Strategy position APS as World's Premier Synchrotron Facility Engineering Applications and Applied Research

Gene Ice (ORNL) *chair*·
Jon Almer (APS)·
Mark Daymond (Queens Canada)
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Lyle Levine (NIST)·
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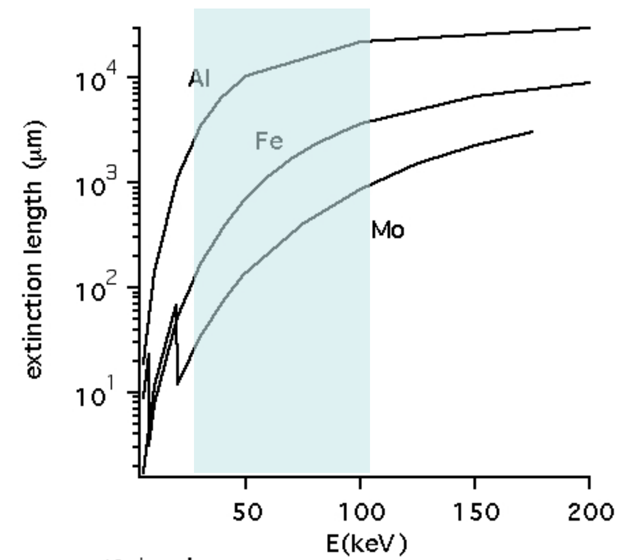
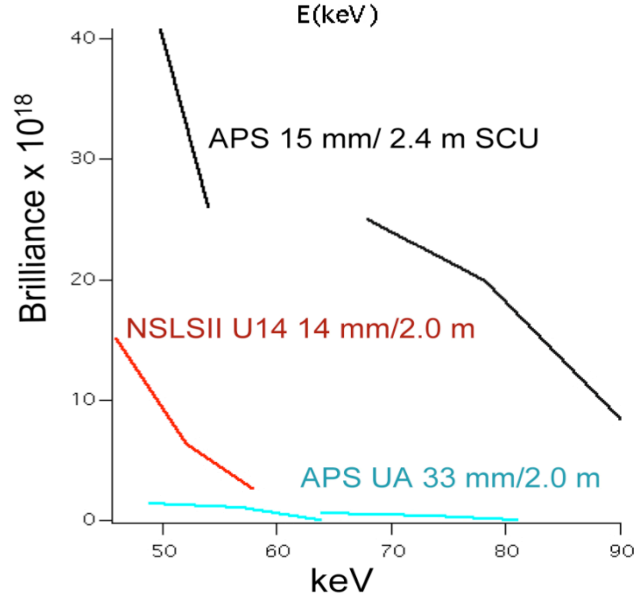
Angus Wilkinson (Georgia Tech)

APS Renewal Retreat 2008

Compelling message

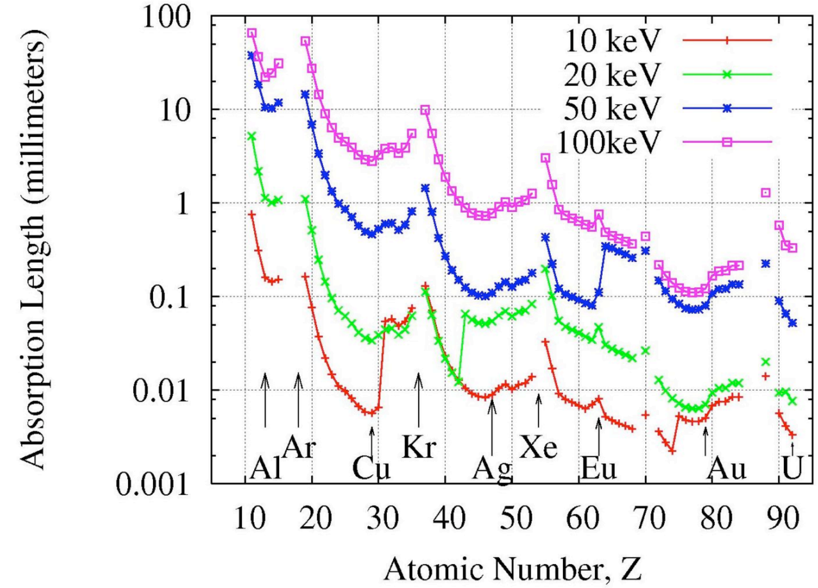
- Hard X-ray brilliance (20-100 keV) essential for engineering applications and applied research
- APS ***is and will remain premier U.S. x-ray source for high-energy brilliance***
- Demand is overwhelming available resources.
- Science critical to American competitiveness
- ***Investment now*** essential to maintain leadership/ meet demand

