University of Toronto
Faculty of Arts and Sciences
APRIL 2011 Examinations
AST121H1S
Duration: 3 Hours
Examination Aids: non-programmable calculators

PLEASE HAND IN

Name: _____ **Student Number:** _____

The test is composed of 20 multiple choice questions (one point each) and 6 short-answer questions (5 points each). For the multiple choices, only one answer is correct and please mark your answers on the scantron sheet. For the short-answer questions, please use the space provided below each question. Hand in **both** the exam paper and the scantron sheet, but don't forget to fill in your name/student number on **both** forms. The exam papers have a total of 10 pages.

A list of physical constants in MKS (or SI) units, kg is kilogram, m is meter, K is Kelvin, s is second, N is Newton, J is Joule, C is coulomb.

parsec $pc = 3.0857 \times 10^{16}$ m

arcsecond 1" $= 4.848 \times 10^{-6}$ radian

elementary charge $e = 1.602 \times 10^{-19}$ C

proton rest mass $m_p = 1.672 \times 10^{-27}$ kg

neutron rest mass $m_n = 1.675 \times 10^{-27}$ kg

hydrogen atom mass $m_H = 1.673 \times 10^{-27}$ kg

electron rest mass $m_e = 9.109 \times 10^{-31}$ kg

mass of the Sun $M_\odot = 1.99 \times 10^{30}$ kg

Planck constant $h = 6.625 \times 10^{-34} J \cdot s$

Speed of light in vacuum $c = 2.998 \times 10^{8} m s^{-1}$

Gravitational constant $G = 6.673 \times 10^{-11} m^3 kg^{-1} s^{-2}$

Fine structure constant $\alpha = 1/137.036$

Boltzmann constant $k = 1.380 \times 10^{-23} J K^{-1}$

Electron volt $eV = 1.602 \times 10^{-19} J$

Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8} J s^{-1} m^{-2} K^{-4}$

Coulomb constant $k_e = \frac{1}{4\pi\epsilon_0^2} = \frac{c^2\mu_0}{4\pi} = 8.988 \times 10^{9} N m^2 C^{-2}$.

Part A, 20 multiple-choice questions. Input your answers on the scantron sheet. One point each

1. Distance to a star that shows an annual parallax of 1 arcsecond is defined to be 1 parsec. How far can the GAIA mission (with a precision of 20 micro-arcseconds) measure parallax out to?

   A) 50 pc, B) 0.5 kpc, C) 5 kpc, D) 50 kpc.

2. CMB photons have experienced a redshift of 1100 since they were emitted. By what factor was the universe smaller, at the time of last scattering, compared to today?

   A) $1100^{1/2}$, B) $1100^{2/3}$, C) 1100, D) $exp(1100)$, E) Indeterminate, need to know the cosmological model.

3. Big bang nucleosynthesis successfully predicted the primordial abundances of hydrogen and helium in our universe. Which of the following is the most relevant number for making such a prediction?

   A) Age of the universe when it underwent inflation.

   B) The number ratio between baryons and photons at the last scattering surface.

   C) The temperature of the CMB at redshift 1100.

   D) The number ratio between neutrons and protons at the end of the particle era.

4. Which one of the following situation would produce an absorption spectrum?

   A) The spectrum of a compact fluorescent bulb.

   B) The spectrum of the CMB after it passes through the atmosphere of a hot star.

   C) The spectrum of the Sun after it passes through the Earth's atmosphere.

   D) The spectrum of CMB at the last scattering surface.

5. Supernova A and supernova B are intrinsically the same type of objects. However, A is at twice the distance of B. Compared to B, the luminosity of A

   A) remains the same, but the apparent brightness is decreased by a factor of two.

   B) is decreased by a factor of two, and the apparent brightness is decreased by a factor of two.

   C) is decreased by a factor of four, but the apparent brightness remains the same.

   D) remains the same, but the apparent brightness is decreased by a factor of four.

   E) is decreased by a factor of four, and the apparent brightness is decreased by a factor of four.

6. Which one of the following events relies on the fact that photons experience gravitational attraction?

   A) Gravitational lensing. B) Expansion of the universe.

   C) Formation of galaxies. D) Formation of stars.

7. How does the luminosity of a star scales with its surface temperature (T) and its radius (R)?

   A) T^2R^2 B) $T^{-4}R^2$ C) T^4R D) T^4R^2. E) T^4.

