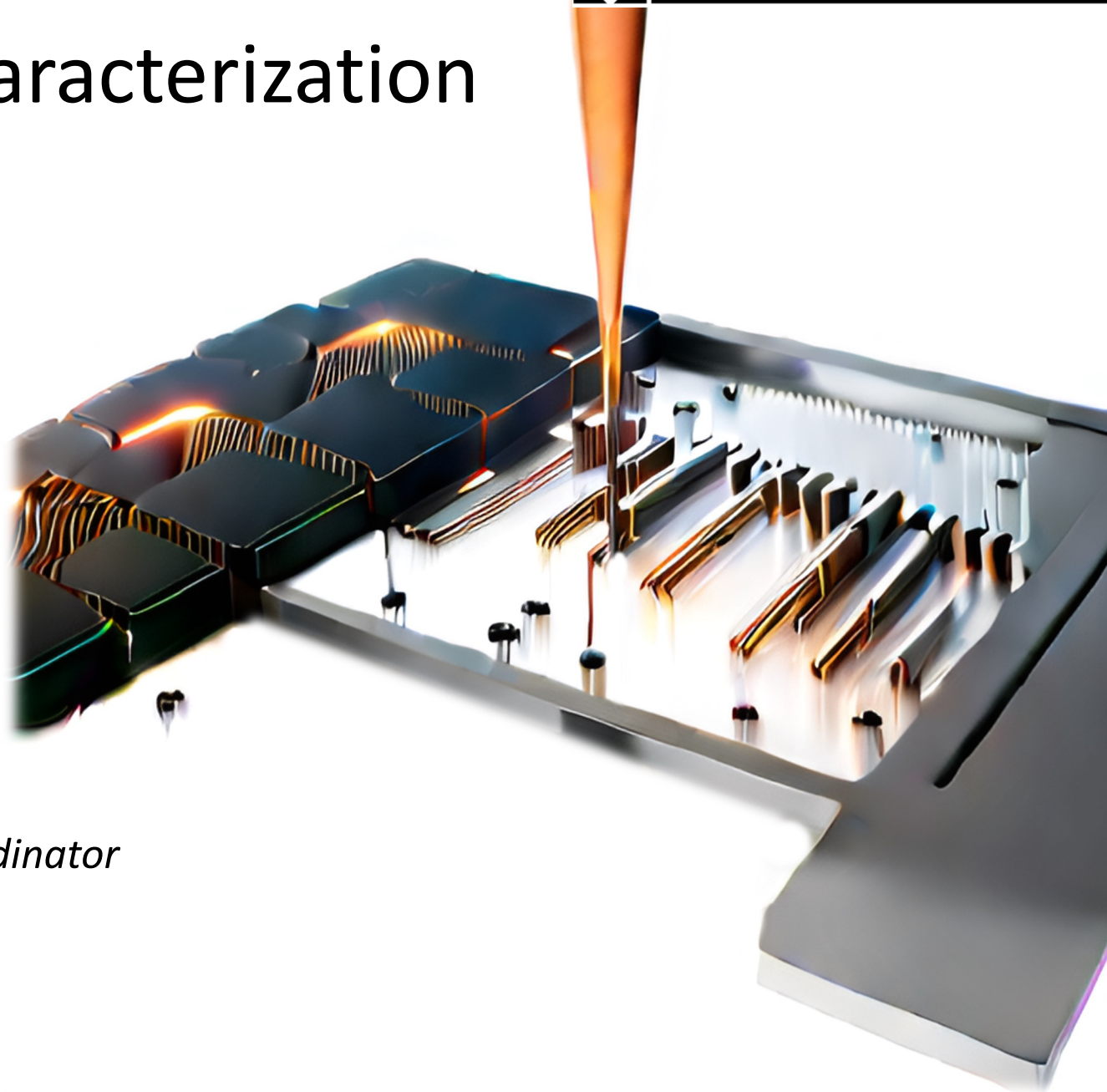
68320 Nanofabrication and Nanocharacterization Techniques

UNIVERSITY OF TECHNOLOGY SYDNEY



Lecture 1
Introduction

Lecturer & Subject Coordinator

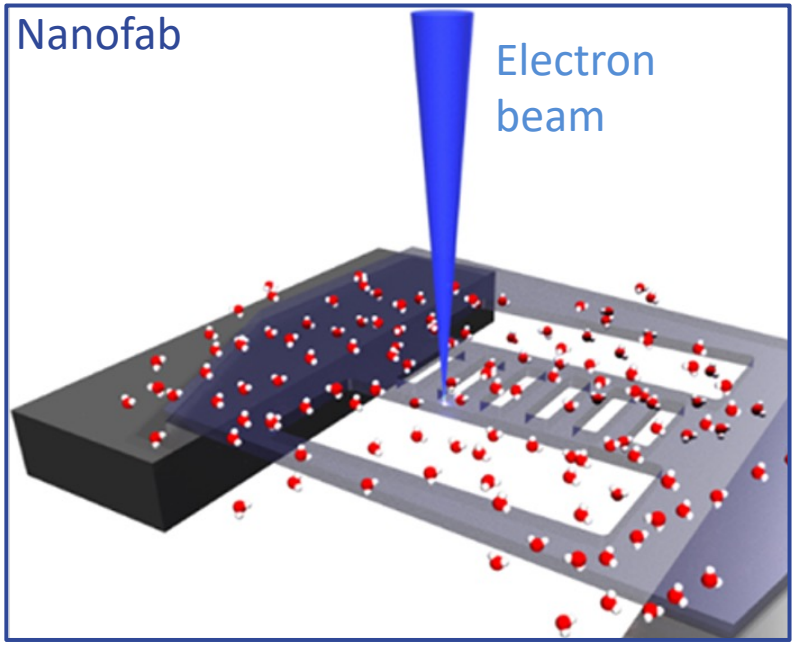
Prof Milos Toth
milos.toth@uts.edu.au

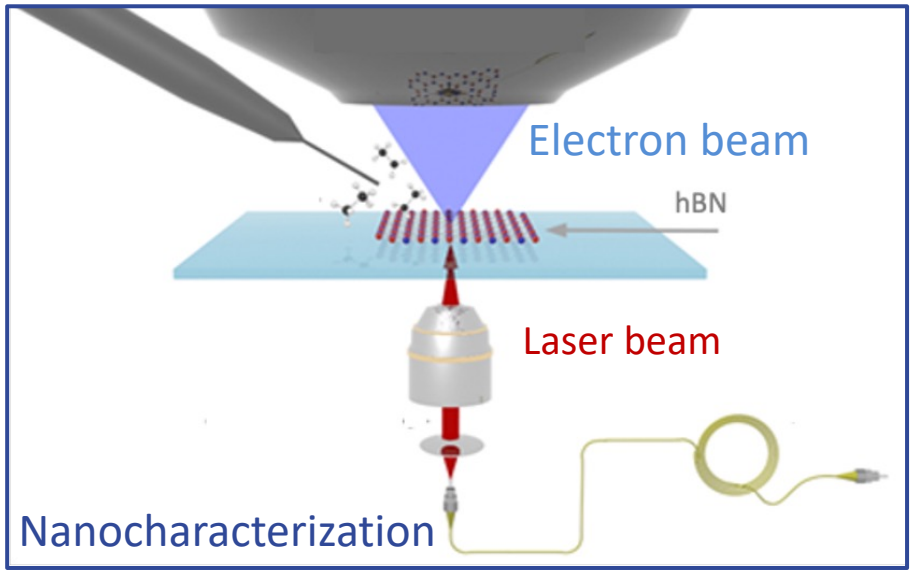
Brief introduction to electron, ion and laser beam techniques:

imaging, analysis and nanofabrication

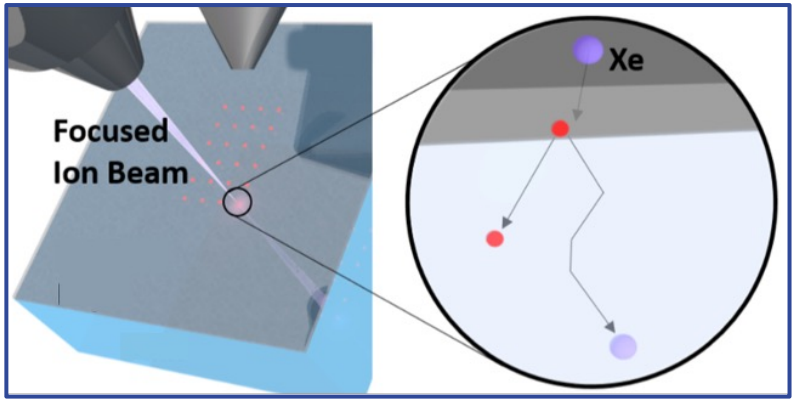
Overview

3D printing on the nanoscale





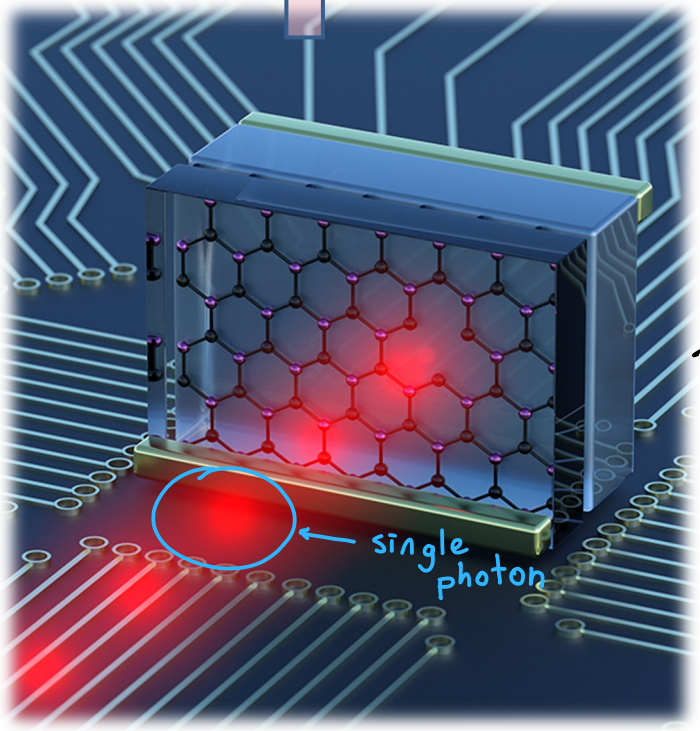
light emitting diode



Material processing: Optical doping

Uncertainty Principle

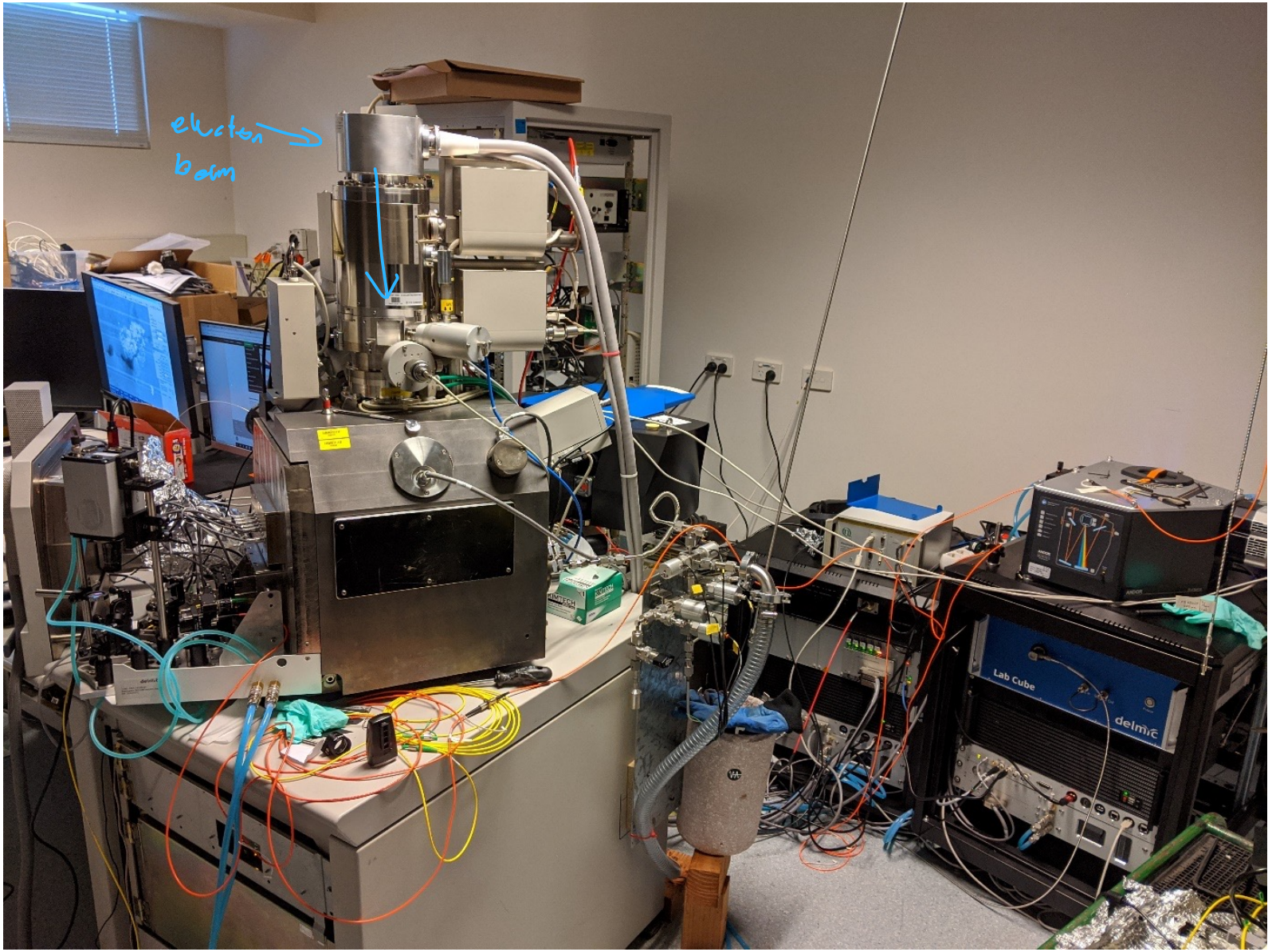
- position & momentum
- energy & time
- limited by size



quantum technologies based on quantum interference

Lab: SEM, FIB, CL, PL

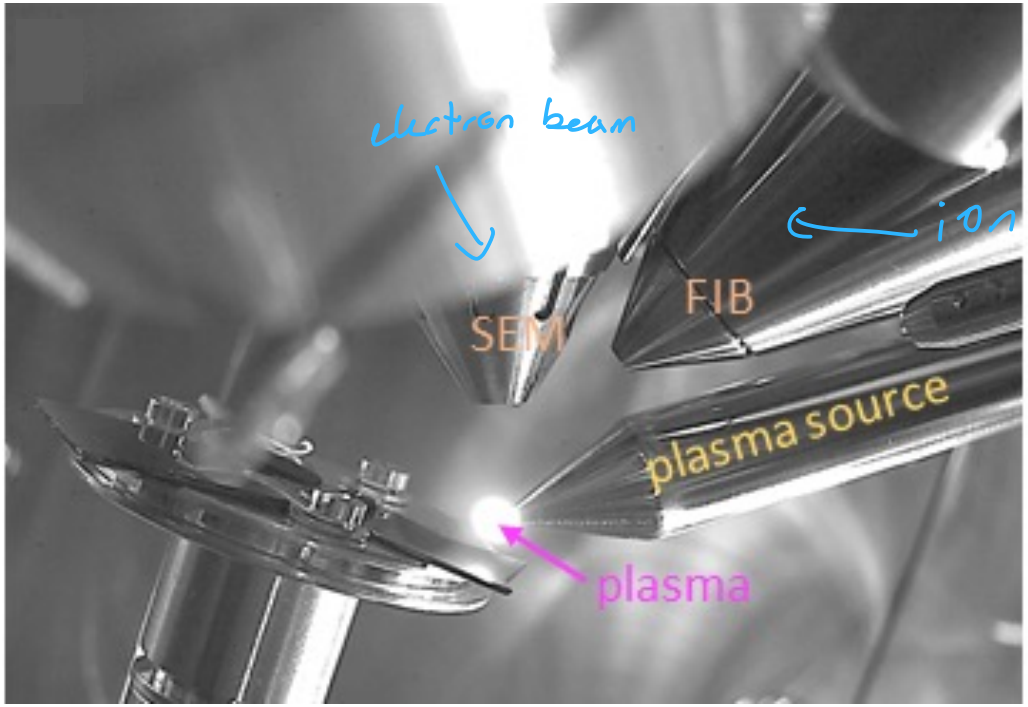
CHATGPT is unreliable!

