General Meteorology

Lecture 3

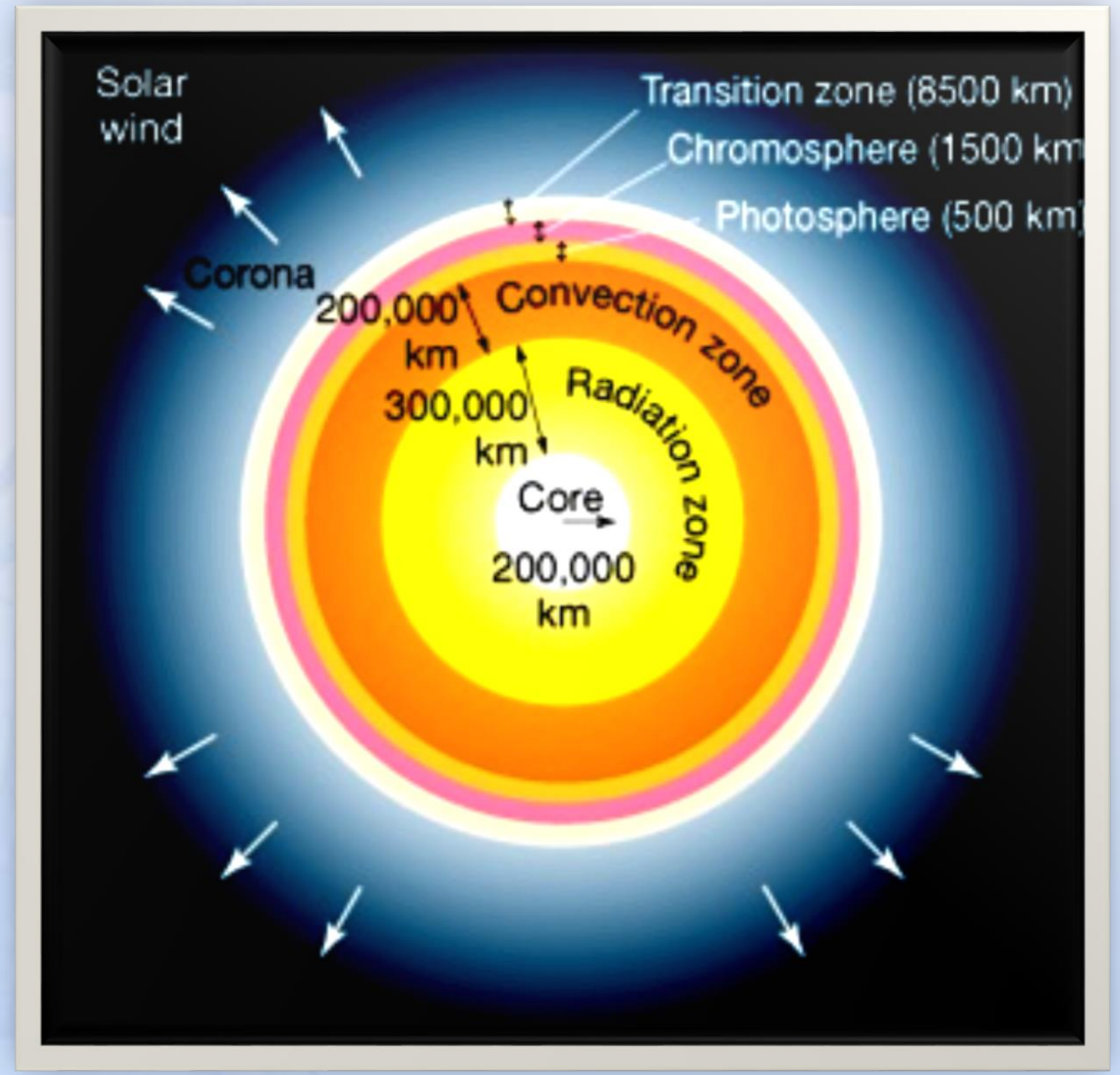
Sahraei

Physics Department,

Razi University

http://www.razi.ac.ir/sahraei

Solar structure



هسته (Core)

منطقه تابشی (radiation zone)

منطقه انتقالی (convection zone)

شید سپهر (photosphere)

رنگین سپهر (chromosphere)

تاج (corona)

