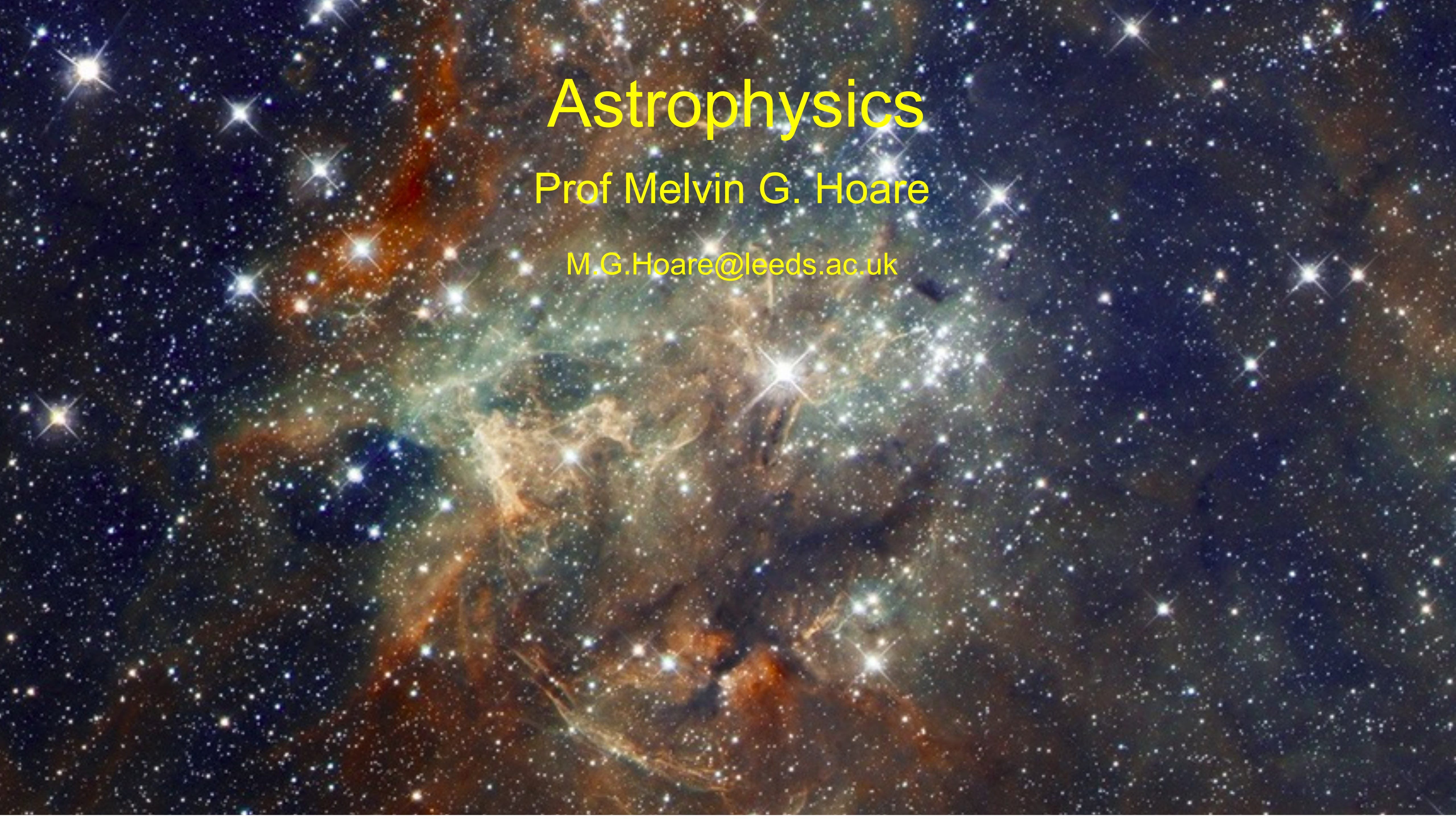

# Astrophysics

Prof Melvin G. Hoare

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