Tie Break = Total points on question #1

Science Olympiad 2017 Fairfax Division C Invitational Tournament

Astronomy Event Test

TEAM NAME: Key

TEAM NUMBER:______________________

TEAM MEMBER NAMES:______________________________________

TOTAL POINTS=______________/75

TEAM RANKING=______________________

Answer each of the following questions as completely as possible. Show work for all calculations.

Points on each question are stated. There will be a one point deduction for each incorrect unit or a missing unit on answers requiring numeric calculation.

1. This question is about the evolution of stars.

(a) Outline the process that provides the source of energy for stars while on the main sequence.

The fusion from hydrogen into helium results in the release of energy. (KE of particle & light)

(2)

(b)

(i) Fill in the missing particles in the first step in the primary proton-proton chain.

$^{1}_{1}p + ^{1}_{1}p \rightarrow ^{2}_{1}H +$ $^{0}_{1}e$ $+$ ν Also accept β^+ **(2)**

(c) State the conditions required for the above process to take place.

There must be enough density/ temperature/pressure for particles to get close enough for fusion to result.

(1)

(c) State the reason why stars leave the main sequence.

Stop hydrogen fusion in core.

(1)

(d) Main sequence stars eventually evolve to form red giants. With reference to the Chandrasekhar limit, describe and distinguish between the **subsequent** evolutionary paths of **red giant** stars that have evolved from main sequence stars of mass about two times that of the Sun.

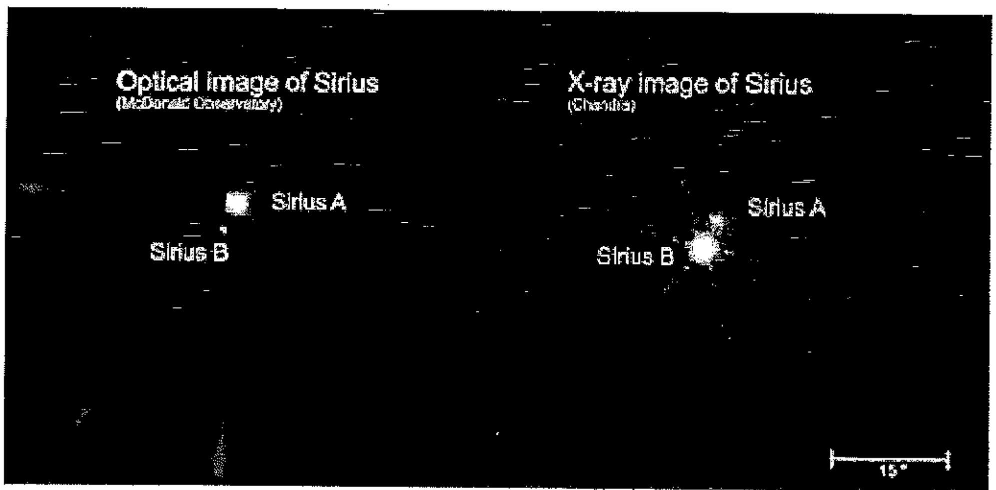
Stars with mass ~~larger than~~ 2 x the Sun will not be able to fuse ~~heavy met~~ heavier elements in core and become red giants (1) Eventually, further fusion will not be sustained and the red giant will release outer gases as a planetary nebula. The remaining core (2) if less than the Chandrasekhar Limit, will be a (3) white dwarf.

(3)

______ **/9 pts**

2. This question is about binary stars.

(a) On the lines below, identify which star (A or B) is the main sequence star and which is the white dwarf.



(i) Sirius A: main sequence Reason: Cooler, & larger more emission in visible (2)

(ii) Sirius B: white dwarf Reason: Hotter, more X-ray emission, smaller (2)

(b) Explain the difference between visual binaries and eclipsing binary stars.

Visual binaries can be resolved optically as two seperate stars. Eclipsing binaries have one star pass in front of the other causing overall lighted emitted from the two to fluctuate. (2)

(c) In a particular binary star system, star A has apparent brightness 8.0×10^{-13} W m^{-2} and star B has apparent brightness 2.0×10^{-14} W m^{-2}.

