Corso di Laurea in Fisica - UNITS

ISTITUZIONI DI FISICA PER IL SISTEMA TERRA

SCATTERING &co

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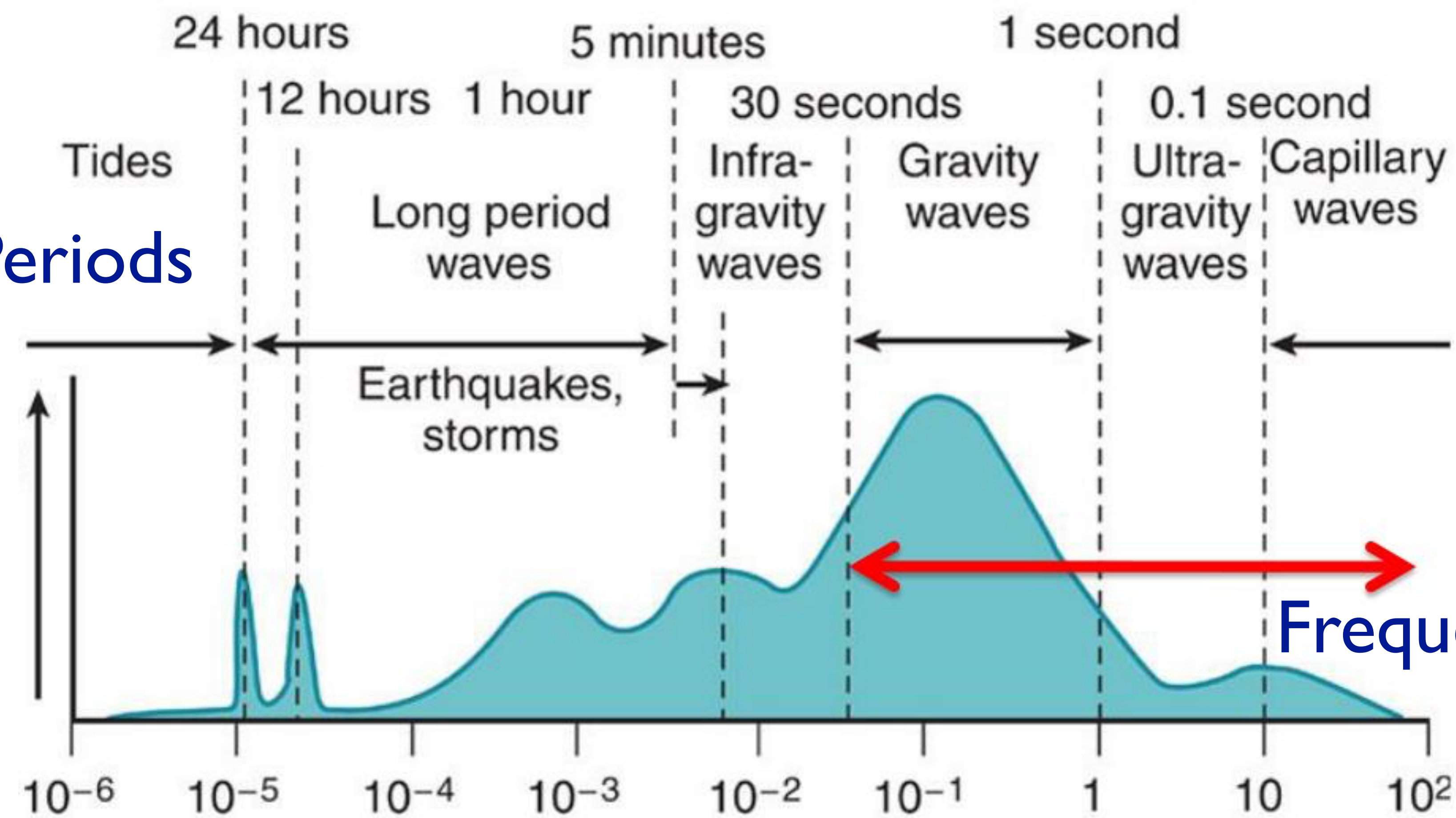
Pitches and wavescapes - GAS

