UNIVERSITY OF OSLO
Faculty of Mathematics and Natural Sciences

Exam AST2110 — The Universe

Date of exam: Tuesday 8 June 2004

Time for exam: 14.30 – 17.30

This exercise set contains 3 pages.

Attachments: None

Allowed sources of help: Rottmann: "Matematisk formelsamling"
Øgrim og Lian: "Størrelser og enheter i fysikk og teknikk"
Calculator
Two A4 pages (can be written on both sides) with your own notes

Check that the exercise set is complete before you start solving the problems.

Exercise 1

a) The centre of mass reference frame for a system of N particles is defined by that observed in it, $\sum_{i=1}^{N} \mathbf{p}_i = 0$. $P_\mu =$

$(E/c, \mathbf{p})$ is a four-vector. Show that for the whole system, observed in the centre of mass frame of reference, $P_\mu^{CM} = (E_0/c, 0)$. Express $P^\mu P_\mu = -E^2/c^2 + p^2$ for the whole system observed in an arbitrary inertial frame of reference by E_0.

Let us now look at two photons which in the laboratory frame of reference have frequencies ν_1 and ν_2, and in the laboratory frame the angle between their directions of propagation is θ.

b) Show that in the centre of mass reference frame, the total energy of the system is $E_0 = 2h\sqrt{\nu_1\nu_2}\sin\frac{\theta}{2}$ (remember that $\sqrt{(1-\cos\theta)/2} = \sin\frac{\theta}{2}$).

c) What is the frequency of each of the photons seen in the centre of mass reference frame?

c) Is it possible to find a centre of mass reference frame for this system for all values of θ?

Exercise 2

a) Show that a Solar System body at distance r from the Sun and with an albedo a under certain assumptions will reach an equilibrium temperature $T_p = (R_\odot/2r)^{1/2}(1-a)^{1/4}T_\odot$, where $R_\odot$ is the radius of the Sun and $T_\odot$ is the surface

temperature of the Sun. Explain the most important assumption that must be made. In the rest of this exercise, assume that $R_\odot = 696000$km and $T_\odot = 5800$K.

b) For the Earth, $a = 0.3$ and $r = 150$ million km. Compare the temperature you get using the equation in exercise a with the average surface temperature of the Earth. What is the main reason for the difference?

c) Neptune's average distance from the Sun is 4.5×10^9 km and its albedo is 0.29. Its surface temperature is 59K. How does this agree with the surface temperature you get? What is the main reason for the difference?

Exercise 3

a) Draw Hubble's tuning fork diagram and show where in it the different galaxy types are situated.

b) What is meant by that the surface brightness in elliptical galaxies and in the bulge of spiral galaxies follow de Vaucouleurs' $r^{1/4}$ law?

c) How can the Tully-Fisher relation by used for determining the distances to spiral galaxies?

d) Express the redshift of a cosmological object by the scale factor of the Universe, R.