(i) Explain how it is possible to deduce that star A has a higher luminosity than star B.

They are approximate the same distance from Earth, so the one with the larger apparent brightness ~~must~~ must be more luminous, so A is more luminous. (2)

2

______/8pts

(ii) The surface area of star B is 10 000 times smaller than that of star A. Calculate the ratio

$$\frac{\text{surface temperature of star B}}{\text{surface temperature of star A}}$$

Since distance is the same, ratio of brightness = ratio of distance

$$\frac{b_B}{b_A} = \frac{L_B}{L_A} = \frac{\sigma \cdot A_B T_B^4}{\sigma A_A T_A^4}$$

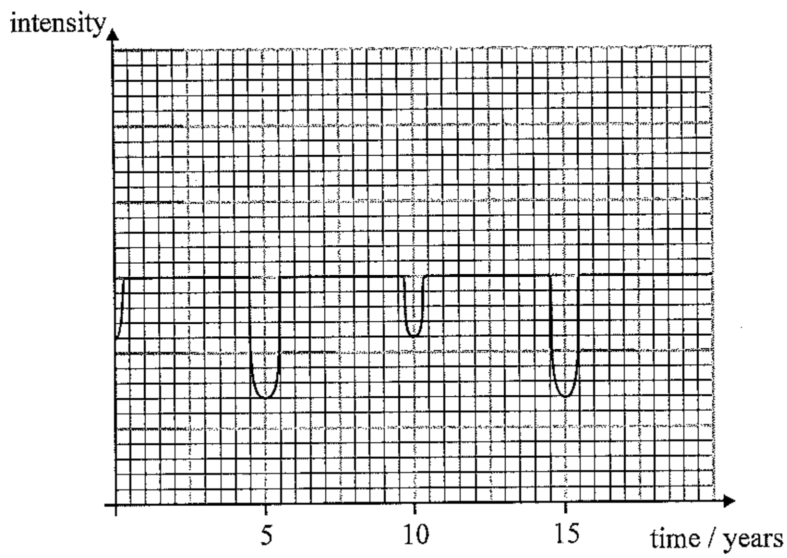
$$L_B \cdot A_A \cdot T_A^4 = L_A \cdot A_B \cdot T_B^4$$

$$\sqrt[4]{\frac{L_B \cdot A_A}{L_A \cdot A_B}} = \sqrt[4]{\frac{T_B^4}{T_A^4}} \Rightarrow \sqrt[4]{\left(\frac{2.0\times10^{-14}}{8.0\times10^{-13}}\right)\left(\frac{10{,}000}{1}\right)}$$

$$= 3.976 \rightarrow 4.0 \text{ or } 4:1$$

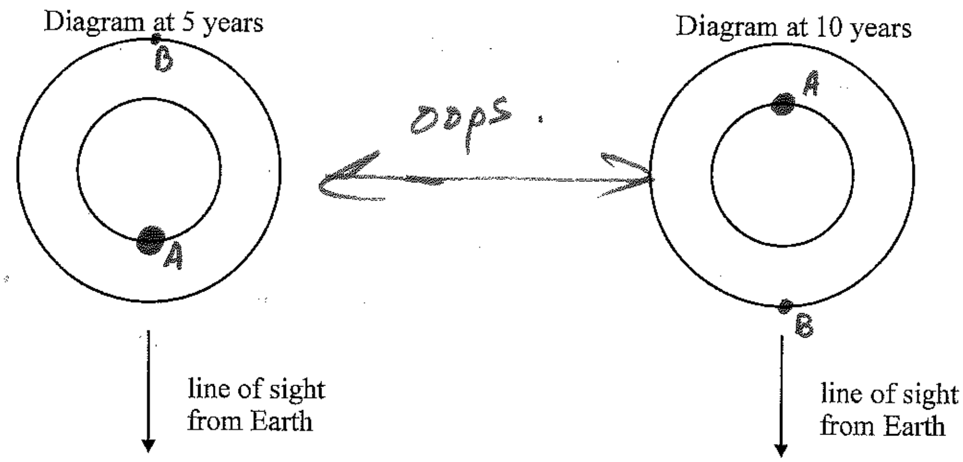
(4)

(d) The graph below shows the variation with time of the intensity of light received on Earth from the two eclipsing binary stars.



