



Overview ODIN – Status and Plans

STAP – September 2025

R. Woracek, A. Tartaglione, R. Ammer, S. Athanasopoulos, S. Schmidt, T. Chulapakorn, S. Xu, M. Morgano, M. Schulz, M. Strobl, V.M. Monge, B. Peric, E. Luca, E. Calzada + support groups (ECDC+DMSC)

### AGENDA



- ☐ Reminder: ODIN in brief
- ☐ ODIN: Updates since last STAP and NeuWave-12
- □ ODIN now: TG5 + Integrated Testing
- ☐ ODIN: Schedule for Hot Commissioning
- □ Summary
- ☐ First Science Strategy

# DIN — legwork state

Started over a decade ago...

30.10.2012

MXCurrent

MXRevision MXPrinted Version

# NIUS2012 - ESS Neut Meeting Report

Apr 15-18, 2012 Hotel zur Therme, Bad Zurzach Europe/Zurich timezone

Home

Registration

Venue / Accommodation

NEUWAVE-12 at ESS: Workshop Series on Wavelength Dependent Neutron Imaging Back in **Full Swing** 

**3** OPEN ACCESS



Timetable

Home



Available online at www.sciencedirect.com

**ESS Instrument Construction Proposal** 

ScienceDirect

Physics Procedia 69 (2015) 18 - 26



Nuclear Inst. and M

journal ho

Contents lists

10 World Conference on Neutron Radiography 5-10 October 2014 of the Imaging Instrument Project ODIN neutron-imaging instrument **ESS Instrument** 

WP coordinator Optics Express Vol. 23, Issue 1, pp. 301-311 (2015) • https://doi.org/10.1364/OE.23.000301

> Neutron guide optimisation for a tin imaging instrument at the European

A. Hilger, N. Kardjilov, I. Manke, C. Zendler, K. Lieutenant, K. Habicht, J.



ELSEVIER



Available online at www.sciencedirect.com

**ScienceDirect** 

-le by these authors ▼

Physics Procedia 69 (2015) 152 - 160

10 World Conference on Neutron Radiography 5-10 October 2014

Detectors requirements for the ODIN beamline at ESS

Manuel Morgano<sup>a\*</sup>, Eberhard Lehmann<sup>a</sup>, Markus Strobl<sup>b</sup>

#### ESS Lund hosted the NEUWAVE-5 Workshop

Wavelength frame multiplicati

P. Schmakat a,b, M. Seifert a,f, M.

P. Böni a, M. Strobl d,c



The NEUWAVE-5 participants met on the ESS-AB (Lund) site expecting positive signs to initiate building the European Spallation Source soon

ergy-selective neutron imaging, took

the neutron imaging instrument proj- attractive for neutron imaging. The

· ERNIS at J-PARC (Japan) . IMAT at ISIS-TS 2 (IIK)

Wavelength-Frame Multiplication Chopper System for the Imaging Instrument ODIN at the ESS

Dipl.-Phys. Univ. Philipp Schmakat







Physik-Department, Institut E21 Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II)

**Neutron Depolarisation Measurements of** Ferromagnetic Quantum Phase Transitions



Apr 15-18, 2012

NIUS2012 - ESS Neut Meeting Report

ODIN Project Update: update TUM

**3** OPEN ACCESS







ac Washan Series on

IKA TUM signed – TA Endorsed

### Contract / TA

- Next German-ESS meeting Nov. 24<sup>th</sup>
- first TA proposed
- Note: TUM is willing to upfront the cost for
- Note: Chopper tender documents under pr
- Tender depends on TUM-ESS pre-contract

Listaina cimulations

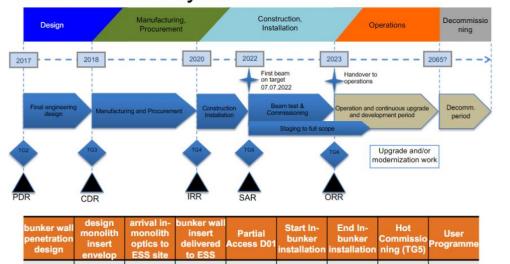
Technische Universität München

SCHEDULE NIK 6.5 t3 "Instrument 13.6.5 (ODIN) alled design, manufacturing and procurement, installation and integration." 6 the contribution agreement signed between EUROPEAN SPALLATION SOURCE ERIC and TECHNICAL UNIVERSITY OF MUNICH on

ТИП

Technische Universität München

### Instrument life cycle



MOU signed

eting, Lund - ESS 15

Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II)

**Neutron Depolarisation Measurements of** Ferromagnetic Quantum Phase Transitions

ength-Frame Multiplication Chopper System for the Imaging Instrument ODIN at the ESS

Dipl.-Phys. Univ. Philipp Schmakat

∂ Ope

Nov., 20th. 2017

10 World Conference on Neutron Radiography 5-10 O

sics Procedia 69 (2015) 152 - 160

Detectors requirements for the ODIN beam.

Manuel Morgano<sup>a\*</sup>, Eberhard Lehmann<sup>a</sup>, Markus surobi

Imaging and Engineering STAP mee

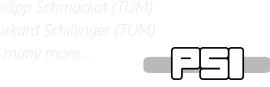
October 15th. 2019

ODIN STAP Meeting, Lund - ESS

03-Mar-17|31-Jun-18|24-Jan-19|15-Nov-20|03-Jun-21|11-Aug-21|25-Feb-22| 06-Jul-22|31-Dec-23

Physik-Department, Institut E21

# ODIN Team ТυП









Aureliano Tartaglione Scientist



Manuel Morgano Scientist



Robin Woracek Scientist





Lead Engineer



Technician



Shuqi Xu Post-Doc (LU)



Søren Schmidt Data Scientist





*Installation Engineer* 



Caroline Curfs Sample **Environment** 



Stefanos Athanasopoulos Commissioning Scientist (LU)



