Name :__________________________________

Student Number :____________________________

Astronomy 202a
Fall 2005

Final Exam
Time: two hours

Answer: **All questions in Part I**
5 of the 7 short-answer questions in Part II
4 of the 5 questions in Part III

You may detach this page if you want to.
A list of constants is provided on the back of this page.
Please make sure your name is written on the next page.

The following formulae may or may not be useful.

$$m_2 - m_1 = 2.5\log_{10}\left(b_1/b_2\right)$$

$$\nu = c/\lambda$$

$$\lambda_{\max}T = 2.90\times10^6 \text{ nm K}$$

$$\mathrm{L} = 4\pi\mathrm{R}^2\sigma T^4$$

$$I(\nu,T) = \frac{2h\nu^3/c^2}{e^{h\nu/kT}-1}$$

$$E = h\nu$$

$$d = 1/p$$

$$m - M = 5\log_{10}\left(d/10\text{ pc}\right)$$

$$1/\lambda = R\left(1/m^2 - 1/n^2\right)$$

$$\frac{n_j}{n_i} = \frac{g_j}{g_i}e^{-\left(E_f-E_i\right)/k_BT}$$

$$\frac{n\left(X_{r+1}\right)}{n\left(X_r\right)} = \frac{2g_r}{n_e g_{r+1}}\left(\frac{2\pi m_r k_B T}{h^2}\right)e^{-E_i/kT}$$

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v_r}{c}$$

$$4\pi R^3/G = \left(m_1+m_2\right)P^2$$

$$\frac{\left(P/2\pi G\right)\left(v_{1r}+v_{2r}\right)^3}{\sin^3 i} = m_1 + m_2$$

$$I = I_0 e^{-\tau}$$

$$R_S = 2GM/c^2$$

$$\frac{dM}{dr} = 4\pi r^2\rho(r)$$

$$V = \tfrac{4}{3}\pi r^3$$

$$E = mc^2$$

$$U = e^2/r$$

$$\frac{dP}{dr} = -GM(r)\rho(r)/r^2$$

$$\Delta p\Delta x \ge h/2\pi$$

$$J = I\omega$$

$$U = -Gm_1m_2/r$$

$$K = \tfrac{1}{2}mv^2$$

$$R_J = \left(\frac{15k_BT}{8\pi Gm\rho}\right)^{1/2} = \left(\frac{15k_BT}{8\pi Gm^2n}\right)^{1/2}$$

$$M_J = \tfrac{4\pi}{3}\left(\frac{15k_BT}{8\pi Gm}\right)^{3/2}\rho^{-1/2}$$

$$M(r) = \frac{v^2(r)r}{G}$$

$$M = \tfrac{5}{3}\frac{\left\langle v^2\right\rangle R}{G}$$

$$v = H_0 d$$

$$\ddot{r} = -\frac{GM(r)}{r^2}$$

$$\frac{\lambda_0}{\lambda} = 1/R$$

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Part I – 20 marks
Answer all questions
Circle the best answer
2 marks each

1. Absorption lines in stellar spectra come from
   a. Aliens with flashlights
   b. Blackbody radiation
   c. Hot gas surrounding the star
   d. Relatively cool gas in the star's photosphere

2. To determine the masses of both components of a binary star system from spectral measurements, we need to know
   a. The orbital period of the system
   b. The Doppler shift of both stars
   c. The angle of inclination of the orbit
   d. All of the above

3. The evolution of a star after its time on the main sequence
   a. Ends with it becoming a white dwarf
   b. Ends with it becoming a black hole
   c. Depends on the star's original mass
   d. Takes much longer than the time spent on the main sequence

4. Pulsars are
   a. Rotating black holes
   b. Rotating neutron stars
   c. Clouds of ionized hydrogen
   d. Active galactic nuclei

5. The interstellar medium contains
   a. neutral hydrogen
   b. grains of dust
   c. molecules such as H_2 and CO
   d. all of the above

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6. A gas cloud with mass less than the Jeans mass
    a. Is gravitationally bound
    b. Will collapse to form a single star
    c. Is not gravitationally bound
    d. May collapse to form a cluster of stars

7. Spiral galaxies
    a. Have active star-forming regions
    b. Have fewer molecular clouds and dust than elliptical galaxies
    c. Are very rare compared to elliptical galaxies
    d. All of the above

8. Hubble's law tells us that distant galaxies are moving away from us with a speed that is proportional to their distance from us. This means that
    a. We are at the center of the universe
    b. Galaxies had more kinetic energy when the universe was younger
    c. The universe is expanding uniformly
    d. The strength of the gravitational force is weaker now than it was earlier in the life of the universe.

