This document contains sample/generic answers which I personally constructed in the weeks leading up to the HSC exams. Each response is essentially a generic response for a given syllabus Dotpoint. Each response was refined and critiqued heavily. Hope it helps!

Describe how spectra can provide information on surface temperature, rotational and translational velocity, density and chemical composition of stars.

Surface Temperature:

Spectroscopes produce an accurate spectrogram of stars, which can be analysed to identify the most intense wavelength. Using Wien's Law, the surface temperature of the star can then be found: T = W/Max Wavelength.

Translational Velocity:

Translational velocity relates to the star's linear velocity relative to the Sun (made up of its radial velocity determined by Doppler shift and proper motion determined by astrometric measurements). The Doppler Effect is the apparent frequency (or wavelength) change due to relative motion between source and observer. A star moving away from Earth will have red-shifted spectral lines, whilst a star moving towards Earth will have blue-shifted spectral lines. The greater the shift in spectral lines, the faster the star is moving towards/away from Earth (extent of shifting can be determined since we already know what wavelengths the absorption lines for a specific element should be at).

Rotational Velocity:

Rotational velocity refers to a star's angular velocity spinning on its axis. Stars that rapidly rotate on their axis will have one side rotating towards Earth, and the other away. Thus, its spectral lines will appear both red and blue shifted, which causes the spectral lines to broaden. The faster the rotational velocity, the greater the broadening effect. Extent of broadening can be used to determine the star's rotational/angular velocity.

Density:

The more dense a star's atmosphere is, the greater the broadening of its spectral lines. In high density stars, increased gas pressure produces more collisions between atoms during emission and absorption, which causes small changes in electron orbits and consequently, spectral lines broaden. Larger stars have less dense outer layers and as such, have narrower spectral lines, so broadening of lines can be used as an indicator of a star's size.

Chemical Composition:

Elements in a star's atmosphere absorb light from the star's continuous spectrum, which is produced by its hot core. Each element produces characteristic spectral lines that correspond to its electron energy level transitions (difference in energy between ground state and higher orbit) in the atoms. By comparing absorption lines found in spectrum with those produced by elements in labs (standards), specific elements found in a star's atmosphere can be identified. Moreover, the intensity of the absorption lines reveals the relative intensities of the elements present.

Note:

Since both angular velocity and density of a star broaden spectral lines, more information than just the width of spectral lines is needed. Knowing the luminosity classes will help distinguish between a red giant and a red main sequence, for example. The red giant has low density outer layers compared to the small main sequence star.

Describe the technology needed to measure astronomical spectra –

Astronomical spectra consist of the range of wavelengths of visible light and can be viewed using a spectroscope. A spectroscope serves to spread light into its spectrum, and has 3 main components:

1. **The Collimator → has several narrow slits and lenses that form parallel beams of light.**
2. **The Dispersive Element → consists of a glass triangular prism, or diffracting grating. This disperses light into its spectrum, based on the principle that different wavelengths of visible light have different refractive indexes. For example, blue light travels slower than red light and thus blue light is refracted more.**
3. **The Recording Device → views, records and analyses the different wavelengths formed. The wavelengths are passed through a small telescope with a photometer/CCD (electronic sensor) attached, which measure the intensity of each wavelength (photons collected), producing an intensity graph vs. wavelength graph (spectrogram). Essentially, the spectrograph produced is a blackbody curve superimposed by dark absorption lines.**

Describe the processes involved in stellar formation –

An interstellar gas cloud (containing mostly H) slowly contracts due to gravity. The density increases most quickly at its centre, and being denser, the centre experiences greater gravity and contracts even faster, thereby separating the gas cloud into a rapidly contracting core, and slower contracting surroundings. Accretion of material occurs as the mass of gas and dust in this core is growing larger, and causing its gravitational field to grow thus attracting more of the surrounding matter. The GPE lost by this material is transformed into EK, heating up the core, whilst some is radiated away (mostly as infrared). This heat radiation (radiation pressure) produces an outward force against gravity, slowing and eventually stopping the collapse (hydrostatic equilibrium) and stabilising the core → PROTOSTAR is formed. Now, if matter from the surrounding cloud continues to accrete onto the protostar, thereby increasing its mass and inwards gravitational force, the pressure in the core will increases. Over time, stellar winds blow away the surrounding cloud remnants, allowing us to see the star. Since the protostar no longer has a surrounding cloud, there is no source of further energy, causing it to contract, becoming less luminous but hotter at the core. When the core reaches 8 million K, nuclear fusion is triggered. As the core fuses H, the star becomes stabilised, producing a ZERO-AGE MAIN SEQUENCE STAR, which is smaller (0.01-100 solar masses) and more luminous than the previous protostar.

