**Dark Matter, Dark Energy, and the Fate of the Universe**

23.1 Multiple-Choice Questions

1) Why do we call dark matter "dark"?

A) It emits no visible light.

B) We cannot detect the type of radiation that it emits.

C) It emits no or very little radiation of any wavelength.

D) It blocks out the light of stars in a galaxy.

Answer: C

2) What is meant by "dark energy"?

A) the energy associated with dark matter through E=mc2

B) any unknown force that opposes gravity

C) the agent causing the universal expansion to accelerate

D) highly energetic particles that are believed to constitute dark matter

E) the total energy in the Universe after the Big Bang but before the first stars

Answer: C

3) Why do we believe 90 percent of the mass of the Milky Way is in the form of dark matter?

A) The orbital speeds of stars far from the galactic center are surprisingly high, suggesting that these stars are feeling gravitational effects from unseen matter in the halo.

B) Although dark matter emits no visible light, it can be seen with radio wavelengths, and such observations confirm that the halo is full of this material.

C) Theoretical models of galaxy formation suggest that a galaxy cannot form unless it has at least 10 times as much matter as we see in the Milky Way disk, suggesting that the halo is full of dark matter.

D) Our view of distant galaxies is sometimes obscured by dark blotches in the sky, and we believe these blotches are dark matter located in the halo.

Answer: A

4) How do we know that there is much more mass in the halo of our galaxy than in the disk?

A) There are so many globular clusters in the halo that their total mass is greater than the mass of stars in the disk.

B) Stars in the outskirts of the Milky Way orbit the galaxy at much higher speeds than we would expect if all the mass were concentrated in the disk.

C) Although the question of mass in the halo was long mysterious, we now know it exists because we see so many brown dwarfs in the halo.

D) The recent discovery of photinos, combined with theoretical predictions, tells us that there must be a huge mass of photinos in the halo.

E) We *don't* know that there is more mass in the halo; it is only a guess based on theory.

Answer: B

5) What evidence suggests that the Milky Way contains dark matter?

A) We observe clouds of atomic hydrogen far from the galactic center orbiting the galaxy at unexpectedly high speeds, higher speeds than they would have if they felt only the gravitational attraction from objects that we can see.

B) We see many lanes of dark material blocking out the light of stars behind them along the band of the Milky Way.

C) We see many dark voids between the stars in the halo of the Milky Way.

D) When we observe in different wavelengths, such as infrared or radio, we see objects that don't appear in visible-light observations.

E) When we look at the galactic center, we are able to observe a large black hole that is composed of dark matter.

Answer: A

6) If there is no dark matter in the Milky Way Galaxy, what is the best alternative explanation for the observations?

A) We are not measuring the orbital velocities of atomic clouds and stars properly.

B) We are not measuring the distances to atomic clouds and stars properly.

C) We are not attributing enough mass to the visible or "bright" matter.

D) We are not observing all the visible or "bright" matter in the galaxy.

E) Our understanding of gravity is not correct for galaxy-size scales.

Answer: E

7) How are rotation curves of spiral galaxies determined beyond radii where starlight can be detected?

A) by extrapolation

B) through observations of the 21 cm line of atomic hydrogen

C) through observations of spectral lines of dark matter

D) by watching the galaxies rotate over a period of years

E) by measuring the broadening of absorption lines

Answer: B

8) The distribution of the dark matter in a spiral galaxy is

A) approximately spherical and about the same size as the galaxy halo.

B) approximately spherical and about ten times the size of the galaxy halo.

C) flattened in a disk and about the same size as the stellar disk.

D) flattened in a disk but about ten times larger than the stellar disk.

E) predominantly concentrated in the spiral arms.

Answer: B

9) How do we determine the amount of dark matter in elliptical galaxies?

A) We measure the orbital velocities of star-forming gas clouds around the outer portions of the galaxy.

B) We measure the speeds of stars at different radii from the galactic center and determine how much mass is interior to the orbit.

C) We count the number of stars in the galaxy and determine its volume, so that we can calculate the galaxy's density.

D) We search for dark lanes of dust and black holes within the galaxy.

E) We measure how fast the galaxy rotates as a whole.

Answer: B

10) When we see that a spectral line of a galaxy is broadened, that is, spanning a range of wavelengths, we conclude that

A) we do not have very good resolution of a star's orbital velocity.

B) there are many stars traveling at extremely high orbital velocities.

C) there are different Doppler shifts among the individual stars in the galaxy.

D) we are actually measuring the orbital velocity of a cloud of atomic gas.

E) we are actually measuring the orbital velocity of dark matter.

Answer: C

11) A large mass-to-light ratio for a galaxy indicates that

A) the galaxy is very massive.

B) the galaxy is not very massive.

C) on average, each solar mass of matter in the galaxy emits less light than our Sun.

