Astronomy C

Michigan Region 8
March 12, 2016

Names:

Team:

Team Number:

General Instructions

- There is a separate answer sheet. PLEASE write your answers on the answer sheet.
- You may take the test apart, but put it back together at the end.
- **This test is 100 points total.** Each correct answer is 1 point, unless otherwise specified.
- Section scores will be used as tiebreakers in this order:
  Topics (part II) → Math (part III) → DSOs (part I)
- Time is NOT a tiebreaker.

Math-Specific Instructions

- Use the constants provided below.
- Use proper sig figs (or at least try).
- Provide answers in the requested units. Answers in other units will not be accepted.
- Full credit will be awarded for answers within ± 10% of the key.

Useful Constants

$b = 0.0029\ m * K$

$c = 3.00 * 10^{8}\ m/s$

$G = 6.67 * 10^{-11} \frac{N\,m^2}{kg^2}$

$H_0 = 72 \frac{km/s}{Mpc}$

$h = 6.63 * 10^{-34}\ J * s$

$k = 1.38 * 10^{-23}\ J/K$

$\sigma = 5.67 * 10^{-8} \frac{W}{m^2\,K^4}$

$L_{sun} = 3.84 * 10^{26}\ W$

$M_{sun} = 1.99 * 10^{30}\ kg$

$R_{sun} = 6.96 * 10^{8}\ m$

$T_{sun} = 5800\ K$

$1\ pc = 3.26\ ly = 206265\ AU = 3.08 * 10^{16}\ m$

$1\ ly = 0.307\ pc = 63240\ AU = 9.46 * 10^{15}\ m$

$Abs. mag\ of\ Type\ Ia\ SNe = -19.6$

Bonus (+1)

LIGO has recently announced the detection of gravitational waves from a black hole merger. However, the existence of gravitational waves has been known since the 1970s – what object provided this early indirect evidence?

Part I – DSOs [36 pts total]

1. Which DSO is depicted in Image [2]?
2. What group of stars is responsible for ionizing the central area of this DSO?

3. Which DSO is classified as a “hot Neptune” exoplanet?
4. What exciting compound was found in this exoplanet’s atmosphere (specify phase)?

5. One of the DSOs was the first brown dwarf discovered, in a binary system with a white dwarf. Which component of the system is represented in the spectrum in Image [8], and why? [2 pts]

6. Which DSO is the namesake of a kind of pre-main sequence stars that can be divided into “classical” and “weak-lined” types?
7. One of the nebulas associated with this DSO has been difficult to see since the pre-main sequence star brightened. What is its name?

8. Which DSO is considered to be a younger analogue of HR 8799?
9. What are the distinguishing characteristics of the two disks associated with this DSO? [2 pts]

10. Which DSO is represented schematically in Image [12]?
11. How is the high metallicity of the central star in this system thought to have come about?

12. Which DSO is the prototype for hot Jupiter exoplanets?
13. Why is this exoplanet much larger than Jupiter, despite having less mass?

14. Why is the central star in Image [6] not visible in x-ray?
15. What is the future of this DSO?

16. A partial spectrum of which DSO is depicted in Image [1]?
17. What causes the dramatic difference in temperatures on opposite sides of this DSO?

18. What type of object related to star formation is depicted in Image [7]?
19. What causes the difference between the visible and infrared images?

20. Which DSO is pictured in Image [3]?
21. Why might this DSO cause a revision of planetary formation theory?

22. The light curve of which DSO is depicted in Image [9]?
23. What does this light curve tell us about the DSO?

24. One of the DSOs is the coldest brown dwarf currently known. Assuming that it can be approximated as a blackbody, what is its peak wavelength?

25. What type of pre-main sequence star is the DSO pictured in Image [11]?
26. What evidence suggests a large planet or brown dwarf forming around this DSO?

27. The light curve in Image [4] belongs to the central star of which DSO (note the timescale)?
28. Name two compounds that have been detected in the atmospheres of the planets in this DSO. [2 pts]

29. Which DSO is represented schematically in Image [5]?
30. What made the discovery of planet "f" in this system exciting?

31. Why does the existence of the DSO in Image [10] conflict with current models of planet formation?
32. What are the *issues* with each of the two leading theories as to how this DSO ended up where it is? [2 pts]

Part II – Star Formation & Exoplanets [40 pts total]

33. What is a color-magnitude diagram more commonly known as?
34. How do we determine color?
35. What would a color-color diagram functionally look like if all stars were perfect blackbodies?

36. Star formation is often "triggered" by some event as opposed to being spontaneous. What is one type of event that would cause a portion of a nebula to collapse?
37. Why are EGGs important to star formation?
38. What element characterizes star-forming regions?

