Name ___________________

Midterm Exam
October 13, 2021

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. The strongest evidence for dark matter in spiral galaxies like ours is that
   A) The orbital speeds of stars and gas clouds do not fall off with distance
   B) Gravitational lensing events from massive compact halo objects (MACHOs)
   C) Gravitational redshift shows that there is much more mass than can be accounted for by stars
   D) Infrared satellites can directly observe the dark matter
   E) The dimming of various distant objects because we have to see through the dark matter

2. In which part(s) of our galaxy are substantial numbers of new stars being born?
   A) The disk (only)
   B) The halo (only)
   C) The bulge (only)
   D) The halo and disk, but not the bulge
   E) The bulge and disk, but not the halo

3. Which of the following stars has the highest surface temperature?
   A) B7 B) F2 C) B3 D) K9 E) M1

4. Galaxies with disks cannot collapse to the center because of conservation of
   A) Mass B) Energy C) Momentum D) Charge E) Angular Momentum

5. The best way to determine the age of a cluster of stars is by
   A) Measuring radioactive decay of elements contained in the stars
   B) Counting the ratio of red giant stars to main sequence stars
   C) Making a Hertzsprung-Russell diagram and seeing where the stars "turn off" from the main sequence
   D) Measuring how much hydrogen has been converted to helium in the stars
   E) Measuring to what extent its core has collapsed towards the center

6. The galaxy pictured at right is approximately what galaxy classification?
   A) E0 B) E7 C) SAd D) SBc E) Im

7. The mass of the black hole at the center of our galaxy was measured by
   A) Gravitational lensing of objects behind it
   B) Measuring the orbits of stars going around it
   C) Measuring the gravitational red shift for light waves coming from it
   D) Direct measurement of the Schwarzschild radius
   E) Studying the acceleration of exploratory spacecraft sent to study it

8. Which of the following types of active galaxies is believed to be powered by a giant black hole at the heart of the galaxy?
   A) Quasars (only)
   B) Radio galaxies (only)
   C) Blazars (only)
   D) All of the above
   E) None of the above

9. Which of the following is true about galaxy collisions?
   A) Galaxy collisions are extremely rare; most galaxies have probably never collided
   B) When galaxies collide, many of the stars are destroyed by the violent collisions
   C) Galaxy collisions have virtually no effect on the shape or structure of a galaxy
   D) The gas in galaxies is so low density it simply passes through gas in the other galaxy
   E) Galaxy collisions are common and can cause galaxies to merge

10. The name of one large galaxy that is near our galaxy is
    A) Coma B) Andromeda C) Fornax D) Virgo E) Laniakea

11. The most massive galaxies tend to be
    A) Spiral B) Barred Spiral C) Irregular D) Elliptical E) Dwarf Spheroidal

12. The way we know what stars are made of is primarily by
    A) Measuring the composition of stellar winds coming from these stars
    B) Comparing the color of stars to the color of similar materials on Earth
    C) Assuming they start as hydrogen and helium and then using computer models
    D) Studying the composition of the Solar System, made from former stars
    E) Measuring the wavelengths and strengths of the dark lines in the stellar spectra

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

14. The name of the <u>collection of galaxies</u> we live in is
    A) Milky Way B) Local Group C) Virgo D) Andromeda E) Coma

15. Laniakea is the name of our ______
    A) Supercluster B) Stellar cluster C) Galaxy D) Galaxy cluster E) Hypercluster

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 what tidal friction is, and what effect it has on galaxies that almost collide but just miss each other.

17. Which portion of the galaxy do we live in? Besides stars, what other objects can be found in the portion we live in?

18. The Sun goes around our galaxy in an approximately circular orbit. In addition to this circular motion, what other types of motion does the Sun undergo as it orbits the center?

19. Explain how the radar distancing method can be used to measure the distance to, for example, the Moon. Explain why it isn't used to measure the distance to the Andromeda galaxy.

