Science Olympiad National Tournament

University of Southern California

Astronomy C

May 23, 2026

Directions:

- Each team will be given **50 minutes** to complete the exam.
- There are three sections: **Deep-Sky Objects** [40 pts], **Qualitative** [27 pts], and **Quantitative** [33 pts].
- Record all answers in the Answer Sheet. Nothing written in the Exam Booklet will be scored.
- All images will be found in the provided Image Set.
- For calculation questions, you may show your work for partial credit.
- Report all numerical answers to **3 significant figures** and **in the proper units**.
- The use of AI tools (e.g., ChatGPT) are expressly forbidden.
- The top five tiebreakers, in order, are: Q28–30, Q48–52, Q12–18, Q37–41, Q53–60.
- The exam will be posted soon after the competition at `nso.js9.org`

Good luck! And may the stars be with you!

Written by the Astronomy A-Team
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Reference Page

Deep-Sky Objects:

- The Orion Molecular Cloud Complex,
- Sharpless 29 (NGC 6559),
- Ophion Star Family,
- HP Tau,
- Mira (Omicron Ceti),
- Helix Nebula (NGC 7293),
- Janus (ZTF J203349.8+322901.1),
- WDJ181058.67+311940.94,
- The Crab (M1),
- The Bone (G359.13),
- Cas A,
- Tycho's SNR.

Conversions and Constants:

$1\,\text{au} = 1.496 \times 10^{11}\,\text{m}$

$1\,\text{ly} = 9.461 \times 10^{15}\,\text{m}$

$1\,\text{pc} = 3.086 \times 10^{16}\,\text{m}$

$1\,\text{yr} = 365.25\,\text{d}$

$1\,\text{d} = 86{,}400\,\text{s}$

$T_{\text{eff},\odot} = 5778\,\text{K}$

$1\,\text{L}_\odot = 3.828 \times 10^{26}\,\text{W}$

$1\,\text{R}_\odot = 6.957 \times 10^{8}\,\text{m}$

$1\,\text{M}_\odot = 1.989 \times 10^{30}\,\text{kg}$

$M_{\text{bol},\odot} = +4.74$ (abs. mag.)

$M_{V,\odot} = +4.83$ (abs. mag.)

$1\,\text{R}_\oplus = 6.378 \times 10^{6}\,\text{m}$

$1\,\text{M}_\oplus = 5.972 \times 10^{24}\,\text{kg}$

$G = 6.674 \times 10^{-11}\,\text{N}\,\text{m}^2/\text{kg}^2$

$b = 2.898 \times 10^{-3}\,\text{m}\,\text{K}$

$\sigma = 5.670 \times 10^{-8}\,\text{W}/(\text{m}^2\,\text{K}^4)$

$h = 4.136 \times 10^{-15}\,\text{eV/Hz}$

$H_0 = 70\,\text{km}/(\text{s}\,\text{Mpc})$

Section A: Deep-Sky Objects

This section consists of 27 questions about this year's deep-sky objects. Unless otherwise specified, each question is worth one point, for a total of 40 points.

1. Imagine you traveled back in time to ancient Rome (∼100 AD) with a modern astronomy telescope. Which of the following objects could you show to your Roman friends?
   A. Cas A
   B. Tycho's SNR
   C. Crab Nebula
   D. Helix Nebula

2. Which feature of the Orion Molecular Cloud Complex is partially the result of multiple supernovae within the last 5–10 million years?
   A. Orion A
   B. Orion B
   C. Orion-Eridanus Superbubble
   D. Lambda Orionis Molecular Ring

3. The Ophion Star Family is notable because
   A. it contains an unusual number of stars.
   B. the stars are unusually young.
   C. the stars are unusually massive.
   D. the stars are dispersing unusually quickly.

For the next three questions, consider the object shown in Image 1.

4. What object is this?
   A. Ophion Star Family
   B. WDJ181058.67+311940.94
   C. G359.1-0.2
   D. Cas A

5. [2 pts] A compact radio and x-ray source has been detected at the location of the black dot in the image. Which of the following is a hypothesized effect of this source on this object's morphology?
   A. This object is a bow shock resulting from the compact object's rapid movement through the surrounding interstellar medium.
   B. This object is composed of the twin emission jets emitted by the compact object. Due to its velocity, they trail behind the compact object.
   C. This object is accelerating the compact object as they collide, speeding it up.
   D. Interaction with the rapidly moving compact object has pulled this object to the side, creating the major kink.

6. Which of the following is likely the main source of energy for the emissions observed from this object?
   A. A supernova
   B. Ionization from nearby young stars
   C. Thermal emission from galactic dust
   D. Pulsar driven synchrotron radiation

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7. [2 pts] Which of the following is evidence the Crab Nebula was **not** created by a type Ia supernova?
   A. Type Ia supernovae don't leave supernova remnants.
   B. Type Ia supernovae don't leave behind compact objects.
   C. Type Ia supernovae don't occur in spiral galaxies like the Milky way.
   D. The Crab nebula was not created by a supernova.

