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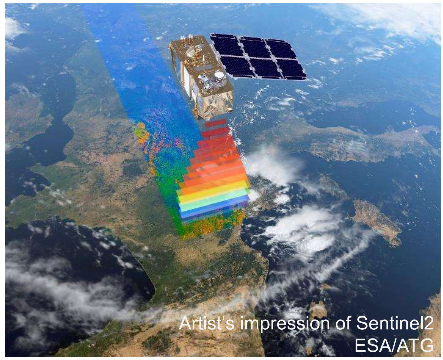
ESSENTIALS OF REMOTE SENSING

DR. MARLOES PENNING DE VRIES

FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

REMOTE SENSING ESSENTIALS - OVERVIEW

- Remote sensing essentials in three lectures:
  - Today: Applications, orbits, radiation, resolution
  - Tomorrow: Radiative transfer in the atmosphere
  - Next week: Atmospheric correction
- Focus on conceptual understanding (not too many equations)
- Approach:
  - Self study
  - Interactive lecture
  - Exercise
  - Exam



Artist's impression of Sentinel2
ESA/ATG

IMAGE INTERPRETATION

Nature news, 23/08/2023

gizmodo.com.au

- "Understanding the basics of electromagnetic (EM) radiation will help you in making more profound choices and enable you to deal with sensors of the future." - Core book, chapter 2.

COURSE LEARNING OUTCOMES

- Explain the basic concepts in geo-information science relevant for the acquisition of geospatial data and for their entry and management in a database.
- Define spatial references, coordinate systems and projections for geospatial data and apply relevant transformations for data integration.
- Explain electromagnetic radiation and the main processes of its interaction with the Earth surface and atmosphere.
- Apply radiometric and atmospheric correction and image enhancement techniques to a remote sensing dataset.
- Explain visualization principles and apply these for the visualization of geospatial data products as input for interpretation and information sharing.

QUESTIONS?

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REMOTE SENSING - APPLICATIONS, ORBITS, RADIATION, RESOLUTION

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INTRODUCTION

- Main topic: Remote sensing - spectral, spatial, temporal resolution trade-offs
- At the end of this lesson, you can:
  - List applications of satellite remote sensing
  - Describe LEO and GEO orbits
  - Explain basic properties of EMR
  - Name the main characteristics of satellite-based sensors
  - Explain the inter-dependencies of image resolution
  - Argue which sensor is most suitable for particular EO study cases

Satellites orbiting Earth in 2019
www.allinallspace.com

OUTLINE

- Intro: applications of satellite data
- Satellite orbits
- Electromagnetic Radiation
- Sources of EMR
- Resolution
- Exercise: which sensor is optimal?

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INTRO: APPLICATIONS OF SATELLITE DATA

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WHAT DO WE USE SATELLITE DATA FOR?

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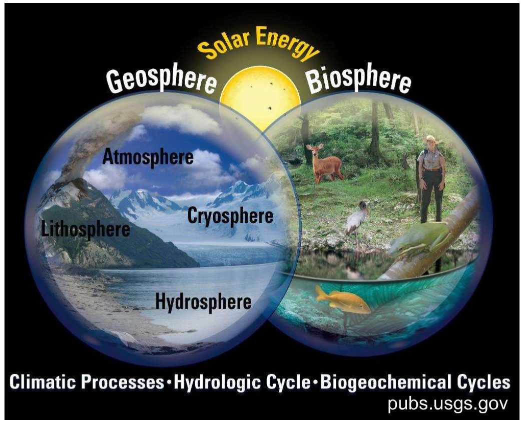
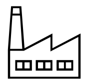
APPLICATIONS: EARTH OBSERVATION (EO)

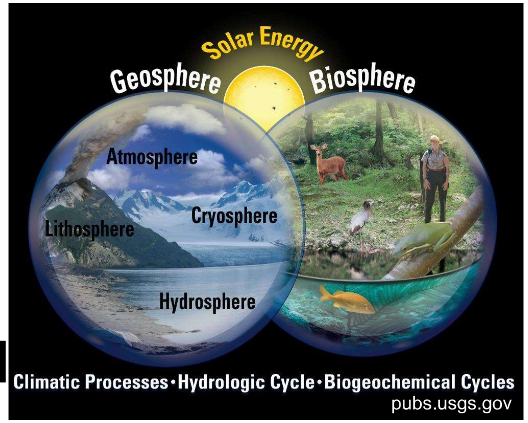
- Observation (characterization, monitoring, classification) of nearly all parts of the Earth System:
  - Atmosphere uap air
  - Lithosphere batu
  - Hydrosphere air
  - Cryosphere es
  - Biosphere kehidupan



APPLICATIONS: EARTH OBSERVATION (EO)

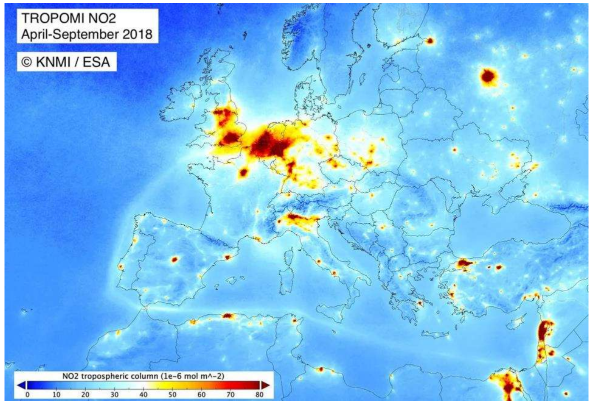
- Observation (characterization, monitoring, classification) of nearly all parts of the Earth System:
  - Atmosphere
  - Lithosphere
  - Hydrosphere
  - Cryosphere
  - Biosphere
  - Anthroposphere





QUIZ: IDENTIFY THE "SPHERE"

