Chapter 18: The Universe

Homework: All questions on the “Multiple-Choice” and the odd-numbered questions on “Exercises” sections at the end of the chapter.

The Universe

- When we use the term universe we are discussing the totality of all matter, energy, and space.
- In this chapter we will examine the stars, galaxies, and cosmology.
  - In particular we will discuss our sun and the classification of the stars.
  - Galaxies are giant assemblages of stars.
  - Cosmology deals with the structure and evolution of the universe.

Studying the Universe

- Stars and galaxies emit the full spectrum of electromagnetic radiation.
- For many years we were only able to gather information from one type of emitted electromagnetic radiation – visible light.
- In 1931 radio telescopes became operational, giving scientists the ability to start gathering information from other wavelengths.

The Sun

- A star is a self-luminous sphere of hot gases, energized by nuclear reaction and held together by the force of gravity.
- The Sun is the nearest star to Earth.
- The Sun is enormous in size relative to the size of Earth.
  - The Sun’s diameter is approximately 4 times the distance between the Earth and the Moon.

Basic Information about the Sun

<table>
<thead>
<tr>
<th>Property</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>1.39 × 10^9 km (8.65 × 10^5 mi)</td>
</tr>
<tr>
<td>Mass</td>
<td>2.0 × 10^{30} kg</td>
</tr>
<tr>
<td>Density (average)</td>
<td>1.4 g/cm^3</td>
</tr>
<tr>
<td>Luminosity</td>
<td>3.8 × 10^{26} W</td>
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<tr>
<td>Tilt of axis</td>
<td>7° from a normal to the ecliptic plane</td>
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<tr>
<td>Period of rotation at equator</td>
<td>25 Earth days (longer at higher latitudes)</td>
</tr>
<tr>
<td>Motion within the galaxy</td>
<td>250 km/s toward the constellation Lyn</td>
</tr>
<tr>
<td>Distance (average) from the Earth</td>
<td>1.5 × 10^{11} km (9.3 × 10^{7} mi)</td>
</tr>
</tbody>
</table>
Structure and Composition of the Sun

- The Sun can divided into four concentric layers:
  - The innermost core
  - The “surface” is called the photosphere.
  - The chromosphere is a layer of very hot gases above the photosphere.
  - The corona is the Sun’s outer solar atmosphere.

Photosphere

- The photosphere is the bright and visible “surface” of the Sun.
  - Temperature of 6000K
  - Composition of 75% H, 25% He, and 1% C, O, N, Ne, and others
- When viewed close-up, the photosphere surface appears to have a ‘granular’ texture.
- Each granule is a hot spot caused by an individual convection cell bringing thermal energy to the surface.
  - Each granule is about the width of Texas.

Sunspots

- Sunspots are huge patches of cooler, and therefore darker material on the surface of the Sun.
  - They are a distinctive feature of the photosphere.
- The late 1600’s were an unusually cold period on Earth, marked by an anomalously fewer number of sunspots.
  - In Europe this time was known as the Little Ice Age.
- Apparently, there is a strong connection between solar activity, as displayed by sunspots, and global climates on Earth.

Sunspot Cycle

- The abundance of sunspots vary through an 11-year sunspot cycle.
- Each sunspot cycle begins with the appearance of a few sunspots near the 30° “N & S” latitudes.
- The number of sunspots slowly increase, with a maximum number in the middle of the cycle at around the 15° region.
- The number of sunspots then slowly taper off during the last half of the 11-year cycle.
- Each 11-year cycle is similar except that the magnetic polarities of sunspots are reversed.
- Therefore the 11-year sunspot cycle is actually a manifestation of a 22-year magnetic cycle.
Flares and Prominences

- Flares are bright explosive events that occur on the Sun’s surface.
- Prominences are enormous filaments of solar gases that arch out and over the Sun’s surface.
  - Prominences may extend hundreds of thousands of km outward.
  - Since they occur along the outer edge of the Sun, they are particularly evident during solar eclipses.

