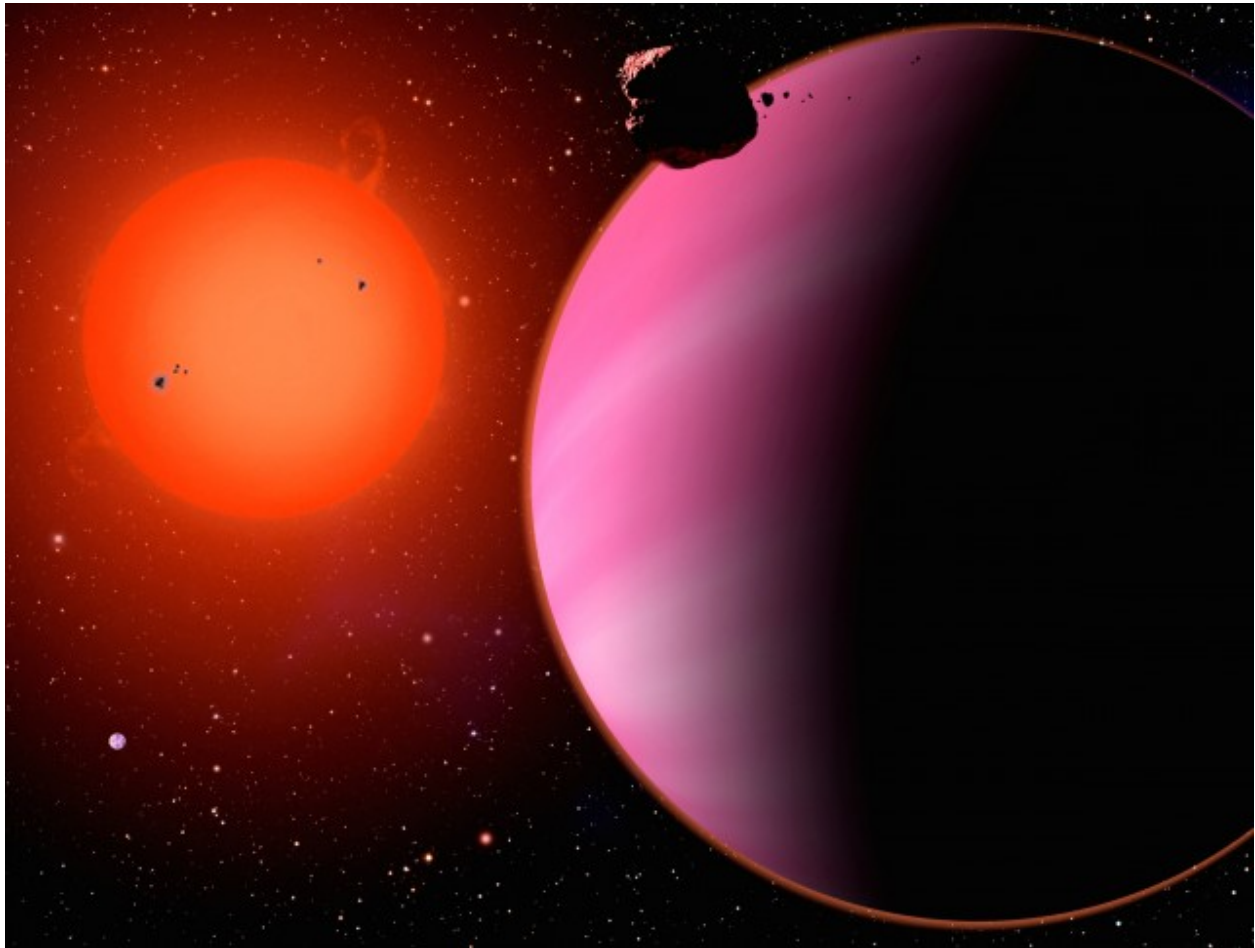


SSSS 2016

Magikarpmaster629's Notes:

Introduction to Astronomy



*Note: The following guide and the event Astronomy require knowledge of basic Algebra and Trigonometry. These will not be addressed, so if you are not familiar with these concepts consult another source.

Lesson 1: Astronomy C

Astronomy is a C division event in Science Olympiad. For those coming in from division B (including those who did Reach for the Stars) it's very different from what you've seen before. You will be competing against high schoolers, many of whom are VERY good at studying. Keep that in mind while considering how much time to put into studying for Astronomy and your other events.

Somewhat relevant; Astronomy is almost never taught in high school curriculum, and when it is, it's usually an elective people take to raise their GPA. Most people consider a lack of background in the event a disadvantage for those competing in Astronomy, however I see it the other way. See, in say Anatomy or Chemistry Lab, most of the people competing already have a basic understanding of the content, making it that much harder to beat all of them. In Astronomy, everyone starts from scratch, and by studying well one can easily get ahead.

Lesson 2: The Rules

As you probably already know, each Science Olympiad event has a page (or two) of rules released in the rules manual every year. The Astronomy rules sheet has some parts that stay the same every year, and other parts that vary year to year. I cannot post a copy of the rules on the internet because that's illegal; however I will give a description of each part of the rules:

1. Description: Very briefly describes the event and lists the two topics for that year's season. One of the topics is always stellar evolution, and the other topic switches every one or two years.
2. Event Parameters: Says what you can and cannot do during the event. You and your partner are allowed to each bring a binder or a computer (I know right, a whole computer! More on that later) and each of you can also bring a programmable or other kind of calculator. Internet access is not allowed, so everything on your computer must be downloaded.
3. The Competition: This constitutes the vast majority of the rules page, as it gives the content of what will actually be asked of you during tests. The details are described later in this guide, but know that it is split into three sections: Part A lists what can be asked for in concept questions, Part B has math topics and Part C lists the 'DSOs.' DSOs, or Deep Sky Objects, are simply objects in space. In the Astronomy event there are 17 specific DSOs related to the two topics for the event that year (e. g. If the topic is 'exoplanets' then most of the DSOs will be or relate to exoplanets). This will all be discussed more later in the guide.

Lesson 3: Distances in Astronomy

Time to get right into the content of the event =D! But before that, I'll briefly answer one question: What is Astronomy?

I'd say Astronomy is the study of the objects and processes of the universe both in general (like all-encompassing astronomical laws) and in specific cases (like the study of the solar system). Astronomy as a Science Olympiad event looks mainly as the study of the universe in general as well as that applied to a few specific details. Knowing this, we can move on to distance equations.

Objects in space are very far away. Far enough away that we had to make up a set of units for distances just within our own solar system, and when we discovered how distant other stars and galaxies were, we needed to create yet another system.

The first system mentioned here (for distances within the solar system) uses the AU, or Astronomical Unit. 1 AU is equal to 1.496×10^{11} meters, which is also the distance from the Earth to the sun. These are now used not only within our own solar system, but also in multiple-star systems and planetary systems of other stars. The latter system is the system of light-years and parsecs, and are generally used for every scale where AU are too small to be used practically. A light year is calculated as the distance light travels in a year (wow!); which is a considerable 9.46×10^{15} meters. However, astronomers (and Scioly test writers) prefer to use the parsec over the light year because they are more useful in equations. Know that **a parsec is 3.26 light years**, since tests can ask for either unit in answers.

