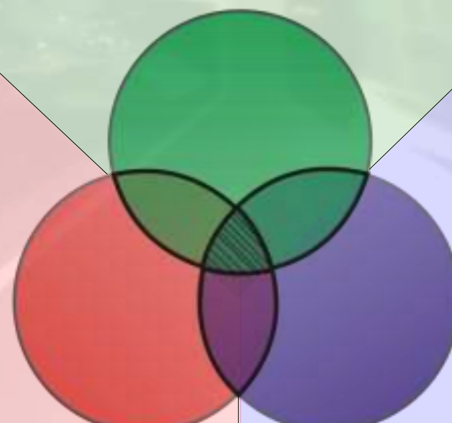


from: *www-pat.llnl.gov/Research/qsg/QSG.html*

pressure

heating coils
laser heating
T **~ 4000 K**

from: *www.sunbeamtech.com*

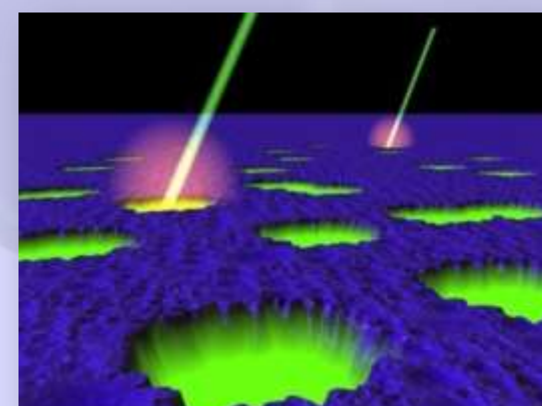


temperature

irradiation

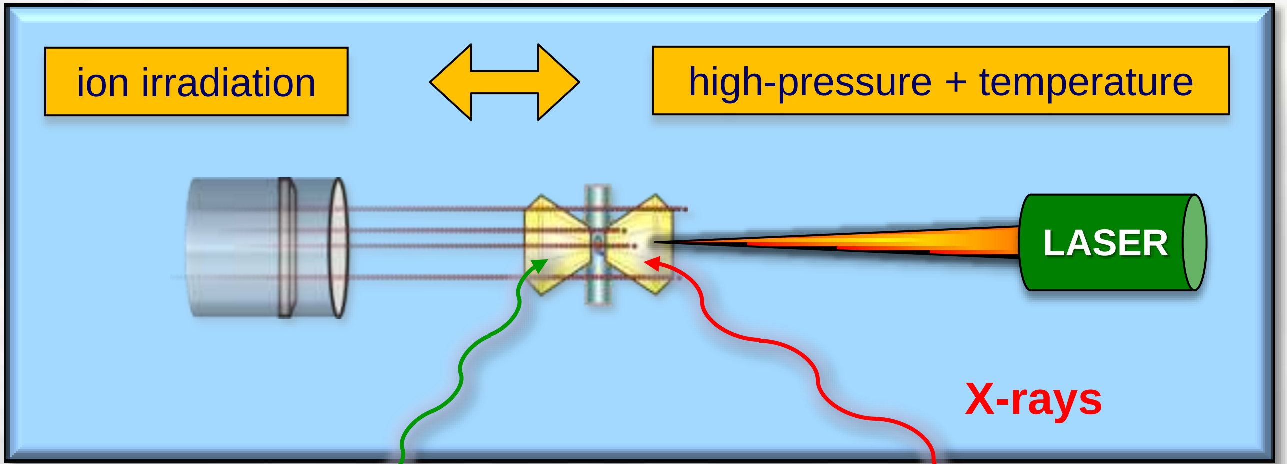
ion accelerator

ρ_E **~ eV/atom**

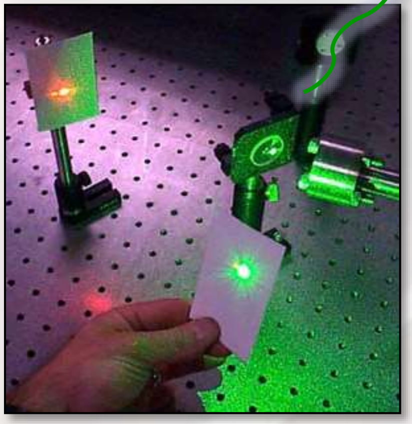


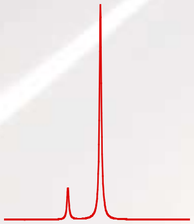
from: *www.simsworkshop.org*

Coupling Ions and High Pressure

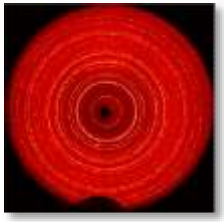


Raman spectroscopy





X-ray diffraction



