LESSON 5.4.2

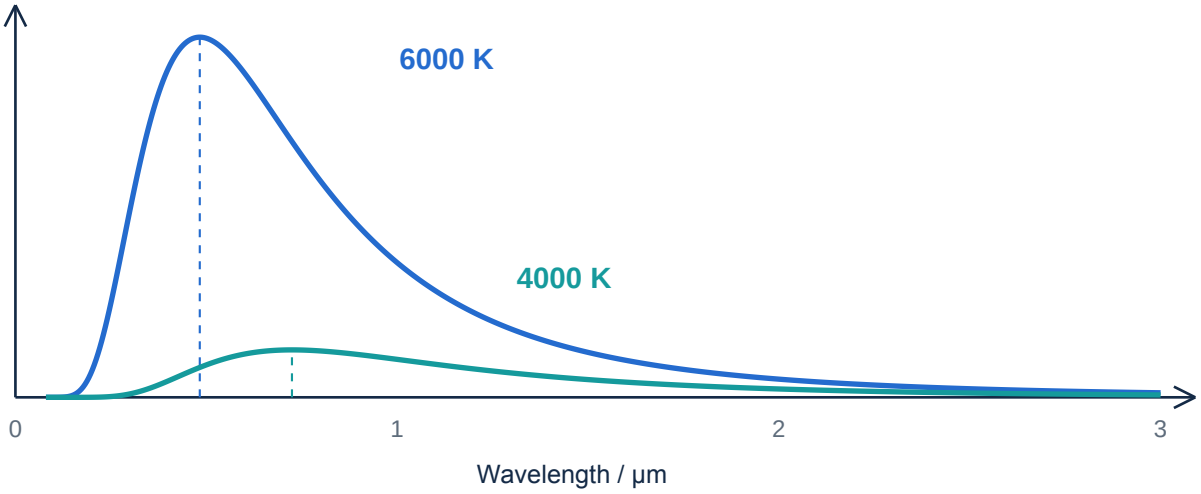
Stars, Luminosity and Black-body Radiation

A star's spectrum reveals its surface temperature. Combine that temperature with its size and the light received on Earth to investigate its luminosity and distance.

A perfect black body absorbs all incident radiation and is the best thermal emitter at a given temperature. Its continuous spectrum depends only on temperature; stars are approximate black bodies.

RADIATED POWER PER UNIT AREA PER UNIT WAVELENGTH

Relative scale, identical for both curves



Higher temperature: a shorter peak wavelength and more power emitted per unit area at every wavelength. The total area under the full curve increases.

$$\lambda_{max} T = 2.898 \times 10^{-3} \text{ m K}$$

WIEN'S LAW: USE METRES AND KELVIN

$$T = \frac{2.898 \times 10^{-3}}{483 \times 10^{-9}} = 6000 \text{ K}$$

Example: a peak at 483 nm. The peak is not the only wavelength emitted.

1 Power emitted versus power received

Luminosity L is a star's total power output in watts. Received intensity I is the power arriving per unit area at the observer, measured in W/m².

A. STEFAN-BOLTZMANN LAW

$$L = \sigma A T^4 = 4\pi R^2 \sigma T^4$$

For a spherical black-body star, $A = 4\pi R^2$. R is the stellar radius and T is its absolute surface temperature. This is power emitted, not net cooling power.

$$\sigma = 5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$$

KEEP RADIUS FIXED

Double T: luminosity increases by a factor of 16. A hotter star emits more power per square metre of its surface.

KEEP TEMPERATURE FIXED

Double R: surface area and luminosity each increase by a factor of 4. A cool giant can outshine a small hot star.

WORKED EXAMPLE: THE 6000 K STAR

$$R = 7.00 \times 10^8\ \text{m} \qquad T = 6000\ \text{K}$$

$$L = 4\pi(7.00 \times 10^8)^2(5.67 \times 10^{-8})(6000)^4$$

$$L = 4.52 \times 10^{26}\ \text{W (three significant figures)}$$

B. THE INVERSE-SQUARE LAW

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

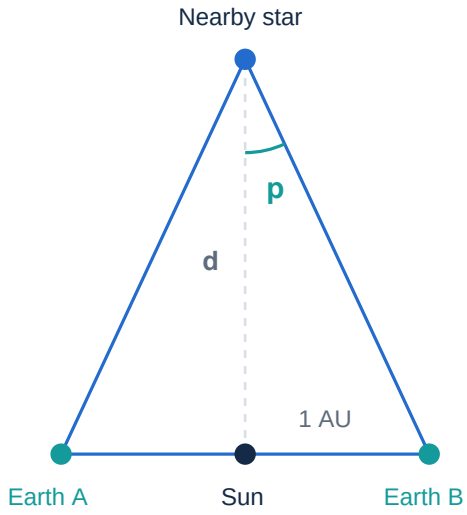
The same luminosity spreads over a sphere of area $4\pi d^2$ at distance d. Double d: I falls to one quarter, while L stays unchanged. Do not confuse observer distance d with stellar radius R.

Assume emission in all directions and negligible absorption. These equations use power across all wavelengths; a single colour band is not automatically the total intensity.

2 Two ways to measure stellar distance

Parallax uses viewing geometry. A standard candle uses a calibrated intrinsic luminosity and the measured intensity received from it.

A. TRIGONOMETRIC PARALLAX



Angles exaggerated; suitable baseline geometry shown.

