Global Energy Balance

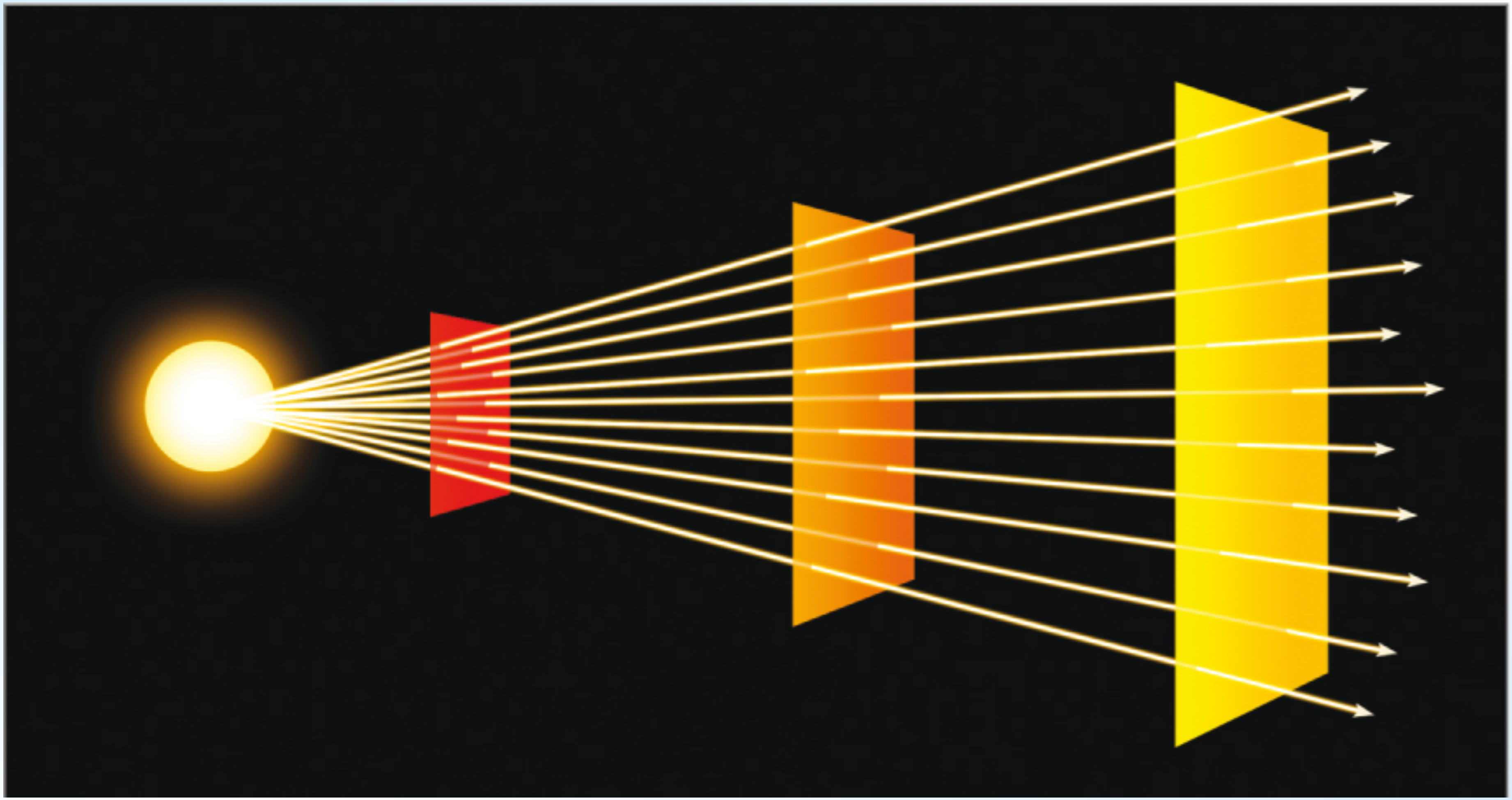
GEOG/ENST 2331: Lecture 4

Ahrens: Chapter 2

Lab 1

Absorption and Transmission

- When radiation reaches the atmosphere, it can be scattered, reflected, absorbed or transmitted
  - *Albedo* determines how much is reflected/scattered
  - *Absorptivity* determines how much of what is left is absorbed or transmitted
- *Black bodies* absorb all non-reflected radiation
- *Selective absorbers* absorb only specific wavelengths, remainder is transmitted



