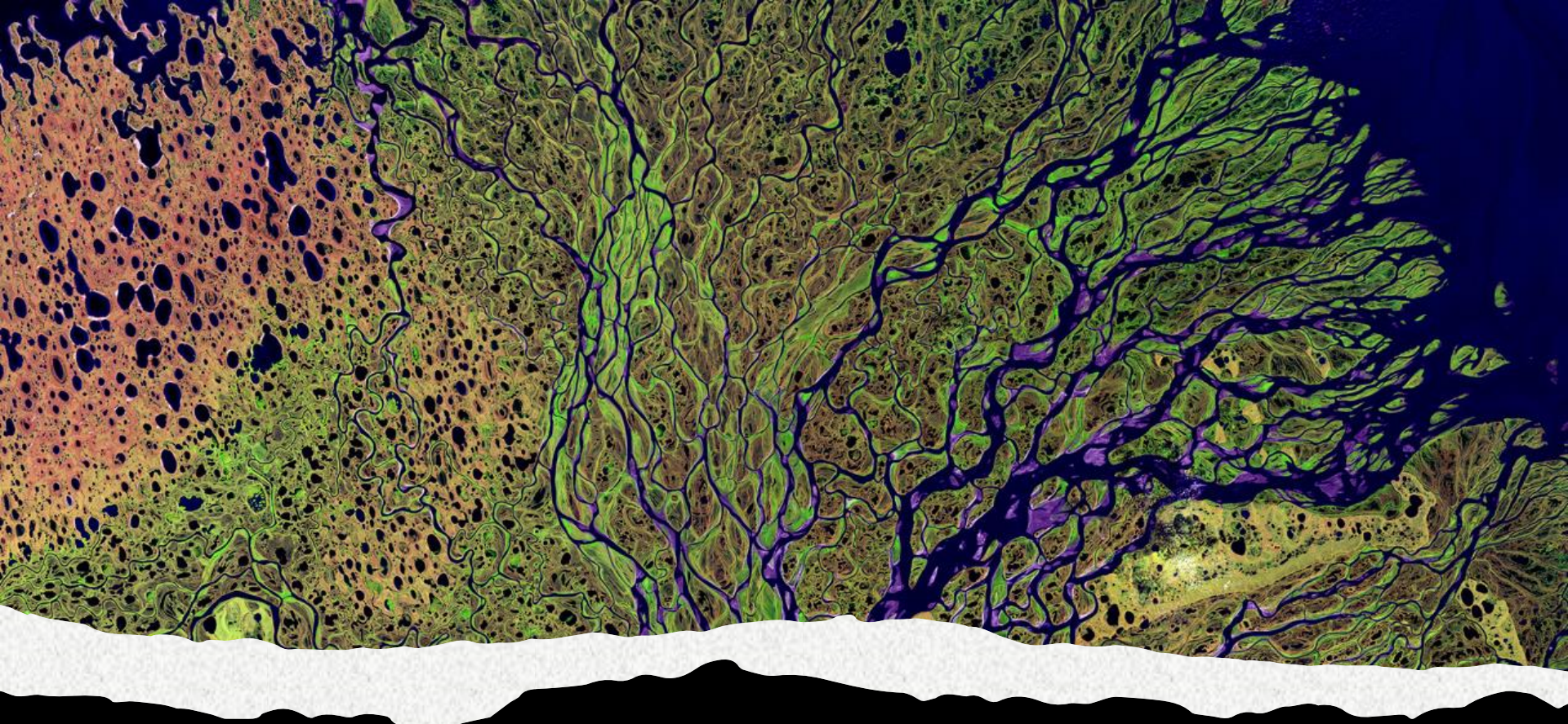


Introduction to Remote Sensing

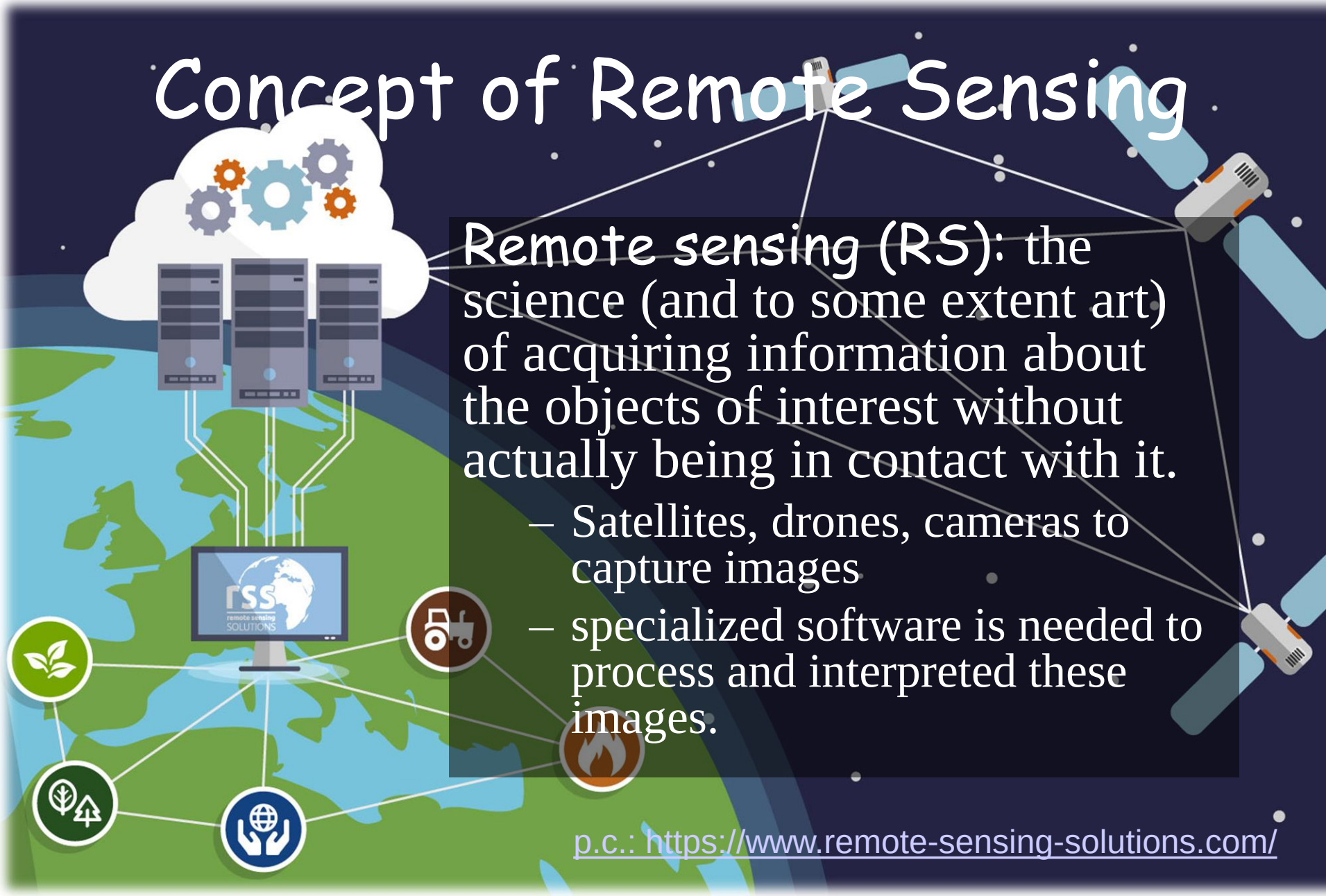
References on Introduction to Remote Sensing

- **Principles of Remote sensing**
- Norman Kerle, Lucas L.E. Janssen and Gerrit C. Huurneman (eds.), ITC Educational Textbook Series, 3rd Edition, 2004, Enschede, The Netherlands.
- **Fundamentals of Remote Sensing**
- Canada Centre for Remote sensing (http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca.earth-sciences/files/pdf/resource/tutor/fundam/pdf/fundamentals_e.pdf)
- **Introductory Remote Sensing: Principles and Concepts**
- Paul J. Gibson, 2000, Routledge, London.

References on Principals of Remote Sensing

- **Principles of Remote Sensing by Tempfli K., Kerle N., Huurneman G.C., Janssen L.L.F. (eds.)**

Concept of Remote Sensing



Remote sensing (RS): the science (and to some extent art) of acquiring information about the objects of interest without actually being in contact with it.

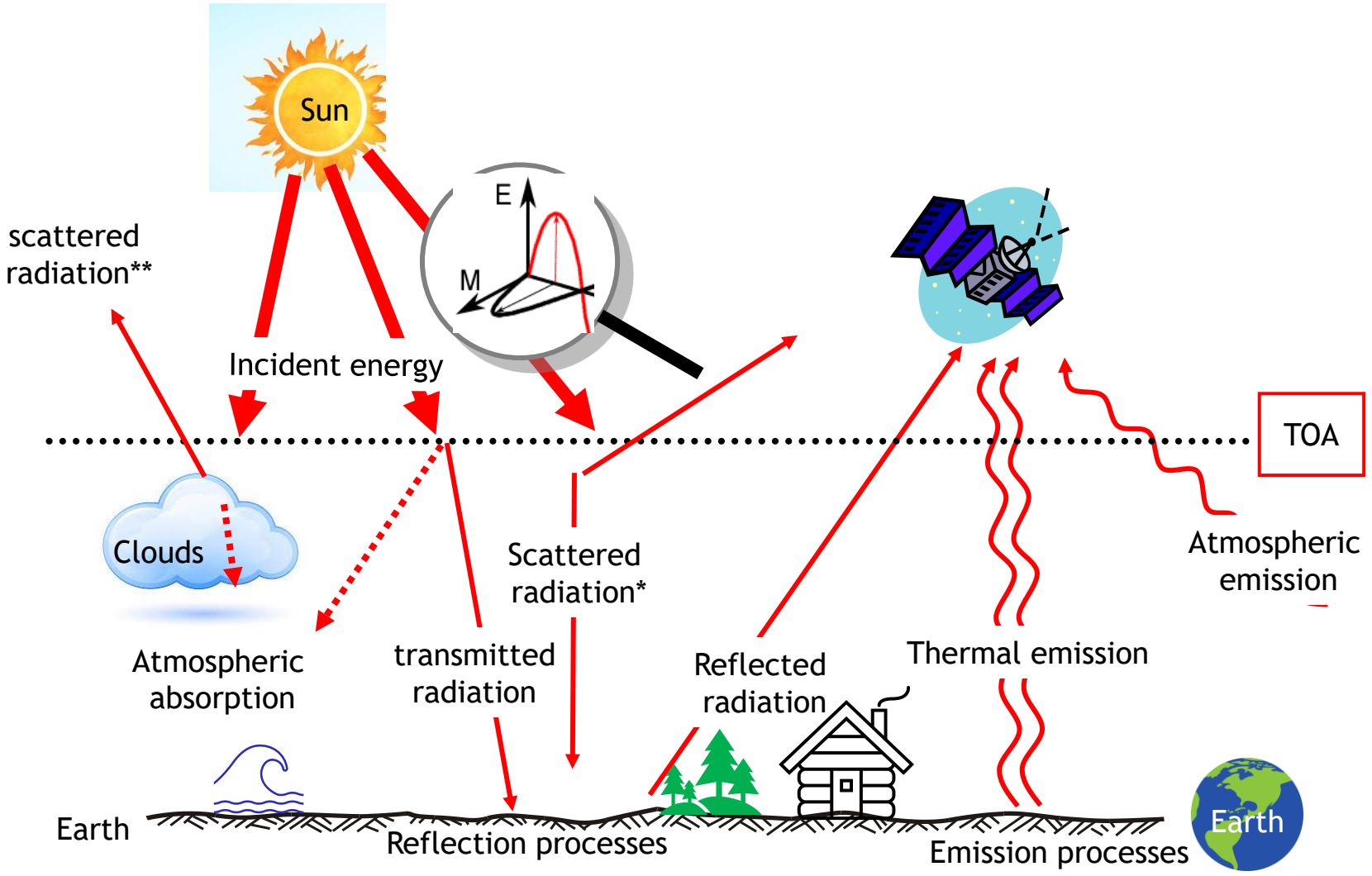
- Satellites, drones, cameras to capture images
- specialized software is needed to process and interpreted these images.

p.c.: https://www.remote-sensing-solutions.com/

Concept of Remote Sensing

Remote Sensing is defined as the science (and to some extent art) of acquiring information about the objects of interest without actually being in contact with it by **sensing and recording reflected or emitted energy** and processing, analyzing and applying that information.

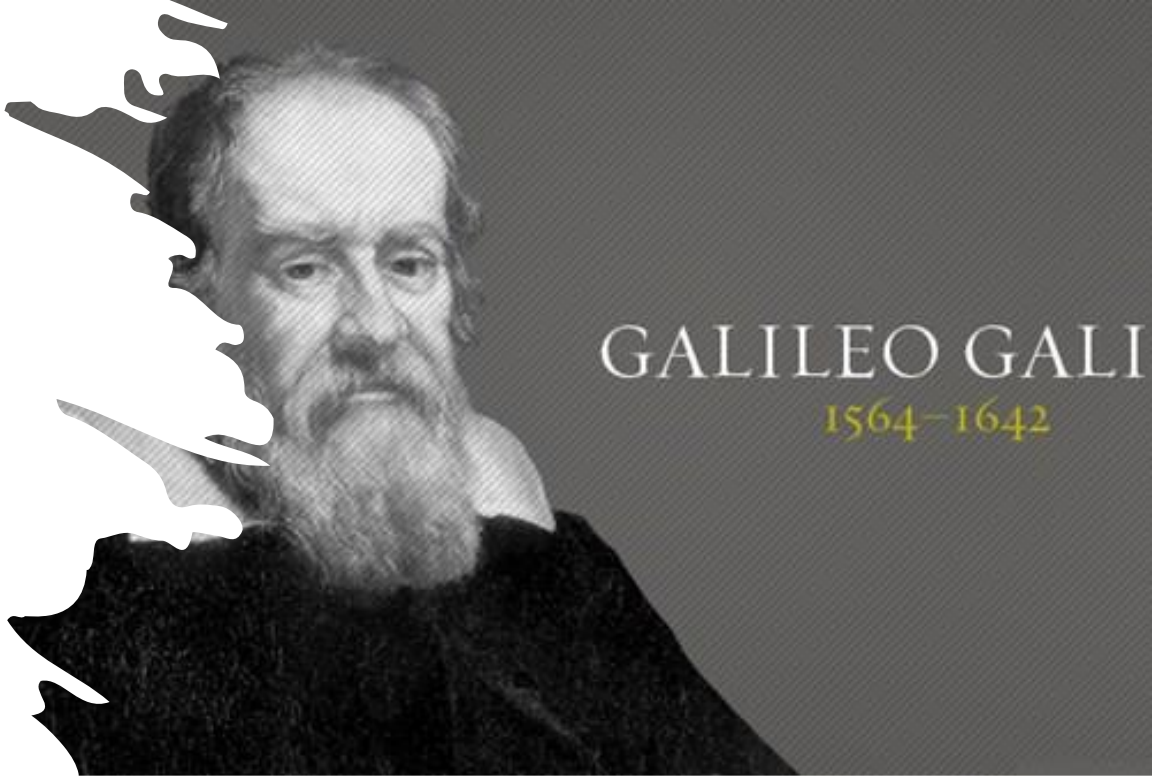
CONCEPT OF REMOTE SENSING



Milestones in the History of Remote Sensing

- Through his spyglass, Galileo saw that there were spots on the Sun, imperfections on the Moon, and that the Milky Way was composed of a myriad of faint stars.

- Galileo made careful observations and measurements, and recorded these in detailed descriptions and drawings.