Head of Imaging group



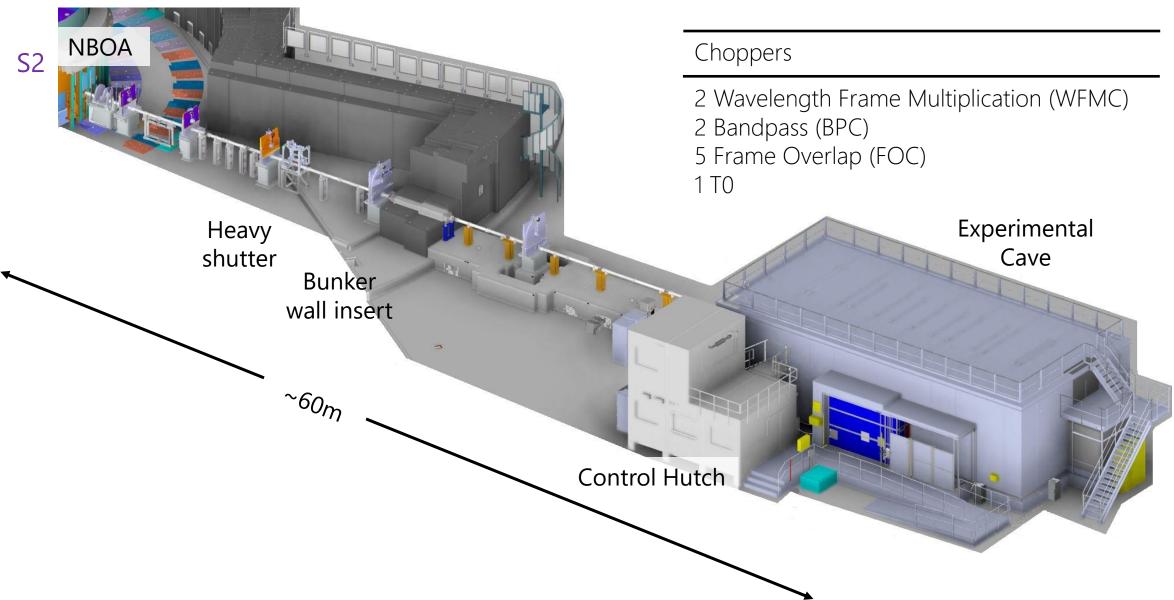
Head of Imaging group



Richard Ammer **Operation Engineer** 



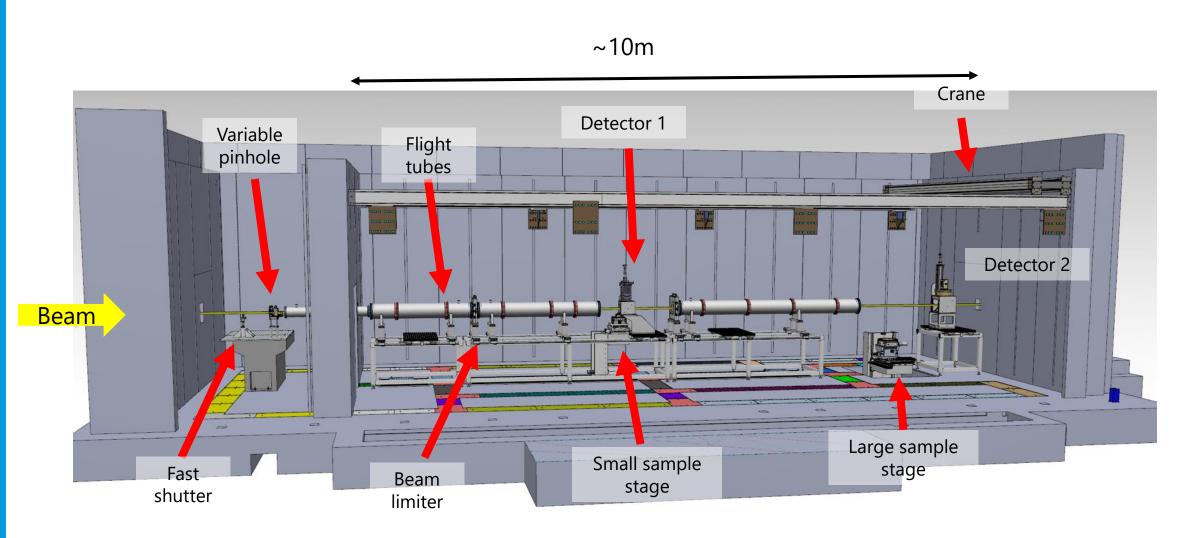
### Layout





### **Experimental Cave**





### In brief

ODIN Quick Eacts

ODIN Quick Facts				
Instrument Class	Imaging			
Moderator	Bispectral			
Primary Flightpath	50 m (to pinhole)			
Secondary Flightpath	2 – 14 m (pinhole to detector)			
Wavelength Range	1 – 10 Å			
Field of View	20 x 20 cm <sup>2</sup>			
L/D Ratio	Tunable 300 – 10000			
Incident Beam Polarisation	Optional			
Polarisation Analysis	Optional			
Bandwidth at 14 Hz	4.5 Å			
White Beam Mode				
Flux at Sample at 2 MW	1.2 x 10 <sup>9</sup> n s <sup>-1</sup> at 10 m, L/D = 300			
Spatial Resolution	< 10 μm			
<b>TOF Mode without Pulse-</b>	Shaping			
Flux at Sample at 2 MW	9 x 10 <sup>8</sup> n s <sup>-1</sup> at 10 m, L/D = 300			
Spatial Resolution	< 10 μm			
Wavelength Resolution	$\Delta \lambda / \lambda = 10\%$ at $\lambda = 2 \text{ Å}$			
<b>TOF Mode width Pulse-Sh</b>	aping			
Flux at Sample at 2 MW	1 x 10 <sup>8</sup> n s <sup>-1</sup> at 10 m, L/D = 300			
Spatial Resolution	< 10 μm			
Wavelength Resolution	Adjustable <0.5% - 1% (constant for all $\lambda$ )			



### Large space

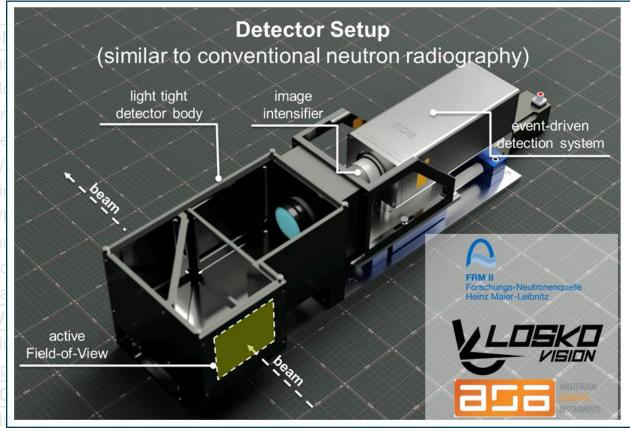
- > sample environments
- > setups (e.g. polarization, grating interferometry)
- Bi-spectral extraction
- Direct line-of-sight (T0 chopper)

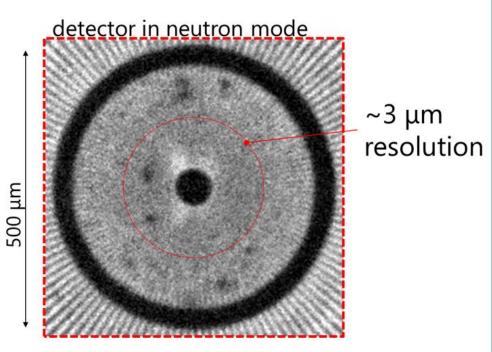
### Three main modes:

- > White beam
- ➤ high flux wavelength dispersive (basic ToF)
- ➤ high resolution wavelength dispersive (WFM)

# 

### In brief





Spatial Resolution

 $< 10 \, \mu m$ 

Wavelength Resolution

 $\Delta \lambda / \lambda = 10\%$  at  $\lambda = 2 \text{ Å}$ 

**TOF Mode width Pulse-Shaping** 

Flux at Sample at 2 MW 1 x 10<sup>8</sup> n s<sup>-1</sup>

< 10 µm

Wavelength Resolution

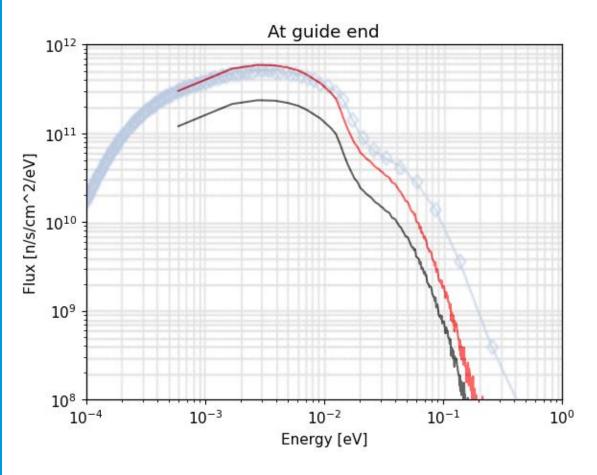
Adjustable < 0.5% - 1% (constant for all  $\lambda$ )

