



Ideas for Astrophysics

Techniques for Enhancing Conceptual Understanding

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Introduction

This workshop will provide you with some simple ideas, demonstrations and analogies that consolidate a conceptual grasp of the theory and skills in the Astrophysics option. Concepts addressed, in varying depths, include photometry, astrometry, spectroscopy and stellar evolution.

Despite the seeming lack of practical investigative work in the revised version of the Astrophysics option, there are many simple demonstrations and analogies that are effective in engaging and challenging students.

This paper aims to provide teachers with a range of ideas and activities plus some useful data with which to cover the syllabus requirements. It is not intended to provide a detailed theoretical background on the concepts as this is better covered in the various references but rather it aims to clarify some key teaching points and misconceptions about them.

Syllabus Requirements

This paper uses the amended NSW Board of Studies Stage 6 Physics Syllabus of October 2002. The four areas targeted in this paper approximately relate to the syllabus outcomes in bold points 2, 3, 4 and 6 from option 9.7 Astrophysics (pages 63 – 65 of the printed edition). It is recommended that you read the paper with access to a current copy of the syllabus. It can be obtained online from the Board of Studies at http://www.boardofstudies.nsw.edu.au/syllabus_hsc/syllabus2000_listp.html#physics.

Astrometry – measuring distance and position

Astrometry is perhaps the oldest branch of astronomy. Accurate positional measurements of stars was one of the major activities of astronomers in the nineteenth century and the quest to detect the parallax of nearby stars was a key challenge in the first half of that century. Despite many attempts from the invention of the telescope, stellar parallax was not actually detected until 1838 by Friedrich Wilhelm Bessel. He measured the parallax of the 5th magnitude binary star 61 Cygni to be 0.3 arcseconds. The parallaxes for the bright stars Vega and α Cen were soon measured by Wilhelm Struve and Thomas Henderson respectively. Parallax measurements were, however, time consuming and complicated, with the result that by the end of the 19th Century parallaxes had been measured for only about 60 stars.

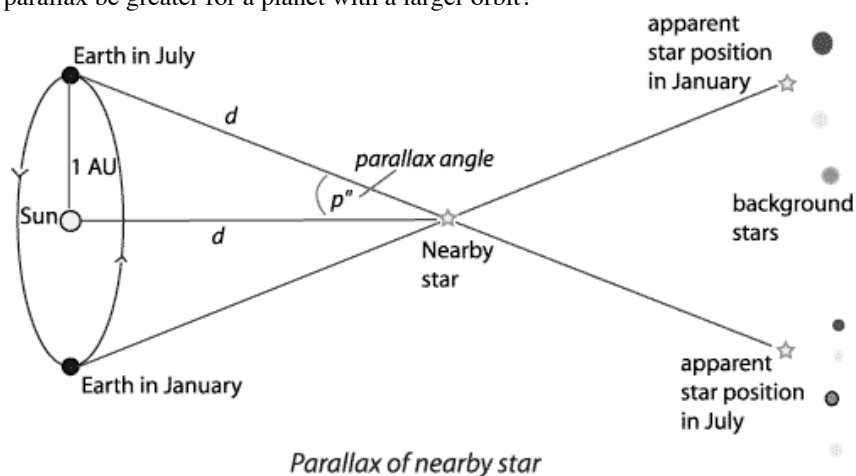
How can we make students appreciate the concepts involved in parallax and distance measurement? The first point to stress is that they are already familiar with parallax – they use it every day. The baseline involved in this is very short – the separation between our eyes, but we use this to gauge the relative distance to objects all the time without consciously thinking about it. The standard method of demonstrating this is to have students hold a finger out at arm's length and look at a reference point between them and, say the board at the front of the classroom. When they look through one eye they should see their finger aligned in one place, closing that eye and opening the other shows the finger to apparently shift. Viewing through the left eye, the finger seems shifted to the right; viewing through the right eye than shifts the finger to the left.

Having started with this simple demonstration you can now challenge them to think what will happen with objects further away, more than an arm length's distance. If you have room go outside so that you have a greater depth of distance over which to examine the variables. If you have a vantage point that provides a view to the far horizon see if you can identify features on the horizon that you can incorporate. Students should quickly realise that the greater the distance between the observer and the object, the less obvious is the observable apparent shift in position between the two eyes. This raises the concept of the limitations of baseline length. A student's eyes are only separated by a few centimetres. We cannot visually detect any apparent shift in the position of stars between our two eyes, as the stars are too distant given the miniscule baseline distance.

Demonstrating Stellar Parallax

Through discussion with students you should be able to hint or suggest (if they have not already offered it) the idea of the need to make observations to a star more than once. Ask them over what time span astronomers would have tried to observe a star to measure its distance? Hopefully once someone has suggested that it may be linked to our motion around the Sun you can extend the simulation to include Earth's relative position to the Sun and star. Students can represent the Earth and star, with a stationary object or point clearly marked as the Sun. The more space you have for this the better. It can work simply by students just eyeballing the relative position of the 'star' against the background from one point in their orbit. As they then walk around the Sun, they should see the star appear to move. When students are on the opposite side of the Sun, they represent the Earth six months part from the first observation. They should now see the star in a different relative position. As they now walk back to their original position, the star now also shifts again back towards its earlier position. Getting students to do a simple walk around should fix the basic concept of parallax with them and can then be used to pose a few more questions:

1. What is the baseline length between the Earth and Sun?
2. What is the maximum baseline length we can obtain from Earth?
3. What would happen if the star were more distant?
4. What times of the day should observations be made to obtain the greatest parallax?
5. Would the parallax be greater for a planet with a larger orbit?



