What Is Spectral Imaging?
An Introduction

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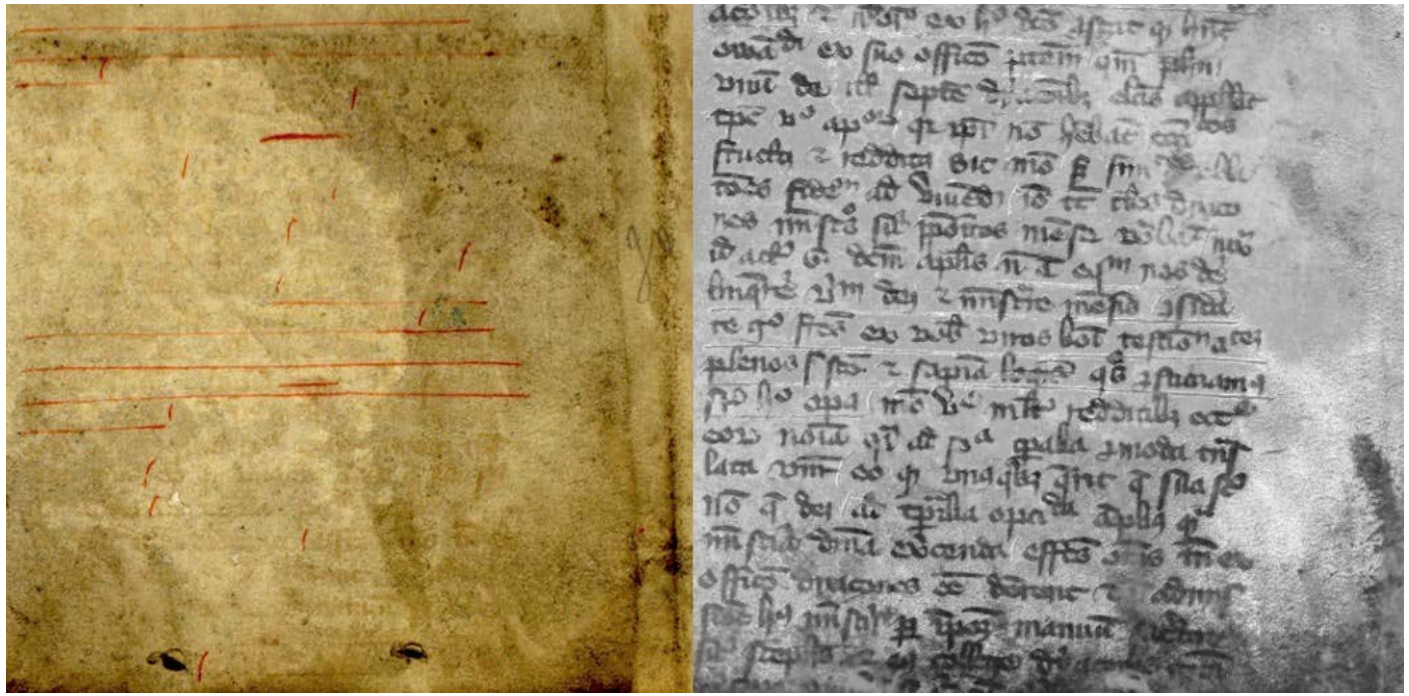


Ricardus Dialogue (University of Rochester, D.460 1000-003) before and after spectral image processing

What is Spectral Imaging?

- Over time (passive) imaging systems have improved their spectral (i.e., color) response, range, and sensitivity
  - B&W (1 spectral band)
  - Color (RGB, 3 spectral bands)
  - “Multispectral” (typically a filtered or colored illumination system)
  - “Hyperspectral” (use of a diffraction element such as a prism or grating)

- Why more bands?
  - *more spectral information* leads to *greater material separability*

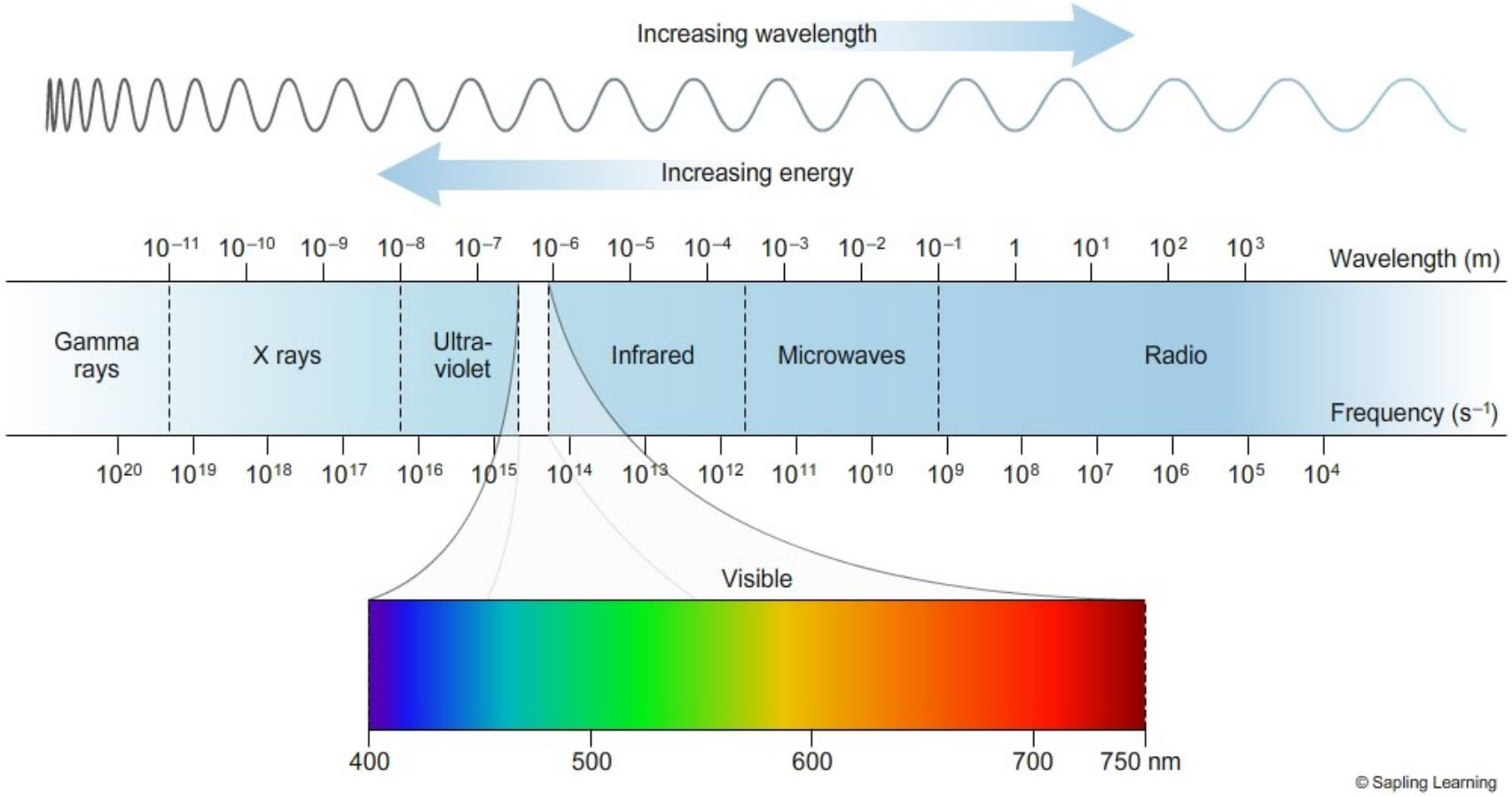
Why Use Spectral Imaging?