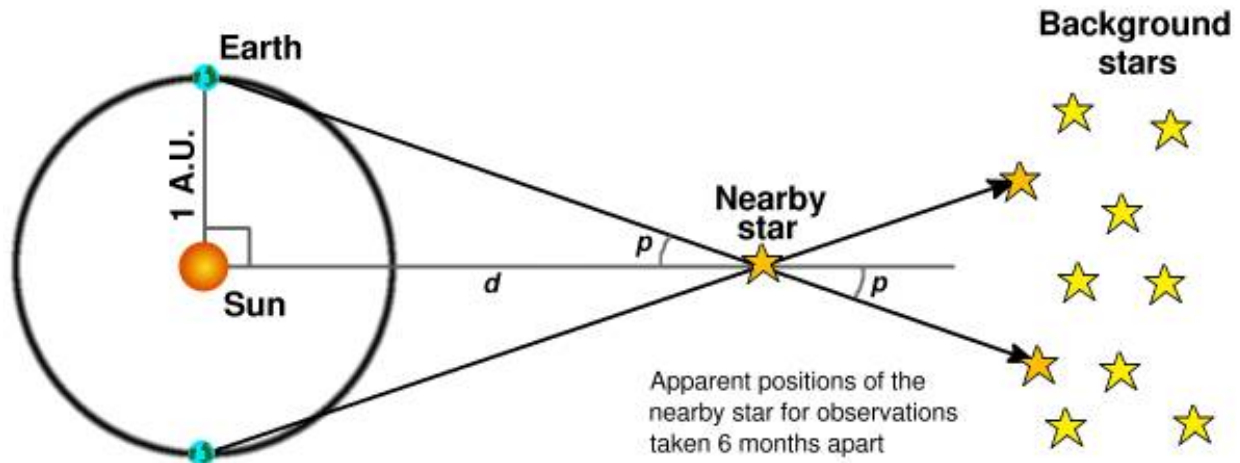
Parallax

However cool it would be, we cannot build giant space meter sticks to measure the distance to objects. There are several indirect methods we can use, though. One of these is **parallax**. Parallax can be understood fairly easily since humans use it all the time with our eyes. Notice how if you look at one thing with one eye closed, then look at it with the other eye closed. It should appear to shift position relative to the background. Try it again with objects of different distances, and these objects will appear to shift more or less depending on if they are closer or farther away. This is the essence of parallax; by looking at things from different angles, we can find the distances to these things.

With objects in space, astronomers make a measurement of an object's position at one part of the year and another measurement six months later. This gives them a wide angle to work with (across Earth's full orbit, which makes the measurements more accurate. After finding the angle in between the different apparent positions of the object, we use the following formula to find the distance to it:

$$1/p = D$$

Where D is the distance to the object in parsecs and p is parallax angle in arcseconds, shown in this image:



In astronomy we also use a different system of angles. Objects are so far away, so the angles between two objects can be incredibly small; too small to effectively use degrees. This angle system is sexagesimal-- one degree is 60 arcminutes (denoted with an apostrophe '), and an arcminute is 60 arcseconds (denoted by quotes " or milliarcseconds by mas). With parallax, the angles used are so small that the closest star, Proxima Centauri, at 1.306 parsecs distant, gives a parallax angle of 0.768" (768 mas), or less than one arcsecond. This is for the star with the largest parallax angle, so instruments that calculate parallax must be extremely precise.

Distance Modulus

The other main way of calculating distances is with the distance modulus. But before I show you more equations, you must first understand a few concepts of light. The first is the inverse square law. This states that the apparent intensity of light is inversely proportional to the square of the distance to the source of the light. You can test this easily; place a lamp or other light source somewhere. Look at it from two meters away, then again from one meter away. Because the second time you were twice as close, it should have appeared four times as bright ($(1/(1/2))^2=4$). Theoretically, if you measured how bright the lamp appeared from either distance, then you could use that and the distance to the lamp to find out how bright it truly is. The relationship between these three is called the distance modulus.

Astronomers call the actual brightness of the object its absolute magnitude (denoted by (capital) M), and how bright it appears from Earth its apparent magnitude (denoted by (lowercase) m). These are measured with the Pogson scale. In this logarithmic (but not base 10) scale, lower numbers are brighter than higher numbers, and every five steps is 100 times brighter/dimmer (which makes each step $\sqrt[5]{100}$ or

around 2.512 times brighter/dimmer). For reference, the Sun has an apparent magnitude of -25, Sirius (the brightest star after the sun) is -1.46, and the dimmest stars in the sky are 6. The Pogson scale is based on the old Hipparchus scale, which was used by the ancient Greeks (and invented by Greek astronomer Hipparchus); this system differed in that it only ranged from 1-6, whereas the Pogson scale can go as dim or bright as we can observe.

Now for some equations. To find the distance to an object once you know its apparent and absolute magnitudes:

$$10^{((m-M)/5)+1} = D$$

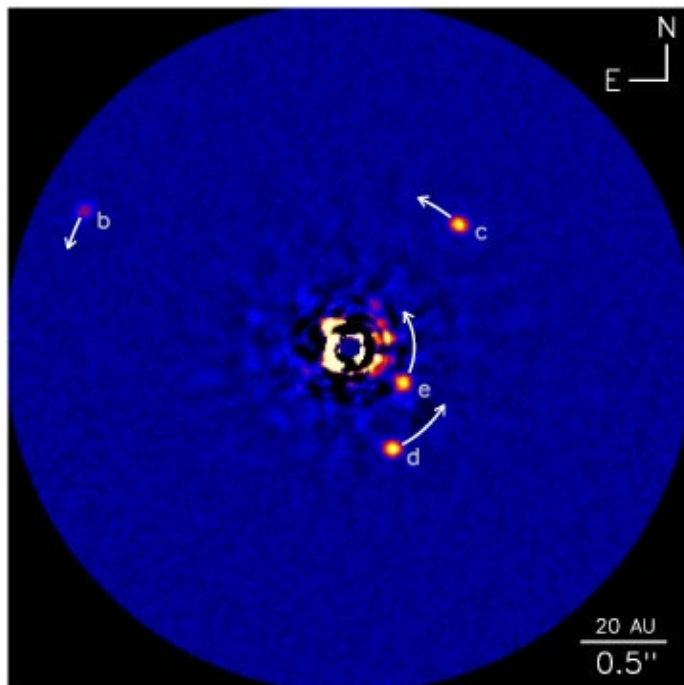
Where D is the distance to the object in parsecs. It is important to note that the magnitudes are unitless variables.

Measuring apparent magnitude is very easy, however absolute magnitude is much harder. There are a number of ways to do this, but right now know two important ones: spectroscopy and standard candles. There will be more details later, but spectroscopy measures the spectrum of a star, and we can use this to find its absolute magnitude. This is called the spectroscopic parallax. A standard candle is an object that either always has the same absolute magnitude, or its absolute magnitude can be found with a certain relationship between another property that can be measured.

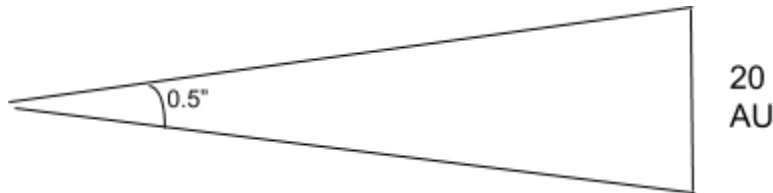
Lesson 4: Angles in Space

Once you know the distance to something, you can start to measure other things, including the distances between objects in space. Solving for these uses only some simple trigonometry. Take a look at this problem:

The image below shows planetary system HR 8799. Using the scale bar on the bottom-right, find the distance to the system.



The scale bar is 0.5 arcseconds, which is 20 AU wide in HR 8799. Using this we can draw an isosceles triangle:



Now draw a line from the leftmost point to the center of the rightmost line. This splits the triangle into two right triangles, which lets us do trigonometry, and also gives the distance line, which we can now solve for:

$$\tan(\theta/2) = \frac{\textit{opposite}}{\textit{adjacent}} = \tan(0.25'') = \tan(0.0000694^\circ) = \frac{10}{D}$$

Solving for D we get $8.26 * 10^6$ AU; dividing by 206265 we get 40.0 parsecs. While this is the most exact answer, there is a much easier way to solve this without drawing triangles. This method is called the **small angle approximation**. The approximation itself states that at very small angles, such as the ones we deal with in Astronomy:

$$\sin(\theta) \approx \tan(\theta) \approx \theta$$

Using this we can simplify the earlier equation to the following:

$$\theta = \frac{d}{D}$$

Where θ is the angular separation between the objects in arcseconds, (lowercase) d is the distance between the objects in AU and (uppercase) D is the distance to the objects in parsecs. With this equation, we can still plug in 0.5" for θ and 20 AU for d, and we still get 40 for D. This method will save you time, which is very important for competition day. There are also different forms of the small angle approximation using different units; you can have the angle in radians, degrees or arcminutes (technically angle measures are unitless, so these are "proportions" not different units), the two distance units can both be in parsecs, or D can be in light years. Whatever works best for you.

