**Cosmic Engine**

These worksheets are designed to be read by students before viewing a CAASTRO in the Classroom video conferencing session. The ‘Pre-visit activities’ can be completed prior to the conference session and the ‘Post activities’ are provided as suggestions for follow-up activities.

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# **Pre-visit Activities**

## **Glossary**

*The following terms may be cited during the video conferencing session. If students need assistance, refer them to the ‘Revision Videos’ section or any Physics textbook.*

|  |  |
| --- | --- |
| **Terms** | **Definition** |
| Star | A huge ball of hot gas that emits radiation from nuclear fusion. |
| Galaxy | A system of stars, planets, gas and dust, held together by gravity. |
| Universe | All of space and everything in it including all stars, planets and galaxies. |
| The Big Bang | A theory of how the universe was formed: a single point of energy that rapidly expanded and evolved to create the universe. |
| Light year (ly) | The distance that light travels in one year: kilometres. |
| Black hole | A region of space with a gravitational force so strong that light cannot escape. |
| Main sequence star | A star like our Sun that fuses mostly hydrogen to produce radiation. |
| White Dwarf | A small remnant of a star with a very high density (high mass for its size). |
| Red giant | A very large, highly luminous star with a relatively low surface temperature. |
| Neutron star | An extremely dense star that results from the death and collapse of a red supergiant star, or from a binary star system. |
| Quasar  (Quasi-Stellar Radio Source) | A shell of superheated gas surrounding a supermassive black hole at the centre of a galaxy that emits tremendous amounts of energy including visible light and radio waves. |
| Nebula | A massive cloud of dust, plasma, hydrogen and helium gas from which stars are born. |
| Accretion | The accumulation of particles into a massive object by gravitational attraction. |
| Supernova | A catastrophic explosion that can occur at the end of a star’s life, producing enough light to outshine a galaxy. |
| Fusion | When two atomic nuclei join to form a new, heavier nucleus and release energy. |
| Thermonuclear fusion | A type of fusion that occurs due to the extreme high temperatures in stars or in thermonuclear weapons. |
| Nucleosynthesis | The process of creating new atomic nuclei from the fusion of smaller nuclei, for example, two hydrogen atoms fusing to create one helium atom. |
| Isotopes | Atoms of the same element, and same number of protons, with different numbers of neutrons. |
| Ionisation | The addition or removal of an electron from an atom to give the atom a positive or negative charge. |
| Photon | A packet of light energy. |
| Luminosity | The total amount of light energy emitted from an object second. Measured in watts (1 W = 1 J.s-1). |
| Apparent magnitude | The brightness of a celestial object as measured from the Earth. |
| Absolute magnitude | The brightness of a celestial object as measured from a standard distance of 10 parsecs (32.6 light years) from the object. |
| Solar mass (M☉) | The standard unit of mass in astronomy equal to the mass of the Sun (1.99 x 1030 kg) |
| Hertzsprung-Russell (H-R) Diagram | A graph that plots the absolute magnitude against the surface temperature (spectral type) for a group of stars. The diagram reveals the evolution of stars and can identify stars into particular types (e.g. main sequence, giants or white dwarf) based on their position on the H-R diagram. |

Extra terminology

*These terms are not in the syllabus but may be mentioned during the presentation.*

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| **Terms** | **Definition** |
| Red supergiant | An extremely large red giant star with a minimum of 15 solar masses. |
| Blue giant | An extremely bright and hot giant star. An evolved star that has exhausted its core hydrogen |
| Blue supergiant | An extremely bright and hot giant star. |
| Hypergiant | Evolved, high luminosity, high-mass stars that lie higher in the HR diagram than any other star type. |

## **Revision Videos**

*The following is a list of useful revision videos. Students can:*

* *Take notes on the videos for themselves; OR*
* *Review one or more of the videos for their classmates as a homework exercise, giving each video a rating and commenting on how well the video communicated the science content.*