9. Which of the following is strong evidence for a Big Bang at the origin of the universe?
    a. Superclusters of galaxies
    b. Active galaxies
    c. The 3K Cosmic Background Radiation
    d. The fact that neutrinos have a small mass

10. Evidence for a black hole with a mass of 10^6 solar masses in the center of the Milky Way galaxy is
    a. Science fiction
    b. Based on the motion of stars near the galactic center
    c. Based on the observation of jets of matter emitted from the center of the Milky Way
    d. Based on observations of other galaxies

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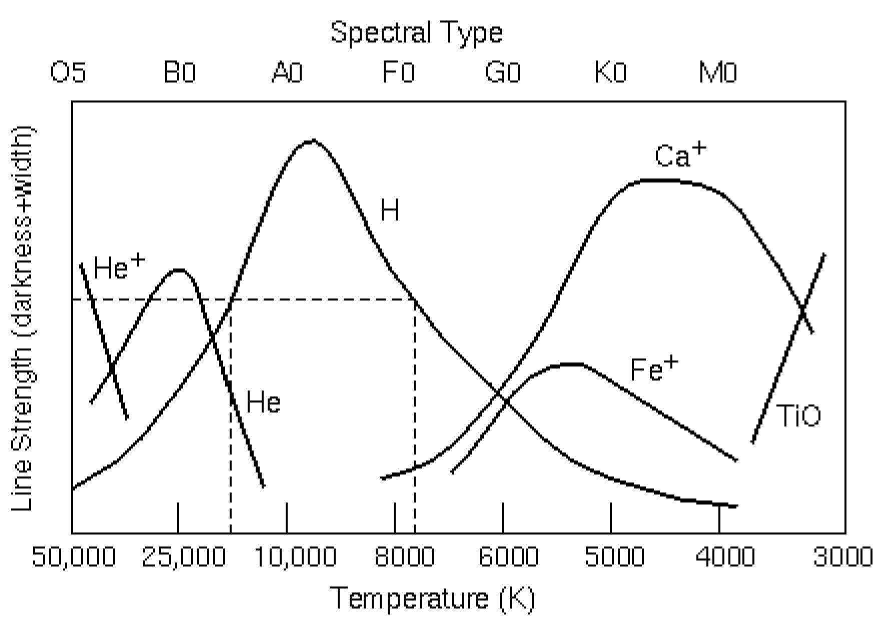
Part II – 20 marks

[4 marks each] **Answer 5 (five) of the following seven short-answer questions.** Answer the questions in the space provided. Use words and/or equations as appropriate. *Your answers should not be more than a couple of lines long at most.*

a) Briefly explain the solar neutrino problem and its resolution.

b) The figure shows the strength of stellar spectral lines as a function of temperature. Briefly explain why the intensity first increases, then decreases as the temperature increases. Why does the strength of the Hydrogen (H) lines peak at lower temperature than the strength of the Helium (He) lines?



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c) The H_α spectral line has a rest wavelength of 656.3 nm, in the red part of the spectrum (1 nm = 10^{-9} m = 10^{-7} cm). In the spectrum of a galaxy, the H_α spectral line is observed to be at a wavelength of 669.6 nm. What is the velocity of this galaxy with respect to us? How far away from us is the galaxy (in Mpc)?

d) A star is observed at two times six months apart. It is observed that its angular position on the sky with respect to the background stars has changed by 0.0023 arc seconds. How far away is this star? If its apparent magnitude is +3.7, what is its absolute magnitude?

e) Consider a spherical molecular cloud with density 10^6 H_2 molecules per cm^3 (mass of H_2 = 3.34×10^{-24} g), temperature 10 K, and radius 50 light years (50 ly = 4.75×10^{19} cm). Calculate the Jeans length for this cloud. Based on your answer, could this cloud collapse to form stars?

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f) Consider a star of radius R with constant density ρ. The mass contained inside a radius r is then

$$M(r) = \frac{4}{3}\pi r^3 \rho .$$

The equation of hydrostatic equilibrium is

$$\frac{dP}{dr} = -\frac{GM(r)\rho}{r^2} .$$

Taking $P = 0$ at $r = R$, integrate this to give an equation for the pressure at the center of the star.

g) The emission from a quasar at a particular wavelength doubles over a period of 3 weeks. Estimate the maximum size of the quasar in cm and in terms of the sun's radius.

