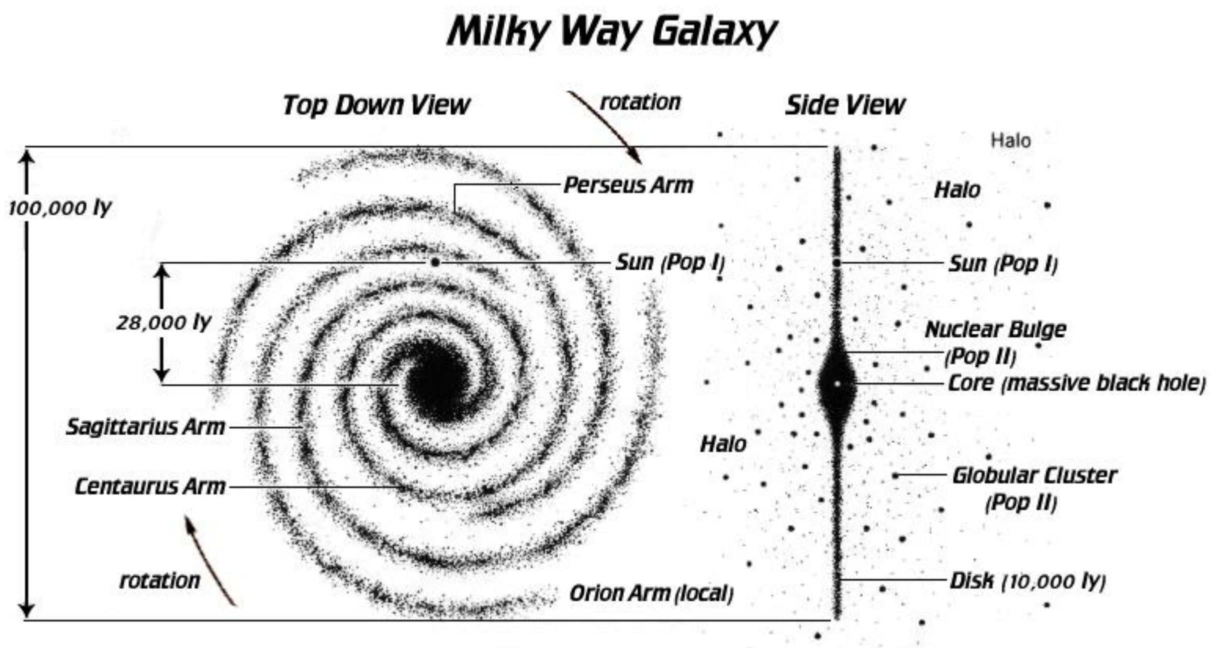
SESSION FIFTEEN: MILKY WAY, GALAXIES, AND THE UNIVERSE



A. **General information about the Milky Way Galaxy**
1. From the side it has an appearance of two saucers placed lip to lip.
2. From the top it looks like a pinwheel.
3. **Diameter:** 100,000 light years; Thickness along the plane: 10,000 light years.
4. **The sun revolves** around the galactic center in about 250 million years.
5. **Total stellar population** is about 400 billion stars/maybe less.
    a. Time to count to 10^6 at one number/sec, 24 x 7 = 12.5 days.
    b. Time to count to 10^9 at one number/sec, 24 x 7 = 34 years.
6. **Total mass:** 0.80 x 10^{12} to 2.43 x 10^{12} solar masses
7. The disk representing the sun in the drawing is about as far as the unaided human eye can see individual stars in the Milky Way.
8. The sun's position is near the galactic plane and as the sun orbits the galaxy, it oscillates "up and down" in response to the gravitation perturbation of the stars and other objects that it is passing.
9. **Stellar Populations**
    a. **Population I Stars:** They were the first to be studied because they were near to the Earth. They are chronologically younger and richer in metals. They are found in the arms of the Milky Way.
    b. **Population II Stars:** They are older chronologically and are metal poor. They are found in the galactic bulge, causing it to appear warmer (yellow) in hue, and in the halo of globular clusters which are evenly distributed around the galaxy.
10. Other galaxies can only be observed when looking away from the spiral arms because the disk of the galaxy is too dusty.

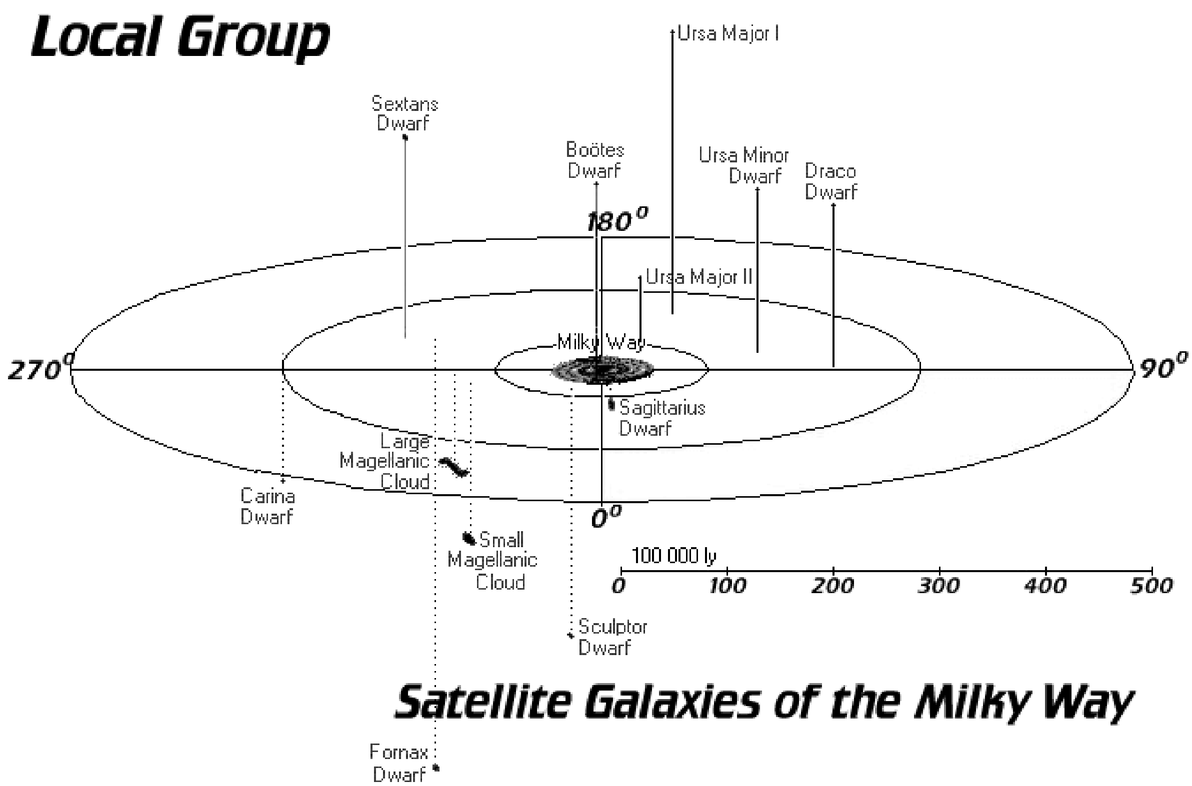
11. **Problems with the Milky Way**
    a. The motion of the inner portion of the galaxy is Keplerian ($p^2 = a^3$), but the outer portion of the Milky Way spins like a disk indicating that there is a substantial amount of mass beyond the visible galaxy.
    b. In the center of the Milky Way there is an inactive black hole of about 3.2 million solar masses. This is indicated by the orbital motions of stars near to it.
    c. **Dark Matter:** Recently (2009) it has been discovered that the Milky Way is surrounded by dark matter in the shape of a deflated beach ball.

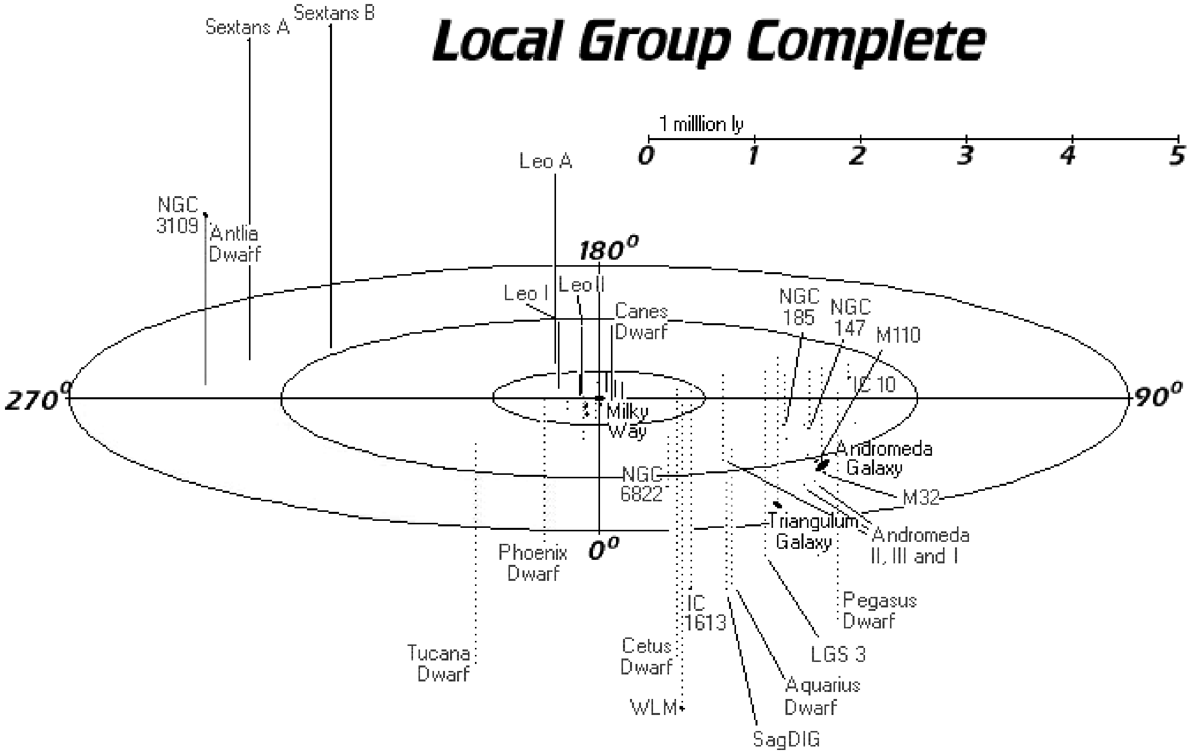
B. **Andromeda Galaxy:**
1. Closest spiral galaxy to the Milky Way which looks like us.
2. Largest and most massive galaxy in the **Local Group** of about 50 galaxies of which the Milky Way is a member.
3. Andromeda is 2.4 million light years in distance.
4. Farthest object that can be observed with the unaided eye.
5. Andromeda, along with the Milky Way, and the great galaxy in Triangulum, M33, comprise the three most luminous and massive members of the **Local Group**.

C. **Local Group (of galaxies)**
1. Composed of about 50 nearby galaxies physically bound together within a sphere of 125 cubic light years.
2. The Local Group is part of the **Virgo cluster** of galaxies
3. Total mass estimate of the Local Group is about 5.27×10^{12} solar masses.
4. **The end game for the Local Group** will be to amalgamate into one huge super galaxy. Currently, the Milky Way and the Andromeda galaxies will physically start colliding in about 3 billion years, although their extensive hydrogen envelopes maybe starting the collision at present.

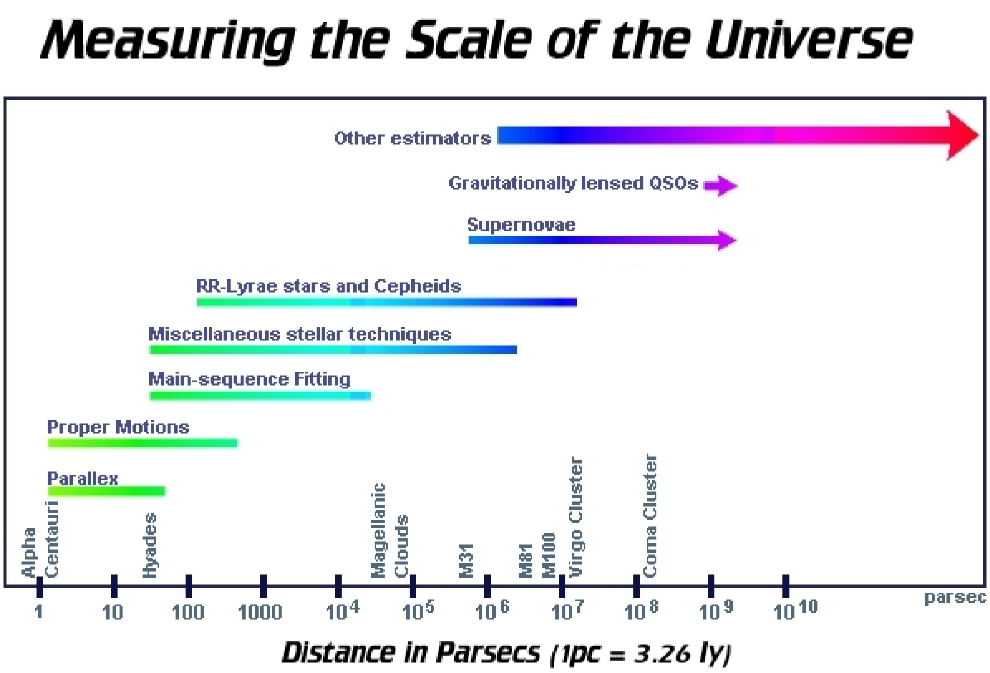
D. **Galaxies in general**
1. **Galaxies are the building block of the universe:** They started formeing within the first 500 millions of the big bang.
2. **Galaxies evolve through cannibalization.** Galaxies evolve through the cannibalization of other galaxies in clusters both large and small.
    a. **The Cartwheel galaxy** is a wonderful example of two galaxies in the process of cannibalizing each other. The Andromeda and Milky Way galaxies are just starting to collide. The latest Hubble Deep Field image (2010) shows some of the first galaxies to form about 600 million years after the big bang. The structures are small, bluish, ragged, and very numerous.
    b. **Distribution:** If a galaxy is the size of a quarter, the distance to the closest galaxy in a cluster of galaxies is about two feet. The separation of galaxies is closer in relative distance then the stars to each other. Since the velocities of galaxies are great, they are bound to collide with one another frequently, unlike the stars.

