Fiat Lux IV

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SU3A 26 Nov 2024

Episode IV

Colour in the Cosmos

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Introduction

Perception of Colour
- Human vision
- Human perception

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- Non-spectral colours

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- Atoms
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- Doppler shift
- Cosmological redshift

Beyond Colour
- False colour
- Infrared

Summary

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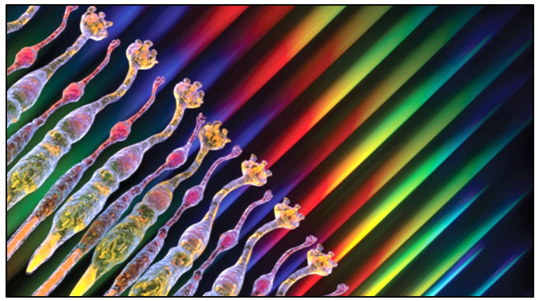
What Is Colour?

Is colour real…

… or is it just a pigment of your imagination?



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Why Do We Have Colour Vision?

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How do we perceive colour?

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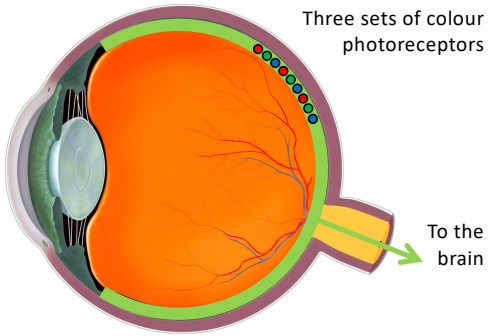
Human Eye



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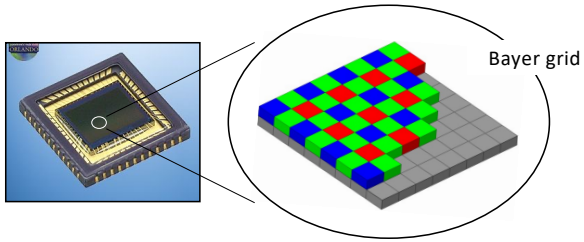
Digital Camera



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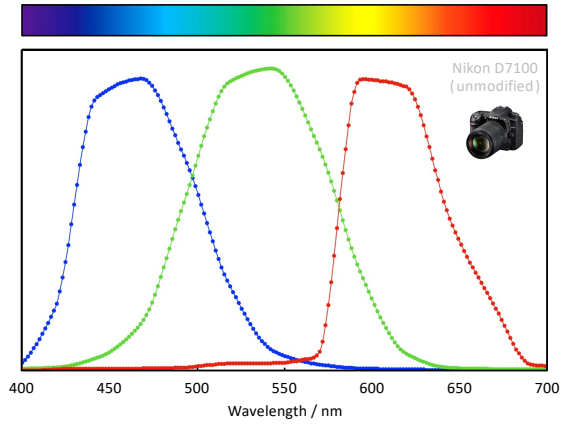
Camera Colour Response



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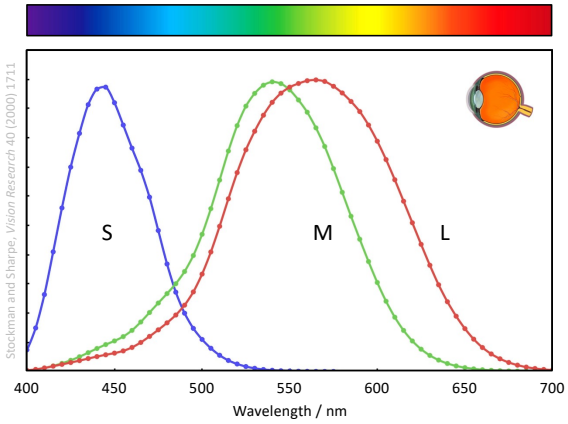
Eye Colour Response



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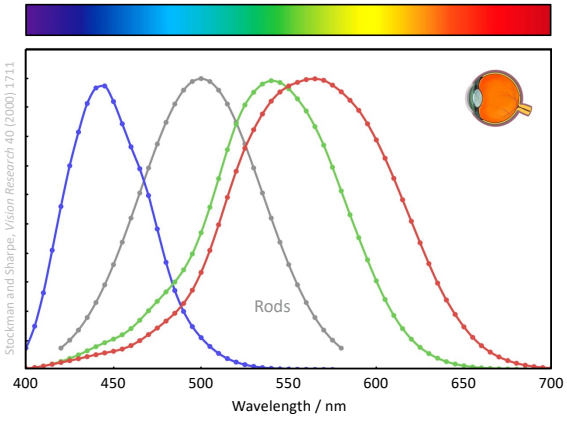
Aside – Eye Rod Response



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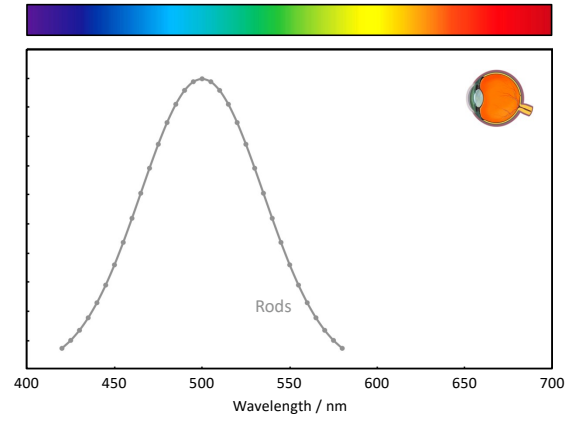
Aside – Eye Rod Response



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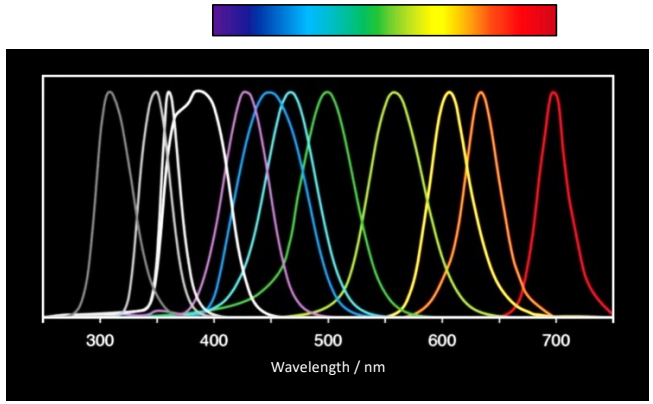
More Photoreceptors?



