

Fiat Lux IV – Colour in the Cosmos



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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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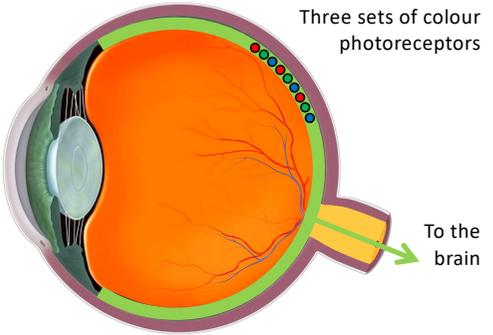
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How do we perceive colour?

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Human Eye



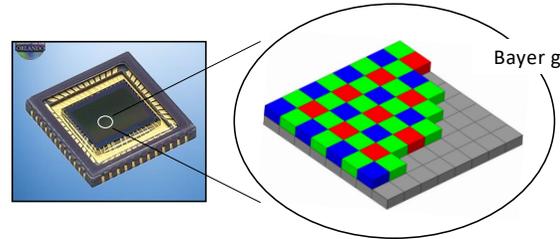
Three sets of colour photoreceptors

To the brain

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Digital Camera

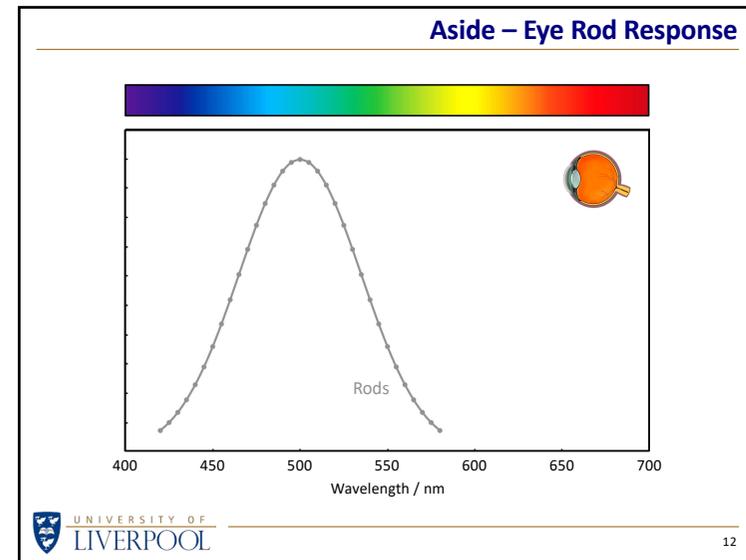
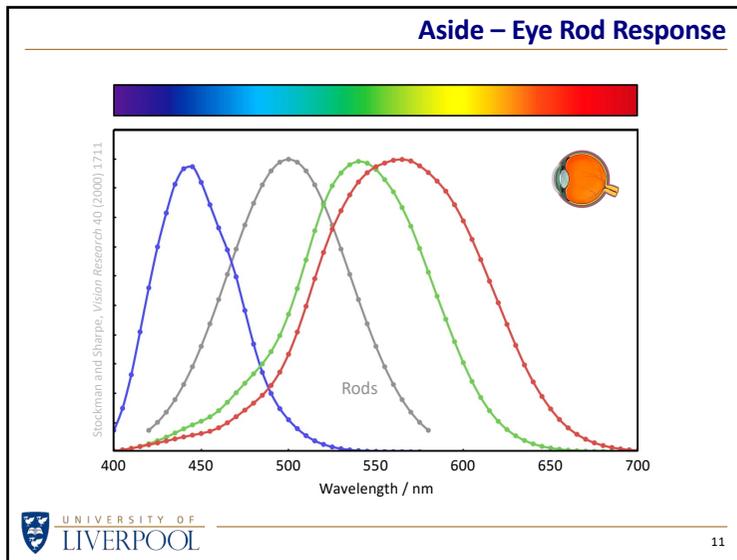
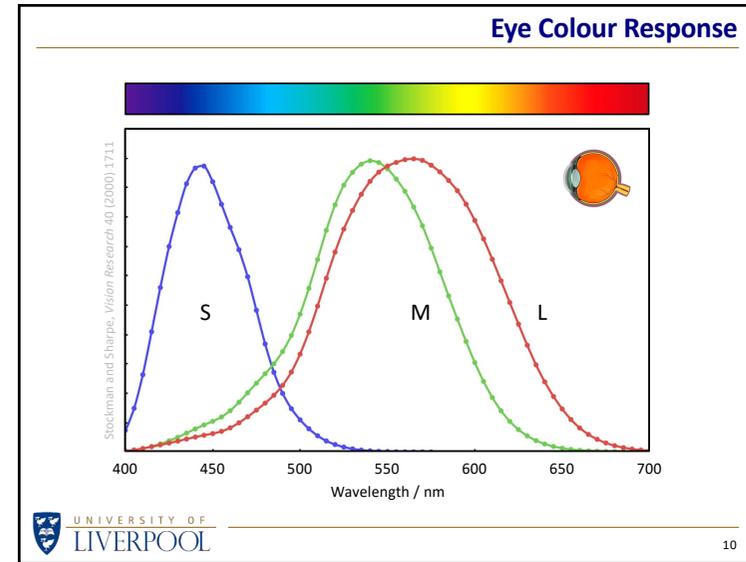
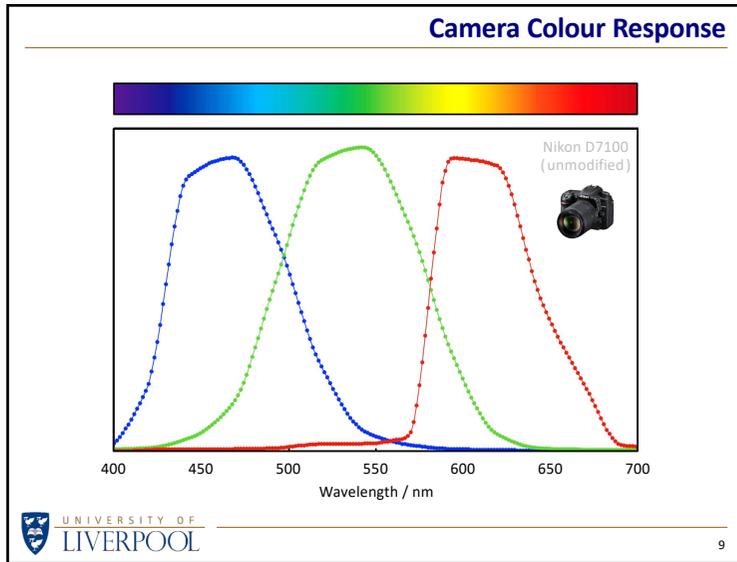