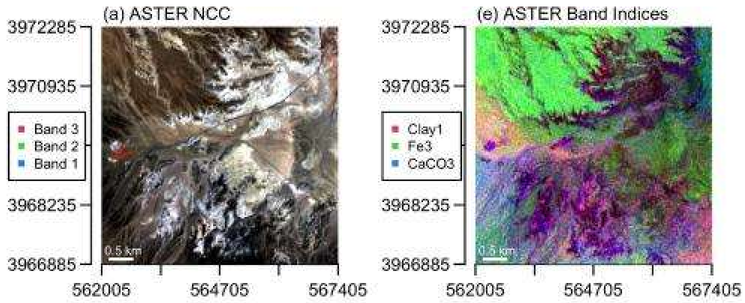
- Figure 1



NO2 : atmosphere

QUIZ: IDENTIFY THE "SPHERE"

- Figure 2

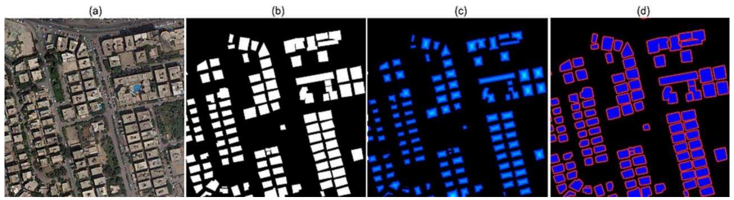


Clay : Litosphere

Kodikara et al., 2023

QUIZ: IDENTIFY THE "SPHERE"

- Figure 3

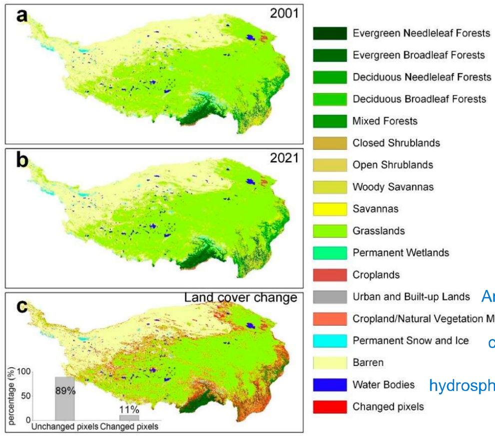


Antroposphere : karena ada rumah dan mobil

Wang et al., 2023

QUIZ: IDENTIFY THE "SPHERE"

- Figure 4



biosphere

Antroposphere

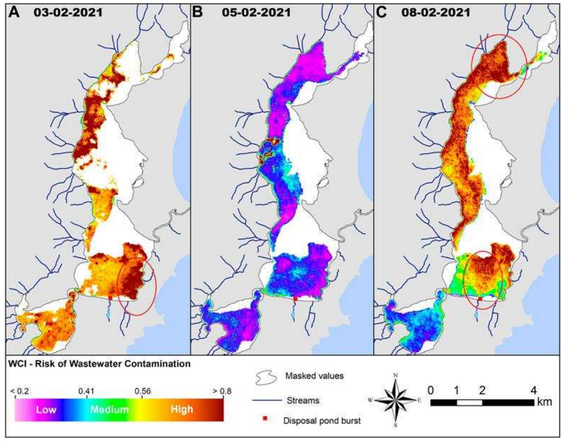
cryosphere

hydrosphere

F. Wang et al., 2023

QUIZ: IDENTIFY THE "SPHERE"

- Figure 5



waste water : hydrosphere

de Liz Arcari et al., 2023

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SATELLITE ORBITS

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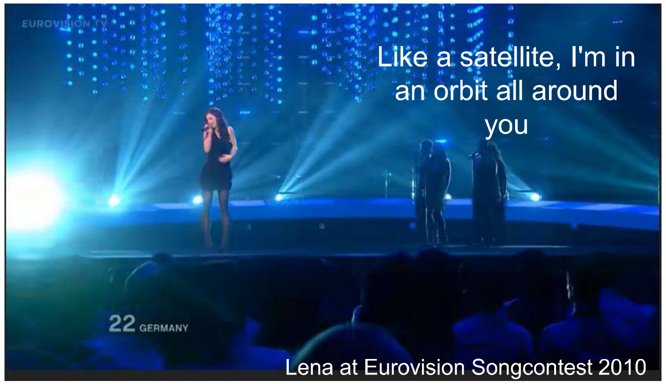
WHAT IS AN ORBIT?

- Regular trajectory of one body around another
-



Lena at Eurovision Songcontest 2010

WHAT IS AN ORBIT?

Orbit : lintasan semua benda langit

- Regular trajectory of one heavenly body around another
- Orbital period depends on distance to Earth

Kalau orbit dekat dengan bumi : satelit semakin cepat supaya tidak tertarik oleh bumi

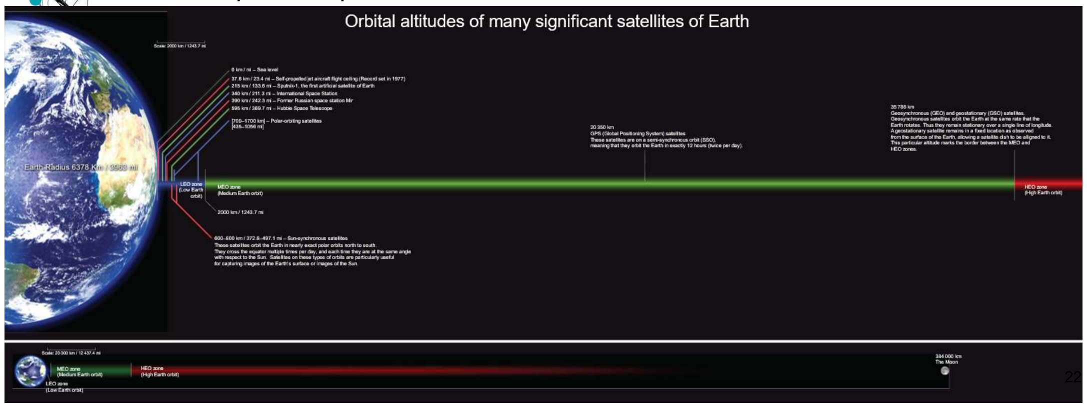
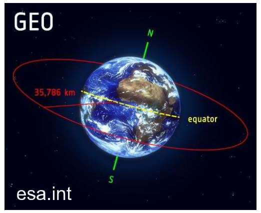