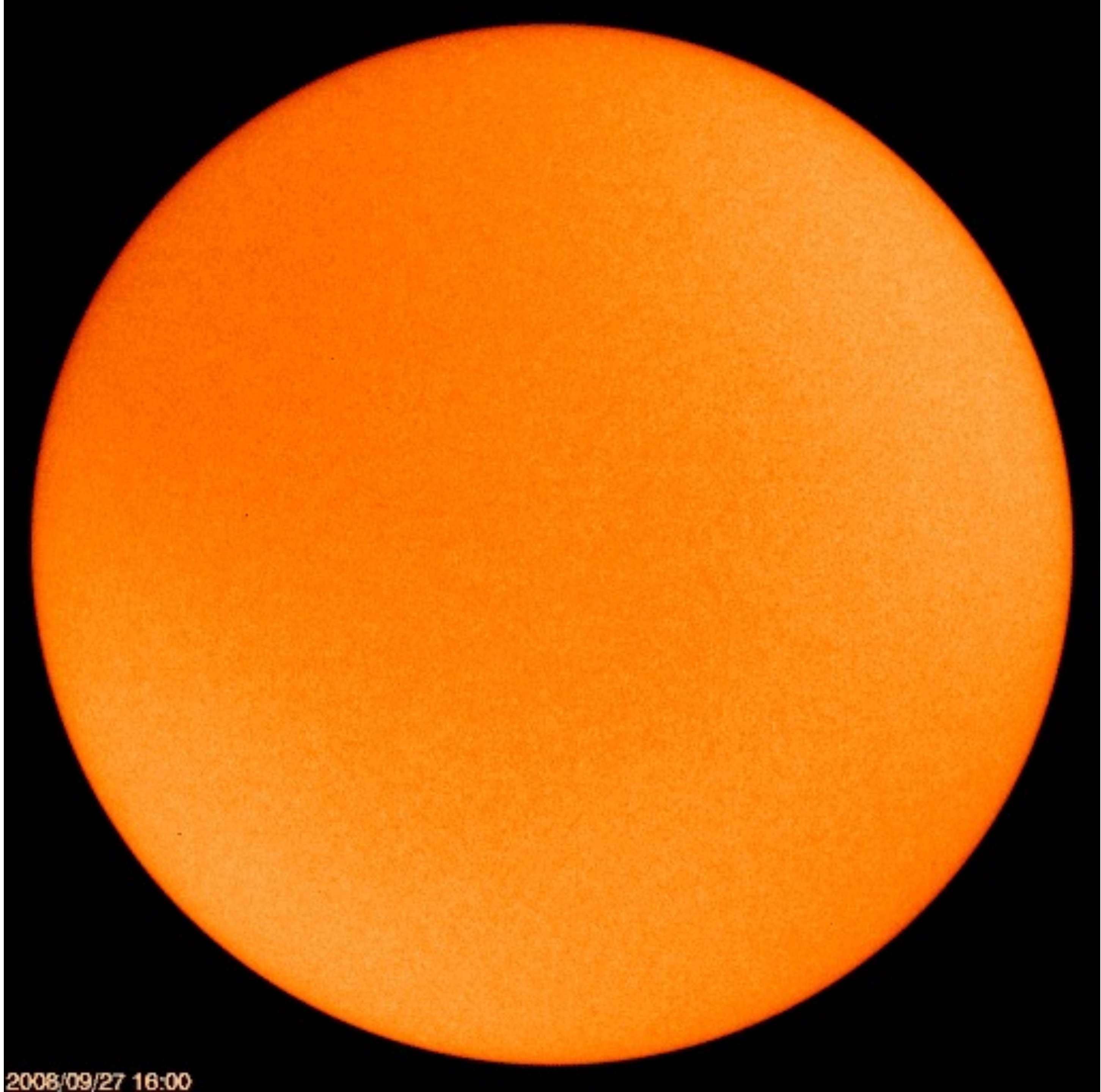
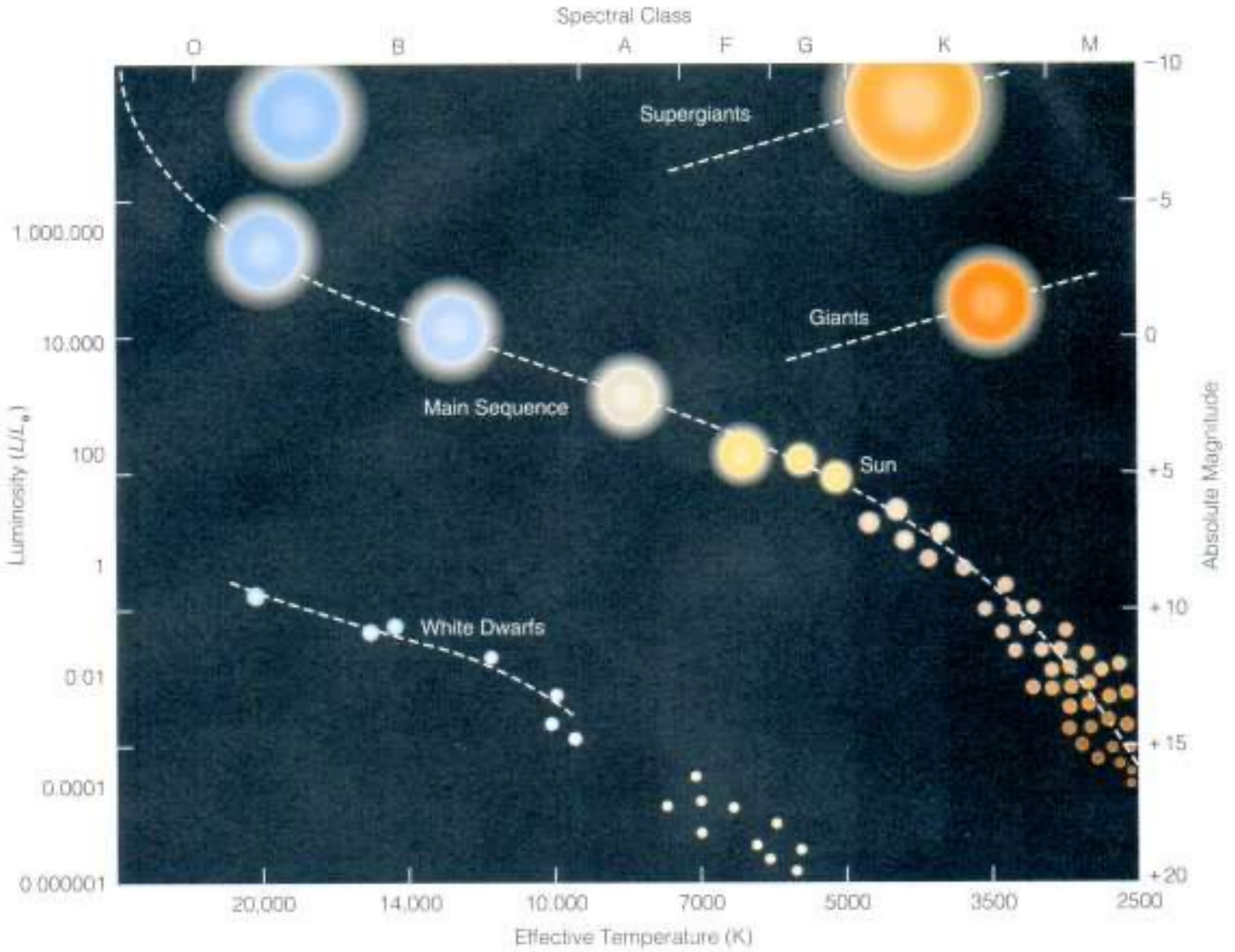
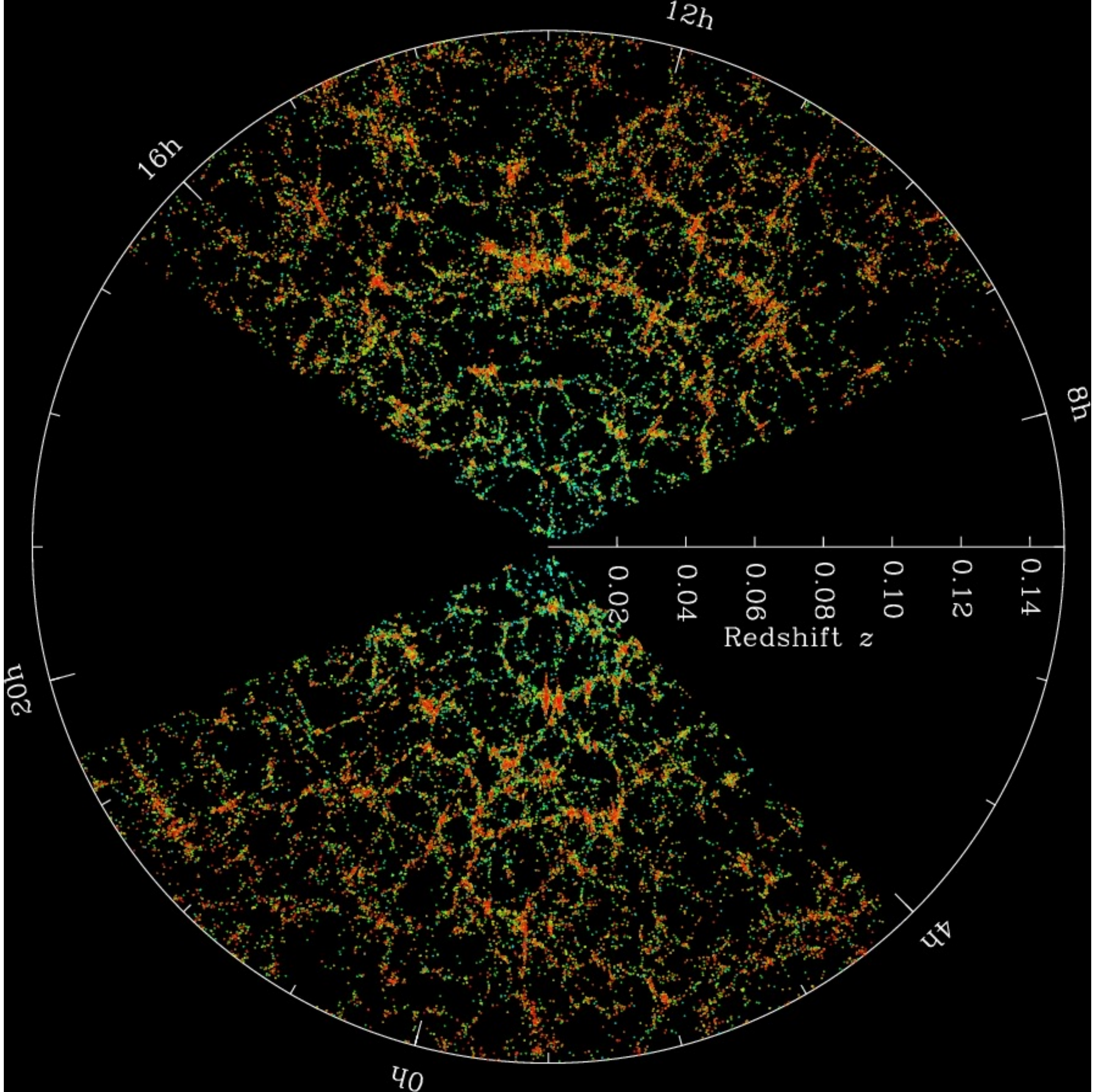
# Topics



