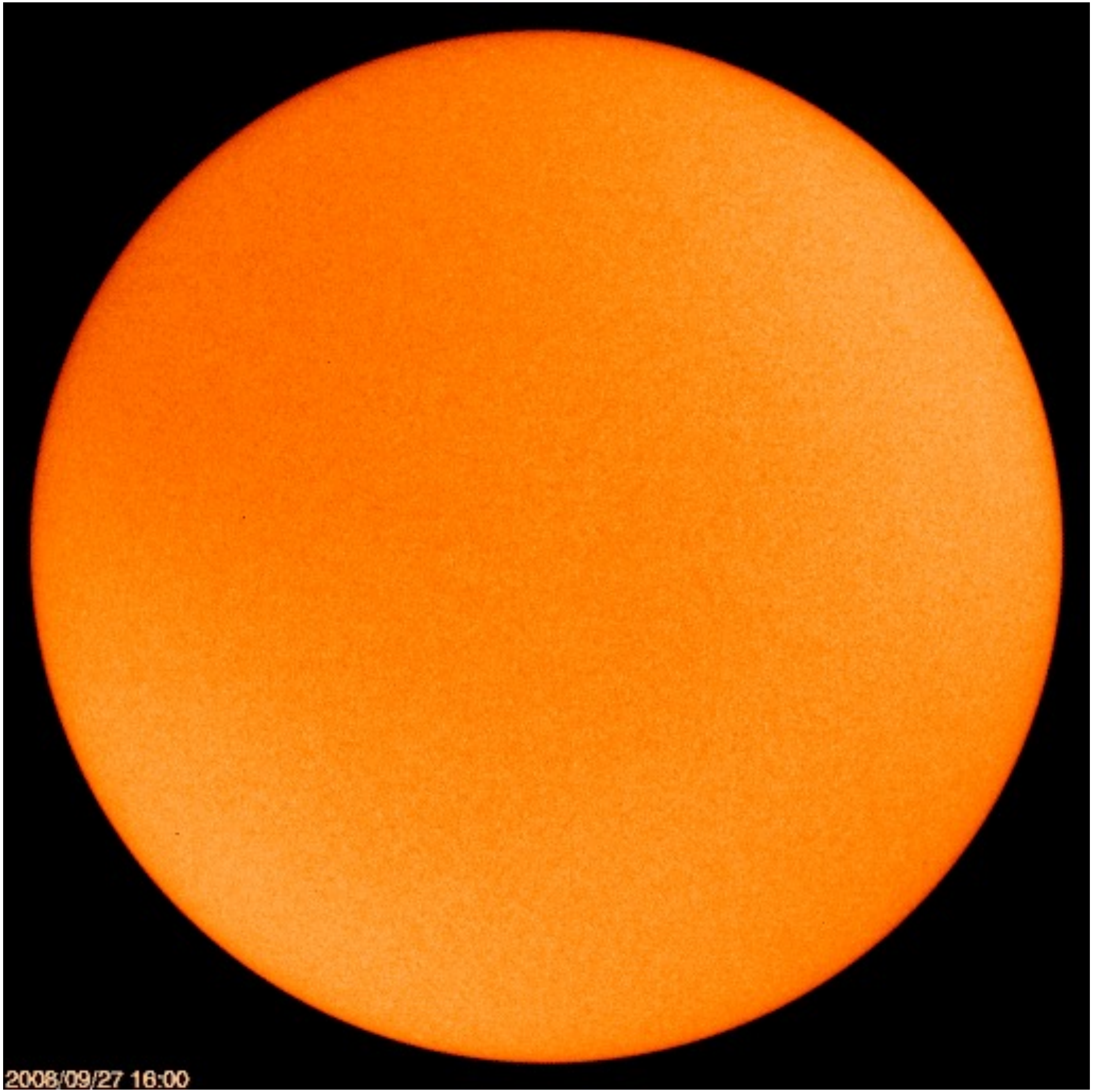
The Sun

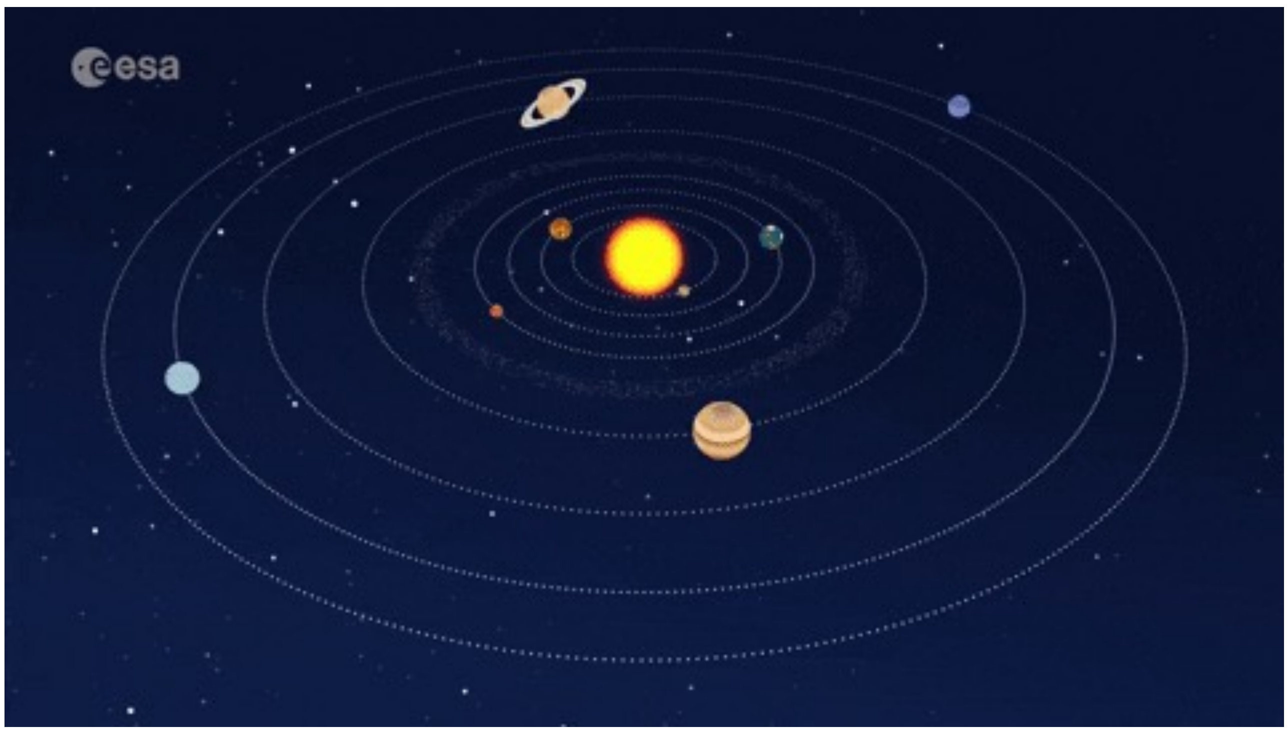
- Properties
- Lifetime
- Energy Source
- Solar Atmosphere