Figure: Mark Mercer via Wikimedia commons

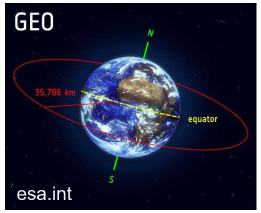
GEO-STATIONARY ORBIT



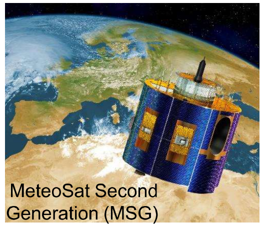
- Altitude: 35,786 km
- Characteristics:
  - continually "stares" at same portion of Earth
  - images acquired once every hour or so
  - low spatial resolution

Posisi satelit tetap terhadap bumi, monitoring sesuatu yg berubahnya cepat

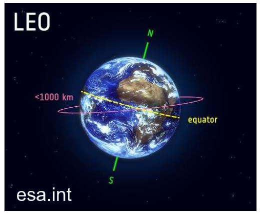
GEO-STATIONARY ORBIT



- Altitude: 35,786 km
- Characteristics:
  - continually "stares" at same portion of Earth
  - images acquired once every hour or so
  - low spatial resolution
- Instrument types:
  - weather
  - communication, navigation
- Examples:
  - MeteoSat, GOES, Himawari, FengYun

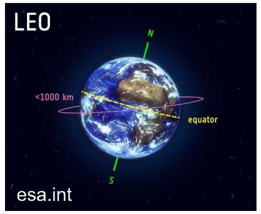


LOW EARTH (POLAR) ORBIT



- Altitude: 200-1200 km
- Characteristics:
  - Passes over whole* globe
  - In sun-synchronous orbit, same local time at each overpass
  - Images acquired between twice per day and once every few days
  - Medium to high spatial resolution

LOW EARTH (POLAR) ORBIT



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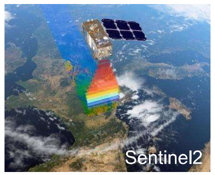
- Characteristics:
  - Passes over whole* globe
  - In sun-synchronous orbit, same local time at each overpass
  - Images acquired between twice per day and once every few days
  - Medium to high spatial resolution
- Instrument types:
  - EO, Deep space observation, ISS, telecom
- Examples:
  - ESA Sentinels, NASA Landsats, Cubesats



WHAT DOES THE SATELLITE SEE?

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ELECTROMAGNETIC RADIATION

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ELECTROMAGNETIC RADIATION IS…

- All around us!

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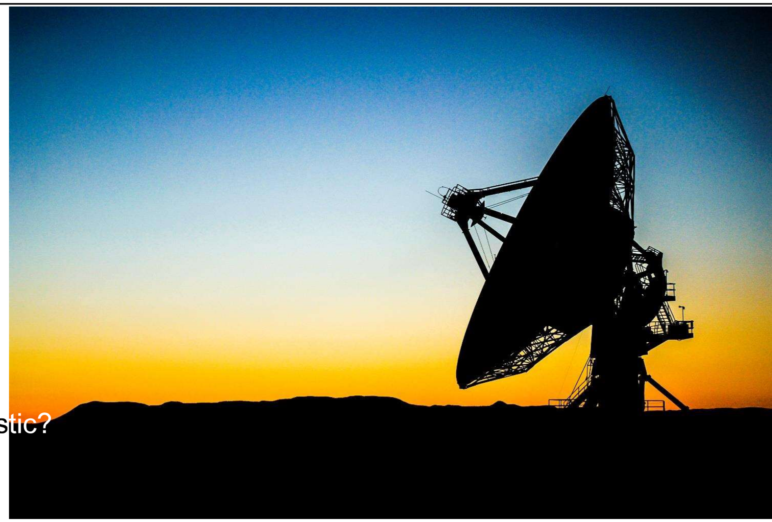


- Key characteristic?

EMR AS A WAVE

- Interference patterns

Water

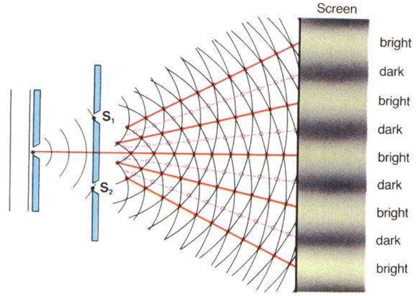
Images: https://phiab.com/holomonitor/holographic-microscopy/
Subodh Ghulaxe (https://physics.stackexchange.com/users/22316/subodh-ghulaxe)

EMR AS A WAVE

- Interference patterns

Water

Light



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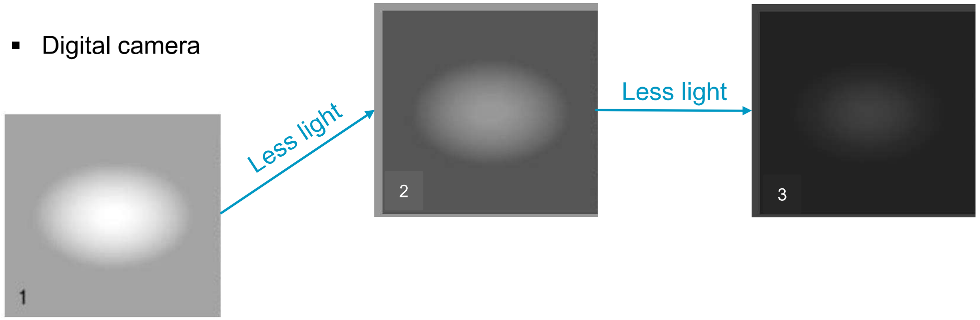
EMR AS A PARTICLE

