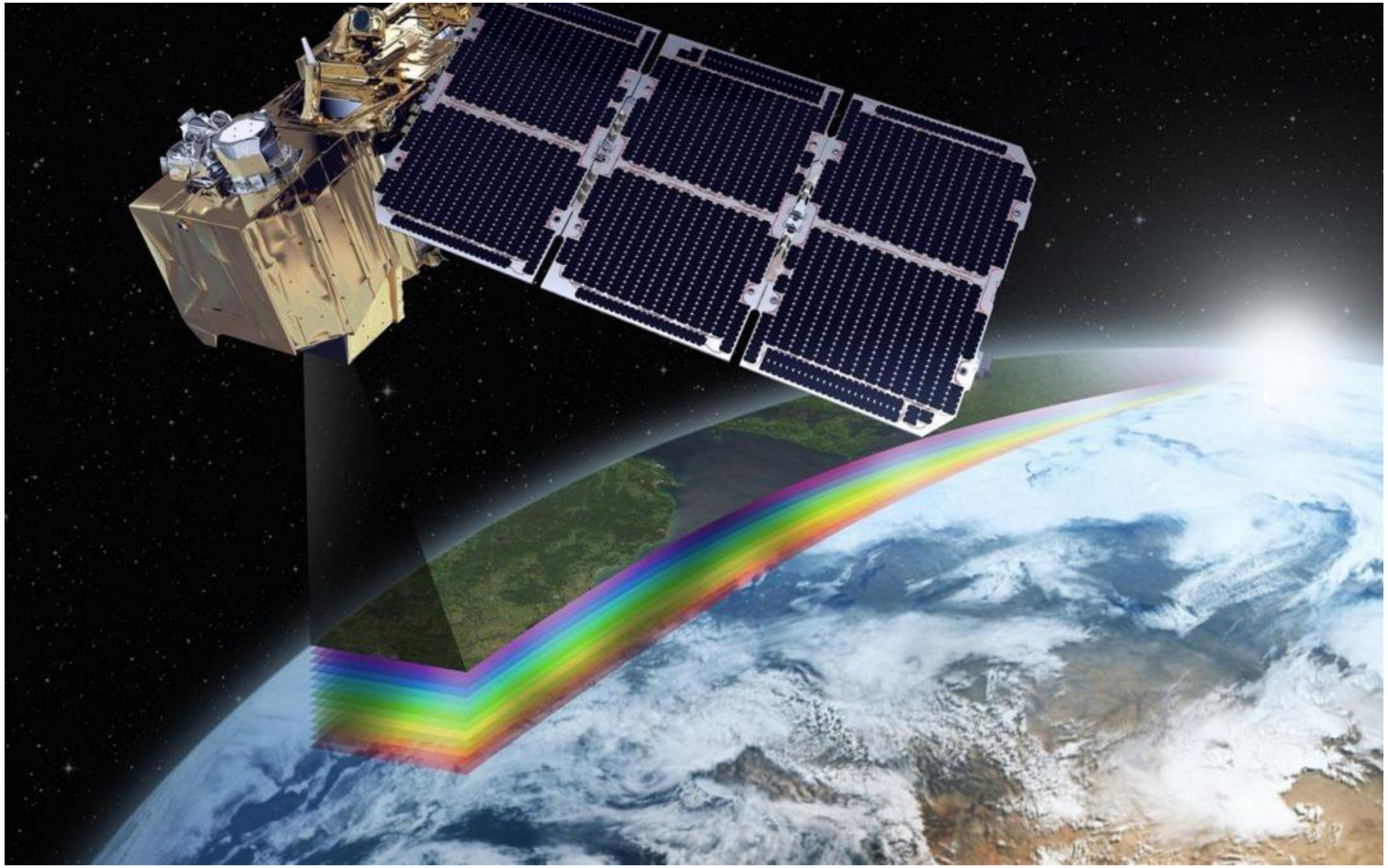


*Course:*

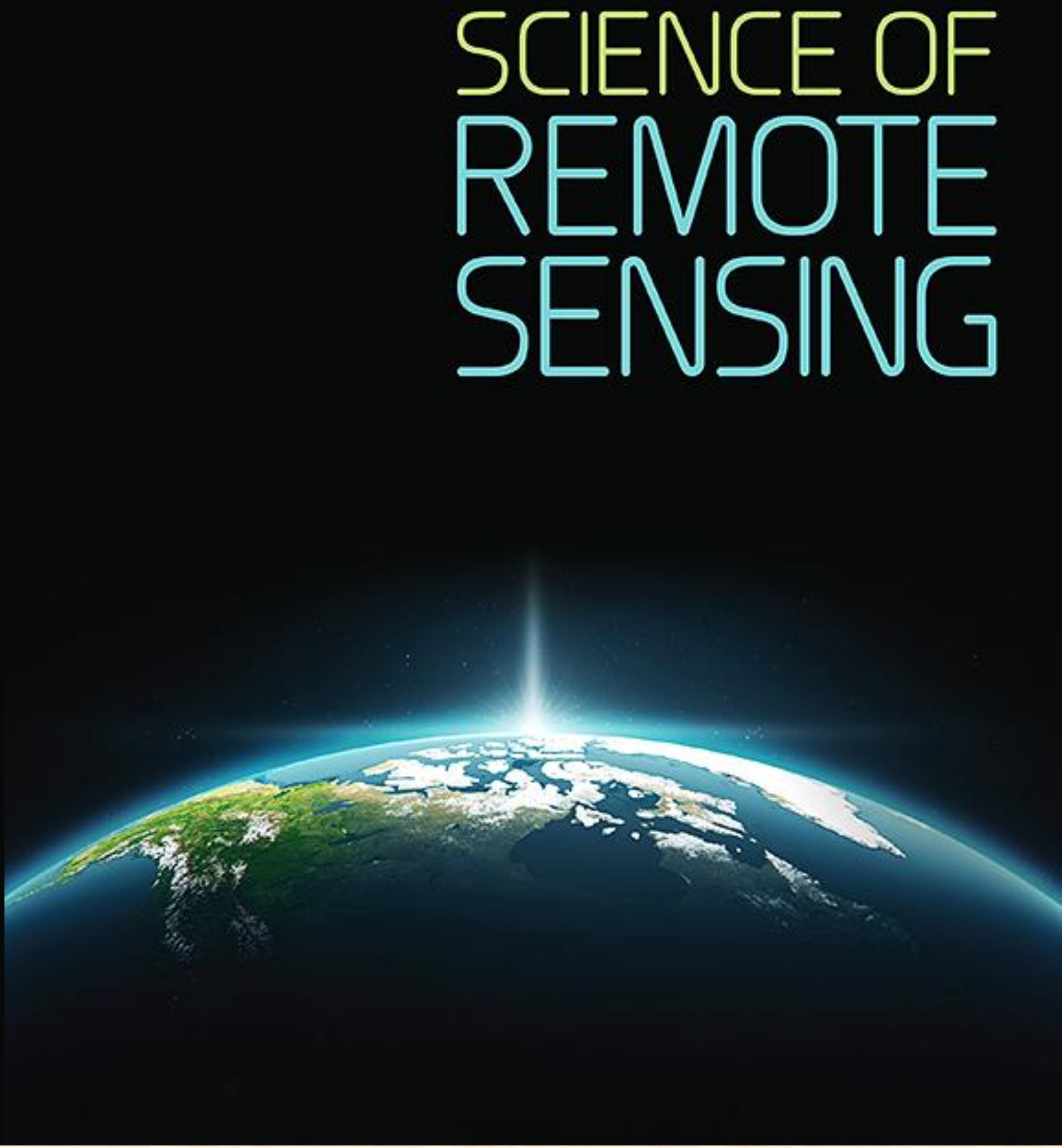
# Remote Sensing of Global Changes

Dr. Francesco Petruzzellis

PhD student Valentina Olmo

# Part 2

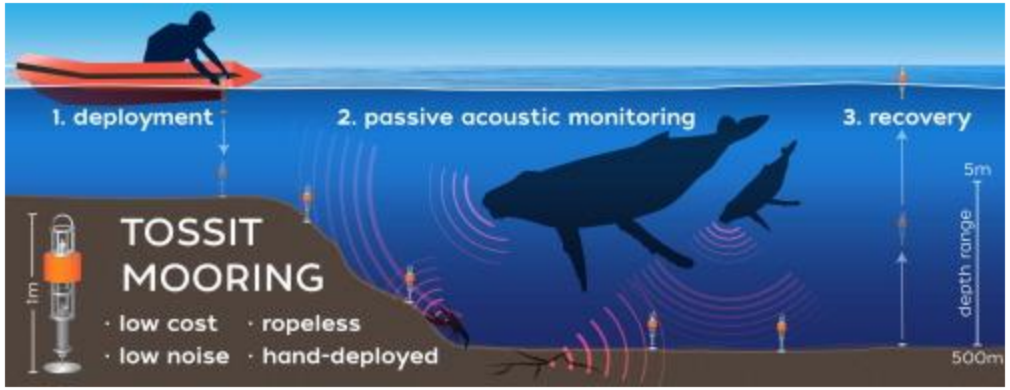
Physical principles of Remote Sensing

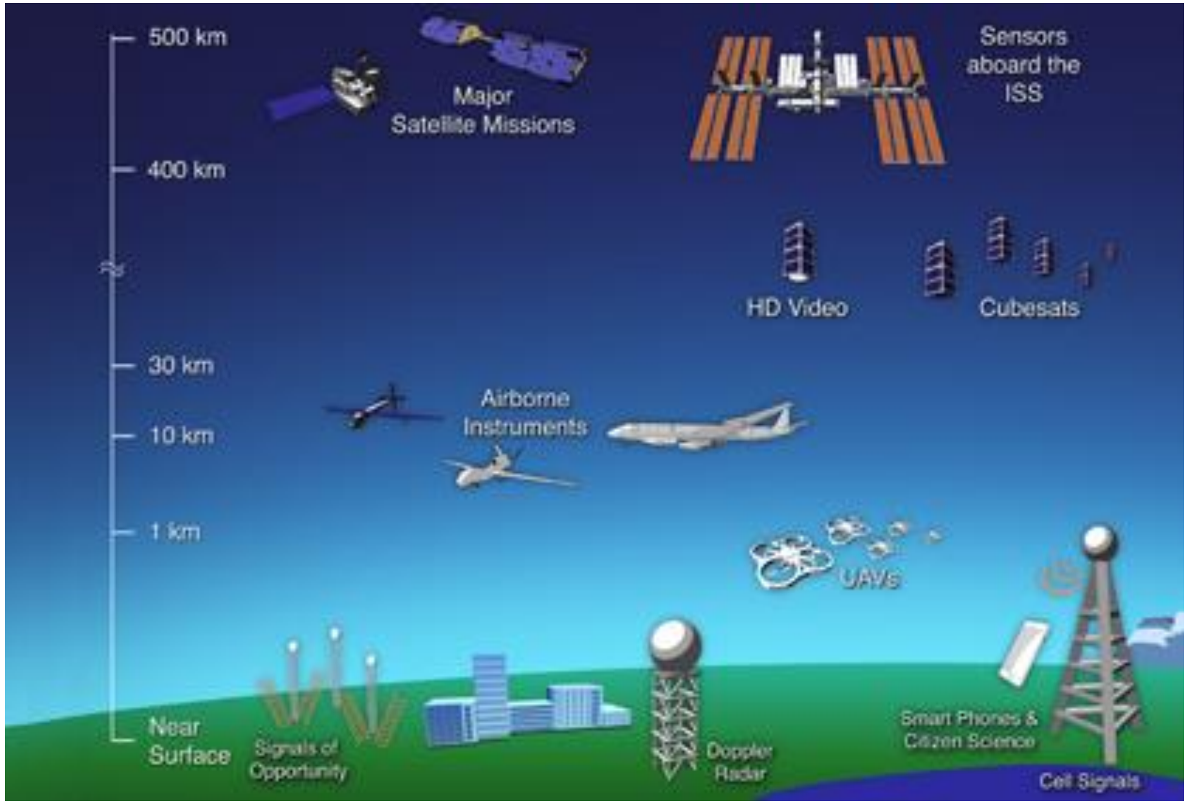


# Definition of Optical Remote Sensing


Broad definition:

RS is the process of **acquisition of information** about an object or a phenomenon **without making physical contact** with the object.

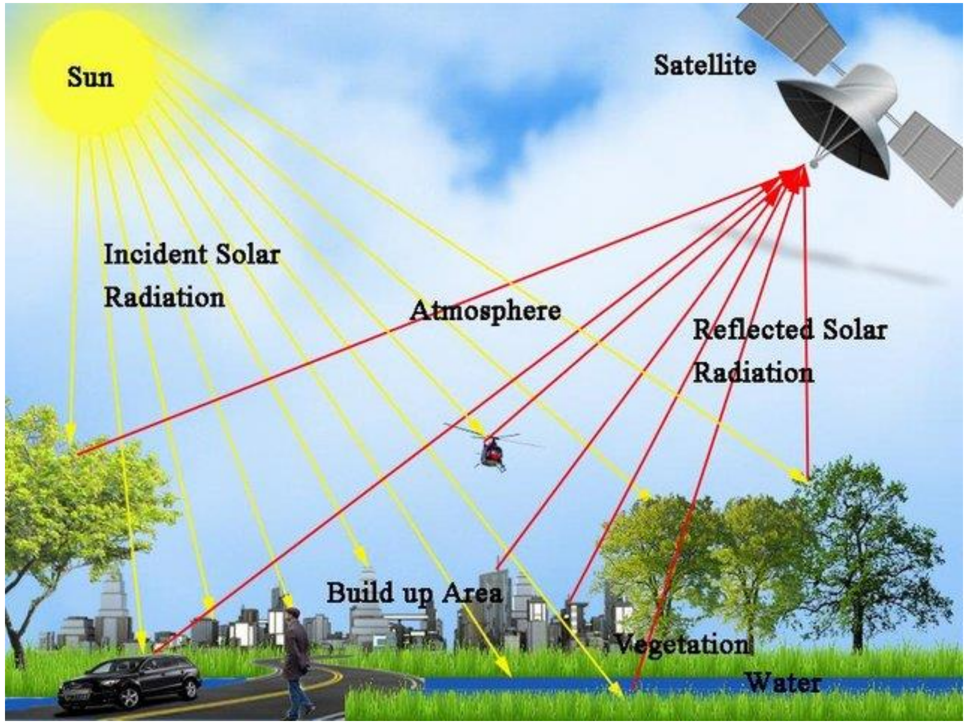


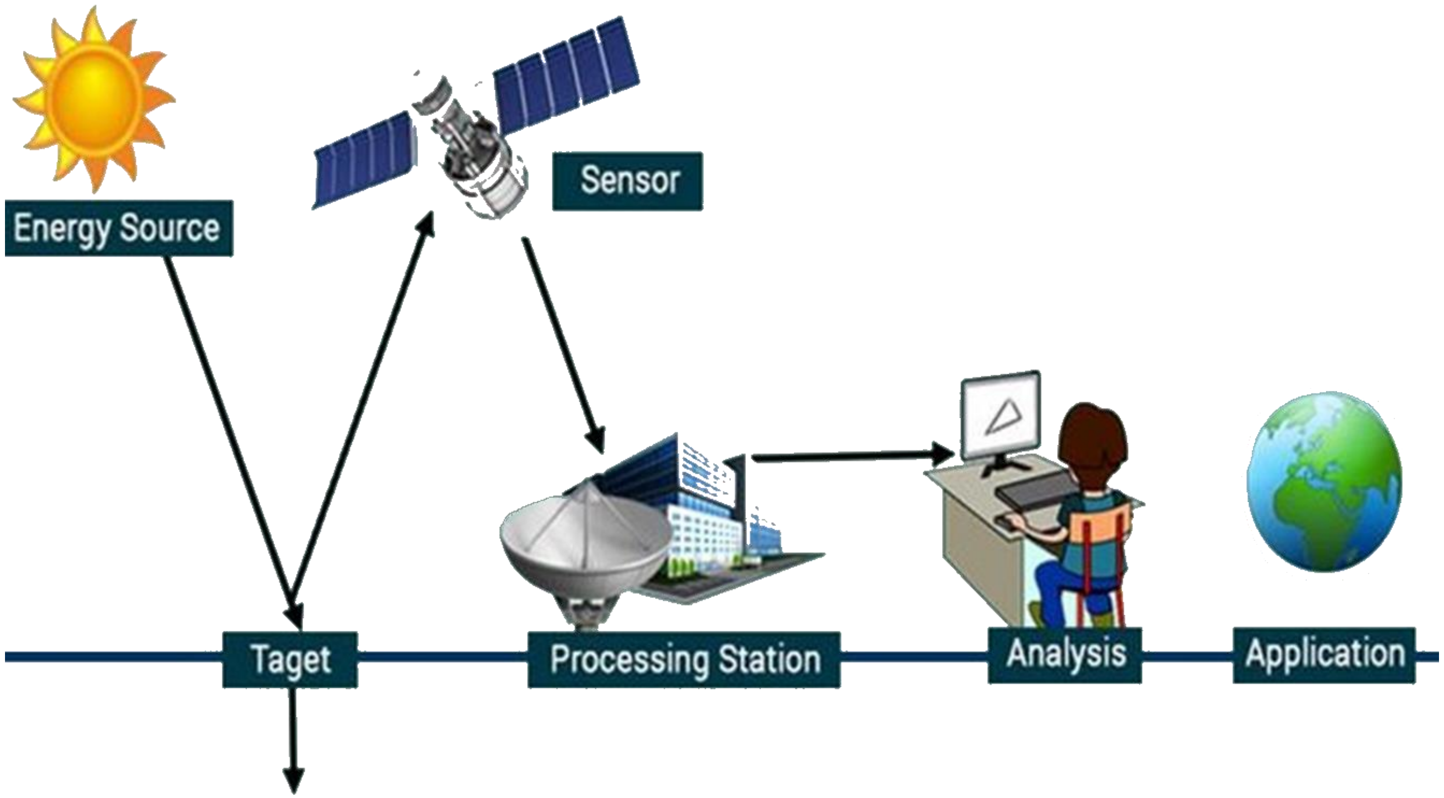
Definition of Optical Remote Sensing


Optical Remote Sensing :

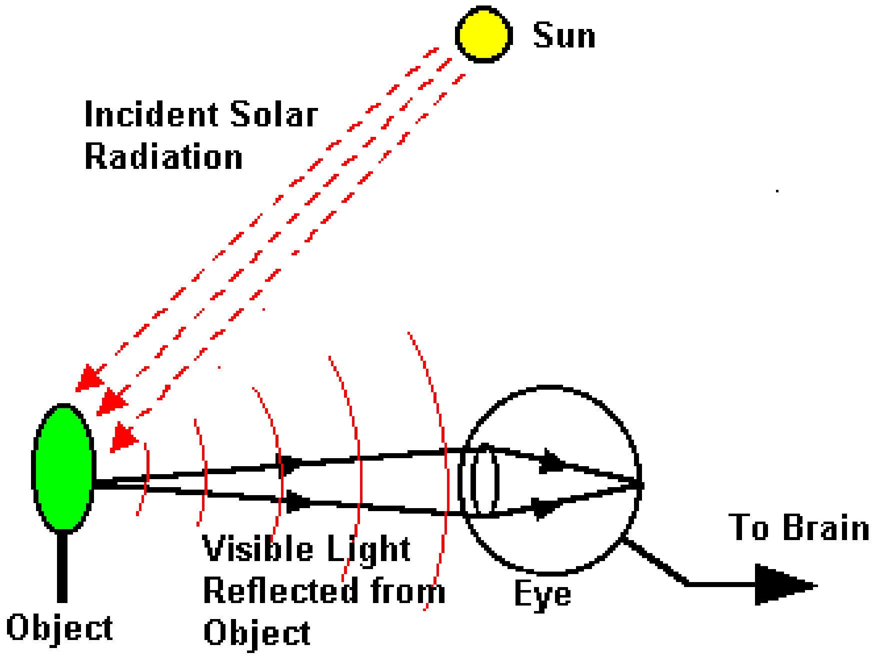
It is the process of **detecting and monitoring** the **physical characteristics of an area** by measuring its **reflected and emitted radiation** at a distance.



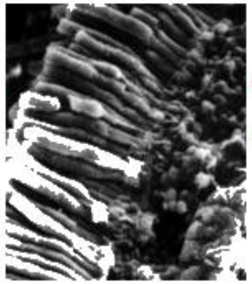
# Components of Optical Remote Sensing systems

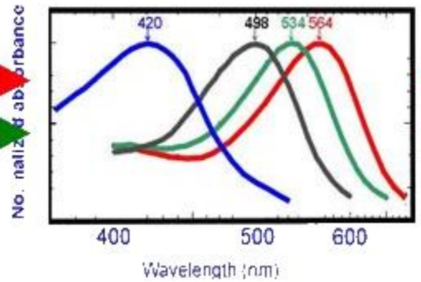


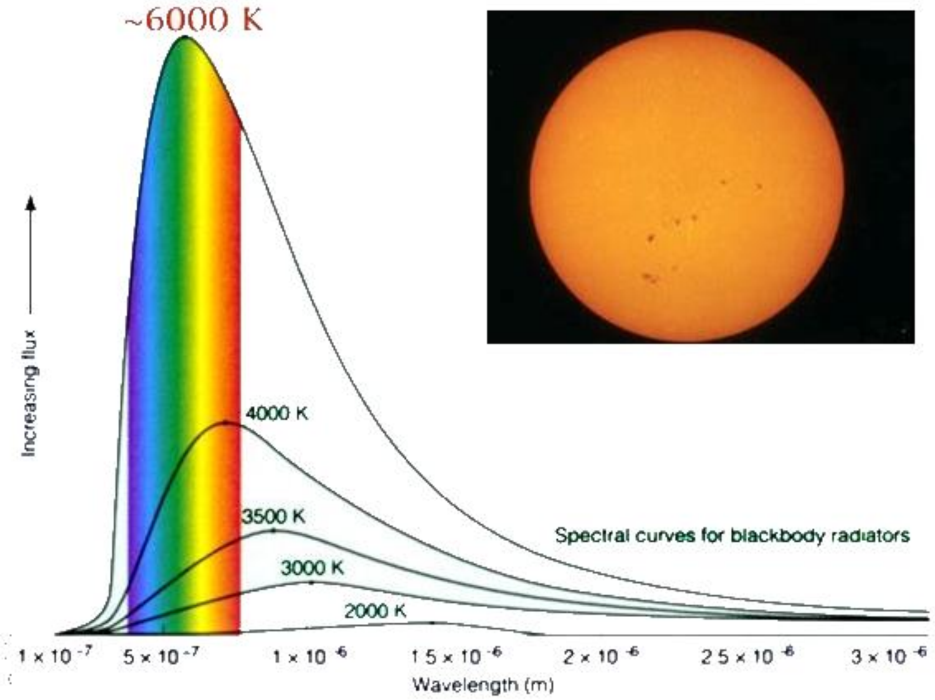

1. **Energy source**: produces the electromagnetic radiation (EMr)
2. **Target: Earth's surface**. It receives EMr and REFLECT or EMIT part of the energy toward a sensor
3. **Sensor and Platform**: instrument measuring and recording the energy incoming from Earth's surface
4. **Ground receiving system**: collect raw digital data
5. **Analyst**
6. **User community**

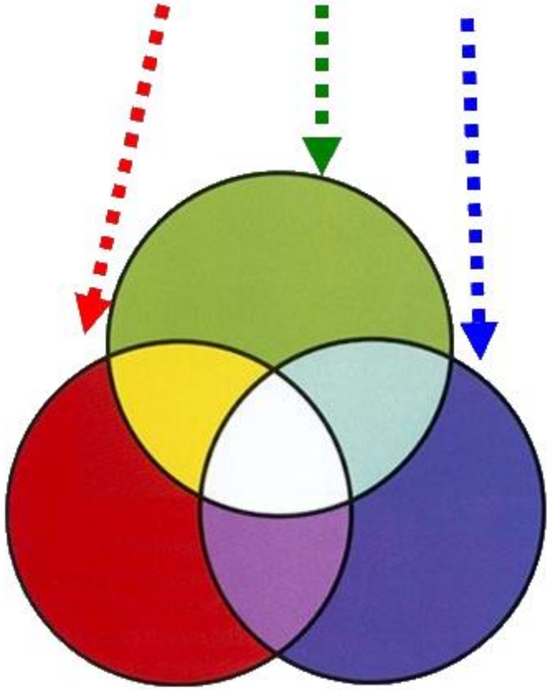




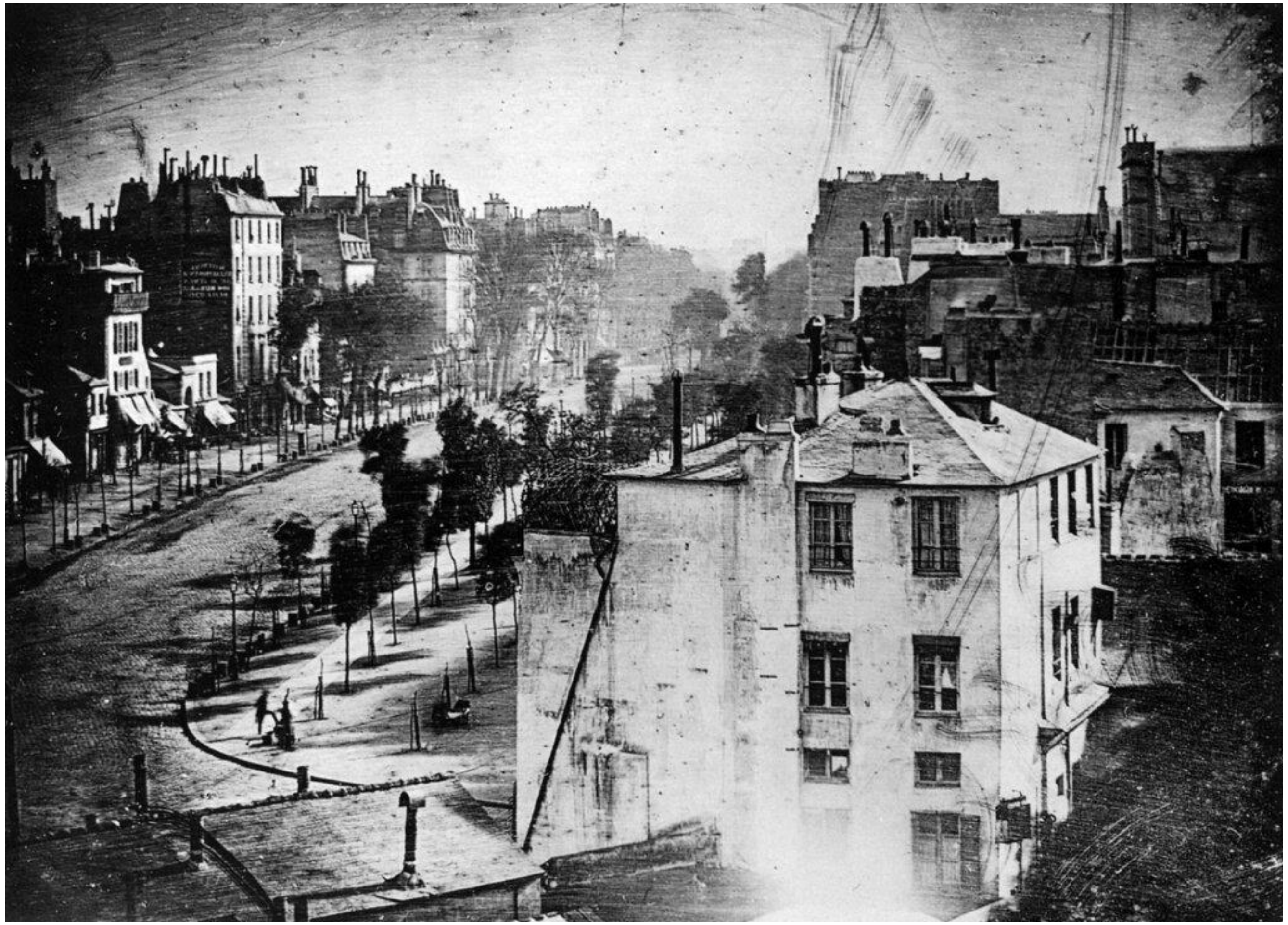




1. Energy source?
2. Target?
3. Sensor?
4. Receiving system?
5. Analyst?
6. User?

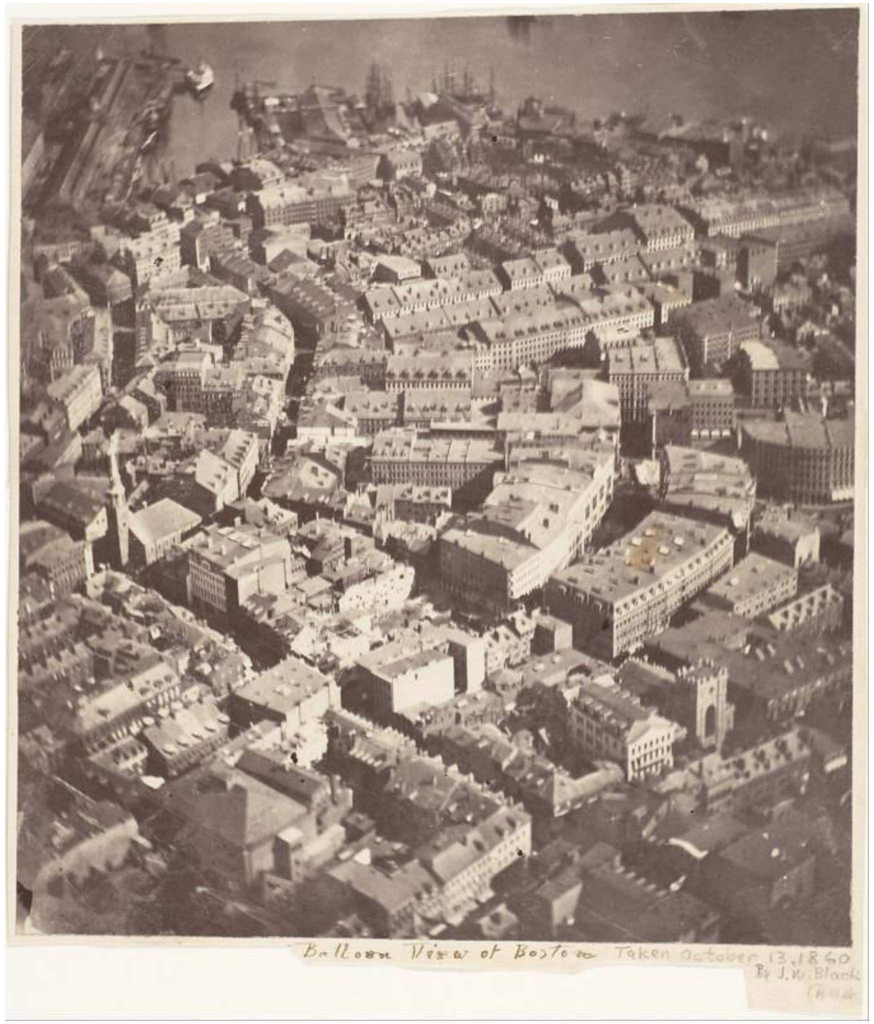


1838: Paris, Boulevard du Temple

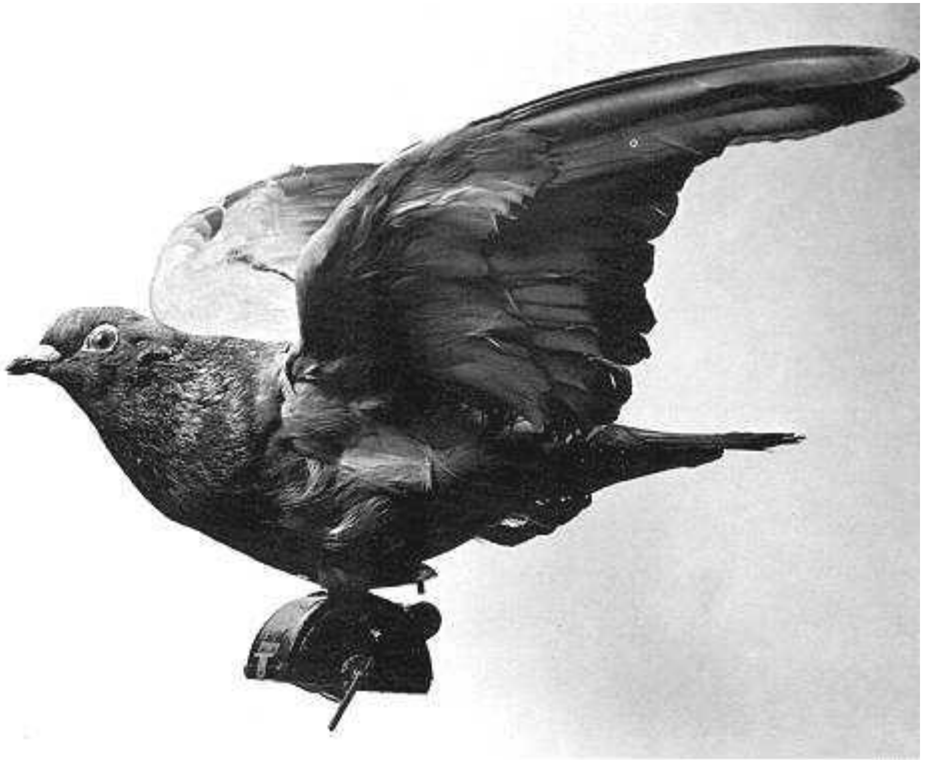
This is one the first picture of the history: a daguerreotype.

- a daguerreotypist polished a sheet of silver-plated copper to a mirror finish; treated it with fumes that made its surface light-sensitive;
- exposed it in a camera for as long as was judged to be necessary;
- made the resulting latent image on it visible by fuming it with mercury vapor;
- removed its sensitivity to light by liquid chemical treatment; rinsed and dried it;
- sealed the easily marred result behind glass in a protective enclosure.

From pigeons to satellites…

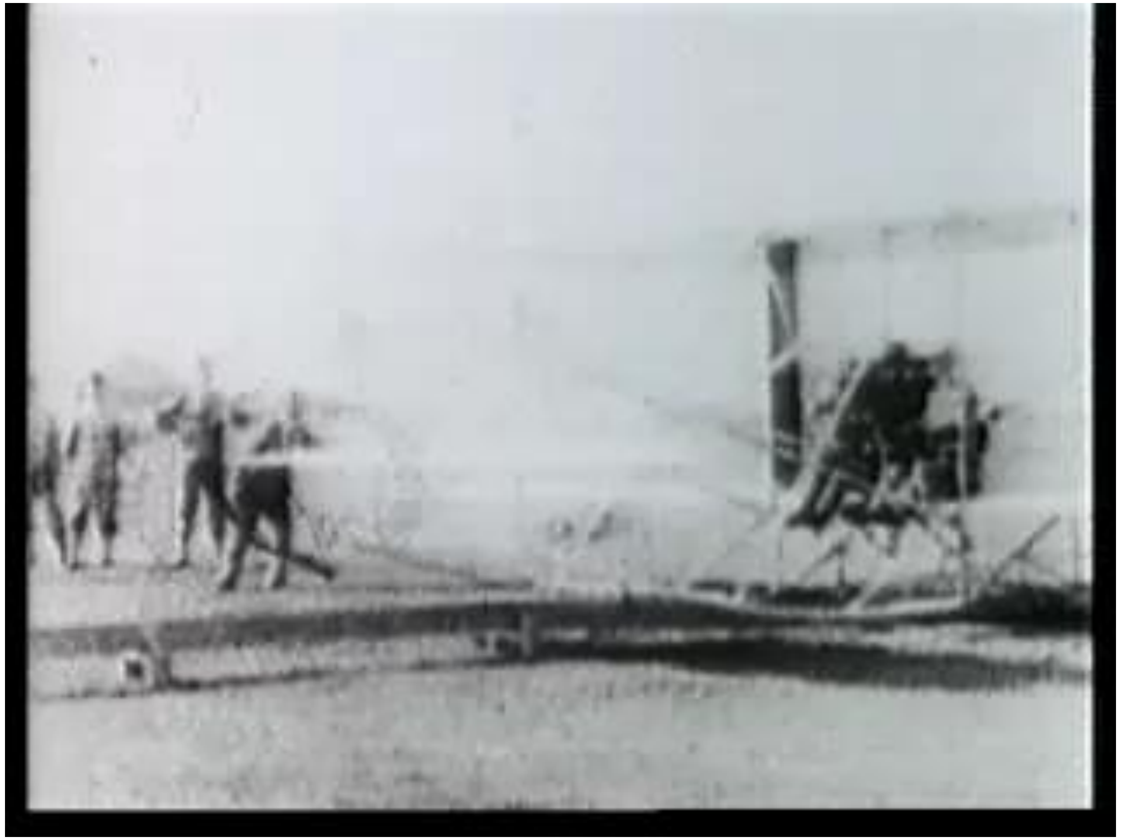



First aerial photo in 1858 using cameras mounted on an AIR BALOON



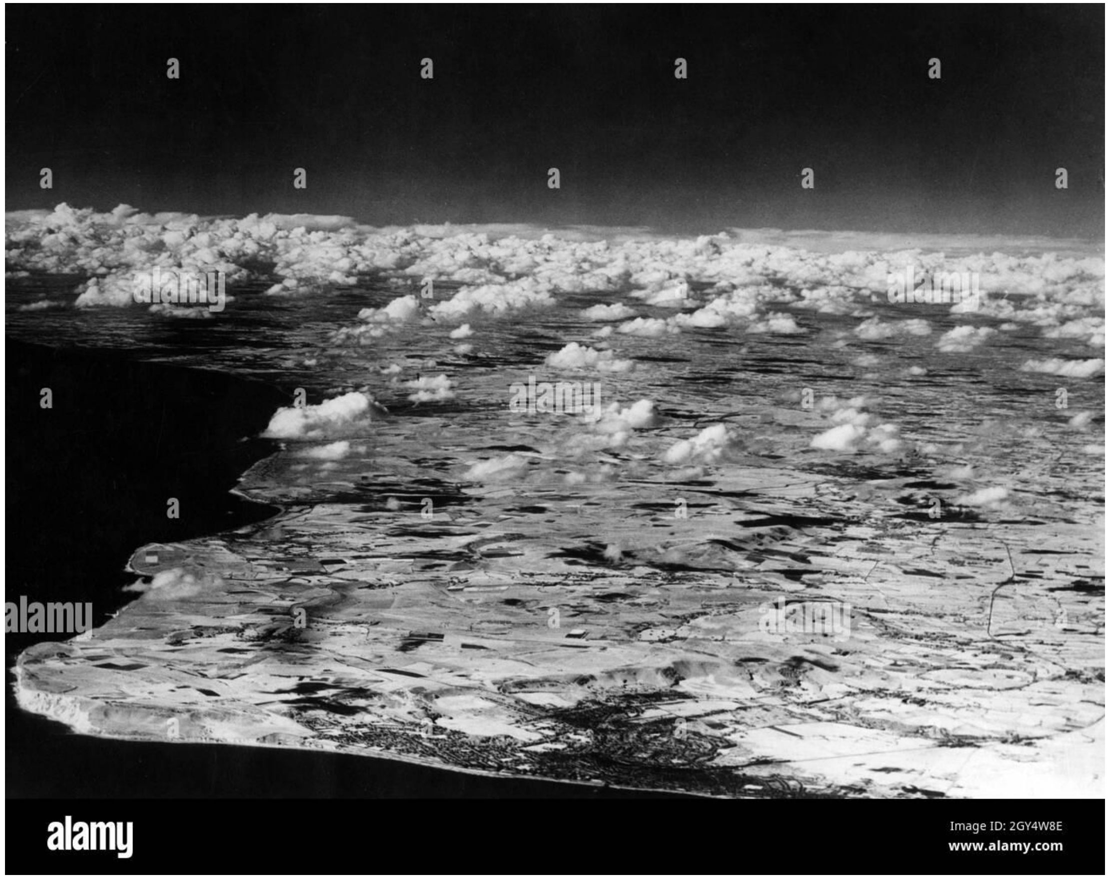
Early 1900s, pigeons with very small and light cameras

From pigeons to satellites…



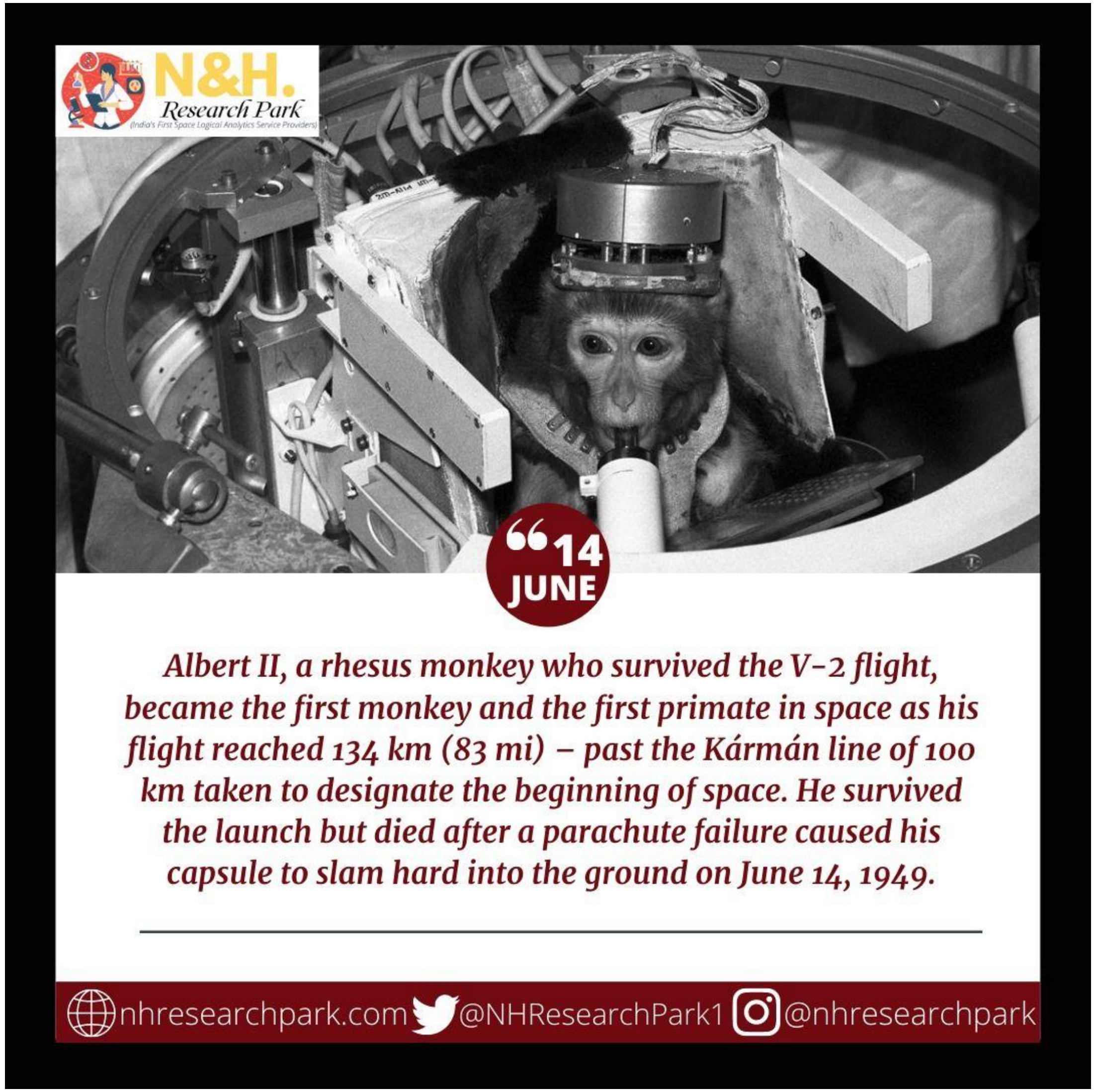
1909, Wilbur Wright took a a photograph from an airplane over Italy.