science.nasa.gov

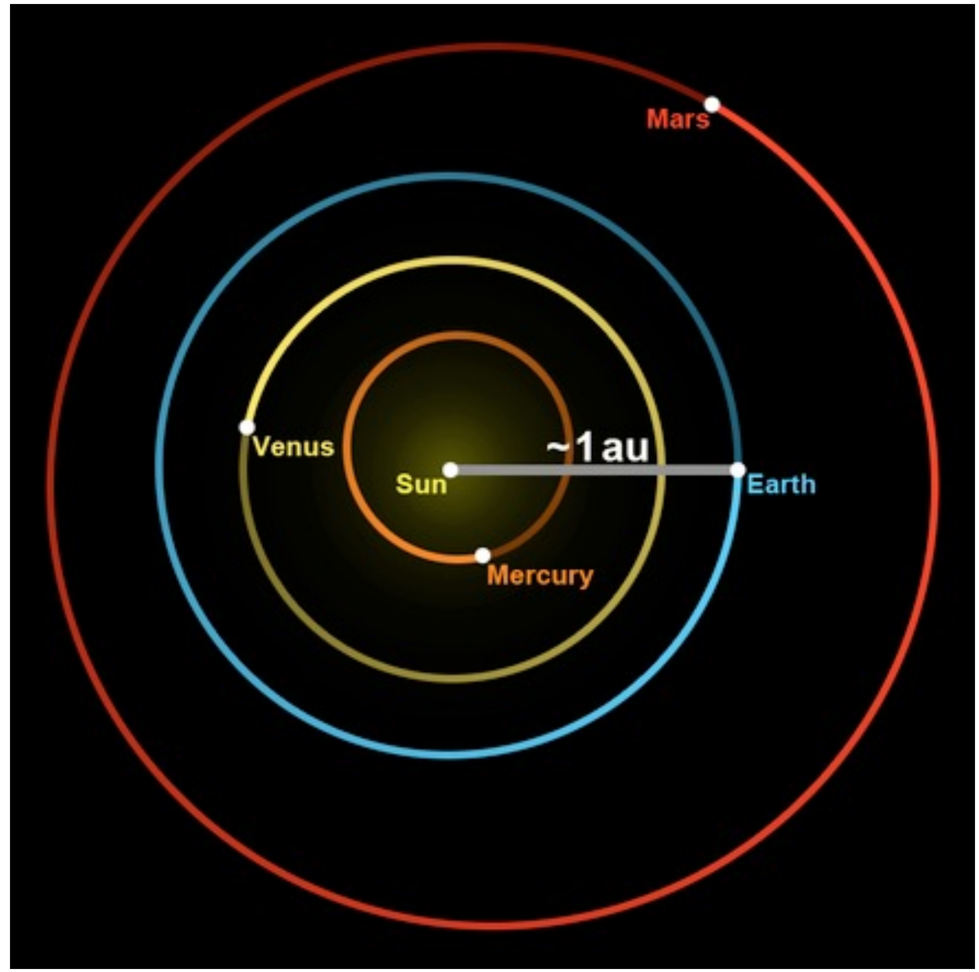
Properties

- Mass = 2×10^{30} kg = 1 $M_{\odot}$
  - (Kepler's Law – later in module)



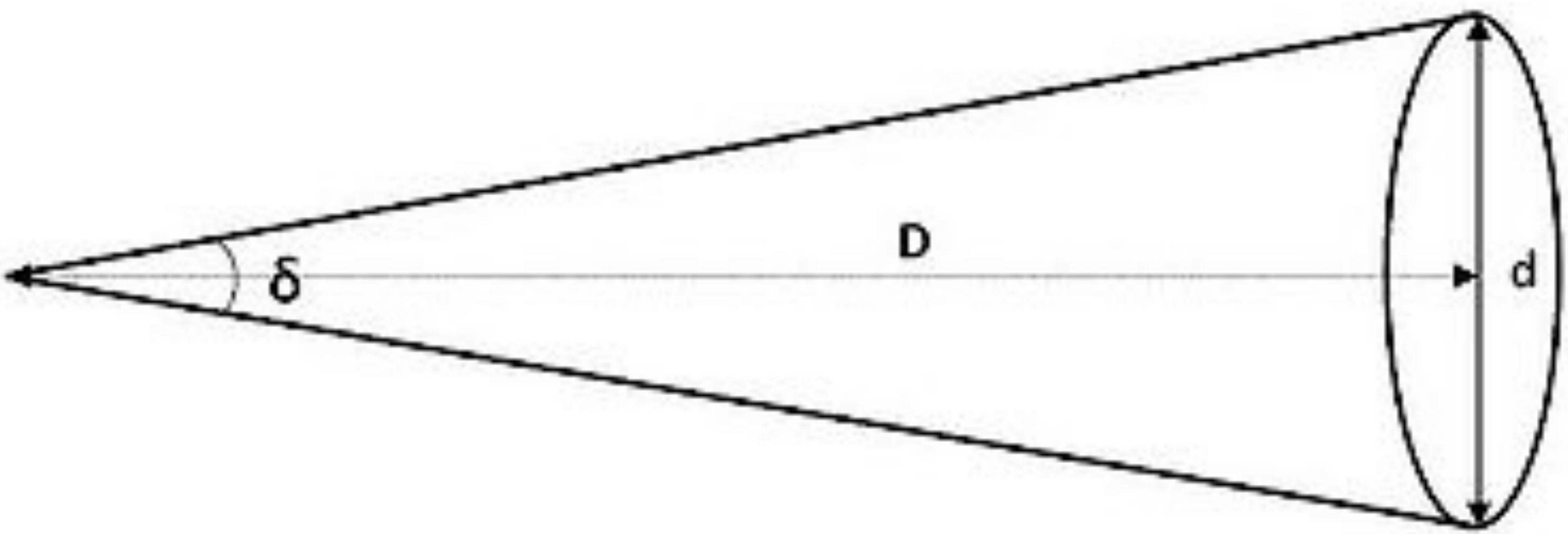
Properties

- Distance = 1.5×10^{11} m = 1 au
  - (Parallax of planets and Kepler's Law)