3. **Structure in Colliding Galaxies:** Gravity (Newtonian mechanics) of just the matter visible in colliding systems cannot account for their strange structures unless dark matter is taken into consideration.
4. **When a census is taken** in the directions of space where there is little dust to obscure light, the total number of galaxies estimated within the universe is given at 100 billion.
5. **Distribution of Galaxies:** Galaxies, like stars, are arranged in groups or clusters. that give the universe a sponge-like texture. But in any direction, the number of galaxies encountered seems uniform.
6. **As space expands, the galaxies are carried along with this expansion** like dots on a balloon which is being inflated. There is no center point to this expansion. All locations in the universe act as center points.



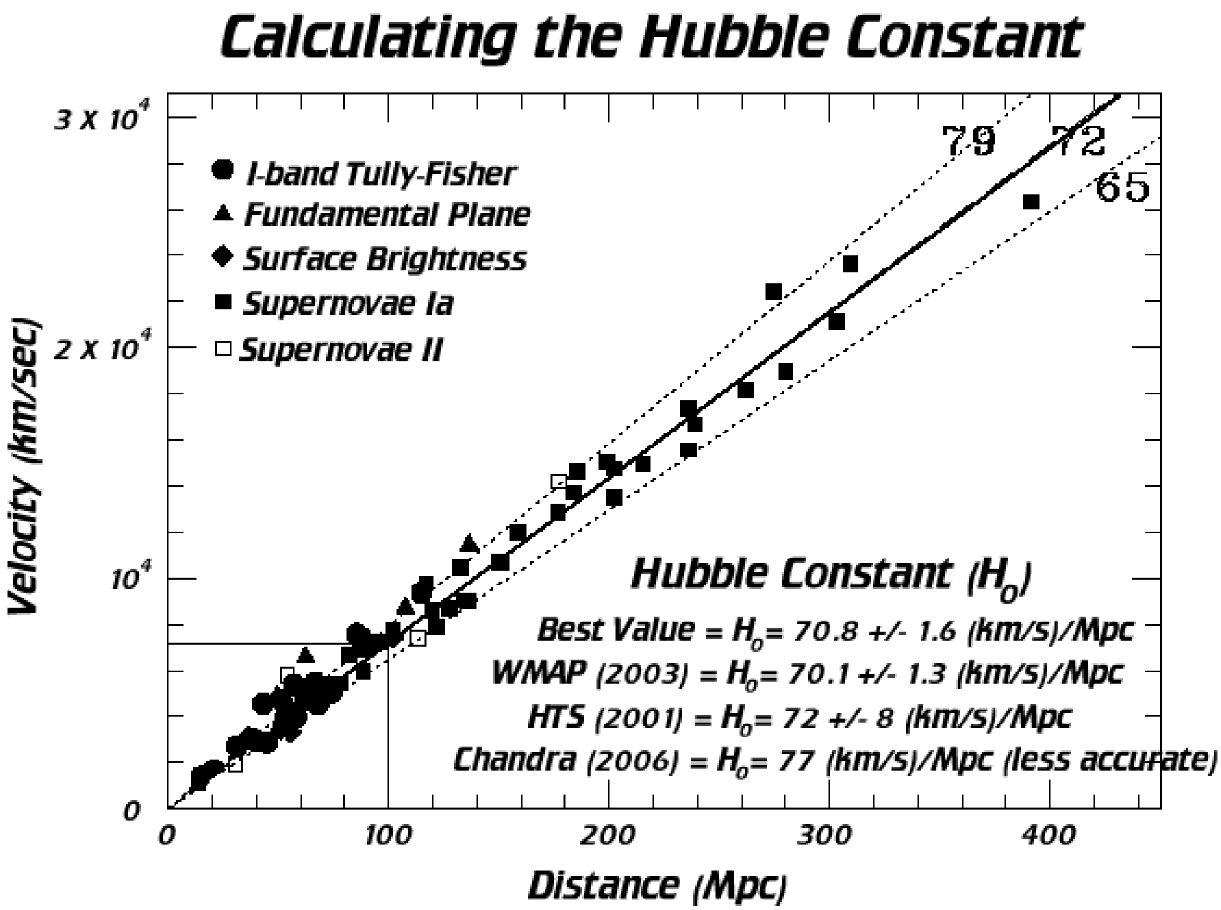


E. **<u>Measuring Difficulties</u>:** Looking into the universe the distances to other galaxies are ascertained by the observations of long-period Cepheid variables, supernovas, and quasars. Small error distances to galaxies close to the Earth lead to much larger discrepancies the farther away we look.



F. **<u>Hubble Law</u>:** The velocities that galaxies are receding from us are proportional to their distances from us.

1. **Recessional velocities were first inferred from a galaxy's red shift** by Vesto Slipher in 1917. Edwin Hubble is normally given credit for first quantifying the red shift (recessional velocity) with distance, now known as Hubble's law. Originally it was quantified as 500 km/sec/megaparsec.
2. $d = v / H_0$: where d is the distance to the source, v is the recessional velocity measured by the red shift, and H_0 is the Hubble constant.
3. **Best value for H_0** = 70.8 +/- km/sec/megaparsec
4. **The Hubble Space Telescope** (HST) yielded a value of $H_0 = 74.2 \pm 3.6$ km/sec/Mpc. The results agree closely with an earlier measurement of $H_0 = 72 \pm 8$ km/s/Mpc obtained in 2001 also by the HST. In August 2006, a less-precise figure was obtained independently using data from NASA's Chandra X-ray Observatory: $H_0 = 77$ km/sec/Mpc, with an uncertainty of ± 15 percent. NASA summarizes existing data to indicate a constant of 70.8 ± 1.6 (km/s)/Mpc if space is assumed to be flat (Wikipedia).
5. **Hubble's Law can be depicted in a "Hubble Diagram"** in which the velocity of an object (assumed approximately proportional to the redshift) is plotted with respect to its distance from the observer. A straight line of positive slope on this diagram is the visual depiction of Hubble's Law. See the Hubble diagram below.



G. **Age of the Universe**

1. **The universe was created** from a highly compressed state in the past, but probably "popped" into existence rather than exploded. The early universe was very uniform.
2. **Calculating the age of the universe** from the Hubble constant

$d = vt$ or $t = \frac{d}{v}$ where d = distance, v = velocity, and t = time

but according to Hubble's law, v = dH, where H = Hubble constant

substituting v = dH into $t = \frac{d}{v}$ $\quad t = \frac{d}{dH}$ or $t = \frac{1}{H}$

H = 70 km/second/megaparsec one megaparsec contains about 3.1×10^{19} km (units must be consistent)

therefore

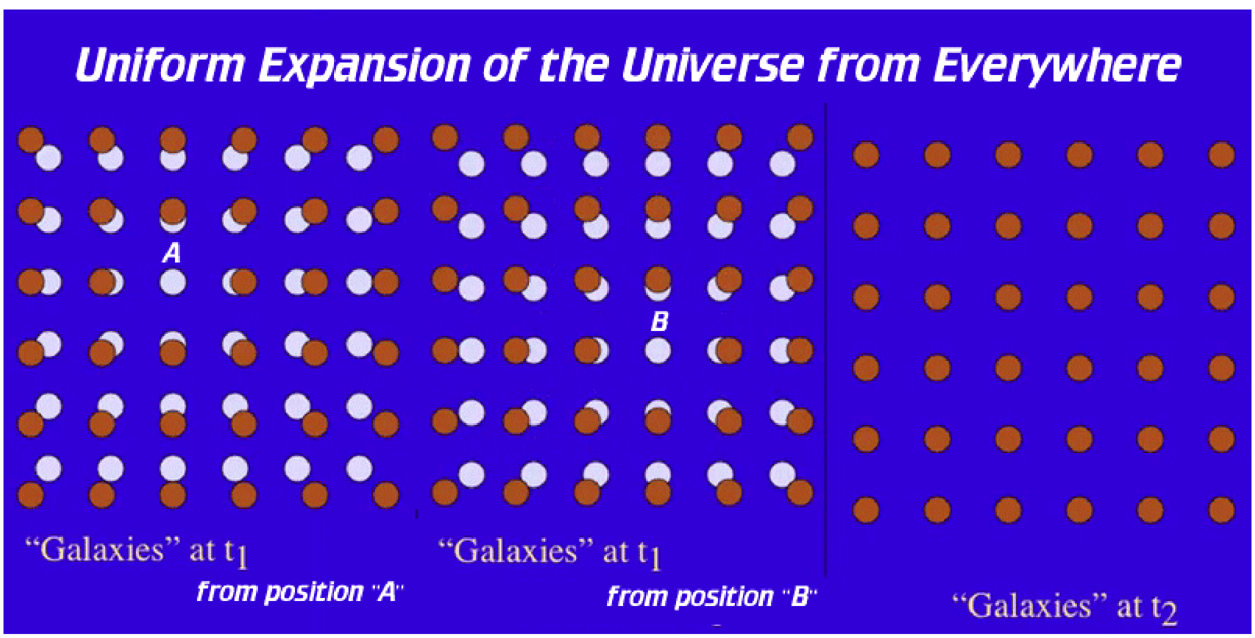
$$H = 70 \frac{\text{km}}{\text{sec}/3.1 \times 10^{19}\ \text{km}}$$

$$H = \frac{70\ \text{sec}^{-1}}{3.1 \times 10^{19}} \quad \text{or} \quad H = 23 \times 10^{-19}\ \text{sec}^{-1} \quad \text{or} \quad 2.3 \times 10^{-18}\ \text{sec}^{-1}$$

$$T = \frac{1}{H} \quad \text{or} \quad t = \frac{1}{2.3 \times 10^{-18}\ \text{sec}^{-1}} \qquad t = 4.3 \times 10^{17}\ \text{sec} \times \frac{1\ \text{year}}{3.2 \times 10^{7}\ \text{sec}} \qquad 1.3 \times 10^{10}\ \text{yr}$$

$T = 13 \times 10^{9}$ years or 13 billion years

H. Everyone thinks that s/he is at the center of a uniformly expanding universe. The lack of a preferred position is called the **cosmological principle**.



I. **<u>Light Travel Time Distance</u>:** How far the light has traveled from a galaxy since the time it was emitted.
1. Because the universe is expanding, there is no simple formula to calculate the distance to remote objects.
2. Since the light was emitted the galaxy has been carried to a much greater distance away from us because of the expansion of space.
3. The **Cosmic Horizon**, the location where light first escaped the expansion of the universe is much farther away then it seems.
4. Distances in the universe are defined by the light travel time distances that we measure via the redshift of galaxies.

J. **<u>CMB—Cosmic Microwave Background (CMB)</u>**
1. The CMB was discovered by Arno Penzias and Robert Wilson in Holmdel**,** NJ in 1965.
2. As the universe expanded it became transparent about 300,000 years after its creation and at a temperature of 3,000K which equals a peak radiation of 10,000 A or about 1000 nm.
3. The uniform expansion of the universe has redshifted this energy into the microwave portion of the electromagnetic spectrum at a peak radiation of about 2.728K.
4. **Confirmation of an Early Hot Universe**
    a. Cosmic Microwave Background radiation was at one time hot, but now appears cool because of the redshift and universe's expansion.
    b. The formation of He through nucleosynthesis to a lever of 24 percent as measured in old stars and nebulae also champions a hot beginning.

