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3 Sensing of Electromagnetic Energy

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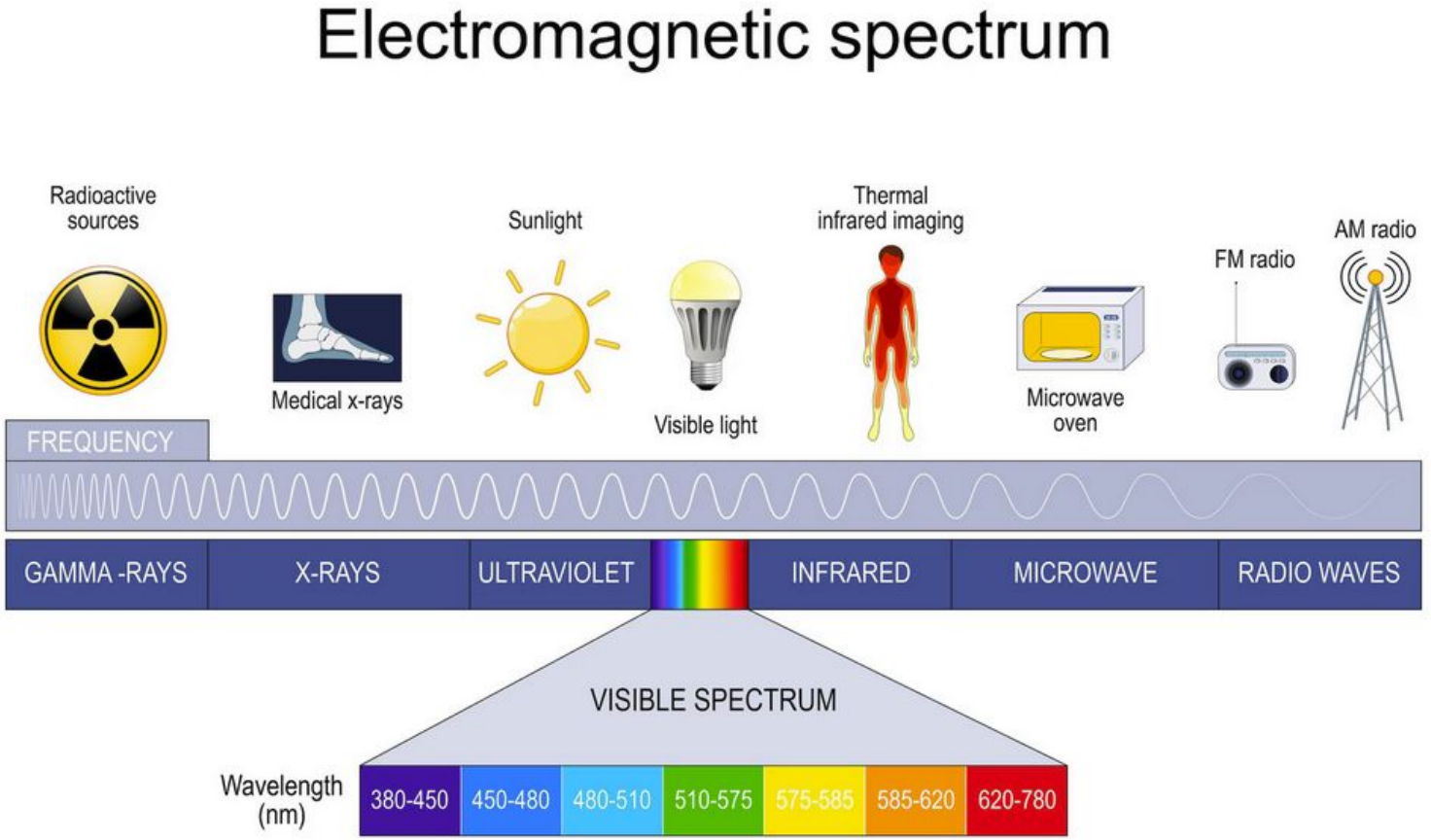
Recap

What is Remote Sensing?



- The electromagnetic spectrum is the full range of **wave frequencies** that characterizes solar radiation.
- Although we are talking about light, most of the electromagnetic spectrum cannot be detected by the human eye.
- Even satellite detectors only capture a small portion of the entire electromagnetic spectrum.

Sensing Properties

Bottlenecks of Sensing

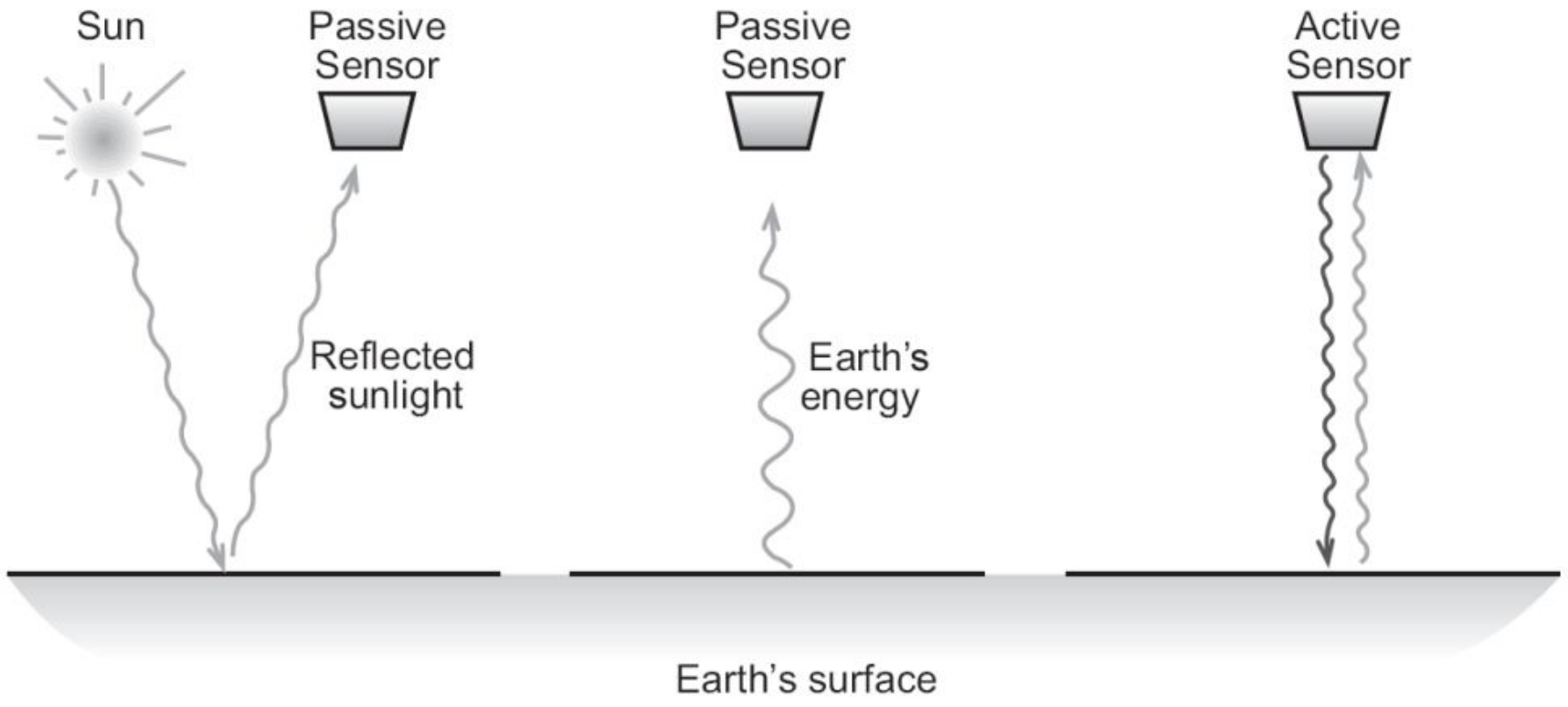
- A remote sensor is a device that detects EM energy, quantifies it, and usually records it
- Many sensors used in earth observation detect reflected solar energy
- Others detect the energy emitted by the Earth itself

