Science Olympiad
Northview Invitational
December 6, 2025

Astronomy C Walkthrough

In this walkthrough, we will go over some select questions from each section. References to various sources (e.g., online material, textbooks) are included to guide the reader towards resources to learn the concepts more in depth. We hope readers find it useful.

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:

$$1\,\mathrm{au} = 1.496 \times 10^{11}\,\mathrm{m}$$
$$1\,\mathrm{ly} = 9.461 \times 10^{15}\,\mathrm{m}$$
$$1\,\mathrm{pc} = 3.086 \times 10^{16}\,\mathrm{m}$$
$$1\,\mathrm{yr} = 365.25\,\mathrm{d}$$
$$1\,\mathrm{d} = 86\,400\,\mathrm{s}$$

$$T_{\mathrm{eff},\odot} = 5778\,\mathrm{K}$$
$$1\,\mathrm{R}_\odot = 6.957 \times 10^{8}\,\mathrm{m}$$
$$1\,\mathrm{M}_\odot = 1.989 \times 10^{30}\,\mathrm{kg}$$
$$M_{\mathrm{bol},\odot} = +4.75\ \text{(abs. mag.)}$$
$$1\,\mathrm{R}_\mathrm{J} = 7.149 \times 10^{7}\,\mathrm{m}$$
$$1\,\mathrm{M}_\mathrm{J} = 1.899 \times 10^{27}\,\mathrm{kg}$$
$$1\,\mathrm{R}_\oplus = 6.378 \times 10^{6}\,\mathrm{m}$$
$$1\,\mathrm{M}_\oplus = 5.972 \times 10^{24}\,\mathrm{kg}$$

$$G = 6.674 \times 10^{-11}\,\mathrm{N\,m^2/kg^2}$$
$$b = 2.898 \times 10^{-3}\,\mathrm{m\,K}$$
$$\sigma = 5.670 \times 10^{-8}\,\mathrm{W/(m^2\,K^4)}$$
$$h = 4.136 \times 10^{-15}\,\mathrm{eV/Hz}$$
$$H_0 = 70\,\mathrm{km/(s\,Mpc)}$$

Section A: Multiple Choice

This section consists of 26 multiple choice and multiple select questions. Unless otherwise specified, each question is worth 2 points, for a total of 60 points.

1. Roughly what percentage of the stars in our galaxy are in the main sequence?
   A. 10 %
   B. 25 %
   C. 50 %
   D. 90 %

2. A-type stars were originally defined by what spectral feature?
   A. Ionized hydrogen (H II)
   B. Balmer lines (H I)
   C. Titanium oxide (TiO)
   D. Neutral helium (He I)

3. A main sequence star with a luminosity one-tenth that of the sun has a ________ core and a ________ envelope.
   A. radiative, radiative
   B. radiative, convective
   C. convective, radiative
   D. convective, convective

4. The Hayashi track, in addition to describing the evolution of low-mass pre-main-sequence stars, may also be used to
   A. approximate the chemical composition of protostars.
   B. determine the conditions under which a star is fully convective or radiative.
   C. estimate the size of the protostar's progenitor gas cloud.
   D. track the formation of low-mass main sequence stars into red giants.

5. [4 pts] During ascent of the red giant branch, a low-mass star primarily increases in luminosity because (Select all that apply)
   A. thin-shell hydrogen fusion becomes increasingly efficient.
   B. the core eventually contracts such that triple-alpha fusion briefly starts.
   C. emitted flux increases as a result of an increase in the star's surface temperature.
   D. the hydrogen envelope expands dramatically, increasing the star's radiating surface area.

6. Which condition triggers the helium flash in low-mass red giants?
   A. Sudden temperature increase causes explosive carbon ignition
   B. Helium degeneracy in the core inhibits expansion
   C. The cessation of hydrogen fusion in the core
   D. Temperature drops under the triple-alpha process threshold

7. A planet orbits a star in a highly eccentric orbit. Which of the following statements must be true?
   A. The planet's average orbital speed is faster than that of a circular orbit at the same semi-major axis.
   B. The planet will escape its orbit if its eccentricity decreases below 1.
   C. The specific orbital energy depends only on the semi-major axis.
   D. The orbital period is dominated by time spent near periapsis.