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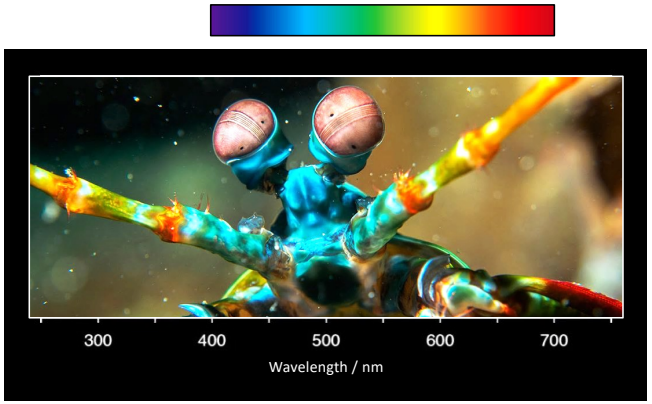
Mantis Shrimp



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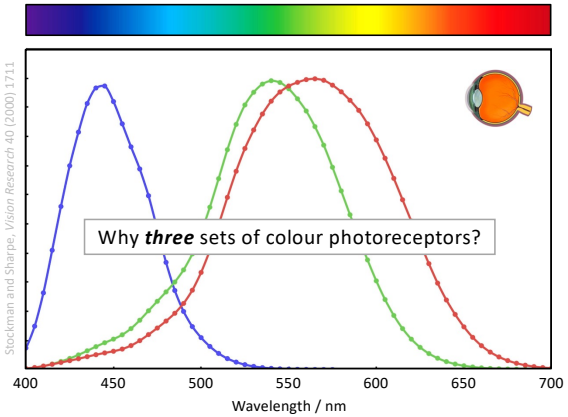
Trichromatic Vision



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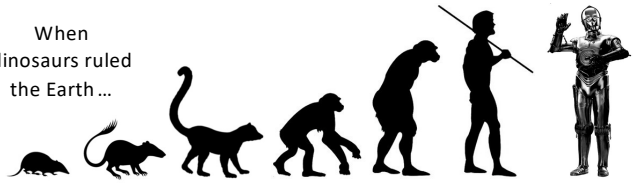
Trichromatic Vision

Our colour vision has evolved over 100 million years.

When dinosaurs ruled the Earth …



… we were nocturnal so had no need for colour vision

Genetic mutation restored our colour vision

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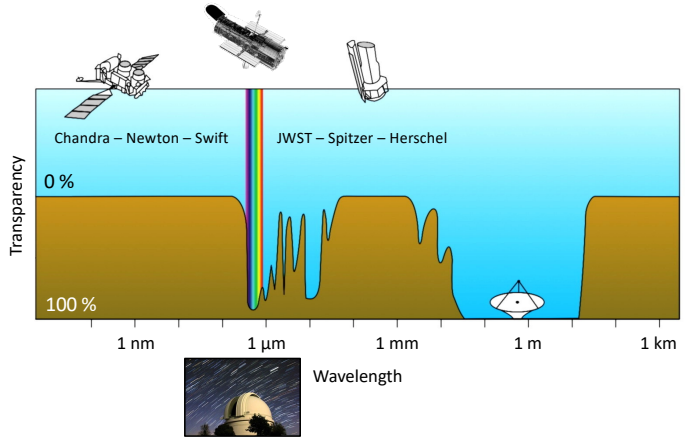
Why Visible Light?



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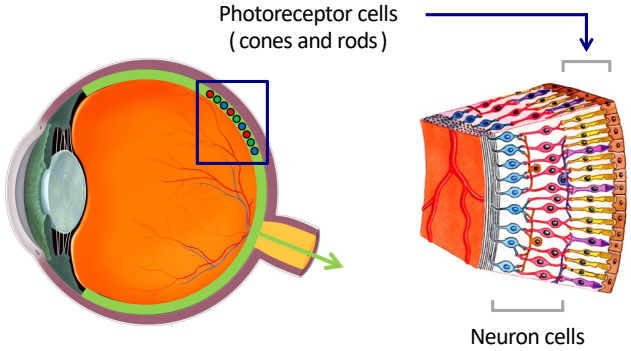
Human Eye



These do some image processing even before the signals are sent to the brain

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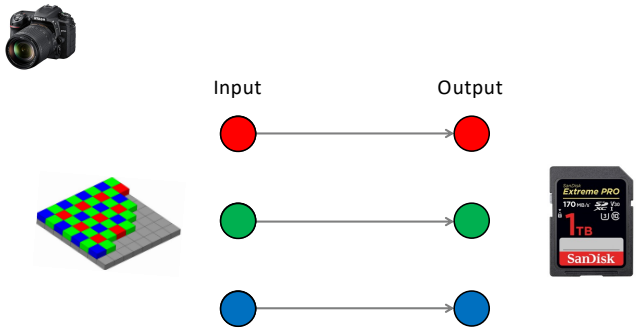
Processing Colour Signals



Camera circuitry

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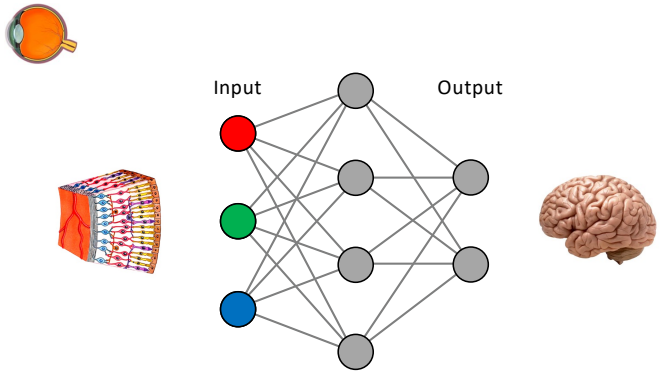
Processing Colour Signals



