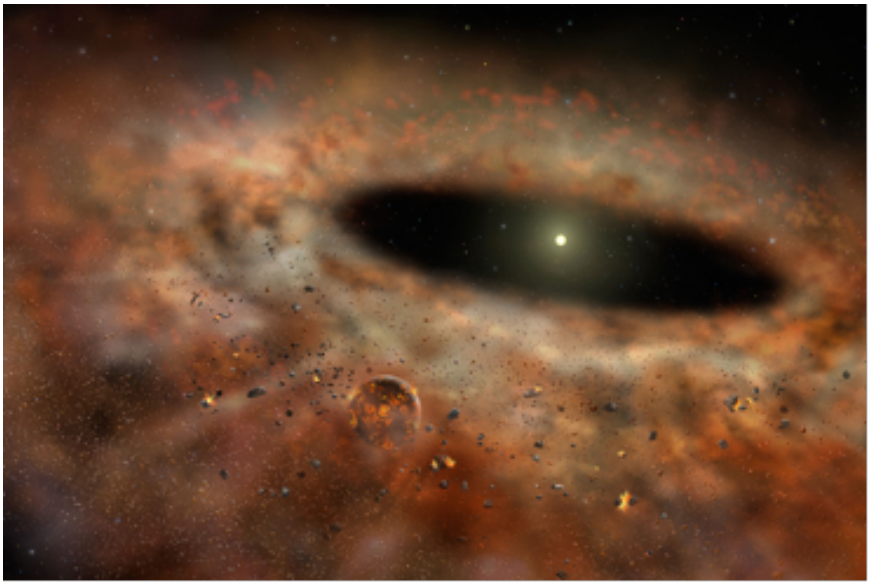
Science Olympiad
Astronomy C Division Event
National Exam

University of Nebraska-Lincoln

May 15-16, 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) 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-2015`.
8) Good luck! And may the stars be with you!

Section A: Use Image/Illustration Set A (Pages 7-9) to answer Questions 1-20. An H-R diagram is shown in Image 29.

1. The illustration in Image 2 shows a newly forming star that is accreting mass.
   (a) What specific type of protostar does this image represent?
   (b) The position of this object on the H-R diagram (Image 29) is represented by what letter?
   (c) Which light curve shows the behavior of this type of protostar?

2. CoRoT-2, illustrated in Image 6, is a system where a planet affects its parent star.
   (a) What type of planet is CoRoT-2b?
   (b) How is this planet increasing the magnetic field of its parent star?

3. Place Images 1, 7, 22, and 26 in evolutionary sequence of star/planet formation.

4. (a) What is the name and image number that shows the observation of one of the first confirmed brown dwarfs?
   (b) Which image shows the first observed evidence of high energy radiation emissions from a brown dwarf?

5. (a) What method of exoplanet detection is illustrated in Image 20?
   (b) What information is determined by the difference in brightness between points 1 and 3?

6. Consider the 5 exoplanet light curves in Image 34. All light curves are for planets with the same apparent orbital inclination.
   (a) Which diagram shows the largest star?
   (b) Which diagram shows the smallest planet?
   (c) Which diagram shows the largest planet?

7. The light curve in Image 12 shows an offset in maximum apparent brightness from the secondary eclipse for Kepler-7b.
   (a) Which image displays the graphic that represents the information inferred from the light curve data?
   (b) What information does this tell us about the planet?

8. (a) What type of objects are located at letter P on the H-R diagram?
   (b) What is the image number and name of the observation of two of these objects orbiting each other?

(c) Image 3 shows a surface map of one of these objects. What could cause the temporal and spatial variation in brightness seen in the image?

9. (a) What are the names of the stellar objects in Images 4 and 21?
   (b) Where are both of these objects located on the H-R diagram? (Hint: it is the same location)
   (c) What kind of disks surround these planets?
   (d) By what method were the planet candidates within the surrounding disks discovered?

10. (a) Which image illustrates a method of detecting exoplanets using the Doppler Effect?
    (b) What is the name of this method?
    (c) This method constrains the product of planet mass and another quantity. This other quantity can only be constrained through transit observations. What is this quantity?

11. (a) Which image shows a Herbig Ae/Be star?
    (b) Which image exhibits the behavior of a Herbig Ae/Be star?
    (c) Where are Herbig Ae/Be stars located on the H-R diagram?
    (d) Circumstellar disks of these stars can be "puffed up," making it so that the outer parts of the disk are heated more. What is the name for this type of disk? Hint: it comes from the shape of the disk, which is modified due to the stellar irradiation.

12. (a) What is the image number and name of a T Tauri star?
    (b) Which image shows the unique composition of part of the disk around this object?

13. (a) What is the name and type of object in Image 11?
    (b) Which other image contains this object?

14. List the following pre-main sequence objects in sequence from smallest to largest: 15, 16, 25.

15. (a) Which graphs show data using transmission spectroscopy?
    (b) List two physical properties of exoplanets that this method provides.

16. (a) What is the image number and name of the first directly imaged multi-planetary system?
    (b) What is the position of the parent star on the H-R diagram?

17. The transmission spectrum of GJ 1214b is shown in Image 36.
    (a) What can be inferred about this planet from the flatness of the data shown?
    (b) What type of exoplanet is this?

18. (a) What is the name and image number of a star formation region in the Large Magellanic Cloud?

(b) What is unique in this region?

19. Which graph plots the behavior exhibited by a Sun-like protostar?

20. Observations of the hot Jupiter HD 189733b showed that the decrease in X-ray emissions was 3 times greater than the corresponding decrease in optical emissions during transits of the planet around the parent star.

    (a) What did this measurement help determine?

    (b) A global temperature map of this exoplanet is shown in Image 6. What causes the shifting of the hottest point ("hot spot") in HD 189733b's atmosphere eastward of the substellar point, where the planet absorbs the most stellar radiation?

    (c) What other hot Jupiter from the object list shows this eastward hot spot shift?

Section B: Use Image/Illustration Set B (Page 10) to answer Questions 21-23.

21. Image 37 shows a directly imaged planetary system.

    (a) Use the scale bar to find the distance to this system, in parsecs.