Basic Outline of Talk

- Definitions: light, wavelength, and color
- Overview of imaging systems
  - What the camera sees
  - How to collect color imagery
  - Difference between multi- & hyperspectral
  - Calibration, registration
- Basic image processing concept
  - Spatial processing
  - Spectral processing
- Questions

Definitions

- Wavelength: related to the energy of light and color; typically written as λ

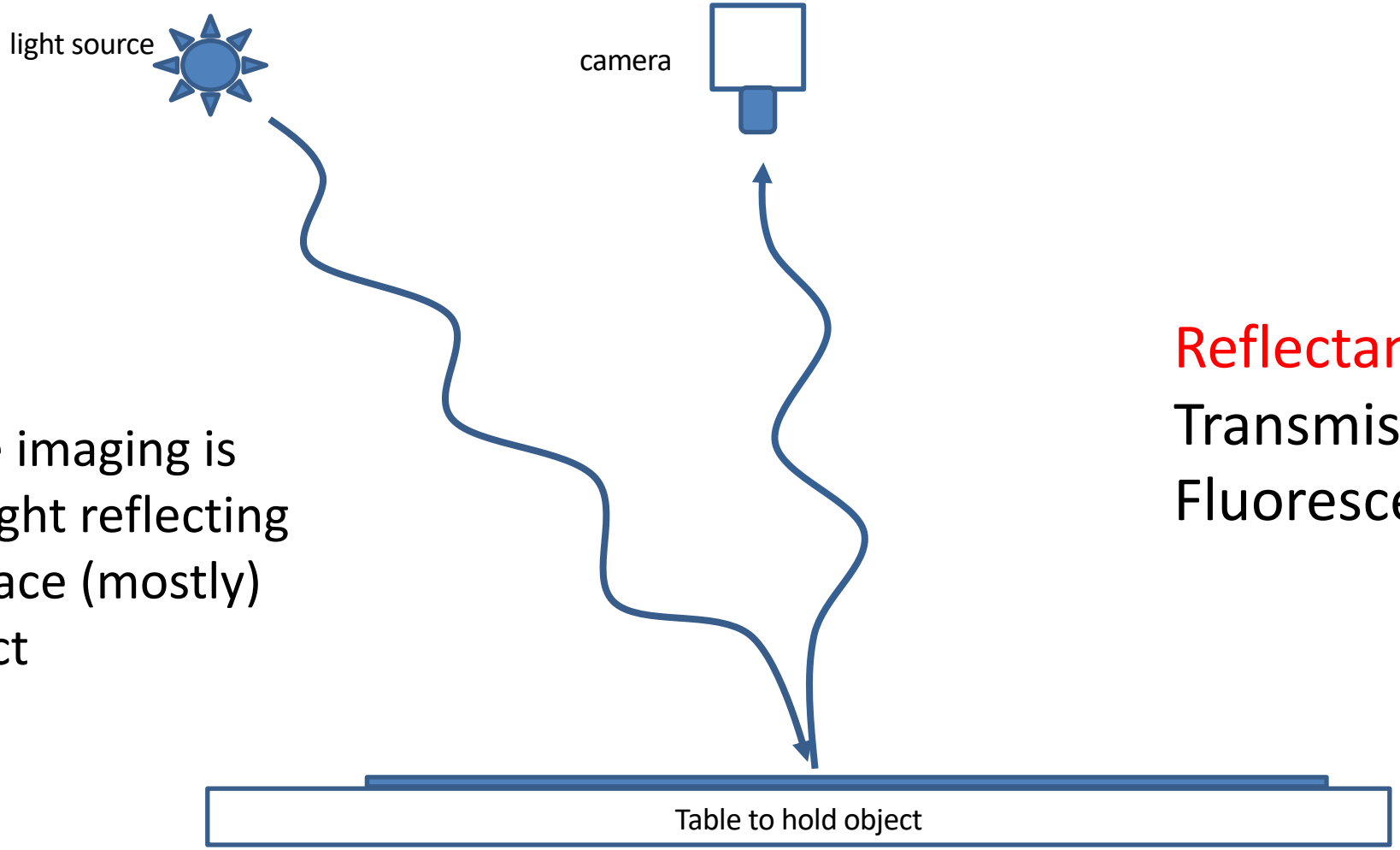


Definitions

- **Color**: optical property of materials; how it selectively reflects light
- **Reflectance**: efficiency with which an object reflects light as a function of wavelength
- **Fluorescence**: material property by which light is emitted at a different wavelength that it is illuminated with
- **Spectral band / channel**: a specific color in an imaging system
- **Resolution**: the projected area of each pixel on the detector onto the object
- **Spectral response**: how sensitive the detector is to each wavelength of light

- **Important:** If we say anything that you don't understand or know the meaning of speak up!

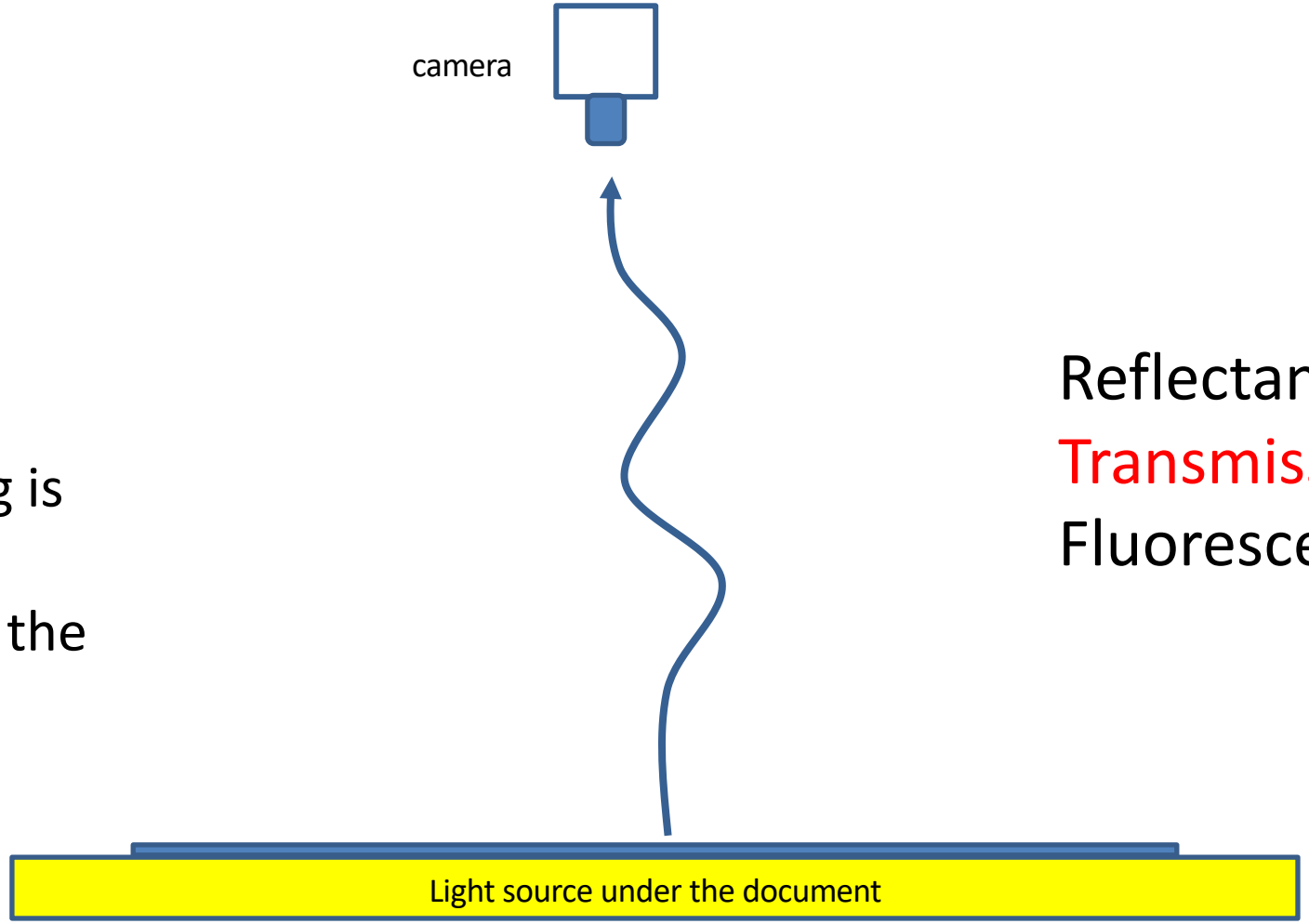
Imaging System: What the Camera Sees



Reflectance imaging is collecting light reflecting off the surface (mostly) of the object