The Internal Structure of the Sun

Core

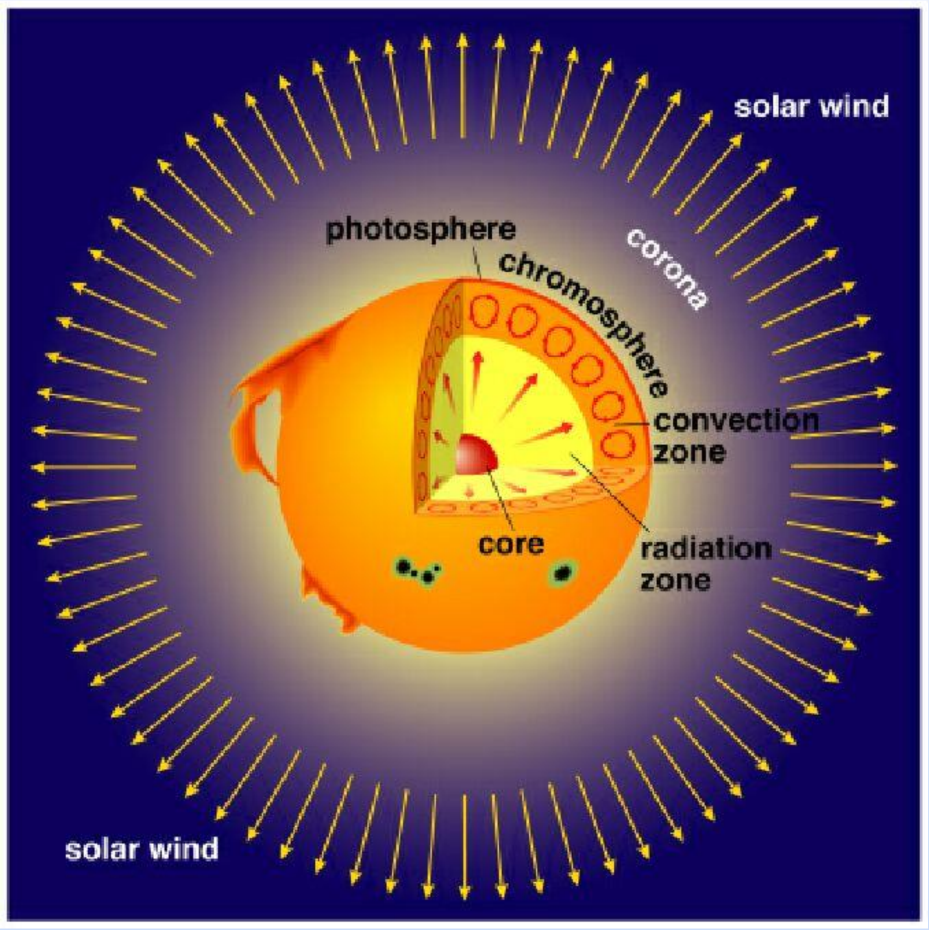
1. ***The region where nuclear fusion takes place to generate the solar energy.***
2. T ~ 15 million degrees K.