A Major Solar Prominence

Flares can also be seen as the bright yellow areas.

Corona

- The corona is the pearly white halo or crown extending far beyond the solar disk.
  - Visible during total eclipses of the Sun.
- The corona can be interpreted to be the Sun’s “outer atmosphere.”
  - Corona’s temperature is approximately 1 million K.
- Prominences occur within the corona region of the Sun.

Solar Wind

- In the extreme high-temperatures of the corona protons, electrons, and ions are furnished with enough energy to escape the Sun’s atmosphere.
  - These particles are accelerated enough to escape the Sun’s tremendous gravitational pull.
- The solar wind extends out from the Sun at least 50 AU.
- Heliosphere is the volume or “bubble” of space formed by the solar wind.
  - Virtually all the material in the heliosphere emanates from the Sun.

Interior of the Sun

- The Sun’s interior is so hot that individual atoms cannot exist.
  - Continuous high-speed collisions result in the separation of nuclei and electrons.
- A fourth phase of matter, called a plasma, is created where nuclei and electrons exist as a high-temperature gas.
- The temperature at the central core of the Sun is 15 million K and the density is 150 g/cm³.
  - The innermost 25% of the Sun, the core, is where H is consumed to form He.

Interior of the Sun

- Moving outward from the core of the Sun, both the temperature and the density decrease.
- It is the nuclear fusion of H into He within the core that is the source of the Sun’s energy.
- In the Sun and other similar stars the nuclear fusion takes place as a three step process called the proton-proton chain.
Proton-Proton Chain or PP Chain
Each reaction liberates energy by the conversion of mass.

- In the net reaction of the PP Chain, four protons form a He nucleus, two positrons, two neutrinos, and two gamma rays.

\[
4 \text{H} \rightarrow \frac{3}{4}\text{He} + 2(\frac{3}{2}\text{e} + \nu + \gamma) + \text{energy}
\]
- The amount of energy released by the conversion of mass conforms with Einstein’s equation, \( E = mc^2 \).

Solar Longevity
- Approximately \( 6.00 \times 10^{11} \) kg of H is converted into \( 5.96 \times 10^{11} \) kg of He every second
- With a total mass of \( 10^{30} \) kg of H, scientists expect the Sun to continue to radiate energy from H fusion for another 5 billion years

The Celestial Sphere
- Celestial sphere – the huge imaginary sphere of the sky on which all the stars seem to appear
- During any given night, the great dome of stars appear to progressively move westward, from an observer's vantage point on Earth.
- North celestial pole (NCP) – the point in the Northern Hemisphere that the stars seem to rotate around – Polaris or the “North Star”
- South celestial pole (SCP) – the point in the Southern Hemisphere that the stars seem to rotate around

Star Trails
- The stars’ apparent movement is due to the Earth’s actual west-to-east rotation.
- The NCP & SCP are simply extensions of the Earth’s rotational axes.

Celestial Distance
- The distance to most celestial bodies is measured in astronomical units (AU), light-years, or parsecs.
- Astronomical unit (AU) – the mean distance between the Earth and the Sun (1.5 x 10^8 km)
- Light-year (ly) – the distance light travels through a vacuum in one year (9.5 x 10^{12} km)
- Parsec – distance to a star when the star exhibits a parallax of 1 second of arc.
Stars

• Recall that stars are composed dominantly of H, with some He, and far lesser amounts of other elements.
• They exist as huge plasma spheres in which nuclear fusion of H to He produces enormous amounts of energy that is emitted.
• Although star masses can vary considerably, most have a mass between 0.08 – 100 solar masses.
  – One solar mass = mass of our Sun

Stars

• Most stars are part of a multiple-star system, unlike our Sun that is a single star.
• Binary stars – stars that consist of two close stars each orbiting about their shared center of mass
  – Most stars are part of a binary system.
• There are also star systems with three or more closely spaced stars but these are far less frequent.

