MSN-C Structural Materials Beamline(s)

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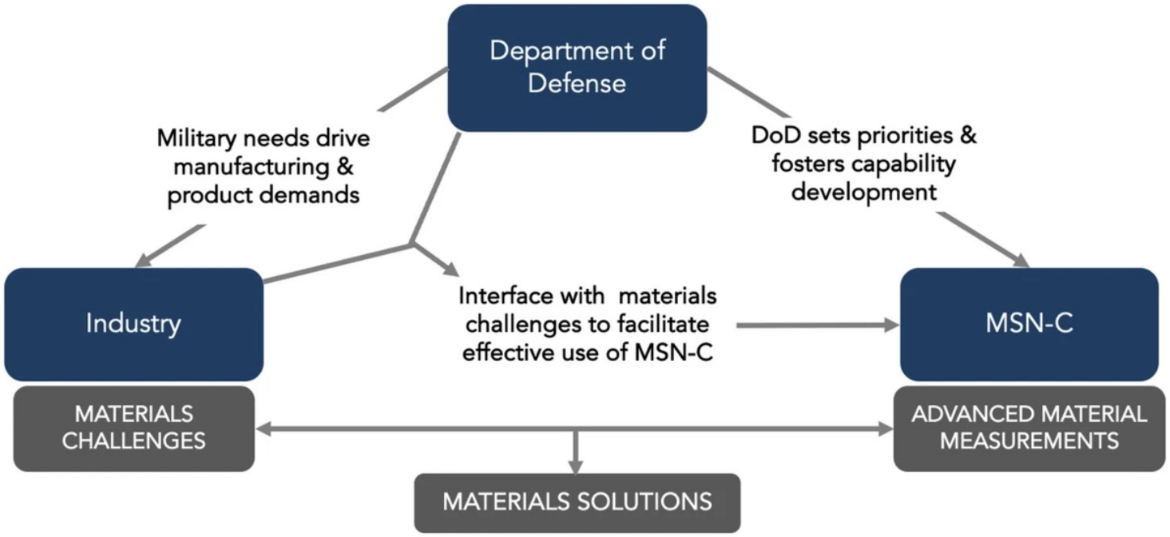
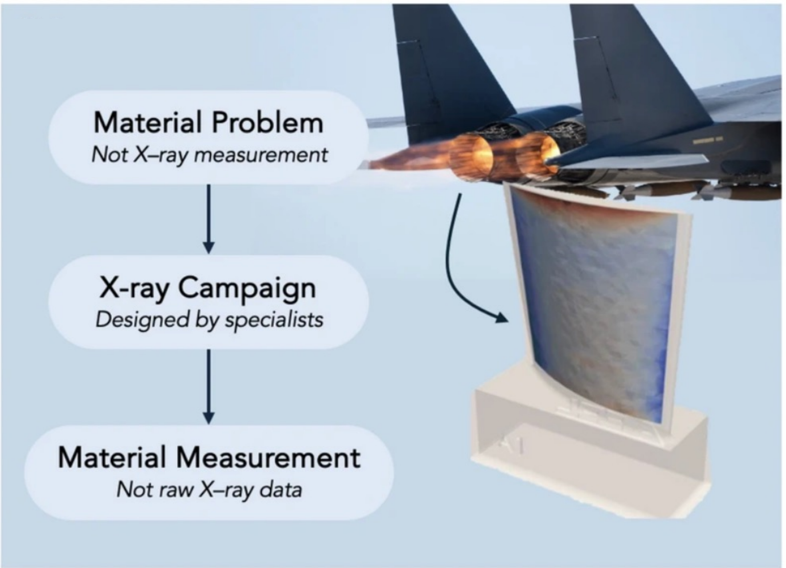
16 Aug 2026

Beamlines Provide Critical Measurements

MSN-C Mission: To advance critical materials solutions for ***defense researchers and industry partners*** through dedicated access to world-leading non-destructive measurements and analysis





DoD maximizes the application of techniques to a broad range of problems, facilitating **industry access on a per-measurement basis**

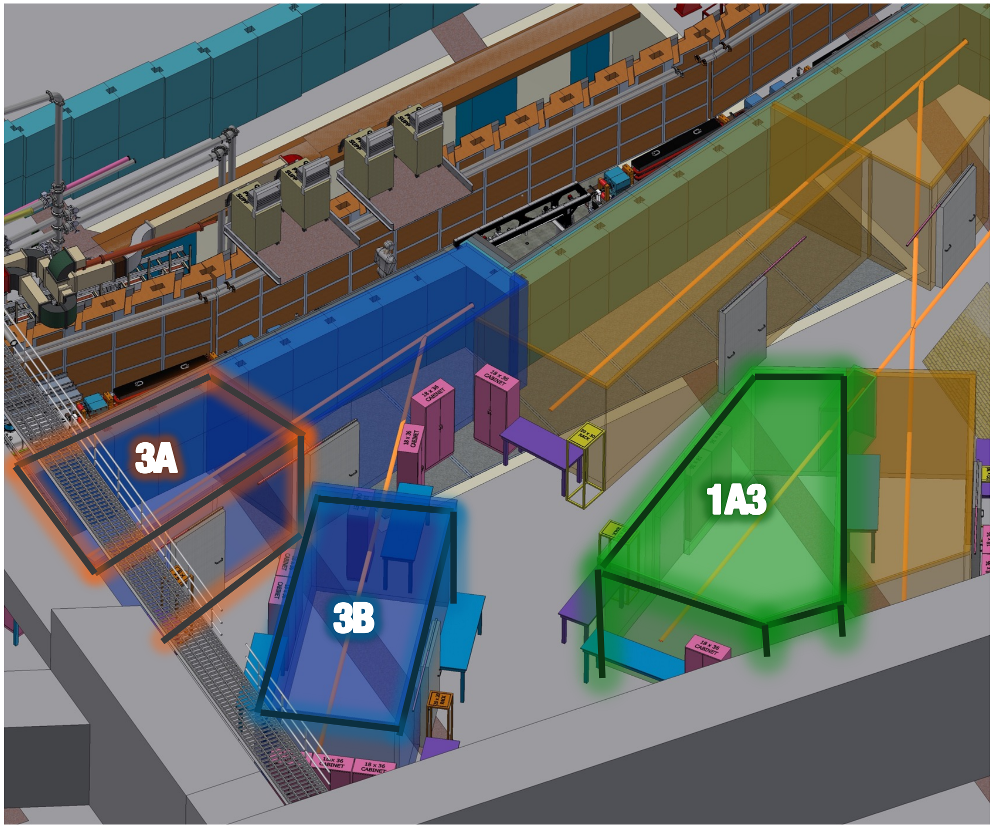
- ✓ Beamlines & Missions
- ✓ Standard Measurements
- ✓ Nuts and Bolts
- ✓ How we get it done

MSN-C Beamlines

All MSN-C beamlines optimized for X-ray **Imaging** & **Scattering**

Forming and Shaping Technologies (3A)
(structural materials)
(CHEXS)

Functional Materials Beamline (3B)
(MSN-C)



Structural Materials Beamline (1A3)
(MSN-C)

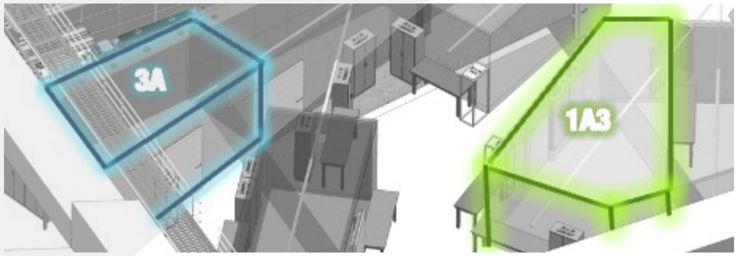
No hard rules on what science can happen at which beamline
Optimized for dense and less dense materials
Ceramic composites fall in the middle of both capabilities

Two Structural Materials Beamlines

Beamlines honor a SWAP program to leverage each program's specialized instrumentation

FAST Beamline Station 3A

Optimized for high-rate studies with monochromatic beam



SMB Station 1A3

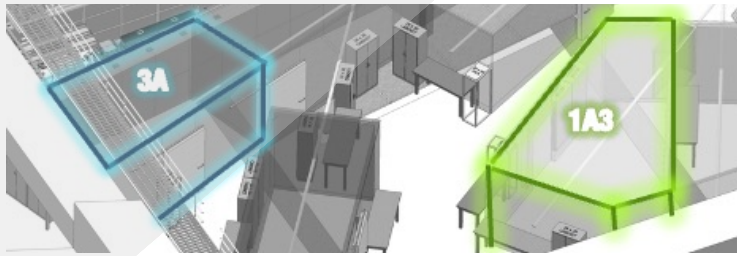
Optimized for dense materials high energy and white beam

