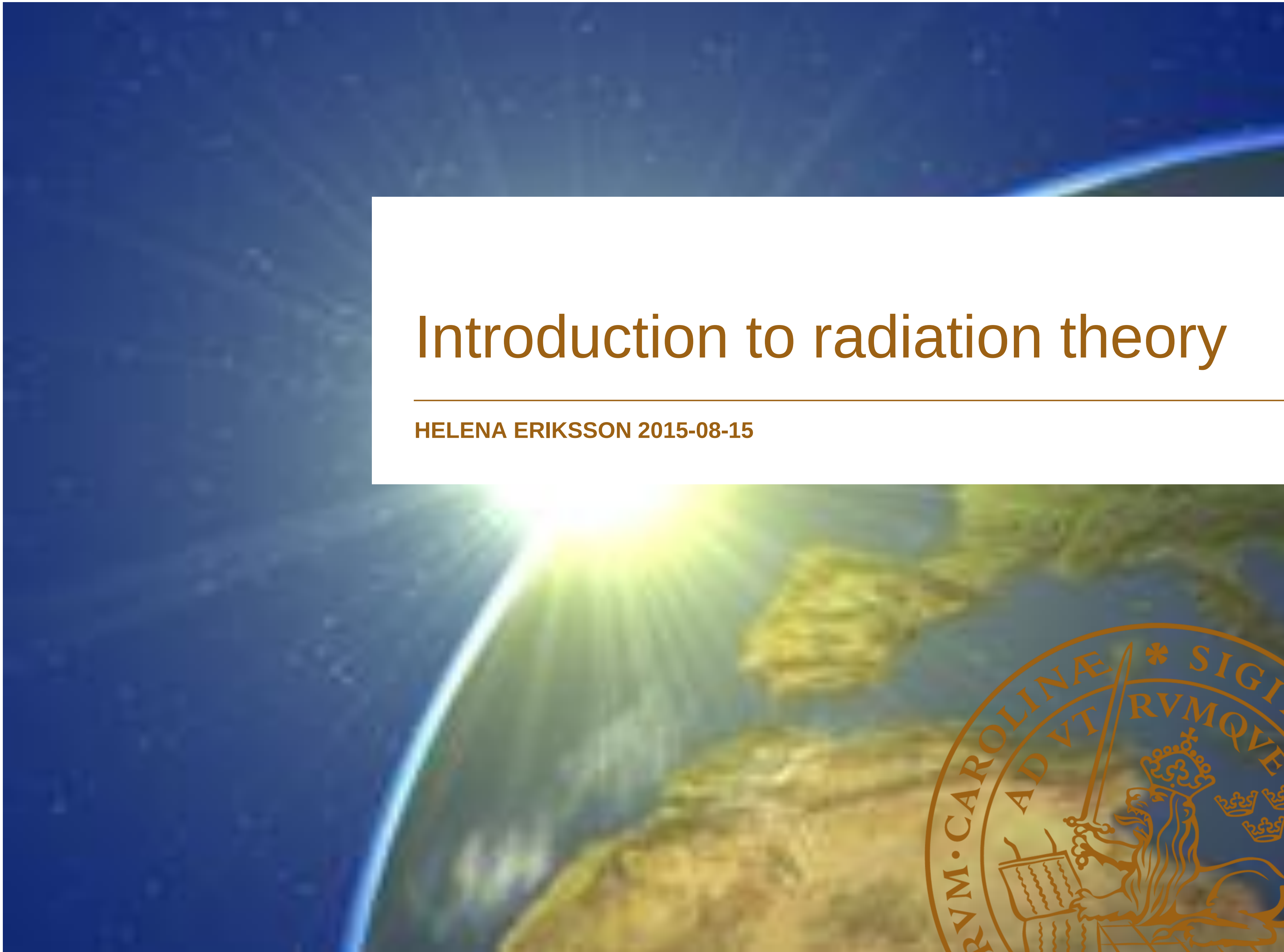
# Introduction to radiation theory

HELENA ERIKSSON 2015-08-15



*Picture freely available from BBC: http://www.bbc.co.uk/*

# Property, symbol and unit

A. Terms/laws/relationships  that are new to me?
B. Terms/laws/relationships I know all about (property, common symbol and unit)
C. Terms/laws/relationships  I know fairly (they are not new to me)

1. Wavelength
2. Frequency
3. Velocity of light
4. Photons
5. Radiance
6. Spectral radians
7. Amplitude
8. Spectral radiant excitance?
9. Irradiance
10. Irradiation
11. Radiant flux
12. Refraction
13. Specular reflection
14. Diffuse reflection
15. Solar constant
16. Radiation
17. Insolation
18. Solar zenit angle
19. Air mass
20. LAI

21. Blackbody/graybody/whitebody

22. How are wavelength, frequency and the velocity of light related?

23. How is photons related to Plancks constant?

24. What does Stefan Boltzmanns law express?

25. What does Wiens displacement law express?

25. What does Kirchoff’s law express?

# Learning outcome on radiation theory

**Knowledge and understanding:**

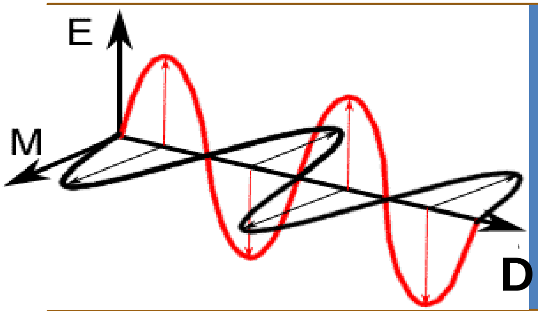
- Any introduced concepts and terminology
- Electromagnetic wave and quanta theory
- Laws of: Stefan Boltzmann, Planck, Kirchoff
- Reflectance signature of common features on earth
- The atmospheric influence on remotely sensed data
- Properties of reflectance direction

**Skills and abilities**

Explain how the energy from the sun travels from source to sensor –including all possible losses and additions from other sources. Where does the energy loss go/additional energy come from?

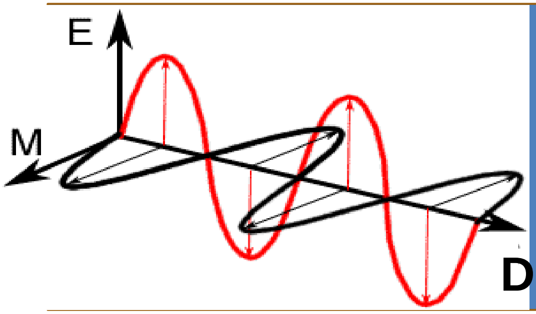
Propose an appropriate wavelength band for a certain application (i.e surface character)

