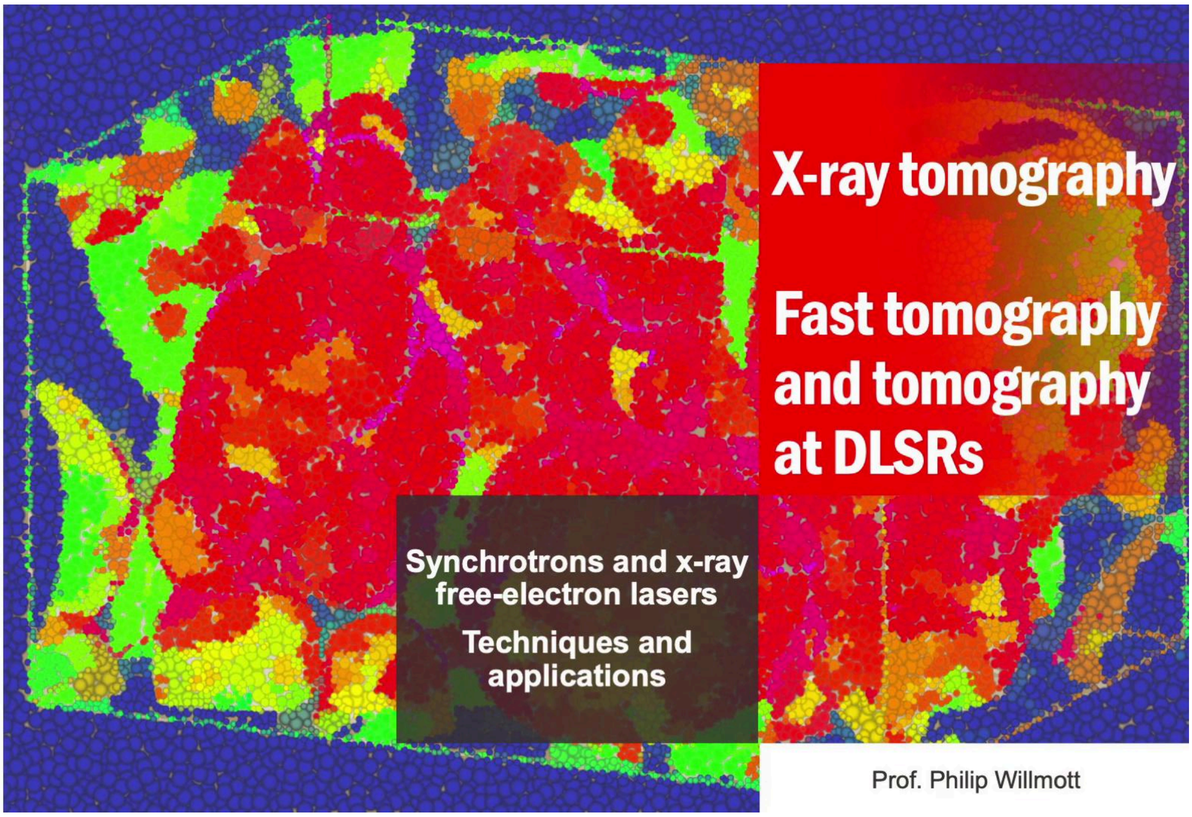
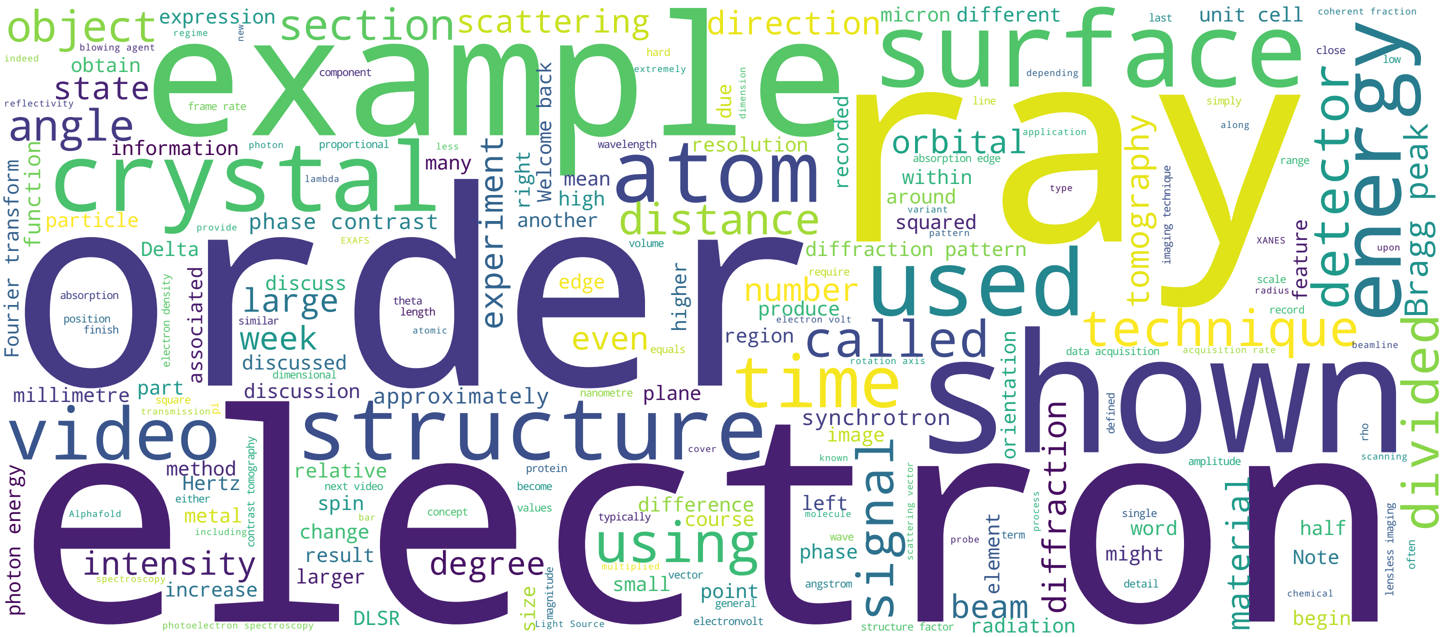
EPFL