Reflectance vs.
Transmission vs.
Fluorescence

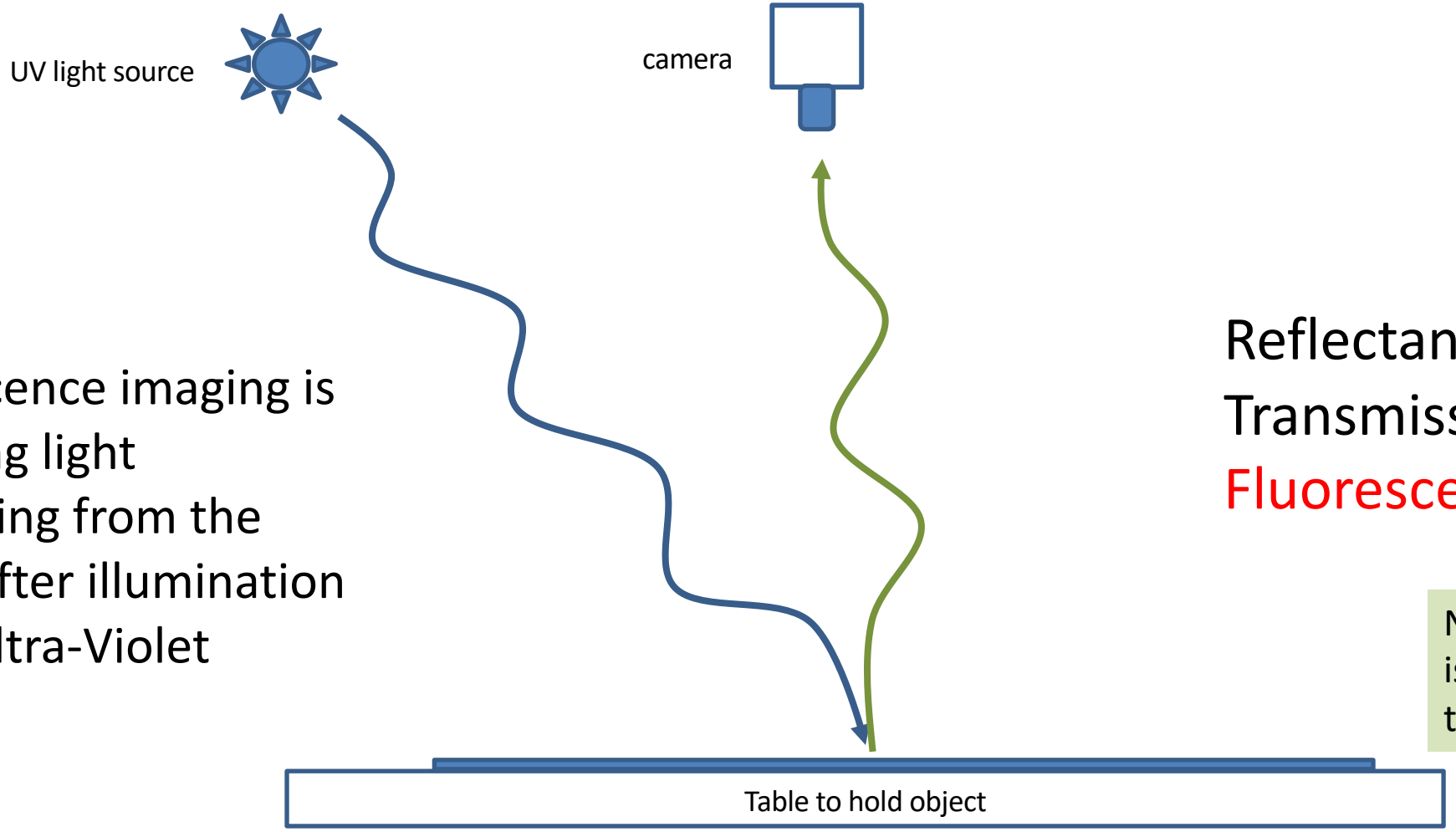
Imaging System: What the Camera Sees



Transmissive imaging is collecting light being transmitted through the object from behind

Reflectance vs.
Transmission vs.
Fluorescence

Imaging System: What the Camera Sees

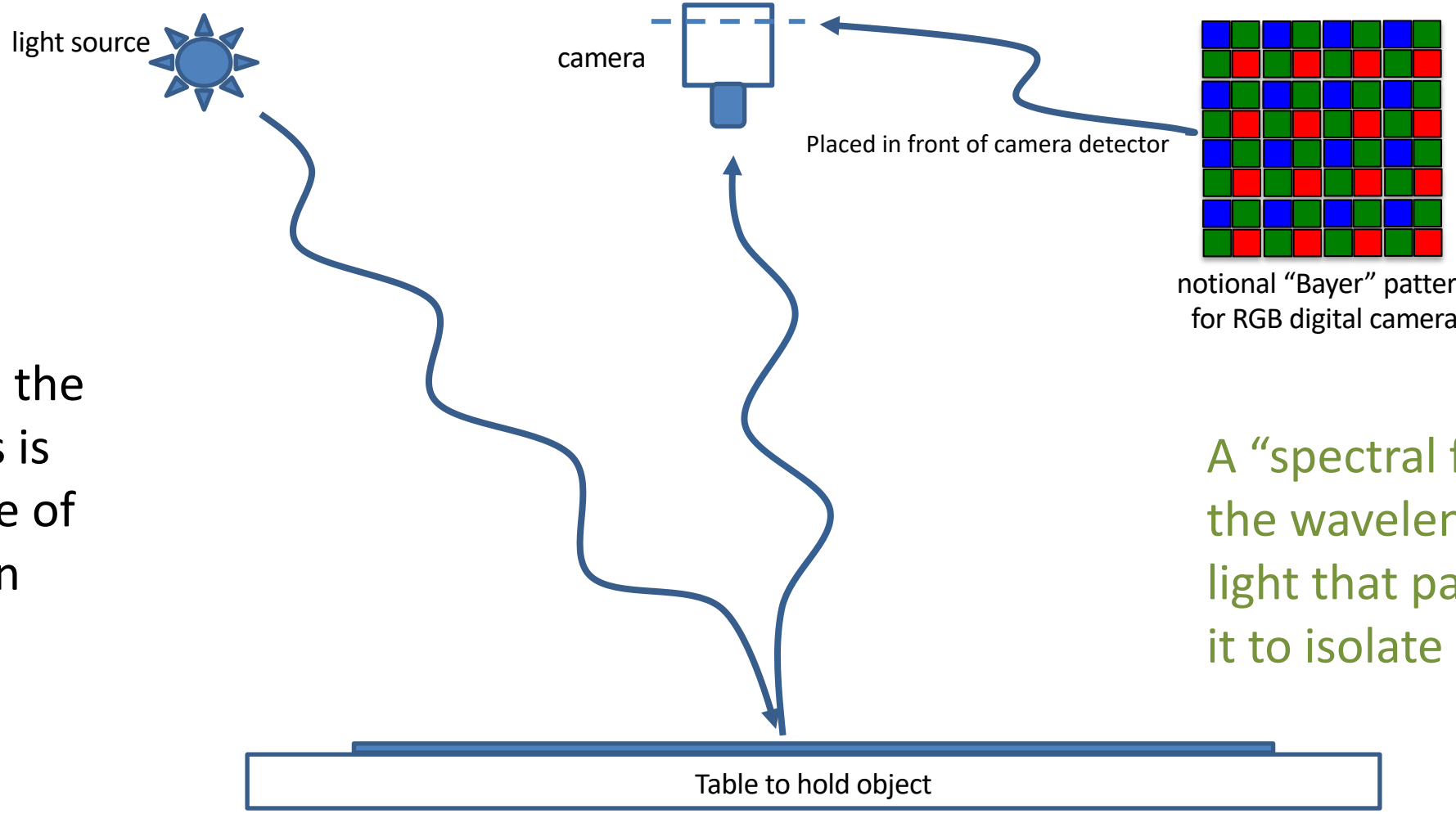


Fluorescence imaging is collecting light fluorescing from the object after illumination in the Ultra-Violet