1. Accretion and the birth of a star

<https://www.youtube.com/watch?v=mkktE_fs4NA>

*Science Channel: How the Universe Works - A Star is Born*

1. The life cycle of stars and nuclear fusion

<https://www.youtube.com/watch?v=PM9CQDlQI0A>

*Institute of Physics: The Life Cycle of Stars*

1. Nuclear fusion

<https://www.youtube.com/watch?v=Ux33-5k8cjg>

*Vertasium: Where does the sun get its energy?*

1. Fission and fusion

<https://www.youtube.com/watch?v=yTkojROg-t8>

*The Science Channel: Fission and Fusion*

1. H-R diagram made from Omega Centauri

<https://www.youtube.com/watch?v=jiSN95WX1NA>

*utexascnsquest: H-R diagram animation*

1. Stars, spectra and the H-R diagram

<https://www.youtube.com/watch?v=ld75W1dz-h0>

*PBS CrashCourse: Stars - Crash Course Astronomy #26*

1. Brian Schmidt explains how he discovered that the universe is expanding

<https://www.youtube.com/watch?v=YHBvOOX3RJQ>

*Veritasium: Physics Nobel Prize 2011 - Brian Schmidt*

1. Star size comparison

<https://www.youtube.com/watch?v=HEheh1BH34Q>

*morn1425: Star Size Comparison HD*

1. Black hole and supermassive black hole size comparison

<https://www.youtube.com/watch?v=QgNDao7m41M>

*morn1415: Black Hole Comparison*

1. Types of Stars explained

<https://www.youtube.com/watch?v=gT8WrjBEaHM>

*The Open University: Types of Stars*

# **Post-visit Activities**

## **Practice Questions**

**Useful formulae**:

|  |  |
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| Alpha Decay ()  The ejection of a helium nucleus from the decaying particle    E.g. | Beta Decay ()  The ejection of an electron or positron from the nucleus.  (electron emission)    E.g.  (positron emission)    E.g. |
| Gamma Radiation ()  The ejection of a gamma ray (a photon)    E.g. |
| Solar Mass (M☉) kg  Solar Luminosity (L☉) W  1 Watt = 1 Js-1  kg (*u* is the atomic mass unit) | Einstein’s energy/mass equation |

### ***Question 1 - Nuclear Fusion***

1. Complete the following table about nuclear radiation.

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| --- | --- | --- | --- | --- |
| **Nuclear Radiation** | **Charge** | **Nature of radiation** | **Ionising ability** | **Penetrating ability** |
| Alpha | +2 | Emission of a helium nucleus | High | Low - stopped by a sheet of paper or a few centimeters of air |
| Beta | -1 for electron emission  +1 positron emission | Emission of an electron  or emission of a positron | Medium | Medium - stopped by sheet of aluminium or a metre of air |
| Gamma | 0 | Emission of a high-energy photon (or high-frequency electromagnetic radiation) | Low | High - stopped by a few centimeters of lead |

1. Gamma rays are released in the core of red giant stars, in a set of nuclear fusion reactions known as the triple-alpha process. Two helium atoms fuse to create one beryllium atom and gamma radiation with energy of -0.0918 MeV. The beryllium atom then fuses with another helium atom to create a carbon atom and gamma radiation with energy of 7.367 MeV. The carbon atom then fuses with another helium atom to create an oxygen atom and gamma radiation with energy of 7.162 MeV. Write the atomic equations for these three reactions.

|  |
| --- |
| 1. (−0.092 MeV) 2. (7.367 MeV) 3. (7.162 MeV) |

1. Elements heavier than Neon are often formed from thermonuclear reactions in supernovae explosions. Numerous nuclear reactions occur during this process involving emission and absorption of 𝛼, 𝛽, and 𝛾 radiation. Complete the following equations by filling in the square brackets (periodic table of elements may be needed).

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1. Various isotopes of hydrogen and helium were formed from nucleosynthesis that occurred within the first three minutes after the Big Bang. Complete the following atomic equations for the nucleosynthesis of hydrogen and helium isotopes.