A new era for observation from airborne platforms.




In 1940, military made a significant advancements in using infrared films, used to distinguish between real vegetation and camouflaged targets.

# From pigeons to satellites…




First space based photo (7th March 1947), 200 km above New Mexico (German V-2 rocket).

# From pigeons to satellites…

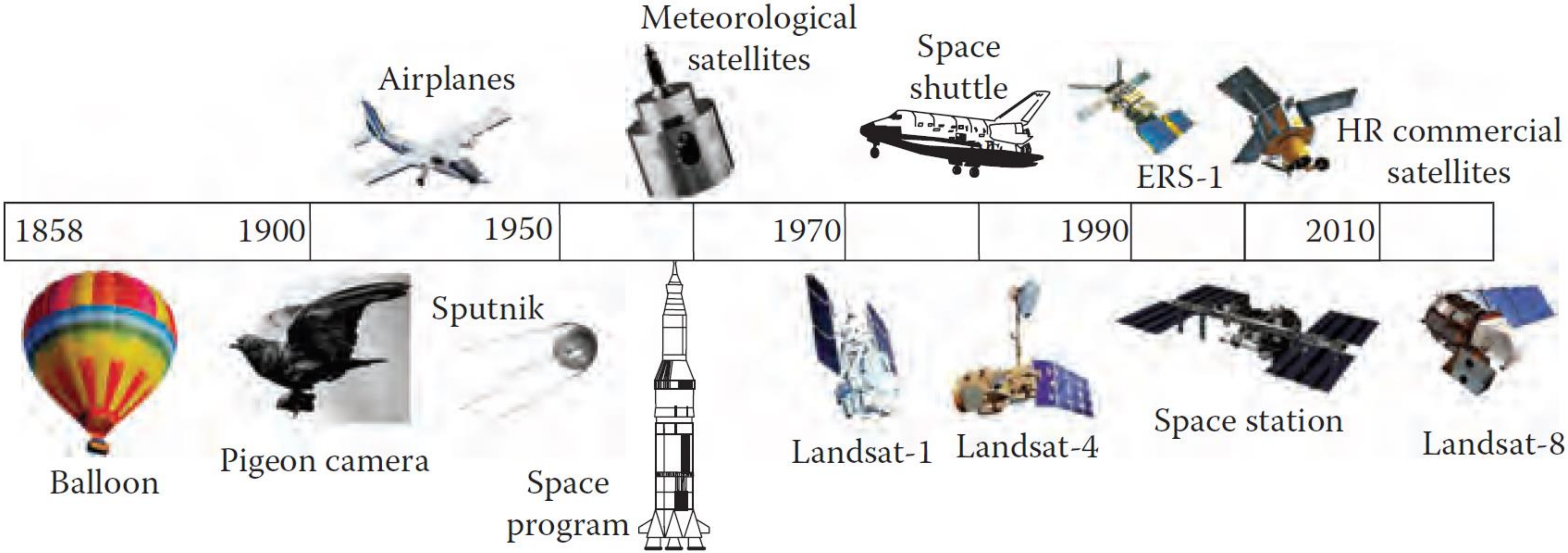
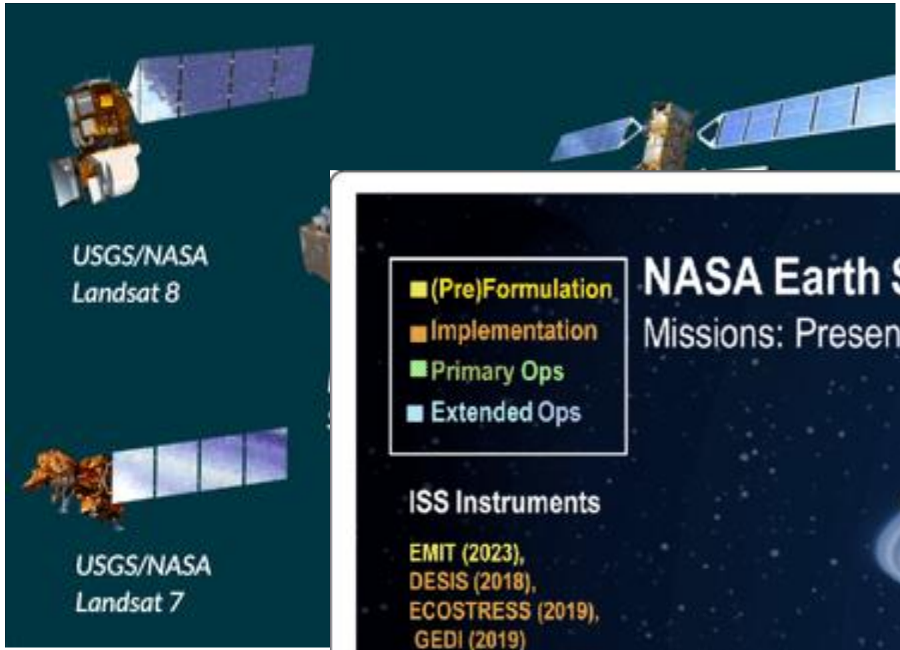
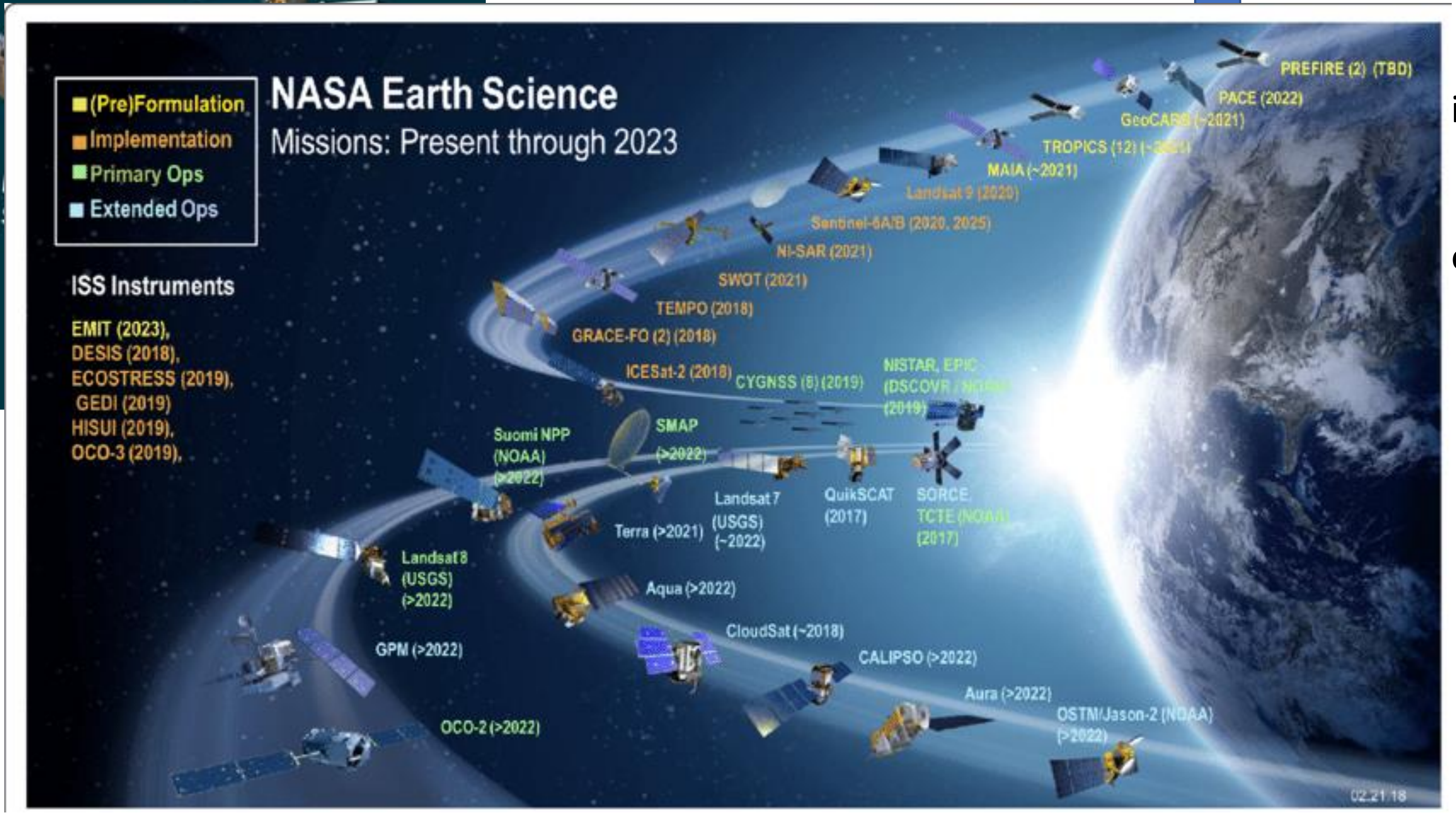



**FIGURE 1.2** Historical development of remote sensing systems.

From pigeons to satellites…




Rapid technological development

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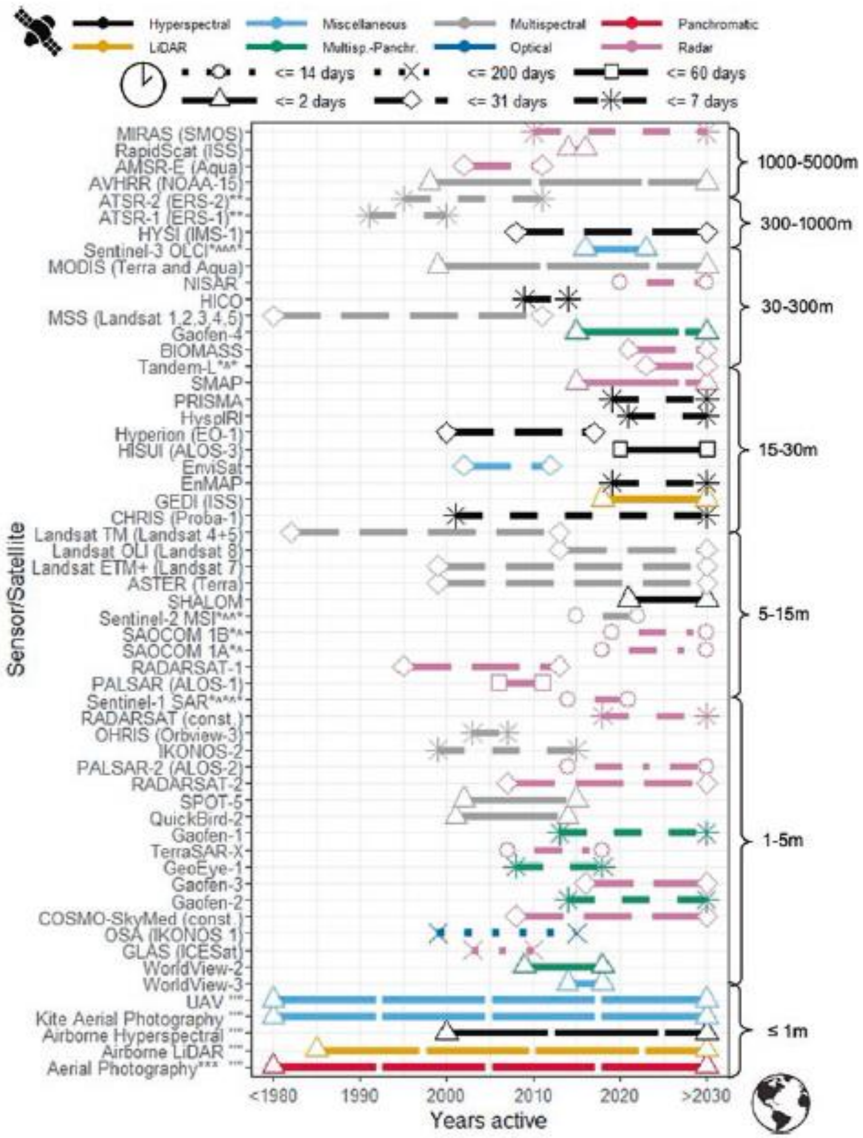
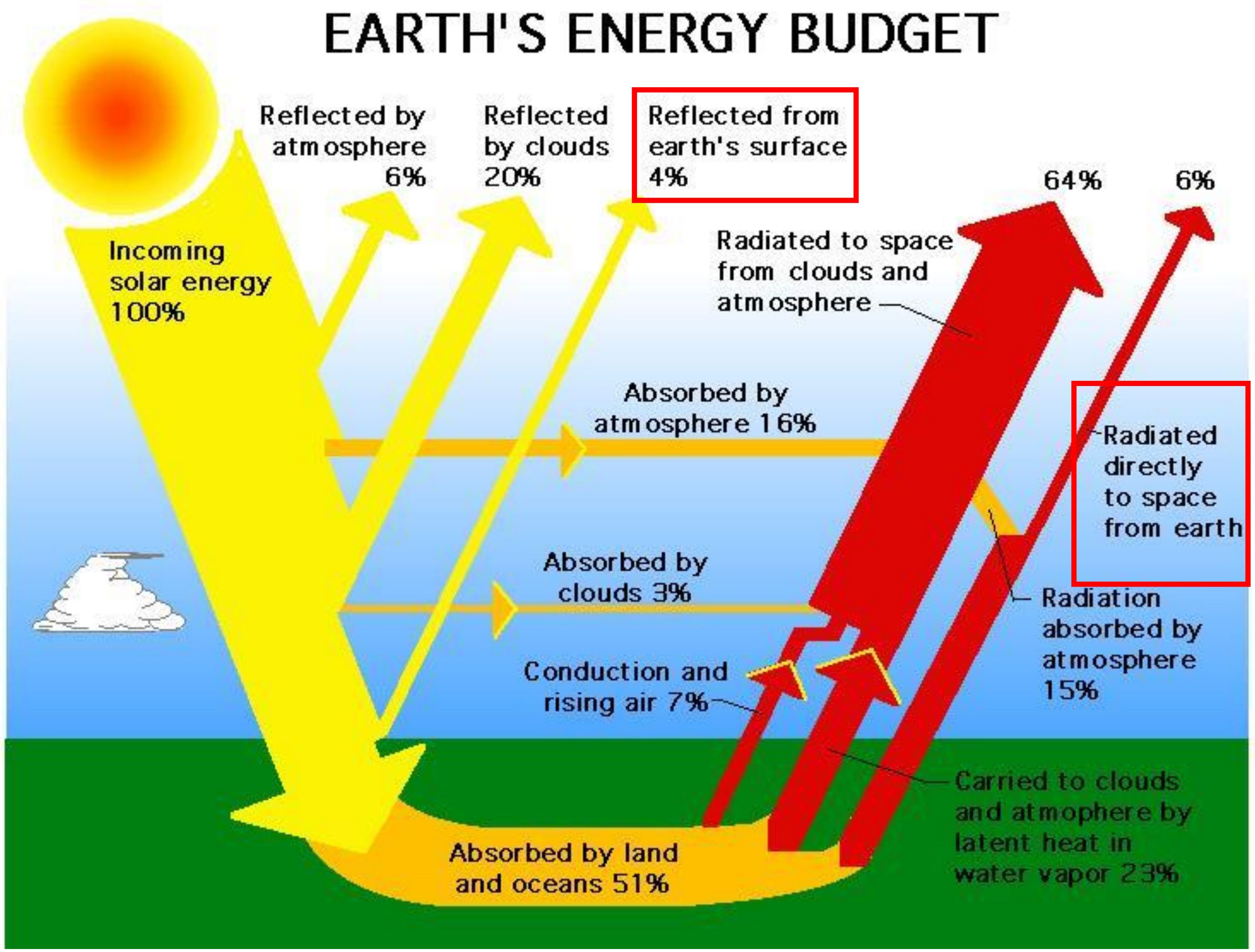
ely sensed data are

Advantages of satellite remote sensing




1. Global view
2. Multiscale observations
3. Observation from non-visible electromagnetic spectrum
4. Repeated information
5. Immediate transmission
6. Digital format
7. Data are free (not all satellite missions)

# PHYSICAL PRINCIPLES OF REMOTE SENSING




Part of the **energy directed toward** the Earth is **reflected/remitted** from Earth's surface towards the space

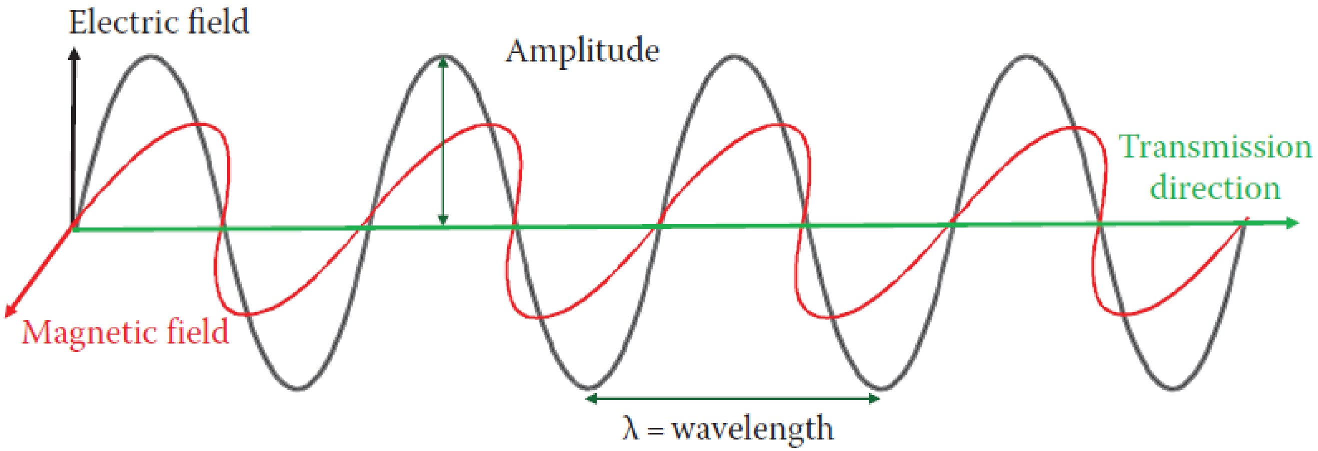
This energy have specific characteristics depending of the object monitored.

These characteristics depend on the properties of the **Electromagnetic radiation**

# Electromagnetic radiation properties (wave theory)

EM radiation properties can be explained by the two theories of light:

1. **Wave theory**: radiation is a form of energy derived from oscillating **magnetic and electrostatic fields that are orthogonal** to each other and to the direction of propagation




EM energy is transmitted following an harmonic and continuous model with a constant velocity:

$c = 3 \cdot 10^8$ m $s^{-1}$

C is the speed of light

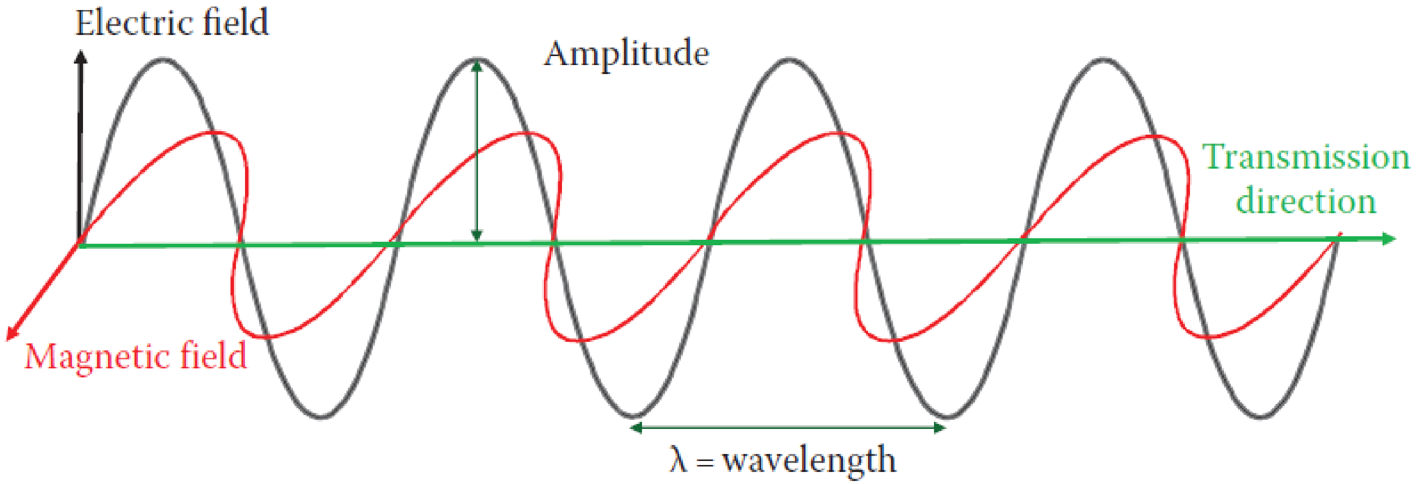
The EM radiation properties can be described according to:

- **Wavelength = λ**
- **Frequency = ν**

$$c = \lambda \cdot \nu$$

**λ** = the distance between two successive peaks (μm or nm)

**ν** = number of cycles that pass over a fixed point per unit time (Hertz, Hz, cycles $s^{-1}$)



EM radiation properties can be explained by the two theories of light:

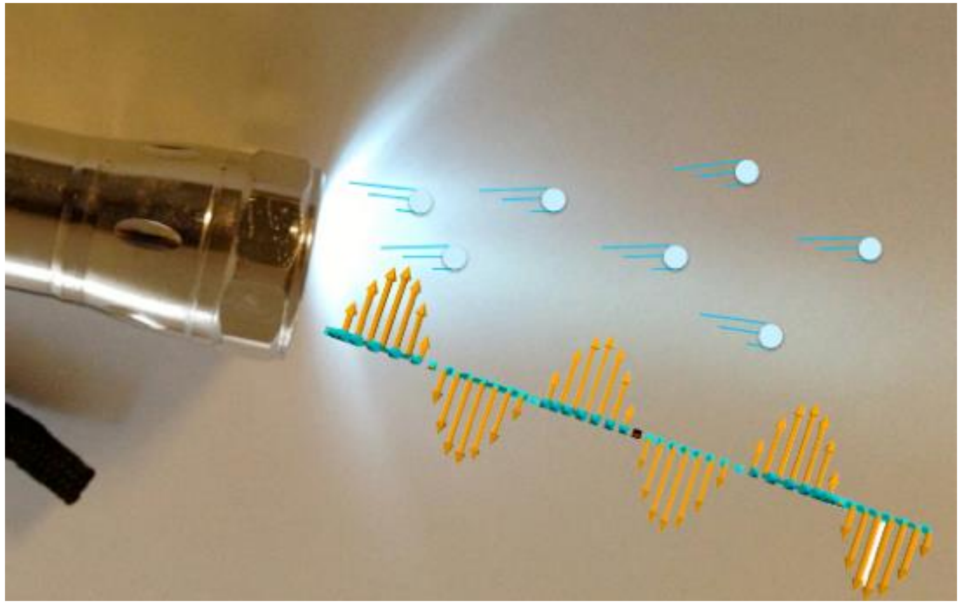
**2. Quantum theory**: radiation is a succession of discrete packets of energy ( = photons or quanta) with mass equal to zero.

The amount of energy transported by a photon:

$$Q = h \cdot \nu$$

Where
Q = radiant energy of a photon (in Joule, J)
h = Planck constant ($6.626 \cdot 10^{-34}$ J s)
ν = frequency

# Electromagnetic radiation properties

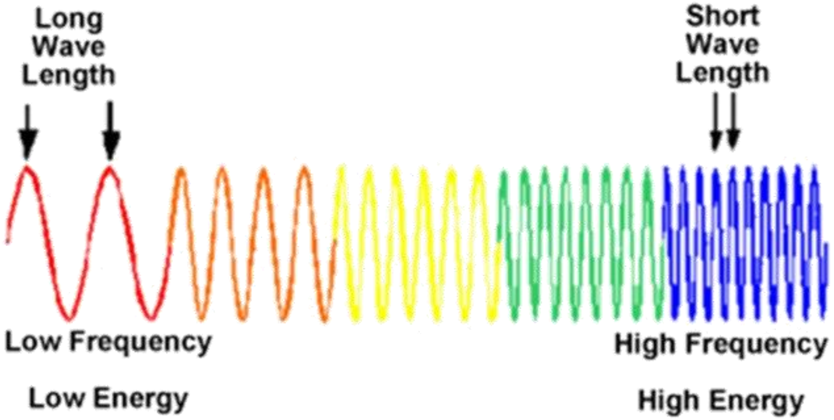


Combining wave and quantum theory:

$$Q = h\left(\frac{c}{\lambda}\right)$$

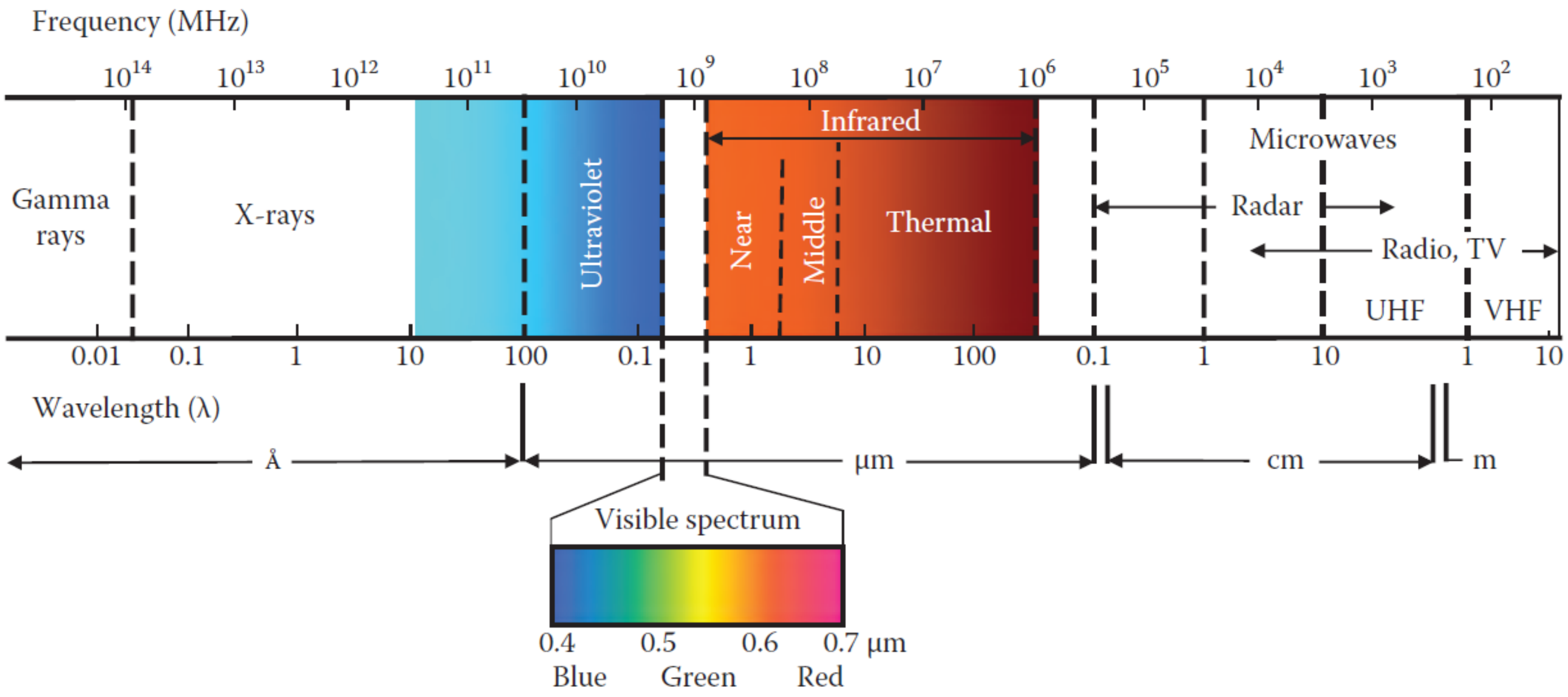
The greater the wavelength is, the lower the energy is

Which wavelength is more difficoult to detect?

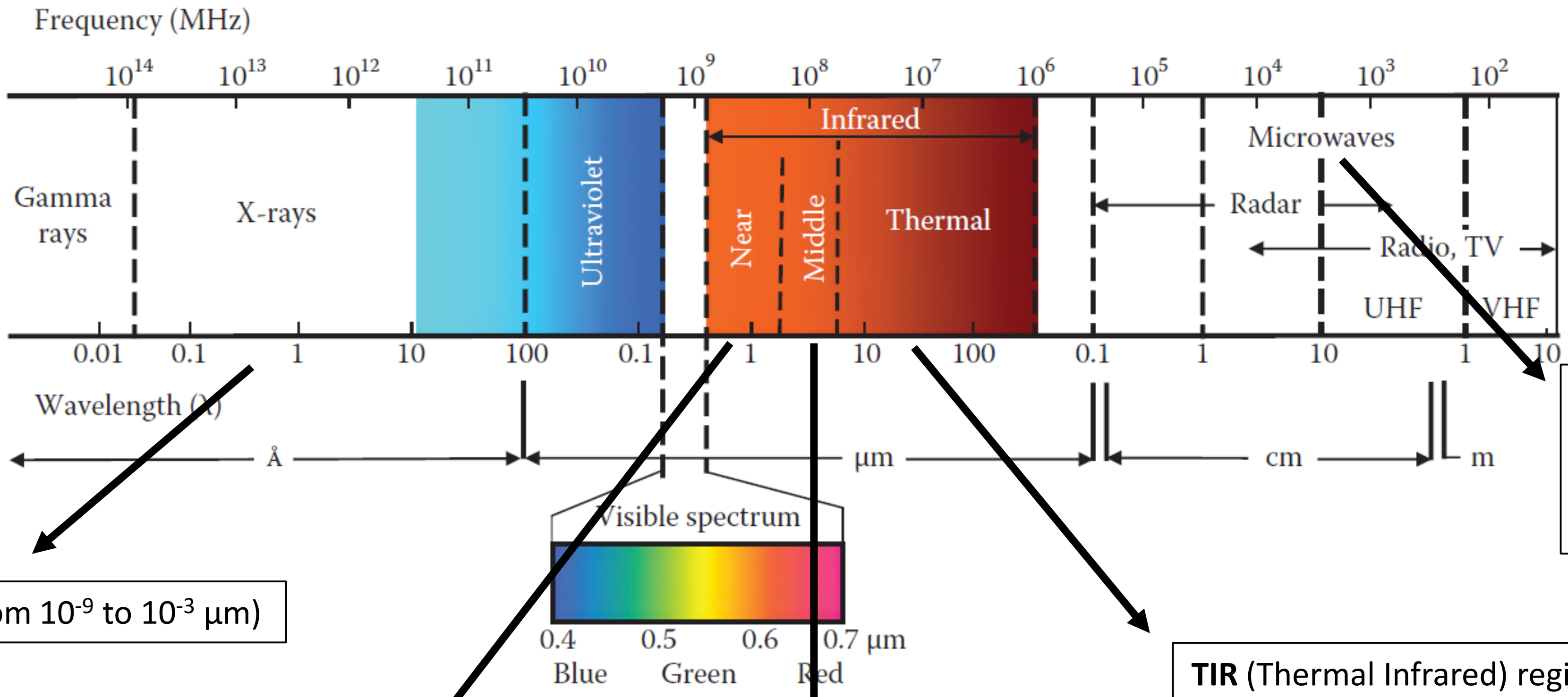


# Electromagnetic spectrum

EM radiation is classified in groups of wavelengths = Electromagnetic Spectrum (EM spectrum)



# Electromagnetic spectrum




**Gamma and x-rays** (from $10^{-9}$ to $10^{-3}$ μm)

**NIR** (Near Infrared) region (0.7 to 1.2 μm) is used to derive information of plant health status

**MIR** (Middle Infrared) region (1.2 to 8 μm): It comprehends **SWIR** (short wave infrared, 1.2 to 2.5 μm) region which is relevant to detect soil and vegetation moisture content

From 3 to 8 μm the signal is a mixture of solar reflected and Earth emitted energy

**TIR** (Thermal Infrared) region (8 to 14 μm): It senses the emitted energy from the Earth's surface

Commonly used to map Temperatures

Also used to detect vegetation evapotranspiration, urban heat effects, rock discrimination

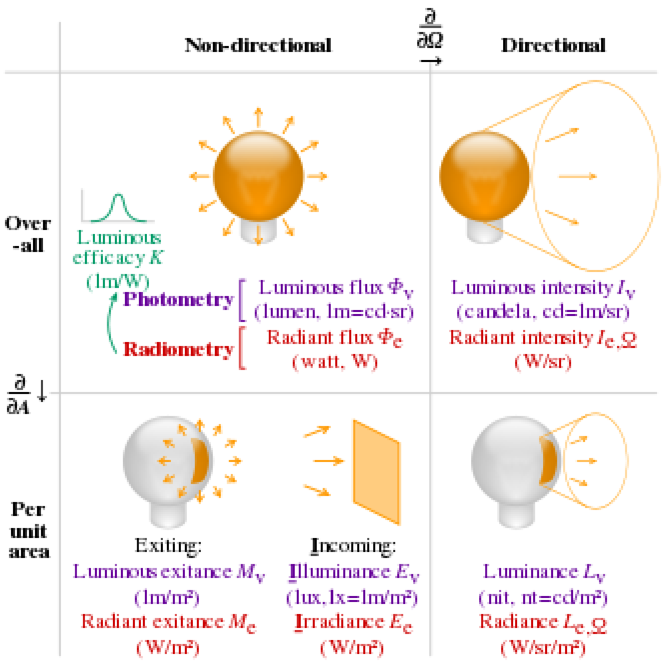
**Microwaves** (> 1 cm) is used by radar sensor and have very low atmospheric absorption

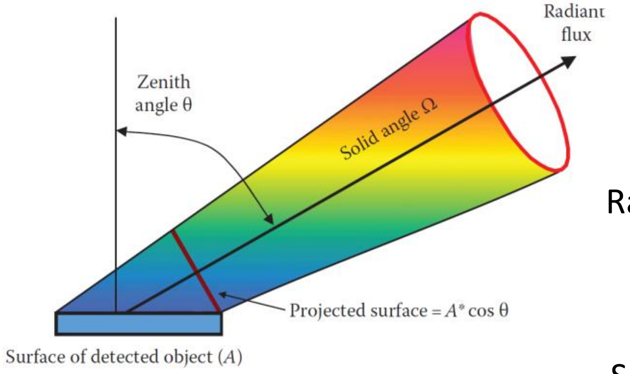
## Radiometric Quantities Commonly Used in Remote Sensing

| Concept | Symbol | Equation | Measured Unit |
|---|---|---|---|
| Radiant energy | $Q$ | — | Joules (J) |
| Radiant flux | $\phi$ | $\delta\phi/\delta t$ | Watts (W) |
| Exitance | $M$ | $\delta\phi/\delta A$ | $W\ m^{-2}$ |
| Irradiance | $E$ | $\delta\phi/\delta A$ | $W\ m^{-2}$ |
| Radiant intensity | $I$ | $\delta\phi/\delta\Omega$ | $W\ sr^{-1}$ |
| Radiance | $L$ | $\delta I/\delta A \cos\theta$ | $W\ m^{-2}\ sr^{-1}$ |
| Spectral radiance | $L_\lambda$ | $\delta L/\delta_\lambda$ | $W\ m^{-2}\ sr^{-1} \mu m^{-1}$ |
| Emissivity | $\varepsilon$ | $M/M_n$ | Unitless |
| Reflectance | $\rho$ | $\phi_r/\phi_i$ | Unitless |
| Absorptance | $\alpha$ | $\phi_a/\phi_i$ | Unitless |
| Transmittance | $\tau$ | $\phi_t/\phi_i$ | Unitless |

*Note:* sr, steradian, measure of the solid angle; μm, micrometer or micron ($10^{-6}$ m); $M_n$, exitance of a black body at the same temperature; $\phi_i$, incident flux; $\phi_r$, reflected flux; $\phi_a$, absorbed flux; $\phi_t$, transmitted flux; $\theta$, angle formed by the energy flux direction and the normal.

# Radiometric quantities




Radiant energy $Q$ — Joules (J)

= total energy radiated in all directions away or toward a surface

Radiant flux $\phi$ $\delta\phi/\delta t$ Watts (W)

= rate of energy transfer in all directions per unit time

Exitance $M$ $\delta\phi/\delta A$ W $m^{-2}$

= known also as Emittance; rate of energy transfer per unit area (radiant flux density) **leaving the surface**

Irradiance $E$ $\delta\phi/\delta A$ W $m^{-2}$

= radiant flux density incident upon the surface

Radiant intensity $I$ $\delta\phi/\delta\Omega$ W $sr^{-1}$

= total energy leaving the surface per unit time and within a solid angle (Ω) measured in steradians (sr)

Radiance $L$ $\delta I/\delta A \cos\theta$ W $m^{-2}$ $sr^{-1}$

= total energy exiting in a certain direction per units area and solid angle

**It is the most fundamental in remote sensing**

**It describes what the sensor measures.**

Radiance (L) can be expressed on a wavelength basis

Spectral radiance $L_\lambda$ $\delta L/\delta_\lambda$ W $m^{-2}$ $sr^{-1}\mu m^{-1}$

= it is the energy output from a unit area, unit solid angle, and unit wavelength

Similarly, spectral irradiance ($E_\lambda$) is the energy incident upon a surface per unit wavelength.