    (b) Planet d in this system has a radius of 1.2 Jupiter radii, and a luminosity of approximately 3×10^{-5} Solar luminosities. What is the effective temperature of Planet d, in Kelvin?

    (c) What is the apparent magnitude of Planet d?

    (d) These planets are all very bright, but are very far from this host star. What does this tell you about the mass and age of the planets?

    (e) There are two debris disks in this system: a warm disk inside the orbit of Planet e, and a cold disk outside the orbit of Planet b. Write a sentence or two stating a theory for why these disks are located in these regions.

22. Image 38 shows the radial velocity curve of Star A. Star A has the same mass, radius, and effective temperature as the Sun. Planet B orbits around Star A, and Planet B has a mass equal to that of Jupiter. Assume that the orbit of Planet B has 0 eccentricity.

    (a) What is the semi-major axis of Planet B's orbit around Star A, in AU?

    (b) What is the velocity of Planet B in its orbit around Star A, in km/s?

    (c) What is the inclination of Planet B's orbit, in degrees?

    (d) Star A has an apparent visual magnitude of 6. What is the distance from Earth to Star A, in parsecs?

23. Image 39 shows the light curve of Star C, around which Planet D revolves in a circular orbit with a 2.2 day period. Star C has an apparent visual magnitude of 10.46, a parallax of 3.125 milli-arcseconds, and an effective temperature of 6444 Kelvin. This system is perfectly inclined to Earth, with an inclination of 90 degrees. Note that parts A and B of Image 39 only differ in their y-axis scales, and part C shows the light curve residuals.

    (a) What is the luminosity of Star C, in Solar luminosities?

    (b) What is the percent decrease in the system flux during the primary eclipse?

    (c) What is the radius of Planet D, in Jupiter radii?

    (d) What is the luminosity of Planet D, in Watts? Assume that the continuum level of the light curve is at a relative flux of 1.0001.

    (e) What is the effective temperature of Planet D, in Kelvin?

    (f) What is the wavelength of peak emission for Planet D in microns, and in what region of the electromagnetic spectrum does this fall? Assume that Planet D radiates as a blackbody.

    (g) What is the radius of Planet D's orbit around Star C, in AU?

Section C: Use Image/Illustration Set C (Page 11) to answer Questions 24-27.

24. Image 40 shows a brown dwarf color-magnitude diagram.

    (a) What quantity is plotted on the top y-axis?

    (b) What quantity is plotted on the bottom y-axis?

    (c) Which brown dwarf spectral type is located at point A?

    (d) Which brown dwarf spectral type is located at point B?

25. Image 41 shows a spectral energy distribution of a nearby object that has a circumstellar disk. The dots are data points, with the various lines showing contributions to the observed spectrum.

    (a) What does the dotted pink line represent?

    (b) What type of circumstellar disk is shown by the data? How do you know?

    (c) What type of circumstellar disk will this evolve into?

26. Image 42 shows the blackbody spectrum of Star E, around which Planet F orbits. Star E has a parallax of 0.01" and luminosity equal to that of the Sun. The angular separation between Star E and Planet F is 5.28 milli-arcseconds. Planet F has a mass of 2 Earth masses, an atmospheric surface pressure of 100 bars, and the acceleration of gravity at its surface is 10 m/s^2.

    (a) What is the distance to this system, in light years?

    (b) What is the radius of Star E, in Solar radii?

    (c) What is the distance from Star E to Planet F, in AU?

    (d) What is the radius of Planet F, in Earth radii?

    (e) Planet F has an average albedo of 0.30. What is the equilibrium surface temperature of Planet F, in Kelvin? Assume perfect redistribution of heat around the planet.

    (f) Is Planet F potentially habitable, i.e., could liquid water exist in stable form on its surface? Use Image 43 as a reference.

27. Image 44 shows a mass-density plot for a variety of exoplanets.

    (a) What is likely the main difference between planets above and below the horizontal black line?

    (b) What type of exoplanet is GJ 3470b? Potential options are: gas giant, terrestrial planet, super-Earth, sub-Neptune, hot Jupiter.

    (c) What type of exoplanet is 55 Cnc e? Potential options are: gas giant, terrestrial planet, super-Earth, sub-Neptune, hot Jupiter.

    (d) What is the radius of HAT-P-11b, in Earth radii?

    (e) Which planet has the largest radius: GJ 1214b, GJ 3470b, GJ 436b, or HAT-P-11b?

Team name: KEY Team number: KEY

Answer Page: Section A

1. (a) FU Orionis or FUOr
   (b) D or E
   (c) 30
2. (a) hot Jupiter and/or gas giant
   (b) Changing its rotation rate
3. 1,22,26,7
4. (a) Gliese 229b, 18
   (b) 27
5. (a) Transit
   (b) Size of planet (relative to that of star)
6. (a) B or D (A-E)
   (b) A (A-E)
   (c) C (A-E)
7. (a) 14
   (b) Western hemisphere brighter, potential cloud cover
8. (a) Brown dwarfs
   (b) 10, WISE 1049-5319
   (c) Patchy clouds rotating in/out of view
9. (a) Beta Pictoris, Fomalhaut
   (b) G
   (c) Debris disks
   (d) Direct imaging
10. (a) 9
    (b) Radial Velocity
    (c) Inclination
11. (a) 16
    (b) 32
    (c) Q
    (d) Flared
12. (a) 25, TW Hydrae
    (b) 35
13. (a) M20 (Trifid Nebula), HII or star formation region
    (b) 22
14. 15,25,16
15. (a) 31,36
    (b) Temperature, composition, presence of clouds
16. (a) 5, HR 8799
    (b) G
17. (a) Has clouds or haze
    (b) Super-Earth or Mini-Neptune
18. (a) N159, 24
    (b) Has 2 massive protostars with bipolar outflow
19. 33
20. (a) Size of the planet/atmosphere
    (b) Strong east-west winds
    (c) HD 209458b

Team name: KEY Team number: KEY

Answer Page: Section B

21. (a) 40 ± 10 Parsecs
    (b) 1219 ± 200 Kelvin
    (c) 19.2 ± 2
    (d) They are self-luminous, must be massive and young
    (e) Planets clear gap in disk