Neural network

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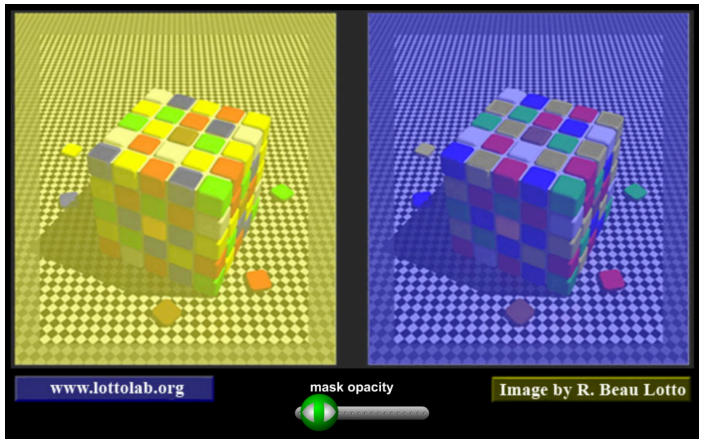
Perception vs Reality



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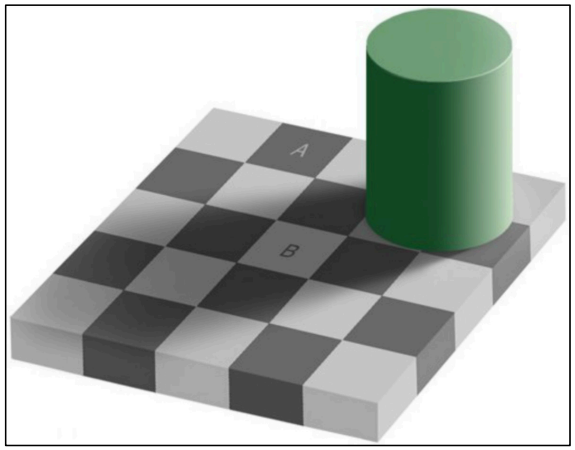
Perception vs Reality



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How can we quantify colour?

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Colour = Spectrum

Ask a physicist to quantify colour and they will probably reply with the knee-jerk response – a spectrum!

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Isaac Newton

Newton's work on optics in the 1660s established that white light is composed of many colours.

Arguments raged as to the nature of light – should it be considered as a stream of particles ('corpuscular') or as a wave?

(Curiously, modern physics developed centuries later gives the answer – both!)

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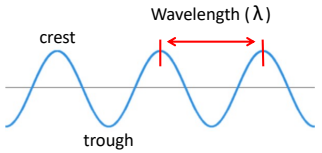
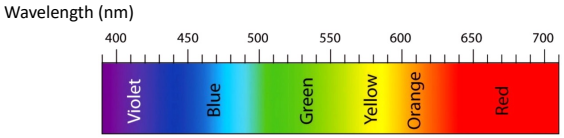
Light as a Wave

When light passes through a glass prism or an optical instrument, like a telescope or microscope, it reveals its wave nature.





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Non-Spectral Colours

That's not all there is to colour, as not all colours are 'spectral' colours.

For instance, where is the colour **beige** in the rainbow of all colours?

To show all colours, we need more than just a 'line of colours'.

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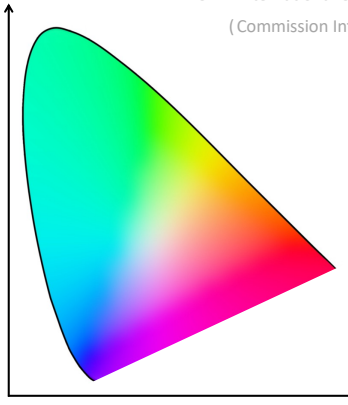
CIE Colour Space

CIE = International Commission on Illumination
(Commission Internationale de l'Eclairage)



All colours can be quantified and plotted in a plane called "colour space"

Let's not worry about what the two axes are

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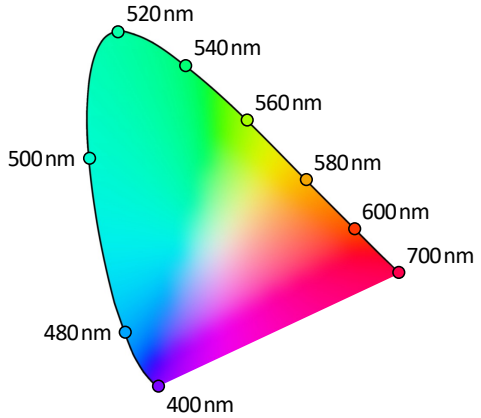
Spectral Colours



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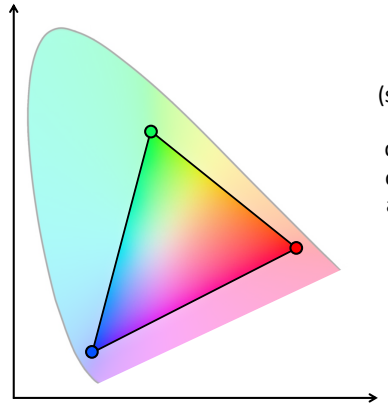
RGB Display Colours



Digital devices (such as phones, tablets, TVs or data projectors) can display only a limited gamut of colours

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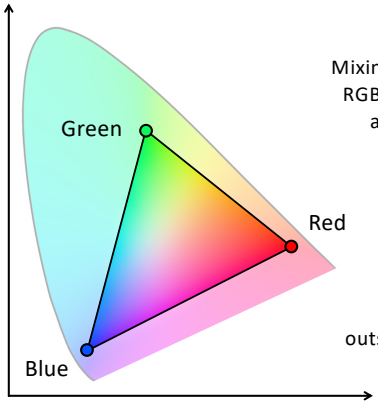
RGB Display Colours