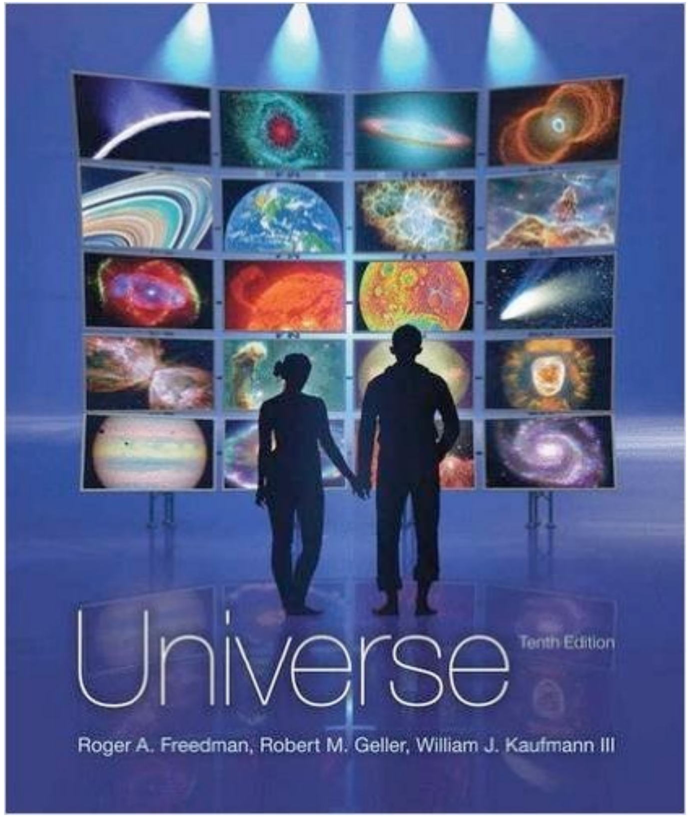


Spectral Class
O
B
A
F
G
K
M
Supergiants
Giants
Main Sequence
Sun
White Dwarfs
Luminosity ($L/L_\odot$)
1,000,000
10,000
100
1
0.01
0.0001
0.000001
Absolute Magnitude
−10
−5
0
+5
+10
+15
+20
20,000
14,000
10,000
7000
5000
3500
2500
Effective Temperature (K)


12h
8h
4h
0h
20h
16h
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Redshift z

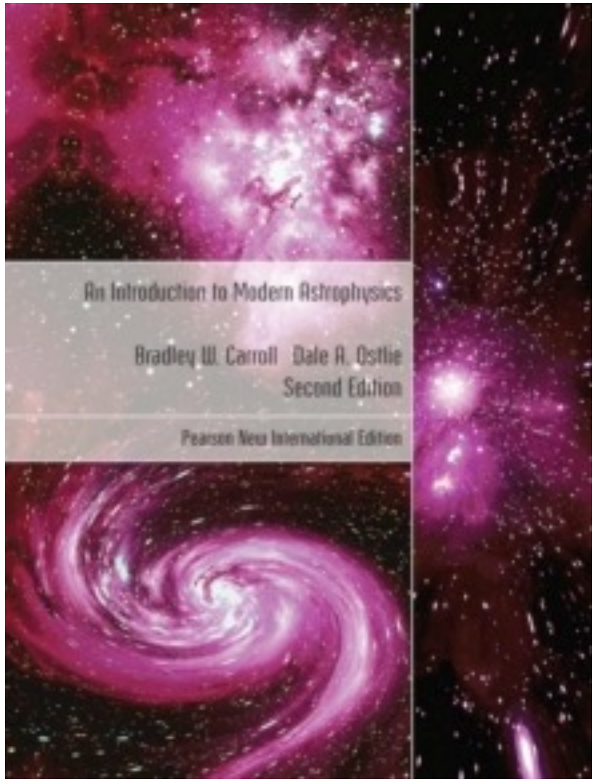
# Textbooks

- R. M. Geller, R.A. Freedman, & W.J. Kaufmann Universe, (11th ed), W. H. Freeman and Co, 2013
  - Readable, not quite the required depth in a few places



# Textbooks

- B. W. Carroll and D. A. Ostlie, An introduction to modern astrophysics , 2nd edition, Pearson, 2014
- technical, more material and depth than required
  – recommended for those on Physics with Astrophysics degree programme