8. The mass estimates of spectroscopic binary stars are generally
   - **A. lower bounds because the inclination of the orbit is unknown.**
   - B. upper bounds because red/blueshift systematically overestimate radial velocities.
   - C. lower bounds because distances to spectroscopic binaries are poorly constrained.
   - D. upper bounds because the more massive star contributes overwhelmingly to the observed spectrum.

9. [4 pts] Which of the following statements about T Tauri variable stars are true?
   (Select all that apply)
   - **A. They exhibit both periodic and aperiodic variation.**
   - B. Internal ram pressure inhibits their direct transition to the main sequence.
   - **C. Gravitational collapse fuels their energy production.**
   - D. They are typically bright in infrared due to their low surface temperatures.

10. [4 pts] Periodic variable stars on the instability strip pulsate due to the kappa mechanism. Which of the following related statements are true?
    (Select all that apply)
    - A. Mira variable stars are on the instability strip.
    - **B. The pulsation frequency is inversely correlated with mass.**
    - C. Convection regulates the distribution of singly and doubly ionized helium.
    - **D. A cool red giant star doesn't pulsate due to their helium ionization zone being too deep.**

11. Type II supernovae show hydrogen lines because
    - A. core collapse causes nearly instantaneous helium fusion.
    - B. their shockwaves strip hydrogen from their associated interstellar gas clouds.
    - **C. the progenitor star retains its outer envelope.**
    - D. hydrogen in the interstellar medium is compacted by the explosion.

12. Which of the following correctly describes the behavior of a white dwarf's radius as its mass increases?
    - A. The radius increases because electron degeneracy pressure pushes outward from the core.
    - **B. The radius decreases because stronger gravity overcomes the degenerate matter.**
    - C. The radius increases because neutron degeneracy pressure takes over at large masses.
    - D. White dwarfs notably have no correlation between mass and radius.

The following three (3) questions refer to the cover image—the Milky Way Galactic Center imaged in radio by MeerKAT.

13. What are the bright streaks known as?
    - A. Webbing
    - B. Strings
    - **C. Filaments**
    - D. Hairs

14. The vertical streaks emit what type of radiation?
    - A. Blackbody
    - **B. Synchrotron**
    - C. Thermal
    - D. Bremsstrahlung

15. Where is the Bone (G359.13) located in the image?
    - A. Left
    - B. Top
    - C. Top right
    - **D. Right**

The next three (3) questions concern Tycho's SNR and refer to Image 1 that shows the high energy x-rays emitted by the SNR.

16. What type of supernova produced Tycho's SNR?
    - **A. Ia**
    - B. Ib
    - C. Ic
    - D. II

17. What telescope took this image?
    - A. Hubble
    - B. IXPE
    - **C. Chandra**
    - D. Swift

18. What is the purported explanation for the presence of the circled x-ray arc?
    - A. The relativistic jet from the stellar remnant pierced a hole in the outer shell of the SNR.
    - B. Collimated material ejected by the progenitor system inhibited expansion in the direction of the arc.
    - **C. It was formed by the shock wave of the supernova stripping the surface of a companion star.**
    - D. A shock front was produced as the supernova hit a nearby dense cold molecular cloud.

The following three (3) questions refer to Image 2.

19. Identify the object shown in the image.
    - **A. NGC 6559**
    - B. The Orion Molecular Cloud Complex
    - C. NGC 7293
    - D. M1

20. Which region of the object scatters the light from newly formed, energetic stars? (A–D) **C**

21. [4 pts] Which of the following statements are true? (Select all that apply)
    - **A. This object is small, only a few-light years across—two orders of magnitude smaller than its neighboring object of the same type.**
    - B. Region D in the image is known as an H II region, composed of ionized atomic hydrogen created by short-lived blue stars.
    - C. The unique interstellar medium of this object does not contain much dust, allowing formation of more high mass stars than usual.
    - **D. Located in the Milky Way and** 1500 pc **away, this object can be seen from the southern hemisphere.**

The next five (5) questions refer to Omnicron Ceti, a binary system.