Mixing three primary RGB colours creates any colour inside the triangle …

… but cannot create colours outside the triangle

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Colours of stars

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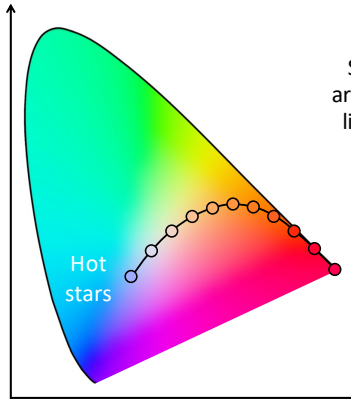
Colours of Stars



Stars cannot be any arbitrary colour – the light they emit must obey the laws of physics

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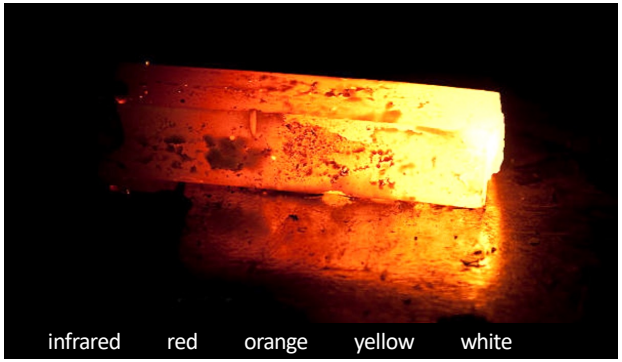
Blackbody Radiation



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Blackbody Radiation

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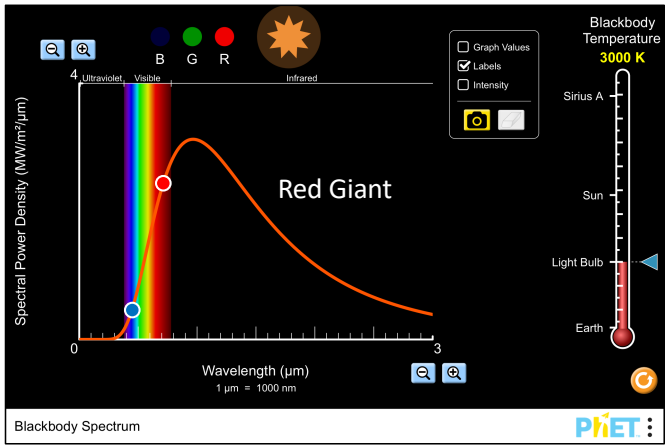
Blackbody Radiation



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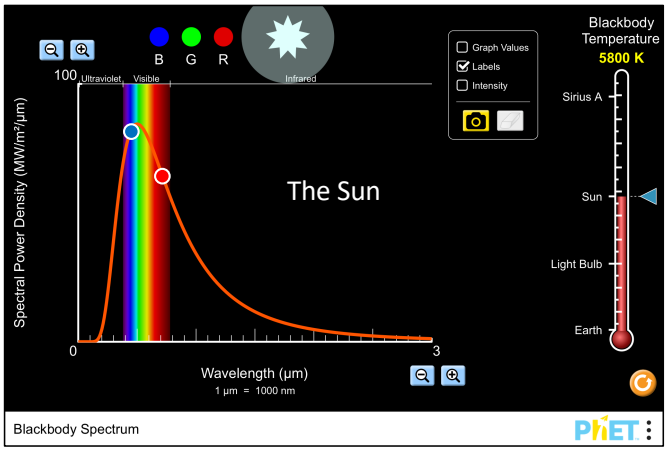
Blackbody Radiation



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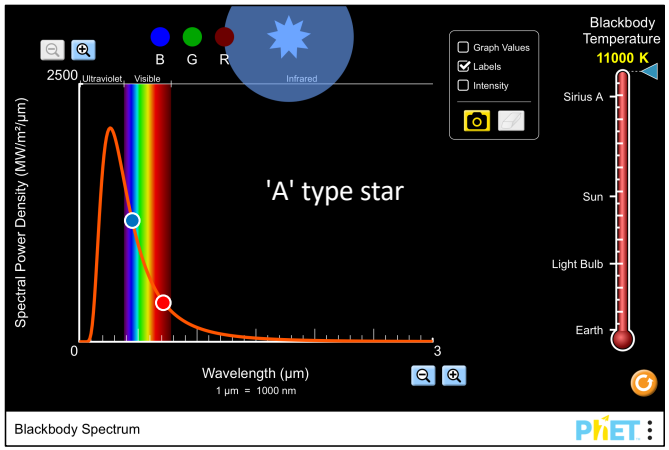
Blackbody Radiation



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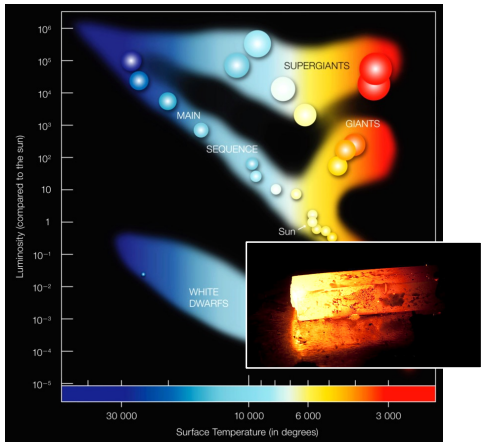
Hertzsprung-Russell Diagram



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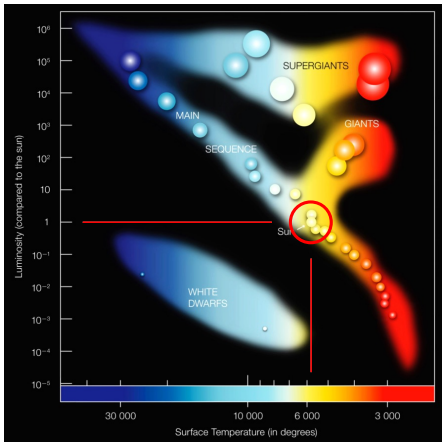
HR Diagram