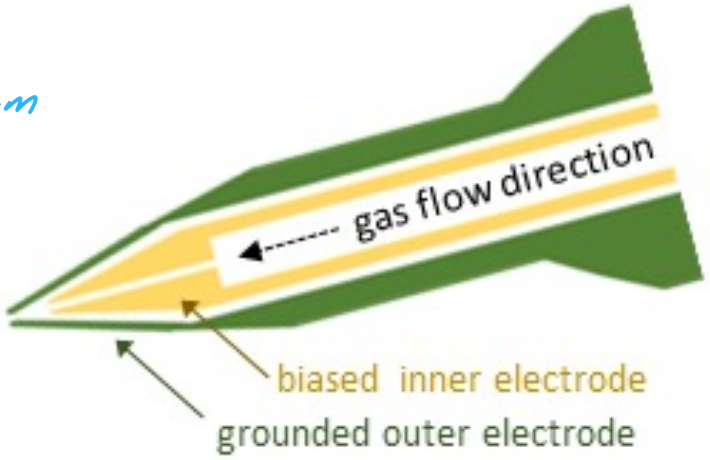


Lab: Inside one of these microscopes

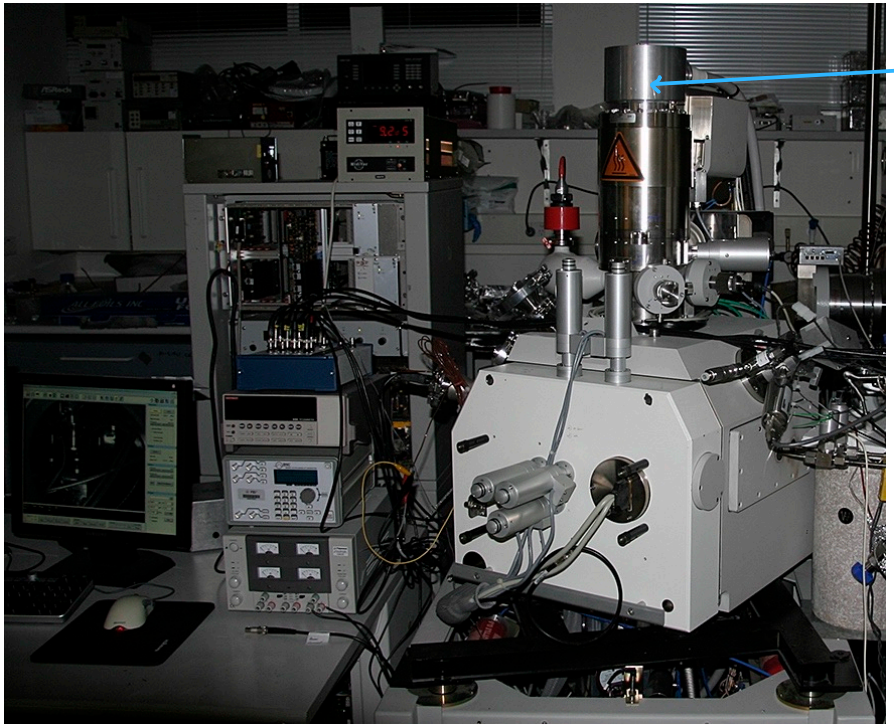
scattering: bumps into particles in the air
- mass
- charge > causes interaction