22. Which types of stars comprise the system? (Select two)
    - A. Red dwarf
    - B. Blue supergiant
    - C. A-type main sequence
    - D. Blue straggler
    - **E. White dwarf**
    - F. K-type main sequence
    - **G. Red giant**

23. [1 pt] The optical variation of the primary star is on the order of ________.
    - A. days
    - B. months
    - **C. years**
    - D. decades

24. [1 pt] The optical variation of the secondary star is on the order of ________.
    - **A. minutes**
    - B. hours
    - C. days
    - D. weeks

25. The stellar interior of Mira A is best characterized by which description?
    - A. Core hydrogen burning
    - B. Inert helium core, shell hydrogen burning
    - C. Core helium and shell hydrogen burning
    - **D. Inert carbon core, shell helium and hydrogen burning**

26. [4 pts] Which image(s) depict the system? (Select all that apply)
    - **A. Image 3**
    - **B. Image 4**
    - C. Image 5
    - D. Image 6

Multiple selection questions (5, 9, 10, 21, 26) are scored like four true/false questions, with the proper inclusion/exclusion of each option being worth one point. Question 22 gives one point for each correct choice.

Section B: Free Response

This section consists of 39 free response questions. Points are shown for each question, for a total of 100 points.

27. [2 pts] Why must molecular clouds be cold for star formation to begin?

28. [2 pts] Most stars have been observed to be in binary systems; our sun is an exception. Briefly explain what physical process causes lone star systems to be rare.

29. [2 pts] What is the primary reason we are unable to detect a vast majority of pulsars in our galaxy?

30. [2 pts] Type Ia supernovae are commonly used as standard candles. Briefly explain why they are effective in computing cosmological distances.

Solution: *(by Eddy)*

27. Molecular clouds must be cold so that thermal pressure is low. If the cloud is too hot, thermal pressure will exceed gravitational force and the cloud will disperse rather than gravitationally collapse.

28. During star formation, collapsing cloud cores fragment due to rotation and turbulence. This fragmentation naturally produces binary or multiple star systems rather than single stars.

29. Most pulsars are undetectable because their emission is confined to narrow beams. If the beam does not sweep across Earth, the pulsar cannot be observed.

30. Type Ia supernovae explode at a similar physical condition near the Chandrasekhar mass. This consistency allows their consistent intrinsic brightness to be used to measure cosmological distances.

On the island of Hven, a famed astronomer observes two clusters, Aepdiles and Houcusphi, collecting B and V band apparent magnitude data of stars within them. The astronomer takes 100 of their best observations (50 from each cluster) and plots them—which you can find on your answer sheet. They ask you to analyze the plots.

31. [1 pt] What are these plots known as?

32. [3 pts] Draw the main sequence line and circle the turnoff point on both plots.

33. [3 pts] Which cluster is older? Justify your answer.

34. [3 pts] Trace and label the subgiant, red-giant, and horizontal branches on the plot of Houcusphi.

35. [1 pt] What type of variable star intersects the horizontal branch?

Observational data of the apparent magnitude from a variable star of that type is collected over a long time.

36. [1 pt] Name a method astronomers would use to determine the unknown period P of the star.

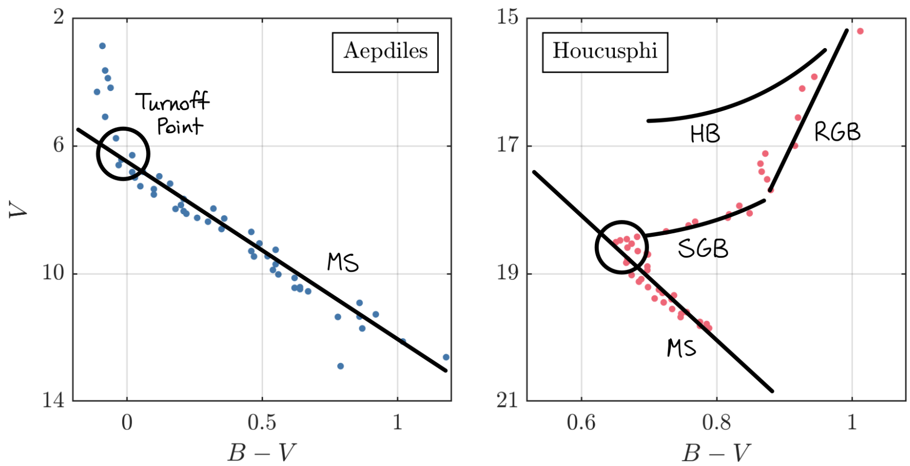
37. [3 pts] With this period P, explain how astronomers would process this data to reveal clear, repeating patterns. Identify this procedure.

