



Advancing Materials Characterization using neutron diffraction at ORNL's Spallation Neutron Source (SNS), the High Flux Isotope Reactor (HFIR) and the future Second Target Station (STS)

Clarina dela Cruz

Distinguished Senior Scientist and Group Leader
Powder Diffraction Group
Neutron Scattering Division

Bredesen Center Recruit Visit March 7, 2025



U.S. DEPARTMENT OF
ENERGY

ORNL IS MANAGED BY UT-BATTELLE LLC
FOR THE US DEPARTMENT OF ENERGY



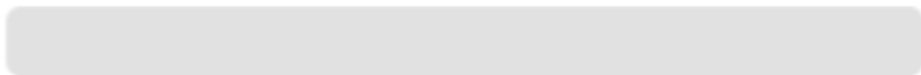
ORNL NEUTRON SCATTERING FACILITIES: SNS AND HFIR

Today ORNL operates two of the brightest neutron sources

High Flux Isotope Reactor

Operating at 85 MW, HFIR provides one of the highest steady-state neutron fluxes of any reactor in the world for materials research.

Operating Status: **Reactor is Off**



Spallation Neutron Source

SNS is the most powerful pulsed neutron source in the world for materials research.

Operating Status: **Beam is Off**



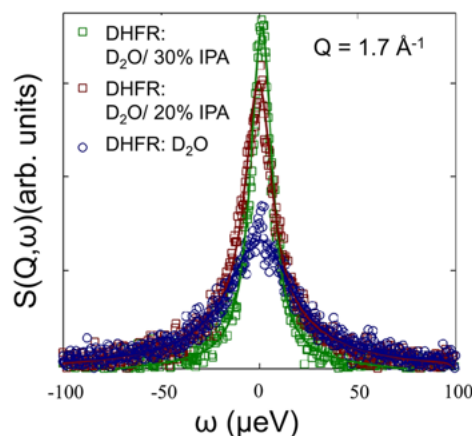
85 MW, steady state
7 fuel cycles/year, Fuel cycle ~ 24 days
~168 neutron production days/year

1.4 (1.7) MW at 60Hz
~200 neutron production days/year

NEUTRONS “SEE” ATOMS IN UNIQUE WAYS

Well-matched (λ & E)

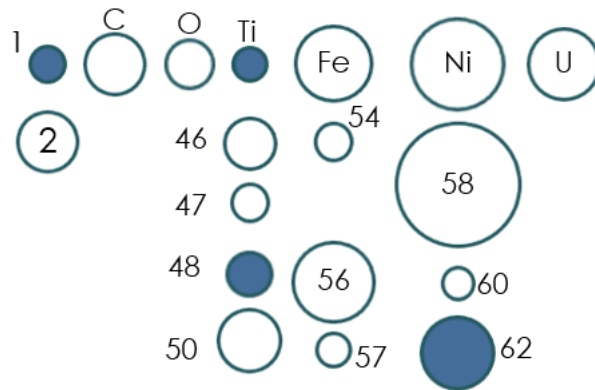
- Wavelength of thermal & cold neutrons matched to atom distances (1-10 Å)
- Neutron energies are matched to excitations in condensed matter (1-100's meV)



Protein diffusion relates motion to function

Scatter from nuclei

- Elemental and isotopic sensitivity
- Light element sensitivity (H, Li, ...)
- Isotopic substitution/contrast matching (H/D)



Neutron scattering lengths

Weakly interacting

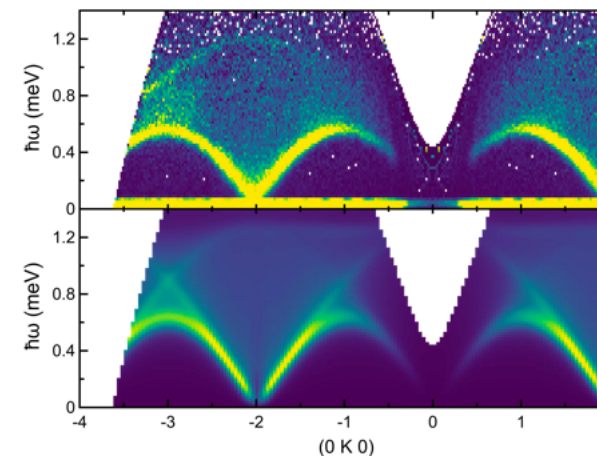
- Penetrate dense materials (cm's)
- Non-destructive
- Direct connection between theory and experiment



Complex sample environments & in op. (Q, ω)

Magnetic moment

- Measure magnetism in condensed matter (both structure and dynamics)
- Separate nuclear from magnetic scattering
- Spin precession methods



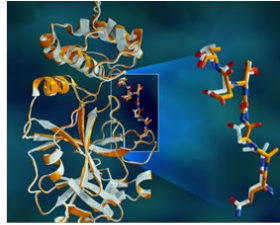
Collective magnetic excitations in YbCl₃

SCIENCE enabled by Neutron Scattering is extensive

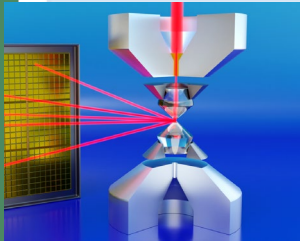
BIOLOGICAL MATERIALS AND SYSTEMS



Flora Meilleur
Protein structure of
COVID19's main
protease



PHYSICS OF MATTER UNDER EXTREMES



Antonio dos Santos
Synthesis of far-from-equilibrium materials for extreme environments



CHEMISTRY

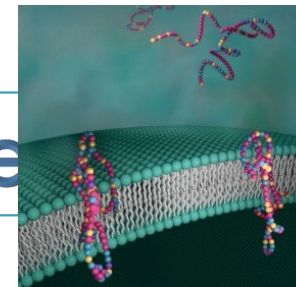
Cheng Li
microporous
MOF traps for
mitigating
toxic gases



SOFT MATTER AND POLYMERS



Wei-ren Chen
proton channels
formed in lipid
bilayers by
designed random
heteropolymers.



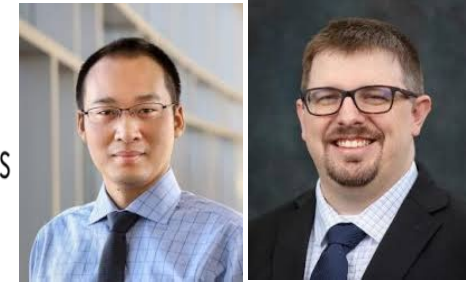
GEOCHEMISTRY AND ENVIRONMENTAL SCIENCES

Gernot Rother
copper key to
more efficient
biomass
breakdown



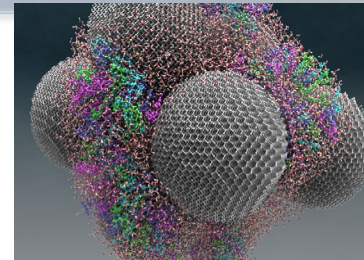
MATERIALS AND ENGINEERING

**Yan Chen
and Jeff Bunn**
New fast ion conductors
for solid oxide fuel cells



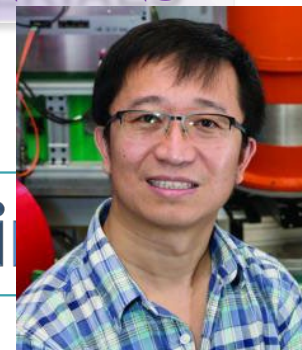
HIGH PERFORMANCE COMPUTING, MODELING AND DATA ANALYTICS INITIATIVE

Thomas Proffen
Modelling total
scattering data for
disordered materials



QUANTUM MATERIALS

Huibo Cao
Magnetism and
competing
interactions in 2D Van
der Waal materials



In 2025....



532

Scientific Publications
in FY25*



1,458

Total Unique Users
in FY25



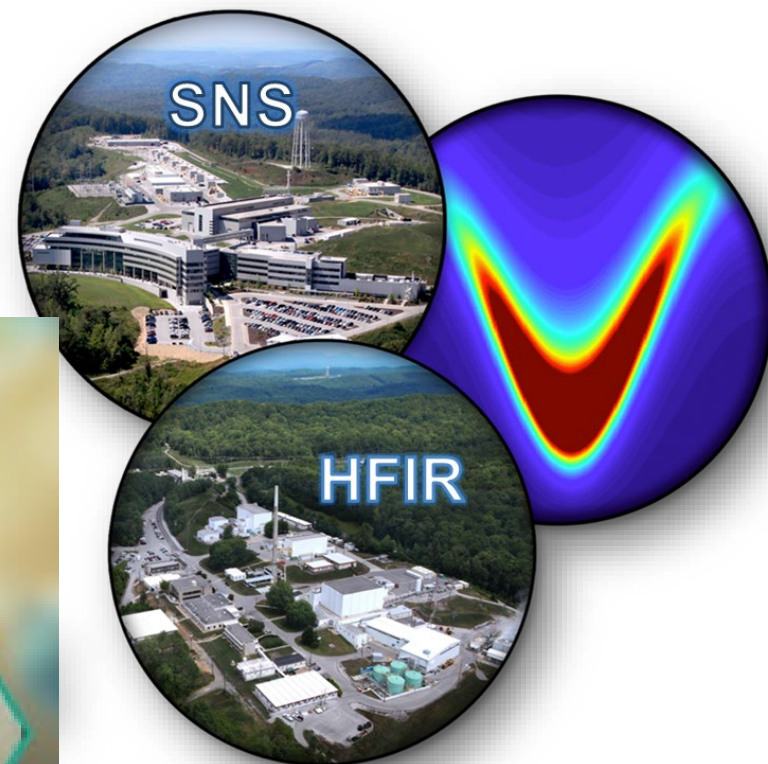
107,088

Hours of Beamtime
in FY25



1,263

Total Experiments
in FY25



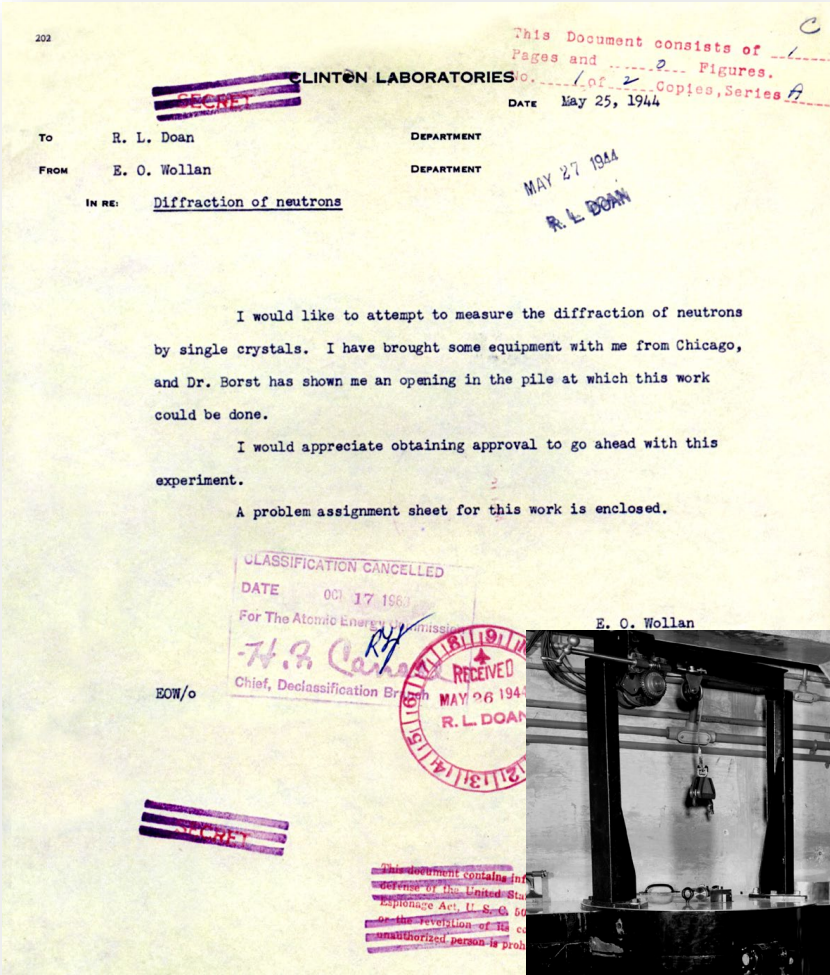
ORNL Neutron Sciences Call for Proposals

SNS and HFIR Submissions

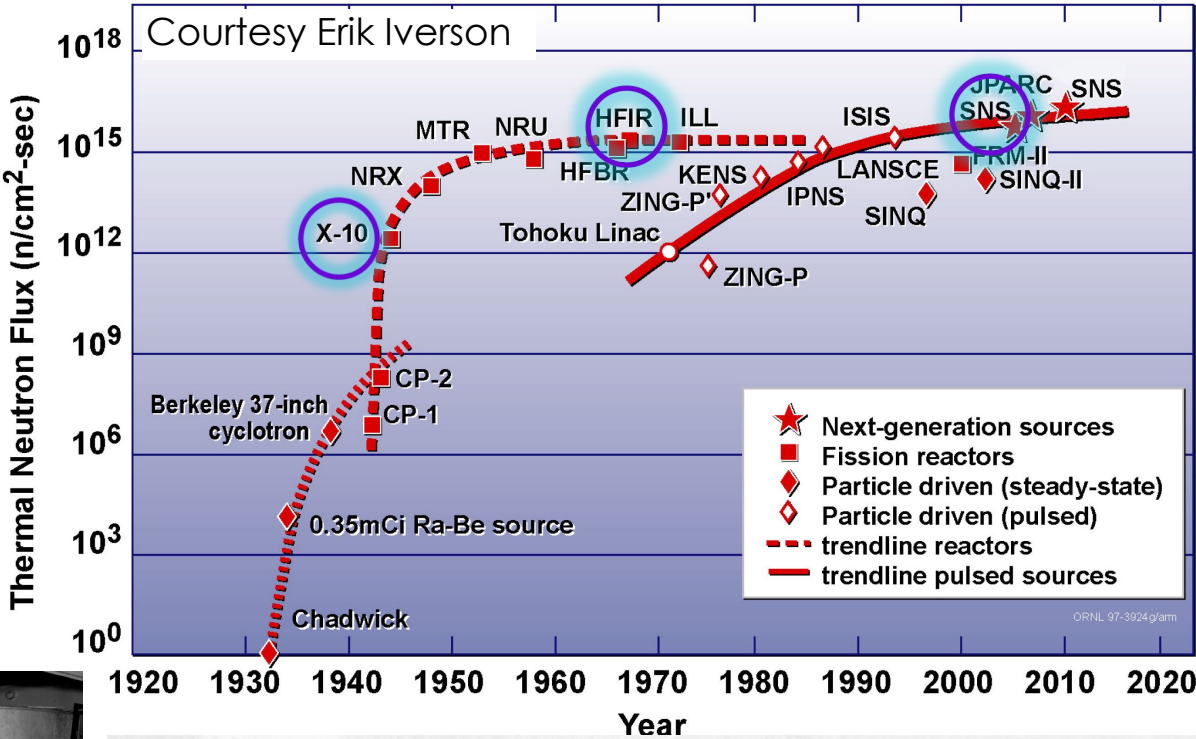
Deadline: Noon (ET), Wednesday,
September 23, 2026



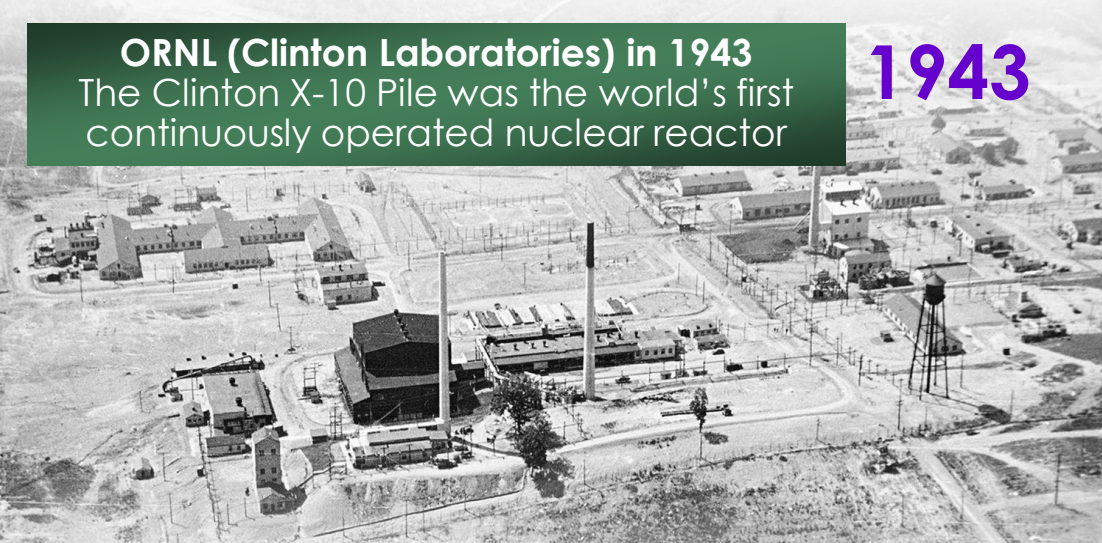
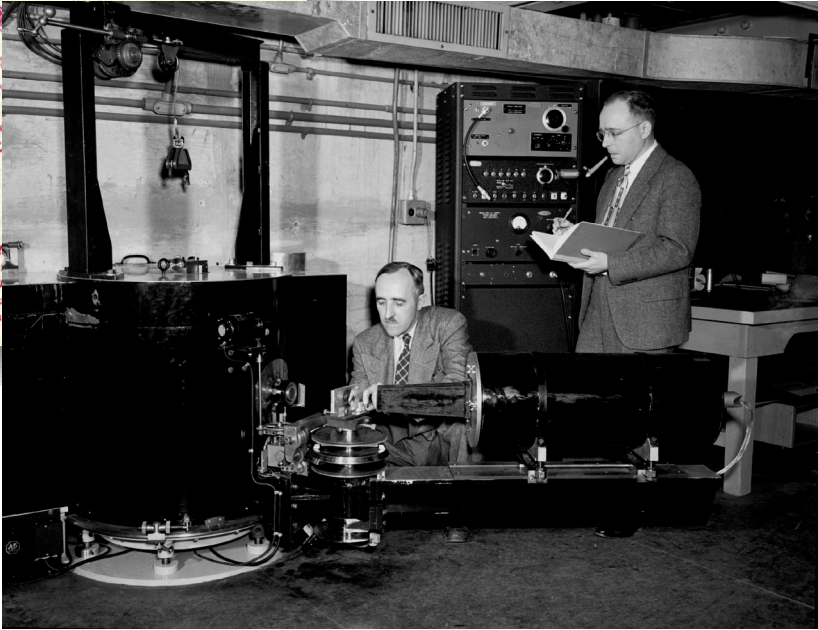
ORNL has a long history of developing neutron sources and neutron sciences