# Radiation energy as an ***Electromagnetic Wave***



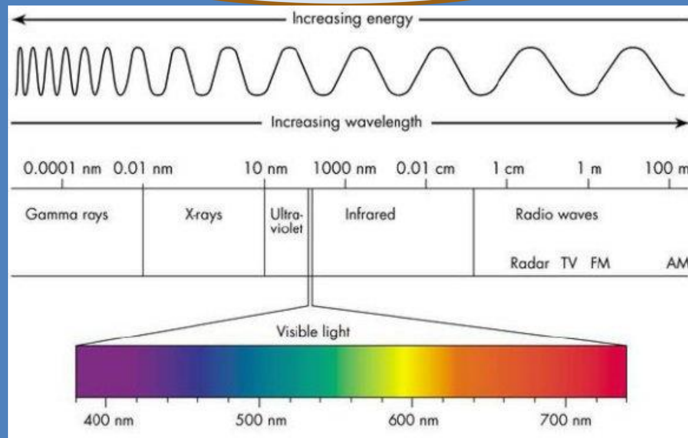

**E = Electric field**
**M = Magnetic field**
**D = Distance**

# Radiation energy as an ***Electromagnetic Wave***

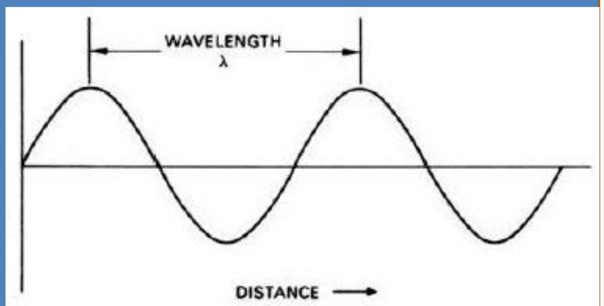


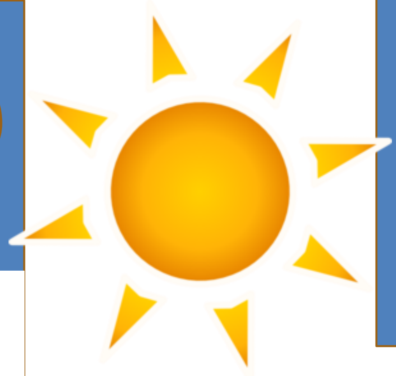

**E = Electric field**
**M = Magnetic field**
**D = Distance**

**Frequency**
= number of wavelengths per second, 1 Hertz (Hz) = 1 wavelength per sec.




**1 wavelength**
= distance between two peaks in the wave

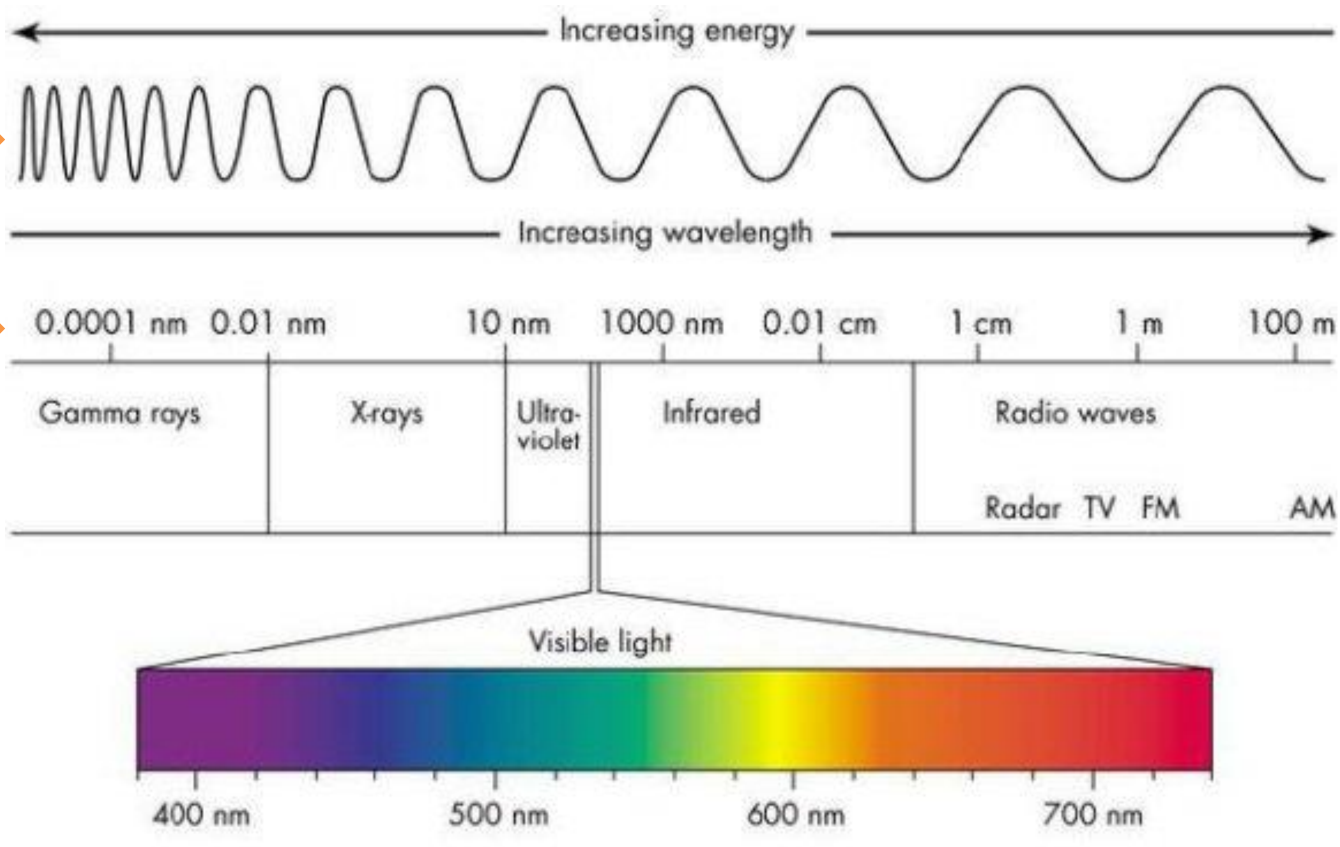


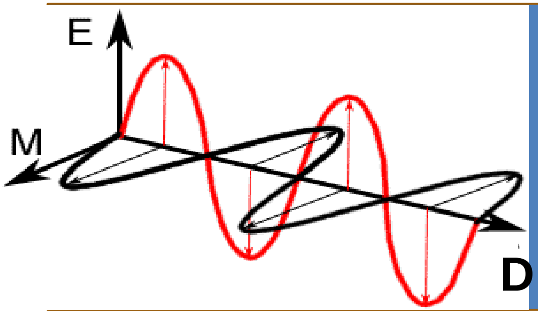
# Energy, wavelengths and frequency

**frequency**

**wavelengths**

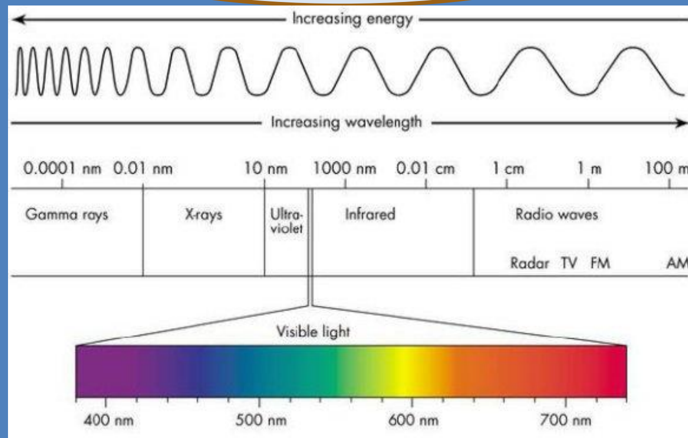


# Radiation energy as an ***Electromagnetic Wave***

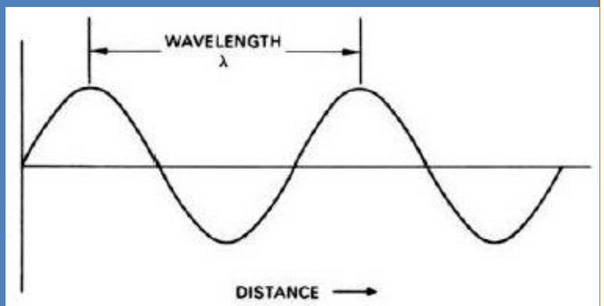


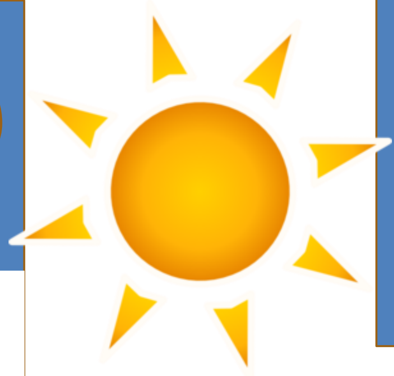

**E = Electric field**
**M = Magnetic field**
**D = Distance**

**Frequency, v**
= number of wavelengths per second, unit = Hertz (Hz)




**1 wavelength, λ**
= distance between two peaks in the wave



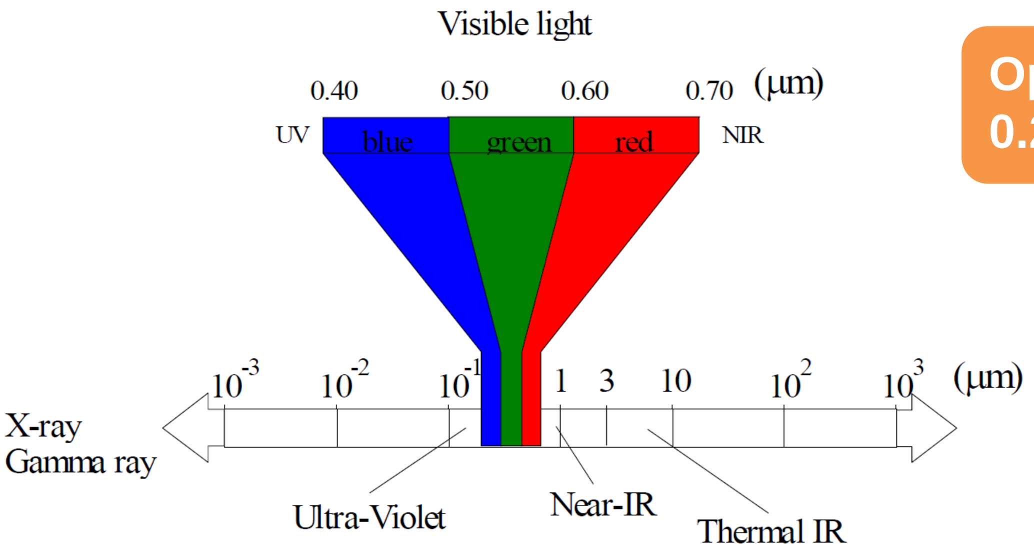



**Speed of light (c) = 3 * $10^8$ m/s**

$$c = v\lambda$$

**→ Wavelengh and frequency are related**

# Wavelength regions

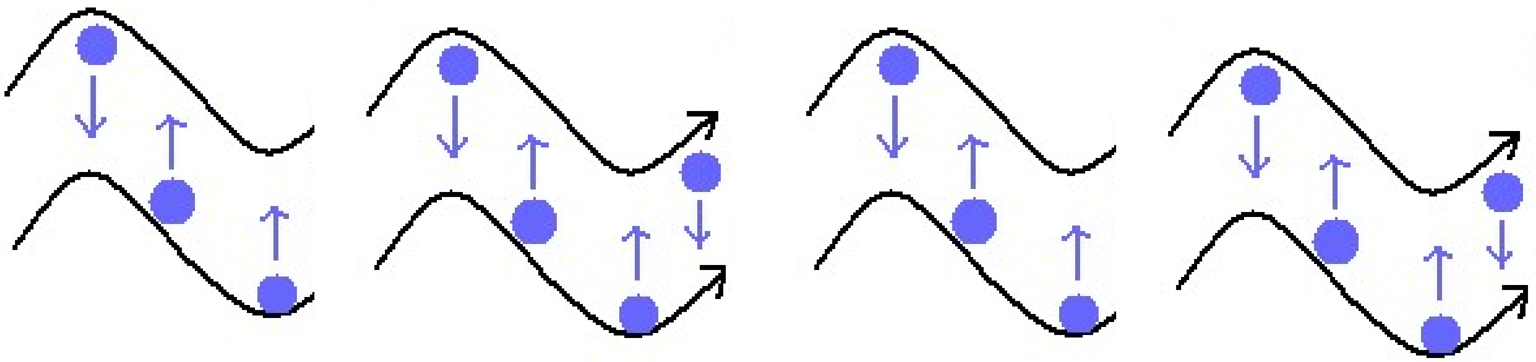



**Optical region: 0.2 µm – 15µm**

| | |
|---|---|
| UV | 0.01 µm – 0.4 µm |
| Visible | 0.4 µm – 0.7 µm |
| Reflected IR | 0.7 µm – 3.0 µm |
| Near IR (NIR) | 0.7 µm – 1.3 µm |
| Middle IR (MIR) | 1.3 µm – 3.0 µm |
| Thermal IR | 3.0 µm – 15 µm |
| Far IR (FIR) | 15 µm – 1000 µm |

# Radiation energy as ***particles - photons***

= the particle properties of an electromagnetic wave (instead of the overall wave itself)



**Energy (Q) of one photon is proportional to frequency:**

$$Q = hv$$

**Q= Energy in Joule (J)**
**h= Plancks constant (6.626 * $10^{-34}$ J/s)**
**v = frequency (Hz)**

# Radiation theory

Electromagnetic wave theory:

$c = v\lambda \rightarrow v = \frac{c}{\lambda}$

+

Particle quanta theory:

Q= $hv$

= $v$ **gives** $\frac{c}{\lambda}$

Combination

Q= $\frac{hc}{\lambda}$

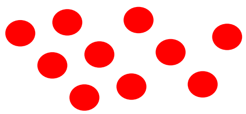
| | | |
|---|---|---|
| λ = wavelength (m) | C = speed of light (3 * $10^8$ m/s) | v = frequency (Hz) |
| Q= Energy in Joule (J) | h= Plancks constant (6.626 * $10^{-34}$ J/s) | |

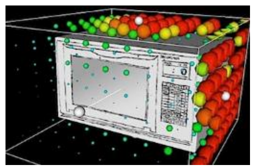
→ The longer the wavelength, the lower the energy

Ex: Energy of

1 uv photon = 10 red photons = 1000000 microwave photons







# Quiz 1

# Quiz

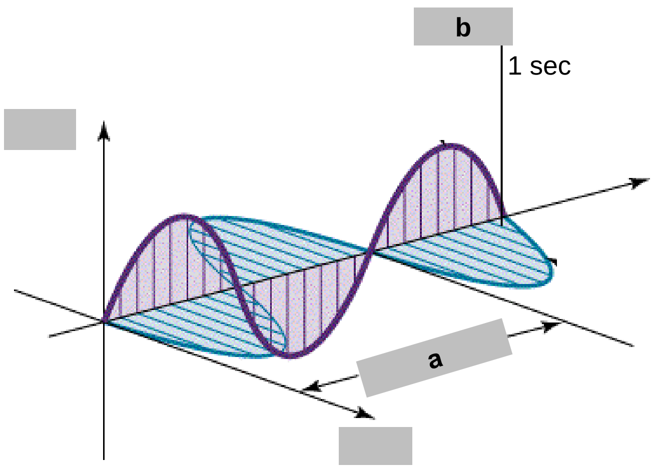
1. What is the wavelength if the frequency is 450 kHz?

2. Present the approximate wavelength ranges for:

- UV
- Blue
- Green
- Red
- Near infrared
- Mid infrared
- Thermal infrared

3. What is the frequency of blue light?

4. This figure illustrates the magnetic field. Insert properties of the axes and present property, symbol and unit of a and b.



# Quiz solutions

1. What is the wavelength if the frequency is 450 kHz?

   $c = v\lambda$ → λ= c/ $v$ →λ= 3 * 10$^{8}$ /(450 * 1000) = 667 m

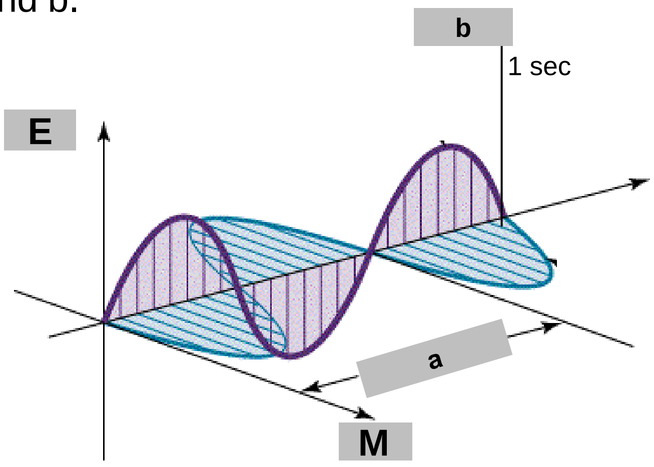
2. Present the approximante wavelength ranges for:

- UV = (0.01 – 0.4) µm
- Blue (0.4 – 0.5) µm
- Green (0.5 – 0.6) µm
- Red (0.6-0.7) µm

- Near infrared = (0.7-1.3) µm
- Mid infrared =(1.3 – 3) µm
- Thermal infrared = (3 – 15) µm

3. What is the frequency of blue light? $c = v\lambda$ → $v$ = c/ λ → $v$ = 3 * 10$^{8}$ /(0.45*10$^{-6}$) = 6.67*10$^{14}$ Hz

4. This figure illustrates the magnetic field. Insert properties of the axes and present property, symbol and unit of a and b.




E = electric field
M = magnetic field
a = wavelength (1 wavelength)
b = frequency 1.5 Hz

# Radiation as: flux, irradiance and exitance

***Flux, Φ = rate of the flow of radiant energy. Energy per second***

$$\Phi = \frac{Q}{t}$$

**Unit = J/s or W (watts)**

Remember:

$$Q = \frac{hc}{\lambda}$$

**→ The shorter the wavlength, the higher the flux**

***Irradiance, E = flux per unit area <u>striking a surface</u>, or the rate of the flow of radiant energy that <u>strykes a surface:</u>***

$$E = \frac{\Phi}{A}$$

**Unit = W/m²**

**Irradiation**
**→ Unit = J/m²**
**1 W = 1 J/s**

***Exitance, M = flux per unit area leaving a surface, or the rate of the flow of radiant energy that leaves a surface***

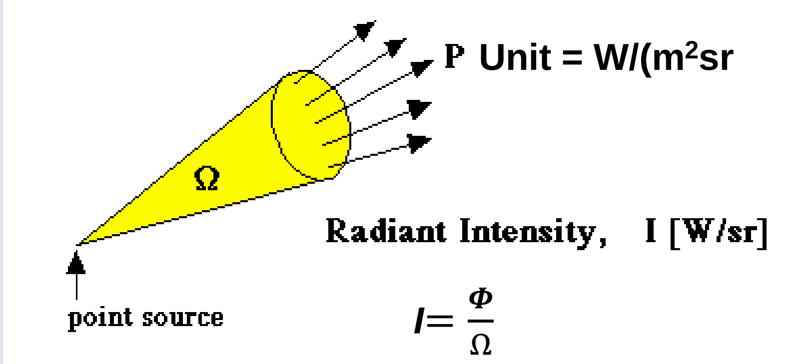
$$M = \frac{\Phi}{A}$$

**Unit = W/m²**

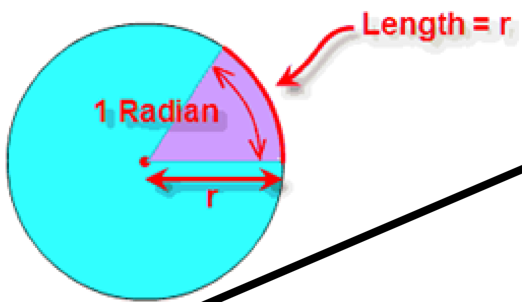
# Intensity and radiance…

**Intensity, I**
= flux per unit solid angle

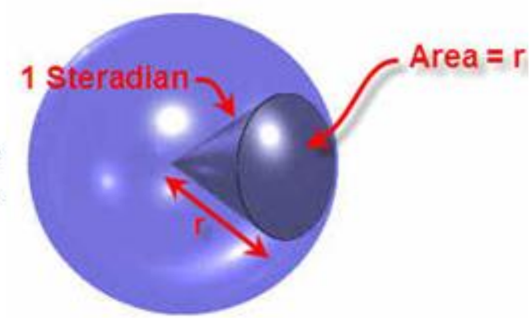
Amount of flux from a point source contained in a small angular volume.
The intensity can vary due to direction
Sr = steradians (unit of the solid angle)
”Solid” = 3d




A **Radian** "cuts out" a length of a circle's circumference equal to the radius.



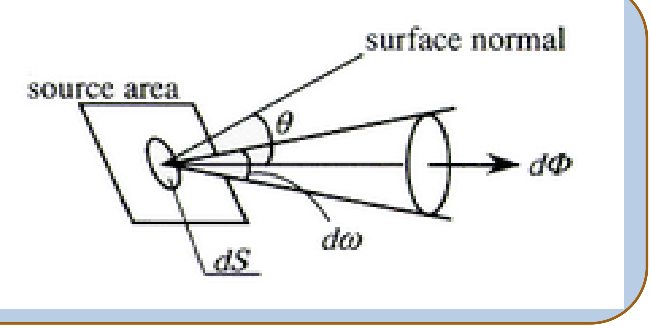

A **Steradian** "cuts out" an area of a sphere equal to (radius)$^2$.



# Intensity and radiance…

***Radiance, L***
= Intensity from a surface in a certain direction compared to what it would be in vertical direction (amount of flux per solid angle***from a unit projected area per unit solid angle***

**Unit = W/(m²sr)**




= irradiance from a cone of directions

= radiant flux per solid angle per projected area

= number of photons per time that arrive at a small area from a certain direction

# The spectral dimension…

Spectral flux
Spectral irradiance
Spectral intensity
Spectral radiance

= amount or radiation per unit wavelength interval

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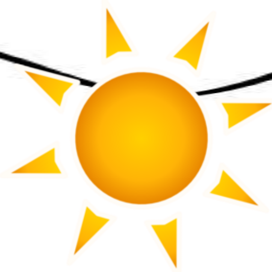

Which objects emits energy except the sun and other stars?

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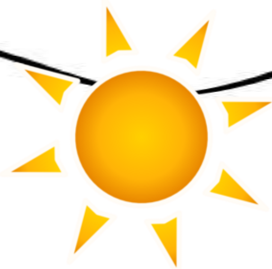

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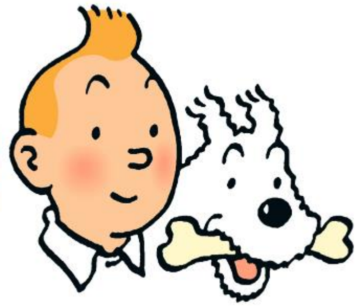

**We all do!**

*-all objects where T > 0 K ( 0 K = -273º C)*

**How much and in which wavelengths then?**

# The spectral dimension…

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Spectral irradiance
Spectral intensity
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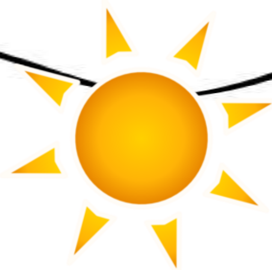
= amount or radiation per unit wavelength interval



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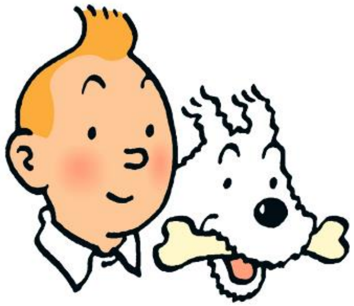
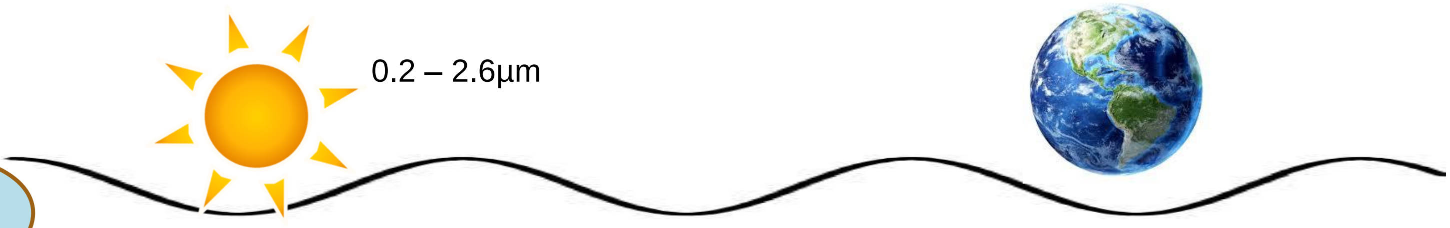


**How much and in which wavelengths then?**

***-Depends on who we are...***

# The black body and Stefan Boltzmann's law

Black body= a ”body” or object that totally absorbs and reemits all energy




How much energy?