Lesson 5: Light and the Electromagnetic Spectrum

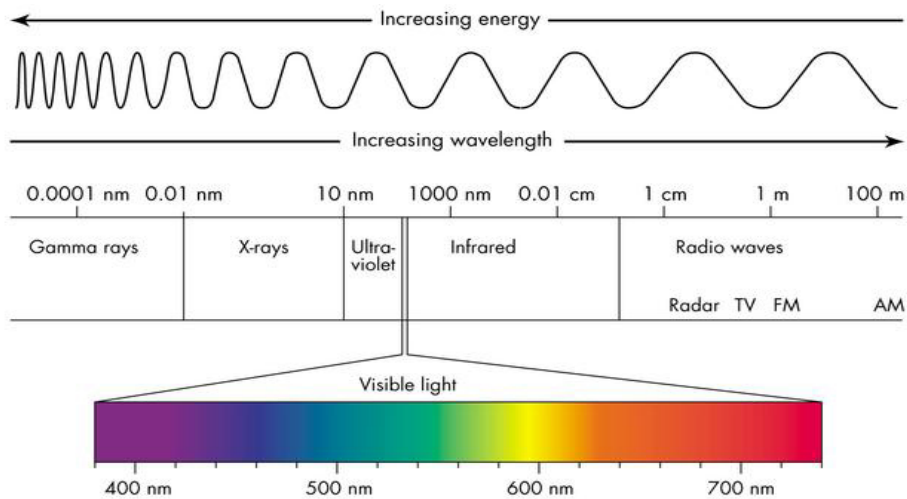
We use light (or as physicists like to call it, electromagnetic radiation) to observe everything in astronomy. Light travels in the form of waves, and is classified by how much energy it has. There are several similarities no matter how much energy it has; first of all, they are made of particles called photons. This means that they're both waves and particles; don't dwell on this for too long. Photons are massless, and objects without mass travel at the speed of light (they travel slower when passing through other

substances, but this is the only exception). The speed of light is measured to be exactly 299,792,458 m/s. This is usually rounded to $3 * 10^8$, which can be plugged into a calculator much faster than the exact speed.

Light as a Wave

Because light is a wave it has all the same properties of waves- frequency, wavelength and speed. The equation $f * \lambda = s$ where f is the frequency of the wave in hertz, λ is wavelength in meters and s is speed in meters per second. However, as mentioned above the speed of light is constant, so we can rewrite the equation as $f * \lambda = c$ where c is the speed of light in meters per second. This means that frequency and wavelength are solely dependent on each other; each wavelength has a corresponding frequency and vice-versa. It is also important to know that the frequency of a photon is directly proportional to its energy, while the wavelength of a photon is inversely proportional to energy.

Light waves are classified by wavelength/frequency in what is known as the electromagnetic spectrum. The main categories are, by decreasing wavelength, radio, infrared, visible, ultraviolet, X-ray and gamma ray as this image shows:



The exact wavelengths are as follows: radio >1 mm, infrared 700 nm - 1 mm, visible 400-700 nm, ultraviolet 100-400 nm, X-ray 0.01-100 nm, gamma ray >0.01 nm.

Stefan-Boltzmann Law

There are several laws governing the formation and propagation of light in space. One of which is the inverse square law, which I described earlier with the distance modulus. Another is the Stefan-Boltzmann Law, which describes how much energy is released by stars (and to a lesser extent other objects in space).

This Stefan-Boltzmann Law is based on the principle that objects with temperature radiate energy in the form of light. The amount of energy released per unit time of an object is directly proportional to the temperature (to the fourth power) and surface area of the object as shown below:

$$L = SA * T^4 * \sigma$$

Where L is luminosity in Watts, SA is surface area in meters squared, T is temperature in Kelvin and σ is the Stefan-Boltzmann constant equal to $5.67 * 10^{-8}$ Joules per meter squared per Kelvin to the fourth per second (Whew!). For stars, planets, or whatever needs its luminosity calculated (astronomers call these objects blackbodies), we can generally assume they are spheres, so we substitute in the formula of the surface area of a sphere:

$$L = 4\pi R^2 \sigma T^4$$

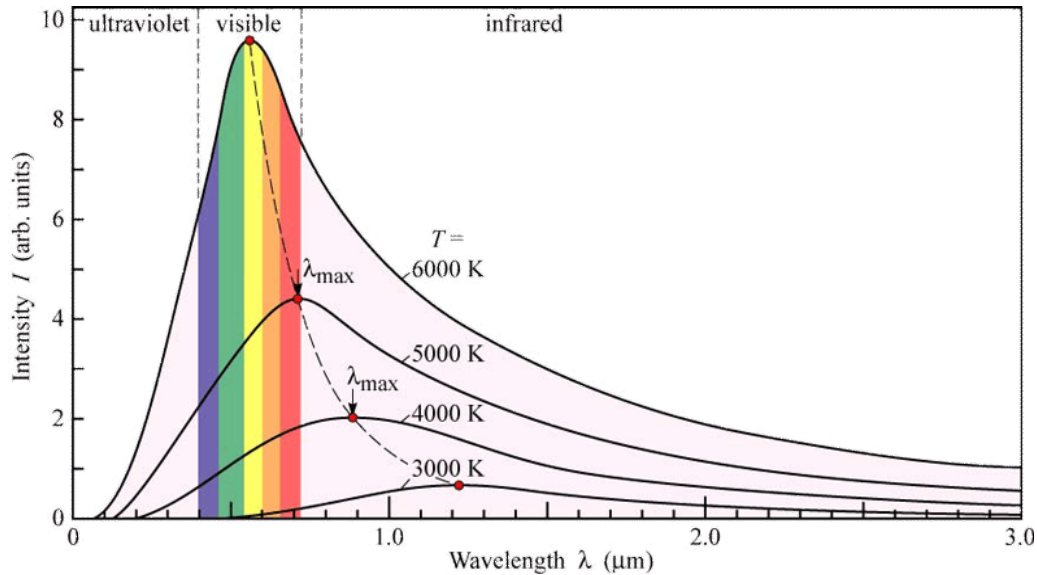
Where R is the radius of the blackbody in meters, T is still temperature in Kelvin and L is its luminosity in Watts. Conveniently, this equation can also be used to solve for radius or temperature. While the Stefan-Boltzmann equation can be used to find the luminosity of just about anything, it is nearly always used for stars. When solving for the luminosity, radius or temperature of a star we use a system of units called **solar units**. This makes problems that use the Stefan-Boltzmann equation easier by getting rid of the constants and simplifying unit conversions. The units themselves are simply the number corresponding to that property of the sun. For example, one solar luminosity is equal to $3.828 * 10^{26}$ Watts, and one solar radius is equal to $6.955 * 10^8$ meters. To find the luminosity of another star in solar luminosities, divide the luminosity of that star in Watts by the luminosity of the sun in Watts. We can do this to the Stefan-Boltzmann equation and rewrite it as:

$$L = R^2 T^4$$

Where L is luminosities in solar luminosities, R is radius in solar radii and T is temperature in solar temperatures (5778 Kelvin).

Wien's Law

The next law related to light is Wien's Law (pronounced vee-ens). It roughly states that as an object gets hotter, its peak wavelength becomes smaller. This is shown in blackbody curves, such as the one on the next page:



A blackbody curve plots the intensity of an object against wavelength- thus showing how bright it is at different wavelengths. As you can see, each curve on the diagram has a corresponding temperature as well as a 'peak' or 'max' wavelength at which the luminosity is highest. Through Wien's Law there is a relationship between the temperature of an object and the peak wavelength, so if we are given a curve like this without the temperature marked, we can find it! The equation for this relationship is:

$$\lambda = \frac{b}{T} \text{ or } T = \frac{b}{\lambda}$$

Where T is temperature in Kelvin and λ is wavelength in meters. Often Wien's Law problems are combined with Stefan-Boltzmann Law problems by giving you the blackbody curve and radius of a star and ask you to calculate the luminosity. You can do this by using the curve to find the temperature, then using the temperature in the Stefan-Boltzmann equation.

Something I forgot to mention earlier- a blackbody is defined as an object that absorbs all of the light that comes into contact with it. It can still emit/radiate light (in fact it always does this). Blackbodies are, however, only approximations of real objects; perfect blackbodies don't exist, but stars are pretty close and can be modelled as such.

