Science Olympiad
Astronomy C
UT Invitational
October 30, 2021

Directions:

- Each team will be given 50 minutes to complete the test.
- There are three sections: §A (General Knowledge), §B (Deep-Sky Objects), and §C (Calculations).
- For significant figures, use 3 or more in your answers unless otherwise specified.
- Tiebreakers, in order: §C, §C1, §A, §B1, ..., §B10.
- Best of luck! And may the odds be ever in your favor.

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Feedback? Test Code: 2022UT-AstronomyC-Pulse
Section A: General Knowledge
Points are shown for each question or sub-question, for a total of 40 points.

1. [2 pts] Which of the following are we not in?
   A. Solar System
   B. Andromeda Galaxy
   C. Local group
   D. Virgo Supercluster
   E. The Universe

2. [2 pts] Star X is found to be dimmer than star Y. If they are the same distance away, which of the following must be true about the two stars.
   A. Star X is cooler than Star Y
   B. Star Y is bigger than X
   C. Star Y emits more total energy than star X
   D. Star Y is a red giant while star X is a main sequence star
   E. None of the above

3. [2 pts] What defines a main sequence star?
   A. The ability to maintain hydrostatic equilibrium (i.e. outward pressure balances gravity)
   B. The Kelvin-Helmholtz mechanism occurring within the star’s core
   C. The star is powered primarily by fusing Hydrogen into Helium
   D. It is an average star, with mass similar to that of the sun
   E. None of the above

4. [2 pts] A star is projected to have a main sequence lifetime of 15 billion years. What is the most likely object to be left behind after it “dies”?
   A. Proto-planetary disk
   B. White dwarf
   C. Neutron star
   D. Black hole
   E. None of the above

5. [2 pts] On a Hertzsprung-Russell diagram, star A is located below and to the left of star T. Given only this information, select all the following statements that are true. Write “none” if none of the statements are true.
   A. We can determine which star is hotter
   B. We can determine which star is more luminous
   C. We can determine which star is older
   D. We can determine which star is more massive
   E. We can determine which star is bigger

6. [2 pts] Why are protostars difficult to observe in visible light?
   A. They only exist as protostars for a short period of their life
   B. They are cool(er than many other stars), and so emit primarily infrared
   C. Gas and dust surrounding young stars block our view
   D. All of the above
   E. None of the above

7. [2 pts] How are T Tauri stars primarily powered?
   A. Conversion of potential energy due to gravitational collapse
   B. Fusion of Hydrogen into Helium
   C. Fission of heavy elements produced by previous supernovae
   D. Hot accretion disks
   E. None of the above
8. [2 pts] Which of the following is likely to either go supernova or be the result of a supernova? **Select all that apply.** Write “none” if none of the options apply.
   A. The sun
   B. A solitary white dwarf
   C. A planetary nebula
   D. An RR Lyrae star
   E. A star that has existed since the birth of the Milky Way

9. [2 pts] The most important defining characteristic of a star is:
   A. Temperature
   B. Volume
   C. Composition
   D. Mass
   E. None of the above

10. [2 pts] Neutron stars are kept from collapse via:
    A. Outwards pressure from fusion
    B. Outward force from magnetic field
    C. Electron degeneracy pressure
    D. Rotating fast enough. (If the neutron star wasn’t spinning, it would collapse)
    E. None of the above

11. [2 pts] You observe a spectrum of a star and notice strong hydrogen lines and neutral lines tend to be weaker than their ionized counterparts. Which class of star is this most likely to be?
    A. O
    B. A
    C. F
    D. M
    E. None of the above


13. T Coronae Borealis

   T Coronae Borealis is a recurrent nova (one of less than a dozen known!). It has been found to consist of a red giant and a white dwarf accreting matter from the red giant.
   (a) [3 pts] What is a recurrent nova?
   (b) [3 pts] Prior to 2016 (and after 1946), T CrB was in its quiescent state. What does this mean?
   (c) [5 pts] During the quiescent state, which part of T CrB do you expect to dominate in visible light? Which part do you expect to dominate in X-ray? (Explain your reasoning).
   (d) [4 pts] Does your answer change when T CrB is not in its quiescent state? (Again, explain your reasoning.)
Section B: Deep-Sky Objects

Use the images in Image Set B to answer the following questions. Points are shown for each question or sub-question, for a total of 60 points.

1. (a) [1 pt] What object is shown in image B2?
   (b) [2 pts] This image is taken in what wavelength and by what telescope?
   (c) [2 pts] What specific feature of the object is shown?