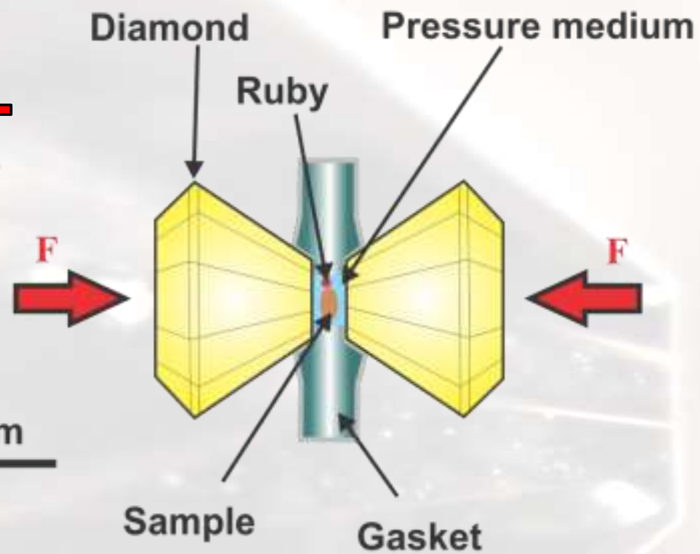
Advanced Photon Source (Argonne Lab)

High-Pressure Technology: DACs

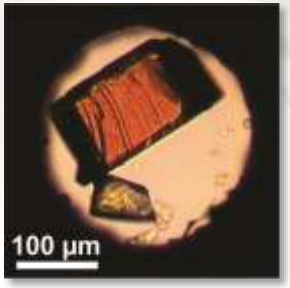
Diamond-Anvil Cell (DAC)

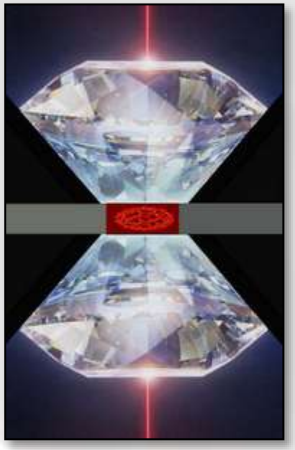
1 GPa = 10 kbar = 100 Kg/mm^2

$$P = \frac{F}{A}$$



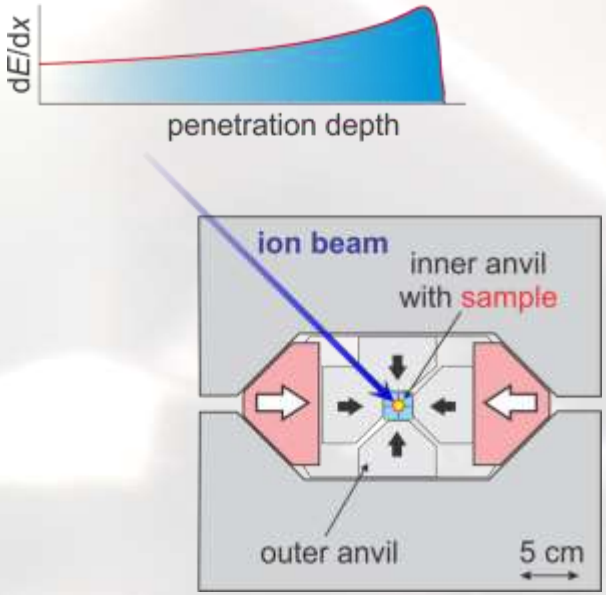
- Pressure: ~300 GPa
- Temperature: 5000 K
- Sample size: 10^{-4} mm^3
- Anvils (2 mm): transparent
- Ion energy: ≥ 200 MeV/u





Laser heating

High-Pressure Technology



Paris-Edinburgh Cell @ GSI

U.A. Glasmacher, *et al*.

