Study Meeting 3: Electron detectors

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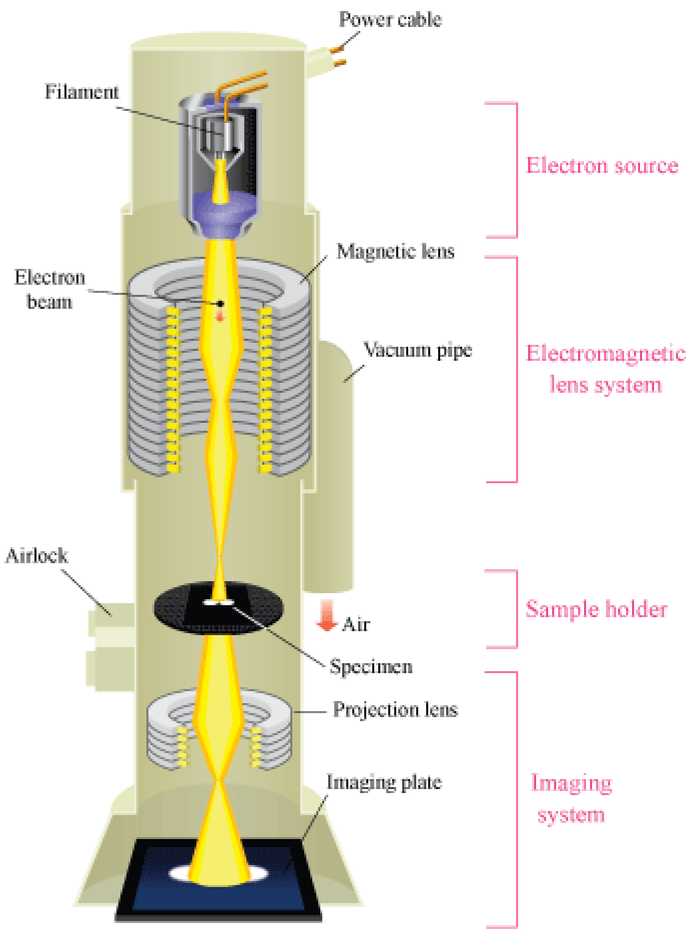


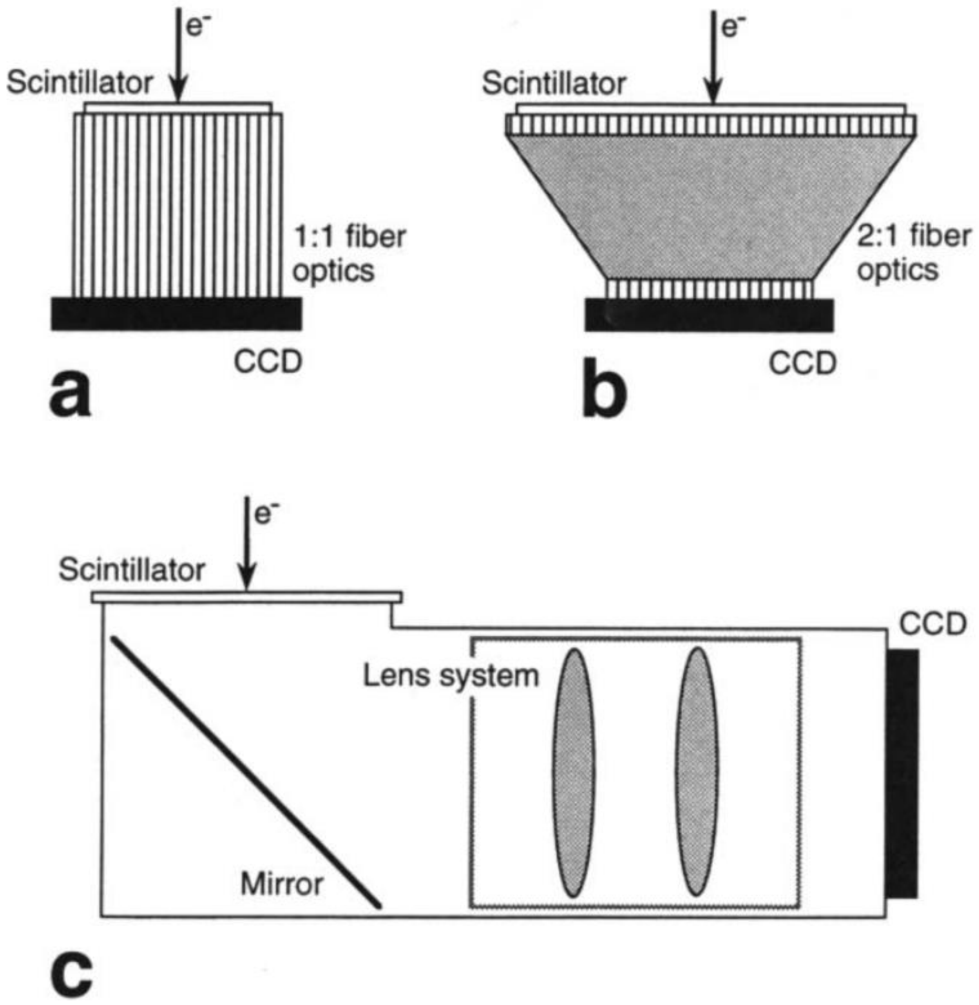
- Two weeks ago

- Today

Summary of Electron lenses

- Two different types:
  1. Electrostatic lenses
  2. Electromagnetic lenses
- Lens aberrations
  1. Spherical aberration
     - Hexapoles, etc
  2. Astigmatism
     - Careful beam alignment / Stigmators
  3. Chromatic aberration
     - Energy filters, FEGs

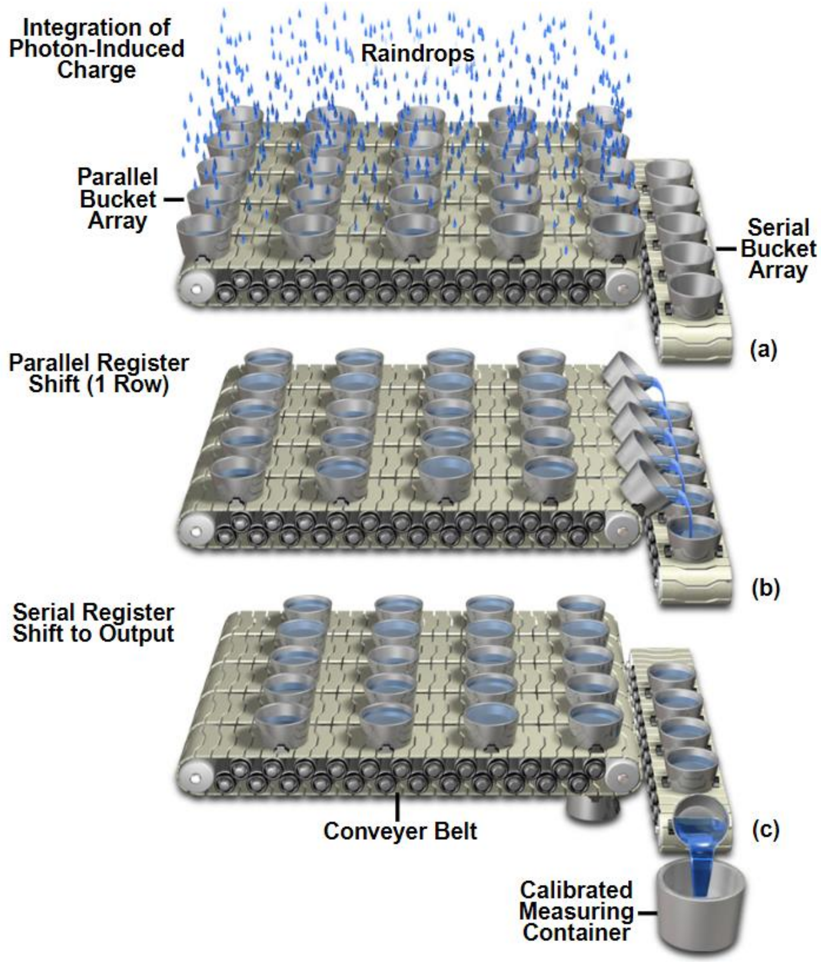
Film & CCD Cameras



- Electrons cause exposure of film
- CCD never had large impact
- Mismatch between scintillator and fiber optics

