# Astronomy C

## UT Regional, Spring 2018

**Contact: Dhruva Karkada**, *dkarkada@gmail.com*

**Competitors:** ______________________________

**School Name:** ______________________________

**Team Number:** ______________________________

This test contains 5 sections, cumulatively worth 150 points. As always, you'll have 50 minutes to complete the test. You may separate the pages; be sure to put your team number at the top of every page. Don't feel obligated to write in complete sentences; your priority is to get all your ideas on paper quickly. No wifi allowed, etc. etc. Tiebreakers are: a) highest score in part 1, b) highest score in part 4, c) best handwriting.

Good Luck, Have Fun! And always remember: The Eyes of Texas Are Upon You!

---

| Page: | 1 | 2 | 3 | 4 | 5 | 6 | 8 | Total |
|---|---|---|---|---|---|---|---|---|
| Points: | 30 | 20 | 20 | 25 | 5 | 30 | 20 | 150 |
| Score: | | | | | | | | |

**PART I: Deep Sky Objects.** 30 points (2 each). Matching. Each choice might be used 0, 1, or more times. :–)

| | | | | | |
|---|---|---|---|---|---|
| **A** | RCW 103 | **B** | Pinwheel Galaxy | **C** | J0617 |
| **D** | SN 1987A | **E** | 1E 161348-5055 | **F** | The Sun |
| **G** | Betelgeuse | **H** | M82 | **I** | Pluto |
| **J** | HR 5171 | **K** | $\sigma$ Oris | **L** | Stringray Nebula |
| **M** | J3429 | **N** | S Doradus | **O** | W49B |
| **P** | ASASSN-15lh | **Q** | Circinus X-1 | **R** | Andromeda Galaxy |
| **S** | M31 | **T** | Jellyfish Nebula | **U** | HD 6542 |
| **V** | M82 X-2 | **W** | GSJ 3.375-7 | **X** | None of the above |

1. **E** The slowest spinning neutron star ever observed.
2. **C** The pulsar at the center of the Jellyfish Nebula.
3. **J** Light curve analysis of this DSO suggests the existence of a contact binary.
4. **Q** Observing light echoes led to a more accurate distance measurement of this DSO.
5. **A** In June 2016, the Burst Alert Telescope onboard *Swift* detected a short x-ray burst originating in the direction of this supernova remnant.
6. **V** A pulsar, 12 million lightyears away, which exceeds the Eddington limit.
7. **O** An assymetric SNR, likely caused by a jet-driven core-collapse SN.
8. **G** A star located in the same constellation as Bellatrix, Rigel, and M42.
9. **T** The SNR depicted in Figure 1.
10. **H** The galaxy containing an ultraluminous X-ray source (ULX).
11. **Q** This X-ray binary is 30,700 lightyears away.
12. **P** A possible explanation for this bright event is a tidal disruption by a supermassive black hole.
13. **J** Contains a perturbing binary companion which may cause YHG outbursts.
14. **X** An example of an H II region.
15. **O** Contains possibly the youngest black hole in the Milky Way.

**PART II: Case Study.** 20 points. Short answer.

NGC 6357, also known as the Lobster Nebula, is an H II region in the Milky Way. An image, taken by the Chandra X-ray observatory, is shown in Figure 2.

16. (4 points) Why are they called H II regions?

**Solution:** They are made of ionized hydrogen, which is denoted H II.

17. (4 points) How are H II regions formed?

**Solution:** They are formed from a molecular cloud. Parts of the molecular cloud fragment and collapse to form stars; these stars will eventually become hot enough to ionize the surrounding gas, forming an H II region.

18. (4 points) Refer to the image. What causes the dark "cavities" to form in the region?

**Solution:** Both stellar winds and supernovae blow away gases, forming cavities.

19. (4 points) Refer to the image. Which color represents X-ray emission?

**Solution:** Pink

20. (4 points) Why would we use Chandra to observe H II regions such as NGC 6357?

**Solution:** Young stars are bright in x-rays, and x-rays can penetrate the gas cloud, so we use Chandra, which is an x-ray observatory.

**PART III: General Astronomy.** 20 points (2 each). Odd one out.

For each question, compare and contrast the answer choices in terms of the attribute given. Pick the choice which is most unlike the others.