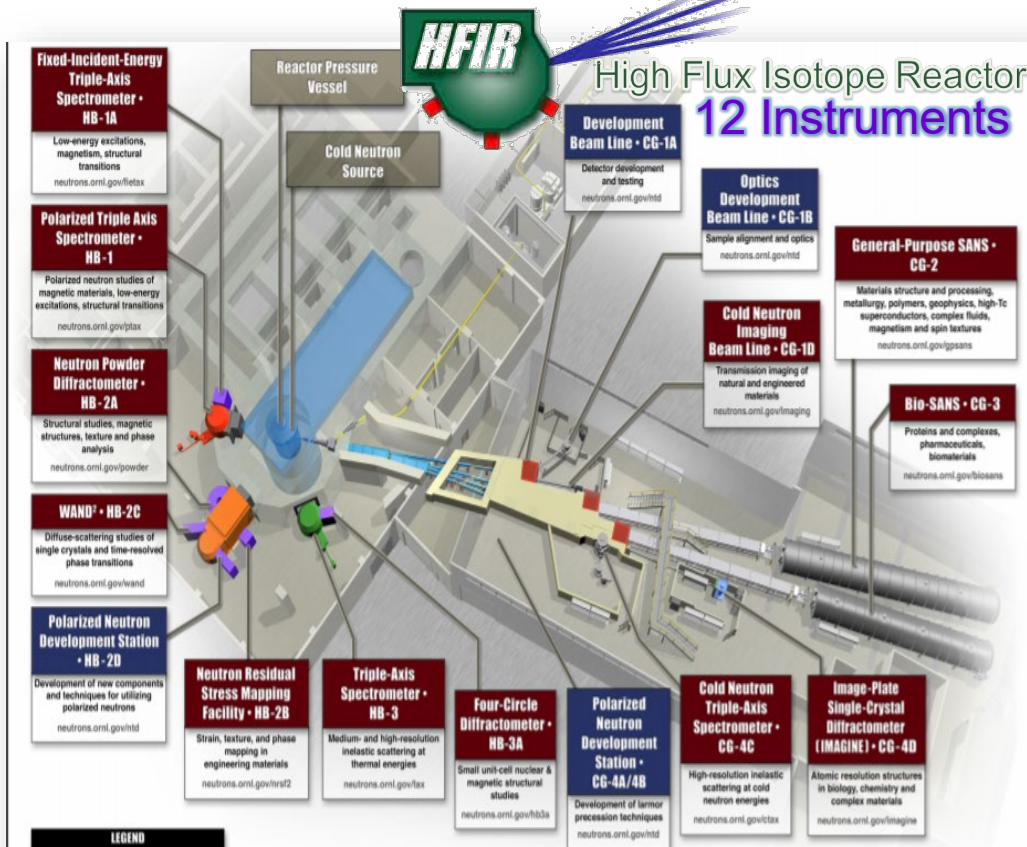


Ernie Wollan requested beam access at “the pile” in 1944



1994 Nobel Prize in Physics awarded to Shull and Brockhouse for development of neutron scattering





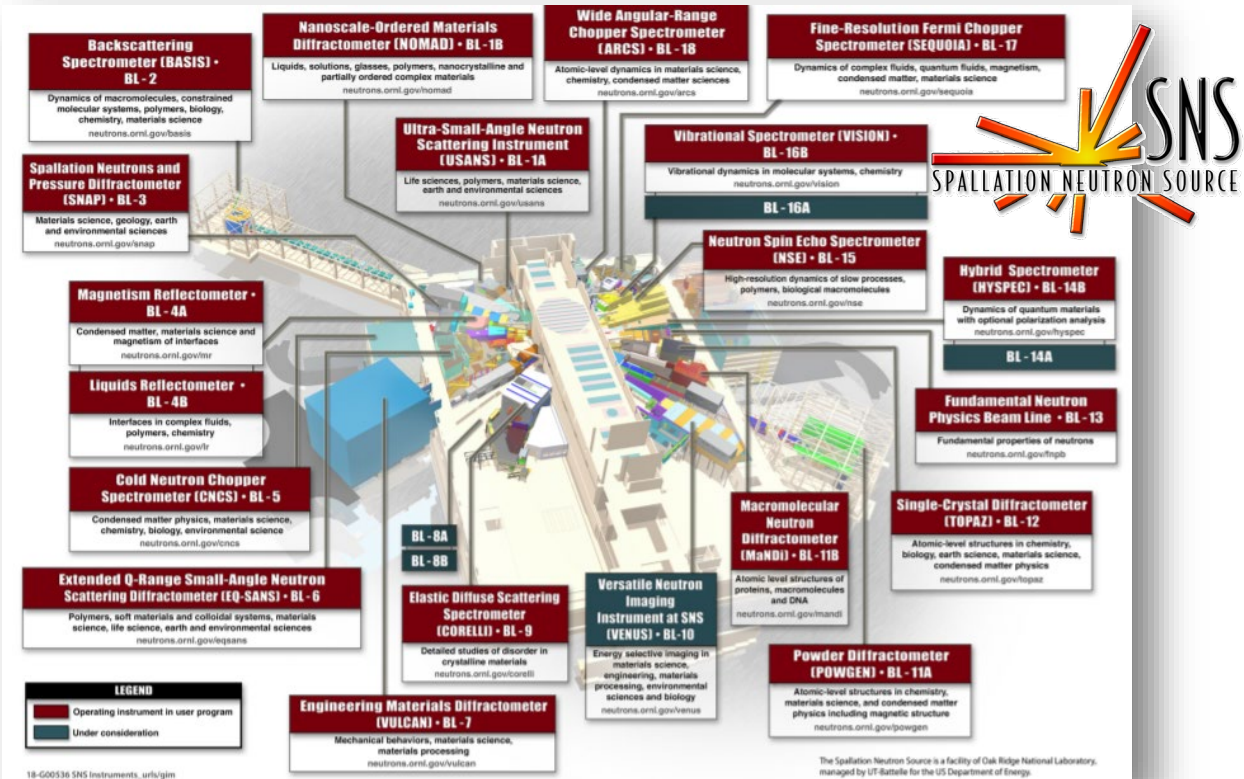
NEUTRON INELASTIC/ SPECTROSCOPY INSTRUMENTS

DYNAMICS
LATTICE EXCITATIONS,
CHEMICAL PHYSICS,
MAGNETIC EXCITATIONS

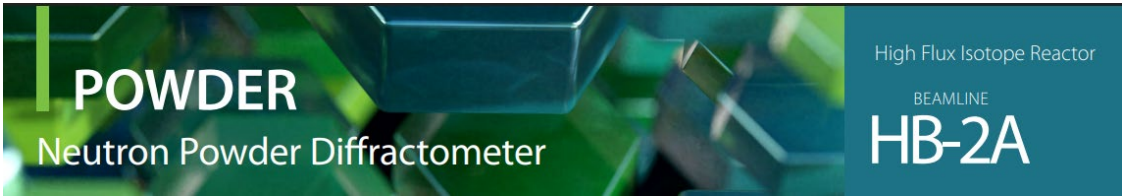
NEUTRON DIFFRACTION INSTRUMENTS

STRUCTURE
NUCLEAR STRUCTURE (LIGHT ATOMS, HYDROGEN, OXYGEN),
MAGNETIC STRUCTURE

Spallation Neutron Source 20 Instruments



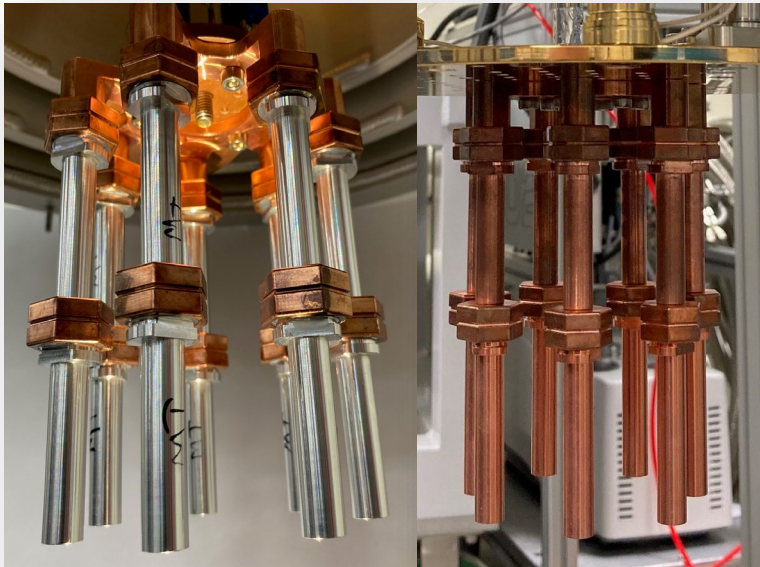
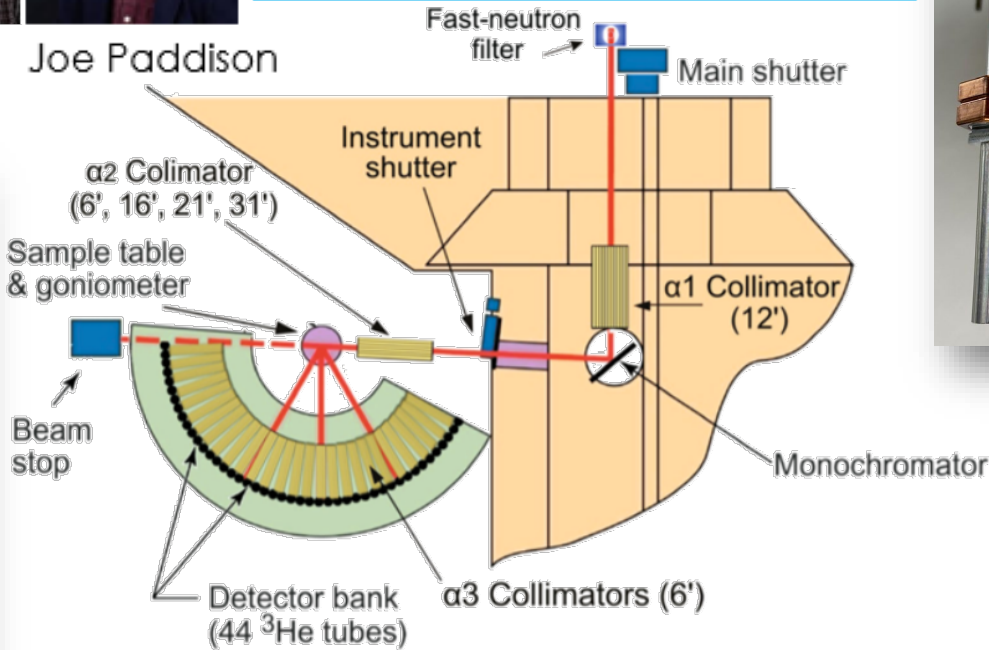
HFIR HB2A: Constant wavelength powder diffractometer with extreme sample environments and polarization



Stuart Calder, Danielle Yahne and Clarina
SA: Malcolm Cochran

Stuart Calder (100%), IS (POC)
Danielle Yahne(100%), IS
Malcolm Cochran (100%),SA
Joe Paddison CIS

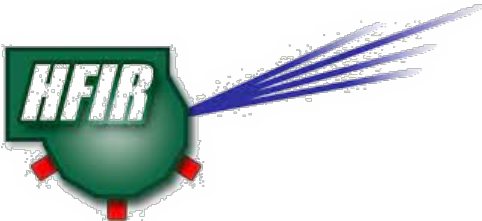
Joe Paddison



Several Unique multiple sample changers at ultra low temperatures, down to dilution 50mK



Ge(hkl)	λ (Å)	d_{max} (Å)	$4\pi\sin\theta/\lambda$	Flux (n/cm ² s)
(113)	2.41	27.6	0.2-5.1	5×10^6
(115)	1.54	17.6	0.35-7.9	1×10^7
(117)	1.12	12.8	0.5-10.9	4×10^6



Danielle's work with gas dosing experiments at HB2A makes it to SCIENCE!!

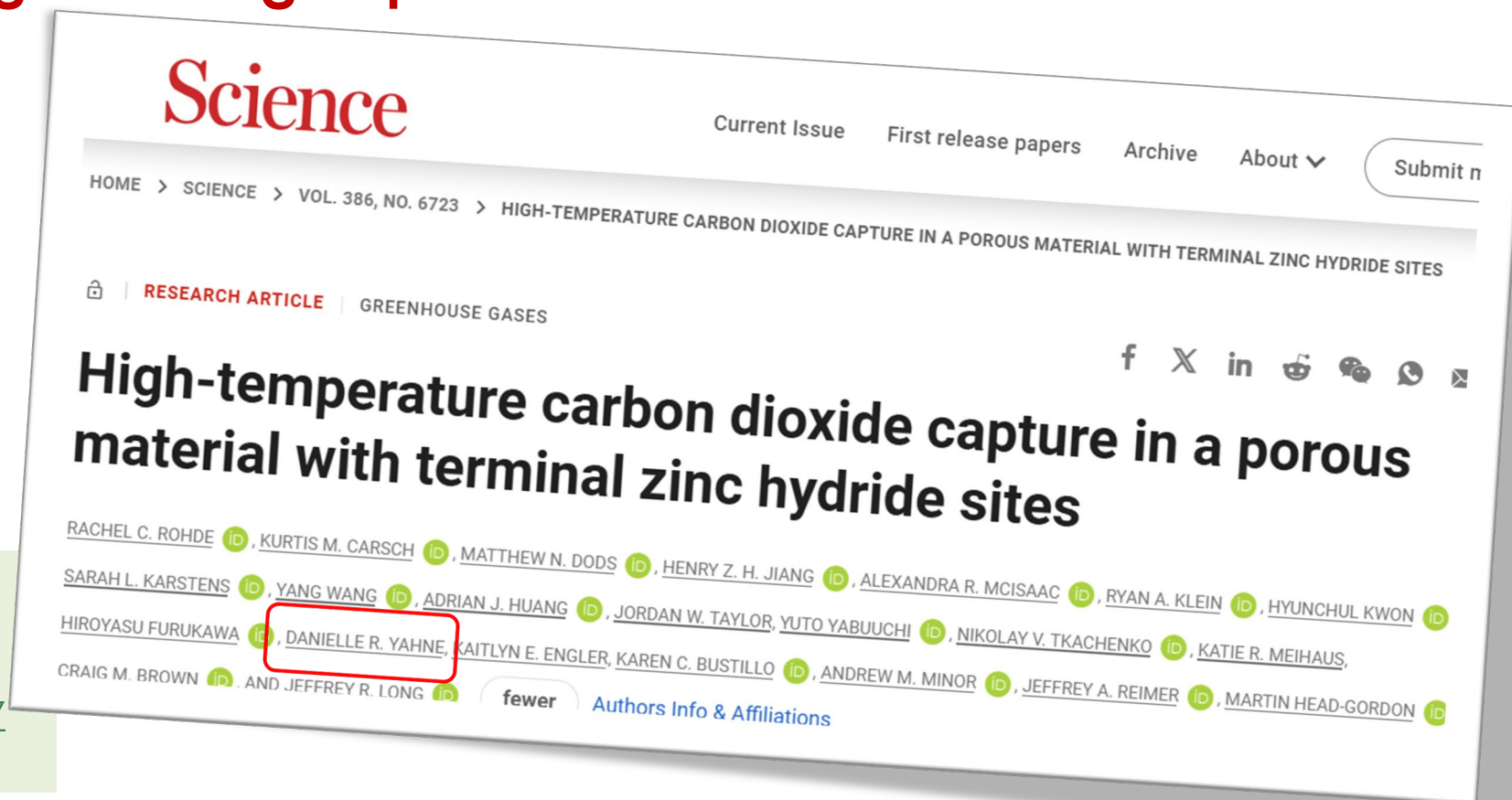


Danielle Yahne

Published online in SCIENCE
(IF=47.7)

