## Cosmology                                         Name:

**Homework 1: History of Cosmology**

1. Did you complete reading for this cosmology lecture before it was lectured/bypassed on in class and the corresponding homework by the day after?

   a) YYYessss!  b) Jawohl!  c) Da!  d) Sí, sí.  e) OMG no!

2. Astronomy is often cited as the:

   a) oldest exact, empirical science.  b) youngest exact, empirical science.  c) oldest inexact, empirical science.  d) youngest, inexact, colonial science.  e) oldest form of folklore.

3. Moon-shaped cut marks on bones in groupings of order 30 from paleolithic times (as long ago as 36,000 BCE) suggest that people then were doing astronomy by:

   a) whiling away the time.  b) counting sheep.  c) whittling.  d) counting fingers and toes.  e) counting days of the lunar month.

4. "Let's play *Jeopardy*! For $100, the answer is: Stonehenge and many other prehistoric monuments suggest that the makers were doing this."

   What is/are ____________, Alex?

   a) special relativity calculations  b) orbital physics  c) simple alignment astronomy  d) casting horoscopes  e) receiving alien visitors from outer space

5. Stonehenge demonstrates that some prehistoric people:

   a) could predict eclipses.
   b) knew the northernmost rising location of the Sun.
   c) knew nothing of astronomy.
   d) knew more than the ancient Greeks about the universe.
   e) suffered from back pain.

6. Sexagesimal angular units were introduced in astronomy insofar as we know by:

   a) the Mayans.  b) the Pueblo Indians.  c) Isaac Newton (1642/3–1727).  d) Renaissance astronomers.  e) the ancient Babylonians.

7. The ancient Babylonians were using a sexagesimal (number) system as early as circa 1800 BCE. We do not know why, but it may well have been to save labor in division. The many whole number factors of 60 (1 2, 3, 4, 5, 6, 10, 12, 15, 20, 30, and 60 for a total of 12 factors) simplifies many division problems. The sexagesimal system seems to have been used consistently only for mathematical and astronomical purposes. For everyday use, the Babylonians often or maybe mainly used other systems including the ubiquitous decimal system: counting on fingers is as old as the hills so to say. In the last centuries BCE the sexagesimal system was taken over into astronomy. Using a large base number with a lot of factors has advantages. But one needs a lot of symbols for all the numerals unless one uses some subsidiary base which is what the Babylonians did: 10. In any case 10 as a base has nothing very special to recommend it, except for the old (very old) finger exercise.

   As a non-finger exercise, subtract $61°43'14''$ from $120°41'03''$. Recall that $'$ stands for arcminutes and $''$ for arcseconds. **HINT:** If sexagesimal subtraction seems too tricky, you can try sexagesimal addition to recover $120°41'03''$.

   a) $182°24'17''$.  b) $58°57'49''$.  c) $58°31'14''$.  d) $59°51'49''$.  e) $58°51'14''$.

8. The earliest 6th century BCE names in ancient Greek science include:

   a) Thales, Copernicus, and Aristotle.  b) Thales, Caesar, and Aristotle.  c) Eratosthenes, Thales, and Kepler.  d) Thales, Anaximander, and Pythagoras.  e) Aristotle, Eratosthenes, and Ptolemy.

9. The spherical Earth theory may have been first proposed by Parmenides of Elea. Parmenides was:

   a) Mayan, but he lived in southern California.  b) Babylonian, but he lived in Ur.  c) Roman, but he lived in Alexandria.  d) Icelandic.  e) Greek, but he lived in what in what is now Italy.

10. The ancient Greek Presocratic philosophers:

    a) may have hypothesized a spherical Earth in order to explain the daily rotation of the celestial sphere. But it is equally likely that they thought that a spherical Earth was proven by the axioms of geometry.
    b) may have hypothesized a spherical Earth in order to explain the daily rotation of the celestial sphere. Thales of Miletus then used the spherical Earth theory to predict a solar eclipse.
    c) may have hypothesized a spherical Earth because they thought the Earth needed to be spherical in order to be in balance at the center of the cosmos. Aristotle (384–322) later summarized empirical arguments for the spherical Earth. These included the varying celestial locations of the stars and planets relative to the horizon as one moved north-south and the fact that the Earth's shadow on the Moon in a lunar eclipse was always round. However, **ARISTOTLE** went on to affirm that Greece must be on top of the spherical Earth because the ground in Greece was nearly level.
    d) may have hypothesized a spherical Earth because they thought the Earth needed to be spherical in order to be in balance at the center of the cosmos. Aristotle (384–322) later summarized empirical arguments for the spherical Earth. These included the varying celestial locations of the stars and planets relative to the horizon as one moved north-south and the fact that the Earth's shadow on the Moon in a lunar eclipse was always round. However, **PTOLEMY** went on to affirm that Greece must be on top of the spherical Earth because the ground in Greece was nearly level.
    e) may have hypothesized a spherical Earth because they thought the Earth needed to be spherical in order to be in balance at the center of the cosmos. Aristotle (384–322) later summarized empirical arguments for the spherical Earth. These included the varying celestial locations of the stars and planets relative to the horizon as one moved north-south and the fact that the Earth's shadow on the Moon in a lunar eclipse was always round.

