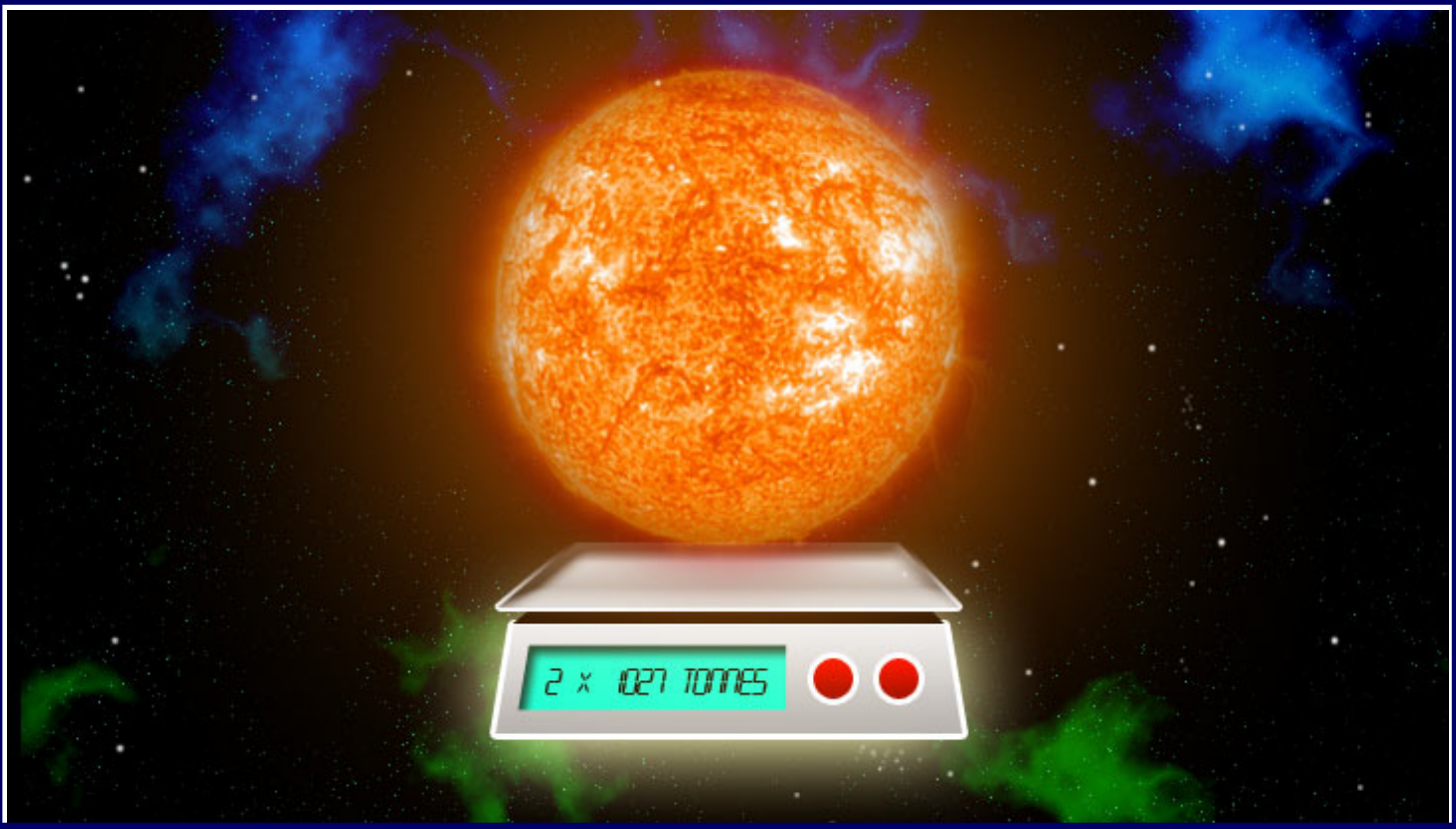

How do you Weigh a Star?

The **Scholars** Programme

[Key Stage 5 Programme - Autumn 2016]

Pupil Name _____

The Scholars Programme – [Autumn 2015] – Pupil Feedback Report

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at first year undergraduate level
2:1	60-69	Performing to a good standard at first year undergraduate level
2:2	50-59	Performing to an excellent standard at A-level
3rd	40-49	Performing to a good standard at A-level
Workings towards a pass	0-39	Workings towards a pass
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Name of Tutor			
Title of Assignment			
Name of Pupil			
Name of School			
ORIGINAL MARK / 100		**FINAL MARK / 100**	
DEDUCTED MARKS		**FINAL GRADE**	

If marks have been deducted (e.g. late submission, plagiarism) the tutor should give an explanation in this section:

Learning Feedback Comment 1 - Enter *Key Learning Priority Here*	
What you did in relation to this Key Learning Priority	**How you could improve in the future**
Learning Feedback Comment 2 – *Enter Key Learning Priority Here*	
What you did in relation to this Key Learning Priority	**How you could improve in the future**
Learning Feedback Comment 3 – *Enter Key Learning Priority Here*	
What you did in relation to this Key Learning Priority	**How you could improve in the future**
Resilience Comment	
How you showed learning resilience during the course	**How you could build learning resilience in the future**

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Course Rationale

A star's mass is its most significant property. The mass determines the star's other characteristics such as temperature and brightness. It affects how the star will live its life, what impact it will have on its surroundings and the likelihood of planets forming around it. But how do we measure the mass of a star that is billions of miles away? Does this mass change during the lifetime of the star? And is there a limit to how massive stars can get?

Astrophysicists are forced to think of indirect methods to estimate the mass of objects in the Universe. This course will explore the different techniques that they apply. You will need to think like an astrophysicist, applying numerical calculations, scientific concepts and reasoning to your work. Armed with this, and you will be able to carry out research of your own.

Mark Scheme

Key Skill	1st	2.2
Contextualising Presentation of the topic relative to current work in the area. The significance or worthiness of context being explored.	• Current theories or work in the field are outlined making it clear how the assignment material fits into that context. • Explains clearly why the topic is significant and worthy of discussion or investigation. • Context and significance are explored through comprehensive use of current literature.	• Little reference is made to current theories or work in the field that is beyond what has been discussed throughout the course. It is not clear how the assignment material fits into that context. • Attempts but no clear discussion of why the topic is significant and worthy of discussion. • 'Worthiness of investigation' is only covered from a personal motivation point of view.
Logical Reasoning Coherence and clarity of the logical argument.	• Correct methods are executed for derivations, proofs and extended calculations. These are structured, easy to follow and justified. • There is a clear and structured flow of argument when using logical reasoning. • Arguments and reasoning are expressed with clarity towards an end goal or conclusion.	• Derivations, proofs and extended calculations are attempted although some mistakes may be made. The structure is less easy to follow and unnecessary steps may be made. • The structure of arguments may be unclear in places and difficult to follow. • There is a lack of clarity within arguments and reasoning towards the end goal or conclusion.
Critical thinking and evaluation Validity, reliability and credibility of scientific information and conclusions. Generalisation of argument and suggested improvements including ideas for future work.	**Critical Thinking** • Validity of all data is discussed without the need to be prompted to do so • Critical evaluation of the data is systematic and logical – the limitations of the data are explained clearly and most to all of the main points are considered. • Evaluation is consistent across the different data sets being used. • Not *too* critical of the data they are using (e.g. does not refuse to use it because of a minor flaw in the experimental design). • Appropriate suggestions are made for improvement of the experimental design to increase the reliability of the results. • **Evaluation** • Shows a good understanding of what a hypothesis is and how the data presented supports or refutes it. • Generalisation of the argument (if appropriate) has been performed correctly and succinctly with no superfluous steps or irrelevant reasoning. • Conclusions are well-reasoned and clearly supported by the data, but the limitations of the data are also recognised and discussed. • Data from a range of sources is used for comparison with their results and any differences are discussed.	**Critical Thinking** • Validity of some of the data used is discussed. • Critical evaluation of the data covers some of the main points but at times the reasoning is not clear or lacks a logical progression. • Can be inconsistent in the evaluation of different datasets (e.g. where two data sets were collected using the same methodology, the reliability of only one set is discussed. • Can be too critical of the data (e.g. refuse to use it because of a minor flaw in the experimental design). • Suggestions are made for improvement of the experimental design, but these can be unrealistic or would not have the desired effect. • **Evaluation** • Some understanding of what a hypothesis is, but this might be confused with a theory. • Discusses how the data presented supports the hypothesis, but some steps in the reasoning may be missing and/or irrelevant points have been included. • Generalisation of the argument has been attempted but not accurately. • Results may not been compared to literature, if so this comparison may be incomplete.
Numerical Analysis Use and interpretation of calculations or data	• All calculations for clearly structured, clear to follow and correct. • Confidently uses a wide range of formulae simultaneously, can choose the correct formulae and follows a structured method to solve problems • Confident to interpret unseen numerical results to inform a physical meaning	• Calculations structures are not always easily followed and contain mistakes in places. • Uses formulae with success although at times it is unclear why particular formulae have been chosen. • Uses simple formulae with confidence, at times struggles with complex methods within calculations • Attempts to infer physics meanings of results