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1. What is binding energy?

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| Binding energy refers to the amount of energy required to break apart a nucleus. It is also referred to as the energy required to hold a nucleus together. |

1. Much of the energy from the Sun is produced from the proton-proton cycle:

This can be simplified into the following net reaction:

Answer the following questions assuming that the mass of an electron is negligible.

* 1. If the mass difference between hydrogen and helium is all converted into energy, how much energy is produced in this reaction? (***Hint***: use the masses for hydrogen and helium provided in the Periodic Table rather than adding individual proton and neutron masses)

|  |
| --- |
| Mass of 1 hydrogen atom kg kg  Mass of 4 hydrogen atoms =kg kg  Mass of helium kg kg  Mass difference before and after fusion kg kg  kg  Energy released:  J  ∴J J (3 sig. figs.) |

* 1. The Sun has luminosity of W. Calculate how many hydrogen atoms must fuse to form helium every second to produce this luminosity.

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| From part i), 4 hydrogen atoms fusing to form 1 helium atom releases Joules of energy.  The Sun produces WJs-1  ∴ the no. of fusions per second:fusions per second  4 hydrogen atoms are involved in each fusion.  ∴ no. of hydrogen atoms fused in every second: (3 sig. figs.) |

* 1. What percentage of hydrogen mass is converted into energy via fusion?

|  |
| --- |
| From part i), difference in mass before and after fusion kg  Total mass of hydrogen before fusion kg  % mass of hydrogen converted into energy % = 0.719246...% = 0.719% (3 sig. figs.) |

* 1. How much mass is being converted into energy every second? (Hint: Use the Sun’s luminosity from part ii)

|  |
| --- |
| Energy is produced by the Sun at a rate of W Js-1  Now,  ∴ Mass converted to energy per second = kg kg kg (3 sig. figs.)  OR:  from i) mass converted to energy per fusion kg  from ii) number of fusions occurring per second  ∴ total mass converted to energy per second kg kg |

* 1. The Sun is composed around 71% hydrogen, 27% helium and some heavier elements. However, only 13% of this hydrogen is available for hydrogen fusion in the core. The rest remains in layers of the Sun where the temperature is too low for fusion to occur. Use these figures and the answers to previous questions to calculate the lifetime of hydrogen fusion in the Sun.

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| From iii) the hydrogen fusion reaction converts 0.719% of the reaction mass into energy. The Sun contains 71% hydrogen and only 13% of that mass undergoes fusion.  ∴% mass of the Sun that converts to energy via fusion:  %%%  ∴ total mass to be converted to energy via fusion kg kg  energy.  The lifetime of hydrogen fusion in the Sun = total mass to be converted to energy via fusion ÷ total mass converted to energy per second (from iv)  ∴ lifetime of hydrogen fusion in the Sunss  ∴ lifetime of hydrogen fusion in the Sun years years billion years |

* 1. The Sun will have approximately 5-6 billion years of active life (fusion of elements in the core) until it becomes a white dwarf and all nuclear reactions cease. Using your answer for v), compare the difference between these two values, and suggest/research possible reasons for the discrepancy.

