

# 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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# Fiat Lux IV – Colour in the Cosmos

**Why Do We Have Colour Vision?**



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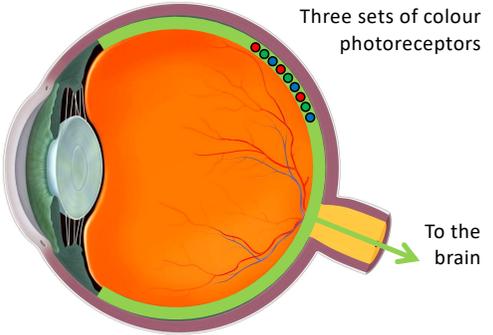
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**How do we perceive colour?**

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**Human Eye**



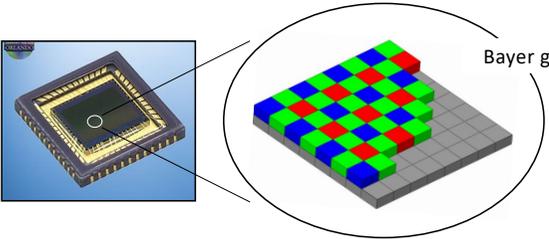
Three sets of colour photoreceptors

To the brain

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**Digital Camera**

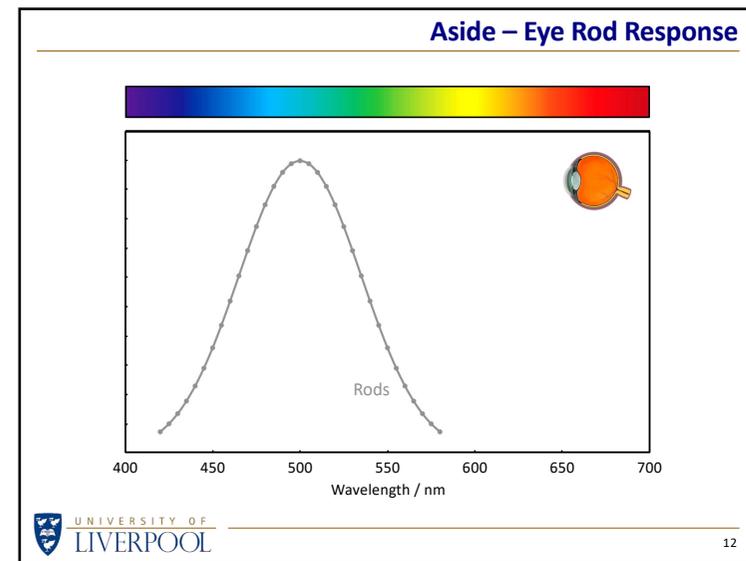
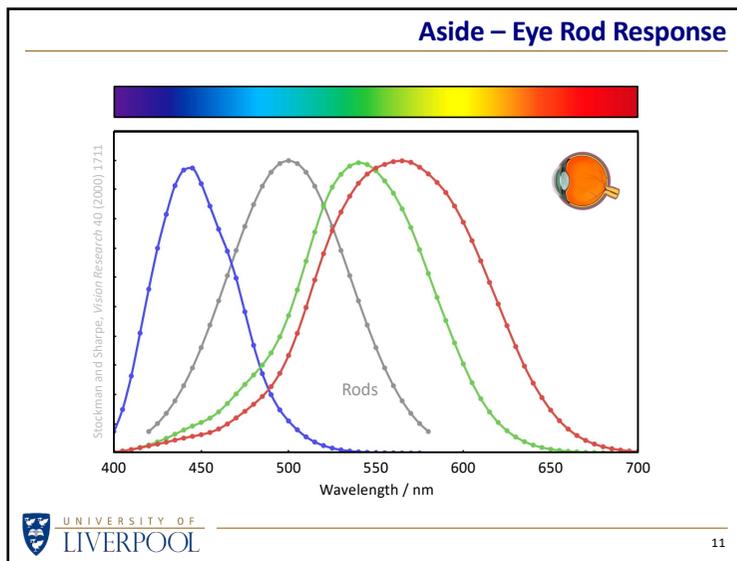
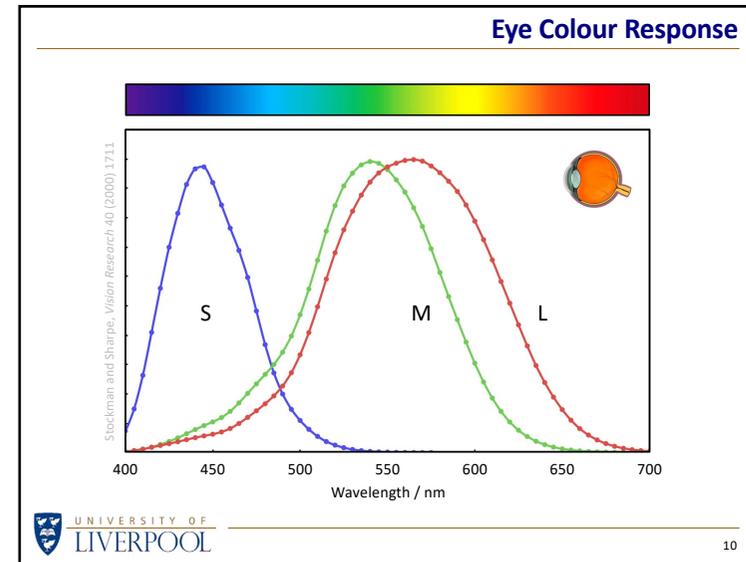
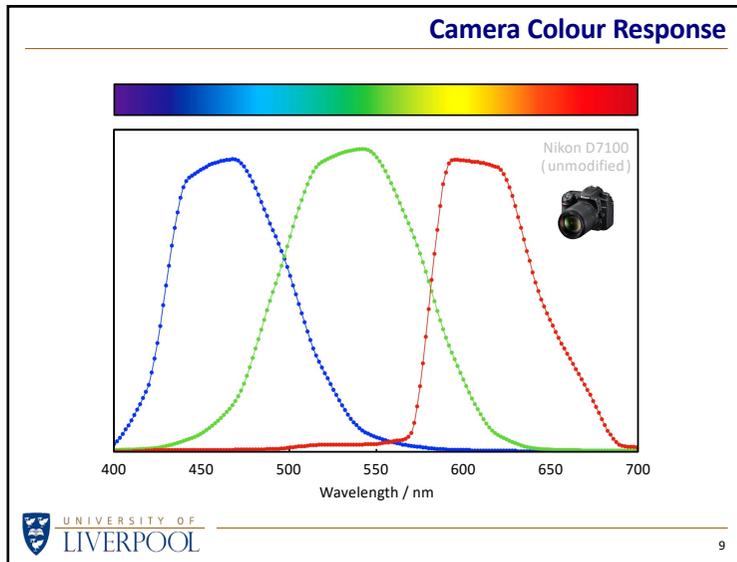