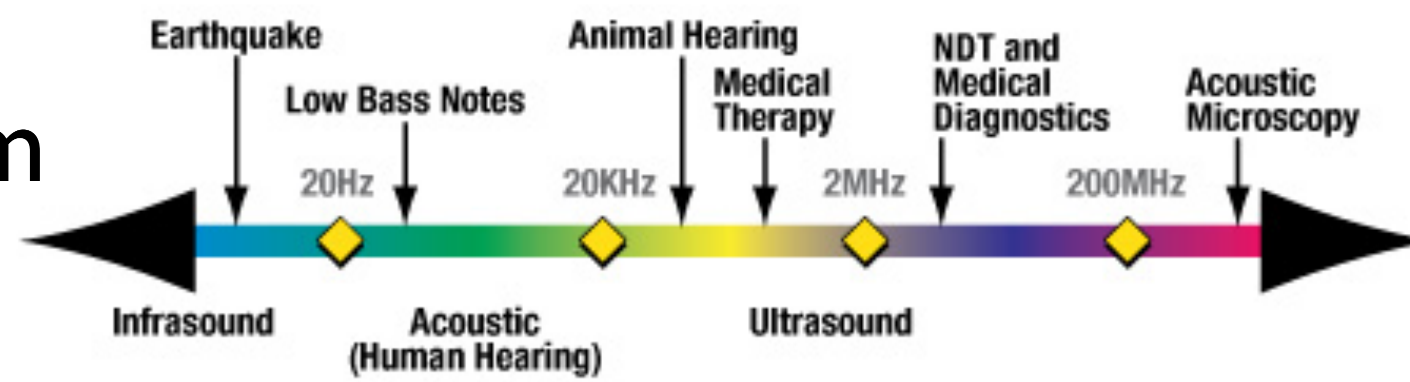
Periods



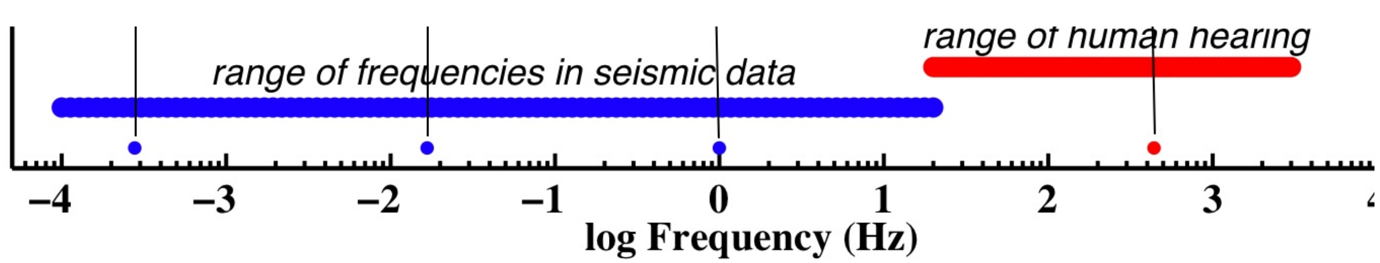
“O” spectrum

Frequencies

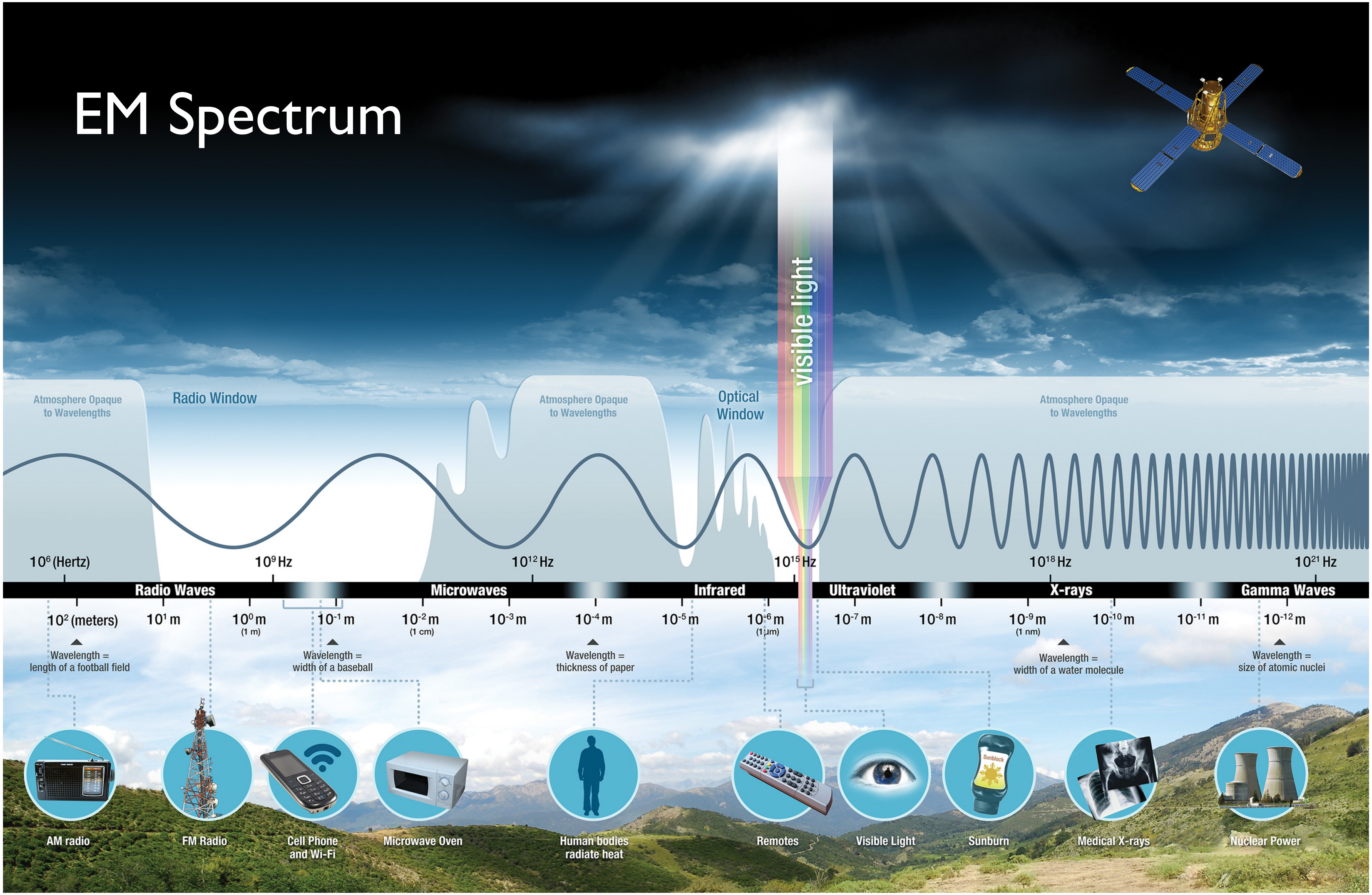
“A” spectrum



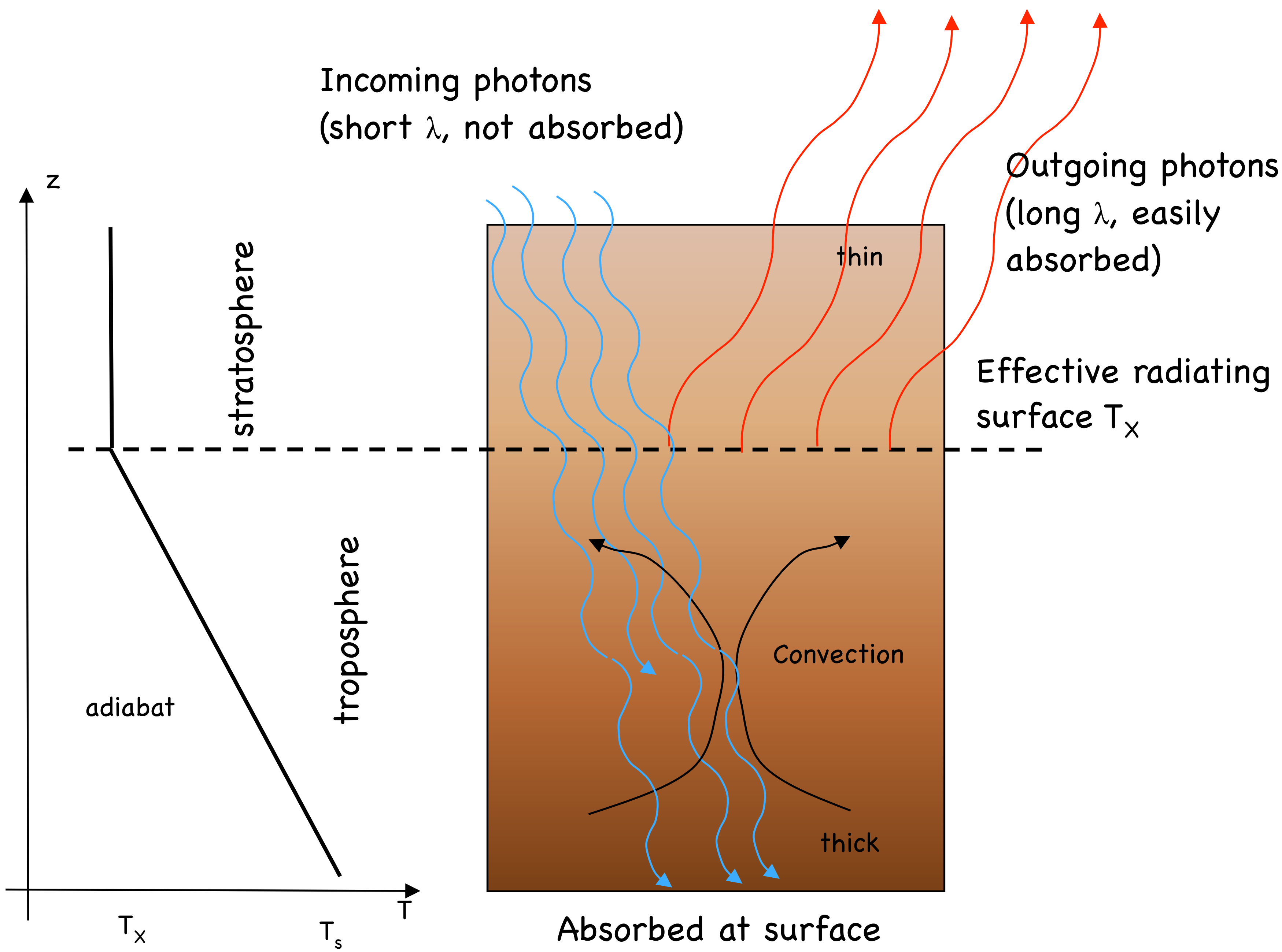
“S” spectrum



Pitches and wavescapes - EM



Typical atmospheric structure



Lower atmosphere consists of a thick part (troposphere) where convection dominates, and a thinner part above (stratosphere) where radiation dominates

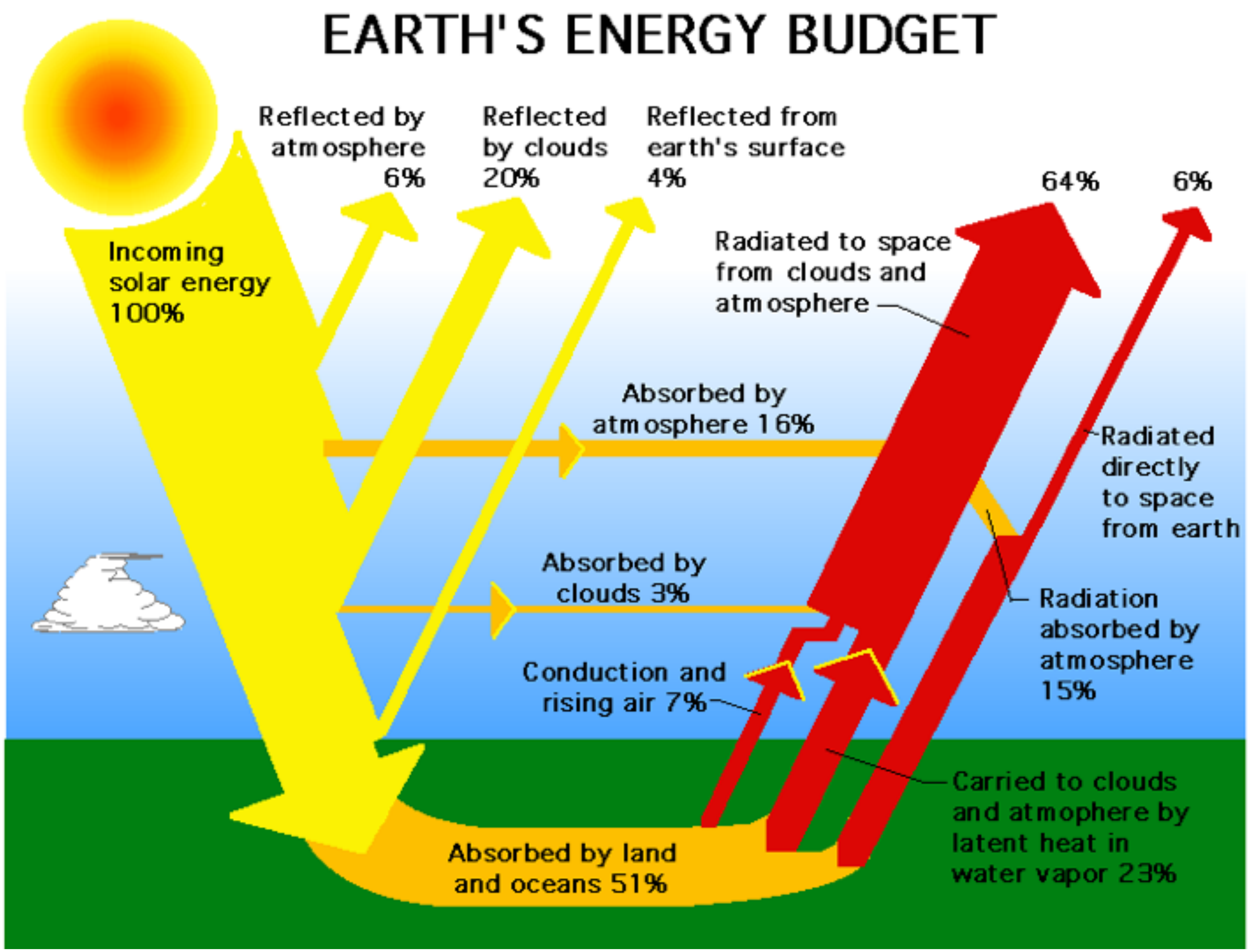
Earth atmosphere

- Gases
  - Constant gases: Nitrogen (78%), Oxygen (21%), Argon, Neon, Helium, Krypton, Xenon etc.
  - Variable gases: Water vapor, Carbon dioxide, Methane, Hydrogen, Nitrous oxide, Carbon monoxide, Ozone
- Aerosols
  - solid or liquid particles or both suspended in air with diameters between about 0.002 μm to about 100 μm.
- Cloud droplets
  - sizes vary from a few micrometers to hundreds of micrometers.

Earth's energy budget

Table 4.3 *Estimates of notable contributions to the Earth's annual energy budget*

Energy source	Annual energy [J]	Normalized [geothermal flux = 1]
Reflection and re-radiation of solar energy	5.4×10^{24}	≈ 4000
Geothermal flux from Earth's interior	1.4×10^{21}	1
Rotational deceleration by tidal friction	$\approx 10^{20}$	≈ 0.1
Elastic energy in earthquakes	$\approx 10^{19}$	≈ 0.01