# VITALS

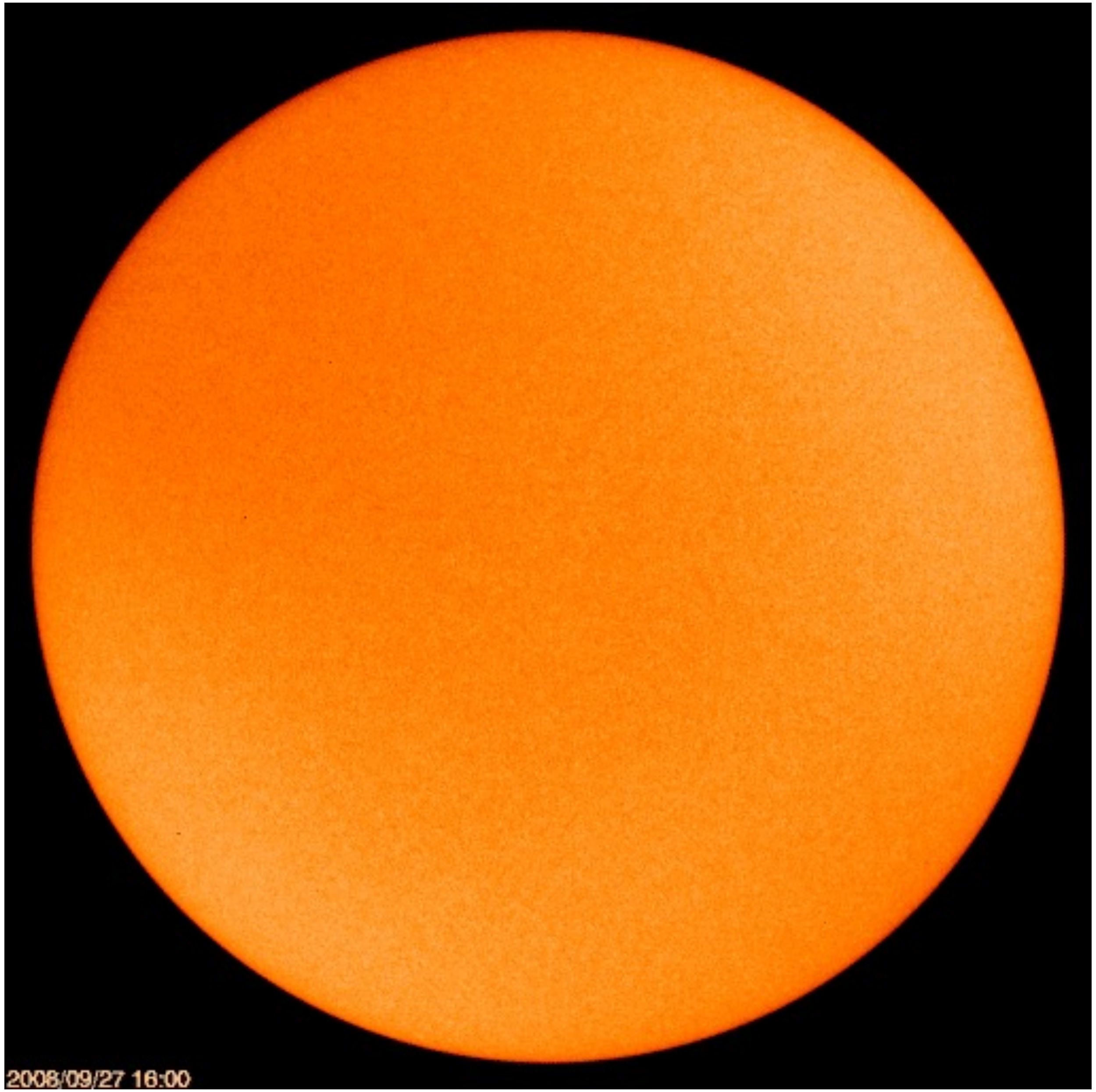
- Three VITALS assessments on the Astrophysics theme on:
  - Radiation in the context of stars
  - Basic properties of stars
  - Basic properties of galaxies

# The Sun

- Properties
- Lifetime
- Energy Source

# The Sun

- The Sun is a typical star
- A giant ball of gas
- Made of about 71% hydrogen, 27% helium and 2% heavier elements

