Understanding Condensed Matter at Extreme Conditions: by Integrating Dynamic and Static Compression Methods

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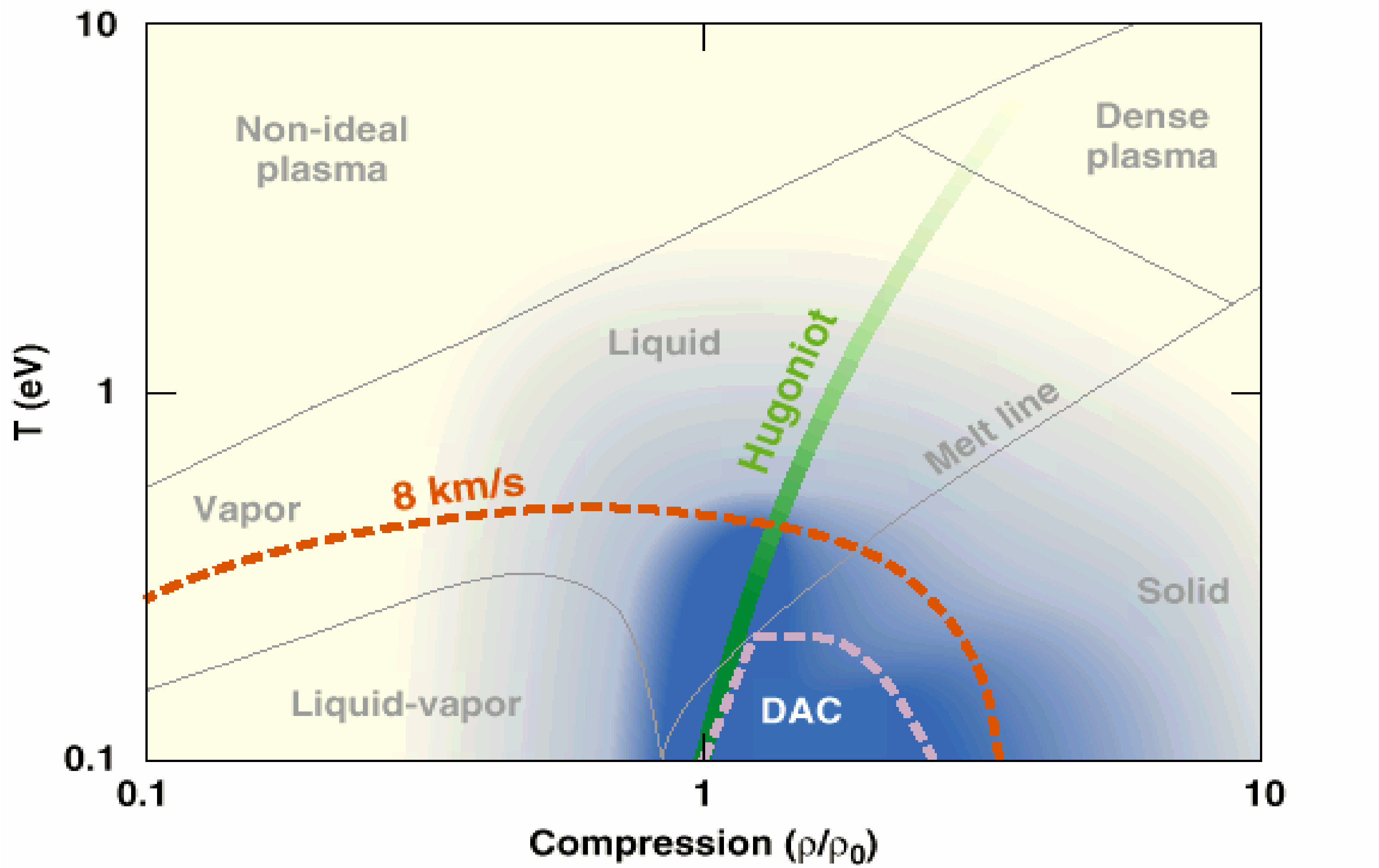
Outline

- Extreme states of matter and dynamic compression
- Time-dependence and multiscale measurements
- Shock wave compression – recent highlights
- New developments in dynamic compression
- Unique role of static compression measurements
- Concluding remarks

States of Matter (Holmes, LLNL)



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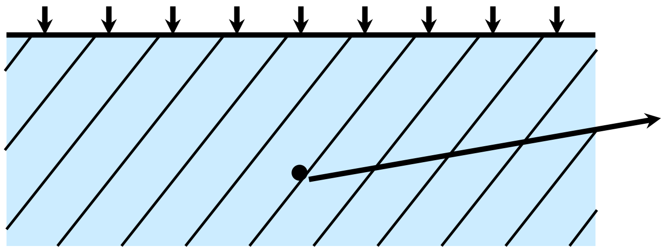
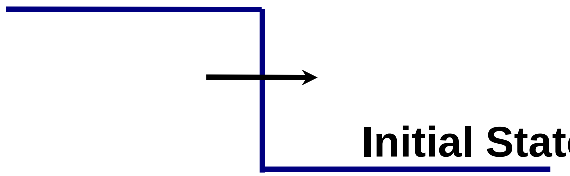
Features of Shock Wave Compression





Supersonic disturbance causing near-discontinuous changes in density, internal energy, particle velocity