Radiation Zone

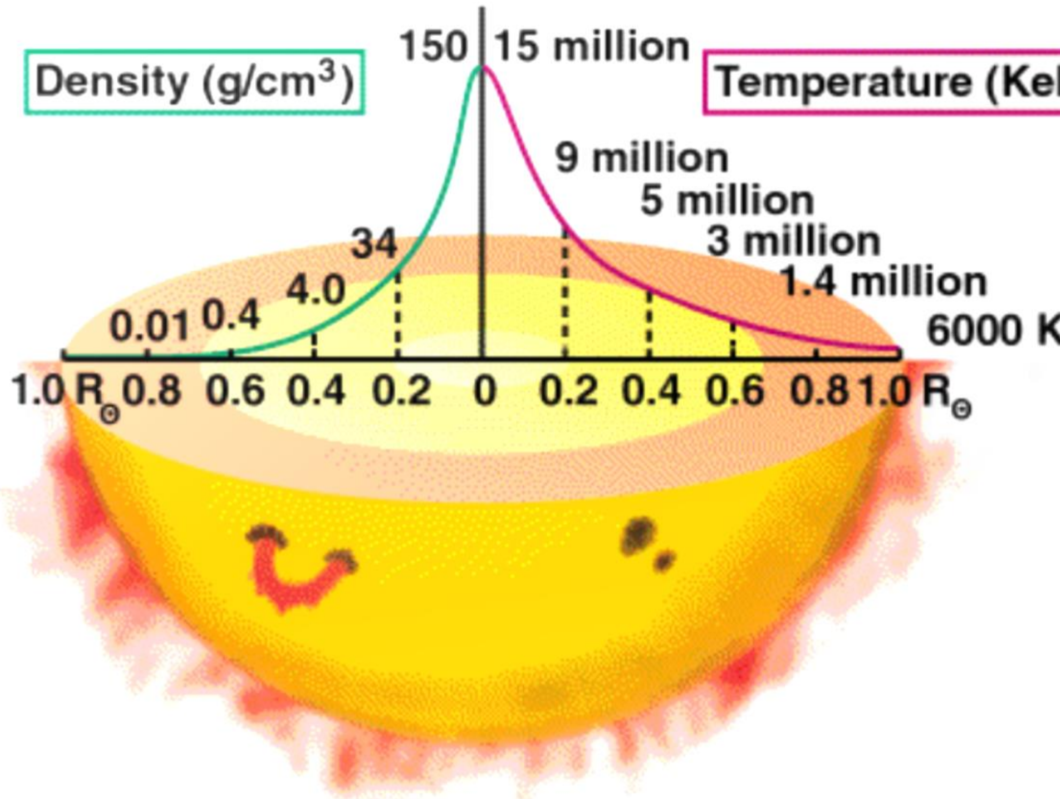
1. Energy is transported outward primarily by photons traveling through this region.
2. T ~ 10 million degrees K and decreases outward.
3. ***No nuclear fusion***.

Convection Zone

1. Energy is transported through convection: hot gas rises, irradiates their energy, and becomes cold. Cold gas sink to the bottom.
   Example at home: boiling water.
   Example at play: glider and hang-glider.



How Temperature and Density Vary Inside the Sun



Electromagnetic Radiation

- Range of wavelengths emitted by any body is a function of its surface temperature

- Hotter Bodies
  - Have higher energy
  - Emit more photons
  - Emit shorter wavelengths

Sun emits visible radiation (~5800K)- short wave

Earth emits infrared radiation (288K)- long wave

Electromagnetic Radiation

$$E = h\nu = \frac{hc}{\lambda}$$

Energy of a photon

Short wave radiation:

- *high frequency*
- *high energy*

Long wave radiation:

- *low frequency*
- *low energy*

Black body radiation

Black Body Radiator

Emits radiation with 100% efficiency at all wavelengths

Energy defined by Stephan-Boltzman Law

Distribution (spectrum) of wavelengths is a function of temperature

Defined by Planck's function

Peak wavelength emitted

Defined by Wein's Law

Laws of Radiation

Stefan-Boltzmann Law

Josef Stefan*, in 1879, found an empirical relation between the power per unit area radiated by a "blackbody" and the temperature. About 5 years later *Ludwig Boltzmann* also derived the same result. It is for that reason that this relationship is called the : *Stefan-Boltzmann Law

$$E = \sigma T^4$$

E = Rate of radiation emitted by a body (W/m^2)

σ= The Stefan-Boltzmann constant 5.67×10^{-8} **W/m^2K^4)**

T = Temperature (K)

Earth = 400 W/m^2

Sun = 73,000 W/m^2

Black Body Radiation Laws

- Planck's law: one of the great fundamental laws of physics, gives the relationship of the energy emitted by a blackbody to the wavelength or frequency and the temperature.

$$E_\lambda(\mathrm{T}) = \frac{2\pi h c^2}{\lambda^5\left(e^{hc/\lambda k \mathrm{T}} - 1\right)}$$

c: speed of light (2.998×10^{8} m s^{-1})

h: Planck's constant (6.626×10^{-34} J sec)

