UNIVERSITY OF TORONTO
Faculty of Arts and Science

DECEMBER 2006 EXAMINATIONS

AST221H1 (Fall 2006)

Duration: 3 hours; Aids: Calculator only; Answers in exam booklets

Marks: All five questions have equal weight, with the weight distributed equally over the subitems.

Solar mass	$1\,M_\odot$	$= 1.989 \times 10^{30}\,\mathrm{kg}$
Solar luminosity	$1\,L_\odot$	$= 3.839 \times 10^{26}\,\mathrm{W}$
Solar radius	$1\,R_\odot$	$= 6.955 \times 10^{8}\,\mathrm{m}$
Solar effective temperature	$T_\odot$	$= 5777\,\mathrm{K}$
Earth mass	$1\,M_\oplus$	$= 5.974 \times 10^{24}\,\mathrm{kg}$
Earth radius	$1\,R_\oplus$	$= 6.378 \times 10^{6}\,\mathrm{m}$
Parsec	1 pc	$= 3.0857 \times 10^{16}\,\mathrm{m}$
Astronomical Unit	1 AU	$= 1.4960 \times 10^{11}\,\mathrm{m}$
Gravitational constant	G	$= 6.673 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$
Speed of light	c	$= 2.9979 \times 10^{8}\,\mathrm{m\,s^{-1}}$
Planck's constant	h	$= 6.626 \times 10^{-34}\,\mathrm{J\,s}$
	$\hbar$	$= h/2\pi = 1.055 \times 10^{-34}\,\mathrm{J\,s}$
Boltzmann's constant	k	$= 1.381 \times 10^{-23}\,\mathrm{J\,K^{-1}}$
Stefan-Boltzmann constant	σ	$= 5.670 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$
Radiation constant	a	$= 4\sigma/c$
Proton mass	m_p	$= 1.67262 \times 10^{-27}\,\mathrm{kg}$
Neutron mass	m_n	$= 1.67493 \times 10^{-27}\,\mathrm{kg}$
atmoic mass unit (amu)	u	$= 1.66054 \times 10^{-27}\,\mathrm{kg}$
Electron mass	m_e	$= 9.10939 \times 10^{-31}\,\mathrm{kg}$
Hydrogen mass	m_H	$= 1.67353 \times 10^{-27}\,\mathrm{kg}$
Electron volt	1 eV	$= 1.6022 \times 10^{-19}\,\mathrm{J}$
Bohr radius	a_0	$= \hbar^2/m_e e^2 = 5.292 \times 10^{-11}\,\mathrm{m}$

Planet	Mass ($M_\oplus$)	Equatorial radius ($R_\oplus$)	Semi-major axis (AU)	Albedo
Mercury	0.05528	0.3825	0.3871	0.119
Venus	0.81500	0.9488	0.7233	0.750
Earth	1.00000	1.0000	1.0000	0.306
Mars	0.10745	0.5326	1.5236	0.250
Jupiter	317.83	11.209	5.2044	0.343
Saturn	95.159	9.4492	9.5826	0.342
Uranus	14.536	4.0073	19.2012	0.300
Neptune	17.147	3.8926	30.0476	0.290

1. Suppose you are observing the Sun from Epsilon Eridani, i.e., at a distance of 3 parsec.

   (a) If you would measure radial velocities of the Sun, how large would be the signal due to Jupiter? And how large that due to Earth? (Assume you are viewing the Solar system edge-on.)

   (b) What would be the maximum angular separation (in arcsec) at which you could see Jupiter from the Sun? And how about Earth?

   (c) Estimate how bright Jupiter and Earth would be *relative to the Sun* in visual, reflected light. *(Feel free to ignore the planet's phase.)* Given your answer, are you surprised no planets have yet been detected in reflected light?

2. At the end of the Sun's life, what will be left is a $0.6M_{\odot}$ core composed of Carbon and Oxygen, in roughly equal amounts.

   (a) Estimate how much energy will have been produced by fusion over the Sun's whole life. *Note: the binding energy per nucleon of Carbon is 7.7 MeV, and for Oxygen it is 8.0 MeV.*

   (b) Estimate the total amount of energy that the Sun will radiate during its *main-sequence* phase. What fraction is this of the total energy you calculated above?

   (c) Following the main sequence, the Sun will go through a number of further phases before becoming a white dwarf. These last about 10 times less long than the main sequence. What will be the average luminosity during these phases?

3. Luminosities of main-sequence and of giant stars

   (a) Main-sequence stars with different mass have very different luminosities. Explain this using physical arguments. *(If you are confused, you can also derive the mass-luminosity relation, and explain it based on that.)*

   (b) Giant stars have a luminosity that increases drastically with age, as they ascend the giant branch. Explain why this is the case.

4. Temperatures on the Earth.

   (a) If the Earth's surface radiated exactly in equilibrium with the amount of sunlight absorbed, what would the average temperature at the surface?

   (b) The true average temperature near the ground on Earth is about 15°C. Why is this different from your estimate above? Be sure to give a physical explanation.

   (c) Estimate the total amount of thermal kinetic energy stored in the Earth's atmosphere. You can assume the atmosphere is isothermal, and composed of ideal gas particles. *(Hint: one way to infer the total amount of air is to use the fact that the air pressure at ground level is* $10^5\,\mathrm{N\,m^{-2}}$ *and that the height of the atmosphere is about* $10\,\mathrm{km}$*).*

   (d) Estimate the thermal time of Earth's atmosphere, using the thermal content and the luminosity emitted by the Earth's atmosphere. Given your answer, by how much do you expect the hottest weather to be delayed from Summer solstice?

5. Formation of the solar system and puzzles posed by extrasolar planets.

   (a) Describe the general idea of how the solar system formed, and how it can reproduce the observed properties of the solar system (you should include at least three properties; an example is the difference between terrestial and jovian planets).

   (b) In the context of the picture of how the solar system formed, what properties of extrasolar planetary systems have been surprising?