Bottlenecks:

- Sun not always shining
- Cloud cover: some regions on the globe are almost permanently under cloud cover
- Regions with seasons of very low sun elevation: long shadows over long periods

Active vs. passive remote sensing

- Active sensor: emits EM energy and detects the energy returning from the object or surface
- Passive sensors: measure solar or terrestrial energy



A remote sensor measures reflected or emitted energy. An active sensor has its own source of energy.

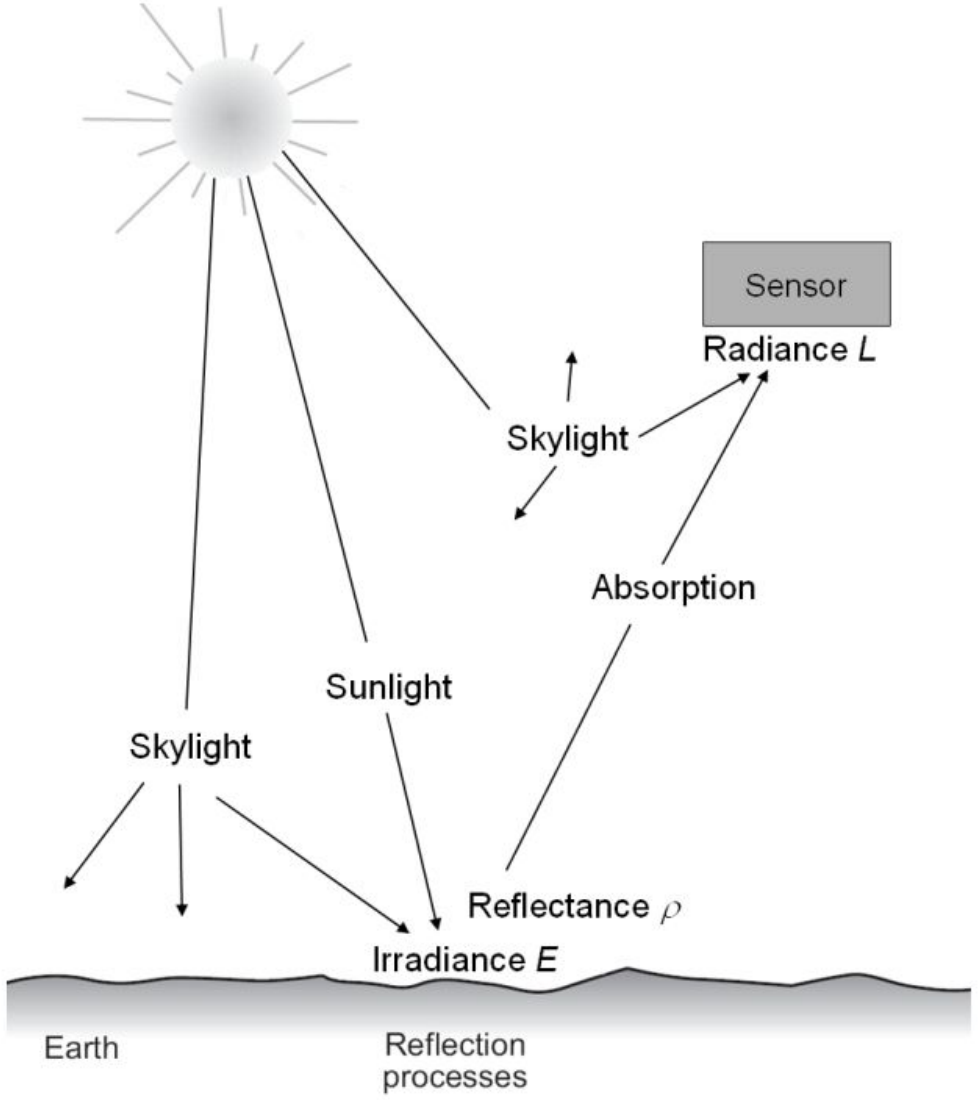
Measuring radiance

- The radiance at the Earth's surface depends on the irradiance, i.e., the intensity of the incident solar radiation and the terrain surface reflectance

- The irradiance stems from direct sunlight and diffuse light, which is caused by atmospheric scattering (enhanced on hazy days!)

- Note: keep in mind the importance of radiometric correction to better infer on surface features