Science, 14 Nov 2024, Vol 386, Issue 6723

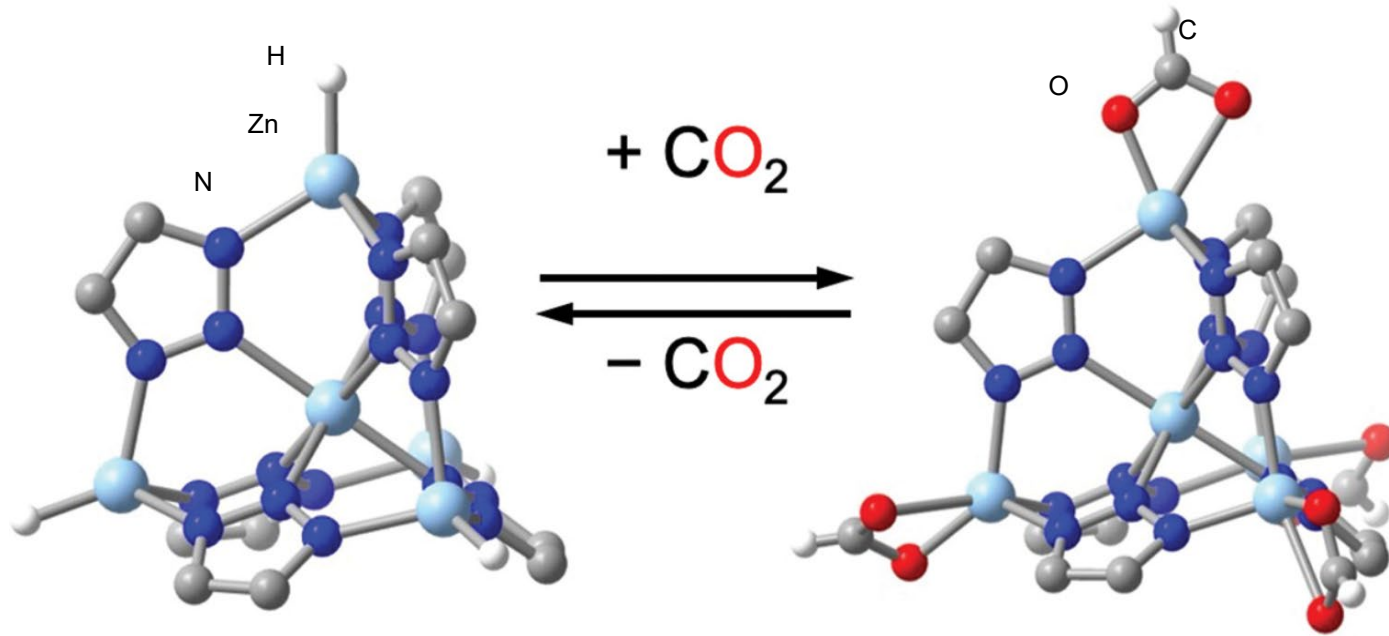
DOI: <http://10.1126/science.adk5697>



Editor's summary

Adsorption of CO₂ by aqueous amines for carbon capture applications usually requires cooling of effluent gases to near-ambient temperatures. Rohde *et al.* found that zinc hydride sites in a metal-organic framework enabled the rapid capture of CO₂ from high-temperature power generation and industrial processes (see the Perspective by Li and Zhao). Adsorption of CO₂ to form zinc formate occurs reversibly through insertion into terminal zinc hydride sites. This process is slow at ambient temperatures but efficient at temperatures between 200°C and 400°C.—Phil Szuromi

HFIR-HB2A POWDER : ZnH-MOF enables hot CO₂ capture relevant to industrial processes



Scientific Achievement

Zinc hydride in a metal-organic framework, ZnH-MFU-4l, is shown to selectively, reversibly, and robustly capture CO₂ above 200°C.

Significance and Impact

This carbon capture technology can help limit CO₂ emissions into the environment at relevant industrial operating temperatures. No other porous solid has been reported to reversibly capture CO₂ at such elevated temperatures.

R. C. Rohde et al., *High-temperature carbon dioxide capture in a porous material with terminal zinc hydride sites*, **Science** **386**, 814-819 (2024). doi/10.1126/science.adk5697

Joe's recent work made it to the cover of ACS Central Science!



ACS
central
science

<http://pubs.acs.org/journal/acscii>

Open Access

This article is licensed under [CC-BY 4.0](https://creativecommons.org/licenses/by/4.0/) 

Article

Discovering Classical Spin Liquids by Topological Search of High Symmetry Nets

Joseph A. M. Paddison* and Matthew J. Cliffe*

"Discovering classical spin liquids by topological search of high symmetry nets" is featured on the cover of ACS Central Science (**IF=13.1**)
ACS Cent. Sci. 2024, 10, 10, 1821–1828
<https://doi.org/10.1021/acscentsci.4c01020>

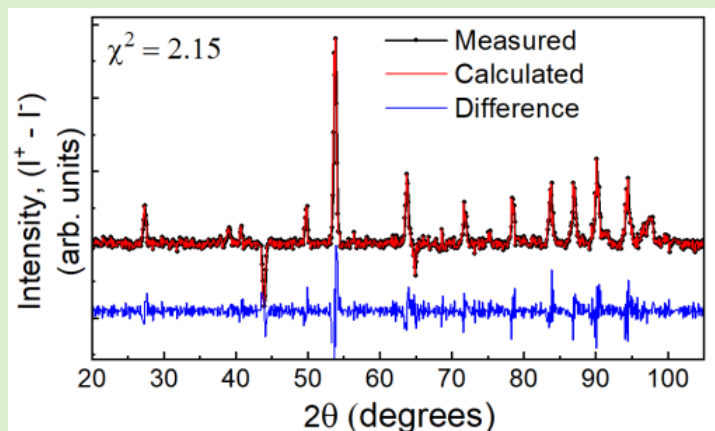


Joe Paddison

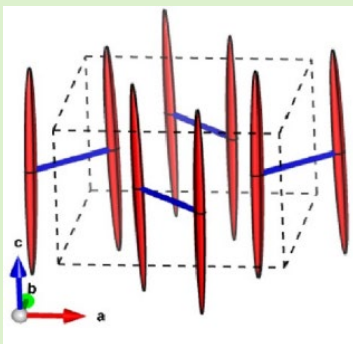
MIDAS: The rebirth of HB2A

Polarized Powder Diffraction

Half-polarized neutron powder diffraction (pNPD) allows extraction of the local site susceptibility to quantify the magnetic anisotropy.

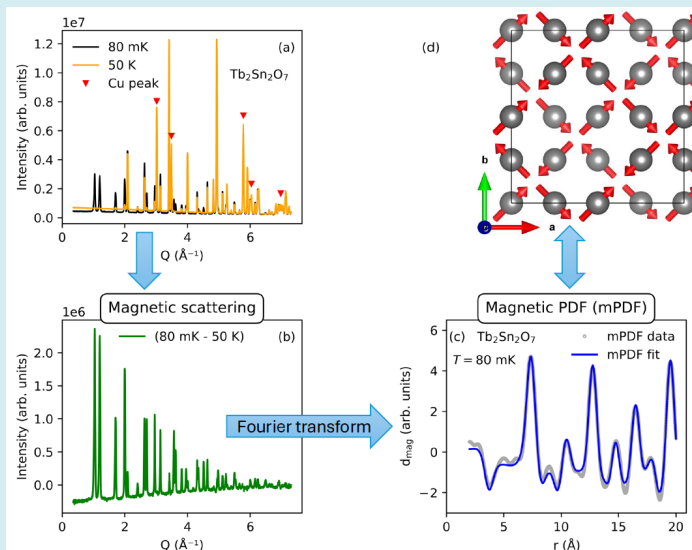


Experiments on a Yb material with low point symmetry provided insights into dimer behavior.



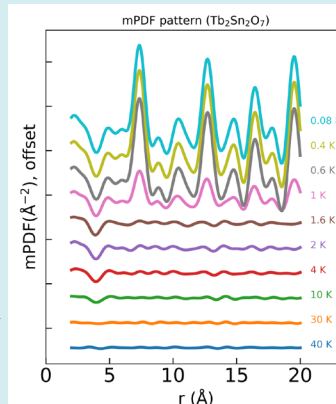
Brassington et. al, Nature Comm. (2026)
arXiv:2505.00766v2

Dilution temperature measurements using mPDF



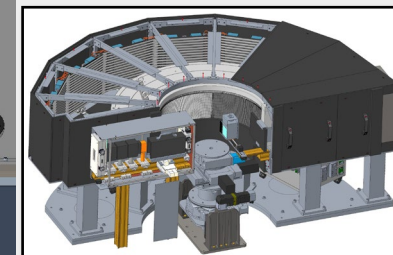
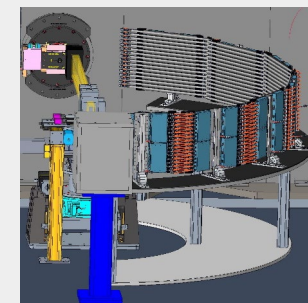
First mPDF measurements to dilution temperatures.

0.08K to 50 K

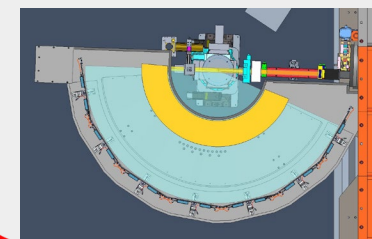


MIDAS (2026):

- ✓ Continuous and increased coverage with standard helium tubes interdigitated.
- ✓ Current 2-10 *hour* scans will take 4-20 *minutes*!
- ✓ Time resolved studies enabled

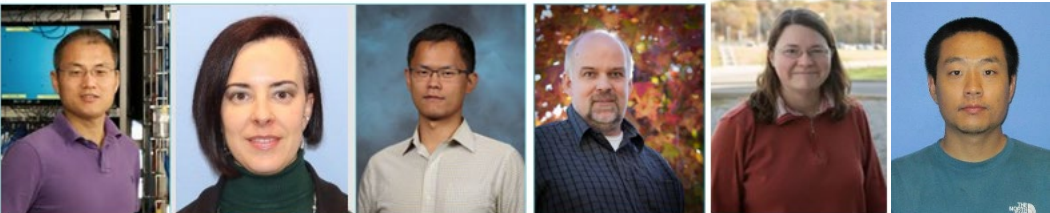


Shielding is non-magnetic and modular.



Oscillating radial collimator design.

SNS BL11A POWGEN: General-purpose powder diffractometer for studying crystal structure, magnetism and local structure

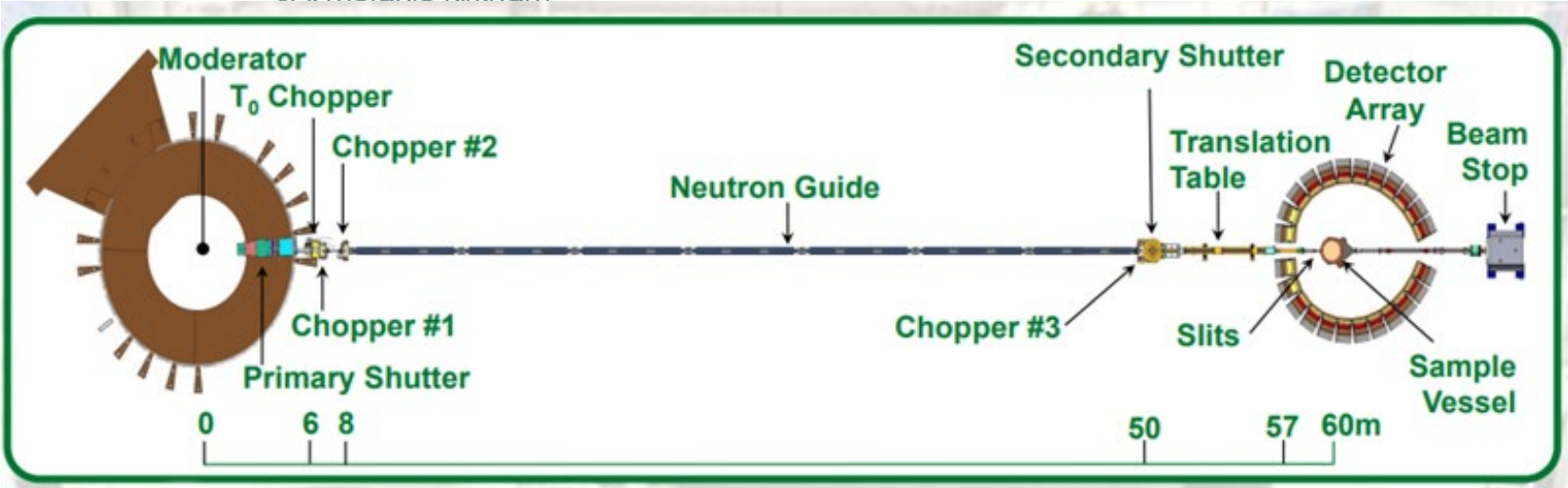


Qiang Zhang, Alicia Manjon Sanz, Cheng Li and Thomas Proffen
SA: Melanie Kirkham
Yuanpeng Zhang

Qiang Zhang (100%), IS (POC)
Alicia Manjon-Sanz (75%), IS
Melanie Kirkham (100%),SA
Cheng Li (50%), IS
Thomas Proffen (75%), IS
Yuanpeng Zhang CIS

Instrument Publication Analysis

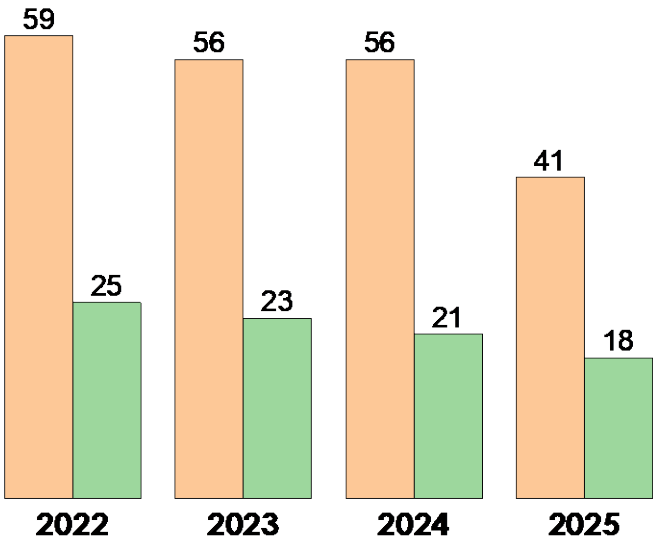
Total Publications: 824
(Top instrument in ORNL)
Instrument H-Index: 76
Publication Impact: 41%
publications with high impact
factor JIF≥7



HIGH FLUX
ISOTOPE
REACTOR
SPALLATION
NEUTRON
SOURCE

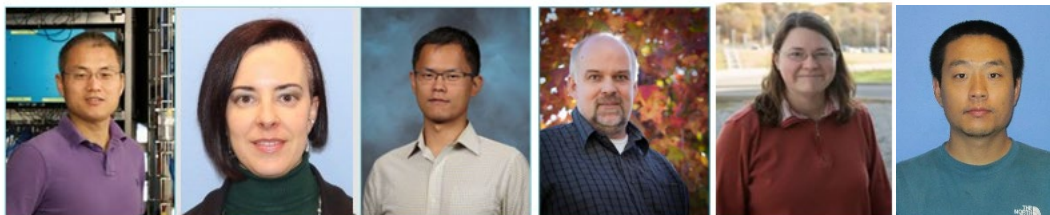
Freq (Hz)	WL center	WL min	WL max	dmin	dmax	Qmin	Qmax	Bank
60	0.533	0.15	1.066	0.075	7.50	0.82	83.45	0
60	0.800	0.27	1.333	0.134	8.00	0.76	46.88	1
60	1.500	0.97	2.033	0.485	13.00	0.48	12.95	2
60	2.665	2.13	3.198	1.070	21.00	0.30	5.87	3
60	4.797	4.26	5.33	2.140	38.00	0.17	2.94	4

Peer reviewed pubs
JIF>7



Calenda Year

SNS BL11A POWGEN: General-purpose powder diffractometer for studying crystal structure, magnetism and local structure



Qiang Zhang, Alicia Manjon Sanz, Cheng Li and Thomas Proffen

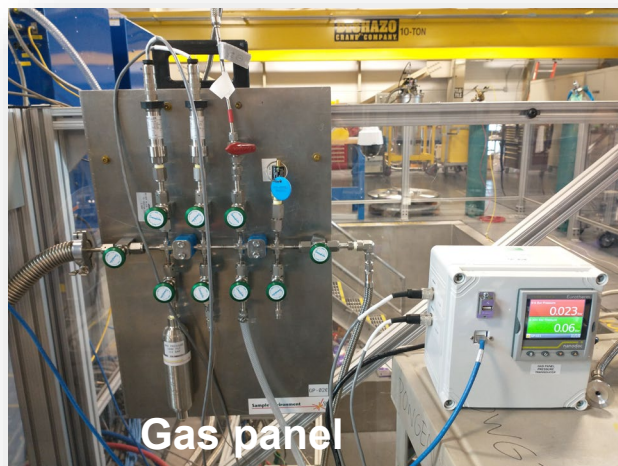
Yuanpeng Zhang

SA: Melanie Kirkham

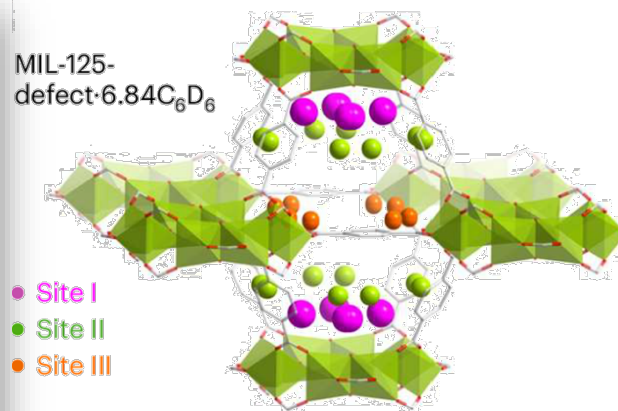
Qiang Zhang (100%), IS (POC)
Alicia Manjon-Sanz (75%), IS
Melanie Kirkham (100%), SA
Cheng Li (50%), IS
Thomas Proffen (75%), IS
Yuanpeng Zhang CIS

