Chapter 1: Introduction

- Photogrammetry:
  - Definition & applications
  - What are we trying to do?
  - Data acquisition systems
  - 3-D viewing of 2-D imagery
  - Automation (matching problem)
- Necessary tools:
  - Image formation (Chapters 2 – 4)
  - Mathematical image manipulation (Chapters 5 – 9)
  - Direct geo-referencing (Chapter 10)
  - Photogrammetric products – DEM and Orthophotos (Chapters 11 & 12)

CE59700: Chapter 2

Electro-Magnetic (EM) Radiation

EM Radiation: Overview

- Terminology
- EM radiation principles
- Active versus passive remote sensing systems
- Bands of the electro-magnetic radiation:
  - Radio waves
  - Microwaves
  - Infrared radiation
  - Visible light
  - Ultraviolet rays
  - X-rays
  - Gamma rays

Terminology and EM Radiation Principles

Terminology

- **Energy** (I) is the capacity to do work.
  - It is expressed in *joules* (J).
- **Radiant energy** is the energy associated with electromagnetic radiation.
- **Radiant flux** (Φ) is the rate of transfer of energy from one place to another (e.g., from the Sun to the Earth).
  - Radiant flux is measured in *watts* (*J/sec*).
  - $\Phi = \partial I / \partial t$

Terminology

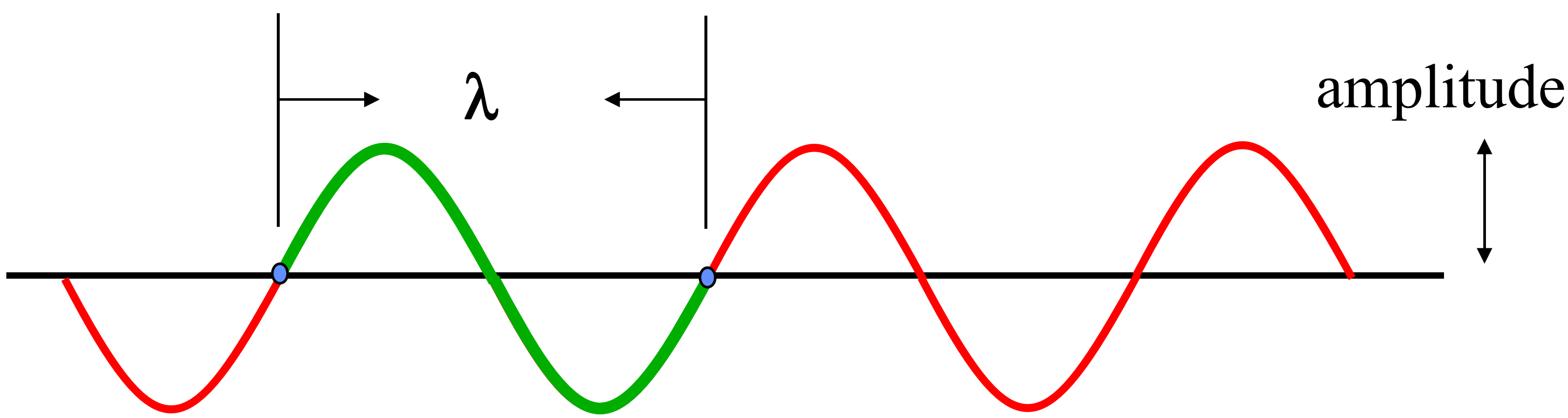
- To understand the interaction between the EM radiation and the surface of the Earth, we need to introduce the term **radiant flux density**.
  - The radiant flux that is *incident upon* or is *emitted by* a surface per unit area.
  - For incident radiation, we use the term **irradiance** (E) to denote the radiant flux density.
  - For emitted radiation, we use the term **radiant exitance** (M) to denote the radiant flux density.
  - Radiant flux density is measured in *watts per square meter* (wm^{-2}).
  - $E/M = \partial \Phi / \partial A$
    - (A) refers to the area along the normal to the radiation direction.

EM Radiation

- Visible light is only one of the many forms of electromagnetic energy.
- Radio waves, heat, ultraviolet rays, and x-rays are other familiar forms.
- EM-radiation can be either considered as:
  - Stream of particles (photons)
    - Allows for a better understanding of the radiation interaction with the surface of the Earth and its atmosphere
  - Waveform
    - Allows for the distinction between different manifestations of radiation (e.g., microwave and infrared radiation)

EM Radiation

- The EM radiation travels in vacuum with the speed of light.
- The relationship between the speed, frequency, and the wavelength of the radiation is defined by:
  - $c\ (m/sec) = \lambda\ (m) * f\ (sec^{-1})$
    - (c) speed of light = 3×10^8 m/sec
    - *(f)* frequency of the radiation (cycles/sec)



Radiation Energy

- The shorter the wavelength, the higher the energy that is carried by the radiation.
- The amount of energy of a single photon is defined as:
  - $I\ (joule) = h\ (joule\ sec)\ \ f\ (sec^{-1})$
    - h is Planck's constant (6.3×10^{-34} *joule sec*)

Sources of EM radiation

- Any object whose temperature is greater than 0° Kelvin (-273° C) emits radiation.
- Black material absorbs all radiation that reaches it (a perfect absorber is referred to as a 'blackbody').
- The distribution of the emitted energy at each wavelength is not uniform.
- The distribution of the emitted energy in different regions of the spectrum depends upon the temperature of the source.

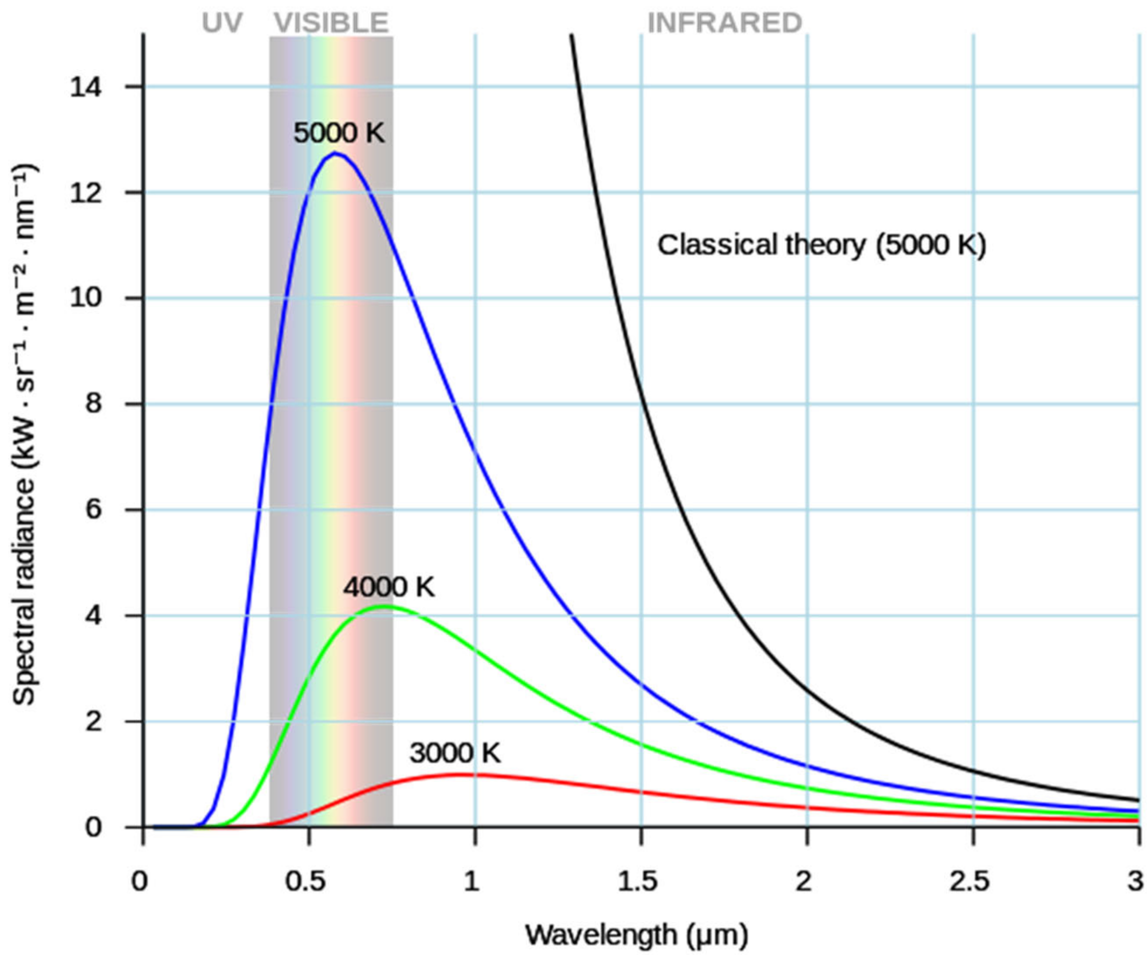
EM Radiation Source

- A blackbody transforms absorbed heat into radiant energy according to Planck's law of spectral exitance:

$$M_\lambda = c_1 \pi^{-1} \lambda^{-5} / [e^{c_2/\lambda T} - 1]$$

  - $c_1 = 3.742 \times 10^{-16}$ ($W\, m^2$)
  - $c_2 = 1.4388 \times 10^{-2}$ ($m\, K$)
  - λ = wavelength (m)
  - T = Temperature (K)
  - M_λ = Spectral exitance per wavelength ($Wm^{-2}m^{-1}$)

Black Body Radiation



http://en.wikipedia.org/wiki/Black-body_radiation

EM Radiation Source

- The integrated radiance (area under the curve) increases as T increases.
- The peak radiance shifts towards shorter wavelengths as T increases.
- The peak of the spectral exitance curve is governed by Wein's Displacement Law:

$$\lambda_{\max} = c_3 \; T^{-1}$$

- $c_3 = 2.898 \times 10^{-3}$ ($m\,K$)