Courtesy: Prof. GM Tarekul Islam, IWFM, BUET

Milestones in the History of Remote Sensing

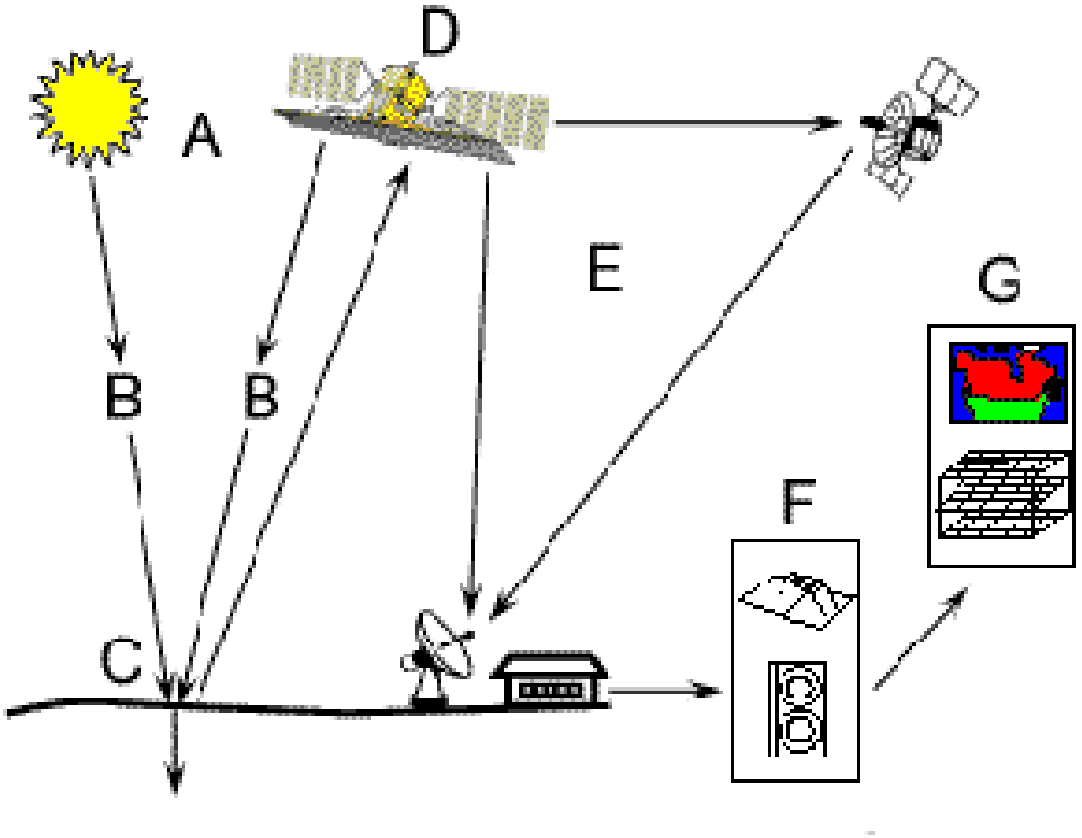
1839	Photography was invented
1858	Parisian Photographer, Gaspard Felix Tournachon used a balloon to ascend to a height of 80 m to obtain the photograph over Bievre, France
1882	Kites were used for photography
1909	Airplanes were used as a platform for photography
1910-20	World War I. Aerial reconnaissance: Beginning of photo interpretation
1920-50	Aerial photogrammetry was developed
1934	Radar development for military use started
1940's	Color photography was invented
1940's	Non-visible portions of electromagnetic spectrum, mainly near-infrared, training of photo-interpretation
1950-1970	Further development of non-visible photography, multi-camera photography, color-infrared photography, and non-photographic sensors. Satellite sensor development - Very High Resolution Radiometer (VHRR), Launch of weather satellites such as Nimbus and TIROS
1962	The term "Remote Sensing" first appeared
1972	The launch of Landsat-1, originally ERTS-1,Remote sensing has been extensively investigated and applied since then

Courtesy: Prof. GM Tarekul Islam, IWFM, BUET

Milestones in the History of Remote Sensing

1982	Second generation of Landsat sensor: Thematic Mapper
1986	French SPOT-1 High Resolution Visible sensors MSS, TM, HRV have been the major sensors for data collection for large areas all over the world. Such data have been widely used in natural resources inventory and mapping. Major areas include agriculture, forest, wet land, mineral exploration, mining, etc.
1980-90	Earth-Resources Satellite from other countries such as India, Japan, and USSR. Japan's Marine Observing Satellite (MOS - 1)
1990-	Proposed EOS aiming at providing data for global change monitoring. Various sensors have been proposed. • Japan's JERS-1 SAR, • European ERS Remote Sensing Satellite SAR, • Canada's Radarsat

Courtesy: Prof. GM Tarekul Islam, IWFM, BUET



Elements Involved in Remote Sensing

- Energy Source or Illumination (A)
- Radiation and the Atmosphere (B)
- Interaction with the Object (C)
- Recording of Energy by the Sensor (D)
- Transmission, Reception and Processing (E)
- Interpretation and Analysis (F)
- Application (G)

Energy Sources and Electromagnetic Radiation



James Clerk Maxwell (13 June 1831 – 5 November 1879)
Scottish mathematical physicist

His most notable achievement was to formulate the classical theory of electromagnetic radiation, bringing together for the first time electricity, magnetism, and light as manifestations of the same phenomenon.

Maxwell's equations for electromagnetism have been called the second great unification in physics after the first one realized by Isaac Newton.

Energy Sources and Electromagnetic Radiation



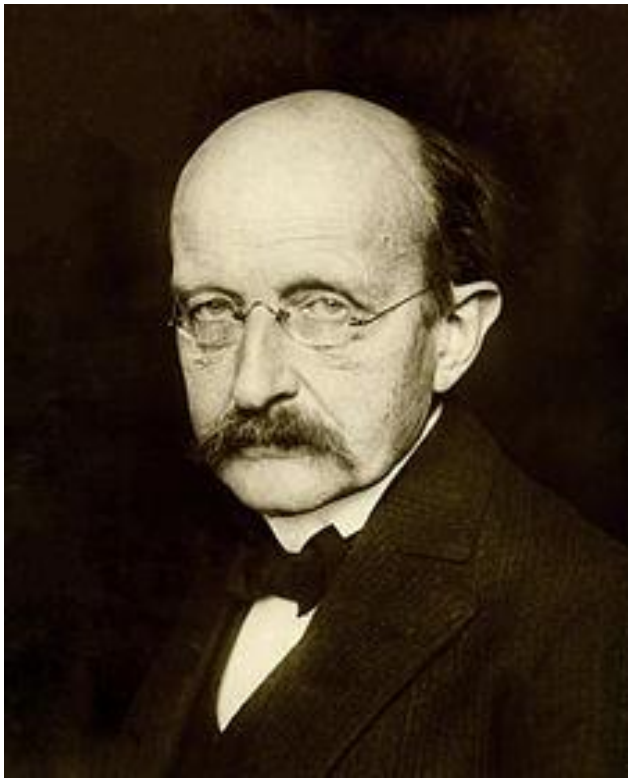
Heinrich Rudolf Hertz (22 February 1857 – 1 January 1894)
German physicist

- He first conclusively proved in 1888 the existence of electromagnetic waves theorized by James Clerk Maxwell's electromagnetic theory of light.
- The scientific unit of frequency – cycles per second – was named the "hertz" in his honor.

Energy Sources and Electromagnetic Radiation

- In 1900, Max Planck was working on black-body radiation and suggested that the energy in electromagnetic waves could only be released in "packets" of energy.

Energy Sources and Electromagnetic Radiation



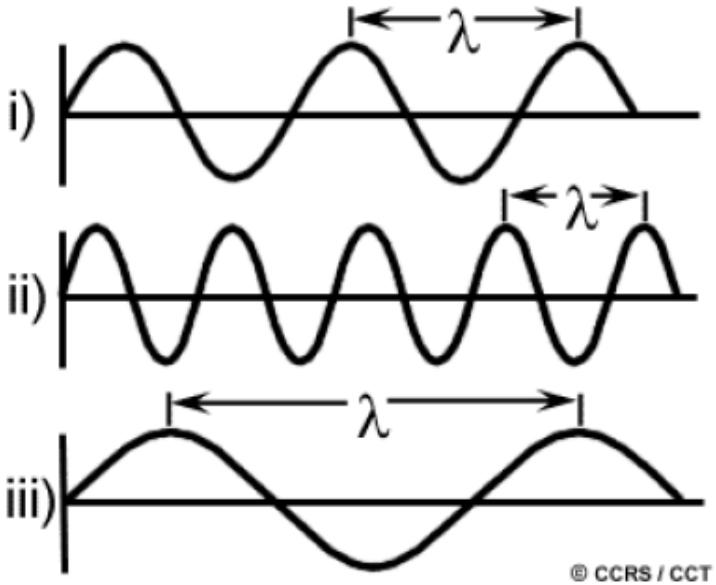
Max Karl Ernst Ludwig Planck (April 23, 1858 – October 4, 1947)
German theoretical physicist

- He originated quantum theory, which won him the Nobel Prize in Physics in 1918.

Energy Sources and Electromagnetic Radiation

Two characteristics of electromagnetic radiation are particularly important for understanding remote sensing. These are the **wavelength and frequency.**

- The wavelength is the length of one wave cycle, which can be measured as the distance between successive wave crests.
- Wavelength (λ) is measured in meters (m) or some factor of meters such as **micrometers** (μm, 10^{-6} meters).
- Frequency refers to the number of cycles of a wave passing a fixed point per unit of time.
- Frequency is normally measured in **hertz** (Hz), equivalent to one cycle per second, and various multiples of hertz.
- Electromagnetic energy can be modeled in two ways: by **wave motion** and **particle motion**.



Wave Motion

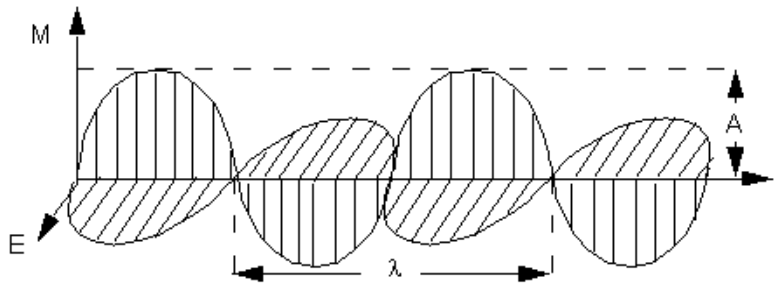
EMR can be considered as a transverse wave with an electric field (E) and a magnetic field (M). The two fields are located at right angles to each other.

$$\nu = \frac{c}{\lambda}$$

c = velocity of EM energy (light) = 3×10^8 m/s

λ = wavelength [m]

ν = frequency [s^{-1} or Hz]



This equation explains that the shorter wavelength has higher spectral frequency.

Particle Motion (Quantum Theory)

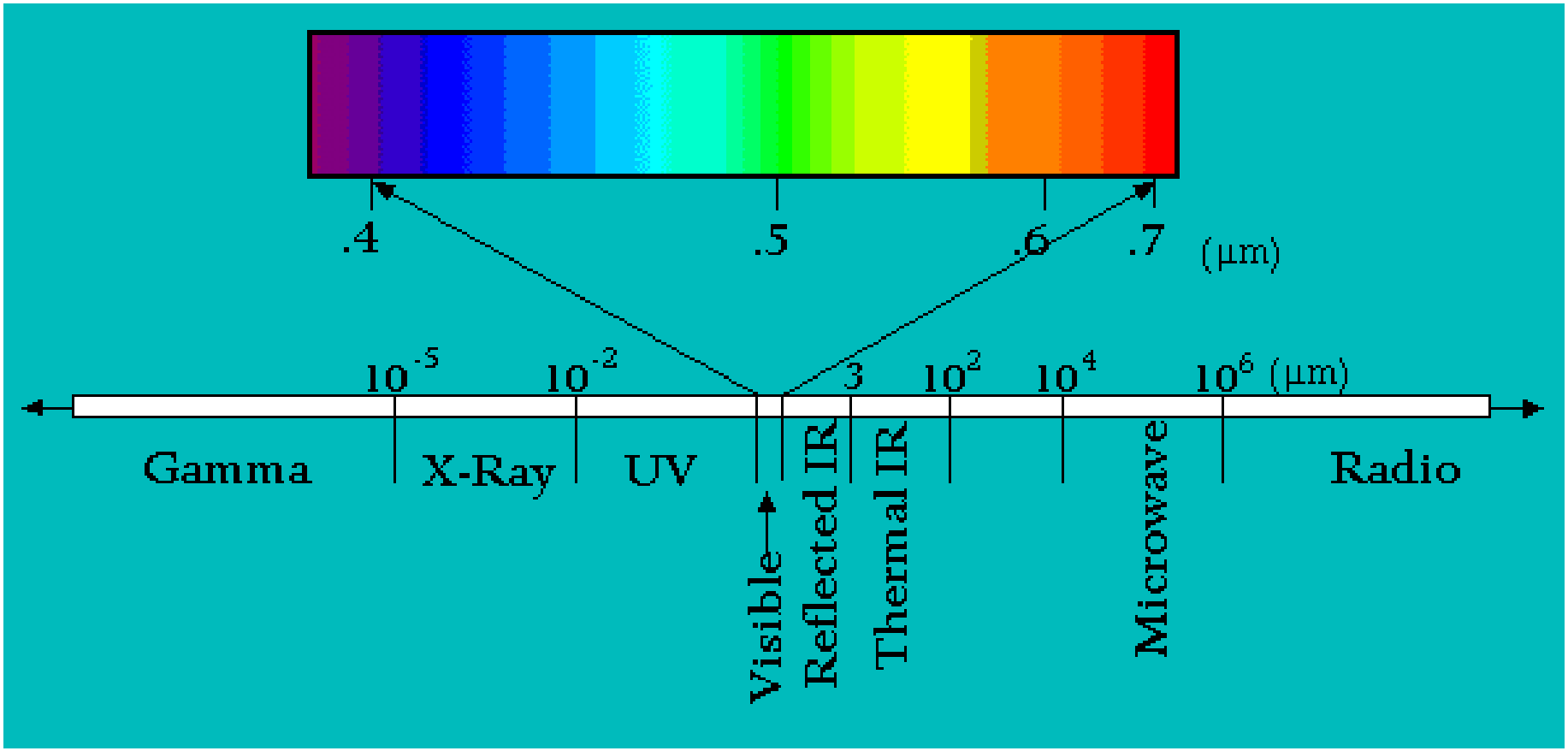
EMR can be treated as a photon or a light quantum. The amount of energy held by a photon of a specific wavelength is given by

$E = h \times \nu = h \times c / \lambda$

where E = energy of a photon [J]
h = Plank's constant [6.6262×10^{-34} J s]
ν = frequency [Hz]

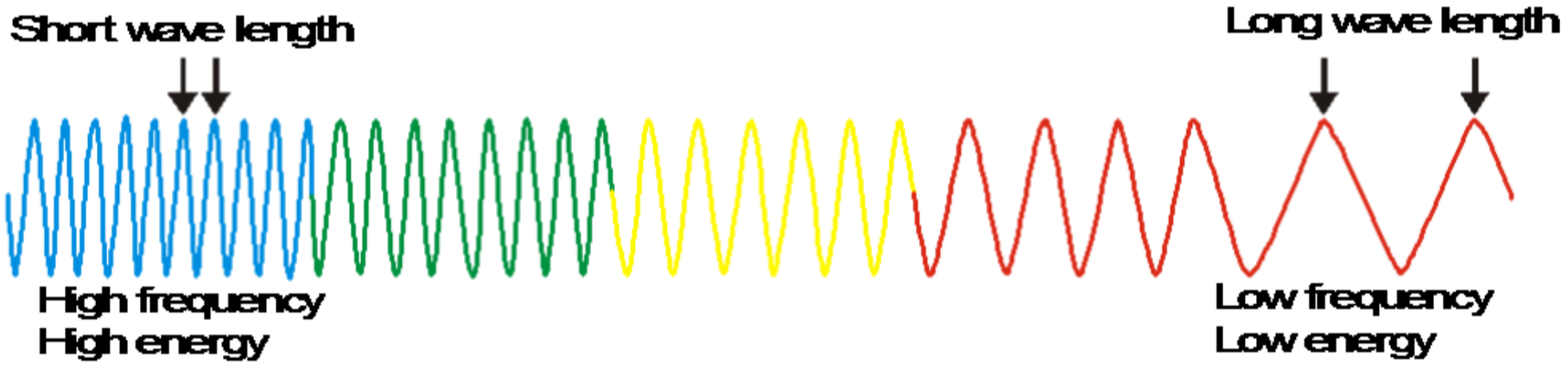
- The longer the wavelength involved, the lower its energy content
- Gamma rays (wavelength is around 10^{-9} m) are the most energetic and radio waves (> 1 m) the least energetic.
- It is more difficult to measure the energy emitted in longer wavelength than in shorter wavelength.