Measuring radiance

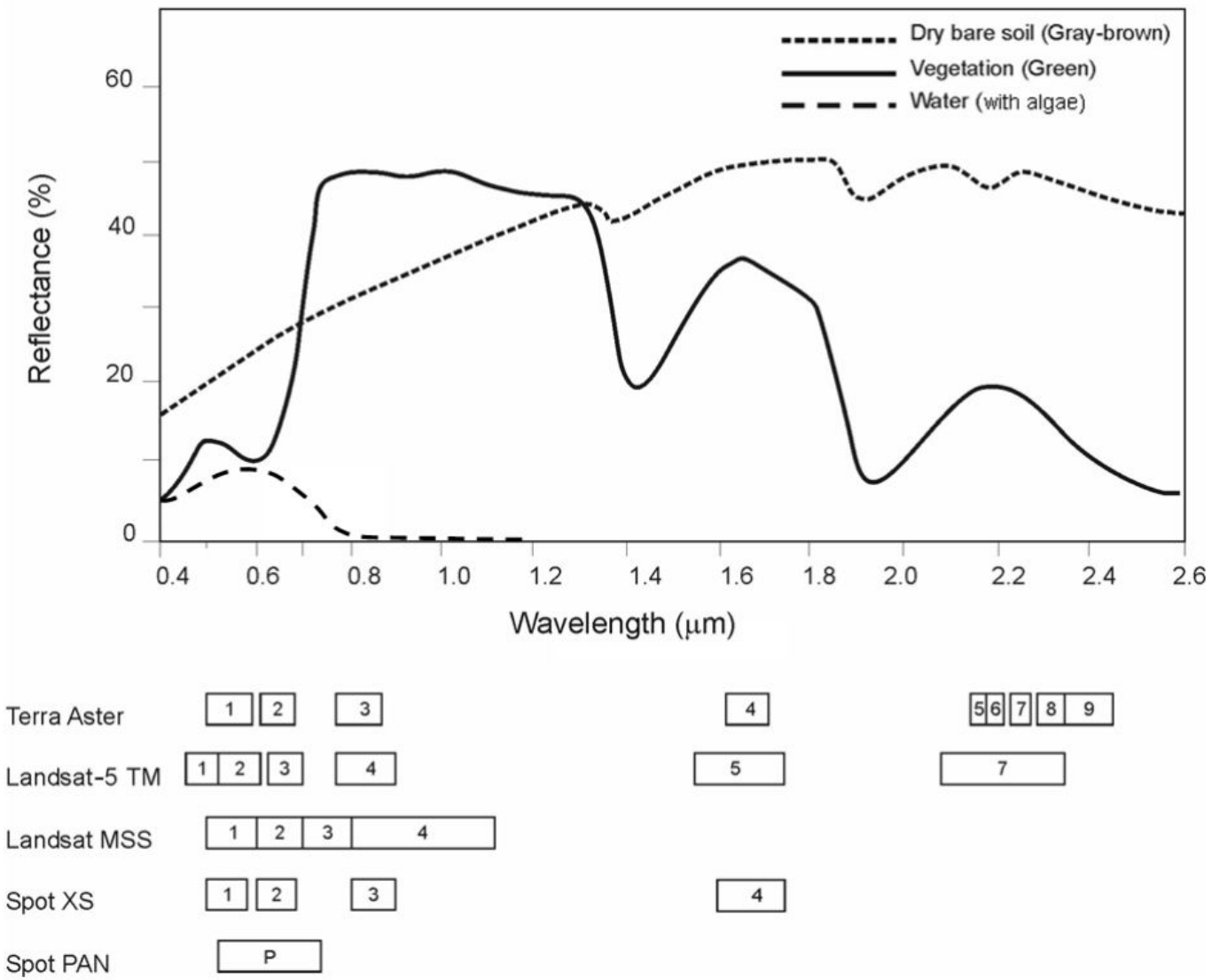


Radiance at the sensor. (Lillesand et al. 2004)

Spectral Band

- The radiance is observed for a **spectral band** (not for a single wavelength!)
- A spectral band is an interval of the EM spectrum for which the average radiance is measured
- Sensors like a radar sensor or a laser scanner only **measure in one specific band**
- A **multispectral** scanner measures in **several spectral bands at the same time**
- Multispectral sensors have several ‘channels’, one for each spectral band

Spectral Band

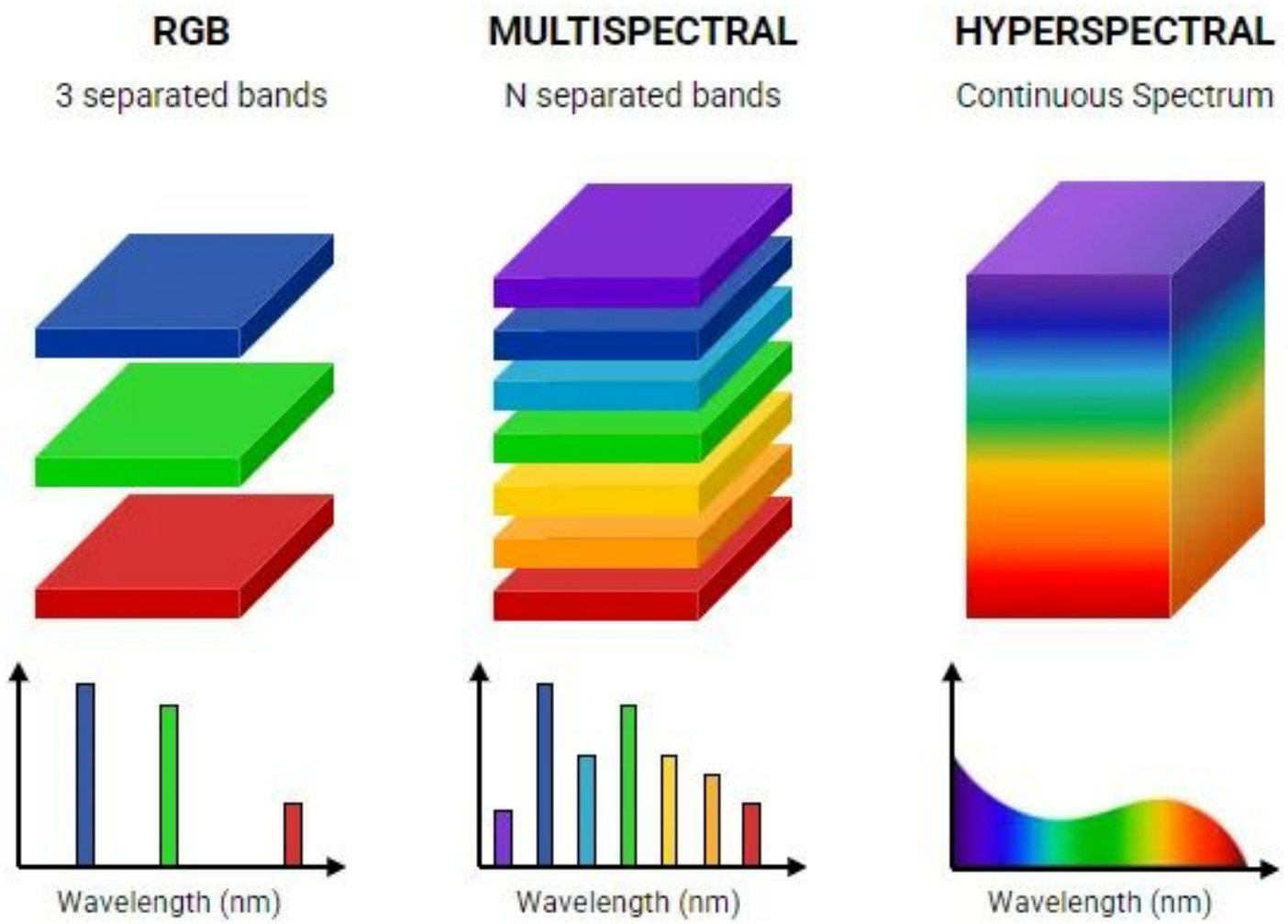


Spectral reflectance curves and spectral bands of some multispectral sensors.

Spectral Band

- Sensing in several spectral bands allows us to relate properties that show up well in specific spectral bands
- E.g. combined reflection characteristics in the red and NIR bands (Sentinel-2 channels 4 and 8) provide information about plant health and biomass
- Landsat MSS (MultiSpectral Scanner), the first civil spaceborne earth observation sensor had detectors for three broad spectral bands in the visible part of the spectrum with a width of 100 nm
- A hyperspectral scanner uses detectors for many more but narrower bands, which may be as narrow as 10 nm or less

Spectral resolution



A hyperspectral sensor has a higher ‘spectral resolution’ than a multispectral one (Nireos 2025).