K. **Expansion Forever or Big Crunch?**
1. We need to evaluate the total amount of mass in the universe. This mass wants to collapse the universe into a big crunch as opposed to the impulse of energy created at the time of the big bang which wants to expand the universe forever.
    a. If gravity dominates the universe crunches
    b. If energy dominates the universe expands forever
2. **<u>Density of the universe</u>:** Astronomers measure all of the matter within a certain volume of space (visible plus dark matter) and come up with a value of 3×10^{-30} gm/cm^3. This number is about 10 times higher than the baryonic (proton, neutron, electron) matter that we see.
3. **<u>Critical Density</u>:** The factor that determines whether the universe is open or closed. Densities are measured relative to the critical density (ρ_c) the density of the universe which just allows it to expand to infinity.
   $\rho_c = 3H^2/(8\pi G)$ where ρ_c is the critical density, H is the Hubble constant and G is the gravitational constant.
4. **<u>Modern Notation</u>:** $\Omega_M = \rho_m$ the actual density of matter / the critical density ρ_c
    a. If $\Omega_M > 1$, then the universe crunches. If $\Omega_M < 1$, the universe expands forever. If $\Omega_M = 1$, then the universe stops expanding when it is infinitely large.

   b. **Cosmological Constant** (Ω_Λ = dark energy) represents the density of the vacuum field.
   c. **Dark Energy is a property of space.** It acts only to make space expand faster and faster. If the cosmological constant is not zero, dark energy contributes energy to the universe's expansion.
   d. In the preferred flat model of the universe, which "naturally" emerges from the inflationary picture of the early universe $\Omega_M + \Omega_\Lambda = 1$.
5. **Critical density of the universe** as observed today is 10^{-29} gm/cm^3. This equals about six hydrogen atoms per cubic meter. The actual density of the universe is 3×10^{-30}. $3 \times 10^{-30}/10^{-29} = 3 \times 10^{-1} = 0.3$ or 30 percent of the closure density.
6. **Critical density should equal actual density** according to the modeling of the big bang. In order to see whether the expansion rate of the universe was changing astronomers wanted to compare the expansion rate during the early universe with the present expansion rate of the universe.
7. **Accelerating Universe:** The breakthrough came with Type Ia supernovas (binary systems in which mass is being accreted onto a white dwarf star). These events are extremely consistent in their light output (M = -19). Their redshift values, coupled with their decrease in luminosity (due to their recessional velocities) over what their brightnesses would be at a standard distance of one megaparsec showed that their redshift values were less than what would be expected in an uniformly expanding universe without mass. In other words, these galaxies were expanding at a much slower rate than what would be expected if the current rate of expansion were extrapolated back to the beginning of time in a universe without mass. The universe had to be accelerating.
8. **Einstein's Universe:** Using general relativity, Einstein derived the first full self-consistent model of the Universe in 1917. At that time the expansion of the universe had not been discovered. To create a static universe, Einstein had to introduce a **cosmological constant** in this equation.
   a. Einstein reasoned that in a static universe the force of gravity would tend to make the universe collapse. He introduced the cosmological constant (Λ) Lambda into his equations to counteract gravity. The resulting universe was closed and had an infinite age. Keep in mind that the expanding universe had not yet been discovered.
   b. The static universe was a balance between the gravitational force that wanted to collapse the universe and the repulsive effects of the vacuum (Λ) that just made the universe static.
   c. **Einstein's Mistake:** When the universe was discovered to be expanding Einstein understood that the cosmological constant needed to be eliminated. The cosmological constant would be shown to be virtually the same pressure that was needed to accelerate the universe. In a way, Einstein still got it correct.
   d. What happens when the cosmological constant is introduced into the equation for the expansion of the universe?

$$\frac{d^2R}{dt^2} = \frac{4\pi G \rho_m}{3R^2} + \frac{1}{3}\Lambda R$$

where ρ_m = density of universe, G = gravitational constant, Λ = cosmological constant

Expanding universe = Deceleration due to gravity + Repulsive affect of the vacuum

If ρ_m (density of the universe) approaches zero there is still a repulsive force that is acting on a particle to push it outward. Today the Λ-term is very closely related to the energy density of the vacuum field—the **dark energy** which composes about 70 percent of the (mass-energy) of the universe.

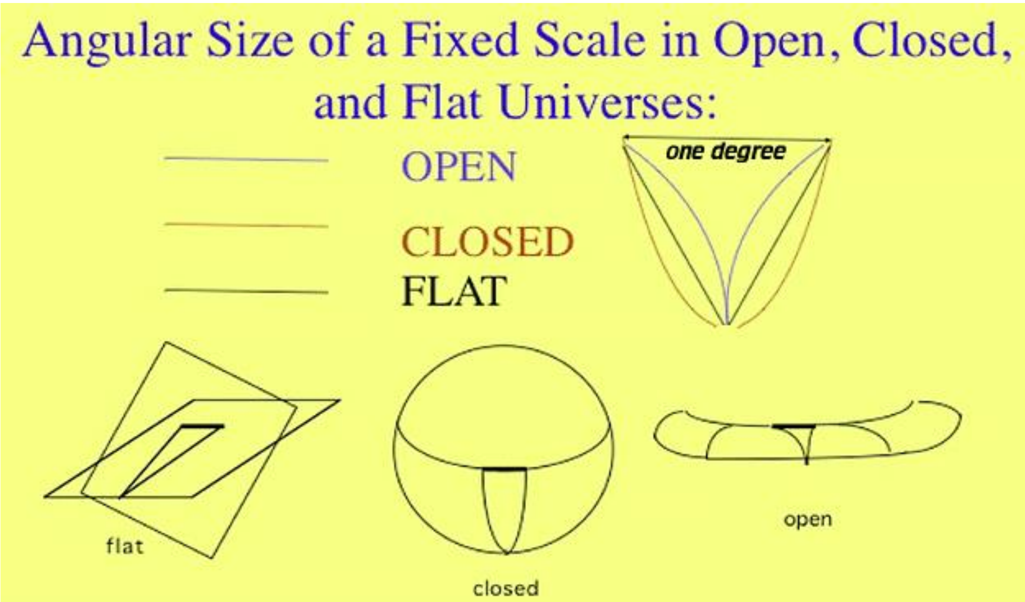
L. **Curvature of the Universe**

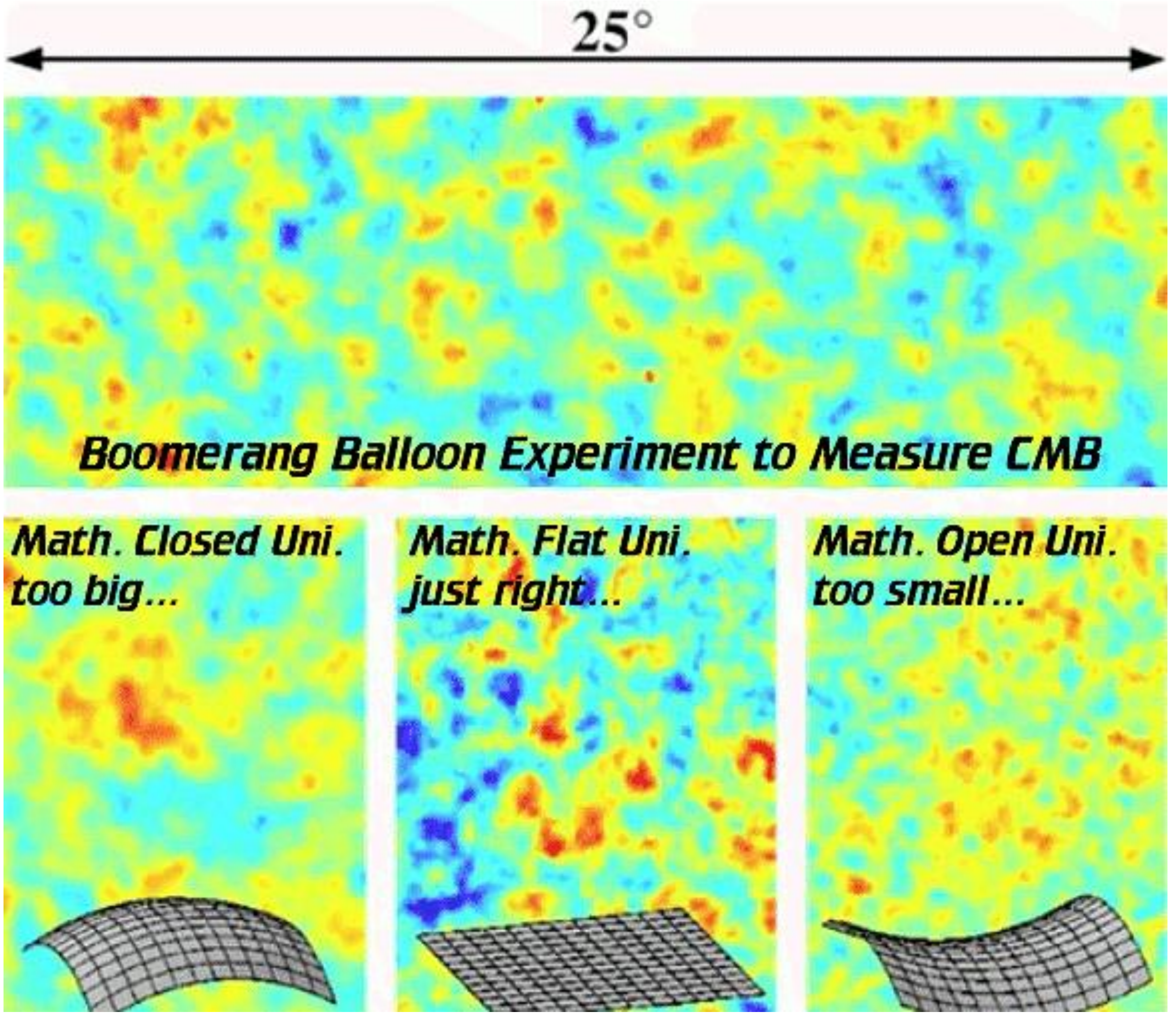
1. Three different scenarios
    a. **Positive curvature:** A closed universe… A universe curved around itself such as a tube or a ball. Moving in a straight line along the curvature brings the traveler back to his/her starting position. The angles of a triangle add up to more than 180 degrees.
    b. **Negative curvature:** An open universe… A universe that might be bent into a saddle like shape. The angles of a triangle add up to less than 180 degrees.
    c. **Flat universe:** parallel lines never meet and the angles of a triangle add up to 180 degrees.

M. **The Cosmic Microwave Background (CMB):**

1. **COBE** (Cosmic Microwave Background Explorer-launched 1989-1994) found that the cosmic background radiation from the Big Bang was essentially uniform.
2. **Temperature** = 2.728 K.
3. **Early Universe Needs to be Uniform:** An early universe that would not have been uniform (anisotropic) would have presented grave problems in explaining how the universe evolved into its present state.
    a. **Anisotropy** in the CBR (cosmic background radiation) relates to the structure of the early universe because it would imply differences in temperatures and therefore differences in density.
    b. **Increasing the sensitivity by 1000** (COBE) it became possible to see those parts of the universe that were red and blue shifted due to our motion in space. This allowed us to obtain an absolute frame of reference of our motion with respect to the cosmic background microwave radiation.
    c. **Increasing the sensitivity by yet another 100** and looking at the CMB in milliKelvins shows very small ripples of anisotropy (one part in 100,000 of the total intensity) consistent with an early universe (300,000 years old) that evolved into what we see today.

4. **Measuring the Curvature of Space:**
   a. No information can propagate faster than the speed of light.
   b. **Temperature Fluctuations in the CMB**: The key has been in the small temperature fluctuations of the cosmic microwave background (CMB). They can only be as large as the time it has taken for light to travel across an area since the beginning of the big bang.
   c. **These lumps or fluctuations in the CMB** also represent the biggest entities of matter that could collapse at this time because if anything larger existed, gravity would not have had enough time to travel across it, so the lump in its entirety would not have had enough information to collapse.
   d. **Fluctuation Sizes at the Cosmic Horizon:** 300,000 years after the big bang… The time at which light began to escape from the expanding universe. The most common size of the CMB fluctuations, about one degree, is determined by the size of the cosmic horizon at the time of escape. In 300,000 year these fluctuations must be less than 300,000 light years across.
   e. **Size of the Fluctuations:** approximately one degree in size.
   f. **Flat Universe**: The cosmic horizon can be mocked up mathematically to see what it would have looked like in a positive, negative, and flat universe. The best fit shows the universe to be perfectly flat because the mathematically calculated sizes of a flat universe best match the observed fluctuations of about one degree.
      1) **Closed Universe:** The CMB fluctuations would be larger than one degree because the angles of a triangle in a closed universe add up to more than 180 degrees.
      2) **Open Universe:** The CMB fluctuations would be smaller than one degree because the angles of a triangle in an open universe always sum to less than 180 degrees.





M. **Standard Model of the Universe, ΛCDM,** or **Lambda-CDM** is an abbreviation for **Lambda-Cold Dark Matter:** We can find exactly the correct answers if we replace the whole universe with a uniformly expanding sphere. Watch "A Universe from Nothing by Lawrence Krauss, 2009, at http://www.youtube.com/watch?v=7ImvlS8PLIo Lawrence M. Krauss biography can be found at http://en.wikipedia.org/wiki/Lawrence_M._Krauss

1. **The standard world models used by all cosmologist** today were discovered in 1922 and 1924 by the Soviet meteorologist Alexander (Alexandrovich) Friedman (Friedman World Models).
2. **Cosmological Principle:** Our observational location in the universe is in no way unusual or special. On a large enough scale, the universe looks the same in all directions (isotropy) and from every location (homogeneity).
3. **The Universe is Expanding:** The combination of Hubble's Law and the isotropy of the Universe show that the universe must be expanding uniformly. This has been documented by
    a. **Red shift of spectral absorption and emission** lines in distant galaxies (Doppler Shift).
    b. **Time dilations in the light decay** of supernova luminosity curves.

   c. The Standard Model allows space to expand at speeds greater than the speed of light.
4. **<u>Flat Spatial Geometry</u>:** Space is defined by straight lines. Interior angles of a triangle defined by three beams of light will sum to 180 degrees. The universe is either flat or slightly closed, the universe will expand forever, and the expansion is accelerating. A flat geometry means:
   a. It is a mathematical beautiful universe.
   b. The total energy of the universe is precisely zero.
      1) The negative energy of gravity balances out the positive energy of matter.
      2) It is a universe that can begin from nothing.
5. **<u>Cosmological Constant = Dark Energy</u>:** Λ (Lambda) stands for the cosmological constant which is currently associated with a vacuum energy or dark energy inherent in empty space that explains the current accelerating expansion of space against the attractive (collapsing) effects of gravity. The cosmological constant is denoted as Ω_Λ, which is interpreted as the fraction of the total mass-energy density of a flat universe that is attributed to dark energy, about 73 percent of the universe.
6. **<u>Cold, Dark Matter</u>** is necessary to account gravitational effects observed in very large scale structures.
   a. Rotational anomalies of galaxies
   b. Enhanced clustering of galaxies which cannot be explained by the mass of the visible members of the group.
   c. Gravitational lensing of distant galaxies.
   d. The Dark Matter is
      a. Cold: Its velocity is far below the speed of light.
      b. Non-baryonic: not composed of protons and neutron and does not interact with baryonic matter.
      c. Cannot cool by radiating photons.
      d. Dark matter particles interact with each other only through gravity.
      e. Constitutes about 23 percent of the mass-energy density of the universe.
7. **<u>Baryonic Matter</u>:** Comprises the remaining 5 percent of all matter and energy observed as
   a. Ordinary, but nonluminous matter (dead stars, gas)—4 percent
   b. Ordinary visible matter (stars and gas)—0.5 percent
   c. Electromagnetic radiation—0.005 percent
8. **Other inclusions of the Standard Model**
   a. **<u>The Big Bang</u>**, which was not an explosion, but the abrupt appearance of expanding space time
   b. **<u>Cosmic inflation</u>:** exponential expansion of space time by a scale multiplier of 10^{27} or more at 10^{-29} second (also seen 10^{-36} sec.) after creation. When the inflation began the universe may have possessed the volume of a proton.
9. **What is the gravitational deceleration of the matter in the universe** as it expands outward? Gravity pulls inward and the speed of recession pulls outward.

