

9702 C25 Astronomy and Cosmology

Luminosity & Radiant Flux

Luminosity (L) = total power of radiation emitted by a star

Radiant flux intensity (F) = radiant power per unit area observed at a distance

inverse square law of flux equation

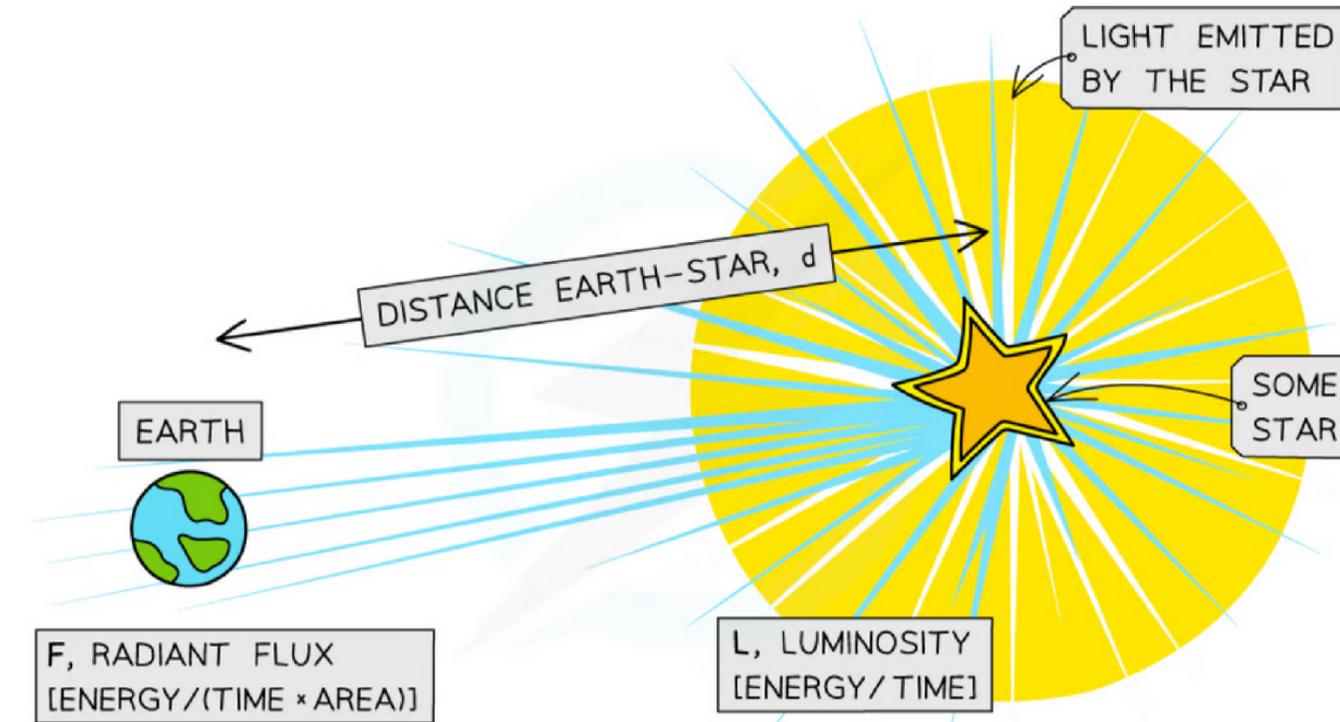
$$F = \frac{L}{4\pi d^2}$$

Where:

- F = radiant flux intensity, or observed intensity on Earth (W m^{-2})
- L = luminosity of the source (W)
- d = distance between the star and the Earth (m)

Radiant flux follows an inverse square law

L is constant for a given star



Standard Candles

standard candle = an object which has a known luminosity due to its properties

2 common types of standard candle

1. Cepheid variable stars - a type of pulsating star which increases and decreases in brightening over a set time period
2. Type 1a supernovae - a supernova explosion involving a white dwarf, the luminosity at the time of the explosion is always the same

To measure astronomical distance, a standard candle is used as a distance indicator

Radiant flux intensity of the EM radiation arriving at Earth is measured

Since the luminosity is known (as the object is a standard candle), the distance can be calculated from inverse square law of flux

Each standard candle method can measure distances within a certain range + collecting data & measurement, a larger picture of the scale of the universe - this is known as cosmic ladder