Bayer grid

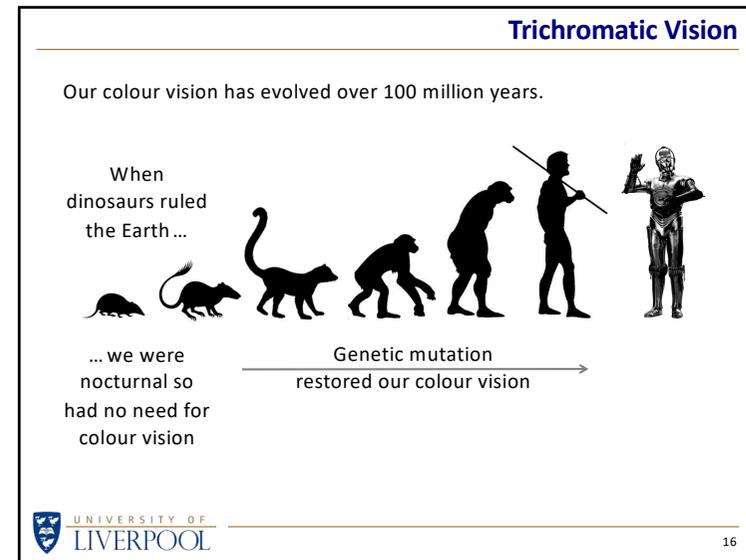
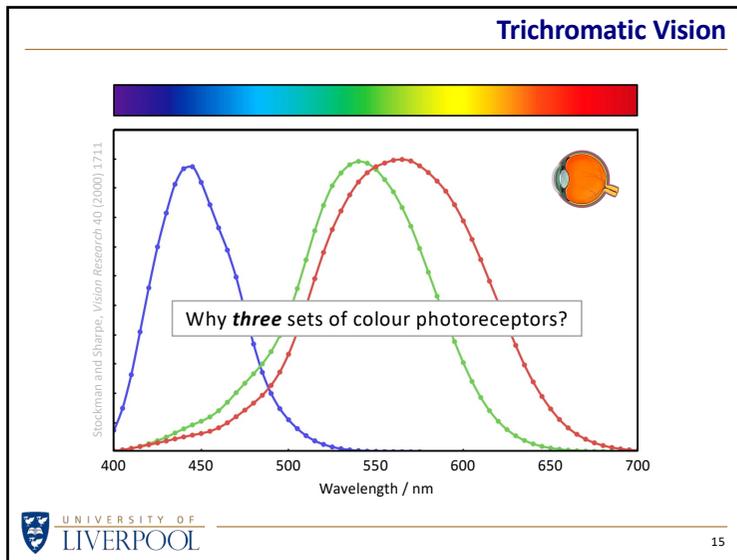
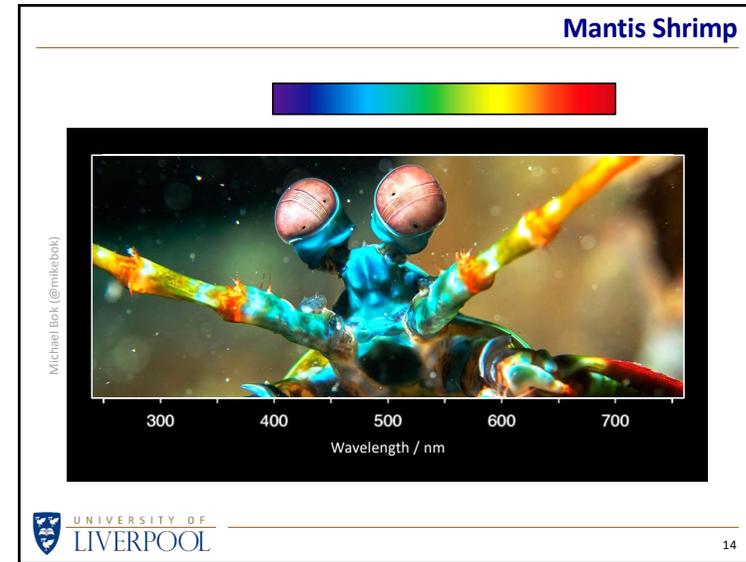
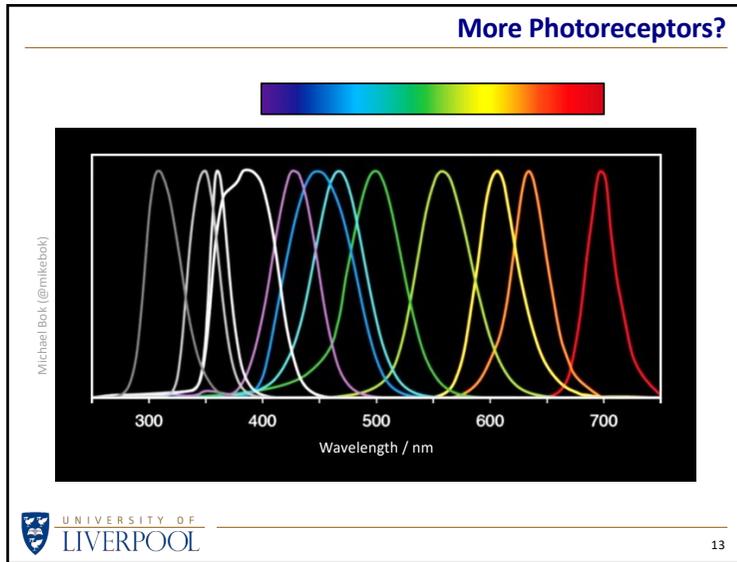
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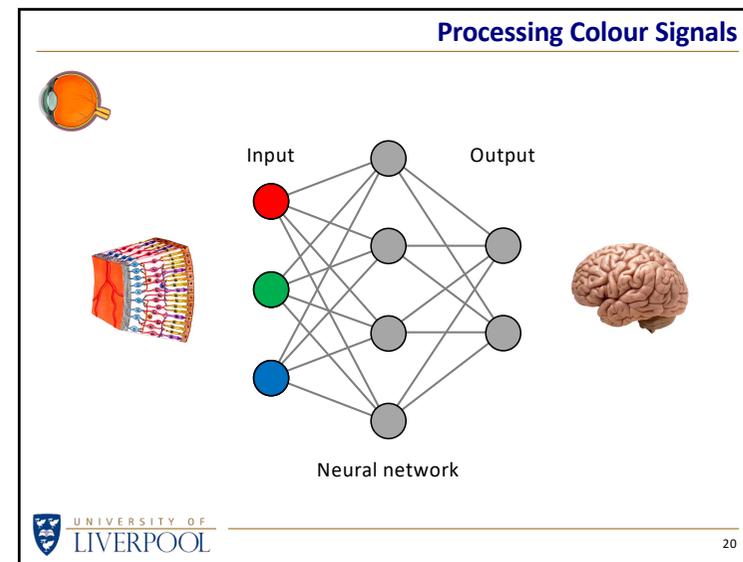
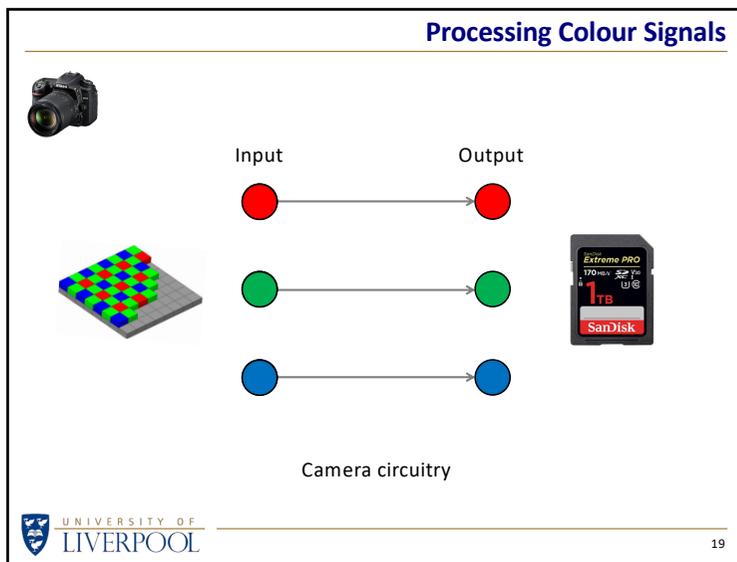
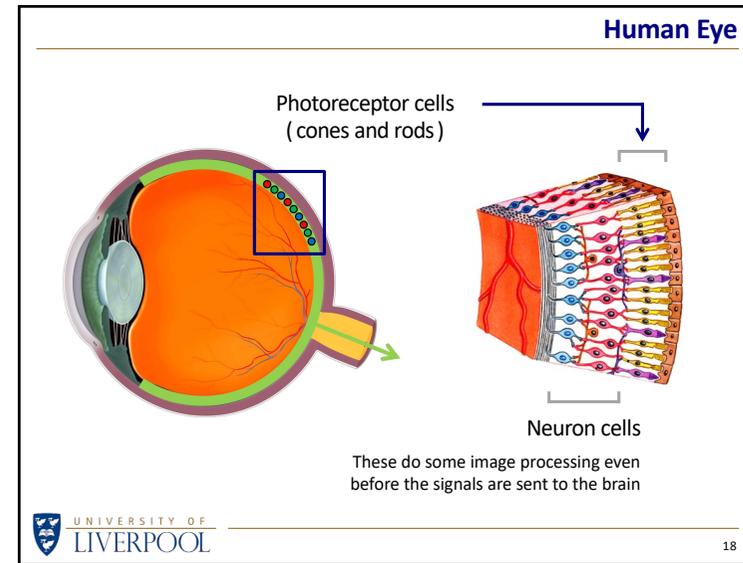
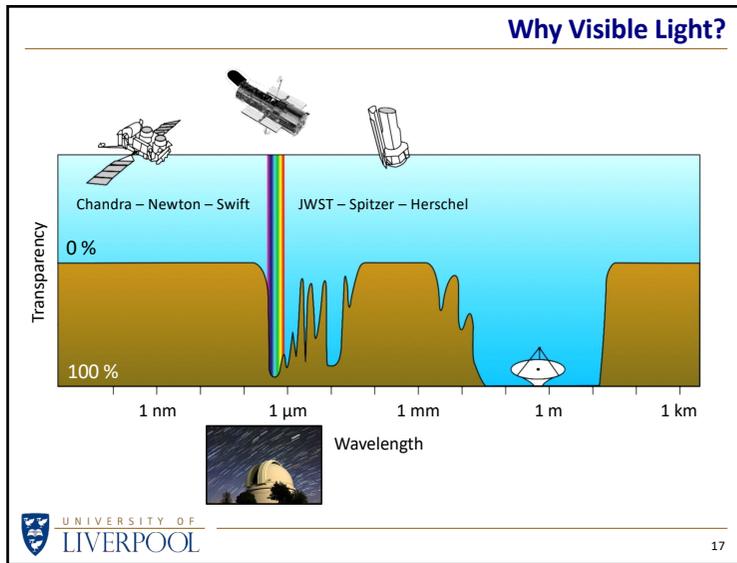
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Fiat Lux IV – Colour in the Cosmos