In which wavelengths?

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# The black body and Stefan Boltzmanns law

Black body= a ”body” or object that totally absorbs and reemits all energy

How much energy is emitted?

**Stefan Boltzmann law**

= applicable for black bodies

$$M = \sigma T^{4}$$

**Energy increases rapidly with temperature**

M = total radiant exitance from the surface (W/m$^2$)
σ = Stefan Boltzanns constant (5.6697*10-8 W/(m2K-4)
T= absolute temperature (K)

In which wavelengths?

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In which wavelengths?

**Wien’s displacement law**

Wavelength at which a blackbody radiation curve reaches its maximum

$$\lambda_m = \frac{A}{T}$$

$\lambda_m$= wavelength of max. Spectral exitance (µm)

A = 2898 µm K

*Wiens displacement constant*

T = Abs. temperature (K)

# Emissivity and Kirchof’s law

Blackbody exist in theory/within certain wavelength regions.
Objects can not absorb and re-emit all energy from all wavelengths.

***Exitance = rate of flow of radiant energy leaving a surface***

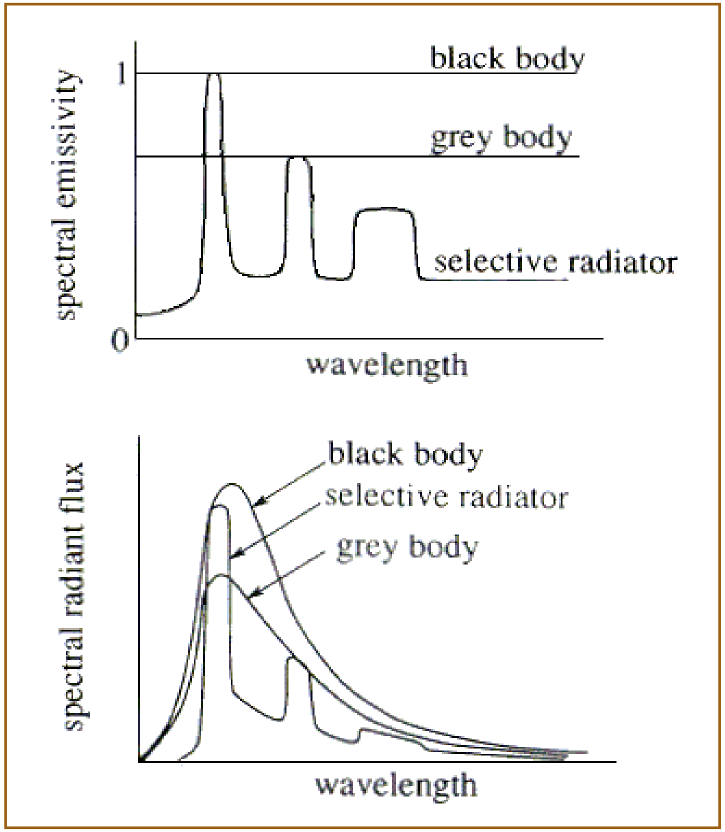
**Emissivity** = capability to emit radiation

**Kirchof’s law**

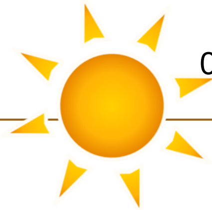
exitance of an object at a given temperature / exitance of a blackbody at the same temperature

$$\varepsilon(\lambda) = \frac{M_{\lambda(\text{material, K})}}{M_{\lambda(\text{blackbody, K})}}$$

**Blackbody** → ε = 1



# Emissivity and Kirchof's law

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Objects can not absorb and re-emit all energy from all wavelengths.

**Emissivity** = capability to emit radiation

**Kirchof's law**

exitance of an object at a given temperature / exitance of a blackbody at the same temperature

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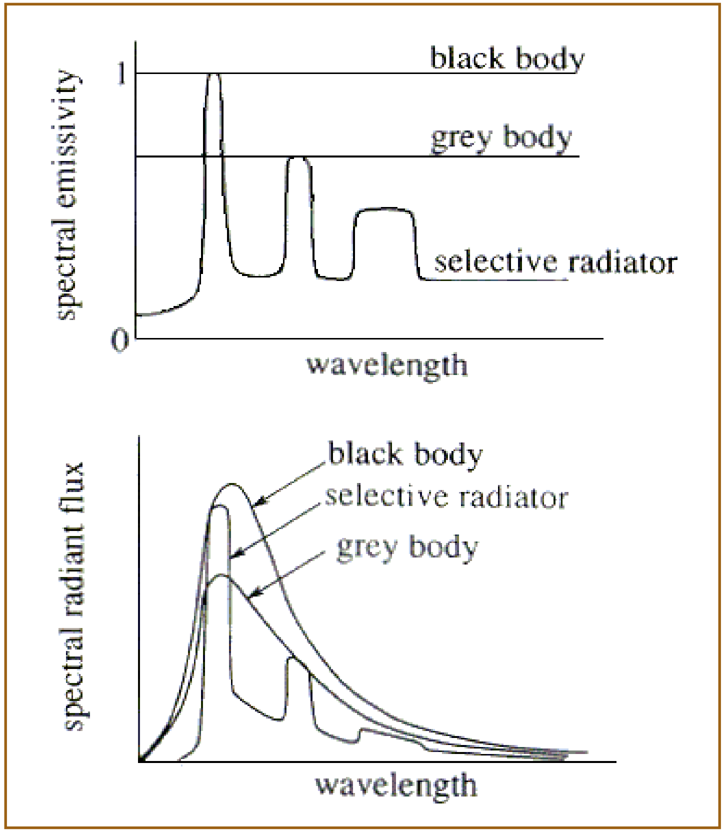



**Blackbody** → ε = 1

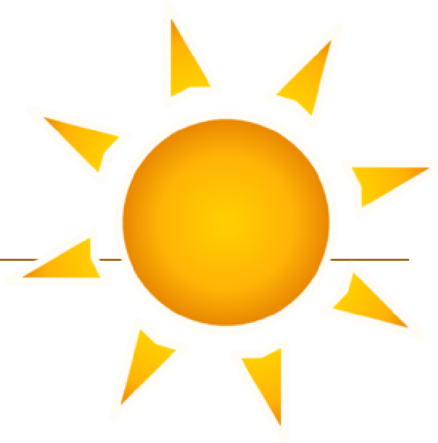
**Graybody** → ε < 1 (constant over all wavelengths)

**Selective radiator** = ε < 1 (varies with wavelength)

**Whitebody** = ε = 0

# Quiz 2

# Quiz 2



1. At which wavelength does the sun emit most of its energy?

2. At which wavelength does the earth emit most of its energy?

3. Most stars are white, but some stars look more blue, while others are more red. Try to explain a possible reason for this, based on your knowledge in radiation theory.

4. The earths temperature is considered to be constant in time (on a yearly basis and disregarding the global warming). It is in *radiative equilibrium*

   a. The earth emits 240 Watts/m2. What should be its equilibrium temperature?

   b. The actual equilibrium temperature is 288 K. Is this the answer that you got? If not, why not?

# Solutions 1 + 2

→ Wien's disp. Law:

$$\lambda_m = \frac{A}{T}$$

**Sun:**
T = (273+5430) = 5700K
λmax = 2898/5700
→ λmax = 0.5 µm

**Earth:**
T = (14 + 273) = 287 K
λmax = 2898/287
→ λmax = 10 µm

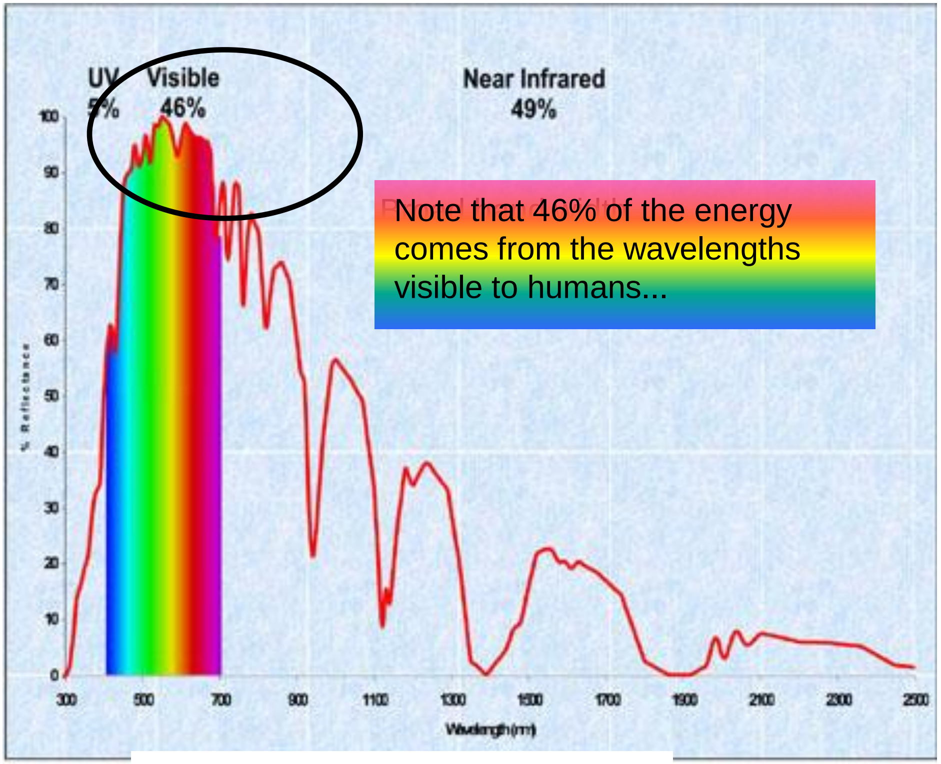
**Questions:**
At what wavelength does the sun emit most of its energy? λmax(sun) = 0.55 µm

At what wavelength does the earth emit most of its energy? λ max(earth) = 10 µm

# Solution to question 3

3. Most stars seem white, but some stars look more blue, while others are more red. Try to explain a possible reason for this, based on your knowledge in radiation theory.

The key is surface temperature of the star.




Typical spectrum of solar radiation

Max energy comes from wavelength of 0.5 µm. This is in the middle of the visible spectrum

A blue colored star has a higher surface temperature, with a maximum wavelength within the uv wavelength region.

$\lambda max = 0.3$ µm
T = 2898/0.3
T = 9660 K (9660-273= 9387$^{o}$ C.)

A red colored star has a lower surface temperature, with a maximum wavelength within the red wavelength region.

$\lambda max = 1.0$ µm
T = 2898/1.0
T = 2898 K (2898-273= 4187$^{o}$ C.)

# Solution to question 4a

The earths temperature is considered to be constant in time (on a yearly basis and disregarding the global warming). It is in *radiative equilibrium*

**a.** The earth emits 240 Watts/m2. What should be its equilibrium temperature in $^o$ C. ?

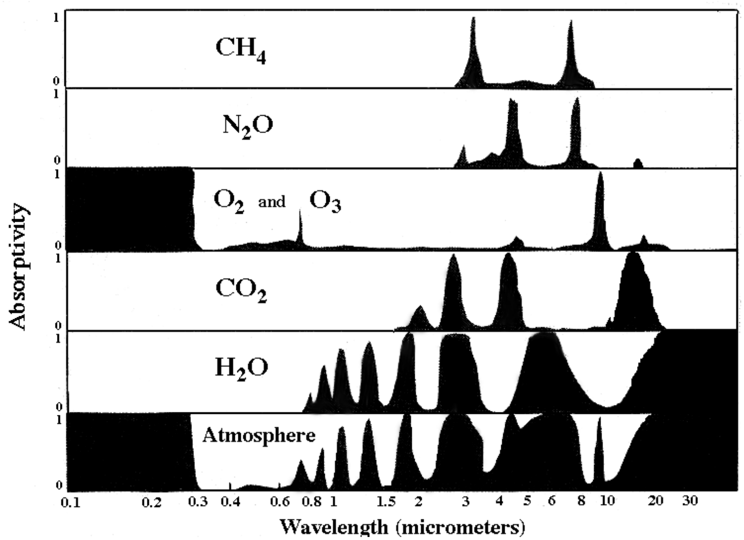
*Anser: Use Stefan Boltzmann's law*

$M = \sigma T^4$ Rearremgement → T = (M/ $\sigma)^{1/4}$
→ T = 255 K = (255 – 273 )$^o$C. = **-18$^o$ C**.

**b.** Does this correspond to the actual equilibrium temperature or the earth? Why not?
No! We know from former question that surface equilibrium temperature of earth = 14 $^o$C.
Why this difference?

# Solution qu. 4b (earth equilibrium temp.)

...The atmosphere! The atmosphere mainly consists of the following gases:




Methane

Nitrous Oxide

Oxygen + Ozone

Carbon dioxide

Water Vapor

- Most energy from sun comes from visible part (λmax = 0.5 µm) → most of this energy also reaches the earth surface
- Most emitted energy from earth are within longer wavelengths (lmax = 10)
- Atm. Gases absorbes energy within longer wavelengths. Some energy is re-emitted back to the ground
- Additional long-wave radiation further warms the earth.

The ”greenhouse” effect

# Energy interaction with surface

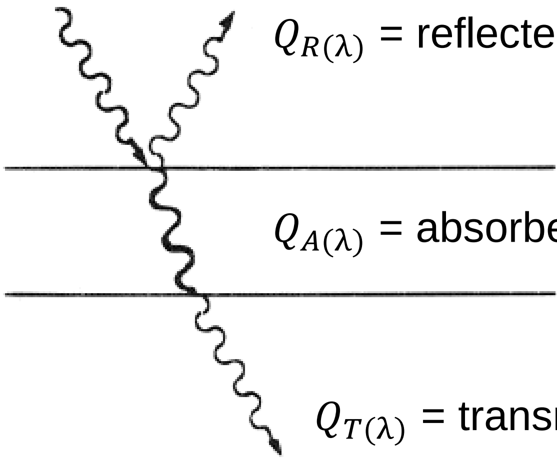
Energy that is not absorbed, will be either reflected or transmitted

Principle of conservation of energy:

$$Q_{I(\lambda)} = Q_{R(\lambda)} + Q_{A(\lambda)} + Q_{T(\lambda)}$$

Often presented as radiance ( Unit = W/m$^2$ )

$Q_{I(\lambda)}$ = incident energy



$Q_{R(\lambda)}$ = reflected energy

$Q_{A(\lambda)}$ = absorbed energy

$Q_{T(\lambda)}$ = transmitted energy

# Reflectance and spectral reflectance

Rearrange principle of energy conservation:

$$Q_{I(\lambda)} = Q_{R(\lambda)} + Q_{A(\lambda)} + Q_{T(\lambda)}$$

→ ***Reflected energy***

$$Q_{R(\lambda)} = Q_{I(\lambda)} - (Q_{A(\lambda)} + Q_{T(\lambda)})$$

***Spectral reflectance***, $\rho_{(\lambda)}$
= the portion of incident energy that is reflected, unit *100 = %

$$\rho_{(\lambda)} = \frac{Q_{R(\lambda)}}{Q_{(I)}}$$

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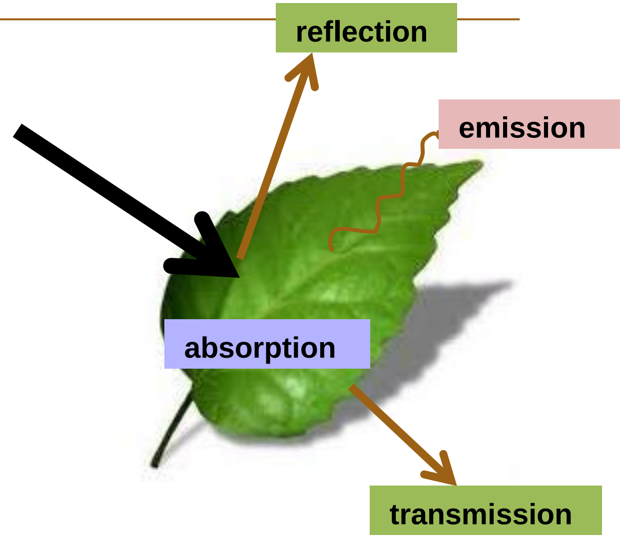
# Energy budget

