

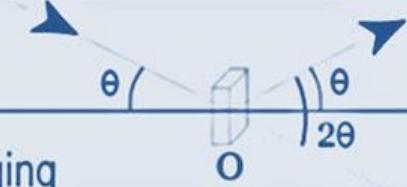
X-ray imaging

REXC Opening, Feb. 14, 2014

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X-ray imaging:

Absorption, phase, scattering loss, diffraction, fluorescent, coherent scattering, bright- & dark-field microscopy,

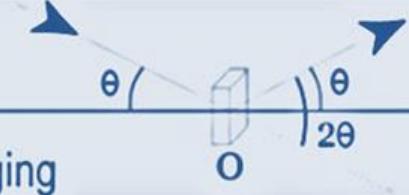
Wavelength ~ atomic length scale => Atomic resolution (as with EM) ?

Limitations:

- Direct X-ray detection $> 5 \mu\text{m}$ pixel resolution
 - Indirect detection: X-ray \rightarrow VL (scintillators) + light microscopy
 - Efficient X-ray optics not possible $\sim M_{xo} < 30$
- => Resolution wo. optics $\sim 700 \text{ nm}$
- w. optics $\sim 50 \text{ nm}$
 - coherent $< 10 \text{ nm}$

Opportunities:

- Penetration depth -> buried-in structures in 3D samples
- Open sample environment -> time-resolved, *in situ/operando* w. real loads



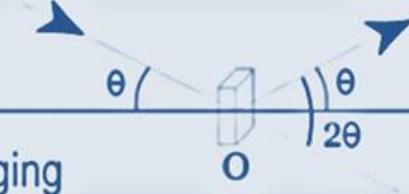
At RECX IFY-NTNU node:

- I. 2D X-ray μradiography - absorption contrast (Oct. 2012 -)
- spatial resolution: $3 \mu\text{m}$ @ $3 \times 3 \text{ mm}^2$ field of view
- ≤ 6 frames/s

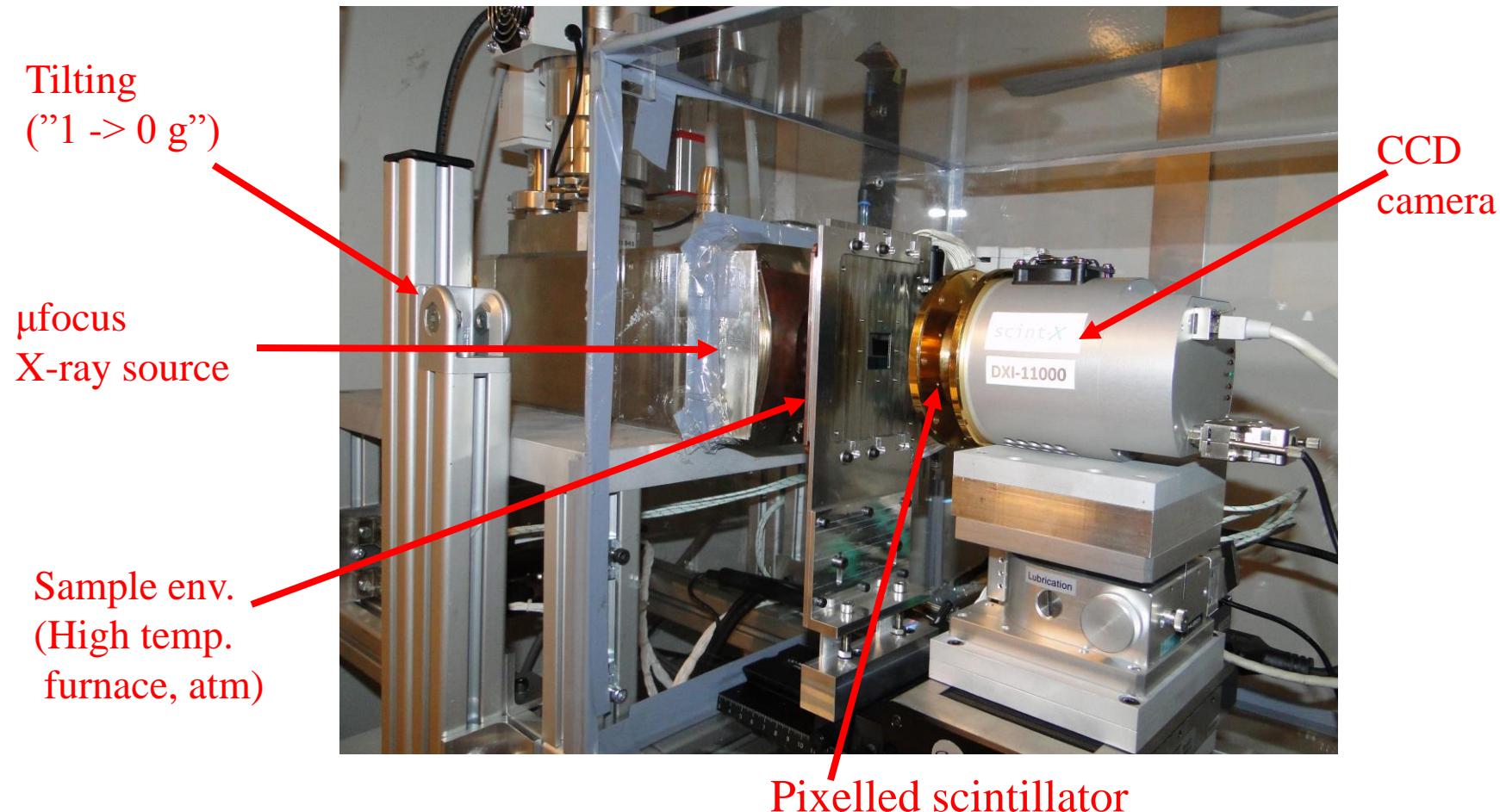
→ *"Time-resolved" studies of microstructure evolution and response in situ under external loads (e.g. temp., mech., chem. env.)*