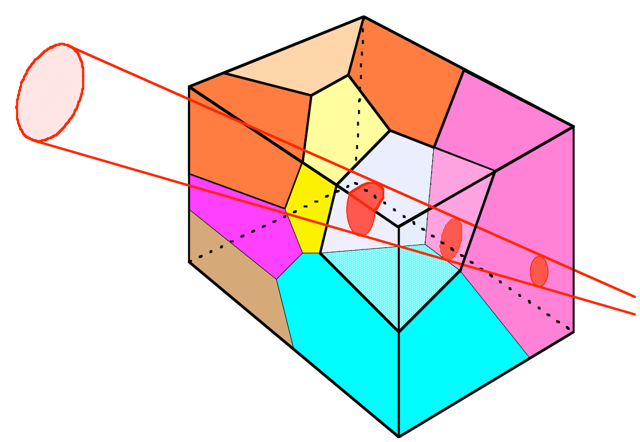




Hard x-rays brilliance critical to Engineering Applications and Applied Research

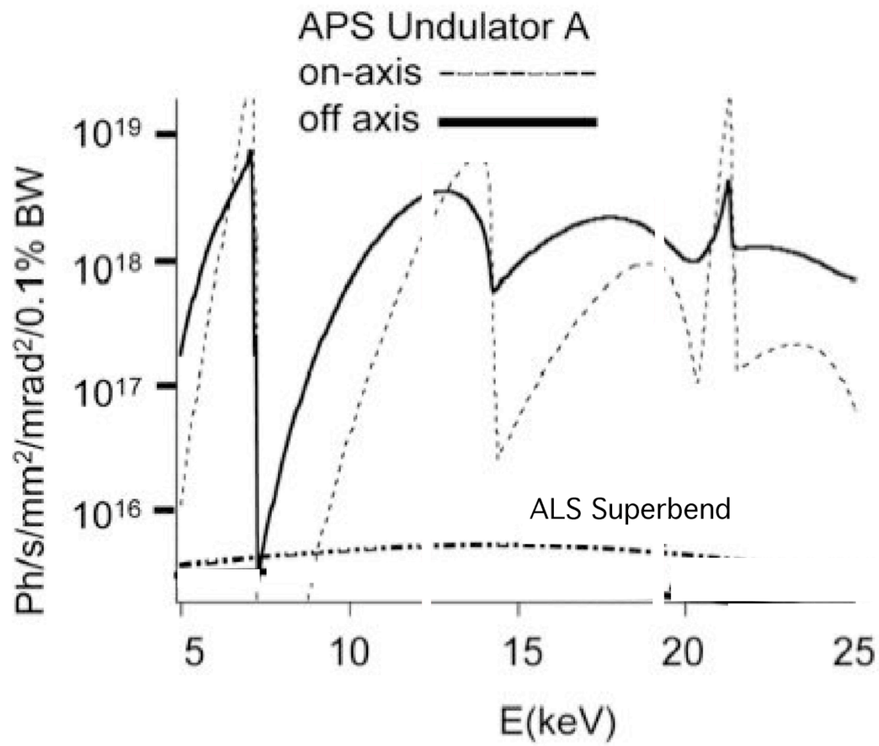
- Penetrating
  - 3D/ bulk behavior
  - Environmental chambers
- Nondestructive for many samples
  - Follow materials evolution
  - Watch complex pathways failure
- Spatially resolved
  - Resolve complex structures
  - Direct comparison to theory on length scales needed
- Real-time/ In-situ
  - Transient
  - Materials evolution

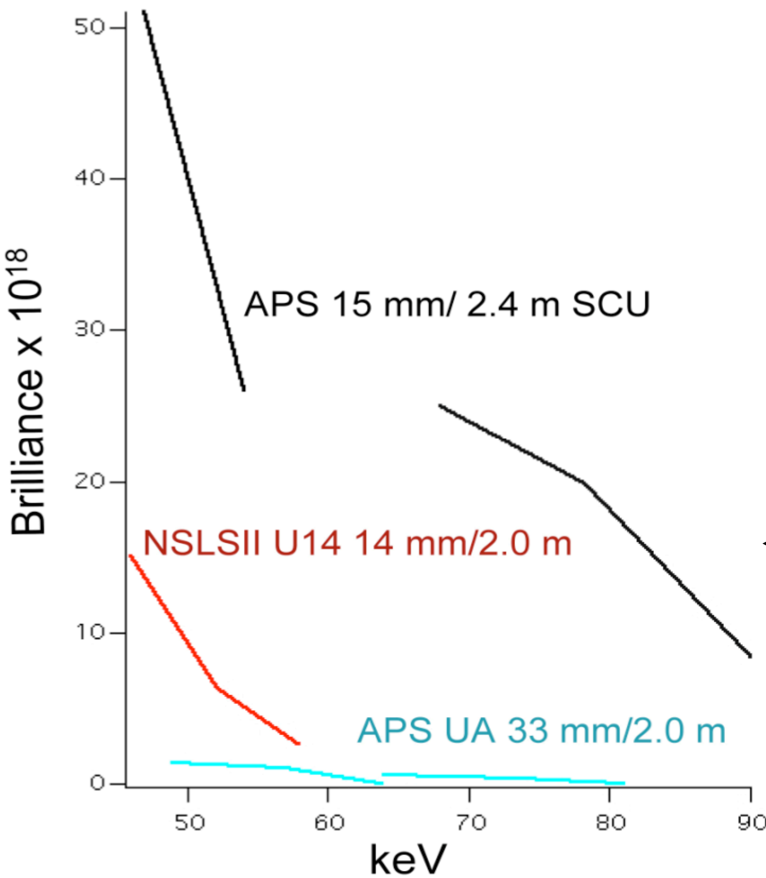




APS superior brilliance at high energies

- **4 orders > existing Western sources**





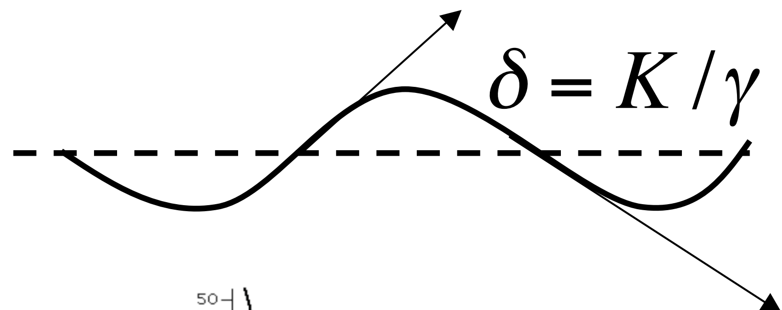
New undulators will outperform NSLSII

APS will need new undulators to maintain advantage

- Compare undulators with similar magnetic structures
  - Same field strength
  - Same magnetic period