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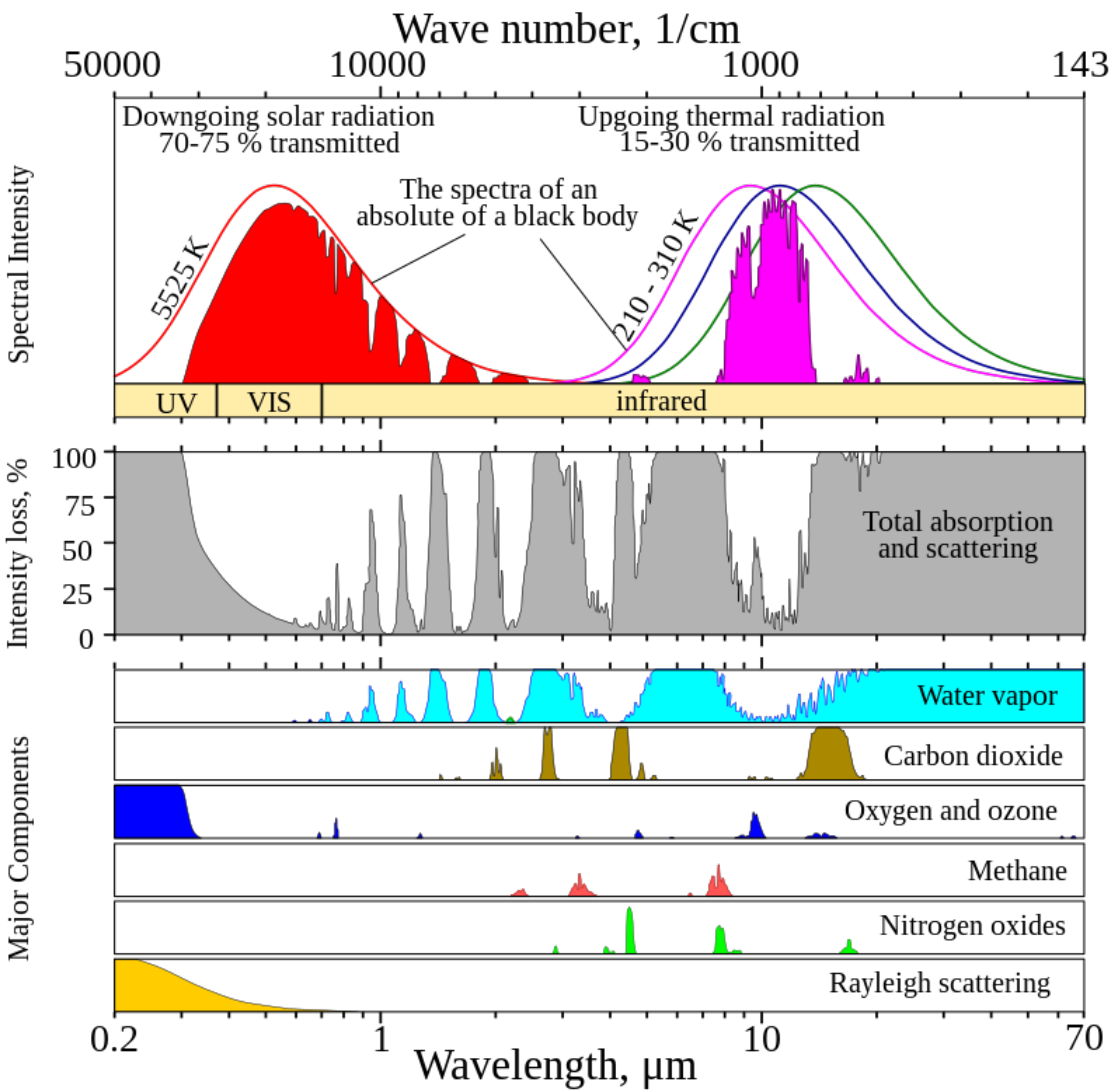
Scattering and Absorption



Basic concepts of EM wavefield

Extinction and **emission** are two main types of the interactions between an electromagnetic radiation field and a medium (e.g., the atmosphere).

Extinction is due to **absorption** and **scattering**.

Absorption is a process that removes the radiant energy from an electromagnetic field and transfers it to other forms of energy.

Scattering is a process that does not remove energy from the radiation field, but **redirect** it. Scattering can be thought of as absorption of radiant energy followed by re-emission back to the electromagnetic field with negligible conversion of energy, i.e.can be a "source" of radiant energy for the light beams traveling in other directions.

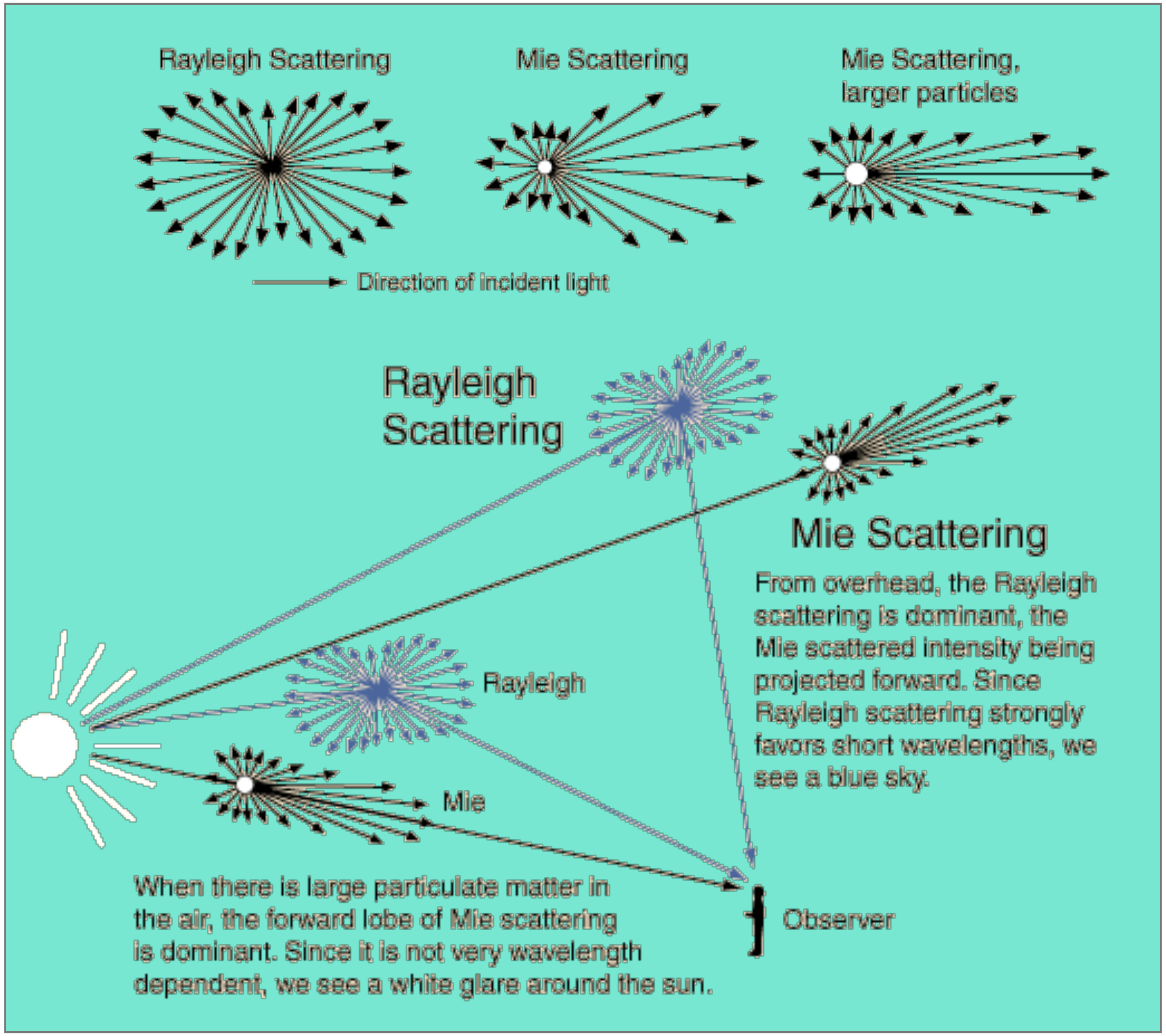
Scattering **occurs at all wavelengths** (spectrally not selective) in the electromagnetic spectrum, for any material whose refractive index is different from that of the surrounding medium (**optically inhomogeneous**).