**Energy ( Joule) /irradiance/radiance etc = rate (Unit = W/m$^2$ )**

Scattered energy

- Incident Radiation = Inc. Electromagnetic energy $Q_I$
- Absorption = interception of radiant energy, $Q_A$
- Reflection = backscattering radiant energy, $Q_R$
- Transmission = forwardscattering radiant energy, $Q_T$




Visible, near infrared radiation:
$Q_A + Q_R + Q_T = Q_I$

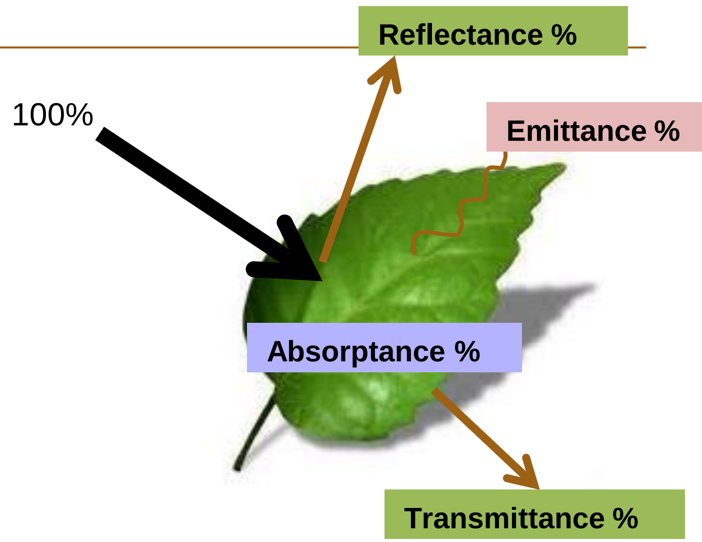
**Ratios: ratio of the radiant energy.**

Absorptance = Absorptivity, α
Reflectance = Reflectivity, ρ
Transmittance= Transmittivity, τ
Emissitance = Emissivity, ε

%

Visible, near-infrared radiation:
$\alpha + \tau + \rho = 1$

Thermal infrared radiation:
$\varepsilon + \tau + \rho = 1$



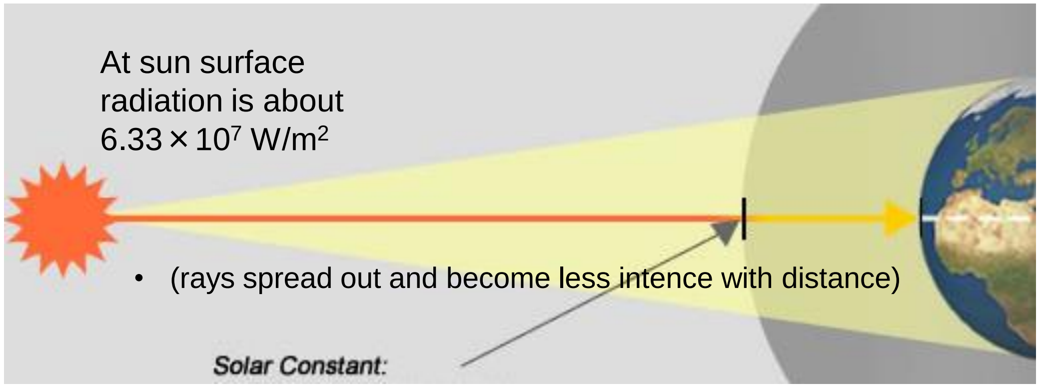
# Reflect*ance* properties

Reflectance (portion if incident energy that is reflected) depends on... incident radiation...

**1. Incident radiation**

...which depends on...

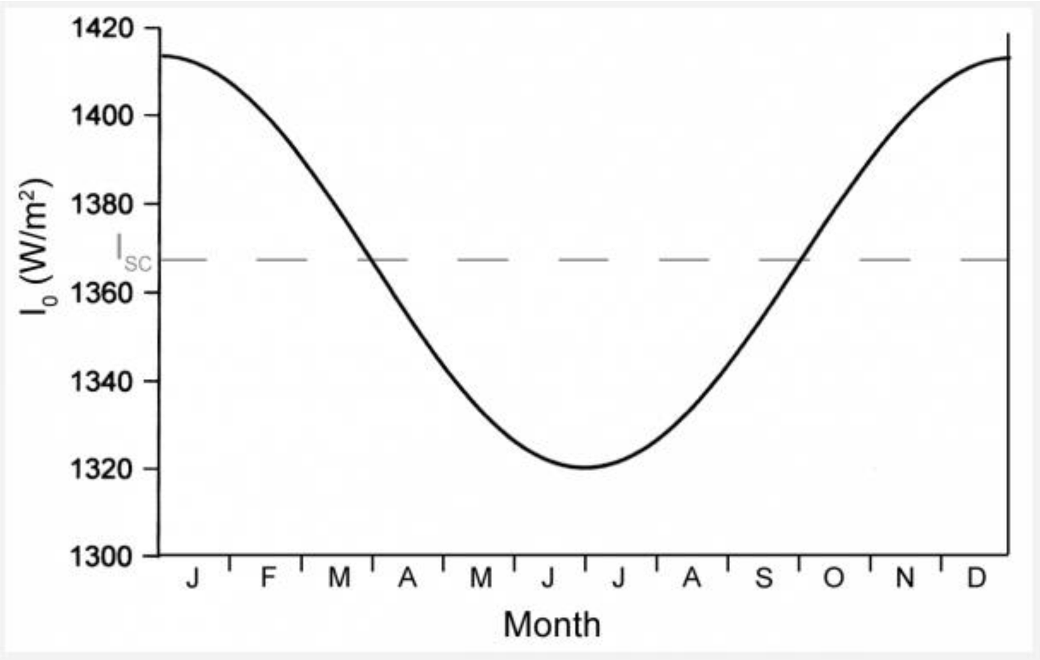
**sun surface radiation** + **distance sun-earth**



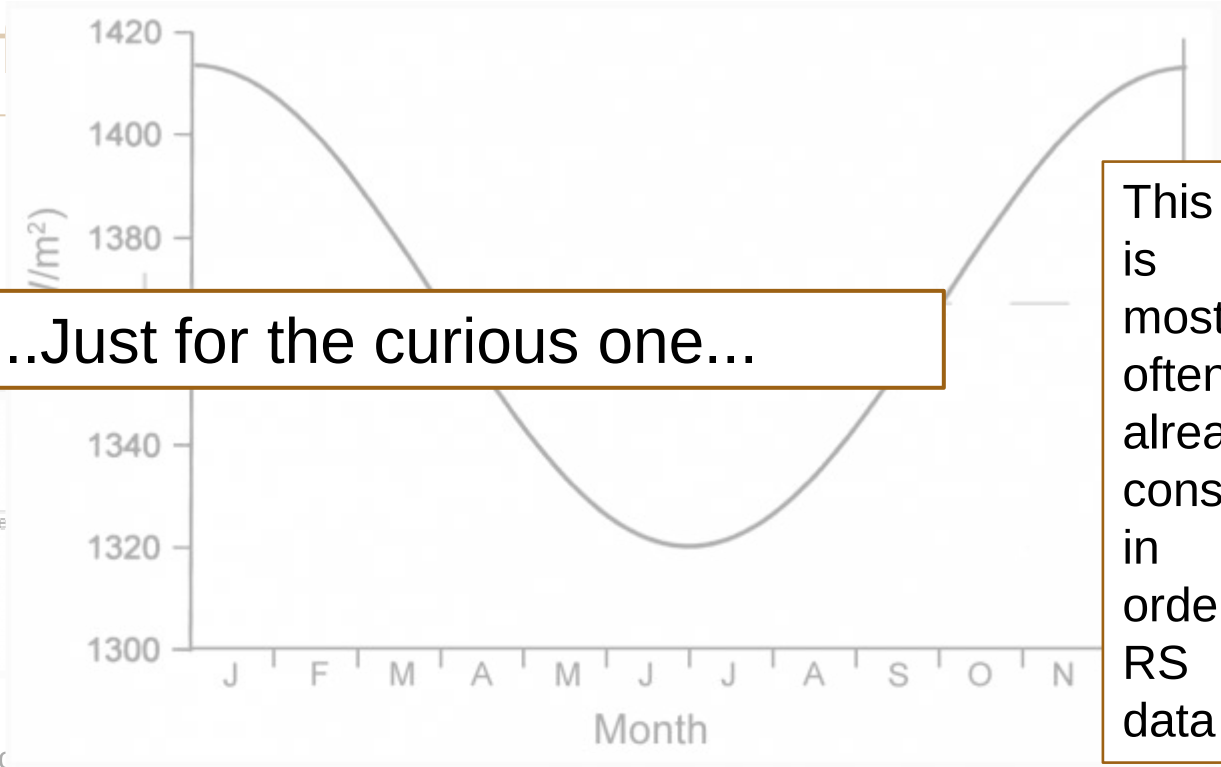

The *solar constant* = average radiation on a surface perpendicular to the Sun's rays at the top of the Earth's atmosphere

Solar constant = 1367 Watt/m$^2$

# Variations due to sun-earth distance




The variation in solar irradiation changes about 7% between January (shortest distance between sun-earth) and July (longest distance between sun and earth).




...Just for the curious one...

This is most often already considered in ordered RS data

$$I_0 = I_{SC}\left[1 + 0.034\cos\left(2\pi\,\frac{n}{265.25}\right)\right]$$

Where:

$I_0$ = extraterrestrial (outside the atmosphere) irradiance on a plane perpendicular to the Sun's rays ($W/m^2$),

$I_{SC}$ = the solar constant (1367 $W/m^2$),

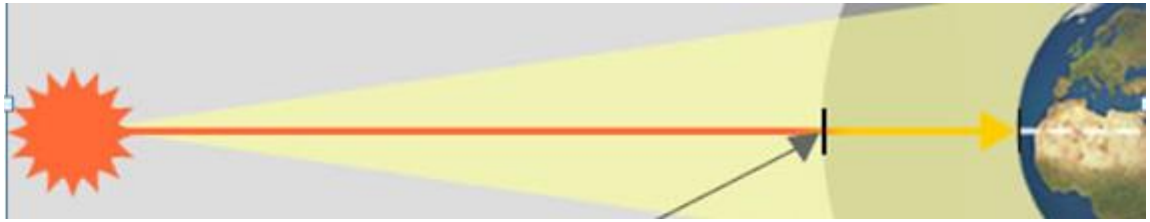
n = the day of the year such that for January the 1st n = 1.

# Reflect***ance*** properties

Reflectance (portion if incident energy that is reflected) depends on... incident radiation...

1. Incident radiation
2. **The angle of the incident radiation**

Solar constant assumes parallell rays to the plan atmospheric surface



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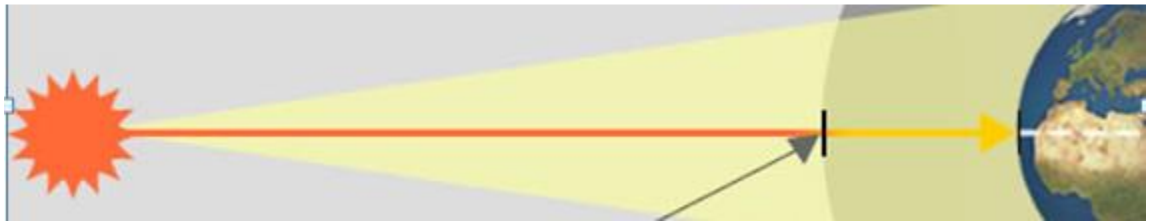
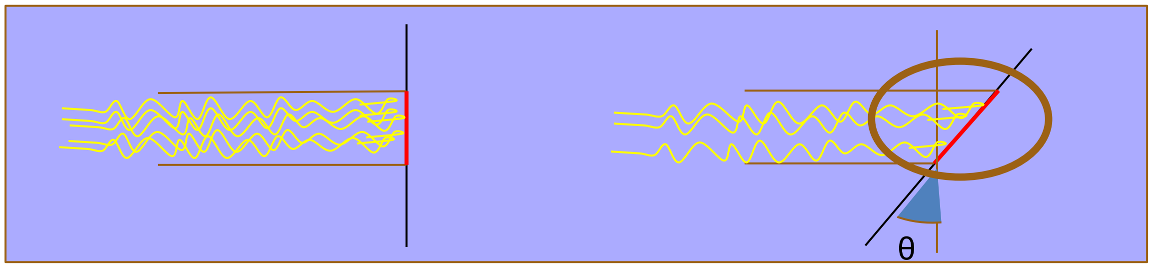


If the surface plane is not parallell, same energy will fall on a larger area
→ less radiation per $m^2$

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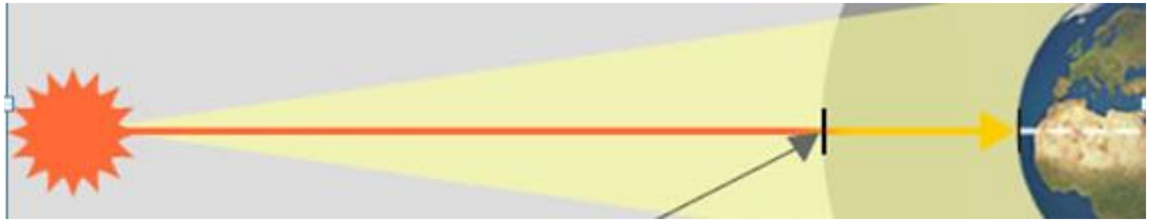


If the surface plane is not parallell, same energy will fall on a larger area
→ less radiation per $m^2$


**Notice the difference**


**Cosine law =**
**the more tilted surface (greater angle), the greater the area**

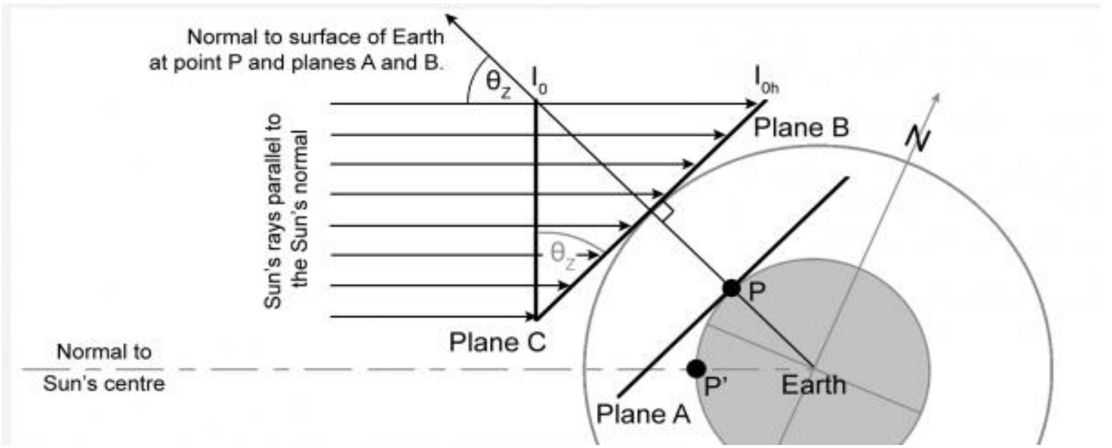
# The cosine effect

$I_{TOA}$ = solar irradiation on a plane parallel to ground (on the top of the atmosphere)

$I_{TOA} = I_o \cos \theta_z$

$I_o$ = solar irradiation on a plane perpendicular to the rays
$\theta_z$ = angle from a plane perpendicular to the to the rays. Note! unit needs to be in radians (1 deg. = pi()/180 rad.)

*Plane A*: horizontal at point P on Earth's surface;
*Plane B*: horizontal to plane A, but on top of the atmosphere (horizontal plane)
*Plane C*, perpendicular to the Sun's rays (normal plane)



# Irradiance at the top of the atmosphere

How much will the irradiance vary due to the cosine effect?

