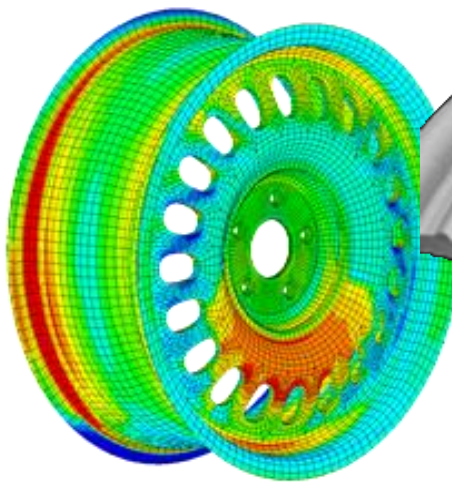
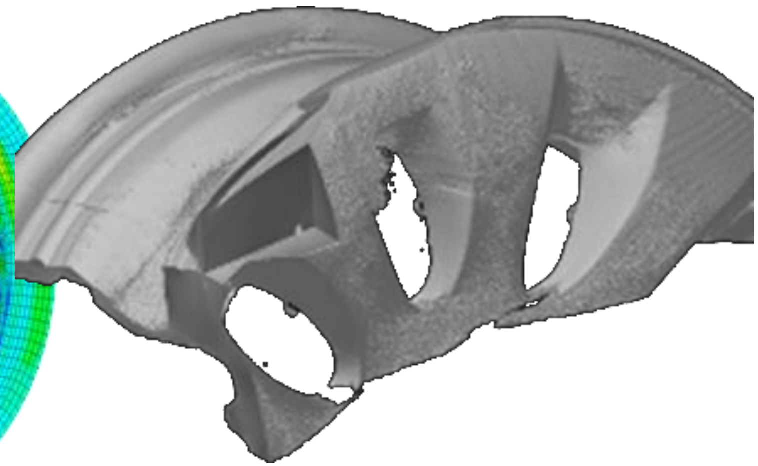
X-ray Tomography in Industry: Current Status and Future Trends

Dr. Simon Zabler – Fraunhofer– Magnetic Resonance- and X-ray Imaging





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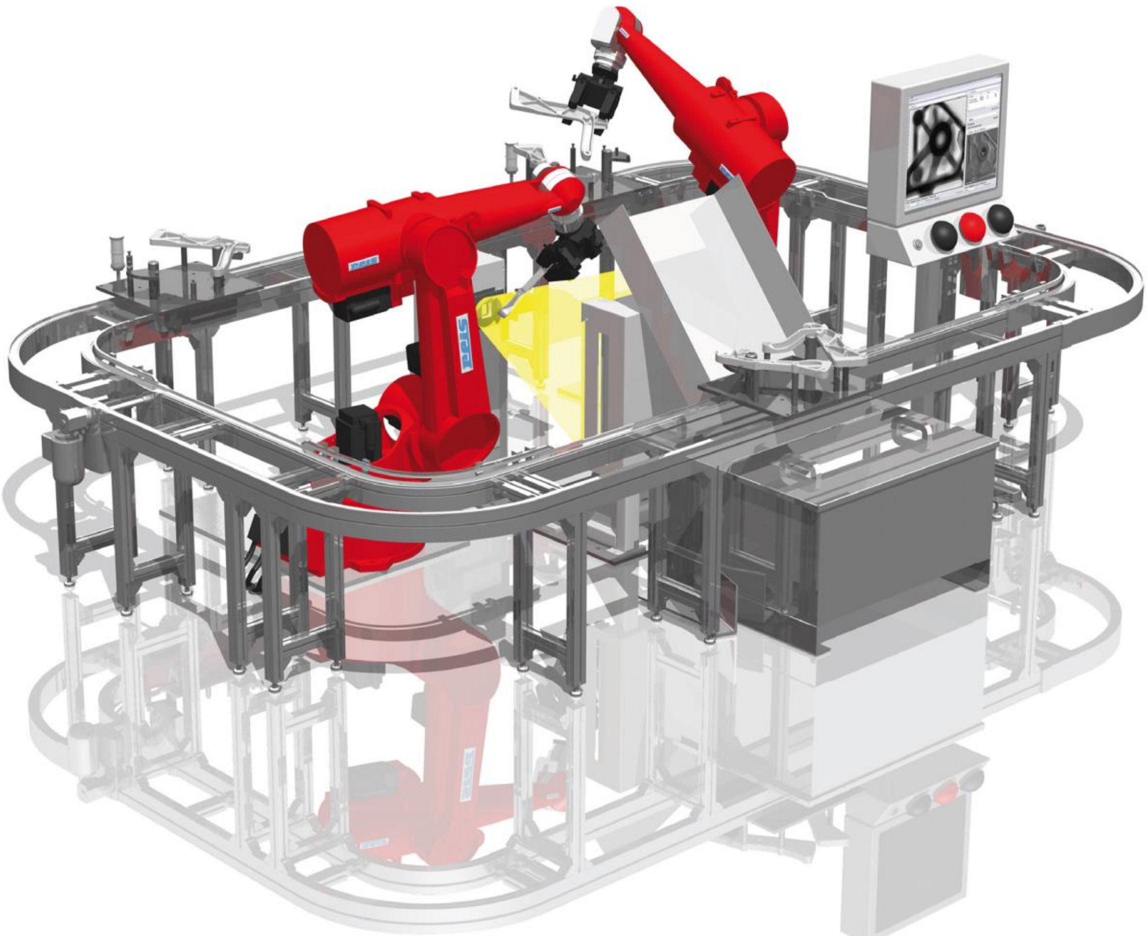
Outline

- Industrial CT
- Current examples and limits of iCT
- Future applications of iCT
- High-troughput CT: the third limit
- Outlook

Industrial Computed Tomography iCT
… sometimes looks different from conventional CT



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Industrial Computed Tomography iCT
Some basic facts from Fraunhofer EZRT

- ISAR: Fully automated wheel inspection (in a few seconds)
- PIDA/Volex: Atline- and Inline-CT (e.g. 3D piston inspection in 30 s)
- Dragonfly: Full CT scan in 0.8 s
- 2D and 3D Inspection tasks require some 0.1 mm resolution

Industrial Computed Tomography iCT
Aims at increasing the speed = time per inspected part