**A diffraction friendly
Magnet: MAG-08 7 T
vertical magnet**

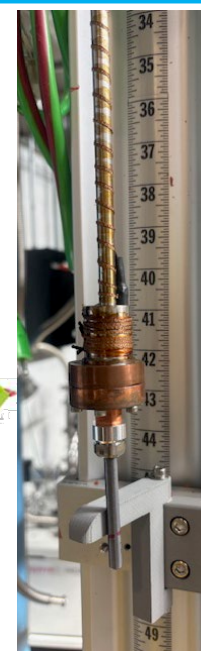
Gas dosing experiments



Gas panel



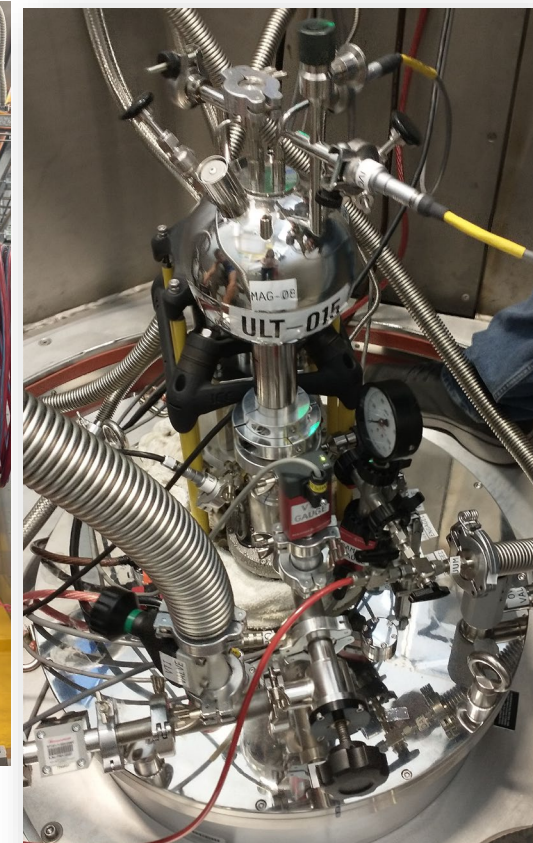
**Neutron powder
diffraction with C₆D₆
directly resolved three
adsorption sites**



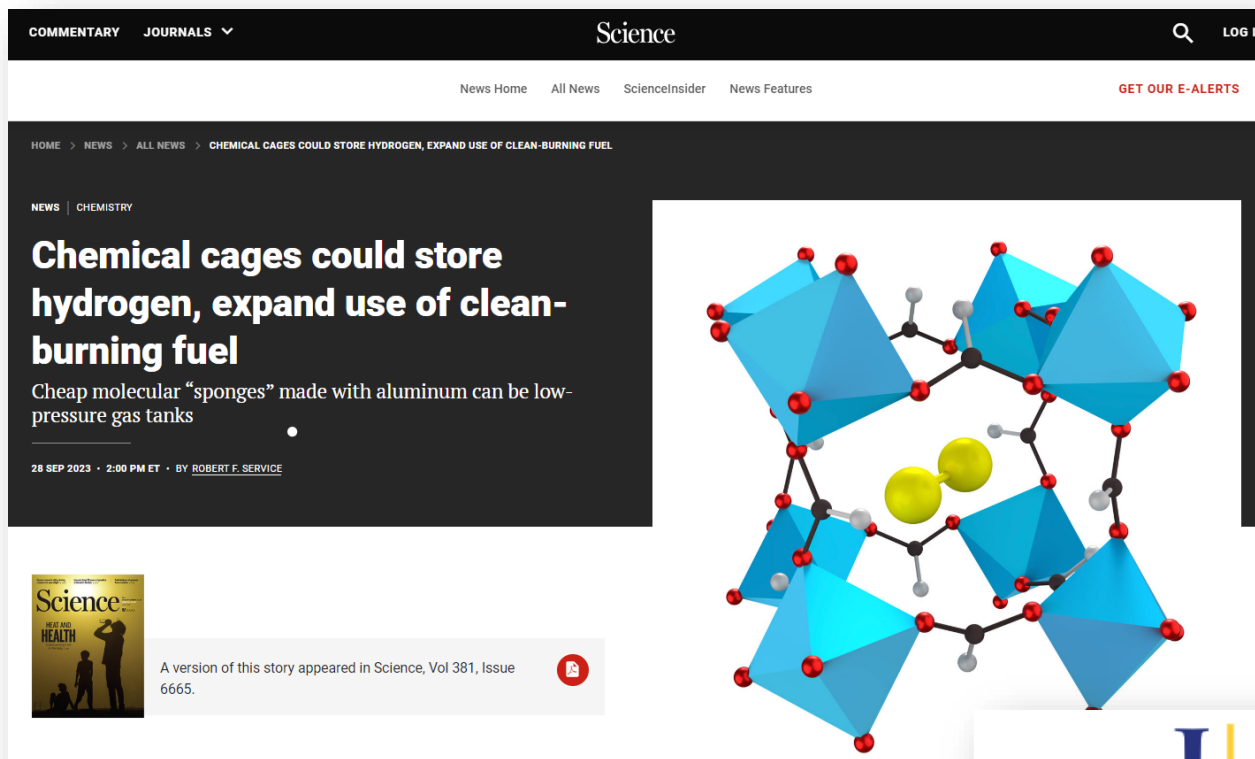
**Low-T stick
T range =
1.7-300 K
Magnetic
field = 7 T**

Ultra Low T (ULT) insert

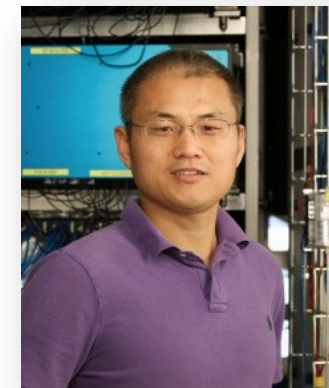
- T range = 300 mK - 300 K
- Magnetic field = -7T-0-7 T



Qiang's work on Hydrogen Storage materials published in JACS makes the Science News!



The article is about the JACS paper that was done with the gas dosing system at POWGEN by Qiang and collaborators from NCNR, LBNL and NUS



Qiang Zhang

Read the news article here:

<https://www.science.org/content/article/chemical-cages-could-store-hydrogen-expand-use-clean-burning-fuel>.

JACS
JOURNAL OF THE AMERICAN CHEMICAL SOCIETY
pubs.acs.org/JACS

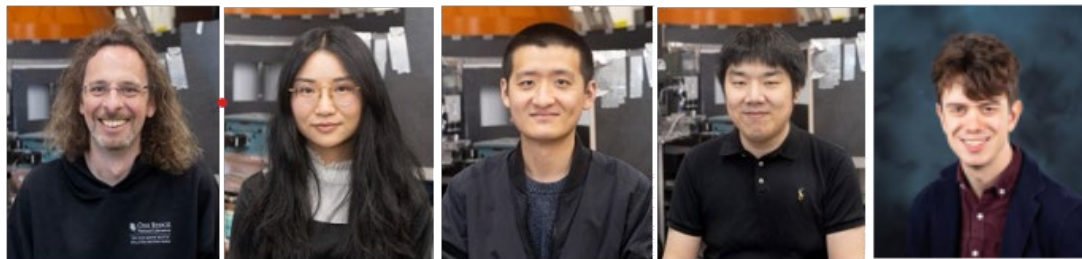
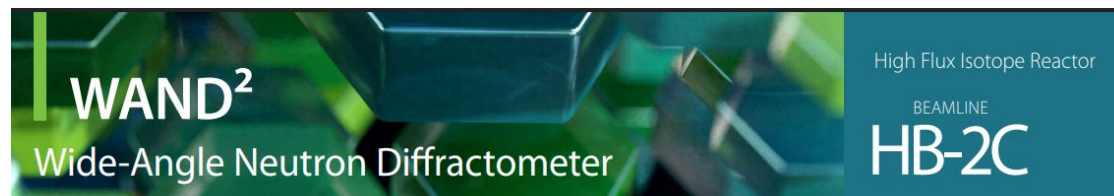
Article

Hydrogen Storage with Aluminum Formate, ALF: Experimental, Computational, and Technoeconomic Studies

Hayden A. Evans,* Taner Yildirim,* Peng Peng, Yongqiang Cheng, Zeyu Deng, Qiang Zhang, Dinesh Mullangi, Dan Zhao, Pieremanuele Canepa, Hanna M. Breunig, Anthony K. Cheetham, and Craig M. Brown*

<https://pubs.acs.org/doi/10.1021/jacs.3c08037?ref=pdf>

HFIR HB2C WAND²: Fast medium-resolution powder and single crystal diffractometer



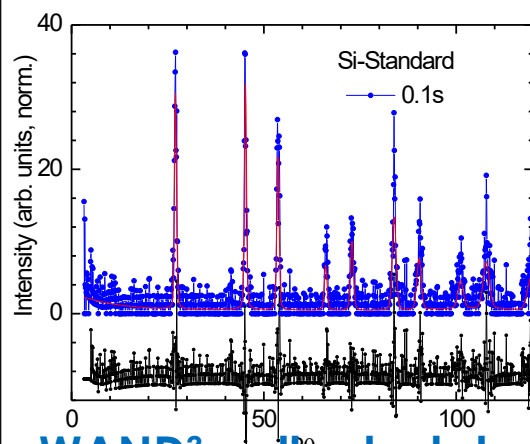
Matthias Frontzek, Athena Chen and Xiao Hu

SA: Jie Xing

Joe Paddison

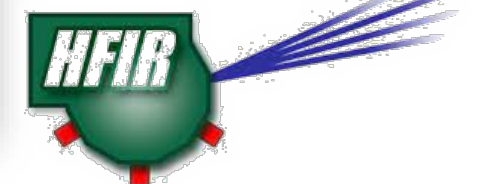
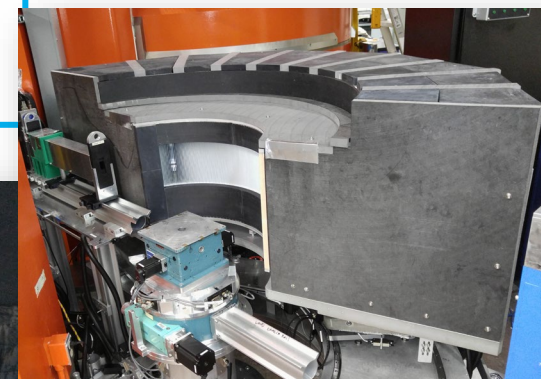
Matthias Frontzek (100%), IS (POC)
Si Athena Chen (100%), IS
Xiao Hu (50%), IS
Jie Xing (100%), SA
Joe Paddison CIS

Fast Powder diffraction



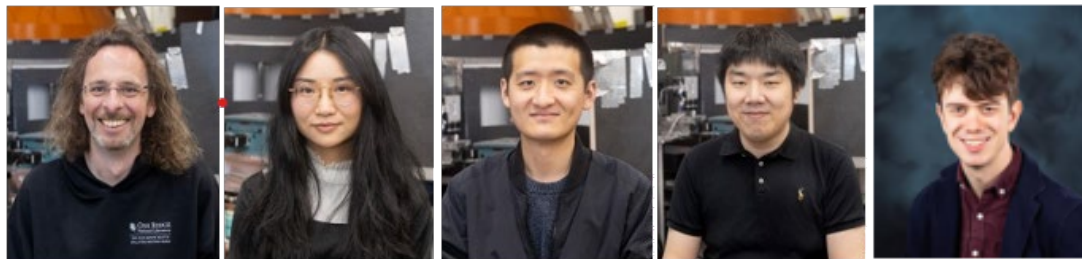
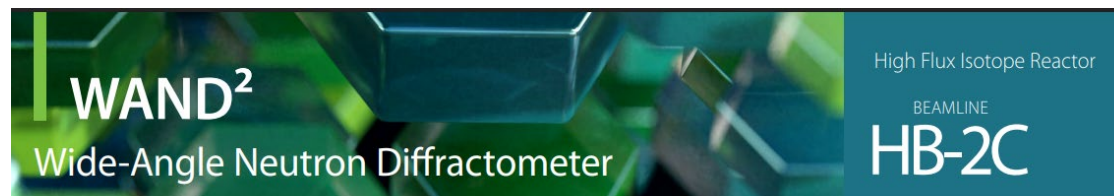
Time (s)	R _{wp}	Bragg R
600	9.02	1.35
60	9.94	1.18
10	10.8	2.52
1	29.2	11.6
0.1	58.5	34.0

WAND² collects data in Event-mode;
Measurement time of seconds is
sufficient for refinement, milliseconds
to track changes



- Wide angle (120° in-plane, 15° out of plane) seamless coverage
- High efficient ³He detector with 0.03125° sub-wire resolution
- High intensity: 10⁷ n/cm² s @ 1.486Å

HFIR HB2C WAND²: Fast medium-resolution powder and single crystal diffractometer

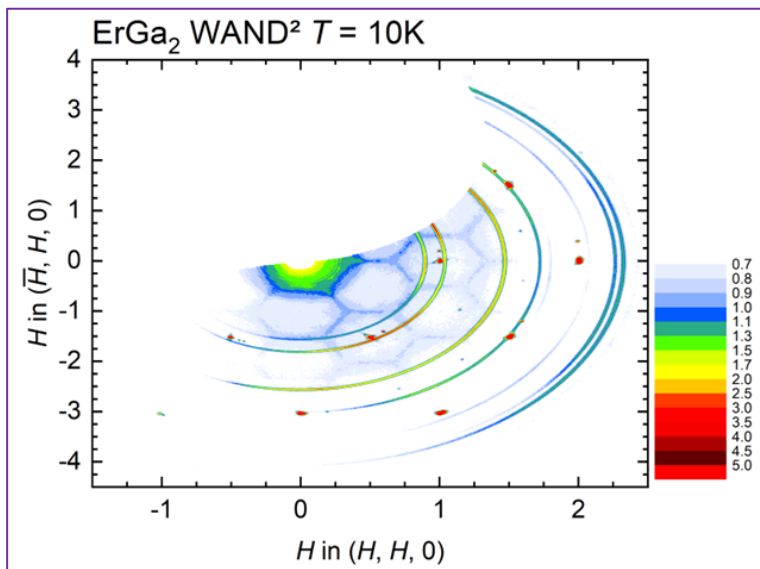


Matthias Frontzek, Athena Chen and Xiao Hu

SA: Jie Xing

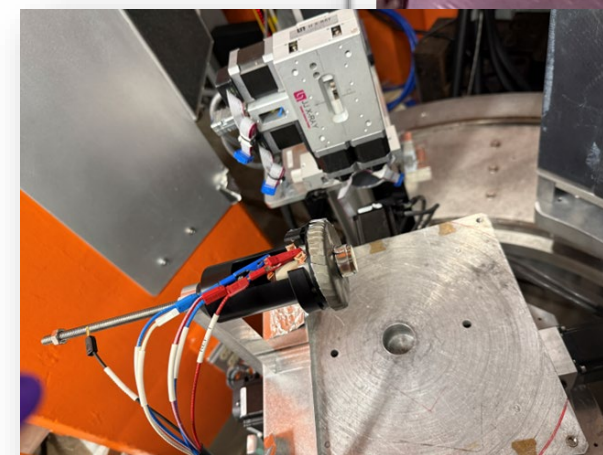
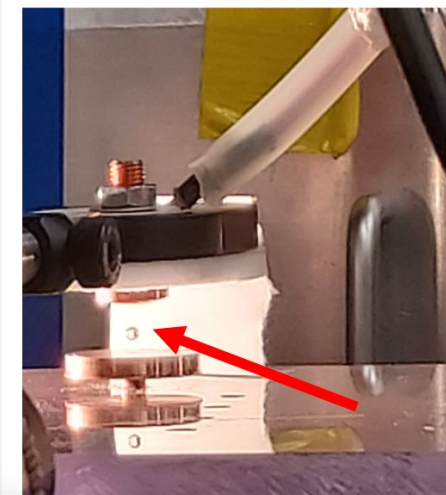
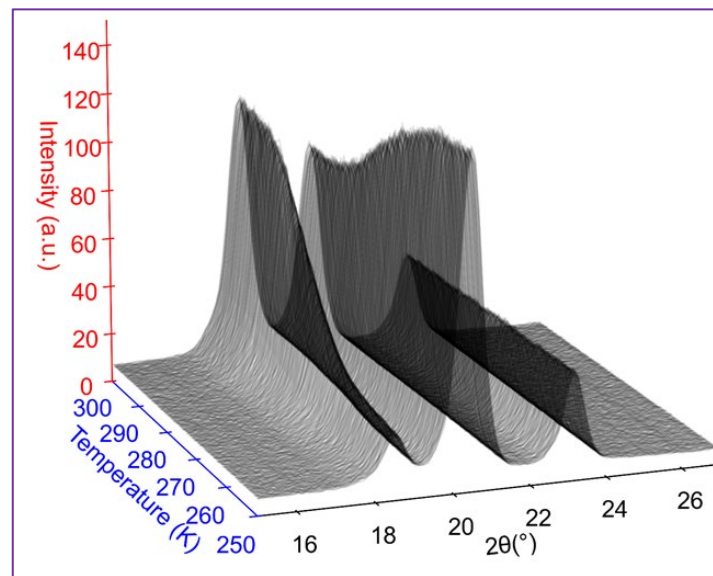
Joe Paddison

Matthias Frontzek (100%), IS (POC)
Si Athena Chen (100%), IS
Xiao Hu (50%), IS
Jie Xing (100%), SA
Joe Paddison CIS



Straightforward Reciprocal space mapping for single crystals

In-situ data collection in event mode



Wide Sample Environment capabilities

Levigator experiment at WAND² makes the news!