Bayer grid

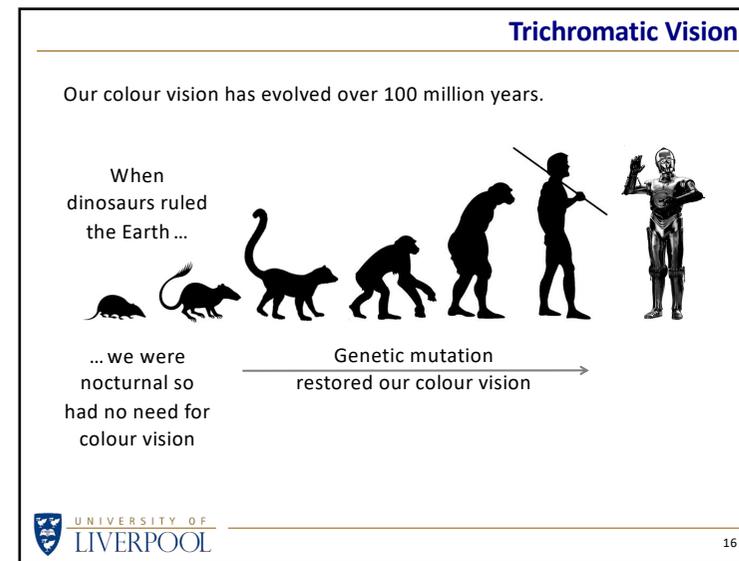
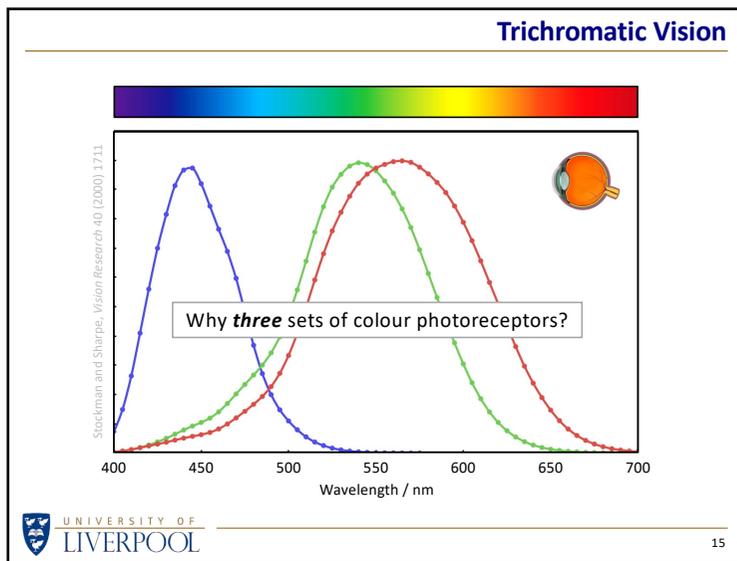
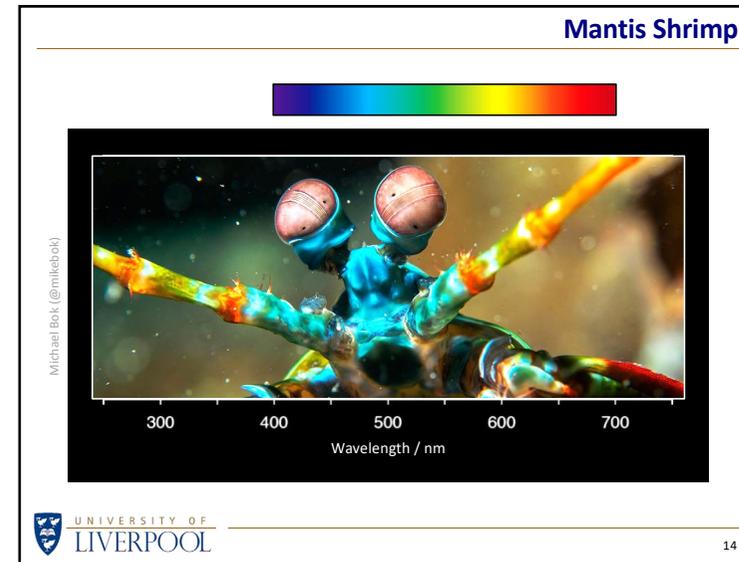
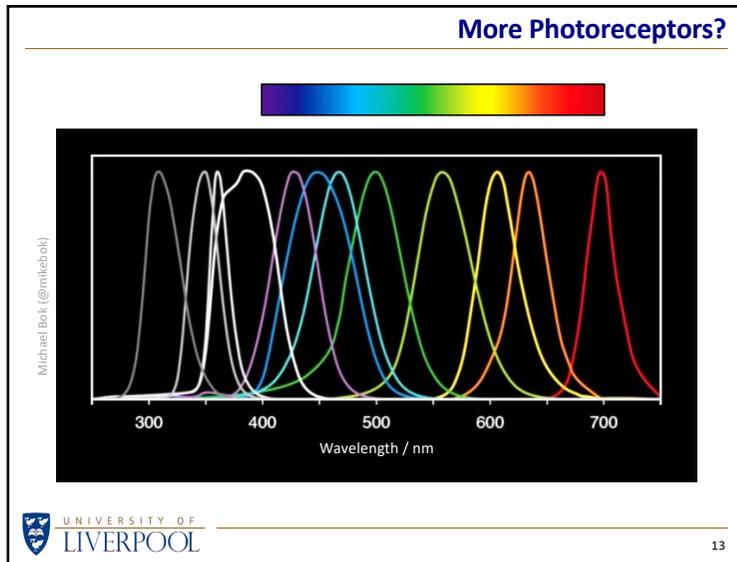
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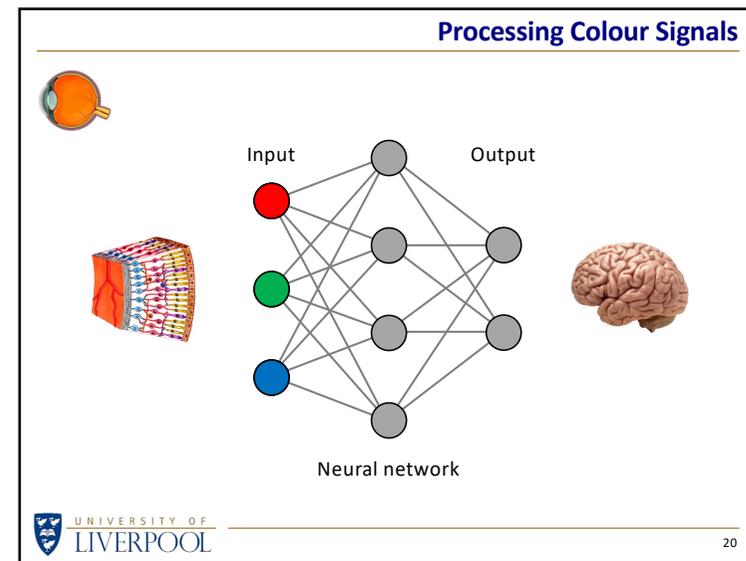
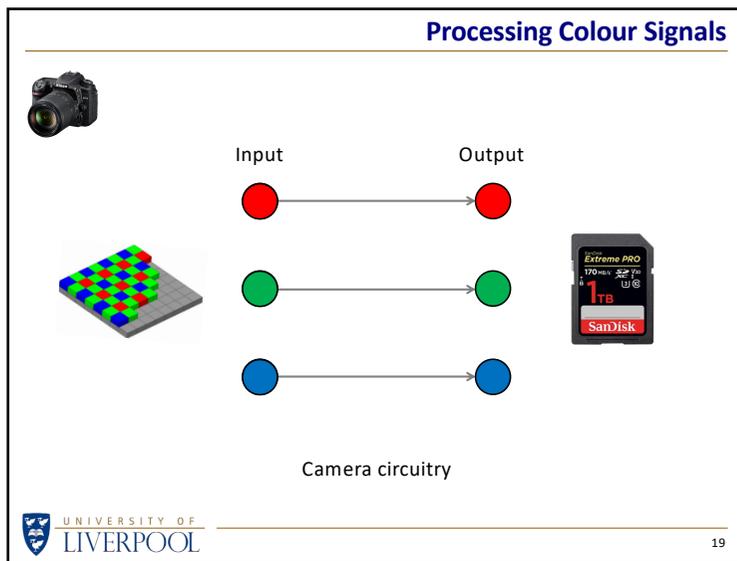
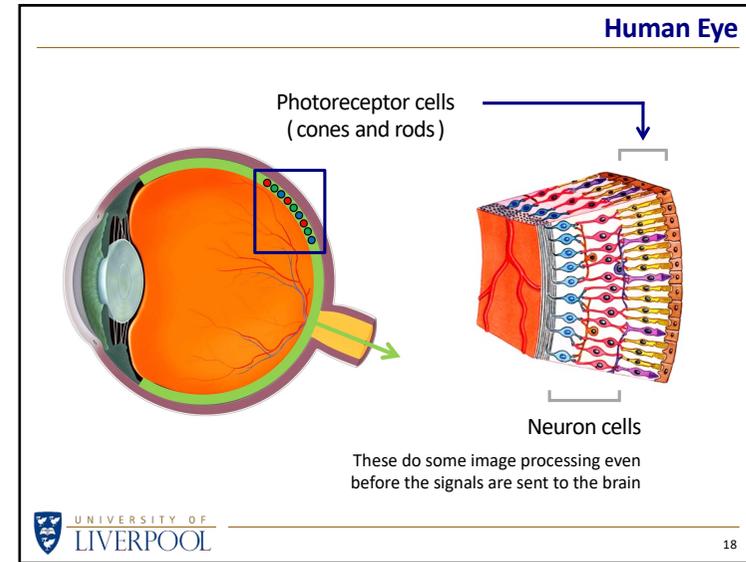
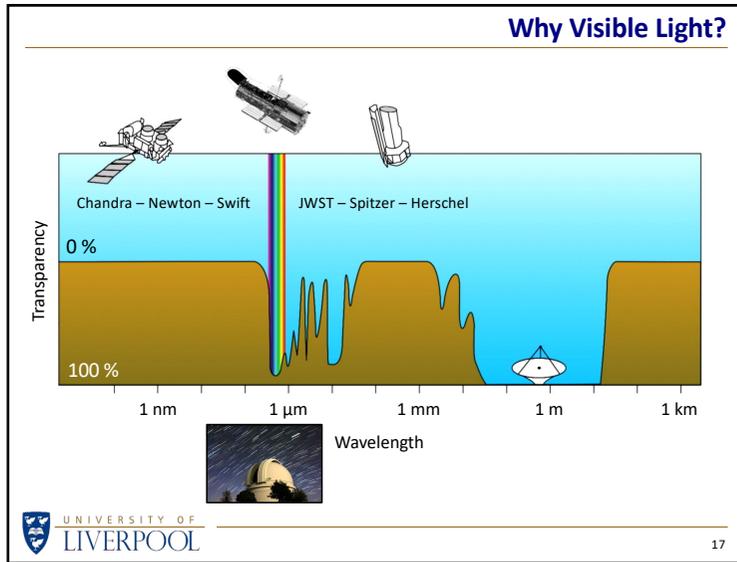
# Fiat Lux IV – Colour in the Cosmos