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| From v) we find that it will take 9.81 billion years for the hydrogen to be depleted, however, we are told that the Sun will only have 5 billion years of active life left (Shröder & Connon Smith 2008). This is a large discrepancy (almost twice as long).  Possible reasons for the discrepancy:   * not all of the energy from the Sun comes from the proton-proton chain, meaning that some of the luminosity from the Sun comes from other nuclear reactions within the Sun. * the reaction and consumption of hydrogen in a star is not linear or constant, but may fluctuate over time, especially as a star exits the main sequence. * the Sun increases in luminosity as it ages and “moves up” the H-R diagram. This is an increase of approximately 1% every 110 million years (Schroder & Connon Smith 2008), which would lead to a higher rate of hydrogen loss.   + *“The helium "ashes" left behind are denser than hydrogen, so the hydrogen/helium mix in the Sun's core is very slowly becoming denser, thus raising the pressure. This causes the nuclear reactions to run a little hotter. After another 4.8 billion years, the Sun will be about 67% brighter than it is now”* [*http://faculty.wcas.northwestern.edu/~infocom/The%20Website/evolution.html*](http://faculty.wcas.northwestern.edu/~infocom/The%20Website/evolution.html) * as the Sun moves into the red giant phase, its luminosity will increase by a factor of 2, leading to an increase in fusion rates (as calculated in question ii) * there are also a number of other factors that affect a star’s mass loss (see/search Reimers’ formula and the mass loss from non-dusty winds) which will all affect the mass loss in the Sun.   Schröder, K. -P.; Connon Smith, R. (2008). "Distant future of the Sun and Earth revisited". *Monthly Notices of the Royal Astronomical Society* **386**: 155–163  <http://arxiv.org/pdf/0801.4031v1.pdf> |

### ***Question 2 - Stellar Evolution***

1. Complete the following table:

|  |  |
| --- | --- |
| **Star type** | **Energy source (elements that are fused)** |
| Main Sequence | Hydrogen |
| Red giant | Hydrogen, Helium, Carbon, Nitrogen, Oxygen |
| Red supergiants | Hydrogen, Helium, Carbon, Nitrogen, Oxygen, Neon, Silicon |
| White dwarf | No nuclear energy source. They shine because they are hot. |

1. Explain why only stars of very large initial mass may develop into a supernova (excluding type Ia supernovae).

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| Supernovae occur when massive stars such as supergiants or hypergiants (type 0 or I stars) explode due to the sudden gravitational collapse of the massive star's core. These events are very short-lived and very bright.  Only stars with very large initial mass develop into supergiants or hypergiants and thus are the only stars capable of “going supernova”. Less massive stars (up to 8 M☉) will evolve into red giants and then white dwarfs without a supernova explosion. Here the outer layers are simply ejected due to a lack of gravity / gravitational force. |

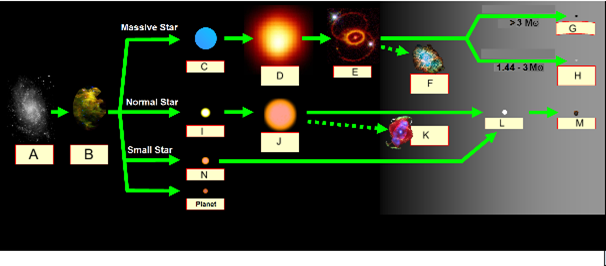
1. Explain how white dwarf stars differ from main sequence stars.

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| A white dwarf is a small remnant of a star. They do not have nuclear reactions in the core and shine only because they are hot. Eventually, a white dwarf will cool into a black dwarf star, however, we are yet to discover a black dwarf star as the universe is not old enough for black dwarfs to have formed.  Main sequence stars (also known as dwarf stars) in comparison are active stars that shine due to nuclear fusion of hydrogen and helium atoms in the core. |

1. Our solar system is made up of 98 naturally occurring elements. However, only 2 elements (hydrogen and helium) are created by the Sun. How is it possible that we observe these heavier elements? i.e. Where did these heavier elements originate?

|  |
| --- |
| Our Sun is a second or third-generation star, meaning that it has formed from the supernova remnants of one or two previous stars. The elements heavier than the primary atoms (hydrogen and helium) originated from nucleosynthesis in massive stars during their giant, supergiant or hypergiant phases, or in supernova explosions. |

1. Identify the following objects in the stellar evolution chart.



*Image edited from* [*https://upload.wikimedia.org/wikipedia/commons/0/0f/Stellar\_evolution\_Hebrew.png*](https://upload.wikimedia.org/wikipedia/commons/0/0f/Stellar_evolution_Hebrew.png)