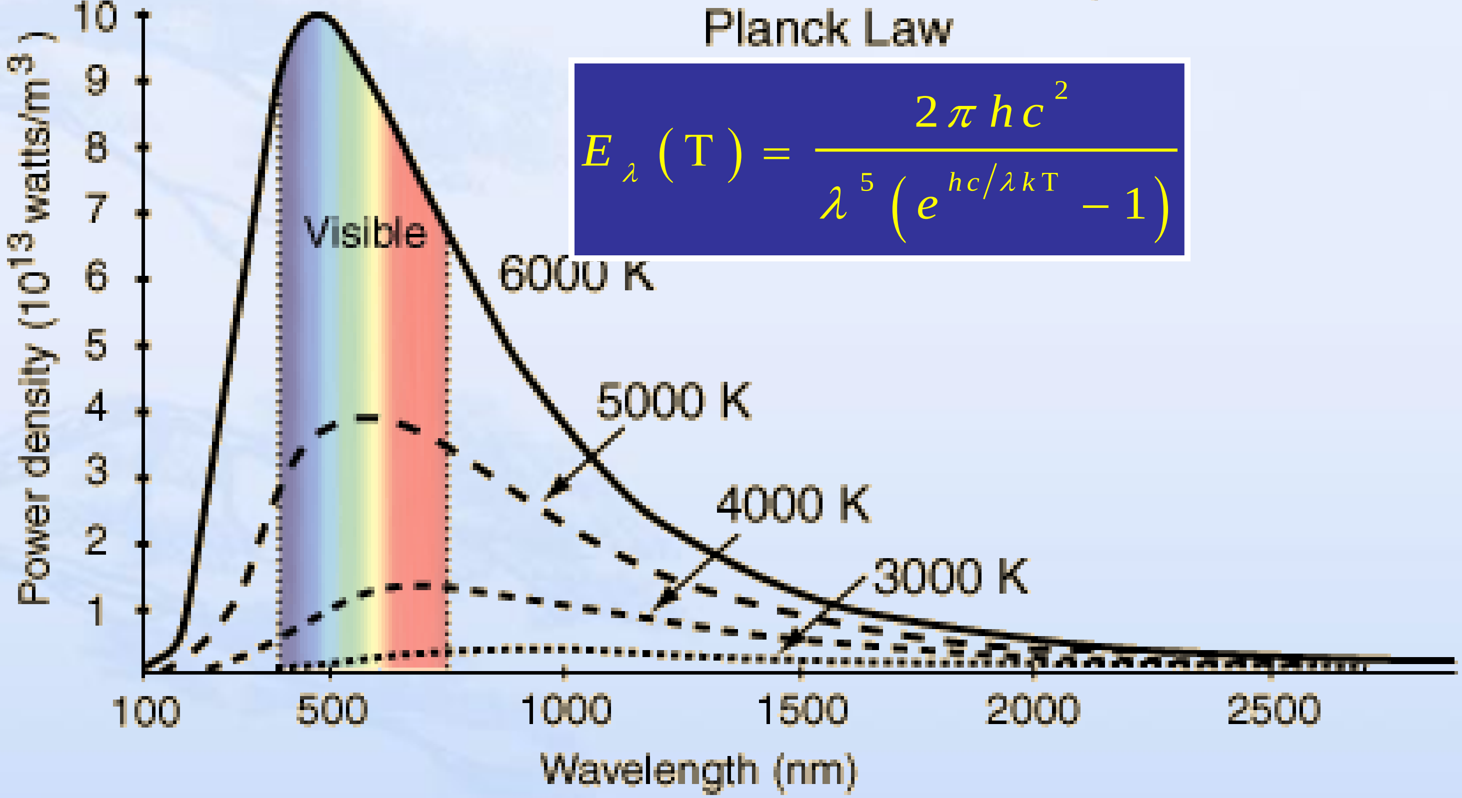
k_B: Boltzmann's constant (1.381×10^{-23} J K^{-1})

Planck's Function

$$E_\lambda(T) = \frac{c_1}{\lambda^5 \left(e^{c_2/\lambda T} - 1\right)}$$

- Collect constants together
- $c_1 = 1.19\times10^{-16}$ W m^2; $c_2 = 1.44\times10^{-2}$ m K
- Temperature in Kelvin (K), wavelength in meters for these constants
- **Need to be careful with units!**