Radiometric resolution

- Multispectral scanners use electronic detectors
- Those are made of semiconductor material
- The electrical signal of these detectors is sampled and quantized
- This process is called A/D conversion **the output is a digital number (DN)**
- The DN is an integer number within a fixed range
- Older sensors have used 8 bits recording (2^8 = 256 levels; DNs range 0 to 255)
- Newer sensors record in a higher radiometric resolution of 11 bits (2^{11} = 2048)
- A higher radiometric resolution requires more storage capacity but has the advantage of a higher information content

Radiometric resolution

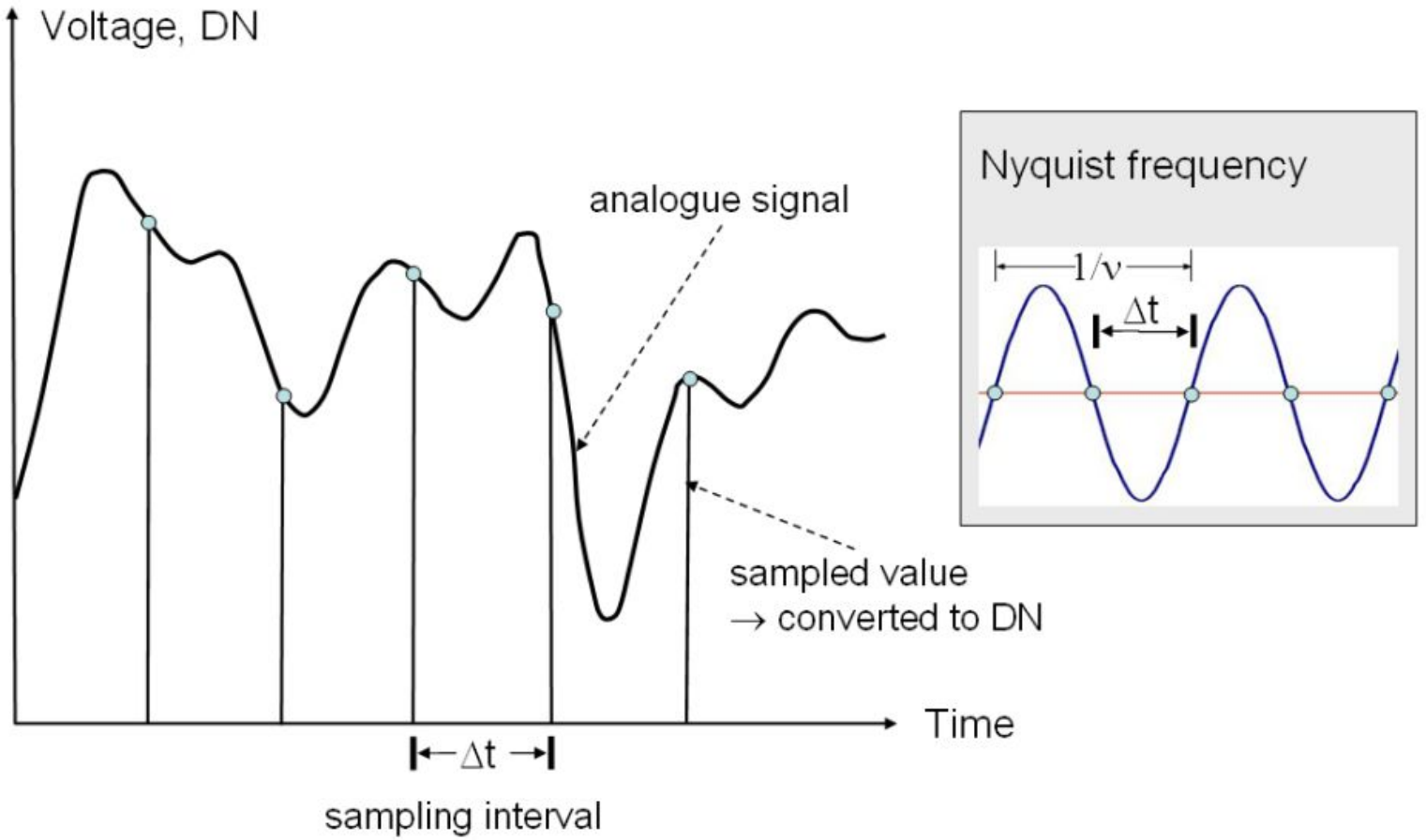
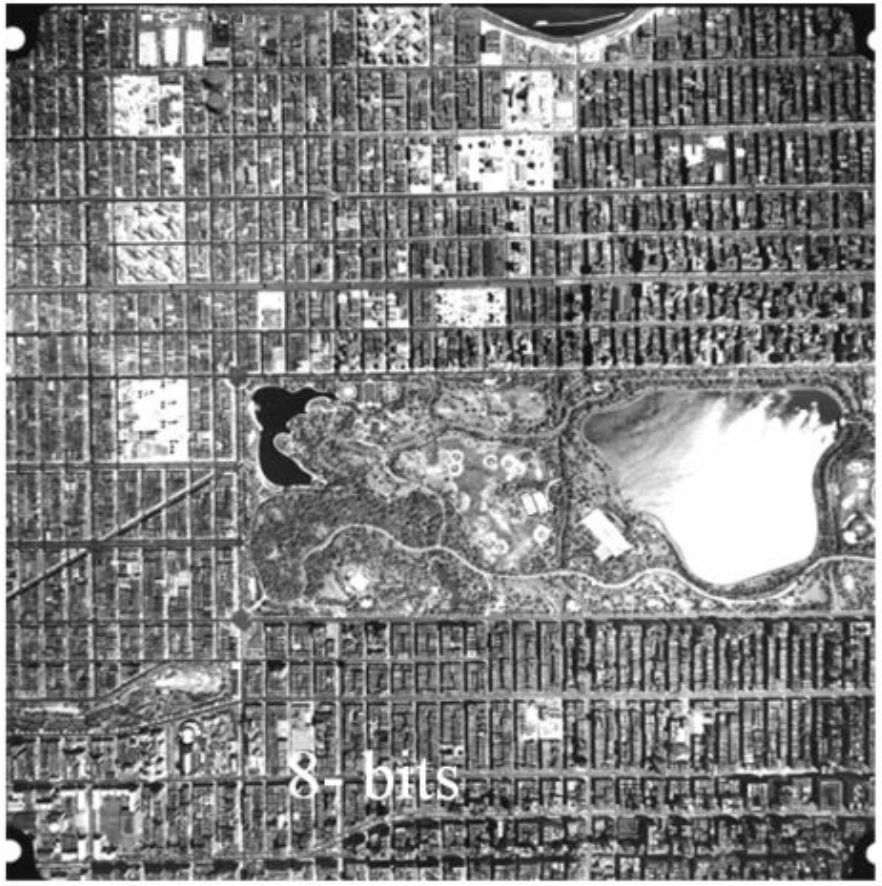


Illustration of sampling as understood in signal processing. The sampling interval should be smaller than half the period of the highest oscillation contained in the signal (Tempfli 2009).

Radiometric resolution



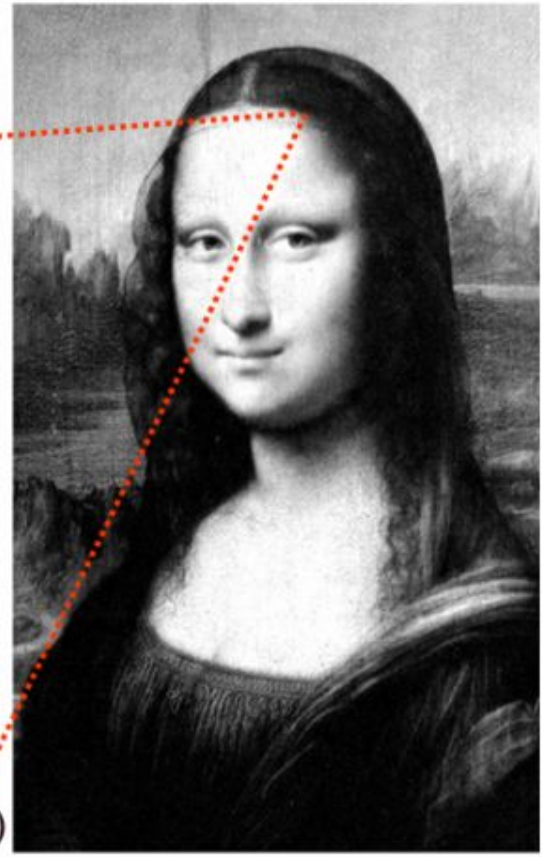
8 bits vs. 1 bit radiometric resolution.