Parallax of nearby star
Figure 1.

There are several possibilities for extending and developing this exercise. You may ask your students how they could measure the apparent shift? This question leads them into an awareness of parallax angle. Parallax is often shown using a diagram similar to Figure 1 above. Whilst such diagrams are schematically useful they can also be misleading for a few reasons. The most obvious trap is that of scale. Most students are either unfamiliar or uncomfortable with small-angle triangle mathematics. The baseline length in the above diagram is 2 Astronomical Units or AU, about 300 million km. The parallax to even the nearest star system, Alpha Centauri, is extremely small and equals 0.74212 arcseconds. This corresponds to a distance of $d = 1/p$, so $d = 1/0.74212 = 1.35$ parsecs. Applying some useful conversion factors;

$$\begin{aligned}
 1 \text{ parsec} &= 3.26 \text{ light years} \\
 1 \text{ parsec} &= 3.086 \times 10^{16} \text{ m} \\
 1 \text{ parsec} &= 3.086 \times 10^{13} \text{ km} \\
 1 \text{ Astronomical Unit} &= 1.496 \times 10^{11} \text{ m so} \\
 1 \text{ parsec} &= 2.063 \times 10^5 \text{ AU}
 \end{aligned}$$

we find that the if we draw a scale triangle with a base of 2 cm (1cm = 1 AU), then the star would be $1.35 \times 2.063 \times 10^5 = 277,987$ cm or nearly 2.8 km distant! The minute difference between a line drawn from the Sun to the star and from the Earth to the Sun explains why it is valid to label " d " on both of these lines in the above diagram.

If you wish, an exercise of this type is also a useful way to introduce errors and uncertainties in measurement. Astute students will realise that in effect, you do not directly measure the parallax angle, p , directly. Given that measurements are taken six months apart over a baseline of 2 AU you end up with a value of $2p$ but even then the angles they actually measure are those between the nearby star and a distant reference star from each observation point. These are then added together then the sum halved to give p . By getting students to physically work and walk through a measurement of parallax they are more likely to be able to **define** the relevant quantities; *parallax* and the *parsec*, **explain** how trigonometry is used to measure distance and **discuss** the limitations of the method. The concept of the *light year* can thus also be seen as almost an add-on that is not directly measured by astronomers who typically use multiples of parsecs in their professional work.

Other Considerations in Astrometry

As discussed above, it is often difficult for students to grasp a sense or scale and relative distance in astrometry. The subtle measurements and large relative errors involved in trying to pin down the parallax of even the closest stars was one reason it took so long to detect after the Copernican, heliocentric model became accepted in the 17th Century. What is an angle of 0.74212 or even 1.00 arcseconds? Most students by Year 12 level should be comfortable with the concept of degrees, minutes and seconds and even be able to state that there are 60 minutes in a degree and 60 seconds in each minute of arc (therefore arcminutes) but they will generally have a poor grasp of the reality of this.

A simple way to get them to think about how large an arcsecond is involves them using their hands. Ask them what the angular diameter of the Moon (or indeed the Sun) is. Most students over estimate the size. Rather than them simply guessing they can actually measure it with respect to their hands and fingers, much as people have used body parts for measurement for thousands of years. Fortunately, lunar measurements can be made during the daytime depending on the phase of the Moon. If it is only up in the night sky then it is a simple task to get them to measure it at home. The Moon actually subtends an angular diameter less than a person's fingertip (about half a fingertip) when the arm is fully outstretched from the body. Students are often surprised to find that their independent measurement agrees with their classmates. There should be little variation between students if they follow the guidelines for using their hands and fingers for measurements as most people are in proportion.

The angular diameter of the Moon is about 30 arcminutes. One-thirtieth of this then is 1 arcminute. If this amount is then divided by 60 you have an angular diameter of 1 arcsecond. This is indeed a very small angle. It may help to put this into an historical perspective. Hipparchus, the Greek astronomer who we credit as the founder of the magnitude system of stellar brightness and cataloguer of stars, could measure stellar positions to an accuracy of about 1 degree. This corresponds to the angular height of a human standing 100 m away. Check it with your students! Using modern ground-based techniques we can now distinguish the height of a person standing 4,000 km away, about the width of Australia. In 1989, the European Space Agency launched the Hipparcos satellite (*High Precision PARallax Collecting Satellite*) to measure the parallax and proper motions of stars. As it orbited the Earth above the effects of the atmosphere, it was able to measure parallaxes to an order of magnitude better precision than previous methods. The resultant Hipparcos catalogue gives positions, distances and proper motions for 118,218 stars to an average accuracy of 1 milliarcsecond (mas). This is equivalent to seeing a person standing on the moon 380,000 km away (Brown, 1998)!

Spectroscopy

Perhaps the most important concept that students should grasp about spectroscopy is that it is the vital tool for most astrophysical observations. A spectrum of an object can normally provide more information than any other single observation. Of course, in reality astronomers will seek to image an object as well but ultimately it is the spectrum that provides the most detail.

Activities for Spectroscopy

Using a Spectroscope

The first specified activity is that students: *perform a first-hand investigation to examine a variety of spectra produced by discharge tubes, reflected sunlight, or incandescent filaments*. This is a traditional investigation well covered in most textbooks. A few points to note however are relevant in the astrophysics context.