Conventional CT can be accelerated up to 0.8 s/scan

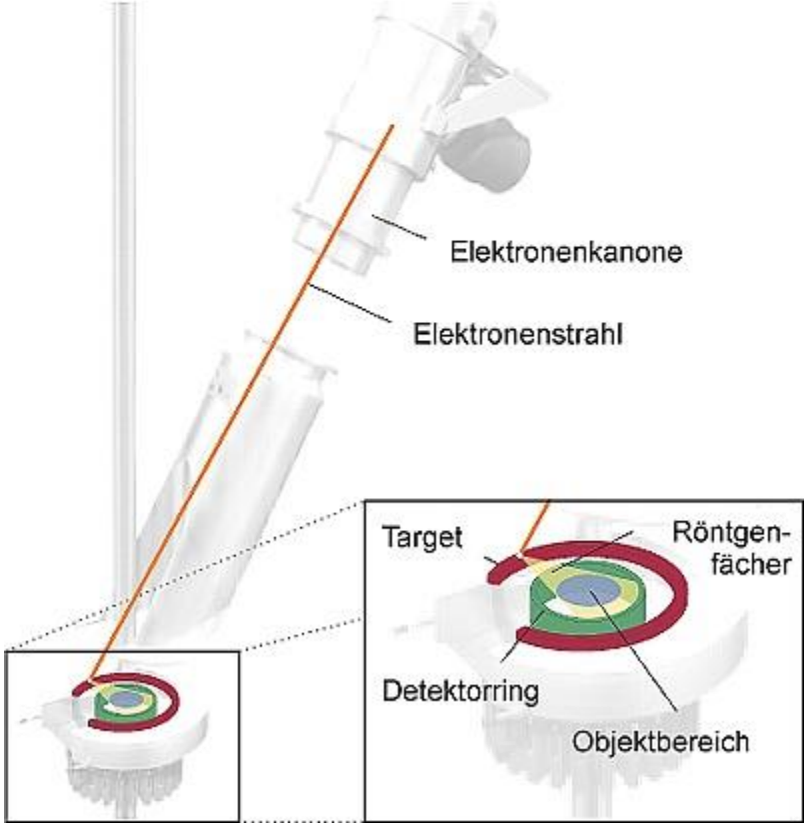
Measuring time: 16 Sec

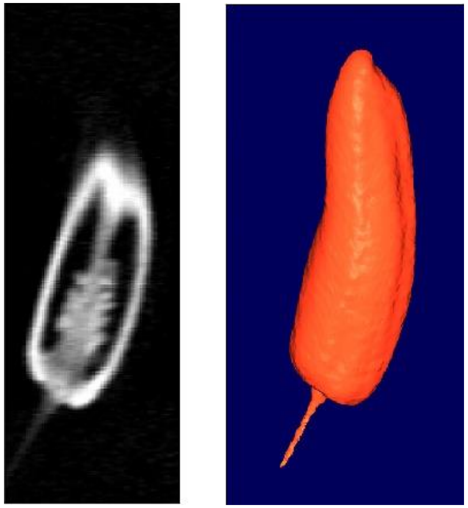
Measuring time: 0,8 Sec

Industrial Computed Tomography iCT

Aims at increasing the speed = time per inspected part

Ultrafast Electron-beam X-ray tomography ROFEX





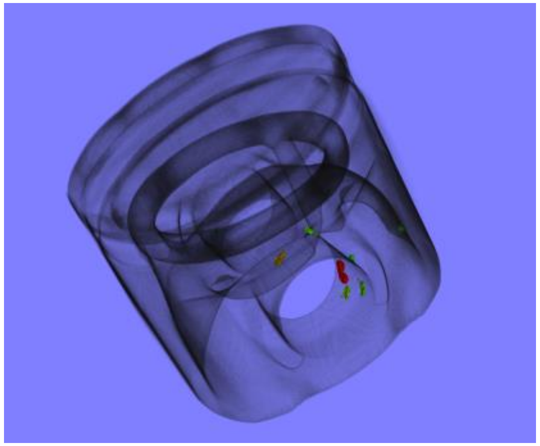
Tomography of a falling Paprika

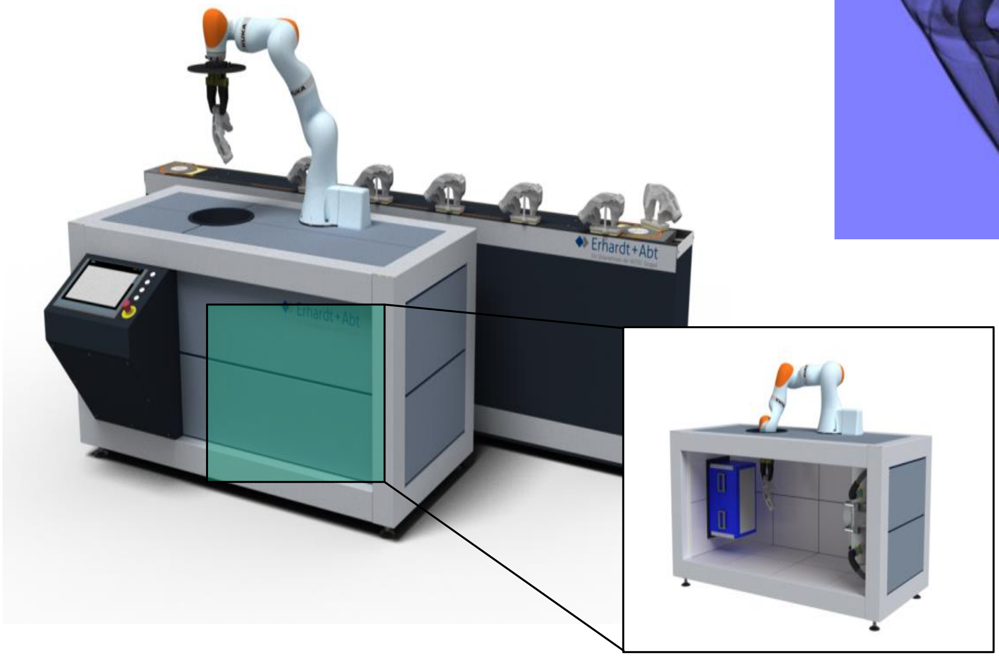
Fischer et al. Meas. Sci. Technol. 19, 094002, 2008

Measuring time: 0,0001 Sec/Slice

Industrial Computed Tomography iCT
Aims at low complexity = costs per inspected part

- Example PIDA/Volex: Atline- and Inline-CT

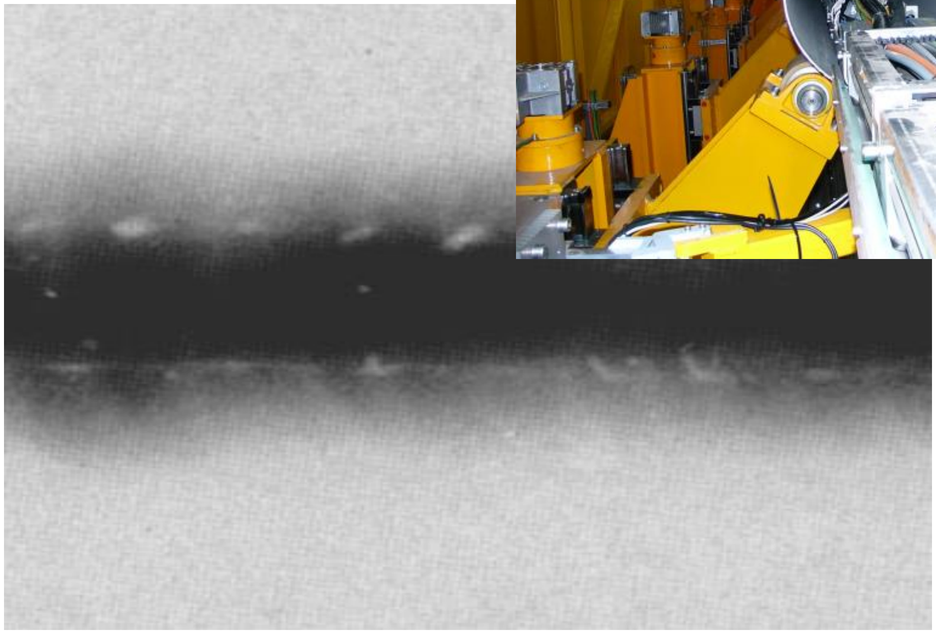




Industrial Computed Tomography iCT
Inspection tasks

Example: Inspection of welding in steel tube

- Voids
- Pores
- Inclusions
- Cracks
- Demixing
- Oxidation



Industrial Computed Tomography iCT
What the industry could measure today…

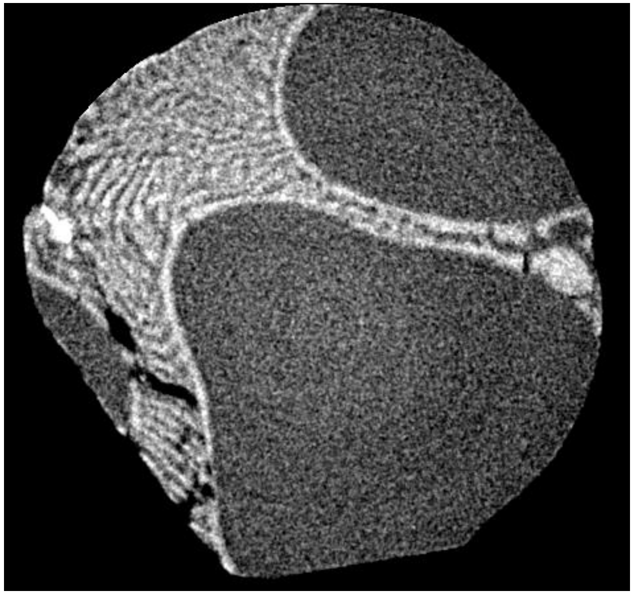
(…if speed and costs were not so important)

Motivation /Limits of conventional CT

Limited materials contrast in CT imaging

Low contrast limit

e.g. aluminum vs. Al_2Cu



$126\ cm^{-1}$ vs. $155\ cm^{-1}$ ≈ 23 %

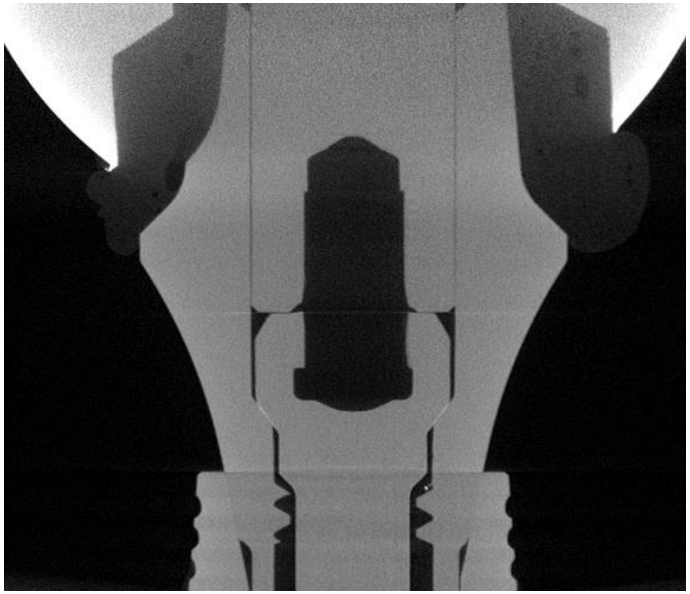
$2{,}5\ cm^{-1}$ vs. $0{,}12\ cm^{-1}$ ≈ 2080 %

ratio ≈ **1 : 90**

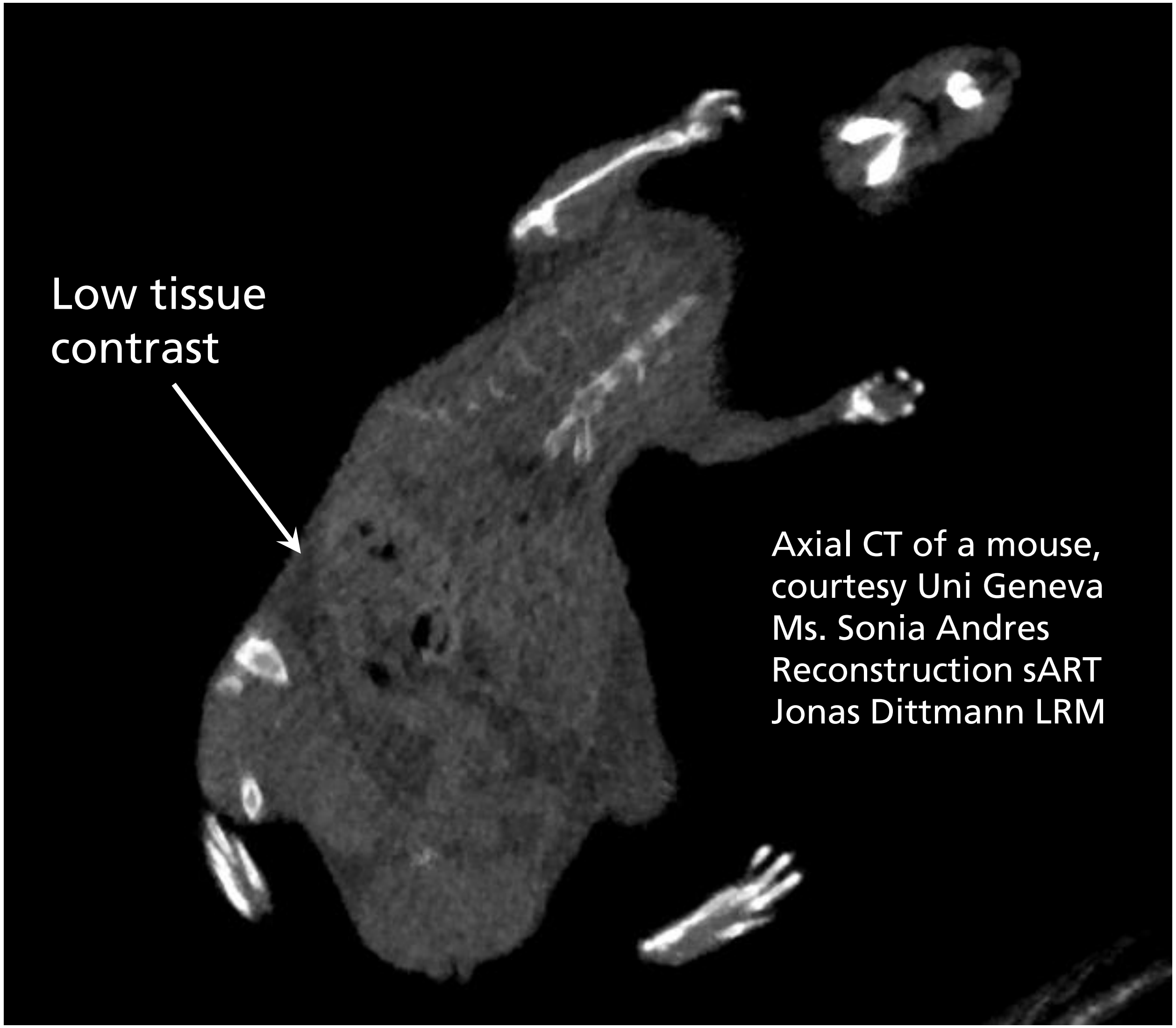
Only two orders of magnitude dynamics in materials contrast