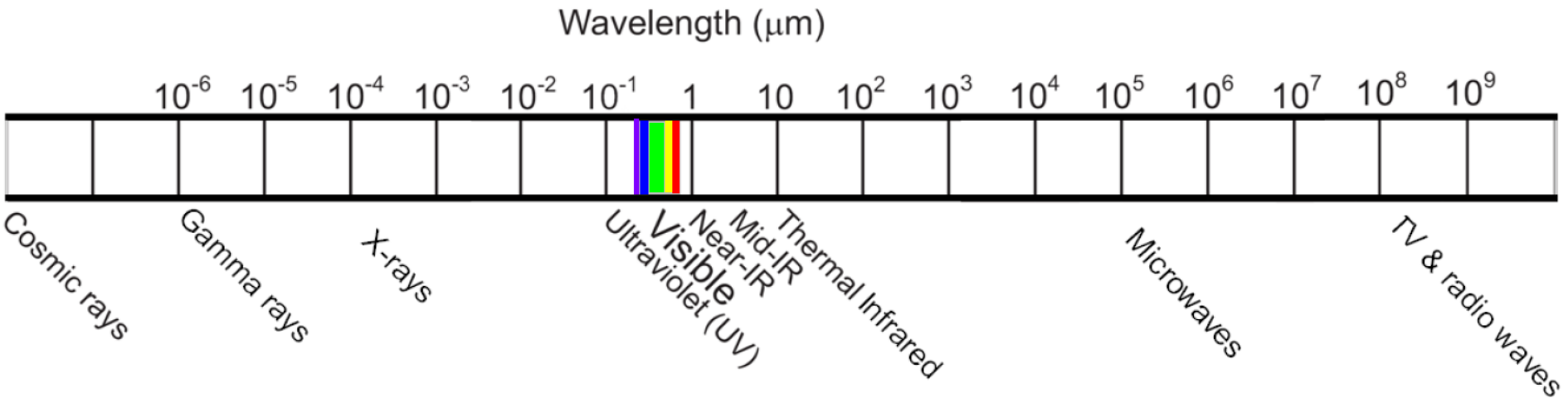
Electromagnetic Spectrum



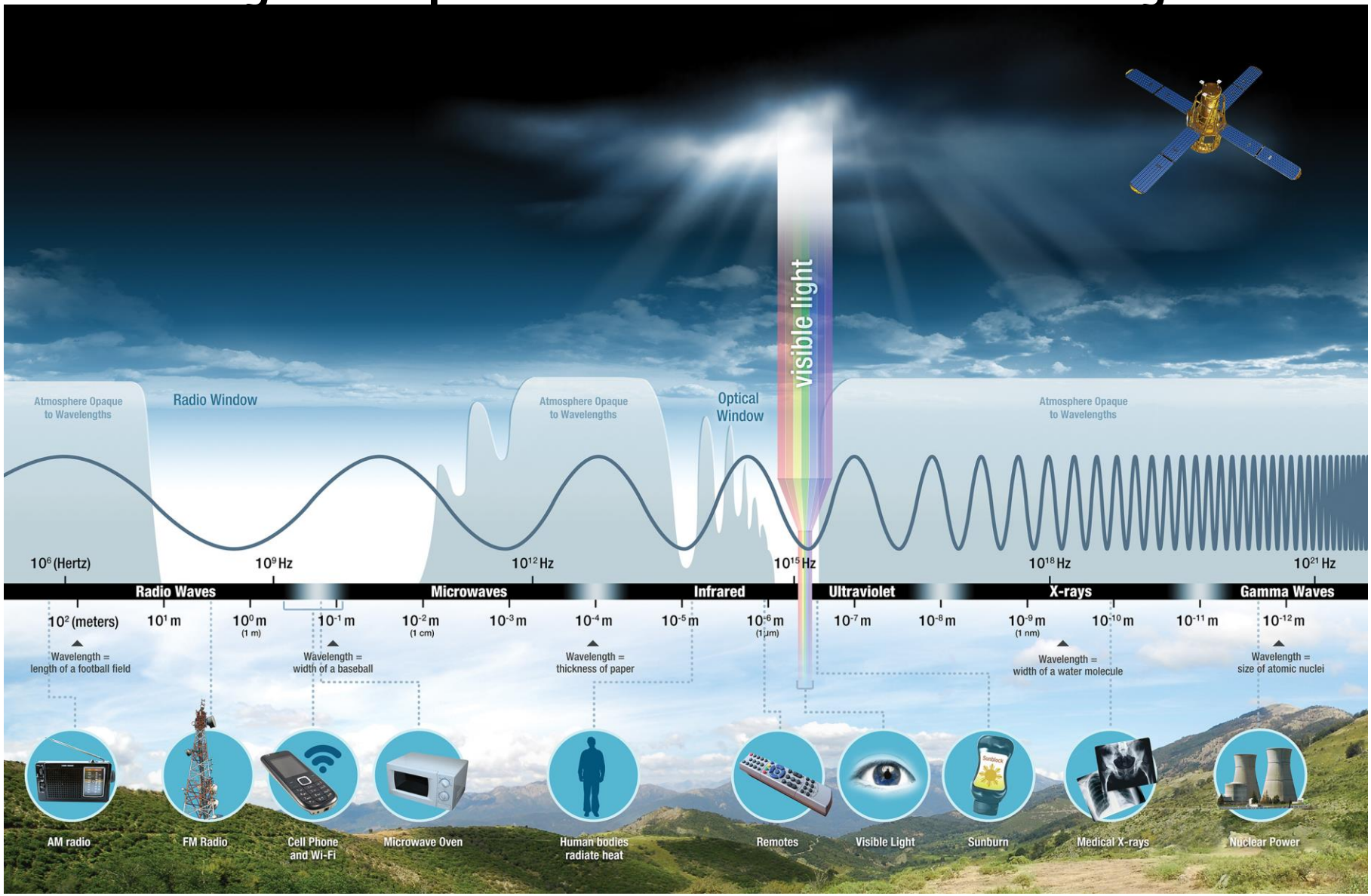
Assume that the speed of light in a media is c=300,000 km.s -1 . Calculate the frequency of a wavelength in the “red” (0.65μm) and in the “blue” (0.45 μm).

THE EM SPECTRUM





Electromagnetic spectrum used in remote sensing



cc: https://earthdata.nasa.gov/learn/backgrounders/remote-sensing

Electromagnetic Spectrum



Any matter with a body temperature greater than 0 K emits electromagnetic energy. Therefore, it has a spectrum.



Furthermore, different chemical elements have different spectra. They absorb and reflect spectral energy differently.



Different elements are combined to form compounds. Each compound has a unique spectrum due to its unique molecular structure.

This is the basis for remote sensing in discriminating one matter from the other.

Spectrum of a material is like the finger print of human being.

Gamma-ray

- Gamma radiation, also known as gamma ray, refers to electromagnetic radiation of an extremely high frequency and are therefore high energy photons.
- Gamma rays are ionizing radiation, and are thus biologically hazardous.
- Paul Villard, a French chemist and physicist, discovered gamma radiation in 1900, while studying radiation emitted from radium. Villard's radiation was named "gamma rays" by Ernest Rutherford in 1903.

X-ray



X-rays have a wavelength in the range of 0.01 to 10 nanometers.

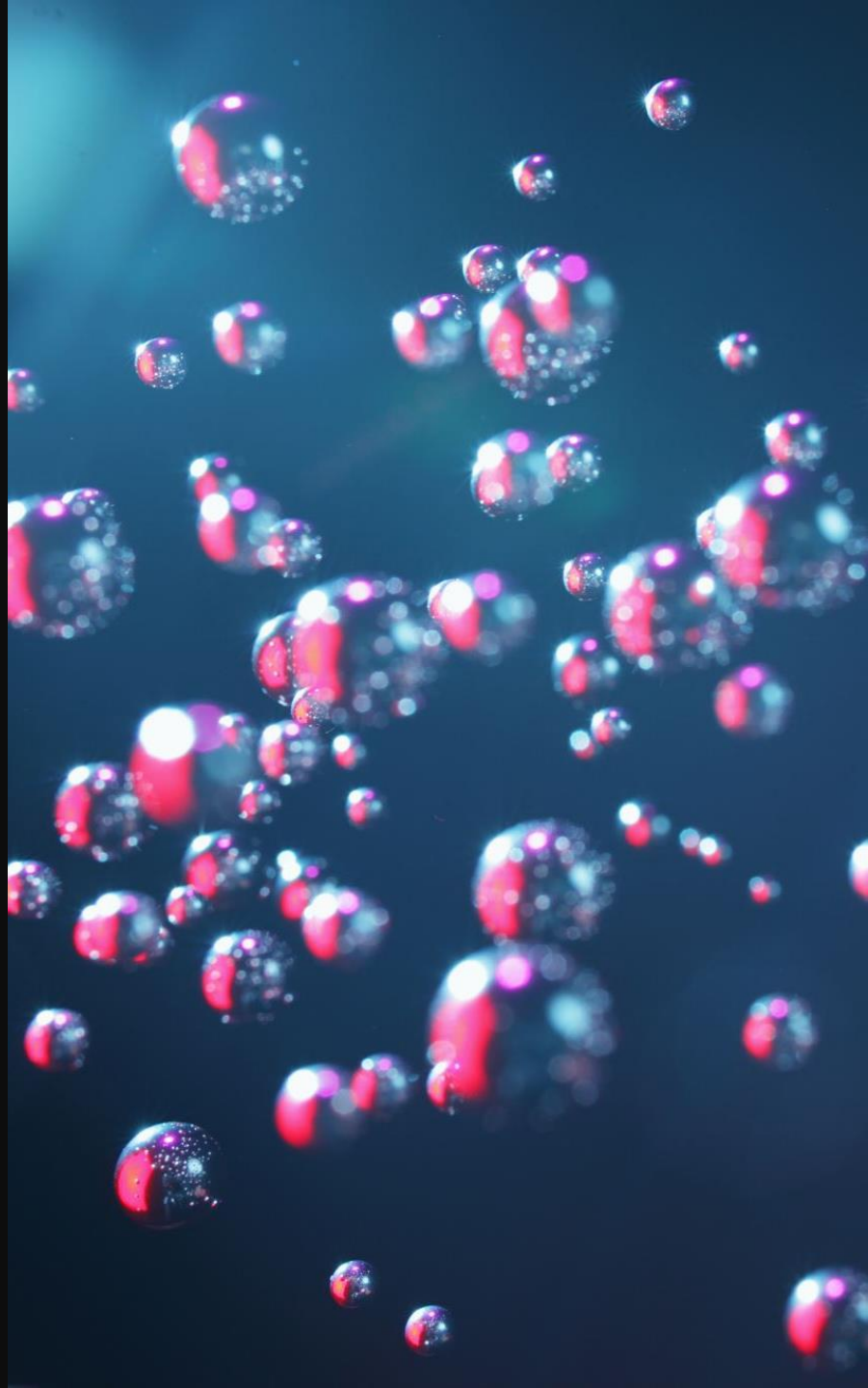


X-ray wavelengths are shorter than those of UV rays and typically longer than those of gamma rays.

Wilhelm Röntgen is usually credited as its discoverer, and he had named it X-radiation to signify an unknown type of radiation.

Ultraviolet (UV)

- Ultraviolet (UV) light is electromagnetic radiation with a wavelength shorter than that of visible light but longer than X-rays (from 400 nm to 10 nm in wavelength).
- Though usually invisible, under some conditions children and young adults can see ultraviolet down to wavelengths of about 310 nm, and people with aphakia (missing lens) can also see some UV wavelengths.
- Near-UV is visible to a number of insects and birds.



Visible light

- The visible spectrum is the portion of the electromagnetic spectrum that is visible to (can be detected by) the human eye.
- Electromagnetic radiation in this range of wavelengths is called visible light or simply light.
- A typical human eye will respond to wavelengths from about 390 to 700 nm. In terms of frequency, this corresponds to a band in the vicinity of 430–790 THz.
- In the 17th century, Isaac Newton discovered that prisms could disassemble and reassemble white light, and described the phenomenon in his book Opticks.

Infrared (IR)

- Infrared (IR) is invisible radiant energy, electromagnetic radiation with longer wavelengths than those of visible light, extending from the nominal red edge of the visible spectrum at 700 nanometers (frequency 430 THz) to 1 mm (300 GHz).
- Most of the thermal radiation emitted by objects near room temperature is infrared.
- Infrared radiation was discovered in 1800 by astronomer Sir William Herschel, who discovered a type of invisible radiation in the spectrum beyond red light, by means of its effect upon a thermometer.

Microwave

- Microwaves are a form of electromagnetic radiation with wavelengths ranging from as long as one 1 meter to as short as 1 millimeter, or equivalently, with frequencies between 300 MHz (0.3 GHz) and 300 GHz.

Radio Waves

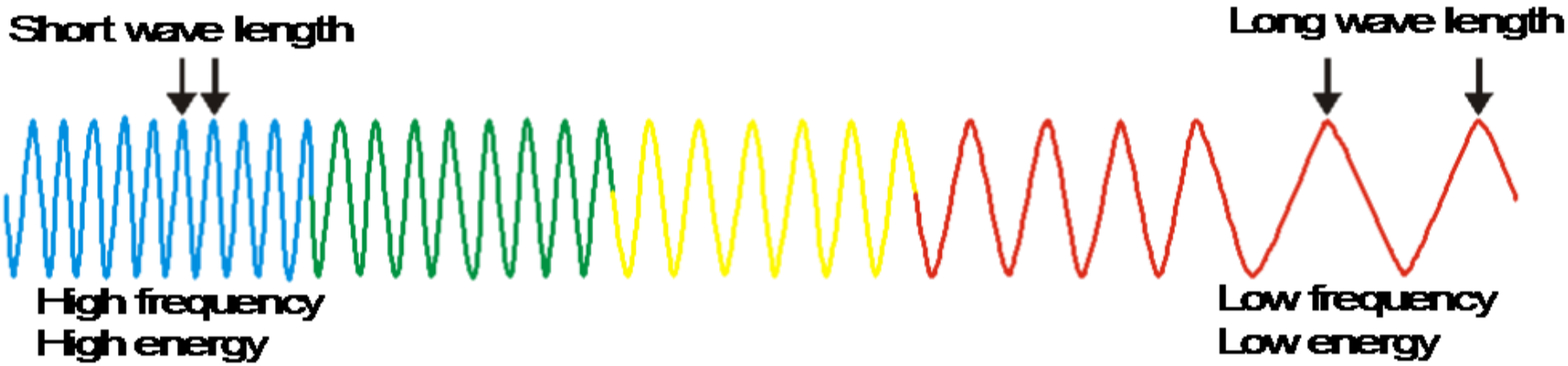


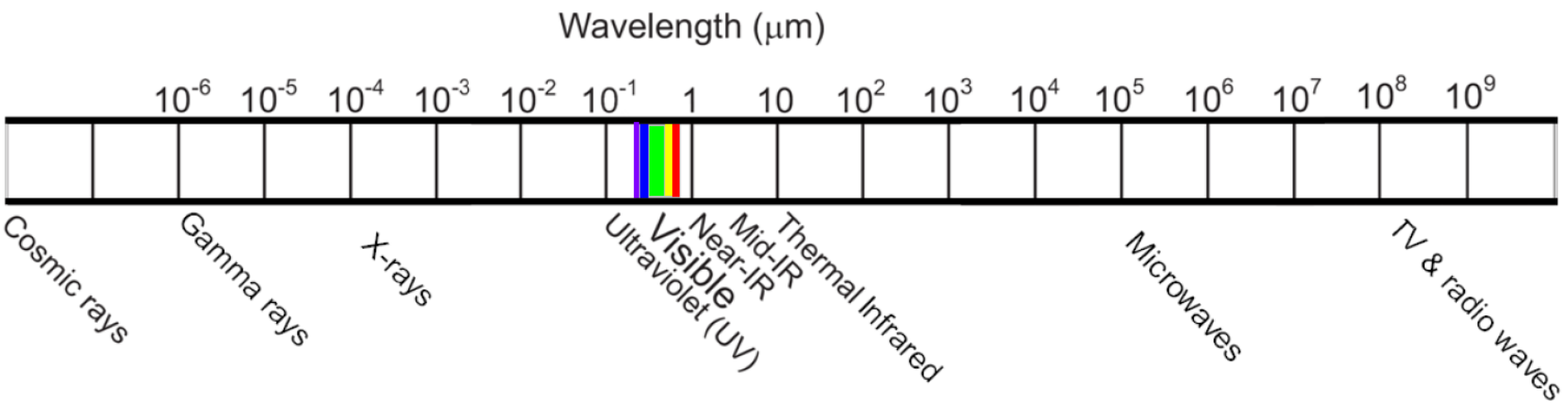
Radio waves are a type of electromagnetic radiation with wavelengths in the electromagnetic spectrum longer than microwaves.



