# Optics for Engineers
# Week 3

Charles A. DiMarzio
EECE–4646
Northeastern University

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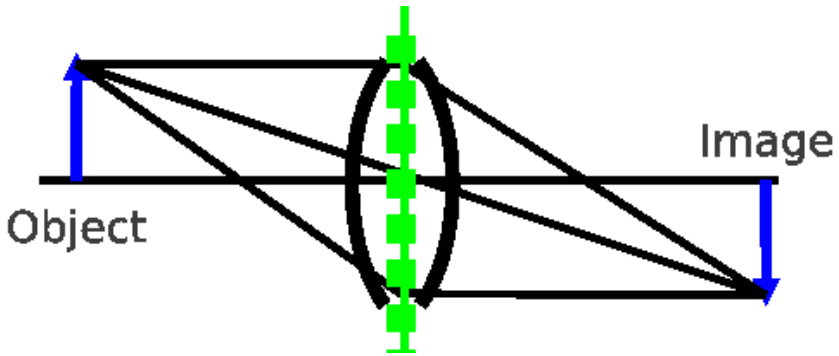
# Week 3 Agenda

- Camera Optics
- Film and Digital
- Photon Detectors Briefly
- Pixels
- Bit Depth
- Noise
- Color Cameras
- Hyperspectral

# Cameras




Object Location

$$\frac{1}{s}+\frac{1}{s'}=\frac{1}{f}$$

Magnification

$$m=-\frac{s'}{s}$$

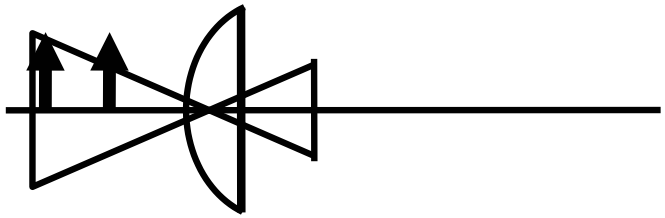
# Camera FOV (1)

- Field of View Limited in Image Rather than Object
  - Camera Chip is the Limit
  - 1/2.3in Compact Digital Camera
  - Diagonal Dimension = 11mm.
  - Image Field of View (Here Defined by Half Angle)

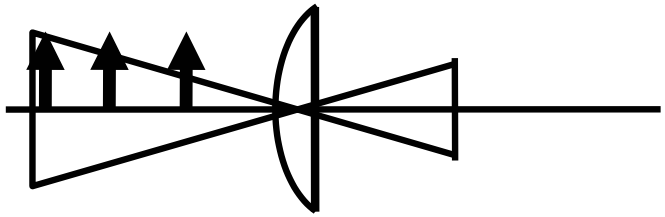
$$f = 10\text{cm} \qquad \text{(Normal Lens)} \qquad s \to \infty$$

$$FOV = 2 \arctan \frac{11\text{mm}/2}{10\text{mm}} = 58^\circ$$

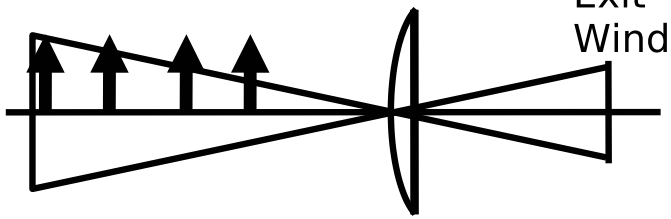
# Camera FOV (2)



Wide–Angle Lens, $f = 5$mm



Normal Lens, $f = 10$mm




Telephoto Lens, $f = 20$mm

$$FOV = 2 \arctan \frac{11\text{mm}/2}{f}$$

- Photographer Moved Away with Increasing $f$
- Same Linear FOV on the Building in Each Image
- Differences in Foreground Images

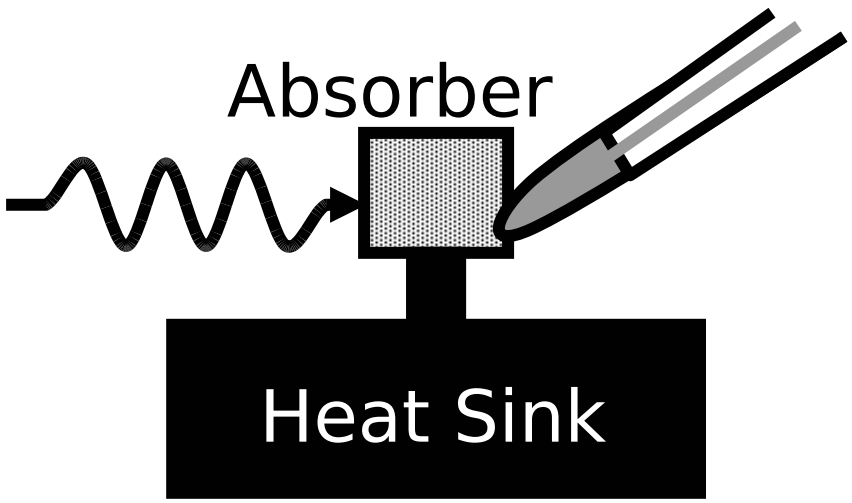
# Camera FOV (3)