$I_{TOA}$ = solar irradiation on a plane parallel to ground (on the top of the atmosphere)

$I_{TOA} = I_o \cos\theta_z$ Unit needs to be in radians

$I_o$ = solar irradiation on a plane perpendicular to the rays ~1370 W/m2
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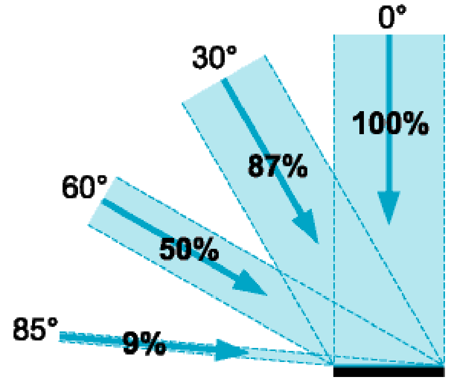
Let's use the obove equation on some angles...

**→ The larger the zenit angle, the less is the energi on the same area**



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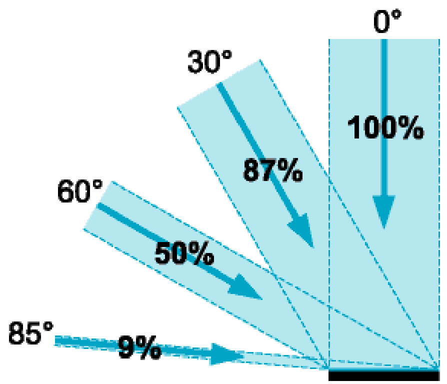

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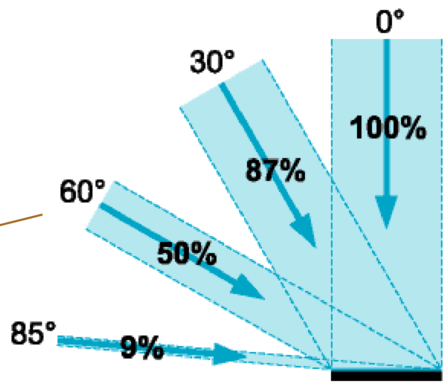
| $\theta_z$ | $I_{TOA}$ W/m2 |
|---|---|
| 0 | 1370 |
| 10 | 1349 |
| 30 | 1186 |
| 60 | 685 |
| 90 | 0 |

sunset



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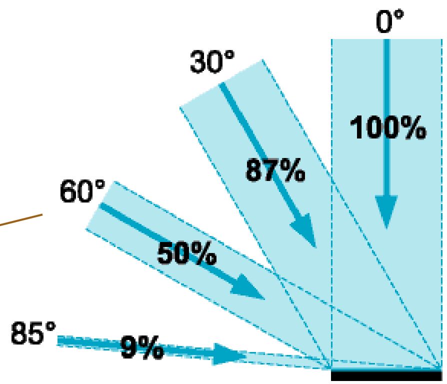
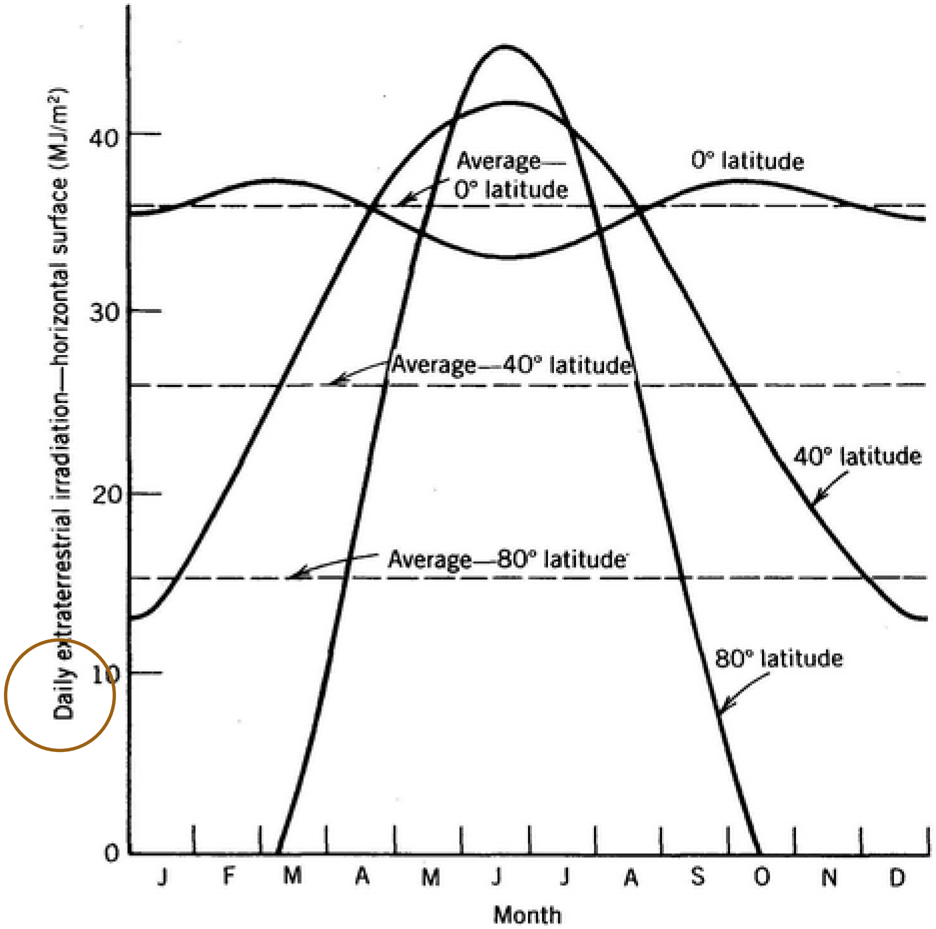



Sun is not always at zenit, this equation is theoretical –and too simple

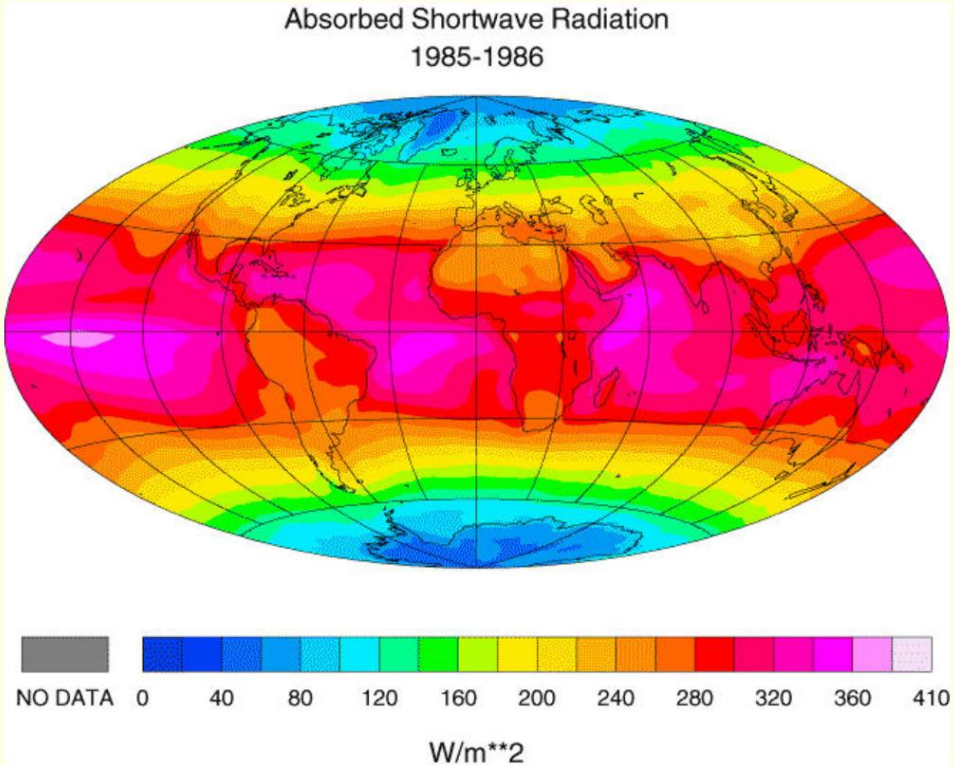
# Solar radiation TOA - all angles account for




Spring and fall: sun in zenit at the equator

Daytime hours accounted for

# Estimates of absorbed incident radiation

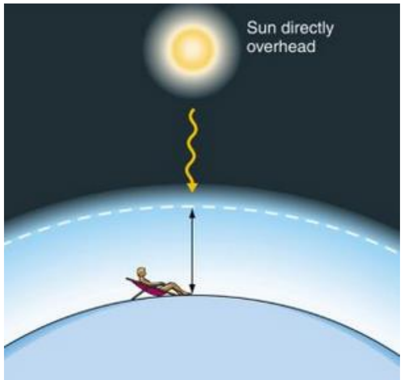


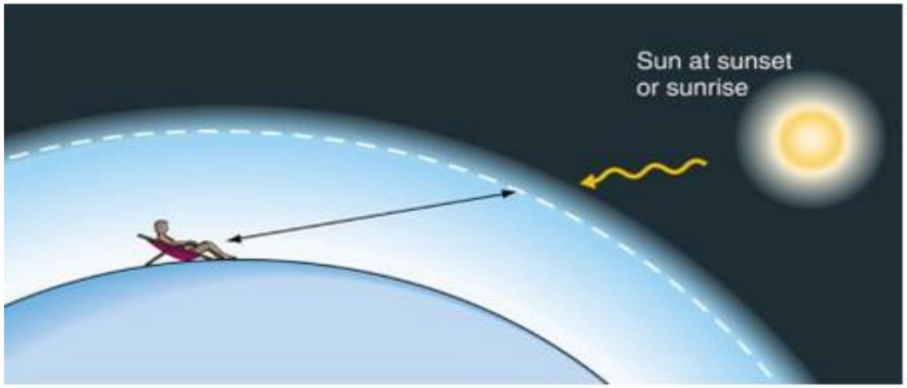

Global distributions of the annual-mean absorbed shortwave radiation at the top of the atmosphere (ERBE data).

# Reflect*ance* properties

Reflectance (portion if incident energy that is reflected) depends on...

1. Incident radiation
2. The angle of the incident radiation
3. **The atmospheric depth (thickness of the atmosphere)**



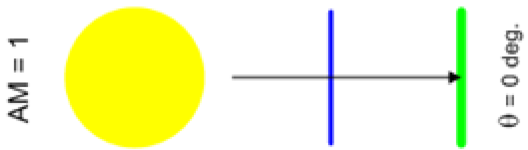

**Air mass**
= the ratio of the distance that solar radiation travels through the earth's atmosphere (path length), to the distance (path length) it would have traveled if the sun had been directly overhead.

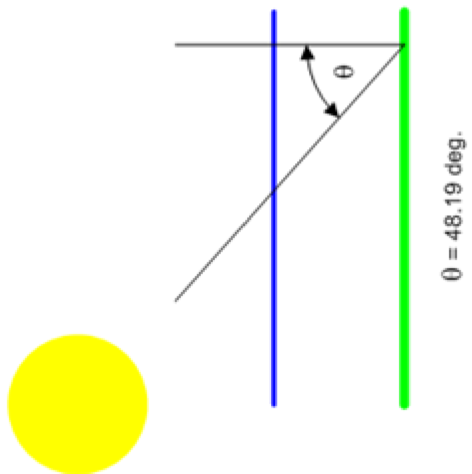
# Air mass computation

= simplified function (cosine law again...)
→approximate values holds well up to zenit angles of  80º

$$AM = \frac{1}{\cos(\theta)}$$

When sun is in zenit
Sun zenit angle = 0 and cos(θ) = 1
→ Air mass = 1




When sun zenit angle = 48.19
→ Air mass = 1.5

| Zenith Angle (degrees) | Plane Parallel |
|---|---|
| 0 | 1.000 |
| 10 | 1.015 |
| 20 | 1.064 |
| 30 | 1.155 |
| 40 | 1.305 |
| 50 | 1.556 |
| 60 | 2.000 |
| 70 | 2.924 |
| 80 | 5.759 |

Solar zenith angles depend on:

- Latitude
- Date and time of the day
- Solar declination
- Altitude (above sea level)

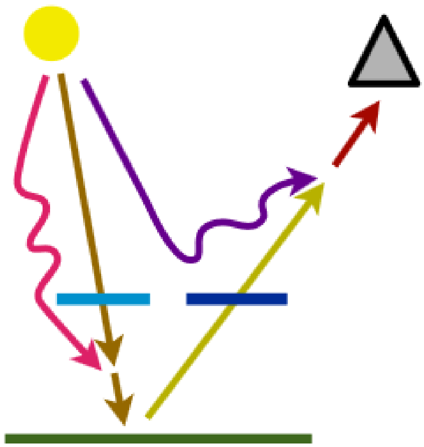
# The effect of the atmosphere

The atmosphere influence the incident radiation in 3 manners:

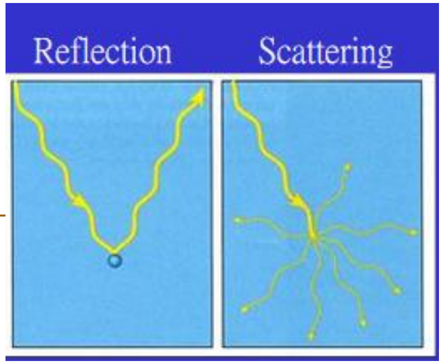
- Scattering/Reflection — Change direction
  - Rayleigh
  - Mie
  - Nonselective/ areosols
- Absorption — Convert energy to heat the atmosphere (goes into earth energy budget
- Transmission — No change on the direction and intensity of radiation

**Indirect radiation**

- Sky irradiance — scattered radiation from atmospheric components that will reach the surface
- Path radiance — scattering radiation not reflected by the surface that will reach the sensor



# Atmospheric reflection/scattering




**Reflection:** energy bounces back to space
= clouds when energy strykes particles of liquid and frozen water. Reflectivity of a cloud = 40 – 90%

**Scattering**: scatters the energy into several directions

**Rayleigh scattering**

**Mie scattering**

**Nonselective scattering**

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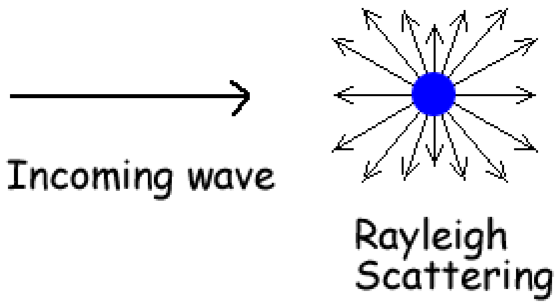
# Rayleigh scattering

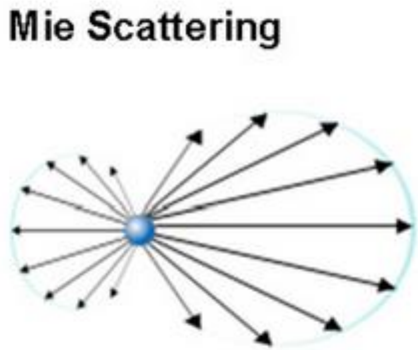
- **Influencing component**: gases with particles that are small relative to the energy wavelengths. Could also be gas molecyles such as N2 or O2.
- **Wavelengths**: shorter wavelengths are scattered most (violet and blue up to 16 times more than red)
- **When?** Always present in the atmosphere → clear sky scattering. Will occur even if we have no pollution.
- **Where?** Dominant at 9-10 km alt. of atmosphere.
- **Effect:** the sky is blue




*Discovered by Rayleigh in the late 1800:ds.*

# Mie scattering = aerosoles

- **Influencing component**: Aerosols – dust, pollen, smoke, water droplets (not in clouds) -Particles are about the same size as the wavelengths.
- **Wavelengths**: Mainly in the VIS + UV + NIR. Non-selective within these wavelengths.
- **When?** When influencing components are present
- **Where?** Greatest in the lower atmosphere (0-5 km), where larger particles are more abundant.
- **Effect:** Produces hazy or grayish skies. Forward scattering in forward direction.