D) on average, each solar mass of matter in the galaxy emits more light than our Sun.

E) most stars in the galaxy are more massive than our Sun.

Answer: C

12) What is the mass-to-light ratio for the inner region of the Milky Way Galaxy, in units of solar masses per solar luminosity?

A) 1,000

B) 600

C) 100

D) 6

E) 0.1

Answer: D

13) Compared to the central regions of spiral galaxies, we expect elliptical galaxies to have

A) higher mass-to-light ratios because stars in elliptical galaxies are dimmer than those in spirals.

B) lower mass-to-light ratios because stars in elliptical galaxies are dimmer than those in spirals.

C) higher mass-to-light ratios because stars in elliptical galaxies do not have high orbital velocities.

D) lower mass-to-light ratios because elliptical galaxies have less gas and dust than spirals.

E) the same mass-to-light ratio because they are made of the same material, stars and dark matter.

Answer: A

14) If a galaxy's overall mass-to-light ratio is 100 solar masses per solar luminosity, and its stars account for only 5 solar masses per solar luminosity, how much of the galaxy's mass must be dark matter?

A) 100 percent

B) 95 percent

C) 80 percent

D) 50 percent

E) 5 percent

Answer: B

15) Which of the following methods used to determine the mass of a cluster does *not* depend on Newton's laws of gravity?

A) measuring the orbital velocities of galaxies in a cluster

B) measuring the temperature of X-ray gas in the intracluster medium

C) measuring the amount of distortion caused by a gravitational lens

D) none of the above

Answer: C

16) Why wasn't the intracluster medium in galaxy clusters discovered until the 1960s?

A) We did not know how much dark matter existed before then.

B) We didn't have the resolution to observe galaxy clusters until then.

C) The Milky Way was blocking our view of distant galaxy clusters.

D) The medium emits X rays, which are blocked by the Earth's atmosphere and require X-ray satellites in space in order to be observed.

E) Radiation emitted by the medium was so dim that we couldn't detect it until we built much larger telescopes.

Answer: D

17) Which of the following statements about rich clusters of galaxies (those with thousands of galaxies) is *not* true?

A) They are sources of X-ray emission due to the presence of hot, intergalactic gas.

B) There likely have been numerous collisions among the member galaxies at some time in the past.

C) Galaxies in the central regions are predominantly spirals, while elliptical galaxies roam the outskirts.

D) They often have a very large, central dominant galaxy near their center, perhaps formed by the merger of several individual galaxies.

E) The speeds of the galaxies in the cluster indicate that most of the cluster mass is dark matter.

Answer: C

18) Gravitational lensing occurs when

A) massive objects bend light beams that are passing nearby.

B) massive objects cause more distant objects to appear much larger than they should and we can observe the distant objects with better resolution.

C) dark matter builds up in a particular region of space, leading to a very dense region and an extremely high mass-to-light ratio.

D) telescope lenses are distorted by gravity.

Answer: A

19) Which of the following is *not* evidence for dark matter?

A) the flat rotation curves of spiral galaxies

B) the broadening of absorption lines in an elliptical galaxy's spectrum

C) X-ray observations of hot gas in galaxy clusters

D) gravitational lensing around galaxy clusters

E) the expansion of the universe

Answer: E

20) Which of the following particles are baryons?

A) electrons

B) neutrinos

C) protons

D) quarks

E) photons

Answer: C

21) Which of the following is an example of *baryonic matter*?

A) you

B) the particles produced by physicists in particle accelerators

C) electrons and positrons produced by pair production

D) WIMPs

E) neutrinos

Answer: A

22) Measuring the amount of deuterium in the universe allows us to set a limit on

A) the temperature of the universe at the end of the era of nuclei.

B) the total amount of mass in the universe.

C) the density of ordinary (baryonic) matter in the universe.

D) the expansion rate of the universe.

E) the current age of the universe.

Answer: C

23) Based on current evidence concerning the amount of deuterium in the universe, we can conclude that

A) ordinary (baryonic) matter makes up most of the mass of the universe.

B) neutrons greatly outnumber protons in the universe.

C) most of the deuterium that was created during the era of nucleosynthesis has since been destroyed.

D) the density of ordinary (baryonic) matter is between 1 percent and 10 percent of the critical density.

E) we live in a critical-density universe.

Answer: D

24) What do we mean when we say that a particle is a weakly interacting particle?

A) It interacts only through the weak force.

B) It interacts only through the weak force and the force of gravity.

C) It is so small that it doesn't affect objects in the universe.

D) It doesn't interact with any type of baryonic matter.

E) It is the only type of particle that interacts through the weak force.

Answer: B

25) Why can't the dark matter in galaxies be made of neutrinos?

A) There are not enough neutrinos to make up all the dark matter.