Ahrens: Ch. 2 Fig. 2

Total Solar Irradiance (S)

- *Quantity* of electromagnetic radiation is not reduced with distance through a vacuum
- *Intensity* is reduced as energy becomes distributed over a larger area
- Therefore, radiation intensity decreases in proportion to the square of the distance

Irradiance

- ***Inverse square law***

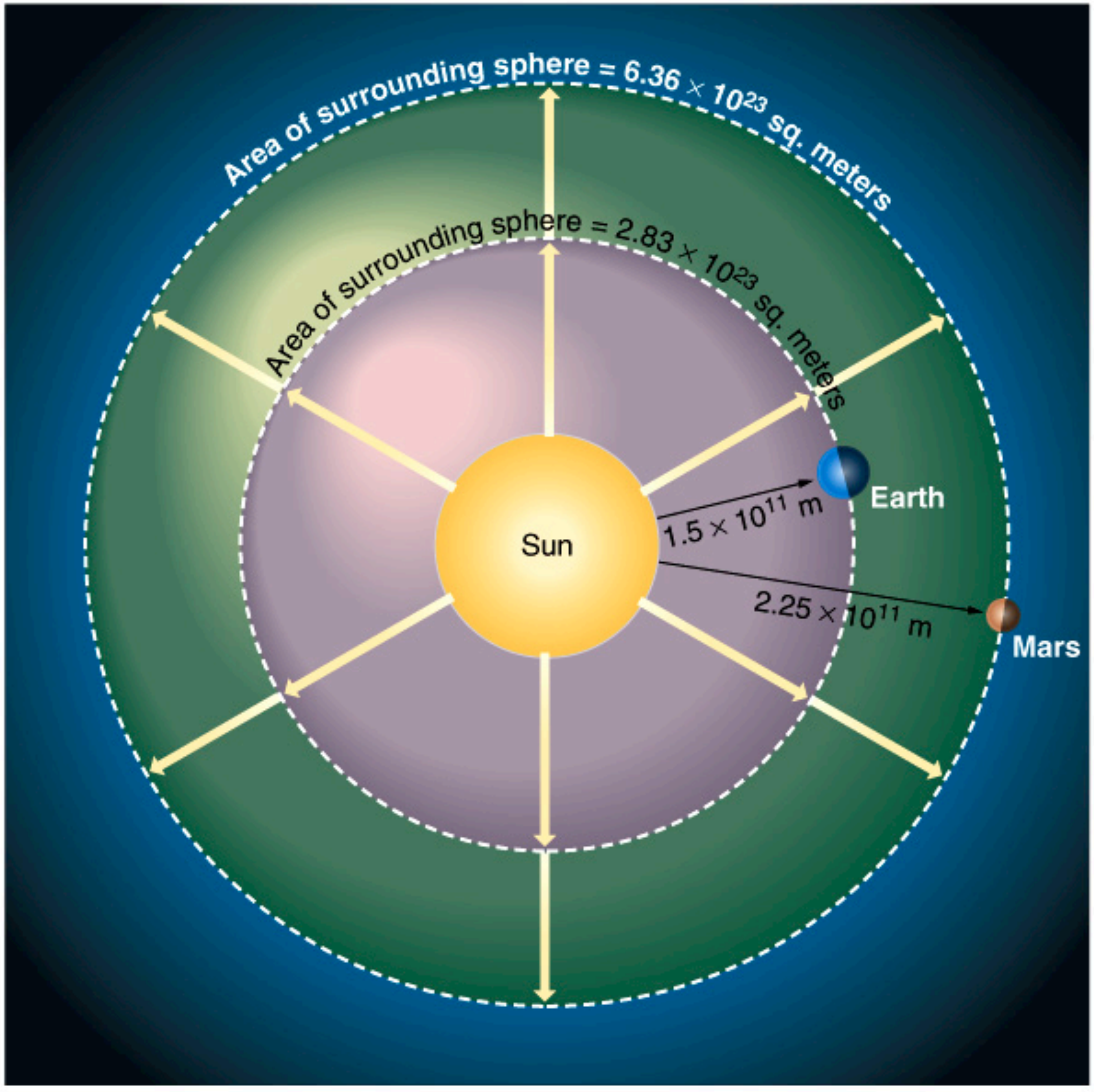
S is proportional to $\dfrac{1}{d^2}$

