Science Olympiad
Golden Gate Invitational

February 11, 2023

Astronomy C

Directions:

- Each team will be given **50 minutes** to complete the test.
- There are four sections: **§A** (General Knowledge), **§B** (Deep-Sky Objects), **§C** (JS9 Image Analysis), and **§D** (Physics).
- All answers must be indicated on your answer document. **Do not write on this exam!**
- For significant figures, **use 3 or more in your answers** unless otherwise specified.
- You may take apart the test, but make sure to staple it back together at the end of the event.
- Tiebreakers, in order: §D, §D1, §D2, §A, §B.
- Best of luck! And may the odds be ever in your favor.

Written by:
Robert Lee, *robertyl@ucla.edu*; **Connor Todd**, *cepheidwatch@gmail.com*
Donna Young, *dlyoung.nso@gmail.com*

Feedback? **Test Code**: *2023GGSO-AstronomyC-Bear*

Section A: General Knowledge

Use the images in Image Set A to answer the following questions. Each multiple choice question is worth 1 point and each multiple select question is worth 2 points, for a total of 30 points.

For multiple select questions, half a point is awarded for each correct option selected and half a point is awarded for each incorrect option not selected.

H-R Diagram The next seven (7) questions are about H-R diagrams. All references to "the diagram" refer to Image A1. Answer questions ending in (A-N) with a single letter from A to N.

1. What value is plotted on the x-axis of the diagram?
   A. Spectral class/type
   B. Frequency of occurrence
   C. Temperature in Kelvin
   D. Temperature in Rankine
2. What value is plotted on the y-axis of the diagram?
   A. Luminosity in solar units
   B. Brightness in lumen
   C. Absolute magnitude
   D. Apparent magnitude
3. Which letter on the diagram best marks the location of a Sun-like star? (A-N)
4. Which letter on the diagram best marks the location of Type II Cepheid variable star? (A-N)
5. Which letter on the diagram represents the largest star by volume? (A-N)
6. Describe the type of variable star characterized by this evolutionary sequence: L, G, J, K, C.
   A. RR Lyrae variable
   B. Cepheid variable
   C. Mira variable
   D. Beta Cephei variable
7. Describe the type of variable star characterized by this evolutionary sequence: A, H, K, off diagram.
   A. R Coronae Borealis variable
   B. Wolf-Rayet star
   C. FU Orionis variable
   D. Pulsar

The Sun's Retirement Plan

The following five (5) questions chronicle the life of a solar-mass star after the main sequence.

8. Right as the star leaves the main sequence, what type of nuclear burning primarily occurs within the star?
    - A. Core hydrogen burning
    - B. Shell hydrogen burning
    - C. Core helium burning
    - D. Shell helium burning

9. Once the helium flash occurs, which direction does the star travel on the H-R diagram?
    - A. Right and up
    - B. Right and down
    - C. Left and up
    - D. Left and down

10. The star passes through the instability strip this many times.
    - A. 0
    - B. 2
    - C. 4
    - D. 6+

11. Eventually this star runs out of energy and ends its life as what degenerate object?
    - A. White dwarf
    - B. Brown dwarf
    - C. Neutron star
    - D. Black hole

12. This object is supported by what force?
    - A. Quark degeneracy pressure
    - B. Proton degeneracy pressure
    - C. Electron degeneracy pressure
    - D. Neutron degeneracy pressure

Energetic Bonanza

For high-mass stars, their end of life plans are much more spectacular with a brilliant display of energy called a supernova. The following four (4) questions relate to the supernovae of these high-mass stars.

13. [2 pts] As high-mass stars age, they fuse heavier and heavier elements. Which element(s) are contained in the inert core prior to a core-collapse supernova? (Select all that apply.)
    - A. Iron
    - B. Cobalt
    - C. Nickel
    - D. Uranium

14. If fusion of iron and heavier elements is an endothermic process, how do the products of such reactions form in a core-collapse supernova?
    - A. At the beginning of the supernova internal pressure exceeds the force of gravity and this excess of energy powers the endothermic fusion reaction.
    - B. The high amount of excess energy and abundance of free neutrons creates a suitable environment for the r-process to occur.
    - C. As elements get heavier, the energy required for its formation decreases until reaching a collection of metastable states which most of the inert core becomes.
    - D. The high pressure and temperature at the stellar core right before the star explodes gives a short window where the p-process is thermodynamically favorable.

15. It is possible that a shockwave ionizes an outer shell of hydrogen, causing it to become opaque. Why does ionization cause opacity?
    A. Photons are absorbed by the free nuclei due to the high binding energy of the strong nuclear force.
    B. Free neutrons are highly stable energy sinks, capable of absorbing even the highest energy photons, forming a thick barrier that light cannot escape.
    C. Exposed protons order themselves in a semi-crystalline structure that naturally reverses the direction of photons.
    D. High density of free electrons are able to reach any energy level, allowing them to absorb all photons.

16. How does this opaque shell affect the observed light curve?
    A. A sharp drop in luminosity occurs right after the hydrogen is ionized.
    B. It creates a plateau effect as energy is slowly released.
    C. It decreases luminosity by a constant factor, significantly reducing the overall energy released.
    D. No significant effects beside a sharp peak in luminosity when the shell cools.

Stellar Fingerprints

The next seven (7) questions are about spectra.

17. What is the primary heat transfer mechanism of a star's energy to an observing telescope?
    A. Emission
    B. Convection
    C. Conduction
    D. Radiation

18. Stars are often approximated to be blackbodies in thermal equilibrium. This means they have an emissivity (ϵ) of what?
    A. 0
    B. 1
    C. ∞
    D. $-\infty$

19. Quinn discovers an A0V and a K7V star located at the same distance and approximates two blackbody spectra. Let their flux be represented as $F_\mathrm{A}(\lambda)$ and $F_\mathrm{K}(\lambda)$ where λ is a particular wavelength. Also let λ_A and λ_K be the peak wavelength of the respective spectra. Which relationship is correct?
    A. $\lambda_\mathrm{A} < \lambda_\mathrm{K}$, $F_\mathrm{A}(1.8\,\mu\mathrm{m}) > F_\mathrm{K}(1.8\,\mu\mathrm{m})$
    B. $\lambda_\mathrm{A} < \lambda_\mathrm{K}$, $F_\mathrm{A}(1.8\,\mu\mathrm{m}) < F_\mathrm{K}(1.8\,\mu\mathrm{m})$
    C. $\lambda_\mathrm{A} > \lambda_\mathrm{K}$, $F_\mathrm{A}(1.8\,\mu\mathrm{m}) > F_\mathrm{K}(1.8\,\mu\mathrm{m})$
    D. $\lambda_\mathrm{A} > \lambda_\mathrm{K}$, $F_\mathrm{A}(1.8\,\mu\mathrm{m}) < F_\mathrm{K}(1.8\,\mu\mathrm{m})$

20. [2 pts] Quinn makes some observations to produce the spectra shown in Image A2 and A3. Which of the following statements are true? (Select all that apply.)
    A. Both spectra closely match their blackbody approximations.
    B. Both spectra contain absorption lines.
    C. The K7V star has a surface temperature of 3500 K.
    D. The A0V star emits at shorter wavelengths than the K7V star.

