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) Do not worry about significant figures. Use 3 or more in your answers, regardless of how many are in the question.
6) Please do not access the internet during the event. If you do so, your team will be disqualified.
7) This event and answer key will be available at the AAVSO website: [www.aavso.org/science-olympiad-2016](http://www.aavso.org/science-olympiad-2016)
8) Good luck! And may the stars be with you!
Section A: Use Image/Illustration Set A to answer Questions 1-18. An H-R diagram is shown in Image 20. All questions in this section are worth 1 point.

1. (a) What is the number of the illustration that shows the system which includes Kepler-186?
   (b) The planet shown in this illustration was the first to be validated to have which property?

2. (a) What is the name of the object in Image 13, and what type of object is this?
   (b) What letter on the H-R diagram shows the location of this object?
   (c) Which image shows the behavior of this object?

3. (a) Image 25 depicts which method of exoplanet detection?
   (b) The difference in flux between position 1 and position 3 on the light curve constrains what quantity of the system?

4. (a) What is the image number and name of the large complex that will collapse into a star formation region?
   (b) What is the image number and name that shows the next stage in the process of star (and therefore planet) formation?

5. Place the following images in order from youngest to oldest: 1,3,9,11,14.

6. (a) What specific type of object is shown in Images 7 and 18?
   (b) What letter(s) on the H-R diagram show the location of this general class of object?
   (c) Which images show the rotational variability that can occur for objects in this class?
   (d) What mechanism is most likely causing this variability?

7. (a) What is the name of the system shown in Image 10?
   (b) What method of detection was used to find the planet in this image?
   (c) Which image illustrates the structure of this object?

8. (a) What is the name of the smallest exoplanet that has been found to have water vapor in its atmosphere?
   (b) What method was used to detect water vapor in this atmosphere?
   (c) What image depicts this detection?

9. (a) What is the number of the image that shows the behavior produced by the object in Image 6?
   (b) What letter represents the location of the object shown in Image 6 on the H-R diagram?

10. Which letters on the H-R diagram mark the locations of pre-main sequence objects?
11. (a) What information do the maps display in Image 17?
   (b) The data in Image 17 resulted from observations of what exoplanet?

12. (a) What is the image number for the object that has an orbital separation too large to have formed by current theories of planet formation?
   (b) What is one way this object could have been formed as expected and then ended up at its current location?

13. (a) Which system is illustrated in Image 16?
   (b) What letters on the H-R diagram show the locations of the host and companion star of this system?
   (c) Which image shows a transit signal from the super-Earth planet in this system?

14. (a) Which image shows the radial velocity method of detecting exoplanets?
   (b) Name 2 planetary characteristics that this method measures.

15. (a) What is the name and type of object in Image 4?
   (b) What effect is the planet having on the parent star?

16. (a) What letter on the H-R diagram shows the location of an FU Ori object?
   (b) Which image shows the behavior exhibited by this type of object?

17. (a) What is the name of the system, consisting of a white dwarf and brown dwarf, illustrated in Image 5?
   (b) What is the spectral type of the brown dwarf in the system?
   (c) What letters correspond to the locations on the H-R diagram for both objects in this system?

18. (a) What is the name of the first exoplanet discovered orbiting a Sun-like star?
   (b) What method was used to detect this exoplanet?
Planets have been discovered around a variety of types of stars, from pulsars to red dwarfs. In Section B we will delve qualitatively into how exoplanet detection differs with stellar type. In Section C we will look at at some current results for how planet characteristics depend on stellar mass, with questions that will ask for insight on planet formation from the observational data.

Section B: Use Image/Illustration set B/C to answer Questions 19-21.

19. Though we exist in orbit around a G-type main sequence star, stars lie in a broad range of effective temperatures and hence luminosities.

   (a) What type of star (O,B,A,F,G,K,M) is most prevalent in our galaxy? (1 point)
   (b) Why is this type of star the most prevalent? (2 points)

20. Detecting planets in the habitable zone of a star can be easier or harder than around Sun-like stars depending on the spectral type of the host star.

