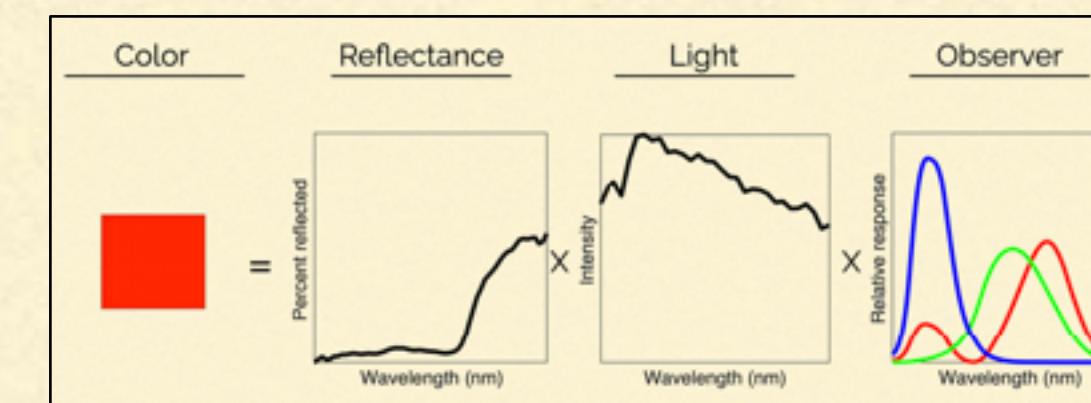


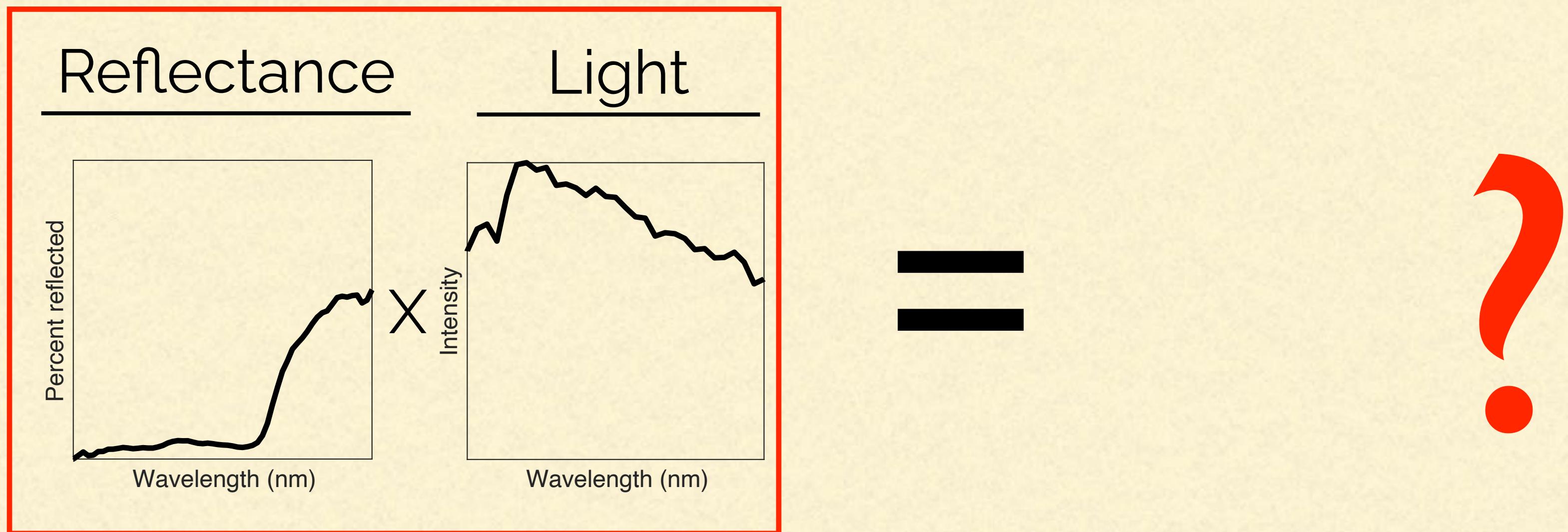
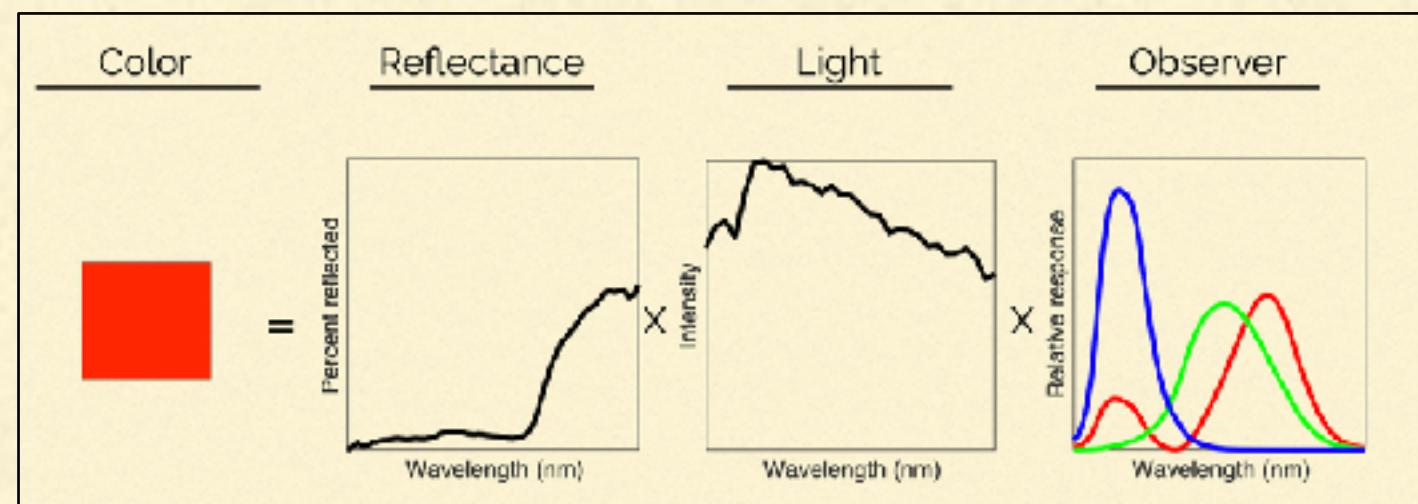
# UNDERWATER COLORIMETRY



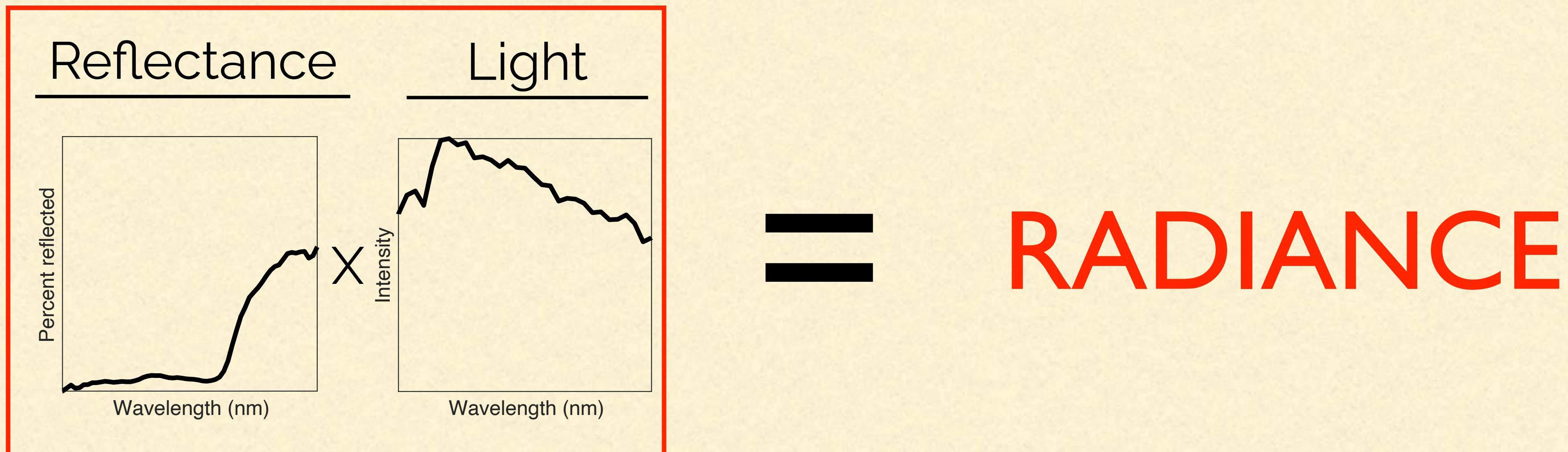
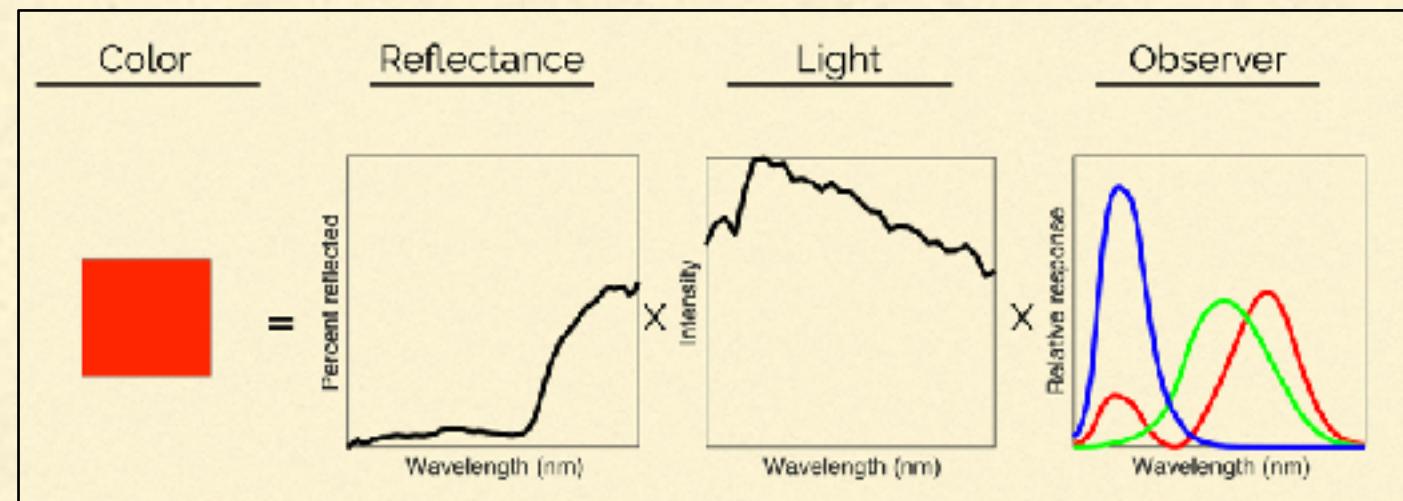
## DIGITAL IMAGE FORMATION - II

Dr. Derya Akkaynak | [dakkaynak@univ.haifa.ac.il](mailto:dakkaynak@univ.haifa.ac.il)

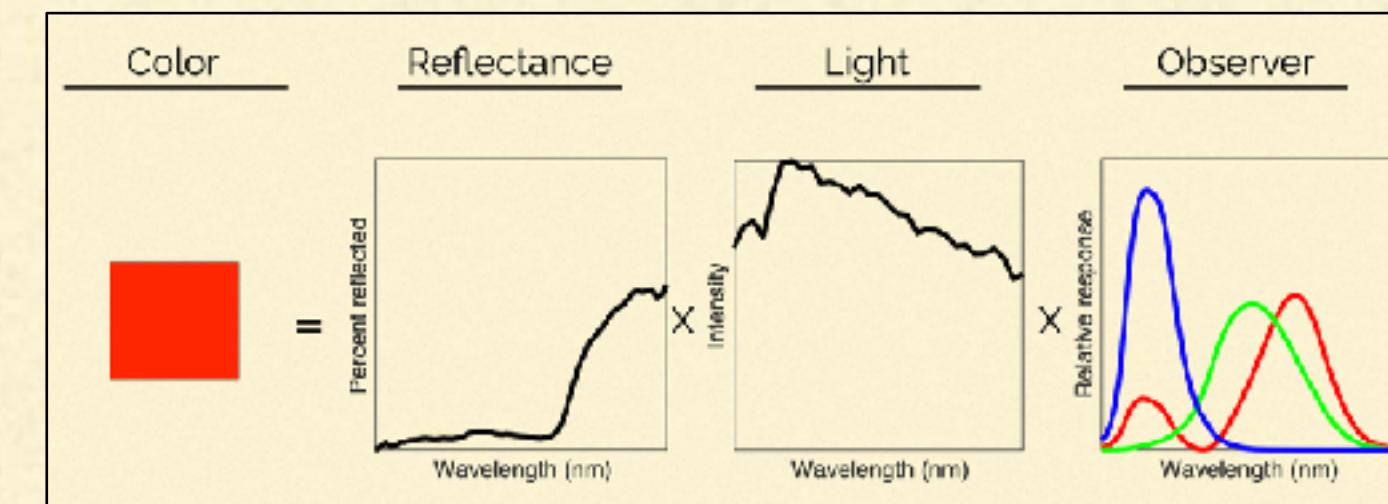
# Image Formation



# Image Formation

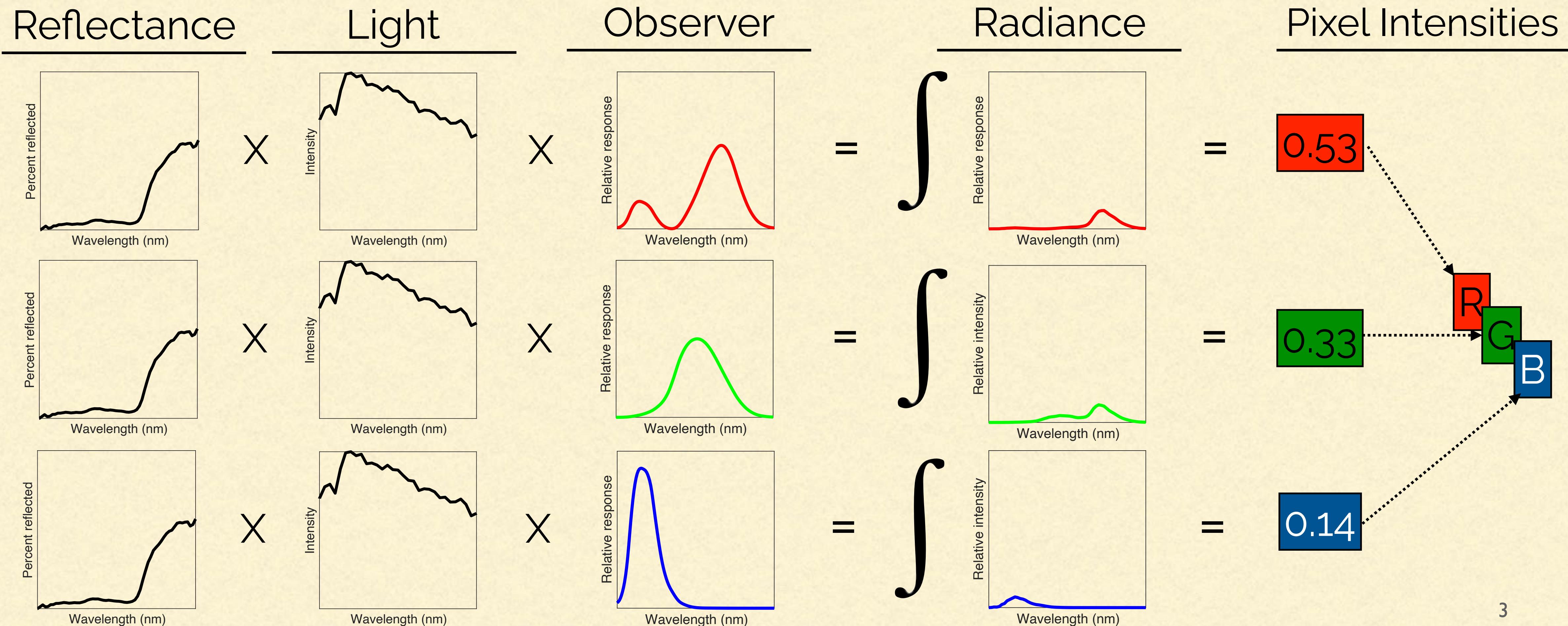


# Image Formation



$$\text{Color} = \frac{1}{\kappa} \int_{\lambda_1}^{\lambda_2} \rho(\lambda) E(\lambda) S(\lambda) d\lambda$$

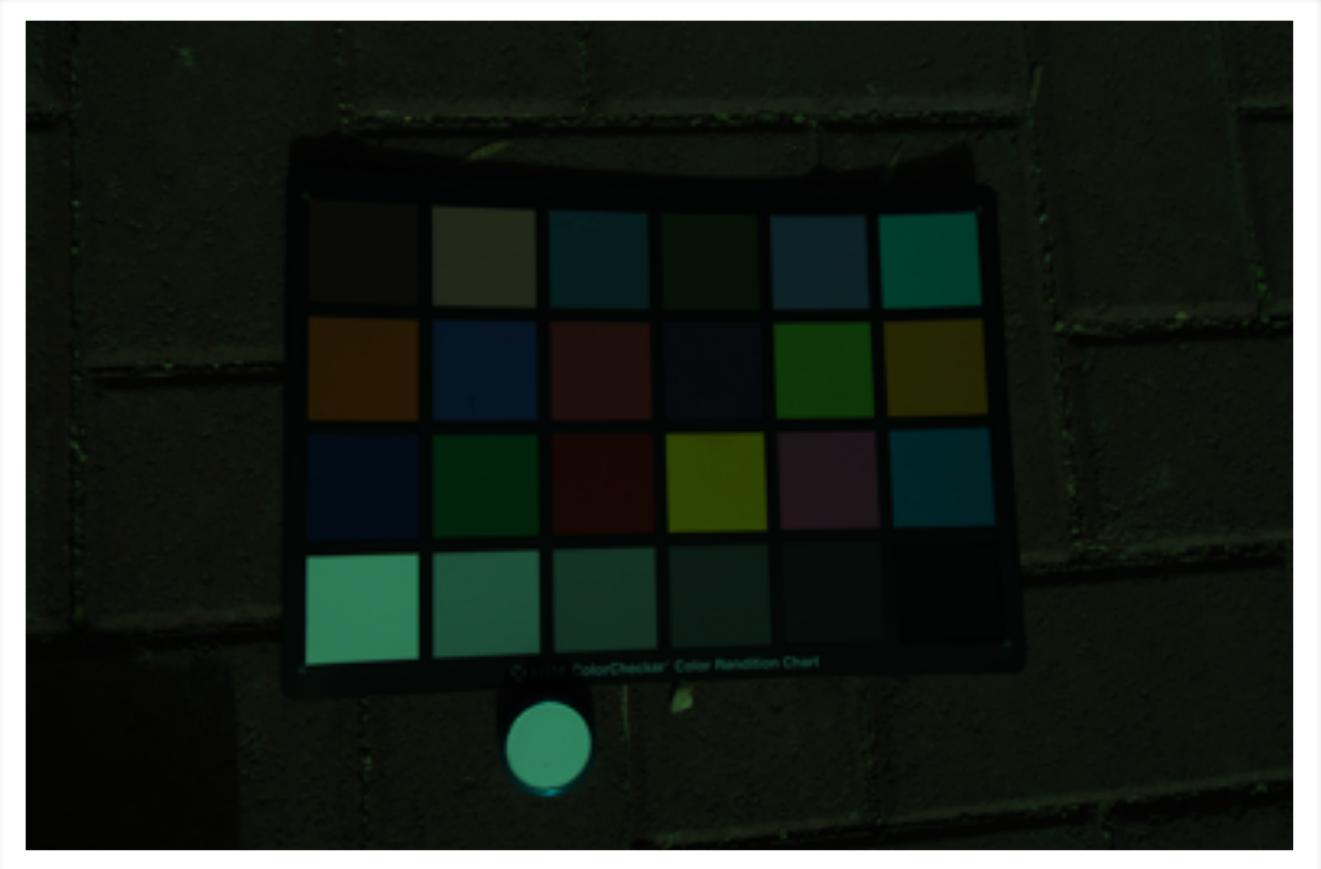
$\kappa$ : exposure-related constant



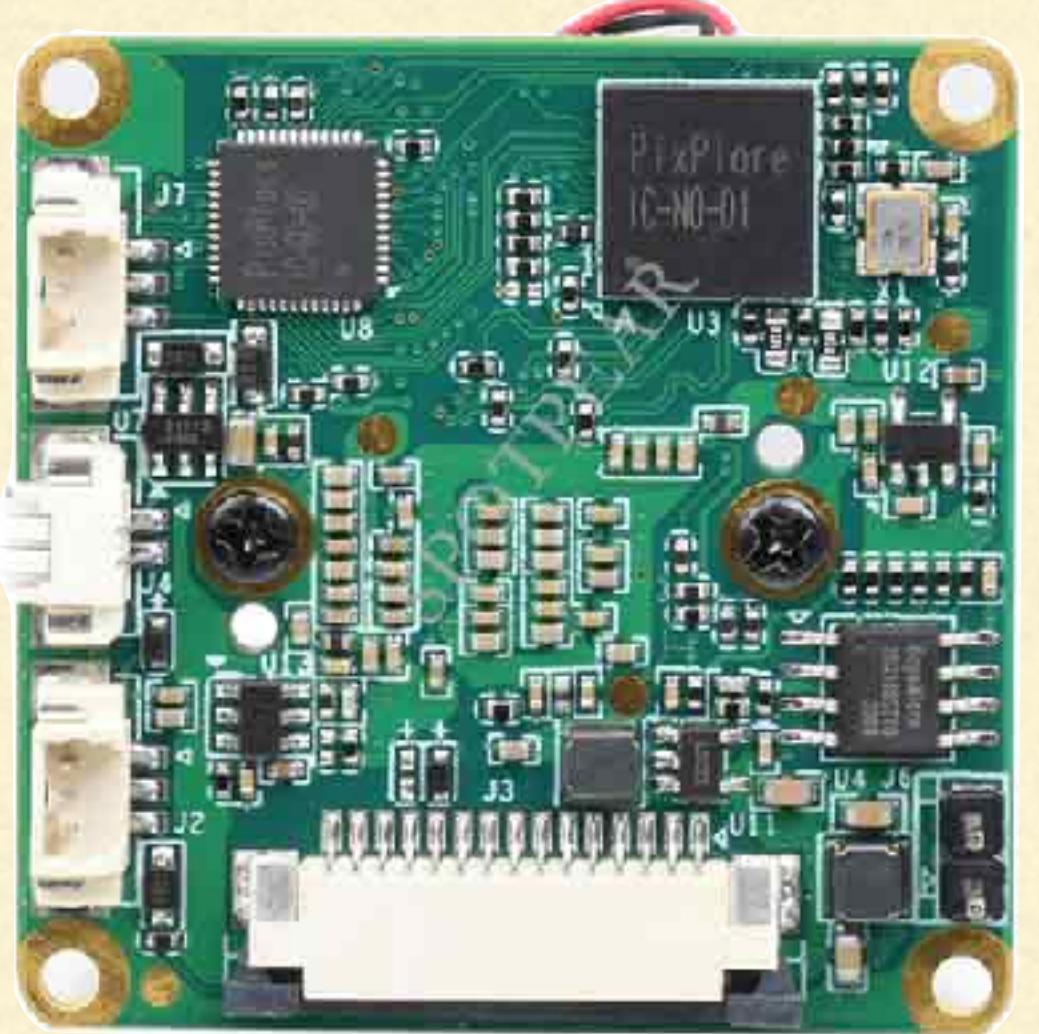
# Color Perception by a Camera

Cameras have built-in modules to enhance images, but they introduce irreversible color biases and artifacts.

