Electron Microscopy Teaching Methodologies

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California NanoSystems Institute (CNSI), UCLA

Western Association of Core Directors

Presentation Date: Wednesday, September 22
Presentation Time: 10 AM - 10:30 AM

CNSI Technology Centers:
Electron Imaging Center for Nanomachines (**EICN**)

EICN Team:
Matthew Mecklenburg – Managing Director

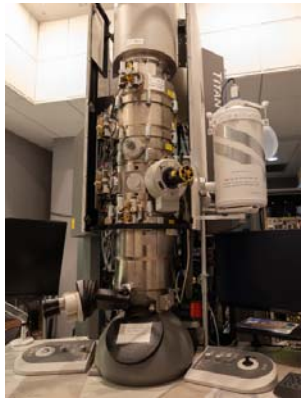
6 TEMs:
Krios G1
Titan 80-300 Low Base
TF20
T20
T12
T12 Cryo

1 SEM:
Zeiss Supra

(Photo credit: Marc Roseboro/CNSI)

Krios G1

Titan 80-300 Low Base



TF20

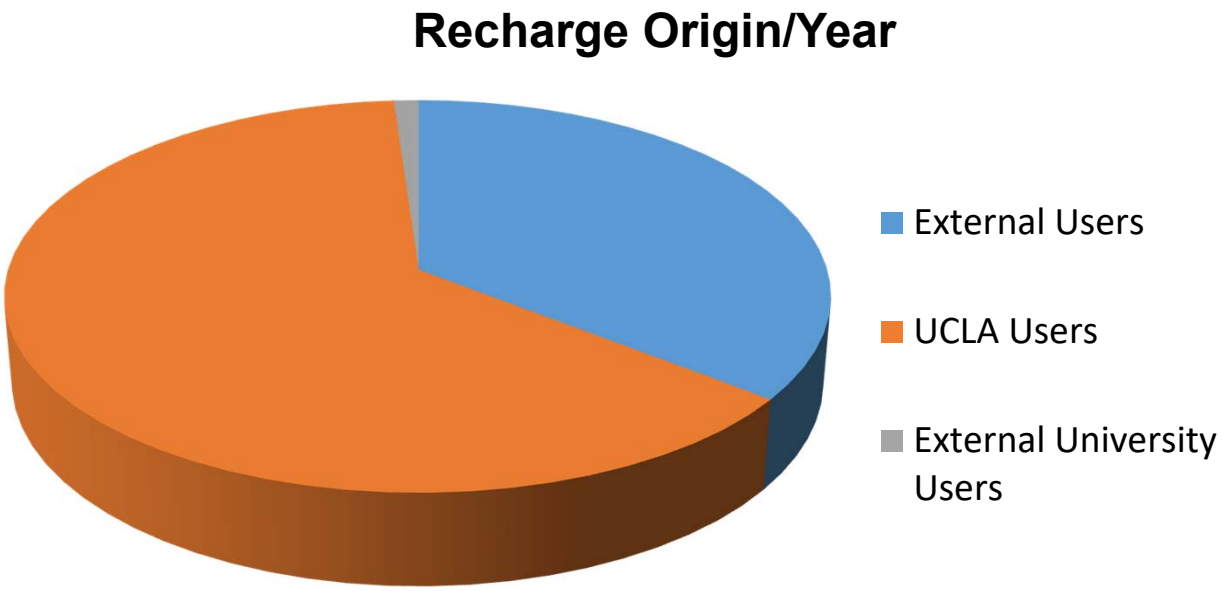
T20

T12

T12 Cryo

Zeiss Supra

Total Users:
External Users: 22
UCLA Users: 406
External University Users: 41



Weekly Users (last week):
External Users: 8
UCLA Users: 86
External University Users: 2

Our center is unusual. We do not have SEMs used all day supporting the large service contracts from TEMs. Instead, our TEMs are used from about 10-6 every day, except the Krios which is used 24/7 and is booked 2 months out.

Incredibly supportive administration who helps setup external users, and help with all manor of issues very quickly!

Outline: **Electron Microscopy Teaching Methodologies**

1. Scales, the atomic scale is too far from their intuition

2. Electron Optics, this is not really taught

3. Fourier Synthesis

Electron microscopes are **weird**.

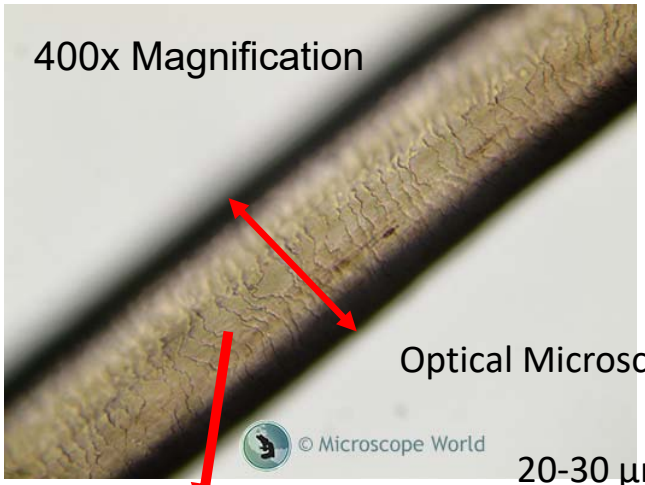
(Photo credit: Marc Roseboro/CNSI)

How big is an atom?

Photo from the Nobel Foundation archive.
Ernst Ruska
Prize share: 1/2

How tall is a person?