   (a) Image 31 depicts transit light curves of planets around a Sun-like star and star with a radius half that of the Sun. The star with a radius half that shows a larger fractional transit depth. What is its spectral type? (1 point)
   (b) Finding planets in the habitable zone of smaller, cooler stars is easier than finding planets in the habitable zone of a Sun-like star, because the habitable zone lies closer in. Write down two reasons why detecting planets closer-in to their host star is easier via the transit method. (2 points)
   (c) Closer-in planets are also easier to detect via radial velocity. Write down two reasons why it is easier to detect planets via radial velocity if they are closer-in (hint: one of these is the same as for the transit method). (2 points)

21. Let’s put it all together, and figure out how to find Earth 2.0!

   (a) Given your answers from Questions 19 and 20, what type of star would it be easiest (i.e. take the least telescope time) to find a planet with the surface temperature and size of Earth around? (1 point)
   (b) However, recall that simply finding the right surface temperature is not enough to determine habitability, at least for Earth-like organisms (e.g. humans). These small, cool stars have one complicating factor in that they emit high amounts of radiation that is damaging to human tissue. What part of the EM spectrum is this radiation in? (1 point)
   (c) Additionally, these stars may be variable. What type of variability do these smaller stars have? (1 point)
Section C. Use Image/Illustration set B/C to answer Questions 22-24.

22. Image 32 shows the occurrence rate of *Kepler* planets with radii 1-4 times that of Earth as a function of semi-major axis, from Mulders et al. (2015a). Image 33 shows the occurrence rate as a function of planet radius, from Mulders et al. (2015b).

(a) Earth-sized planets are most prevalent around stars of which spectral type? (1 point)
(b) Stars of this spectral type do not have many Neptune or Jupiter-sized planets, however. Why is this? (2 points)

23. Image 34 shows the trend between heavy-element and planet masses for modeled gas giant planets, while Image 35 shows the fraction of the planet-to-star metallicity as a function of planet mass, both from Thorngren et al. (2015).

(a) There is a known correlation (not shown here) between giant planet mass and the metallicity of the host star. How can this observation be described using planet formation theory? (2 points)
(b) The slope of the increase of heavy-element mass with planet mass in Figure 34 shows that planets with higher mass have relatively higher fractions of what two atomic species? (1 point)
(c) There is a negative correlation between heavy-element abundances (relative to that of the star) and planet mass in Image 35. What theory of planet formation does this point towards? How do you know? (2 points)

24. Consider a planet with the radius and mass of Earth, at a distance where it has an equilibrium temperature of 255 Kelvin, which is similar to that of Earth (before including the greenhouse effect). We’ll compute properties of the planet-star system considering two different types of stars: Star A, which has all the properties (radius, mass, effective temperature) of the Sun, and Star B, which has a mass of 0.4 Solar masses, radius of 0.39 Solar radii, and effective temperature of 3,400 Kelvin.

(a) Assuming the planet has an albedo of 0.3, what is its distance from Star A, in AU? (1 point)
(b) Again assuming an albedo of 0.3, what is its distance from Star B, in AU? (1 point)
(c) What is the orbital period of the planet around Star B, in days? (1 point)
(d) How many times greater is the fractional transit depth of the planet around Star B than around Star A? (2 points)
(e) How many times greater is the radial velocity of Star B than Star A? (2 points)
(f) Star A and Star B both have a parallax of 0.05”. What is their distance from Earth, in parsecs? (1 point)
(g) How many times brighter does Star A appear to us than Star B? (2 points)
(h) Let’s put it all together. If you wanted to detect biosignatures (e.g. ozone, methane) in the atmosphere of this planet, which star (A or B) would you prefer to observe? Does the benefit of larger transit depth around Star B outweigh the lower signal to noise from the lowered brightness of the star? (1 point)