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Temperature measurements of dynamically compressed materials

SEM conference

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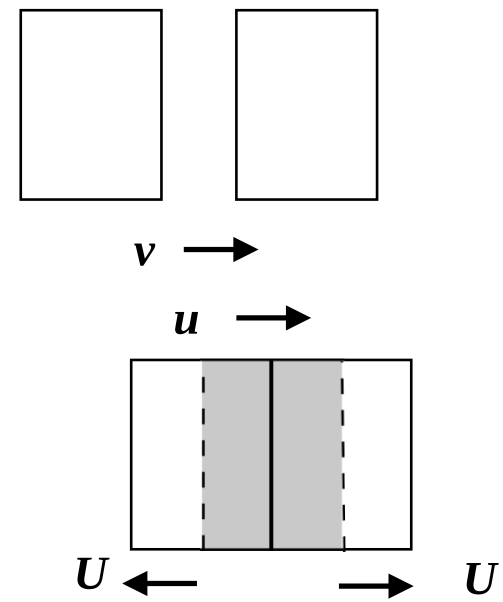
D.H. Dolan
S. Becker and R. Hacking (BN)

Overview

- **Mechanical measurements**
  - **Measure stress or velocity directly**
  - **Calculate other quantities (e.g., density) from conservation laws**
- **Complete EOS requires temperature**
  - **Helmholtz free energy: F(T,v)**
  - **Not explicit in conservation laws**
  - **Calculations very sensitive to response functions: c_v, k_t**
  - **Reveals underlying material physics**
- **Temperature is hard to measure**
  - **Fast rise times (1-100 ns)**
  - **Hostile environments**

Impact experiment



Jump conditions

$$\frac{v}{v_0} = 1 - \frac{u}{U}$$

$$P - P_0 = \rho_0 \, U \, u$$

$$E - E_0 = \frac{1}{2}(P + P_0)(v_0 - v)$$

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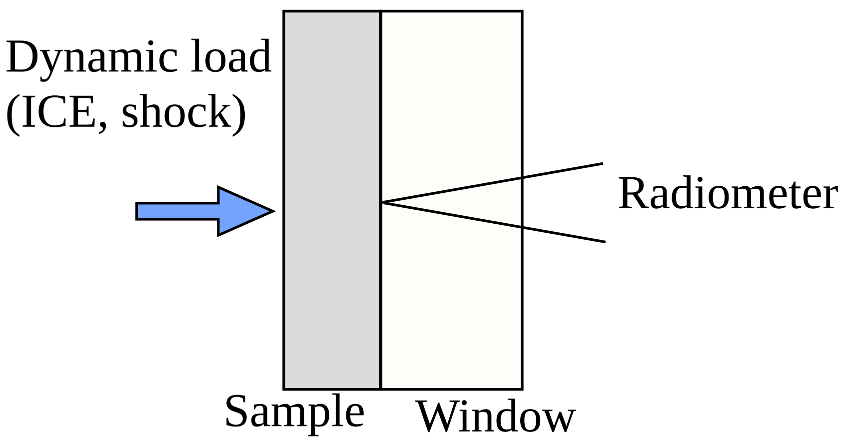
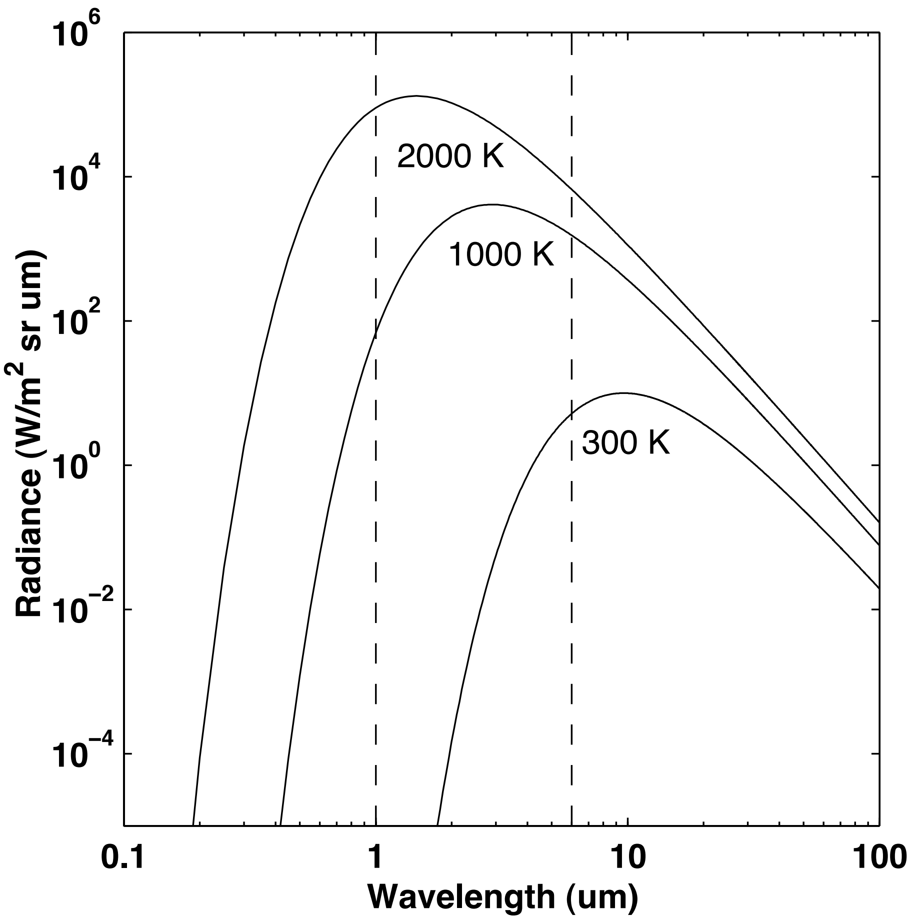
Pyrometry overview