1. **Discharge tubes** produce obvious emission lines but may not be very bright. The tubes are often difficult to align with handheld spectroscopes as students try and cluster around the bench. Care is needed with classroom management.
2. **Reflected sunlight** should show the absorption lines, first recorded by Fraunhofer.
3. **Incandescent filaments** approximate a continuum emission. Rather than just using a ray box lamp on one setting, by varying the voltage you vary the luminosity and colour of the lamp. This can be seen through a spectroscope as the spectrum gets brighter but also shows more of the blue in the continuum as the bulb is hotter.
4. Although not specified in the syllabus, the spectrum from a **fluorescent lamp** is particularly interesting to observe, as it should show bright emission lines on an already bright continuum. This is a useful analogy for spectra produced by objects such as quasars and Wolf-Rayet stars.

There are some interesting alternative ways to demonstrate spectra in the classroom. Holographic film works better than a normal diffraction grating but either will do the job. Place a slide transparency covered in aluminium foil with a small vertical slit (mm or so) in it in a slide projector. When you hold or place the holographic film or diffraction grating in front of it you can project a spectrum on to a wall or screen. Students may already be familiar with the spectral pattern produced from CDs, which act as a diffraction grating. The value of using these methods is that you can then relate them directly to astronomical spectrographs that use diffraction gratings rather than passing light through a prism as is typically done in junior science classes. You may even ask students why gratings are preferred to prisms and relate this back to issues of sensitivity and resolution. Holographic film may be difficult to track down but is often sold as "Firework" or "Laser" novelty glasses or similar products and can be ordered over the internet.

Using Astronomical Spectra

If you want sources of real stellar spectra there are several good websites. One thing to reinforce with astronomical spectra is that most spectra these days are intensity plots obtained by photometric means rather than the more traditional photographic spectra (or their negatives). The Anglo-Australian Telescope's 2dF instrument can obtain 400 spectra simultaneously feeding two spectrographs that have Charged Couple Devices (CCDs) in them to record the spectra. It is worthwhile showing several photographic spectra alongside (even better above or below) the corresponding intensity plot. This allows you to emphasise what astronomers mean by absorption and emission lines and the continuum. Intensity plot spectra are also more effective in conveying the shape of the blackbody curve. Wien's Law can be used if the intensity peak is present on a plot to determine the effective temperature of the star.

Two computer-based activities listed below will help students address the other skill requirement in the syllabus that requires students to *analyse information to predict the surface temperature of a star from its intensity/wavelength graph*.

An excellent activity where students use real data to classify stars can be found online at the SkyServer site at <http://cas.sdss.org/dr2/en/proj/advanced/spectraltypes/>. This activity utilises spectra obtained as part of the Sloan Digital Sky Survey in the USA. The home site also provides activities for the HR Diagram, color (sic) and image processing as well as others related to galaxies and cosmology. Figure 2 below shows one of the stellar spectra from their site.

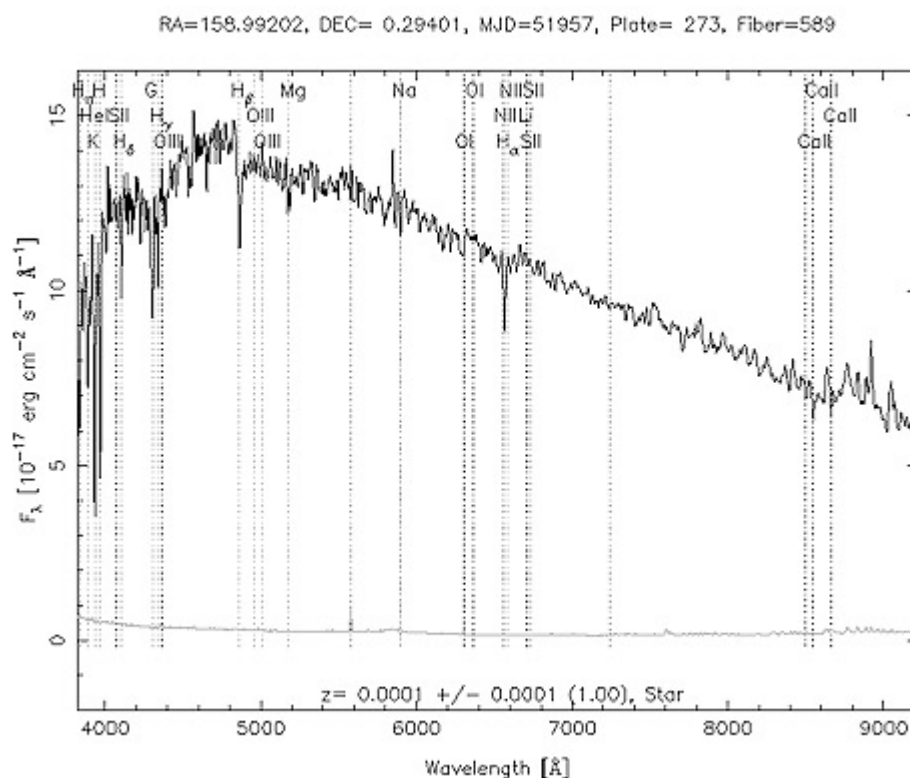


Figure 2. Intensity Plot Stellar Spectrum, (Credit: Sloan Digital Sky Survey, <http://cas.sdss.org/dr2/en/>)

An excellent simulation whereby students can “drive” a telescope, take then analyse spectra for a range of stars is the Project CLEA exercise, *Spectral Classification of Stars*. It, along with other useful activities, can be downloaded from the Project CLEA website at: <http://www.gettysburg.edu/academics/physics/clea/CLEAhome.html>.