/4 pts

(i) The diagrams below each show the orbits of the two stars. Star A is in the inner orbit. Annotate the diagrams to show the relative positions of stars A and B as seen from Earth, that correspond to the intensity-time graph above at time of 5 and 10 years.



(2)

(ii) State the period of this binary star system.

10 years

(1)

(iii) State what can be deduced from knowing the period of the binary and the separation of the stars.

The total mass of the binary system

(1)

3. The diagram below is a flow chart that shows the stages of evolution of a main sequence star such as the Sun. (Mass of the Sun, the solar mass = $M_{\odot}$). Fill in the missing names in the sequence.

main sequence star mass $\approx M_{\odot}$ → red giant → Planetary nebula → White dwarf

(2)

(b) Outline

(i) why white dwarf stars cannot have a greater mass than $1.4M_{\odot}$;

There would not be enough ① electron degeneracy pressure to balance out the gravitational pressure. The mass would exceed the ② Chandrasekhar limit and collapse.

(2)

____________/8 pts

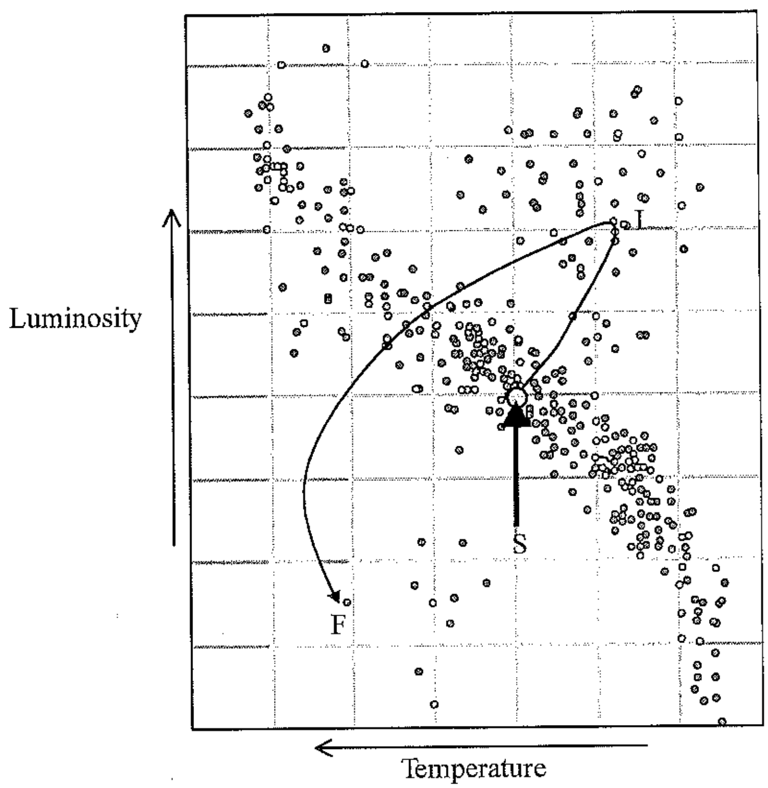
(ii) how a white dwarf is thought to, under special circumstances, undergo a type 1a supernova

① If the white dwarf is in a binary orbit with another star (such as a red giant), it can ② siphon/pull off mass from the other star due to its large gravitational pull. ③ Once the mass exceed 1.4 $M_{\odot}$ / Chandrasekhar limit it will collapse in a type 1a Supernova.

(3)

4. This question is about stellar evolution.

A partially completed Hertsprung-Russel (H-R) diagram is shown below.



The line indicates the evolutionary path of the Sun from its present position, S, to its final position, F. An intermediate stage in the Sun's evolution is labelled by I.

_____________/3 pts

(a) State the condition for the Sun to move from position S.

Stops fusing hydrogen in its core into helium.

(1)

(b) State and explain the change in the luminosity of the Sun that occurs between positions S and I.

① Increases in luminosity, ② due to huge increase in size ($L \propto R^2$) while only small (relatively small) drop in temperature.