Blackbody radiance (Power/area/solid angle)

$$L_{BB}(\lambda, T) = \frac{c_1}{\lambda^5 \left(e^{c_2/\lambda T} - 1\right)}$$

Challenge #1: Radiance measurements

- Nanosecond radiance measurements are difficult
  - Limited number of photons
  - Stray light mitigation issues
  - Single event experiments
- Low temperatures (<1000 C) demand IR sensing
  - Limited responsivity/bandwidth
  - Standard optical fiber doesn’t work beyond 2000 nm
  - Chromatic aberrations

Challenge #2: Temperature calculation

$$L(\lambda,T) = \varepsilon(\lambda,T)\frac{c_1}{\lambda^5\left(e^{c_2/\lambda T}-1\right)}$$

Underdetermined system!

- **Real materials are not blackbodies!**
  - **Gray body assumption only useful for closely spaced, narrowband measurements**
- **Emissivity= 1 - Reflectance - Transmittance**
  - **0≤ Emissivity ≤ 1**
  - **Well characterized at ambient conditions**
  - **~0.1 for metals (infrared)**
- **How does emissivity change under dynamic compression?**
  - **Material changes (temperature, pressure, phase)**
  - **Geometric changes (specular-diffuse)**

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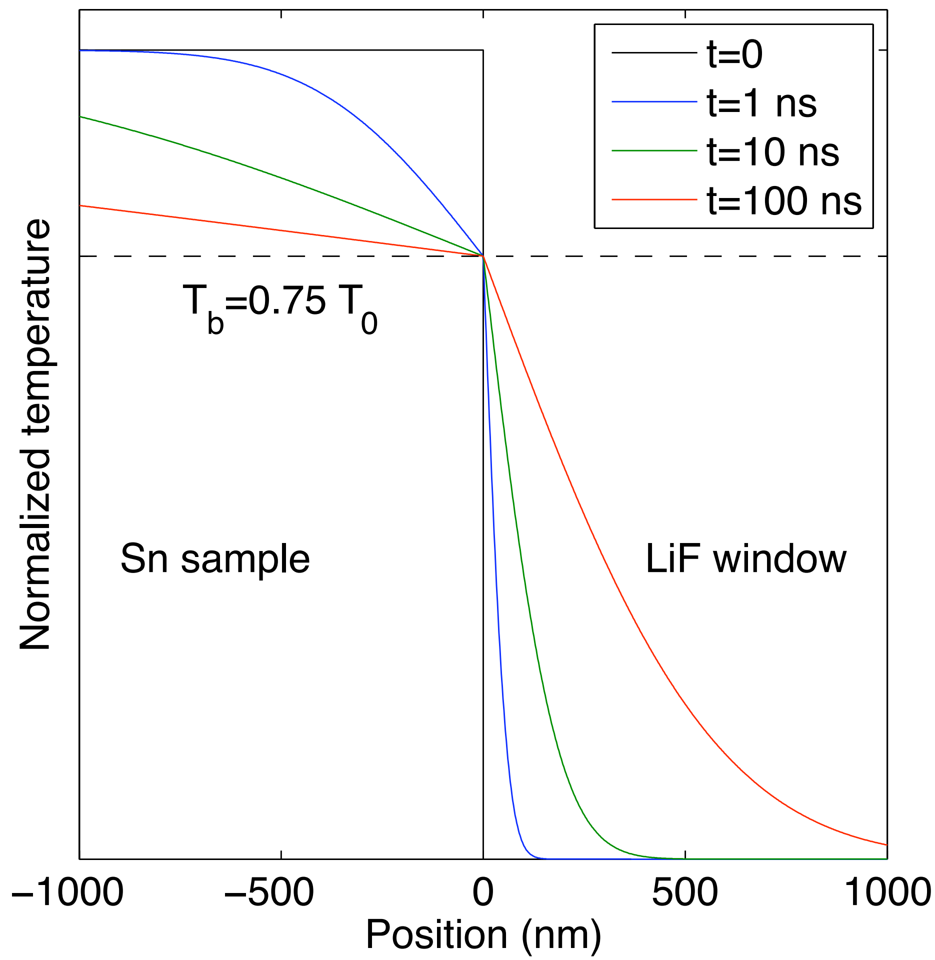
Challenge #3: Interpretation

- What temperature is being measured?
  - Window changes loading
  - Cold window draws heat from warm sample
  - What about epoxy?

- Windowless experiments...
  - Zero stress state
  - Spallation issues



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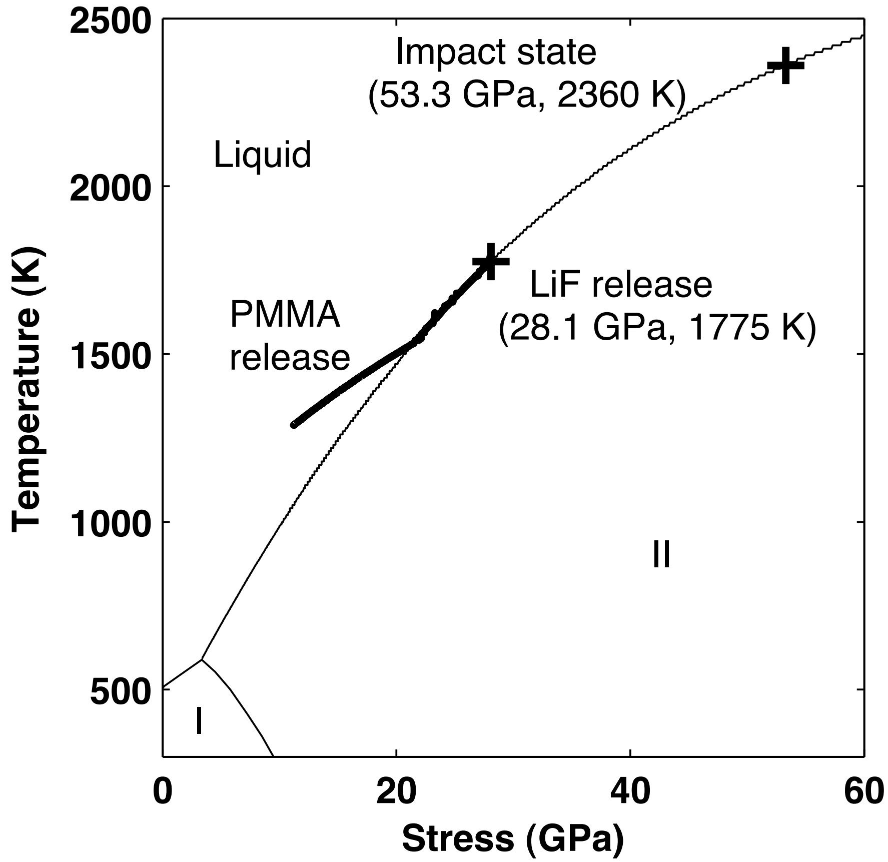
Challenge #4: Validation