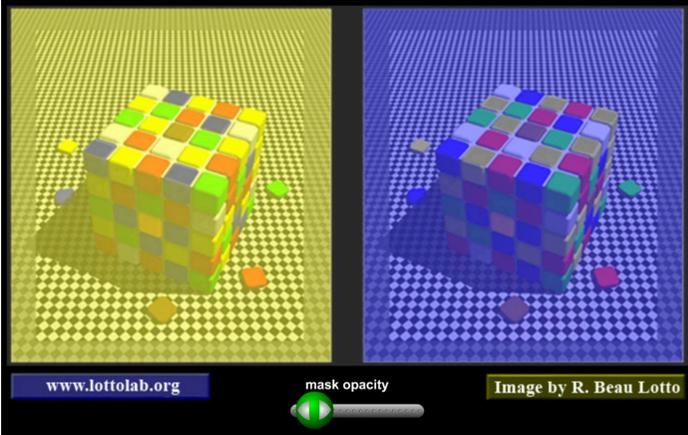


Fiata Lux IV – Colour in the Cosmos



Fiat Lux IV – Colour in the Cosmos

Perception vs Reality

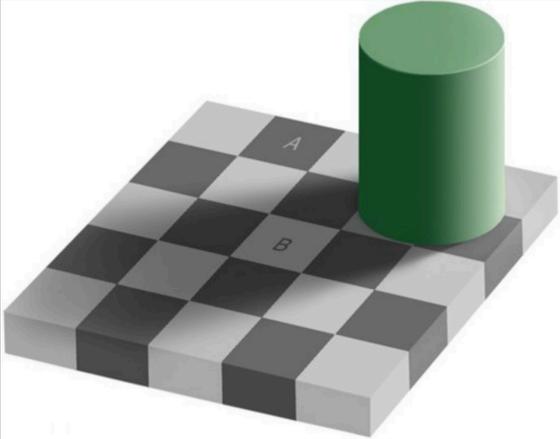


www.lottolab.org mask opacity Image by R. Beau Lotto

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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!

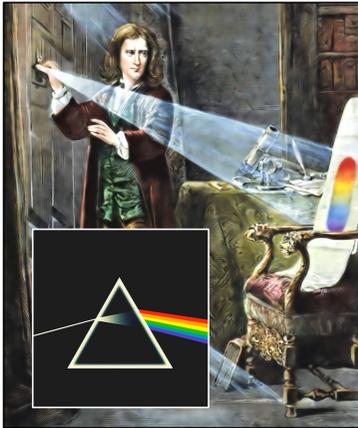


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Isaac Newton



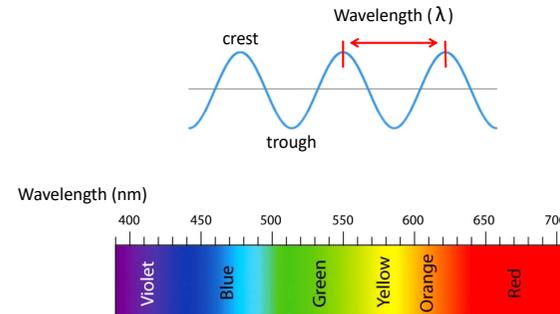
Newton's work on optics in the 1660s established that white light is composed of many colours.

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!)

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.



Non-Spectral Colours

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

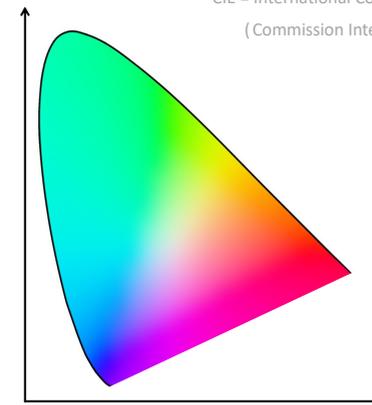
For instance, where is the colour **beige** in the rainbow of all colours?



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

CIE Colour Space

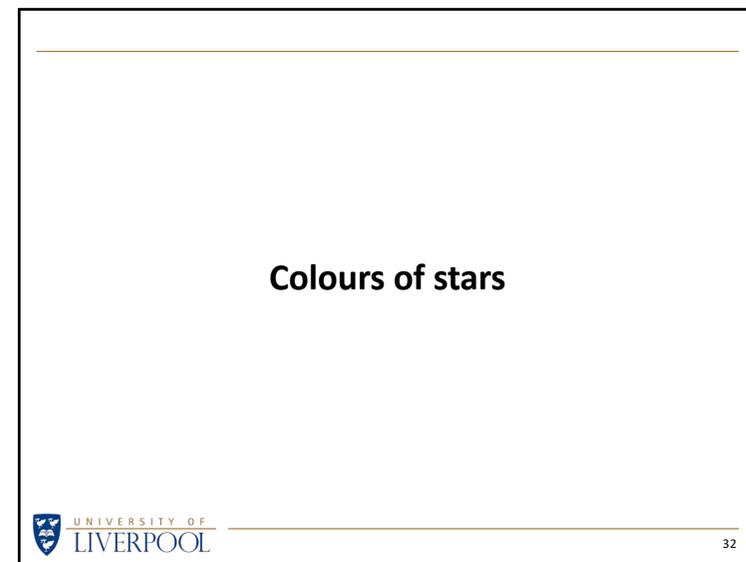
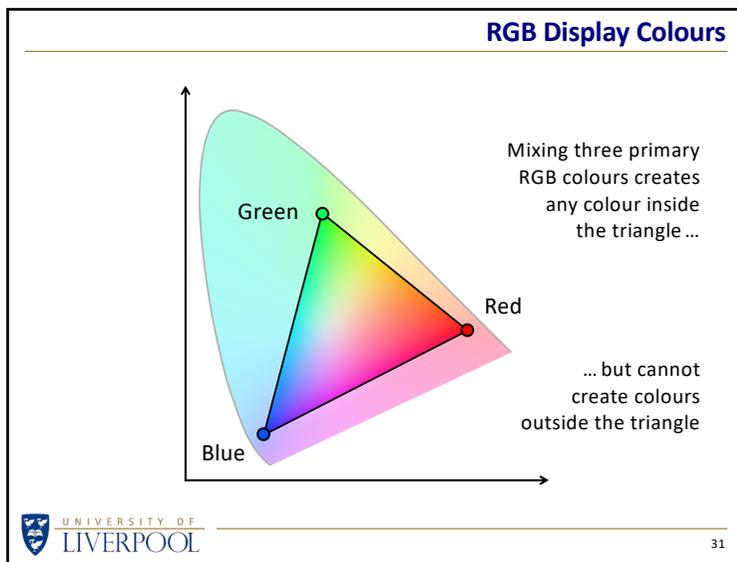
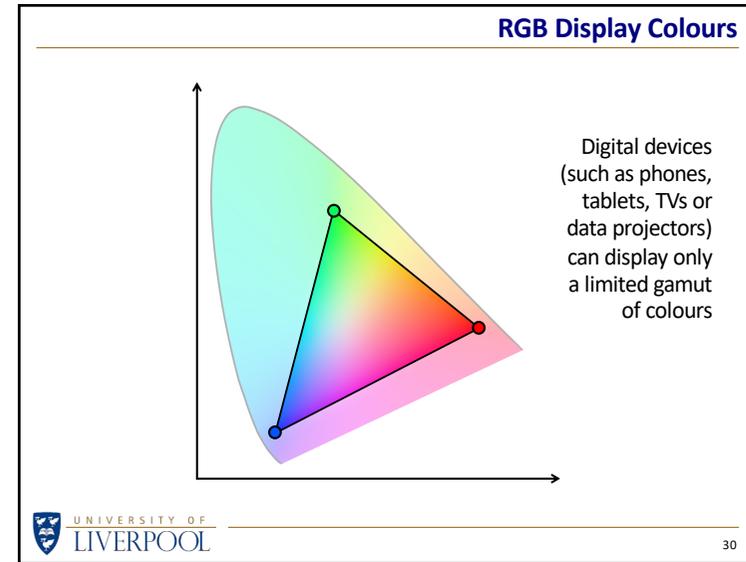
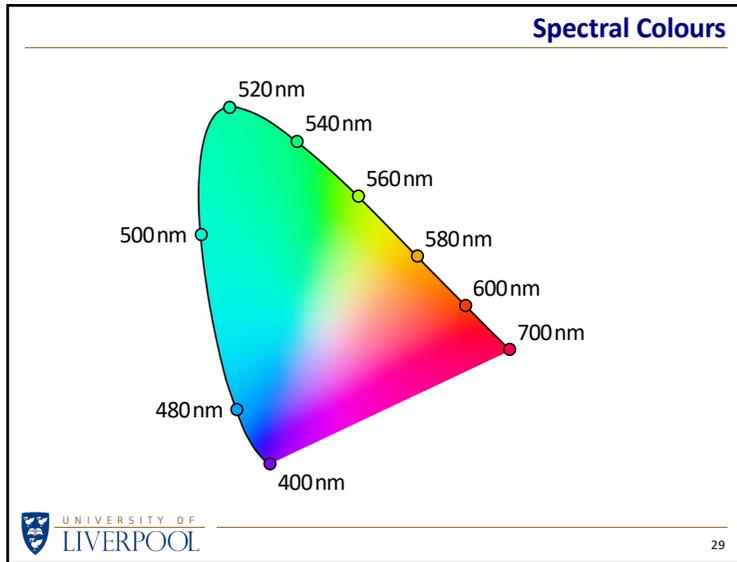
CIE = International Commission on Illumination
(Commission Internationale de l'Eclairage)