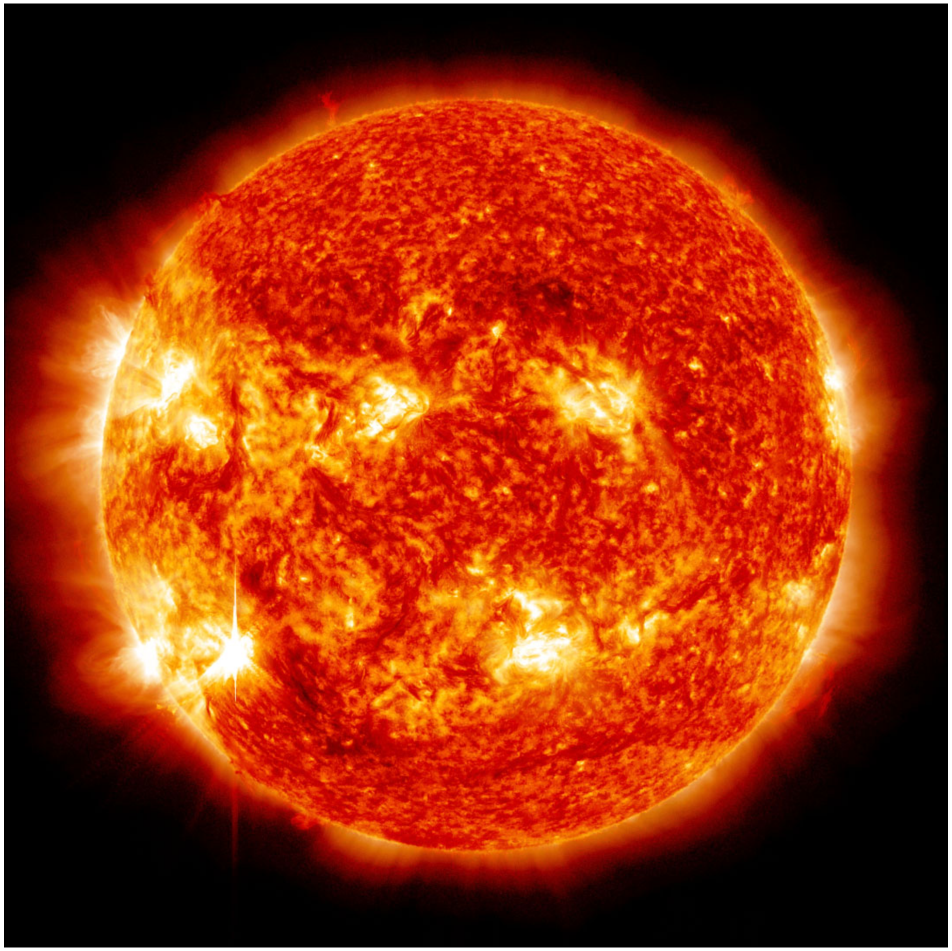
EM Radiation Source

- The total exitance of a blackbody at temperature T is given by the Stefan-Boltzmann Law as:

$$M = \sigma\, T^4 \;\; (W\, m^{-2})$$

- $\sigma = 5.6697 \times 10^{-8}$ (W m^{-2} K^{-4})

EM Radiation Source



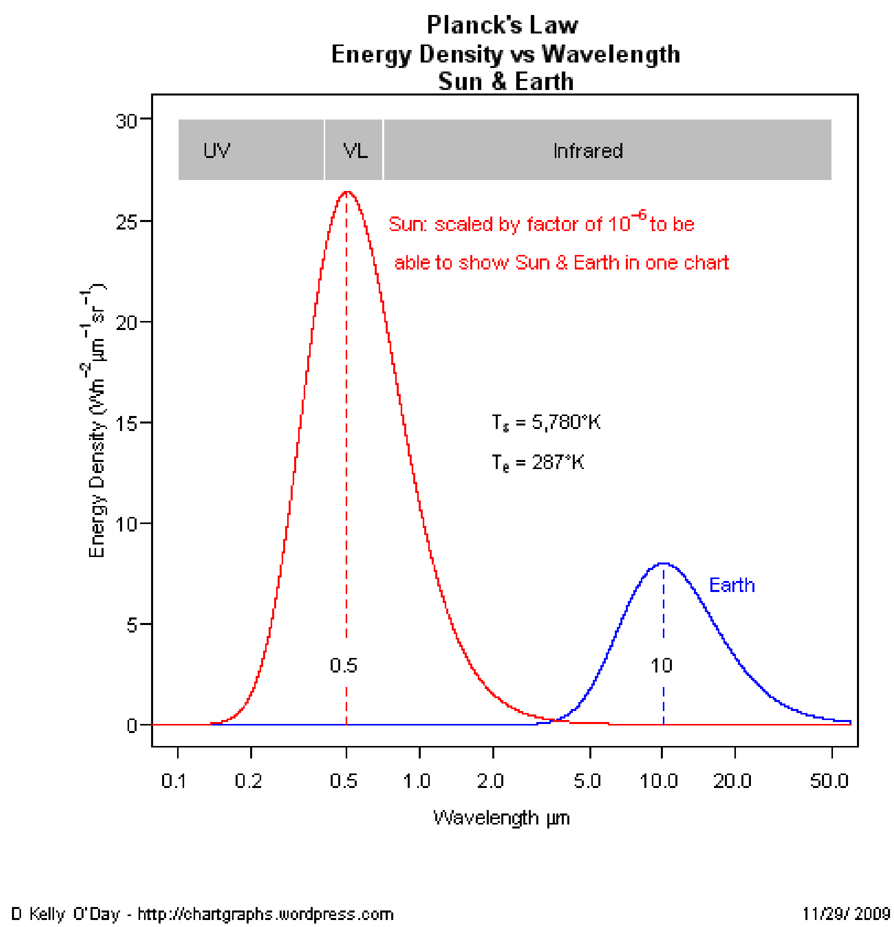
- The Sun is the most common source of radiation.

http://www.nasa.gov/images/

EM Radiation Source

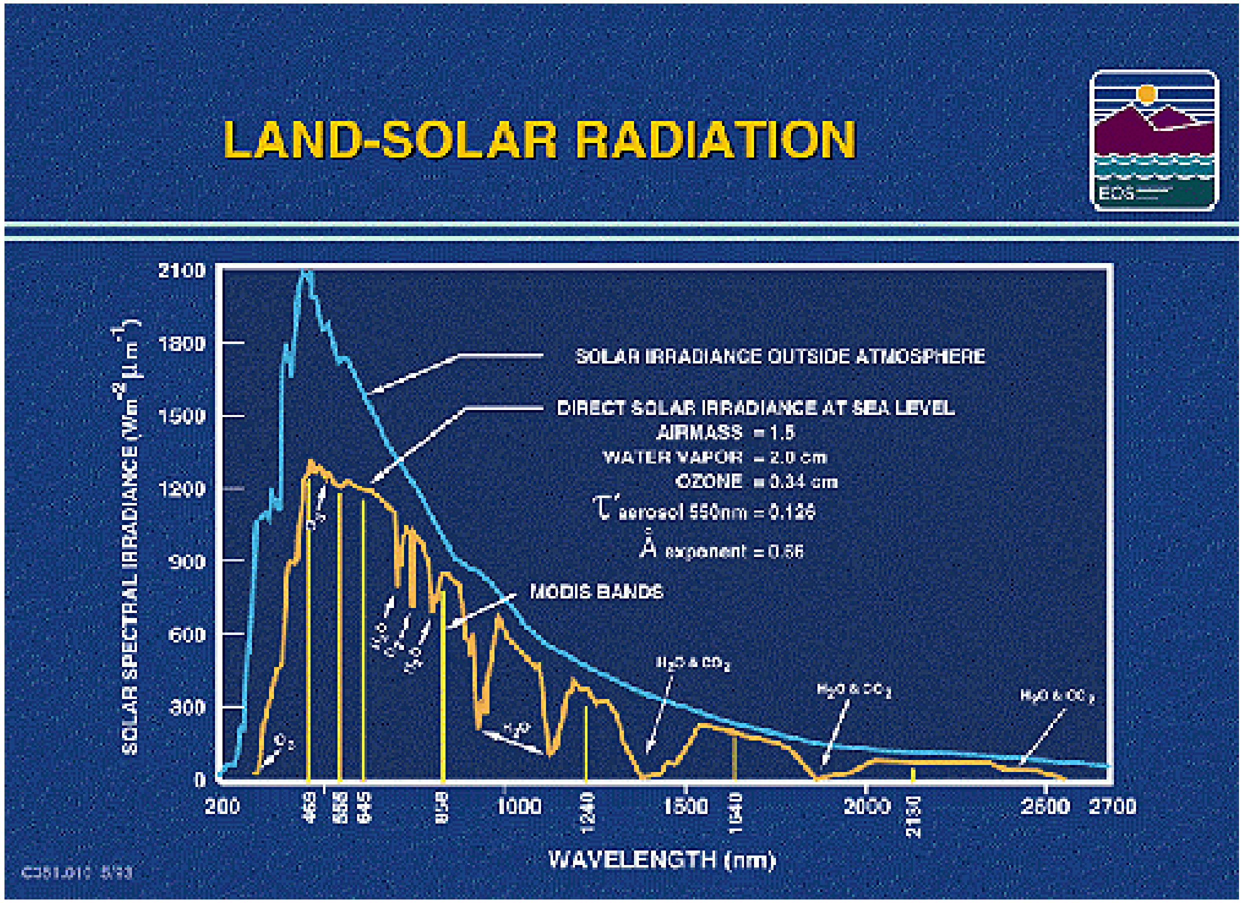
- The distribution of the spectral exitance from a black body at 5900°K closely approximates the Sun's spectral exitance.
- The Earth approximately acts as a blackbody with a temperature of 290°K.
- The maximum solar radiation takes place in the visible spectrum (λ_{max} = 0.47μm).
  - 46% of the Sun's total energy falls into the visible waveband (0.4 - 0.76 μm).