High contrast limit

e.g. titanium vs. bone-cement



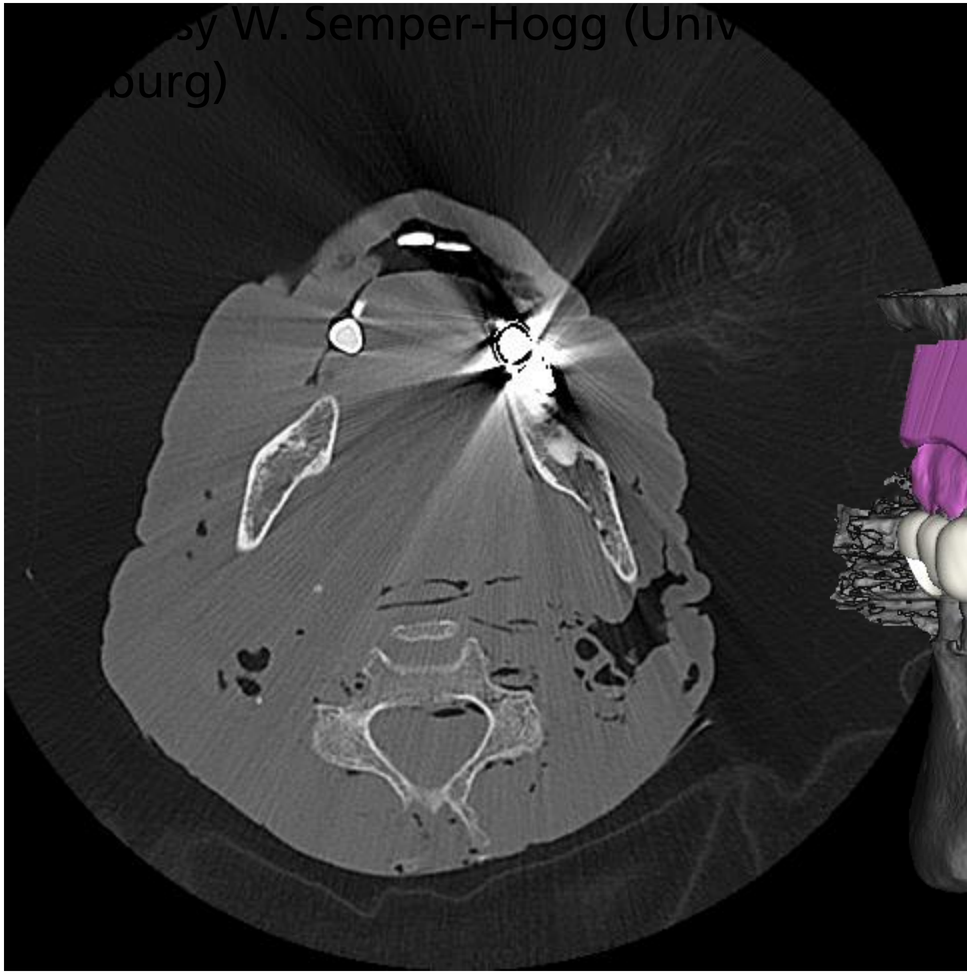
Reminder: Low contrast limit of conventional medical CT



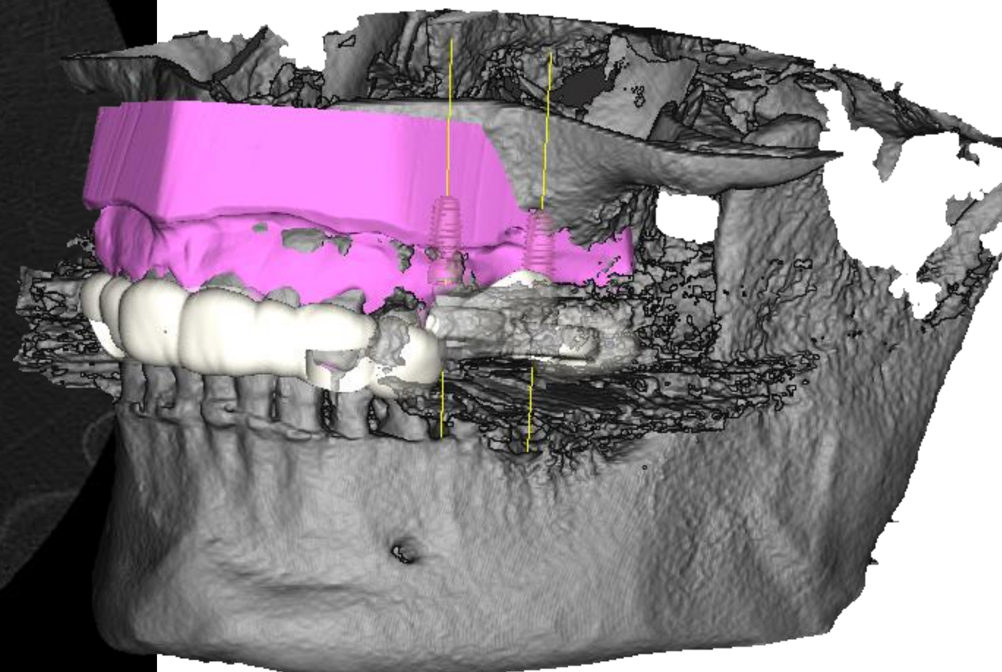
Reminder: High contrast limit of conventional medical CT

DVT scan from patient with metallic inclusions

sy W. Semper-Hogg (Univ
burg)



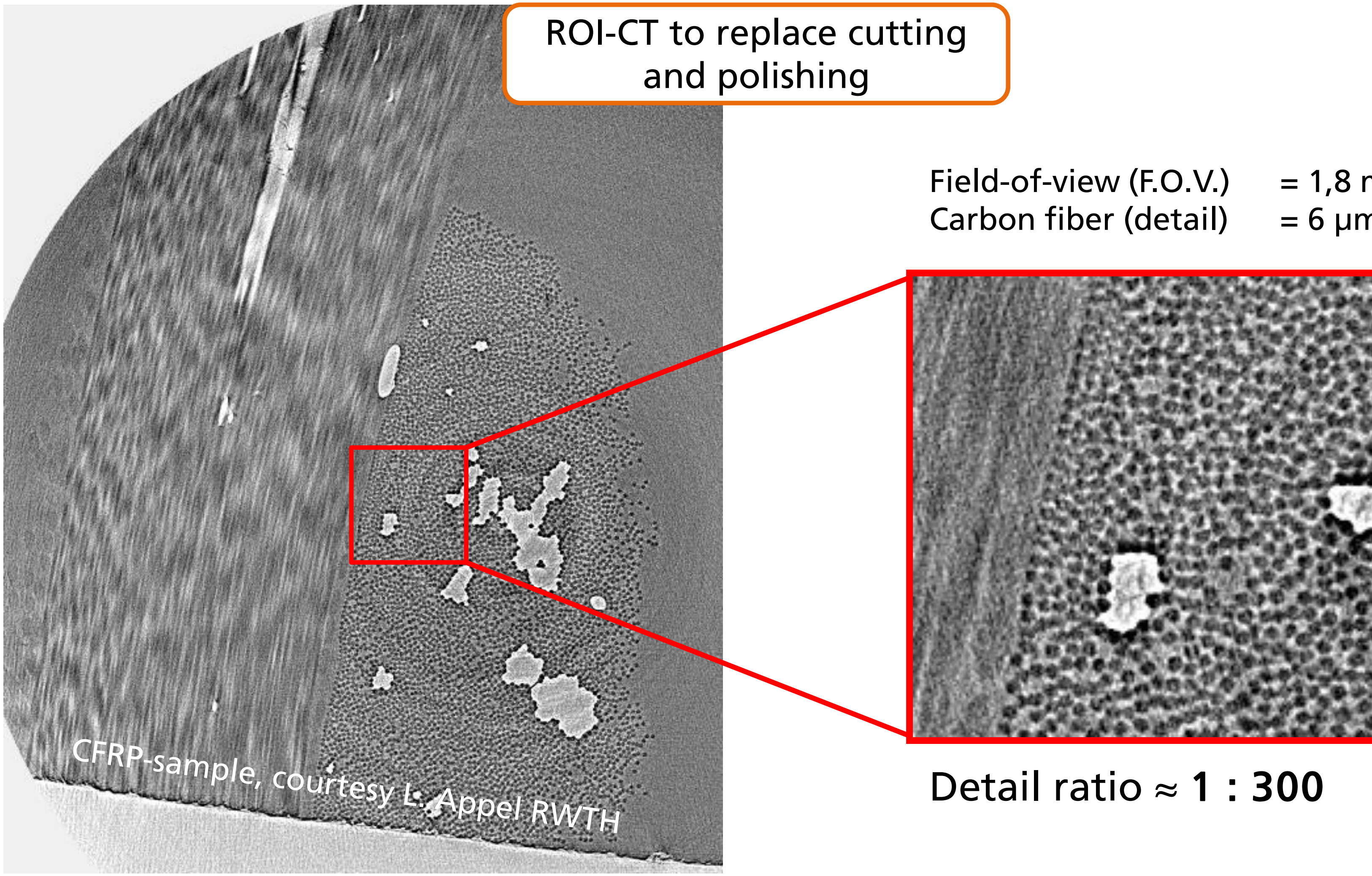
Metal artifacts make an automated planning for dental restauration impossible.



