

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

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

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

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

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

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. δ Scuti stars
- D. β 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 ± 0.072 nm, while the $H\alpha$ of star B deviates sinusoidally by ± 0.0068 nm.

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

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

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

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

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

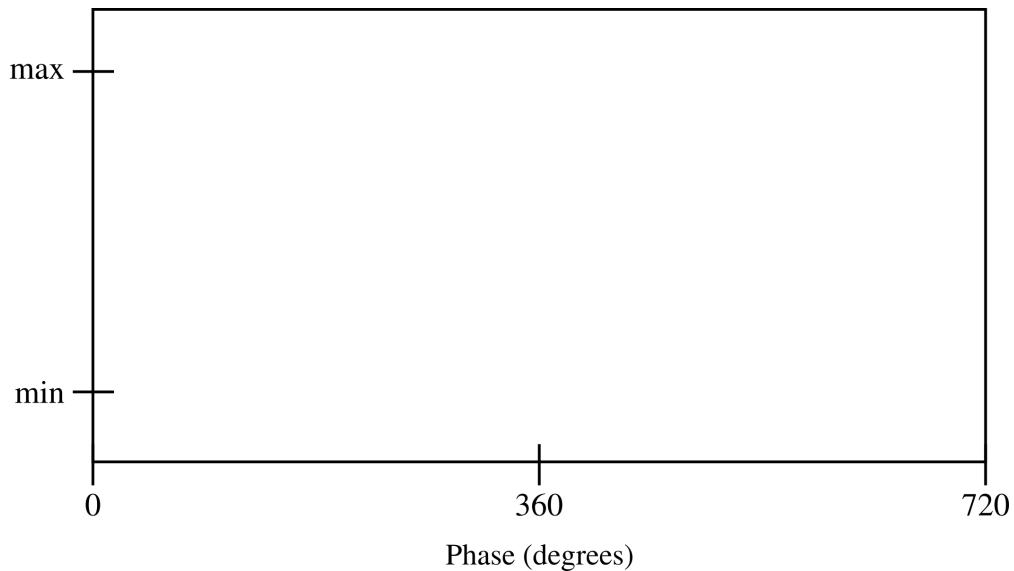
(e) (5 points) Mass of each star individually.

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.

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?
- (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.
 - ii. (4 points) In partial ionization zones, gas opacity increases with compression. Why?
 - iii. (5 points) Explain how this reversal leads to the unstable pulsation of the star.
- (c) (2 points) Which partial ionization zone is responsible for the pulsation of Cepheids?

- (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.



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

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.

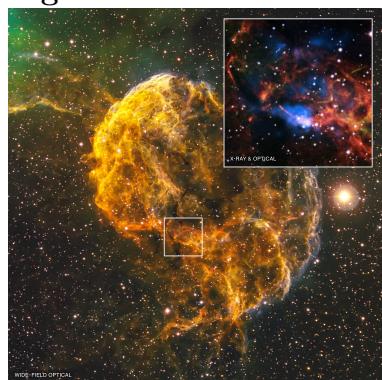
(b) (3 points) As sun-like stars begin to evolve into their late life, they begin to develop an onion-like structure, in which the core is layered with different elements. Why does this structure emerge (as opposed to a homogeneous mix, or some other structure)?

(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?

(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.

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

Diagrams

Figure 1**Figure 2****Figure 3**