21. Image A4 shows one series of emission lines of element X, which represents the energy emitted when an electron transitions from one principal quantum number to another. What element is this?

A. Hydrogen
C. Carbon
B. Helium
D. Oxygen

22. How does the emission lines of element X relate to the sudden drop in flux in the UV region?

A. The transitions of element X are not energetic enough to emit photons in the UV region.
B. The assumption that stars act like blackbodies breaks down at high effective temperatures as the emission lines of element X do not extend into short wavelengths.
C. Photons in the UV region are likely to be absorbed as they pass through an element X rich stellar atmosphere.
D. Emission lines are not seen in the A0V spectrum so photons cannot be energized by the electron transitions into the UV region.

23. [2 pts] Your previous answer implies that there should be little UV emission, but a sizable amount is still observed. How can this be reconciled? (Select all that may apply.)

A. The energy of high-energy photons are only partially absorbed in each element X interaction, some may still escape the star.
B. Photons collide and merge together to increase their energy to the UV region.
C. The surface of the star does not emit in the UV emission, but higher energy emission trapped below the surface can still be observed.
D. Other elements in the stellar atmosphere have transitions energetic enough to reach the UV regions.

Big, Blue, and Bright

The next four (4) questions are about luminous blue variables (LBV).

24. The minimum initial mass of a main sequence star that becomes an LBV.

A. $5\,M_\odot$
B. $13\,M_\odot$
C. $17\,M_\odot$
D. $21\,M_\odot$

25. What is the primary observable change required to classify the variability of a star as S Dor?

A. Radius
B. Luminosity
C. Temperature
D. Rotation rate

26. What is the approximate change in magnitude of a giant eruption?

A. 3
B. 5
C. 7
D. 10

27. Image A5 depicts a plot of the gas-phase metallicity of nearby galaxies versus their distance and spatial resolution. Galaxies with LBVs and/or LBV candidates are plotted as red dots, the other galaxies are plotted as blue dots. From this data, would you expect to detect more or less LBVs in metal-poor galaxies as opposed to metal-rich ones?

A. More
B. Less

Section B: Deep-Sky Objects

Use the images in Image Set B to answer the following questions. Unless otherwise specified, each sub-question is worth 1 point, for a total of 70 points.

1. (a) [2 pts] The illustration in Image B17 shows what type of event and what type of energy did this energy produce in addition to radiation?
   (b) What image shows the motions of the energy?
   (c) Which of the following binary objects can coalesce to produce this type of explosion? (Select all that apply.)
   A. Two neutron stars B. Neutron star and white dwarf C. Neutron star and black hole

2. [2 pts] List the three main types of pulsating variable stars in order from the shortest to the longest period.

3. (a) [2 pts] What is the name and type of object in Image B6?
   (b) [2 pts] Which letter on the H-R diagram (Image B1) shows the location of this object and what is the image number of the graph that shows its behavior?
   (c) Due to the massive amount of ejected materials, what is the projected final outcome for this star?

4. (a) [2 pts] What is the name and type of variable star in Image B8?
   (b) [2 pts] What is the name and image number of an object that shows the next evolutionary stage for this star?

5. (a) [2 pts] What effect is shown in the diagram in Image B31 and what can it be used to measure?
   (b) What is the image number of an object that was measured with great accuracy using the method in part (a)?
   (c) [2 pts] What letter on the H-R diagram (Image B1) shows the location of this object? What is the name of the region where this object is located?
   (d) This object is what specific type of variable star?

6. (a) The light curve in Image B22 is specific to what type of object?
   (b) There are two locations within the galaxy where these Population II objects reside. Name one.
   (c) [2 pts] One of the two locations is shown in Image B10. What type of object is it, and what is its name?

7. (a) [2 pts] Image B10 also contains an exotic binary system as illustrated in Image B21. What is the name for this binary and what specific type of binary system is it?
   (b) What is the number of the image that shows an X-ray image of this system?
   (c) What is thought will happen to the least dense object in this system?

8. [2 pts] Image B18 is W Virginis. What type of variable is it, and which of the following letters on the H-R diagram (Image B1) show where W Virginis is located: E, H, or Q.

9. (a) What letters on the H-R diagram (Image B1) show the locations of Long Period Variables (LPVs)?
   (b) [2 pts] The behavior of objects in this region of the H-R diagram is displayed by which light curves?

10. (a) What type of stellar core is shown in Image B3?
    (b) The stream of particles from this object is comprised of what type of material?
    (c) What happened that enabled the particle jet to form?
    (d) [2 pts] Two physical properties of the stellar core allowed the jet to leak into the ISM. What are they?
11. (a) [2 pts] What is the name and image number of a symbiotic variable star?
    (b) This binary system is composed of what two types of objects?
    (c) [2 pts] Which two letters on the H-R diagram (Image B1) show the locations of these two objects?
    (d) The light curve produced by this system is shown in which graph?
    (e) What is the number of the image that shows the observational data in X-rays?
12. (a) Which two images show the optical and X-ray observations of the first ever observation of a supernova witnessed from the very beginning?
    (b) [2 pts] What is the name of this supernova and its type?
13. (a) [2 pts] What is the name of the object in Image B12 and what type of object is it?
    (b) In what way is this object unique from objects of its type?
14. [2 pts] Arrange the following light curves in order of increasing period: Images B22, B23, B24, and B26.
15. [2 pts] Give the letters on the H-R diagram (Image B1) that show the locations of the light curves in Images B22, B23, B24, and B26.
16. (a) The light curve in Image B28 shows the behavior for what type of variability?
    (b) [2 pts] The dynamics that produce this type of behavior are illustrated in Image B19. What type of objects comprise this system and what are the letters that show the the locations of these objects on the H-R diagram (Image B1)?
17. (a) [2 pts] What is the name and type of object in Image B13?
    (b) What makes this type of star unique?
    (c) This type of rare object is usually embedded within a bubble of material. What is the number of the image that includes this bubble?
18. (a) [2 pts] What is the name and image number of an object that is the same type as the object in Image B13?
    (b) What feature of this object is so different from the object in Image B13?
    (c) This feature is thought to have been formed from what type of event?
    (d) Why have so few of these types of objects been observed?
19. (a) The supernova remnant in Image B14 is unique and it is the first of its kind found outside the Milky Way galaxy. What is unusual about its motions?
    (b) What is unusual about the stellar core?