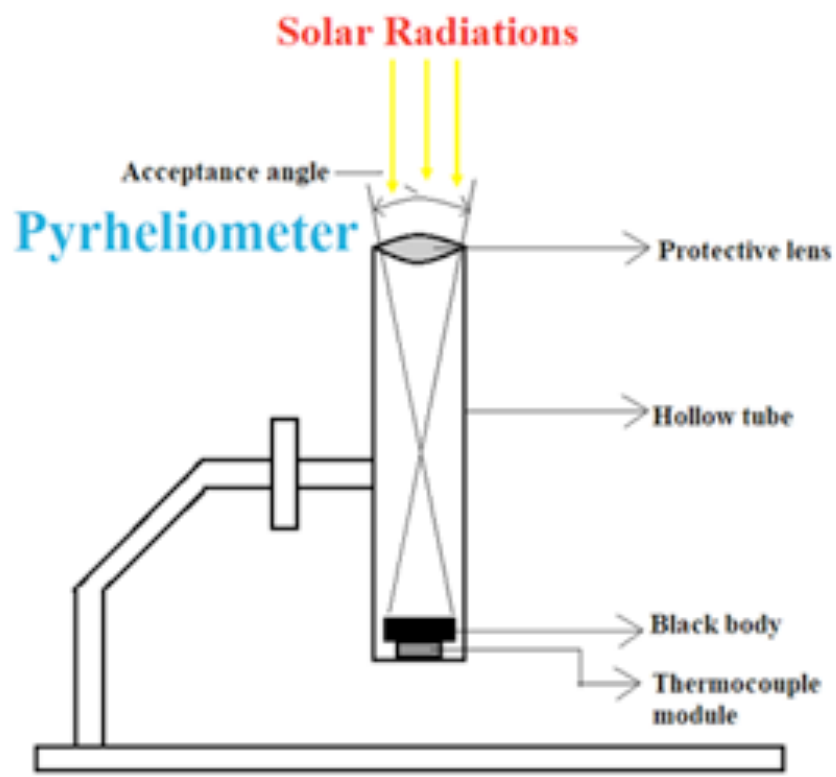
Properties

- Radius = 7 x 10^8 m = 1 $R_\odot$
  - (θ and d)



Properties

- Luminosity = 4 x 10^{26} W = 1 $L_{\odot}$
  - (Flux and d)



Class exercise

- Assuming the Sun is made of pure ionized hydrogen calculate how many protons are in the Sun

Class exercise

- Assuming the Sun is made of pure ionized hydrogen calculate how many protons are in the Sun

$$N = \frac{M}{m_H}$$

$$= \frac{2 \times 10^{30}}{1.7 \times 10^{-27}}$$

$$= 1 \times 10^{57}$$

Lifetime

- Geological evidence

  $\rightarrow$ at least 5 x 10^9 years
- Stellar evolution theory

  10 x 10^9 years
- Energy required

$$
\begin{aligned}
E &= L\tau \\
&= 4.10^{26} \times 10.10^{9} \times 3.10^{7} \\
&= 1.10^{44}\ \mathrm{J}
\end{aligned}
$$

Nuclear Fusion

- In the core of the Sun
  - $T = 1 \times 10^7$ K
  - $P = 10^9$ atmospheres
- Sufficient for fusion of hydrogen nuclei into helium

$$4\,{}^{1}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \nu + \gamma$$

- Energy arises from mass difference

$$m(4\,{}^{1}\mathrm{H}) - m({}^{4}\mathrm{He}) = 0.0286\ \mathrm{amu}$$

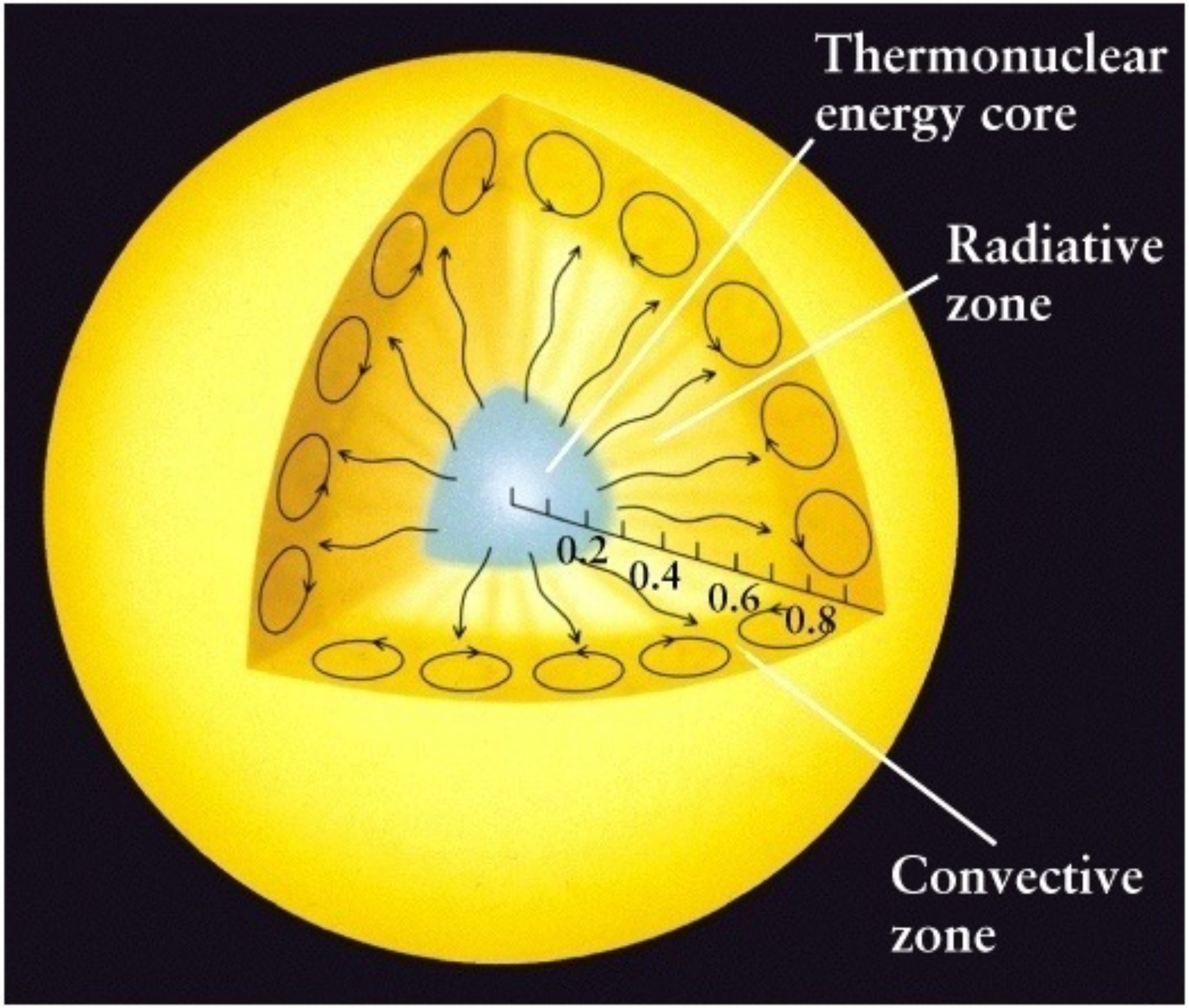
or 0.7% of the mass.