10. **Is the universe expanding fast enough to escape from its own gravity?** The behavior depends upon the average density of matter in the universe. There is a critical density ρ_c which separates the models which expand forever from those which eventually collapse into a "Big Crunch."
    a. **High Density Universe:** Collapse into a big crunch
    b. **Low Density Universe:** Expansion forever
    c. **Critical Density:** Expansion slows eventually coming to a stop at an infinitely distant time.

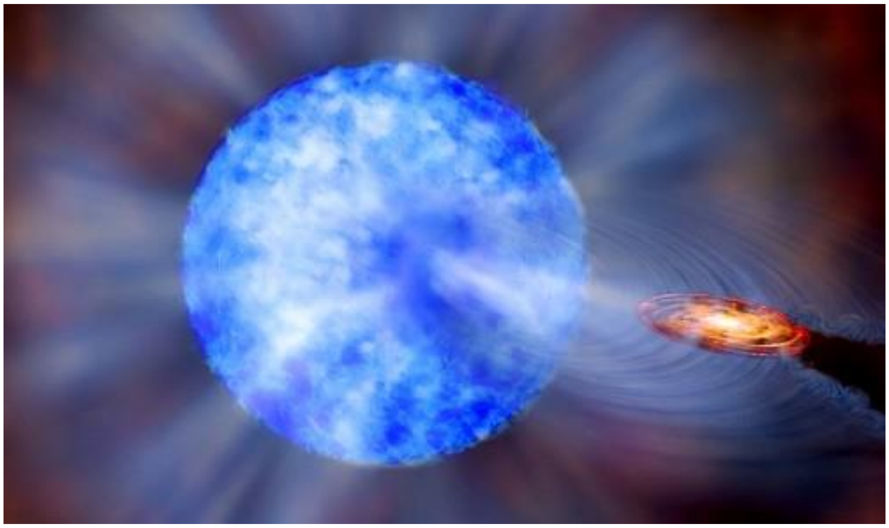
NOTES

DARK THINGS IN THE UNIVERSE

Black Holes-easy; Dark Matter-hard, Dark Energy, very hard

A. **The unifying theme is gravity**
   1. **Black holes** are the ultimate in gravitational collapse. They are part of the furniture of modern astronomy.
   2. **Dark matter**: we know that it exists because it exerts a gravitational influence, but we don't know what it is. That is not overly important at present.
   3. **Dark energy**: It is a force that is making the universe accelerate despite the fact that the universe is full of gravitating matter that should pull it together.

B. **Dead Stars**
   1. **Holding up the stars**: Stars are held up by the pressure of hot gas (plasma). The source of energy is nuclear reactions occurring in their cores or shells. These reactions can only last for a finite time. All astronomical objects are fighting an ultimately unsuccessful battle against gravity. The sun is 4.6 billion years into its life cycle with about 5.4 billion years to go.
   2. **White dwarfs:** 1.4 solar masses or less. Sustained through degenerate electron pressure electron. They are the size of the Earth.
   3. **Neutron stars:** further mass increase >1.4 < 2.5 solar masses. Star collapses still further until degenerate neutron pressure supports the object which is about 10 miles in diameter.
   4. **Einstein's two great theories of Relativity** in a nutshell
      a. **Special Relativity:** We live in a space-time continuum, not a space continuum and time continuum. Space and time are interrelated in a four dimensional space-time. This realization lead Einstein to the equivalency of matter and energy, $E = mc^2$.
      b. **General Relativity:** Matter (mass) bends space-time, not just space and not just time. Matter bend the four dimensional manifold of space-time in which we live. Matter moves along paths in bent space-time. The theory has self-consistency.
   5. **Black Hole:** If the core remnants of a supernova are between are greater than three times the mass of the sun, the star will collapse into a singularity or black hole.



a. **Non-rotating Black Hole**: If the matter falls directly into the black hole without undergoing any orbital (rotational) motion, no energy from the matter will be released. This scenario is highly unlikely because all matter is in motion.

b. **Accretion Disk**: Conservation of angular momentum (rotation) will occur as matter spirals towards the hole. As the matter collapses along the black hole's axis of rotation, it forms an accretion disk.

c. **Schwarzschild radius:** The volume of space from the center of the black hole to its boundary where the escape velocity equals or exceeds the speed of light. The Schwarzschild radius is directly and linearly related to the mass of the hole.
   1) Solar mass black hole: Schwarzschild radius = 3 km
   2) A 10^9 solar mass black hole: Schwarzschild radius = 3 x 10^9 km

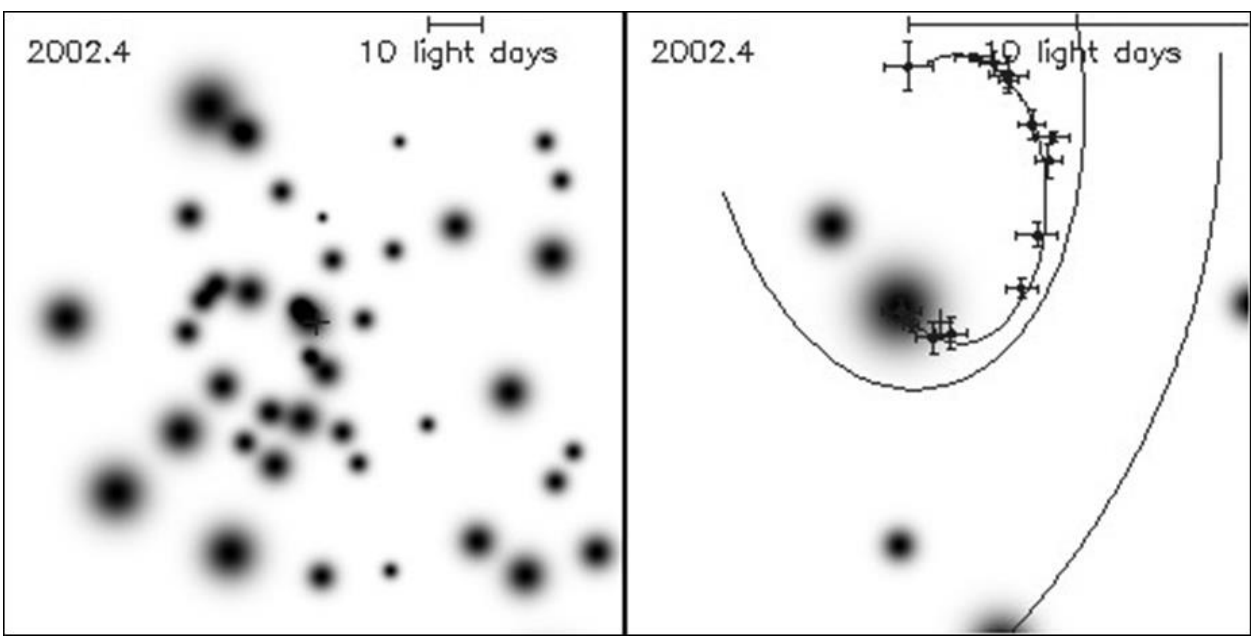
d. **Magnetic viscosity effects** heat the material via friction and release its binding energy. This occurs before the location of the last stable orbit.

e. **As a blob of matter spirals** in towards the black hole, magnetic viscosity transfers the angular momentum of the accretion disk outward as the matter passes through it before the matter passes into the last stable orbit and the hole.

f. **Evidence for Black Holes:** Black holes are only detectible if they are close to a source of fuel or if they cause gravitational deflections of background sources. The best cases are stellar black holes in X-ray binary systems, and black holes in active galactic nuclei.
   1) **Binary X-ray Emitters:** The mass of the X-ray emitter must be greater than three times the mass of the sun. About 20 cases are known (2009). The X-rays are produced as the in falling matter approaches the last stable orbit and is heated the most. X-ray fluorescence lines of iron have

been observed. The classical techniques of orbital analysis of binary star systems are used to estimate the mass of the unseen massive companion (Newton's derivation of Kepler's Third Law). The most spectacular case is M33X-7 an eclipsing X-ray source where the mass of the primary has been determined to be 70 ± 6.9 solar masses. The companion is 15.65 ± 1.45 solar masses so it must be a black hole.

2) **Quasi-periodic Oscillations:** Since black holes do not have a solid surface, material falling into the hole exhibits frequency (Doppler) shifts with the period varying with time. This is indicative of the matter actually spiraling into the hole.
3) **Black Hole in the center of the Milky Way (Sagittarius A/S_2):** Infrared images of the center of our Milky Way taken since 1992 by Reinhard Genzel, show stars moving at velocities of 1000 km/sec. They orbit around a point which is not producing any visible radiation. Ninety-five percent of the matter sensed by the orbiting stars near Sagittarius A comes from the black hole. One star, S_2 gets to within 17 light hours of the suspected hole which has been estimated at 3.6 x 10^6 solar masses. At its periastron, S_2 is still 100 times more distant than the last orbit of stability.



Stars photographed in the infrared at the very center of the Milky Way are orbiting a 3.6 x 10^6 solar mass black hole known as Sagittarius A. It is marked with a "cross" at the center of the image on the left. On the right, stars can be seen orbiting around this mass which cannot be seen. The star near the center on the right is S_2. Images supplied online by the European Southern Observatory (ESO).

4) Most galaxies are thought to have supermassive black holes at their centers. Several examples follow:
   a) **Omega Centauri** (largest globular cluster in the Milky Way and possibly a galaxy captured by the Milky way): 4 x 10^5 solar masses
   b) **M32** (satellite galaxy of M31): 3 x 10^6 solar masses
   c) **M31** (Andromeda Galaxy): 30 x 10^6 solar masses
   d) **NGC 4151** (brightest of the Seyfert galaxies): 10^9 solar masses
   e) **M87** (large active elliptical galaxy): 3 x 10^9 solar masses
   f) **3C 273** (brightest of the quasars): 3 x 10^9 solar masses

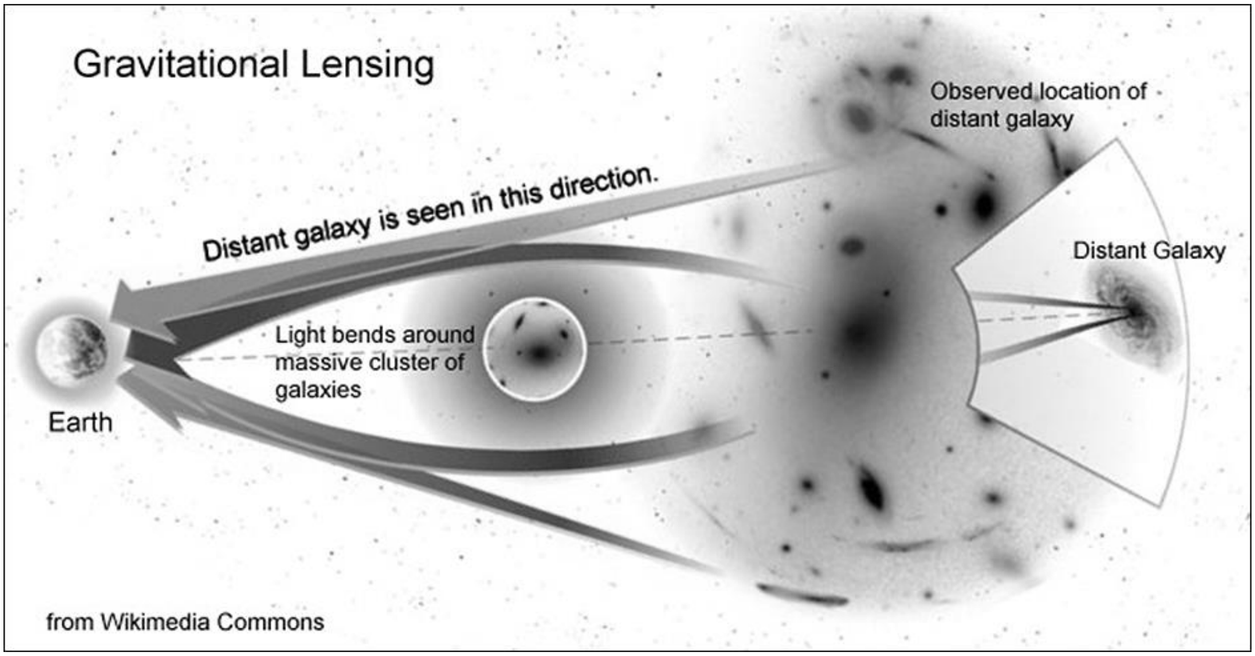
6. **Schwarzschild Black Holes (non-rotating):**
   a. In an isolated, non-rotating black hole, the event horizon or Schwarzschild radius is much farther away than in a rotating black hole. The Schwarzschild radius can be defined as $R_s = 2Gm/c^2$ where G = the gravitational constant 6.67 x 10^{-8} dynes cm^2/sec^2, m = the mass of the system in grams, and c = the speed of light 3 x 10^{10}cm/sec and c^2 = 9 x 10^{20} cm^2/sec^2.
   b. Non-rotating black holes can only possess three properties: mass, angular momentum (rotation), and electric charge.
   c. At the Schwarzschild radius, light is infinitely redshifted. No radiation can escape the black hole.
   d. The last stable circular orbit is last region where an object can maintain a circular orbit. Internal to this position, the object must spiral into the black hole.