- Digital camera



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EMR AS A PARTICLE

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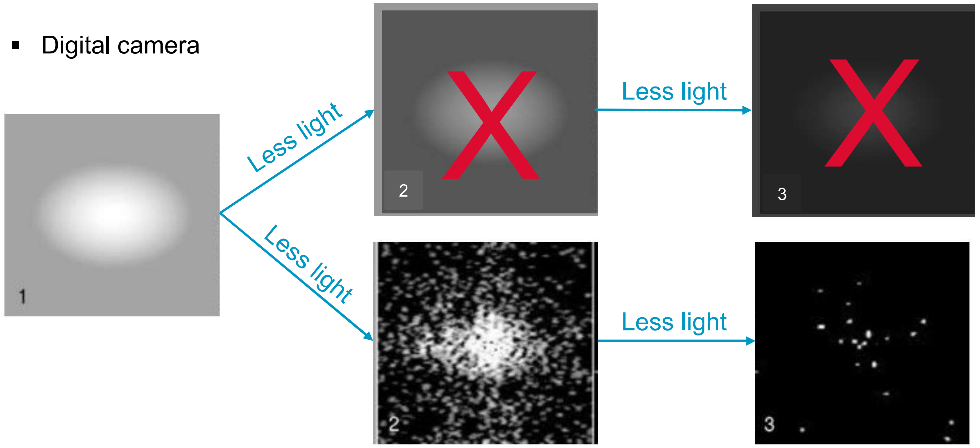

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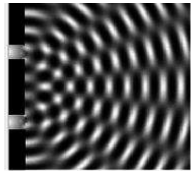
SO WHICH IS IT?

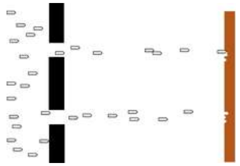
SO WHICH IS IT?

- Double-slit experiment
- Expected result:

Wave



Particle



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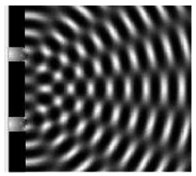
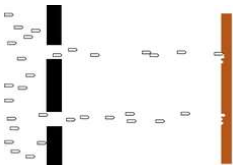
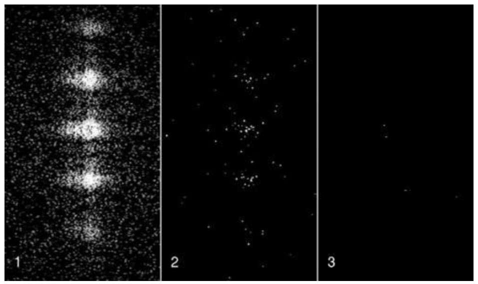


Particle



Real result:

Wave & particle!



https://phys.libretexts.org/Bookshelves/Conceptual_Physics/Book%3A_Conceptual_Physics_(Crowell)/14%3A_Quantum_Physics/14.02%3A_Light_As_a_Particle

SO WHICH IS IT?

- We need both approaches for different aspects of remote sensing:

Wave	Particle
Reflection memantulkan	Absorption menyerap
Refraction patahan	Scattering menghamburkan
Emission mengeluarkan	Emission

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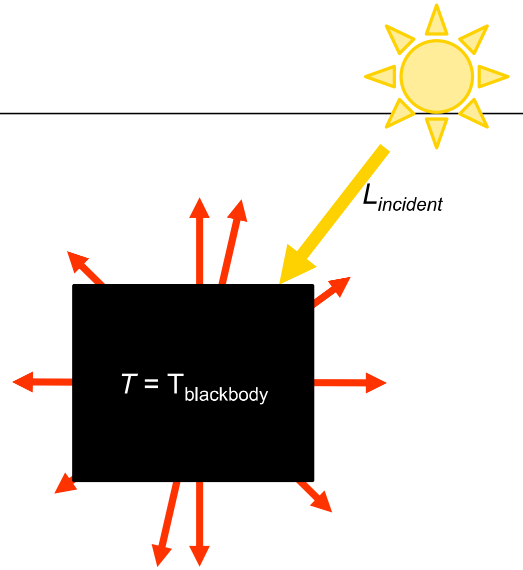
SOURCES OF ELECTROMAGNETIC RADIATION

BLACKBODY RADIATION

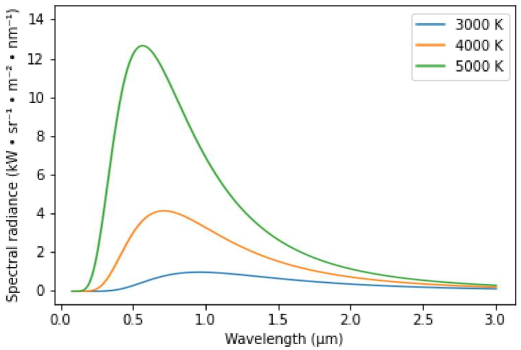
- Every object with T>0 K emits radiation
- Blackbody:
  - Absorbs all incident radiation
  - Emitted radiation depends only on its temperature
- Planck's law: $L_{BB} = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}}-1}$
- In thermal equilibrium (no change in *T*): $L_{BB} = L_{incident}$



PLANCK'S LAW OF RADIATION

- Emission of radiation is governed by Planck's law:

$$L_{BB}(\lambda, T) = \frac{2hc^2}{\lambda^5} \cdot \left(e^{hc/\lambda kT} - 1\right)^{-1} \text{ [Wm}^{-2}\mu\text{m}^{-1}]$$



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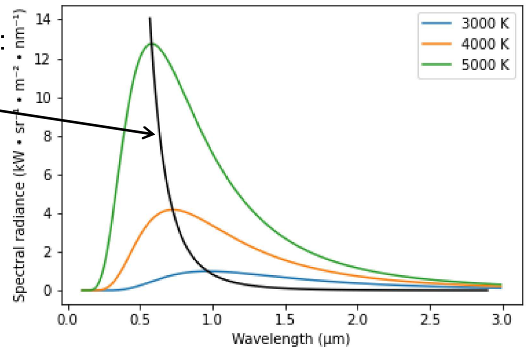
- Derivations from Planck's law:
- Wien's law: $\lambda_{max} = \frac{b}{T}$