Industrial Computed Tomography iCT

Local fiber orientation in composites (project 3D Volant)

ROI-CT to replace cutting and polishing



Field-of-view (F.O.V.) = 1,8 mm Ø
Carbon fiber (detail) = 6 µm Ø

Detail ratio ≈ **1 : 300**

Motivation /Limits of conventional CT

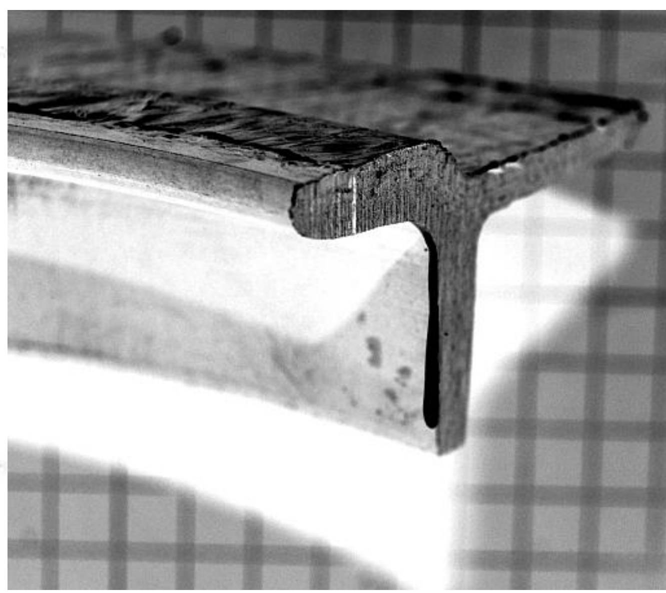
Overcome the detail ratio's limits:

- CFRP components
- Biological structures (lung, bone)
- Rocks and soil

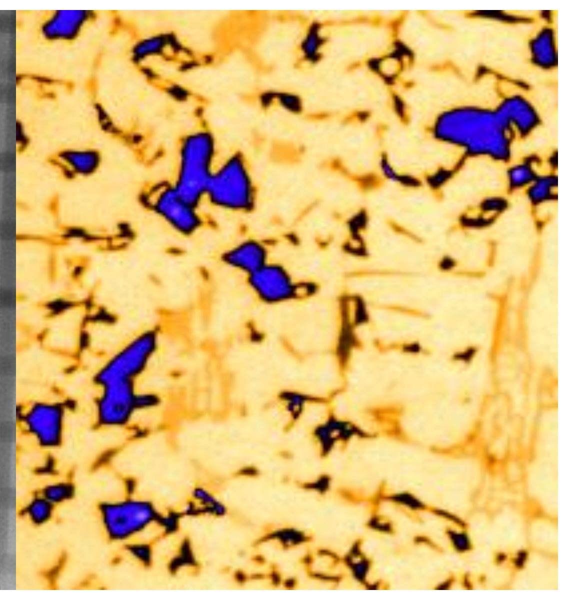
Overcome materials contrast limits:

- Al-Si casting alloys
- Medical implants (teeth, cochlea)
- Organic materials

Detail ratio (x 20) ≈
1 : 6000



Contrast ratio (x 3) ≈
1 : 270



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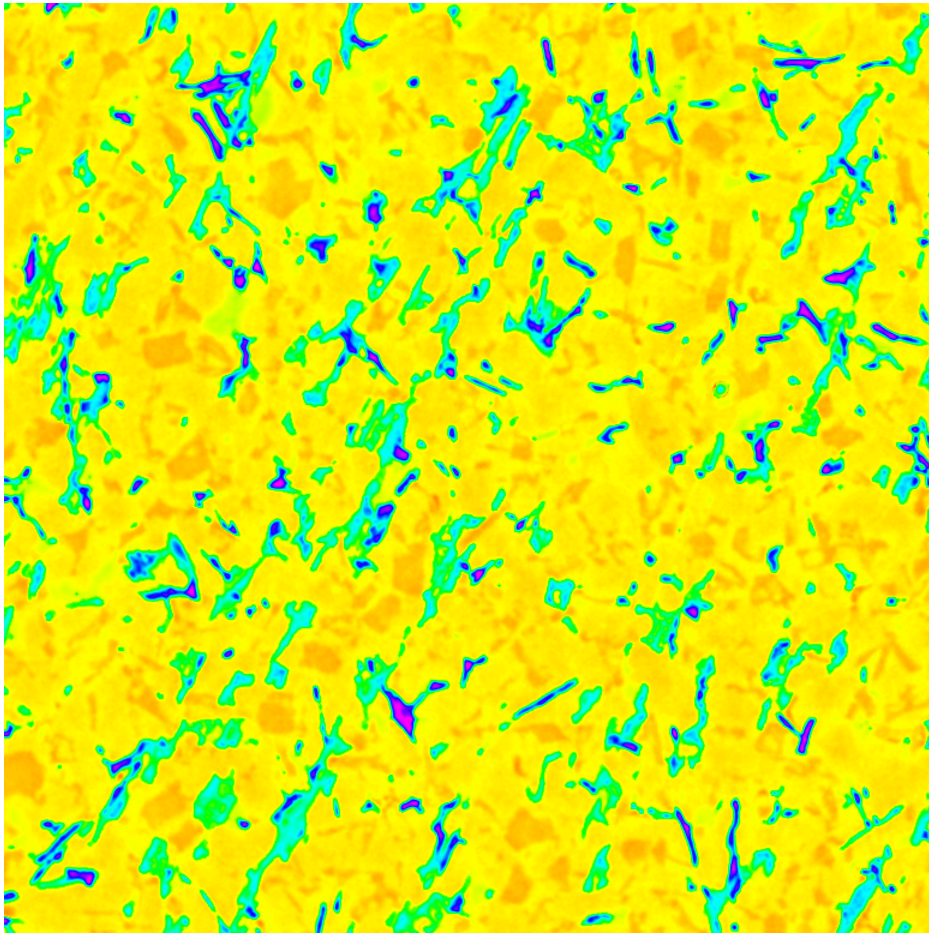
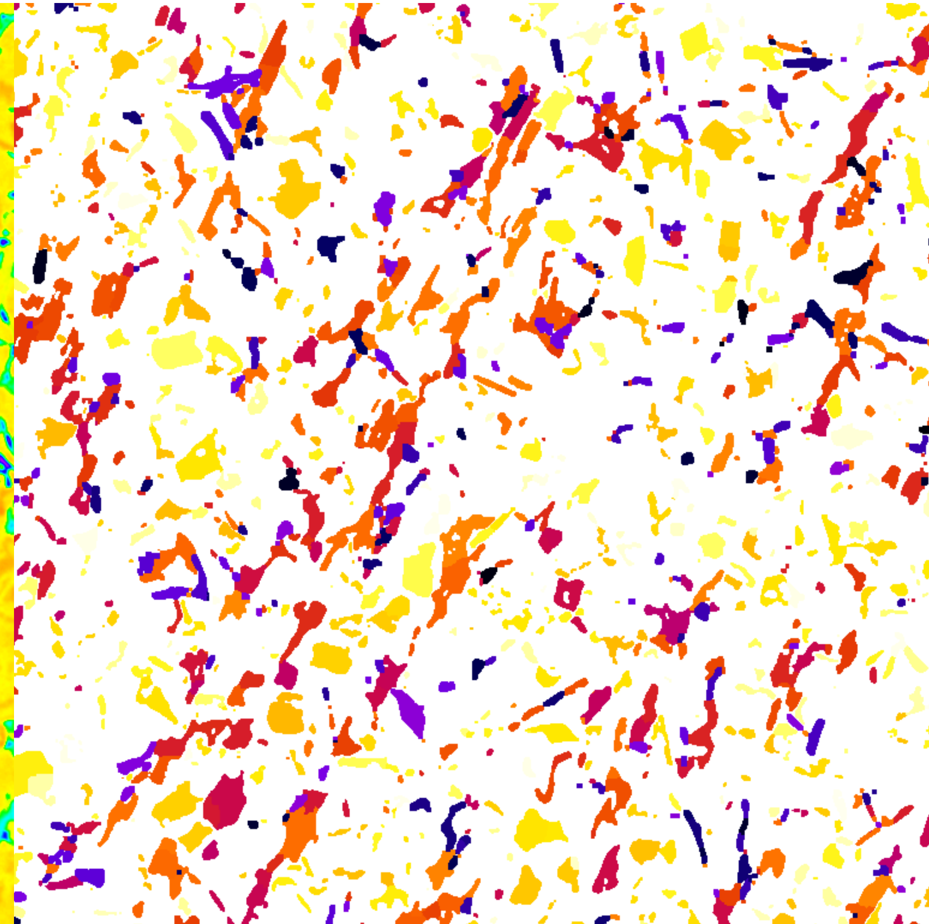
Industrial Computed Tomography iCT