Outline the key stages in a star's life in terms of the physical processes involved and discuss the synthesis of elements in stars by fusion –

Initially, a star starts as a cloud of dust and gas. This nebula contracts due to gravity. As accretion occurs, lost GPE of the material is converted to EK and some is radiated out as infrared. When radiation pressure = gravitational force, a protostar is formed. As accretion continues, gravitational force exceeds radiation pressure, the protostar will contract and core pressure will increase. Eventually, it may become hot enough to trigger nuclear fusion (8million K), thereby becoming a main sequence star. The greater the mass of main sequence stars, the greater the gravitational pressure on its core and thus the greater the radiation pressure acting outwards must be to balance the inward pressure (to achieve hydrostatic equilibrium). Therefore, heavier stars consume their fuel faster so they exhaust it more rapidly and thus have shorter lifetimes. Extra energy released by higher mass stars reaches the surface of the star and is radiated off into space, appearing more luminous.

As pp chain or CNO cycle takes place and H fuel is depleted, the core collapses and gravitational force increases the core's density and temperature. In larger stars, the He shell around the core is compressed, producing high temperatures causing fusion of He into C to begin (helium flash – explosive triple-alpha reaction). The star is now a red-giant or supergiant, and radiation pressure exceeds that of a main sequence star, and is enough to achieve equilibrium between pressure and gravity. Red giant shells fuse H, and heavier elements are pushed closer to the core. Once He is exhausted, a similar process is repeated with carbon, which fuses to form Ne and Mg. This process repeats until the star cannot reach core temperatures large enough to fuse heavier elements (Fe core is max), which are endothermic (consume energy) rather than exothermic (produce energy) → energy input is greater than energy output. Fe and heavier elements form through a net input of energy, which occurs in a supernova. Supernova result when the nuclear fuel of stars of mass >5 is exhausted, and thus radiation pressure cannot balance gravitational force, crushing inwards and causing the star to implode. The large, rapid loss of GPE is converted into EK & HEAT causing the supernova explosion that lasts several weeks during which fusion reactions do not need to be exothermic (they provide a big energy input). The massive explosion synthesises all naturally occurring elements and many unstable isotopes, which are blasted off in all directions into the surrounding galaxy/nebulae where new stars eventually form.

Describe the types of nuclear reactions involved in Main-Sequence and Post-Main Sequence Stars:

Main Sequence Stars fuse H → He with the net equation: 4 Hydrogen → Helium + 2 Positrons + 2 Neutrinos + Energy. Smaller, cooler (Core <16 Million K) main sequence stars achieve this net equation through the proton-proton chain reaction where proton are successively added, producing helium. This reaction is the starting point of zero-age main sequences. This method of hydrogen fusion occurs more frequently and is more likely to occur. It may occur for 10 billion years. Larger, hotter (Core >16 Million K) main sequence stars operate at higher temperatures can fuse hydrogen via the CNO cycle where carbon is a catalyst in the nuclear fusion thereby producing helium. This process is cyclical and may occur for a few million years.

Red Giants (post main-sequence stars) fuse heavier elements successively in their core when temperature/pressure is high enough to ignite helium flash ~100 million K). H has been mostly consumed, red-giants fuse He in their cores via triple-alpha reaction, whilst shell H fuses to He.

Explain the concept of star death in relation to planetary nebula, supernovae, white dwarfs, neutrons stars/pulsars and black holes –

When a giant star eventually develops a core of material that it cannot fuse (core doesn't get hot enough or core is Fe which will not fuse to produce energy) surrounded by shells that are still fusing. Now, the death of every star follows a similar pattern → shells are shed into space and core collapses under gravity. The way this occurs depends on the original mass of the star. A star will always proceed from the red giant/supergiant stage into one of these.

Planetary Nebula (Original Mass <5):

Planetary nebula are discs of glowing gas that surround a core, and occur when a star of <5 solar masses dies. Since radiation pressure stops, the unsupported shells of red giants are unstable, producing thermal pulses/superwinds (bursts of energy). These combine to flow material rapidly away from the star, dispersing the shells, leaving the contracted core as a white dwarf. The white dwarf emits UV, exciting the nebula, causing it to grow as it forms rings of material around core.

White Dwarfs (Core Mass <1.4):

White dwarfs are not stars as they do not fuse elements in their core. They are the white hot, very dense core of an older star that remains after the planetary nebula stage. They have a small SA thus low luminosity. As core fusion has stopped, it contracts under gravity to very high pressures. The electron degeneracy pressure (resist being forced into nucleus) balances gravity (quantum effect - Pauli Exclusion Principle). The Chandrasekhar Limit is the greatest mass a white dwarf can have since if core >1.4M, electron degeneracy pressure cannot withstand gravitational collapse

Supernovae (Original Mass >5):

Supernovas are violent explosions of uncontrolled nuclear reactions that completely blows away the layers of a massive star leaving behind a highly dense core. As core fusion stops, the star collapses under its own gravity, releasing a huge amount of GPE thus superheating the collapsing matter, igniting a forceful explosion that blows the star apart. The matter spreading out from the exploding star glows and emits gamma/x-rays giving out as much energy in days as it has in its whole life. The star drastically increases in luminosity but only for a few days/weeks, with the remnant core forming a neutron star or black hole depending on its mass.