Radiometric resolution

73	8	26	43	22	22	37	15	45
60	54	42	30	32	30	21	12	12
244	228	132	31	22	21	30	6	27
235	223	225	120	87	37	38	12	25
255	255	225	189	140	62	40	7	24
255	255	255	229	167	94	34	24	17
255	255	235	226	181	117	90	16	27
255	255	255	238	203	159	136	80	35
246	255	255	227	232	205	214	138	38

a)

b)



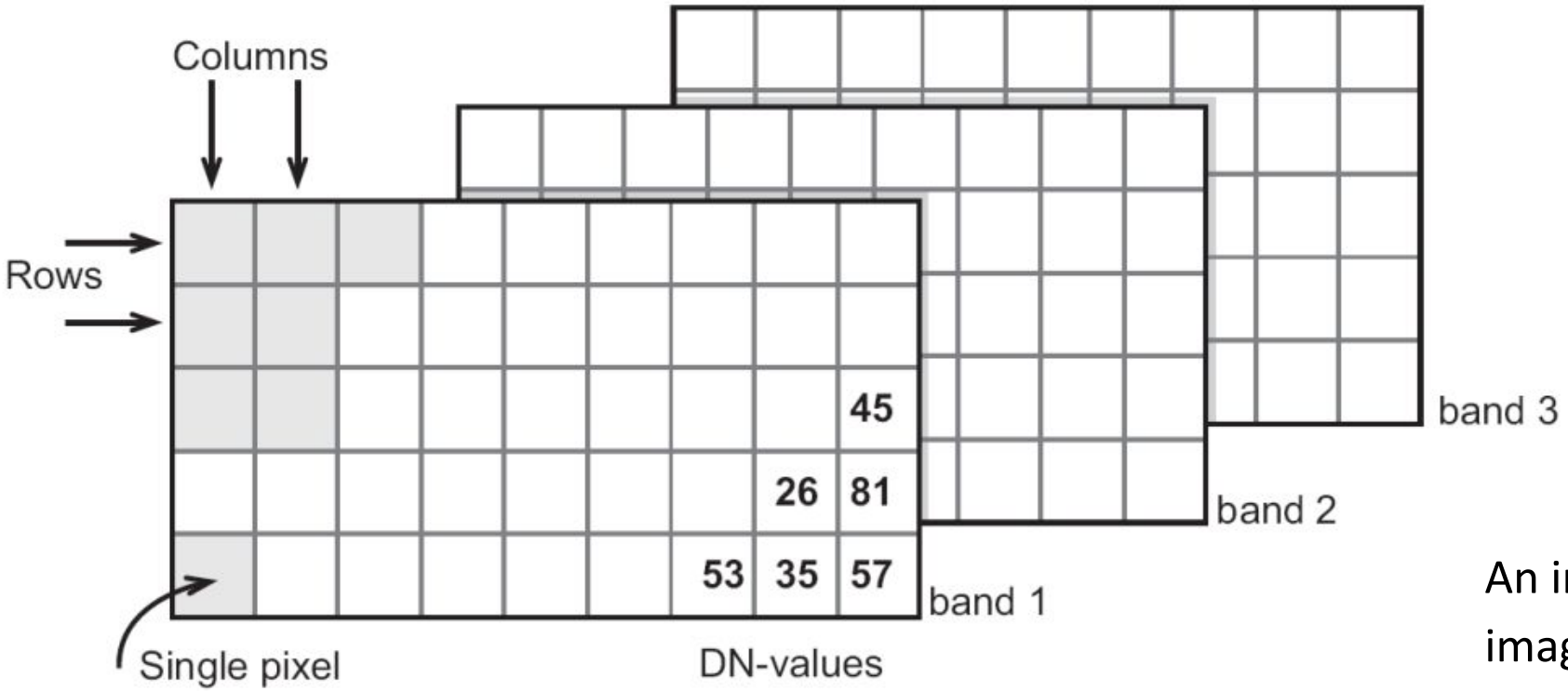
c)

Digital image (a) data from sensors, (b) display by grey values, (c) image zoomed out.

Imaging, spatial resolution

- We refer to the obtained image from a spaceborne camera as digital image and
- To a sensor producing digital images as imaging sensor
- The array of DNs represents an image in terms of discrete picture elements pixels
- The value of a pixel – the DN – corresponds to the radiance of the light reflected from the small ground area viewed by the respective detector

Imaging, spatial resolution



An image file comprises a digital image for each of the spectral bands in the sensor. For every band the DN-values are stored in a row-column arrangement.