$$K = eB_0\lambda_u / 2\pi mc$$
$$= 0.934\, B_0[T]\lambda_u[cm]$$

$$\delta = K/\gamma$$

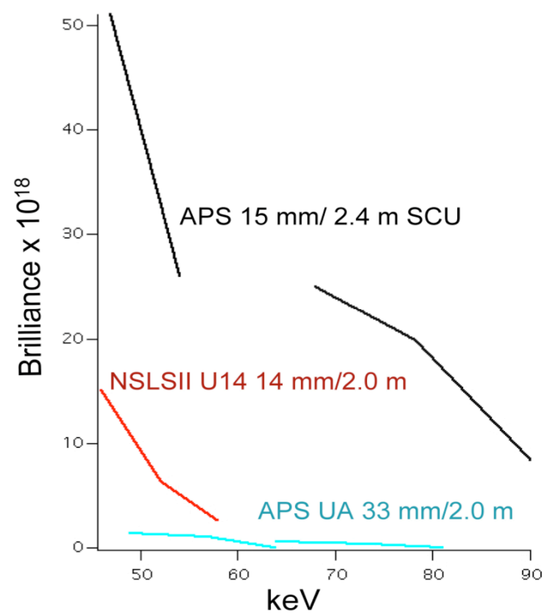


- Assume thermal loads can be accommodated-similar to NSLSII

$$P \propto \left(E^2 I\right)\left(B^2 L\right)$$

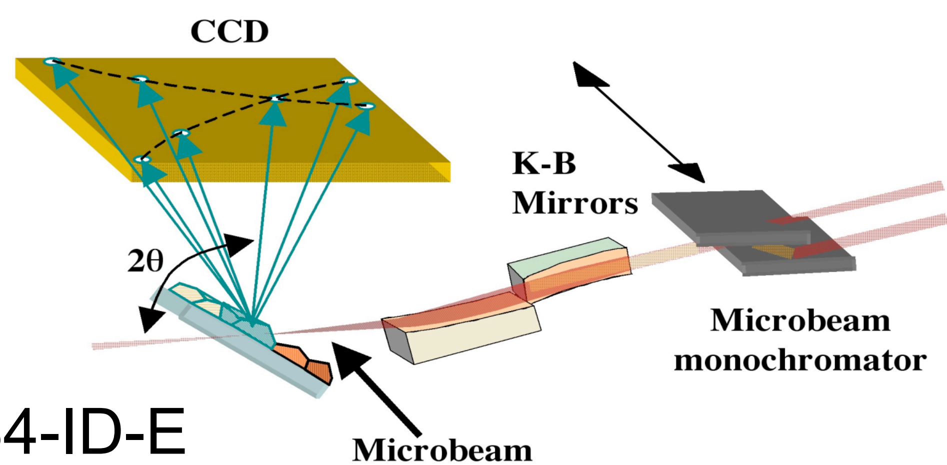
ring Insertion device

APS has superior high-energy brilliance and flux potential

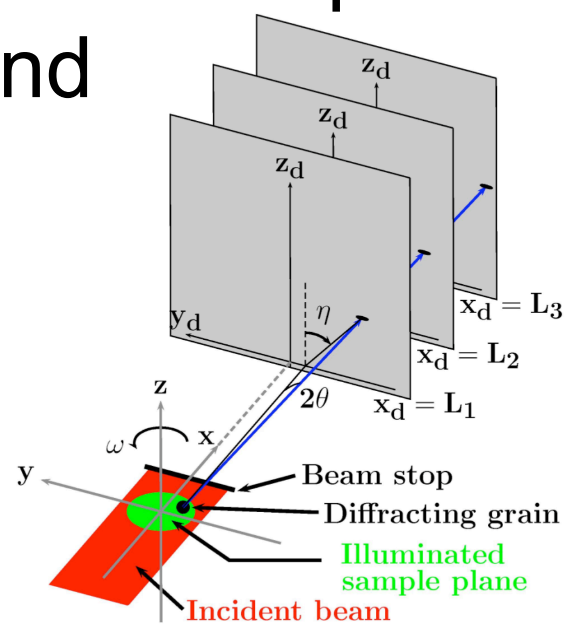


Existing resources overwhelmed

- > 400% oversubscription on some lines
- Outstanding ratings do not receive time
  - 1.5 not good enough
- Oversubscribed beamlines with multiple missions cannot meet demand



