UNIVERSITY OF BIRMINGHAM

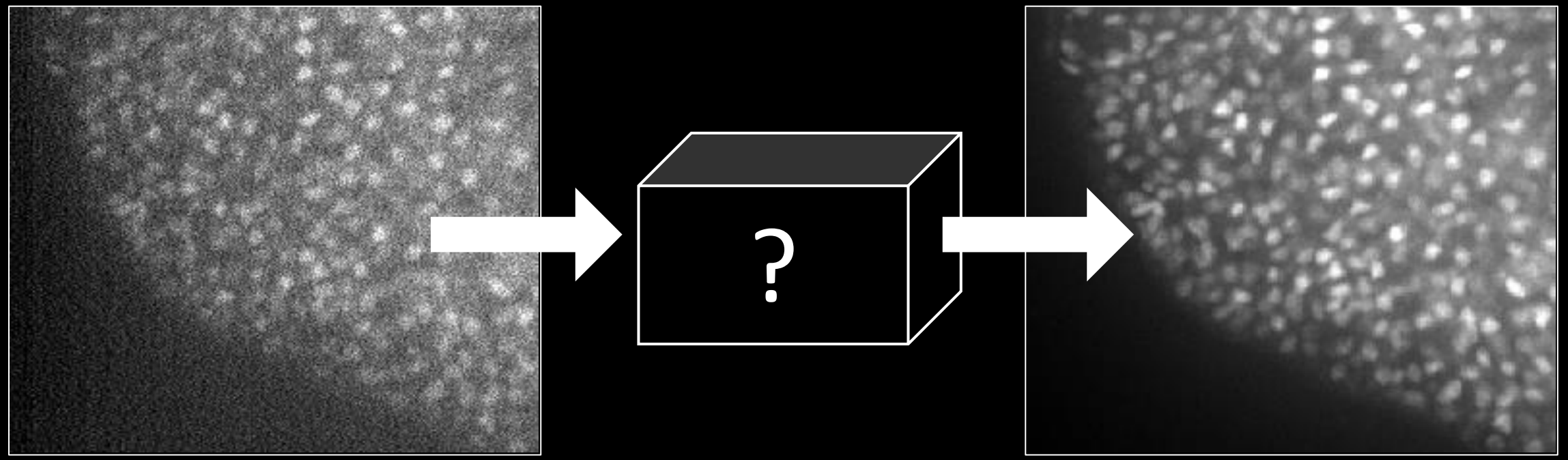
Current Topics in Data Science and AI

Denoising in Scientific Imaging

Background:

Fluorescence Microscopy and Noise

The Problem of Noise



Low exposure:

- Gentle ☺
- Noisy ☹

High exposure:

- Damaging ☹
- Clean ☺

What is Fluorescence Microscopy?

What is Fluorescence?

Fluorescence

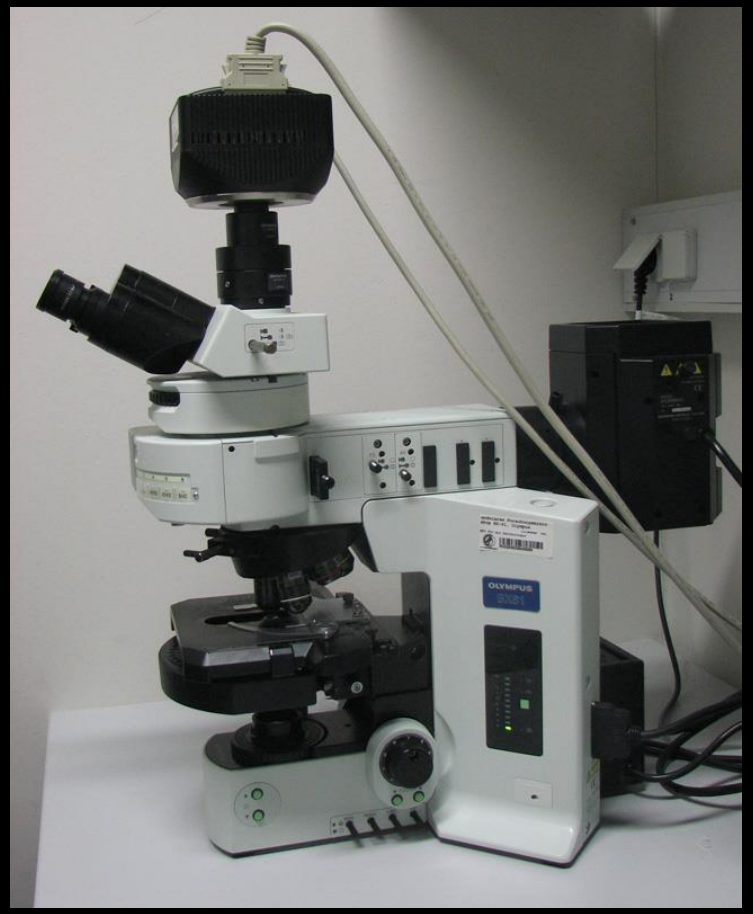
UV Light

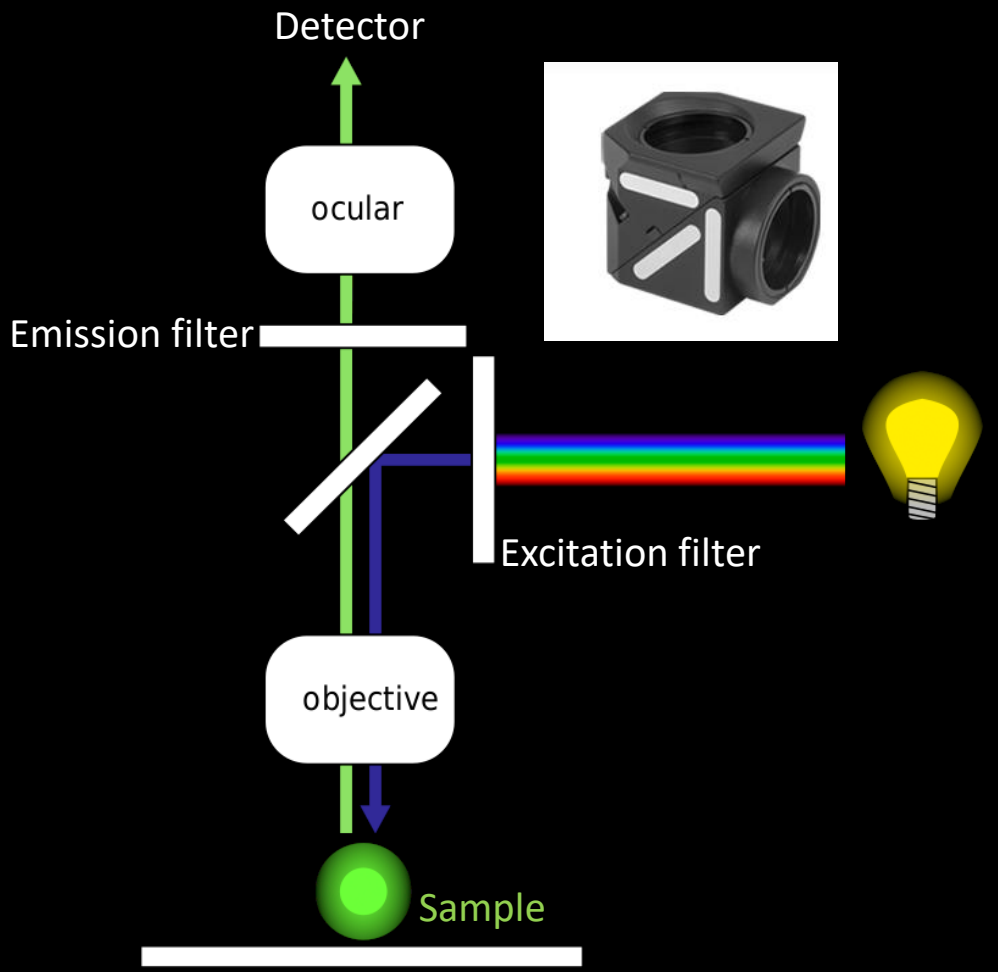
Blue Light

https://www.iceandaslice.co.uk/blogs/news/why-does-your-gin-and-tonic-glow-blue-in-ultraviolet-light

https://en.wikipedia.org/wiki/Optical_brightener#/media/File:LaundrydetergentGlow.jpg