11. A determination of the radius of the Earth was:

    a) made by **ERATOSTHENES** in the **15TH CENTURY CE**. This measurement proved the Earth was spherical and was the inspiration for Columbus's voyage.
    b) made by **ARISTOTLE** in the **15TH CENTURY CE**. This measurement proved the Earth was spherical and was the inspiration for Columbus's voyage.
    c) made by **ERATOSTHENES** in the **3rd CENTURY BCE**. This measurement was based on the assumption that the Earth was **SPHERICAL** and the Sun was very distant from the Earth. If the Earth was not spherical, the measurement would have required the **SAME** interpretation.
    d) made by **ERATOSTHENES** in the **3rd CENTURY BCE**. This measurement was based on the assumption that the Earth was **SPHERICAL** and the Sun was very distant from the Earth. If the Earth was not spherical, the measurement would have required a **DIFFERENT** interpretation.
    e) made by **ERATOSTHENES** in the **3rd CENTURY BCE**. This measurement was based on the assumption that the Earth was an **OVAL SHAPE**. When the result came out spherical, Eratosthenes was surprised.

12. A major obstacle that ancient Greek astronomers had in trying to determine the nature of the Solar System was:

    a) the eastward motion of the planets.
    b) the inability to measure any distances beyond Pluto.
    c) the inability to measure any distances beyond the Moon.
    d) the lack of all theoretical biases.
    e) the lack of geometrical skills.

13. Which of the following sequences is correctly ordered in time?

    a) Aristotle, Ptolemy, Kepler, Copernicus, Thales.
    b) Aristotle, Ptolemy, Galileo, Copernicus, Thales.
    c) Thales, Aristotle, Ptolemy, Copernicus, Galileo.
    d) Ptolemy, Aristotle, Thales, Copernicus, Galileo.
    e) Kepler, Aristotle, Thales, Copernicus, Galileo.

14. The ancient Babylonians of the 5th century BCE probably invented horoscopic astronomy (No-41), but its main structure as passed down to the present probably evolved in the Greco-Roman world from the 2nd century BCE onward (Ne-170–171).

This Greco-Roman astrology has left some unusual imprints on modern conventions. For example, each hour of the 24-hour day—which itself came from the ancient Egyptians of the 2nd millennium BCE by no very logical process (Ne-86)—has a ruler (Ne169). The rulers are the seven moving stars which are ordered in decreasing order by their sidereal periods: Saturn, Jupiter, Mars, Sun, Venus, Mercury, and Moon. The Greco-Roman astronomers (including Ptolemy) believed this was the order of decreasing distance from the Earth: actually it is the order of decreasing distance from the Sun if Earth replaces Sun in the list and you eliminate the Moon.

The rulers of each hour are assigned using the ordered sequence of moving stars. The assignment of rulers starts with the 1st hour of Saturday being Saturn. The next hour is assigned Jupiter as its ruler and so on. When one completes assigning the sequence of 7 stars, then one starts the sequence over again.

Each day of the week has a ruler too: its ruler is the ruler of that day's first hour. A little calculation—or knowing that Jupiter's day got assigned to Thor in English—shows that the day rulers starting from Saturday's ruler Saturn are:

a) Saturn, Sun, Moon, Mars, Saturn, Sun, and Moon.
b) Saturn, Saturn, Saturn, Saturn, Saturn, Saturn, and Saturn.
c) Saturn, Sun, Saturn, Mars, Saturn, Mercury, and Saturn.
d) Saturn, Sun, Moon, Mars, Jupiter, Mercury, and Venus.
e) Saturn, Sun, Moon, Mars, Mercury, Jupiter, and Venus.