Also while all objects radiate light, not all light arises due to the Stefan-Boltzmann Law. Hot gases emit light through their electrons dropping in energy levels (we use this light to study nebulae, which are giant clouds of gases). An example of this on Earth is incandescent vs. fluorescent light bulbs. Incandescent light bulbs create light by heating up the metal filament inside them enough for it to generate light via the Stefan-Boltzmann Law. Fluorescent light bulbs excite the electrons of the gas inside them; these electrons then drop in energy levels and emit light.

Doppler Effect

I know this section with all of the math has been really fun, so I'll switch it up now with...get ready...more math! (yay!) This bit is on the Doppler Effect. The Doppler Effect is simply the effect a moving source has on the light it emits. If a light source is moving towards you, the light you receive will be **blueshifted**- it will appear to have a shorter wavelength than the light that was actually emitted. Conversely, if the light source is moving away from you it will be **redshifted**- you will perceive it to be of longer wavelength than what was emitted. The doppler effect takes place not only for a moving source but for any relative motion- so it is actually the sum of the motion of the source and the motion of the observer. There is an equation relating the relative velocity to the wavelength emitted; this is used by astronomers to find the velocity of a light-emitting object:

$$\frac{\lambda_{app}}{\lambda_{true}} = 1 + \frac{v}{c}$$

Where λ_{app} is the wavelength of the observed light, λ_{true} is the real wavelength of the light emitted, v is the relative velocity of the object and c is the speed of light.

Lesson 6: Orbital Mechanics

Determining the properties of orbits was one of the first problems in astronomy, but now it's a problem you get to solve! So, get a calculator and get ready for some orbital laws!

Newton's Law of Gravitation

Since orbits are determined solely by the force of gravity, it's good to know how gravity works even though questions directly related to gravity are rare. Gravity is a force in the universe acting on all things with mass. The value of this force is found with the equation:

$$F = \frac{Gm_1m_2}{R^2}$$

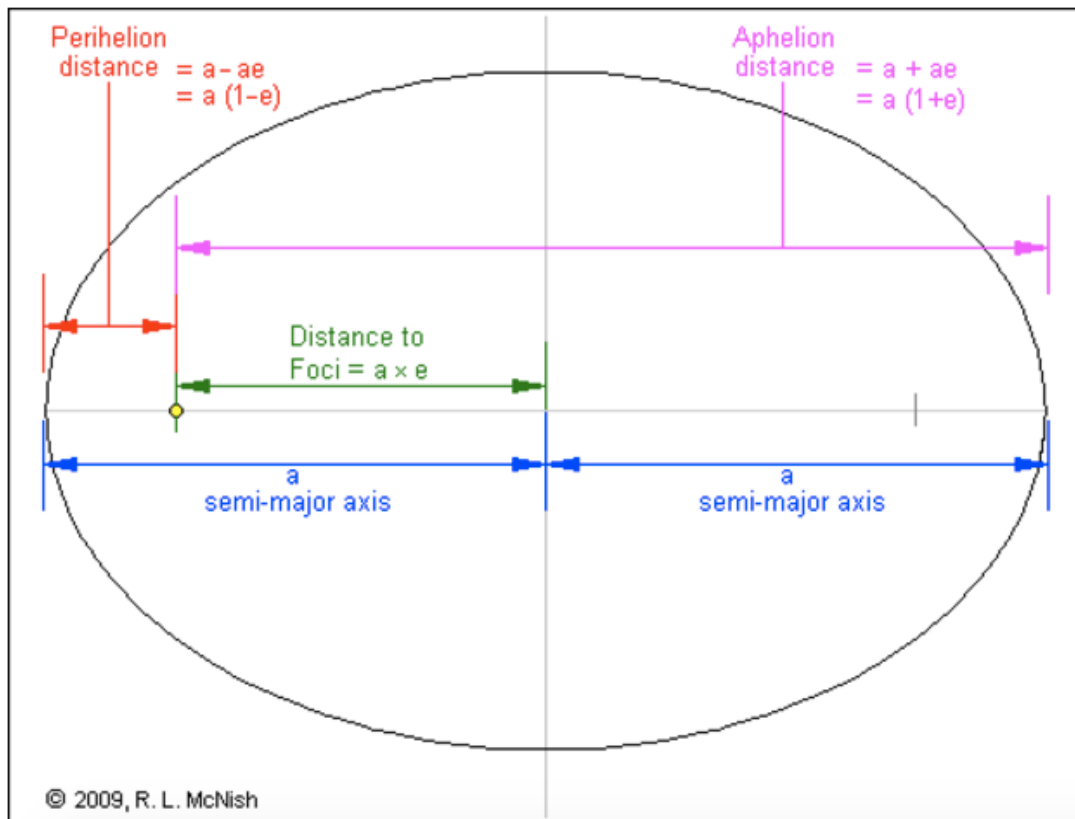
Where F is the force of gravity in Newtons, G is Newton's gravitational constant $G = 6.67 * 10^{-11} \frac{m^3}{kg*s^2}$, m_1 and m_2 are the masses of two objects in kilograms and R is the distance between the two objects (technically the distance between the centers of the objects) in meters. This equation only works for two objects, and since gravity is a mutual interaction of everything in the universe it is only a simplification.

Kepler's Laws

Johannes Kepler was a 17th century astronomer who made a number of great discoveries; one of which was his three laws of planetary motion. These laws form the basis of orbital mechanics, an area of physics describing the motion of bodies in gravitational orbit.

Kepler's First Law: Any object in orbit takes an elliptical path. This simply means that the shape of the path an object makes through its orbit is an ellipse; also, we can use the properties of ellipses to find the properties of orbits. An ellipse is a geometric shape kinda like a circle but stretched out. Imagine a circle with two of its radii marked at right angles. If the radii are the same length, it is a circle; however if they are different lengths, the shape is called an ellipse. In an ellipse, the longer radius is called the **semi-major axis**, and the shorter radius is the **semi-minor axis**.

Eccentricity is the measure of how stretched out the ellipse is, where $e=0$ is a circle to $e=1$ is so stretched it becomes a parabola. The image on the next page shows the elements of an ellipse:



Another important element noted is the **focus** (plural foci). The foci are two points along each of the semi-major axes; its distance f from the center is equal to the semi-major axis multiplied by the eccentricity. In any orbit the **barycenter**, or center of gravity of the orbital system is located at one of the foci. In most planetary orbits this is where the central star is located. There are also two points located on the ellipse and one of the semi-major axes; these points are the **periastron and apastron** (or some variation of the prefixes 'peri-' and 'ap-'). These are the closest and furthest points in the orbit from the barycenter respectively. The following table sums all of this up with a list of equations for each of the ellipse elements. Don't memorise these, but they could show up on a test:

Ellipse Element	If you know	Use
dist_{ap}	a and e	$\text{dist}_{\text{ap}} = a(1 + e)$
$\text{dist}_{\text{peri}}$	a and e	$\text{dist}_{\text{peri}} = a(1 - e)$
a	dist_{ap} $\text{dist}_{\text{peri}}$	$2a = \text{dist}_{\text{ap}} + \text{dist}_{\text{peri}}$
e	dist_{ap} $\text{dist}_{\text{peri}}$	$e = (\text{dist}_{\text{ap}} - \text{dist}_{\text{peri}}) / (\text{dist}_{\text{ap}} + \text{dist}_{\text{peri}})$
f	a and e	$f = ae$
f	a and b	$f = \sqrt{a^2 - b^2}$
f	dist_{ap} $\text{dist}_{\text{peri}}$	$2f = \text{dist}_{\text{ap}} - \text{dist}_{\text{peri}}$
e	a and b	$e = \sqrt{1 - b^2/a^2}$
e	a and f	$e = f/a$
b	e and a	$b = a\sqrt{1 - e^2}$
a	e and b	$a = b/\sqrt{1 - e^2}$

Kepler's Second Law: Kepler's second law states that an orbiting body will 'sweep out' equal areas of its orbit in equal amounts of time. This essentially means a body will accelerate as it approaches the barycenter, and slow down as it approaches the opposite focus. The difference in acceleration is greater with greater eccentricities.