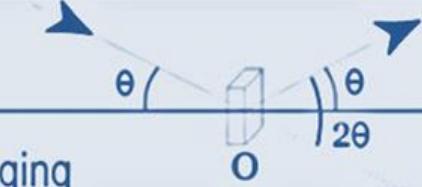
- II. 3D X-ray μtomography - absorption contrast (May 2013 -)
- spatial resolution: $1 \mu\text{m}$ @ $3 \times 3 \times 3 \text{ mm}^3$ volume
- ≥ 20 min/tomogram

→ *3D buried-in microstructures, static or in evolution under realistic in operando conditions (e.g. mech., env., ...)*

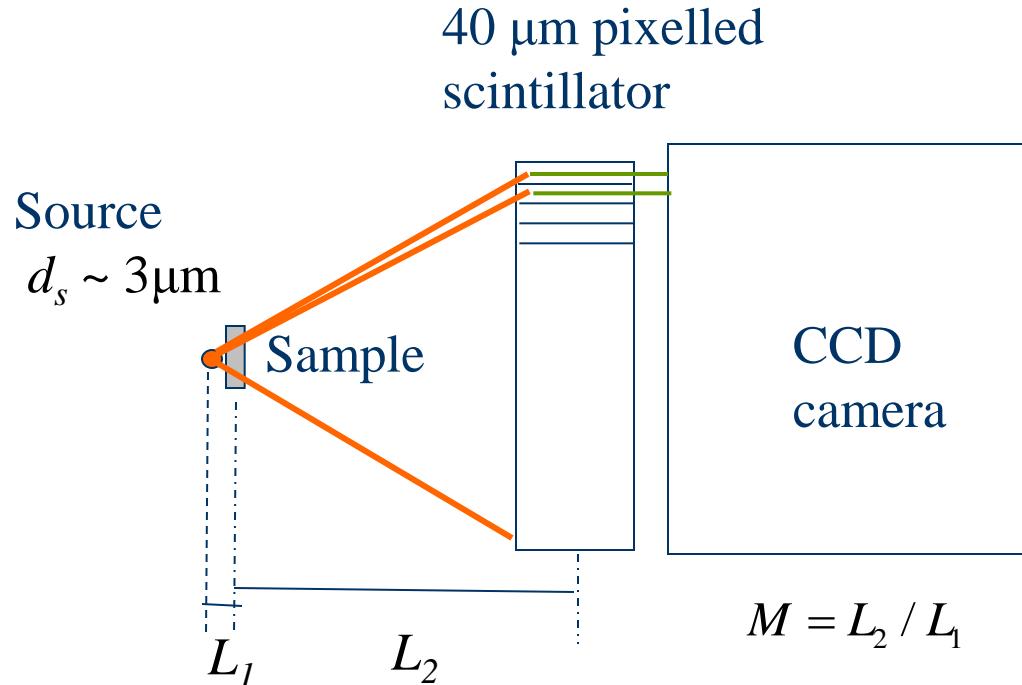


I. RECX µradiography



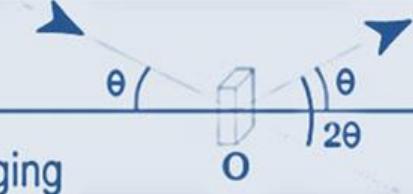


1. RECX μ radiography



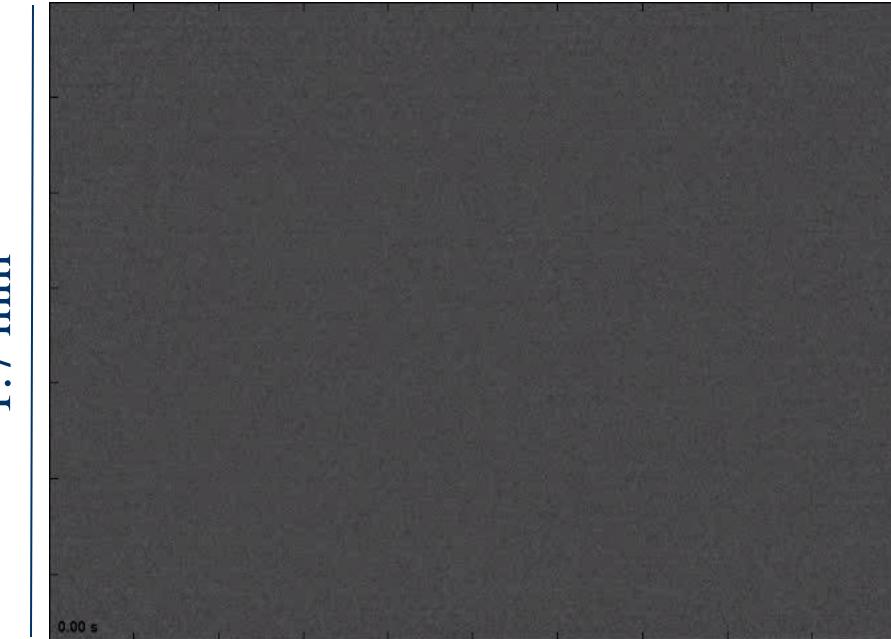
Unique – 1 other setup world-wide

Spatiotemporal performance $\sim \mu\text{img}$ setup ID22, ESRF (1999).



*Equiaxed dendritic crystal growth in Al-Cu
– diffusive interaction/impingement between adjacent grains*

RECX IFY (2012)

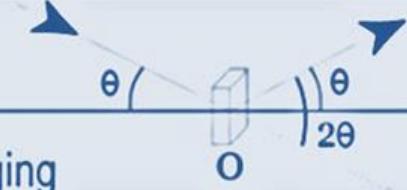


Near-isothermal &
purely diffusive ("0g")

ESRF ID22 (2001)



Non-isothermal &
diffusive-convective (1g)



RECX μ radiography activities:

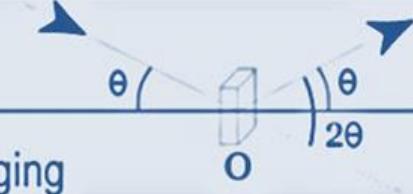
2012-13: *Equiaxed dendrite impingement & growth restriction* (UC Dublin).
A. Murphy, PhD thesis 2013; Acta Mat 2013.

2013-16: FP7 NMP ExoMet.
@NTNU: *Particle – growth front interactions in NP-MMC processing*.
1 PhD & 1 Post Doc.

