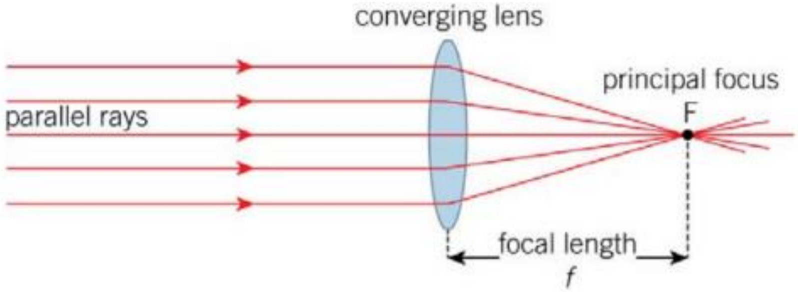
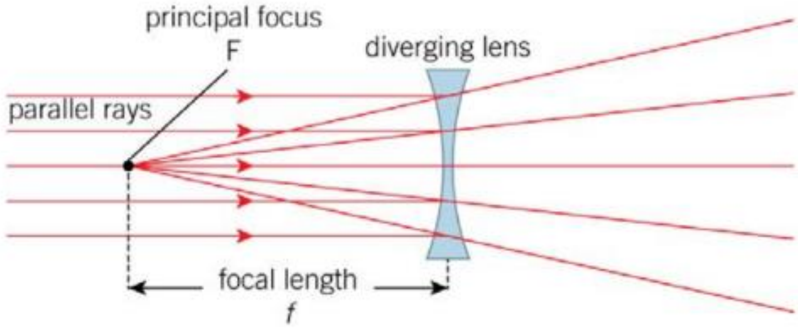
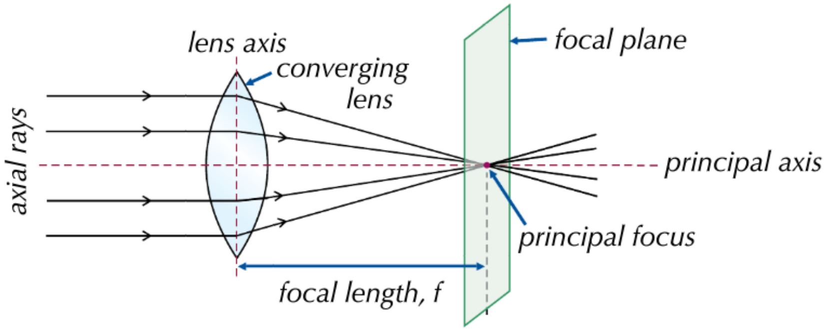
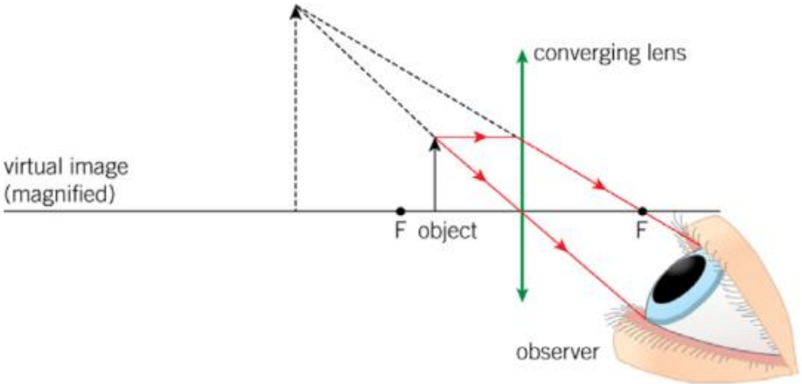
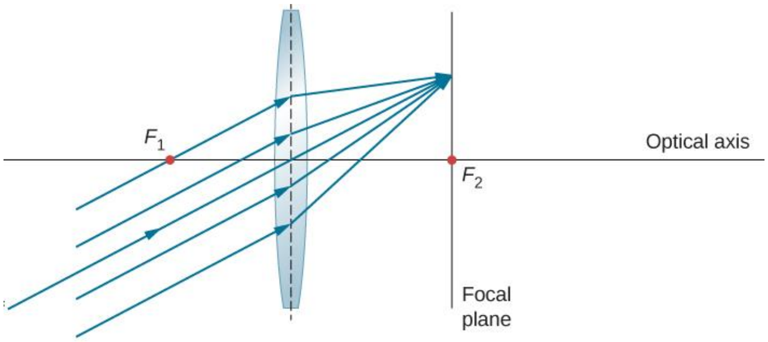
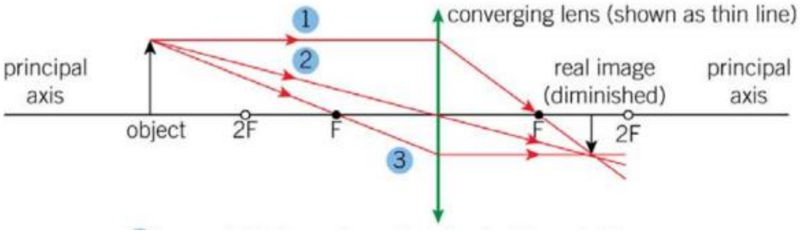
U9 - Astrophysics

