**Final Exam**  Astronomy 311  January 17, 2014  Name:________ KEY________

Professor Menningen

You have a full 120 minutes to complete the exam. The only allowed tool is a calculator.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
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<tbody>
<tr>
<td>(D)</td>
<td>diameter of object</td>
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<tr>
<td>(r)</td>
<td>distance to object</td>
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<tr>
<td>(\theta)</td>
<td>angular size of object</td>
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<tr>
<td>(X)</td>
<td>parallax baseline</td>
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<tr>
<td>(\theta_p)</td>
<td>parallax angle ((^{\circ}))</td>
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<tr>
<td>(P)</td>
<td>period of orbit (yr)</td>
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<tr>
<td>(a)</td>
<td>semimajor axis (AU)</td>
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<tr>
<td>(M)</td>
<td>mass (solar masses)</td>
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<tr>
<td>(m)</td>
<td>mass (kg)</td>
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<tr>
<td>(G)</td>
<td>(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)</td>
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<tr>
<td>(F)</td>
<td>force (N)</td>
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<tr>
<td>(S)</td>
<td>solar constant (W/m(^2))</td>
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<tr>
<td>(\rho)</td>
<td>density (kg/m(^3))</td>
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<td>(V)</td>
<td>volume (m(^3))</td>
</tr>
<tr>
<td>(c)</td>
<td>(3.00 \times 10^8 \text{ m/s} = 3.00 \times 10^5 \text{ km/s})</td>
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<tr>
<td>(h)</td>
<td>Planck constant</td>
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<tr>
<td>(T)</td>
<td>temperature (K)</td>
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<tr>
<td>(\lambda)</td>
<td>wavelength</td>
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<tr>
<td>(E_{\text{photo}})</td>
<td>photon energy</td>
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<tr>
<td>(\sigma)</td>
<td>(5.67 \times 10^{-8} \text{ W} \cdot \text{m}^2/\text{K}^4)</td>
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<tr>
<td>(r)</td>
<td>radius (m)</td>
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<tr>
<td>(B)</td>
<td>apparent brightness</td>
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<tr>
<td>(\Delta\lambda)</td>
<td>Doppler shift (nm)</td>
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<tr>
<td>(\theta_{\text{res}})</td>
<td>angular resolution (arcsec)</td>
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<tr>
<td>(v)</td>
<td>velocity</td>
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<tr>
<td>(MP)</td>
<td>magnifying power</td>
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<td>(f)</td>
<td>focal length</td>
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<tr>
<td>(E)</td>
<td>energy (J)</td>
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<tr>
<td>(H_0)</td>
<td>Hubble constant</td>
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**Section I.** (40 pts). Show all of your work, including the symbolic formula (from the above list) that you are using, when solving the following problems. Include the appropriate units in your answer.

A. (4 pts) A typical VCR remote control emits infrared light at a wavelength of about 785 nm (1 nm = \(10^{-9}\) m). Calculate the temperature of blackbody whose peak radiation occurs at the same wavelength as the VCR remote control.

\[
\lambda_{\text{max}} = \frac{2.9 \times 10^6 \text{ nm} \cdot \text{K}}{T} \quad \text{now solve for } T
\]

\[
T = \frac{2.9 \times 10^6 \text{ nm} \cdot \text{K}}{785 \text{ nm}} = 3690 \text{ K}
\]

(b) (4 pts) What is the energy in eV of a photon of wavelength 785 nm?

\[
E = hf = \frac{hc}{\lambda} = \frac{1240 \text{ eV} \cdot \text{nm}}{785 \text{ nm}} = 1.58 \text{ eV}
\]

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It's somewhere between a nova and a supernova... probably a pretty good nova.
B. Design a telescope that can resolve features 0.10 arcsec across and magnify them 100×. Use a wavelength of 550 nm and an objective lens (or primary mirror) focal length of 5.0 m for your calculations.