Kinesthetic and Other Approaches

If you are game you can have the students simulate the processes involved in producing the different types of spectral lines. There are several methods by which this can be done (for a fuller explanation read Chapter 9 of Pompea, 2000 *Great Ideas for Teaching Astronomy* – an extremely useful source of ideas). Indeed a useful challenge could even be for students to design a way to demonstrate the production of an emission or absorption line using several students and various balls.

Mnemonic devices are a traditional way of getting students to learn the spectral sequence *O, B, A, F, G, K, M* (and possibly *R, N & S*). Rather than just use the standard “Oh, Be A Fine Girl (or Guy), Kiss Me, (Right Now, Slap)” or “Oh Beastly And Fearsome Gorilla Kill My Roommate Next Saturday” ask your students to develop their own. A space-related confectionary item often seems to work as an appropriate incentive for the winner!

Photometry

Photometry is essentially the measurement of the brightness of celestial objects. In practice the brightness of a source is measured within a range of wavelengths of the electromagnetic spectrum, that is a waveband. The concept of photometry can be traced back to Hipparchus of Rhodes (161-126 BC) who used Babylonian records to compile a celestial sphere showing the position and brightness of 850 stars. He developed the concept of **magnitude** as a measure of a star's brightness. His six-point scale classified the brightest stars as being magnitude 1 whilst the dimmest stars were magnitude 6. This scheme has been adapted but in essence continues in use today although it has been extended given the discovery of much fainter stars using telescopes. Pogson adapted the magnitude scale in 1856 and proposed a logarithmic scale. As the human eye's response is nearly logarithmic, Hipparchus' original scheme could be easily adjusted to the new standard.

Student problems with the magnitude scale

The basic concept of the magnitude scale is relatively easy but many students, with good reason, often find it hard to put into practice. There are several reasons for this and points to watch out for when teaching it.

1. **The Reverse nature of the scale.** A very bright star has a lower magnitude number than a dim star. With the now open-ended nature of the system we even have negative magnitudes that sometimes compounds the problem for students. Celestial objects detected thus far range from a magnitude of -26.5 (our Sun) to about $+30$ using the most sensitive telescopes and detectors.
2. **Standard or reference point.** The mathematical basis of the scale always defines the magnitude of an object relative to another one such as a star. The version of this given in the syllabus is: $\frac{I_A}{I_B} = 100^{(m_B - m_A)/5}$ although it can also be expressed as $m_A - m_B = -2.512 \log(I_A / I_B)$ where m refers to the (apparent) magnitude of the stars, A and B and I the intensity or energy per unit surface area at the Earth's surface. Many students are uncomfortable with ratios and relative measurements – they like absolutes. Astronomers determine the magnitude of a star with respect to one or more “standard” non-variable reference stars.
3. **Dimensionless quantity.** As magnitude is ultimately just a ratio it is simply expressed as a number with no unit. Often, having tried to drum into students the need to express all physical quantities with the relevant SI unit some of them then have problems when presented with one without a unit! Make sure you discuss this point with them and clarify why it has no unit.
4. **Logarithms.** Modern students are less familiar with logarithms than those who grew up using log tables in the pre-calculator days. Most will have had little practice in applying them in a non-theoretical mathematics classroom use. Whilst the nomenclature of **log** implies \log_{10} it is important to emphasise this point as some students will try and use natural logarithms, **ln** when trying to solve equations.
5. **Rewriting formulae.** Even though students are now provided with two forms of magnitude formulae in the Higher School Certificate exam and so do not need to “remember” it some struggle in rewriting it to find a different unknown. Students need to practice taking the original form and reworking it as needed. They will be more successful at this if they are competent at algebra (obviously) but also if they understand the underlying meaning of the formula and how magnitude is determined.
6. **Different types of magnitude** – apparent and absolute. It is important to stress the need for clear writing when calculating or discussing magnitude. Absolute magnitude, M must be clearly distinguished from apparent magnitude, m in any equation. In general, try and always prefix the term “magnitude” with “absolute” or “apparent” if appropriate. Students need to be able to explain the difference between the two and why the concept of absolute magnitude is so useful and important.
7. **Colour Index.** Just to complicate matters, once students are comfortable with apparent magnitude they have to extend their understanding to the need for magnitudes at different wavebands. Such measurements are normally made through filters. In fact this is the norm in photometry – astronomers want to know the wavebands they are receiving light at. Stress the great advantage in obtaining a magnitude value for an object at specific wavebands. Although the syllabus only specifically mentions B and V it is worthwhile to also discuss the other three filters in common use, U , R and I . This would also be a relevant time to discuss the differing spectral responses on most photographic emulsions compared with most CCD chips. If probed, some students will have experience of red lights in dark rooms and suggest that film must be relatively insensitive to red light. CCDs on the other hand are normally more sensitive to red than blue light.

Demonstrations and ideas for showing magnitude

There are many simple ideas you can use in the classroom or elsewhere to reinforce concepts related to magnitude.