# Fiat Lux IV – Colour in the Cosmos

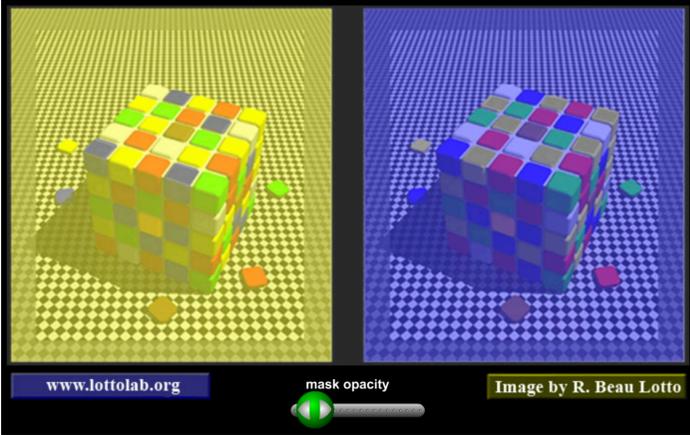


# Fiata Lux IV – Colour in the Cosmos



# Fiat Lux IV – Colour in the Cosmos

**Perception vs Reality**

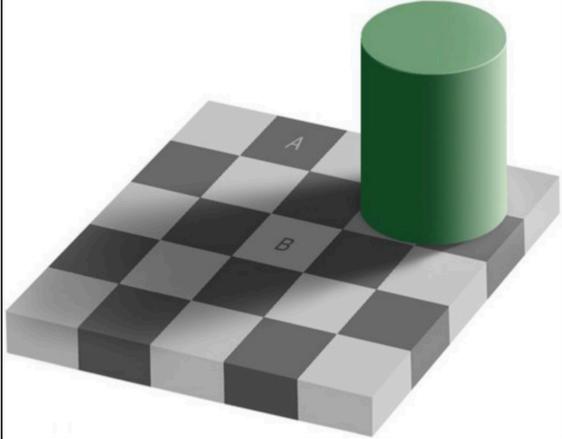


www.lottolab.org mask opacity Image by R. Beau Lotto

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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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# Fiat Lux IV – Colour in the Cosmos

## Isaac Newton



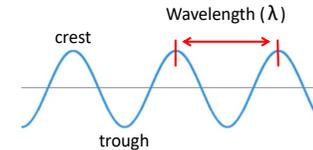
Newton's work on optics in the 1660s established that white light is composed of many colours.

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

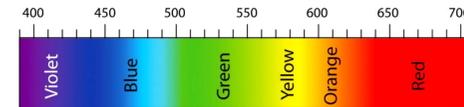
(Curiously, modern physics developed centuries later gives the answer – both!)

## 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.



Wavelength (nm)



## Non-Spectral Colours

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

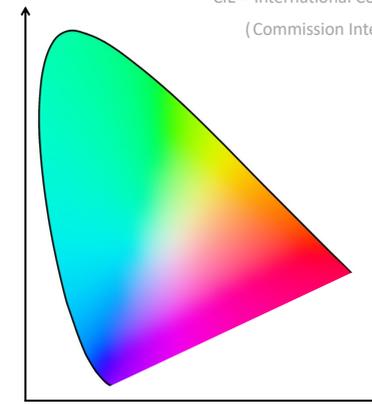
For instance, where is the colour **beige** in the rainbow of all colours?



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

## CIE Colour Space

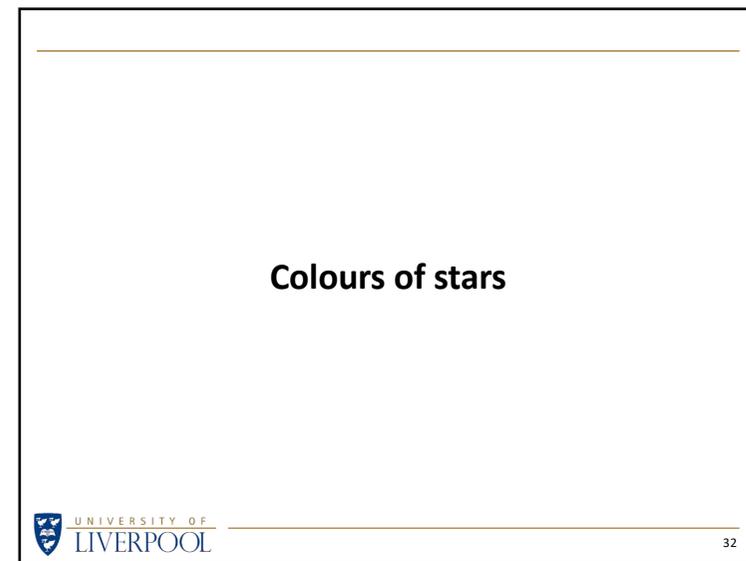
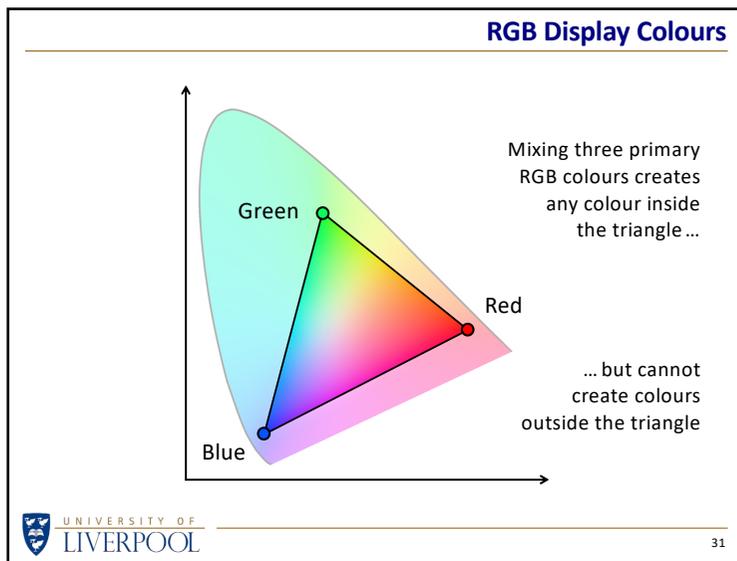
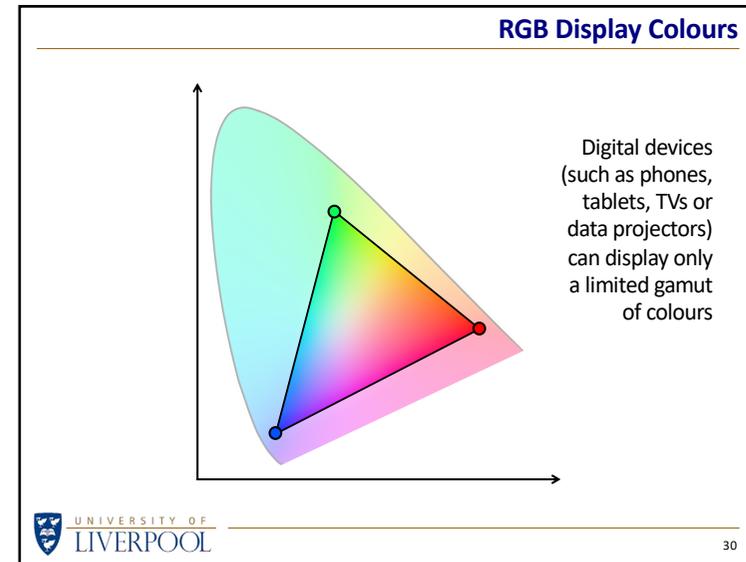
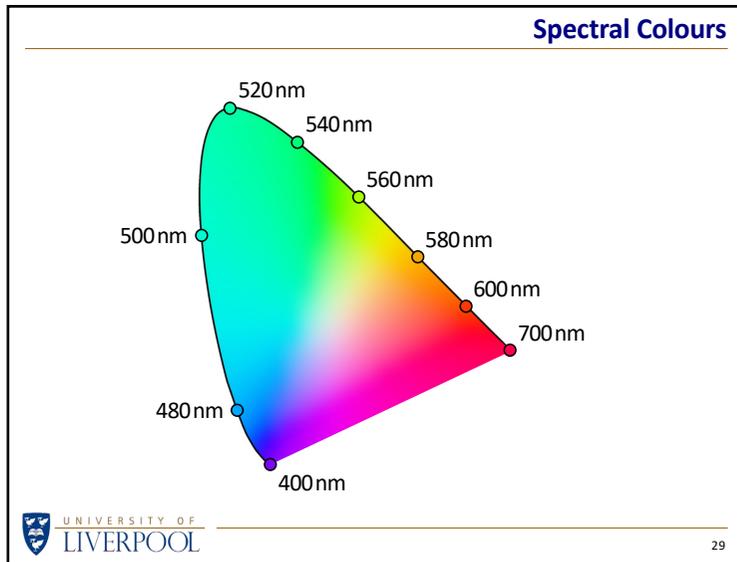
CIE = International Commission on Illumination  
(Commission Internationale de l'Éclairage)