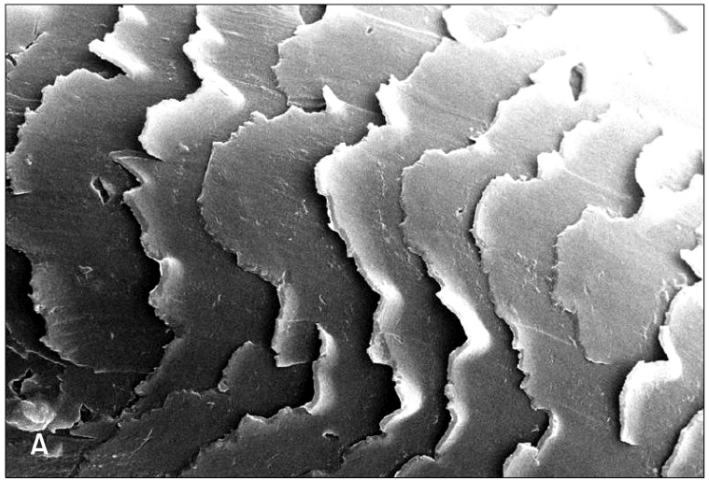
~ 1.8 meters or 6 feet



Optical Microscope

This is a nice image but what does 400x magnification mean? And how big is this hair?

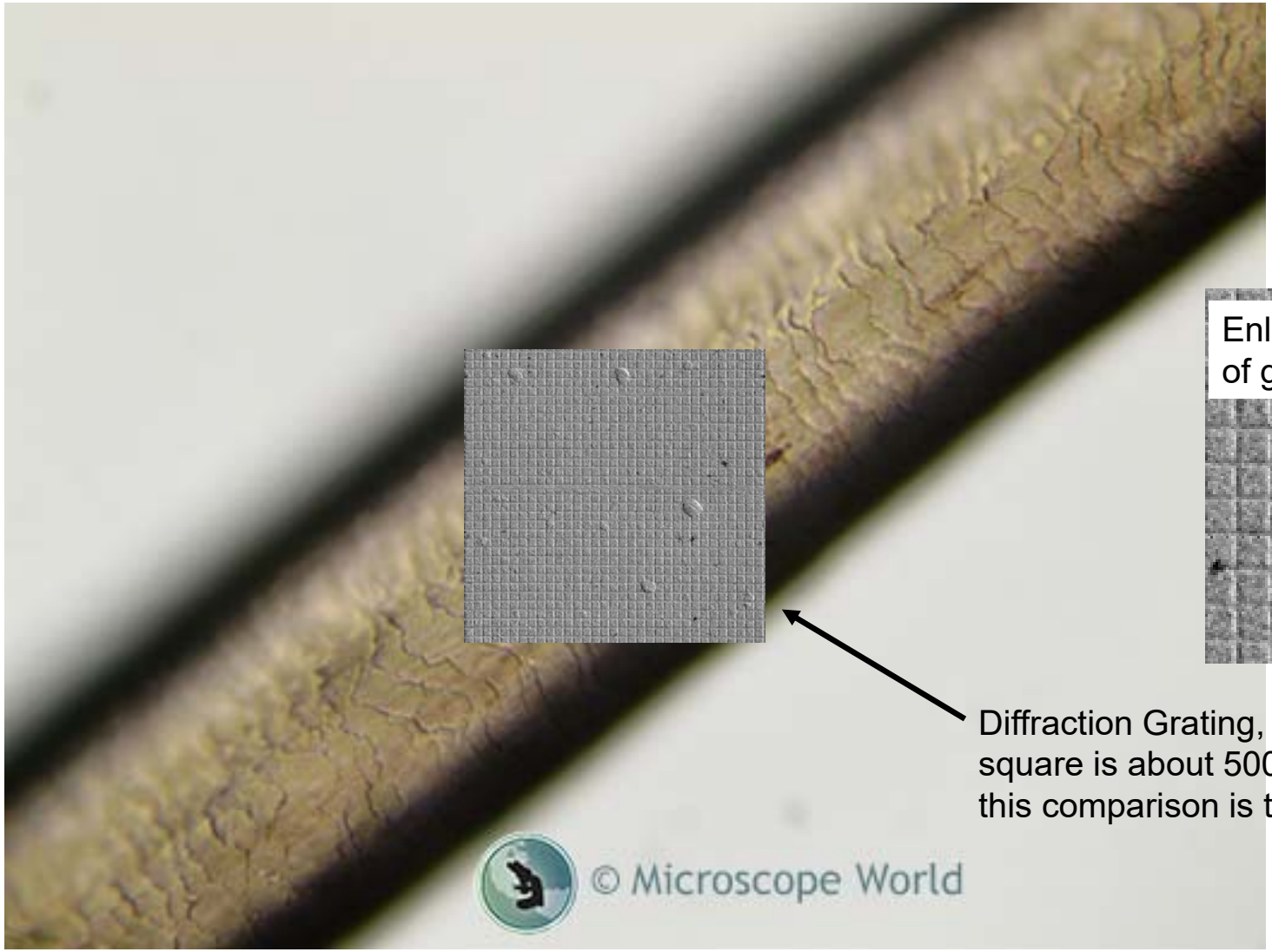
20-30 µm = 0.0008-0.001 inches



Electron Microscope

A hair is about 5 orders of magnitude (in width) smaller than we are.

Lee, Yoonhee, Youn-Duk Kim, Hye-Jin Hyun, Long-quan Pi, Xinghai Jin, and Won-Soo Lee. "Hair shaft damage from heat and drying time of hair dryer." *Annals of Dermatology* 23, no. 4 (2011): 455-462.