Scattering of EM wavefield (1)

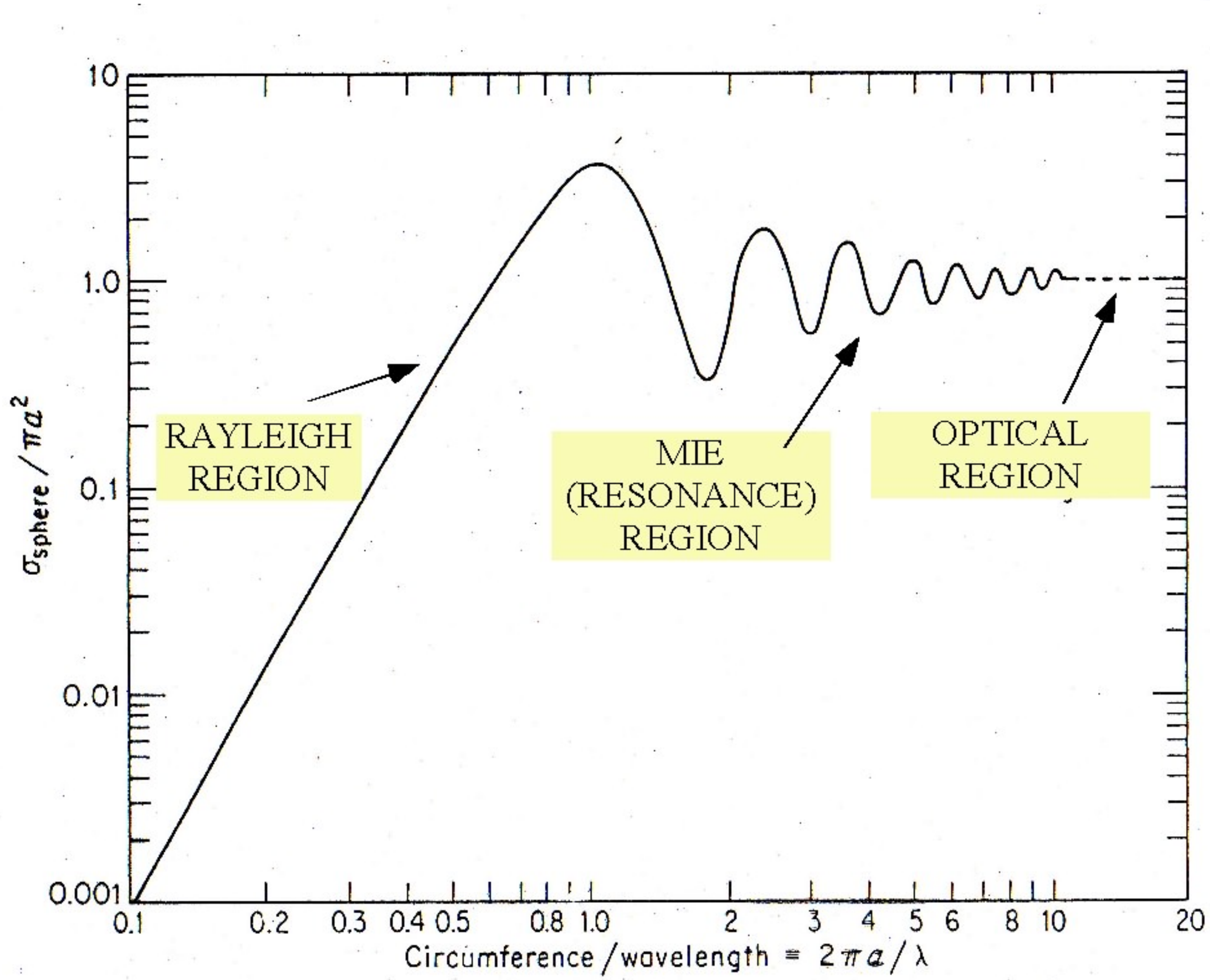
The amount of scattered energy depends strongly on the ratio of: particle size (a) to wavelength (λ) of the incident wave

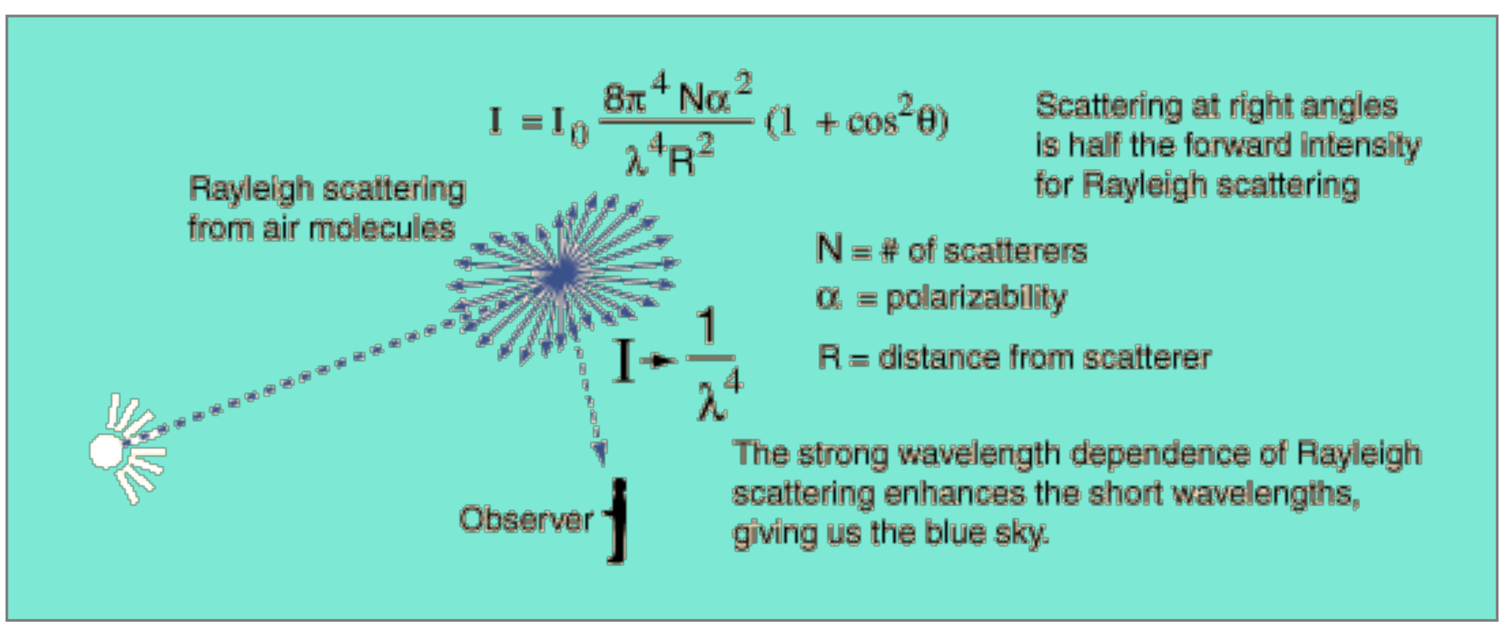
When **($a < \lambda/10$)**, the scattered intensity on both forward and backward directions are equal. This type of scattering is called **Rayleigh scattering**.