B) Neutrinos do not have any mass; they interact only through the weak force.

C) We know that dark massive objects such as planets and neutron stars are not made of neutrinos.

D) Neutrinos travel at extremely high speeds and can escape a galaxy's gravitational pull.

E) Big Bang nucleosynthesis constrains how many neutrinos there are in the Universe.

Answer: D

26) Which of the following are candidates for dark matter?

A) brown dwarfs

B) Jupiter-size objects

C) WIMPs

D) faint red stars

E) all of the above

Answer: E

27) Why do we expect WIMPs to be distributed throughout galactic halos, rather than settled into a disk?

A) They are light enough that they have expanded out into the halo.

B) WIMPs were produced at the early stages of galaxy evolution, and objects in the halo, such as globular clusters, were formed at the beginning of the galaxy.

C) Since they do not interact with the electromagnetic force, they do not feel friction or drag and hence do not contract with the rest of the protogalactic cloud.

D) Shock waves from supernovae have blown the WIMPs out into the halo.

E) Jets from the early active stage of a galaxy's life shot out most of the WIMPs from the disk.

Answer: C

28) Why isn't space expanding within systems such as our solar system or the Milky Way?

A) Hubble's law of expansion applies only to the space between galaxies.

B) We are so close to these systems that we don't observe their expansion.

C) The universe is not old enough yet for these objects to begin their expansion.

D) Their gravity is strong enough to hold them together against the expansion of the universe.

Answer: D

29) What are *peculiar velocities*?

A) velocities perpendicular to our line of sight

B) velocities directly along our line of sight

C) velocities that we cannot explain by only the force of gravity

D) velocities caused by the expansion of the universe

E) velocities of distant objects that are not caused by the expansion of the universe

Answer: E

30) What do peculiar velocities reveal?

A) the amount of dark matter in a galaxy

B) the distribution of dark matter in large-scale structures

C) the composition of dark matter

D) the error in our observations of Hubble's law

E) the critical density of the universe

Answer: B

31) How do astronomers create three-dimensional maps of the universe?

A) through comparison of computer models of the structure formation with observations

B) by using the position on the sky and the redshift to determine a distance along the line of sight

C) by using the position on the sky and the galaxy brightness as a measure of distance along the line of sight

D) by interpreting the peculiar velocities of each galaxy

E) by carefully measuring the parallax of each galaxy

Answer: B

32) What does the universe look like on very large scales?

A) Galaxies are uniformly distributed.

B) Galaxies are randomly distributed.

C) Galaxies are distributed in a hierarchy of clusters, superclusters, and hyperclusters.

D) Galaxies appear to be distributed in chains and sheets that surround great voids.

E) Galaxies are distributed in a great shell expanding outward from the center of the universe.

Answer: D

33) What fraction of the mass needed to halt expansion is known to exist in the form of visible mass in the universe?

A) 1 percent

B) 4 percent

C) 22 percent

D) 74 percent

E) 100 percent

Answer: A

34) Based on inventoried matter in the universe, including dark matter known to exist in galaxies and clusters, the actual density of the universe is what fraction of the critical density?

A) 1 percent

B) 10 percent

C) 26 percent

D) 74 percent

E) 100 percent

Answer: C

35) If all the "dark matter" in the Universe were to be, somehow, instantaneously removed, which of the following would *not* happen?

A) The Solar System would fly apart.

B) The Milky Way would fly apart.

C) Clusters of galaxies would fly apart.

D) The Universe would expand forever.

E) all of the above

Answer: A

36) Which model of the universe gives the youngest age for its present size?

A) a recollapsing universe

B) a coasting universe

C) a critical universe

D) an accelerating universe

E) all models give the same age

Answer: A

37) What is the ultimate fate of an open universe?

A) the Big Crunch

B) Stars will expand away from each other and galaxies effectively "evaporate."

C) All matter decays to a low-density sea of photons and subatomic particles.

D) All matter eventually ends up in massive black holes.

E) Individual stars die but their gas is recycled through the interstellar medium and new stars form in a never-ending process.

Answer: C

38) Recent measurements of the expansion rate of the universe reveal that the expansion rate of the universe is doing something astronomers did not expect. What is that?

A) The measurements show that the universe may not be expanding at all.

B) The measurements show that the universe may be shrinking rather than expanding.

C) The measurements show that the expansion is accelerating, rather than slowing under the influence of gravity.

D) The measurements indicate that the universe is at least 30 billion years old, meaning that more than 10 billion years passed between the Big Bang and the formation of the first stars and galaxies.

E) The data show that the expansion rate varies widely in different parts of the universe.

Answer: C

39) What is the evidence for an accelerating universe?

A) White-dwarf supernovae are the same brightness regardless of redshift.

B) White-dwarf supernovae are slightly brighter than expected for a coasting universe.