Solution: *(by Robert)*

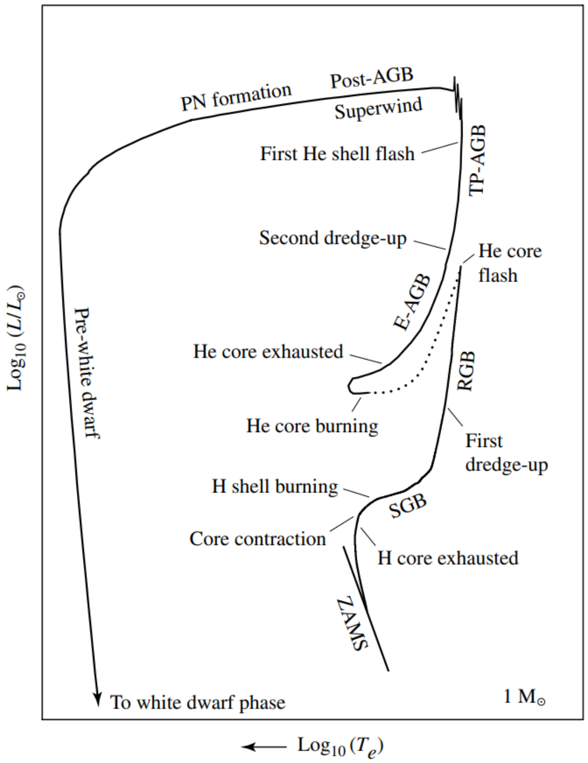
These plots are known as *color-magnitude plots*. They are similar to H–R diagrams but not quite the same. Astronomers collect color magnitude measurements (typically B and V) of many stars they presuppose to be in the same star cluster. The separation of these stars *should* be much smaller than our distance to them, so the *difference* in their apparent magnitudes will be the same as the *difference* in their absolute magnitude. And, since $B - V$ is a decent measure of effective surface temperature (see Ballesteros' formula), plotting V vs. $B - V$ provides a snapshot of an H–R-like diagram where all the stars are at roughly the same age.

The plots are produced from real data of the Pleiades (Source, Data) and M12 (Source, Data).

Using our understanding of the H–R diagram, we can identify the location of the main sequence in both clusters and the different post main sequence branches in Houcusphi (anagram of Ophiuchus, the constellation M12 is in). Notably, the horizontal branch is devoid of stars; so its position has to be inferred. Since the turnoff point of Houcusphi is further down the main sequence than Aepdiles, it is the older cluster.



Compare the above with the schematic diagram below, fig. 4 on p. 504, ch. 13 of *An Introduction to Modern Astrophysics* (2013) by Bradley W. Carroll and Dale A. Ostlie (ISBN: 9781292022932) (hereafter referred to as C/O). Ch. 13 of C/O gives an advanced overview of stellar evolution. Some intermediate resources: OSU lecture notes on low/high mass and Sheffield lectures notes on low/high mass evolution.



A schematic diagram of the evolution of a low-mass star of $1\,M_\odot$ from the zero-age main sequence to the formation of a white dwarf star. The dotted phase of evolution represents rapid evolution following the helium core flash. The various phases of evolution are labeled as follows: Zero-Age-Main-Sequence (ZAMS), Sub-Giant Branch (SGB), Red Giant Branch (RGB), Early Asymptotic Giant Branch (E-AGB), Thermal Pulse Asymptotic Giant Branch (TP-AGB), Post Asymptotic Giant Branch (Post-AGB), Planetary Nebula formation (PN formation), and Pre-white dwarf phase leading to white dwarf phase. *(Caption from C/O)*

The horizontal branch intersects the instability strip, a region of the H–R diagram that contains a variety of pulsating variable stars. The stars located at this intersection are known as *RR Lyrae* stars. Pulsating variable stars are extremely important in astronomy, as they are accurate standard candles identifiable from great distances.

Once astronomers collect enough time series data from a particular star, they need to determine whether it contains a periodic signal (vs., aperiodic signals from eruptive variable stars, recurrent novae, etc.). There are many methods to do so—most famously the Fourier transformation takes time domain data and transforms it into the frequency domain. Understanding the details of these methods are beyond the scope of this event, but knowing what they are and how they are used is important. Once one finds the period P of the star, they can *phase-fold* the data by replacing the time t with $t \,\%\, P$, revealing the underlying periodic light curve.

Here are some resources on light curves and period finding: NASA Imagine the Universe! (primer), UNL Astronomy variable star photometry lab (intermediate), RIT lecture notes (intermediate), SUNY lecture notes (intermediate).