- Pressure: ~10 GPa
- Loads: 100 tons
- Temperature: 2000 K
- Sample size: 1 mm^3

increase of volume

$$P = \frac{F}{A}$$

25 GPa Pressure apparatus @ DESY

Facilities for Extreme Conditions

DESY

Deutsches Elektronen Synchrotron

ESRF

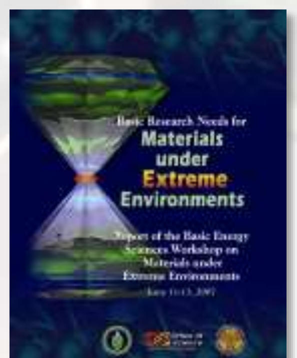
European Synchrotron Radiation Facility

OAK RIDGE NATIONAL LABORATORY
NEUTRON SCIENCES
Spallation Neutron Source • High Flux Isotope Reactor

SNS
SPALLATION NEUTRON SOURCE

Spallation Neutron Source
Oak Ridge National Lab

Advanced Photon Source
Argonne National Lab



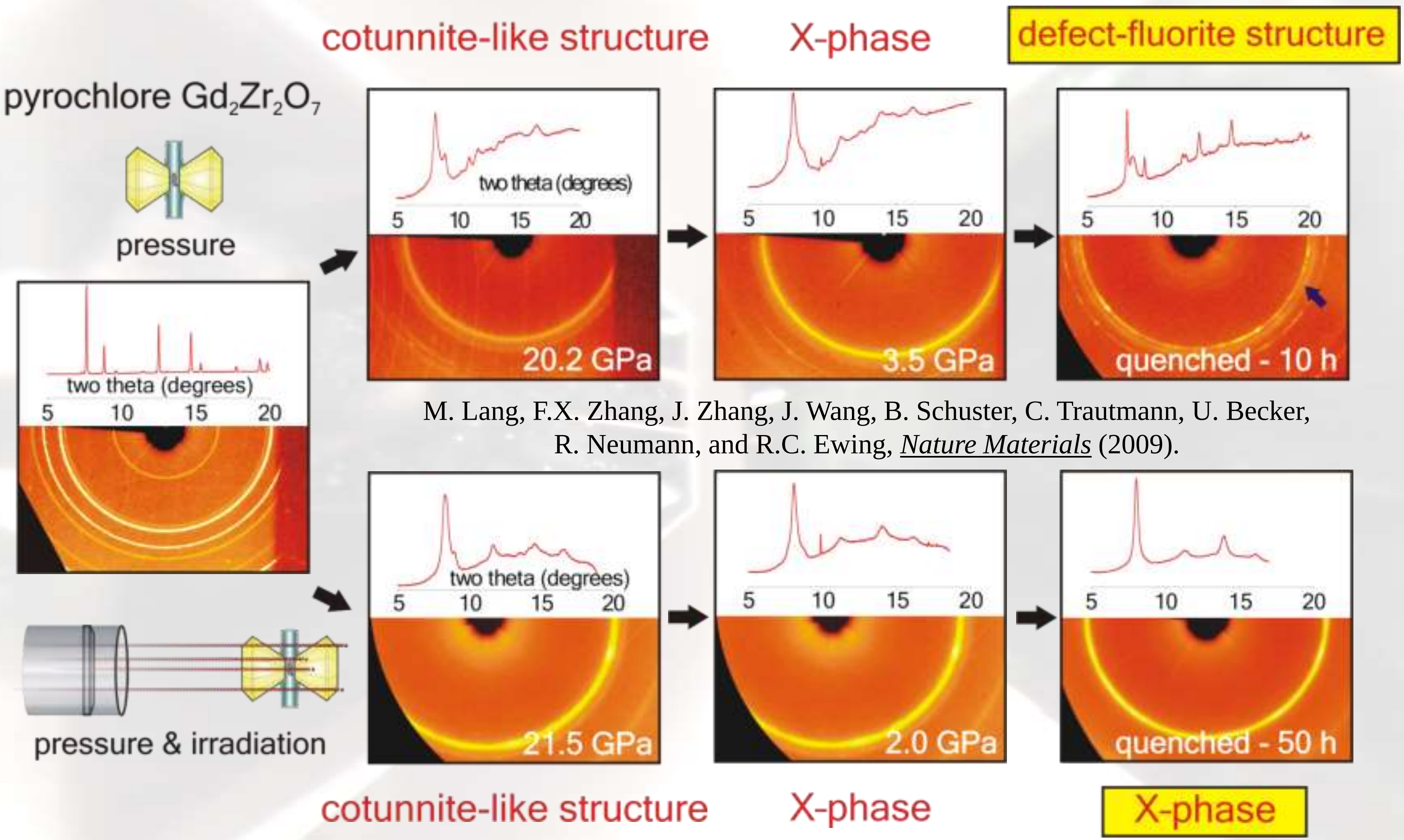
Department of Energy:
“Research Needs” Workshops