Physical Constants	**Units**	**Distance/Magnitude**	**Doppler Shift**
$k_B = 1.381\times10^{-23}$ J/K $\hbar = 1.055\times10^{-34}$ J·s $h = 6.626\times10^{-34}$ J·s $G = 6.673\times10^{-11}\,\mathrm{m^3/kg/s^2}$	$\mathrm{pc} = 3.086\times10^{16}$ m $M_\odot = 1.989\times10^{30}$ kg $\mathrm{rad} = 206{,}265''$	$d = 10^{1+\frac{m-M}{5}}$ pc $m - M = 5\log(d) - 5$	$1+z = \dfrac{\lambda}{\lambda_0} = \sqrt{\dfrac{1+v_r/c}{1-v_r/c}}$

Brightness/Magnitude	**Type Ia Supernova**	**Black Body Radiation**	**Black Hole**
$F = 2.518\times10^{-8}\,\mathrm{W/m^2}\left(10^{-\frac{2}{5}m}\right)$	$M_{\max} = -19.3$	$u = \dfrac{\pi^2}{15}\dfrac{(k_B T)^4}{(\hbar c)^3}$ $\lambda_{\max} T = 0.00290$ m·K	$R_s = \dfrac{2GM}{c^2}$

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. We will shortly learn that the universe is filled with black body radiation. The peak of the power is at a wavelength of $\lambda_{\max} = 1.064\times10^{-3}$ m.
    (a) What is the energy of one photon with this wavelength?
    (b) What is the black-body temperature of the Universe?
    (c) What is the energy density of the black body radiation in $\mathrm{J/m^3}$?
    (d) If we treat the energy of a photon from part (a) as typical, use the energy density from part (c) to estimate the number density of photons.

21. The star β-Cygni is actually a double star, with components β-Cygni A having an apparent magnitude of $m_A = 3.10$ and β-Cygni B having an apparent magnitude of $m_B = 5.10$.
    (a) What is the flux in $\mathrm{W/m^2}$ coming from each of these stars? By naked eye, the two stars appear to be one star. What is the total flux of this combination?
    (b) What is the apparent magnitude m of the stars together?
    (c) The system has a parallax of $0.00816''$. What is the distance to β-Cygni?
    (d) What is the absolute magnitude M for the combined star system?

22. The calcium K-line has a normal wavelength of $\lambda_0 = 393.4$ nm, but is detected in a distant galaxy to occur at a wavelength of $\lambda = 457.3$ nm.
    (a) Find the value of $1+z$, and the velocity of this galaxy in km/s. The value of z is too large to use the non-relativistic approximation.
    (b) A type Ia supernova goes off in this galaxy! It peaks at an apparent magnitude $m_{\max} = 19.7$. Find the distance to this galaxy in Mpc.
    (c) Using this single data point, estimate the value of Hubble's constant in km/s/Mpc.

23. Perhaps the dark matter is black holes of mass $M = 500\,M_\odot$. If they are this large, could we notice them if they happen to be in front of a nebula that glows, as a dark spot?
    (a) Find the Schwarzschild radius for a black hole of this mass.
    (b) The local mass density (mass/volume) of dark matter is estimated to be $0.0914\,M_\odot/\mathrm{pc}^3$. Find the size of the average volume containing one black hole of this mass. Take the cube root to get an approximate distance to the nearest such black hole in pc.
    (c) What would be the angular radius of such a black hole at the distance found in part (b) in arc-seconds? We probably can't see anything smaller than $0.001''$. Are we able to detect these black holes by this method?

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

24. A distance method we didn't discuss uses a period-luminosity relation for RR-Lyrae stars, another type of variable star. Listed at right is a table of five RR-Lyrae stars and their period of pulsation in days.
    (a) Calculate log(P) for each of the stars listed. Then plot log(P) vs. absolute magnitude M. You may put your answers directly on the provided table and chart.
    (b) Explain roughly why RR-Lyrae stars can be used as a distance indicator. A trend line on the graph might help.
    (c) Star X is an RR-Lyrae star with a period of 0.462 days and an apparent magnitude m = 18.03. Estimate the distance to star X.

Star	P (days)	log(P)	M
A	0.375		-0.07
B	0.903		-0.97
C	0.804		-0.85
D	0.573		-0.50