Complementary structural materials beamlines

Beamlines honor a SWAP program to leverage each program's specialized instrumentation

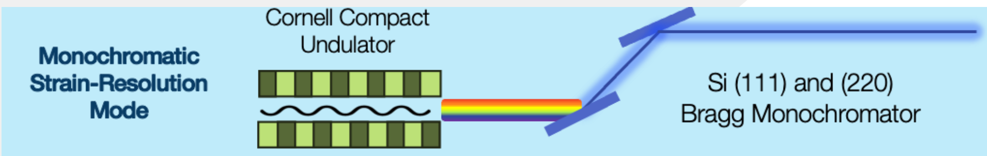
FAST Beamline Station 3A

Optimized for high-rate studies with monochromatic beam



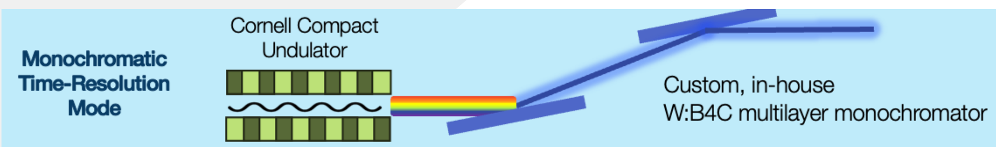
SMB Station 1A3

Optimized for dense materials high energy and white beam

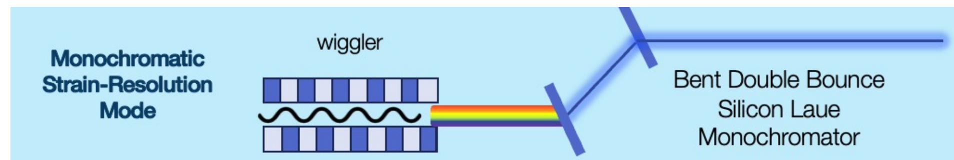


111 crystal set **(20 - 42 keV)**
- Bandwidth: ΔE/E = 2×10^{-3}

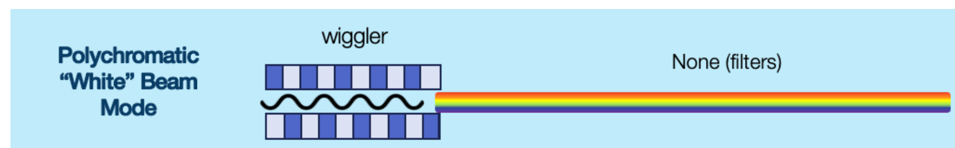
220 crystal set **(40 – 70 keV)**
- Bandwidth: ΔE/E = 6×10^{-4}



10-30x increase in flux compared to DCM
- Bandwidth: ΔE/E = 2.9×10^{-2} (30 keV), 5×10^{-3} (60 keV)



Energy Range **(40 - 90 keV)**
- Bandwidth: ΔE/E < 4×10^{-3}



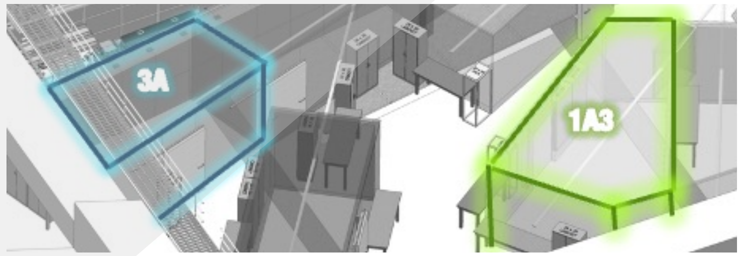
Continuous Wiggler spectrum from 50-200keV

No focusing optics - beam size defined by slitting

Beam Size	Biggest (w x h)	Smallest (w x h)
Monochromatic	2 mm x 1 mm	20 um x 20 um
White Beam	20 mm x 2 mm	5 um x 5 um

Complementary structural materials beamline programs

Beamlines honor a SWAP program to leverage each program's specialized instrumentation



FAST Program
CHEXS NSF-funded

Developing Techniques, Encouraging Discovery and Exploration
Emphasis on novel problems

High Rate + Material Processing

Open User Program

SMB Program
MSN-C DoD-funded

Maturing Techniques, Developing Standards, Automation
Emphasis on applied problems

Material Performance & Residual Stress

Closed User Program

SMB Mission:

- Transform X-ray techniques from academic capabilities to engineering tools
  Development of standards, automation and mature workflows
- Prioritize maturation of select techniques over measurements that are unique / first-of-a-kind
- Prioritize applied measurements that address a defense problem over measurements that lead to a scholarly publication

Explicitly cater to materials/mechanical domain experts with the assumption they will NOT become X-ray experts

The Structural Materials Community

Structural materials can sustain a load or withstand impact

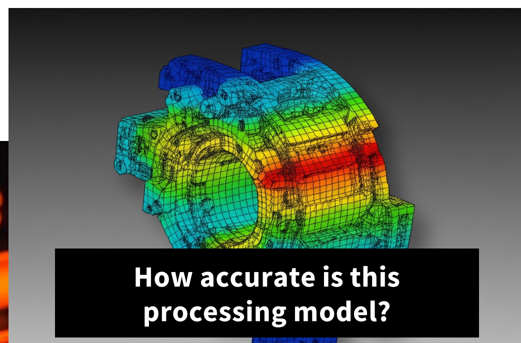
Primary focus to date has been ***engineering alloys***
some coatings, ceramic composites, CMCs

①
Materials and processing we *already* use

Current understanding allows for ***managing*** use of these materials and processes

②
Materials and processing we need to design

Current understanding allows for ***trial and error*** to design these materials and processes



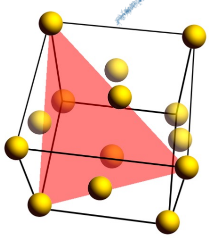
③
New Alloying Strategies and Advanced manufacturing techniques

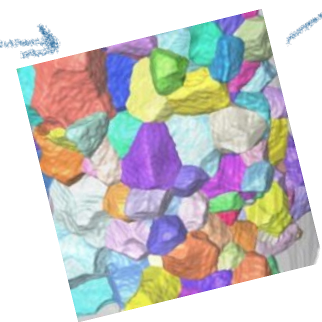
④
Parts sometimes fail in service

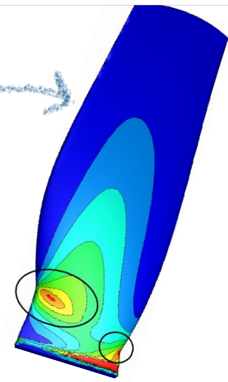
Measurements required at **critical length scales** within parts, to understand what's happening inside the material—at **relevant times** during **processing, manufacturing,** or **service conditions.**

Synchrotron X-rays are an invaluable probe for structural materials

Crystalline structure enables **diffraction-based techniques**— directly probing **atomic arrangements across length scales**







Synchrotron X-rays are a *non-destructive* probe that can **resolve the micromechanical and microstructural state of crystalline solids**

(phase, orientation, or strain mapping)

Engineering alloys are **dense** and require **high-energy X-rays** for penetration

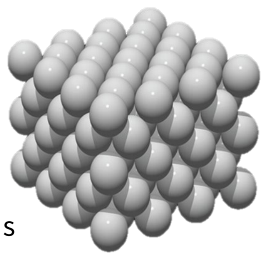
SMB's "white beam" can penetrate 40 mm of steel

Microstructure of the material dictates its behavior… it also **dictates the accessible techniques**