Ruijter (1995)
Micron, 26(3):247

Film & CCD Cameras



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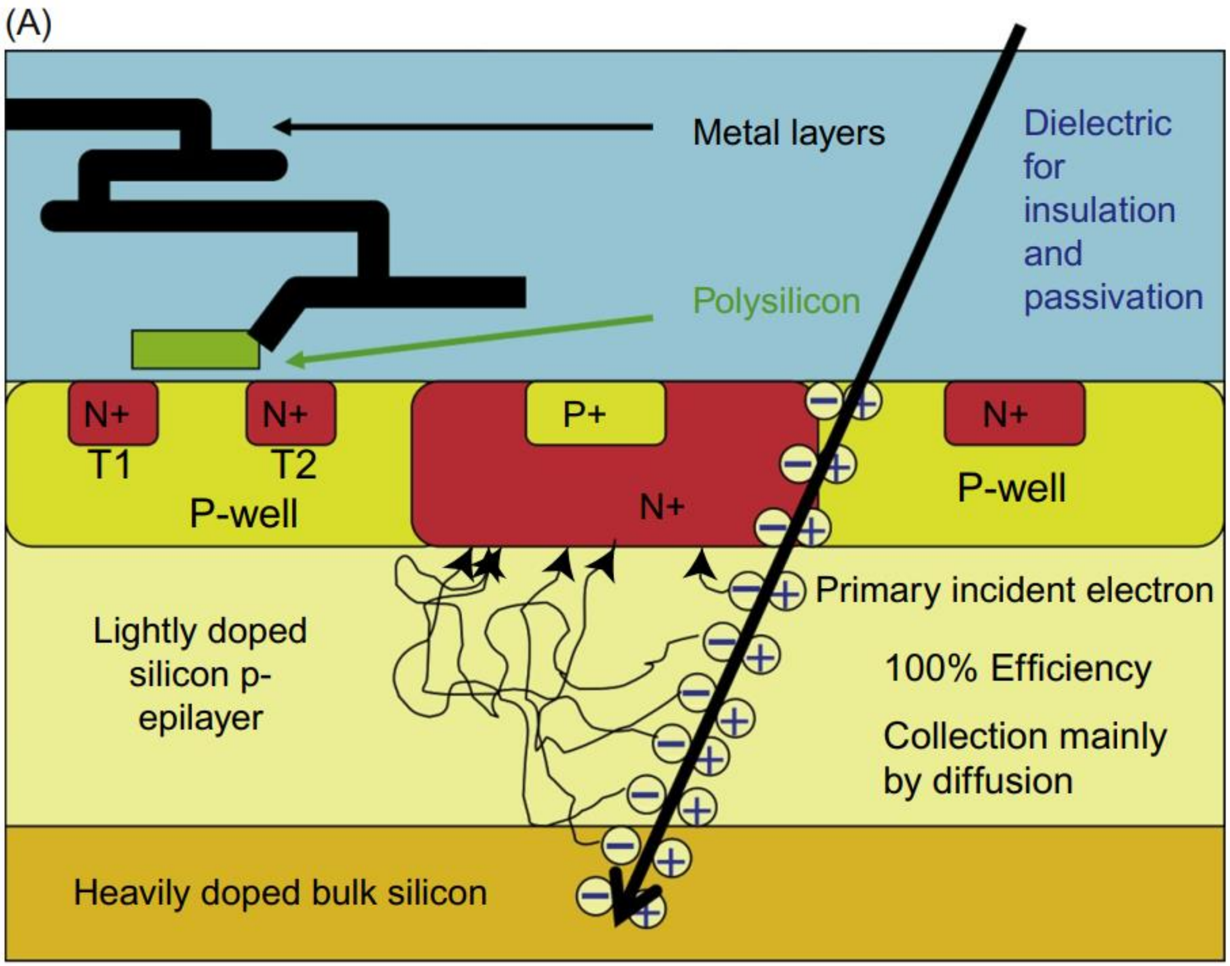
Ruijter (1995)
Micron, 26(3):247

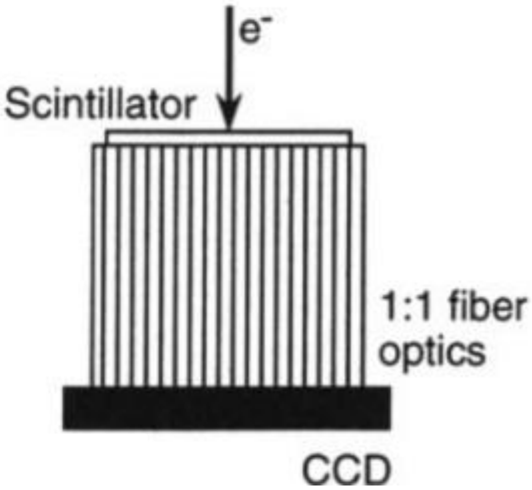
Direct Electron Detector



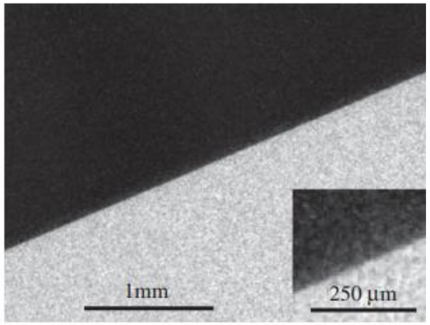
McMullan, Faruqi, Henderson (2016)
Methods in Enzymology, Vol. 579

Why are DEDs so much better?

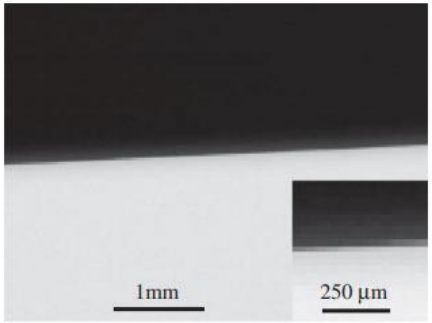
- No scintillation layer
- Reduced shot noise
- Backscattering
- Faster readout → Motion correction
- Electron counting → Reduce coincidence loss
  → Landau problem