Section C: JS9 Image Analysis

In this section, teams will be called up to demonstrate completion for the exam proctor using the provided JS9 imaging software. Each team will have 5 minutes to complete all questions in Section C, and may send one or both competitors. Each question is worth 2 points, for a total of 20 points.

Section D: Physics

Use the images in Image Set D to answer the following questions. Points are shown for each sub-question, for a total of 50 points.

1. **Box of Assorted Candles**

   A "Standard Candle" may refer to any astronomical object or event which is used by astronomers as a reliable measurement of distances. You identify one such potential light source in the night sky and begin to take measurements in the K-band with a bolometric correction factor of -0.1.

   (a) [5 pts] You take six measurements of the light source over three days and put them into a computer model with a hard-coded visual bolometric correction factor of -0.3, which produces Image D1 as an estimated phase-long light curve (normalized to K-band apparent magnitude). Based on this model, what specific type of object is this source most likely, and what is its distance in pc?

   (b) [5 pts] You configure your observatory to continue periodically measuring the light source in the B-band over the next three months, producing the light curve in Image D2. Based on this new empirical data, what specific type of object is this source most likely, and what is its distance in pc?

   (c) [2 pts] You continue measurements like so for another three months, over which time your observatory suffers a database overwrite. Magnitude data is not periodically backed up, so you are only left with astrometric logs over the last year, indicating that the light source has traversed 0.98 milliarcseconds. Using only this information, estimate the distance to this light source in pc.

   (d) [4 pts] Rank these three distance measurements from least to most reliable as "Standard Candles"' and explain your rankings.

2. **Stellar Business**

   Image D3 depicts the chemical composition of a cool, luminous star with a mean radius of $\sim 190\,R_\odot$.

   (a) [3 pts] What is the approximate mean surface temperature and mean luminosity of this star, in degrees Kelvin and Solar units respectively?

   (b) [2 pts] Image D4 depicts the behavior of this star over almost two months. What type of star is this (be as specific as possible), and how is it unique compared to others of its type?

   (c) [3 pts] Based solely on Image D4, estimate the mean luminosity of this star in Solar units, assuming no bolometric correction factor. Why might this value differ from that of part (a)?

3. **Double Trouble**

Image D5 depicts a landmark produced by a binary system and obtained by LIGO in 2017.

(a) [2 pts] How was this signal produced, and what type of binary system produced it?

(b) [3 pts] By what factor does the orbital separation of this binary system reduce from start of measurement to time of max signal intensity?

(c) [2 pts] What physical process is occurring at max signal intensity, and what parameter of both objects in this binary system defines the initiation of this process?

(d) [5 pts] Given your answer to part (c) above, what is the total mass of the system in Solar units at time of max signal intensity?

(e) [2 pts] Empirical analysis of the signal data following max intensity resulted in a total system mass that differed from the combined mass calculated above by $\sim 2\,\mathrm{M}_\odot$. Which of these values (calculated in part (d) vs. analyzed from signal data) would you expect to be the greater of the two and why?

4. **Walking on Eggshells**

The simplest model of a stellar interior is known as the one-zone model, where a star of mass M, concentrated in a singular point at its center, is surrounded by an infinitesimally-thin shell of mass m of radius R. The interior of the star is filled with a massless gas of pressure P, whose sole purpose is to support the star against the force of its own gravity.

(a) [4 pts] Apply Newton's second law to the one-zone stellar model to derive the equation for hydrostatic equilibrium of the model.

(b) [8 pts] Image D6 depicts three potential modes of radial pulsation in a star, where $\delta r/R$ represents displacement of gas from its equilibrium position at any distance from the star's center r, out to maximum stellar radius R. Let the one-zone stellar model now be a pulsating variable star in the first overtone mode, and derive the star's mean density ρ at the interior point of zero displacement, in terms of only fundamental constants and given values. Let pressure be given as:

$$P(r) = \frac{2}{3}\pi G\rho^2(R^2 - r^2)$$

Partial credit will be granted where accurate work is shown.

Science Olympiad
Golden Gate Invitational
February 11, 2023

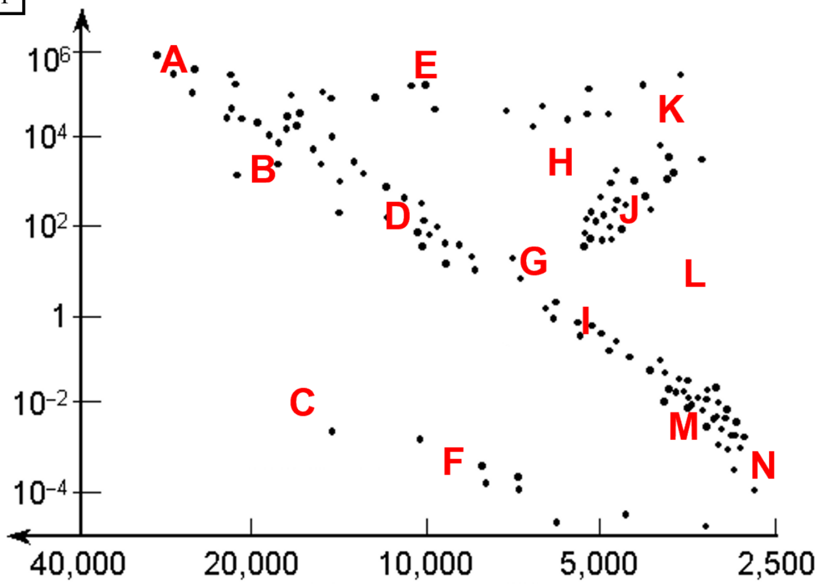
Astronomy C Image Sheet

Directions:

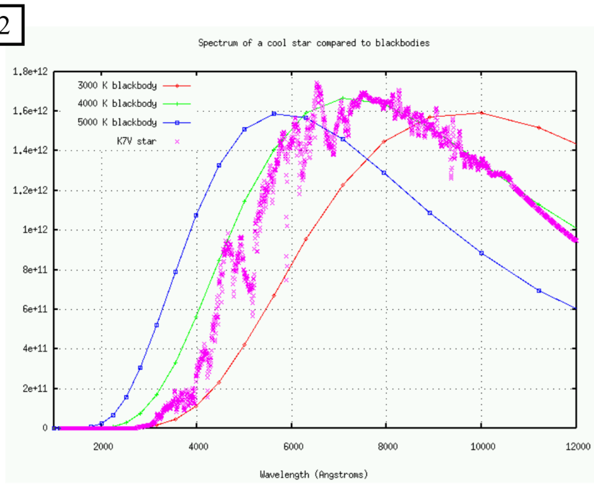
- Do not open until the test begins.