15. Aristotelian cosmology:

a) consisted of perfect eternal cubes rotating about the Earth.
b) put the Earth at the center of the cosmos. The planets and fixed stars were located on sets of solid spheres that rotated about the Earth. The celestial phenomena were eternal exactly repeating motions. Beyond the sphere of the fixed stars was a **CHAOS** of primordial material in which were embedded other finite cosmoses.
c) put the Earth at the center of the cosmos. The planets and fixed stars were located on sets of solid spheres that rotated about the Earth. The celestial phenomena were eternal exactly repeating motions. Beyond the sphere of the fixed stars was **NOTHING**, not even empty space. The universe was finite.
d) was **DISCARDED** by everyone in the medieval Islamic period. It put the Earth at the center of the cosmos. The planets and fixed stars were located on sets of solid spheres that rotated about the Earth. The celestial phenomena were eternal exactly repeating motions. Beyond the sphere of the fixed stars was **NOTHING**, not even empty space. The universe was finite.
e) was never seriously considered again after Ptolemy's time.

16. Stellar parallax is:

a) the westward motion of the planets.
b) the daily westward motion of the fixed stars.
c) an optical illusion.
d) the change in angular position of a star relative to background stars due to the Earth's yearly motion around the Sun.
e) the change in magnitude of a star due to the Earth's year motion around the Sun.

17. Take a pencil (or pen or finger). Hold it upright at arm's length in front of some distant object of smallish angular size such as a wall clock. Center the pencil on the object. Then keeping your hand steady (rock steady) shift your head until the object is just out of eclipse. Neither the pencil nor the object has moved in space, but they have shifted in relative angular position because of the movement of the observer. This change in angular position of objects due the shift in the spatial position of the observer is called **PARALLAX**. (Note the term **PARALLAX** is used both for the phenomena of shift in general [e.g., "we know this from parallax"] and for particular angular shifts [e.g., "the parallax" caused by this motion is $10^\circ$].) Try the experiment again but this time with the pencil right in front of your eye: move your head as much as before. Is the angular shift between the pencil and object larger than before? Yes/No? Well maybe after you've tried it carefully a few times it will be clear that parallax effects are bigger for closer objects since the same head movement (the same observational baseline) gives a larger angular shift or parallax. If the Earth were moving in space, would the stars show parallaxes relative to each other?

a) Yes, unless they were so distant that we couldn't detect parallax or unless they were all flying in formation with the Earth. The latter exception was so obviously **REASONABLE** that the ancient Greeks decided the Earth must be moving around the Sun.
b) Yes, unless they were so distant that we couldn't detect parallax or unless they were all flying in formation with the Earth. The latter exception was so obviously **CONTRIVED** that it doesn't seem to have been discussed in history as a means of accounting for the lack of stellar parallax in moving-Earth theories. Stellar parallax was, in fact, first observed in **1838**.
c) Yes, unless they were so distant that we couldn't detect parallax or unless they were all flying in formation with the Earth. The latter exception was so obviously **CONTRIVED** that it doesn't seem to have been discussed in history as a means of accounting for the lack of stellar parallax in moving-Earth theories. Stellar parallax was, in fact, first observed in **2008**.
d) No, never, no matter how close or far they were. Stars unlike any other object just cannot show parallax.
e) Parallax is the change in angular position of an object due to the change in spatial position of the observer.

18. "Let's play *Jeopardy*! For $100, the answer is: A cosmology became something of a philosophical dogma in Greco-Roman Antiquity, the Medieval Islamic and European societies, and in Europe up until the 17th century."

    What is ____________, Alex?

    a) Democritean cosmology  b) Newtonian cosmology  c) Big Bang cosmology
    d) inflation cosmology  e) Aristotelian cosmology

19. In modern times (which here we mean to be after circa 1450), who first proposed the heliocentric theory of the solar system?

    a) Nicolaus Copernicus (1473–1543).  b) Thomas Digges (c. 1546–1595).
    c) Tycho Brahe (1546–1601).  d) Galileo Galilei (1564–1642).
    e) Isaac Newton (1643–1727).