Radio waves have frequencies from 300 GHz to as low as 3 kHz, and corresponding wavelengths ranging from 1 millimeter (0.039 in) to 100 kilometers (62 mi).

THE EM SPECTRUM



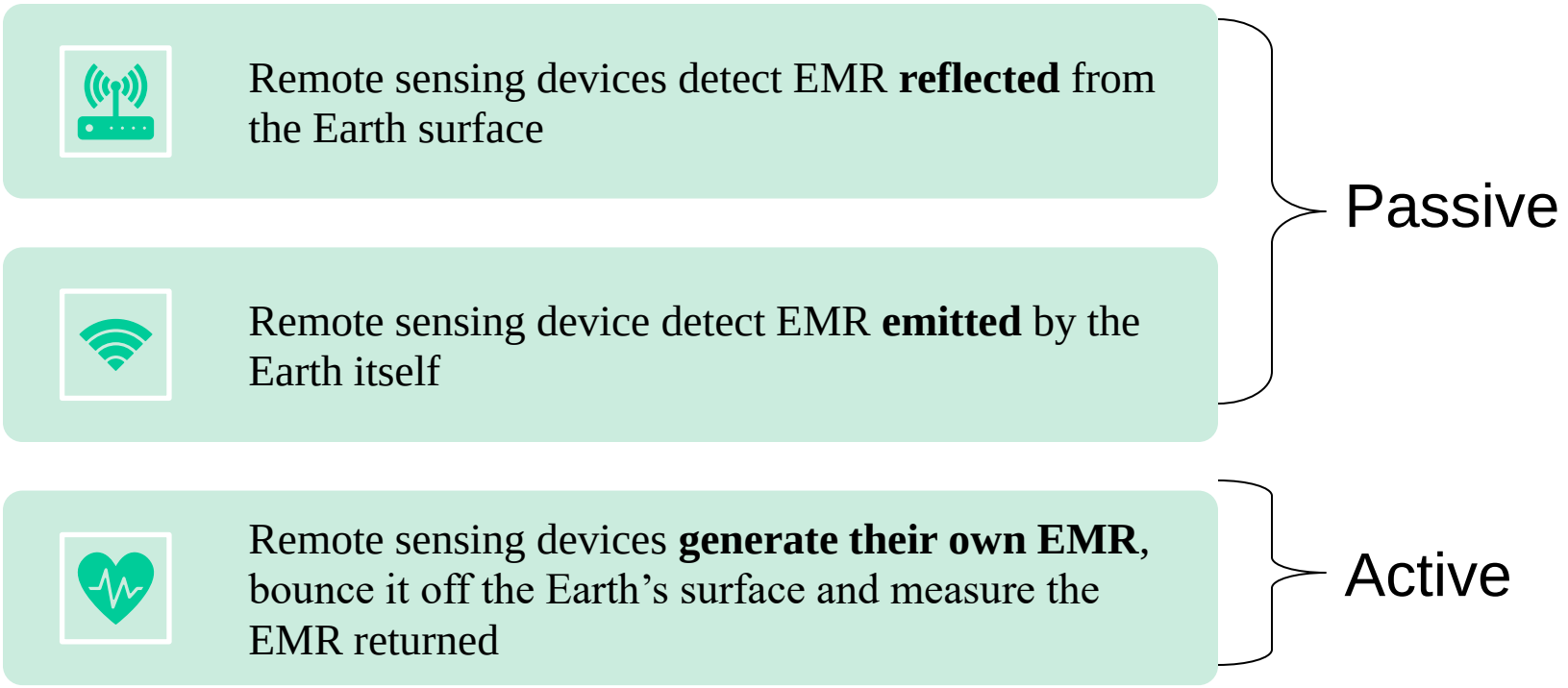


Electromagnetic spectrum used in remote sensing

- Near UV(ultra-violet): 0.3-0.4 μm
- Visible light:
  Blue: 0.4-0.5 μm
- Green: 0.5-0.6 μm
- Red: 0.6-0.7 μm
- Infrared (IR):
  Near IR: 0.7-1.1 μm
- Middle IR: 1.3-1.6 μm
- Shortwave IR: 2-2.5 μm
- Thermal IR: 3-5, 8-14 μm
- Microwave:
  0.3 to 300 cm

How is EMR used in Remote Sensing

Three main ‘models’ of how EMR is used in Remote Sensing



Electromagnetic spectrum used in remote sensing

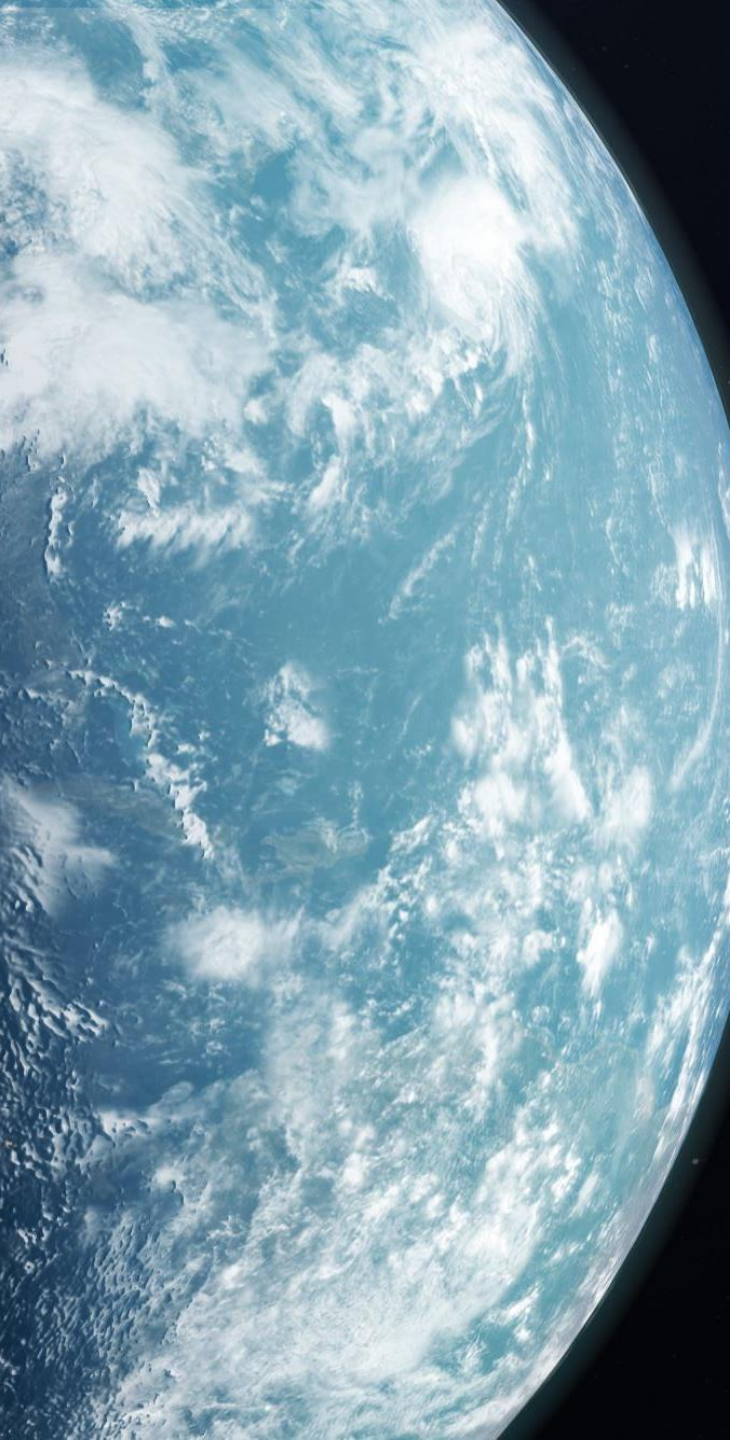
Band	Wavelength	Remarks
Gamma ray	<0.03 nm	Incoming radiation from the sun is completely absorbed by the upper atmosphere, and is not available for Remote Sensing. Gamma radiation from radioactive minerals is detected by low-flying aircraft as a prospecting method.
X-ray	0.03 to 0.3 nm	Incoming radiation is completely absorbed by atmosphere. Not employed in Remote Sensing.
Ultraviolet, UV	3 nm to 0.4 mm	Incoming UV radiation atmosphere wavelengths <0.3 mm is completely absorbed by ozone in the upper atmosphere.
Photographic UV	0.3 to 0.4 mm	Transmitted through the atmosphere. Detectable with film and photodetectors, but atmospheric scattering is severe.
Visible	0.4 to 0.7 mm	Detected with film and photodetectors. Includes earth reflectance peak at about 0.5 mm.
Infrared, IR	0.7 to 300 mm	Interaction with matter varies with wavelength. Atmospheric transmission windows are separated by absorption bands.
Reflected IR	0.7 to 3 mm	This is primarily reflected solar radiation and contains no information about thermal properties of materials. Commonly divided into the following regions: • Near Infra Red (NIR) between 0.7 to 1.1 mm. • Middle Infra Red (MIR) between 1.3 to 1.6 mm. • Short Wave Infra Red (SWIR) between 2 to 2.5 mm. Radiation from 0.7 to 0.9 mm is detectable with film and is called photographic IR radiation.
Thermal IR	3 to 5 mm 8 to 14 mm	These are the principal atmospheric windows in the thermal region. Imagery at these wavelengths is acquired through the use of optical-mechanical scanners, not by film.
Microwave	0.3 to 300 cm	These longer wavelengths can penetrate clouds and fog. Imagery may be acquired in the active or passive mode.
Radar	0.3 to 300 cm	Active mode of microwave Remote Sensing.

In short

Principals of Remote Sensing

References on Principals of Remote Sensing

Principles of Remote Sensing by Tempfli K., Kerle N., Huurneman G.C., Janssen L.L.F. (eds.)



Interactions of EM Radiation

- The most important source of energy is the Sun. Before the Sun’s radiation reaches the Earth's surface it has to travel through some distance of the Earth's atmosphere.
- The composition of the atmosphere is thus of importance in remote sensing because EMR must pass through it in order to reach the Earth’s surface.



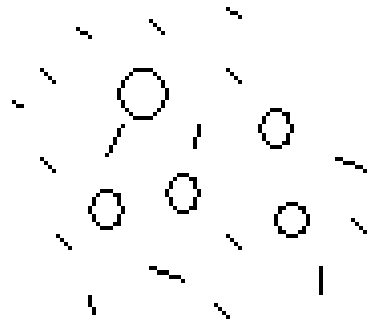
Interactions of EM Radiation

Interactions of EM Radiation with the Atmosphere

Composition of the atmosphere

Component	Percentage
N_2	78.08
O_2	20.94
Ar	0.93
CO_2	0.0314
O_3	0.00000004

The atmosphere also contains **particles** with a range of sizes and sources which are of great importance in remote sensing.



molecules
dust, smoke
water droplet

} different diameters

Interactions of EM Radiation

EMR interacts with particles and gases in the atmosphere. Three processes serve to attenuate the signal we are trying to detect

1. **Scattering:** Redirection of EMR from its original path
2. **Absorption:** Retention of EMR by molecules in the atmosphere
3. **Refraction:** Passing of EMR through the atmosphere

Scattering occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path.

- **Scattering** depends on several factors including the
- - Wavelength of the radiation,
- - Abundance of particles or gases, and
- - Distance the radiation travels through the atmosphere.
- Light at shorter wavelengths (like blue and violet visible light) are scattered by small particles that include NO_2 and O_2

Rayleigh Scatter

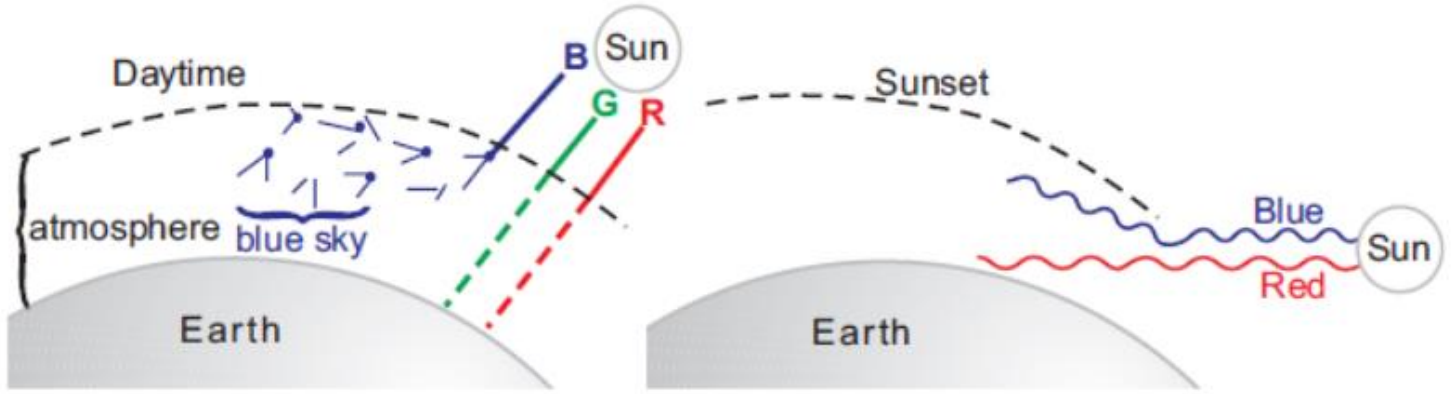


Image Source: Principles of Remote Sensing (Tempfli et al.)

Rayleigh Scatter

For visible wavelengths, 100 % (in case of cloud cover) to 5 % (in case of clear atmosphere) of energy received by the sensor is directly contributed by the atmosphere.

Scattering occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path.



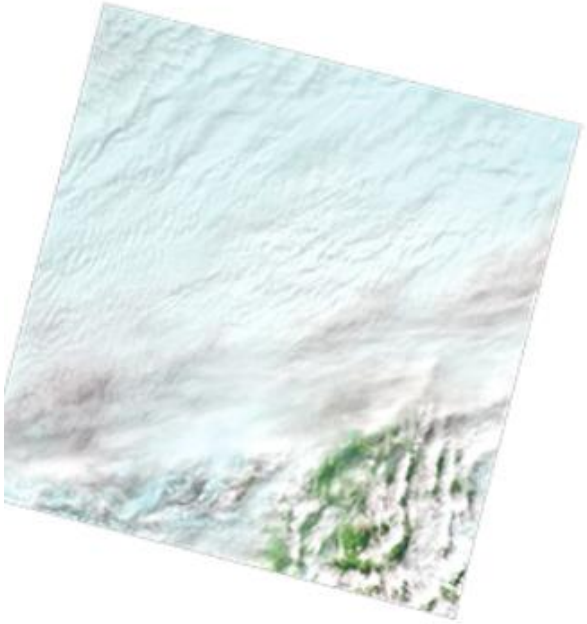
Haze in Shanghai, China due to air pollution

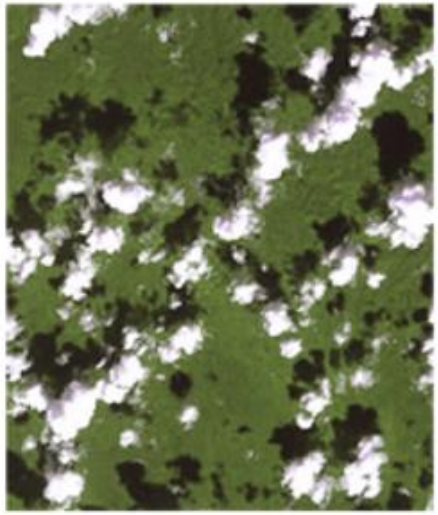
Mie Scatter

Mie scatter occurs when the wavelength of the electromagnetic radiation is a *similar* size to the atmospheric particles. Mie scatter generally influences radiation from the near UV through the mid- infrared parts of the spectrum.