**Radiometric quantities can be expressed dimensionless:**

| | | | |
|---|---|---|---|
| Emissivity | $\varepsilon$ | $M/M_n$ | Unitless |

= relationship between **radiant exitance (M) relative to that of a perfect emitter** at the same T° ($M_n$)
Black bodies are perfect emitter, $\varepsilon = 1$

| | | | |
|---|---|---|---|
| Reflectance | $\rho$ | $\phi_r/\phi_i$ | Unitless |

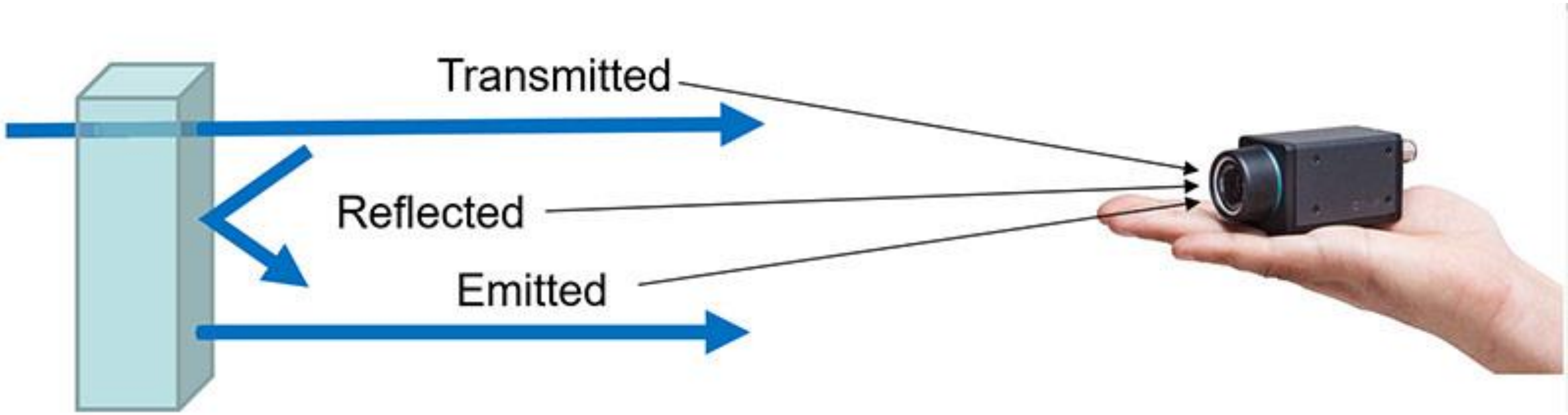
= **relationship** between **energy reflected** by the surface and the **energy incident** the surface

| | | | |
|---|---|---|---|
| Absorptance | $\alpha$ | $\phi_a/\phi_i$ | Unitless |

= **relationship** between **energy absorbed** by the surface and the **energy incident** the surface

| | | | |
|---|---|---|---|
| Transmittance | $\tau$ | $\phi_t/\phi_i$ | Unitless |

= **relationship** between **energy transmitted** by the surface and the **energy incident** the surface



Other relationships derived:

ALBEDO: $\rho_{hemisperical} = \frac{M}{E}$

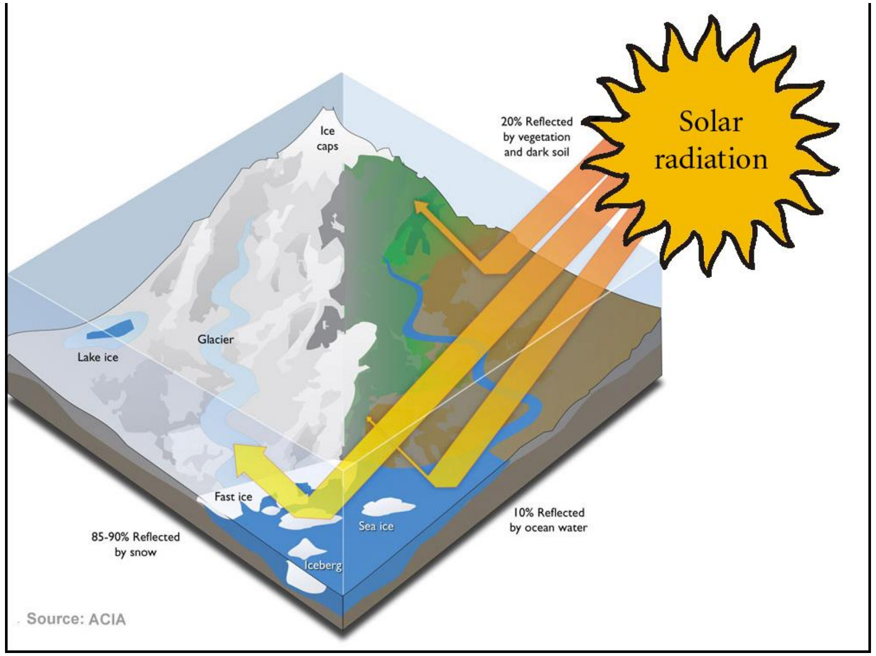
exitance (M)

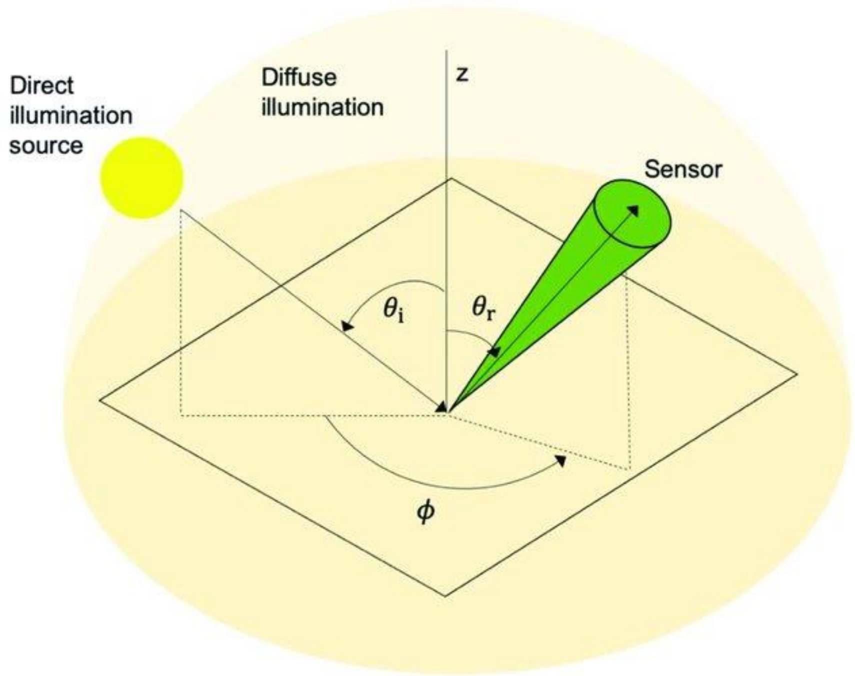
irradiance (E)

It is equivalent to hemispherical reflectance, that is reflectance integrated over all directions

It is possible to calculate spectral albedo:

$$\rho_{hemisperical,\lambda} = \frac{M_\lambda}{E_\lambda}$$






- Satellite sensor do not measure outogoing hemispherical energy over all directions
- They can **measure the directional radiance ($L_\lambda$) from only a narrow angular FOV** (field of view)
- Directional radiance ($L_\lambda$) is related to hemispherical spectral exitance ($M_\lambda$):

$$\mathbf{M_\lambda = \pi \cdot L_\lambda}$$

- Similarly, surface reflectance derived from satellite are directional reflectances, and refer to a specific geometry between the satellite sensor and the sun, relative to the surface

$$\rho_\lambda = \frac{\pi L_\lambda}{E_{0,\lambda}}$$

Spectral radiance received by the sensor

Solar irradiance arriving at the surface

# Electromagnetic radiation laws

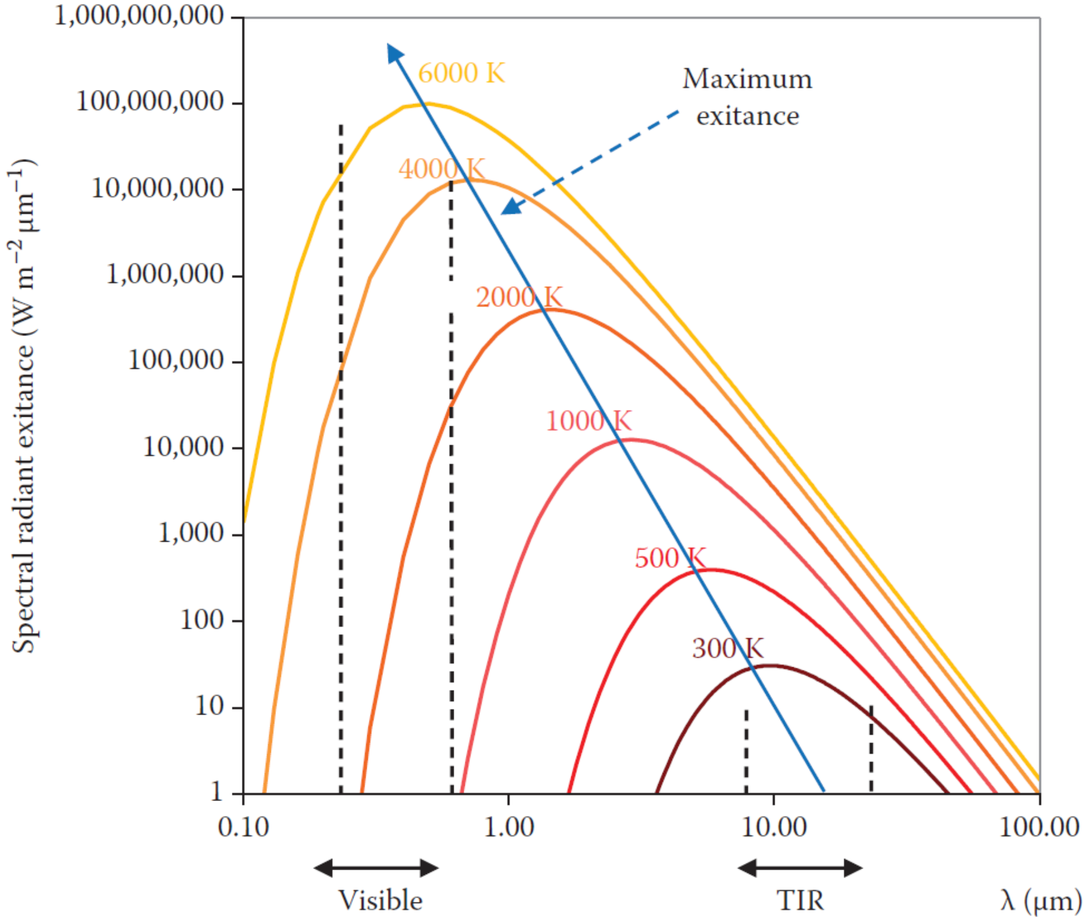
There is a set of physical laws that govern the behaviour of the EM radiation.

Radiant spectral exitance (or emittance)

**Planck's radiation law:**

$$M_{n,\lambda} = \frac{c_1}{\lambda^5 (e^{(c_2/\lambda T)} - 1)}$$

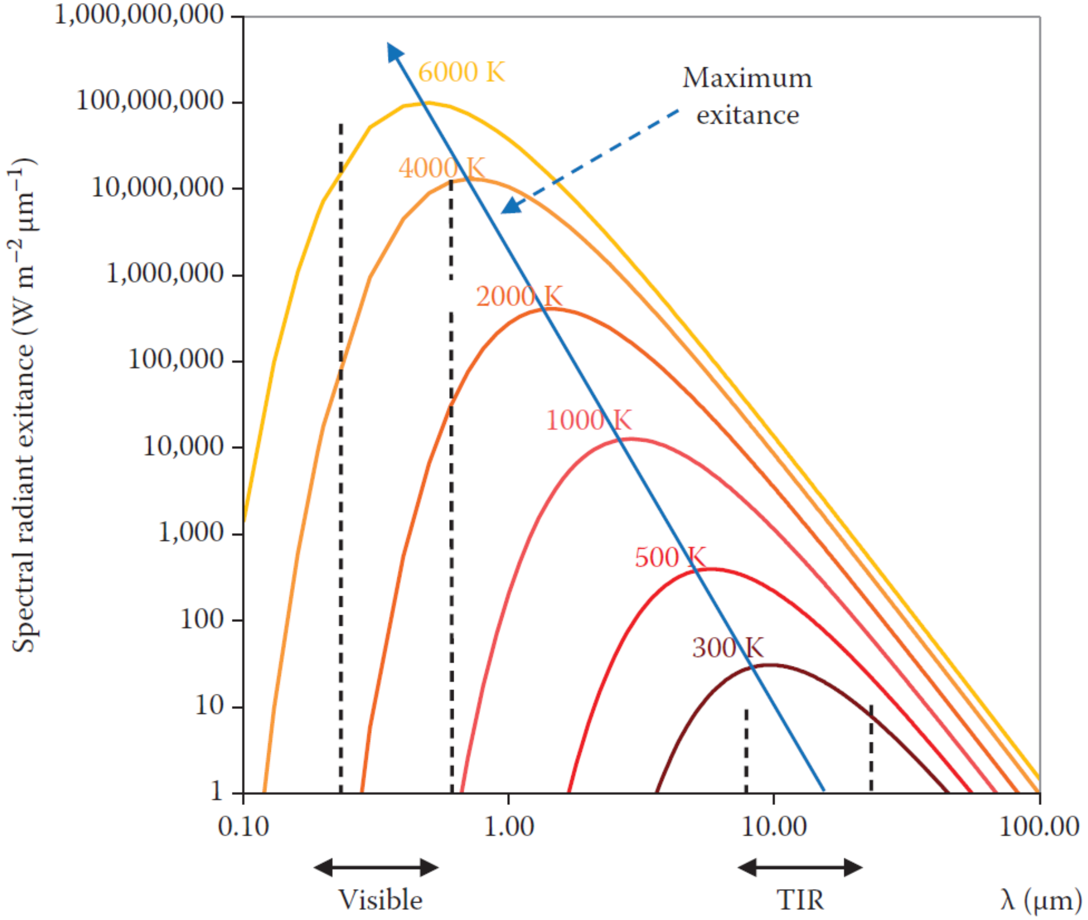
$c_1 = 3.741 \cdot 10^8$ µm K
$c_2 = 1.438 \cdot 10^4$ µm K




This equation describes the **spectral exitance distribution** of a blackbody at a certain T **as a smooth curve** with a single maximum.

**blackbody** = idealized physical body that absorbs all incident electromagnetic radiation, regardless of frequency or angle of incidence. The name "black body" is given because it absorbs all colors of light.

This indicates that each object with T > absolute zero (-273°C) emits radiant energy, which increases in proportion to its T




Total radiant energy per unit surface can be obtained through **Stefan-Boltzmann law:**

$$M_n = \sigma T^4$$

Stefan-Boltzmann constant: $5.67 \cdot 10^{-8}$ W $m^{-2}$ $K^{-4}$

This is valid for **blackbodies**

To calculate spectral radiant exitance of natural surfaces, we can use **Kirchoff's law:**

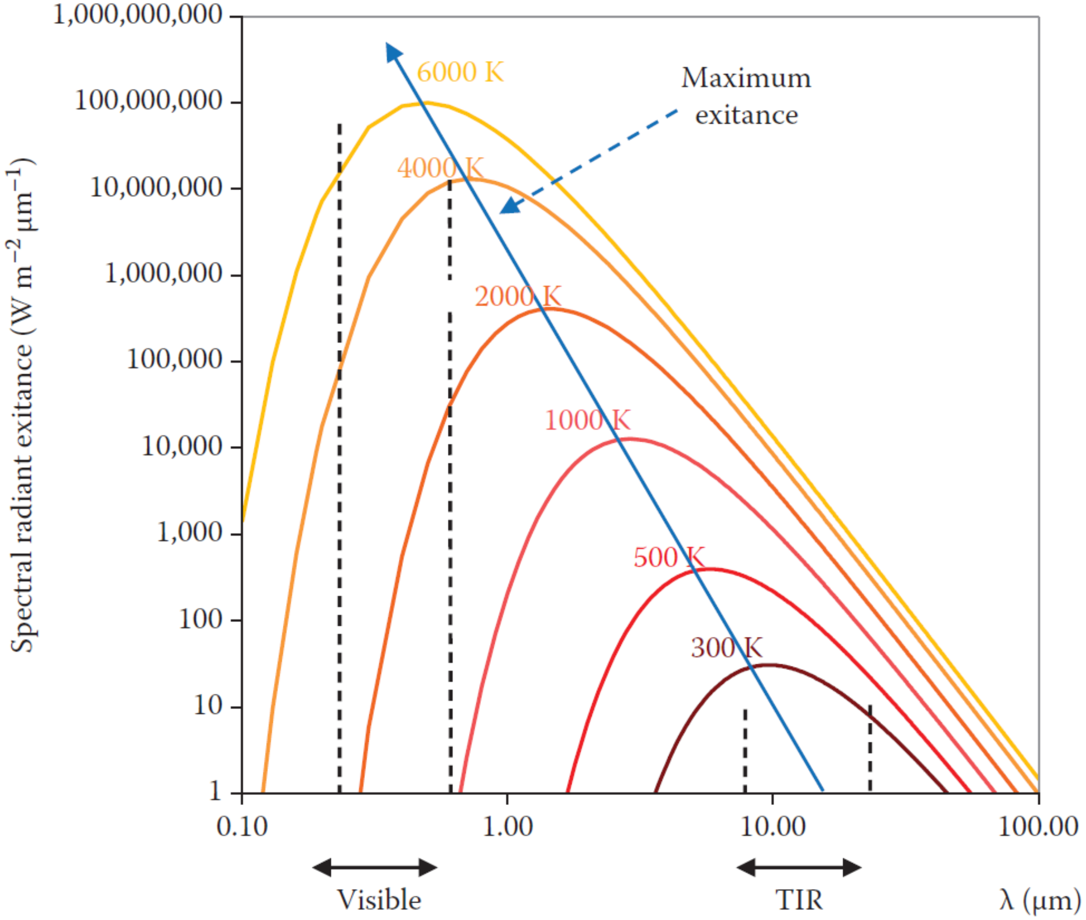
$$M = \varepsilon \sigma T^4$$

Emissivity correction, changes according to nature of the material of the detected object

ε = 1 for blackbody

ε = 0 for whitebody

# Electromagnetic radiation laws…to sum up



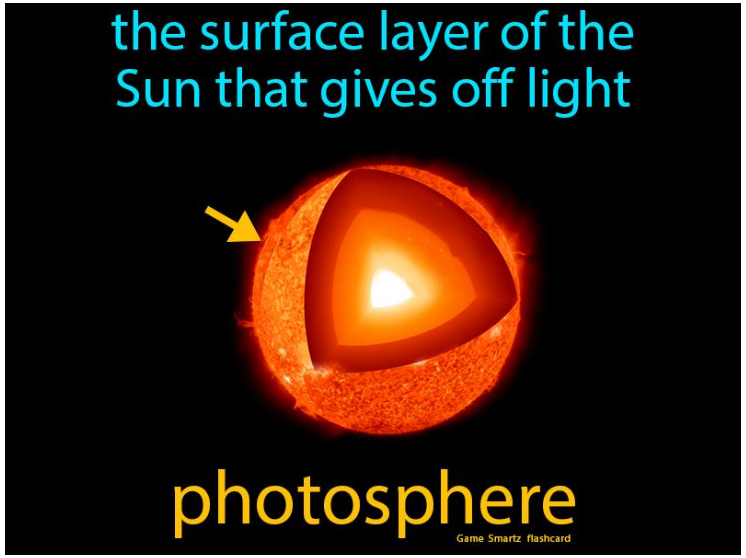

The amount and spectral distribution of energy radiated by an object vary according to:

1. **The Temperature of the object**

2. **The nature of the material as the depicted by its emissivity**

$$M = \varepsilon \sigma T^4$$

# SPECTRAL SIGNATURES IN THE SOLAR SPECTRUM

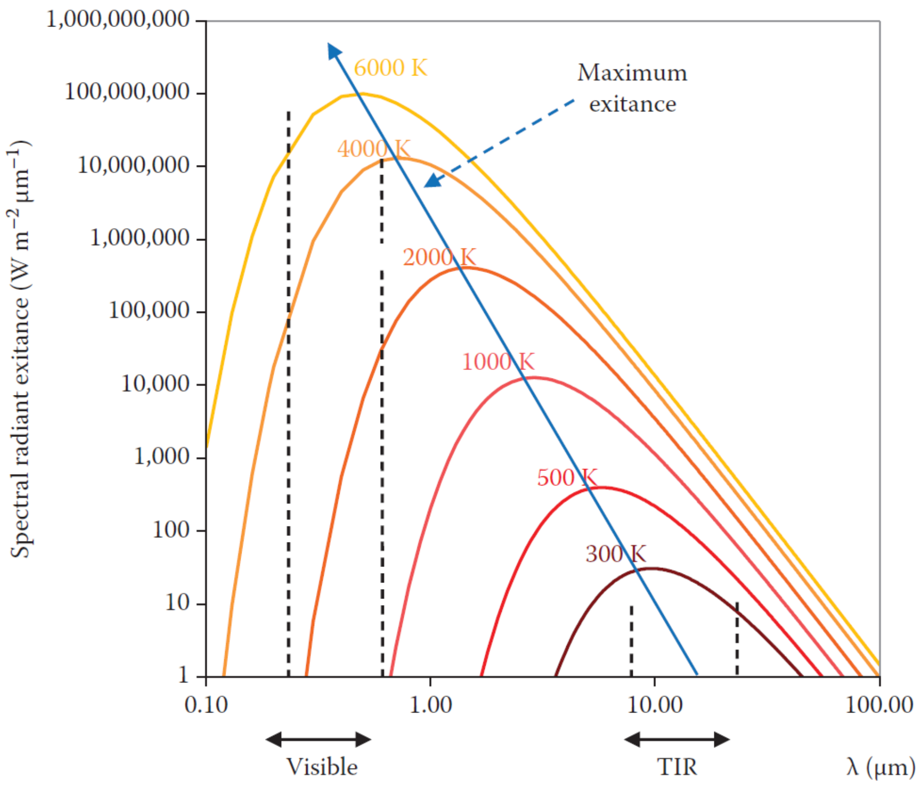



How much solar radiation arrives to Earth?

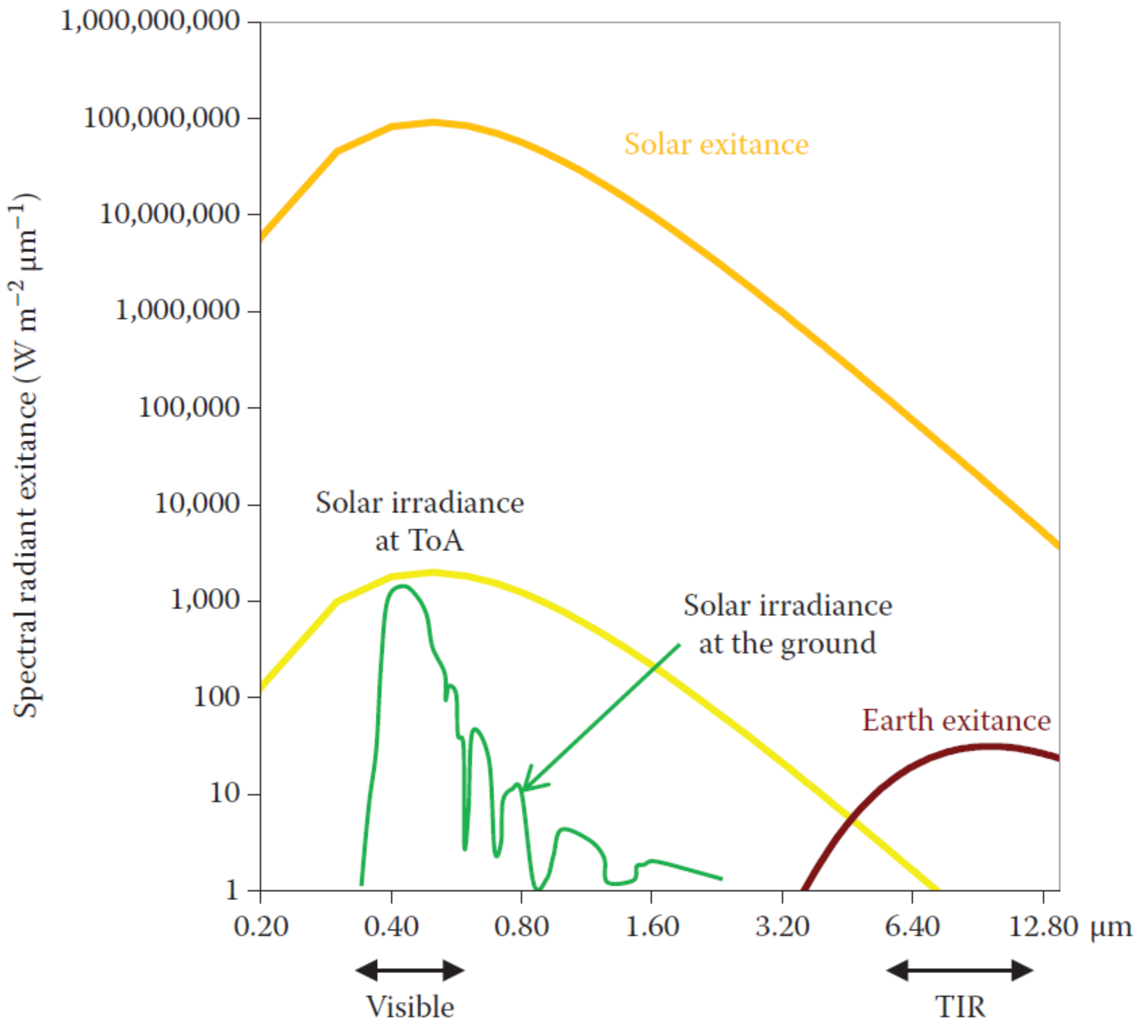
Photosphere = 6000 °K

$$E_{0,\lambda} = M_{6000,\lambda} \frac{R^2}{D^2}$$

R = radius of the Sun, $6.96 \cdot 10^5$ km
D = distance between Earth and Sun, approx. $149.5 \cdot 10^6$ km



# SPECTRAL SIGNATURES IN THE SOLAR SPECTRUM

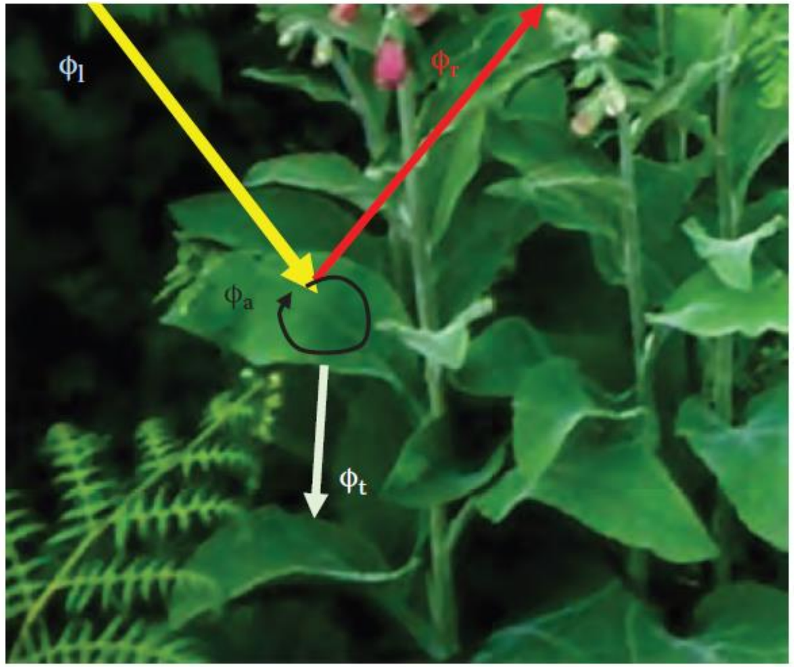



- Solar radiation arriving on Earth (solar irradiance) is relevant between 0.4 – ca. 3 µm = **SOLAR SPECTRUM**
- Maximum solar irradiance is reached in VIS (0.4 – 0.7 µm), with a peak at 0.5 µm
- For long wavelengths (> 3 µm), Earth exitance is > than Solar radiation. Earth has internal T = 300 °K, so its maximum exitance = 8 – 14 µm (Thermal Infrared, TIR)
- Solar irradiance at the ground is lower than Solar irradiance at Top of the Atmosphere (ToA). This is because of gases and aerosols in atmosphere which filters out part of the solar spectrum
- The sum of total solar irradiance over all wavelengths = 1370 W m$^{-2}$= SOLAR CONSTANT. It varies according to latitude, day of the year (DOY), hour of the day (HOD). WHY????

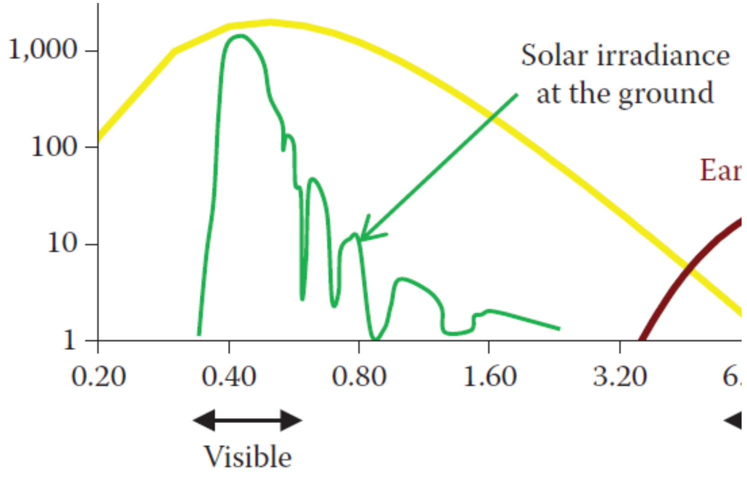
At the ground, solar radiation interacts with objects:

- Soils
- Water
- Vegetation
- Asphalt….

Three possible interaction mechanisms!




$\phi_I$ Incident energy
$\phi_r$ Reflected energy
$\phi_a$ Absorbed energy
$\phi_t$ Transmitted energy

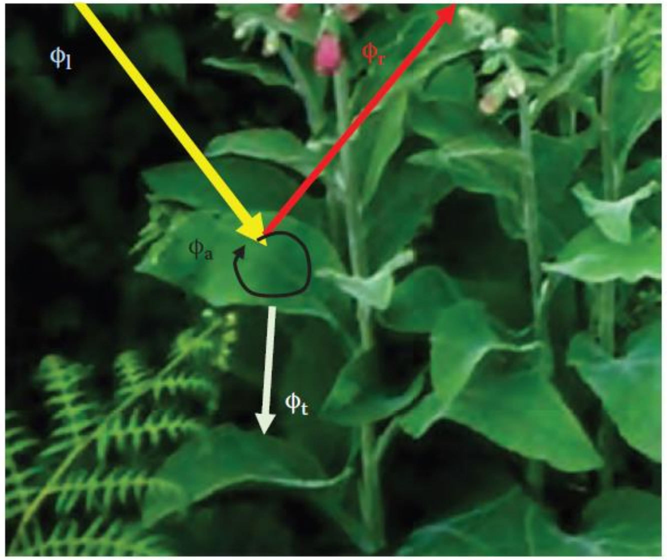



$$\phi_i = \phi_r + \phi_a + \phi_t$$

Or in terms of radiance:

$$L_i = L_r + L_a + L_t$$

# SPECTRAL SIGNATURES IN THE SOLAR SPECTRUM




$\phi_I$ Incident energy
$\phi_r$ Reflected energy
$\phi_a$ Absorbed energy
$\phi_t$ Transmitted energy

In relative terms:

$$\frac{L_i}{L_i} = \frac{L_r}{L_i} + \frac{L_a}{L_i} + \frac{L_t}{L_i}$$

Which is equal to:

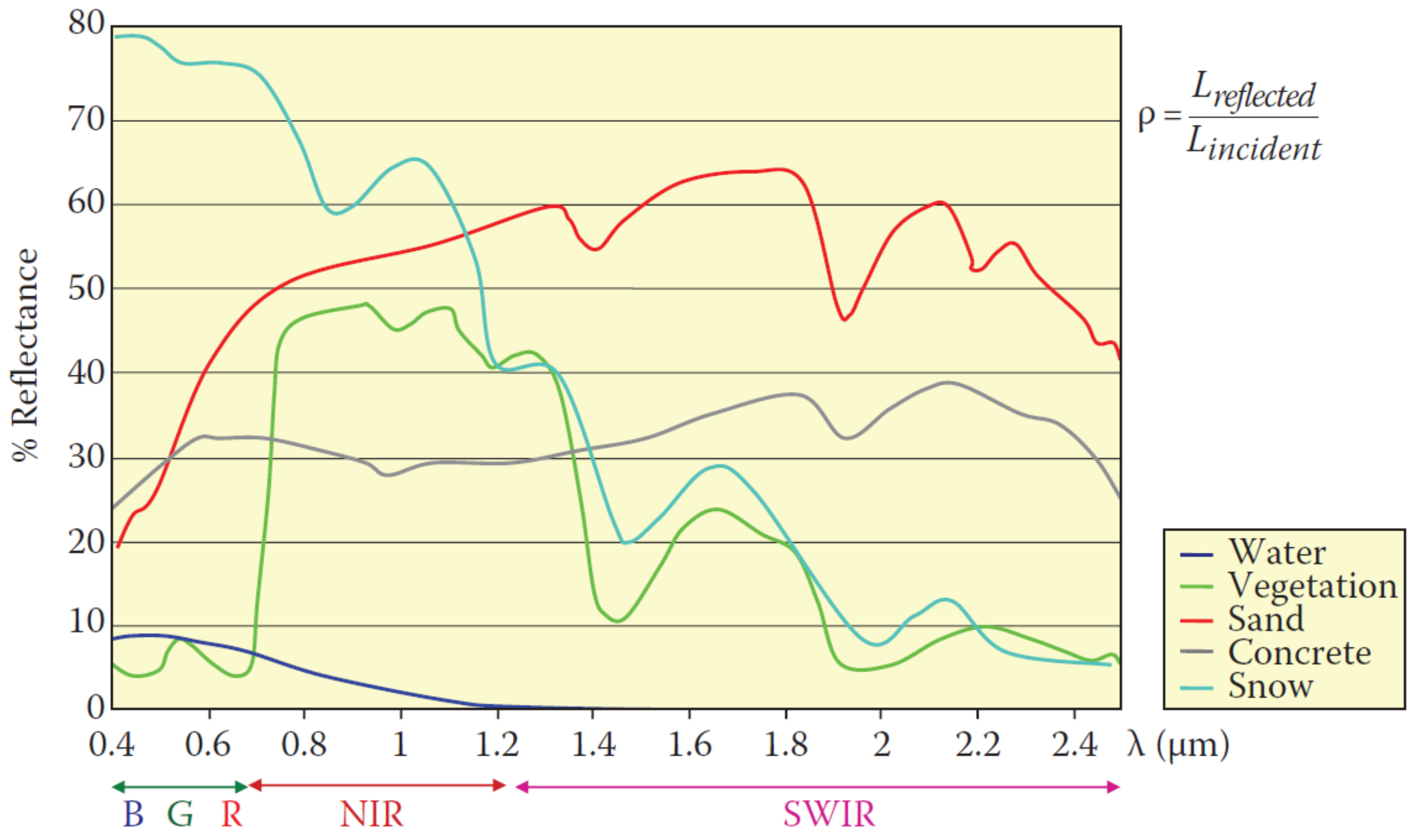
$$1 = \rho + \alpha + \tau$$

ρ = reflectance
α = absorbance
T = transmittance

The magnitude of the three components are not constant:

$$1 = \rho_\lambda + \alpha_\lambda + \tau_\lambda$$

The proportion of incident energy that are reflected, absorbed and transmitted are a function of the unique characteristics of the surface, and these proportions vary with wavelength.




$$\rho = \frac{L_{reflected}}{L_{incident}}$$

$$1 = \rho_\lambda + \alpha_\lambda + \tau_\lambda$$

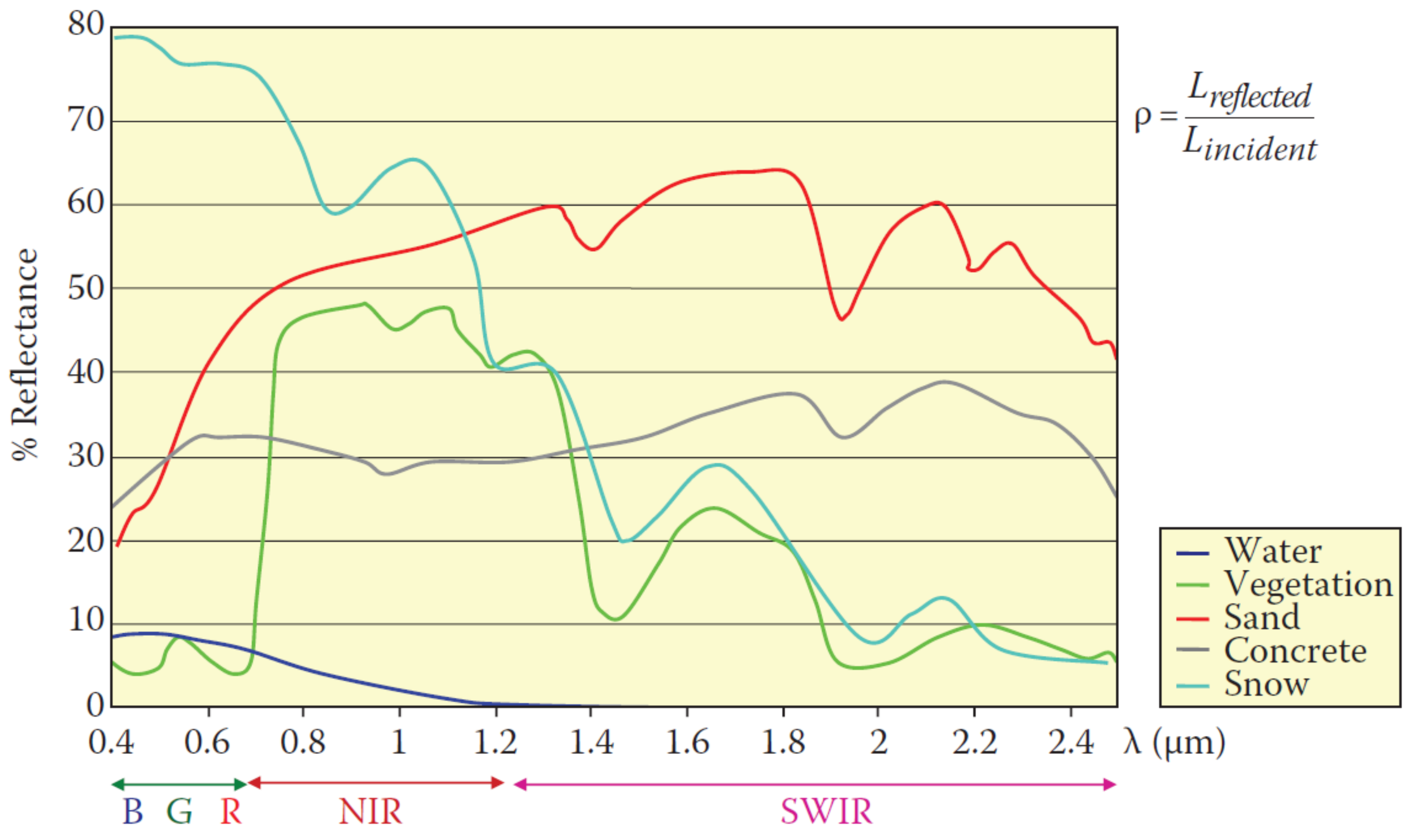
**The reflectance behaviour oh an object over various wavelength of EM spectrum = SPECTRAL SIGNATURE**

This coefficients varies according to:

- physico-chemical properties of the hitted surface
- surface roughness

In VIS, the variation in reflectance behaviour of an object = COLOR

# SPECTRAL SIGNATURES IN THE SOLAR SPECTRUM




Spectral signatures (SS):

Snow:

High ρ in VIS
Low ρ after VIS and ca. 0 in SWIR(1.2-2.5)

Water:

Low ρ in VIS and even lower in NIR + SWIR

For both, the presence of pollutants, dust, plankton can modify the spectral signature

Vegetation:

Low ρ in VIS
High ρ in NIR
Low ρ in SWIR

SS is influenced by leaf type, morphology, chlorophyll content, moisture, senenescence….

Soils:

reflectance gradually increase with λ
Depends on structural and morphological characteristics, presence of litter…

# SPECTRAL SIGNATURES IN THE SOLAR SPECTRUM

Spectral signatures form the basis to discriminate objects, but are not constant.

The radiance flux detected by RS sensor depends not only by object's nature but also:

1. ATMOSPHERIC COMPONENTS
   Affects absorption and cause scattering of incoming and reflected radiation

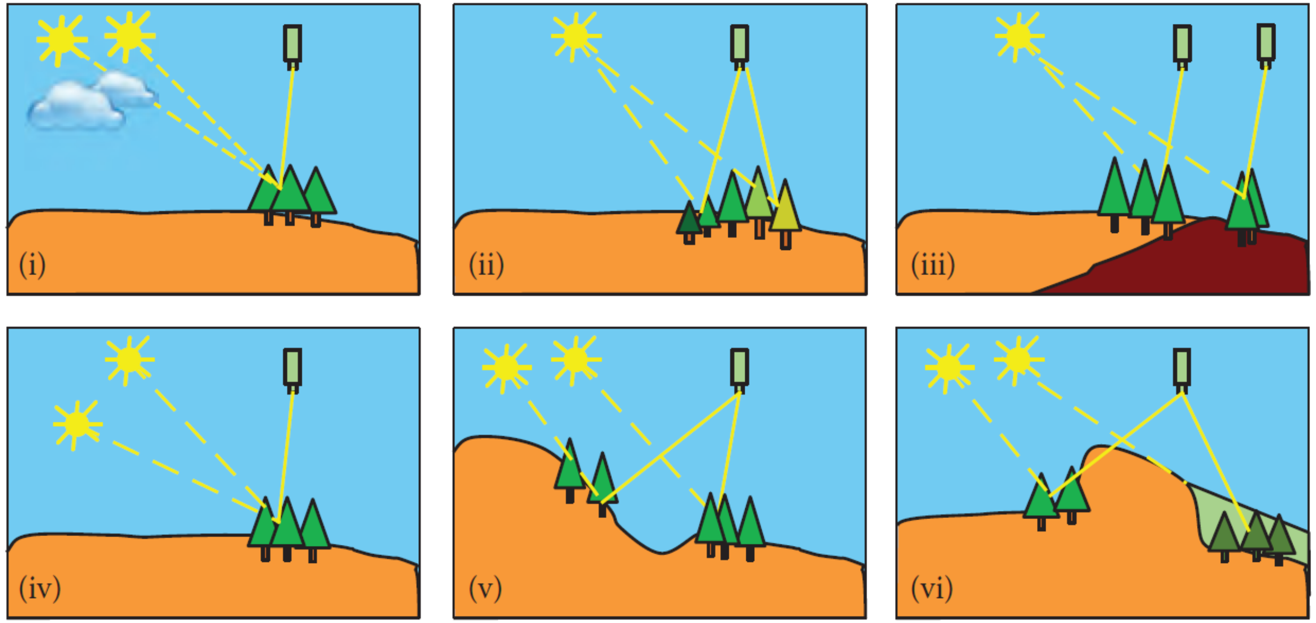
2. LAND COVER VARIATIONS
   Cause changes in chemical-physical composition; e.g. crops rotation

3. SOIL AND GEOLOGICAL STATE

4. SOLAR ILLUMINATION CONDITIONS

5. TERRAIN SLOPE

6. ASPECT

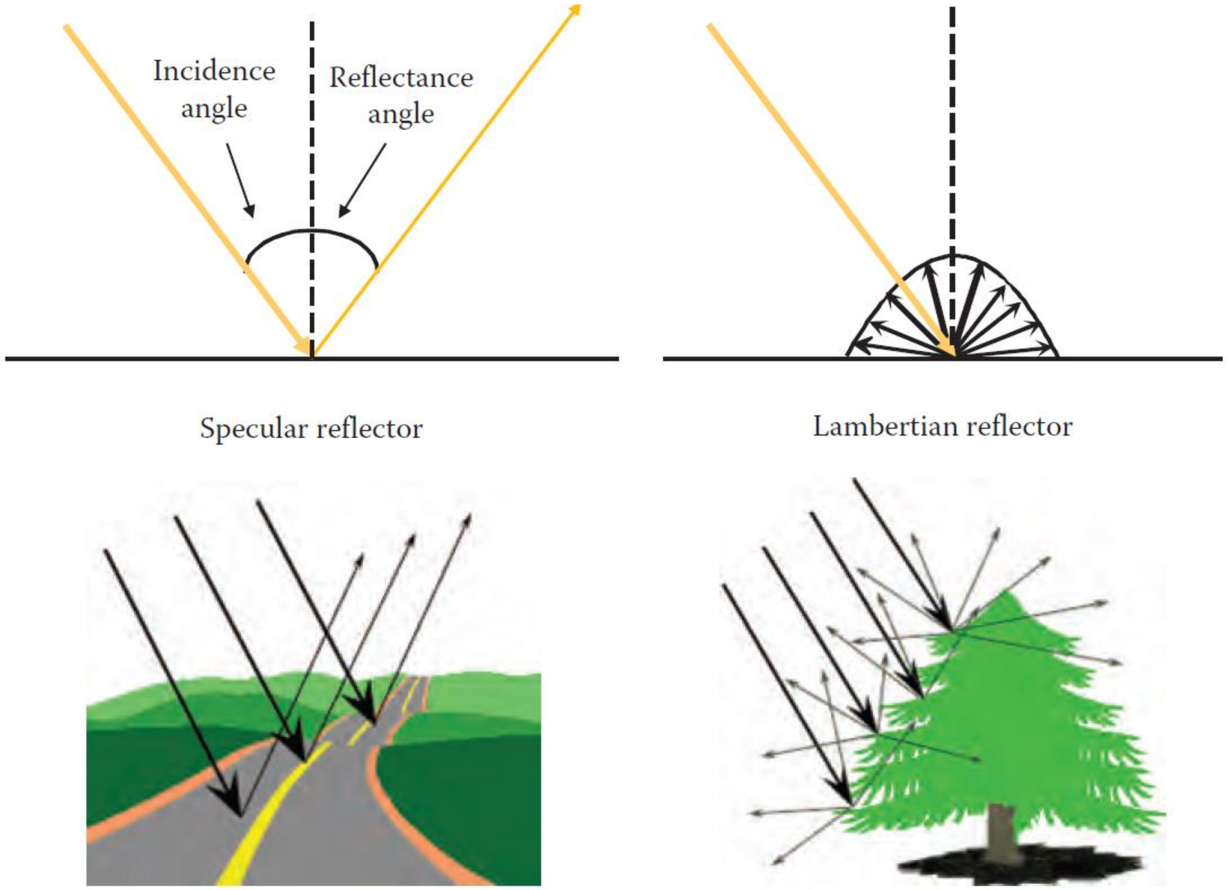


Geometric conditions are also important!

- Incidence and viewing angle
- Roughness

These factors determine scattering, which can be subdivided in three main types:

1. **Specular reflection**: incidence and viewing angle have the same value
2. **Isotropical reflection**: incident energy is scattered in all directions (e.g. Lambertian surface)
3. **Anisotropic reflection**: most surfaces cause this type of scattering, and both diffuse and specular scattering occurs (e.g. vegetation).