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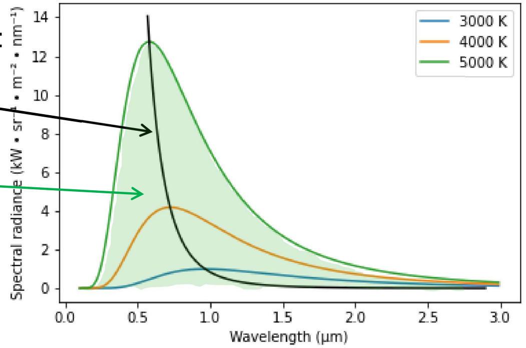
- Derivations from Planck's law:
- Wien's law: $\lambda_{max} = \frac{b}{T}$
- Stefan-Boltzmann equation:

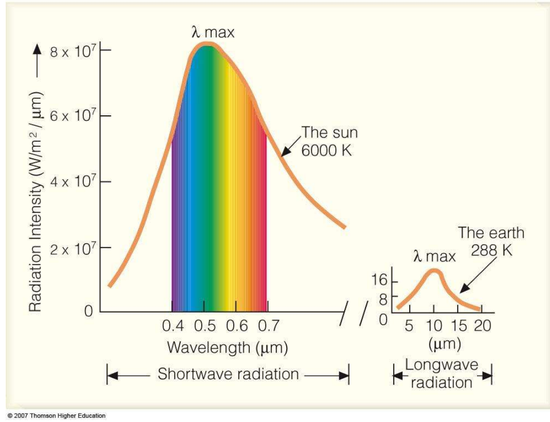
$M = \sigma T^4$



EMISSION BY SUN AND EARTH

- Sun is much hotter than Earth -> λ_{max} shorter and M much greater

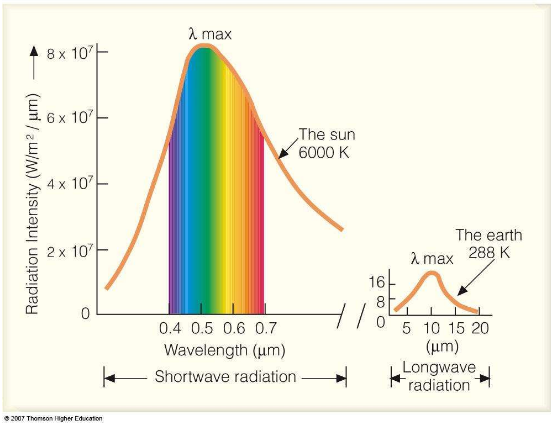
di matahari lamda semakin pendek dan energi semakin besar



EMISSION BY SUN AND EARTH

- Sun is much hotter than Earth -> λ_{max} shorter and M much greater
- Emission curves of Sun and Earth barely overlap

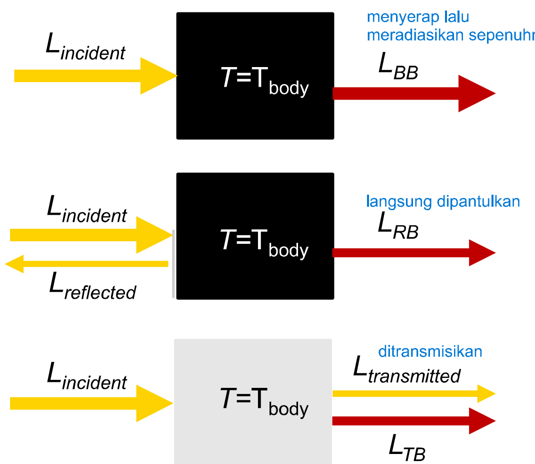
Colder objects as Earth emit less radiation in longer wavelengths



REAL OBJECTS

- Real objects are not blackbodies, they
  - reflect and/or
  - transmit
- In thermal equilibrium (T constant):

$$L_{in} = L_E + L_T + L_R$$

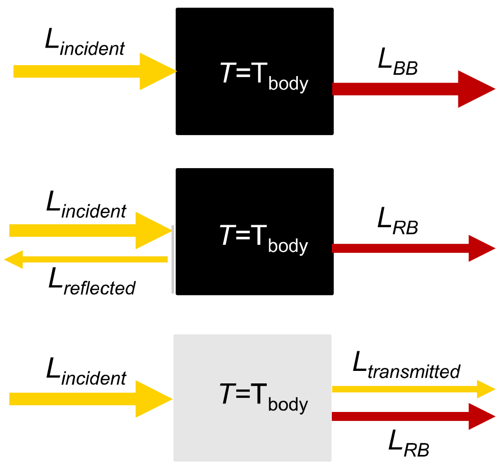


REAL OBJECTS

- Real objects are not blackbodies, they
  - reflect and/or
  - transmit
- In thermal equilibrium (T constant):

$$L_{in} = L_E + L_T + L_R$$

- It follows: $L_{BB} > L_{RB}$
- Emissivity $\varepsilon_{RB} = \frac{L_{RB}}{L_{BB}}$



QUIZ ON BLACKBODY RADIATION

How to participate?