Analysis Use of defined processes relating to data and sources to arrive at a conclusions	• Uses all sources of data and evidence to support a strong conclusion. • A quantitative form of analysis is used to infer a relationship (e.g. Stating proportionality due to doubling of quantities). • Stages of analysis covered in tutorials (numeric or written) are correctly implemented and easy to follow, these are affectively applied to unseen problems. • Has considered the limitations of data/evidence sources where appropriate. Using this to support their conclusion. • The argument towards the conclusion is well developed and logical.	• Uses some but not all sources of data/evidence to support a conclusion. • Uses qualitative analysis effective, quantitative analysis may be incorrect at times. • Stages of analysis covered in tutorials are correctly used; there may be some difficulty in applying these to unknown problems. • There is some consideration into the limitations of the evidence sources. • The argument towards the conclusion is less well developed and difficult to follow.

Glossary of Keywords

Apparent Magnitude (*m*) – the apparent brightness of an object as observed from Earth. It is measured on a scale such that m=1 is 100x brighter than m=6. Therefore, each magnitude is 2.512x brighter than the next. NOTE: Lower magnitudes indicate brighter objects.

Absolute Magnitude (*M*)– the apparent brightness of an object as observed from 10 parsec.

Aperture – the diameter of the primary lens or mirror of a telescope. The aperture determines the resolving power and light-gathering ability of a telescope.

Astronomical Unit (AU) – the average orbital distance between the Earth and Sun. Equivalent to $1.50\text{x}10^{11}$m.

Black Body – an idealised body that is a perfect absorber of radiation. It is also a perfect radiator, and shows a continuous spectrum that depends only on the temperature of the source. The emission from a black body is as a good fit to the emission from a number of astronomical objects such as stars, interstellar dust clouds and the cosmic microwave background.

Dark Matter – a theoretical matter that has no interaction with light or the electromagnetic force. However, its gravitational effects are thought to be observable such as in the rotation curves of galaxies.

Hertzsprung-Russell Diagram (H-R Diagram) – a plot of the luminosity of stars against their surface temperature. Plotting the absolute magnitude of stars against their spectral class can make an equivalent diagram. The H-R diagram can combine observational and theoretical stellar data, and demonstrate the evolution of any star.

Initial Mass Function (IMF) – the distribution of stellar masses at birth. Observations show that there are more low mass stars than high mass stars within a given region. The IMF draws a relation between these numbers.

Luminosity (*L*) – the energy emitted by a star per second across all wavelengths. $L = 4\pi R^2 \sigma T_{\text{eff}}^4$, where R is the radius of the star, T_{eff} is the effective temperature of the star and σ=5.67×10^{-8} W m^{-2} K^{-4} is the Stefan-Boltzmann constant.

Main Sequence – the region of the Hertzsprung-Russell Diagram that runs diagonally from high temperature, high luminosity to low temperature, low luminosity. Stars spend most of their lifetime on the main sequence where they fuse hydrogen into helium in their core.

Mass-loss Rate – the rate at which a star loses mass. Mass loss will mainly occur through stellar winds, but more massive stars could suffer from eruptions and lose entire envelopes.

Nebula (pl. nebulae) – a cloud of interstellar gas and dust.

Parsec (pc) – the distance of an object that has a parallax angle of 1 arcsecond. Equivalent to 3.09×10^{16}m

Photometry – the measurement of the brightness of objects. The data obtained is able to provide information on astronomical objects such as temperatures, distances and ages.

Spectral Classification – a system for classifying stars according to the appearance of their spectra. It is predominantly based on the stellar temperature, luminosity and chemical composition.

Spectroscopy – the method of obtaining a spectrum of an object. Spectroscopy is performed across a range of wavelengths and provides the fingerprints for astronomical objects.

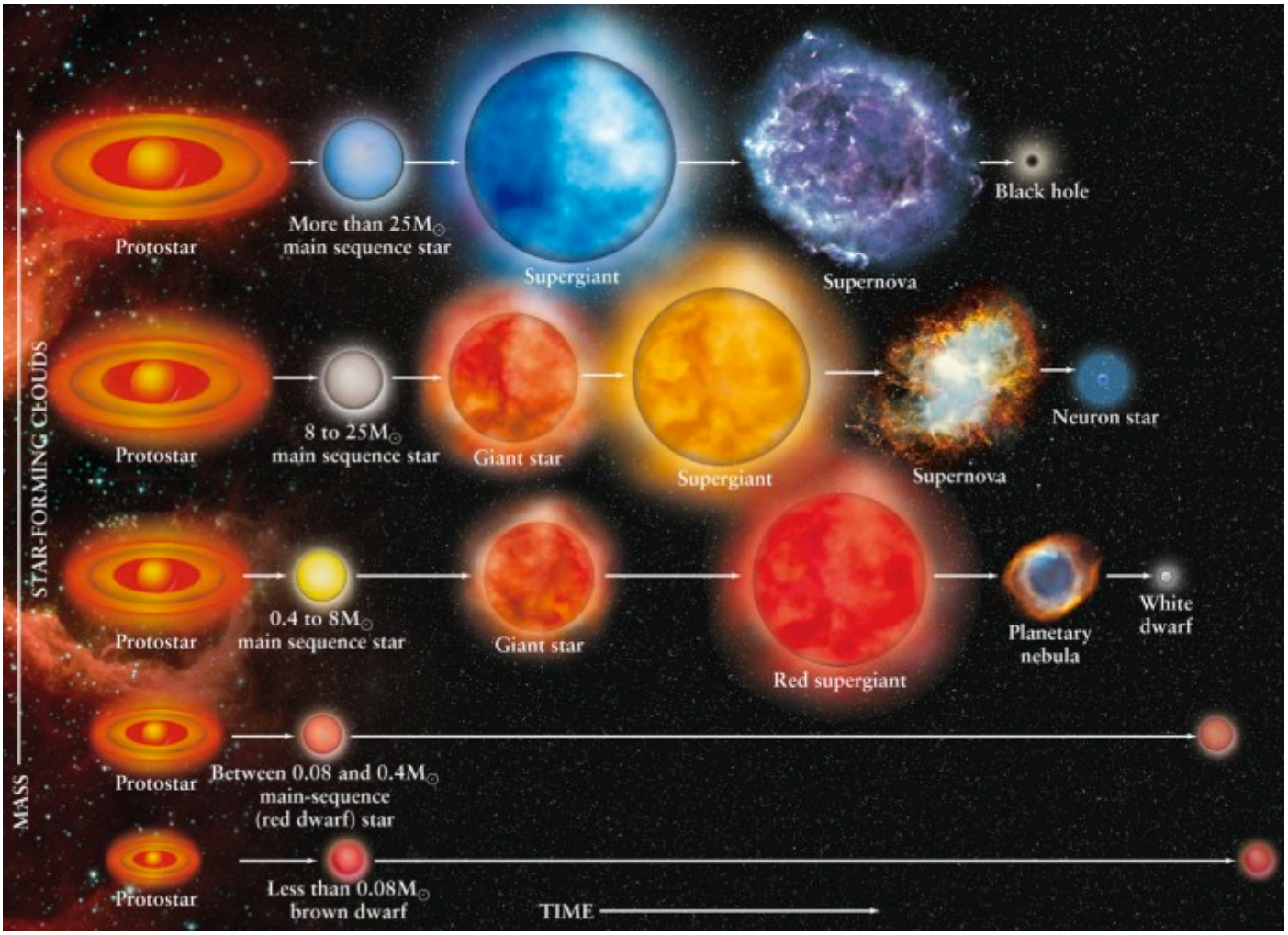
Spectrum (pl. spectra) – the distribution of electromagnetic radiation with respect to wavelength.

Stellar Feedback – over the course of its lifetime, a star will influence its surroundings in a number of ways. In particular, it will have an impact on the radiation, the mechanics and the chemistry of a region.

Stellar Wind – along with radiation, stars also emit a stream of charged particles that make up their stellar wind.

Supernova (pl. supernovae) – the explosion of a star that can release energies that outshine entire galaxies. Supernovae are thought to occur via two main routes. A core collapse supernova occurs when a massive star exhausts its nuclear fuel supply. Alternatively, a white dwarf star in a close binary system can accumulate mass from its companion. Runaway nuclear reactions can follow, resulting in a supernova.