### Detectors:

- Scintillator CMOS (+optional gating)
- LumaCam (Scintillator event mode)
- > + Berkeley MCP in procurement

### Updated McStas results





### Results for white beam, no choppers, 2 MW

- End of guide (4.27 cm x 2.24 cm<sup>2</sup>):
  - Total intensity 2.98E10 n/s
  - Average flux 3.31E9 n/s/cm<sup>2</sup>
  - See figure with comparison to earlier results, black curve is 2 MW (red is 5 MW for comparison)
- Pinhole 3.0 x 3.0 cm^2
  - Total intensity 2.40E10 n/s
  - Average flux 2.67E9 n/s
- Sample (center, L/D 350 with the 3.0x3.0 cm pinhole and 10.5 m distance)
  - Peak flux in center 1x1 cm^2: 2.92E7 n/s/cm^2
  - Average flux over 30x30 cm^2: 1.49E7 n/s/cm^2
  - Instrument suite paper claims 1.2E9 n/s/cm<sup>2</sup> at L/D 300 and 2 MW (unknown if peak or detector average)

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# ODIN general status

#### Other components/activities:

- CUP (ESS): Installation complete
- CEP (ESS): Installation complete
- PSS (ESS): Installation complete
- Fire detectors and fire sprinklers: Installation complete



Choppers: Disc choppers: Installed Installed. Common shielding: Cave interior components: T0 chopper: bottom housing *In installation/storage,* Cave roof, beam stop , stairs Installed Installed installed, upper part in and railing: *In manufacturing* Cave walls: MCA SAT ongoing manufacturing Installed Installed NBOA: installed Bunker wall Remote handling area feedthrough: Out-of-bunker Control hutch: Cave internal door: Installed Heavy quides In bunker guides: Installed Installed Installed guides Installed External door: installed shutter: BBG with BBGOA installed

Installed

# ODIN general status

#### Other components/activities:

CUP (ESS): Installation completeCEP (ESS): Installation complete



Installed,

allation complete In installati r components: igoing

Cave roof, beam stop ,stairs and railing: Installed

NBOA: installed

Remote handl guides BBG with BBG



### A lot happened since last STAP and Neuwave-12





### A lot happened since last STAP and Neuwave-12







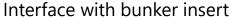
### A lot happened since last STAP and Neuwave-12



•All guides were installed and aligned, but then...



Installed guides in bunker





-> damaged vacuum bellow



Clearances between chopper and guides:

FOC 1  $\rightarrow$  1,04 mm clearance

FOC  $2 \rightarrow 1$ , 051 mm clearance

FOC  $3 \rightarrow 0.45$  mm clearance

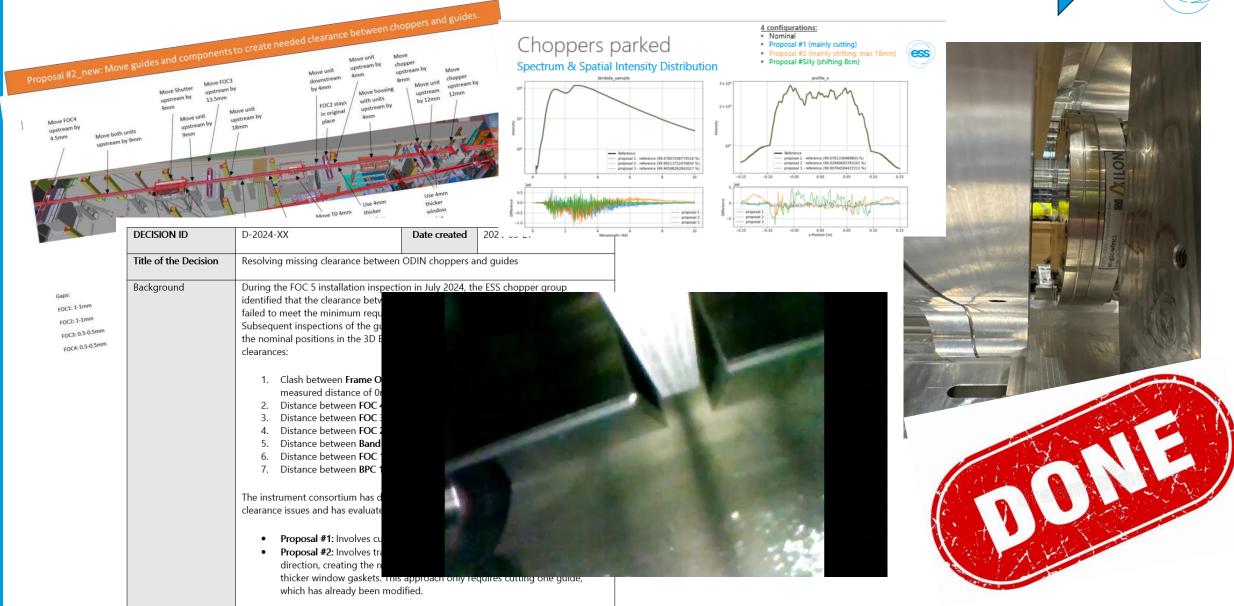
FOC  $4 \rightarrow 0.46$  mm clearance

FOC  $5 \rightarrow 0.413$  mm clearance

**Requirement:** Gap between neutron guides and chopper disks should be at least **5mm**.

### A lot happened since last STAP and Neuwave-12



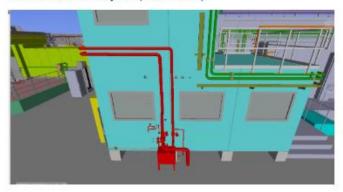


### A lot happened since last STAP and Neuwave-12

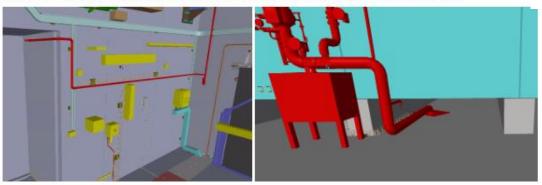


•ODIN now has a fire sprinkler system... (we "need" to have it..)

