Exercise walk-through

Standard candles ▪ 25.1

eXercise

You must be able to

- use **luminosity** and the **inverse-square law** $F = \dfrac{L}{4\pi d^2}$
- explain how **standard candles** give distances

Method — Luminosity and flux

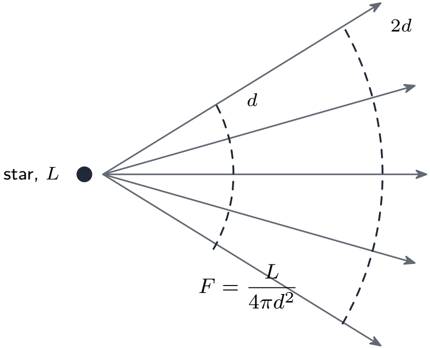
The **luminosity** L is the total power a star radiates. At distance d this power is spread over a sphere of area $4\pi d^2$, so the **radiant flux intensity** is:

$$F = \frac{L}{4\pi d^2}, \qquad d = \sqrt{\frac{L}{4\pi F}}.$$

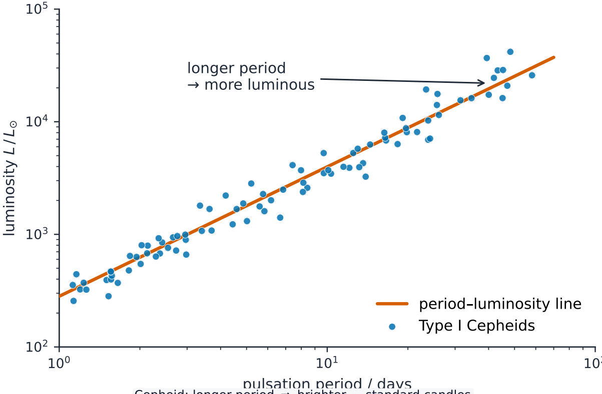
A **standard candle** is an object of **known luminosity**; measuring its flux F gives its distance.

Worked example. Sun $L = 3.8 \times 10^{26}$ W, $d = 1.5 \times 10^{11}$ m:

$$F = \frac{3.8 \times 10^{26}}{4\pi(1.5 \times 10^{11})^2} = 1.4 \times 10^3 \text{ W m}^{-2}.$$



Method — Luminosity and flux



Cepheid: longer period ⇒ brighter · standard candles

Cepheids as standard candles

Practice 2.1 ▪ 1 mark

Define the **luminosity** of a star.

Solution 2.1

Method: Luminosity and flux

Worked steps

The **total power** of radiation emitted by the star (in all directions) B1.

Practice 2.2 ▪ 1 mark

Write the **inverse-square law** for radiant flux intensity.

Solution 2.2

Method: Luminosity and flux

Worked steps

$$F = \frac{L}{4\pi d^2} \quad \boxed{\textbf{B1}}.$$

Practice 2.3 ▪ 2 marks

The Sun's luminosity is 3.8×10^{26} W. Find the flux at Earth ($d = 1.5 \times 10^{11}$ m).

Solution 2.3

Method: Luminosity and flux

Worked steps

$$F = \frac{3.8 \times 10^{26}}{4\pi(1.5 \times 10^{11})^2} = 1.4 \times 10^3 \text{ W m}^{-2} \quad \textbf{M1}\,\textbf{A1}.$$

Practice 2.4 ▪ 1 mark

State what a **standard candle** is.

Solution 2.4

Method: Luminosity and flux

Worked steps

An object of **known luminosity** B1.

Exam-style 3.1 ▪ 1 mark

If the distance to a star **doubles**, the radiant flux intensity becomes:

A twice as large

B half as large

C one quarter as large

D four times as large

Solution 3.1

Method: Luminosity and flux

A twice as large

B half as large

C one quarter as large ✓

D four times as large

Worked steps

C — one quarter.

Exam-style 3.2 ▪ 3 marks

A standard candle has luminosity 4.0×10^{28} W. Its measured flux is 2.0×10^{-9} W m^{-2}. Calculate its **distance**.

Solution 3.2

Method: Luminosity and flux

Worked steps

$$d = \sqrt{\frac{L}{4\pi F}} = \sqrt{\frac{4.0 \times 10^{28}}{4\pi(2.0 \times 10^{-9})}} \ \boxed{\text{M1}}\boxed{\text{M1}} = 1.3 \times 10^{18}\ \text{m} \ \boxed{\text{A1}}.$$

Exam-style 3.3 ▪ 4 marks

An astronomer wants the distance to a galaxy several million light-years away. Explain how a **standard candle** in that galaxy makes this possible, giving the quantity that must be measured, the quantity that must be known in advance, and the assumption the method depends on.

Solution 3.3

Method: Luminosity and flux

Worked steps

Find an object in that galaxy whose **luminosity is known in advance** from its type — a Type Ia supernova or a Cepheid variable — which is what "standard candle" means B1. **Measure** the radiant flux intensity F arriving at Earth B1. Then $F = \dfrac{L}{4\pi d^2}$ gives $d = \sqrt{\dfrac{L}{4\pi F}}$ B1. The method assumes the radiation spreads out evenly and nothing absorbs it on the way, so the inverse-square law holds over that distance B1.

Exam-style 3.4 ▪ 2 marks

A star has a luminosity of 6.5×10^{27} W. Its radiant flux intensity measured at the Earth is 2.9×10^{-9} W m^{-2}.

(a) **Define** the **luminosity** of a star and the **radiant flux intensity** received from it.

(b) **Determine** the distance of the star from the Earth.

(c) The star's surface temperature is 9600 K. Taking $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}, **determine** its radius.

(d) A second star at the same distance has the same radius but **half** the surface temperature. **Determine** the flux intensity received from it, as a fraction of that from the first star.

(e) **Suggest** why the flux intensity actually measured at the Earth may be **lower** than the calculation predicts.

Solution 3.4

Method: Luminosity and flux

Worked steps

(a) **Luminosity** is the total power radiated by the star in all directions B1; **radiant flux intensity** is the power received per unit area at the observer, perpendicular to the direction of the star B1.

(b) $F = \dfrac{L}{4\pi d^2}$ M1, so $d = \sqrt{\dfrac{L}{4\pi F}} = \sqrt{\dfrac{6.5 \times 10^{27}}{4\pi \times 2.9 \times 10^{-9}}}$ M1 $= 4.2 \times 10^{17}$ m A1.

(c) $L = 4\pi r^2 \sigma T^4$ M1, so $r = \sqrt{\dfrac{L}{4\pi\sigma T^4}} = \sqrt{\dfrac{6.5 \times 10^{27}}{4\pi(5.67 \times 10^{-8})(9600)^4}}$ M1

$= 3.3 \times 10^7$ m A1.

Solution 3.4

(d) At the same radius and distance, $F \propto T^4$ **M1**, so halving T gives $\left(\frac{1}{2}\right)^4 = \frac{1}{16}$ of the flux intensity **A1**.
(e) Interstellar dust and gas **absorb and scatter** some of the light on the way **B1**; and the Earth's atmosphere absorbs part of it too, so a ground-based measurement is lower still **B1**.