1. **Standard candles.** In discussing how to determine stellar and extragalactic distances students should be introduced to the concept of “standard candles”. Whilst this often occurs when discussing variable stars and Cepheids in particular it is probably better to introduce it early when discussing magnitude. A number of tea candles at different distances in a room can simulate stars at different distances. In asking students to identify

which “star” is furthest away, challenge them to state the assumptions on which their answer is based. Are they assuming that stars have the same “brightness”? Probe them to explain what they mean by “brightness” then try and lead them to linking this with the energy given off by a star or candle then the energy per unit time, that is the power output or **luminosity** of a star. Variations on the candle theme could use low power bulbs or LEDs at different distances. Of course, if using bulbs you can then complicate matters by running them at different voltages to produce “stars” of differing intrinsic luminosities and even colour.

2. **Intrinsic and extrinsic luminosity & brightness.** Once students are comfortable with brightness and luminosity use different size candles or bulbs connected to a variable power pack to produce “stars” with different intrinsic luminosities. The concept of extrinsic luminosity can be shown using sheets of Perspex or stiff transparent plastic. If you have more than one sheet, coat one with soot from a candle flame. It represents a dark nebula, a cold cloud of dust and gas blocking out light from stars behind it.
3. **Star field images and photos.** One of the most versatile resources for teaching is the magnificent poster *The Southern Cross and the “Pointers”* produced by CSIRO Parkes Observatory using a photo by the renowned astrophotographer, Akira Fujii. It shows Crux and the Pointers in colour plus the region around Eta Carinae. If possible, have a laminated copy in your classroom when teaching astrophysics. A view similar to the poster is shown in Figure 3 that also has some of the key objects labelled. The unlabelled original of this photo by Professor Mike Bessell can be found online at <http://www.mso.anu.edu.au/~bessell/thumbnails/>. Ask students to identify the brightest star in the photo then ask them to justify their choice. Challenge them to think why it is brightest. Most should soon see the relationship between the width of the star image and its brightness. Using a laminated copy of the poster students could actually measure the width of various stars and try and determine a relationship between image size and magnitude. If really keen here you can go into the photochemistry of photons interacting with the film material. It is important to point out that all the stars on the image are so far away that they should still be point sources. (The poster is available from Parkes Observatory Visitors Centre, phone 02 6861 1777, or email parkes-vdc@csiro.au).

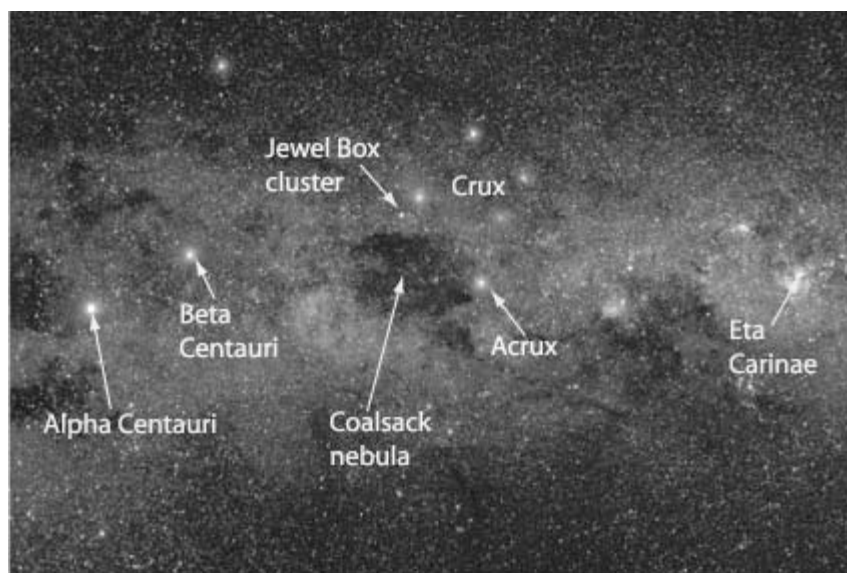


Figure 3: Crux Region with key features labelled (Credit: Adapted from an image by M. Bessell)

4. **Colour and Colour Index.** Using either the online photo or the poster of the Crux region, students are easily able to detect the variations in colours of stars. This provides an effective way of introducing colour, blackbody curves, Wien's Law, and the value of observing through different filters. Provide students with red, yellow and blue cellophane filters. Many ray box kits used to come with colour transparency filters and these are excellent as they are robust and easily held. When students view a coloured star field through different filters they will see that different stars are brighter through different filters; red stars are brighter through red filters and blue stars brighter through blue filters. If you have a Polaroid instant camera or a digital camera and a darkened room you may like to try and photograph different coloured "stars" through different coloured filters. To create the stars simply use a ray box with different coloured transparency slides in the outlet slit or use a fibre optic torch with red, clear, yellow and blue cellophane over different fibres. Use coloured cellophane or ray box transparencies as the filters in front of the camera. Using different filters compare the relative image size of the stars.
5. **Using comparative brightness to calculate distance to stars.** One important application of the concept of magnitude is to use it to determine the distance to a star. A star's apparent magnitude can be readily measured (methods range from naked-eye estimation, measurement of photograph or even CCD photometry). If you know the spectral and luminosity classes of that star then you can also obtain a value for its absolute magnitude from a Hertzsprung-Russell diagram or tables. Knowing M and m students then traditionally rework the equation $M = m - 5 \log\left(\frac{d}{10}\right)$ to find d in parsecs. Students must, of course, practise using this formula given

any two of the three variables. There is, however, an interesting practical experience that will challenge them and hopefully consolidate their understanding of the principles involved. This activity works best if you are holding a viewing evening and involves students trying to calculate the distance to a bright star of known luminosity such as Alpha Centauri using a torch, some simple mathematics and perhaps a measuring tape (though even the distances can be estimated by pacing).