RAW IMAGE



IN-CAMERA PROCESSING



JPG IMAGE



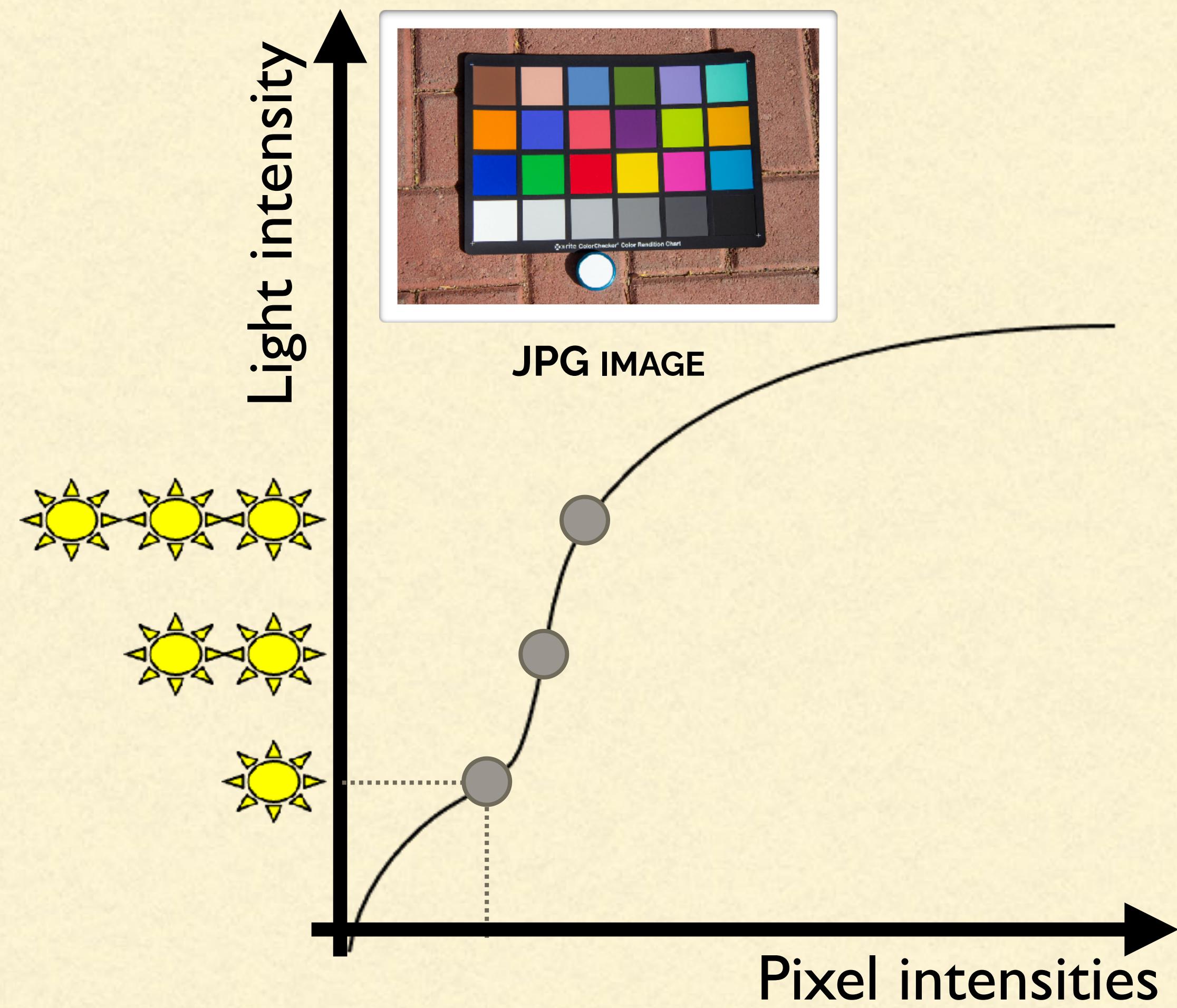
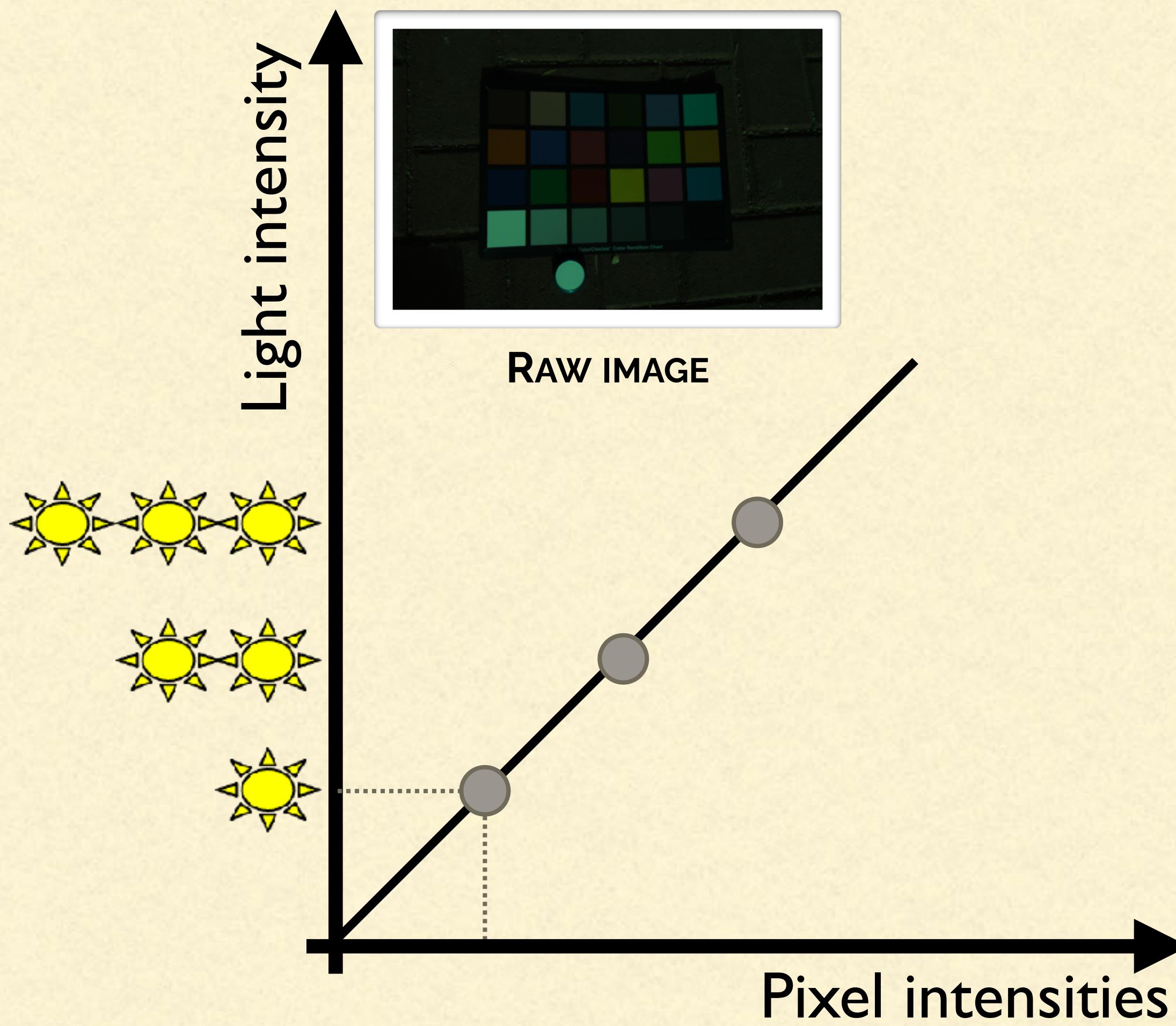
- .CR2 (Canon), .NEF (Nikon), .GPR (GoPro), etc
- **Linear**
- Uncompressed
- Can be used for color science

- Make & model specific
- Undocumented
- Proprietary
- **Non-linear**
- Irreversible

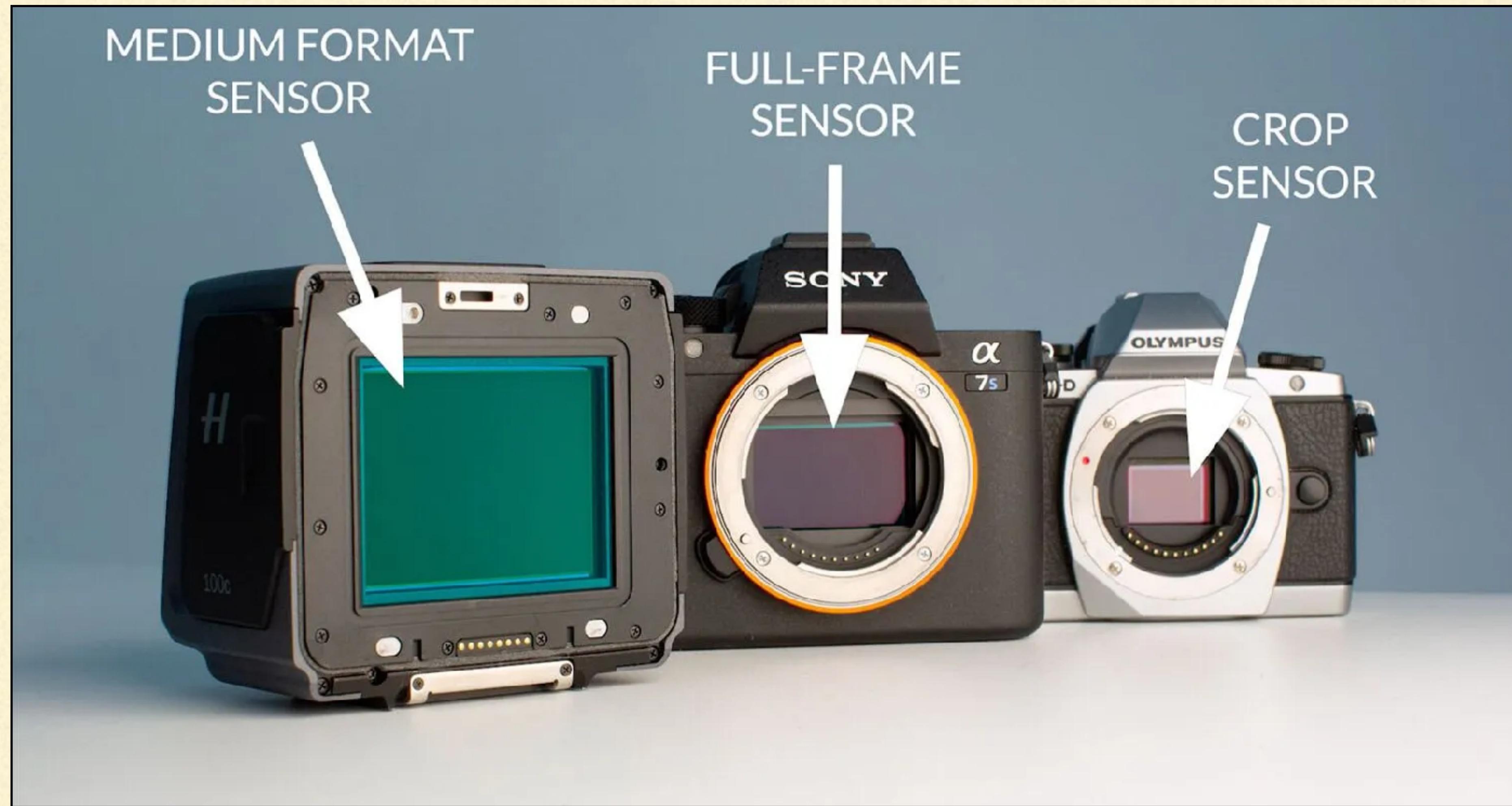
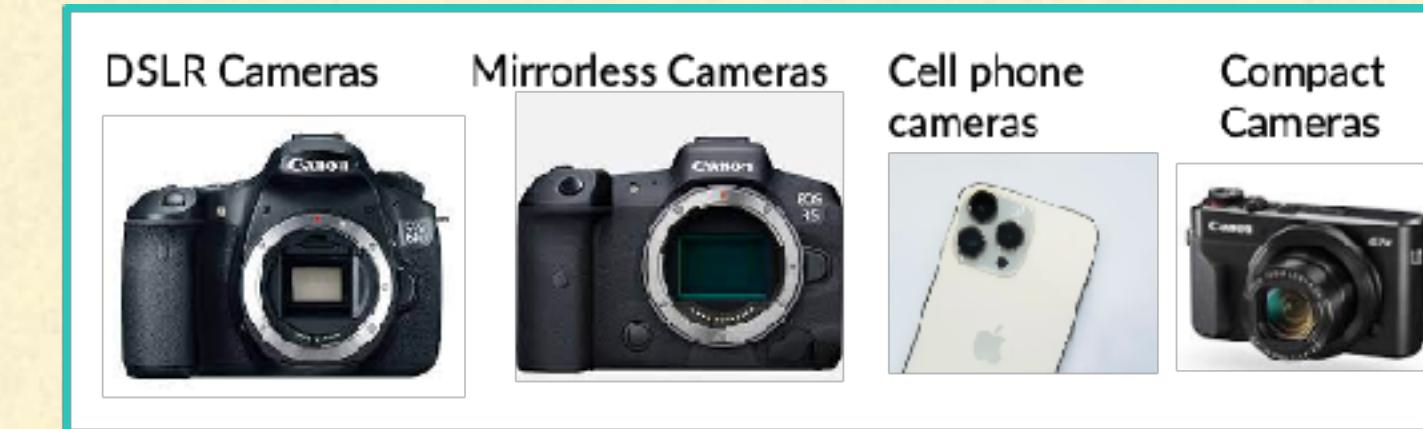
- .JPG for still images
- .MP4 for videos
- **Non-linear**
- Compressed
- Cannot be used for color science

# What Is a Linear Image? (and with what is it linear?)

Most modern sensors produce images that have a linear relationship with scene radiance.



# Image Sensors

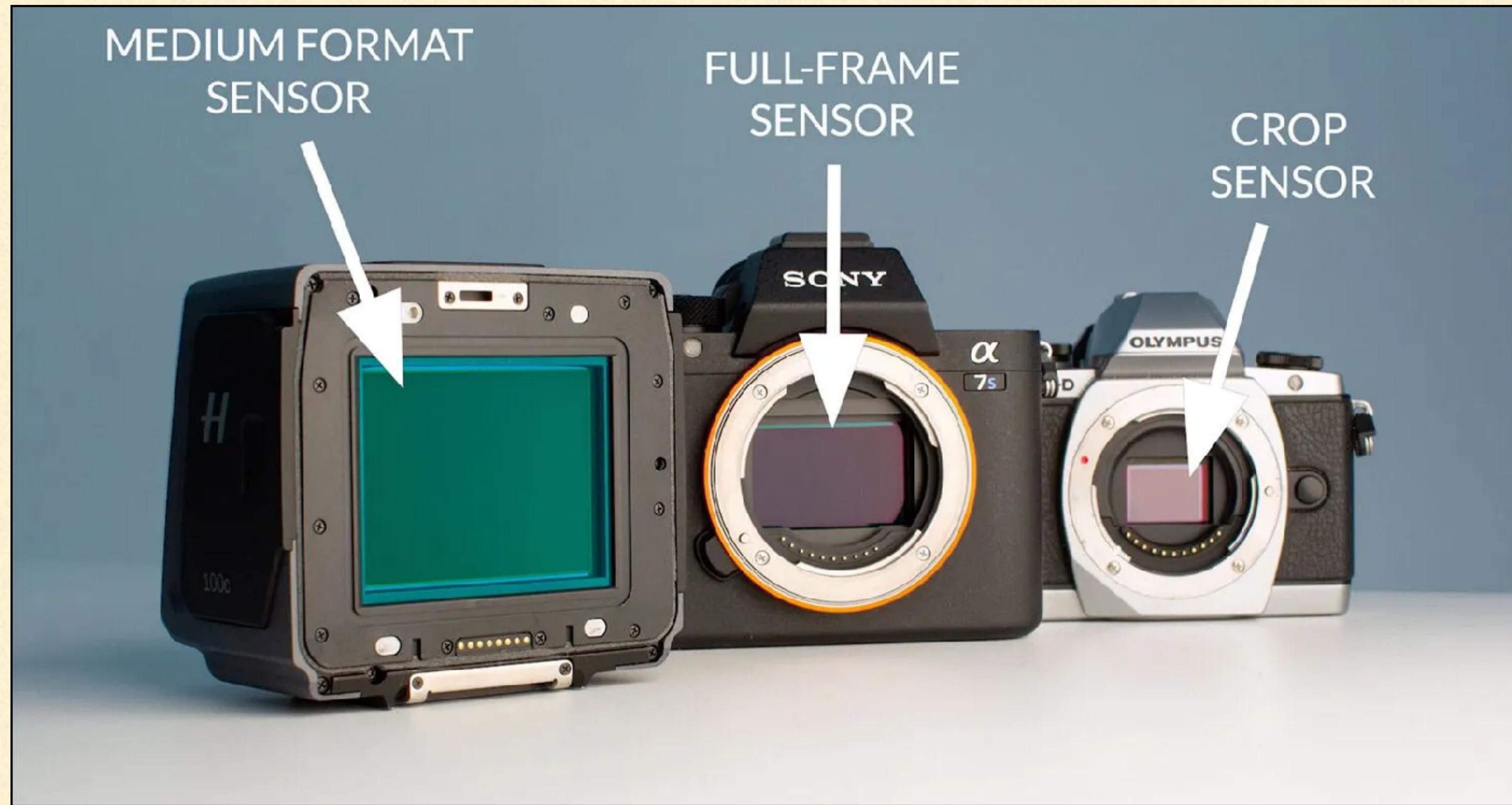
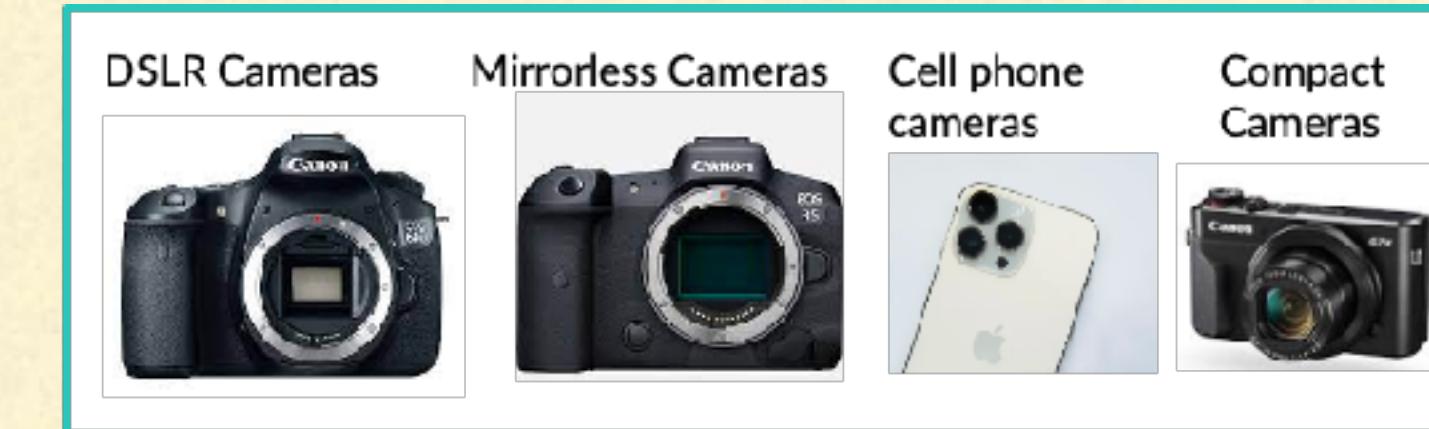


A linear image is  
—almost— the image  
formed at the sensor.