Observe against distant background stars from opposite sides of Earth's orbit, six months apart. The total maximum angular shift is 2p, not p.

A larger distance gives a smaller parallax. Tiny angles eventually become difficult to measure precisely.

$$d \approx \frac{1\ \text{AU}}{p\ (\text{radians})} \qquad d\ (\text{pc}) = \frac{1}{p\ (\text{arcsec})}$$

A parsec is the distance giving a parallax of 1 arcsecond for a 1 AU baseline. One arcsecond is 1/3600 degree; 1 pc is about 3.26 light-years.

p = 0.040 arcsec gives d = 1/0.040 = 25 pc.

B. STANDARD CANDLES

If an object's luminosity is independently known or calibrated, use its observed intensity to infer distance. Cepheid pulsation periods, for example, can be calibrated against luminosity.

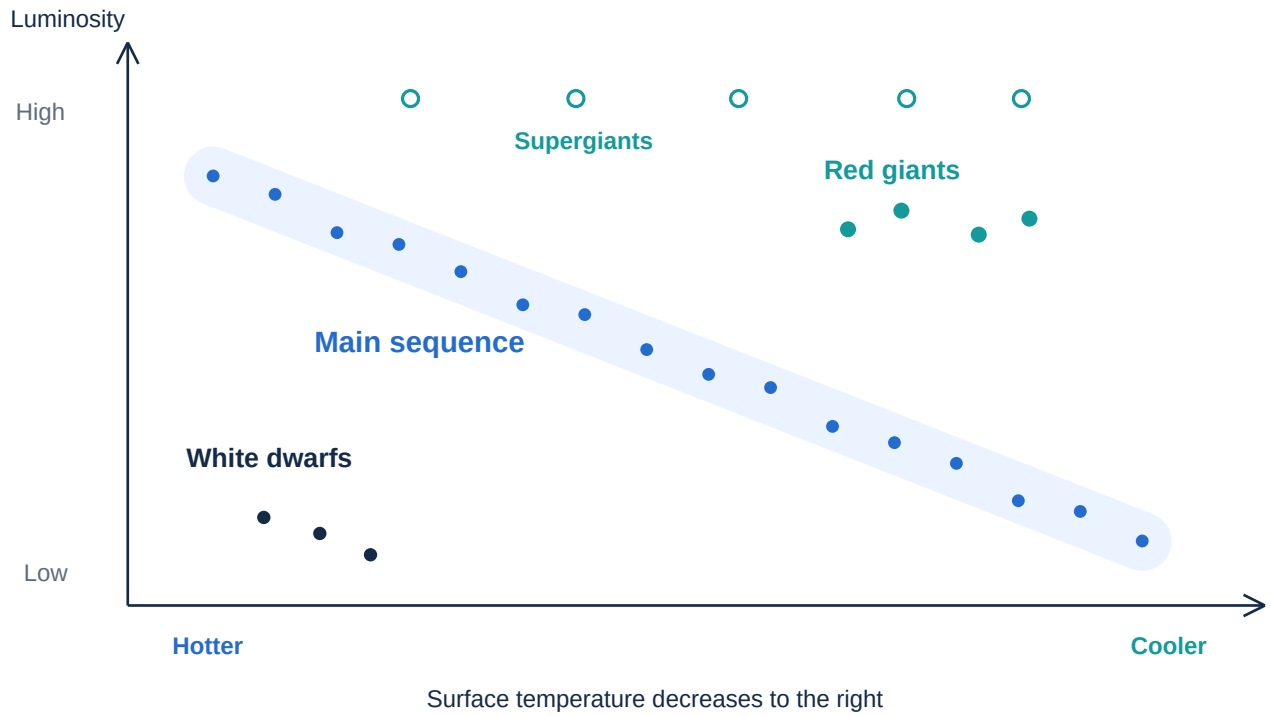
$$d^2 = \frac{L}{4\pi I}$$

Calculate d^2, then take the square root. An uncorrected loss of light to dust makes I too small and the inferred distance too large. An ordinary star is not a standard candle merely because it is bright.

Distance allows measured intensity to become intrinsic luminosity: $L = 4\pi d^2 I$.

3 Read the H-R diagram

An H-R diagram plots luminosity against surface temperature. It is a map of stellar properties, not a map of positions in space or a single universal ageing path.



Schematic regions; axes usually use logarithmic scales.

Cool but luminous means a very large radius: red giants. Hot but faint means a small radius: white dwarfs. The Stefan-Boltzmann law explains both regions.

FROM FORMATION TO REMNANT

1. Gravity contracts gas and dust into a protostar. Core hydrogen fusion starts the main-sequence stage; an outward pressure gradient balances gravity.

2A. A SUN-LIKE STAR

Core hydrogen runs low; the envelope expands into a red giant. Later it sheds its outer layers as a planetary nebula, leaving a white dwarf that cools over time.

2B. A MASSIVE STAR

It may become a supergiant and fuse heavier elements. Core collapse can produce a supernova, leaving a neutron star or black hole, depending on the remnant mass.

Higher-mass main-sequence stars consume fuel faster and have shorter lifetimes.

Curriculum: Pearson IAL Physics p. 36, points 161-168.

Sources: OpenStax Astronomy 2e §§5.2, 18.4, 19.2; NASA Stars.

Next: 5.4.3 Redshift, Hubble's law and the expanding universe.