U.S. DEPARTMENT OF ENERGY | Office of Science

EFree

49 Energy Frontier
Research Centers

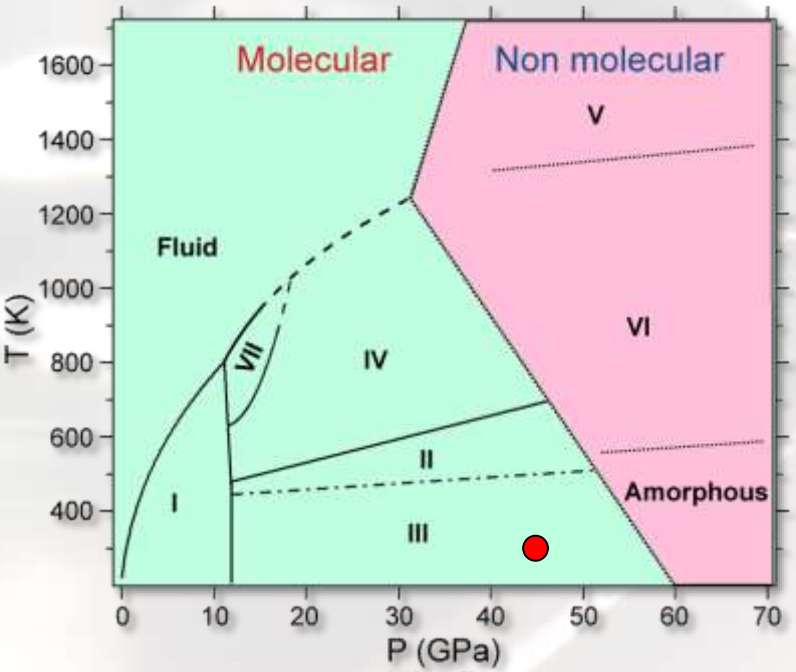
New Materials under Extremes



M. Lang, F.X. Zhang, J. Zhang, J. Wang, B. Schuster, C. Trautmann, U. Becker, R. Neumann, and R.C. Ewing, *Nature Materials* (2009).

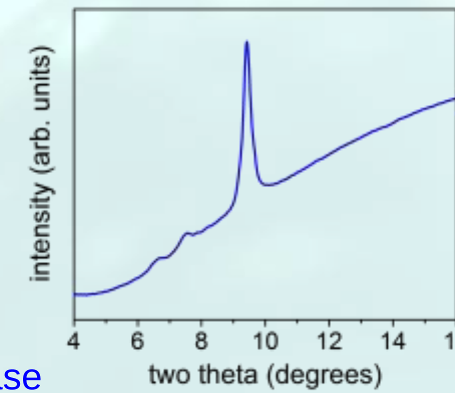
Changing Phases under Extremes

pressure-solidified CO_2



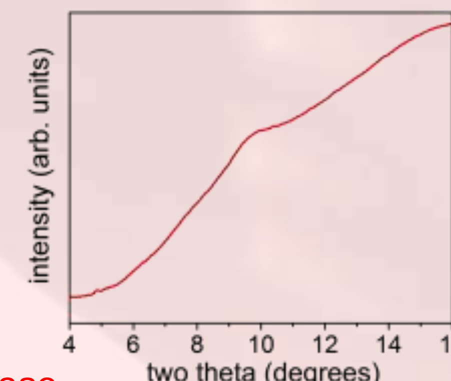
Phase diagram after: F. Datchi, V.M. Giordano, P. Munsch, and A.M. Saitta, *Phys. Rev. Lett.* **103**, 185701 (2009).