Kepler's Second Law also states that the sum of the kinetic and potential energies of an orbit always add up to the same number. This is known as the principle of conservation of energy. From here, we also find that the angular momentum of orbiting objects is conserved, in the law of conservation of angular momentum. This gives us the equation:

$$M_1 V_1 = M_2 V_2$$

Where M_1 and V_1 are the mass and velocity (respectively) of object 1 and M_2 and V_2 are the mass and velocity of object 2; in an orbit with object 1 and 2. Note this only applies so circular orbits; elliptical orbits are more complicated. Some questions give you the mass of a central body and the orbital period of another body and ask you to

find the mass of the second body. As you'll see later in this lesson you'll be able to find it with this and other equations.

Kepler's Third Law: This is the big one, with lots of math. It relates the semi-major axis, orbital period and mass of the system in one equation, which is:

$$p^2 * M = a^3$$

Where p is the orbital period in years, M is the mass of the system (make sure to include the total mass of the system- include all stars; you can ignore any planets given) in solar masses and a is the semi-major axis in AU. The units are important on this one- always convert into these units before calculating; other units do not work. The period of an orbit is the amount of time it takes for an object in orbit to return to its original position.

Orbital and Radial Velocity: Now that we know how to find the period and semi-major axis of an orbit we can apply those to find the velocity of an object in orbit. There are two ways to find the velocity of an orbiting object; however these really only work for orbiting planets. The first one looks like:

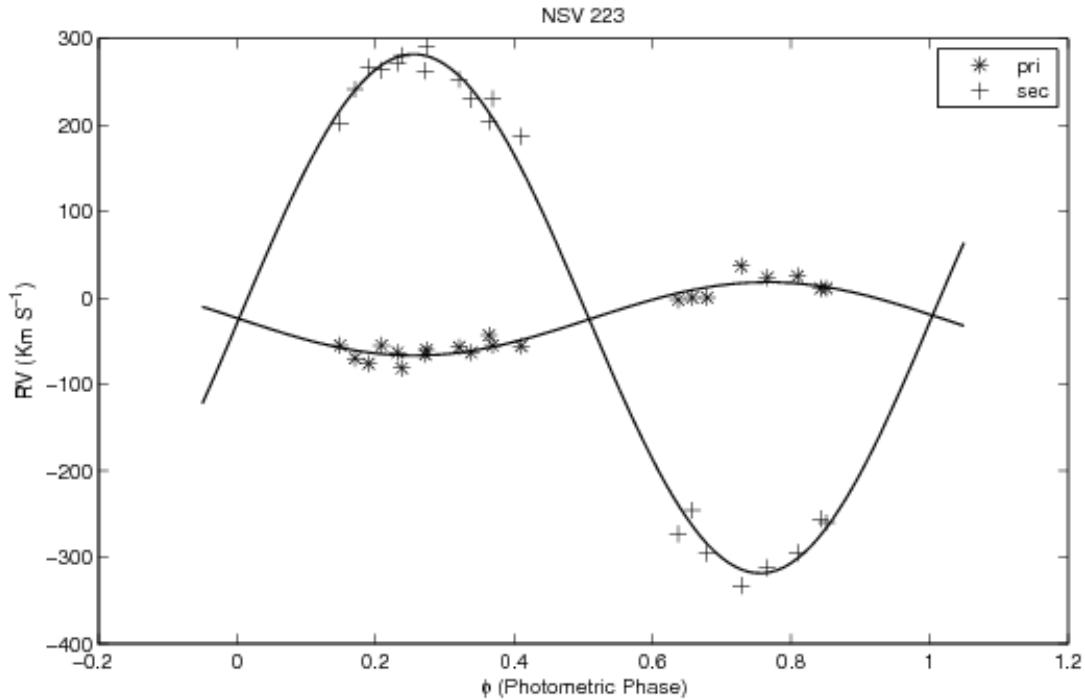
$$v = \frac{2\pi a}{p}$$

Where v is velocity of the planet in m/s, a is the semi-major axis in meters and p is the period of the orbit in seconds. This is simply the standard form of the velocity equation (velocity = distance/time) since the distance of an orbit its circumference (here we approximate with a circle) and the time is just the period. The other form is:

$$v = \sqrt{\frac{GM}{a}}$$

Where G is the gravitational constant, M is the mass of the system in kilograms and a is the semi-major axis in meters. In both of these forms you need to convert the units into the right form, otherwise the numbers will be wrong.

Radial velocity is a method used to determine the orbital velocity of stars in binary systems (star systems with two stars). It works using the doppler effect; as the two stars in the system orbit they move towards and away from us. We can measure the wavelengths of light the stars emit, and if they blueshift and redshift in a periodic fashion then we can use the doppler equation to find out how fast they are moving. A radial velocity curve looks like this:

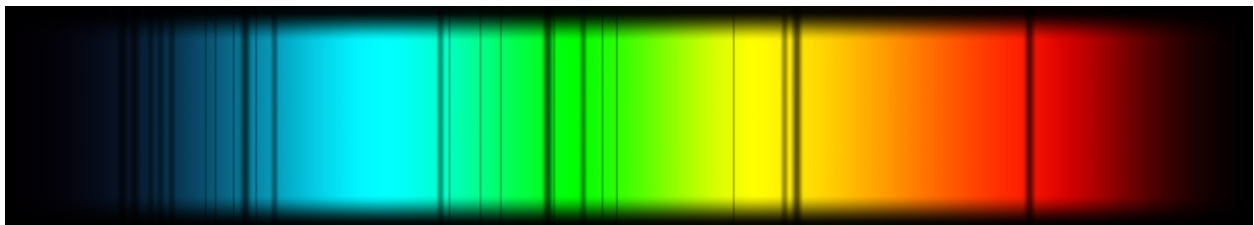


From here you can find the semi-major axis or the mass of the system depending on what you're given.

Lesson 7: Stellar Spectra and Classification

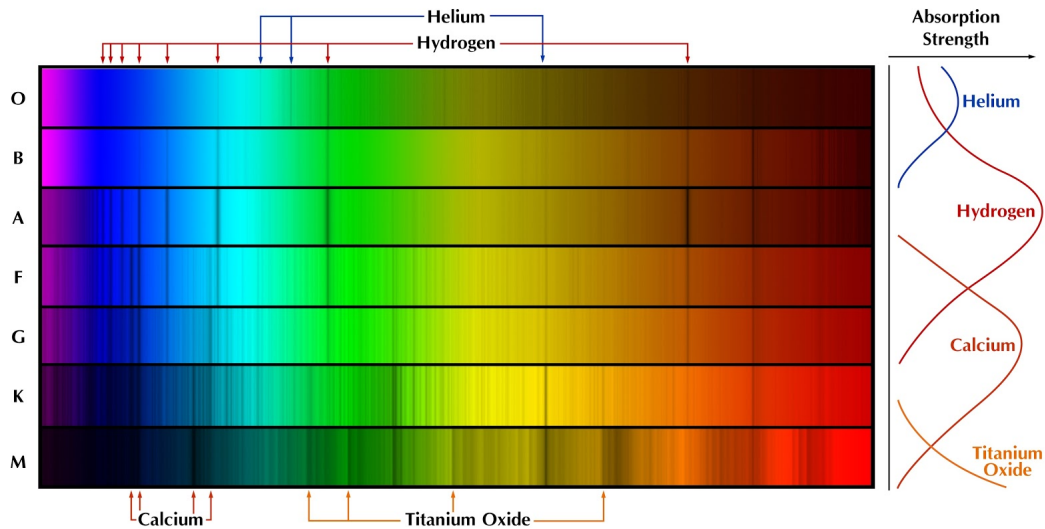
A star is typed by its spectrum and absolute magnitude. Any star fits into one of seven spectral classes, with each class having 10 subclasses. The classes are distinguished mainly by temperature. The seven classes are: O, B, A, F, G, K, M from highest to lowest temperatures. There are ten subclasses in every class, these are: 0, 1, 2, 3, ..., 9 again from highest to lowest temperature. Spectral classes are notated by class first then subclass (for example, G2 is the Sun's class). This website: <http://www.uni.edu/morgans/astro/course/Notes/section2/spectraltemps.html> has a list of the temperatures for many of the spectral classes and subclasses.