(2)

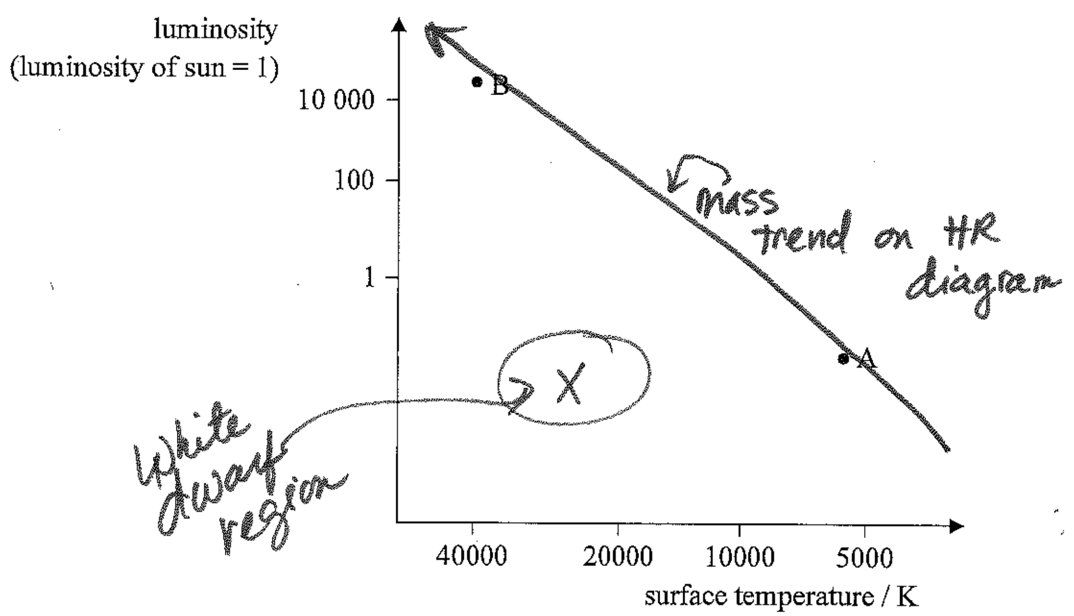
(c) Explain, by reference to the Chandrasekhar limit, why the final stage of the evolutionary path of the Sun is at F.

If the core of the star left over ① after the planetary nebula stage has a mass less than or equal to the Chandrasekhar limit it will be a ② white dwarf.

(2)

5. This question is about two different stars.

The diagram below shows the position of two main-sequence stars A and B with respect to the labeled axes of a Hertzsprung-Russell diagram.



_____________/5 pts

(a) Suggest which of the stars has the larger mass.

① B does. ② $L \approx M^{3.5}$ for main sequence stars, so the one with larger luminosity will have more mass.

(2)

(b) State **one** difference between the changes in nucleosynthesis that take place in star B compared to star A after both stars leave the main sequence.