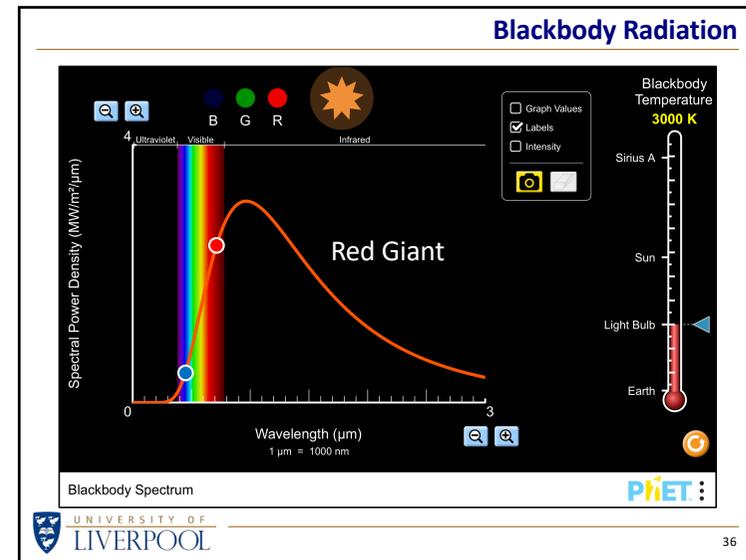
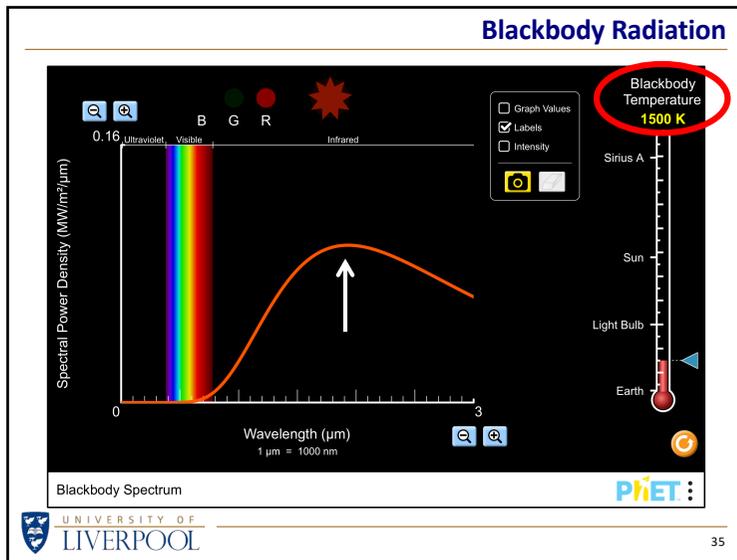
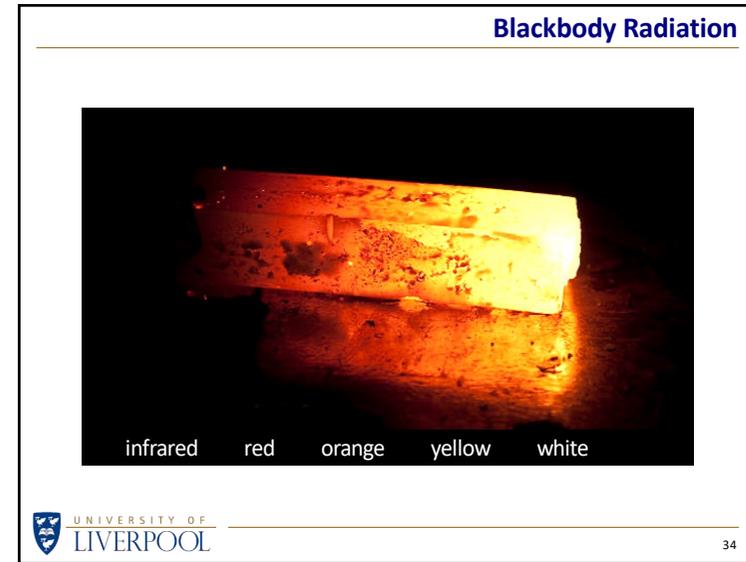
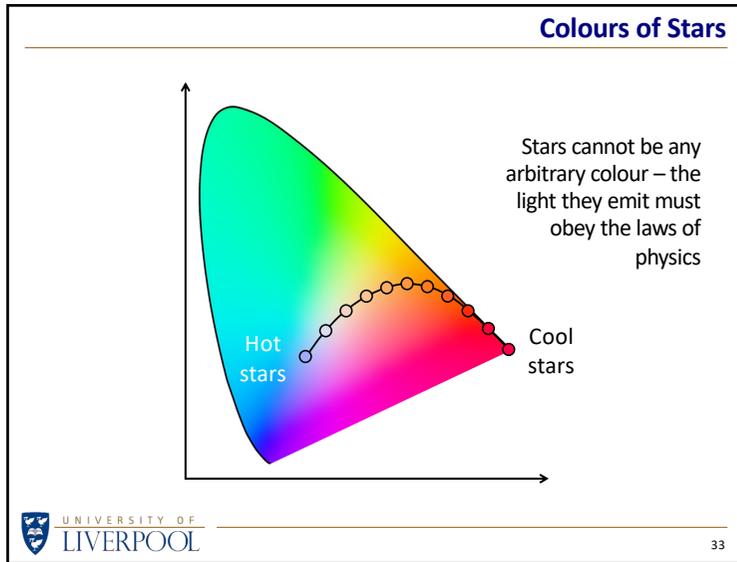
All colours can be quantified and plotted in a plane called "colour space"