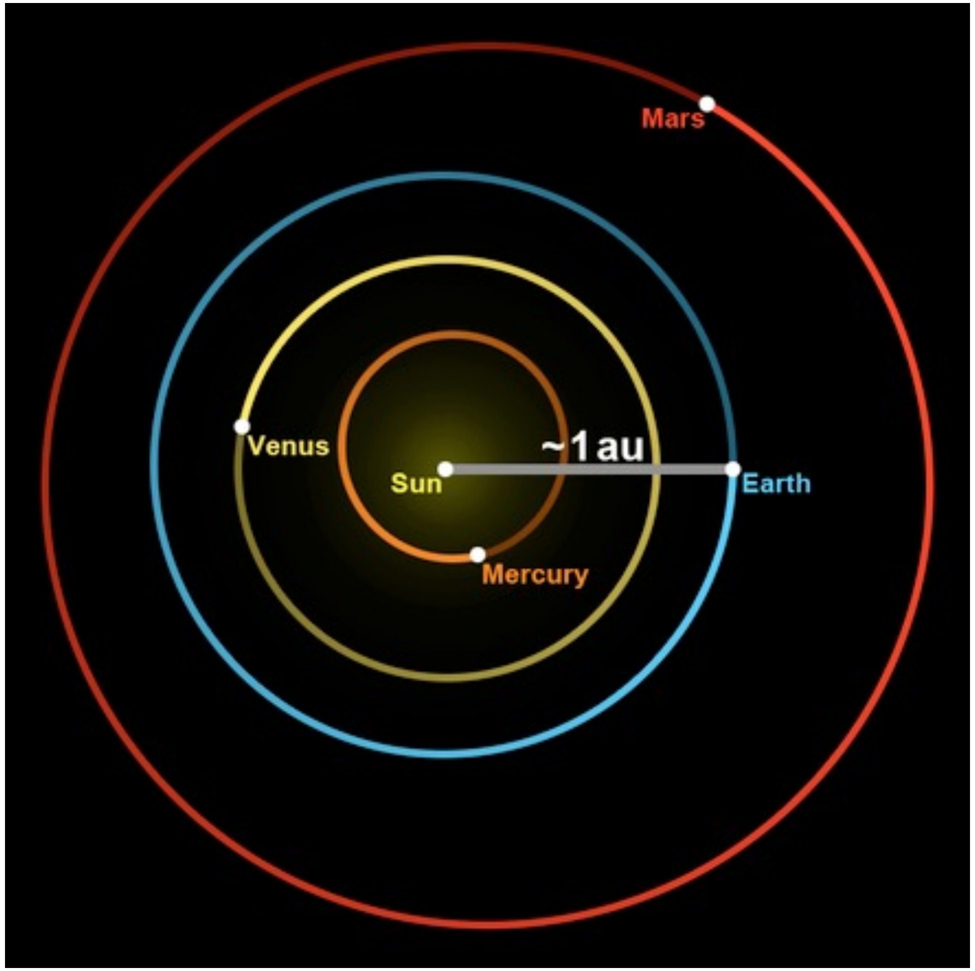



science.nasa.gov

# Distance

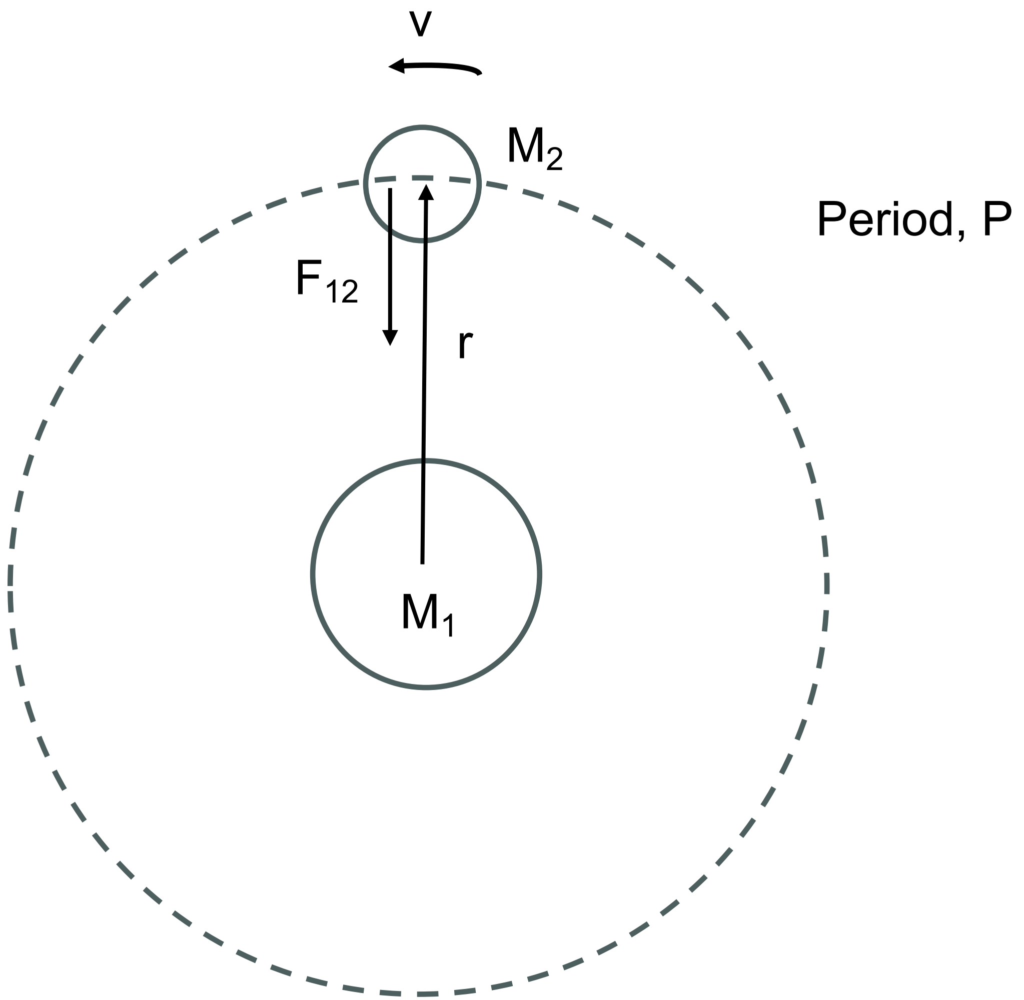
- Distance = $1.5 \times 10^{11}$ m = 1 au

  (Parallax of planets and Kepler's Law)



# Mass

- Estimate the mass of the Sun, $M_1$, using the effect of its gravity on the Earth (mass $M_2$), assuming circular motion
- Equate force due to gravity with centripetal force



$$\frac{GM_1M_2}{r^2} = \frac{M_2v^2}{r}$$

$$\frac{GM_1}{r} = v^2$$

- Circular velocity

$$v = \frac{2\pi r}{P}$$

$$\frac{GM_1}{r} = \frac{4\pi^2r^2}{P^2}$$

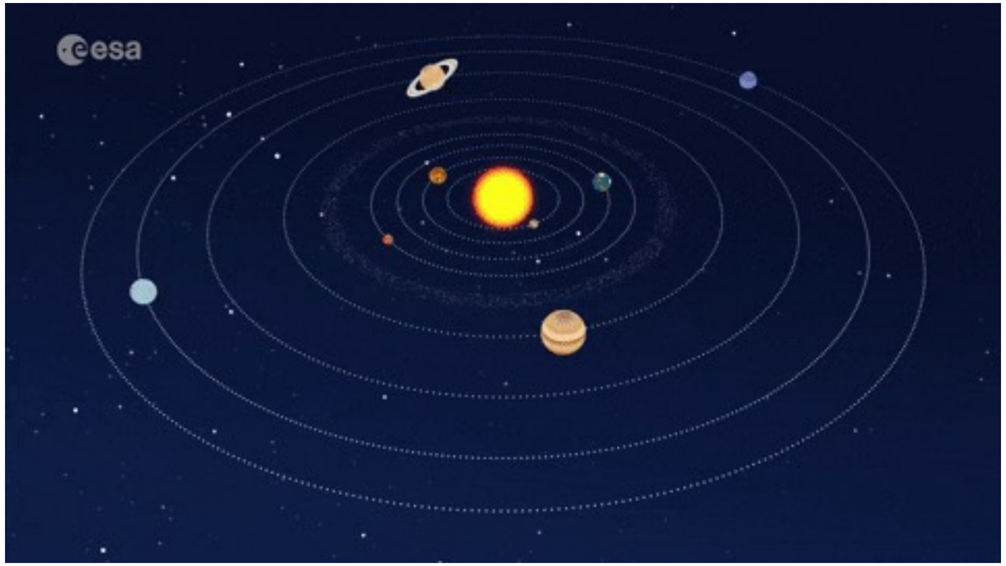
$$M_1 = \frac{4\pi^2r^3}{GP^2}$$

$$\text{Period } P = 365 \times 24 \times 60 \times 60 = 3.1 \times 10^7 \text{ seconds}$$