Image Set A

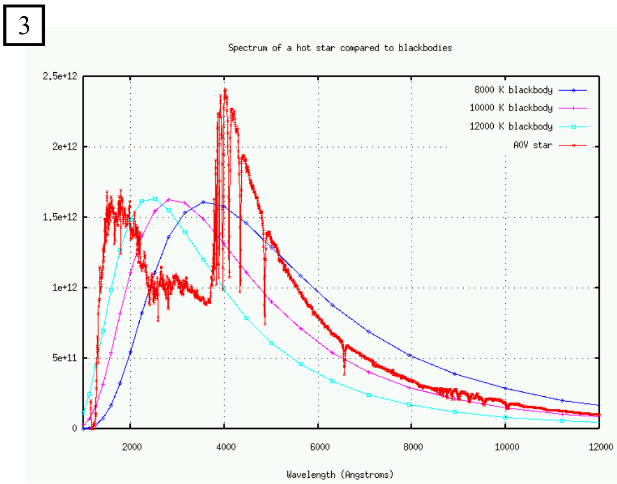
1



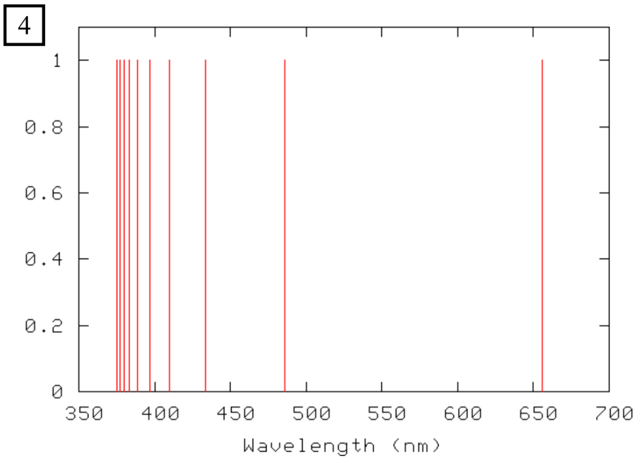
2



3



4



5

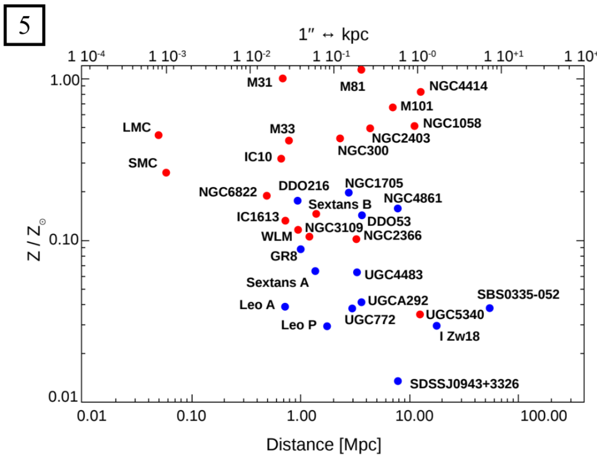
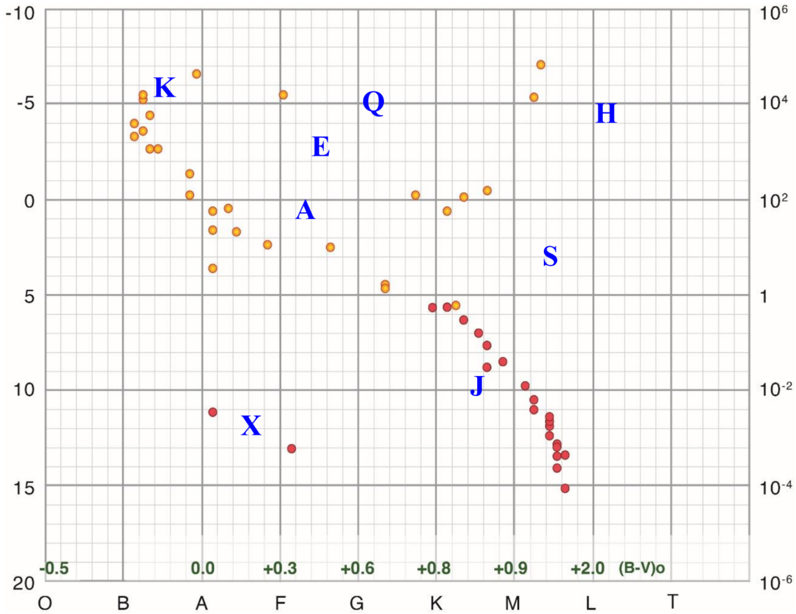
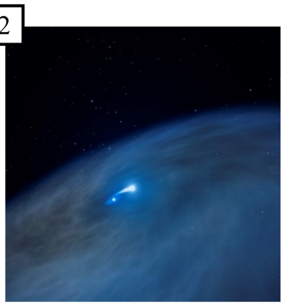


Image Set B (1/3)