- Pressure Range: 10 Kbar - 100 Mbar
- Time Scales: 100 fs - 10 μs
- Directionality of loading
- Non-isotropic loading
- Large temperature rise (after thermal equilibration)
- Nonlinear coupling between wave propagation and material response

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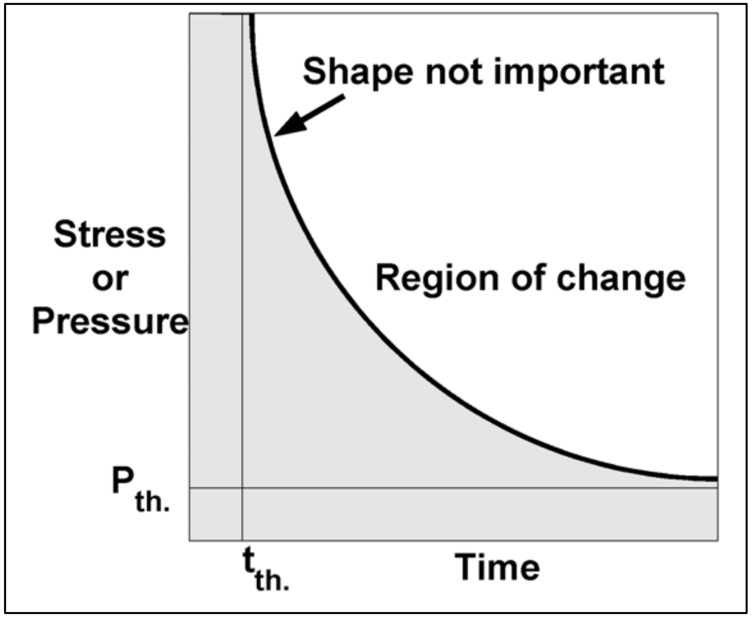
Time-Dependent Material Response

- Material Phenomena
  - Phase changes
  - Inelastic deformation
  - Spall or tensile failure
  - Chemical reactions
- Loading Conditions
  - Temporal relevance
- Real-Time Measurements
  - Resolution and duration



Incorporation of time-dependent response in shock wave propagation has 40 plus years of history at WSU