SO-163 film



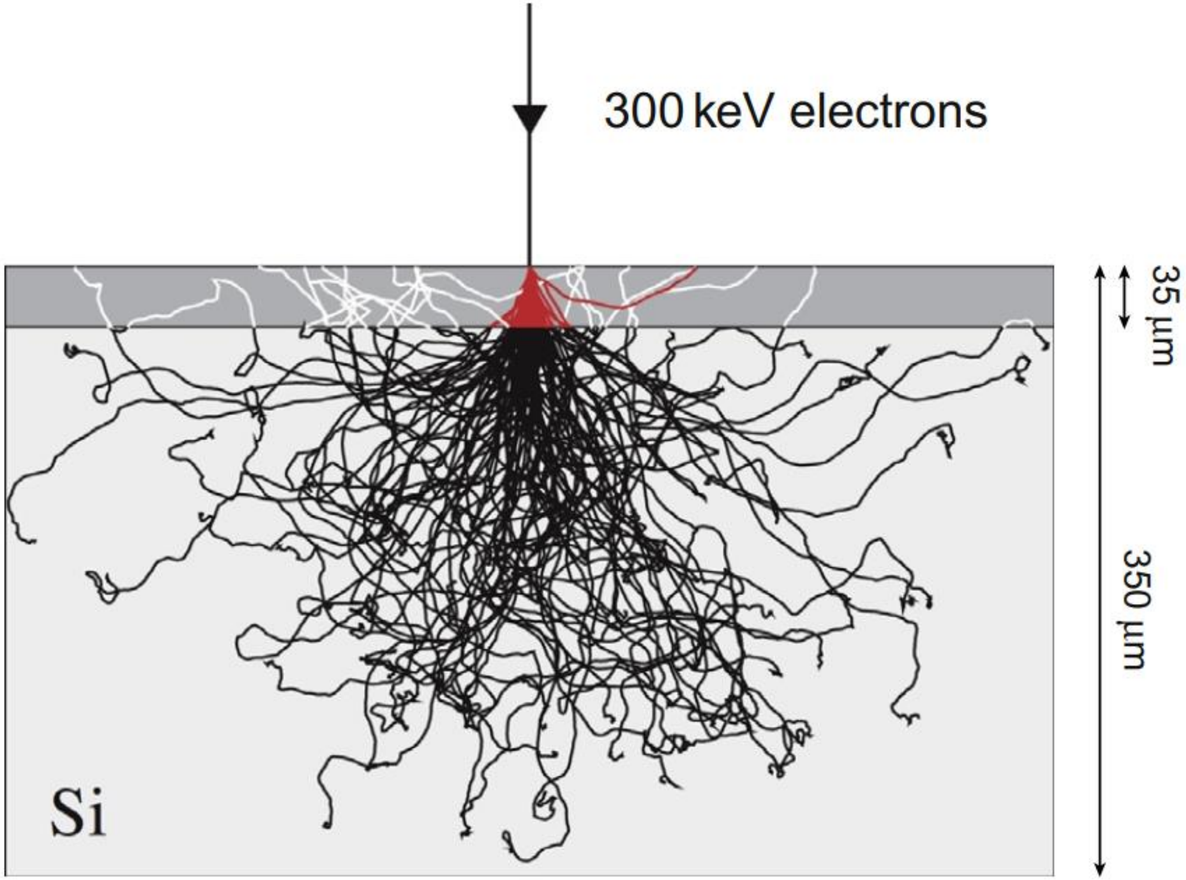
Prototype DED



Ruijter (1995)
Micron, 26(3):247

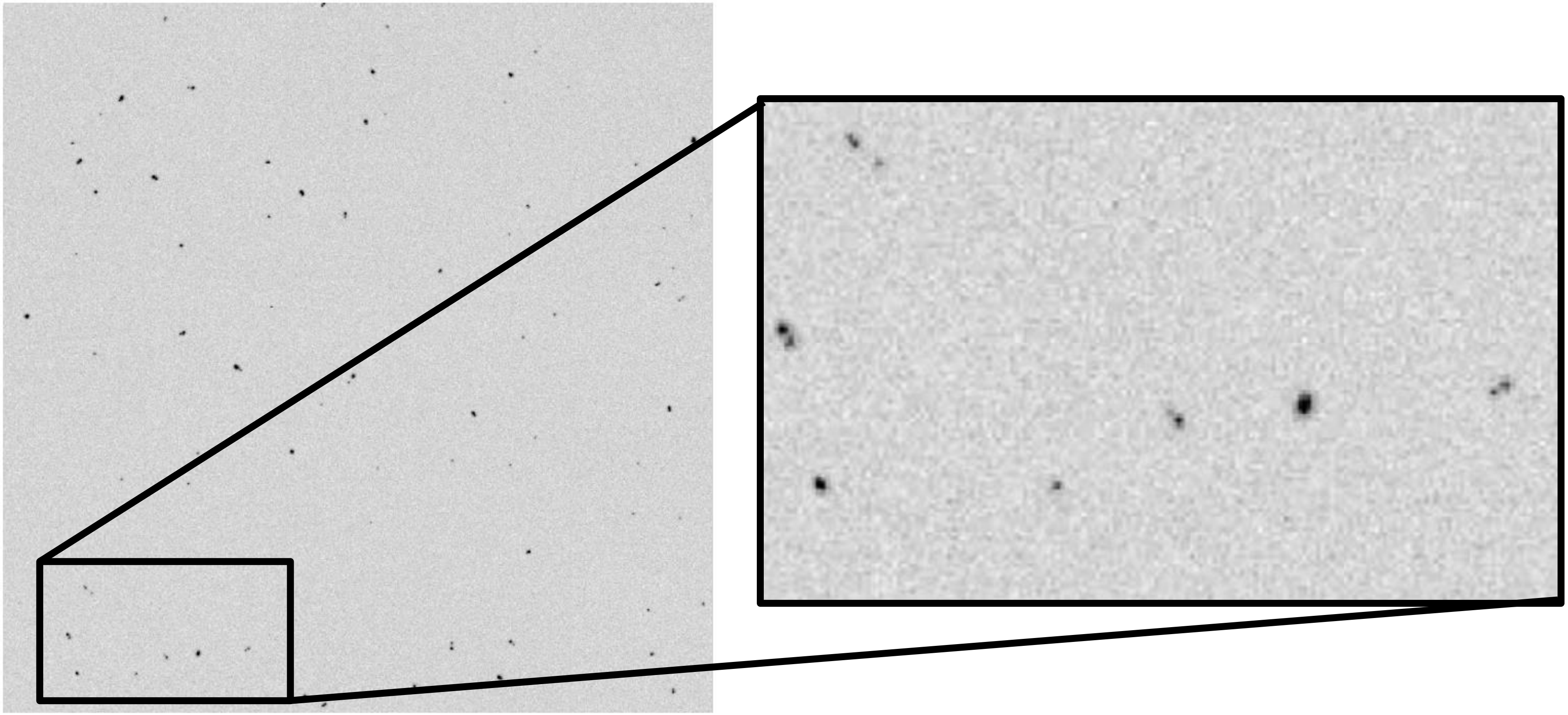
McMullan, Chen, Henderson, Faruqi (2009)
Ultramicroscopy. 109:1126