Constellations

• Constellations – prominent groups of stars that appear as distinct patterns to an observer on Earth
• In similar fashion to the individual stars, the constellations also appear to move westward across the sky each night
  – Due to Earth’s rotation.
• Constellations also exhibit an annual cycle of movement due to the tilt of the Earth and its annual orbit around the Sun.

Asterisms

• Asterisms – familiar groups of stars that only comprise part of a constellation, or perhaps parts of two constellations
• The Big Dipper, the Little Dipper, and the Summer Triangle are each an example of an asterism.

Apparent Magnitude

• The apparent magnitude scale in use today is a modified version of Hipparchus’ scale.
  – Instruments are used to accurately measure and quantify the apparent magnitudes.
• The modern scale is constructed such that a difference of 5 magnitudes represents a difference of 100 in apparent brightness.
  – Therefore a first-magnitude star appears 100 times brighter than a sixth-magnitude star.

Apparent Magnitude

• Each step in magnitude is therefore equal to the fifth root of 100, or about 2.51.
• The equation is \( \Delta B = (2.51)^{\Delta M} \)
  – \( \Delta B = \) difference in brightness for two stars
  – \( \Delta M = \) difference in magnitude for two stars
• Therefore, a first-magnitude star is 2.51 times brighter than a second-magnitude star.
  – A first-magnitude star is \((2.51)^2\) times brighter than a third-magnitude star and \((2.51)^3\) times brighter than a fourth-magnitude star.
  – The greater the positive number the dimmer the star
Calculating Brightness Difference for Two Stars

- Sirius has an apparent magnitude of about \(-1\), whereas Polaris has a magnitude of about +2. Which star appears brighter, and by what factor?

- Sirius has the lower magnitude, so it is the brighter. (-1 is less than +2)

- Use Equation \( \Delta B = (2.51)^{\Delta M} \) to determine by what factor.

- The difference in magnitude (\( \Delta M \)) between Sirius and Polaris is 3.

- Thus \( \Delta B = (2.51)^3 = 15.8 \)

- Sirius has an apparent brightness 15.8 times that of Polaris.

Calculating Brightness Difference for Two Stars - Confidence Exercise

- The star Procyon A has an apparent magnitude of about 0, whereas the star 61 Cygni A has a magnitude of about +5. Which star appears brighter, and by what factor?

- Procyon A has the lower magnitude, so it is the brighter. (0 is less than +5)

- Use Equation \( \Delta B = (2.51)^{\Delta M} \) to determine by what factor.

Apparent Magnitude of other Celestial Bodies

- The brightest celestial body is the Sun.
  - The Sun has an apparent magnitude of \(-27\).

- The full moon is the second brightest celestial body.
  - The full moon has an apparent magnitude of \(-13\).

- Venus is the brightest planet.
  - Venus has an apparent magnitude of \(-4\).

- Sirius is the brightest star. (8.7 ly in distance)
  - Sirius has an apparent magnitude of \(-1\).

Absolute Magnitude

- Obviously, a star’s distance from Earth tremendously affects its apparent brightness.

- **Absolute magnitude** – the brightness a star would have if it were placed 10 pc (32.6 ly) from Earth

- Our Sun, for example, has an absolute magnitude of +5.

- If we know the distance to a star and its apparent magnitude, the absolute magnitude can be calculated.

The H-R (Hertzsprung-Russell) Diagram

- The H-R Diagram results from plotting the stars’ absolute magnitudes versus the temperatures of their photospheres.

- Most stars become brighter as they get hotter.

- These stars plot as a narrow diagonal band in the diagram.

- The hottest (and generally brightest) stars are blue. The coolest (and generally least bright) stars are red.

Spectral Classes

- In the H-R diagram, stars have been placed in seven spectral classes -- O,B,A,F,G,K,M.
  - Note the horizontal axis of the diagram.
Stars off the H-R Main Sequence

• Several types of star do not fall on the main sequence.
• Red giants – very large stars that are cool, yet still very bright
  – The very brightest are called red supergiants.
• White dwarfs – stars that are very hot, yet are dim due to their small size

Spectral Analysis of the Stars

• Spectral analyses of stars shows that even the most distant stars contain the same elements we find in our solar system.
• However, there are variations in the spectra depending on the temperature of the individual star’s photosphere.
• Therefore, the patterns of the absorption lines in the spectra can be used to determine both the composition and the surface temperature.