(a) (4 pts) Diameter of objective lens/primary mirror:

\[ \theta = 2.5 \times 10^5 \frac{\lambda}{D} \text{ if } \lambda \text{ and } D \text{ are in meters and } \theta \text{ in arcsec. Solve for } D: \]

\[ D = 2.5 \times 10^5 \frac{\lambda}{\theta} = \left(2.5 \times 10^5\right) \frac{550 \times 10^{-9} \text{ m}}{0.10 \text{ arcsec}} = 1.38 \text{ m} \]

(b) (4 pts) Focal length of eyepiece lens:

\[ M = \frac{f_{\text{objective}}}{f_{\text{eyepiece}}} \text{ so } f_{\text{eyepiece}} = \frac{f_{\text{objective}}}{M} = \frac{5.0 \text{ m}}{100 	imes} = 0.050 \text{ m} = 5.0 \text{ cm} \]

C. (8 pts) The two stars that make up a binary star have estimated masses of $1.2M_\odot$ and $0.80M_\odot$ and they orbit with a period of 8.0 hours. Find the average separation between the two stars (the orbital semimajor axis) in kilometers. { 1 AU = $1.496 \times 10^8 \text{ km} \}

\[ a^3 = (m + M) P^2 = (2.00 \text{ solar masses}) \left(\frac{1 \text{ day}}{3 \text{ orbits}} \times \frac{1 \text{ yr}}{365 \text{ day}}\right)^2 = 1.67 \times 10^{-6} \text{ AU}^3 \]

\[ a = \sqrt[3]{1.67 \times 10^{-6} \text{ AU}^3} = 1.19 \times 10^{-2} \text{ AU} \times 1.496 \times 10^8 \text{ km/AU} = 1.77 \times 10^6 \text{ km} \]

D. (8 pts) Suppose a star has a luminosity of $500L_\odot$ and a surface temperature of 3000 K. If the Sun’s surface temperature is 5800 K, how much bigger is this star than our Sun?

From \( L = \sigma T^4 4 \pi R^2 \) we have: \( \frac{L}{L_\odot} = \left(\frac{R}{R_\odot}\right)^2 \left(\frac{T}{T_\odot}\right)^4 \) now solve for \( \frac{R}{R_\odot} \):

\[ \frac{R}{R_\odot} = \sqrt[4]{\frac{L}{L_\odot}} \left(\frac{T_\odot}{T}\right)^4 = \sqrt[4]{\frac{500L_\odot(5800 \text{ K})^4}{L_\odot(3000 \text{ K})^4}} = 83.6 = 84 \times \]
E. (a) (4 pts) Galaxy X is observed to be receding from the Sun at a rate of 7500 km/s. If the Hubble constant is 70 km/s/Mpc, what is the approximate distance in Mpc to this galaxy?

\[ v = H_0 r \] so that

\[ r = \frac{v}{H_0} = \frac{7500 \text{ km/s}}{70 \text{ km/s/Mpc}} = 107 \text{ Mpc} \]

(b) (4 pts) Suppose we observe a Type Ia supernova of absolute magnitude \(-19.9\) in Galaxy X. What will be the apparent magnitude of the supernova? \( m - M = 5 \log d - 5 \), \( d \) is in parsecs, \( 1 \text{ Mpc} = 10^6 \text{ pc} \)

\[ m = M + 5 \log d - 5 = -19.9 + 5 \log (107 \times 10^6 \text{ pc}) - 5 \]

\[ m = +15.2 \]

Section II. (28 pts) Please answer True (+) or False (O) by filling in the appropriate space on your answer sheet.

____ 1. The spiral arms of the galaxy consist primarily of young O and B stars, dust, and gas.

____ 2. Distances to a nearby galaxy can be determined most accurately by measuring the period of pulsating stars.

____ 3. The rotation speeds of galaxies are slower faster than that expected by Newton’s law of gravity and Kepler’s laws of orbits.

____ 4. The Hubble distance-velocity relation states that all objects appear to have the same velocity away from the Sun, irrespective of distance from the Sun. The further a distant object is from the Sun, the faster it appears to be moving away from the Sun.

____ 5. The main reason for placing astronomical telescopes and detectors on satellites is to avoid light pollution from cities and other built-up areas, absorption by water vapor in the Earth’s atmosphere.

____ 6. The average number of sunspots visible on the Sun’s surface is not constant but varies with a period of about 11 years.

____ 7. You can double quadruple the amount of light collected by a telescope by doubling the diameter of the primary mirror.

