Deep Learning with Satellite Imagery

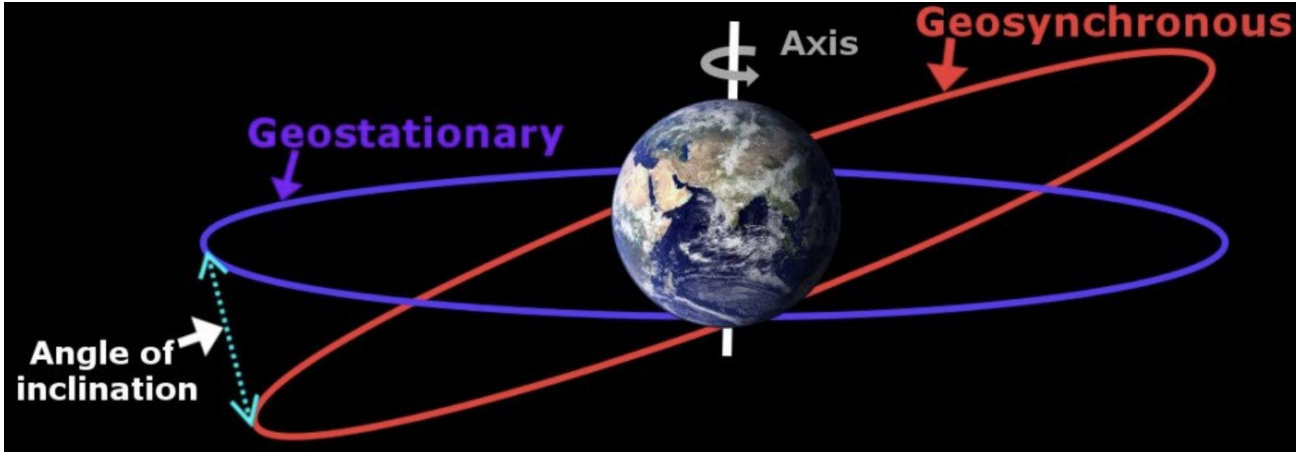
Satellite Imagery

Overview

- Satellite orbits.
- Satellite resolution.
- Satellite collection.
- Color spaces.
- Satellite spectral bands.
- Satellite imagery processing:
    - Demosaicing.
    - Georeferencing.
    - Atmospheric correction.
    - Pansharpening.
    - Orthorectification.
    - Dynamic range adjustment.
- NIRS scale.

Orbits

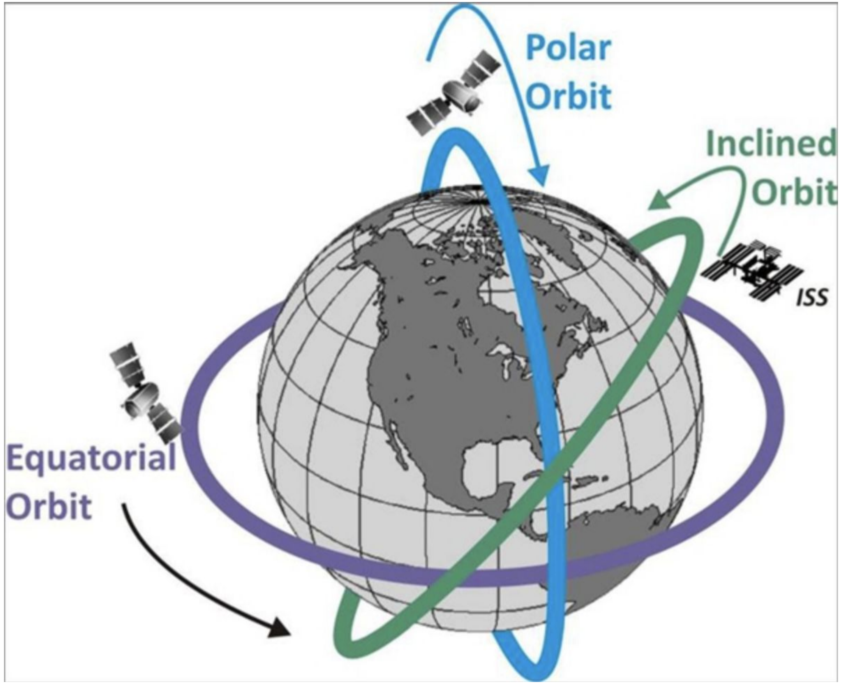
- **GeoSynchronous Orbit** (GSO):
  - An orbit with an orbital period matching Earth's rotation.
  - GSO is at 35,786 km above Earth's surface.
  - **GeoStationary Orbit**: A special type of GSO with 0 angle of inclination.
  - Application: Communication (radio, tv, etc).



Angle of inclination: Angle between the orbit and the equatorial plane.

Orbits

- **Low Earth Orbit** (LEO):
  - An orbit with an orbital period between 84 and 127 minutes.
  - LEO is within 2,000 km from Earth's surface.
  - **Polar Orbit**: Orbit passes by both poles.
    - **Sun Synchronous Orbit**: Satellite passes over region at roughly the same local solar time.
  - **Inclined Orbit**: Orbit with an angle of inclination between 0 and 90 degrees.
  - Application: Remote sensing.



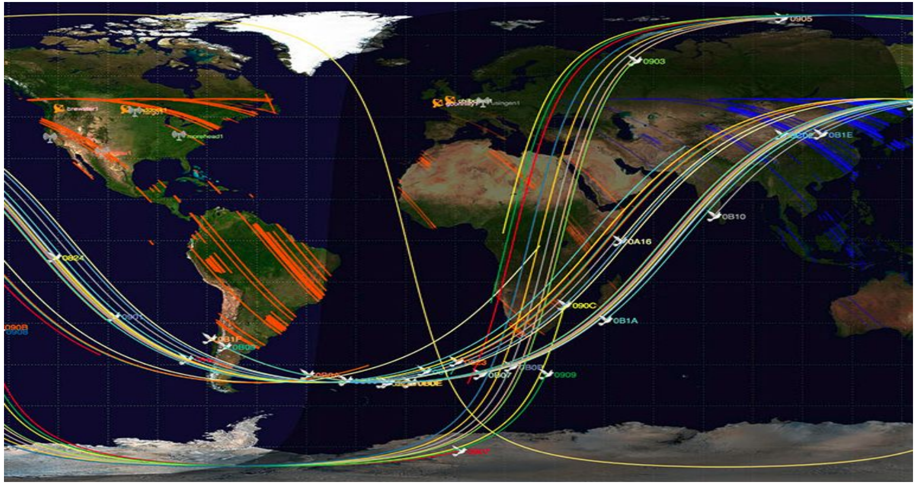
Satellite Ground Sample Distance (GSD)

- **GSD**: The distance between pixel centers measured on the ground.
- Inversely proportional to resolution.
- Higher orbits tend* to increase GSD and increase field of view.
- Lower orbits decrease GSD and decrease field of view.

Top: Low resolution. **Bottom**: High resolution.

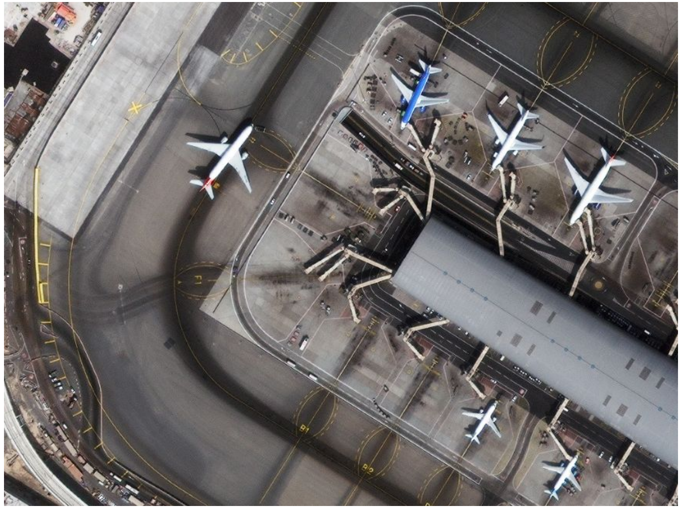
Low Resolution Satellite Imagery

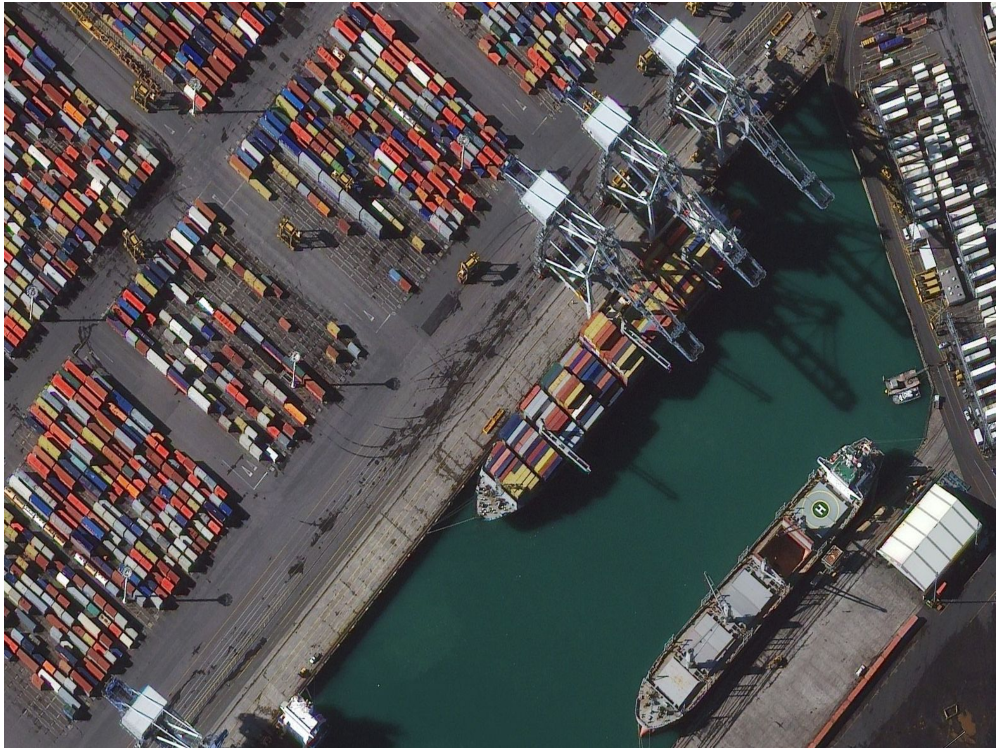
- Mapping missions.
- Crop monitoring
- Natural disaster assessment.



