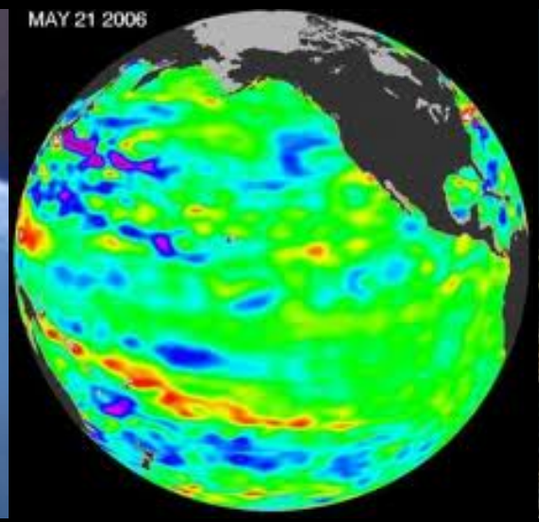
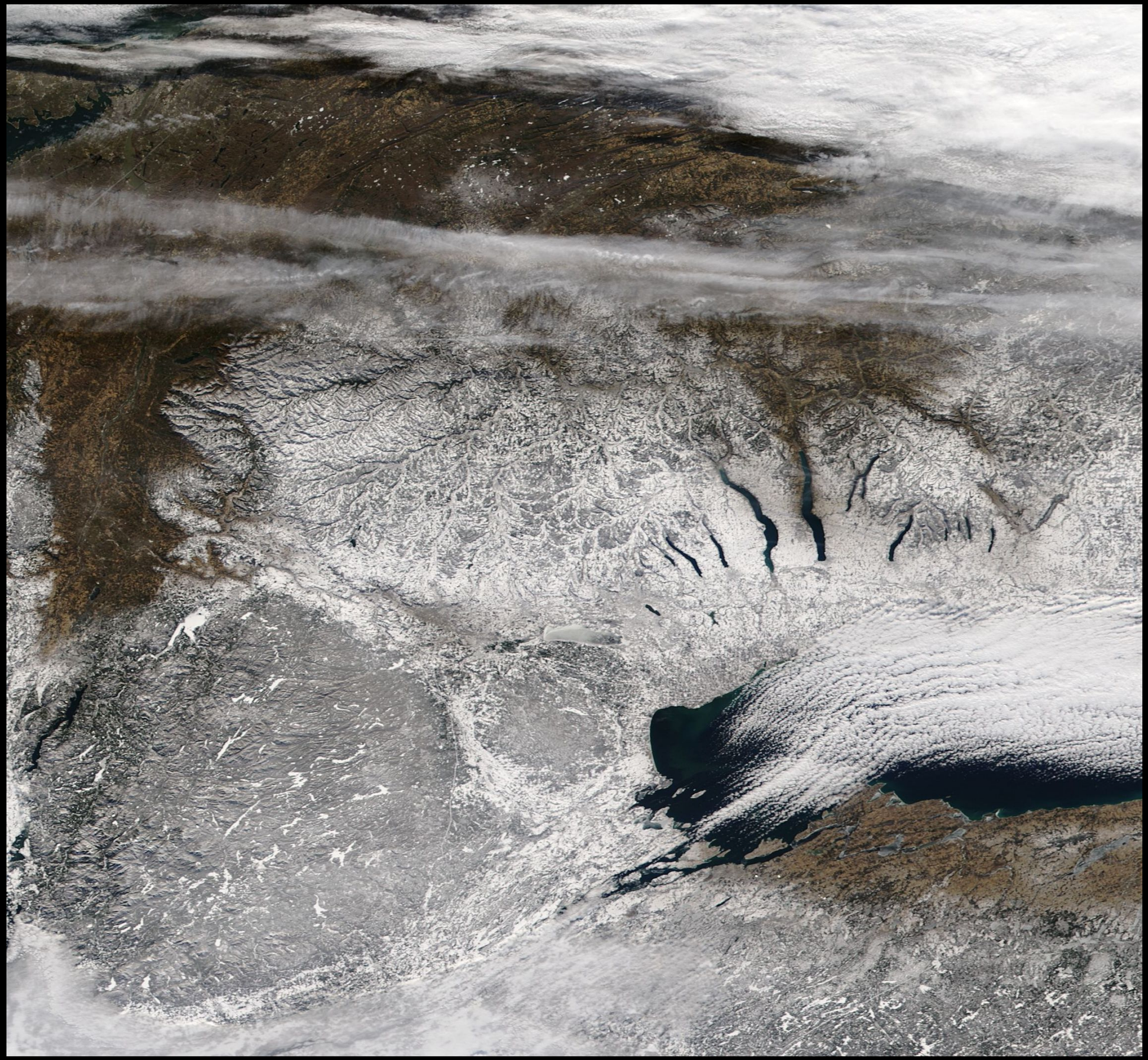




Basic Physical Principles in Remote Sensing

Xi Yang
Department of Environmental Sciences
University of Virginia
xiyang@virginia.edu
390 Clark Hall

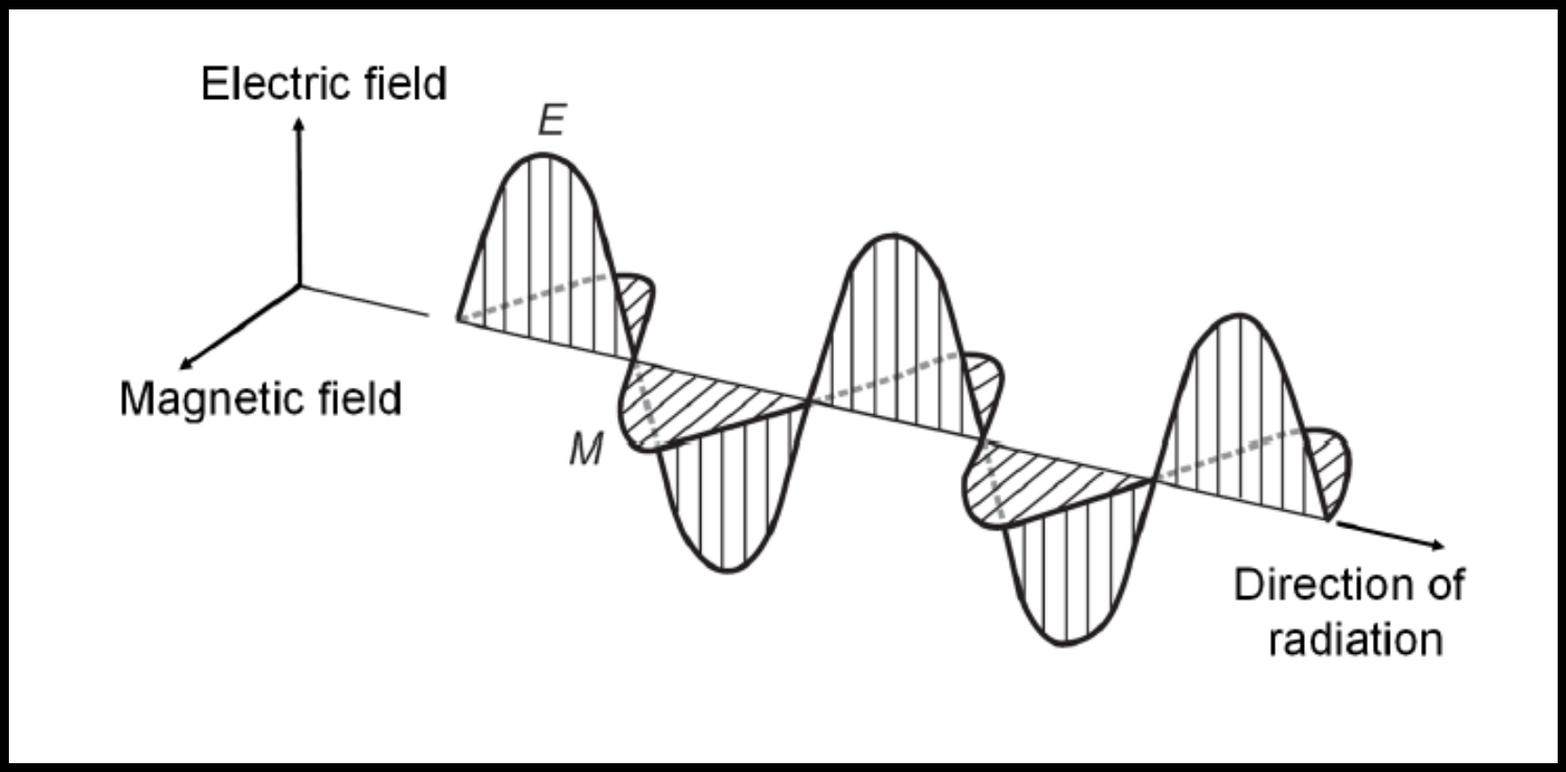
EVSC 4010/7010 Week 2

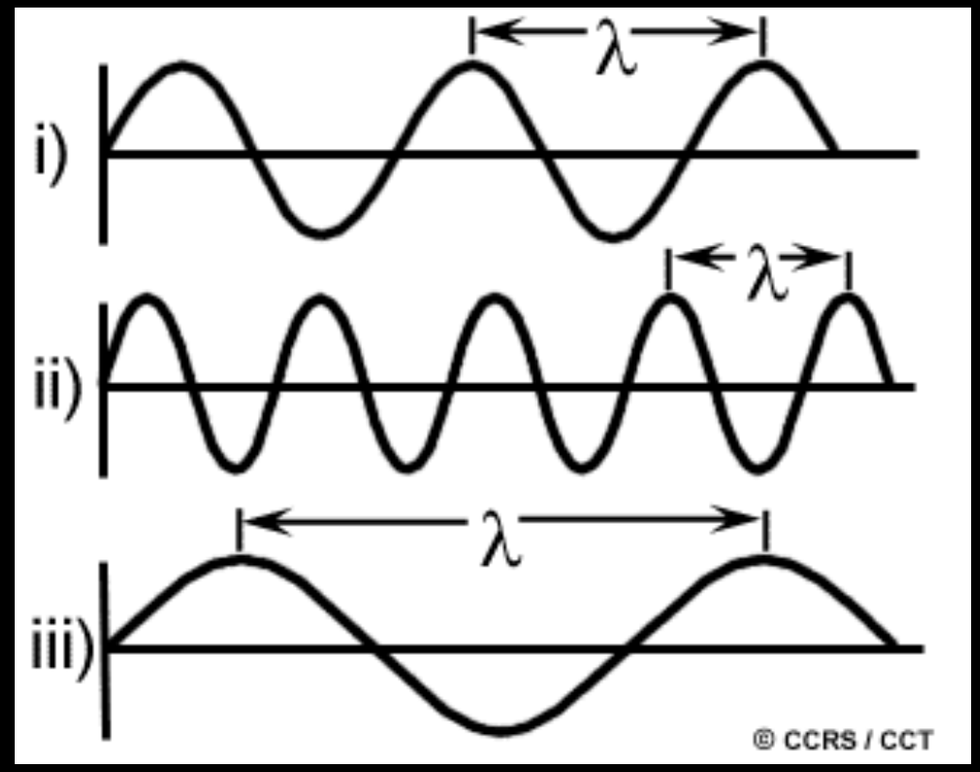


Outline of Week 2

- Electromagnetic radiation (EMR)
- Key concepts in remote sensing
- Laws of EMR
- Solar radiation and surface reflectance