7. **Kerr—Rotating Black Hole:**
   a. In a maximally rotating black hold with the same mass as a non-rotating black hold, the size of the hole is smaller by a factor of two. The last stable orbit shrinks to half the radius as well. The importance is that matter can get much closer to the hold before it falls into it.
   b. Rotating black holes are formed during the gravitational collapse of a massive spinning star. Since almost all stars are thought to have spin, initially all black holes will be rotating very rapidly after collapse, as with the star in our Milky Way, GRS 1915 +105 which is spinning up to 1150 times per second. Because the black hole is rotating, the mass of the system seems to be less and the event horizon is smaller. An accretion disk (ergosphere) forms around the event horizon. Matter passing through this viscous region may excise energy from the system, causing the black hole to rotate more slowly (viscous dissipation). The outer boundary of the accretion disk represents the last stable orbit Within the ergosphere a particle is forced (dragging of space and time) to

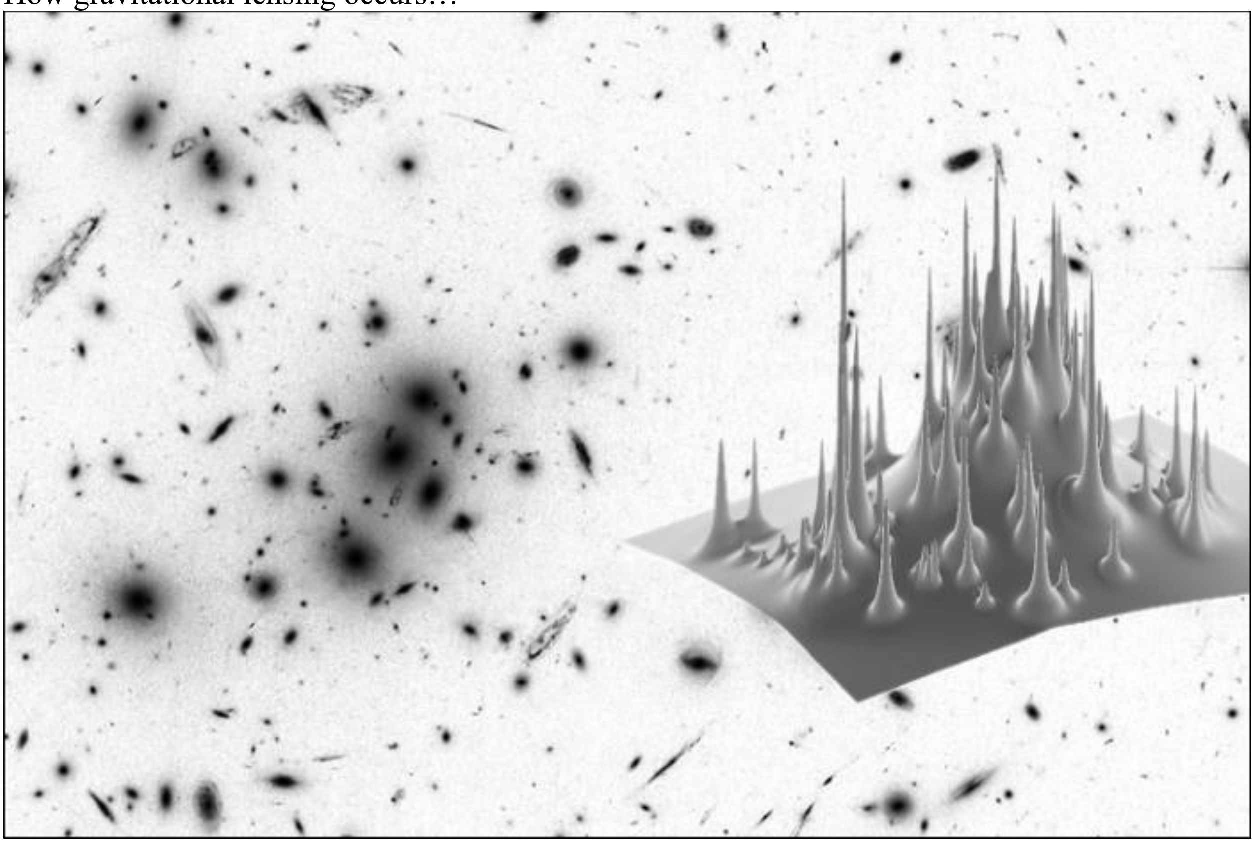
rotate and may gain energy at the cost of the rotational energy of the black hole. The theoretical maximum of possible energy extraction is 29% of the total energy of a rotating black hole. When this energy is dissipated, the black hole loses its spin and the ergosphere no longer exists. This process of viscous dissipation is considered a possible source of energy for gamma ray bursts. Observational proof of this may lie in X-ray binary systems such as M33X-7 where the accretion disk surrounding a black hole is eclipsed by the primary source. This allows for the calculation of the mass of the system as well as the mass of the individual components. The primary star is 70 ± 6.9 solar masses while the secondary source is a 15.7 solar mass black hole. See the image courtesy of NASA below.

C. **<u>Gravitational Lensing as a Proof of Dark Matter</u>:** The distortion of the background image of a distant galaxy resulting from the matter which lies in between.

1. It involves a cluster of galaxies with a distant galaxy behind it. Light from a distant galaxy or quasar is bent around a cluster of galaxies containing dark matter.
2. Light from the distant galaxy is bent by the cluster causing the distant galaxy to appear smeared and as a series of arcs around the cluster. The position of the distant galaxy is changed. The lensing effects cannot be accounted for by the visible matter alone.
3. Knowing the cluster’s distance and therefore its volume, the cluster’s mass can be deduced from the electromagnetic radiation emanation from the system.
4. The mass of the dark matter in the system can be deduced from the amount of gravitational lensing which the cluster is producing minus the mass of the cluster as seen by traditional techniques. This mass of the cluster is always much larger than that which can be deduced by electromagnetic radiation alone. This is excellent proof of the existence of dark matter.



How gravitational lensing occurs…



Astronomers use gravitational lensing to map the dark matter in the universe. This is a reconstruction of the mass distribution in CL 0024+1624: The spikes in the diagram on the right represent the galaxies of the cluster. The humping effect towards the center is representative of the dark matter embedded within the cluster and is about **50 times the mass of the visible spikes**.

D. **<u>Dark Matter Keeps Galaxies From Flying Apart</u>:** Galaxies are rotating too fast. Most of the rotational motion is Keplerian (closer orbiting objects revolve faster than objects farther from the center). Near the edges of galaxies the motion become more like a record or CD, with the inner part of the disk moving at the same angular rate as the outer part of the disk. Dark matter can account for these awkward types of motion. Similar types of motions can also be seen for clusters of galaxies as well. These giant structures should simply spin themselves apart. Based on everything we know about stars and gas, there should not be enough gravity to hold them together.

1. **<u>Standard Model of the Universe</u>, ΛCDM,** or **Lambda-CDM** is an abbreviation for **Lambda-Cold Dark Matter:** We can find exactly the correct answers if we replace the whole universe with a uniformly expanding sphere. Watch "A Universe from Nothing by Lawrence Krauss, 2009, at http://www.youtube.com/watch?v=7ImvlS8PLIo Lawrence M. Krauss biography can be found at http://en.wikipedia.org/wiki/Lawrence_M._Krauss

The standard world models used by all cosmologists today were discovered in 1922 and 1924 by the Soviet meteorologist Alexander (Alexandrovich) Friedman (Friedman World Models).

a. **<u>Cosmological Principle</u>:** Our observational location in the universe is in no way unusual or special. On a large enough scale, the universe looks the same in all directions (isotropy) and from every location (homogeneity).

b. <u>The Universe is Expanding</u>: The combination of Hubble's Law and the isotropy of the Universe show that the universe must be expanding uniformly. This has been documented by

1) Red shift of spectral absorption and emission lines in distant galaxies (Doppler Shift).
2) Time dilations in the light decay of supernova luminosity curves.
3) It allows distant galaxies to recede from each other at speeds greater than the speed of light.

c. **<u>Flat Spatial Geometry</u>:** Space is defined by straight lines. Interior angles of a triangle defined by three beams of light will sum to 180 degrees. The universe is either flat or slightly closed, the universe will expand forever, and the expansion is accelerating. A flat geometry means:

1) It is the only mathematical beautiful universe.
2) The total energy of the universe is precisely zero.
    a) The negative energy of gravity balances out the positive energy of matter.
    b) It is a universe that can begin from nothing

d. **<u>Cosmological Constant = Dark Energy</u>:** Λ (Lambda) stands for the cosmological constant which is currently associated with a vacuum energy or dark energy inherent in empty space that explains the current accelerating expansion of space against the attractive (collapsing) effects of gravity. The cosmological constant is denoted as Ω_Λ, which is interpreted as the fraction of the total mass-energy density of a flat universe that is attributed to dark energy, about 73 percent of the universe.

e. **<u>Cold, Dark Matter</u>** is necessary to account gravitation effect observed in very large scale structure.
   1) Rotational anomalies of galaxies
   2) Enhanced clustering of galaxies which cannot be explained by the mass of the visible members of the group.
   3) Gravitational lensing of distant galaxies.
   4) The Dark Matter is
      a) Cold: Its velocity is far below the speed of light.
      b) Non-baryonic: not composed of protons and neutron and does not interact with baryonic matter.
      c) Cannot cool by radiating photon.
      d) Dark matter particles interact with each other only through gravity.
      e) Constitutes about 23 percent of the mass-energy density of the universe.

f. **<u>Baryonic Matter</u>:** Comprises the remaining 5 percent of all matter and energy observed as
   1) Subatomic particles
   2) Chemical elements
   3) Electromagnetic radiation

g. Other inclusions of the Standard Model
   1) **<u>The Big Bang</u>**, which was not an explosion, but the abrupt appearance of expanding space time
   2) **<u>Cosmic inflation</u>:** exponential expansion of space time by a scale multiplier of 10^{27} or more at 10^{-29} second (also seen 10^{-36} sec.) after creation. When the inflation began the universe may have possessed the volume of a proton.

h. **What is the gravitational deceleration of the matter in the universe** as it expands outward? Gravity pulls inward and the speed of recession pulls outward.

i. **Is the universe expanding fast enough to escape from its own gravity?** The behavior depends upon the average density of matter in the universe. There is a critical density $\rho_c$which separates the models which expand forever from those which eventually collapse into a "Big Crunch."
   1) **High Density Universe:** Collapse into a big crunch
   2) **Low Density Universe:** Expansion forever
   3) **Critical Density:** Expansion slows eventually coming to a stop at an infinitely distant time.

Name ___________________________________ Date_________________ Moravian University

RELATIVITY AND STRINGS

1. _______________ _______________ (1879-1955) developed the special (1905) and general (1915) theories of relativity from the need to explain phenomena of nature that could not be understood from a classical Newtonian approach. How would our observations of the universe change if we varied our speed through space?
2. In this new way of thinking, Einstein considered the speed of light the only _______________ that exists in the universe. It did not fall into the same realm of vector addition and subtraction that governs our concepts of classical physics.
3. The speed of light in a vacuum is _______________ km/sec or _______________ mi/sec.
4. If you are traveling in a spaceship at 140,000 mi/sec and a light beam catches up and passes you from the back of the ship, the speed of the beam of light that is passing you will be calculated to be _______________ mi/sec.
5. Traveling at 100,000 mi/sec, a light beam approaches you. Equipment on your spacecraft measures the light beam passing your ship at ________________ mi/sec.
6. The speed of light in a vacuum is an absolute _______________.
7. In fact, the speed of light is the only _______________ in the universe.
8. Because of this, what we normally consider to be absolutes in nature—space and time—can be observed to _______________ change when traveling at different speeds.
9. Space is composed of the dimensions of _______________, _______________, and ________________.
10. Time is a measurement made between the occurrence of two _______________.
11. The _______________________________ experiment helped pave the way for this new reality.
12. At that time physicists thought that light (electromagnetic radiation) needed a _________________ through which it could travel.
13. This medium was called the _______________.
14. As the Earth moved in its orbit around the sun, it created an ether _______________ which could be measured in the following way.
15. By splitting a light beam and allowing one part of it to travel back and forth in the direction of the ether wind and the other half to travel at _____________________ to the wind, it would be possible to measure the absolute _______________ of the Earth by observing how the two light beams combined at the collector.
16. The light beam traveling with the Earth's orbital motion would be moving faster/slower (circle one) than the light beam traveling against the Earth's orbital velocity.
17. The combination of the two light beams would create an _______________ pattern at the eyepiece end of the interferometer, which would allow the Earth's absolute velocity in space to be calculated.
18. When this experiment was performed in Cincinnati, Ohio in 1887, the split light beams went back and forth at right angles to each other and combined at the detector completely in _______________________________.
19. No matter how the interferometer was positioned, the speed of the two light beams was always the _______________.
20. Michelson and Morley felt that their equipment did not have an _______________ sufficient enough to record the differences in the velocity of the two light beams.

