Science Olympiad
Astronomy C
GullSO Invitational 2025

December 14th, 2024

Instructions:

- Each team has 50 minutes to complete the test.
- There are four sections: §A (General Knowledge), §B (JS9), §C (DSOs), and §D (Math).
- For calculation questions, use 3+ sig. figs. in your answers unless otherwise specified.
- Showing work can earn you partial credit on calculation questions
- The use of the internet and AI tools (e.g. ChatGPT) are expressly forbidden. The internet may only be used to access the JS9 website.
- Tiebreakers, in order: points in §A, §D, §C, §B.
- Good luck and have fun!

DO NOT WRITE ON THIS TEST PACKET

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Section A: General Knowledge

This section consists of multiple choice questions about general concepts in section A of the rules. There are a total of 30 questions worth 49 points. The first 13 questions are worth 1 point, the rest are worth 2 points except the last 2.

1. T/F: Gaps in protoplanetary disks can indicate the presence of planets
2. T/F: T Tauri stars are considered variable stars
3. T/F: H I regions are better at producing stars than H II regions
4. T/F: A planet that is 5x the mass of Earth and twice the radius of Earth is a super-Earth
5. T/F: Having frozen water is one of the major requirements to be considered an ice giant
6. What type of star is our Sun?
   A. Red Giant
   B. T Tauri
   C. Main-sequence
   D. White Dwarf
7. Which of the following is NOT a method of detecting exoplanets?
   A. Transit Method
   B. Radial Velocity
   C. Microlensing
   D. Trigonometric parallax
8. What is the minimum mass threshold for a brown dwarf?
   A. 13 M_J
   B. 36 M_J
   C. 80 M_J
   D. 96 M_J

   The next 3 questions refer to images A1-A3. Based on the image, determine which detection method was used. A) Transit Method, B) Radial Velocity, C) Microlensing, D) Trigonometric Parallax, E) Direct Imaging, F) Pulsar Timing
9. Image A1
10. Image A2
11. Image A3
12. What process describes how planetesimals gather mass?
    A. Accretion C. Weak force
    B. Strong force D. Pressure
13. What is another name for Jovian planets?
    A. Ice Giants C. Gas Giants
    B. Terrestrial D. Mini-Suns
14. Each question is now worth 2 points. What are the most common spectral classes for brown dwarfs? Select all that apply: R, O, B, A, F, G, K, M, L, T, Y
15. The debris disk around main-sequence stars is typically optically-________ and gas-________.
    A. Thick, rich
    B. Thick, poor
    C. Thin, rich
    D. Thin, poor
16. A planet at the closest part of the habitable zone to a red dwarf would not be habitable for what primary reason?
    A. Heat
    B. Pressure
    C. Solar Flares
    D. Tidal Locking
17. An exoplanet is detected with the following characteristics: Hydrogen and helium in the atmosphere, the core is composed of rocks and metals, and thick clouds. What type of exoplanet is this?
    A. Super Earth C. Neptunian
    B. Hot Jupiter D. Sub-Earth

18. Which of the following planets would be considered a super-Earth? Select all that apply.
    A. 0.5 $R_\oplus$, 4 $M_\oplus$
    B. 3 $R_\oplus$, 10 $M_\oplus$
    C. 5 $R_\oplus$, 5 $M_\oplus$
    D. 0.4 $R_\oplus$, 0.9 $M_\oplus$

19. When particles are extremely small (before planetesimals), gravity can't pull particles together, so what does?
    A. Strong nuclear force
    B. Static electricity
    C. Stellar winds
    D. Accretion

20. What is the most likely cause of X-rays in Herbig Ae/Be stars?
    A. Presence of a low-mass companion star
    B. Magnetically driven coronal emission
    C. Gravitational contraction
    D. Disk accretion

21. How does the duration of a star's life in the T Tauri phase usually compare to the duration in the Herbig Ae/Be phase?
    A. Heavily depends on the stars that are being compared
    B. About the same
    C. Herbig Ae/Be is longer
    D. T Tauri stage is longer

22. Why is the optical wavelength not ideal for studying Herbig-Haro objects?
    A. The 'bow' of the HH is too bright so looks like a star
    B. Optical is better for cooler objects
    C. Dust obscures the vision
    D. All of the above

23. Refractory materials are most commonly associated with what type of exoplanet?
    A. Gas Giants
    B. Super-Earths
    C. Sub-Neptunes
    D. Terrestrial planets