Enlarged section of grating.
Diffraction Grating, each square is about 500 nm, and this comparison is to scale.
© Microscope World

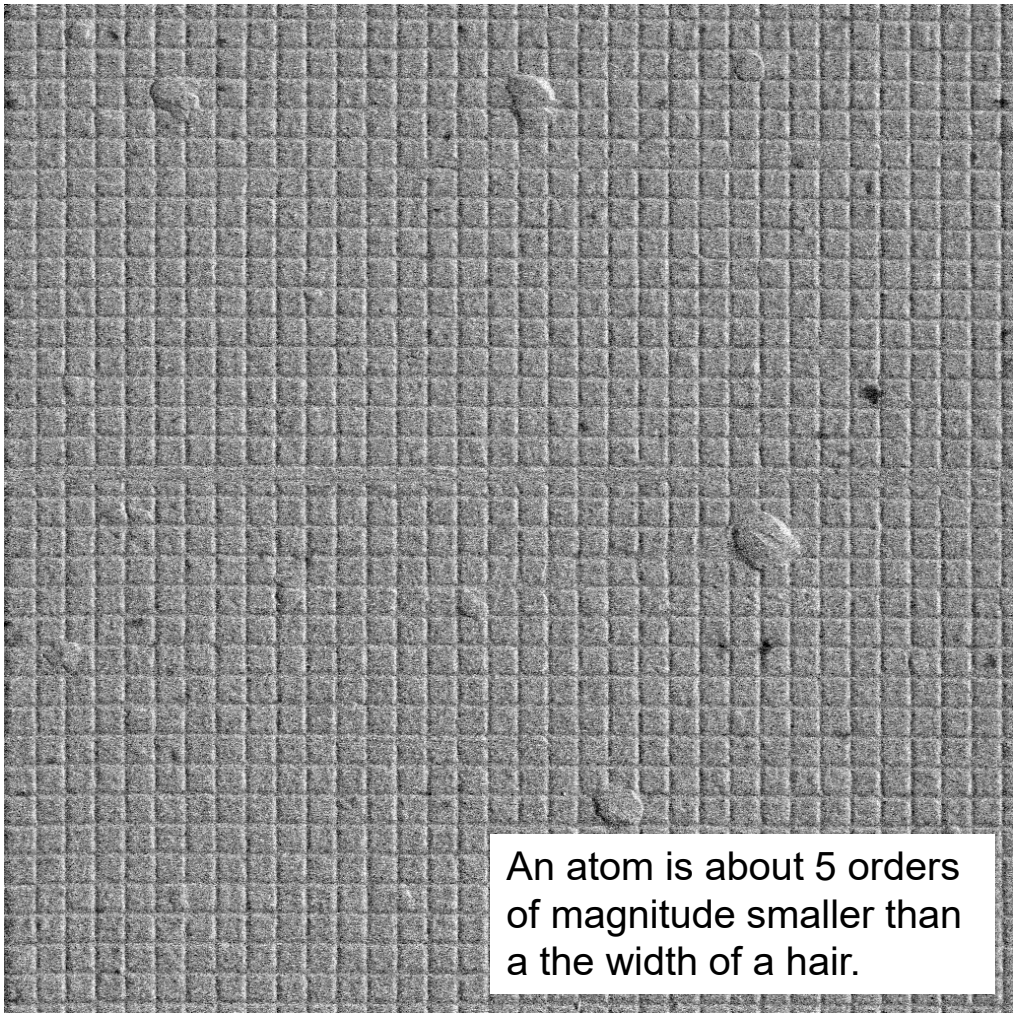
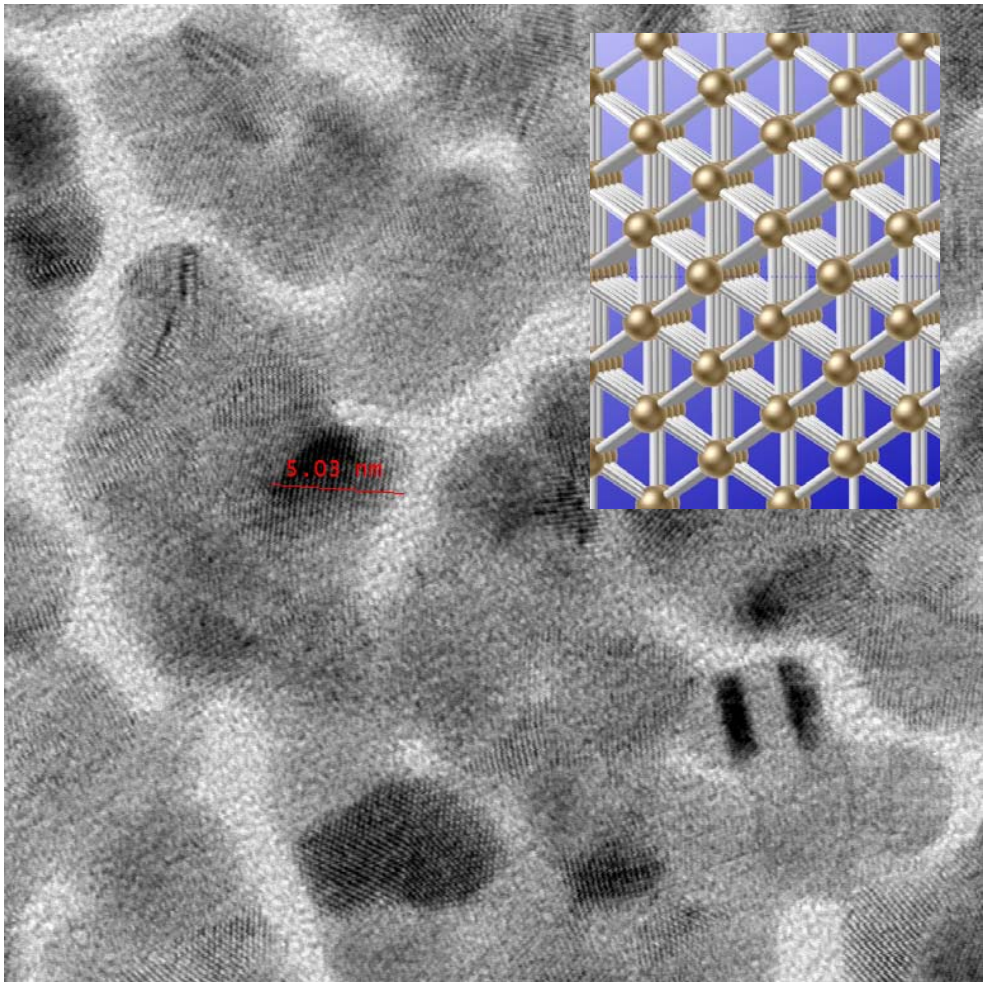