Structural analysis of cast aluminium alloys



Al-Si12 casting alloy



Particle segmentation and labelling

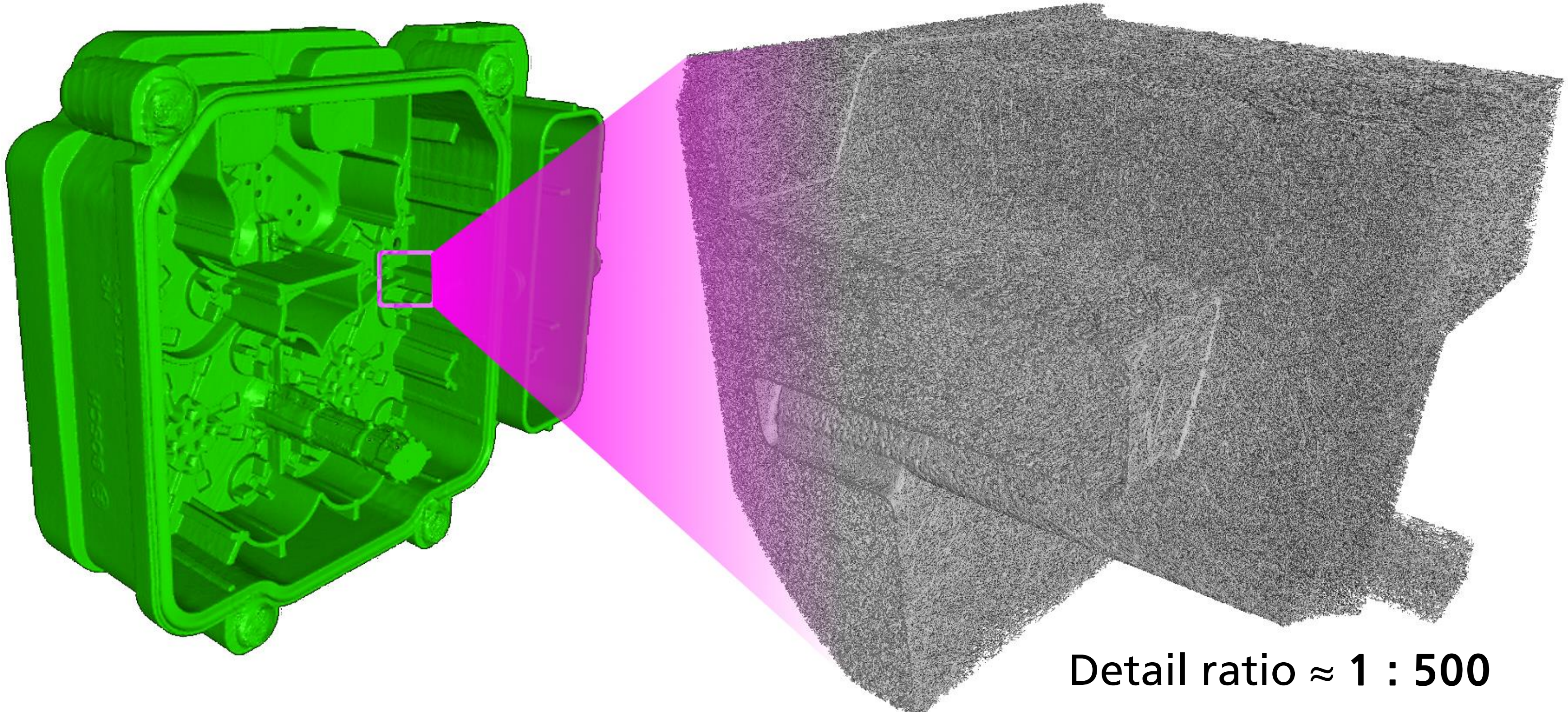
Industrial Computed Tomography iCT

Local fibre orientation in composites (project 3D Volant)

Short glass fiber composite plastics

GF housing for electronics, courtesy J. Strauch

Field-of-view (F.O.V.) = 6 mm Ø
Glass fiber (detail) = 12 µm Ø



Detail ratio ≈ **1 : 500**

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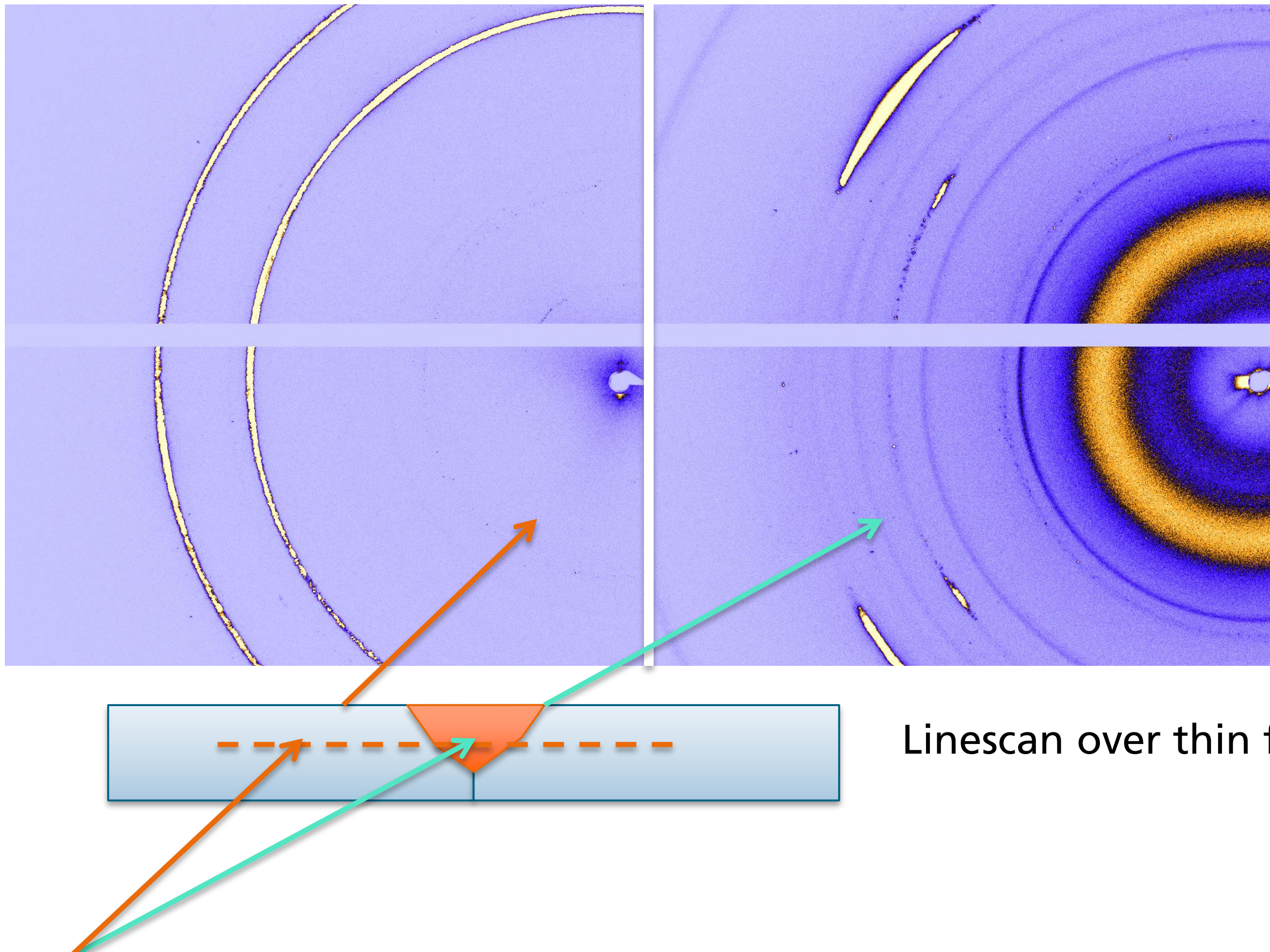
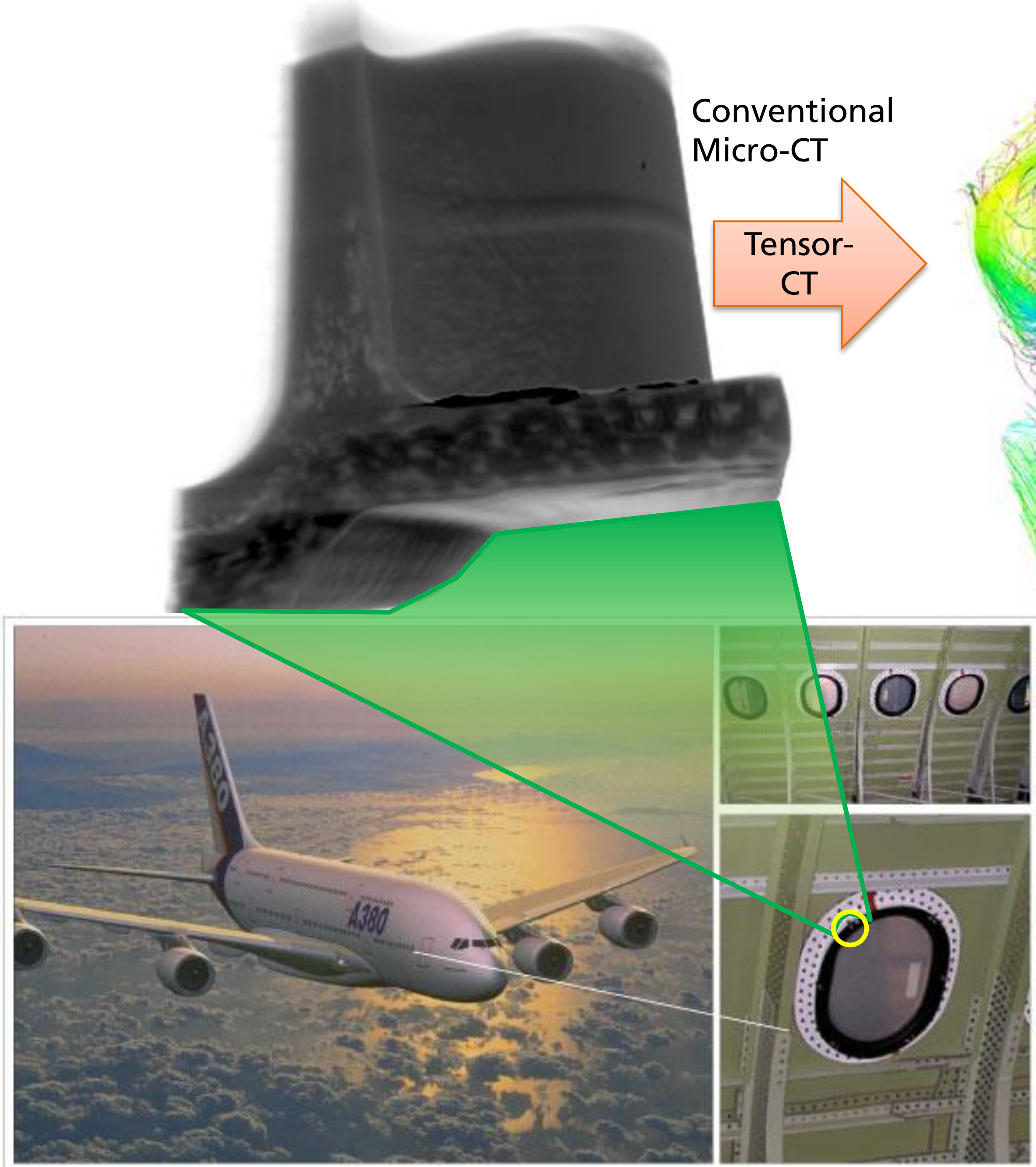
Structural analysis of aluminium weld