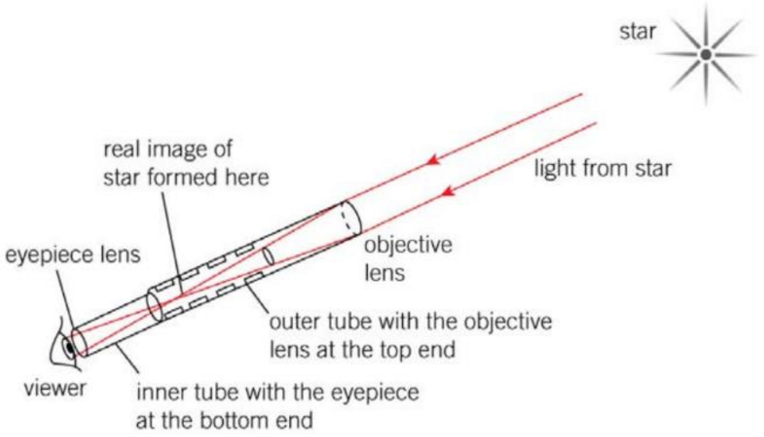
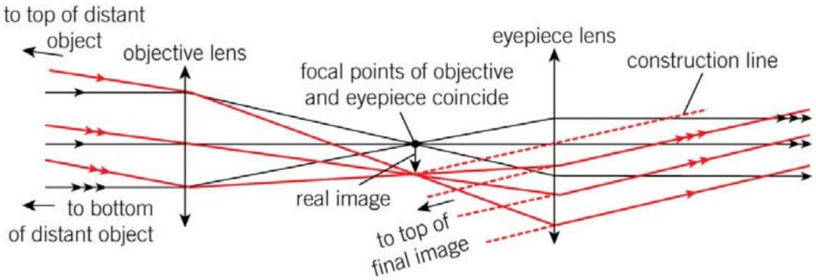
1.1 - Lenses

What is the principal focus / focal point and ray diagram for a converging lens?	The point where rays parallel to the principal axis are focused to. 
What is the principal focus / focal point in a diverging lenses?	The point where diverging rays from rays parallel to the principal axis appear to come from. 
What is focal length defined as?	The shortest distance from the lens axis to the focal plane.
What is the focal plane of a lens?	The plane on each side of a lens perpendicular to the principal axis and containing the principal focus. See below:  *Rays non parallel to the principal axis will be focused somewhere on the focal plane.*

Define both real and virtual images	- Real - when rays actually go to that point. - Virtual - when rays don't go to that point yet appear to come from it.
What are the 3 cases for objects lying along the principal axis?	1. Between the principal focus and lens. 2. On the focal plane. 3. Between the principal focus and infinity.
What is the ray diagram and image for object lying between principal focus and lens?	 Virtual, magnified, and upright. *This is essentially a magnifying glass.*
What is the ray diagram of object lying on focal plane under a converging lens?	 It appears to from at infinity.
What is the ray diagram for object lying between principal focus and infinity?	 Real, diminished, and inverted.
How does distance to lens affect image clarity?	The closer it is to the principal focus (yet > the focal length) the further a clear image is formed by the lens.

	This is because the lens can only bend the light so much, otherwise, you need a stronger lens.

1.2 - Refracting telescopes

Describe a simple refracting telescope	● Has two converging lenses of different focal lengths. ● Lens with longer focal length is the **object**ive (since it's facing the **object**). ● Outer and inner tube (attached to objective and eyepiece lens respectively) move until image is in focus.  ● Magnified, virtual, and inverted from eyepiece lens. *The objective lens focuses light from an object onto a point along the principal axis. We'd see the object if we placed a screen here.*
When is a telescope in normal adjustment and how does this affect the image?	● When the distance between the lenses is the sum of their focal lengths (i.e., focal points coincide). ● Image forms at infinity since the image from objective lens forms on the focal plane of the eyepiece lens.  *The eye is completely relaxed when viewing this image.*

<table>
<tr>
<td>Describe the light rays from distant objects</td>
<td>Light rays from distant objects are effectively parallel when they reach the telescope.</td>
</tr>
<tr>
<td>What is the angular magnification of a telescope and when can it be used?</td>
<td>

$$M = \frac{\text{angle subtended by final image}}{\text{angle subtended by distant object}}$$

OR

$$M = \frac{f_o}{f_e}$$

Where f_o is the focal point of the objective and f_e is the focal point of the eyepiece.

