Cosmology Final Exam **Name _____**

Instructions:

- Place your name on all of the pages.
- Do all of your work in this booklet. Do not tear off any sheets.
- Show all of your steps in the problems for full credit.
- Be clear and neat in your work. Any illegible work, or scribbling in the margins, will not be graded.
- Put a box around your answers when appropriate..
- If you need more space, you may use the back of a page and write *On back of page #* in the problem space or the attached blank sheets. **No other scratch paper is allowed.**

Try to answer as many problems as possible. Provide as much information as possible. Show sufficient work or rationale for full credit. Remember that some problems may require less work than brute force methods.

If you are stuck, or running out of time, indicate as completely as possible, the methods and steps you would take to tackle the problem. Also, indicate any relevant information that you would use. Do not spend too much time on one problem. **Pace yourself.**

Pay attention to the point distribution. Not all problems have the same weight.

Be careful to note **units** and use an appropriate number of **significant digits.**

Page	Pts	Score
1	**19**	
2	**18**	
3	**16**	
4	**15**	
5	**18**	
6	**14**	
Total	**100**	

Constants and More

$$\frac{H^2}{H_0^2}=\frac{\Omega_{r,0}}{a^4}+\frac{\Omega_{m,0}}{a^3}+\Omega_{\Lambda,0}+\frac{1-\Omega_0}{a^2},\ \dot{a}^2=\frac{8\pi G}{3c^2}\sum_w \varepsilon_{w,0}a^{-1-3w}-\frac{\kappa c^2}{R_0^2},$$

$$\varepsilon_w=\varepsilon_{w,0}a^{-3(1+w)},\ L_x=78.7L_{sun},\ f_x=2.53\times10^{-8}\,\mathrm{Wm}^{-2}$$

$$M_{sun}=1.989\times10^{30}\,\mathrm{kg},\ M_{earth}=5.98\times10^{24}\,\mathrm{kg},\ 1\,Mpc=3.086\times10^{22}\,\mathrm{m},$$

$$G=6.673\times10^{-11}\,\mathrm{m^3kg^{-1}s^{-2}},\ h=6.626\times10^{-34}\,\mathrm{Js},\ \varepsilon_{c,0}=8.3\times10^{-10}\,\mathrm{Jm^{-3}},$$

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1. (3 pts) Provide the following based on our current observations/theory:
   a. How old is the universe? _____
   b. How many galaxies are there? _____
   c. What is the current CMB temperature? _____

1. (4 pts) Give the Benchmark Model values:
   a. $\Omega_{r,0} =$ _____
   b. $\Omega_{m,0} =$ _____
   c. $\Omega_{\Lambda,0} =$ _____
   d. $\Omega_{\mathrm{dm},0} =$ _____

2. (12 pts) Answer the following:
   a. The best standard candles are _____.
   b. In beta decay, a neutron decays into a proton plus a(n) _____ and a(n) _____.
   c. _____ assigned the magnitude range for stars.
   d. M31 is also known as _____.
   e. An _____ universe is one in which it looks the same in every direction.
   f. After studying the Coma cluster, _____ introduced the idea of dark matter.
   g. $Y \approx 24\%$ is the fraction of total mass that is _____.
   h. The Cepheids were first classified by _____ as standard candles.
   i. _____ was the first to measure red shifts of nebulae, particularly M31.
   j. The _____ model was proposed by Fred Hoyle and others in the late 1940s in competition with the Big Bang Model.
   k. A flat, matter dominated universe will end in a _____.

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3. (6 pts) Recall that $a(t) \approx 1 + H_0(t - t_0) - \frac{1}{2} q_0 H_0^2 (t - t_0)^2$.
   a. In terms of a determine
      i. H_0

      ii. q_0

4. (6 pts) A star has luminosity $L = 250 L_{sun}$.
   a. What is the absolute magnitude?

   b. If the apparent magnitude is 2.50, what is the luminosity distance?

5. (3 pts) Find $a(t)$ for a flat, Λ - only, universe.

6. (3 pts) Consider a positively curved universe which contains only radiation. Find *a(t).*

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7. (16 pts) Describe these pictures as specifically as you can.