C) White-dwarf supernovae are slightly dimmer than expected for a coasting universe.

D) The Andromeda Galaxy is moving away from the Milky Way at an ever-increasing speed.

E) There is far more dark matter than visible matter in the universe.

Answer: C

40) What might be causing the universe to accelerate?

A) WIMPs

B) neutrinos

C) white-dwarf supernovae

D) dark gravity

E) We don't know!–but we call it "dark energy."

Answer: E

41) What is Einstein's *cosmological constant*?

A) the value of the expansion rate of the universe

B) the value of the acceleration of the universe

C) the value that measures the strength of gravity across the universe

D) the size of the cosmological horizon

E) a repulsive force that counteracts gravity and was introduced to allow for a static universe

Answer: E

42) What is *not* a main source of evidence for the existence of dark matter?

A) massive blue stars

B) rotation curves of disk galaxies

C) stellar motions in elliptical galaxies

D) velocities and positions of galaxies in clusters of galaxies

E) gravitational lensing by clusters of galaxies

Answer: A

23.2 True/False Questions

1) Approximately 90 percent of the mass of the Milky Way is located in the halo of the galaxy in the form of dark matter.

Answer: TRUE

2) Dark matter is purely hypothetical, because we have no way of detecting its presence.

Answer: FALSE

3) If the universe is *accelerating*, it will expand forever.

Answer: TRUE

4) If we learn that the universe is a *recollapsing* universe, it will mean that the universe is presently contracting, rather than expanding as generally believed.

Answer: FALSE

5) By definition, our Sun has a mass-to-light ratio of 1 solar mass per solar luminosity.

Answer: TRUE

6) One possible ingredient of dark matter is known as WIMPs, or weakly interacting massive particles. WIMPs probably are made of protons and neutrons.

Answer: FALSE

7) Although we don't know exactly when clusters, galaxies, or stars began forming, we *do* know that clusters came first, with galaxies and stars forming later.

Answer: FALSE

8) Individual galaxies generally have higher mass-to-light ratios than clusters of galaxies.

Answer: FALSE

9) Some galaxy clusters are still growing today.

Answer: TRUE

10) The visible parts of galaxies contribute about one-tenth of the critical density of the universe.

Answer: FALSE

11) The only possible geometry of an accelerating universe is open.

Answer: FALSE

23.3 Short Answer Questions

1) Explain why observations suggest the presence of dark energy in the universe?

Answer: Observations show that the expansion rate of the universe was *slower* in the past than its current value. Gravity slows the expansion rate with time so the observed acceleration implies the existence of a new force or energy that h as not been recognized before.

2) Briefly describe how we can use the orbital characteristics of stars at many distances from the galactic center to determine the distribution of mass in the Milky Way.

Answer: Using the orbital velocity law, related to Newton's version of Kepler's third law, we can determine the mass of the galaxy that lies within a particular radius if we know the average orbital velocity of stars or clouds at that radius. Therefore, by applying the orbital velocity law to the orbits of stars at many distances from the galactic center, we can determine how much of the mass of the galaxy lies within each radius. We then can plot the mass of the galaxy as a function of radius and obtain the distribution of the mass in the Milky Way. We often use the 21-cm line from atomic hydrogen to measure velocities of gas clouds, because light at radio wavelengths can penetrate the dust that would normally obscure our vision in other wavelengths. Thus, we can measure orbital velocities of gas clouds wherever the gas is located in the galaxy.

3) How do we know that there are insignificant amounts of dark matter in the solar system?

Answer: We can measure the distribution of mass in the solar system through analysis of the rotation curve, i.e. the velocity at which planets at different distances from the Sun rotate, in an analogous way to the rotation curves of galaxies. Since the rotation curve of the solar system decreases with increasing distance in the same way that we would predict for a central mass (the Sun), we infer that there are no "hidden" sources of gravitational mass in the solar system. Dark matter must be distributed over much larger scales.

4) Suppose you discovered a galaxy with a mass-to-light ratio of 0.1 solar mass per solar luminosity. What would this measurement say about the nature of the stars in this galaxy?

Answer: If a galaxy has a lower mass-to-light ratio than 1, then the ratio of massive hot stars to dim cool stars in this galaxy must be higher than that ratio in our own galaxy (or indeed every other galaxy observed to date). If I had confidence in my observations, I might suspect that the star formation in this galaxy must have produced an unusual predominance of high-mass stars.

5) How do mass-to-light ratios for the inner regions of galaxies compare to the mass-to-light ratios we find when we look farther from a galaxy's center? What does this tell us about dark matter in galaxies?

Answer: The farther we look from a galaxy's center, the higher mass-to-light ratios we find. In fact, this ratio grows as we go from single galaxies to clusters of galaxies. This tells us that mass is concentrated not at the centers of galaxies but in the halos of galaxies and the intergalactic medium.