*Attribution: DMY at Hebrew Wikipedia [GFDL (http://www.gnu.org/copyleft/fdl.html) or CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| A | Nebula (or gas and dust) |  | F | Nebula |  | K | Planetary nebula |
| B | Protostar |  | G | Black hole |  | L | White dwarf |
| C | Massive star |  | H | Neutron star |  | M | Black dwarf |
| D | Red supergiant |  | I | Mid-sized star |  | N | Small star |
| E | Supernova |  | J | Red giant |  |  |  |

### ***Question 3 - Stellar Properties (New South Wales HSC)***

1. Describe the relationship between a star's temperature and its colour.

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| The hotter a star, the more blue in colour the light emitted from that star will be. Cooler stars are more red in colour. |

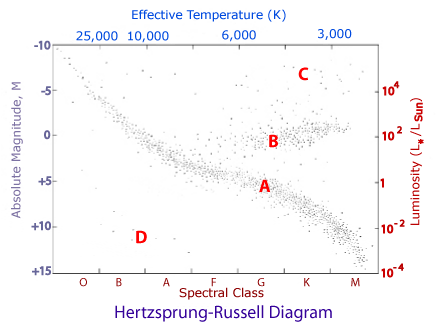
1. What two factors affect a star’s luminosity (by looking at an HR diagram)?

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| The two factors that affect a star’s luminosity are the temperature and the radius (or size).  We can also see this in the Stefan–Boltzmann equation: L = 4πR2σT4  Where: L = luminosity; R = radius of the star; T = temperature of the star; σ = the Stefan–Boltzmann constant. |

1. Re-order these two lists from hottest to coolest stars:
   1. Star colours: Yellow, Red, Orange, White, Blue
   2. Spectral classes: M, G, A, K, B, O, F

|  |
| --- |
| 1. Blue, White, Yellow, Orange, Red 2. O B A F G K M |

### ***Question 4 - Hertzsprung-Russell Diagrams (NSW Syllabus only)***



HR Diagram from: <http://www.atnf.csiro.au/outreach/education/senior/cosmicengine/stars_hrdiagram.html>

Answer the following questions using the Hertzsprung-Russell Diagram provided above.

1. Indicate the regions of:
   1. hottest stars
   2. coolest stars
   3. biggest stars
   4. smallest stars
   5. brightest stars
   6. least bright stars

|  |
| --- |
| https://docs.google.com/drawings/d/s7a3cOxa0znTP4MoC-xmdvQ/image?w=489&h=363&rev=1&ac=1 |

1. Using the HR diagram, which letters (A, B, C or D) represent the region of:
   1. main sequence stars
   2. white dwarfs
   3. Giants
   4. Supergiants

|  |
| --- |
| * 1. A   2. D   3. B   4. C |

1. On the HR diagram, Label the evolutionary track (evolution path) for an average mass star (1 solar mass) using a pen of a different colour.

|  |
| --- |
| Typical evolution path of a 1 M☉ star:  https://docs.google.com/drawings/d/s_2YuRR_E_y4ZgvMFRota1w/image?w=481&h=359&rev=1&ac=1 |

## **Online Interactives**

### ***Interactive 1 - Stellar Evolution***

|  |  |
| --- | --- |
|  | Chandra X-Ray Observatory, NASA, United States  <http://chandra.harvard.edu/edu/formal/stellar_ev/stellar_ev_flash.html>  *This interactive shows the various stellar evolutions of stars based on their masses. It outlines what is occurring at each stage with a real example for each stage collected by the Chandra X-Ray Observatory.* |

**Instructions**:

* Select “**Continue**” and to get to the stellar evolution chart displaying images of various stages a star could reach during its lifetime.
* Hover the mouse over each stage to read its name. Click one of the stages to learn about it in detail.
* Select “**Play**” on the image to see an animation of the evolutionary process.
* Hover the mouse over “**Comparison**” to see a real example of the selected stage from the Chandra X-Ray Observatory.
* Select “**Back**” or “**Next**” to move back and forth between the stages of that particular stellar evolution.
* Select “**Home**” to return to the stellar evolution chart.
* Select “**Print PDF**” to download a PDF version of this interactive (this can take some time).

