INTRODUCTION TO THE PROBLEM SET

By how much work I expect the problem to influence your understanding of the problem set.

Problem Point Credit: In Problem Set 1 each problem was worth 2 points. For this problem set the number of points per problem varies, depending on how much work I expect the problem to influence your understanding of the problem set. The total number of points available is 30 points.

PROBLEM SET 2

1. Find the time at which the light from the galaxy was emitted.

2. Determine the distance to the galaxy.

3. Find the time at which the light from the galaxy was received.

4. Find the present value of the physical distance of the galaxy from the Earth. (Use Problems 1 and 2 in the text and results of your calculations to solve this problem.)

5. Find the time at which the light from the galaxy arrived at the Earth.

6. Find the redshift of the galaxy.

7. Find the redshift of the galaxy based on only one spectral line, and the result has been refuted by other astronomers.

8. Find the redshift of the galaxy based on multiple spectral lines.

9. Find the redshift of the galaxy based on the observed flux and the redshift of the galaxy as measured by other astronomers.

10. Find the redshift of the galaxy based on the observed flux and the redshift of the galaxy as measured by other astronomers.

11. Find the redshift of the galaxy based on the observed flux and the redshift of the galaxy as measured by other astronomers.

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30. Find the redshift of the galaxy based on the observed flux and the redshift of the galaxy as measured by other astronomers.

DUE DATE: September 18, 2007

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Physics Department

Physics 8.96: The Early Universe

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Physics Department

Physics 8.286: The Early Universe September 11, 2007

Massachusetts Institute of Technology
PROBLEM 3: DISTANCE IN TERMS OF REDESHIFT

Express the present value of the physical distance in terms of the present value of the Hubble constant $H_0$ and the redshift $z$. Taking $H_0 \approx 72 \text{ km-sec}^{-1}\text{-Mpc}^{-1}$, how far away is the galaxy? Express your answer both in light-years and in Mpc.

PROBLEM 4: SPEED OF RECESSION

Find the rate at which the physical distance between the distant galaxy and us is changing. Express your answer in terms of the redshift $z$ and the speed of light $c$, and evaluate it numerically for the case $z = 6.58$. Express your answer as a fraction of the speed of light. [If you get it right, this “fraction” is greater than one! Our expanding universe violates special relativity, but is consistent with general relativity.]

PROBLEM 5: APPARENT ANGULAR SIZES

Now suppose for simplicity that the galaxy is spherical, and that its physical diameter was $w$ at the time it emitted the light. (The actual galaxy is seen as an unresolved point source, so we don’t know its actual size and shape.) Find the apparent angular size $\theta$ (measured from one edge to the other) of the galaxy as it would be observed from Earth today. Express your answer in terms of $w$, $z$, $H_0$, and $c$. You may assume that $\theta \ll 1$. Compare your answer to the apparent angular size of a circle of diameter $w$ in a static Euclidean space, at a distance equal to the present value of the physical distance to the galaxy, as found in Problem 1. [Hint: Draw diagrams which trace the light rays in the comoving coordinate system. If you have it right, you will find that the angular size of the galaxy is invariant with $z$ for $z < 1$.]

PROBLEM 6: RECEIVED RADIATION FLUX

At the time of emission, the galaxy had a power output $P$ (measured, say, in ergs/sec) which was radiated uniformly in all directions. This power was emitted in the form of photons. What is the radiation energy flux $J$ from this galaxy at the earth today? Energy flux (which might be measured in ergs-cm$^{-2}$-sec$^{-1}$) is defined as the energy per unit area per unit time striking a surface that is orthogonal to the direction of energy flow. The easiest way to solve this problem is to consider the trajectories of the photons, as viewed in comoving coordinates. You must calculate the number of photons per unit area per unit time striking a surface that is orthogonal to the direction of energy flow. You may again use the redshift equation, $z = \frac{\theta}{2\theta_0} - 1$, where $\theta_0$ is the comoving angular size of the galaxy. Find the rate at which photons arrive at the detector, and you must also use the fact that the energy of each photon is proportional to its frequency, and is therefore decreased by the redshift. You may also use the fact that the area of each photon is proportional to its frequency, and is therefore decreased by the redshift the same amount. Express your answer in terms of the redshift $z$ and the speed of light $c$. You may assume that $\theta_0 \ll 1$. Compare your answer to the received radiation flux from a point source of diameter $w$ in a static Euclidean space, at a distance equal to the present value of the physical distance to the galaxy, as found in Problem 1. [Hint: Draw diagrams which trace the light rays in the comoving coordinate system. If you have it right, you will find that the radiation flux is proportional to the distance to the galaxy and $z$.]