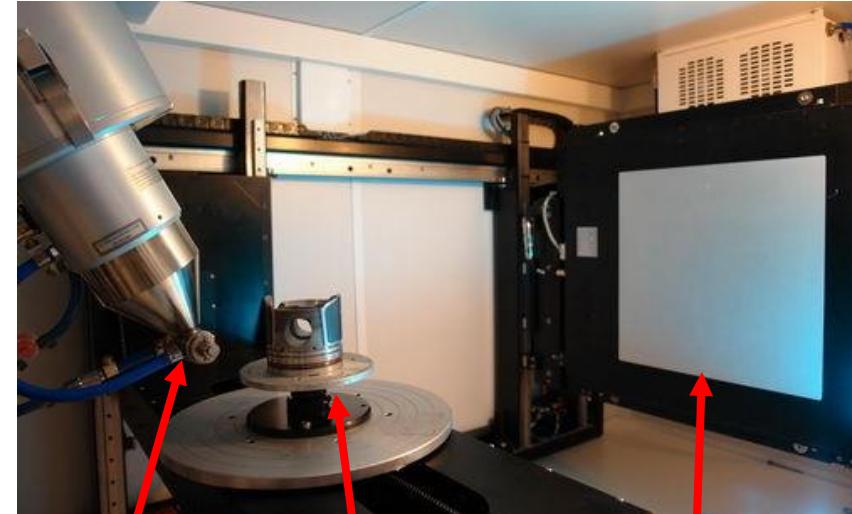
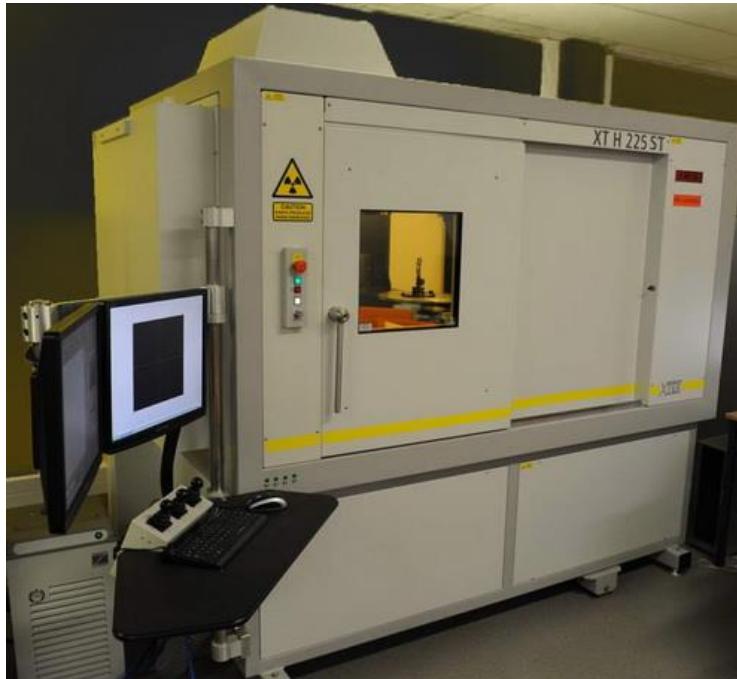
2014-: *Fe intermetallic phase formation in Al-Si* (U. Jonkoping)

Two applications from SINTEF MC to NFR FRINATEK 2013:

Equiaxed dendritic growth/growth restriction/inoculation (not granted)