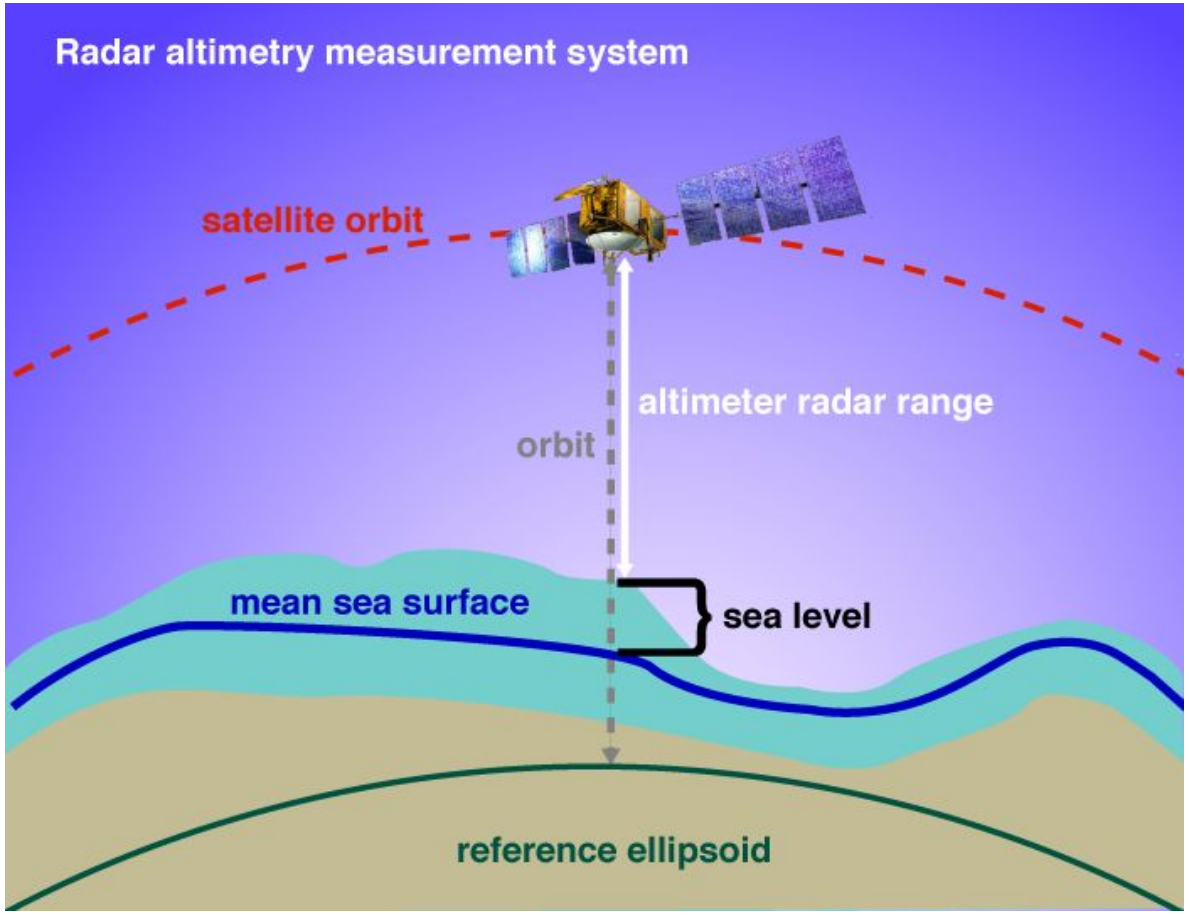
Storage media

- Satellites usually have recorders on board
- Light sensor systems often transmit data to ground receiving stations at night
- Data can also be transmitted directly to a receiving station using satellite communication technology
- Airborne sensors often use the hard-disk of a laptop computer as recording device

Classification of sensors

Altimeter

- According to the focus of interest in earth observation (geometric properties, spectral differences, intensity distribution of an object or scene) three types can be distinguished
- Altimeters, spectrometers, radiometer
- Laser and radar altimeters are non-imaging sensors, providing us with information on elevation of water and land surfaces



NOAA 2024

Radiometer

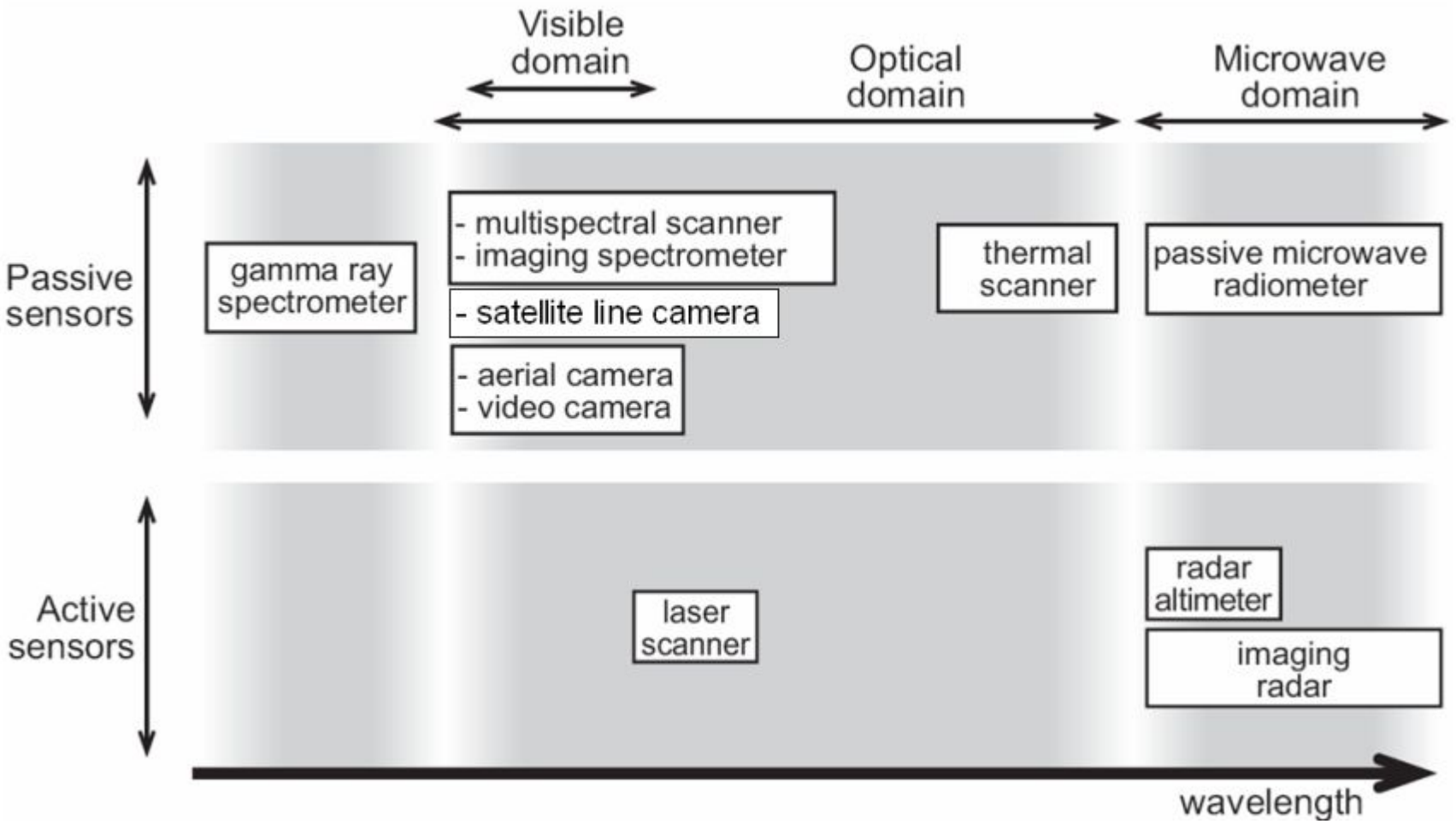
- Thermal sensors are called (imaging) radiometers
- Radiometers measure radiance and typically sense in a broad spectral band or in only a few bands, but with high radiometeric resolution
- Panchromatic cameras and passive microwave sensors are other examples
- Radiometers have a wide application range:
  - they are used to detect forest/bush/coal fires
  - Determine soil moisture and plant response
  - Monitor ecosystem dynamics
  - Analyze energy balance across land and sea surfaces

NASA 2024

Spectrometers

- Spectrometers measure radiance in many narrow, contiguous spectral bands, thus have a high spectral resolution
- Spatial resolution is moderate to low
- Prime use of imaging spectrometers is identifying surface materials