For **($a > \lambda$)**, the angular distribution of scattered intensity becomes more complex with more energy scattered in the forward direction. This type of scattering is called **Mie scattering**



Scattering of EM wavefield (2)





Single Scattering

$\chi = 2\pi \mathbf{a}/\lambda$

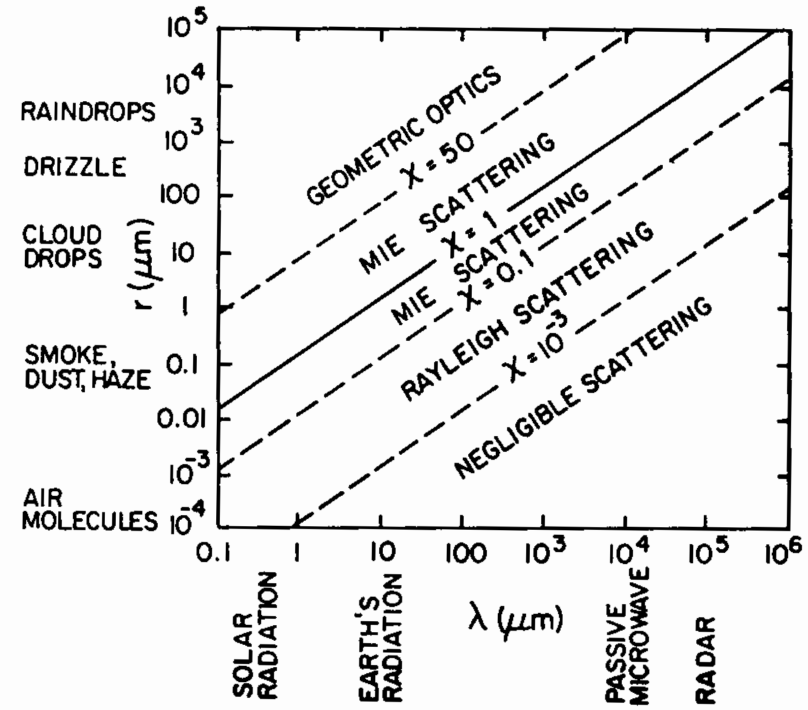
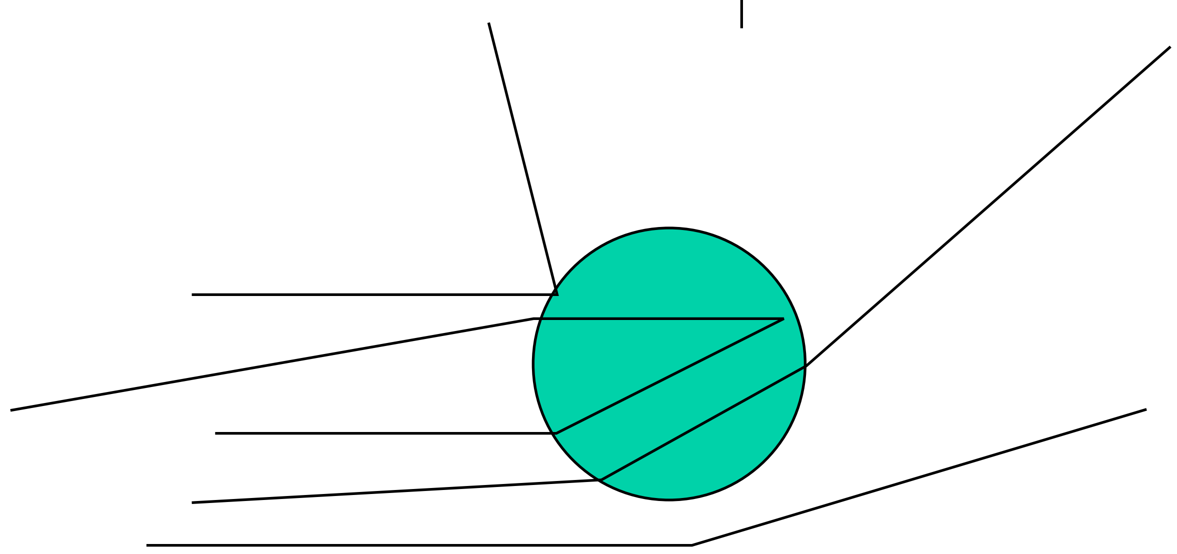


FIGURE 3.18. Scattering regimes. [Adapted from Wallace and Hobbs (1977). Reprinted by permission of Academic Press.]



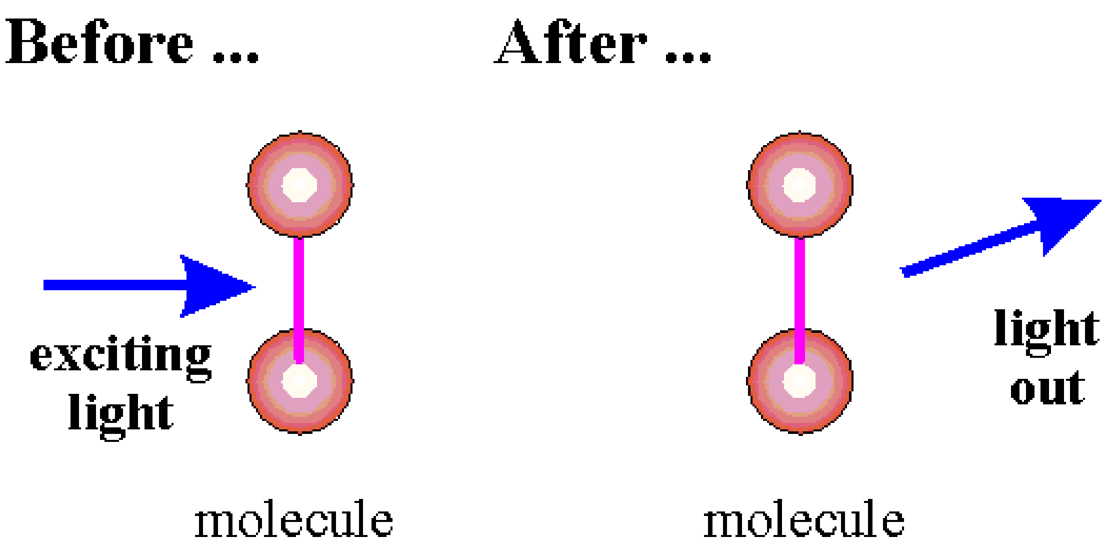
For **(a >> λ)**, the Scattering characteristics are determined from explicit Reflection, Refraction and Diffraction: **Geometric "Ray" Optics**