Planck curves

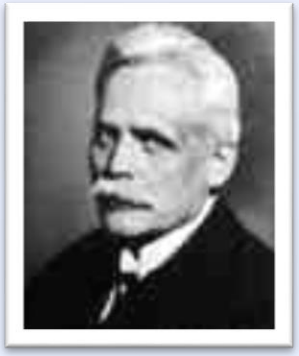


$$E_\lambda(T) = \frac{2\pi h c^2}{\lambda^5 \left(e^{hc/\lambda k T} - 1\right)}$$

Solar Spectrum

- For solar spectrum
  - Planck's function ~ reality (is a blackbody)
  - 50% = visible light (400 – 700 nm, peaks ~yellow-orange)
  - 40% = infrared (IR) (>700nm)
  - 10% = ultraviolet (UV) (<400 nm)

Wien's Displacement Law



Wilhelm Carl Werner Otto Fritz Franz Wien **experimentally found that the wavelength of maximum radiation of a thermal body is proportional to the inverse of its temperature (known as "Wien's law") using an oven with a small hole as an approximation to a theoretical blackbody. Wien received the 1911 Nobel Prize for his work on heat radiation.**

$$\lambda_{peak} = b / T$$

λ = **wavelength of radiation** (**b** =2897 K μm) **The Wien constant**

T = Temperature (K)

Wien’s Displacement Law

- Wien’s displacement Law - Peak wavelength emitted by a body

$$\lambda_{peak}\text{ (in }\mu\text{m)} = 2897/T(K)$$

- For Sun:

5800K = temperature of photosph

$\lambda_{peak\ sun}$ = 2897/5800= 0.5 μm

- For Earth:

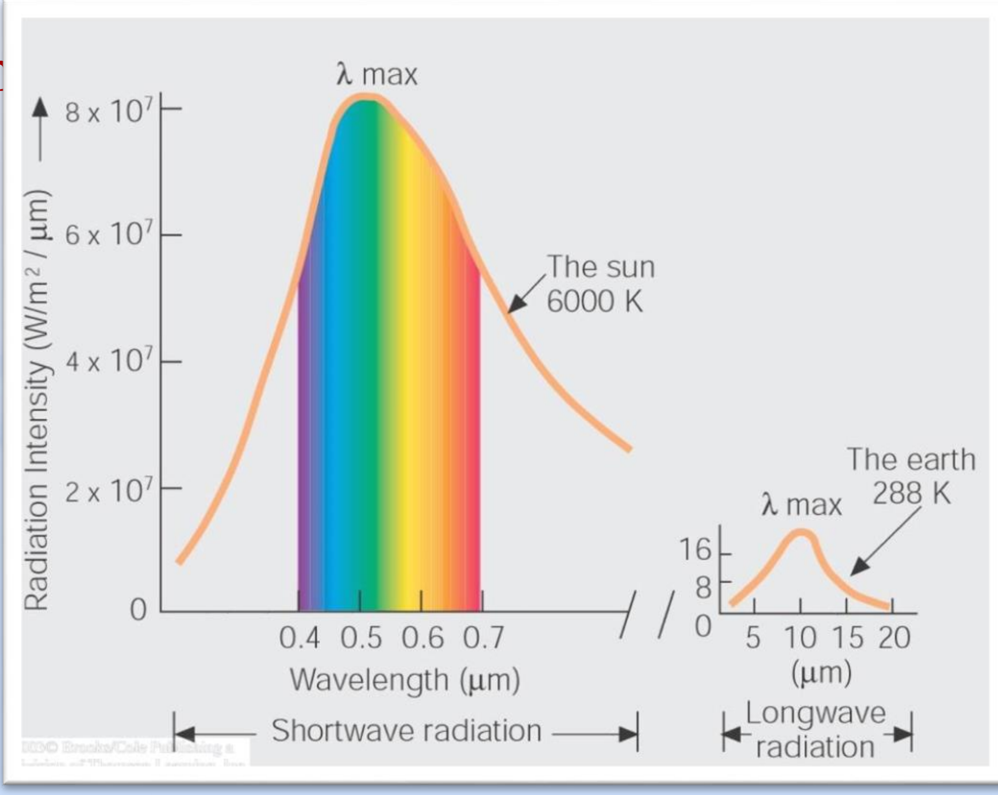
288K = temperature of Earth

$\lambda_{peak\ Earth}$ = 2897/288= 10 μm

NOTE: The hotter the object the shorter the wavelength of the maximum intensity emitted