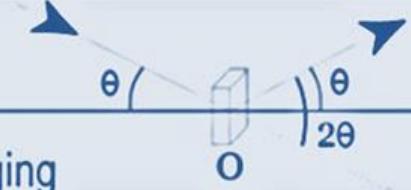


2. RECX µtomography (2013-)

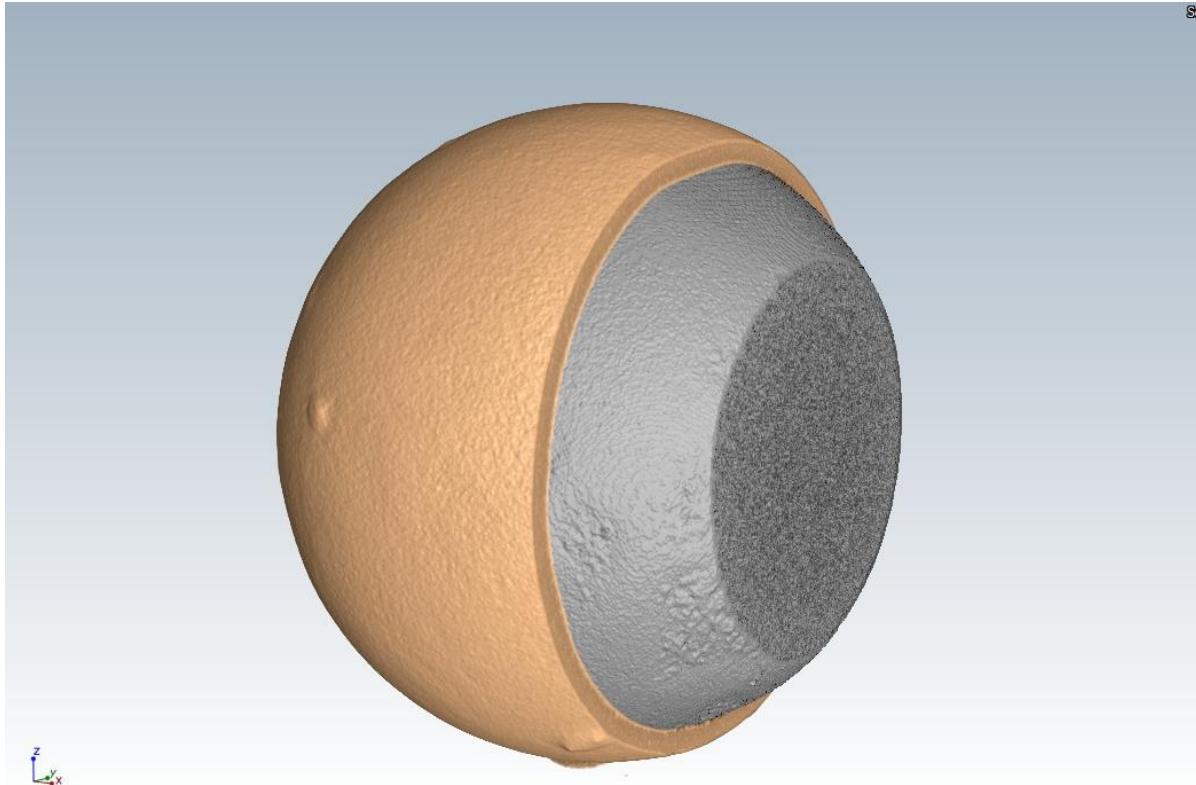


Nikon XT H225 µ-CT station

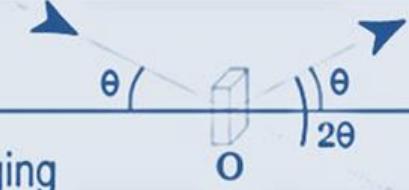
- High-power dual microfocus source
- Wide range of applications: materials, environments, sample sizes