8. What is the next stage of evolution for Mira?
   A. A supernova leading to a black hole
   B. A supernova leading to a neutron star
   C. A Wolf–Rayet star
   D. A white dwarf

9. What mechanism will cause the orbits of the stars in WDJ181058.67 to decay and eventually merge?
   A. The two stars are close enough that the effect of atmospheric drag will compound, slowing them enough to collide.
   B. Gravitational waves will slowly cause a loss of angular momentum.
   C. Magnetic attraction will ultimately pull the objects together.
   D. Tidal drag will transfer orbital energy to rotational energy.

10. What is the source of the prominent arch structure seen in Sharpless 29?
   A. A shockwave from a supernova
   B. A ripple caused by a passing star
   C. Radiation pressure and stellar winds from young stars
   D. Gravitational waves triggered by nearby star formation

11. [2 pts] One alternative explanation for the transitions seen in Janus' spectrum was that the object may actually be a binary system. Which of the following is **not** a reason this is unlikely?
   A. The orbit would be too close and the two objects would have collided.
   B. The light curve is sinusoidal, and would be more complicated if there were two objects.
   C. Large Doppler shifts due to a short orbital period would be expected, and were not seen in the spectrum.
   D. Eclipses would be expected in the light curve, and are not seen.

Consider the objects shown in Images 2, 3, and 4.

12. [2 pts] Identify the objects in (a) Image 3 and (b) Image 4.

13. [2 pts] Order these **three** images by evolutionary stage of the given object (with earlier stages listed first).

14. Which of these images depict the object that would fall on the position indicated by a star symbol on the H-R diagram in Image 12?

Take a look at Images 5 and 6.

15. [2 pts] Identify the objects in (a) Image 5 and (b) Image 6.

16. [2 pts] Which image depicts a nebula with an object at its center? Where does this object come from?

Consider the objects shown in Images 7 and 8.

17. [2 pts] Identify the objects in (a) Image 7 and (b) Image 8.

18. In both of these images, we see regions of ionized gas glowing in the visible and near infrared wavelengths. What causes the gas to ionize in these regions?

The next three questions are about the binary star system WDJ 181058.67+311940.94.

19. Both objects in this system are located near which letter on the HR diagram in Image 12?

20. [2 pts] What is the combined mass of the 2 objects, and how does this affect the resulting supernova?

21. [2 pts] A radial velocity plot of the system is shown in Image 11. What can you conclude about the overall motion of the **overall system**, and what information does the ratio of the amplitudes of the curves of A and B tell you about the masses of the **two stars**?

The next set of questions is about one of the most well-known nebulae, the Crab Nebula.

22. This object was produced from a supernova explosion that happened a long time ago. Why does it still glow today instead of having faded?

23. The Crab Nebula is a very bright object in the sky. In fact, it is known to be one of the brightest in what type of radiation?

24. [2 pts] Image 9 shows images of wisps near the central object of the nebula. What really are these wisps, and why do they change position over time?

The next three questions are about the long-period variable star, Omicron Ceti.

25. During its pulsations, by roughly how much does Mira's visible brightness change between its minimum and maximum brightness? Give your answer in terms of magnitudes.

26. [2 pts] Mira's tail is shown in Image 10. What wavelength is this tail primarily visible in? How is this tail produced by Mira A?

27. [2 pts] A diagram of the interior structure of a star like Mira A with 2 shells and a core is provided. Label each layer with the element(s) it is made of: **one** for each shell, **two** for the core.

Section B: Qualitative

This section consists of 20 qualitative questions on core astronomy concepts. Unless otherwise specified, each question is worth one point, for a total of 27 points.

For the next three questions, consider the following table of properties for four stars.

Star	**Luminosity** [$L_\odot$]	**Temperature** [K]
A	18	7000
B	0.01	15000
C	73	5730
D	0.07	3800

28. Which of these stars has a spectral type most similar to our sun?

29. Which of these stars is producing the most energy per unit area on its surface?

30. Which of these stars will have the greatest difference in blue- and visible-band magnitude (highest $B - V$ color index)?

Refer to the diagram of an x-ray binary shown in Image 13 for the next three questions.

31. What is the structure labeled II called?

32. [2 pts] What evolutionary phase is the object labeled III in? Why is this important to the formation of a system like this?

33. Consider the event shown in Image 14. As material accretes on the surface of the object labeled I, several different types of fusion occur. Fusion ignition of which element triggers the thermonuclear runaway that causes the observed spike?

For the next three questions, refer to Image 15 which shows the pre-main sequence evolutionary track of a $0.8\,M_\odot$ star, with two sections of this evolutionary track highlighted as Track A and Track B.

34. As the pre-main sequence star follows Track A, how does its radius change?

35. What is the primary source of energy for a pre-main sequence star on Track A?

36. [2 pts] While the pre-main sequence star is on Track B, the envelope of the star becomes opaque. Why does this halt the rapid drop in luminosity observed in Track A?