## PROPERTIES

- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
- Pixel Size (Pixel Pitch)
- Dynamic Range
- ISO Sensitivity/Dual-Native ISO
- Frame Rate / Readout Speed
- Global Shutter vs Rolling Shutter
- Signal-to-Noise Ratio (SNR)
- Color Filter Array (CFA)
- Spectral Response
- Low-Pass Filter (Anti-Aliasing Filter)
- Backside Illumination (BSI)
- Heat Management
- Sensor Stabilization (IBIS)
- Multi-Layer

# Image Sensors

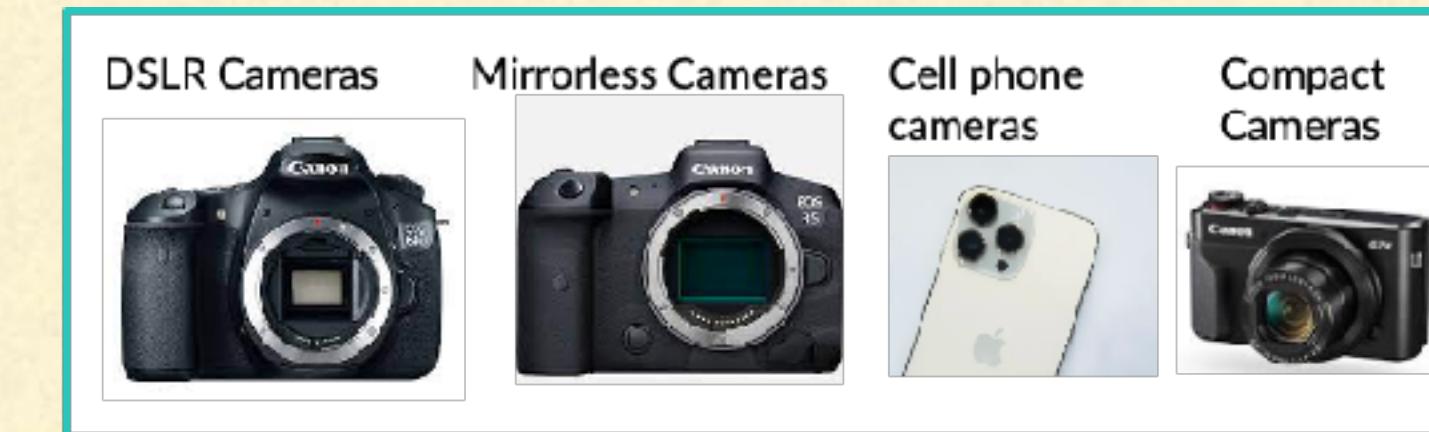


A linear image is  
—almost— the image  
formed at the sensor.

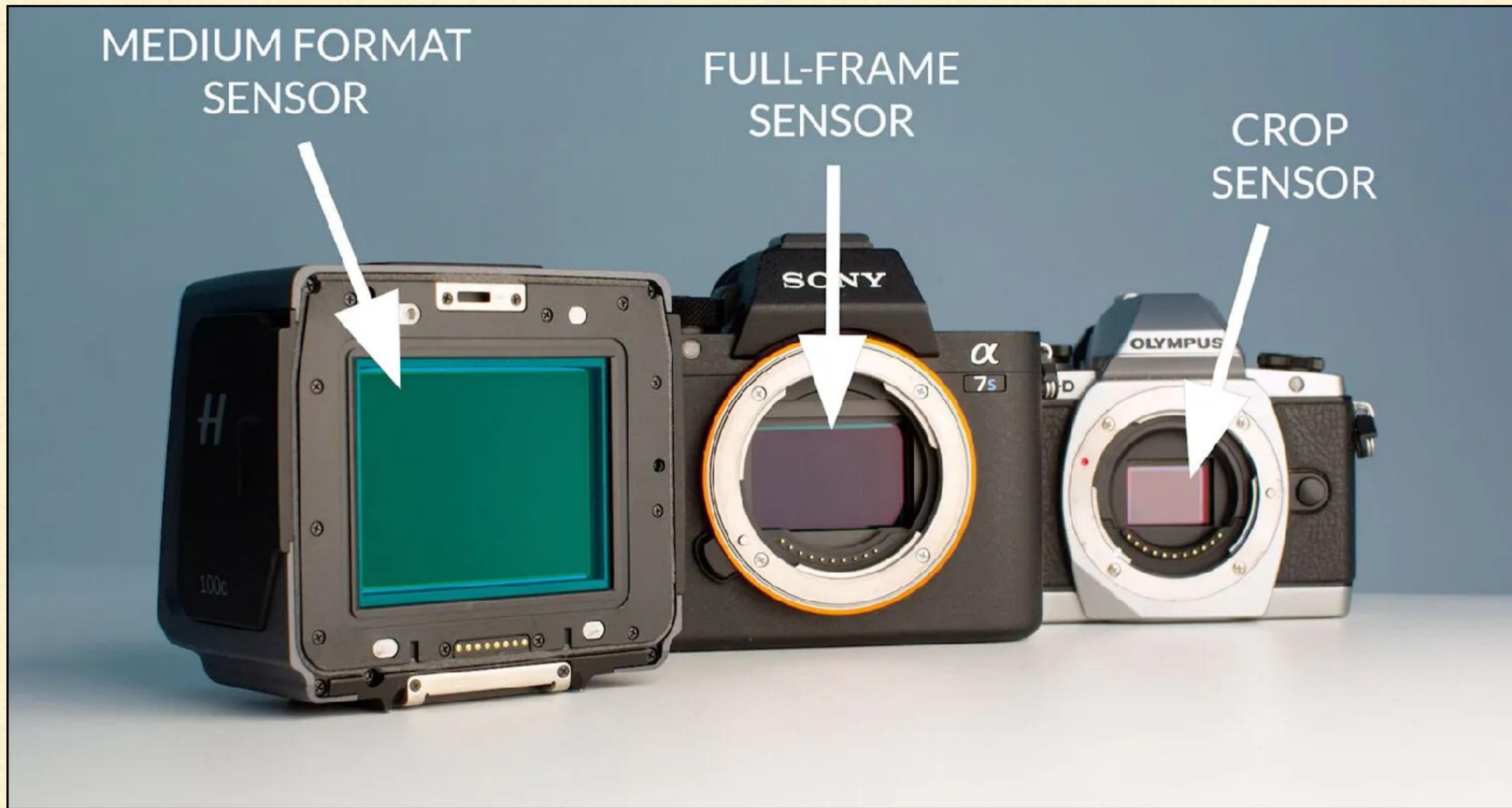
## PROPERTIES

- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
- Pixel Size (Pixel Pitch)
- Dynamic Range
- ISO Sensitivity/Dual-Native ISO
- Frame Rate / Readout Speed
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# Image Sensors



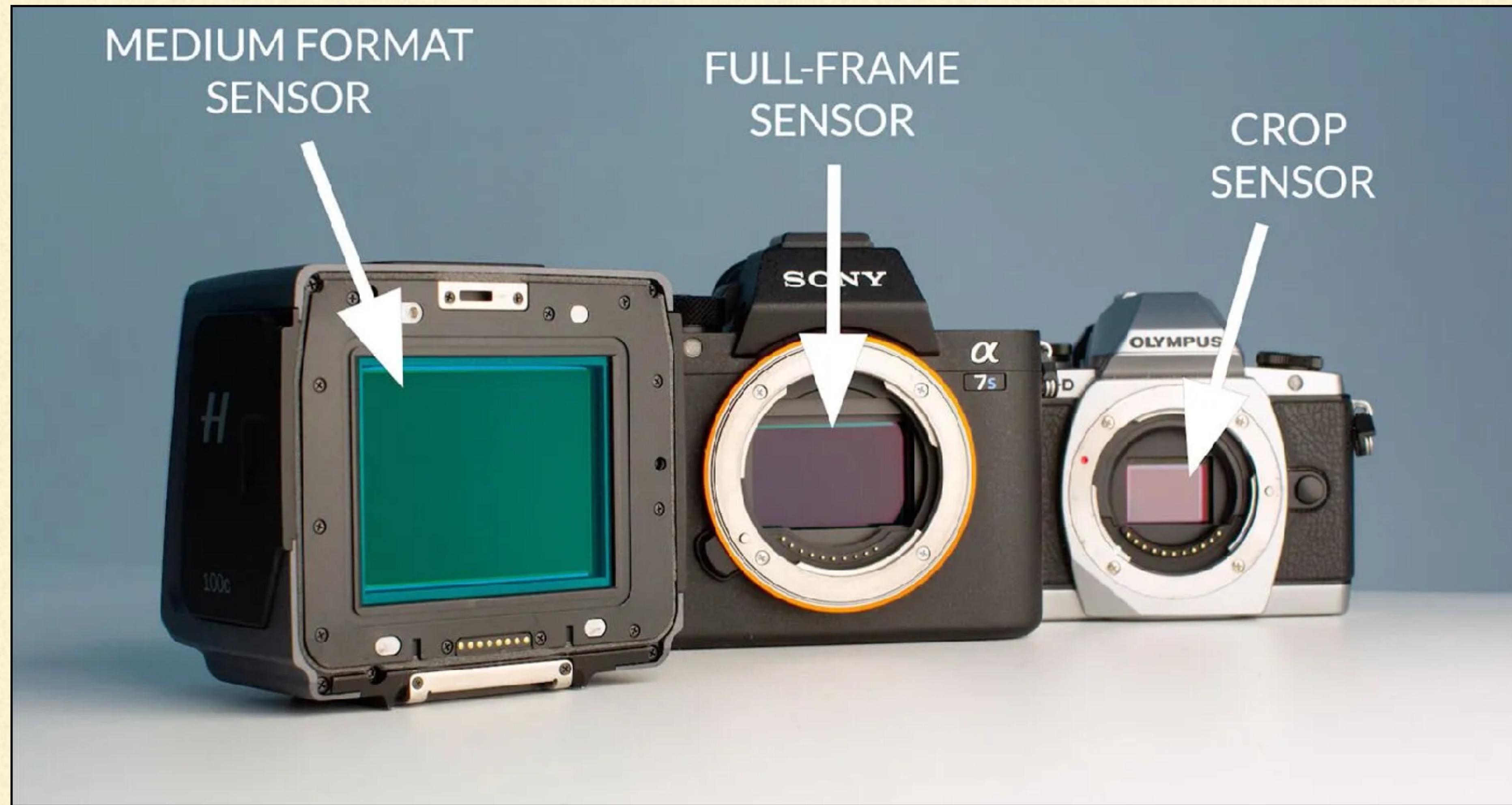
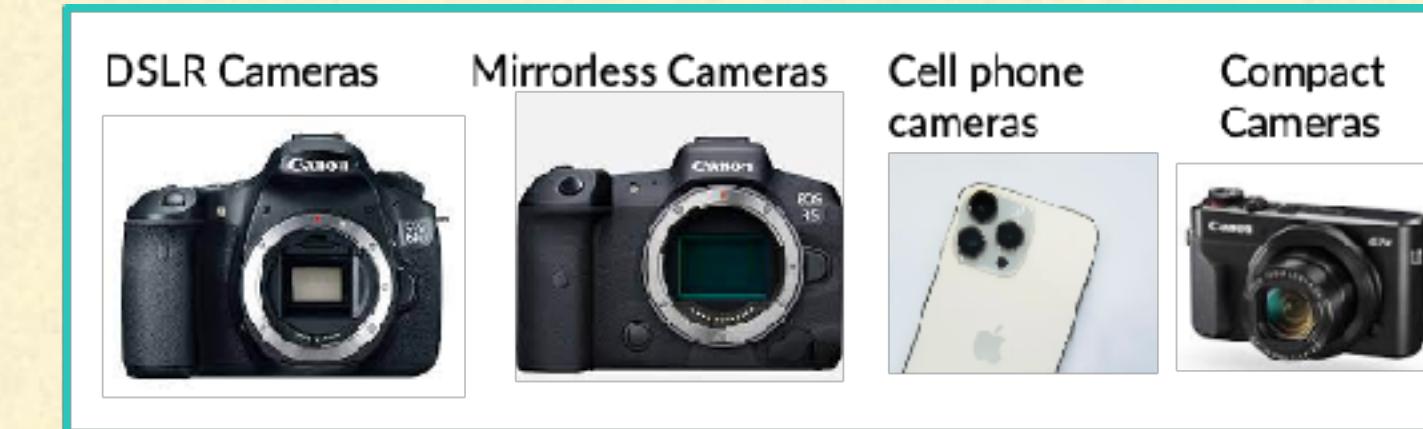
A linear image is  
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- Size
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- Sensor Stabilization (IBIS)
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# Image Sensors



FULL-FRAME  
SENSOR

CROP  
SENSOR

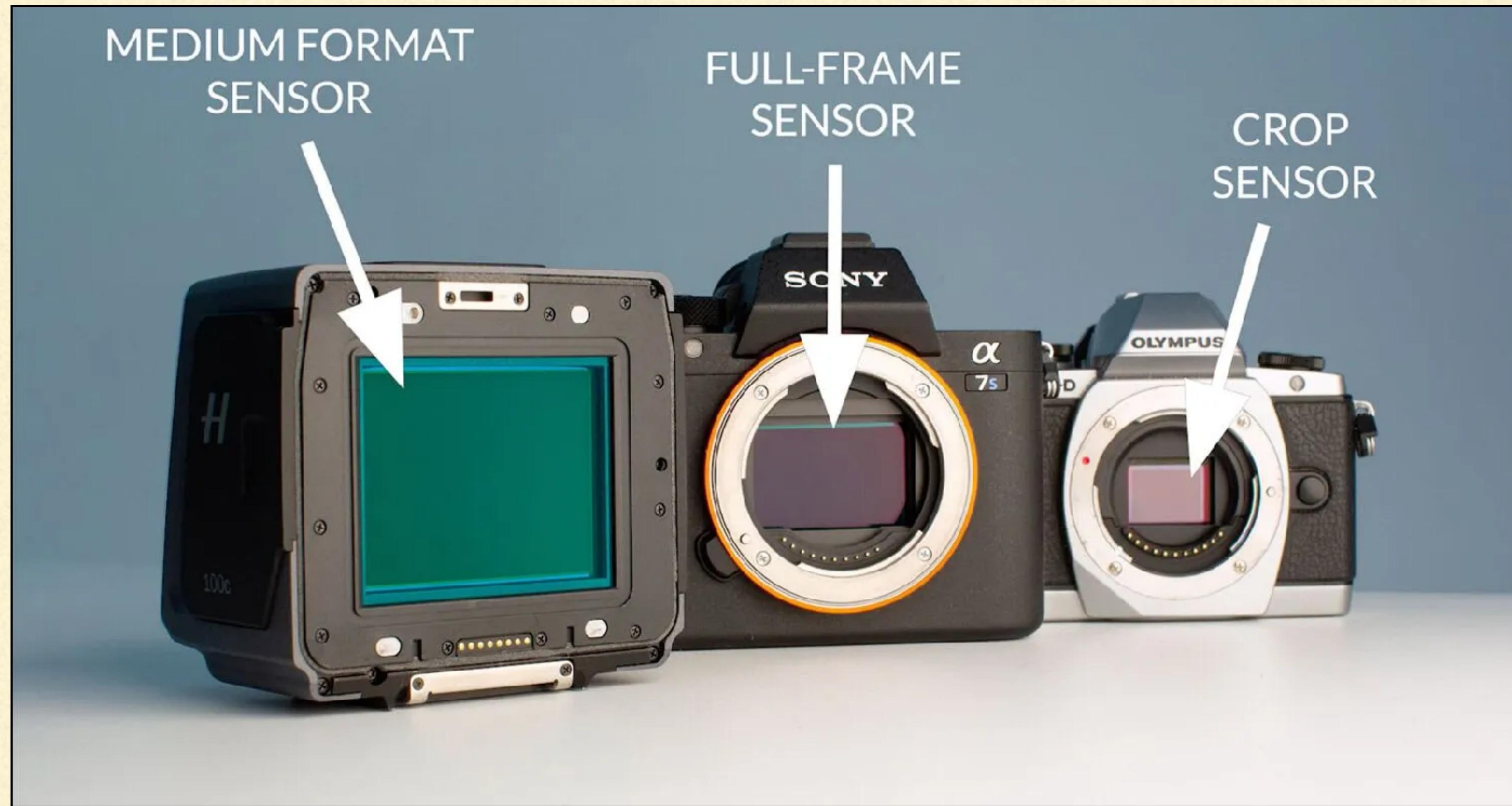
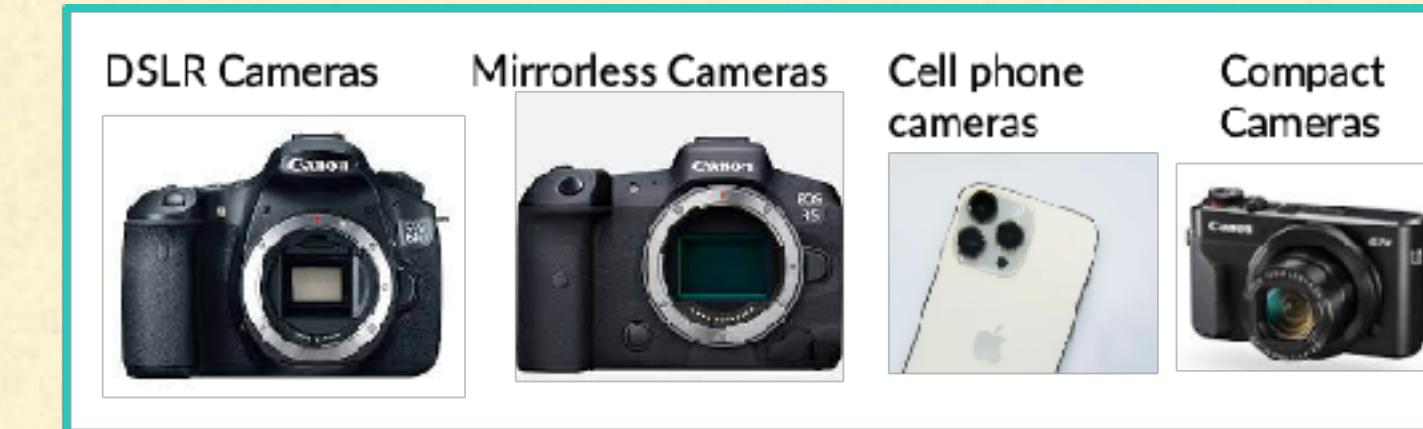
MEDIUM FORMAT  
SENSOR

## PROPERTIES

- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
- Pixel Size (Pixel Pitch)
- Dynamic Range
- ISO Sensitivity/Dual-Native ISO
- Frame Rate / Readout Speed
- Global Shutter vs Rolling Shutter
- Signal-to-Noise Ratio (SNR)
- Color Filter Array (CFA)
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A linear image is  
—almost— the image  
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# Image Sensors



FULL-FRAME  
SENSOR

CROP  
SENSOR

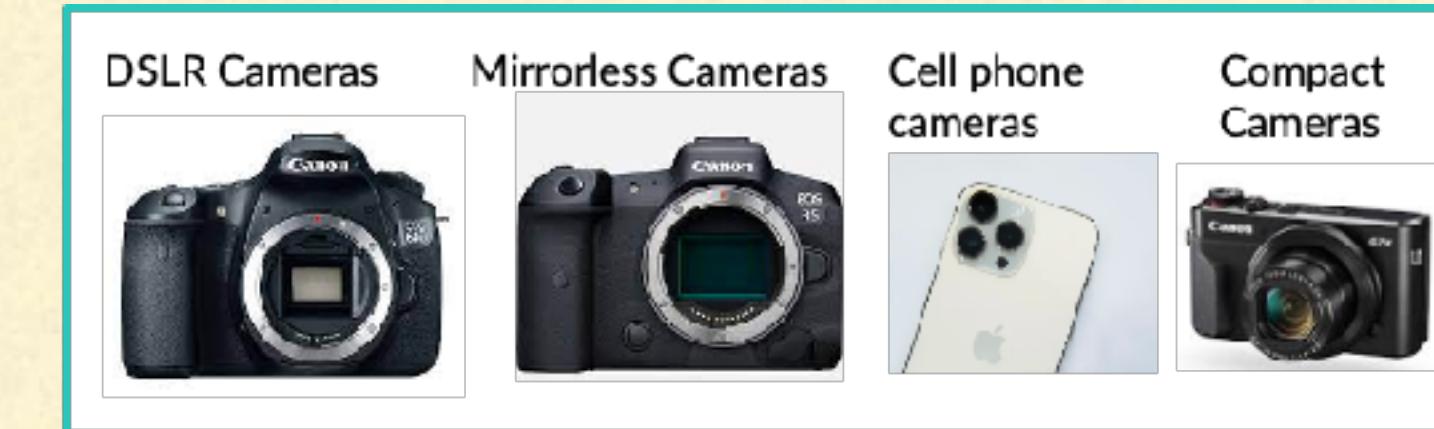
MEDIUM FORMAT  
SENSOR

## PROPERTIES

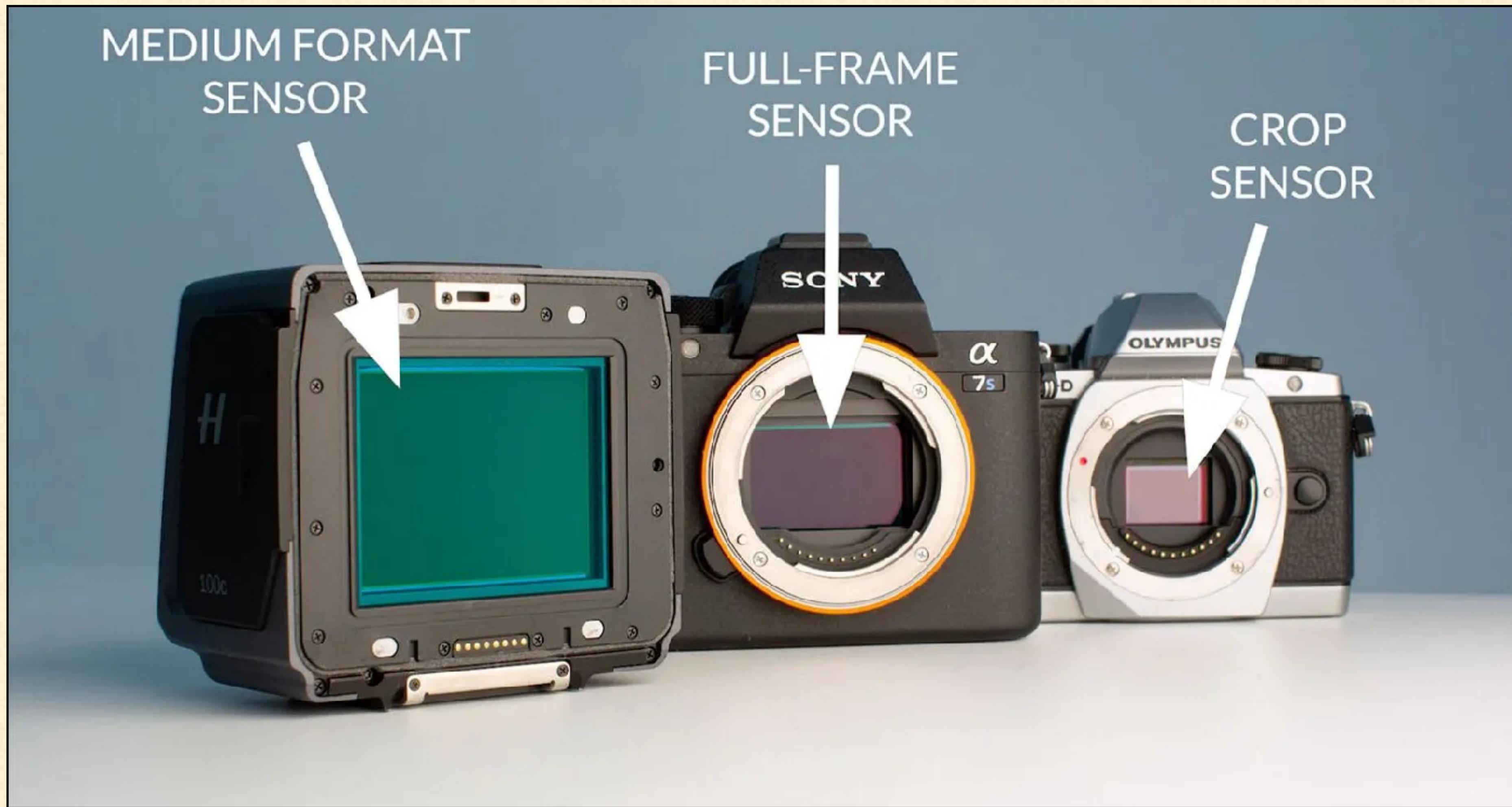
- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
- Pixel Size (Pixel Pitch)
- Dynamic Range
- ISO Sensitivity/Dual-Native ISO
- Frame Rate / Readout Speed
- Global Shutter vs Rolling Shutter
- Signal-to-Noise Ratio (SNR)
- Color Filter Array (CFA)
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- Heat Management
- Sensor Stabilization (IBIS)
- Multi-Layer

A linear image is  
—almost— the image  
formed at the sensor.