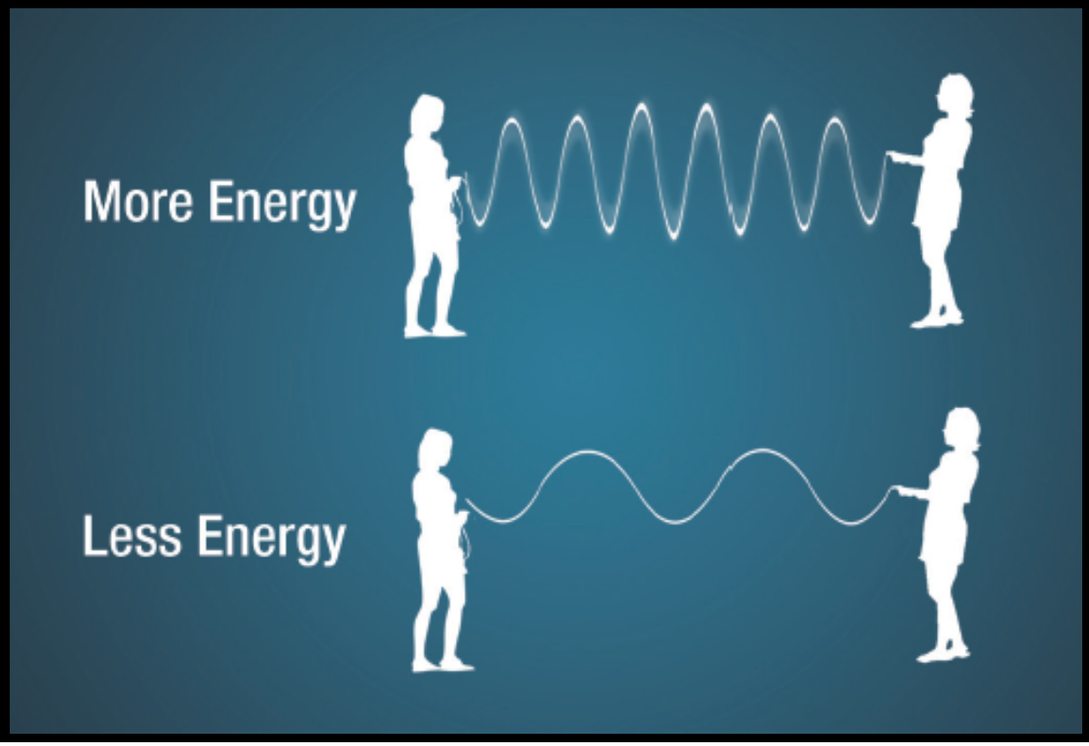
Electromagnetic wave

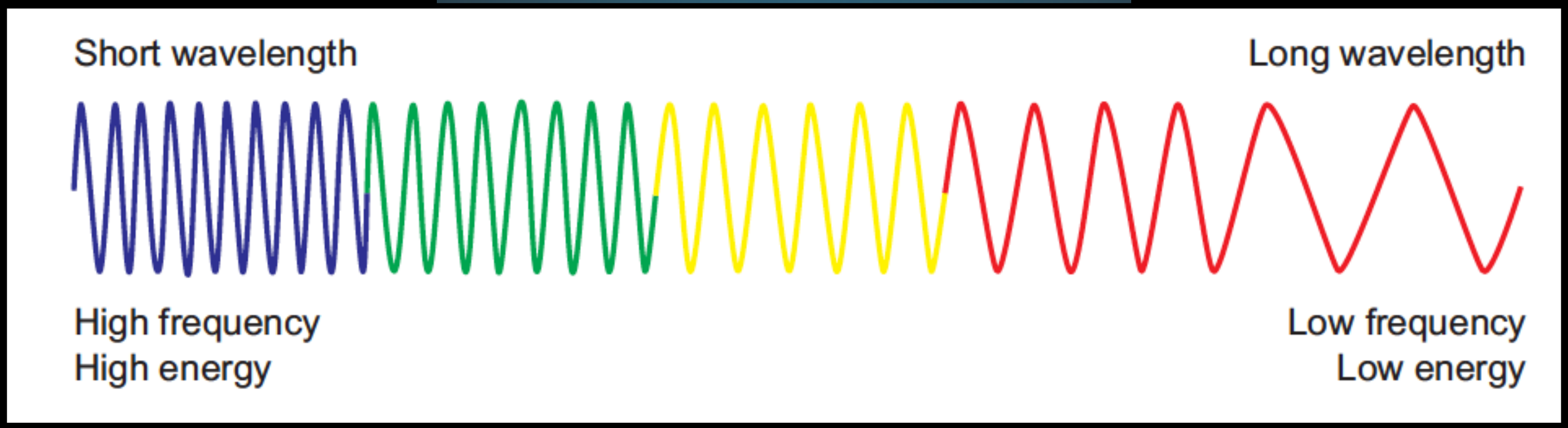




- Wavelength (λ): the distance between successive crests of a wave
- Frequency (ν) = c/λ.
- Wavenumber (1/λ), unit: cm^{-1}.

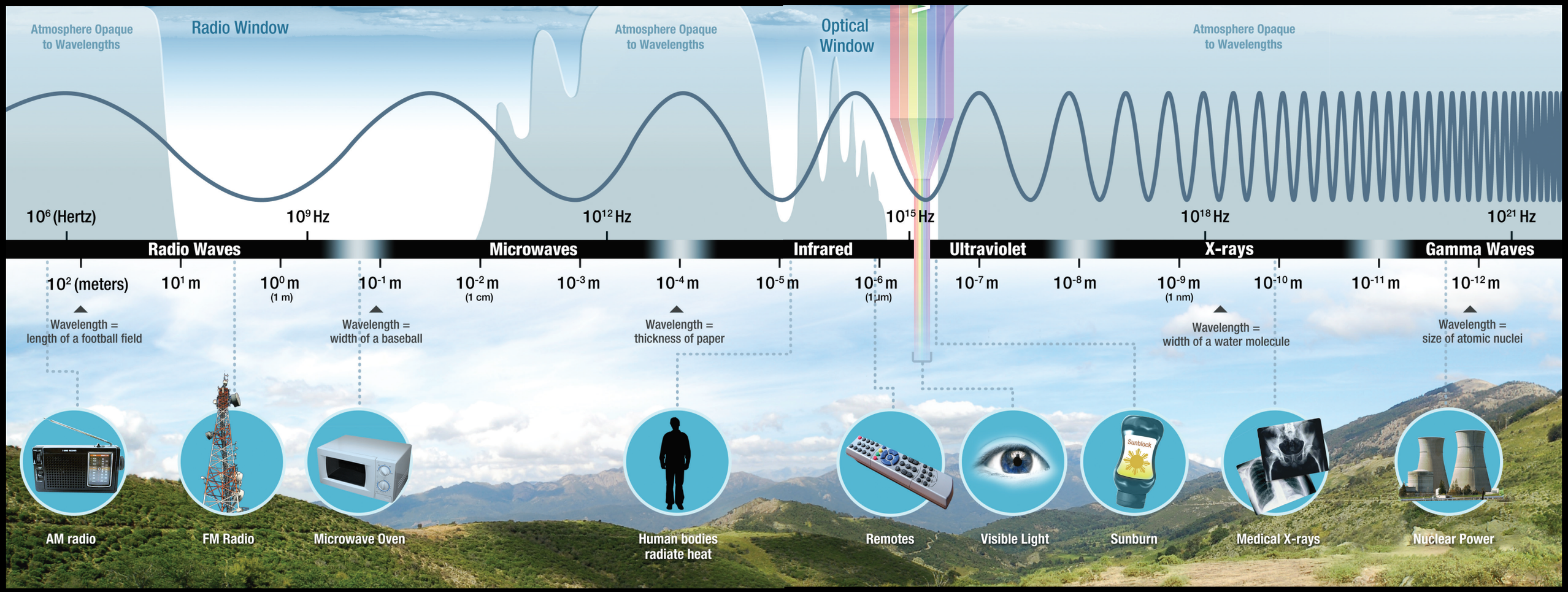
Energy of electromagnetic wave

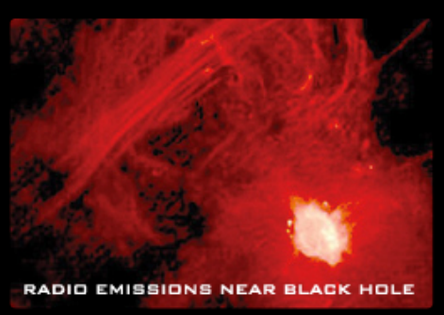


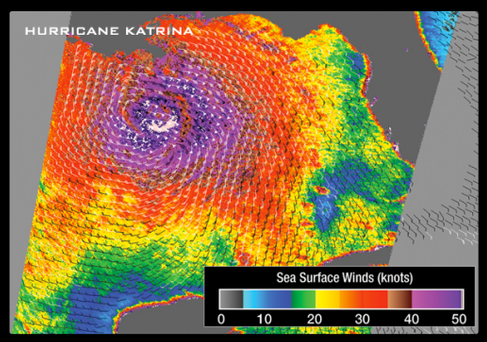


- $Q = hc/\lambda = h\nu$. Q is in joule, h is Planck's constant (6.626×10^{-34} J s).

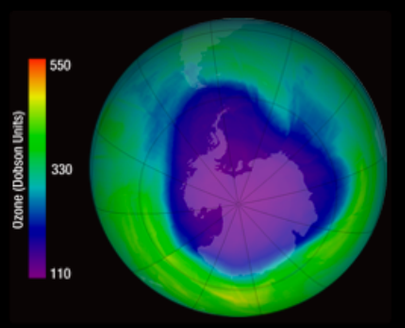
Types of EMR


Atmosphere Opaque to Wavelengths
Radio Window
Atmosphere Opaque to Wavelengths
Optical Window
Atmosphere Opaque to Wavelengths
10^6 (Hertz)
10^9 Hz
10^12 Hz
10^15 Hz
10^18 Hz
10^21 Hz
Radio Waves
Microwaves
Infrared
Ultraviolet
X-rays
Gamma Waves
10^2 (meters)
10^1 m
10^0 m (1 m)
10^-1 m
10^-2 m (1 cm)
10^-3 m
10^-4 m
10^-5 m
10^-6 m (1 μm)
10^-7 m
10^-8 m
10^-9 m (1 nm)
10^-10 m
10^-11 m
10^-12 m
Wavelength = length of a football field
Wavelength = width of a baseball
Wavelength = thickness of paper
Wavelength = width of a water molecule
Wavelength = size of atomic nuclei
AM radio
FM Radio
Microwave Oven
Human bodies radiate heat
Remotes
Visible Light
Sunburn
Medical X-rays
Nuclear Power

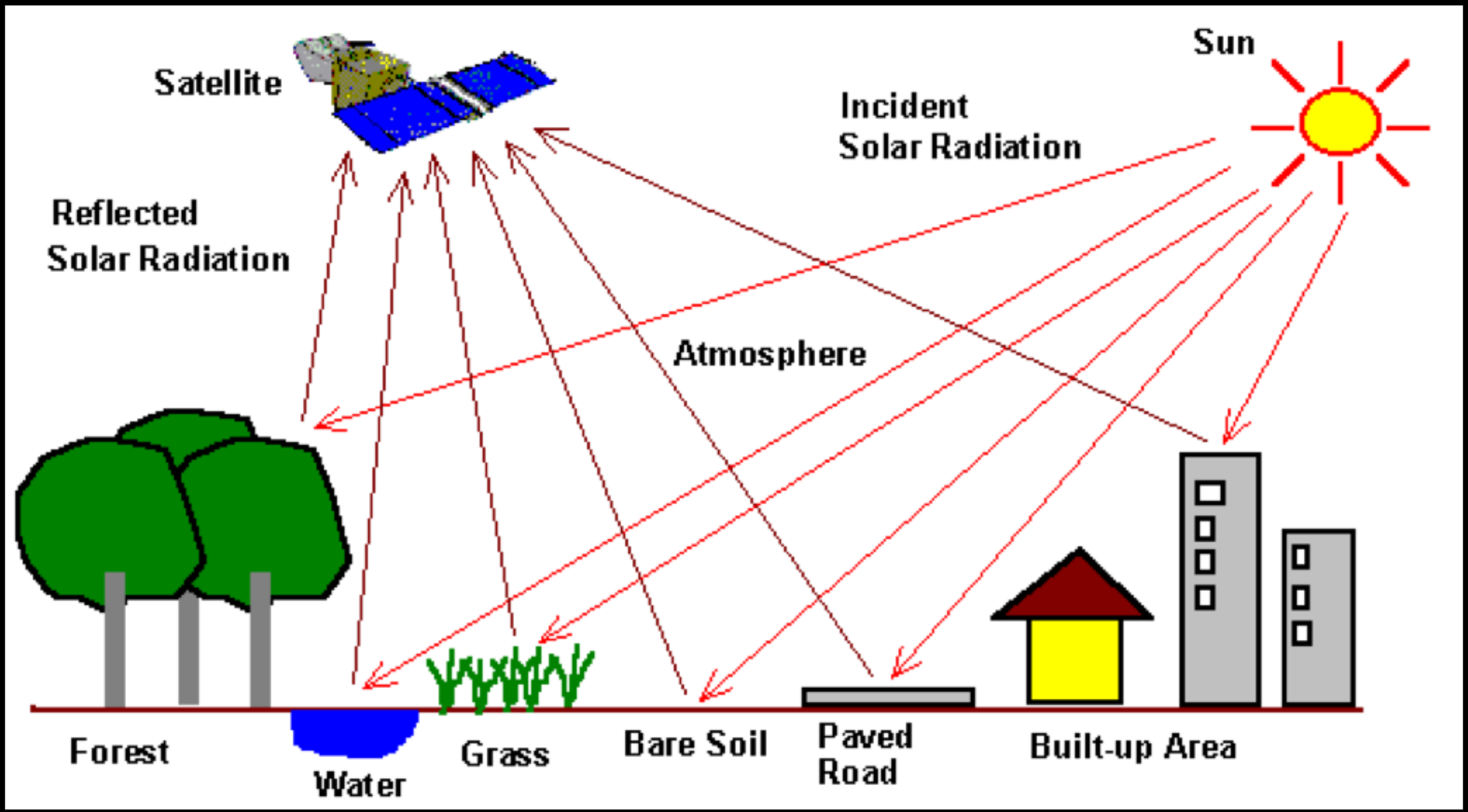

RADIO EMISSIONS NEAR BLACK HOLE


HURRICANE KATRINA
Sea Surface Winds (knots)
0 10 20 30 40 50


35.6 °C
37.5
8.6
FLIR


Ozone (Dobson Units)
550
330
110

How does EM radiation reach the satellite?



