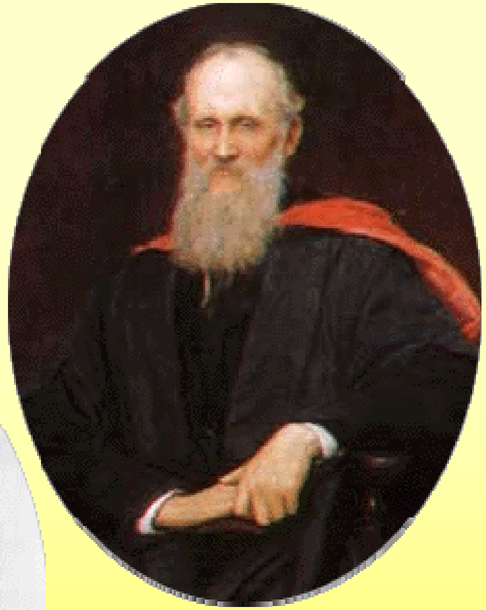
Temperature & Energy
Chapter 2

Anders Celsius
1701 - 1744 Sweden

Joseph Stefan
1835 - 1893 Austria

Ludwig Boltzmann
1844 - 1906 Austria

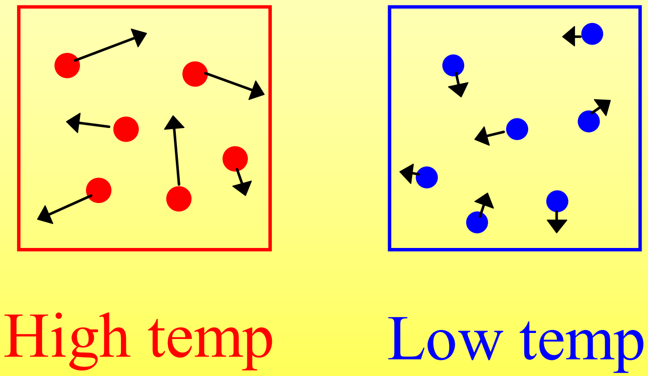


Lord Kelvin (Wm Thomson)
1824 - 1907 Scotland

Wilhelm Wien
1864 - 1928 Germany

Temperature

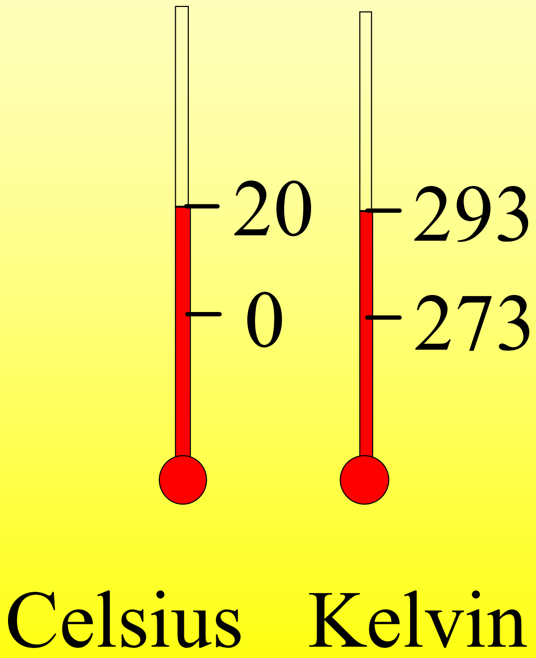
- Temperature is a measure of how much energy of motion (**kinetic energy**) the molecules of a material possess
  - the higher the temperature, the higher the average speed of the molecules
  - at **absolute zero** of temperature, all the kinetic energy of molecules that can be removed has been taken away



- Cold bodies can't heat hotter bodies

Temperature Scales

- Usual temperature scale is °C (*degrees Celsius*)
  - e.g. 20°C; 0°C, etc. [page 27/29]
- In basic relations in physics, temperature is measured **from absolute zero**, in K (*degrees Kelvin*)
  - e.g. 293 K; 273 K
- General conversion:



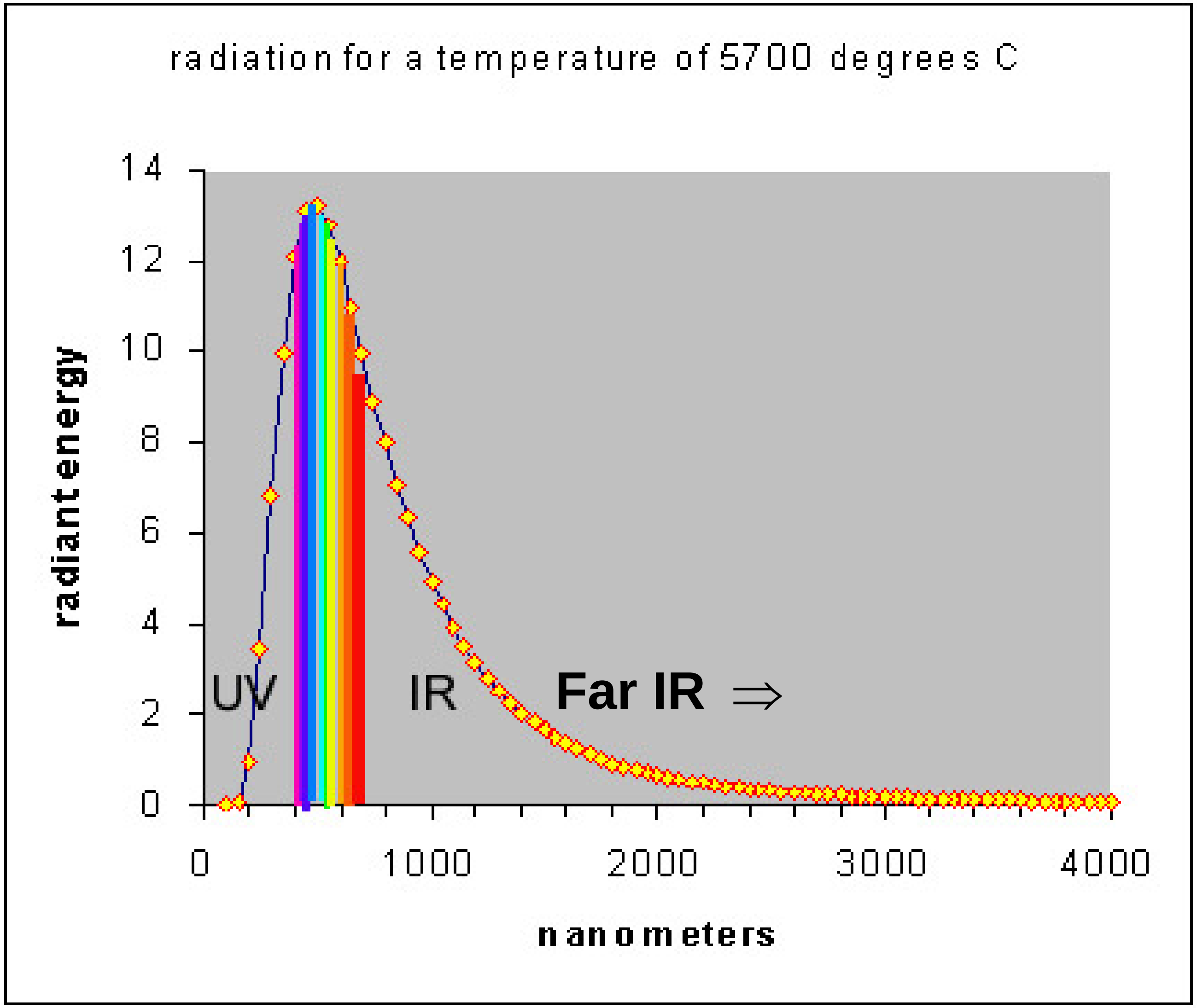
$$\boxed{K = {}^\circ C + 273}$$

The Sun's Radiation

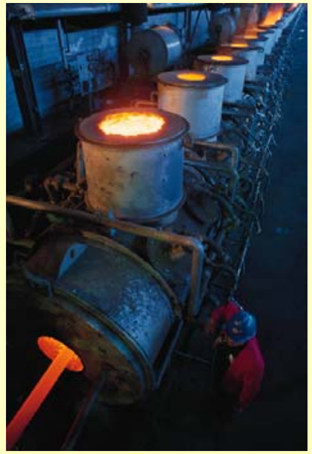
- Radiation from the Sun keeps us and the weather going
- UV (ultra-violet), visible and IR (infra-red) radiation are all important
- Hot bodies usually radiate with a characteristic spread of electromagnetic energy known as **blackbody radiation** [figure 2.9]
  - all bodies radiate electromagnetic energy; what counts is the difference between radiation received and radiation emitted

Blackbody Radiation

- Figure 2.9 simplified



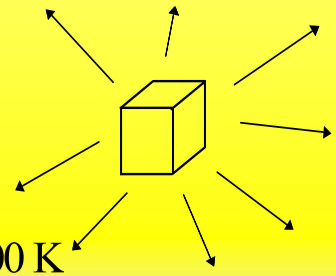
What is a Blackbody?