Image Credit: Yueyun Chen



Light's visible wavelength about the size of one square
At the highest mag, a pixel is about 3x an electron wavelength

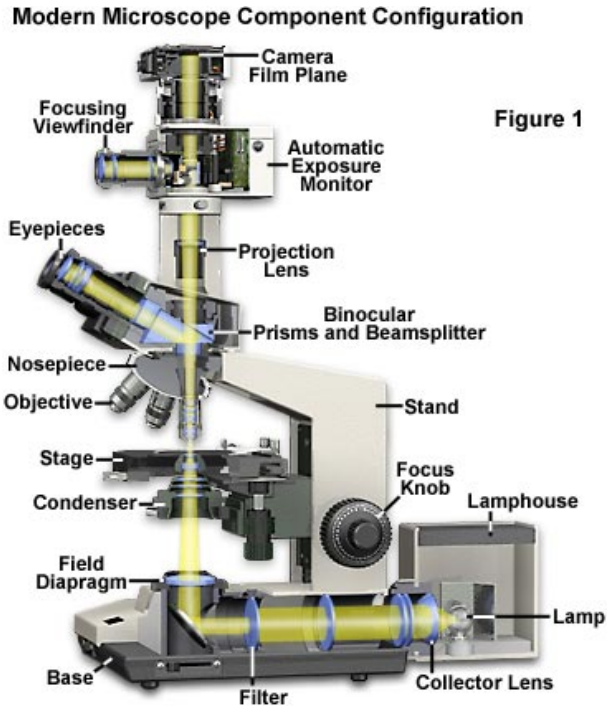
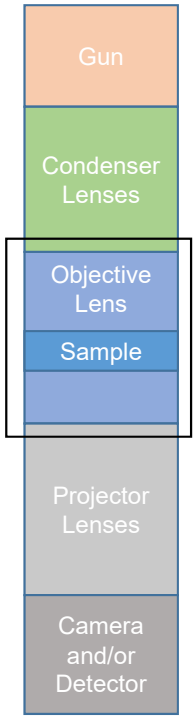
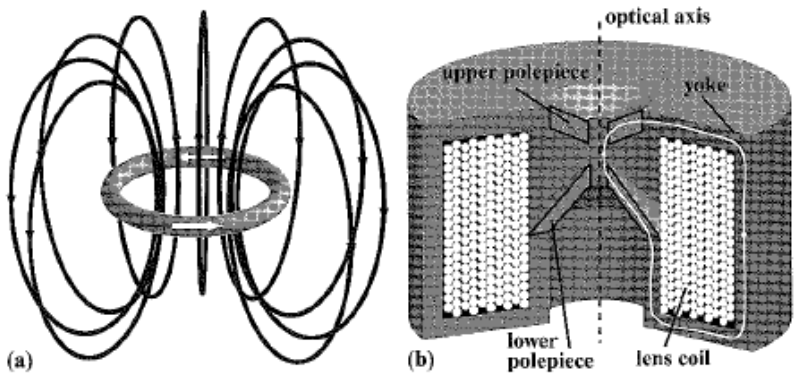


Figure 1

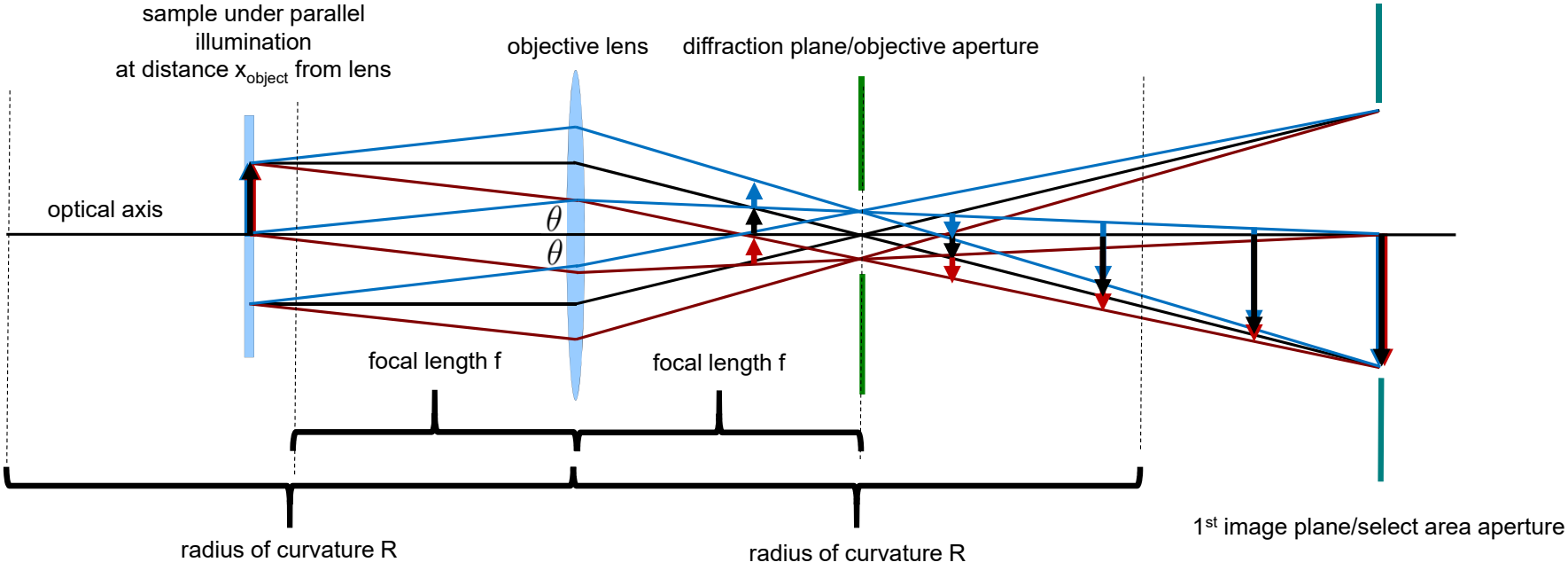
https://www.olympus-lifescience.com/en/microscope-resource/primer/anatomy/components/