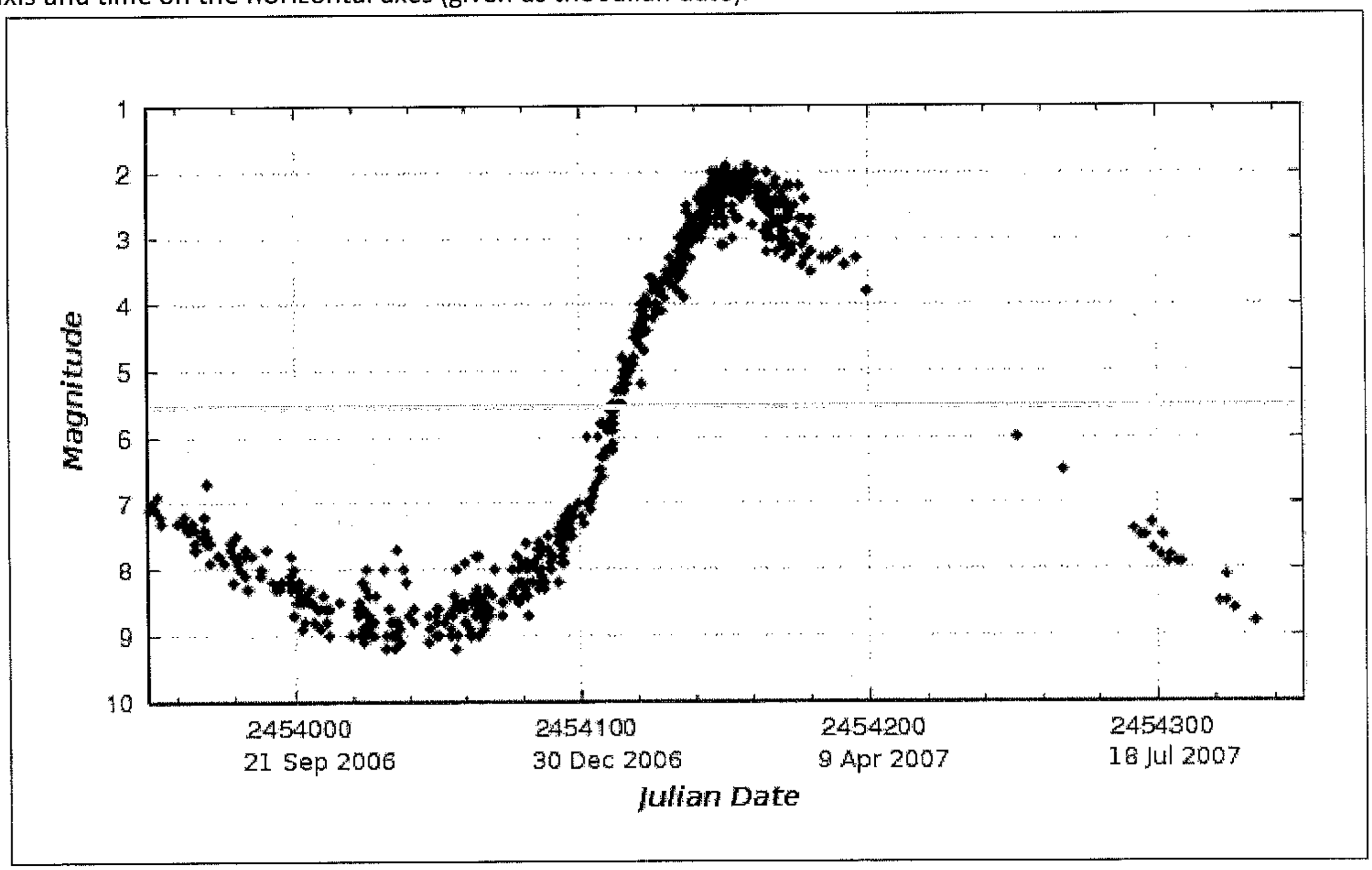
B can fuse much heavier elements in its core.

(1)

(c) On the H-R diagram on the previous page, mark with the letter X, the approximate final position of star A after it has left the main sequence.

(1)

6. The image below shows a light curve from a particular star showing the apparent magnitude on the vertical axis and time on the horizontal axes (given as the Julian date).

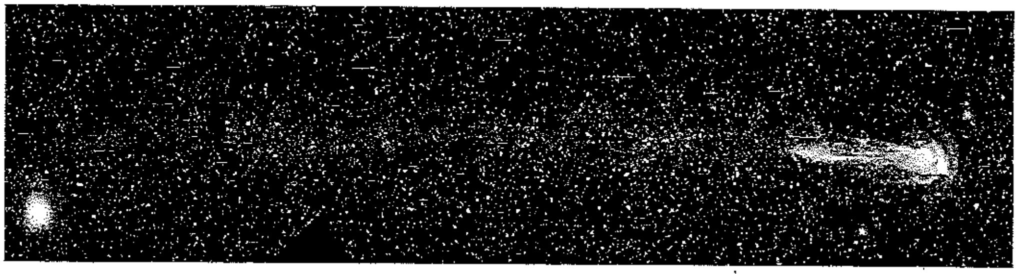


_____________/4 pts

(a) Which DSO is this light curve most likely from?

Mira/Omicron Ceti (1)

(b) The image below is from the star whose light curve is depicted above.



Explain the most likely origins of the "tail" shown in this image.

Mira/Omicron Ceti is ① shedding material as it speeds through the universe at 80 mi persecond.