Reflectance vs.
Transmission vs.
Fluorescence

Note that the fluorescence is at a different wavelength than the illumination

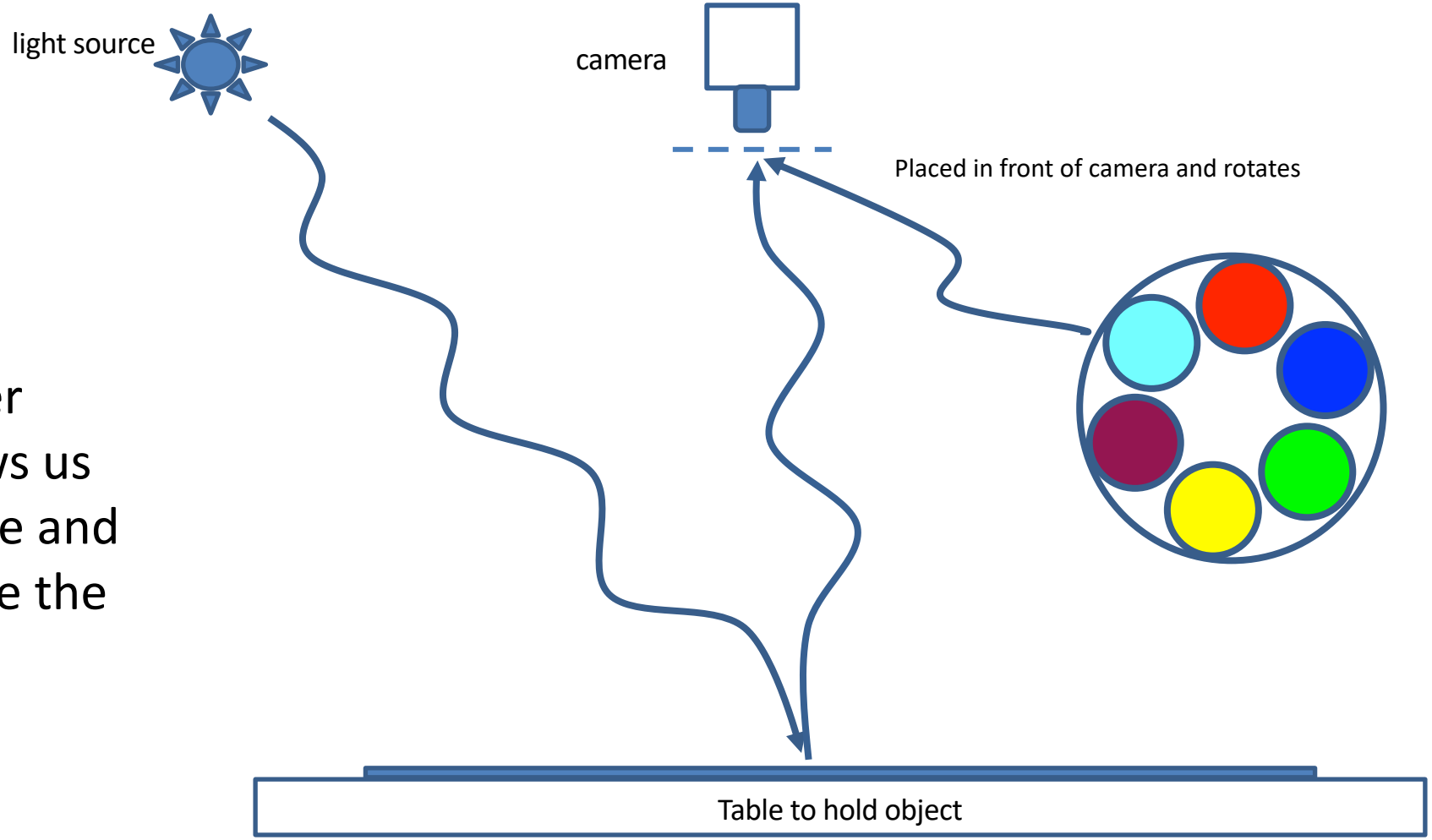
Imaging System: Your Cell Phone



In this case, the set of filters is fixed at time of construction

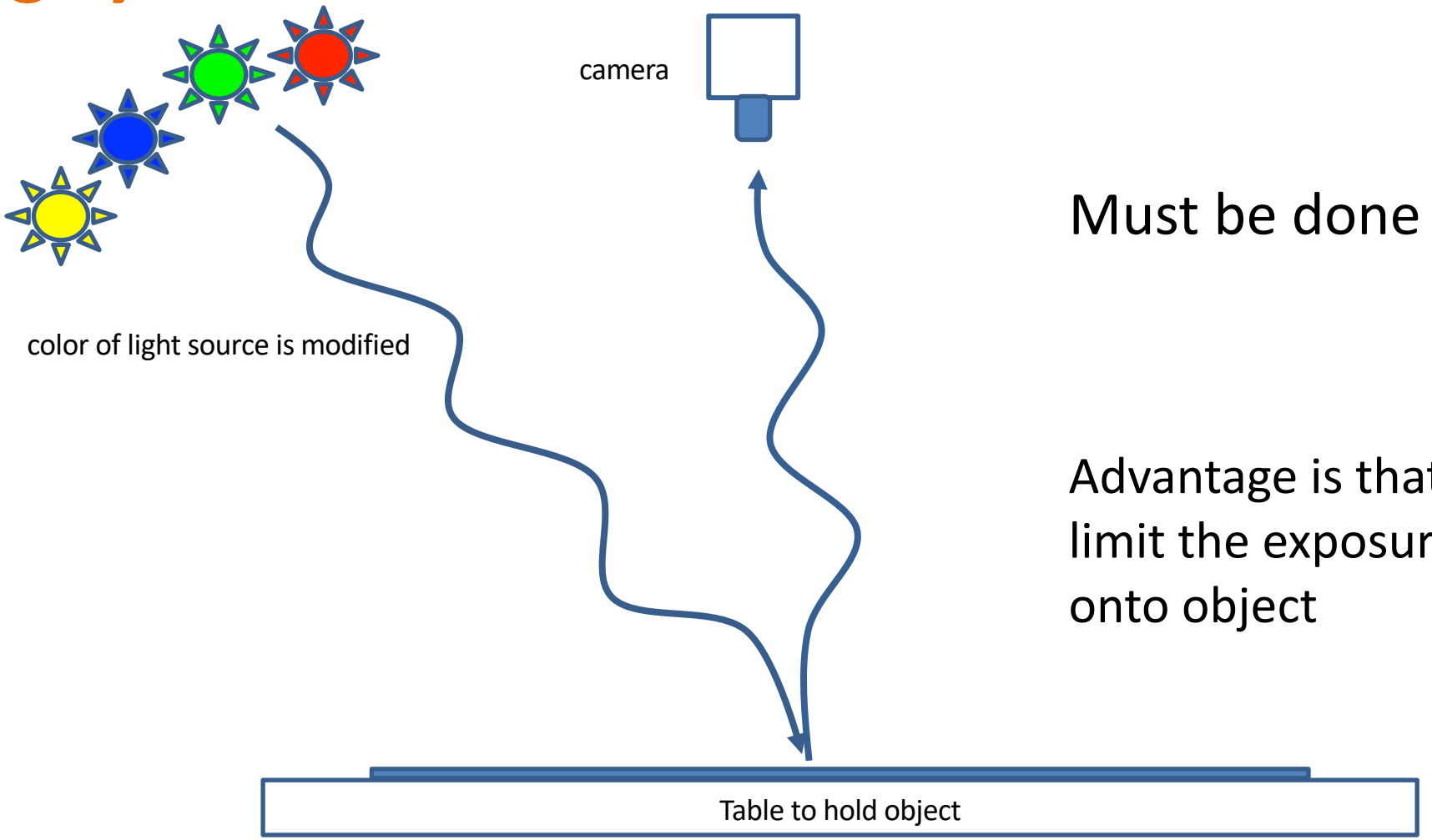
A “spectral filter” limits the wavelengths of light that pass through it to isolate them