Wien's Displacement Law

Wien's displacement law = the black body radiation curve for different temperatures peaks at a wavelength which is inversely proportional to the temperature

$$\lambda_{\max} \propto \frac{1}{T}$$

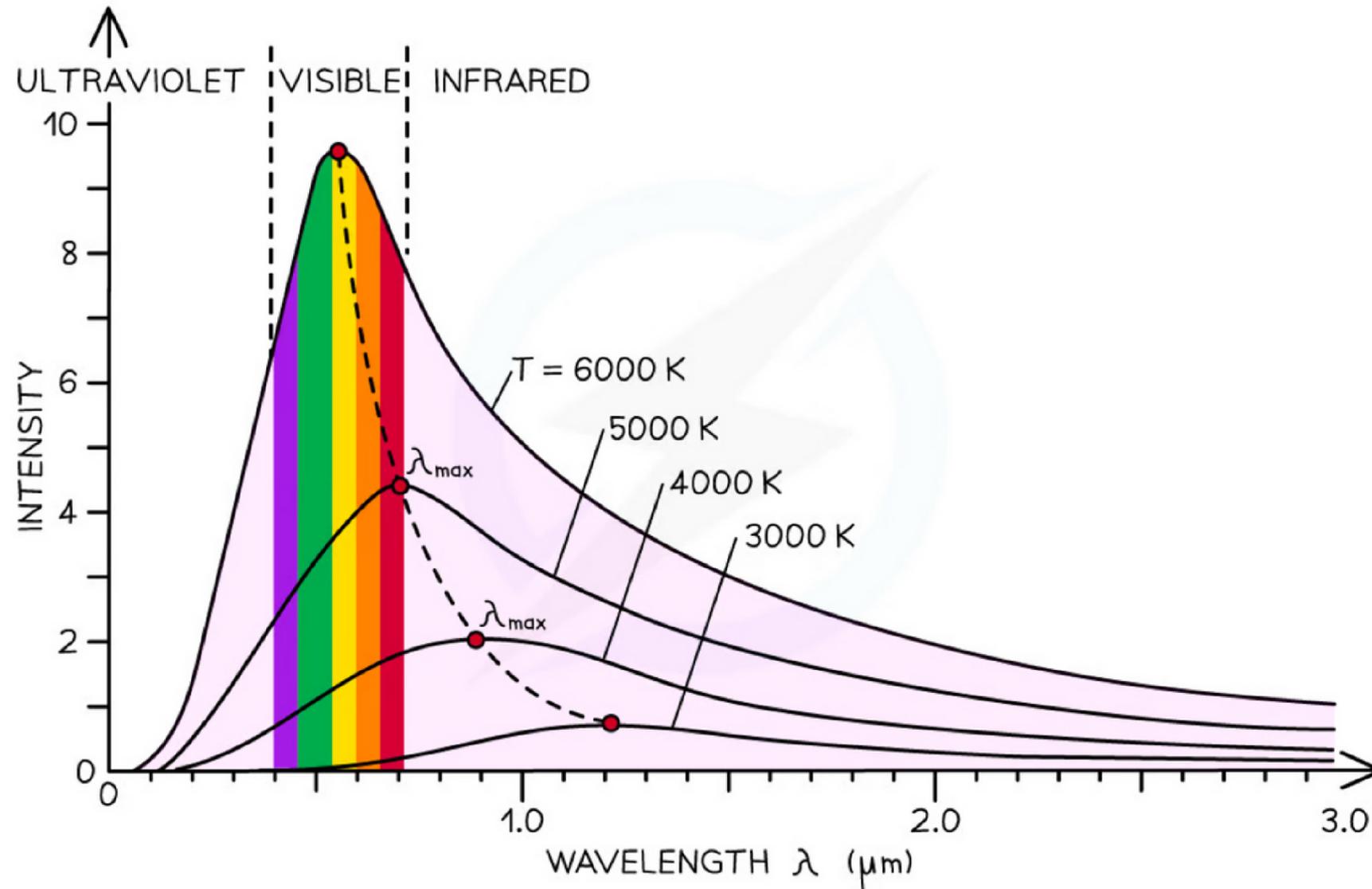
λ_{\max} is the maximum wavelength emitted by the star at the peak intensity

A black body is an object which:

1. absorbs all the radiation that falls on it + good emitter
2. does not reflect or transmit any radiation

A black body is a theoretical object, however stars are the best approximation

Spectrum of radiation emitted from a black-body



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Full equation of Wien's Law

$$\lambda_{\text{max}} T = 2.9 \times 10^{-3} \text{ mK}$$

Where:

- λ_{max} = peak wavelength of the star (m)
- T = thermodynamic temperature at the surface of the star (K)

This equation tells us:

temp inc = wavelength shorter at the peak
 intensity = greater radiation intensity = hotter stars (tends to be white/blue)

Cooler stars tend to be red/yellow

Stefan-Boltzman Law

Stefan-Boltzman Law = total energy emitted by a black body per unit area per second is proportional to the fourth power of the absolute temperature of the body

$$L = 4\pi r^2 \sigma T^4$$

Where:

- L = luminosity of the star (W)
- r = radius of the star (m)
- σ = the Stefan-Boltzmann constant
- T = surface temperature of the star (K)

summary (these equations can be combined and rearrange):

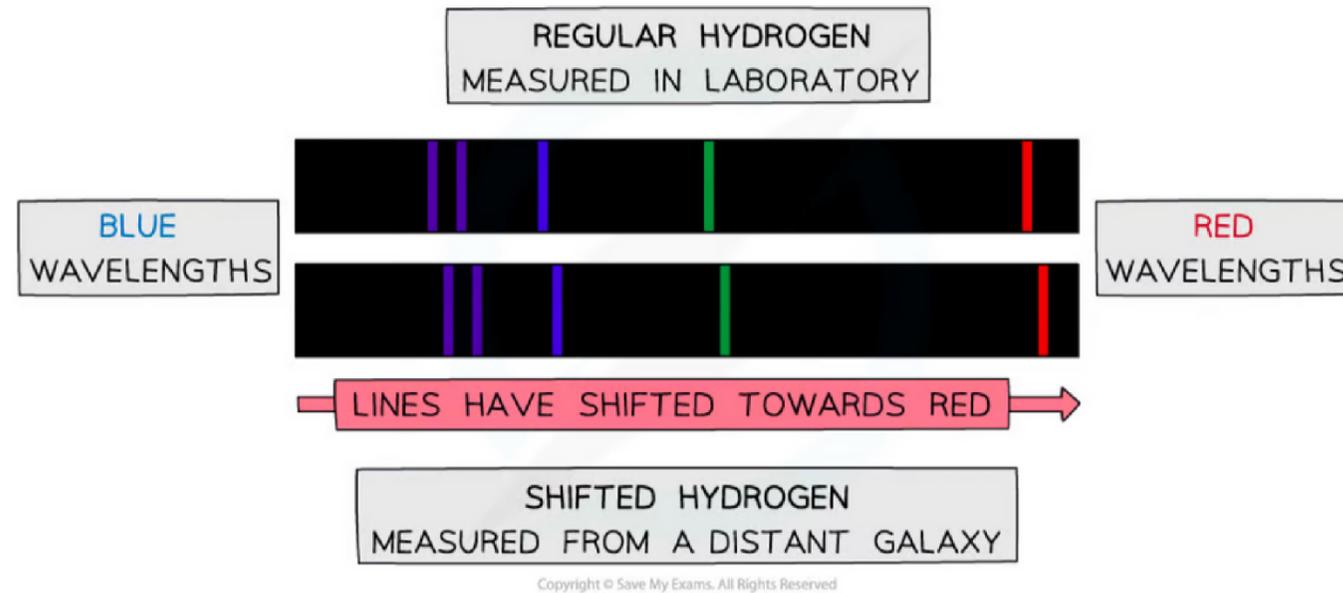
Stefan-Boltzman Law: $L = 4\pi r^2 \sigma T^4$

Wien's Displacement Law: $\lambda_{\max} \propto \frac{1}{T}$

Inverse square law of flux: $F = \frac{L}{4\pi d^2}$

Emission Spectra (see more in C22)

Star predominantly made of hydrogen and helium, absorb some of the emitted wavelengths



The top emission spectra shows spectral lines of hydrogen measured on Earth

The bottom emission spectra shows the shifted spectral lines of hydrogen measured from a distant galaxy

Observed light from distance galaxies is different in the spectral lines to the light from the Sun

If the lines have the same pattern, meaning the element can still be easily identified, they just appear to be shifted slightly:

-->lines in spectra from distance galaxies show an increase in wavelength + shift towards red end of the spectrum

Doppler Redshift

Recall from AS:

Doppler effect = the apparent change in wavelength/frequency of the radiation from a source due to its relative motion **AWAY FROM** or **TOWARD** the observer

In space, the Doppler effect of light can be observed:

Redshift = object is moving away from the Earth

Blueshift = object is moving towards the Earth

$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta f}{f} = \frac{v}{c}$$

Redshift = fractional increase in wavelength(decrease in frequency) due to the source and observer receding from each other

Where:

- $\Delta\lambda$ = shift in wavelength (m)
- λ = wavelength emitted from the source (m)
- Δf = shift in frequency (Hz)
- f = frequency emitted from the source (Hz)
- v = speed of recession (m s^{-1})
- c = speed of light in a vacuum (m s^{-1})

An Expanding Universe

After the discovery of Doppler Redshift, astronomers began to realise that **almost all the galaxies in the universe are receding**