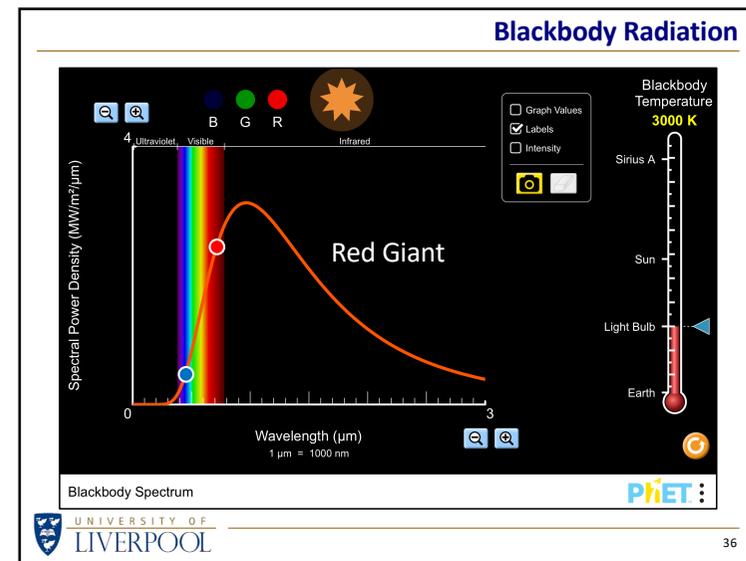
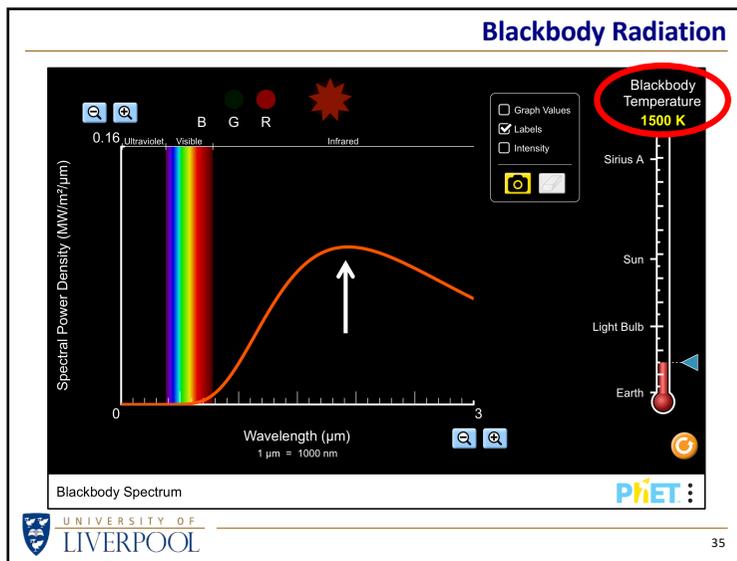
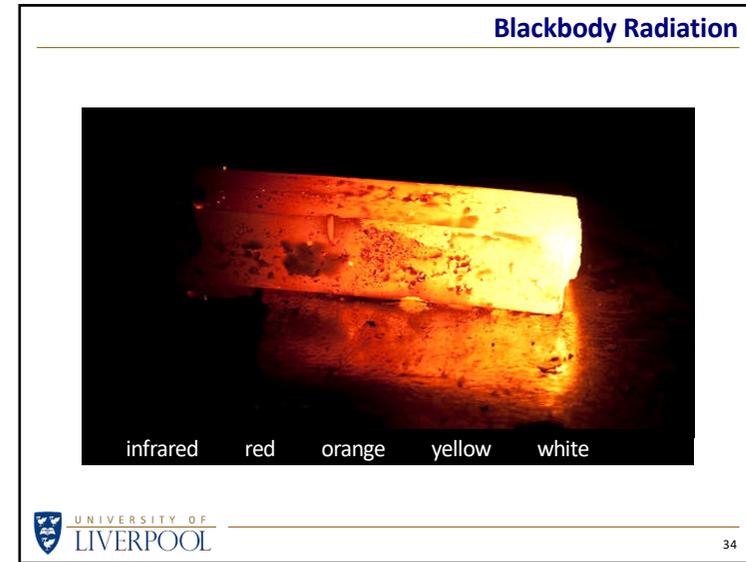
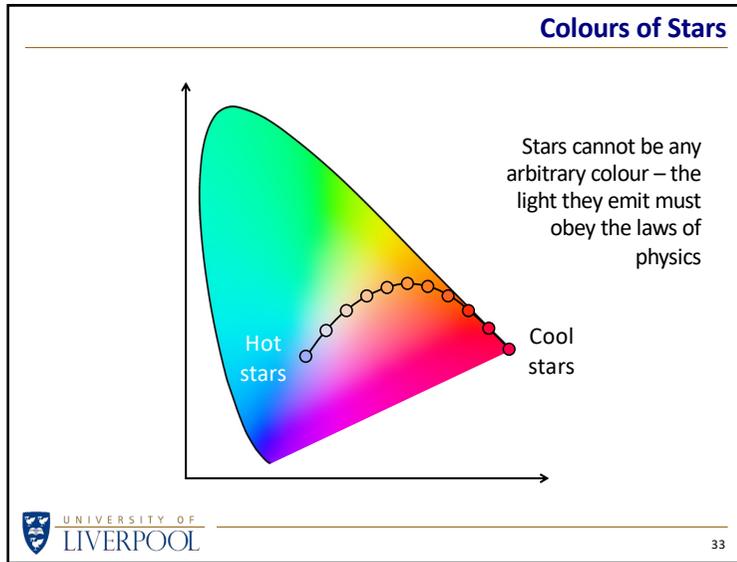
All colours can be quantified and plotted in a plane called "colour space"

