Name ___________________

Midterm Exam
October 18, 2019

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. Type Ia supernovae became a popular distance method for measuring distances in the late 20th century. Why don't we just always use it to measure distances?
   A) These supernovae are not bright enough to measure at large distances
   B) Light extinction due to dust causes huge problems, since these mostly occur in the plane of our galaxy
   C) Parallax is a much more accurate way to measure the distance to typical galaxies
   D) Their enormous gravitation causes the light to be red-shifted, distorting our views
   E) These events are rare, so you can't automatically use it for most objects

2. Which of the elements iron (Fe), carbon (C), neon (Ne), and helium (He), according to astronomers, contributes to the metallicity of a star?
   A) None of them B) Fe only C) Fe and C D) Fe, C, and Ne E) All of them

3. Why do clusters of stars tend to get redder as they age?
   A) Dust accumulates around the cluster, reddening it
   B) The cluster moves away from us, and the reddening is due to red shift
   C) Blue supergiant stars turn red after a few billion years
   D) All the high mass (blueish) stars are dead, and the brightest remaining stars are red giants
   E) Red stars get gradually brighten over time, while blue stars gradually get dimmer

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

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

6. Approximately what percent of our galaxy's mass is in the form of dark matter?
   A) 1% B) 15% C) 50% D) 85% E) 99%

7. If an astronomer says they are studying O and B stars, what types of stars are they studying?
   A) Hottest B) Coolest C) Most luminous D) Least luminous E) Brightest

8. The main way we know that most of the dark matter in the galaxy is not solar mass black holes (for example) is because
   A) We should see these black holes forming from stars blowing up
   B) All other stars, including ours, would have been sucked into them long ago
   C) They should cause gravitational lensing events from stars behind them more often than we see them
   D) Large portions of the sky should look black from the black holes sucking up all the light
   E) The gravitational effects of nearby black holes should be obvious

9. In what way were galaxies different a long time ago?
   A) They often had high mass short-lived stars, now there are only old stars
   B) They were often smaller and there were more irregular galaxies
   C) They hadn't accumulated any gas yet
   D) They had much higher metallicities back then
   E) None of the above; they are pretty much the same as modern galaxies

10. When two galaxies nearly collide, energy is conserved. So how can the galaxies slow down as they pass?
    A) Gas clouds outside the galaxies collide, absorbing energy
    B) Gravitational waves are emitted by the nearly colliding galaxies
    C) Gravitational forces convert the energy of the net motion of the galaxies into the internal motion of the stars in each galaxy, in a process called tidal friction
    D) Though the stars don't collide, the dark matter does, and that extends out of the galaxies
    E) Actually, unless they actually collide, the galaxies do not slow down

11. Why are Cepheid variable stars so useful to astronomers?
    A) It is easier to do parallax on them, allowing us to get the distance
    B) They are the brightest stars, so they can be seen at the greatest distance
    C) They produce lots of infrared light, so they can be seen through dust
    D) There have a known relationship between their period and their <u>distance</u>
    E) They have a known relationship between their period and their <u>luminosity</u>

12. At the center of our galaxy lies a
    A) Supernova B) Black hole C) Supergiant star D) Nebula E) Void

13. How old, approximately, are the oldest stars in the galaxy?
    A) 9 My B) 13 My C) 17 My D) 9 Gy E) 13 Gy

14. Which of the following might be the approximate value of Hubble's constant today?
    A) 50 km/s/Mpc B) 100 km/s/Mpc C) 70 km/s/Mpc D) 50 m/s/Gpc E) 70 m/s/Gpc

15. For the stars in a galaxy or cluster, the potential energy E_P is negative and the kinetic energy E_K is positive. If the galaxy or cluster is in a state of equilibrium, so it satisfies the virial theorem, how are the magnitudes of these two quantities related?
    A) $|E_K| = 2|E_P|$ B) $|E_P| = 2|E_K|$ C) $|E_K| = |E_P|$ D) $|E_K| = 4|E_P|$ E) $|E_P| = 4|E_K|$

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. Galaxy collisions are common, and yet the stars within them rarely collide. Give at least three reasons why galaxy collisions still have significant effects.

17. Astronomers think that radio galaxies, radio quasars, and blazars may all possibly be the same thing. Explain how this might be possible. A simple sketch might help.

18. Explain qualitatively how we can estimate the total mass of a cluster of galaxies, including all the dark matter, etc.

19. Hubble's Law states that the distance and velocity of galaxies are given by $v = H_0 d$. Explain why this formula is imprecise (a) at small distances, and (b) at large distances.