Case 1: 35 mm Film  Case 2: 11 mm chip

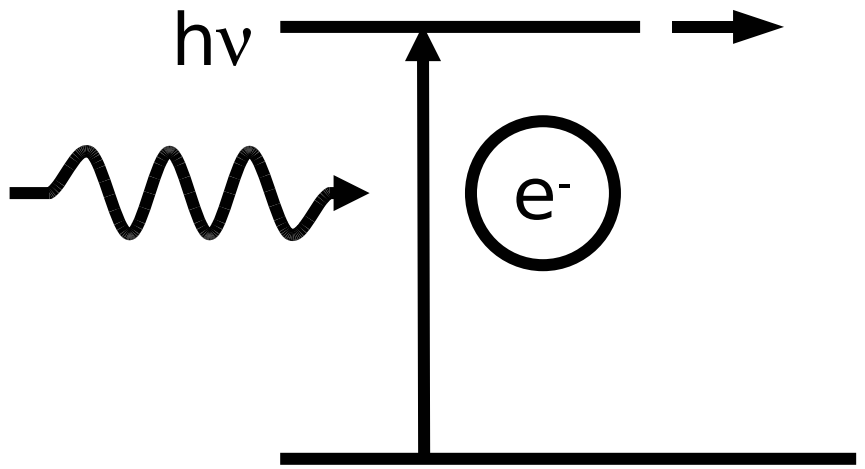
What focal length for

- Telephoto
- Normal
- Wide Angle

# Optical Detectors



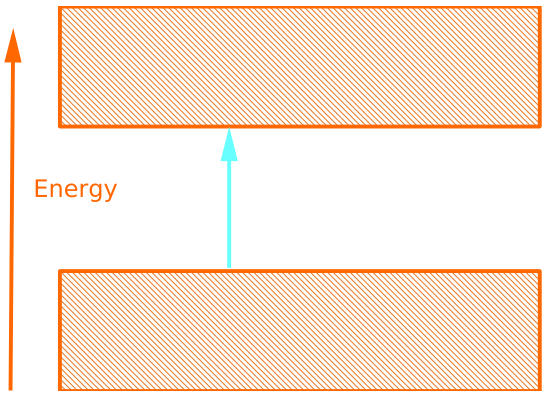

Thermal Detector

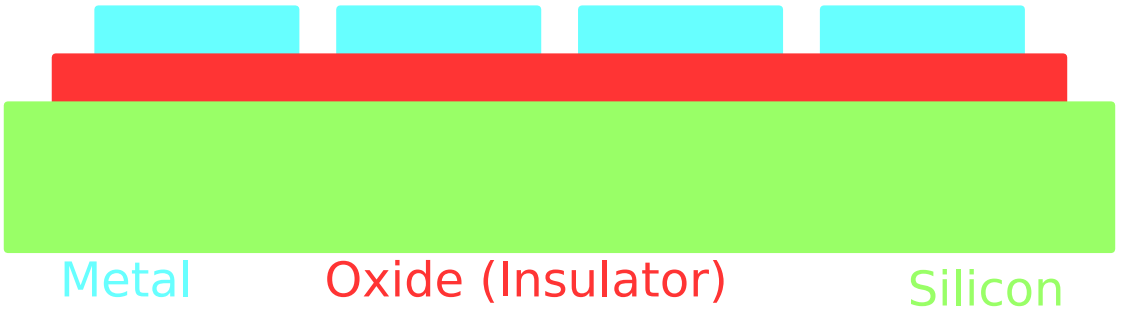



Photon Detector

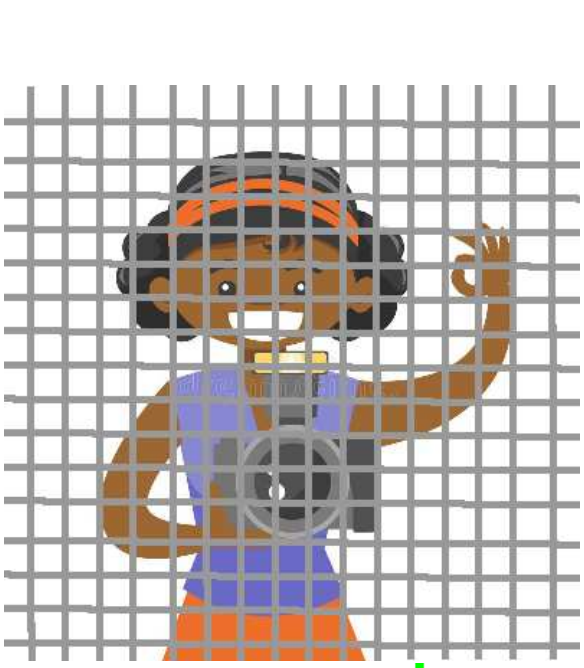
# Digital Imaging

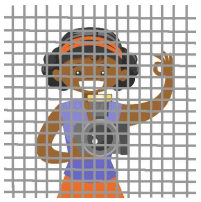
- Photon Absorbed: Electron Excited to Conduction Band
- Electron Used in Circuit or Stored
- Massive Arrays are possible using MOS Technology