Reducing backscattering



McMullan et al. 2009
Ultramicroscopy 109:1144

Backscattering



- Thick back layer in early DED

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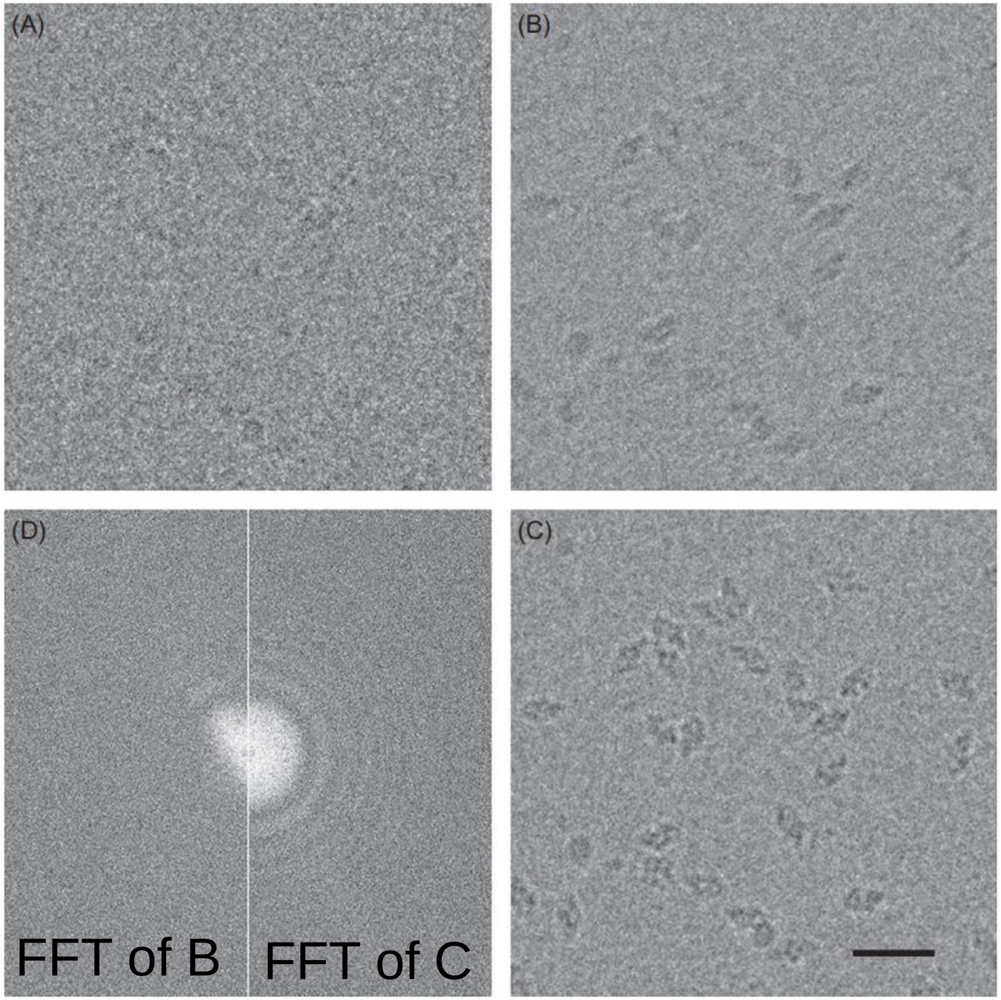
McMullan et al. 2009
Ultramicroscopy 109:1144