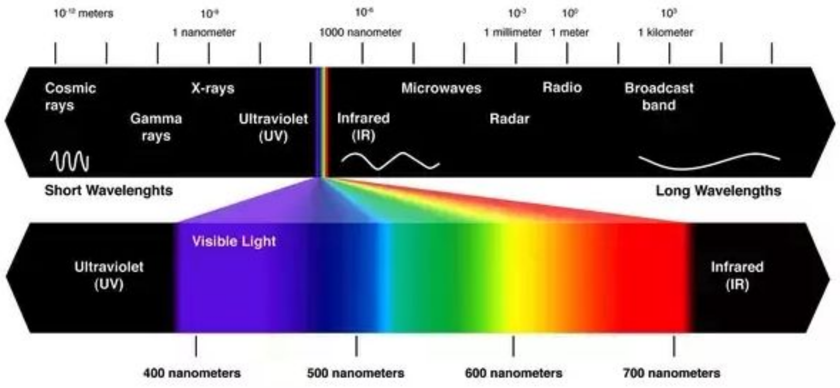
High Resolution Satellite Imagery

- Supply chain monitoring.
- Military surveillance.
- Construction monitoring.





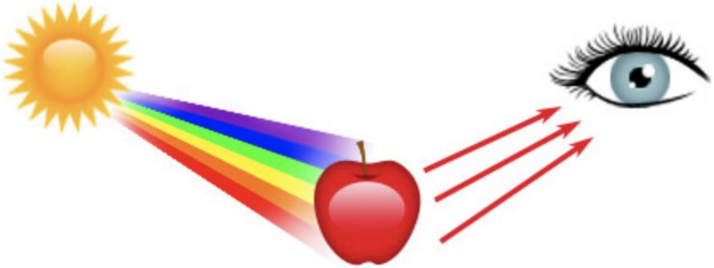
Visible Spectrum



- Part of the electromagnetic spectrum.
- Visible to the human eye.
- Wavelengths range from 380 - 740 nm.

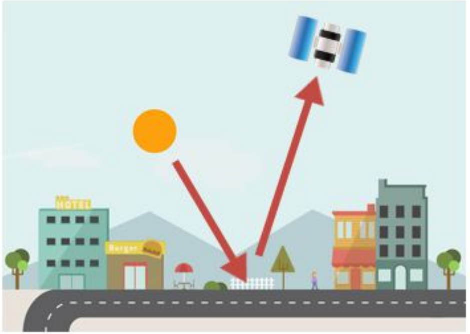
How we perceive colors:

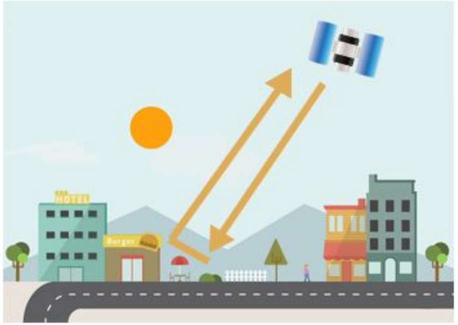
1. Sunlight illuminates an object.
2. Object absorbs certain bands and reflects others.
3. The eye associates the reflected bands as the object's color.

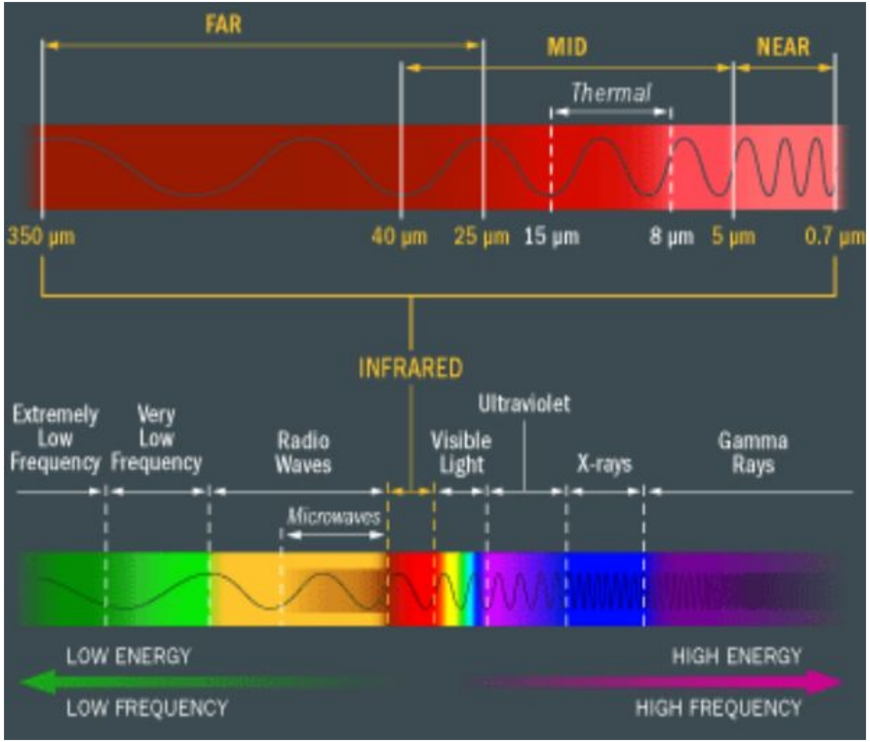


Satellite Bands: Active and Passive Remote Sensing

- Passive: Measures natural energy.
  - Multispectral (e.g. RGB+SWIR).
  - Infrared (near, short-wave, thermal).
  - Panchromatic.
  - Hyperspectral.
- Active: Provides own energy.
  - Light Detection and Ranging (LIDAR).
  - Synthetic Aperture Radar (SAR).







Why do we use the RGB color space?

- What do we get when mixing red and green paint?

- What do we get by combining red and green pixels?

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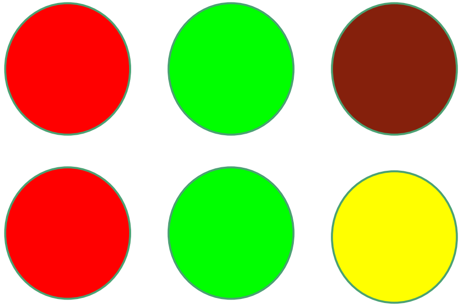
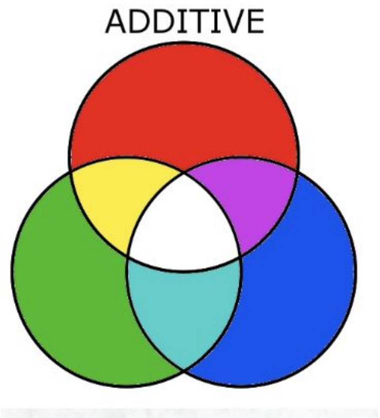
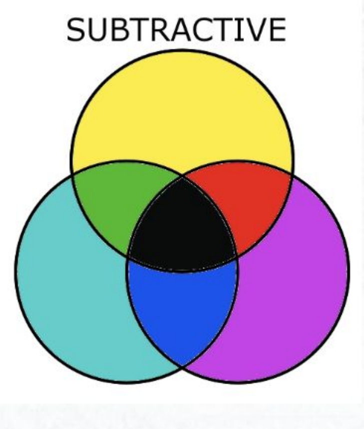




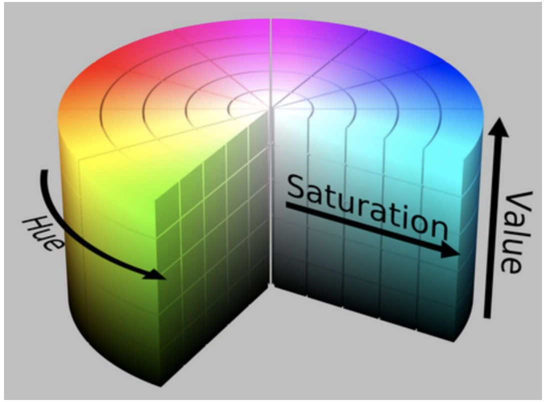


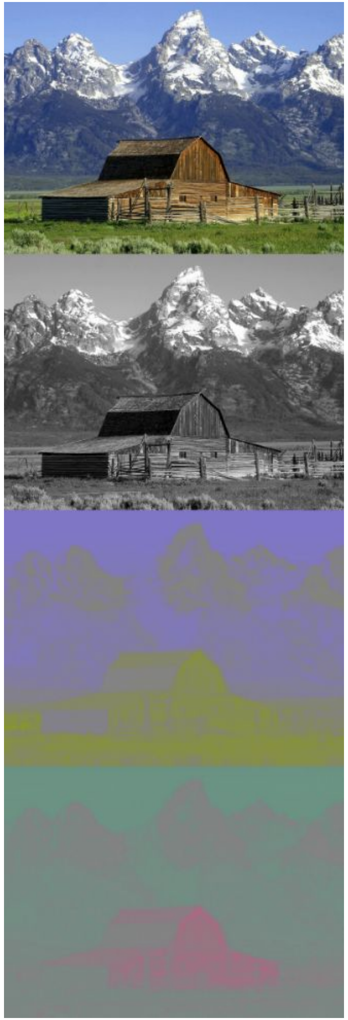
- **Additive space**: Colors are created from light, e.g. computers.
- **Subtractive space**: Colors act as filters to natural light, e.g. paint.