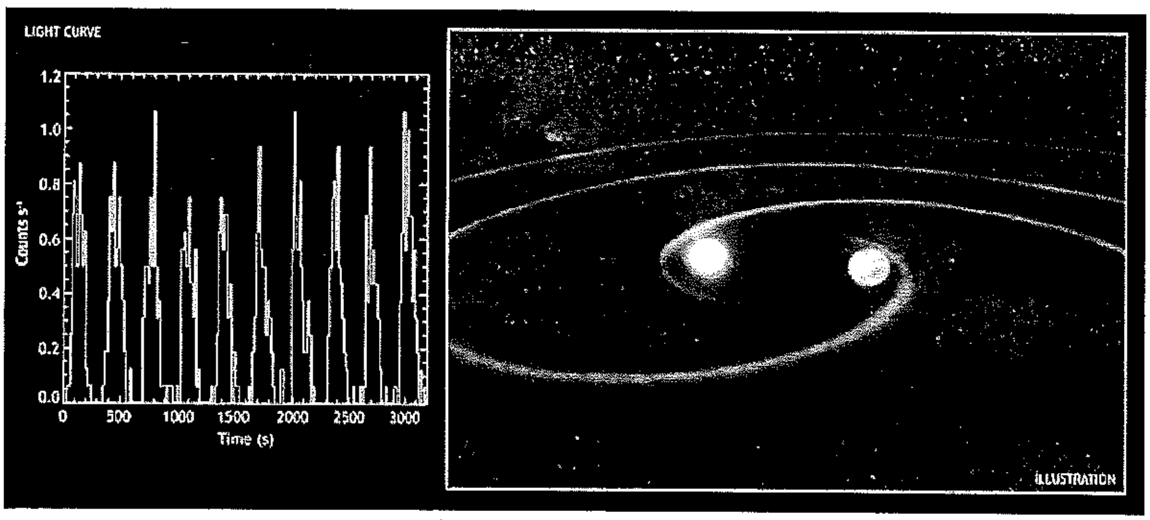
(3)

(c) Is the object visible to the naked eye? If so, when? Explain.

① Yes. ② Its peak magnitude is 2.0 and its average is 5.5. ③ Human vision allows for observing stars $m \leq 6$.

(3)

7. The image below shows the light curve from and an illustration of one of this year's DSOs.



_______________/7pts

(a) Which DSO is this most likely?

[redacted] HM Cancri (1)

(b) From the light curve, estimate the period of orbit of the binary stars.

About 300s. ≈ 5 min ± 30s (1)

(c) Using an estimated mass of each star to be the same as the Sun and the period estimated in (b), estimate the distance separating the two stars. Convert your answer to miles (1 mi≈1600m).

$T^2 = \frac{4\pi^2 d^3}{G(M_1+M_2)} \Rightarrow d = \sqrt[3]{\frac{GT^2(M_1+M_2)}{4\pi}}$

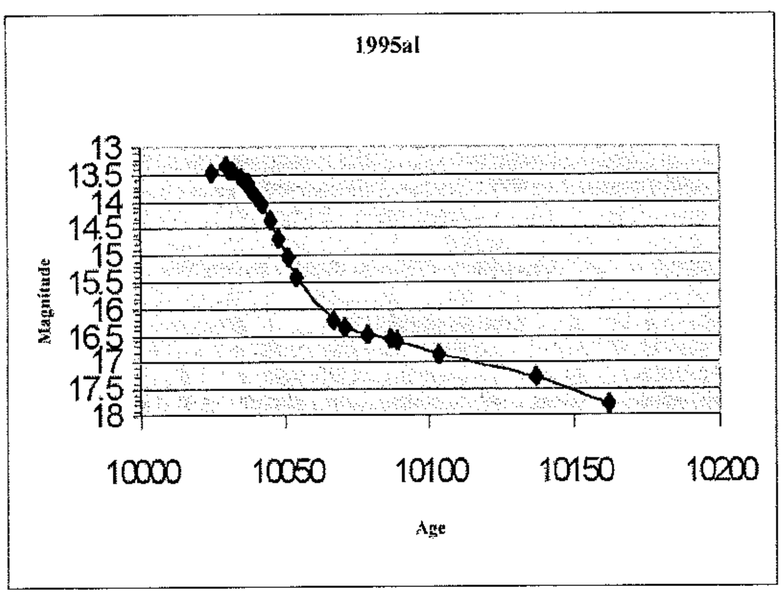
$d = \sqrt[3]{\frac{(6.67E\text{-}11)(300)^2(4\times10^{30})}{4\pi^2}} = 84{,}700{,}000\ m$ (3)