Let's not worry about what the two axes are

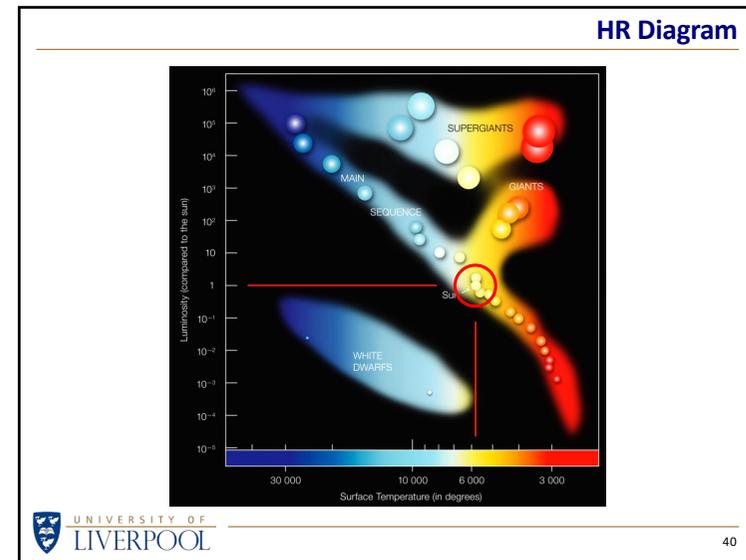
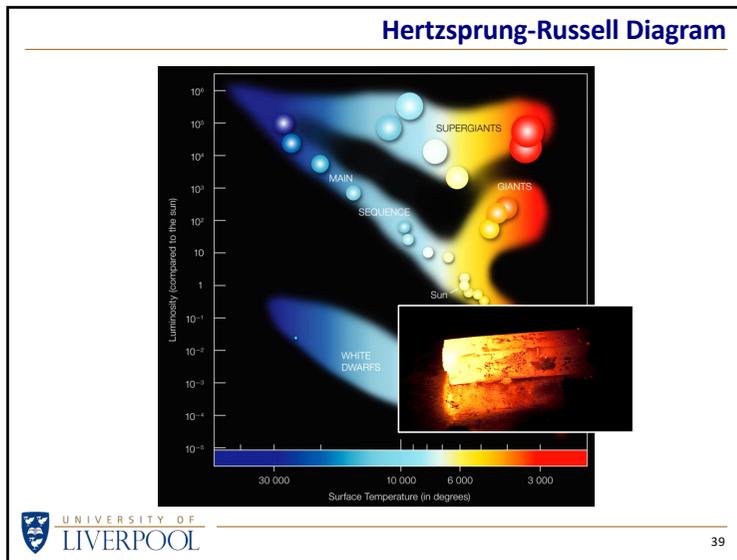
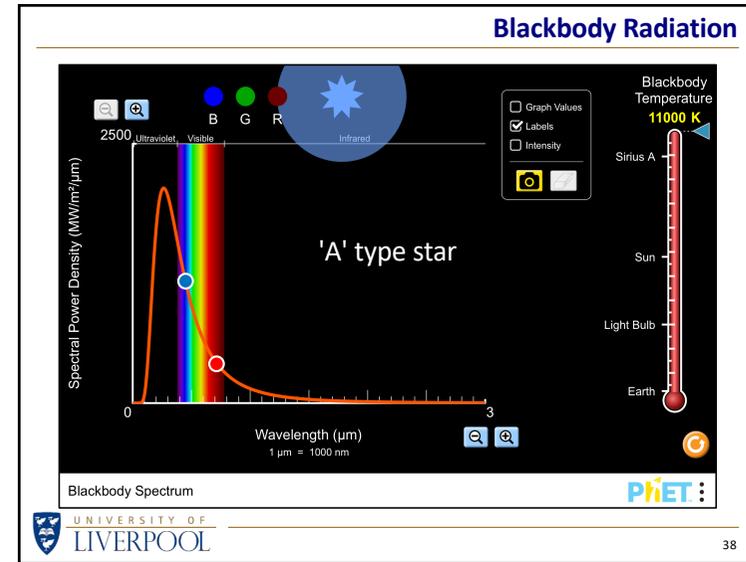
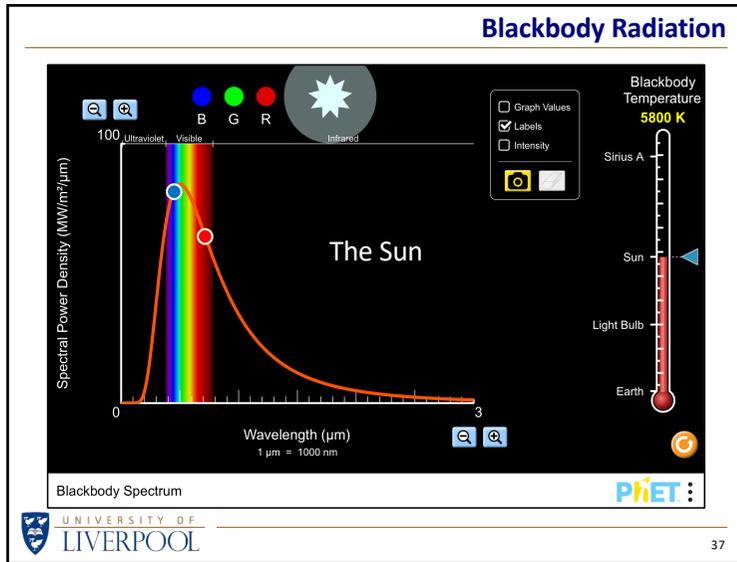
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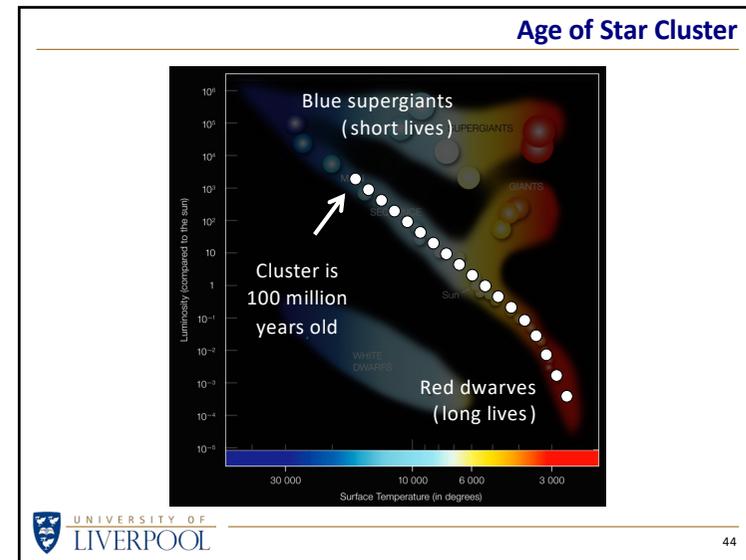
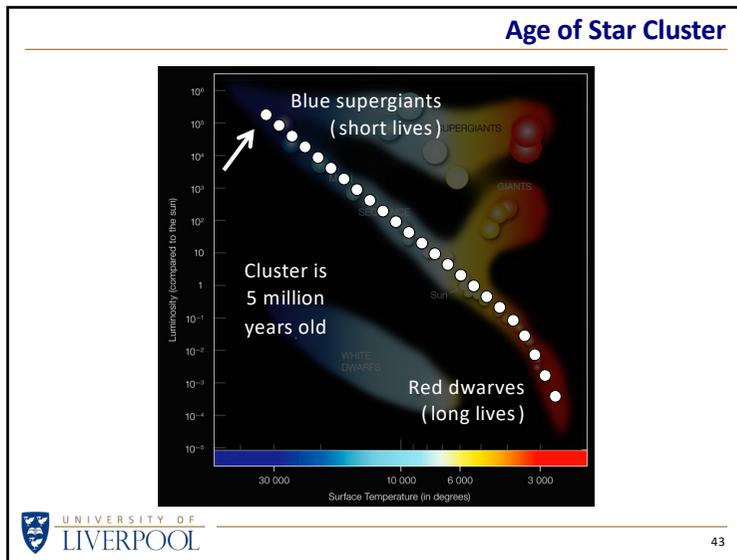
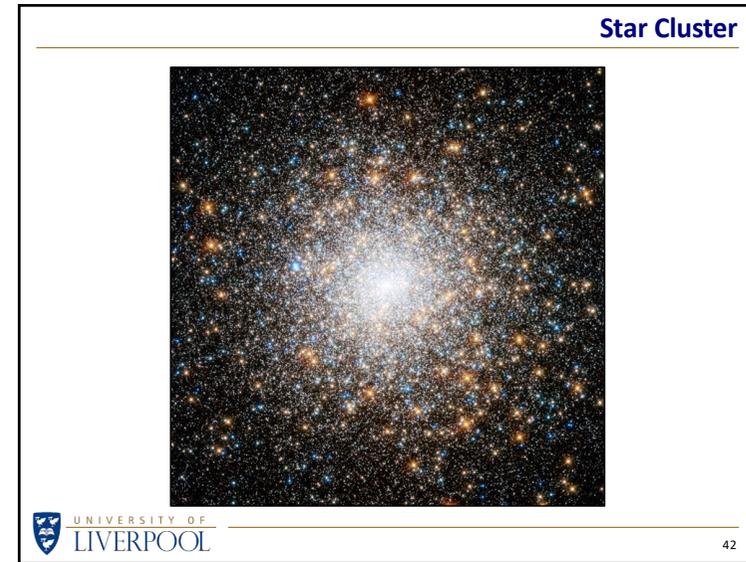
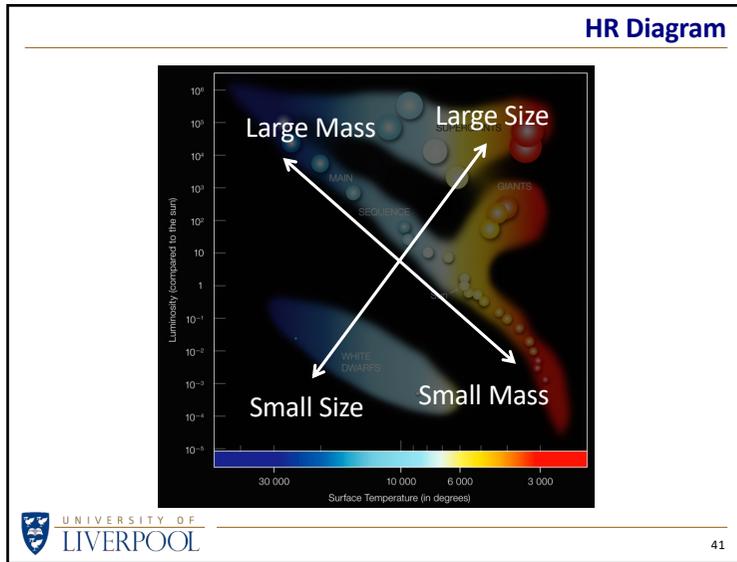
Fiat Lux IV – Colour in the Cosmos