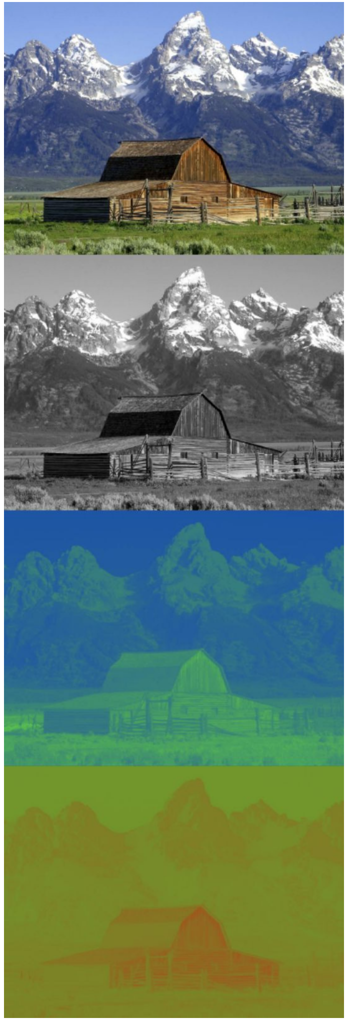
More Color Spaces

- **Hue** (H)**:** Related to wavelength of color.
- **Saturation** (S)**:** Pureness of color.
- **Value** (V)**:** Brightness of color.
- **Luminance** (Y): Brightness of color.
- **Chrominance** (C): Color information.
- Cb: C - Blue. Cr: C - Red.
- U: B - Y. V: R - Y

Color Spaces: HSV (bottom), YUV (middle), YCbCr (right).

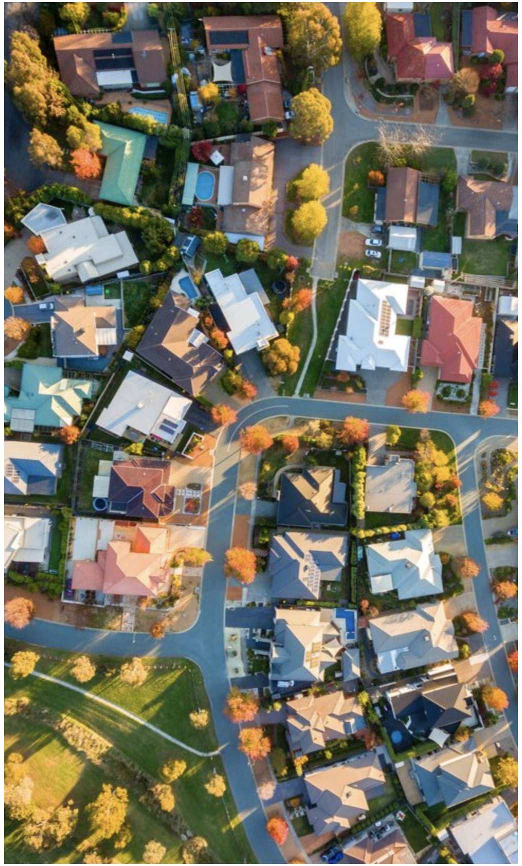






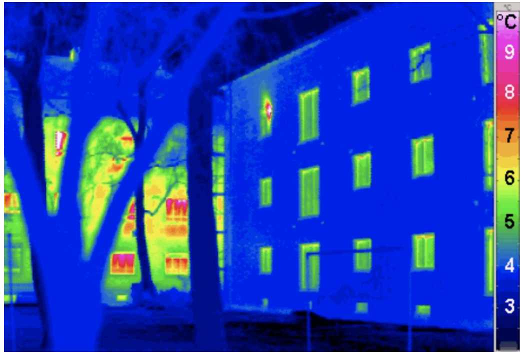
RGB Imagery:

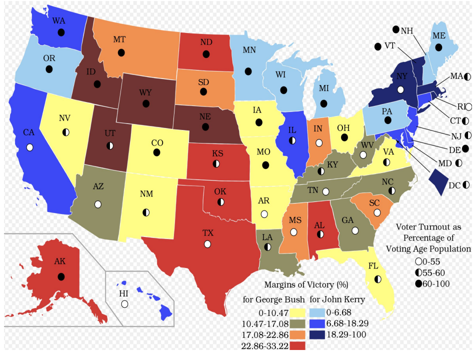
- Visible imagery.
- Blue wavelength: 450 - 490 nm.
- Green wavelength: 520 - 560 nm.
- Red wavelength: 640 - 700 nm.

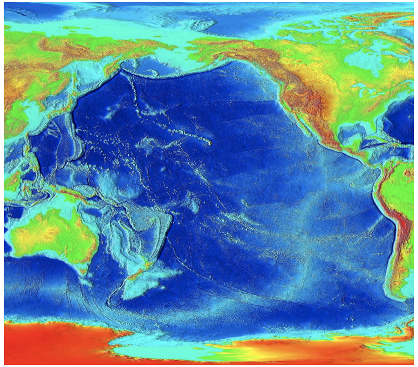


False Color Images

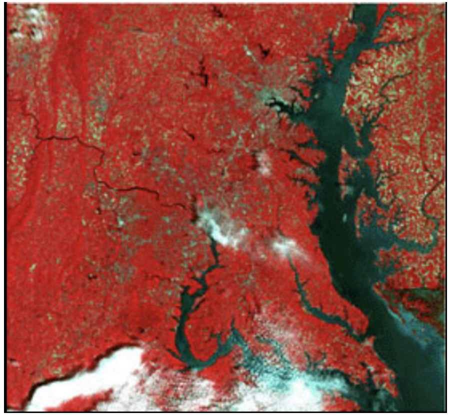
Images depict an object in colors that differ from those in the visible range.





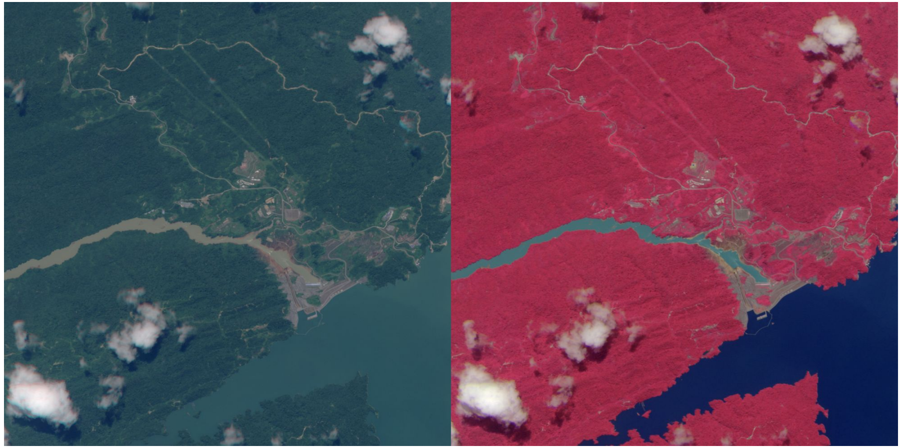


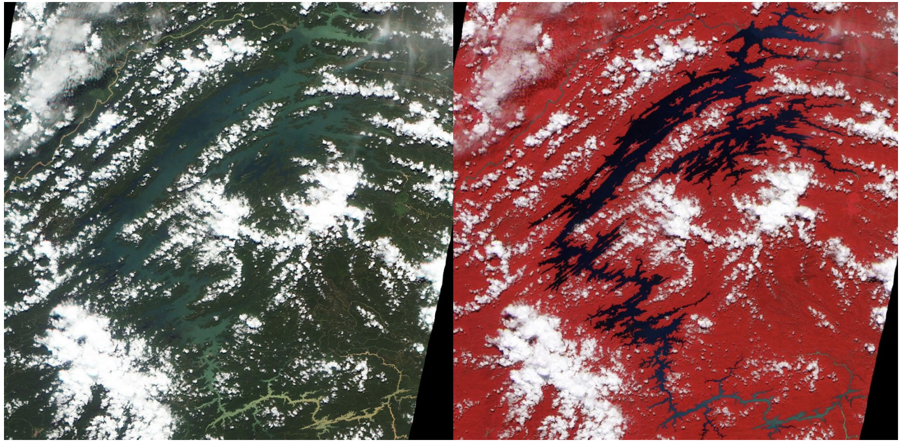
Left: Visual. **Right**: False color.