before irradiation at 45 GPa:



crystalline CO_2-ice phase

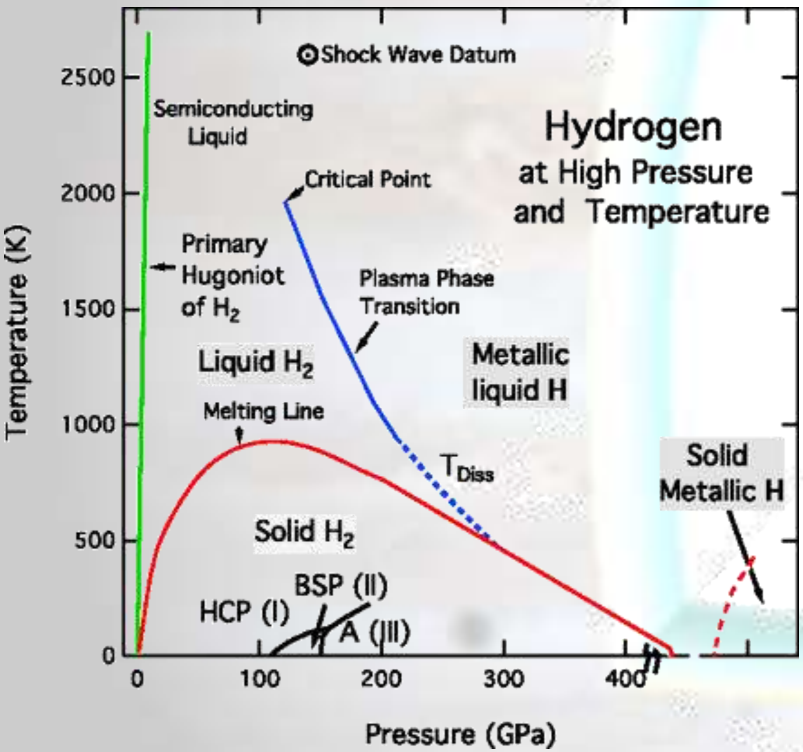
after irradiation at 45 GPa: 6-GeV Au, 2×10^{12} cm^{-2}