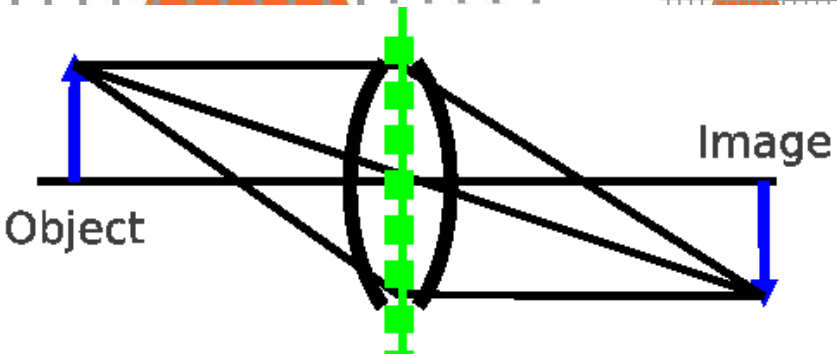


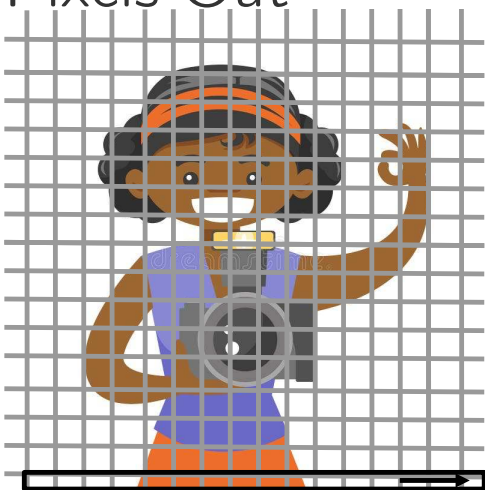
# Camera for Imaging



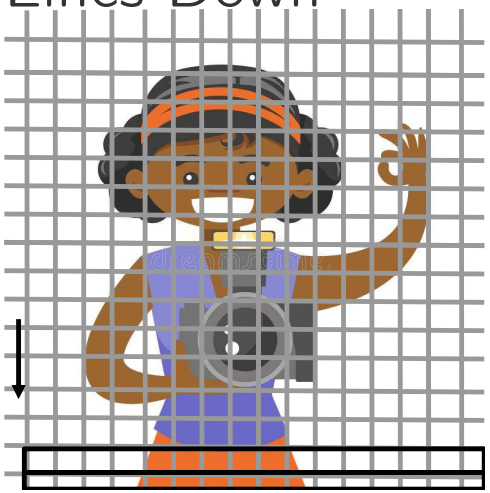




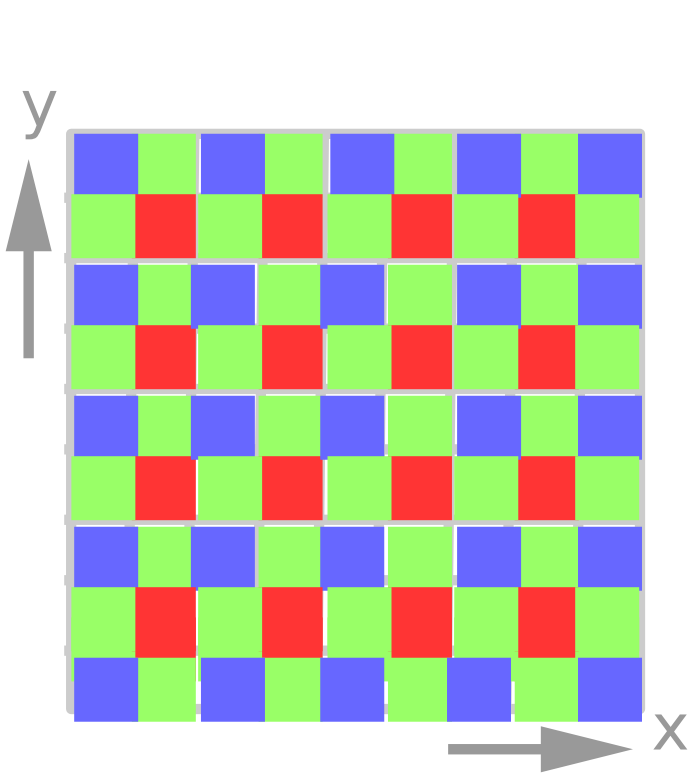

Pixels Out



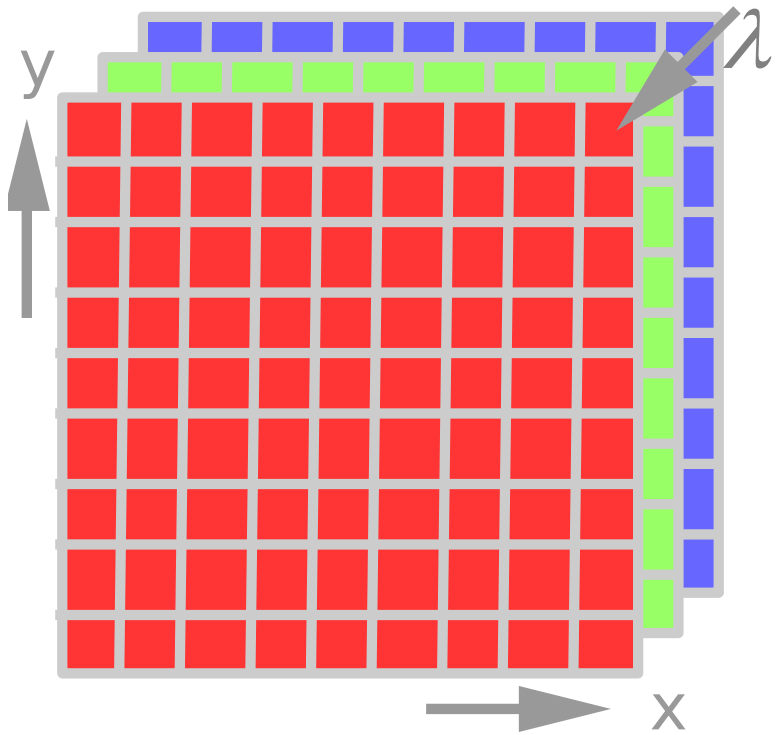
Lines Down



# Typical RGB Camera




Bayer Matrix Camera



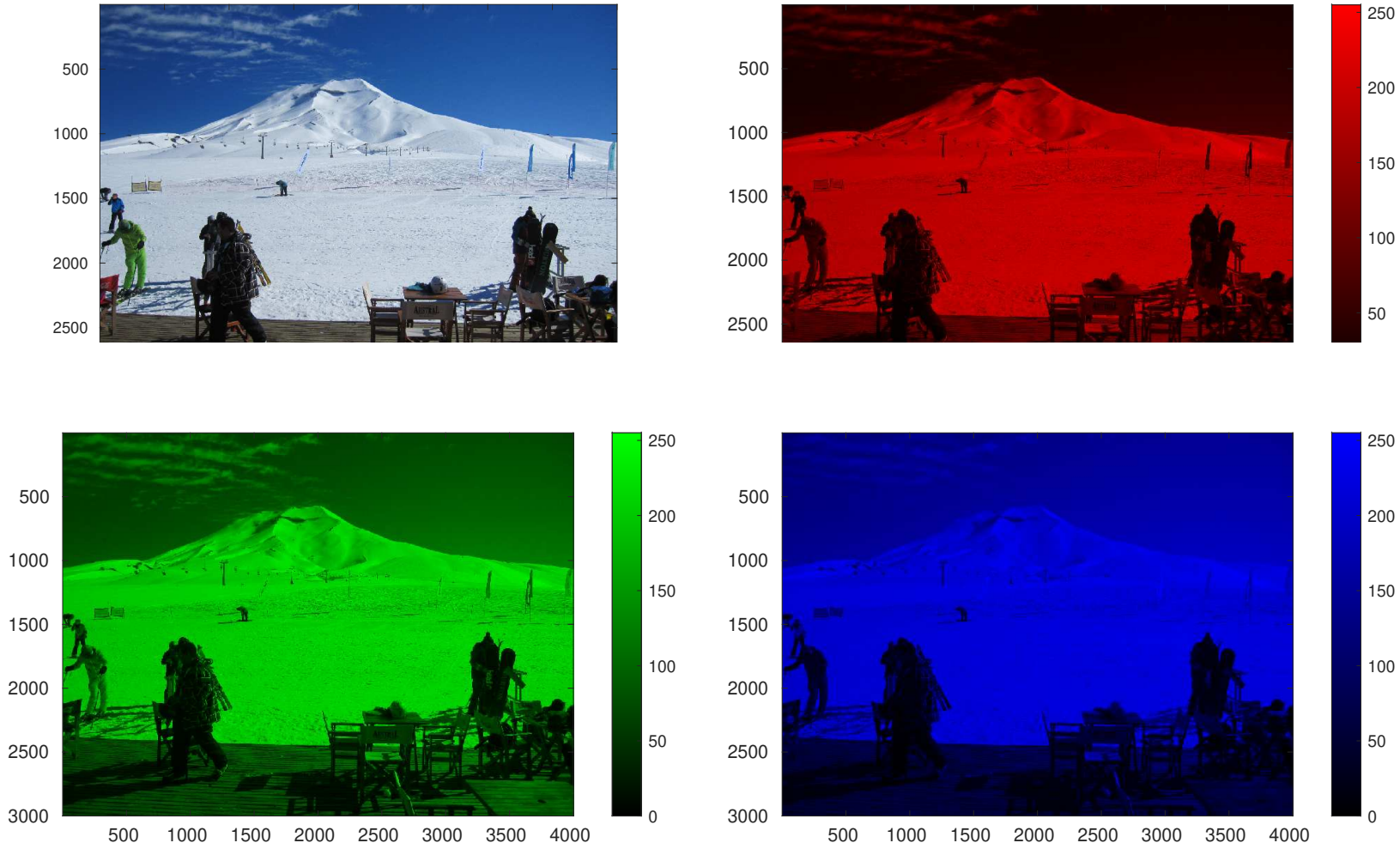

Typical Image Format

Rearrange

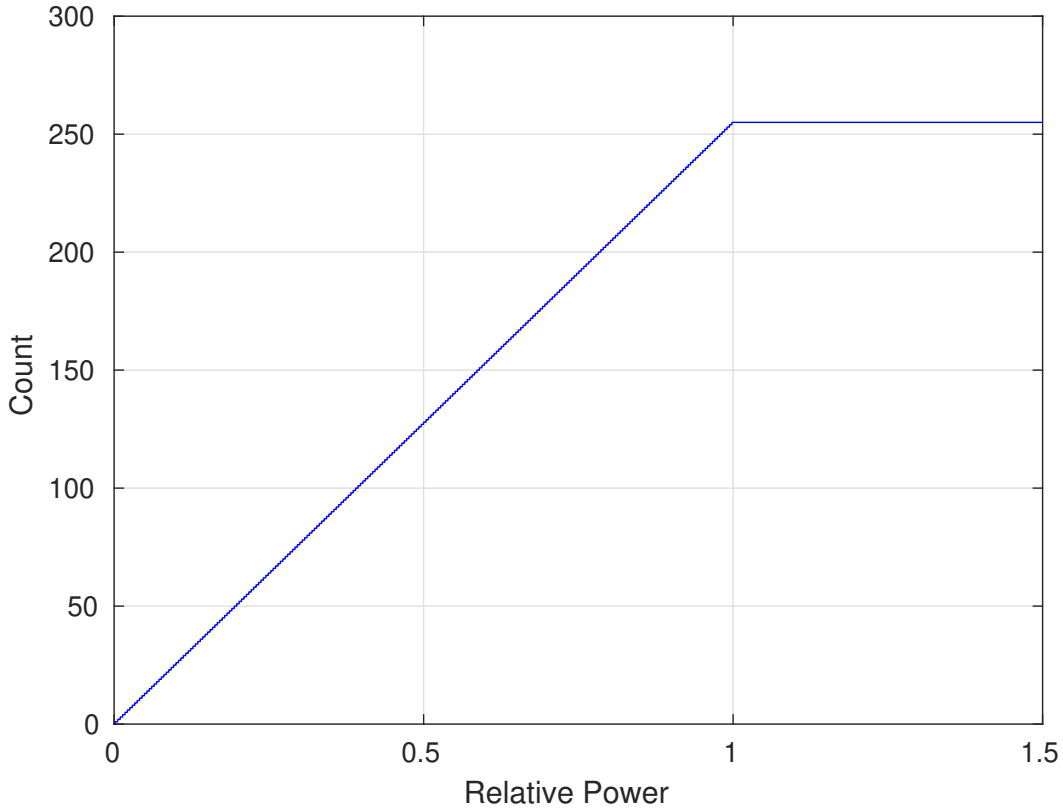
Green Appears Twice in Each 2X2; Average