6) Briefly describe two different ways of measuring the mass of a cluster of galaxies.

Answer: There are three basic methods: The first method is to apply a form of the orbital velocity law to a group of galaxies. The second method relies on how hot X-ray gas in the intracluster medium is. Since the intracluster medium is nearly in a state of gravitational equilibrium, the average kinetic energies of the gas particles (which we can find by measuring the temperature of the gas) are determined primarily by the strength of gravity and hence by the amount of mass within the cluster. The third method uses gravitational lensing to determine the mass of the cluster. The light-bending angle of a gravitational lens depends on the mass of the cluster, so we can measure the mass by observing how strongly the cluster distorts light paths of more distant galaxies. All three methods generally agree with one another.

7) Briefly explain how dark matter affects the expansion rate of the universe and the significance of the term critical density in the absence of any mysterious repulsive force.

Answer: Dark matter slows the expansion of the universe, because gravity is an attractive force. In the absence of any mysterious repulsive force (or dark energy), a universe with the average mass density equal to the critical density is the densest universe that will expand forever. A denser universe will eventually reverse its expansion and contract; a less dense universe will expand forever.

8) Explain how observations of white-dwarf supernovae provide information on the expansion of the universe when it was younger.

Answer: White-dwarf supernovae attain the same maximum brightness and are therefore good standard candles with which to measure galaxy distances. Therefore, if we see a white-dwarf supernova in a distant galaxy we can measure how far away it is, and thus how old the universe was when the supernova exploded. We can also measure the Doppler shift of spectral lines in the galaxy and find how fast it is moving away from us. This tells us how fast the universe was expanding when it was much younger.

9) Briefly describe the four possible expansion patterns of the universe.

Answer:

1. Recollapsing universe: the density of the universe is greater than critical. Gravity will eventually reverse the expansion, resulting in a "Big Crunch."

2. Critical universe: the density of the universe is equal to the critical density. Gravity just balances the expansion which slows increasingly down toward zero as time progresses.

3. Coasting universe: the density of the universe is less than the critical density. The expansion overwhelms the attractive force of gravity and the universe expands without limit.

4. Accelerating universe: a mysterious repulsive force that acts against gravity on large scales causes the universe to expand with ever-increasing speed.

10) Why does the value of Hubble's constant alone not tell us the fate of the universe?

Answer: Hubble's constant tells us how fast the universe is expanding today but the fate of the universe (whether it will expand forever or whether the expansion will eventually reverse) depends also on the gravitational pull of all the matter in the universe. Thus to learn about the fate of the universe we must measure not only how fast it is expanding but also how much matter it contains.

11) For a given value of Hubble's constant, how does the age of the universe depend on the overall density of the universe?

Answer: The higher the density, the younger is the universe. This is because Hubble's constant measures the expansion rate at present. If the density is high, then the expansion has slowed substantially with time and must have been much faster in the past. Faster expansion in the past means it took less time for the universe to reach its current size, so the universe would be younger.

12) What do we mean by the critical density of the universe?

Answer: In the absence of any mysterious repulsive force (or dark energy), a universe with the average mass density exactly equal to the critical density is the densest universe that will expand forever. A denser universe will eventually reverse its expansion and contract; a less dense universe will expand forever.

13) *Process of Science*: Scientists have not been able to observe the ultimate fate of our universe. On what evidence do they base the idea that it will expand forever?

Answer: Calculations of the mass in the universe indicate that it is insufficient to halt the expansion.

14) *Process of Science:* Evidence for dark matter in galaxy clusters can be seen in observations of the motions of individual galaxies, X-ray observations of hot intra-cluster gas, and gravitational lensing. What is different about lensing that further strengthens the case that dark matter really does exist.

Answer: Gravitational lensing provides a mass estimate that is not derived using Newton's laws of motion. Thus a possible argument that Newton's laws do not apply on the scales of galaxy clusters does not negate all the lines of evidence for dark matter. (Moreover, the fact that gravitational lensing gives the same answer as the other methods is evidence that Newton's laws are in deed applicable on these scales.)

15) *Process of Science:* Given that Einstein's equations naturally showed the possibility of an accelerating Universe, why have astronomers only recently found strong evidence for dark energy?

Answer: The difference between a coasting and accelerating expansion is only apparent at very large lookback times. It therefore requires careful observations of white dwarf supernovae in distant galaxies. This only became possible a little over a decade ago. Similarly, we have only recently gained the instrumentation possible to study the tiny fluctuations in the cosmic microwave background that also point to a flat Universe that is indicative of dark energy.

23.4 Mastering Astronomy Reading Quiz

1) Which of the following best summarizes what we mean by *dark matter*?

