Teaching ideas for Option D: Astrophysics

Most students are amazed by stars and galaxies. The variety of cosmic objects to observe and find out about makes astrophysics a popular choice for students to learn. This option provides students with an overview of what is out there, how we are able to observe it, what we have learnt from our observations and what we think our future is going to be. Wow!

Some useful points to consider are:

- There is a large amount of factual information in this option topic, and it is worthwhile getting students to cover much of the easy-to-read material for themselves. It is the collecting together of various factual details that creates the patterns that astrophysicists use to understand the way in which the universe behaves.
- The very nature of learning about the universe from making observations on it means that this is a topic that is difficult to do without the use of second-hand observational material. Schools and colleges are unlikely to have the kind of observational facilities that will allow students to make direct observations of stars and galaxies for themselves, and so teachers and students are reliant on observations made by professional astronomers and astrophysicists to illustrate the aspects of the course to which they are vital. This usually means that use of websites is necessary to provide good examples.
- The comments above also mean that practical activities for students are limited to processing information that others have produced. There is some scope for this, using specialist websites, but teachers may find that it is the processes themselves that students need to learn. These can be done by using information available from a star catalogue or any stellar database.
- The additional HL material in the course, for those students taking the HL course, concentrates on two aspects of astrophysics: the role of nuclear physics in star lifetimes and the modern ideas of cosmology that have required physicists to accept the role that dark matter and dark energy play.

Ideas for teaching the topic

- A good way to begin this topic is to make sure that students have an appreciation of the scale of the distances involved. Any kind of visual model that will allow students to see the comparative sizes and distances will be very helpful. This will also allow teachers to introduce the various terms and units used in measuring astronomical distances.
- Once students have become familiar with just how empty much of space appears to be – and how far one object is from another, it is time to look at stars themselves. Even quick glances at photographs of stars should show that they come in a variety of colours and brightnesses. This provides a good introduction to the lines along which students must follow in their learning about stars. It also allows teachers to introduce some key words and phrases that students will need to be confident using, such as ‘luminosity’, ‘apparent brightness’, ‘absolute brightness’, ‘apparent magnitude’ and ‘absolute magnitude’. This might be a good point to introduce the Hertzsprung–Russell (HR) diagram.
- Being able to find out how far away a star is will be an important skill for students. This is best done in three stages, each stage depending on how far the star is away. For example: the parallax method for stars up to 100 parsecs away, the spectroscopic parallax method for stars up to several thousand parsecs away and the use of Cepheid variable stars for stars up to several million parsecs away.
- The lifetime and evolution of stars is best done with the use of an HR diagram. Students should be able plot evolutionary paths for a range of star masses, certainly for our own Sun. This allows investigation of the physical processes involved in:

(i) the hydrostatic equilibrium of stars: the balance of gravitational force inwards with the radiative pressure outwards; this is important because it will help students to understand why stars become unstable

(ii) the production of energy in stars by proton–proton chain and by the carbon–nitrogen–oxygen cycle; this is important because it will help students to understand the nuclear processes that stars undergo during their lifetime.

- It is a good idea to ensure that students are comfortable making calculations of ratios of radii, brightness and distance, using the three methods suggested earlier. Familiarity with the links between absolute and apparent magnitude and distance is crucial if students are going to be able to solve quantitative questions.
- Now that students have seen how stars behave, why they behave that way and what their evolutionary paths are, it is time to direct students' attention to a bigger scale: that of the universe as a whole. It is a good idea to direct this part of teaching to asking the question: What observational evidence is there for the model we currently use to explain how our universe came into being and what has happened to it since? This can be done by looking at three things:

  (i) Hubble's law, cosmological red-shift and observations of type Ia supernovae to indicate an accelerating, expanding, universe and an estimation of how old the universe is using the Hubble constant

  (ii) the presence of cosmic microwave background (CMB) radiation, measured initially by Penzias and Wilson

  (iii) the relative abundance of hydrogen and helium in the universe and the early nucleosynthesis of elements.

- For those students following the HL course it is necessary to explore (1) the large-scale physical process involved with the Jeans criterion for the initial formation of a protostar, and (2) the nuclear processes occurring in stars that produce elements heavier than iron. This leads naturally to learning about type Ia and type II supernovae.
- The last section of work for students to cover is on modern concerns with cosmology. It will be important to show the relevance of observations made by, for example, COBE and WMAP and by the Hubble telescope and the Planck space observatory. Students should be able to derive a simple equation for the critical density of the universe (using Hubble's law and the ideas of gravitational potential energy and kinetic energy) so that three possible futures can be envisaged: the open, flat or closed universe.
- As a final view of this topic, teachers should get students to consider the nature of dark matter and what observations we have that point to its existence. This will inevitably lead to dark energy and its role in the relevance of the cosmic scale factor. This links nicely with aims 1 and 9 of the group 4 aims in the IB Physics guide.