- Core of the Sun contains about 10% of the total mass
- Total energy available

$$= \Delta m c^2$$

$$= 0.10 \times 0.007 \times 2 \times 10^{30} \times \left(3 \times 10^{8}\right)^2$$

$$= 1 \times 10^{44}\ \mathrm{J}$$



From Universe textbook

Class Question

What stops the Sun collapsing under its own weight?

A. The strong nuclear repulsion between the atoms of these layers.
B. The outward flow of neutrinos exerts a strong outward pressure.
C. The pressure of the radiation flowing out through the star.
D. The pressure of the very high-temperature gas within the Sun supports the outer layers.
E. The interior of the Sun is under such high pressure that it is solid.

Class exercise

- Use the atomic masses of ^{1}H and ^{4}He (e.g. Tipler 40-1 or any physical data handbook) to show that 0.7% of the rest mass is converted to energy during the nuclear fusion process in the Sun.

Class Question

What stops the Sun collapsing under its own weight?

A. The strong nuclear repulsion between the atoms of these layers.
B. The outward flow of neutrinos exerts a strong outward pressure.
C. The pressure of the radiation flowing out through the star.
D. The pressure of the very high-temperature gas within the Sun supports the outer layers.
E. The interior of the Sun is under such high pressure that it is solid.

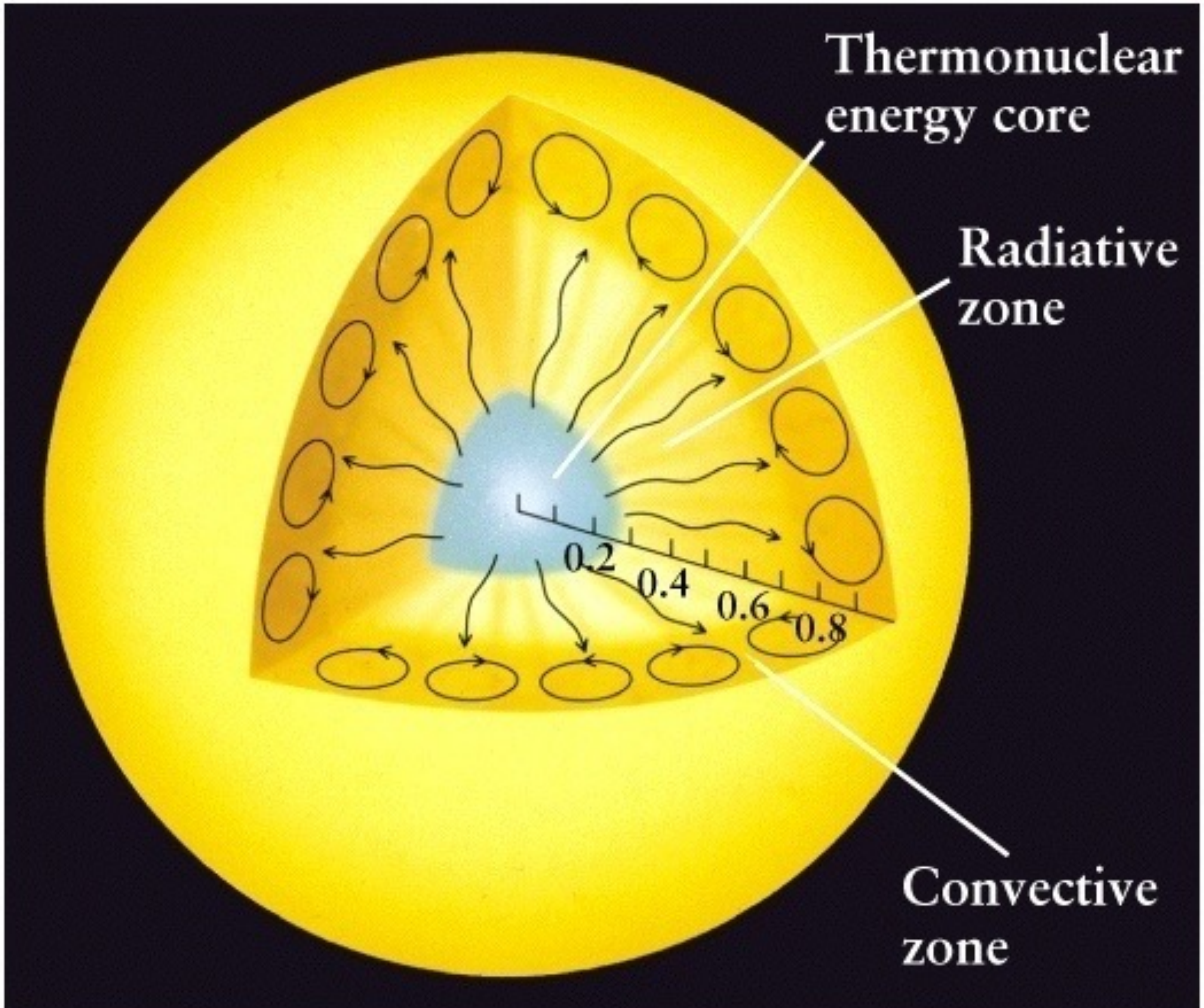
Class exercise

$$4\,{}^{1}\mathrm{H} \rightarrow {}^{4}\mathrm{He}$$

$$\text{so } \Delta m = 4 \times 1.0078 - 4.0026$$

$$= 4.0312 - 4.0026 = 0.0286 \text{ amu}$$

$$\text{and } \frac{\Delta m}{m} = \frac{0.0286}{4.0312} = 0.0071 = 0.7\%$$



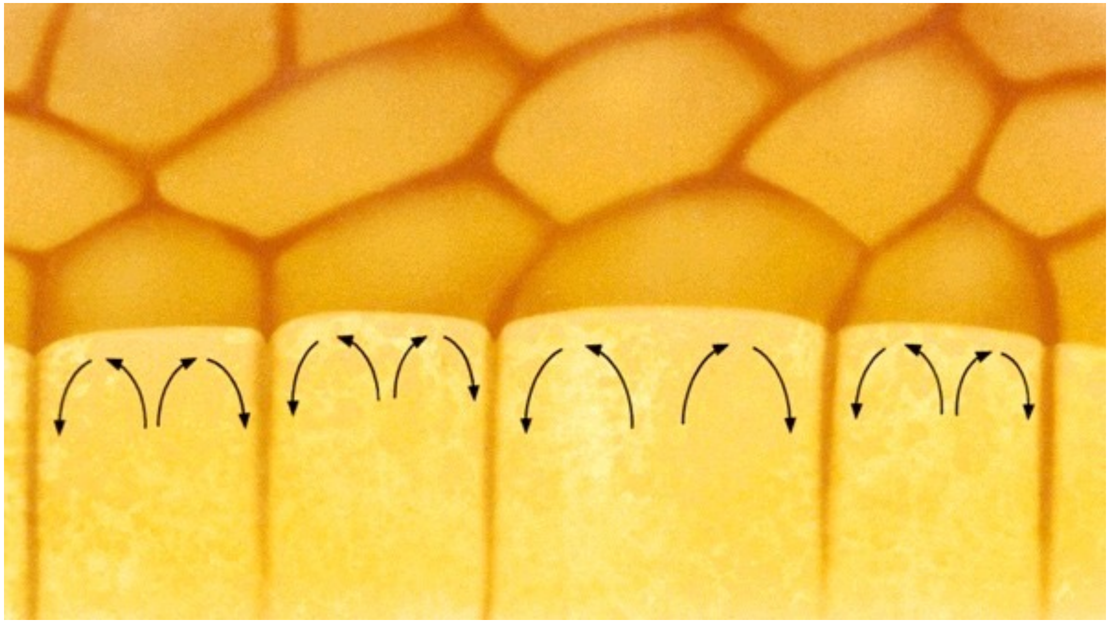
From Universe textbook

Energy Transport

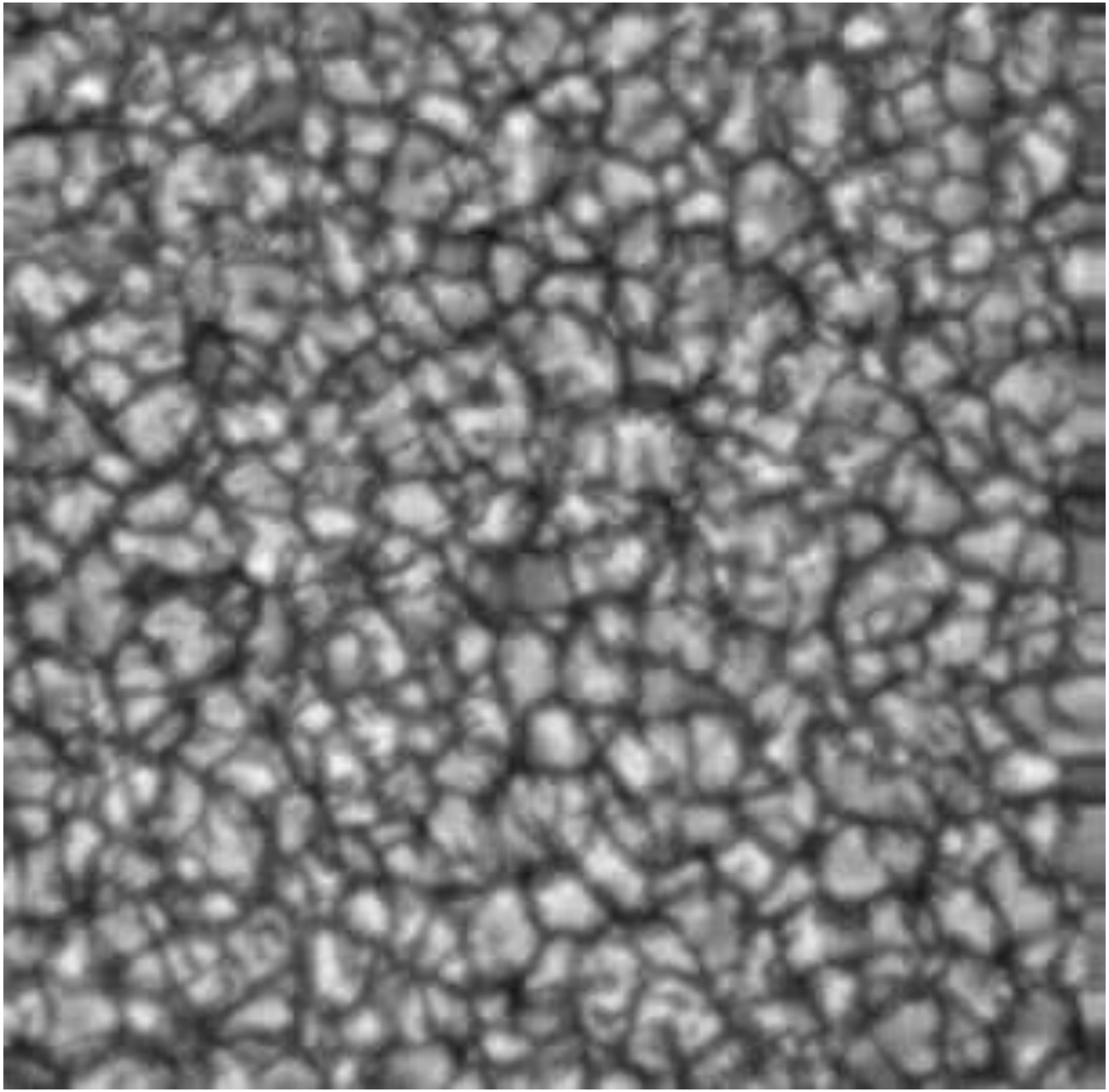
- Heat energy generated in the core is transported to the surface
- Firstly by radiation and then by convection
- The outer third of the Sun is in constant convective motion

Granulation

- Columns of hot gas rise up to the surface, cool, and then fall again
- Tops of convection cells give the photosphere a granular appearance



From https://astrobites.com/wp-content/uploads/2012/07/kauf18_4.jpg



Close-up of granulation. Credit: Royal Swedish Academy of Sciences www.solarphysics.kva.se