Spectral Classification

• Our Sun falls close to the middle of the main sequence and is a class G star.
• Sirius is quite a bit hotter than our Sun and is a class A star.
• Astronomers have found that the majority of stars are small, cool, class M stars, also called red dwarfs.
  – Proxima Centauri is the closest star to Earth (besides our Sun) and is a red dwarf or class M star.

Interstellar Medium

• Interstellar medium – gases and dust that is distributed amongst the stars
• The gases consists of about 75% H, 25% He, and a trace of heavier elements by mass.
• The dust (only about 1% of the interstellar medium) consists primarily of C, Fe, O, & Si.
  – About the size of particles in smoke

Bright Nebulae – Two Types

• The gases and dust do not appear to be distributed uniformly throughout space.
• Nebulae – concentrations of cool, dense clouds of gases and
• Bright nebulae can, in turn, be divided into:
  – Emission nebulae – energy from nearby stars ionize the hydrogen gas resulting in fluorescence
  – Reflection nebulae – dust within the nebulae reflect and scatter starlight, giving off a characteristic blue color

Dark Nebulae

• Dark nebulae – produced by the obstruction of a relatively dense cloud of interstellar dust
• Dark nebulae are visible as relatively dark areas as they are framed against some type of light-emitting region behind them.
• The most famous of the dark nebulae is located in the constellation Orion.
• It appears like the head of a horse, back-lit by a bright emission nebula.
The Horsehead Nebula
A Dark Nebula

The Great Nebula in Orion (M42)
An Emission Nebula

General Evolution of a Low-Mass Star

• Stars begin to form as interstellar material (mostly H) gathers together. (accretion)
• The accretion of the interstellar material may be due to several factors:
  - Gravitational attraction of the material
  - Radiation pressure from nearby stars
  - Shockwaves from exploding stars
• A protostar forms as the interstellar material condenses and the temperature rises.

General Evolution of a Low-Mass Star

• As the protostar continues to condense, the temperature continue to rise.
• As the temperature continue to rise, the thermonuclear reaction begins in which H is converted to He as given below. (fusion)
• When thermonuclear fusion begins, this is the time a star is actually born.
• It moves onto the H-R main sequence, in a position determined by its temperature and brightness.

\[
4 \, ^1\text{H} \rightarrow ^2\text{He} + 2(\, ^0\text{e} + v + \gamma) + \text{energy}
\]

Stellar Evolution

• As the star continues to fuse H into He, it remains on the H-R main sequence.
• The period of time that a star remains on the main sequence can vary widely.
• A low-mass star, such as our Sun, will remain on the main sequence for 10 billion years.
• A very low-mass star may stay on the main sequence for trillions of years.
• High-mass stars fuse fuel fast, and only remain on the main sequence a few million years.

Stellar Evolution

• As H in the core continues to convert to He, the core begins to contract and heat up even more.
• This extra heat eventually causes the H in the surrounding shell to proceed more rapidly, which in turn destabilizes the star’s hydrostatic equilibrium, resulting in expansion.
• At this point, when the star expands, it enters the red-giant phase, and moves off the main sequence.
Red-Giant Phase

- When our Sun moves into its red-giant phase (several billion years from now) it will swell and engulf Mercury and possibly Venus.
- The core of a red-giant eventually becomes so hot that He will fuse into C and perhaps will create elements up through Ne.
- Nucleosynthesis is the creation of elemental nuclei inside stars.
- In high-mass red supergiants nucleosynthesis may continue all the way up to Fe.

Variable Star

- Variations occur in the star’s temperature and brightness during the red-giant phase.
- For a short time it becomes a variable star, as its position on the H-R diagram moves left.