Matthias Frontzek

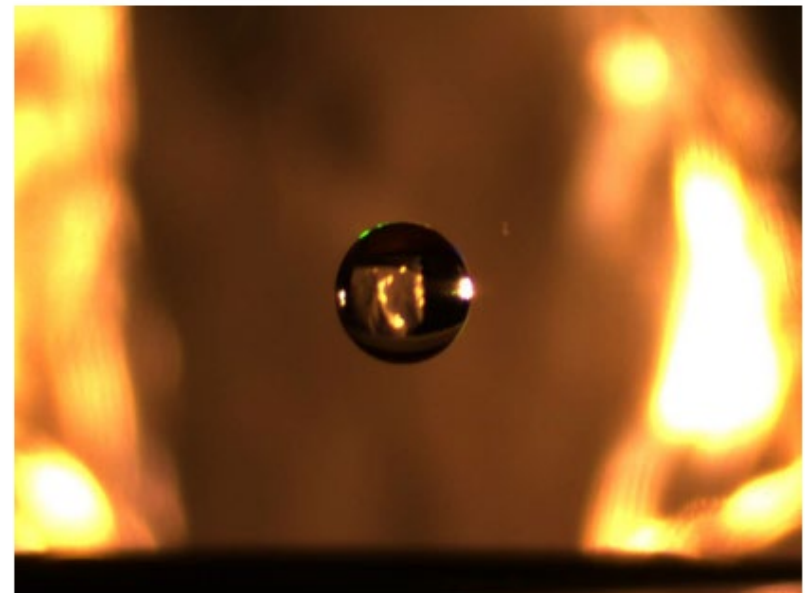
Matthias worked with Dante Quirinale (Sample Environment) to develop this capability at WAND² first used for the research led by Iowa State Professor John Jonghyun Lee and his students Brayden Berg, Gilbeom Seo, Yonghwa Yi, and Sai Katamreddy.



News

Iowa State researchers use scientific wand to suspend solutions in midair

<https://www.ornl.gov/news/iowa-state-researchers-use-scientific-wand-suspend-solutions-midair>



A small droplet of water is suspended in midair via an electrostatic levitator that lifts charged particles using an electric field that counteracts gravity. Credit: Iowa State University/ORNL, U.S. Dept. of Energy

Athena WON the Early Career Development Program LDRD Award 2026

OAK RIDGE
National Laboratory

2025 LDRD EARLY CAREER COMPETITION

Neutron Studies of Critical Mineral Extraction in Nonequilibrium Conditions

Si Athena Chen

Powder Group, Diffraction Section
Neutron Scattering Division
Neutron Sciences Directorate

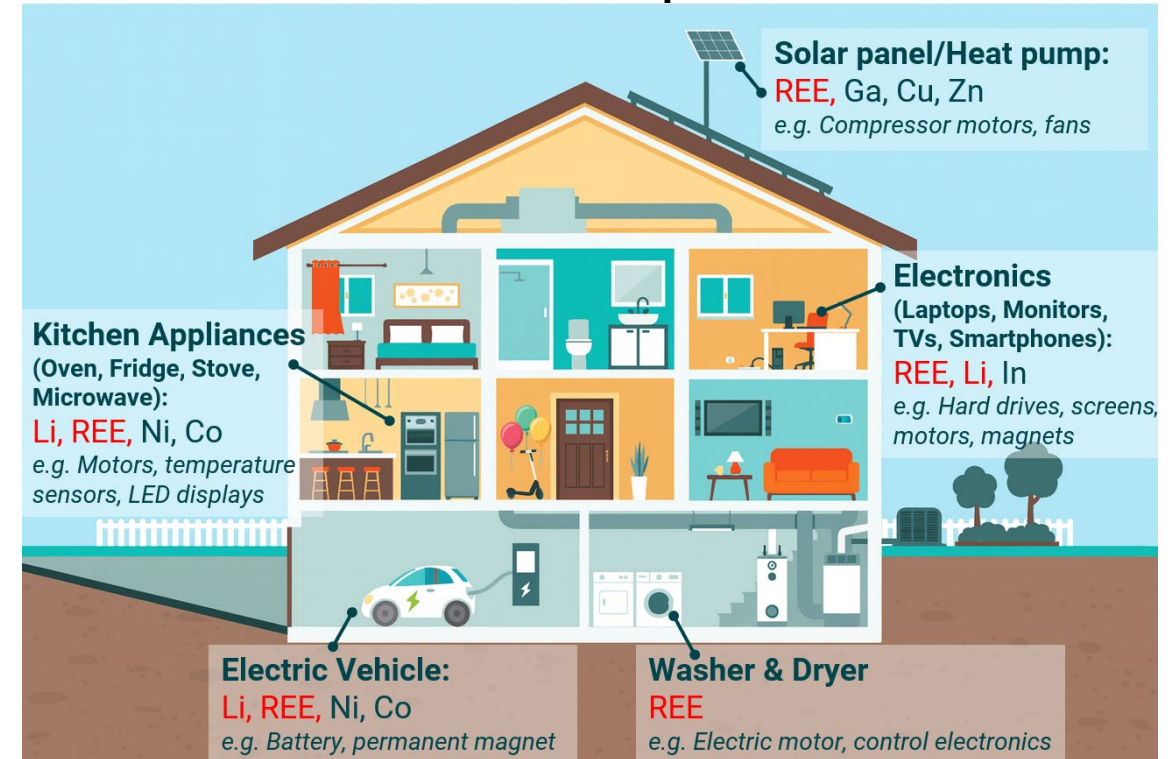
November 6, 2025

U.S. DEPARTMENT OF **ENERGY** ORNL IS MANAGED BY UT-BATTELLE LLC FOR THE US DEPARTMENT OF ENERGY



Si Athena Chen

Critical Minerals are Ubiquitous in Modern Life



<https://ornl.sharepoint.com/sites/ResearchEdu/SitePages/Early-Career-Development-Program.aspx>

OAK RIDGE National Laboratory Office of Research Education ☆ Not following

2025 EARLY CAREER DEVELOPMENT PROGRAM

Early Career Development Program

SNS BL3 SNAP: high-flux, medium resolution, neutron diffractometer designed to study materials subjected to high-pressure



Antonio Moreira dos Santos(100%), IS (POC)
Chris Ridley (100%) IS
Jasmine Hinton (100%),SA
Malcolm Guthrie, CIS

Antonio Moreira dos Santos and Chris Ridley Malcolm Guthrie
SA: Jasmine Hinton

Comprehensive suite of Pressure cells for a wide range of sample environments

Gas Cells



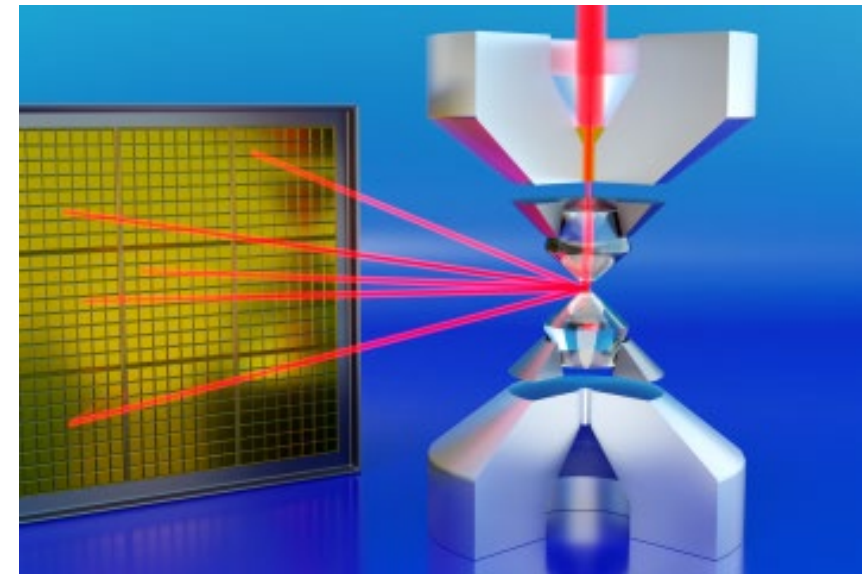
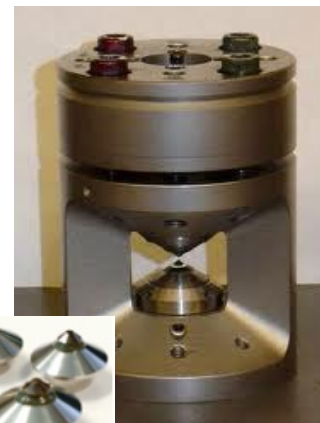
Clamp Cells



Paris-Edinburgh Presses



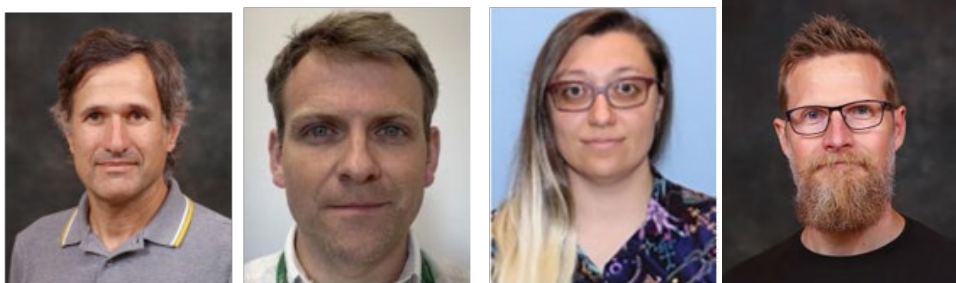
DACs



SNAPwrap - Full-Service Data Reduction



SNS BL3 SNAP: high-flux, medium resolution, neutron diffractometer designed to study materials subjected to high-pressure



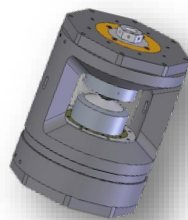
Antonio Moreira dos Santos and Chris Ridley Malcolm Guthrie
SA: Jasmine Hinton

Antonio Moreira dos Santos (100%), IS (POC)
Chris Ridley (100%) IS
Jasmine Hinton (100%), SA
Malcolm Guthrie, CIS

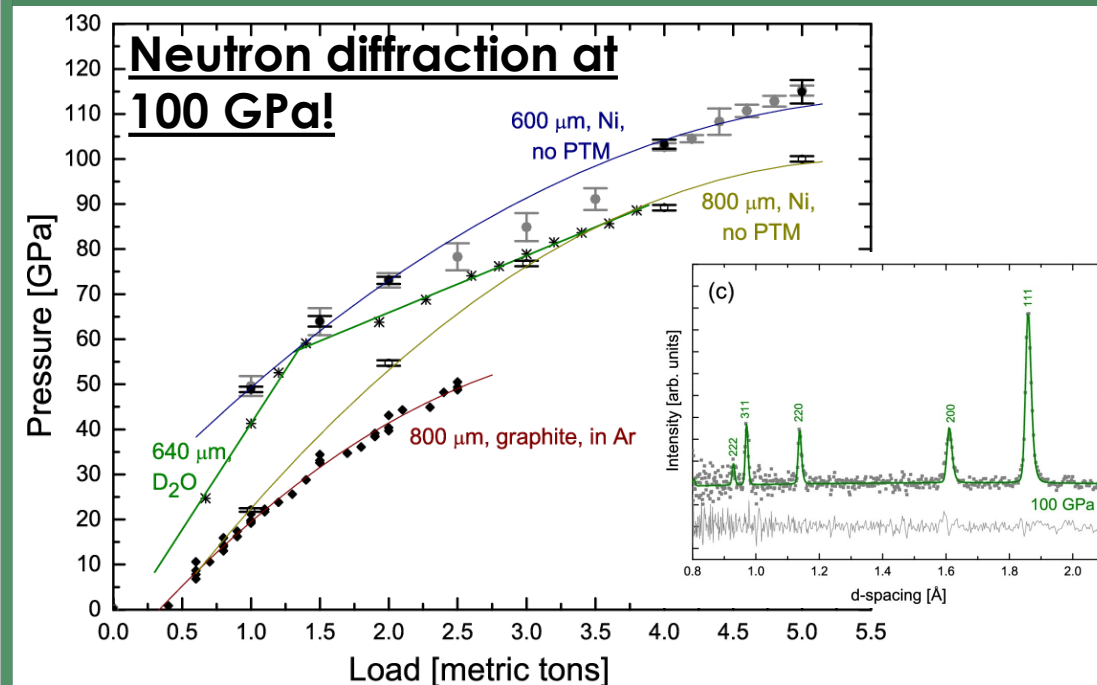
Mail-in Program:

The only mail-in service available for high-pressure neutron diffraction

- PE press at ambient temp.
- up to 20 GPa



• A promise fulfilled:



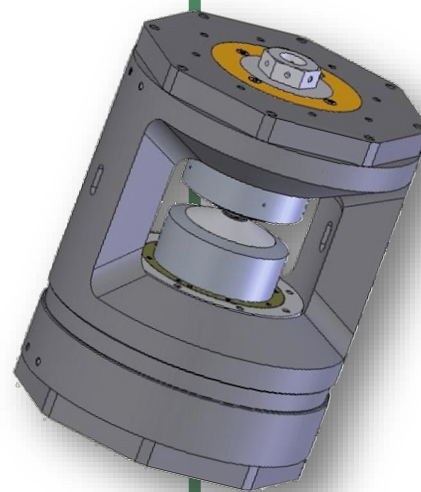
B. Haberl, M. Guthrie & R. Boehler Sci. Reports (13), 4741 (2023)

NEW! The MAIL-IN Program at SNAP AND WAND²

Mail-in Program:

The only mail-in service
available
for high-pressure neutron
diffraction

- PE press at ambient temp.
- up to 20 GPa



<https://neutrons.ornl.gov/snap/mail-in>

<https://neutrons.ornl.gov/wand/mail-in>

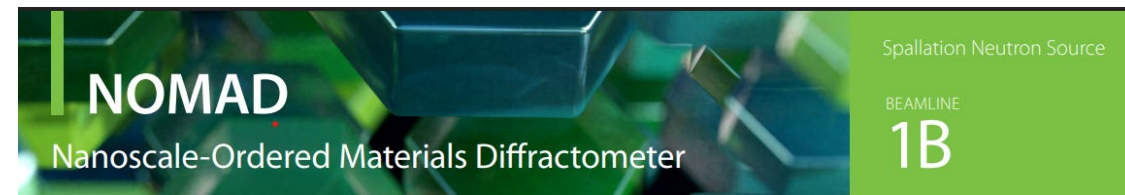
SNAP
Spallation Neutrons and Pressure Diffractometer

Spallation Neutron Source
BEAMLINE
3

WAND²
Wide-Angle Neutron Diffractometer

High Flux Isotope Reactor
BEAMLINE
HB-2C

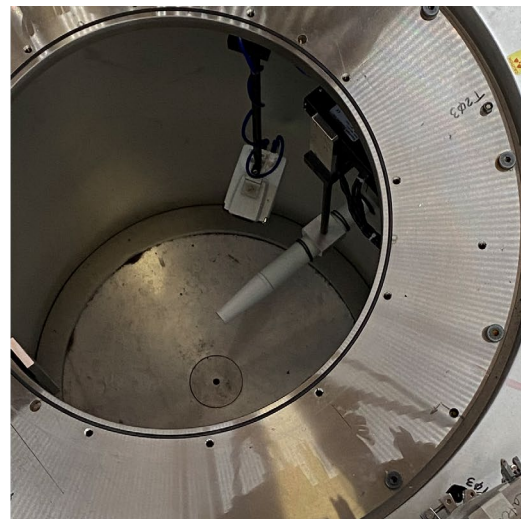
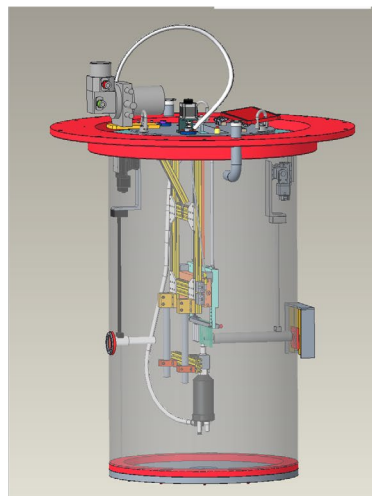
SNS BL1B NOMAD: Nanoscale-Ordered Materials Diffractometer



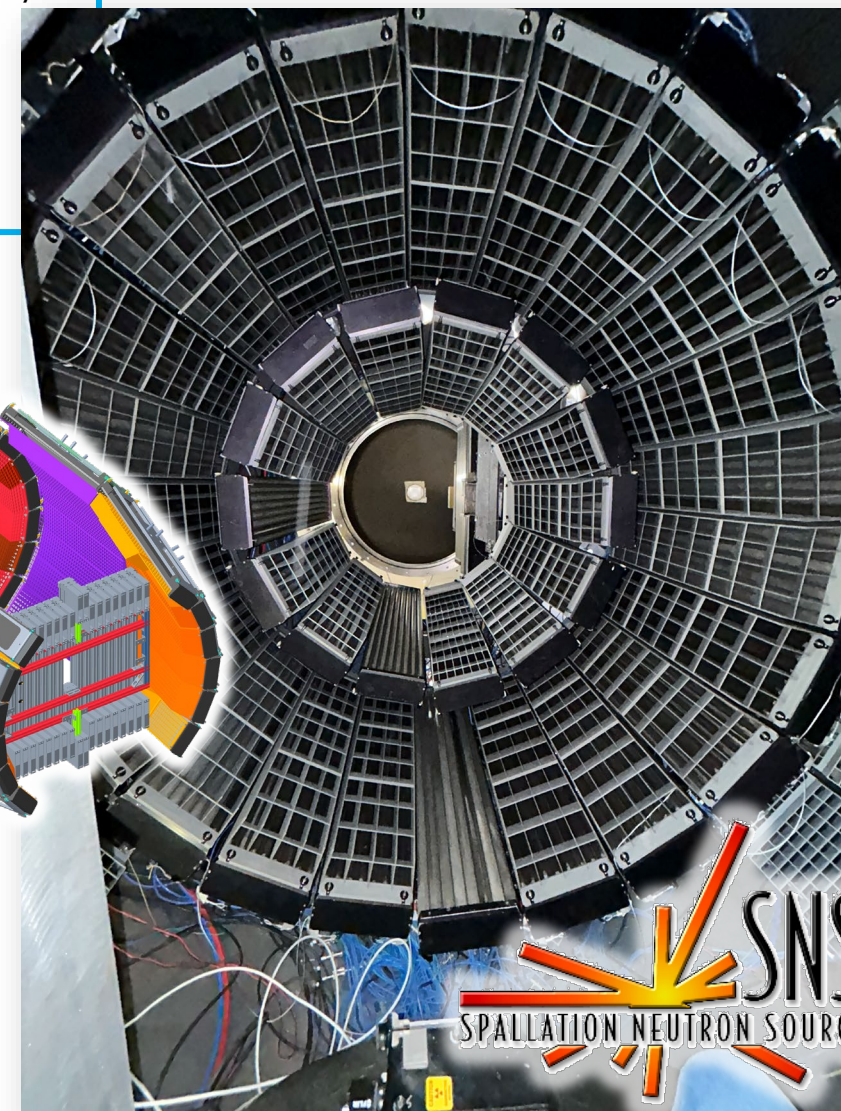
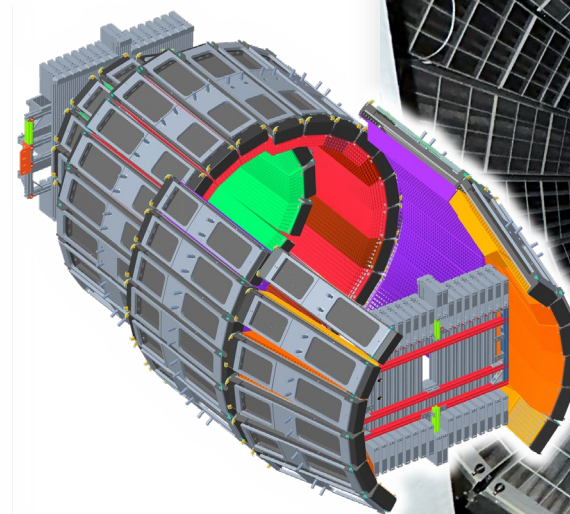
Joerg Neufeld, Cheng Li, Jue Liu,
SA: Emily VanAuken