24. Why do rocky planets form within the frost line?
    A. Rocks are heavier so more gravitational attraction
    B. The Sun fuses to create heavier elements which stay close
    C. Rocks condense at higher temperatures
    D. All of the above

25. Order the following phases of low mass stellar formation in sequential order: A) Outflow, B) collapse, C) Disk dispersal, D) Protostellar, E) T Tauri

26. In an adiabatic collapse, temperature __________, while in an isothermic collapse, temperature __________.
    A. increases, doesn't change
    B. increases, decreases
    C. decreases, doesn't change
    D. decreases, increases

27. What method is used to measure the distance between a star and its protoplanetary disk?
    A. Parallax
    B. Light echoes
    C. Redshift
    D. Faber-Jackson relationship

28. Where are molecular clouds usually found?
    A. Intergalactic space
    B. Globular Clusters
    C. Halos of Galaxies
    D. Spiral arms of galaxies

29. [3 pts] What are the types of gravitational lensing and how are they different?

30. [3 pts] What is planetary disk migration and why are hot jupiters thought to form through disk migration?

Section B: JS9

For this section, use the JS9 imaging software on a computer to answer the questions. There are 9 questions in the section and points are shown for each question, for a total of 14 points.
Setup Instructions: (If you need help loading/seeing the image, raise your hand)

- Turn your wifi on.
- Go to chandra.cfa.harvard.edu/js9
- Select the button on the right with the text [The Unofficial Chandra Archive Search Page]. A pop-up should appear.
- In the [Chandra Obs ID] box, enter “12548” and select [Search].
- Drag the title into the JS9 software page. The image should load in a few seconds.
- Feel free to adjust the scale and color using the buttons above. You can also adjust the contrast and bias by dragging left/right and up/down to see the image more clearly.

1. [1 pt] What is the Julian date of this observation?
2. [1 pt] What instrument took this image? Provide the full form.
3. [2 pts] What is the approximate radius of this object in arcseconds?
4. [3 pts] Generate a light curve using the Server-Side analysis. Briefly describe the light curve and explain what this light curve likely indicates.
5. [1 pt] Run an energy spectrum on this object. Identify the tallest peak in eV.
6. [2 pts] This peak indicates the presence of which element?
7. [1 pt] What type of object is this based on the analysis done previously?
8. [2 pts] There is a small bright spot in this DSO that is brighter than the rest. What are the coordinates (Right ascension and declination) of this spot? You might need to change the color scheme (I suggest using sls, but most of them should work) and the contrast/bias.
9. [1 pt] What type of object is likely at this point?

Section C: Deep-Sky Objects

This section consists of short answer questions about this year's objects of interest. This section contains 51 points. Images are located on Image Sheet C.

1. [2 pts] Order the following exoplanets based on their semi-major axis from smallest to largest: WASP-17b, Wasp-121b, TOI-270d, HD 80606b.
2. [2 pts] Order the following exoplanets based on their period from smallest to largest: LTT 9779b, K2-18b, LHS 3844b, GJ 1214b
3. [6 pts] This question refers to the DSO shown in Image C1.
   (a) [1 pt] Identify the DSO shown in the image and its alternate name.
   (b) [1 pt] This exoplanet was the first planet discovered to have what type of orbit? Briefly describe this type of orbit.
   (c) [2 pts] This image shows the presence of what chemical compound in the atmosphere which has never been seen before? Why does this compound block light in that specific wavelength range?
   (d) [2 pts] Despite having almost twice the radius of Jupiter, this DSO only has half the mass. Explain the cause(s) of this large discrepancy compared to Jupiter.
4. [7 pts] Extremely Eccentric
   (a) [1 pt] This title (Extremely Eccentric) could only apply to the orbit of one DSO. Identify that DSO.
   (b) [1 pt] What is the eccentricity of the DSO?
   (c) [2 pts] Name and explain a mechanism that could lead to this crazy eccentricity.
   (d) [1 pt] What is the maximum rate of change of the temperature over time?
   (e) [2 pts] Explain the effect of this temperature change on the weather of the planet.
5. [9 pts] A comparison of the 2 nebulae 30 Doradus and the Orion Nebula
   (a) [2 pts] Identify the image(s) that show 30 Doradus and the telescope(s) that took those images
   (b) [2 pts] Identify all the images that show the Orion Nebula and the wavelengths those images were taken in.
   (c) [1 pt] Both these regions contain/are ______ regions, so they are great for star ______.
   (d) [2 pts] Which DSO has the higher star formation rate and why?
   (e) [2 pts] Both objects have their own "important" clusters. The Orion Nebula has the Trapezium, while 30 Doradus has the R136 cluster. Compare/contrast these 2 clusters with each other based on the stars within each region.
6. [5 pts] One of the DSOs is a white dwarf + exoplanet system, which is quite an unusual combination.
   (a) [0.5 pts] Which DSO is this?
   (b) [2.5 pts] Explain why this sort of system is unusual, and list two possible mechanisms that might explain why the system exists.
   (c) [1 pt] Image C2 depicts the transit plot for the object. The one on the left is done in visible light and the one on the right is in infrared. What is the transit duration, in minutes?