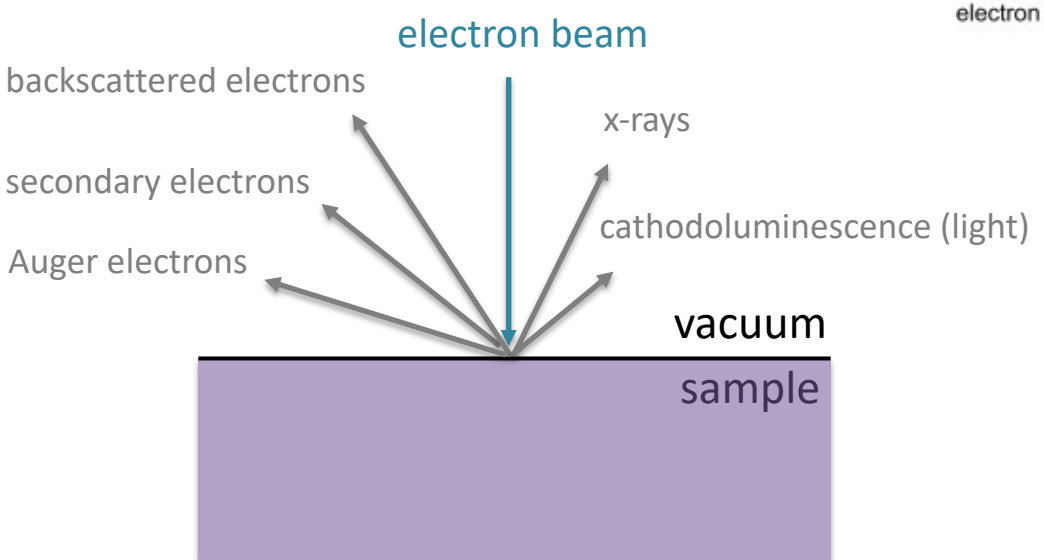
This is under vacuum

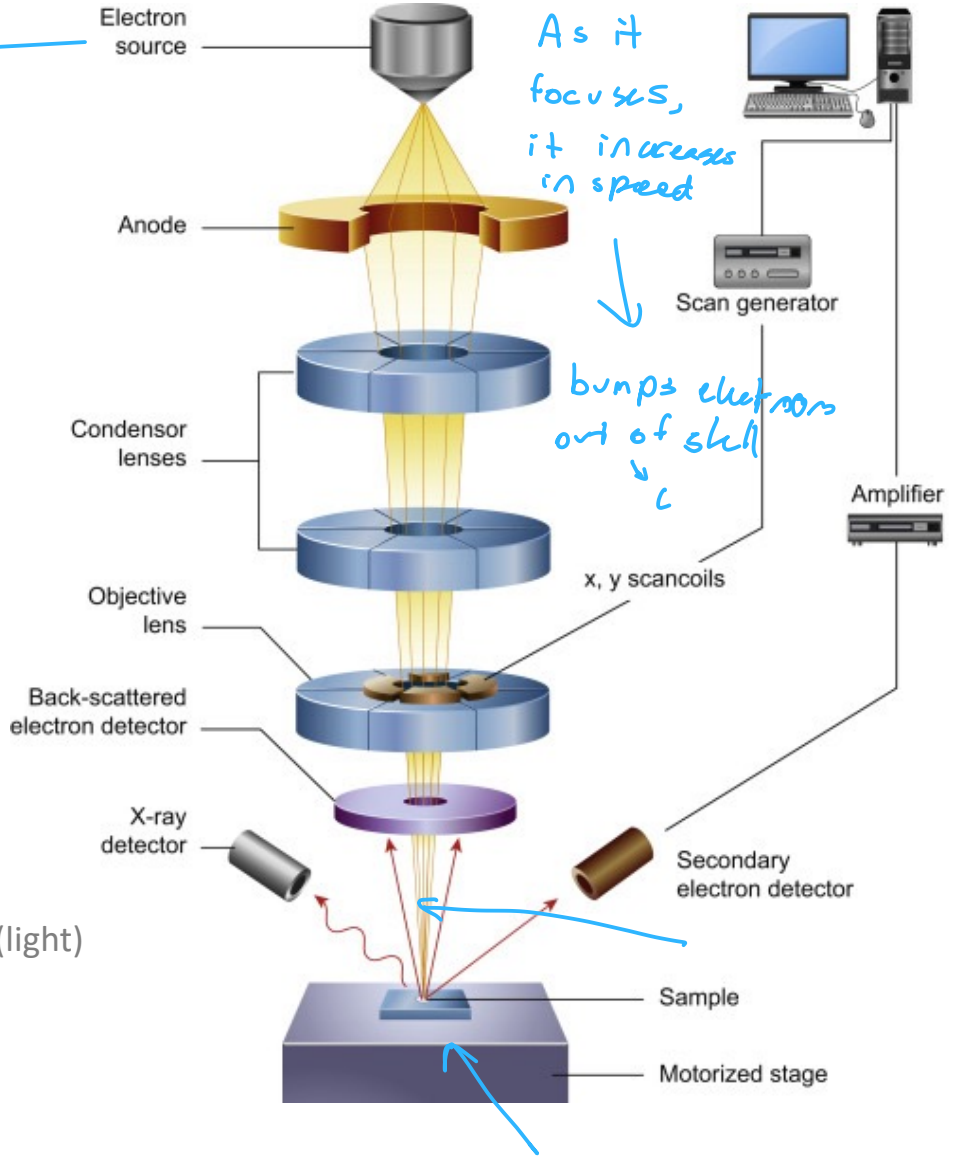




Intro: Scanning electron microscope





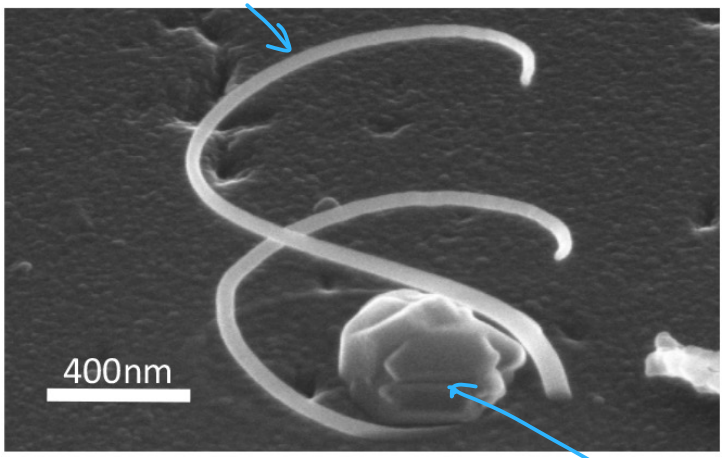


Intro: SEM image formation

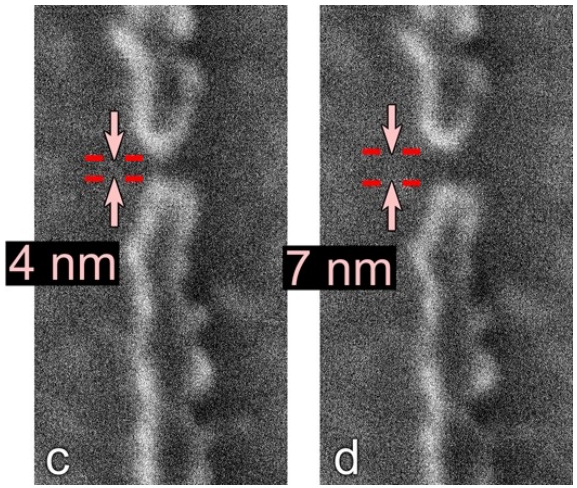
↳ scanning Electron Microscope

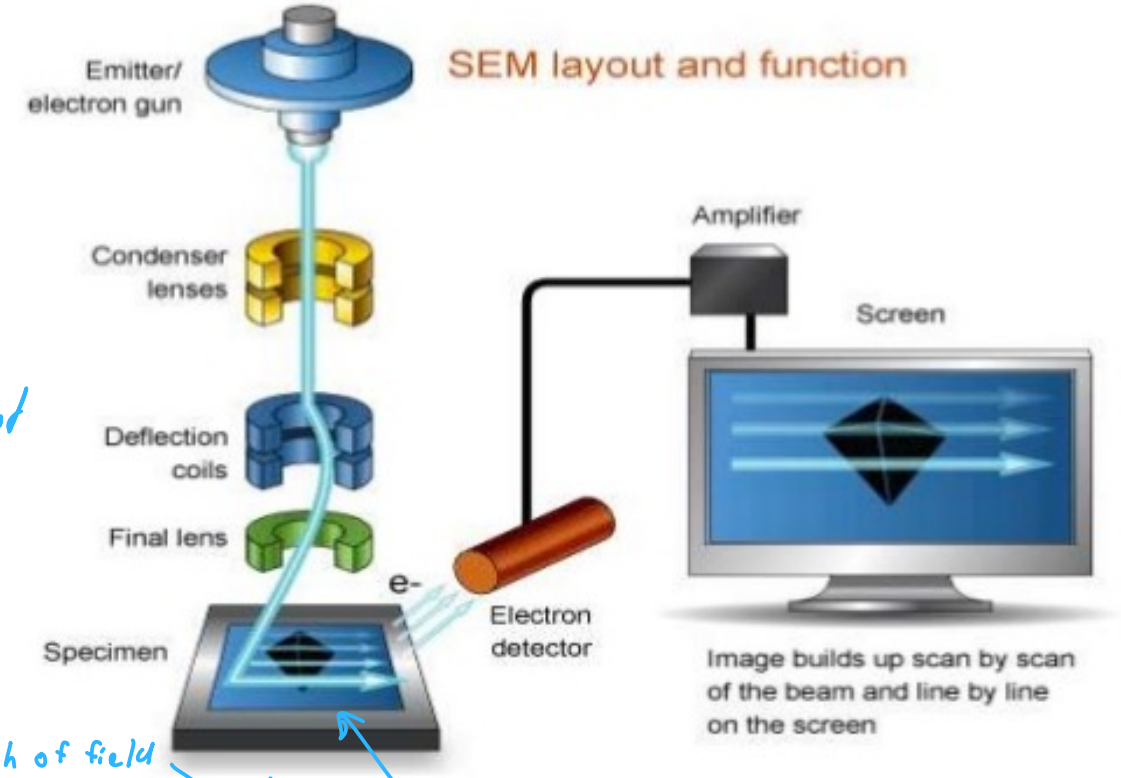
secondary electron images

metallic nano antenas



diamond



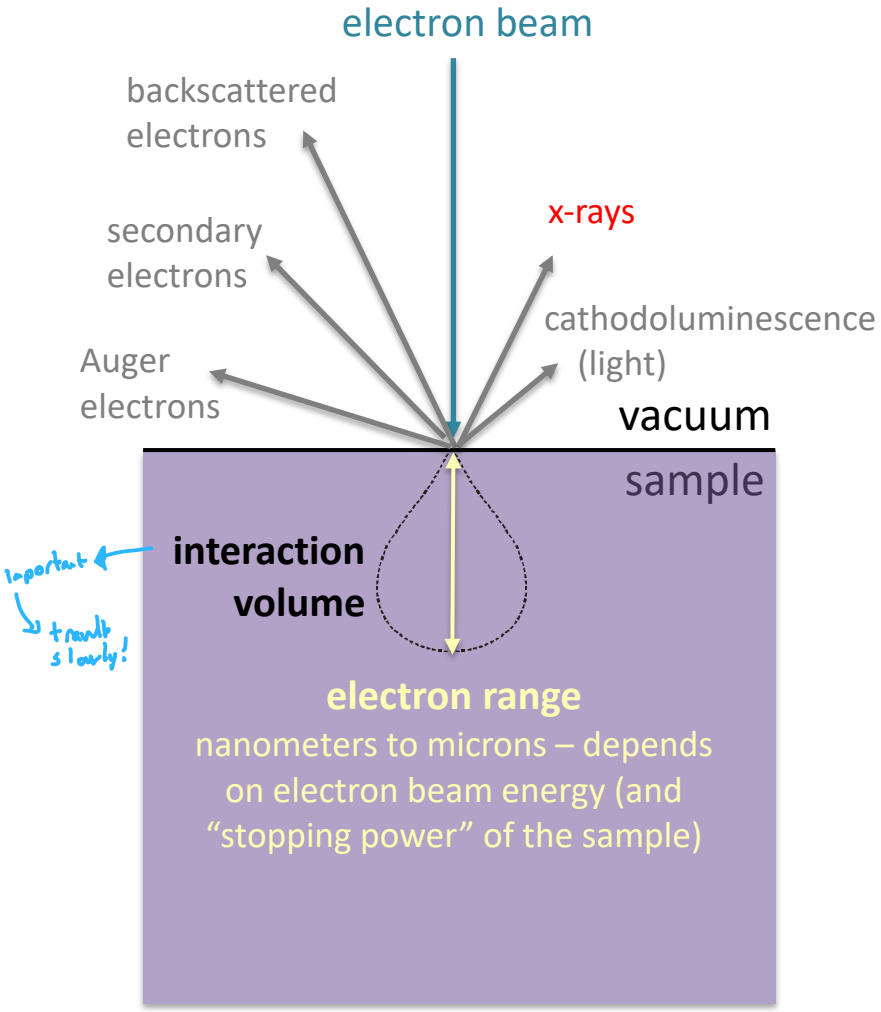


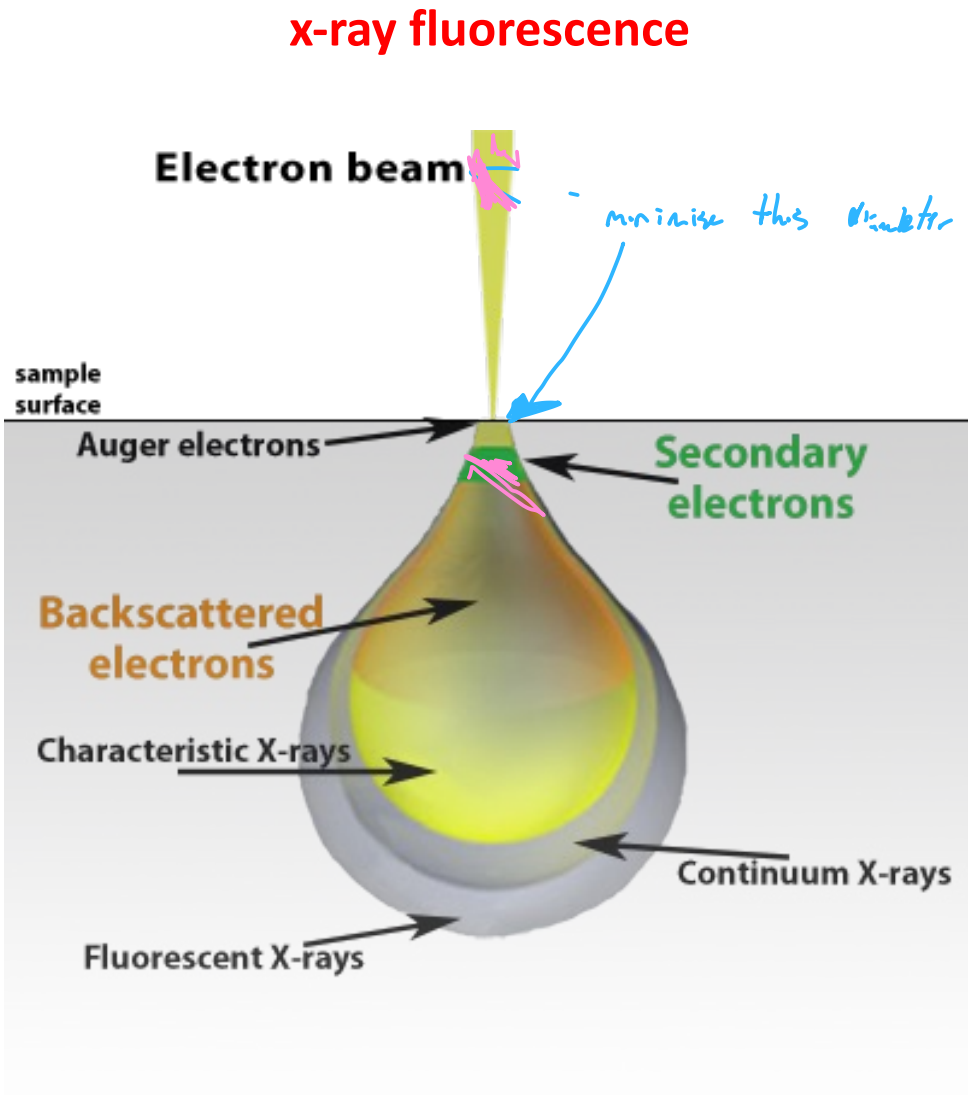
- depth of field
- resolution
- contrast
- signal to noise ratio

→ determined by emerging angles

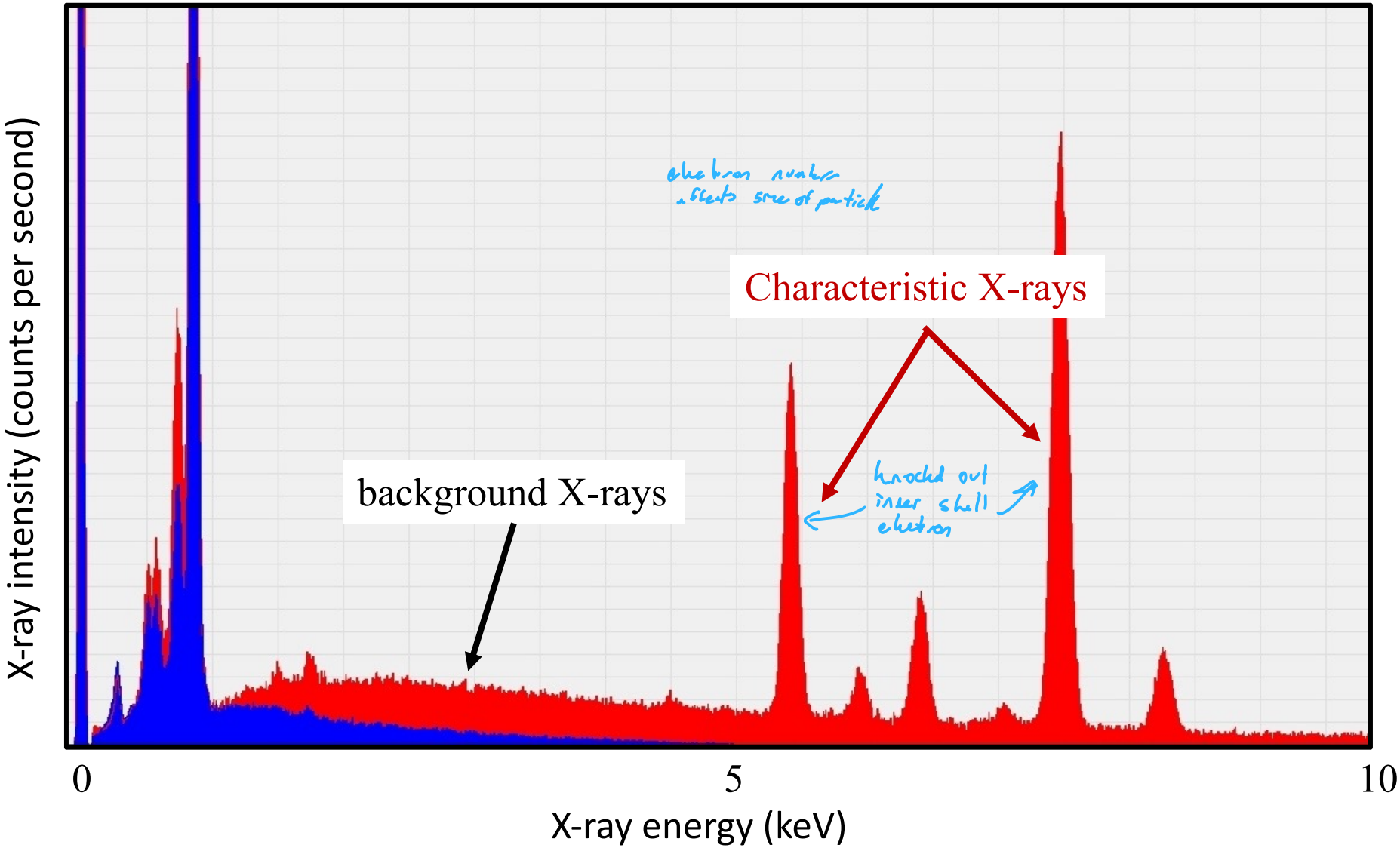
correct toground to replace the electrons being knocked out by the electron beam

SEM: imaging/analysis signals



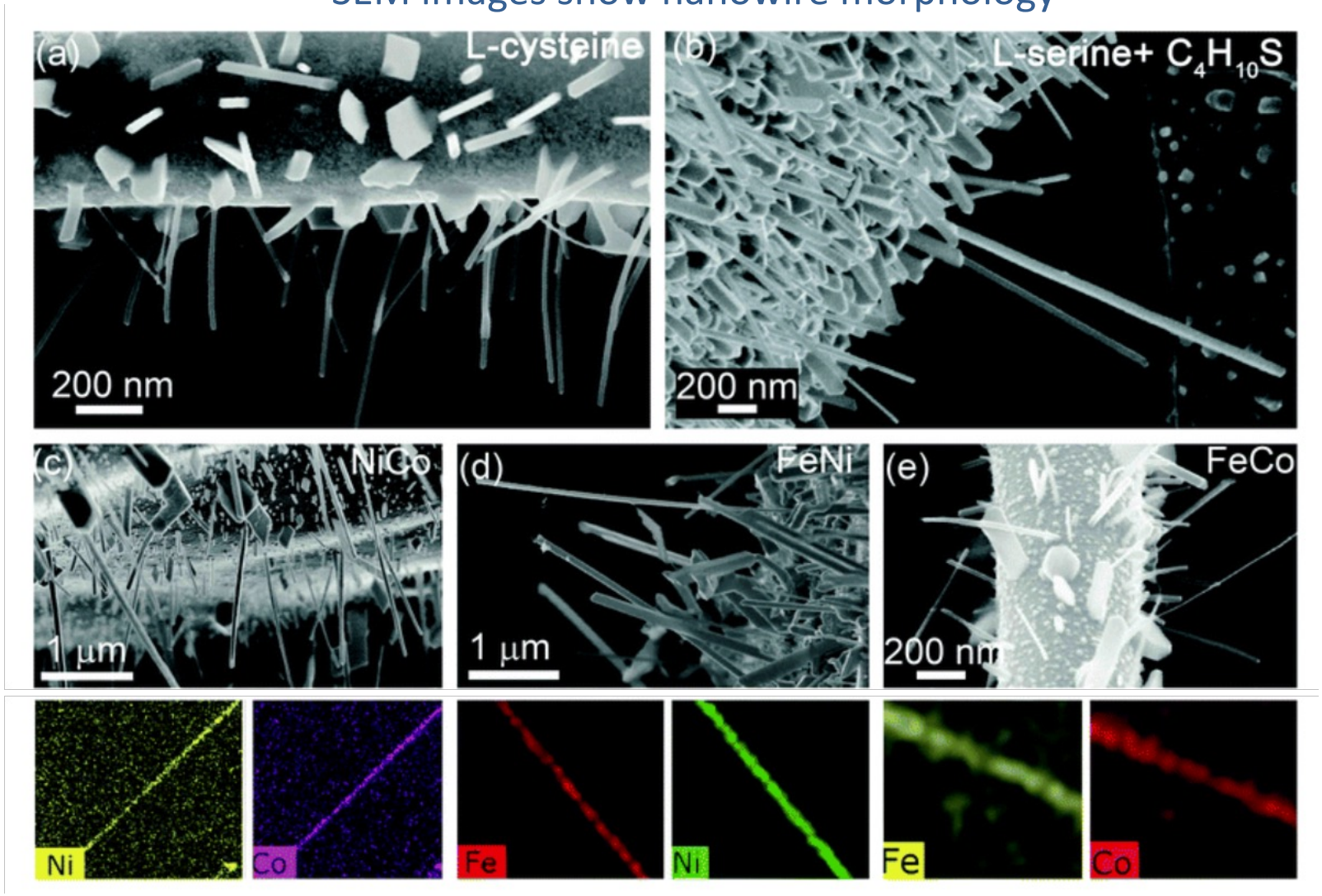


X-ray fluorescence: Spectroscopy



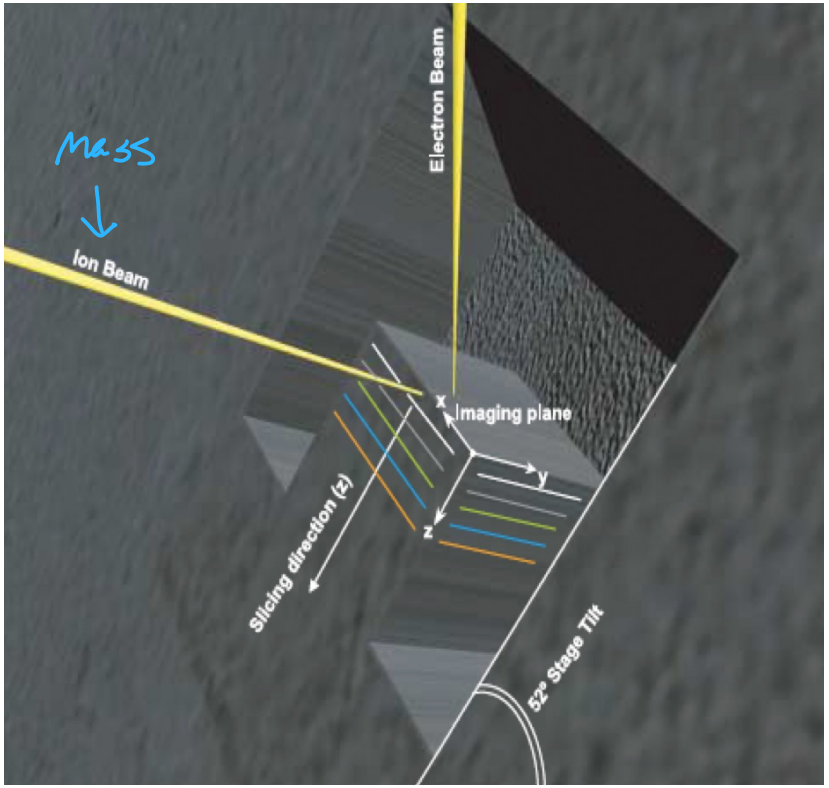
X-ray imaging (of nanowires)

