

14. Stellar Evolution

Edexcel GCSE Astronomy Course

What is this topic about?

Students will gain an understanding of how and why stars evolve. They will study how stars form and how they end their life, depending on their size.

So, let's look at some stars! Pump up the volume and hold tight...

https://www.youtube.com/watch?v=GoW8Tf7hTGA&ab_channel=morn1415

If your mind is not blown, are your REALLY interested in Astronomy??



14.3 Understand the effects of the interaction between radiation pressure and gravity in a main sequence star

How does a star work?

This BBC video is a good introduction to the idea of nuclear fusion in stars:

https://www.youtube.com/watch?v=BM7W7z9UVoY&ab_channel=BBCTeach (4:39)

The basic ideas to remember are:

- Very high pressures and temperatures in the core of a star allow protons to be squeezed together close enough for them to fuse, or join, and this turns a small amount of their mass into pure energy.
- A single proton is the same as the nucleus of a hydrogen atom, so fusing protons creates heavier nuclei, maybe deuterium, tritium, helium or even heavier ones - each fusion releases some energy. Billions of fusions per second in a star release huge amounts of energy.

Take a look at this link and use it to find a written explanation of 'hydrostatic pressure' in a star:

<https://imagine.gsfc.nasa.gov/science/objects/stars1.html>

14.4 Understand changes to the radiation pressure-gravity balance at different stages in the life cycle of a star with a mass similar to the Sun

Using the same website as on the previous slide, look at the diagram and follow the left hand loop for a star with a similar mass to the Sun.

(<https://imagine.gsfc.nasa.gov/science/objects/stars1.html>)

Starting from the star forming nebula in the centre and moving anticlockwise to protostar, make a list of all the stages in the lifecycle of such a star like this:

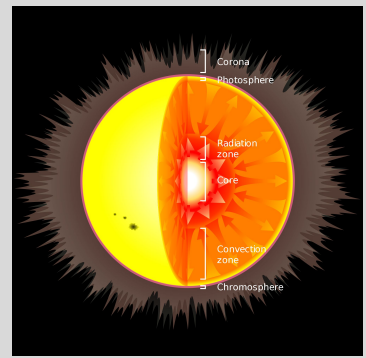
Sun-like star:

1. Star-forming nebula 2. Protostar 3. ... 4. ... 5. ... 6. ...

Continued on next slide...

The lifecycle of a star

Why do stars have a lifecycle, what is going on?



- Simply put, it's a question of balance between **gravity** and **radiation pressure**.
- First gravity pulls a lot of matter from a nebula together until a protostar is big enough for nuclear fusion to start.
- Nuclear fusion causes radiation pressure which pushes outwards, against the gravity pulling inwards. If they are equal, the star will be in hydrostatic equilibrium and is known as a main sequence star - this name is explained in Topic 13.
- At some point the fusion will slow down once there are not enough protons left to fuse, so radiation pressure will weaken and the gravity will be able to pull the star inwards.
- This causes more pressure and higher temperatures, so larger nuclei can fuse releasing more energy and increasing radiation pressure again - the star expands!

14.6 Understand changes to the radiation pressure-gravity balance at different stages in the life cycle of a star with a mass much greater than the Sun

14.8 Understand the effect the Chandrasekhar Limit has on the outcome on the final stages of the life cycle of a star

If the amount of material pulled together by gravity is larger, then a larger star will be formed. Going back to this website look at the diagram and follow the *right* hand loop for a star with a larger mass than the Sun:

<https://imagine.gsfc.nasa.gov/science/objects/stars1.html>

Starting from the star forming nebula in the centre and moving clockwise to protostar, make a list of all the stages in the lifecycle of such a star like this:

Massive star:

1. Star-forming nebula 2. Protostar 3. ...4. ... 5. ... 6a ... 6b. ... (notice there are two possible options at the end this time - the outcome depends on the Chandrasekhar limit <https://astronomy.swin.edu.au/cosmos/c/Chandrasekhar+Limit>)

The lifecycle of stars in more detail:

<p>14.9 Understand the principal stages and timescales of stellar evolution for stars of similar mass to the Sun, including:</p>	<p>14.10 Understand the principal stages and timescales of stellar evolution for stars of much larger mass than the Sun, including:</p>
<ul style="list-style-type: none">a emission and absorption nebulab main sequence starc planetary nebulad red giante white dwarff black dwarf	<ul style="list-style-type: none">a emission and absorption nebulab main sequence starc red giantd white dwarfe supernovaf neutron starg black hole

You can investigate the different stages in the lifecycles of stars with different masses using an excellent simulation called Star in a Box - see the next slide.