Used for a telescope in normal adjustment.

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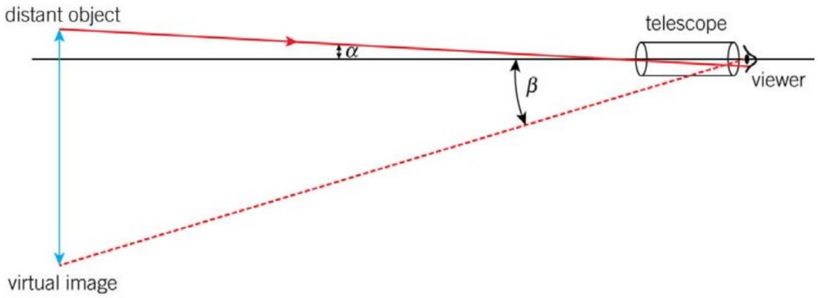
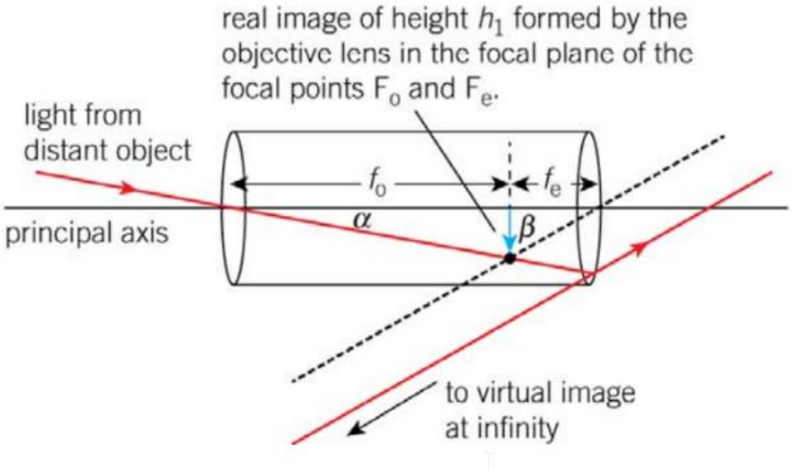


You can derive the second relationship by using the diagram below.
Note: small angle is applied here since the angles ≤ 10°.



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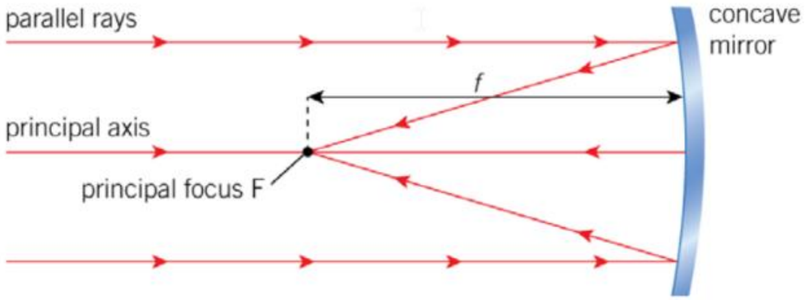
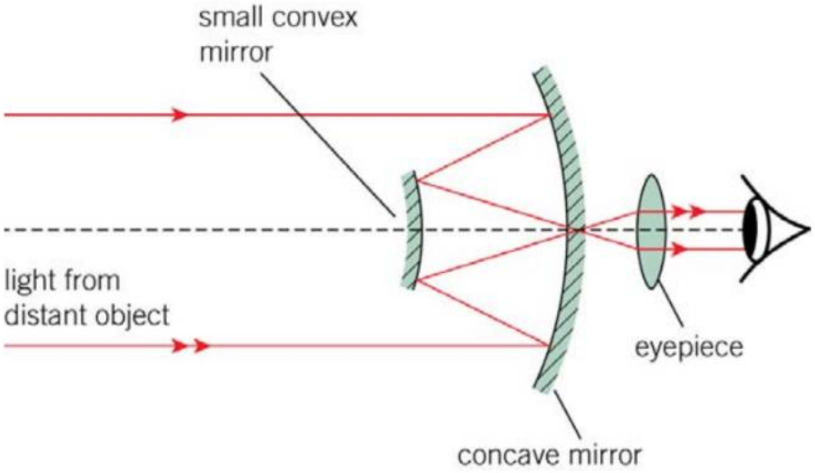
How does the collecting power of a lens relate to its size?	$\text{Collecting Power} \propto \text{Area} \propto \text{Radius}^2$
How does brightness vary when viewing different astronomical objects?	● When viewing stars, they appear as brighter points objects ∵ the telescope collects more light. ● Planets and other bodies appear no brighter ∵ not point objects ∴ when more light is collected, it's spread over a larger area.