École polytechnique fédérale de Lausanne

Prof. Philip Willmott



EPFL

Search MOOC

Video

Contents and objectives of this video

- Tomography at DLSRs
- Fast tomography
  - Example

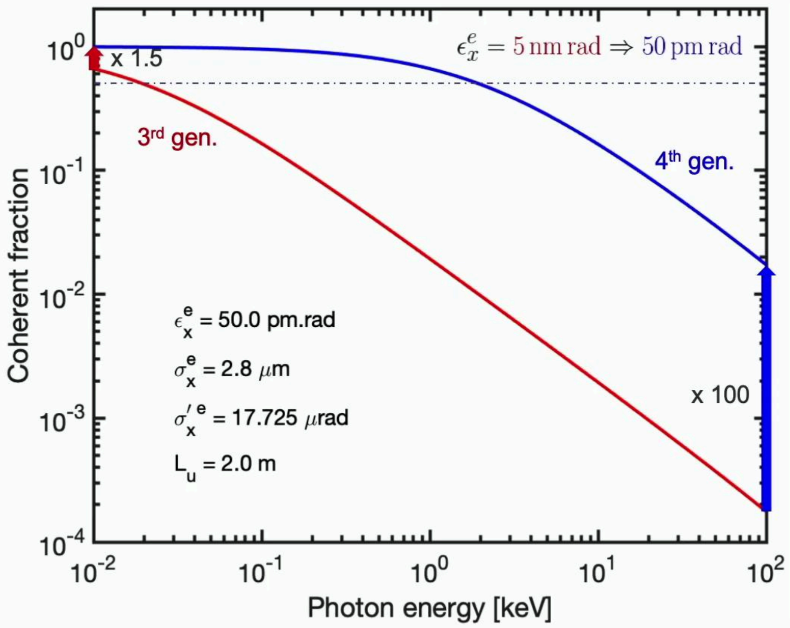
Welcome back to this introductory course on synchrotron and XFEL radiation. In this last video of the second section of the fifth week, we will discuss fast tomography.