Motion Correction

Single frame

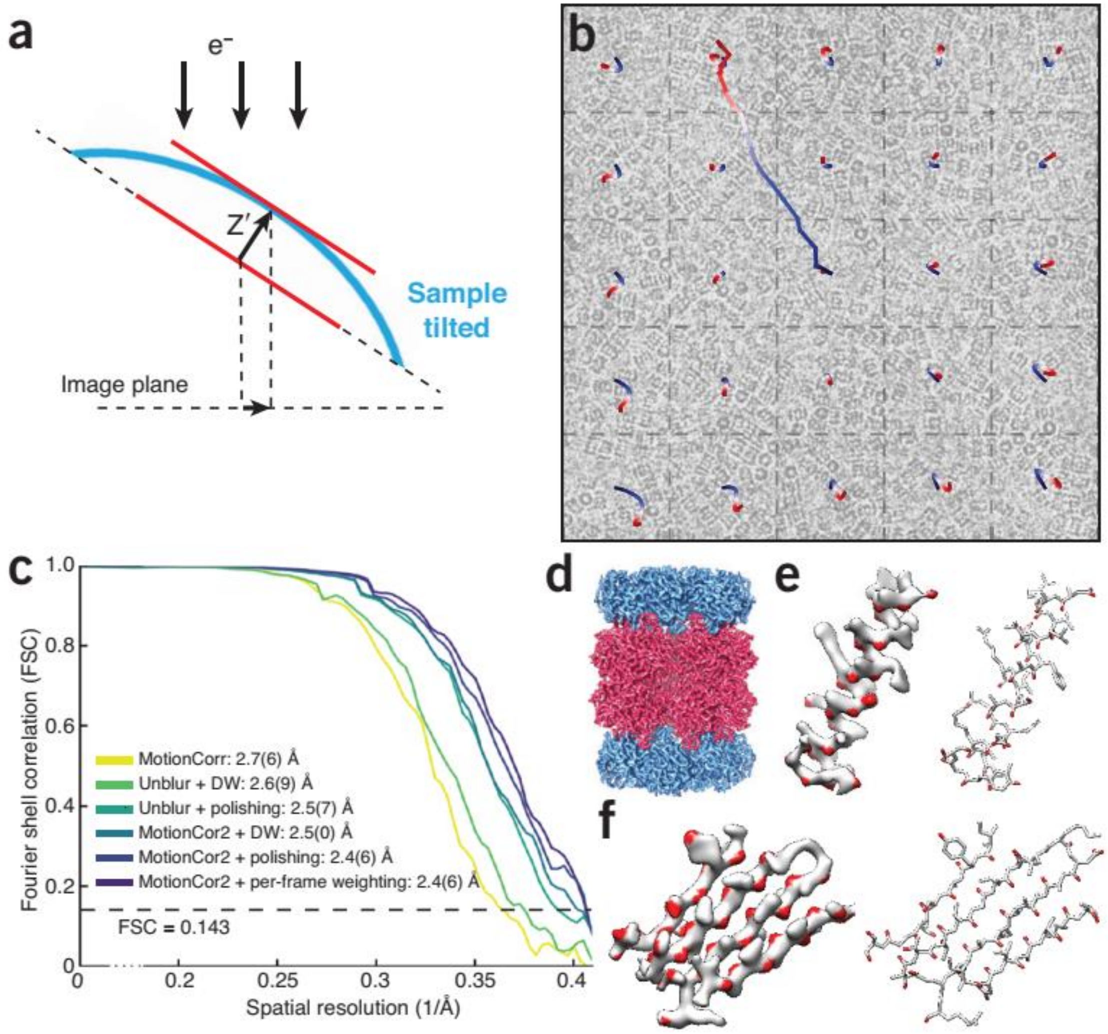


Direct alignment

MotionCor1

McMullan, Faruqi, Henderson (2016)
Methods in Enzymology, Vol. 579

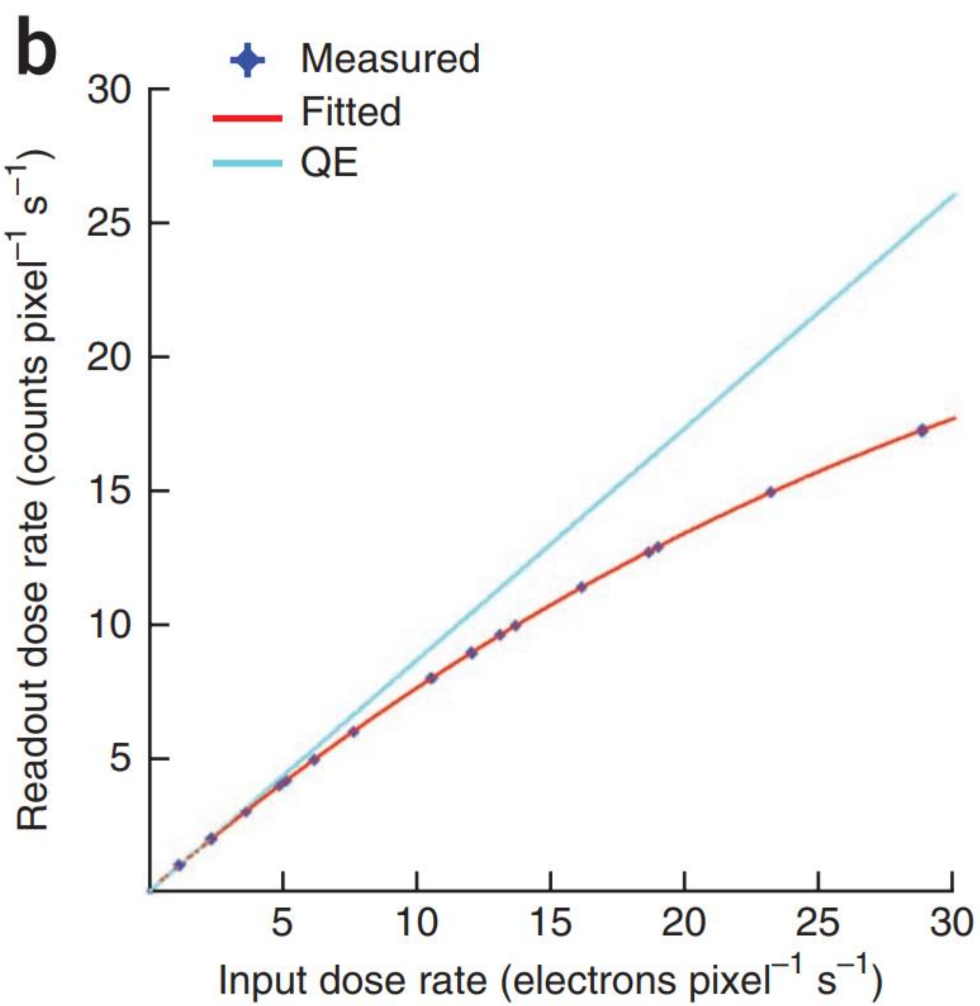
MotionCorr2



- Does global and local (patch) alignment

Zheng *et al.* (2017)
Nat. Meth. 14(4):331

Coincidence loss



K2 counts each electron rather than the charge of each pixel which eliminates the Landau noise (as each pixel could be a sum of different electrons)

8 e^-/px/s is really 10 e^-/px/s

Li *et al.* (2013)
Nat. Meth. 10(6):584

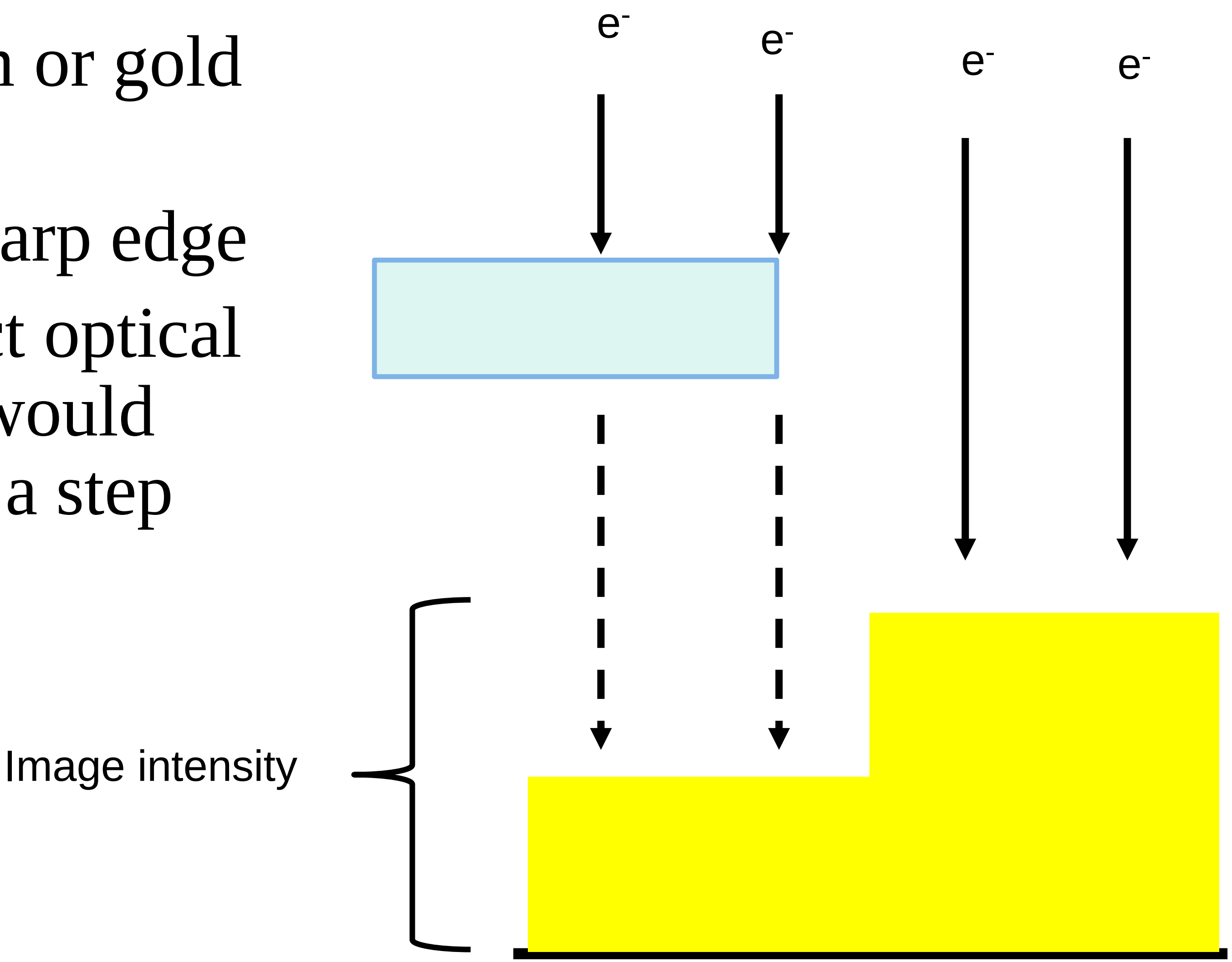
Camera performance

- Modulation Transfer Function (MTF)
  - Envelope function of the camera
- Detector Quantum Efficiency (DQE)