1.3 - Reflecting telescopes

Describe a simple reflecting telescope	● Uses concave mirror to act as objective / primary mirror. ● A secondary smaller mirror reflects light from the primary onto an eyepiece. ● Principal axis is normal to centre of concave mirror.  *Rays parallel to the principal axis meet at the principal focus. All others are reflected to another point on the focal plane.*
Draw a Cassegrain reflecting telescope	 ● The effective focal length is…

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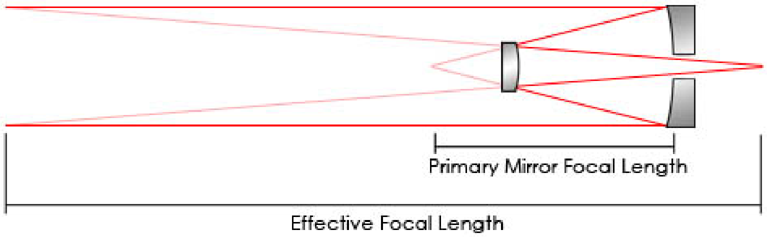

</td>
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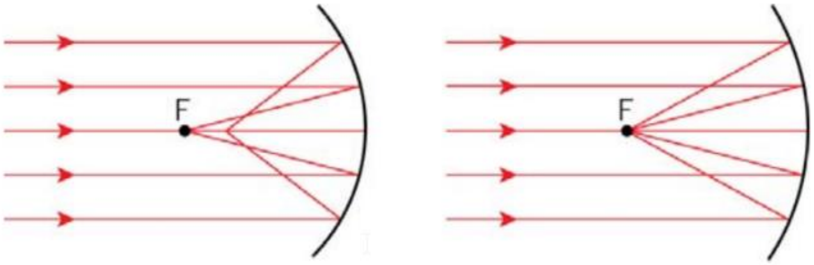
<tr>
<td>What is spherical aberration?</td>
<td>

When the outer rays are brought to focus a nearer the focal point leading to distortion.
Solved by using a parabolic mirror in telescopes.



(a) spherical mirror
(b) parabolic mirror
<i>This is because the angle of incidence = angle of reflection.</i>
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<td>Compare refractors and reflectors</td>
<td>
<table>
<tr><th>Reflectors</th><th>Refractors</th></tr>
<tr><td>Easier to manufacture large concave mirrors allowed for more light.</td><td>No secondary mirror to block out light.</td></tr>
<tr><td>Shorter than refractors with same angular magnification.</td><td>Wider field of view with less ∵ angular magnification ∴ finds more objects more easily.</td></tr>
<tr><td>Leads to spherical aberration (∵ reflection).</td><td>Wide lenses (required to match reflectors) would make top-heavy telescopes ∴ difficult to support.</td></tr>
<tr><td></td><td>Leads to chromatic aberration (∵ refraction.)</td></tr>
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<tr>
<td>What is chromatic aberration and when does it happen?</td>
<td>Shorter wavelengths are refracted more since refractive index depends on wavelength.</td>
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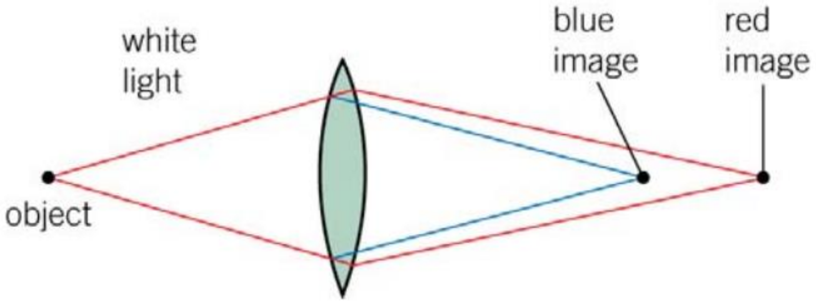
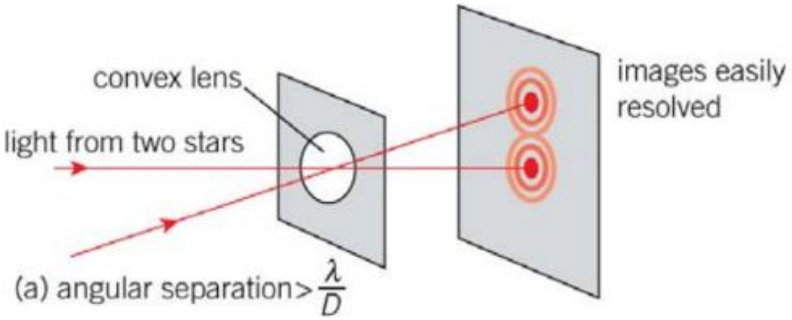
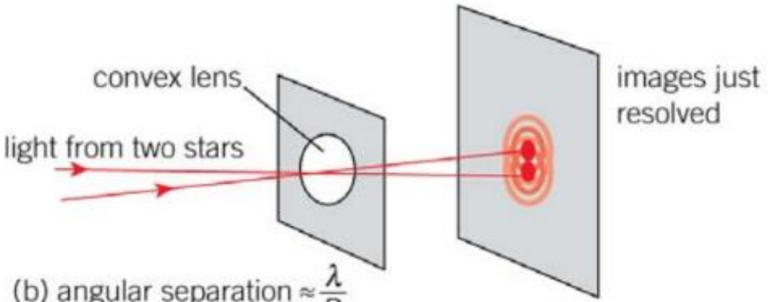
	 Happens with refracting telescope. *Shorter wavelengths are refracted more as you can imagine them jiggling and interacting more because they have a higher energy, so they will bend more.*
How do radio and optical telescopes compare?	• Radio have less precision in their design since larger wavelength. • Radio have to be bigger to resolve or linked up.