Use a reasonably low-powered torch but one where you can determine its power output. If the wattage is not visible students could try and calculate it using Ohm's Law. Cover the front of the torch with foil, making a small hole of known diameter, 1 or 2mm for example. Making some assumptions, students should be able to estimate and calculate the luminosity of the torch through the hole. With one student as the observer, the other student simply walks away, holding the torch up and pointed at the observer until the torch appears as bright as the selected star. Once this spot is located they simply measure the distance between the torch and observer. Using ratios they can now calculate a distance in metres to Alpha Centauri! In practice there is some uncertainty and several assumptions made in this investigation but students are often surprised at how close their value is to the true distance. Having a number of pairs perform the investigation allows them to compare results, discuss their assumptions and refine their technique. (This activity is summarised from one presented to me by Dr Case Rijdsijk from the South African Astronomical Observatory and used with thanks).

A classroom variation on this activity is the use of a grease spot photometer. A sheet of brown or white paper with a drop of olive oil is held upright between two bulbs as shown in figure 4 below. In this situation, the power output of an unknown bulb can be determined by moving it until the grease spot "disappears" when it is equally illuminated by a known lamp on the other side. Using ratios, students can easily calculate the luminosity of the unknown bulb. This activity really draws together ratios and the inverse-square relationship of light.

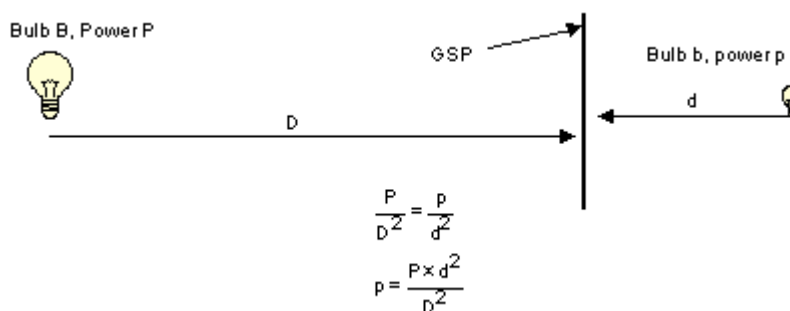


Figure 4: Grease Spot Photometer (Figure from *The Inverse Square law – A workshop module for teachers* by Case Rijdsijk, SAAO)

Stellar Evolution

One point that you may need to emphasise is that astronomers use the word "evolution" in a slightly different sense to biologists. What is really meant by the term is the life cycle of a star. When a star "evolves" it is not being naturally selected rather it is simply changing its physical appearance due to changes in its structure and sources of energy.

The Hertzsprung-Russell Diagram

The key tool to aid students in understanding stellar evolution is the Hertzsprung-Russell (HR) Diagram. If they can understand what it represents they are well on the way to explaining stages in stellar evolution.

The **HR Diagram** poses problems for some students for a few reasons:

1. The **horizontal scale** is reversed from what they normally expect in a graph. The hot stars are placed on the left and the cooler ones on the right hand side. This may not be immediately obvious if you use spectral class to plot the position on the horizontal axis. Colour index can be a better approach, as it will be negative on the left hand side and increasingly positive as you move across to the right. Ultimately students need to be comfortable plotting any of the three types of data, effective (surface) temperature, spectral class and colour index.
2. The **vertical axis** represents the luminosity of a star. This is normally expressed in one of two ways, luminosity compared to the Sun or absolute magnitude. Generally plotting values as luminosity poses few problems apart from the large range of values plotted (10^4 or 5 to 10^{-4} times that of the Sun). If plotting absolute magnitude, some students are likely to arrange the scale in ascending order, that is they put the most positive value (and hence the dimmest star) at the top of the axis. If you are not specific with your instructions or worksheets and simply provide them with a table of data it may be worthwhile letting students make this mistake and then discuss it with them.

One way to introduce students to the concept of the HR Diagram is to ask them to plot a set of data such as shoe size versus a person's height, or height versus mass. The advantage of shoe size is that it is a discrete quantity that simulates spectral classes somewhat. An even better introduction is to ask them to estimate rather than directly measure the data before plotting. You can link this to the concept that astronomers have to infer stellar data by observing it from Earth rather than going to the star itself to obtain accurate measurement. When students plot this data they will generally plot it in the normal manner with increasing quantities going to the right and up the respective axes. In asking what type of relationship their plot shows it is worth emphasising the non-random distribution, that is there is a physical relationship between height and shoe size. Once they replot their data with a reversed horizontal scale they have something that approximates a main sequence for stars on an HR diagram. When students come to plot stellar data you can re-emphasise the idea about distribution and relationships so that they start asking why stars cannot be located just anywhere on the diagram.

Simple Demonstrations related to stellar evolution

Here are a few ideas to help convey some tricky concepts related to stages of stellar evolution.