A) matter that we have identified from its gravitational effects but that we cannot see in any wavelength of light

B) matter that may inhabit dark areas of the cosmos where we see nothing at all

C) matter consisting of black holes

D) matter for which we have theoretical reason to think it exists, but no observational evidence for its existence

Answer: A

2) Which of the following best summarizes what we mean by *dark energy*?

A) It is a name given to whatever is causing the expansion of the universe to accelerate with time.

B) It is the energy contained in dark matter.

C) It is the energy of black holes.

D) It is a type of energy that is associated with the "dark side" of The Force that rules the cosmos.

Answer: A

3) The text states that luminous matter in the Milky Way seems to be much like the tip of an iceberg. This refers to the idea that

A) luminous matter emits white light, much like the light reflected from icebergs.

B) black holes are much more interesting than ordinary stars that give off light.

C) dark matter represents much more mass and extends much further from the galactic center than the visible stars of the Milky Way.

D) the luminous matter of the Milky Way is essentially floating on the surface of a great sea of dark matter.

Answer: C

4) What is a *rotation curve*?

A) a precise description of the shape of a star's orbit around the center of the Milky Way Galaxy

B) a graph showing how orbital velocity depends on distance from the center for a spiral galaxy

C) a curve used to decide whether a star's orbit places it in the disk or the halo of a spiral galaxy

D) a graph that shows a galaxy's mass on the vertical axis and size on the horizontal axis

Answer: B

5) What is the primary way in which we determine the mass distribution of a *spiral* *galaxy*?

A) We calculate its mass-to-light ratio.

B) We apply Newton's version of Kepler's third law to the orbits of globular clusters in the galaxy's halo.

C) We count the number of stars we can see at different distances from the galaxy's center.

D) We construct its rotation curve by measuring Doppler shifts from gas clouds at different distances from the galaxy's center.

Answer: D

6) What do we mean when we say that the rotation curve for a spiral galaxy is "flat"?

A) The amount of light emitted by stars at different distances is about the same throughout the galaxy.

B) Gas clouds orbiting far from the galactic center have approximately the same orbital speed as gas clouds located further inward.

C) The disk of a spiral galaxy is quite flat rather than spherical like the halo.

D) All the galaxy's mass is concentrated in its flat, gaseous disk.

Answer: B

7) Although we know less about dark matter in elliptical galaxies than in spiral galaxies, what does current evidence suggest?

A) Elliptical galaxies probably contain about the same proportion of their mass in the form of dark matter as do spiral galaxies.

B) Elliptical galaxies probably contain far less dark matter than spiral galaxies.

C) Elliptical galaxies probably contain far more dark matter than spiral galaxies.

D) Unlike the broad distribution of dark matter in spiral galaxies, elliptical galaxies probably contain dark matter only near their centers.

Answer: A

8) In general, when we compare the mass of a galaxy or cluster of galaxies to the amount of light it emits (that is, when we look at it *mass-to-light ratio*), we expect that

A) the higher amount of mass relative to light (higher mass-to-light ratio), the lower the proportion of dark matter.

B) the higher the amount of mass relative to light (higher mass-to-light ratio), the greater the proportion of dark matter.

C) the amount of light should be at least one solar luminosity for each solar mass of matter (mass-to-light ratio less than or equal to 1).

D) the higher the amount of mass relative to light (higher mass-to-light ratio), the older the galaxy or cluster.

Answer: B

9) Which of the following is not one of the three main strategies used to measure the mass of a *galaxy clusters*?

A) measuring the speeds of galaxies orbiting the cluster's center

B) studying X-ray emission from hot gas inside the cluster

C) observing how the cluster bends light from galaxies located behind it

D) measuring the temperatures of stars in the halos of the galaxies

Answer: D

10) When we say that a cluster of galaxies is acting as a *gravitational lens*, what do we mean?

A) It magnifies the effects of gravity that we see in the cluster.

B) It is an unusually large cluster that has a lot of gravity.

C) It bends or distorts the light coming from galaxies located behind it.

D) The overall shape of the cluster is that of a lens.

Answer: C

11) Which of the following statements best summarizes current evidence concerning dark matter in individual galaxies and in clusters of galaxies?

A) Dark matter is the dominant form of mass in both clusters and in individual galaxies.

B) Dark matter is present between galaxies in clusters, but not within individual galaxies.

C) Dark matter is present in individual galaxies, but there is no evidence that it can exist between the galaxies in a cluster.

D) Within individual galaxies, dark matter is always concentrated near the galactic center, and within clusters it is always concentrated near the cluster center.

Answer: A

12) What is the distinguishing characteristic of what we call ordinary or *baryonic* matter?

A) It emits a great deal of light.

B) It can attract other matter through the force of gravity.

C) It is made of subatomic particles that scientists call WIMPs.

D) It consists of atoms or ions with nuclei made from protons and neutrons.