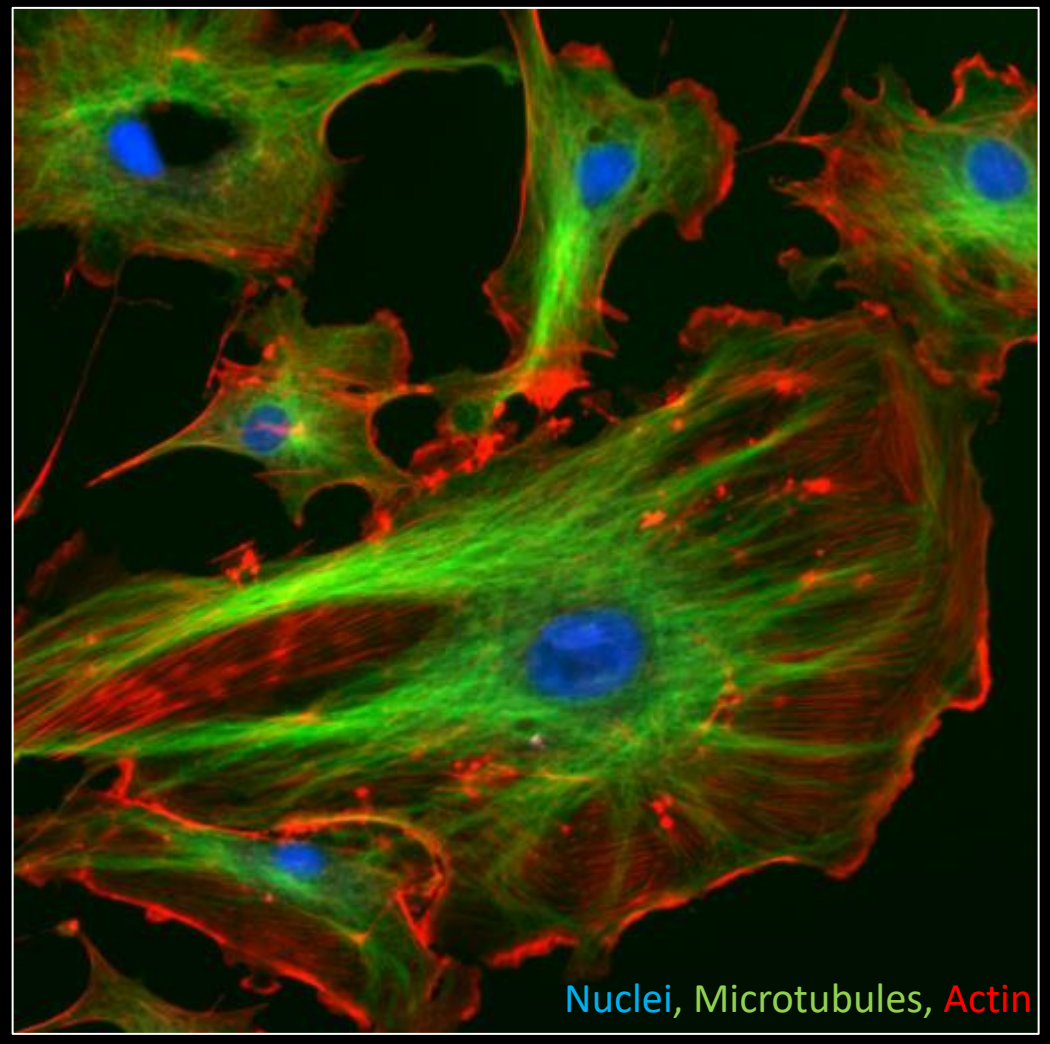
Fluorescence Microscopy

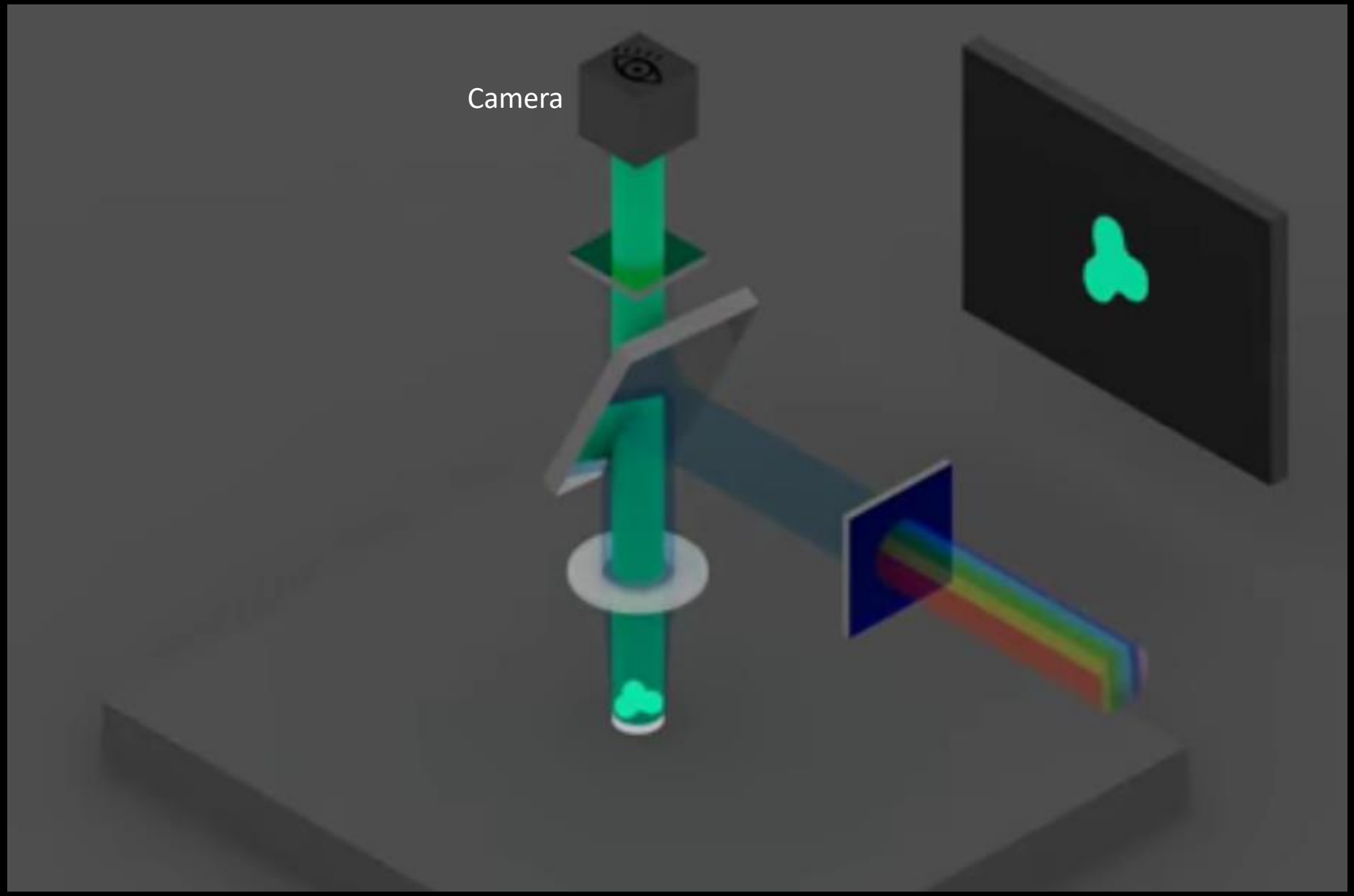




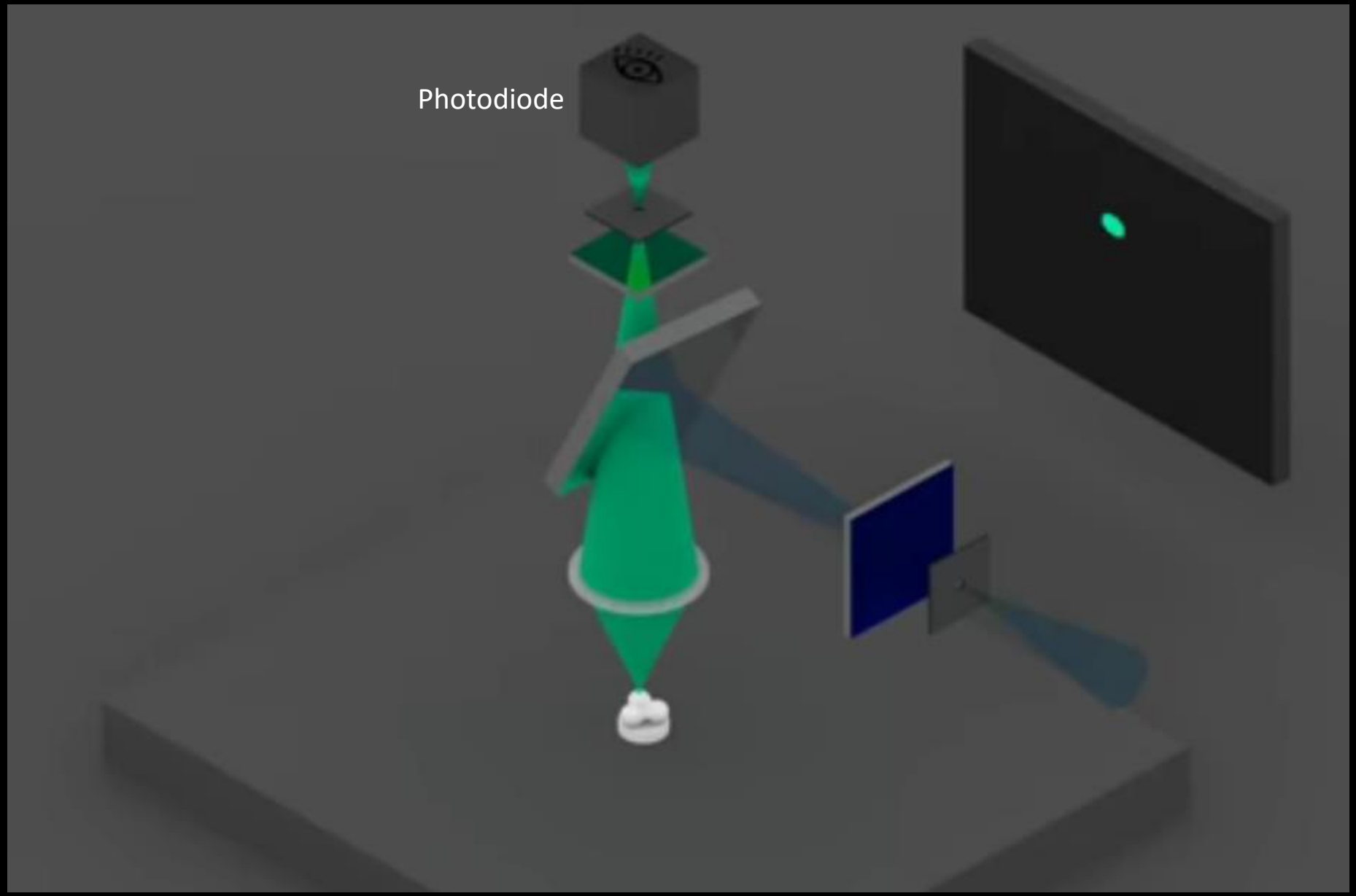
https://en.wikipedia.org/wiki/Fluorescence_microscope#/media/File:FluorescenceFilters_2008-09-28.svg
https://en.wikipedia.org/wiki/Fluorescence_microscope#/media/File:Olympus-BX61-fluorescence_microscope.jpg
https://www.thorlabs.com/

Fluorescence Microscopy