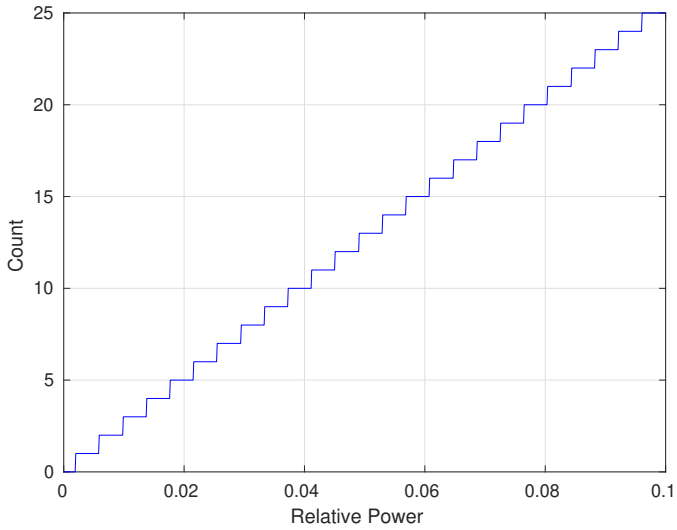
2D Original, $N_x \times N_y$ to 3D, $(N_x/2) \times (N_y/2) \times 3$

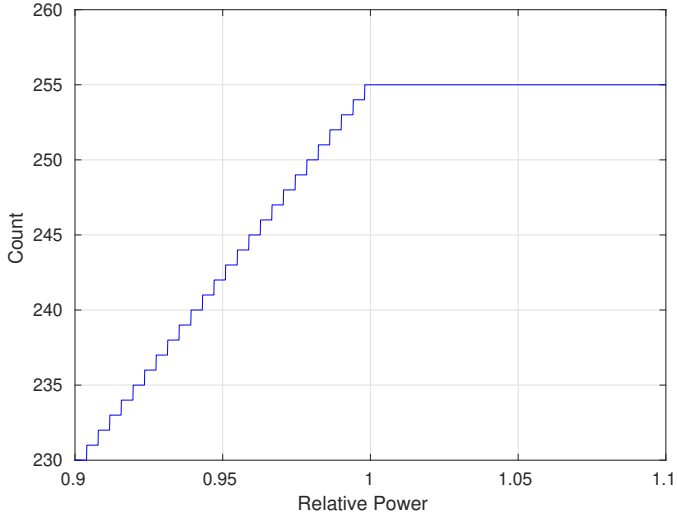
# Color Image



# Digitization




Zoom

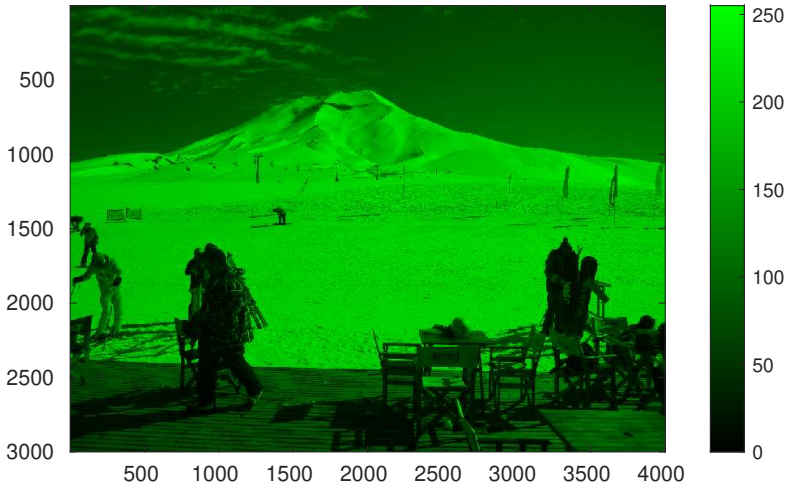
A/D Converter:
Example: 8 Bits: 0 to 255
Smallest to Largest
8–Bit Numbers

# Saturation

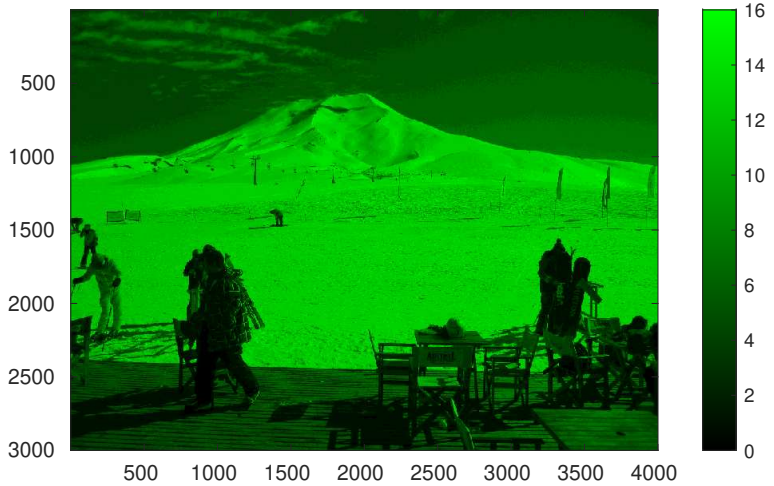
**In Practice**

- Too Much Light — Clipping Whites
- Too Little Light — Clipping Blacks
- Noise
- Beware the Auto–Scale