Tutorial 1 – Why do we care about the mass of a star?



What is the Purpose of Tutorial 1?

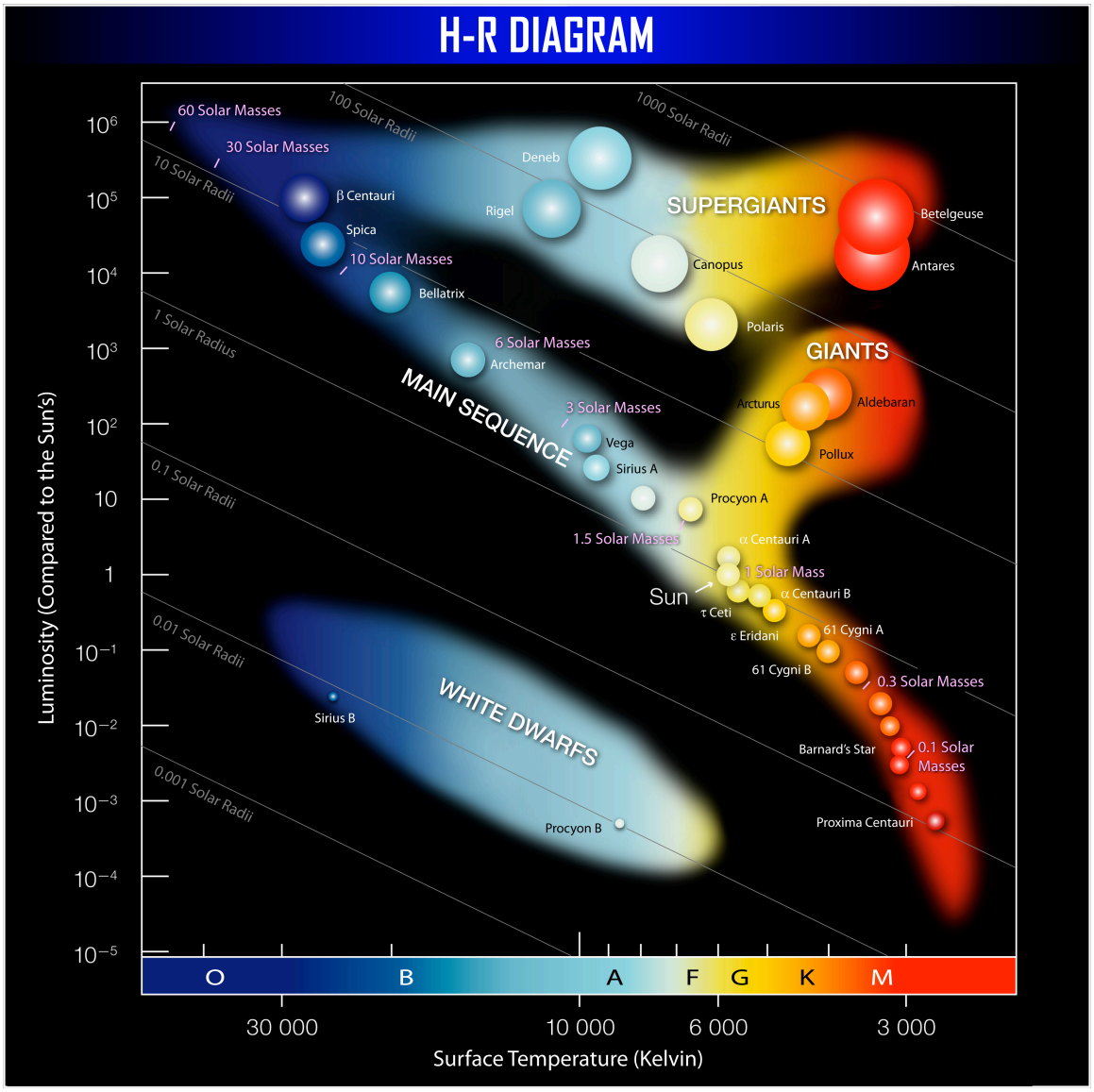
- To provide an introduction to the course, its content and objectives.
- To define what a star is and the role stars play in the Universe.
- To understand the importance of stellar mass and its affect on other stellar properties.
- To understand why the determination of stellar mass is important to our understanding of the Universe.

What is a star?

Why is the Sun a star, yet Jupiter is a planet?

Stellar mass
What are the variations in stellar mass?

Stellar properties and evolution
What properties do we observe in stars? How might these be affected by the mass of the star?



Stellar feedback
In what ways do stars affect their environments?

Radiative Feedback

Mechanical Feedback

Chemical Feedback

Stars in the Universe
"The total number of stars in the Universe is larger than all the grains of sand on all the beaches of the planet Earth"
- Carl Sagan

"Put three grains of sand inside a vast cathedral, and the cathedral will be more closely packed with sand than space is with stars."
- Sir James Jeans

Further reading and resources:

http://astronomy.swin.edu.au/cosmos/S/stellar+evolution

http://www.stellar-database.com/

http://www.astro.washington.edu/users/anamunn/Astro101/LecturesBennett/EvolutionStars/evolutionstars.html#backism

http://htwins.net/scale2/

Tutorial 1 – Baseline Test

The homework assignment for the first tutorial is a baseline test to see your initial level of attainment in this subject area. The assignment will test for some or all of the subject specific skills that are required later in the final assignment. However, it is shorter than the final assignment and will be an introduction to the subject as well as a challenge!

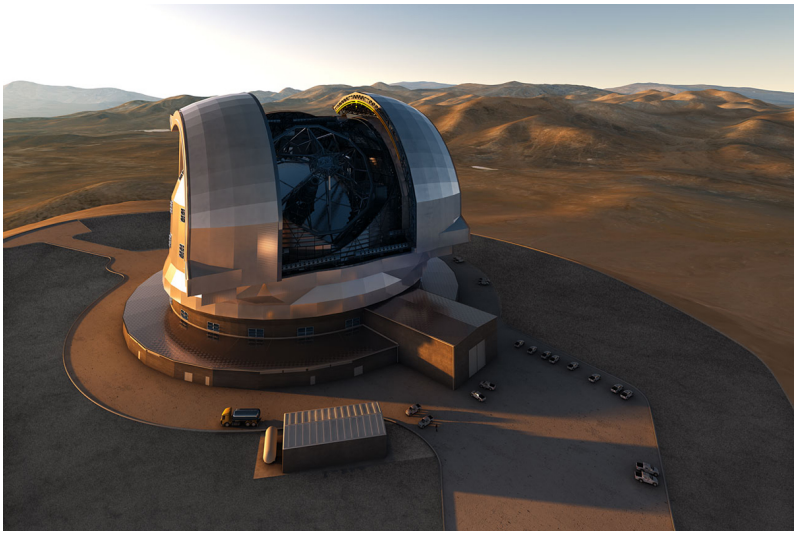
Do not worry too much about doing 'well' or 'badly' on the baseline test, it takes into account the fact that you may not be familiar with the subject area. It is designed to help you and your tutor identify where you are at the start of the programme and to help you measure your progress along the way.

Explain the evolutionary processes that take place during the life of a:
i) low-mass ($1M_\odot$) star
ii) high-mass ($30M_\odot$) star

You should consider the different evolutionary phases and explain how different properties of the star will vary as a result of the stellar mass, as well as over their lifetimes. Evaluate the impact each star will have on its surroundings.

You may use a H-R diagram to illustrate this evolutionary process if you wish.

Tutorial 2 – How do we obtain data to determine the mass of a star?



What is the Purpose of Tutorial 2?

- To differentiate between the theoretical and empirical approaches in research.
- To understand the observation methods of photometry and spectroscopy and their applications.
- To recognise the benefits of observing at different wavelengths and locations.
- To understand what difficulties are faced when attempting to acquire astronomical data, and what steps can be taken to overcome them.

Theoretical vs Empirical?