or ≈ 50,000 mi

(d) Measurements show that the period of orbit of the two stars is decreasing by 1.2ms every year. Explain the reason that the stars losing kinetic energy in their orbit.

① Energy is leaving the system as ② gravitational waves since these are very dense objects. ③ This decrease in energy results in a smaller orbit and decrease in period. (3)

8. This question is about Type Ia supernova and atomic spectra.



_____________/8 pts

The graph on the previous page shows a Type 1a supernova light curve,

(a) Explain how scientist can distinguish whether a supernova is Type I or Type II.

The Shape of the light curve is different. Type II's curves are broader.

(2)

(b) Using information from the graph, calculate the distance to this supernova in light years.

$m_{peak} \approx 13.3$

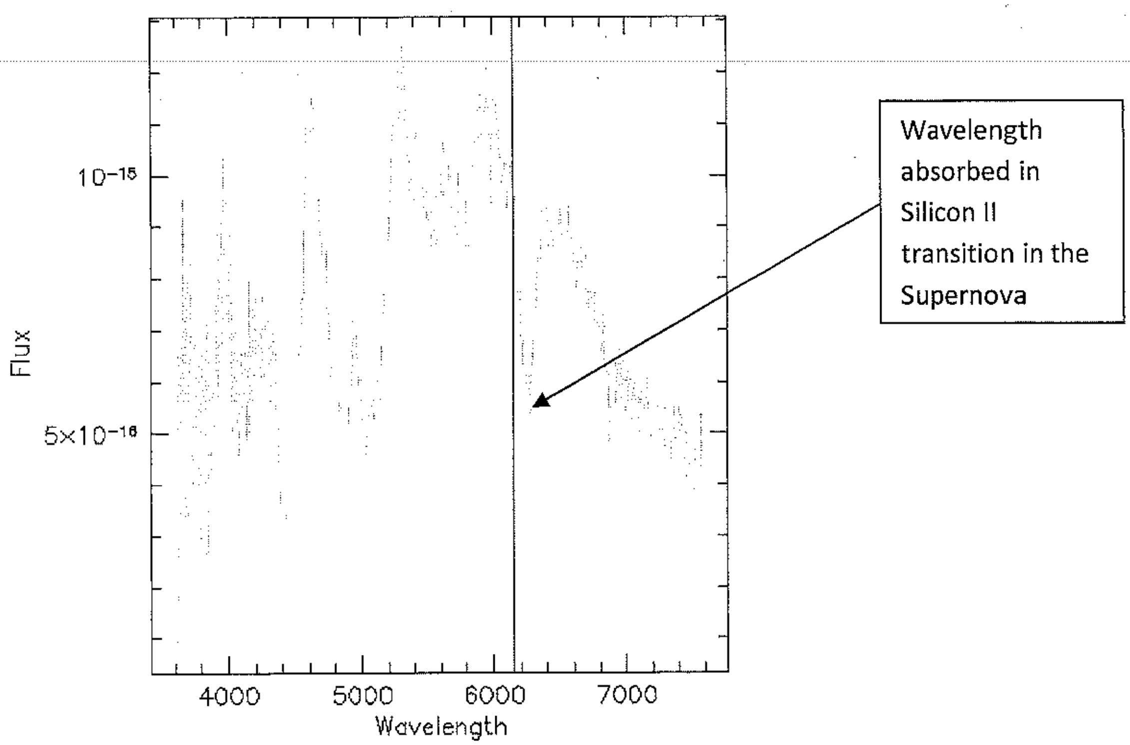
$M = -19.5$ ← All Type Ia Supernovas!