Notes

Summary

0m 05s

Phase-contrast tomography and DLSRs



- Phase-contrast tomography uses coherent fraction of beam f_c
- DLSRs
  - Two orders of magnitude increase in f_c
    - 3rd-gen. facilities: ~ 0.1% HXR
    - DLSRs: ~ few %
  - More isotropic transverse coherence function
  - Blurring of fringes due to convolution of source size significantly reduced
- Concomitant increase in data acquisition rates

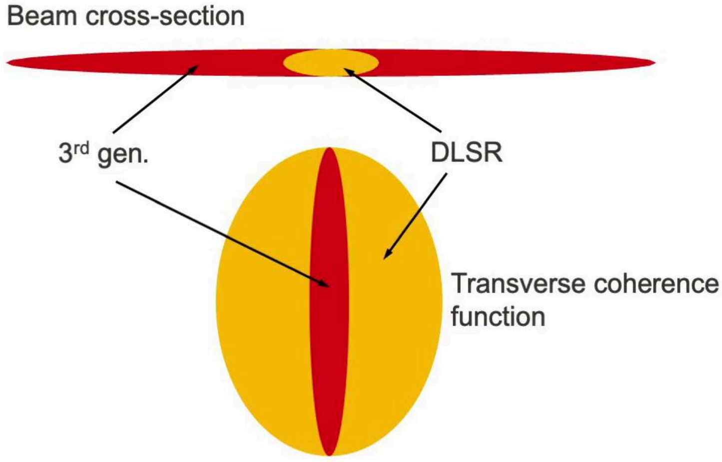
Both absorption and phase-contrast tomography capture radiographs of entire samples. The speed of an experiment depends on the required exposure time and the number of rotation steps determined by the Crowther criterion, which we explained in the first section of this week. In general, absorption tomography doesn't lend itself to rapid frame rate acquisition, and instead, phase contrast methods are preferred. In order to obtain fringes, the bedrock of phase-contrast techniques, the beam must have some coherent component. As a side note, when absorption contrast tomography is being performed, it's often desirable to scramble the coherent aspect of the incident radiation by placing a granular and rotating phase object upstream of the sample to minimise artefacts due to fringing. Many a circular sheet of thick paper mounted on a rotating axis has been burned through in this service. DLSRs offer approximately two orders of magnitude greater coherent fraction than do third-generation facilities. Moreover, novel developments in source technologies such as superconducting undulators with ultra-short periods of around 10 millimetres, also means that the absolute flux is now around an order of magnitude higher than previously possible. This means the rate of coherent photons impinging on a sample might be a thousand times larger at DLSRs than at third-generation facilities.

Notes

Summary

0m 16s

Phase-contrast tomography and DLSRs



$$l_c^{(t)} = \lambda/2\Delta\theta = \lambda R/2D$$

- Phase-contrast tomography uses coherent fraction of beam f_c
- DLSRs
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An added benefit of DLSRs in phase contrast imaging is that the beam cross-section is much rounder at DLSRs than before. Consequently, the difference in the transverse coherent fraction in the vertical and horizontal planes is more modest, thus reducing anisotropic blurring of fringes. All of these factors contribute to orders of magnitude increases in possible data acquisition rates.

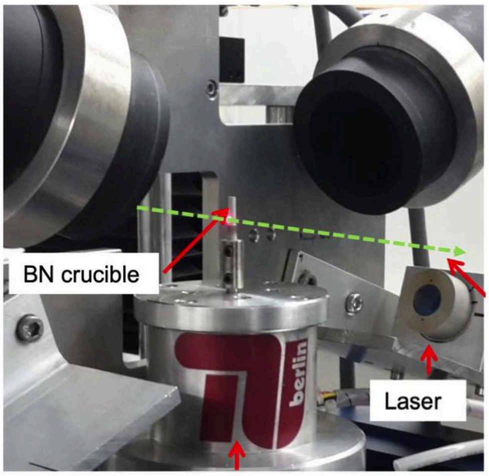
Notes

Summary

1m 56s

Fast tomography

- Sub-second tomogram acquisition times
- Record to date = 200 tomograms/s (100 Hz rotation rates)