1.4 - Angular resolution

What is angular separation?	The separation of the straight lines from the Earth to each star.
How can diffraction in telescopes affect image resolutions?	Due to diffraction of light, a small objective cannot resolve two objects. *This is less important for x-rays / gamma ray telescopes due to the wave's small wavelength.*
What is the Rayleigh criterion?	Cannot resolve two point objects if the central spot of one lies within the first dark ring of the other ∴ $\theta \approx \lambda / D$ is the minimum angular resolution / resolving power.

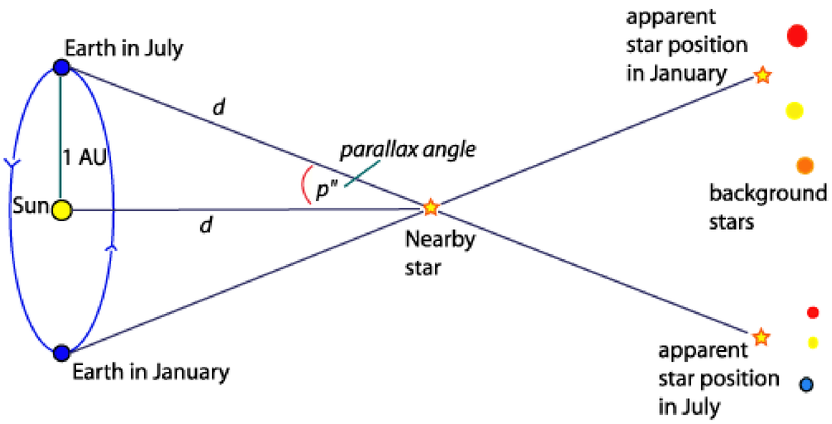
	 (a) angular separation> $\frac{\lambda}{D}$  (b) angular separation ≈ $\frac{\lambda}{D}$ *This still applies to detailed visible objects like lunar crates. It's interesting to note that around half the stars in the night sky we see are collections of two or more stars yet our eyes see them as a single star since the angle is too small to resolve.*
How does atmospheric refraction affect angular separation?	Atmospheric refraction means ground-based telescopes don't meet their theoretical value.

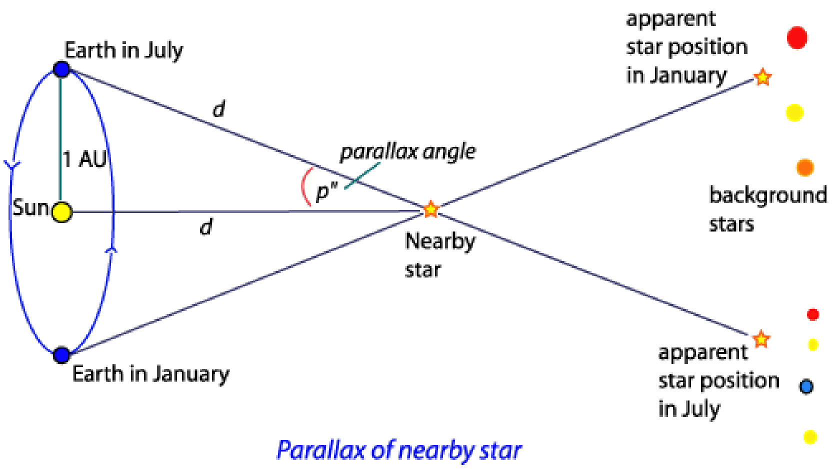
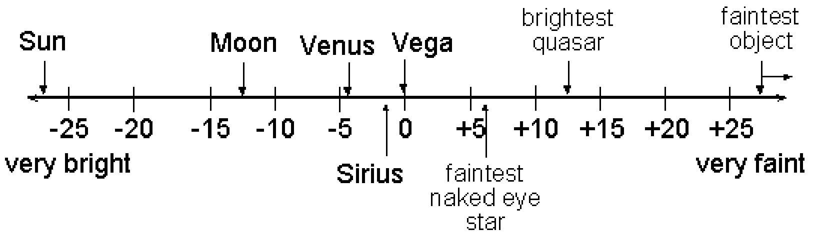
1.5 - Telescopes and technology