22. (a) 0.057 ± 0.02 AU
    (b) 125 ± 25 km/sec
    (c) 12.1 ± 4 Degrees
    (d) 17.5 ± 5 Parsecs

23. (a) 5.73 ± 2 Solar luminosities
    (b) 0.7 ± 0.2 %
    (c) 1.57 ± 0.3 Jupiter radii
    (d) $(2.7 \pm 1) \times 10^{23}$ Watts
    (e) 2332 ± 500 Kelvin
    (f) 1.04 ± 0.3 Microns, Infrared
    (g) 0.031 ± 0.015 AU

Team name: KEY Team number: KEY

Answer Page: Section C

24. (a) Absolute J-band magnitude
    (b) Effective Temperature
    (c) T
    (d) L

25. (a) Radiation from star
    (b) Transition disk, dip in near-infrared
    (c) Debris disk

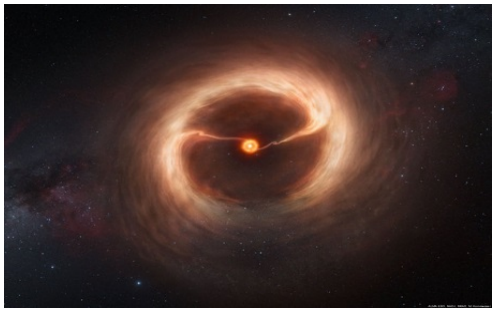
26. (a) 326 ± 50 Light years
    (b) 0.926 ± 0.2 Solar radii
    (c) 0.528 ± 0.2 AU
    (d) 1.4 ± 0.3 Earth radii
    (e) 350 ± 75 Kelvin
    (f) Yes!

27. (a) Planets below the line are largely gaseous/icy, planets above rocky
    (b) Sub-Neptune
    (c) Super-Earth
    (d) 4.7 ± 2 Earth radii
    (e) HAT-P-11b

Image/Illustration Set A:

1

2



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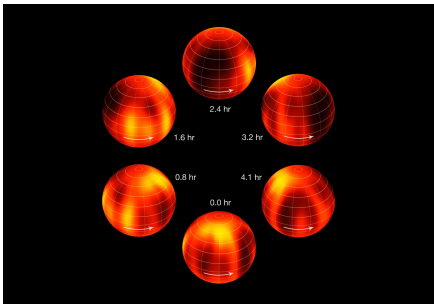

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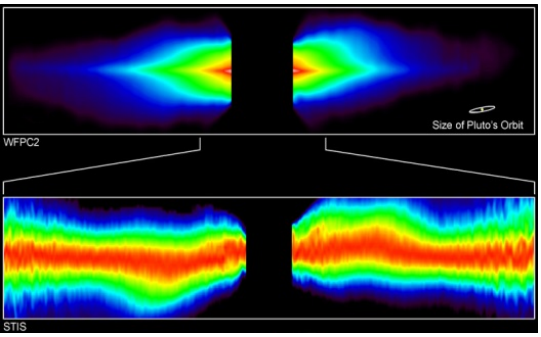

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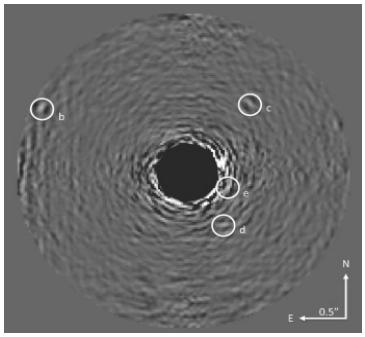

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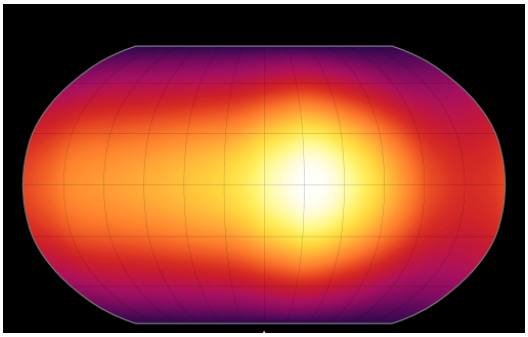

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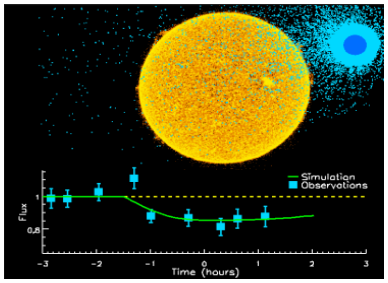

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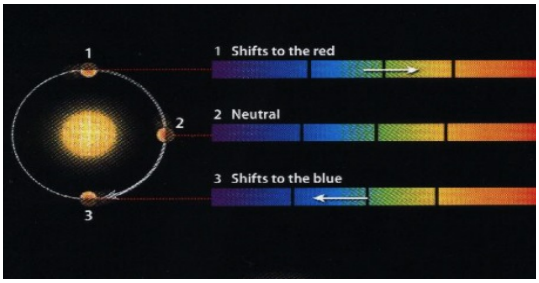

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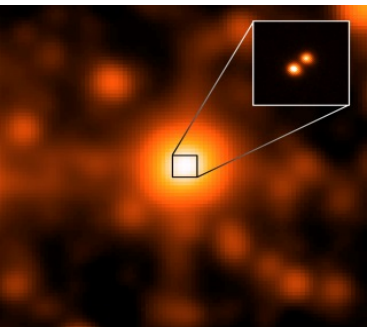

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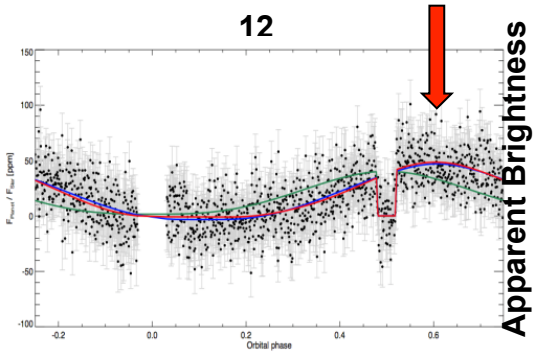