Yuanpeng Zhang

Joerg Neufeld(100%), IS (POC)
Jue Liu (100%) IS
Emily Van Auken (100%),SA
Cheng Li (50%), IS
Yuanpeng Zhang CIS



**Developed sample environments
for small sample and in situ/operando studies**



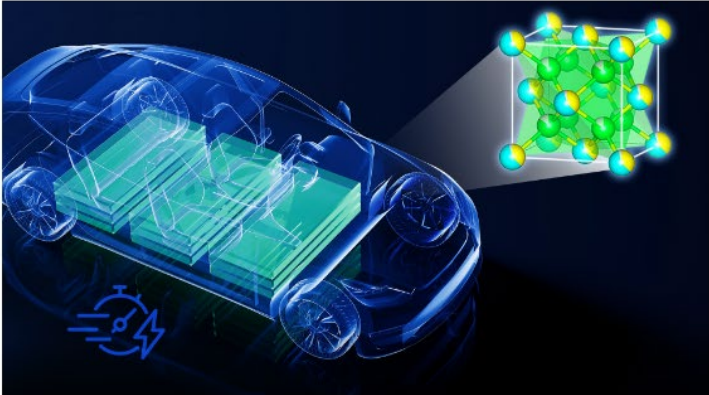
Jue and collaborator's all solid state battery work featured in ORNL news

<https://ornl.sharepoint.com/Pages/Article.aspx?articleId=44620>

ORNL Today | 80

Index Key Links News ORNL & Campus Staff Services Safety & Security Lab Director's Office ORNL Gives

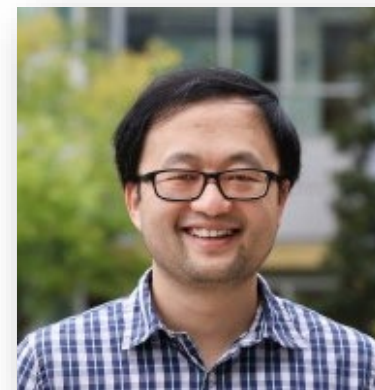
INTERNAL NEWS Research



Zeroing in on EV batteries with more storage and faster charging

November 16, 2023

Researchers have shown how an all-solid lithium-based electrolyte material can be used to develop fast charging, long-range batteries for electric vehicles that are also safer than conventional designs.



Jue Liu

"The material's dry air stability, efficient lithium-ion transport, and high compatibility toward metallic lithium are crucial advances. It's the best of both worlds," he said. "It offers all the performance benefits of liquid-electrolyte batteries that we use every day, but it's safer and more reliable."

SCIENCE ADVANCES | RESEARCH ARTICLE

ELECTROCHEMISTRY

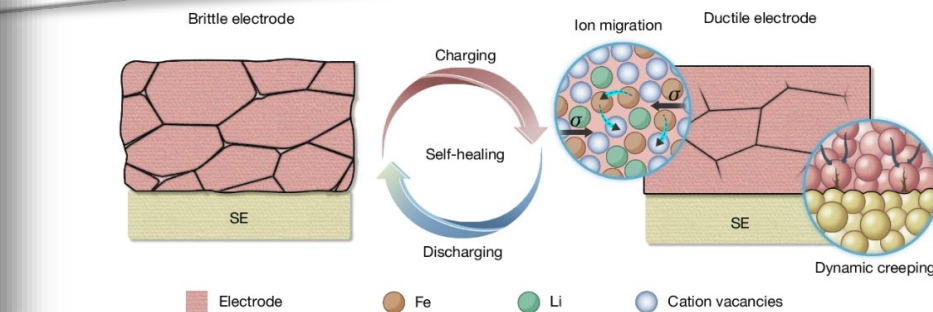
Lithium-compatible and air-stable vacancy-rich $\text{Li}_9\text{N}_2\text{Cl}_3$ for high-areal capacity, long-cycling all-solid-state lithium metal batteries

Weiham Li^{1,2+}, Minsi Li^{1,2+}, Po-Hsiu Chien³⁺, Shuo Wang⁴⁺, Chuang Yu¹, Graham King⁵, Yongfeng Hu⁵, Qunfeng Xiao⁵, Mohsen Shakouri⁵, Renfei Feng⁵, Bolin Fu¹, Hamidreza Abdolvand¹, Adam Fraser¹, Ruying Li¹, Yining Huang³, Jue Liu^{3*}, Yifei Mo^{4,6*}, Tsun-Kong Sham^{2*}, Xueliang Sun^{1,7*}

Jue and collaborator's work on all solid state battery (ASSB) work published in NATURE!



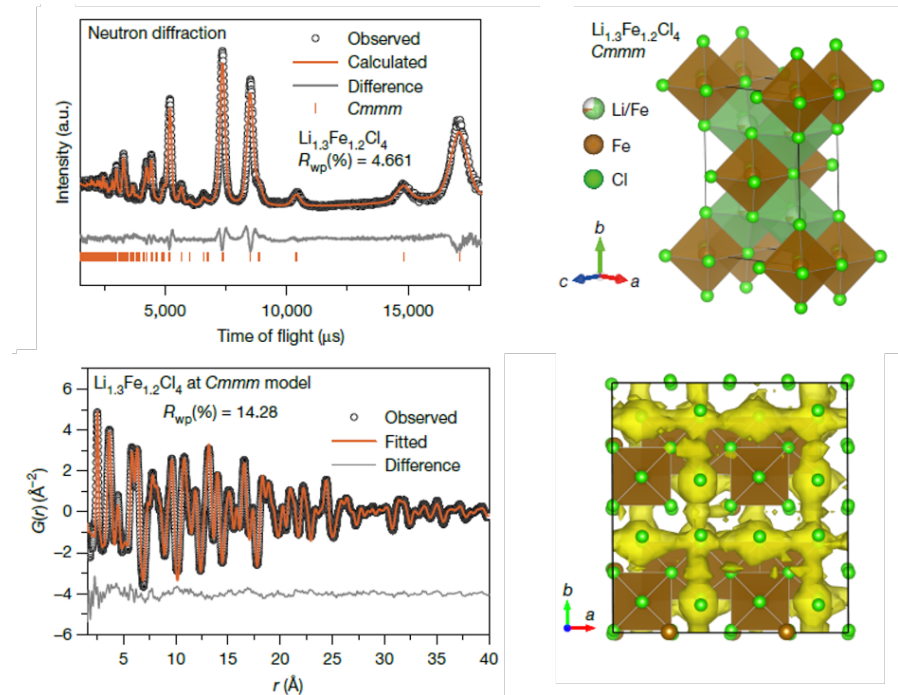
Jue Liu



Schematic of the brittle-to-ductile transition of the $\text{Li}_x\text{Fe}_{1.2}\text{Cl}_4$ electrode and the self-healing of the mechanical failures.

Significance and Impact

Functioning as a trinity of cathode, catholyte, and electronic conductor, $\text{Li}_{1.3}\text{Fe}_{1.2}\text{Cl}_4$ simplifies fabrication, cuts costs, and achieves high energy densities. Leveraging abundant, low-cost iron, this work provides a sustainable, practical path to competitive ASSBs.



Structure of $\text{Li}_{1.3}\text{Fe}_{1.2}\text{Cl}_4$ is determined using combined neutron, X-ray diffraction and PDF data.

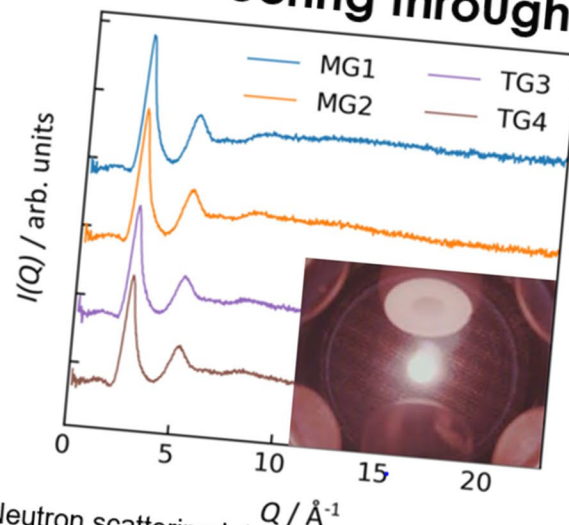
Joerg and collaborator's "Space glass" paper will be presented as a Highlight for SNS for May's Conference meeting with DOE Program Managers



Joerg Neufeind

"Space glass"
measured at NOMAD
using the electrostatic
levitator furnace

Peering through Glasses that were Made in Space



Neutron scattering intensity from two glasses made in space and two made terrestrially.

Wilke, S. K. et al. *npj Microgravity* 10, 26 (2024),
doi: 10.1038/s41526-024-00371-x

Work was performed at NOMAD, SNS BL-1B

MDI
Instruments for Innovation®

OAK RIDGE
NATIONAL LABORATORY
HIGH FLUX ISOTOPE REACTOR
SPALLATION NEUTRON SOURCE



Science and
Technology
Facilities Council
ISIS Neutron and
Muon Source

Argonne
NATIONAL LABORATORY

OAK RIDGE
National Laboratory

11

NSD Progress Report
October 2010

Building the Future in Microgravity

Using neutrons at ORNL, The Ohio State University researchers are mapping stress in space welds to help make off-world manufacturing a reality.

Mankind's Next Leap



Safer Launches:

Space welding allows the opportunity to launch structures into space with less concern about damage caused by high-G forces.

Repair Work During Missions



A "Mechanic" in Space:

Space welding allows astronauts to make repairs and do maintenance on spacecraft.

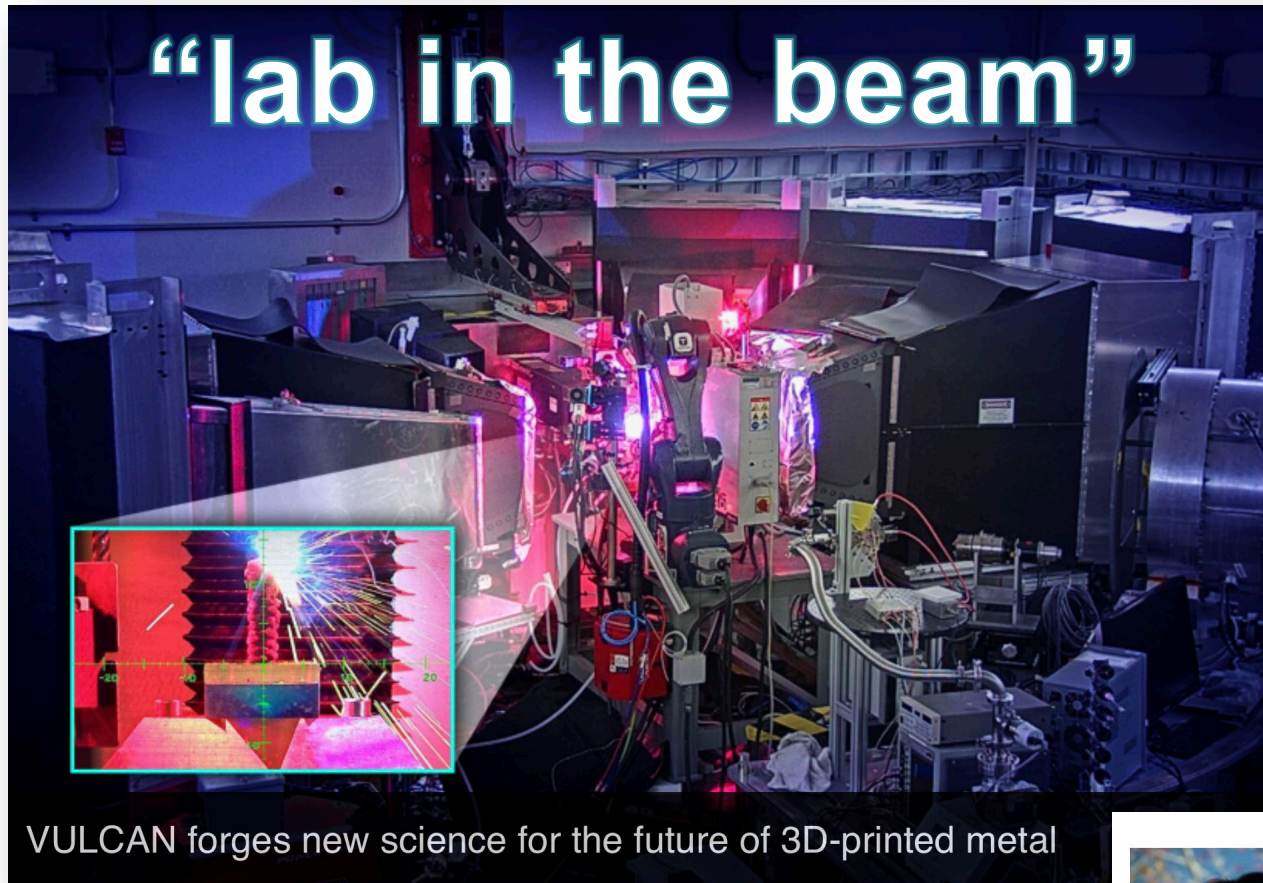
Enabling Future Discoveries



Reaching New Limits:

Welding is a fundamental fabrication process required for deep-space exploration.

SNS-BL7 VULCAN: The Engineering Diffractometer at SNS



- VULCAN is designed for understanding engineering and functional materials behavior under complex environments
- Enables resolving sciences spatially and temporally under extreme, e.g. grain orientation-dependent evolution in lattice strain, damage, phase transformation etc. in structural, functional, energy materials during in-situ/operando processing/synthesis/manufacturing.
- Special sample environments e.g. +/-10KN fatigue mechanical loadframe with induction heating, additive manufacturing device, high temperature atmosphere or vacuum furnaces up to 1600°C, 100Ah battery cyclers etc.

<https://neutrons.ornl.gov/content/vulcan-forges-new-science-future-3d-printed-metal>

Plotkowsky et al, **Nature Communications** 2023



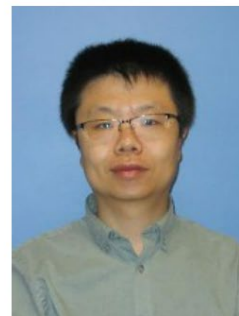
Ke An
Instrument Scientist



Yan Chen
Instrument Scientist



Harley Skorpenske
Scientific Associate



Dunji Yu
Scientific Associate

Microstructure Effects on Infiltrated Molten Salt Distribution Revealed by Neutron Imaging (Neutron Computed Tomography or nCT)



Research article • Full text access [Get rights and content](#)

Viewing is understanding: Graphite microstructure effects on infiltrated molten salt distribution revealed by 3D neutron tomography ☆

Jisue Moon ^a ✉, Nidia C. Gallego ^b ✉, Cristian I. Contescu ^c, James R. Keiser ^d, Yuxuan Zhang ^e, Hassina Bilheux ^e [Show more](#) ▾

MOTIVATION:

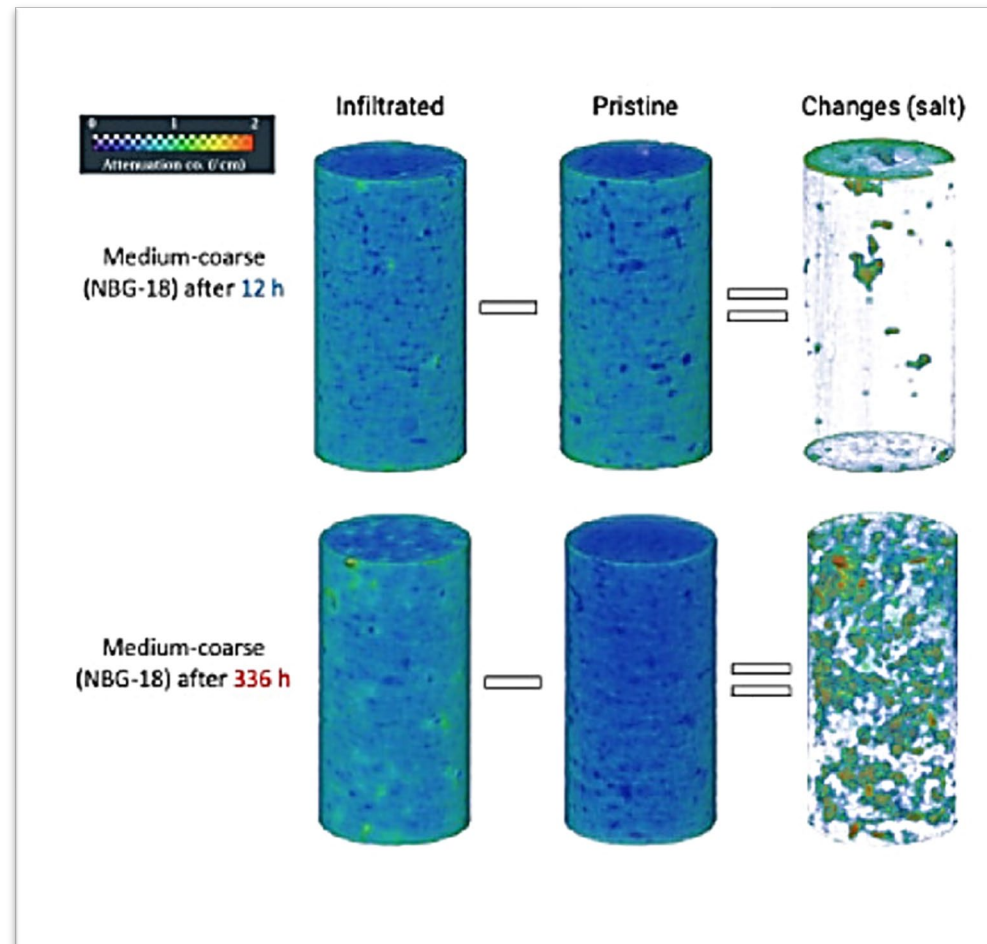
Find graphite moderator with least molten salt impregnation in advanced nuclear reactors (molten salts as the cooling agent has higher energy efficiency, improved reliability, and safer operation)

CHALLENGE:

Need to “see inside” the graphite moderator and/or reflector components as they are in continuous contact with the molten salts.