Image 16 shows the interior structure of a solar-mass star over its evolution; use this image for the following four questions. The y-axis gives the amount of mass below a given position in the star; for instance, at $m = 0.4\,\mathrm{M}_\odot$, there are $0.4\,\mathrm{M}_\odot$ of material below that position. The x-axis gives the time since the had star reached the zero-age main sequence. Gray shaded regions show regions of convection in the star and red hatched regions show regions where nuclear fusion is occurring and generating energy.

37. When this star is on the main sequence, estimate the mass contained in the core, in solar masses.

38. [2 pts] At time T_1, why doesn't nuclear fusion reach all the way to the center of the star?

39. Now, notice how the convective region of the star changes as it evolves T_1 to T_2. How might these changes end up affecting the surface composition?

40. What event occurs at time T_2 that causes the interior structure of the star to dramatically change?

41. [2 pts] After time T_2, two regions of nuclear fusion emerge in the star. Provide a reason for why the lower region of nuclear fusion remains deep in the core, and does not combine with the upper layer to form a single, continuous layer of nuclear fusion.

Consider the spectra of Star A (upper) and Star B (lower) given in Image 17 for the following three questions.

42. [2 pts] At an effective temperature of roughly 11,000 K, almost all of the hydrogen in a star's atmosphere becomes ionized. Do we expect the effective temperature of these two stars to be warmer or colder than 11,000 K? Why?

43. How would we expect the spectral lines of a star with higher surface gravity to compare to a similar star with lower surface gravity?

44. [2 pts] Provided that these two stars have the same spectral class, which of these two stars would you expect to have a greater radius? Why?

For the next four questions, consider the light curve shown in Image 18.

45. At the time marked T_1 on the light curve, what chemical change occurs to helium in the star's envelope?

46. [2 pts] Image 19 depicts the post-main sequence evolution of a $5\,\mathrm{M}_\odot$ star. Suppose a $5\,\mathrm{M}_\odot$ Cepheid variable is on its third crossing of the instability strip. Would we expect the pulsation period to be increasing or decreasing during *this* transition? Why?

47. Image 20 shows the rate of change of a Cepheid's period as a function of its period. Additionally, we know that longer periods correspond to higher mass Cepheids. Why might the period of a high-mass Cepheid change faster than a low-mass Cepheid?

Section C: Quantitative

This section consists of 19 quantitative questions related to astrophysics.
Points are shown for each question, for a total of 33 points.

Astrometric Twins [10 pts] — The binary star system Fictionas lies in the southern constellation Ersatz Major. Astrometric measurements (positions in the sky) from telescope observations of each star in Fictionas were taken over the course of a decade and a half. This data is shown in Image 22: Plots A–F.

For the purposes of this analysis, assume the observed motion for each star is fully **one-dimensional**. Furthermore, assume the stars follow **circular orbits**, and that any proper motion of the system has been resolved and subtracted.

For each star, two periodic signals are present. For your convenience they have been decomposed and the period and peak-to-peak amplitude has been identified and labeled. Note the vertical scales are **not the same** for each plot.

48. [1 pt] What type of binary system is Fictionas?

49. [2 pts] How far away is this star system, in parsecs?

50. [3 pts] What is the combined mass of Fictionas, in solar masses?

51. [2 pts] What is the mass of the primary object in Fictionas, in solar masses?

52. [2 pts] We assumed circular orbits in our previous analysis. Now we consider a new binary system, Eccentrus, whose stars follow elliptical orbits. The same plots of one-dimensional motion we considered in the previous questions are shown for each object in Image 22: Plots G and H. At which labeled time (I–IV) does Eccentrus B have the greatest speed relative to the barycenter of the system? How do you know?

From Life to Death [12 pts] — Astronomers are studying a cold molecular cloud named Trojan, located 500 parsecs from Earth. A dense clump within Trojan will collapse under gravity to create a star called Rose. On the main-sequence, Rose will have a mass of $8\,M_\odot$, a temperature of 22,000 K, and a luminosity of $4100\,L_\odot$.

53. [1 pt] The light that we observed from Trojan left it quite a while ago. What is the lookback time, in years, for Trojan?

54. [2 pts] The Jeans mass is the minimum cloud mass needed for gravitational collapse. A simplified Jeans mass expression can be written as

$$M_J = C\sqrt{\frac{T^3}{\rho}},$$

where C is a constant, T is the temperature, and ρ is the density. Trojan has a temperature of 15 K and a density of 3.0×10^{-18} kg/m^3. Its neighboring cloud, Bruin, has a temperature of 120 K and a density of 4.0×10^{-22} kg/m^3. What is the Jeans mass ratio of cloud Trojan to cloud Bruin? Your answer should be written as $1 : X$ or $X : 1$, where X is a number. Based on this ratio, which cloud is more likely to form stars?

55. [1 pt] Let's say the star has been formed and has reached the zero-age main sequence. Which letter on the HR Diagram in Image 12 shows the location of star Rose?