____ 8. The more massive the star, the faster it will evolve through its life.

____ 9. The event horizon of a non-rotating black hole is located at the center of the singularity Schwarzschild Radius.

____ 10. Elements heavier than oxygen iron cannot be produced by ordinary nuclear fusion reactions because fusion reactions for elements heavier than oxygen iron require energy rather than release energy.

____ 11. According to Wien’s law, hot stars are blue and cool stars red in color.

____ 12. Stars in the disk of the Milky Way move in nearly circular orbits, in roughly the same plane, but at vastly different about the same speeds, with stars near the center orbiting at more than three times the speed of stars near the edge of the disk.

____ 13. The lower chromosphere is the coolest region in the Sun.

____ 14. There is no lower or upper limit to the wavelength of electromagnetic radiation.
Section III. (132 pts). Answer the following questions by writing the appropriate letter in the blank to the left of the question number. Choose the BEST answer.

15. A piece of iron is heated from 400 K to 800 K. By what factor will the total energy per second emitted by this iron increase?
   a. 2
   b. 4
   c. 8
   d. 16
   \[
   \frac{F_{\text{new}}}{F_{\text{old}}} = \frac{\sigma T_{\text{new}}^4}{\sigma T_{\text{old}}^4} = \left(\frac{800}{400}\right)^4 = 2^4 = 16
   \]

16. What is an atmospheric window?
   a. A region in the atmosphere where light can get through.
   b. A region in the atmosphere where infrared radiation can penetrate.
   c. A range of wavelengths of electromagnetic radiation which transmit through the Earth’s atmosphere.
   d. A part of the upper atmosphere with depleted ozone.

17. In a radio wave transmitter (such as that used by a radio or TV station), when the frequency of the signals is increased, the
   a. wavelength is decreased.
   b. speed of transmission of the waves is increased.
   c. wavelength and speed of transmission both increase.
   d. wavelength remains constant.

18. The star P Cygni (in the constellation Cygnus, the Swan) is surrounded by an extensive low-density atmosphere. Its spectrum consists of a bright, continuous spectrum with many narrow, dark absorption lines and a few bright emission lines. The bright, continuous part of the spectrum is produced by
   a. all parts of the star, the stellar surface and the atmosphere, equally.
   b. only the part of the low-density atmosphere that is between us and the surface of the star.
   c. the hot, dense, opaque gas of the star's surface.
   d. the hot, low-density atmosphere of the star emitting light in all directions.

19. Violet light differs from red light in that violet light
   a. has a longer wavelength than red light.
   b. travels more slowly (through a vacuum) than red light.
   c. travels more quickly (through a vacuum) than red light.
   d. has a shorter wavelength than red light.

20. An astronomer photographs the spectrum of an object and finds a spectral line at 499 nm wavelength. In the laboratory, this spectral line occurs at 500 nm. According to the Doppler effect, this object is moving
   a. toward the Earth at 499/500 the speed of light.
   b. toward the Earth at 1/500 the speed of light. \[ \Delta v = \frac{\Delta \lambda}{\lambda} = \frac{500 - 499}{500} \text{ nm} = \frac{1}{500} \]
   c. away from the Earth at 499/500 the speed of light.
   d. away from the Earth at 1/500 the speed of light.
21. The specific colors of light emitted by an atom in a hot, thin gas (e.g., in a tube in a laboratory or a gas cloud in space) are caused by
   a. electrons absorbing photons and jumping to higher energy levels.
   b. an electron dropping into the nucleus and causing changes in the energy of the nucleus.
   c. electrons jumping to lower energy levels, losing energy and emitting photons.
   d. protons jumping from level to level.

22. The figure at right shows that a blackbody with a temperature of 3000 K emits radiation that peaks at a wavelength much longer than wavelengths in the visible part of the spectrum. This means that
   a. the object is not visible but might be detected with equipment sensitive to nonvisible radiation.
   b. the object, like all blackbodies, emits no radiation.
   c. the object emits visible radiation, but not as intensely as at longer wavelengths.
   d. no visible radiation is emitted, but visible radiation would be emitted if the temperature of the object were increased.