unomaha.edu

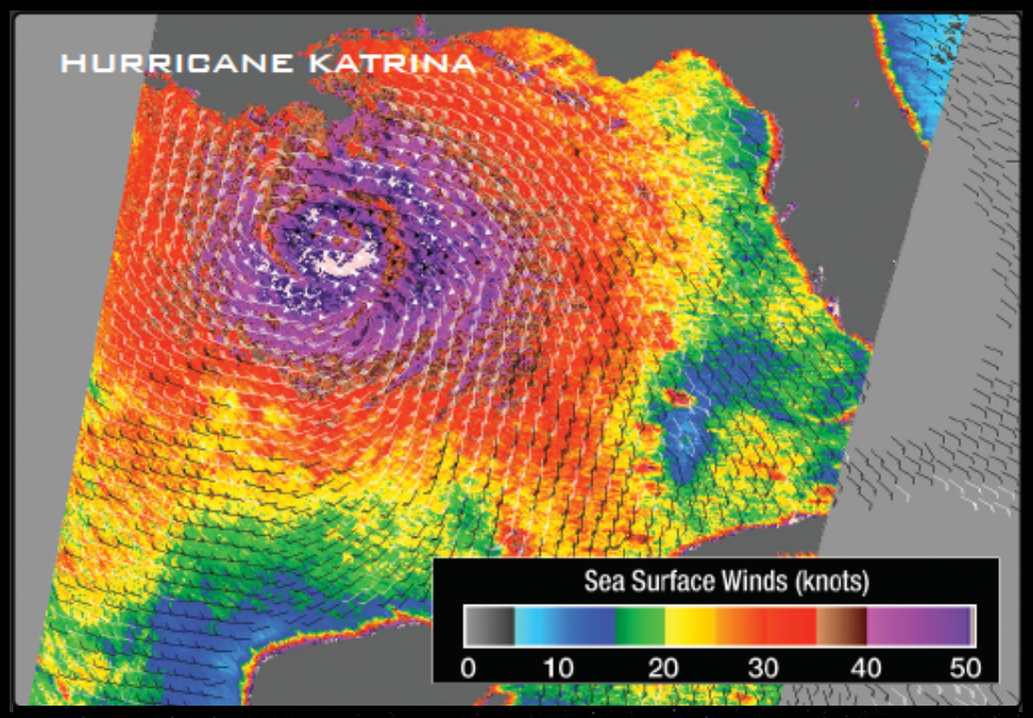
Near infrared and optical remote sensing

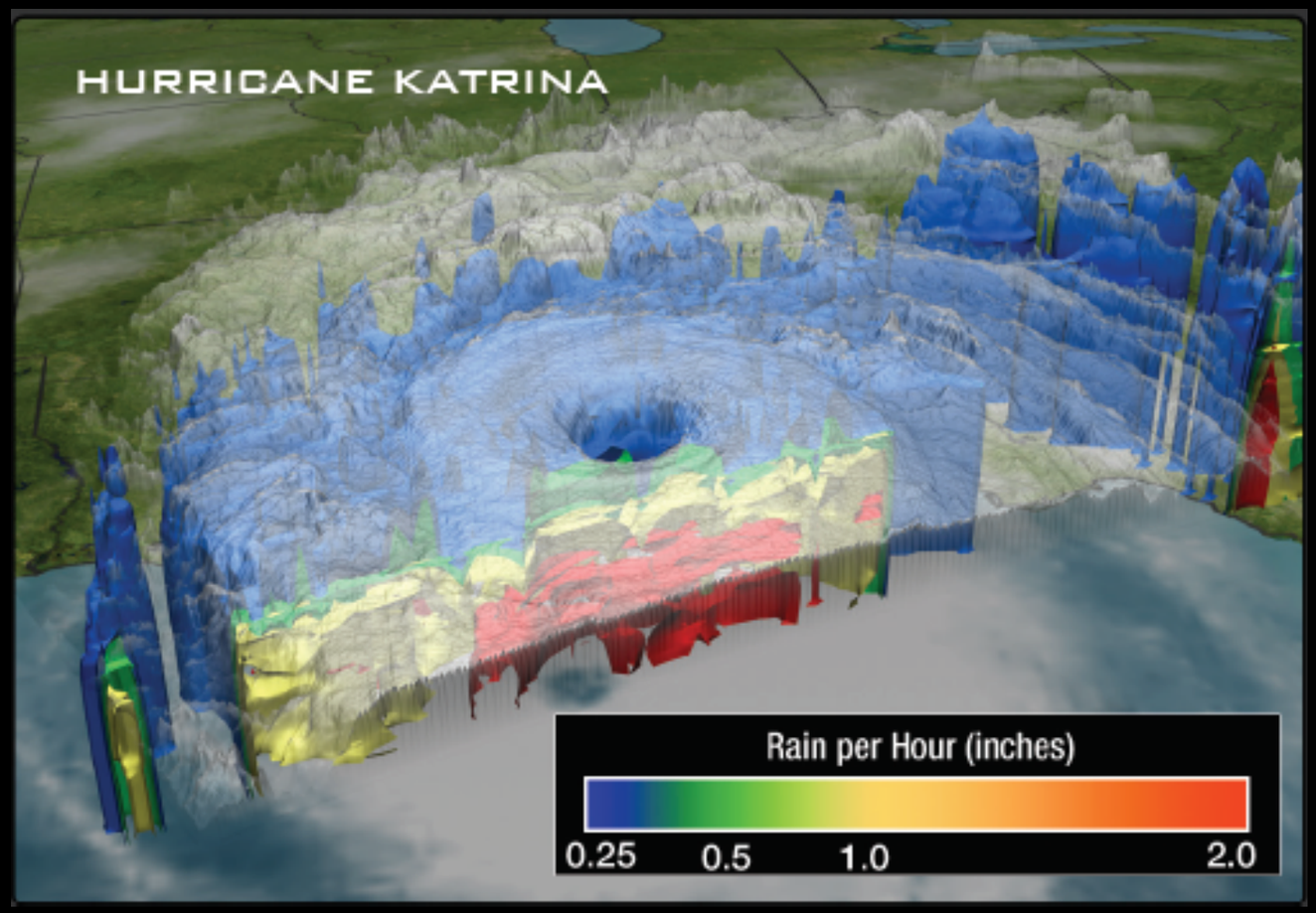
Vegetation; Urbanization

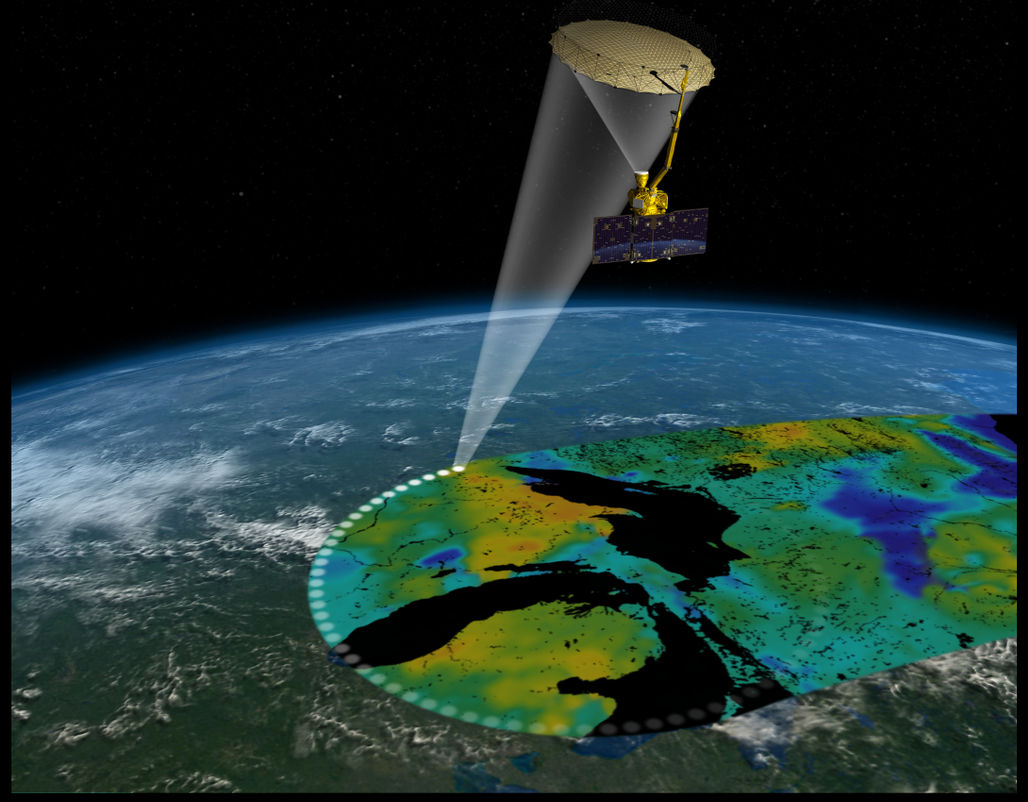
Thermal remote sensing

It is based on observations of visible and shortwave infrared light from OLI and of surface heat from Landsat's Thermal Infrared Sensor (TIRS). Active fires appear orange; the burn scar is brown. Unburned vegetation is green; developed areas are gray.

Microwave remote sensing







GPS; Sea surface winds; rainfall; soil moisture.

Basic concepts

- Radiant Energy (Q, unit: joule): the total energy radiated toward a surface.

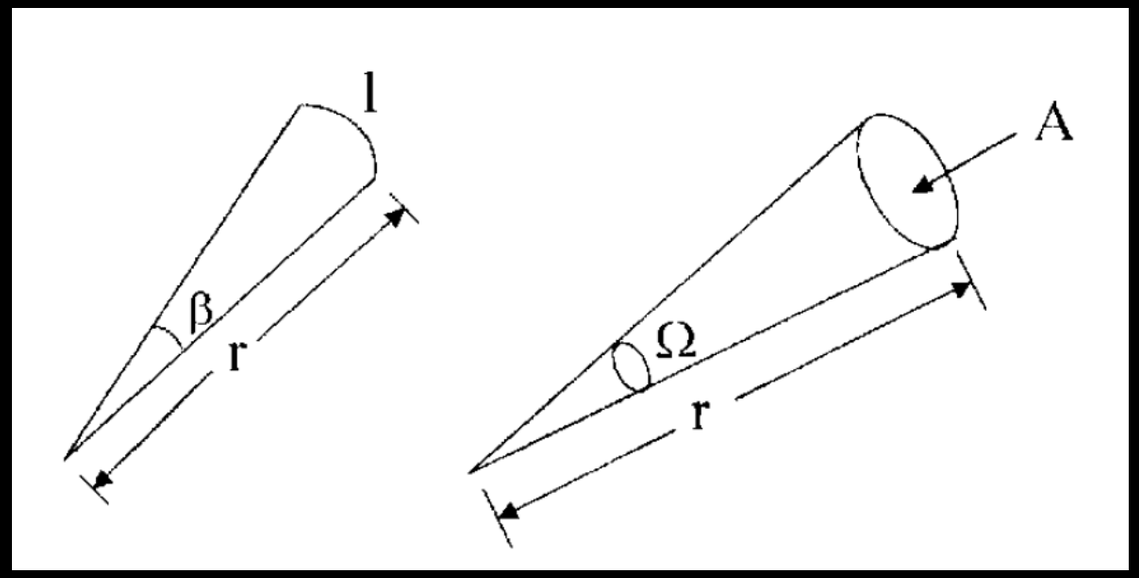
- Radiant Flux ($\Phi = \delta Q/\delta t$, unit: joule/s=watt): the energy per unit of time.
  - Photon flux: no. of photons per unit time.