8. Bohr's hydrogen model. Compared to the wavelength of the photon emitted when the electron jumps from the $n = \infty$ (free state) to the $n = 1$ state, how long is the wavelength of the photon emitted when the electron undergoes the $n = 2$ to $n = 1$ transition?

   A) Half. B) Twice. C) Four times. D) A quarter. E) Three-quarters. F) Four-thirds.

9. Gravity in the Galactic center is dominated by a massive black-hole. Its mass can be obtained by

   A)measuring the orbital speed and distance from center for a galactic center star.

   B)measuring the orbital period and distance from center for the Sun.

   C)measuring the neutrino flux from the interior of such a black-hole.

   D)measuring the luminosity of the black-hole as it accretes gas.

   E)measuring the motion of baryons, but not the motion of photons as photons have no mass and do not experience gravity.

10. Different physical processes have different energy scales associated with them. Which one of the following arrangements gives the correct energy scale for the following processes: GUT force; nuclear reactions; chemical reactions; proton/anti-proton pair creation.

    A) 10^{15} ev; 1 Mev; 1 ev; 1 Gev. B) 10^{25} ev; 1 ev; 1 Mev; 1 Gev.

    C) 1 Gev; 1 Mev; 1 ev; 10^{15} ev. D) 1 Gev; 1 Gev; 1 Mev; 1 Gev.

11. Dark matter is responsible for binding galaxies and galaxy clusters together. Which of the following statement is **false**?

    A) If dark matter particles move at nearly the speed of light, they will escape the galaxies or clusters.

    B) Were it not for dark matter, the Solar System will also become unbound.

    C) The expansion of the universe will be faster if dark matter does not exist.

    D) Dark matter particles need to have non-zero masses and zero charges.

12. Gravity between two protons is much weaker than the electrostatic force between them. But why need we worry only about gravity at macroscopic scales?

    A) Gravity wins at large scale because the electrostatic force is in nature a short-ranged force, like the strong force and the weak force.

    B) Gravity wins at large scale because the amount of mass in the universe is so large.

    C) Gravity wins at large scale because the electrostatic force relies on net charges, while most structures in the universe are charge neutral.

    D) Gravity wins because protons are much more massive than electrons and thus feels strong gravity, while electrons mostly feel the electrostatic force.

    E) None of the above.

13. We live in a matter universe, not an anti-matter universe. Which of the following statement is **false**?

A) Anti-matter has never been observed in our universe and is a hypothetical particle. Their existence will cause catastrophic consequences.

B) Matter is produced in the big bang in an amount slightly more than anti-matter.

C) Anti-matter may exist in abundance outside our visible universe, or in another universe.

D) The early universe is completely dominated by photons. Matter and anti-matter occur in roughly equal proportion.

14. Fusion in stars convert hydrogen and helium into metals. Which of the following process is insensitive to the presence of metal?

A) Formation of gas giant planets like Jupiter.

B) Metabolism in live organisms.

C) Formation of rocky planets like Earth.

D) Expansion of the universe.

15. Anisotropies in the cosmic microwave background (CMB) have been measured since the 1980s. Which statement **incorrectly** describes these anisotropies ?

A) They originate in the Big Bang where quantum fluctuations in microscopic scales can be stretched to the macroscopic scales.

B) The amplitude for the anisotropy is of order 10^{-5} and is not explained.

C) CMB hot and cold spots determine where clusters and voids form at later epochs.

D) These anisotropies have a preferred spatial scale of ~ 1 degree. This is related to the size of the horizon at inflation.

16. We have measured the Hubble constant to be 70 km/s/Mpc today. Which of the following is correct?

A) Galaxies lying at redshift $z = 1$ from us are currently measuring a different Hubble constant.

B) Galaxies lying at redshift $z = 1$ will see us receding with a speed of 70 km/s.

C) Nobody can recede away from us faster than the speed of light.

D) The Hubble constant was larger in the past.

17. Dark energy can not explain which of the following fact?

A) Curvature of the universe is zero despite the fact that matter (baryons and dark matter) density falls below unity.

B) Actual age of the universe is greater than that in a matter-only universe.

C) Expansion of the universe is picking up speed, as opposed to slowing down.

D) The Milky Way and the Andromeda galaxy will merge in a few Gyrs.

18. Which fate is currently considered the most likely fate for our universe?

A) "Big chill" where almost all galaxies recede out of our horizon.

B) "Big crunch" where the entire universe collects back onto the same point.

C) "Big rip" where even atoms are ripped apart, as gravity as a force continuously weakens with time.