- **Earth:**

$S = 1380\ \mathrm{Wm^{-2}}$

- **Mars:**

$S = 445\ \mathrm{Wm^{-2}}$



A&B: Figure 2.9

Area of interception

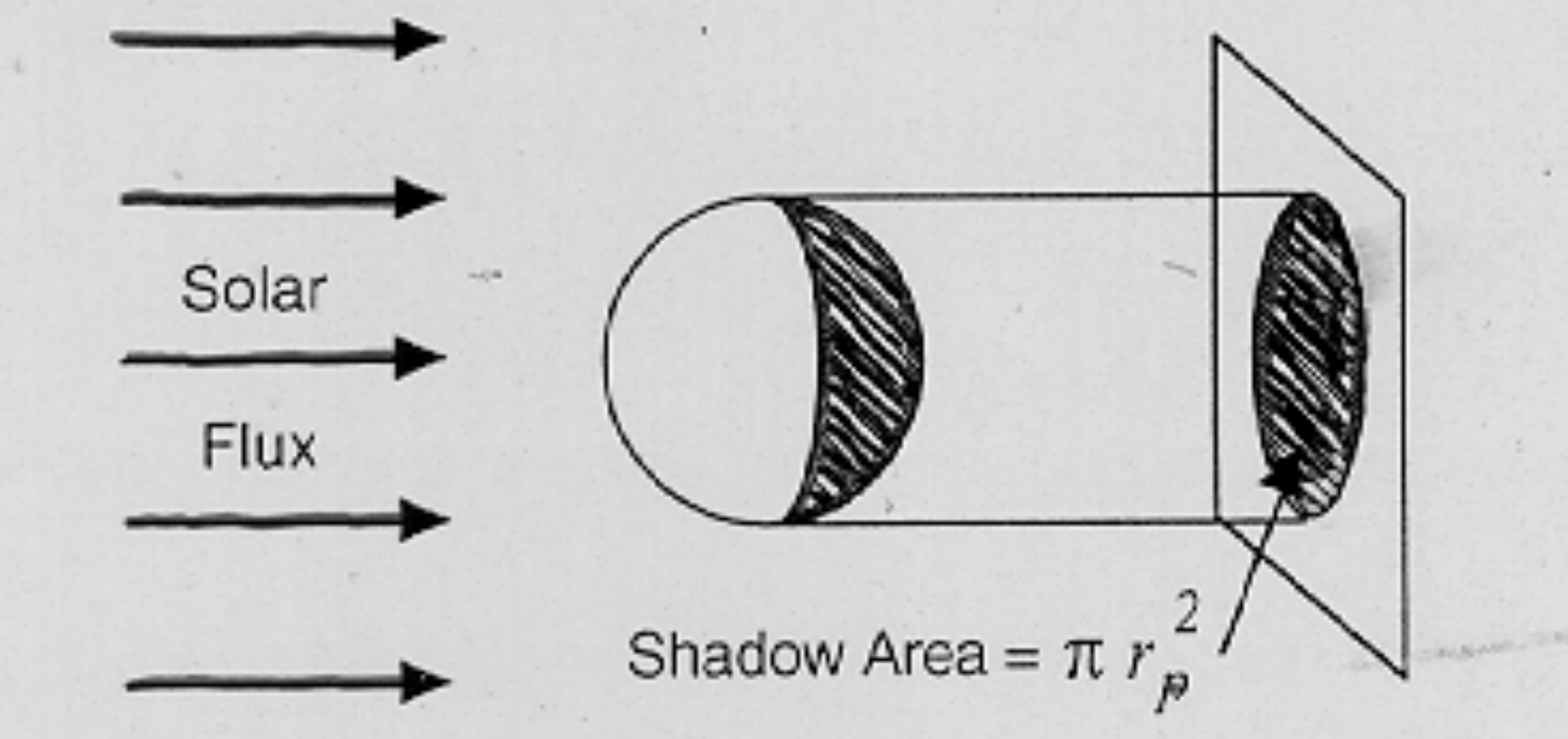


Fig. 2.2 Diagram showing the shadow area of a spherical planet.

First Law of Thermodynamics

- Energy cannot be created or destroyed

- If a system is at equilibrium, the amount of energy coming in must be equal to the amount of energy going out.