56. [1 pt] The main-sequence lifetime of a star can be approximated using

$$t \approx t_\odot \times \frac{M/M_\odot}{L/L_\odot}.$$

What is the ratio of the lifetime on the main-sequence of Rose to the lifetime on the main-sequence of our sun? Your answer should be written as $1 : X$ or $X : 1$, where X is a number.

57. [2 pts] What is the flux received on Earth from Rose, in W/m^2?

58. [2 pts] After the main-sequence, where it uses up core hydrogen, Rose goes through a sequence of shell and core burning stages. Image 21 shows the binding energy per nucleon. Rank the following transitions in decreasing energy released per nucleon:

$^{2}\text{H} \rightarrow {}^{4}\text{He}$, $^{4}\text{He} \rightarrow {}^{12}\text{C}$, $^{12}\text{C} \rightarrow {}^{16}\text{O}$, $^{28}\text{Si} \rightarrow {}^{56}\text{Fe}$.

59. [1 pt] Using the answer from the previous question, explain how this binding energy per nucleon affects the duration of the burning stages and what this tells us about the fusion stages in stars.

60. [2 pts] After silicon burning, Rose's iron core grows until it reaches the Chandrasekhar limit. The core then collapses from a radius $R_i = 1.0 \times 10^7$ m to a neutron star of radius $R_f = 1.2 \times 10^4$ m. Assuming the core mass is at the Chandrasekhar limit, calculate the gravitational potential energy released during this collapse. Given that our sun has a total main sequence energy output of 10^{44} J, how many times larger is the energy from the collapse compared to the total main sequence energy output of our sun? Assume that Rose is uniformly dense at all times.

Under Pressure [11 pts] — Pressure waves inside variable stars are a critical factor into how their pulsations function. This subfield of astrophysics is called asteroseismology. These waves are driven by phenomena like the κ-mechanism, preventing the pulsation waves from being damped each cycle.

61. [2 pts] Suppose the pulsation period Π_0 of a star depends on it's average radius R, pressure P, and density ρ in the form

$$\Pi_0 = C \cdot R^{n_1} \cdot P^{n_2} \cdot \rho^{n_3}$$

where C is a dimensionless constant. Using dimensional analysis, solve for n_1, n_2, and n_3. That is, find the values of n_1, n_2, and n_3 such that the units are consistent with a pulsation period.

The formula we derived is a good initial model. To obtain a closer estimate, we assume the star has uniform density and derive the expression

$$\Pi_0 \approx \sqrt{\frac{3\pi}{2G\gamma\rho}} \qquad \text{where} \qquad \gamma = \frac{5}{3}.$$

62. [2 pts] RS Puppis is a Classical Cepheid located ~6000 ly away, with a mass of $9.2\,M_\odot$ and average radius of $191\,R_\odot$. Using our assumed pulsation model, what is the pulsation period, in days, for RS Puppis? What is the range of known Cepheid periods, and is this within it?

63. [1 pt] ZZ Ceti stars are pulsating white dwarfs that have cooled to a temperature that allows for partial ionization of hydrogen. How would the pulsation period of ZZ Ceti stars compare to that of Cepheids? Justify your answer using the equation above.

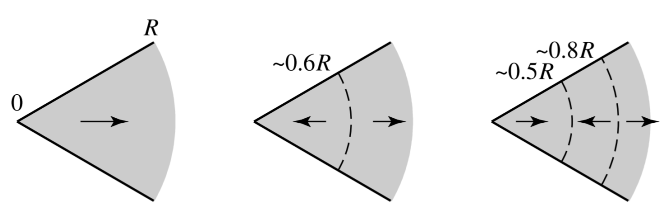
A period-average (visible) absolute magnitude relationship for Classical Cepheids is

$$\bar{M}_V = -2.43[\log_{10}(P) - 1] - 4.05$$

where P is in days.

64. [3 pts] Using the period in days from Question 62 and other known information, find the average surface temperature of RS Puppis, in Kelvin.

Our formula $\Pi_0(\rho)$ only represents variable stars pulsating in the fundamental mode—which most Cepheids pulsate in. The diagrams below present the fundamental (left), first overtone (center), and second overtone (right) pulsation modes, where multiple regions of the star could be expanding and contracting at once (indicated by arrows). Depending on the mode, there are nodal line(s) (dashed line), a radius where the stellar gas does not expand nor contract.



65. [2 pts] At higher overtones, would you expect the pulsation period of Cepheids to increase or decrease? Why?

66. [1 pt] Provide a reason why the distance from the core of the star to the first nodal line tends to be greater than the distance between the other nodal lines.

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Astronomy C

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Image Set

This packet contains all 22 images referenced in the Exam Booklet.