Non-Selective Scatter

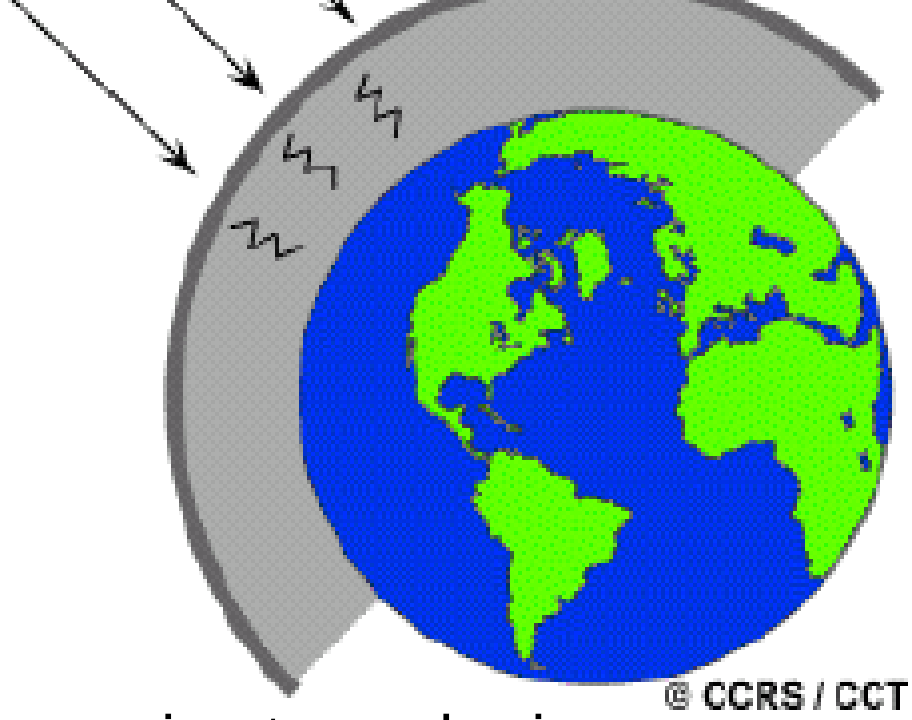
Non-selective scattering occurs when the diameter of the particles in the atmosphere are much *larger* than the wavelength of radiation. Non-selective scatter is primarily caused by water droplets in the atmosphere.





Sunset on Mars
Image Source: NASA/JPL





Three main atmospheric constituents which absorb radiation are

1. Ozone (O_3)

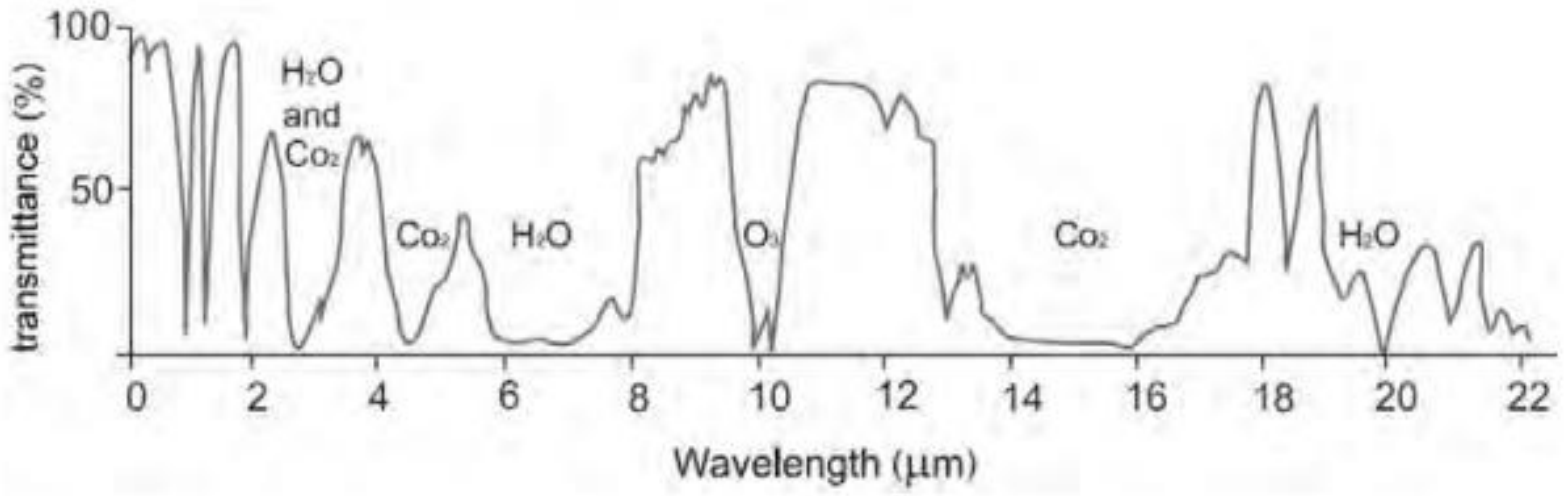
2. Carbon dioxide (CO_2)

3. Water vapor (H_2O)

- **Absorption** is the other main mechanism when electromagnetic radiation interacts with the atmosphere.
- In contrast to scattering, this phenomenon causes molecules in the atmosphere to absorb energy at various wavelengths.

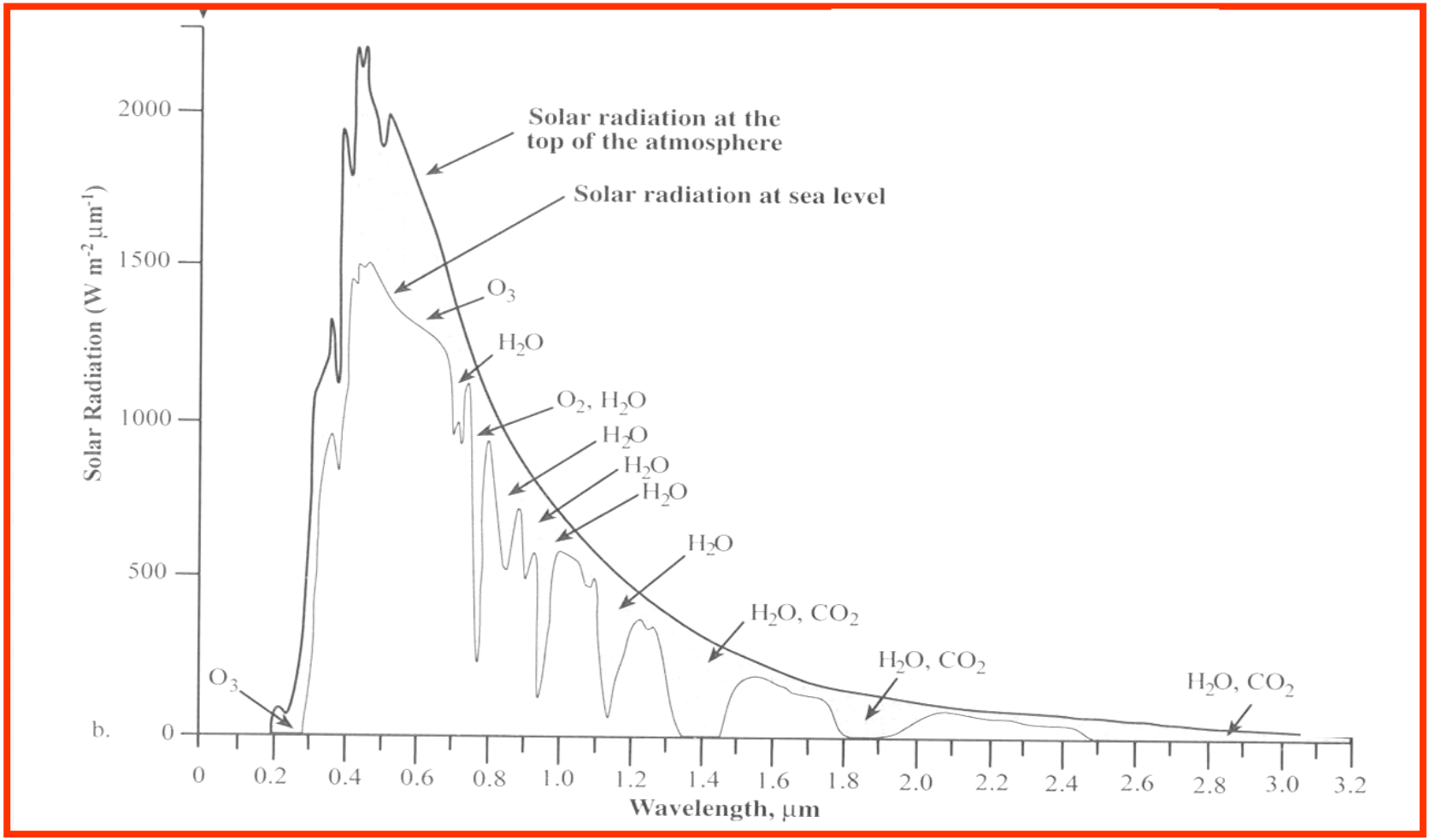
Absorption

- **Ozone** absorbs the harmful (to most living things) ultraviolet radiation from the sun.
- **Carbon dioxide** absorbs radiation strongly in the far infrared portion of the spectrum - that area associated with thermal heating - which serves to trap this heat inside the atmosphere.
- **Water vapor** in the atmosphere absorbs much of the incoming longwave infrared and shortwave microwave radiation.



Absorption

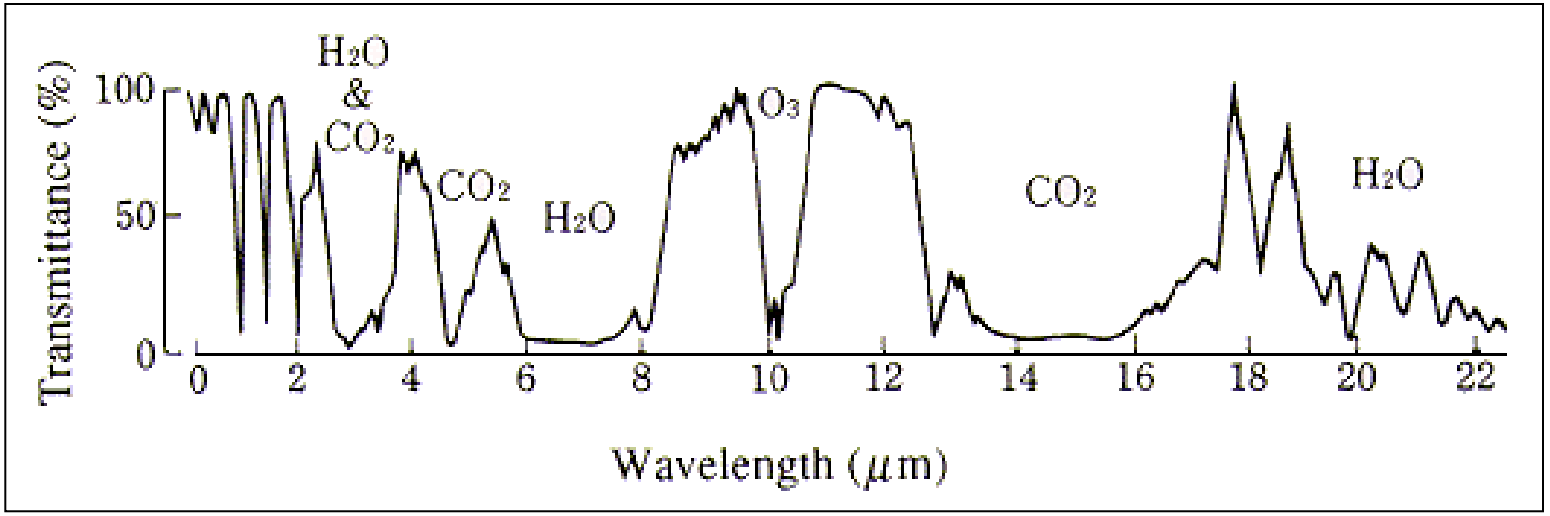
Parts of the EM spectrum are heavily affected by scattering and absorption and useless for remote sensing, other parts are less affected and useful



Transmission

The remaining amount of energy after being absorbed and scattered by the atmosphere is transmitted.