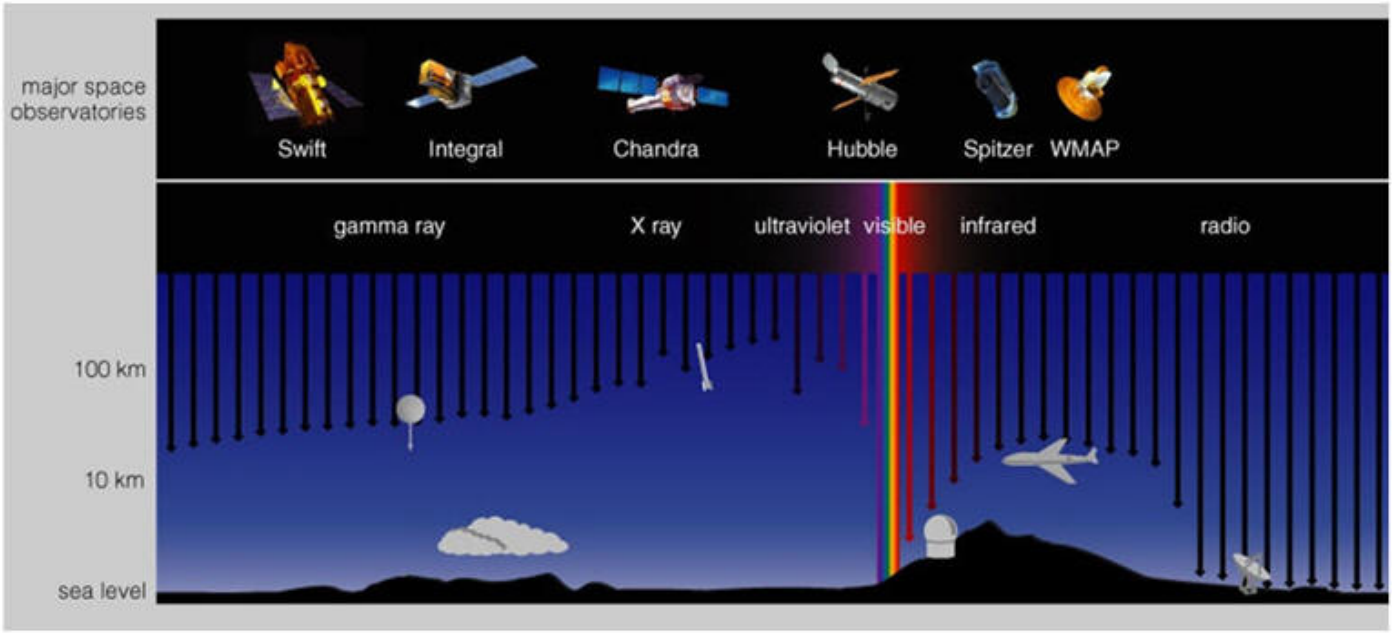
What are the differences between these two research approaches and in what ways do they contribute to a research area? Think of an example, not necessarily related to astronomy.

Photometry and Spectroscopy

What are the basic principles behind the methods of photometry and spectroscopy? How do these approaches vary. What information can they bring us about stars and other astronomical bodies?
How are they used in other areas of science?

Which wavelength?

Revise the different wavelengths of the electromagnetic spectrum. What are the properties of the different wavelengths and what benefits do they offer when observing different targets?



What telescope?

What type of telescope should be used? Earth-based or space based?

Background noise and uncertainties
What factors might lead to uncertainties or spurious data? Are the factors terrestrial or astronomical? Can anything be done to counteract them?

Further reading and resources:

http://www.eso.org/public/videos/archive/category/featuremovies/

http://coolcosmos.ipac.caltech.edu/cosmic_classroom/multiwavelength_astronomy/multiwavelength_astronomy/index.html

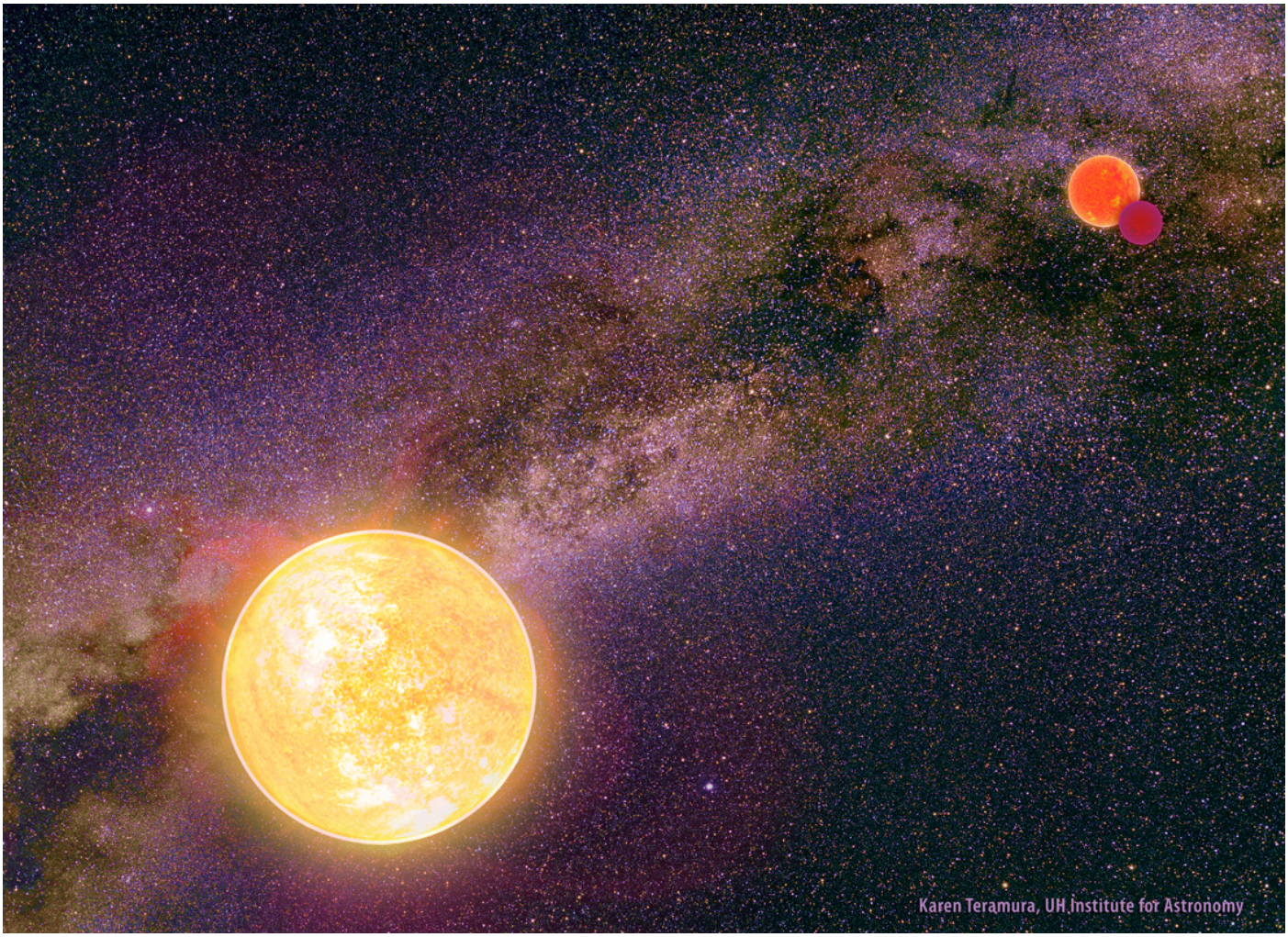
http://www.chromoscope.net/

Tutorial 2 – Assignment

The James Webb Space Telescope (JWST) and European Extremely Large Telescope (E-ELT) are two of the most state-of the-art telescopes that are currently under construction. Evaluate the importance of their roles in the future of observational astronomy. Consider the following:

- The targets that they will observe (stellar and others)
- The wavelengths that they will observe at
- The apertures of the telescopes and the instruments they will have
- The observing locations of the telescopes

Tutorial 3 – What direct analysis can we carry out on our data to determine the mass of a star?



What is the Purpose of Tutorial 3?

- To understand the different laws of motion and how they can be applied to astronomical scenarios.
- To investigate the *direct* methods which are used to determine stellar mass.
- To appreciate the benefits and limitations of this method of analysis.

So how do you measure the mass of star? Let's start with a star a bit closer to home, the Sun!

After hours of observing the motions of the planets, Johannes Kepler was able to publish his three laws of planetary motion:

1. The Law of Orbits: All planets move in elliptical orbits, with the Sun at one focus.
2. The Law of Areas: A line that connects a planet to the Sun sweeps out equal areas in equal times.
3. The Law of Periods: The square of the period of any planet is proportional to the cube of the semi-major axis of its orbit.

$$T^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3$$

Isaac Newton linked these laws to his theory of gravity.

$$F = G\left(\frac{m_1 m_2}{R^2}\right)$$

This applies to all bodies, even those as massive as the planets and Sun in our solar system.