https://en.wikipedia.org/wiki/File:Fluorescent_and_confocal_microscopes.ogv

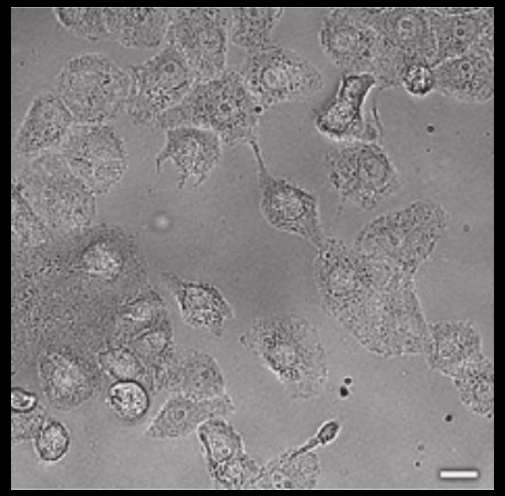


https://en.wikipedia.org/wiki/File:Fluorescent_and_confocal_microscopes.ogv

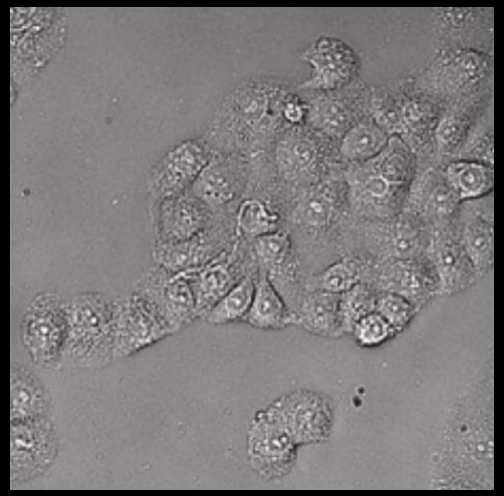
Why is too much Light Harmful?

Phototoxicity

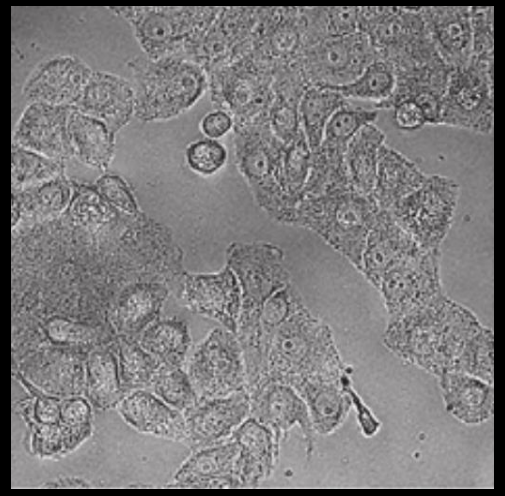
- Cells do not like fluorophores + light.
- Prevents cells from dividing.
- Can damage and kill cells.