21. In reality, Michelson and Morley had discovered the one true, absolute constant of the _______________.
22. This constant is the speed of _______________ in a vacuum.
23. In this case "light" is a general term for all of the various forms of energy that travel at the speed of light and which are also part of the ____________________ spectrum.
24. Something moving at a constant speed describes what Einstein called a frame of _______________.
25. According to Einstein, the universe becomes a very strange place when one observes the events which are occurring in a _______________ moving frame of reference.
26. Looking into what appears to be the faster moving frame of reference, time _______________ down, length _______________ in the direction of motion, and mass _______________.
27. In fact, if matter could reach the speed of light, time would _______________, the dimension in the direction of motion would become _______________, and the mass of and object would become ______________.
28. These changes are called the _______________ of space and time.
29. But there is a possible misconception here. As a person in frame of reference "A" looks at someone in a frame of reference "B," "A" also sees a _______________ of space and time in "B."
30. This occurs because there is no experiment that can prove whether "A" is at rest and "B" is moving, or "A" is moving and "B" is at rest, or both frames of reference are in motion. Observers in both frames of reference see exactly the same effects in the _______________ of space and time.
31. Each person in his own frame of reference does/does not (circle one) observe a dilation of space and time.
32. The perceptions of both frames of reference are considered equally _______________.
33. Inertia is a resistance to _______________, and it is a function of that object's speed and mass.
34. By accelerating any quantity of mass faster and faster, its inertia increases/decreases (circle one).
35. As the velocity of an object increases, so does its inertia. The increase in the inertia, however, is not only a function of the the mass's change in velocity, but also results because of the object's change in _______________.
36. At the velocity of light the inertia of the object becomes infinite. Since the speed of light is a finite number, it is the accelerating mass that must become _______________.
37. The amount of dilation can be calculated through algebraic formulas that have become known as the _______________ transformation equations.
38. We have been talking about special relativity, which considers only objects that are in _______________ motion.
39. In the general theory of relativity, Einstein states that the effects of acceleration and the force of gravity are exactly the _______________.
40. In Einstein's concept of the universe, space and time are interconnected and are represented as a fabric that can be stretched or _______________ near very massive objects.
41. Less massive objects orbit more massive bodies because they follow the _______________ of space that surround the more massive bodies.
42. In fact the force of gravity is the _______________ of space.

43. The greater the curvature, the greater the _______________ that is creating it.
44. According to Einstein, gravity travels at the speed of ________________. A gravitational source is therefore not felt instantaneously throughout the universe.
45. Light is really the same as ________________. ($E=mc^2$)
46. When light passes near a very massive body, the path of the light is also ________________, just like the space around the massive body. There are ________________ basic forces in nature. These forces govern how the universe operates from the very small to the very large.
47. There are _________________ fundamental forces in nature.
48. How many forces deal with the very small? ________________
49. How many forces deal with the very big? ________________
50. The weakest force or the four, which is called ________________, acts over large distances and is responsible for keeping planets in their orbits and holding galaxies together.
51. According to Einstein's general theory of relativity, the weakest of the four forces moves outward into space at the speed of ________________ mi/sec.
52. The force that binds the protons and neutrons of an atom together is called the ________________ ________________ force.
53. At extremely small distances this force is stronger than the ________________ forces being exerted by the positively charged protons that want to rip the nucleus apart.
54. The ________________ ________________ force is responsible for the splitting or the fissioning of nuclei in radioactive isotopes.
55. An isotope of an element contains a greater or lesser number of ________________ than is contained by an average atom of the same element.
56. This force is responsible for the way that electrons orbit their nuclei and the manner in which electrons can gain or lose energy. It is called the _____________________ force. Light falls under the umbrella of this force too.
57. Atomic bombs (nuclear fission) and hydrogen bombs (nuclear fusion) give demonstrable proof that there are incredible amounts of ________________ locked within the weak and the strong nuclear forces.
58. The physics of the very large, how gravity operates within the structure of the universe, seems to be fundamentally different from the physics of the very small, called ________________ ________________. Gravity operates in a very predictable manner, but the physics of the very small deals only in the probability of an event taking place.
59. The three forces which govern the world of the very small are the
    a. _______________________
    b. _______________________
    c. _______________________
    d. _______________________
60. String theory attempts to unify these three forces (as well as gravity), by proposing that at the heart of all matter and forces lie tiny vibrating strands of pure ________________.
61. In other words, ________________ disguises itself as energy.

62. Originally it was thought that at the heart of all matter lay three fundamental subatomic particles. They were the:
    a. _____________________

b. ____________________
c. ____________________
63. Later, it was discovered that these three fundamental particles were in themselves composed of three additional smaller particles called _______________.
64. Now it is thought that each _______________ (answer for 63) is composed of an unimaginable number of vibrating _______________.
65. Put simply, strings are composed of matter or energy (Circle one).
66. Therefore, it appears that matter is really a concentrated form of _______________.
67. What gives the quarks which lead to protons, neutrons, and electrons their fundamental characteristics are the directions that the strings inside of the quarks are _______________.
68. The arrangements, characteristics, and interactions of the differing quantities of protons, neutrons, and electrons which construct the atoms and molecules in the material world that surrounds us is described by a branch of science called _______________.
69. Strings do not wiggle in random directions. Their motions are tightly controlled or confined by a set of _______________ additional dimensions which are predicted by the mathematics of the theory.
70. In size these additional dimensions are extremely _______________.
71. In fact, if an atom were enlarged to the size of our solar system, a single string would be about the size of a _______________.
72. The four fundamental forces of nature according to string theory are composed of m_______________ particles which are in themselves composed of strings.
73. The ________________ particle for gravity is called the ________________, while the messenger particle for electromagnetic force is called the _______________.
74. Some individuals have gone so far as to say that we humans, by virtue of concentrated thought can influence the _______________ of strings and therefore the material world which surrounds us—mind over matter.
75. The fundamental problem with string theory is that science has proposed no _______________ to prove or disprove the existence of strings.
76. Scientific theories are based upon understanding the relationships that can be discovered through experimentation and observation, something that science calls the _________________________.
77. Based upon the last two questions, should string theory, for all of its mathematics and brilliant physicists working to unravel its details, be characterized as a **science** or a **philosophy** (circle one).

AN ELEGANT UNIVERSE

StarWatch 469, August 14, 2005

Physics, the study of matter, energy, forces, and motion and how they interrelate is in the midst of a revolutionary journey which may ultimately allow us to comprehend everything rationally. String theory, the new Holy Grail of physics, is so bizarre, yet so appealing, that maybe you'll want to learn more about it. Let me pitch just one of its ideas. We all know that matter, the chair that you are sitting on, the printer's ink that forms the words which are allowing you to read this article, is composed of atoms and molecules. Atoms are composed of three more basic units, protons and neutrons which form the nucleus of the atom and electrons which orbit the nucleus. Each of these subatomic particles, the proton, neutron, and electron are composed of still smaller units called quarks. Now quantum physicists are starting to believe that quarks are composed of billions of vibrating, wriggling string-like entities. The strings themselves are energy, not matter, and their vibrations are governed by six very small dimensions which control the manner in which these oscillations occur, thus giving us a sense of order and predictability to the matter that surrounds us. In its essence, energy disguises itself as matter. In the macro, string theory predicts multiple universes which co-exist and are influenced by the decisions we make in this universe. On the micro, string theory suggests that our thoughts, wishes, and desires influence matter on the quantum (smallest) level. It lends credence to the benefits of positive thought, the power of prayer, and that we have an essence, a spirit, or a soul that continues after we die. Would it not be ironic, if in the end, string theory allowed science to prove the existence of God?

NOTES

CONTACT: A PRIMER FOR MEETING ALIENS

StarWatch* 557, April 22, 2007**: When time and scheduling permit, I like to show my astronomy students the movie, ***Contact. It's not your typical alien film where humanity battles back from the brink of extinction, outwitting a technologically superior enemy, such as ***Independence Day*** or ***War of the Worlds*** portray. Directed by Robert Zemeckis, ***Contact's*** well-crafted 150 minutes pits feisty radio astronomer and atheist, Ellie Arroway (Jodie Foster) against religious scholar and eye candy hunk, Palmer Joss (Matthew McConaughey). Based upon astronomer Carl Sagan's fictional work by the same title, this is one instance where the film translation is superior. ***Contact*** is not exactly a young adult's top choice in cinematic entertainment, but when my classes view the film, they are made to consider the fundamental differences between science and religion and the fact that they can co-exist and mutually aid one another in the quest for truth. When we finally make contact with an alien culture, it probably won't happen with a handshake, but rather as the movie portrays through a message carried on the wings of radio energy and intercepted by a radio telescope. ***Contact's*** author, Carl Sagan, was an atheist who believed that humanity was at the brink of truly great achievements or self-annihilation. Through Ellie and Palmer the viewer can gain insights into Sagan's own struggles with spirituality and the human condition as he neared the end of his life. Sagan never saw his feature film to completion. Perhaps even more poignant was the question asked by Allen senior, Chris Sanchez, who recently came to the Lehigh Valley via the Bronx. "May I have permission to cry? This movie always makes me cry." I nodded yes, telling him that his tears of hope would be shared by at least one other individual in the room.

Cast of Characters in *Contact*:

- **Dr. Eleanor "Ellie" Ann Arroway**: Jodie Foster as the SETI (Search for Extraterrestrial Intelligence) scientist who first discovers the alien contact message. Arroway is the only character that evolves during the feature film. Nominated for an Oscar for her role in this film.
    - **Young Eleanor Arroway:** Jena Malone
- **Palmer Joss:** Matthew McConaughey, a renowned Christian philosopher, who becomes romantically involved with Arroway.
- **Kent Clark:** William Fichtner as a blind SETI scientist who assists Arroway in her studies and hears things that no one else can perceive.
- **David Drumlin:** Tom Skerritt as a scientific aide to the President of the United States and director of the National Science Foundation.
- **Michael Kitz:** James Woods as the skeptical National Security Advisor who also heads the Congressional investigation of Arroway's mission.
- **S.R. Hadden:** John Hurt as an eccentric and reclusive billionaire industrialist who is fundamental in financing Dr. Arroway's research and deciphering the alien's message.
- **Rachel Constantine:** Angela Bassett as the White House Chief of Staff to President Clinton.
- **Theodore Arroway:** David Morse as Ellie's father, who encourages his daughter to study amateur radio. He also later plays the alien: the first extraterrestrial to make contact with humanity.
- **Joseph:** Jake Busey as a religious fanatic.

- **Richard Rank:** Rob Lowe as the leader of the Conservative Coalition (a parody of Ralph Reed and the Christian Coalition).
- **Fisher:** Geoffrey Blake as a SETI scientist.
- **Willie:** Max Martini as a SETI scientist.
- **President Bill Clinton** as himself.

Contact operates on three different levels:

- Main Story line details the Search for Extraterrestrial Intelligence (SETI) through radio astronomy which is Eleanor Arroway's passion. It highlights her trials and tribulations and her successes in that pursuit. SETI is not considered an important area of research by professional astronomers because it requires large amounts of telescope time without any specific or guaranteed outcome. Eleanor Arroway is an ethical person who is confronted by several individuals who are basically good, but will compromise their ethics for personal gain.
- Love Interest between Eleanor Arroway and Palmer Joss: It smolders during the entire story, and forces Joss to ask Arroway the definitive question of the film, "Do you believe in God?"
  - Always know who has the compass and particularly what Arroway says to Joss when she first receives it. It becomes a key aspect of ***Contact*** near the end of the film.
- Theological aspect of the film: Palmer Joss believes in God and the concept of faith, which is a belief in something that cannot be proven. Eleanor Arroway is an atheist who believes that only through experimentation and the scientific method can humanity be led to the ultimate truths. This conflict weaves itself throughout the film, but watch how Arroway evolves to understand the meaning of faith at the end of the movie.
  - Faith: Faith is believing in something that cannot be proven scientifically (Becker). Faith is being sure of what we hope for and certain of what we do not see (Hebrews 11:1).
  - Note how Arroway becomes a Christ figure when she is willing to die for humanity's quest to make contact with an alien civilization (Scene with Washington Monument in the background).

Contact is a finely crafted film: Watch how director, Robert Zemeckis, ties the various parts of the film together through flashbacks, surprise moments, and scenes that are very well conceived from a visual and artistic standpoint.

Name ________________________________ Date________________ Moravian University

CONTACT
Based on the Novel by Carl Sagan
(20 points)

1. After watching the video, ***Powers of Ten*** by Charles and Ray Eames, contrast the accuracy of the opening segments of the movie ***Contact*** with respect to the velocity of light.
View the Power of Ten video here: https://www.youtube.com/watch?v=0fKBhvDjuy0

2. ____
____
____

3. In ***Contact***, as the camera zooms away from the Earth and solar system the sound bites that you are hearing in the background become ______________ with respect to time. **0:01:20**

4. The sound fades by the time that Eagle Nebula/Pillars of Creation become visible with a faint Morse code audible in the background. We have been transmitting radio signals for about one century. According to the movie, the Eagle Nebula is ________________________ from our solar system. The actual distance of the Pillars of Creation is approximately 7000 light years. **0:02:30**

5. A light year is equal to the
____

6. As the Eagle Nebula fades into the background, the ______________________ becomes visible followed by the Large Magellanic Cloud. We pass through Centaurus A, an active galaxy that is very bright in the X-ray and radio frequencies and probably contains a large supermassive ______________. **0:03:08** Centaurus A is about 16 million light years distant. Finally, we see the entire universe in the eye of Ellie Arroway.

