PHYSICS 313 - Winter/Spring Semester 2017 - ODU

Astrophysics – LAST Problem Set 12 – DUE THURSday, April 20

***IMPORTANT NOTE*:**

You **MUST** submit your contribution for the 2nd half of the "participation credit" (summary of an article, improvement of formula sheet, presentation, lecture note - see our website) by Friday, April 21, midnight if you haven't already done so. Ask me for suggestions if you don't know where to start. Don't leave those extra points "on the table"!!

GENERAL INSTRUCTIONS:

Please submit your solution using the following format. You can submit it as an email to skuhn@odu.edu anytime before midnight on the day on which the Problem Set is due; in this case, you **must** use an electronic file format (like MS Word, LaTeX, .pdf, Mathematica etc.) or simple text (follow the rules of some programming language like Fortran or C to write mathematical expressions like x**2 for the square of *x* etc.). Alternatively, you can write your solution by hand on paper and turn it in **in class** on the same day (no late submissions); please write clearly and cleanly!

For each problem (part), type the problem number (e.g., "1a." or "2c"), followed by a space, and then your solution. For "yes/no" questions, enter "Y" or "N", for multiple choice questions, enter the correct choices ("1" or "3" or…) without any additional characters, and for numerical questions, quote the result in the form "3.1415" or "3.1415e12". For conceptual questions, just write the text (no special formatting needed). Some problems require mathematical derivations or equations in addition to text or numbers (clearly stated in the problem text). **Only** for those cases may you use a **clean** scanned image of a handwritten derivation, included in your electronic submission (if you choose that route).

IN ALL CASES, make sure that your full name appears on all your submissions to guarantee you get credit for your work! Also, do NOT simply copy someone else's solution (honor code!) – you can ask for help if you get stuck, but you must submit your OWN work. (I will randomly ask questions during class to check whether you understand the solution you submitted.

Problem 1

Mark each of the following statements with "Y" or "T" if they are correct, and with "F" or "N" if they are incorrect:

1a) To the best of our knowledge, the Universe has a significant positive radius of curvature.
1b) Unless something changes in the composition of the universe, it will eventually grow exponentially with time.
1c) The redshift of the light from any far-away source embodies the change in the size of the universe since emission of that light.
1d) Some of the objects from which we receive light today are nearly 50 Billion light years away from us right now.
1e) Since emission of the CMB radiation, the universe has increased nearly 1100 times in size.
1f) If 1e) is correct, then it follows that the emission of the CMB radiation must have happened at a time when the universe was exactly 1/1100 of its present age (time since the big bang).

PHYSICS 313 - Winter/Spring Semester 2017 - ODU

Problem 2

The following are NOT multiple choice questions! Instead, answer each question with **five ordered** single digits (i.e., arrange the digits 1-5 in the correct order):

2a) The following ingredients are all affecting the evolution of the universe. Please write down **all of the 5 numbers in the correct order** indicating the relative importance of each ingredient for the dynamic evolution (i.e., its energy density) **today**. Begin with the most important and end with the least important.
1 – Radiation
2 – Dark matter (nonrelativistic "dust")
3 – Curvature
4 – Dark energy
5 – Baryonic matter (the stuff of galaxies and intergalactic gas – also nonrelativistic "dust").

2b) How would this ordering change if you look back to a time where the universe was only 1000 years old?

Problem 3 – Give written responses (in complete sentences) and show the mathematical derivation as well as your final result for each question

Before the modern cosmological standard model including dark matter and dark energy, people thought that the universe was practically empty (which it would nearly be without these two ingredients – baryonic matter makes up only 4-5% of the critical density ρ_0 today). Yet they knew it was expanding (by observing the light from that puny amount of matter that is in stars and galaxies). For the following, assume a Hubble constant H_0(today) = 70 km/s / Mpc = 1/14Byr. Also let's use for the present age of the Universe t_0 = 14 Byr.
a) Let's begin assuming $\rho_{tot}(t) = 0$ exactly (no matter, no radiation, no dark energy; of course, even without dark matter this is only an approximation and only valid for more recent times). What can you conclude about the curvature of the Universe?
b) Under the same assumption above, what will be the time-dependence of the scale parameter a(t)? [Hint: it turns out to be the same as the simple example we did in lecture. If you are unable to derive this yourself, you may still use that example for c) below.]
c) Still using the same assumptions, calculate how far away from us a quasar was when it emitted a lightray 12 Byr ago that we observe today. What will be the redshift of this light? How far is that same quasar away today?
d) XC! Now let's add the 5% of matter. Without **detailed** calculation, explain why (and roughly at what value of the scale factor, a(t)/a_0) the importance of the curvature term would become smaller than the importance of the cold matter ("dust") term in the evolution of a(t).
e) XC! Ultimately, in any universe that contains any radiation at all, the radiation must have dominated the evolution of a(t) at some (very early) time. Explain why!

NOTE (for all 3 problems): You may use the spreadsheet that I posted on the website to figure some of these things out (if you have access to Microsoft Excel), but to answer the actual questions, you need to show how you (could) calculate the answer yourself. Also, I urge you to download the newest version of the Astrophysics Formula Sheet for relevant information.