Sun/Earth Radiation



http://chartsgraphs.files.wordpress.com/2009/11/sun_earth_spec_rad1.png

EM Radiation: Interaction with the Atmosphere



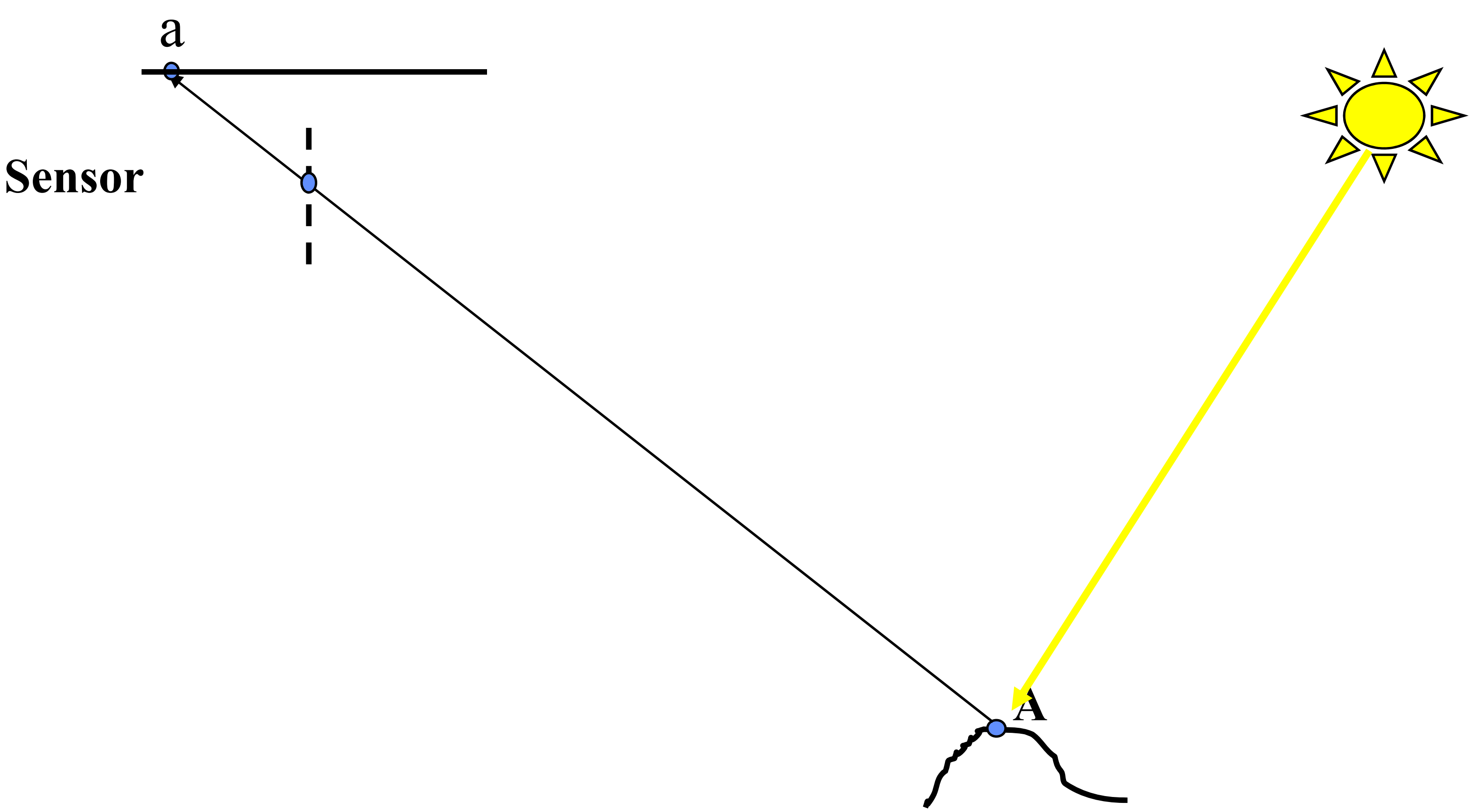
https://www.fas.org/irp/imint/docs/rst/Sect9/originals/Fig9_13.gif

Passive Versus Active Remote Sensing Systems

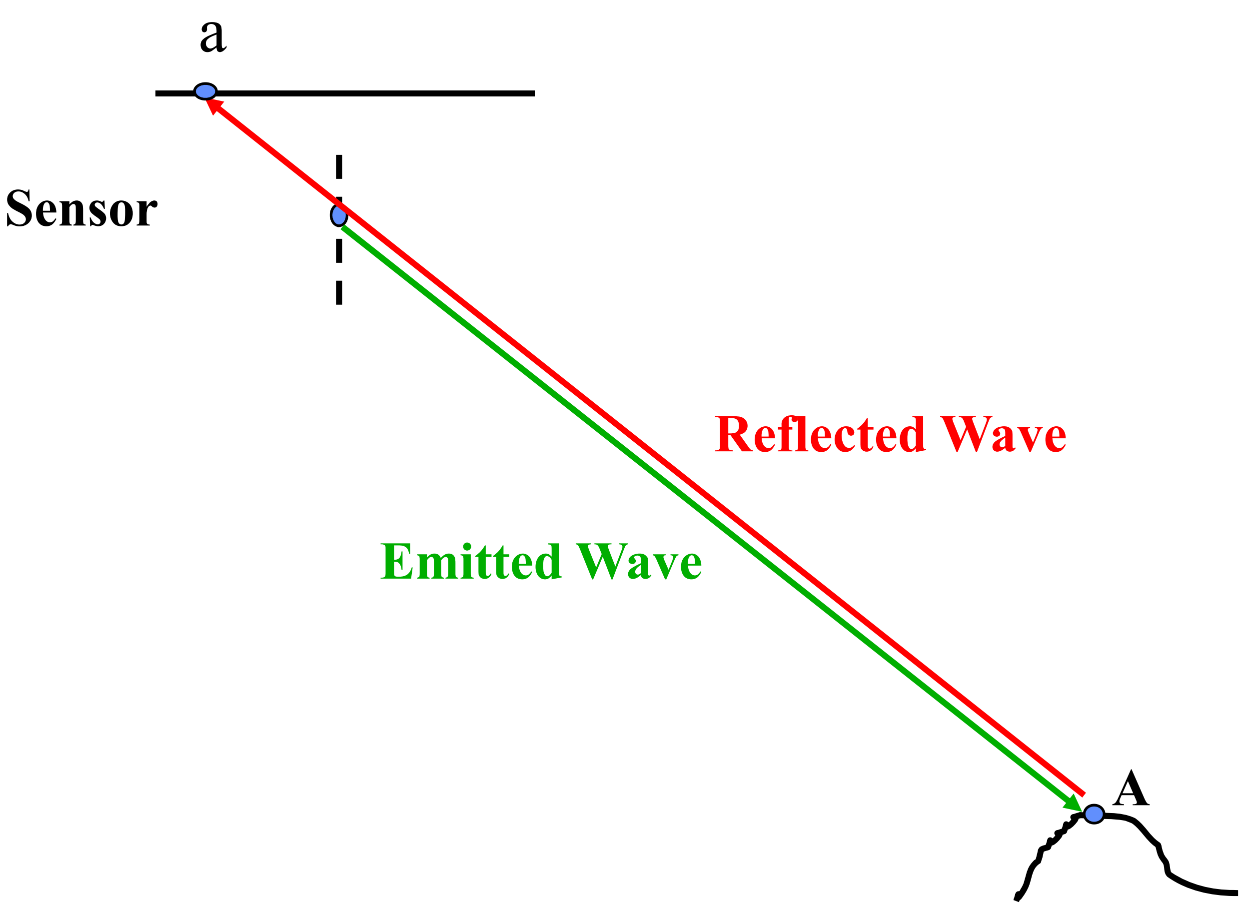
Active Versus Passive Sensors

- Remote sensing systems can be divided into two categories: *active and passive sensors*.
- Active sensors send out a signal and react to the response.
  - Active sensors need their own power to operate.
- Passive sensors simply process received signal from the surrounding environment (like thermometers).
  - Passive sensors do not need separate power to operate.

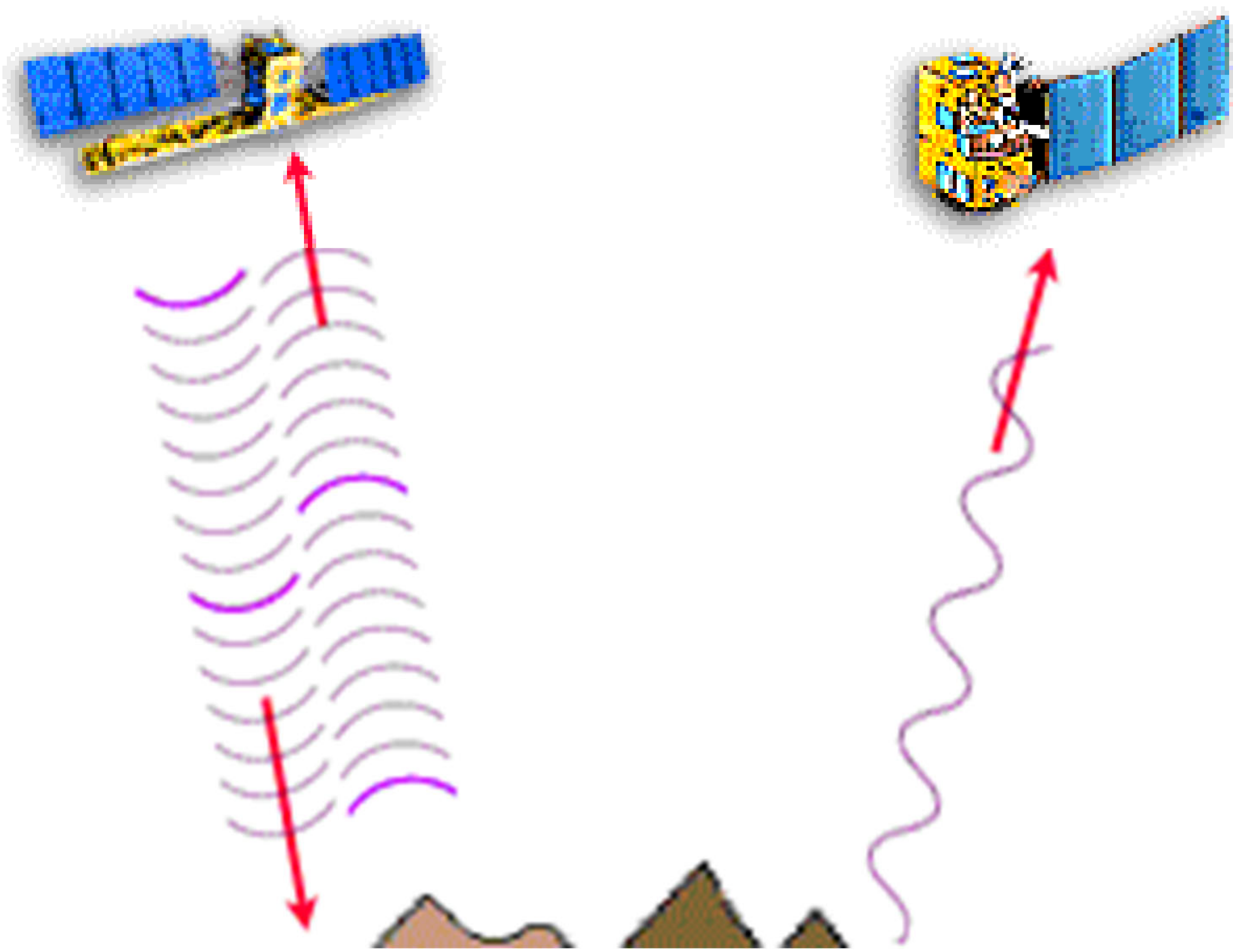
Passive Sensors (e.g., Passive Cameras)



Active Sensors (e.g., LiDAR & RADAR)