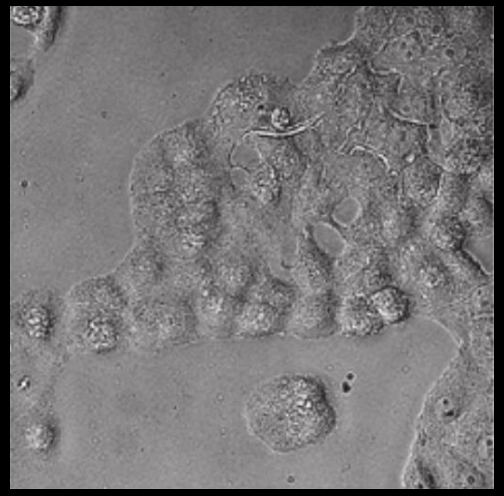
5min of blue light



After 24 hours

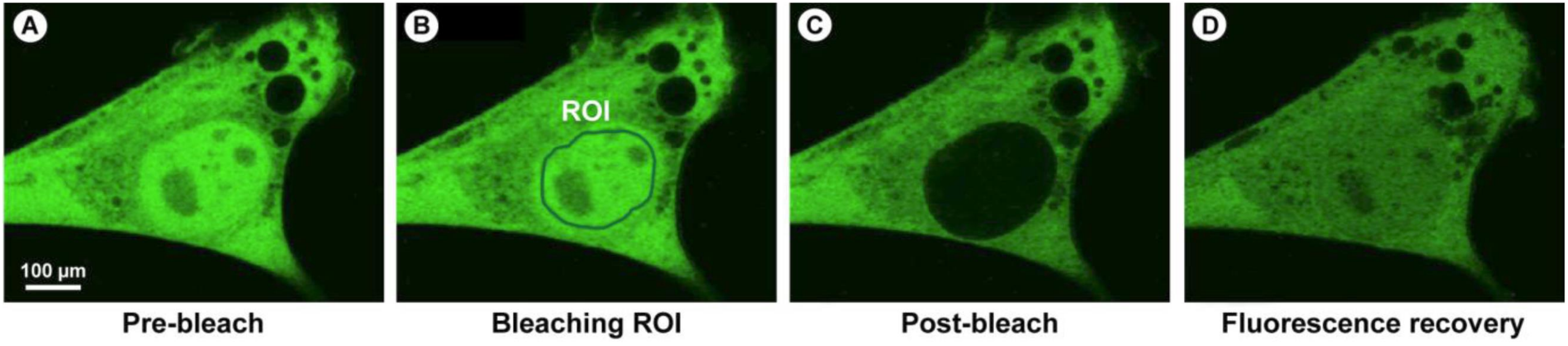


After 24 hours



Laissue et al. 2018

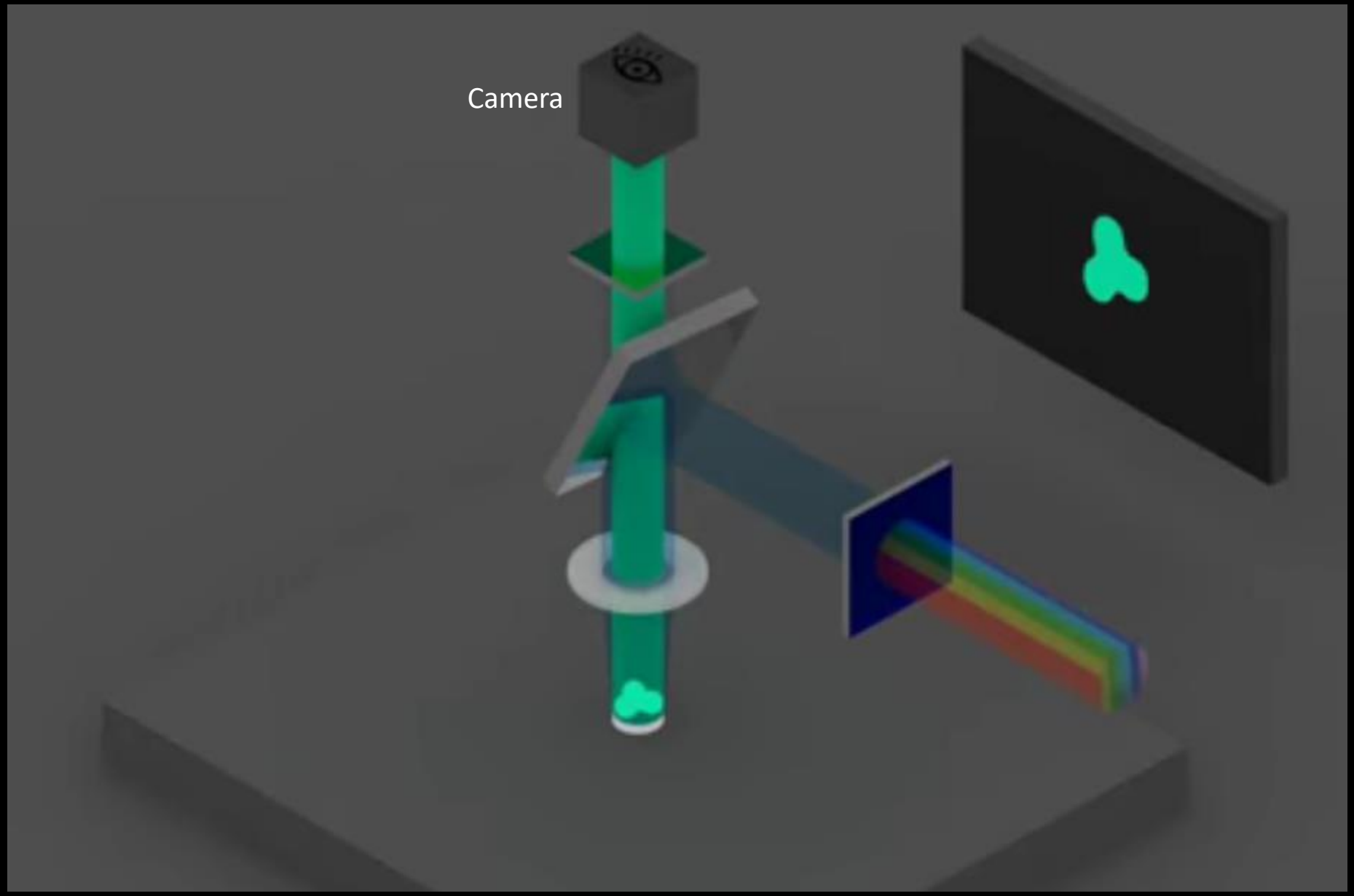
Photobleaching



- Too much light damages fluorophores

