

Exercise walk-through

# 25.1

## Standard candles

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A-Level Physics

## An object whose luminosity is known from its type

Find one in a distant galaxy, measure  $F$ , get  $d = \sqrt{L/(4\pi F)}$ . Reaches far beyond **parallax**.

### Cepheids

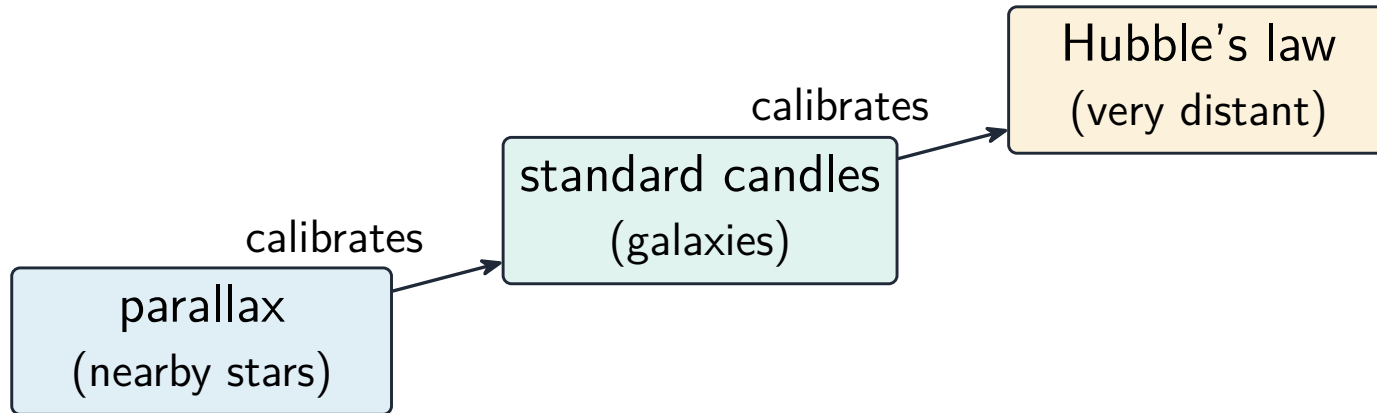
pulsation period is tightly  
linked to luminosity  
– the period gives  $L$

### Type Ia supernovae

a white dwarf at critical  
mass always has about  
the same peak luminosity

## Each rung calibrates the next

Parallax reaches the nearest stars; Cepheids reach nearby galaxies; supernovae reach the far ones. Every rung is calibrated by the one below it.



each rung is calibrated by the one below, reaching ever further

## Exercises 2.1-2.3

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**2.1** Define the **luminosity** of a star.

[1]

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

[1]

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**2.3** The Sun's luminosity is  $3.8 \times 10^{26}$  W. Find the flux at Earth ( $d = 1.5 \times 10^{11}$  m). [2]

## Exercises 2.1·2.3

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2.1 Define the **luminosity** of a star. [1]

2.1

- the **total power** of radiation emitted by the star (in all directions)
- 

2.2 Write the **inverse-square law** for radiant flux intensity. [1]

2.2

- $F = L/(4\pi d^2)$
- 

2.3 The Sun's luminosity is  $3.8 \times 10^{26}$  W. Find the flux at Earth ( $d = 1.5 \times 10^{11}$  m). [2]

2.3

- $F = L/(4\pi d^2)$

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

## Exercises 2.4·3.1

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**2.4** State what a **standard candle** is.

[1]

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

[1]

☐

**A** twice as large

**B** half as large

**C** one quarter as large

**D** four times as large

## Exercises 2.4·3.1

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2.4 State what a **standard candle** is.