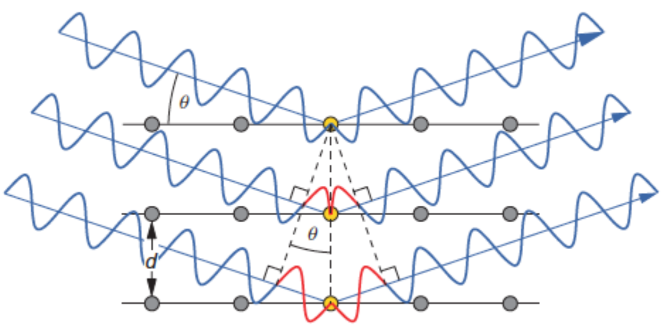
Transmission Diffraction Techniques

Braggs Law

$n\lambda = 2d\sin\theta$

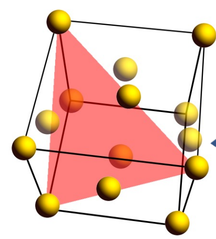


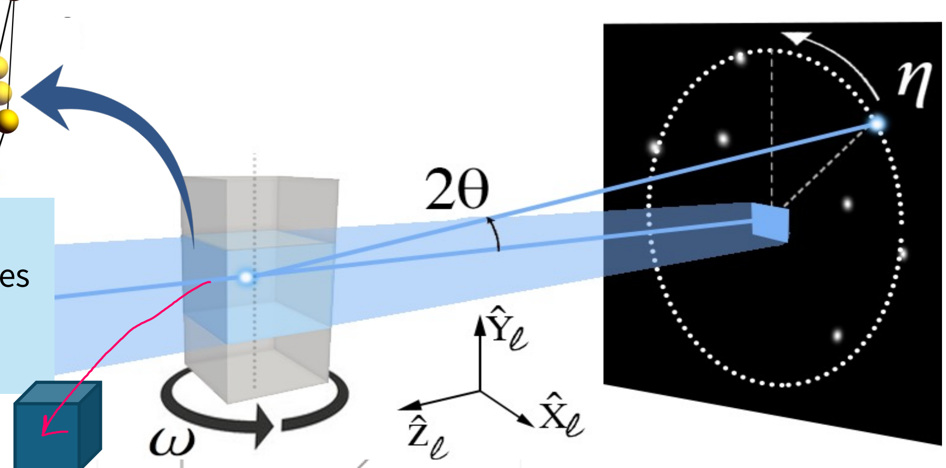
λ = wavelength of light
d = spacing of planes of atoms
θ = diffraction angle



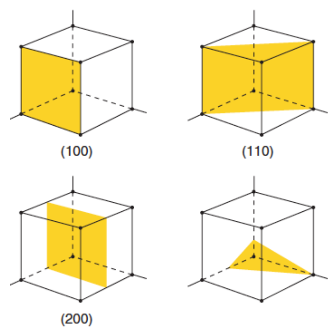
Utilize Large-Format Area Detectors

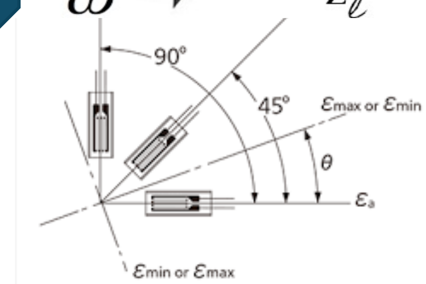
- **> 1 ft x 1 ft area**
- **18 million pixels**





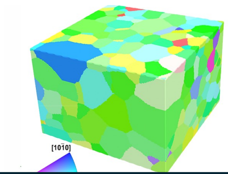
Captures:
Spacing of lattice planes
Crystal orientations
Crystal type

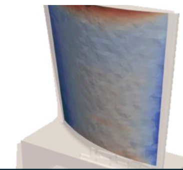




Rotating enough, we can extract microscale strain tensors for **calculating stress**

Microstructure and diffraction volume dictate the information we can extract



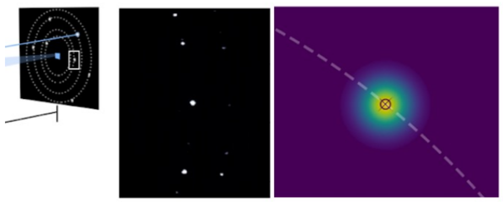


Isolated Peaks

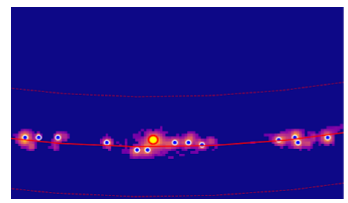
Overlapping Peaks

Contiguous Diffraction Rings

Monochromatic
discrete energies
18 – 90 keV

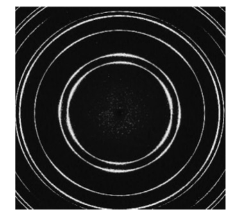


Crystal-differentiated
micromechanical and
microstructural state



Region-averaged
phase and
orientation state

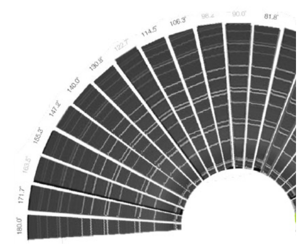
Area of active
investment



Region-averaged
micromechanical and
microstructural state

Polychromatic
White Beam
Continuous Spectrum
50-200 keV

Crystal-differentiated
microstructural state



Region-averaged
micromechanical and
microstructural state

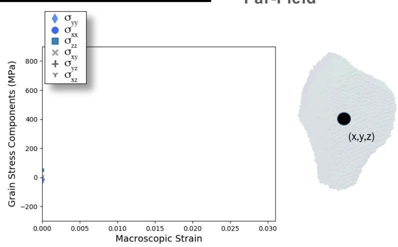
Workhorse Techniques/Capabilities

Monochromatic Techniques

High Energy X-ray Diffraction Microscopy

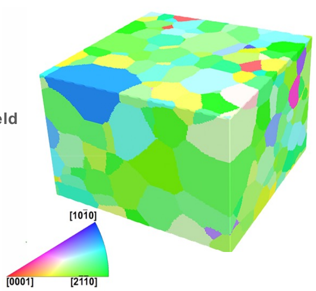
PROVIDES:
Grain centroid
Grain strain tensor
Grain orientations

Far-Field



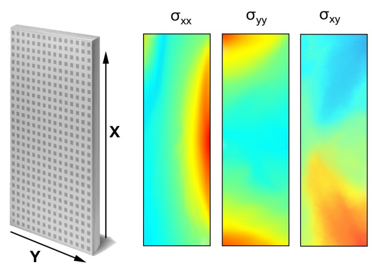
PROVIDES:
Spatial orientation maps of grains
Grain morphology

Near-Field

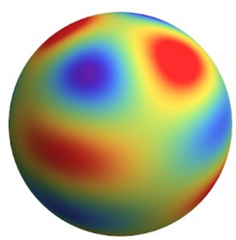


Angular Dispersive X-ray Diffraction

PROVIDES:
1D, 2D stress/strain distributions

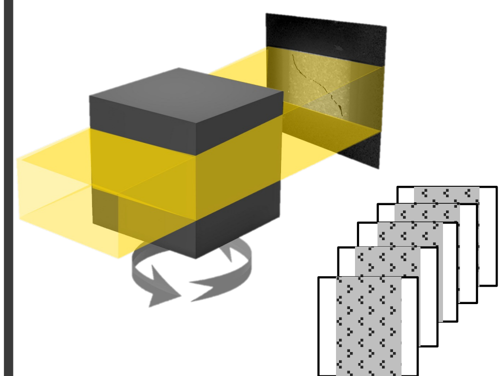


PROVIDES:
Texture pole figures
Strain pole figures



Absorption Tomography

PROVIDES:
Variation of porosity/cracks
Variations in phase

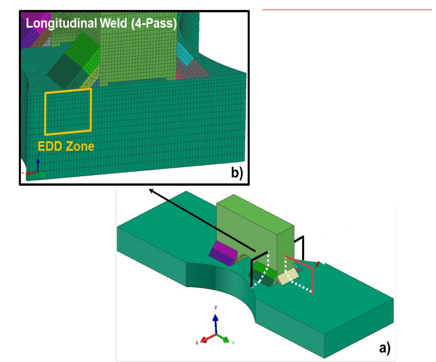


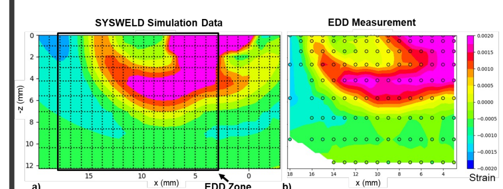
Sample is rotated 180° and a series of projection images are obtained

Polychromatic Technique

Energy Dispersive X-ray Diffraction

PROVIDES:
High-throughput, spatially-resolved distributions of strain / texture in large volumes (cm)

