Stars and Galaxies

Coursework Sheet 3 – Feedback

1.
The mass - luminosity relation is

$$L/L_\odot = \left(M/M_\odot\right)^\alpha$$

If we use the average value of $\alpha \approx 3.3$ from the notes then the maximum luminosity is

$L = 100^{3.3} = 4.0\,10^6\ L_\odot$ (1 mark)

and the minimum is

$L = 0.08^{3.3} = 2.4\,10^{-4}\ L_\odot$ (1 mark)

More accurate expressions taking into account the changes of slope can be used, but this range is about right.

2.

$$\tau_{MS} = \frac{E}{L} \propto \frac{M}{M^{3.3}} \propto M^{-2.3}$$

The MS lifetime for the Sun is 10^{10} years or you can work this out from when 10% of the hydrogen in the Sun has been fused to make helium using $E = mc^2$.
Scaling the Sun's MS lifetime we find for the most massive MS stars :

$\tau_{MS} = \tau_{MS}(\odot)\left(M/M_\odot\right)^{-2.3} = 10^{10}.100^{-2.3} = 10^{5.4} = 2.5.10^5$ years (1 mark)

and for the least massive :

$\tau_{MS} = 10^{10}.0.08^{-2.3} = 3.10^{12}$ years (1 mark)

i.e. much older than the Universe.

3.
a) Average density for the Sun is

$$\bar{\rho} = \frac{M}{V} = \frac{3M}{4\pi R^3} = \frac{3\ 2\,10^{30}}{4\pi\left(7\,10^8\right)^3} = 1.10^3\ \text{kg m}^{-3}$$

i.e. very similar to the density of water.

(1 mark)

b) White dwarfs have a radius similar to that of the Earth, i.e. about 6000 km. So the average density is:

$$\bar{\rho} = \frac{3M}{4\pi R^3} = \frac{3\,0.6\,2\,10^{30}}{4\pi\left(6000\,10^3\right)^3} = 1.10^9\ \text{kg m}^{-3}$$

i.e. 100 000 times more dense than lead.

(1 mark)

c) For neutron stars

$$\bar{\rho} = \frac{3M}{4\pi R^3} = \frac{3 1.4 2 10^{30}}{4\pi\left(10 10^3\right)^3} = 7.10^{17} \text{ kg m}^{-3} \qquad (1 \text{ mark})$$

This is similar to the density of nuclear material, i.e. a neutron star is like a giant atomic nucleus.

d) Schwarzschild radius :

$$R_S = \frac{2GM}{c^2} \qquad (1 \text{ mark})$$

$$= \frac{2 6.7 10^{-11} 10 2.10^{30}}{\left(3.10^8\right)^2} = 3.0.10^4 \text{ m} = 30 \text{ km} \qquad (1 \text{ mark})$$

Hence, the effective size of a black hole is similar to that of a neutron star.

(1 mark)

Hence, it is difficult to tell the difference between them in most cases like in accreting binary systems.