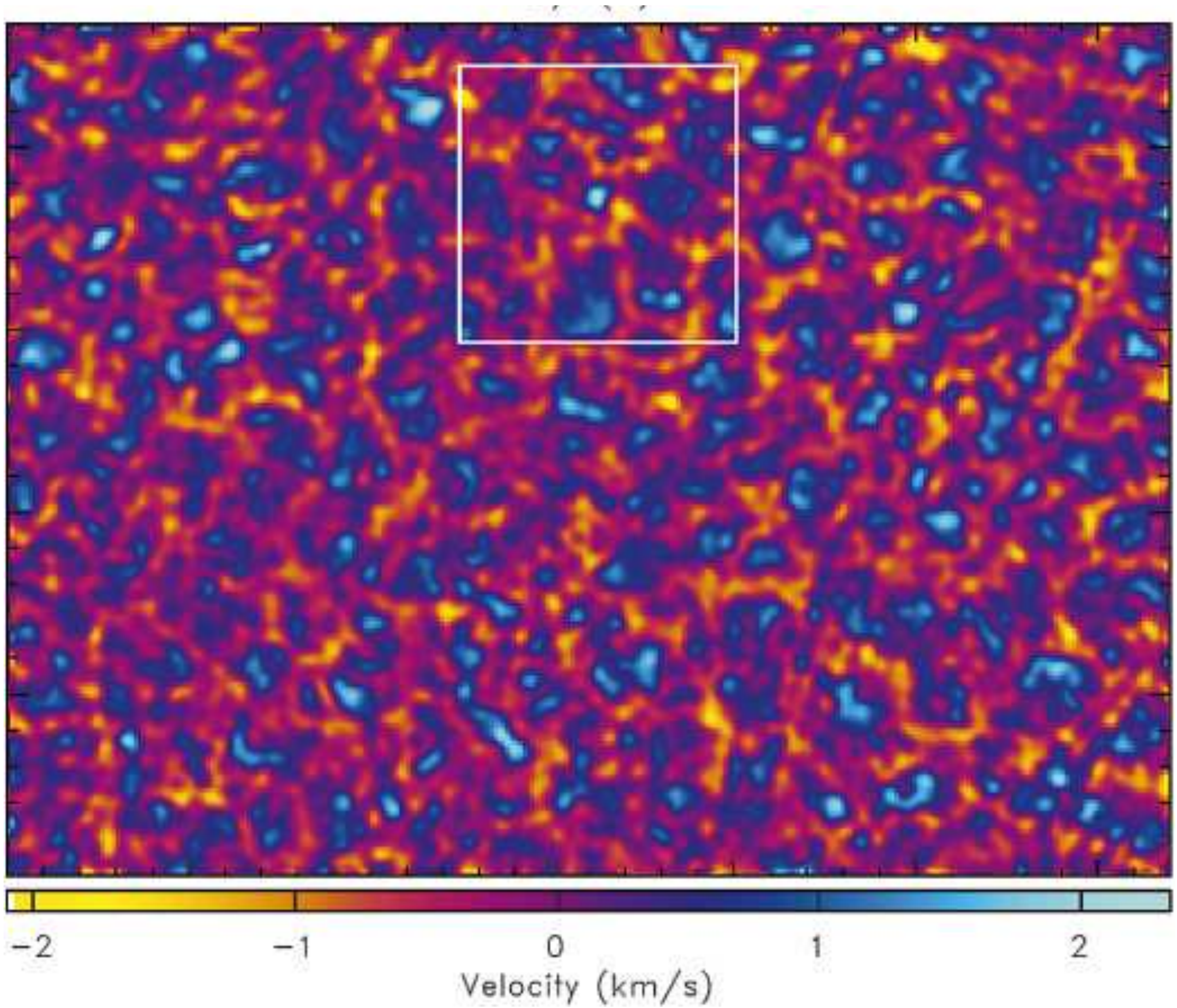
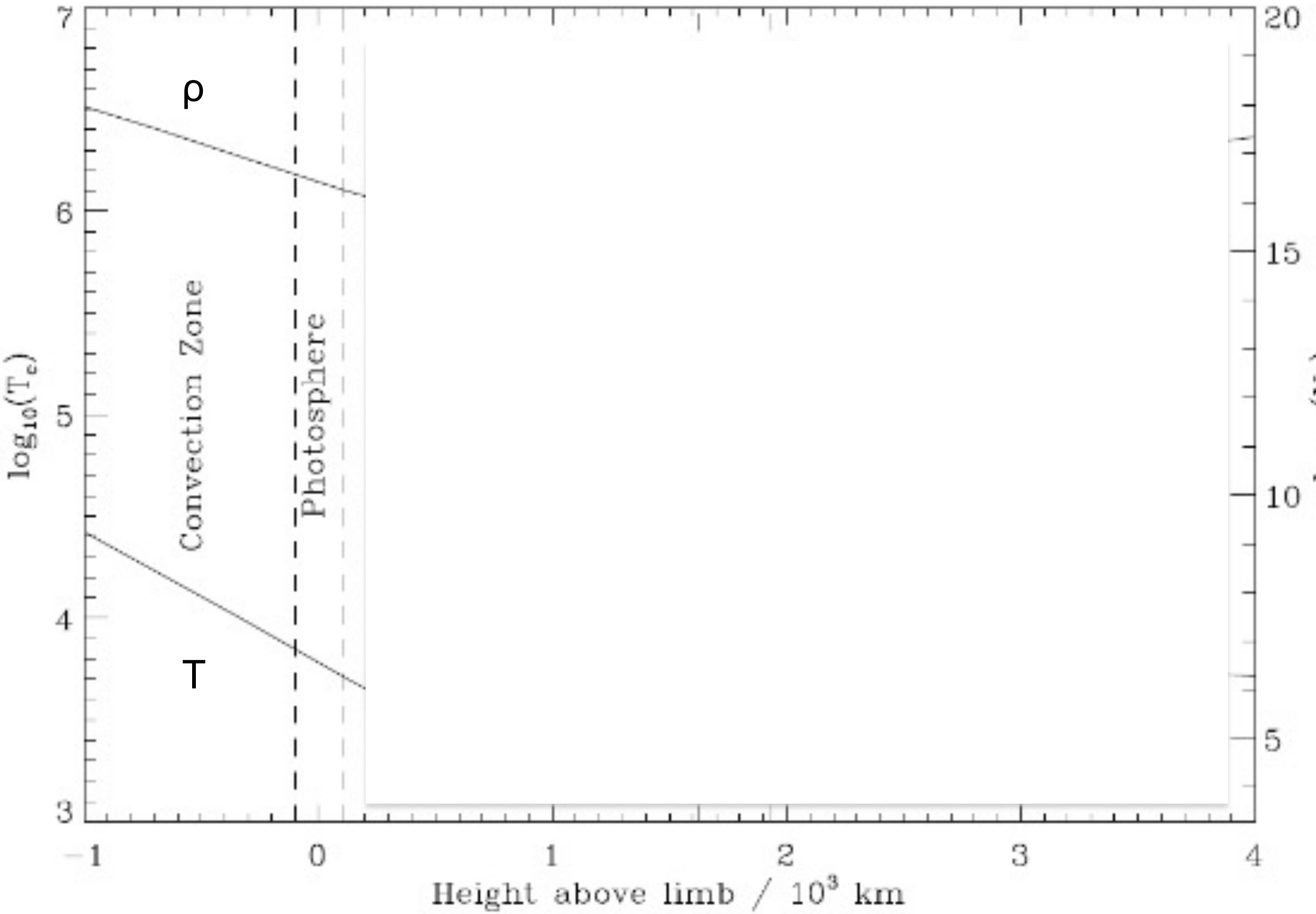