Rotation stage

- Centrifugal accelerations $a = \omega^2 r$

  $$a[\mathrm{g}] = 4.026 \times 10^{-3} \, (f[\mathrm{Hz}])^2 \, r[\mathrm{mm}]$$

  - e.g. 100 Hz, r = 1 mm ⇒ a = 40 g!!
  - Maximum tolerable forces depend on system being investigated
- Data acquisition rates ~ 10 – 100 GB/s
  - e.g. 100 Hz ≡ 200 tomograms/s
  - 180 frames/tomogram
  - 2 MB/frame
  - ⇒ 72 GB/s !!! (after 1 minute: 4.3 TB!!!!)

Now, fast tomography takes advantage of these new capabilities. Recent experiments at the TOMCAT beamline at the Swiss Light Source have recorded entire tomograms as rapidly as 200 per second, equating to frame rates well into the several ten thousands per second. This much increased rotation rate raises the question of the impact of centrifugal forces on the sample. It can be easily calculated that in practical units of multiples of g, the Earth's gravitational acceleration, which is approximately equal to 10 metres per second squared, the acceleration felt by an element of an object at a distance r in millimetres from the rotation axis and rotating at f Hertz is equal to f squared times r divided by 250. Hence, an object at a distance of only 1 millimetre from the rotation axis rotating at 100 Hertz would experience accelerations of 40g. The maximum tolerable forces depend on the system under investigation, of course. Now, another important challenge down the technological chain is the required computer data acquisition rate. Again, if running at 100 Hertz and recording 180 frames per tomogram, each frame being 2 megabytes in size, results in an acquisition rate of 72 gigabytes per second.

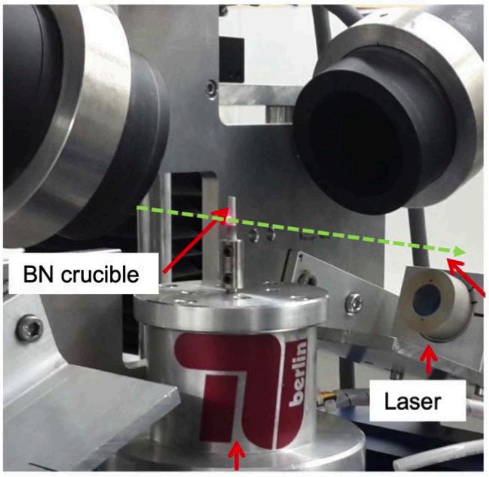
Notes

Summary

2m 27s

Fast tomography

- Sub-second tomogram acquisition times
- Record to date = 200 tomograms/s (100 Hz rotation rates)



- Centrifugal accelerations $a = \omega^2 r$

$$a[\mathrm{g}] = 4.026 \times 10^{-3} \, (f[\mathrm{Hz}])^2 \, r[\mathrm{mm}]$$

  - e.g. 100 Hz, r = 1 mm ⇒ a = 40 g!!
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  - 2 MB/frame
  - ⇒ 72 GB/s !!! (after 1 minute: 4.3 TB!!!!)

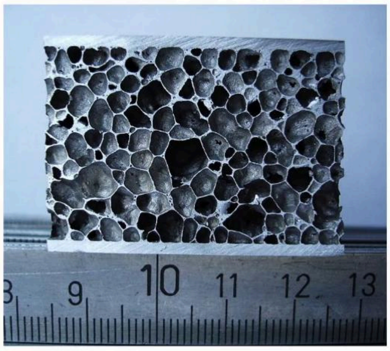
After a minute, you will have filled up over 4 terabytes of disc space. Clever onboard data compression algorithms, parallel data acquisition hardware, and on-the-fly processing are all essential components for the IT aspect of fast tomography to keep pace with advances in the experimental hardware. On the left is a photograph of the sample setup used in the example shown in the following slides about the production of metallic foams.