NOTE: this law is simply derived from

$$\boxed{\partial E_{\lambda} / \partial \lambda = 0}$$



Kirchhoff's Law

The Kirchhoff's law states that the emissivity, e_λ, of a medium is equal to the absorptivity, a_λ, of this medium under thermo-dynamic equilibrium:

$$\boxed{\mathbf{e_\lambda = a_\lambda}}$$

where e_λ is defined as the ratio of the emitting intensity to the Planck function; a_λ is defined as the ratio of the absorbed intensity to the Planck function.

$$(1 - a_\lambda) F_B$$

$$e_\lambda = \frac{F_\lambda}{F_B}$$

$$a_\lambda = e_\lambda$$

$$F_B - F_\lambda - (1 - a_\lambda) F_B = 0$$

$$\frac{F_\lambda}{F_B} = a_\lambda$$

For a blackbody: $\boxed{e_\lambda = a_\lambda = 1}$

For a non-blackbody: $\boxed{e_\lambda \neq a_\lambda < 1}$

For a gray body: $\boxed{e_\lambda = a_\lambda < 1}$

BASIC RADIOMETRIC QUANTITIES

Flux (or irradiance) is defined as radiant energy per unit time per unit wavelength (or frequency) range per unit area perpendicular to the given direction:

$$F_\lambda = dE_\lambda / dt\ dA\ d\lambda$$

UNIT: J sec^{-1} m^{-2} μm = W m^{-2} μm

Intensity (or radiance) is defined as radiant energy in a given direction per unit time per unit wavelength (or frequency) range per unit solid angle per unit area perpendicular to the given direction:

$$I_\lambda = dE_\lambda / d\Omega\ dt\ dA\ d\lambda$$

UNITS: (J sec^{-1} m^{-2} μm^{-1} sr^{-1}) = (W m^{-2} μm^{-1} sr^{-1})

PROPERTIES OF INTENSITY

In general, intensity is a function of the coordinates, direction, wavelength (or frequency), and time. Thus it depends on seven independent variables: three in space, two in angle, one in wavelength (or frequency) and one in time.

Intensity, as a function of position and direction, gives a complete description of the electromagnetic field.

If intensity does not depend on the direction, the electro-

SCATTERING

- Scattering can be broadly defined as the *redirection of radiation out of the original direction of propagation*, usually due to interactions with molecules and particles
- Reflection, refraction, diffraction etc. are actually all just forms of scattering

TYPES OF SCATTERING

- Elastic scattering – the wavelength (frequency) of the scattered light is the same as the incident light (*Rayleigh and Mie scattering*)

- Inelastic scattering – the emitted radiation has a wavelength different from that of the incident radiation (*Raman scattering, fluorescence*)

More on Scattering: Rayleigh and Mie Scattering

The amount of scattered energy depends strongly on the ratio of particle size to wavelength of the incident wave.

When scatters are very small compared to the wavelength of incident radiation ($r < \lambda/10$), the scattered intensity on both forward and backward directions are equal. This type of scattering is called Rayleigh scattering.

For larger particles ($r > \lambda$), 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.

Difference Between Scattering and Absorption

Both scattering and absorption remove flux from an incident wave.

During scattering process flux is not lost from the incident beam but is redistributed over the total solid angle centered around the scatterer and it does not change the internal energy states of the molecules. Absorption changes the internal energy states of the molecules.

Absorption is spectrally selective, scattering is not.

Scattering depends on the ratio of particle size to wavelength of light.

The size of the scattering particle, usually expressed as the non-dimensional size parameter, x:

$$x = \frac{2\pi r}{\lambda}$$

r is the radius of a spherical particle, **λ** is wavelength.

Scattering regimes:

x << 1 : Rayleigh scattering

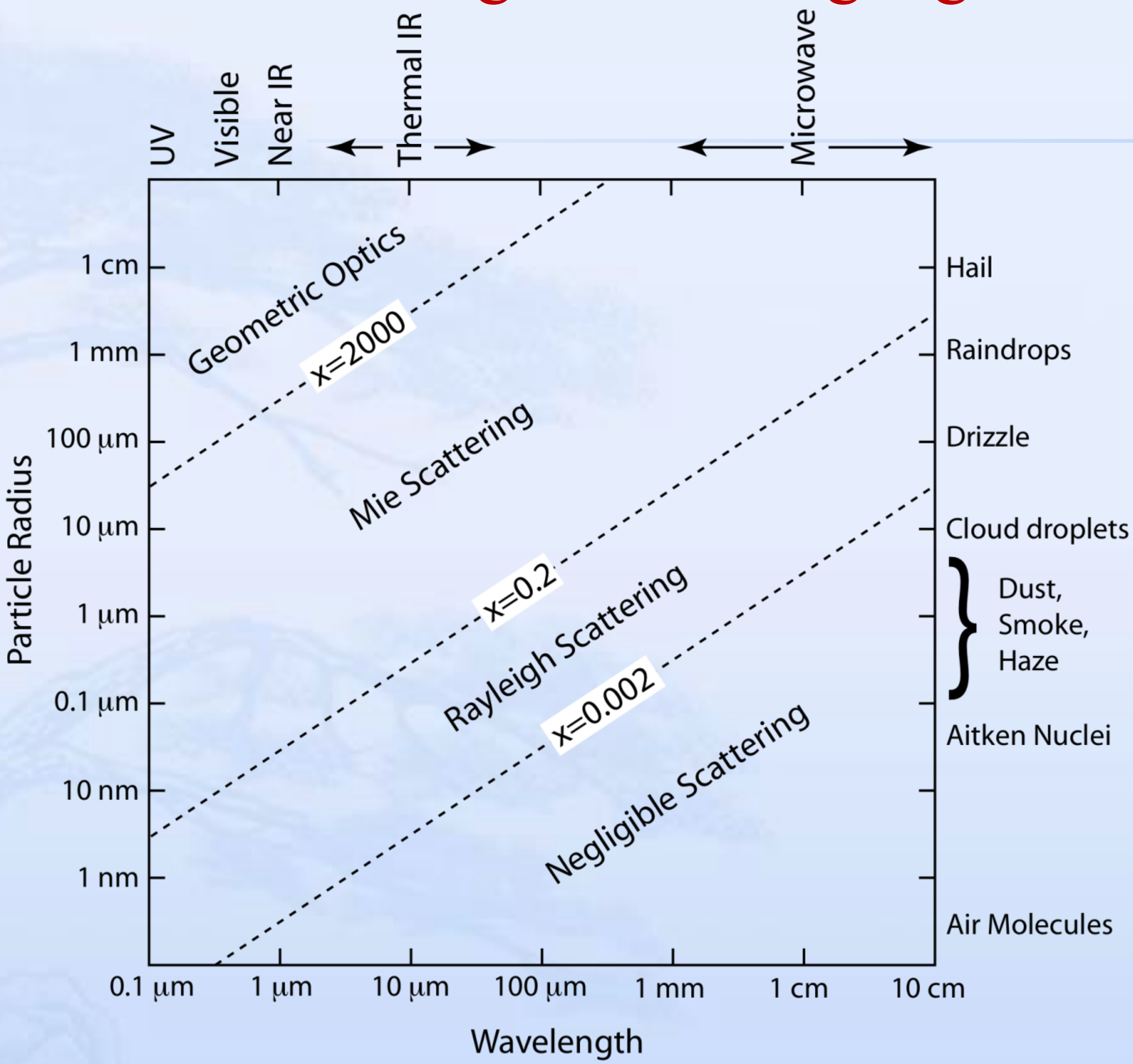
x ~ 1 : Mie scattering

x >>1 : Geometric scattering

Atmospheric particles

Type	Size	Number concentration
Gas molecule	$\sim 10^{-4}$ μm	$< 3\times10^{19}$ cm^{-3}
Aerosol, Aitken	< 0.1μm	$\sim 10^{4}$ cm^{-3}
Aerosol, Large	0.1-1 μm	$\sim 10^{2}$ cm^{-3}
Aerosol, Giant	> 1 μm	$\sim 10^{-1}$ cm^{-3}
Cloud droplet	5-50 μm	10^{2}-10^{3} cm^{-3}
Drizzle drop	~ 100 μm	$\sim 10^{3}$ m^{-3}
Ice crystal	10-10^{2} μm	10^{3}-10^{5} m^{-3}
Rain drop	0.1-3 mm	10-10^{3} m^{-3}