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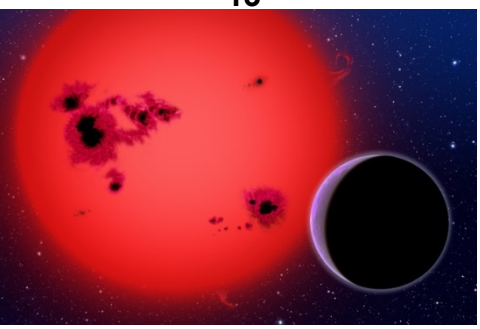

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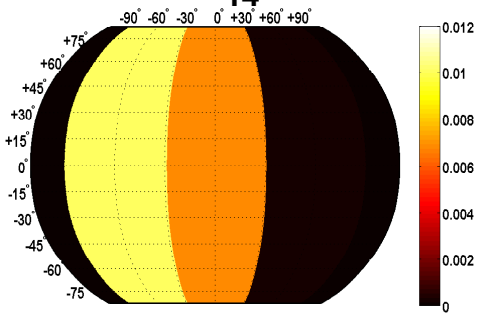

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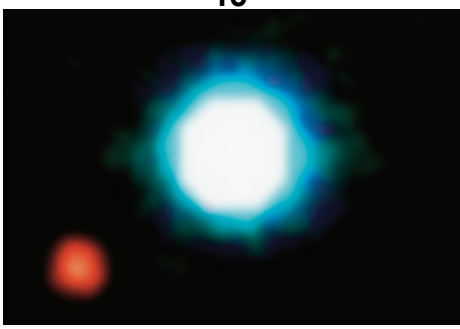

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Image/Illustration Set A:

16

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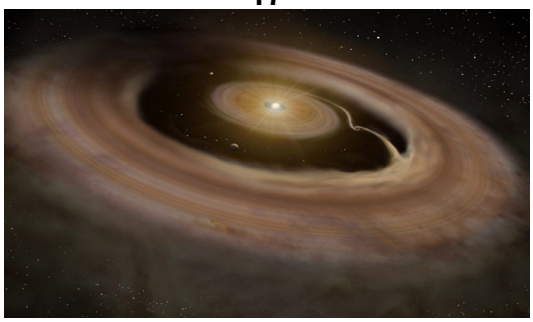

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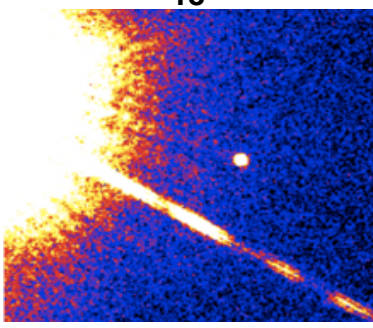

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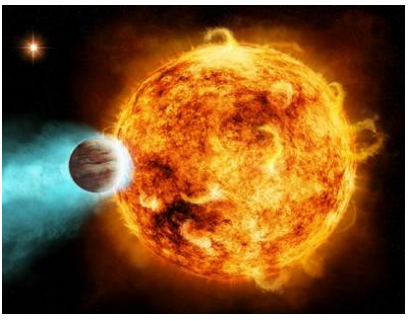

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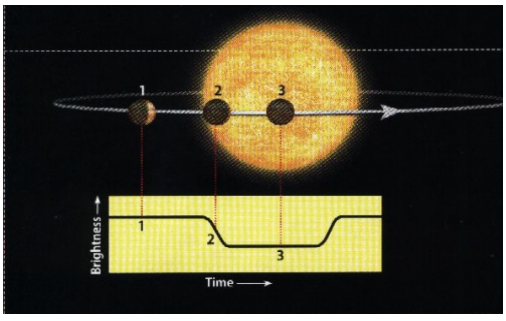

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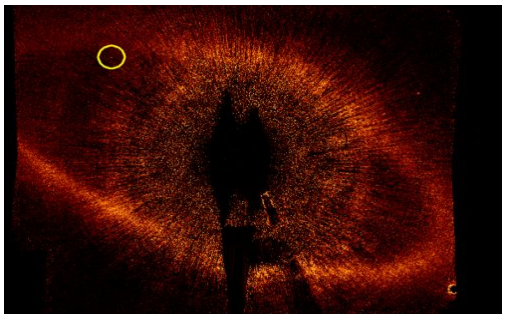

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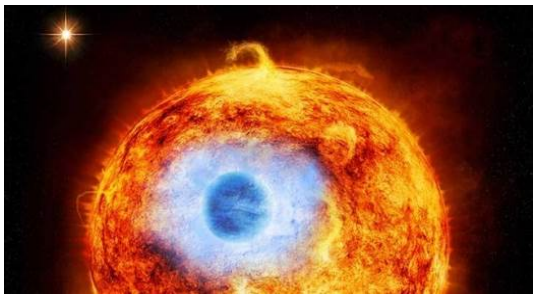

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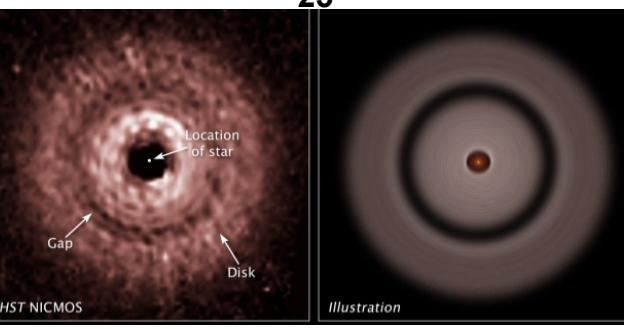

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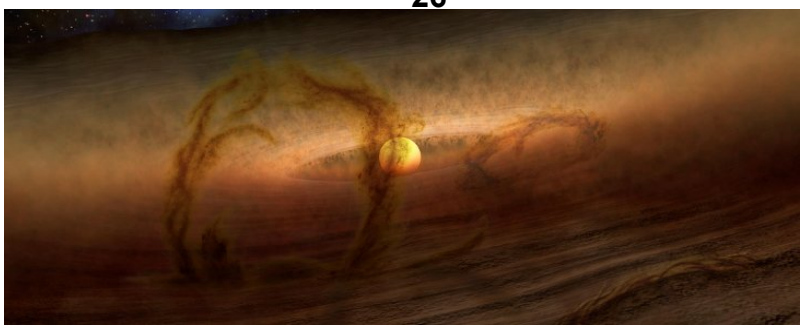