# Image Sensors



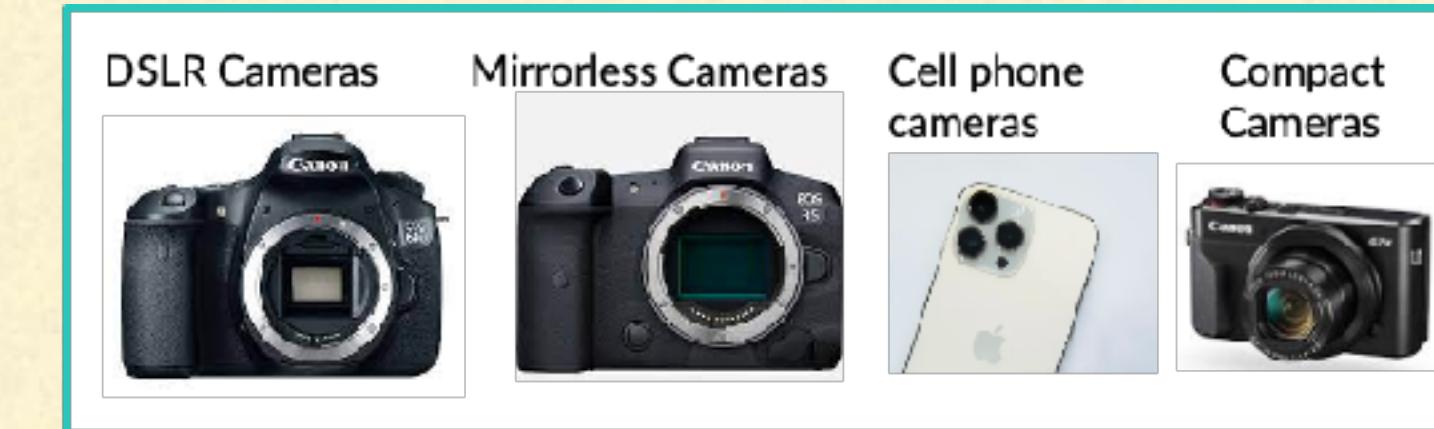
A linear image is  
—almost— the image  
formed at the sensor.



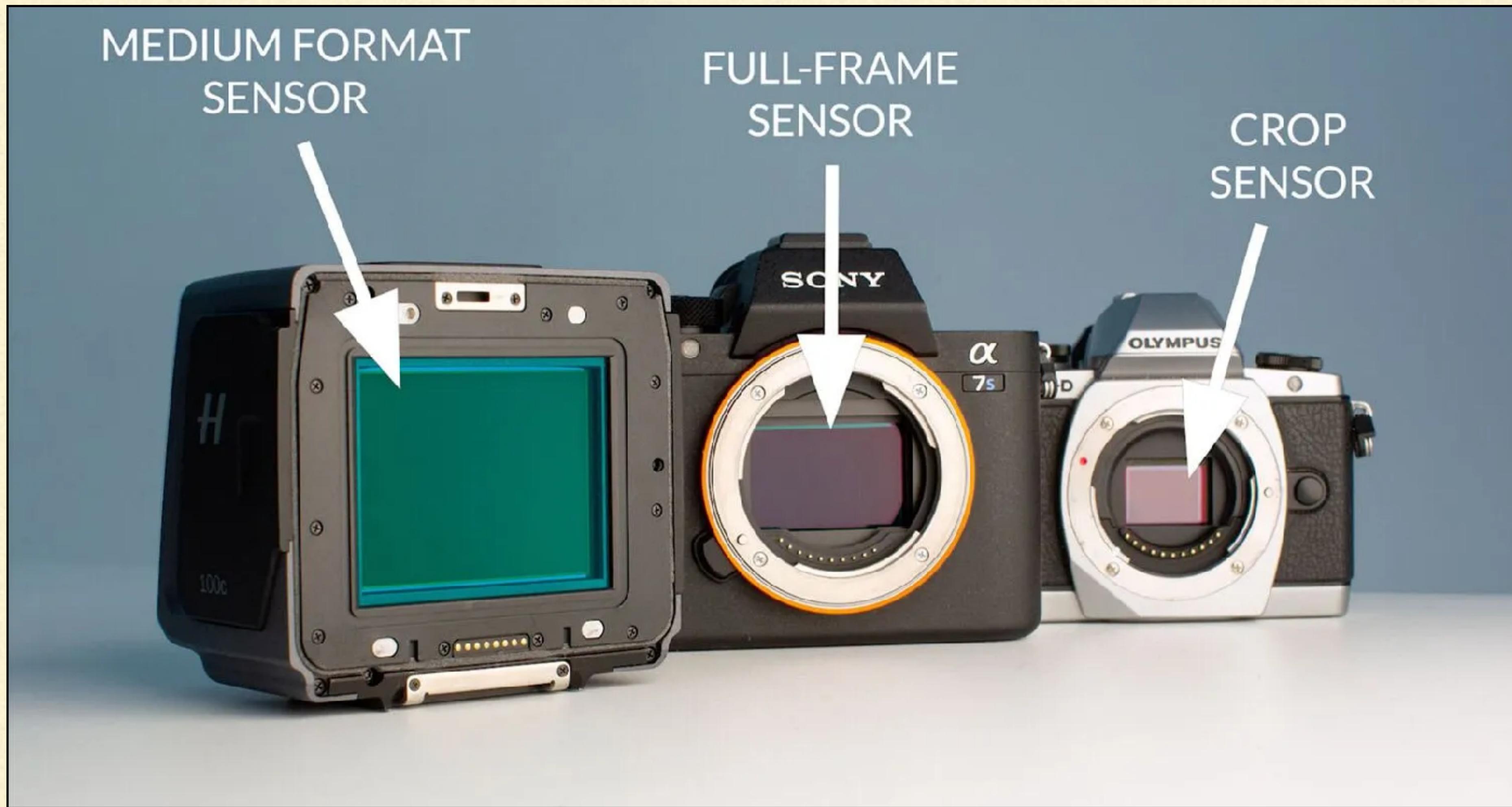
## PROPERTIES

- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
- Pixel Size (Pixel Pitch)
- Dynamic Range
- ISO Sensitivity/Dual-Native ISO
- Frame Rate / Readout Speed
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# Image Sensors



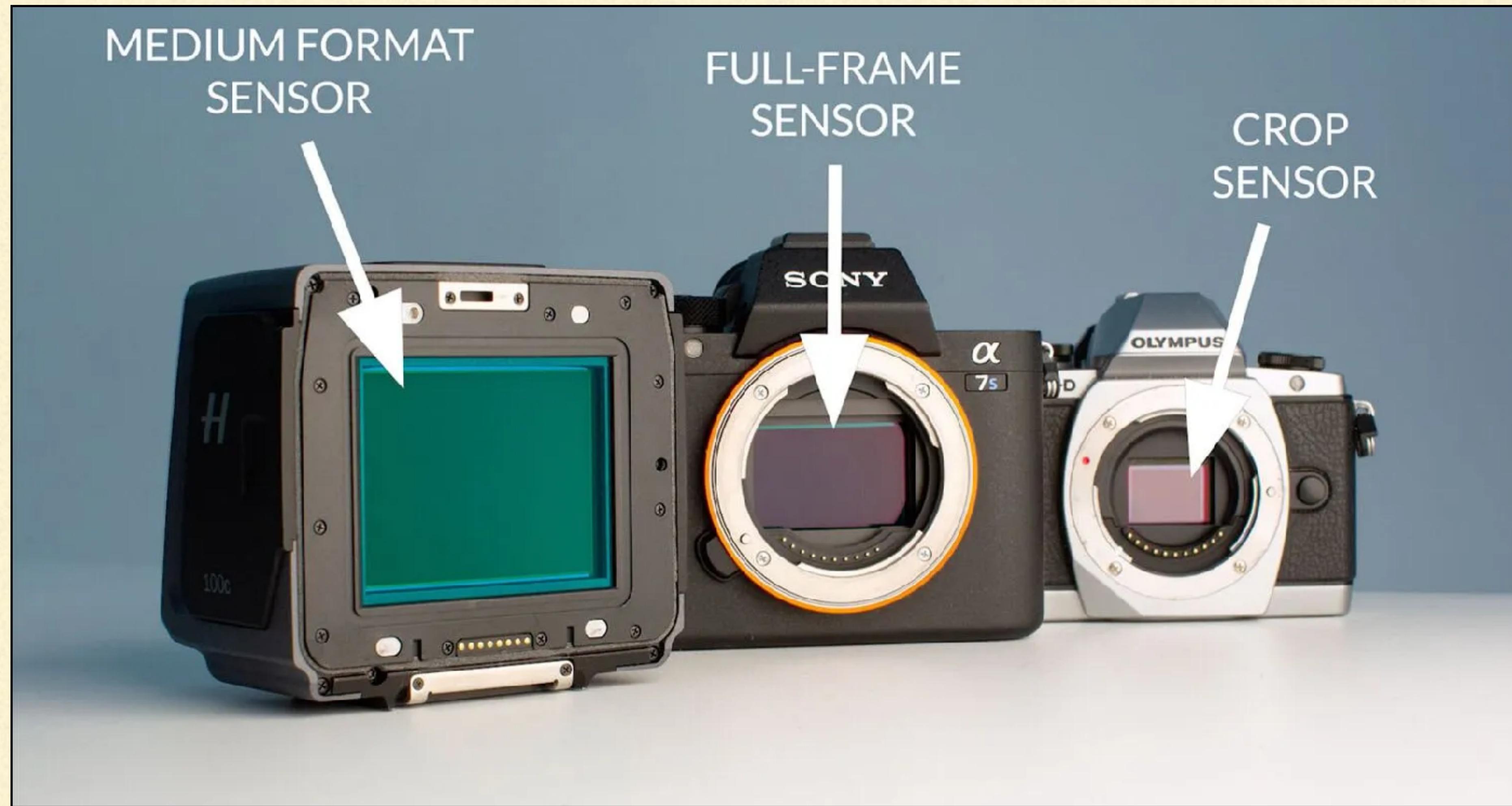
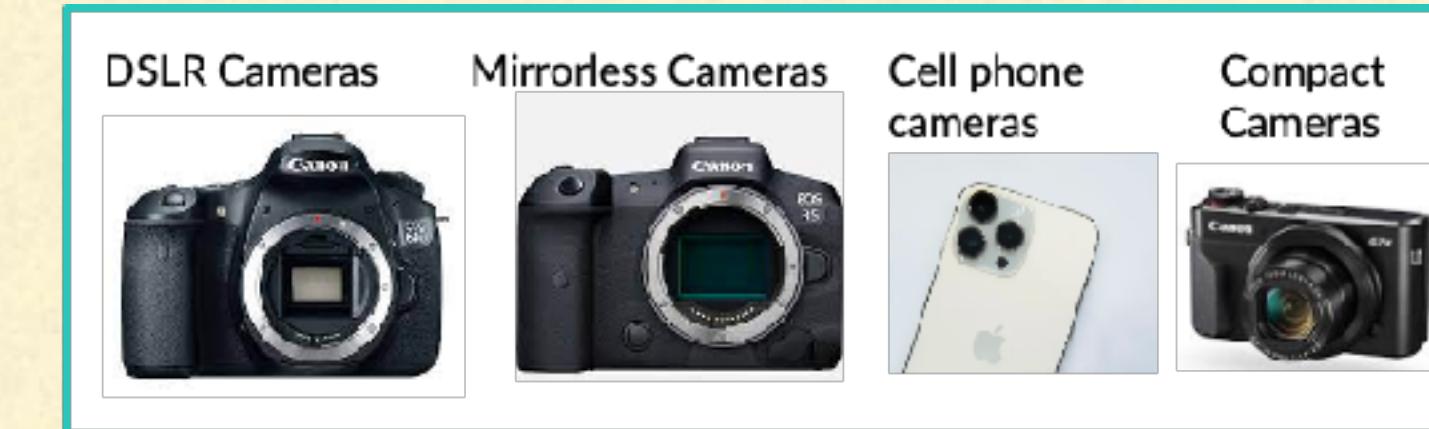
A linear image is  
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- Signal-to-Noise Ratio (SNR)
- Color Filter Array (CFA)
- Spectral Response
- Low-Pass Filter (Anti-Aliasing Filter)
- Backside Illumination (BSI)
- Heat Management
- Sensor Stabilization (IBIS)
- Multi-Layer

# Image Sensors - Size

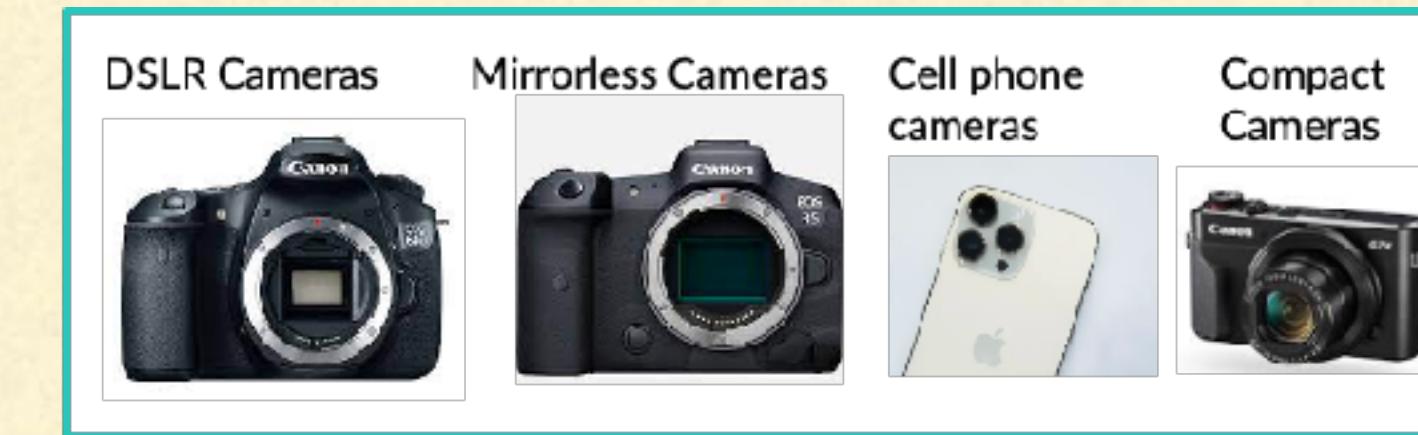


A linear image is  
—almost— the image  
formed at the sensor.

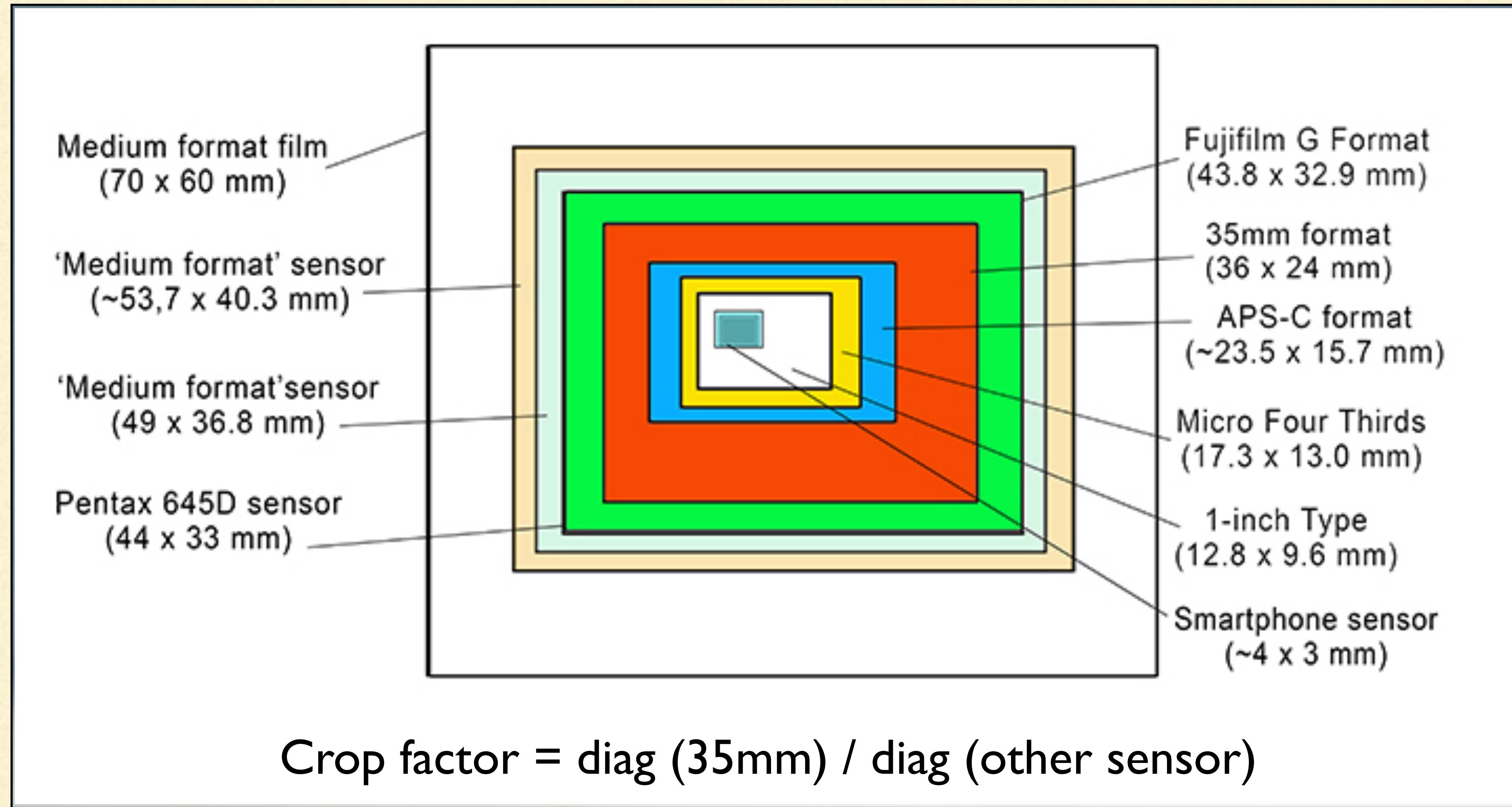
## PROPERTIES

- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
- Pixel Size (Pixel Pitch)
- Dynamic Range
- ISO Sensitivity/Dual-Native ISO
- Frame Rate / Readout Speed
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- Color Filter Array (CFA)
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- Low-Pass Filter (Anti-Aliasing Filter)
- Backside Illumination (BSI)
- Heat Management
- Sensor Stabilization (IBIS)
- Multi-Layer