Connection from valve system (outside hutch):



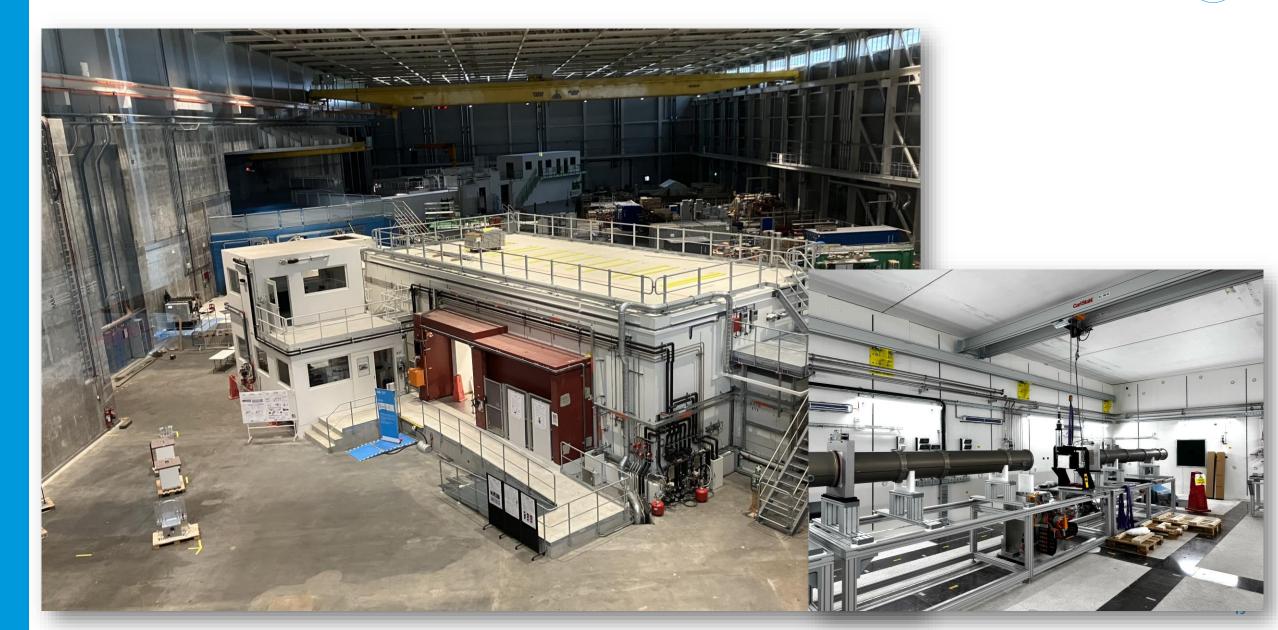
There is a small sprinkler to protect the sprinkler. At CDR: We decided to use insulation (rockwool?) instead.





## ODIN Construction – Finished

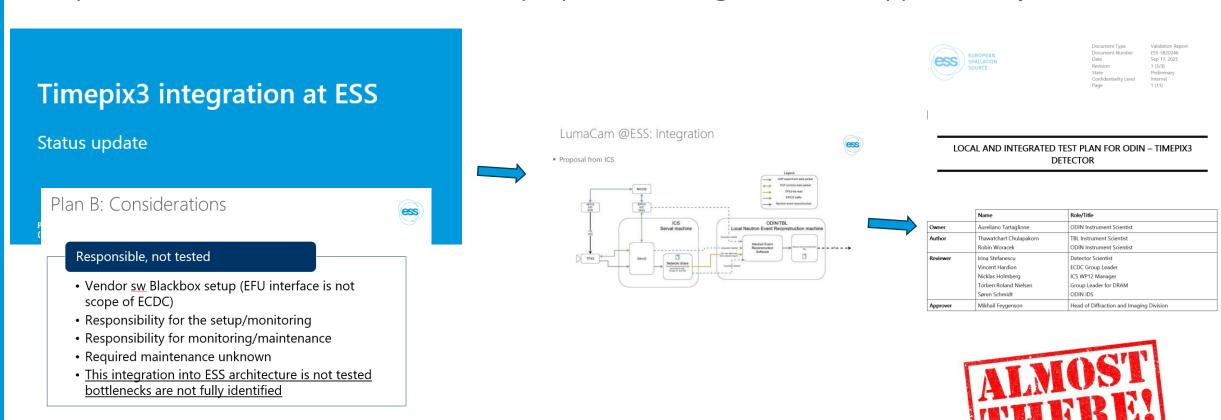




### ODIN – ToF Detetcor

ess

- Integration into the **ESS DAQ architecture** was pending for several years
- A solution has now been agreed and implemented at ESS
  - → Based on **EMPIR framework** for neutron event reconstruction
- Despite earlier concerns, this still enables proper DAQ integration and supports analysis needs



STAP April 2024

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# Document compilation and assessment: Confluence and TG5



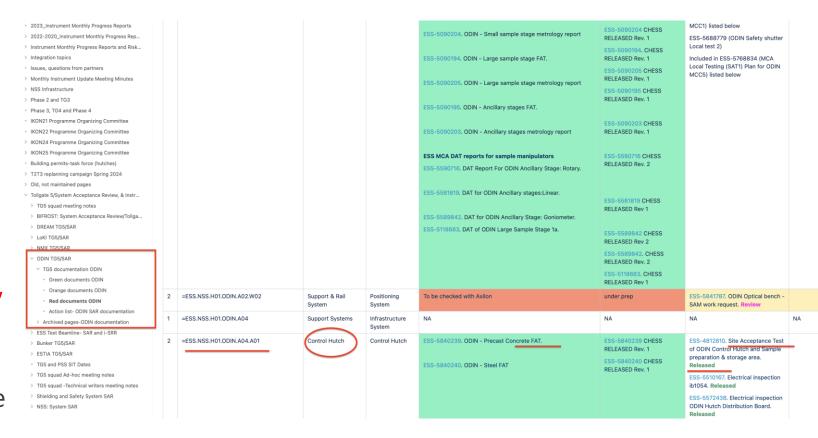
There are three categories of documents:

Green: TG3 documents

Orange: Operation and maintenance Manuals, Verification & Validation Plans

Red: FAT & SAT documents, Integrated test reports

They are organized and tracked in three Confluence pages with tables and FBS labels



Example: part of red documents table...

24.09.25 ODIN TOWARDS ITS TG5

# Document compilation and assessment: Confluence and TG5



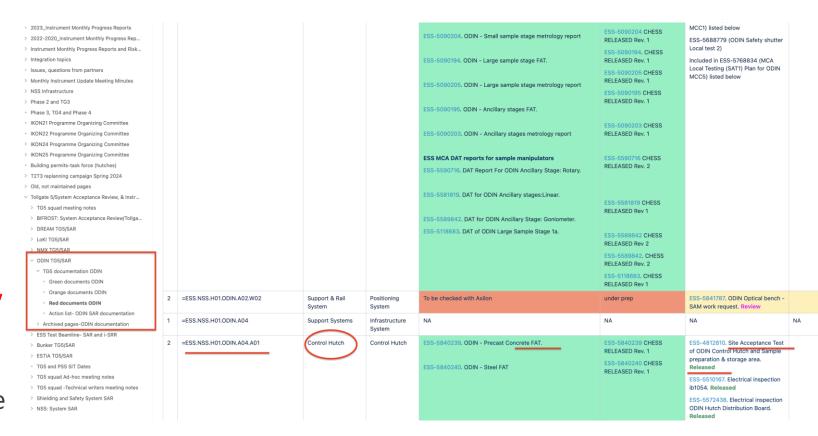
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Example: part of red documents table...

24.09.25 ODIN TOWARDS ITS TG5

### Procedure to get documents ready for TG5



#### **Green documents:**

The instrument team provided/compiled all TG3 relevant CHESS numbers and a team from ESS (technical reviewers and technical writers) took over the final curation and getting them released.

### **Orange documents:**

- -The instrument team identified CHESS numbers of **Operation & maintenance manual documents**. Many of them were already released just after the individual FAT/SAT of the system by the suppliers (i.e. Choppers, Cave door, Sample stages, etc.)
- The instrument team identified those sub systems applicable to have a **V & V plan**, generated a document in CHESS and initiated the workflow. When it concerns technical groups (i.e. Beam monitors, CUP, CEP) asked for it and included in the list.