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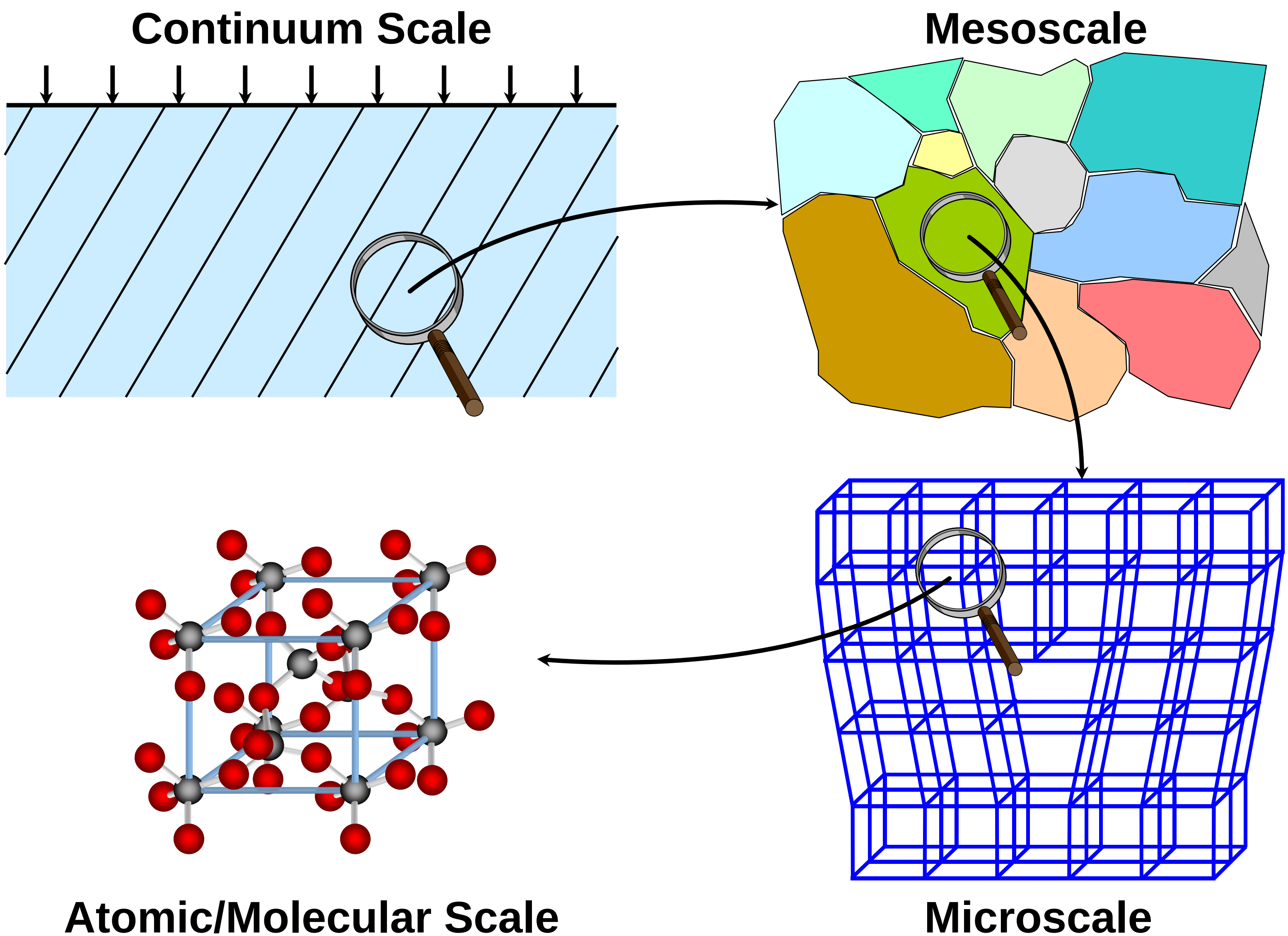
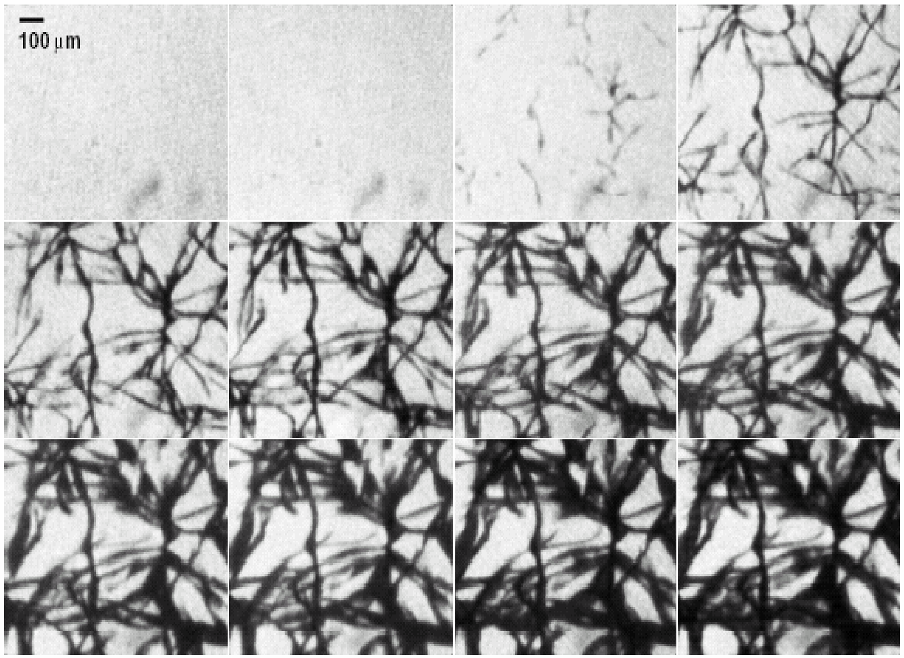
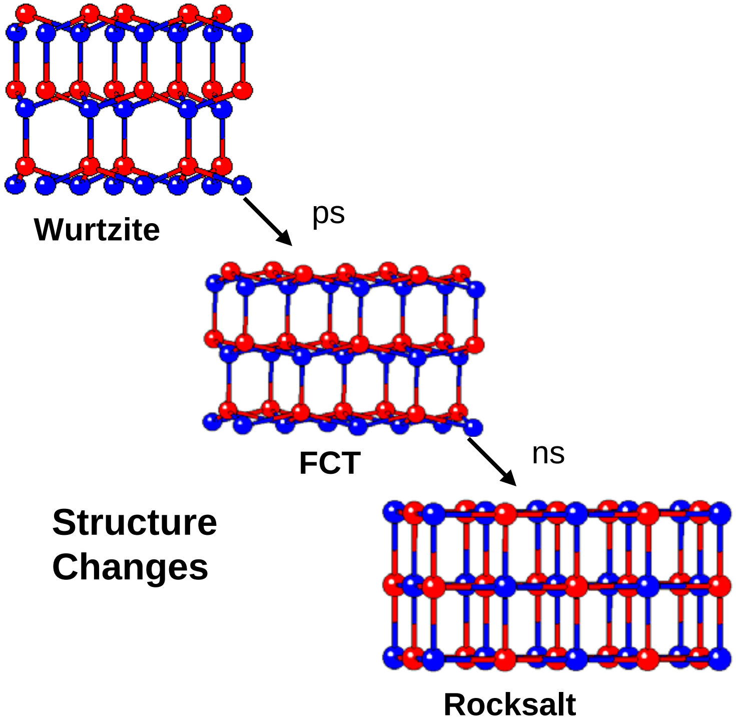
Measurements at Different Scales