So you may be asking, "so these spectra seem cool and all, but what do they look like?" An example of a spectrum is shown below:



The dark lines throughout the spectrum are called absorption lines. These are wavelengths of light that were first emitted by the star, then absorbed by materials in the

star corresponding to the wavelengths that are no longer in the spectrum. By matching the lines to the materials that create those absorption lines we can find the spectral class of the star. This chart shows what the spectra of each main class looks like:



Sometimes tests will give a spectrum and ask what spectral class it is. Use the chart above or a similar one and match the picture they give you to the correct spectral class.

The width of the absorption lines can also help classify stars. The spectrum of a denser star will give wider absorption lines, and a less dense star will give thinner absorption lines. This effect is called spectral broadening, and we can use this to determine the luminosity class of the star. The luminosity classes are:

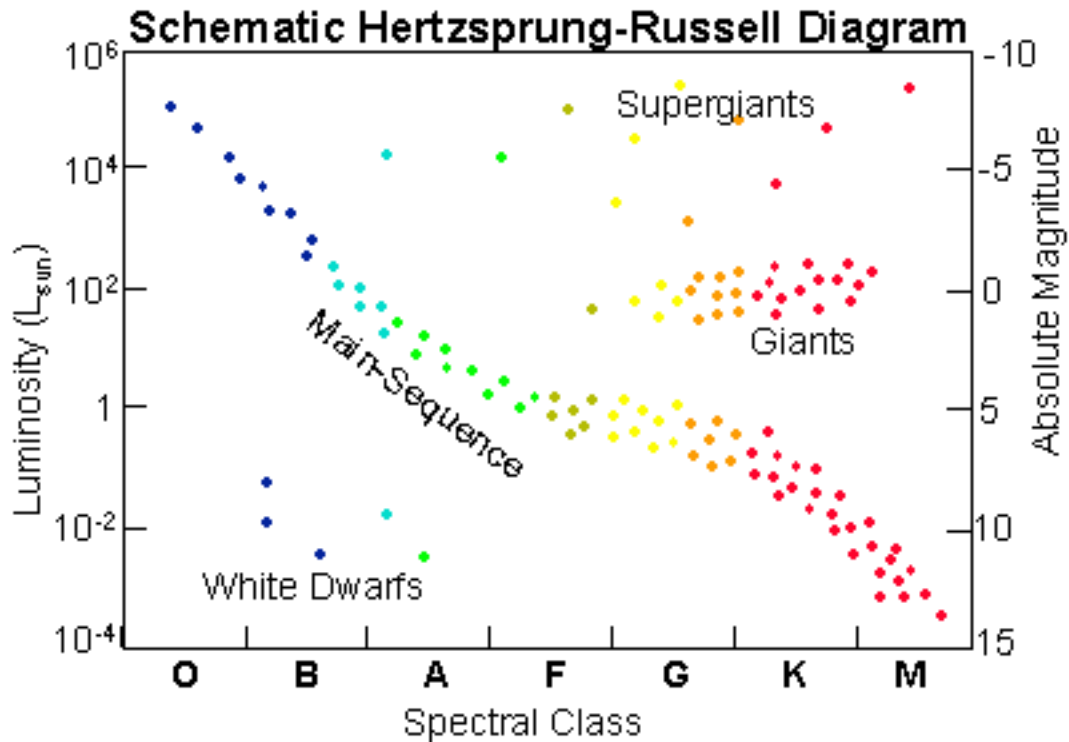
- I: Supergiants
- II: Bright Giants
- III: Giants
- IV: Subgiants
- V: Main Sequence
- VI: White Dwarfs

Each luminosity class corresponds to a stage in stellar evolution. Speaking of stellar evolution...

Lesson 8: Stellar Evolution

Before we jump into stellar evolution, you need to know about a very useful tool in astronomy: the HR diagram. HR stands for Hertzsprung-Russell, the two scientists who came up with it. This diagram plots luminosity on the y-axis and spectral class or temperature on the x-axis (note that the x-axis is reverse- as a point moves rightward on the diagram it becomes cooler). Because these two properties change throughout a star's life, a star will move its position on the HR diagram; thus, we can make

generalisations about different stages of evolution based on the position of stars in that stage of evolution on the HR diagram. Here is an example of an HR diagram:



Also mass- mass is the single most important property of any star because the initial mass a star has predicts everything in its evolution. In addition, stars with more mass go through their lives- and each stage of evolution- more quickly than less massive stars. Remember these two points when reading about stellar evolution.

Nebulae

A nebula is a cloud of gas in space. There are many different types of nebulae, but for now we're focusing on one kind- star formation regions. This is an umbrella term for any nebula in the process of forming stars; whether some stars have already formed there or no stars will form for millions of years. These regions are composed of several elements and usually molecules too, but are overwhelmingly composed of hydrogen. Hydrogen is the most common element in the universe, so naturally it's what makes up stars too.

This hydrogen (and other stuff as well) pretty much just sits in place for millions of years, moving around a bit, occasionally colliding with other hydrogen. At some point a center of mass forms in the cloud and the material in the cloud begins orbiting around it. The cloud smooths out into a sphere. Eventually, the material near the center of the cloud aggregates into a core, which begins to build up more hydrogen from gravitational interactions. This core will become a protostar.

Protostars

A protostar does emit light, however this light cannot be seen due to being surrounded by the sphere (now envelope, basically a hollowed-out sphere). The light comes from material falling into the core due to gravitational potential energy; the loss of this energy is converted into light. Along with an envelope, a disk of material around the star also forms, this is mainly where the material accreting onto the core comes from.

Eventually the envelope fragments and the material in the envelope is blown away via radiation pressure from the protostar. At some point the protostar becomes a pre-main-sequence star. The difference between protostars and pre-main-sequence stars isn't clear-cut, but the most agreeable difference I've seen is that pre-main-sequence stars are visible on Earth and protostars cannot be seen because of the envelope surrounding them.

Pre-main-sequence stars

Pre-main-sequence stars go into one of two (technically three) categories based on their mass. Pre-main-sequence stars (abbreviated as PMS star from now on) of <2 solar masses are called T Tauri stars and PMS stars of 2-8 solar masses are called Herbig Ae/Be stars. They have different types of variability, but are otherwise mostly the same. Above 8 solar masses, stars move through the PMS stage so quickly that they cannot be observed as PMS stars; only as main-sequence stars.

PMS stars follow a specific path along the HR diagram called the Hayashi track. Technically, their actual path is a combination of the Hayashi track and the Henyey track; the Hayashi track is the phase that the star transfers energy through convection and the Henyey track is the phase the star uses radiation to transfer energy. Low-mass stars spend more (relative) time on the Hayashi track and high-mass stars spend more time on the Henyey track. I'll just refer to it as the Hayashi track for simplicity. Anyway, the Hayashi track moves downwards and to the right on the HR diagram- meaning the temperature of the star is increasing but its luminosity is decreasing. From this we can tell that PMS stars are brighter but cooler than main-sequence stars. The Hayashi track takes ~3-60 million years (depending on the mass of the star) and ends when the star establishes hydrostatic equilibrium. Hydrostatic equilibrium is when the force of gravity on the star pushing inward is balanced by a force pushing outward. For main-sequence stars this force is nuclear fusion, the process of turning multiple atoms into a single atom. This converts mass into energy, which releases enormous amounts of energy.

Main-sequence stars

The main sequence takes up 90% of a star's life- by the time our sun will have reached the end of the main sequence it will have spent 10 billion years on the main-sequence. Main-sequence stars slowly move up and to the right (on the HR diagram) as they age, but other than this they don't move.

Main-sequence stars are comprised mainly of hydrogen- this is also the element they fuse. Specifically they fuse hydrogen into helium. Over time this builds up in the core and leads into the next stages in stellar evolution.

From here the paths of low and high mass stars differ, where the boundary between low and high mass is ~ 8 solar masses.