Image 1

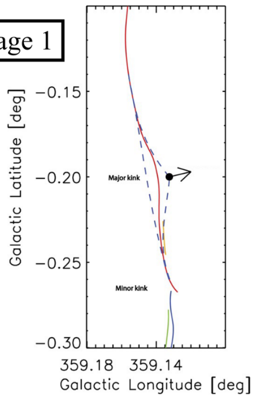


Image 2

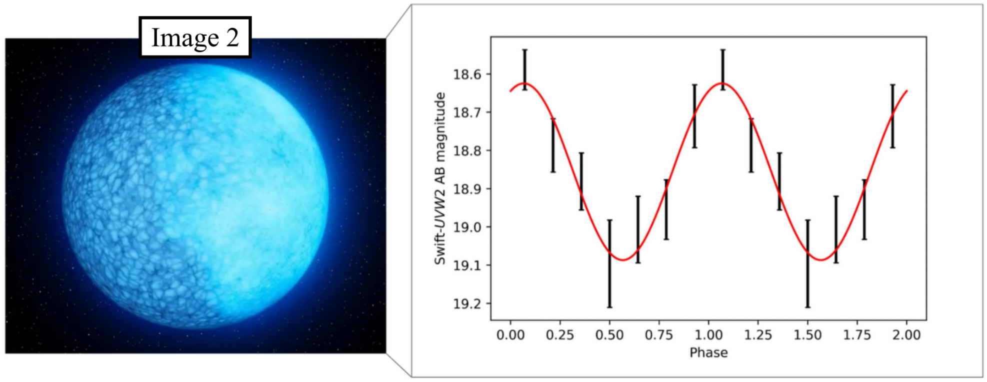


Image 3

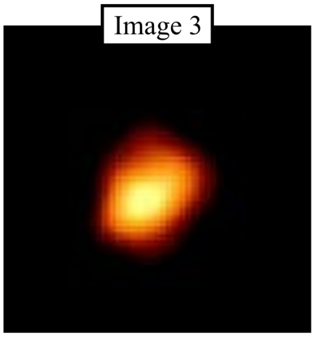


Image 4

Image 5

Image 6

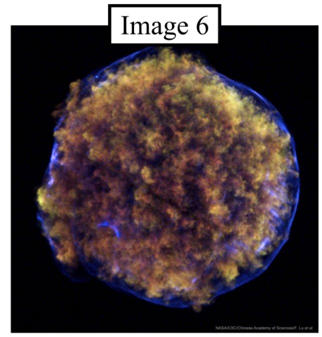


Image 7

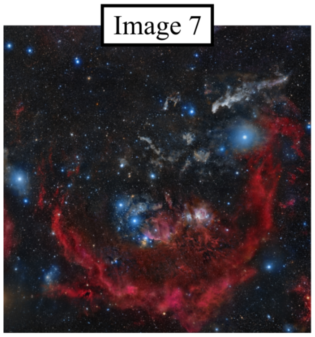


Image 8

Image 9

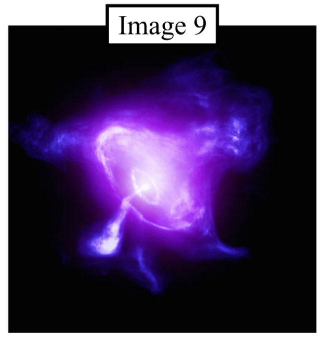