Let's not worry about what the two axes are

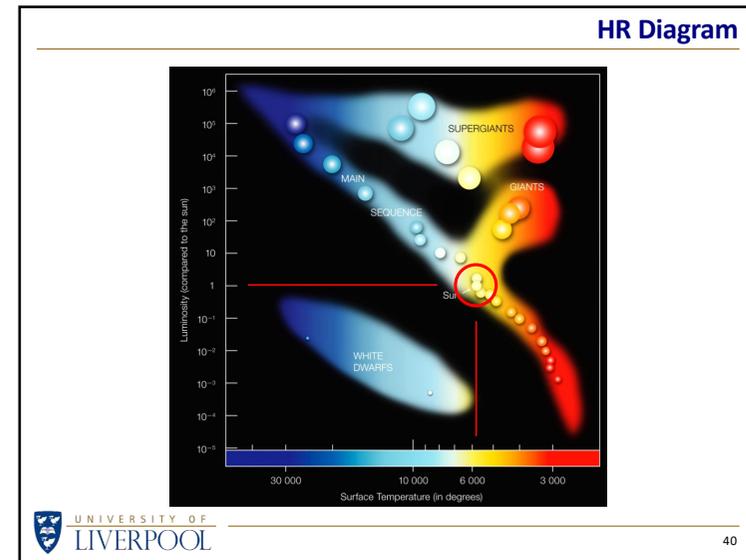
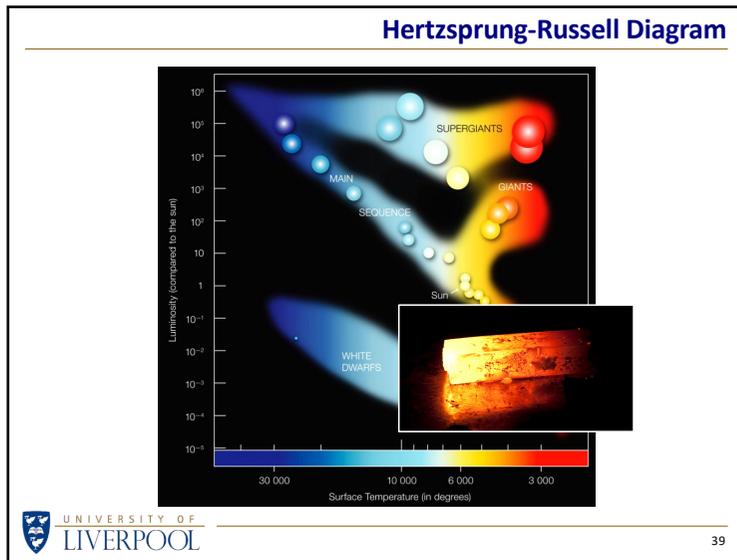
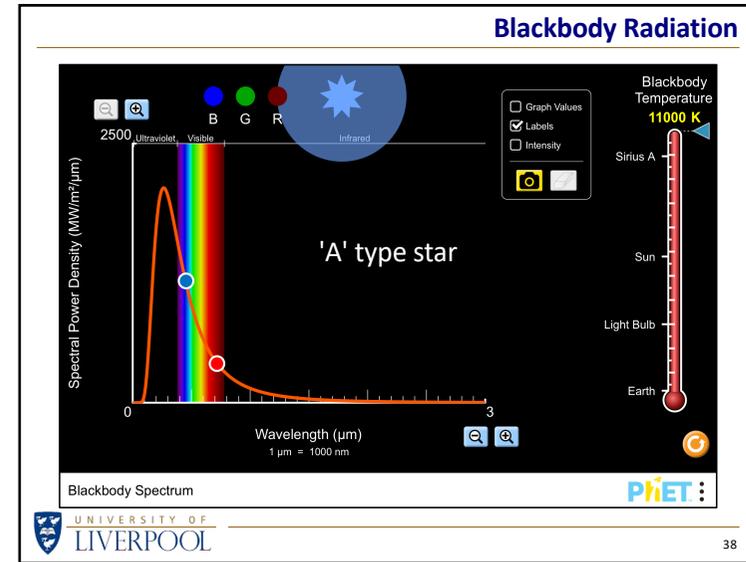
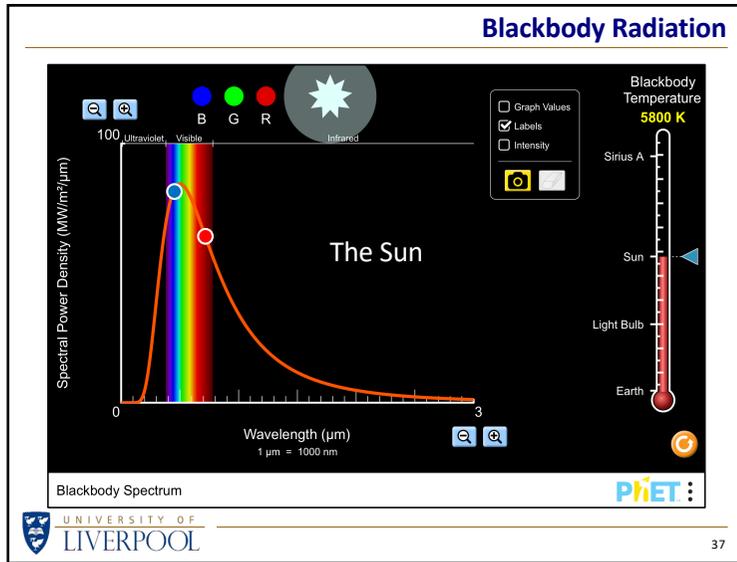
# Fiat Lux IV – Colour in the Cosmos



