Name: ______________________

You have three hours to complete this exam. I suggest you read through the entire exam before you spend too much time on any one question.

Part I is 25 multiple choice questions worth two points each. Part II is five problems worth 10 points each.

You may use any books, notes, or other materials you have brought with you. You may NOT consult any other students during the exam, but I will be here the entire exam period to answer any questions.

Good luck!

___  PART I

___  PART II, Problem 1

___  PART II, Problem 2

___  PART II, Problem 3

___  PART II, Problem 4

___  PART II, Problem 5

___  TOTAL
PART I: Two points each. Circle the choice which best answers the question.

1. HR diagrams of stars in our Galaxy show many stars with absolute magnitude $M \approx 2.0$ and between $K$ and $M$ spectral types. In the center of these stars, the dominant nuclear process is
   A. Hydrogen burning into helium
   B. Hydrogen burning into carbon
   C. Helium burning into carbon
   D. Carbon burning into silicon
   E. Silicon burning into iron

2. You want to resolve the shape of an HI region in a galaxy using a 100 m diameter radio telescope. If the region is 10 kpc in diameter, the galaxy can be no farther away than
   A. 10 kpc
   B. 1 Mpc
   C. 5 Mpc
   D. 100 Mpc
   E. 1000 Mpc

3. A star’s visible magnitude is 0.56 brighter than its blue magnitude. Assuming the star is on the main sequence and ignoring interstellar reddening, its spectral type is most likely
   A. B0
   B. A0
   C. F0
   D. G0
   E. K0

4. Cepheid variable stars belong to the larger class of stars called
   A. Main sequence stars
   B. White dwarf stars
   C. RR-Lyrae stars
   D. Long-period variables
   E. Red giants
5. A star’s spectrum shows the Balmer $H_\alpha$ line at 650 nm. Its velocity is
   A. $3 \times 10^6$ m/sec towards us
   B. $1.5 \times 10^6$ m/sec towards us
   C. Zero
   D. $1.5 \times 10^6$ m/sec away from us
   E. $3 \times 10^6$ m/sec away from us

6. A billion years from now, the Hubble “constant”, compared to today, will be
   A. Larger.
   B. Smaller.
   C. The same.
   D. It depends on whether the universe is open, closed, or flat.
   E. The answer depends on details of the inflation theory of cosmology.

7. Which of the following statements about the galaxy M100 is true?
   A. It is not part of the Local Group.
   B. It is a member of the Virgo cluster.
   C. It is the most distant galaxy for which Cepheids have been identified.
   D. We see it face-on with clear two-arm spiral structure.
   E. All of the above.

8. A collapsing molecular cloud is on the verge of becoming a star. Its surface temperature is 2500 K. It is best observed in the
   A. Radio
   B. Infrared
   C. Visible
   D. Blue
   E. Ultraviolet
9. The mechanism by which a nova increases its brightness is most closely related to
   A. Cepheid pulsation
   B. Solar flare-type events on large stars
   C. T-Tauri stars
   D. Type I Supernovae
   E. Type II Supernovae

10. The density wave theory of spiral galaxies predicts that vigorous star formation occurs in
    the spiral arms. Which of the following wavelength bands is therefore best used to show
    spiral structure in a distant galaxy?
    A. Blue
    B. Red
    C. 21 cm radio
    D. Continuous radio
    E. X-ray

11. Which of the following statements is now known to be false:
    A. Our sun is a typical star.
    B. Our solar system is from a typical protoplanetary disk.
    C. Our Galaxy is a typical galaxy.
    D. Our Local Group of galaxies is a typical cluster.
    E. Our motion relative to the “Hubble flow” is typical of galaxies.

12. A star with no distinct color has exceptionally strong Balmer absorption lines in its spec-
    trum. Its surface temperature is approximately
    A. 5000 K
    B. 6000 K
    C. 7000 K
    D. 10,000 K
    E. 20,000 K
13. A star cluster in our Galaxy is shown to consist mostly of main sequence stars. An F5-type star in the cluster has apparent magnitude $m = 8.0$. Ignoring interstellar reddening, the distance to the cluster is most likely
   A. 1.0 pc
   B. 10 pc
   C. 40 pc
   D. 200 pc
   E. 2 kpc

14. Massive Population II stars live longer than Population I stars of the same mass because
   A. Low metal abundances inhibit hydrogen burning.
   B. Low metal abundances inhibit helium burning.
   C. High metal abundances accelerate helium burning.
   D. High metal abundances accelerate carbon burning.
   E. None of the above.

15. Star clusters generally show a clear main sequence line which cuts off abruptly for effective temperatures greater than some value. This cutoff temperature indicates the cluster’s
   A. Extent in distance
   B. Total mass
   C. Population type
   D. Number of stars
   E. Age

16. Which of the following statements about white dwarf stars is not true?
   A. More massive stars have smaller radii.
   B. No stars exist with masses greater than 1.5 solar masses.
   C. They typically live for many billions of years.
   D. Their radiated energy comes from carbon burning.
   E. Their density is equivalent to a solar mass packed into the Earth’s radius.
17. The HST measured the gas velocity around the “disk” at the core of M87 (15 Mpc away) using Doppler shift spectroscopy. They found a rotation speed of 550 km/sec within 0.2” on either side of the center of the disk. The mass within this region is

A. At least one solar mass.
B. $2 \times 10^{33} \text{ kg}$
C. $2 \times 10^{39} \text{ kg}$
D. $4 \times 10^{44} \text{ kg}$
E. There is not enough information to determine the mass.