Remote Sensors with respect to their spectral domains

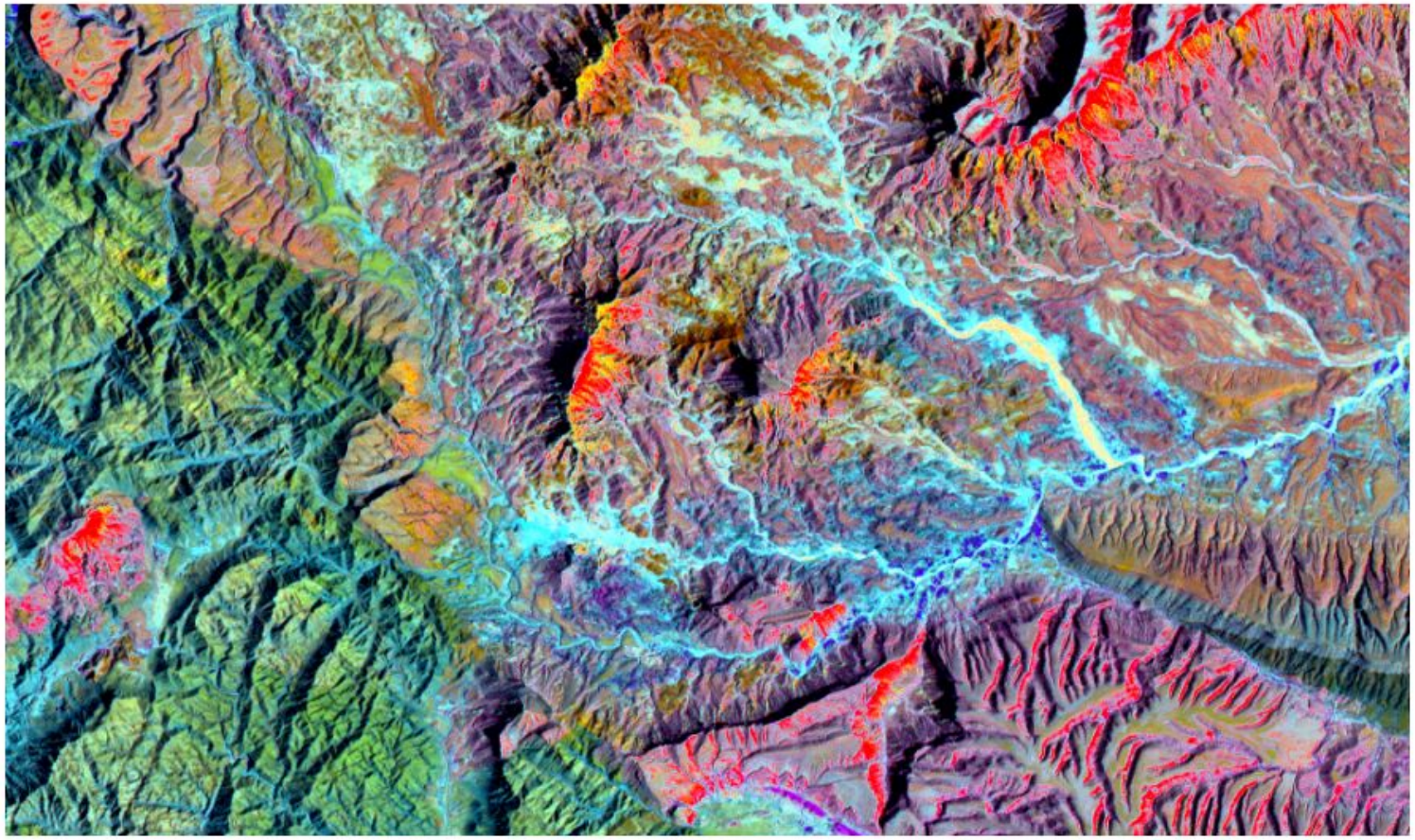


Overview of the sensors with respect to their spectral domains (Tempfli 2009).

Multispectral scanners

- Multispectral scanners are mostly operated from satellites
- The essential difference with satellite line cameras is in the imaging/optical system
- Usage of a mirror to ‘scan’ a line (i.e., a narrow strip of the ground) and a single detector instead of recording intensity values of an entire line at one instant by an array of detectors

Multispectral scanners

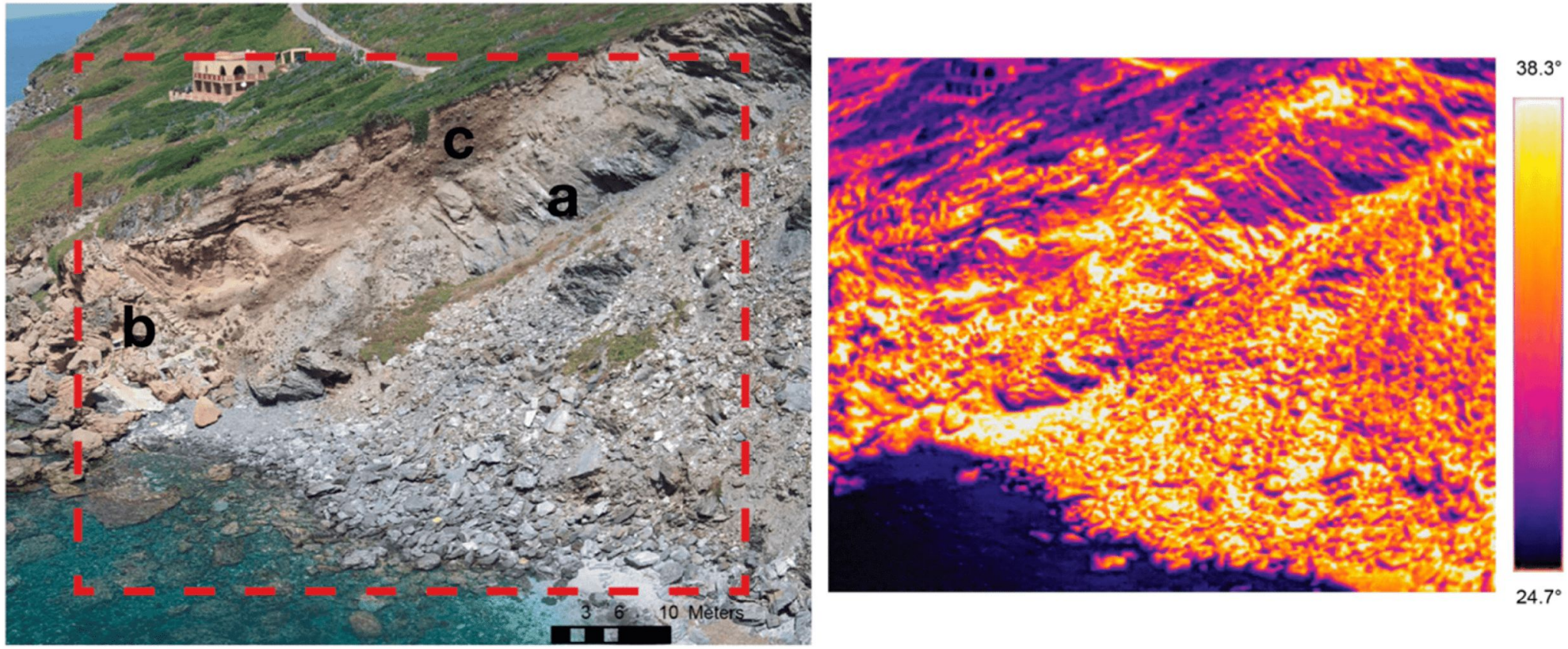


Landsat-5 TM false color composite of an area of 30 km by 17 km. The image was obtained by combining the images of the Landsat TM channels 4, 5, and 7, which are displayed in red, green and blue, respectively.

Thermal scanners

- Thermal remote sensing is a technique to measure radiation emitting from the ground object of any entity
- Thermal scanners are special instruments and a component of multispectral radiometers
- Thermal scanners provide data, which can directly be related to object temperature
- Applications: forest fires, landslides

Thermal scanners



Costal Cliff near Villaggio Nurra, Sassari, Italy. (A) Optical data and (B) thermal data in the area in the dotted red box (Melis et al. 2020).