Notes

Summary

4m 02s

Fast tomography example – metallic foams



https://commons.wikimedia.org/
wiki/File:Aluminium_foam_sandwich.jpg

- Applications
  - Civil engineering, house construction
  - Car crumple-zones
  - …
- Formation dynamics very poorly understood
- Optimize fabrication process

Images: creative commons

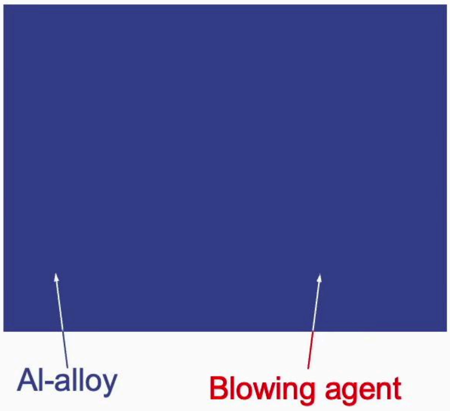
Okay, metallic foams are interesting materials to use for lightweight, robust applications, such as in civil engineering, house construction, and as part of car crumple zones, for example. They are created by adding volatile materials inside metals such as aluminium alloys, that, when the metals are heated to their melting temperature, rapidly vaporise and produce a foam-like architecture. The formation dynamics of these metal foams is as yet only poorly understood.

Notes

Summary

4m 32s

Fast tomography example – metallic foams



- Fabrication process
  - Liquid metal + gas
  - Gas
    - Blow in
    - Pressure drop
    - Shake
    - "Blowing agent" e.g. TiH_2 + heat

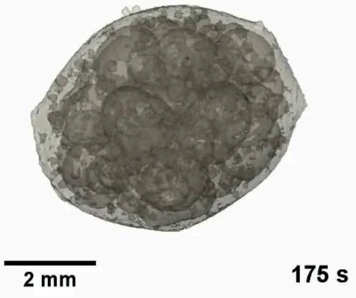
The fabrication process is shown as a cartoon here. The volatile component added to the metal forms a gas. How this component is added can be either through blowing it in, through a sudden drop in ambient pressure, via shaking, or as in this example, by the use of a blowing agent mixed into the metal, here, titanium hydride.

Notes

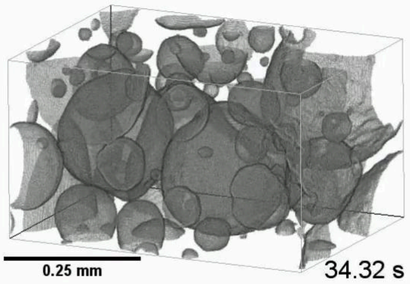
Summary

5m 03s

Fast tomography example – metallic foams



Temporal overview



High temporal resolution
Δt = 2.5s/64 = 40 ms

- TOMCAT-beamline, SLS
  - Polychromatic x-rays
    - Higher flux required
  - Al-alloy, laser-heated
  - 104 rotations/s ⇒ 208 tomograms/s
  - Ca. 10 min. recording
  - ⇒ ≃ 24 million frames
  - ⇒ ca. 50 terabyte data!!

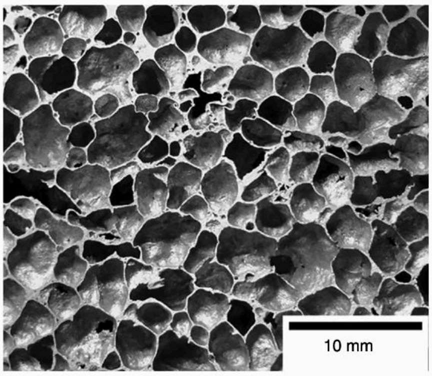
The experiment was carried out at the TOMCAT beamline of the Swiss Light Source. Shown upper left is a temporal overview of the process, while bottom left, a high temporal resolution region is shown in which the time between frames was 40 milliseconds, equating to frame rates of 25 Hertz. The beam was partially polychromatic in order to achieve the necessary flux. The actual rate of tomographic production was over 200 per second. A 10-minute recording gobbled up 50 terabytes of disc space in order to record this.