(d) [1 pt] According to Vanderberg et. al 2020, the transit was initially observed from TESS. Unfortunately, the DSO was very close to several background stars so it was initially unclear which star had the transit. How does your transit duration from part (c) imply that the white dwarf was experiencing the transit?

7. [4 pts] A small problem

   (a) [1 pt] Which DSO is located in the constellation Microscopium?

   (b) [1 pt] This DSO is notable for its age. How old is it?

   (c) [2 pts] What kind of star is in the system and what could that mean for the habitability of the planets in the system?

8. [5 pts] This question refers is about the exoplanet K2-18b.

   (a) [1 pt] Although K2-18b is thought to be habitable like Earth, it is quite different, with a mass that is ______ times that of Earth's and a radius that is ______ times that of Earth's.

   (b) [1 pt] Recent detections by the JWST revealed the possible detections of dimethyl sulfide on K2-18b. Based on this, many scientists believe that there could be the possibility of life here. Explain why the presence of dimethyl sulfide could lead astronomers to this conclusion.

   (c) [1 pt] Astronomers refer to K2-18b as a Hycean Planet. What does this mean?

   (d) [2 pts] Image C3 shows possible models that can be fitted to the data from the JWST spectra. There are 3 models that are shown. The bottom right (mini-Neptune) can be considered a lifeless gas-rich planet. Which model is likely the most possible? Provide data and scientific reasons to back your answer.

9. [5 pts] Water Detected???

   (a) [0.5 pts] Which DSO is the first planet to have liquid water detected?

   (b) [1.5 pts] Image C5 shows a plot of absorption vs wavelength taken from this DSO (Evans et al. 16). The different colors are for each of the different models tested. Note that the bottom plot has the same data as the top one but zoomed in from 1.1 to 1.7 µm. What region of the EM spectrum was used to create these plots? Why is this region useful for detecting molecules like water?

   (c) [2 pts] Why would it make sense for the y axis to be in terms of (R_p/R_*)? (Hint: think about transit depth)

   (d) [1 pt] Which model best fits the data?

10. [6 pts] This question refers to image C4 on the image sheet.

    (a) [1 pt] Identify the DSO shown in image C4.

    (b) [1 pt] This object is known to have the highest what of any planet? What is the value of this?

    (c) [2 pts] This planet is in the "Neptunian desert". What is the Neptunian desert and what does this mean in terms of the atmospheres of these planets?

    (d) [1 pt] The images on the right in C4 have a slightly grayed out zone which indicates that this region can be ruled out for this DSO. Based on this information, what can you say about the metallicity of the object?

    (e) [1 pt] This object is close to its host star and it is tidally locked. This causes a huge difference in dayside and nightside temperatures. What is the dayside brightness temperature and what is the nightside brightness temperature in kelvin?

Section D: Math

This section is about astrophysics. This section contains 51 points. Use the images in Image Set D to answer these questions. Round calculations to 3 significant figures and show your work which can earn you partial credit.

1. [8 pts] **A Few (Mostly) Basic Distance Questions**
   (a) [1 pt] Stellar parallax is actually quite misunderstood. A star moved 8 milliarcseconds from January 1st, 2023 to July 1st, 2023 (a period of about 6 months). What is the distance to this star in parsecs? (Hint: the problem says that parallax is misunderstood, so it might not be as simple as 1/0.008 although it is still simple)
   (b) [2 pts] Explain why you can not simply do 1/0.008 to find the distance to the star in the previous question.
   (c) [2 pts] There is a type 1a supernova that is 40 times as far as this star. What is the apparent magnitude of the supernova?
   (d) [1 pt] Would we be able to see this with our naked eyes?
   (e) [2 pts] What is the physical diameter of this Type 1a supernova if it has an angular diameter of 0.008 arcseconds in pc?
2. [6 pts] **Some Radiation Questions**
   (a) [2 pts] What is the power radiated by an object with emissivity 0.8, radius 1 solar radius, and temperature of 6000 K in W?
   (b) [2 pts] What is the peak wavelength of this object in nm?
   (c) [1 pt] What is the frequency of this light in Hz?
   (d) [1 pt] Which region of the EM spectrum does this fall in?
3. [17 pts] **Data Analysis**
   Oh, no! You've forgotten Kepler's 3rd law, and you have a SciOly test coming in two days! You've also forgotten how Newtonian gravity works so you can't re-derive it either. The only thing you kind of remember that Kepler's 3rd law is something of the form $T = ka^{\beta}$, where T is the period, k is some constant, a is the semi-major axis, and β is a dimensionless constant.
   You observe a distant star system with six exoplanets and a sun-like star and gather the following information: The raw data is not very useful on its own. If we look back at our