Near Infrared (NIR) Imagery:

- Essential for crop monitoring.
- High contrast between water and land.
- Penetrate through light fog, haze, smoke
- Wavelength range from 700 - 1400 nm.
- **False color**: NIR, Red, Green to RGB.





Left: Visual. **Right**: NIR, R, G.

Short-Wave Infrared (SWIR) Imagery:

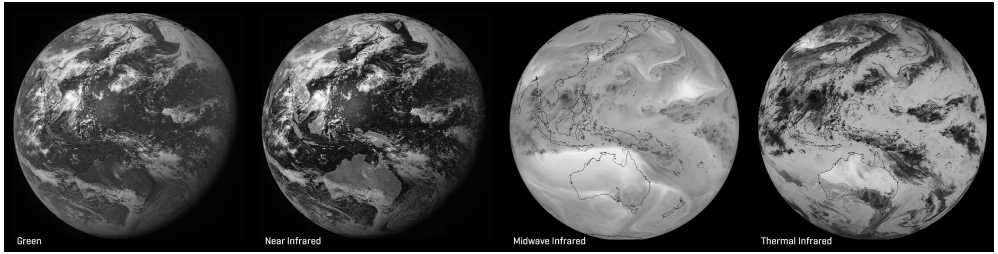
- Detects moisture in soil and vegetation.
- High contrast between water and snow.
- Penetrate through thin clouds, light fog, haze, smoke
- Provide day and night collection.
- Wavelength range from 1400 - 3000 nm.
- **False color**: varies.

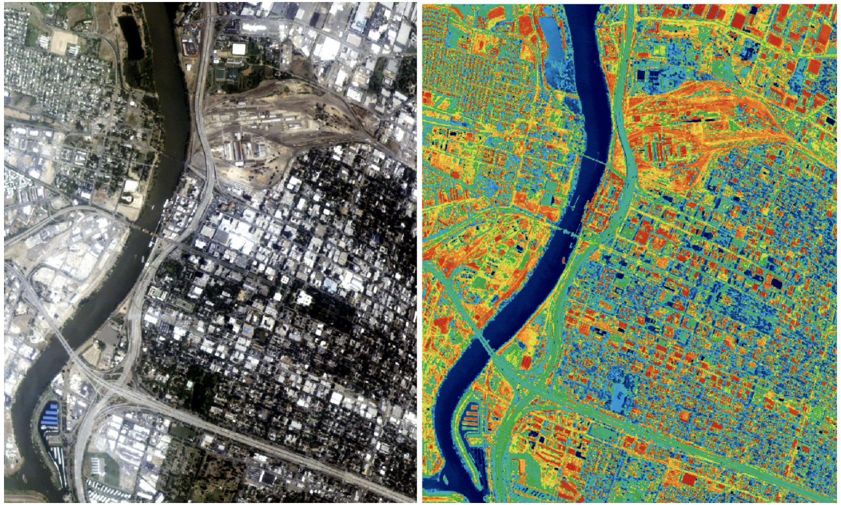
Left: Visual. **Right**: SWIR, NIR, R.

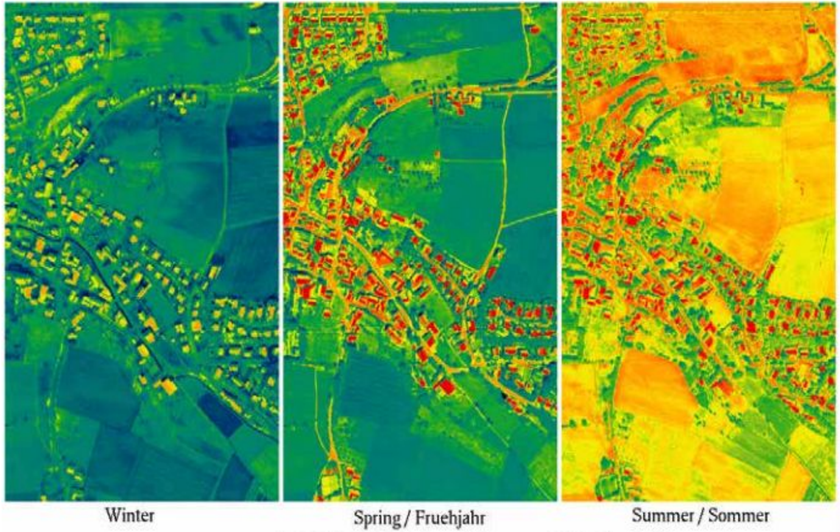
Top: NIR, R, G. **Bottom**: SWIR, NIR, G.

Thermal Infrared (TIR):

- Measures water and land temperatures.
- Penetrate through clouds, smoke, haze, and fog.
- Provide day and night collection.
- Wavelength range from 8000 - 15000 nm.

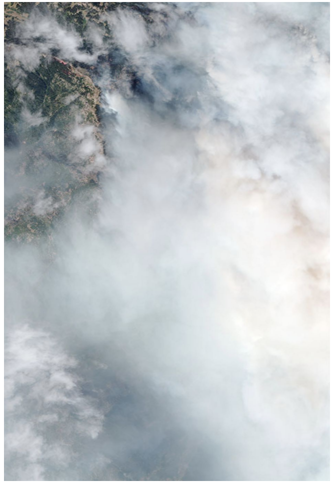


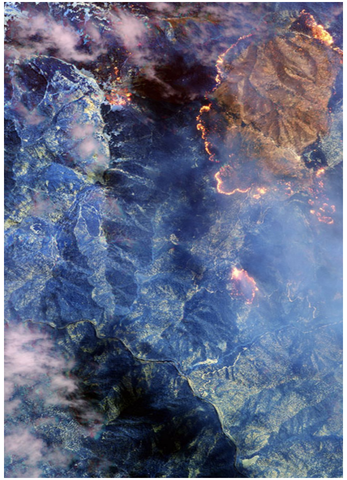


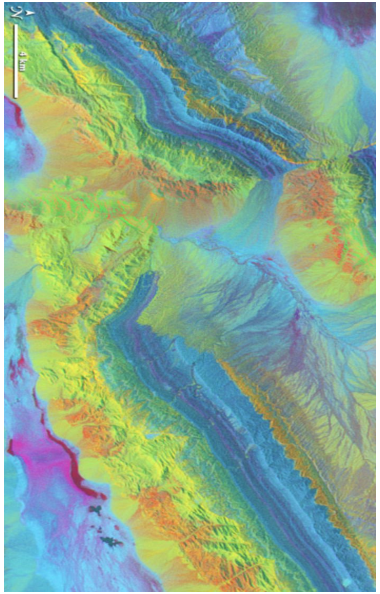


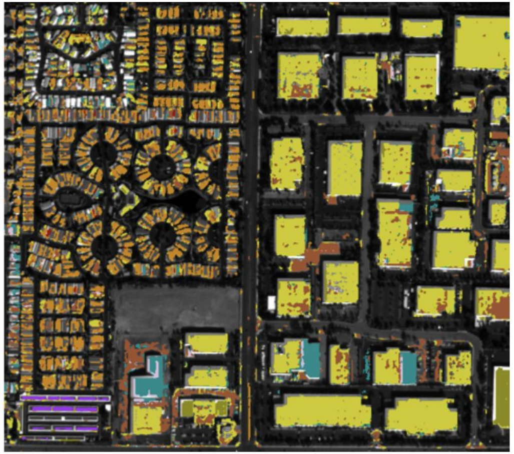
Multispectral (MSI) Imagery:

- Generally refers to 3 - 10 bands.
- RGB*.
- Detects geological and materials spectral signature.
- Reduces influence of clouds, smoke, haze, and fog.
- Provide day and night* collection.
- Wavelengths from visible and IR parts of spectrum.



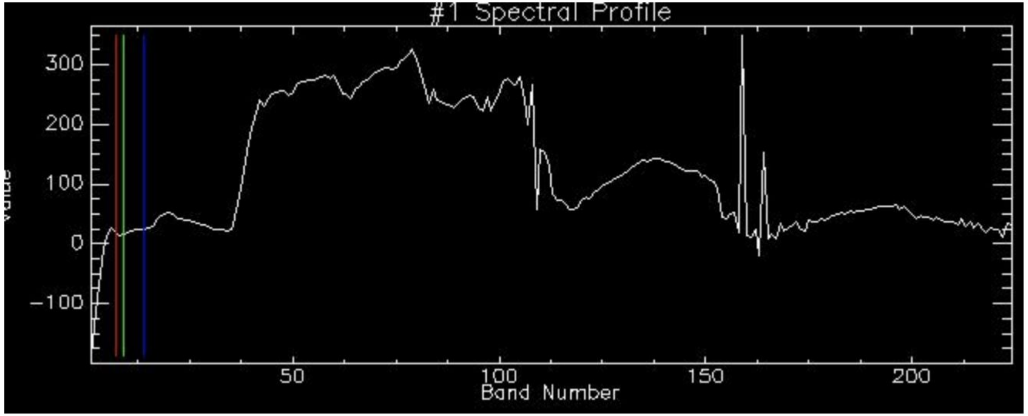


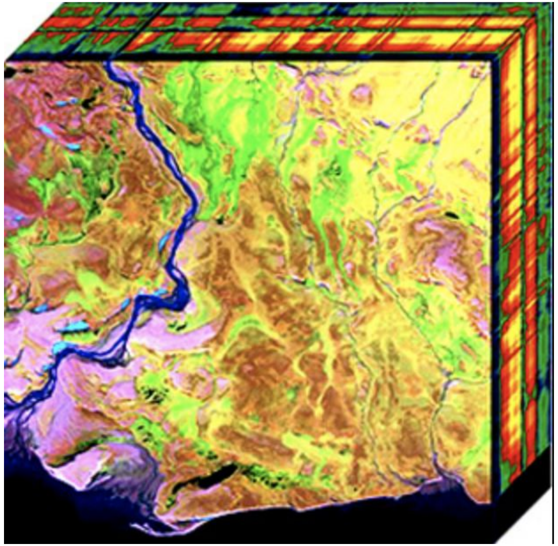




Hyperspectral (HSI) Imagery:

- Hundreds of narrow bands.
- Detects materials by their unique spectral signature.
- Wavelengths from visible and IR parts of spectrum.
- Also known as imaging spectroscopy.