Planetary Nebula

- During and after the variable star stage the star becomes very unstable, resulting in the outer layers being blown off forming a planetary nebula.
- Planetary nebula have nothing to do with planets.
  - Early and fuzzy photographs of planetary nebula reminded astronomers of an evolving solar system.
- The expelled material diffuses into space, providing material for future generations of stars.

White Dwarf

- Following the formation of a planetary nebula the remaining core is called a white dwarf.
- Thermonuclear fusion no longer occurs in a white dwarf and it slowly cools by radiating its residual energy into space.
- White dwarfs are not very bright and fall low on the H-R diagram.
  - A single teaspoon a matter in a white dwarf may weigh 5 tons!

Sirius – a Binary Star

- Sirius A is a class-A main sequence star.
- Sirius B is a white dwarf.

Brown Dwarfs

- During stellar evolution, what if a protostar cannot sustain thermonuclear fusion due to its small mass?
- In this situation the protostar would not progress to the star phase and would result in a “failed star” or a brown dwarf.
- Obviously brown dwarf are very dim.
- The first brown dwarf was not discovered until 1996. – Gleise 229B
  - About 100 brown dwarfs have now be found.
Nova

- Nova – a white dwarf that temporarily and suddenly increases in brightness
  - Although the word nova mean “new star,” it is not.
- Novas result from a nuclear explosion on the surface of a white dwarf.
  - This explosion is caused by small amounts of material falling onto the white dwarf’s surface from its much larger binary companion.

Supernova

- Supernova – the gigantic and catastrophic explosion of a star
  - Large amounts of material and radiation are thrown off as a result of this explosion.
- There are two types of supernovas:
  - Type I supernovas result from the destruction of a white dwarf containing a carbon-oxygen core.
  - Type II supernovas result from the collapse of an iron core of a red supergiant.

Supernova

- The Type I and Type II supernovae can be distinguished by their different spectral signatures:
  - Type I supernova do not have hydrogen spectra nor do they emit radio waves.
  - Type II supernova display hydrogen spectral lines and emit radio waves.

Crab Nebula

- The Crab Nebula is the best known and one of only three supernovae that have been recorded in the Milky Way Galaxy.
- The supernova that resulted in the Crab Nebula was reported in Chinese and Japanese records around 1054.
- During the first two weeks of this supernova’s appearance, the night sky was bright enough to read by.

Nucleosynthesis

- The energy and neutrons emitted during a supernova explosion result in the nucleosynthesis of the elements heavier than iron.
- Other than H and He, all of the elements up to Fe are thought to be made during normal fusion processes in stars of various masses.
- Elements past Fe are thought to be generated exclusively during supernova explosions.
**Neutron Stars**
- When the nuclear fuel interior of a red supergiant is depleted, the interior undergoes a catastrophic collapse to form a small neutron star.
  - Approximately 20 km in diameter
- As a result of this inner collapse, the outer layers also collapse, bounce off the rigid inner core, and expand into space, resulting in an ever expanding supernova, leaving behind the core (neutron star.)
- The name “neutron star” comes from electrons and protons combining to form neutrons.
- Neutron stars are extremely dense – in the order of 1 billion tons per teaspoon.

**Pulsar**
- Any angular momentum that the original star had must be maintained.
- Therefore, the small size of the neutron star dictates that it may spin rapidly.
- A pulsar emits radio waves that are detected on Earth in regular pulses apparently due to its rapid rotation.
  - Each pulsar has a constant period between 0.03 - 4s.
- Pulsars are interpreted to have a magnetic axis which is tilted relative to its magnetic axis.
- The pulsar at its center spins 30 time/second. This nebula also emits pulses of visible light.

**Black Holes**
- Black hole – a celestial object so dense that the escape velocity is equal to or greater than the speed of light
  - Gravity’s ‘final’ victory over all other forces
  - Not even light cannot escape from its surface
- Black holes are thought to result from a supernova explosion when the core remaining is greater than 3 times the mass of the Sun.
- The star’s matter continues to condense down to an extremely small point, a singularity.