$$\mathrm{DQE} = (S/N)^2{}_{\mathrm{OUT}} / (S/N)^2{}_{\mathrm{IN}}$$

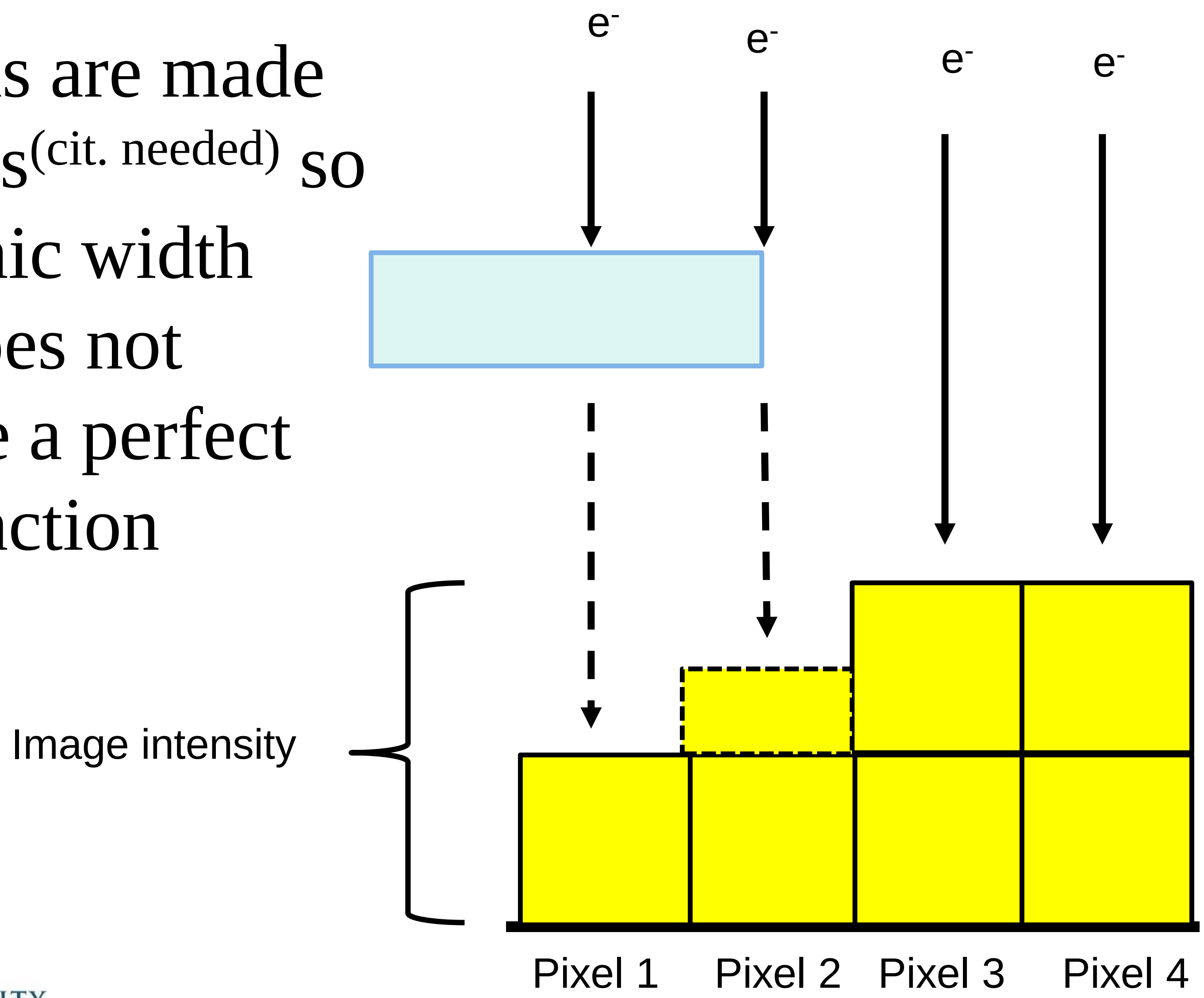
How to measure the MTF

- Platinum or gold knife
- Has a sharp edge
- A perfect optical system would produce a step function

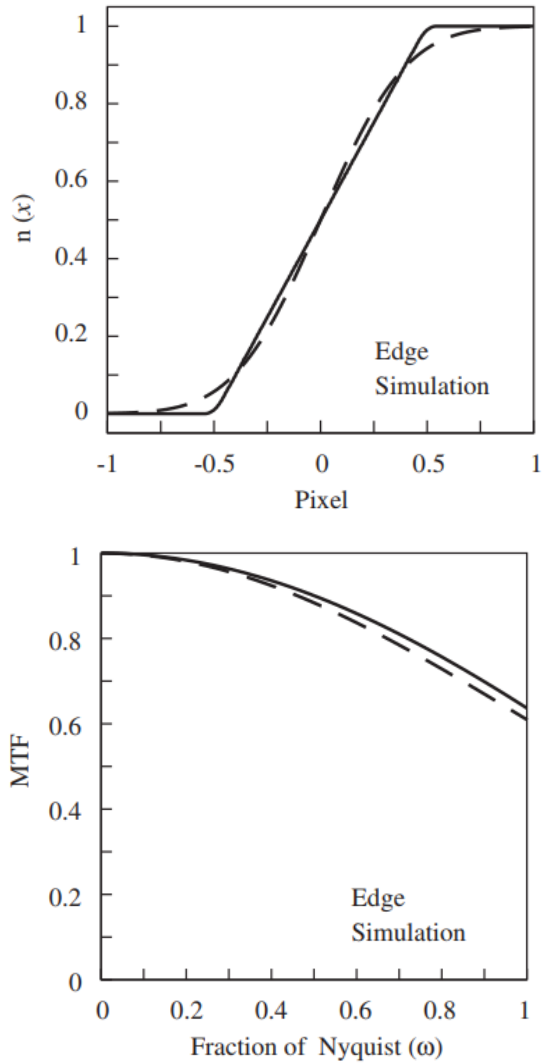


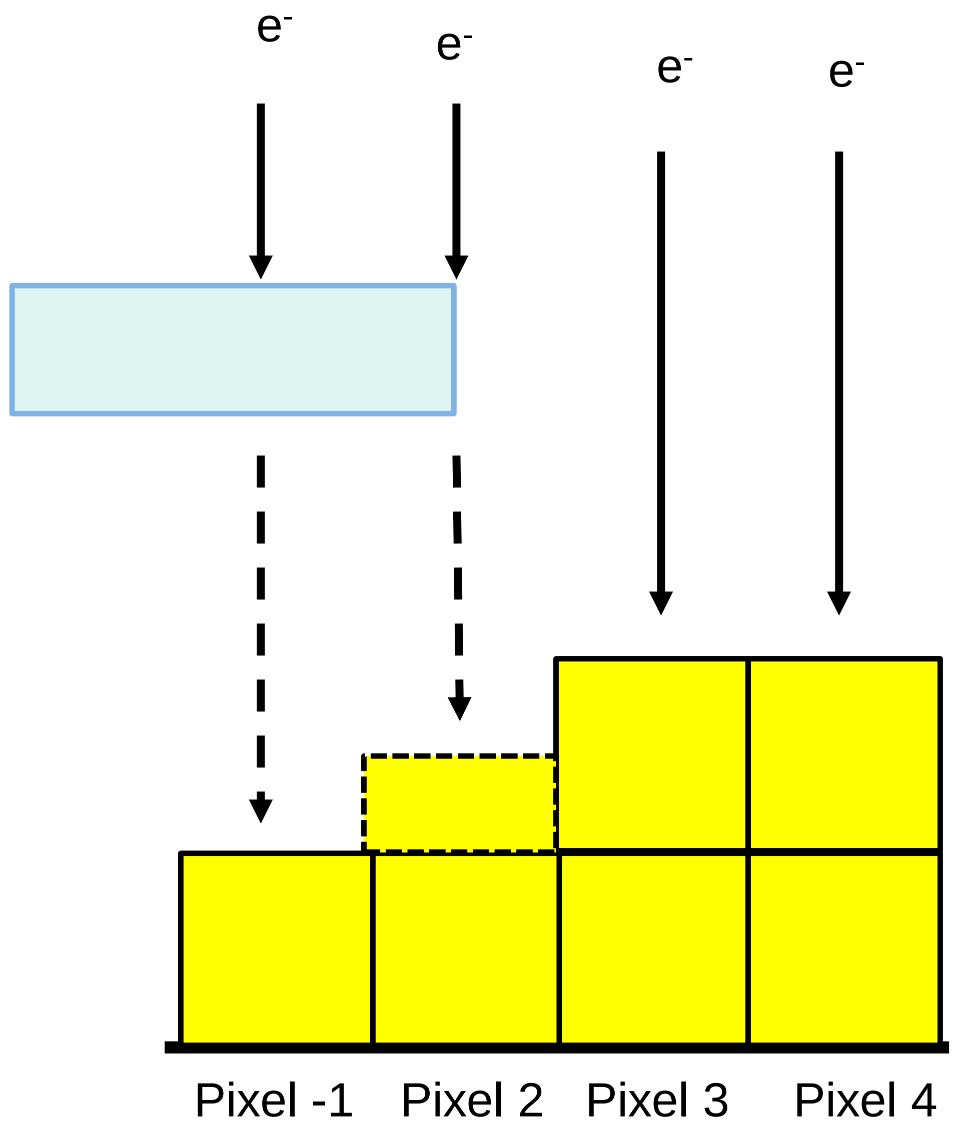
How to measure the MTF

- Cameras are made of pixels[cit. needed] so an atomic width edge does not produce a perfect step function