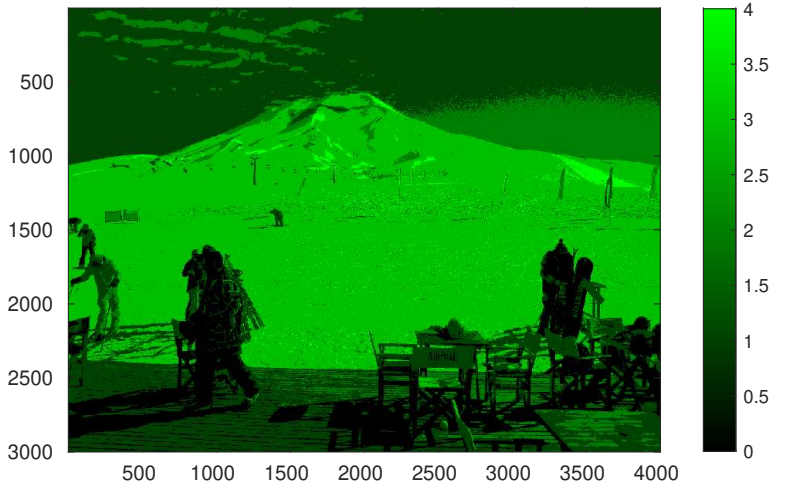
# Bit Depth



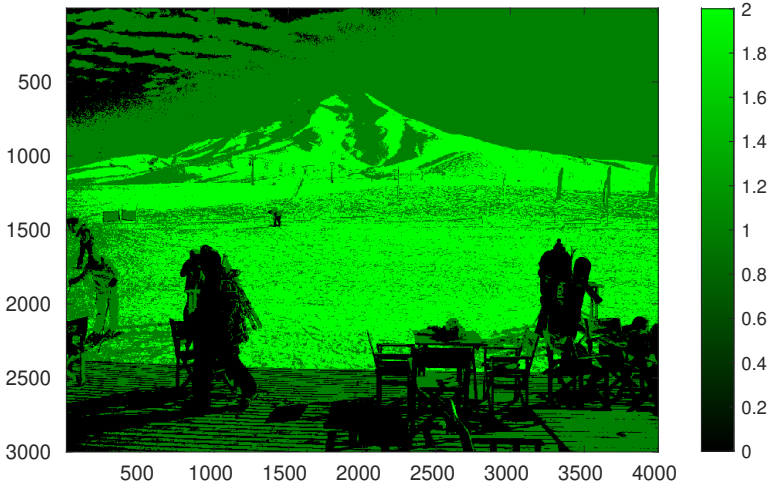

Native 8–Bit




4–Bit

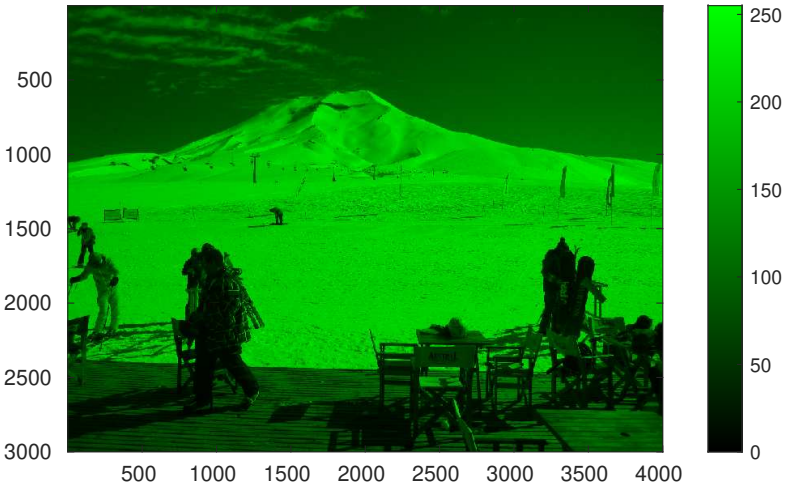



2–Bit

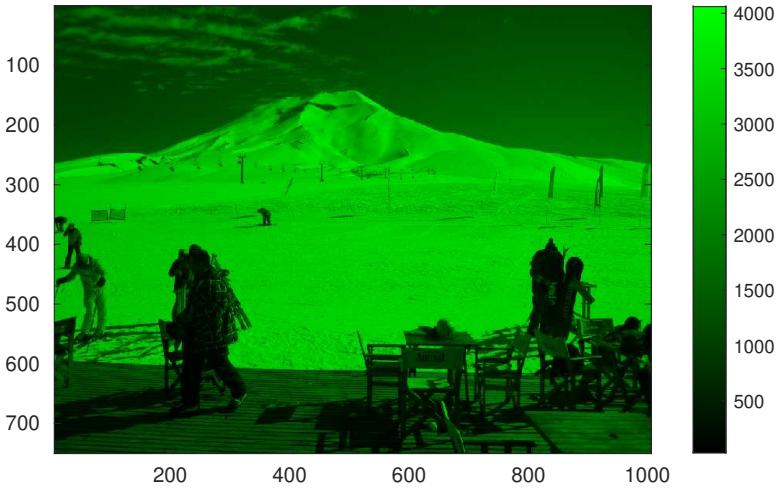



1–Bit

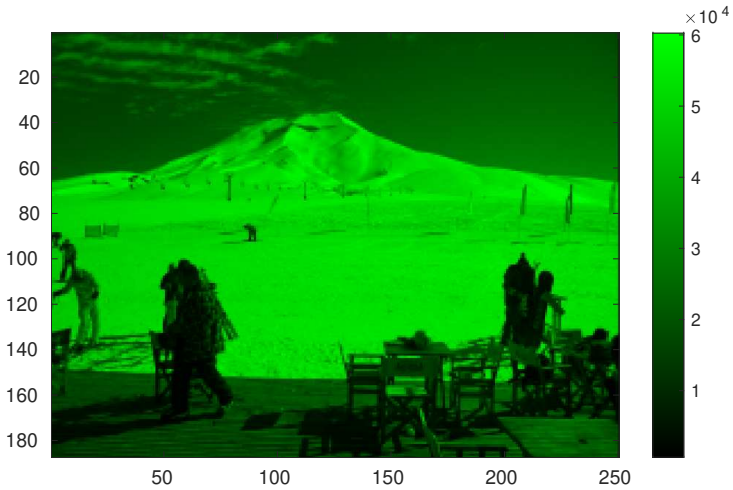
# Pixel Size



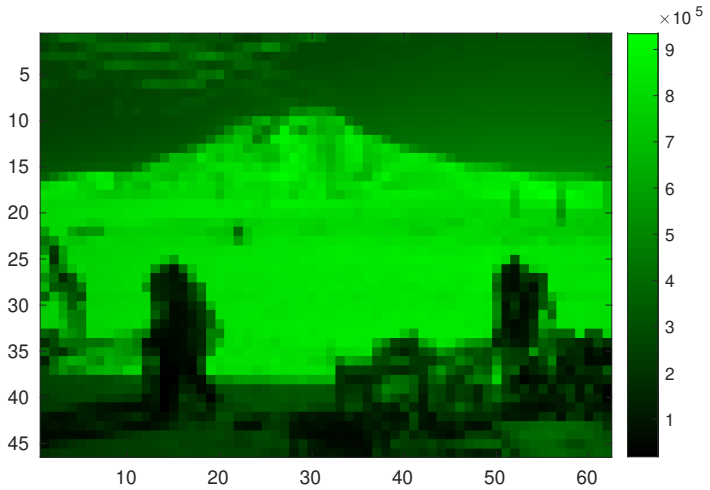

Native 1




4

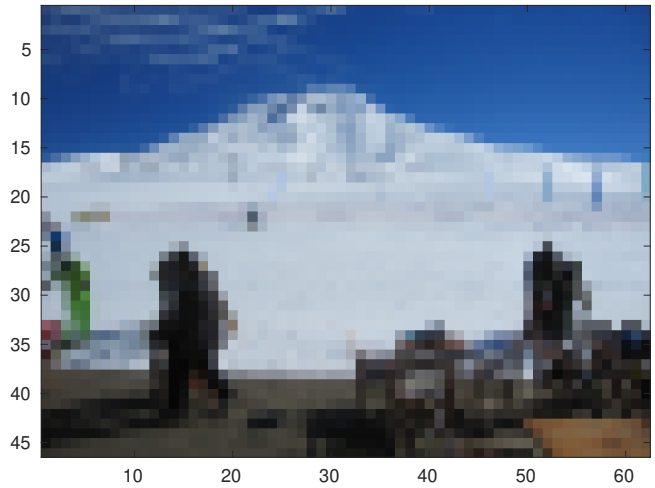



16

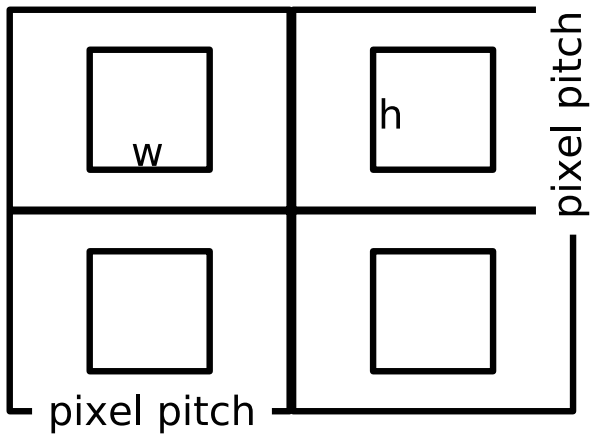



64

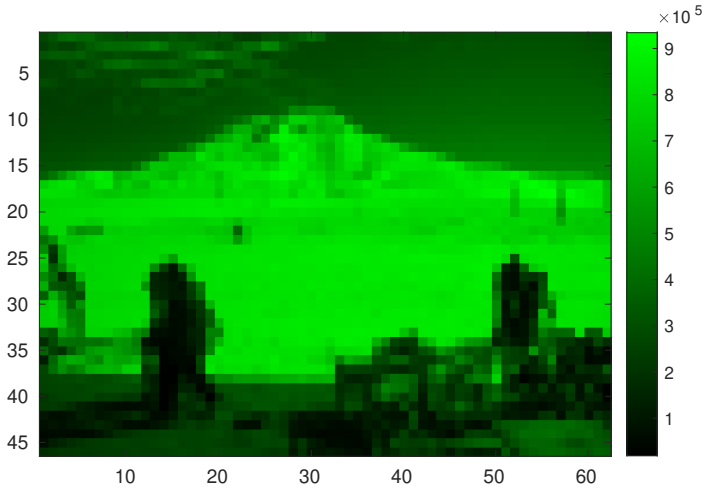
# Fill Factor



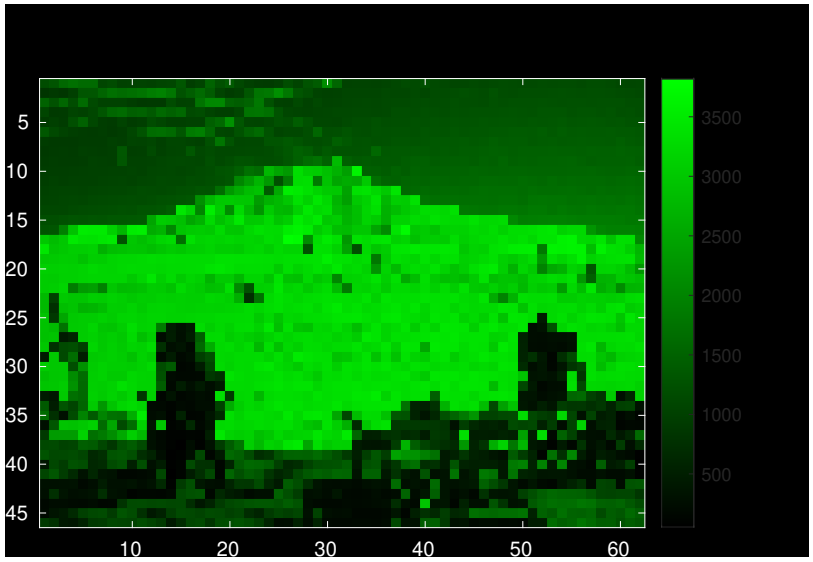