34-ID-E



1-ID

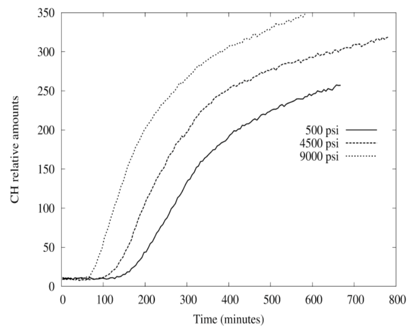
Scientific case has two components

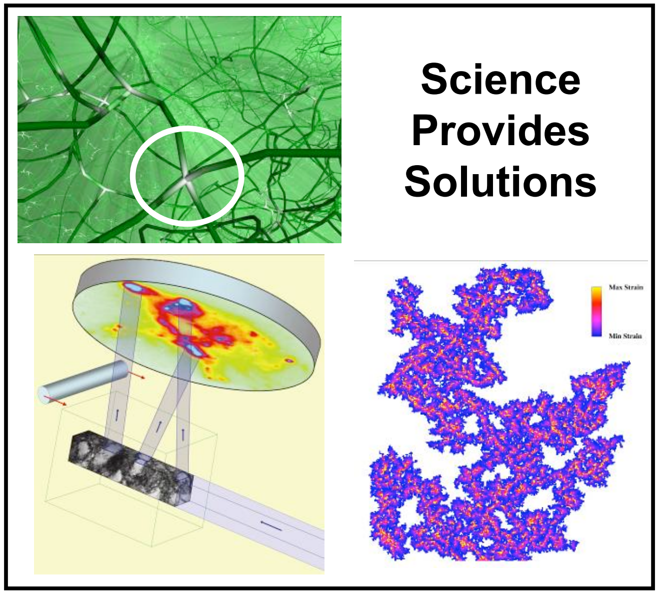
- Fundamental research on grand-challenge engineering-materials issues
  - Inhomogeneous Deformation/Fracture/Grain and phase evolution
  - Direct comparison to theory/ predictive theories

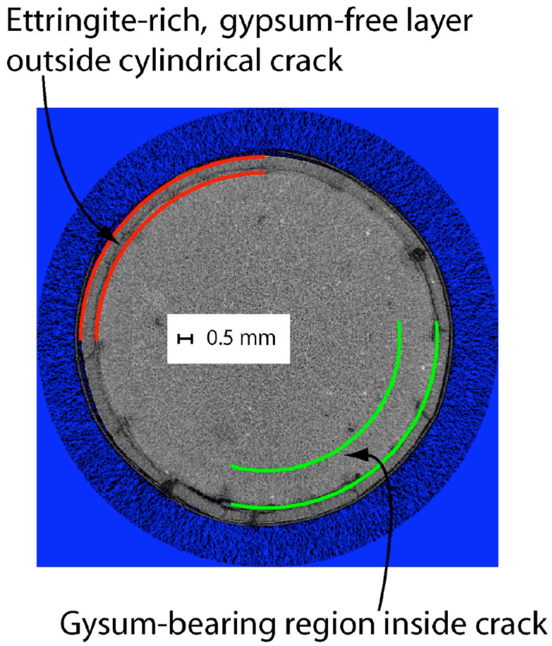
- Critical insights into *specific* applied issues with high impact on economy
  - Failure mechanisms-engineering parts/ stress corrosion/ Whisker growth/
  - Efficiency-combustion/fuel cells

"Concrete" scientific examples

- In situ 3D microscopy of structures, defects, strain
- Phase evolution
- Minor phases
- Tomography/ phase contrast imaging/radiography
- High impact and national priority examples!







Deformation of Metals at the APS

NIST National Institute of Standards and Technology

Lyle Levine

Reducing the Economic and Environmental Price of Energy *Dependence*

Reducing the weight of automobiles and light trucks by just 10 % would reduce U.S. oil imports by approximately 8 %, saving $36 billion/year at $90/barrel.