How to measure the MTF





McMullan, Chen, Henderson, Faruqi (2009)
Ultramicroscopy. 109:1126

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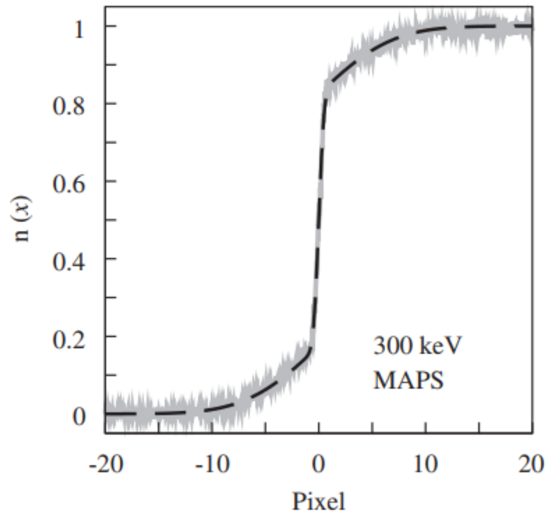
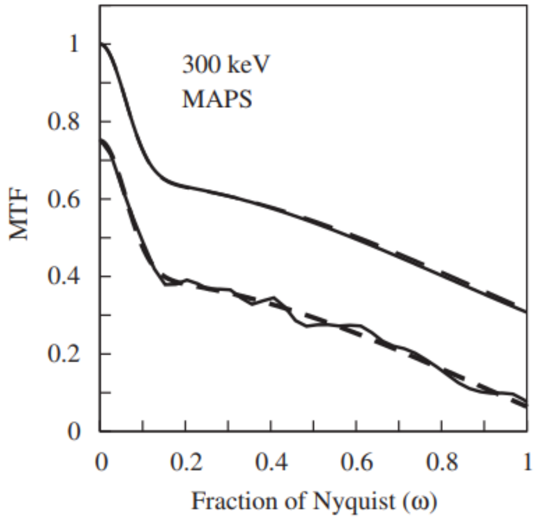
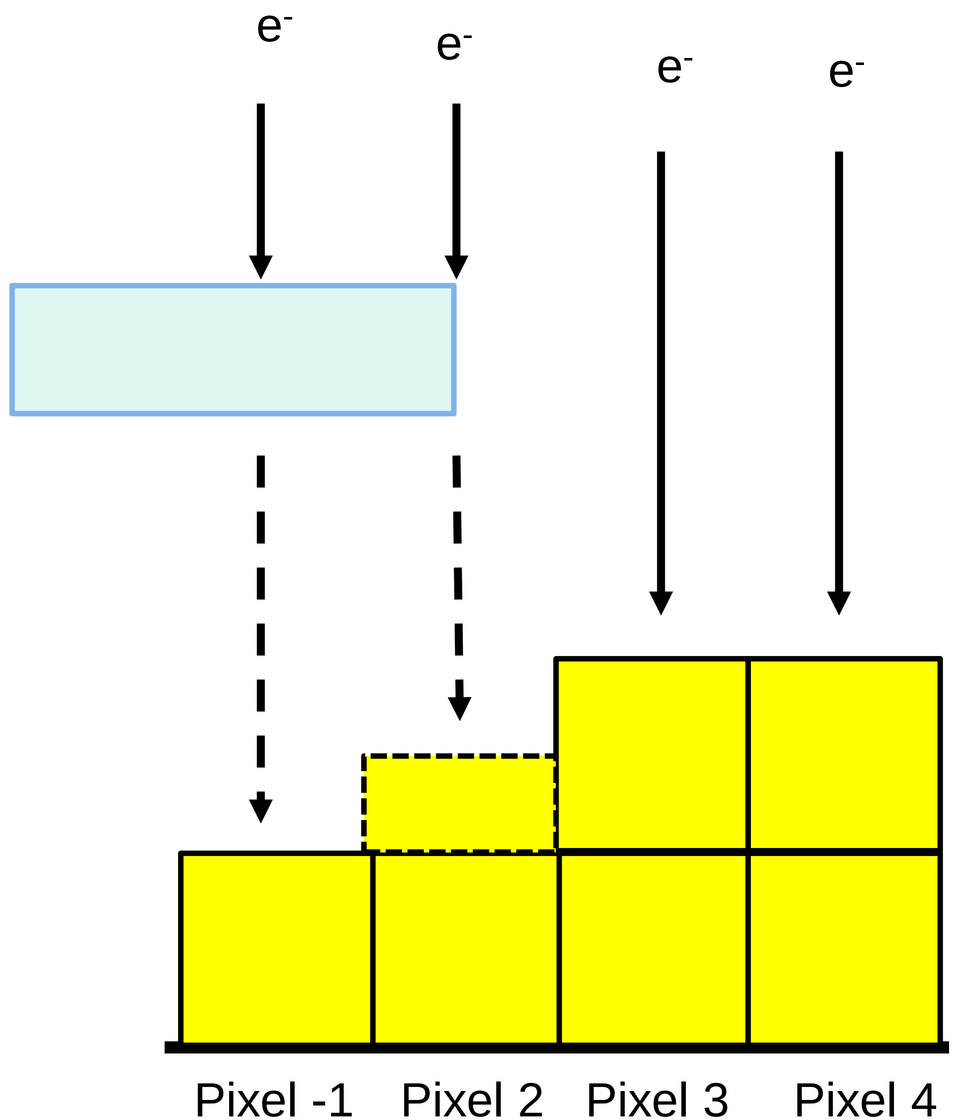
How to measure the MTF







