A05505

OPEN NOTE
ANY CALCULATOR

UNIVERSITY OF BIRMINGHAM

School of Physics and Astronomy

DEGREE OF BSc & MSci WITH HONOURS

THIRD YEAR EXAMINATION

03 00716

OBSERVATIONAL COSMOLOGY

Total time allowed: $1\frac{1}{2}$ Hours

SUMMER 2007

Answer Section 1 and any one question from Section 2.

Section 1 counts for 40% of the marks for the examination. Full marks may be obtained by correctly answering four questions. You may attempt as many questions as you wish, but any marks in excess of 40% will be disregarded.

Section 2 consists of two questions, each carrying 30% of the marks. If you answer more than one question from this Section, only the first will be marked.

A further 30% of the course credit derives from coursework assignments already submitted.

The approximate allocation of marks to each part of a question is shown in brackets [ ].

Calculators may be used in this examination but must not be used to store text. Calculators with the ability to store text should have their memories deleted prior to the start of the examination.

Students may use their course notes in the examination, but textbooks are not permitted.

Tables of physical constants and units that may be required will be found at the end of this question paper.

A05505 **OPEN NOTE**
ANY CALCULATOR

SECTION 1

Full marks may be obtained by correctly answering four questions. You may attempt as many questions as you wish, but any marks in excess of 40% will be disregarded.

1. Explain, with the aid of a suitable plot, why the Universe must have been radiation-dominated at early epochs. **[10]**

2. Why is it that structure builds up hierarchically in our Universe? **[10]**

3. Explain the role of the scale factor and curvature in the radial term of the Robertson-Walker metric. **[10]**

4. Why could the dark matter not consist entirely of faint, low mass stars? **[10]**

5. What is cosmic time, and how could all comoving observers agree upon its value? **[10]**

6. If the value of the Hubble constant were to be revised from 72 to 80 km s^{-1} Mpc^{-1}, what effect would this have on the luminosities inferred for galaxies? **[10]**

SECTION 2

You should attempt one question from this Section. If you answer more than one question, only the first will be marked.

7. Consider a universe with Ω_m=1, $H_0 = 75$ km s^{-1} Mpc^{-1} and $\Omega_\Lambda = 0.6$ at the current time.

(a) Explain how the three terms in the Friedmann equation depend upon the increasing scale factor as this universe evolves, and outline the implications of this for the dynamics of the universe. **[10]**

(b) Is this space positively or negatively curved? Find the radius of curvature in Mpc. **[8]**

(c) Find the value of the deceleration parameter q_0, and hence say whether this universe is currently accelerating or decelerating. **[4]**

(d) What was the value of the Hubble parameter at $z = 1$ in this universe? **[8]**

8. (a) Explain carefully why there is, at first sight, a difficulty in reconciling the low amplitude of the CMB fluctuations with the presence of high density structures like galaxies in the local Universe. **[10]**

(b) How does the existence of dark matter resolve this problem, and what role does radiation play in the solution? **[12]**

(c) Adopting the current 'concordance cosmology', show that the brightness of a population of galaxies will *increase* with redshift if their luminosity evolves at least as fast as

$$L \propto z^2(1 + 1.55z).$$

(Use the low redshift approximation for luminosity distance, involving q_0.) **[8]**

Physical Constants and Units

Acceleration due to gravity	g	$9.8\ \mathrm{ms}^{-1}$
Gravitational constant	G	$6.673 \times 10^{-11}\ \mathrm{Nm}^{-2}\mathrm{kg}^{-2}$
Avogadro constant	N_{A}	$6.022 \times 10^{23}\ \mathrm{mol}^{-1}$
	Note: 1 mole = 1 *gram* molecular-weight	
Ice point	T_{ice}	273.15 K
Gas Constant	R	$8.314\ \mathrm{JK}^{-1}\mathrm{mol}^{-1}$
Boltzmann constant	$k,\ k_{\mathrm{B}}$	$1.381 \times 10^{-23}\ \mathrm{JK}^{-1} = 0.862 \times 10^{-4}\ \mathrm{eV\ K}^{-1}$
Stefan constant	σ	$5.670 \times 10^{-8}\ \mathrm{Wm}^{-2}\mathrm{K}^{-4}$
Rydberg constant	R_∞	$1.097 \times 10^{7}\ \mathrm{m}^{-1}$
	$R_\infty\, hc$	$13.606\ \mathrm{eV}$
Planck constant	h	$6.626 \times 10^{-34}\ \mathrm{Js} = 4.136 \times 10^{-15}\ \mathrm{eV\ s}$
	$\hbar = h/2\pi$	$1.055 \times 10^{-34}\ \mathrm{Js} = 6.582 \times 10^{-16}\ \mathrm{eV\ s}$
Speed of light *in vacuo*	c	$2.998 \times 10^{8}\ \mathrm{ms}^{-1}$
	$\hbar c$	$197.3\ \mathrm{MeV\ fm}$
Charge of proton	e	$1.602 \times 10^{-19}\ \mathrm{C}$
Mass of electron	m_{e}	$9.109 \times 10^{-31}\ \mathrm{kg}$
Rest energy of electron		$0.511\ \mathrm{MeV}$
Mass of proton	m_{p}	$1.673 \times 10^{-27}\ \mathrm{kg}$
Rest energy of proton		$938.3\ \mathrm{MeV}$
One atomic mass unit	u	$1.66 \times 10^{-27}\ \mathrm{kg}$
Atomic mass unit energy equivalent		$931.5\ \mathrm{MeV}$
Electric constant	ϵ_0	$8.854 \times 10^{-12}\ \mathrm{Fm}^{-1}$
Magnetic constant	μ_0	$4\pi \times 10^{-7}\ \mathrm{Hm}^{-1}$
Bohr magneton	μ_{B}	$9.274 \times 10^{-24}\ \mathrm{Am}^2\ (\mathrm{JT}^{-1})$
Nuclear magneton	μ_{N}	$5.051 \times 10^{-27}\ \mathrm{Am}^2\ (\mathrm{JT}^{-1})$
Fine structure constant	$\alpha = e^2/4\pi\,\epsilon_0\,\hbar c$	$7.297 \times 10^{-3} = 1/137.0$
Compton wavelength of electron	$\lambda_{\mathrm{C}} = h/mc$	$2.426 \times 10^{-12}\ \mathrm{m}$
Bohr radius	a_0	$5.2918 \times 10^{-11}\ \mathrm{m}$
angstrom	Å	$10^{-10}\ \mathrm{m}$
torr (mmHg, $0°\mathrm{C}$)	torr	$133.32\ \mathrm{Pa}\ (\mathrm{Nm}^{-2})$
barn	b	$10^{-28}\ \mathrm{m}^2$