Shock Compression – Time Dependence



Freezing of Water



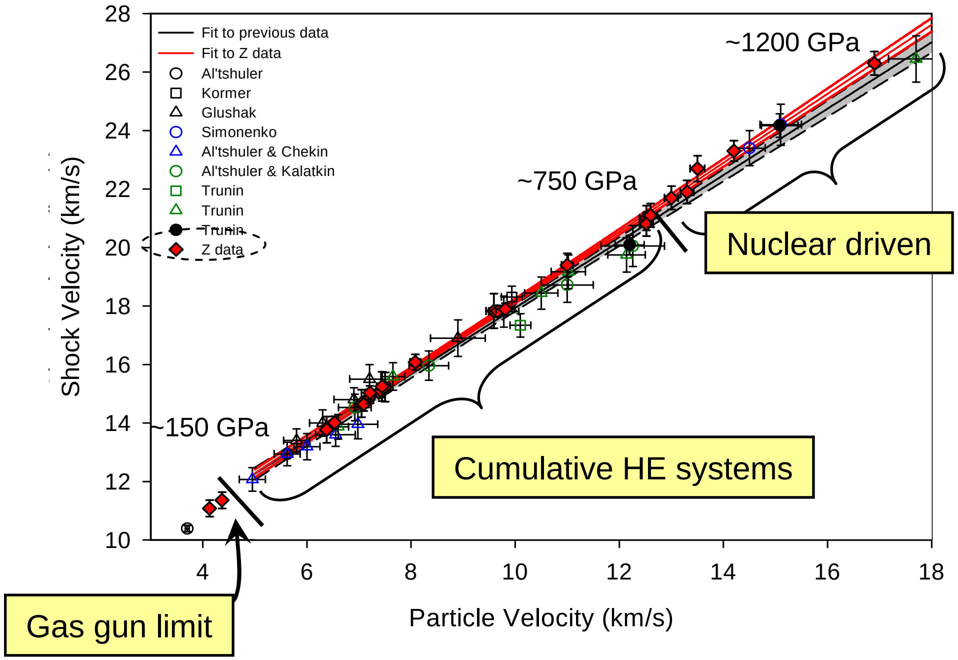
Structure Changes

D. Dolan, Ph.D. Thesis

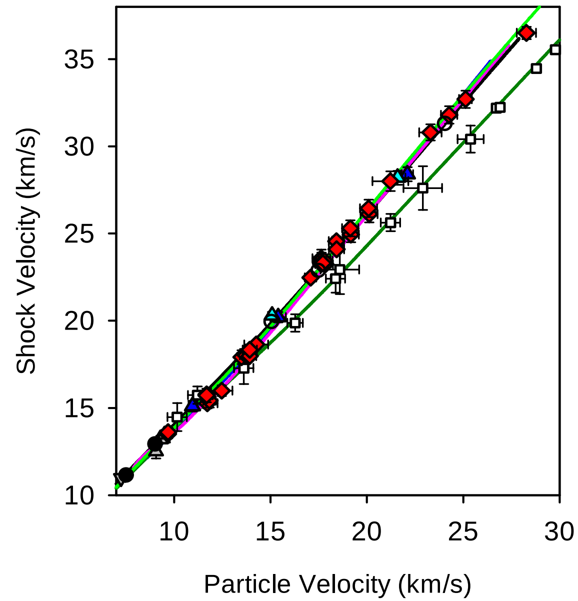
M. Knudson, Ph.D. Thesis

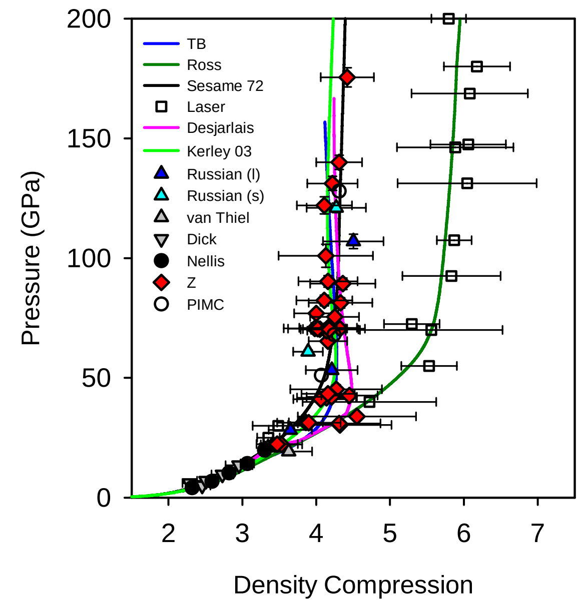
Shock Compression (Knudson, Sandia)