23. An astronomer studying a particular object in space finds that the object emits light only in specific, narrow emission lines. The correct conclusion is that this object
   a. cannot consist of gases but must be a solid object.
   b. is made up of a hot, dense gas surrounded by a rarefied gas.
   c. is made up of a hot, dense gas.
   d. is made up of a hot, low-density gas.

24. What is the correct explanation of the bending of a beam of light as it passes close to a massive object like the Sun?
   a. The gravitational field interacts with the electromagnetic field of the photons to bend the light.
   b. It is traveling across and must follow the curved spacetime surrounding a massive object.
   c. The gravitational field of the massive object changes the refractive index of the nearby space, leading to bending of the light.
   d. The massive object causes the diffraction of the light waves into different directions.

25. A planetary nebula is created
   a. over several hundred years, during mass transfer in a close binary star system.
   b. in seconds, during the helium flash in a low-mass star.
   c. slowly over 10,000 years or more, due to thermal pulses in a low-mass star.
   d. in hours or less, during the explosion of a massive star.

26. Certain stages of stellar evolution, such as birth of a protostar and post-main sequence red giant evolution, come about because of an imbalance between gravity and
   a. high-energy neutrino pressure.
   b. radiation intensity.
   c. the centrifugal force from rotation.
   d. internal gas pressure.
27. The spectral class of the Sun is G2 and the star Enif is K2. From this information, we know that Enif is
   a. intrinsically fainter than the Sun.
   b. cooler than the Sun.
   c. intrinsically brighter than the Sun.
   d. hotter than the Sun.

28. What causes the granular appearance of the surface of the Sun?
   a. the regular impact of meteoroids and comets on the solar surface
   b. differential rotation of the surface layers
   c. thermonuclear fusion in its interior
   d. convective motion under the solar surface

29. Which of the following statements is NOT correct in describing a disadvantage of large refracting telescopes when compared to large reflecting telescopes?
   a. Air bubbles in the lens are more of a problem in refracting than reflecting telescopes.
   b. Sagging of the primary optical element under its own weight is a problem with refracting telescopes but not with reflecting telescopes.
   c. Refracting telescopes gather light in proportion to their diameter but reflecting telescopes gather light in proportion to the square of their diameter.
   d. Refracting telescopes suffer from chromatic aberration and reflective telescopes do not.

30. Compared to a star in the middle of the diagram, a star in the lower left part of the Hertzsprung-Russell diagram is
   a. brighter.
   b. cooler.
   c. larger.
   d. smaller.

31. At which phase of a star's life will nuclear fusion reactions that convert helium into carbon and oxygen in the central core of a star occur?
   a. during and immediately after the (first) red giant or supergiant stage
   b. during the protostar stage, before the main sequence
   c. during the main sequence stage, after the star runs out of hydrogen
   d. after the main-sequence phase, before the star becomes a red giant

32. Among the following locations in the universe, where would you expect to find a neutron star?
   a. at the center of the galaxy
   b. at the center of a white dwarf
   c. at the center of a supernova remnant
   d. at the core of a red giant star

33. The Schwarzschild radius of a body is
   a. the distance from its center at which nuclear fusion ceases.
   b. the distance from its surface at which an orbiting companion will be broken apart.
   c. the maximum radius a white dwarf can have before it collapses.
   d. the radius of a body at which its escape velocity equals the speed of light.

34. Which of the following descriptions does NOT represent a property of neutron stars?
   a. emitters of relatively narrow beams of radio energy and other electromagnetic radiation
   b. rotation rates from one to thirty times each second
   c. strong gravitational fields but weak magnetic fields
   d. composed almost entirely of neutrons
35. Which of the following processes is **NOT** involved in the supernova explosion of a massive star?
   a. passage of a shock wave through the star's envelope
   b. formation of a white dwarf star
   c. photodisintegration of nuclei by gamma rays
   d. collapse of the star's core

36. Long-exposure color photographs of the night sky often show regions that glow red, such as parts of the Orion Nebula. This distinctive red color is caused by
   a. the $\text{H}_\alpha$ emission line of atomic hydrogen.
   b. the emission of red and infrared light by warm dust grains.
   c. the collective glow of many red giant stars in the region.
   d. scattering of starlight by dust grains in the nebula.