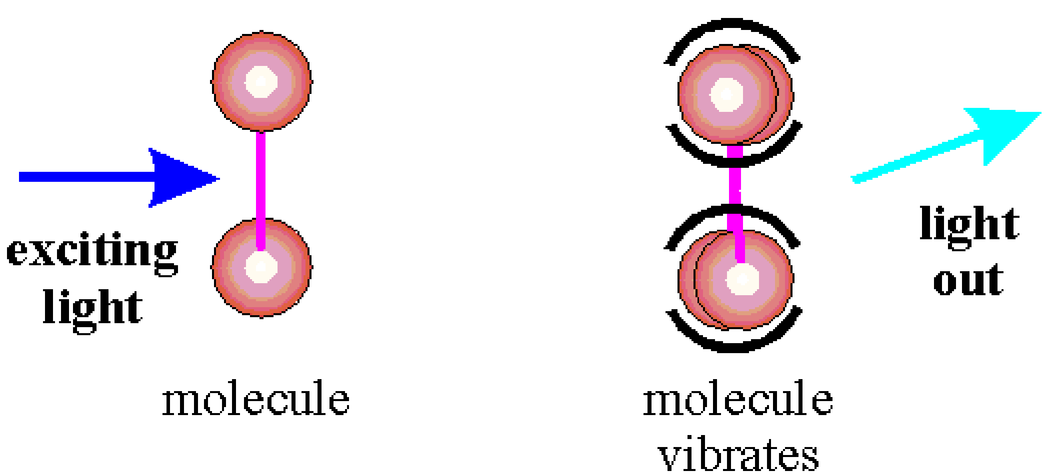
Scattering of EM wavefield (3)

Composition of the scatterer (n) is important!

The interaction (and its redirection) of electromagnetic radiation with matter May or may not occur with **transfer of energy**, i.e., the scattered radiation has a slightly different or the same wavelength.

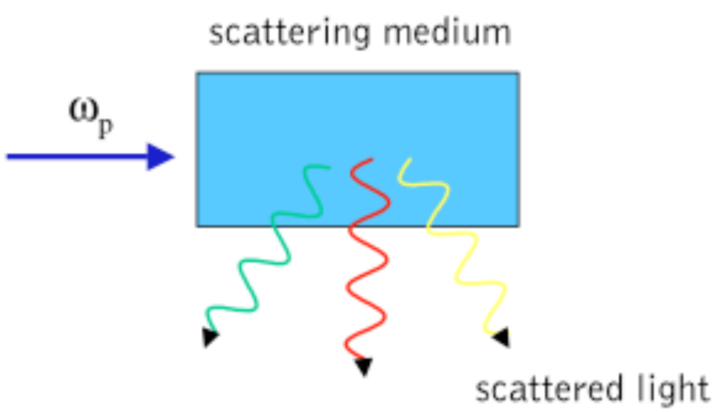
Rayleigh scattering - Light out has same frequency as light in, with scattering at many different angles.



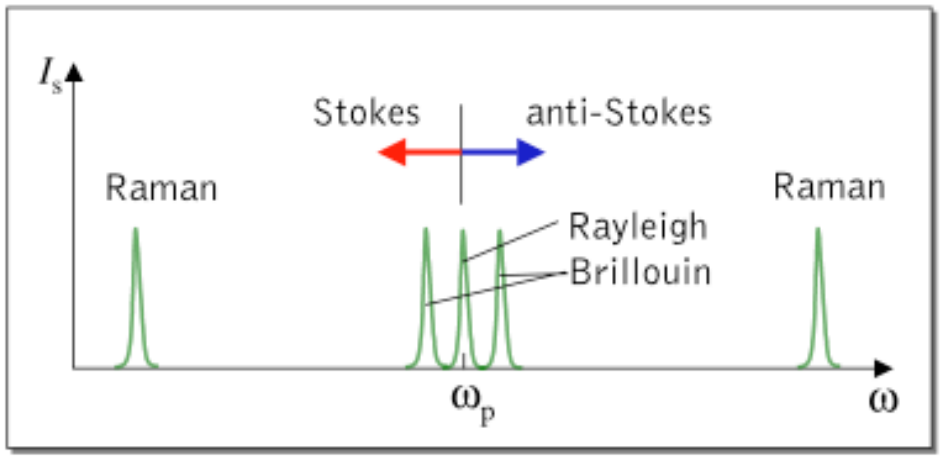


Raman scattering - Light is scattered due to vibrations in molecules or optical phonons in solids. Light is shifted by as much as 4000 wavenumbers and exchanges energy with a molecular vibration.

Scattering of EM wavefield (4)



spectrally resolved detection



Rayleigh scattering
 scattering from *nonpropagating* density fluctuations (elastic)

Brillouin scattering
 scattering from *propagating* pressure waves (sound waves, acoustic phonons)

Raman scattering
 interaction of light with vibrational modes of molecules or lattice vibrations of crystals (scattering from optical phonons)

Raman scattering

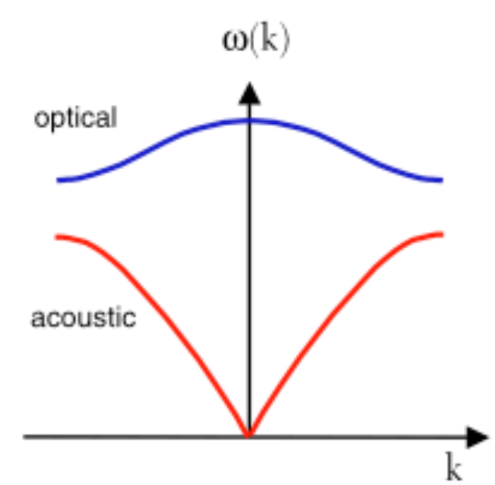
✓ optical phonon

Brillouin scattering

✓ acoustic phonon

Phonons
 quanta of the ionic displacement field in a solid

phonon dispersion curve



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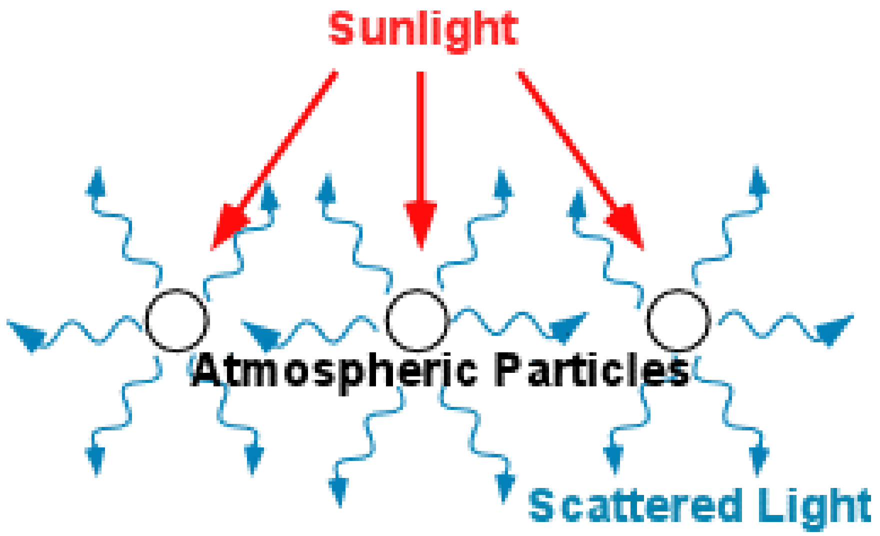
Scattering and Diffusion

In single scattering, the properties of the scatterer are important, but multiple scattering erases these effects - eventually **all** wavelengths are scattered in **all** directions.