De Graef, Introduction to Conventional Transmission Electron Microscopy, Cambridge University Press, Fig 3.3

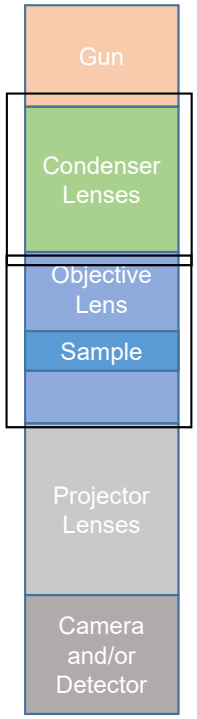
Basic Microscope Optics

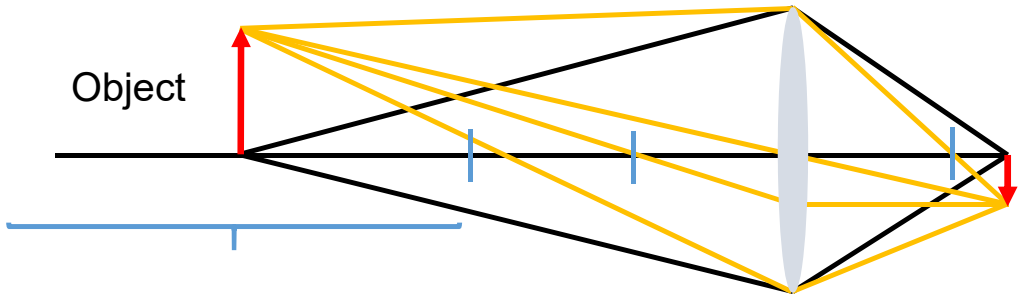


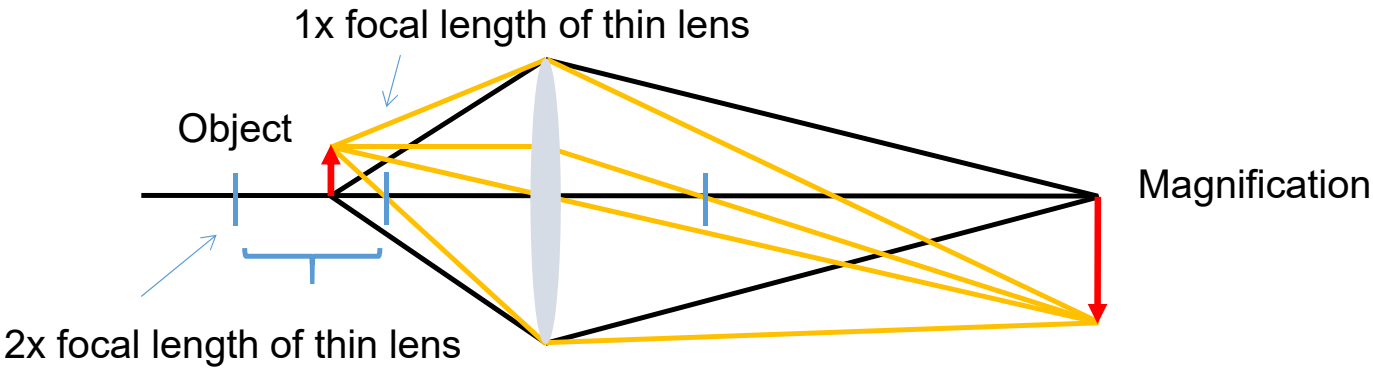
x_{object}>R, image demagnified (condensers)

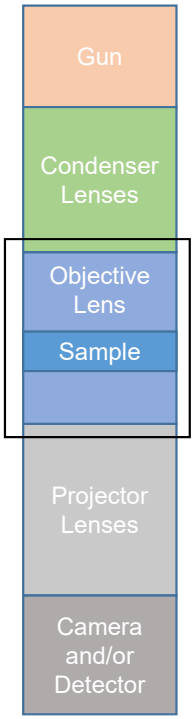
R>=x_{object}>f, image magnified (objective and projectors, $M_1xM_2xM_3xM_4$)

The gun has a physical tip radius of ~0.5 μm, virtual size of ~15 nm, and these scales are far larger than the ~100 pm we need to resolve: the solution is to demagnify the source to make it smaller. The condenser lenses are there to provide different ways of demagnifying the source.









Spherical Aberration!

Symbol: C_s or C_3

Conventional TEM: C_s~ 1 mm

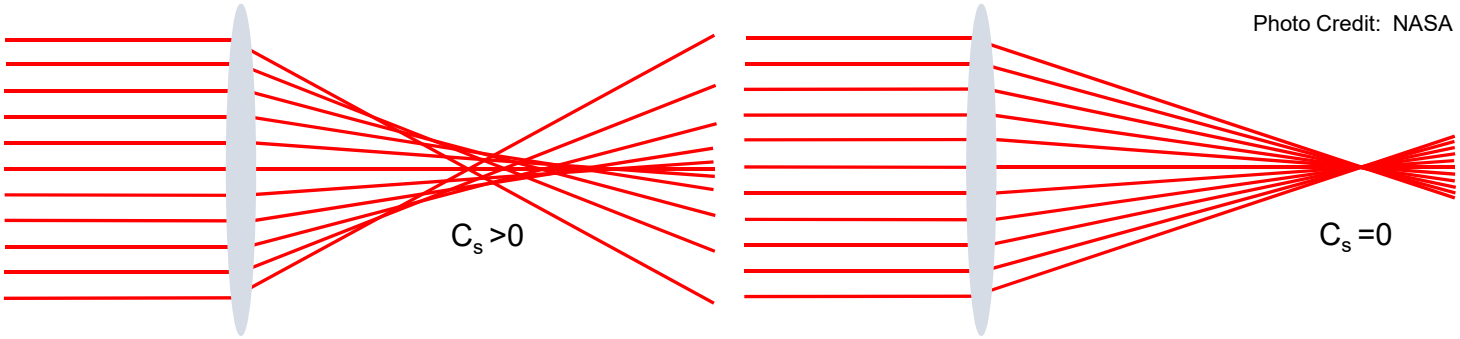
TEM: C_s> 0 w/ lens having azimuthal symmetry

Within the last ~15 years, C_s correction has become commercially available.