64 Pixel Size Color




Fill Factor

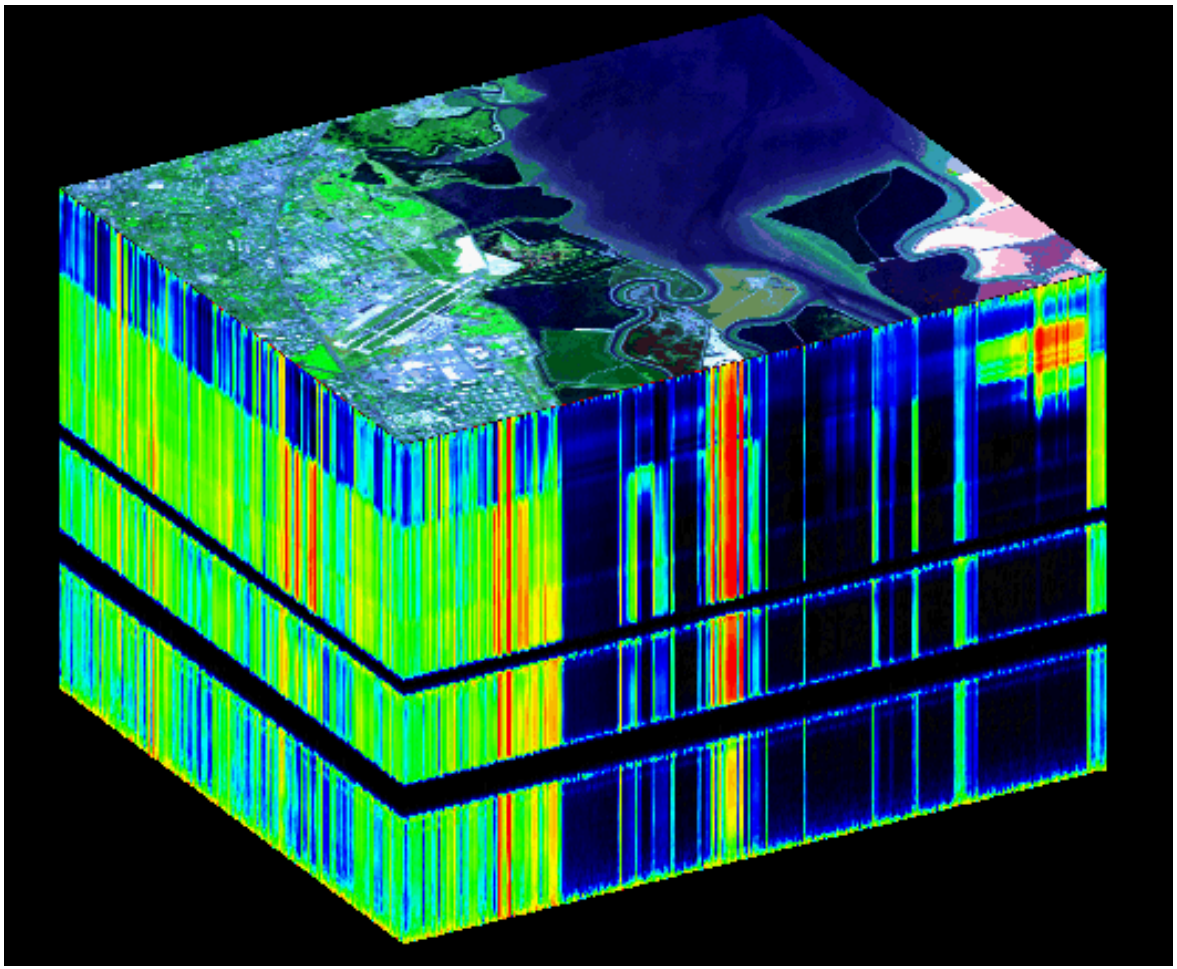



64 Pixel Green




64 Pitch, 4 Pixel

# Hyperspectral Imaging

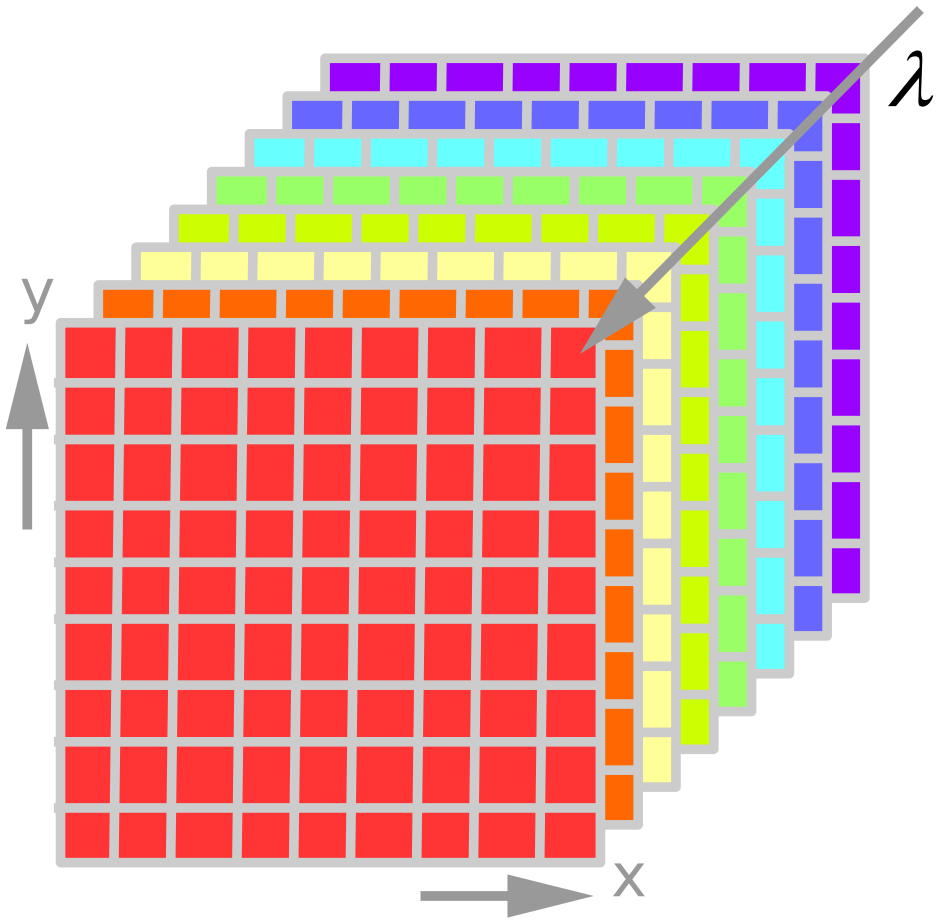


Right $\approx$ North, Down = [400 to 2400 nm] (not Linear)
South Bay of California; 101 curves down on the left.

# Hardware

- Tunable Filter (Lyot Filter, Pronounced "Leo")
  - $x, y$ on camera
  - $\lambda$ with time
- Grating spectrometer with Pinhole
  - $\lambda$ on Camera
  - $x, y$ with time (whiskbroom: Slow)