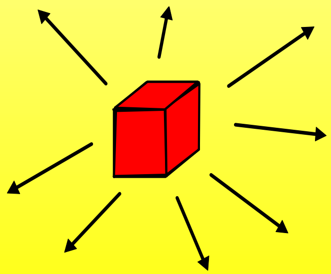
- A blackbody is one that absorbs completely any radiation that falls on it
  - a glowing coal fire or the Sun are good approximations to a blackbody
- Most bodies don't absorb all the radiation that falls on them (this a major reason why bodies are coloured)
  - their radiation is described as blackbody × *an emissivity*, which is a factor ≤ 1 (that may vary with wavelength)

Total Radiant Energy

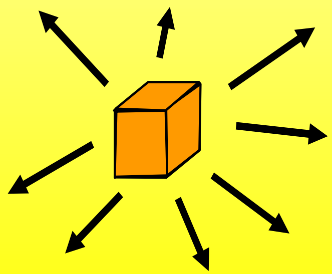
- The total radiant energy (E) emitted per m^2 of surface per second depends on a blackbody's absolute temperature (T) [page 34/36]
- $\boxed{E = \sigma T^4}$, where σ is 5.67×10^{-8} $Wm^{-2}K^{-4}$
  - this is called the **Stefan - Boltzmann Law** and σ is *Stefan's constant*



blackbody at 300 K emits 450 W m^{-2}



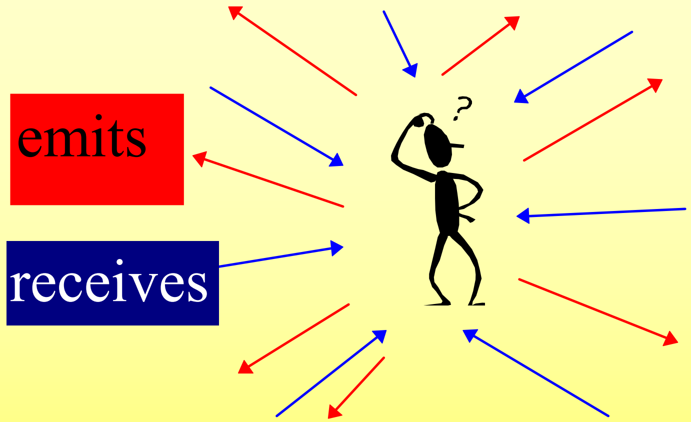
Hot coal 1100 K emits 83 kW m^{-2}



Sun at 6000 K emits 73 MW m^{-2}

Radiation Example

- Non blackbodies typically emit at 0.1 to 0.9 rate of blackbodies
- A blackbody at blood heat of 37°C (310 K) in surroundings at 0°C (273 K):



  - blackbody emits energy $E = \sigma \times 310^4 = 524\ \mathrm{Wm^{-2}}$
  - blackbody receives energy $E = \sigma \times 273^4 = 315\ \mathrm{Wm^{-2}}$
  - net loss of energy = 524 - 315 = 209 $\mathrm{Wm^{-2}}$, which is quite a rate of loss of energy. A person of surface area 2 m^2 emitting at 0.2 blackbody rate loses 88 W

Global Warming Requirement

- **If** the earth were a blackbody at 288 K and you heated it by 1 K, then you would need to provide 5.4 Wm^{-2} to sustain the increased radiation
  - 27.6 $W\ m^{-2}$ for a 5 K temperature increase
- The Earth is not a blackbody but what is its average emissivity?
  - the answer depends on the surface cover (e.g. ice or soil, trees or corn, etc.)
  - the answer is crucial to models of global warming

Wavelength of Maximum Radiation (λ_{max})