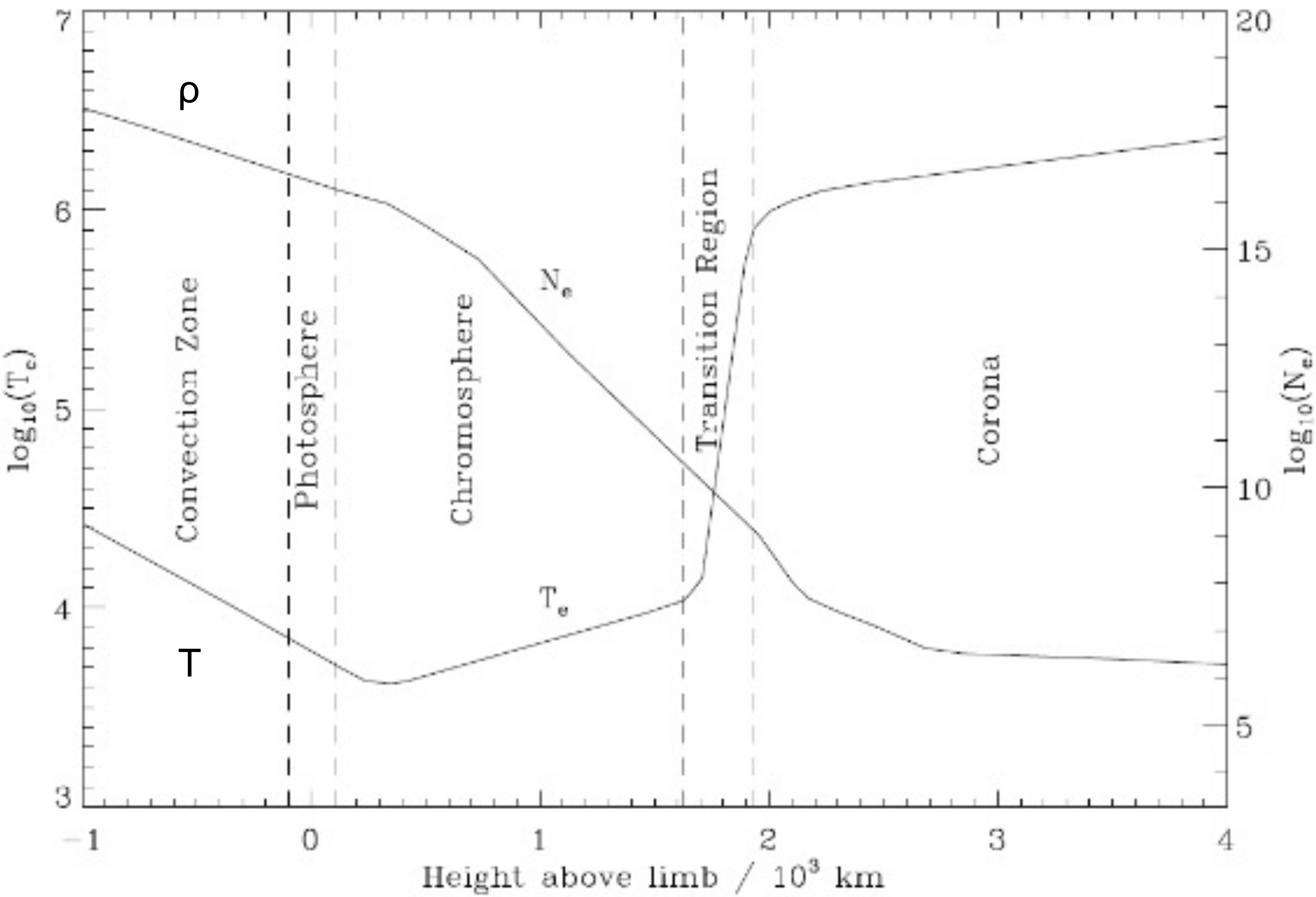
Image showing velocities associated with granulation. The hot rising parts of the convection cells are the blue regions moving towards us and cool sinking parts are the yellow regions moving away from us. From Krieg et al. (2000).

Photosphere

- ‘Visible surface’ of the Sun
- No solid surface – density and temperature of the gas just fall steadily with height through the photosphere
- ‘Effective’ temperature of 5800 K



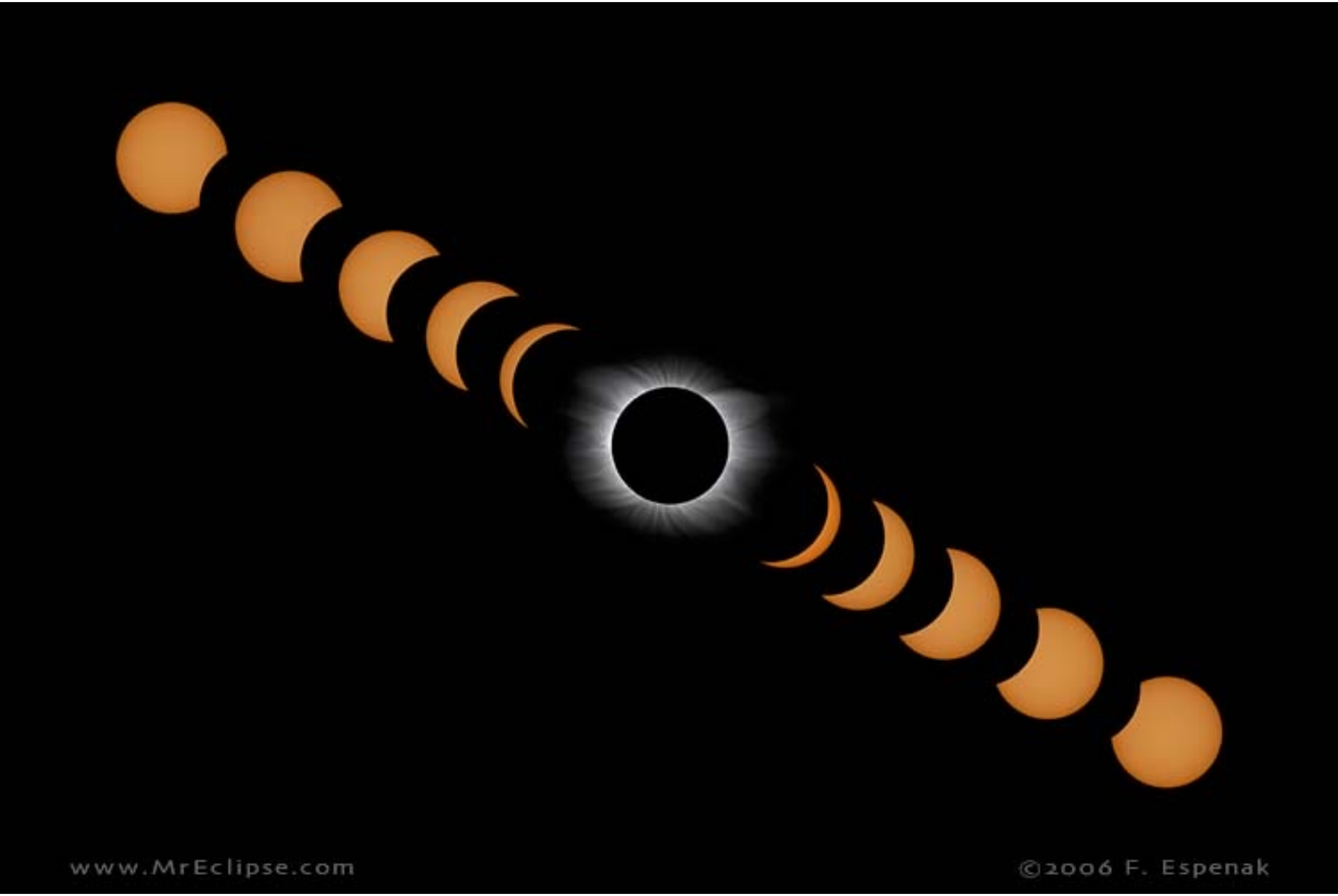
ρ
T
Convection Zone
Photosphere
log₁₀(Tₑ)
log₁₀(Nₑ)
Height above limb / 10³ km