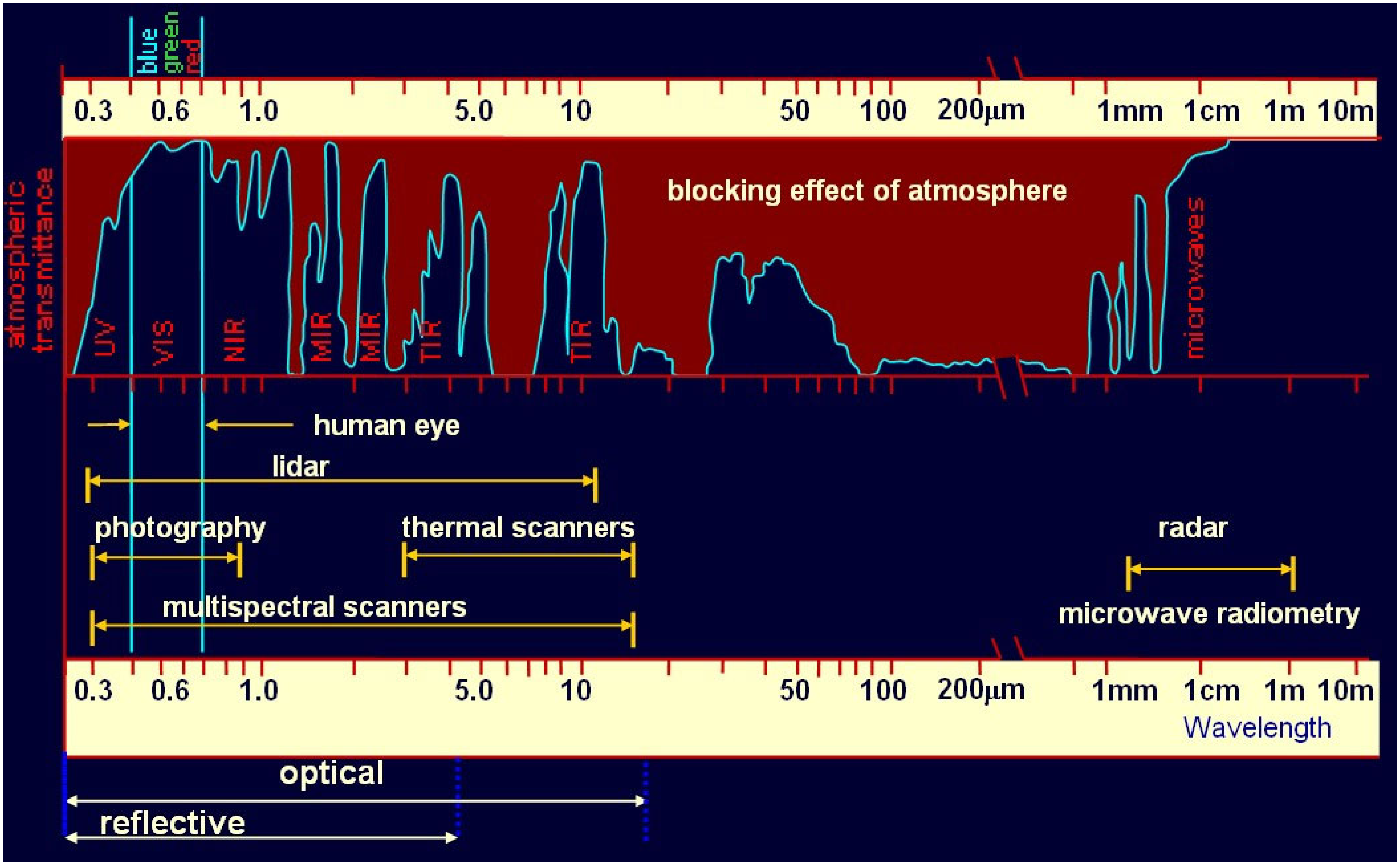
Active Versus Passive Sensors



http://www.neis.gov.cn/kjddYG/index.jhtml

EM Radiation Wavebands

EM Radiation Wavebands



http://foto.hut.fi/opetus/350/k04/luento6/luento6.html

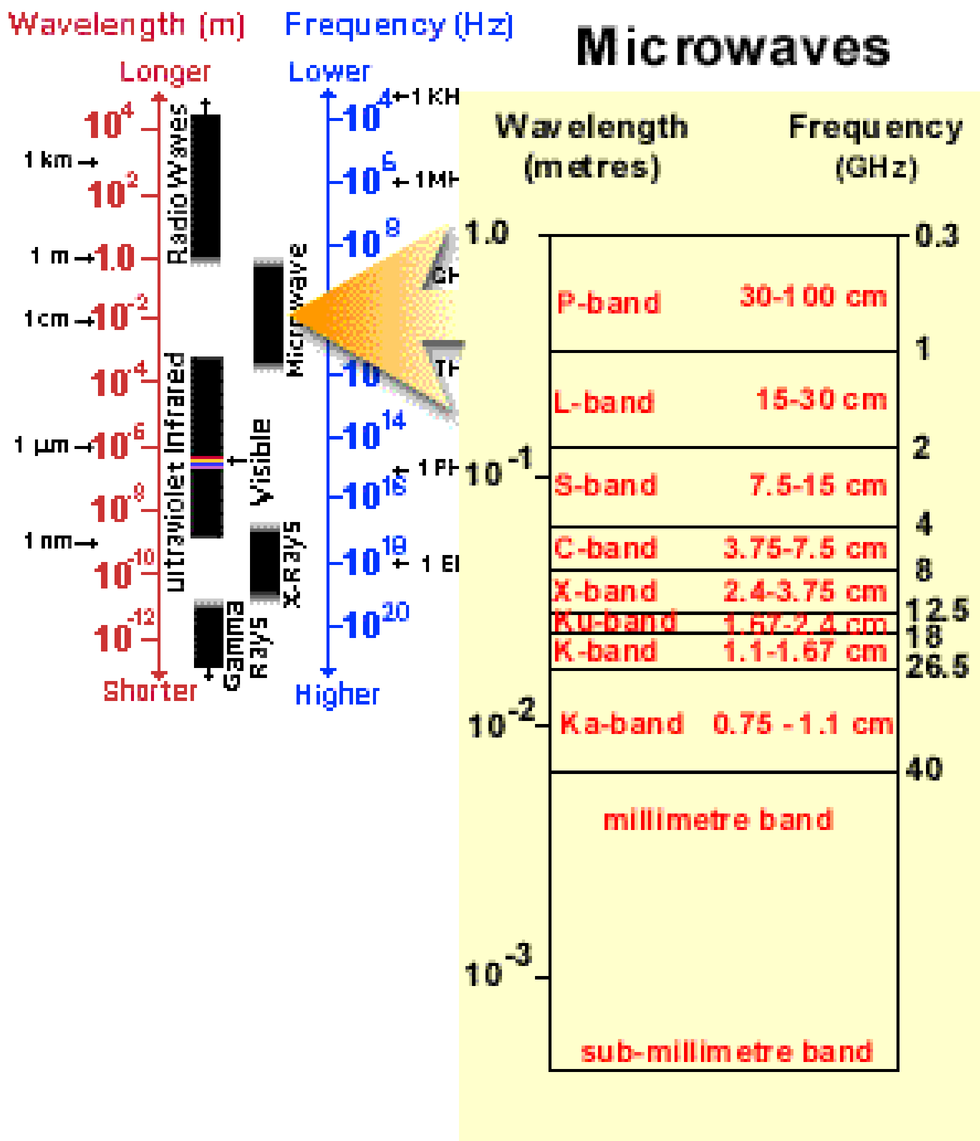
Radio Waves

- They are used to transmit radio and TV signals.
- Wavelength ranges from less than centimeter to hundreds of meters.
- FM radio waves are shorter than AM radio waves.
- Natural objects do not emit radio waves.
- Radio waves are used in remote sensing to exchange information between the satellites and the ground stations.

Microwave

- It has a wavelength that extends from 1mm – 300 cm.
  - This radiation can penetrate clouds (valuable region for remote sensing).
- Microwave are emitted from:
  - Earth surface,
  - Cars,
  - Planes, and
  - Atmosphere.
- Q: Should active or passive sensors be used?
- The emitted microwave is function of the object's temperature.
  - The emitted energy is too small for high resolution remote sensing.

Microwave



Microwave Sensors

Active Microwave

- For applications with high resolution requirements, we use active microwave remote sensing systems (RADAR):
  - RAdio Detection And Ranging
- Advantages of RADAR include:
  - All weather, day-night systems
  - Radiation is not scattered or absorbed by clouds
  - Detect roughness, slope, and electrical conductivity information
    - They do not detect color and temperature information.

RADAR

Black bulge under fuselage covers the radar antenna

http://www.tungsten-alloy.com/airborne-antenna-bases.htm

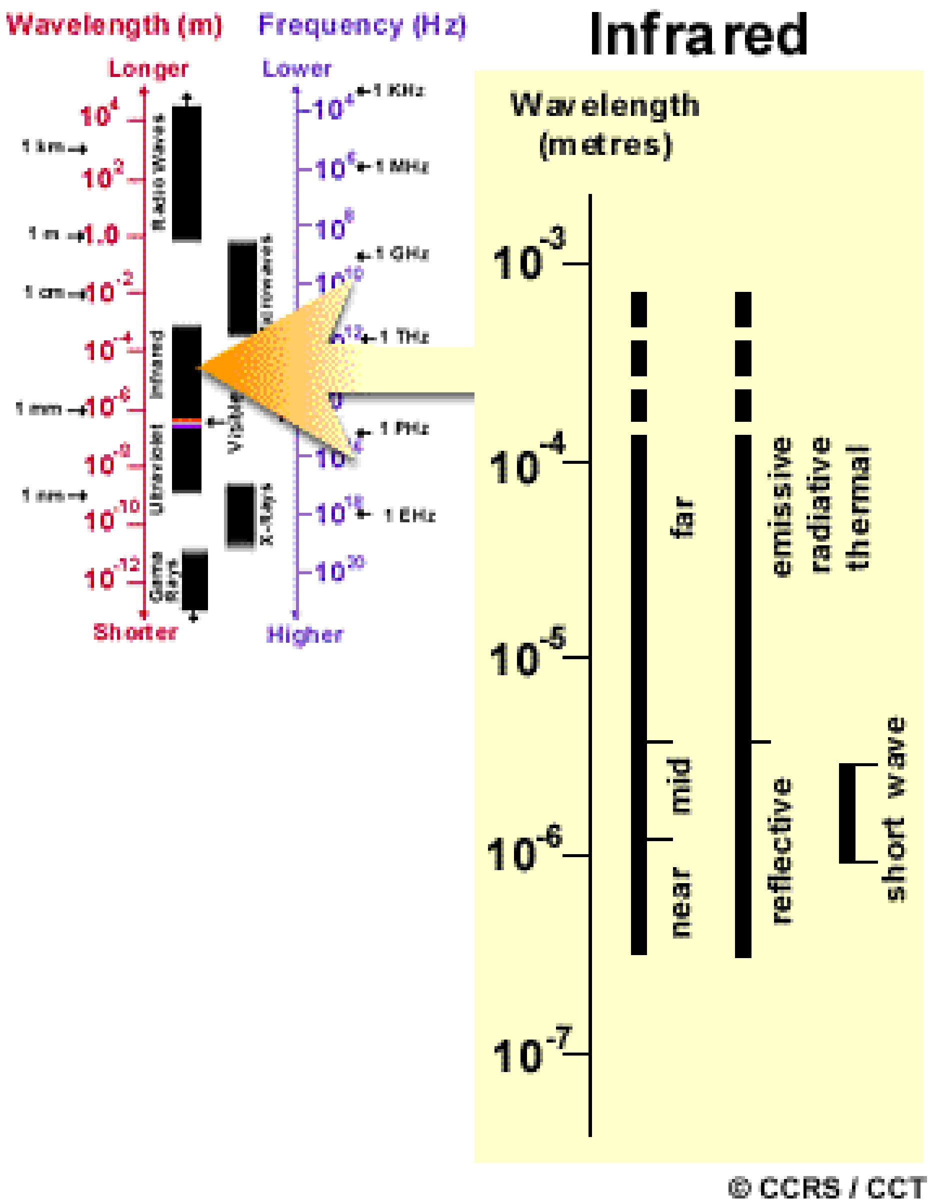
RADAR & Visible Imagery

http://www.sandia.gov/radar/imageryku.html

Infrared (IR)