Panchromatic (PAN) Imagery:

- PAN uses the visible and IR parts of the EM spectrum.
- One wide wavelength: 250 - 900 nm.
- Lower GSD than multispectral imagery.
- PAN sharpening: Increase spatial resolution of multispectral image.

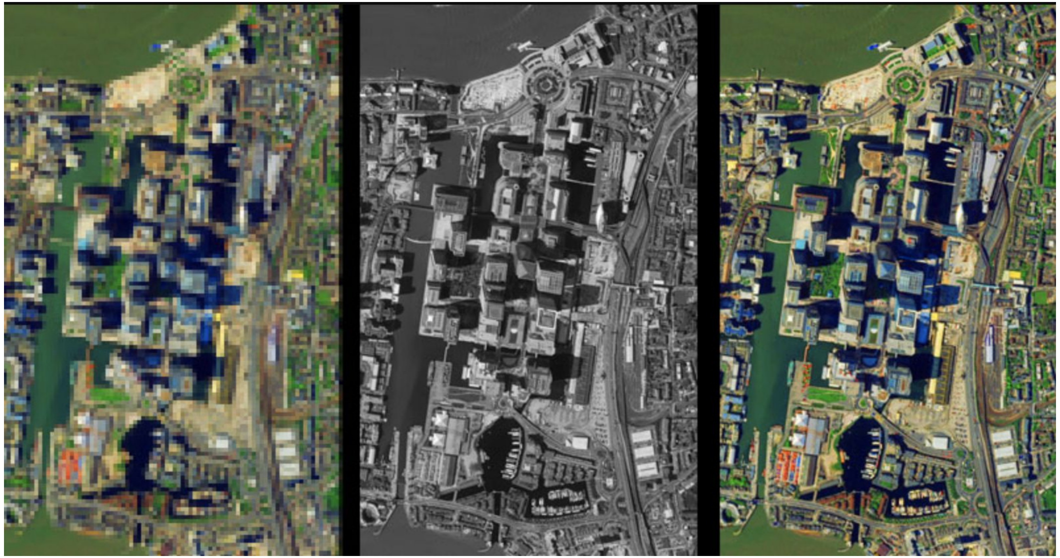
PAN Sharpening Methods:

Brovey transform:

$$R_{new} = \frac{R}{(R+G+B)} \times PAN$$

$$G_{new} = \frac{G}{(R+G+B)} \times PAN$$

$$B_{new} = \frac{B}{(R+G+B)} \times PAN$$



Simple-Mean transform:

$$R_{new} = \frac{R+PAN}{2}$$

$$G_{new} = \frac{G+PAN}{2}$$

$$B_{new} = \frac{B+PAN}{2}$$

Color Map Substitution:

- Convert to HSV, YUV, or YCbCR and replace intensity (V or Y) by PAN channel.

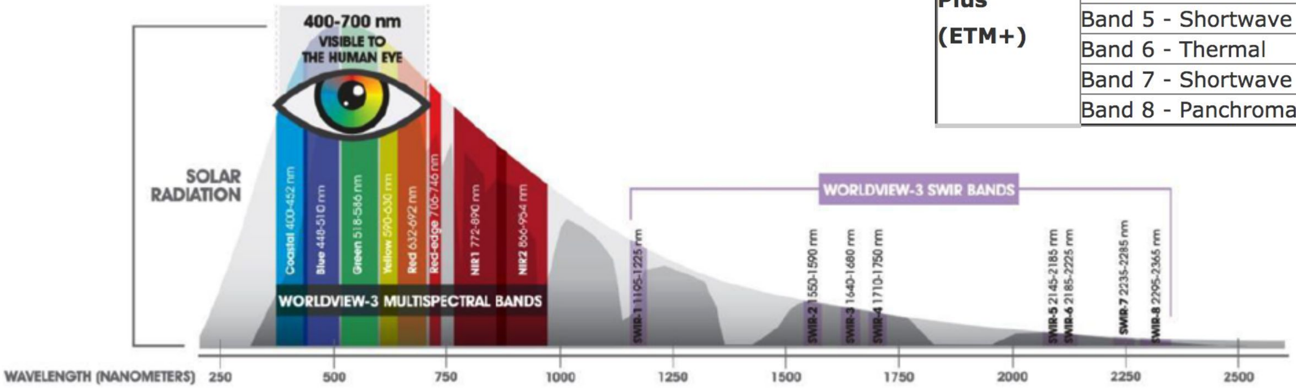
Multispectral Satellites: Examples

KOMPSAT-3 Satellite Sensor Specifications

Spectral bands	450-900 nm Pan (Panchromatic) 450-520 nm MS1 (Multispectral), blue 520-600 nm MS2, green 630-690 nm MS3, red 760-900 nm MS4, NIR (Near Infrared)

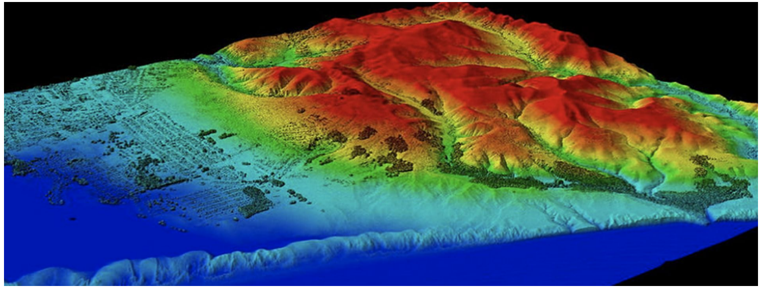
Landsat 1-5	Landsat 1-3	Landsat 4-5	Wavelength (micrometers)
Multispectral Scanner (MSS)	Band 4 - Green	Band 1 - Green	0.5-0.6
	Band 5 - Red	Band 2 - Red	0.6-0.7
	Band 6 - Near Infrared (NIR)	Band 3 - Near Infrared (NIR)	0.7-0.8
	Band 7 - Near Infrared (NIR)	Band 4 - Near Infrared (NIR)	0.8-1.1

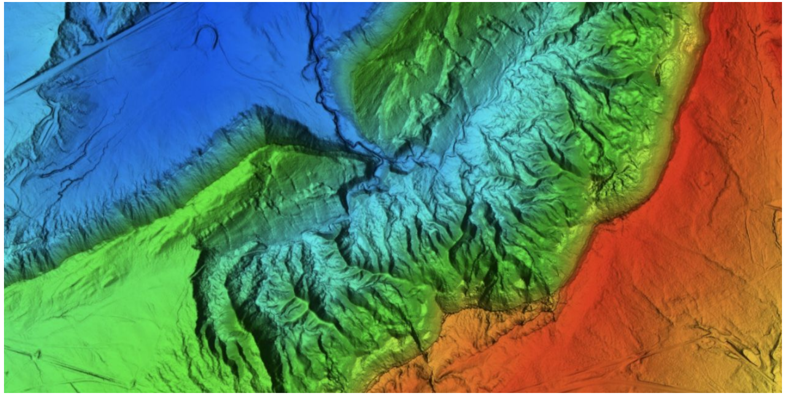
Landsat 7	Bands	Wavelength (micrometers)
Enhanced Thematic Mapper Plus (ETM+)	Band 1 - Blue	0.45-0.52
	Band 2 - Green	0.52-0.60
	Band 3 - Red	0.63-0.69
	Band 4 - Near Infrared (NIR)	0.77-0.90
	Band 5 - Shortwave Infrared (SWIR) 1	1.55-1.75
	Band 6 - Thermal	10.40-12.50
	Band 7 - Shortwave Infrared (SWIR) 2	2.09-2.35
	Band 8 - Panchromatic	.52-.90

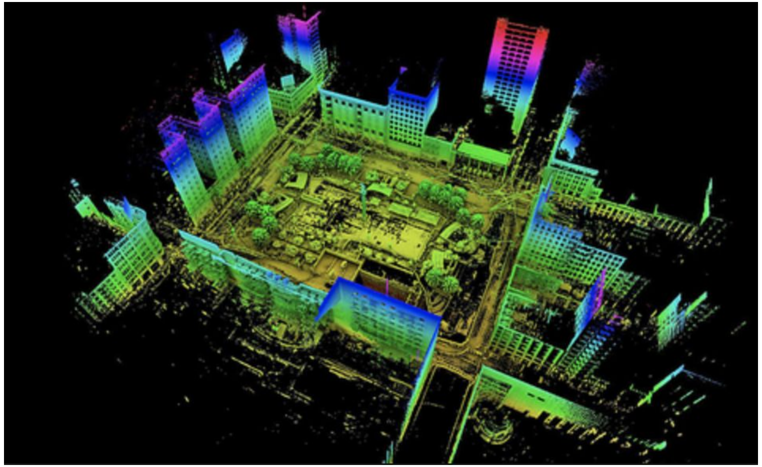


Light Detection and Ranging (LIDAR) Imagery:

- Emits laser pulses in the visible and IR portions of the spectrum onto the Earth's surface.
- Measures time it takes for the energy to return.
- Highlights distances and heights.
- Develops 3D models of objects.
- Provides day and night collection.
- Cannot penetrate clouds or smoke.

