Midterm Exam Name _____
October 17, 2023

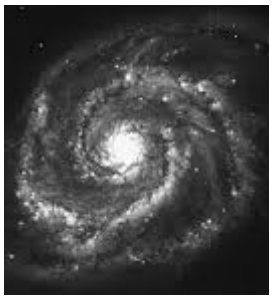
This test consists of three parts. For the first and second parts, you may write your answers directly on the exam, if you wish. For the other parts, use separate sheets of paper.

Part I: Multiple Choice Everyone: Answer all questions.
For each question, choose the best answer (2 points each)

1. Which of the following is probably **false** about a typical open cluster of stars?
   A) The stars will mostly all remain in this cluster indefinitely
   B) The stars will all be moving in approximately the same direction and speed
   C) The stars might have metallicity comparable to ours
   D) The cluster is typically somewhere in the disk
   E) Actually, all of these are true about open clusters

2. The driving engine that makes active galaxies so bright is assumed to be
   A) O and B stars B) A black hole C) A supernova D) Molecular cloud E) Antimatter

3. Spectroscopic parallax is useful for finding the distance to which types of stars?
   A) Main sequence
   B) Red giants
   C) White dwarfs
   D) Type Ia supernovae
   E) Neutron stars

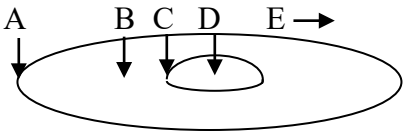


4. The galaxy pictured at right is approximately what galaxy classification?
   A) E0 B) E7 C) SAc D) SB0 E) Im

5. Radar distancing has limited application because
   A) Peculiar velocities add random (unknown) errors to the distance measurement
   B) The time is so short for measuring to nearby objects that you can't get it accurately
   C) Methods like Cepheid variable stars work even better at the relevant distance
   D) Blurring by our atmosphere messes up the measurements
   E) You can only get radar reflections back in reasonable times from nearby objects

6. List the three elements Carbon (C), Hydrogen (H) and Helium (He) in order from most common to least common in a typical star
   A) He, H, C B) H, He, C C) H, C, He D) He, C, H E) C, H, He

7. At right is a crude sketch of our galaxy. Where are we in this sketch?
   A) A B) B C) C D) D E) E



8. The best way to detect HI regions (neutral hydrogen atoms) in our galaxy is by detecting
   A) X-rays from the hot gas
   B) Spectral lines from molecular vibrations
   C) Dimming of light from stars behind them caused by absorption
   D) Gravitational lensing by these clouds
   E) The 21 cm line from electrons flipping their spin

9. The cause of tidal friction, that slows down the relative speed of two galaxies that pass each other, is
   A) Magnetic attraction between the galaxies
   B) Light pressure from one galaxy pushing on the other
   C) Different acceleration of different parts of the galaxies due to the passing galaxy's gravity
   D) Collision of gas clouds surrounding the galaxies
   E) Collisions of dark matter fluid as the galaxies interact

10. Hubble's Law fails at large distances because
   A) "Distance" is ambiguous for sources moving at high velocity (only)
   B) Relativistic effects need to be taken into account (only)
   C) You are looking into the past, when Hubble's "constant" may have been different (only)
   D) All of the above
   E) None of the above

11. Why is it that there are often very massive elliptical galaxies at the centers of galaxy clusters?
   A) The gas all flows to the center to make these massive galaxies
   B) Spirals in the center have their spiral arms stripped away, making them into ellipticals
   C) Mergers of large numbers of galaxies formed these giant ellipticals
   D) Galaxies in the middle can most easily transfer their angular momentum to other galaxies, converting them to ellipticals
   E) I have no idea; please mark this one wrong

12. The name of the galaxy supercluster we live in is
   A) Milky Way B) Virgo C) Andromeda D) Laniakea E) Coma

13. Most of the dark matter in a galaxy is in the
   A) Nucleus B) Bulge C) Disk D) Halo E) None of these

14. We now know that dark matter is made mostly of
   A) Black holes B) Neutron stars C) White dwarfs D) Planets E) None of these

15. What is the approximate fraction of a typical galaxy's mass that is made of ordinary matter?
   A) 15% B) 50% C) 75% D) 85% E) 99%

Part II: Short Answer PHY 310: Choose three of the four questions PHY 610: Answer all four questions. Write 2-4 sentences about each of the following [10 each]

PHY 310: You may skip one question

16. Explain qualitatively how Cepheid variable stars can be used to measure distances to other galaxies.

17. At a naïve level, the Sun moves in a circular orbit in the plane of our galaxy around the center of our galaxy. Describe two types of motion that Sun actually has which differ from this simple circular motion.

18. Give at least four differences between a typical elliptical galaxy and a typical spiral galaxy

19. What is Hubble's Law? Assuming Hubble's Law works perfectly, explain what one would have to measure about a particular galaxy to use Hubble's Law to get the distance to that galaxy.