Low Mass Post-Main-Sequence Evolution

Subgiant Phase

After the hydrogen fuel has run out in the core, the star will no longer be able to sustain hydrostatic equilibrium, as nuclear reactions have stopped. Thus, gravity will overtake the outward force, and the star will begin to contract. As the star contracts the star's temperature increases. At some point, it will increase enough to begin hydrogen fusion in a shell outside the core. This pushes the photosphere outward, making the star appear brighter, and since the photosphere is now spread over more area its temperature drops. Thus, from end main-sequence the star moves up and to the left on the HR diagram during the subgiant phase. As this phase continues, the helium as a byproduct of fusion in the shell outside the core moves towards the core and builds up.

Red Giant Branch

There is no fine line between subgiant and red giant branches; the red giant is mainly a continuation of what began in the subgiant phase. The core contracts more and more, the outer layers continue to expand. It moves much further upward on the HR diagram, because of how much larger the outer layers are. The temperature is spread out over a much larger volume because they are much larger, so the total temperature decreases, and the star moves to the right on the HR diagram.

Horizontal Branch

At the end of the red giant branch, the core will have enough heat and pressure to begin fusing helium into beryllium, carbon and oxygen (but mostly just carbon). This reinvigorated nuclear reaction (also known as the helium flash) heats up the star, but it also makes the star larger; this creates a (roughly) zero net change in luminosity so it moves horizontally to the left on the HR diagram. Hence, the horizontal branch. As the core becomes increasingly made up of carbon, the star will start heating up again and the star moves to the right on the HR diagram.

During this stage the star will be part of a class of stars called 'pulsating variables'. These stars vary in brightness by becoming larger and smaller periodically. There are many types of pulsating stars; some notable ones are RR Lyrae and Cepheid variables. Both of these are used as standard candles; RR Lyrae stars always have the same range of luminosities and Cepheids have something called a period luminosity relationship. In both of these cases we can use the distance modulus to find the distance to objects.

Asymptotic Giant Branch and Planetary Nebula

For the star there is nothing left other than a dense core in the middle and some loosely bound layers of gas outside of it. This stage is similar to the red giant branch, but instead of helium buildup at the core it's carbon buildup. The radius of the star is so big that the distance separating the outer layers and the core is large enough that the core can't keep in the outer layers, and they are ejected away from the core. This spreads the gas over a huge volume, so the luminosity stays really high, and without the cooler outer layers, the core becomes very hot; the star moves to the upper-left corner of the HR diagram. The outer layers form a planetary nebula. At some point the planetary nebula is so far spread out that it no longer contributes to the luminosity of the core, so the star drops to the bottom left corner, and becomes a white dwarf.

White Dwarfs

White dwarfs are small and hot. Their surface gravity is extremely high. If a white dwarf is formed in a single-star system, then it will radiate its energy away, which slowly cools it off, and eventually becomes a black dwarf. This is basically a floating ball of carbon and other elements in space. The universe hasn't been around long enough for black dwarfs to form, but current astrophysics predicts their existence.

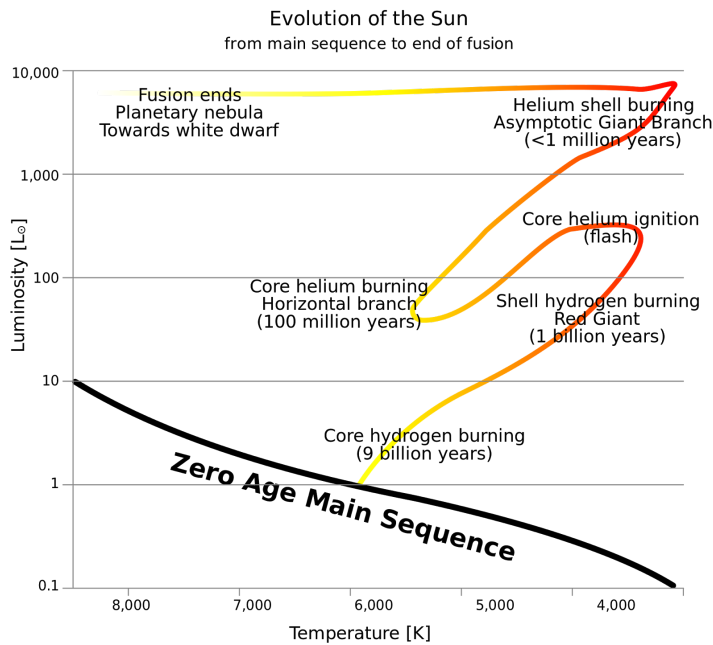
White dwarfs aren't made of "normal" matter like you find on Earth; instead they are made of degenerate matter. In normal matter electrons fit into orbitals, something you've probably learned in chemistry class. Two important quantum mechanical laws apply to electrons: 1) two electrons cannot occupy the same space and 2) the smaller space an electron is confined to, the greater its momentum. Now, this normal matter has a relatively constant distance between each of the electron orbitals. However, the gravity of white dwarfs presses down with an immense force. This forces the electrons in the white dwarf to be pushed closer together. As a result of the electrons being confined to a smaller space, their momenta increases dramatically; considering this occurs over the entire white dwarf it adds up to enough pressure to stop the star from collapsing. This pressure is known as electron degeneracy pressure. However, this can only sustain white dwarfs up to a certain amount of mass. If the mass of a white dwarf exceeds this limit, it will violently explode in an event called a supernova.

Type Ia Supernovae

The limit mentioned is the Chandrasekhar limit. At 1.44 solar masses, very few stars end up exceeding the limit. However, if the white dwarf is in a binary system, it has a good chance of going supernova. Take a binary system with main-sequence stars of different initial masses. The higher-mass star will go through its life faster than the lower-mass star, and will become a white dwarf while the other star is still in main-sequence. Once the lower-mass star has reached the end of the main-sequence and begins to expand, if the two stars are close enough the white dwarf can pull in some of the mass of the giant via gravity. If it pulls in enough mass to exceed the

Chandrasekhar limit, it will go supernova. The extra mass on the white dwarf triggers all of the matter in the white dwarf to fuse, releasing a huge amount of energy in a thermonuclear explosion.

There are two ways for the type Ia supernova to occur; the above is one of them, however there is another. A binary system of two white dwarfs will slowly give off gravitational radiation (aka gravitational waves). This causes the distance between the white dwarfs to shrink, culminating in the merging of the stars. As the resulting star is more massive than the Chandrasekhar limit, it explodes in a type Ia supernova.



Note that this is a type Ia supernova. High mass stars can undergo a type II supernova. Speaking of high mass stars, this is the post-main-sequence evolution of stars with masses >8 solar masses:

High Mass Post-Main-Sequence Evolution

High mass stars evolve mostly the same way as low mass stars up through the horizontal branch (only they do each stage faster). That's where things begin to differ.

Horizontal Branch / Asymptotic Giant Branch

Just like low mass stars, high mass stars burn helium in their cores into carbon and other elements. However, stars above eight solar masses can fuse carbon once the carbon core has contracted enough. Carbon fuses into neon and other elements; the neon builds up and begins fusing into other elements- this continues until the core fuses elements into silicon. Each time a new element is fused the star makes another 'loop' on the HR diagram; heating up while fusing the element in the core and cooling down while fusing it in outer shells. Silicon fusion creates iron. Iron is different because it

cannot fuse in the core of a star; instead it undergoes fission. Fission is the reverse process of fusion; it breaks apart an atom. Iron fission is really inefficient, so when this process begins it takes all of the energy out of the core. This unbalances the hydrostatic equilibrium and the core collapses. This leads to a type II supernova.

Type II supernova

The collapse of the core from iron fusion is stopped by one of two things- neutron degeneracy pressure or black hole formation. Either way, the collapse creates a shockwave that travels outwards with an extreme amount of energy. This meets the outer layers and sends them outwards with an extreme amount of energy. This energy heats up the material enough to fuse more heavy elements, and also makes the remnant very luminous.

Neutron Stars and Black Holes

Back to the core now. If the original star was 8-25 solar masses, then a force called neutron degeneracy pressure will stop the collapse of the star. Basically, a neutron star is the remaining core from a high mass star. When electron degeneracy pressure isn't high enough to stop the collapse of the star, the electrons of all the atoms are forced into the atomic nuclei. Due to a weird quirk, the protons and electrons merge to become neutrons, and the star is made up mostly of neutrons. The collapse of the neutron star is held back by a force called neutron degeneracy pressure; this is similar-ish to electron degeneracy pressure but much stronger.