20. The Aristotelian and Ptolemaic cosmologies were:

    a) mutually **COMPLETELY CONSISTENT**. Together they gave a reasonable explanation of celestial phenomena. In the Medieval Islamic and European cultures, they were regarded as totally satisfactory. The heliocentric model of Copernicus was introduce only due to Copernicus' personal eccentricity. He merely made a lucky guess.
    b) **ABANDONED** almost as soon as they were proposed. In the Medieval Islamic and European cultures, no theoretical interpretation was put on celestial phenomena at all. The prediction of celestial events was done entirely using Babylonian cycles.
    c) were largely accepted during in the Medieval Islamic and European cultures despite their **PARTIAL INCONSISTENCY** and their lack of any definite size scale or ordering for the planets. Occasional attempts to improve these cosmologies came to little. The Copernican theory was a **RADICAL ALTERNATIVE**.
    d) were largely accepted during in the Medieval Islamic and European cultures despite their **PARTIAL INCONSISTENCY** and their lack of any definite size scale or ordering for the planets. Occasional attempts to improve these cosmologies came to little. The Copernican theory was **NOT A RADICAL ALTERNATIVE**. It was completely consistent with Aristotelean physics and even kept epicycles.
    e) were largely accepted during in the Medieval Islamic and European cultures despite their **PARTIAL INCONSISTENCY** and their lack of any definite size scale or ordering for the planets. Occasional attempts to improve these cosmologies **ALWAYS SUCCEEDED** in making their quantitative predictions much more accurate. The Copernican theory was only the lucky last of these attempts. Sheer bias kept the Aristotelean and Ptolemaic cosmologies dominant until then.

21. A key reason (perhaps the most important reason) that led Copernicus to propose the heliocentric Solar System was to:

    a) get rid of uniform circular motion.
    b) appease the Sun god.
    c) answer Galileo's insult.
    d) get a prediction of the relative positions of the planets.

e) prove that the universe was infinite.

22. Apparent retrograde motion is:

 a) the **westward** motion of a **star** on the sky.
 b) the **westward** motion of a **planet** on the sky.
 c) the **eastward** motion of a **planet** on the sky.
 d) the **eastward** motion of a **star** on the sky.
 e) the result of an inter-planetary collision.

23. "Let's play *Jeopardy*! For \$100, the answer is: He/she discovered that the planets orbited the Sun in elliptical orbits."

 Who is ____________, Alex?

 a) Apollonios of Perga (circa 3rd century BCE) b) Nicolaus Copernicus (1473–1543)
 c) Galileo Galilei (1564–1642) d) Johannes Kepler (1571–1630)
 e) Caroline Herschel (1750–1848)

24. Kepler's three laws of planetary motion:

 a) **PROVED** the Copernican theory. But this was not immediately realized because it was difficult to master the mathematical techniques and data needed to verify the three laws.
 b) were partially empirical discoveries made by analyzing Tycho's data. The laws were inconsistent with the Tychonic model, and hence **PROVED** the Copernican model.
 c) were partially empirical discoveries made by analyzing Tycho's data. The laws were consistent geometrically with both the Tychonic and Copernican theories. Thus they were **INSUFFICIENT** by themselves to prove the Copernican theory. Nevertheless, since the Earth fit so well as a planet obeying the three laws and was so exceptional as the center of the Solar System (given the three laws), an unbiased person might well have said that the three laws strongly favored the Copernican theory.
 d) were partially empirical discoveries made by analyzing Tycho's data. The laws were consistent geometrically with both the Tychonic and Copernican theories. Thus they were **SUFFICIENT** by themselves to prove the Copernican theory.
 e) were partially empirical discoveries made by analyzing Tycho's data. The laws were consistent geometrically with both the Tychonic and Copernican theories. Thus they were **SUFFICIENT** by themselves to prove the Copernican theory. Realizing this Kepler **SUPPRESSED** them for term of his life.

25. According to Kepler's 3rd law, the orbital period of a planet (i.e., the planet's year) depends on planet:

 a) mass. b) diameter. c) distance from Sun. d) color. e) axis tilt.

26. Kepler's 3rd law for the Solar System planets can be conveniently written

$$P_{\text{year}} = A_{\text{AU}}^{3/2} \qquad \text{or, less conveniently,} \qquad P_{\text{year}}^2 = A_{\text{AU}}^3 \ ,$$

 where $P_{\text{year}}$ is the orbital period in Earth years and $A_{\text{AU}}$ is the mean Sun-planet distance in astronomical units (AU) (i.e., in mean Sun-Earth distances). If an asteroid is 9 AU from the Sun, what is its orbital period in years?

 a) 9. b) 3. c) 27. d) 729. e) 1.

27. If a planet has a mean distance from the Sun of 9 astronomical units, what is its orbital period in years?

 a) 28 years. b) 3 years. c) 9 years. d) 81 years. e) 27 years.

28. Galileo's discovered that Venus showed a full set of phases like the Moon. But it was already known since Antiquity that Venus is never opposite the Sun on the sky and in fact is never further than 46° from the Sun. Thus, Galileo's discovery proved:

 a) Venus orbited the Earth.
 b) Venus orbited the Moon.
 c) Venus orbited the Sun.
 d) Venus executed an orbit about an empty point in space that always lies between the Earth and Sun on the Sun-Earth line.

e) Venus is falling into the Sun perpetually.