Imaging System: Filter Wheel



Using a filter wheel allows us to customize and even change the filters used

Imaging System: Colored Illuminant

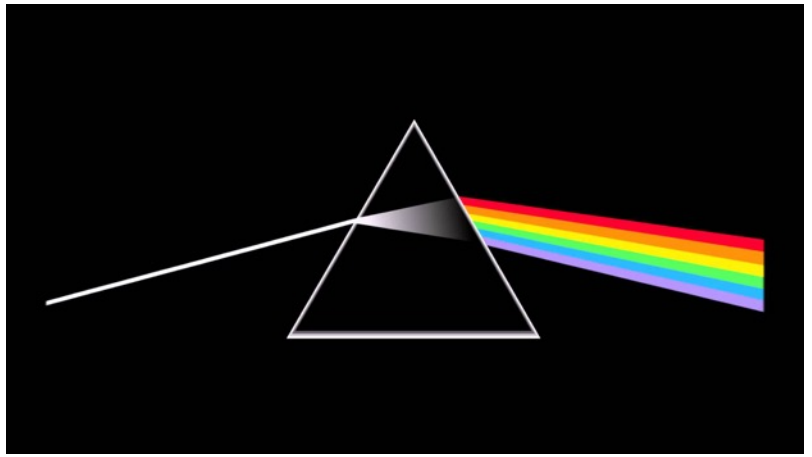


Must be done in the dark!

Advantage is that you can limit the exposure of light onto object

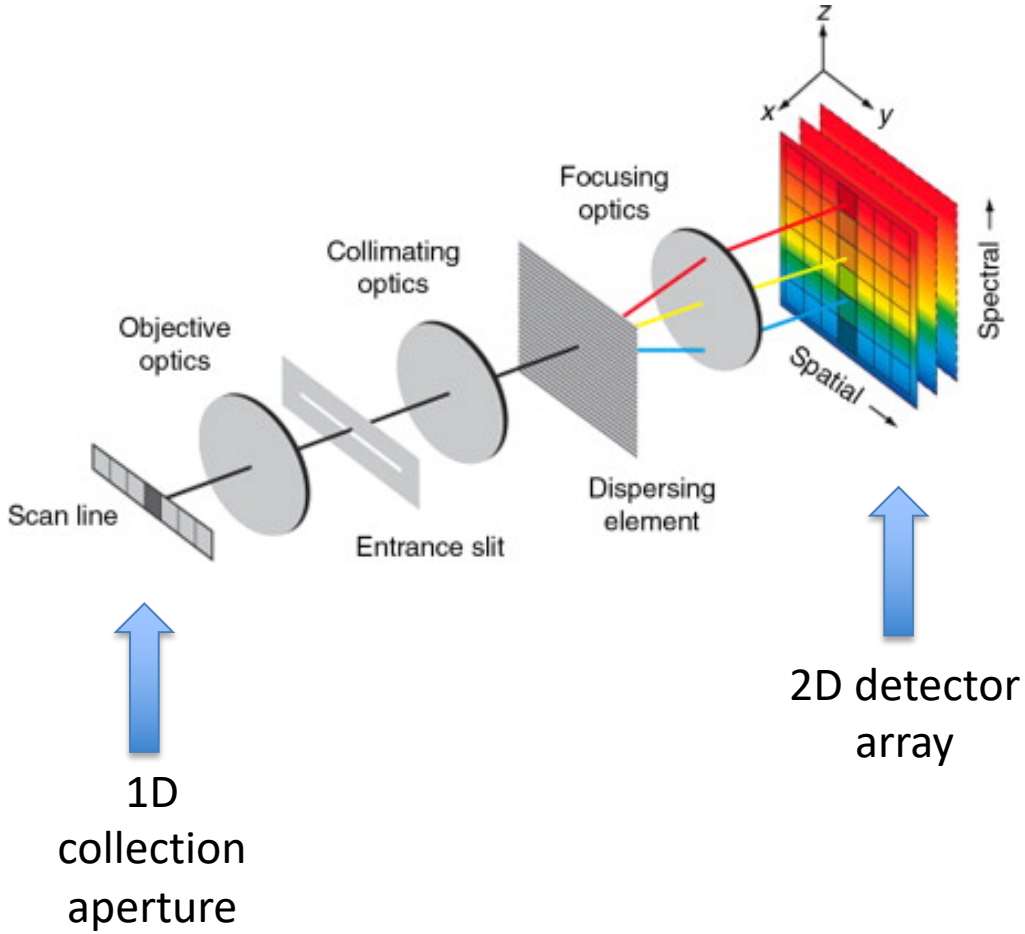
Multi- vs. Hyper- Spectral

- My definitions
- MSI
  - Spectral imaging system that uses filters or colored illumination
  - Generally has 10's of spectral bands without continuous spectral coverage
  - Generally has higher spatial resolution
- HSI
  - Uses a dispersion element to project "rainbow" onto detector (i.e., a prism)
  - Either the object or the camera has to move
  - Produces continuous spectrum per pixel
  - Generally lower spatial resolution



Basic Hyperspectral Imaging System

- For spectroscopy, we need to spread the light out using a diffraction grating or a prism
- Image is collected one line at a time, but full spectral information is collected for each line on 2D array
- Second spatial dimension collected by platform or object motion

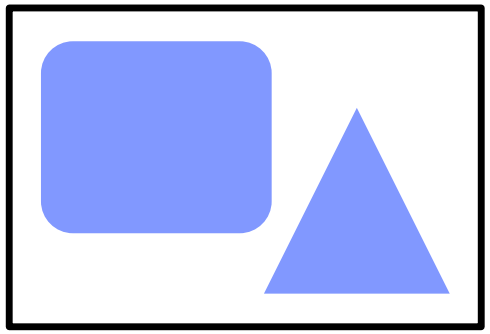


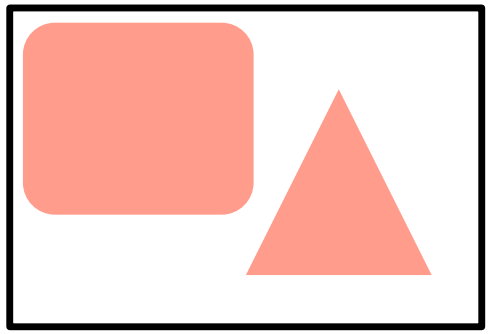
Calibration

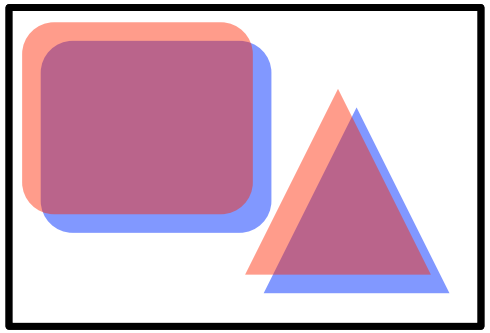
- Camera records digital counts – raw data
  - Basically the electrical signal off the detector
  - Contains desired signal plus any sources of noise
- Can be converted to radiance (physical units) with calibration coefficients
- Can be converted to reflectance with known target in scene
  - Gold standard: this is the inherent physical property of the object in each pixel
- Different from color balancing

Image Registration

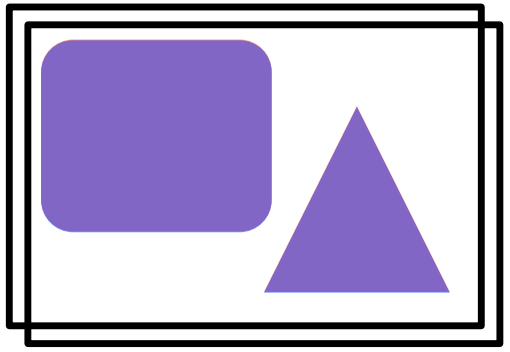
Two images of same object at different wavelengths but slightly offset