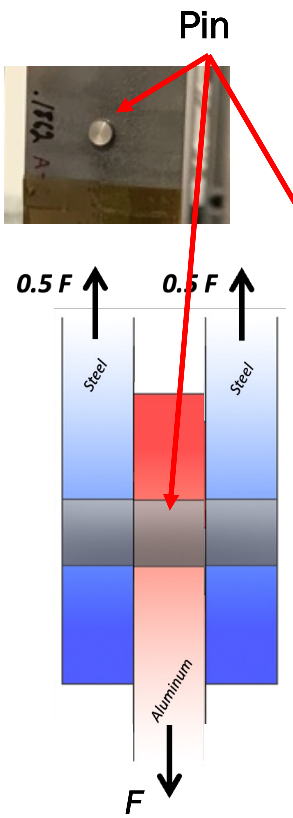


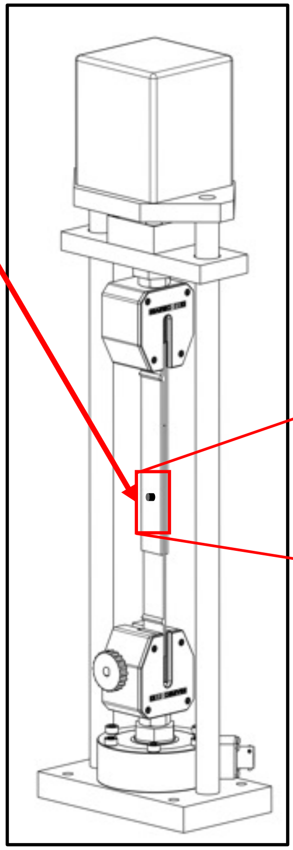


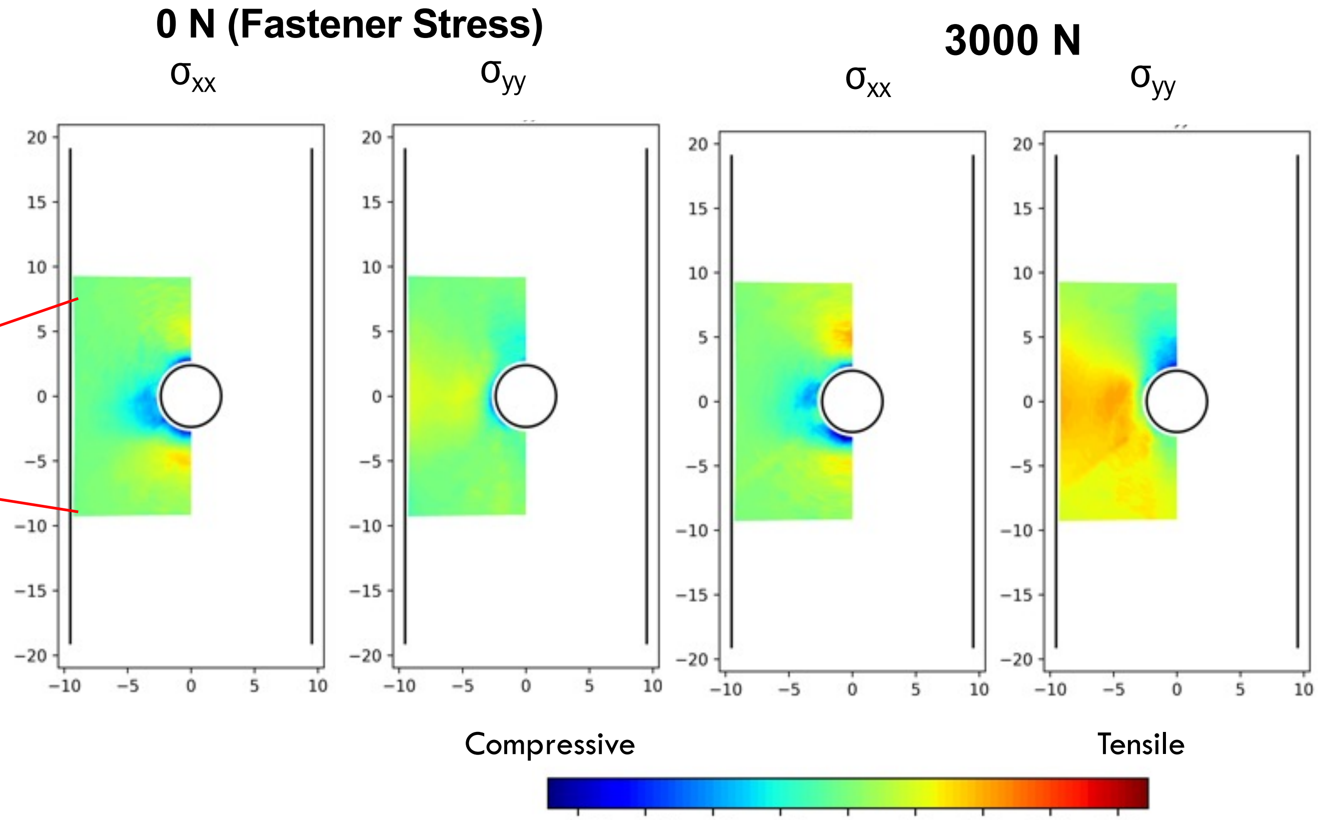
SMB Highlight: Residual Stress Caused by an Interference Fit Fastener

How does stress transfer from the pin to the **Aluminum sample?**

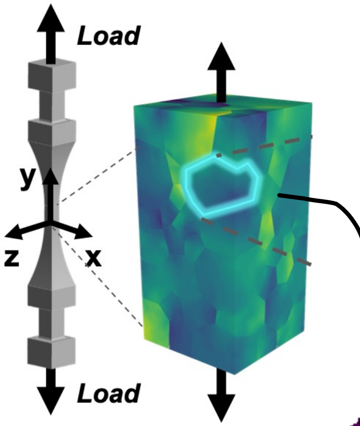
Chris Budrow, TJ Spradlin (AFRL), Katelun Wertz (AFRL), James Sabotka (Southwest Research Institute), Paul Shade (AFRL), Kelly Nygren (CHESS), Peter Ko (CHESS)





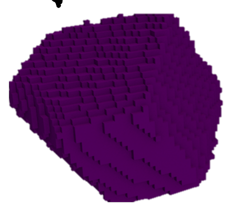


In Situ Mechanical Testing with RAMSIV

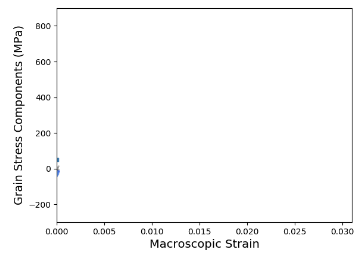


Capture grain-scale micromechanical state and microstructural character for **each crystal in the volume *simultaneously***

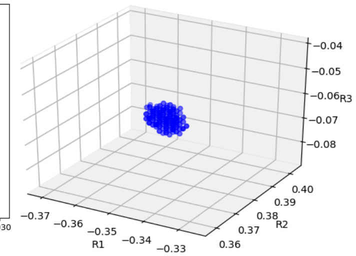
Grain Morphology
Initial



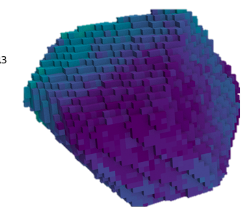
Micro-Mechanical Evolution



Orientation Evolution



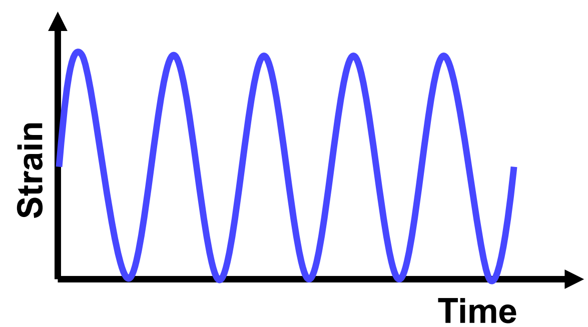
Grain Morphology
Final



Avg. Data collection time for rotation series:

- Previously 6 min
- Currently <30 sec

Recent Advancement:
Strain-Controlled
High Cycle Fatigue



SMB's approach to industrial readiness

The synchrotron is an academic's land

Meeting Industrial Needs:

- ✓ Measure complex parts - not expect to tailor the microstructure/part for the measurement
- ✓ Mature techniques so they are reproducible engineering measurements with error bars
- ✓ Develop instrumentation so industry can come on a measurement-by-measurement basis
- ✓ Protect IP and export-controlled data, in addition to no publishing requirement
- ✓ Interface with 3D part and materials models directly
- ✓ Return final dataset as soon as possible after measurement – Ideally 1 week