In a distant galaxy, there are two stars: Nadir (G9V) and Barnes (K2I).

38. [5 pts] Compare and contrast these two stars against our sun:
    (a) [2 pts] Are they hotter or cooler?
    (b) [2 pts] Are they more or less massive?
    (c) [1 pt] Are they more or less luminous?

39. [3 pts] What is the name of the spectral feature in Image 7? Which star is more likely to exhibit his feature? Why?

Solution: *(by Robert)*

Stellar classification largely follows from the Morgan–Keenan system, made up by the Harvard spectral class (e.g., G9 for Nadir and K2 for Barnes) and the Yerkes luminosity class (e.g., V for Nadir and I for Barnes). Our sun has the classification G2V. From this, we know both Nadir and Barnes are cooler than our sun.

The following two parts can be answered with an understanding of the main sequence and a bit of supergiants. Since Nadir is cooler than our sun and both are main sequence stars, we can infer it is less massive and less luminous. On the other hand, Barnes is a supergiant and we can infer it is more massive and more luminous.

The spectral feature is a *P Cygni profile*, named after the star first found to exhibit it. This feature forms from stars with strong stellar winds where redshifted emission lines are superimposed over blueshifted absorption lines. Due to the low surface gravity of supergiant stars, they typically possess strong stellar winds, so Barnes is more likely to exhibit this feature. The figure is fig. 17 on p. 480, ch. 11 of C/O.

In the following eight (8) questions, we will investigate some young stellar objects in a region of star formation in X-rays. To set up the image, follow the following instructions.

Setup Instructions

- Go to `nso.js9.org`
- Select `[The Unofficial Chandra Archive Search Page]` button on the right of the screen. A pop-up should appear.
- In the box labeled `[Chandra Obs ID]`, enter "`17739`"; then click `[Search]`.
- Then, scroll down and drag and drop the `Title` link into the JS9 window.
- Select `[Scale > log]` so you can see the image.
- Under `[Analysis > Blur, equivalent sigma]`, enter "`1`".
- Zoom in once.
- Your image should look similar to Image 8.

40. [1 pt] Look for the "`OBJECT`" field. What is the name of the object shown in this observation? *(Hint: Use `[Analysis > FITS Header(s)]`.)*

41. [3 pts] Click on the circle icon in the top bar to create a circle region. Resize and move this region over Object A, as shown in Image 8. Select `[Analysis > Light Curve]`.
    Use the one under "`Server-side Analysis`", NOT the one under "`NSO Analysis`".

    Estimate the average brightness measured from this object, in counts. Estimate the range of the brightness measured from this object, in counts.

42. [3 pts] Now, move the circle over Object B, as shown in Image 8. Select `[Analysis > Light Curve]`.
    Use the one under "`Server-side Analysis`", NOT the one under "`NSO Analysis`".

    What is different about this light curve from the one you observed previously?

43. [3 pts] What is likely causing the behavior you observe in the x-ray light curve of Object B?

44. [2 pts] Now, estimate the angular separation between any two adjacent stars. Which of the following is the best estimate of the angular separation between the objects in this star-forming region?

    A. $0.1''$

    B. $10''$

    C. $1000''$

    D. $10\,000''$

45. [3 pts] This object is at a distance of roughly 1030 ly. For the angular separation you selected above, what is roughly the distance between these objects, in ly?

46. [2 pts] The stars in this region remain gravitationally bound over the next 10 Gyr. As the cosmic dust clears and the stars evolve, what type of cluster will be formed?

47. [2 pts] By the time the cluster from the previous question is formed, what will likely have happened to the bright objects we observe here?

Solution: *(by Rio)*

A complete video walkthrough of the JS9 parts of this question can be found here!

The object we're looking at here is IC 348, a dusty star-forming region filled with young stellar objects (YSOs). See this JWST image for a look at this object in the infrared.

Questions 40–43, looked into the light curves of two of the individual YSOs using Chandra x-ray data from its ACIS instrument. One of these objects was found to have a notable spike in its x-ray light curve. YSOs tend to behave quite erratically in the x-ray regime because they're extremely active objects. So, when a young star flares (similar to a flare occurring on our sun but much more powerful), it sends out a bombardment of x-rays, which are picked up by Chandra and displayed in the light curve. This HEASARC article describes similar behavior from young stars in the Rho Ophiuchi cloud complex.