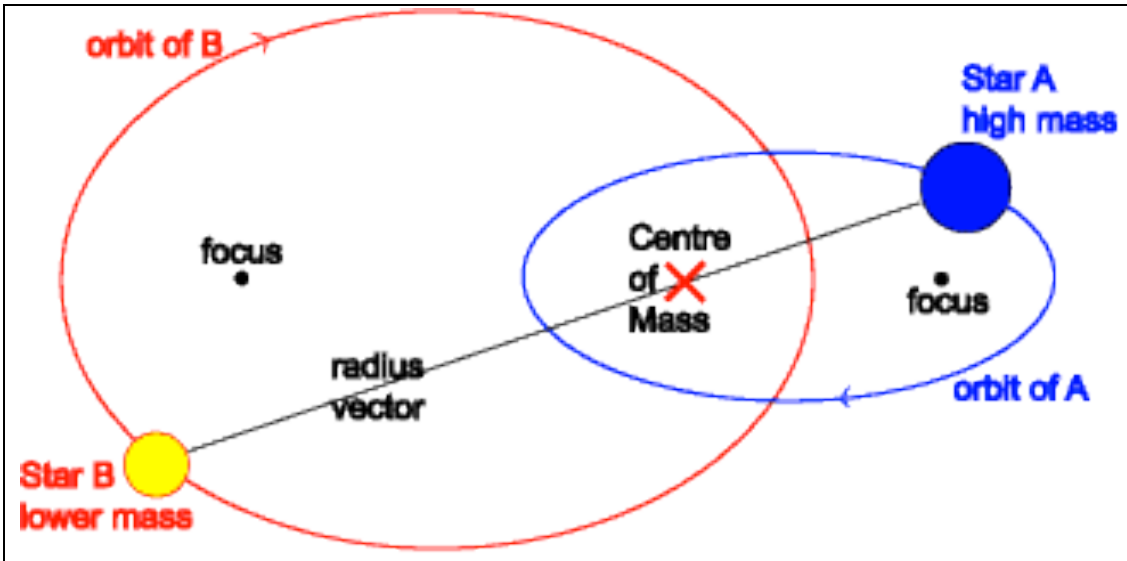
In cases where an object is travelling along a curved path, like a planet orbiting the Sun, it is displaying a **centripetal force** that is always directed towards the centre of the orbit.

$$F_{centripetal} = m\frac{v^2}{r}$$

We can set the centripetal force and the gravitational force equal to one another.

Now let's use all of these tools to calculate the mass of the Sun. What other parameters will be needed?

Now let's apply this method to determine the mass of a distant star. What objects could replace the planets and Sun in our solar system example?



Orbits of Stars in a Binary System

What type of binary star systems do we observe? How do they help us determine the necessary parameters we need to calculate our masses?

What difficulties and limitations are there when analysing binary star systems?

Further reading and resources:

http://hyperphysics.phy-astr.gsu.edu/hbase/orbv.html

http://www.atnf.csiro.au/outreach//education/senior/astrophysics/binary_types.html

http://www.astro.caltech.edu/~george/ay20/Ay20-Lec4x.pdf

Tutorial 3 – Assignment

Sirius is a known binary system with the following parameters:

- Orbital period = 50.1 years
- Semi-major axis of system = 7.5 arcseconds
- Distance to system = 2.7 pc

1. Calculate the total mass of the combined system in solar masses.

2. If the two stars, Sirius A and Sirius B, have an average distance ratio from the centre of mass of r_A/r_B= 0.45, find their individual masses in solar masses.

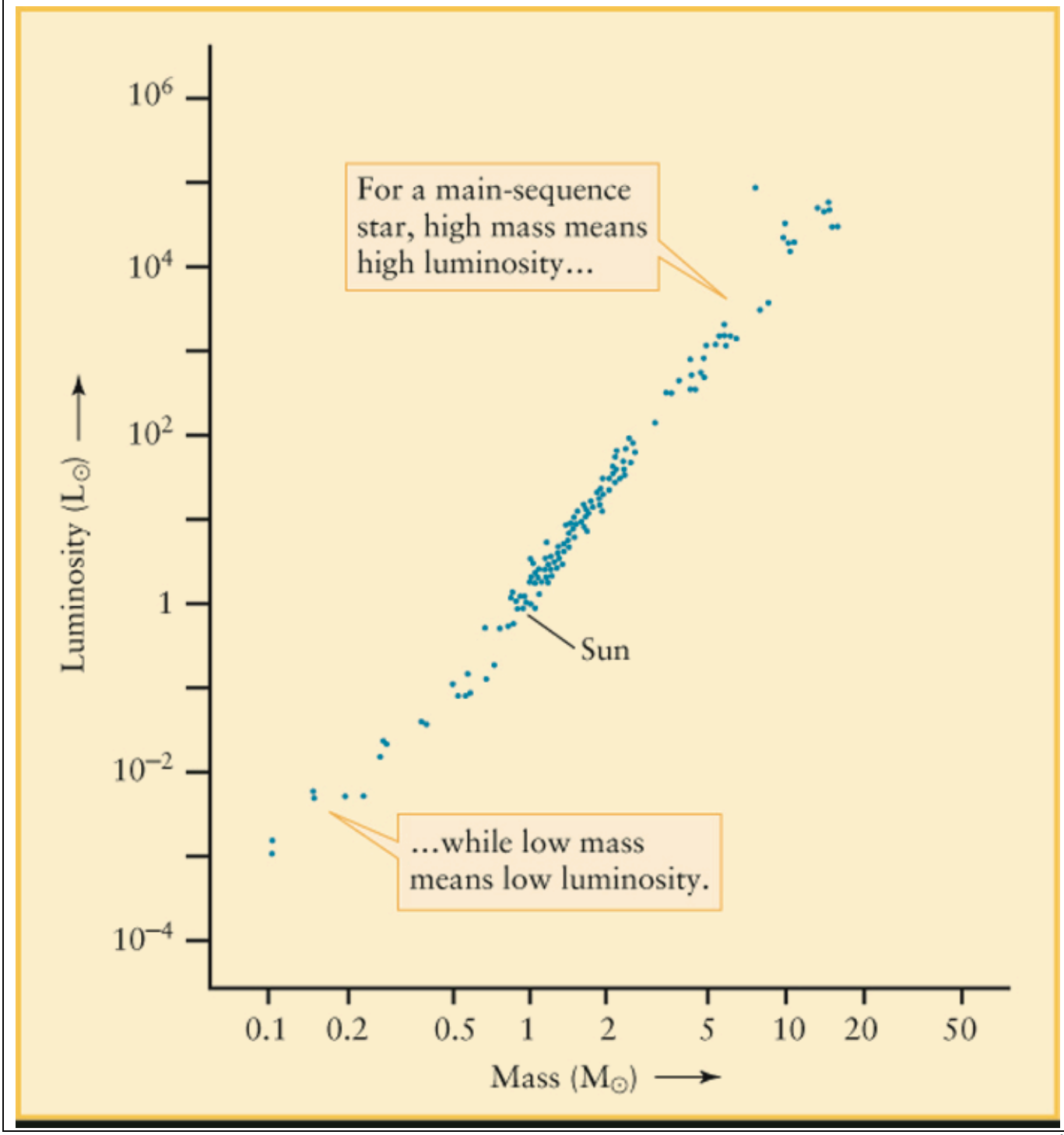
Tutorial 4 – What indirect analysis can we carry out on our data to determine the mass of a star?

What is the Purpose of Tutorial 4?

- To investigate the *indirect* methods which are used to determine stellar mass.
- To appreciate the benefits and limitations of this method of analysis.
- To consider what new approaches could be used to determine stellar mass in the future.