21. Energy produced per second:

    A. The Sun B. Sirius A **C. Type II supernova (peak)** D. Sirius B

22. Lifespan:

    **A. Type O star** B. Type F star C. Type G star D. Type K1 star

23. Effectiveness in measuring distance to galaxies:

    A. Type Ia supernovae **B. Parallax** C. Cepheids D. Hubble's Law

24. **(OMIT!)** X-rays produced:

    A. Planets B. Type O stars **C. Black hole accretion disk** D. White dwarfs

25. Amount of hydrogen in the core:

    **A. ZAMS** B. Subgiant Branch C. Red Giant Branch D. Horizontal Branch

26. Strength of spectral Balmer lines:

    A. Type O B. Type M C. Type G **D. Type A**

27. Type of stellar remnant based on core mass:

    A. 0.75 $M_\odot$ B. 1 $M_\odot$ C. 1.25 $M_\odot$ **D. 1.5** $M_\odot$

28. Immediate relevance and significance to the development of astronomy:

    A. T. Brahe **B. G. Mendel** C. A. Eddington D. L. Boltzmann

29. **(OMIT!)** Radius:

    A. Neptune B. Jupiter **C. Sun** D. White dwarf

30. Period of pulsation:

    **A. LPVs** B. RR Lyrae stars C. $\delta$ Scuti stars D. $\beta$ Cephei stars

**PART IV: Binary Systems.** 30 points. Calculations and interpretations.

You are studying a binary system, whose light curve is shown in Figure 3. The $H\alpha$ of star A deviates sinusoidally from 656.281 nm by $\pm 0.072$ nm, while the $H\alpha$ of star B deviates sinusoidally by $\pm 0.0068$ nm.

31. (25 points) Determine the following. Show work where possible.

(a) (5 points) Orbital period, in years.

**Solution:** 8.6 years, looking at the light curve (primary minimum to primary minimum).

(b) (5 points) Velocity of each star relative to their barycenter, in km/s.

**Solution:** Using

$$v = \frac{\Delta\lambda}{\lambda} c$$

we have $v_A = 33$ km/s and $v_B = 3.1$ km/s.

(c) (5 points) Mass ratio ($M_B/M_A$).

**Solution:**

$$\frac{M_B}{M_A} = \frac{v_A}{v_B} = 10.6$$

(d) (5 points) Semimajor axis, in AU.

**Solution:** Using

$$a = \frac{vP}{2\pi}$$

we have $a_A = 9.5$ AU and $a_B = 0.90$ AU. So $a = a_A + a_B = 10.4$ AU.

(e) (5 points) Mass of each star individually.

**Solution:** Using Kepler's 3rd law,

$$M_A + M_B = a^3/P^2 = 15.2 \text{ M}_\odot.$$

Using the mass ratio, we can plug in to find $M_A = 1.3 \text{ M}_\odot$ and $M_B = 13.9 \text{ M}_\odot$.

32. (5 points) Is it possible to determine during which minimum (X or Y) the hotter star passes behind the cooler star? If so, which? Explain your answer.

**Solution:** Minimum Y, or the primary minimum, is when the hotter star passes behind. The size of the star is not relevant. One way to think of it is that when the star eclipses, some amount of star is covered. Namely, when the small star comes in front, it covers some area, with size $A$, of the large star; when the small star passes behind, the large star covers the small star, which also has size $A$. So, either way, an area of size $A$ is being covered up. Which of these areas is brighter? Well, according to the Stefan-Boltzmann equation, a hotter star emits more light *per unit area*. So, when the hot star passes behind, more light is being blocked, compared to when the hot star passes in front – this is regardless of whether the hotter star is bigger or not. This corresponds to minimum Y.

**PART V: Stellar Astrophysics.** 50 points. Short answer.

33. (30 points) Here is a question about Cepheids and pulsation.

(a) (3 points) Kramers' opacity law relates gas opacity to its density and temperature. What is the proportionality relation?

> **Solution:**
> $$\kappa \propto \rho T^{-3.5}$$

(b) (12 points) The pulsation mechanism of Cepheids is closely related to the opacity of its atmosphere.

i. (3 points) Generally, the gas opacity of a star's atmosphere decreases with compression. Explain why, in terms of Kramers' opacity law.

> **Solution:** Compression usually increases both density and temperature, and since temperature dominates in the Kramer equation, the opacity usually decreases.

ii. (4 points) In partial ionization zones, gas opacity increases with compression. Why?