29. Galileo did **NOT** discover:

a) the four largest moons of Jupiter. b) the full phases of Venus. c) the moons of Mars.
d) sunspots. e) the mountainous surface of the Moon.

30. Galileo's discovery of the moons of Jupiter:

a) had no bearing on the debate over the Copernican theory.
b) meant that the Earth was the center of Jupiter's orbit.
c) explained the full phases of Venus.
d) meant that the Earth was not the physical center of all motion in the Solar System, and that Earth could have a moon and still be on an **EPICYCLE**.
e) meant that the Earth was not the physical center of all motion in the Solar System, and that Earth could have a moon and still be a **PLANET**.

31. From his observations of Saturn in 1610, Galileo's discovered:

a) that Saturn had an obvious ring.
b) that Saturn had odd protuberances, but he couldn't make out what they were. Christiaan Huygens later in the **17TH CENTURY** concluded that Saturn had a ring.
c) that Saturn had odd protuberances, but he couldn't make out what they were. Christiaan Huygens later in the **20TH CENTURY** concluded that Saturn had a ring.
d) that Saturn had 3 obvious rings that he labled A, B, and C.
e) that Saturn's rings, which are visible to the naked eye were green.

32. Galileo's telescopic discoveries:

a) **PROVED** Copernicanism absolutely. Resistance to this proof was simply irrational.
b) proved that the ancients had been wrong about the cosmos and that they had not had all the evidence. But Kepler's laws had already **PROVEN** Copernicanism to all the mathematically-minded including Galileo. Not everyone had accepted these proofs, of course. Soon—but not soon enough for Galileo—they would.
c) proved that the ancients had been wrong about the cosmos and that they had not had all the evidence. Now Tycho's demonstrations that the heavens were mutable and the crystalline spheres had no existence in a strong sense had already proved some of the ancient beliefs wrong. And Kepler's first two laws, published 1609 just a year before the telescopic discoveries were published in 1610, were so much better descriptions—that is they were more accurate, more unique, and simpler (with a certain interpretation of "simpler" of course)—that they made the ancient descriptions seem implausible. But Tycho's work and Kepler's work (at least prior to the publication of the *Rudolphine Tables* [1627]) was **NOT EASILY VERIFIABLE** by anyone else. The telescopic discoveries could be verified fairly easily (some very easily) by anyone and no expertise with mathematical astronomy was needed. Thus, the telescopic discoveries tore the mask from the cosmos (well a bit anyway) and opened minds to new ideas, even Copernicanism.
d) proved that the ancients had been wrong about the cosmos and that they had not had all the evidence. Now Tycho's demonstrations that the heavens were mutable and the crystalline spheres had no existence in a strong sense had already proved some of the ancient beliefs wrong. And Kepler's first two laws, published 1609 just a year before the telescopic discoveries were published in 1610, were so much better descriptions—that is they were more accurate, more unique, and simpler (with a certain interpretation of "simpler" of course)—that they made the ancient descriptions seem implausible. But Tycho's work and Kepler's work had been mostly ignored because they were **BOTH COPERNICANS** when Copernicanism was still considered to be **COMPLETELY DISCREDITING**. The telescopic discoveries, on the other hand had been made by a Copernican whose Copernicanism was still secret (a closet Copernican), and therefore were generally taken as being well founded. Thus, the telescopic discoveries tore the mask from the cosmos (well a bit anyway) and opened minds to new ideas, even Copernicanism.
e) were completely irrelevant to the debate over Copernicanism. The fact that they were made at about the same time that Copernicanism became a hot topic is a historical coincidence.

33. Newtonian physics unified:

a) thermodynamics and special relativity. b) terrestrial and celestial physics. c) terrestrial and substantial physics. d) terrestrial and Martian physics. e) talking and walking physics.

34. "Let's play *Jeopardy*! For $100, the answer is: They are large, gravitationally-bound systems of stars that range from dwarf versions that are kiloparsec in size scale to the large ones that are tens of kiloparsecs or even a couple hundred kiloparsecs in size scale."

    What are ____________, Alex?

    a) binaries b) open clusters c) globular clusters d) galaxies e) universes

35. Galaxies come in five main types: ellipticals, lenticular, unbarred spirals, barred spirals, and:

    a) globulars. b) regulars. c) irregulars. d) Cepheids. e) Vermeers.