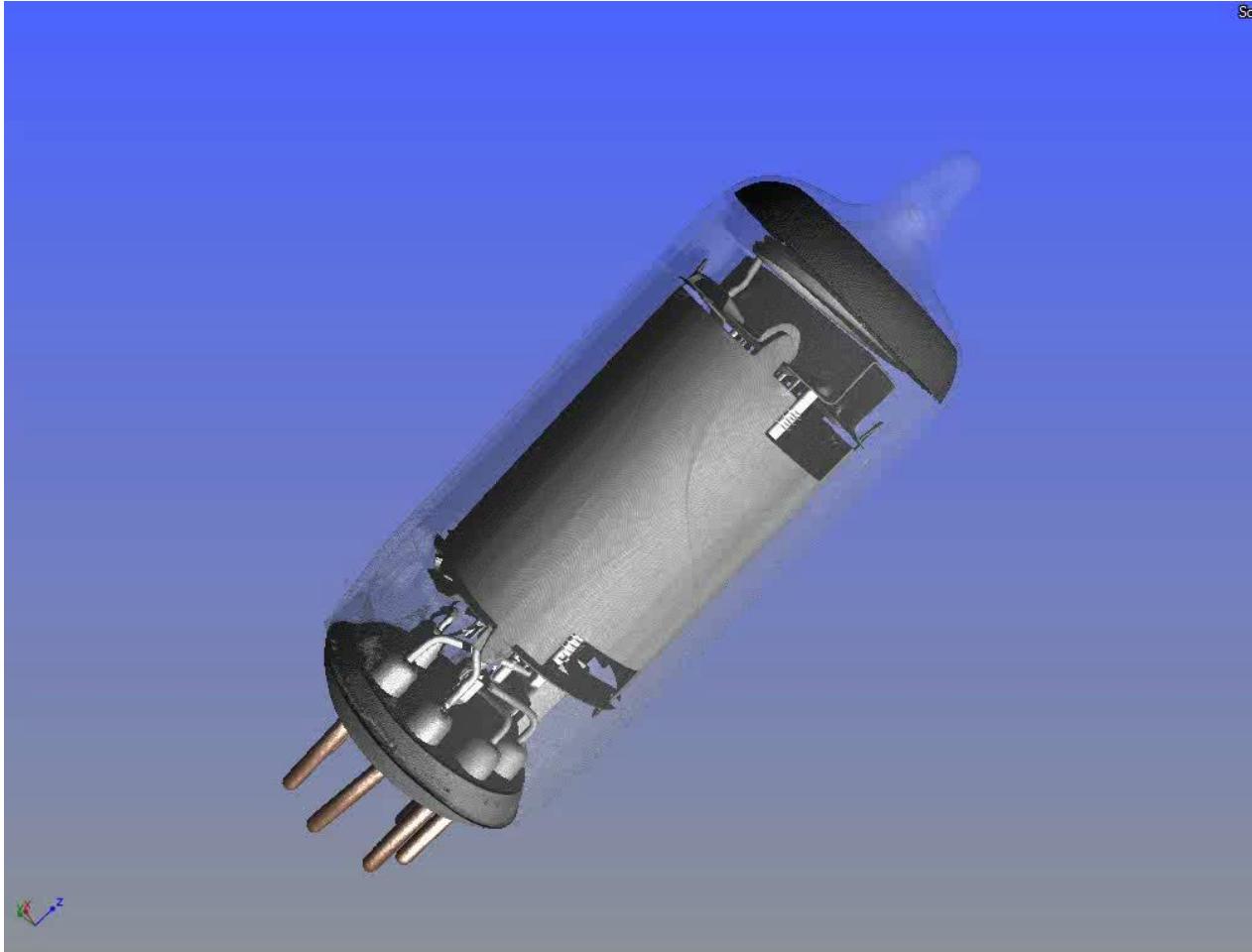
RECX µtomography training samples



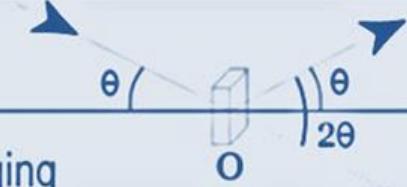
400 μm metal-coated polymer sphere



RECX µtomography training samples



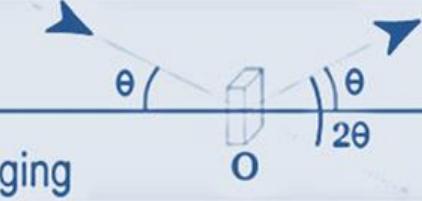
Radio tube



RECX µtomography training samples



Our future Olympic athletes ?



RECX μtomography activities:

Yara – Polymer template morphologies

UC Dublin – μporosity in BMG