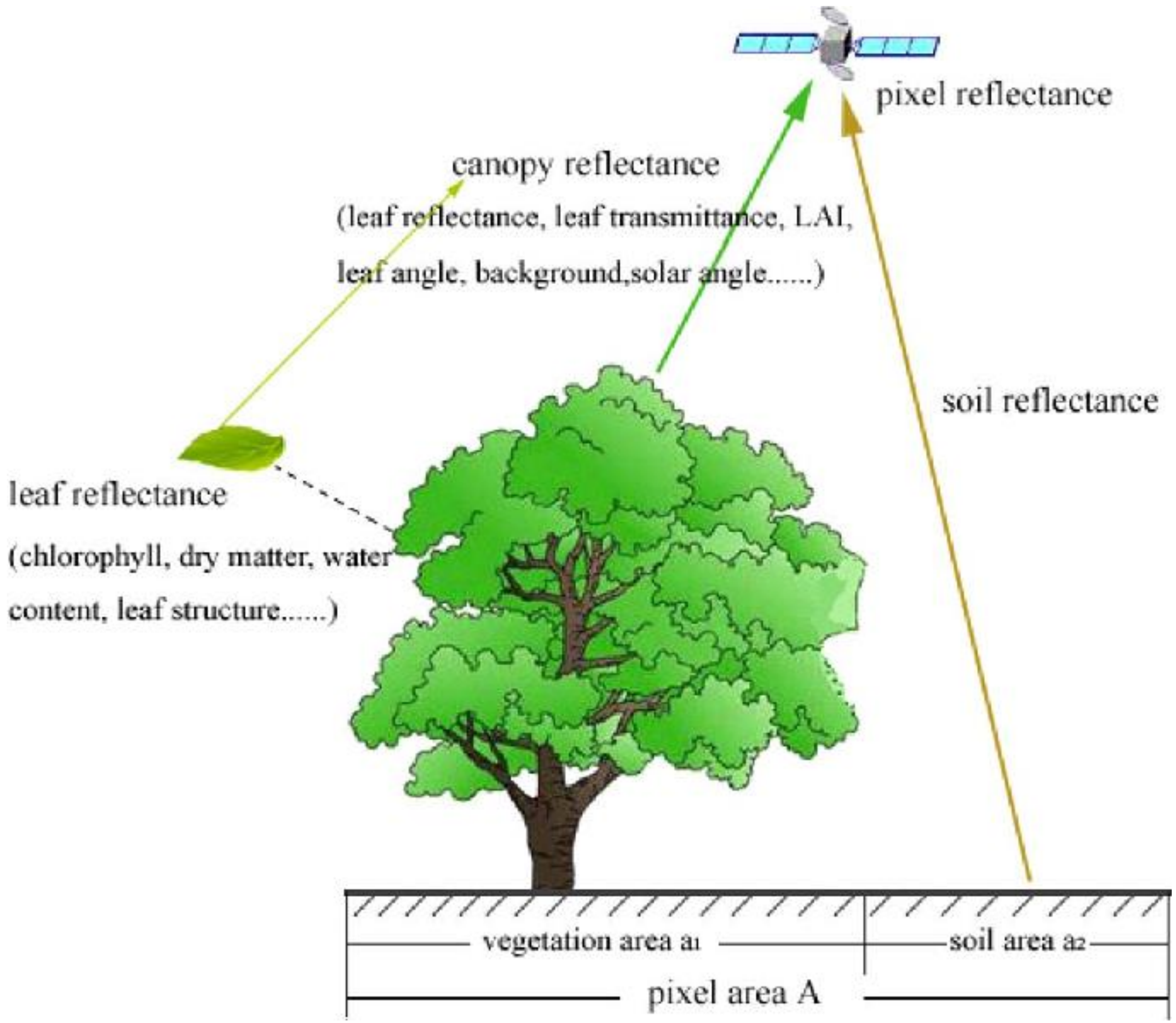


# VEGETATION REFLECTANCE

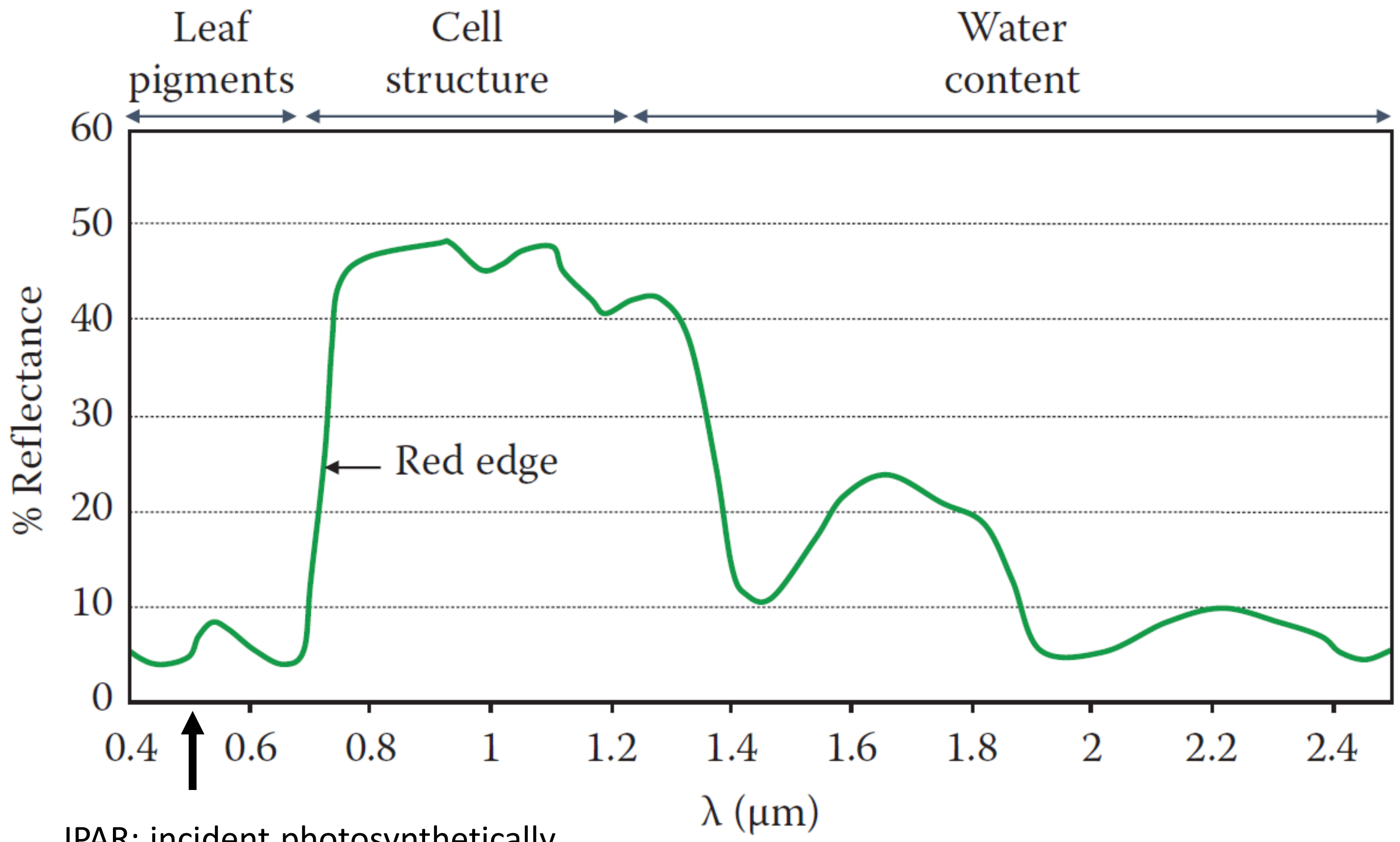
The reflectance properties of vegetation canopy depends on:

1. Biochemical and biophysical canopy attributes
   - Differences in leaf pigment concentration (it is responsible for colors)
   - Leaf moisture content
   - Phenology and stress, which affects nutrient, water and light availability
   - Structural properties: Leaf Area Index (LAI), Leaf Angle Distribution (LAD), fractional vegetation cover, plant height, crown diameter….

2. External factors that influences the signal detected by the sensor



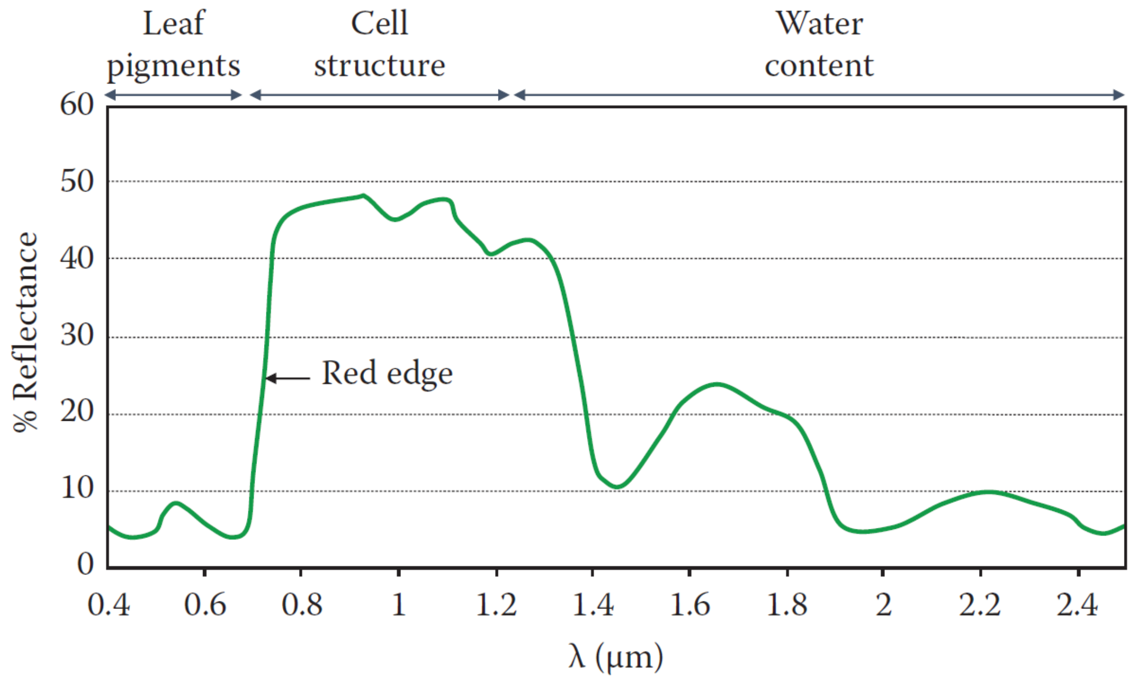
# VEGETATION REFLECTANCE

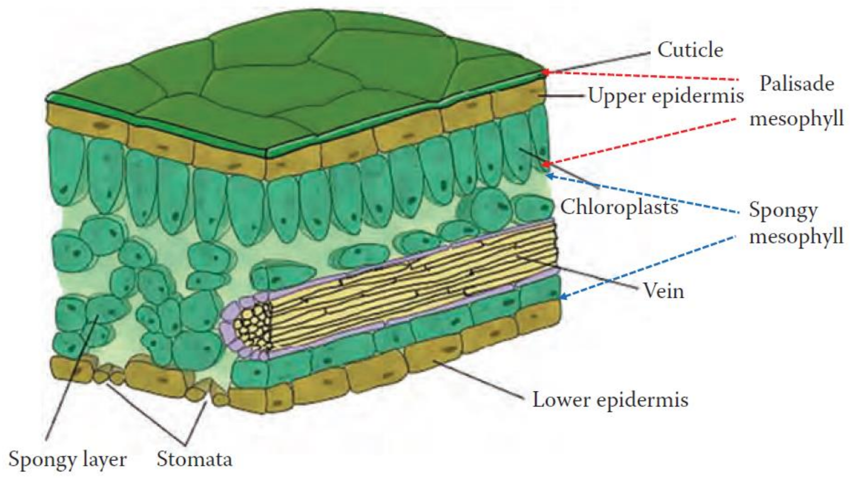



IPAR: incident photosynthetically active radiation

- **Low reflectance in VIS**, due to absorbing effect of leaf pigments:
  - ✓ Chl a and Chl b (60-75% of energy absorbed)
  - ✓ Xantophylls
  - ✓ Carotenoids
- Beyond VIS, there is an increase in leaf reflectance.
- **Sharp RED EDGE transition region** (0.74-0.78 μm). Very low absorbance (10%) and high reflectance (50%).

# VEGETATION REFLECTANCE



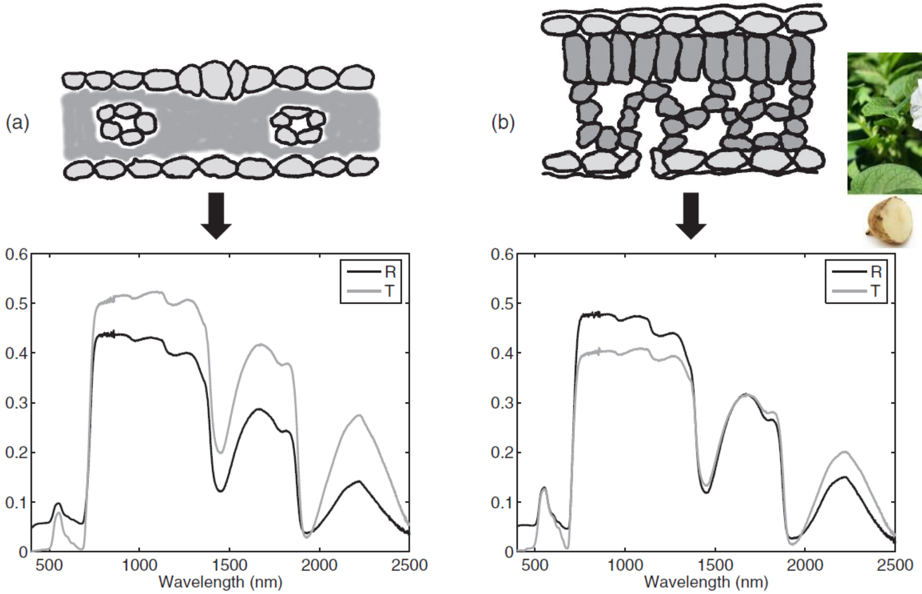



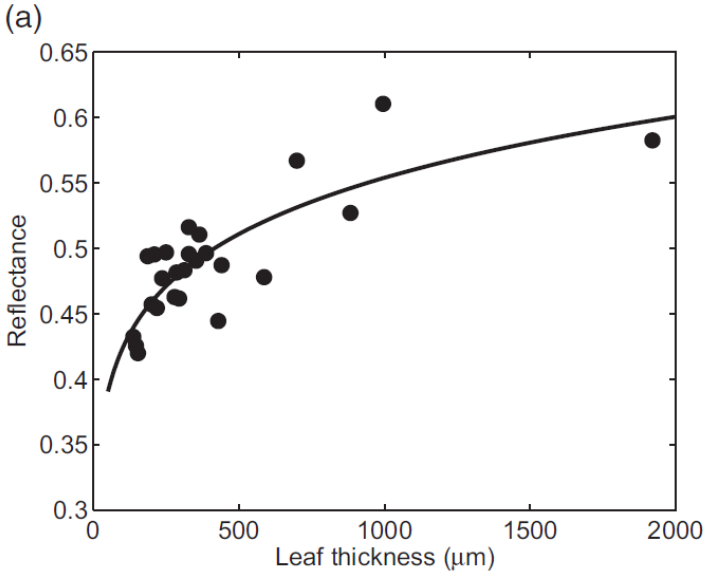

- In the region 0.7-1.1 μm, NIR REFLECTANCE PLATEAU. High reflectance in 2 water related absorption bands (0.96 and 1.1 μm), which depends on internal leaf cellular structure.

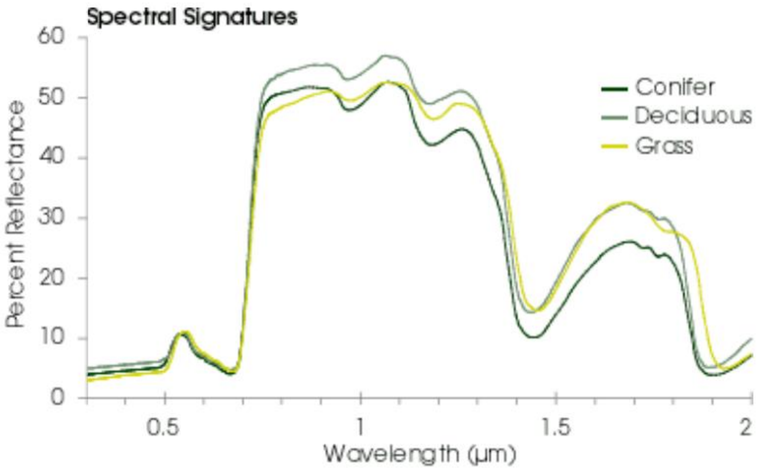
- NIR reflectance strongly depends on **leaf thickness of mesophyll layer**, which contains air spaces that favours radiation scattering.

VEGETATION REFLECTANCE

Leaf reflectance increases for heterogeneous cell shapes and content, with high number of cell layers, intercellular airspaces, variation in cell size

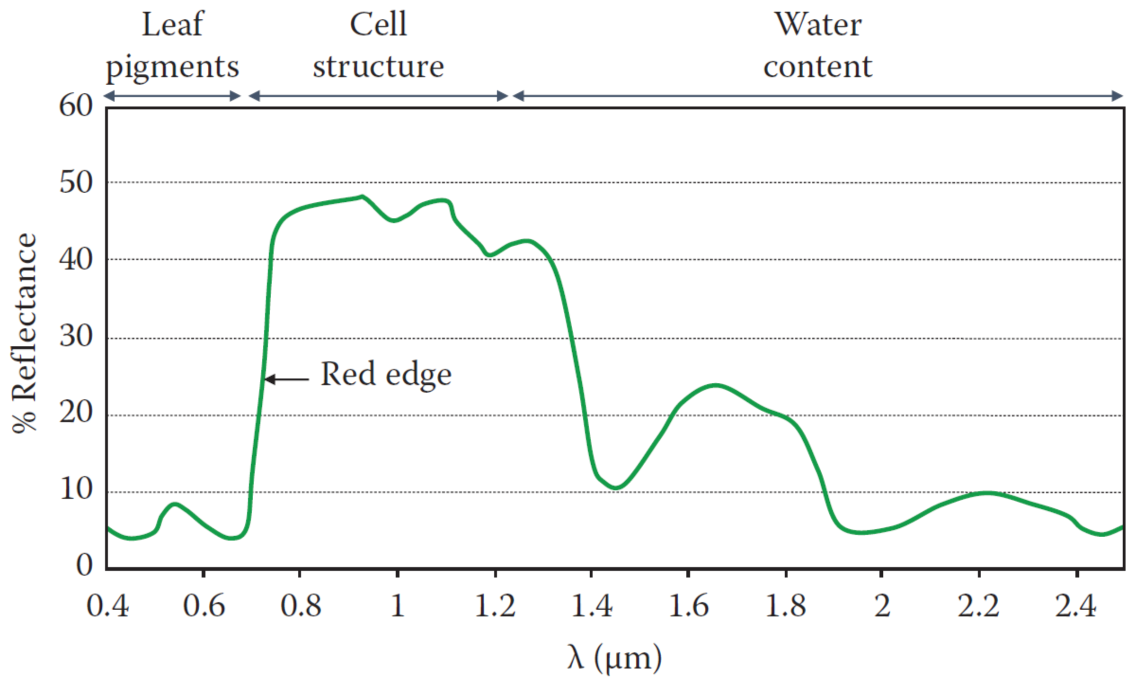


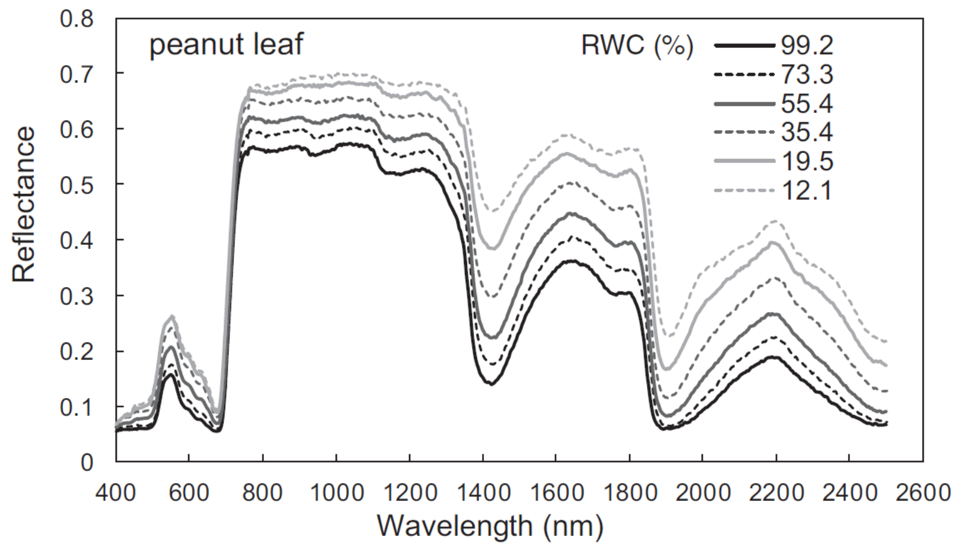

NIR is useful in biodiversity studies and in discriminating among plant species that are not distinguishable in the VIS.

# VEGETATION REFLECTANCE

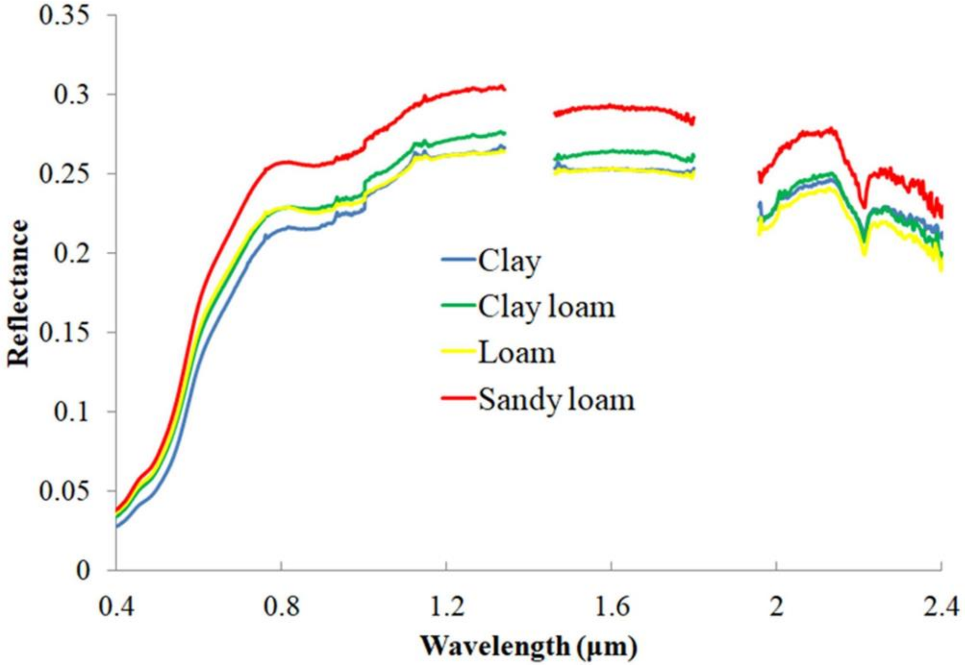


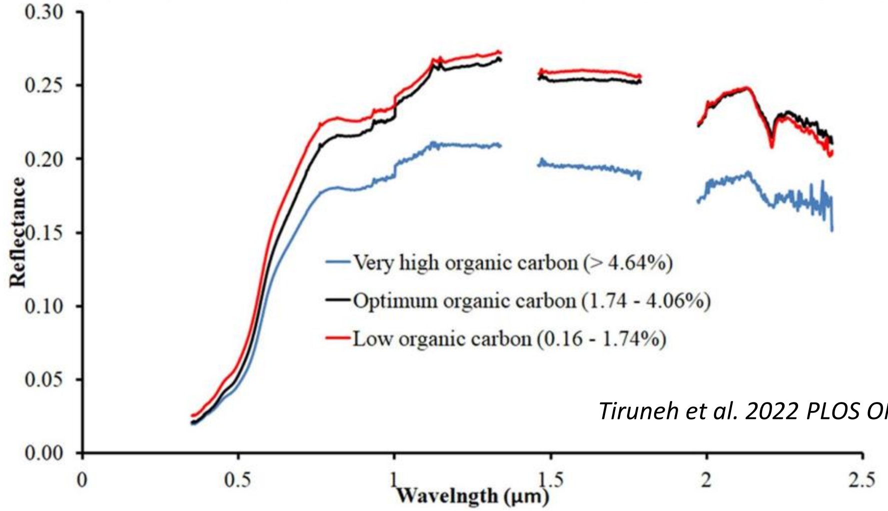

- NIR region has a transition area between 1.1-1.3 μm, where reflectance decreases.
- Low reflectance in SWIR region (1.3-2.5 μm). In this region we have high leaf absorption and low reflectance.
- Reflectance in SWIR increases along with water content.

- High contrast beween RED region (0.645 μm) and NIR (0.7-1.3 μm).
- The higher this contrast is, the higher is the vegetation vigour.
- **RED and NIR are extremely useful for VEGETATION DISCRIMINATION and extraction of useful information on vegetation.**



# SOIL REFLECTANCE



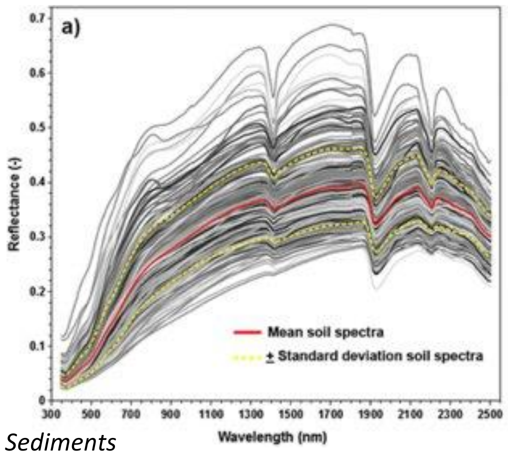




*Tiruneh et al. 2022 PLOS ONE*

- Very little EM is transmitted through soil, and its spectral signature is mainly related to the most superficial conditions.
- Spectral signature depends on:
  1. Biogeochemical constituents:
     - Iron oxydes are very important: FeO (ferrous iron) absorbs @ 1 μm; $Fe_2O_3$ (ferric iron) cause weak absorption @ 0.7-0.87 μm.
  2. Optical-geometrical scattering
     - Clayish soils results darker because clays aggregates behave as large and rough surface
  3. Moisture conditions (SWIR region)

Soil spectra database provided by ASTER sensor on [Terra satellite]

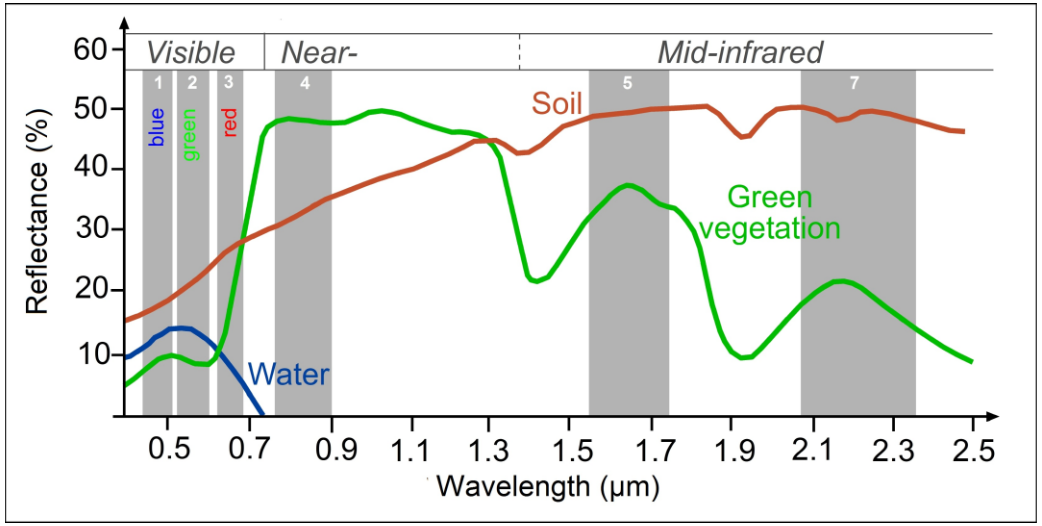
[https://speclib.jpl.nasa.gov/]

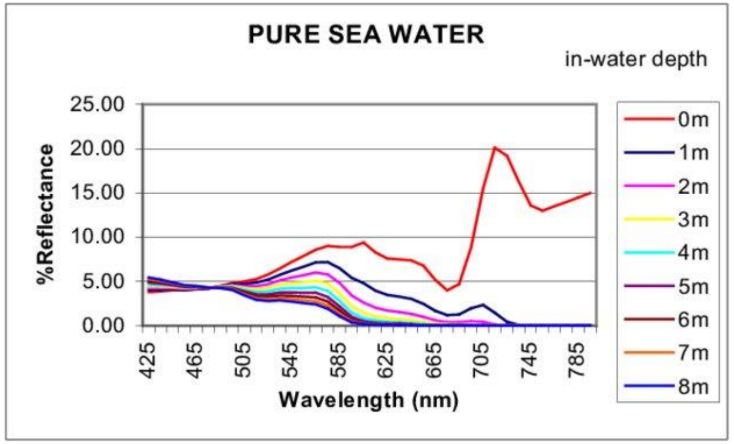


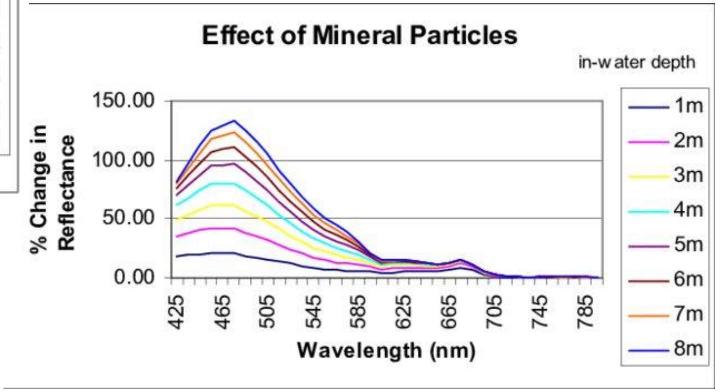

*Conforti et al. 2018 J Soils Sediments*

# WATER REFLECTANCE

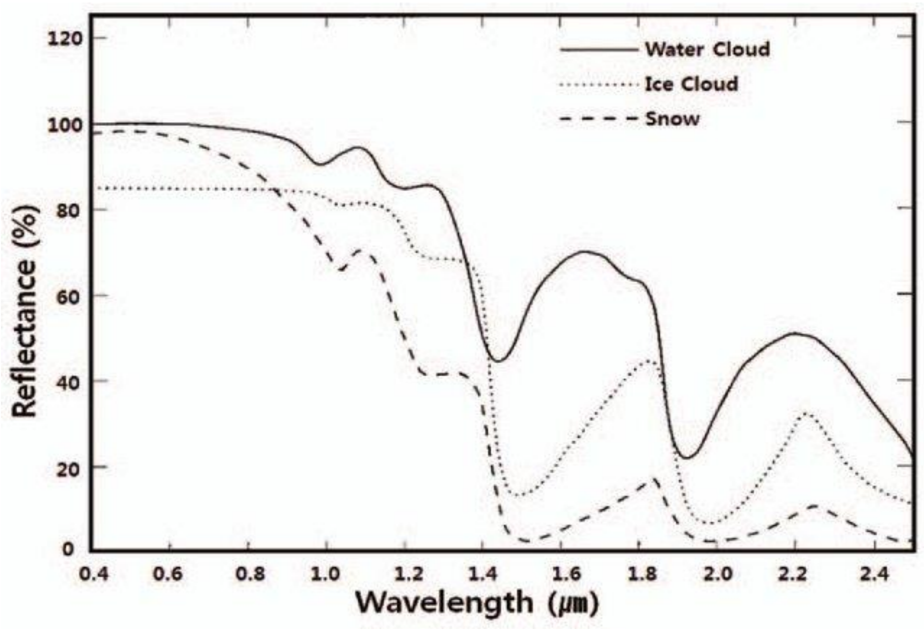
- Water bodies ABSORB or TRANSMIT most of the radiation
- Decreasing reflectance with increasing wavelength
- Highest reflectance in BLUE, gradual decrease in NIR and SWIR = 0.
- Variation in water bodies is detectable at short wavelengths (Blue-Green) and is related to:
  - ✓ Water depth: higher water depth = high absorbance
  - ✓ Chl content: high Chl content = low reflectance in blue
  - ✓ Dissolved particles: absorption, reflection and scattering
  - ✓ Surface roughness: reflection and scattering



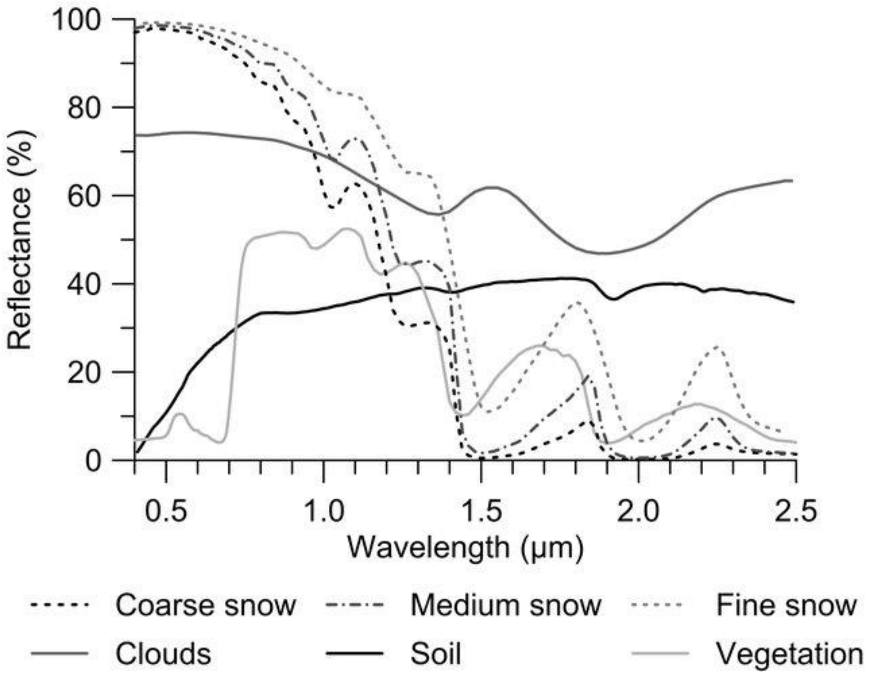



# WATER REFLECTANCE




*Park et al. 2012 Korean J Remote Sensing*




*Dong 2018 J of Hydrology*

- Snow, water and ice have different spectral signature
- Snow and clouds are hardly distinguishable in VIS, but better in SWIR
- Snow reflectance depends by age, frozen/non frozen, presence of particles/dirt

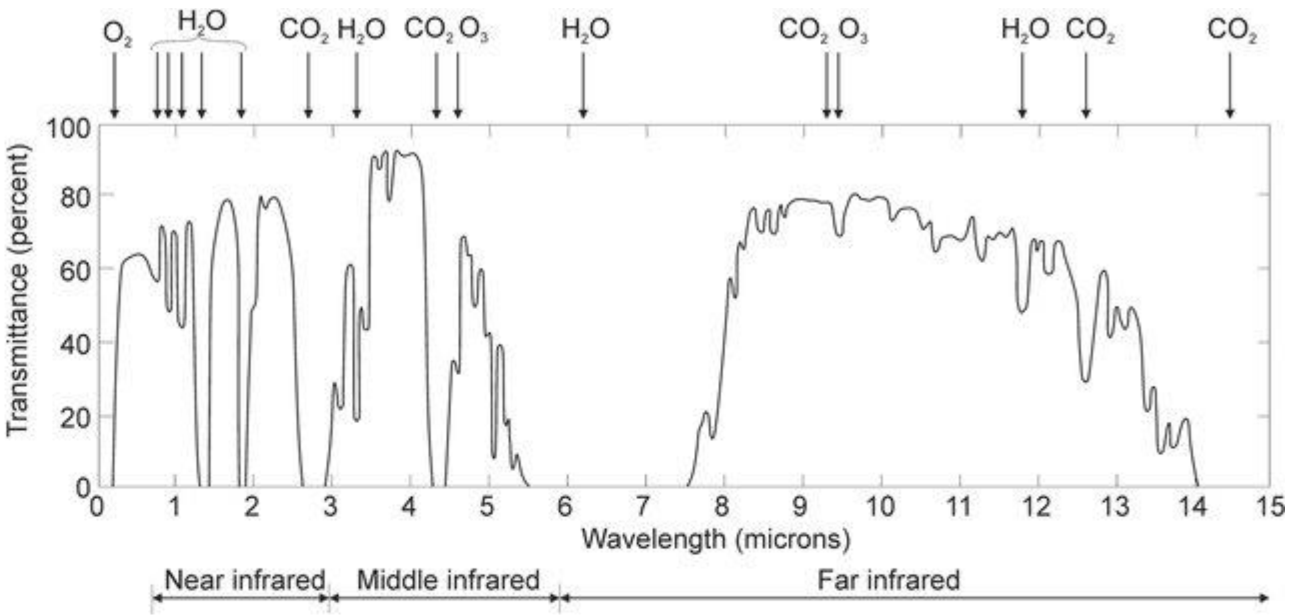
# ATMOSPHERIC WINDOWS

- The detection of EM radiation does not occur in vacuum
- Atmosphere is placed between the energy source and the target
- Beyond gases, AREOSOLS:
  - Ocean salts
  - Carbon
  - Dust
  - Particulate matter
- Possible effects:
  1. **TOTAL or PARTIAL absorption**
  2. **REFLECTION and SCATTERING**
  3. **EMISSION**

**Table 1–2** Principal gases of dry air

| Constituent | Percent by Volume | Concentration in Parts Per Million (PPM) |
|---|---|---|
| Nitrogen ($N_2$) | 78.084 | 780,840.0 |
| Oxygen ($O_2$) | 20.946 | 209,460.0 |
| Argon (Ar) | 0.934 | 9,340.0 |
| Carbon dioxide ($CO_2$) | 0.036 | 360.0 |
| Neon (Ne) | 0.00182 | 18.2 |
| Helium (He) | 0.000524 | 5.24 |
| Methane ($CH_4$) | 0.00015 | 1.5 |
| Krypton (Kr) | 0.000114 | 1.14 |
| Hydrogen ($H_2$) | 0.00005 | 0.5 |

ATMOSPHERIC WINDOWS

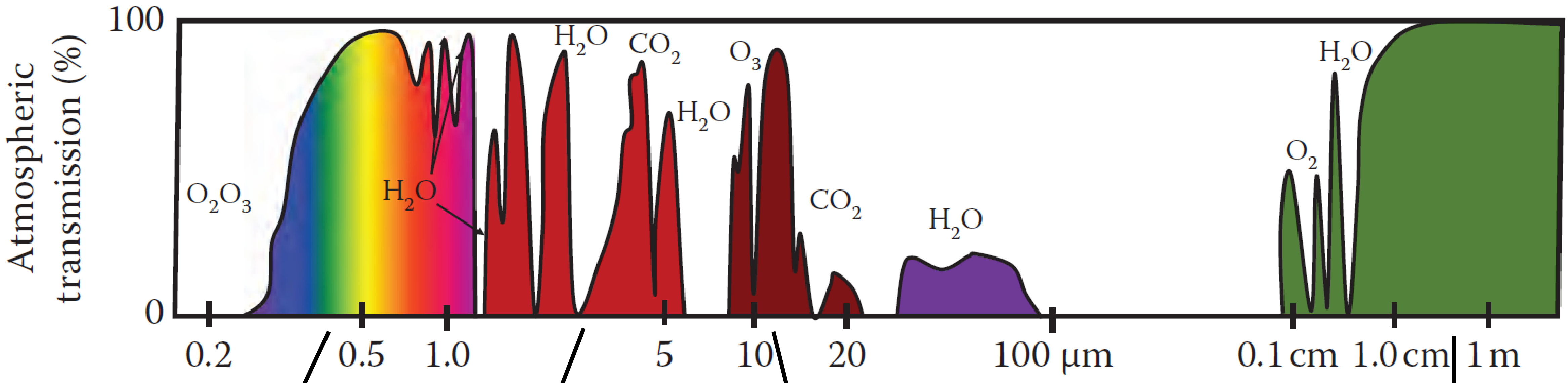



*Mikołajczyk et al. 2017 MMS*

- $O_2$ filters ultraviolet < 0.1 µm
- $O_3$ absorb ultraviolet < 0.3 µm and some narrow bands in VIS
- $H_2O$ has strong absorption @ 6 µm and a secondary absorption between 0.6-2 µm.
- $CO_2$ absorbs in TIR @ 15 µm and in MIR (2.5 – 4.5 µm)

# ATMOSPHERIC WINDOWS

**The spectral sensitivity of RS sensors is adjusted to FOCUS on SPECTRAL REGIONS where the ATMOSPHERIC ABSORPTION IS LOW (or when TRANSMITTION IS HIGH).**



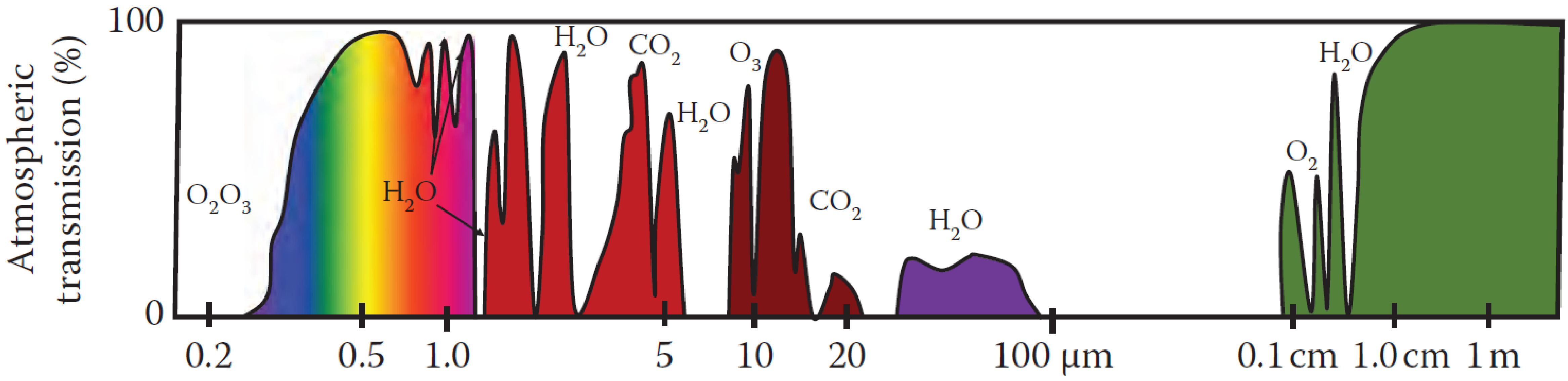

**VIS and NIR:** 0.4 – 1.35 µm

**SWIR and MIR:**
1.5 - 1.8 µm; 2.0 - 2.4 µm;
2.9 - 4.2 µm; 4.5 – 5.5 µm

**TIR:** 8 – 14 µm

**MW:** > 1cm

# ATMOSPHERIC WINDOWS



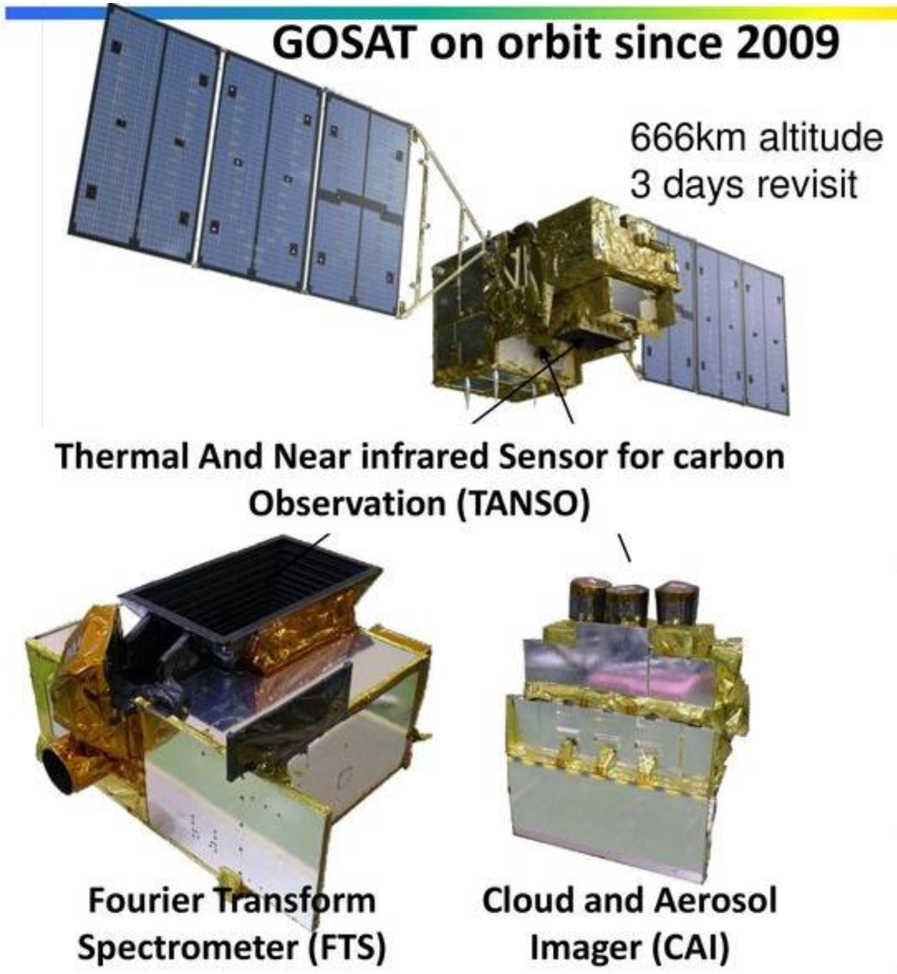

Transmittance is not always 100% in all atmospheric windows, and this depends on atmospheric conditions