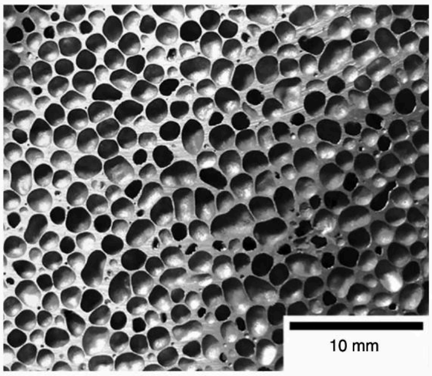
Notes

Summary

5m 26s

Fast tomography example – metallic foams





- With blowing agent
  - Large bubbles
    - Primarily located at BA-particles
  - Inhomogeneous size distribution

- Without blowing agent
  - Only intrinsically trapped gases
  - Smaller bubbles
  - More homogeneous size distribution

F. García-Moreno *et al*., https://doi.org/10.1038/s41467-019-11521-1

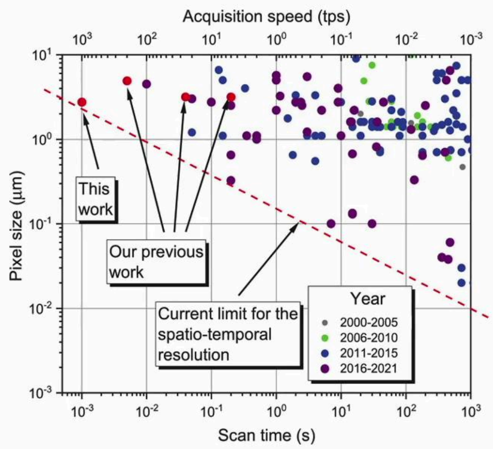
It was discovered that with blowing agent, the foam consisted of large bubble voids centred, not very surprisingly, where the blowing agents had been located. The size distribution was very inhomogeneous. Now, in contrast, foams could also be produced simply by the expansion of intrinsically trapped gases formed when the metal was being first cast. These produced smaller bubbles with a much more homogeneous size distribution.

Notes

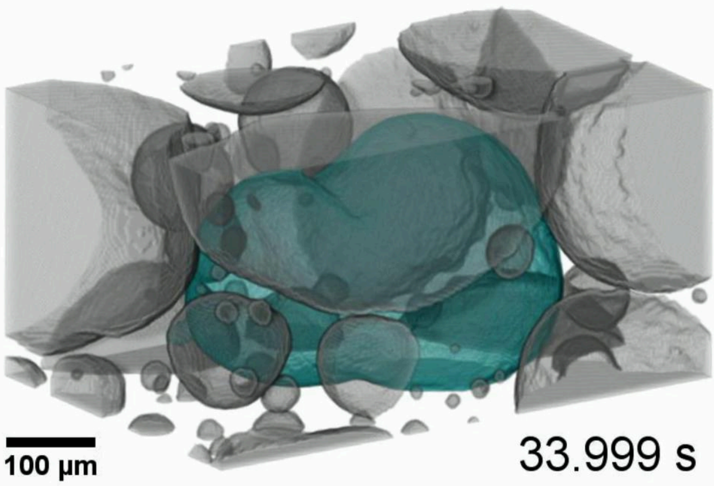
Summary

6m 00s

Fast tomography example – progress since 2019



- July 2021
  - New publication, Advanced Materials
  - 1000 tomograms/s!!
  - In. Sane.