- Hot bodies emit the maximum amount of radiation at a wavelength that is inversely proportional to their absolute temperature
- **Wien's Law**: [page 34/36]

$$\boxed{\lambda_{max} = \frac{3000}{T}, \lambda \text{ in } \mu\text{m}, T \text{ in K}}$$

  - e.g. Sun at 6000 K, $\lambda_{max} = 0.5\ \mu m$ (*green*)
  - e.g. us at 300 K, $\lambda_{max} = 10\ \mu m$ (*far infrared*)

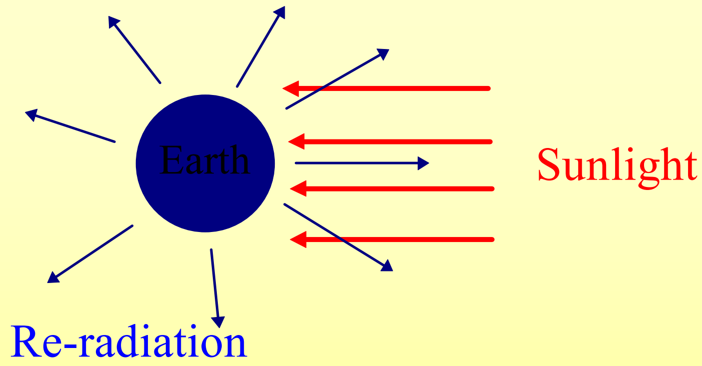
Long and Short Wave Radiation

- Hot Sun emits most of its radiation as *short-wave radiation* [page 35/37], transmitted by the atmosphere
  - UV - 7%
  - visible - 44%
  - near IR - 37%

- Far infrared, longer wavelengths than 1.5 µm, is known as *long-wave radiation*
  - Sun emits 11%
  - Earth emits 100%

Radiation Balance

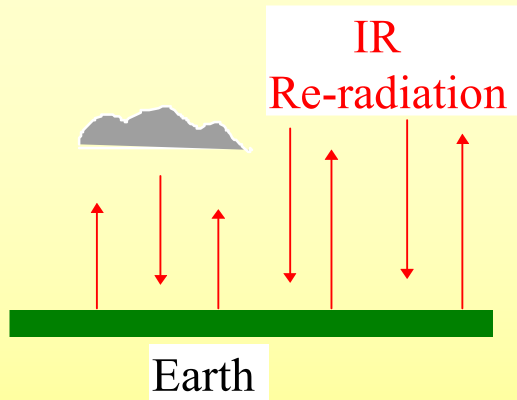
- The Earth receives the Sun's energy from one direction and radiates it back into space in all directions



- Energy balance gives the Earth's **radiative equilibrium temperature** as 255 K (-18°C)
- The average temperature on the Earth's surface is 288 K (15°C)
- The difference is caused by the **atmospheric greenhouse effect**