Presence of THICK CLOUDS

Corrections needed

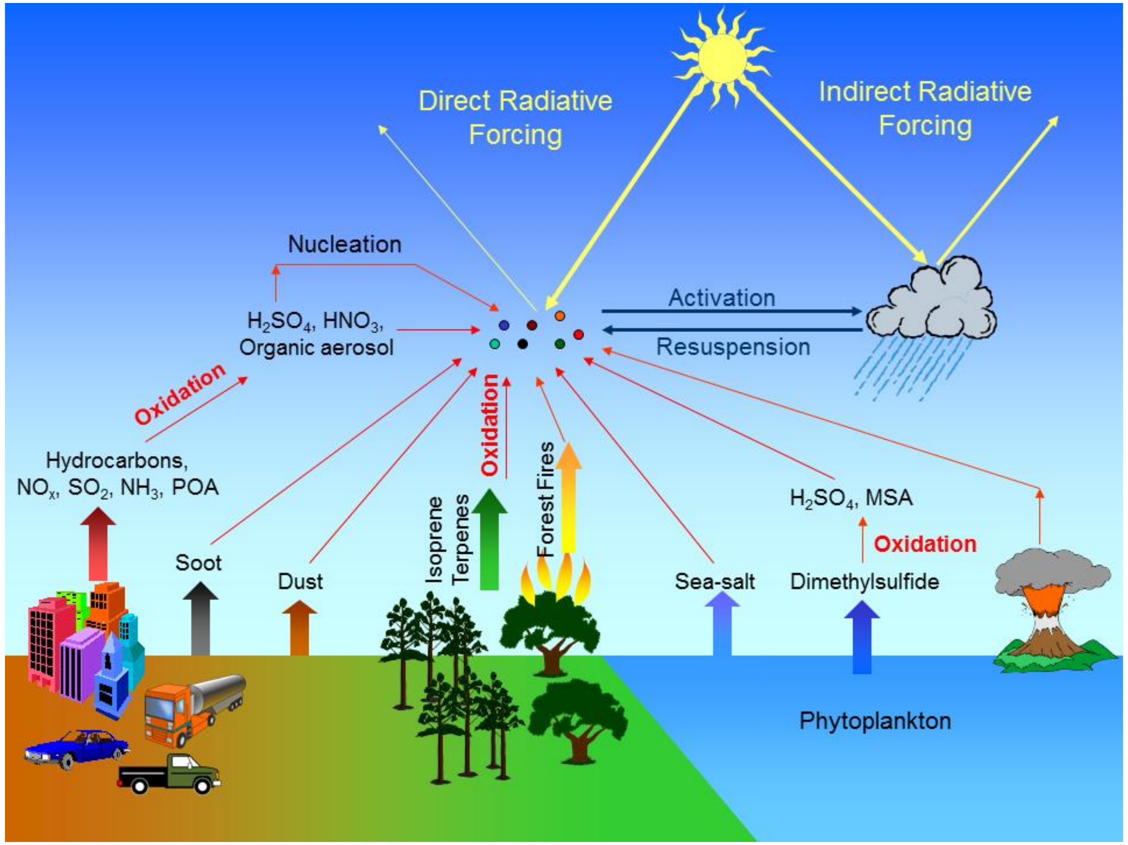
# ATMOSPHERIC WINDOWS


ESA, 2002



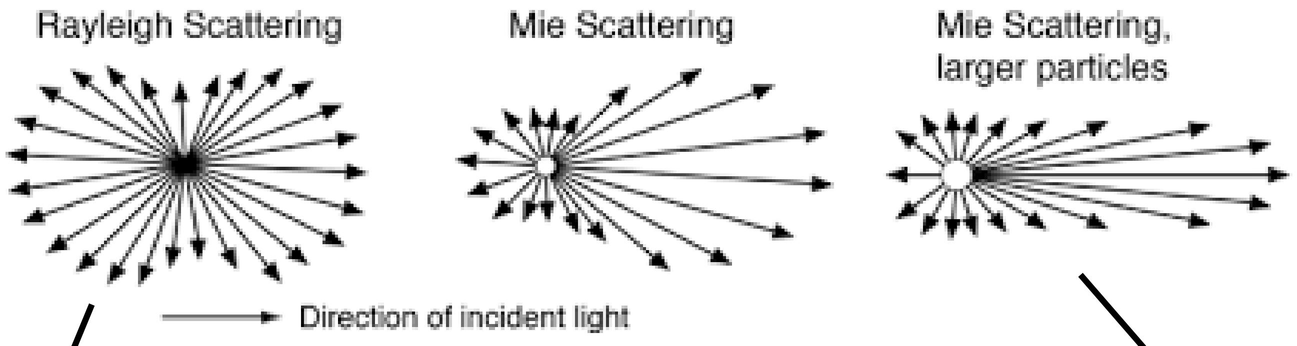

| Fourier Transform Spectrometer (FTS) | |
|---|---|
| Mission | GHGs measurements |
| Band | SWIR-0.76μm, 1.6μm, 2.0μm bands with P/S polarization ($O_2$-A, $CO_2$, $CH_4$, $H_2O$ band) |
| | TIR-5.5~14.3μm ($CO_2$, $CH_4$, $O_3$ band) |
| SPC Res. | $0.2 cm^{-1}$ |
| Swath | 750km(3 points every 260km) |
| IFOV | 10.5km |

| Cloud and Aerosol Imager (CAI) | |
|---|---|
| Mission | Cloud detection and aerosol correction within FTS IFOV |
| Band | Nadir view<br>0.38, 0.67, 0.87, 1.60μm band |
| Swath | 750-1000km |
| Footprint | 0.5 and 1.5km |




Different type of aerosols, thus it is difficult to predict scattering.

1. RAYLEIGH SCATTERING:
   - Caused by particles smaller than radiation wavelength
2. MIE SCATTERING:
   - Particle size is similar to radiation wavelength
3. NONSELECTIVE SCATTERING:
   - Particle size is higher than radiation wavelength




**Do you know why the sky is blue?**

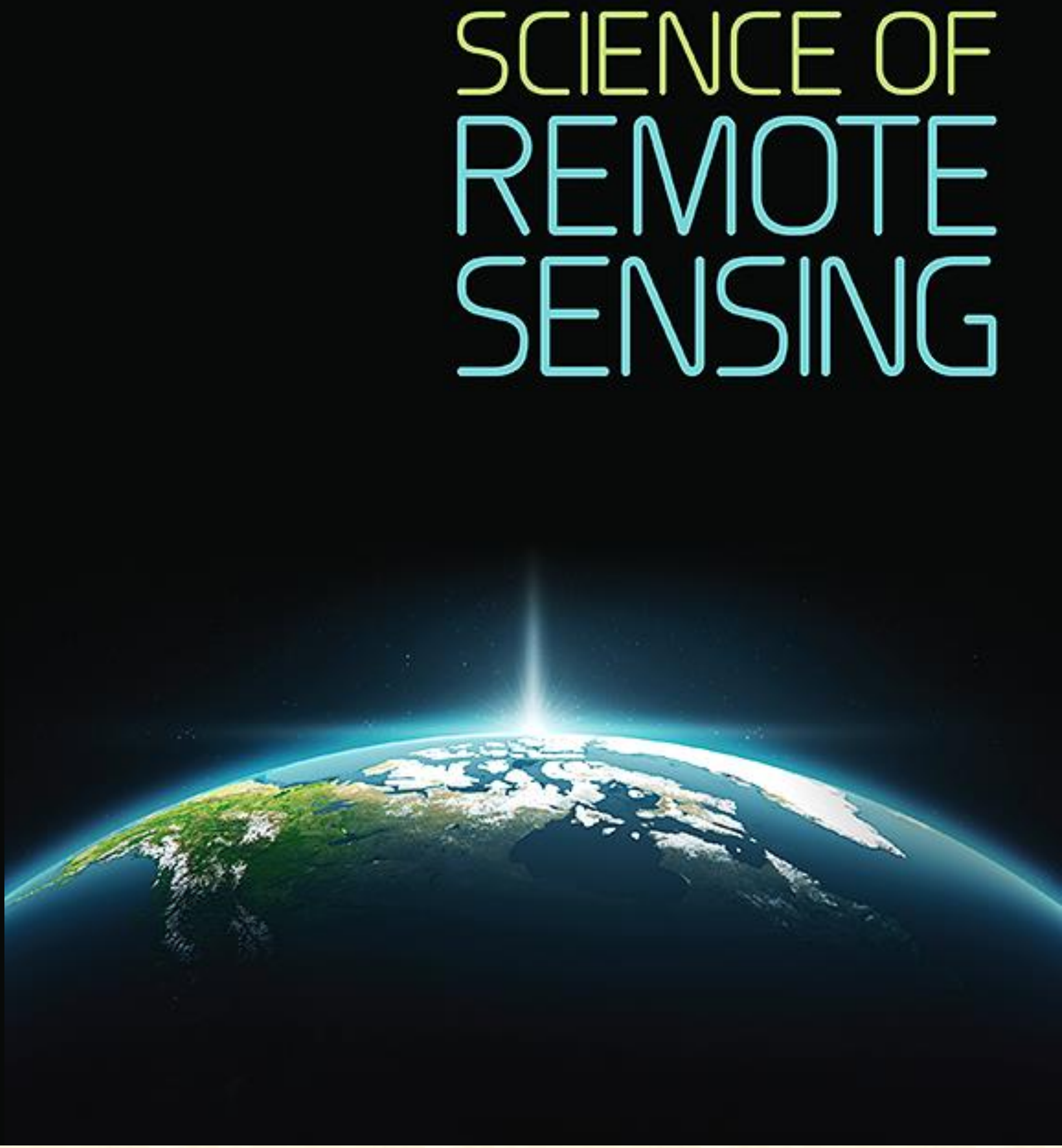
Affects lowest λ in VIS region…

Caused by particles released from forest fires and coastal mists

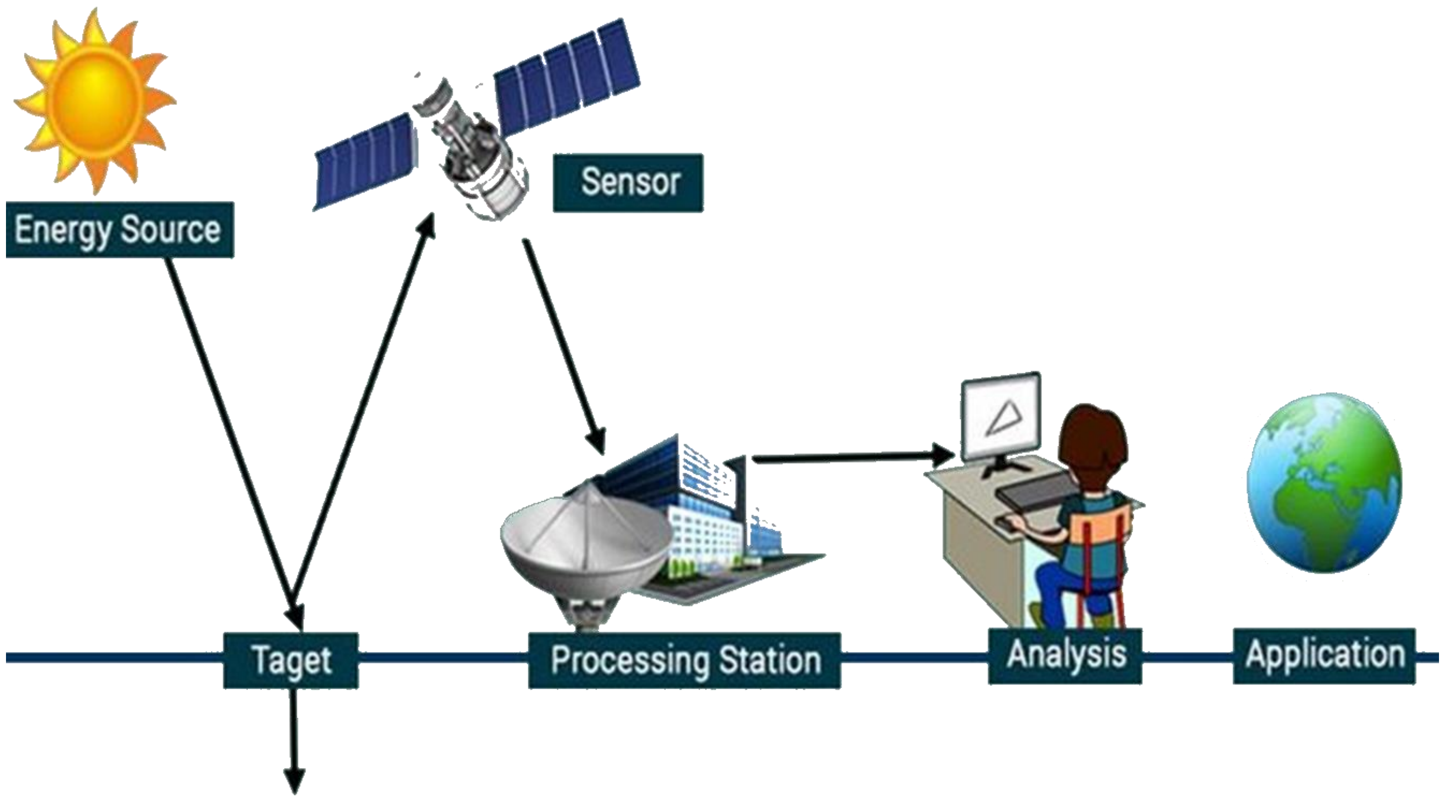
Causes the grey color of clouds and fog, since all λ in VIS region are disperse equally

# Part 2

Satellites' SENSORS

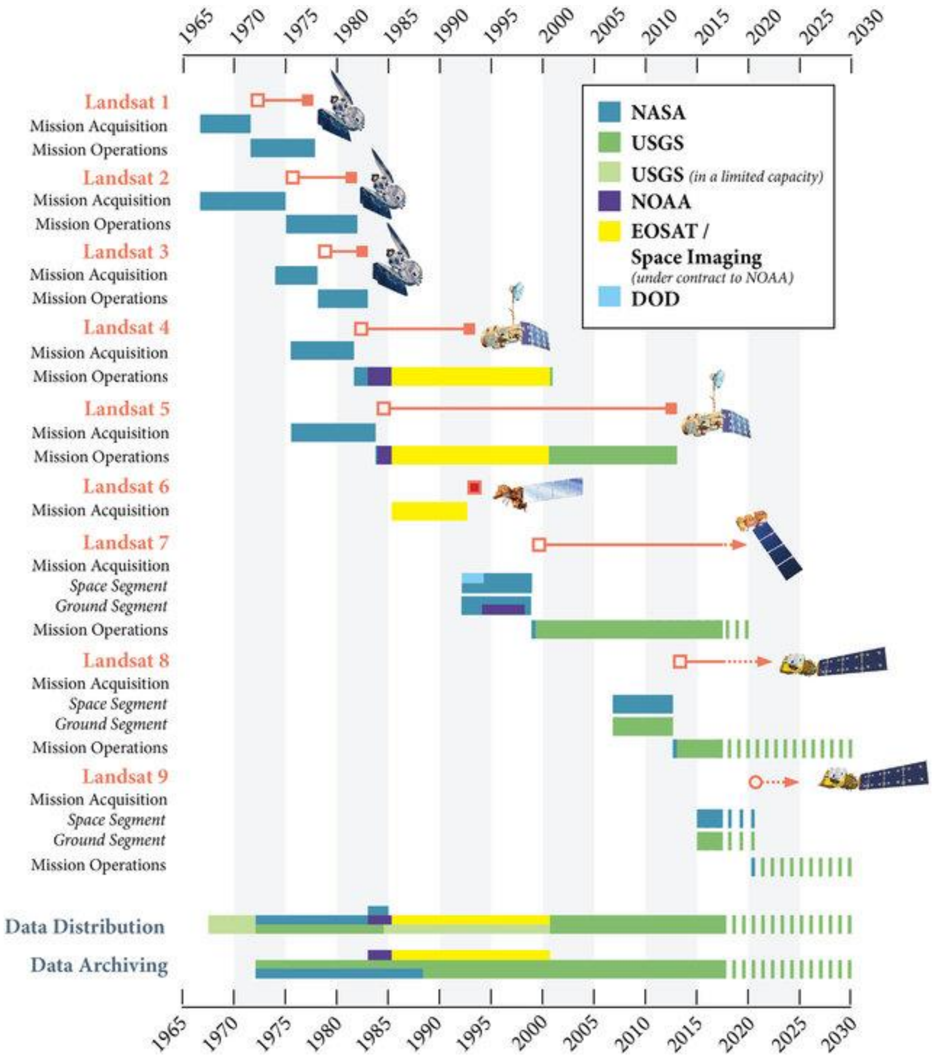


# Satellite systems properties

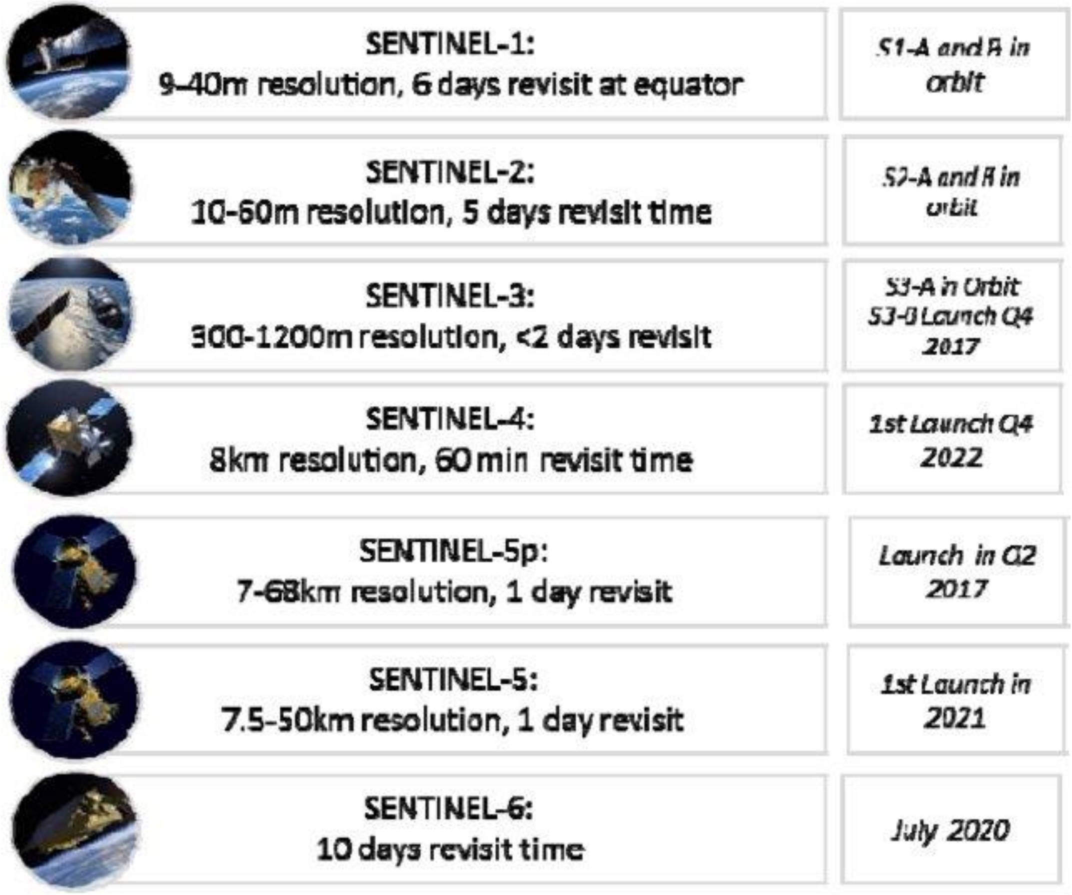


# Satellite systems properties

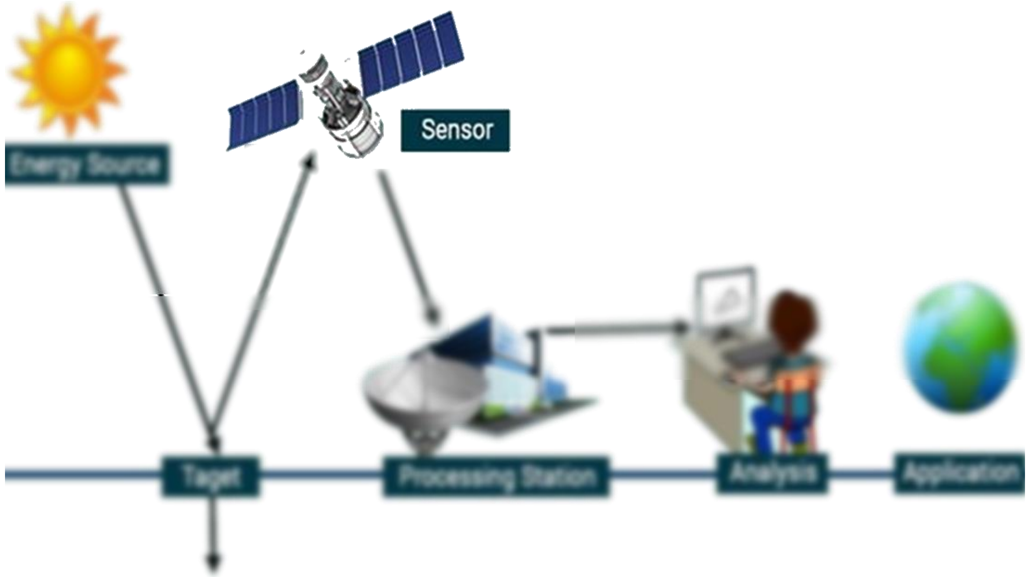
## Landsat mission




## Sentinel mission



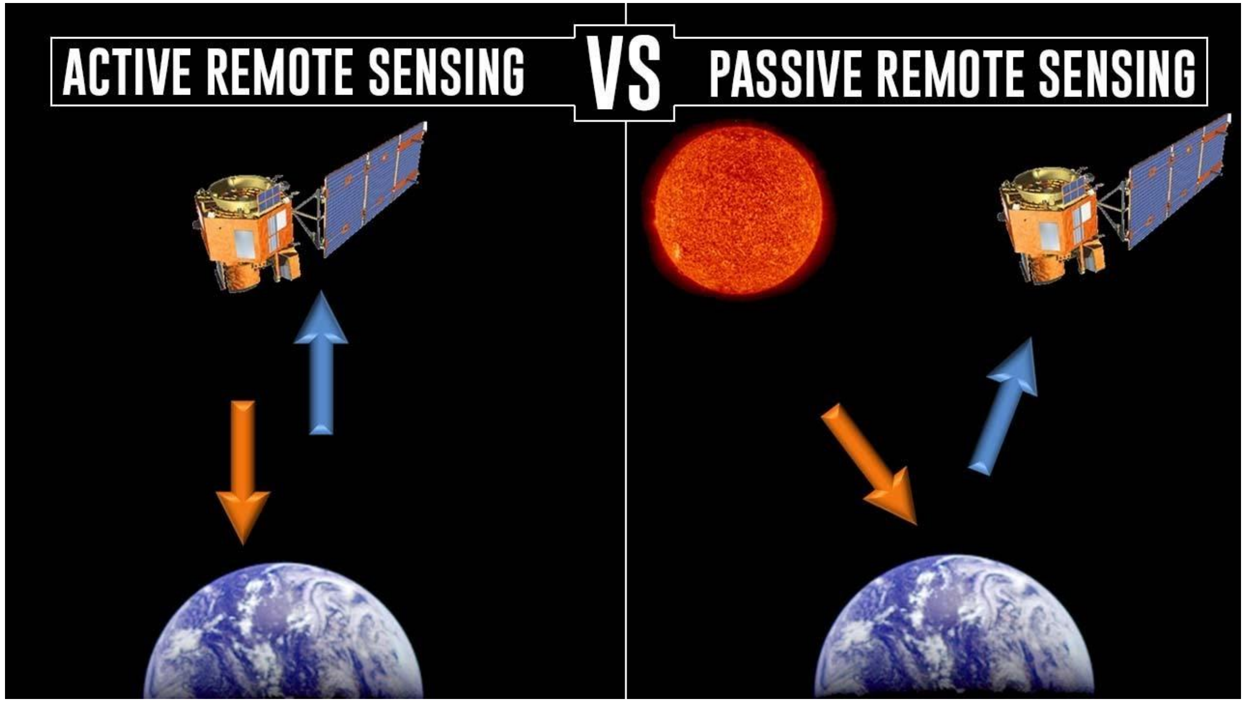
# Satellite systems properties




Satellites can be classified according to:

1. SENSOR TIPOLOGY
2. ORBIT TIPOLOGY
3. SCANNING TECHNIQUE
4. RESOLUTIONS
5. FIELD OF VIEW

# Sensor typology




Based on energy source:

1. **<u>Active sensors</u>**:
   These systems generate the energy pulses and collect them after the surface target reflects them back

2. **<u>Passive sensors</u>**:
   These systems measures the electromagnetic radiation derived from external sources (e.g. Sun), either reflected from solar radiation or emitted by Earth's surface

# Sensor typology: Active sensors

## 1. <u>RADAR</u>

- Works in different spectral bands in the microwave region (between 0.1 and 1 cm )
- Each pixel in the image represent the backscattering coefficient of that area on the ground.
- The value of the pixel is greater as more intense signals are received.
- Useful for soil mapping, vegetation change (after fires), forest biomass estimation

- Minimum size of an object:

$$R_s = \left(\frac{\lambda h}{\phi}\right)$$

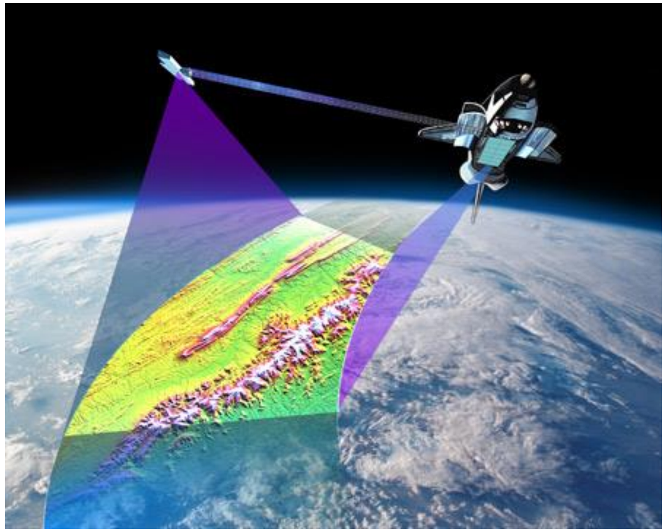
Height of the observation

wavelength

Diameter of the antenna/sensor

Sentinel 1

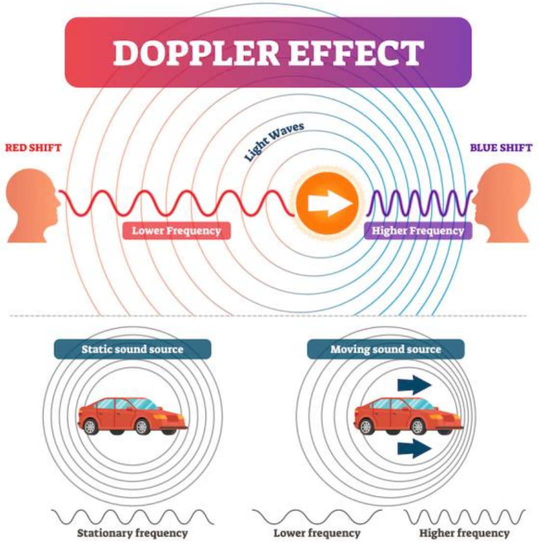

Shuttle Radar Topographic Mission (STRM)

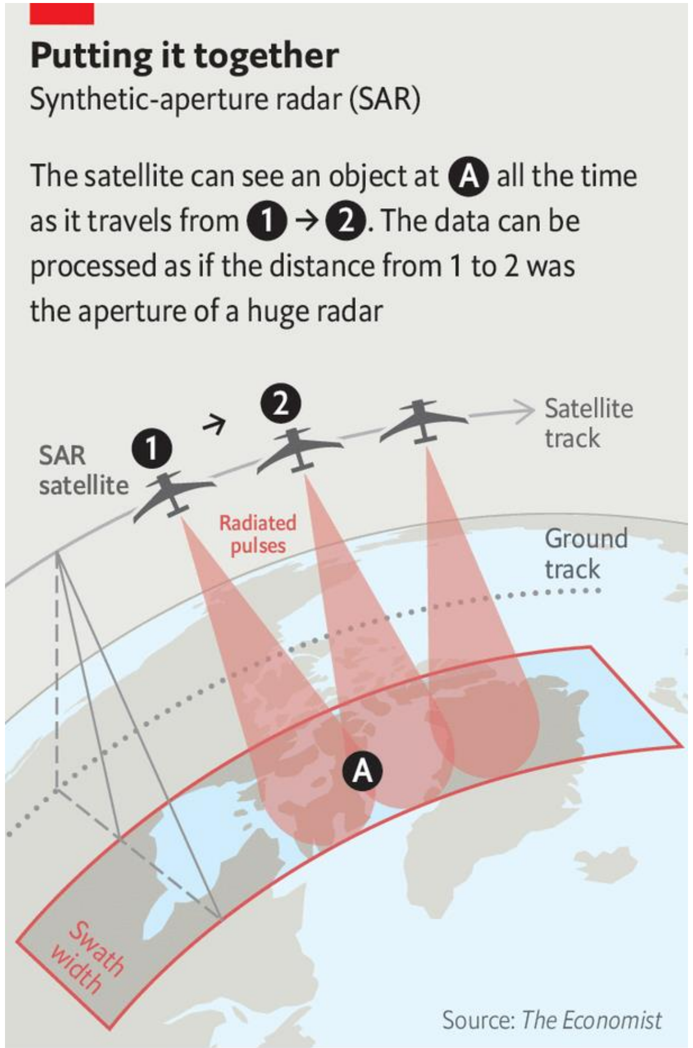


# Sensor typology: Active sensors

For satellite programs, very large antennas are required to have a high resolution.

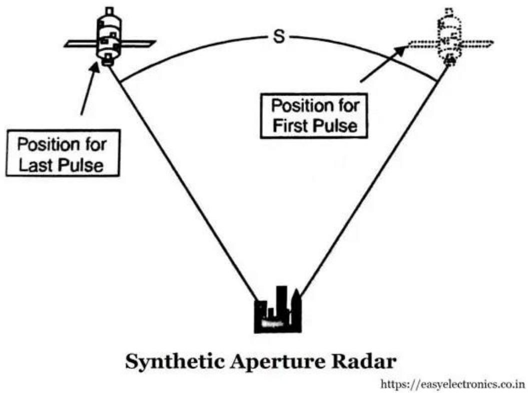
A solution is provided by **Synthetic Aperture Radar (SAR) systems**, which benefits from **DOPPLER EFFECT** = change in radiation frequency resulting from relative movement between the sensor and the observed surface.



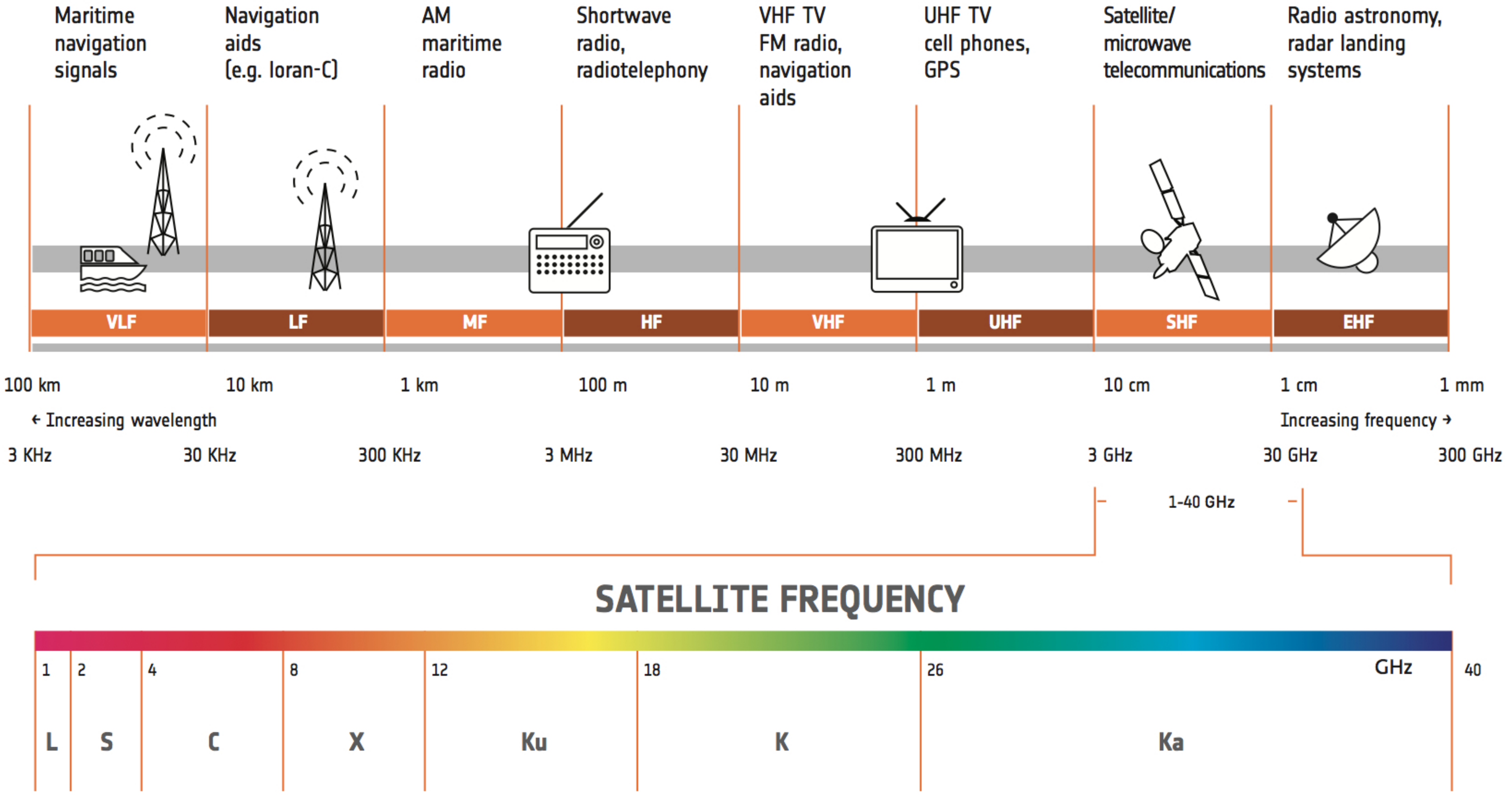




The Economist

- Space born radars emits continuously MW pulses to the ground
- As satellite orbits, emitted pulses are backscattered along satellite's path with a different frequency than the original
- The system can locate the point from where backscattered emission originates
- **The observed surface will be as precise as it if it was observed with an antenna which size = distance between the two points**



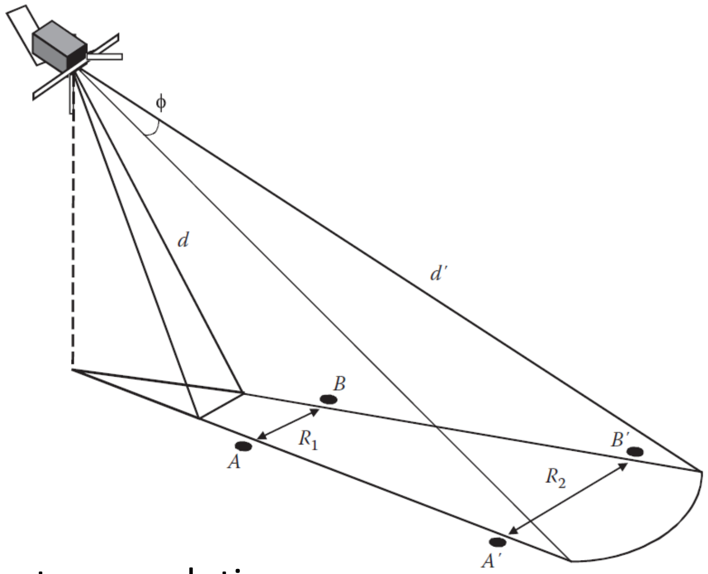
# Sensor typology: Active sensors



# Sensor typology: Active sensors


https://www.youtube.com/watch?v=g-YICKbcC-A

https://www.youtube.com/watch?v=em41MxplcDc




SAR have two resolutions:

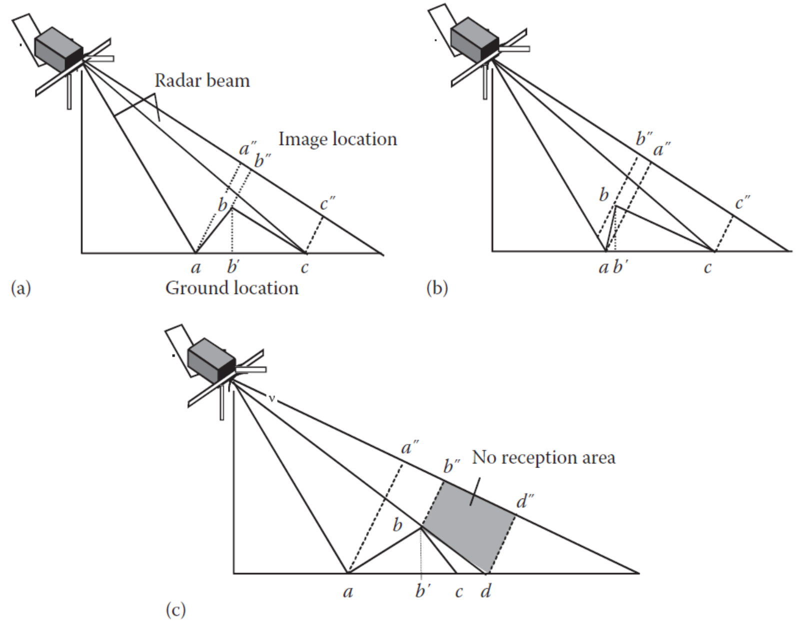
- Range resolution (parallell to satellite direction)

$$r_{range} = \frac{c}{2Bsen\phi}$$

- Azimuth resolution (perpendicular to satellite direction)

$$r_{az} = \frac{h\lambda}{L_a}$$

antenna length




a) If the surface slope is lower than incidence angle, then the distances in the image are SHORTER than in reality

b) If the slope is steep enough, there is a LAYOVER EFFECT = inversion of real position

c) According to surface roughness, some objects are not detected

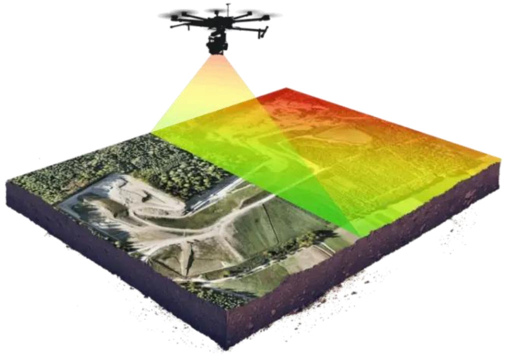
Multiangular observation can help in correcting for these distorsions

# Sensor typology: Active sensors

**<u>2. RADAR ALTIMETERS</u>**
Provide vertical measurements of distances between sensor and surfaces

**<u>3. RADAR INTERFEROMETERS</u>**
Measure differences in phase from two backscattered signals, which are produced by variations in terrain heights or object position

**<u>4. LIDAR</u>**
= LIght Detection And Ranging
Differences from radars:



- Works at different wavelengths: from Ultraviolet to NIR (affected by atmospheric conditions)

- Acquires energy pulses vertically
- Can be mounted on Unmanned Aerial Vehicles (e.g. drones, airplanes)

- For Earth Observation (EO) purposes, the time lag between pulse emission and sensing

$$d = \frac{ct}{2}$$

Distance from sensor to object

Measured EM from Earth's surface derived from external sources:
Energy **REFLECTED** from solar radiation
Energy **EMITTED** by Earth's surface

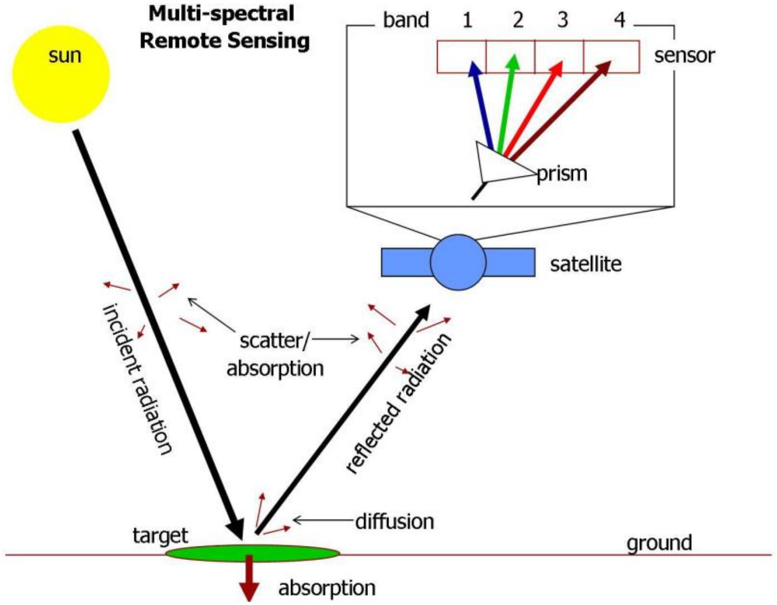
1. **Photographic cameras**:
   - *Panchromatic* films: all VIS region is captured and displayed in gray tones
   - *Color films*: several layers, each sensible to a band (color) in VIS
   - *IR black and white*: radiation between 0.7 – 0.9 µm is captured and displayed in gray tones
   - *Color IR films*: sensitive to three bands: green, red and NIR