# Image Sensors - Size



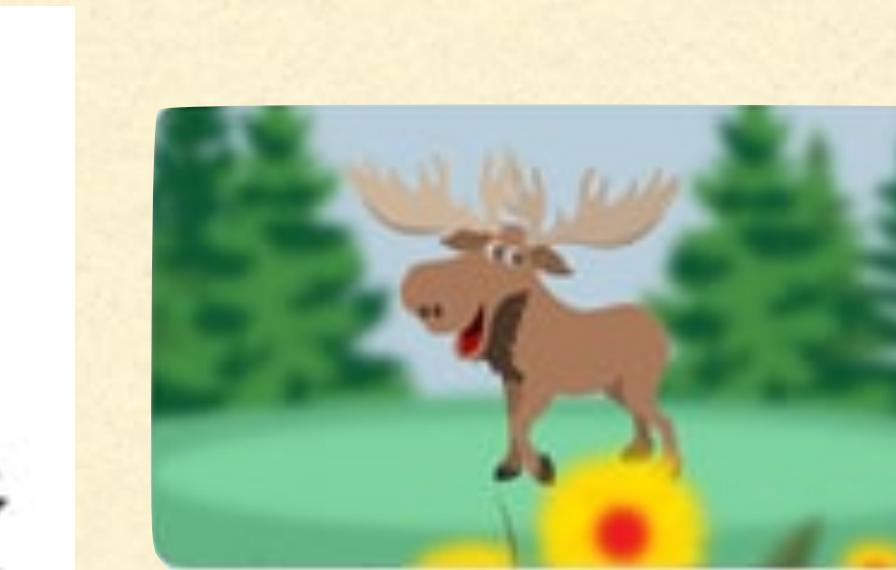
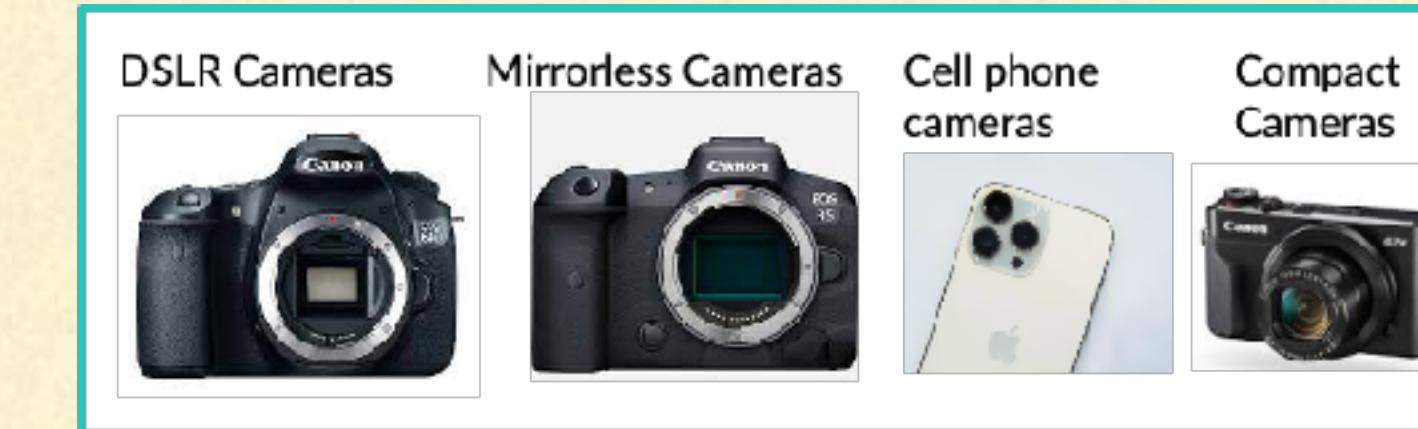
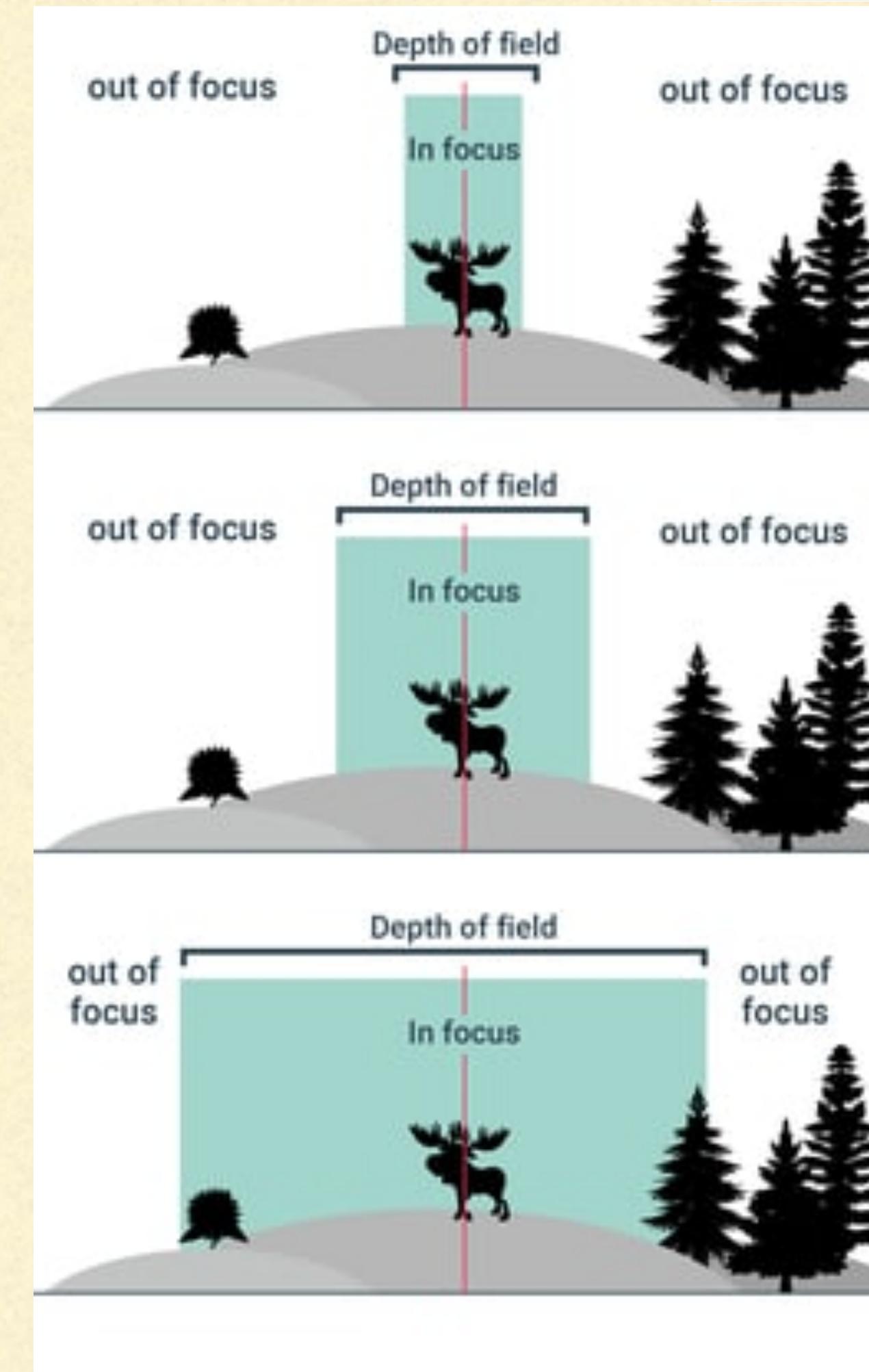
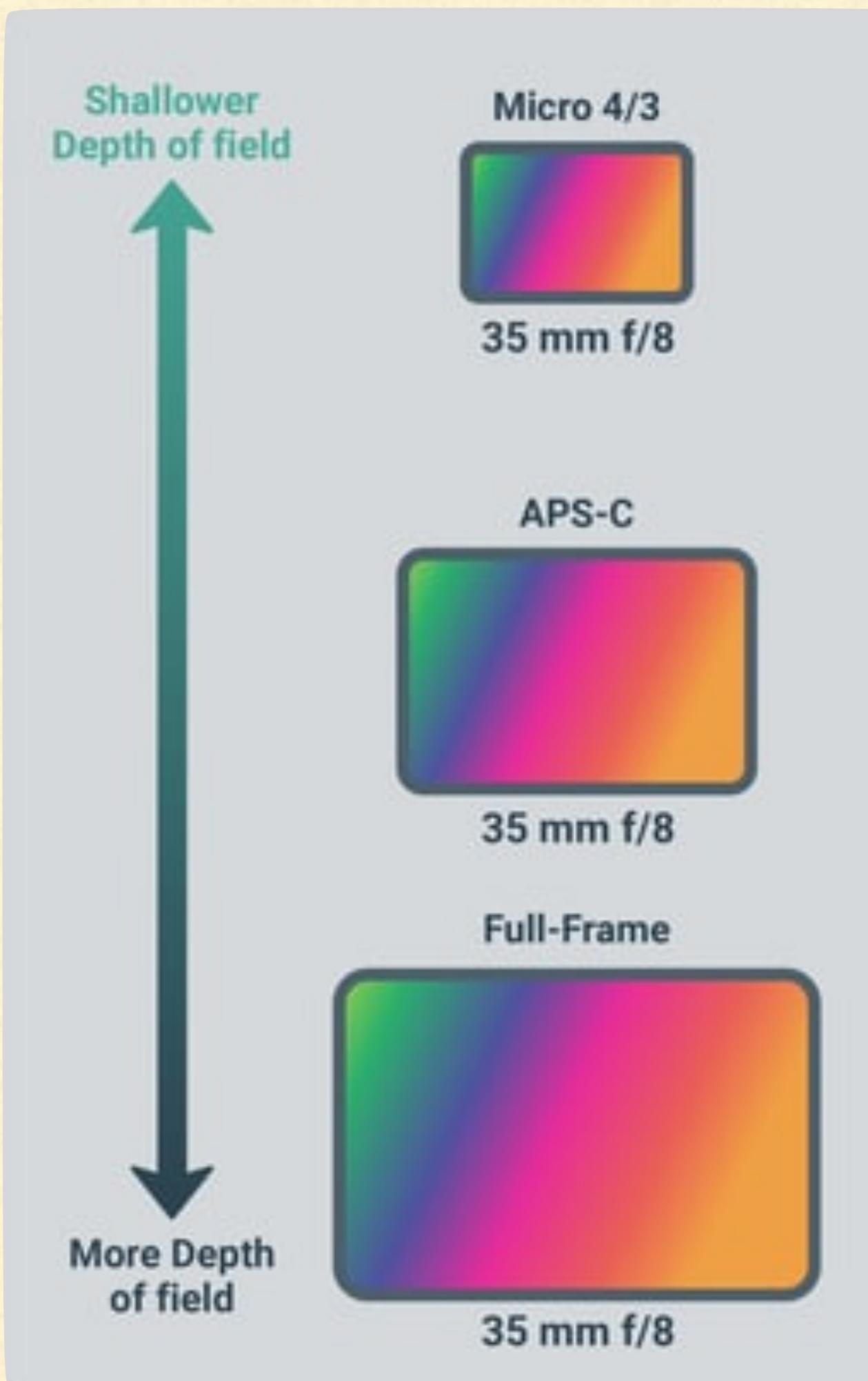
A linear image is  
—almost— the image  
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## PROPERTIES

- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
- Pixel Size (Pixel Pitch)
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- Low-Pass Filter (Anti-Aliasing Filter)
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- Sensor Stabilization (IBIS)
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# Image Sensors - Size

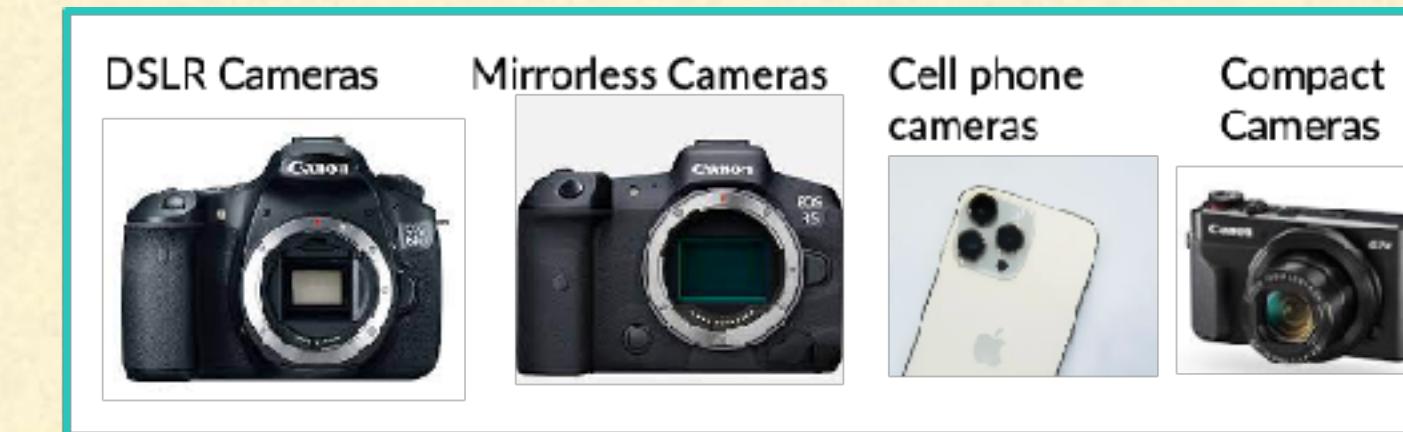
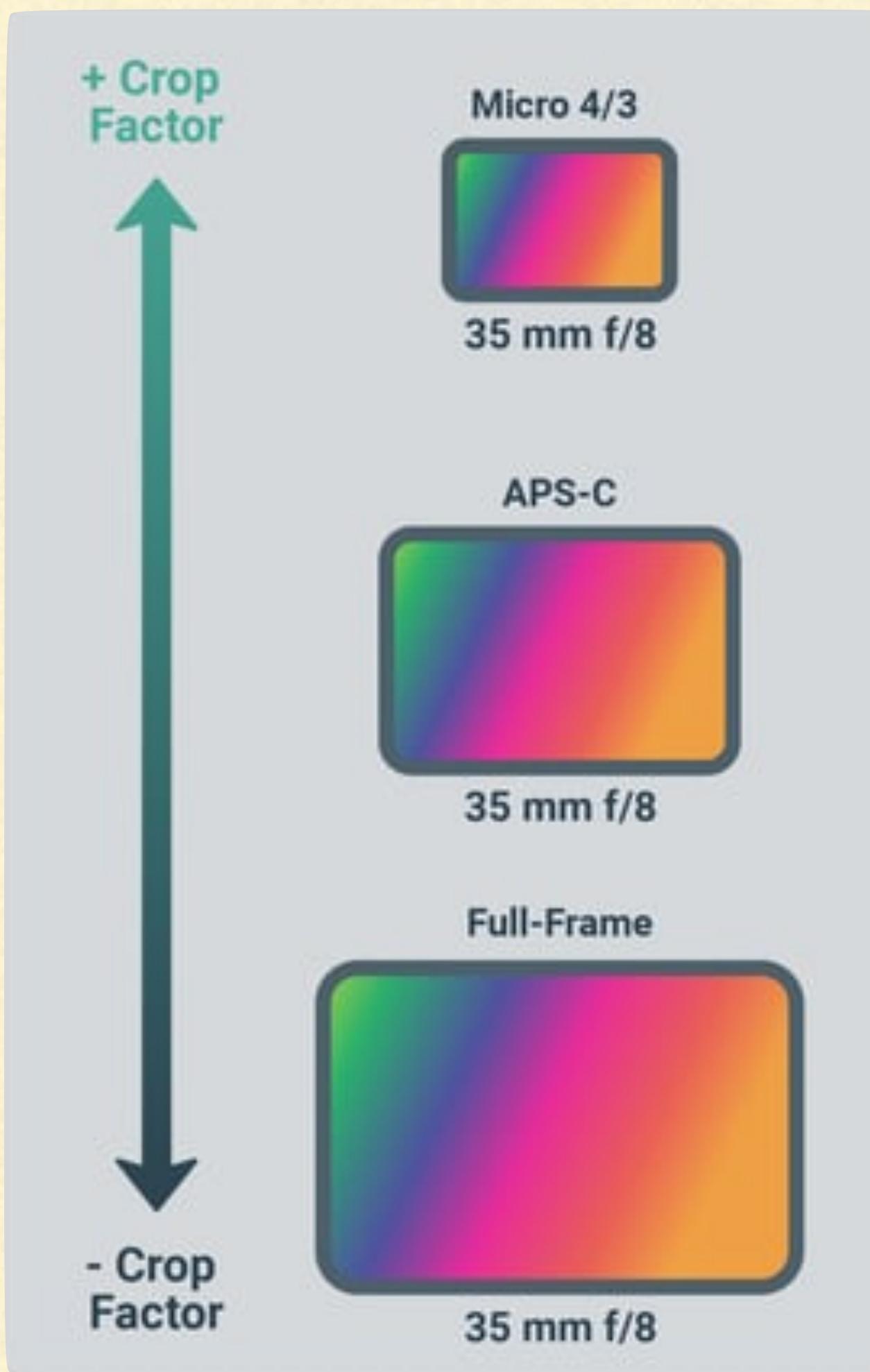


Larger sensors have larger depth of field (more areas in focus).

## PROPERTIES

- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
- Pixel Size (Pixel Pitch)
- Dynamic Range
- ISO Sensitivity/Dual-Native ISO
- Frame Rate / Readout Speed
- Global Shutter vs Rolling Shutter
- Signal-to-Noise Ratio (SNR)
- Color Filter Array (CFA)
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# Image Sensors - Crop Factor

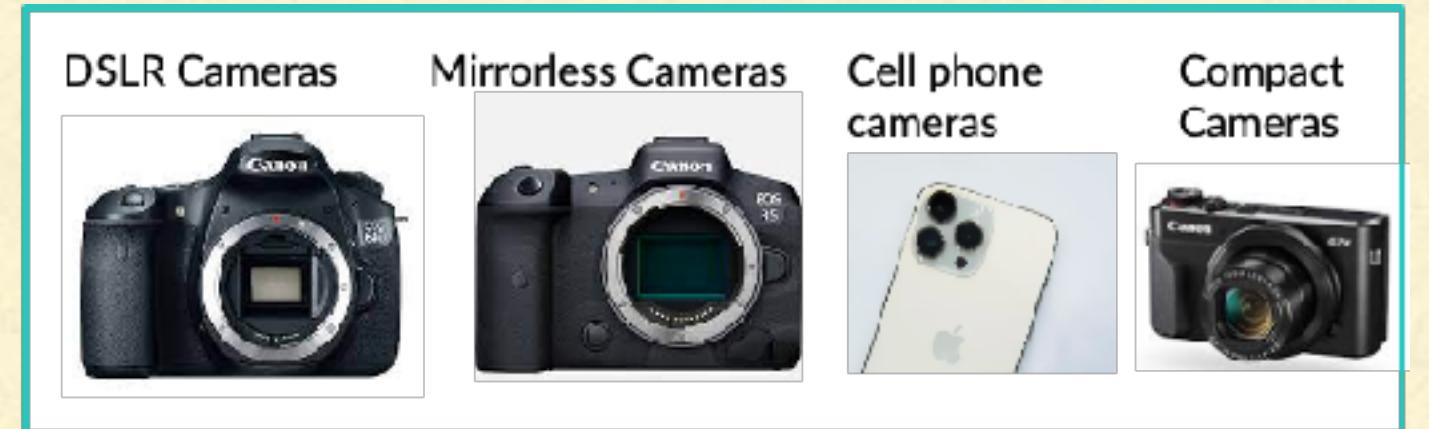


Smaller sensor (high crop factor) crops the view of what a full-frame sensor would capture.

## PROPERTIES

- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
- Pixel Size (Pixel Pitch)
- Dynamic Range
- ISO Sensitivity/Dual-Native ISO
- Frame Rate / Readout Speed
- Global Shutter vs Rolling Shutter
- Signal-to-Noise Ratio (SNR)
- Color Filter Array (CFA)
- Spectral Response
- Low-Pass Filter (Anti-Aliasing Filter)
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- Heat Management
- Sensor Stabilization (IBIS)
- Multi-Layer

# Pixel Size/Count/Pitch



Larger sensors have bigger pixel sizes and let more light in (better image quality), but many small pixels can achieve the same.

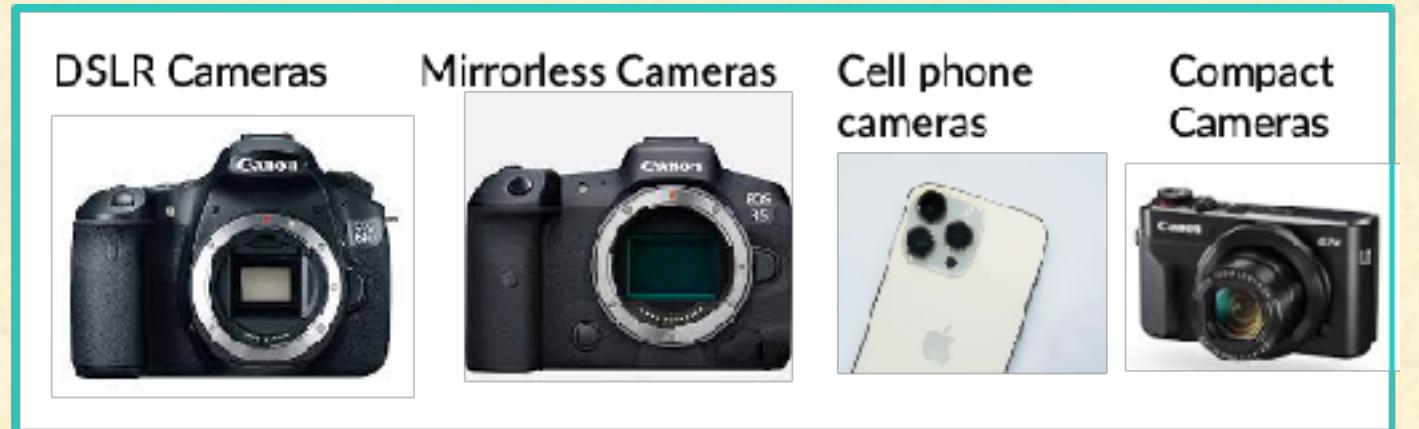
## PROPERTIES

- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
- Pixel Size (Pixel Pitch)
- Dynamic Range
- ISO Sensitivity/Dual-Native ISO
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- Low-Pass Filter (Anti-Aliasing Filter)
- Backside Illumination (BSI)
- Heat Management
- Sensor Stabilization (IBIS)
- Multi-Layer