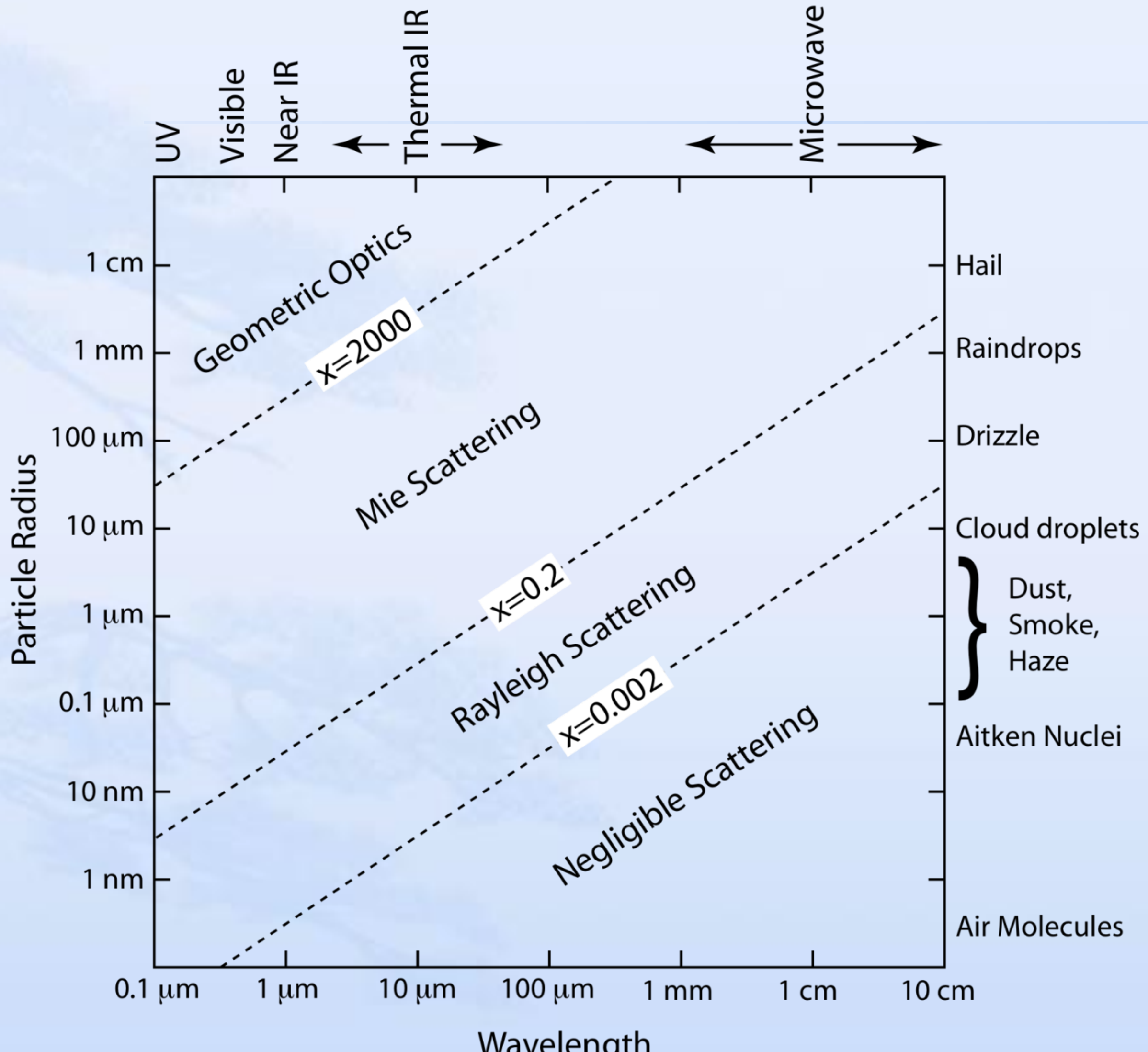
Light scattering regimes



There are many regimes of particle scattering, depending on the particle size, the light wave-length, and the refractive index.

This plot considers only single scattering by spheres. Multiple scattering and scattering by non-spherical objects can get really complex!

Rayleigh regime for raindrops



The Rayleigh regime for raindrops corresponds to wavelengths of ~10 cm

US Operational Weather Radar network: λ = 10.71 cm