Aluminum Data



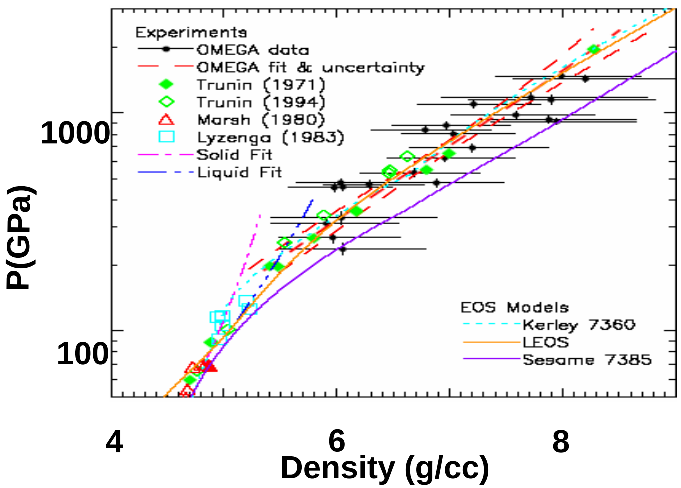
D_2 Data →

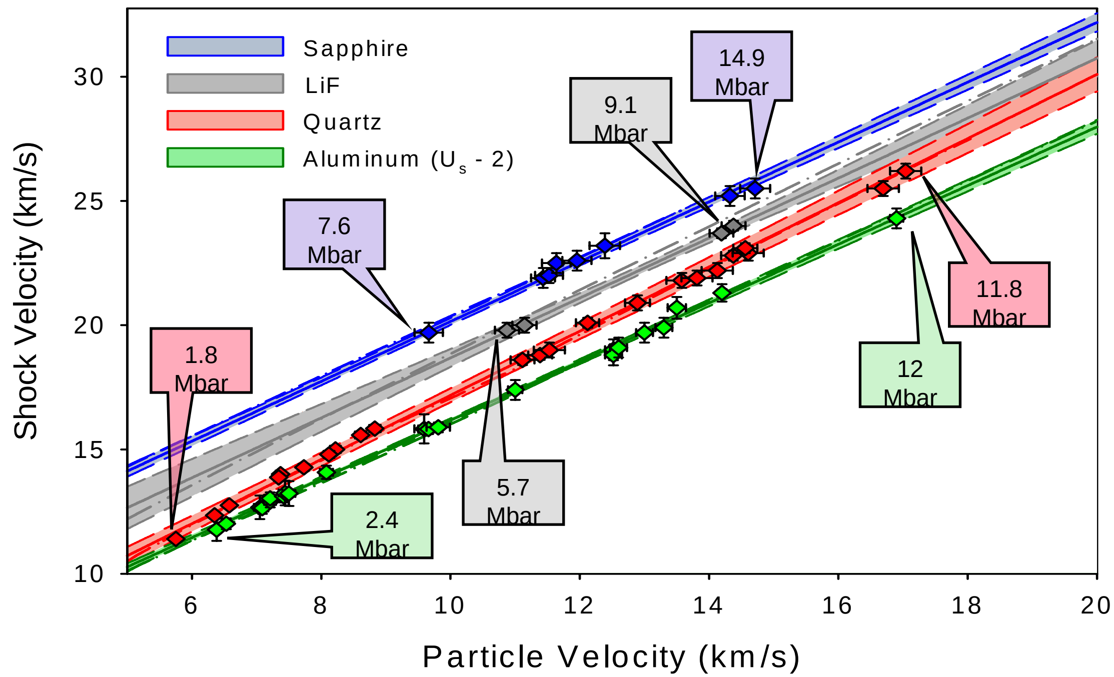


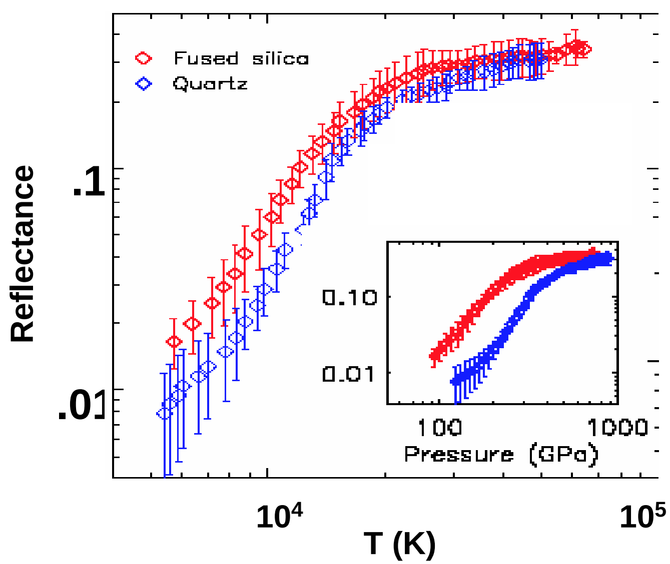


M.D. Knudson, et al., Phys. Rev. Lett. **87**, 225501 (2001); Phys. Rev. B **69**, 144209 (2004)

Shock Compression (Collins et al., LLNL)



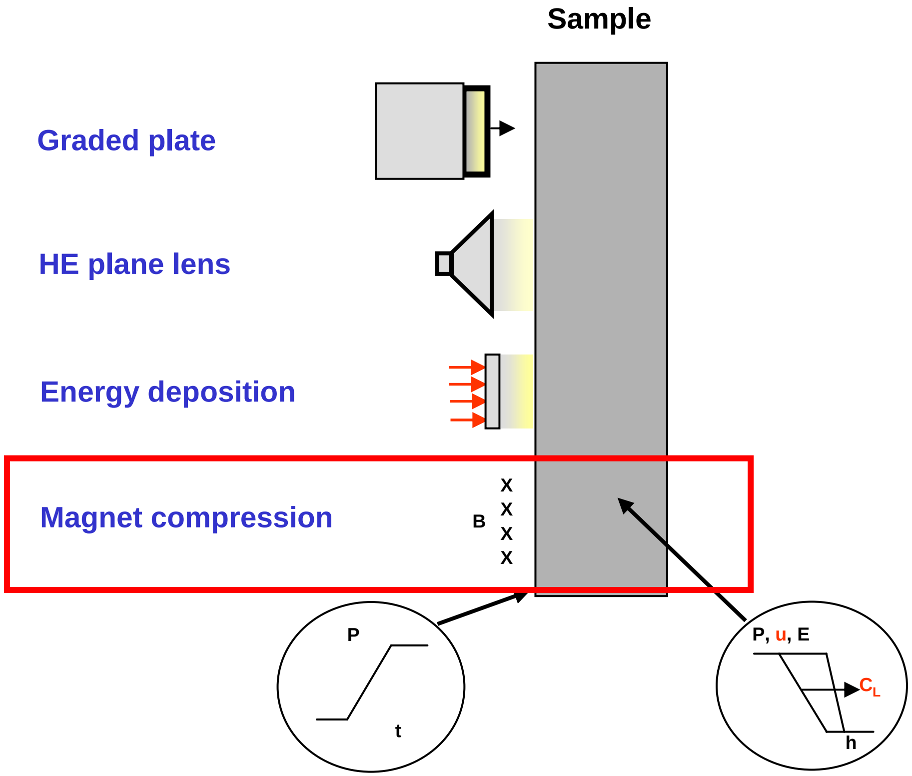




Shocked Silica becomes more compressible and an electronic conductor above 1 Mbar