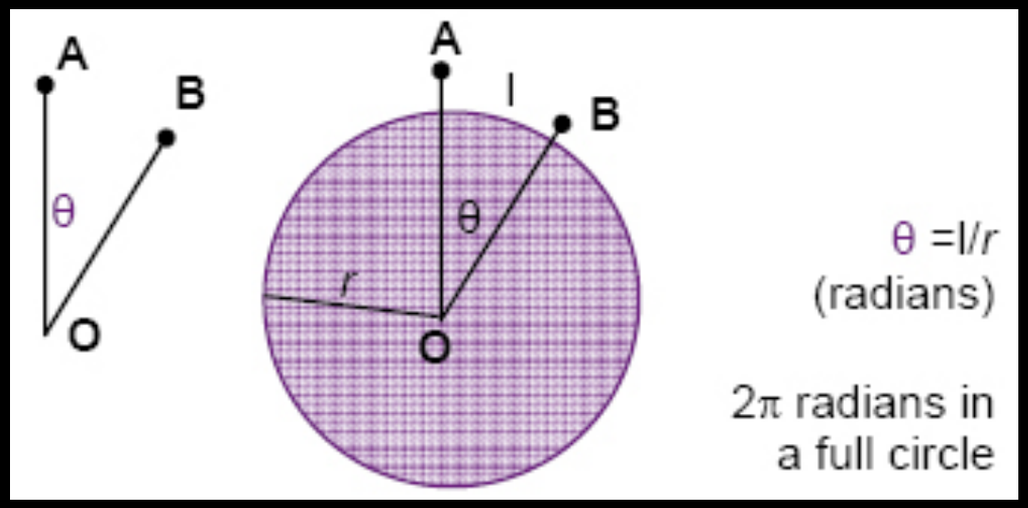
- Irradiance ($E = \delta\Phi/\delta A$, unit: w/m^2): the radiant flux arriving on a surface per unit area [flashlight vs. the Sun]

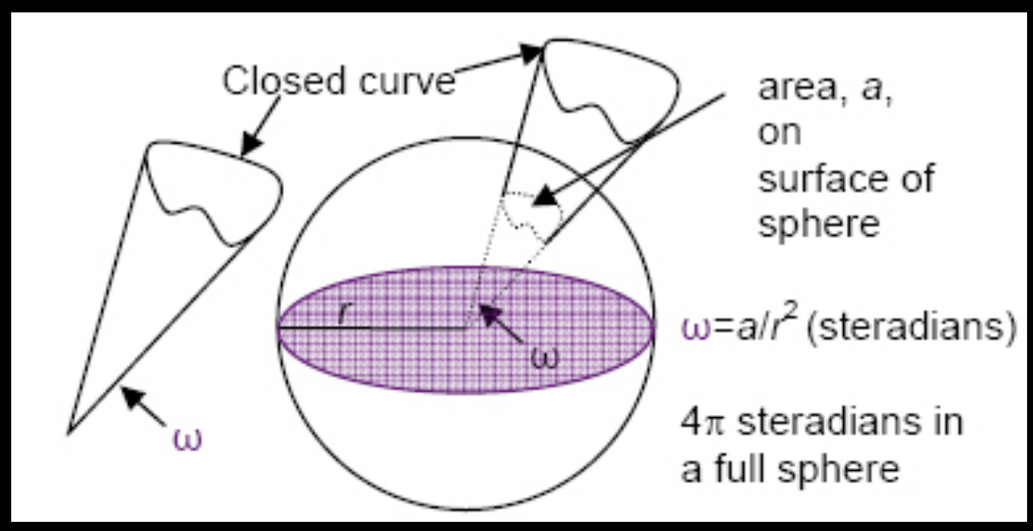
- Exitance or Emittance (M, w/m^2): the radiant flux *leaving* a surface

Solid angle

- Solid angle (Ω, unit: steradian): a solid angle is, analogus to an angle in the 2D world, but in a 3D world.



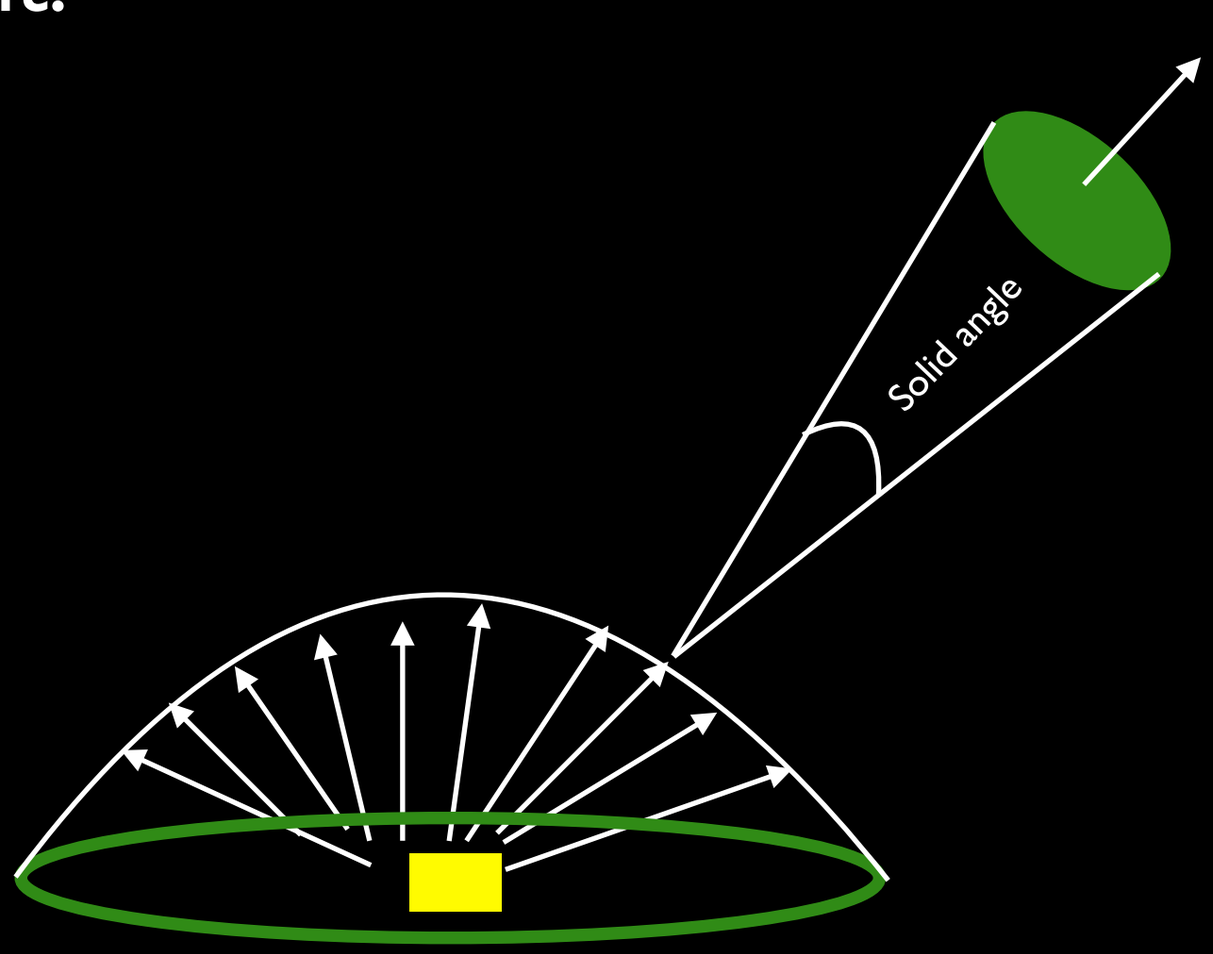




What is the solid angle of a sphere?

Radiance

- Radiance (L, unit: w m^{-2} sr^{-1}): the total energy exiting in a certain direction per unit area per solid angle of measurement.



Spectral irradiance/radiance

- Spectral Irradiance ($E = \delta\Phi/\delta A/\delta\lambda$, unit: $w/m^2/nm$): the radiant flux arriving on a surface per unit area per unit wavelength.
- Spectral Radiance (L, unit: $w\ m^{-2}\ sr^{-1}\ nm^{-1}$): the total energy exiting in a certain direction per unit area per solid angle of measurement per unit wavelength.

$1\ m = 10^3\ mm = 10^6\ \mu m\ (micron) = 10^9\ nm$

Visual interpretation of remote sensing data

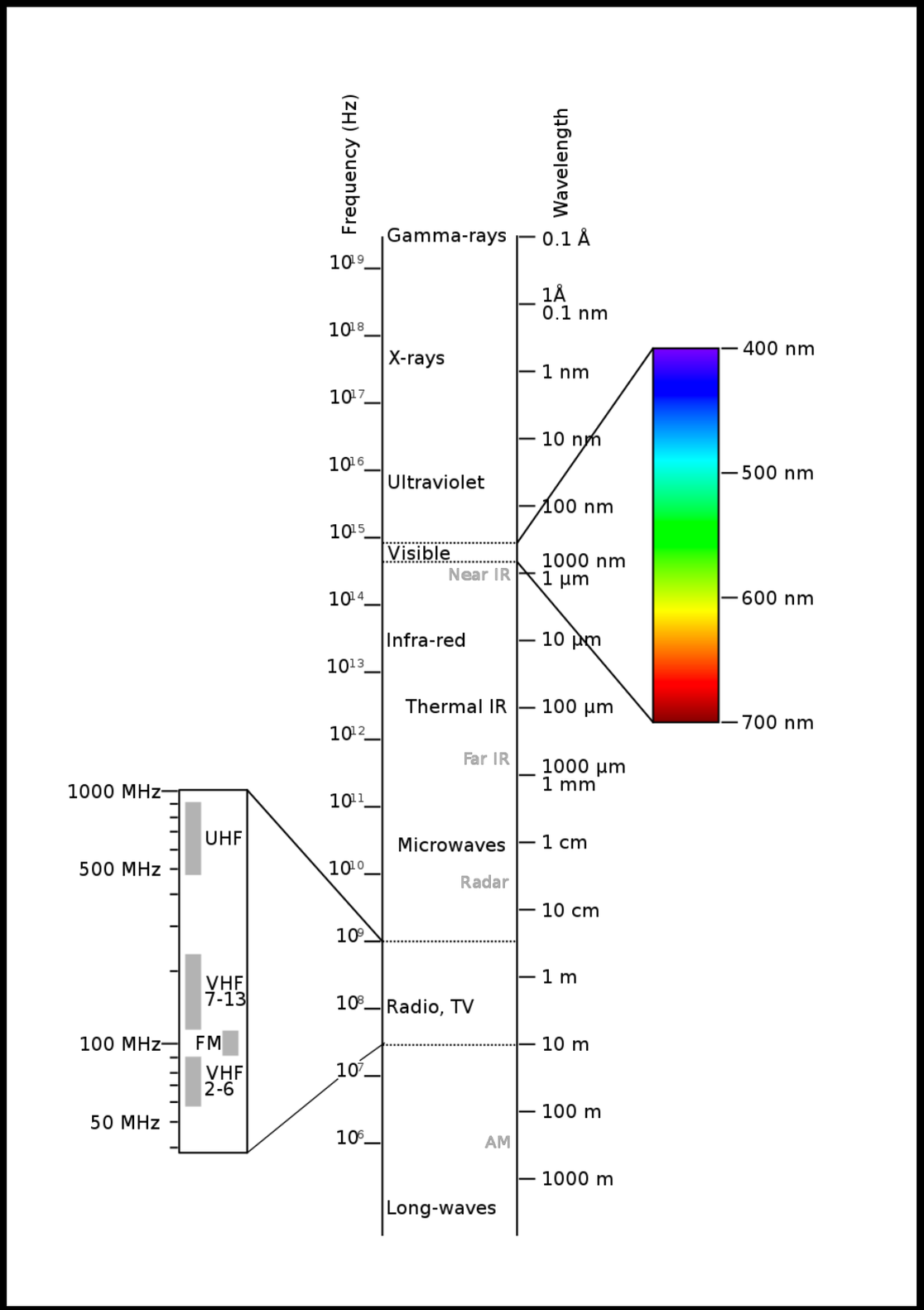
- Brightness
- Color
- Texture
- Shape and size
- Shadows
- Period of acquisition

EMR wavelengths

- ***Visible*** (400 nm-700nm). Red: 620-700 nm; Green: 500-578 nm; Blue: 446-500 nm.