SINTEF/SAPA – casting defects in Al alloys

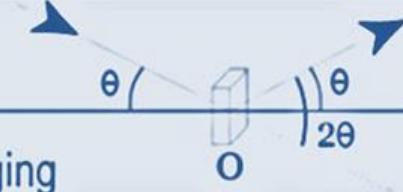
NTNU

- IMT: Metal intrusion in carbon electrodes
- IKJ: Cultural heritage/paintings
- IDT: Wiring in microcircuits
- IFY: Eutectics, various hybrid-structures



Hot tear and porosity in Al-casting

Several new projects and users expected in 2014!



NTNU RECX imaging Intl. links :

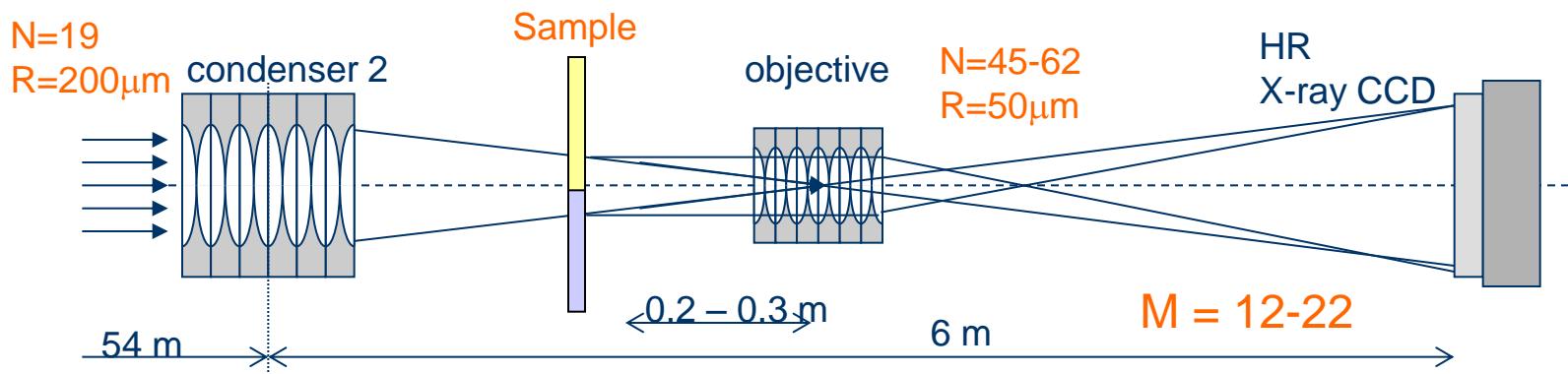
X-ray imaging centre, DTU, Denmark (Poulsen)