Hubble Satellite Before Fix

After

Photo Credit: NASA



How to get high resolution?

Abbe's Diffraction Limit:

$$\delta \cong \frac{\lambda}{2NA}$$

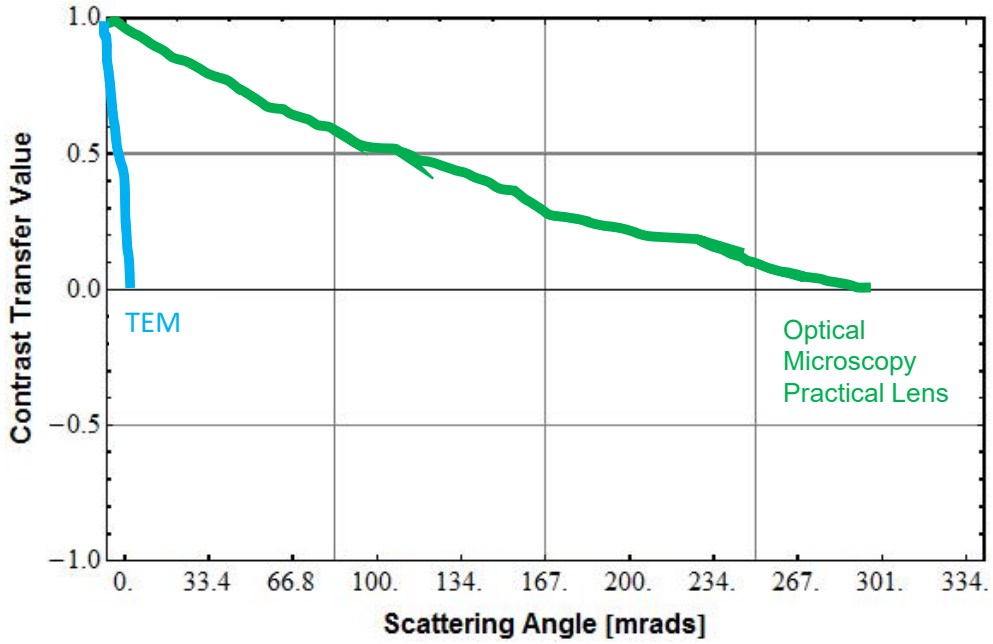
λ ← Wavelength

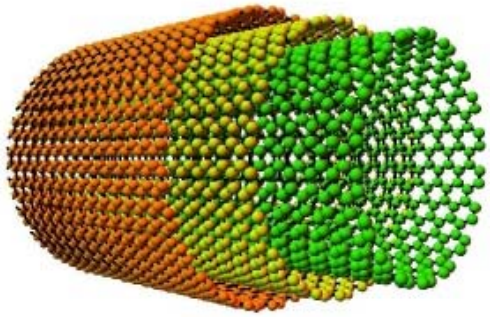
δ ↑ Resolution

$2NA$ ↖ Optics

Electron Wavelengths: λ ~ 0.001 nm

Electron Optics: NA <<1



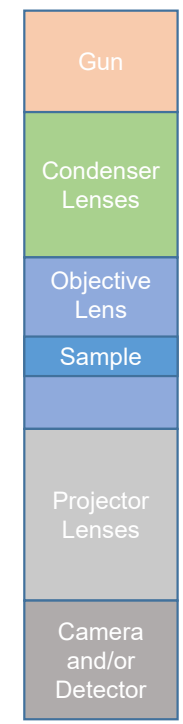


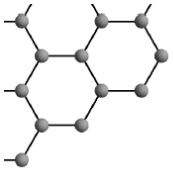
Cartoon of a multi-walled carbon nanotube.