Policy and Legislation Defining Government Role

GM

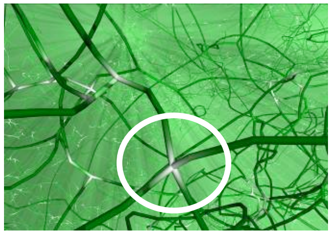
Industry Requests Help

USS

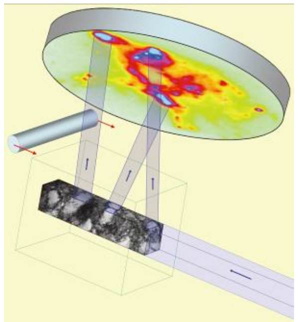
CHRYSLER

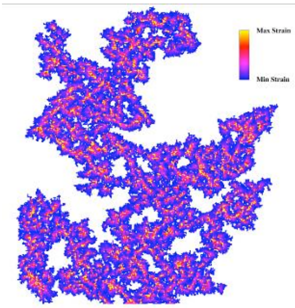
ALCOA

Ford



Science Provides Solutions

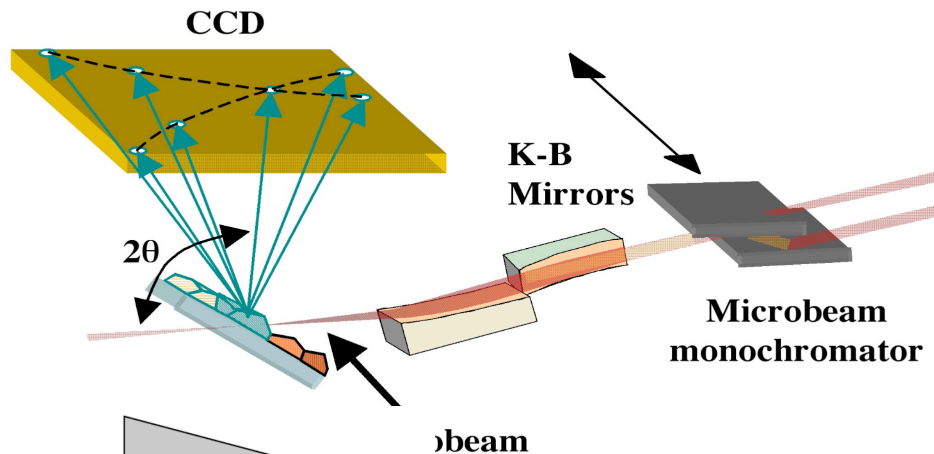


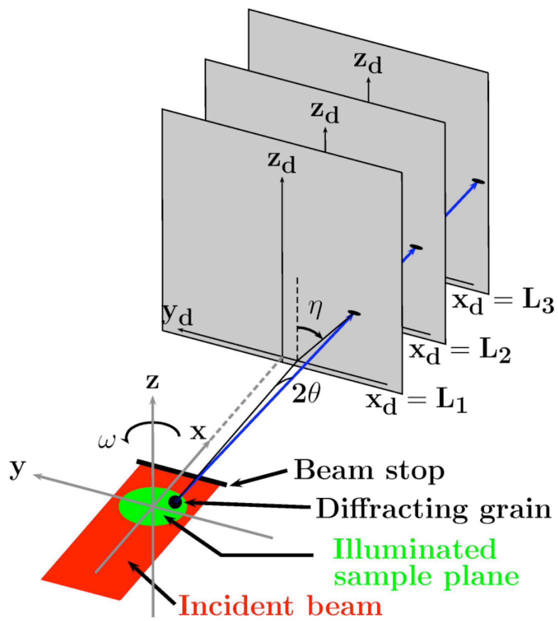


Deformation is an area where APS has leadership

- **Only 3D polychromatic microprobe**
  - **<1 μm spatial resolution**
  - **Quantitative elastic strain tensor and Nye Tensors**

- **Advanced 4D microprobe**
  - **In-situ evolution**
  - **Deep penetration**



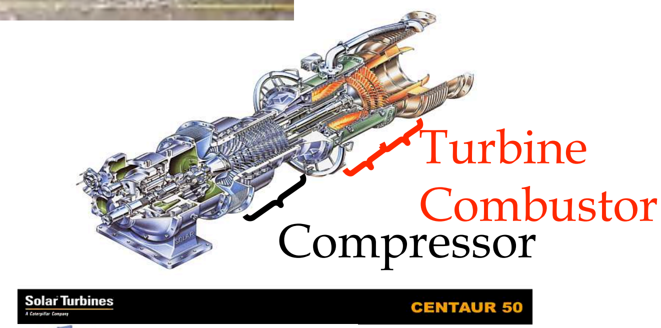


Investment needed to maintain-extend leadership position

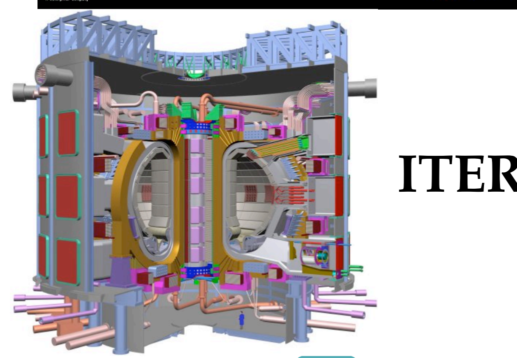
EAAR-based challenges

- Critical infrastructure – fundamental mesoscale properties of 'common' materials (steels, cements) including fatigue, corrosion and fracture.

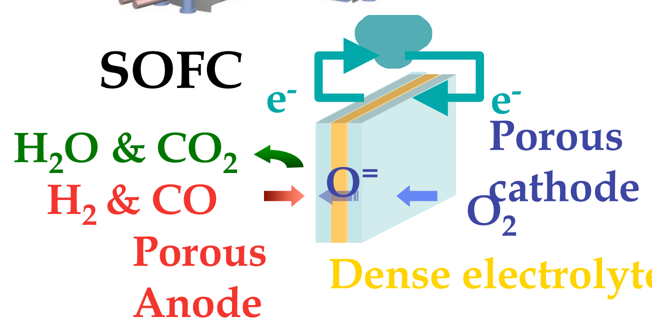
- Energy efficiency: (1) advanced lightweight materials, (2) advanced tribology, (3) high-temperature systems (e.g. TBC-based turbine blades).



- Fission – (1) microstructural evolution and phase stability in fuels, claddings and waste forms, (2) verifying critical component integrity (e.g. welds)
- Fusion – extreme conditions require new materials (e.g. ODS-steels, SiC/SiC composites)

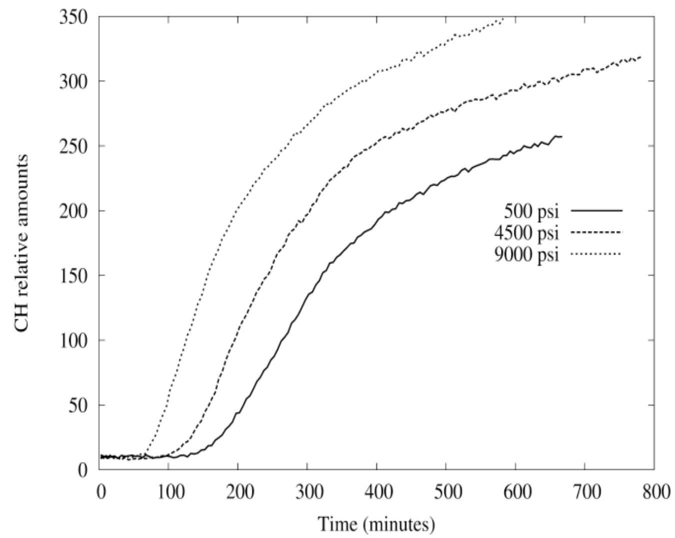


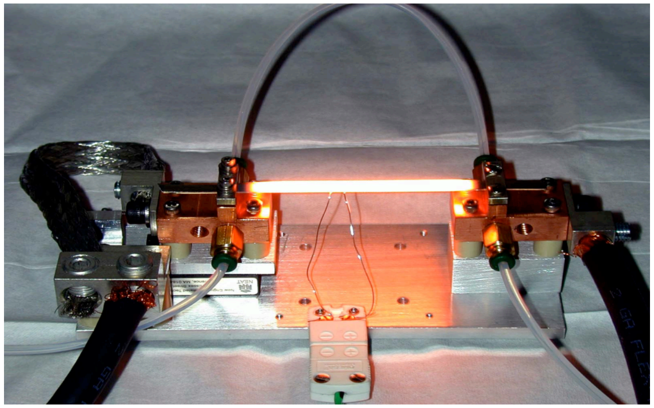
- Energy conversion – electrode/electrolyte interfaces in fuel-cells, batteries