Measurements that historically took 6 months to year+ to fully reduce…

AFRL

Funds Enhanced Support

CHESS/MSN-C + AFRL Scientists & Specialists + AFRL Contractors + Beamline Equipment

AFRL sets priority and allocation policies

Industry Menu Items

Prioritized two, high-demand workhorse techniques for industrial readiness

Of critical value to industry, synchrotrons offer **one of the only ways to measure strain deep inside *intact* parts**—enabling engineers to calculate stress, detect hidden weak spots, and extend the life of critical components

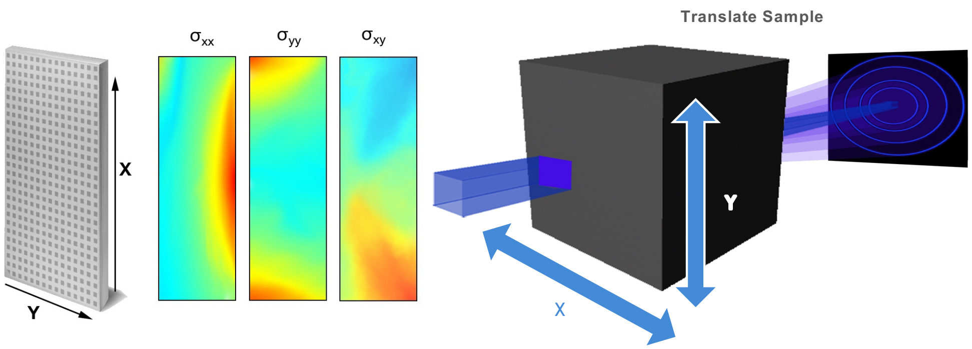
Angular Dispersive X-ray Diffraction (ADXRD) "Powder Diffraction" Technique

Monochromatic technique (40-90keV)

PROVIDES: 1D, 2D strain/orientation distributions

$$\lambda = 2d \sin\theta$$

Set (λ) · Solve (d) · Measure (θ)



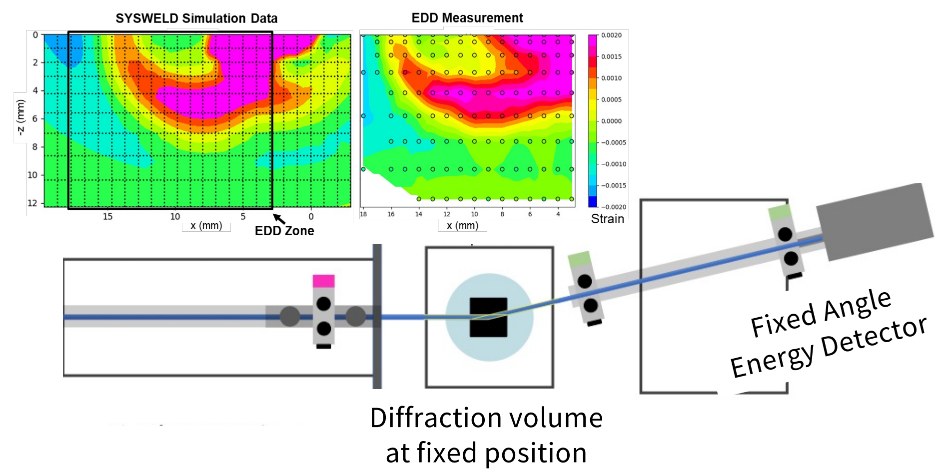
Energy Dispersive X-ray Diffraction (EDXRD)

Polychromatic technique (50-200kev)

PROVIDES: High-throughput, 3D distributions of strain / texture in large volumes (cm)

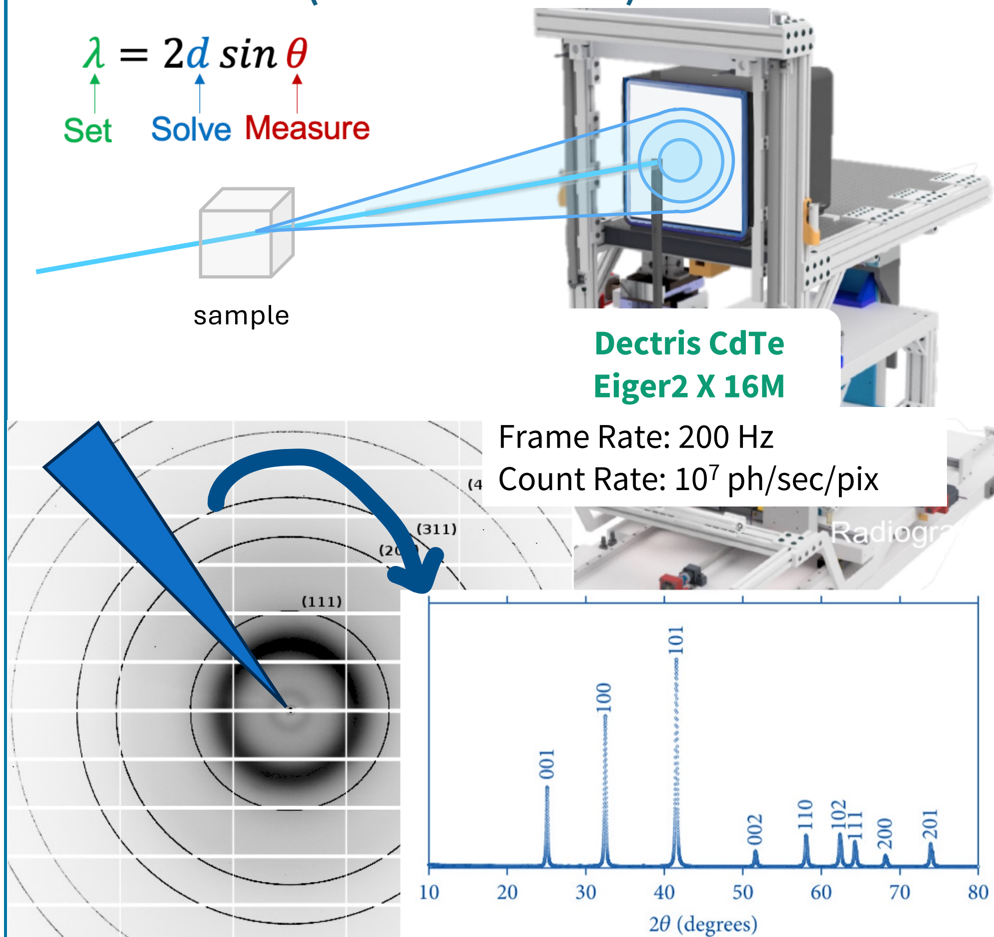
$$\lambda = \frac{hc}{E} = 2d \sin\theta$$

Measure (E) · Solve (d) · Set (θ)