Planet	a [m]	T [s]
b	1.80e10	1.28e6
c	1.44e11	2.96e7
d	3.11e11	9.24e7
e	8.08e11	4.41e8
f	1.67e12	1.04e9
g	4.59e12	5.69e9

   original equation of $T = ka^{\beta}$, we realize it's not very nice to work with. We probably want to "linearize" our equation and get β as our slope, i.e. we want something of the form $A = \beta B + C$ (A is in terms of T and B is in terms of a)
   (a) [2 pts] What can we do to both sides of the equation to get to this form?

(b) [4 pts] Apply your change from part **a** to a and T and fill in the table accordingly on the answer sheet.

(c) [4 pts] Graph your new calculated values from your table in part **b** on your answer sheet. Try to fill up at least of the graph space given.

(d) [3 pts] Draw a best-fit line on your graph. Give an estimate of the slope β (please do NOT use data points for your estimate).

(e) [4 pts] Congrats! You (kind of) empirically re-derived Kepler's 3rd law. Now, let's try finding how gravity works. Let's say gravitational force $F_g \propto r^{\alpha}$. Using your value of $beta$, find the observational value of α.

4. [20 pts] **Elliptical Transit**
Sid looks up in the night sky and sees a star. He decides to name the star Jack. Sid has extremely good eyesight so he notes that the $B - V$ color index of the star is 0.

(a) [2 pts] What is the spectral class of the star (give the letter & an estimate of the number)? You may neglect extinction.

(b) [2 pts] Estimate the mass and radius of the star, in $M_{\odot}$ and $R_{\odot}$, respectively.

(c) [3 pts] Sid decides to go visit the local observatory to take more detailed observations. After waiting a month, he obtains the light curve in **Image D1**. The periodic decrease in flux from Jack means that Sid has discovered a new exoplanet! He decides to name the exoplanet Greycen. Using Image D1 and your answer to part (b), estimate the radius of Greycen, in meters. If you couldn't answer (b), assume that Jack is a Sun-like star. State explicitly whether you are assuming that Jack is a Sun-like star or not.

(d) [4 pts] Using the graph and your answer to (b), estimate the semi-major axis of the orbit in AU (note the orbital period is 5.7 days). What type of planet is Greycen most likely to be given the information? Explain the reasoning for your conclusion for the type of planet.

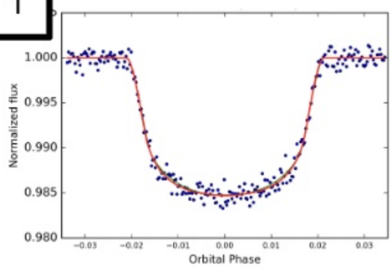
(e) [3 pts] Estimate the equilibrium temperature of Greycen, assuming a circular orbit and that Greycen has an albedo of 0.3.

(f) [6 pts] When looking at the light curve, Sid notices a secondary transit caused by Greycen passing behind Jack in **Image D2** (note secondary transit is in blue, primary is in red). You may have noticed from the graphs that the primary transit is longer than the secondary transit. This isn't a mistake; the orbit is actually slightly elliptical! Calculate the lower bound for the eccentricity of the orbit (hint: lowest calculated eccentricity occurs when the major axis is aligned with your line of sight). You may assume that $R_{\text{Jack}} \gg R_{\text{Greycen}}$ and that the system is viewed from very far away.