36. "Let's play *Jeopardy*! For $100, the answer is: In the celestial-sphere picture of the sky, this object is luminous band on celestial sphere that straddles a great circle that is at an angle of about 60° to the celestial equator."

    What is the ____________, Alex?

    a) Zodiac b) celestial axis c) ecliptic d) Milky Way e) Andromeda Nebula

37. The center of the Milky Way is in:

    a) Orion. b) Sagittarius. c) Virgo. d) Cassiopeia. e) Pegasus.

38. The first three recorded persons, all living in the 18th century, to speculate about the structure of the Milky Way in the context of Newtonian physics were:

    a) Larry, Curly, and Moe. b) Voltaire, Talleyrand, and Robespierre. c) Ben Franklin, Thomas Jefferson, and George Washington. d) Thomas Wright, Goethe, and Frederick the Great. e) Thomas Wright, Immanuel Kant, and J. H. Lambert.

39. "Let's play *Jeopardy*! For $100, the answer is: He/she attempted to map the Milky Way using star counts (or star gauges)."

    Who is ____________, Alex?

    a) Nicolaus Copernicus (1473–1543) b) Galileo Galilei (1564–1642)
    c) Isaac Newton (1642/3–1727) d) William Herschel (1738–1822)
    e) Caroline Herschel (1750–1848)

40. "Let's play *Jeopardy*! For $100, the answer is: He/she obtained a roughly correct size estimate for the Milky Way and was the first to roughly correctly locate the center of the Milky Way using Cepheid variable stars in globular clusters in the halo of the Milky Way."

    Who is ____________, Alex?

    a) Henrietta Swan Leavitt (1868–1921) b) Heber Curtis (1872–1942)
    c) Harlow Shapley (1885–1972) d) Edwin Hubble (1889–1953)
    e) Stephen Hawking (1942–2018)

41. Clouds in space or, when speaking historically, those objects regarded as cloud-like are called:

    a) shapleys. b) stars. c) galaxies. d) nebulae. e) curtises.

42. The spiral nature of some nebulae was discovered using visual astronomy and the largest telescope of its time: the 183-cm diameter Leviathan of Parsonstown located at Birr Castle, Parsonstown, Ireland. Because the spiral nebula are rather faint, it takes are large telescope to make out the spiral arms visually. With long-exposure photography it is relatively easy to discover spirals. But visual astronomy beat the recently invented photography by some years in this case: the discovery was made in 1845 April by the builder of the Leviathan:

    a) Caroline Herschel (1750–1848). b) the Earl of Rosse (1800–1867).
    c) Henrietta Swan Leavitt (1868–1921). d) Harlow Shapley (1885–1972).
    e) Edwin Hubble (1889–1953).

43. On 1920 April 26, a debate about the nature of the spiral nebulae was held at a meeting of the National Academy of Sciences in Washington, D.C. The debaters both made sound points in the printed

presentations that they later made if not on the day of. This debate is called the Great Debate or the:

a) Einstein-de Sitter debate. b) Rosse-Hubble debate. c) Shapley-Hubble debate. d) Shapley-Curtis debate. e) Kant-Einstein debate.

44. Using Cepheid variable stars as distance indicators and the inverse square law for electromagnetic radiation flux, this famous astronomer was able to prove that M31 (the Andromeda spiral nebulae) was a giant star system (i.e., a galaxy) outside of the Milky Way. His/her name is:

    a) Caroline Herschel (1750–1848). b) Henrietta Swan Leavitt (1868–1921). c) Harlow Shapley (1885–1972). d) Edwin Hubble (1889–1953). e) Knut Lundmark (1889–1958).

45. Edwin Hubble (1889–1953) was able to prove the extragalactic nature of the spiral nebulae because, among other things, he had available the world's:

    a) largest telescope of our day. b) largest telescope of his day. c) smallest telescope of his day. d) smallest telescope of our day. e) largest telescope of Newton's day.

46. The science of the universe as a whole is called:

    a) proctology. b) universology. c) cosmetology. d) inflation. e) cosmology.

47. Given $v$ as recession velocity and $r$ as cosmological physical distance, Hubble's law is:

    a) $r = Hv$. b) $r = H/v$. c) $v = Hr$. d) $v = H/r$. e) $v = Hr^2$.

48. "Let's play *Jeopardy*! For $100, the answer is: He/she is the person who observationally discovered Hubble's law."