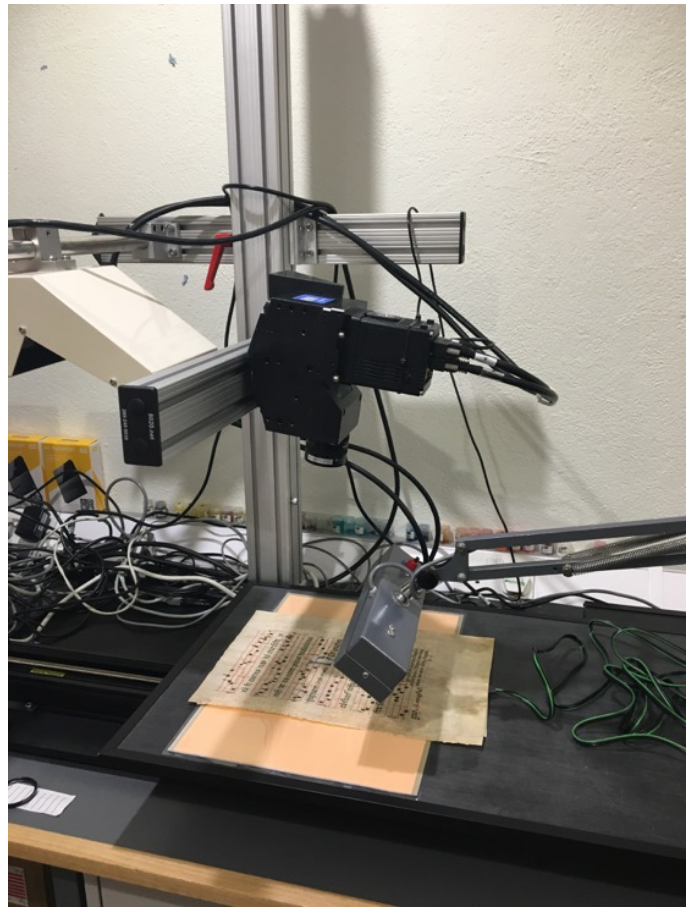
Images simply overlaid in pixel space



Images registered by content

Spatial Image Processing

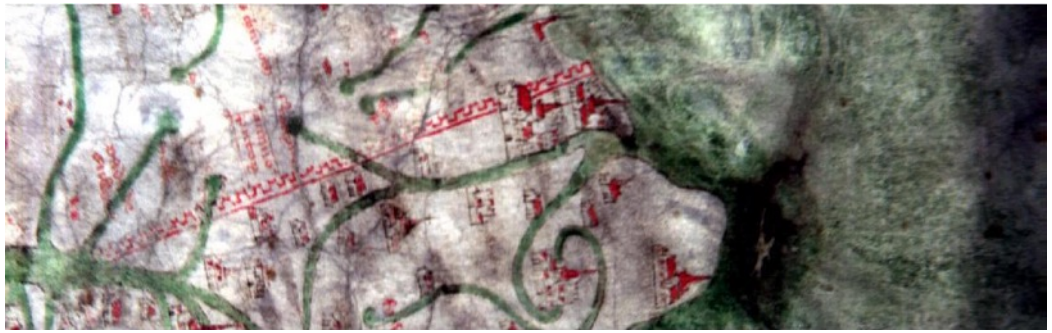
- Uses information contained in the spatial domain
  - Pixels are next to each other
- Typically (but not always) done on a single band image
- Examples
  - Sharpening and filtering, attempting to remove blur
  - Edge detection



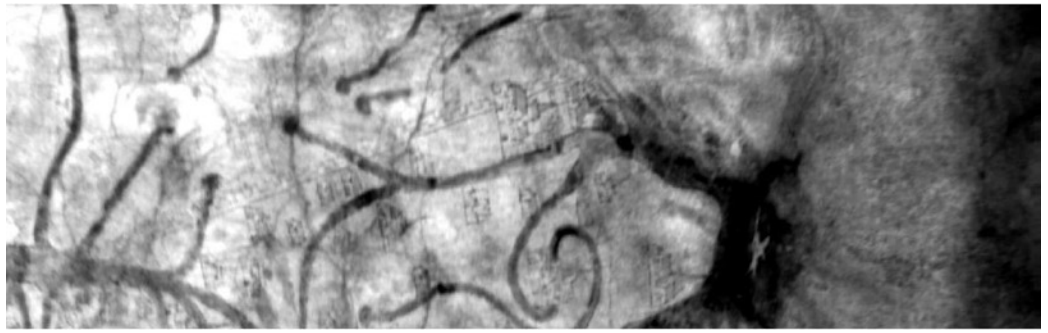
Hyperspectral fluorescence imaging at Bodleian Library, Univ. of Oxford

Spatial Image Processing Example

RGB from hyperspectral

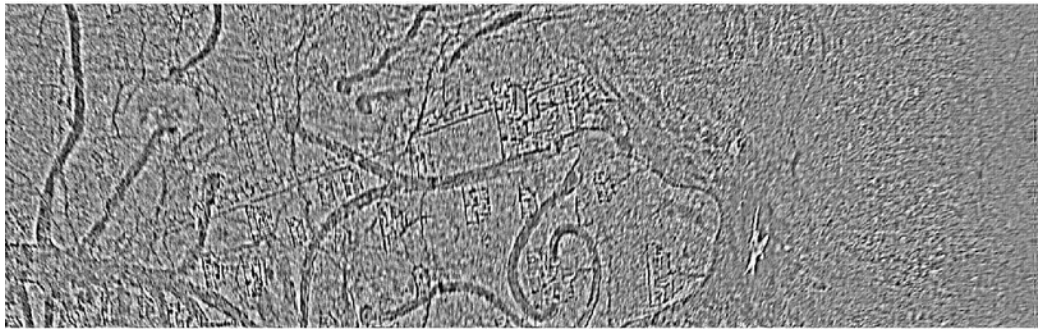


PC band 1



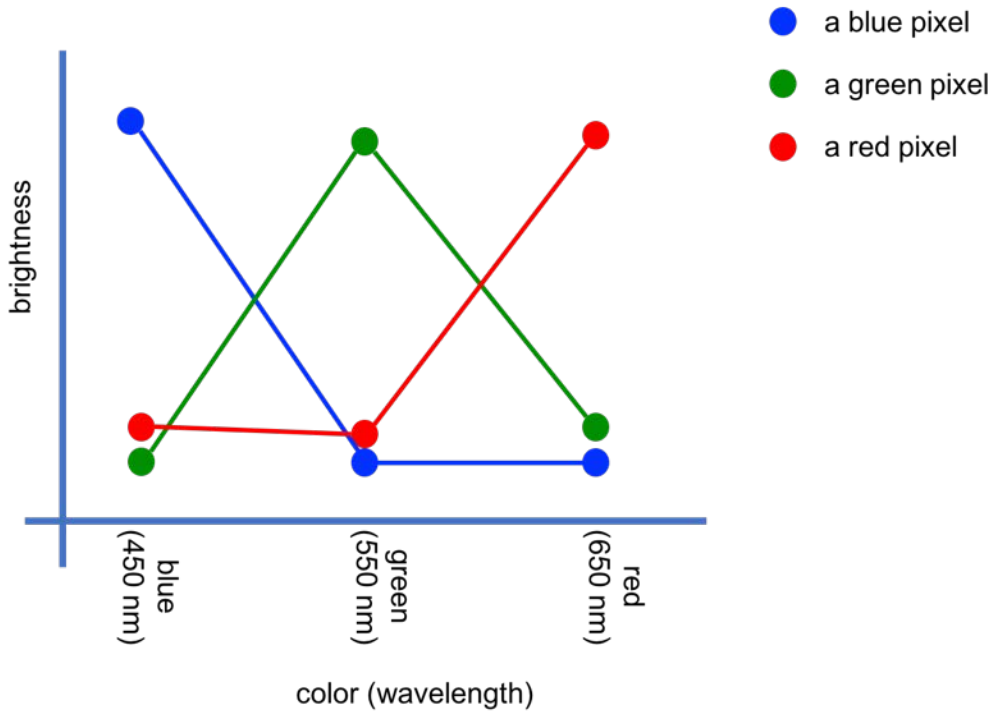
The “high pass” filter enhances sharp edges