Total solar irradiance

- 1380 W m^{-2}
  - Incoming shortwave radiation
  - 30% reflected, 70% is absorbed

- $1380 \times 0.7 = 967$ Wm^{-2}
  - *Absorbed* incoming radiation
  - Must be matched by outgoing IR radiation

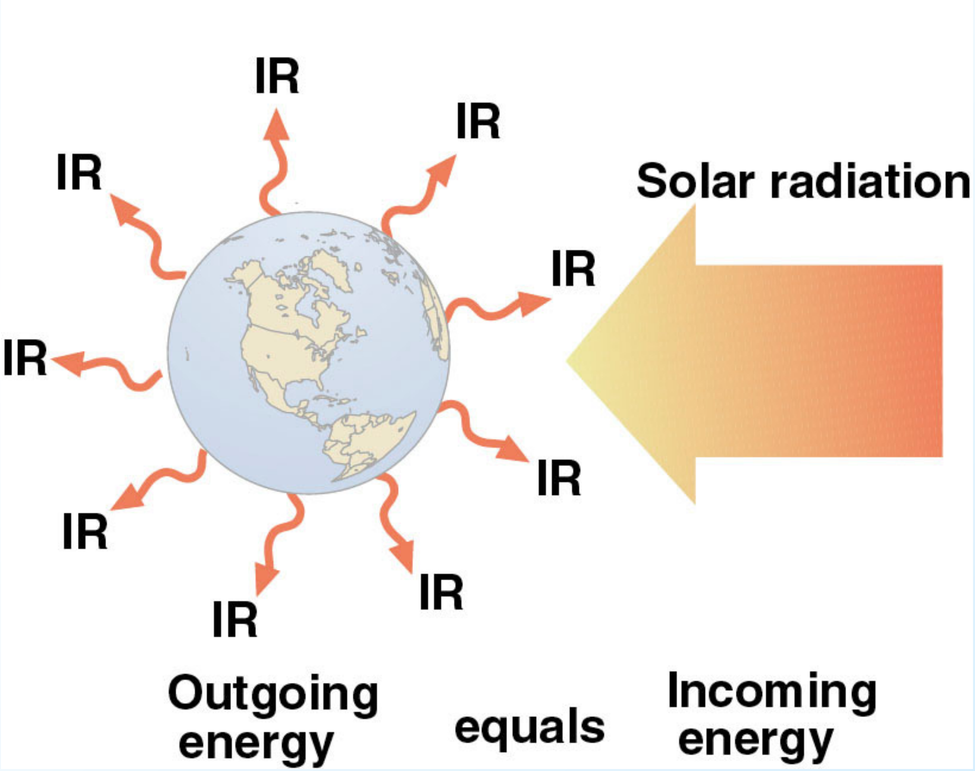
Incoming and Outgoing

- Incoming radiation
  - Intercepted on a circle

$$\text{area} = \pi r_e^2$$

- Outgoing radiation
  - Radiated over a sphere

$$\text{area} = 4\pi r_e^2$$



Ahrens, p. 44, Fig. 4

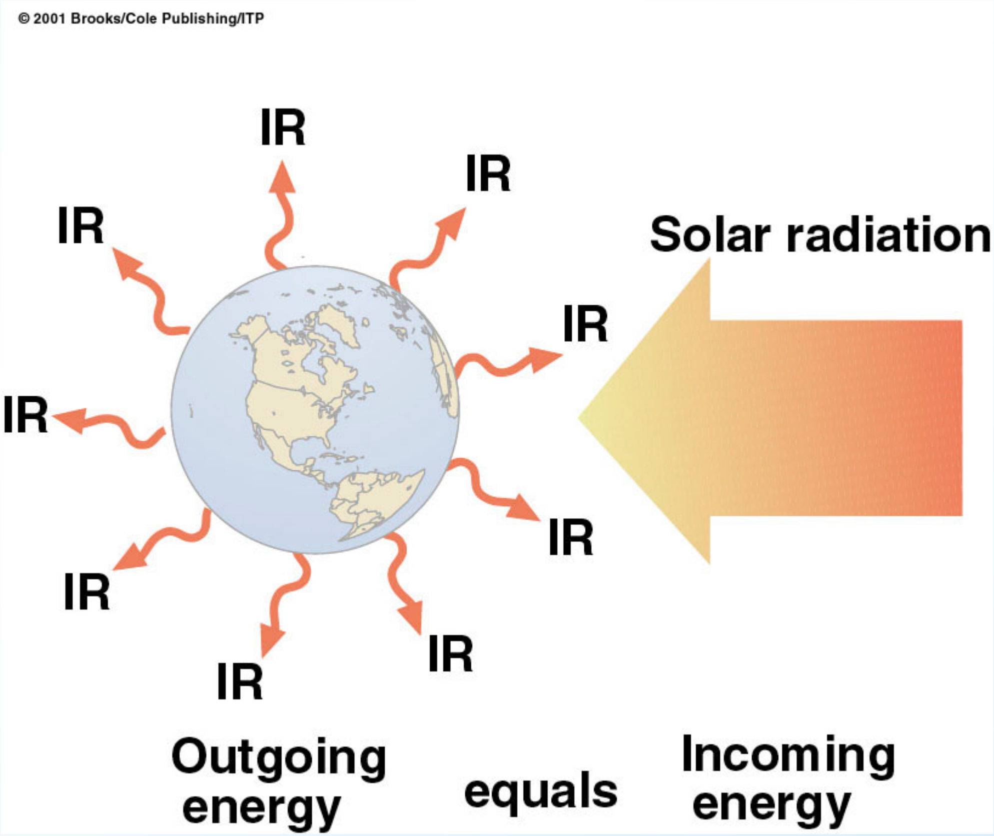
Energy Balance

Incoming = $967 \times \pi r_e^2$

Outgoing = $\sigma T_e^4 \times 4\pi r_e^2$
(Earth is a blackbody)

Therefore: $\sigma T_e^4 = 967/4$
$= 242\ \mathrm{Wm^{-2}}$

Solve to get $T_e = 255$ K



Radiative Equilibrium Temperature

- Longwave emission matches shortwave absorption
- If you measured the Earth's outgoing radiation from space, this would be the temperature you would calculate
- 255 K = -18°C

Exchange with the atmosphere