> **Solution:** In PIZs, some energy from compression goes into ionizing the gas, which means that the temperature increase is less. Since the gas is denser but not much hotter, the mean free path of photons is decreased, which makes the gas more opaque.

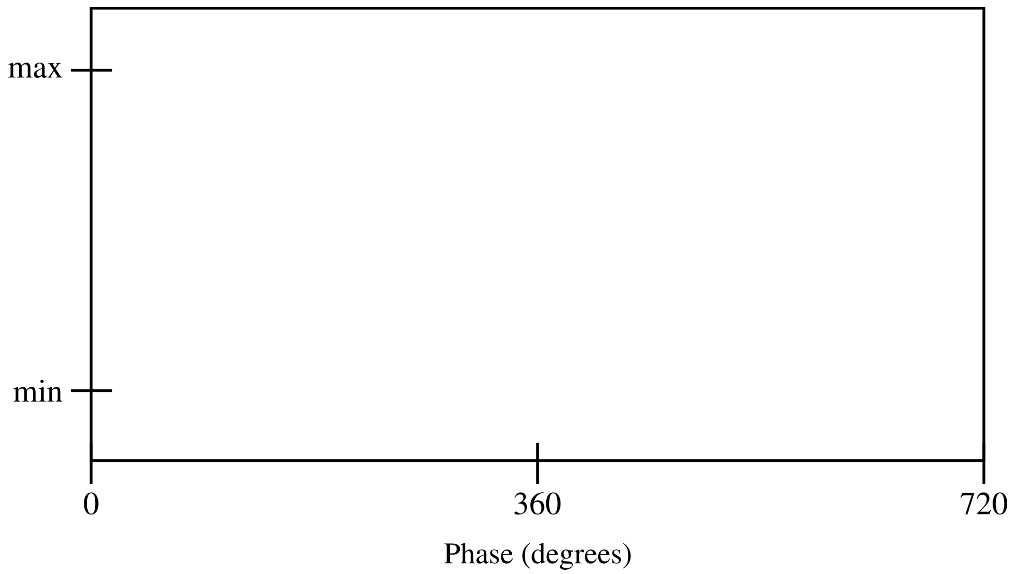
iii. (5 points) Explain how this reversal leads to the unstable pulsation of the star.

> **Solution:** Compression $\rightarrow$ increase opacity $\rightarrow$ trap luminosity $\rightarrow$ expand envelope $\rightarrow$ temperature decreases $\rightarrow$ envelope falls $\rightarrow$ compression

(c) (2 points) Which partial ionization zone is responsible for the pulsation of Cepheids?

> **Solution:** He II PIZ

(d) (3 points) Consider some arbitrary Cepheid star. In the graph below, sketch the curve for luminosity (with a solid line) and radius (with a dotted line). The x-axis represents time, in terms of the phase angle of the period. The y-axis represents both luminosity and radius, with the upper and lower bounds shown.




**Solution:** Should indicate: synchronized cyclic behavior, max luminosity near minimum radius, and phase lag between luminosity and radius.

(e) (4 points) Cepheids are thought to pulsate radially in the fundamental mode. What does this mean?

**Solution:** Radial: Star pulsates inwards and outwards, uniformly in all directions. Fundamental mode: all parts of the atmosphere move in the same direction.

(f) (6 points) Why is the instability strip located where it is? In other words, why do stars in that temperature range pulsate, while hotter and cooler stars generally don't?

**Solution:** At hotter temperatures, the He PIZ is too close to the surface, and pulsation is minimal. In cooler stars, there is surface convection, which means heat is transported efficiently to the surface when compressed, which means heat isn't trapped.

34. (20 points) The stellar evolution of sun-like stars can be well-visualized on the HR diagram.