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Part III – 40 marks
Answer 4 (five) of the following 5 questions.
10 marks each

1.

a. Explain what the CNO cycle and the p-p chain are. What determines which process is more important?
b. In the fusion of hydrogen to helium, four protons are converted to a helium nucleus of mass 6.6447×10^{-24} g. Calculate the energy released in this process (in ergs; 1 erg = 1 g cm^2/s^2).
c. Calculate the gravitational potential energy released by a proton falling under gravity from $r = \infty$ to $r = R_{\odot}$. Here $R_{\odot}$ is the radius of the sun.

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2.

a. Briefly describe how you would measure the rotation velocity of a galaxy.
b. The mass contained within a radius r in a particular (rather strange) galaxy is given by $M(r) = ar^{1.5}$. Calculate the rotation velocity of this galaxy as a function on r.
c. The mean density of universe is 10^{-29} g/cm^3. At this density, what would be the mass of a region with the volume of the sun?

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3.

a. Procyon (α Canis Minoris) is a type F5 subgiant. Its continuous spectrum peaks at a wavelength of 310 nm in the near UV. What is the surface temperature of this star?
b. Procyon has a companion star – Procyon B, a white dwarf separated from it by 14.9 AU. Procyon has a mass of 1.77 solar masses, and Procyon B has a mass of 0.63 solar masses. What is the orbital period of the binary system? (Incidentally, there is a Procyon C as well, but don't worry about that.)

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4.

a. Using Newtonian gravity with the integration constant $k = 0$, we derived this equation for the scale factor $R(t)$ of the universe:

$$\dot{R}^2 = \frac{8\pi}{3}\frac{G\rho_0}{R}$$

Take the square root of this equation, then separate variables and integrate to show how R depends on t in this model.

b. Briefly explain what is meant by "open", "closed", and "flat" universe.

c. Give one effect due to General Relativity that has been observed, and describe the observation.

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5.

a. Briefly explain what "electron degeneracy pressure" is. When is it important in stars?

b. The electron degeneracy pressure is given by

$$P = 2\left(\frac{h}{2\pi}\right)^2 \left(\frac{Z}{A}\right)^{5/3} \left(\frac{\rho}{m_p}\right)^{5/3} \frac{1}{m_e}$$

where h is Planck's constant, $Z/A = 0.5$ is the ratio of atomic number to mass number, ρ is the mass density, m_p is the proton mass, and m_e is the electron mass.

The density in the core of the sun is 150 g/cm^3, while the density in the center of a white dwarf where the density is 1.2×10^6 g/cm^3.Calculate the ratio of the electron degeneracy pressure in the white dwarf to that in the sun. *Hint: Do not waste your time calculating the pressures themselves. All you need is the ratio.*

c. The angular momentum J of a rotating star is given by

$$J = \frac{2}{5} MR^2 \omega$$

where M is the star's mass, R its radius, and ω its angular frequency. The sun has $\omega = 2.4 \times 10^{-6}$ s^{-1}. Assuming that the angular momentum and mass stay constant, calculate the sun's rotation rate after it collapses to form a white dwarf of radius 0.01 solar radii.

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Extra

11. Star forming regions
    a. Contains lots of dust and gas
    b. Are associated with the spiral arms of galaxies
    c. Have strong infrared emission
    d. All of the above

12. We know that quasars are very distant objects because
    a. They emit a lot of energy
    b. Their spectra have very large red shifts
    c. Their spectra have very large blue shifts
    d. They are very faint

13. The wavelength at which a blackbody spectrum has its maximum intensity
    a. Increases with increasing temperature of the blackbody
    b. Decreases with increasing temperature of the blackbody
    c. Is independent of temperature
    d. Depends on both temperature and density

14. Stars on the main sequence
    a. Get most of their energy from fusion of H into He
    b. Are nearing the end of their evolution
    c. Are not hot enough for fusion reactions to occur
    d. Have an onion-like structure, with different nuclear reactions taking place in the different shells

15. A flat universe
    a. Will expand forever but with an expansion rate that approaches zero at long times
    b. Must have zero density
    c. Will expand forever, with an expansion rate that approaches a non-zero constant
    d. Will eventually stop expanding and start to contract