High Pass Filtered



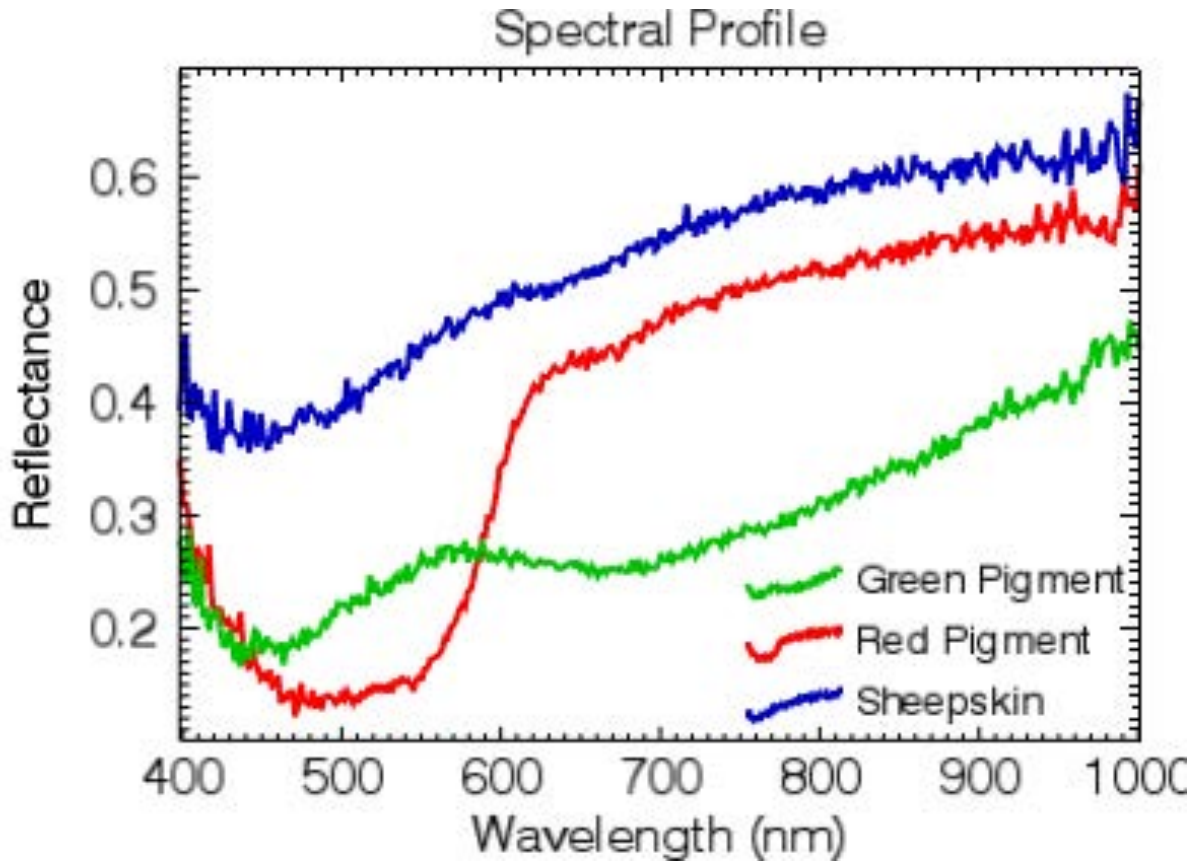
Spectral Imaging Processing: Signatures

- The actual measurement in each band
- How “bright” is this object in this band relative to the other bands?
- Useful for identifying bands of high contrast and for assessing spectral similarity



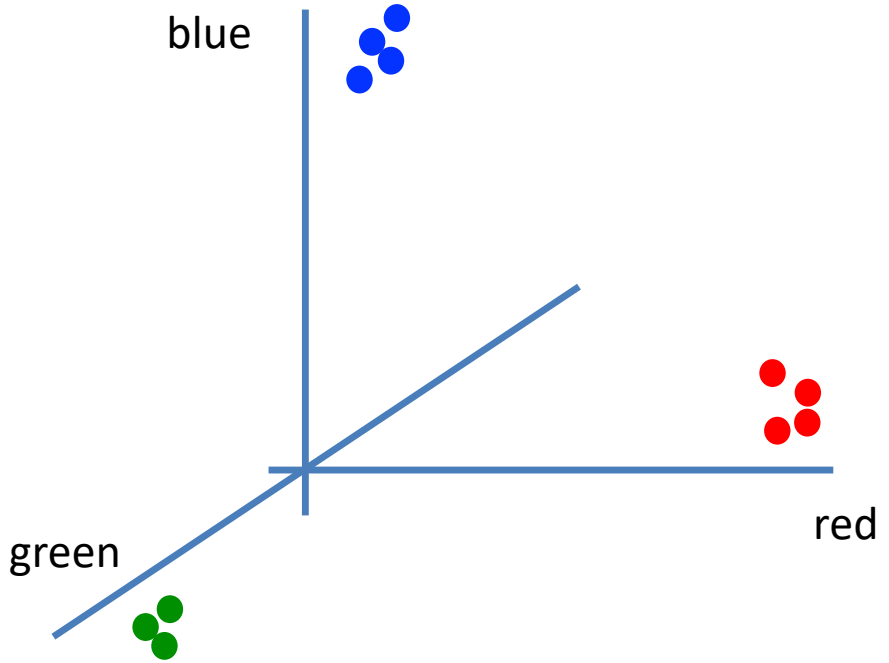
Hyperspectral Pixel Signatures

Spectral measurement (reflectance) as a function of wavelength for three different materials

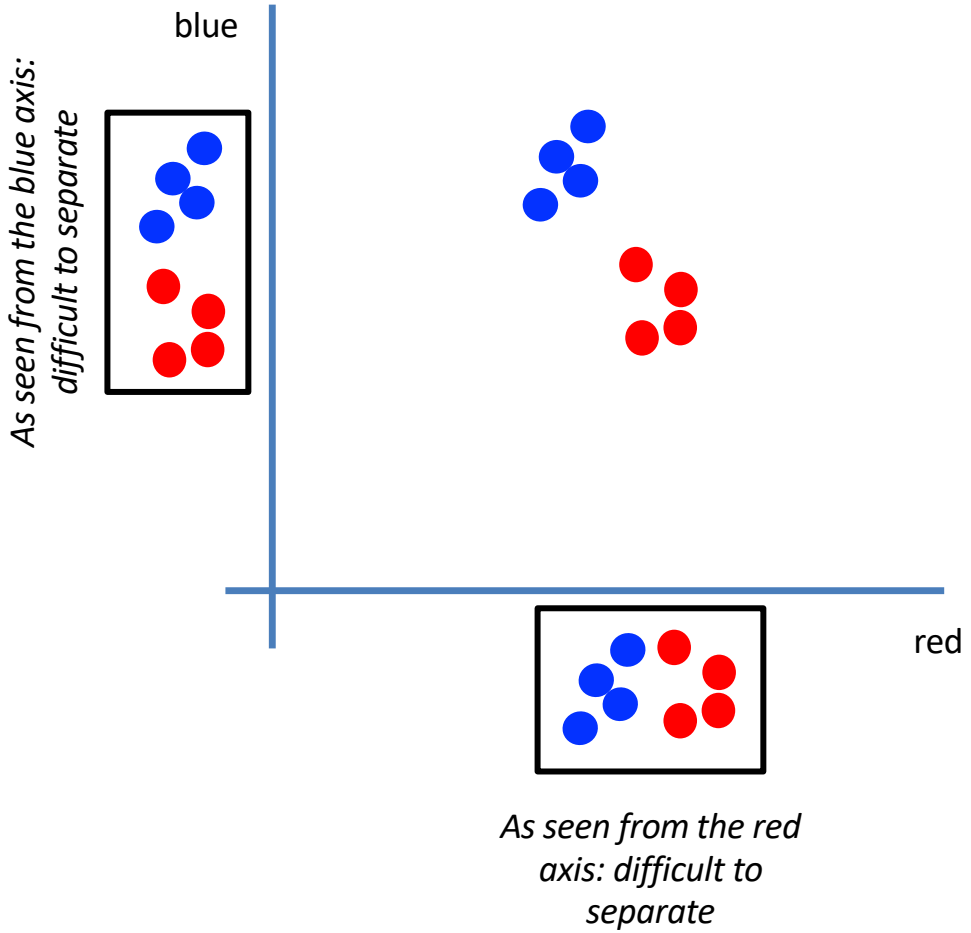


Spectral Signatures in the Color Space

- We think of pixels as points in a space where the axes are the various colors
- Specific colors fall on the axes, mixtures fall in the space in between
- Provides a mathematical description of the data that is useful