- It has a wavelength that extends from 0.7µm → 1 mm.
  - Near IR (0.7µm – 1.5µm) behaves like visible light and can be detected by special photographic films.
  - Mid IR (1.5µm – 3.0µm) is of solar origin and is reflected by the surface of the earth.
  - Thermal/Far IR (3.0µm – 15µm) is emitted by the Earth surface and can be sensed as a heat.
    - The amount of emitted energy depends on the temperature of the target.
    - Much of the emitted energy is absorbed by the atmosphere (it heats the atmosphere).
  - Sub-millimeter IR (15µm – 1mm)

Infrared (IR)



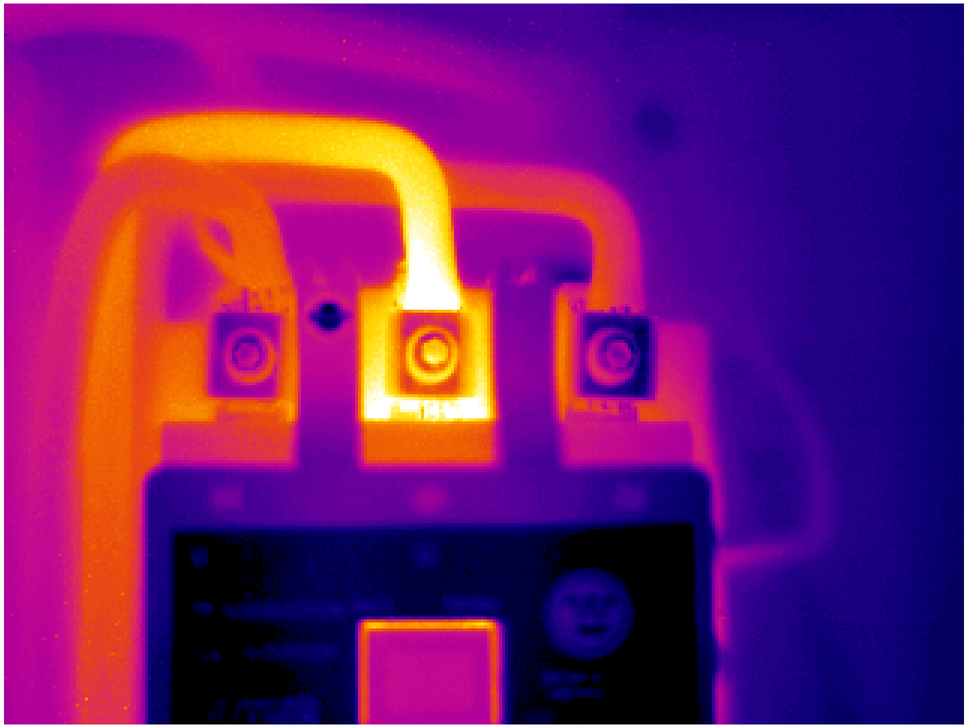
Infrared Band

Infrared (IR)

- Q: Active or passive sensor?
- Infrared images can give us information about:
  - Health of crops
  - Forest fires (even under cloud coverage)
  - Heat leakage from houses