    - Slit, Grating and 2D Camera
      - $y, \lambda$ on camera
      - $x$ with time (pushbroom)
- Snapshot Hyperspectral

# Lyot Filter



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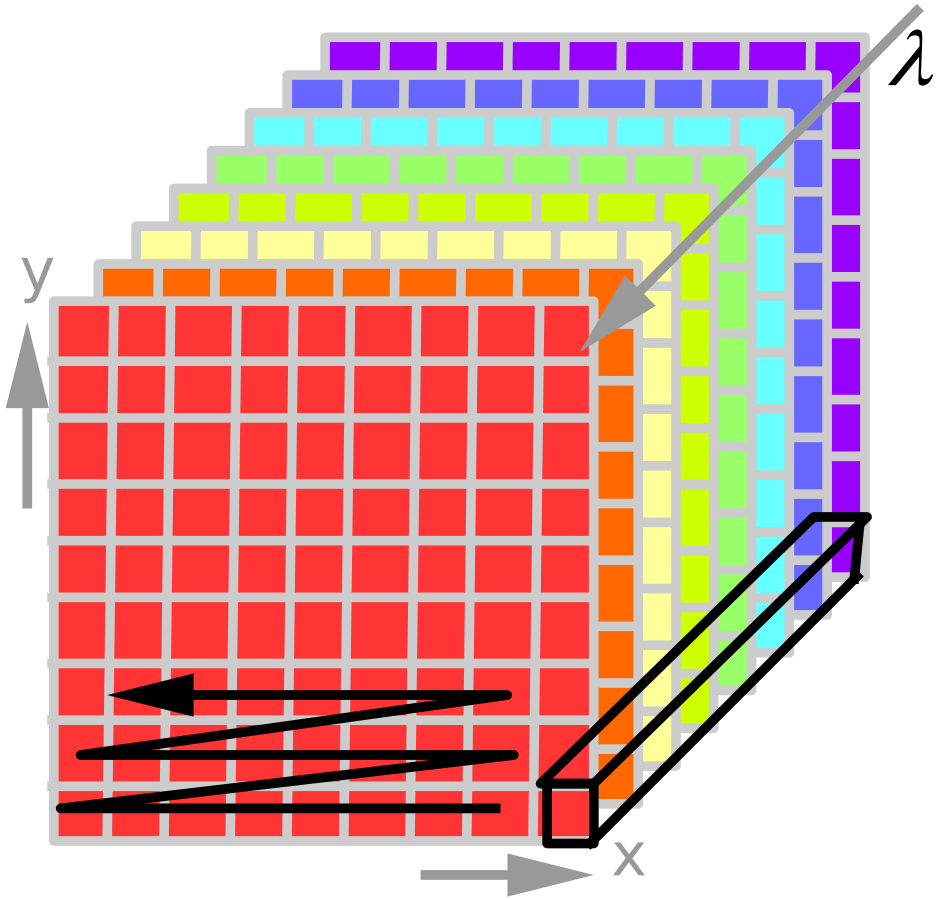
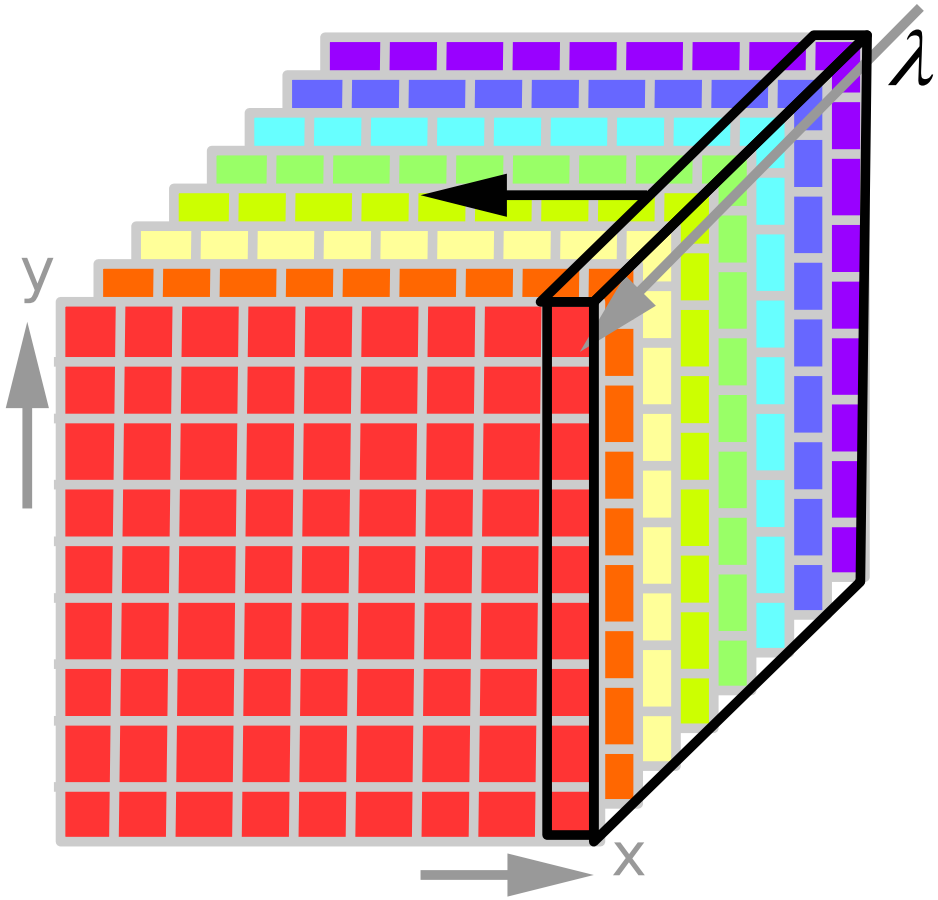
  - $x, y$ on camera
  - $\lambda$ with time
- Grating spectrometer with Pinhole
  - $\lambda$ on Camera
  - $x, y$ with time (whiskbroom: Slow)
    - Slit, Grating and 2D Camera
      - $y, \lambda$ on camera
      - $x$ with time (pushbroom)
- Snapshot Hyperspectral