When neutron degeneracy pressure isn't enough to stop the collapse of the star, there is one last force that can stop it. Haha, just kidding. The star collapses, completely. To a single point of infinite density; a black hole. This occurs at an initial mass of >25 solar masses. Black holes are currently one of the frontiers of modern physics, and rarely show up on scioly tests, but can be quite interesting if you want to study them in your freetime.

Lesson 9: Strategy

However interesting astronomy is as a subject, you won't place first by studying aimlessly. This section focuses on the competition and how to beat the other teams.

Laptop or Binder?

For the Astronomy event, your team (assuming you bring two people to competition) is allowed to bring two laptops, two binders or a laptop and a binder. Each has its pros and cons, which will be discussed here:

Laptop:

- Pros
 - Can hold much more information than a binder
 - No printing required

- Easy search function if you know what you're looking for (Ctrl+f)
- Fits better on a desk than a massive binder
- Can write/download programs
- Cons
 - Has lag :/
 - Can be expensive if you don't already have a personal laptop
 - Hard to switch between pages
 - Navigation is difficult when trying to find a specific section
 - More breakable than a binder (this happened to my partner a few days before nationals)
 - Can run out of battery at inconvenient times

Alternatively, tablets count as laptops, which has its own set of pros/cons.

Binder:

- Pros
 - Viewing is much easier with two pages at a time
 - Zero lag (you fly through the pages with sheet protectors- also sheet protectors allow you to do two-sided pages)
 - Cheap (except for printing costs), basically indestructible and battery never runs out
 - You gain valuable info by writing the content in the binder
 - No Ctrl+f, but you can use tabs if you know where to find stuff
- Cons
 - Printing can be a problem if you don't have easy access to school/home printers
 - Takes a long time to prepare, which is troublesome if state is a week away
 - No programs
 - Takes up a lot of space on a desk

So much of this is circumstantial- if you and your partner each have a personal laptop and no easy access to printing, then two laptops would be totally fine. On the other hand, if your families don't let you have a computer then binders would be the better choice. However, if you have the option to, **make at least one binder, even if you never bring it to competition. The knowledge you gain by writing one is priceless.** At regionals this past year I thought using two laptops would be okay. I placed first, but I didn't deserve to- in the end, writing a binder made me better at Astronomy than anything else. I don't suggest the binder for its use in competition- I only used it once or twice during nationals- but because after writing it you won't need it.

A second binder really won't help you much more than the first one, so overall I suggest one binder and one laptop. But of course, it's up to the preference of you and your partner.

Write all of your resources yourself

I cannot stress this enough. I've seen entire binders- some from teammates- that look really impressive with 300+ pages...printed off Wikipedia and other online resources they found. You'll have no time to use those during competition. A binder you write yourself may have less info overall, but it will probably be worth a lot more if it's information you know you'll need. If you do all the research and write everything in your own words, you'll probably remember most of it; then you won't need to reference it during competition.

Use Wikipedia responsibly

Often test writers will pull questions directly from Wikipedia pages; usually because they don't care to do the proper research. Use this to your advantage- take everything listed on the Astronomy rules (including the DSOs) and print off the wikipedia page for it, then place it where it fits in your binder. However, don't rely on wikipedia; make sure to do most of your own research and write it up yourself.

Ratio Method (also called proportionality)

This is a method to do math questions more quickly. Often test writers will ask a question like "star A is 10 times larger than star B and the same temperature; how many times more luminous is star A than star B?" The easiest way to do this is to take the ratio of the Stefan-Boltzmann Law of star A and divide it by the SB Law of star B. This will look something like this:

$$\frac{L_A}{L_B} = \frac{(4\pi)R_A^2\sigma T_A^4}{(4\pi)R_B^2\sigma T_B^4}$$

Since $4\pi = 4\pi$, $\sigma = \sigma$, and $T_A^4 = T_B^4$ we can remove them from the equation. This leaves us with:

$$\frac{L_A}{L_B} = \frac{R_A^2}{R_B^2}$$

Now we can substitute 10 for R_A and 1 for R_B , which gives us an answer of 100 times more luminous. You can do this for almost any equation in astronomy; try using it to figure out the best way to do math problems.

Binder Structure

The way you set up your binder is mainly up to you, but there are two important things to have: 1) a separate section for DSOs (and one page for every DSO) and 2) an easily accessible page with important equations and constants (Wien's Constant, the solar radius in meters, the parsec in meters, etc). These two will be the pages you'll use the most during the competition so know where they are.

DSOs

As I mentioned near the beginning of this guide, DSOs are Deep Sky Objects; there are 17 listed on the rules every year, and they represent the topics for that

season. Questions of any kind can be asked for on tests; anything from its distance from Earth to whether it has methane in its atmosphere, so make sure to have plenty of info on each one. Test writers also ask for basic identification of the object from pictures; the best way to do this is to pull as many pictures as possible from google images onto your notes sheet for that DSO. Here (on the next page) is an example of a DSO page I used for last season:

Overview: T Tauri is a variable PMS star in the constellation Taurus, and the prototype for T Tauri stars in general. It appears near the Hyades open cluster, and is physically close to Hind's Reflection Nebula, giving it a characteristic look in photos.

Physical Details

Absolute Magnitude: 4.42

Apparent Magnitude: 10.27

Spectral Type: G5

Mass: 2.1 Solar Masses

Age: 0.4 Ma

Distance and Appearance

Distance: 481 LY, 147.6 Pc

Constellation: Taurus

Right Ascension: 04^h 21^m 59.43445^s

Declension: +19° 32' 06.4182"

Parallax Angle: 0.00548 arcseconds (5.48 mas)

Color Indices: *U-B*: +0.8 *B-V*: +1.22

Other Features

Radial Velocity: 23.9 km/s

Proper Motion: +15.51 mas/yr (RA), -13.67 mas/yr (Dec)

Other Names: T Tau, **AG**+19° 341, **BD**+19° 706, **HBC** 35, **HD** 284419, **HH** 355, **HIP** 20390, **JP11** 3794, **VDB** 28

-The T Tauri system has 3 stars. The visible one is called T Tau N (the one I've been talking about) and shows silicate emissions. T Tau Sa is the largest body in the system, shows silicate absorption and emits with huge variations in the infrared. T Tau Sb is the smallest one, has no observations of silicates and is observed as an 8th magnitude star with a spectral class of M0.

Discovery

It was first discovered in 1852 by John Hind. At that time, it had been dimmer, but started increasing in luminosity; was at the 10th magnitude. He also discovered next to it Hind's reflection nebula (NGC 1555), which also varies in luminosity based on that of T Tauri. Papers in the 1860s noted it was no longer visible. In 1890, Shelburn Burnham found that T Tauri was in a small nebula, now called Burnham's nebula (not a

reflection nebula). This nebula is no longer visible. A Herbig-Haro object (HH 355) is 30 AS west of NGC 1555, and could be related to either T Tauri or 1555.

T Tauri South was discovered by Simon Dyck in 1982, due to strange variations in the infrared. This was confirmed and data had begun to be collected, it was later found that it has variations of 2 magnitudes in the L and K bands.

Koresco et. al. in 2000 with the M. Keck observatory discovered another body next to T Tau S. This was called T Tau Sb, and T Tau S was renamed to T Tau Sa.

Other Stuff:

- Chosen as prototype for T Tauri stars because it was the best studied, had clear absorption and emission features to characterize the group and was the brightest
- From around its discovery to the 1920s it had variability of 3-4 magnitudes, and the nebulae varied along with it. But in the 1920s the variability slowed down to a mere 0.4 magnitude.
- Shows a property of face-on and edge-on disks where we can't see all of the spectra; called disk inclination.
- This results in a spectra including special absorption and emission lines for silicates. This type of spectra is called a P Cygni profile.
- Eventually was found that the initial variability of T Tauri was due to movements related between the three bodies.
- Resulted in a theory that all T Tauri stars start off as multiple star systems, but one ejects the other stars farther away.
- Surrounded by Burnham's nebula. This was formerly visible however it is not anymore.