### ***Interactive 2 - Interactive H-R Diagram***

|  |  |
| --- | --- |
|  | Edward Gomez and Jon Yardley, Las Cumbres Observatory Global Telescope Network (LCOGT)  <https://lcogt.net/files/flash/hr-diagram/main.html>  *This interactive allows students to explore the evolution of a star of 1 solar mass. It displays its evolutionary pathway on the H-R diagram, an image of a real example for each key stage in the evolutionary process, description of stellar properties and what is occurring at each stage.* |

**Instructions**:

* Click “**START**” on the home screen. The top right corner of the interactive notes what stage of the evolution the star is in (e.g. Stellar nursery, Main sequence star, White dwarf), and the bottom left corner indicates the age of the star.
* Read “**What’s going on**” for a brief explanation of the processes occurring at each stage of evolution.
* Click “**Continue**” and watch the animation of the star on the H-R diagram. At each stage the stellar properties are provided in the “**Data**” table.
* Click “**Restart**” to restart the animation.

### ***Interactive 3 - Evolution from Main sequence to giant stage***

|  |  |
| --- | --- |
|  | Rochester Institute of Technology, New York, United States  <http://spiff.rit.edu/classes/phys230/lectures/star_age/evol_hr.swf>  *This interactive shows the evolution of simple non-metal stars evolving from the main sequence to the start of their giant phase. The interactive includes exercises for students, along with stellar properties for each star along its evolution.* |

**Instructions**:

* Select “**Introduction**” tab to learn about the history of the H-R diagram.
* Select **“How to”** to learn how to operate the interactive.
* Select “**Interactive**” to start.
* Move the “**Mass**” slider bar to select the desired mass of the star.
* Check the “**Auto**” box in the speed section then click “**Create Star**”. Check   
  “**Show Regions**” to display regions where the main sequence stars and the giants are located.
* Once the animation is complete, click on any part of the star’s evolutionary path on the H-R diagram to see the size, colour and the stellar properties of the star at that particular point in its life.
* Run the simulation for different masses of the star for differences and/or similarities.
* Select “**Exercises**” to access questions associated with this interactive. The answers to these questions can be accessed by selecting the “**Solutions**” tab.

### ***Interactive 4 - Hertzsprung-Russell Diagram Explorer***

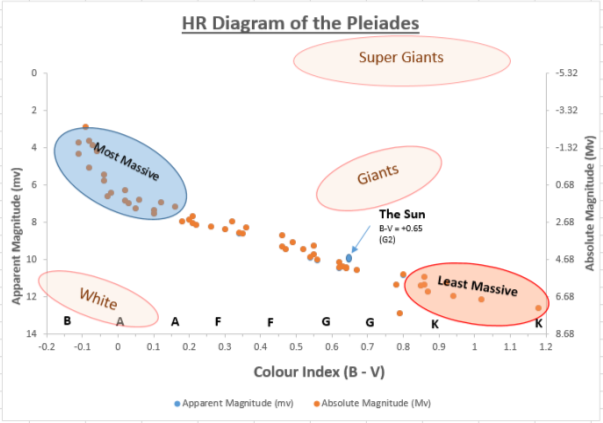
|  |  |
| --- | --- |
|  | Astronomy Education at the University of Nebraska-Lincoln  <http://astro.unl.edu/naap/hr/animations/hr.html>  *This interactive allows users to compare stars on the HR diagram to the Sun by either selecting a point on the HR diagram, or by designating/assigning temperature and luminosity values.* |

**Instructions**:

* Click anywhere on the HR diagram on the right to see the temperature and luminosity values for a star in the region that is selected (indicated by a red cross **x**). The radius is calculated using the formula below and a size comparison to the sun is shown above.
* Click the temperature or luminosity slider bar, or manually input these values into the text box to change the values. The new star will be indicated by a red cross **x** on the HR diagram and size comparison will be shown.
* The HR diagram can be adjusted by selecting various settings under the “**Options**” located directly below the diagram.
* Specific groups of stars can be plotted onto the HR diagram by selecting the desired group under “**Plotted Stars**”.
* Select the “**reset**” button above the HR diagram to reset the interactive, or “**help**” to read about the interactive.