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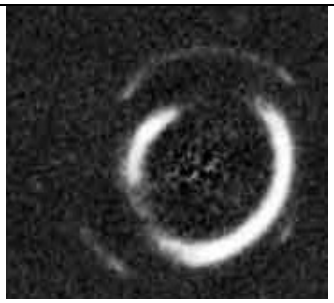

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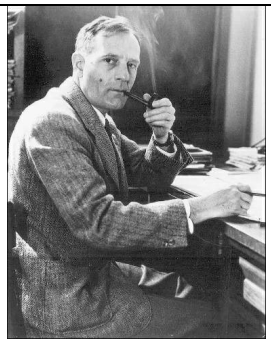

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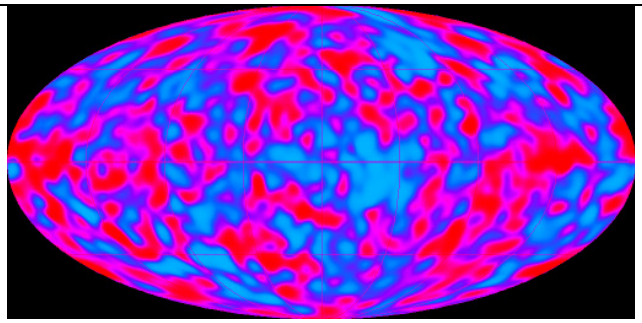

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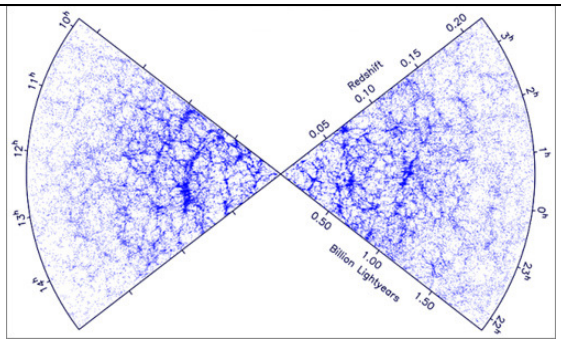

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8. (9 pts) Fill in the blanks in this timeline.

Time	a	Temp (K)	z	Event
13.5 Gy	_____	2.7		Now
9.8Gy	0.75			Λ Dominant
950 Myr			6	_____
300 Myr			14	Reionization
0.35 Myr			1100	_____
0.35 Myr		3000	_____	Decoupling
0.24 Myr		3740	1370	_____
0.047 Myr	0.00028			photoionization
10 min		_____		photon scattering
_____		7.8×10^{8}		BBN
1s		1.5×10^{10}		pn freezeout
10^{-12}s		10^{16}		_____
10^{-36}s		10^{28}		_____
10^{-43}s		10^{32}		TOE

9. (3 pts) On the above timescale, indicate
   a. Eras of radiation, matter and cosmological constant domination.
   b. Inflationary period
   c. Deuterium synthesis

10. (3 pts) Consider the Friedmann equation: $\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3c^2}\varepsilon - \frac{\kappa c^2}{R_0^2 a^2}$. Rewrite this equation at the current time in terms of H_0 and Ω_0.

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11. (10 pts) A measured red shift for a particular star is measured as 2.0.
    a. If the star emitted a wavelength of 550 nm, then what wavelength was observed?

    b. How far away might the star be?

    c. How fast is it moving?

    d. What was $a(t_e)$ for the universe at a time t_e when the light was emitted?

12. (6 pts) Consider the cosmic microwave background temperature. Using $\varepsilon_\gamma = aT^4$, $\alpha = 7.56\times10^{-16}\ \text{Jm}^{-3}\text{K}^{-4}$, and $n_\gamma = \beta T^3$, $\beta = 2.03\times10^{7}\ \text{m}^{-3}\text{K}^{-3}$,
    a. Determine the wavelength of the microwave radiation.

    b. Find the contribution to Ω due to the background photons.

13. (2 pts) The equation of state takes the form $P = w\varepsilon$. What is w for
    a. A photon gas? _____
    b. Hydrogen gas? _____

14. (3 pts) What are three problems resolved by inflation?

15. (2 pts) Define inflation.

16. (3 pts) Assume the density of the universe is $\rho \approx 10^{-28}$ kg m^{-3} and the universe is 10^{10} years old. If there are 10^{11} stars per galaxy and the sun is a typical star, give an estimate of the number of galaxies in the universe.

17. (4 pts) Describe two observations that support the existence of dark matter.

18. (2 pt) What was Einstein's Biggest blunder? Why did he make this blunder?