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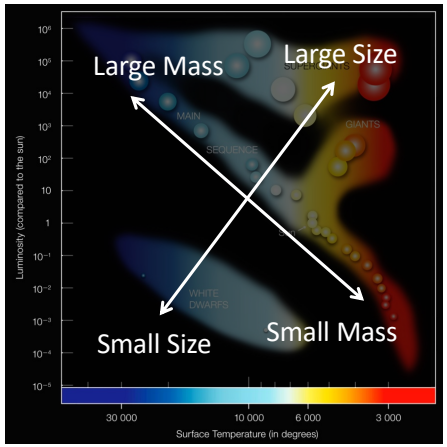
HR Diagram



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Star Cluster

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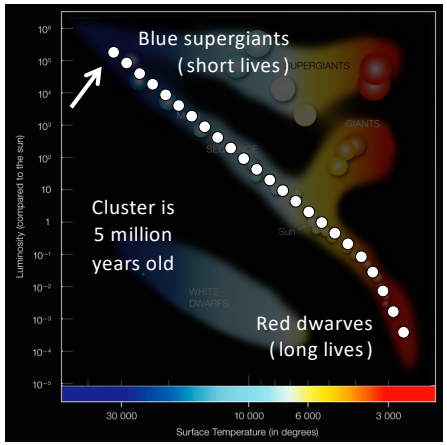
Age of Star Cluster



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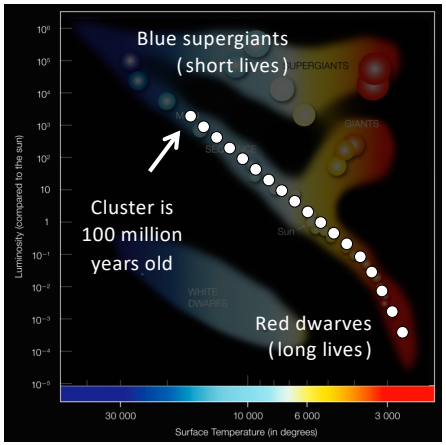
Age of Star Cluster



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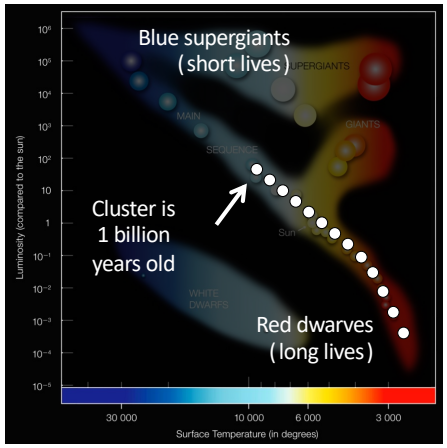
Age of Star Cluster



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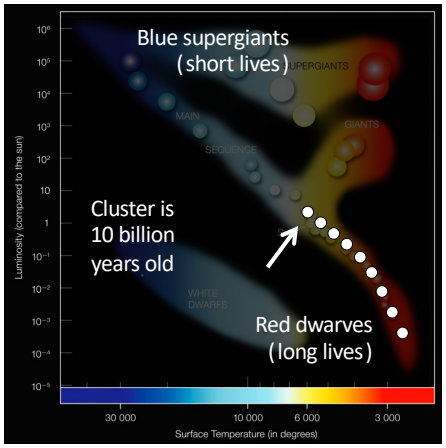
Age of Star Cluster



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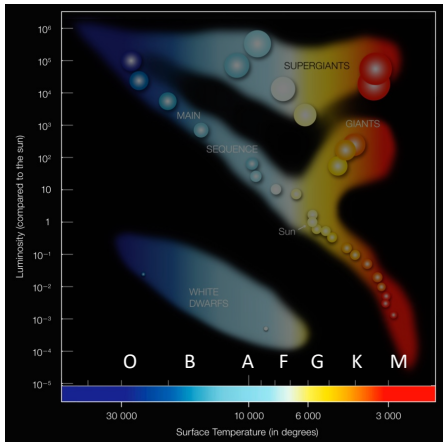
Stellar Classifications



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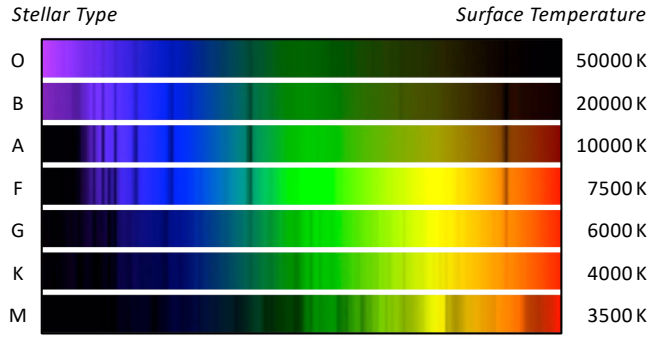
Stellar Classifications



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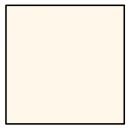
Colour of the Cosmos

Summing up all the light of all the stars in all the galaxies, what is the 'average' colour of the Universe?

By analysing the light from 200,000 galaxies within 2 billion light-years the conclusion was …



"Cosmic latte" or "Skyvory"

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Colours of nebulae

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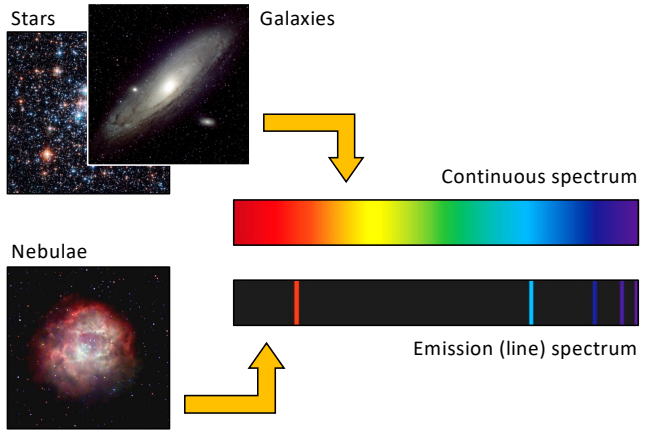
Astronomical Spectra