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Event code
CINZCA

1 Send @CINZCA to 0970 1420 2908

2 You can participate

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CHARACTERISTICS OF ELECTROMAGNETIC RADIATION

- Maxwell's theory: coupled electric and magnetic fields travelling through space

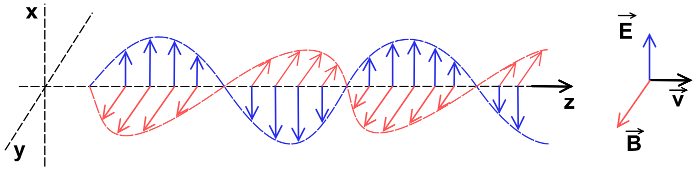

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Figure from Wikipedia (By SuperManu - Self, based on Image: Onde electromagnetique.png, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2107870

CHARACTERISTICS OF ELECTROMAGNETIC RADIATION

- Maxwell's theory: coupled electric and magnetic fields travelling through space

x
E
z
v
y
B

- Key characteristic of waves: $c = \lambda\nu$ (c speed of propagation, here: speed of light)
- It follows: wavelength λ is inversely related to frequency ν

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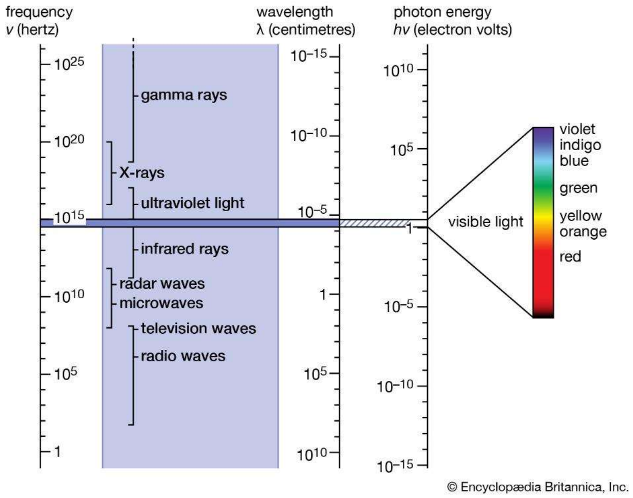
Figure from Wikipedia (By SuperManu - Self, based on Image: Onde electromagnetique.png, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2107870

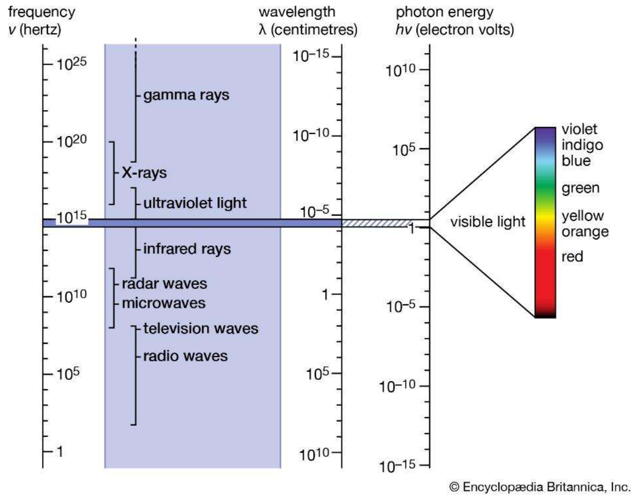
ENERGY OF EMR

- If wavelength λ is small, frequency ν is large



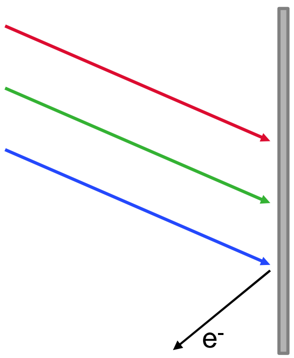
ENERGY OF EMR

- If wavelength λ is small, frequency ν is large
- Max Planck: energy of a photon $Q = h\nu = \frac{hc}{\lambda}$



EVIDENCE: LIGHT AS A PARTICLE

- The photo-electric effect:
- Only radiation with correct wavelength causes ejection of electron
- $Q = h\nu = \frac{hc}{\lambda}$



QUIZ - SORT THE EMR RANGES

- By frequency
- By wavelength
- By photon energy

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RESOLUTION

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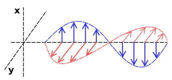
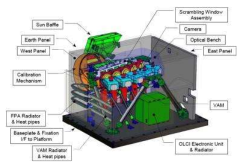
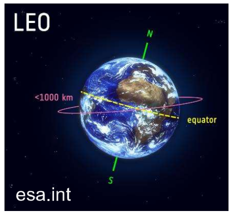
WHAT DO WE MEAN BY RESOLUTION?

- Degree to which two features can be distinguished
- "Knowledge of image resolution is a prerequisite for understanding the information recorded on the images we examine." (Campbell, chapter 10)

WHAT DO WE MEAN BY RESOLUTION?

- Degree to which two features can be distinguished
- "Knowledge of image resolution is a prerequisite for understanding the information recorded on the images we examine." (Campbell, chapter 10)
- Resolution of whole system:



radiation + instrument + platform + orbit + computer

RELEVANT RESOLUTION DOMAINS

ukuran pixel — Spatial

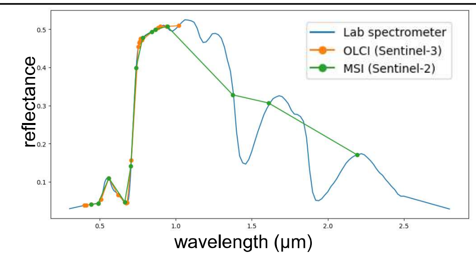
cara membedakan kontras, kecerahan — Radio-metric

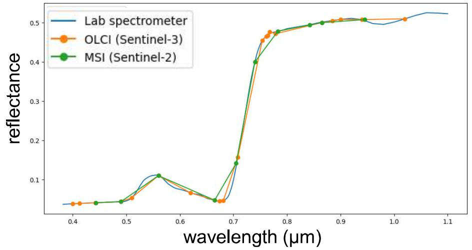
Spectral — seberapa banyak spektrum yg direkam

Temporal — waktu

SPECTRAL RESOLUTION

- Distance between consecutive steps
- In UV-visible-NIR range, 0.1 - 100s of nm
- Examples:
  - Lab (2 nm (vis) or 100 nm (NIR))
  - MSI on Sentinel-2 (23-500 nm)
  - OLCI on Sentinel-3 (10-100 nm)