    Who is ____________, Alex?

    a) Henrietta Swan Leavitt (1868–1921) b) Knut Lundmark (1889–1958) c) Edwin Hubble (1889–1953) d) Georges Lemaître (1894–1966) e) Adriaan van Maanen (1884–1946)

49. The current value of the Hubble time and the Λ-CDM model (AKA the concordance model) value for the age of the universe are both about:

    a) 14 Gyr. b) $10^{100}$ yr. c) 10 years. d) 4.6 Gyr. e) 0.

50. The Hubble length is $4.283h_{70}^{-1}$ Gpc (where $h_{70}$ is the reduced Hubble constant: it is equal to 1 to within a few percent). It is a characteristic size scale for the:

    a) quantum of the inflaton. b) Milky Way. c) total universe. d) observable universe. e) Solar System.

51. The Einstein universe presented by Einstein in 1917 is a/an ____________ universe model.

    a) contracting, hyperspherical b) expanding, hyperspherical c) static, hyperspherical d) static, hypercritical e) expanding, hypercritical

52. "Let's play *Jeopardy*! For $100, the answer is: These models were the first plausible universe models (in that they contained mass-energy) to predict the expansion of the universe."

    What are the ____________ models, Alex?

    a) Alpher-Behte-Gamow b) Einstein-Lemaître c) Einstein d) Friedmann-equation e) Gamow

53. "Let's play *Jeopardy*! For $100, the answer is: In the Friedmann-equation models, it is the symbol for density parameter which is the parameter that that specifies the geometry of the universe: if less than 1, the universe is hyperbolic and infinite; if equal to 1, the universe is flat and infinite; if greater than 1, the universe is hyperspherical and finite. The symbol name is often used as synonym for density parameter."

    What is ____________, Alex?

    a) $\Lambda$ (spelt Lambda) b) $\Psi$ (spelt Psi) c) $\Delta$ (spelt Delta) d) $\Gamma$ (spelt Gamma) e) $\Omega$ (spelt Omega)

54. According to observations of several kinds beginning in 1998, it is almost certain that the universal expansion is currently:

    a) decelerating. b) stopped. c) negative: i.e., the universe is contracting. d) in doubt. e) accelerating.

55. The simplest explanation considered for the accelerating expansion of the universe is:

    a) planet explosions. b) supernovae. c) stellar winds. d) green energy. e) a cosmological constant.

56. The Friedmann-equation $\Lambda$ model (i.e., the Friedmann-equation model with a nonzero cosmological constant $\Lambda$ or nonzero dark energy but still using the letter $\Lambda$ since one knows what one means) with parameters adjusted to fit current observations was once often called the concordance model, but nowadays is more usually nowadays called the:

    a) $\Lambda$-CDM model. b) $\Omega$-CDM model. c) $\Lambda$-HDM model. d) $\Omega$-HDM model. e) discord model.

57. After the dark energy (whatever that is and assuming it's not just an effect of a true cosmological constant), the most abundant form of mass-energy in the universe is apparently some form of matter known only (at least to circa 2020) through its gravitational effects. We call this matter:

    a) luminous matter. b) dark matter. c) baryonic matter. d) invisible matter. e) mirror matter.

58. The Big Bang, in brief, is the:

    a) explosion of a supernova. b) explosion of a star. c) origin of the observable universe. d) explosion of a quasar. e) end of the observable universe or our pocket universe.

59. In Big Bang nucleosynthesis, the two most abundant products are:

    a) hydrogen and iron in about a 1:1 mass ratio. b) hydrogen and helium in about a 3:1 mass ratio. c) hydrogen and helium in about a 1:1 mass ratio. d) hydrogen and iron in about a 3:1 mass ratio. e) helium and iron in equal amounts by mass.

60. Most of the elements in the observable universe heavier than lithium were formed in:

    a) stars and supernovae. b) black holes. c) the Big Bang. d) nuclear reactors. e) planets.

61. The relic primordial electromagnetic radiation field which decoupled from matter in the recombination era circa 400,000 years after the Big Bang when hydrogen became neutral making the observable universe transparent and which has since free streamed through space and cooled off because of the expansion of the universe is called the:

    a) Cosmic Gamma-ray Background (CGB). b) Cosmic X-ray Bare Ground (CXBG). c) Cosmic X-ray Foreground (CXF). d) Cosmic Microwave Background (CMB). e) Cosmic X-ray Background (CXB).

62. Five observational evidences are:

    1. the expansion of the universe.
    2. the abundances of the light elements: H, D, He, and Li.
    3. the existence of the cosmic microwave background (CMB).
    4. that the fluctuations in the CMB are accounted for by primordial density fluctuations that account adequately so far for the initial conditions for the large-scale structure of the universe.
    5. that the oldest stars ($\gtrsim 13.6$ Gyr) are not older than the observable universe.