SEM images show nanowire morphology

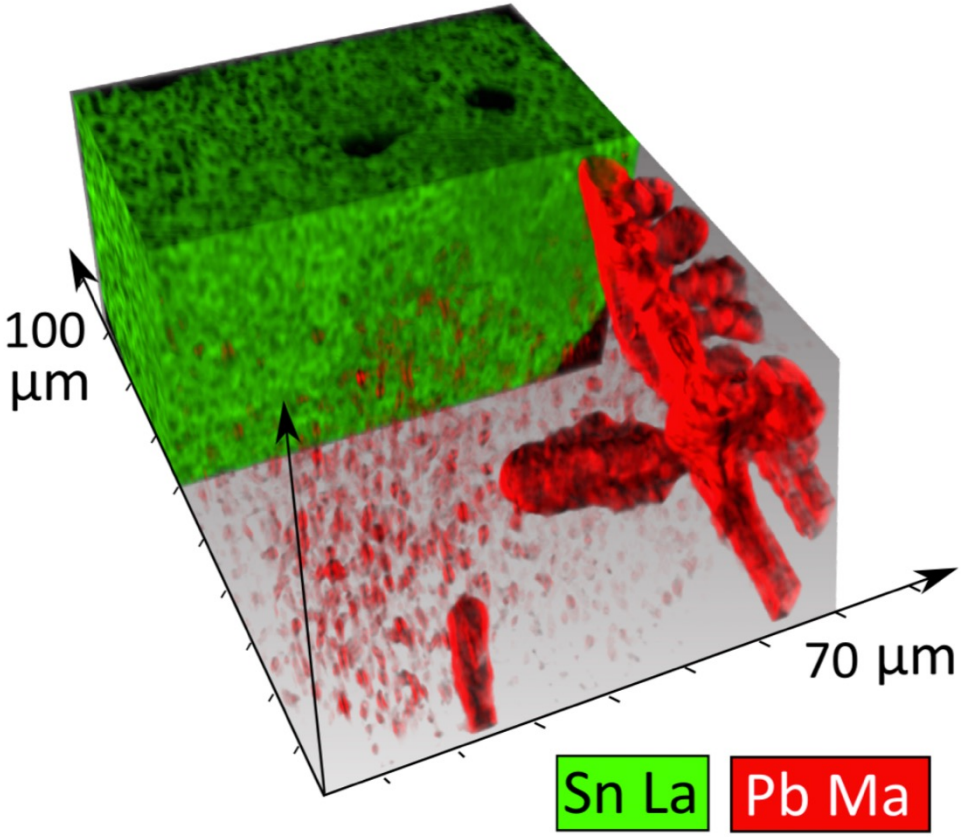


X-ray maps reveal elemental composition of individual nanowires

3D SEM & x-ray analysis: Focused ion beam (FIB) microscopy

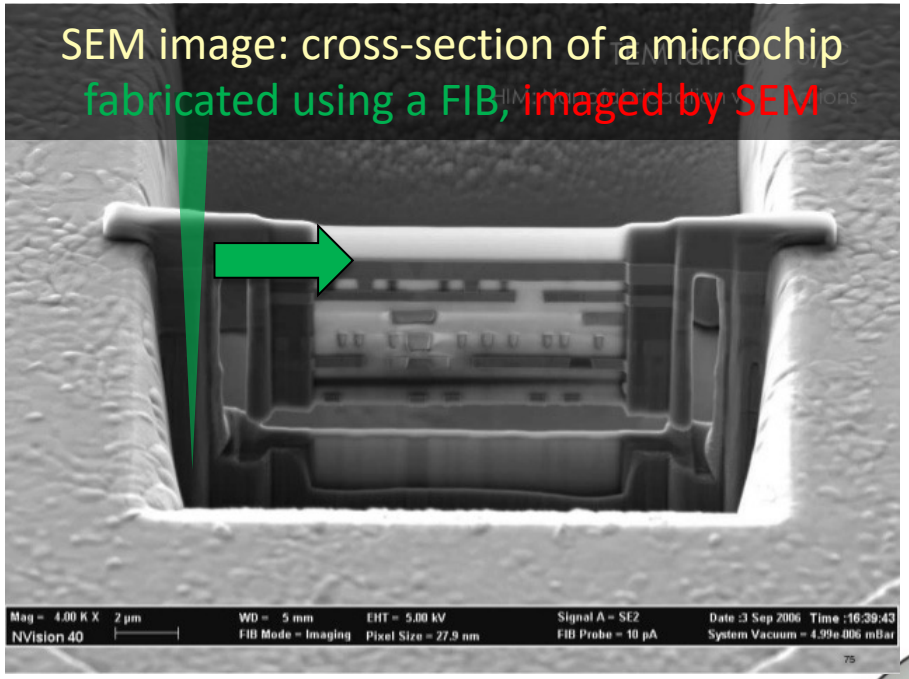


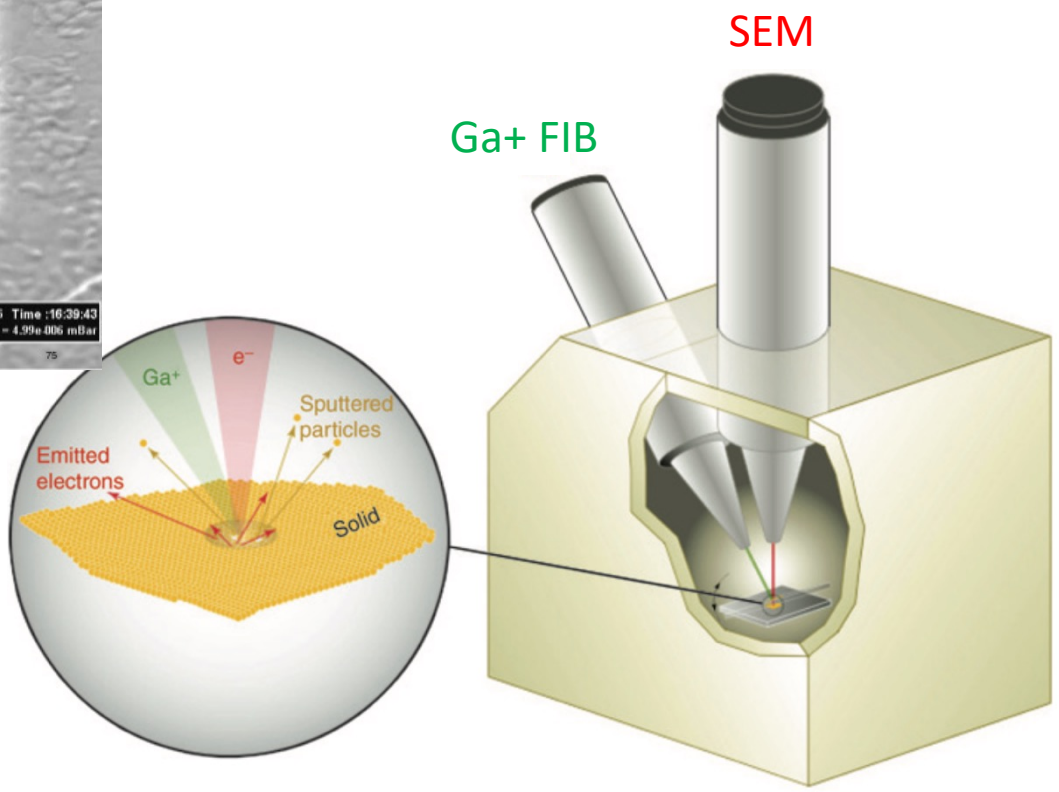
L. HOLZER, et al., *Journal of Microscopy Vol. 216, Pt 1 October 2004, pp. 84–95*



3D EDS reconstruction of $Sn_{60}Pb_{40}$ solder (TESCAN)

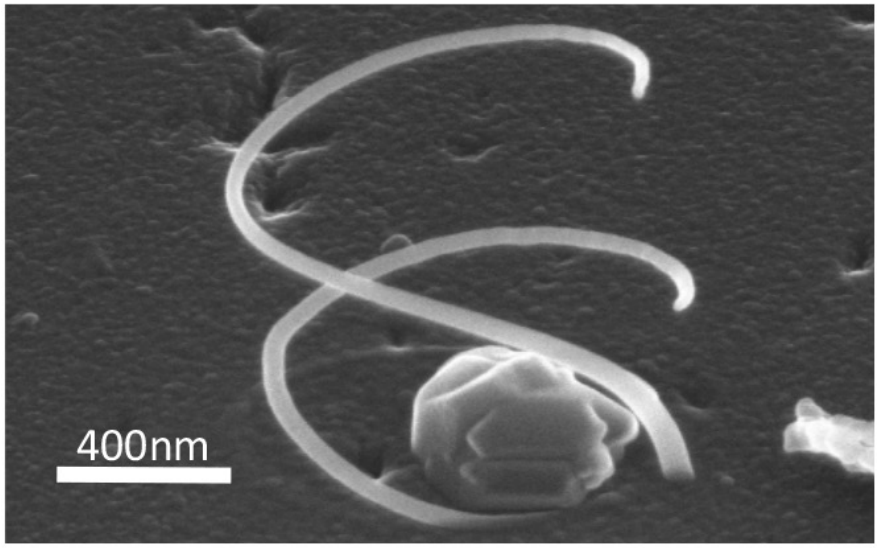
SEM of cross-sections fabricated using a focused ion beam (FIB)

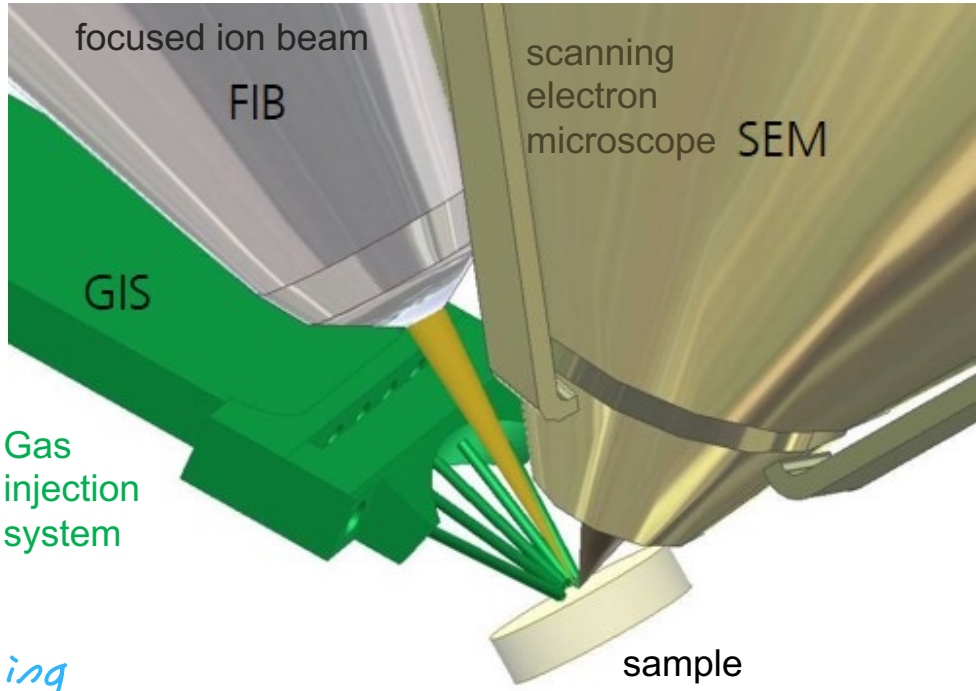


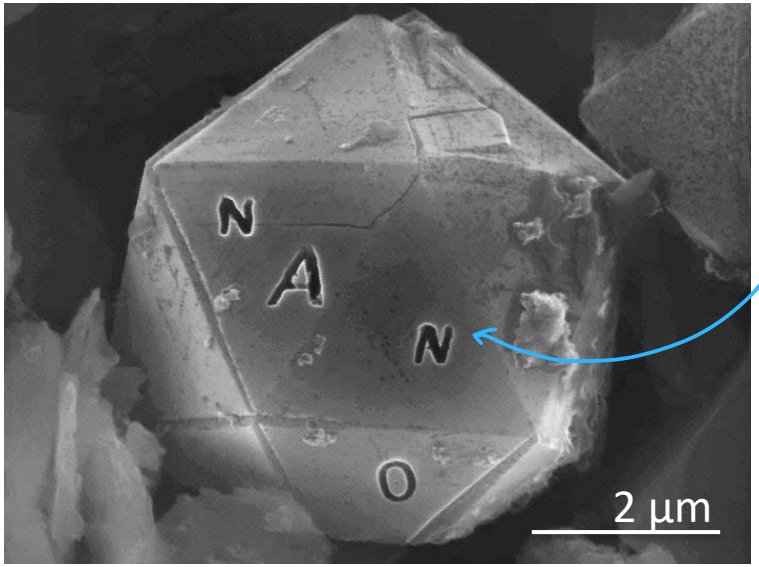


Gas-assisted nanofabrication

3D spirals grown by a (slowly) scanned electron beam







Etching

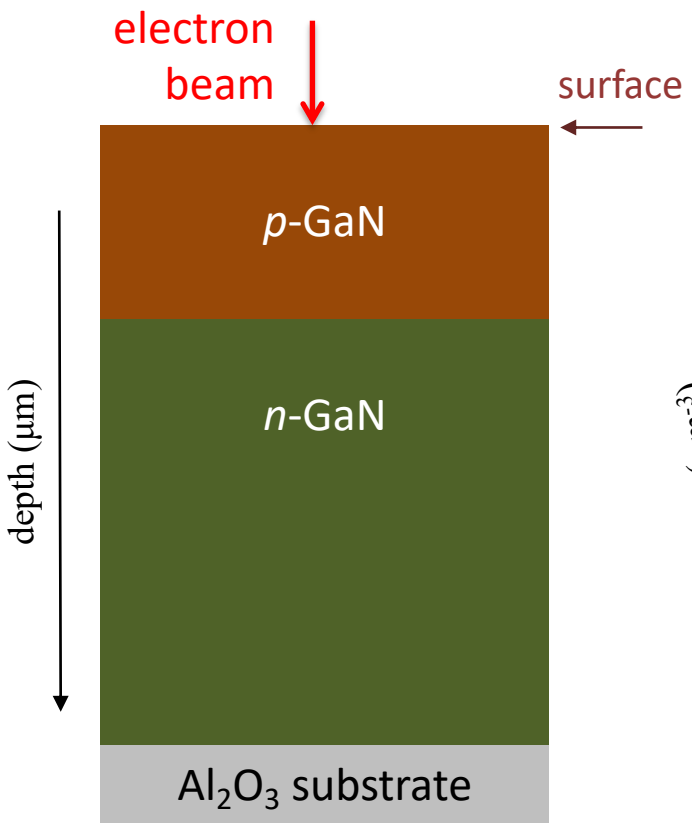
"NANO" etched into a microdiamond by an electron beam

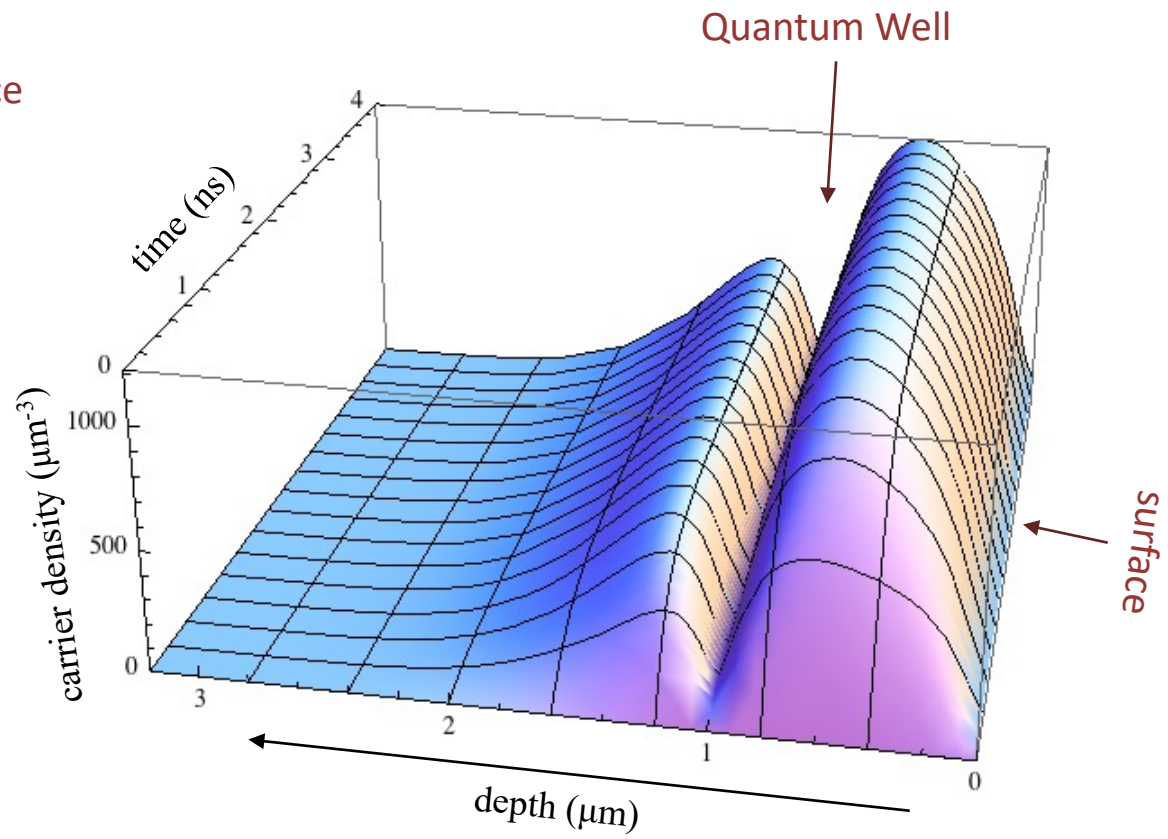
Example of physics that we will cover

SEM & CL: rate of change of concentration of free carriers *vs* depth (z) & time (t)

generation recombination diffusion

$$\frac{\partial n}{\partial t}(t,z) = \frac{E_0(1-\eta)}{E_{eh}} \frac{1}{\Lambda_1} \frac{\partial \Lambda}{\partial z} f - n \sum_i k_i + D_n \frac{\partial^2 n}{\partial z^2}$$