- ***Infrared*** (0.7 um-100um). NIR: 0.7 - 1.4 um; SWIR: 1.4-3 um; TIR: 3-15um. Far IR: 15-1000um

- **Microwave** (1 mm - 1 m).



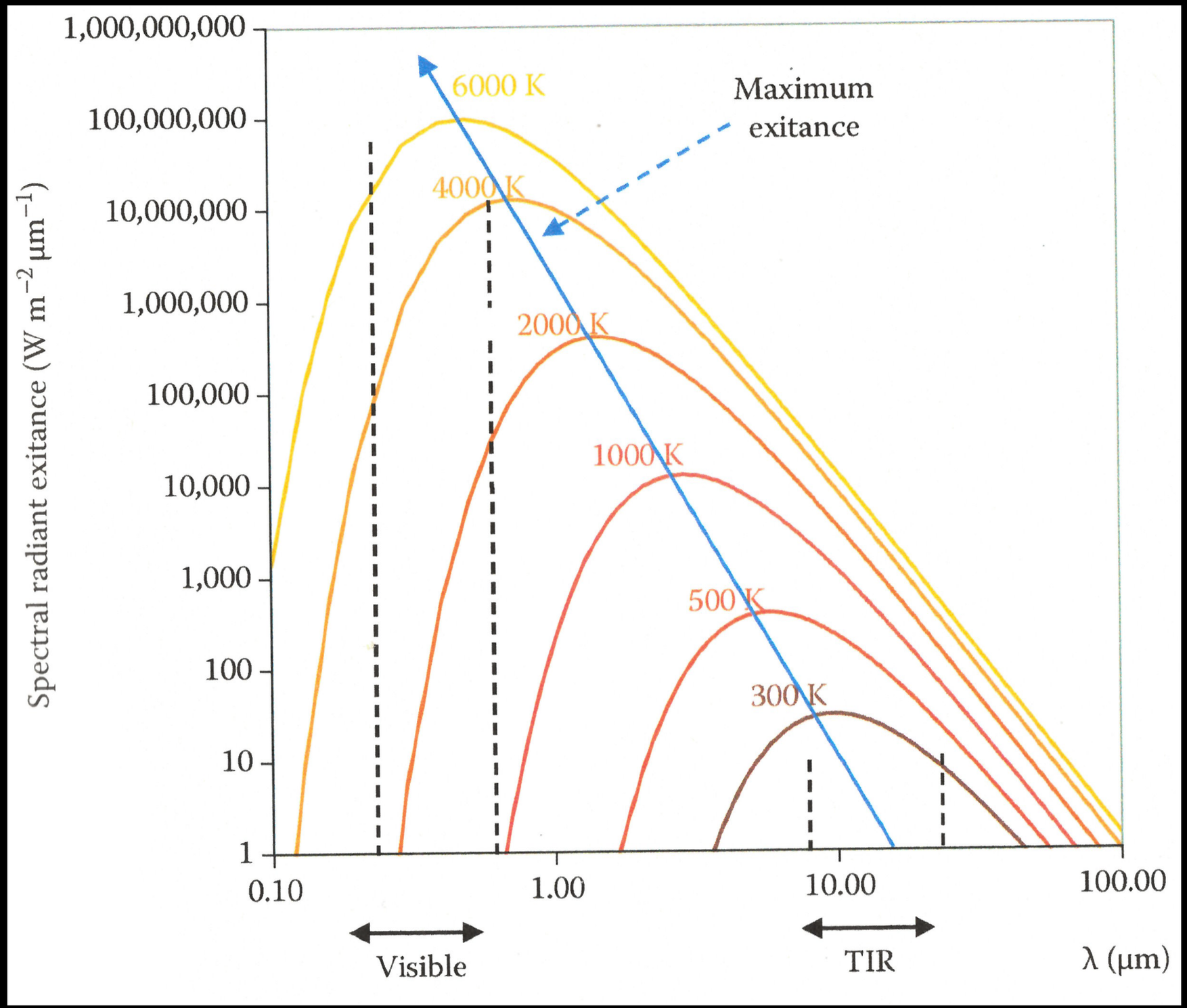
Electromagnetic radiation laws (1)

- Planck's law of radiation: the spectral distribution of the emittance of a blackbody is a function of its temperature and wavelength.

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

c_1=3.741x10^8 W m^{-2} um^{-1};
c_2= 1.438x10^4 um K

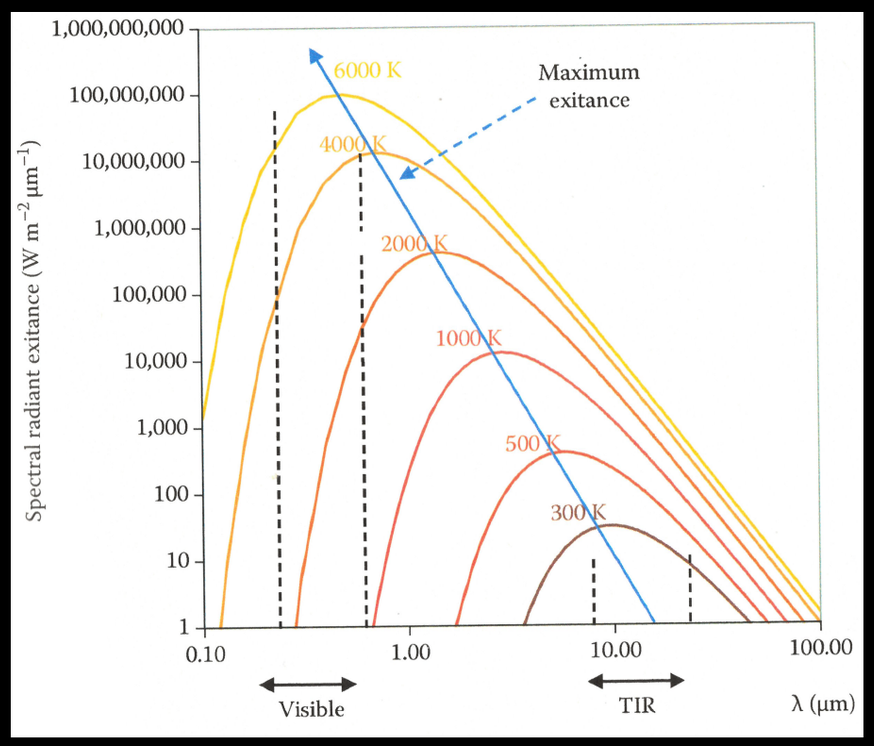
Blackbody radiation curves

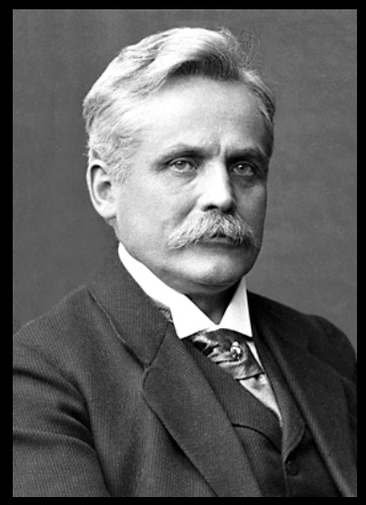


Electromagnetic radiation laws (II)

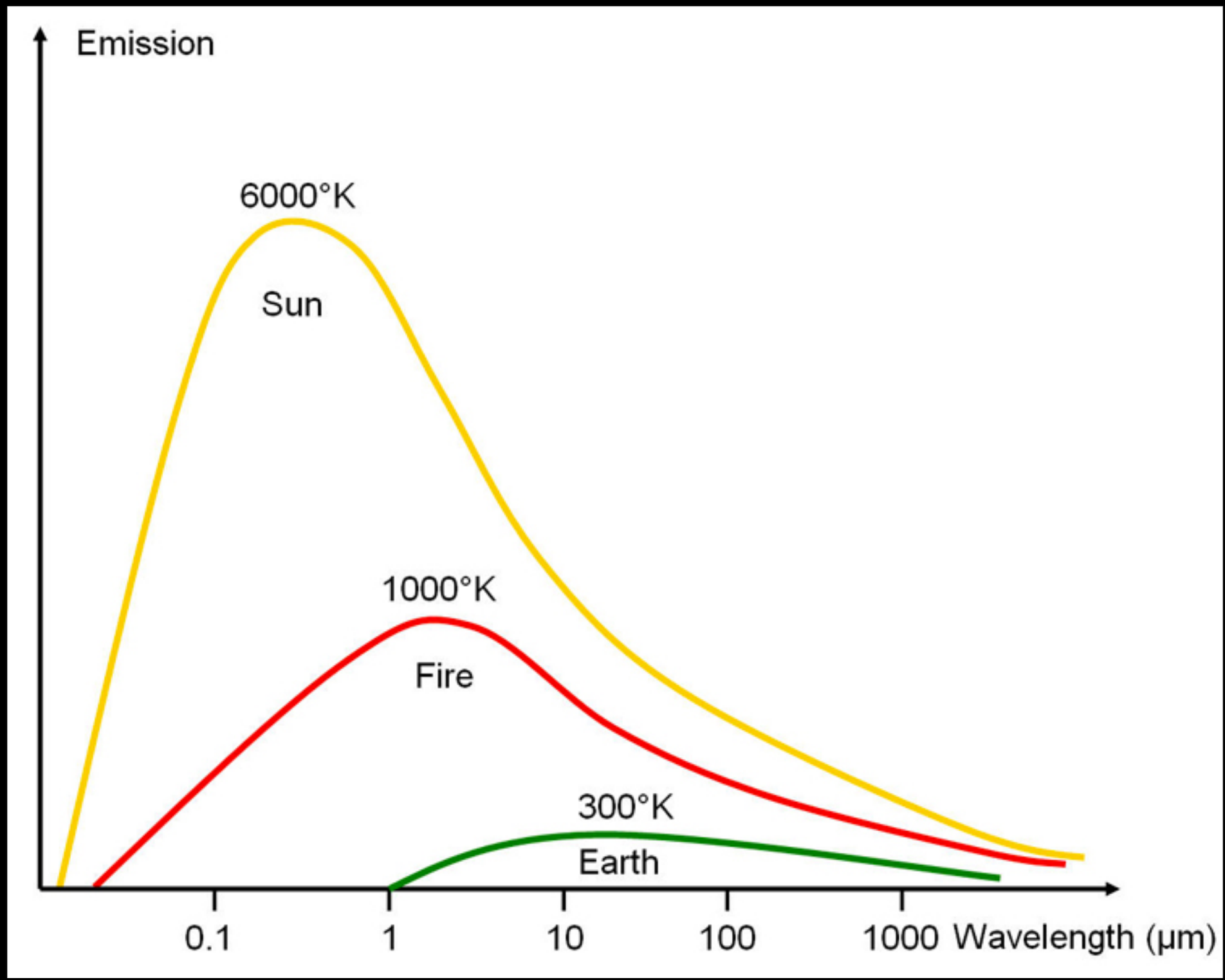
- Wien's Displacement Law:

$$\lambda_{\max} = \frac{2898}{T}$$





A remote sensing application

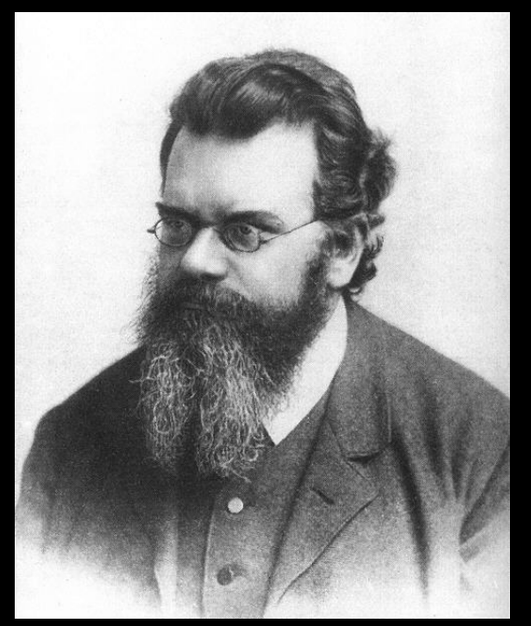


Electromagnetic radiation laws (III)

- Stefan-Boltzmann law:

$$M = \sigma T^4$$

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



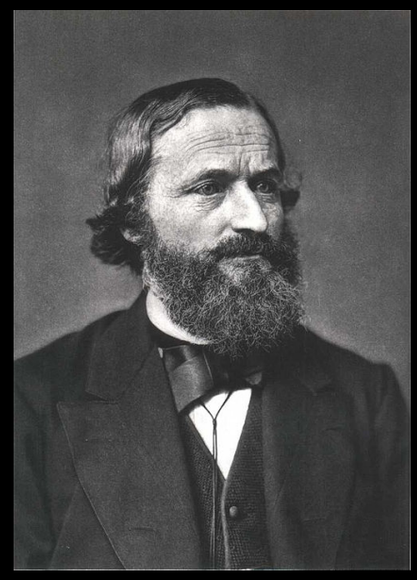
Electromagnetic radiation laws (IV)