Dynamic Compression – New Developments

- Magnetic launch – 34 km/s; expected to be 45-50 km/s in the future
- Laser shocks – tens of Mbar; Gbar on NIF
- Precompressed samples (DAC) subjected to laser shocks
- Ramp wave loading (rise times ~ tens to hundreds of ns)



Ramp wave loading

(Jim Asay)

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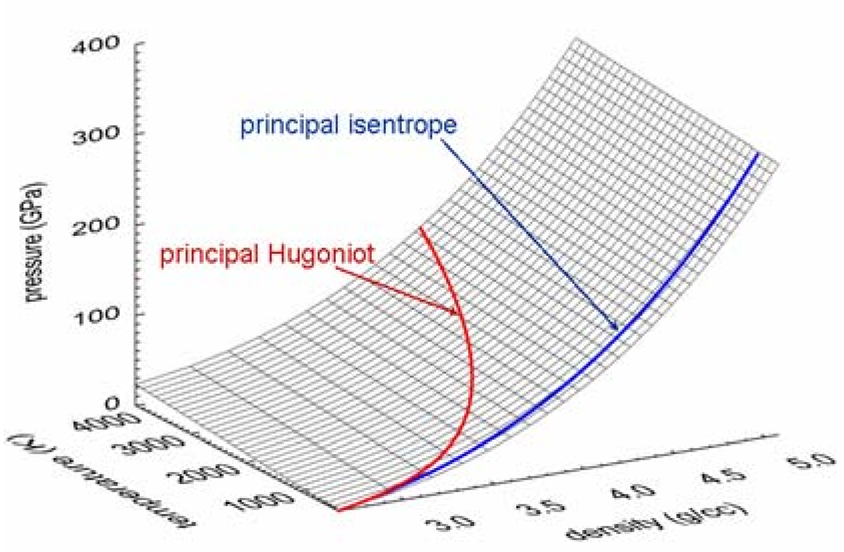
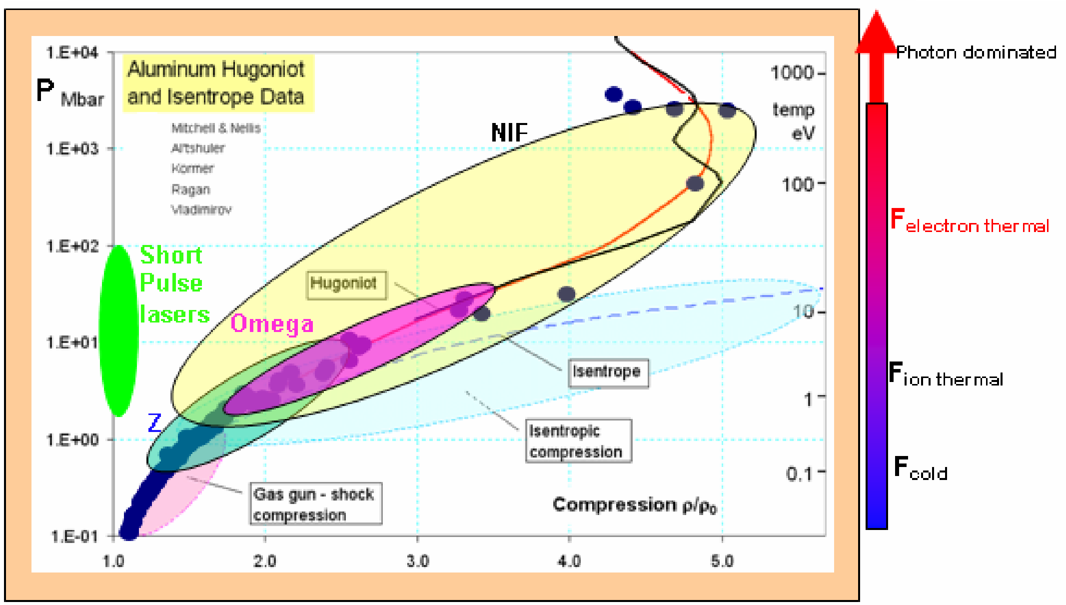
Why Ramp Wave Loading?



- **Shock compression produces high-pressure, high-temperature states**
- **Quasi-isentropic compression produces high-pressure, low-temperature states**

(Jim Asay)



HED facilities explore ultra-high pressure properties of materials

(G. Collins)