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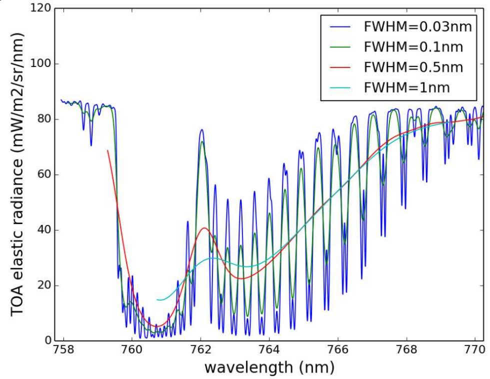
SPECTRAL RESOLUTION

- Distance between consecutive steps
- In UV-visible-NIR range, 0.1 - 100s of nm
- Examples:
  - Lab (2 nm (vis) or 100 nm (NIR))
  - MSI on Sentinel-2 (23-500 nm)
  - OLCI on Sentinel-3 (10-100 nm)
- For atmospheric composition: <0.1 nm!



PhD thesis B. Kremmling

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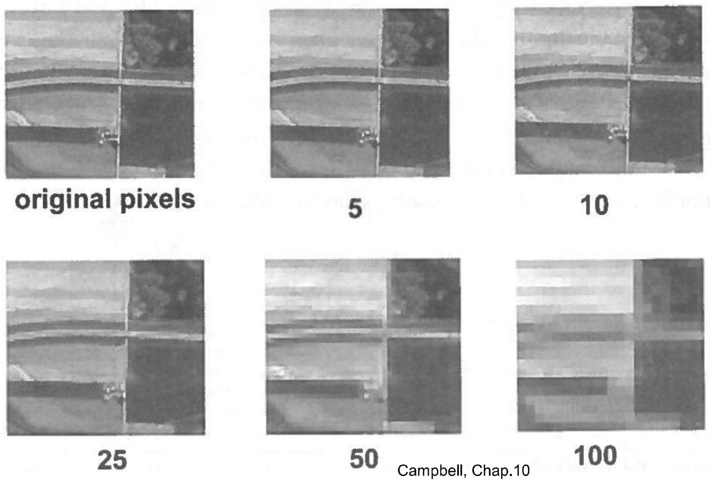
SPATIAL RESOLUTION

- Footprint extent
- Definition dependent on shape



Campbell, Chap.10

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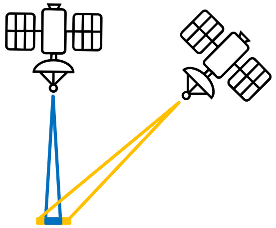
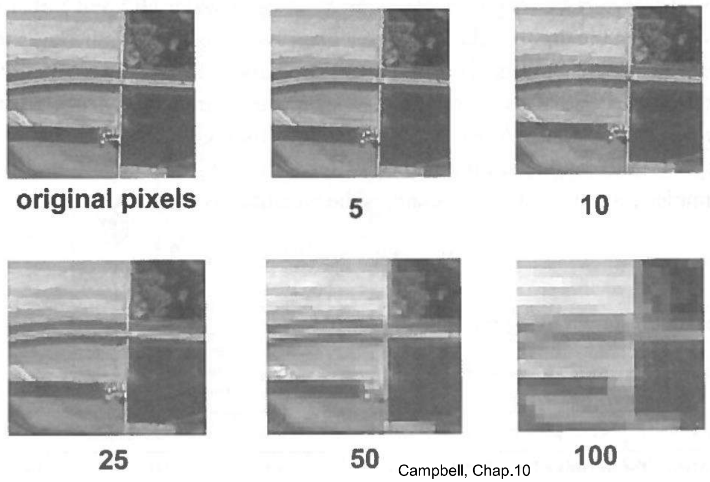
SPATIAL RESOLUTION

- Footprint extent
- Dependent on viewing geometry!

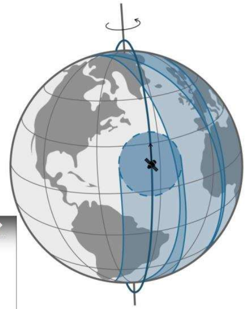


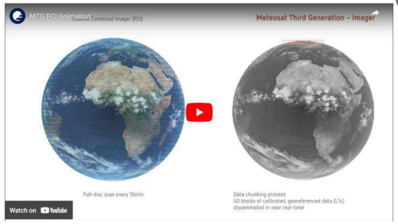


Campbell, Chap.10

TEMPORAL RESOLUTION

- Frequency of observation
  - LEO: orbit inclination and scan width (swath)
  - GEO: repeat time (GEO)

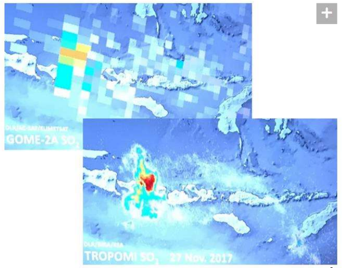


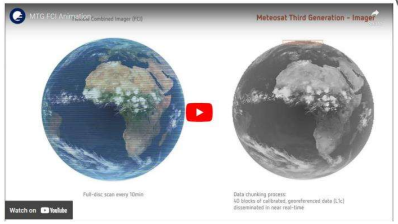


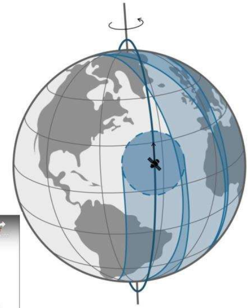
https://aerospace.csis.org/aerospace101/earth-orbit-101/
https://www.eumetsat.int/mtg-flexible-combined-imager-fci

TEMPORAL RESOLUTION

- Frequency of observation
  - LEO: orbit inclination and scan width (swath)
  - GEO: repeat time (GEO)
- Accuracy (time averages)