18. Electrons and positrons fell out of equilibrium with the radiation field when the time after the big bang was

A. $10^{-32} \text{ sec}$
B. $2 \mu \text{sec}$
C. 0.4 sec
D. 1.6 sec
E. 3 minutes

19. Two A0-type stars are shown to be in the same open cluster in our Galaxy. Star #1 is 16 times brighter than star #2. Which of the following statements is necessarily true?

A. Both stars are on the Main Sequence.
B. Star #1 is twice as hot at its surface than star #2.
C. Star #1 is twice as large as star #2.
D. Star #1 is four times hotter at its surface than star #2.
E. Star #1 is four times larger than star #2.

20. A Type I supernova with $M_V = -20$ in a distant galaxy is observed with apparent magnitude $m = 15$. The absorption lines of stars in this galaxy will likely show a redshift

A. Between 0.002 and 0.003.
B. Between 0.02 and 0.03.
C. Between 0.2 and 0.3.
D. Greater than 0.1
E. There is not enough information to determine the redshift.
The last five multiple choice questions concern Messier Catalog objects 1, 15, 16, 31, and 57. Photographs of these objects are available at the front of the room.

21. An example of very young stars is shown in
   A. M1  
   B. M15  
   C. M16  
   D. M31  
   E. M57

22. An example of very old stars is shown in
   A. M1  
   B. M15  
   C. M16  
   D. M31  
   E. M57

23. The fate of the glowing object in the center of M57 is most likely a
   A. Black hole  
   B. Neutron star  
   C. White dwarf  
   D. \( \approx 1 \) solar mass main sequence star  
   E. A blue giant star

24. A faint object at the center of M1 is known to be a
   A. Black hole  
   B. Neutron star  
   C. White dwarf  
   D. \( \approx 1 \) solar mass main sequence star  
   E. A blue giant star

25. The nebulous red region in M16 is an example of
   A. A radio galaxy  
   B. A reflection nebula  
   C. Balmer \( H\alpha \) emission  
   D. A supernova remnant  
   E. Interstellar reddening
PART II: Answer all problems in this part fully.

**Problem 1.** Cepheid variable stars are used to measure the distance to some galaxies. Assume you can determine a Cepheid variable from other kinds of variable stars only if its period is less than 100 days, and that your telescope has a limiting magnitude of $m = 18$. What is the distance to the farthest galaxy you can measure? Ignore bolometric corrections and interstellar reddening. *Be sure to indicate any parameters you assume or determine from formulas or from graphs.*
Extra Space for Problem 1.
Problem 2. (A) *Five points.* A small mass $m$ falls from a large distance onto a black hole. Show that the change in gravitational potential energy is $\frac{1}{2} m c^2$.

(B) *Five points.* Imagine that the sun gets its power from a small black hole in the middle which “eats” the matter around it at a constant rate. Estimate the lifetime of the sun and compare it to the known value of the sun’s age. Assume 1% efficiency to convert gravitational potential energy to luminosity.
Extra Space for Problem 2.
Problem 3. Shown below are the optical spectrum of a Seyfert galaxy and a table of various spectral lines in the laboratory. Calculate the distance to this galaxy. *Clearly indicate any values you determine from the spectrum and/or any other parameter values you assume.*
Extra Space for Problem 3.
Problem 4. The star $\mu$-Cep has absolute visual magnitude $M_V = -8$ and M0 spectral type. Calculate the radius of this star. (You may ignore the bolometric correction.) Compare this radius to the radius of the Earth’s orbit around the sun.
Extra Space for Problem 4.
**Problem 5.** When we write the age of the universe \( t_0 = 1/H_0 \) in terms of the present value of the Hubble Constant, we know this is an overestimate since the expansion rate of the universe must be slowing due to gravitational attraction. In this problem, we use Newtonian Cosmology to get a better estimate of \( t_0 \), assuming a flat universe.

(A) *Four points.* Show that the Hubble Constant can be written as

\[
H = \frac{V_{	ext{ESCAPE}}}{R} = \frac{1}{R} \frac{dR}{dt} = \left( \frac{2GM}{R^3} \right)^{\frac{1}{2}}
\]

where \( M \) is the mass of the universe contained within the scale radius \( R \).

(B) *Four points.* Integrate the above equation from \( t = 0 \) to \( t = t_0 \) assuming \( R(0) = 0 \) and \( \dot{R}(t_0) = \dot{R}_0 \) to show that

\[
\frac{2}{3} \dot{R}_0^2 = (2GM)^{\frac{2}{3}} t_0
\]

You can assume that \( M \) does not change as the universe expands.

(C) *Two points.* Show that \( t_0 = \frac{2}{3}(1/H_0) < (1/H_0) \) is a better estimate for the age of the universe.
Extra Space for Problem 5.