Thermal Imaging

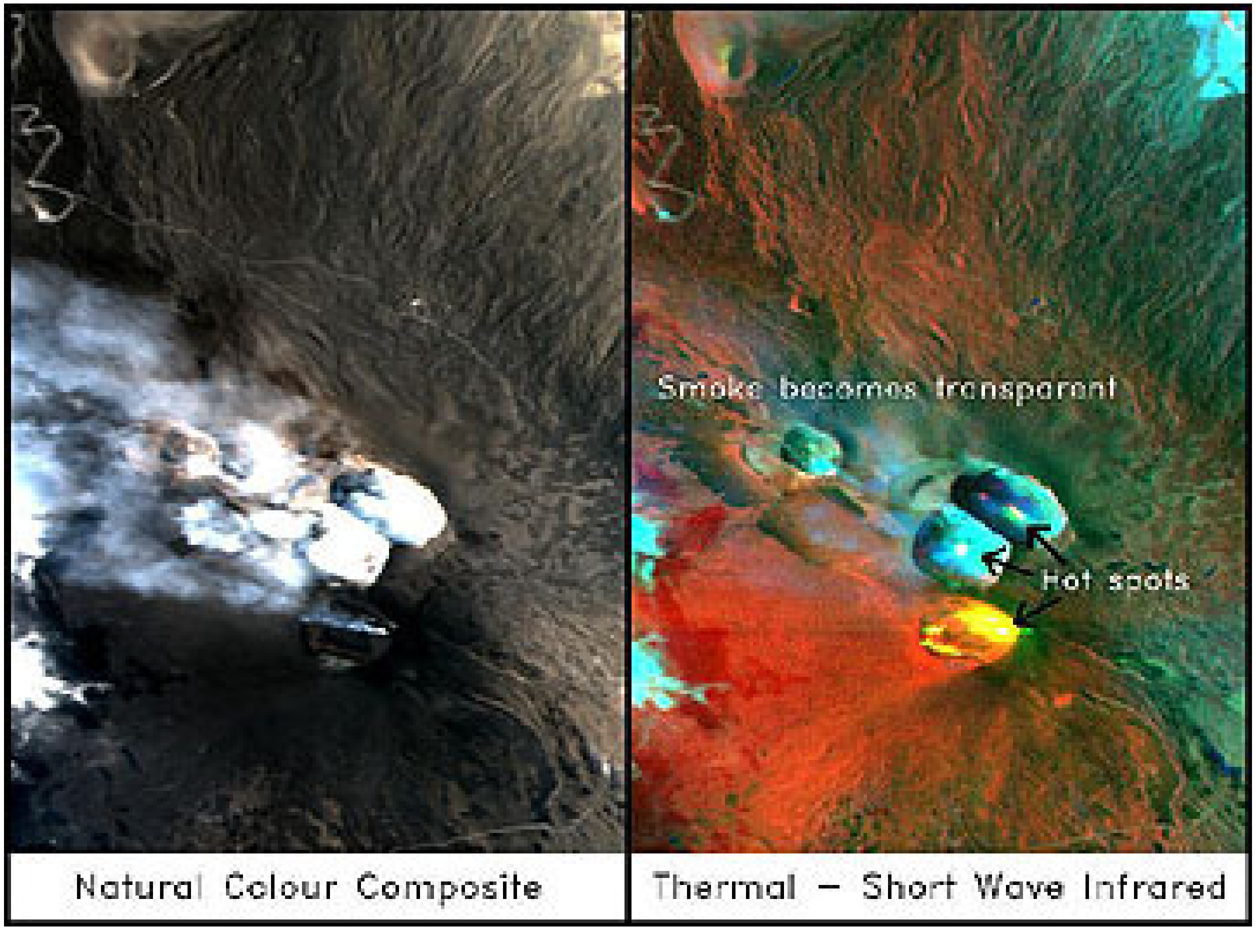
EZ THERM



Loose Connection in Breaker Box

http://www.electrophysics.com/

Visible & Thermal (Far-Infrared) Imagery



https://www.fas.org/irp/imint/docs/rst/Sect13/originals/Fig13_50.jpg

Visible & Thermal Imagery

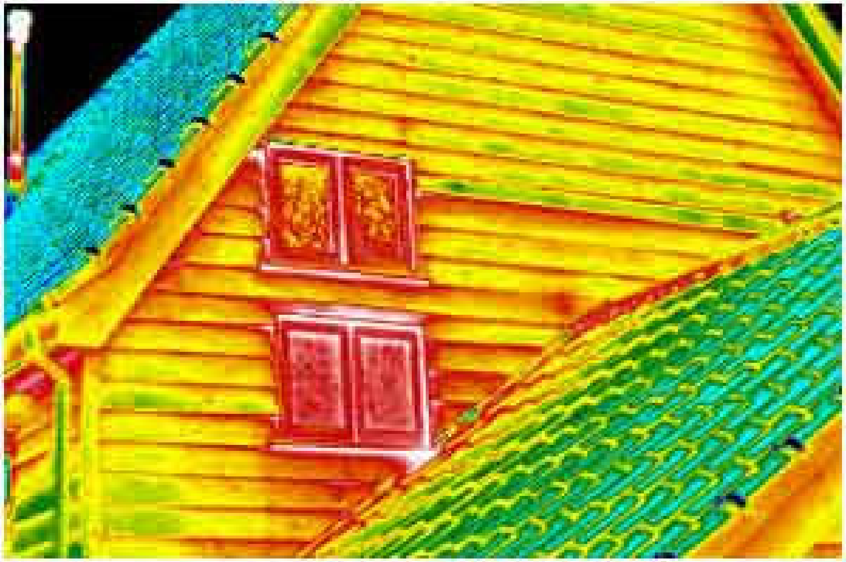
Visible

Thermal

http://www.atmarine.fi/?id=103

Visible & Thermal Imagery

Visible



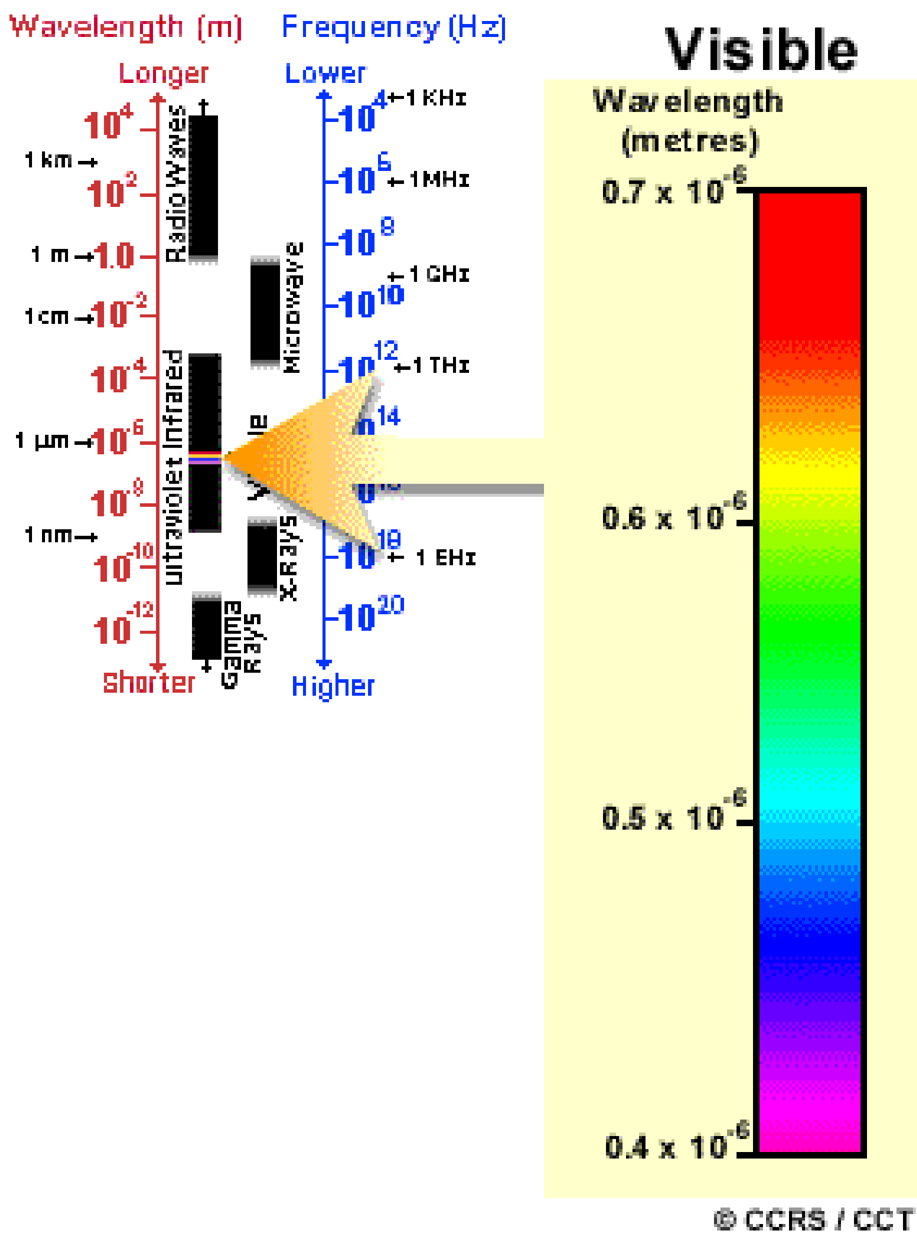
Thermal

http://www.imaging1.com/thermal/thermoscope-FLIR.html

Visible Light

- It has a wavelength ranging from:
  - 0.4 μm to 0.7 μm.
- It contains the Blue, Green, and Red portions of the electromagnetic spectrum.
- This portion of the spectrum is sensed by the human eye and most photographic films.
- Q: Active or passive sensor