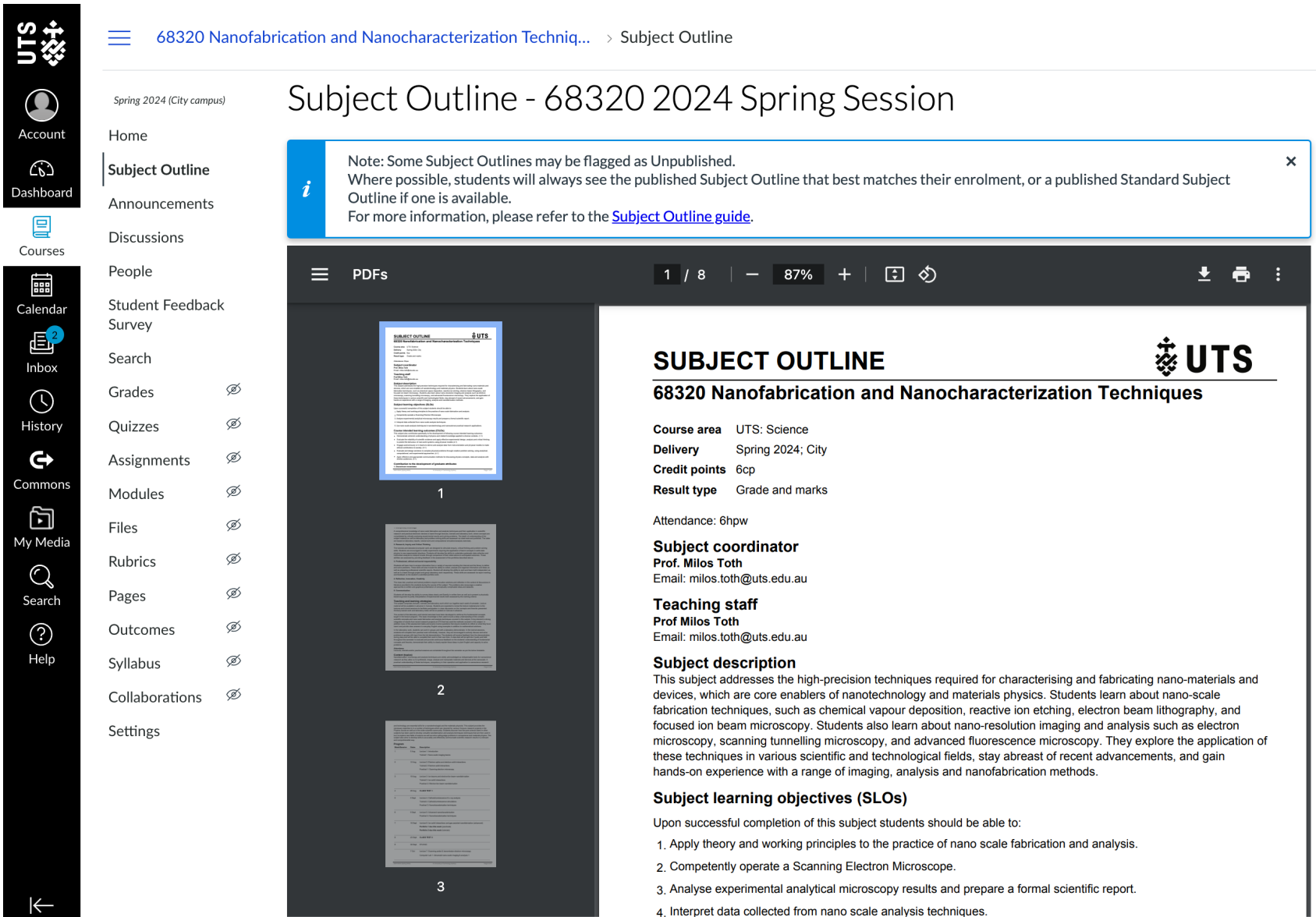




End of “brief introduction”/teaser

Calendar/timetable/assessments

Subject Outline → Canvas



Calendar/timetable

weeks 1 – 9

Lectures
Tues 9 AM [CB05D.03.014]

Tutes & class tests
Tues 12 PM
[CB04.04.331_341]

Labs
Thurs 1 PM
[CB04.02.310]

"MAU lab", corner of Harris & Thomas St, building 4, street-level, opposite the gym]

close book

this is a revision lecture still in the tutorials

• Multiple choice / must get 50%

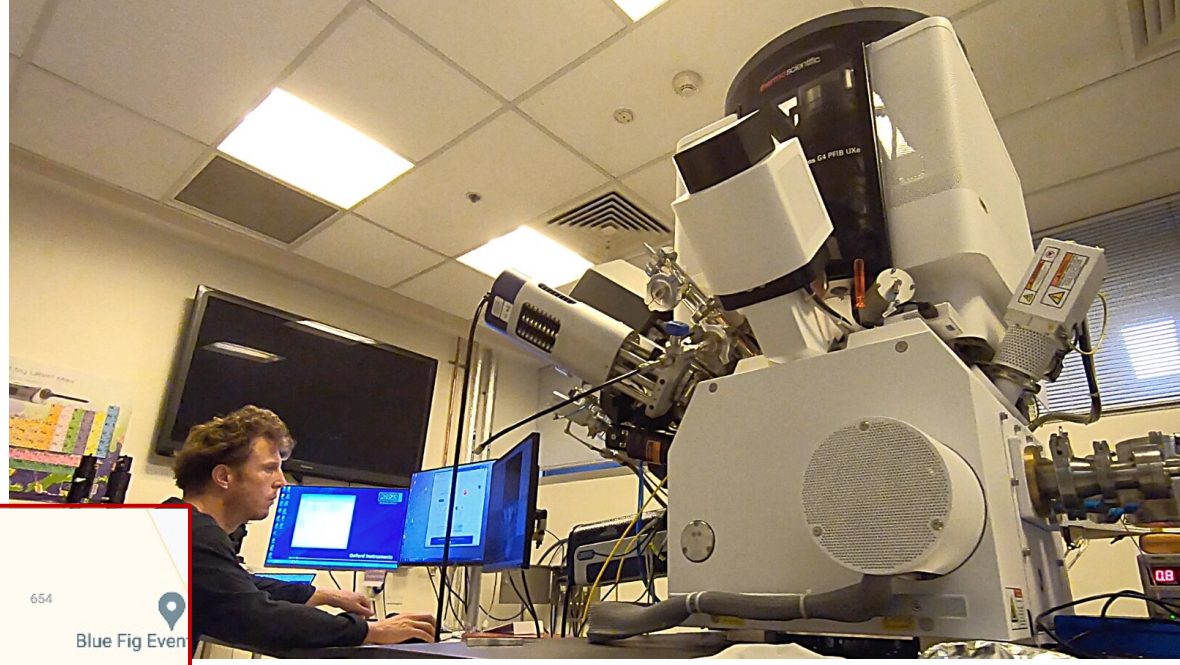
Program

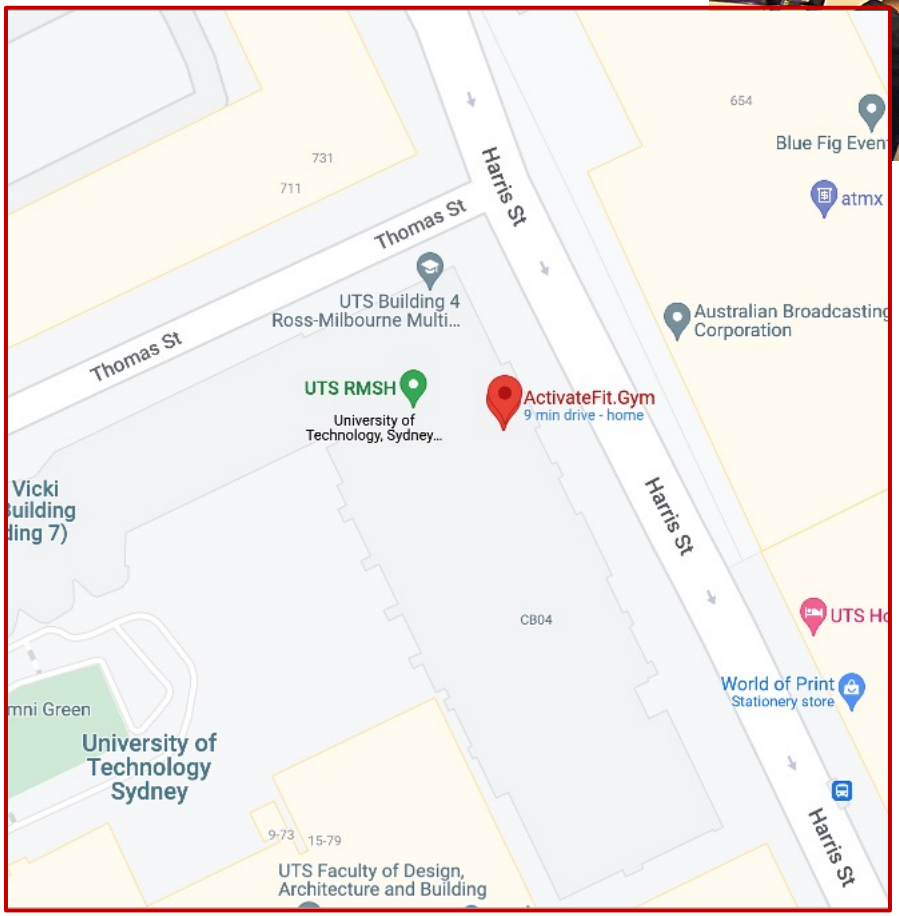
Week/Session	Dates	Description
1	5 Aug	Lecture 1: Introduction Tutorial 1: Nano-scale imaging basics
2	12 Aug	Lecture 2: Electron optics and electron-solid interactions Tutorial 2: Electron-solid interactions Practical 1: Scanning electron microscopy
3	19 Aug	Lecture 3: Ion beams and electron/ion beam nanofabrication Tutorial 3: Ion-solid interactions Practical 2: Electron/ion beam nanofabrication
4	26 Aug	**CLASS TEST 1**
5	2 Sept	Lecture 4: Cathodoluminescence & x-ray analysis Tutorial 4: Cathodoluminescence simulations Practical 3: Nanocharacterisation techniques
6	9 Sept	Lecture 5: Advanced nanocharacterisation Practical 4: Nanocharacterisation techniques
7	16 Sept	Lecture 6: Ion-solid interactions and gas-assisted nanofabrication (advanced) **Portfolio 1 due this week** (practicals) **Portfolio 2 due this week** (tutorials)
8	23 Sept	**CLASS TEST 2**
9	30 Sept	STUVAC

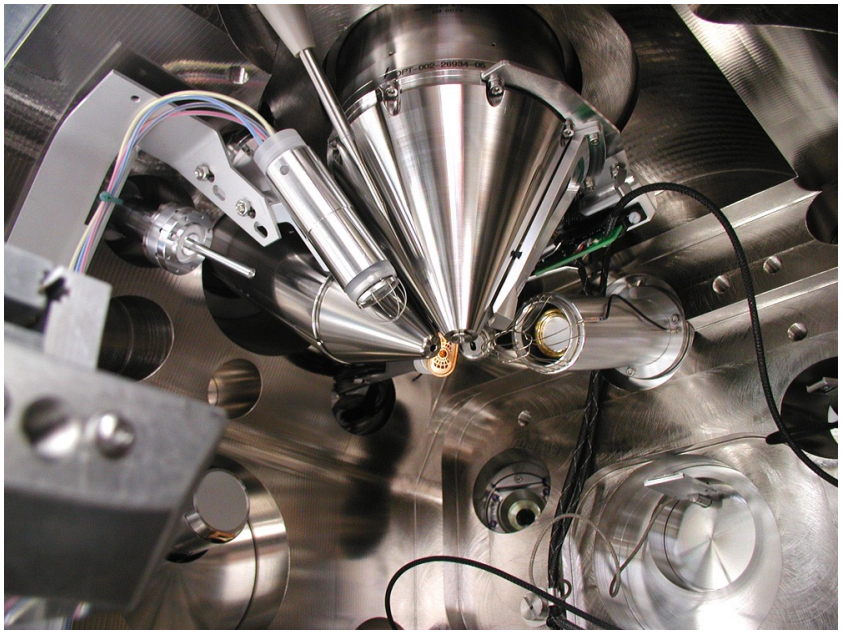
NOTE: tutes and labs are on some weeks, but not every week, as shown here

Labs

CB04.02.310
Corner of Harris & Thomas St
Near the UTS gym



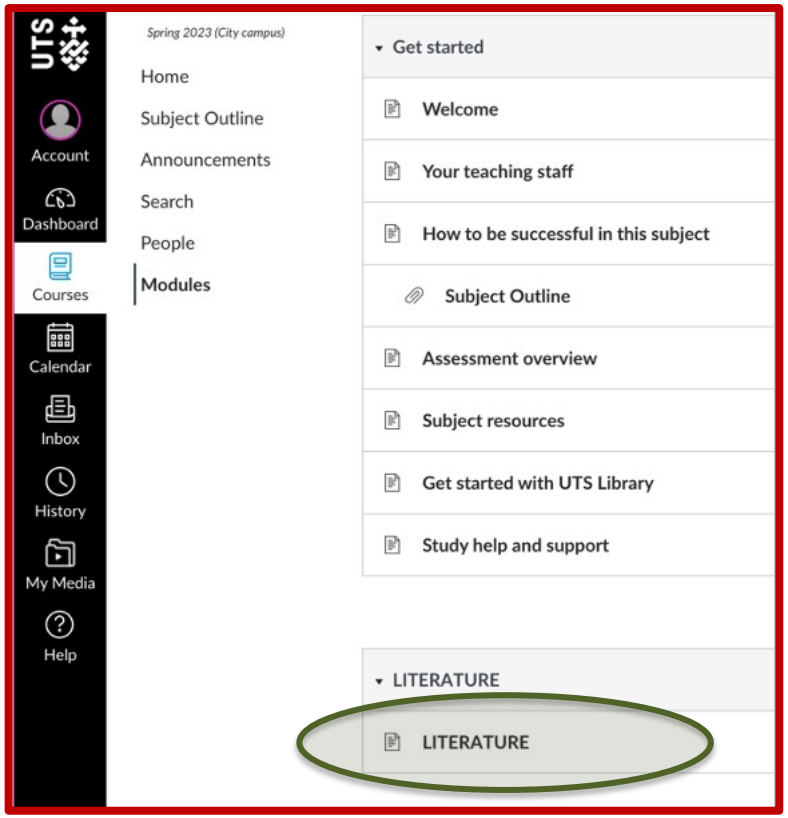


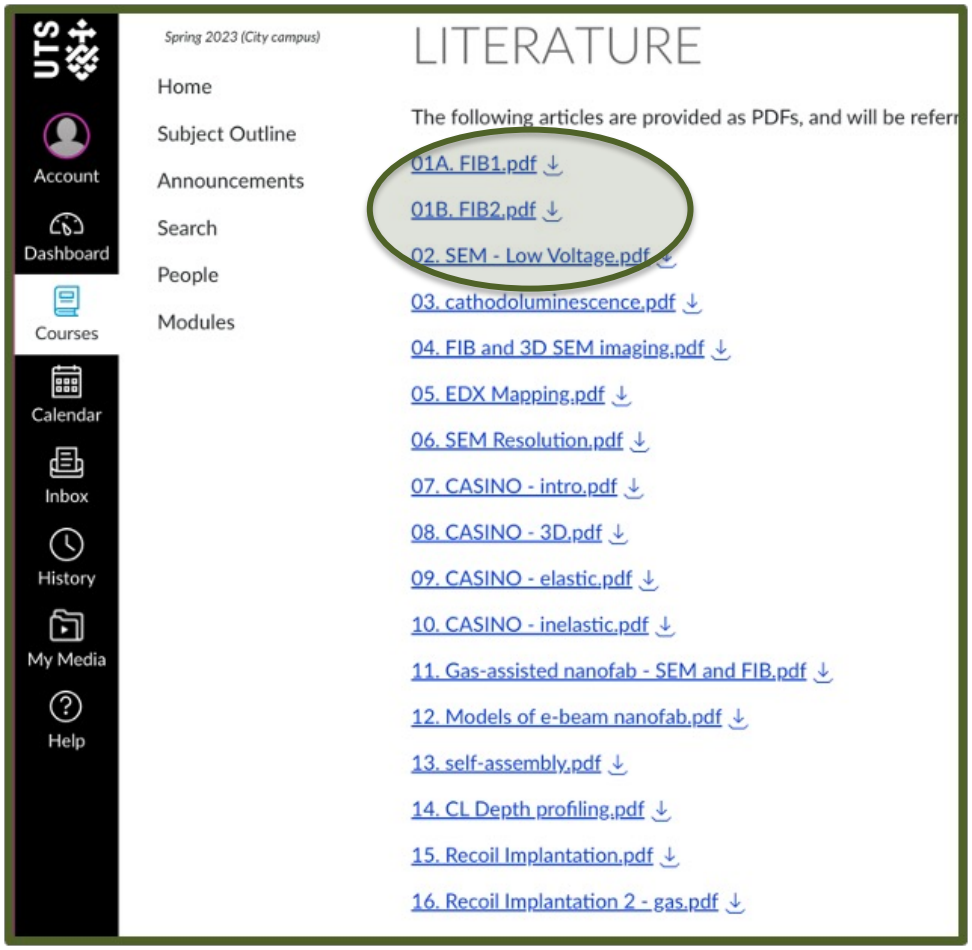


Reading material

- Read up to introduction
  - Email
  - Ask questions
  - Will be refered to in lectures

Start with these 3 papers





Assessments

- 50% for Practical and Tutorial Work submitted in the form of **3 portfolios** throughout the semester
- 50% for Class Tests held on 3 dates throughout semester

The best way to prepare is to attend lectures and participate in discussions – I will ask many questions that are representative of what will be in the tests.

Tests & Portfolio due dates are in the subject outline.
Reminders will be posted on Canvas.