- Kirchhoff's law:

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

ε=0-1

σ=5.6697x10^{-8} W m^{-2} K^{-4}



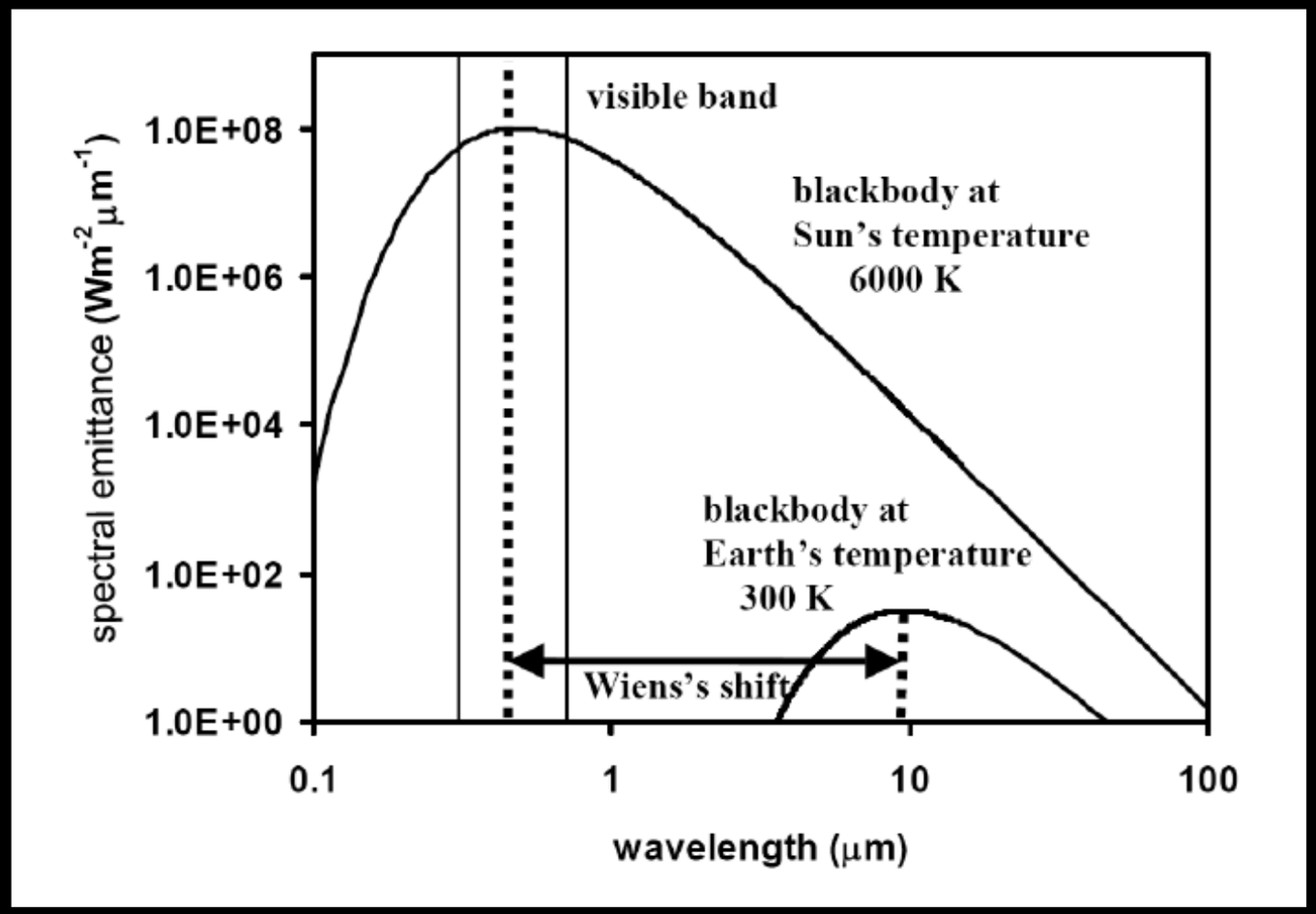
Electromagnetic radiation laws summary

- Four EMR laws tell us:

  The magnitude and spectral distribution of energy depends on 1) the temperature; 2) the emissivity.

  Knowing the temperature of the object, we can determine the most suitable wavelength for detecting objects of interest.

Sun and Earth can be treated as a blackbody

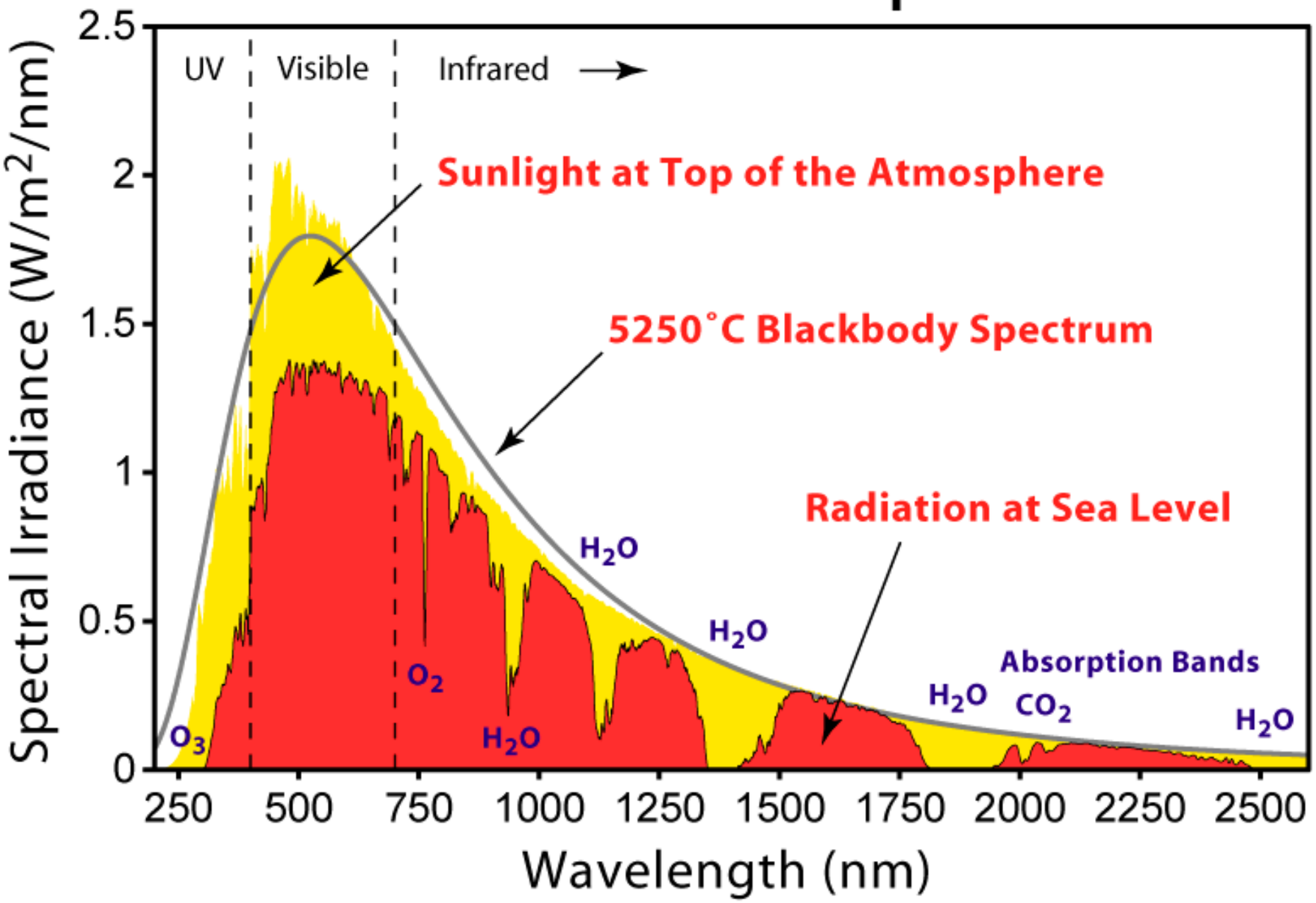


And the solar radiation (irradiance) at the top-of-atmosphere (E) is:

$$E = M\frac{R^2}{D^2}$$

M is the exitance at the solar surface
R is radius of the sun
D is the sun-earth distance