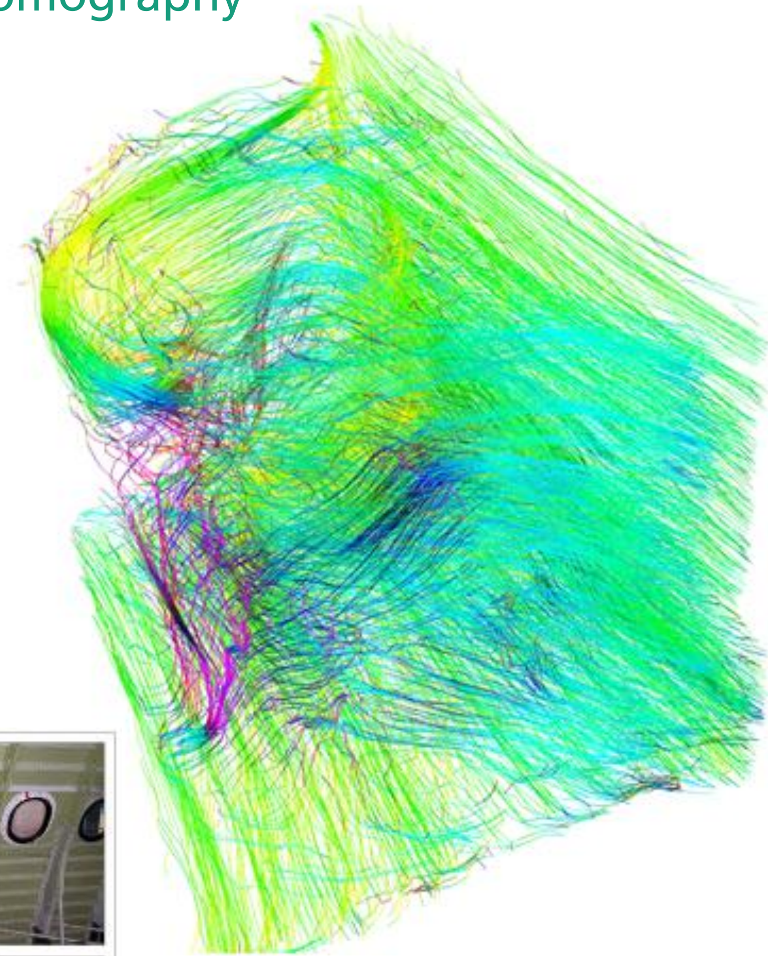
X-ray diffraction patterns (WAXS) show the different crystalline structures in the bulk and in the weld (texture).



Linescan over thin foil

Local fiber orientation in composites : Tensor tomography

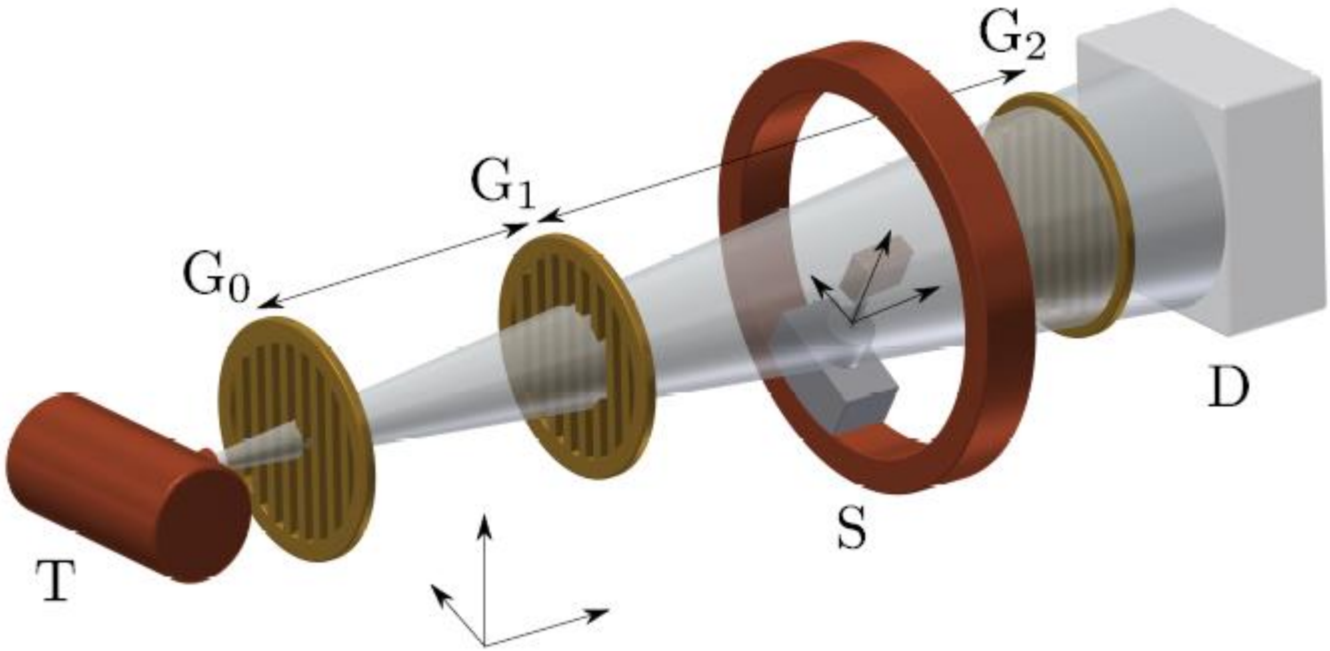




Mapping the fiber orientation in complete plastic parts (courtesy M. Willner, Mithos)

Detail ratio ≈ 1 : 3000

Example: Tensor Tomography = high throughput of data

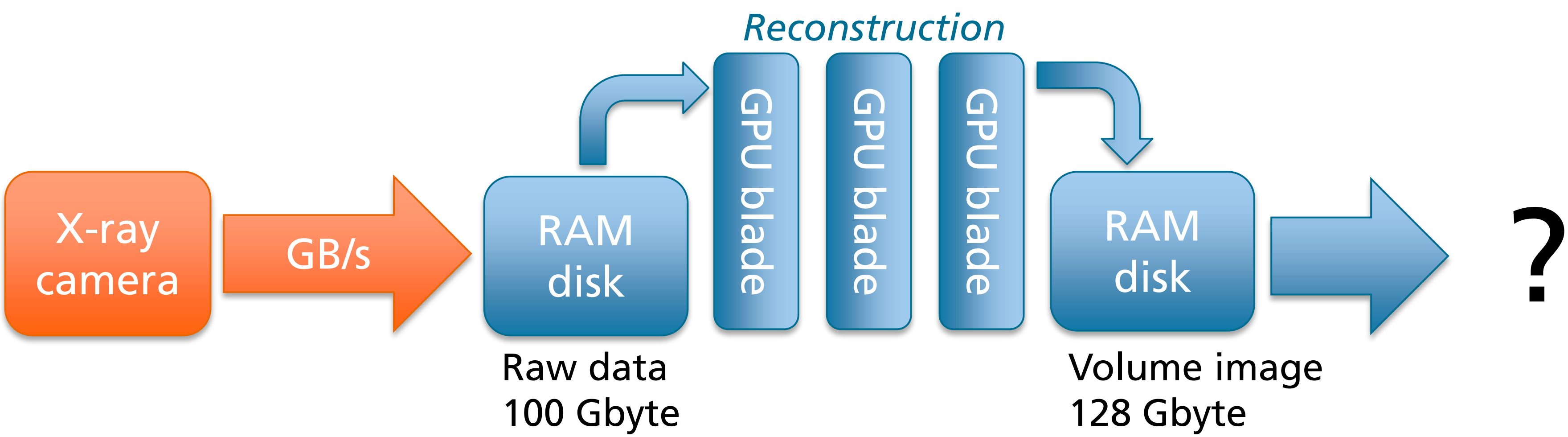


/Lasser et al. OptExpress 2015/

- Projections are recorded for 13 differently oriented CT-axes (bouquet)
- 8 phase-steps (1 s exposure) are used for each projection (between 551 and 902 over 360°) → up to 26 hours of exposure + motor time
- Reconstruction takes between 2 and 15.5 hours (100 iterations)
- 127 µm/pixel at 185 cm SDD (symmetric setup, M<2)

High-throughput CT means…

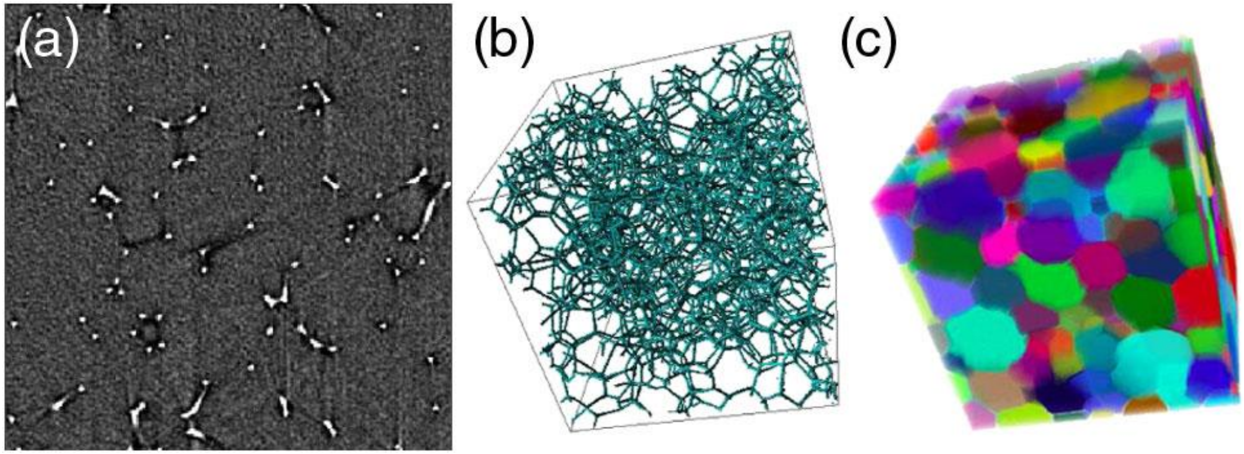
1. Increasing the detail ratio (aim 1:20000) = High-troughput of data
2. Increasing the scan rate = High-troughput of samples
3. Increasing the repetition rate = In situ CT



High-throughput requires an efficient and intelligent handling of data!