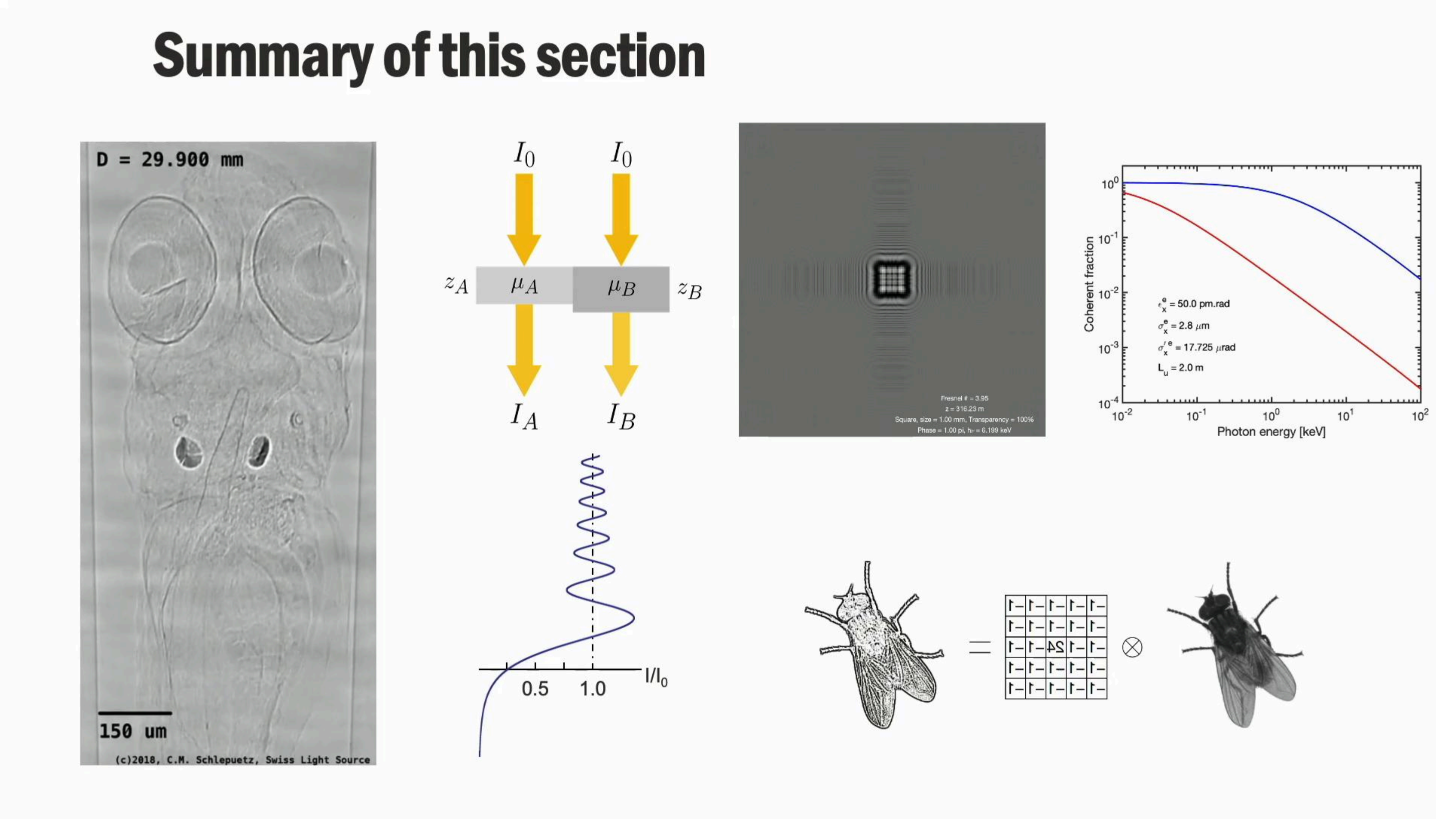
F. García-Moreno *et al.*, https://doi.org/10.1002/adma.202104659

Interestingly, speaking to the contact author for this example in order to request permission to use their data from 2019, he brought to my attention a more recent publication on the same subject published in the summer of 2021. As one can see from the graph on the left, they were able to increase the number of tomograms recorded per second from 200 to 1,000, and that with marginally smaller detector pixel size. This is insane.