The Mass-Luminosity relation

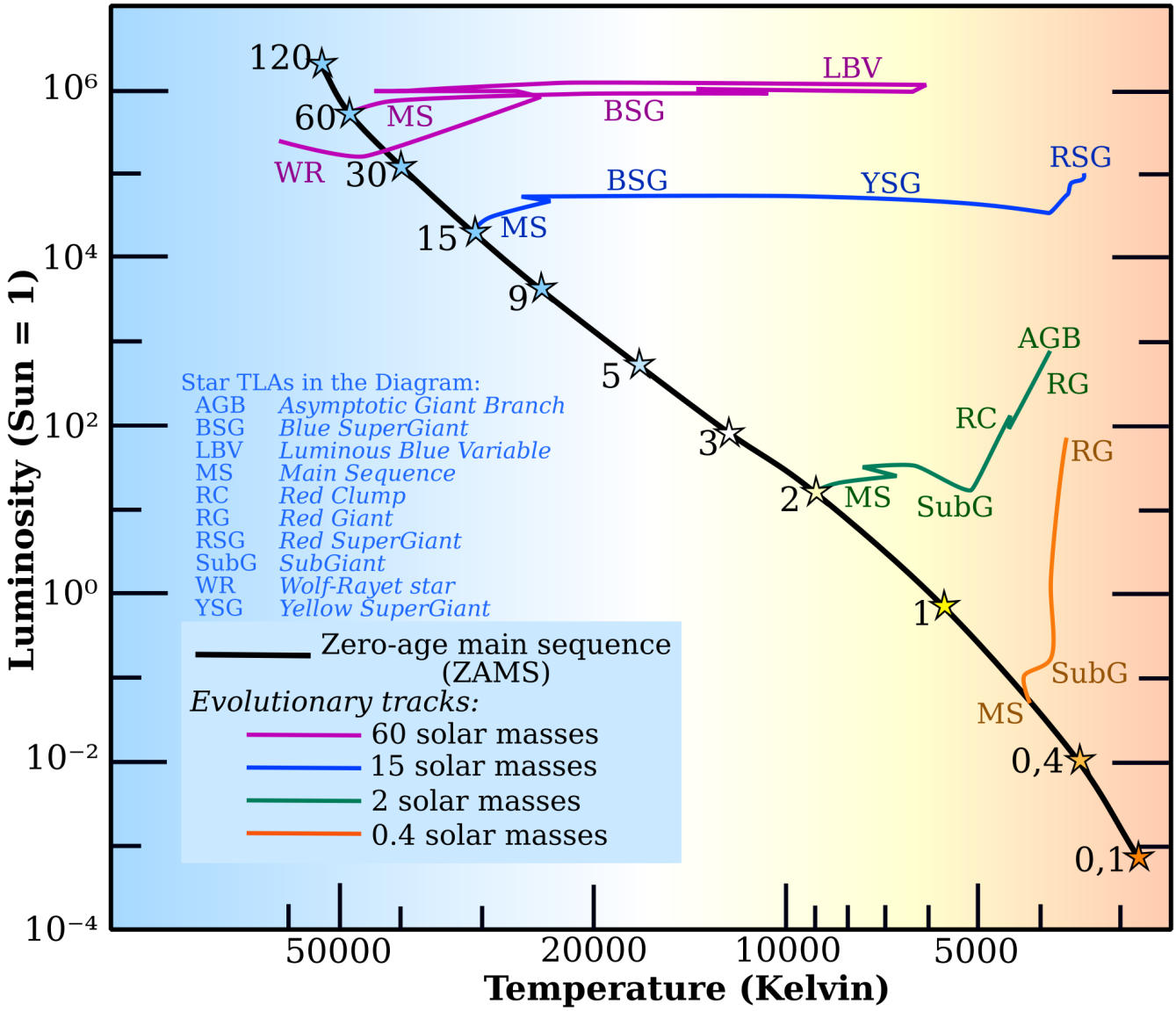
Accurate stellar masses have been determined by using the orbital motions of stars in binary systems. Relations have since been drawn between these masses and other properties of the star. One of the most important relations was found between the mass and luminosity of stars on the main sequence.



Evolutionary mass

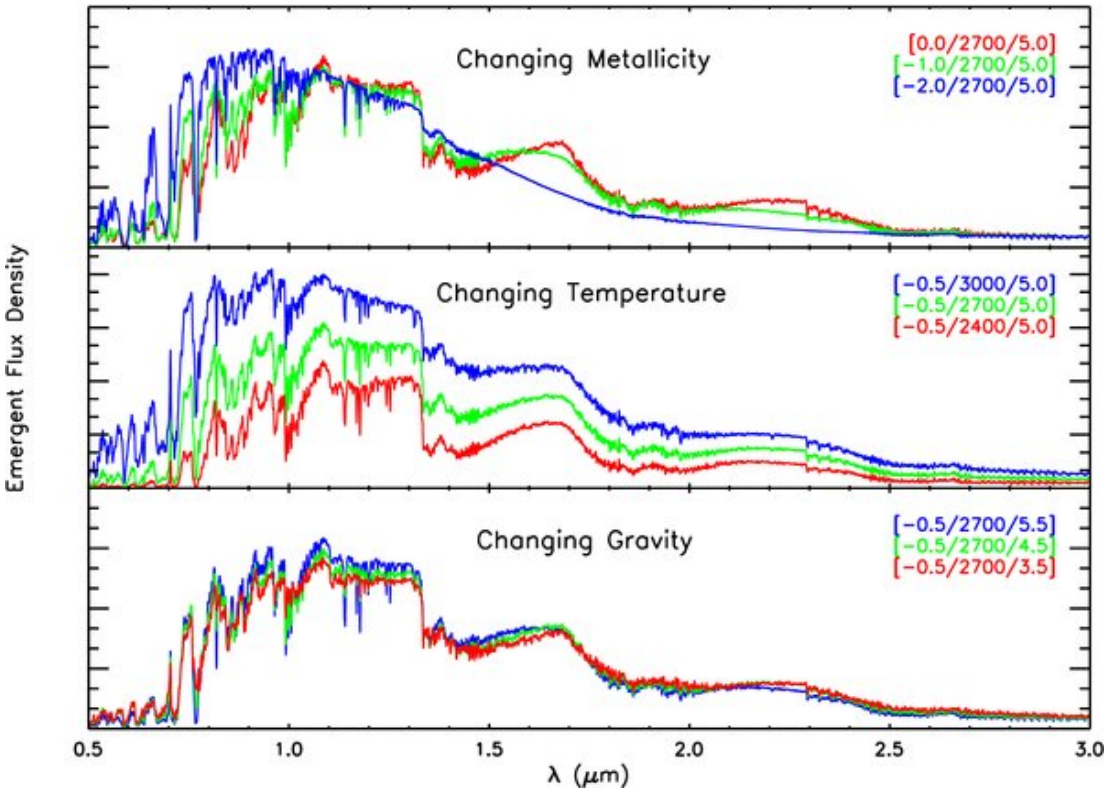
Stars of different masses will evolve off the main sequence and trace different evolutionary tracks across the H-R Diagram. How quickly a star evolves and the path it takes is greatly influenced by its mass. Many stellar parameters will change during the evolution.

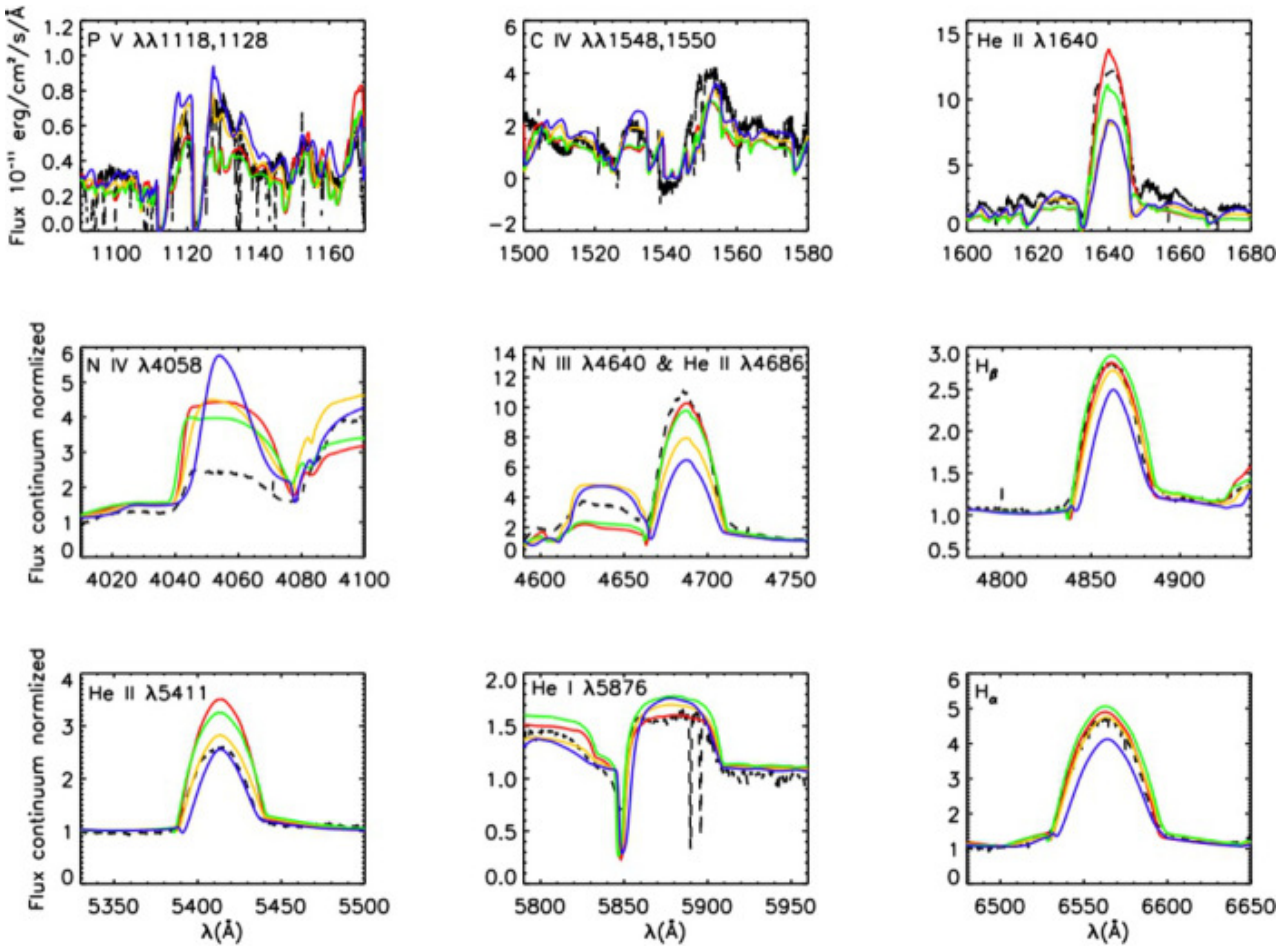
Why are the evolutionary paths different? Are there any areas of the H-R Diagram that are "forbidden"?