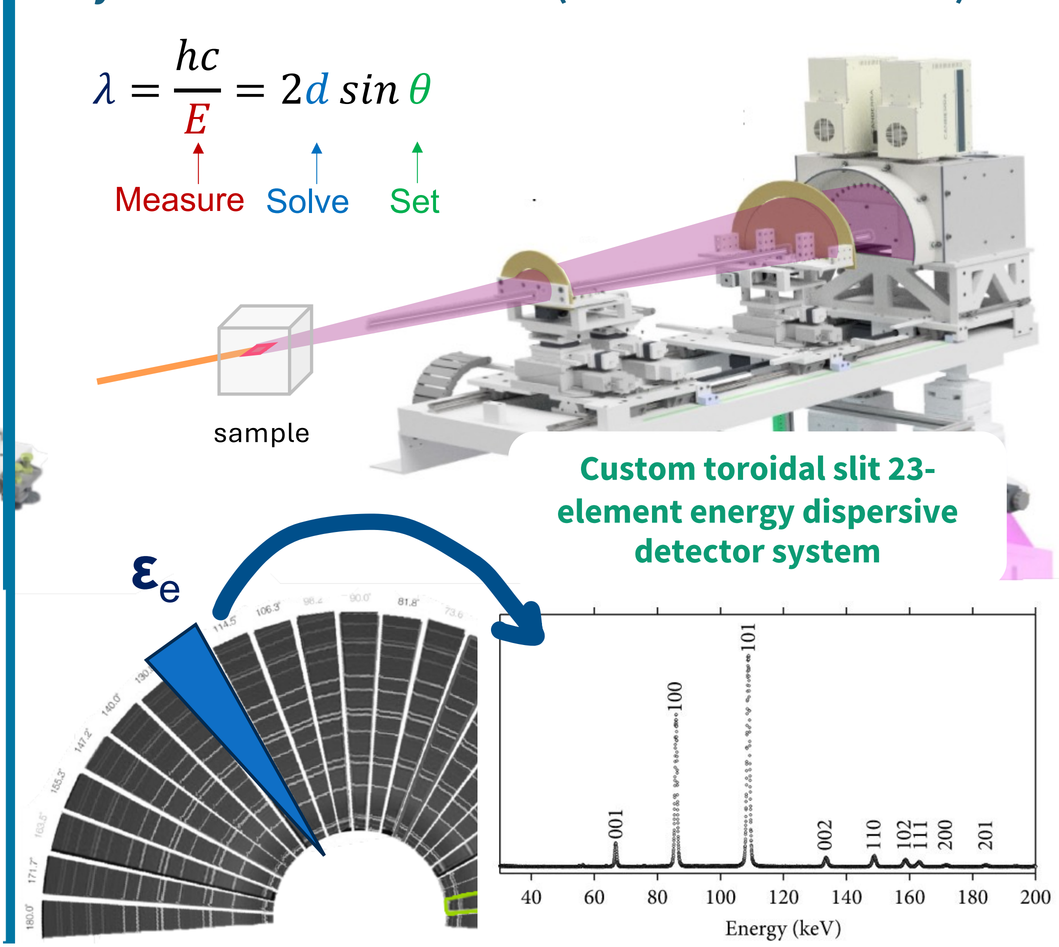


Measurement Needs Required State of the Art Detector Systems

Monochromatic (discrete 40-90keV)



Polychromatic "white beam" (continuous 50-200 keV)



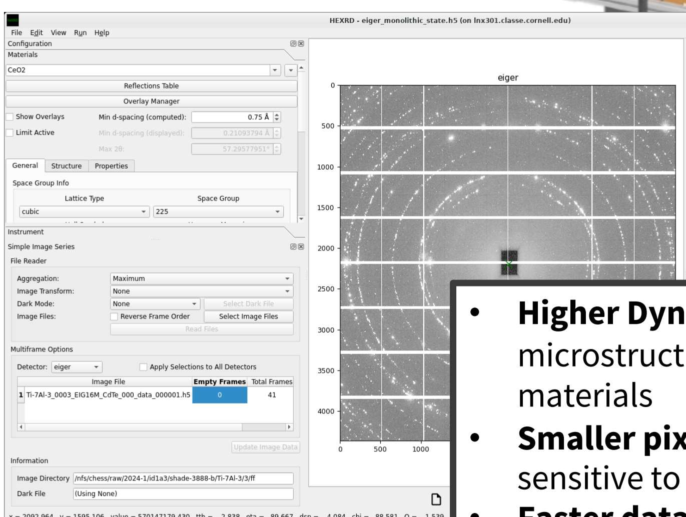
Detectors capture many in-plane strain components simultaneously

Measurement Needs Required State of the Art Detector Systems

Monochromatic (discrete 40-90keV)

Dectris CdTe Eiger2 X 16M

Frame Rate: 200 Hz
Count Rate: 10^7 ph/sec/pix



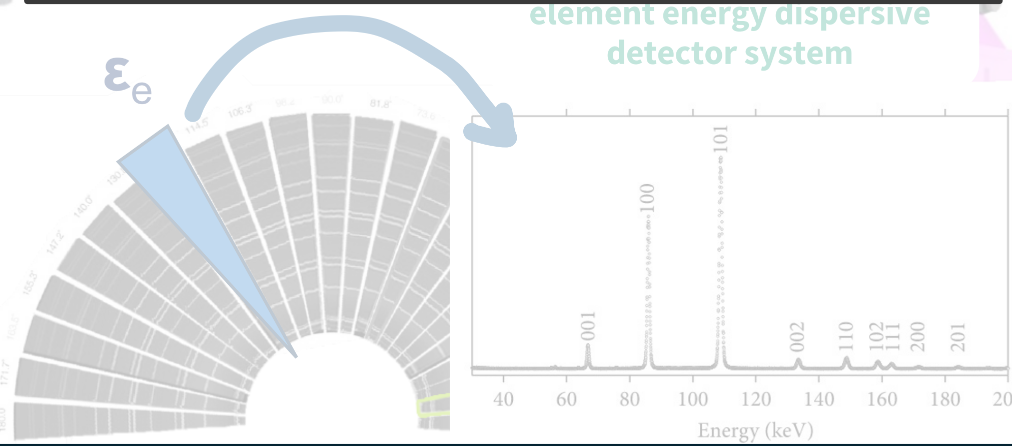
- **Higher Dynamic Range** –see microstructure in real materials
- **Smaller pixel size** - more sensitive to strains
- **Faster data collection times**

Polychromatic "white beam" (continuous 50-200 keV)

$$\lambda = \frac{hc}{E} = 2d\,sin\,\theta$$

Measure Solve Set

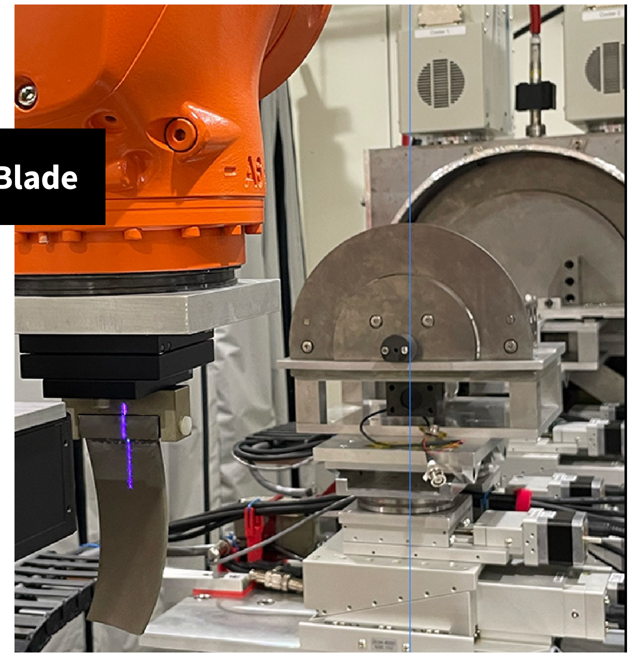
Especially relevant **for multi-phase materials** and **complex microstructures** (e.g. large and small crystals diffracting)



If you can't detect the signal - you can't perform the characterization

State of the Art Sample Manipulation

MSN-C program requires **evaluation of large parts with complex geometries** – sample positioning challenge



Verdant Evolution

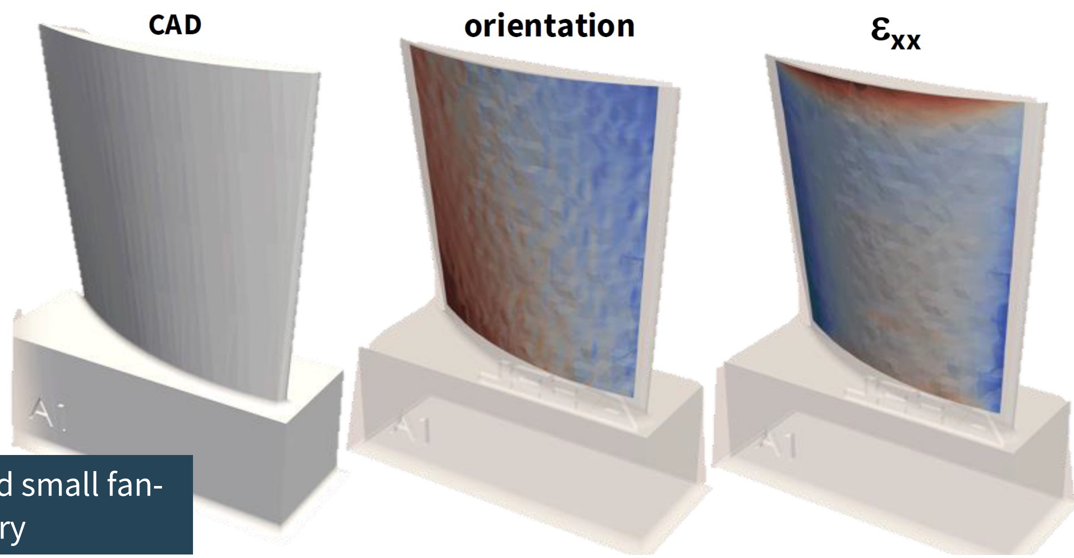
Integration of robotic arm into strain measurement workflow – robot path planning with laser-feedback