Image 10

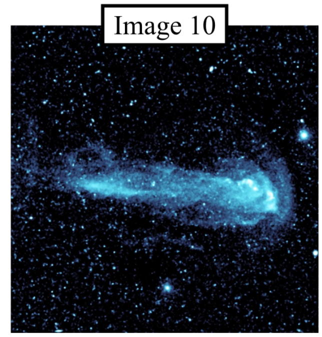


Image 11

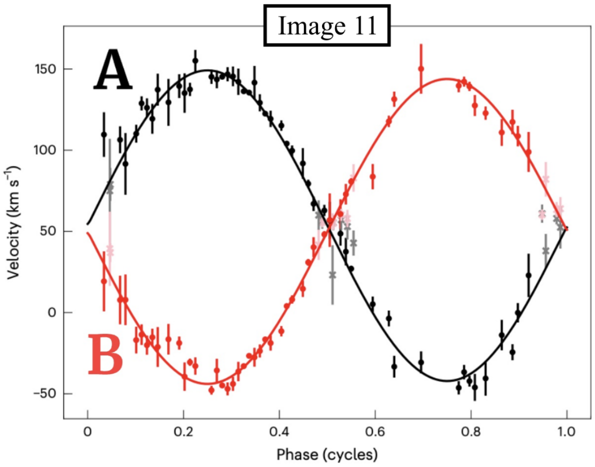


Image 12

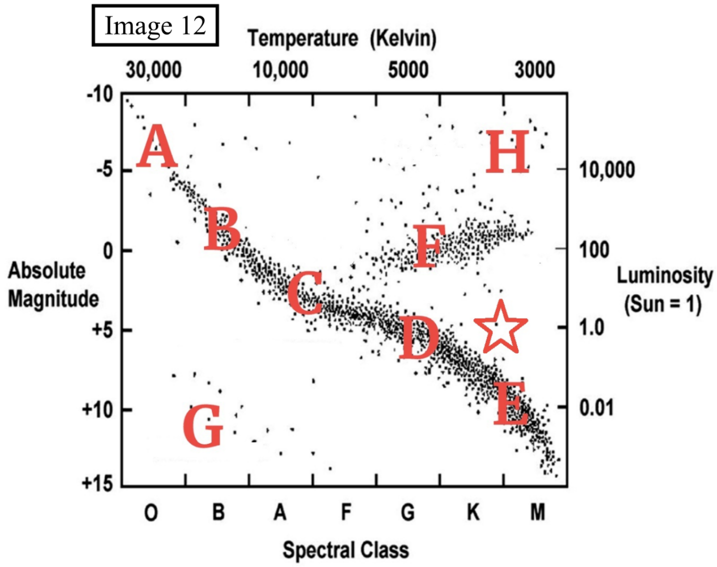


Image 13

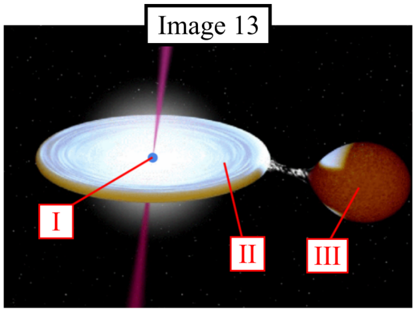


Image 14

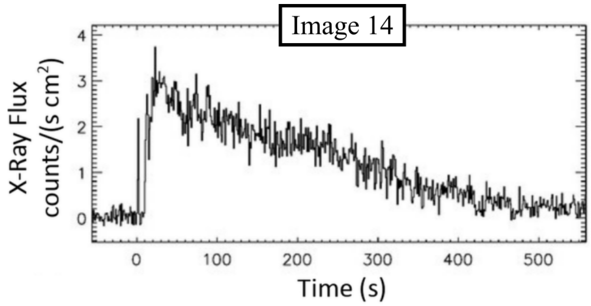


Image 15

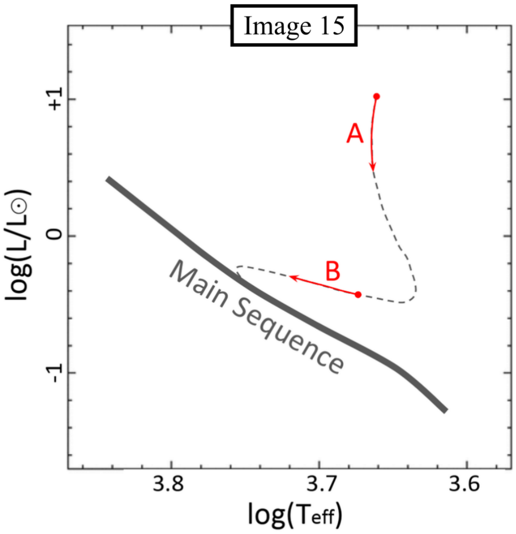


Image 16