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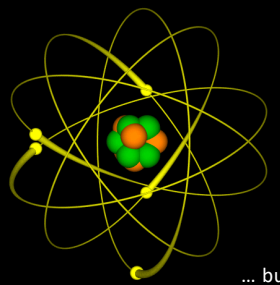
Electrons in Atoms

This might be how we imagine atoms with electrons buzzing around a nucleus like bees …



… but it doesn't show us that all the electrons have different energies

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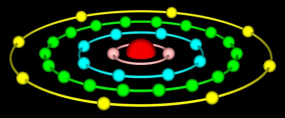
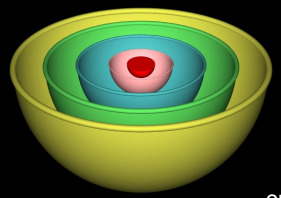
Electrons in Shells

It is better to think of the electrons in different sized orbits ...





... or concentric shells surrounding the nucleus

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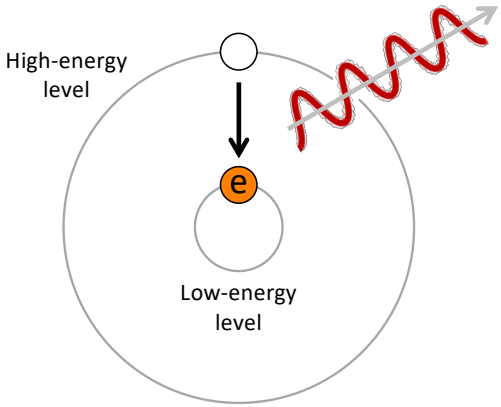
Quantum Jump –> Light Emission



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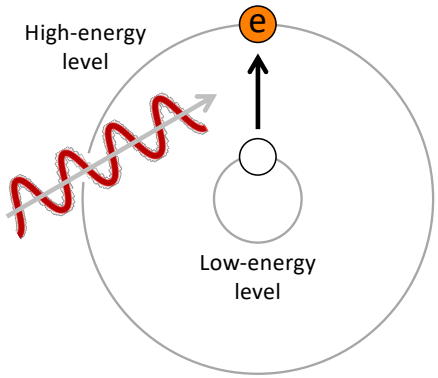
Light Absorption –> Quantum Jump



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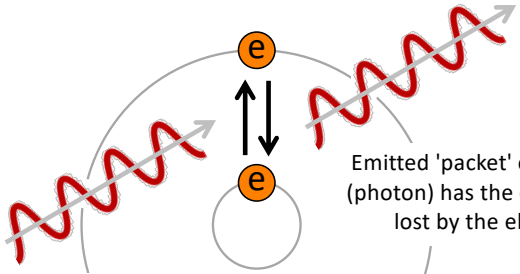
Absorption and Emission



Emitted 'packet' of light (photon) has the energy lost by the electron

The electron can only absorb the energy of the photon if the energies are an EXACT match

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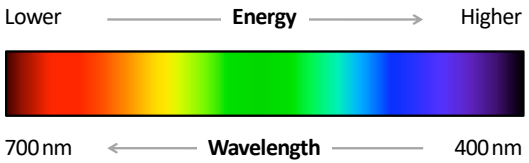
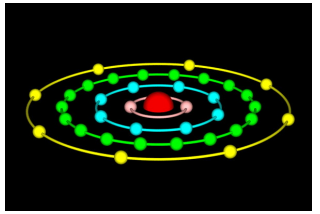
Photon Energy and Colour

According to Quantum Mechanics – the laws of Physics that describe how things work on very small scales – a photon of light with a given energy has a particular wavelength, and hence a particular colour.

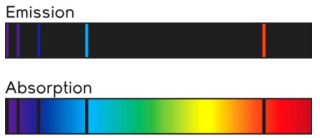


Emission Spectrum

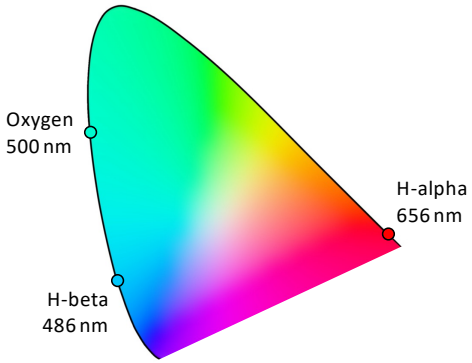
Every atom has many energy levels and so an electron can make quantum jumps with a number of specific energies that are characteristic of the atom.



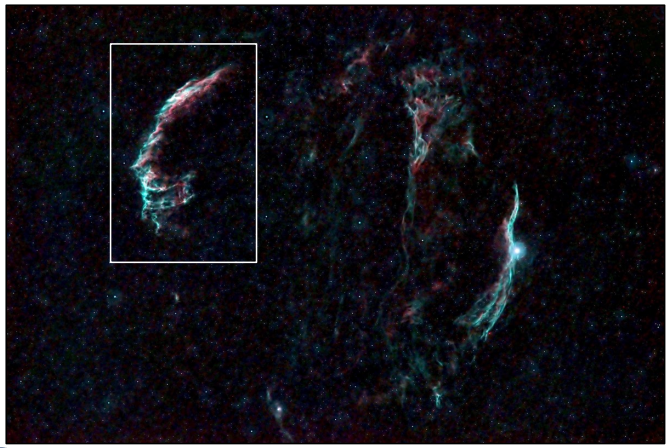
Hence atoms emit or absorb photons with characteristic patterns of energies and hence colour spectra.