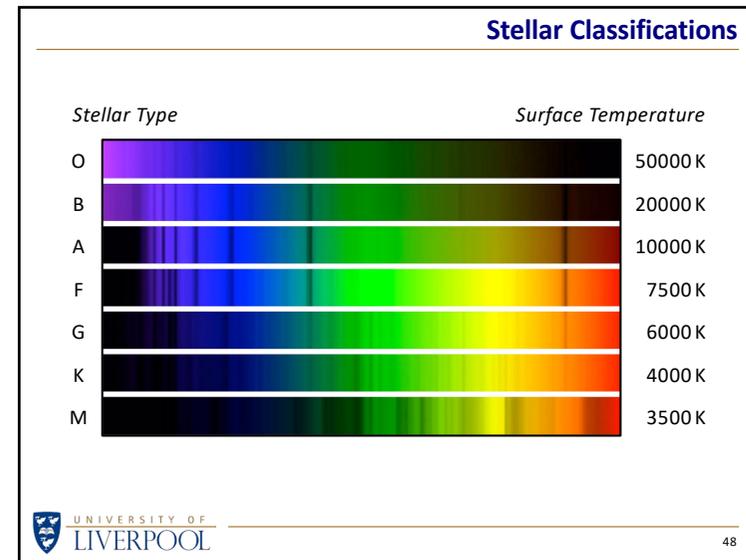
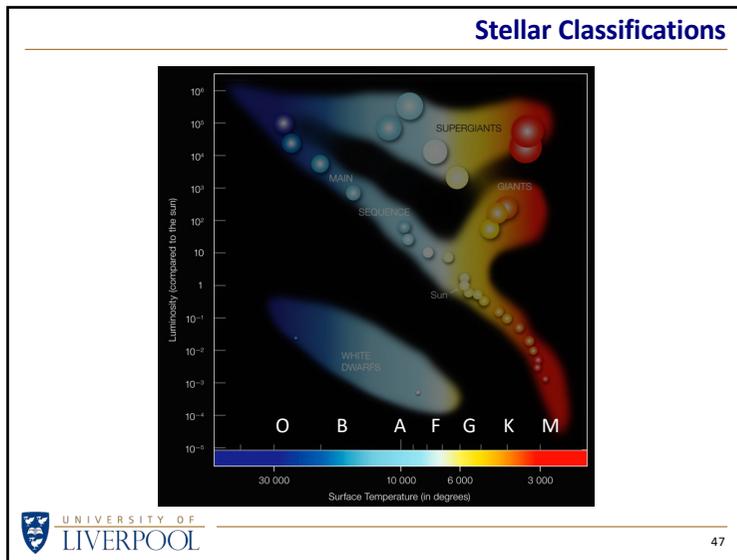
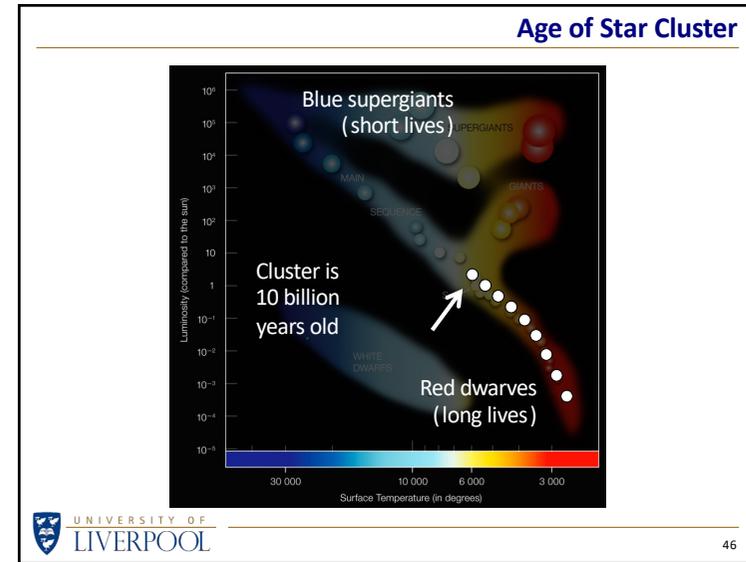
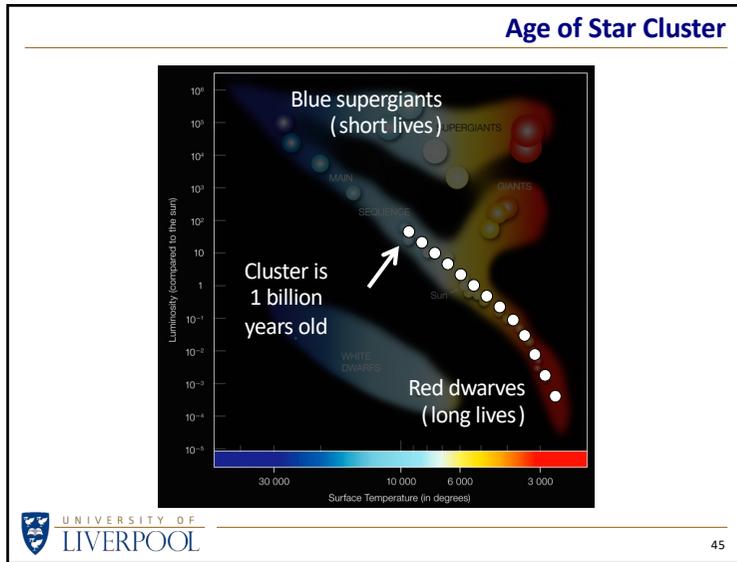
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Colour of the Cosmos

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

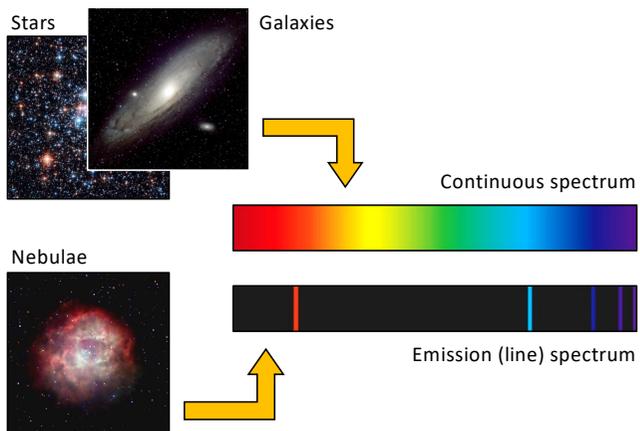
By analysing the light from 200,000 galaxies within 2 billion light-years the conclusion was...