### **Red documents:**

Same as for **Orange** documents, but for **FAT/SAT** documentation. A large number of documents have been reviewed and released consistently along the installation phase (2022-2025), as soon as the components delivered by external suppliers were FAT or SAT approved. Integrated test report shall be filled once the test have been performed, based on the V&V plans.

24.09.25 ODIN TOWARDS ITS TG5

### Documentation: Present status



	Operation&Main Verification&			Total	Total evicting	Total	Remaining		
	tenance Manuals	Validation Plans	FAT	SAT	SDD&SSDD	recquired	Total existing in CHESS	released	until TG5/SAR
Green documents	NA	NA	NA	NA	36	36	36	36	0%
Orange documents	46	9	NA	NA	NA	55	55	25	55%
Red documents	NA	NA	56	43	NA	99	99	85	14%
All	46	9	56	43	36	190	190	146	23%

Preliminary status table: TUM version...

# The Integrated Tests



#### ✓ TG5: Integrated Testing ODIN

CMOS camera detector (13-14 Oct 2025)-

LumaCam Integrated Test (29 Sep - 03 Oct)

ODIN BM Integrated Test (When?)

ODIN Choppers (06-08 Oct 2025)

ODIN MCA - Integrated tests (09-16 Oct 2025)

= TBL

= TBL

= TBL

Thanks to Toon!! ODIN will profit from the work done at TBL.

TBL and Bifrost as baseline (-> ODIN chopper controller different)

TBL and Bifrost as baseline

# The Integrated Tests

Verification Report

### Thanks to Toon!! ODIN will profit from the work done at TBL.





Document Type Document Number

FSS-5690183 Sep 18, 2025 Released Confidentiality Level Internal 1 (17)

#### INTEGRATED TEST REPORT FOR THE TBL CMOS DETECTOR SYSTEM



	Name	Role/Title		
Owner	Thawatchart Chulapakorn	TBL Instrument Scientist		
Author	Thawatchart Chulapakorn	TBL Instrument Scientist		
	Robin Woracek	Senior Scientist for Imaging and Engineering Diffraction		
	Marco Filho	Control System Integrator		
	Andre de Oliveira Favoto	Control System Integrator		
	Douglas Araujo	Control System Integrator		
	Caissa Roque	Control System Integrator		
	George Kontogiorgos	Data Acquisition Software Engineer		
	Jonas Petersson	Data Acquisition Software Engineer		
	Neil Vaytet	Senior Research Software Engineer		
Reviewer	Irina Stefanescu	Detector Scientist		
	Thomas Gahl	MCA Group Leader		
	Vincent Hardion	ECDC Group Leader		
	Nicklas Holmberg	ICS WP12 Manager		
	Søren Schmidt	Senior Instrument Data Scientist for ODIN		
Approver	Mikhail Feygenson	Head of Diffraction and Imaging Division		

Sep 18, 2025 Document Type Verification Report Document ESS-5690183 Released Number Revision Confidentiality Level Internal Section A: Camera system 5.1 Workstation inside the TBL hutch is connected to NIN. N/A Pass Fail Remark: 5.2 NICOS interface can monitor live-view of sample. □N/A ☑ Pass □ Fail □ Remark: via SetDetector(orca area detector collector) → live() 5.3 Exposure time can be set and recorded correctly. 5.4 Number of recorded projections can be set and recorded correctly. N/A Pass Fail Remark: 5.5 Acquisition modes in Single, Multiple, and Continuous are available. N/A ⊠Pass □Fail □Remark: Section B: Cooling

Verification Report Sep 18, 2025 Document Type ESS-5690183 State Released Document Number Revision Confidentiality Level Internal

- b) Ongoing rectification before completion of all test cases rectification to be confirmed and documented in test report (test case remarks and/or revision history of this document) - to be filed in NSS Issue Tracker
- c) Tests to be repeated to be documented in test report via release revisions and revision history of this document.
- d) Modifications to be made after tests, before the system is operated/accepted explain why no re-testing is needed - to be filed in NSS Issue Tracker
- e) Non-conformity (quality or compliance issue) to be filed in EAM

ITEM	DESCRIPTION	CATEGORY	RESPONSIBLE	COMPLETION DATE
1	Cable connection needs to be checked before closing the test case 2.8 before Hot commissioning NIT-86 Connectors are provided, and verified by data streaming.	С	Thawatchart Chulapakorn	29-May-2025
2	Analysis tool in Test case 8.1 shall be provided before Hot commissioning NIT-87 No new revision is needed, since Instrument Team can achieve this requirement without IDS. Scipp tool will be uploaded on https://git.esss.dk/dram/code-shelf/tbl.	D	Neil Vaytet	
3				
4				

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# Schedule: Planning of HC

### Accelerator commissioning same time as ODIN commissioning!



- 12 weeks test beam, 1 Hz, 5 us, 17 W (3 months)
- 4 weeks with 8 beam days, 140 kW (1 month)
- 14 week shutdown (3.5 months)
- 14 weeks with 28 beam days, 270 kW (3.5 months)
- 11 week shutdown (2.5 months)
- 16 weeks with 40 beam days, 570 kW (4 months)
- 8 week shutdown (2 months)
- 8 weeks 44 beam days, 570 kW (2 months)

Total duration in real time: 21.5 months, roughly 1 year and 9 months

		Expected duration	Resources
#	Activity	(days)	needed
1	Shielding (steered by PSS)	5	see text
2	Hot Commissioning of beam monitors	3	
3	white beam profile with an imaging detector	3	
4	Flight path calibration	3	
5	Beam spectrum	3	
6	Gold foil measurement	1	
7	Choppers phases verification	<del>15</del> 10	
8	Beam limiters and pinhole	2	
			We will need time
	WFM		later on (when
	VVFIVI		accelerator is
9		4 <del>5</del> 20	stable)
10	Characterization of background (incl. T0 chopper)	5	
11	Gamma strikes	2	
12	Characterization of position and tilt of detectors	2	
	Resolution (ToF and spatial), including potential spatial		
13	dependencies.	<del>15</del> 10	
14	Tomography and Bragg edge (First science).	<del>15</del> 10	
15	Commissioning of SE	5	
	Total	<del>124</del> 84	