Emission Lines

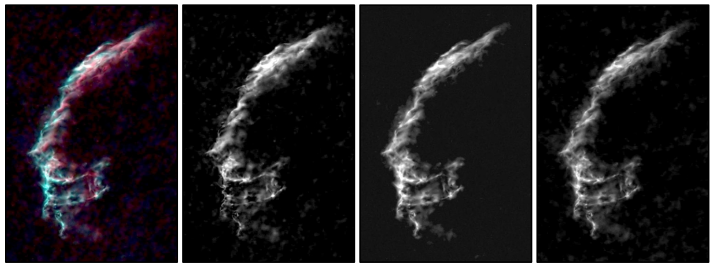


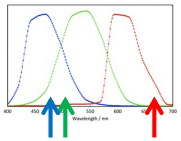
Veil Nebula



Nikon D7500 + 300mm / 60 x 60s / Tri-band

Eastern Veil Nebula





Red	Green	Blue
H-alpha	Oxygen + H-beta	H-beta + Oxygen

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Discrete or Continuous?

Light from a nebula is made up of a few discrete colours that depend on the atoms in the nebula:

Light from a star is a continuous spectrum with colour intensities that depend on its surface temperature:

Both are made of atoms, so why the difference?

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Discrete or Continuous?

The difference is the **density** of the object emitting the light.

If atoms are well-separated, each emits the colours dictated by the laws of quantum theory:

If atoms are close together, always bumping into each other, then the discrete colours are 'smeared out' into a continuous spectrum:

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How Many Atoms?

How many atoms are there in one cubic centimetre of…

A lump of metal	100,000,000,000,000,000,000,000
Earth's atmosphere	10,000,000,000,000,000,000,000
Sun's surface (photosphere)	100,000,000,000,000,000,000,000
Sun's atmosphere (corona)	10,000,000
Nebula	10,000
Interstellar medium	1
Intergalactic medium	0

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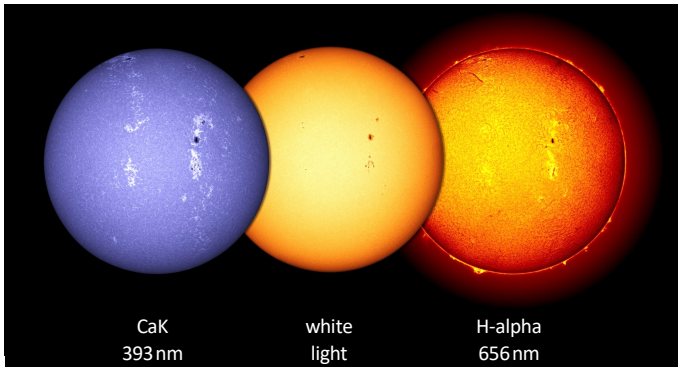
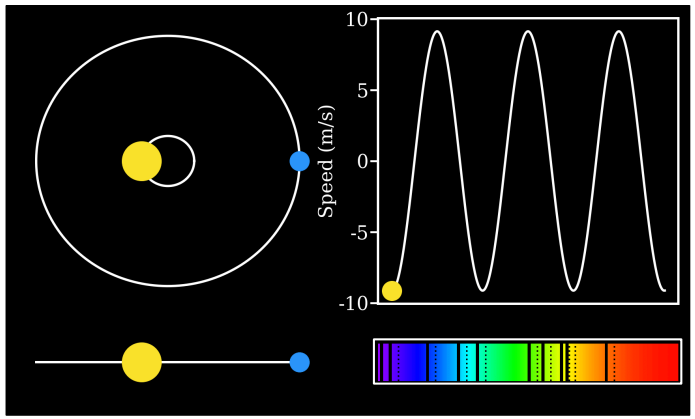
Photosphere of the Sun

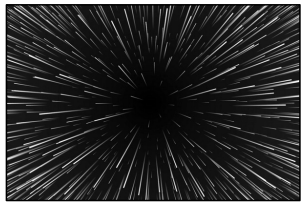


Spectroscopy

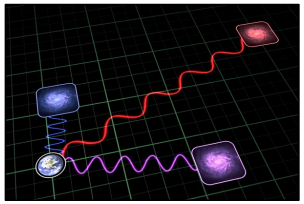
Doppler Shift



Redshift



In an expanding Universe, light gets stretched (redshifted) as it travels through space.

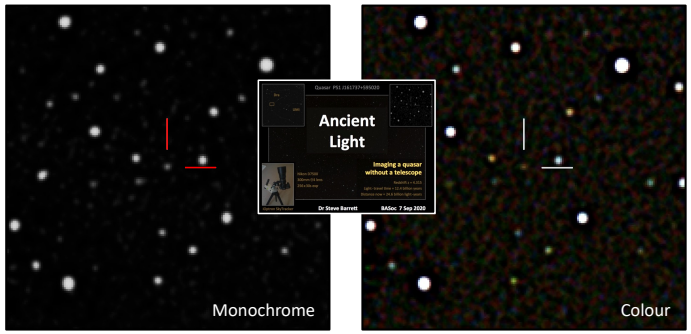


The amount that the light is shifted compared to its original wavelength is given the symbol z.

The redshift gives us the distance to the object that emitted the light. A redshift of z = 1 corresponds to an object that is 10 billion ly distant.

Quasar J161737+595020

Redshift z = 4.3



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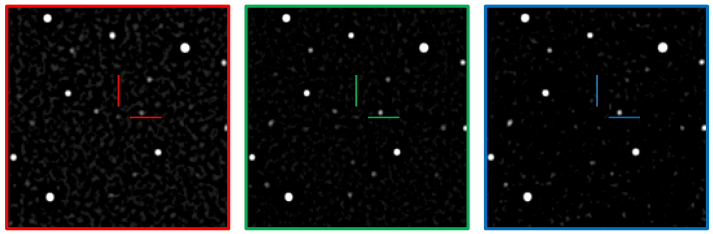
Quasar J161737+595020

Redshift z = 4.3

Distance = 25 billion light-years



Red (some light)

Green (less light)

Blue (no light)

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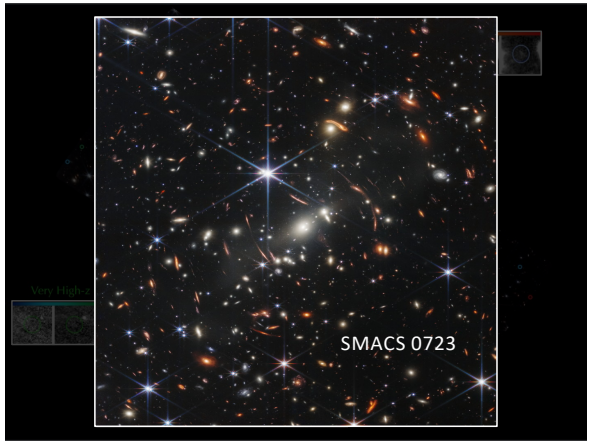
JWST Photometric Redshift