Practical activities

- It should not be difficult to find a good variety of photographs of stars, so that students can see a range of colours and brightnesses. An interesting exercise is to use a star field photograph (i.e. a photograph with many stars visible in it) and get students to investigate the relative number of stars that have a particular colour. A nice line of questioning is then: What might this tell us about the relative abundance of these different kinds of stars in the galaxy or universe as a whole? If teachers have introduced the different star classes (from O to M), then students might like to use their investigation to see whether their result is borne out by the HR diagram.
- The measurement of stellar distances using the parallax effect can be modelled well with students going outside and measuring angles and distances that mimic the Earth in its position

on its orbit around the Sun half a year later and a student in the distance representing a far-away star. If the term 'parsec' has not yet been introduced, now would be a good time.

- As it is possible for students to research a lot of different areas of this topic, this might be a good opportunity for students to further improve their presentation skills by making suitable presentations to the rest of the class (or indeed, to others.) If each section of the course is divided up carefully between several groups of students, it may turn out to be a really good exercise to have them teach each other what they have learnt in their research. It provides excellent opportunity for students to conduct their own lesson, with questions and answers exchanged in such a way as to allow you to monitor who has prepared themselves well and who has not! For those teachers familiar with the 'Harkness method' of conducting lessons, this is an ideal format for this kind of learning.
- A number of online exercises might be very helpful in getting students to use a range of techniques on real observational data. The following website is an excellent example of this and will provide many opportunities for practical activities: http://www.astroex.org/english/exercises.php.
- Another useful website is found at http://astro.unl.edu/naap/. This contains a variety of activities for students to do and is a good for reinforcing the ideas in the option topic.
- You might also find the following website useful for resources: http://www.compadre.org/osp/search/search.cfm.
- The online exercises link well with aims 4 and 6 of the group 4 aims.
- Please see the available practical notes for further ideas.

ICT

- There are a number of interesting apps that can be used with tablets and smartphones that will allow students to scan the sky and identify various objects in it. The nice thing about these is that they will show students where the objects are without being able to see them, i.e. when the sky is cloudy or during the daytime.
- A number of good websites have excellent practical activities on them for students to try. Three examples of these are listed above in the practical activities section.

Common problems

- The large amount of factual information involved in this topic means that students frequently become confused between the meaning of one term and another. Getting students to be correct in their use of language, especially when asking or answering questions and when making presentations on their research, is vital if they are to feel confident in their learning.
- Students often find the link between the magnitude scale for stars and the brightness of stars a difficult concept. It is not made any easier by the apparently arbitrary idea that a difference of 5 in the magnitude scale corresponds to a difference of a factor of 100 in its brightness. Getting students to accept that the smaller a magnitude is the brighter it is will be a challenge to some, while the idea of a magnitude being negative meaning that the object is extremely bright is also difficult.

Theory of knowledge (TOK)

- Knowledge of stars and of the universe comes from the analysis and interpretation of observations. How important is it in other areas of natural science to be able to interpret observational details in order to put together a coherent picture of our current knowledge? Are any of the techniques applied in the interpretation of scientific observations similar to the techniques applied in interpreting data from other areas of knowledge?

- The use of a magnitude scale as a logarithmic way of describing brightness may be something that mathematically able people can cope with. But what other ways of describing physical phenomena are also described with a logarithmic scale? Is it possible to understand a logarithmic scale without using mathematics?
- Our use of logic and our knowledge of gravity lead us to expect that the universe should be slowing down in its expansion – a kind of deductive argument for knowledge. Thirty or forty years ago this was the accepted view. Now, in the 21st century, our observations have improved and shown that the universe is, in fact, accelerating in its expansion. This has forced physicists to introduce the concepts of dark energy and dark matter, about which we know nothing. This is the opposite way of gaining knowledge: it is an inductive argument. Should we, therefore, accept that both kinds of argument are required by scientists and that sometimes it is necessary to invent something that we do not really know about in order to attempt to build a model that can explain our observations? Will we ever truly know something (is it even possible?), or is everything we know merely a best guess?
- If it is seen to be necessary to invent an idea or a concept to make a model work better, just how important is imagination in natural science? How important is it in other areas of knowledge?

International-mindedness

- Modern astrophysical research is done in a wide range of countries, with each global location offering different observational advantages.
- International collaboration between scientific research groups has been a significant factor in the success of several projects, for example the mapping of the CMB radiation across the visible universe and its implications.