"Cosmic latte" or "Skyvory"

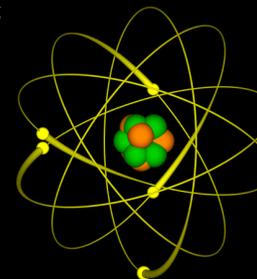
Colours of nebulae

Astronomical Spectra



Electrons in Atoms

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

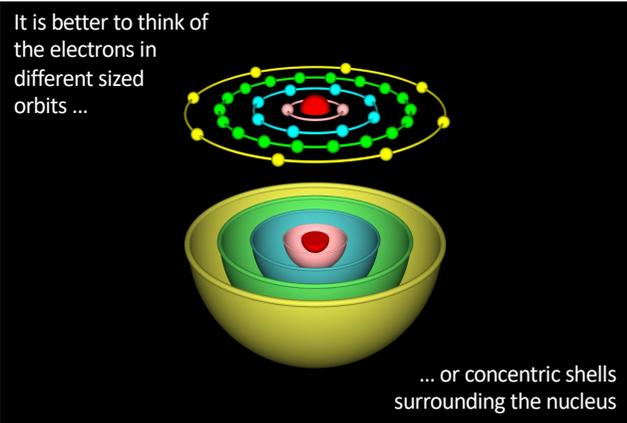


... but it doesn't show us that all the electrons have different energies

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Electrons in Shells

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

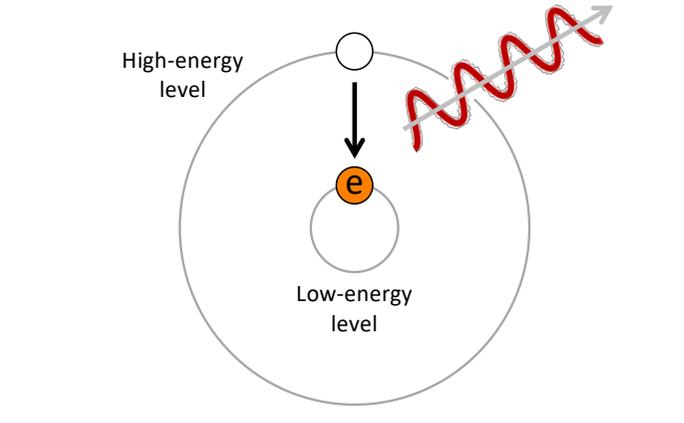


... or concentric shells surrounding the nucleus

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Quantum Jump → Light Emission



High-energy level

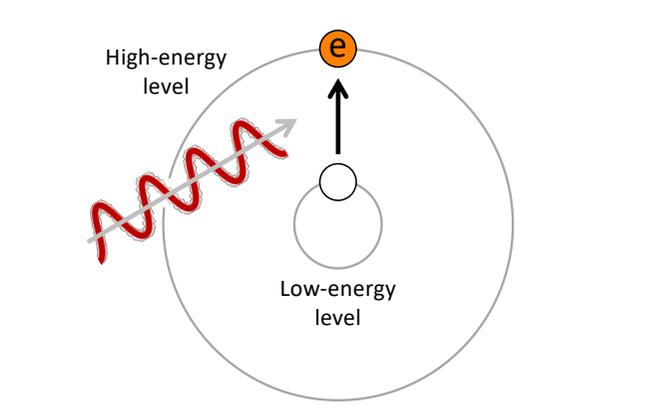
Low-energy level

e

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Light Absorption → Quantum Jump



High-energy level

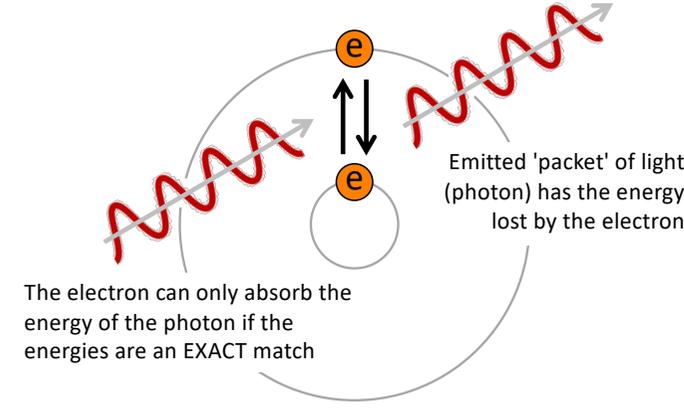
Low-energy level

e

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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

e

e

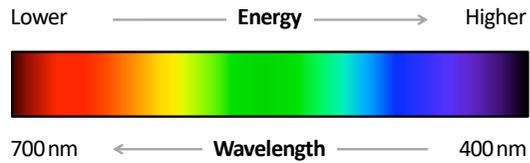
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Flat Lux IV – Colour in the Cosmos

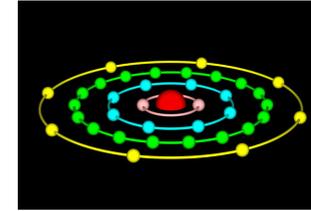
Photon Energy and Colour

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.

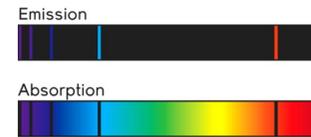


Emission Spectrum

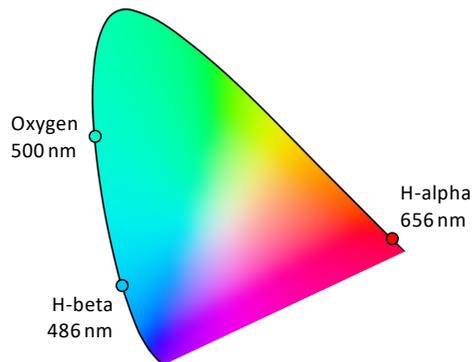
Every atom has many energy levels and so an electron can make quantum jumps with a number of specific energies that are characteristic of the atom.



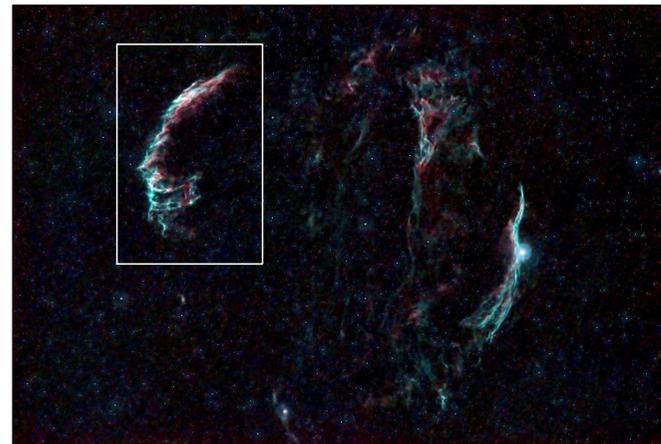
Hence atoms emit or absorb photons with characteristic patterns of energies and hence colour spectra.



Emission Lines



Veil Nebula



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Eastern Veil Nebula

Red
H-alpha

Green
Oxygen
+ H-beta

Blue
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?