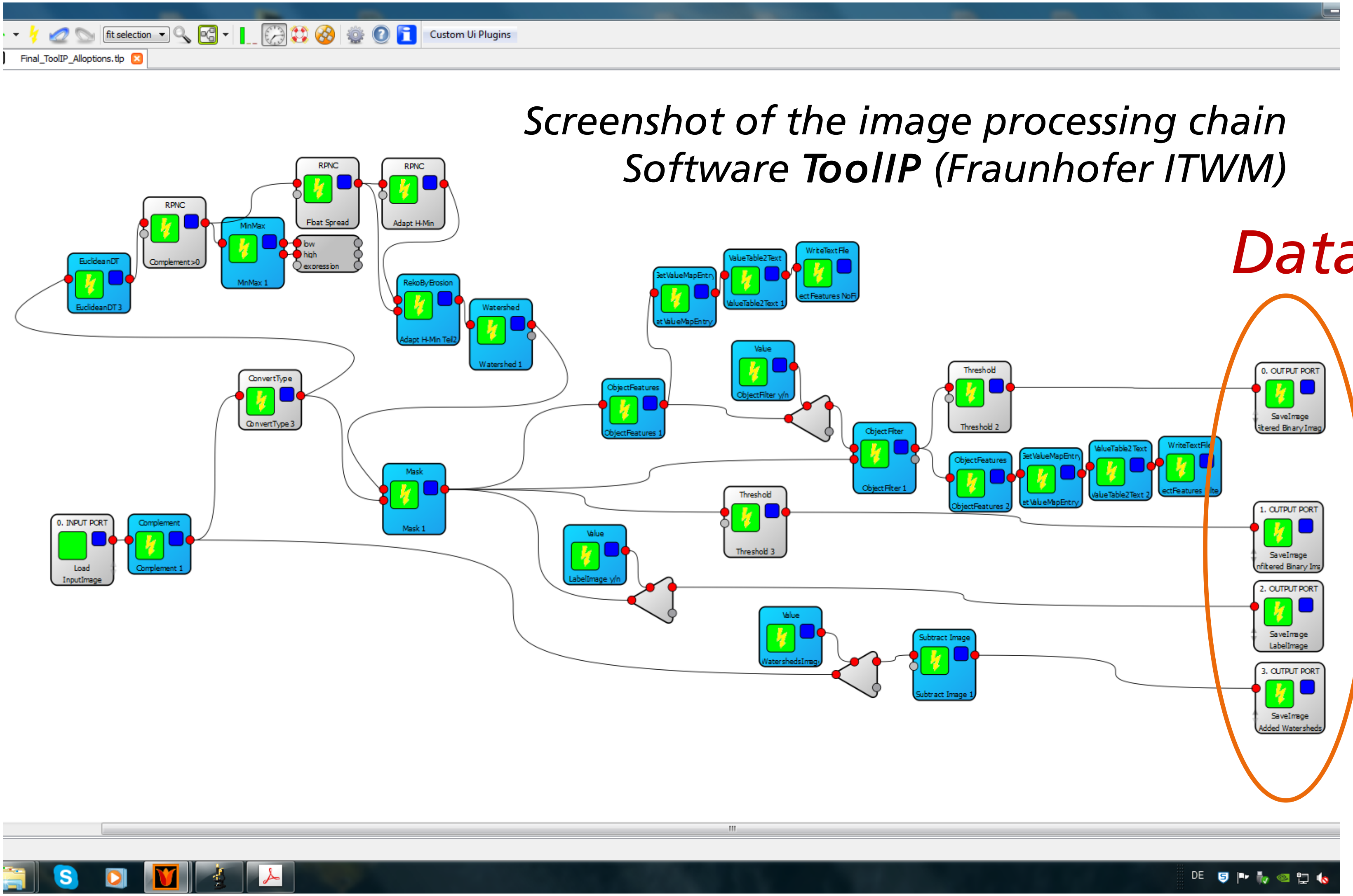
Towards manageable data from high-throughput CT

1. Strategy „Measure only what is needed“
2. Strategy „Reconstruct only what is important“
3. Strategy „Automated volume image processing“



/J. Lambert et al., Phys Rev Lett 104, 248304 (2010)/

Strategy „Automated volume image processing“



*Screenshot of the image processing chain Software **ToolIP** (Fraunhofer ITWM)*

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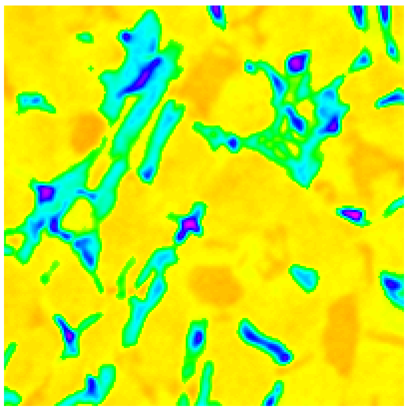
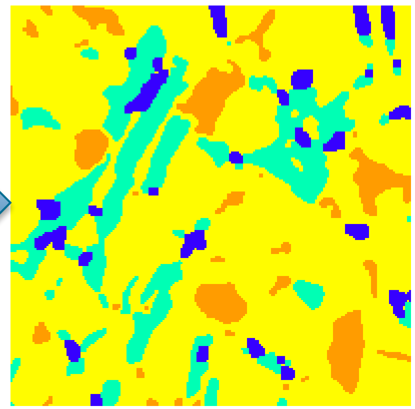
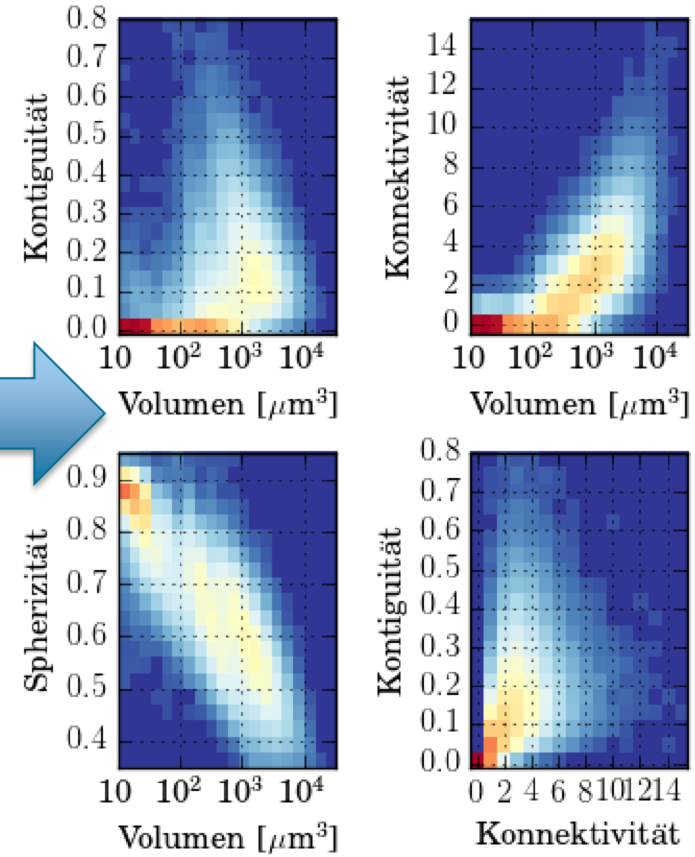
Volume image processing: e.g. aluminum cast alloy



Reconstructed
volume image
16 Gbyte grey



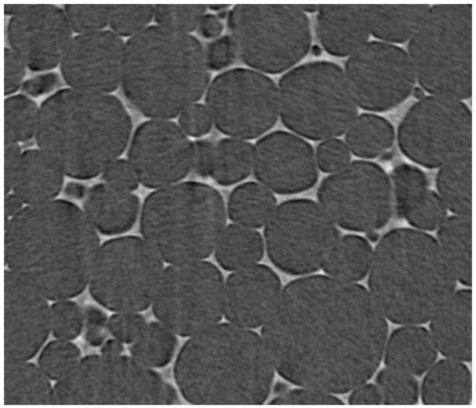
Filtering
Segmentation
Fragmenting
Labelling
→500 Mbyte
label+orientation