$$M_1 = \frac{4\pi^2 (1.5\times10^{11})^3}{6.7\times10^{-11}(3.1\times10^7)^2}$$

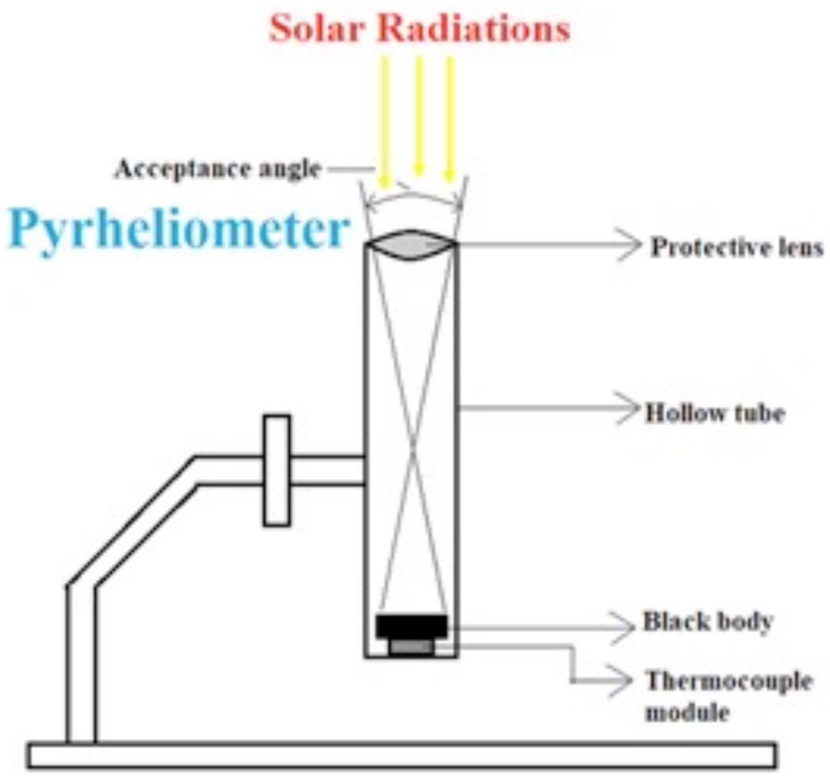
$$M_1 = 2.0\times10^{30} \text{ kg}$$

- Solar Mass = 1 $M_\odot$
  - (Kepler's Law – later in module)



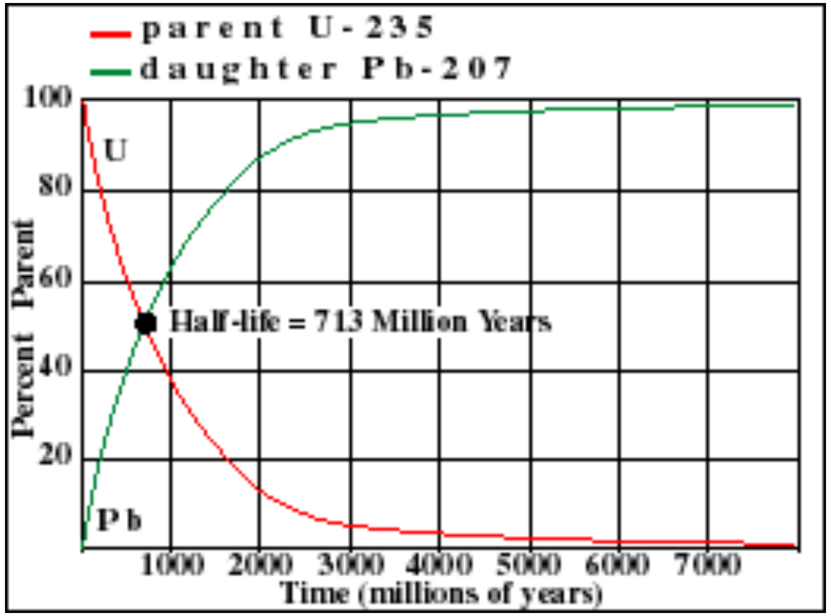
# Luminosity

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



# Lifetime

- Geological evidence
  $\rightarrow$ at least 5 x $10^9$ years
- Stellar evolution theory
  10 x $10^9$ years
- Energy required




earthsci.org/space/space/geotime/radate/radate.html

$$E = L\tau$$

$$= 4\times10^{26} \times 10 \times10^{9} \times 3 \times10^{7}$$

$$= 1\times10^{44}\mathrm{J}$$

# Energy Source

- In the core of the Sun

  T=1 x $10^7$ K

  P=$10^9$ atmospheres

- Sufficient for fusion of hydrogen nuclei into helium

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

- Energy comes from difference in mass

# Class exercise

- Calculate the difference in mass between four $^{1}H$ nuclei (mass = 1.0078 amu) and one $^{4}He$ nucleus (mass = 4.0026 amu) and express as a percentage change in mass

# Class exercise

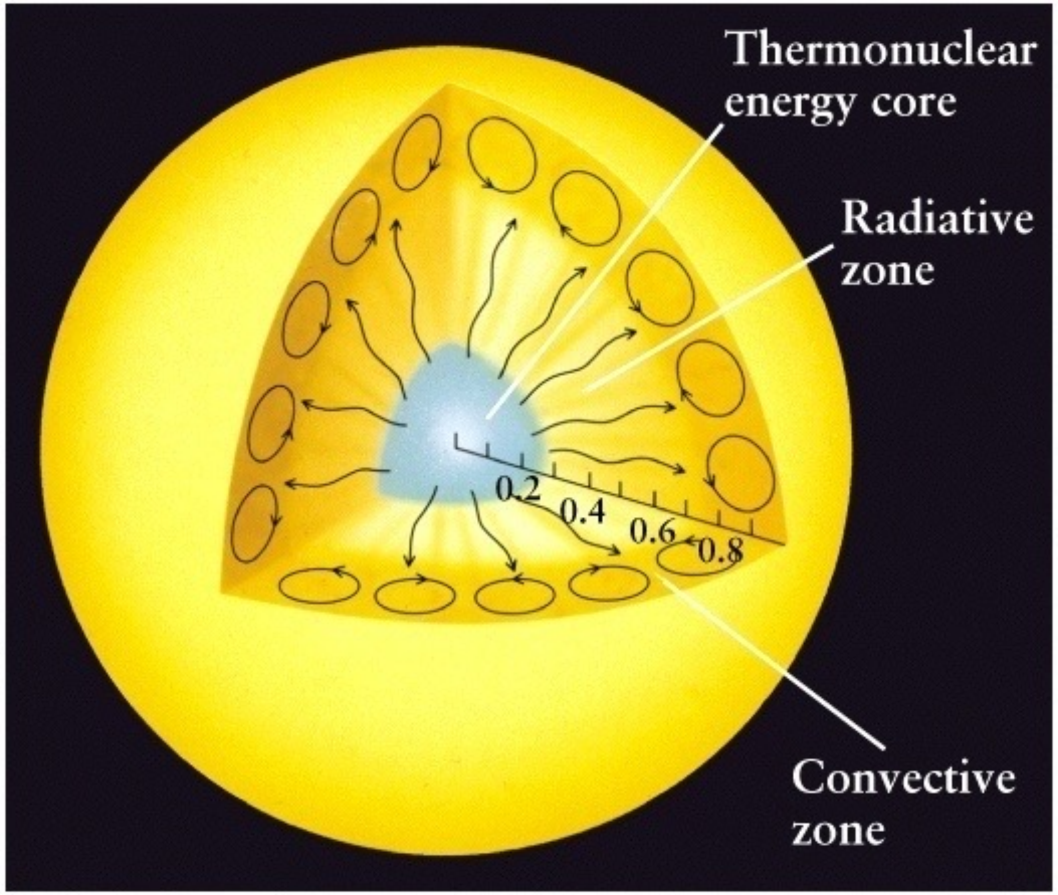
$$4\,{}^{1}\mathrm{H} \rightarrow {}^{4}\mathrm{He}$$