- **How does one verify temperature?**
  - **No mechanical analogue**
- **Alternate diagnostics**
  - **Microsensors**
  - **Nuetron resonance spectroscopy (LANSCE)**
- **Mixed phase measurements**
  - **High pressure “ice/water bath”**
  - **Melt line data is ambiguous at high pressures**

Conceptual mixed phase measurement (Sn)



What can we do?

- Low temperatures demand IR pyrometry
  - Open beam relay
    - Mirror based to avoid chromatic aberrations
    - Only practical for short distances
  - New fiber materials: sapphire, fluoride
- Control the emissivity problem
  - High emissivity films
  - Dynamic emissivity characterization
  - Design probe to boost “effective emissivity”
- Design experiments to probe thermal conductivity
- Develop temperature standards
  - DAC melt line studies (resistive + laser heating)
  - Tailored samples?

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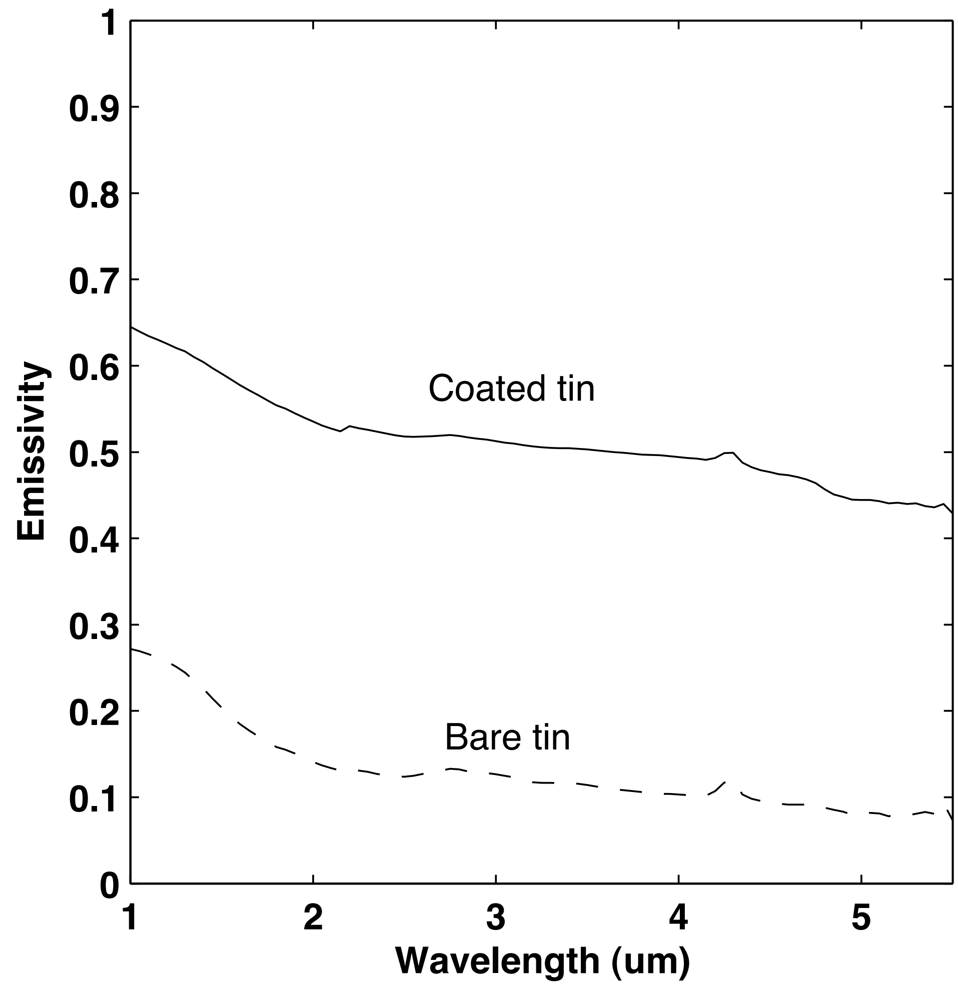
High emissivity films