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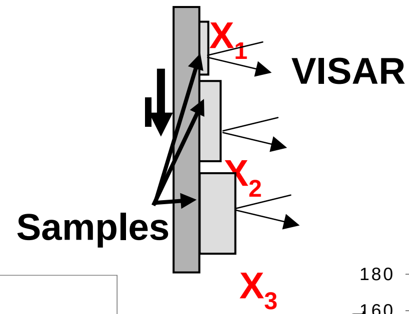
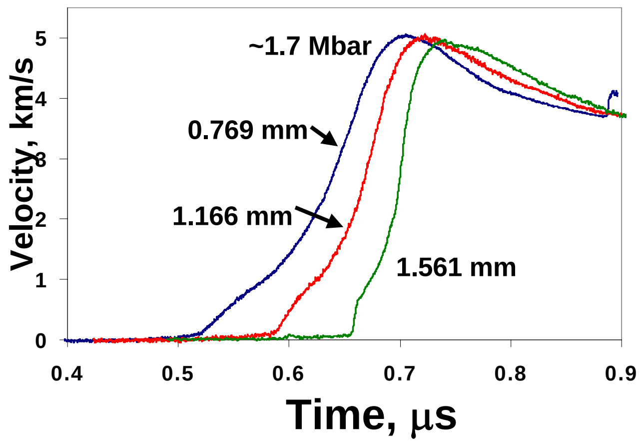
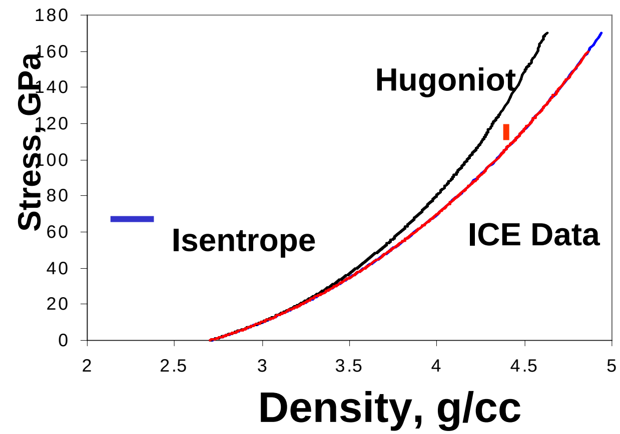
Ramp Wave Loading -- Challenges







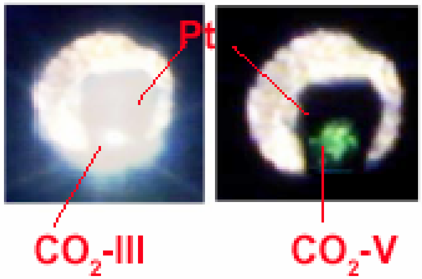
- •Analysis of unsteady wave data
- •Evolution into a shock wave
- •Simulations of unsteady waves require care

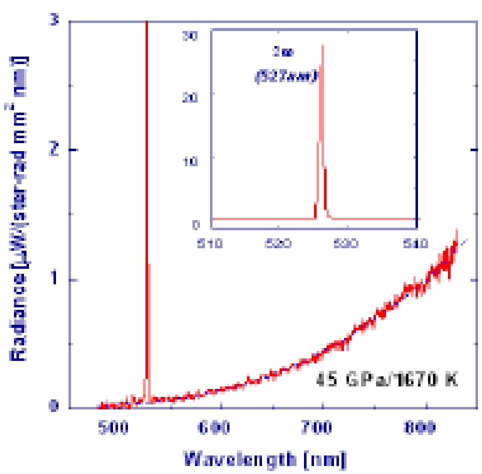
(Jim Asay)

Novel properties of extended solids (Yoo, LLNL)

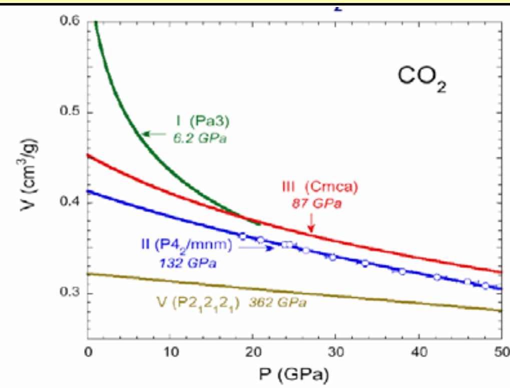
Optical nonlinearity

During and after polymerization



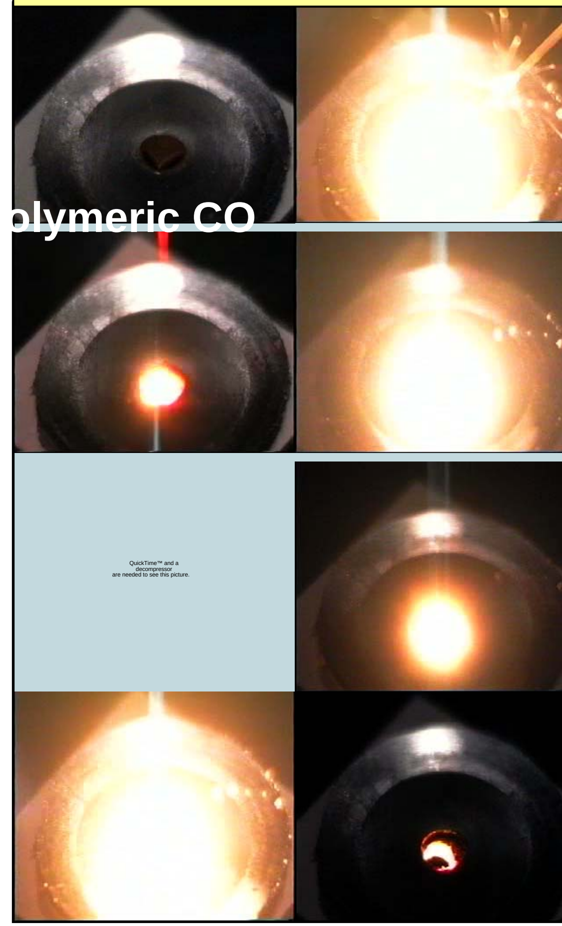


Superhard



Soilds	ρ (g/cm³)	B_o (GPa)
Diamond	3.50	450
cubic-BN	3.48	369
CO_2-V	2.90	362
Al_2O_3	4.00	239
hcp-Fe	8.29	165
CO_2-II	2.45	130
Silicon	2.33	98
CO_2-III	2.22	87
CO_2-I	1.75	6
δ-N_2	1.03	3