In-situ phase evolution guides understanding

- Cement evolution vs. pressure
- Phase retention during rapid cooling/heating
- Oxide formation/ strain

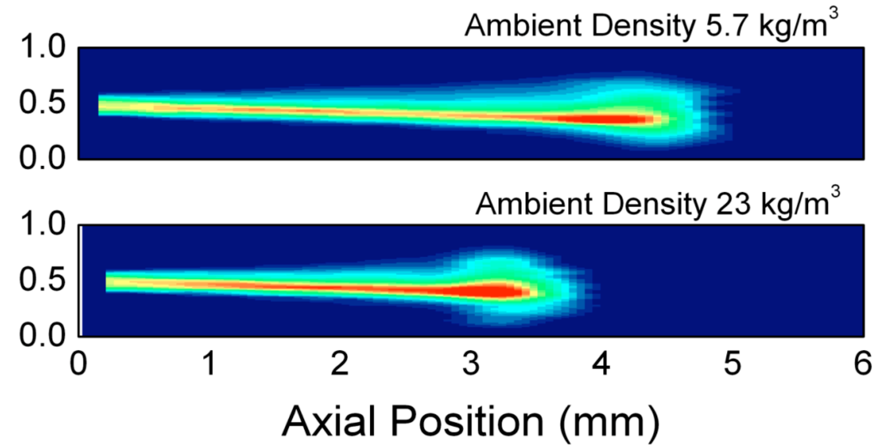


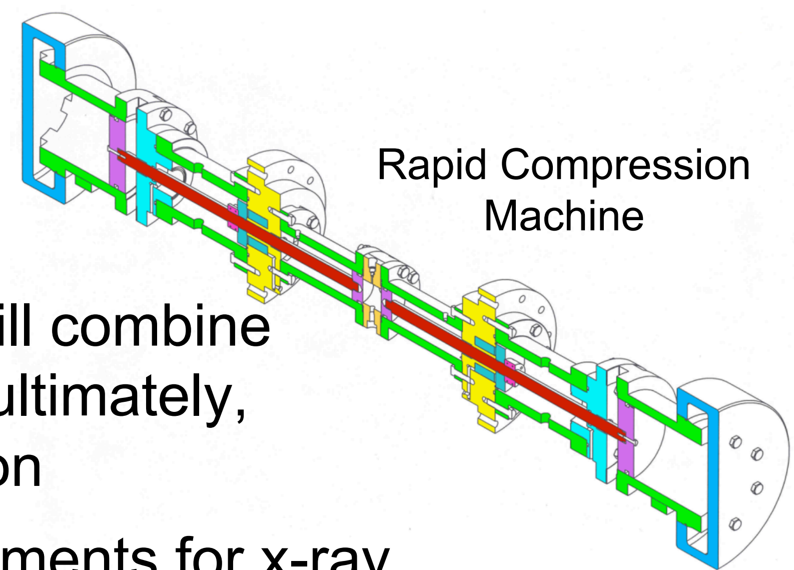


Tortorelli:Corrosion Strain evolution during in-situ oxidation

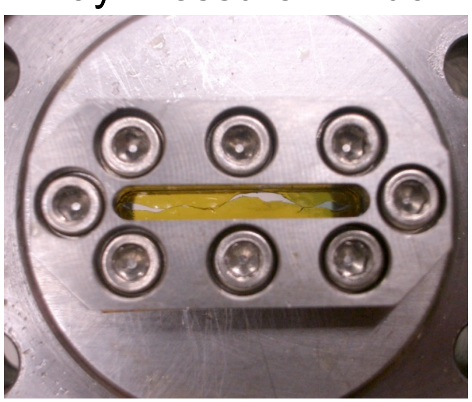
Fuel Spray Characterization Using X-Ray Diagnostics at High Temperature and Pressure

- Fuel Injection occurs at high T, P
- Measurements must mimic these conditions to remain relevant
- Current studies can match in-cylinder density