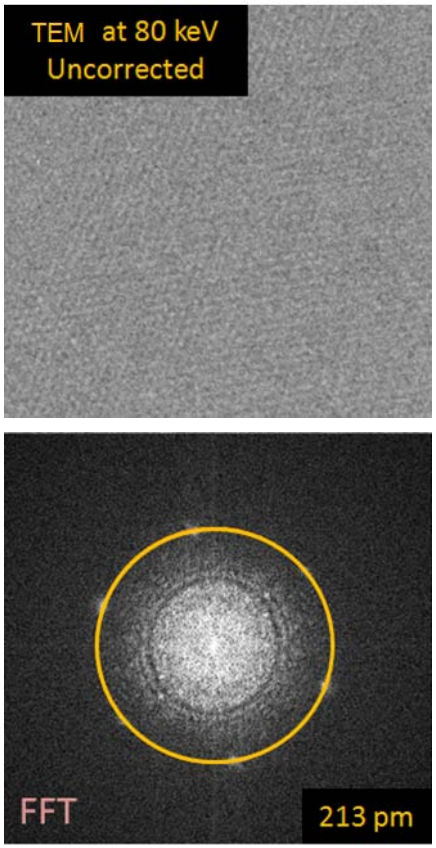
Optical Photon Wavelength: λ ~ 500 nm

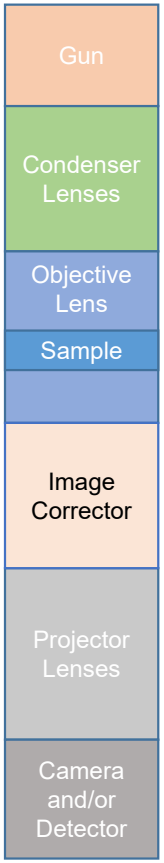
Optical Photon Optics: NA ~ 0.5

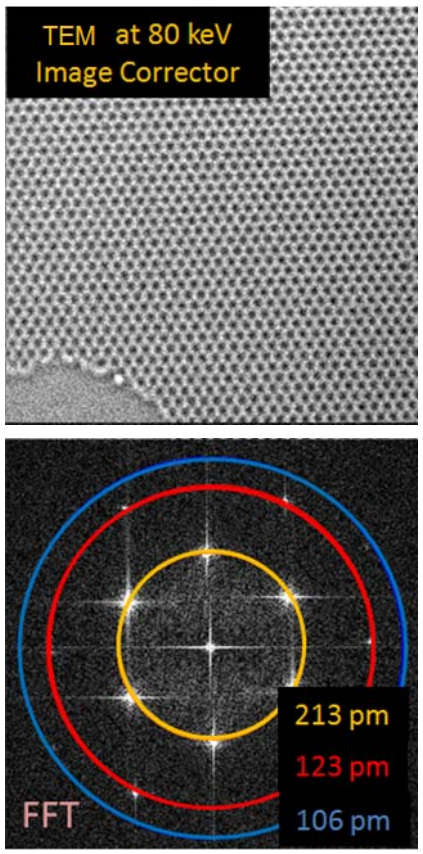
Crystal lattice planes ~ 0.2 nm
Wall Spacing ~ 0.3 nm

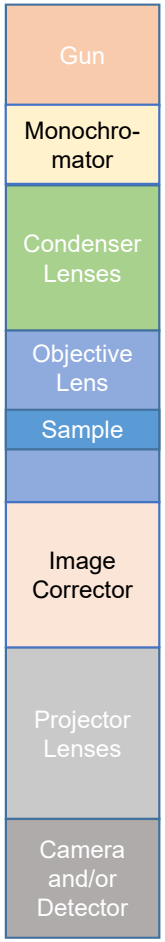


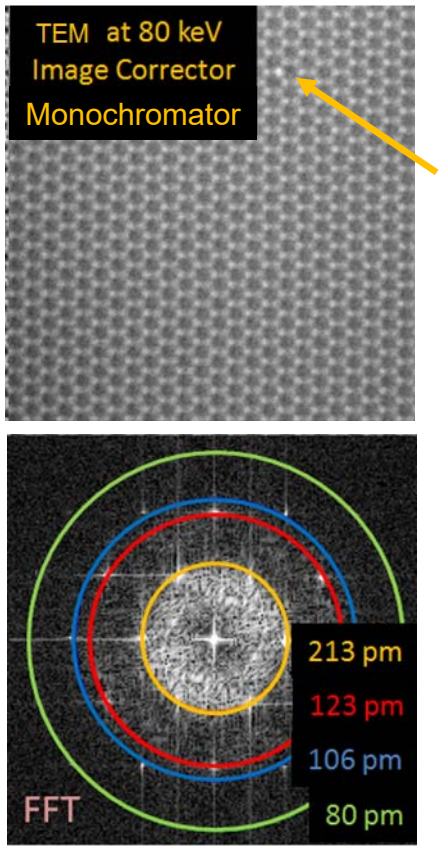






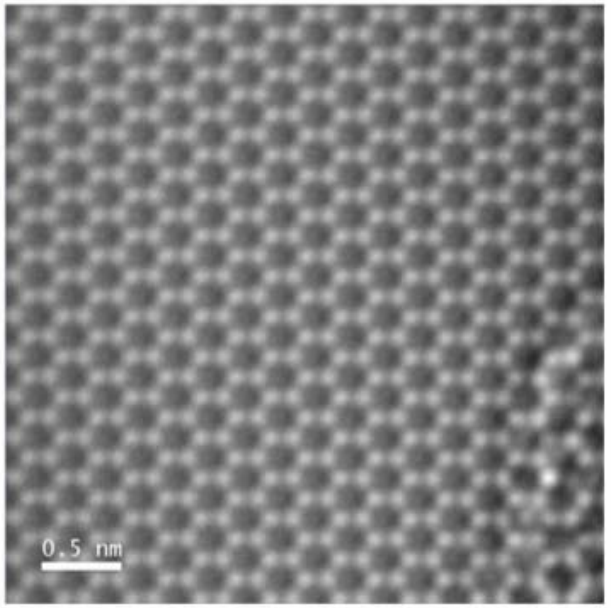




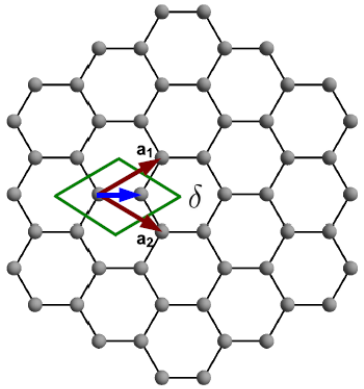


Test Sample:
Graphene

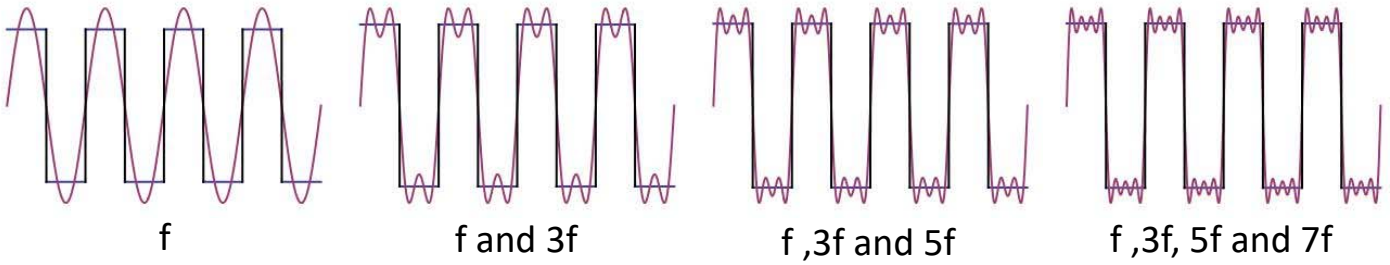
Microscope Images
approximately to scale