Notes

Summary

6m 34s

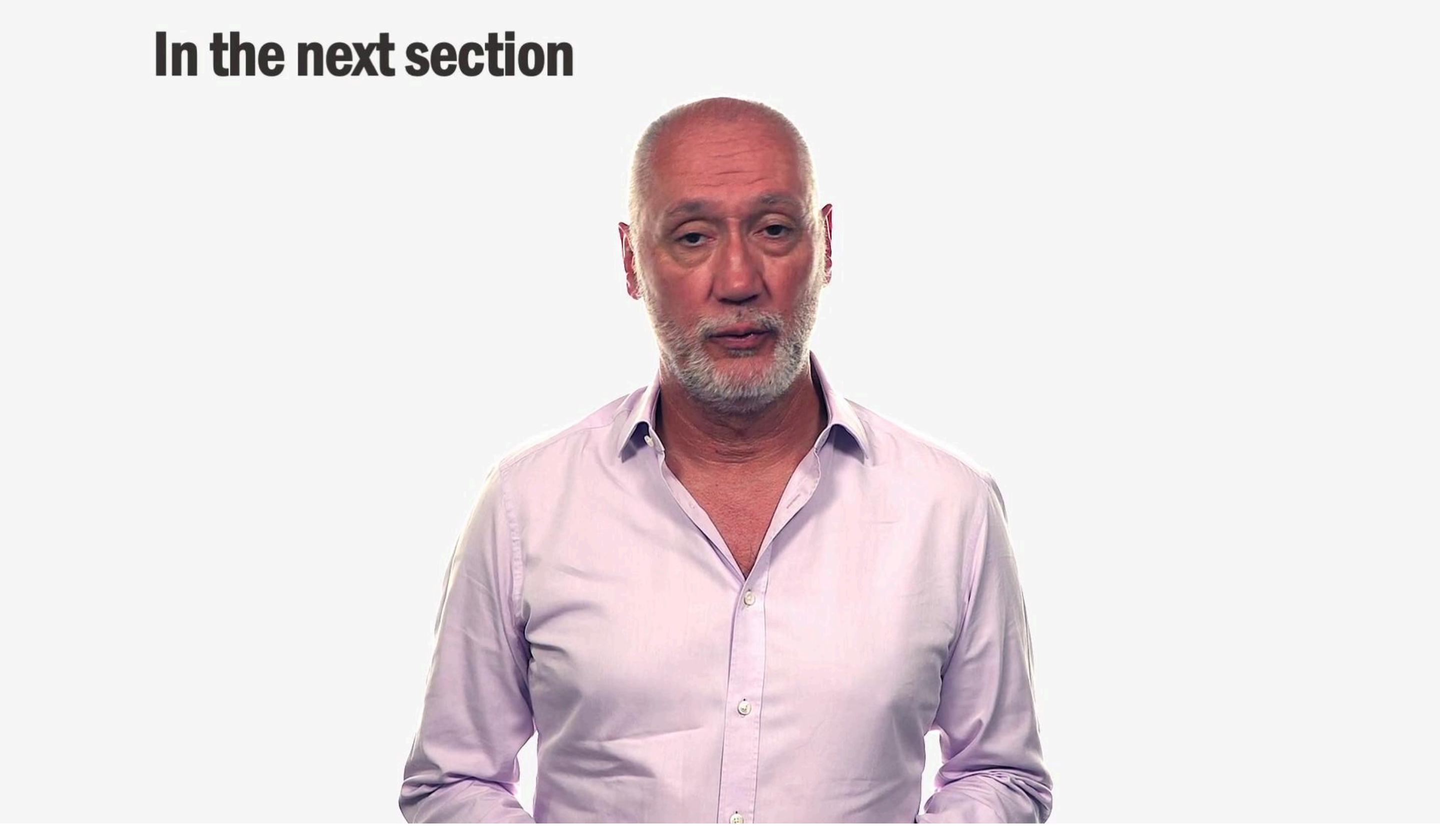


All right, so summarising this section, we have discussed the increasingly important technique of phase-contrast tomography. We saw that for weakly absorbing samples, absorption contrast fails and edge diffraction and fringing come to our rescue. We discussed the concept of phase objects in which induced phase shifts alone in transparent objects can induce fringes. We then discussed how one converts the line drawings of raw phase-contrast images to aerial-contrast images, before finishing with a discussion of tomography at DLSRs and the exploitation of the significantly higher and more homogeneous coherent fraction to push fast tomography into the hundreds of Hertz regime.

Notes

Summary

7m 04s



In the final section of this week, consisting of three videos, we wrap up our discussion of imaging techniques that are either direct propagation imaging, like in tomography, or use lenses in full-field microscopies. We leave lensless imaging techniques to be discussed in the final sixth week.

Notes

Summary

7m 55s