37. If the temperature near the center of a particular sunspot is 4350 K and the temperature of the surrounding photosphere is 5800 K, then the energy flux (energy passing through each square meter per second) from the center of the sunspot is what fraction of the energy flux from the surrounding photosphere?
   a. 75%
   b. 87%
   c. 56%
   d. **32%**

38. The angular resolution attainable with a radio telescope, compared to that attainable with an optical telescope of the same diameter, is significantly inferior because
   a. the wavelength of radio waves is larger than that of visible light.
   b. it is difficult to make a reflector for radio waves since these waves penetrate most materials.
   c. the Earth's atmosphere disturbs radio waves from space much more than it does visible light.
   d. radio wavelengths are smaller than visible wavelengths, making it difficult to produce a reflector sufficiently smooth to produce images.

39. We can tell that some stars are relatively close to us in the sky because
   a. they appear to move periodically back and forth against the background stars because of Earth's movement around the Sun.
   b. they appear to be extremely bright.
   c. they are occasionally occulted or eclipsed by our Moon.
   d. they have a combination of high luminosity and low apparent brightness.

40. Our Sun will end its life by becoming a
   a. black hole.
   b. **white dwarf**
   c. molecular cloud.
   d. pulsar.
41. What is the most important use of Cepheid variables for astronomers?
   a. The diameter of a Cepheid variable can be found very easily.
   b. The distance to a Cepheid variable can be found very easily.
   c. The metal content of a Cepheid variable can be found very easily.
   d. The characteristics of the pulsation of a Cepheid variable can be used to investigate conditions in the core of the star.

42. The nuclei of which chemical elements are converted to other nuclei to produce the requisite energy in the thermonuclear process that heats the Sun?
   a. Hydrogen is converted to helium.
   b. Helium is split into hydrogen.
   c. The abundant iron is successively split into lighter elements in a chain reaction to produce helium and hydrogen.
   d. Carbon, nitrogen, and oxygen are used as catalysts in a chain reaction to combine hydrogen to produce helium.

43. Which of the following processes does NOT lead to star formation?
   a. compression of a cold interstellar gas-and-dust cloud by the shock wave from a nearby supernova explosion
   b. compression waves passing through interstellar clouds in the arms of spiral galaxies
   c. compression of a hot interstellar gas cloud by its own gravity
   d. compression of a cold part of a large interstellar cloud by another part which contains a group of hot, young, massive stars

44. The rotation of the Sun is
   a. fastest at mid-latitudes, slower at the equator, and slowest near the poles.
   b. fastest at the equator, slower at mid-latitudes, and slowest near the poles.
   c. the same at all latitudes.
   d. fastest at the equator, slowest at mid-latitudes, but spinning up to intermediate speeds around the poles.

45. The luminosity of a star is
   a. its total energy output into all space.
   b. another name for its color or surface temperature.
   c. its brightness as seen by people on the Earth.
   d. its brightness if it were to be at a distance of 10 pc (32.6 ly) from the Earth.

46. The star Regulus must be ________ than Aldebaran because it is _________. (Refer to the diagram at right.)
   a. more luminous … hotter
   b. less massive … cooler
   c. cooler … larger
   d. smaller … hotter

47. The apparent reddening of light from stars after its passage through the interstellar medium (ISM) is caused by
   a. Zeeman shift of the light by the powerful magnetic fields existing within the ISM.
   b. scattering of this light by rapidly moving material, this light being Doppler-shifted toward the red end of the spectrum.
   c. the additional contribution to this starlight by emission from hydrogen gas in the ISM.
   d. preferential scattering of blue starlight by fine dust grains in the ISM.
48. What is the relationship between the mass of a protostar and the time needed for it to reach the main sequence after it forms inside an interstellar cloud?
   a. The time needed is independent of the mass of the protostar.
   b. The time needed is least for a protostar of approximately 4 solar masses and longer for protostars of either greater or lesser mass.
   c. More massive protostars reach the main sequence in a shorter time than less massive protostars.
   d. Less massive protostars reach the main sequence in a shorter time than more massive protostars.

