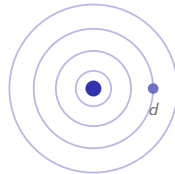


Astronomy and Cosmology

A2 Physics ■ Topic 25

A-Level Physics



Astronomy and Cosmology

What we will cover

- 1 Luminosity and flux
- 2 Standard candles
- 3 Stellar surface temperature
- 4 Redshift, Hubble, the Big Bang
- 5 Recap

1 Luminosity and flux

Total power, then power per unit area

Luminosity 光度 L is the total power a star radiates in all directions. Unit: W. At distance d that power has spread over a sphere $4\pi d^2$, so the **radiant flux intensity** 辐射通量密度 is

$$F = \frac{L}{4\pi d^2}$$

Inverse-square: doubling d cuts the flux to a quarter. A telescope measures F ; if L is known,

$$d = \sqrt{\frac{L}{4\pi F}}$$

Worked example – flux at the Earth

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

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

2 Standard candles

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** 视差.

Cepheids

造父变星

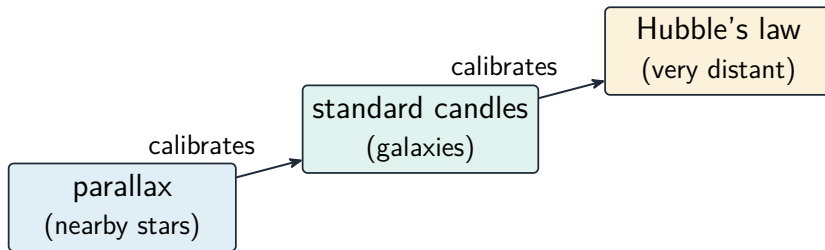
pulsation period is tightly
linked to luminosity
– the period gives L

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

3 Stellar temperature

Wien – hotter means bluer

A blackbody spectrum peaks at λ_{max} set by temperature:

$$\lambda_{\text{max}} T = b \approx 2.90 \times 10^{-3} \text{ m K}$$

Cool red star $\sim 3000 \text{ K}$ peaks in the infrared; the Sun $\sim 5800 \text{ K}$ near 500 nm ; a hot blue-white star $\sim 20000 \text{ K}$ in the ultraviolet.

$$\lambda_{\text{max}} = 500 \text{ nm}$$

$$T = b/\lambda_{\text{max}} = 2.90 \times 10^{-3} / (500 \times 10^{-9}) \approx 5800 \text{ K}$$

Stefan–Boltzmann – $L \propto r^2 T^4$

A star as a blackbody sphere:

$$L = 4\pi\sigma r^2 T^4, \quad \sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$$

Twice the radius $\Rightarrow$ four times L . Twice the temperature $\Rightarrow$ sixteen times L . To estimate a radius: $\lambda_{\text{max}} \rightarrow T$ (Wien); F and $d \rightarrow L$; then

$$r = \sqrt{\frac{L}{4\pi\sigma T^4}}$$

Estimating a star's radius

Wien, then Stefan–Boltzmann

- 1 $\lambda_{\text{max}} \Rightarrow T$
($\lambda_{\text{max}} T = 2.9 \times 10^{-3} \text{ m K}$)
- 2 $L = 4\pi d^2 F$ from flux and distance
- 3 $L = 4\pi r^2 \sigma T^4 \Rightarrow r = \sqrt{\frac{L}{4\pi\sigma T^4}}$



Two laws and a distance are enough to size a star nobody can resolve.

4 Redshift and Hubble

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└ Redshift and Hubble

Spectral lines shifted to the red

Lines from distant galaxies sit at longer wavelengths than in the lab – **redshift** 红移. Read as a Doppler shift, the galaxy is receding. For $v \ll c$:

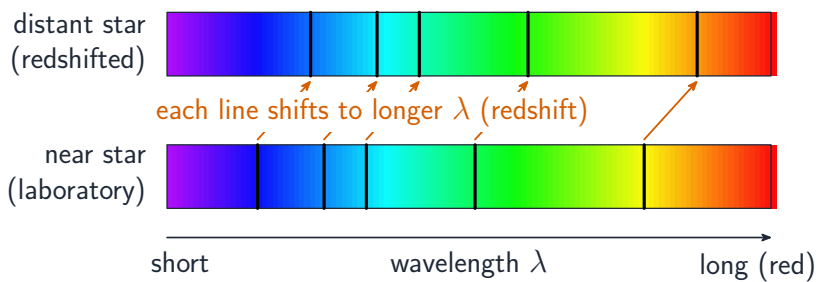
$$\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$$

Almost every distant galaxy is redshifted (a few near ones are **blueshifted** 蓝移 by local motion). Galaxies are, on average, moving apart – the Universe is expanding.

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└ Redshift and Hubble

The same lines, moved

A galaxy's lines keep their **pattern** but sit at longer wavelengths — which is how the shift is recognised as a shift, and not as different elements.



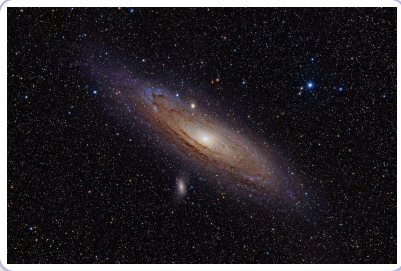
Hubble's law

$$v \approx H_0 \cdot d$$

$H_0 \approx 2.3 \times 10^{-18} \text{ s}^{-1}$. Always SI units. Running the expansion backwards, distances shrink to zero at $t = -1/H_0$ – the **Big Bang** 大爆炸. For steady expansion the age is

$$T_{\text{age}} \approx \frac{1}{H_0} \approx 14 \text{ billion years}$$

How far the ladder reaches



Andromeda — Cepheids put it well outside our own galaxy.



Almost every smudge here is a galaxy, most of them receding.

Worked example – a receding galaxy

Emitted $4.62 \times 10^{-7} \text{ m}$, **seen at** $4.91 \times 10^{-7} \text{ m}$. $H_0 = 2.3 \times 10^{-18} \text{ s}^{-1}$.

$\Delta\lambda = 0.29 \times 10^{-7} \text{ m}$, so $v \approx (\Delta\lambda/\lambda)c \approx 1.9 \times 10^7 \text{ m s}^{-1}$.

Distance $d = v/H_0 \approx 8.3 \times 10^{24} \text{ m}$.

5

Recap

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└ Recap

Topic 25 – key takeaways

1 Flux

$$F = L / (4\pi d^2); \text{ inverse-square}$$

2 Candles

Cepheids, Type Ia; d from known L

3 Star

$$\text{Wien } \lambda_{\text{max}} T = b; L = 4\pi\sigma r^2 T^4$$

4 Hubble

$$v = H_0 d; \text{ age } \approx 1/H_0$$

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└ Recap

Check yourself

- 1 Double the distance: what happens to flux?
- 2 What makes a Cepheid a standard candle?
- 3 A hotter star: longer or shorter λ_{max} ?
- 4 Hubble's law points to what origin of the Universe?

Answers 1. falls to a quarter 2. period gives luminosity 3. shorter 4. the Big Bang