IMAGE SHEET

Section A

1



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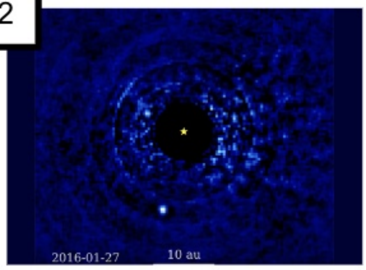

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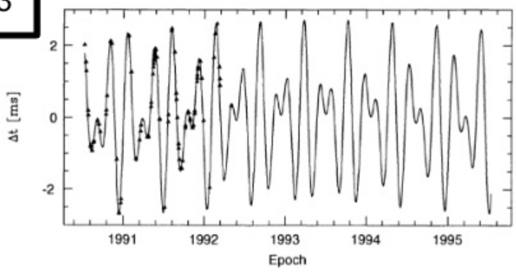
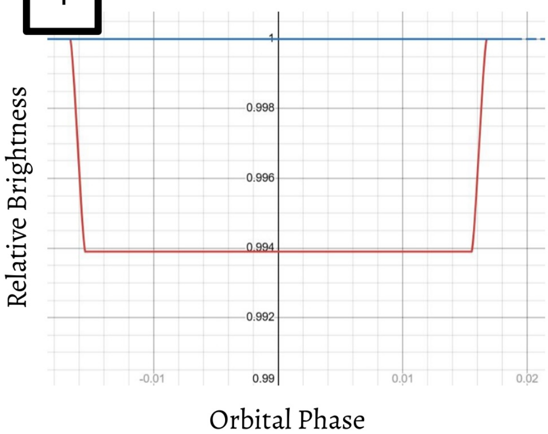


Section D

1



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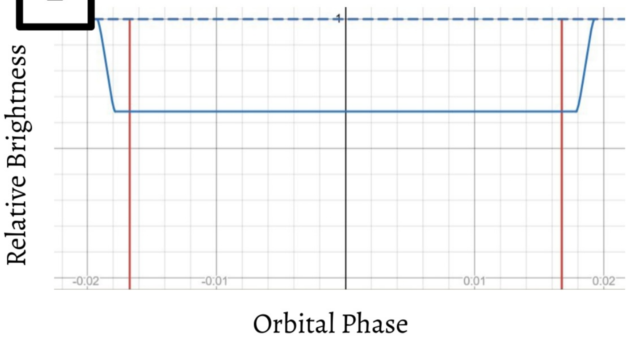
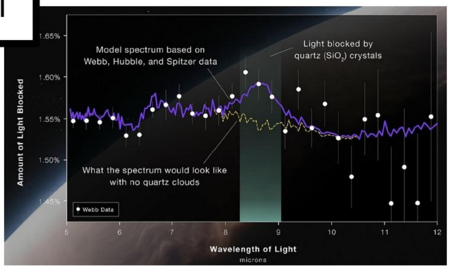


Section C

1



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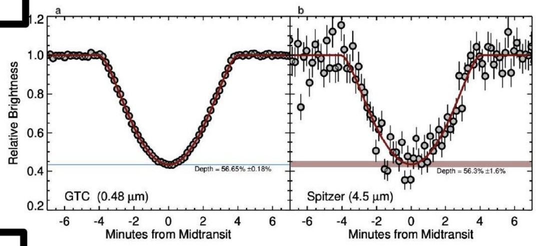

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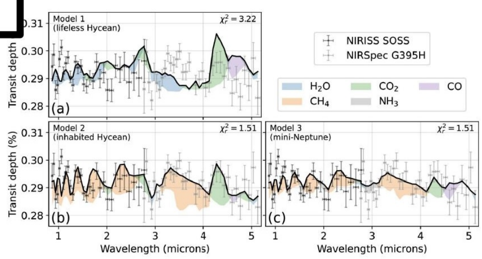

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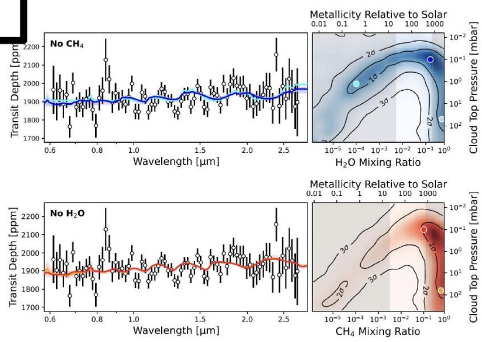

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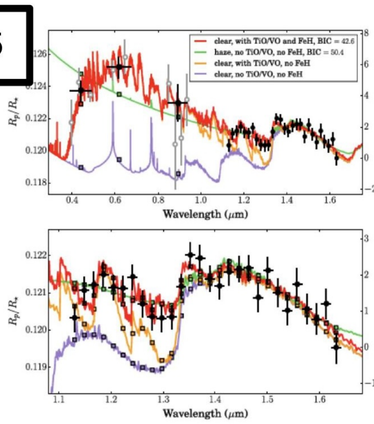