Assessments: Portfolios (assignments)

Portfolio 1 (16.7%)

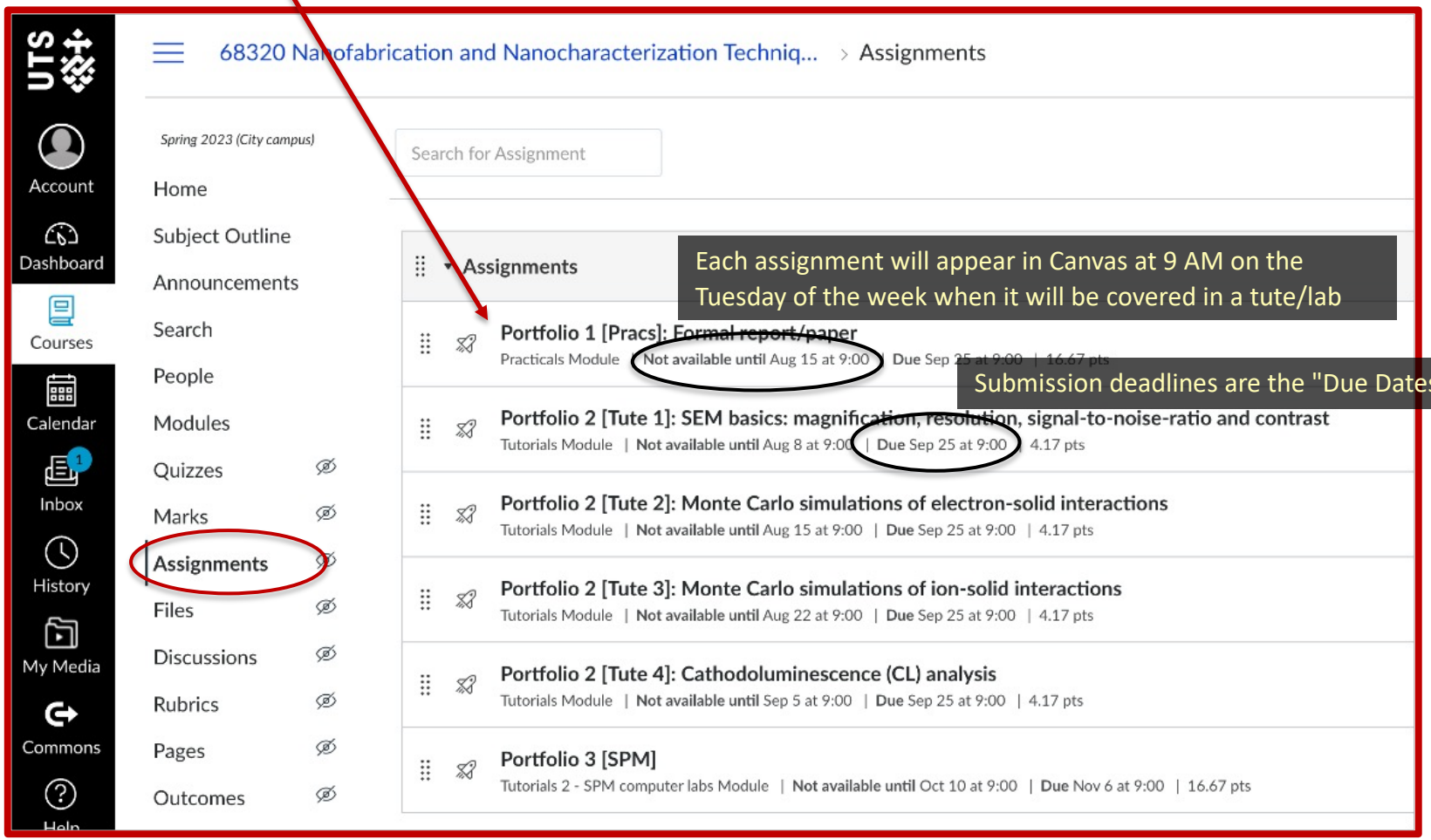
Report based on lab work, written in the style of a scientific research paper (submitted as a PDF file in Canvas).

Portfolio 2 (16.7%)

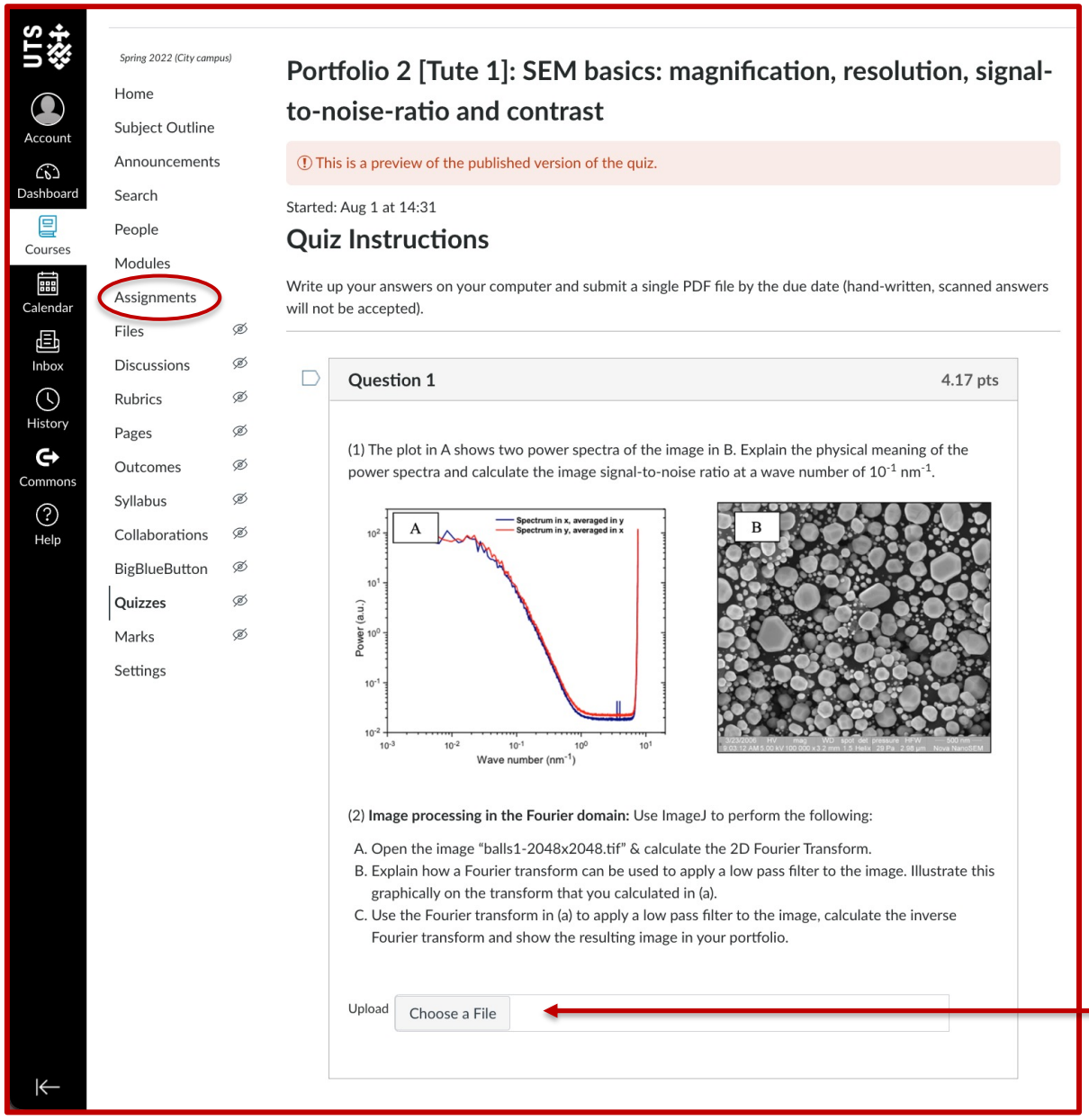
4 assignments in Canvas, each of which covers one tute & is worth 4.17% of your total mark

Portfolio 3 (16.7%)

Assignment in Canvas based on tutes that will be done in the 2nd half of the semester.



Example: Week 1: Portfolio 2, Tute 1



Typed on word

↳ upload as PDF

Type your answers and submit it as a PDF file in Canvas by the due date (see previous slide).

Photos of hand-written answers will not be accepted.

Software

Subject resources and equipment

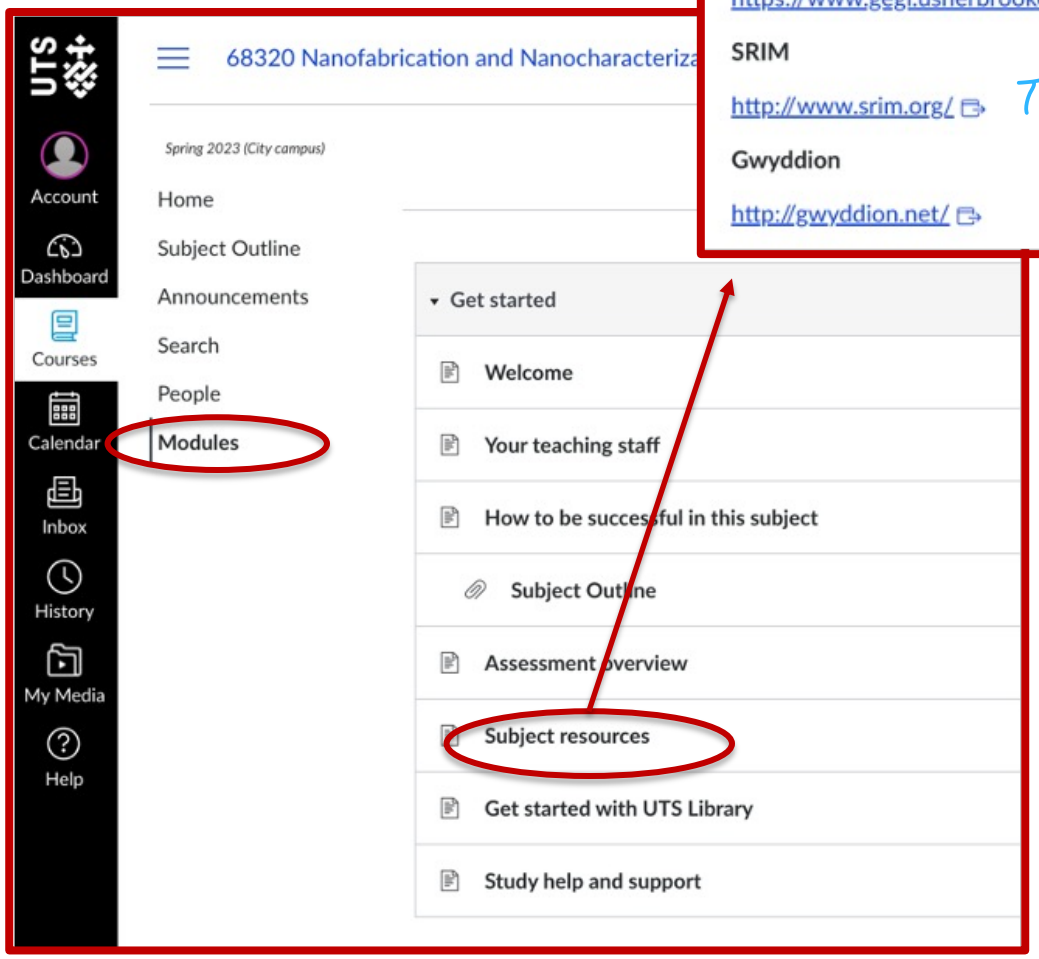
Some specialised (free) software packages will be used in the tutorials. These are installed on computers in the room that you will use for tutorials, and you can also install these on your own computers:

ImageJ/FIJI: Tut 1
https://fiji.sc/

CASINO
https://www.gegi.usherbrooke.ca/casino/What.html Tut 2 / Tut 4

SRIM
http://www.srim.org/ Tut 3

Gwyddion
http://gwyddion.net/

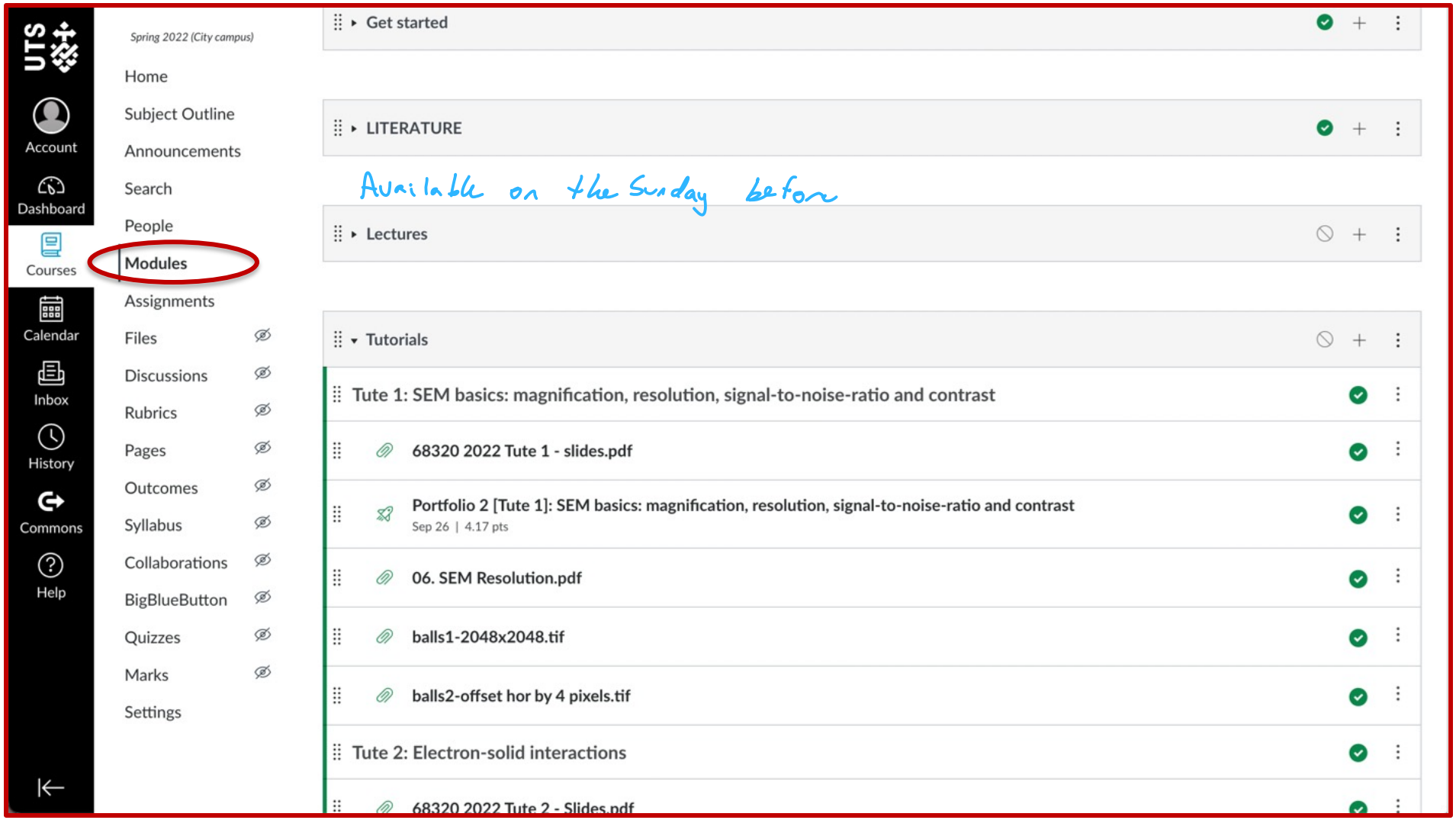


- Software you will use in tutorials.
- It's all free.
- You can install it on your computers or use it on UTS computers in the tutorial sessions.
- Check out the online documentation, YouTube tutorials…

Lecture notes, tutes, pracs

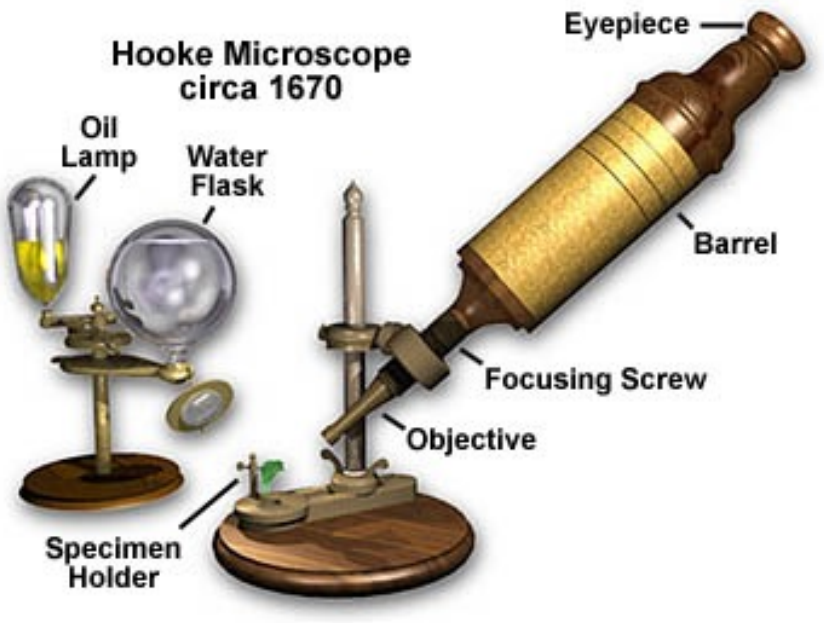
MUST GO TO LECTURES!