Physical Constants	Units	Distance/Magnitude	Black Body Radiation
$k_B = 1.381\times10^{-23}$ J/K	$\text{pc} = 3.086\times10^{16}$ m	$d = 10^{1+\frac{m-M}{5}}$ pc	$u = \frac{\pi^2}{15}\frac{(k_B T)^4}{(\hbar c)^3}$
$\hbar = 1.055\times10^{-34}$ J·s	$M_\odot = 1.988\times10^{30}$ kg	$m - M = 5\log(d) - 5$	$\lambda_{\max} T = 0.00290$ m·K
$h = 6.626\times10^{-34}$ J·s	$R_\odot = 6.96\times10^{8}$ m	**Brightness/Magnitude**	**Tip of the Red Giant**
$G = 6.674\times10^{-11}\text{m}^3/\text{kg/s}^2$	$T_\odot = 5772$ K	$F = 2.518\times10^{-8}\text{ W/m}^2\left(10^{-\frac{2}{5}m}\right)$	$M_t = -4.10$

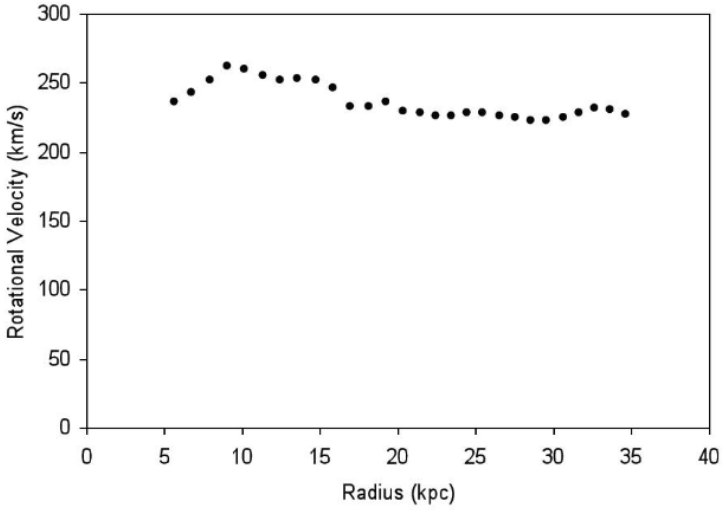
Part III: Calculation:
PHY 310: Choose four of the five problems; PHY 610: Do all five problems.
For each of the following problems, give the answer, explaining your work. [20 points each]

PHY 310: You may skip one question on this page or the next

20. An important event in the early universe was matter-radiation equality, when the energy density in matter (including dark matter) matched the energy density in radiation. It is estimated that the black-body radiation at this time had an energy density of 4.56 J/m^3.
    (a) What was the approximate temperature T at this time?
    (b) What wavelength $\lambda_{\max}$ would have been the peak of the electromagnetic spectrum at this time?
    (c) Find the energy of one photon with the wavelength you found in part (b), in J and in eV (1 eV = 1.602×10^{-19} J).

21. Sirius is a double star, and the brighter one is the brightest star in the sky (other than the Sun). The star's apparent magnitudes are $m_1 = +8.44$ and $m_2 = -1.46$.
    (a) Which of these stars is brighter, and by what factor?
    (b) The parallax of the Sirius system is approximately 0.372″. What is the distance to the Sirius system, in pc?
    (c) What is the absolute magnitude M for the brighter of the two stars?
    (d) The H-α line normally occurs at a wavelength of 656.279 nm, but the same line coming from Sirius is measured to have a wavelength of 656.267 nm. Approximately how fast is Sirius moving relative to us, and is it towards us or away from us?

22. At right is a graph of the rotation curve for M31, the Andromeda galaxy, which is at a distance of 765 kpc .
    (a) Consider the points at 15 kpc and 35 kpc away from the center. How far away in degrees are they from the center?
    (b) Measure the rotational velocities at 15 and 35 kpc from the center. Assuming the mass is spherically symmetric, what is the enclosed mass M at these two distances in units of $M_\odot$?
    (c) Does this galaxy show signs of dark matter?



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PHY 310: You may skip one question on this page or the previous

23. The star Betelgeuse has an estimated mass of 18 $M_\odot$, radius of 300 $R_\odot$, and luminosity of 10,200 $L_\odot$.
    (a) Find the surface temperature of Betelgeuse compared to the Sun, and its value in K.
    (b) Find the estimated surface gravity of Betelgeuse in m/s^2, and in units of Earth's gravity $g = 9.8$ m/s^2.
    (c) Escape velocity is the velocity v such that the kinetic energy of an object of mass m matches the magnitude of the gravitational potential energy in the presence of a gravitational source. Find the escape velocity from the surface of Betelgeuse.

24. Three galaxies have their brightest red giants (RG) and brightest globular cluster (GC) apparent magnitudes measured, as shown at right.

Gal.	m (RG)	m (GC)	d (Mpc)	M (GC)
A	19.75	16.36		
B	21.63	18.22		
C	23.47	20.07		
D	?	22.46		

    (a) For galaxies A, B, and C, estimate the distance using the tip of the red giant method
    (b) For the same three galaxies, find the absolute magnitude of the brightest globular clusters.
    (c) Are the brightest globular clusters a decent standard candle? Why or why not?
    (d) Galaxy D is too far away to see individual red giants, but not too far to see globular clusters. Estimate the distance to galaxy D.