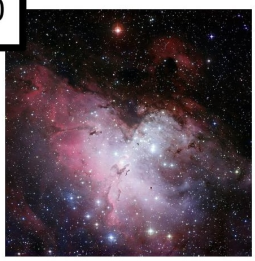
6

7

8

9

10



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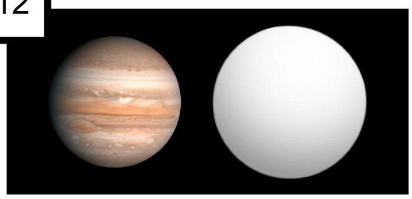

Science Olympiad
GullSO Invitational
Astronomy C Answer Sheet

December 14th, 2024

Team Name and Number: ____________________

Participant Name(s): ____________________

Total Score: ____________/165 Rank: ____________

Instructions:

- Refer to the test cover

Section	A	B	C	D	Total
Points	49	14	51	51	165
Earned					

Section A (49 points)

1. ______ 2. ______ 3. ______ 4. ______ 5. ______

6. ______ 7. ______ 8. ______ 9. ______ 10. ______

11. ______ 12. ______ 13. ______ 14. ______ 15. ______

16. ______ 17. ______ 18. ______ 19. ______ 20. ______

21. ______ 22. ______ 23. ______ 24. ______ 25. ______

26. ______ 27. ______ 28. ______

29. ______

30. ______

Section B (14 points)

1. ______

2. ______

3. ______

4. ______

5. ______

6. ______

7. ______

8. ______

9. ______

Section C (51 points)

1. ______

2. ______

3. (a) ______
   (b) ______
   (c) ______
   (d) ______

4. (a) ______
   (b) ______
   (c) ______
   (d) ______
   (e) ______

5. (a) ______
   (b) ______
   (c) ______
   (d) ______
   (e) ______

6. (a) ______
   (b) ______

(c) __________

(d) __________

7. (a) __________

(b) __________

(c) __________

8. (a) __________

(b) __________

(c) __________

(d) __________

9. (a) __________

(b) __________

(c) __________

(d) __________

10. (a) __________

(b) __________

(c) __________

(d) __________

(e) __________

Section D (51 points)

1. (a)

(b)

(c)

(d)

(e)

2. (a)

(b)

(c)

(d)

3. (a)

(b) Use the table below and label columns

Planet		
b		
c		
d		
e		
f		
g		

(c) Graph the data on the graph on the previous page.

(d) Use the graph on the previous page to draw the line of best fit.

Slope estimate: ______________________

(e)

4. (a) ______________________

(b) ______________________

(c)

(d)

(e)

(f)

Science Olympiad

GullSO Invitational

Astronomy C KEY

December 14th, 2024

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Section A (49 points)

1.	**T**	2.	**T**	3.	**F**	4.	**T**	5.	**F**
6.	**C**	7.	**D**	8.	**A**	9.	**A**	10.	**E**
11.	**F**	12.	**A**	13.	**C**	14.	**M L T Y**	15.	**D**
16.	**C**	17.	**C**	18.	**B C**	19.	**B**	20.	**B**
21.	**D**	22.	**C**	23.	**D**	24.	**C**	25.	**B D A E C**
26.	**A**	27.	**B**	28.	**D**				

29. 3 types: weak, strong, microlensing (+0.33 each). Strong: lens is massive and source is close, weak: collective light from background sources like galaxies is brightened a bit, Micro: when stars/objects move in front of each other from our point of view and cause a small change in light (+0.67 each)

30. Planetary disk migration is when a planet's orbit moves because of the gas and dust in the protoplanetary disk (+1). Hot Jupiters are thought to form farther out in the disk because they need to accrete lots of mass which can't happen close due to low density near the star (+1). To become "hot", hot jupiters migrate inside through angular momentum (+1).

Section B (14 points)

1. 55510
2. Advanced CCD Imaging Spectrometer
3. 550-570 arcseconds
4. +1 peaks at the beginning, +1 for small fluctuations/relatively constant after, +1 indicates big burst of light/supernova
5. 900-930 eV
6. Neon
7. Supernova Remnant, +0.5 for only Supernova
8. 8:23:25.372, -42:50:06.51
9. Neutron Star

Section C (51 points)

1. WASP-121b, WASP-17b, TOI-270d, HD 80606b (+0.5 for each correct placement)

2. LHS 3844b, LTT 9779b, GJ 1214b, K2-18b (+0.5 for each correct placement)

3. (a) WASP-17b (+0.5), Ditso (+0.5)

   (b) Retrograde (+0.5): object orbits opposite the rotation of an object (+0.5)

   (c) quartz (+1), it scatters and absorbs specific wavelengths of light because of its natural vibrations/frequencies (+1).