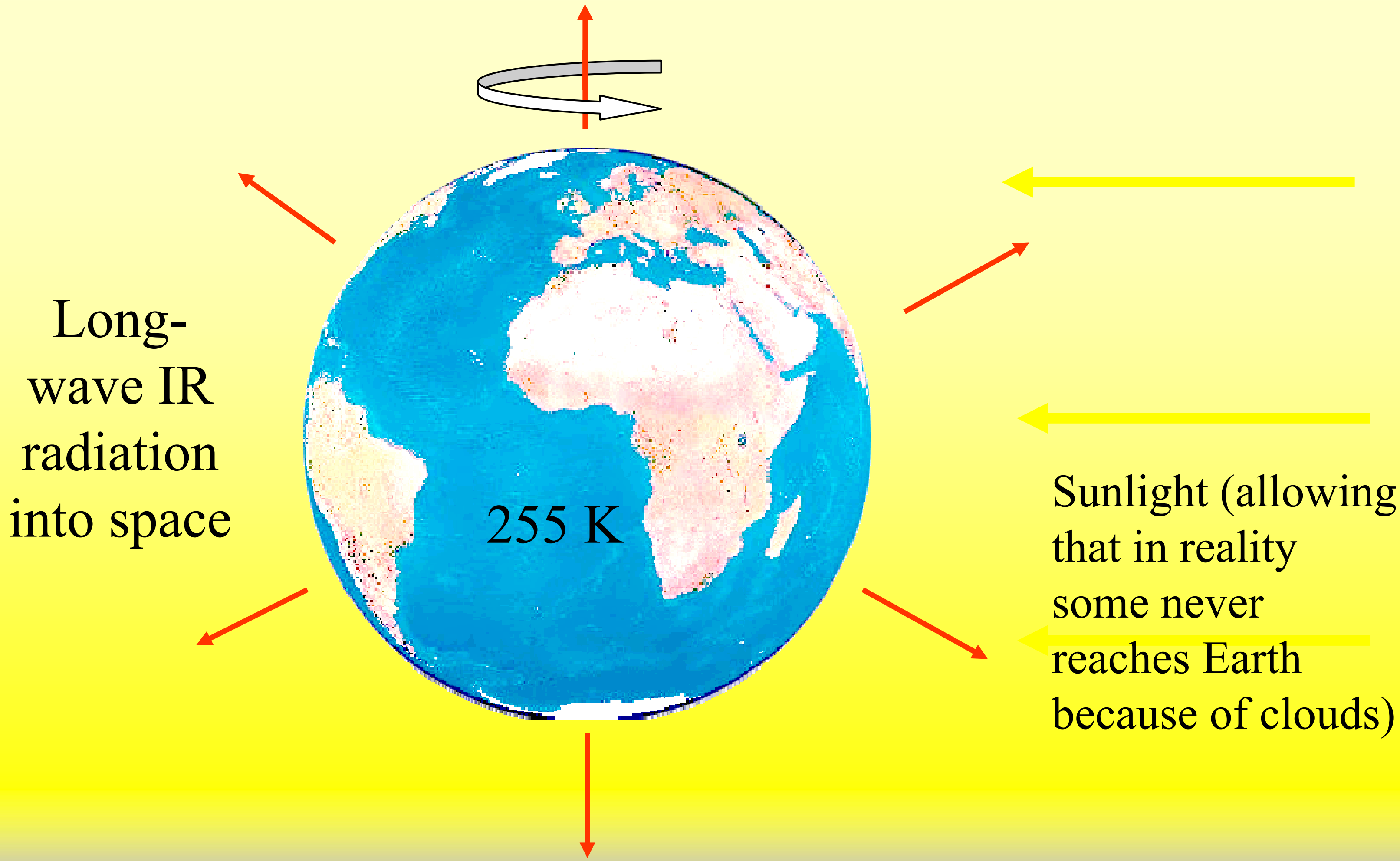
Greenhouse Effect

- Caused by the absorption of escaping long-wave radiation by H_2O, CO_2, CH_4, N_2O, O_3 & CFCs and its re-radiation back to the surface [page 38/40, figure 2.12]