# Pixel Size/Count/Pitch



## 1 PIXEL

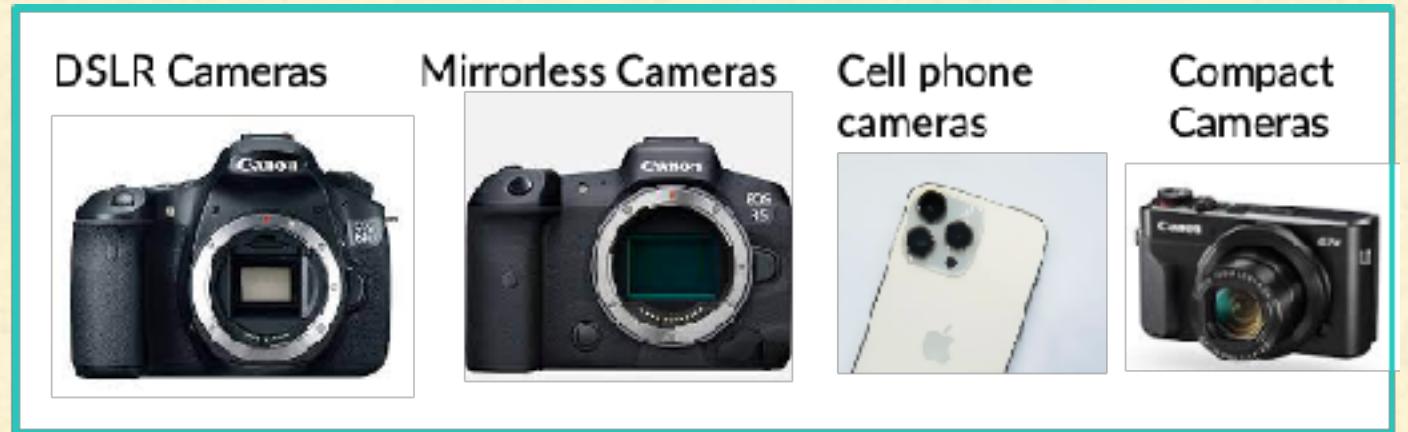


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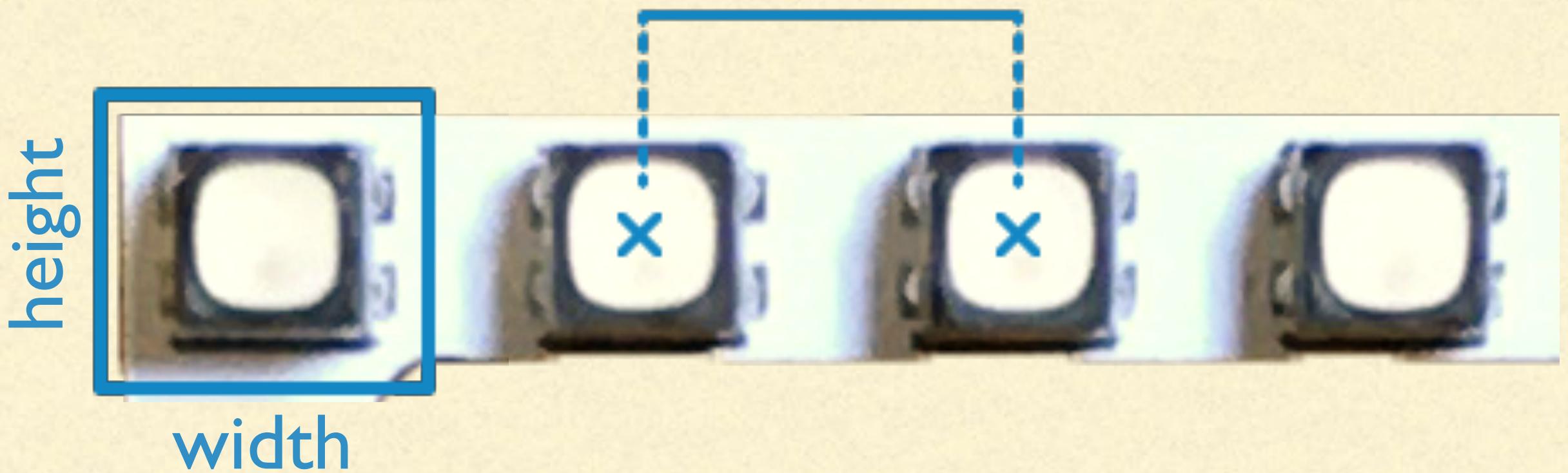
## PROPERTIES

- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
- Pixel Size (Pixel Pitch)
- Dynamic Range
- ISO Sensitivity/Dual-Native ISO
- Frame Rate / Readout Speed
- Global Shutter vs Rolling Shutter
- Signal-to-Noise Ratio (SNR)
- Color Filter Array (CFA)
- Spectral Response
- Low-Pass Filter (Anti-Aliasing Filter)
- Backside Illumination (BSI)
- Heat Management
- Sensor Stabilization (IBIS)
- Multi-Layer

# Pixel Size/Count/Pitch



## 1 PIXEL      PIXEL PITCH (mm)

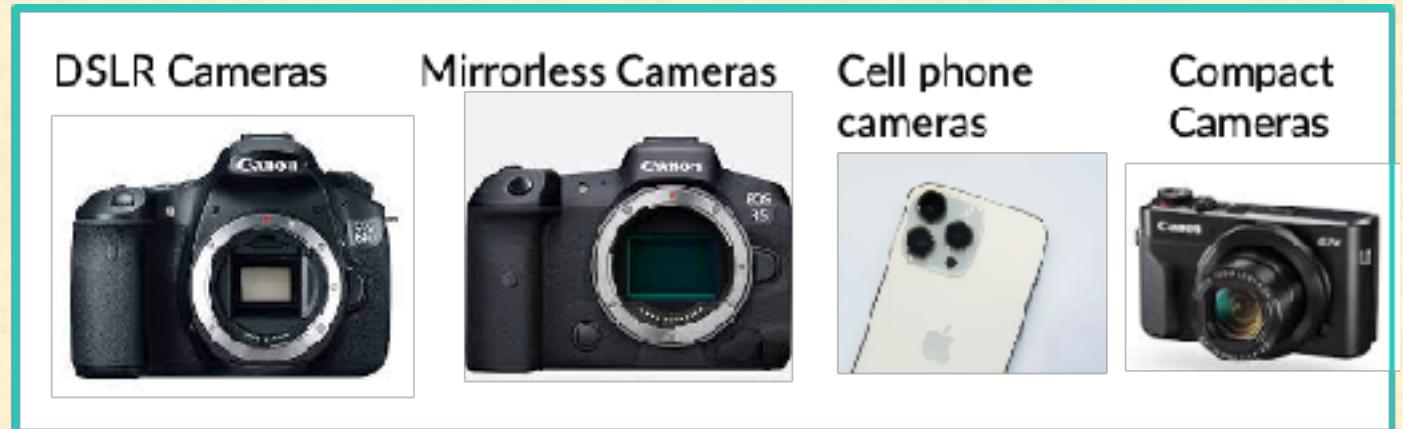


Larger sensors have bigger pixel sizes and let more light in (better image quality), but many small pixels can achieve the same.

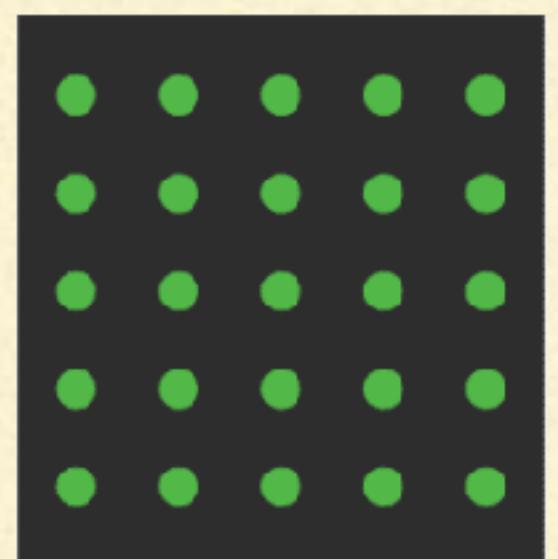
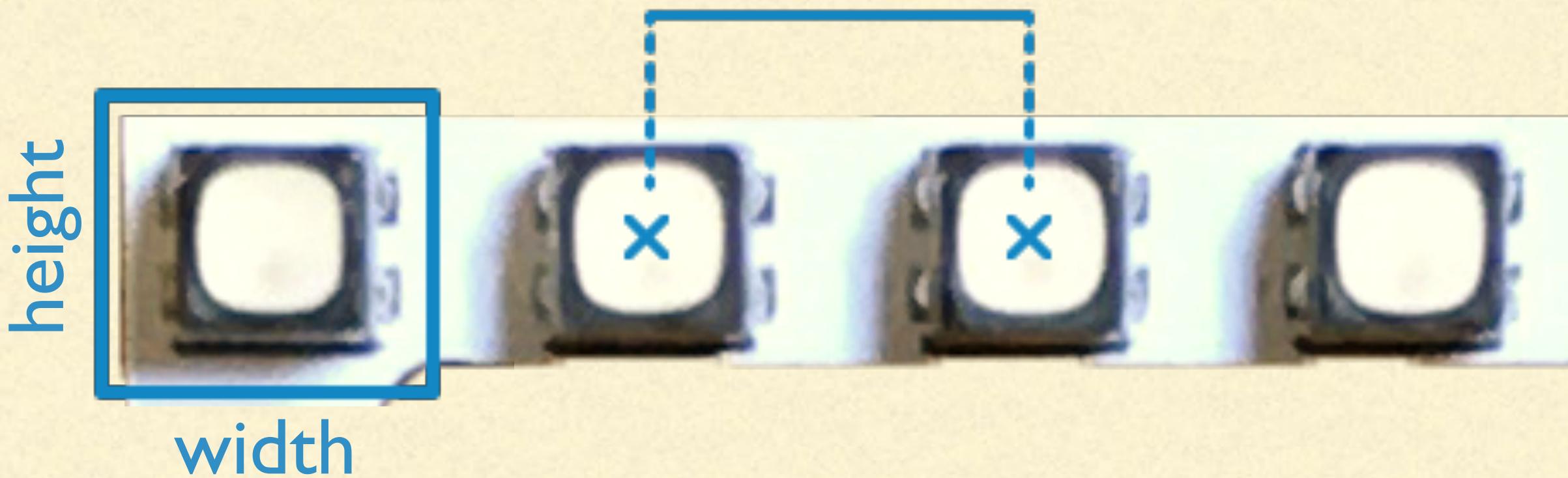
## PROPERTIES

- Size
- Aspect Ratio
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- Type (CCD vs CMOS)
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- Pixel Size (Pixel Pitch)
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- Multi-Layer

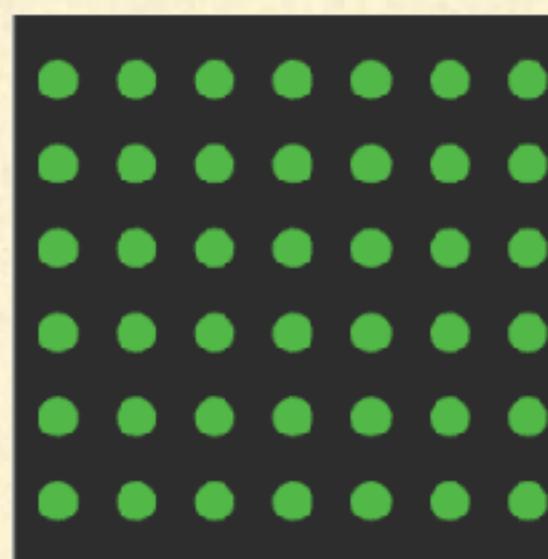
# Pixel Size/Count/Pitch



## 1 PIXEL      PIXEL PITCH (mm)



Higher pixel pitch  
e.g. P6



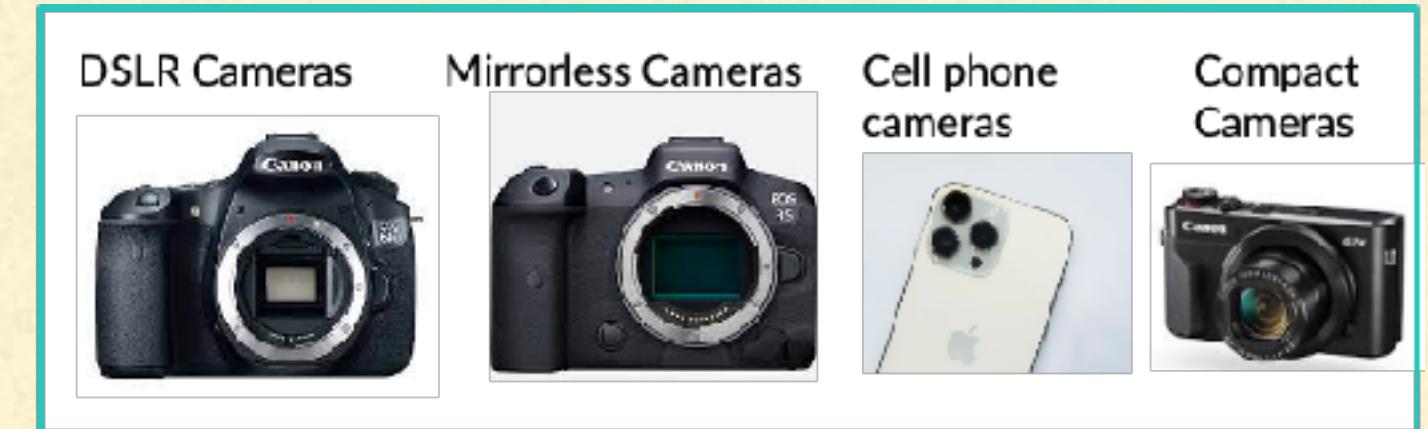
Lower pixel pitch  
e.g. P2

Larger sensors have bigger pixel sizes and let more light in (better image quality), but many small pixels can achieve the same.

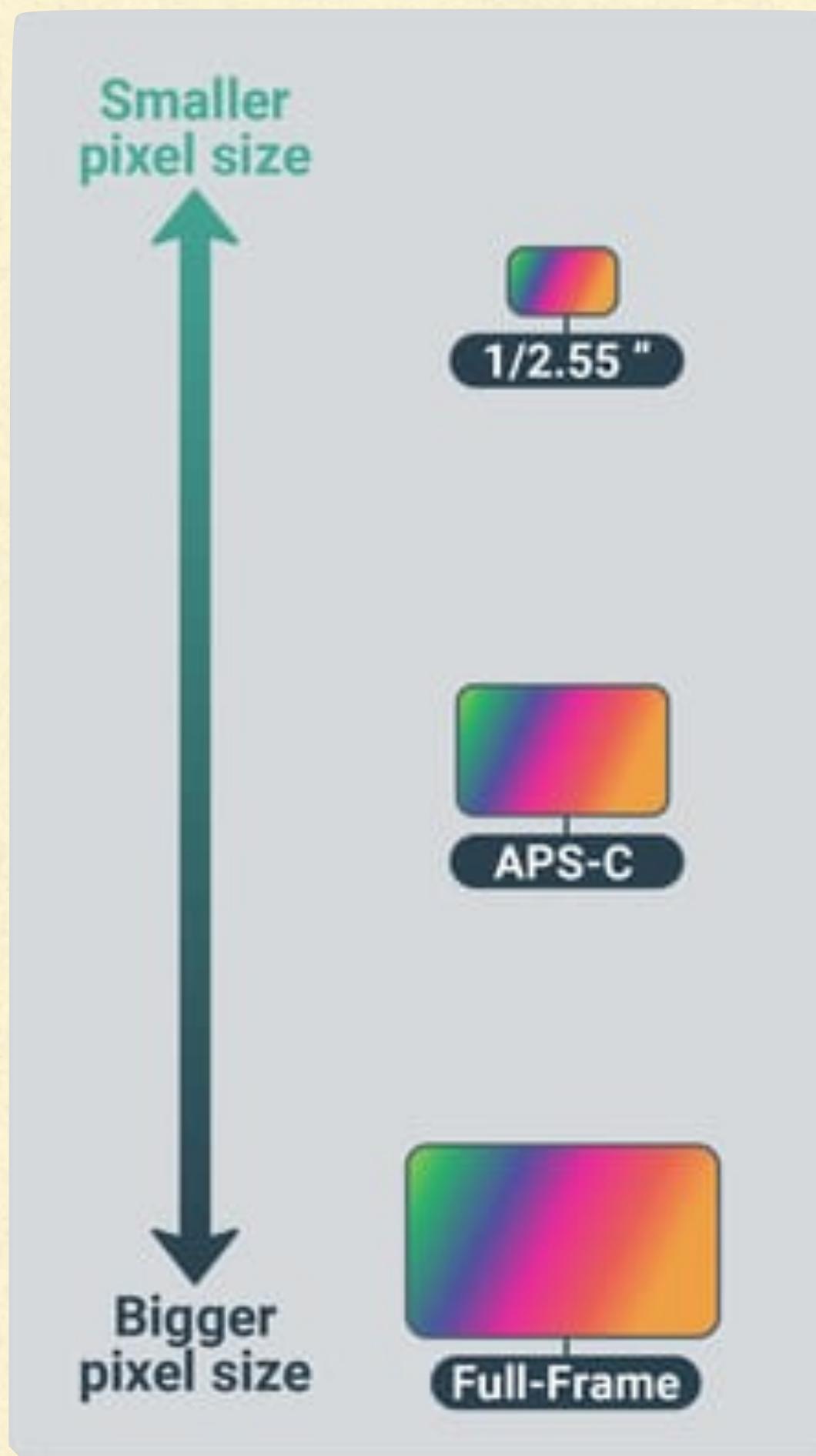
## PROPERTIES

- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
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- Pixel Size (Pixel Pitch)
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- Backside Illumination (BSI)
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- Sensor Stabilization (IBIS)
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# Pixel Size/Count/Pitch



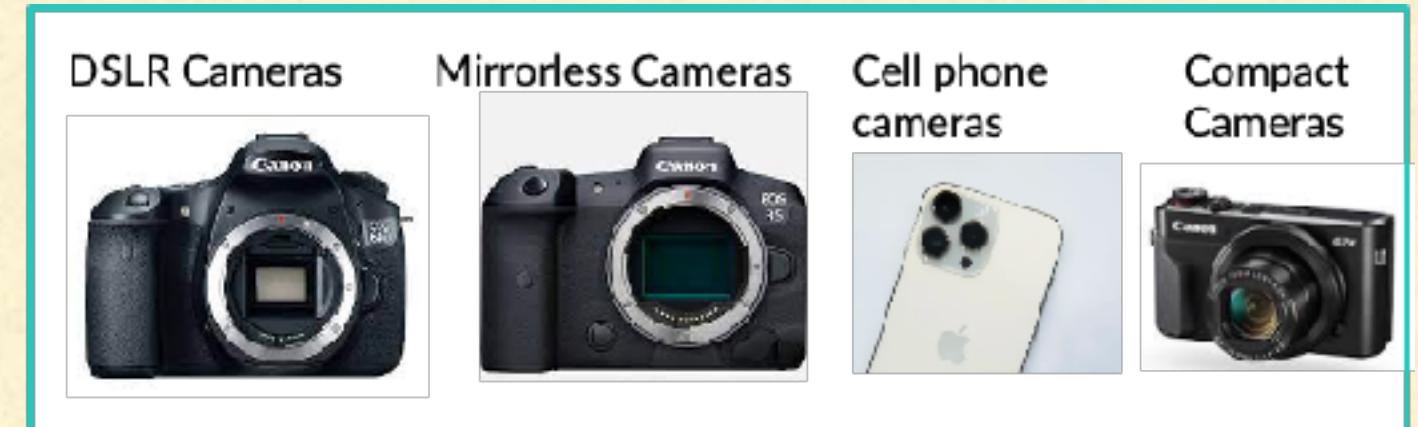
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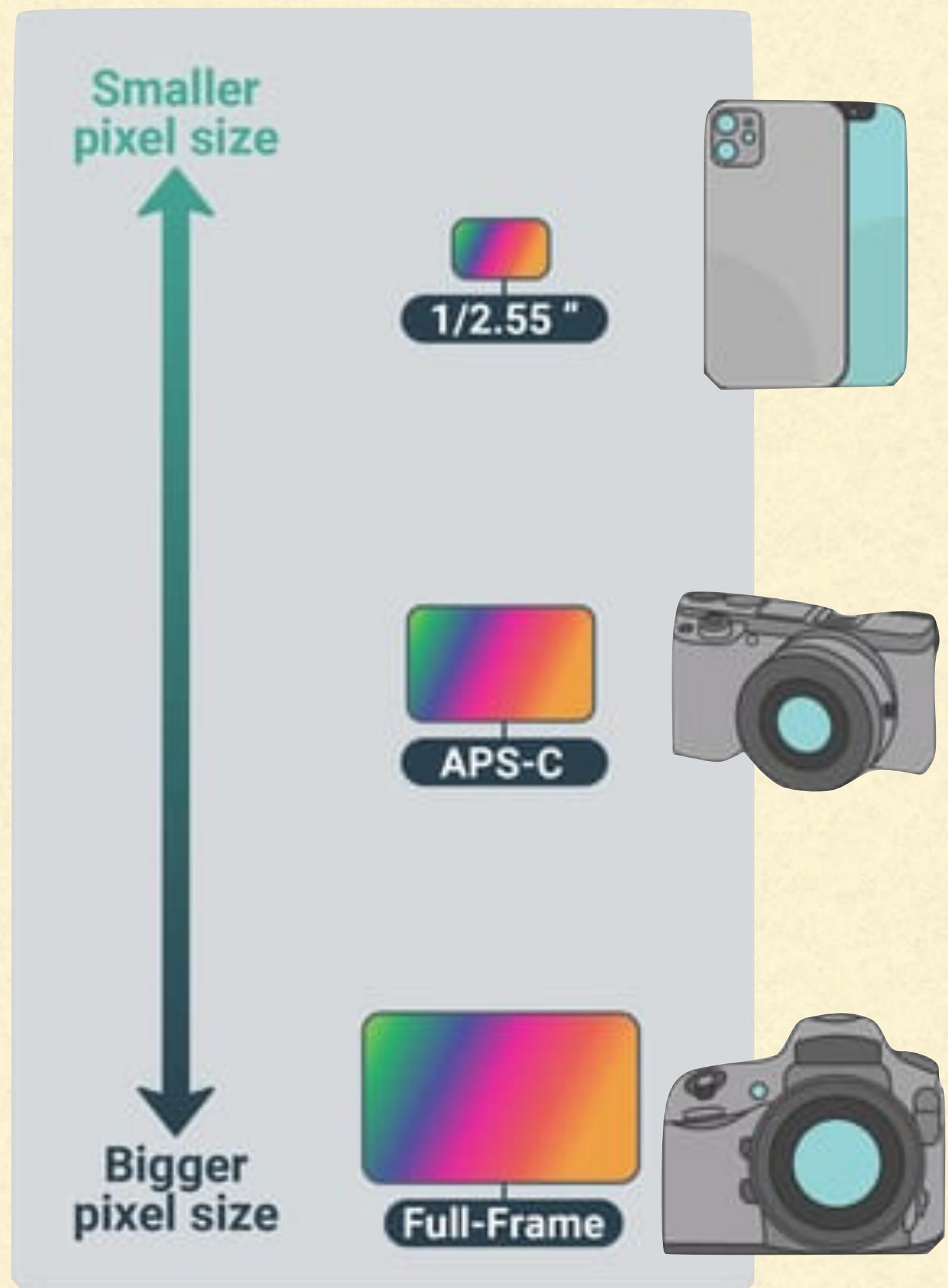
## PROPERTIES

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- Aspect Ratio
- Crop Factor
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- Multi-Layer

# Pixel Size/Count/Pitch



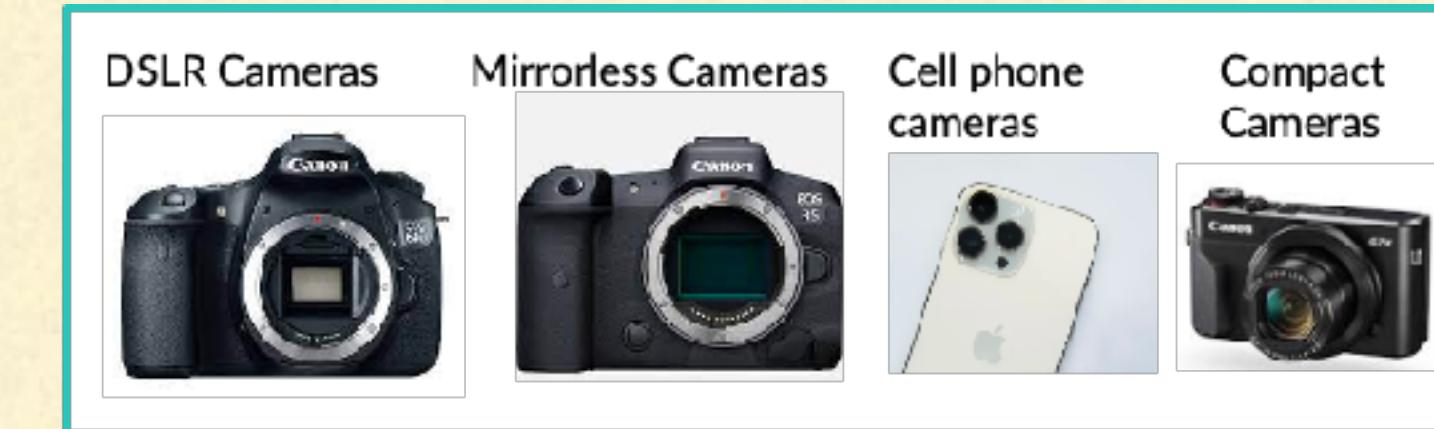
Larger sensors have bigger pixel sizes and let more light in (better image quality), but many small pixels can achieve the same.