    These evidences strongly support:

    a) Big Bang cosmology. b) the steady-state universe. c) little bang cosmology. d) the hierarchical universe. e) Democritean cosmology.

63. "Let's play *Jeopardy*! For \$100, the answer is: It is name for the super-rapid expansion that the observable universe and maybe beyond may have undergone at very early times.

    What is ____________, Alex?

a) inoculation b) infestation c) hybridization d) hydration e) inflation

64. Can we prove the Pythagorean theorem semi-rigorously? Yes.

a) Assume an homogeneous, isotropic (homist) 2-dimensional space. Assume there is a geodesic rule: i.e., there is a rule for measuring distance and for measuring the stationary distance between two points. Draw intersecting equal length geodesics that intersect at their midpoints and that have 4-fold rotational symmetry about their intersection point. A full rotation about the intersection point is measured as 360°. How would you describe size of the angles subtended at the intersection point separating the crossed geodesic arms and why would you say this? Note draw the geodesics vertical and horizontal, so that the descriptions in the following parts are consistent with the diagram.

b) Now draw geodesics between the endpoints of your crossed geodesics, but note we are not assuming Euclidean (i.e., flat space) so that these geodesics could bend outward/inward from intersection point in some projection or another. You now have a square (but not necessarily a Euclidean square). Call it square 1. Now copy square 1 to square 2 and translate square 2 to the upper right so that the lower left corner endpoints of square 2 lie on the upper right corner endpoints of square 1. Is there a space between geodesics of the two squares joining common endpoints? Why or why not?

c) Now copy square 2 to square 3 and translate square 3 to the lower right, but otherwise with the same intructions as in part (b). Now copy square 3 to square 4 and translate square 4 to the lower left, but otherwise with the same intructions as in part (b). Does square 4 necessarily share a common geodesic with the original square 1? Why or why not?

d) The answer to part (c) was no. However, if there is a common geodesic then the space is a Euclidean plane and, at the common corner of the 4 squares, the angles between the geodesics that meet there are all 90°. Postulating that they are 90° is equivalent to Euclid's 5th postulate. For long ages mathematicians wondered if 5th postulate was derivable from Euclid's first 4 postulates. The answer is no. Even somewhat obviously no since, among other things, geodesics that are parallel on a sphere at the equator (i.e., separated by a mutually perpendicular geodesic there) meet at the poles.

Assuming a Euclidean plane, prove that ines (as we now call geodesics) parallel at one location (i.e., separated by a mutually perpendicular line) stay the same perpendicular distance apart no matter how extended. There are probably many ways of proving this, but one path is to start by noting that equal squares of any size can tile the whole Euclidean plane without overlap which actually is an immediate consequence of our considerations above.

e) The fact that one can tile the Euclidean plane completely with squares without overlap suggests an area concept. Consider differential rectangles of side lengths $dx$ and $dy$. Define their area to be $dx\,dy$. We define area to be countable in the sense that the area of $N$ rectangles is $N\,dx\,dy$. You can tile completely any region surrounded by a closed curve with equal differential rectangles with no rectangles wholly out of the region. We define the area of the region by

$$A = \lim_{N\to\infty,\, dx\,dy\to 0} N\,dx\,dy\ .$$

That such limit exists in general requires a rigorous proof that we will not do here. However, one can prove the limit exists in special cases easily and those special cases they also show why defining the area of the differential rectangles in terms of the lengths of their sides is reasonable since finite regions of sufficient symmetry also have areas specified by their defining lengths. An important point is that area is independent of the ordering of the adding up the differentials areas. As a nonce expression, we call this independence the area principle.

Determine the area of a large rectangle of sides $a$ and $b$ in terms of differential rectangles and take the limit so that the properties of the differential rectangles vanish.

f) Prove that the area of a right triangle with sides forming the right angle being of length $a$ and $b$ is $ab/2$. **Hint:** You do need to use the area principle.

g) Draw a diagram of a square with sides of length $a+b$ and an inscribed square with side of length $c$ with corners touching the sides of the first square (which is the circumscribed square) at points $a$ from each corner of the first square.

h) Use the area principle to prove the Pythagorean theorem: i.e., $c^2 = a^2 + b^2$.

i) Prove the metric $ds^2 = dx^2 + dy^2$ holds for a Euclidean plane. **Hint:** This is easy.