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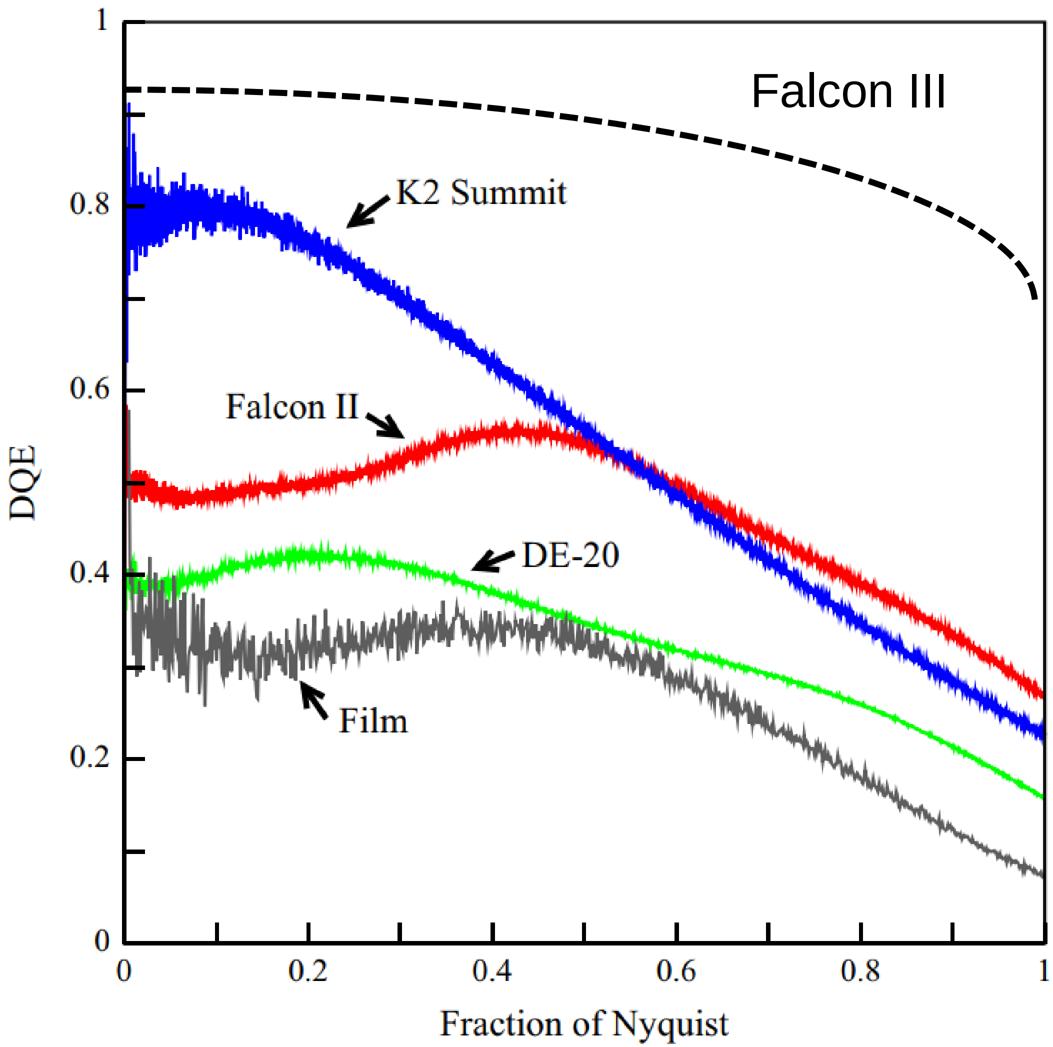
Calculating the DQE

- Complicated
- Partially related to the MTF
- Read: McMullan, Chen, Henderson, Faruqi (2009) Ultramicroscopy. 109:1126

DQE



- Measures how strong the signal will be relative to the noise at a certain spatial frequency.

The DQE relates the level of instrumentation noise to the level of inherent shot noise in the image. It is therefore *the* tool to quantify detector instrumentation noise. The noise in the recorded image follows by

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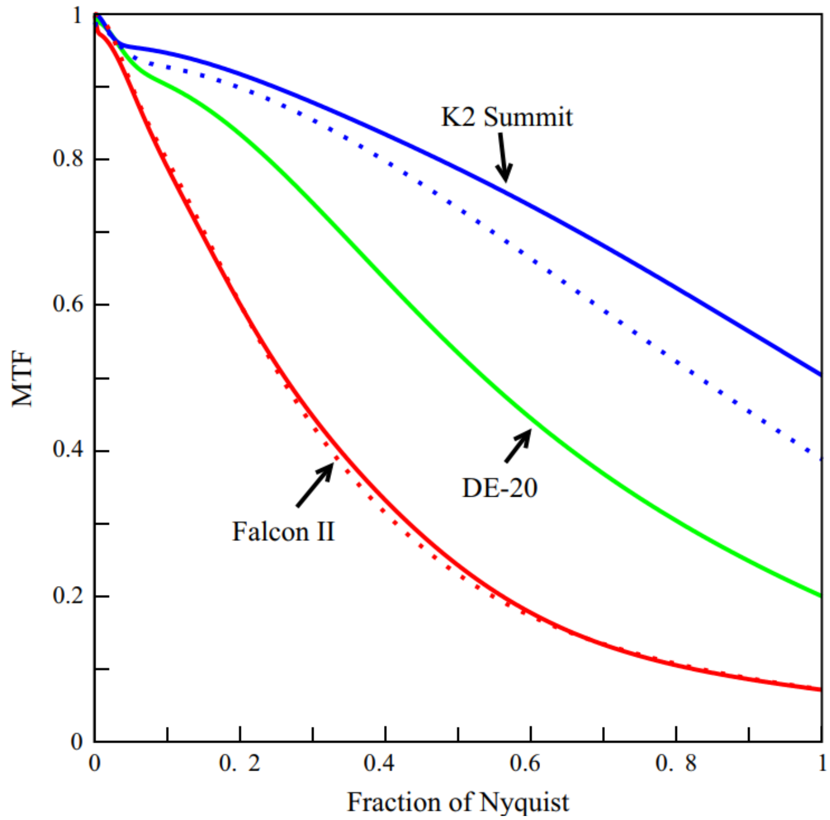
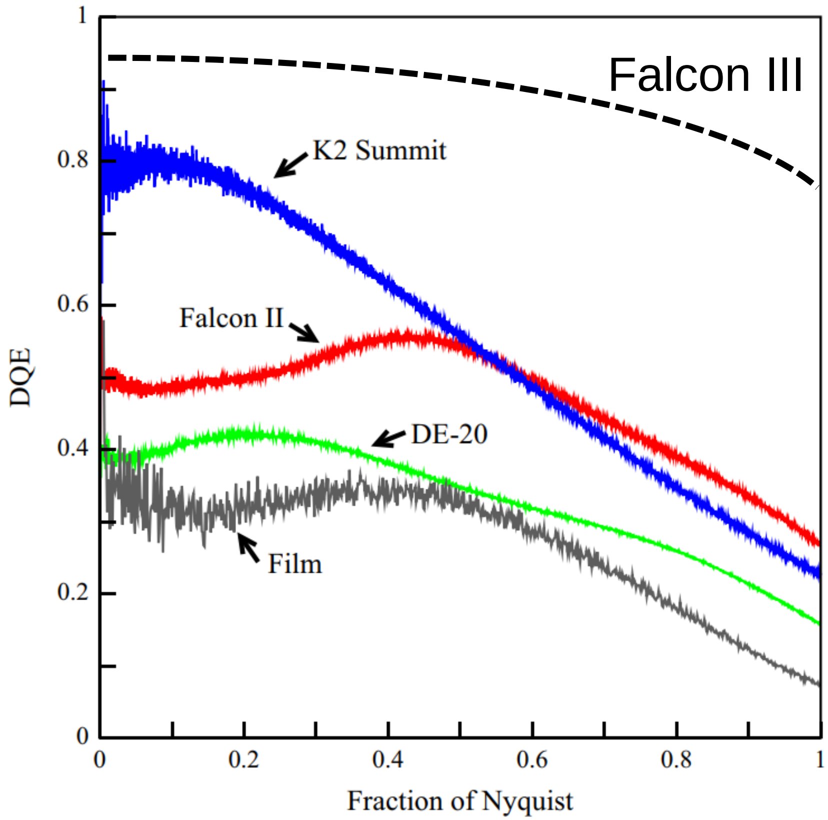
McMullan *et al.* (2014)
Ultramicroscopy, 147:156

MTF & DQE





$$DQE = (S/N)^2_{OUT} / (S/N)^2_{IN}$$

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McMullan *et al.* (2014)
Ultramicroscopy, 147:156

Summary

- DED are better
  - Shot noise
  - Back thinning
  - Motion correction
  - Coincidence loss
- MTF: the camera envelope function
- DQE: Input SNR to output SNR

Next session

- Image formation / CTF