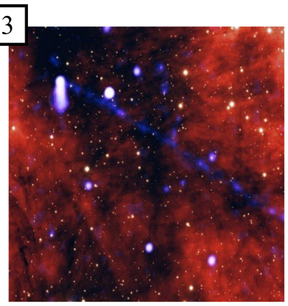
1



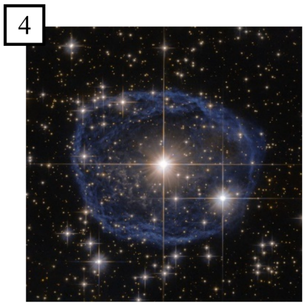
2



3

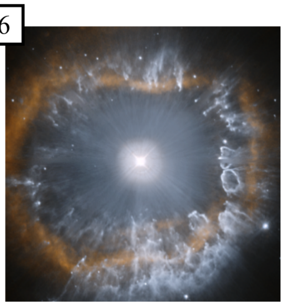


4

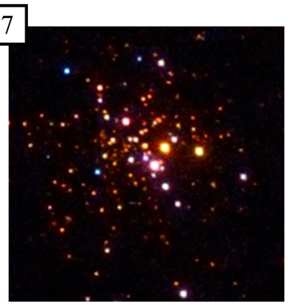


5

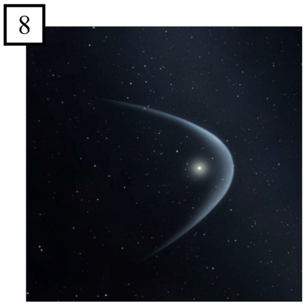
6



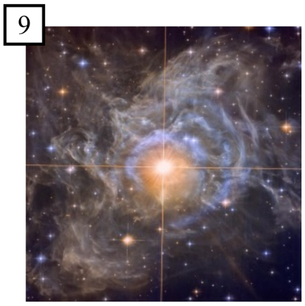
7



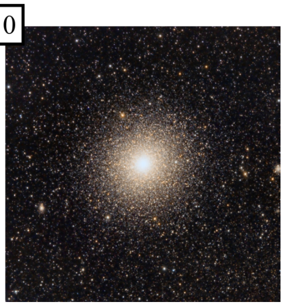
8



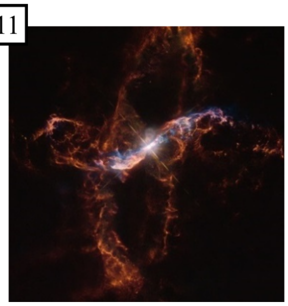
9



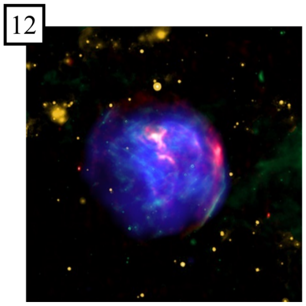
10



11



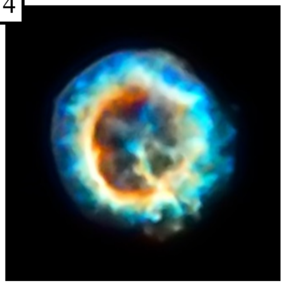
12



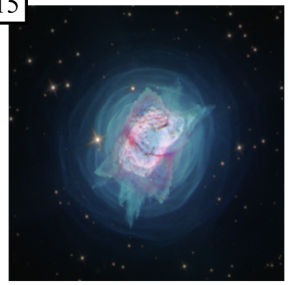
13

Image Set B (2/3)