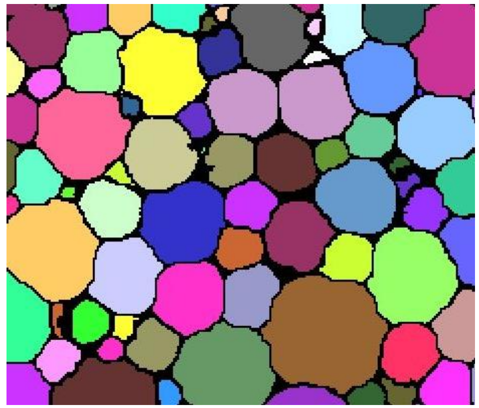
Object parameters: 40 Mbyte

Volume image processing: e.g. in situ CT of BLG foam

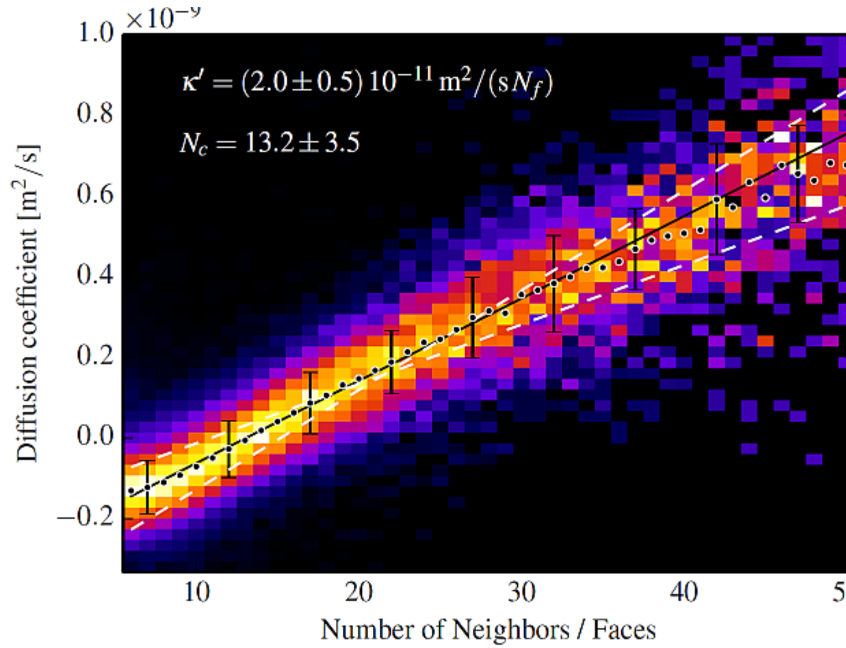
/Dittmann et al. JCIS 2016/



measurement



labelling



5 scans, 16 Gbyte each → 80 Gbyte

250 000 pores in all volumes →100 000 matches

Diffusion constant and critical neighbor count → 8 bytes

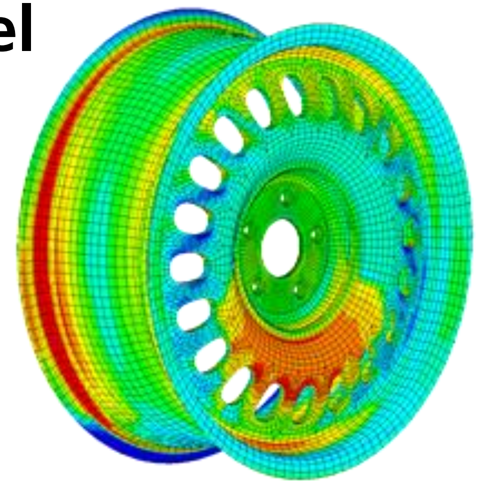
Information is reduced by a factor of **10 000 000 000**!

High-throughput industrial Computed Tomography iCT requires intelligent handling and analysis of results…

(…very similar to medical diagnostics)

Example: "Reinventing" the Wheel

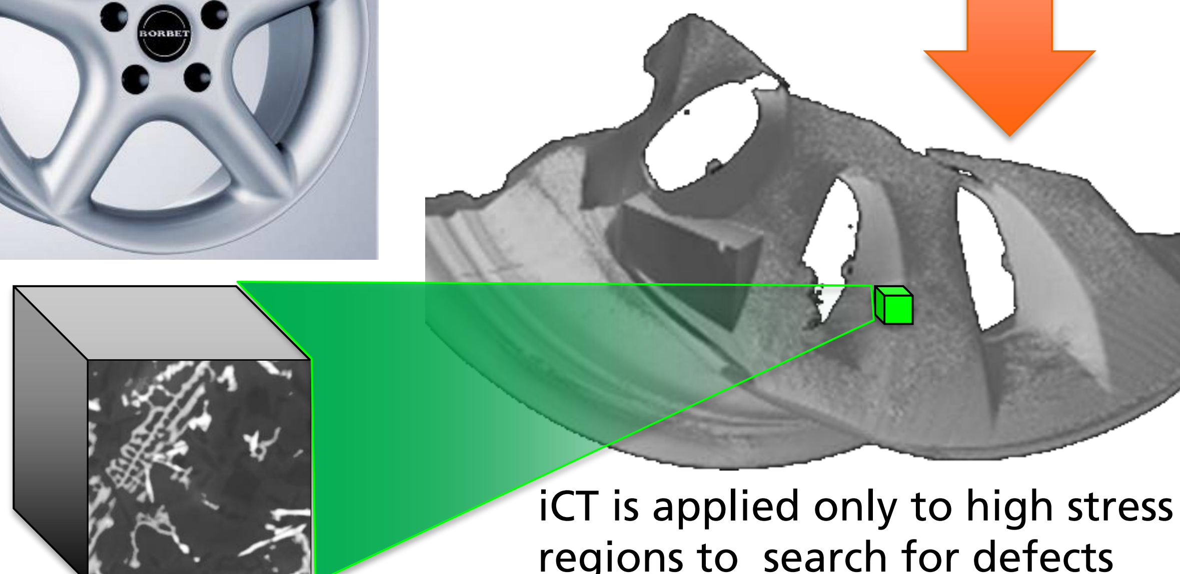
Feedback is generated for casting process



FE analysis of cyclic loading shows regions of high cyclic stress/ strain.

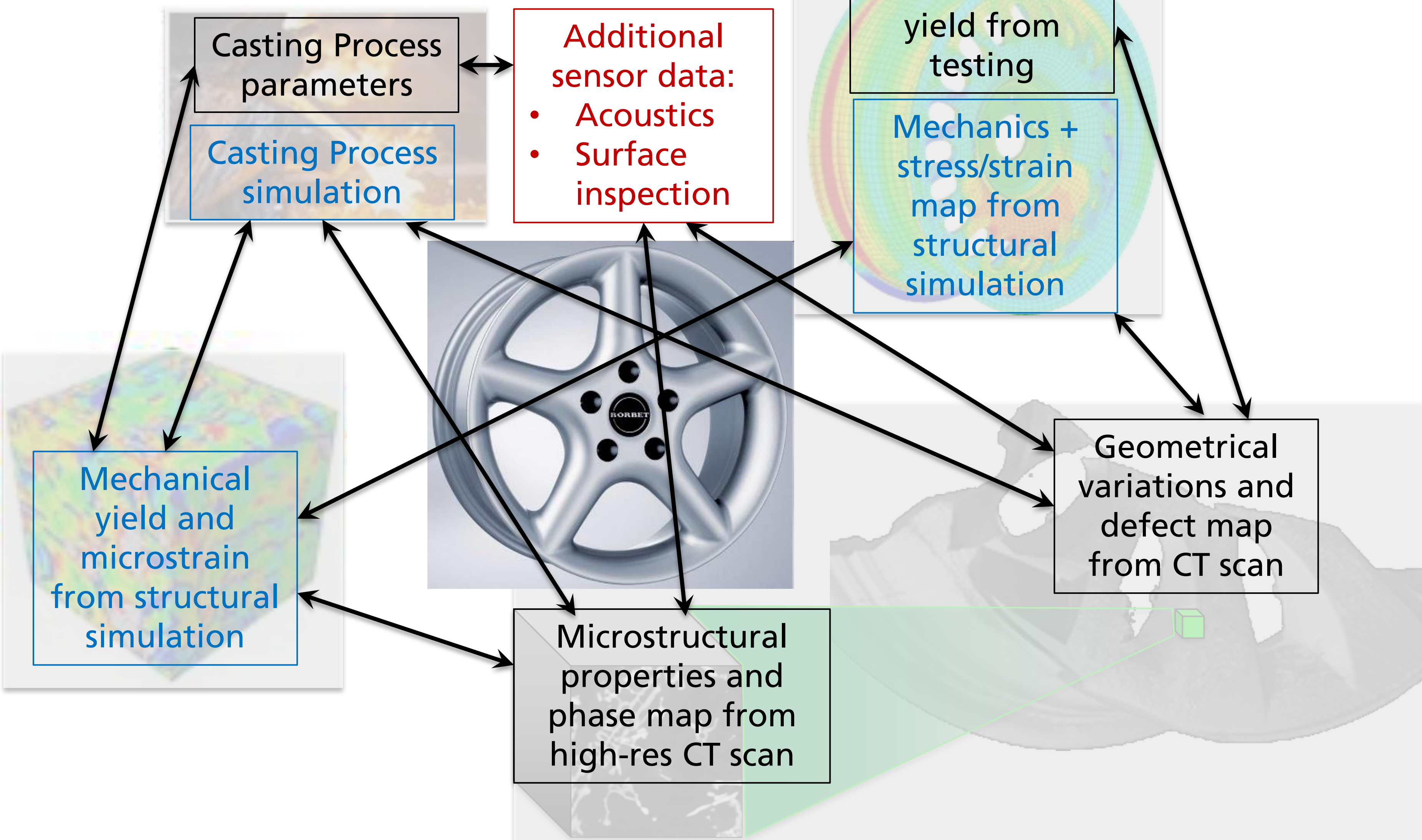
Mulitphase FE model is generated for structural simulations

High-resolution micro-CT locally measures the cast microstructure



iCT is applied only to high stress regions to search for defects

Example: Aluminum Wheel



Industrial Computed Tomography
Resumé - Outlook

- Currently most inspection tasks are 2D
- Increasing demand for 3D inspection in
  - Metallic alloys microstructure
  - Fiber composite materials
- 3D inspection includes the standardized analysis of CT data and may be facilitated by use of an atlas (similar to anatomy)
- Cross-linking of multiple sensor data can be coupled by cognitive machine learning (materials dataspace)
- Automotive parts are going to carry these parameters along their service life (S.P.)