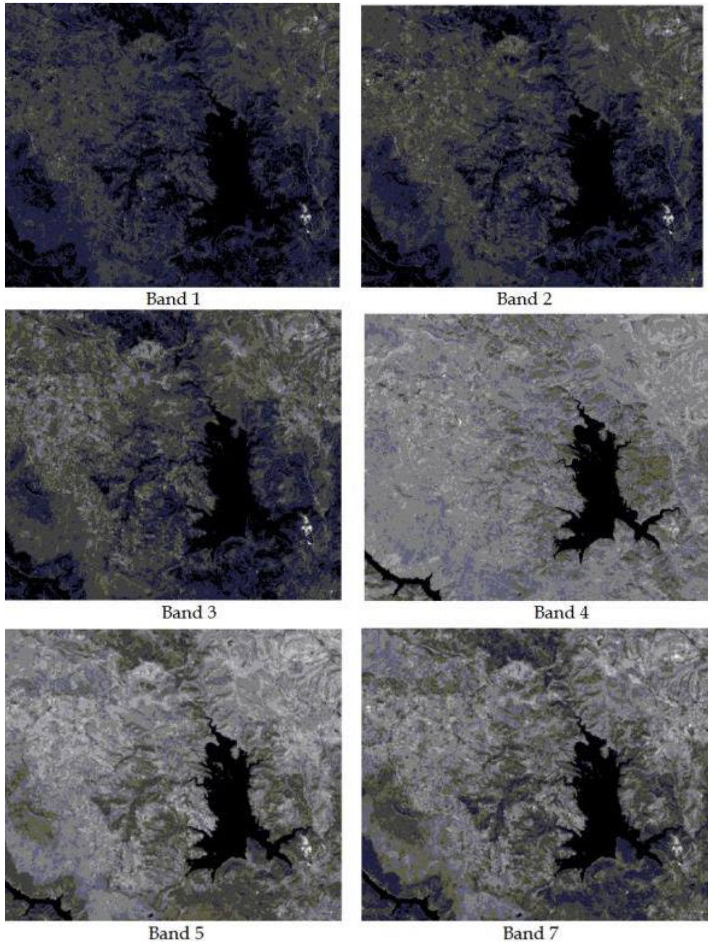
   - From 1991: ESC = Electronic Still camera which produced images in digital format

Bob Dylan, 1968. Photograph taken on infrared colour film by Elliott Landy / Magnum Photos

## 2. Electro Optical Scanner:

- Measures EM from VIS to TIR
- Are divided in IMAGERS vs NON IMAGERS sensors
- IMAGER SENSOR = **OPTICAL RADIOMETERS**, are the instruments that collects radiant energy
- There are different types of optical radiometers, differing for the method to separate wavelength contributions to detected radiation:
  1. PRISMS
  2. FILTER-WHEEL
  3. GRATING SPECTROMETERS
  4. INTERFEROMETERS



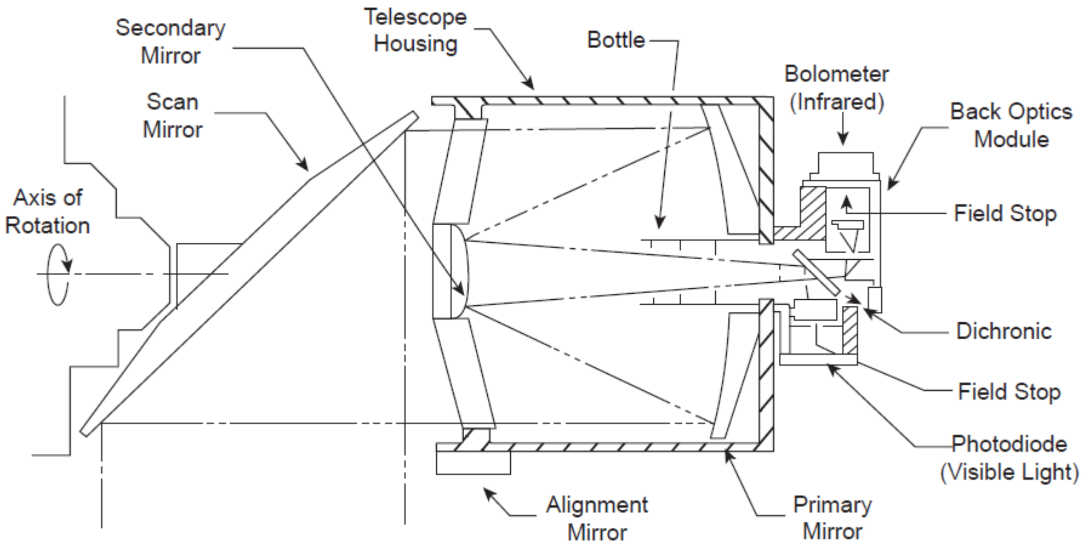



**FILTER WHEELS:**

- The most used ones
- A wheel of radiative filters is cycled through the radiation path to separate the different wavelength

- Large scan mirror rotates collecting radiation from Earth's surface
- Radiation is then focused by the primary mirror on the secondary mirror
- Radiation is then focused through the dichroic detector/filter (1 filter for each wavelength range)

- Dichroic (filtro interferenziale)=designed to pass EM radiation only in a relatively narrow wavelength range



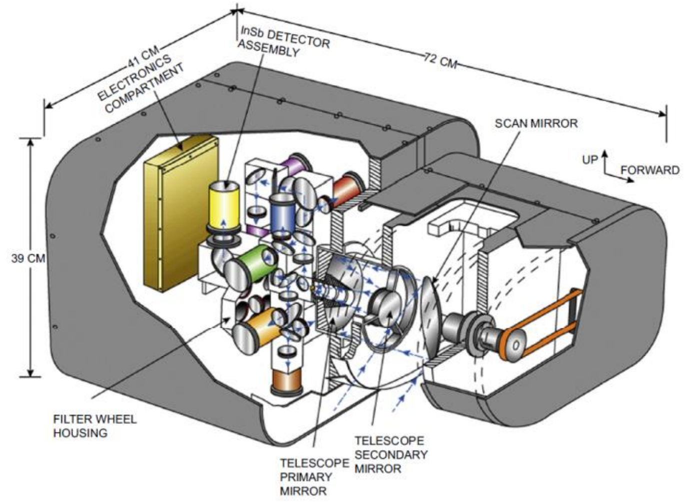
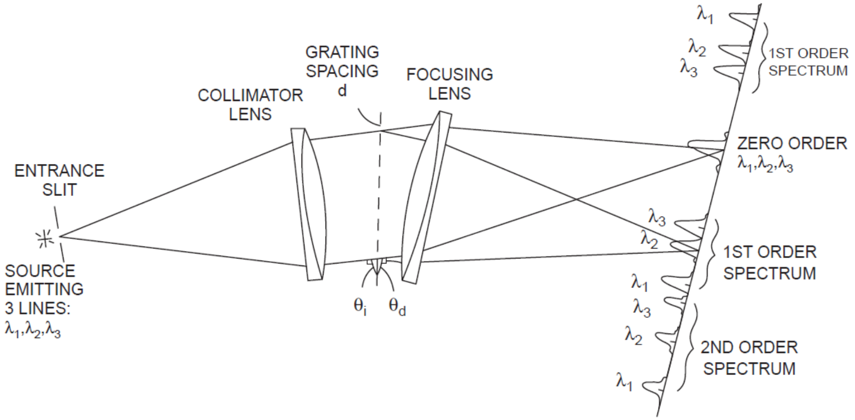




Diagram of the Cloud Absorption Radiometer (CAR): designed to measure light scattered by clouds in 14 walenght ranges (= spectral bands)

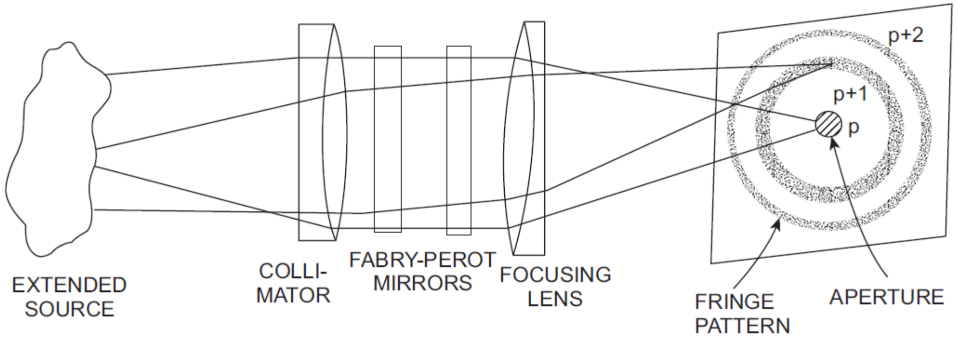
**GRATING SPECTROMETER:**

- Uses a grating to generate the interference pattern that separates radiation in different wavelength ranges
- An array of detectors is needed (as in prisms)



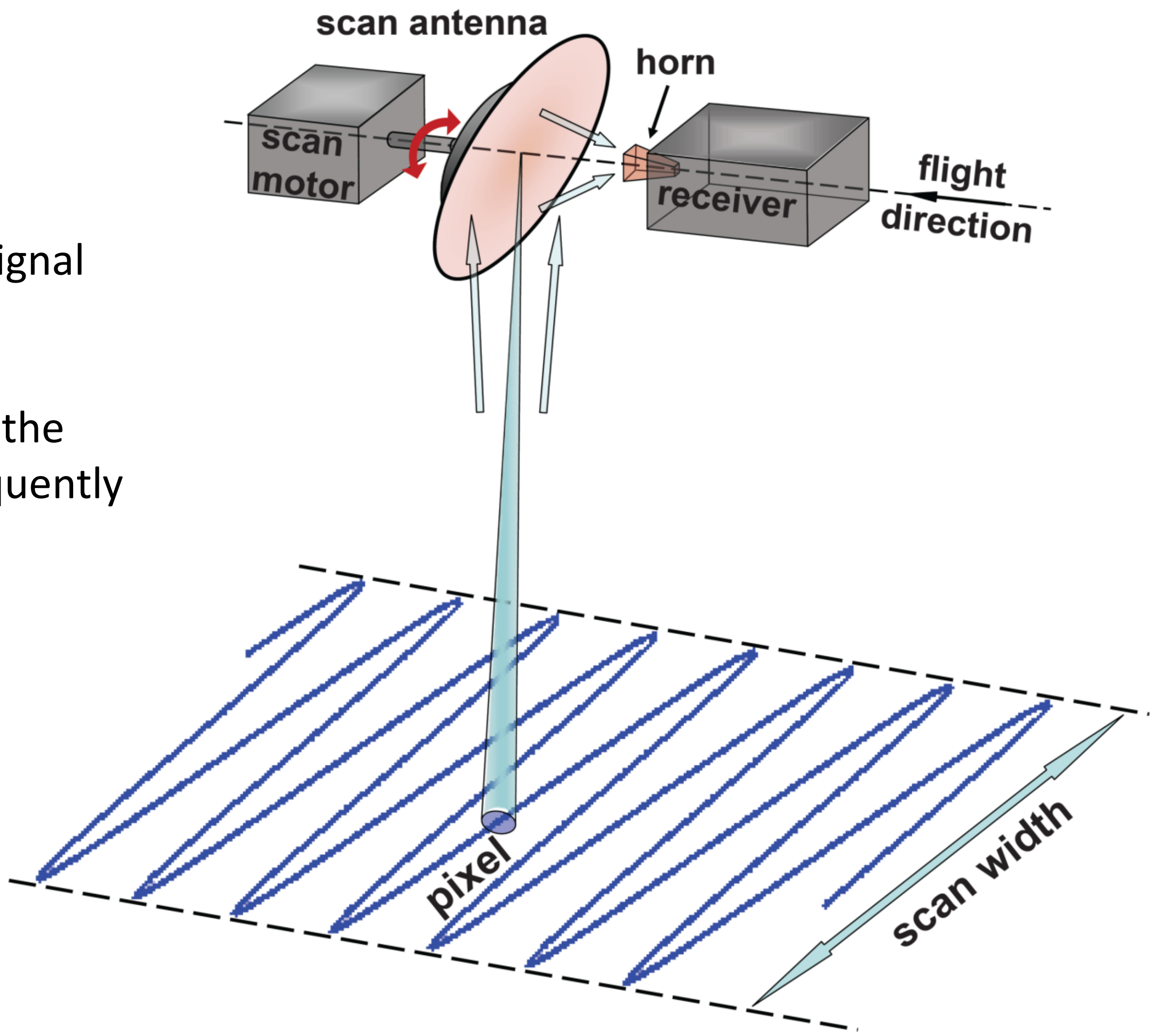

**INTERFEROMETERS**

- Dispersion mechanism is created by the spacing between two mirrors
- Different stepping intervals allow to separate out desired wavelength signals
- ADV: simple operation to adjest wavelength separation
- DISADV: finite amount of steps



**3. Microwave radiometer:**

- The sensors are integrated by:
  - A direction element
  - A RECEPTOR, which detects and amplify the signal
  - A DETECTOR
- The aperture of the receptor (antenna) affects the intensity of the collected radiation, and consequently affects the spatial resolution
- Useful to measure Earth's surface Temperature



# Orbit typology

Satellites orbit around the Earth thanks to the equilibrium between Earth gravitational force and the centrifuge effect.

Two different orbit types:

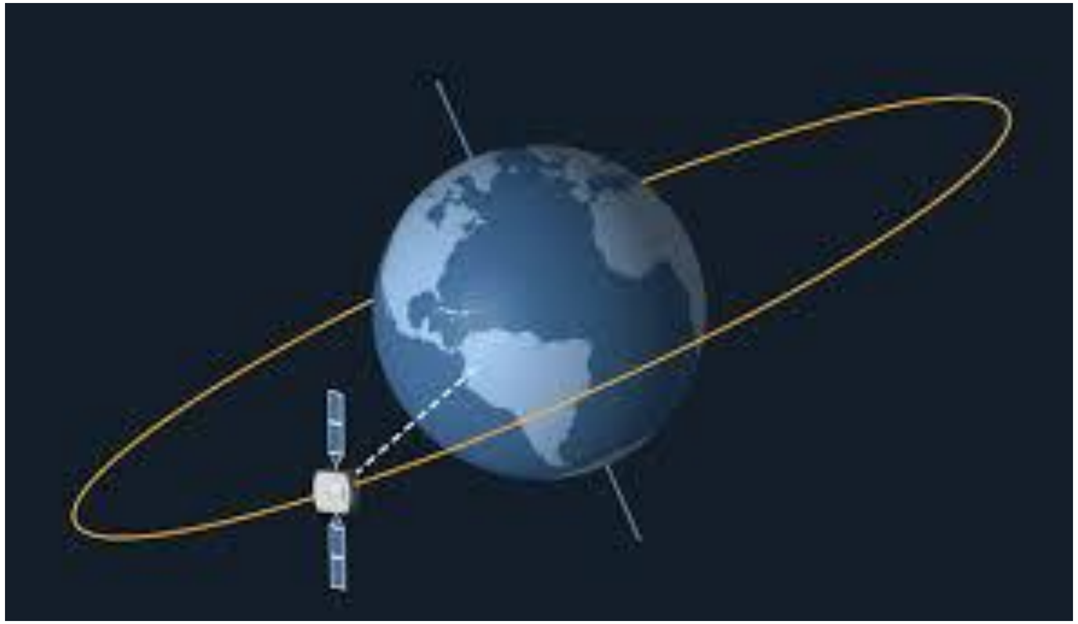
1. **<u>Geostationary orbits</u>**

   Located at very high equatorial orbits (36,000 km)

   <u>Always the same area is observed</u> (stationary respect to the Earth)

   In this way, one satellite can observe quite half an emisphere

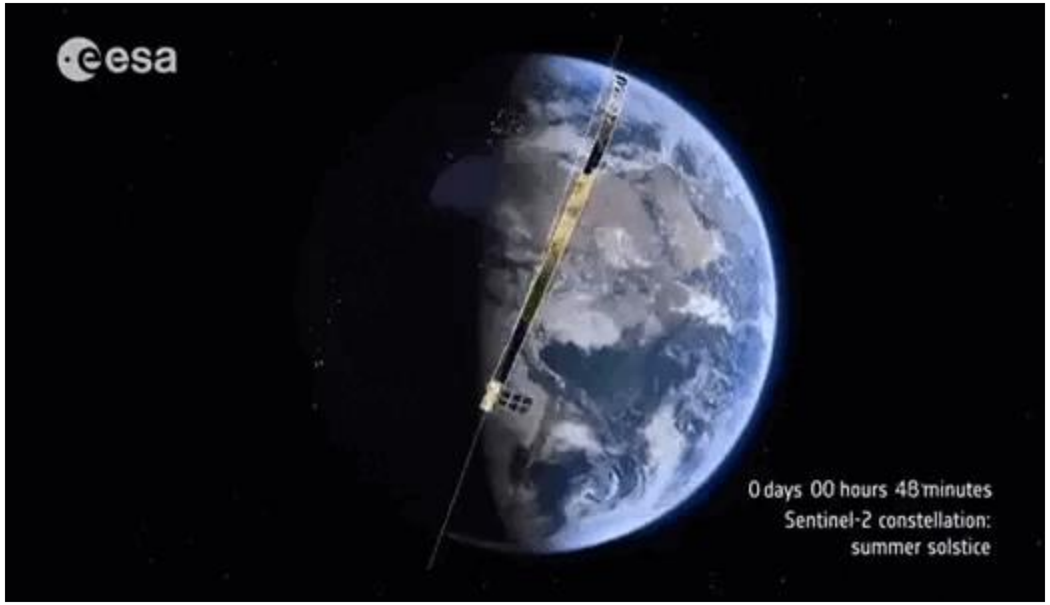
   Generally used for satellite developed to observe metereological conditions

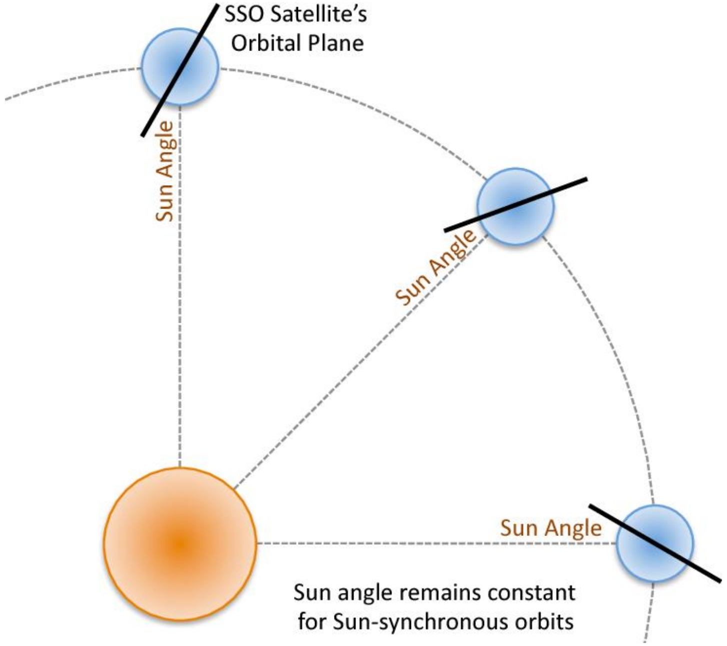


**2. Sun-synchronous orbits**

- lower altitudes (700-900 km)
- Most of them are near-polar orbits, as the orbital plane is approximately perpendicular to the equatorial plane (inclination 95-100°)

- As Earth rotates, satellites observes different areas
- Can cover the whole globe in hours/days depending on satellite's height




- These satellites can avoid the problem of different light conditions that occur according to latitudes, seaons and hours of the day

- This is thanks to angle between the line connecting Sun's centre to Earth and the orbital plane of the satellite, which is CONSTANT

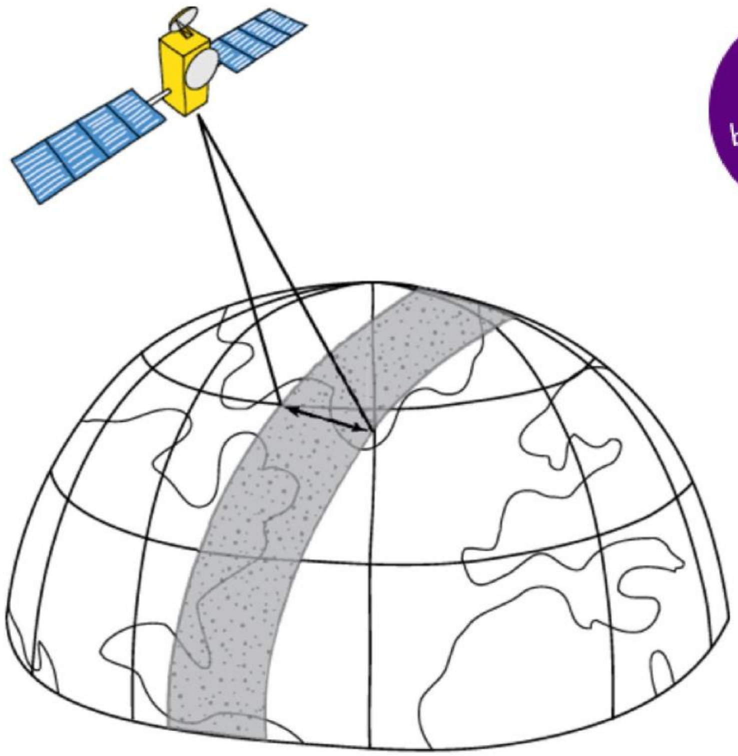
- Satellites pass on the same hour of the day in the same place:
  For FVG: Landsat 8 [9:40 GMT], Sentinel-2 [10:00 GMT]

# Scanning technique

For Sun-synchronous orbits, each time the satellite complete a rotation around the Earth, a new portion of Earth's surface.

The surface scanned is called **swath** (strisciata) and generally range between 10 and hundreds of kilometres depending on the orbit and sensor typology used.

The swath is comprised between a view angle and it represents the Field Of View (FOV) of the satellite.



developed by NASA scientists

# Scanning technique

Two different scanning techniques:

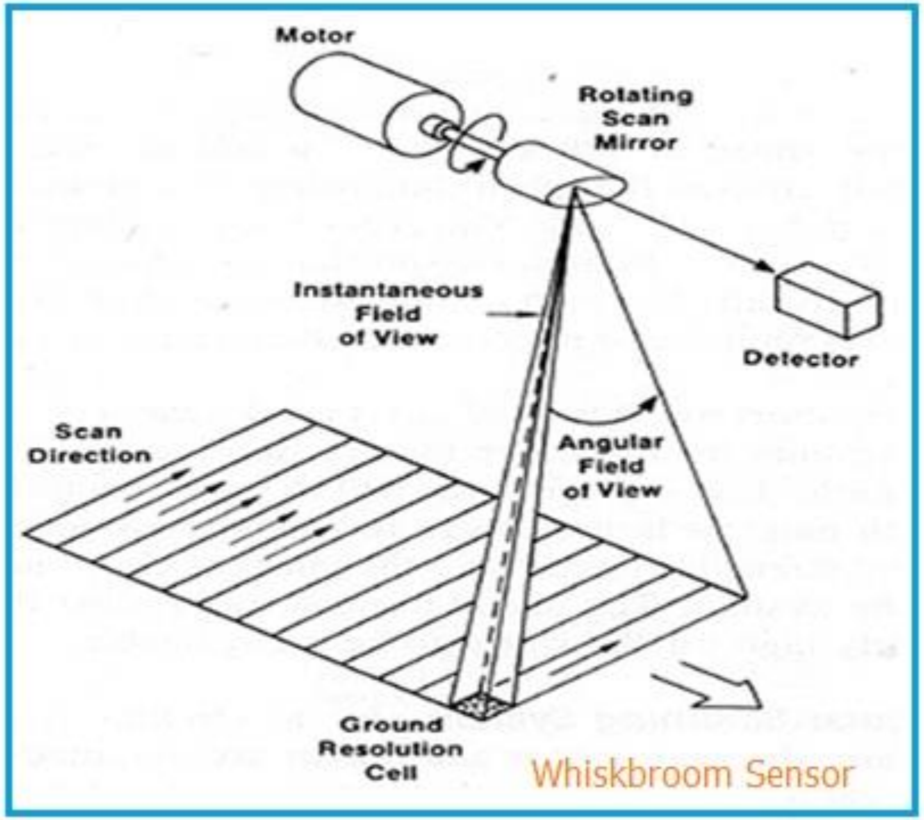
1. **<u>Cross-track scanner (whisk-broom)</u>**

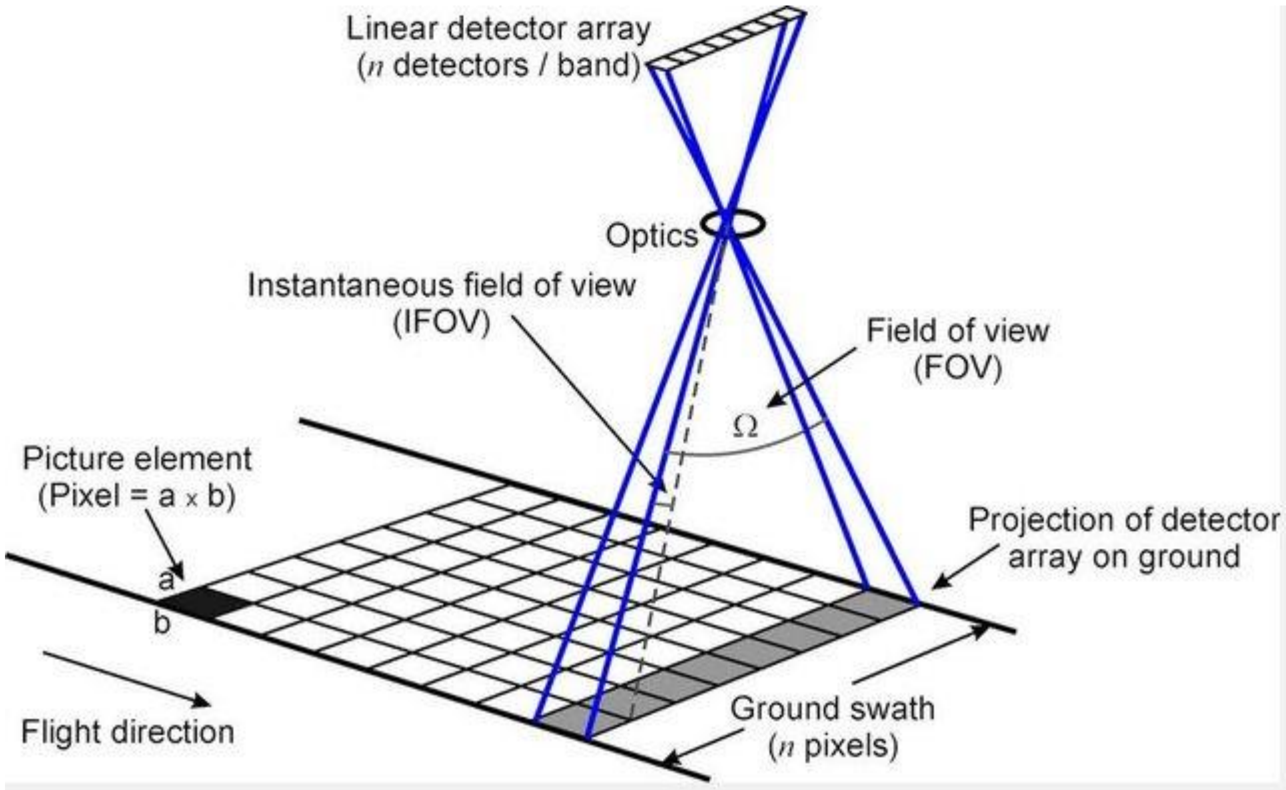
   The incoming radiation is focused by a set of lenses and mirrors that rotate perpendicularly to the satellite track

   The collected radiance is directed to a series of detectors that amplify the signal and convert it in a value that can be stored on the satellite or directed to a receiving antenna

   Examples: MODIS or MultiSpectral Scanner (MSS) on Thematic Mapper (TM) on Landsat

   <u>Each pixel and each swath are registered in sequence</u>






**2. <u>Across-track scanner (push-broom)</u>**

They avoid the use of mirrors, but use a linear array of detectors

<u>The whole FOV is detected by the sensor at once</u>

The sensor explore each line simultaneously

The advantage is that the integration time is improved, and the same point is scanner for longer time

Used in Operational Land Imager (OLI) in Landsat 8 and Landsat 9, as well as in MultiSpectral Instrument (MSI) Sentinel-2

## Scanning technique

## SPATIAL RESOLUTION

It is the size of the pixel in the image (in m)

It identifies the minimum separation at which objects appear independent and isolated

In optical electronics, it is identified with the Instantaneous Field Of View (IFOV)

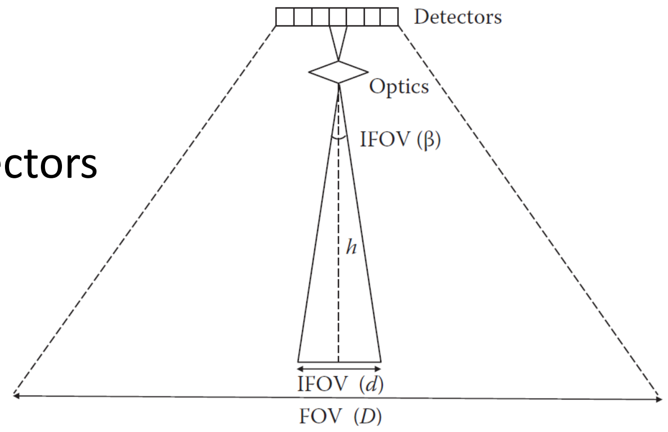
$$d = 2h \tan\left(\frac{IFOV}{2}\right)$$

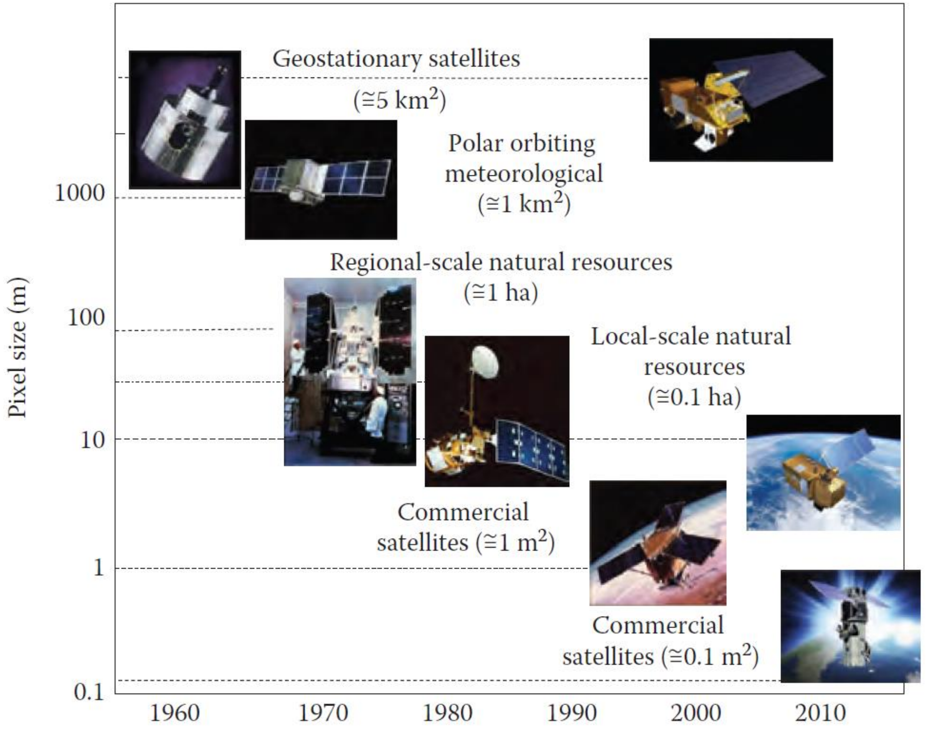
Height of the observation ($h$)

Distance on the ground per each information unit (pixel) ($d$)

It depends on:

- Orbital height
- Number of detectors
- Aperture angle




Swath: Landsat = 185 km, Sentinel-2 = 290 km in tiles 100x100 km

# Satellite resolutions

## SPECTRAL RESOLUTION

It refers to the **number of bands** (=regions of the EM spectrum) provided by the sensor and **their spectral bandwidth**

Ideally, the higher the number of band is, the higher the discrimination capacity is.

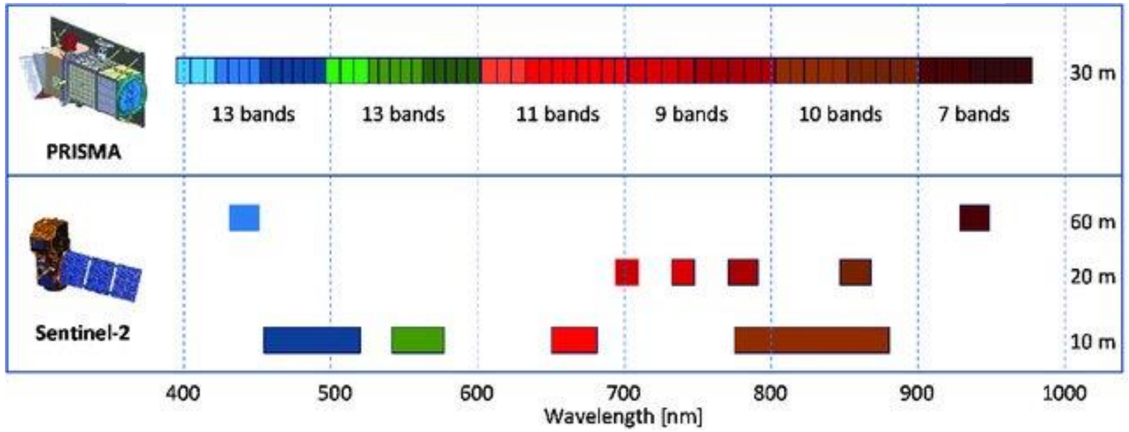
Each spectral band should be narrow enough to identify specific absorption features

Type of sensor according to spectral resolution:

1. Radar system, generally 1 band in MW region
2. PANCHROMATIC, 1 band containing all the radiation in VIS
3. COLOR, 3 bands in VIS (RGB bands)
4. **MULTISPECTRAL**: 4 to 13/15 bands, can range from ultraviolet to TIR
5. **HYPERSPECTRAL**: hundreds of bands, generally from VIS to SWIR

Sentinel-2

| BAND | SPECTRAL | WAVELEN. [μm] | GEOM. [m] |
|---|---|---|---|
| 1 | aerosols | 0.429 – 0.457 | 60 |
| 2 | blue | 0.451 – 0.539 | 10 |
| 3 | green | 0.538 – 0.585 | 10 |
| 4 | red | 0.641 – 0.689 | 10 |
| 5 | red edge | 0.695 – 0.715 | 20 |
| 6 | red edge | 0.731 – 0.749 | 20 |
| 7 | red edge | 0.769 – 0.797 | 20 |
| 8 | NIR | 0.784 – 0.900 | 10 |
| 8a | narrow NIR | 0.855 – 0.875 | 20 |
| 9 | water vapour | 0.935 – 0.955 | 60 |
| 10 | SWIR cirrus | 1.365 – 1.385 | 60 |
| 11 | SWIR | 1.565 – 1.655 | 20 |
| 12 | SWIR | 2.100 – 2.280 | 20 |



**RADIOMETRIC RESOLUTION**

It **denotes the sensitivity of a sensor**, which is defined as the capacity to discriminate small variations in the recorded spectral radiance

In photographic systems, it is given by the number of gray levels captured by the film

In optical sensors, it is expressed as the range of values used for coding the input radiance = n bits used to store the input signal.

Example: how many input radiances can an 8-bit sensor discriminate??
$2^8$=256 (range: 0-255) – each bit = grey value on a gray scale

Thanks to improvement in data transmission and data storage, radiometric resolution is improving

Example: Landsat 8 OLI = 16-bit; Sentinel-2 MSI = 12 bit (0-4095 brightness levels)

**TEMPORAL RESOLUTION**

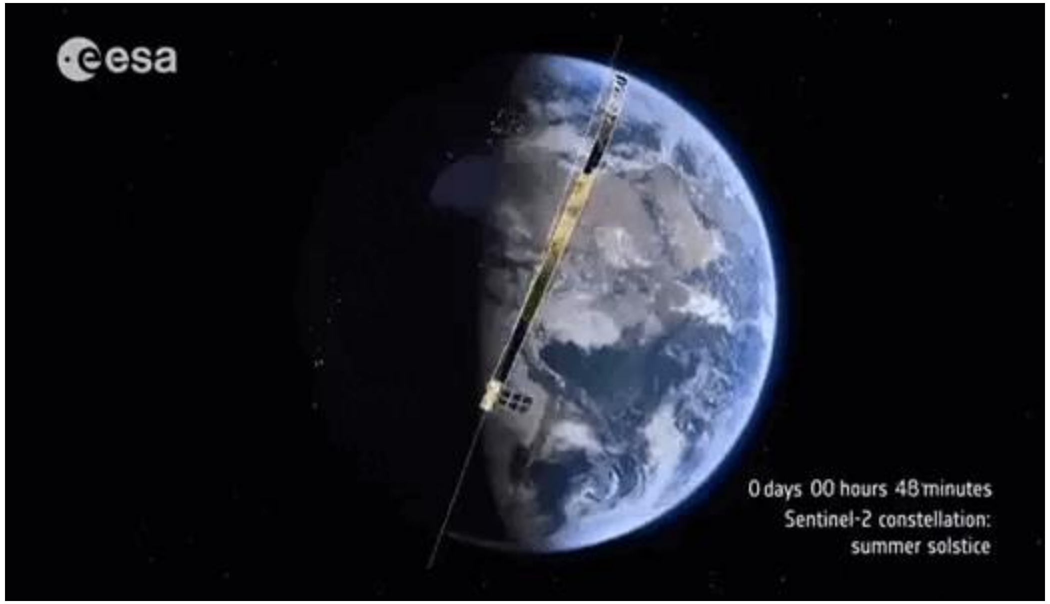
It is the observation frequency or **REVISITING PERIOD provided by the sensor**

Depends on orbital type and FOV of the satellite

Generally, sensor with HIGH temporal resolution, have LOW spatial resolution (HIGH FOV)

On the other hand, sensors with lower FOV need MORE ORBITS to scan one given area and MORE TIME to return to the same area

Solutions??
Sentinel-2A and Sentinel-2B
Revisiting time = 5 days



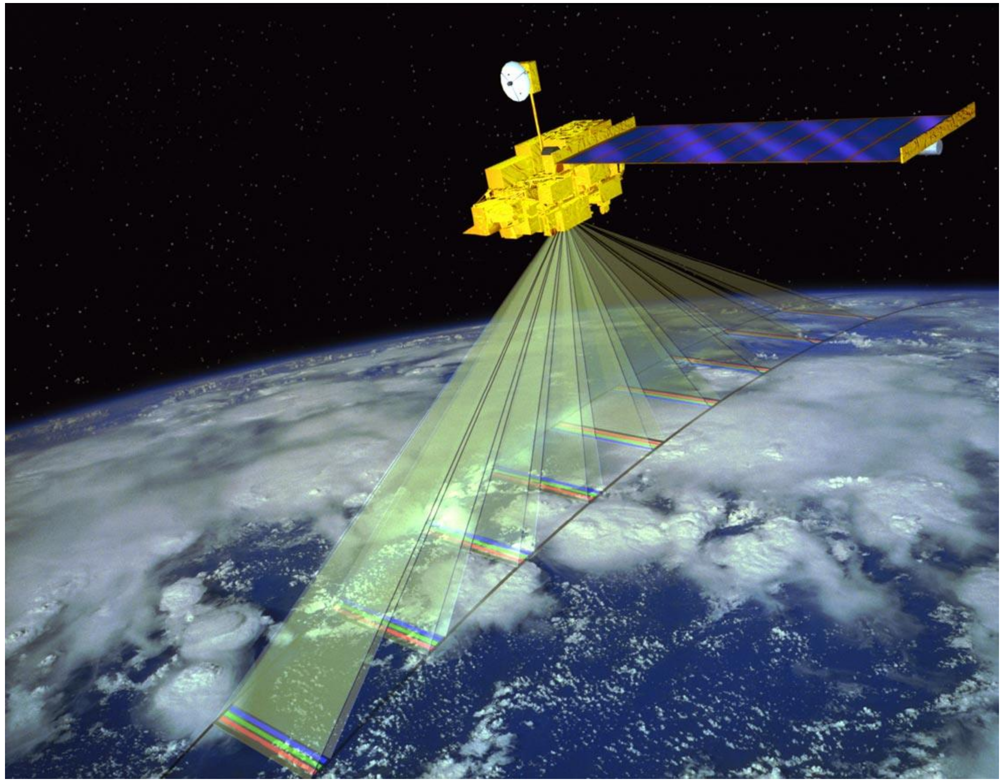
**ANGULAR RESOLUTION**

It is a recent concept

It refers to sensor's capacity to make observations of the same area from different angles

DISTORSION! The variations in reflectance with viewing and illumination angles are commonly named Bidirectional Reflectance Distribution Function (BRDF)

Some satellites improves their FOV by detecting signal from multiple angles, thus better characterising the BDRF.