39. What element is generally used to distinguish brown dwarfs from low-mass stars
40. What element distinguishes brown dwarfs from high-mass planets?
41. What type of spectral lines, often denoted by square brackets like [O III], are produced in low density environments and distinguish pre-main sequence stars and nebulae from other astronomical objects?

42. What theorem states that mass is, by far, the most important factor in determining a star's future evolutionary path?
43. What two paths can pre-main sequence stars follow on the HR diagram on their way to the main sequence? [2 pts]
44. What form of heat transport distinguishes the path that is exclusively for stars above 0.5 Msun?

45. What is the primary criterion for determining the habitable zone around a star?
46. What happens to the habitable zone as a main-sequence star evolves, and why? [2 pts]
47. In addition to the habitable zone, what other distance from a star is important because it is the point beyond which volatile compounds condense into solid ice grains?

48. What is the term for a probability distribution of the masses of a (newly-created) stellar population?
49. Low-mass pre-main sequence stars go through periods of dramatically increased instability. What is the name for this highly unstable phase?
50. What is the term for a jet of gas ejected from a protostar that glows brightly as it collides with the interstellar medium?
51. What is the upper mass limit for pre-main sequence stars?
52. Why does this limit exist?

53. What causes pre-main sequence stars to shine during their contraction?
54. What state occurs when the inward and outward forces within stars balance each other?

55. What is the process by which dust in disks of evolving protostars gravitationally attracts and then accumulates to form protoplanets?
56. What processes result in the dust in debris disks falling inward or being pushed outward, respectively? [2 pts]
57. Which type of stars are debris disks found around?
58. Why are exoplanets (of any type) unlikely to be found in old stellar populations?

59. What is the term for a gas giant that has had its atmosphere stripped away?
60. How are ocean planets thought to form?
61. What is one possibility for why a planet may be orbiting in the opposite direction to the rotation of its parent star?
62. What are the two main reasons for why we preferentially detect hot Jupiter exoplanets (over other types of exoplanets)? [2 pts]
63. What type of exoplanets tend to form around stars with slightly higher metallicity than the Sun?

The following questions are related to exoplanet detection methods:
64. Which method relies on measuring the Doppler shift of a star's spectral lines?
65. Which method only works if the orbit of the exoplanet is nearly edge-on?
66. What wavelengths are usually used to perform direct imaging of exoplanets, and why? [2 pts]
67. When an exoplanet passes in front of its (rotating) parent star, it will produce a small redshift and blueshift. What is the name of this effect?

Part III – Calculations [24 pts total]

All questions in this section are worth 2 points each.
Remember to give your answers in the units requested in the problem!

68. An Earth-sized planet orbits a Sun-like star with a mass of 0.95 Msun with a period of 120. days.
    a. What is the radius of this orbit, in AU? Assume the mass of the planet is insignificant compared to that of the star.
    b. The star has a luminosity of 0.88 Lsun. What is the solar flux incident on the planet, in W/m^2?
    c. The planet has an albedo of 0.15. Ignoring any kind of greenhouse effect, what is the equilibrium temperature of this planet in K? Is it habitable by human standards?

69. A planet with a mass of $1.12 * 10^{25}\ kg$ (just under 2 Earth masses) orbits an M dwarf with a mass of 0.42 Msun at a radius of 0.29 AU and with a period of 88 days.
    a. What is the maximum radial velocity, in m/s, that we could measure for the M dwarf (if the system were perfectly edge-on)? Assume circular orbits.
    b. Is this radial velocity detectable with current instruments? Assume that we can detect wavelength shifts of 1 part in 1 billion.
    c. What would the measured radial velocity, in m/s, be if the system had an inclination of 30°?

70. A spherical cloud of monatomic hydrogen (to make your lives easier) has a radius of $2.20 * 10^{14}\ m$ and a temperature of 15 K. The mass of a hydrogen atom is $1.673 * 10^{-27}\ kg$.
   a. What is the Jeans mass of this hydrogen cloud, in kg? If the actual mass of the cloud is 5 Msun, will it collapse?
   b. Suppose the cloud is (just barely) rotating with a rotational period of 1.0 Myr. What would the rotational period be, in hours, if the entire cloud collapsed to form a single protostar with a radius of 1.5 Rsun?

71. A star is observed to have an apparent magnitude of +7.3, and we know from other methods that this star has an absolute magnitude of –2.4.
   a. What is the distance to this star, in pc?
   b. We realize that a nebula 200 pc thick is between us and the star, causing 1.5 magnitudes of extinction per kpc. Taking this into account (and ignoring any other sources of extinction), what is the actual distance to the star, in pc?

72. A star classified as K5V has a mass of 0.82 Msun and a luminosity of 0.34 Lsun.
   a. How much mass, in kg, does this star lose in a year from fusion (assume 100% efficient conversion of mass to energy)?
   b. What is the main sequence lifetime of this star, in Gyr?