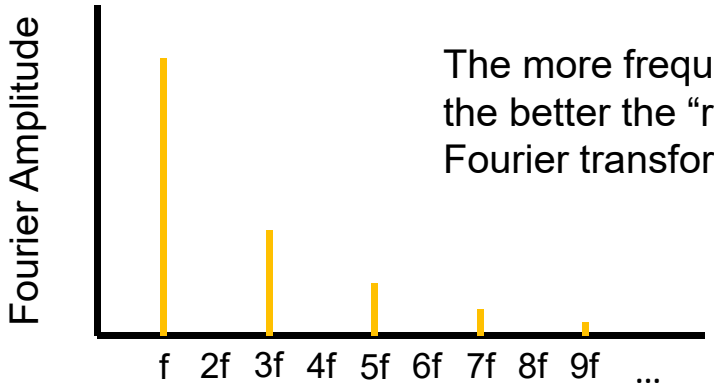


-LBNL

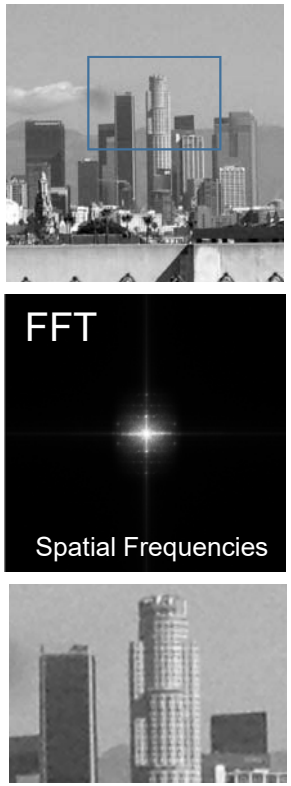


Reminder about Fourier Transforms

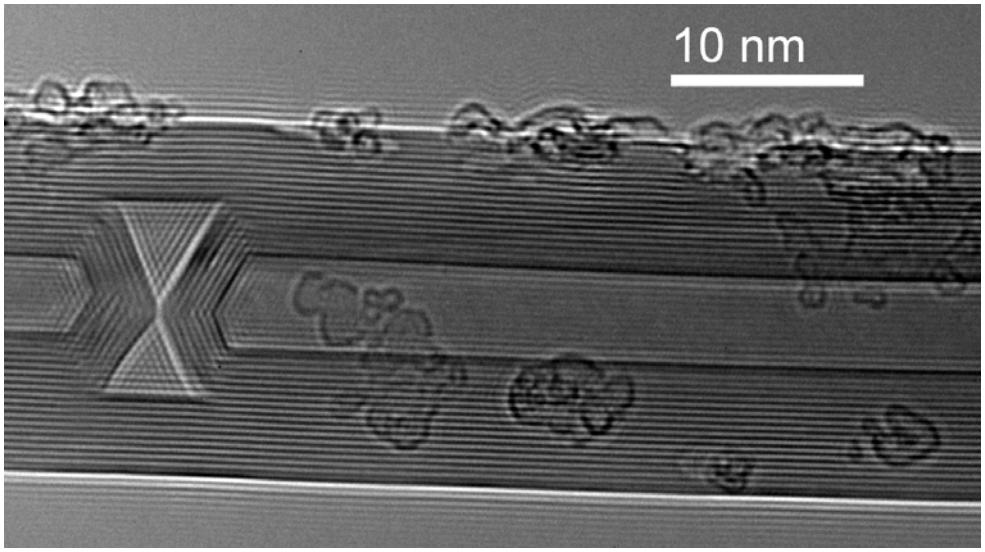


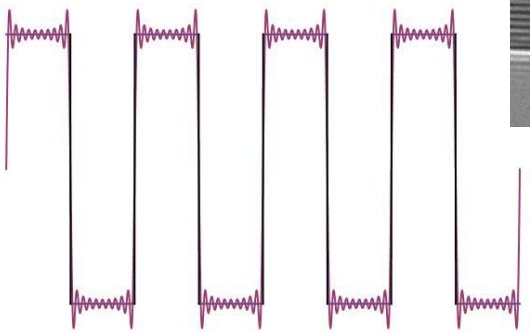


The more frequencies we include, the better the "resolution" of our Fourier transform.

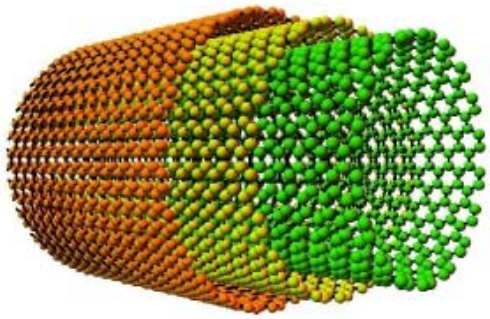


FFT: Fast Fourier Transform





More spatial frequencies mean better resolution!



Every single image ever is an incomplete Fourier synthesis of the object.

Conclusions

- The CNSI EICN is largely bio-focused.
- Students and users usually have no familiarity with electron microscopes when they enter our facility.
- We have an enormous amount to teach them about imaging and optics.
- One of the biggest challenges is to get them to understand the enormous length scales between their size, and the size of atoms.
- The basic concepts underlying every optical microscope can be translated to electron microscopy, but this is rarely done!