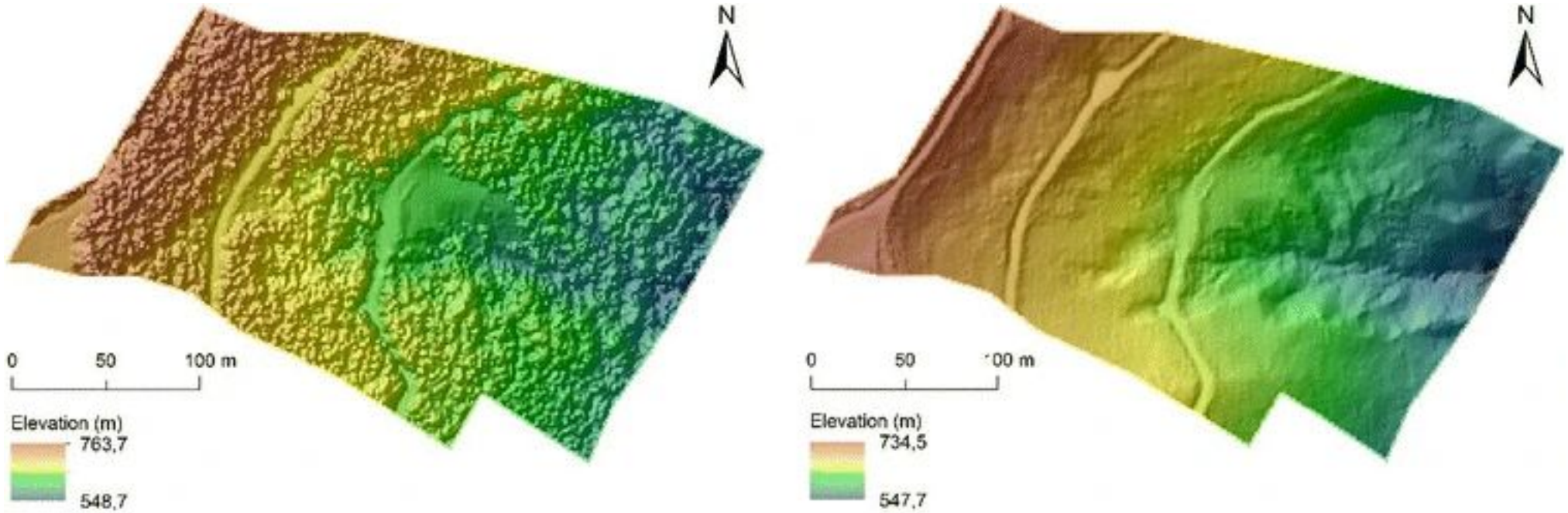
Microwave radiometers

- Passive microwave radiometers detect emitted radiation of the Earth's surface in the 10 to 1000 mm wavelength range
- Main applications: mineral exploration, monitoring soil moisture changes, snow and ice detection

Laser Scanners

- Laser scanners are a scanning variant of laser rangefinders and laser altimeters
- They measure the distance from the laser instrument to many points of the target
- Laser ranging is often referred to as LIDAR (**LI**ght **D**etection **A**nd **R**anging)
- Main applications (of airborne laser scanning): create high resolution digital surface models and digital terrain relief models

Laser Scanners

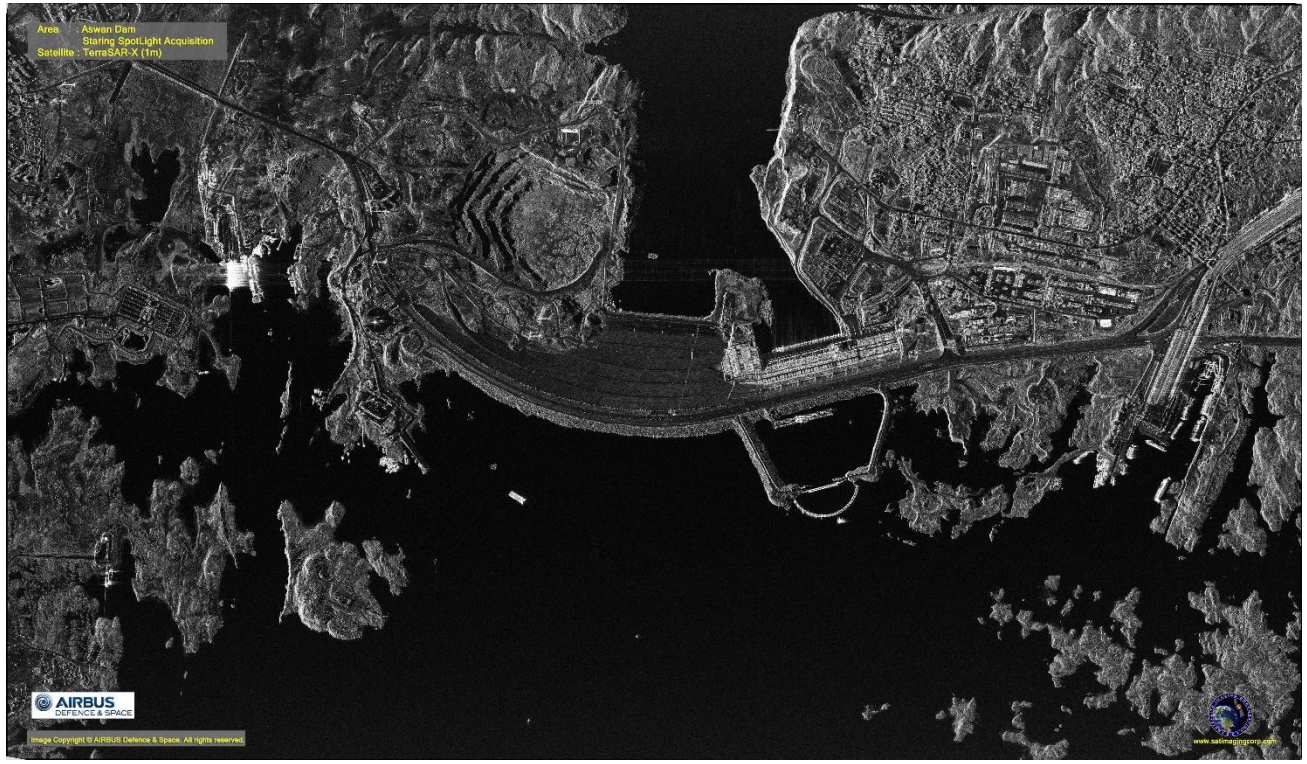


LIDAR-DSM (left) and LIDAR –DTM (right)

Eker et al. 2018

Imaging radar

- Imaging radar (**RA**dio **D**etection **A**nd **R**anging) operates in the spectral domain from 10 to 1000 mm
- Radar instruments are active sensors and because of the used wavelength they can provide us with data day and night, and under all weather conditions
- Radar waves can penetrate clouds, only heavy rainfall affects imaging



Radar altimeters

- Radar altimeters are used to measure elevation profiles of the Earth's surface parallel to the satellite orbit
- They operate in the 10 to 60 mm range
- Allow us to calculate elevation with an accuracy of 20 to 50 mm.
- Useful for measuring relative smooth surfaces

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Thank you for your attention!

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