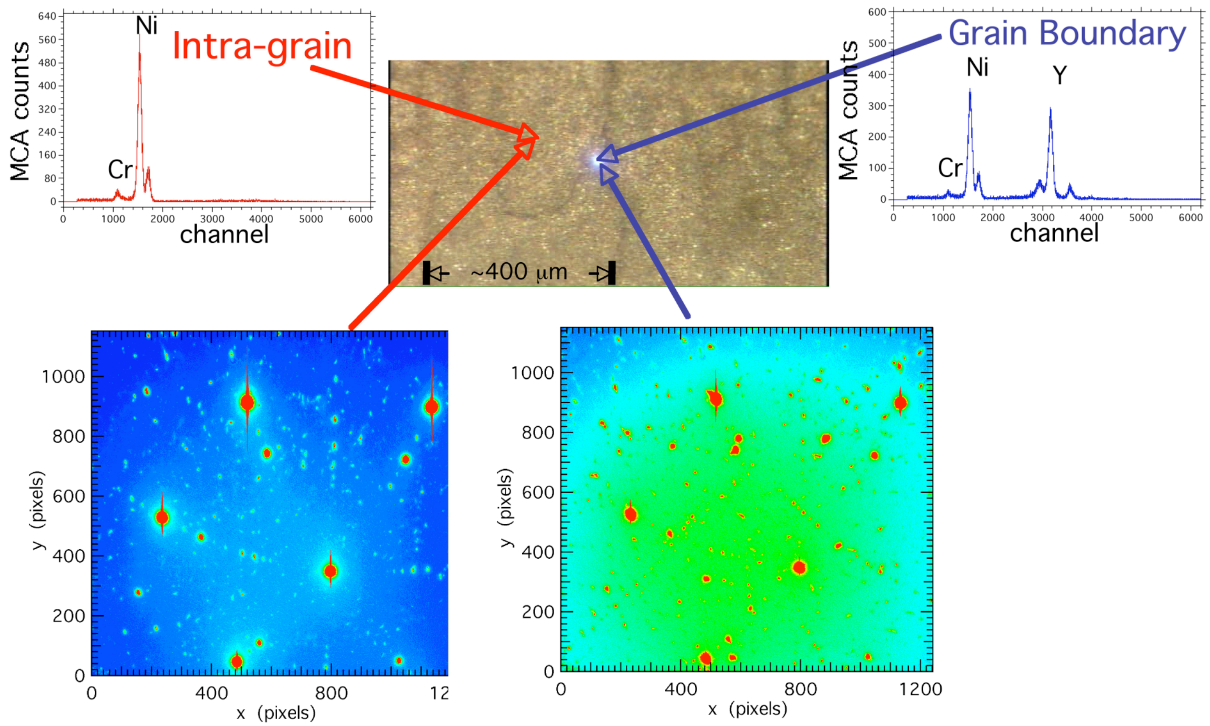


X-Ray Pressure Window



- Future studies will combine high P & T, and ultimately, rapid compression
- Stringent requirements for x-ray windows

Combined techniques multiply power



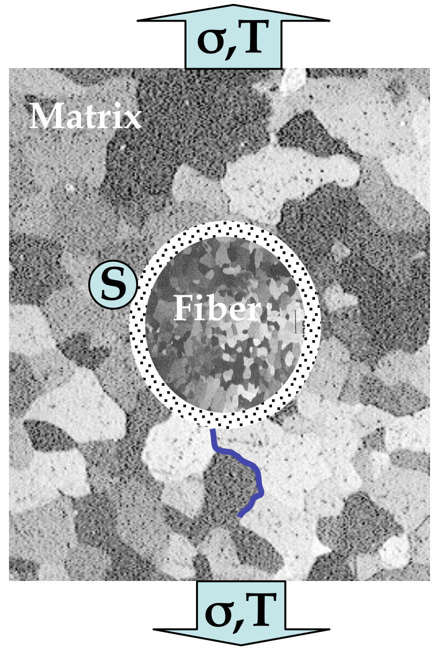
Key is to avoid compromise

Combined techniques needed in many problems

Full-field imaging (1um-mm)

SAXS/WAXS (local)

External probe, eg:
- **Photoluminescence**
- **Digital image correlation**



Area detectors for each mode

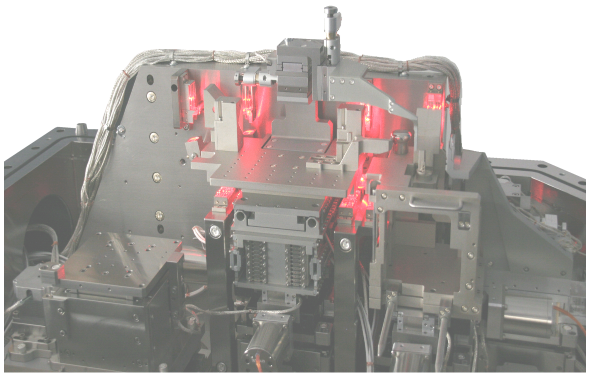
- Non-invasive 3-D probes
- *In situ*
- Multi-scale
- Imaging
  - 'big picture' ustructure
- WAXS/SAXS
  - Strain
  - Phase fractions
  - Porosity
  - Texture

Enhancing NDE
- 'Smart' materials == embedded sensors for damage monitoring
  - fiber composites (aircraft, turbines); reinforced concrete; biomaterials
  - sensors include piezos, fiber optics, resistive wires, tracer phases
- Use X-rays to quantify key quantities
  - strain in sensors and parent phases
  - microstructural evolution (cracking, corrosion products, etc)
  - monitor sensor output simultaneously (eg. PL in Al_2O_3 tracers)

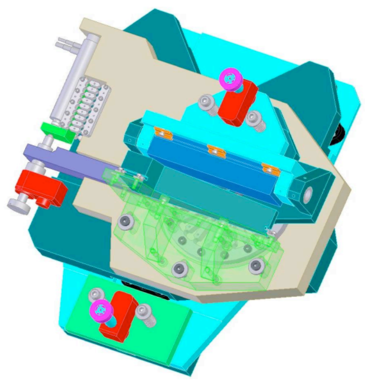
***In situ* process monitoring**
- Welding
- Material formation
  - Concrete – shrinkage etc
  - Recrystallization
- Tribology

New generation of optics essential for next level of spatial resolution

- ***Both passive and active control schemes are needed for a thermally and vibrationally ultra stable hardware system***
- ***Advanced nanopositioning technique is the key for ultra stable hardware design***



Scanning stages with laser-based active vibration control for nanometer scale repeatability and stability requirement