$$\text{Transmission} = \frac{\text{Transmitted Energy}}{\text{Input Energy}}$$

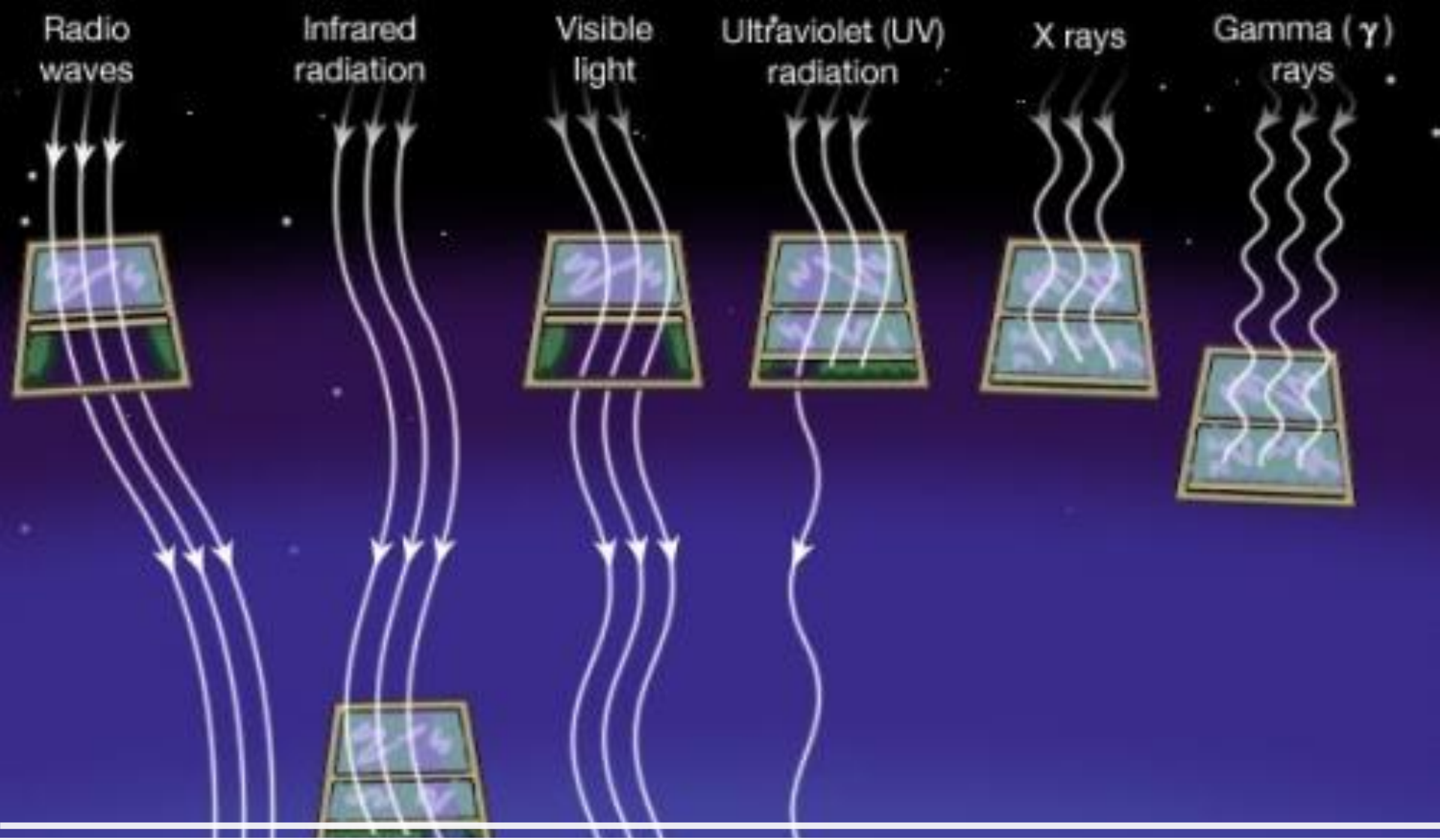


Atmospheric transmission expressed as percentage

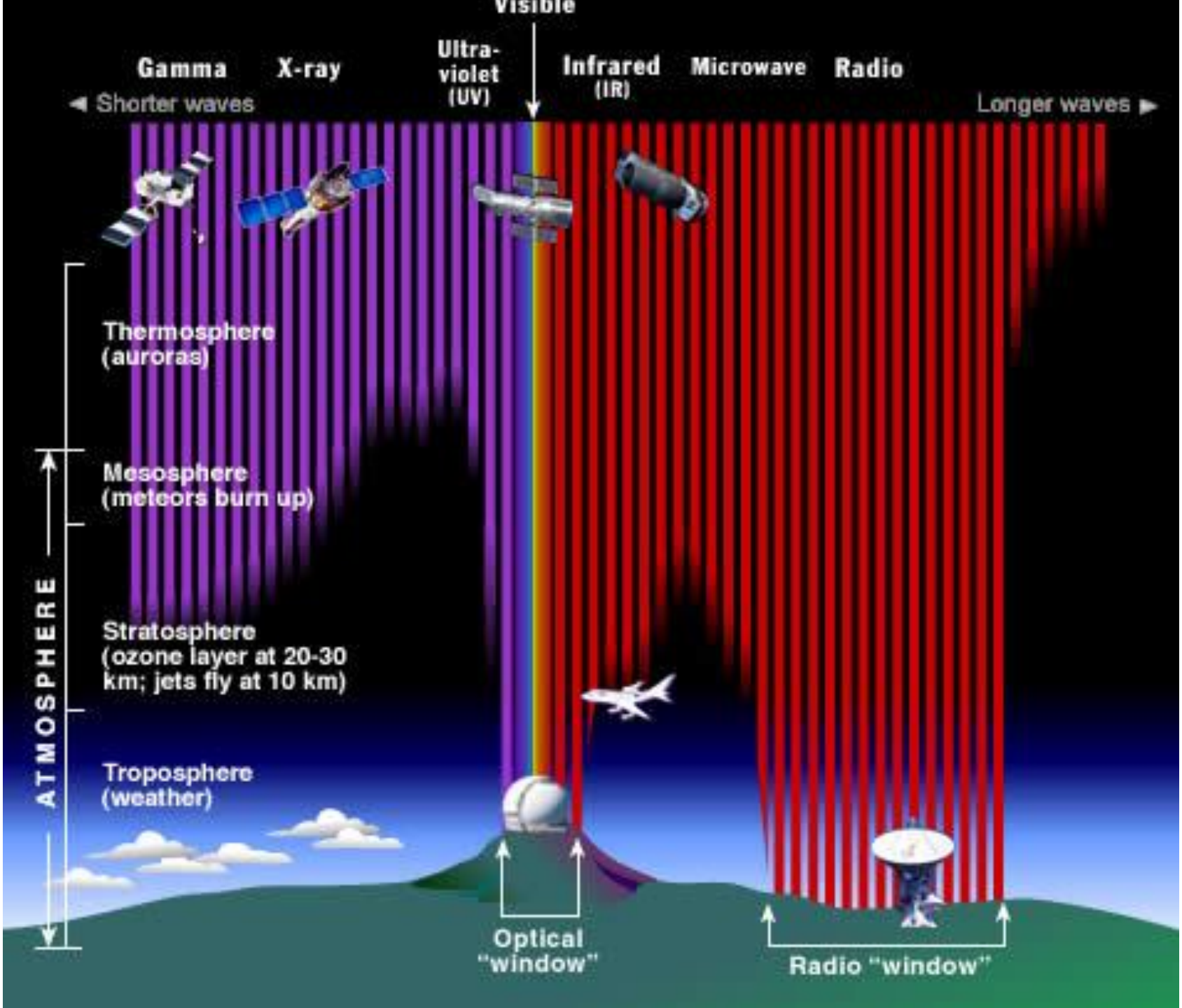
Atmospheric Windows

- It refers to the relatively transparent wavelength regions of the atmosphere.
- The wavelengths at which EMR are partially or wholly transmitted through the atmosphere are known as **atmospheric windows**.

Atmospheric windows	Wavelength (μm)
Upper UV – photographic IR	0.3 – 1(approx.)
Reflected IR	1.3, 1.6, 2.2
Thermal IR	3-5, 8-14
Microwave	>5000



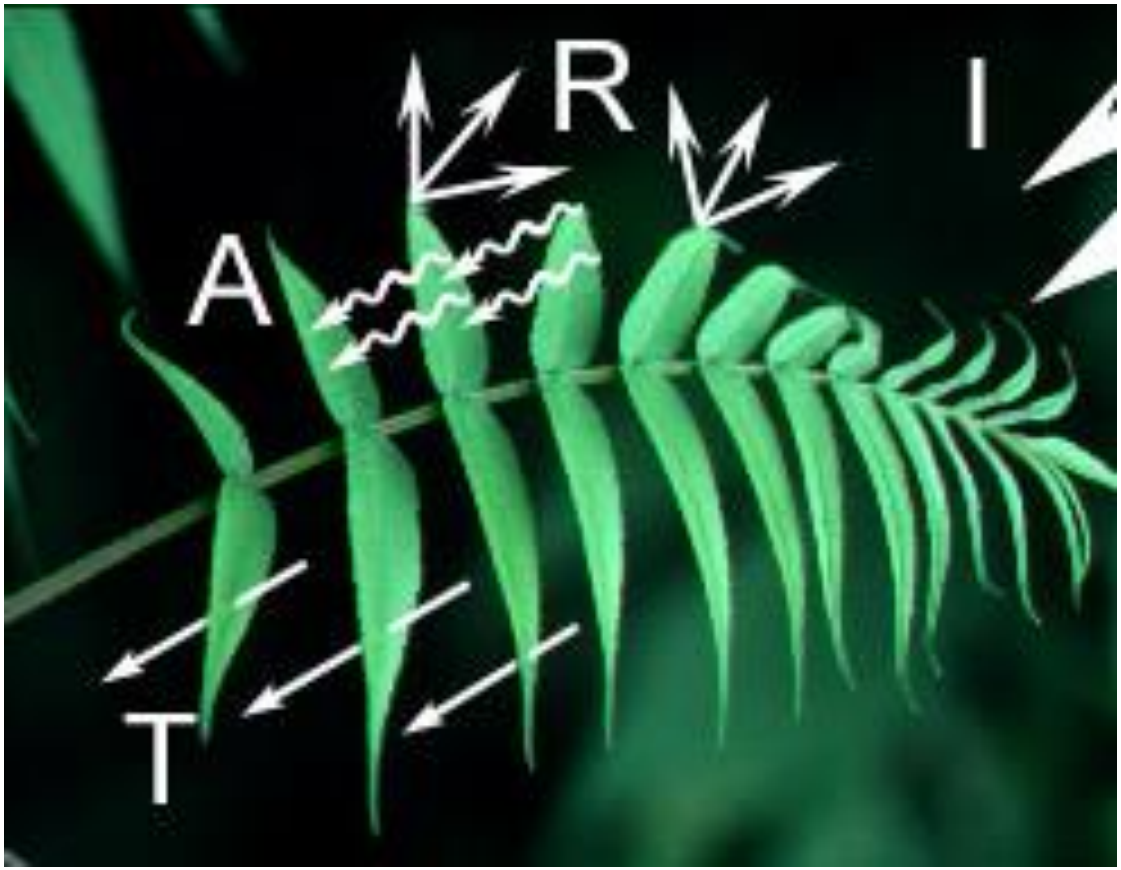
Atmospheric windows


Visible
Gamma
X-ray
Ultra-violet (UV)
Infrared (IR)
Microwave
Radio
Shorter waves
Longer waves
Thermosphere (auroras)
Mesosphere (meteors burn up)
Stratosphere (ozone layer at 20-30 km; jets fly at 10 km)
Troposphere (weather)
ATMOSPHERE
Optical "window"
Radio "window"



Interactions of EM Radiation with the Earth's Surface

- Radiation that is not absorbed or scattered in the atmosphere can reach and interact with the Earth's surface.
- When the EM energy reaches the Earth surface, total energy breaks into three parts: **reflected, absorbed, and/or transmitted**.



- **Interactions of EM Radiation with the Earth's Surface**
- When electromagnetic energy is incident on any given earth surface feature, three fundamental energy interactions are possible. These are:

1. Absorption (A)

2. Transmission (T)

3. Reflection (R)

- The proportions of each will depend on the
- **- wavelength of the energy,**
- **angle at which the radiation intersects with the surface and**
- **roughness of the material and condition of the feature.**

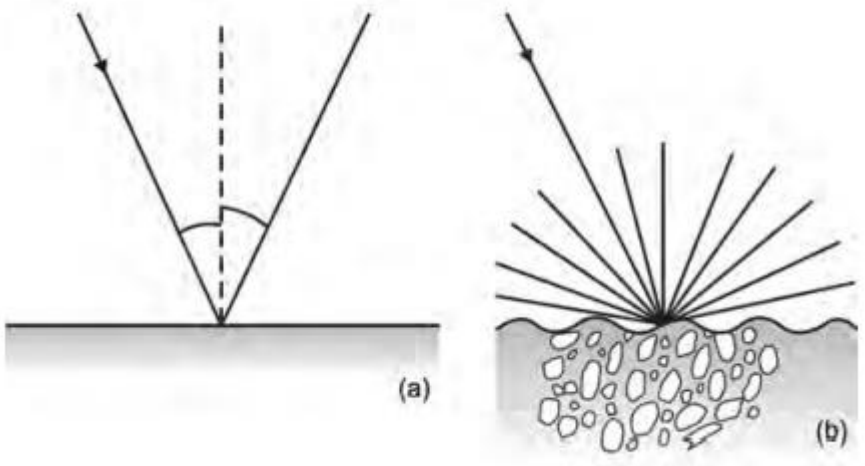
Interactions of EM Radiation with the Earth's Surface

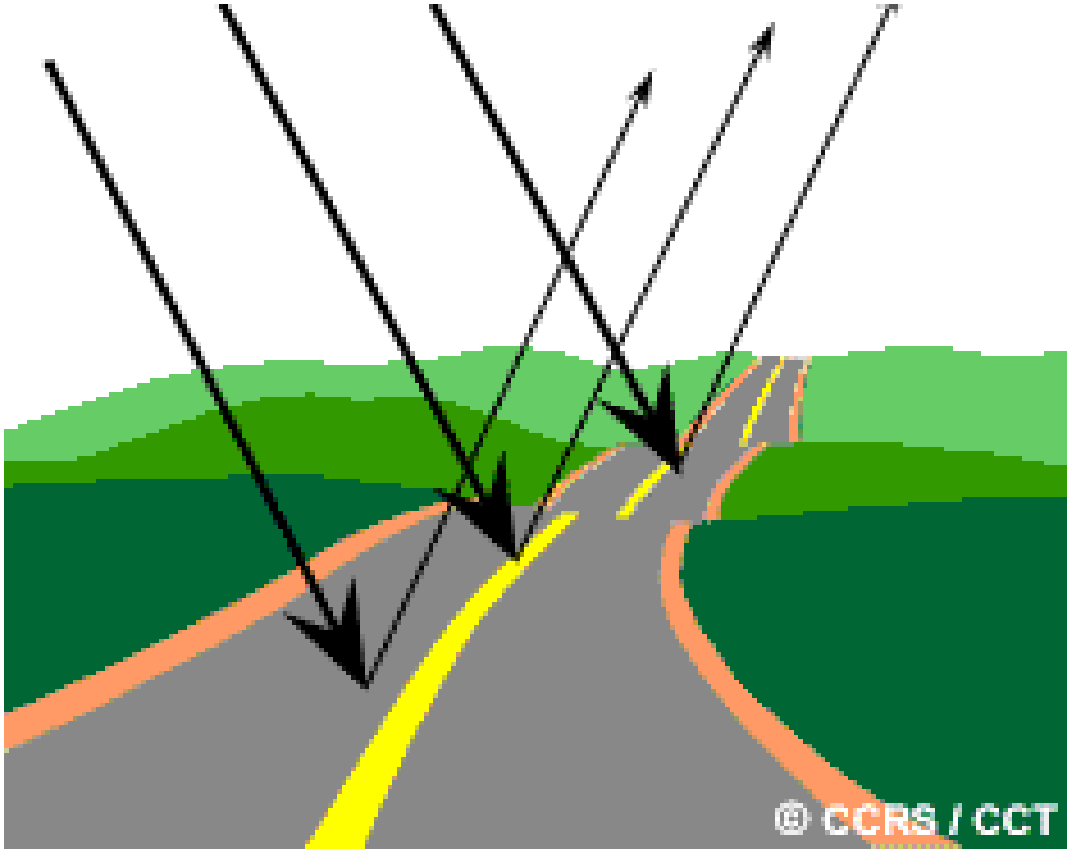
Reflection

- Two types of reflection, which represent the two extreme ends of the way in which energy is reflected from a target are:

1. Specular reflection

2. Diffuse reflection.





Interactions of EM Radiation with the Earth's Surface

- **Specular** or mirror like reflection, typically occurs when surface is smooth and all (or almost all) of the energy is directed away from the surface in a single direction.



Interactions of EM Radiation with the Earth's Surface

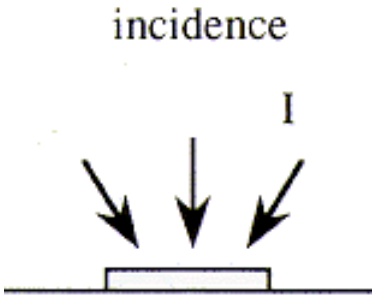
- **Diffuse** or Lambertian reflection occurs when the surface is rough and the energy is reflected almost uniformly in all directions.

Interactions of EM Radiation with the Earth's Surface

- Whether a particular target reflects specularly or diffusely, or somewhere in between, depends on the **surface roughness of the feature in comparison to the wavelength of the incoming radiation**.
- If the wavelengths are much smaller than the surface variations or the particle sizes that make up the surface, diffuse reflection will dominate.
- For example, fine-grained sand would appear fairly smooth to long wavelength microwaves but would appear quite rough to the visible wavelengths

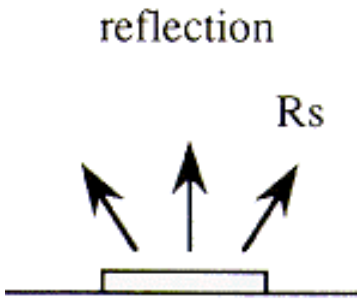
Spectral Reflectance Curve

The reflectance characteristics of earth surface feature may be quantified by measuring the portion of incident energy (*Irradiance*) that is reflected (*Radiance*).