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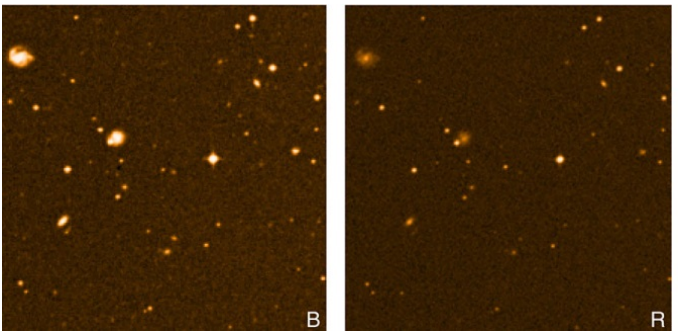

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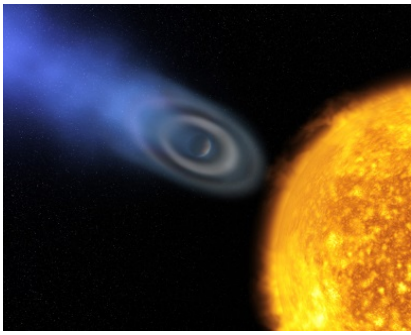
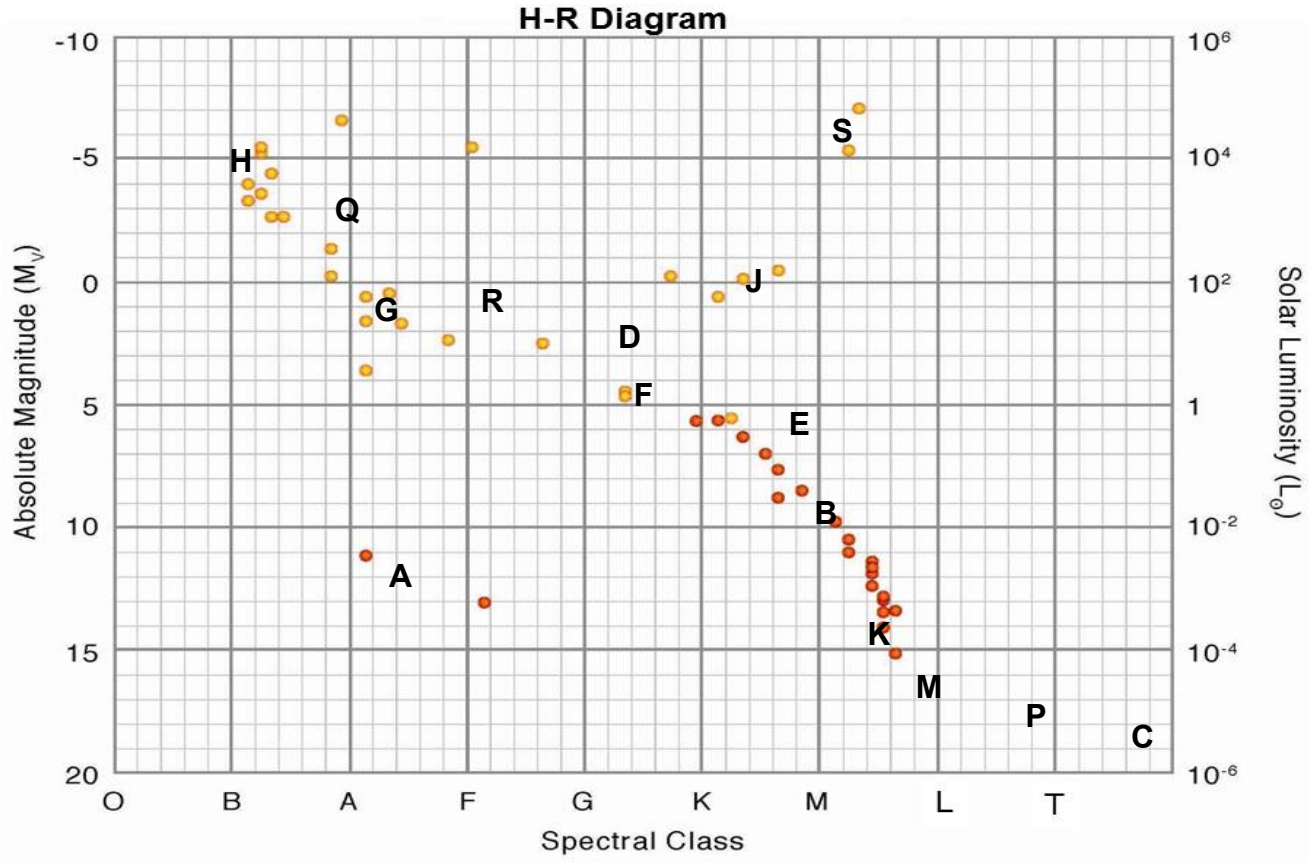


Image/Illustration Set A: 29



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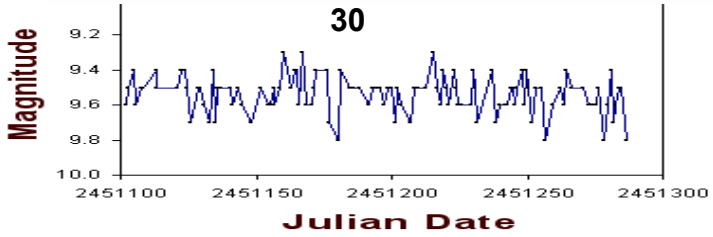

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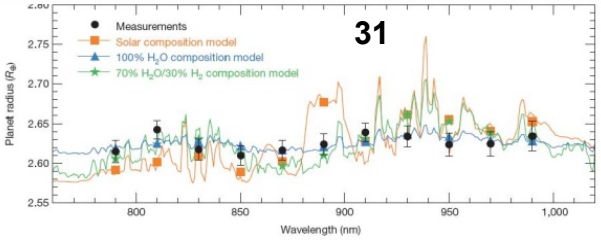