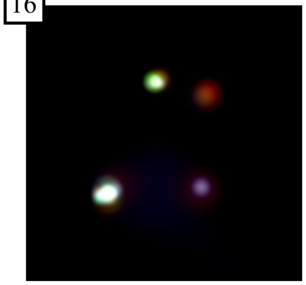
14



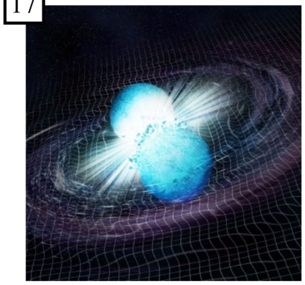
15



16

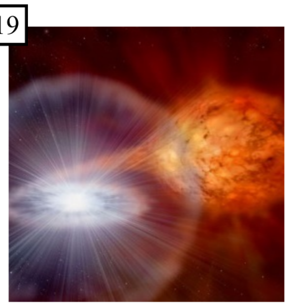


17

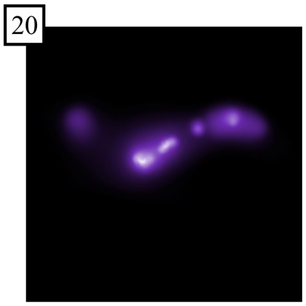


18

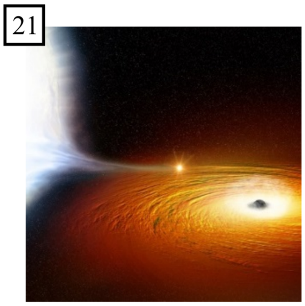
19



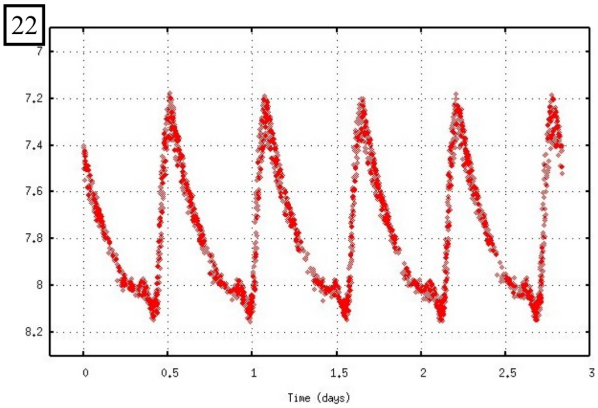
20



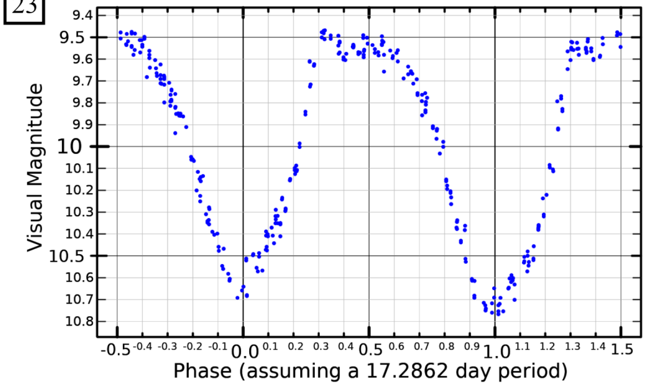
21



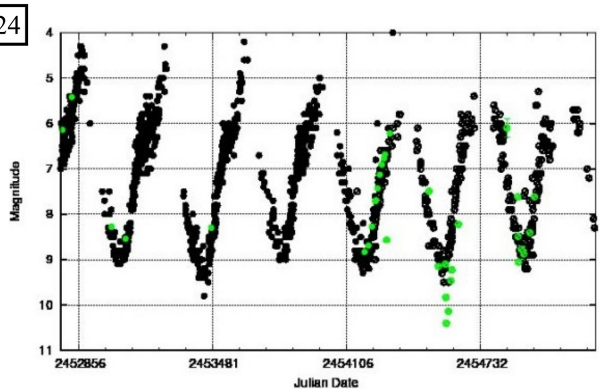
22



23



24



25

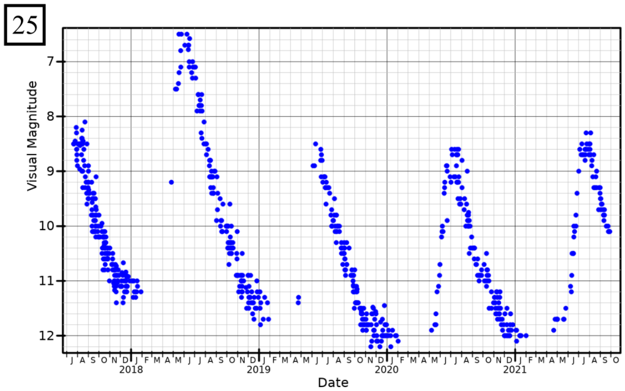
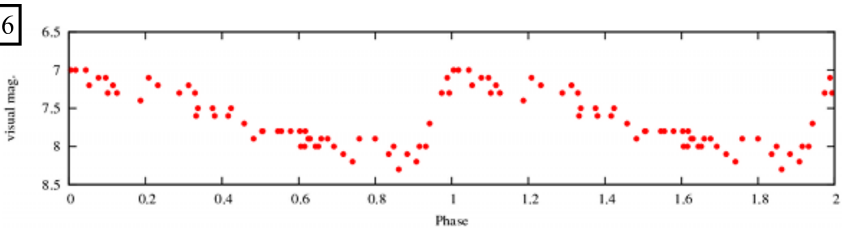


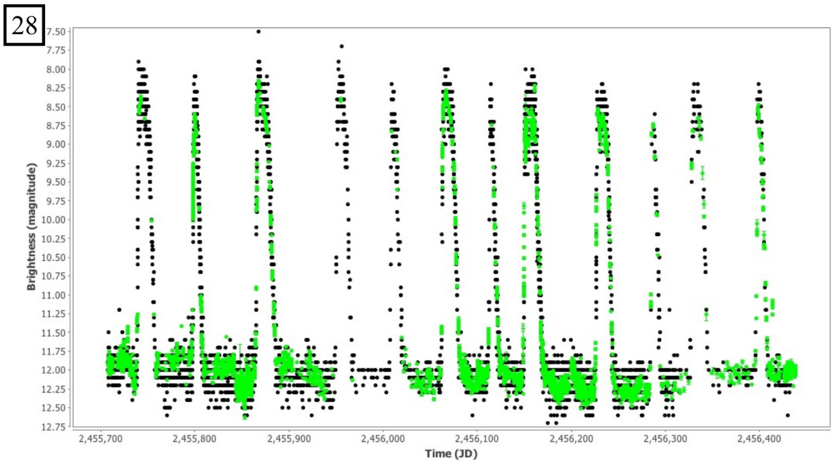
Image Set B (3/3)

26

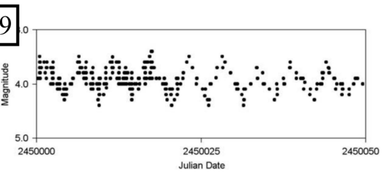


27

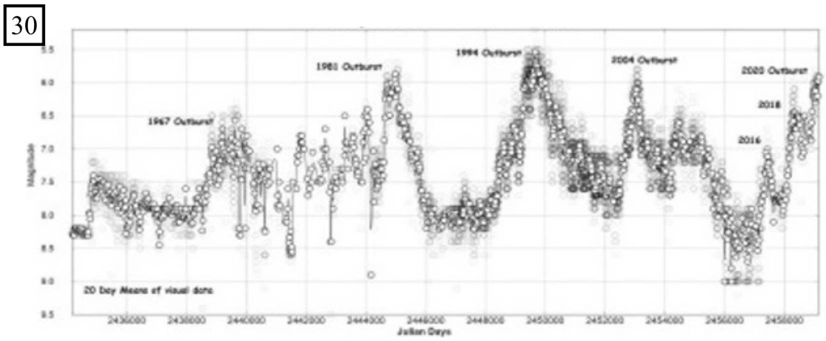
28



29



30



31

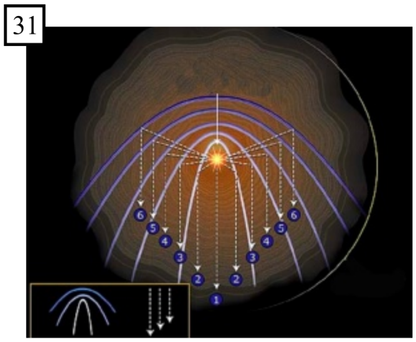
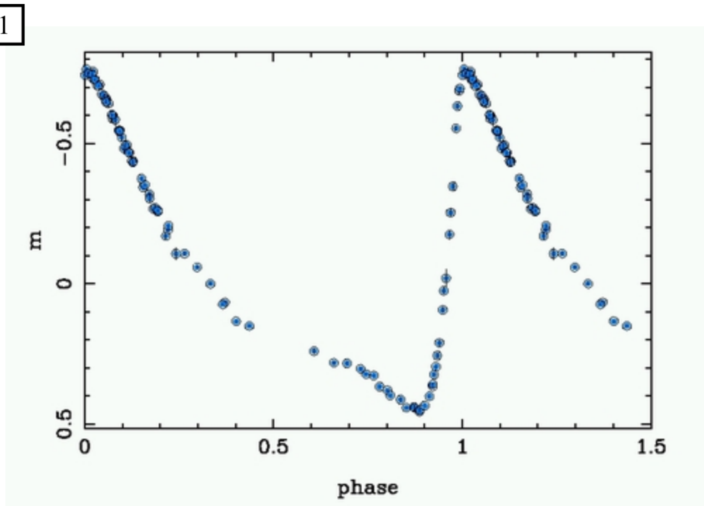
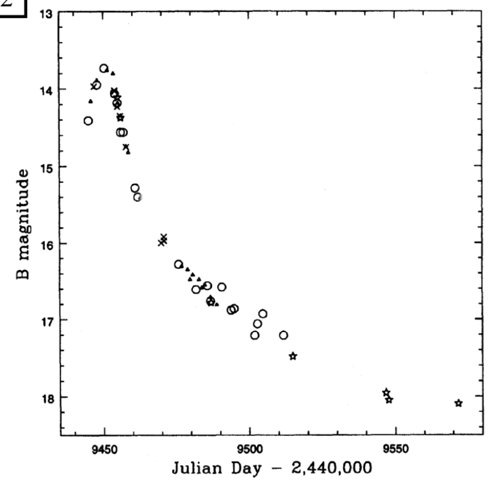