D) "Big bang" where a new big bang will occur somewhere in the universe.

19. Which of the following correctly captures the chronological sequence among different stages in the big bang?

A) Eras of Planck, Inflation, Atoms, Nucleosynthesis, Galaxies.

B) Eras of Inflation, Atoms, Nucleosynthesis, CMB, Galaxies.

C) Eras of Inflation, Hadrons, Nucleosynthesis, Atoms.

D) Eras of Atoms, Nucleosynthesis, Galaxies, Nuclei.

20. Why do dark matter reside preferentially in the galactic halo, but not the galactic disk or bulge?

A) Dark matter do not experience collisions so could not get rid of the primordial angular momentum. They are therefore circling at large radii.

B) Dark matter can not lose energy by radiating photons so they maintain their high temperature and are circling at large radii.

C) Stars collide frequently so they settle to the galactic disk and bulge. Dark matter only interact weakly when they collide so they cannot settle.

D) Dark matter do not experience gravity as strongly as baryons do. So they are circling at larger radii.

Part B, 6 short-answer questions. Write your answers in the space provided below. Five points each

1. Spot sizes in the cosmic microwave background have been used to measure curvature of the universe at large scales. Illustrate the physics and geometry behind this measurement, using words and simple diagrams.

   A)What is the meaning of a "standard ruler"? (two sentences or fewer)

   B) why are the CMB spots standard rulers? (two sentences or fewer)

   C) how the apparent angular sizes of the CMB spots can be used to infer the curvature?

2. Explain how one uses the standard candles (like a Cepheid variable or a Type Ia Supernova) to measure the expansion rate of the universe, namely, the Hubble constant.

A) What is the meaning of a 'standard candle'? (two sentences or fewer)

B) How does one measure distances using the standard candle? (write down the key equation relating distance to brightness, and explain in two sentences or fewer)

B) How does one measure recession velocities for galaxies? (write down the key equation relating recession velocity to redshift, and explain in two sentences or fewer)

D) Explain how then does one obtain the Hubble constant. (write down the key equation relating the Hubble constant with distance and recession velocity, then explain in two sentences or fewer)

3. In ~ 5 Gyrs there will be two events of relevance to us. One is the collision between the Milky Way Galaxy and the Andromeda Galaxy, the other is that the Sun will exhaust its central hydrogen and becomes a red giant star. Assume life still exists by then,

   A) what would be the effects of galaxy-galaxy collision on us? (two sentences)

   B) and what would be the effects of the Sun turning into a giant ? (two sentences)

4. The molecular gas ring in the elliptical galaxy NGC 2974 resides at a distance of 12,000 parsecs away from the center. It is observed to be rotating with a line-of-sight velocity of 305 km/s. Let this be the full rotation velocity and assume that the galaxy has a spherically symmetric mass distribution. What is the total mass of the galaxy inside the ring? and what is the dark matter fraction if the total baryon (star + gas) mass inside the ring is $\sim 6 \times 10^{10} M_{\odot}$, where $M_{\odot}$ is Solar mass.

5. Start from the Friedmann's equation for a flat universe,

$$H^2 = \frac{1}{a^2}\left(\frac{da}{dt}\right)^2 = \frac{8\pi G}{3}\rho_m + \frac{\Lambda c^2}{3}, \tag{1}$$

where ρ_m is the average matter density, and Λ the cosmological constant.

A) Demonstrate that matter density dominates in the early universe, while dark energy dominates in the future.

B) Solve for expansion of the universe $a = a(t)$ for when matter density dominates (i.e., ignore dark energy in the above equation). Since we have assumed that the universe is flat, matter density remains at the critical density.

C) Solve for expansion of the universe when dark energy dominates (i.e., ignore matter density in the above equation).

D) Draw a diagram illustrating how the scale factor of the universe varies with time as these two terms alternately take importance. In other words, the scale factor should smoothly follow one solution to the other.

6. The early universe was so hot that photons continuously create pairs and pairs quickly annihilate back to photons. To generate a pair of electron and positron, we need two photons with a total energy exceeding the rest mass energy of the pair.

A) What is the energy of these photons (assuming identical photons, express in unit of Joules)?

B) What are the wavelength of these photons? (express in unit of meters)

C) If these photons have wavelengths that lie at the blackbody peak of their respective environment, what is the temperature of the environment? (express in unit of kelvins) FYI, the blackbody peak for your skin (300K blackbody) is at a wavelength of 10 microns (1 micron $= 10^{-6}$ m).

Total Marks = 50