In questions 44–45 the goal is to determine the distance between the x-ray bright YSOs in this region. We can't directly measure the distance between these objects with the data we're given, though; the instrument can only measure the angular distance between objects. This is the measurement we make in question 44. Then, in question 45, we use the small angle formula to determine the physical distance between adjacent objects. This process is described in this Las Cumbres Observatory article. In our case, we determined the angular distance subtended between two objects to be $\sim 10''$.

In our case, we determined that $\theta_{\text{arcsec}} = 10''$ in question 44 (see the video walkthrough for more information). So, from the small angle formula,

$$\theta_{\text{arcsec}} = 206265\,\theta_{\text{radians}} = 206265 \times \frac{d}{D},$$

for the cluster a distance D away from Earth, with stars a distance d apart from each other, which is what we're interested in. So, rearranging, and plugging in $D = 1030\,\text{ly}$ (as given in the problem) and $\theta_{\text{arcsec}} = 10''$, we find $d = 0.05\,\text{ly}$.

This object is a cluster of forming stars. Under the assumption of question 46–47 that this object has sufficient mass to remain gravitationally bound for $\sim 10^{10}\,\text{yr}$, this would be a highly evolved globular cluster. The objects we're looking at here also are the hottest and brightest stars in the cluster, which would be the first to burn through their fuel, ultimately exploding as supernovae.

If you're looking to dig further in to JS9, this is an interesting image to look into. Some possibilities for further investigation might be seeing if there are any other flare-like events occuring, or test other analysis features, like an `Energy Spectrum`, or run an `Event Filter` on the `time` column to see what the image looks like just during the period of brightening for Object B.

The Helix Nebula is a planetary nebula located 650 light-years away from Earth. Image 9 depicts the nebula in 3.6 µm (left) and 24 µm (right).

48. [2 pts] Identify the wavelength regime of the two images.

49. [4 pts] Describe the physical process producing the knots at the periphery of the nebula. Why do their tails all point away from the central star?

50. [2 pts] What is the dust mass of the central extended region in 24 µm, in $M_\oplus$?

Solution: *(by Robert)*

The two images are taken in infrared wavelengths, one near-infrared and one far-infrared. The images are from this paper which also includes a dust mass estimate of $0.13\,M_\oplus$.

The Helix nebula is a planetary nebula, which form in the final stages of low to intermediate mass stars as they balloon up to giant stars. As the star expands, its gravitational pull on its outermost layers weakens and they begin to shed as radiation pressure overcomes the weakened gravity. This stellar wind is hot, ionized, and sparse (low density), expanding radially out from the central star. It eventually collides with cooler, neutral, denser gas ejected earlier in the star's lifespan (e.g., thermal pulses, previous stellar wind). This collision produces shocks that "light up" the planetary knots. The hot gas eventually breaks through the denser medium and the ionized front is swept back to produce the tails we see, pointing away from the central star since the stellar wind expand from it.

Many teams mentioned Rayleigh–Taylor instability—presumably because it's listed on the Wikipedia article for the nebula—which net them minimal credit. Simply writing down key terms doesn't answer the question at hand: describing the physical process producing the knots. R–T instability is a general phenomenon applicable to the Helix nebula for explaining why they look that way; however, the radial expansion of stellar winds explains why the tails point away, *not* R–T instability. Advanced fluid dynamics is beyond the scope of this event.

Read more about the Helix nebula: NASA article (primer), NASA article (intermediate), and Chandra article (intermediate).

Janus is a white dwarf of great interest. Image 10 shows phase-resolved and phase-binned spectra of Janus, normalized and shifted vertically for clarity. The numbers on the right indicate the centre of each phase bin. The blue vertical lines highlight the position of the hydrogen Balmer lines and the red vertical lines indicate neutral helium lines.

51. [2 pts] Janus was discovered by what survey? Provide the *full name*, **not** the acronym.
52. [3 pts] Describe what "phase-resolved spectra" means in this context.
    (What does "phase" mean? How is it "resolved"?)
53. [3 pts] Are the lines absorption or emission lines? The lines correspond to the composition of what part of the white dwarf?
54. [2 pts] Based on the spectra, helium is dominant near which phase?

Solution: *(by Robert)*

Janus (ZTF J203349.8+322901.1) was discovered by the Zwicky Transient Facility, a wide-field survey of the northern sky aimed at discovering variable stars and transients.

This Ars Technica article gives an introduction to this object.