Define CCD	An array of light-sensitive pixels that charge when exposed to light and discharge when connected to a circuit.
Define quantum efficiency	The percentage of photons turned into electrons.
What are the pros and cons of a CCD compared to the eye?	+ Quantum efficiency of 80% compared to eye's 2% (∴ can see fainter objects) + Can record faster-changing images than the eye + Sensitive to more wavelengths than the eye - CCD is more expensive than normal cameras - CCD has to be supercooled

Why are steerable telescopes used?	To compensate for the Earth’s rotation.
How was the Milky Way mapped? Why does this work?	● Using radio waves. ● Since e^-'s in ^1H in gas and dust clouds flipped their spin.
What are IR telescopes used to do and what precautions are taken on Earth?	● Detect IR emitted by dust clouds. ● On Earth, they have to be cooled to stop IR from their own surface **<u>AND</u>** have to be high and dry to prevent water vapour absorbing IR.
Which telescopes have to be in space and why?	● UV, X-Ray, and Gamma Ray. ● Since these wavelengths are absorbed by the atmosphere.

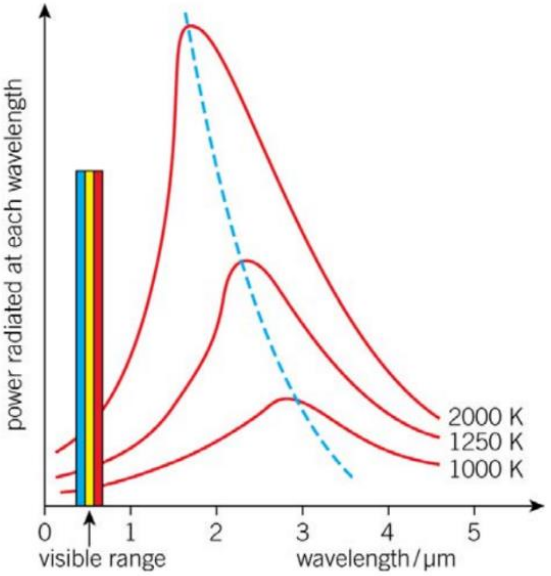
2.1 - Star magnitudes

Describe the parallax method	 *Parallax of nearby star* ● Used to measure distances to stars. ● Parallax angle is half the angular shift.
What is 1 pc defined as?	● 1 pc is the “the distance at which 1 AU subtends an angle of 1/3600th a degree”. ● Using d ≈ r / theta from the diagram below, 1 pc = 1 AU / (1 degree in arcseconds).

	 *Parallax of nearby star*
When does the parallax method only work?	- For stars that are close enough to see movement. - On the ground, we can measure up to 100 pc because atmospheric refraction gets in the way.
Describe the star magnitude scale	 **Apparent brightnesses of some objects in the magnitude system.** Every 5 numbers is 100 x brighter/dimmer.
Define absolute magnitude and apparent magnitude	- Absolute magnitude - the brightness of a star as seen 10 pc away from Earth. - Apparent magnitude - the brightness of a star seen from Earth.
What is intensity and its relation to stars?	- I = P / A. - Intensity of Star = Power / $4\pi d^2$ (thus following inverse square law). - Where the power comes from Stefan's Law. - Brightness of star ∝ intensity at Earth.

2.2 - Classifying stars

What is a black body?	A perfect absorber of radiation (absorbing 100% of incident radiation at all wavelengths) thus emitting a continuous spectrum of wavelengths.

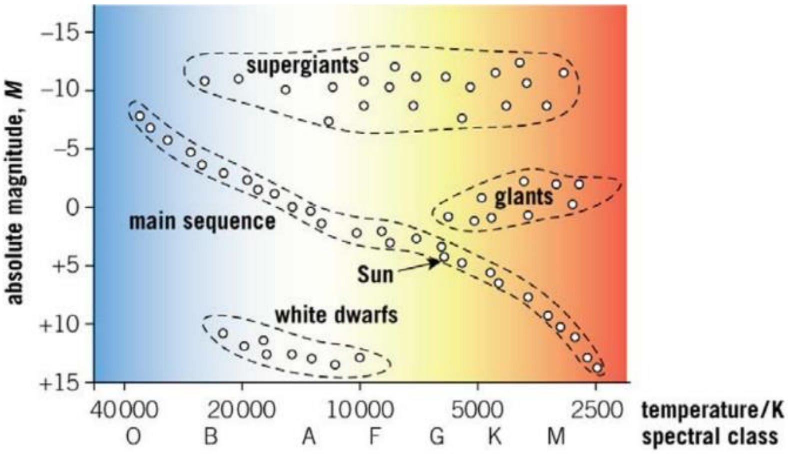
	Recall from GCSE that a matt black surface is the best absorber and emitter of infrared radiation.
Why are stars assumed to be black bodies?	1. As any incident radiation would be absorbed (none reflected). 2. The thermal radiation from a star closely matches the black body radiation curve.
Draw the black body radiation curve / spectra of stars for different temperatures	 The peak of the graph move towards shorter wavelengths as the temperature increases. *Be careful when looking at the shift.*
What is Wien's Displacement Law?	● The higher the surface temperature of an object, the shorter the **peak wavelength of black body radiation curve**. ● $\lambda_{max}T = 2.9 \times 10^{-3}$ mK mK is metres Kelvin.
What is Stefan's Law?	● $L = \sigma A T^4$ ● Where L is luminosity (synonymous with power), σ is the Stefan-Boltzmann constant, A is surface area, T is temperature.
What are Balmer Lines and when are they seen?	● Absorption lines due to transition from n = 2 to a higher energy level in an hydrogen atom.