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

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

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

- Core of the Sun contains about 10% of the total mass




From Universe textbook

- Therefore total energy available

$$= \Delta m c^2$$

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

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

- Explains lifetime of 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.

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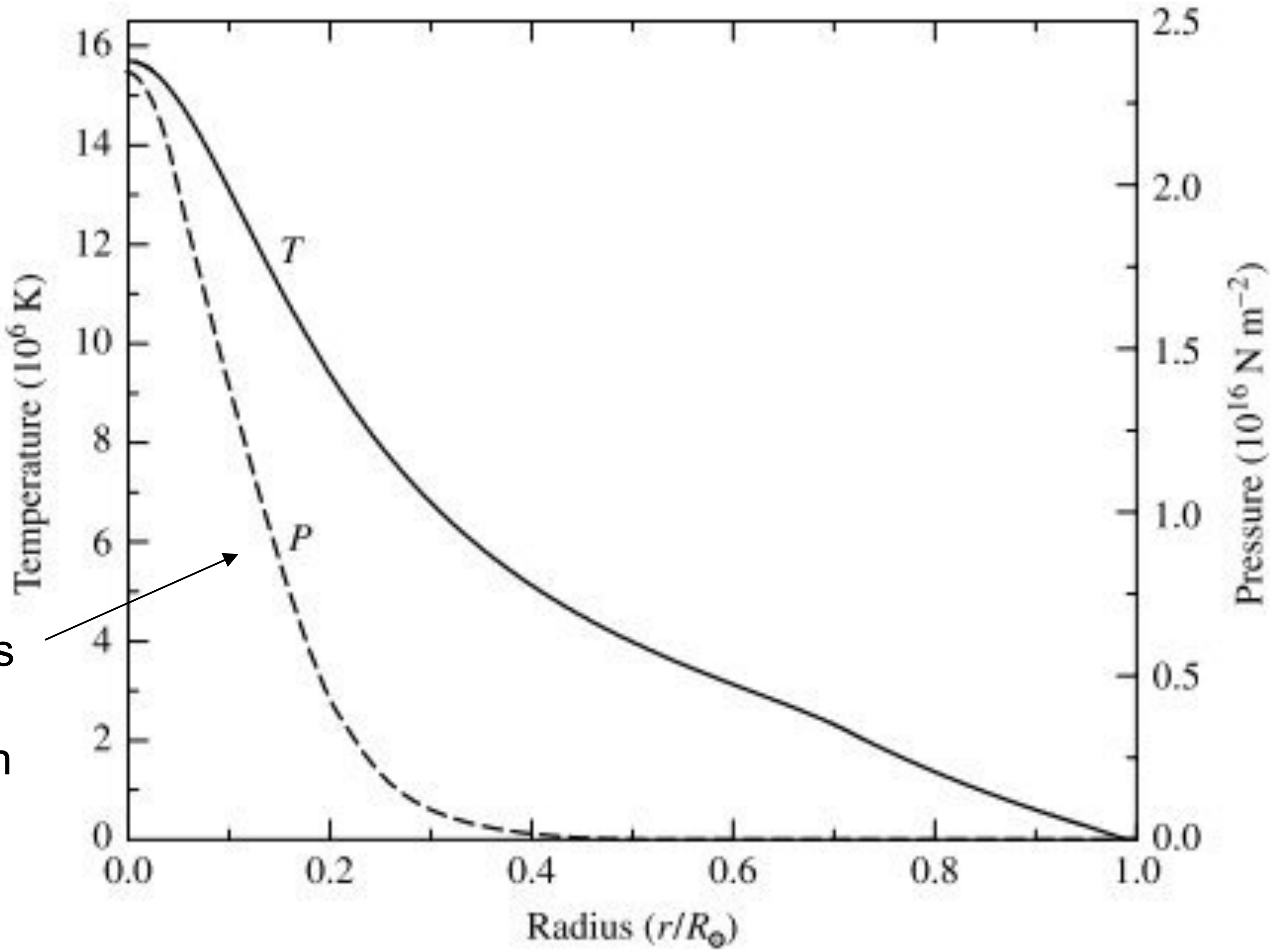
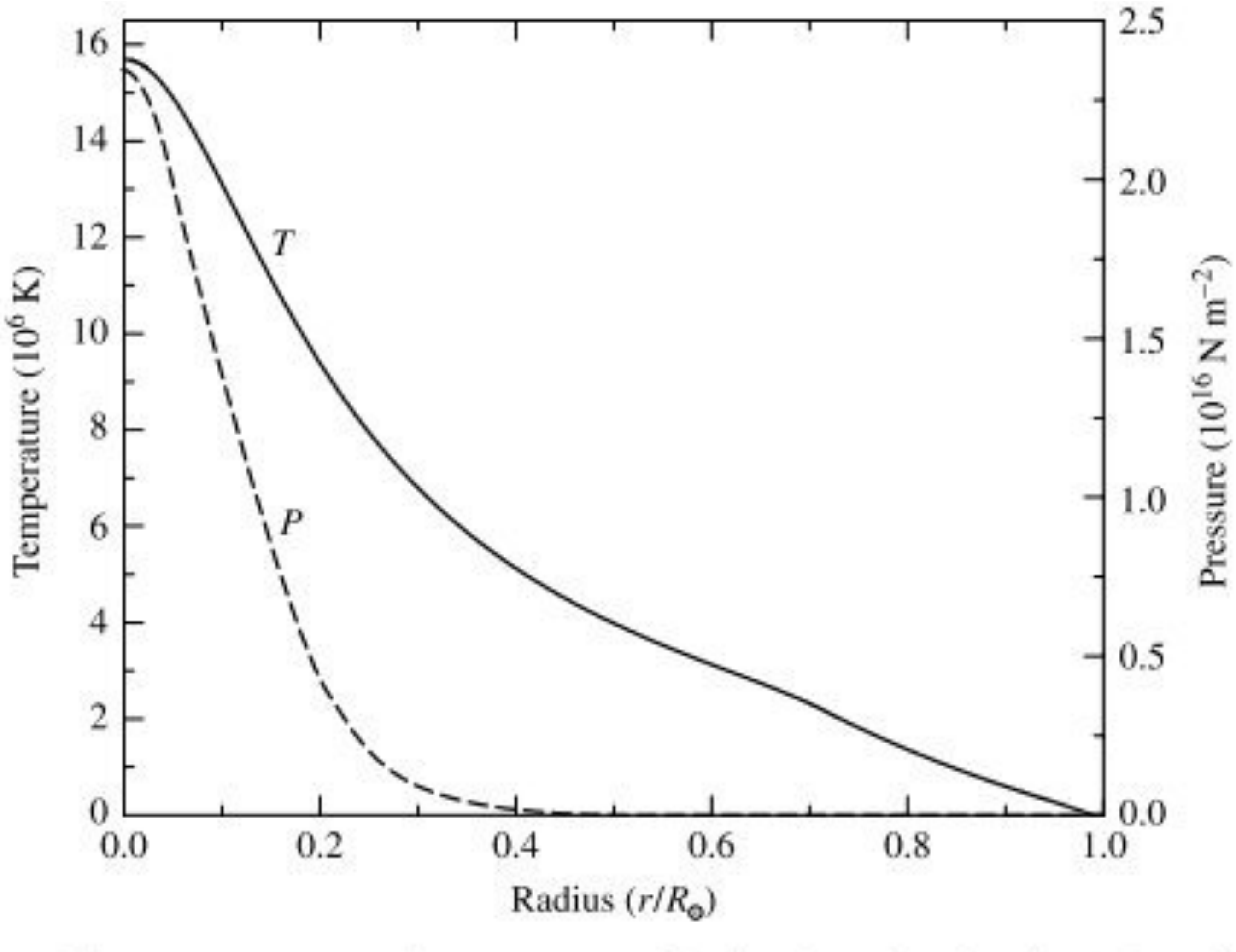
# Why is the pressure at the centre of the Sun so high?