1. **Difference between main sequence and red giants.** Stars evolve off the main sequence once they run out of hydrogen in their core. In doing so the outer layers of the star expand enormously. The radius of a red giant is typically 100 times that of a main sequence progenitor for stars similar to our Sun. The red giant however is actually slightly less massive than the progenitor star as a small fraction of the mass has been converted into energy via fusion. As the outer layers of a red giant are also held more weakly by gravity the rate of mass loss out from such stars is also greater than that for main sequence stars. Our Sun currently loses about $10^{-17} M_{\odot}$ (solar masses) annually whereas as a red giant it will lose about $10^{-7} M_{\odot}$ per year. One conceptual problem students may have is that the larger red giant is no more massive than the main sequence star from which it has evolved. How to show this? One simple analogy is that of a bag of microwave popcorn. The flat pack represents a main sequence star. Once it is microwaved it swells up to much greater volume with little or no apparent gain in mass. Even if the bag bursts and popcorn flies out you can put this down to mass loss by out gassing. To extend and perhaps trivialise the analogy further you could relate the expected lifespan of a bag of freshly popped popcorn in a classroom full of teenagers with the lifespan the bag spent sitting on a supermarket shelf – that is, much shorter!
2. **Pulsars.** These rapidly rotating superdense neutron stars beaming intense beams of radiation off into space can be very hard objects for people to visualise. You can download animations and sound files of pulsars, including the recent binary pulsar from sites such as the ATNF (http://www.atnf.csiro.au/news/press/double_pulsar/) and Jodrell Bank. (One effective way of playing the sound files is to use something such as *Windows Media Player* and use the *View* → *Visualizations* → *Bars and Waves* → *Scope* setting to display the waveform similar to that obtainable on an oscilloscope. An example of this is shown in figure 5 below for the Crab pulsar file from Jodrell Bank's website (<http://www.jb.man.ac.uk/research/pulsar/>).

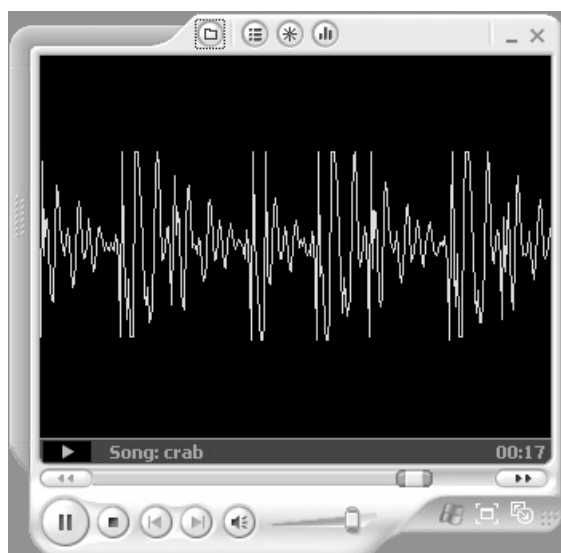


Figure 5: Visualisation of Pulsar Sound File Using *Windows Media Player*

Computer Visualisations and Simulations

As discussed in the section on spectroscopy, sites such as Project CLEA and SkyServer provide effective sources of either simulations or real data for a range of aspects of the syllabus including spectroscopy, photometry and the HR diagram. There is one other piece of free software that is outstanding and extremely effective in visualising space to

students. *Celestia* is freeware that has been developed for a range of platforms including *Windows*, *Mac*, and *Linux*. To quote from the *Celestia* website (<http://www.shatters.net/celestia/>) from which it can be freely downloaded:

Celestia is a free real-time space simulation that lets you experience our universe in three dimensions. Unlike most planetarium software, Celestia doesn't confine you to the surface of the Earth. You can travel throughout the solar system, to any of over 100,000 stars, or even beyond the galaxy. All travel in Celestia is seamless; the exponential zoom feature lets you explore space across a huge range of scales, from galaxy clusters down to spacecraft only a few meters across. A 'point-and-goto' interface makes it simple to navigate through the universe to the object you want to visit.

What makes the program even more valuable for education use is the large number of add-ons that have been developed by people around the world. These include simulations of a large range of space probes, extra textures for planetary and star surfaces and even spacecraft from movies such as *2001 - A Space Odyssey*. A separate website of educational add-ons at <http://www.fsgregs.org/celestia/> includes educator notes, classroom activities and extra modules on a range of topics including "The Life and Death of Stars". You can, therefore take your students on a virtual tour of real objects showing all the stages in stellar evolution. *Celestia* is also excellent in showing that stars are at different distances from us. As you journey to the *Hyades* or *Pleiades* you will see the stars clustered together relative to other stars but then you can "fly-through" the cluster itself. Students can explore systems themselves or you can use it for classroom presentations. This is a highly addictive package with great value for educational use. Figure 6 below shows a screenshot of *Betelgeuse* from *Celestia*. The actual colour screen view is far more impressive.