2. (a) [2 pts] What type of system is ASASSN-16oh and what does it consist of?
   (b) [1 pt] What does ASASSN stand for?
   (c) [1 pt] What notable type of light was detected from ASASSN-16oh?
   (d) [2 pts] List the telescopes used to detect this.

3. (a) [1 pt] Image B9 contains which object?
   (b) [1 pt] What is the spectral type and luminosity type of the object?
   (c) [2 pts] What type of variable star is the object?

4. (a) [1 pt] RR Lyrae is a star that changes brightness, also known as a ________ star.
   (b) [2 pts] What is the physical process behind this change in brightness?
   (c) [2 pts] Two properties in the star are normally inversely related. However, the physical process in part b requires the two properties to be directly related. What are the two properties?
   (d) [4 pts] Explain why the two properties must be directly related for changes in brightness to occur.

5. (a) [1 pt] Name the object in image B5.
   (b) [1 pt] What telescope took the image?
   (c) [1 pt] What is the spectral type of the central star?

6. (a) [1 pt] What does the HH in HH 24-26 stand for?
   (b) [2 pts] Define collimated.
   (c) [2 pts] Using the word collimated, briefly explain how HH objects form.
   (d) [2 pts] Why are collimated stellar ejecta generally observed far away from its progenitor star?

7. (a) [1 pt] Name the object seen in image B7.
   (b) [2 pts] Give the reason for the missing outer arc segment.
   (c) [1 pt] One refuted hypothesis is that the dark nebula the object resides in blocks the arc. What is the name of the dark nebula?
   (d) [3 pts] What piece of evidence refuted the hypothesis in part c?

8. (a) [2 pts] Which image(s) depict HOPS 383?
   (b) [1 pt] What does HOPS stand for?
   (c) [1 pt] By what factor did the 24μm flux increase from 2004-2008?
   (d) [4 pts] One alternative reason for this rise in flux would be the removal of a large amount of extinction. Explain how this can be ruled out.

9. (a) [1 pt] Image B4 shows what object?
   (b) [1 pt] What type of object is it?
   (c) [1 pt] How far is this object located, in pc?

10. (a) [1 pt] Which image shows the constellation V Sagittae resides in?
    (b) [2 pts] What information is shown in image B6?
    (c) [3 pts] Describe the trend of the data and what it implies.
    (d) [2 pts] How does our conclusion from part c support the claim that V Sagittae is inspiraling very fast?
Section C: Calculations

Use the images in Image Set C to answer the following questions. Points are shown for each question or sub-question, for a total of 70 points.

1. A Well-Known Variable

   (a) [2 pts] The Bayer designation of the circled star in image C1 is ____________.

   Stars of the class of variable stars this star belongs to are used as standard candles because their period of pulsation is strongly correlated with their luminosity, a relationship discovered by astronomer Henrietta Swan Leavitt. The relationship is given below, where $M_V$ is the mean visual absolute magnitude and $P$ is the period in days:

   $$M_V = (-2.43 \pm 0.12)(\log_{10} P - 1) - (4.05 \pm 0.02)$$

   (b) [2 pts] This star belongs to which class of variable stars?
   
   A. T Tauri variable
   B. Classical Cepheid
   C. Type II Cepheid
   D. Mira variable
   E. RR Lyrae variable

   Image C2 is a light curve of this star, with apparent magnitude on the y-axis and time in days on the x-axis.

   (c) [2 pts] Compute the star’s mean visual absolute magnitude.
   
   A. -3.4
   B. -3.7
   C. -4.0
   D. -4.3
   E. -4.6

   (d) [2 pts] Compute the star’s distance from Earth. (This star is a standard candle!)
   
   A. 300 pc
   B. 350 pc
   C. 400 pc
   D. 450 pc
   E. 500 pc

   (e) [2 pts] Compute the star’s range in luminosity.
   
   A. 800 – 1400 L⊙
   B. 400 – 1800 L⊙
   C. 1800 – 2400 L⊙
   D. 1400 – 2800 L⊙
   E. 3000 – 4000 L⊙

   (f) [2 pts] These types of variables are driven by pulsation. When the star expands outward, the temperature:
   
   A. Decreases
   B. Stays the same
   C. Increases

   (g) [2 pts] And the luminosity of the star:
   
   A. Decreases
   B. Stays the same
   C. Increases

   (h) [2 pts] Spectroscopic measurements indicate that the peak temperature shifts from around 450 nm to 530 nm across one period. What is the approximate temperature range of this star?
   