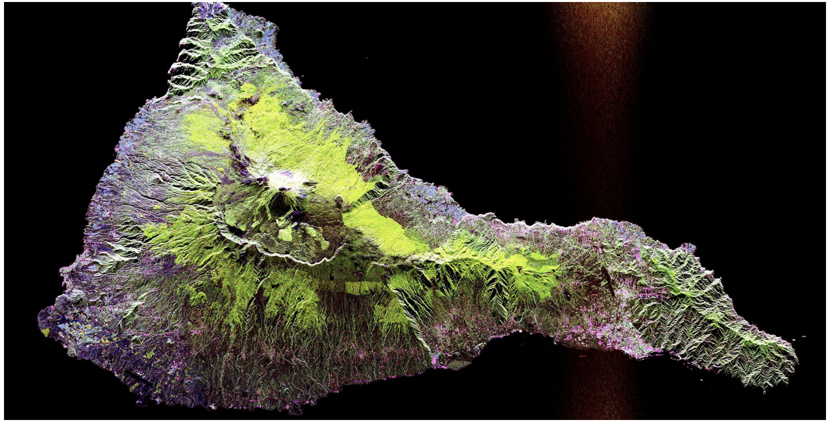


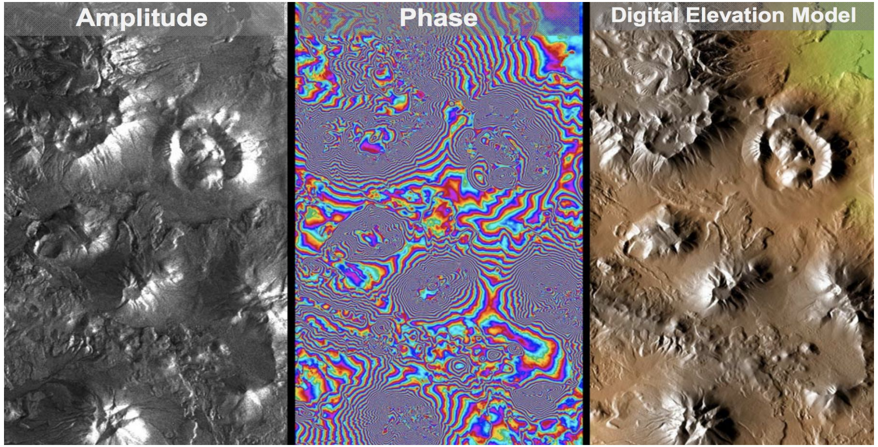




Synthetic Aperture Radar (SAR) Imagery:

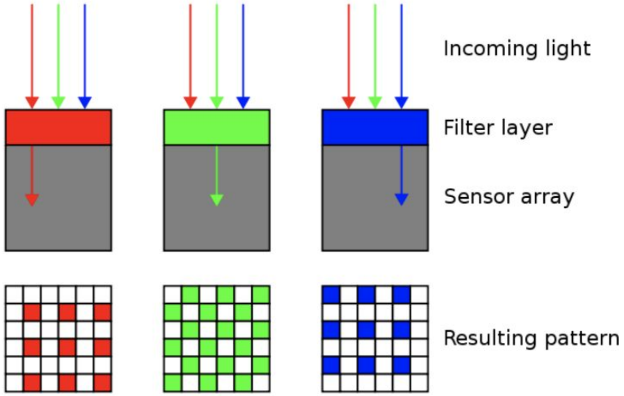
- Emits pulses of radio waves onto the Earth's surface.
- Measures time it takes for the energy to return.
- Signal processing is needed to process (complex-valued) frequencies.
- Highlights distances and heights.
- Develops 3D models of objects.
- Provides day and night collection.
- Penetrates through clouds, fog, smoke, and haze.

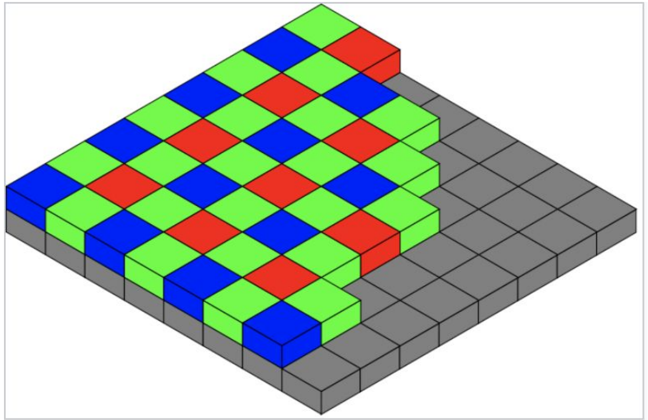




Demosaicing: Bayer Color Filter Pattern

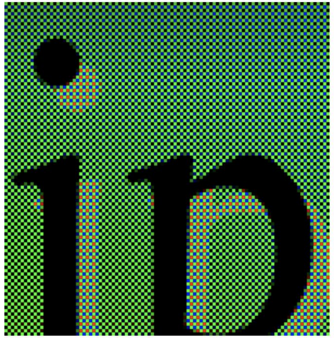
- A color filter array for arranging RGB on a grid.
- Pattern repeats every 2x2 block.
- Filter pattern (mosaic) is 50% green, 25% blue and 25% red.
- More green filters due to human's eye sensitivity to green light.



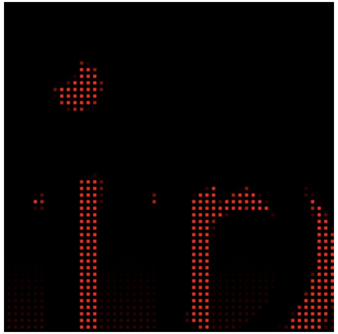


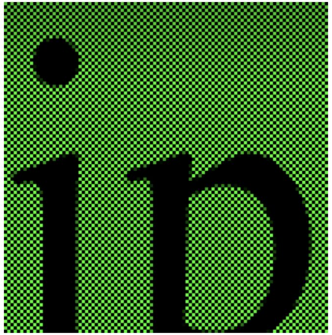
Demosaicing: Interpolation Approach


Original


Bayer filter samples

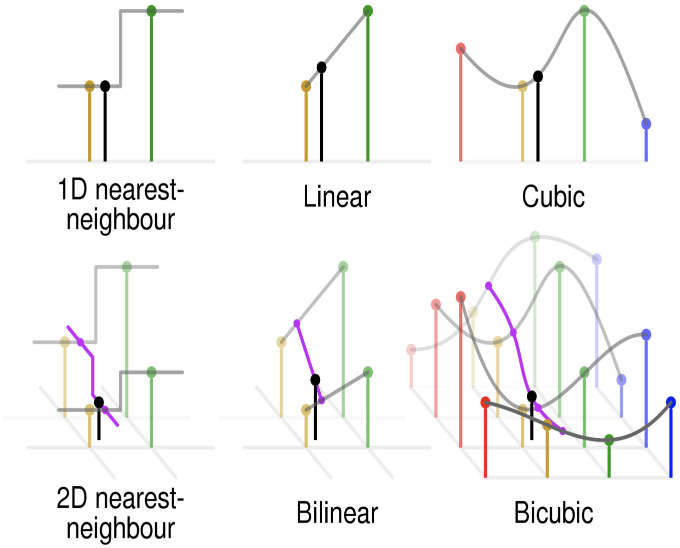

Reconstructed


Red


Green

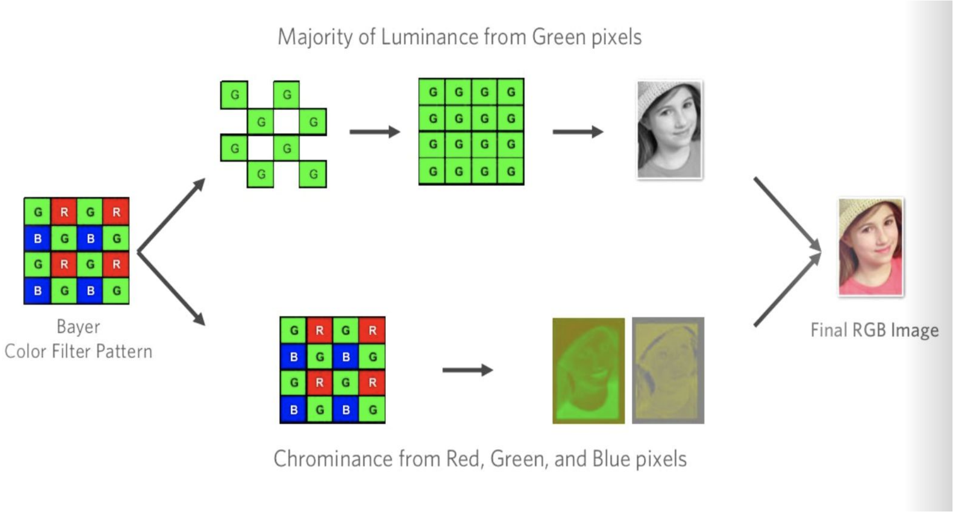

Blue

Interpolation Schemes:



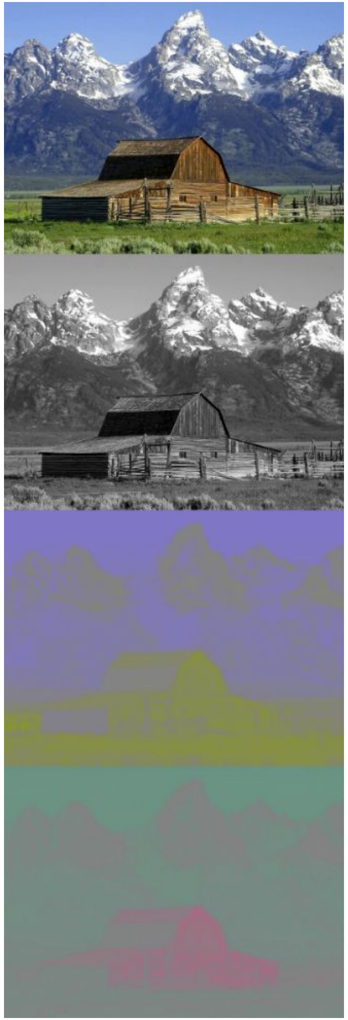
Demosaicing: YCbCr Approach

- Luminance (Y): Brightness of color.
- Chrominance (C): Color information.
- Cb: C - Blue. Cr: C - Red.