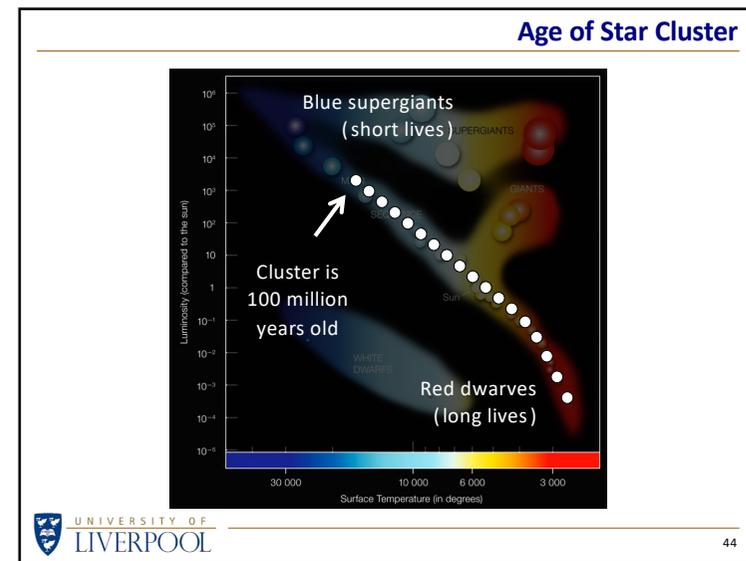
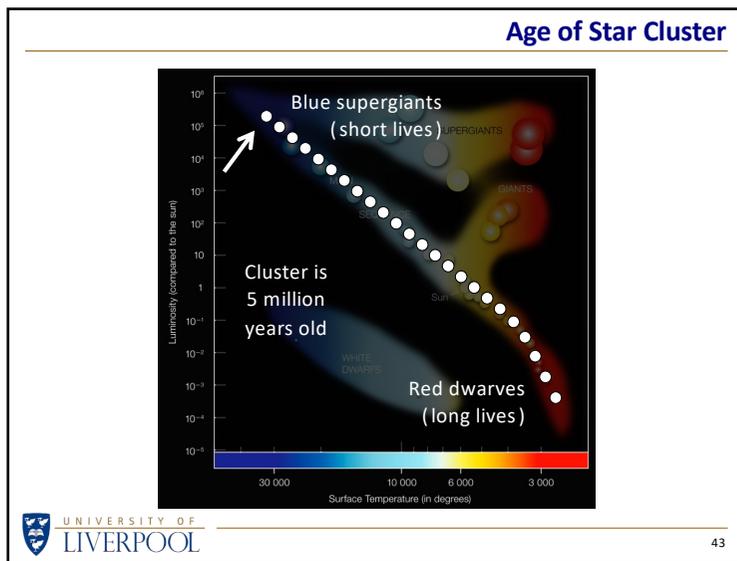
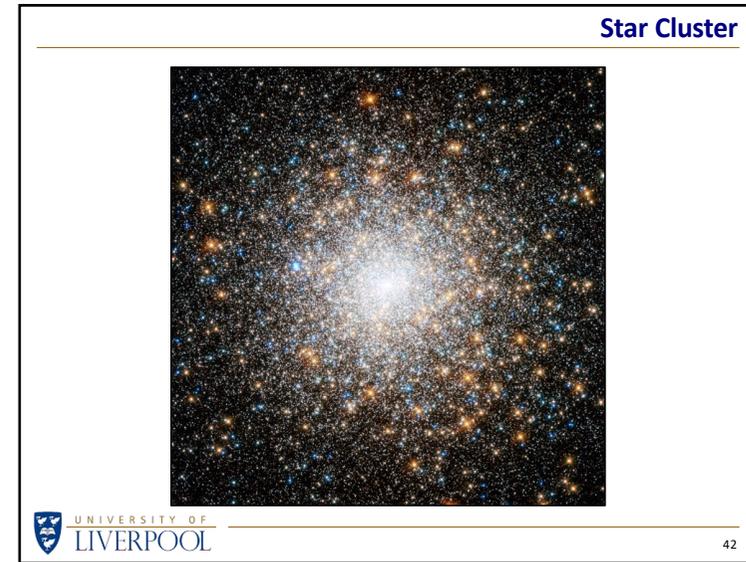
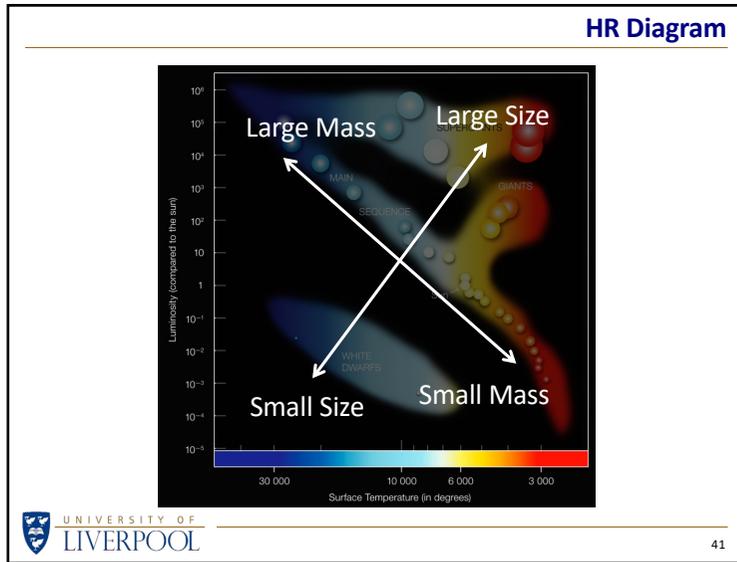
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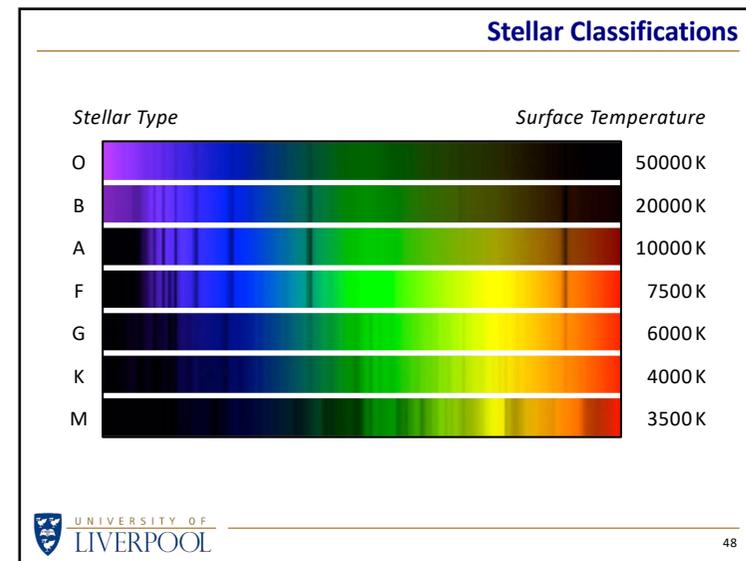
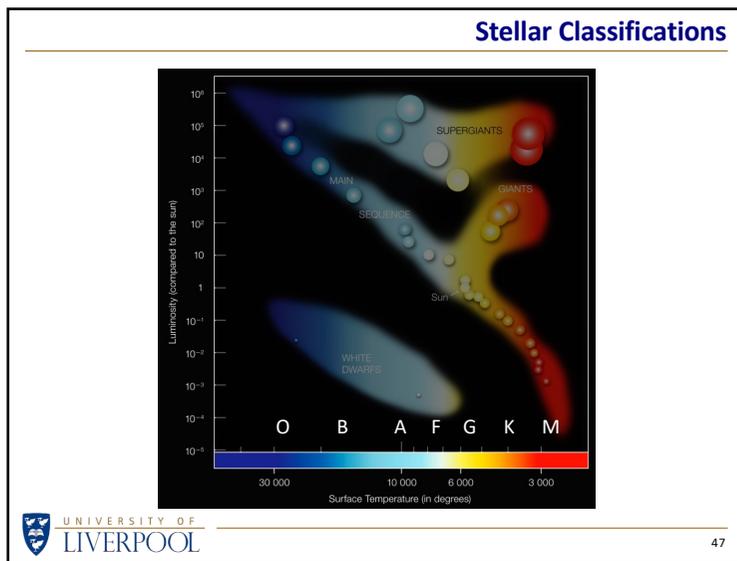
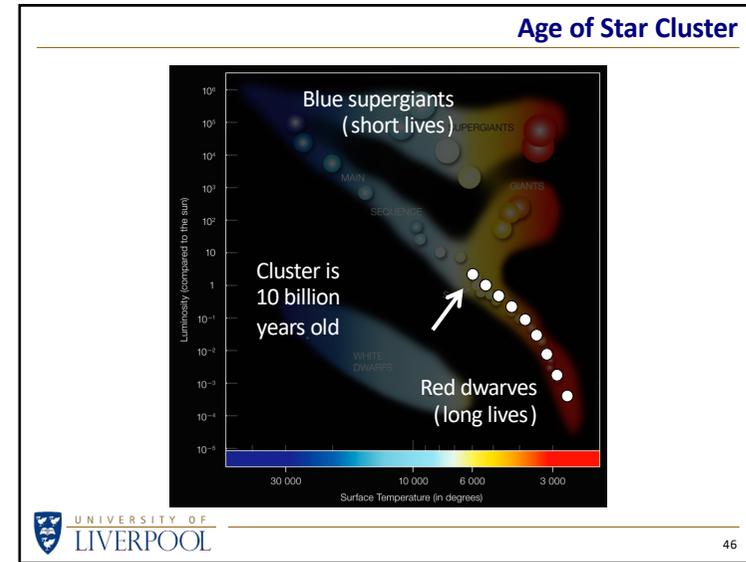
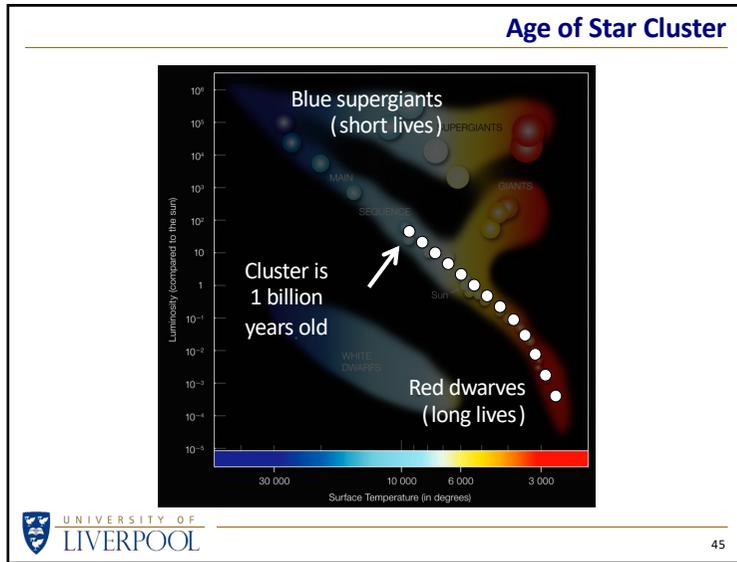
# Fiats Lux IV – Colour in the Cosmos