Answer: D

13) What do we mean when we say that particles such as neutrinos or WIMPs are *weakly* *interacting*?

A) The light that they emit is so weak that it is undetectable to our telescopes.

B) They are only weakly bound by gravity, which means they can fly off and escape from galaxies quite easily.

C) They respond to the weak force but not to the electromagnetic force, which means they cannot emit light.

D) They interact with other matter only through the weak force and not through gravity or any other force.

Answer: C

14) Which of the following best sums up current scientific thinking about the nature of dark matter?

A) Most dark matter probably consists of weakly interacting particles of a type that we have not yet identified.

B) Dark matter consists 90% of neutrinos and 10% of WIMPs.

C) There is no longer any doubt that dark matter is made mostly of WIMPs.

D) Dark matter probably does not really exist, and rather indicates a fundamental problem in our understanding of gravity.

Answer: A

15) When we speak of the *large-scale structure* of the universe, we mean

A) the structure of any large galaxy.

B) the structure of any individual cluster of galaxies.

C) the overall shape of the observable universe.

D) the overall arrangement of galaxies, clusters of galaxies, and superclusters in the universe.

Answer: D

16) The *critical density* of the universe is the

A) average density the universe would need for gravity to someday halt the current expansion *if* dark energy did not exist.

B) actual average density of the universe.

C) density of dark matter in the universe.

D) density of water.

Answer: A

17) What is the primary form of evidence that has led astronomers to conclude that the expansion of the universe is accelerating?

A) observations of the speeds of individual galaxies in clusters

B) measurements of the rotation curve for the universe

C) measurements of how galaxy speeds away from the Milky Way have increased during the past century

D) observations of white dwarf supernovae

Answer: D

18) Which of the following best sums up current scientific thinking about the nature of *dark energy*?

A) Dark energy most likely consists of a form of photons that we can't see or detect.

B) Dark energy is most likely made up of weakly interacting particles that do not interact with light.

C) Dark energy probably exists, but we have little (if any) idea what it is.

D) Dark energy is the source of the mind weapon used by Sith Lords in *Star Wars*.

Answer: C

23.5 Mastering Astronomy Concept Quiz

1) Why do we call dark matter "dark"?

A) It is dark brown or dark red in color.

B) It blocks out the light of stars in a galaxy.

C) It emits no radiation that we have been able to detect.

D) It contains large amounts of dark-colored dust.

Answer: C

2) Although most astronomers assume dark matter really exists, there is at least one other possible explanation for the phenomena attributed to dark matter. What is it?

A) The so-called dark matter is really just ordinary stars that are enshrouded in clouds of dust.

B) There could be something wrong or incomplete with our understanding of how gravity operates on galaxy-size scales.

C) There could be something wrong with our understanding of how atoms produce light.

D) We could just be having a hard time understanding the observations because they involve very distant galaxies.

Answer: B

3) Spiral galaxy rotation curves are generally fairly flat out to large distances. Suppose that spiral galaxies did *not* contain dark matter. How would their rotation curves be different?

A) The orbital speeds would fall off sharply with increasing distance from the galactic center.

B) The orbital speeds would rise upward with increasing distance from the galactic center, rather than remaining approximately constant.

C) The rotation curve would be a straight, upward sloping diagonal line, like the rotation curve of a merry-go-round.

D) The rotation curve would look the same with or without the presence of dark matter.

Answer: A

4) The flat rotation curves of spiral galaxies tell us that they contain a lot of dark matter. Do they tell us anything about *where* the dark matter is located within the galaxy?

A) Yes, they tell us that dark matter is concentrated near the center of the galaxy.

B) Yes, they tell us that dark matter is spread uniformly throughout the galactic disk.

C) Yes, they tell us that dark matter is spread throughout the galaxy, with most located at large distances from the galactic center.

D) No, we cannot determine anything about the location of dark matter from the rotation curve.

Answer: C

5) It is more difficult to determine the total amount of dark matter in an elliptical galaxy than in a spiral galaxy. Why?

A) Elliptical galaxies lack the atomic hydrogen gas that we use to determine orbital speeds at great distances from the centers of spiral galaxies.

B) Elliptical galaxies contain much less dark matter than spiral galaxies, so it's much more difficult to measure.

C) Stars in elliptical galaxies are dimmer, making them harder to study.

D) We cannot observe spectral lines for elliptical galaxies.

Answer: A

6) How do we know that galaxy clusters contain a lot of mass in the form of hot gas that fills spaces between individual galaxies?

A) We infer its existence by observing its gravitational effects on the galaxy motions.

B) The hot gas shows up as bright pink in visible-light photos of galaxy clusters.

C) We can observe the frictional effects of the hot gas in slowing the speeds of galaxies in the clusters.

D) We detect this gas with X-ray telescopes.