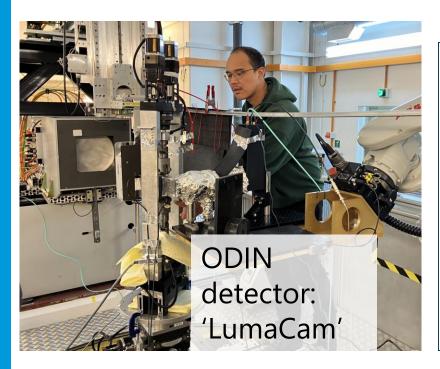
Table 2

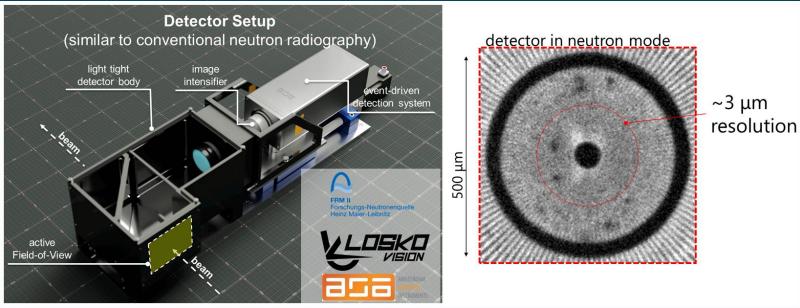
84 days

# ToF @ ODIN: Preparing Commissioning

A 'demo' experiment at IMAT





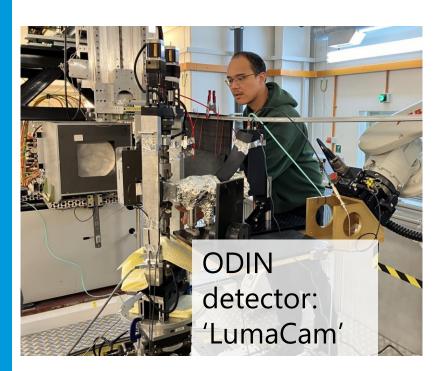




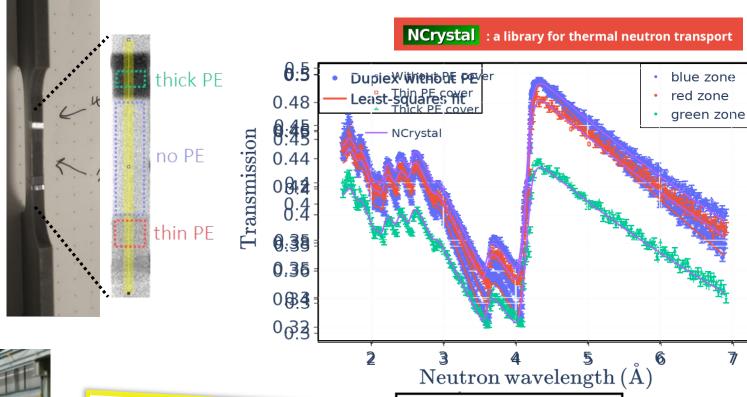
# ToF @ ODIN: Preparing Commissioning

A 'demo' experiment at IMAT





### **Example: 8mm Duplex-Stainless Steel + PE sheets**







Poster C2
Shuqi Xu
NCrystal

Fitted thickness: thin PE: 44±2 μm thick PE: 230±2 μm

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# Summary – What is left to do?



### **Integrated Tests** (next 4 weeks)

- Finalise and release 5 integrated test plans
- Perform integrated tests for:
  - Detectors:
    - LumaCam
    - CMOS detector
    - Beam Monitor
  - Motion Systems:
    - Stages, rotations, sample environments
  - Choppers:
    - Bunker 1 & Bunker 2 choppers (FOC cascade, BWC)
- Publish all test reports after execution

#### **Other Technical Tasks**

- Perform activation analysis of cave components (responsibility of ODIN; in collaboration with external company)
- Complete MCA cabling (responsibility: MCA group)
- Conduct integrated test of PSS and heavy door (responsibility: PSS group)
- Outside TG5 Scope: X-ray CT setup → Stefanos is progressing this for readiness before BoT

### **Final Adjustments**

- Implement minor mechanical fixes (e.g. camera breadboards)
- Fix issues with heavy door

# Summary



### **M** Key Challenges

#### **Administrative Burden on Instrument Team**

- Frequent documentation requests from non-experts lack technical clarity
  - → Time-consuming to interpret and respond
- Minor issues often overemphasised (e.g. vacuum flight tube orientation)
- Distracts from core instrument work reporting ≠ building

### **Lack of Agile Decision-Making**

- Critical decisions sometimes lack trust in instrument experts
  - Example: TOF detector integration delayed until management backed a vendor-based solution
    - → Resolved through new DH and ECDC effort but late

### **Scope Transfers and Scope Creep**

- Responsibilities shifted to ESS, but unclear or incomplete follow-up
  - Example: Common guide shielding (signed 2018 as turnkey) never released now reinvolves instrument team
  - Example: €5k CR raised just to connect heat exchanger hoses

### **Software and Interface Integration**

- Many systems depend on DMSC, but deliverables and timeline no 100% clear (not under IDS control)
- No early testable outputs on real data so far but work started now -> See Soeren presentation
- DMSC's remote location complicates integration

# Summary



### What's Working Well

### **Empowered Instrument Teams**

Science Management increasingly supports and trusts instrument teams

→ Clearer ownership and direction

### **Slow but Steady Progress**

Despite complexity, ODIN systems and integration are advancing Team commitment remains strong

### **Practicality Emerging at ESS**

Gradual shift toward more hands-on, realistic project coordination

→ Focus on what's needed to make the instrument work

### **Outside ESS and outside TG5: Growing External Interest**

High level of interest in ODIN and ESS from outside

→ Many new requests for collaboration and involvement



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# Preparing ODIN for 1st Science

Meet the Local Team & Get in touch to discuss your ideas!





Robin Woracek

Instrument Scientist

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Stefanos Athanasopoulos

Instrument Scientist/Post-Doc

stefanos.athanasopoulos@ess.eu



Søren Schmidt

Instrument Data Scientist

Soren.Schmidt@ess.eu



Richard Ammer

Operation Engineer

richard.ammer@ess.eu



Caroline Curfs

Sample Environment

caroline.curfs@ess.eu



Thawatchart Chulapakorn

Instrument Scientist TBL

thawatchart.chulapakorn@ess.eu



Shuqi Xu

Post-Doc

shuqi.xu@ess.eu

## ToF @ ODIN: What can we do with it?

ess

Hyper-Spectral imaging: Adding another dimension to the data

## ToF @ ODIN: What can we do v

Hyper-Spectral imaging: Adding another dimension to the





Stefanos

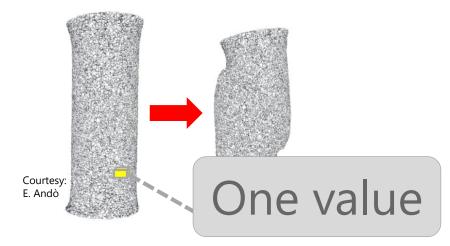
Athanasopoulos

Thermography

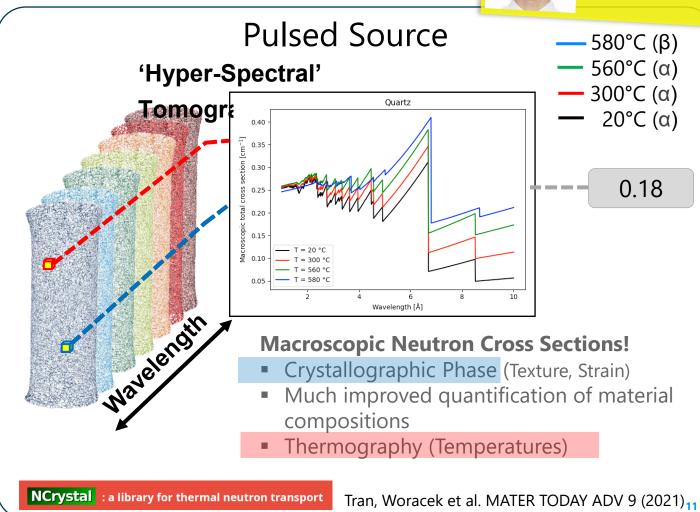
Shuqi Xu NCrystal

### **Example:** Deformation Quartz Sand

# Steady State Source 'White Beam' Tomography



- Morphology, Cracks, Porosities,...
- Density differences
- Particle size distribution
- Digital Volume Correlation (DVC): displacement and strain fields
- Dynamic changes (e.g. fluid flow)



# ODIN – 1st Science Strategy



### **Partners & Context**

- TUM & PSI: strong in-kind partners, deeply involved since design phase. Will play key role also in 1st Science.
- ESS team leads commissioning; TUM/PSI support commissioning activities at best effort.
- Build and maintain a trusted collaborative network for 1st Science (e.g. this workshop).

