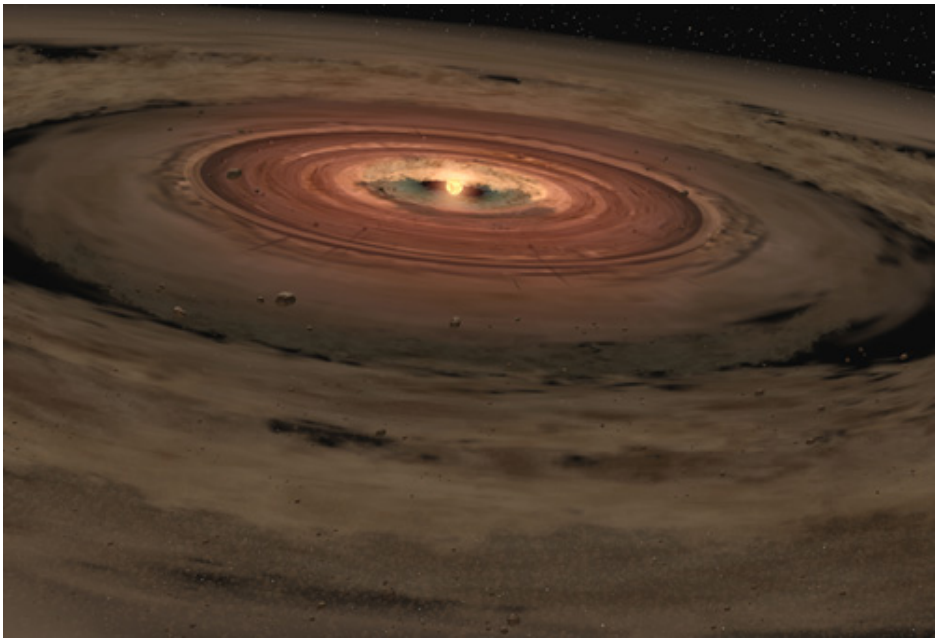
Science Olympiad
Astronomy C Division Event
Sample Exam

Stellar Evolution: Star and Planet Formation

2014-2015



Team Number: _____

Team Name: _____

Instructions:
1) Please turn in all materials at the end of the event.
2) Do not forget to put your team name and team number at the top of all answer pages.
3) Write all answers on the answer pages. Any marks elsewhere will not be scored.
4) All quantitative answers are expected to have a precision of 3 or more significant figures.
5) Please do not access the internet during the event. If you do so, your team will be disqualified.
6) This test was downloaded from: www.aavso.org/science-olympiad-2015.
7) Good luck! And may the stars be with you!

Section A: Use Image/Illustration Set A to answer Questions 1-19. This section focuses on qualitative understanding of stellar evolution, specifically relating to star formation and planets.

1. A schematic of a T-Tauri star is shown in Image A1.
   (a) Which point (A-F) marks the location of the disk surrounding the protostar?
   (b) Which point (A-F) displays the bipolar outflow that may form Herbig-Haro objects?
   (c) Which point (A-F) shows the strongly variable hot spots on the protostar?

2. A color-magnitude diagram for a sample of brown dwarfs is shown in Image A2. The x-axis shows the J-K color index, while the y-axis displays J-band magnitude. The different colors represent different brown dwarf spectral types.
   (a) Which lettered region (A-D) corresponds approximately to a spectral type L2 brown dwarf?
   (b) Which lettered region (A-D) corresponds approximately to a spectral type T6 brown dwarf?
   (c) Which lettered region (A-D) corresponds approximately to the brown dwarf L-T type transition?

3. The spectrum of a star with a circumstellar disk is shown in Image A3.
   (a) Which line (red or blue) represents the blackbody spectrum of the star itself?
   (b) Which point (A-C) shows where the disk emission dominates over that of the star?
   (c) This point is at much longer wavelengths than the peak emission from the star. Why is this?

4. Light curves from a variety of objects are shown in Images A4-A8.
   (a) Which light curve is from a star with a transiting exoplanet in orbit around it?
   (b) Which light curve is from a T Tauri star?
   (c) Which light curve is from an FU Orionis star?
   (d) Which light curve is from a variable brown dwarf?
   (e) Which light curve is from a Herbig Ae/Be star?

The following questions (5-19) correspond to Images A9-A24.

5. Which two images show star formation regions?

6. TW Hydrae is the closest T Tauri star to the solar system.
   (a) Which image shows TW Hydrae?
   (b) What surrounds TW Hydrae in the image?

7. WISE 1049-5319 harbors the closest brown dwarf to Earth.
   (a) Which image shows this system?
   (b) How many brown dwarfs are in this system?
8. Which one of the following images shows an object with a debris disk?
   (a) A15
   (b) A20
   (c) A10
   (d) A17
9. Which image shows LP 944-20?
10. One of the images displays a star that is bright in X-Rays and has a planet in a close-in orbit.
    (a) Which image shows this star?
    (b) What is the name of this star?
11. FU Orionis is a prototype of a class of variable stars with its namesake.
    (a) Which image shows FU Orionis?
    (b) What distinguishes this type of object from normal T Tauri stars?
12. Beta Pictoris is a nearby star with a circumstellar disk.
    (a) Which image shows this object?
    (b) Beta Pictoris has a planet, Beta Pictoris b, in orbit around it. Is the distance from Beta Pictoris to Beta Pictoris b greater or less than the distance from the Sun to Neptune?
13. The 2M 1207 system was discovered in 2004.
    (a) Which image shows this object?
    (b) What two types of objects comprise this system?
14. HR 8799 is a star with both a debris disk and planets in its system.
    (a) Which image shows this object?
    (b) Which method was used to detect the orbital motion of its planets?
15. Gliese 229B is a brown dwarf orbiting a star, Gliese 229.
    (a) Which image shows this object?
    (b) What type of variable star is Gliese 229?
16. Image A21 shows a simulated atmospheric temperature map of HD 209458b.
    (a) What longitude and latitude is the substellar point located on this map?
    (b) Why is the hottest point not located directly at the substellar point?