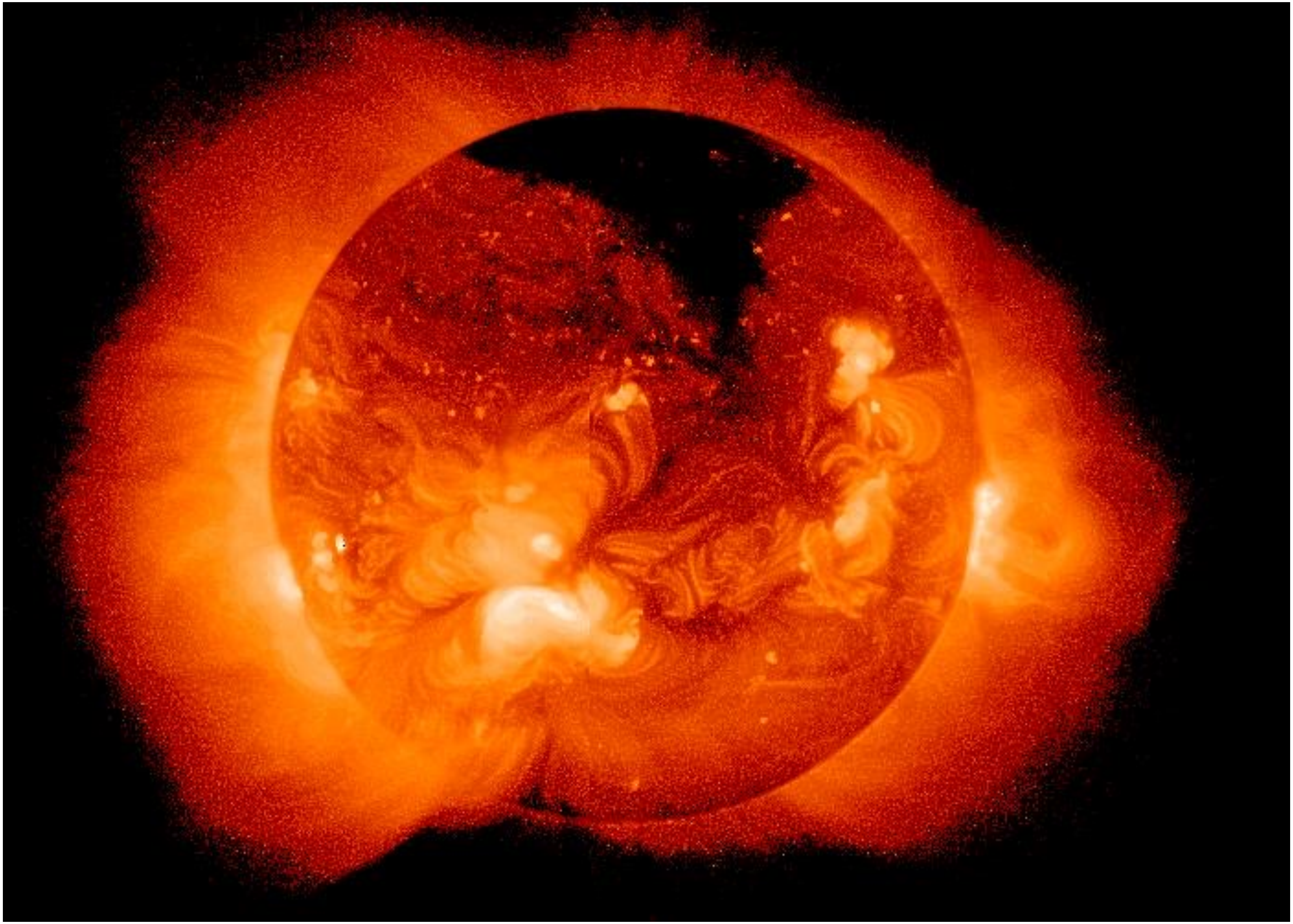
ρ
T
Convection Zone
Photosphere
Chromosphere
Transition Region
Corona
N_e
T_e
$\log_{10}(T_e)$
$\log_{10}(N_e)$
Height above limb / 10^3 km

Corona

- The outer atmosphere of the Sun is very hot ($T \sim 10^6$ K) and tenuous
- White halo seen during eclipses extends several solar radii
- Also emits strongly in UV and X-rays observed from satellites


www.MrEclipse.com
©2006 F. Espenak

From Universe textbook



From Universe textbook

Summary

- The Sun is a very average star about half way through its 10 billion year lifetime
- Energy generated in core by nuclear fusion is transported by radiation and convection to the photosphere where it radiates into space
- A hot corona is powered by magnetic activity

Class exercise

- Use an estimate of the typical velocity of convective motion seen in the Doppler shifts above to evaluate how long it takes a hot cell of gas to rise 300 km in the photosphere. (This is thought to be the typical vertical distance travelled by each convective cell.)

Additional Learning

- Watch the video of the total solar eclipse on the Web Resources section of the module on Minerva
- Read the directed section of the textbook(s)