   A. 2500 – 3500 K
   B. 3500 – 4500 K
   C. 4500 – 5500 K
   D. 5500 – 6500 K
   E. 6500 – 7500 K

   (i) [4 pts] Use this information to calculate the minimum and maximum radius of this star across one pulsation cycle, in Rsolar.
2. The Density of Compact Objects

It is well known that white dwarfs and neutron stars are very dense. But how dense is very dense?

(a) [2 pts] White dwarfs are the degenerate cores of what type of star?

(b) [2 pts] What force or pressure prevents normal main sequence stars from collapsing in on themselves?

(c) [2 pts] What force or pressure prevents white dwarf stars from collapsing in on themselves? What is the quantum mechanics principle behind this force?

(d) [2 pts] White dwarfs typically have masses around 1 solar mass packed in a radius around 1 Earth radius. Use this to estimate the typical density of a white dwarf, in kg m$^{-3}$.

(e) [2 pts] How much would one teaspoon (5 mL) of white dwarf weigh, in kg?

(f) [2 pts] Neutron stars typically have masses around the Chandrasekhar limit packed in a radius the size of a small city (10 km). Use this to estimate the typical density of a neutron star, in kg.

(g) [2 pts] How much would one tablespoon (15 mL) of a neutron star weigh, in kg?

To give a sense of scale, a large car weighs around 2000 kg, and Mt. Everest weighs around $1.6 \times 10^{13}$ kg.

Are black holes dense? Intuitively, one might think that black holes are even denser than white dwarfs and neutron stars, but are they really? Consider two classes of black holes: stellar mass black holes and supermassive black holes.

(h) [2 pts] Cygnus X-1, the first confirmed stellar mass black hole, has a mass of 21.2 solar masses. Use this to calculate its Schwarzschild radius, in m.

(i) [3 pts] Calculate the density of Cygnus X-1, in kg m$^{-3}$, assuming its mass is confined within the event horizon. Is this more or less dense than a typical neutron star?

(j) [2 pts] On the other hand, the supermassive black hole at the center of the Milky Way (called Sagittarius A*) has weighs a whopping 4.1 million solar masses. Calculate its Schwarzschild radius, in m.

(k) [3 pts] Calculate the density of Cygnus X-1, in kg m$^{-3}$. Is this more or less dense than a typical neutron star? What about a white dwarf? Water?

(l) [3 pts] In general, how does the density of a black hole scale with its mass?

(m) [3 pts] Is it possible for a black hole to have the density of water? If so, what would be the mass of this black hole, in solar masses?
3. **The Proton-Proton Chain**

In this problem, we’ll investigate the proton-proton chain — an important nuclear fusion process necessary to sustain Sun-like stars on the main sequence. In reality, the proton-proton chain consists of multiple steps, but we’ll just consider one overall reaction. The mass of a proton, neutron, and α particle is 1.00728, 1.00866, 4.00153 amu respectively.

(a) [3 pts] Assuming hydrogen nuclei and free electrons are available as reactants, write down the fusion reaction that produces an α (He-4) nucleus.

(b) [3 pts] Compute the energy released by this reaction, in MeV.

(c) [3 pts] How many reactions per second would need to occur in the Sun’s interior to sustain its current luminosity?

(d) [3 pts] Supposing that the Sun’s mass is 90% hydrogen, compute derive a rough estimate for the time the Sun can spend on the main sequence, in Gyr. (In reality, only a small fraction of the hydrogen is usable for proton-proton fusion.)

(e) [2 pts] The answer you derived is about an order of magnitude larger than the estimated main-sequence lifetime of the Sun. Give one reason why.

(f) [4 pts] Consider the system of two hydrogen nuclei fusing. Estimate the temperature at which the kinetic energy of the nuclei would be sufficient to overcome their Coulomb repulsion, in K.

(g) [2 pts] The Sun’s core temperature is actually about $10^7$ K, but nuclear fusion is still a viable source of energy. What phenomenon allows fusion to still occur?
Image Set B
Section A (40 points)

1. 

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10. 

11. 

12. 