Laser Metrology

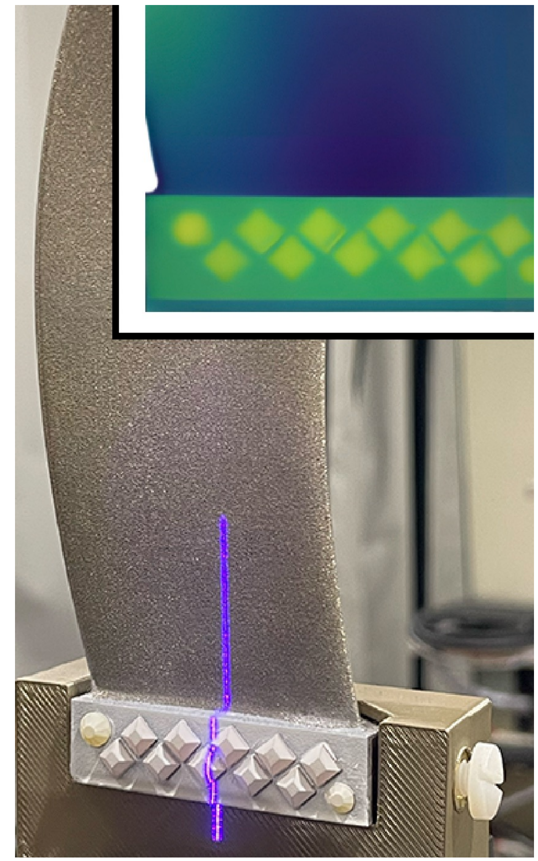
Complex parts **require digital twin** for planning and mapping

- CAD models do not always reflect the actual sample dimensions!

Additively Manufactured small fan-blade geometry

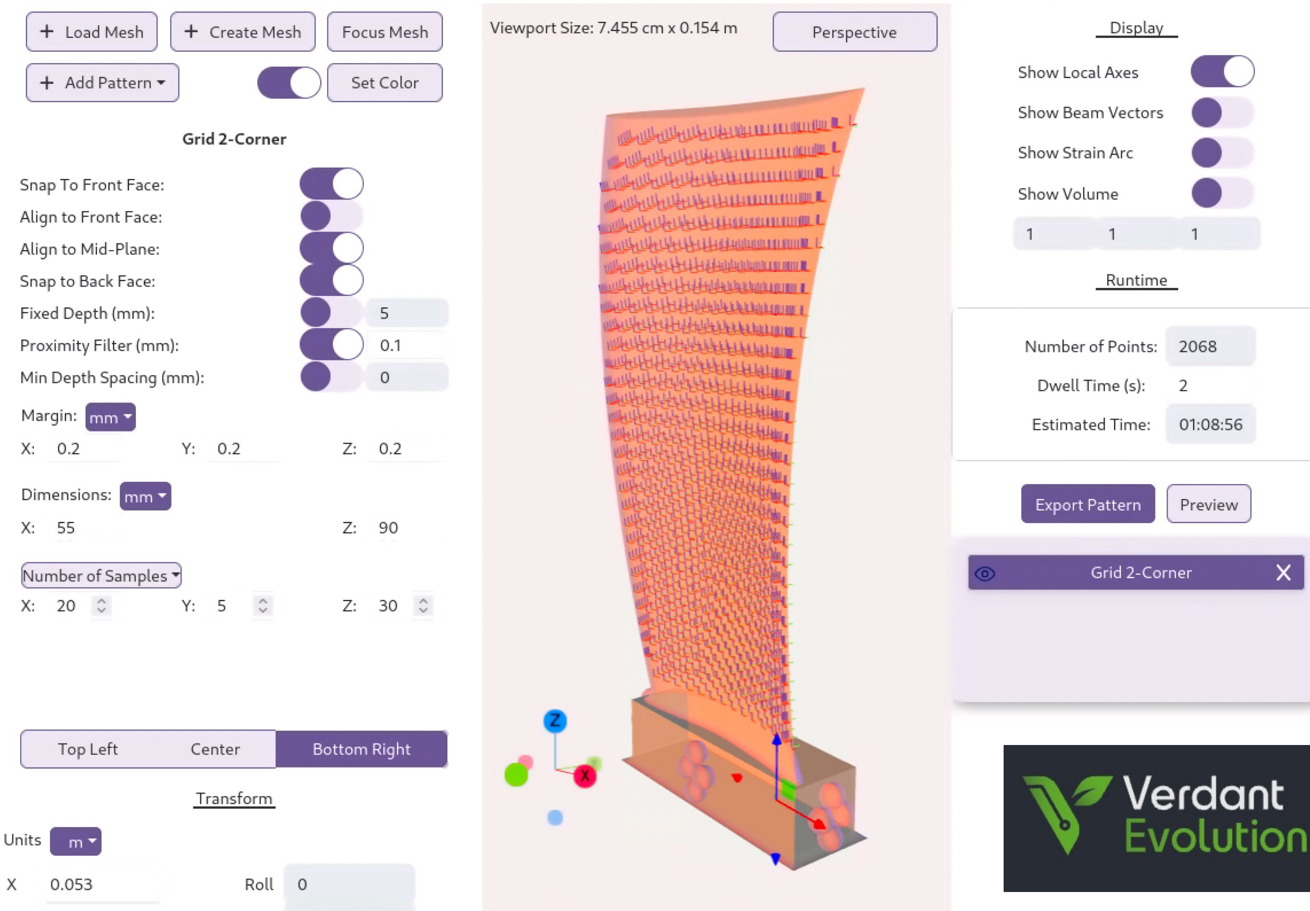


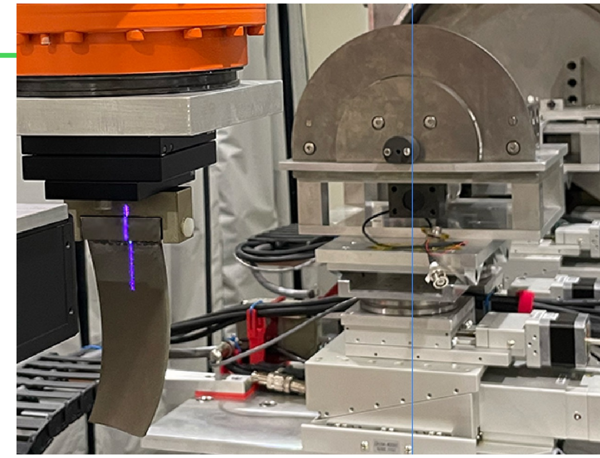
Profiling Laser



- Laser metrology facilitates evaluation of complex geometries
- Enables mapping in local coordinate system

Measurement Point Planner





- **Takes in CAD / Meshed samples or Point Clouds**
- **Pre-built patterns / grids**
  - Options to snap grid to faces or mid-planes planes of sample
  - Options to align orientation of point locally with respect to a surface normal
- **Import custom point patterns**
- **Calculate time based on number of points and dwell time**
- **Visualize points, diffraction volumes, beam vectors, and more**