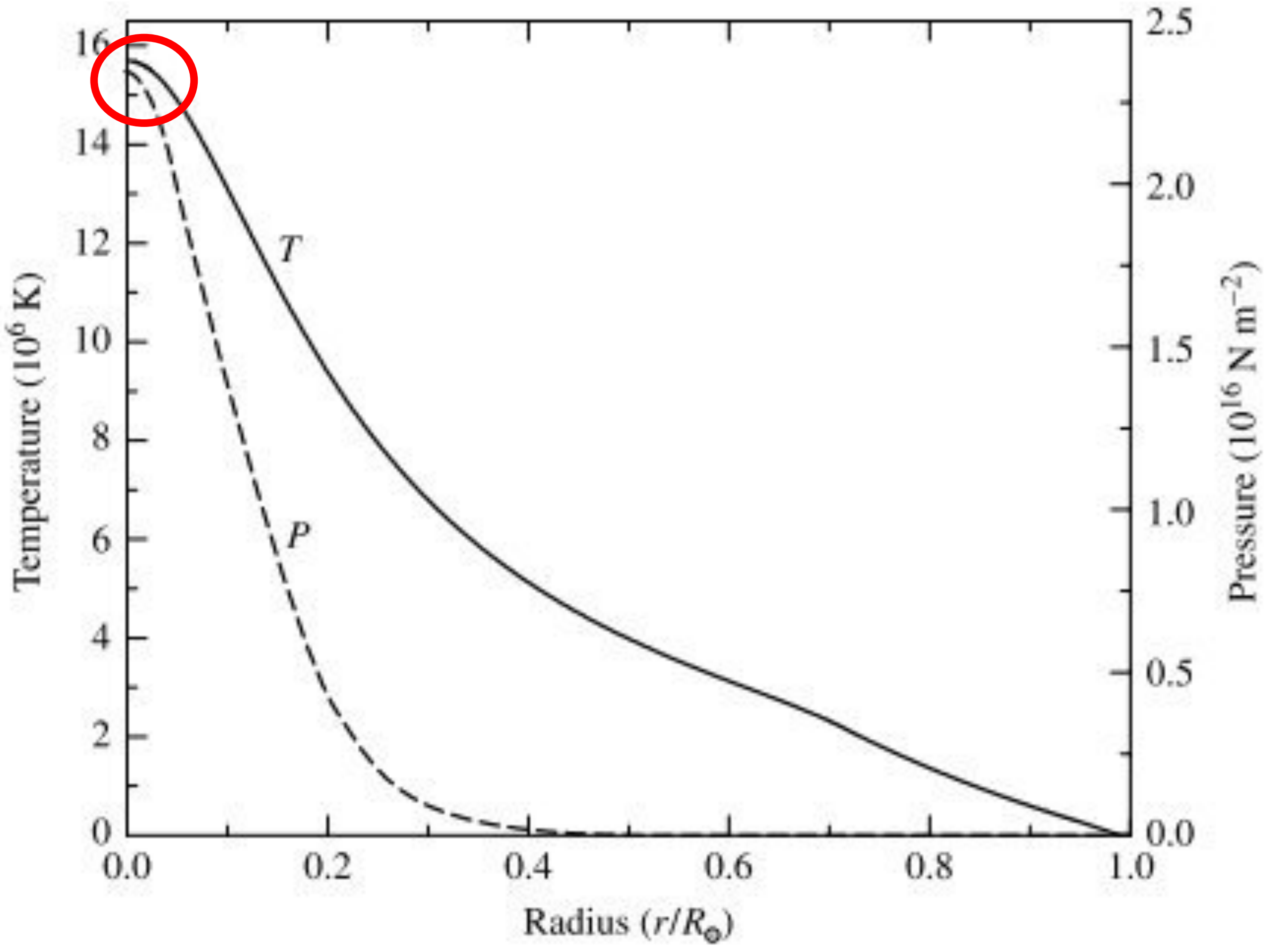

Thermal gas pressure – not radiation pressure!

From Carroll & Ostlie

# Why is the temperature at the centre of the Sun so high?



# Only innermost 10% of the total mass has right conditions for fusion



# Summary

- The Sun is a very average star about half way through its 10 billion year lifetime
- Energy generated in core by nuclear fusion
- Held together by its own gravity balancing the thermal pressure