Neutron Stars/Pulsars (If Remnant of Supernova has Core 1.4-3M):

Neutron stars are extremely dense remnants of a massive star's core. Pulsars are rotating neutron stars that emit beams of EM from their magnetic poles that are seen from Earth as timed-pulses. When larger mass stars die in a supernova, gravity is so strong it causes contraction, forcing protons and electrons to combine producing neutrons. Degenerate neutron pressure stops further contraction, producing a neutron star/pulsar. Pulsars rotate very rapidly (600 revolutions/second), emitting intense, focussed beams of radiowaves/x-rays/gamma from their intense magnetic fields, which are detected as pulses when Earth is in the path of rotation.

Black Holes (If Remnant of Supernova has Core >3M):

Black holes are dense, crushed remnants of a massive star's core. Since remnant >3M, degenerate neutron pressure cannot stop contraction. Gravity surrounding this point is so strong that the core is crushed to a point of infinite density (a singularity → point of infinite density and 0 volume). Here, gravity is so strong that not even light can escape from within a certain radius (event horizon). Black holes are detected due to their effects on surrounding matter.

Describe methods in which ground-based systems can have their resolution and sensitivity improved –

1) Active Optics → uses a slow feedback system to correct deformities and sagging in the primary mirror of large reflecting telescopes, which result from the effect of gravity on them. Starlight that leaves the primary mirror is slowly sampled by a wavefront sensor that uses interferometry to detect changes in the incoming light. A computer analyses data from the wavefront sensor and calculates the optimal mirror shape needed to correct distortions. The thin, segmented primary mirror is fitted with actuators that push/pull the large mirror into the correct shape. Therefore, the primary mirror's shape is altered to correct factors affecting image quality once per minute (slowly), thereby improving resolution.
2) Adaptive Optics → uses a fast-feedback system to correct for atmospheric distortion, thereby improving resolution. Light from a bright reference star (if present) or an artificial one made by shining a laser beam up is used to measure blurring caused by the atmosphere. A computer processes the information from the reference star. Corrections are made and applied to a deformable mirror that has actuators (thrusters) that push/pull the secondary mirrors around 1000 times per second. Detection and correct must occur quickly as atmospheric changes occur constantly.
3) Interferometry → involves a cluster of small telescopes (e.g. Radio Telescopes linked via fibre optics) in a large pattern. The wavefront (data) of the same celestial radiation source from each telescope is added by computers that analyse the interference patterns. The image yielded has a resolution of a single objective lens with a diameter equal to the distance between the telescopes and thus, is sharper with a greater resolution and sensitivity.

Explain how the age of a globular cluster can be determined from its zero-age main sequence plot for an H-R diagram –

Open Clusters are physically related groups of stars held together by mutual gravitational attraction and hence populate a limited region of space. Together, they are at the same distance away from Earth. They have very interesting properties: stars are all about same distance away, same age, same chemical composition but different masses (0.08-100 Solar Masses).

Globular Clusters are gravitationally bound concentrations of hundreds and thousands of stars spread over a large area of space (10-200ly in diameter). They contain less elements than main-sequences and are thus believed to be very old. HR diagrams for globular clusters typically have short main-sequences and prominent horizontal branches.

<u>AGE OF CLUSTERS</u> can be determined from its zero-age main sequence plot on an HR diagram. As a cluster ages, the main sequence shortens from the top as the stars progressively evolve into red giants in order of their mass. The highest remaining point of the main-sequence group is the turn-off point. The lower this point, the older the cluster. Using this method, globular clusters are estimated to be relatively old (12-15 billion years), whilst open clusters are relatively young (100 million years). Stars close to the turn-off point suggests they are near the end of their lifetime (its age can thus be predicted) and the age of a star at the turn-off point, the age of the globular cluster (since all stars in same cluster have same age). Scientists have determined an age scale for clusters, which is sometimes used on the y-axis.

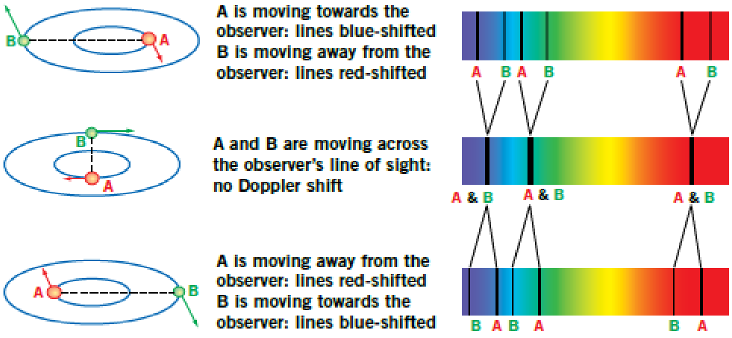

Figure 23.2.3 The changing pattern of spectral lines in a spectroscopic binary (very exaggerated)