**Configuration of a Nonrotating Black Hole**
*Within the event horizon boundary (the Schwarzschild radius R), the escape velocity is equal to or greater than the speed of light. Therefore no matter or radiation can escape.*

**Detection of a Black Hole**
- The event horizon of a black hole represents a one-way boundary: anything can enter but nothing can escape.
- If nothing, not even electromagnetic radiation, can escape a black hole then how can one be detected?
- One way is the detection of x-ray emission in the vicinity of a black hole.
- Captured gases, just outside the event horizon emit x-rays and form an accretion disk.

**Class O Star and Black Hole - Cygnus X-1**
The x-rays that are being generated are apparently due to an accretion disk of gases being captured by the black hole.
High-Mass vs. Low-Mass Stars

- High-mass stars and low-mass stars form initially in similar manners.
- High-mass stars are hotter and brighter than low-mass stars.
  - High-mass star move onto the main sequence at higher points.
- High-mass stars do not stay on the main sequence as long as low-mass stars, due to their higher rate of thermonuclear fusion.

Evolution of a High-Mass Star

When high-mass stars move off the main sequence they become red supergiants and eventually explode as Type II supernovae. Much of the material is scattered into space leaving behind a neutron star or black hole.

The Fate of Celestial Objects

<table>
<thead>
<tr>
<th>Final Mass of Object</th>
<th>Fate of Object</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 0.01 mass of Sun</td>
<td>Planet or moon</td>
</tr>
<tr>
<td>0.01 to 0.07 mass of Sun</td>
<td>Brown dwarf</td>
</tr>
<tr>
<td>0.08 to 1.4 mass of Sun</td>
<td>White dwarf</td>
</tr>
<tr>
<td>1.5 to 3.0 mass of Sun</td>
<td>Neutron star</td>
</tr>
<tr>
<td>Greater than 3.0 mass of Sun</td>
<td>Black hole</td>
</tr>
</tbody>
</table>

Classification of Galaxies

- Galaxy – a very large aggregate of stars, gas, and dust held together by their mutual gravitational attraction
- Edwin P. Hubble (1889 – 1953) established a system to classify galaxies into four types:
  - Elliptical
  - Normal spiral
  - Barred spiral
  - Irregular
- Hubble initially studied law under a Rhodes Scholarship but switched professions and completed his Ph.D. in astronomy in 1917.

Elliptical Galaxies

- **Elliptical galaxy** – stars are arranged into a spherical or elliptical shape
- An elliptical galaxy does not have extending curved “arms.”

Normal Spiral Galaxies

- **Normal spiral galaxy** – consists of two more-or-less definable regions
- The central nuclear bulge is the region where vast numbers of stars are tightly bunched together.
- Extending out from the nuclear bulge is a curved or spiral disk also containing numerous stars.
Andromeda Galaxy (M31)
*Normal spiral galaxy*

Barred Spiral Galaxies
- Barred spiral galaxy – two broad expansions ("bars") extend out from opposite side of the nuclear bulge before the arms start to curve from the outer boundaries of the bars

Irregular Galaxy
- *Irregular galaxy* – a galaxy with no geometric shape

Galaxy Facts
- Several hundred thousand galaxies have been identified.
- Astronomers estimate there are 60 billion galaxies in the universe.
- In order of abundance:
  - Elliptical galaxies are a majority of the galaxies.
  - Normal spiral galaxies greatly outnumber barred spiral galaxies.
  - Irregular galaxies comprise only about 3% of the galaxies.

Galaxy Distances
- The nearest galaxy to the Milky Way is Sagittarius Dwarf - About 50,000 ly.
  - Discovered in 1994
  - Sagittarius Dwarf is a small elliptical galaxy being pulled into the gravity of the Milky Way.
- Second nearest galaxy to the Milky Way is LMC, at about 160,000 ly.
- SMC is the third closest to the Milky Way, at about 200,000 ly.
- The Andromeda Galaxy (M31) is about 2.2 ly from the Milky Way.