Physical Constant

$k_B = 1.381\times10^{-23}$ J/K

$\hbar = 1.055\times10^{-34}$ J·s

$h = 6.626\times10^{-34}$ J·s

$G = 6.673\times10^{-11}\,\text{m}^3/\text{kg/s}^2$

Units

$\text{pc} = 3.086\times10^{16}$ m

$M_\odot = 1.989\times10^{30}$ kg

$\text{y} = 3.156\times10^{7}$ s

$\text{rad} = 206{,}265''$

Distance and Magnitudes

$d = 10^{1+\frac{m-M}{5}}$ pc

$m - M = 5\log(d) - 5$

Galactic Orbits

$\Omega = \dfrac{V_0}{R_0}$

$\kappa^2 = \dfrac{2V_0^2}{R_0^2} + \dfrac{1}{R_0}\dfrac{d}{dR}V^2\Big|_{R_0}$

$\nu = \sqrt{4\pi G\rho_0}$

Black Body Radiation

$u = \dfrac{\pi^2}{15}\dfrac{(k_B T)^4}{(\hbar c)^3}$

$\lambda_{\max} T = 0.00290$ m·K

Planetary Nebula

$M^* = -4.47$

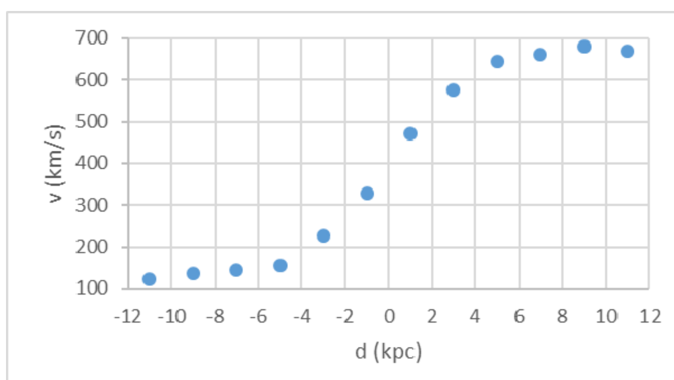
Part III: Calculation:
PHY 310: Choose four of the five problems
PHY 610: Do all five problems.
For each of the following problems, give the answer, explaining your work. [20 points each]

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

20. One important event in the early universe is called *recombination*, and occurred when the temperature of the universe was approximately $T = 2970$ K. The universe was filled with almost perfect black body radiation at this time.
    (a) Find the energy density of the blackbody radiation at this time in J/m^3.
    (b) Find the wavelength where the blackbody radiation was strongest at this time, in nm.
    (c) Find the energy for a single photon with the wavelength you found in part (b).
    (d) Using the energy density you found in part (a) and the energy you found in part (c), estimate the number of photons per unit volume (in m^{-3}) at this time.

21. Barnard's Star has a parallax of $p = 0.547''$ and is moving with proper motion $\mu_x = -0.803''/\text{y}$ and $\mu_y = 10.36''/\text{y}$. The Lyman-α line, normally at a wavelength of $\lambda_0 = 121.567$ nm, is detected from this star at $\lambda = 121.522$ nm.
    (a) What is the distance to Barnard's Star in pc?
    (b) What is the velocity perpendicular to our line of sight v_x and v_y compared to us in km/s?
    (c) What is the radial velocity v_r of the star compared to us in km/s?

22. A spiral galaxies has stars in various places measured compared to us via Doppler shift. The resulting velocities are as plotted at right.



    (a) Estimate the rotational velocities (ignoring the net motion of the galaxy) at distances of 5 kpc and 10 kpc from the center of the galaxy.
    (b) Assume the mass of the galaxy is distributed in a spherical symmetric manner. What is the total mass of the galaxy contained within spheres of radius 5 kpc and 10 kpc of the center of the galaxy?
    (c) Does this galaxy show evidence for dark matter?

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

23. A group of galaxies has their brightest planetary nebulas (PN) and brightest red giants (RG) apparent magnitudes measured, as shown at right.
   (a) For galaxies A, B, and C, estimate the distance using planetary nebulae.
   (b) For the same three galaxies, find the absolute magnitude of the red giant stars.
   (c) Are the brightest red giants a decent standard candle? Why or why not?
   (d) Galaxy D hasn't had its planetary nebulas measured. Estimate the distance anyway.

Gal-axy	m (PN)	m (RG)	d (Mpc)	M (RG)
A	20.21	20.68		
B	22.30	22.76		
C	24.86	25.34		
D	?	21.63		

24. A long time ago in a faraway spiral galaxy, the star system Tatoo orbits at an average distance of $R_0 = 12.00\text{ kpc}$ from the center of its galaxy. The velocity rotation curve for the galaxy fits the formula $V^2 = AR$, where $A = 8{,}800\text{ km}^2\text{s}^{-2}\text{kpc}^{-1}$. The mass density in the neighborhood of Tatoo is $\rho = 0.132\ M_{\odot}\text{pc}^{-3}$.
   (a) What is the orbital velocity V_0 at the distance R_0? What is the angular velocity Ω at this radius in My^{-1}, and what is the period T_Ω to complete one orbit?
   (b) Tatoo doesn't stay exactly at R_0, but also wanders in and out compared to the center of the galaxy. What is the frequency κ for these epicycles in My^{-1}, and the corresponding period T_κ?