Ishikawa-Ankerhold et al. 2012

Why does Low Light Lead to Noisy Images? How can we Quantify Noise?



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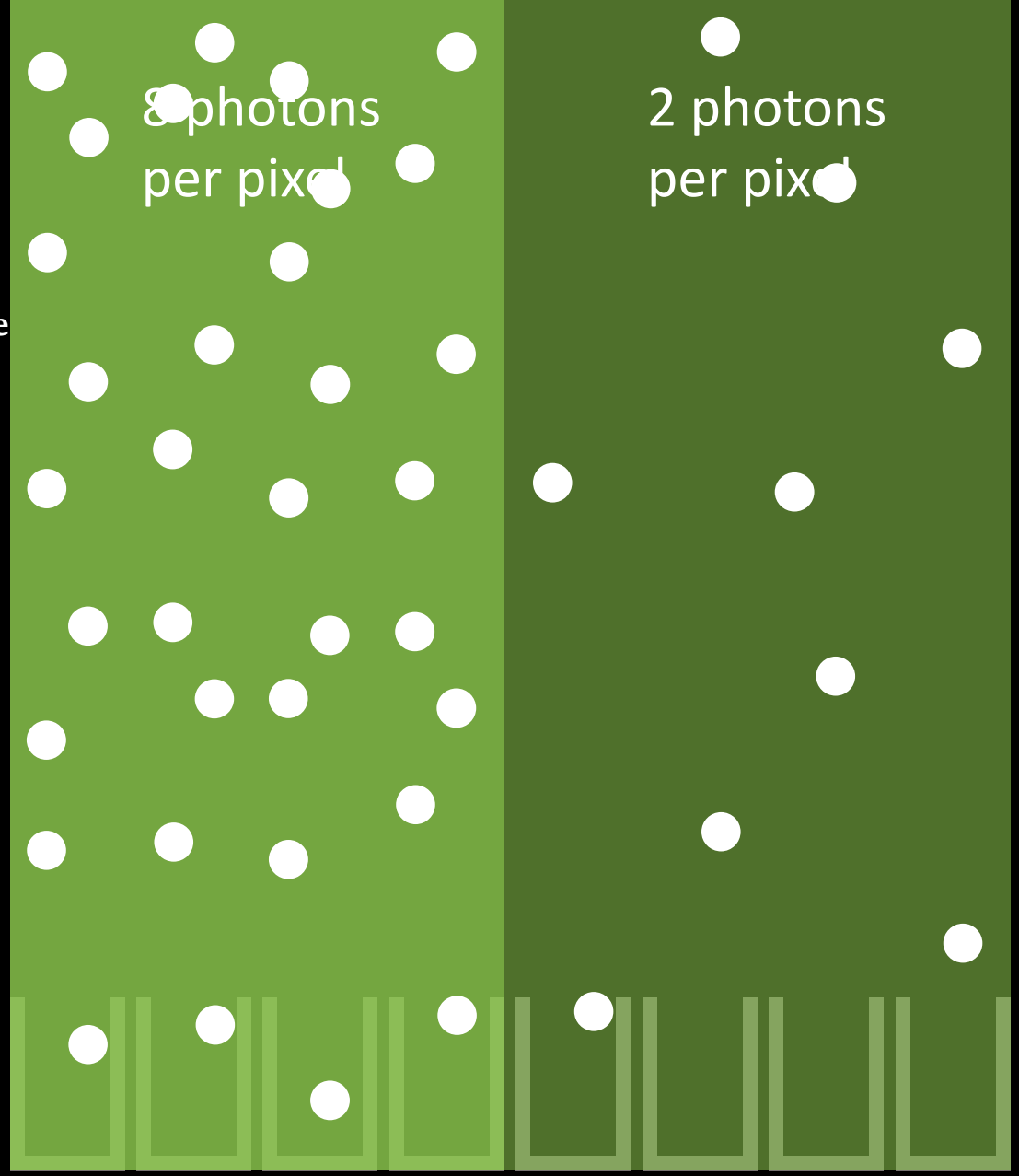
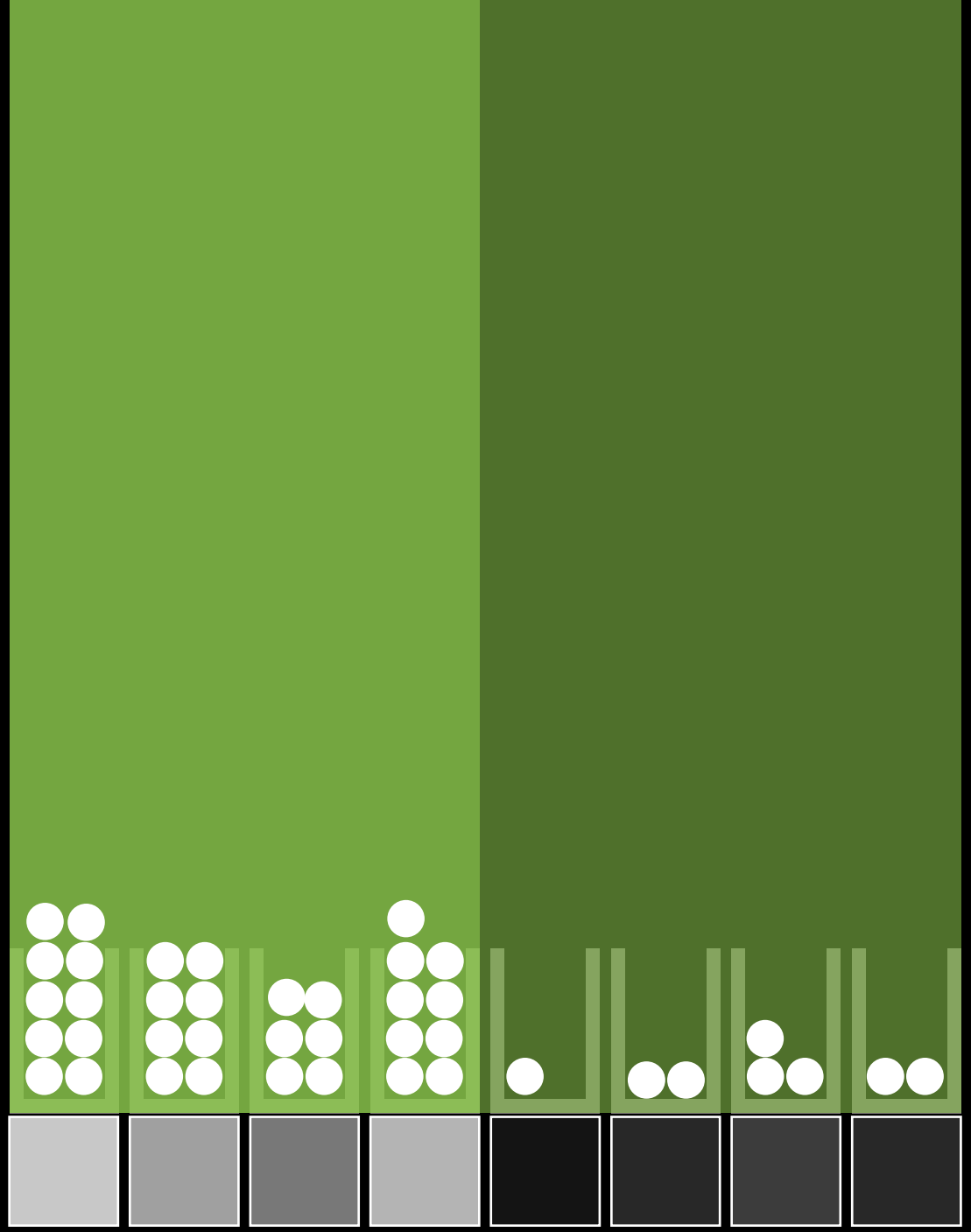
100% light