# Nonselective scattering = clouds or white haze

- **Influencing component**: Water droplets in clouds (larger water droplets), and particles with a diameter much larger than the energy wavelengths
- **Wavelengths**: Visible, near infrared + mid-infrared are scattered equally
- **When?** When influencing components (clouds) are present
- **Where?** Lower part of the atmosphere
- **Effect:** Produces white or grayish skies.

# Absorption

= very little in the visible wavelengths

**3 gases are responsible for most absorption:**

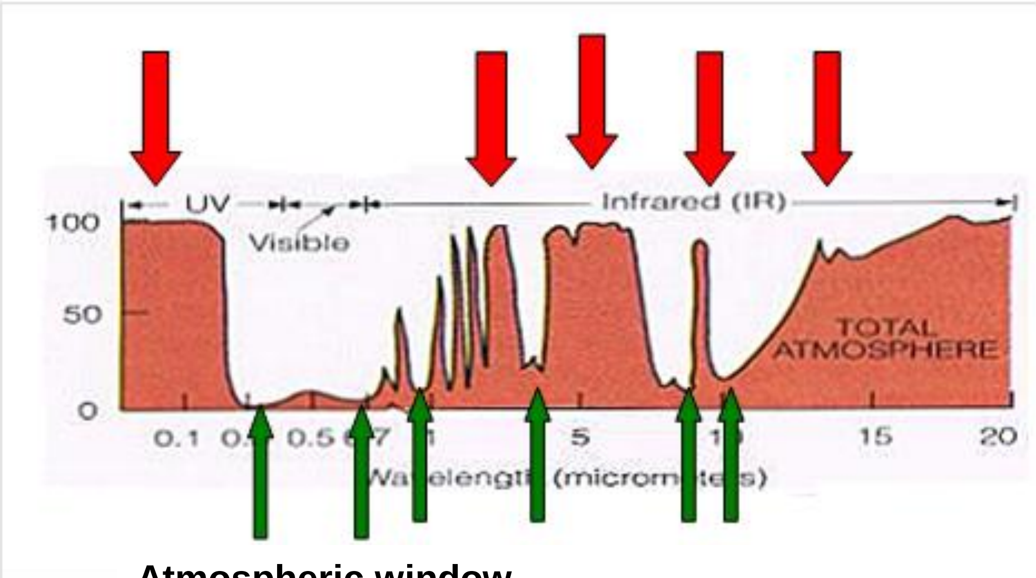
- **Ozone:** (interaction of uv-radiation and oxygen molecules high in the atmosphere, 20-30 km) Absorbs short wavelength portions of the UV spectrum (0.2 – 0.3 µm)

- **Carbon dioxide:** Absorbs radiation in the mid and far infrared regions (13 – 17.5 µm). Lower atmosphere.

- **Water vapor**: Abundance varies! Lower atmosphere (below 100 km). Specific absorption bands:

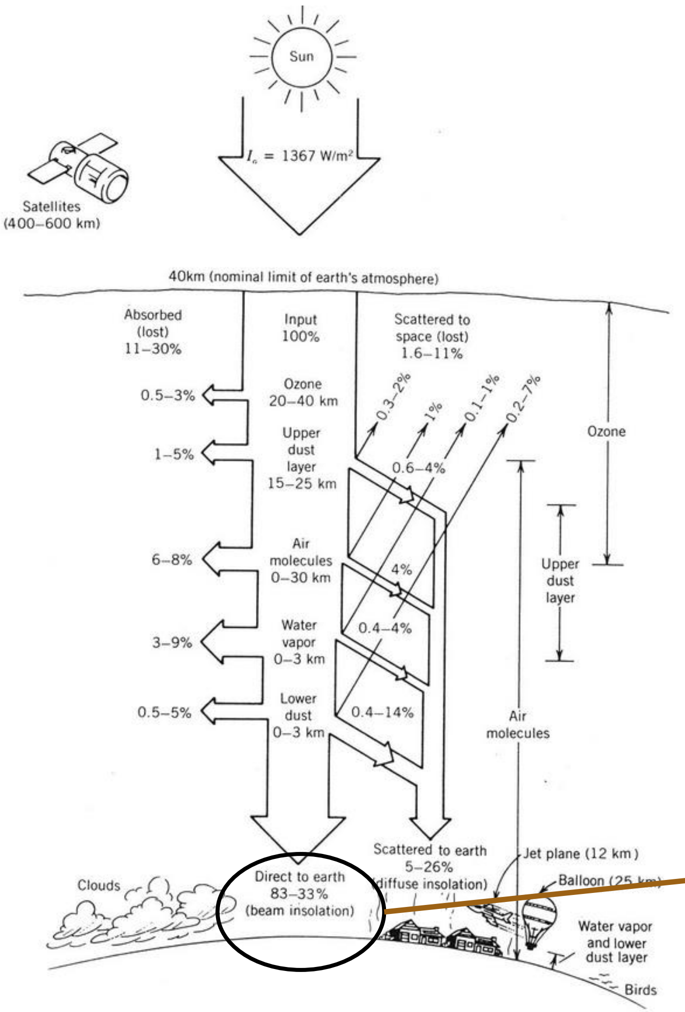
# Absorption bands and atmospheric window

**Absorption bands**
**= Atmospheric influence on radiant energy is major.**




**Atmospheric window**
**= Atmospheric influence on radiant energy is minor.**

# The atmospheric composition




**NEXT STEP...**

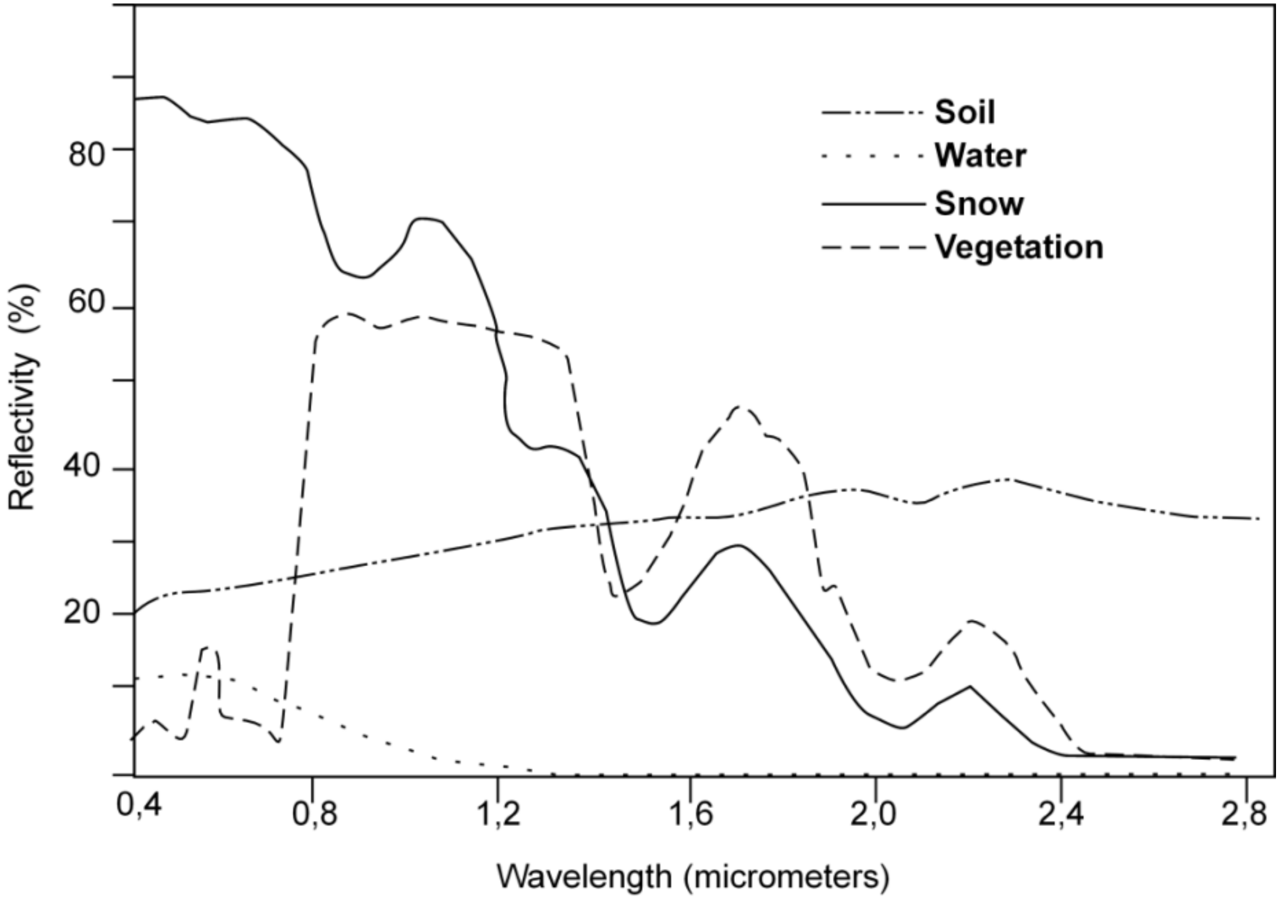
# Interaction with surface

$$Q_A + Q_R + Q_T = Q_I$$

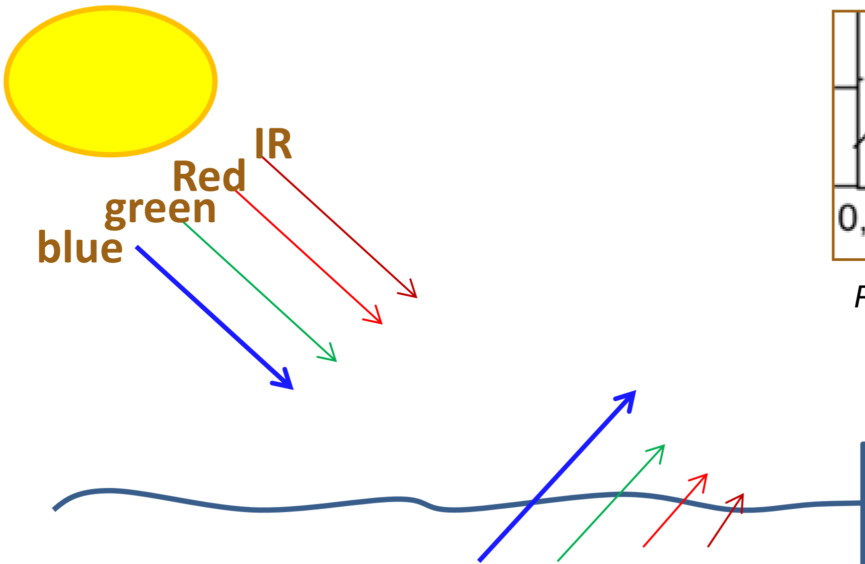
The part of **reflected**, **transmitted** and **absorbed** energy in different wavelengths depend on:

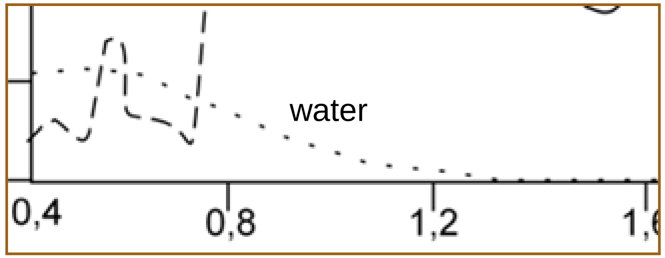
- **The properties of the surface**
- Angle of illumination

# Spectral reflectance curves



# Reflectance of water



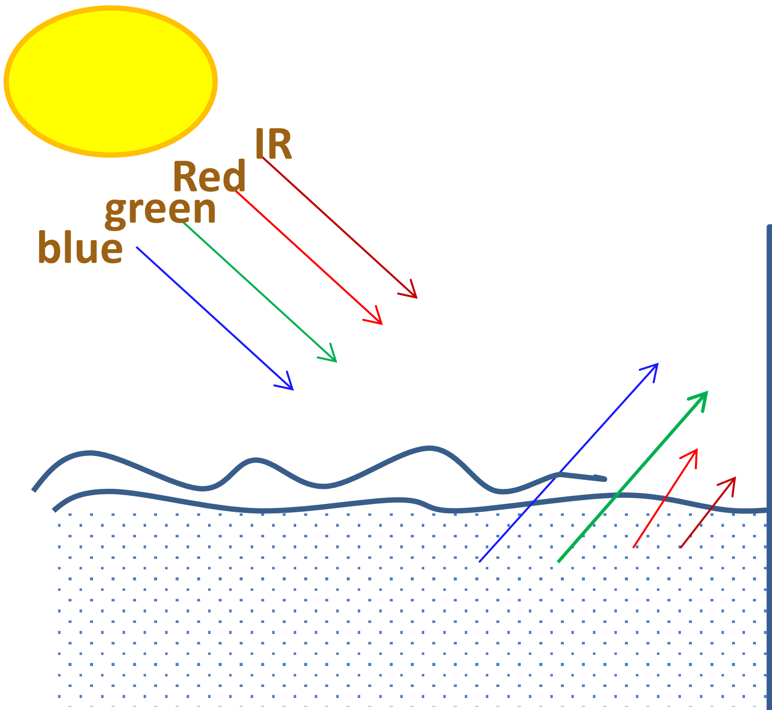

*From former slide*

- Water is an absorber…
- Water only reflect (to some extent) in the visible spectrum

→ dark color

- Shorter wavelengths are more reflected than longer → blue color
- No reflectance in NIR

# Reflectance of surface water

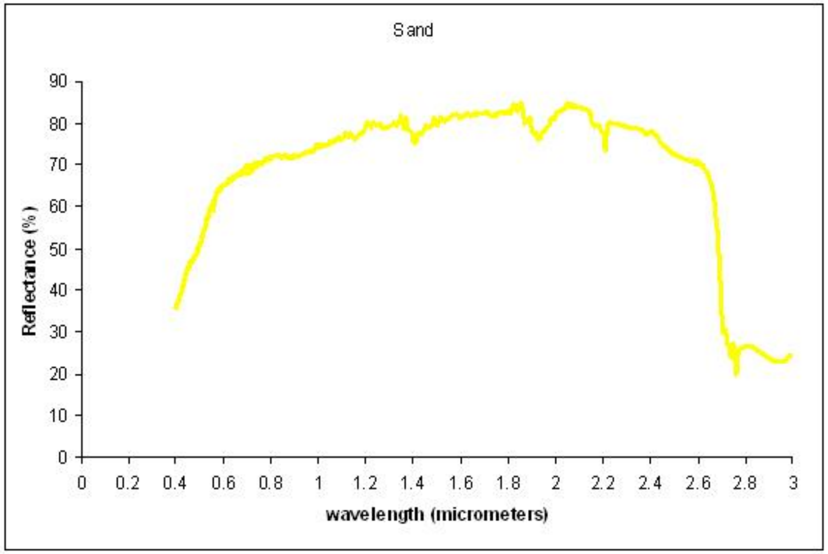



- Suspended material
  → more reflectance
  → brighter
- Chlorophyll algae
  → absorbs blue  and reflects green
  → green color
- Turbid water
  → overall higher reflectance  (more scattering)

  → brighter image

# Reflectance of sand

- High reflectance in "all" wavelengths
- VIS: Green and red wavelengths reflected → light yellow-brownish tone