SOLUTION:

Neutron Computed Tomography (nCT)



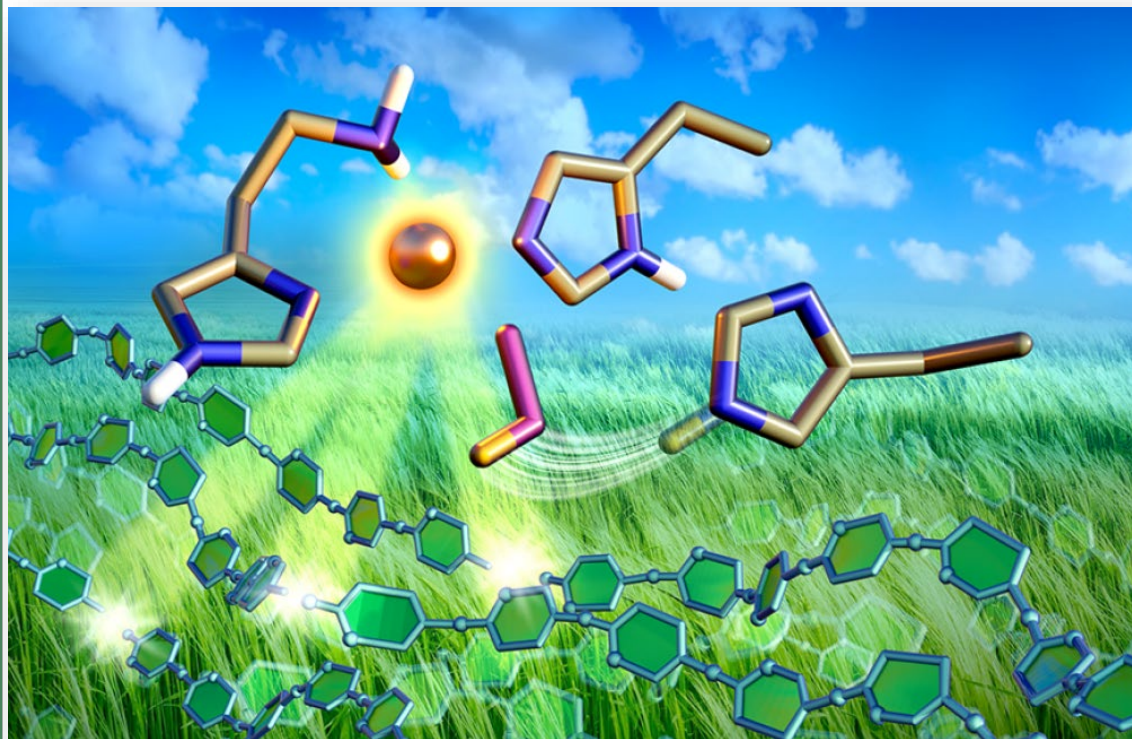
Hassina Bilheux



Yuxuan Zhang

Reconstructed 3D volumes of graphite before and after molten salt infiltration. Volume subtraction is performed to extract the 3D distribution of infiltrated salt.

Neutrons reveal “the copper key” to more efficient biomass breakdown



Neutron scattering experiments at the Spallation Neutron Source revealed how the dynamics between copper and oxygen make a special type of enzyme excel at breaking down biomass. Insights could lead to lowering the cost of biofuel production

Motivation:

Non food, plant-based biofuels have potential as a green alternative to fossil fuels

Challenge:

the enzymes required for production are too inefficient and costly to produce

Solution

LPMOs, excel at breaking down organic matter, neutrons showed “how”



Flora Meilleur
NCSU/ORNL

**Biochemistry at
the atomic scale**

ROYAL SOCIETY OF CHEMISTRY

Search...

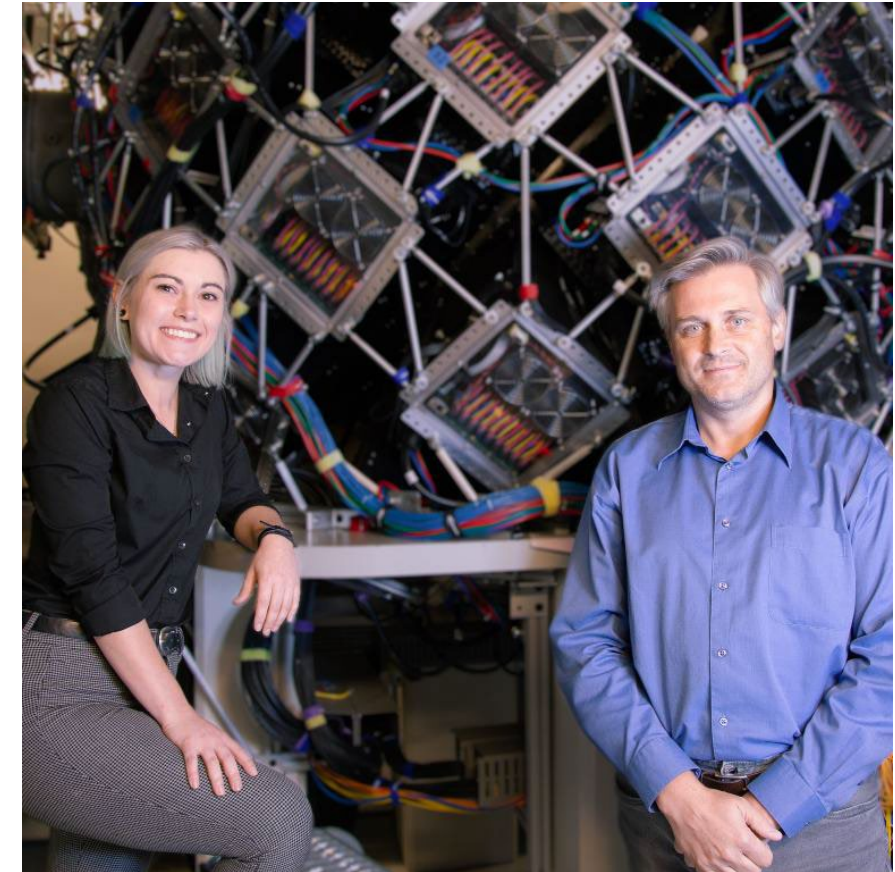
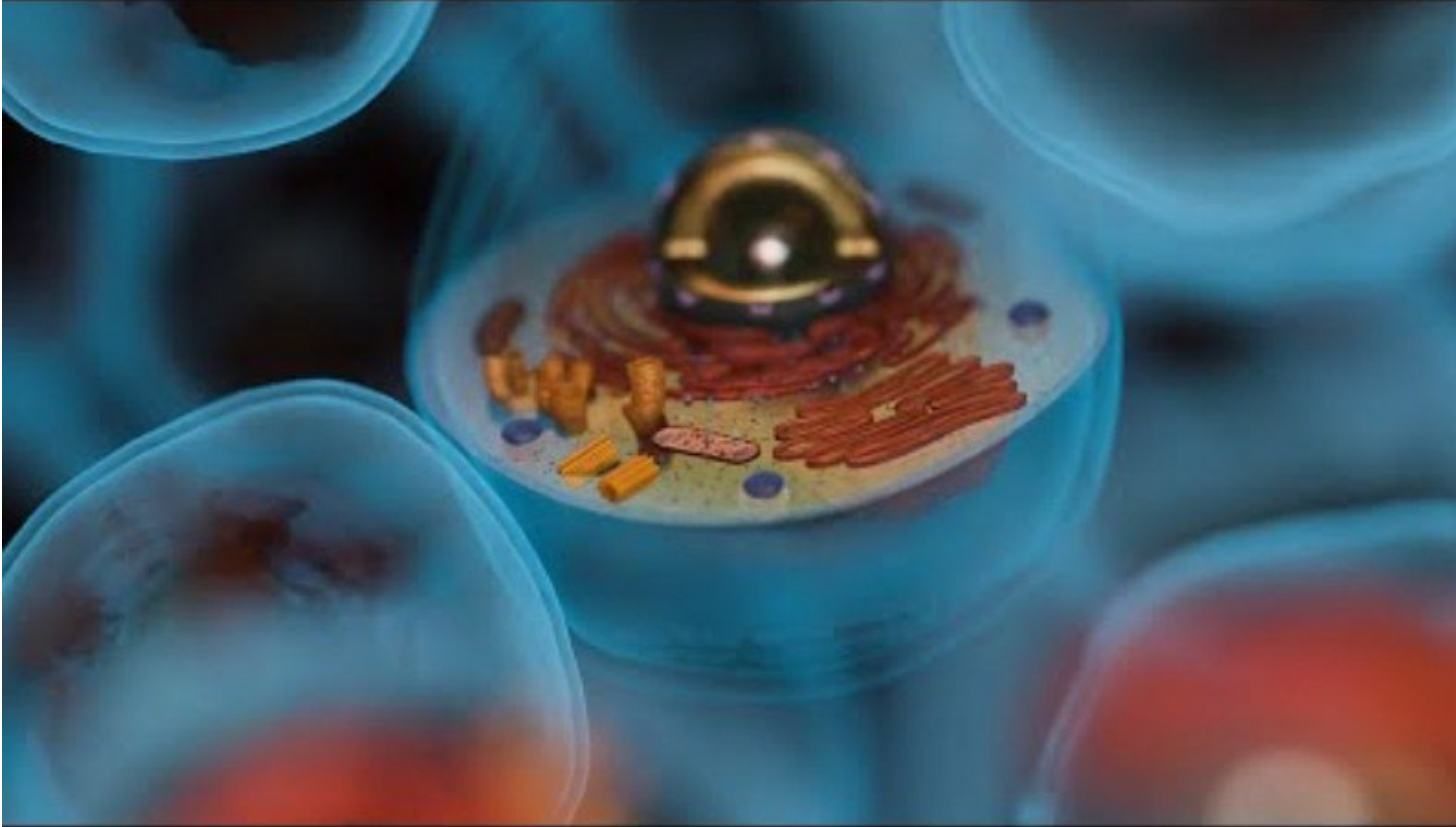
Chemical Science

Capture of activated dioxygen intermediates at the copper active site of a lytic polysaccharide monooxygenase[†]

Themed collections: [Most popular 2022 chemical biology articles](#)

[Gabriela C. Schröder](#) ; [William B. O'Dell](#) ; [Simon P. Webb](#) ; [Pratul K. Agarwal](#) ; [Flora Meilleur](#)

Neutrons settle 40-year debate on enzyme for cancer drug design



Victoria Drago and Andrey Kovalevsky used the MaNDi at SNS and IMAGINE at HFIR to discover new details of an enzyme that can aid cancer drug design.

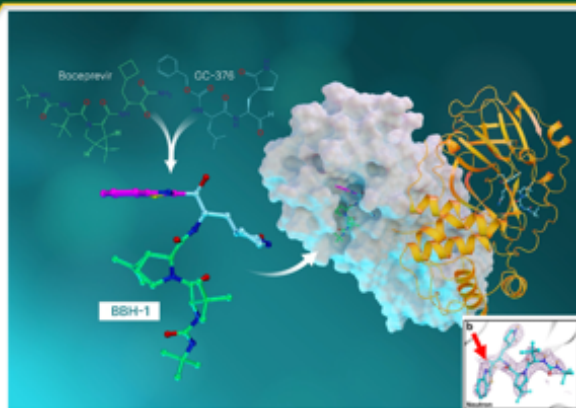
HFIR CG-4D IMAGINE: Image plate quasi-Laue neutron diffractometer

Neutrons uncover atomic details of SARS-CoV-2 macrodomain to guide design of novel antivirals

Scientific Achievement

We determined and compared the room

Neutrons help design inhibitors of SARS-CoV-2 main protease



Scientific Achievement

SARS-CoV-2 main protease (*M_{pro}*) enzyme is indispensable for virus replication and is an essential drug target for the design and development of small-molecule antivirals to treat COVID-19. Neutron crystallography was used to help design and characterize covalent hybrid protease inhibitors (BBH-1, BBH-2 and NBH-2) created by splicing components of known hepatitis C and SARS-CoV-1 protease inhibitors. These inhibitors demonstrated efficient inhibition of SARS-CoV-2 in cell-based assays, paving the way for further design of improved antivirals.

Significance and Impact

Hydrogen atoms are crucial players in drug binding, their locations determine protonation states and electric charges of ionizable residues. Knowledge of hydrogen atom positions provides unique information for drug design and was used to design potent (nanomolar) inhibitors of SARS-CoV-2 *M_{pro}*, map essential hydrogen bonding interactions between inhibitors and enzyme, and evaluated antiviral properties. Comparison with the FDA-approved *nirmatrelvir* from Pfizer indicated how inhibitor design can be further improved.

Research Details

- Neutron structure of *M_{pro}*/BBH-1 complex visualized critical hydrogen atoms and hydrogen bonds for the inhibitor binding; X-ray structures of *M_{pro}* in complexes with BBH-2, NBH-2, and *nirmatrelvir* were determined.
- Thermodynamics of inhibitor binding to *M_{pro}* evaluated by isothermal titration calorimetry.
- Antiviral properties of the inhibitors were evaluated in cell-based assays.



Andrey Kovalevsky
Instrument Scientist



Flora Meilleur
Instrument Scientist



Dean Myles
Instrument Scientist

The image shows how hybrid inhibitor BBH-1 was designed from boceprevir (hepatitis C protease inhibitor) and GC-376 (SARS-CoV-1 inhibitor) and its neutron structure with SARS-CoV-2 *M_{pro}*. Inset shows nuclear density of BBH-1 revealing deprotonated negatively charged oxyanion (red arrow).

D.W. Kneller, H. Li, G. Phillips, K.L. Weiss, Q. Zhang, M.A. Arnould, C.B. Jonsson, S. Surendranathan, J. Parvathareddy, M.P. Blakeley, L. Coates, J.M. Louis, P.V. Bonnesen, A. Kovalevsky, *Nat. Commun.* **13** 2268 (2022). DOI: 10.1038/s41467-022-29915-z.

Work performed on IMAGINE at High Flux Isotope Reactor, Center for Structural Molecular Biology, Center for Nanophase Materials Sciences, LADI-DALI at Institut Laue-Langevin, Grenoble, France.