### **Technical Outlook**

- Early flux:  $\sim 1 \times 10^6$  n/cm<sup>2</sup>/s @200 kW, scaling to  $\sim 3 \times 10^7$  @2 MW. (sample position; L/D=350),
- 300 kV X-ray source available in commissioning phase.

### **Strategy Principles**

- Commissioning is first priority, First Science begins as subsystems come online (and demo capabilities)
- Early cases:
  - radiography/tomography (e.g. cultural heritage) to showcase baseline capability & workflows.
  - Simple tensile tests show wavelength resolution (strain) and serve as First Science cases
- Goal: demonstrate reproducible performance, build trust & visibility.
- Trusted partner experiments ensure early challenges are contextualized.
- Use core capabilities and expertise to develop ODIN into a world leading instrument
- Collaborate on advanced modalities (like NGI and PNI) with leading partners (e.g. TUM and PSI)
- Exploit existing tools and collaborations for advanced analysis of 3d data (e.g. SPAM)

### **Process**

- Maintain & update list of candidate experiments. Review with in-kind partners + STAP.
- Internal planning document for each experiment: define goals (link to instrument capability to be demonstrated), safety, schedule, integration into Hot Commissioning

# ODIN – 1st Science Strategy (Example Areas)

Poster C2





### ODIN Optical and Diffraction Imaging with Neutrons



### ODIN Optical and Diffraction Imaging with Neutron



### Analysis Toolkit: NCrystal

### **Applications: Geomechanics**

#### Why it matters

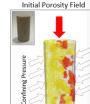
- Understanding how soils and rocks de infrastructure, energy storage, and su
- · Fluid flow and stress interact in comp term stability of geomaterials.

#### The example shows

- Simultaneous neutron and x-ray tome and fluid injection.
- · Strain fields derived from x-ray digita from time-resolved neutron tomogra
- · How porosity dictates strain localisati How deformation alters permeability

#### Why ODIN

Open possibilities to investigate more changes with the added capabilities of



### ODIN

Why i

Optical and Diffraction Imaging with Neutrons

### Applications: Solid State Batteri

- · Solid-state batteries promise higher energy density and safety, but we still don't fully understand how lithium moves inside them.
- We need methods that can see inside working batteries in 3D and over time without taking them apart.

#### The example shows

- First combined operando neutron + X-ray tomography study of a solid-state Li-ion battery.
- Used Li-7 isotope contrast to enhance visibility of lithium in neutron data
- · Identified lithium transport pathways and inhomogeneities in the separator (solid electrolyte).
- Identified preferential diffusion linked to microstructural features (like grain size and electrode)

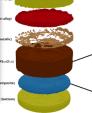
Athanasopoulos

Thermography

ODIN will enable 5D neutron imaging (3D + ToF + time) with additional sensitivity due to wavelength dependent transmission spectra (spectral neutron imaging) and simultaneous X-ray tomography.









Talk MAT05 Philip Vestin Solid State Batteries



### Data reduction and analysis @ODIN



### ODIN

Optical and Diffraction Imaging with Neutrons

### Applications: Electrification

#### Why it matters

- · Efficient electric motors (e.g., PMSM, SynRM) require precise magnetic flux guidance in rotor for optimal torque and energy conversion
- Conventional guidance via cut-outs compromises mechanical stability, especially at high speeds
- . Understanding bulk magnetic domain behavior is critical for designing next-generation highnerformance machines

#### The Example shows

- A novel concept using embossed patterns in the rotor to induce flux guidance via inverse
- Traditional methods (MOKE, Bitter) can't image these domains in 3D neutron techniques offer spatially resolved bulk insight

#### Why ODIN

Combines spatially resolved domain mapping (via Neutron Grating Interferometry) with



### ODIN



### Applications: Advanced Manufacturing

- · Additive manufacturing (AM) enables complex, multi-material metal components but process optimization is limited by lack of bulk insight
- · Internal phenomena like thermal gradients, phase transformations, and magnetic changes determine global properties, yet often remain hidden from standard characterization tools.

#### The example shows

Polarized Neutron (phase mapping) and Inelastic Scattering Contrast Imaging (temperature mapping) duri

Shieren Sumarli

- Top row: tem; Talk MAT05
- Mid row: evol

#### Bottom row: f

→ temperature d → temperature gr

#### → the obtained p Why ODIN

Add. Manufacturing pathways for f

Operando temperature and ferritic phase evolution in 316L/CuCrZr LPBF AM for different mixing ratio



Exemple token from: 5. Sumarii, F. Malamud, A. Baganis, S. Gaudez, M. Busi, E. Polatidis, S. Van Petegem, C. Leinenbach, R. Logé, and M. Strobl Operando phase mapping in mutil-material laser powder bed fusion. Virtual and Physical Prototyping 19(1) (2024) https://doi.org/10.1000/17452799.2024.249152

### Talk MAT06

**Tobias Neuwirth** Magnetic Flux Guidance

### Poster C2

Thawatchart Chulapakorn **Diffraction Contrast** 

### Talk MAT05

Luise Theil-Kuhn **Na-Ion Batteries** 



### ODIN



Poster A1

Estrid Naver

### Applications: Planetary Geosciences

#### Why it matters

- Neutron + X-ray imaging reveals his damage or contamination
- Missions like Mars Sample Return

#### The example shows

- Luizi impact melt rock: Clay (vellow (green); confirmed by SEM-BSE
- Martian meteorite MIL 03346.231: iddingsite concentrated in/around
- Insights into impact cratering and the

### Meteorites

Hyperspectral ToF neutron imaging with even higher sensitivity to elements and isotopes wil be complemented with simultaneous X-ray imaging

Luizi Impact Melt - 3D Structure and Hydration Features





### **Examples of Ongoing Collaborations**

### Spectral Neutron Imaging

2018-2023

ongoing

HZB Helmholt

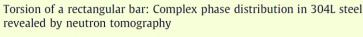
Spectral neutron tomography

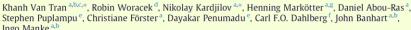
K.V. Tran a, b, c, \*\*, R. Woracek d, \*, N. Kardjilov a, H. Markötter a, h, A. Hilger a, W. Kockelmann <sup>e</sup>, J. Kelleher <sup>e</sup>, S.B. Puplampu <sup>f</sup>, D. Penumadu <sup>f</sup>, A.S. Tremsin <sup>g</sup>,

J. Banhart <sup>a, b</sup>, J. Manke 4.14 Å 4.09 Å



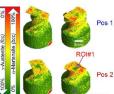








3D phase distributions in a complex geometry using neutron tomography





### 3D Printing

2021-2023 ongoing

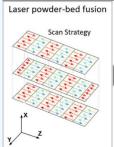


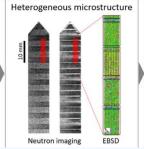


HZB<sub>Helm</sub>

On the relationship between laser scan strategy, texture variations and hidden nucleation sites for failure in laser powder-bed fusion