7. Arroway at age nine is a licensed radio operator better known as a ______________.
0:03:37

8. Arroway asks her father, "Do you think there're people on other planets?" "I don't know Sparks," her father answers, "but I'd guess I'd say if it is just us, seems like an awful ______________ of space." **0:06:36**

9. The movie fades to an adult Eleanor Arroway at the ______________ Observatory operated by Cornell University in ________________________. **0:07:29**

10. This observatory features the second largest unsteerable __________________________ telescope (type of telescope) in the world. What part of the electromagnetic energy does it collect for analysis? That is the general name of this telescope.
    Below, circle the correct answer.
    T / F: Radio frequencies are part of the electromagnetic spectrum.
    T / F: Radio frequencies are shorter than visible light.
    T / F: Radio frequencies are in the same general category of frequencies that allow us to listen to radio and watch TV.
    T / F: Radio frequencies allow us to look deeper into galaxies and into the universe because they are less affected by dust than shorter wavelengths of energy.
    T / F: Radio telescopes can be used during the daytime.
    T / F: We search for extraterrestrial life using radio telescopes.

11. Near the end of her first evening of observations, Arroway finds a suspicious radio signal that turns out to be J1741 +2748, catalogued November 4, 1982 and is known as a ________________. **0:09:48**

12. Pulsars are rapidly ________________ neutron stars that formed after an old, red supergiant star has gone _____________________.

13. The diameter of a typical pulsar might be about _____________ miles. Pulsars may emit beams of radio radiation created by electrons spiraling around magnetic field lines. The number of pulses per second indicates the number of ________________ of the pulsar per second.

14. Why would anyone want to study Markarian (galaxy) 541 a major gamma ray source? **0:10:56**
    Gamma rays indicate an **energetic/not very energetic** (Circle One) source.

    Gamma rays indicate a **hot/cold** source (Circle One).

    Gamma rays emanating from a galaxy indicate that this galaxy may have a __________________________ at its center.

15. The numbers associated with J1741 +2748 represent the pulsar's ____________________ in the sky. A general term may be used here.

16. The coordinate system that gives navigators the ability to locate objects on the surface of the Earth is called _____________________ and ________________. See page 117 in your text for answers to questions 16-21.

17. On Earth, ________________ measures angular distance north and south of the equator while ________________ gauges angular distance east and west of the prime meridian. These two circles serve as reference circles that allow the establishment of Earth's grid system.

18. If the coordinate system of latitude and longitude is projected into space, a new grid system is formed that is very useful to astronomers. It is called the ______________________ coordinate system.

19. Where the equator intersects the sky, a new circle is formed called the __________________________. Latitude circles become circles of _____________________, while longitude meridians become hours of _______________________.

20. Latitude must be designated north or south of the terrestrial equator. Its counterpart in the sky, mentioned in the last problem, is denoted as ________________, depending upon its location with respect to the ________________ equator. North of the celestial equator, it is designated as a ________________, while south of the celestial equator this coordinate is given a ________________ sign.

21. Longitude is specified as east or west of the prime meridian. Its sky counterpart is measured eastward from the intersection point of the (ce)____________________ and the (e)__________________________. This position is called the (ve)__________________________, and it represents the position of the sun at the first moment of (s)________________.

Now, let's get back to the feature film…

22. The locals call Arecibo Observatory _____________________ because they are convinced that it has some dark military purpose. **0:11:51**

23. Ellie Arroway meets Palmer Joss and confesses to him that she is working on a project called SETI, ____**0:12:22**

24. Joss opens up the prize in the Cracker Jack box and pulls out a compass. He offers it to Ellie. Does she accept it, **yes or no** (Circle the correct answer)?

The compass plays a pivotal role in the movie. Always know who has it. 0:13:07

25. At the party for David Drumlin, head of the National Science Foundation, Drumlin considers the need to make scientific research accountable and practical to the taxpayers who are footing the bill. One of the astronomers Drumlin is talking to comments, "Not unlike my L band globular clusters...," which is suppose to be a joke. The L band is an X-ray region of the electromagnetic spectrum with energies between 100-400 eV. Globular clusters are tightly packed symmetrical groupings of very old stars. A typical globular may have between 10,000-1,000,000 solar masses. This astronomer probably is looking for _____________________ at the centers of these globular clusters. **0:14:44**

26. Joss interrupts Drumlin by saying that there is nothing wrong with science being practical "…as long as your motive is the search for ________________ which is exactly what the pursuit of science is." Palmer Joss is not against technology, he is against the men who deify it at the expense of human truth. **0:15:17**

27. Palmer Joss is a man of the cloth without the cloth. Joss could not deal with the ________________ requirement of being a Catholic priest. **0:15:51**

If it hasn't struck you yet, Joss very much believes in a God and in the concept of faith—believing in something that cannot be scientifically proven. Ellie is an atheist. She believes that God cannot possibly exist because there is no scientific proof that will verify God's existence. This is another major theme of the movie. *Contact* is not just about searching for ET. It is important to know that Carl Sagan was an atheist and at the time that the book *Contact*, was written, he was having serious health issues which eventually caused his death. We might be getting a glimpse into Sagan's mind and how he was wrestling with his own mortality near the end of his life.

28. That "W" shaped constellation is called _______________. **0:16:11**

29. How many stars does the Milky Way Galaxy possess? _______________________ **0:17:19**

30. Ellie says that if only one in a million of those stars in our galaxy had planets; and if only one in a million of those planets had life; and if only one in a million of those planets that had life had intelligent life, there would be literally millions of civilizations out there. Is Ellie correct in her conclusion? See the math below if you need help in determining an answer.

    Yes or No (Circle one) **0:17:39**

    10^{-6} x 10^{-6} x 10^{-6} x 400 x 10^{9} stars in the galaxy = 10^{-18} x 4 x 10^{11} = ____________

    If we assume that 50 percent of the stars in our galaxy have planets and that one in 10,000 have life and that one in 10,000 of those planets that have life have intelligent life, how many planets with intelligent life would exist in our galaxy.

    5 x 10^{-1} x 10^{-4} x 10^{-4} x 400 x 10^{9} = _______________

31. After Drumlin pulls the plug on Ellie's SETI research at Arecibo, who has the compass? _______________ **0:27:20**

32. Ellie decides to go it alone without NSF funding and search for grants so that she can observe at the VLA in New Mexico. **0:27:48**

    NSF stands for ____.

    VLA stands for ____.

33. At Hadden Industry, Ellie's presentation is well received but thought to be more like science fiction than scientific research. She's angered at their response and lectures the committee about having a little vision, "to look at the big picture, to take a chance on something that might be the most profoundly impactful moment for humanity, for the history of history." What is she talking about? **0:30:30**

    ____

    ____

34. Four years later, the scene shows many of the 27 linked radio telescopes of the Very ____________________ near Socorro, New Mexico. **0:31:11**

35. The scene also depicts an error as it did at Arecibo Observatory. It makes the movie more personal, but radio astronomers would never do this. **31:18** ___________________________

____

in fact, radio telescopes listen to several million frequencies at one time.

36. Who would make the best astronomers? Who has the perfect blend of career and lifestyle? ________________ **34:45**

37. Ellie screams, "right ascension 18 hours 36 minutes 56.2 seconds, Declination +38 degrees 46 minutes 56.2 seconds. What is she doing? ____ **37:02**

38. This is the RA and Dec of the star ________________ in the constellation of ________________. This star is only ________________ light years away. **40:45**

39. Two, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37, 41, 43, 47, 53, 59, 61, 67, 71, 73, 79, 83, 89, 97, 101 are the number of pulses in the sequence. These are ________________ numbers, ________________ integers which are only dividable by one and ________________ **42:09**

40. According to Ellie's team, what is wrong with Vega being the origin of the signals? ____**42:20**

41. Michael Kitz, National Security Advisor to the president asks, "if the source of the signal is so sophisticated, why the remedial math? Ellie responds that this is perfectly normal since the language of ________________ is mathematics. **44:45**

42. The first message received from Vega is a movie made in 1936 of Adolph Hitler saying "I declare the games in Berlin at the celebration of the first Olympics of the new era open." Why is Hitler our first ambassador from space?

____

____

____**49:09**

43. What is the problem with the sheets of data that have been received? ____ **59.00**

44. What does S. R. Hadden discover which turns out to the key to understanding the message from Vega? ____

____**1:06:40**

45. State Ockham's Razor (The concept of the razor results from the cutting away of unnecessary material: ____

____ **1:13:50**

46. Special Relativity—Einstein This machine… If it works and you travel to Vega at even close to the speed of light, when you come back, you'll only be four years older, but the rest of the world will be ________________ years older. **1:21:10**

47. Who gets the compass after Palmer Joss asks the question in front of the Machine Seat Selection Committee as to whether Ellie believes in God? ________________ **1:27:25**

48. What is the probable affiliation of the religious fanatic who blew himself up to bring a halt to the Machine experiment? ________________

49. What is the first rule in government spending? ____________________________________
____ **1:40:55**

50. On the boat off Okido Island in Japan, Ellie is handed a glass vial with a blue tablet inside during the briefing prior to trip in the Machine. What does the vial contain? ________________________________ **1:43:25**

51. Palmer Joss visits Ellie just prior to her journey. What does he give her? ________________ **1:45:00**

52. For astronauts, the walk across the gantry prior to entering the rocket has been called the loneliest / longest walk that an astronaut has to take. Why? __________________________
____**1:46:00**

53. As the machine revs up to maximum energy a tremendous EMF, develops around the structure. EMF stands for ____ **1:54:30**

54. The EMF in the movie is depicted as flashes of ________________. Inside the capsule, however, the weather is beautiful.

55. As soon as the capsule is dropped Ellie is whisked away into a wormhole. What is a wormhole? ____
____ **1:55:36**

56. Her first stop is at ________________. What is its color? ________________. Note the clouds of debris surrounding this young star. **1:57:00**

57. How does the compass save Ellie's life? ____
____
____
____**1:58:58**

58. What Ellie sees when the capsule finally comes to a stop is so beautiful the she says "They should have sent a _______________." **2:00:00**

59. While Ellie is unconscious, she is transported down to a beach on a strange and exotic world where she meets an alien. What was your first reaction regarding Ellie's condition when you saw the alien?
____
____**2:02:43**

60. While Ellie was unconscious the aliens downloaded her memories and thoughts, even the beach where they met which is in ____________________ Florida. **2:03:42**

61. Why did the aliens decide to do it this way? ___________________________________
____ **2:03:46**

62. Describe or draw the symbol that briefly flashes in the sand grains as the alien lets the sand slip from his hand. **2:04:15**

63. "You are an interesting species, an interesting mix. You're capable of such beautiful dreams and such horrible nightmares. You feel so lost, so cut off. Only you're not. See, in all our searching, the only thing we found that makes the emptiness bearable is ____________________." **2:05:36**

64. Ellie quickly returns back to Earth, but the capsule simply appears to have dropped into the net. According to witnesses on Earth the experiment seems to have been a _______________. **2:06:48**

    In the debriefing, Ellie describes her experiences, but is shown the IPV dropping into the net from numerous camera angles. She knows she has had an experience, but she cannot offer anyone any proof.

65. In the public inquiry, Ellie explains that she believes that the machine opened up a _______________, a tunnel through the fabric of space-time, also known as an Einstein-Rosen Bridge. Because of the effects of General Relativity, what Ellie experienced over a period of 18 hours occurred in only a fraction of a second in Earth time. **2:09:50**

    Ellie's response at the hearing to her realization that she has no proof to back up her story is as follows: 2:14:30
    "I had an experience… I can't prove it. I can't even explain it. But everything that I know as a human being, everything that I am tells me that it was real. I was given something wonderful, something that changed me forever, a vision of the universe that tells us undeniably how tiny and insignificant and how rare and precious we all are. A vision that tells us that we belong to something that is greater than ourselves that we are not, that none of us are alone. I wish I could share that… I wish that everyone, if even for one moment could feel that awe and humility, and the hope. But… That continues to be my wish."

66. Ellie now has a clearer understanding of the concept of faith—something that you know to be true, but cannot ________________.

67. The confidential findings report from the investigating committee indicated that Ellie's video unit recorded approximately ________________ hours of static. **02:18:47**

68. ***Contact's*** final scene shows Ellie Arroway sitting by an imaginary canyon (really Canyon de Chelly National Monument in NE Arizona near the VLA. She puts some dirt in her hand and we see the same __________________________________ that the alien saw in his hand on the faraway planet where they met. **2:20:55**

    As the screen fades to black, we see in the lower right-hand corner of the screen "for Carl." Carl Sagan died on December 20, 1996 at the age of 62 before the completion and release of his film in 1997.

Revised November 25, 2019

CAN YOU ANSWER THE FOLLOWING QUESTIONS/STATEMENTS ABOUT THE MILKY WAY, GALAXIES, AND THE UNIVERSE?

INTERSTELLAR MATTER

1. Clouds of interstellar gas and dust which can be seen throughout a galaxy are broadly termed _______________. There are four basic varieties: reflection, diffuse or emission, dark, and planetary.

2. The densities of gaseous nebulae are very low. Even the brightest contain only about 100 / 10,000 / 1,000,000 (circle one) atoms or ions per cubic centimeter. Under standard conditions, air has a particle density of 2.7 x 10^{19} molecules per cubic centimeter.

3. _______________ nebulae are normally found in OB-associations where ultraviolet light from nearby luminous stars (T > 25,000 K) causes the gases in the cloud to emit light in their own colors. The Orion nebula, located in the center of the sword of Orion, the hunter is probably the best example of this type of nebulosity. These types of nebulae are associated with stellar BIRTH/MATURITY/DEATH (Circle One). They almost always have cold regions of _______________ embedded in the hot (approx. 10,000 K) gas implying a lack of thermodynamic equilibrium. These types of nebulosities produce an EMISSION/CONTINUOUS/ABSORPTION (circle one) spectrum.