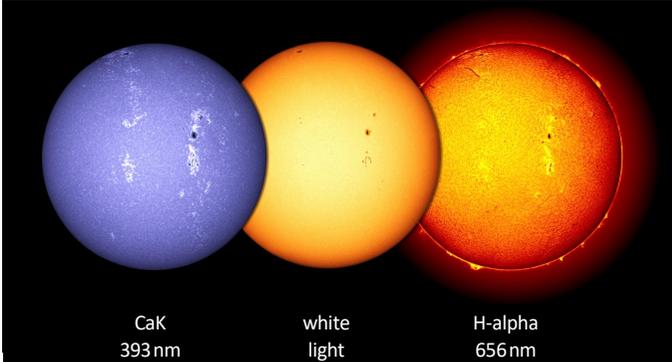
How many atoms are there in one cubic centimetre of ...

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

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Photosphere of the Sun



www.facebook.com/lukasz.sujka.astronomy

CaK
393 nm

white
light

H-alpha
656 nm

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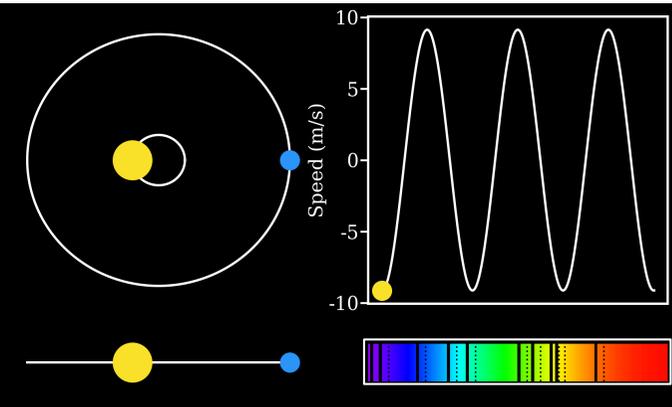
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Spectroscopy

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Doppler Shift



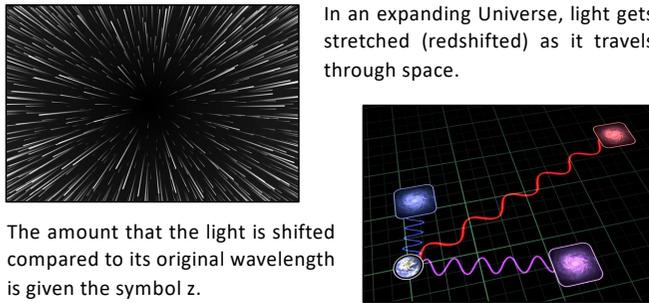
Alysa Oberas (@AstroAlysa)

Speed (m/s)

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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.

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Quasar J161737+595020

Redshift $z=4.3$

Ancient Light

Monochrome Colour

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Quasar J161737+595020

Redshift $z=4.3$
Distance = 25 billion light-years

Red Green Blue

(some light) (less light) (no light)

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JWST Photometric Redshift

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JWST Photometric Redshift

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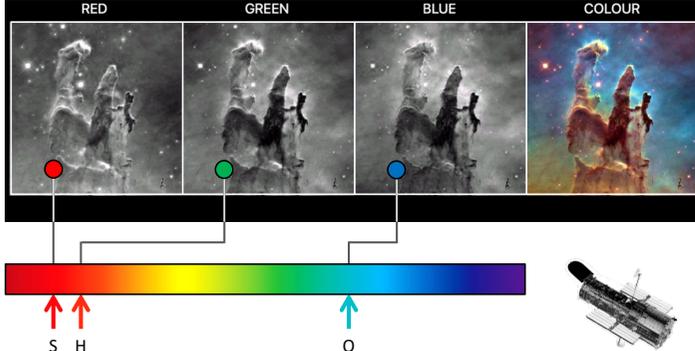
Beyond colour



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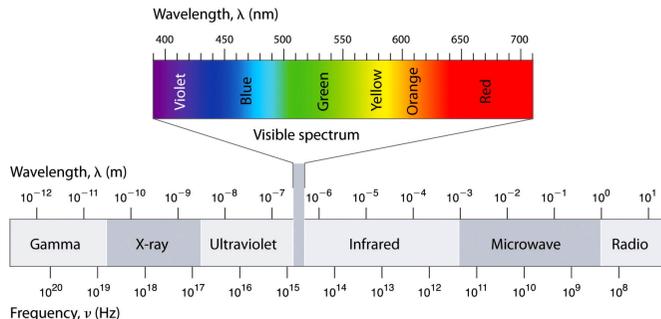
Hubble Palette

Do Hubble Space Telescope images represent 'true' colours?



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Electromagnetic Spectrum



Wavelength, λ (nm)

Wavelength, λ (m)

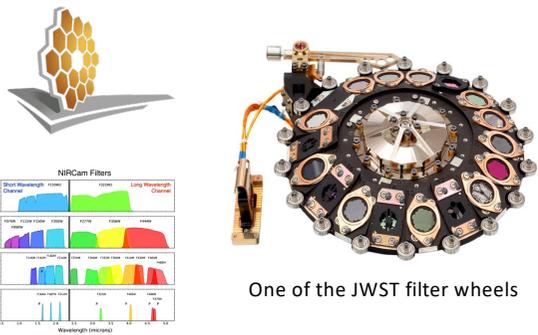
Frequency, ν (Hz)



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JWST Imaging

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

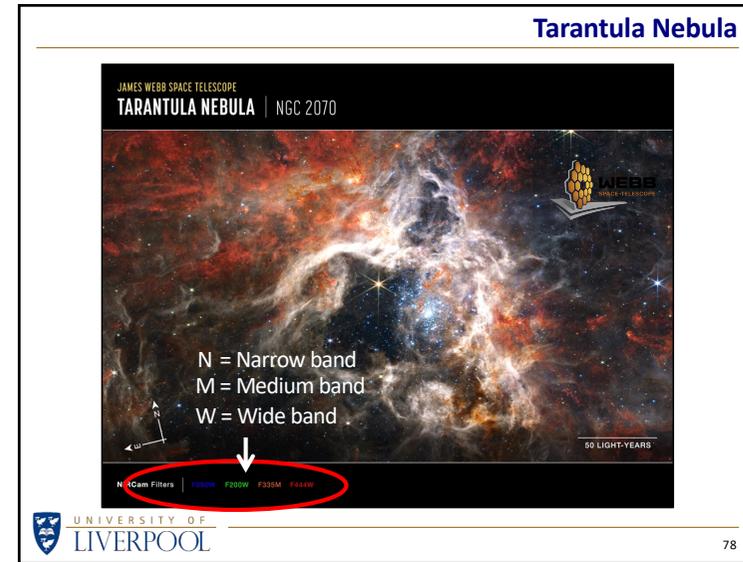
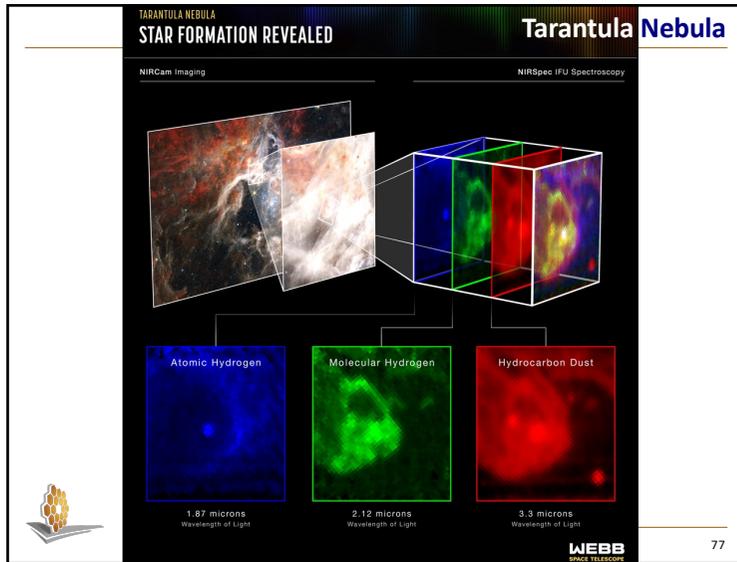


One of the JWST filter wheels



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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 measure velocities and distances.

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

Dr Steve Barrett UoL 2 Jun 2023