Therefore, the space between the Earth and the galaxies must be **expanding**
-->expansion stretches out the light waves as they travel through the space, shifting them towards the red end of the spectrum

more red shifted the light from a galaxy is = faster the galaxy is moving away from the Earth

galaxies move away from each other, however, they themselves do not move

Hubble's Law & the Big Bang Theory

Hubble's Law = recesssion speed of galaxies moving away from Earth is proportional to their distance from the Earth

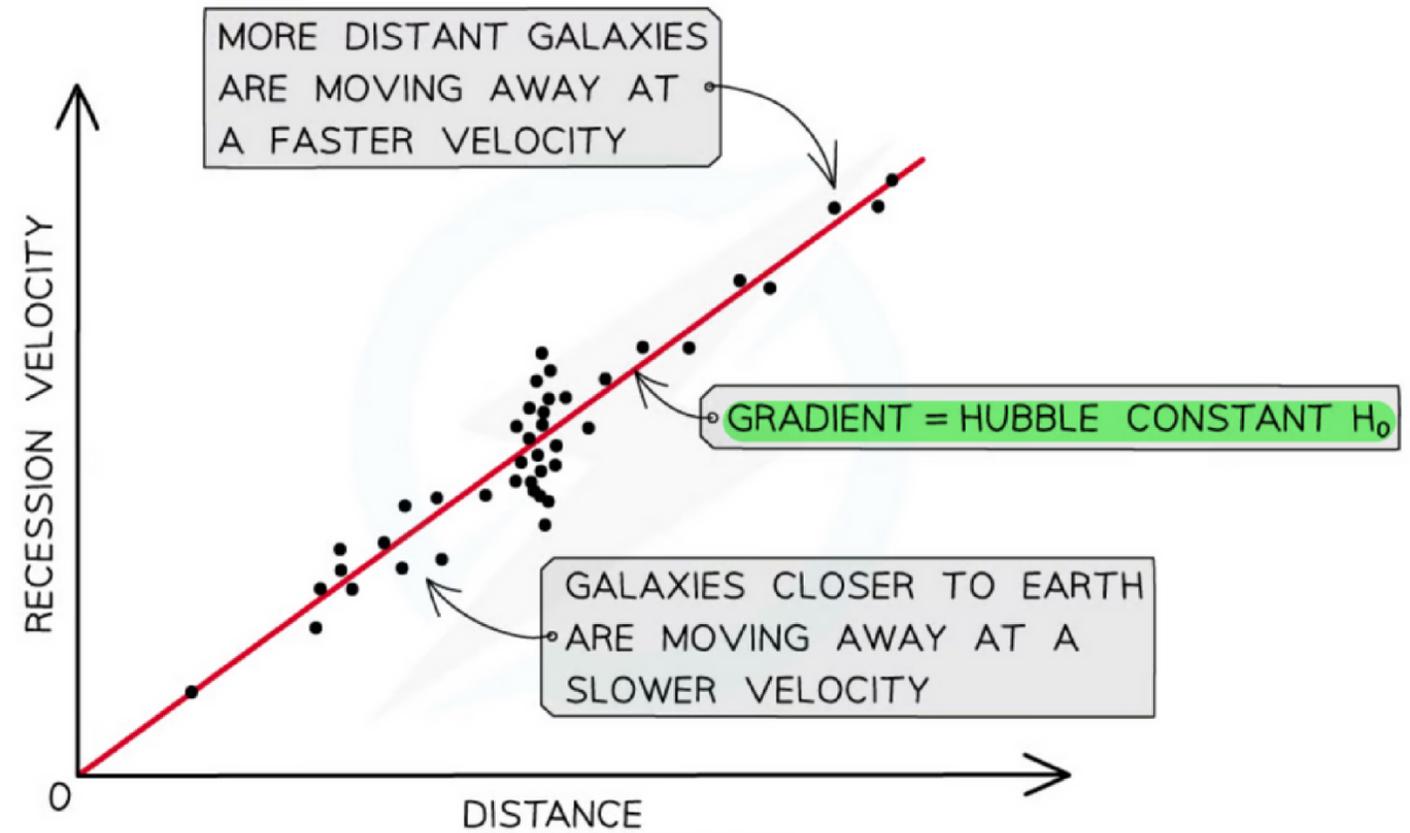
$$v = H_0 d$$

Where:

- v = the galaxy's recessional velocity (m s^{-1})
- d = distance between the galaxy and Earth (m)
- H_0 = Hubble's constant, or the rate of expansion of the universe (s^{-1})

If the galaxies are moving from each other, then they must have started from the same point at some time in the past

Redshift of galaxies and the expansion of the universe are the most prominent piece to support Big Bang Theory



Data from Hubble's law can be extrapolated back to the beginning point of the universe: $T_0 = \frac{1}{H_0}$