X-ray imaging centre, U. Manch./Diamond (Withers, Lee)

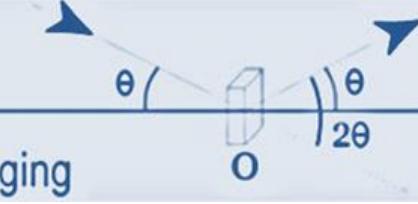
Inhouse instrument development ID6@ESRF (Detlefs, Snigirev)

Conceptual layout HXRM – ID6@ESRF

Bright-field mode



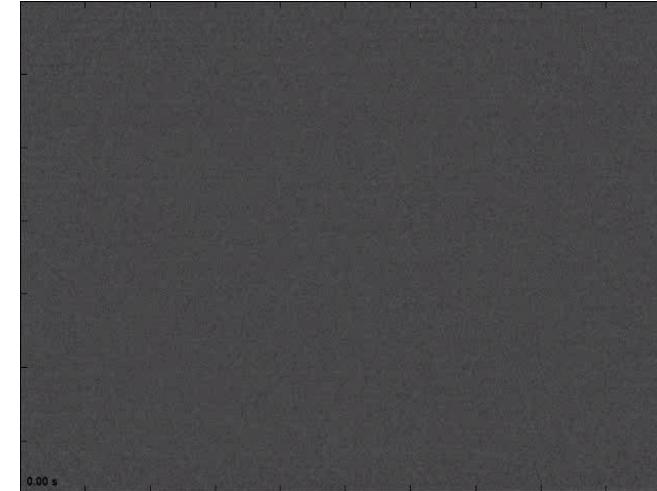
- 2D-Bright Field microscopy: ~ 50 nm@1 kHz, A & φ
- 3D-Bright Field microscopy: ~ 100 nm@0.5 Hz, A & φ
- 3D-Dark Field microscopy: < 50 nm
- 3D Coherent-Dark Field microscopy: < 10 nm



RECX X-ray imaging – summary:

- 2D μ radiography:
 - Unique instrument
 - Intl. attractive
 - Usage:

*Academic research
Preparing synchrotron exp.*



- 3D μ tomography:
 - Flexible & versatile instrument
 - Strong domestic demand
 - Access to other μ tomography via intl. links.
 - Usage:

*Inspection/control
Industrial and applied res.
Academic res.
Preparing synchrotron exp.
Teaching*



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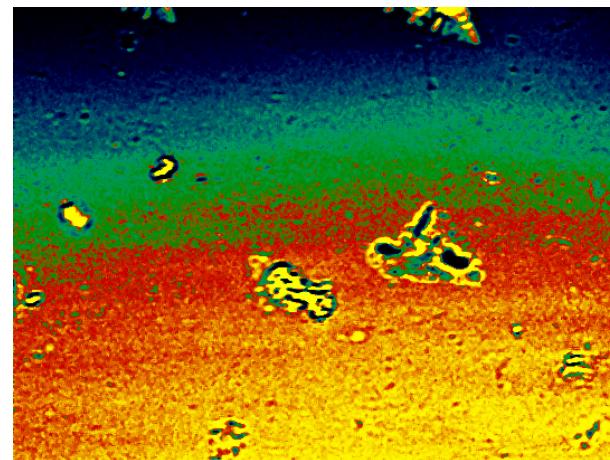
TU Dresden

Christian Schroer
Vivienne Meier

ESA

Daniela Voss
Olivier Minster
David J. Jarvis

ESRF, ID6, 2009



Al dendritic growth restricted by diffusive & convective transport of Cu