Star in a Box Exercises

You can investigate the consequences of changes in this balance using this simulation called 'Star in a Box'. This shows various things changing as the star moves through its lifecycle - notice that the temperature on the x-axis increases from RIGHT to LEFT and that the star's brightness on the y-axis goes up in 10's compared to then brightness of the Sun (1,10,100,1000 etc - this is called a logarithmic scale and is also used in the graphs shown in the government's daily briefings)

Exercise 1:

Just set the animation speed, next to the Play button, to slow and then press play. This shows the evolution of a star with the same mass as our Sun. Watch the time in years changing, the size in the box on the left and the position of the star on the chart as its temperature and brightness change. At top right it tells you what stage the star has reached e.g Main Sequence, Red Giant etc.

<https://starinabox.lco.global/> (Use the Advanced setting!)

Continued...

Exercise 2: The lifecycle of a star with the same mass as the Sun.

Now pause the animation and fill in some observations in a table like this in your notes by hovering over the dotted line until red cross hairs appear that will show brightness, compared to the Sun, on the left and temperature at the bottom. Use Star in a Box to complete the table for each point where the dotted line changes direction:

Stage	Time from start (millions of years)	Temperature (K)	Brightness	Size
Main Sequence	0			
Red Giant	10000			
White Dwarf	12000			

Exercise 3: The lifecycle of a star with ten times the mass of the Sun.

Repeat the Star in a Box exercise but set the mass to 10 times the mass of the Sun before you start the animation - try to stop it at these significant points again:

Stage	Time from start (millions of years)	Temperature (K)	Brightness	Size
Main Sequence	0			
Red Giant	24			
Red Giant	26			
Supernova				
	33			

Summarising the lifecycle of stars

This BBC Bitesize page gives a really clear flowchart for you to learn showing the lifecycle of small mass and high mass stars. It also gives a detailed definition of each stage which you could copy into your notes:

<https://www.bbc.co.uk/bitesize/guides/zpxv97h/revision/1>

If you want a different way of looking at the ideas, this site is written to cover all the specific learning points needed in the GCSE Astronomy course Topic 14:

<https://www.space.fm/astronomy/starsgalaxies/gravitypressure.html>

14.5 Understand the balance between electron pressure and gravity in a white dwarf star

14.7 Understand the balance between neutron pressure and gravity in a neutron star

These two links explain the amazing physics that creates a white dwarf from small mass stars and neutron stars from higher mass stars - the highest masses of all produce black holes!

<http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/whdwar.html#c3>

<http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/pulsar.html#c3>

This gives a bit more detail about the amazing features of neutron stars:

<http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/pulsar.html#c1>

14.11 Understand how astronomers study and gather evidence for the existence of black holes

How do we know that black holes exist? This video explains:

https://www.youtube.com/watch?v=SpmDF6aunhl&ab_channel=GoogleArts%26Culture (2:15)

Now let's take an imaginary journey into the heart of galaxy Messier 87 (M87):

https://www.youtube.com/watch?v=19to087TYv8&feature=emb_logo&ab_channel=ehtelelescope (0:55)

This is the first direct image ever made of a black hole at the centre of a galaxy and was made with a radio telescope called the Event Horizon Telescope (EHT) in 2019. Why IS Messier 87 called that? Our final slides are about star catalogues.

14.1 Be able to use the Messier and New General Catalogue (NGC) in cataloguing nebulae, clusters and galaxies

Here's a website about the Messier catalogue - look at the images and make a list of your favourite spiral galaxy, elliptical galaxy, nebula and star cluster:

<https://www.nasa.gov/content/goddard/hubble-s-messier-catalog>

Here's another site where the different types of objects are grouped and where you can search for the details of each Messier object:

<https://www.messier.seds.org/>

Why do you think it is useful for astronomers to have a catalogue or classification system like this? Where else is classification used in science?

14.2 Be able to use the Bayer system for naming the brightest stars within a constellation

The Bayer system uses a Greek letter and the Latin name of the constellation to put the stars in that constellation in order of their brightness. It's useful to know your Greek letters to understand it properly:

<https://web.mit.edu/jmorzins/www/greek-alphabet.html>

The brightest star in a constellation is called alpha e.g. Alpha Ursa Major, the next brightest is beta etc. This site explains it very nicely:

<http://www.pas.rochester.edu/~blackman/ast104/naming.html>

Do a search to find the common names of these stars:

Alpha Orionis; Beta Ursae Majoris; Alpha Canis Majoris; Alpha Cygni