- Objects radiate in all directions
  - Earth and Sun radiate outward from all around their spherical surface
  - Atmosphere is a hollow sphere; radiates both out (up) and in (down)

- There is an exchange of radiation between Earth and atmosphere

Greenhouse calculation

- Model the atmosphere as one thin layer that:
  - Absorbs 10% of the incoming solar radiation
  - Absorbs 80% of the outgoing terrestrial radiation
- For the entire sphere, let:
  - x be the radiation emitted from the surface,
  - y be the radiation emitted from the atmosphere, and
  - I be non-reflected radiation entering the top of the atmosphere from the Sun.

I: *non-reflected incoming radiation*

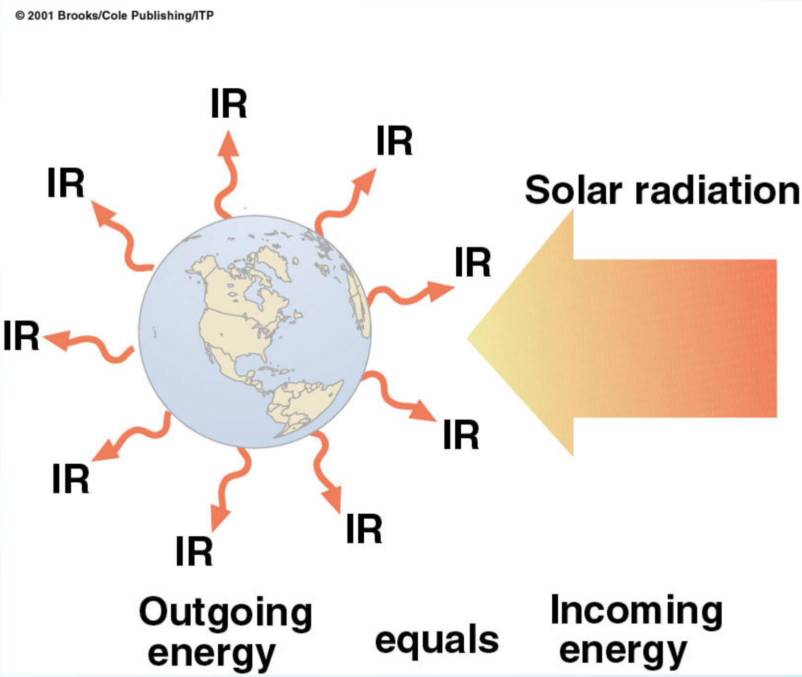
Total solar irradiance

S = 1380 W m^{-2}

The average albedo A = 0.3

Ratio of area of absorption (circle) to area of emission (sphere) is 1/4

$I = S(1-A)/4 = 967/4 = 242$ Wm^{-2}



Greenhouse calculation

What do we know about x and y?