[1]

2.4

- an object of **known luminosity**

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

[1]

☐

A twice as large

B half as large

C one quarter as large

D four times as large

3.1 C

- $F \propto 1/d^2$ , so doubling  $d$  makes  $F$  **one quarter**

## Exercise 3.2

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**3.2** A standard candle has luminosity  $4.0 \times 10^{28}$  W. Its measured flux is  $2.0 \times 10^{-9}$  W m<sup>-2</sup>. Calculate its **distance**. [3]

## Exercise 3.2

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**3.2** A standard candle has luminosity  $4.0 \times 10^{28}$  W. Its measured flux is  $2.0 \times 10^{-9}$  W m<sup>-2</sup>. Calculate its **distance**. [3]

**3.2**

- $d = \sqrt{L/(4\pi F)}$

$$d = \sqrt{\frac{L}{4\pi F}} = \sqrt{\frac{4.0 \times 10^{28} \text{ W}}{4\pi(2.0 \times 10^{-9} \text{ W m}^{-2})}} = \mathbf{1.3 \times 10^{18} \text{ m}}$$

## Exercise 3.3

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**3.3** 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. [4]

## Exercise 3.3

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### 3.3

- find an object in that galaxy whose **luminosity is known in advance** from its type – a Type Ia supernova or a Cepheid variable
- **measure** the radiant flux intensity  $F$  arriving at Earth
- then  $F = L/(4\pi d^2)$  gives  $d = \sqrt{L/(4\pi F)}$
- the method assumes the radiation spreads out evenly and nothing absorbs it on the way

## Exercise 3.4 (a)

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

(a) **Define** the **luminosity** of a star and the **radiant flux intensity** received from it.[2]

## Exercise 3.4 (a)

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

- (a) **Define** the **luminosity** of a star and the **radiant flux intensity** received from it.[2]
- (a) **luminosity** is the total power radiated by the star in all directions
- **radiant flux intensity** is the power received per unit area at the observer, perpendicular to the direction of the star

## Exercise 3.4 (b)

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

(b) **Determine** the distance of the star from the Earth. [3]

## Exercise 3.4 (b)

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

(b) **Determine** the distance of the star from the Earth. [3]

(b)  $F = L/(4\pi d^2)$ , so  $d = \sqrt{L/(4\pi F)}$

$$d = \sqrt{\frac{L}{4\pi F}} = \sqrt{\frac{6.5 \times 10^{27} \text{ W}}{4\pi \times 2.9 \times 10^{-9} \text{ W m}^{-2}}} = \mathbf{4.2 \times 10^{17} \text{ m}}$$

## Exercise 3.4 (c)

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

(c) The star's surface temperature is 9600 K. Taking  $\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$ , **determine** its radius. [3]

## Exercise 3.4 (c)

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**3.4** A star has a luminosity of  $6.5 \times 10^{27}$  W. Its radiant flux intensity measured at the Earth is  $2.9 \times 10^{-9}$  W m<sup>-2</sup>.

(c) The star's surface temperature is 9600 K. Taking  $\sigma = 5.67 \times 10^{-8}$  W m<sup>-2</sup> K<sup>-4</sup>, **determine** its radius. [3]

(c)  $L = 4\pi r^2 \sigma T^4$ , so  $r = \sqrt{L/(4\pi\sigma T^4)}$

$$r = \sqrt{\frac{L}{4\pi\sigma T^4}} = \sqrt{\frac{6.5 \times 10^{27}}{4\pi(5.67 \times 10^{-8})(9600)^4}} = \mathbf{3.3 \times 10^9 \text{ m}}$$

## Exercise 3.4 (d)

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

(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.

[2]

## Exercise 3.4 (d)

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

(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. [2]

(d) at the same radius and distance,  $F \propto T^4$

- so halving  $T$  gives  $(1/2)^4 = \mathbf{1/16}$  of the flux intensity

## Exercise 3.4 (e)

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

(e) **Suggest** why the flux intensity actually measured at the Earth may be **lower** than the calculation predicts. [2]

## Exercise 3.4 (e)

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

(e) **Suggest** why the flux intensity actually measured at the Earth may be **lower** than the calculation predicts. [2]

(e) interstellar dust and gas **absorb and scatter** some of the light on the way

- and the Earth's atmosphere absorbs part of it too, so a ground-based measurement is lower still