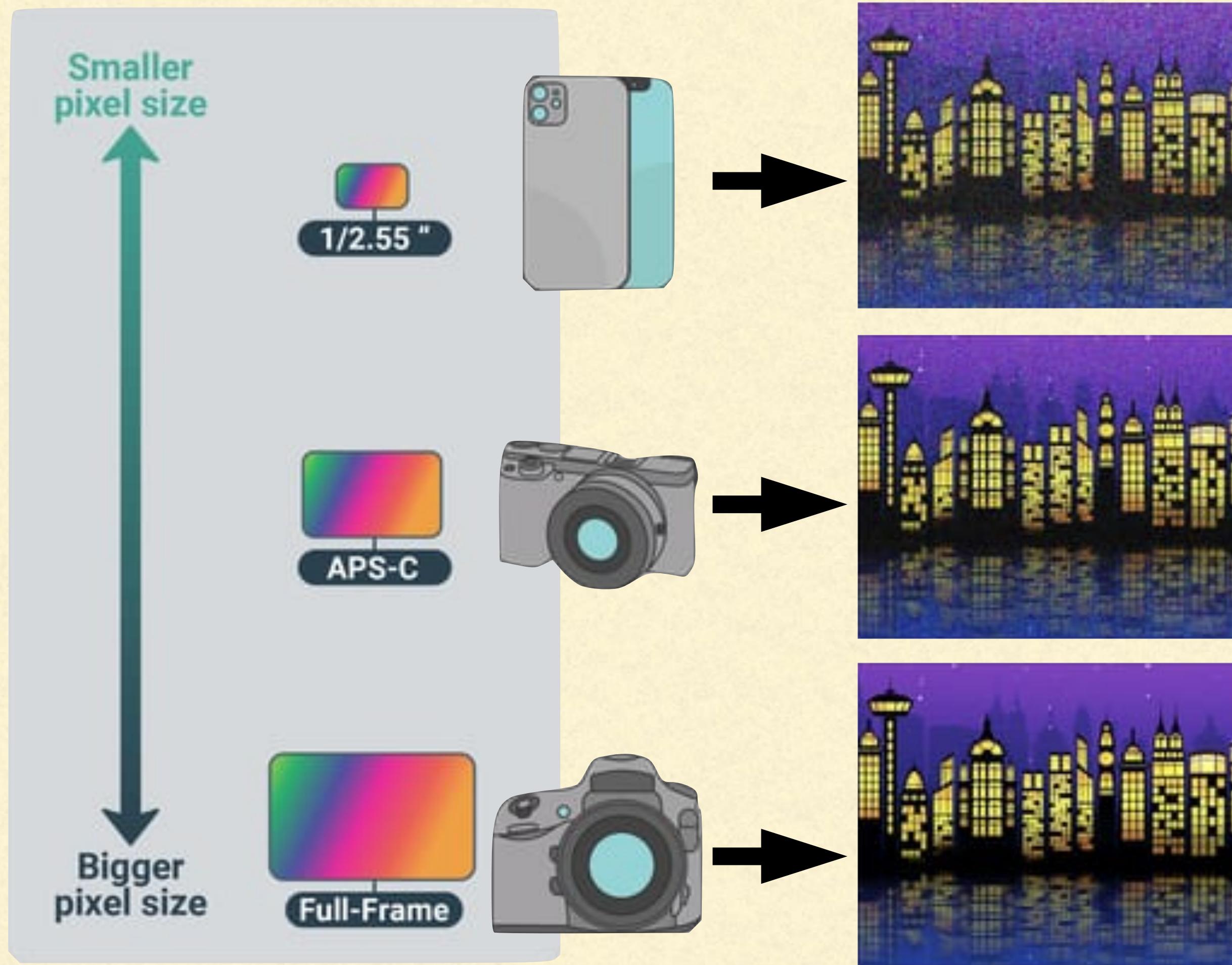
## PROPERTIES

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- Crop Factor
- Type (CCD vs CMOS)
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- Pixel Size (Pixel Pitch)
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- Sensor Stabilization (IBIS)
- Multi-Layer

# Pixel Size/Count/Pitch



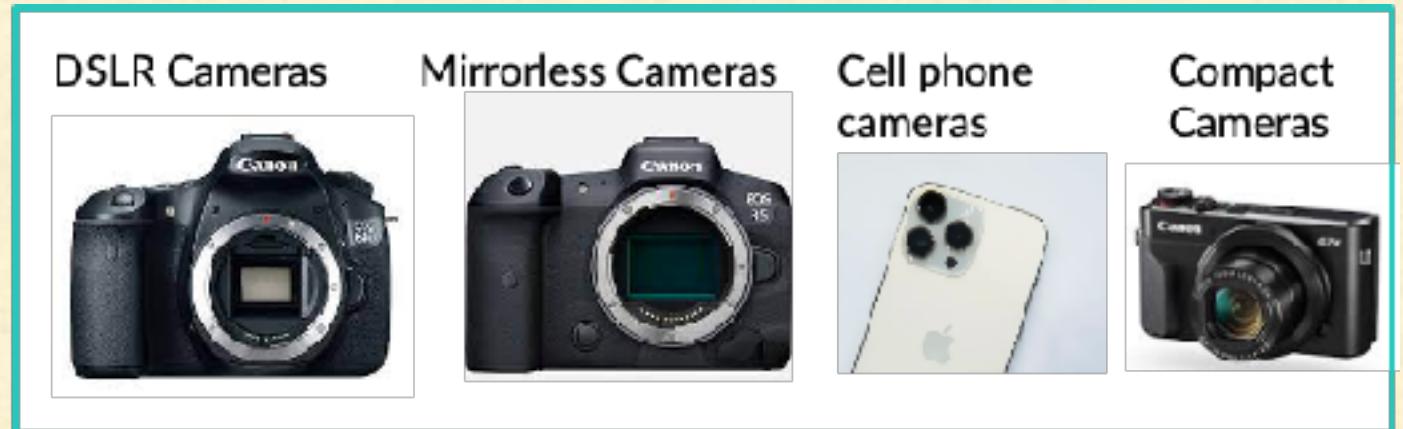
Larger sensors have bigger pixel sizes and let more light in (better image quality), but many small pixels can achieve the same.



## PROPERTIES

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# CCD vs CMOS



Larger sensors have bigger pixel sizes and let more light in (better image quality), but many small pixels can achieve the same.

## Types of Image Sensors

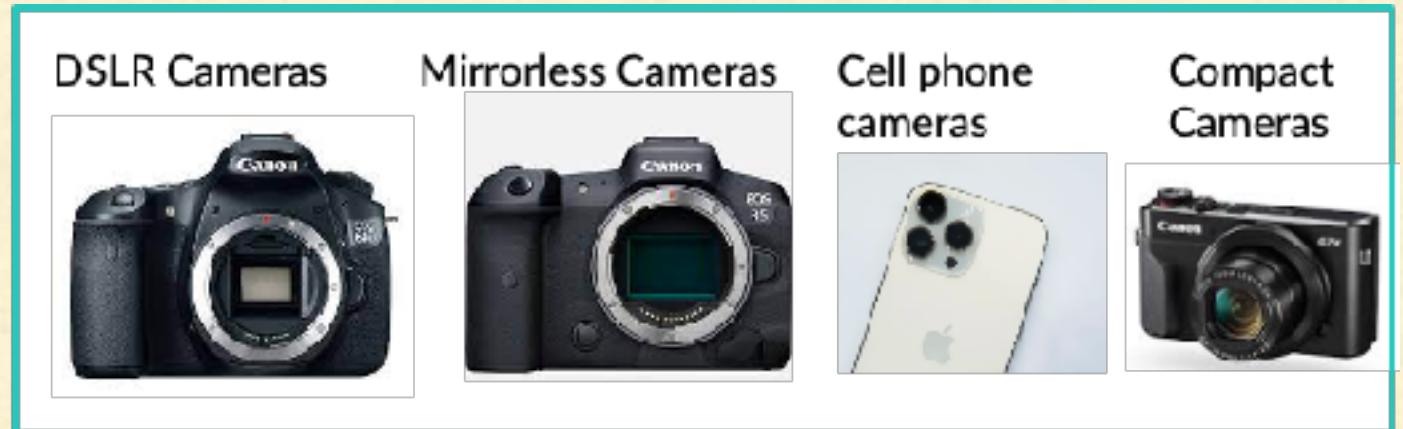
Shree K. Nayar  
Columbia University

Topic: Image Sensing, Module: Imaging  
First Principles of Computer Vision

### PROPERTIES

- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
- Pixel Size (Pixel Pitch)
- Dynamic Range
- ISO Sensitivity/Dual-Native ISO
- Frame Rate / Readout Speed
- Global Shutter vs Rolling Shutter
- Signal-to-Noise Ratio (SNR)
- Color Filter Array (CFA)
- Spectral Response
- Low-Pass Filter (Anti-Aliasing Filter)
- Backside Illumination (BSI)
- Heat Management
- Sensor Stabilization (IBIS)
- Multi-Layer

# CCD vs CMOS



Larger sensors have bigger pixel sizes and let more light in (better image quality), but many small pixels can achieve the same.

## Types of Image Sensors

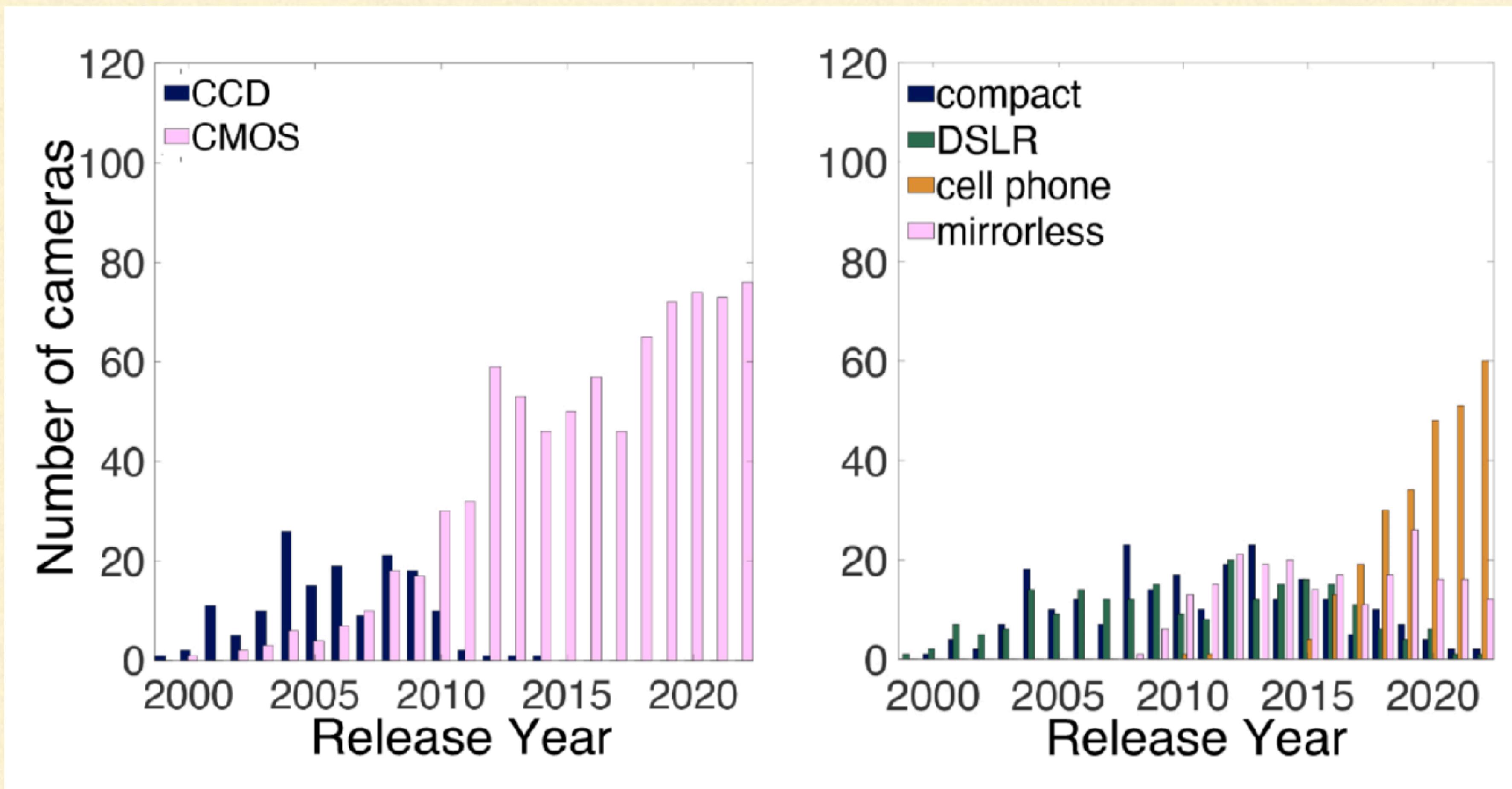
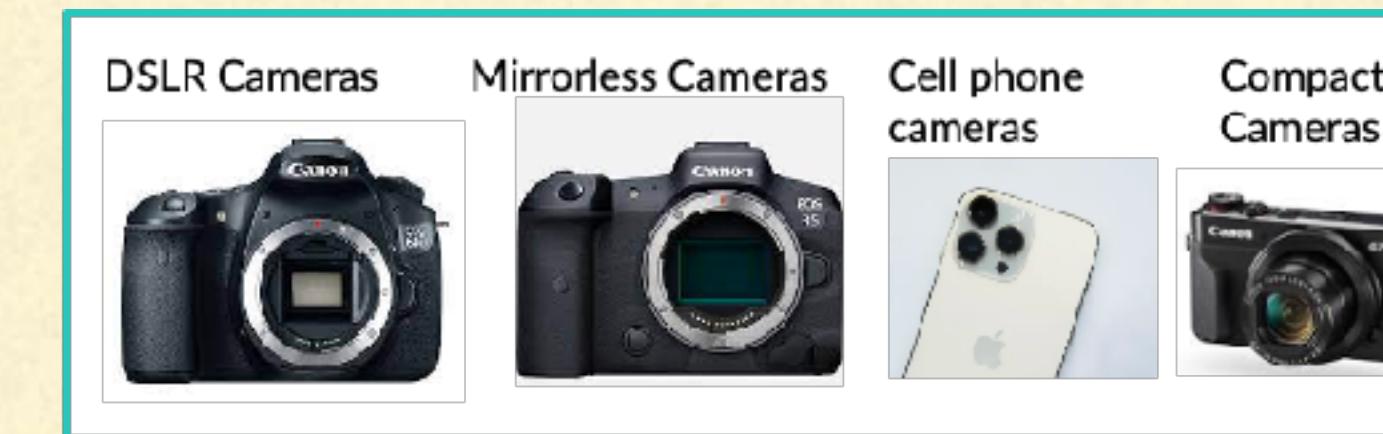
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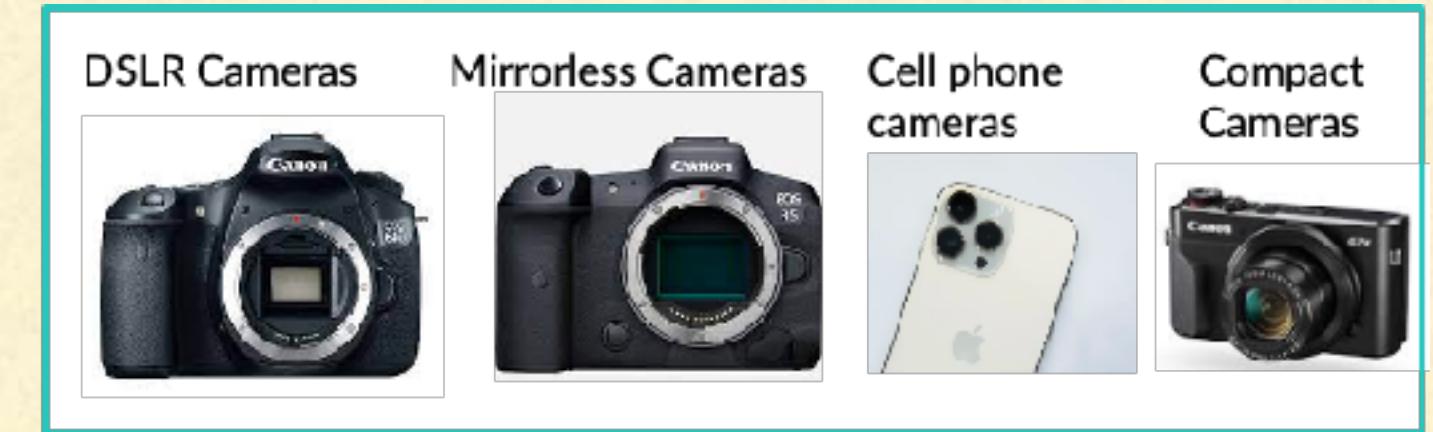
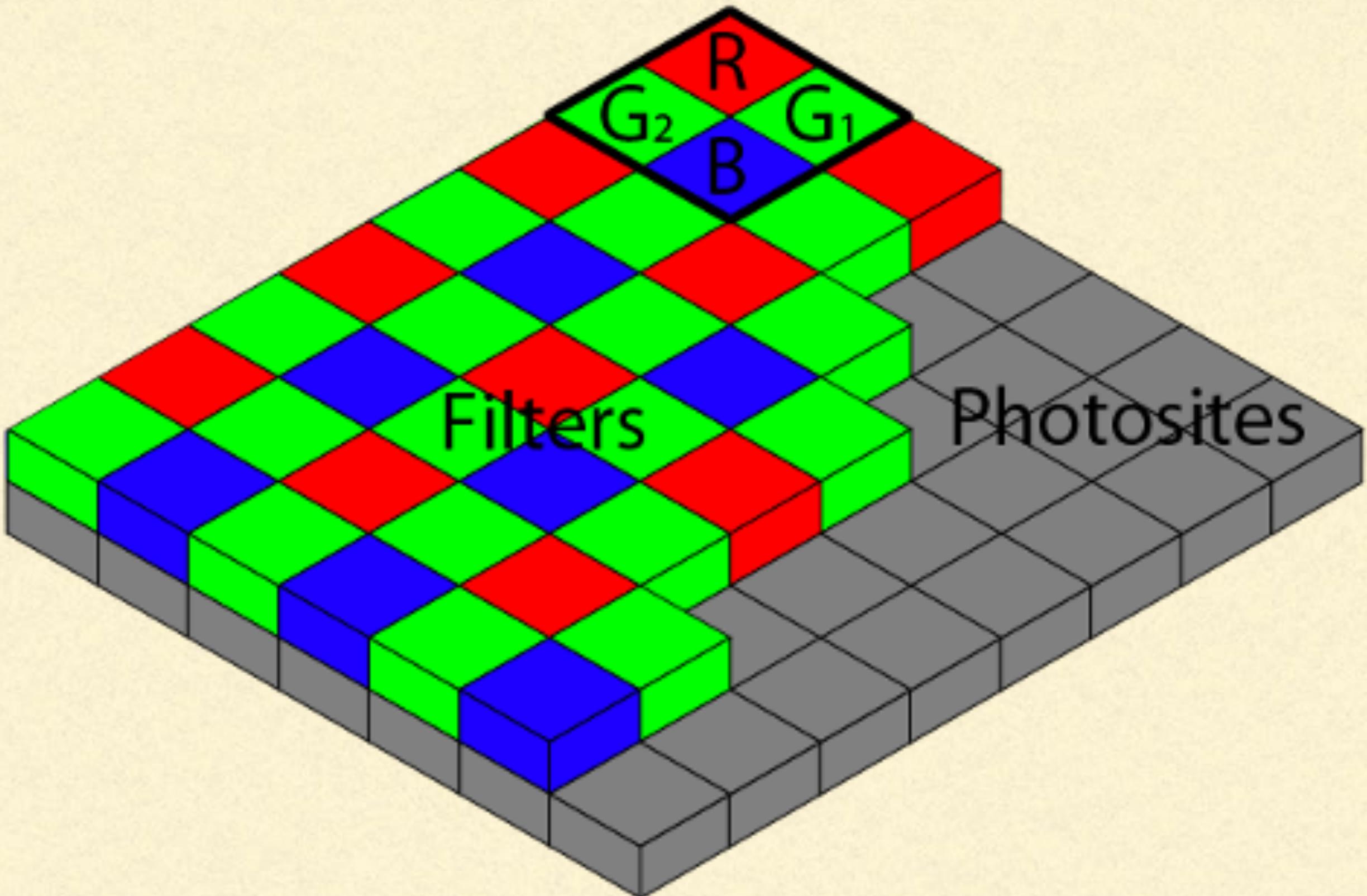
# CCD vs CMOS