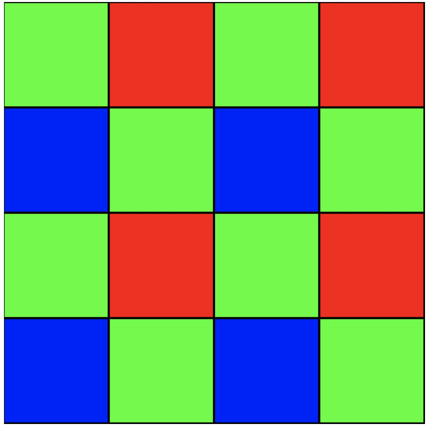
Top: Visible.
Middle: C.
Bottom: Y.

Top: Visible.
Middle: Y.
Middle: Cb.
Bottom: Cr.

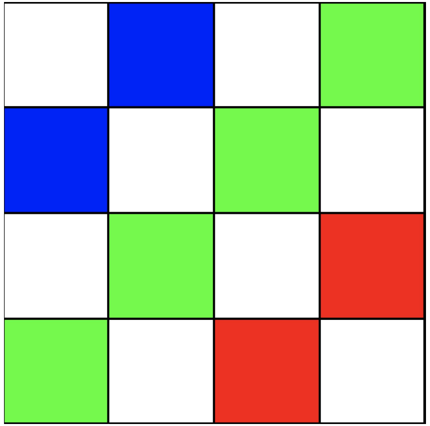


Demosaicing: TrueSense Color Filter Pattern

- Similar to Bayer filter.
- Pattern repeats every 4x4 block.
- Filter pattern is 50% pan, 25% green, 12.5% blue, and 12.5% red.
- More PAN filters to sharpen RGB image.



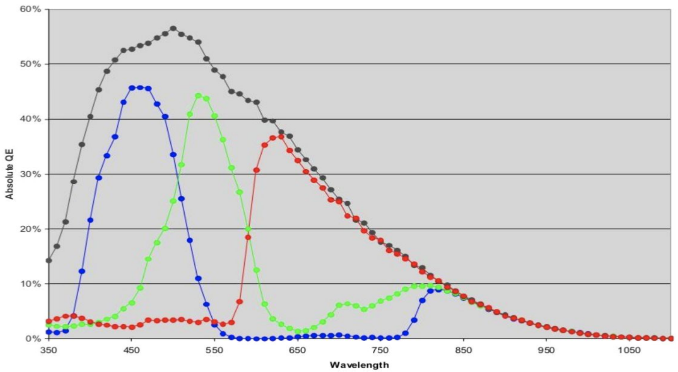
Bayer filter

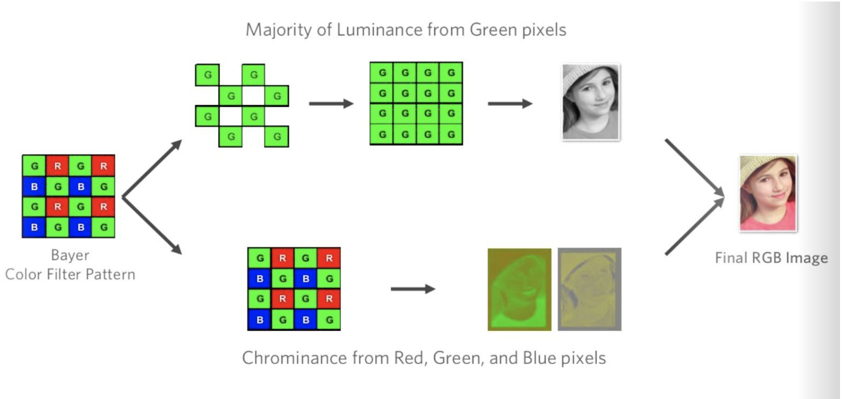


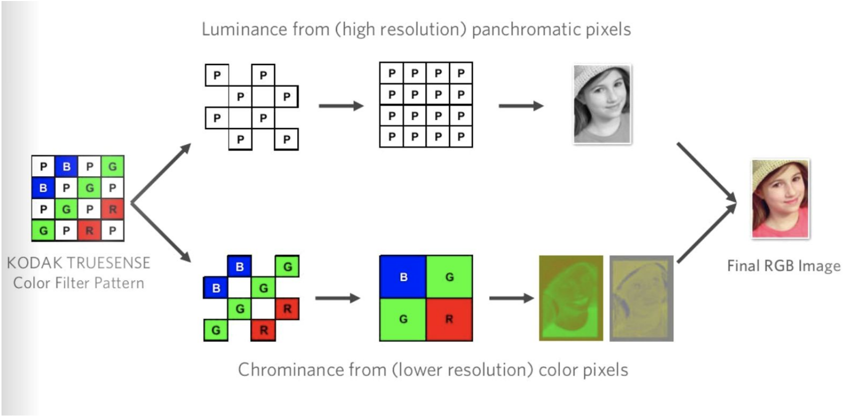
TrueSense filter

Demosaicing: Bayer vs. TrueSense

- PAN channel provides higher light absorption.
- PAN pixels create luminance from higher resolution.
- Fewer RGB pixels for chrominance.

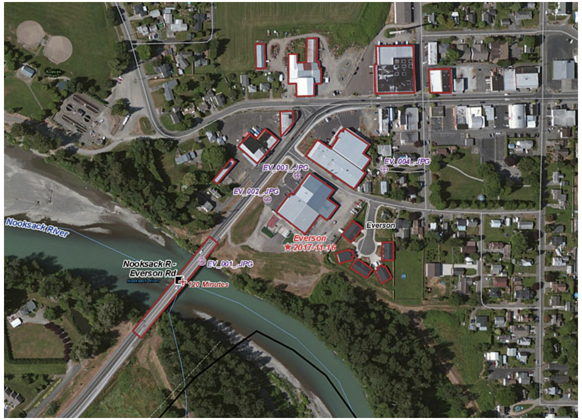






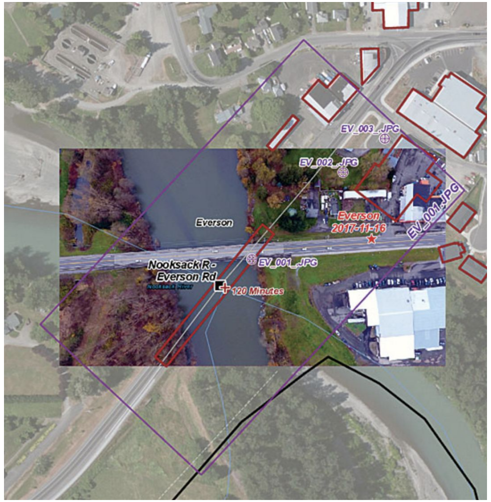
Georeferencing

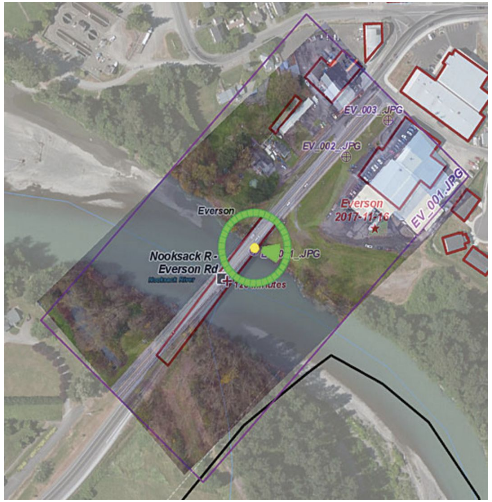
- Satellite imagery presents geolocation error after collection.
- **Georeferencing** reduces error and prepares imagery ready for mapping.