Answer: D

7) Why does the temperature of the gas between galaxies in galaxy clusters tell us about the mass of the cluster?

A) The temperature is always directly related to mass, which is why massive objects are always hotter than less massive objects.

B) The temperature tells us the average speeds of the gas particles, which are held in the cluster by gravity, so we can use these speeds to determine the cluster mass.

C) The temperature of the gas tells us the gas density, so we can use the density to determine the cluster's mass.

D) The question is nonsense—gas temperature cannot possibly tell us anything about mass.

Answer: B

8) How does *gravitational lensing* tell us about the mass of a galaxy cluster?

A) The lensing allows us to determine the orbital speeds of galaxies in the cluster, so that we can determine the mass of the cluster from the orbital velocity law.

B) The lensing broadens spectral lines, and we can use the broadening to "weigh" the cluster.

C) Using Einstein's general theory of relativity, we can calculate the cluster's mass from the precise way in which it distorts the light of galaxies behind it.

D) Newton's universal law of gravitation predicts how mass can distort light, so we can apply Newton's law to determine the mass of the cluster.

Answer: C

9) If WIMPs really exist and make up most of the dark matter in galaxies, which of the following is *not* one of their characteristics?

A) They travel at speeds close to the speed of light.

B) They are subatomic particles.

C) They can neither emit nor absorb light.

D) They tend to orbit at large distances from the galactic center.

Answer: A

10) Is space expanding *within* clusters of galaxies?

A) No, because the universe is not old enough yet for these objects to have begun their expansion.

B) No, because expansion of the universe affects only empty space, not space in which matter is present.

C) Yes, and that is why clusters tend to grow in size with time.

D) No, because their gravity is strong enough to hold them together even while the universe as a whole expands.

Answer: D

11) Which of the following statements about large-scale structure is probably not true?

A) Galaxies and clusters have grown around tiny density enhancements that were present in the early universe.

B) Voids between superclusters began their existence as regions in the universe with a slightly lower density than the rest of the universe.

C) Many cluster and superclusters are still in the process of formation as their gravity gradually pulls in new members.

D) Clusters and superclusters appear to be randomly scattered about the universe, like dots sprinkled randomly on a wall.

Answer: D

12) Based on current evidence, a supercluster is most likely to have formed in regions of space where

A) the density of dark matter was slightly higher than average when the universe was very young.

B) there was an excess concentration of hydrogen gas when the universe was very young.

C) supermassive black holes were present in the very early universe.

D) the acceleration of the expansion was proceeding faster than elsewhere.

Answer: A

13) Based on current evidence, how does the actual average density of matter in the universe compare to the *critical* density?

A) If we include dark matter, the actual density equals the critical density.

B) The actual density, even with dark matter included, is less than about a third of the critical density.

C) The actual density of dark matter and luminous matter combined is no more than about 1% of the critical density.

D) The actual density of matter is many times higher than the critical density.

Answer: B

14) Which of the following statements best describes the current state of understanding regarding the apparent acceleration of the expansion of the universe?

A) The cause of the acceleration is well-understood, and attributed to the particles that make up *dark energy*.

B) We have moderately strong evidence that the acceleration is real, but essentially no idea what is causing it.

C) The acceleration is very important in the cosmos today, but the evidence indicates that it will eventually slow down, allowing the universe to recollapse.

D) The acceleration probably is not real, and what we attribute to acceleration is probably just a misinterpretation of the data.

Answer: B

15) Some people wish that we lived in a recollapsing universe that would eventually stop expanding and start contracting. For this to be the case, which of the following would have to be true (based on current understanding)?

A) Dark energy is the dominant form of energy in the cosmos.

B) Dark energy does not exist and there is much more dark matter than we are aware of to date.

C) Neither dark energy nor dark matter really exist.

D) Dark energy exists but dark matter does not.

Answer: B

16) Hubble's constant is related to the age of the universe, but the precise relationship depends on the way in which the expansion rate changes with time. For a given value of Hubble's constant today (such as 24 km/s/Mly), the age of the universe is *oldest* if what is true?

A) The expansion rate has remained nearly constant with time (a coasting universe).

B) The expansion rate has slowed by the amount expected for a universe with the critical density (a critical universe).

C) The expansion rate has been increasing with time (an accelerating universe).

D) The expansion rate is slowing dramatically with time (a recollapsing universe).

Answer: C

17) Imagine that it turns out that dark *matter* (not dark energy) is made up of an unstable form of matter that decays into photons or other forms of energy about 50 billion years from now. Based on current understanding, how would that affect the universe at that time?

A) Stars would cease to exist when the dark matter is gone.

B) Planetary systems would expand and disperse.

C) The galaxies in clusters would begin to fly apart.

D) The universe would cease its expansion.

Answer: C