PHYC30019 Astrophysics
Due: Tuesday 10 May

Motivation for Workshop 2:
We have almost water-tight evidence for the existence of supermassive black holes (SMBH). However it is unclear how and when they formed? We will use this workshop to explore these questions, and in particular ask 'Can it be done?'

We will start by distinguishing between SMBH and Intermediate Mass BH (IMBH), and will ignore the 'stellar' mass black holes that we explored last workshop.

Research Task 1:
What is the range that we generally consider to be IMBH? Have any been discovered?

Research Task 2:
What is the age of the universe? How is this calculated? Is this consistent with all known observations?

Order-of-Magnitude Estimate 1:
The Earth's atmosphere is projected to rise by 3.5C over the next century due to the increase in CO_2 in the atmosphere. If the ocean temperatures were to rise by the same amount, what would be the increase in sea levels? Neglect melting of ice in this first calculation, but the second part of the calculation should now determine the rise in sea levels if all the ice in the Antarctic melted. Would it make much difference if the Arctic ice melted as well?

Calculation 1: the accretion route
How long does it take to grow a 10^9 M_{sun} SMBH if the growth is all by accretion onto a 'seed'? Set up a basic calculation: variables you might need to consider include accretion rate, mass of the 'seed', age of the universe etc. Outline any limitations on the values of these variables. A graph may help?

Order-of-Magnitude 2:
Estimate the annual cost of running the University of Melbourne.
Estimate the amount of this budget provided by student fees.
Now scale this to cover all the universities in Victoria.
What would each Victorian have to add to their taxes to make universities free for students again.

Research task 3:
Read the following article – I will tell you something about Dan the author.
http://www.space.com/28499-finding-the-most-distant-quasar.html
What is the redshift of this object?
Use the following calculator to obtain the physical coordinates of this quasar, being careful to specify the cosmology you have used.
http://ph.unimelb.edu.au/cosmocalc/session.php

Calculation 2:
You now have the age of the most distant quasar – can you form the SMBH by accretion? What are the limitations on this method of formation? What would happen if we fund a quasar at z=8.5

Order-of-Magnitude 3:
Which is the most likely: two planets colliding; two stars colliding; or two galaxies colliding? Carefully outline the assumptions you make. You need to think carefully about the conditions required before two objects can collide.

Calculation 3: the merger route
One option considered, that might reduce the tight timescales, is to form IMBHs to act as seeds. In order for this to be a viable route for the formation of SMBHs, they need to form quickly, and early. In a dense environment of compact objects, objects can merge due to dynamical friction (there are some issues when they get close which we will ignore).

Below is a formula for the timescale for merging, and a short paper that traces the derivation following the classic textbook, Binney and Tremaine – Galactic Dynamics is in the LMS. Specifying your assumptions, you should consider a BH of mass M in a dense environment of compact objects. A good model would be something like a globular cluster (although you should be able to work out the Jeans mass at the redshifts in question, it is sufficient to just take a globular cluster-sized object). Specify reasonable values for the cluster of objects and decide on a value for M. Work out the timescales for the mass M to merge with the central object, and discuss any issues that you think would need to be considered if you were to take this option seriously.

$$t_{fric} = \frac{1.17}{ln\Lambda}\frac{r_i^2 v_c}{GM}$$
$$= \frac{2.64\times10^{11}}{ln\Lambda}\left(\frac{r_i}{2kpc}\right)^2\left(\frac{v_c}{250km/s}\right)\left(\frac{10^6 M_{sun}}{M}\right)yr$$

Note the 'normalising' values are for a galaxy; a globular cluster will be much smaller.

Conclusion:
Summarise what you have learned about the possible formation of IMBH and SMBH. Do you think the issues are resolved?