The spectra of Janus are from this paper (direct image link). The term "phase" typically refers to the percentage along a particular period. For example, a phase of 0 corresponds to the start of the period, one of 0.5 corresponds to the middle of the period, and one of 1 corresponds to the end of the period *which is equivalent to the start*. Since Janus is a periodic variable white dwarf, whose periodicity comes from its rotation, "phase" refers to the rotation angle of the star we are currently viewing. The spectra is collected over many periods, "binned" (split) by their phase, and stacked (read: averaged and/or summed) to "resolve" the spectra at each angle. This process has to be done because the star is spinning much faster than the exposure time necessary to collect a sufficiently accurate spectrum. So combining many short-exposure spectra provides the next best picture.

The features highlighted in the spectra are *absorption lines*. These correspond to absorption by the *atmosphere* of the white dwarf and reveal its composition. The deeper an absorption line is, the greater its concentration. We see that the helium absorption lines at $\sim$3900 Å and $\sim$5900 Å are strongest at a phase of 0.5, so the helium is most dominant then.

Learn more about absorption and emission lines here and here.

The helium flash is a rapid and extreme phase of nuclear burning for low-mass stars—namely those between $0.6\,M_\odot$ and $2.0\,M_\odot$.

55. [1 pt] Is the helium flash a positive or negative feedback loop?

56. [4 pts] Explain why a helium flash does not occur for stars with masses less than $0.6\,M_\odot$ or greater than $2.0\,M_\odot$.

57. [3 pts] It is said that the peak energy production during the helium flash rivals that of our Milky Way. The majority is efficiently transported to the edge of the core. From here, where does the energy go?

Solution: *(by Robert)*

The helium flash is a brief runaway nuclear reaction that occurs in some low mass stars. This phenomenon is the result of a *positive* feedback loop between increasing temperature and increasing helium fusion rate.

Stars with too low of a mass are unable to raise their cores to high enough temperature for the triple-alpha process (helium burning). Stars with too high of a mass begin burning helium before its helium core becomes fully degenerate, so the runaway reaction does not occur.

When the helium flash occurs, it is true that the peak energy production is extremely massive. But the majority of that energy goes into lifting the helium core out of degeneracy. The rest of the energy is then transported to the edge of the core and flows into the outer layers. These layers are still extremely massive, so effectively all of the energy goes into their expansion against their gravitational potential. Many teams mentioned the energy would radiate out of the star, but this doesn't happen! If it did, then we'd see many orders of magnitude more bursts of supernova-level brightness than we do.

Read more: notes by Northwestern University lecturer David Taylor, video lecture by Michel van Biezen, and §12-2c of Foundations of Astronomy, 14e (2019) by Michael A. Seeds and Dana E. Backman (ISBN: 9781337399920).

One December night, Fredenandus looks towards the north ecliptic pole and observes the star Jregory from Fairbanks, Alaska. Six months later, he returns to the same spot and measures a parallax angle of 150 milliarcseconds (mas) relative to the background galaxies.

58. [3 pts] Calculate the distance to Jregory in parsecs (pc).

59. [3 pts] Using photometry, Fredenandus measures Jregory's V-band apparent magnitude to be $m_V = 9.2$. Calculate the V-band absolute magnitude of Jregory.

60. [3 pts] Fredenandus obtains a spectrum of Jregory and notices that its emission peaks at a wavelength of $\lambda = 483\,\text{nm}$. Estimate the surface temperature T of Jregory, in kelvin.

61. [3 pts] To learn more about Jregory, Fredenandus later measures its total luminosity and finds that Jregory radiates about five times the luminosity of our sun (i.e., $5.0\,\mathrm{L}_\odot$). Calculate the radius of Jregory, in meters.

Solution: *(by Eddy)*

This problem set tests basic knowledge of distance and magnitude formulae. If the specific formula application is known, the problems are a simple plug-and-chug and/or unit conversion.