Image Set D

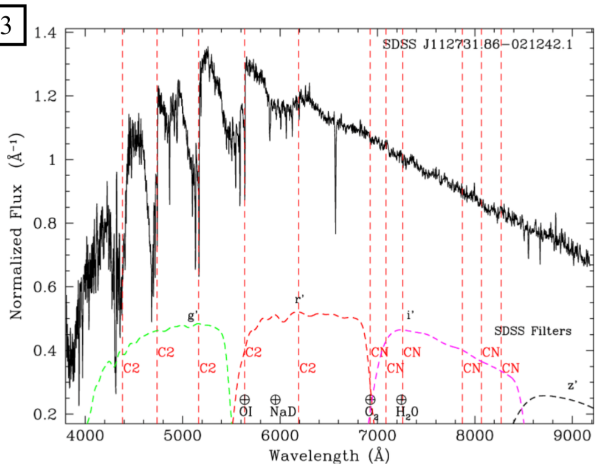
1



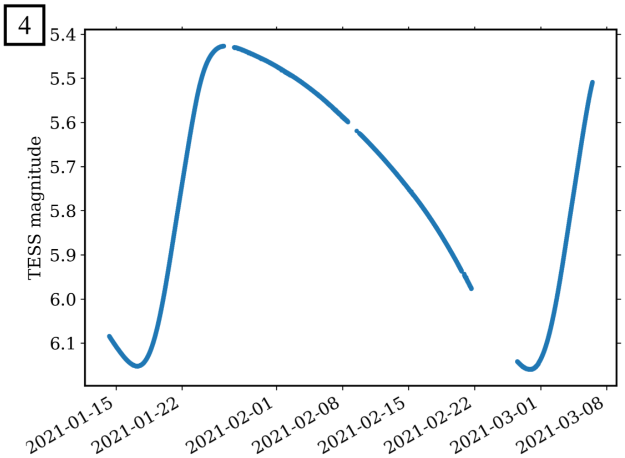
2



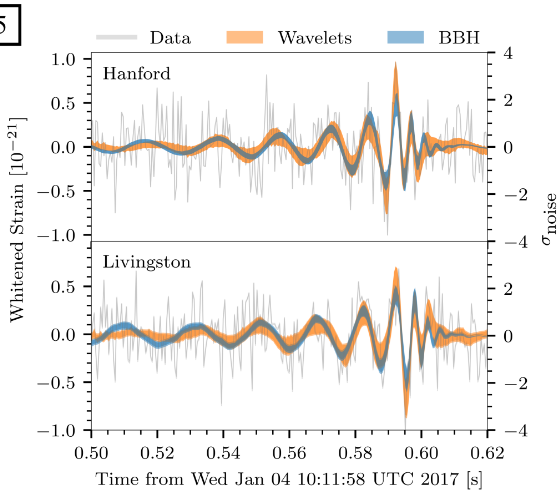
3



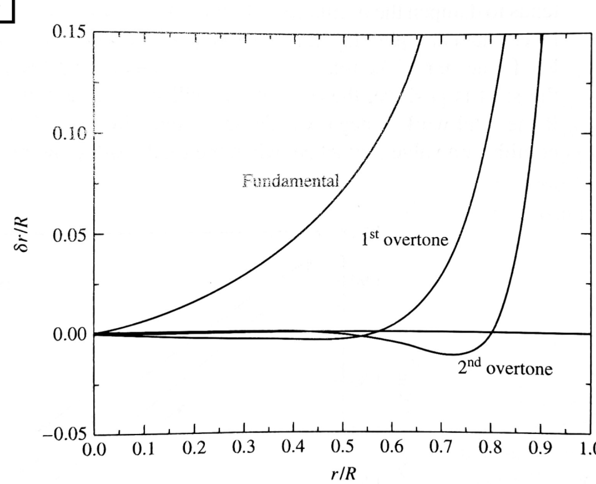
4



5



6



Science Olympiad
Golden Gate Invitational
February 11, 2023

Astronomy C JS9 Image Analysis

Directions:

- Do not open until prompted.

Section C: JS9 Image Analysis

In this section, teams will be called up to demonstrate completion for the exam proctor using the provided JS9 imaging software. Each team will have 5 minutes to complete all questions in Section C, and may send one or both competitors. Each question is worth 2 points, for a total of 20 points.

1. Retrieve the FITS header for the image and report the name of the instrument that captured this image.
2. Identify the PI of the image and the object's coordinates in RA/Dec.
3. Under- and over-saturate the image.
4. Alter the image to grayscale and invert its coloring via biasing.
5. Reset the image to its initial coloring and change the colormap.
6. Apply blurring and inverting filters to the image.
7. Apply linear and power scaling to the colormap.
8. Zoom the fit the image and invert it across the y-axis.
9. Select a circular region of the image and encompass the entire object.
10. Create radial projection and histogram plots of the selected region.

Science Olympiad
Golden Gate Invitational
February 11, 2023

Astronomy C Answer Key

ANSWER KEY ANSWER KEY
ANSWER KEY ANSWER KEY
ANSWER KEY ANSWER KEY
ANSWER KEY ANSWER KEY
ANSWER KEY ANSWER KEY
ANSWER KEY ANSWER KEY
ANSWER KEY ANSWER KEY
ANSWER KEY ANSWER KEY

Section A (30 points)

1. C	2. A	3. I	4. H	5. K
6. A	7. B	8. B	9. D	10. A
11. A	12. C	13. AC	14. B	15. D
16. B	17. D	18. B	19. A	20. BD
21. A	22. C	23. AD	24. D	25. C
26. B	27. B			

Section B (70 points)

1. (a) Kilonova, gravitational wave
   (b) B27
   (c) A and C
2. RR Lyrae, Cepheid, LPV (Mira acceptable)
3. (a) AG Car, LBV or Wolf-Rayet
   (b) K, B30
   (c) Type Ib or Ic supernova
4. (a) R Hydrae, Mira
   (b) NGC 7027 or Jewel Bug nebula, B15
5. (a) It is a light echo and is used to measure distances
   (b) B9
   (c) Q, (Cepheid) instability strip
   (d) Classical Cepheid
6. (a) RR Lyrae
   (b) Galactic bulge or halo
   (c) Globular cluster, 47 Tuc
7. (a) X-9, X-ray binary
   (b) B7
   (c) Evaporate or form exotic planet
8. Type II Cepheid (W Virginis not accepted), E
9. (a) H, S
   (b) B24, B25, B29 (+0.5 for all 3)
10. (a) Gamma ray pulsar (pulsar acceptable)
    (b) Antimatter or positrons
    (c) The bow wave stalled
    (d) Rapid rate of rotation and strong magnetic field
11. (a) R Aquarii, B11
    (b) Red giant or Mira variable, white dwarf
    (c) S, X
    (d) B25
    (e) B20
12. (a) B5, B16
    (b) SN2008D, Type Ibc
13. (a) G344.7-0.1, Type Ia supernova or SNR
    (b) It is older and the shock wave has had time to travel through the entire shock wave, allowing study of a latter phase of Type Ia evolution.
14. B22, B23, B26, B24
15. A, E, Q, S
16. (a) Dwarf nova
    (b) White dwarf, X, red dwarf, J
17. (a) Campbell's star (HD 184738), Wolf-Rayet or WC
    (b) Mass ejections and strong stellar winds (unusual spectra, low H)
    (c) B4
18. (a) NaSt1, B2
    (b) 2 trillion-mile disk
    (c) NaST1 had a companion star
    (d) Transient, evolves rapidly and only last ~100,000 years
19. (a) A small ring of gas is moving more slowly than the shockwave
    (b) It is an isolated neutron star with a low magnetic field offset from center