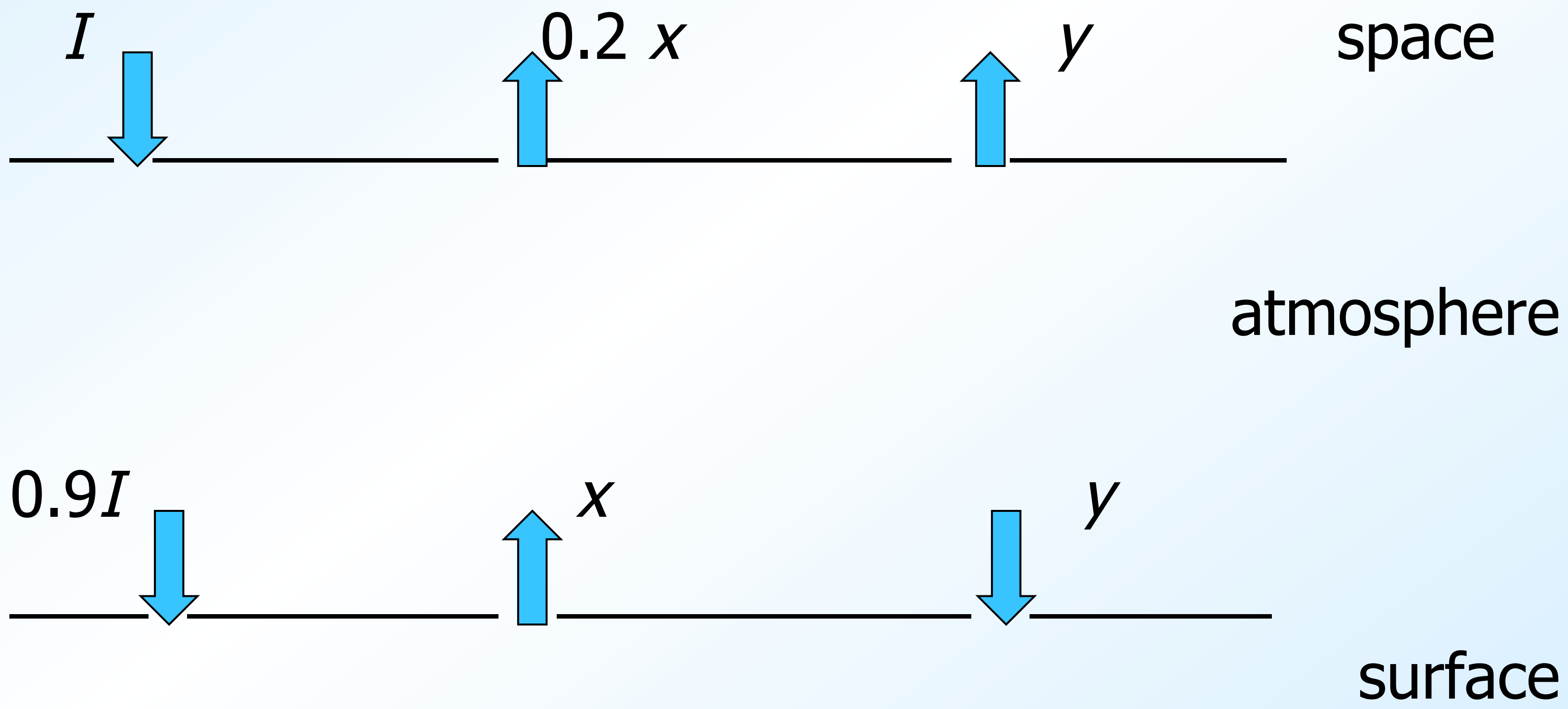
Stefan-Boltzmann law:

$x = \sigma T_s^4$

$y = \varepsilon\sigma T_a^4 = 0.8\ \sigma T_a^4$

Why 0.8? Kirchhoff's law: $\varepsilon_\lambda = a_\lambda$

Greenhouse model



Greenhouse calculation

Balance for each level

Space: $I = 0.2x + y$

Surface: $0.9I = x - y$

Two equations, two unknowns

Greenhouse gas calculation

- Solve for *x* and *y*

$$1.9I = 1.2x$$

$$x = \frac{1.9}{1.2}I = 382.8\ \mathrm{Wm}^{-2}$$

$$y = I - 0.2x = 165.2\ \mathrm{Wm}^{-2}$$

Greenhouse calculation

We now have:

$x = \sigma T_s^4 = 382.8\ \mathrm{Wm^{-2}}$

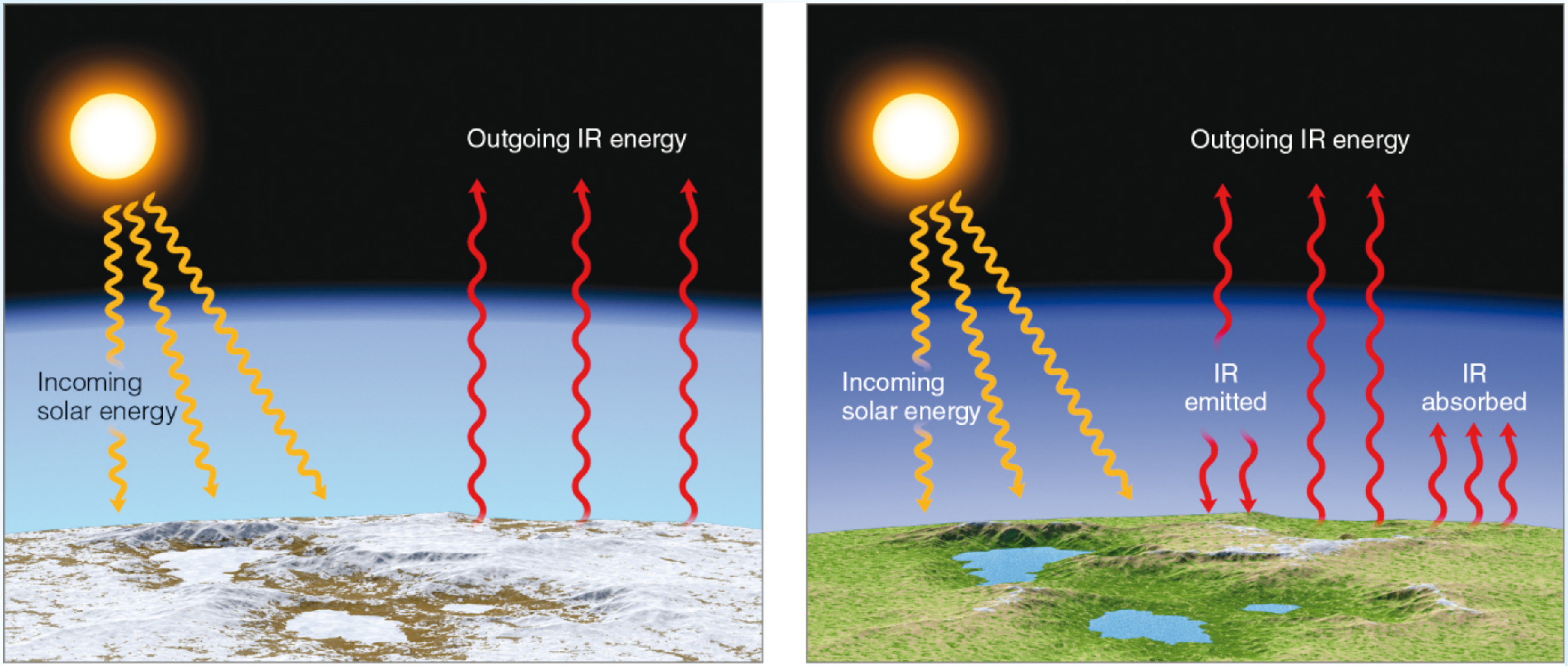
$y = 0.8\sigma T_a^4 = 165.2\ \mathrm{Wm^{-2}}$

Therefore:

$T_s = 287$ K, $T_a = 246$ K

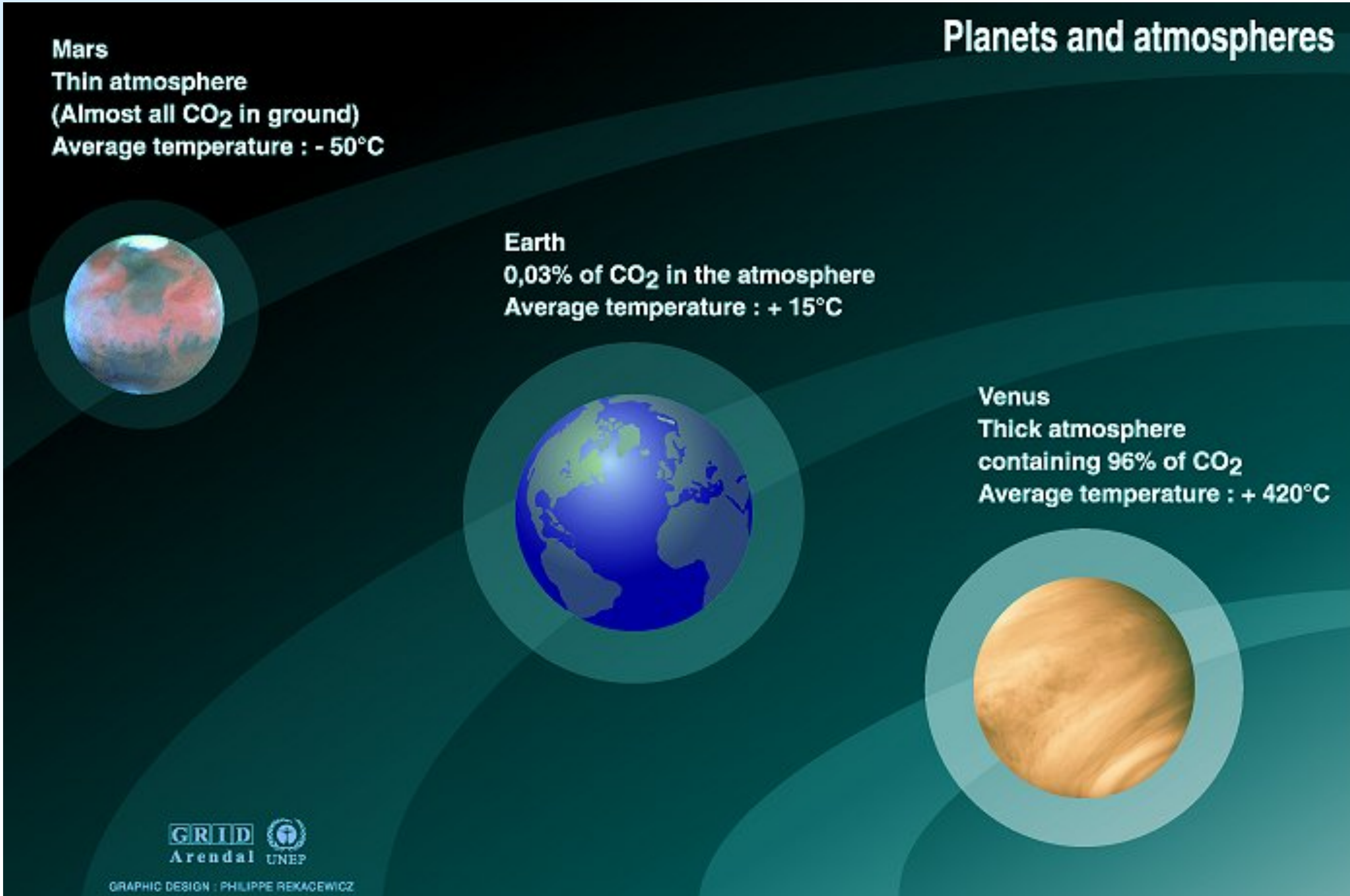
Note: Surface temperature is higher than 255 K calculated without atmosphere

The Greenhouse Effect



255 K   288 K

Ahrens, Fig. 2.12



Sources: Calvin J. Hamilton, Views of the solar system, www.planetscapes.com; Bill Arnett , The nine planets, a multimedia tour of the solar system, www.seds.org/billa/tnp/nineplanets.html

Next lecture

- Temperature distribution
  - Not uniform in time and place
- Ahrens: Chapter 3