58. Calculation of distance given parallax angle is done with the formula $d = 1/p$, where d is in parsecs and p is in arcseconds. However, the parallax angle in this problem is given in *milliarcseconds*, so we need to do a quick unit conversion before plugging $p = 0.150''$ into the equation, yielding a distance of $\boxed{d = 6.67\,\text{pc.}}$

59. Apply the distance modulus formula: $m - M = 5\log_{10}(d) - 5$, where d is in parsecs. We are given $m = 9.2$, and we use the value of d given in the previous problem to solve for M, the absolute magnitude. This yields $\boxed{M_V = 10.1.}$

60. For this problem, use Wien's displacement law, which describes the inverse relationship between the temperature of a blackbody and the wavelength at which it emits peak radiation: $T \approx 2.898 \times 10^{-3}\,\text{m K}/\lambda_{max}$. We are given $\lambda_{max} = 483\,\text{nm}$, so we plug it in to yield $\boxed{T \approx 6.00 \times 10^3\,\text{K.}}$

61. The Stefan–Boltzmann law relates the radius, luminosity, and surface temperature of a star. We are given Jregory's luminosity and have its temperature from the previous problem. The Stefan–Boltzmann law is $L = 4\pi R^2 \sigma T^4$, where L is in watts, R is in meters, $\sigma = 5.670 \times 10^{-8}\,\text{W}/(\text{m}^2\,\text{K}^4)$ is a constant, and T is in kelvins. Using the Sun's luminosity of $L_\odot \approx 3.83 \times 10^{26}\,\text{W}$, we rearrange the formula to solve for R:
$$R = \sqrt{\frac{L_\odot}{4\pi\sigma T^4}}.$$
Plugging in given values yields $\boxed{R \approx 1.44 \times 10^9\,\text{m.}}$

A star named Altheon and a neutron star orbit each other around their common center of mass. Altheon has the same mass as our sun ($1\,\mathrm{M}_\odot$), while the neutron star has a mass of $1.4\,\mathrm{M}_\odot$. The binary's orbital motion can be described equivalently as a *reduced-mass* particle moving in a **circular** orbit of radius a, the separation between the two stars.

62. [3 pts] The orbital period of the Altheon-neutron star binary is measured to be $P = 10.0\,\text{days}$. Calculate the semi-major axis a of the relative orbit in meters.

63. [2 pts] Using your value of a from the previous question as the separation between Altheon and the neutron star, calculate the gravitational force between them in newtons.

64. [4 pts] The total mechanical energy of the system in the center of mass frame is calculated by adding the kinetic and gravitational potential energies:

$$\frac{1}{2}\mu v^2 - \frac{GMm}{a},$$

where $\mu = Mm/(M+m)$ is the reduced mass. Compute the speed v of the reduced-mass particle (the relative orbit) in km/s and the total mechanical energy in joules.

65. [3 pts] What is the sign of the total mechanical energy and what does it tell you about the dynamics of the binary system?

Solution: *(by Eddy)*

This problem set aims to introduce a simplified concept of the two-body problem: how to approximate two-body motion through a single-body system. All quantities below refer to the *relative orbit*.

62. Kepler's Third Law relates the orbital period P and the semi-major axis a of the relative orbit (in SI units):

$$\frac{P^2}{a^3} = \frac{4\pi^2}{G(M+m)}.$$

Rearrange Kepler's Third Law to solve for a:

$$a = \left(\frac{G(M+m)P^2}{4\pi^2}\right)^{1/3}.$$

Now, use $M + m = 2.4\,\mathrm{M}_\odot$ (from the question text). Converting with $1\,\mathrm{M}_\odot = 1.989 \times 10^{30}\,\text{kg}$ and $P = 10.0\,\text{d} = 8.64 \times 10^5\,\text{s}$, we find $\boxed{a \approx 1.82 \times 10^{10}\,\text{m.}}$

63. The gravitational force between the two stars is given by Newton's law of gravitation:

$$F = \frac{GMm}{a^2}.$$

Substituting the values for M, m, and the separation a,

$$F \approx \boxed{1.12 \times 10^{30}\,\text{N.}}$$

64. The speed of the reduced-mass particle in a circular relative orbit is

$$v = \frac{2\pi a}{P}.$$

Using the values from above,

$$v \approx 1.32 \times 10^5 \text{ m/s} = \boxed{132\,\text{km/s.}}$$

The total mechanical energy of the system in the center-of-mass frame is

$$E = \frac{1}{2}\mu v^2 - \frac{GMm}{a},$$

where $v = 1.32 \times 10^5$ m/s is taken from the previous problem and the reduced mass is

$$\mu = \frac{Mm}{M+m}.$$

Evaluating this expression yields

$$\boxed{E \approx -1.02 \times 10^{40}\text{ J.}}$$

65. The total mechanical energy of the system is negative, indicating that the binary system is gravitationally bound. This implies the two objects remain in a stable closed orbit unless additional energy is supplied to the system.