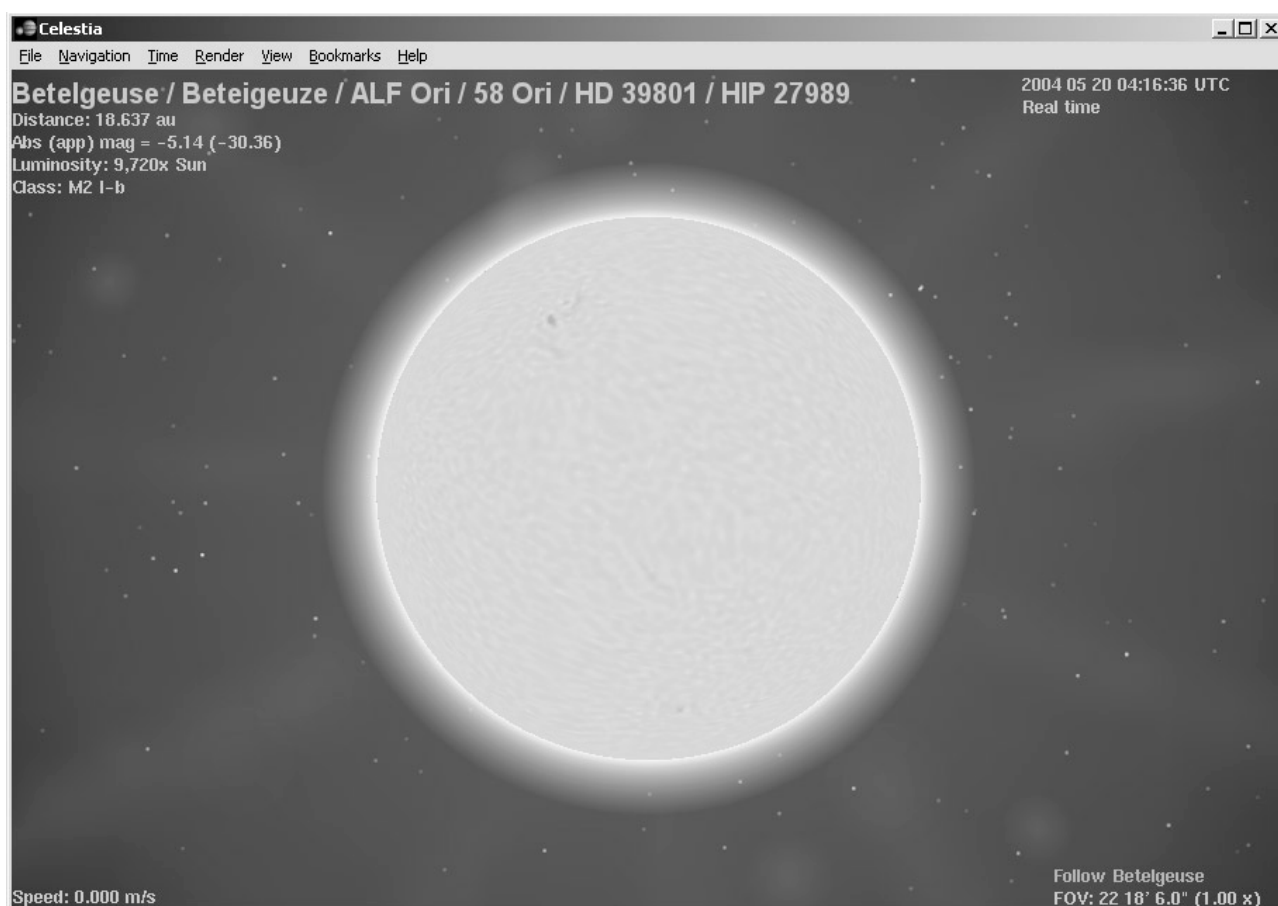


Figure 6: Screenshot of *Celestia* showing *Betelgeuse*.

Conclusion

This paper provides some ideas to help you try and relate some of the necessary concepts for astrophysics to students in a manner which may challenge them but also hopefully make them think and gain a better understanding. It has not covered every possible aspect of the syllabus nor addressed even all the dot points within the chosen sections. Try some of these ideas out and see if you can develop some of your own. If you come up with something that works and you think may be of use to others please contact me and we may be able to put it on Outreach and Education website at ATNF.

References and other useful books

- Andriessen, M., Pentland, P., Gaut, R., and McKay, B., 2001, *Physics 2 HSC Course*, Y. McCallum (consultant), (Jacaranda: Milton), ISBN 0 7016 3466 9 (a revised edition incorporating amendments to the syllabus is now available).
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- Zeilik, M., 2002, *Active Learning Astronomy for "Astronomy: The Evolving Universe"*, (CUP, Cambridge), ISBN 0-521-52901-8

Useful Web Sites

There is a wealth of information available on the web and far too many to list separately here. Sites provide information at a range of depths. Some are more suited as general introductions whilst others provide detailed technical information.

Australia Telescope Outreach and Education <http://outreach.atnf.csiro.au/> is the new outreach and education website of the Australia Telescope National Facility. It has a range of material available and is continually being added to.

A major part of the site is the new online material for senior Physics. The first part of this is a complete online module for the 9.7 *Astrophysics* option. This can be reached directly at:

<http://outreach.atnf.csiro.au/education/senior/astrophysics> and contains pages that directly address each syllabus point and beyond. The material incorporates up-to-date observations and emphasises Australian facilities and research. There are hundreds of links to other sites, too many to list them all here. Questions with solutions are provided, as are some activities that can be downloaded and printed out for class use.

Another valuable starting point is the *UniServe Science* resource page for the Astrophysics option for the NSW HSC Physics course at: <http://science.uniserve.edu.au/school/curric/stage6/phys/astrophys.html>. It has a wealth of annotated links.

Sites referred to in text:

Australia Telescope National Facility Home Page: <http://www.atnf.csiro.au>

Celestia: <http://www.shatters.net/celestia/>

Celestia Educational Materials: <http://www.fsgregs.org/celestia/>

Jodrell Bank Pulsar group Home Page: <http://www.jb.man.ac.uk/research/pulsar/>

Professor Mike Bessell's Image page: <http://www.mso.anu.edu.au/~bessell/thumbnails/>

Project CLEA: <http://www.gettysburg.edu/academics/physics/clea/CLEAhome.html>

SkyServer, the educational site for the Sloan Digital Sky Survey: <http://cas.sdss.org/dr2/en/>