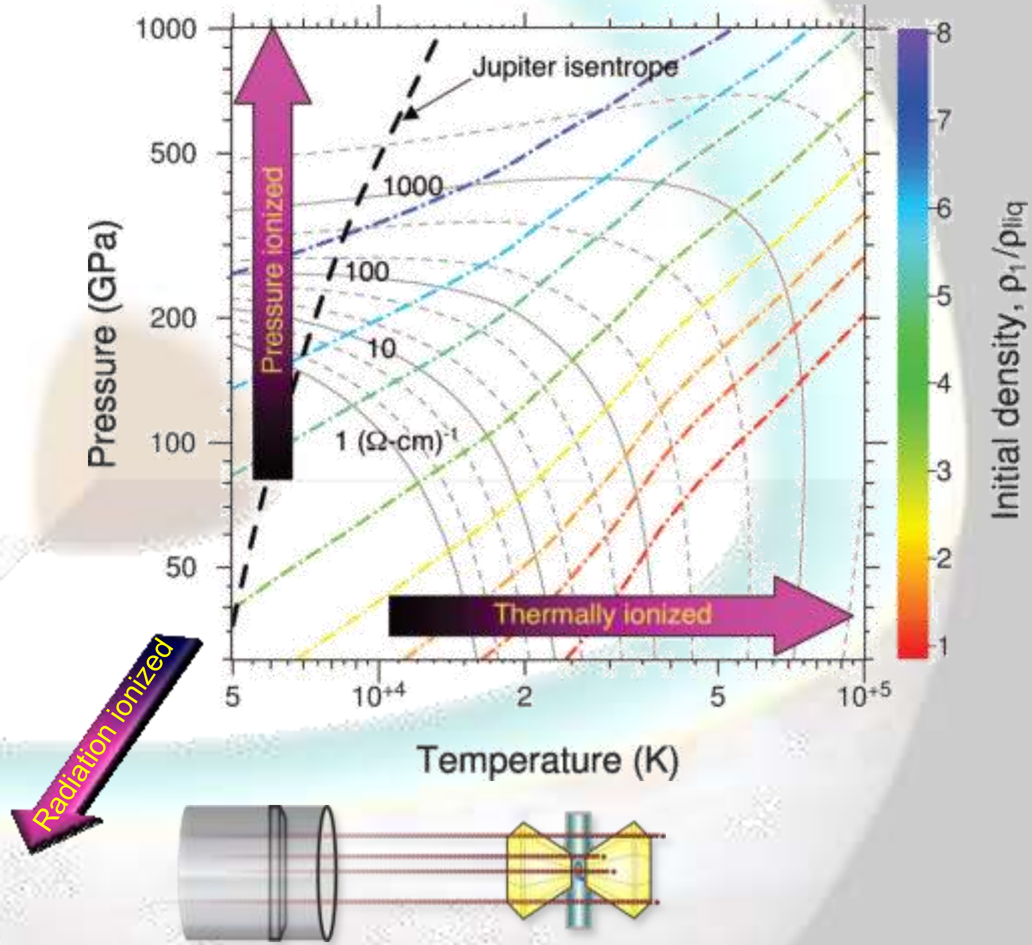
amorphous CO_2-ice phase

First Experiment: e.g., Hydrogen

Phase diagram of hydrogen

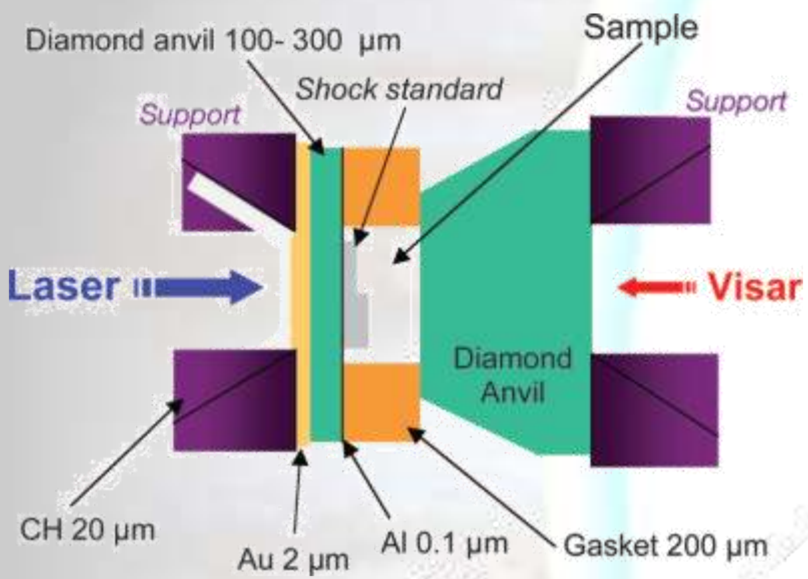


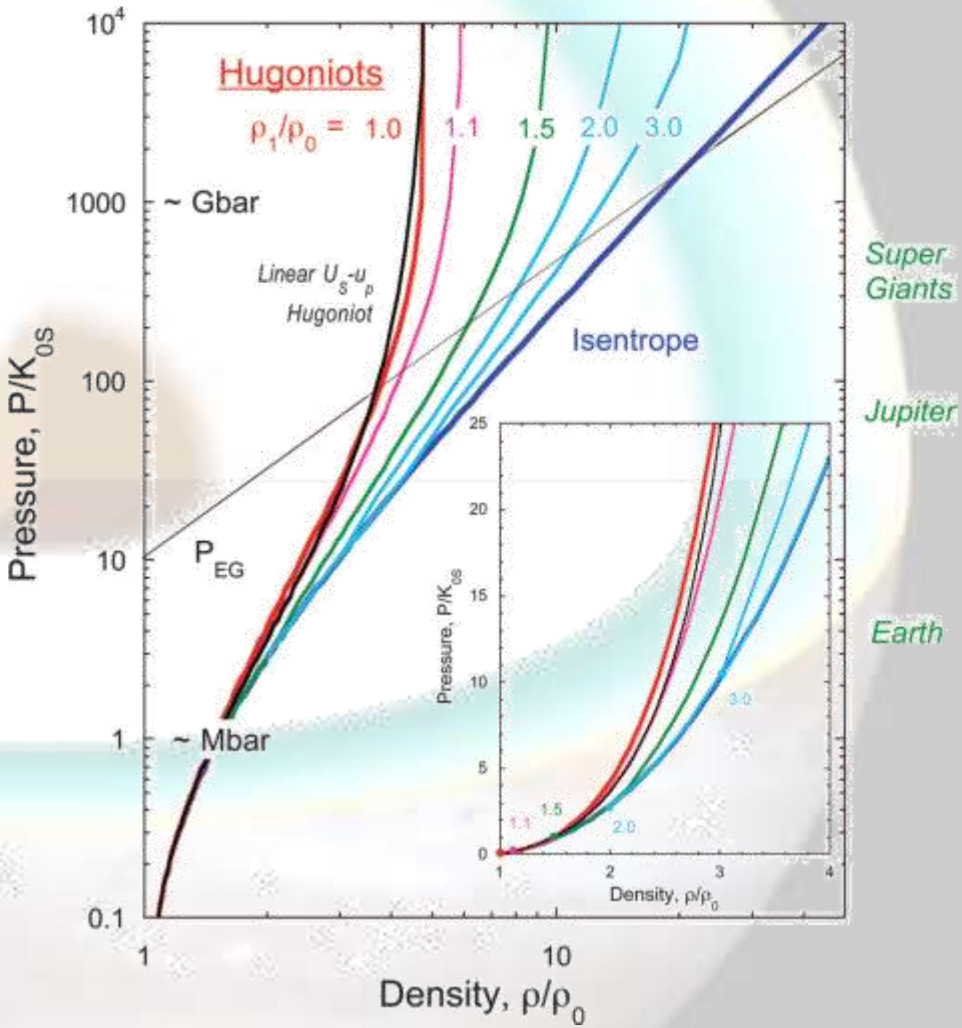
R. Jeanloz, *et al.*, PNAS (2007)