…all on Canvas, which will be updated each week



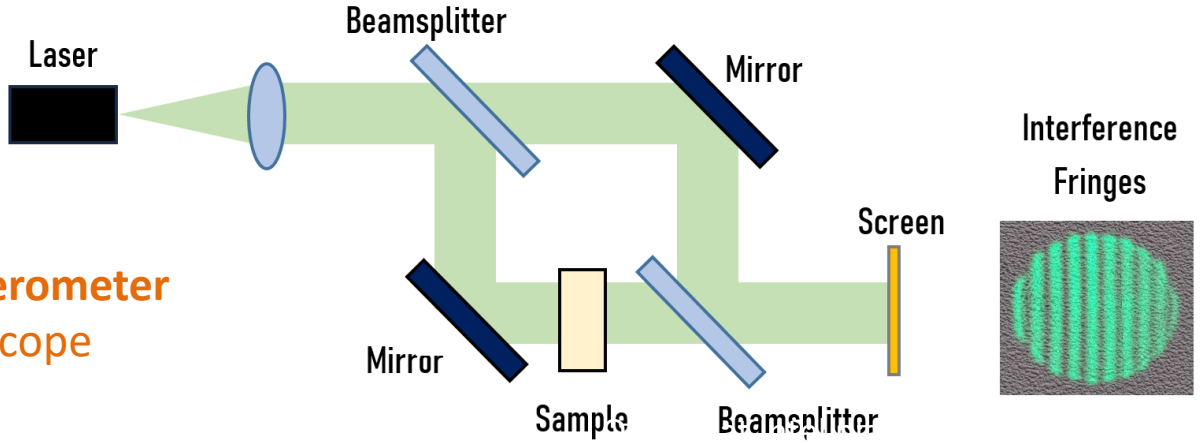
Microscopy

First Microscope (magnification ~270x)

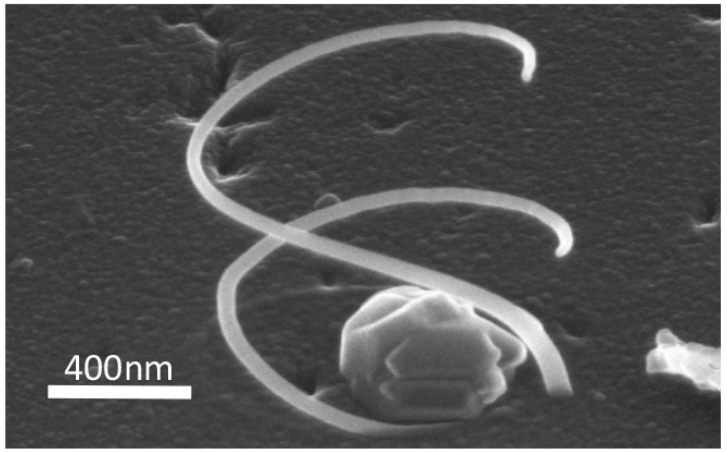


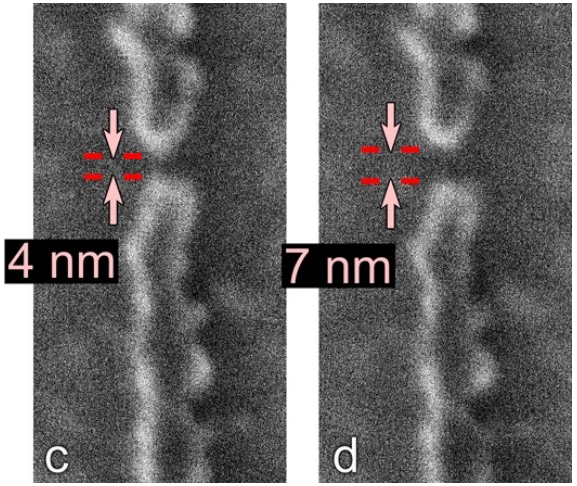
Transmission electron microscope
(magnification >10,000,000x)

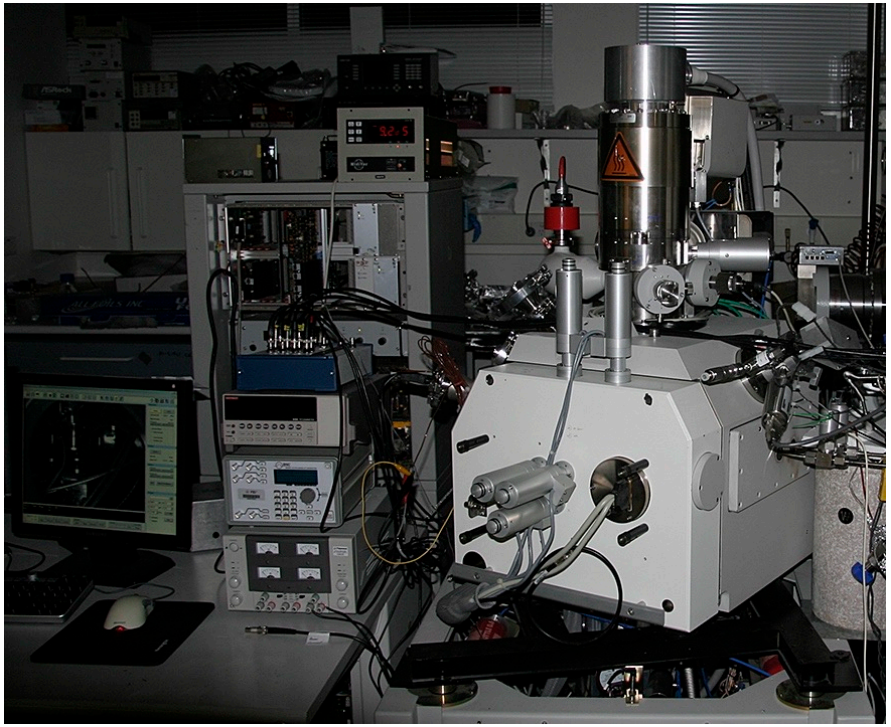
Mach-Zehnder interferometer
phase contrast microscope



Scanning electron microscopy







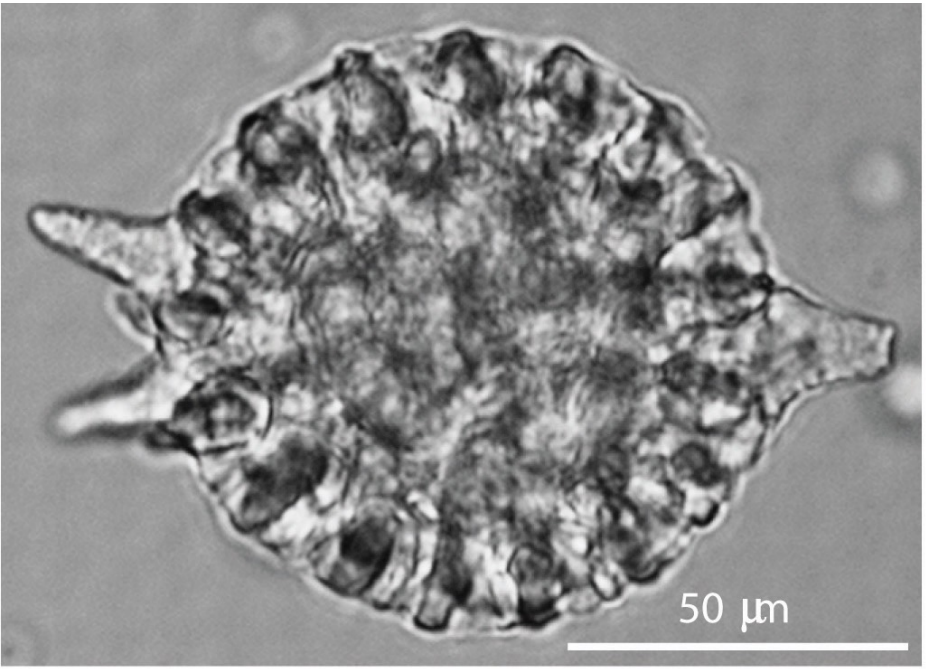
Optical/light vs SEM/electrons

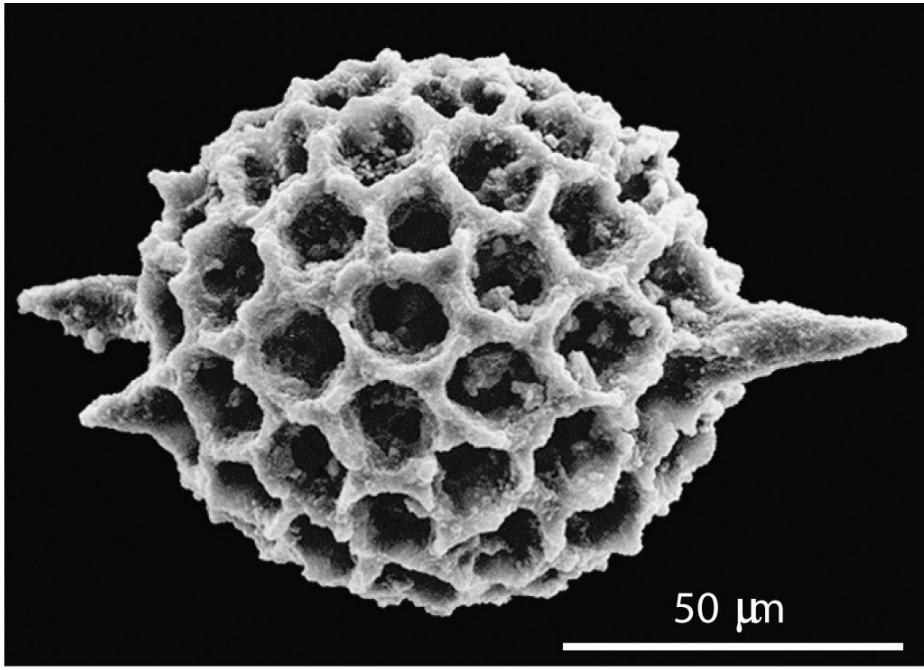
Quantifying: - signal to noise ratio
- contrast
-

Plot in one

Light Microscope

Scanning Electron Microscope (SEM)





(a) Radiolarian under light microscope

low resolution

(b) Radiolarian under electron microscope

high resolution / angle / depth of field

SEM: Improved "spatial detail", sharper edges and contrast, larger depth of field

no depth of field

The Radiolaria, also called Radiozoa, are protozoa of diameter 0.1–0.2 mm that produce intricate mineral skeletons, typically made of silica, and contain a central capsule dividing the cell into the inner and outer portions of endoplasm and ectoplasm.

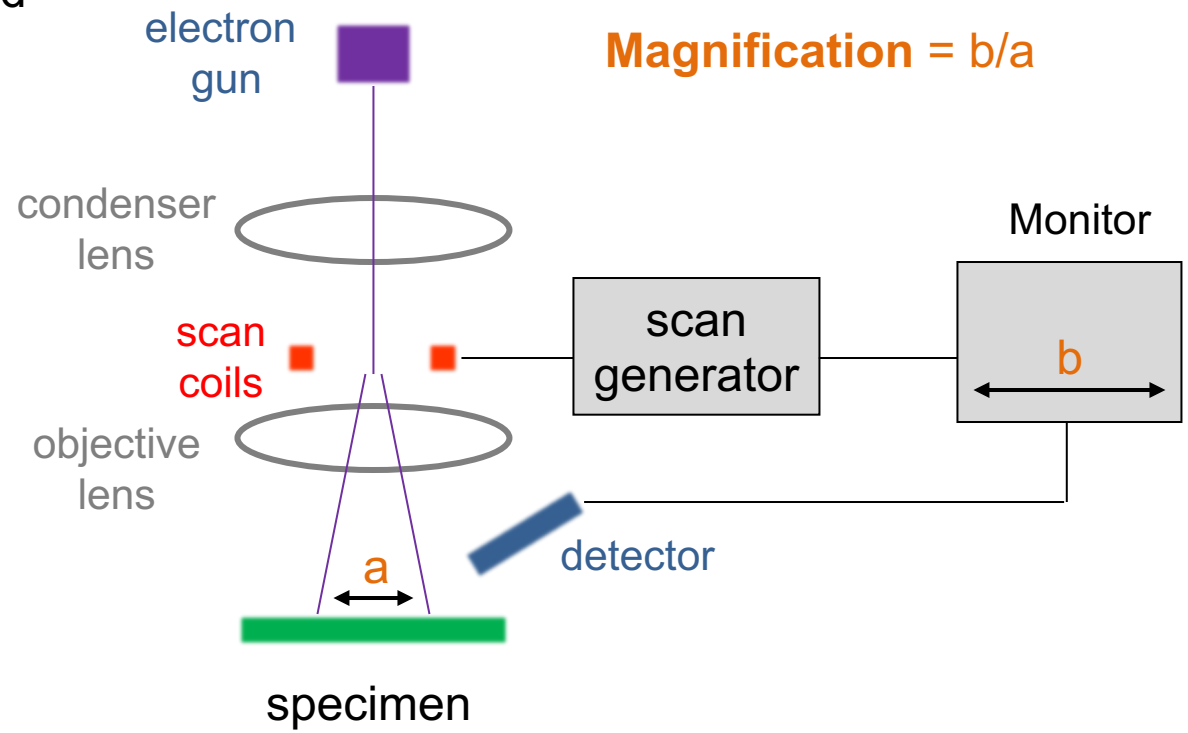
SEM basics & magnification

all SEMs operate by irradiating the specimen with a finely focussed beam of electrons, producing emission signals (SE, BSE, X-ray, etc.) that can be used to form an image

Electron Gun: used to produce electrons, pre-focus beam and accelerate to 1 - 30 keV

Electron Lens: used to provide a focussed, de-magnified spot at the specimen plane

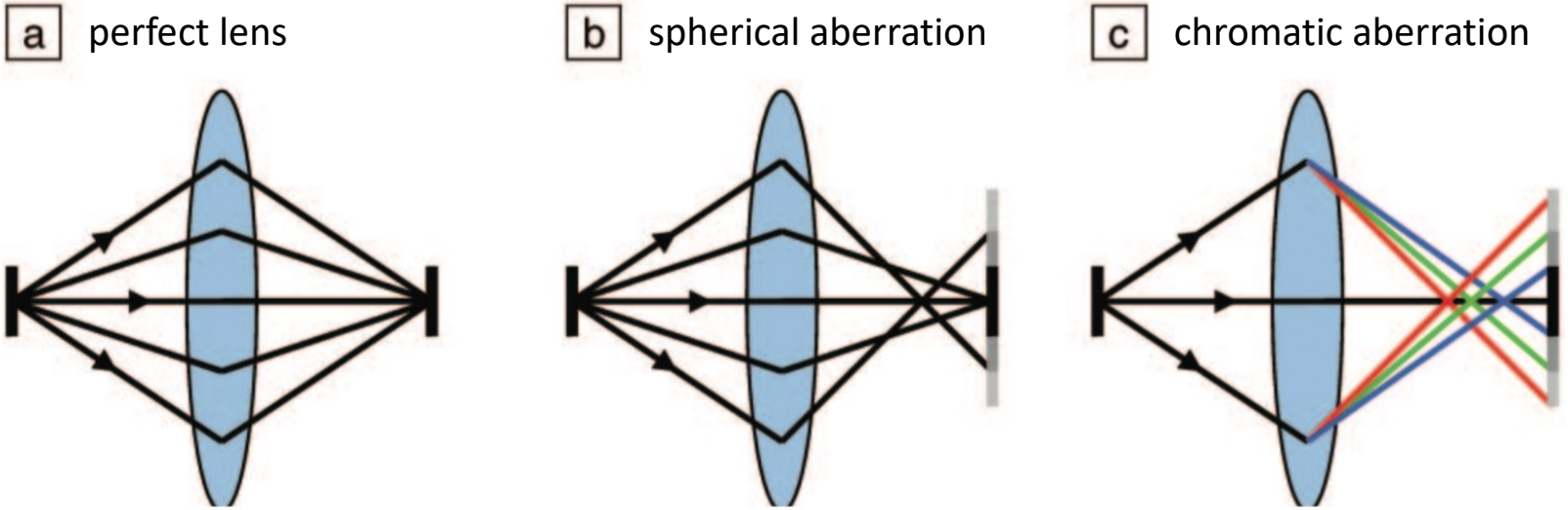
Imaging System: used to scan the beam, achieve magnification, and produce image contrast



What limits spatial resolution?