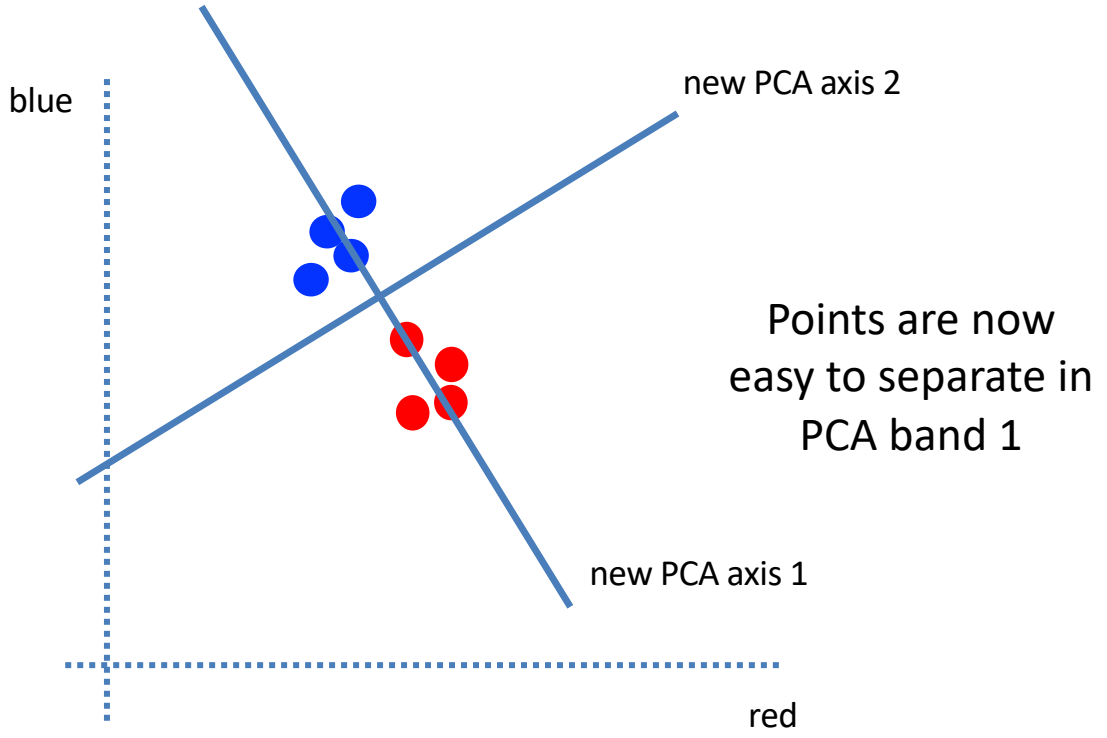
Principal Components Analysis (PCA)



- Consider this collection of pixels in two colors
- They represent two different materials, but their color differences are subtle
- Looking at them in either red or blue alone makes it difficult to distinguish

Principal Components Analysis (PCA)

- PCA provides a way to represent them with new axes
- New axes are derived to maximize separation in first PCA dimension (band)
- Now materials are easy to separate



Spectral Similarity Measures

- We measure how similar pixels are to each other based on their spectral similarity
- Pixels of similar material will have similar spectral signatures
  - And will appear of similar color in original image and in transformed images such as PCA
- Spectral angle is one measure, but there are others
  - In the case of spectral angle, smaller values indicate more similar

RIT MISHA system

Summary

- Spectral imagery is becoming a much more useful tool for digitization, preservation, and discovery

- Leverages differences in material properties in every pixel across the image to highlight sometimes subtle differences

- Tasks of interest:
  - Faded text enhancement
  - Erased / damaged text enhancement
  - Pigment analysis

Questions?

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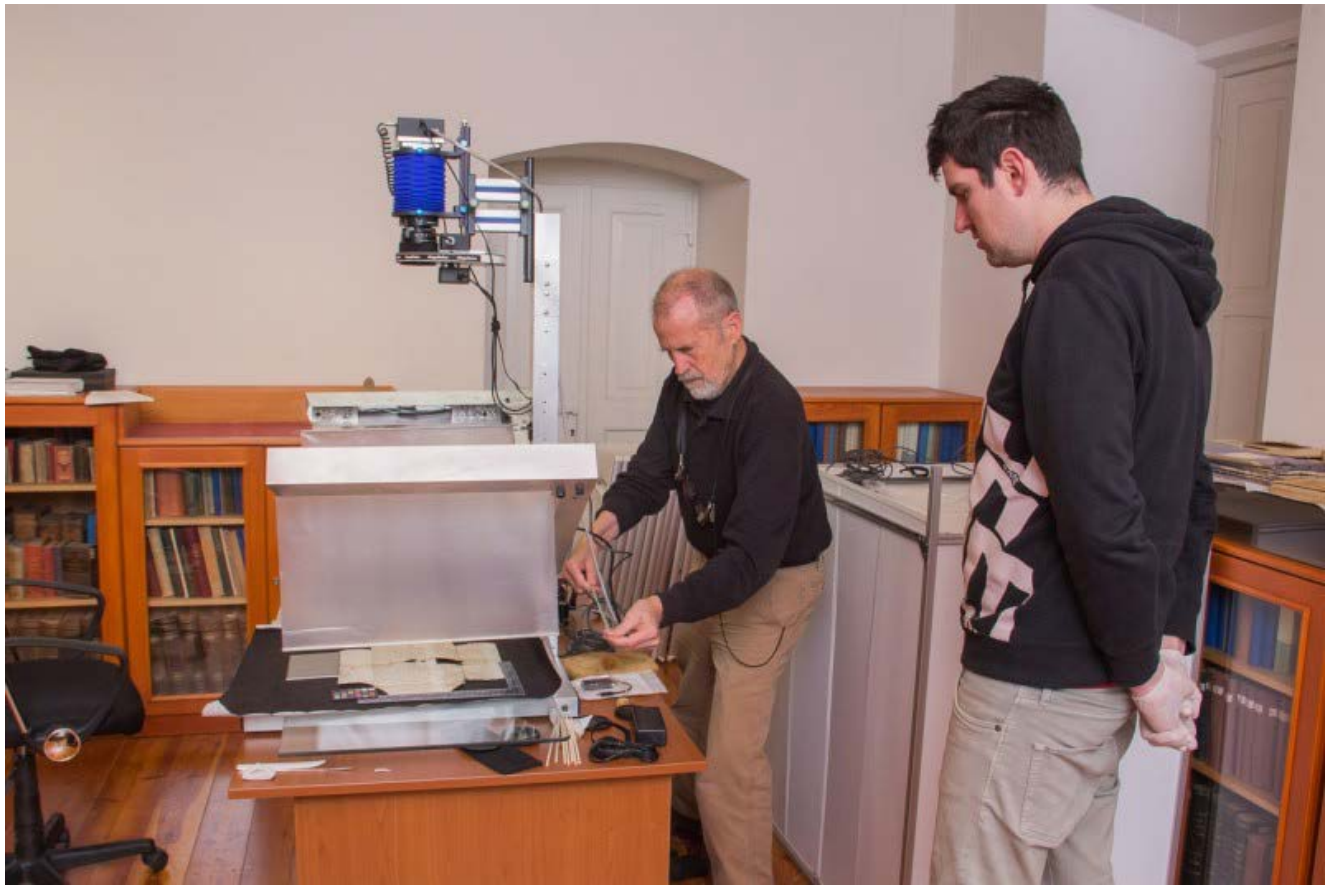

Ken Boydston imaging in the Research Library in Dubrovnik, Croatia