Visible Light

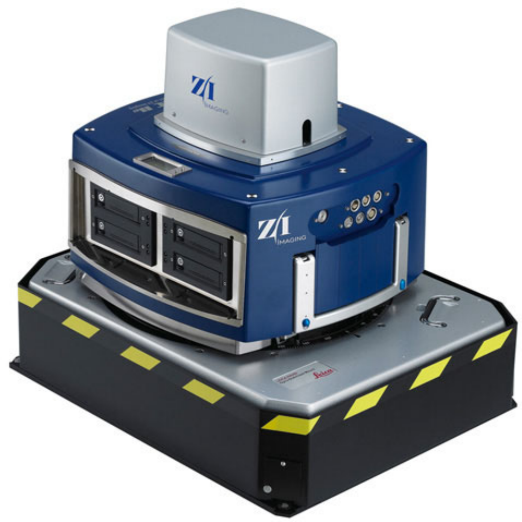


Visible Sensors

Sensors Operating in the Visible Band

RC 30

http://www.leica-geosystems.com



Z/I DMC IIe 250

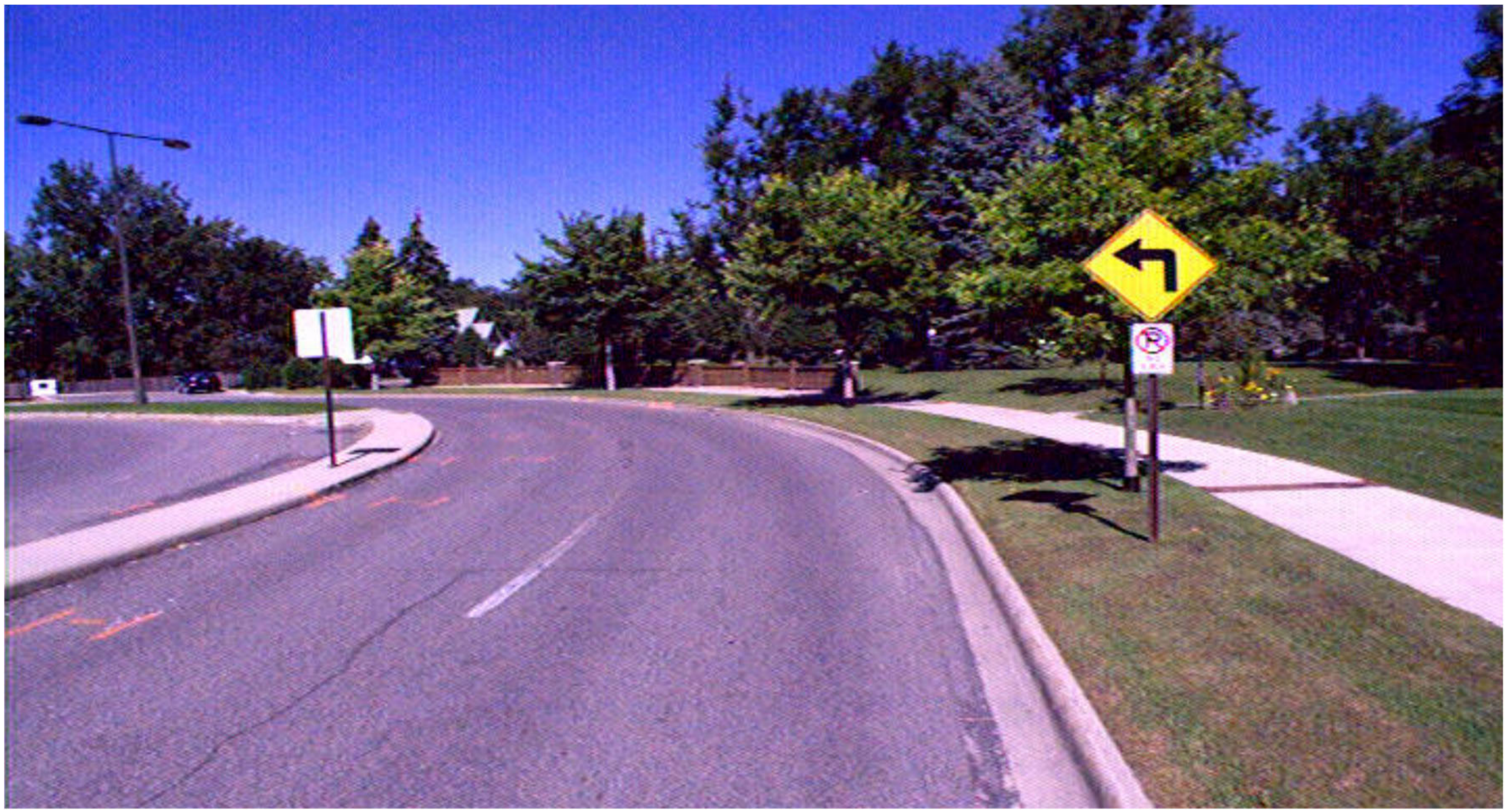
http://www.ziimaging.com

http://ptd.leica-geosystems.com

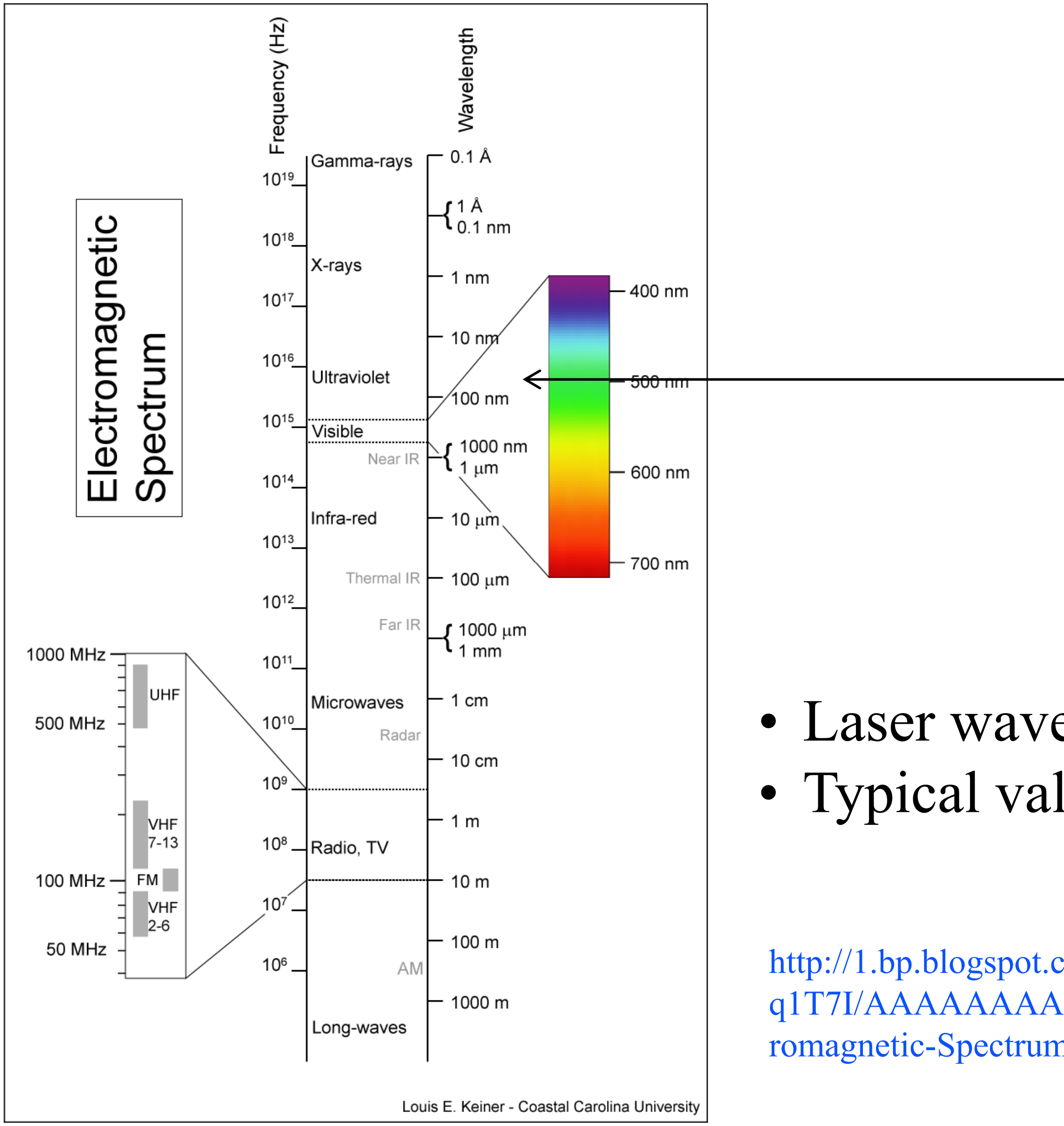
ADS 100

Black and White Image

Color Image



LiDAR



- Laser wavelength 500-1500 nm
- Typical values 1040 – 1060 nm

http://1.bp.blogspot.com/_nD_R3gXtq2Y/TENeUoq1T7I/AAAAAAAAAfs/8bgoq4l8D5c/s1600/Electromagnetic-Spectrum-3.png

LiDAR

http://www.optech.ca/prodaltm.htm

OPTECH ALTM 3100

LiDAR

Teledyne Optech ALTM Galaxy T1000

http://www.optech.ca/prodaltm.htm

LiDAR

Leica-Geosystems: ALS 40

http://www.albireo.in/data_acquisition/assets/lidar_cameras.html

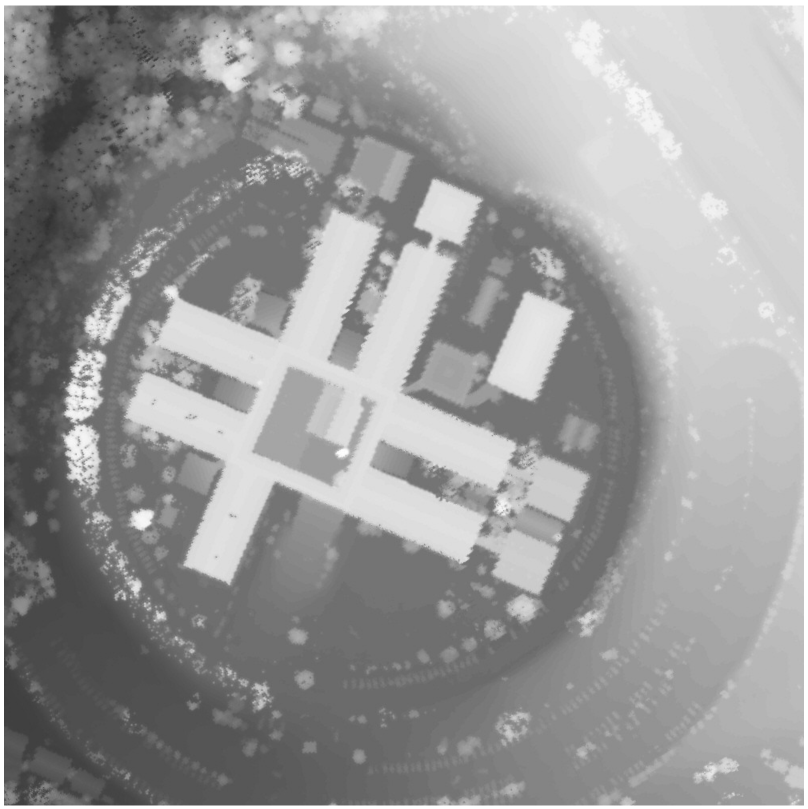
LiDAR

Leica-Geosystems: ALS 80

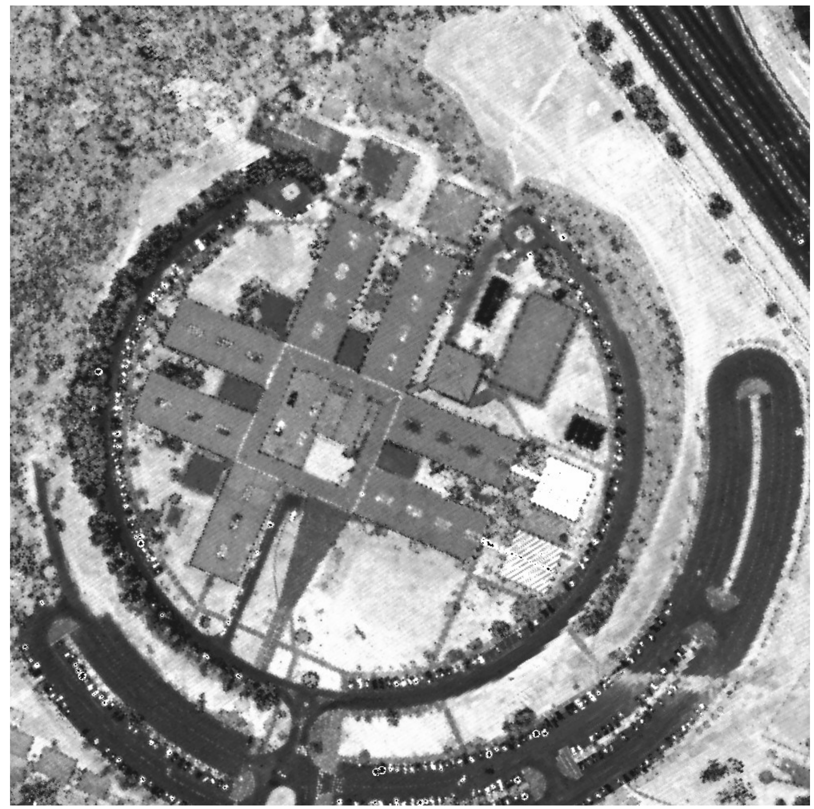
http://www.albireo.in/data_acquisition/assets/lidar_cameras.html