Irradiation of hydrogen at extreme pressures with swift heavy ions!

New Thermodynamic States





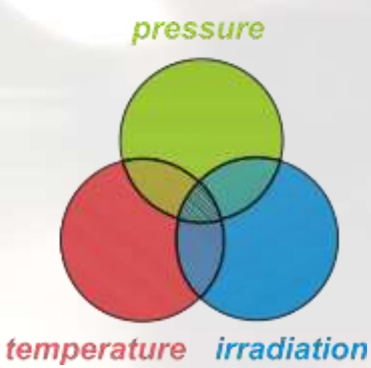
R. Jeanloz, *et al.*, PNAS (2007)

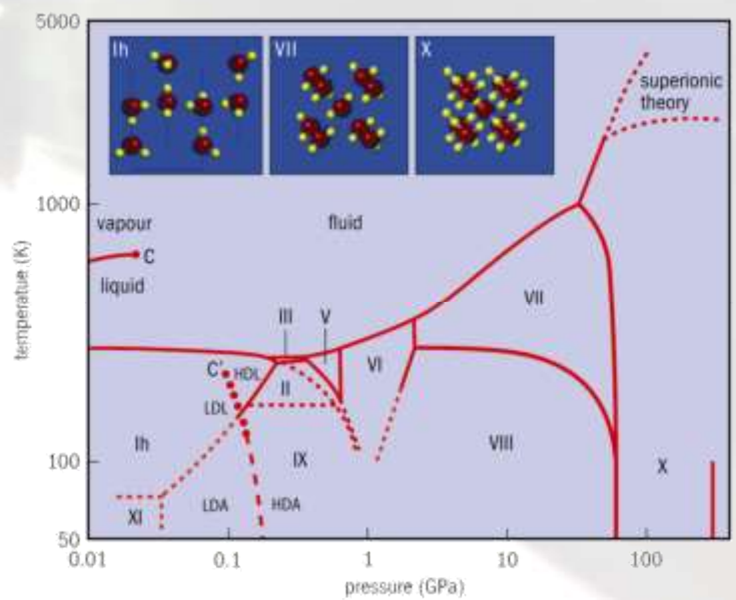
→Laser-induced shockwaves in pre-compressed materials

→ Similar experiments with short and intense ion-beam pulses

Materials Research at FAIR

- Unique experimental capabilities at FAIR:
  - very high energies
  - intense beams
  - short beam pulses
- Coupled with high-pressure and high temperature this provides:
  - access to unexplored thermodynamic states
  - new phases and materials





Research and Intern. Collaborations

Materials research with wide range of applications in:

- Materials Science
- Solid State Physics
- Nanotechnology
- Geoscience
- Nuclear Engineering

GSI
C. Trautmann
Daniel Severin
Markus Bender
E. Toimil-Molares
Kay-Obbe Voss
Marilena Tomut

Stanford University
Rod Ewing
Wendy Mao

University of Tennessee
Maik Lang
Bill Weber

University of Heidelberg
U.A. Glasmacher

Australian National University
Patrick Kluth

Rensselaer Polytechnic Institute
Jie Lian

CIMAP
Marcel Toulemonde

Oak Ridge National Lab
Yanwen Zhang

University of Wien
Ronald Miletich


Thanks!