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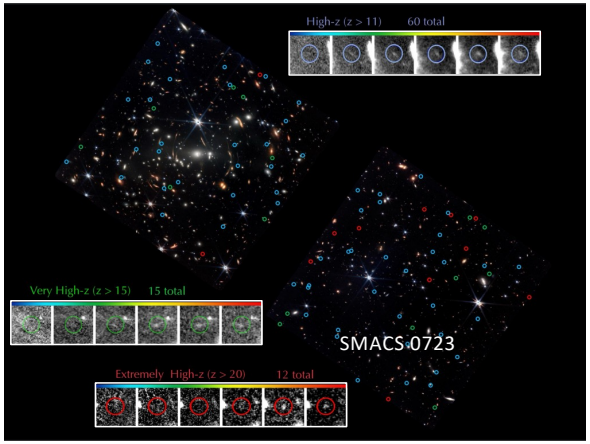
JWST Photometric Redshift



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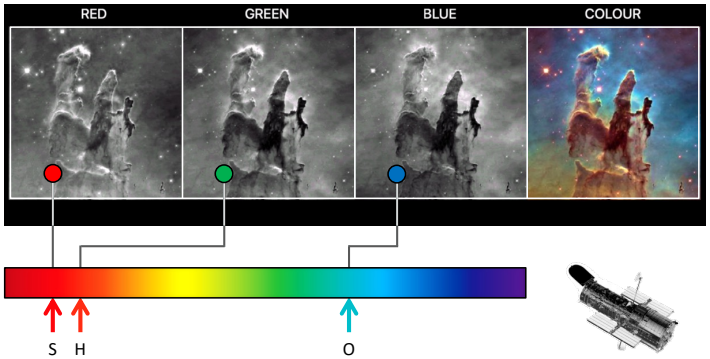
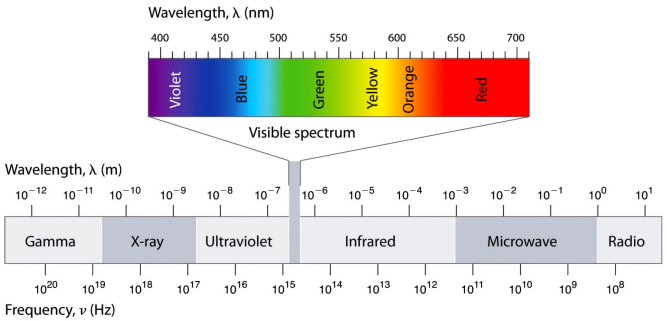
Beyond colour

Hubble Palette

Do Hubble Space Telescope images represent 'true' colours?

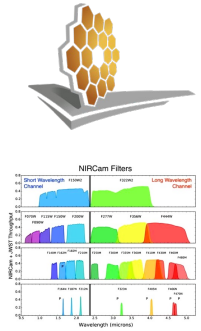


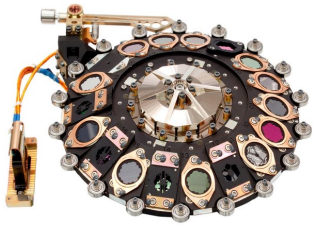
Electromagnetic Spectrum



JWST Imaging

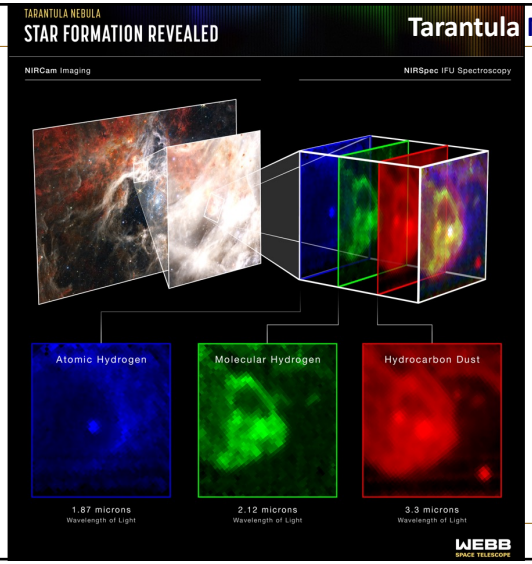
JWST works in the infrared, so none of its images are in 'true' colour.





One of the JWST filter wheels

Tarantula Nebula



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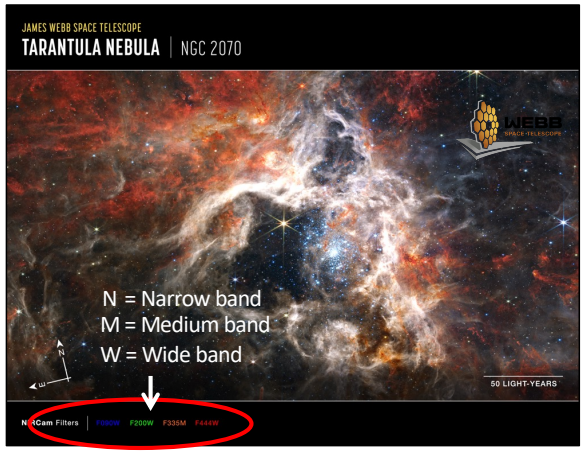
Tarantula Nebula



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Summary

- The eye is not a camera – it does not simply detect colour intensity and feed those signals to the brain.
- The colours of stars are determined by blackbody radiation and range from red to white to blue.
- The colours of nebulae are determined by quantum jumps in their constituent atoms.
- Breaking light down into spectra can be used to determine atomic composition and to measure velocities and distances.

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Fiat Lux IV

www.liverpool.ac.uk/~sdb/Talks

Dr Steve Barrett

SU3A 26 Nov 2024