Algorithm:

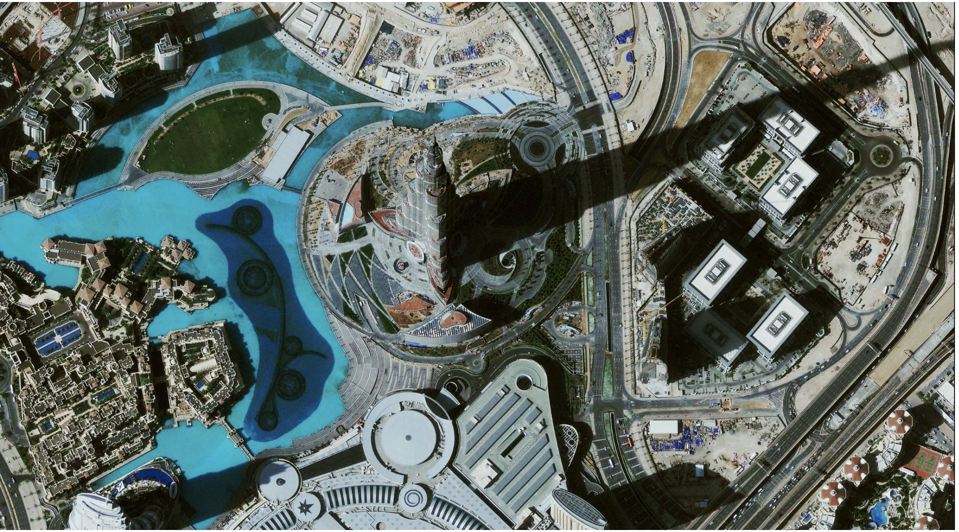
1. Features are identified in satellite imagery.
2. Corresponding features are found in basemap (Top).
3. Each pair forms a tie point (Left).
4. Minimize distance of each tie point (Right).
5. Outlier tie points are discarded.
6. Repeat 4, 5 until convergence.
7. Apply transformation to all pixels.





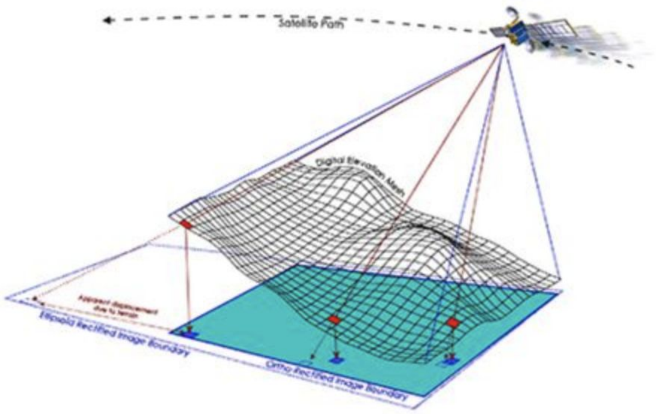
Off-Nadir Collection

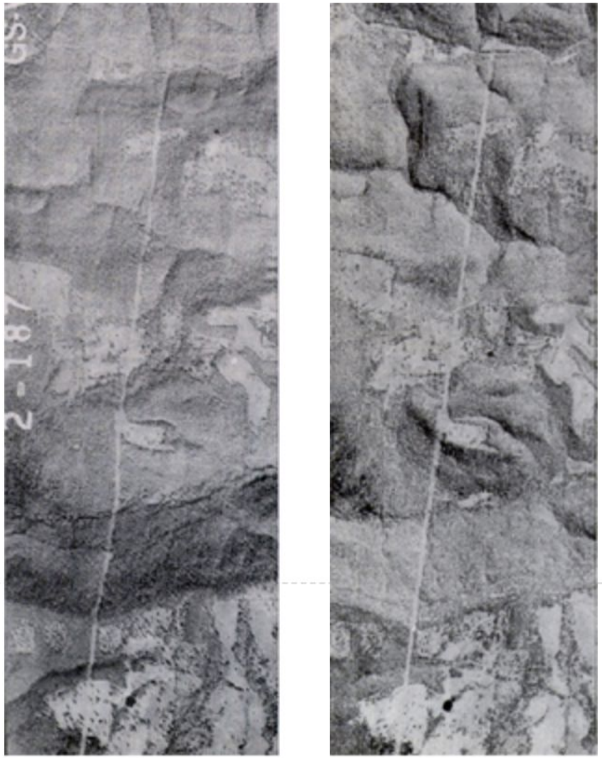
Bottom left: at-nadir collection.
Bottom right: off-nadir collection.
Top right: very off-nadir collection.



Orthorectification

- **Orthorectification** removes perspective (off-nadir) effects and terrain (elevation) effects.
- Model uses elevation data.
- Reduces geolocation error arising from features with high elevation.
- Hidden pixels are created by sampling neighbors.
- **Algorithm**: Rational polynomial coefficients (RPC).





Orthorectification: Rational Polynomial Coefficients (RPC)

1) Sets up a transformation from satellite image (X, Y, Z) to orthorectified image (x,y) with cubic polynomials.

$$\begin{cases} \mathrm{x} = \dfrac{P_1(X,Y,Z)}{P_2(X,Y,Z)} \\ y = \dfrac{P_3(X,Y,Z)}{P_4(X,Y,Z)} \end{cases}$$

2) Rewrite system to solve for errors.

$$\begin{cases} F_x = P_1(X,Y,Z) - xP_2(X,Y,Z) \\ F_y = P_3(X,Y,Z) - yP_4(X,Y,Z) \end{cases}$$

3) Linearized system, set up iterative scheme, and solve using least squares.

$$\mathrm{V = BX - L}$$

$$B = \begin{bmatrix} \dfrac{\partial F_x}{\partial a_i} & \dfrac{\partial F_x}{\partial b_i} & \dfrac{\partial F_x}{\partial c_i} & \dfrac{\partial F_x}{\partial d_i} \\ \dfrac{\partial F_y}{\partial a_i} & \dfrac{\partial F_y}{\partial b_i} & \dfrac{\partial F_y}{\partial c_i} & \dfrac{\partial F_y}{\partial d_i} \end{bmatrix}$$

$$L = [\mathrm{x} \quad y]^T$$

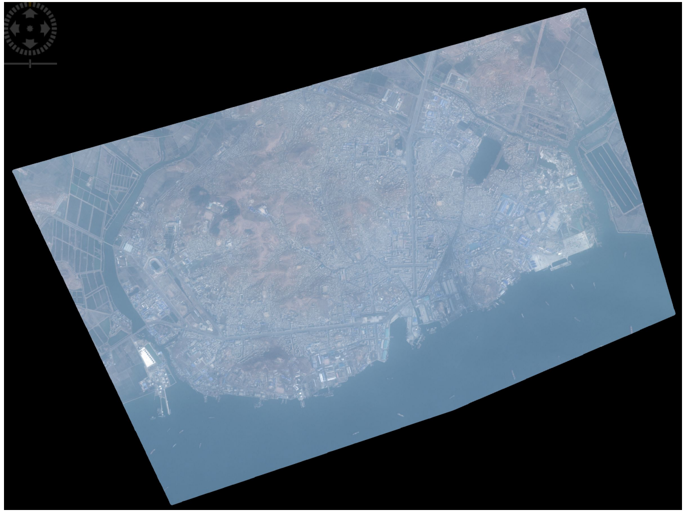
$$X = [\, a_i \quad b_i \quad c_i \quad d_i \,]^T$$

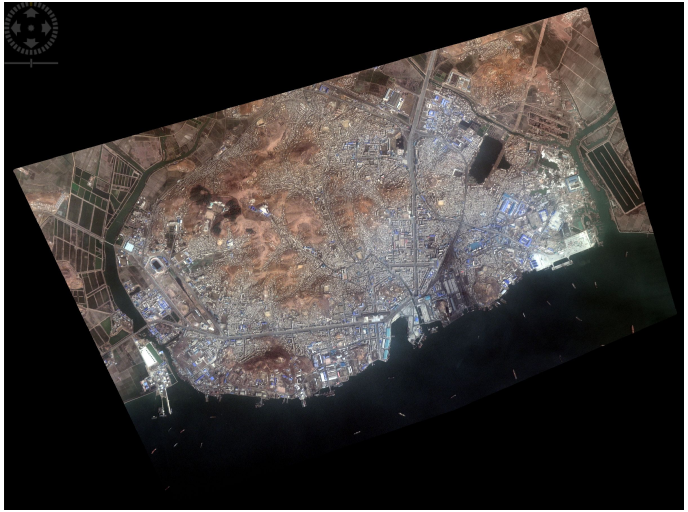
Atmospheric Correction

- **Atmosphere correction** removes atmospheric effects from imagery.
- Atmosphere scatters colors with smaller wavelengths.
- Blue has the smallest wavelength in the spectrum.
- **Simple Algorithm**: Subtract darkest pixel from each channel.
- **Complex Algorithm**: Use a model of the atmosphere and reverse the scattering process.

Dynamic Range Adjustment (DRA)

- Dynamic range adjustment (DRA) automatically adjusts contrast and brightness of satellite imagery.
- DRA is prone to fail in certain cases.
- In such cases, a manual adjustment yields better results.





National Image Interpretability Range Scale (NIIRS)

- Rates quality of imagery.
- Ranges from 0 (worst quality) to 9 (best quality).
- Score depends on the tasks achieved with imagery.
- Uses General Image Quality Equation 5 (GIQE5):

$$NIIRS = c_0 + c_1 \log_{10} GSD + c_2 \left(1 - e^{\frac{c_3}{SNR}}\right) \log_{10} RER_0 + c_4 (\log_{10} RER_0)^4 + \frac{c_5}{SNR} + c_6 smear$$

- GSD: ground sample distance.
- SNR: signal to noise ratio.
- RER: relative edge response.
- Smear: quality degradation during integration time.

Next Time: Classical Computer Vision Methods

Thank you.