## **Practical Activities**

### ***Activity 1 - Creating a HR Diagram of the Pleiades***

*This investigation uses data from the Pleiades cluster to create a Hertzsprung-Russell diagram in Microsoft Excel.*

**Method**:

Follow the method given in the link below.

**Source**:

*Australia Telescope Outreach and Education, CSIRO, Australia* <http://www.atnf.csiro.au/outreach/education/senior/astrophysics/stellarevolution_pleiadesact.html>

*Note:*

* *This activity makes reference to colour index (B-V) which is not in the Cosmic Engine New South Wales Physics Syllabus*
* *To plot absolute magnitude on the same graph you need to add a* ***secondary axis*** *and adjust the max/min values of the secondary axis.*

### 

# **Useful Links**

*Below is a list of further links to supporting materials that may assist in teaching this topic.*

* <https://www.youtube.com/watch?v=b22HKFMIfWo>

*PBS CrashCourse - The Sun: Crash Course Astronomy #10*

* <https://www.youtube.com/watch?v=DEw6X2BhIy8>

*BBC 2 - Wonders of the Universe: Star Death and the Creation of Elements (Brian Cox)*

* <http://goo.gl/2KU8DK>

*Space.com - Your Universe: The Life And Death Of Stellar Fusion Engines*

* <https://www.youtube.com/watch?v=EIgr3KyJ9S4>

*History - The Universe: Life & Death of a Star (S01 E10)*

* <https://www.youtube.com/watch?v=Dq7fmftneaY>

*Discovery Channel - How the Universe Works: Extreme Stars (S01 E04)*

* [http://ciera.northwestern.edu/Research/stellar\_evolution/stellar\_evolution.php#](http://ciera.northwestern.edu/Research/stellar_evolution/stellar_evolution.php)

*Ciera, Northwestern University - stellar evolution animations. Animations can be downloaded*

* <https://www.youtube.com/watch?v=uRGZFJ98hlg>

*John Fleurant - Star Spectral Types and Star Sizes*

* <https://www.youtube.com/watch?v=2uxfGNxNMg8>

*MrNinjaMittens - Star Types & Classifications*

* <http://astro.unl.edu/classaction/browser.html>

*Astronomy Education Group, University of Nebraska-Lincoln - Class Action. An interactive tool containing information, quizzes, animations and images.*

* <http://www.atnf.csiro.au/outreach//education/senior/cosmicengine/sun_questions.html>

*CSIRO - Questions on Sun - Earth Interactions*

* <http://www.atnf.csiro.au/outreach/education/senior/cosmicengine/cosmology_questions.html>

*CSIRO - Questions on Cosmology & Big Bang*

* <http://skyserver.sdss.org/dr1/en/proj/advanced/hr/intro.asp>

*SDSS - Making a HR diagram*

* <http://www3.gettysburg.edu/~marschal/clea/CLEAsoft_overview.html>

*Department of Physics, Gettysburg College - CLEA. Old but excellent interactive applications that can be downloaded to Windows 7 & 8 machines.*

* <http://www.learner.org/teacherslab/science/light/color/spectra/>

*Annenberg Learner - stellar spectra and classification*

* <https://in-the-sky.org/ngc3d.php>

*Dominic Ford - 3D interactive map of the universe*

* <http://mrges.com/labs/assets/Star%20Evolution.pdf>

*Mr Goldstein’s Earth Science - Stellar Evolution Lab: The life-cycle of a star*

* <http://chandra.harvard.edu/resources/handouts/constellations/activities/stellar_evol.pdf>

*Chandra X-Ray Observatory, NASA - From Earth to the Universe Activity: Stellar Evolution Scavenger Hunt*