   (d) it's a combination of the low orbital eccentricity which means it would not be able to reach many particles to accrete (+1), and the puffing up of the atmosphere/surface due to tidal heating (+1)

4. (a) HD 80606b (+1)

   (b) Anything between 0.93 and 0.94 (+1)

   (c) Lidov-Kozai mechanism (AKA Kozai or similar) (+1), which is where a distant 3rd body perturbs the orbit resulting in an oscillation with orbital inclination and eccentricity. (+1)

   (d) Anything on the order of around 700 K in 6 hours (+1)

   (e) A large temperature gradient (+1) is created between the heated side of the planet and the side facing away from the star, resulting in "shock wave storms" (+1).

5. (a) C7 (+0.5): Chandra and spitzer (+0.25 each), C11 (+0.5): JWST (+0.5)

   (b) C8 (+0.5): Visible and IR (+0.25 each), C9 (+0.5): Infrared/near-IR (+0.5)

   (c) HII (+0.5), formation (+0.5)

   (d) Tarantula nebula (+1), high density and lots of young/hot stars create winds and radiation which creates more stars faster (+1)

   (e) Trapezium has mostly low-mass and sun-type stars (+1), while R136 is extremely dense with lots of massive stars (+1)

6. (a) WD 1856+534 (+0.5)

   (b) The envelope from a red giant phase would likely destroy any planets nearby (+0.5). This system could be the result of either a Lidov-Kozai mechanism resulting in a farther planet migrating inwards (+1) or surviving a common-envelope phase where other planets expelled enough of the envelope for the planet to survive (+1).

(c) about 8 minutes (+1)

(d) A transit duration of 30 minutes is expected for normal stars; the much smaller radius of a white dwarf allows for shorter transit durations.(+1)

7. (a) AU Microscopii (+1)

   (b) Around 22 million years (+1)

   (c) An extremely young flare star is in the system (+1), which likely renders the planets not habitable because of highly variable radiation. (+1)

8. (a) 8.6 for mass (+0.5), 2.6 for radius (+0.5).

   (b) Dimethyl sulfide can be a biosignature since most of this on Earth is produced by phytoplankton (+1)

   (c) Liquid water (+0.5) and a hydrogen atmosphere (+0.5)

   (d) From the data, both the mini-neptune and inhabited hycean are equally likely based on the chi-squared values (+0.5). However, the mini-neptune/gas-rich is more likely (+0.5) because the other model requires life and it's also difficult to have both a cool surface temperature for life but also have a high probability of a runaway greenhouse effect like Venus (+1).

9. (a) WASP-121b (+0.5)

   (b) Infrared (+0.5), possible reasons may include that a lot of spectral lines are in IR or that IR usually lacks extinction compared to visible (1 point for either explanation)

   (c) The transit depth is $k = (R_p/R_*)^2$ so it is convenient to express the absorption (kind of) in terms of k (+1). The absorption vs wavelength graph shows compounds that could (or could not) be found in the atmosphere. (+1)

   (d) clear, with TiO/VO and FeH, BIC = 42.6 (the red one) (+1)

10. (a) LT 9779b (+1)

    (b) albedo (+0.5), 0.8 (+0.5)

    (c) Neptunian desert is a region very close to a star where no Neptune-sized planets should be found (+1). Because of strong radiation due to close proximity (+0.5), the planets do not usually have an atmosphere composed of gas (+0.5)

    (d) High metallicity (+1)

    (e) Dayside: 1800 ± 120 K (+0.5), Nightside: 700 ± 430 K (+0.5)

Section D (51 points)

1. (a) 250 parsecs (+1): 1/0.004 = 250 pc

   (b) The shift is largest after 6 months because Earth moves to opposite sides (+1). The parallax is half of this since it provides a baseline of 1 AU (+1)

   (c) -4.6 (+2).