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# Fiata Lux IV – Colour in the Cosmos

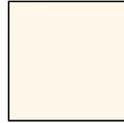


# Fiat Lux IV – Colour in the Cosmos

## 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?

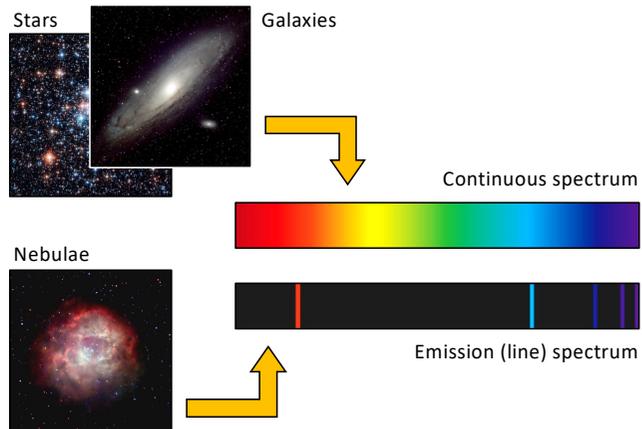
By analysing the light from 200,000 galaxies within 2 billion light-years the conclusion was...



"Cosmic latte" or "Skyvory"

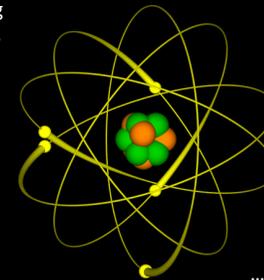
## Colours of nebulae

## Astronomical Spectra



## Electrons in Atoms

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

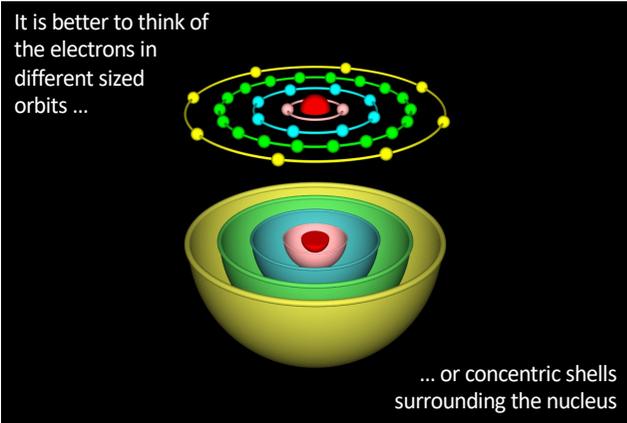


... but it doesn't show us that all the electrons have different energies

# Fiat Lux IV – Colour in the Cosmos

### Electrons in Shells

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

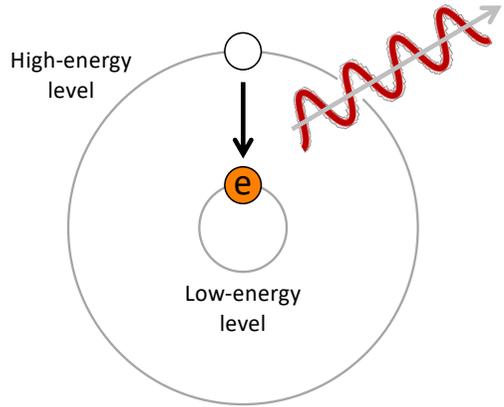


... or concentric shells surrounding the nucleus

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### Quantum Jump → Light Emission



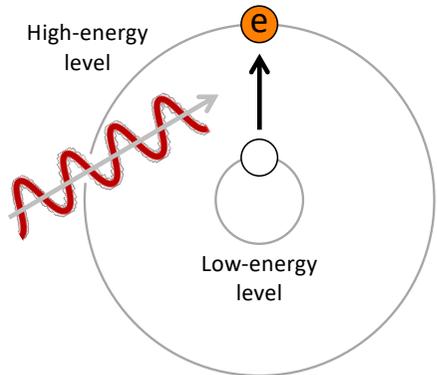
High-energy level

Low-energy level

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### Light Absorption → Quantum Jump



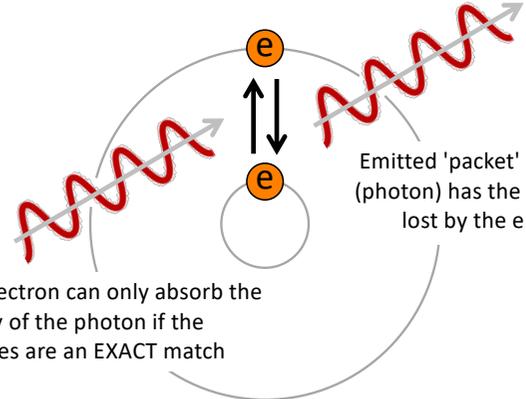
High-energy level

Low-energy level

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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

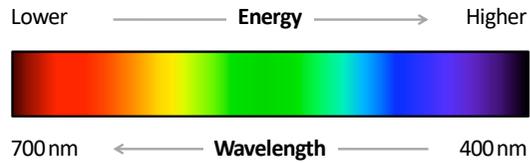
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# Fiat Lux IV – Colour in the Cosmos

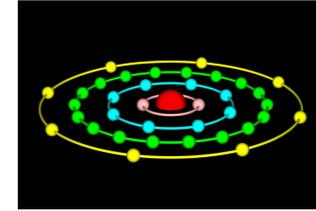
## Photon Energy and Colour

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.

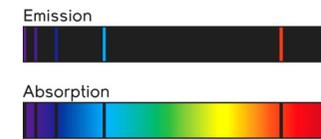


## Emission Spectrum

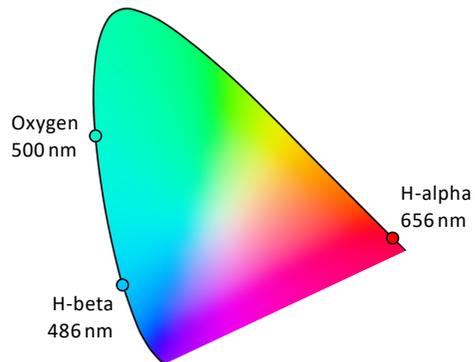
Every atom has many energy levels and so an electron can make quantum jumps with a number of specific energies that are characteristic of the atom.



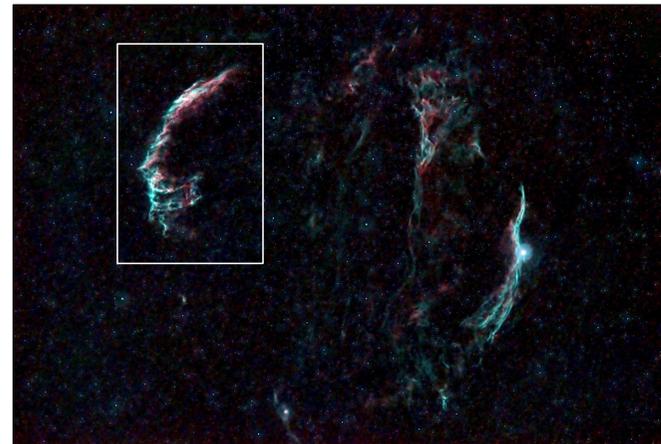
Hence atoms emit or absorb photons with characteristic patterns of energies and hence colour spectra.



## Emission Lines

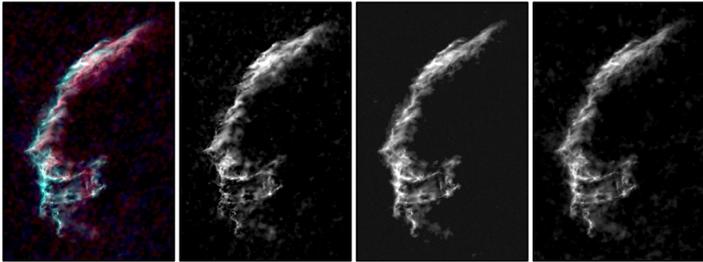


## Veil Nebula



# Fiat Lux IV – Colour in the Cosmos

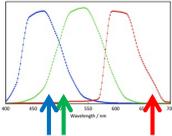
### Eastern Veil Nebula



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:



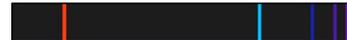
Both are made of atoms, so why the difference?