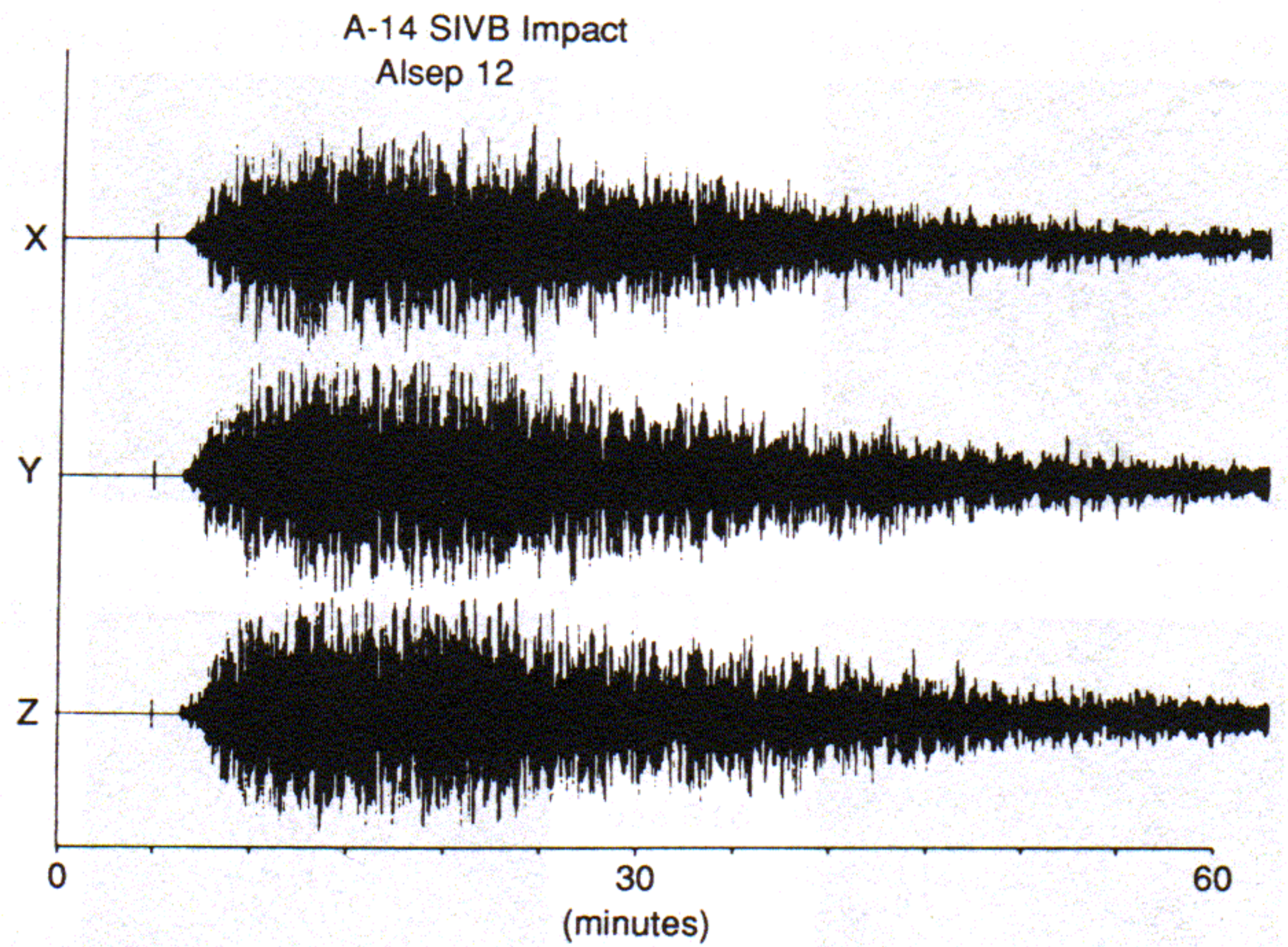


Works for turbid media: clouds, beer foam, milk, etc...

Example: when a solid has a very low temperature, phonons behave like waves (long mean free paths) and heat propagate following ballistic term.
At higher temperatures, the phonons are in a diffusive regime and heat propagate following Maxwell law.

Scattering on the Moon

The observed wavefield of an impact on the moon looks very different from similar experiments on Earth, since attenuation is much smaller and scattered waves can propagate more efficiently. Coda waves, due to energy arriving from all directions, are stronger:



What is a **wave?** – 3

Small perturbations of a **stable** equilibrium point → **Linear restoring force** → **Harmonic Oscillation**

Coupling of **harmonic oscillators** → the disturbances can **propagate**, superpose, stand and be **dispersed**

WAVE: organized propagating imbalance, satisfying differential equations of motion

Organization can be destroyed, when interference is destructive

non linearity → **Turbulence**

strong scattering → **Diffusion**

Exceptions

Solitons

Phonons

Dispersion & Non linearity

The dynamics of water waves in shallow water is described mathematically by the Korteveg - de Vries (KdV) equation

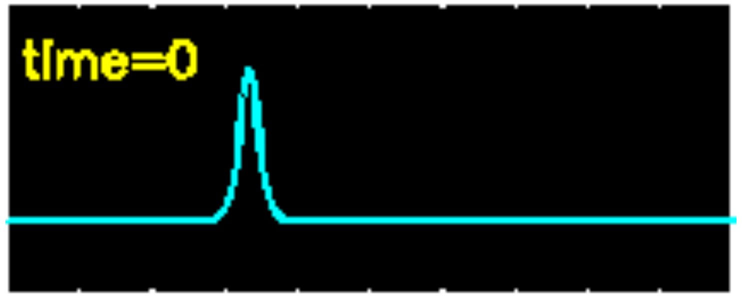
u=u(x,t) measures the elevation at time t and position x, i.e. the height of the water above the equilibrium level

Dispersive term

$$u_t + u_{xxx} = 0$$

Nonlinearity

$$u_t + u\,u_x = 0$$



KdV

$$u_t + u_{xxx} + u\,u_x = 0$$