Full light exposure

Photon
光子

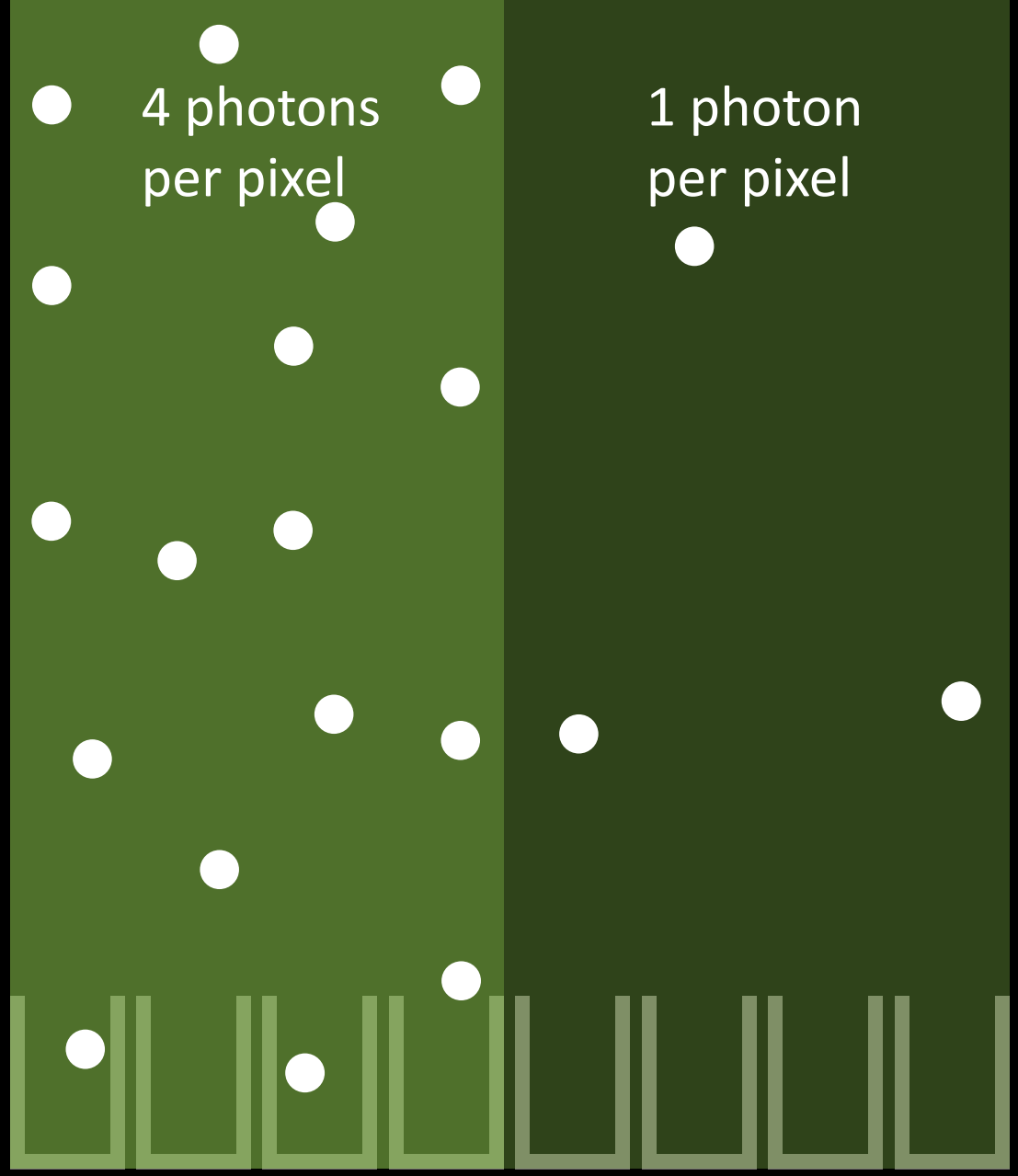


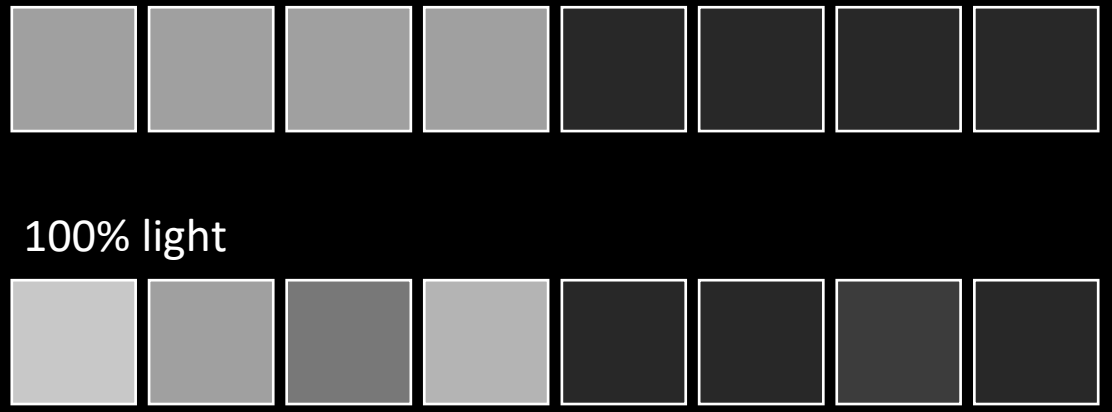
100% light



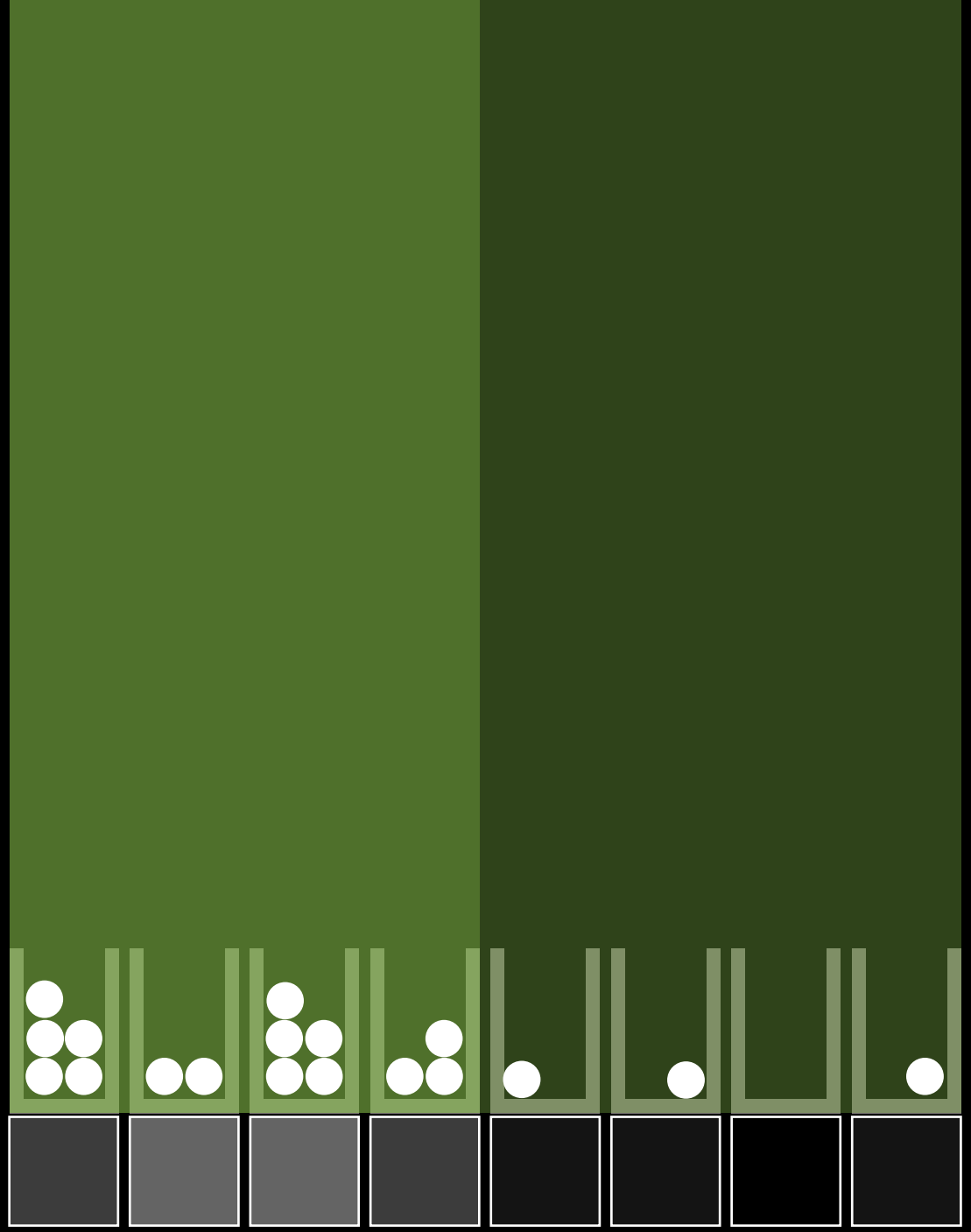
100% light

50% light





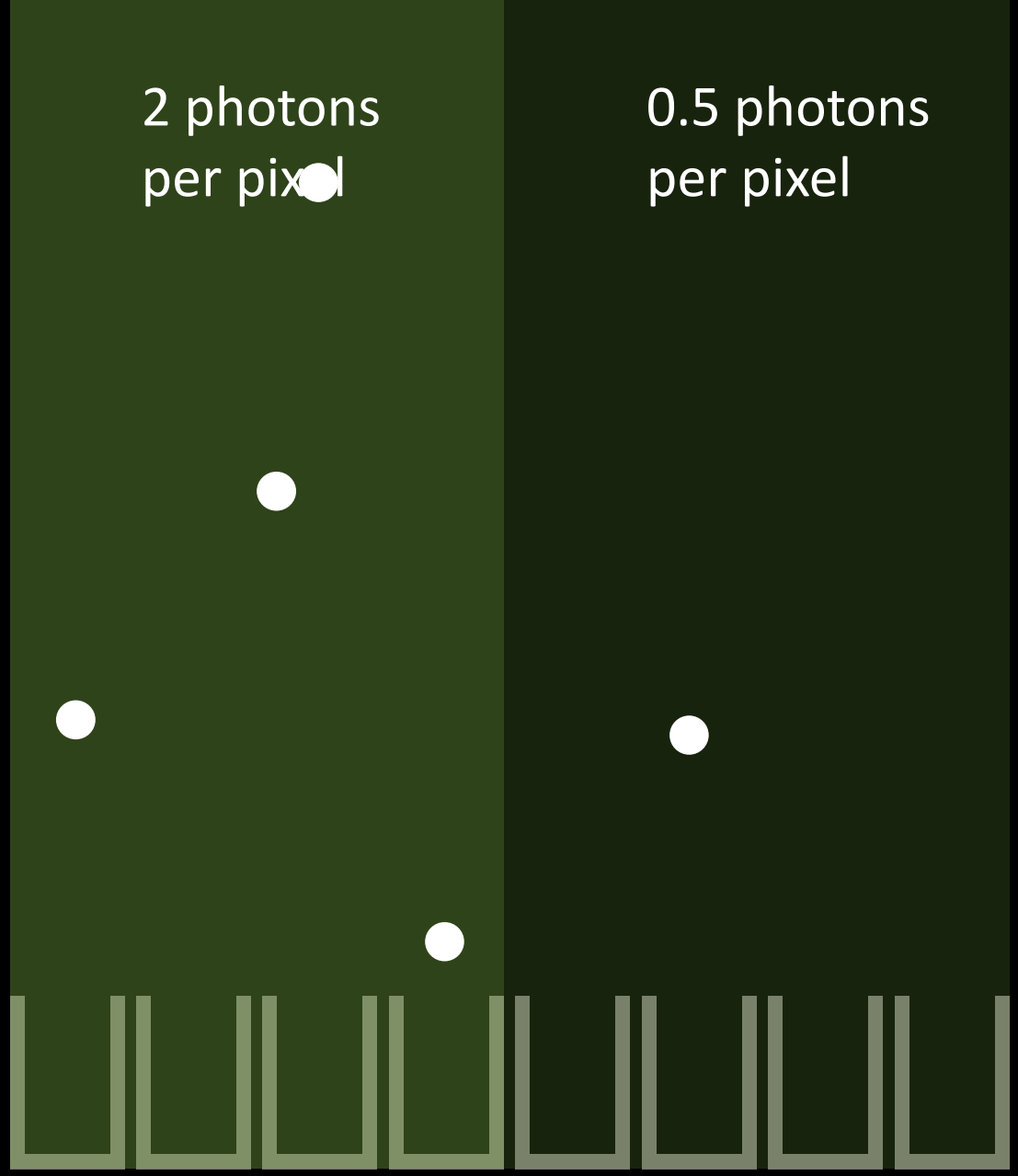
50% light



100% light

50% light x 2

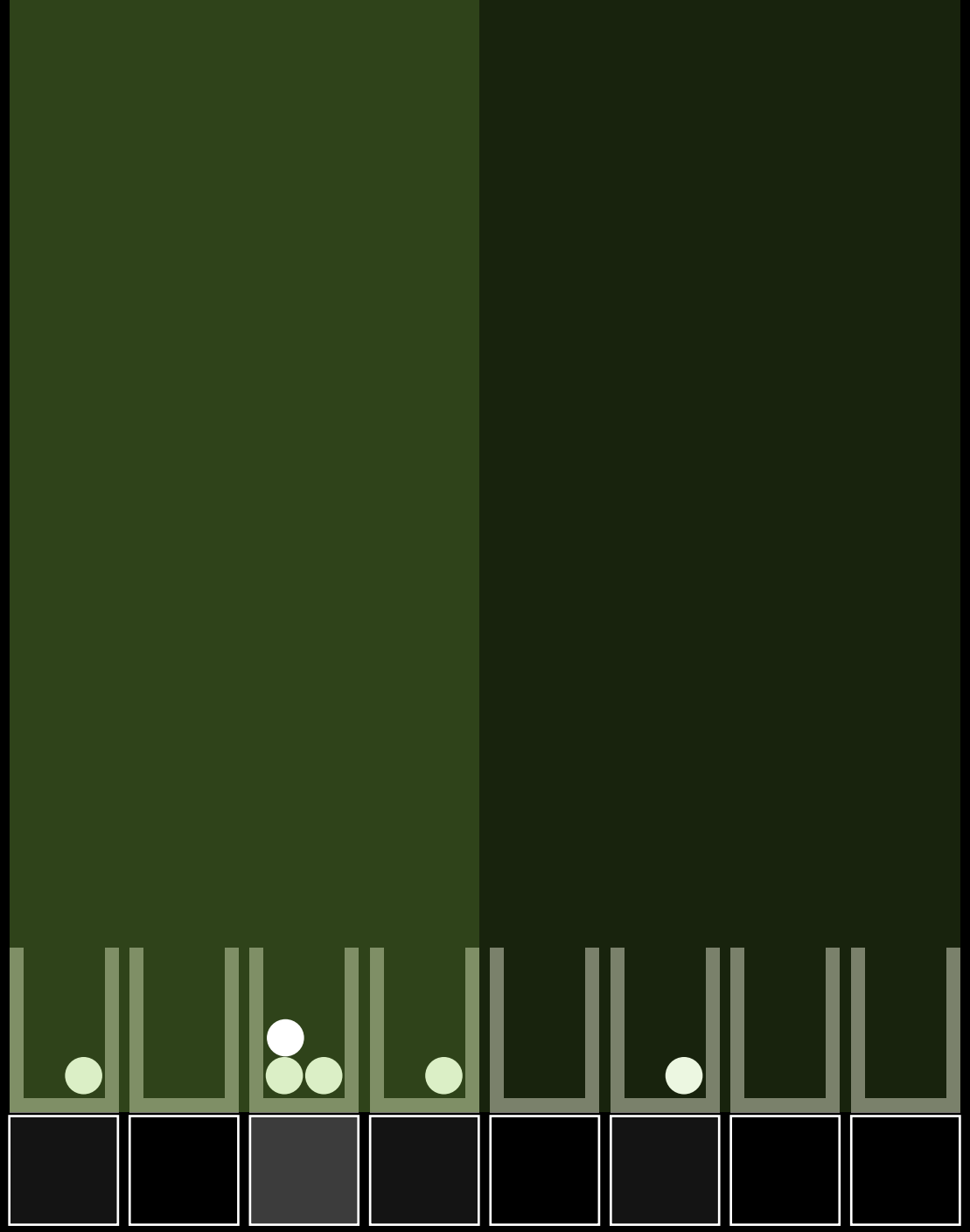
25% light



100% light

50% light x 2

25% light



100% light

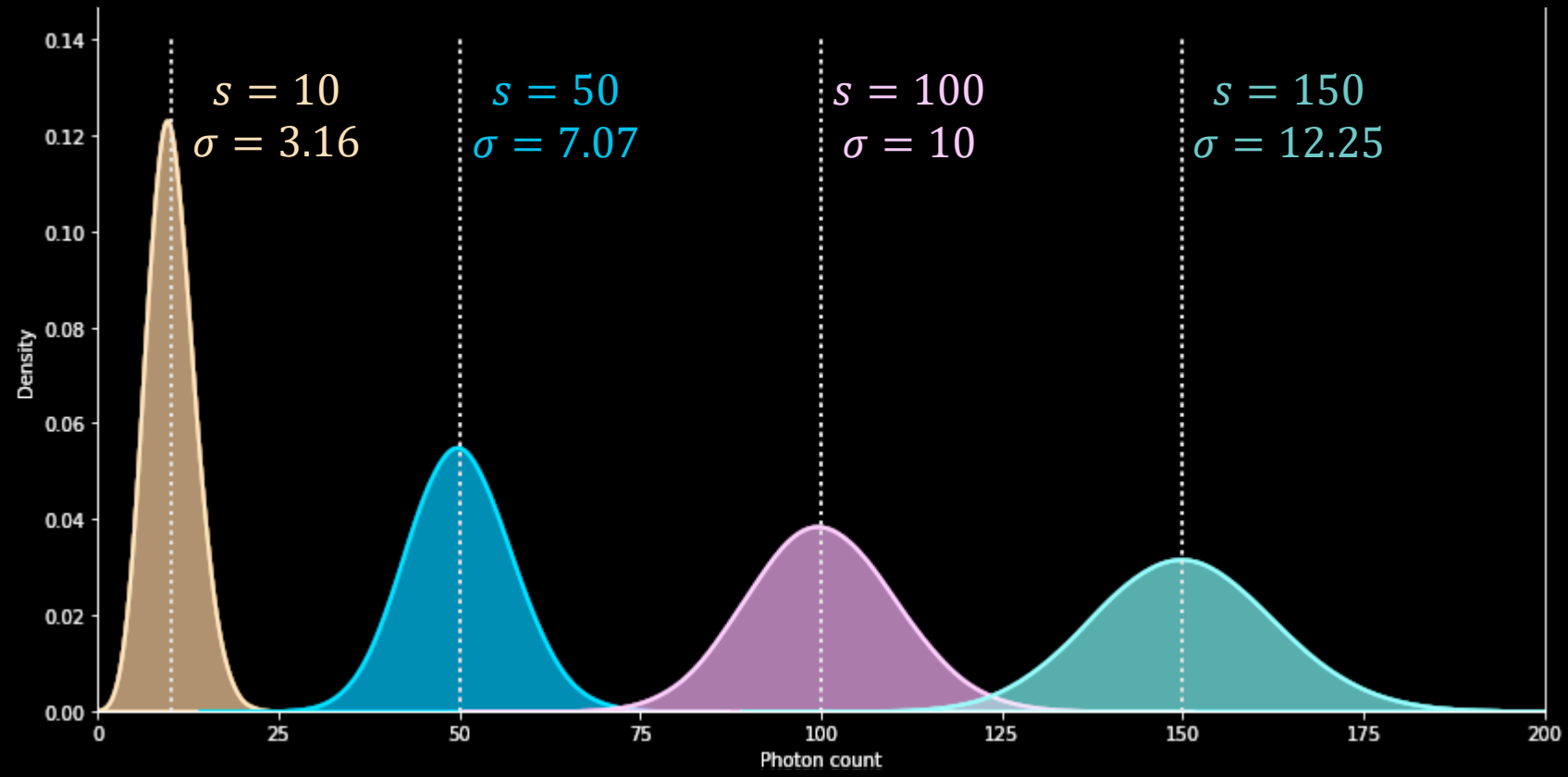
50% light x 2

25% light x 4

Poisson Shot Noise

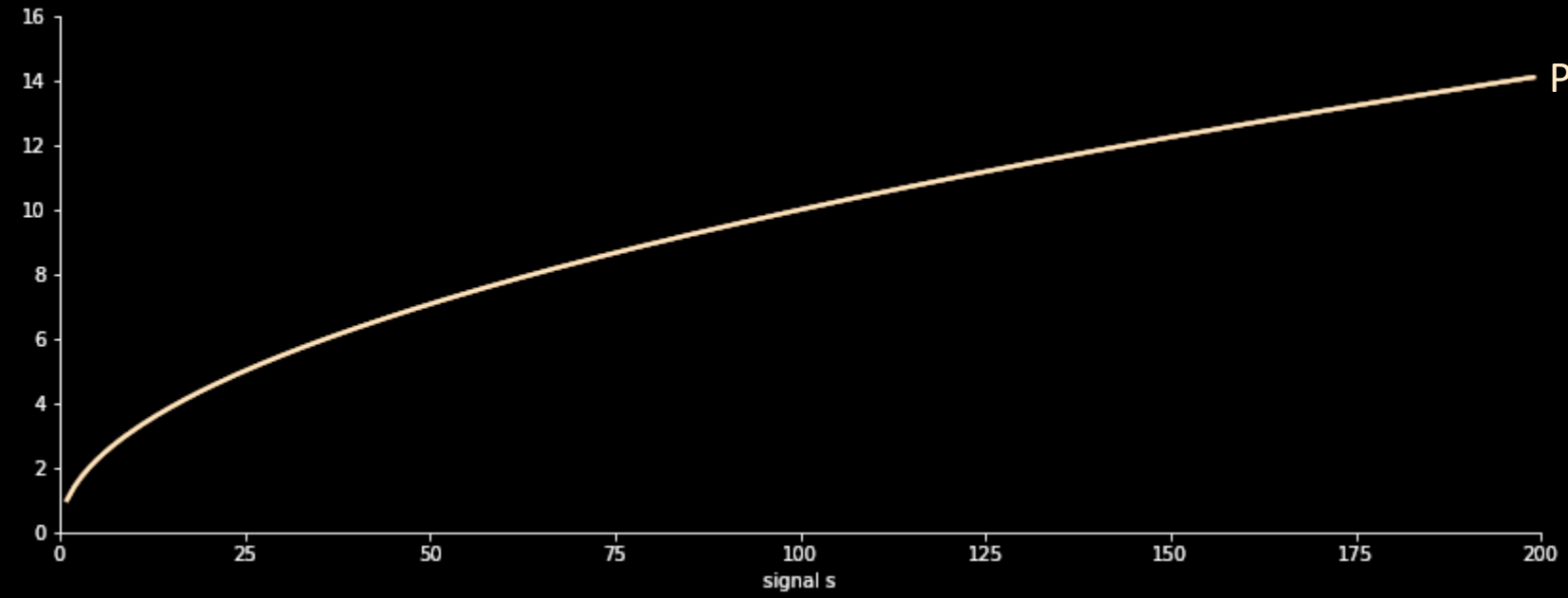
$$p(x_i|s_i) = \frac{s_i^{x_i} e^{-s_i}}{x_i!}$$