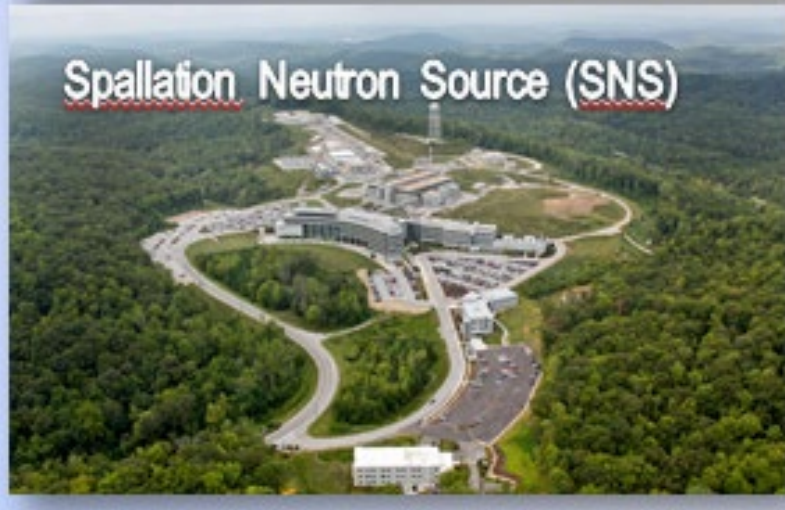


U.S. DEPARTMENT OF
ENERGY

Office of
Science



THE FUTURE OF NEUTRONS IN THE US: THREE COMPLIMENTARY SOURCES

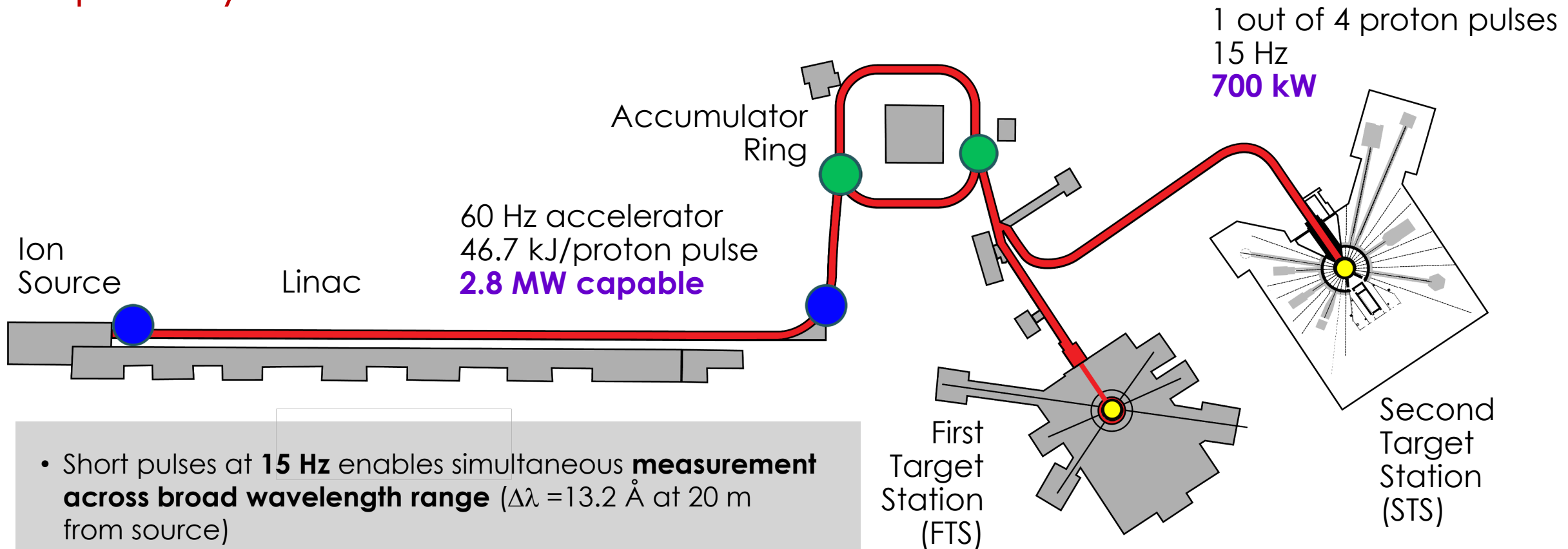


Second Target Station (STS) 22 instruments

→ combined use of intense, cold (longer wavelength) neutrons and instruments that are optimized for exploration of complex materials that can only be produced in small quantities



STS will make optimal use of the PPU-upgraded SNS accelerator capability

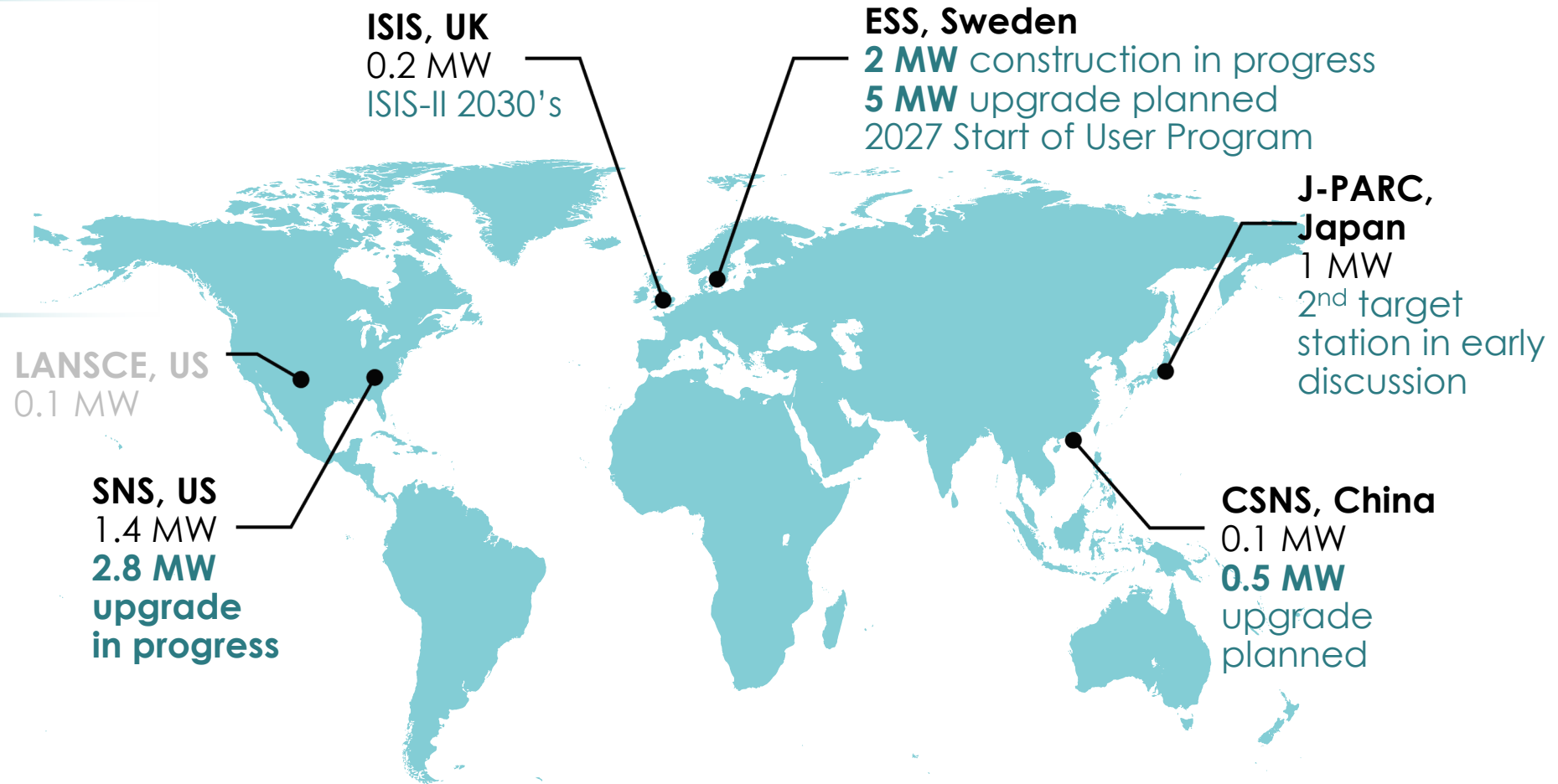


- Short pulses at **15 Hz** enables simultaneous **measurement across broad wavelength range** ($\Delta\lambda = 13.2 \text{ \AA}$ at 20 m from source)
- Complementarity with FTS – **uses all available accelerator capability provided by PPU**
- **Flexibility** will be provided to **operate** both FTS and STS at the same time or separately if either is shutdown

3 out of 4 proton pulses
45 pulses/sec
2 MW

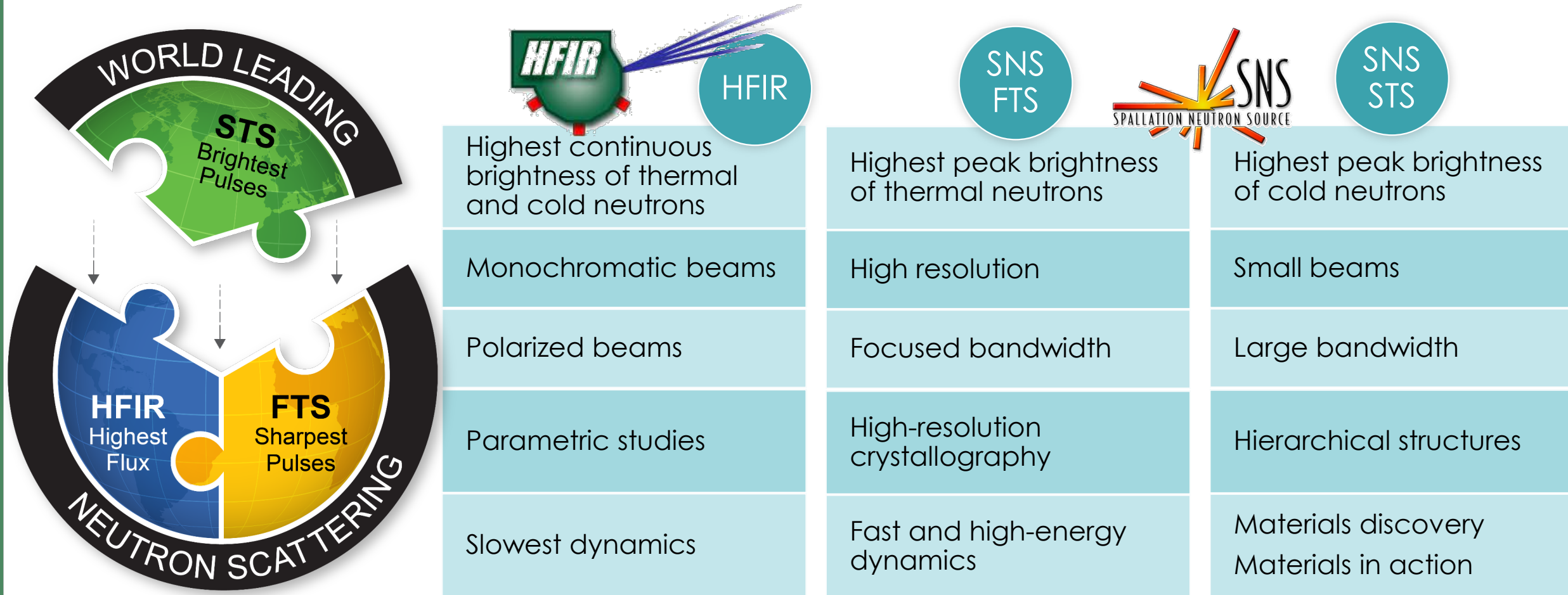
The international pulsed neutron landscape has evolved since the Spallation Neutron Source (SNS) began operating in 2006

Other nations
are investing
in spallation
neutron sources



ORNL's NEUTRON SCIENCES VISION: 3-SOURCE STRATEGY

- Capability provided at source where it performs best
- Three facilities provide complementary capabilities





Summer 2027 Internships at Oak Ridge National Laboratory

Join 800+ interns this summer at the world's premier research institution,
mentored by some of the best scientists and engineers in the world

Many of whom... started as interns.



Learn more at education.ornl.gov

Contact us at education@ornl.gov

Most program deadlines
for Summer 2027 are in
January 2027

Apply now at
education.ornl.gov!

- 10 weeks – 12 months
- Full-time, on-site
- All academic majors
- 800+ students each summer
- Stipend, Travel, Housing Allowance

Program
Flyers



Program
Slides



Education and Outreach

<https://education.ornl.gov/>

→ 10-20 weeks under the mentorship of an ORNL staff member
→ through ORISE, UT-ORII, and various external programs.

- High school to doctoral students, including recent graduates
- All disciplinary areas included (*not just research*)
- Aligned with academic terms
- Follow standard start/end dates



- Students and faculty can participate
- Duration of one month to five years working with a staff researcher at ORNL
- through ORISE, UT-ORII, FWPs, subcontracts, and various external programs.
 - All academic levels, but most opportunities are for PhD students
 - 3-12 months for formal programs with opportunities to renew annually
 - No alignment with academic terms
 - Some formal programs, like GRO, have no deadlines
 - Flexible start/end dates



OPPORTUNITIES for UNDERGRADS fully funded by DOE's Workforce Development for Teachers and Scientists



Science Undergraduate Laboratory Internships (SULI)

Eligibility

For full eligibility details, please visit the student application page through education.ornl.gov.

- Undergraduate Students
- Recent Graduates (BS) 0-2yrs
- US Citizen / LPR
- GPA 3.0+
- Age 18+

<https://science.osti.gov/wdts/suli>

OPPORTUNITIES for UNDERGRADS fully funded by DOE's Workforce Development for Teachers and Scientists



Community College Internships (CCI)

Eligibility

- Community College Students only
- GPA 3.0+
- Age 18+
- US Citizen / LPR

<https://science.osti.gov/wdts/ci>

- **OPPORTUNITIES for GRADUATE STUDENTS fully funded by DOE's Workforce Development for Teachers and Scientists**

Eligibility

Graduate students currently pursuing Ph.D. degrees in areas of physics, chemistry, material sciences, biology (non-medical), mathematics, engineering, computer or computational sciences, or specific areas of environmental sciences

- **Minimum Age and U.S. Citizenship or Lawful Permanent Resident (LPR)**
- **Academic Status**
- **Enrollment in a Qualified Graduate Program**
- **Graduate Research aligned with DOE Office of Science Research Programs**
- **Establishment of a Collaborating DOE Laboratory Scientists**



OPPORTUNITIES for GRADUATE STUDENTS funded by ORNL



THE GEM FELLOWSHIP AT ORNL (GEM)

Eligibility

- GPA: 3.0
- US Citizen / LPR Only
- Recent grad (BS)
- Recent grad (MS)
- Graduate (MS)
- Graduate (PhD)

➔ This highly selective program aims to increase the participation of underrepresented groups in science and engineering through mentorship in one of ORNL's current research or technical programs

➔ student must first be awarded a fellowship by the National Gem Consortium and then be invited to an internship at ORNL.

OPPORTUNITIES for GRADUATE STUDENTS funded by ORNL

GRADUATE RESEARCH AT ORNL (GRO)

<https://education.ornl.gov/GRO/>

- ➔ offers students the opportunity to supplement your degree program from a leading research university by conducting research at ORNL.
- ➔ highly flexible program allows for the student and ORNL scientist to maximize research opportunities at ORNL

Eligibility Overview

- Currently enrolled as a full-time graduate student in a doctoral degree program at a regionally accredited U.S. university
- Minimum cumulative GPA of 3.0 on a 4.0 scale

There is no USA citizenship or permanent residency requirement to participate in the GRO program.

OPPORTUNITIES for Faculty fully funded by DOE's Workforce Development for Teachers and Scientists

Eligibility

- Be a US Citizen or Lawful Permanent Resident at the time of application
- Be a full-time faculty member at an institution of higher education:
 - Historically underrepresented in the US research community
 - Any institution also listed as an Historically Black College or University (HBCU)
 - Cannot be a Doctoral-Granting University assessed as being either very high research activity, or high research activity as determined in the 2010 Carnegie Classification of Institutions of Higher Education™
- Be a full-time faculty member in an area of: Physics, chemistry, biology (non-medical), mathematics, engineering, environmental sciences, materials sciences, or computer or computational sciences.



<https://science.osti.gov/wdts/vfp>



NEUTRONS “SEE” ATOMS IN UNIQUE WAYS

Weakly interacting

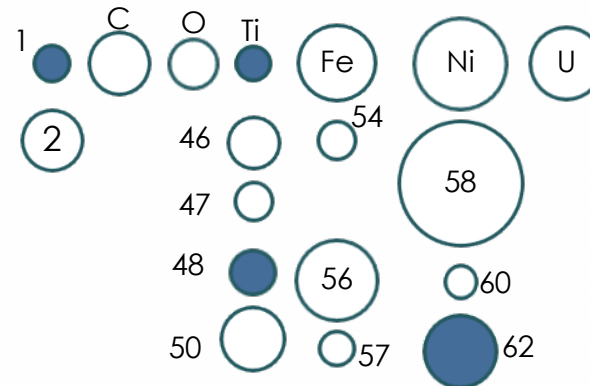
- Penetrate dense materials (cm's)
- Non-destructive
- Direct connection between theory and experiment



Complex sample environments & in operando

Scatter from nuclei

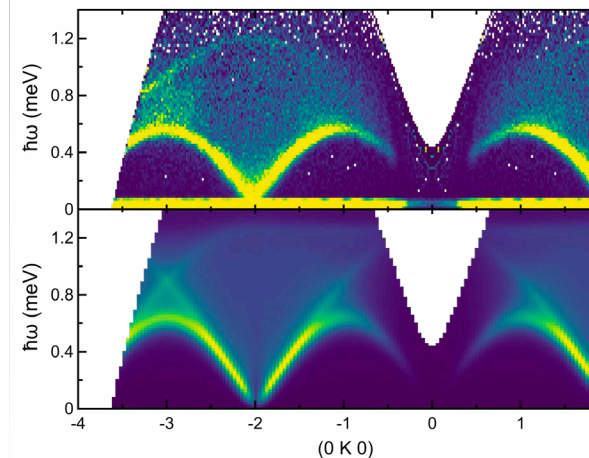
- Elemental and isotopic sensitivity
- Light element sensitivity (H, Li, ...)
- Isotopic substitution/contrast matching (H/D)



Neutron scattering lengths

Magnetic moment

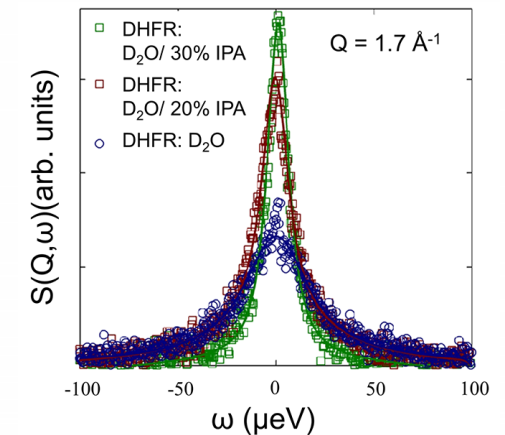
- Measure magnetism in condensed matter (both structure and dynamics)
- Separate nuclear from magnetic scattering
- Spin precession methods



Collective magnetic excitations in YbCl_3

Well-matched (λ & E)

- Wavelength of thermal & cold neutrons matched to atom distances (1-10 Å)
- Neutron energies are matched to excitations in condensed matter (1-100's meV)



Protein diffusion relates motion to function