17. Image A22 shows an observed atmospheric temperature map of an exoplanet.

    (a) Which exoplanet is this?

    (b) Does this object have a hotter or colder substellar point than HD 209458b?

18. Image A23 shows a transmission spectrum of an exoplanet. The black points show observations, with the lines indicating models for different atmospheric compositions.

    (a) Which exoplanet is this?

    (b) What is indicated by the misfit between the data points and expectation?

19. Image A24 shows the brightness map of an exoplanet.

    (a) Which exoplanet is this?

    (b) What is a possible implication of the brightest point on this planet being on the opposite side of the planet than expected?

Section B: Use Image/Illustration Set B to answer Questions 20-25. This section discusses radial velocity and transit methods, working through the advantages of each, and concluding with calculations of planet properties using these methods.

20. Which of the following planet properties is best constrained via the transit method?

    (a) Mass
    (b) Atmospheric Composition
    (c) Density
    (d) Radius

21. Which of the following planet properties is best constrained via the radial velocity method?

    (a) Mass
    (b) Atmospheric Composition
    (c) Density
    (d) Radius

22. How can an observer obtain the effective temperature of a planet via the transit method?

23. When using the radial velocity method, is an observer measuring the maximum or minimum mass of a planet? Why?

24. Image B1 shows the radial velocity curve of host Star A, around which Planet B orbits. Star A has the same mass, radius, and luminosity as the sun. Assume that the system has no inclination and Planet B has 0 eccentricity (a circular orbit).

    (a) What is the distance from Star A to Planet B, in AU, assuming Planet B has a mass much less than that of Star A?
    (b) What is the velocity of Planet B in its orbit around Star A, in km/s?
    (c) What is the mass of Planet B, in Jupiter masses?
    (d) Planet B has a radius of 0.8 Jupiter radii. What is the density of Planet B, in g/cm^3?

25. Image B2 shows the light curve of Star C, displaying transits due to Planet D. Star C is a K1 star with a mass of 0.80 Solar Masses and radius of 0.79 Solar Radii. The orbital period of Planet D is 2.22 days. Assume that the system has no inclination and Planet D has 0 eccentricity.

    (a) Which point (A-E) shows the Primary Eclipse, when Planet D blocks light from Star C?
    (b) Which point (A-E) shows the Secondary Eclipse, when Star C blocks light from Planet D?
    (c) What is the transit depth of the Primary Eclipse, in terms of the % of normal (non-eclipse) system flux?
    (d) What is the radius of Planet D, in Jupiter radii?
    (e) What is the total duration of the Primary Eclipse, in seconds?

Section C: Use Image/Illustration Set C to answer Questions 26-29. This section focuses on the mathematics of stars & planetary systems.

26. Image C1 shows the blackbody spectrum of Star E, which is a main-sequence star with a parallax of 0.1" and radius of 0.480 Solar Radii. Planet F orbits Star E, has the same mass and radius as Earth, and lies at a distance of 0.176 AU from Star E.

    (a) What is the distance to Star E, in parsec?

    (b) What is the effective temperature of Star E, in Kelvin?

    (c) What is the Spectral Type of Star E?

    (d) What is the equilibrium temperature of Planet F, in Kelvin, assuming it has 0 albedo?

    (e) Is Planet F potentially habitable? Use the phase diagram for water in Image C2 to aid your response. Assume that habitability only requires the existence of liquid water on the surface of a planet, and that Planet F has the same atmospheric surface pressure as Earth.

    (f) Your response for Part (d) did not include the greenhouse effect. Would the greenhouse effect be stronger or weaker for Planet F than for Earth? Why?

27. Images C3, C4, and C5 show spectra from 3 different main-sequence stars.

    (a) Which image corresponds to the star with the highest luminosity?

    (b) Which image corresponds to the star with the lowest effective temperature?

    (c) Which image corresponds to a spectral type F5 star?

28. Star G is a M2V star at a distance of 50 parsec. Planet H orbits Star G at a distance of 0.01 AU, and has a radius equal to that of Jupiter.

    (a) What is the apparent visual magnitude of Star G?

    (b) Assuming that Planet H has 0 albedo, how many times brighter is Star G than Planet H?

29. A plot of planet Radius (in Earth Radii) vs. Mass (in Earth Masses) for the Kepler-11 system is shown in Image C6, with the Solar System planets over-plotted as triangles and a sample of transiting exoplanets plotted as squares. Lines of constant density for a given composition are also shown.

    (a) Which planet orbiting Kepler-11a has the highest density (b-f)?

    (b) What is the density of Kepler-11c, in g/cm^3?

    (c) Kepler-11g is a recently discovered member of the system, with a yet-undetermined density. Its semi-major axis is 0.46 AU, and it has an orbital period around Kepler-11a of 118.4 days. What is the mass of Kepler-11a, in Solar Masses, assuming the mass of Kepler-11g is much smaller than Kepler-11a?