PHAS1511 – problem sheet 2 14 January 2010

Please return this, either via e-mail or to my pigeon-hole, by 16 February 2010

1. Draw and label a Hertzsprung-Russell Diagram. What is happening inside stars that are on the *main sequence*?

(5)

The diagram should have temperature decreasing on the x-axis, and luminosity increasing on the y-axis. It should show the main sequence, the giants and supergiants, and the white dwarfs. Stars on the main sequence are fusing hydrogen into helium, and are in a state of *hydrostatic equilibrium* – that is, the weight of the gases in their outer layers is balanced by the energy generated in the core, and the star is neither contracting nor expanding.

2. What will happen to a star with a mass of 1 solar mass after it runs out of hydrogen in its core?

(5)

When the hydrogen runs out, the core no longer produces the energy required to support the outer layers of the star. The core starts to contract, and heat up. The outer layers will expand vastly, and cool. Eventually the core will become hot enough for helium fusion to start. This will halt the contraction and return the star to a steady state, temporarily. When helium in the core runs out, the core will again contract and heat up. Helium burning continues in a shell around the core. This is very unstable, and giant pulsations will eventually kick off the outer layers of the stars. These will be lit up by the exposed core, forming a planetary nebula. Once this has drifted away, a white dwarf is all that's left behind.

3. Give two reasons why collisions between stars are extremely rare. Explain why these two reasons don't apply to galaxies. (4)

Stellar collisions are extremely rare because the distances between stars are very large compared to the sizes of stars – eg, the diameter of the Sun is about 1.5 million kilometres, while the distance to the nearest star, Proxima Centauri, is 1.3 parsecs, or $4x10^{13}$km. This is millions of times larger than the diameter of the Sun.

In addition, in galaxies, stars in a particular region will generally be moving in similar orbits around the centre of mass of the galaxy. In our spiral arm of the Milky Way, all the stars are moving in the same direction in their orbits around the galaxy.

Galaxy collisions are much more frequent. Firstly, the sizes of galaxies are large compared to the distances between them – for example, the Milky Way and the Andromeda Galaxy are both around 100,000 light years across, and the distance between them is about 2.2 million light years, so the separation is only about 20 times their size.

And galaxies within clusters are not orbiting in the ordered way that stars in the Solar neighbourhood are orbiting – their motions are much more random, and their paths much more likely to intersect.

4. What observations of a star do we need to measure its motion along the line of sight? What observations do we need to measure its motion in the plane of the sky? (3)

We need spectroscopic observations to measure the motion of stars along the line of sight. By observing spectral lines whose wavelength in the laboratory we know, we can measure the Doppler shift and therefore the velocity of the star.

To measure motions in the plane of the sky, we need two images separated by a long enough time to detect the very slow apparent motion of the star across the sky. The time may be a year or two for the closest, fastest-moving stars (such as Barnard's Star), but will be longer for more distant or slow-moving objects. To convert apparent motions into actual velocities, we also need to know the distance of the star.

5 a) The star Vega in Lyra has a parallax of 129 milli-arcseconds. What is its distance in parsecs? (1)

Distance in parsecs = 1 / parallax in arcseconds, therefore its distance is 7.75 parsecs

b) If we carefully measure the amount of energy we receive at Earth from Vega, we find that it is $2x10^{-8}$ W/m^2. What amount of energy is being emitted by Vega? The solar luminosity is $3.839x10^{26}$ W – how much more luminous than the Sun is Vega? (4)

The distance of Vega is 7.75 parsecs, which is equal to $2.4x10^{17}$ metres. The energy we receive from Vega here is equal to the energy it emits, spread out over the surface of a sphere with a radius equal to the distance between here and there. The surface area is $4\pi R^2$ = $7.18x10^{35}$m^2, and so multiplying this by the energy we receive gives us the energy emitted: $1.44x10^{28}$ W.

If the solar luminosity is $3.839x10^{26}$W, then Vega is 37.4 times as luminous as the Sun.

c) If we look at the spectrum of Vega and find that the wavelength of the peak of the emission is at 300nm, what is the temperature of Vega? (1)

Wien's law relates the peak wavelength of a black body spectrum to its temperature: $T=2,900,000/\lambda$. Assuming Vega is a black body, then T = 2,900,000/300 = 9,670K

d) What is the radius of Vega in metres? The Sun's radius is 700,000 kilometres – how much larger than the Sun is Vega? (4)

To answer this, recall that the luminosity of a star is related to its temperature and radius by $L = 4\pi R^2\sigma T^4$, where σ is Stefan's Constant. We now have Vega's luminosity and temperature, so its radius is $\sqrt{(L/4\sigma\pi T^4)}$ = $1.52x10^9$ m. This is 2.2 times larger than the Sun.

6. Give three pieces of evidence that suggest that the universe began with a Big Bang. (3)

1. **All clusters of galaxies outside the Local Group are observed to be receding from**

Earth, and the speed at which they are receding is proportional to their distance. This means the universe must once have been much smaller than it is today.

2. **In all directions, microwave emission is detected, almost perfectly uniform in its intensity, and with a temperature of about 2.7 K. This is the thermal radiation from a young hot universe, which has expanded and cooled over time.**
3. **The amounts of helium and lithium observed in the universe today closely match the predictions made by theories of how the elements would form in a big bang.**
4. **The constituents of the universe are not uniformly distributed throughout it. Some objects, like quasars, are only seen at large distances and not near by.**