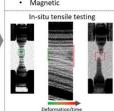
Victor Pacheco<sup>a</sup>, Jithin James Marattukalam<sup>b</sup>, Dennis Karlsson<sup>a</sup>, Luc Dessieux<sup>c</sup>, Khanh Van Tran<sup>d</sup>, Premysl Beran<sup>e</sup>, Ingo Manke<sup>d</sup>, Nikolay Kardjilov<sup>d</sup>, Henning Markötter<sup>d,f</sup>, Martin Sahlberg a, Robin Woracek e,\*





#### Anisotropic properties Mechanica

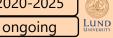
· Chemical/Corrosion



### Geo-Materials

2020-2025

Carl F.O. Dahlberg a,



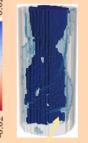
Multi-scale characterization of the hydromechanical behavior of a heterogeneous porous sandstone using neutron and X-ray tomographies

Fernando Vieira Lima<sup>1</sup> · Stephen Hall<sup>1</sup> · Jonas Engqvist<sup>1</sup> · Erika Tudisco<sup>2</sup> · Robin Woracek<sup>3</sup> Alessandro Tengattini<sup>4,5,6</sup> • Cyrille Couture

### Porosity

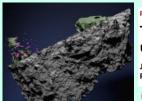


# Strain



Flow

### Planetary Geosciences



The scale of a martian hydrothermal system explored using combined neutron and x-ray tomography

2018-2023

Josefin Marteli<sup>1\*</sup>, Carl Alwmark<sup>1</sup>, Luke Daly<sup>2,3,4</sup>, Stephen Hali<sup>5,6</sup>, Sanna Alwmark<sup>1,7,8</sup>, Robin Woracek<sup>9</sup>, Johan Hektor<sup>10,11</sup>, Lukas Helfen<sup>12</sup>, Alessandro Tengattini<sup>12,13</sup>, Martin Lee<sup>2</sup>

### **Science** Advances



ongoing





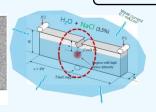
### H-Fmbrittlement





David Lindblom <sup>a</sup>, Armin E. Halilović <sup>a</sup>, Robin Woracek <sup>b</sup>, Alessandro Tengattini <sup>c</sup>, Lukas Helfen <sup>c</sup>,

In-situ neutron imaging of delayed crack propagation of high strength martensitic steel under hydrogen embrittlement conditions





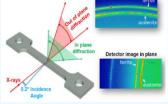
2022-ongoing











### Solid State Batteries

2022-ongoing



### Several smaller collaborations:

Residual stress in cemented carbides by diffraction

- Additive manufacturing (diffraction+imaging)
- Diffractive imaging





### Where ESS could be leading....



### Unprecendet Quantification of Neutron Imaging data via ToF Transmission Spectra

- Material decomposition
  - Hardware → detectors, scatter correction
  - Modelling → spectra & scattering
  - Novel contrast modalities → inelastic scattering, diffraction contrast
- Texture (cf. F. Malamud, PSI)
- A new/unified extinction model

### **ToF Tomography**

Extension of above to tomography with 'noisy' data sets

### **Sample Environments**

- In-situ testing: Tensile/Compression/Torsion/3PB/4PB/Heating/Freezing (in-house + ongoing collaborations)
- Unique opportunity: generous instrument space + lab infrastructure

### We have ideas... but what's missing?

- Time... (we are swamped with tasks to get ODIN ready...)
- Dedicated personnel to stay focused on these developments while working on a relevant science case
- End-to-end workflow: acquisition → analysis → publication

Additional Funding and Collaboration Opportunities

### Active involvement in collaborations / Inhouse Research



### **Hydrogen embrittlement**

- ReHeart (2 Postdocs, KTH+LU/ESS)
- ISOTOPE (1PhD, KTH, defending soon)
- ILL-ESS-KTH PhD (starting 2026)

### **Solid State Batteries**

ANISSA (1 Postdoc, 3PhDs, UU, LTH, HZB, UM)

### **Freezing mortar**

Malmo, LTH (ongoing, no dedicated resource yet)

### **Thermography/Sand Batteries**

LTH (ongoing, Stefanos project)

**Wolter optics** (1st step towards a neutron microscope)

1 PhD,1 postdoc at DTU (starting 2026)

### Improving quantitative neutron transmission interpretation

Coloration with ESS Spallation Physics Group & DMSC

# ess

### Pending applications

### <u>Submitted 3 proposals to "VR ESS-ISIS Bilateral Call on Instrumentation & Methods"</u>

- Polarization/SEMSANS Pls: Max Wolff (UU), Elizabeth Blackburn (LU).
- Development of neutron grating interferometry and application of diverse neutron scattering and imaging methods for unravelling the hierarchical structure of edible soft matter PI: Marjorie Ladd Parada (KTH).
- **MINDI**: Mechanics-Informed Neutron Diffraction and Imaging for Degradation and Phase Transformation in Structural Metals PI: Carl Dahlberg (KTH).

### **Upcoming: Röntgen-Ångström Cluster (RÅC) – Germany-Sweden**

ESS semi-initiated Multi-Directional Neutron Dark-Field Tomography (MD-NDFT) Stockholm University

- tensor tomography: multiscale characterization of anisotropic structures in macroscopic samples.
- new grating geometries, automated alignment systems, and data analysis pipelines

### **ESS initiated ESS initiated RAC on Hydrogen Embrittlement**

KTH (CFO Dahlberg, J Pan) & TUM+FAU (M. Fritton, S. Neumeier, R.Gilles)

### ESS contacted Laser powder bed fusion (LPBF) (LLT-RWTH+Fraunhofer ILT Aachen + Luleå University of Technology)

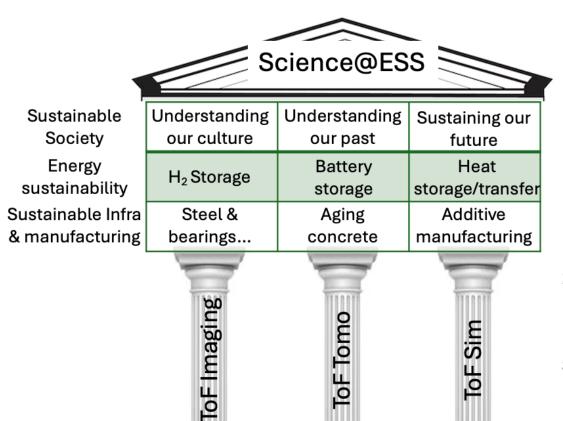
- development of a system for imaging during laser powder bed fusion (LPBF)
- study the process while printing materials with complex compositions such as magnetocaloric materials and HEA

### Upcoming dedicated call

### **Swedish initiative for First Science at ESS and ODIN**

KTH / CTH

/SKF



LU / CTH

/ DTU



- ToF-Imaging: Crystalline Insights with hyperspectral Imaging
  - Lead: Dahlberg, KTH
  - Associated: CTH?, UU?, SKF?
- 2. ToF-Tomo: Decoding Materials and processes in 3D with ToF Tomography
  - Lead: Hall, LU

MaU / KTH

/ RISE

- Associated: Dijkstraa (CTH), Jørgensen (DTU)
- 3. ToF-Sim: Pioneering ToF Imaging for new challenges and materials
  - Lead: Hektor, MaU
  - Associated: Söderberg (KTH), RISE