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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:



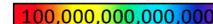
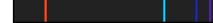
If atoms are close together, always bumping into each other, then the discrete colours are 'smeared out' into a continuous spectrum:




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### How Many Atoms?

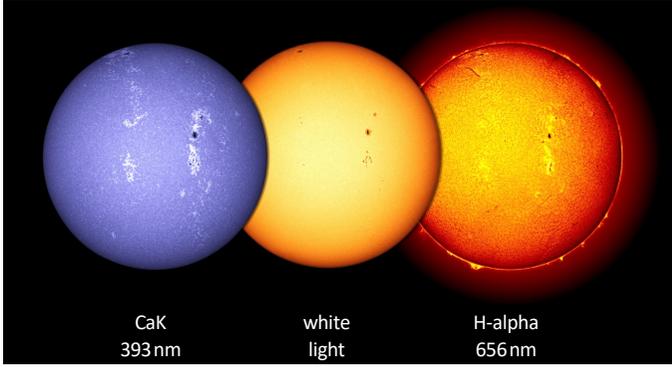
How many atoms are there in one cubic centimetre of ... 

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


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# Fiat Lux IV – Colour in the Cosmos

### Photosphere of the Sun



www.facebook.com/lukasz.sujka.astronomy

CaK  
393 nm

white  
light

H-alpha  
656 nm

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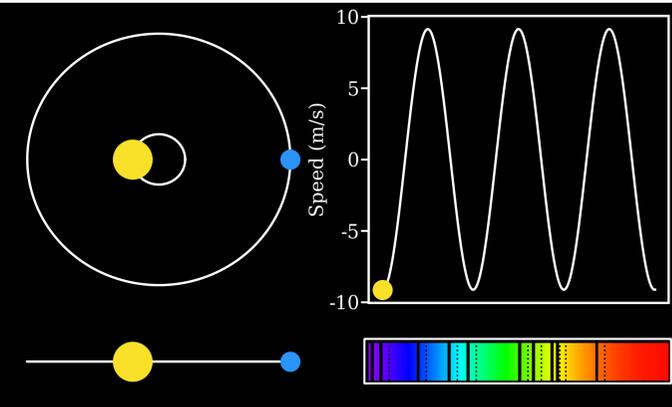
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### Spectroscopy

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### Doppler Shift



Alysa Oberas (@AstroAlysa)

Speed (m/s)

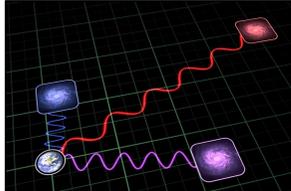
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### Redshift



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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# Fiats Lux IV – Colour in the Cosmos

**Quasar J161737+595020**

Redshift  $z=4.3$

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**

SMACS 0723

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**JWST Photometric Redshift**

SMACS-0723

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# Fiata Lux IV – Colour in the Cosmos

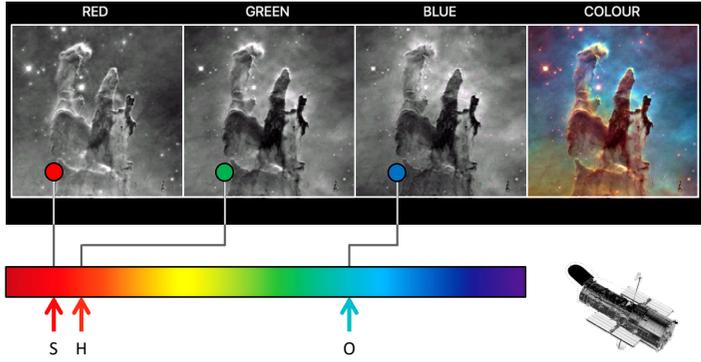
**Beyond colour**



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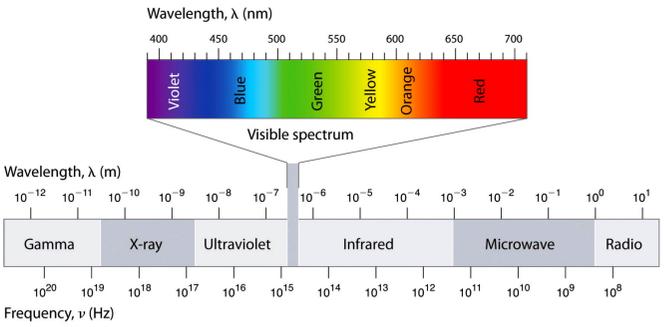
**Hubble Palette**

Do Hubble Space Telescope images represent 'true' colours?




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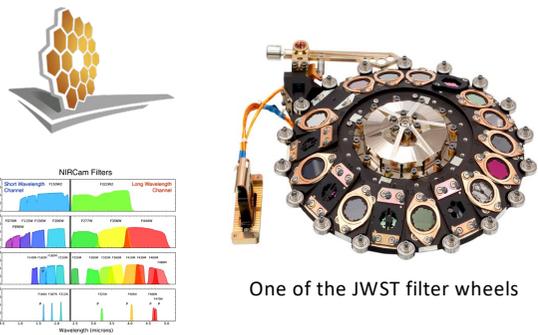
**Electromagnetic Spectrum**




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**JWST Imaging**

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

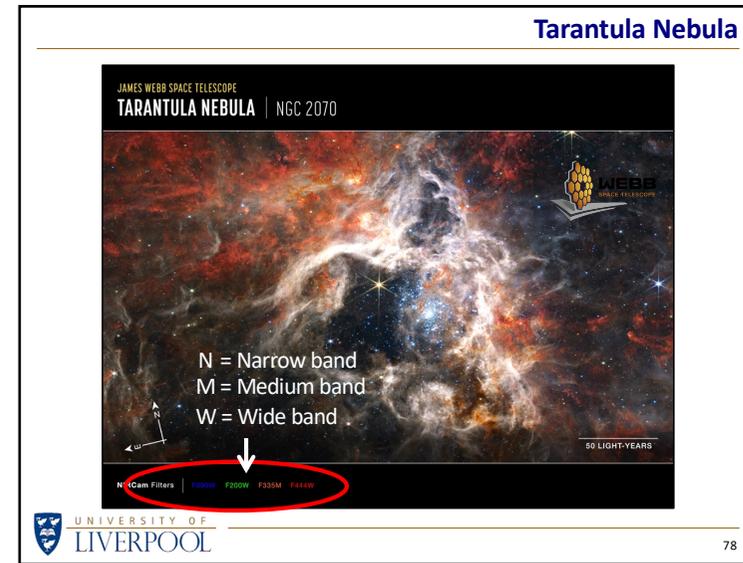
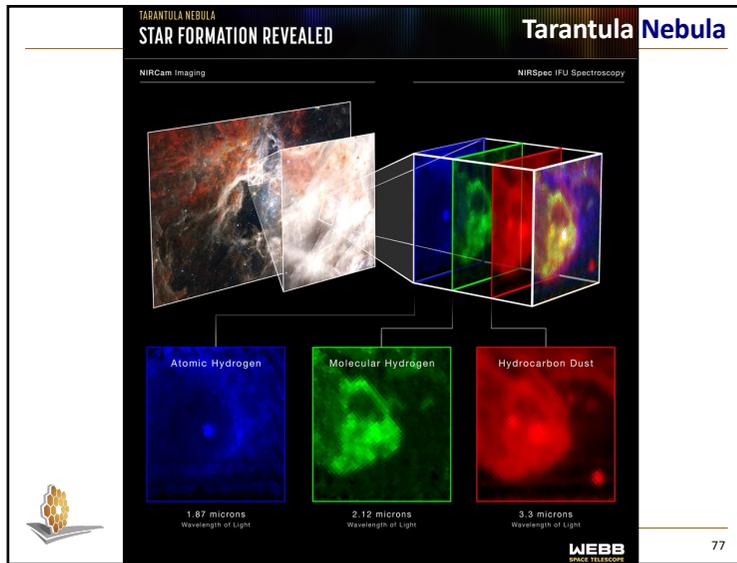


One of the JWST filter wheels



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# Fiat Lux IV – Colour in the Cosmos



**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](http://www.liverpool.ac.uk/~sdb/Talks)

Dr Steve Barrett      ChAS 25 Mar 2026