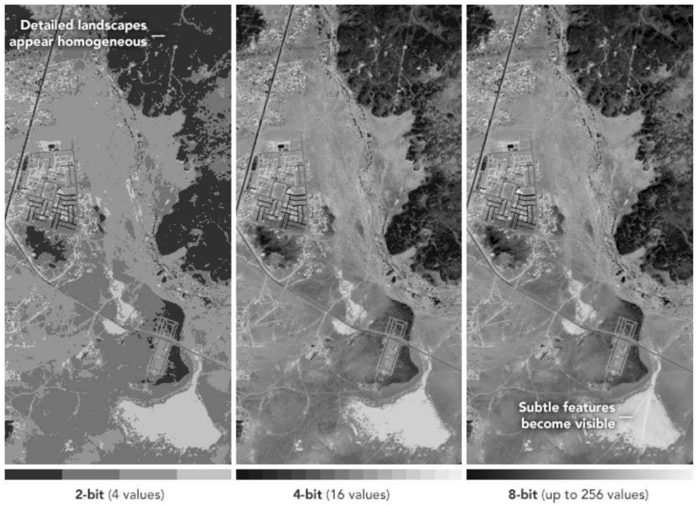




knmi.nl

https://aerospace.csis.org/aerospace101/earth-orbit-101/
https://www.eumetsat.int/mtg-flexible-combined-imager-fci

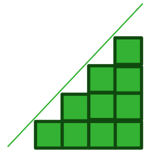
RADIOMETRIC RESOLUTION



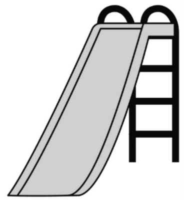
NASA Earth Observatory

RADIOMETRIC RESOLUTION

- Discrete observation <-> continuous signal
- Number of bits used to record (or save) signal
- More discrete bits -> closer to real signal



Real price	0.87 Euros
In cents	0.87 Euros
In 10s	0.90 Euros
In Euros	1.00 Euros



RADIOMETRIC RESOLUTION

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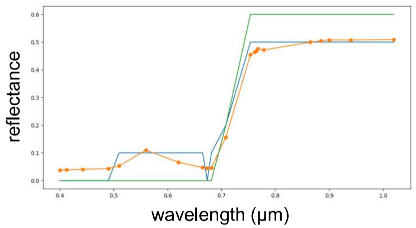


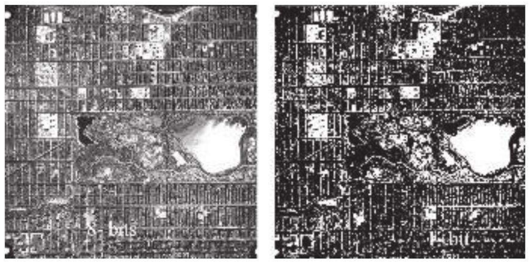
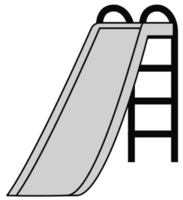


Figure 2.19
8-bit versus 11-bit radiometric resolution.

?

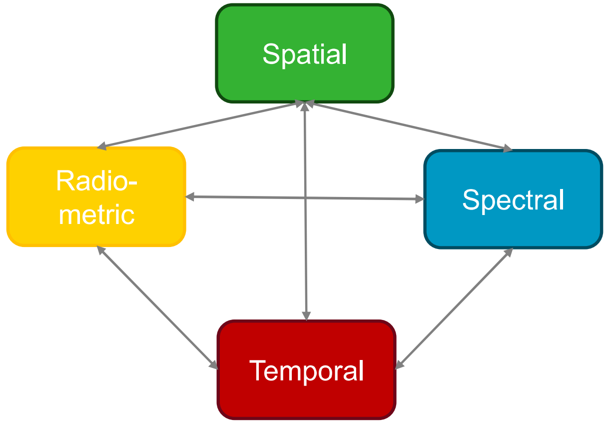
typo : 1 bit

Core textbook, chapter 2.



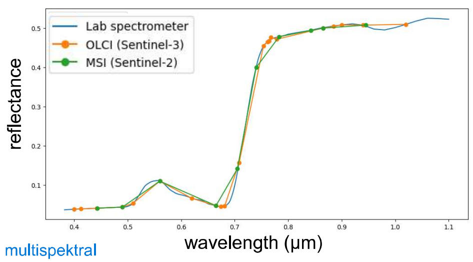
RELEVANT RESOLUTION DOMAINS

- Interplay



RESOLUTION TRADE-OFFS

- Trade offs between spatial & spectral
  - OLCI spectral resolution
  - MSI spatial resolution
  - and temporal!

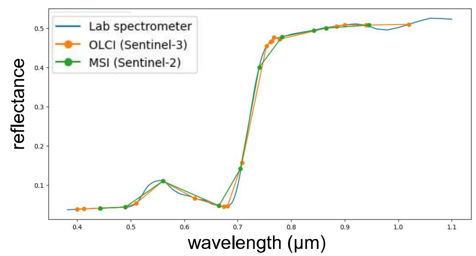


resolusi spektral yg tinggi, resolusi spatialnya jadi rendah : multispektral
banyak band yg direkam

kalau resolusi spatialnya tinggi, resolusi spektralnya rendah : pankromatik
banyak band yg direkam

RESOLUTION TRADE-OFFS

- Trade offs between spatial & spectral
  - OLCI spectral resolution
  - MSI spatial resolution
  - and temporal!



- Confounding factors: atmosphere, illumination
  - Topic of atmospheric correction (lecture next week!)

TODAY'S EXERCISE

- Supervised exercise:
  - Farzaneh Dadrass Javan
  - Srinidhi Gadde
- 10:45 - 15:30
- Rooms 2405 and 2409
- At the end of this exercise, you will be able to:
  1. Remember how to apply basic physical and mathematical skills for EO applications
  2. Perform basic calculations with properties of EMR
  3. Argue which sensor is most suitable for particular EO study cases

LITERATURE

- Core textbook: The core of GIScience: Tolpekin & Stein (eds), 2013
- Introduction to Remote Sensing, 4th Edition, J.B. Campbell, 2007