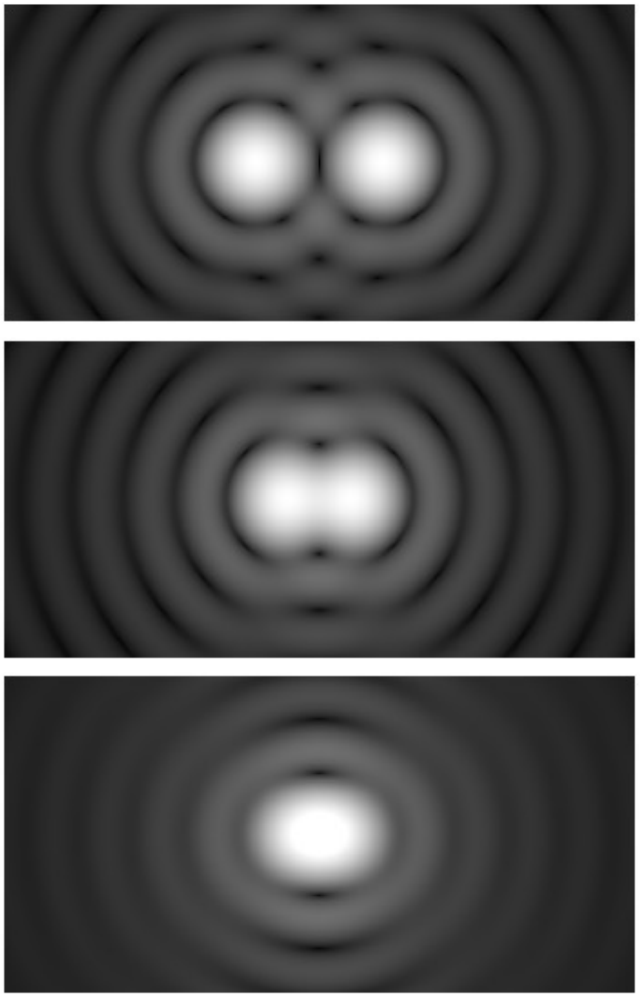
Resolution is limited by **aberrations** and by **diffraction** that cause blurring of images

caused by imperfections of the imaging system
2 examples:



Diffraction aberration

fundamental resolution limit imposed by the wave nature of particles (photons ,electrons and all other particles/objects)



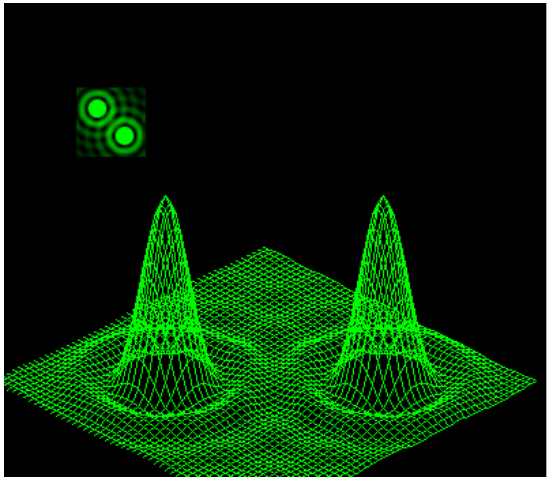
2 objects far apart – well resolved

2 objects at the diffraction limit of resolution defined by the Rayleigh criterion

2 objects close together – unresolved

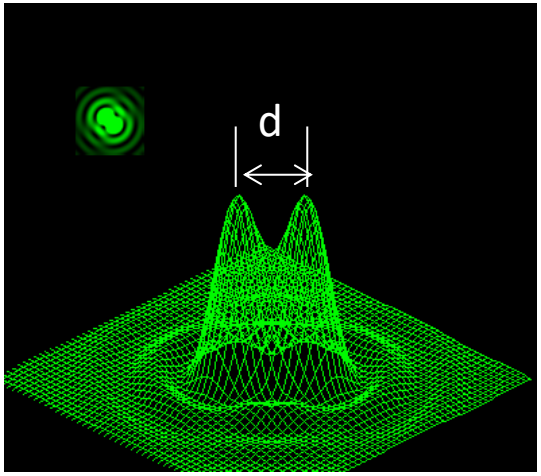
What is resolution?

resolved

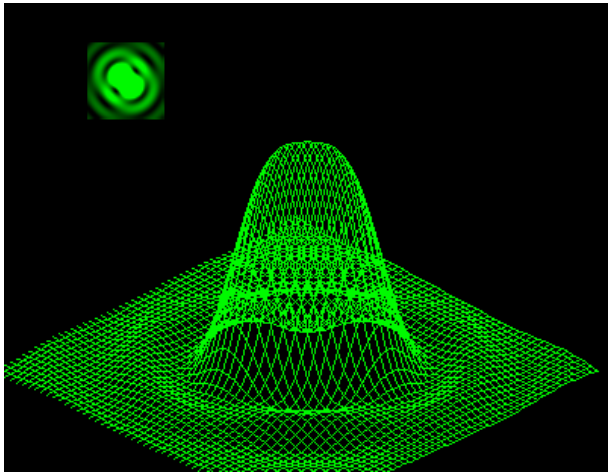


diffraction-limited image of 2 features much smaller than the resolution

resolved



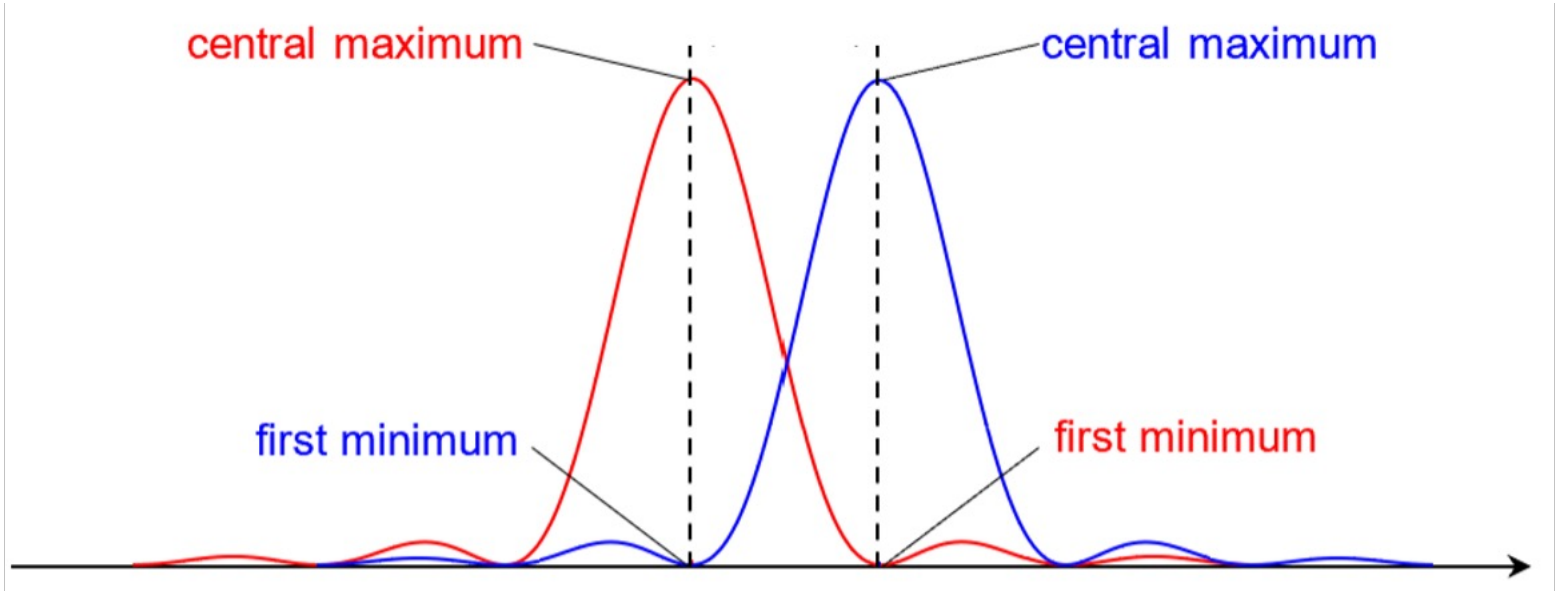
unresolved



is this an image of 1 broad feature or 2 small features?

spatial resolution: smallest <u>distance</u> between two features that can be distinguished as two separate entities

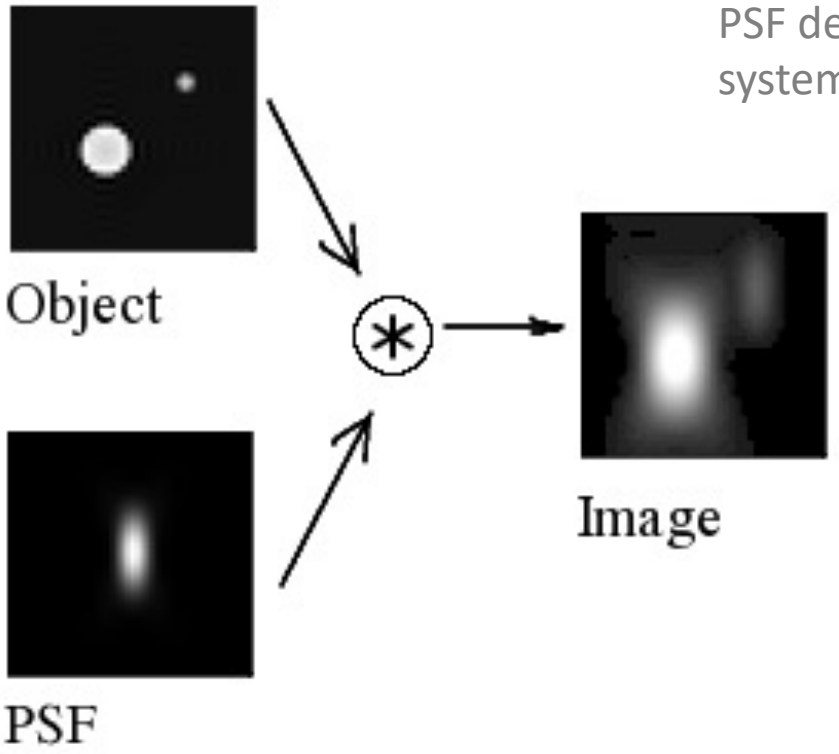
Rayleigh criterion



A generally accepted definition of the resolution of a diffraction-limited image:

The first diffraction minimum of the image of one source point coincides with the central maximum of another.

Point spread function (PSF)



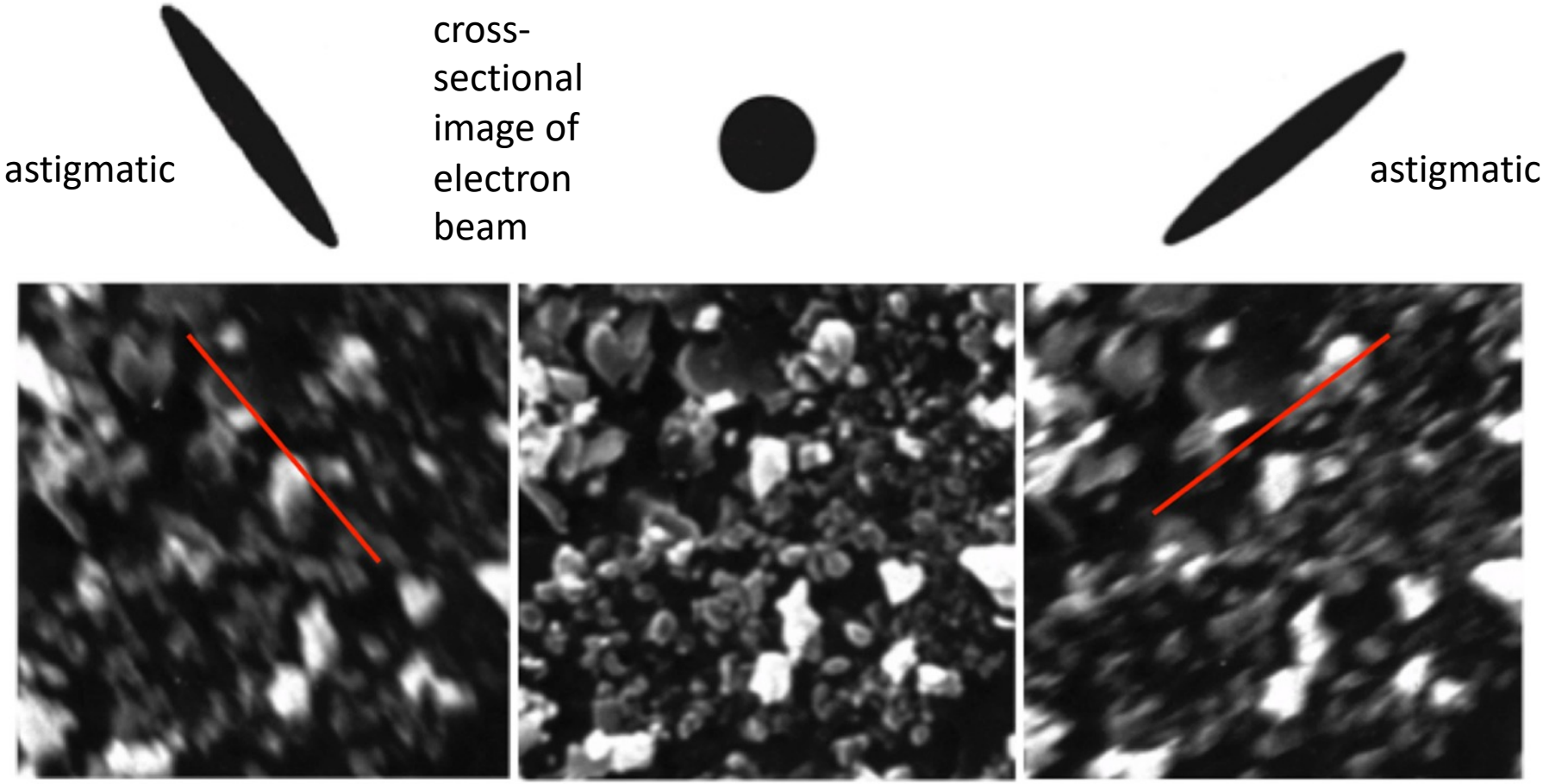
PSF describes the response of an imaging system to a point source or point object.

(here, ∗ is the convolution operator)

e.g., cross-sectional "shape" of the electron beam used in a scanning electron microscope

Useful concept in 2D (and 3D) microscopy as it describes all aspects of resolution in 2D (or 3D), as shown above by a 2D *astigmatic* PSF. Astigmatism is a type of aberration that makes the resolution of an imaging system anisotropic. It therefore makes the 2D PSF to be non-circular, and gives rise to geometric distortions in images.

Astigmatism aberration



What's next?

Today, Aug 8	**Tutorial 1:** 12 PM
Next week	**Lecture 2:** Tues **Tutorial 2:** Tues **Lab 1:** Thurs

Program

Week/Session	Dates	Description
1	5 Aug	Lecture 1: Introduction Tutorial 1: Nano-scale imaging basics
2	12 Aug	Lecture 2: Electron optics and electron-solid interactions Tutorial 2: Electron-solid interactions Practical 1: Scanning electron microscopy
3	19 Aug	Lecture 3: Ion beams and electron/ion beam nanofabrication Tutorial 3: Ion-solid interactions Practical 2: Electron/ion beam nanofabrication
4	26 Aug	**CLASS TEST 1**
5	2 Sept	Lecture 4: Cathodoluminescence & x-ray analysis Tutorial 4: Cathodoluminescence simulations Practical 3: Nanocharacterisation techniques
6	9 Sept	Lecture 5: Advanced nanocharacterisation Practical 4: Nanocharacterisation techniques
7	16 Sept	Lecture 6: Ion-solid interactions and gas-assisted nanofabrication (advanced) **Portfolio 1 due this week** (practicals)