13. (a) 

   (b) 

   (c) 

   (d)
**Section B (60 points)**

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Section C (70 points)

1. (a) 
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(d) 
(e) 
(f) 
(g) 
(h) 
(i) 

2. (a) 
(b) 
(c) 
(d) kg m$^{-3}$ 
(e) kg 
(f) kg m$^{-3}$ 
(g) kg 
(h) m 
(i) kg m$^{-3}$ 
(j) m 
(k) kg m$^{-3}$ 
(l) 
(m) M$_{\odot}$ 

3. (a) 
(b) MeV 
(c) reactions per second 
(d) Gyr 
(e) 
(f) K 
(g) 

3
Section A (40 points)

1. B
2. C
3. C
4. B
5. ABE
6. D
7. A
8. None
9. D
10. E
11. C
12. OBAFGKM
13. (a) An object that has been observed to experience at least two nova eruptions  
    (b) T CrB was emitting energy at the rate it normally does (between nova eruptions)  
    (c) Since the red giant is cooler (but also much bigger), it will likely dominate in the visible range  
        [1.5 pts]. Accretion disks are significantly hotter, so the accretion disk/white dwarf part should  
        dominate the X-ray range [1.5 pts]. (Wein’s Law tells us that temperature is inversely proportional  
        to the wavelength an object most strongly radiates in [2 pts].)  
    (d) Yes [1 pt]. The nova eruptions are caused by the white dwarf/accretion disk part of the system,  
        and increase the overall luminosity by a few orders of magnitude; so, the white dwarf/accretion disk  
        part has completely dominated the entirety of the spectrum during the nova eruptions [3 pts].
Section B (60 points)

1. (a) IC 4593
   (b) X-ray, Chandra
   (c) Bubble of hot gas

2. (a) Binary system, white dwarf and (lobe-filling) companion star
   (b) All-Sky Automated Survey for Supernovae
   (c) Supersoft x-rays
   (d) Chandra, Swift

3. (a) Alpha Tauri
   (b) K5III
   (c) Slow irregular, LB

4. (a) Variable
   (b) Kappa-mechanism
   (c) Temperature and opacity
   (d) Normally, an increase in temperature causes a decrease in opacity of the atmosphere, thus allowing more energy to escape. However, an increase in both temperature and opacity creates a build-up of pressure forcing the star to periodically expand and contract.

5. (a) U Antliae
   (b) ALMA
   (c) C-N3

6. (a) Herbig-Haro
   (b) Moving in the same direction
   (c) Collision of collimated ejecta
   (d) Only material moving together in the same direction stay together over long distances

7. (a) V1331 Cyg
   (b) Shadowing from circumstellar disk
   (c) LDN 981
   (d) Extinction analysis showed that the cloud is behind the star and the dark cloud has weak surface brightness

8. (a) Image B1 and B3
   (b) Herschel Orion Protostar Survey
   (c) 35
   (d) Implausible extinction reduction of 70 (column density of $1.3 \times 10^{23} \text{cm}^{-2}$). Increase at submillimeter wavelengths correlates with increase in envelope temperature from more heating.

9. (a) LP 40-365
   (b) White dwarf
   (c) 632 (half credit for 300)

10. (a) Image B12
    (b) Observed minus calculated of its orbit period
    (c) Concave-down parabola implies that its orbit period is decreasing at a constant rate
    (d) From Kepler’s Third Law, if orbit period decreases, then binary separation decreases, which implies in-spiraling.
Section C (70 points)

1. (a) $\delta$ Cephei
   (b) B
   (c) A
   (d) A
   (e) D
   (f) A
   (g) C
   (h) D
   (i) $30 R_\odot$ at minimum brightness and $58 R_\odot$ at peak brightness

2. (a) Red giant (also accept $< 8 M_\odot$ star)
   (b) Thermal pressure and radiation pressure
   (c) Electron degeneracy pressure
   (d) $2 \times 10^9$ kg m$^{-3}$
   (e) 9000 kg
   (f) $7 \times 10^{17}$ kg m$^{-3}$
   (g) $10^{13}$ kg
   (h) 3125 m
   (i) $3.3 \times 10^{17}$ kg m$^{-3}$, less dense
   (j) $1.2 \times 10^{10}$ m
   (k) $8.8 \times 10^{6}$ kg m$^{-3}$, much less dense than all three
   (l) Proportional to $1/M^2$
   (m) $4 \times 10^8 M_\odot$

3. (a) $4H_1^1 + 2\beta_{01} \rightarrow He_2^2 + 2\nu_e$ (Neutrinos $\nu_e$ not necessary for full credit)
   (b) 26.7 MeV
   (c) $9 \times 10^{37}$ reactions per second
   (d) 95 Gyr
   (e) Not all of the hydrogen in the entire Sun goes towards proton-proton fusion
   (f) $10^{10}$ K
   (g) Quantum tunneling