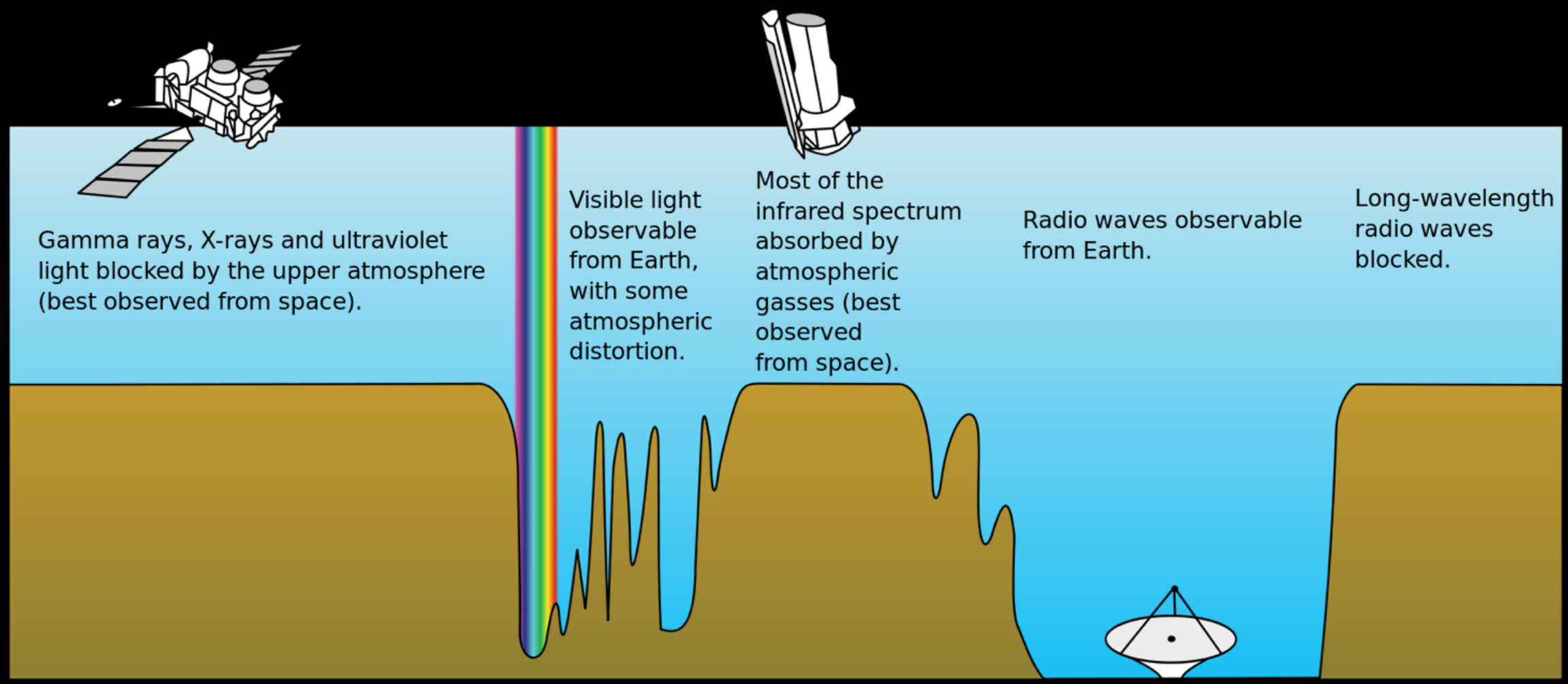
Solar Radiation Spectrum



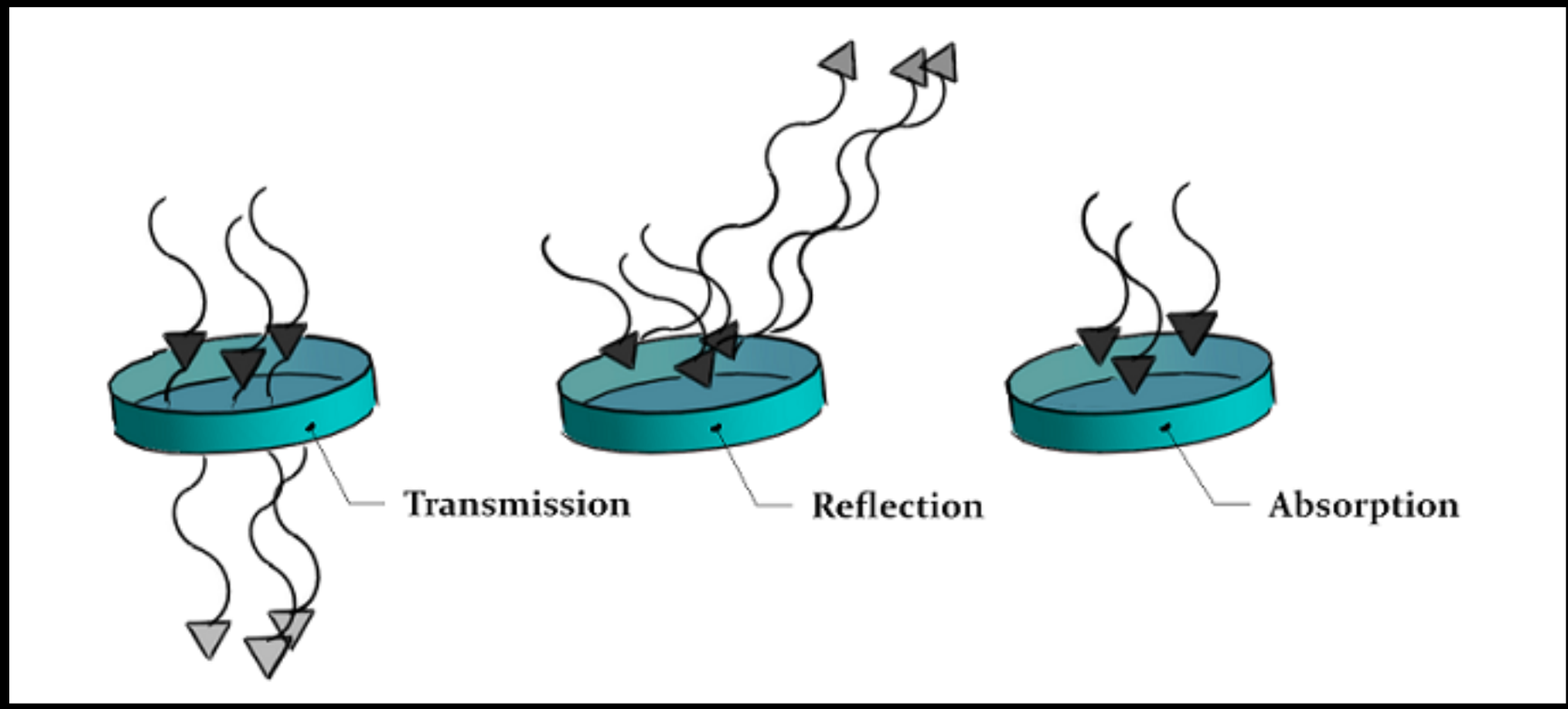
- ~ 40% of the solar energy is in visible wavelength (400 - 700nm)

Wikipedia

Atmospheric window



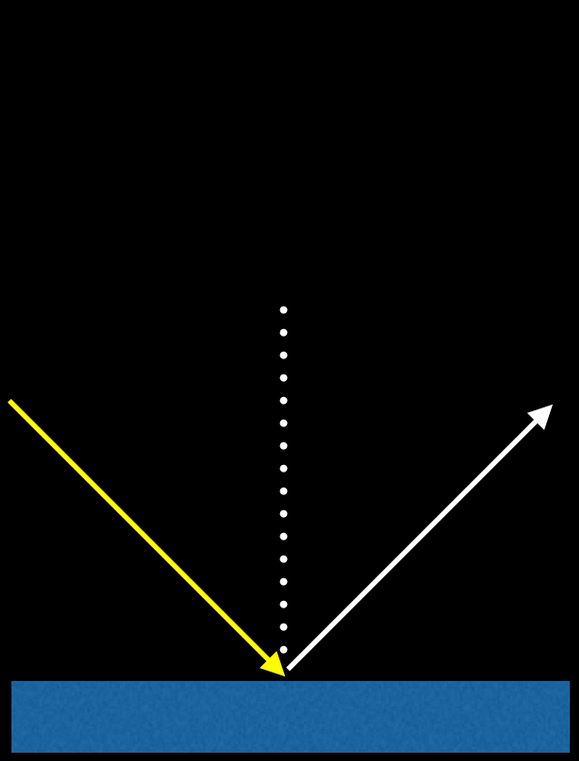
Reflectance



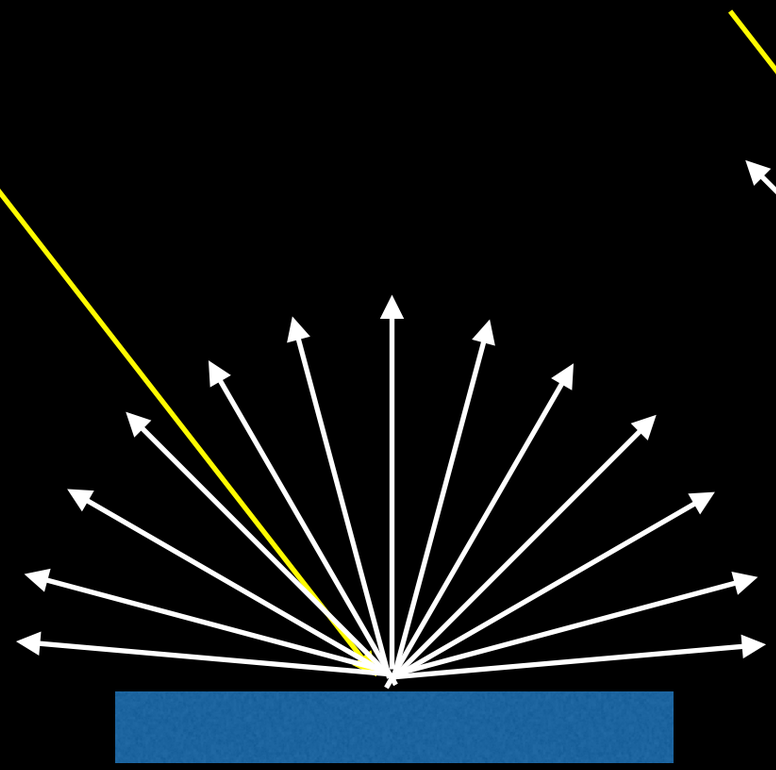
Incoming radiation = Transmission + Reflection + Absorption

I = Transmittance + Reflectance + Absorbance

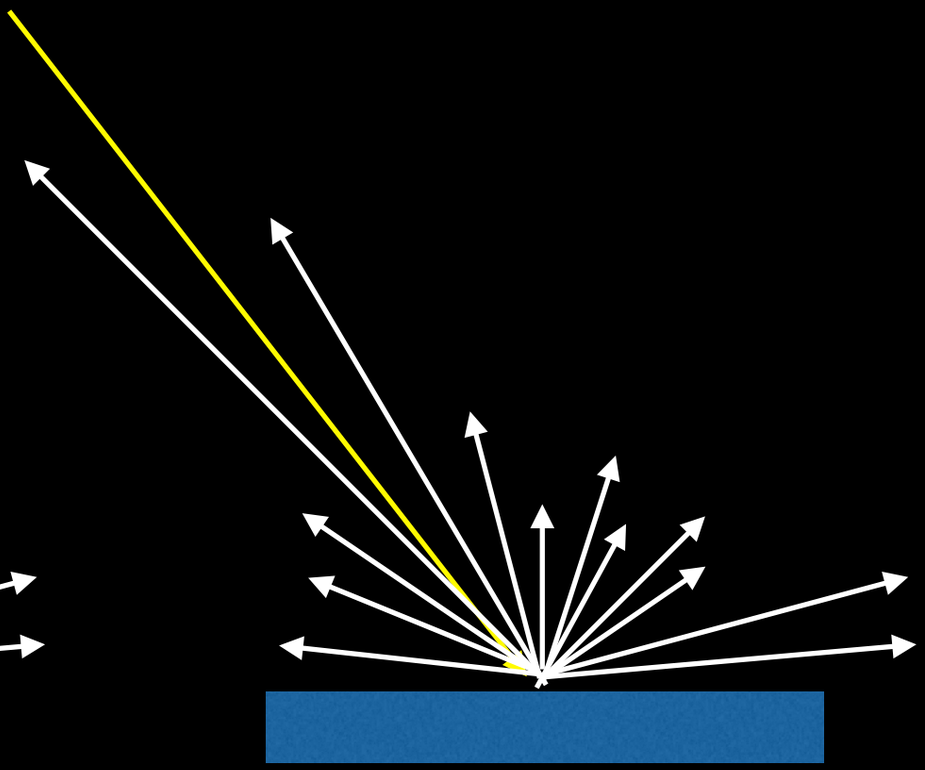
Three types of surfaces



Specular



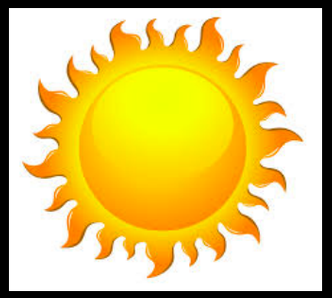
Lambertian
(isotropic)



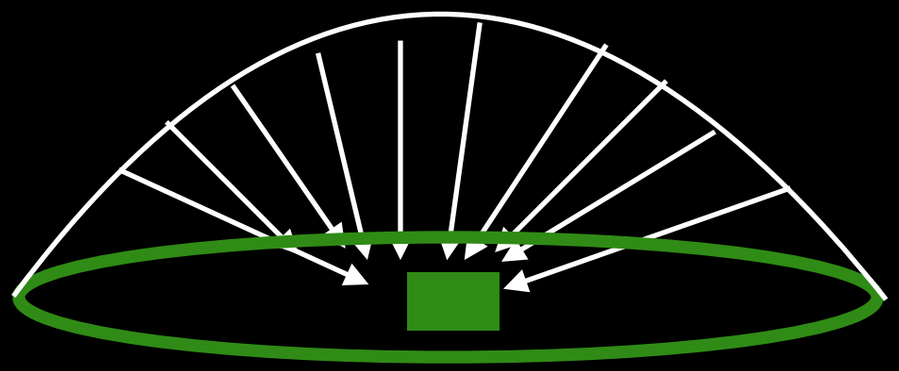
Anisotropic

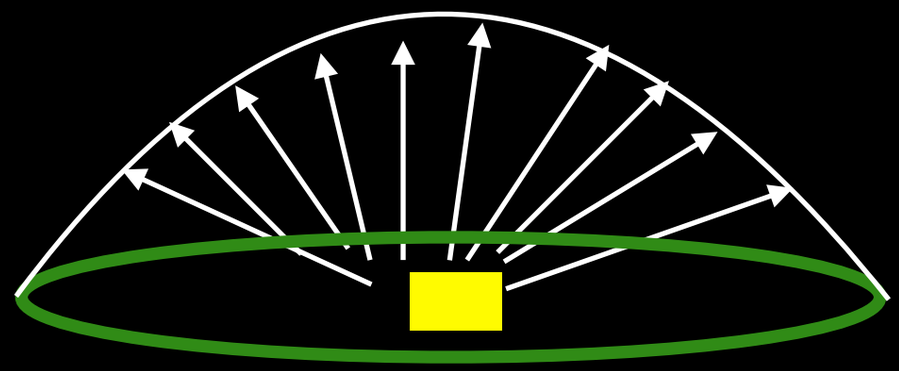
For a Lambertian surface, if we know the radiance in one direction, L, then the exitance $M = \pi L$.