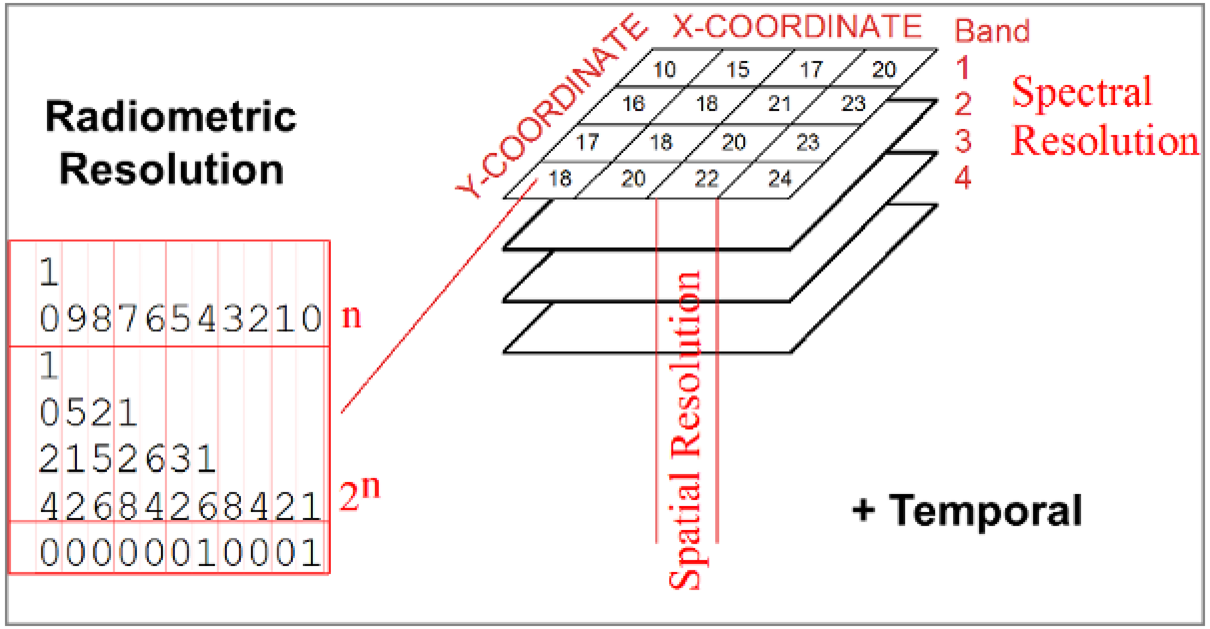
# Relationships between satellite resolutions

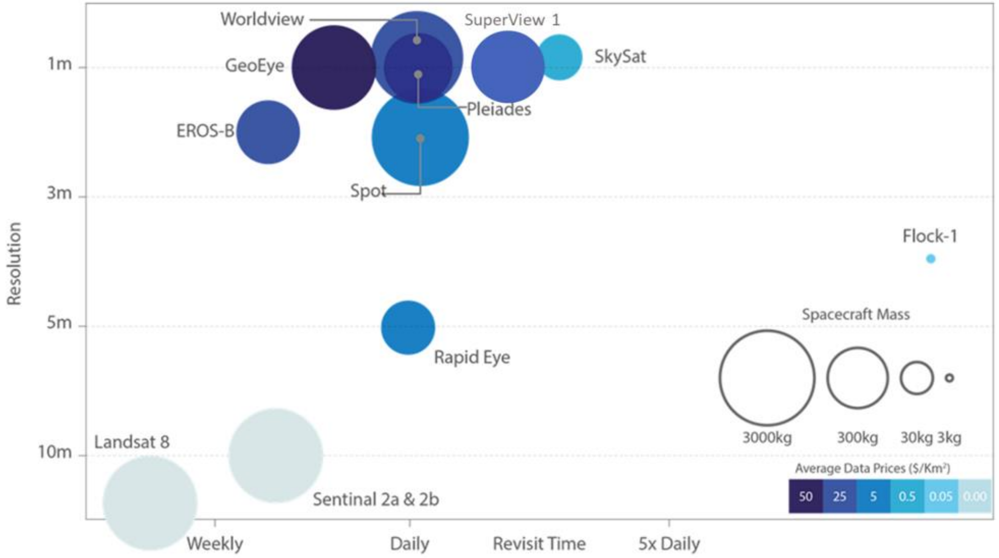
The resolutions of a sensor are closely interconnected.

Example: to increase spatial resolutions, usually temporal and /or spectral are decreased.

Considering limitations in data transmission or record, a sensor can optimize one or two resolutions. The main problem is the volume of data…

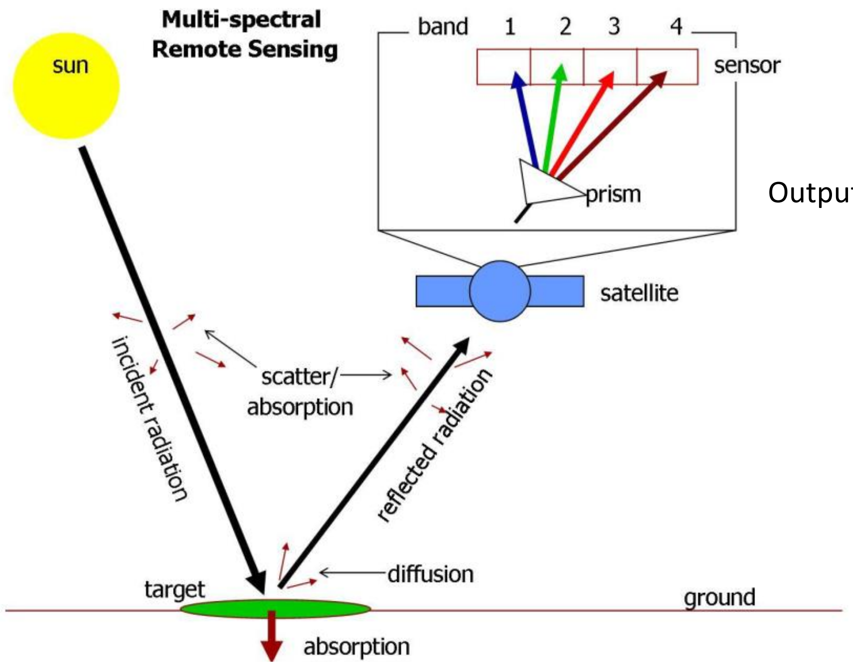
Unless you pay…



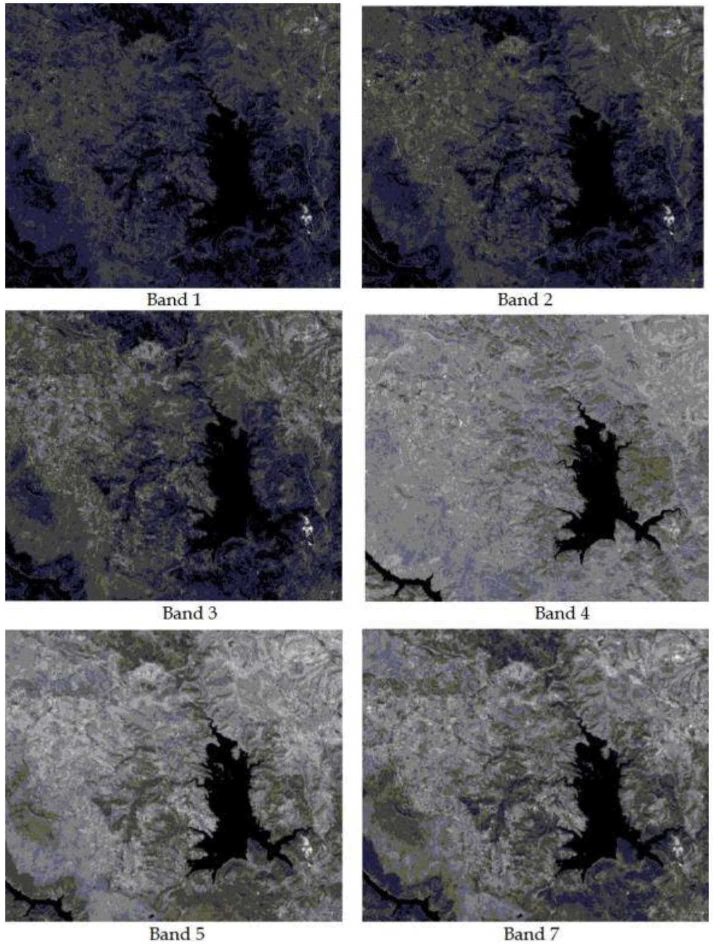

How does satellite images generate?

Once the radiation reaches the detectors within the sensor, it induces VOLTAGE and CURRENT.




$$V_0 = \frac{L_i}{G_\#} A_{\text{det}} \cdot \Delta\lambda \cdot R$$

- $L_i$: Incoming radiance
- $V_0$: Output voltage
- $G_\#$: G number, related to the inverse of FOV
- $A_{\text{det}}$: Area of the photodetector
- $\Delta\lambda$: Spectral width
- $R$: Photodetector's responsivity



Digital Images are a numeric translation of the original radiances received by the sensor.

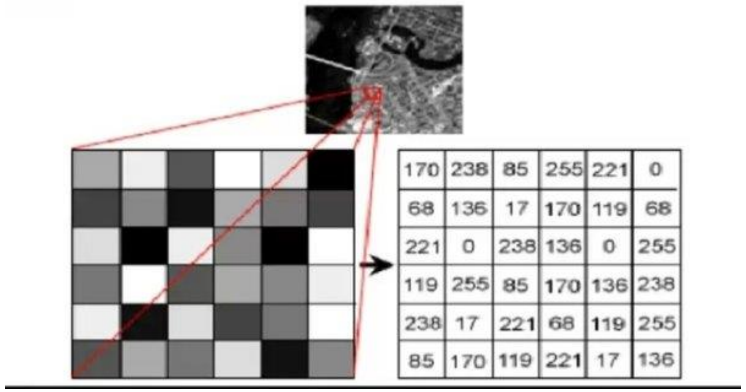
They can be described as 2D matrices (3D if we include the spectral dimension)

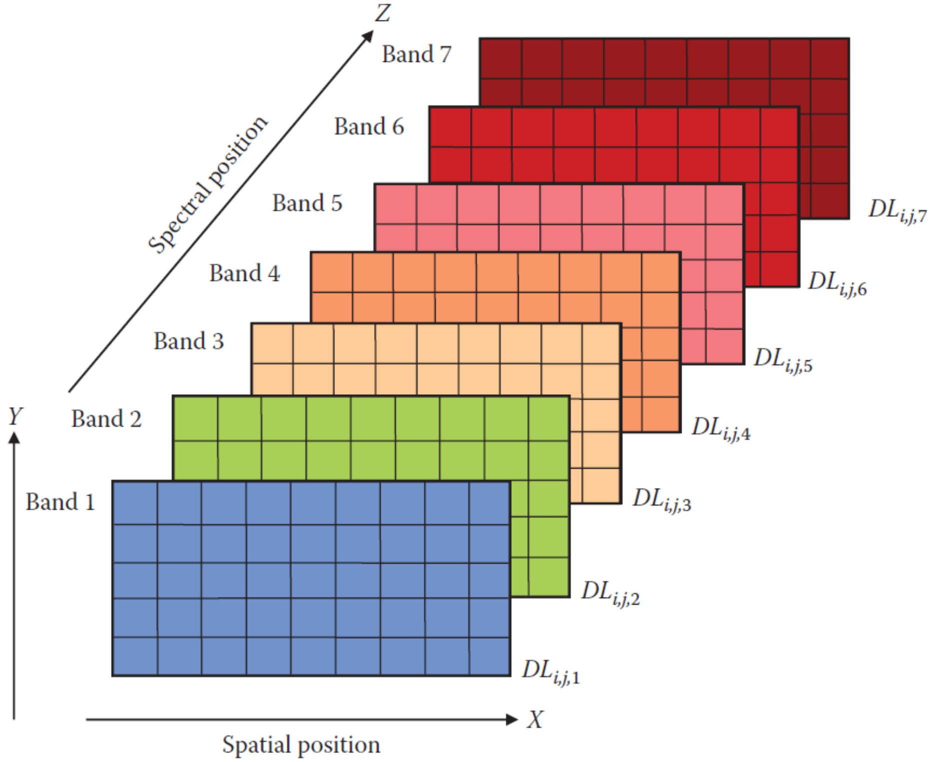
Radiances are observed every x-meter, where x is the projected area of IFOV on the ground (=pixel).

For each band, **radiance is transformed into a values indicating the brightness of the pixel**. These values are called Digital Numbers (DNs) or Digital Levels (DLs).

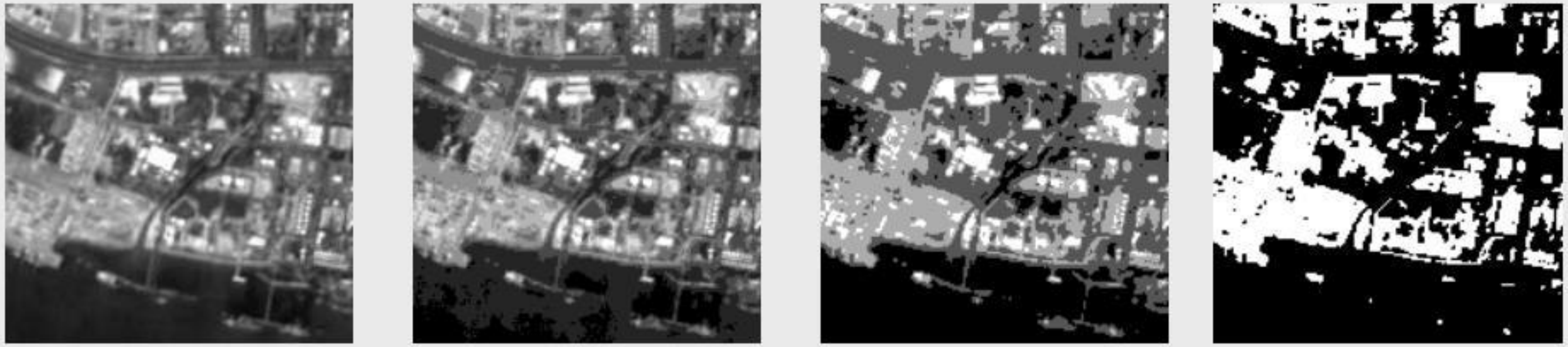
**There are as many DNs as the radiometric resolution of the sensor.**
The coding range is expressed in the number of bits per pixel required to store that DN.

From DNs it is possible to retrieve physical parameters such as reflectance and temperature.



# STRUCTURE of a DIGITAL IMAGE

8 bit (256 levels) | 3 bit (8 levels) | 2 bit (4 levels) | 1 bit (2 levels)

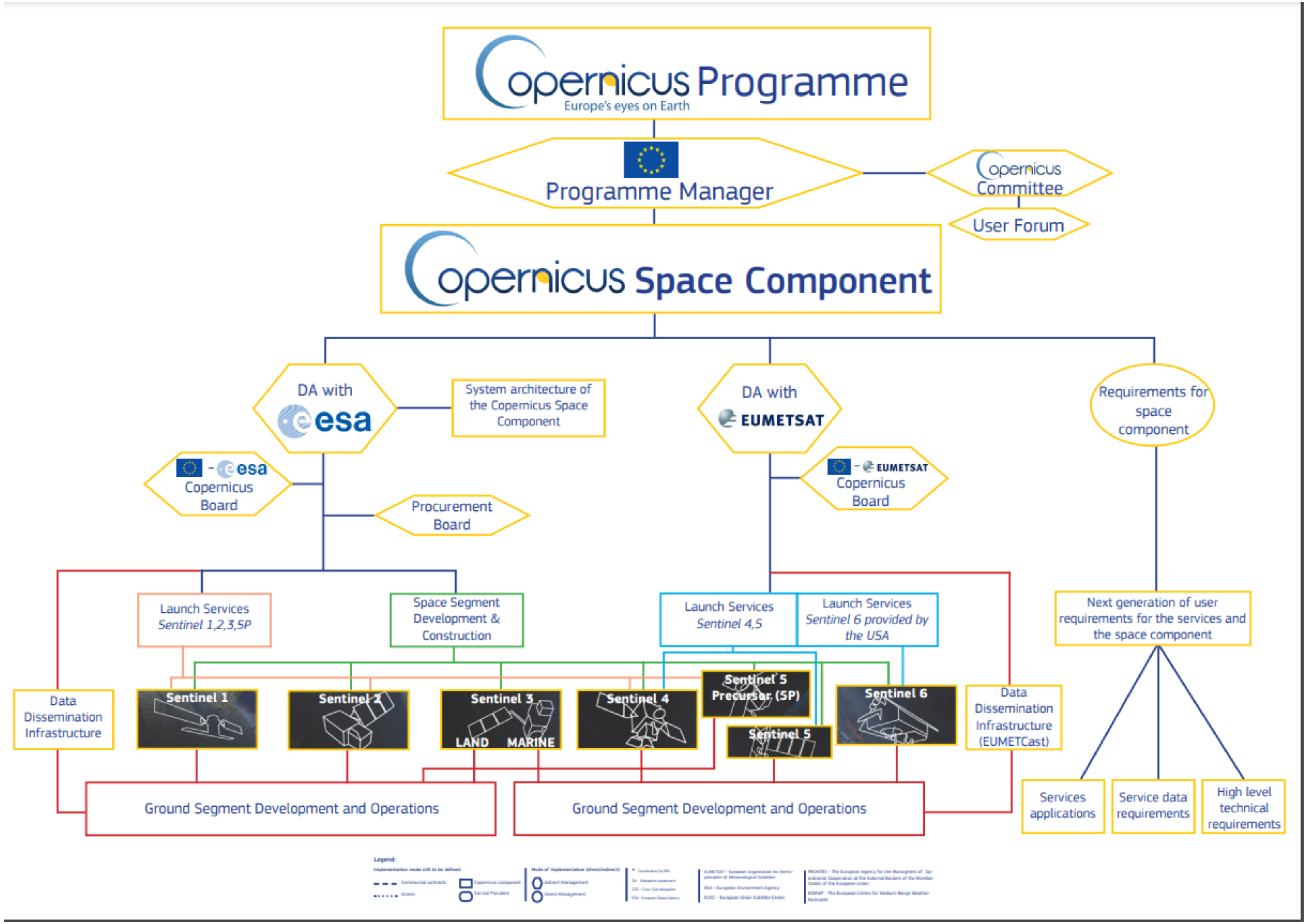
# SENTINEL MISSION

It is part of the ESA Copernicus Programme (launched in 2014) (https://www.copernicus.eu/en/about-Copernicus)

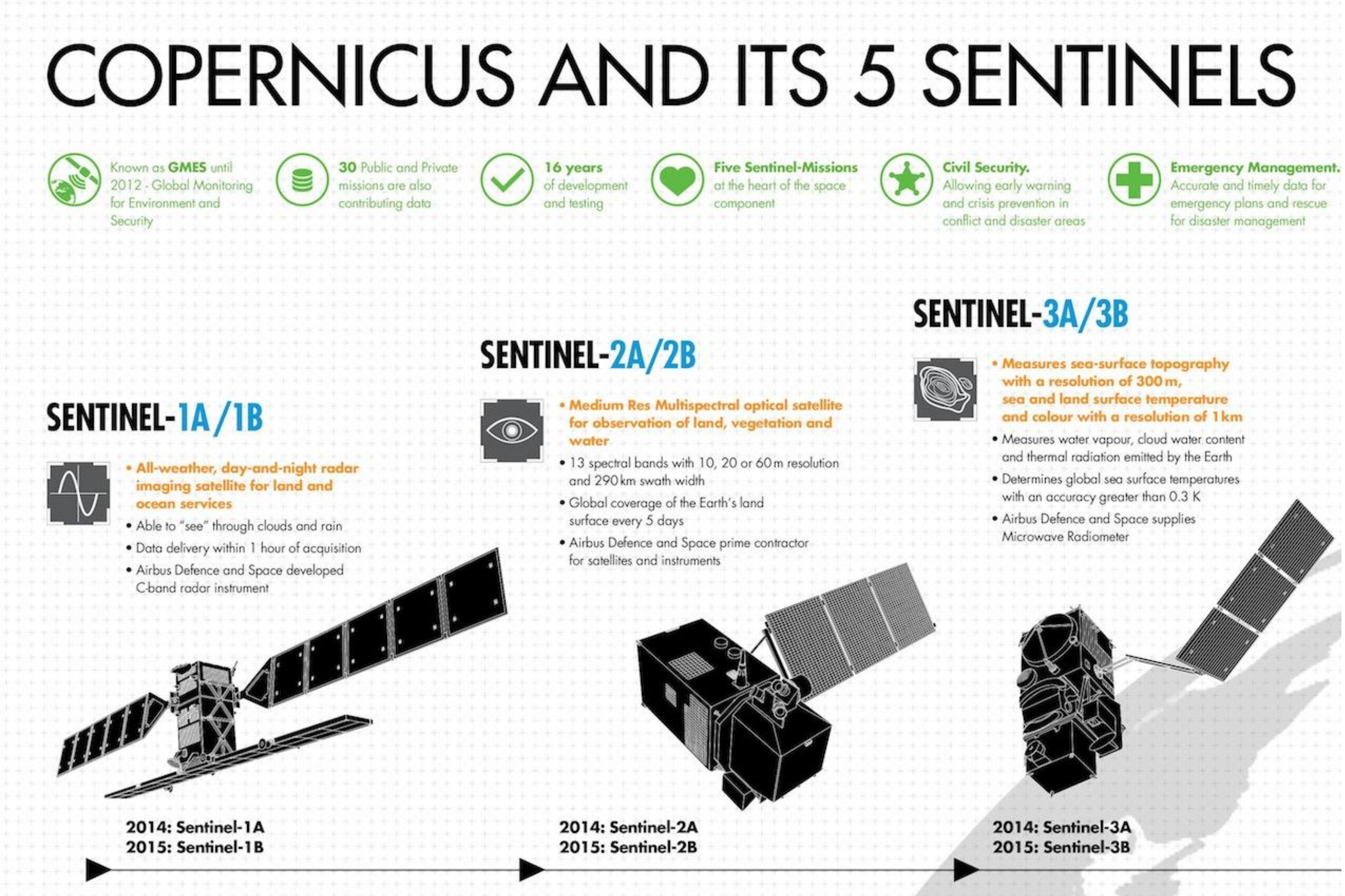
Copernicus' objectives:

1. Produce and disseminate information to support EU global policies for environment and security
2. Provide a platform of stakeholders, providers and users
3. Provide a legal, financial, organisational and institutional framework for the function of ESA satellites

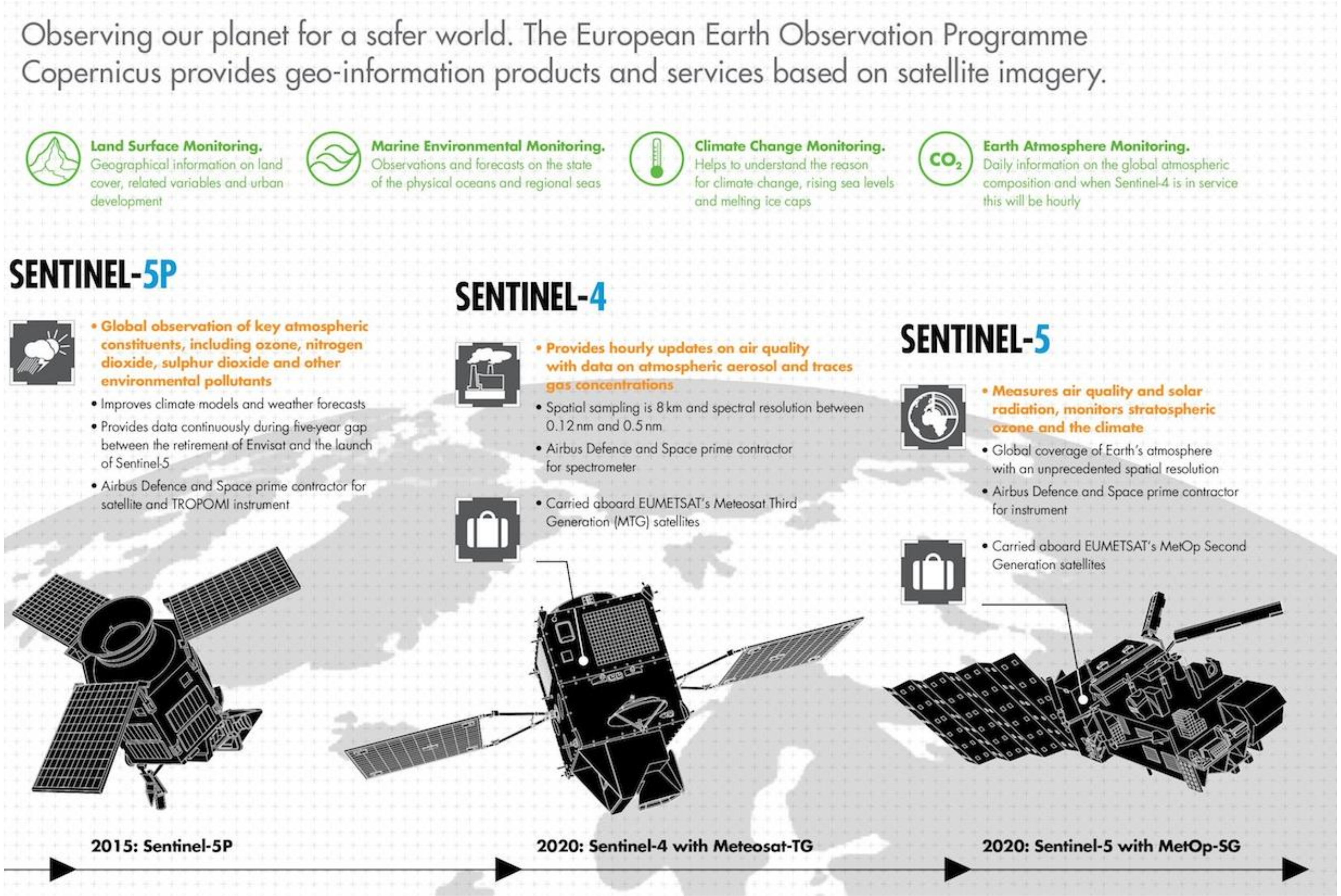
https://www.youtube.com/watch?v=MGJss4lDaBo&t=1s



SENTINEL MISSION

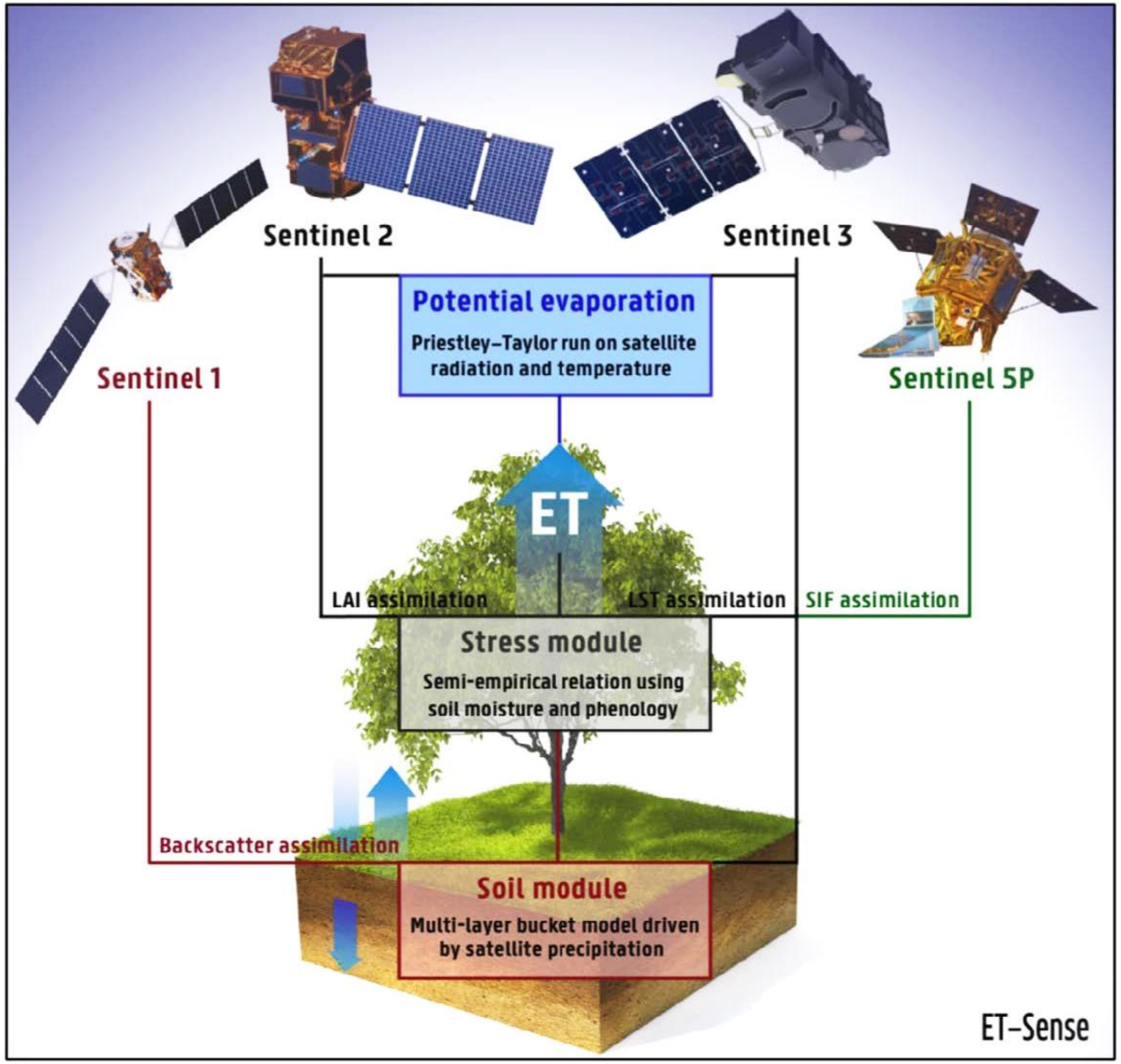


# SENTINEL MISSION

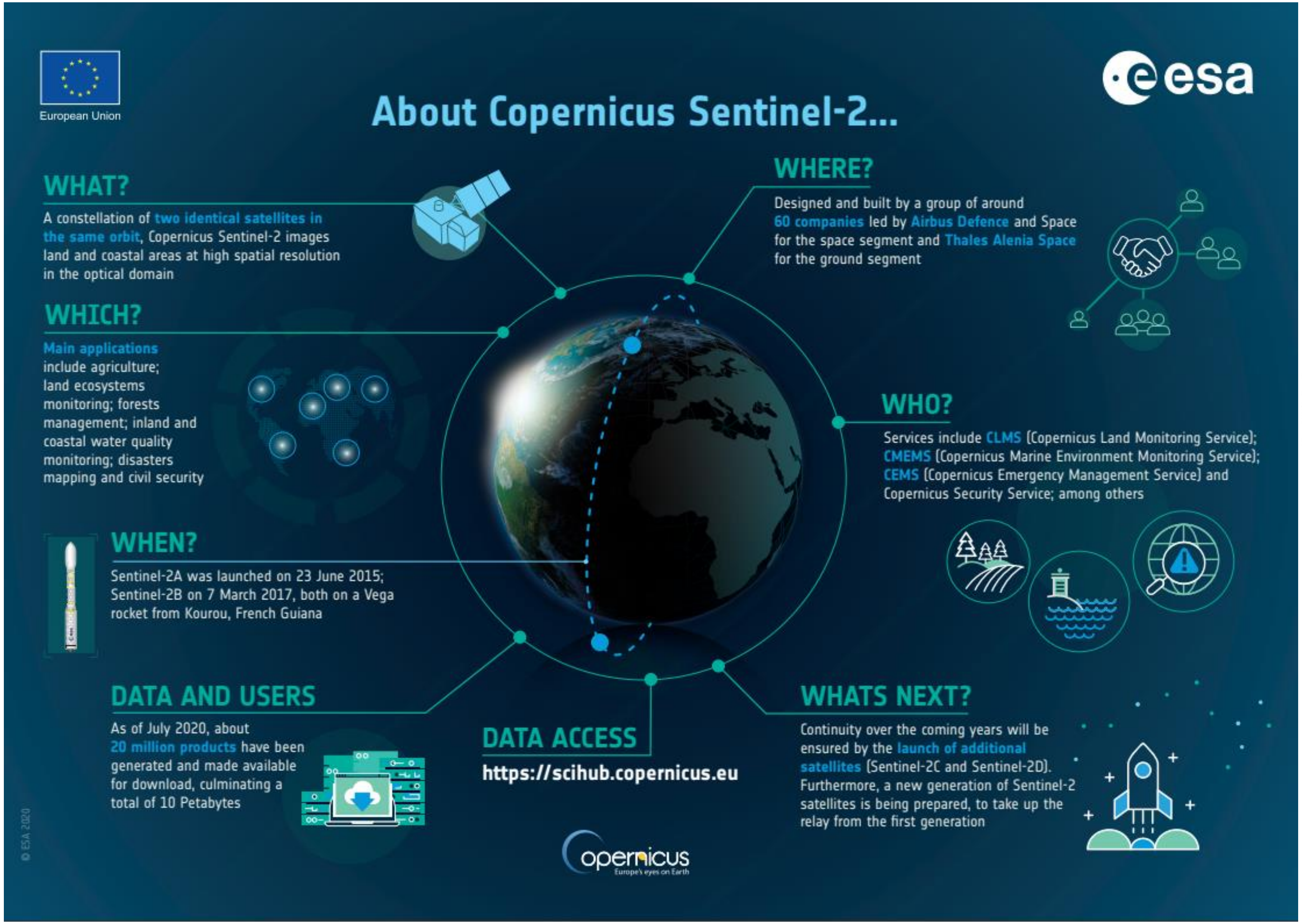


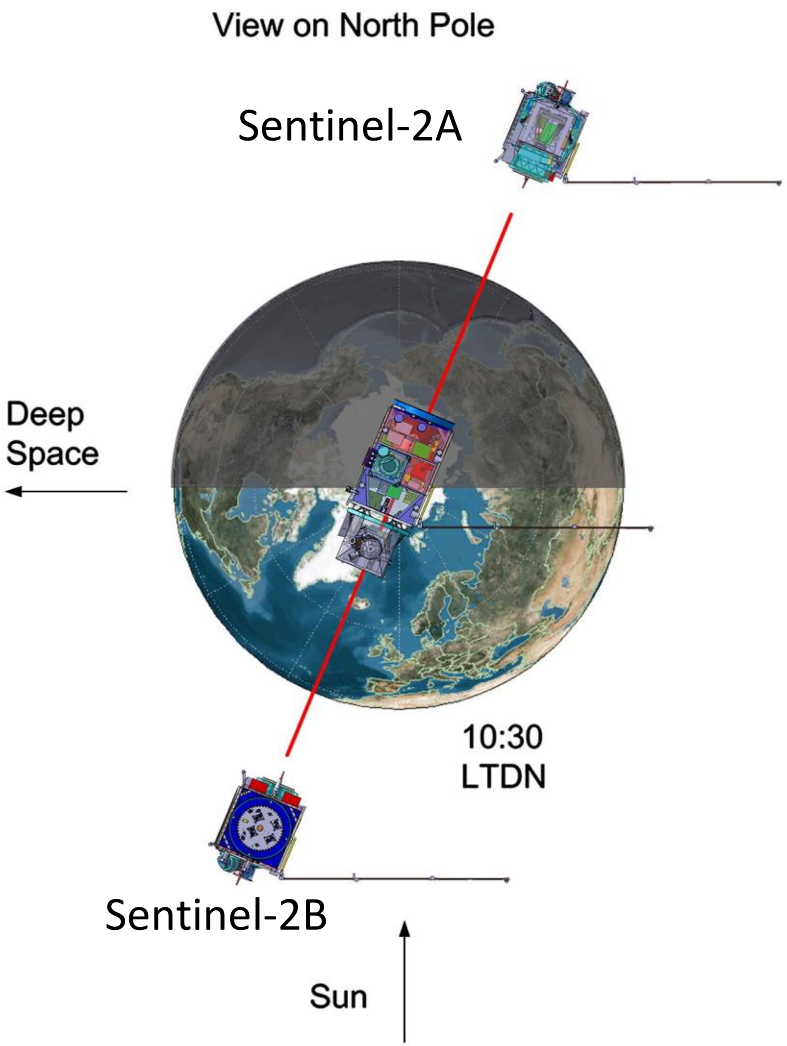
# SENTINEL MISSION

https://eo.belspo.be/en/news/et-sense-high-resolution-evaporation-and-soil-moisture-based-sentinel-constellation



# SENTINEL MISSION



MultiSpectral Instrument (MSI)

Orbit characteristics:

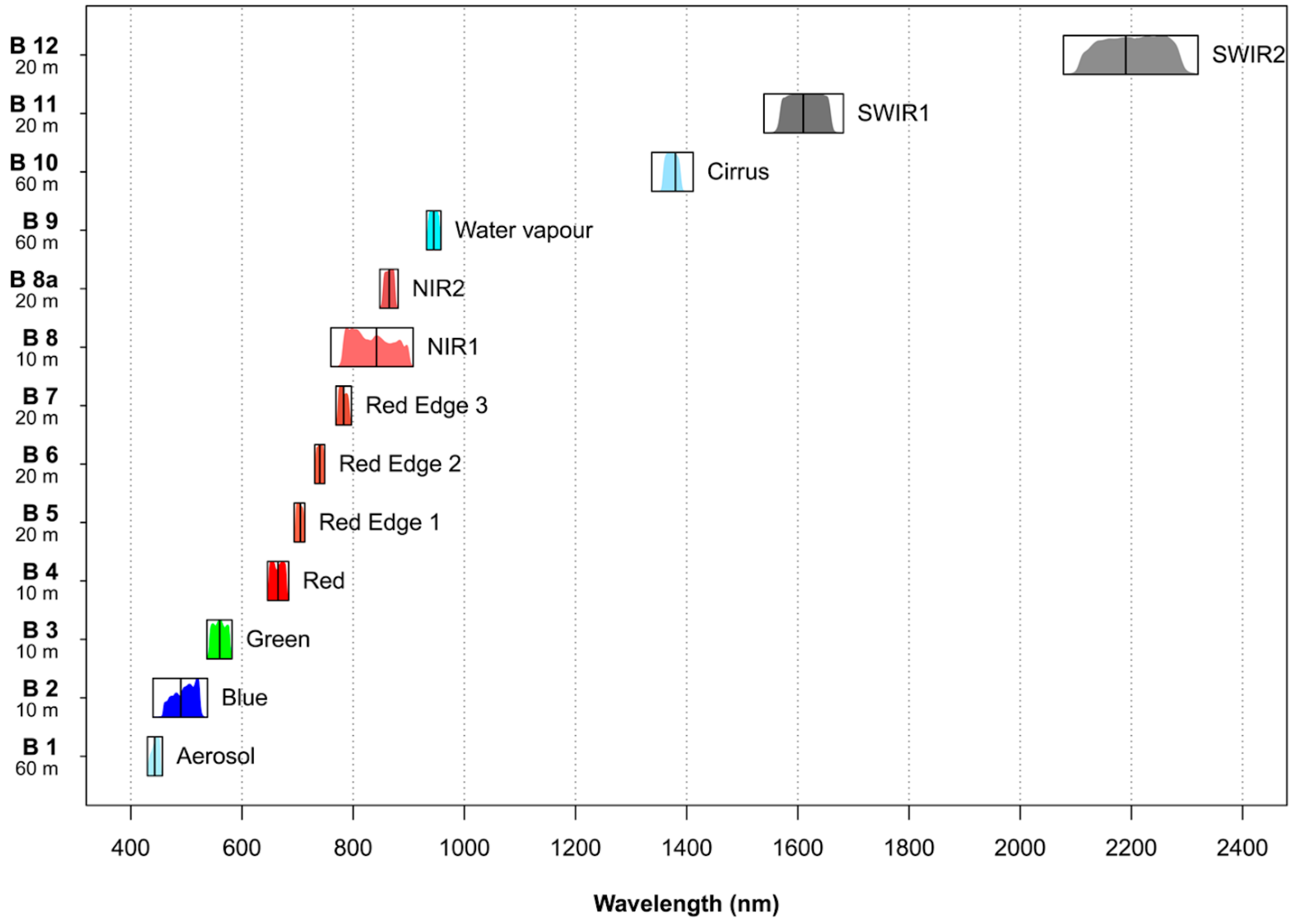
- sun-synchronous
- Altitude = 786 km
- 14.3 revolutions per day

Swath = 290 km, but images are provided in tiles 100x100 km

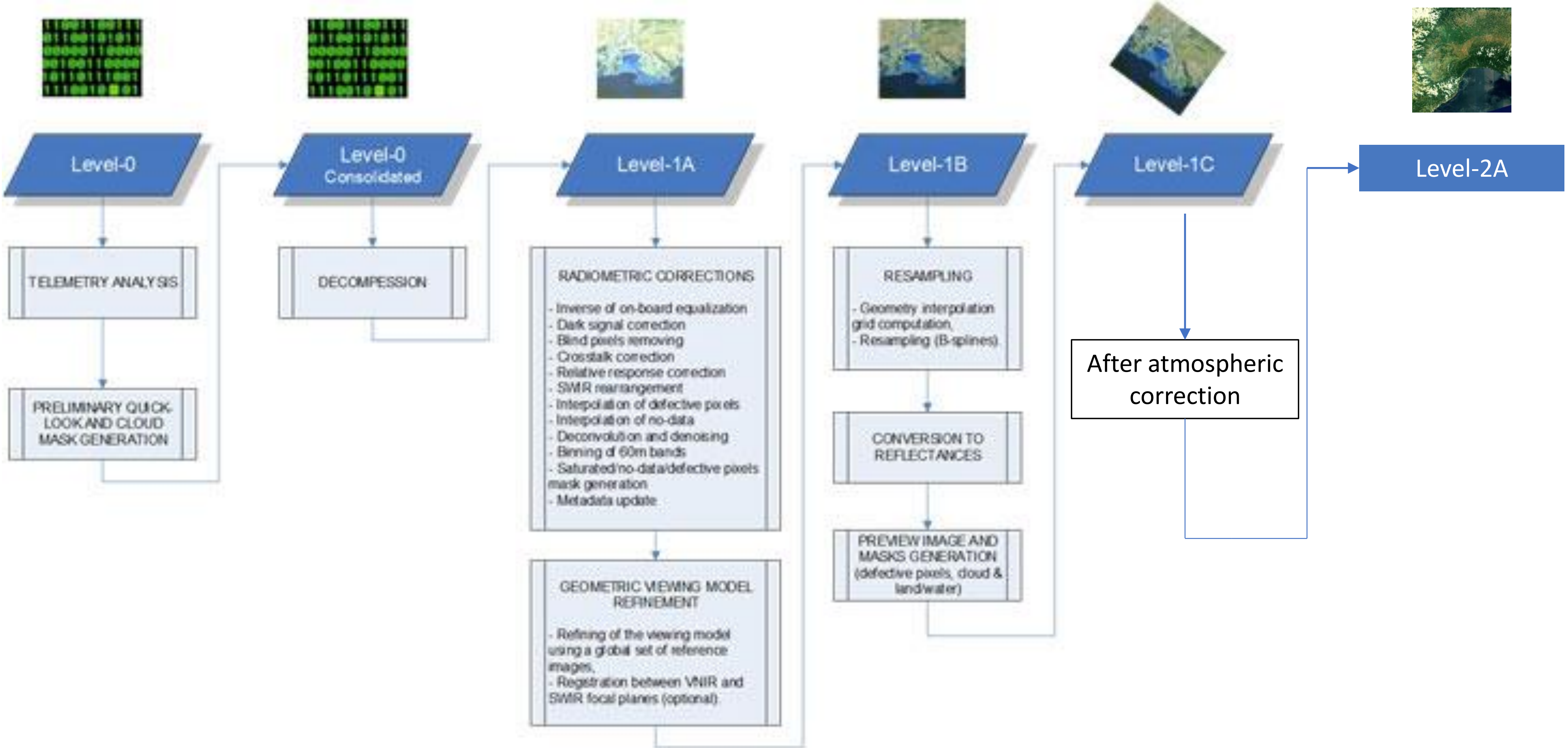
Spatial and spectral resolutions

Radiometric resolution: 12 bit

Low radiometric uncertainity = from 0.03% to 0.4%



Sentinel-2 products are available in different processed forms, since they undergo different stages of processing.