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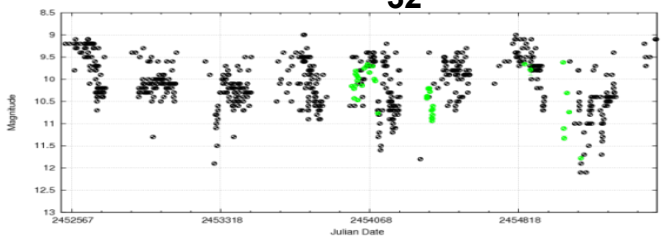

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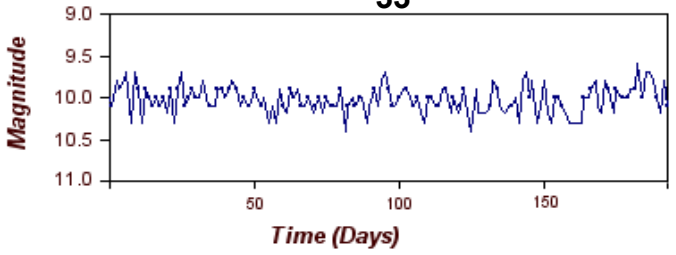

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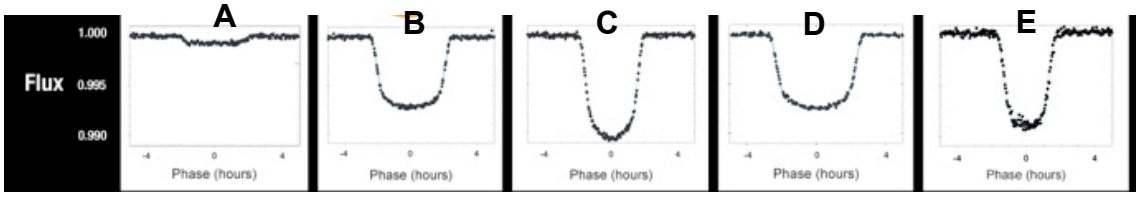

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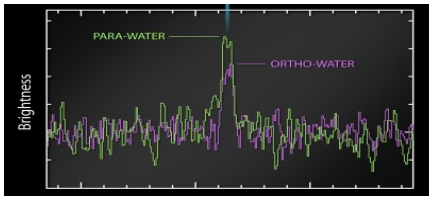

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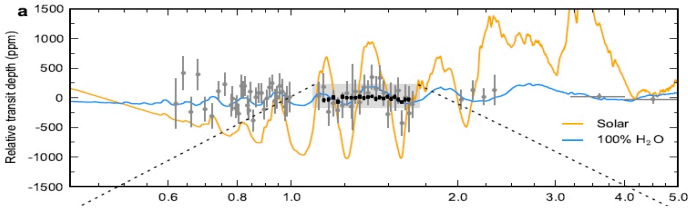
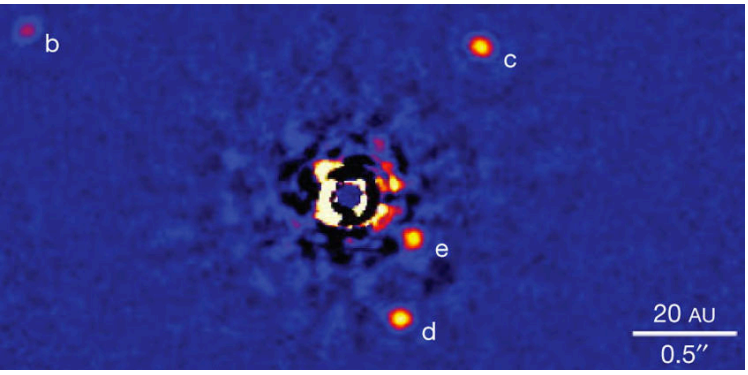


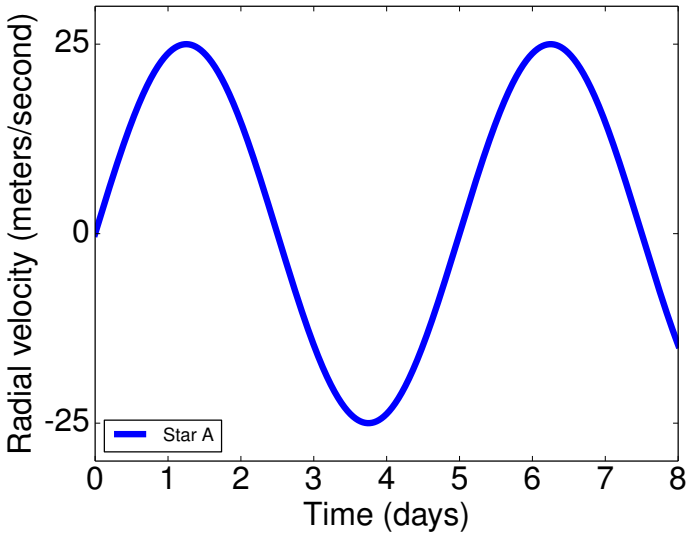
#9

Image/Illustration Set B:

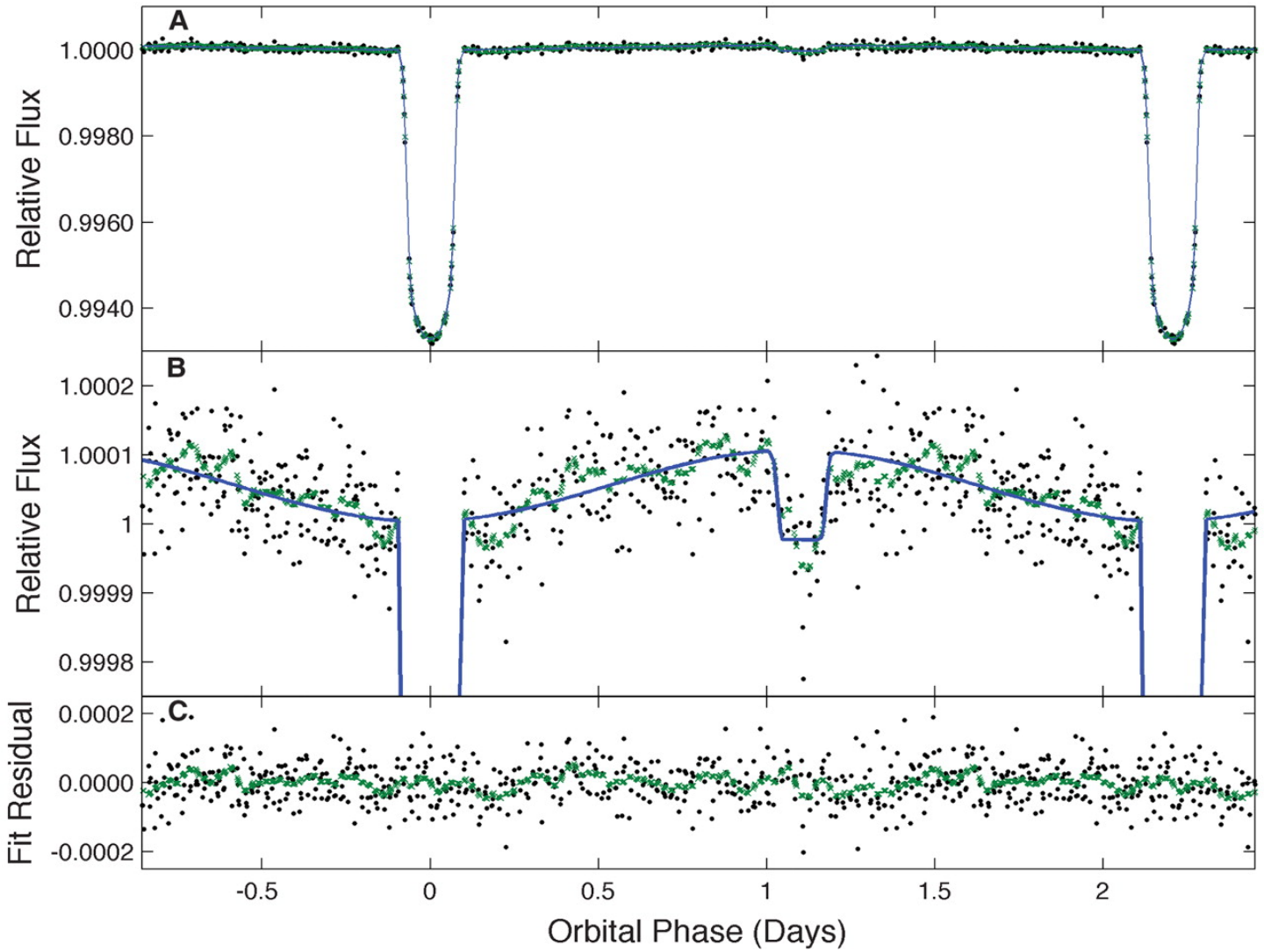
37



38

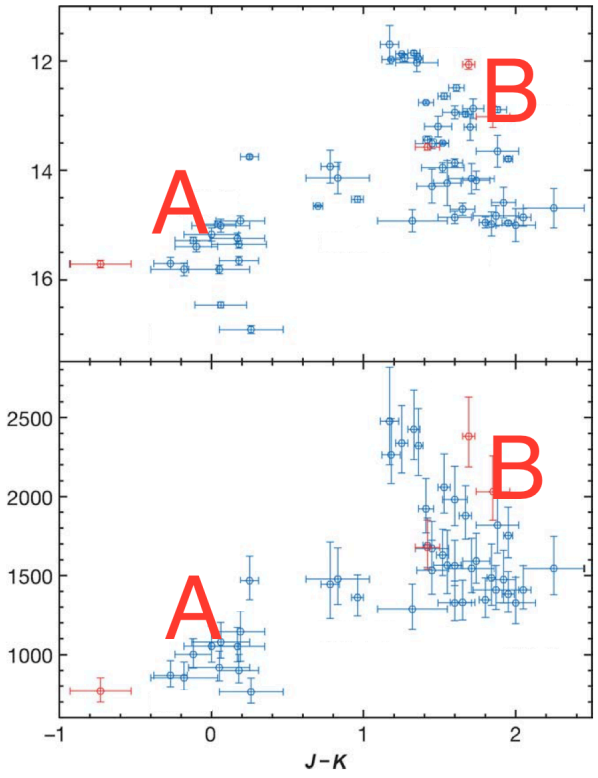


39

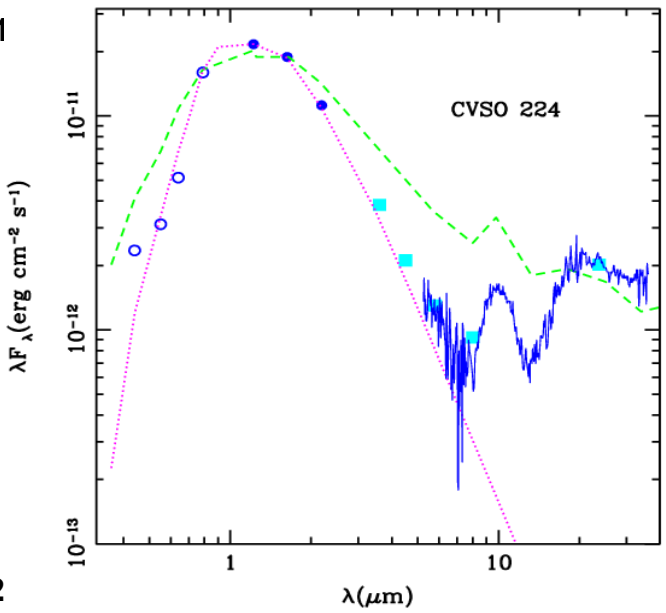


Image/Illustration Set C:

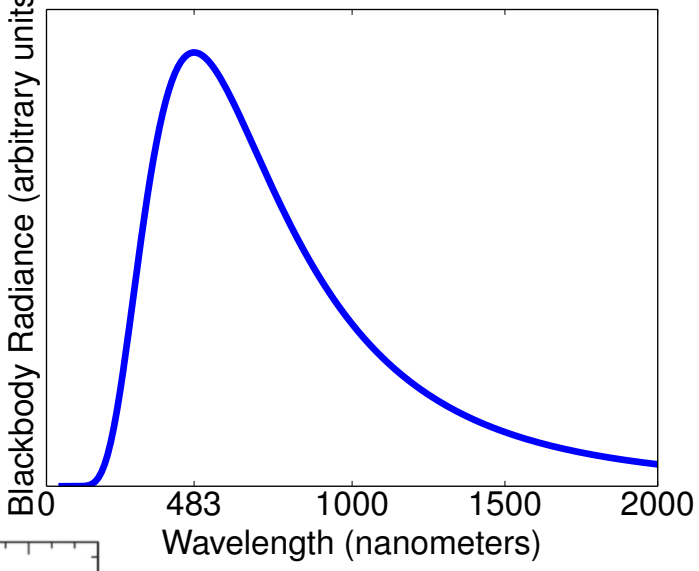
40



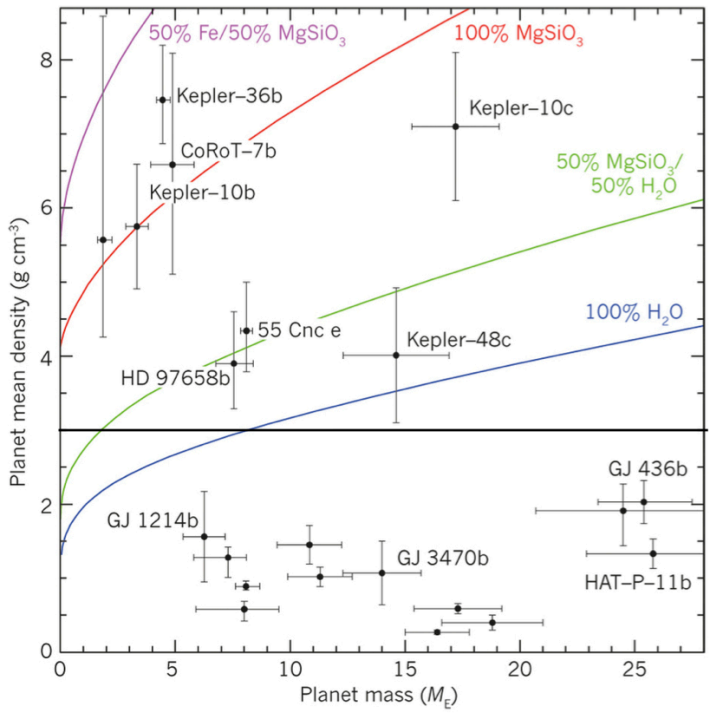
41



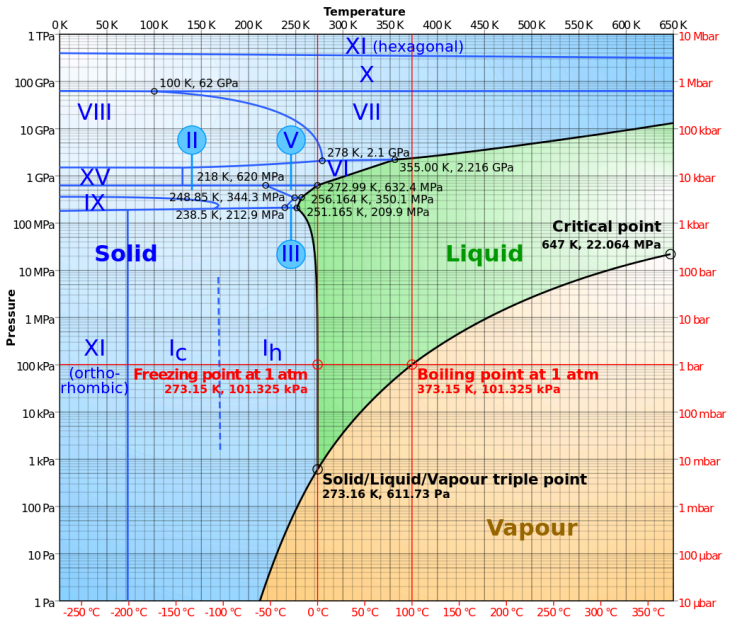
42



44



43



#11

Team name: _____ Team number: _____

Answer Page: Section A

1. (a) _____
   (b) _____
   (c) _____
2. (a) _____
   (b) _____
   _____
3. _____
4. (a) _____
   (b) _____
5. (a) _____
   (b) _____
6. (a) _____ (A-E)
   (b) _____ (A-E)
   (c) _____ (A-E)
7. (a) _____
   (b) _____
   _____
8. (a) _____
   (b) _____
   (c) _____
   _____
9. (a) _____
   (b) _____
   (c) _____
   (d) _____
10. (a) _____
    (b) _____
    (c) _____
11. (a) _____
    (b) _____
    (c) _____
    (d) _____
12. (a) _____
    (b) _____
13. (a) _____
    _____
    (b) _____
14. _____
15. (a) _____
    (b) _____
    _____
16. (a) _____
    (b) _____
17. (a) _____
    (b) _____
    _____
    (c) _____
18. (a) _____
    (b) _____
    _____
19. _____
20. (a) _____
    (b) _____
    (c) _____

Team name: _____ Team number: _____

Answer Page: Section B

21. (a) _____ Parsecs

    (b) _____ Kelvin

    (c) _____

    (d) _____

    (e) _____

22. (a) _____ AU

    (b) _____ km/sec

    (c) _____ Degrees

    (d) _____ Parsecs

23. (a) _____ Solar luminosities

    (b) _____ %

    (c) _____ Jupiter radii

    (d) _____ Watts

    (e) _____ Kelvin

    (f) _____ Microns, _____

    (g) _____ AU

Team name: _____ Team number: _____

Answer Page: Section C

24. (a) _____

(b) _____

(c) _____

(d) _____

25. (a) _____

(b) _____

(c) _____

26. (a) _____ Light years

(b) _____ Solar radii

(c) _____ AU

(d) _____ Earth radii

(e) _____ Kelvin

(f) _____

27. (a) _____

(b) _____

(c) _____

(d) _____ Earth radii

(e) _____