4. ______________ nebulae can be seen because of the light which they scatter from nearby stars. These clouds are composed of very small grains of _______________ which are nearly the same size as the light being emitted by the stars which are causing them to shine. This light is therefore SCATTERED/REFLECTED (circle one). The Pleiades, a star cluster located on the "shoulder" of Taurus, the bull contains one of the best examples of this type of nebulosity.

5. _______________ nebulae are formed when low mass stars, near the end of their lives, eject a shell of gaseous matter which is made to glow from energy escaping the degenerate, hot core of a ____________________ star. The ring nebula in Lyra highlights such an object. These types of nebulosities produce an EMISSION/CONTINUOUS/ ABSORPTION (circle one) spectrum.

6. _______________ nebulae reveal themselves when large interstellar clouds of dust absorb the radiation from stars which lie behind them. These clouds which also contain hydrogen and helium gas, are associated with stellar BIRTH/MATURITY/DEATH (circle one). The Horsehead nebula, near the southern end of the belt of Orion is a prime example of this type of structure.

7. In interstellar nebulae there ore often compact clouds of dust having moderately high densities. These can shield the local environment from high energy radiation (particularly the short ultraviolet) allowing for the formation of molecules which can be detected through their radio emissions. The detection of interstellar molecules by radio astronomers serves as a tracer for the location of regions where stellar _______________ may be occurring.

8. Cold neutral hydrogen atoms neither absorb nor emit light at optical wavelengths, but they do emit radiation at a wavelength of 21 cm in the _______________ region of the electromagnetic spectrum. This results when the ground state electron of a hydrogen atom spontaneously changes its spin from the same direction as the proton to the opposite direction of the proton.

9. Clouds of interstellar neutral hydrogen are referred to as _______________ regions while clouds of ionized hydrogen, found in diffuse and planetary nebulae are called _______________ regions.

10. Absorption by interstellar dust is more prevalent NEAR THE PLANE OF THE GALAXY/
NEAR HIGH GALACTIC LATITUDES (circle one). All stars at substantial distances from us appear BRIGHTER/FAINTER (circle one) and ________________ (color) due to the scattering effects of dust in the galaxy and throughout intergalactic space. This tells astronomers something about the average size of the dust particles, which can be no more than about 0.1 micron or 10^{-5} cm in diameter. Typically this dust is composed of ________________, ________________, ________________, and ________________.

11. The vast majority (about 99 percent) of interstellar matter is found in the form of DUST/GAS (circle one) which DOES/DOES NOT (circle one) absorb starlight.

THE MILKY WAY GALAXY

12. The sun is located in a huge stellar system known as the ____________________ galaxy. The word galaxy is derived from "galas," the Greek word for _______________.

13. From the top down, our galaxy appears similar to a _______________ with huge _______________ arms emanating from a central _______________ where the density of stars is the greatest.

14. Viewing our galaxy from its equatorial plane, it appears as a _______________ (shape) structure with a central _______________. Mapping the galaxy has proven to be a very complex matter. We cannot observe the center of the galaxy, because there is an enormous amount of interstellar matter between us and the galactic nucleus. This fog results from the GAS/DUST (circle one) component of interstellar matter found within the Milky Way.

15. Our galaxy's diameter is approximately _______________ light years. While most of the matter appears to reside near the galactic plane, a huge halo of ________________ clusters, spherically symmetrical compact groupings of stars, each containing from about 10,000 to one million members occupies the regions above and below the plane of the Milky Way.

16. The galactic equator runs through the middle of the band of light we refer to as the ____________________. It is inclined 62 degrees to the plane of the celestial equator and extends 360 degrees around the sky. This implies that we are not at the ________________ of this system. Current estimates place the solar system at a distance of approximately ________________ light years from the galactic center.

17. There appears to be two different populations of stars in the Milky Way. These can be described as ________________ rich or poor stars. These two broad categories of stars occupy specific regions in spiral galaxies like our Milky Way. Before a star is considered metal rich, at least ________________ percent of its mass must be contained in elements heavier than hydrogen and helium.

18. Population ________________ stars can be found in the galactic center, as well as the halo, which defines the realm of the globular clusters. Population ________________ stars are found in the spiral arms of the galaxy.

19. Identify the two populations of stars found in the Milky Way with respect to:

	Population I	Population II
Color:		
Age:		
Metal Content:		
Interstellar Gas and Dust:		

20. The mass of the Milky Way is now believed to be about ________________ solar masses. This is higher than earlier estimates, because it is now realized that the galactic ________________ is much more massive than previously assumed. Not all of the mass in the galaxy appears to be observable in stars and interstellar matter. In the center of the galaxy, where densities are HIGHEST/LOWEST (circle one), a super massive _____________________ may reside.

21. As the galaxy rotates, stars in the galactic plane travel in ________________ (shape) orbits around the nucleus. The orbital speed of the sun is about 150 $^{miles}/_{sec}$ (250 $^{km}/_{sec}$) and it takes about 200 million years to complete one orbit.

GALAXIES IN GENERAL

22. The basic way that matter congregates in the universe is in the form of ____________.

23. The Milky Way Galaxy is one of several THOUSANDS/MILLIONS/BILLIONS (circle one) of island universes which are known to inhabit the universe in which we live. Only three other systems are easily visible to the unaided eye. The largest and most distant of these is the great spiral galaxy called _________________, which lies at a distance of 2.1 million light years from the sun. It is slightly more massive than the Milky Way. The other two are the Large and the Small _________________________, satellite systems of our own Milky Way which can only be observed from the Southern Hemisphere.

24. Galaxies were classified by the astronomer Edwin _______________ in the 1920's according to their appearance and structure. These fall into three broad categories: spirals, ellipticals, and irregulars.

25. _______________ galaxies tend to be large to very large as galaxies go and have population II stars in their nuclei and halos, plus population I stars with plenty of interstellar gas and dust in their arms.

26. _______________ range from very small, for galaxies, to extremely large. They seem to consist of population II stars only, and they have little gas or dust.

27. _______________ tend to be smallish, for galaxies, and have many population I stars along with substantial quantities of gas and dust.

28. The Milky Way and Andromeda galaxies are the two largest members of a cluster of about _______________ (number) galaxies called the ____________________. At least one other spiral (Messier 33) and several irregular and dwarf elliptical galaxies coexist in this assemblage. Most galaxies are FOUND/NOT FOUND (circle one) in clusters.

29. The nearest giant cluster of galaxies is the _______________ cluster which contains several DOZENS/THOUSANDS (circle one) of galaxies. The largest galaxy of this cluster is Messier 87, a giant elliptical, which is among one of the most massive galaxies known.

30. Most typical galaxies produce ABSORPTION/EMISSION (circle one) spectra which arise as a composite signature of the different types of stars which are contained in them. A group of peculiar galaxies, known as _______________ galaxies, however, have emission lines and very bright nuclei.

31. There also exists another type of peculiar galaxy which emits far more radio noise than normal. These galaxies are known as _______________ galaxies. Some of the radio radiation arises from the cores of these structures, but most of these galaxies also display lobes filled with high-energy electrons which are located outside the optical limits of the object.

32. The two types of peculiar galaxies mentioned in the last several problems are also referred to as ________________ galaxies. They apparently have violent processes taking place in their cores which may be the result of rapidly rotating disks of matter plunging into large, super massive ______________________.

33. Even more peculiar than the active galaxies are ________________, which are only seen at very great distances. They appear starlike and are often variable in light. These objects generate huge amounts of energy across the entire electromagnetic spectrum from a very small volume of space. They are probably the cores of very young and extremely active galaxies.

THE UNIVERSE

34. All matter-energy everywhere is a good definition for the ____________________.

35. The study of the large-scale structure of the universe is known as ____________________. It is by far the most speculative branch of present-day astronomical research.

36. In 1823 Heinrich ___________________ published a paper on why the sky is dark at night. If the universe were infinite in extent, there would be an infinite number of stars in the sky and every available space in the heavens would be occupied by a luminary. The night sky should therefore have the same brightness as the surface brightness of a typical star. Why then is the nighttime sky dark? Explain the riddle of __________________ Paradox using the following clues as a guide.
a. Is the universe infinite? ____

____

b. The expanding universe: ____

____

____

____

c. The red shift: ____

____

d. Dust: ____

37. In 1916 Albert Einstein demonstrated that the universe could not be static; it must either expand or contract. During the next two decades, Georges Lemaitre and George Gamow proposed that the entire visible universe had been formed from a single primordial event, known as the _____________________.

38. In 1924 Edwin ________________ was able to conclusively prove that the so-called spiral and elliptical nebulae were in fact galactic systems in their own right. In 1929 he

determined that all of the more distant galaxies were _______________ from us at rates which were proportional to their distances. Remember, that the determination of the distances to galaxies must be obtained without knowing their red shifts or there is no way one can independently correlate expansion rates (red shifts) with distances.

39. The Hubble constant, H0, is a determination of the rate at which the universe is _______________. It is measured in $^{kilometers}/_{second}$-- megaparsec. The best determination of H0 at present is _______________ $^{km}/_{sec}$-- Mpc. One megaparsec equal one million parsecs or 3.26 million light years.

40. Current estimates of the Hubble constant range from 45-75 $^{km}/_{sec}$-- Mpc. It is an extremely important number to clarify, for it gives astronomers the ability to determine the _______________ of the universe. The current value of H0 implies a 20 billion year old universe, or the maximum time since the big bang. A lower constant suggests an (a) OLDER/YOUNGER (circle one) universe because if would take objects longer to reach their observed distances. If H0 = 30 km/sec-- Mpc, then the universe would be approximately 30 billion years of age. A higher constant implies just the opposite. In fact if H0 = 75 km/sec-- Mpc, then the universe can only be about 13 billion years of age. The reciprocal of the Hubble constant is known as the Hubble time (T0 = $^{1}/_{H0}$).

41. The oldest stars in the Milky Way galaxy are about _______________ billion years of age. Since these luminaries could only have been formed well after the big bang, it is EASY/DIFFICULT (circle one) to reconcile their ages with a Hubble constant as large as 75 $^{km}/_{sec}$-- Mpc.

42. When we look out into space we are also looking back into ______________. The farther out we see, the EARLIER/LATER (circle one) into the history of the universe we peer.

43. Quasars have provided astronomers with evidence for an evolutionary universe, that is, a universe which changes with time. How?____

____

The 3 K microwave background radiation represents the first visible artifact of the big bang itself, where the universe had thinned and cooled to the point that energy could escape. It also gives credence to an evolutionary universe since the big bang was a once and done event which happened at the creation of space and time.

44. One variant of the big bang hypothesis is a universe that will have a sufficiently high enough mean _______________ so that gravity will halt its expansion and force it to collapse upon itself to perhaps rekindle yet another big bang event sometime in the future. This type of accordion universe is called an _______________ universe.

45. If the mean density of the universe is less than the closure density, the universe will ____________________. Such a universe is termed an _______________ universe. Present observations indicate that the universe is probably _______________.

46. Over the years there have been other cosmological models which do not invoke a primordial event. One of these hypotheses, first proposed in 1948 by Gold, Hoyle, and Bondi suggested a universe that was infinite in space and time, expanding, and homogeneous. Hydrogen was being created in the voids formed by the expanding galaxies. This hypothesis, no longer considered valid, is called the ____________________ theory.

NOTES

ANSWERS TO SESSION FIFTEEN QUESTIONS

INTERSTELLAR MATTER

1. nebulae (singular = nebula)
2. 10,000
3. diffuse or emission, BIRTH, dust, EMISSION
4. reflection, dust, SCATTERED
5. planetary, white dwarf, EMISSION
6. dark, BIRTH
7. birth
8. radio
9. H I, H II
10. NEAR THE PLANE OF THE GALAXY, FAINTER, redder, iron, carbon, silicates, ices
11. GAS, DOES NOT

THE MILKY WAY GALAXY

12. Milky Way, milk
13. pinwheel, spiral, hub (bulge or nucleus)
14. pancake (flattened), hub (bulge or nucleus), DUST
15. 100,000, globular
16. Milky Way, center, 30,000
17. metal, 2
18. II, I
19.

	Population I	Population II
Color	bluer	redder
Age	newer	older
Metal Content	higher >2%	lower <2%
Interstellar Gas and Dust	abundant	scarce

20. trillion, halo, HIGHEST, black hole
21. circular

GALAXIES IN GENERAL

22. galaxies
23. BILLIONS, Andromeda, Magellanic Clouds
24. Hubble
25. spiral
26. ellipticals
27. irregulars
28. 20, Local Group, FOUND
29. Virgo, THOUSANDS
30. ABSORPTION, Seyfert
31. radio
32. active, black holes
33. quasars

THE UNIVERSE

34. universe
35. cosmology
36. Olbers, Olbers's
    a. The universe is infinite: No, the universe is finite. It does not contain an infinite number of stars.
    b. The expanding universe: Because the universe is so large and getting larger by the second, there has not been enough time to fill it completely with the light from every star which it contains.
    c. The red shift: Displaces (weakens) much of the visible radiation of stars to longer wavelengths, particularly into the infrared, which the eye cannot see. But the sky is dark in most wavelengths, including the infrared. Thus the red shift by itself cannot explain Olbers' Paradox.
    d. Dust: Absorbs and scatters some of the radiation before it reaches us, but again this is not an explanation for Olbers' Paradox because the dust must reradiate the energy in a longer wavelength.
37. big bang
38. Hubble, receding
39. expanding, about 50
40. age, OLDER,
41. 13, DIFFICULT
42. time, EARLIER
43. All quasars are far away. There are none close to us. This means that quasars were once part of a younger universe and that quasars no longer exist or have evolved into other objects.
44. density, oscillating
45. expand forever, open, open
46. steady state

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