Section D (50 points)

1. (a) RR Lyrae; $d \in [6.76, 7.76]$ pc
   (b) Type Ia SN; $d \in [3.63, 36.3] \times 10^6$ pc
   (c) $d = 2.04 \times 10^5$ pc
   (d) Method A is least reliable (based on minimal modeled data and improper BC for a strong-IR object);
   Method B better but not great (parallax inaccurate at angles < 10 mas);
   Method C best (most data, longest observation time).

2. (a) $T \in [5200, 5700]$ K; $L_{\text{avg}} \in [2.3, 3.4] \times 10^4$ $L_\odot$
   (b) Classical (or Type I) Cepheid variable, with an unusually long period
   (c) $L_{\text{avg}} \in [1.1, 1.6] \times 10^4$ $L_\odot$; likely an underestimate, because it assumes star spends equal amount of time at high- and low-luminosity, when actually it spends proportionally more of a single phase on the higher end of its luminosity

3. (a) Produced via gravitational wave detection by a double black hole binary
   (b) $[2.44, 3.03]$
   (c) Max intensity at point of black hole merge event, defined by meeting of Schwarzschild radii
   (d) $[48.3, 53.4]$ $M_\odot$
   (e) Expect the calculated one in part (d) to be greater, since the signal data includes loss of system mass due to conversion to gravitational wave energy

4. (a) $\frac{GMm}{R^2} = 4\pi R^2 P$

(b) Gravitational Force [2 pts]:

$$M(r) = \frac{4}{3}\pi r^3 \rho$$
$$F_{\text{grav}}(r) = \frac{GM(r)m}{r^2}$$

Pressure Force [2 pts]:

$$P(r) = \frac{2}{3}\pi G\rho^2 (R^2 - r^2)$$
$$F_{\text{pres}}(r) = 4\pi r^2 P(r)$$

Read Image D6 and let $r = 0.6R$ [1 pt].

Hydrostatic Equilibrium [1 pt]:

$$F_{\text{grav}}(r) = F_{\text{pres}}(r)$$

Substitute $r = 0.6R$ and Simplify [1 pt]:

$$\begin{aligned} F_{\text{grav}}(r) &= \frac{GM(r)m}{r^2} \\ &= \frac{Gm}{r^2}\left[\frac{4}{3}\pi r^3 \rho\right] \\ &= \frac{4}{3}\pi Gmr\rho \\ &= \frac{4}{3}\pi Gm(0.6R)\rho \\ F_{\text{pres}}(r) &= 4\pi r^2 P(r) \\ &= 4\pi r^2 \left[\frac{2}{3}\pi G\rho^2 (R^2 - r^2)\right] \\ &= \frac{8}{3}\pi^2 G\rho^2 (r^2R^2 - r^4) \\ &= \frac{8}{3}\pi^2 G\rho^2 (0.2304R^4) \end{aligned}$$

Substitute and Solve for ρ [1 pt]:

$$\frac{4}{3}\pi Gm(0.6R)\rho = \frac{8}{3}\pi^2 G\rho^2 (0.2304R^4) \implies 0.6m = 2\pi\rho(0.2304R^3)$$
$$\implies \rho = \frac{0.6m}{2\pi(0.2304R^3)} = \frac{1.3m}{\pi R^3}$$

Science Olympiad
Golden Gate Invitational
February 11, 2023

Astronomy C Answer Sheet

Team Name and Number: ______________________________

Participant Name(s): ______________________________

Total Score: ____ / **170** **Rank:** ____

Directions:

- Read the directions on the test cover.

Section A (30 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. ________

Section B (70 points)

1. (a) ____
   (b) ____
   (c) ____
2. ____
3. (a) ____
   (b) ____
   (c) ____
4. (a) ____
   (b) ____
5. (a) ____
   ____
   (b) ____
   (c) ____
   (d) ____
6. (a) ____
   (b) ____
   (c) ____
7. (a) ____
   (b) ____
   (c) ____
8. ____
9. (a) ____
   (b) ____
10. (a) ____
    (b) ____
    (c) ____
    ____
    (d) ____
    ____
11. (a) ____
    (b) ____
    (c) ____
    (d) ____
    (e) ____
12. (a) ____
    (b) ____
13. (a) ____
    (b) ____
    ____
    ____
    ____
14. ____
15. ____
16. (a) ____
    (b) ____
17. (a) ____
    (b) ____
    ____
    (c) ____
18. (a) ____
    (b) ____
    (c) ____
    (d) ____
    ____
19. (a) ____
    ____
    (b) ____
    ____

Section C (20 points)

THIS SECTION IS TO BE COMPLETED BY YOUR EVENT SUPERVISOR

1. Complete? ☐ Yes ☐ Partial ☐ No
2. Complete? ☐ Yes ☐ Partial ☐ No
3. Complete? ☐ Yes ☐ Partial ☐ No
4. Complete? ☐ Yes ☐ Partial ☐ No
5. Complete? ☐ Yes ☐ Partial ☐ No
6. Complete? ☐ Yes ☐ Partial ☐ No
7. Complete? ☐ Yes ☐ Partial ☐ No
8. Complete? ☐ Yes ☐ Partial ☐ No
9. Complete? ☐ Yes ☐ Partial ☐ No
10. Complete? ☐ Yes ☐ Partial ☐ No

Section D (50 points)

1. (a) ______ ______ pc
   (b) ______ ______ pc
   (c) ______ pc
   (d) ______

2. (a) ______ K ______ $L_\odot$
   (b) ______
   (c) ______ $L_\odot$ ______

3. (a) ______
   (b) ______
   (c) ______
   (d) ______ $M_\odot$
   (e) ______

4. (a) (b)