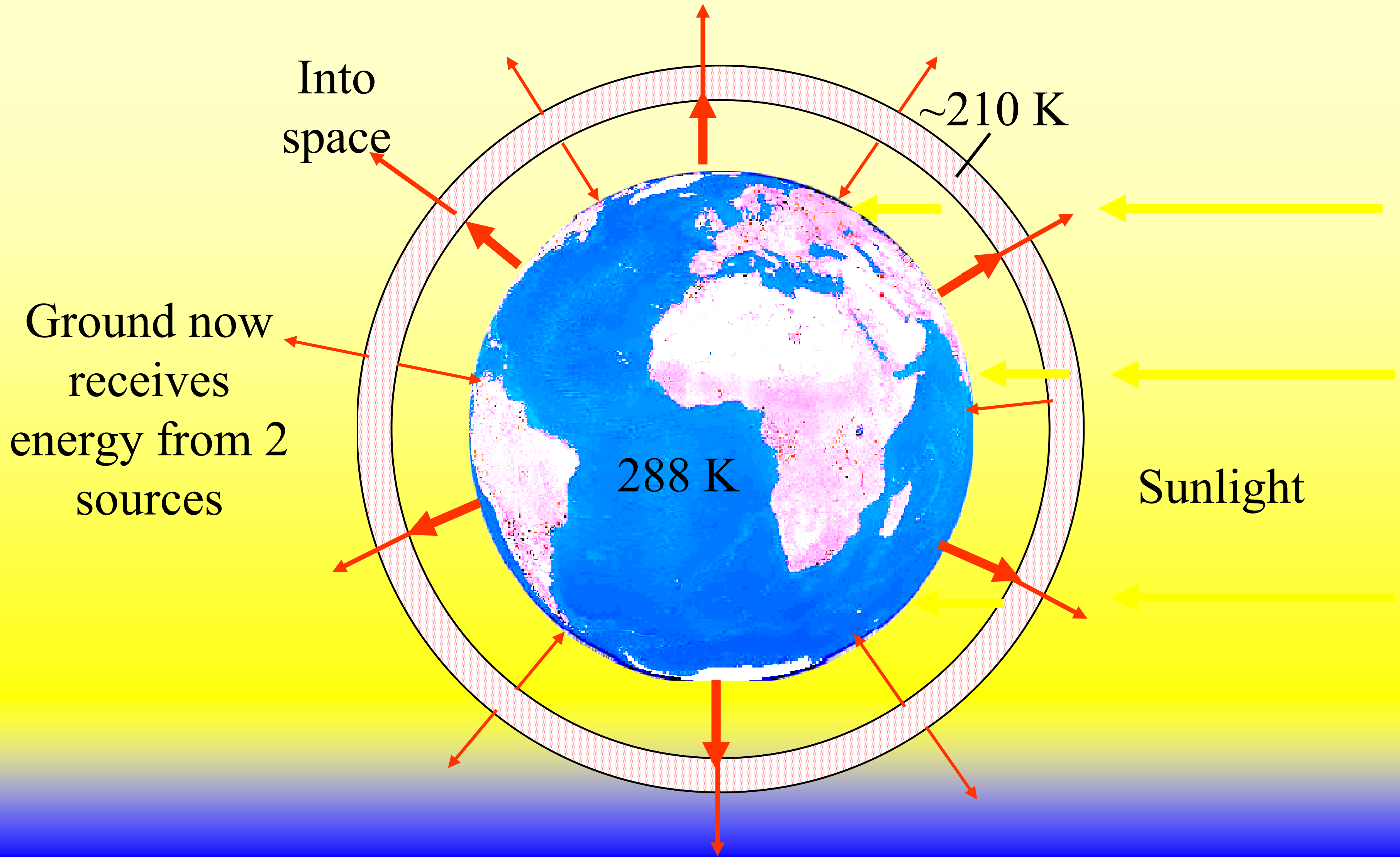


- These *greenhouse gases* make the atmosphere almost opaque to longwave radiation and effectively screen the Earth's surface from the cold of space, raising the temperature by 33°C

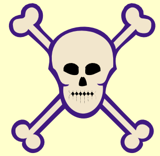
Earth from Space
No atmosphere



Add some atmosphere partly absorbing IR



The Media's Greenhouse Effect

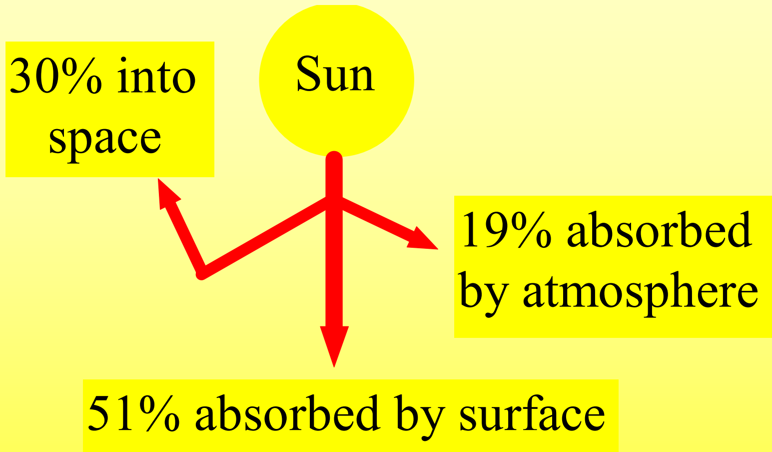


- Overall warming of the Earth due to increased absorption and re-radiation of IR back to the Earth

  - best estimate of observed warming is ~ 0. 6° - 0.8°C for 20^{th} century
    - predicted 2°- 5°C for this one
  - global climate changes will be caused by a few °C rise
- Emphasis on CO_2 is an oversimplification
  - climate change is about more than CO_2