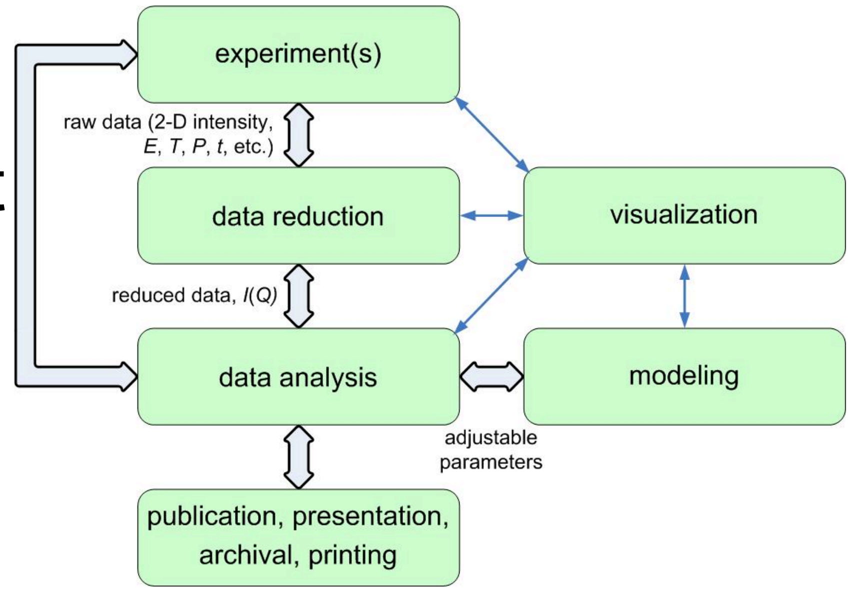


Weak-link versatile collimating crystal stage for Bonse-Hart USAXS Instrument with 100-nrad scale stability

- ***Experiment with variable sample environment control is a challenging case for ultra stable apparatus design***

Software is key

- All APS experiments rely on software
- Often, research teams are left to coordinate data acquisition software with science objectives
- Majority of contemporary experiments conducted “open loop”
(that is, analysis is started only after beam time is complete)



Investment *now* essential to meet demand and leverage unique opportunies

- More dedicated high-energy beamlines- increase capacity/ cope with demand

- Advanced undulators-extend capabilities/ insure APS maintains leadership in U.S./ competitiveness worldwide

- Better optics and detectors-Throughput/capabilities

- Sophisticated “smart system” data analysis and collection software
  - Higher throughput
  - Wider community of users

9 specific recommendations

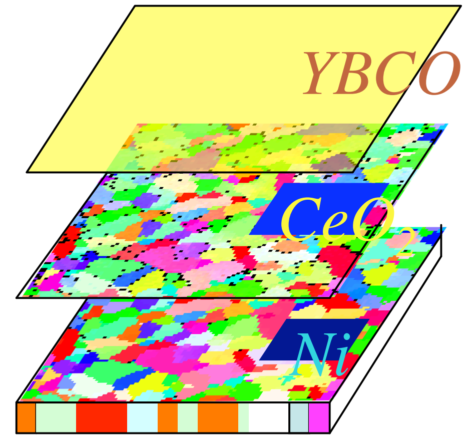
1. Dedicate a high-energy beamline for PDF, SAXS and powder diffraction with phase and strain sensitivity and good spatial resolution.
2. Build a dedicated high-energy diffraction microscope with extinction tomography, diffraction tomography, and strain sensitivity.
3. Build a dedicated polychromatic nanoprobe hutch and install canted undulators on 34-ID to allow for simultaneous and independent use of polychromatic mesoscale and nanoscale probes.
4. Optimize at least one bend-magnet beamline for high-energy energy-dispersive diffraction.

Recommendations continued

5. Develop a dedicated high-energy tomography station with phase contrast sensitivity.
6. Develop a range of environmental chambers for powder diffraction and SAXS targeted for catalysis, thermo-mechanical loading and other applied studies.
7. ***Develop user-friendly "expert" software for all engineering stations that insures users walk away from experiments with data sufficiently processed for analysis at their home institution.***
8. Coordinate combined techniques/characterizations to follow materials evolution.
9. Develop user-friendly mail-in capabilities in anticipation of the growing difficulty of travel with high energy costs.

Questions?

- Other applications?
  - Combinatorial science
  - Biomimetics



- Is message clear?
  - Too detailed?
  - Not coherent?
- What else needed?
  - It's the economy stupid!

Industry Requests Help

Engineering Applications and Applied Research Breakout Session

2:00- 2:05 Gene Ice charge to working group: ***Concrete scientific problems that can be addressed by APS renewal.***

Science drivers

2:05-2:15 Lyle Levine: Deformation of Metals
2:15-2:25 Robert Suter: Dynamics of polycrystalline materials
2:25-2:35 Matthew Miller: Measuring and modeling stress state where it matters: in the grains .
2:35-2:45 Gene Ice: Fracture/Transient and interface phases/ structures
2:45-2:55 Stuart Stock: Biomimetics and Phase-contrast High-energy tomography/radiography
2:55-3:05 Chris Powell: Extreme environmental chambers/conditions
3:05-3:15 Jon Almer: Addressing engineering challenges using combined techniques

Floor presentations of science drivers and discussion of science case
3:15-3:45

Technical possibilities

3:45-3:55 Dean Haeffner: Undulators
3:55-4:05 Pete Jemian: Software
4:05-4:15 Deming Shu: Ultra stable hardware
4:15-4:25 Steve Ross: Detectors

Follow up discussions and presentations from the Floor
4:25-5:00