This energy is measured as a function of wavelength and is called **spectral reflectance**. It is defined as:

$$Reflectance = \frac{Rs}{I}$$

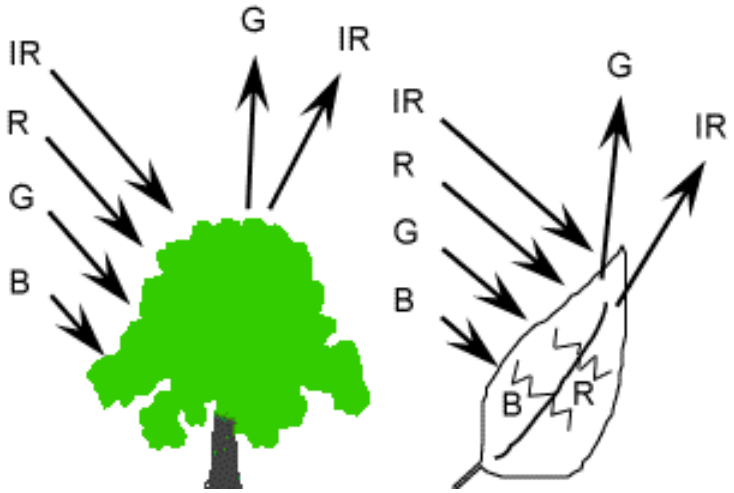


Reflectance ranges from 0 to 1 or 0 to 100%. Equipment to measure reflectance is called **spectrometer**

A graph of spectral reflectance as a function of wavelength is termed as **spectral reflectance curve**

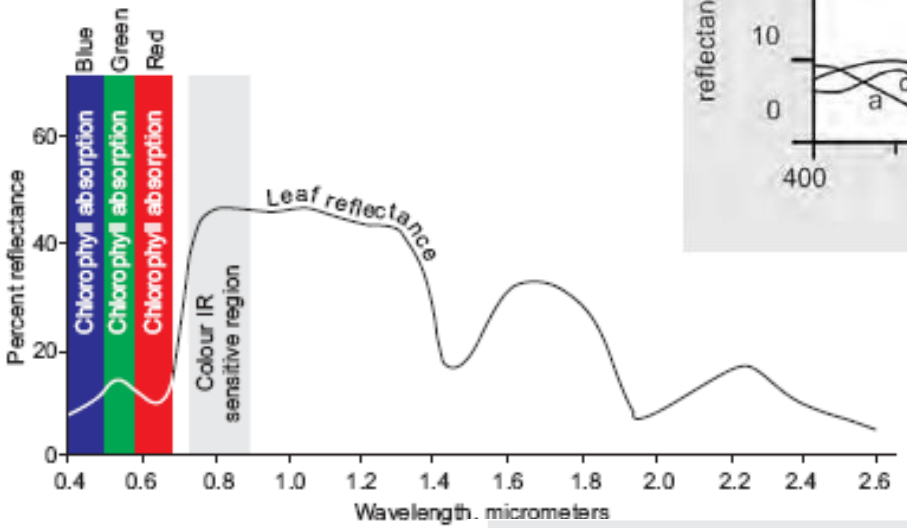
Spectral Reflectance of Healthy Vegetation

Vegetation: A chemical compound in leaves called chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects green wavelengths.

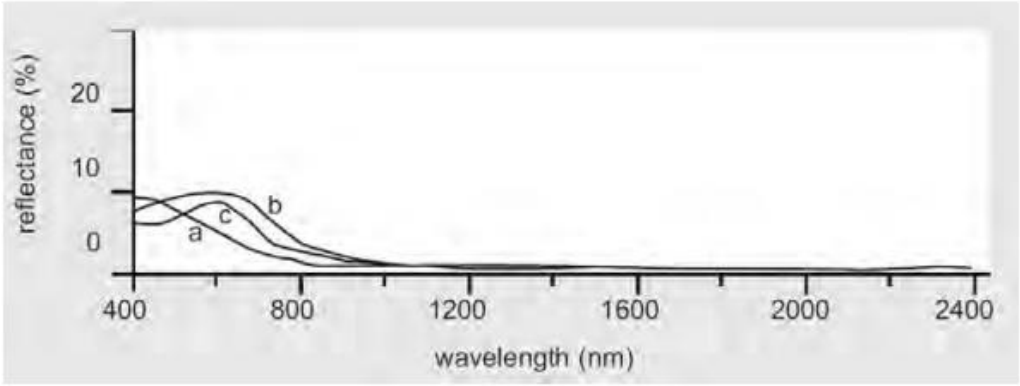


The internal structure of healthy leaves act as excellent diffuse reflectors of near-infrared wavelengths.

Spectral Reflectance of Healthy Vegetation

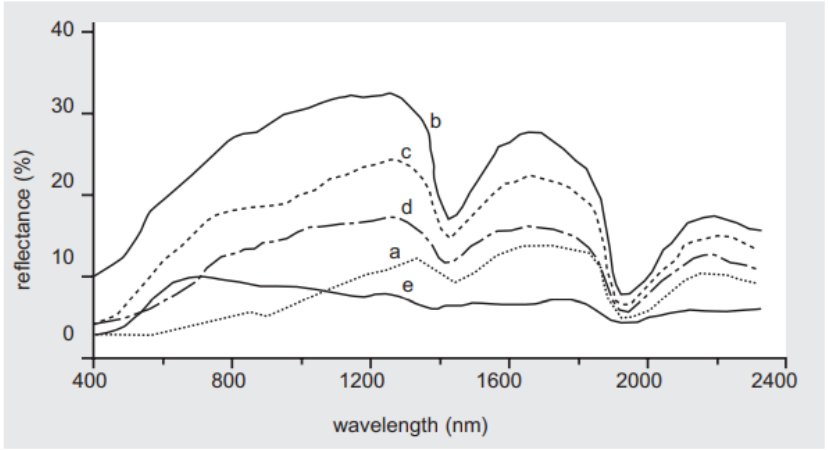


Water



(a) ocean water, (b) turbid water, (c) water with chlorophyll

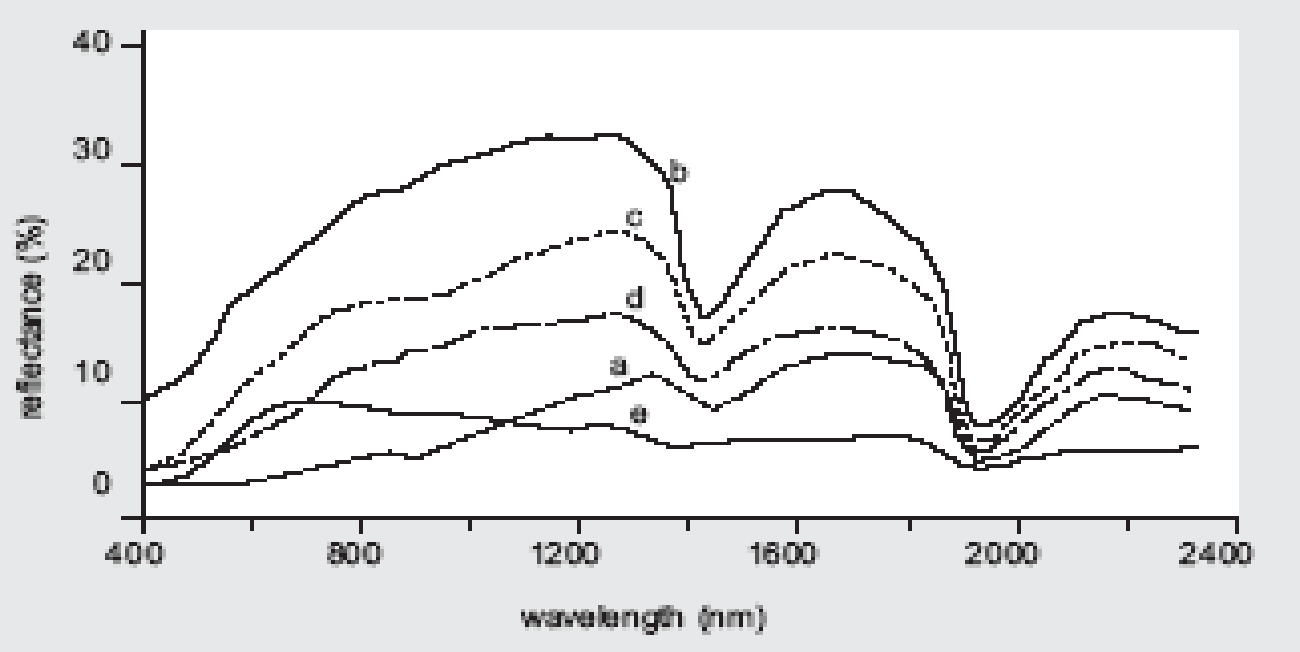
Bare soil



(a) organic dominated, (b) minimally altered, (c) iron altered, (d) organic affected and (e) iron dominated

Spectral Reflectance of Bare Soil

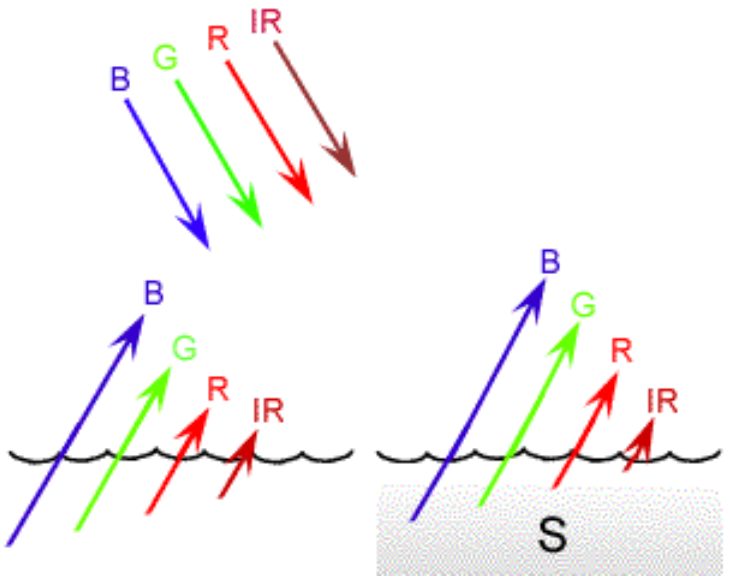
The surface reflectance from bare soil depends on many factors such as color, moisture content, presence of carbonate and iron oxide content.



Refelectance spectra of surface samples of five mineral soils, (a) organic dominated, (b) minimally dominated, (c) iron altered, (d) organic affected and (e) iron dominated

Spectral Reflectance of Water

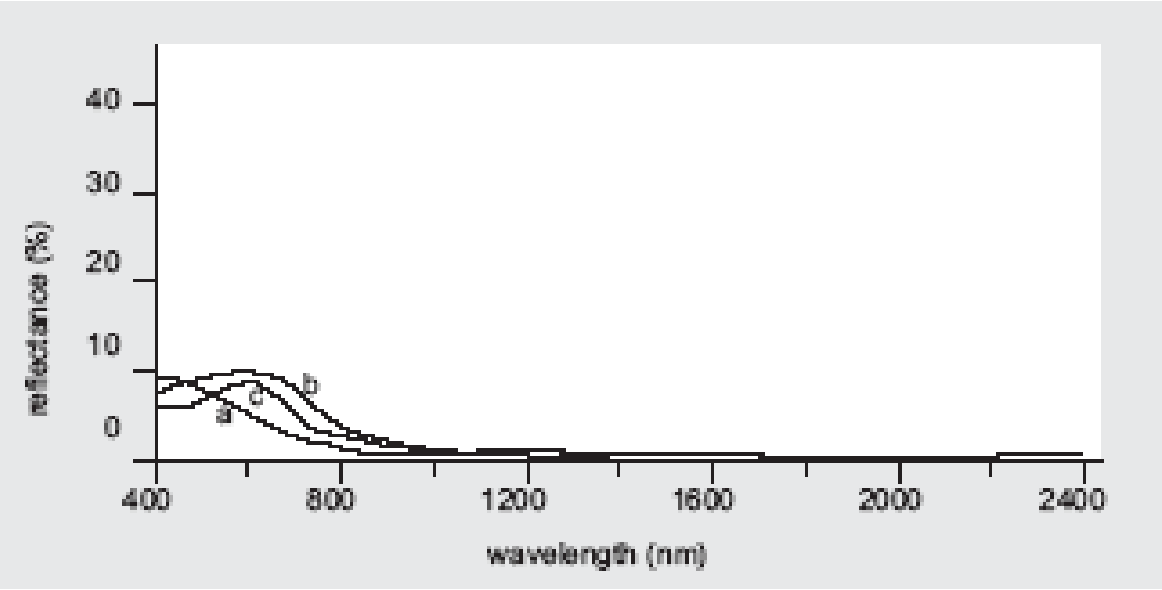
Water: Longer wavelength visible and near infrared radiation is absorbed more by water than shorter visible wavelengths.



- Water typically looks blue or blue-green due to stronger reflectance at these shorter wavelengths, and darker if viewed at red or near infrared wavelengths.
- Chlorophyll in algae absorbs more of the blue wavelengths and reflects the green, making the vegetation may be.

Spectral Reflectance of Water

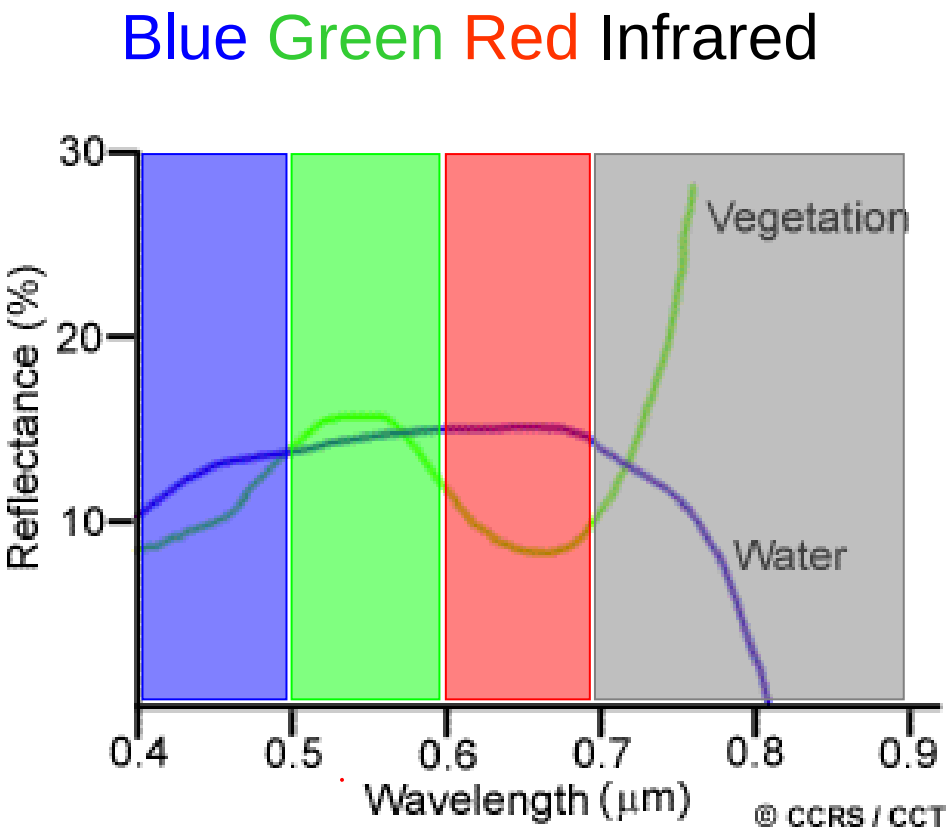
- Compared to vegetation and soils water has lower reflectance.
- Vegetation may reflect up to 50%, soils up to 30-40% while water reflect at most 10% of the incoming radiation.
- Beyond 1.2 um, all energy is absorbed.



Typical effects of chlorophyll and sediment on water reflectance: (a) Ocean water, (b) turbid water and (c) water with chlorophyll

Spectral Reflectance Curve for Water and Vegetation

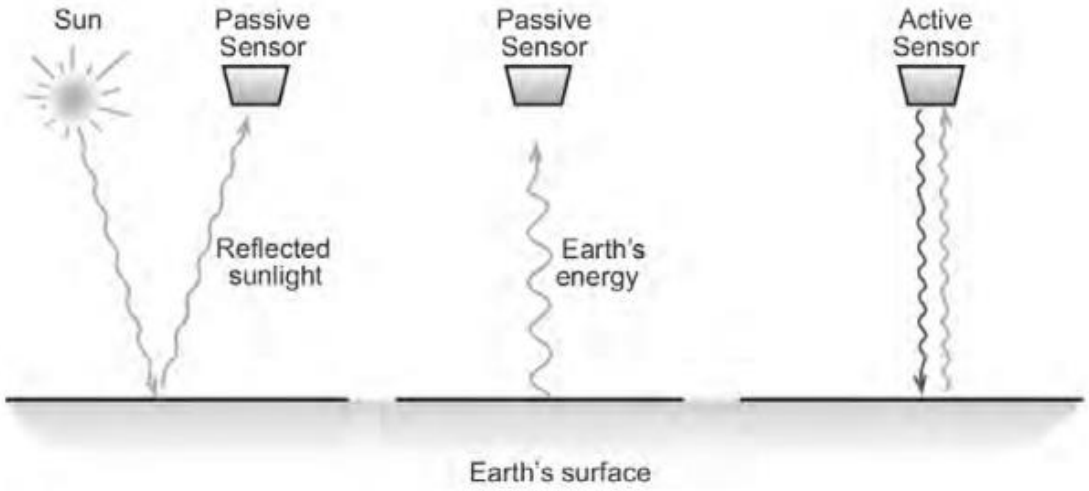
- By measuring the energy that is reflected (or emitted) by targets on the Earth's surface over a variety of different wavelengths, it is possible to build up a **spectral response** for that object.
- By comparing the response patterns of different features we may be able to distinguish between them.