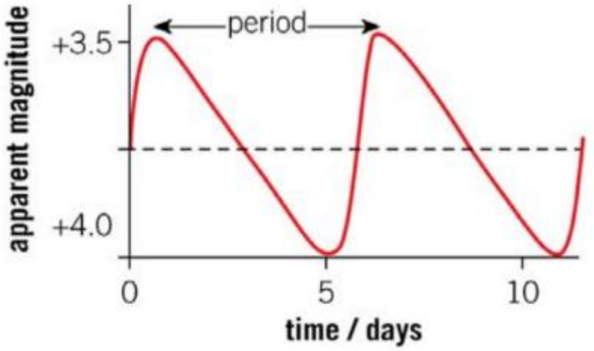
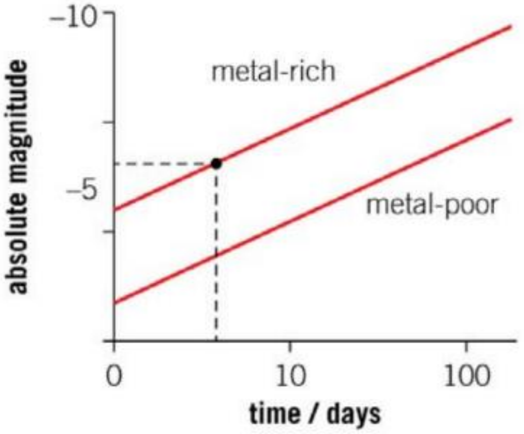
	● They are only seen in hot stars - specifically B, A spectral classes - in the visible spectrum. *Hydrogen atoms from the n = 1 ground state do not absorb visible photons since the energy required is too large.*
What are the spectral classes, colors, temperature, and prominent absorption lines?	See below.

Spectral Class	**Colour**	**Temperature / Thousands of K**	**Prominent Absorption Lines**	
O	Blue	25 - 50	He	H
B		11 - 25		
A	Blue-White	7.5 - 11	Ionised Metals	
F	White	6 - 7.5		
G	Yellow-White	5 - 6		Neutral Metals
K	Orange	3.5 - 5		
M	Red	2.5 - 3.5	TiO	

This can be remembered as ‘Oh Boy, An F Grade, Kill Me’.

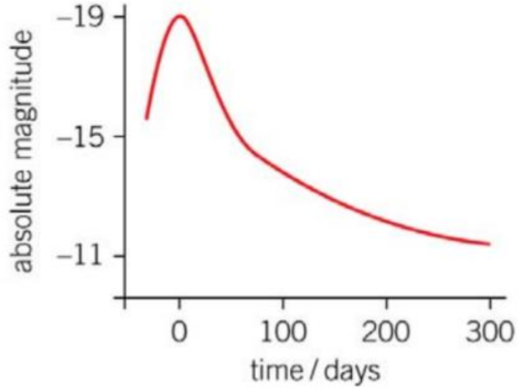
2.3 - The Hertzsprung–Russell diagram

Draw the Hertzsprung-Russell diagram with the sun's position	 **Figure 2** *The Hertzsprung–Russell diagram* *The bottom ranges from 50k to 2.5k.* The Sun has spectral class of G and absolute magnitude of 4.8.
Describe the formation of stars	1. Dust and gas clouds contracts under gravity becoming denser and denser forming a protostar (star in making). 2. During collapse, GPE becomes KE making it hotter. 3. Once sufficient mass is reached, the temp. becomes high enough for fusion to occur. 4. Energy released as fusion occurs further heats the protostar into a main sequence star. *If sufficient mass isn't reach, it will gradually cool.*
How are main sequence stars in equilibrium?	The inward gravitational attraction = outward radiation pressure.
When does a star become a red giant?	When it runs out of hydrogen fuel to burn.
When does a star become a white dwarf?	When the remaining core mass ≤ $1.4m_{sun}$ after first becoming a red giant. *It cannot fuse anymore and its outer layers are thrown off in shells called a planetary nebulae.*