LiDAR

LiDAR: Range/Intensity Data

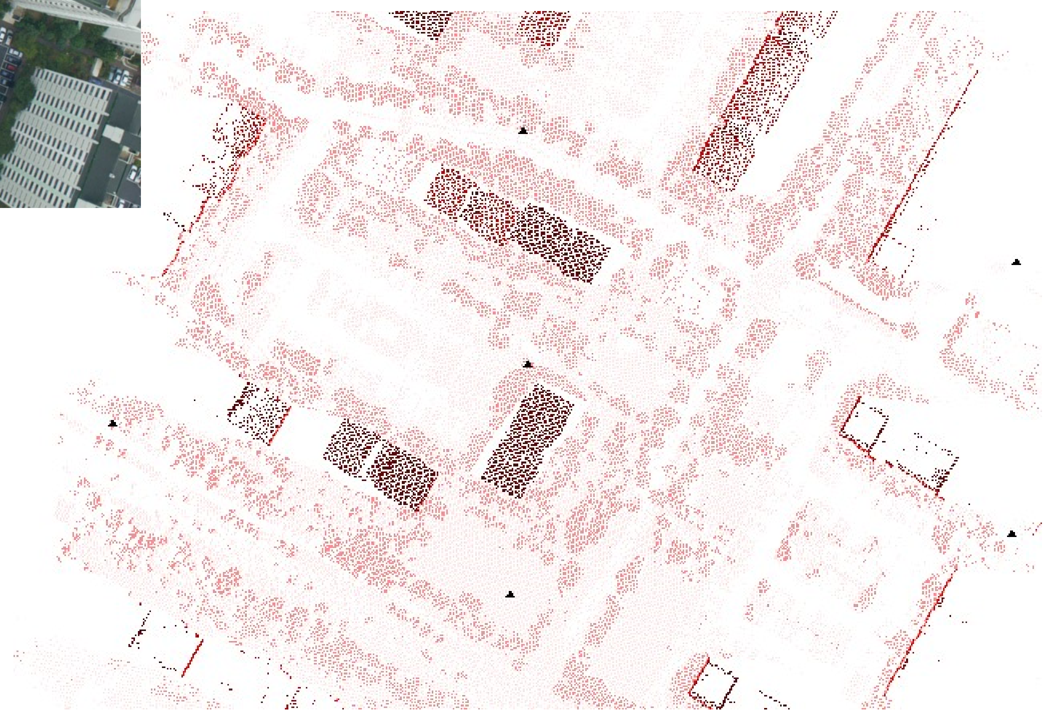


Range Image



Intensity Image

Visible & LiDAR Range Imagery



Visible & LiDAR Intensity Imagery

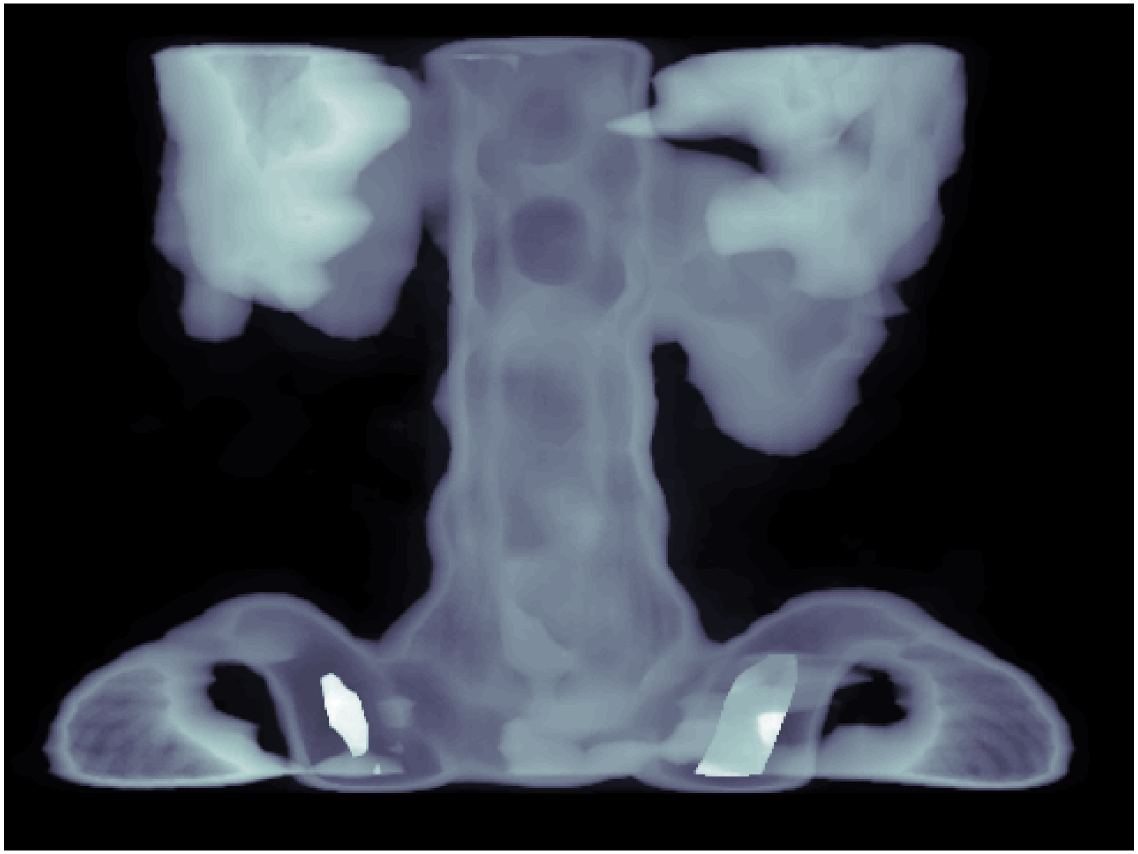
Ultraviolet

- It has a wavelength ranging from:
  - 0.01 μm to 0.4 μm.
- It is a portion of the sunlight that can burn the skin and cause skin cancer.
- This portion of the spectrum should be blocked by the ozone in the earth's upper atmosphere.
  - It is not used in satellite remote sensing.

X-Rays

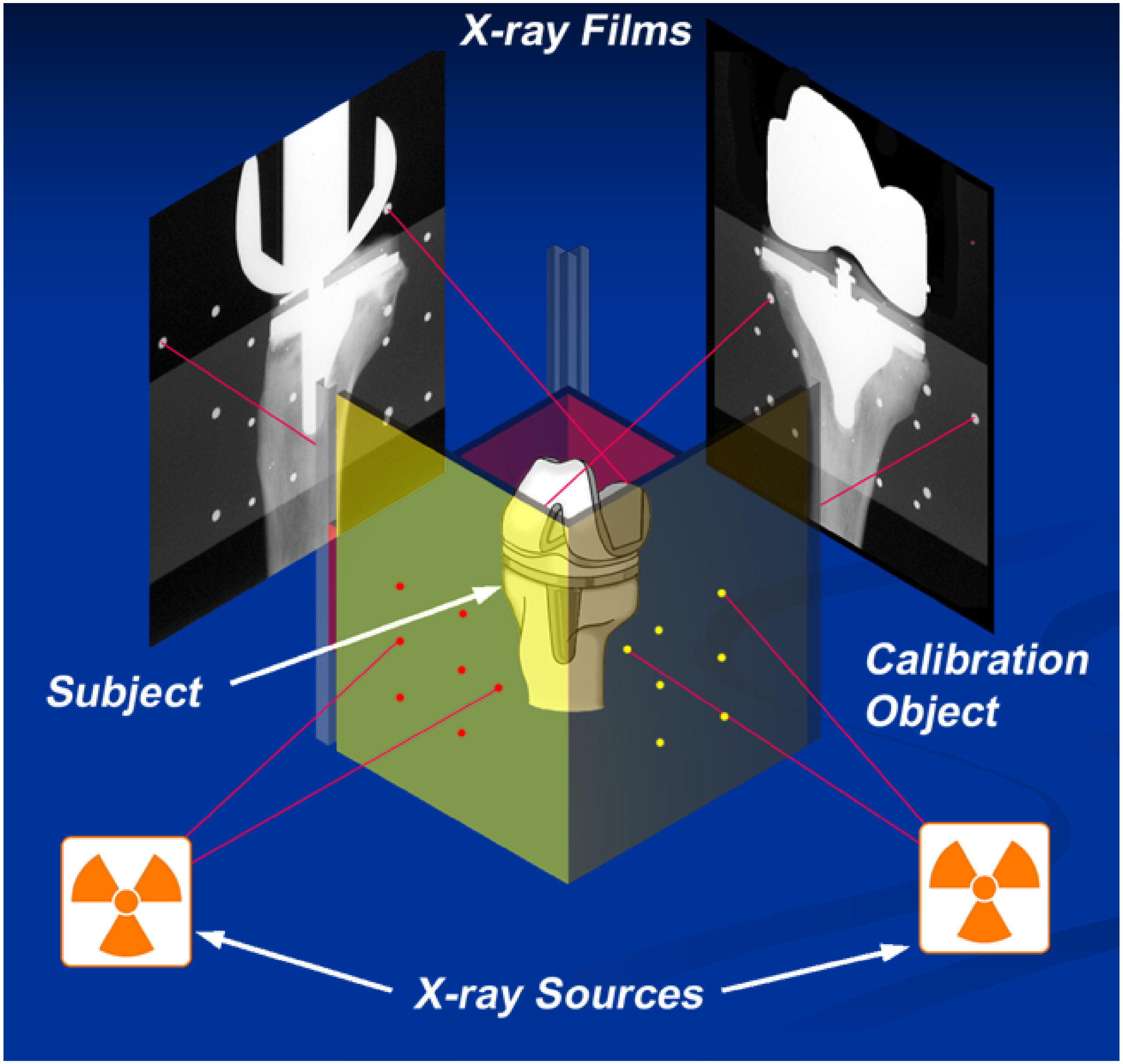
- Wavelength ranging from:
  - 0.01 μm to 10^{-5} μm.
- Short wavelength → High energy content → high penetration power
- Extensively used in medical applications

X-Rays



http://www.ieee-uffc.org/ultrasonics/software/MATLAB/Lecture6/Lecture6_4.htm

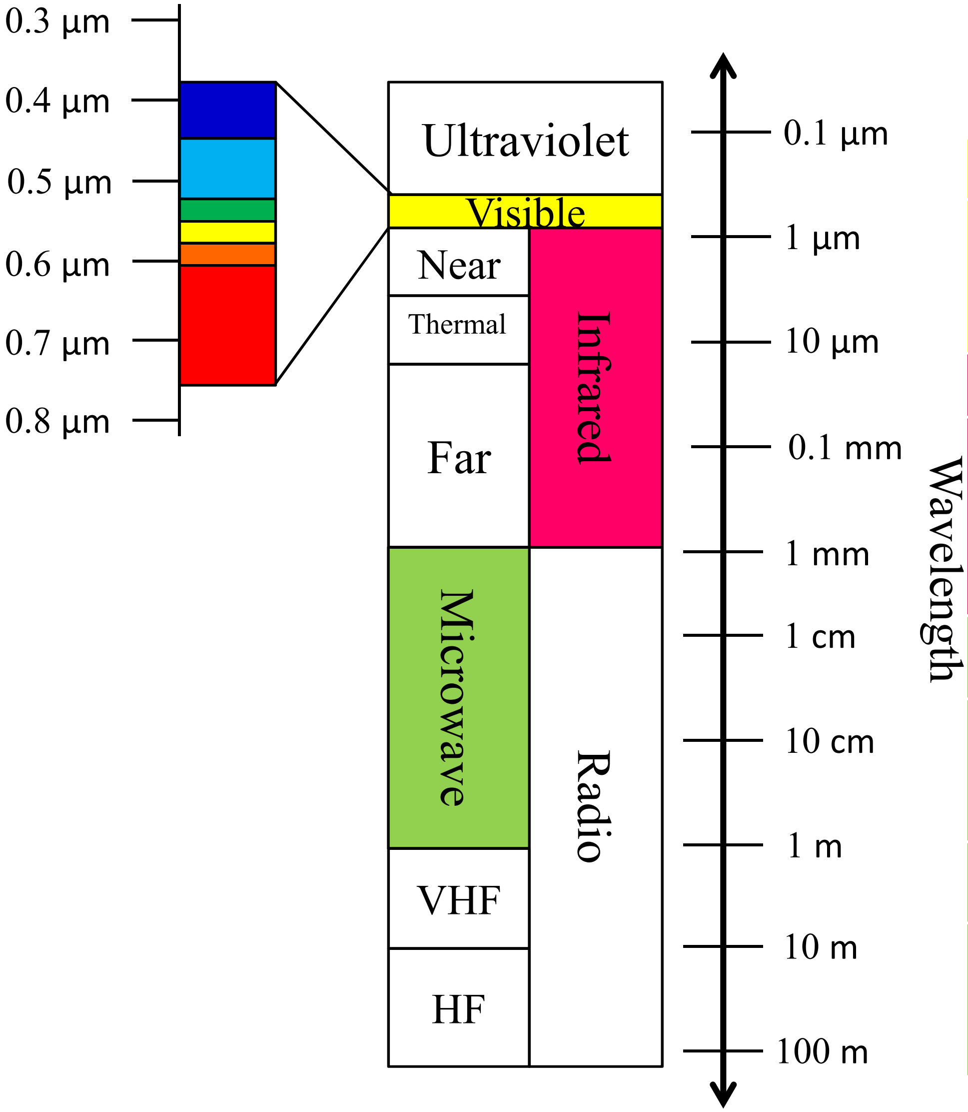
X-Rays: Stereo-Photogrammetric Analysis



Gamma Rays

- Wavelength of approximately $3 * 10^{-6}$ μm
- More penetrating power than X-Rays
- They are generated by radioactive atoms and nuclear explosions.
- Gamma rays from radio active material can be recorded by low-flying aircrafts.
- Due to atmospheric scattering and absorption, gamma rays cannot be detected by satellite sensors.
- They are in use in some medical applications.

EM Radiation Wavebands: Final Remarks



Advantages	Disadvantages
Visible	
• High resolution • Large atmospheric window	• Daytime only • Cloudless, clear atmosphere
Infrared	
• Day or night • Peak in Earth's emissions • Good resolution	• Cloudless, clear atmosphere • Solar interference
Microwave (passive)	
• Day or night • All weather	• Low resolution • Small signal
Microwave (Active)	
• Day or night • All weather • High resolution	• Power demand