Spectroscopic mass

The spectrum of a star provides a fingerprint of the stellar properties. Models are made of the stellar atmospheres that attempt to match the observed spectrum by carefully adjusting stellar parameters. A range of information about the star can then be estimated.





Mass discrepancy?
How consistent are the two methods, and does this change depending on the stars being studied? How can we test these models?

Further reading and resources:

http://www.astronomynotes.com/starsun/s8.htm

http://www.atnf.csiro.au/outreach//education/senior/astrophysics/stellarevolution_mainsequence.html

http://www.astro.caltech.edu/~george/ay20/eaa-stellarmasses.pdf

Tutorial 4 – Assignment

Using the data provided, plot a graph of stellar luminosity against stellar mass. What value do you arrive at for the mass-luminosity relation? Do you think that the value is constant for all masses or does it vary? How could you go about improving your value?

You should plot your graph on logarithmic axes as shown in the example on page 20. Consider the uncertainties on your value.

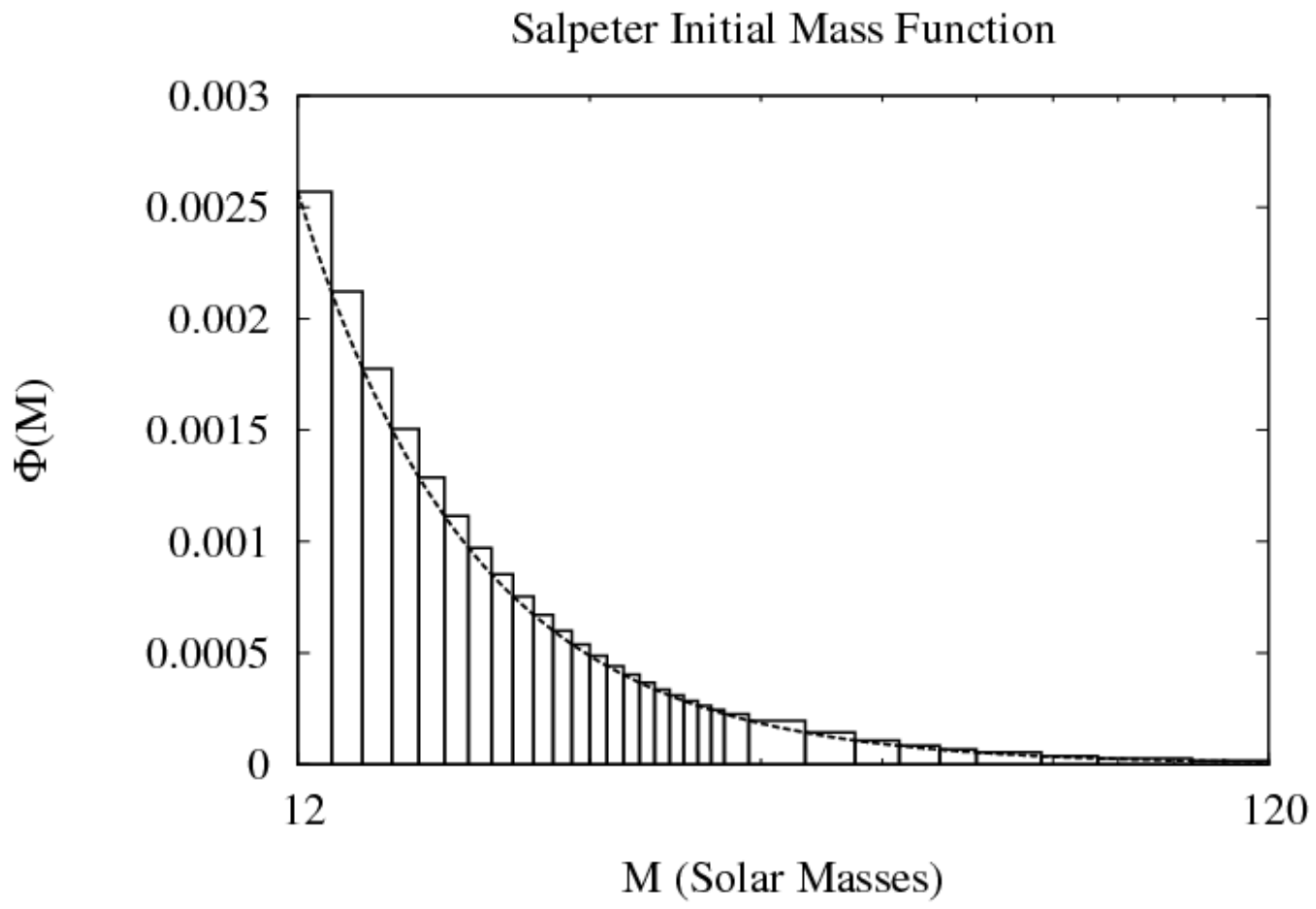
Tutorial 5 – What do our findings tell us about the stellar mass distribution and how do they support our understanding of the Universe as a whole?

What is the Purpose of Tutorial 5?

- What mass distribution do we observe for stars in the Galaxy?
- Is there an upper or lower mass limit for stars?
- What can we learn from stellar and cluster dynamics?
- How does the mass of stars compare to the rest of the mass in the Universe?

The Initial Mass Function

When a cluster of stars forms, we can count up the number stars that fall into particular mass ranges – the initial mass function. How does this value change for different clusters across the Galaxy? Does it change over time?



Upper and lower mass limits
Does the IMF set an upper stellar mass at a particular limit? Is there a stellar mass limit if we use the Eddington Limit?