# Differences in leaf reflectance

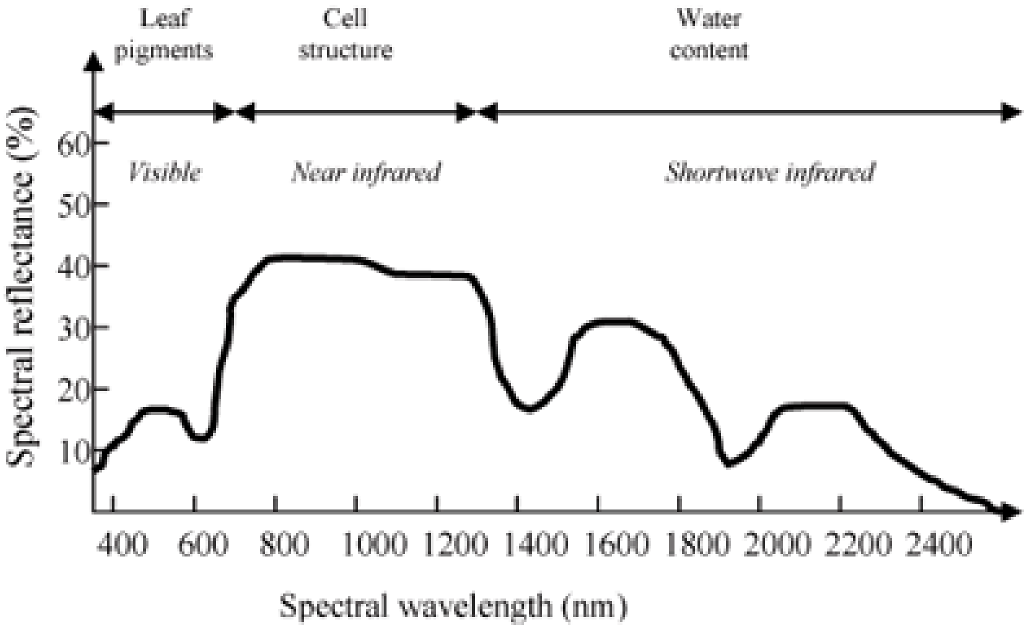



***Figure 1***

*Typical reflectance sensitivities as controlled by leaf pigments, cell structure and water content (adapted from Gaussman, 1977)*

# Vegetation

Strong absorper in VIS:

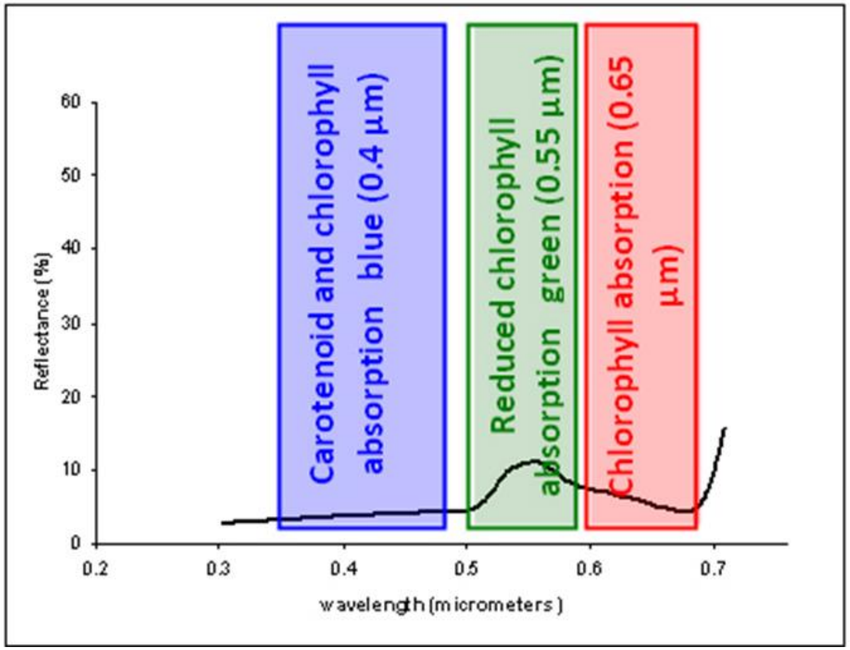
-due to leaf pigments

**Chlorophyll**

- High content in healthy leaves
- High photosynthetic rate

**Carotenoids**

- High content in senescent leaves
- Potential sign of unhealthy, stressed vegetation




**How about reflectance in NIR?**

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# Absorption/Reflectance of a leaf

**Upper epidermis:** layer of closely fitted cells

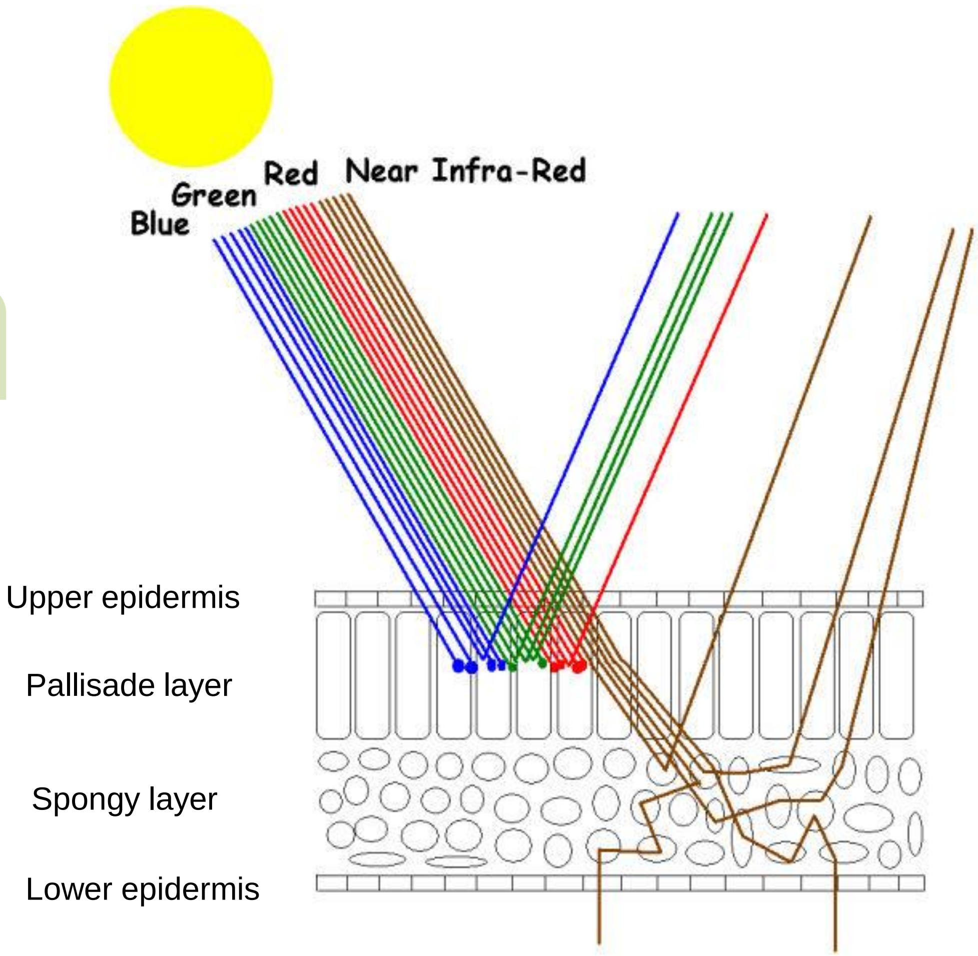
**Pallisade** – chloroplasts = cells that holds pigments: chlorophyll, carotenoids, anthocyanins..

**Absorbs blue and red light for the photosynthesis process:**

$$6\ CO_2 + 6\ H_2O \rightarrow 6(CH_2O) + 6\ O_2$$

**Spongy mesophyll** –irregular shaped cells + space. Near infrared light is either reflected (50% or transmitted 50%)

**Lower epidermis**: stomata and guard cells to control access of CO2 and H2O



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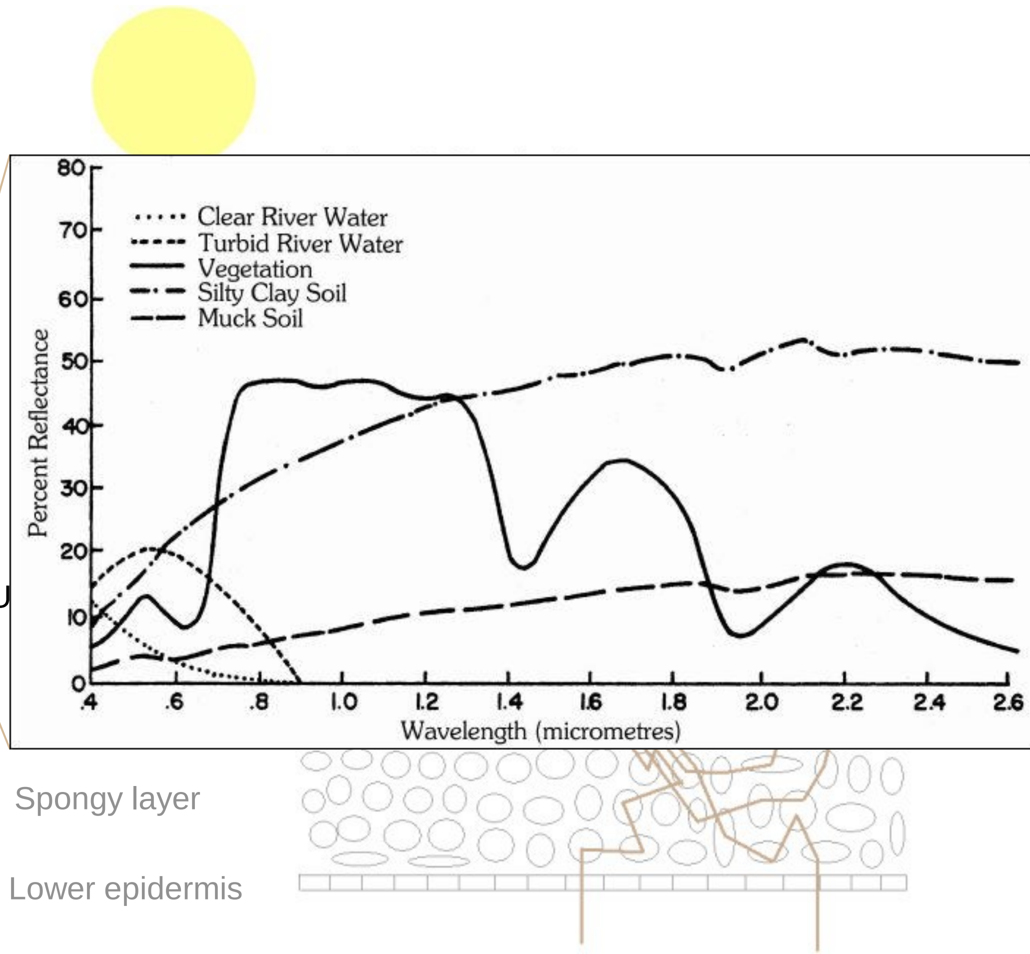
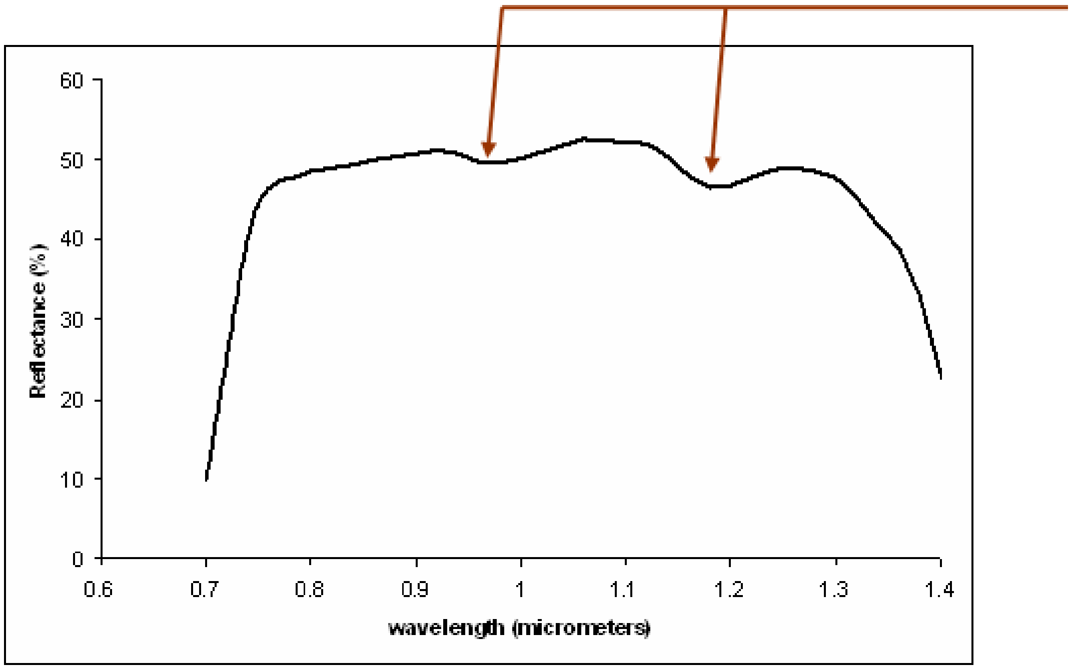
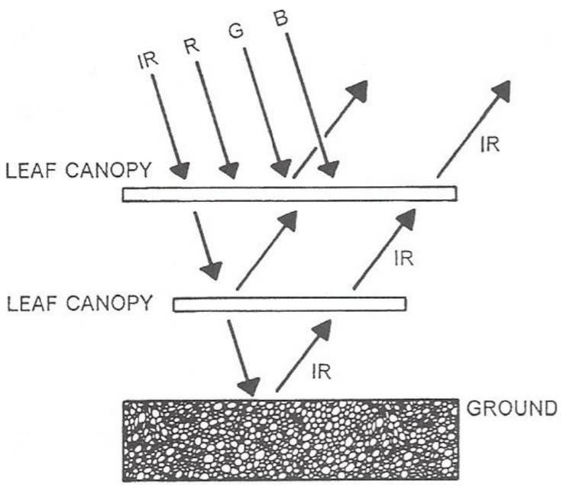


# Vegetation reflectance in NIR

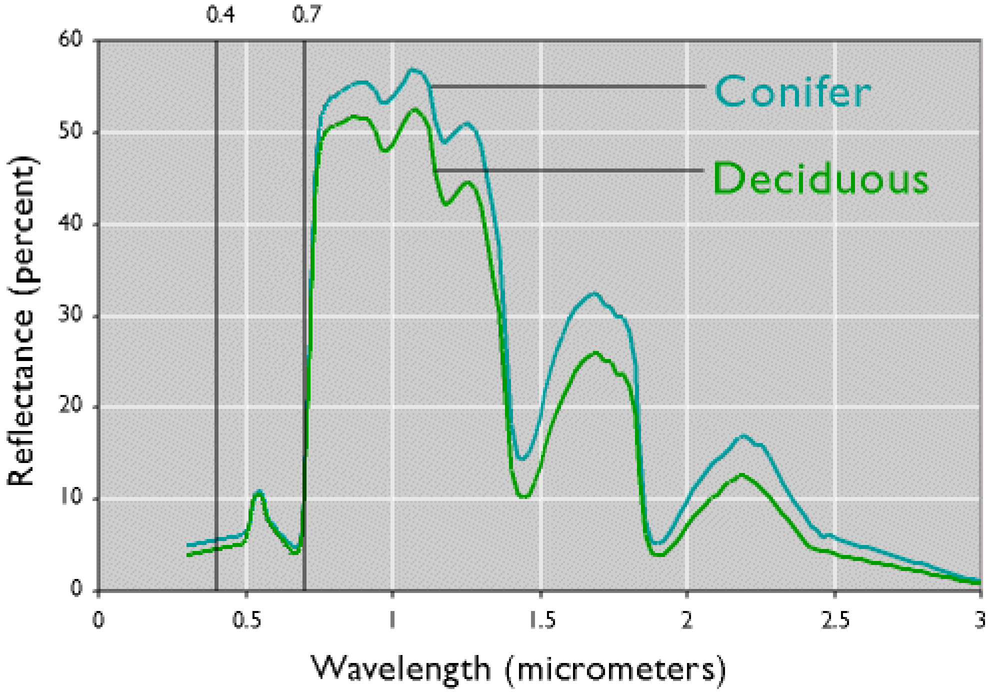
**Vegetation has a high reflectance in NIR!!!**

High foliar reflectance except in two minor water related absorption bands, 0.96µm and 1.1µm.