Sun’s Short-wave Energy

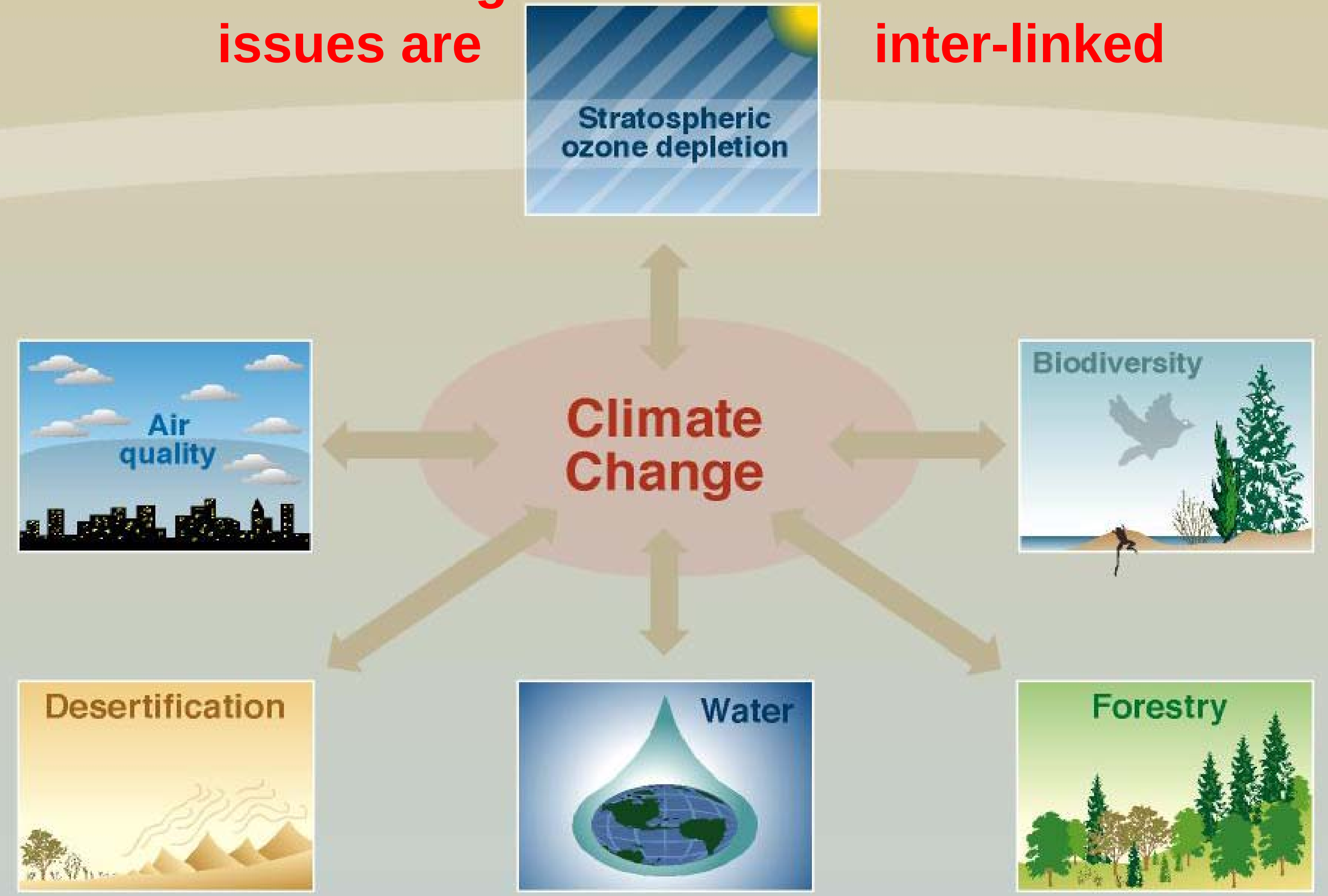
- 30% goes back into space
  - 20% from clouds
  - 6% from atmosphere
  - 4% from surface
  - Earth’s **albedo** is 0.3
- 19% absorbed by clouds
- 51% absorbed by Earth’s surface



Ground - Atmosphere Energy Balance

- The Earth's surface receives 147% of the Sun's incident radiation
  - 51%, only, comes directly from the Sun
  - 96% comes from IR re-radiated by clouds and atmosphere [figure 2.16]
    - 96% = 47% IR from ground, 19% from Sun; 30% latent heat and convection

Climate change and other environmental issues are inter-linked



Courtesy: IPCC, see the next chapter