   (d) yes (+1)

   (e) 0.00388 pc (+2)

2. (a) $3.58 \times 10^{26} W$ (+2)

   (b) 483.3 nm (+2)

   (c) $6.21 \times 10^{14} Hz$ (+1)

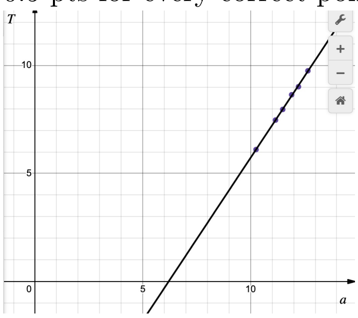
   (d) Visible (+1)

3. (a) take any sort of log on both sides (+2) (ln or log base 10 both work). I will be using log base 10 for the rest of the problem key.

   (b) See the table below as an example, 0.5 pt for every correct value (according to their method from part **a**). 0.5 for each column label.

Planet	$\log(a)$ [log(m)]	$\log(T)$ [log(s)]	$\ln(a)[\ln((m)]$	$\ln(T)[\ln(s)]$
b	10.26	6.11	23.61	14.06
c	11.16	7.47	25.69	17.20
d	11.49	7.97	26.46	18.34
e	11.91	8.64	27.42	19.90
f	12.22	9.02	28.14	20.76
g	12.66	9.75	29.15	22.46

   (c) 0.5 pts for every correct point plotted, 1 point for labeling axes appropriately.



   (d) 1.5 points for a good best-fit line, 1.5 points for value of β between 1.3 and 1.7 (my calculator gives a linear regression slope of 1.507).

(e) Working backwards with proportional reasoning (a_c is acceleration, r is the orbit distance), $a_c = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$(+1.5), $r^\alpha \propto \frac{r}{T^2}$(+1.5) $\implies T^2 \propto r^{1-\alpha} \implies T \propto r^{\frac{1-\alpha}{2}}$(+1) $\implies \beta = \frac{1-\alpha}{2} \implies \alpha = -2$

4. (a) It's useful to know for a star of spectral class A0, the absolute magnitude for the star in any passband is 0, so the difference in apparent magnitudes is zero barring extinction. +1 for answering A or B without number, +2 for answering A3, A2, A1, A0, or B9

(b) Mass: [1.78, 2.42] $M_\odot$ and Radius: [1.53, 2.07] $R_\odot$ (+1 each)

(c) $0.0061 = k \approx \left(\frac{R_{Greycen}}{R_{Jack}}\right)^2$ is the proportion of the dip in flux. Solving for $R_{Greycen}$ gives about $[8.33 \times 10^7, 1.13 \times 10^8]$ meters. (+2 points for formula, 1 point for answer). For $R_{Jack} = R_\odot$: $[4.59 \times 10^7, 6.21 \times 10^7]$ meters

(d) Using Kepler's third law and solving for a, we get $a = 0.08$ AU (2 points, must be within 0.01 AU). With the assumption of a Sun-like star, $a = 0.06$ AU. Based on how close Greycen is and also the radius of around 1.4 R_J, we can pretty confidently say that Greycen is a hot Jupiter. (2 points)

(e) The fastest way to do this is to estimate the temperature of an early A class star, which turns out to be around 10000 K. Now we just use the standard formula: $T_{eq} = T_* \sqrt{\frac{R_*}{2a}}(1-\alpha)^{\frac{1}{4}}$. This formula gives a value of $T_{eq} = [2060, 2460]$ K (2 points for formula, 1 point for numerical value). If Sun-like star, $T_{eq} = [1180, 1440]$ K.

(f) Greycen travels the same distance during both primary and secondary transits. Let T_a be the primary transit duration and T_p be the secondary transit duration. Subscripts a and p denote apoapsis and periapsis, respectively. By conservation of angular momentum, $\frac{T_a}{T_p} = \frac{v_p}{v_a} = \frac{r_a}{r_p}$. Let this quantity be called x. If we make the substitution $r_a = 2a - r_p$, we obtain $2a - r_p = xr_p \implies 2a = (x+1)r_p \implies ax - 2a = ax - (x+1)r_p \implies (x-1)a = (x+1)(a - r_p)$

Recall that the eccentricity is $e = \frac{a - r_p}{a}$, so $e = \frac{x-1}{x+1}$ Substituting the numbers, we get $[0.055, 0.085]$. This answer still holds even for a Sun-like star since only the ratio of the transit durations actually matters. 1 point for using conservation of angular momentum, 1 point for using $r_a = 2a - r_p$ or equivalent substitution, 1 point for using a definition of eccentricity ($e = \frac{a-r_p}{a}$ or $e = \frac{r_a - a}{a}$ or equivalent), 2 points for correctly solving for eccentricity in terms of knowns, 1 point for the correct numerical value.