Spectral Reflectance

- Water and vegetation may reflect somewhat similarly in the visible wavelengths but are almost always separable in the infrared.
- Spectral response can be quite variable, even for the same target type, and can also vary with time and location.
- Knowing **where to look spectrally and understanding the factors which influence the spectral response of the features of interest are critical to correctly interpreting the interaction of electromagnetic radiation with the surface.**
- More than one wavelength (frequency) may be required to be able to detect differences and identify targets with a high degree of reliability.

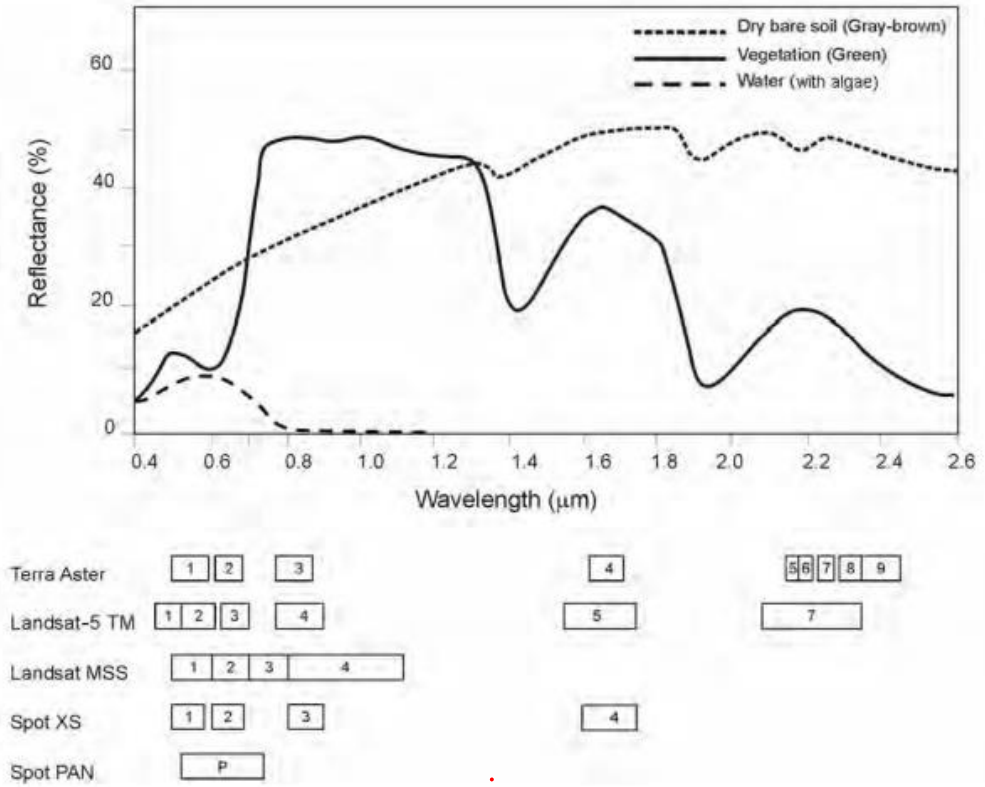
Sensing of EM energy



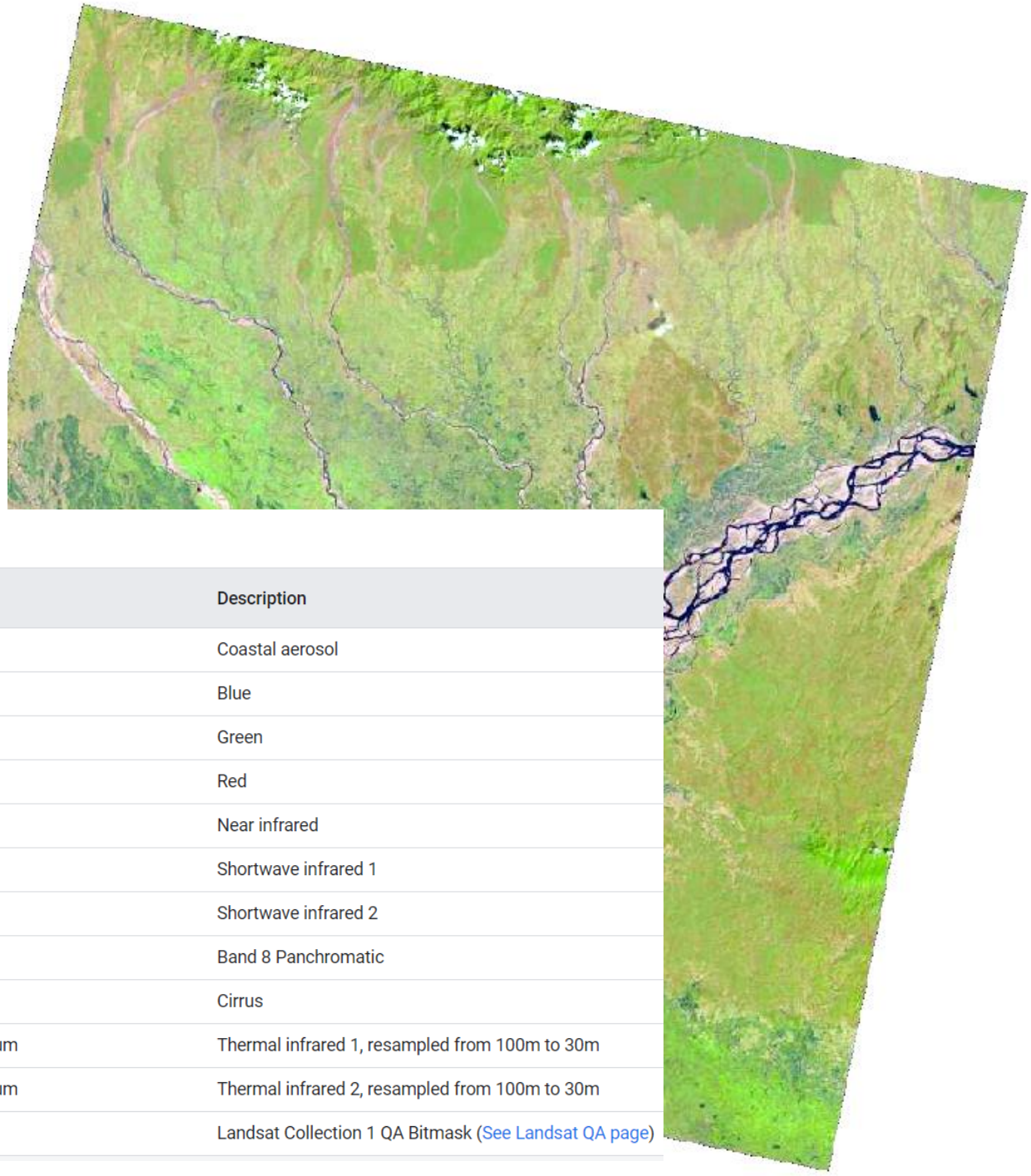
Most remote sensors measure either an intensity change or a phase change of EM radiation.

Radar sensors may Intensity or phase measure both intensity and phase. Phase measuring sensors are used for precise ranging (distance measurement), eg, by GPS ‘phase receivers’ or continuous wave laser scanners.

Sensing of EM energy



Landsat 8



Bands

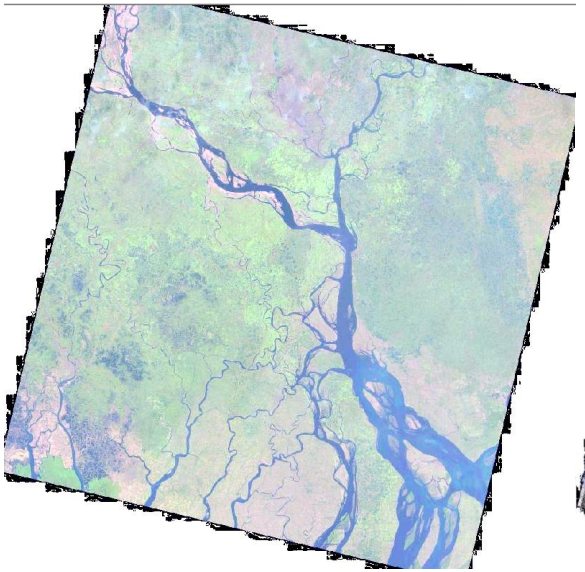
Name	Pixel Size	Wavelength	Description
B1	30 meters	0.43 - 0.45 µm	Coastal aerosol
B2	30 meters	0.45 - 0.51 µm	Blue
B3	30 meters	0.53 - 0.59 µm	Green
B4	30 meters	0.64 - 0.67 µm	Red
B5	30 meters	0.85 - 0.88 µm	Near infrared
B6	30 meters	1.57 - 1.65 µm	Shortwave infrared 1
B7	30 meters	2.11 - 2.29 µm	Shortwave infrared 2
B8	15 meters	0.52 - 0.90 µm	Band 8 Panchromatic
B9	15 meters	1.36 - 1.38 µm	Cirrus
B10	30 meters	10.60 - 11.19 µm	Thermal infrared 1, resampled from 100m to 30m
B11	30 meters	11.50 - 12.51 µm	Thermal infrared 2, resampled from 100m to 30m
BQA			Landsat Collection 1 QA Bitmask (See Landsat QA page)

Class work

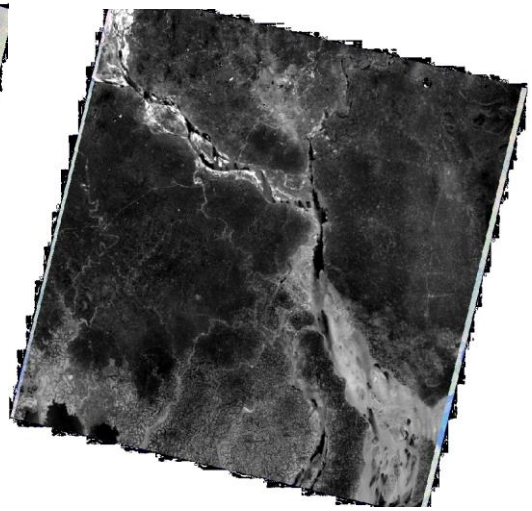
A farmer (also a RS fan) who looks at two reflectance curves of his rice taken on two different dates, can recognize if there is a drop in the near infrared NIR range of the spectrum (where reflection is usually high for vegetation) and through this, he can realize that something is wrong in the field. The graph that represents reflectance as a function of wavelength is called spectral reflectance curve, sometimes referred to as spectral signature.

Spectral reflectance curves are measured by ‘spectrometers’ at a continuous (but limited) range of wavelengths. This is done by measuring the incident and reflected energy. Compare them to the ones generated for the same material at the spectroscopy laboratory of the Jet Propulsion Laboratory (JPL), NASA.

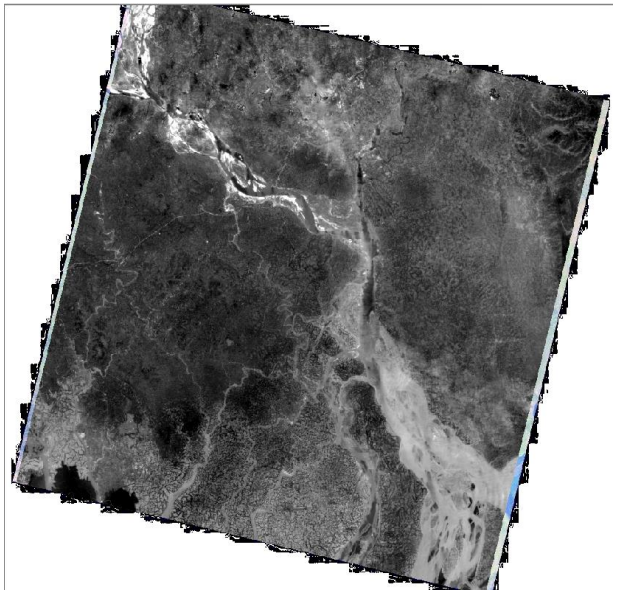
Explain your results



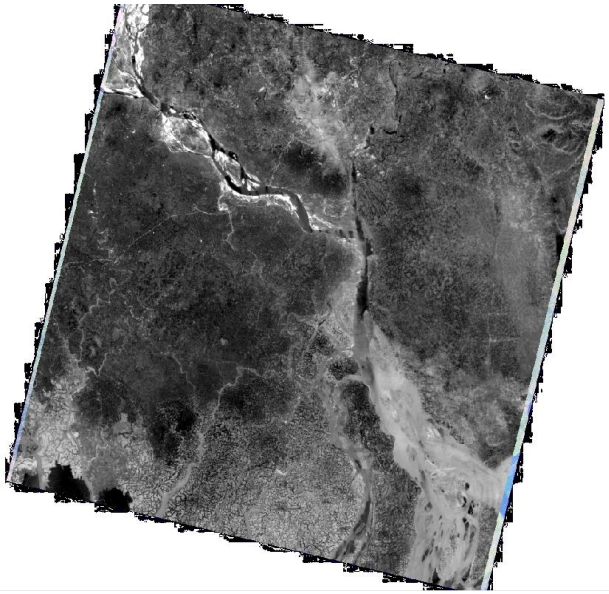
Human eye



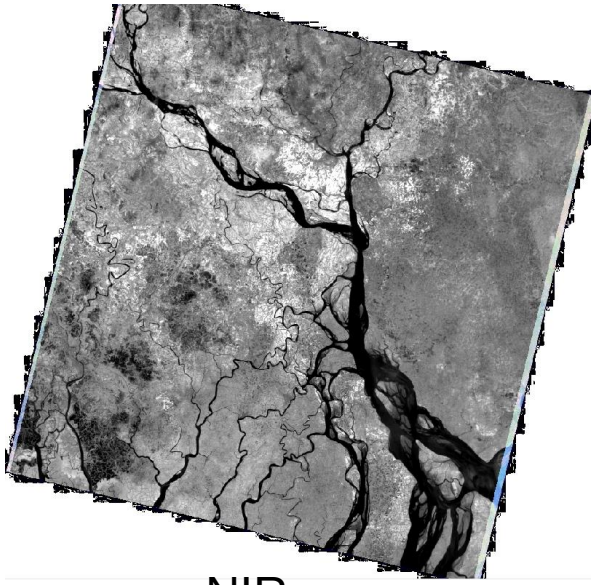
Blue



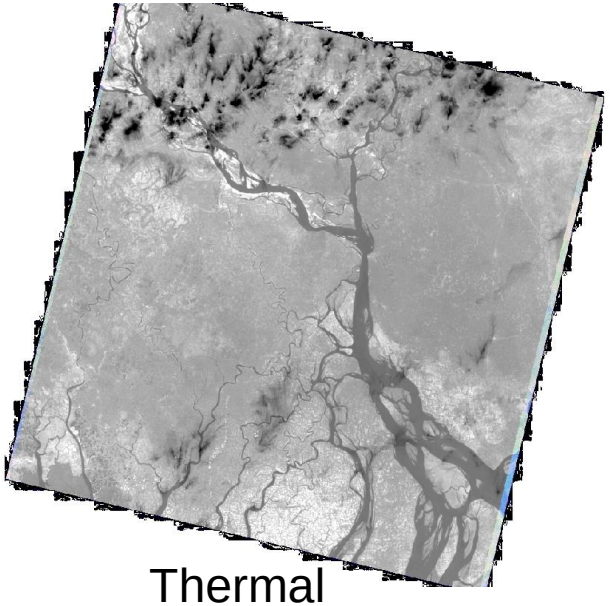
green



Red



NIR



Thermal