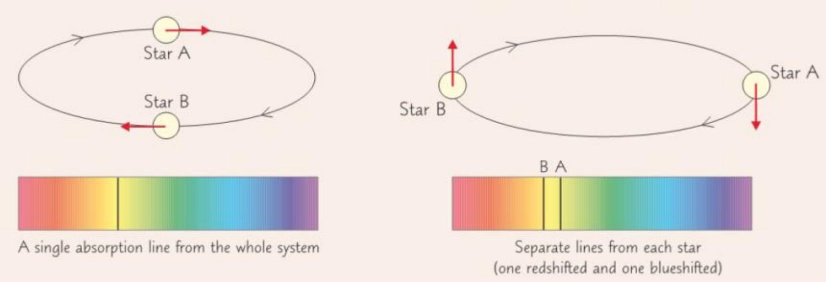
What is a cepheid variable and how can the distance to it be calculated?	● A star whose luminosity varies.  (a) variation of apparent magnitude with time for a typical cepheid variable ● It can be calculated by measuring the period which gives the absolute magnitude then using the apparent-absolute magnitude formula.  (b) absolute magnitude v period relationship

2.4 - Supernovae, neutron stars, and black holes

What is a supernova?	An astronomical object that has a rapid increase in brightness.
When does a supernova occur? What is left behind and why?	● When the remaining core mass $\geq 1.4m_{sun}$ fuses upto iron and it’s no longer energetically favourable to fuse any heavier elements. ● Leaving behind a neutron star or black hole.
What is a Type 1a supernova and how are they used?	Supernovae that reach a known peak luminosity used to find the distance to the host galaxy. They are called standard candles.

What is the light curve for a type 1a supernova?	 Peaks at around M = -19.
What are neutron stars?	Relatively small and very dense stars made up of neutrons.
What are pulsars?	Neutrons stars that emit radio waves in two beams as they rotate.
What is a black hole?	An object so dense even light cannot escape it.
What is the Schwarzschild radius?	The radius of the event horizon.

3.1 - The Doppler effect

What is the formula for the Doppler Effect and when can it be applied to EM waves?	$z = \frac{v}{c} = \frac{\Delta f}{f} = -\frac{\Delta \lambda}{\lambda}$ Can only be applied to EM waves when v << c.
What is radial velocity?	The velocity of an astronomical body along the line of sight of the observer.
How does redshift affect binary stars? (with diagram)	

	● Redshifts alternate between a minimum and maximum value (when the star is moving towards / away from Earth). ● They meet halfway when they're moving perpendicular to our line of sight. *It's halfway when the stars are the same mass. Otherwise, they'll move with different speeds and orbital radii (due to a barycentre) so greater Δλ for the faster, less massive, star.*

3.2 - Hubble's Law and beyond

What is recessional velocity?	The rate at which an astronomical object is moving away, typically from Earth.
How can Hubble's Law be used to estimate the age of the universe and why is this rough?	● Set the v in v = Hd to c and go from there. ● It's rough since we've assumed H is constant (which we cannot know for sure) and it's based off redshift measurements in which v must be << c.
What is the cosmological principle?	The universe is homogeneous (same composition throughout) and isotropic (looks the same in all directions).
Give 4 pieces of evidence for the Big Bang	1. Redshift of galaxies showing expansion. 2. CMBR detected in all directions - remanent of Big Bang cooling down. 3. Relative abundance of H:He. ■ Universe cooled as it expanded allowing quarks for form baryons. Protons formed more readily than neutrons due to lower rest mass so more hydrogen found in universe. 4. Dark energy. ■ Thought to be causing the acceleration of the expansion of universe. ■ Yet, there is some controversy surrounding this.

3.3 - Quasars

What were quasars discovered as?	Bright radio sources.

What are quasars thought to be?	Fast-moving clouds of gas/matter ejected by active supermassive black holes at the centre of galaxies.
Give 3 characteristics of quasars	1. Very powerful light output (much more than our Sun). 2. Relatively small size (≈size of solar system). 3. Large redshift.

3.4 - Exoplanets

What are exoplanets and why are they hard to detect?	● Planets are don't orbit our Sun. ● They don't emit their own light.
What 2 ways can exoplanets be detected and their disadvantages?	1. Radial velocity method: ■ Look for a periodic shift in wavelength from a star wobbling around its barycentre. - Only works for large planets close to their star. - Other planets can cancel out their motion 2. Transit photometry: ■ Look for regular dips in intensity of a star caused by a planet passing. - Only works for planets close to their star and in the line of sight of Earth.