49. Electron degeneracy occurs when
   a. solar wind particles become trapped in the Earth’s magnetic field.
   b. thermonuclear reactions halt the contraction of a protostar.
   c. magnetic fields inhibit the motion of charged particles in sunspots.
   d. electrons inside a star resist being pushed closer together than a certain limit.

50. What causes the core of a high-mass star to collapse?
   a. An excess of hydrogen atoms causes an explosion that crushes the star’s core.
   b. When the iron core becomes sufficiently massive, the electrons merge with protons to form neutrons, reducing core pressure and allowing it to collapse.
   c. As carbon builds up in the core, helium shell burning pushes away the outer layers of the star’s atmosphere, leaving behind a small white dwarf.
   d. The pressure at the center increases until a small black hole forms, collapsing the star.

51. The spectrum of an ordinary main-sequence star is a
   a. series of emission lines, mostly from hydrogen, the major constituent of stellar surfaces, that occasionally overlap to produce sections of continuous color.
   b. continuum of colors crossed by dark absorption lines caused by absorption by cooler atoms and molecules at the star's surface.
   c. continuum of colors, crossed by brighter lines caused by emission from the hot atoms and molecules on the star's surface.
   d. smooth continuum of color, with no sharp emission or absorption lines.

52. Energy is transported from the center of the Sun to the surface by
   a. mostly convection, and by radiation only in the outer layers.
   b. mostly radiation, and by convection only in the outer layers.
   c. radiation in the thermonuclear core, and by convection everywhere else.
   d. convection in the thermonuclear core, and by radiation everywhere else.

53. The temperature of the corona of the Sun
   a. is about twice as hot as the photosphere, 12,000 K.
   b. is about the same as that of the photosphere, 5800 K.
   c. is very cool because it is farthest from the heat source.
   d. is very hot, about $10^6$ K.

54. What is a lenticular (S0) galaxy?
   a. A galaxy with a lot of gas and dust and no particular structure.
   b. A spiral galaxy with fuzzy and poorly formed spiral arms.
   c. An elliptical galaxy with a smooth brightness profile and lacking the central bulge and disk of a spiral galaxy.
   d. A galaxy with a disk and central bulge like a spiral galaxy, but with no spiral arms.
55. When distances were carefully measured from Earth to globular clusters above and below the Milky Way plane (where our view of them is not obscured by interstellar dust and gas), their distribution was found to be
   a. in a relatively flat disk almost perpendicular to the plane of the galaxy, with relatively higher density of clusters toward its center.
   b. **spherically symmetric about a point in the constellation Sagittarius and concentrated in that direction.**
   c. concentrated in the plane of the Milky Way and clustered around the Sun's position, indicating that the Sun is close to the galaxy's center.
   d. uniformly distributed throughout space, with no concentration in any area of the Milky Way.

56. The following distance measuring techniques, arranged in order of the distance for which they are most effective, from smallest to greatest, are
   a. Cepheid variables, spectroscopic parallax, Type Ia supernovae, Tully-Fisher Relation.
   b. Tully-Fisher Relation, spectroscopic parallax, Type Ia supernovae, Cepheid variables.
   c. **spectroscopic parallax, Cepheid variables, Tully-Fisher Relation, Type Ia supernovae.**
   d. Cepheid variables, Type Ia supernovae, Tully-Fisher Relation, spectroscopic parallax.

57. Astronomers have found the existence of spiral arms in galaxies difficult to account for because
   a. **the inner part of a galaxy rotates in a shorter time than the outer parts, so the arms should have wound up so tightly that they would have disappeared over the lifetime of the galaxy.**
   b. the arms should have been destroyed by collisions with other galaxies over the galaxy's lifetime.
   c. the outer regions of a galaxy including the spiral arms have no significant rotation, so the arms should have fallen into the center of the galaxy.
   d. the outer parts of a galaxy rotate faster than the inner parts, so the arms should have straightened out into spokes like those of a bicycle wheel.

58. The possible presence of a supermassive black hole at the center of our galaxy has been deduced from
   a. powerful magnetic fields in the huge filaments arching away from (or toward) the center.
   b. the number of globular clusters that are concentrated near to the galactic center.
   c. gravitational radiation being emitted from stars as they are swallowed by the black hole.
   d. **the very high orbital speed of stars close to the galactic center.**