- **Wanted: opaque thin films (<1 um) that are not reflective**
  - **Match sample temperature**
  - **Mimic blackbody emission**

- **Need to know (P,T) dependence**
  - **Then you have an emissivity standard!**



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Dynamic emissivity characterization

- Measure reflectance of opaque materials under shock compression
  - Controlled temperature
  - Well defined stress
- Bright, broadband light source required
  - NSLS VUV ring (Brookhaven National Laboratory)
  - Simultaneously cover near- and mid-infrared
- Many technical challenges
  - Few (if any) real time synchrotron studies
  - New environment for impact experiments
  - Reflectance geometry (specular vs. diffuse)

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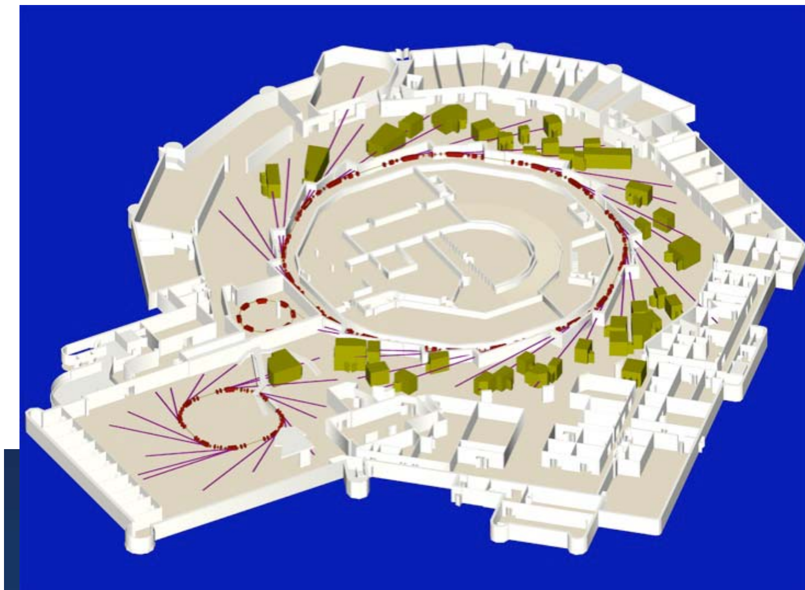
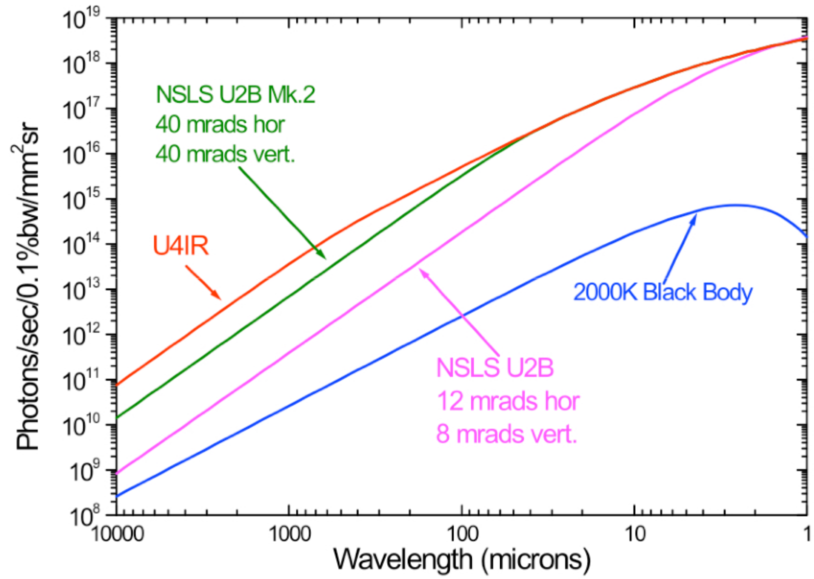
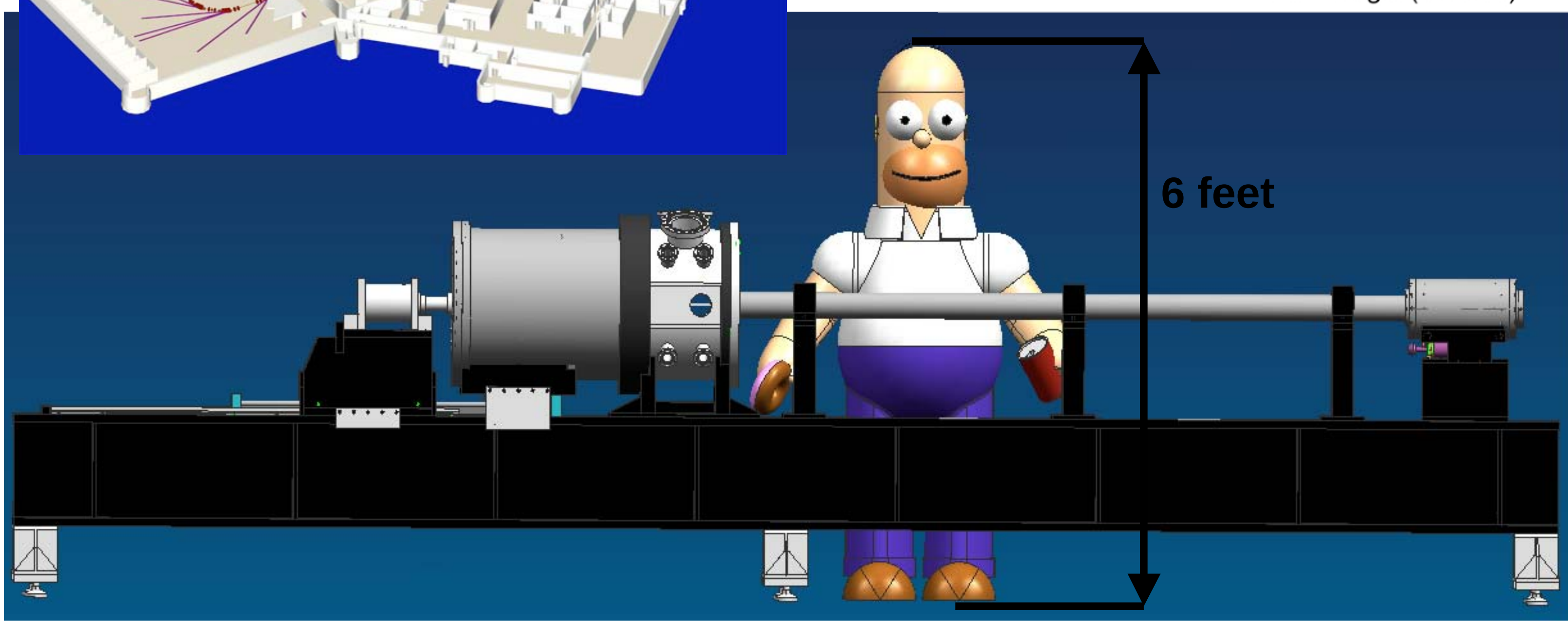
NSLS impact system

National Synchrotron Light Source (BNL)







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Summary

- Temperature measurements are hard, but important
- Numerous challenges remain
  - Practical issues
  - Emissivity problem
  - Interpretation (e.g., thermal conduction)
  - Validation
- Dynamic broadband emissivity measurements are forthcoming

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