(a) (10 points) Draw an HR diagram with the following information:

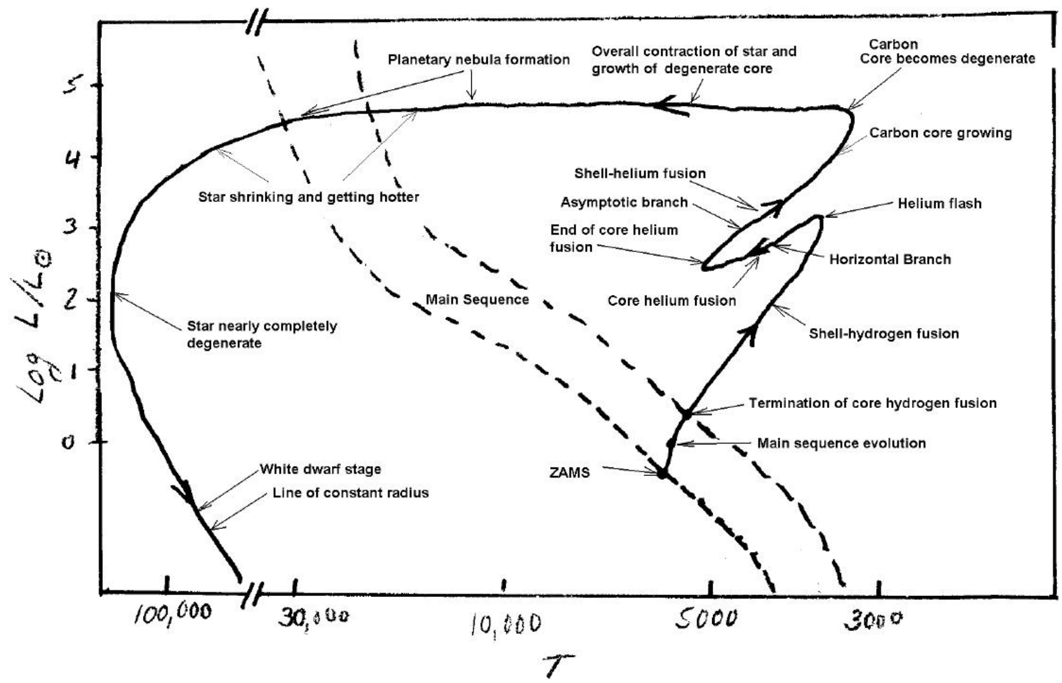
i. (2 points) Axes labeled with effective temperature (K) and luminosity ($L_\odot$). Include some tickmarks for numerical context.

ii. (1 point) The main sequence.

iii. (1 point) The location of the Sun on the diagram.

iv. (6 points) The sun's evolutionary path to planetary nebula. Label ZAMS, RGB, AGB. Indicate where the star begins H shell burning and He shell burning.

**Solution:** I found this on the internet. The RGB is the upward track before the helium flash.




(b) (3 points) As sun-like stars begin to evolve into their late life, they begin to develop an onion-like structure, in which the core is layered with different elements. Why does this structure emerge (as opposed to a homogeneous mix, or some other structure)?

**Solution:** Heavier elements sink to the core when they are synthesized. (This is why a H shell develops around a He core, and then a He shell develops around a Carbon/Oxygen core, etc.)

(c) (5 points) During the red giant branch, the amount of lithium at the surface of sun-like stars decreases. What process causes this, and why does that process decrease the surface lithium concentration?

> **Solution:** First dredge-up. Surface convection, which occurs in cooler stars to transport energy more efficiently through opaque layers, reaches far enough into the star where lithium is burned, so that lithium-rich material from the surface is replaced by lithium-free material from the inner star.

(d) (2 points) The 500.7 nm [O III] line is commonly associated with the death of sun-like stars. What is the connection between them? BONUS: What phenomenon do the square brackets signify? Explain the physics of this phenomenon.

> **Solution:** The [O III] line is emitted by planetary nebulae, and sun-like stars eject planetary nebulae when they die. BONUS: The square brackets indicate that it's a forbidden line. Forbidden lines break certain selection rules for electron transitions, so they are seen only when the gas is rarified enough for the electrons to occupy meta-stable energy states. Denser gases host frequent collisions between atoms, which prevent electrons from occupying meta-stable states.

35. ANOTHER BONUS: Write your favorite astronomy joke or pick-up line or something.

# Diagrams

**Figure 1**

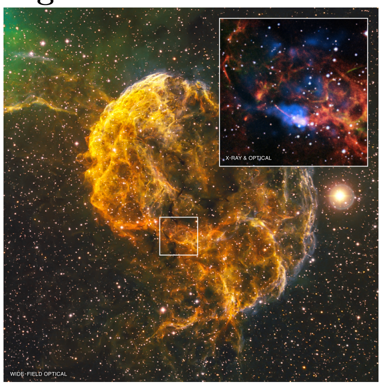



**Figure 2**

**Figure 3**