# Whiskbroom



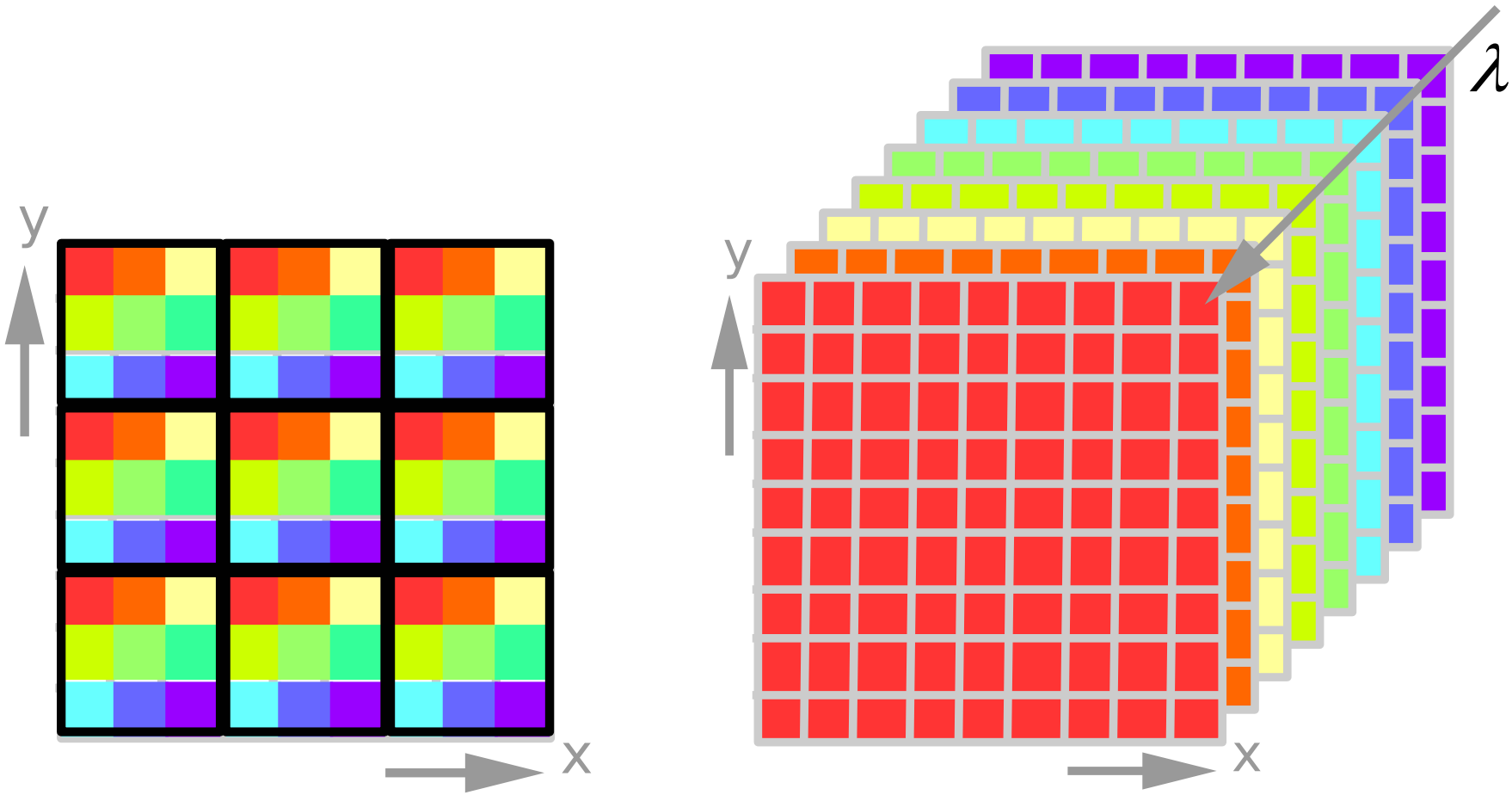
# Pushbroom



# Hardware

- Tunable Filter (Lyot Filter, Pronounced "Leo")
  - $x, y$ on camera
  - $\lambda$ with time
- Grating spectrometer with Pinhole
  - $\lambda$ on Camera
  - $x, y$ with time (whiskbroom: Slow)
    - Slit, Grating and 2D Camera
      - $y, \lambda$ on camera
      - $x$ with time (pushbroom)
- Snapshot Hyperspectral

# Snapshot Hyperspectral




Camera with Filters Hyperspectral Data Cube

Rearrange Pixels in Computer to Make a 3–D Array

# Applications

- Military (Where's the Tank in the Trees?)
- Law Enforcement (Which crop is illegal?)
- Agriculture (*e.g.* Crop Health)
- Environmental (*e.g.* Oil Spill, Invasive Plants
- Commercial (*e.g.*Food Qualty)
- Biomedical
  - Fluorescence Spectroscopy (Multiple, Overlapping Fluorophores)
  - Hemoglobin Spectroscopy