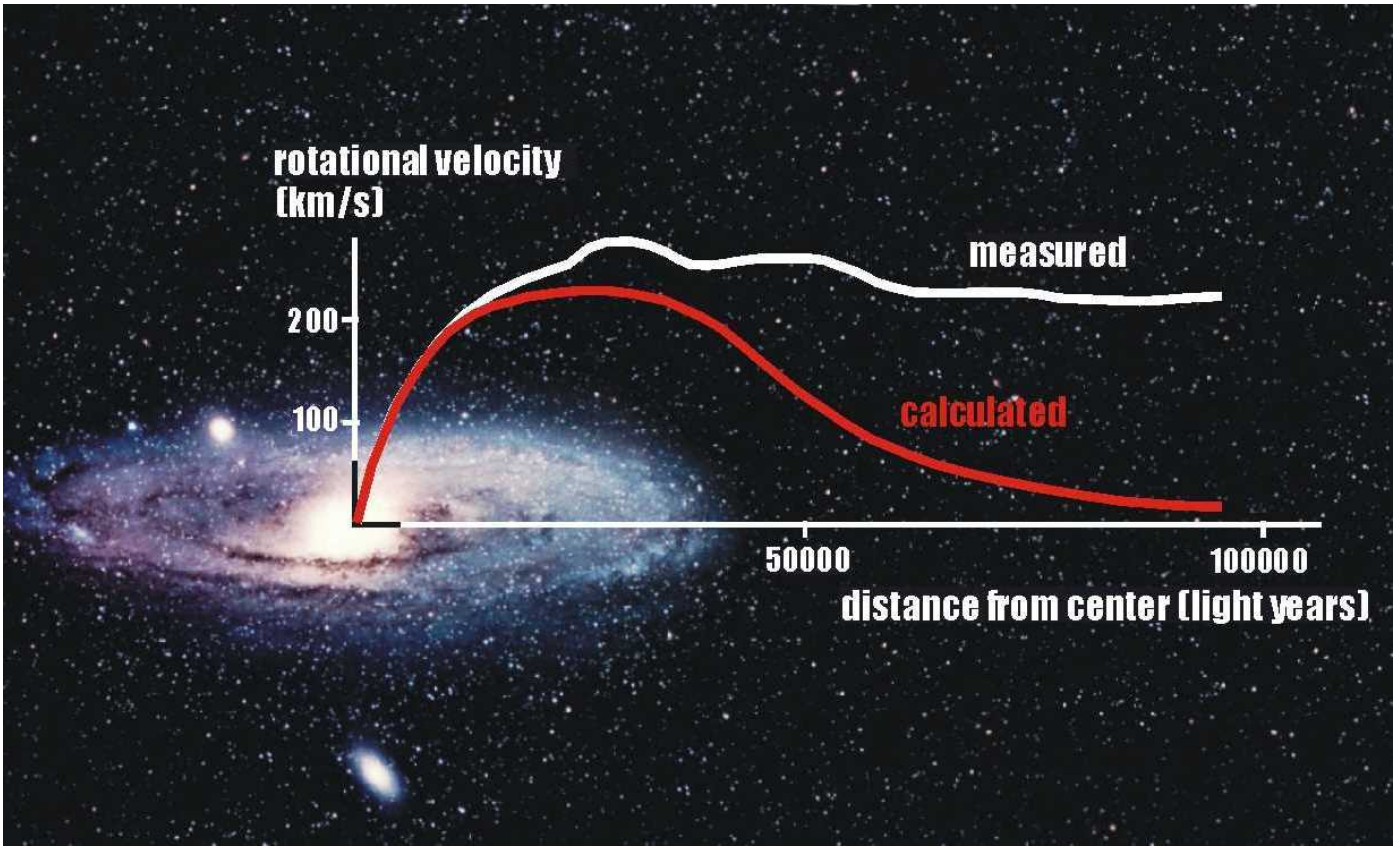
How about the lower mass limit? At what point does a star become a Brown Dwarf?

Star Formation
How is the mass distribution of stars that we observe connected to the formation processes of different stars? Do all stars form in the same way?

Stellar clusters and stellar dynamics
How are stars distributed within their clusters? How are stellar clusters distributed within the Galaxy?

We have used the dynamics of stars in binary systems, but where else are stars moving?

The Big Picture
How can we use the motions of these stars and clusters to understand the nature of more massive objects in the Universe?



Further reading and resources:

http://www.nature.com/nature/journal/v434/n7030/abs/nature03293.html

http://phys.org/news/2014-10-upper-limit-massive-stars.html

http://hyperphysics.phy-astr.gsu.edu/hbase/astro/darmat.html

Tutorial 5 – Final Assignment

You are carrying out a research investigation that seeks to learn more about the properties of high-mass stars and their impact on the evolution of the Galaxy. You must write a telescope proposal for an observing run that will collect data to support your investigation.

Your proposal should include the following details:

- A concise title for your proposal
- A clear outline of the aims of your investigation and why they are necessary
- Your chosen telescope and instrument, and explanations of why you have selected them and why they should be used rather than an alternative
- Target(s) of observation and justifications for why they have been selected
- Explanations of what the observations hope to achieve and how the data will be analysed
- Details on how your work can be linked to astronomical research as a whole

Tutorial 6 – Feedback

What is the Purpose of Tutorial 6?

- Reflect on skills learned on the programme with a view to encouraging resilience
- Receive feedback on final assignment

What are the key questions?

- What strengths have I demonstrated in my work and what areas of development are left for me to address?
- What steps do I need to take to improve my academic output?

Activity 2 – Marking your own

Using the mark scheme, identify three things you did well and three things you could improve.

What went well?

1.

2.

3.

What could be improved?

1.

2.

3.

Activity 3 – Responding to feedback

Read through your feedback sheet and highlight on your assignment where you received positive feedback (one colour) and areas for improvement (different colour). You might find it helpful to annotate this with a brief comment or two.

(Acknowledgement: The structure and the activities in this feedback tutorial were first designed by Hannah Manktelow in January 2015. We have repeated them here as they demonstrate thoughtful and excellent planning, and can be used by all tutors to ensure a successful and productive feedback tutorial.)

University Applications Guidance

For course choices and careers information: www.brightknowledge.org.uk

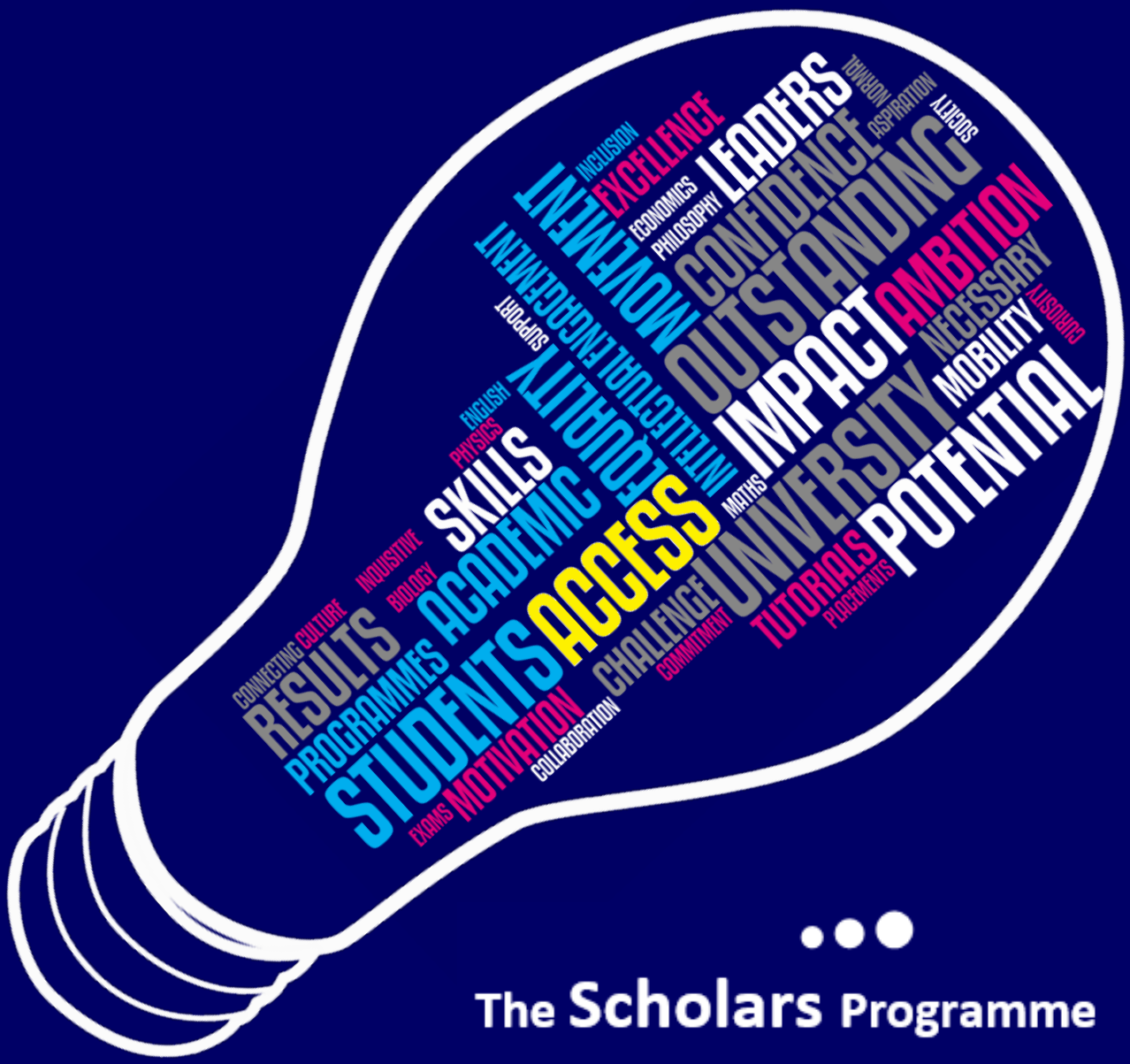
For information and statistics on universities and course: www.unistats.direct.gov.uk

For comprehensive information on universities, including rankings:
www.thecompleteuniversityguide.co.uk

PLEASE NOTE – The Scholars Programme is designed to support the university applications process at your school. The work you complete for the programme should add to your schoolwork rather than detract

Subject Specific Top Tips for Strengthening your application

What could you read around the subject?
Suggestions of podcasts/videos that can be found online? Are there any age-appropriate, good films on this topic?
What cheap or free events and talks would be good to attend?



The Scholars Programme