Sentinel-2 products are available in different processed forms, since they undergo different stages of processing.

| Product | Characteristics |
|---|---|
| Level 0 | Compressed raw image, not provided to users |
| Level 1-A | Decompressed raw image, not provided to users |
| Level 1-B | Granules 25x23 km, radiometric and geometric correction applied, not provided to users |
| Level 1-C | 100x100 km tiles, radiometrically corrected and geometrically refined Top-Of-Atmosphere (**TOA**) radiance values |
| Level 2-A | 100x100 km tiles, radiometrically corrected and geometrically refined Bottom-Of-Atmosphere (**BOA**) radiance values after **atmospheric correction** |

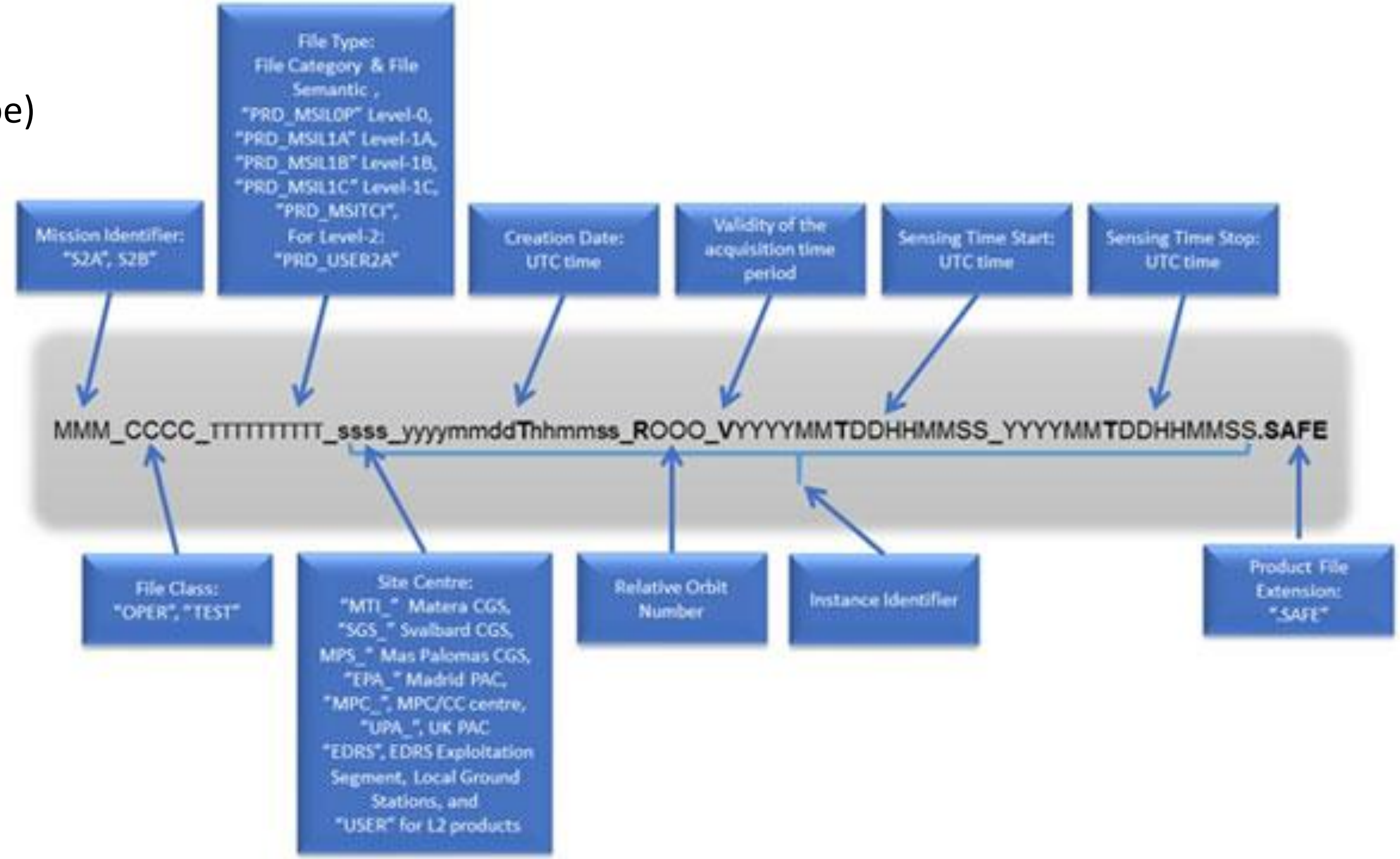
# SENTINEL MISSION

| Name | High-Level Description | Production & Distribution | Data Volume |
|---|---|---|---|
| **Level-1C** | Top-Of-Atmosphere reflectances in cartographic geometry | Systematic generation and online distribution | ~600 MB (each 100km x 100km$^2$) |
| **Level-2A** | Bottom-Of-Atmosphere reflectances in cartographic geometry | Systematic and on-User side (using Sentinel-2 Toolbox) | ~800 MB (each 100km x 100km$^2$) |

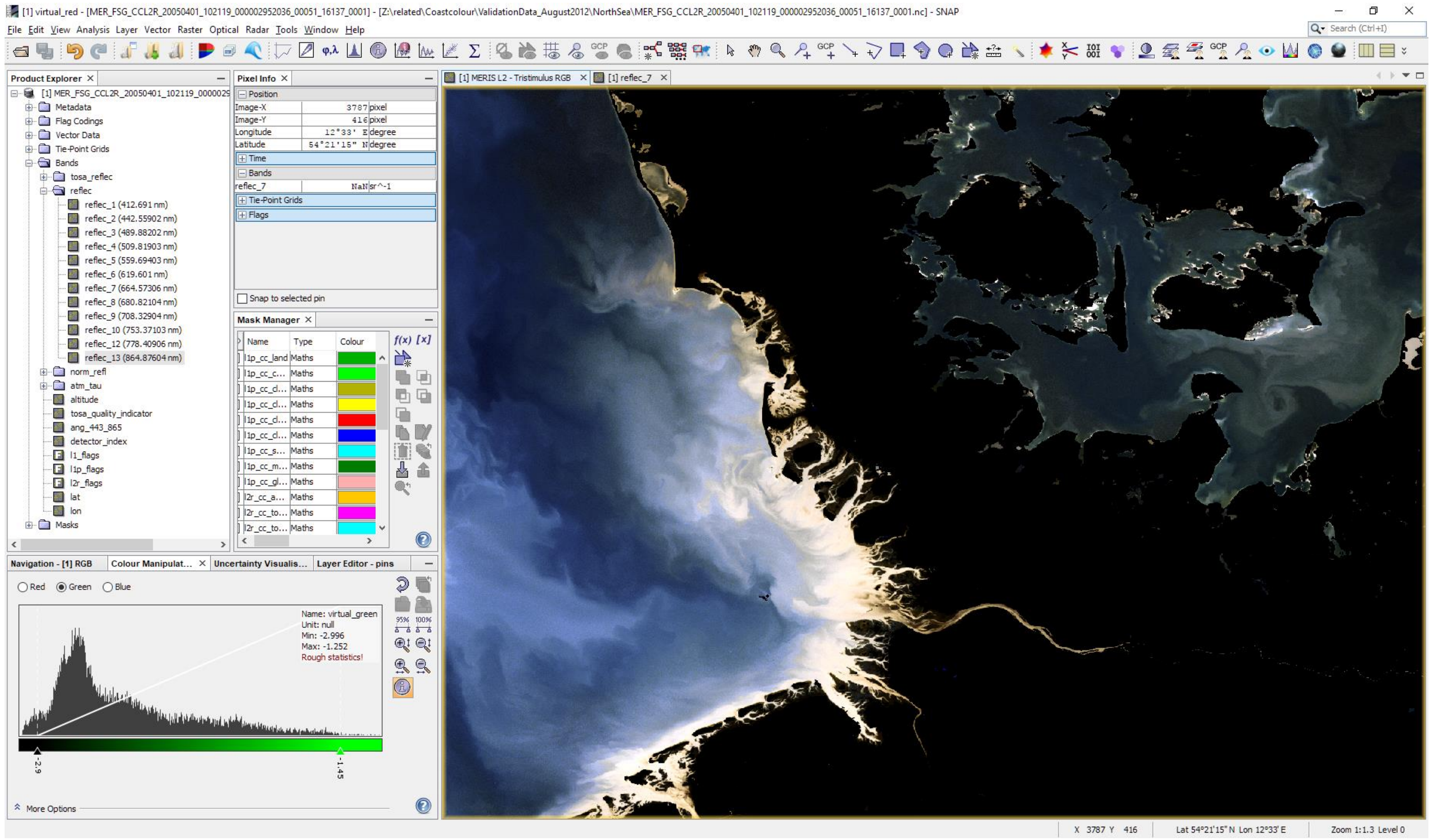
| Name | Level-2A |
|---|---|
| **High-level Description** | Surface reflectances in cartographic geometry for 12 spectral bands (Cirrus band B10 is not included). |
| **Algorithm used** | Sen2Cor – Version 2.10 |
| **Data Characteristics** | • UTM/WGS84 projection<br>• JPEG2000 image format<br>• 12-bit pixel values<br>• < 12 m at 95.5% confidence of Absolute Geolocation<br>• < 5 m at 95.5% confidence of Multitemporal Registration<br>• < 0.3 px at 99.7% confidence of Multispectral Registration |
| **Additional Layers** | • Scene Classification Map at 20 m and 60 m (resampled from 20 m)<br>• AOT Maps (10 m, 20 m, and 60 m)<br>• Water Vapour Maps (10 m, 20 m, and 60 m) |
| **DEM used** | Copernicus DEM at 90 m |
| **Auxiliary Data used** | • ECMWF (for ozone correction)<br>• CAMS<br>• ESA CCI LC Products<br>• ESACCI_WaterBodies_Map: ESACCI-LC-L4-WB-Map-150m-P13Y-2000-v4.0.tif<br>• ESACCI_LandCover_Map: ESACCI-LC-L4-LCCS-Map-300m-P1Y-2015-v2.0.7.tif<br>• ESACCI-LC-L4-Snow-Cond-500m-MONTHLY-2000-2012-v2.4 (derived from above ESACCI-LC-L4-Snow-Cond)<br>• Download ESA CCI data package for sen2cor 2.10 ESACCI-LC-L4-ALL-FOR-SEN2COR-2.10.tar.gz |
| **Quality Indicators** | • CLOUDY_PIXEL_PERCENTAGE<br>• CLOUDY_PIXEL_OVER_LAND_PERCENTAGE<br>• NODATA_PIXEL_PERCENTAGE<br>• SATURATED_DEFECTIVE_PIXEL_PERCENTAGE<br>• DARK_FEATURES_PERCENTAGE<br>• CLOUD_SHADOW_PERCENTAGE<br>• VEGETATION_PERCENTAGE<br>• NOT_VEGETATED_PERCENTAGE<br>• WATER_PERCENTAGE<br>• UNCLASSIFIED_PERCENTAGE<br>• MEDIUM_PROBA_CLOUDS_PERCENTAGE<br>• HIGH_PROBA_CLOUDS_PERCENTAGE<br>• THIN_CIRRUS_PERCENTAGE<br>• SNOW_ICE_PERCENTAGE<br>• AOT_RETRIEVAL_METHOD<br>• GRANULE_MEAN_AOT<br>• GRANULE_MEAN_WV<br>• OZONE_SOURCE<br>• OZONE_VALUE |
| **Production & Distribution** | Systematic generation and on-line distribution |
| **Data Volume** | Data Volume 800 MB (each 110x110 km2) |
| **Data Delivery** | Available within 8 hours from sensing |

# SENTINEL MISSION

MMM: is the mission ID(S2A/S2B)
MSIXXX: MSIL1C denotes the Level-1C product level/ MSIL2A denotes the Level-2A product level
YYYYMMDDHHMMSS: the datatake sensing start time
Nxxyy: the PDGS Processing Baseline number (e.g. N0204)
ROOO: Relative Orbit number (R001 - R143)
Txxxxx: Tile Number field
SAFE: Product Format (Standard Archive Format for Europe)

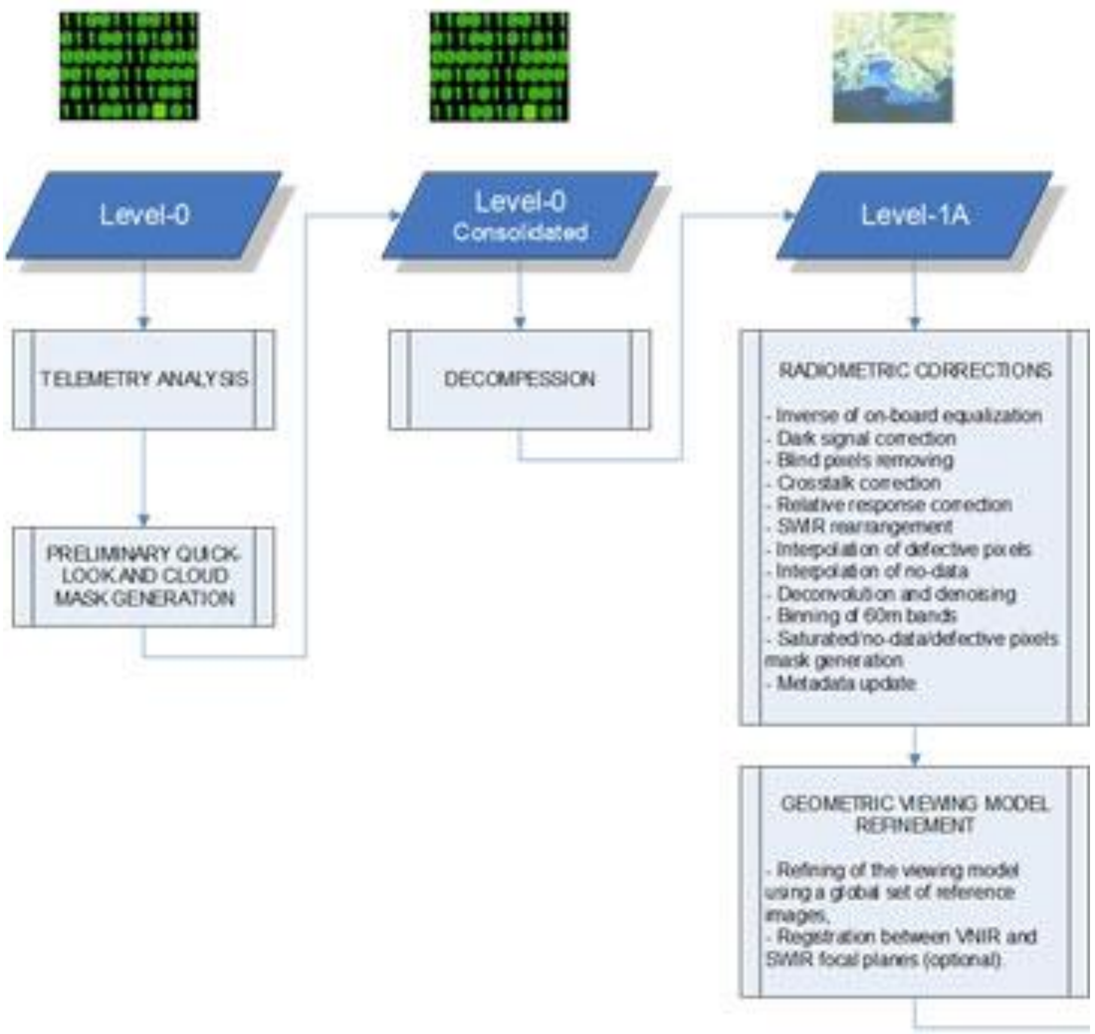



https://scihub.copernicus.eu/




SNAP
SeNtinel
Applications
Platform

# Geometric correction

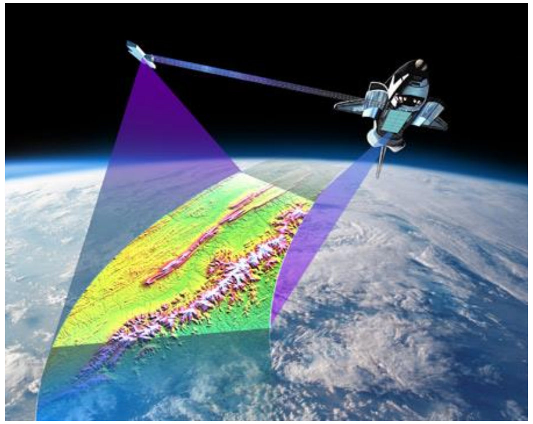



Geometric correction = adjusts the position of the images in line with the ground position.

Sentinel-2 uses a physical model by employing Ground Control Points (GCPs).

To improve geometric accuracy, also Digital Elevation Model (DEM) from Shuttle Radar Topographic Mission (STRM).

STRM provides a database containing a global 90m DEM; http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1



Shuttle Radar Topographic Mission (STRM)

# Atmospheric correction


It performs a pre-processing of Level 1-C TOA image data and applies a scene classification (SC) and a subsequent transformation to ortho-image Level 2-A BOA.

**Step 1. Scene classification (SC):**

- allows to detect clouds, snow and cloud shadows and
- allows to generate a classification map, which consists of 4 different classes for clouds (including cirrus), together with six different classifications for shadows, cloud shadows, vegetation, soils / deserts, water and snow.
- for each classification, it does a THRESHOLD TEST that is based on input TOA reflectance radiances

- at the end: a probabilistic cloud and snow mask quality map is created.

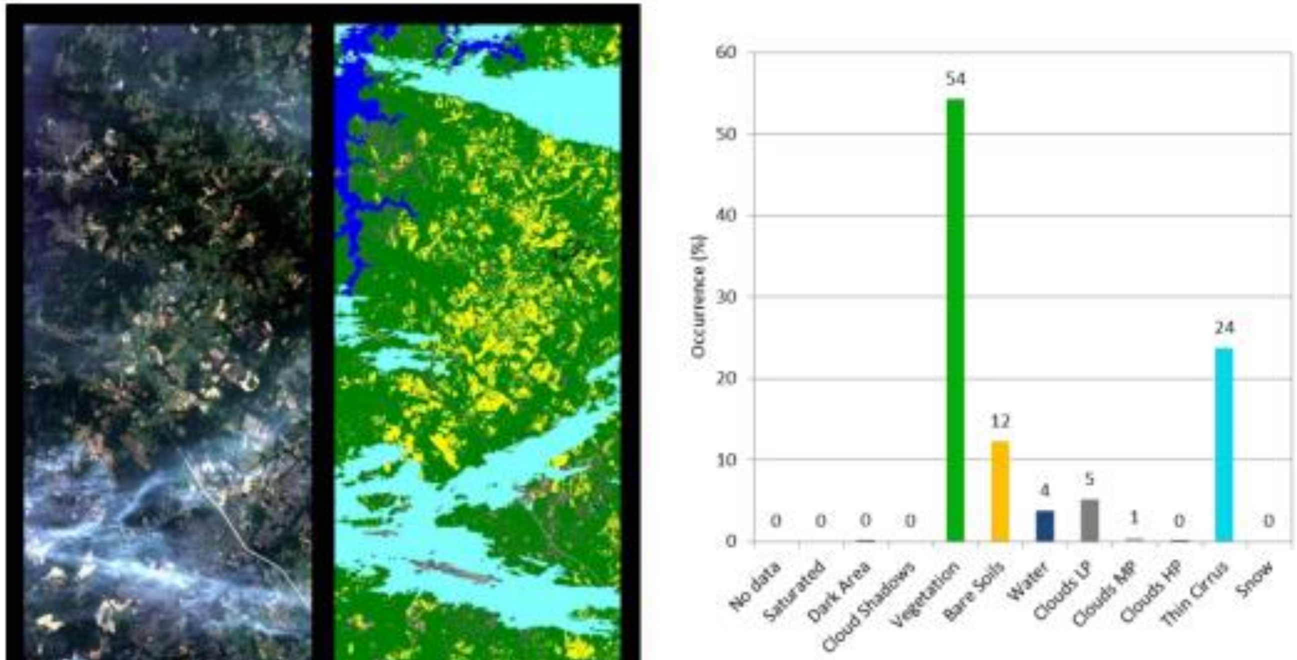



**Figure 2-6 – Scene Classification**

**Table 2-1 – Classification Map**

| Label | Classification |
|---|---|
| 0 | NO_DATA |
| 1 | SATURATED_OR_DEFECTIVE |
| 2 | DARK_AREA_PIXELS |
| 3 | CLOUD_SHADOWS |
| 4 | VEGETATION |
| 5 | NOT_VEGETATED |
| 6 | WATER |
| 7 | UNCLASSIFIED |
| 8 | CLOUD_MEDIUM_PROBABILITY |
| 9 | CLOUD_HIGH_PROBABILITY |
| 10 | THIN_CIRRUS |
| 11 | SNOW |

# Atmospheric correction

| | |
|---|---|
| **Name** | Level-2A |
| **High-level Description** | Surface reflectances in cartographic geometry for 12 spectral bands (Cirrus band B10 is not included). |
| **Algorithm used** | Sen2Cor – Version 2.10 |
| **Data Characteristics** | • UTM/WGS84 projection<br>• JPEG2000 image format<br>• 12-bit pixel values<br>• < 12 m at 95.5% confidence of Absolute Geolocation<br>• < 5 m at 95.5% confidence of Multitemporal Registration<br>• < 0.3 px at 99.7% confidence of Multispectral Registration |
| **Additional Layers** | • Scene Classification Map at 20 m and 60 m (resampled from 20 m)<br>• AOT Maps (10 m, 20 m, and 60 m)<br>• Water Vapour Maps (10 m, 20 m, and 60 m) |
| **DEM used** | Copernicus DEM at 90 m |
| **Auxiliary Data used** | • ECMWF (for ozone correction)<br>• CAMS<br>• ESA CCI LC Products<br>• ESACCI_WaterBodies_Map: ESACCI-LC-L4-WB-Map-150m-P13Y-2000-v4.0.tif<br>• ESACCI_LandCover_Map: ESACCI-LC-L4-LCCS-Map-300m-P1Y-2015-v2.0.7.tif<br>• ESACCI-LC-L4-Snow-Cond-500m-MONTHLY-2000-2012-v2.4 (derived from above ESACCI-LC-L4-Snow-Cond)<br>• Download ESA CCI data package for sen2cor 2.10 ESACCI-LC-L4-ALL-FOR-SEN2COR-2.10.tar.gz |
| **Quality Indicators** | • CLOUDY_PIXEL_PERCENTAGE<br>• CLOUDY_PIXEL_OVER_LAND_PERCENTAGE<br>• NODATA_PIXEL_PERCENTAGE<br>• SATURATED_DEFECTIVE_PIXEL_PERCENTAGE<br>• DARK_FEATURES_PERCENTAGE<br>• CLOUD_SHADOW_PERCENTAGE<br>• VEGETATION_PERCENTAGE<br>• NOT_VEGETATED_PERCENTAGE<br>• WATER_PERCENTAGE<br>• UNCLASSIFIED_PERCENTAGE<br>• MEDIUM_PROBA_CLOUDS_PERCENTAGE<br>• HIGH_PROBA_CLOUDS_PERCENTAGE<br>• THIN_CIRRUS_PERCENTAGE<br>• SNOW_ICE_PERCENTAGE<br>• AOT_RETRIEVAL_METHOD<br>• GRANULE_MEAN_AOT<br>• GRANULE_MEAN_WV<br>• OZONE_SOURCE<br>• OZONE_VALUE |
| **Production & Distribution** | Systematic generation and on-line distribution |
| **Data Volume** | Data Volume 800 MB (each 110x110 km2) |
| **Data Delivery** | Available within 8 hours from sensing |


| | |
|---|---|
| **Quality Indicators** | • CLOUDY_PIXEL_PERCENTAGE<br>• CLOUDY_PIXEL_OVER_LAND_PERCENTAGE<br>• NODATA_PIXEL_PERCENTAGE<br>• SATURATED_DEFECTIVE_PIXEL_PERCENTAGE<br>• DARK_FEATURES_PERCENTAGE<br>• CLOUD_SHADOW_PERCENTAGE<br>• VEGETATION_PERCENTAGE<br>• NOT_VEGETATED_PERCENTAGE<br>• WATER_PERCENTAGE<br>• UNCLASSIFIED_PERCENTAGE<br>• MEDIUM_PROBA_CLOUDS_PERCENTAGE<br>• HIGH_PROBA_CLOUDS_PERCENTAGE<br>• THIN_CIRRUS_PERCENTAGE<br>• SNOW_ICE_PERCENTAGE<br>• AOT_RETRIEVAL_METHOD<br>• GRANULE_MEAN_AOT<br>• GRANULE_MEAN_WV<br>• OZONE_SOURCE<br>• OZONE_VALUE |

**Step 2. Atmospheric correction:**

4 different subtasks:

- Aerosol retrieval
- Water vapour retrieval
- Terrain retrieval
- Cirrus correction

The atmospheric model of Sen2cor is dependent on the calculation of radiative transfer functions for different sensor and solar geometries, ground elevations, and atmospheric parameters.

A set of lookup table (LUT) are used:

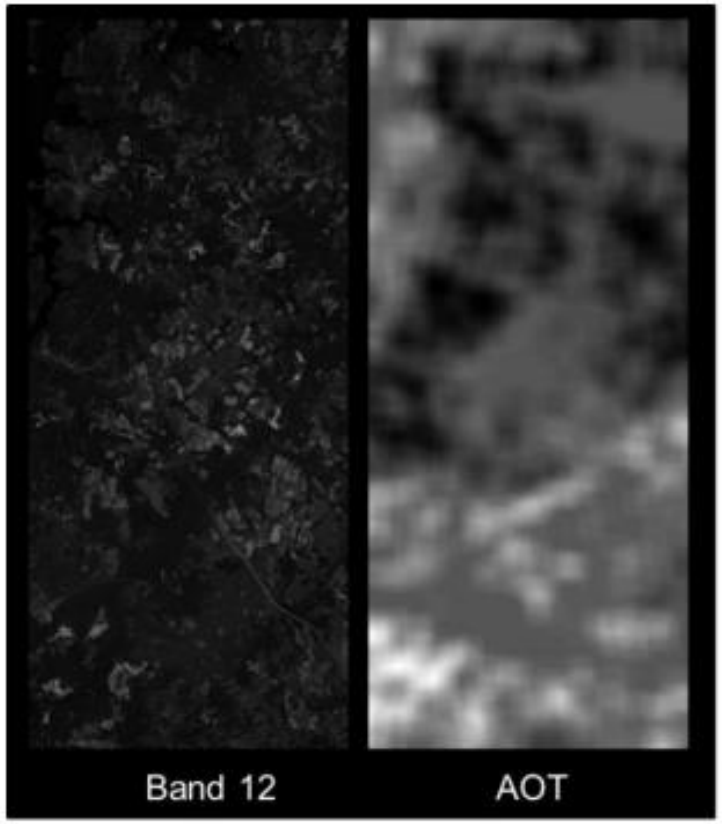
- 2 for different types of aerosols (rural and marine)
- 2 for different types of atmospheres (mid-latitude summer and mid-latitude winter)
- 6 for different types of ozone concentrations (summer or winter)
- 6 or 4 for different amounts of water vapour column (summer or winter)

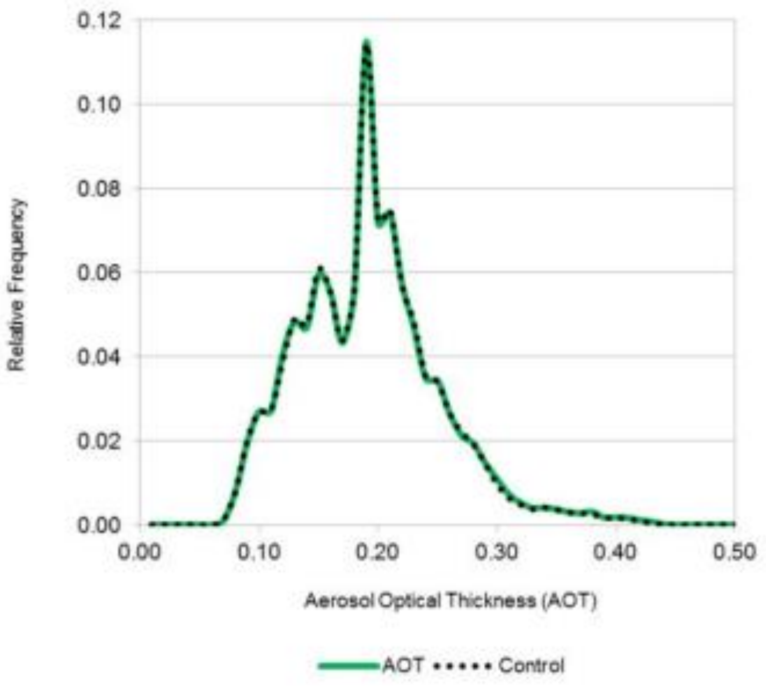
| Ozone concentration | Band X | Band Y |
|---|---|---|
| Low | 34 | 46 |
| High | 22 | 11 |

## Aerosol retrieval (Aerosol Optical Thickness, AOT)

Band 12: SWIR
Band 4: Red
Band 2: Blue

| BAND | SPECTRAL | WAVELEN. [µm] | GEOM. [m] |
|---|---|---|---|
| 1 | aerosols | 0.429 – 0.457 | 60 |
| 2 | blue | 0.451 – 0.539 | 10 |
| 3 | green | 0.538 – 0.585 | 10 |
| 4 | red | 0.641 – 0.689 | 10 |
| 5 | red edge | 0.695 – 0.715 | 20 |
| 6 | red edge | 0.731 – 0.749 | 20 |
| 7 | red edge | 0.769 – 0.797 | 20 |
| 8 | NIR | 0.784 – 0.900 | 10 |
| 8a | narrow NIR | 0.855 – 0.875 | 20 |
| 9 | water vapour | 0.935 – 0.955 | 60 |
| 10 | SWIR cirrus | 1.365 – 1.385 | 60 |
| 11 | SWIR | 1.565 – 1.655 | 20 |
| 12 | SWIR | 2.100 – 2.280 | 20 |

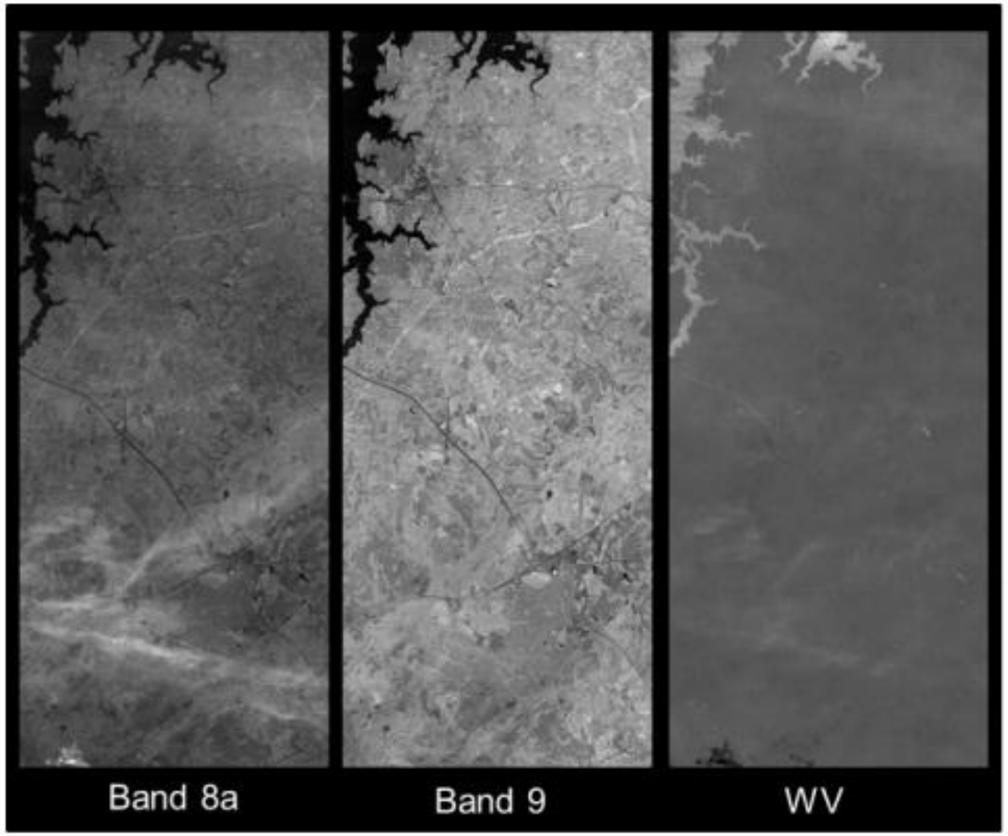


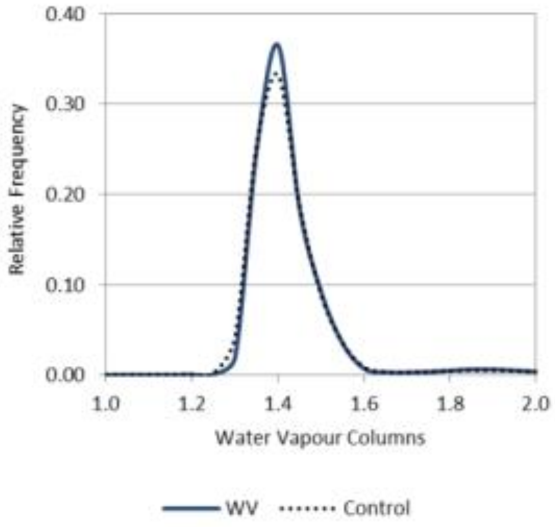



## Water vapour retrieval (WV)

Band 8a: NIR (0.855-0.875)
Band 9: NIR (0.935-0.955)

| BAND | SPECTRAL | WAVELEN. [µm] | GEOM. [m] |
|---|---|---|---|
| 1 | aerosols | 0.429 – 0.457 | 60 |
| 2 | blue | 0.451 – 0.539 | 10 |
| 3 | green | 0.538 – 0.585 | 10 |
| 4 | red | 0.641 – 0.689 | 10 |
| 5 | red edge | 0.695 – 0.715 | 20 |
| 6 | red edge | 0.731 – 0.749 | 20 |
| 7 | red edge | 0.769 – 0.797 | 20 |
| 8 | NIR | 0.784 – 0.900 | 10 |
| 8a | narrow NIR | 0.855 – 0.875 | 20 |
| 9 | water vapour | 0.935 – 0.955 | 60 |
| 10 | SWIR cirrus | 1.365 – 1.385 | 60 |
| 11 | SWIR | 1.565 – 1.655 | 20 |
| 12 | SWIR | 2.100 – 2.280 | 20 |



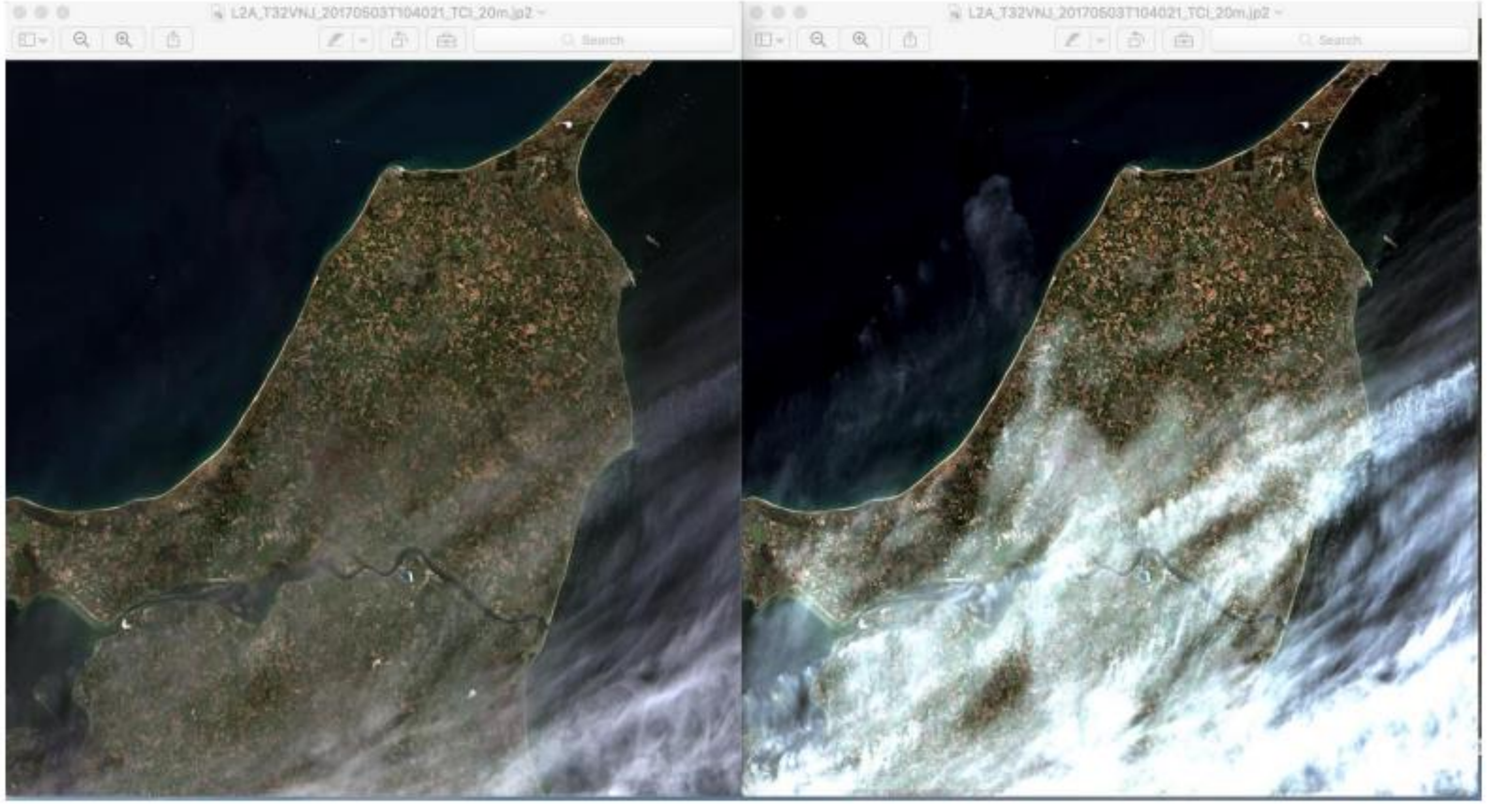



# Atmospheric correction

## Cirrus correction

Band 10: SWIR (1.365-1655)

| BAND | SPECTRAL | WAVELEN. [µm] | GEOM. [m] |
|---|---|---|---|
| 1 | aerosols | 0.429 – 0.457 | 60 |
| 2 | blue | 0.451 – 0.539 | 10 |
| 3 | green | 0.538 – 0.585 | 10 |
| 4 | red | 0.641 – 0.689 | 10 |
| 5 | red edge | 0.695 – 0.715 | 20 |
| 6 | red edge | 0.731 – 0.749 | 20 |
| 7 | red edge | 0.769 – 0.797 | 20 |
| 8 | NIR | 0.784 – 0.900 | 10 |
| 8a | narrow NIR | 0.855 – 0.875 | 20 |
| 9 | water vapour | 0.935 – 0.955 | 60 |
| 10 | SWIR cirrus | 1.365 – 1.385 | 60 |
| 11 | SWIR | 1.565 – 1.655 | 20 |
| 12 | SWIR | 2.100 – 2.280 | 20 |



## 2.2.6 Surface Reflectance Retrieval

Surface Reflectance retrieval is performed for each sequential Band B1 – B12. Figure 2-9 below shows the Level 1C input data and the corresponding Level 2A output after atmospheric correction from a scene of La Paz, retrieved on 28.03.2016.

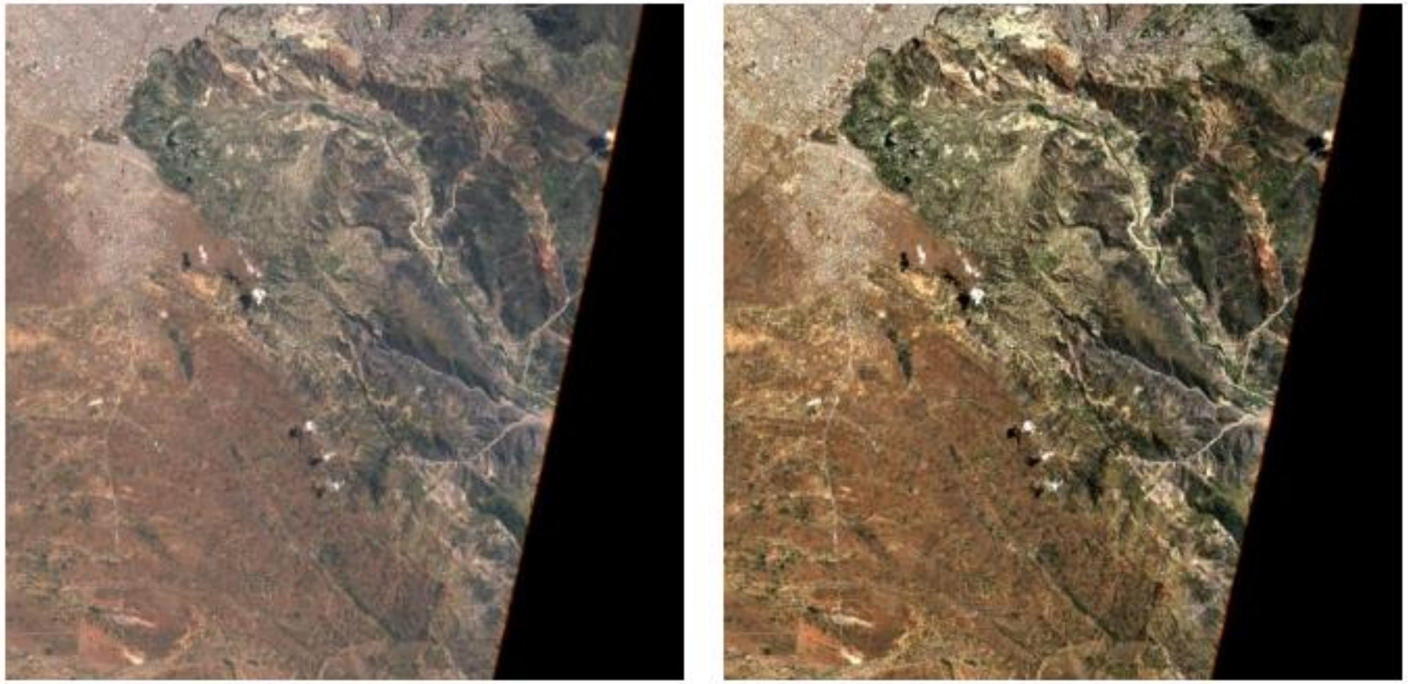


**Figure 2-12 – Left: Level 1C Input, Bands 2-4; right: Level 2A Output, Bands 2-4, RGB composite images, scene from La Paz on**

# Examples of information retrieved from spectral signature

*remote sensing* MDPI

*Article*

**Use of Sentinel-2 Satellite Data for Windthrows Monitoring and Delimiting: The Case of "Vaia" Storm in Friuli Venezia Giulia Region (North-Eastern Italy)**

Valentina Olmo [1,2], Enrico Tordoni [3], Francesco Petruzzellis [1,2], Giovanni Bacaro [2,*] and Alfredo Altobelli [2]