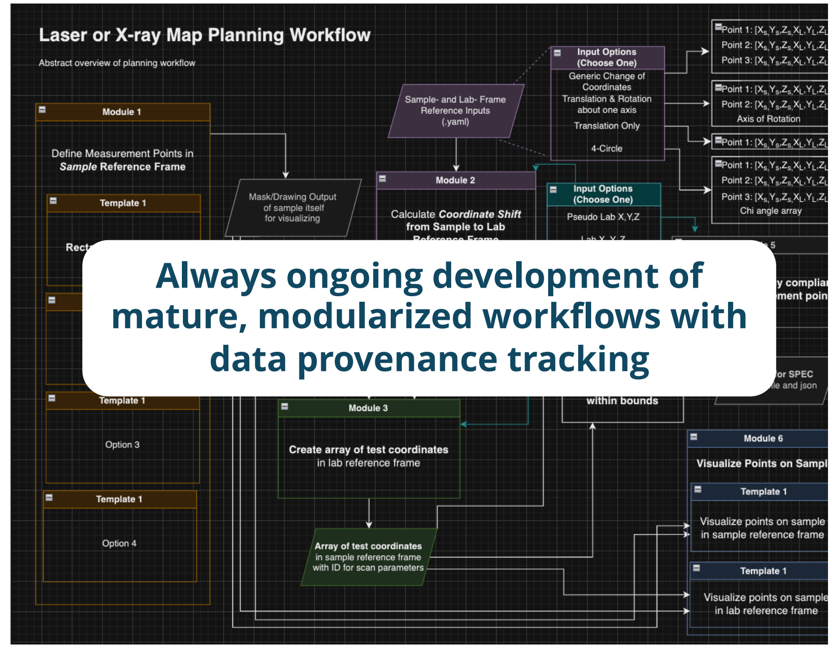
Data Processing and Analysis Workflows

https://hexrd.github.io

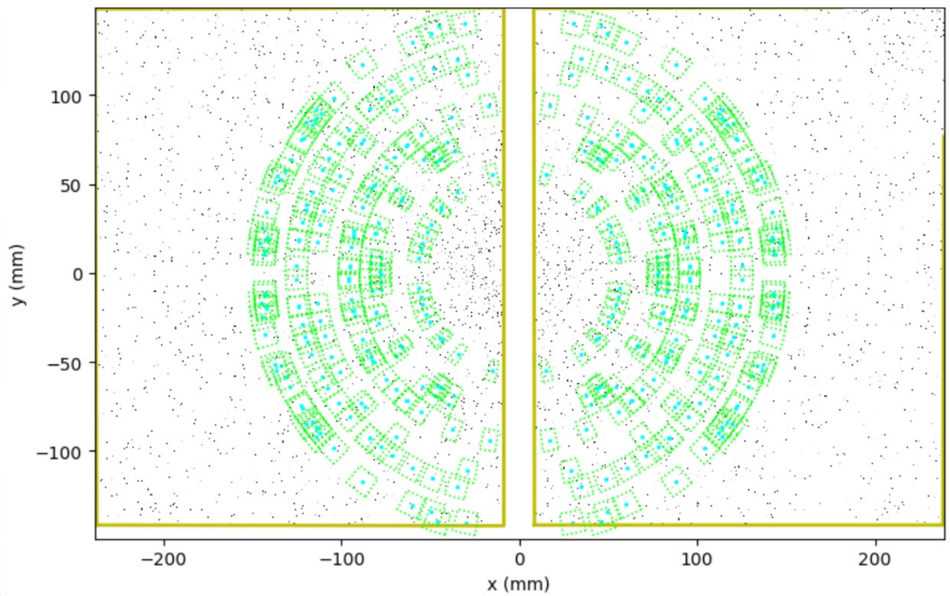
Highly Extensible X-ray Diffraction Toolkit (HEXRD)

Backbone of our analysis tools – especially for **highly sensitive elastic strain measurements**

MSN-C and AFRL team core developers and contributors



Always ongoing development of mature, modularized workflows with data provenance tracking



HEXRD designed for ALL crystal structures – works for ceramics too!

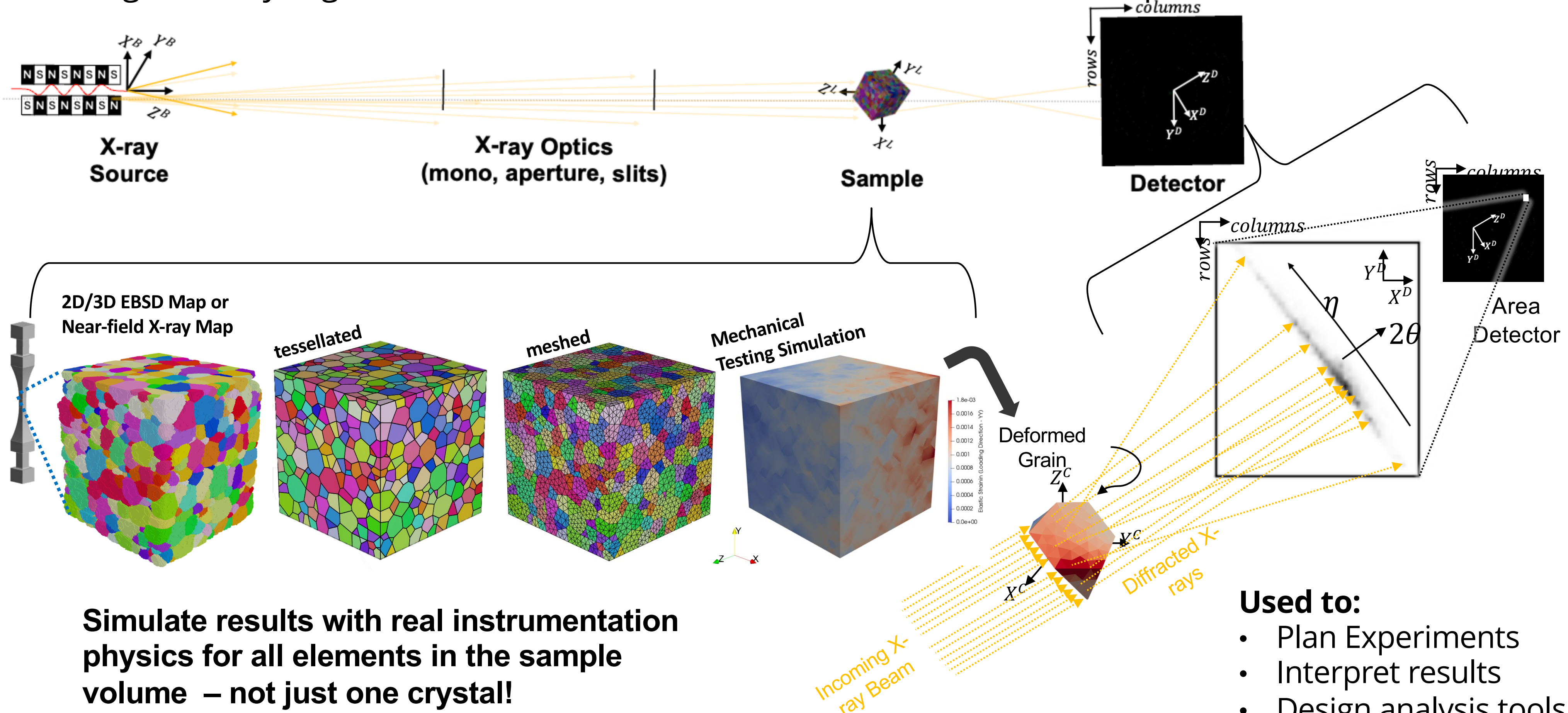
Team of Talented Software Engineers

Keara Soloway | Rolf Verberg | Zack Singer | Kevin Welsh | Patrick Avery

MSN-C | **Verdant Evolution** | **Kitware, Inc**

Mechanical Virtual Diffraction Experiment - MechVDE

High Fidelity Digital Twin of the Beamline, Instrumentation, and Sample



Simulate results with real instrumentation physics for all elements in the sample volume – not just one crystal!

Used to:

- Plan Experiments
- Interpret results
- Design analysis tools!

Challenges informed SMB Structure & Access Model

***Start with a material problem** – *not an X-ray measurement* → **Deliver a reduced data product** – *not raw X-ray data*

DoD Research
OEM has a
materials pro
(part is break

or

DoD Research
OEM has a
research prob
(model/mecha
validation

MSN-C Consultant

Chris Budrow:
Mechanical Engineering (Metals), X-ray Diffraction

CHESS Scientist

Kelly Nygren:
Materials Science and Engineering (Metals), X-ray/electron diffraction

CHESS Scientist

Amlan Das:
Materials Science and Engineering (Metals), X-ray Technique Development

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Mechanical Engineering (Metals), X-ray Diffraction

CHESS Scientist

Sven Gustafson:
Materials Science and Engineering (Metals), X-ray diffraction

ction (e.g. Strain Map):
ientists + AFRL
acted scientist

Data Reduction (e.g. Stress Map):
acted scientist, SMB
llaborator

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Only
nal Report
Scientific Paper

Due to the nature of structural alloys each measurement campaign is unique

Better product when the X-ray campaign is designed by those who understand both the materials problem and the technique

Structural Materials Beamline is part of the
Materials Solutions Network at CHESS
A defense sub-facility at CHESS (tri-service)

Unique mission, AFRL **enhanced support**, and **beamtime allocation policy** enabled development and maturation of transmission X-ray techniques and instrumentation for Defense needs

The **Structural Materials Beamline is** sponsored by AFRL under agreement number FA8650-22-2-5200.