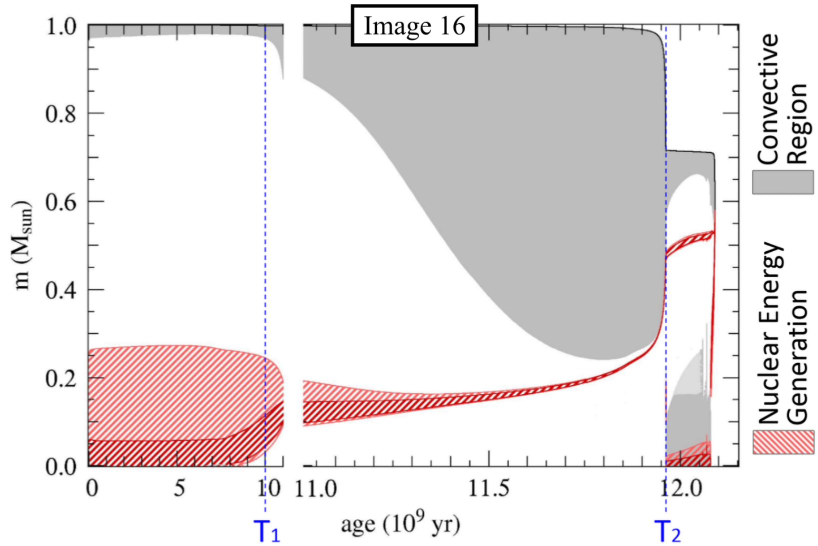


Image 17

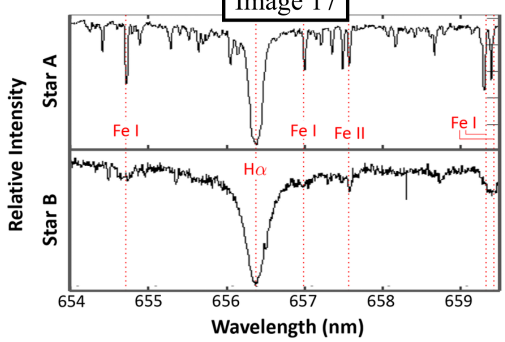


Image 18

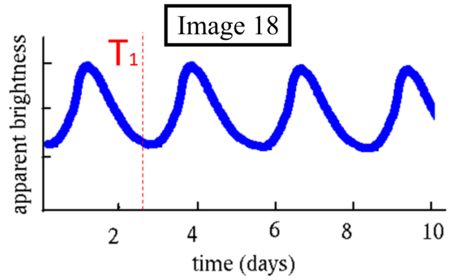


Image 19

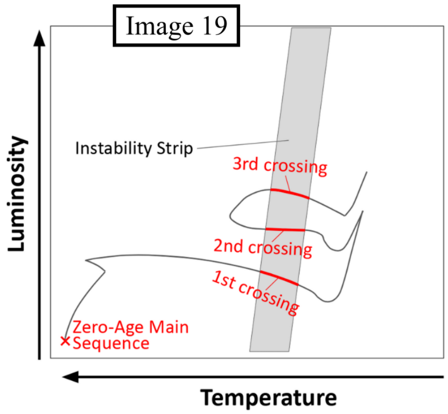


Image 20

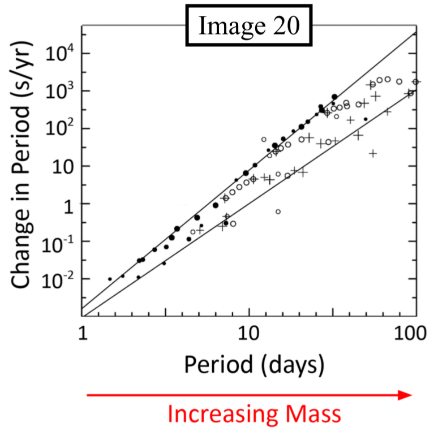


Image 21

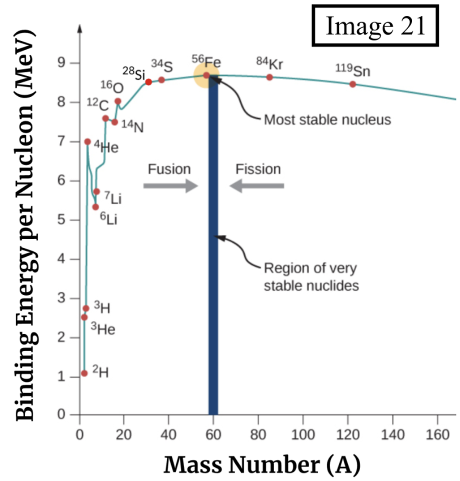
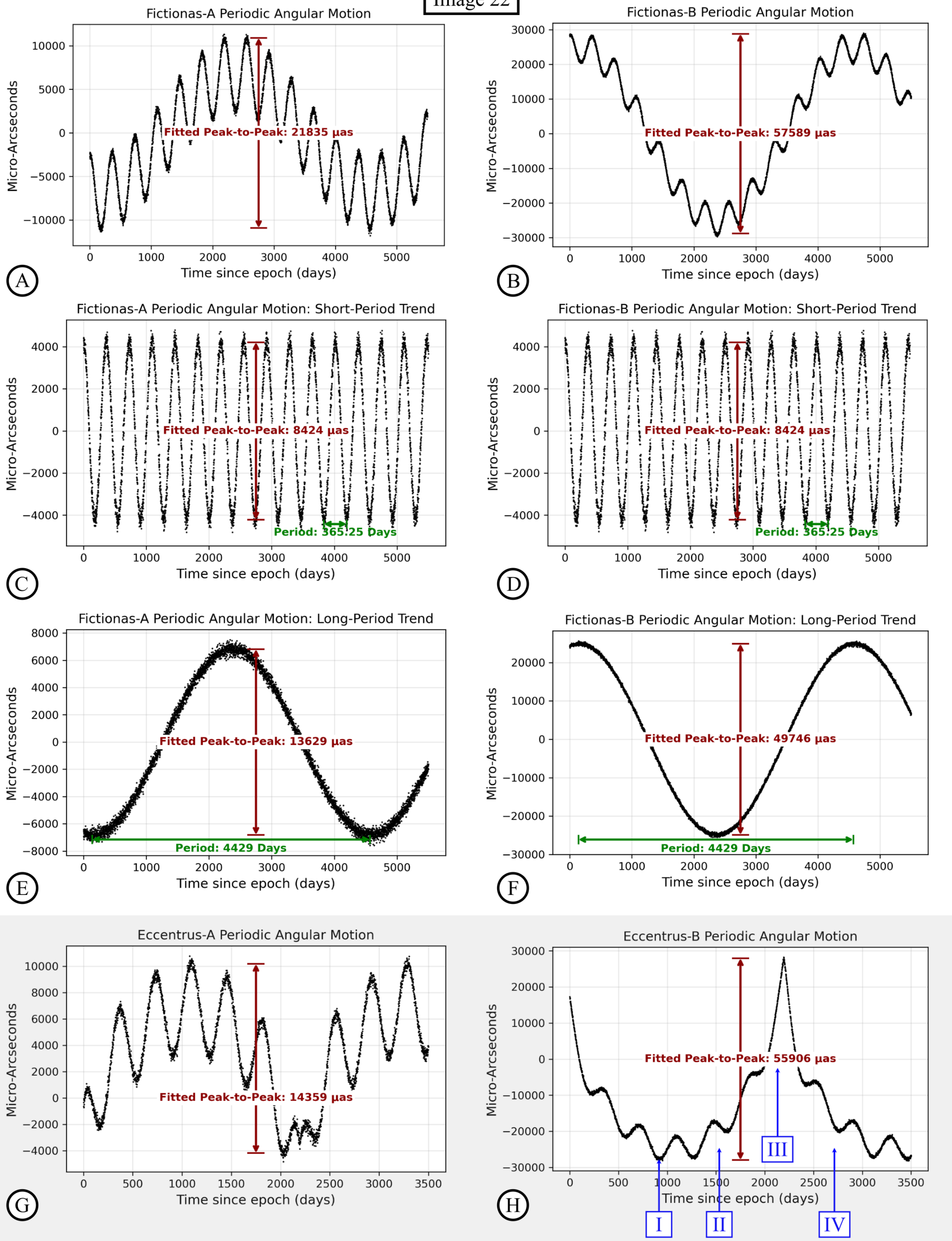