Distance modulus $d = 10^{\frac{m-M+5}{5}} = 10^{\frac{13.3-(-19.5)+5}{5}}$

$= 9.12 \times 10^6$ pc ≈ 30 million light-years

→ 10 – 40 Mpc accept 10 – 40 million lys.

The graph below shows the absorption spectra of the 1995al ~~supernova.~~ The red line indicates the wavelength of light absorbed for one energy transition of Silicon II. This is measured on Earth in the lab at 6150 Angstroms.



_________/5 pts

(c) The wavelength corresponding to the same energy transition in Silicon II however is shifted in the spectra of the supernova explosion. Explain why the wavelength absorbed is *longer* for the same transition in the light coming from the Supernova. What does this indicate about the star's motion?

(1) The star is moving away from us; Thus the light is (2) red shifted indicating an (3) expanding universe. (3)

(d)(i) A student estimates the shifted wavelength at 6200 Angtroms. Use this estimate to find the recessional velocity of the supernova in km/s.

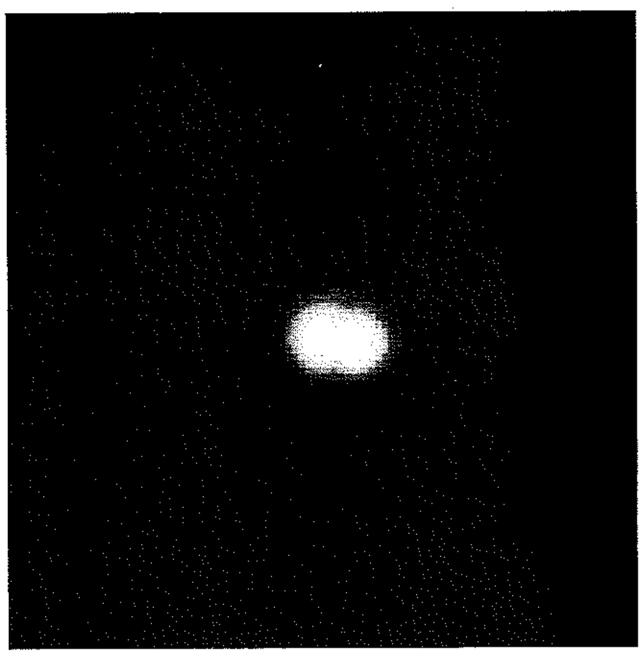
Doppler shift: (1) $\frac{\Delta\lambda}{\lambda_0} = \frac{V}{c}$ or $V = \frac{\Delta\lambda}{\lambda} \cdot c$

(2) $V = \frac{50.}{6150} \cdot 3\times10^5 km\cdot s^{-1}$ = (3) $2400\ km\cdot s^{-1}$ (3)

(ii) Use the recessional velocity found in (d)(i) to estimate the distance to the supernova in Megaparsecs. . Use $H_0 \approx 70$ km/s/Mpc.

Hubble's law: (1) $d = \frac{V}{H_0} =$ (2) $\frac{2400\ km\cdot s^{-1}}{70\ km\cdot s^{-1}/Mpc}$ = (3) $34\ Mpc$ (3)

7. This question is about binary stars. The image below is a false-color image of x-ray radiation coming from the M15 cluster.



__________/9 pts

As you can tell, scientists found two intense x-ray signals coming from the cluster. They believe the source of the x-rays are two neutron star X-ray binary systems: 2U2127 and M15 X-2.

(a) Suggest a process by which the neutron binaries would radiate such intense x-ray emission flares.

Material from the larger donor accretes onto the other neutron star causing bursts of X-rays. (2)

(b) The period of the X-2 binary system is 22.58 minutes. Estimating the neutron star as 2 solar masses and its binary companion as 1 solar mass, calculate the distance (in meters) separating this binary pair.

Kepler's 3rd / Kepler-Newton for binaries

$$d = \sqrt[3]{\frac{GT^2(M_1+M_2)}{4\pi^2}}$$

$$d = \sqrt[3]{\frac{(6.67E-11)(22.58 * 60)^2(6\times10^{30})}{4\pi^2}}$$ ← 3 solar masses.

$d = 2.39\times10^7\,m$ → $2.4\times10^7\,m$ (3)

__________/5 pts