standard deviation is the square root of variance



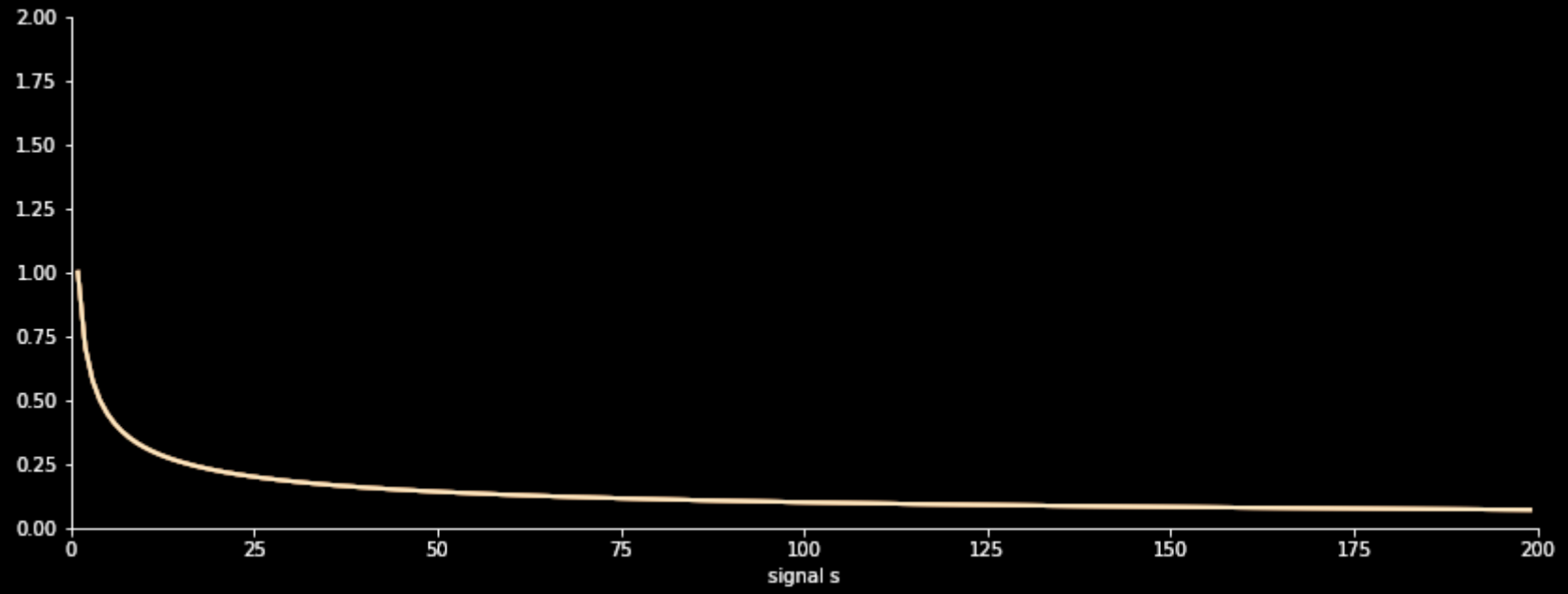
$\sigma = \sqrt{s}$

Noise std.
σ



Poisson noise

Noise std.
per signal
σ/s



Quantifying Noise

- The noise increases with the signal.
- We must consider the ratio between signal and noise.

Peak Signal to Noise Ratio (PSNR):

$$\mathrm{MSE}(\boldsymbol{s},\boldsymbol{x}) = \frac{1}{n}\sum_{i}^{n}(s_i - x_i)^2$$

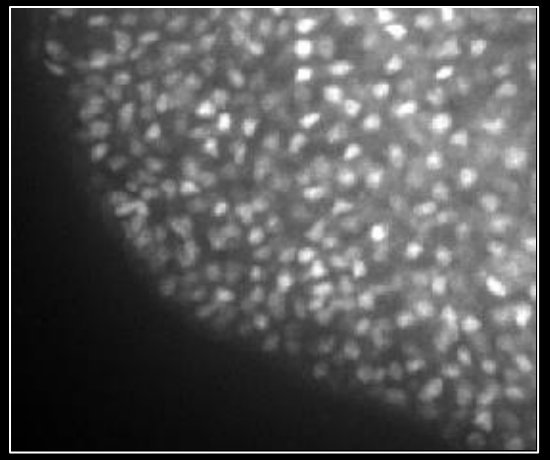
Clean value

Noise value

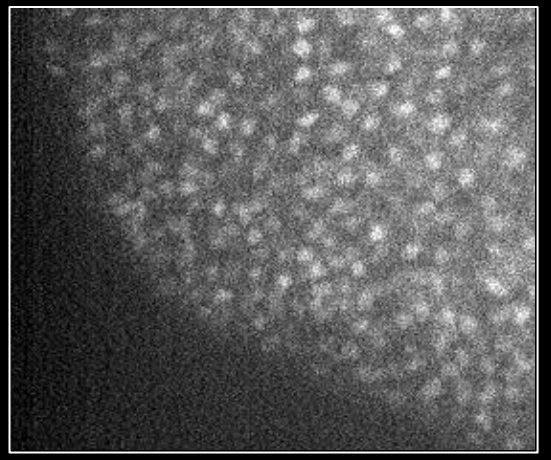
$$\mathrm{PSNR}(\boldsymbol{s},\boldsymbol{x}) = 20\log_{10}\left(\frac{\max(\boldsymbol{s}) - min(\boldsymbol{s})}{\sqrt{\mathrm{MSE}(\boldsymbol{s},\boldsymbol{x})}}\right)$$

decibel

Content preseveration



Clean image $\boldsymbol{s}$



Noisy image $\boldsymbol{x}$

Summary

- Fluorescence microscopy:
  - Excitation in one wavelength
  - Emit in other wavelength
  - Trade off between noise and sample preservation
- Noise:
  - Shot noise is result of discrete photons
  - Stronger signal:
    - More noise
    - Better signal to noise ratio
  - Measured in Peak Signal to Noise Ratio
    - Requires clean image