Image 22


Fictionas-A Periodic Angular Motion
Fitted Peak-to-Peak: 21835 µas
Micro-Arcseconds
Time since epoch (days)
A
Fictionas-B Periodic Angular Motion
Fitted Peak-to-Peak: 57589 µas
Micro-Arcseconds
Time since epoch (days)
B
Fictionas-A Periodic Angular Motion: Short-Period Trend
Fitted Peak-to-Peak: 8424 µas
Period: 365.25 Days
Micro-Arcseconds
Time since epoch (days)
C
Fictionas-B Periodic Angular Motion: Short-Period Trend
Fitted Peak-to-Peak: 8424 µas
Period: 365.25 Days
Micro-Arcseconds
Time since epoch (days)
D
Fictionas-A Periodic Angular Motion: Long-Period Trend
Fitted Peak-to-Peak: 13629 µas
Period: 4429 Days
Micro-Arcseconds
Time since epoch (days)
E
Fictionas-B Periodic Angular Motion: Long-Period Trend
Fitted Peak-to-Peak: 49746 µas
Period: 4429 Days
Micro-Arcseconds
Time since epoch (days)
F
Eccentrus-A Periodic Angular Motion
Fitted Peak-to-Peak: 14359 µas
Micro-Arcseconds
Time since epoch (days)
G
Eccentrus-B Periodic Angular Motion
Fitted Peak-to-Peak: 55906 µas
Micro-Arcseconds
Time since epoch (days)
I
II
III
IV
H

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Answer Sheet

Only answers recorded in this packet will be scored.
Write your team number on the top of each page.

Team Name: ______________________ **Team #:** __________

Participant Name(s): ______________________

Total Score: __________ / **100** **Rank:** __________

Section A

Team #: ________

1. ________ 2. ________ 3. ________ 4. ________

5. ________ 6. ________ 7. ________ 8. ________

9. ________ 10. ________ 11. ________

12. (a) ________________

(b) ________________

13. ________________

14. ________________

15. (a) ________________

(b) ________________

16. ________________

17. (a) ________________

(b) ________________

18. ________________

19. ________________

20. ________________

21. ________________

22. ________________

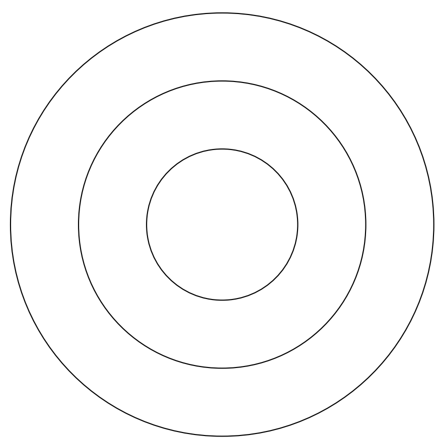
23. ________________

24. ________________

25. ________________

26. ________________

27.



Section B

Team #: ________

28. ________ 29. ________ 30. ________

31. ________

32. ________

33. ________

34. ________

35. ________

36. ________

37. ________

38. ________

39. ________

40. ________

41. ________

42. ________

43. ________

44. ________

45. ________

46. ________

47. ________

Section C (1/3)

Team #: ________

48.

49.

50.

51.

52.

Section C (2/3)

Team #: ________

53.

54.

55.

56.

57.

58.

59.

60.

Section C (3/3) Team #: ________

61.

62.

63.

64.

65.

66.