Albedo (α)



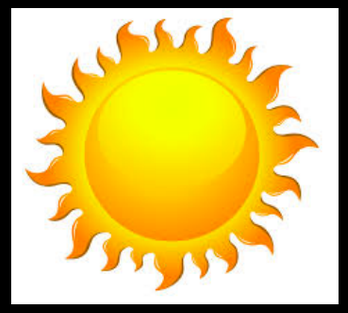
Ocean: 0.06
Conifer: ~0.10
Deciduous: 0.15
Grass: 0.25
Ice: 0.5-0.7
Fresh snow: 0.8



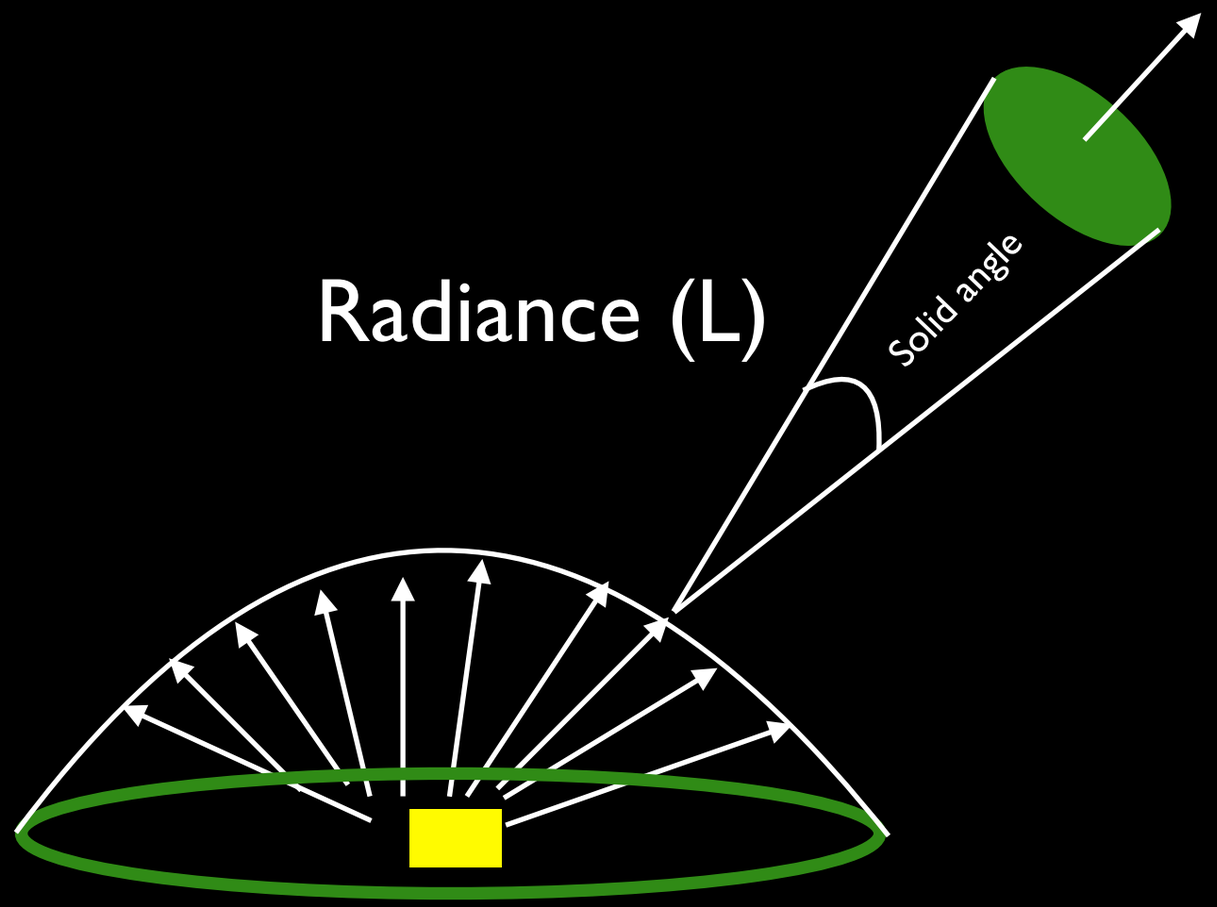


α = exitance/irradiance = M/E

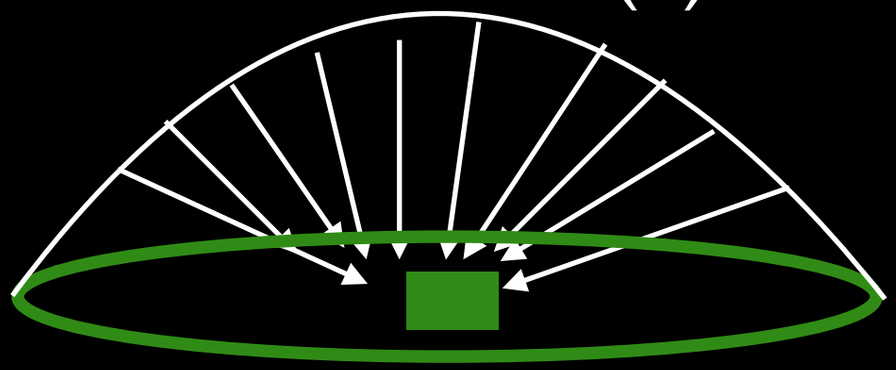
Reflectance in remote sensing (ρλ)



Radiance (L)

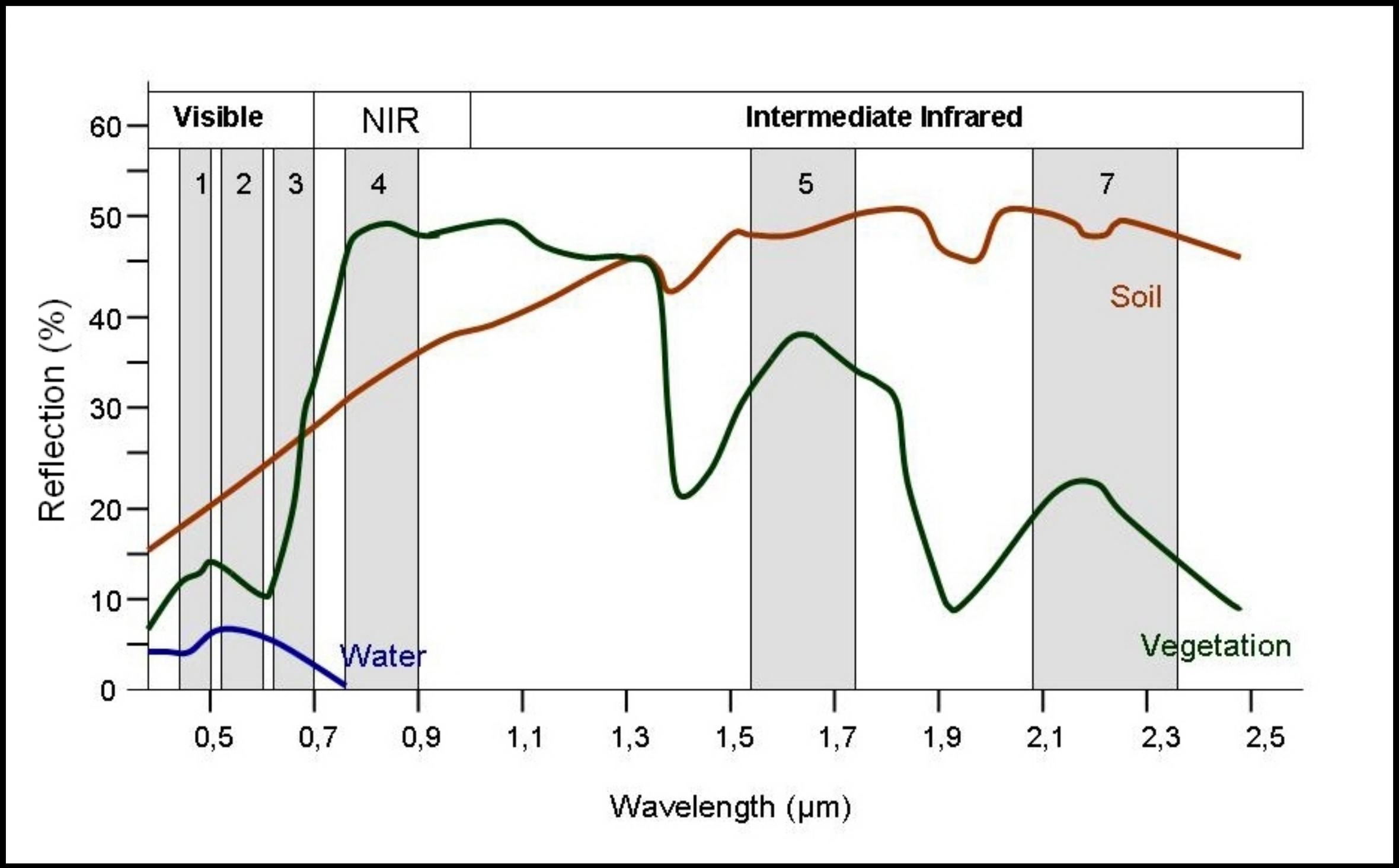


Irradiance (E)

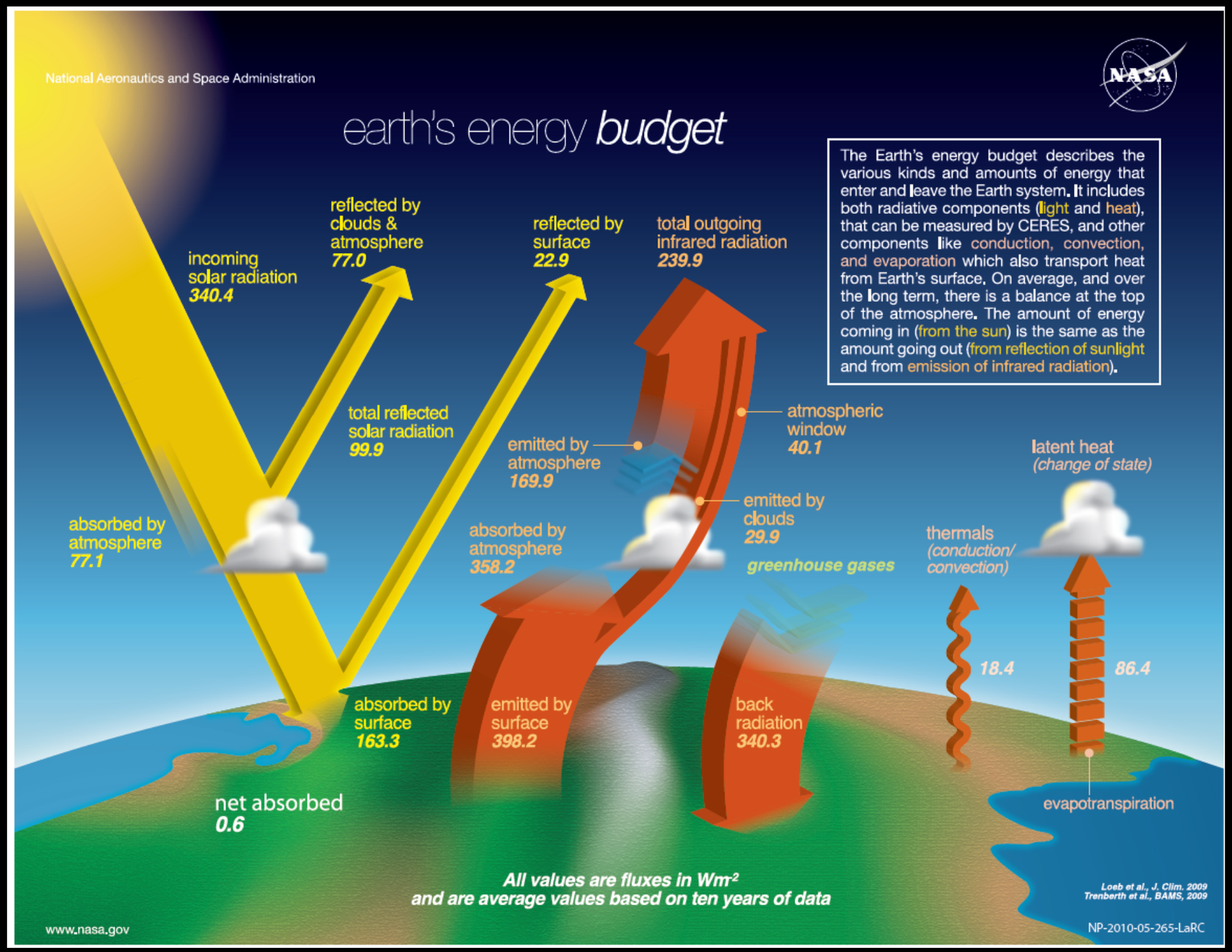


$$\rho_\lambda = \pi L / E$$

Reflectance of typical objects



Earth's energy balance



https://www.youtube.com/watch?v=O0B8Yi7AZvQ

Recap

- Wavelength, frequency, and energy.
- Regions of EM wave.
- Solid angle. Irradiance. Radiance.
- Data of the Week.
- Laws of EMR.
- Solar radiation. Reflectance. Albedo