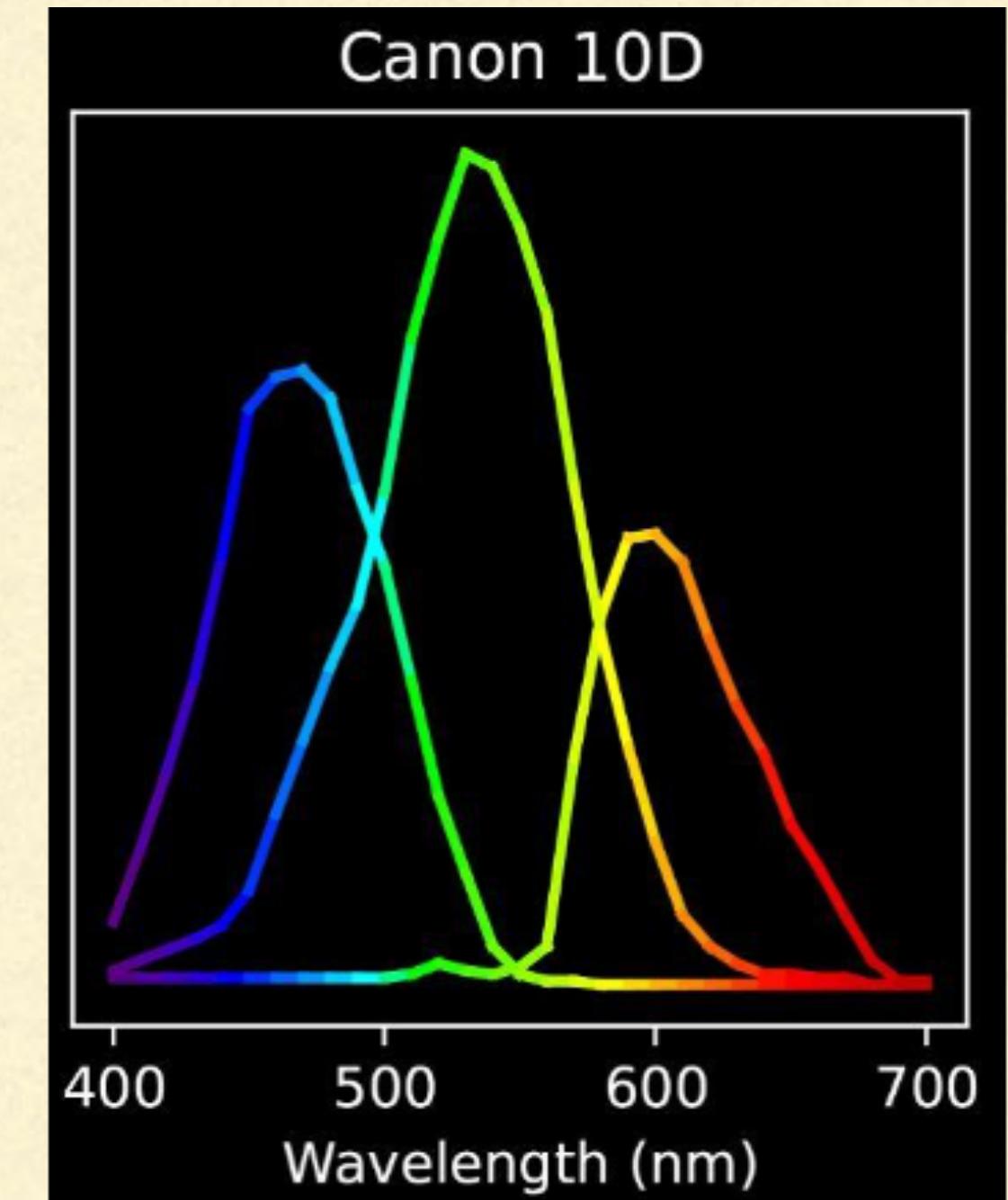
## PROPERTIES

- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
- Pixel Size (Pixel Pitch)
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- ISO Sensitivity/Dual-Native ISO
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# Color Filter Array



## Spectral Sensitivity

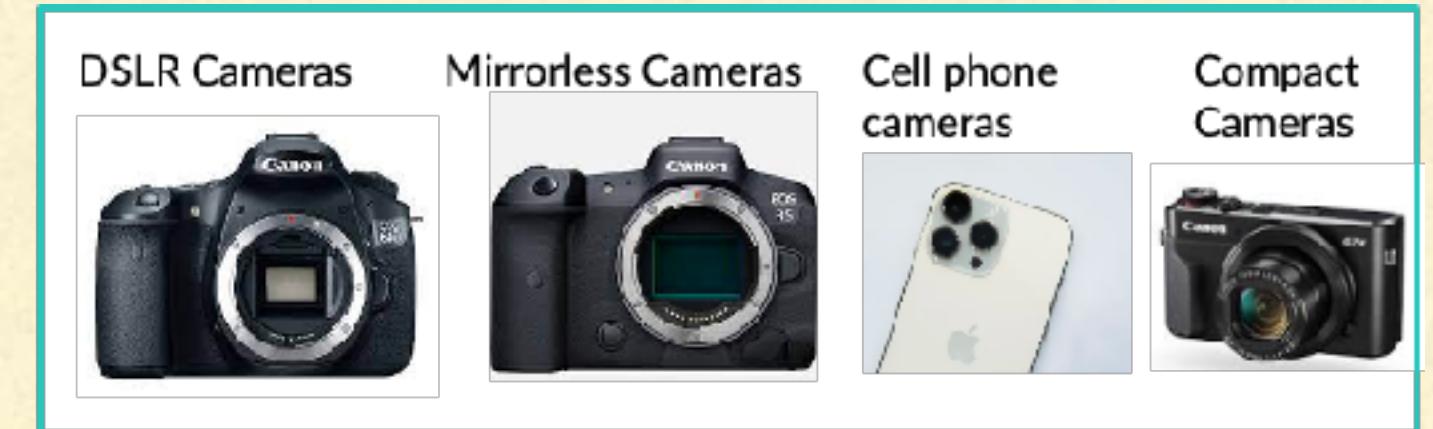


## PROPERTIES

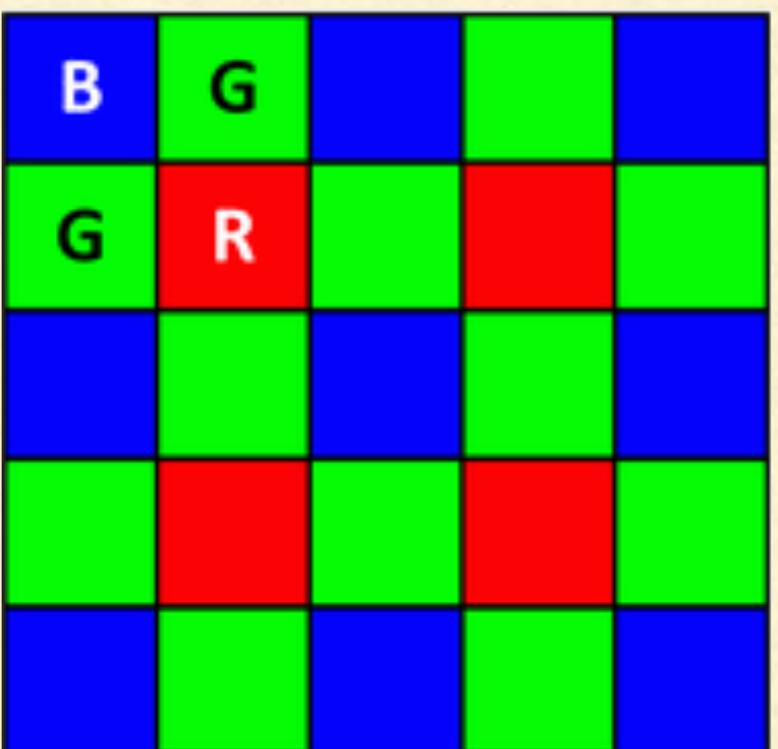
- Size
- Aspect Ratio
- Crop Factor
- Type (CCD vs CMOS)
- Resolution
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The combined sensitivities of the photosites + filters give the overall camera spectral sensitivities.

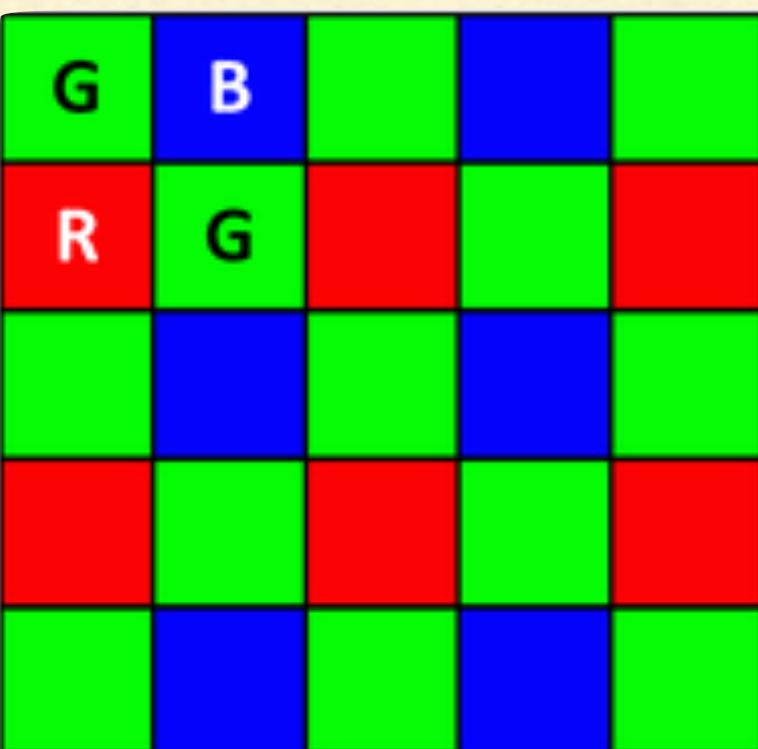
# Color Filter Array



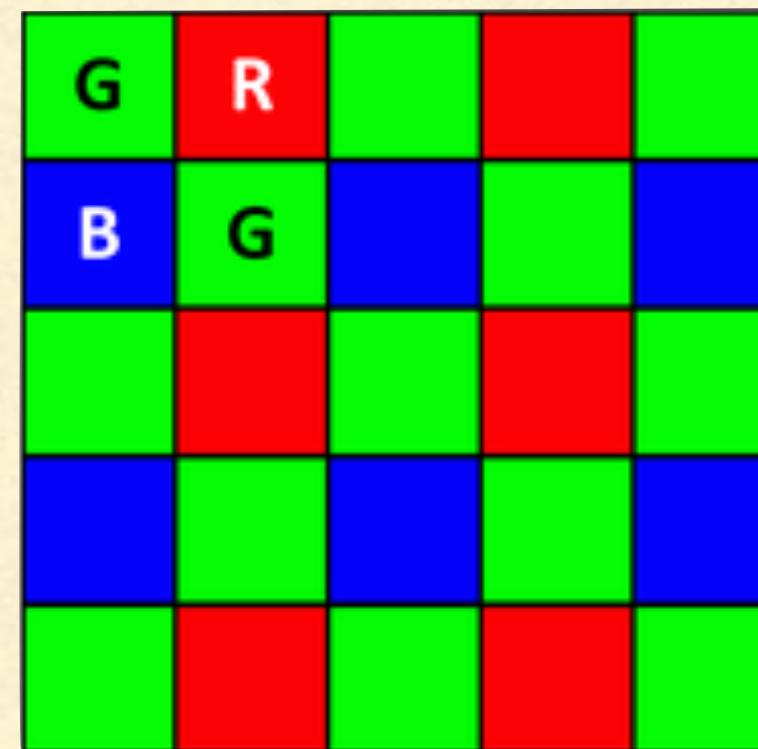
Bayer pattern is the most commonly used sensor mosaic, 2 G, 1 B, 1 R. Others have been developed for different purposes.



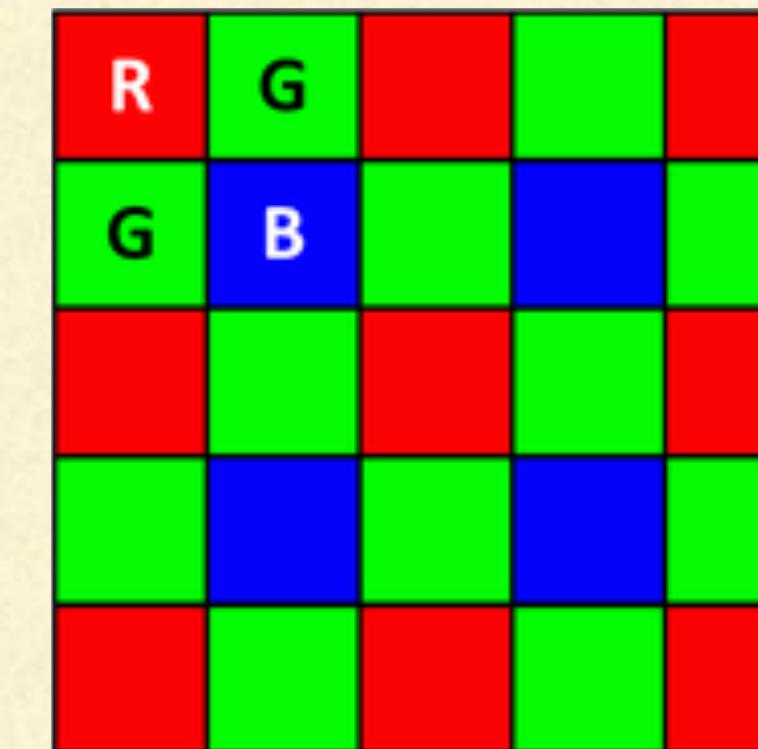
**BGGR**



**GBRG**



**GRBG**

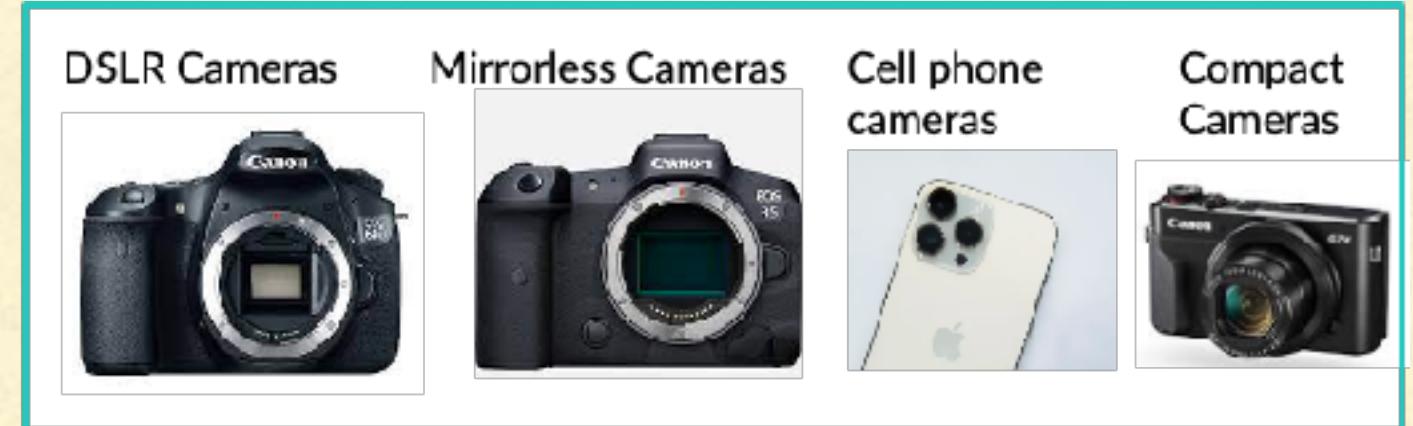
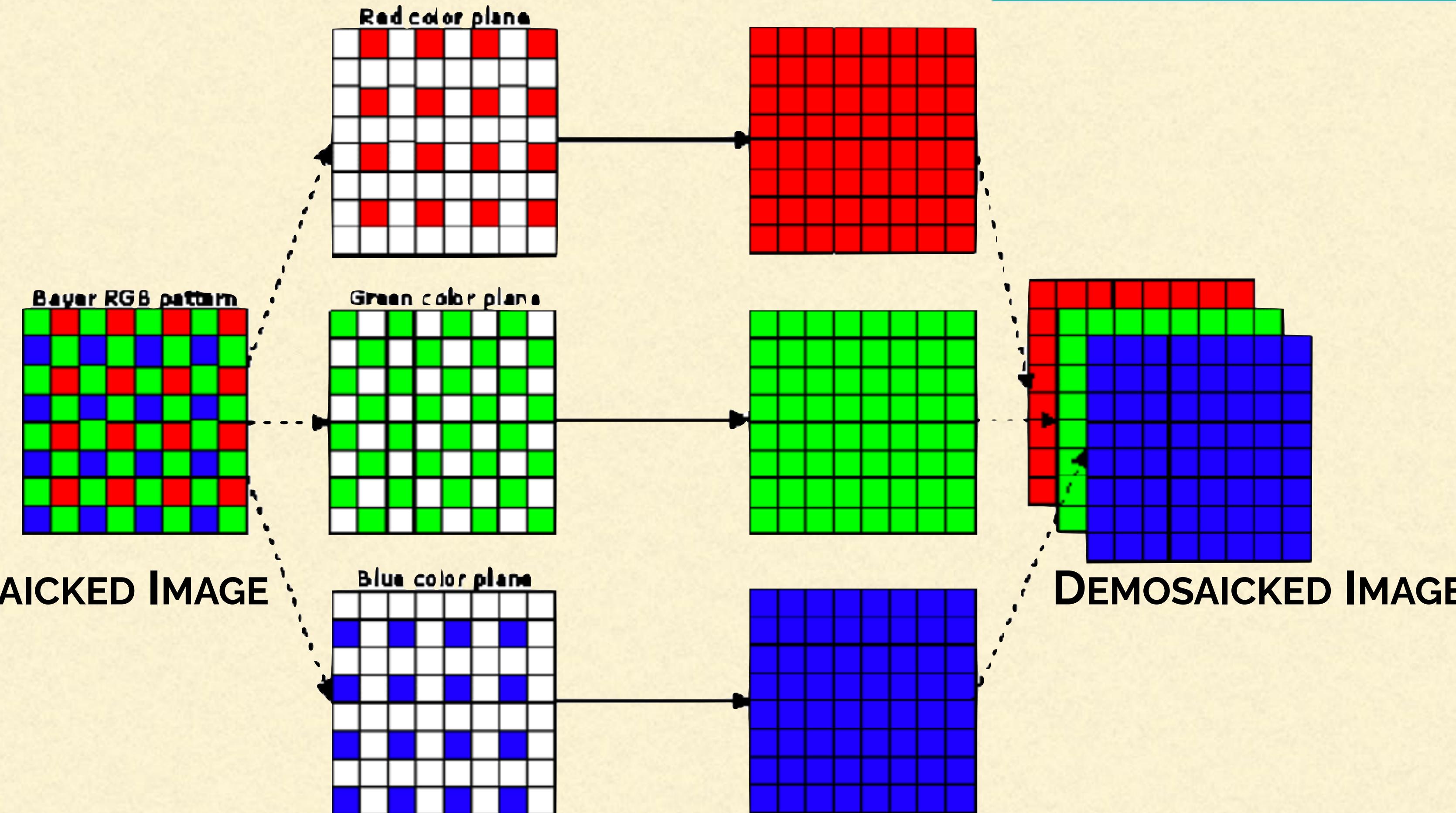


**RGGB**

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- Crop Factor
- Type (CCD vs CMOS)
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## PROPERTIES

# Demosaicking



Demosaicking algorithms are an area of research on their own. Do you think demosaicking affects linearity?

## PROPERTIES

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# Break

- Thank you for not using your cell phones during the lectures.
- **Nomophobia:** The irrational fear of being without a mobile phone.

## ARE YOU ADDICTED TO YOUR MOBILE PHONE?

Here are some warning signs:

Constantly checking  
your phone  
for no reason



You feel anxious or  
uneasy if you think  
your phone is missing



You avoid social  
interaction to spend  
time on your phone



Waking up in the middle  
of the night to check  
your phone



Your academic or  
work performance has  
deteriorated



You are easily  
distracted by emails  
or smart apps



## How to overcome Nomophobia?



Recognise that you  
have an addiction



Try to leave your  
home without your  
mobile phone.



Restrict some  
hours of use



Silence  
notifications

# RAW Image Manipulation Workflow

1.

RAW image in  
proprietary format  
(e.g., .CR2)

Convert using  
Adobe DNG converter



Image in .DNG  
format

2.

Image in .DNG  
format

Convert using  
Matlab or python

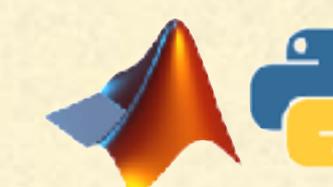


Image in .tiff  
format  
(uncompressed)

3.

Image in .tiff  
format  
(uncompressed)

Resize using  
Matlab or python

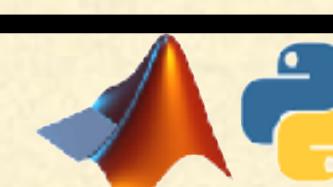


Image in .png  
format (losslessly  
compressed)

(Optional: If you don't have enough compute power)