High energy density



Iota et al., Science 283,1510 (1999) *Yoo et al., PRL83, 5527 (1999)* *Lipp et al., Nature-Mat 4, 211 (2005)*

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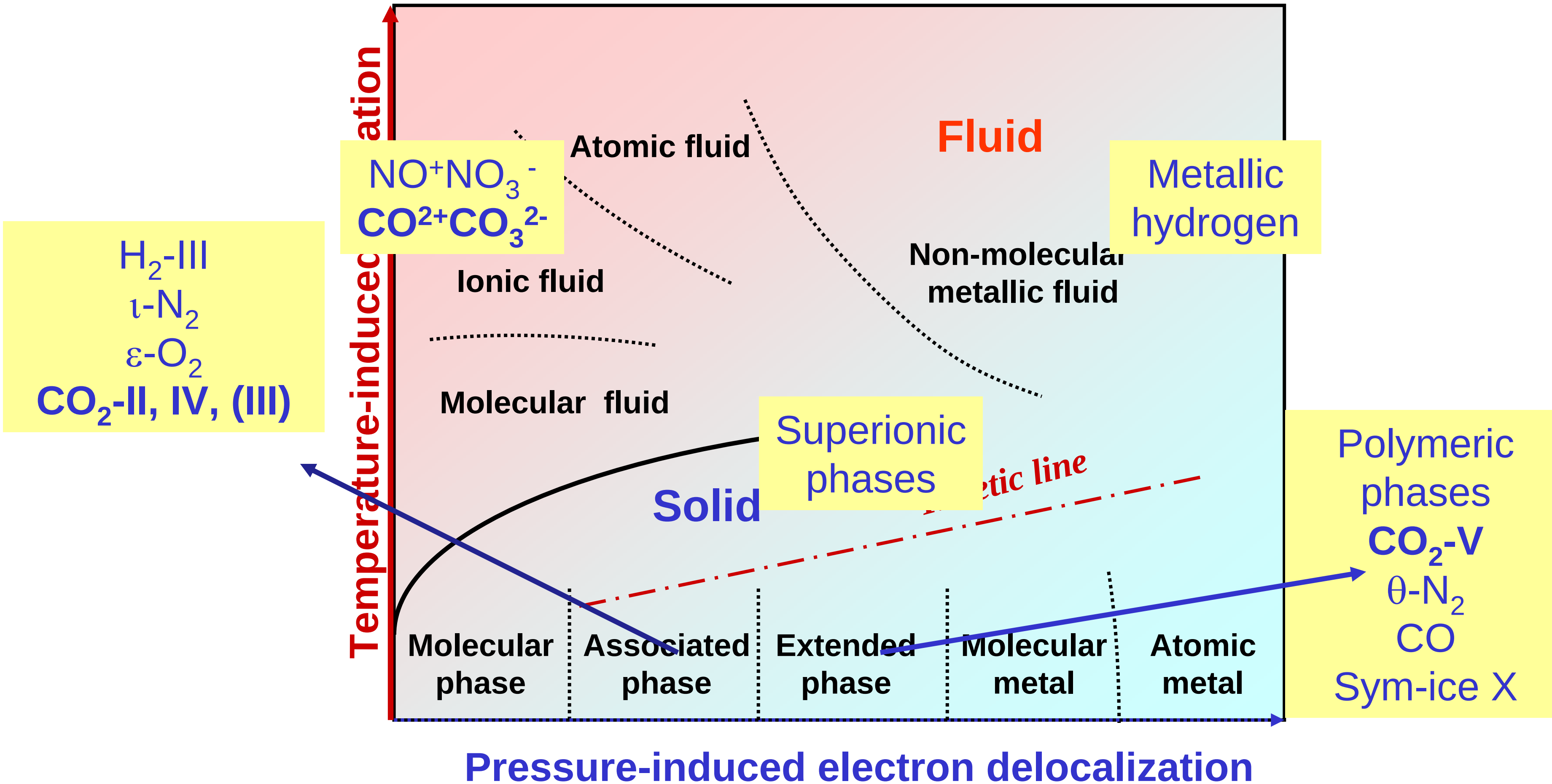
Mbar chemistry to exotic states (Yoo, LLNL)



Strong disparity in bonding results in a huge kinetic barrier (metastability); new opportunities for synthesis of exotic materials

Concluding Remarks – Looking Ahead

- **Comprehensive approach to address scientific needs**
  - **Shock waves: compression, deformation, temperature, time**
  - **Ramp waves: separation of compression, temperature, loading rates**
  - **Static pressure: separation of compression, temperature, deformation**
  - **Theory/computations: provide insights at different length scales**

- **Need to integrate dynamic and static compression efforts more effectively**

- **How to carry out dynamic experiments routinely at facilities like CHESS, APS, and LCLS (to take advantage of diagnostics)?**

The next twenty years in high pressure science promise to be exciting

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