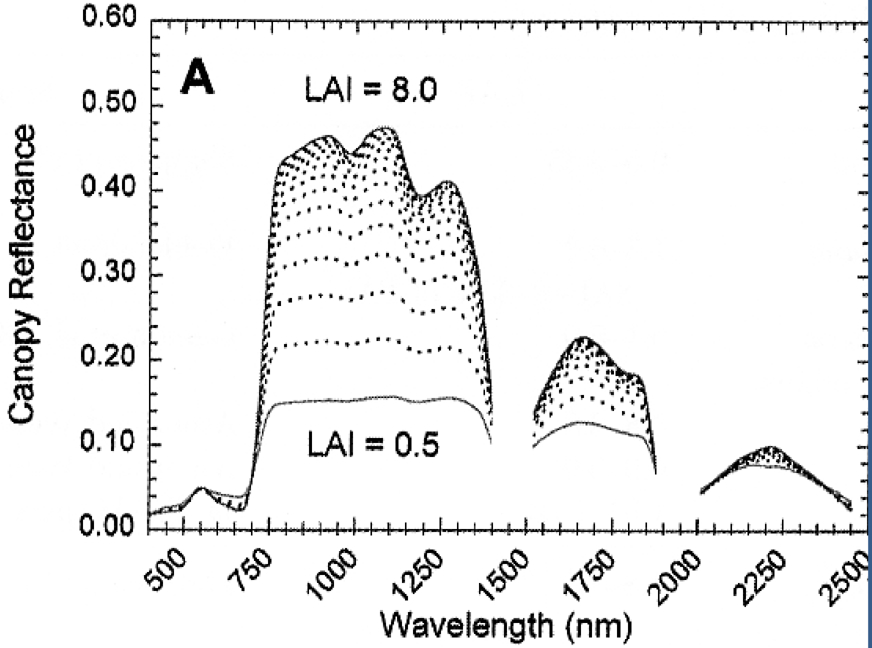



# Example of vegetation spectral signatures




Reflectance in NIR = good for segregation of species

# Reflectance at canopy level




LAI = Leaf Area Index = leaf area per unit ground area = vegetation density.

- Reflectance in NIR depend on vegetation density

From:
Asner, G.P., 1998, *Biophysical and Biochemical Sources of Variability in Canopy Reflectance*, Remote Sensing of Environment, 64:234-253.

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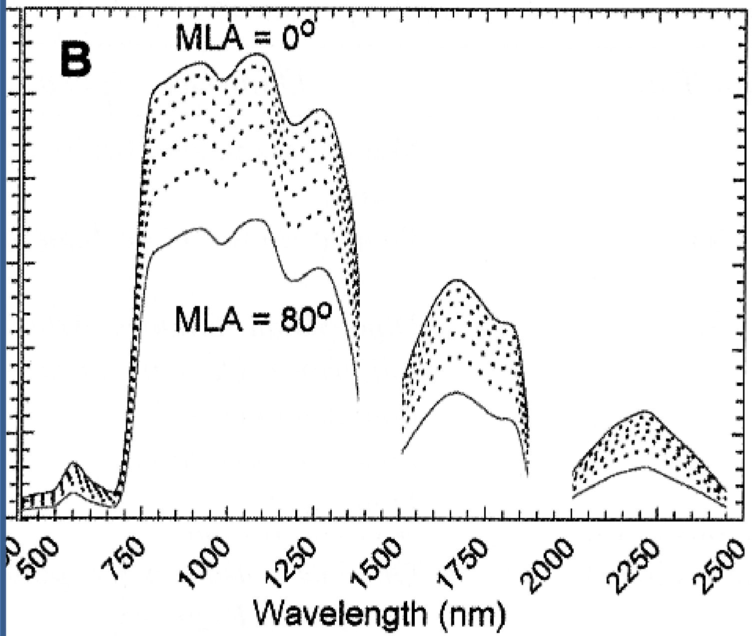
# Reflectance at canopy level

MLA = mean leaf angle.
horizontal = 0°
vertical = 90°

- Reflectance in NIR depend the leaf angle
- Sun and view angles are also important

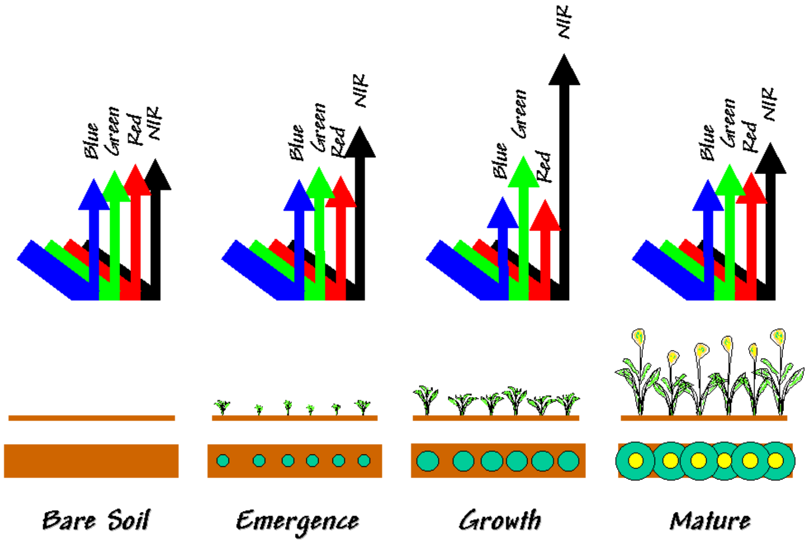



From:
Asner, G.P., 1998, *Biophysical and Biochemical Sources of Variability in Canopy Reflectance*, Remote Sensing of Environment, 64:234-253.

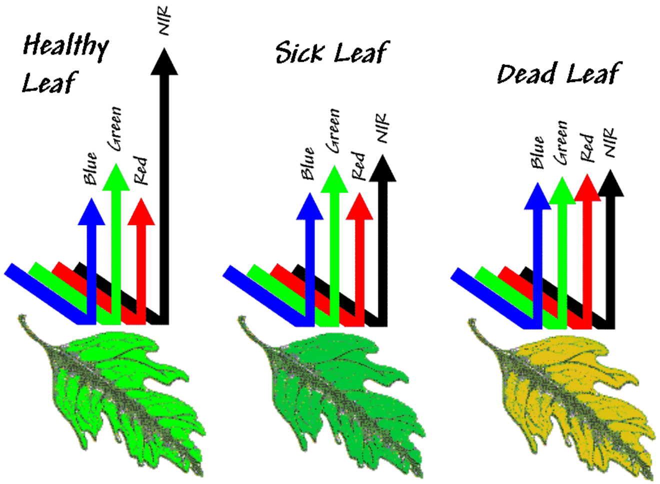
# Reflectance vs. phenology and health

**Reflectance and phenology**

Phenology = study of vegetation growth



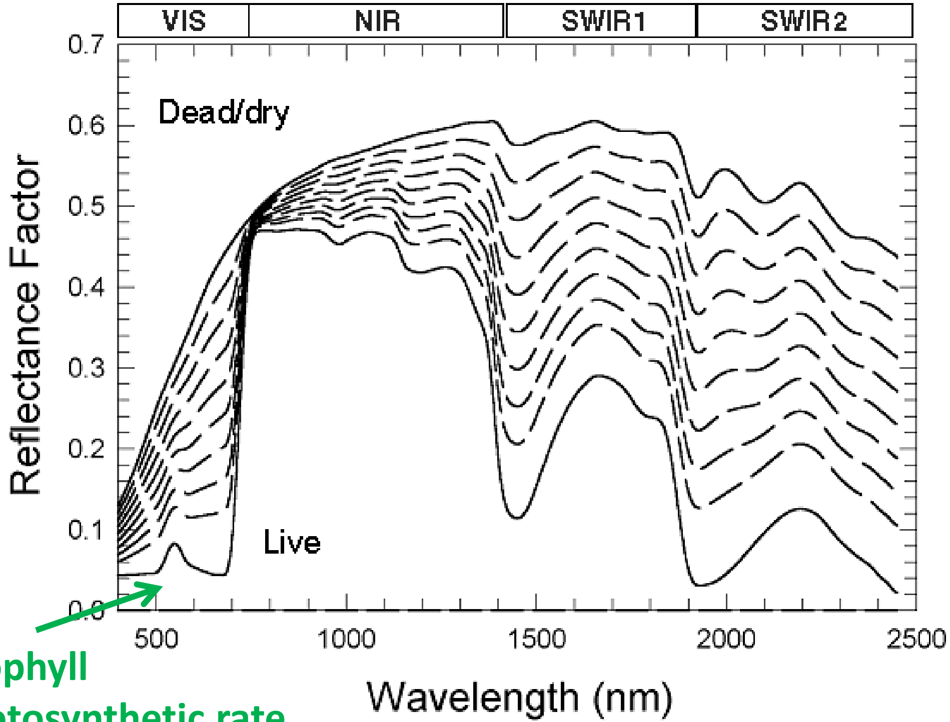

**Reflectance and health**




It is in NIR that we see the main difference between a healthy leaf and a mature/sick/dead leaf...

# Reflectance vs health/maturity

- → More active vegetation
- → Steeper slope from red to NIR




More chlorophyll
= higher photosynthetic rate

**From:**
**Asner, G.P., 1998, *Biophysical and Biochemical Sources of Variability in Canopy Reflectance*, Remote Sensing of Environment, 64:234-253.**

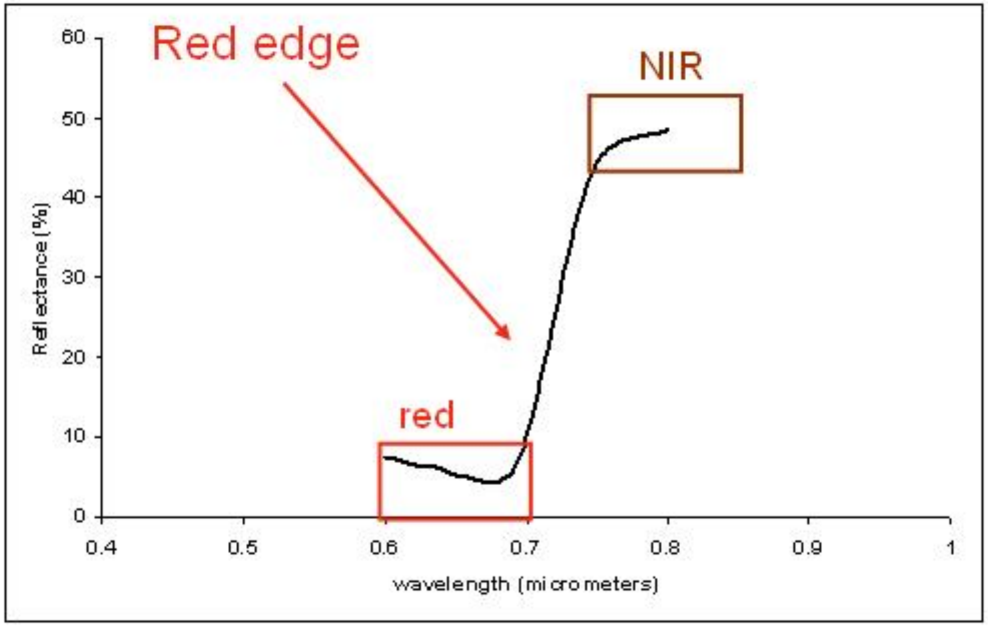
# The red edge/shift

Strong absorption in red (λ<0.7 µm)
+
weak absorption in NIR (λ>0.7 µm)
→ sharp increase in reflectance at 0.7 µm
= red edge

**High chlorophyll concentration**
→ Lower reflectance

**Mature leaves**
→ Red edge move to longer wavelengths

→ Form of the slope changes




**Many satellite sensors try aim for wavelength bands near the ”red edge”**

# Interaction with surface

$$Q_A + Q_R + Q_T = Q_I$$

The part of **reflected**, **transmitted** and **absorbed** energy in different wavelengths depend on:

- The properties of the surface
- **Angle of illumination**

# Reflectance

Specular

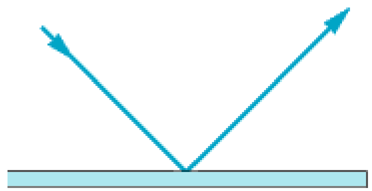
Diffuse

Bidirectional

# Specular reflectance

*=mirror reflectance*

- Smooth surfaces.
- The angle of reflection equals the angle of incidence.
- Dark for all observers who are not looking along the reflection angle.



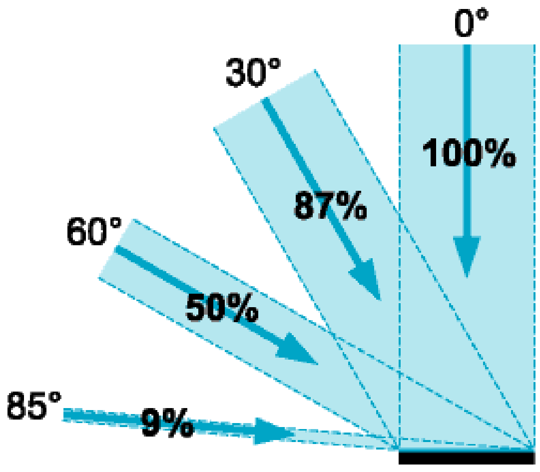
# Diffuse reflectance

Lambertian surfaces follow the law of cosine

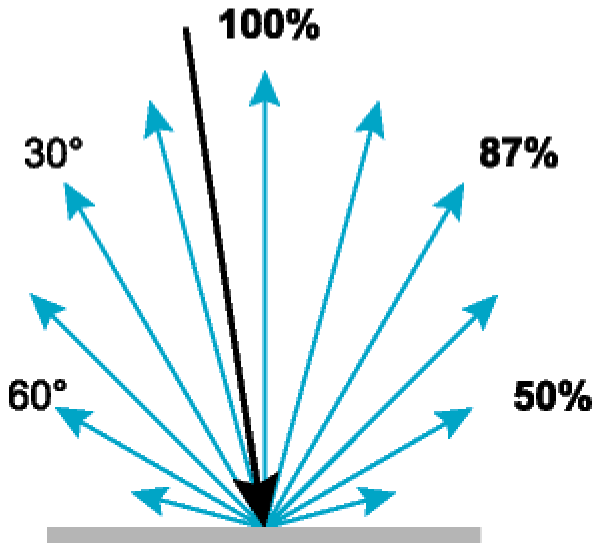
Lamberts law:

→ **reflected energy from a specified surface area in a particular direction is proportional to the cosine of the angle between that direction and the surface normal**

$$R = R_o \cos\theta_z$$




The function works the same for incident radiation as for reflectance



# Summary: passage from sun to sensor

1. **Solar irradiance -** amount of energy from the sun that arrives at the earth
   -varies slightly over the years

Influences on the way down:

- incident angle of sunlight onto the atmosphere
  - depends on latitude, date and time, terrain slope
- Atmospheric absorption and reflection/scattering downwards
  -depends on atmospheric composition + path length

**2. Reflectance of surface**
-varies depending on surface property (spectral signature curve)

Influences

- Incident angle onto the surface (→ specular, lambertian, diffuse ref.), roughness
- Amount of direct vs. diffuse energy

Influences on the way up:

- Atmospheric absorption and reflection/scattering upwards
  -depends on atmospheric composition + path length
- Additional energy that has been scattered from other surface objects or athmospere

**3. Registration by the sensor**

- View angle of the sensor
- Resolution (spectral, radiometric, spatial etc).
- Ability to register signal input –sensor specifics.
- Calibrations , functions to estimate the reflectance…

# Evaluation

2. **The level of this lecture was...**
a) ..too difficult
b) ..too trivial
c) ..fine

*Comment:*

**3. Breaking the lecture with quizzes is...**
a) not a good idea
b) a good idea

*Comment:*

4**. What will you remember about the lecture tonight?**

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