The Milky Way Galaxy
- The Milky Way is a normal spiral galaxy, so-named because ancient people thought it appeared like a trail of spilled milk on a clear night.
- The broad band that we observe in the night sky is a view into the plane of the galactic disk.
- Although the unaided eye can distinguish about 6000 stars in the Milky Way, astronomers estimate there are actually between 100-200 billion.
The Milky Way Galaxy

Face-on and edge-on Views of our Galaxy

• Globular Clusters – “small” globular clusters of a few 10,000’s of stars
  – These clusters form a halo around the outside of the Milky Way.
• In 1917 Harlow Shapley mapped the locations of the 93 then-known globular clusters and found that our solar system was not their center.
• The center of these globular clusters was about 28,000 ly away – marking the nuclear bulge of the Milky Way Galaxy.

The Milky Way Galaxy

• Shapley correctly inferred that our solar system was about 30,000 ly away from the center of the nuclear bulge.
• Dimensions of the Milky Way galaxy are:
  – 100,000 ly in diameter
  – 2,000 ly is thickness of disk
  – 20,000 ly is the thickness of the nuclear bulge
• Accumulating evidence suggests that massive black hole are located at the core of nearly all galaxy’s nuclear bulge.

Quasars

• Quasar – short for quasi-stellar radio sources
  • The most distant objects in the universe, perhaps the bright centers of distant galaxies
  – One quasar is thought to be 13 billion ly away.
  • They are the source of huge amounts of electromagnetic radiation.
  • This large release of energy is probably due to material as it orbits and is drawn into a supermassive black hole.

Looking Back in Time:
Distant Stars and Galaxies

• The farther we look into space, the further we are looking back in time.
• Photographs taken today, are using light that may have left the star or galaxy thousands, millions, or even billions of years ago.
• When we look at a quasar that is 13 billion ly away, that light left the quasar 13 billion years ago, when the universe was very young.
  – Most astronomers think the universe is 14 billion years old.

Expanding Universe

• Hubble noted that some spectrum shifts of galaxies were blue and some red.
  – The blue shift indicates that the galaxy is moving toward us.
  – The red shift indicates that the galaxy is moving away from us.
• Hubble noticed that far-away galaxies all exhibited red shifts and that the farther away the galaxy, the larger the red shift.
• As a result, Hubble concluded that the universe must be expanding.
Hubble's Law

The greater the distance, the greater the recessional velocity (calculated from the observed red shift)

\[ v = Hd \]

- \( v \) = recessional velocity of the galaxy
- \( d \) = distance away from us
- \( H \) = the Hubble constant

H has not been precisely established yet but lies somewhere between 55 to 70 km/s per million parsecs.

Cosmology

- Cosmology – the study of the structure and evolution of the universe
- By detecting and analyzing electromagnetic radiation from these galaxies, astronomers can determine the structure of the universe.
- From work accomplished thus far, most galaxies occur in clusters and linear filaments.
  - One long broad concentration of galaxies is known as the "Great Wall."

Consequence’s of Hubble’s Law

- What does it mean if all the other galaxies are all receding from away from us?
- We must be at the center of the universe – No!
- Almost all astronomers agree that we live in an ever expanding universe.
- Therefore, every galaxy is receding from every other galaxy.
  - An observer, from anywhere in the universe would witness the same phenomena – receding galaxies.

Ever Expanding Universe?

- Earlier theories predicted that gravity would eventually rein in the expansion.
- Recent evidence points toward the universe expanding forever.
- In fact recent data suggests that the expansion is actually accelerating.
- Some astronomers have proposed a new form of energy – dark energy – to explain the acceleration.
The Big Bang

• While the galaxies are all moving away from each other at the present time, they must have been closer together in the past.
• The universe must have been much more compressed.
• In fact most astronomers think that the universe began as a small, hot, extremely dense entity that rapidly expanded (exploded) about 14 billion years ago – the Big Bang.

The Big Bang – Progression of Events

• With our present knowledge of subatomic particles and the structure of the universe we can extrapolate back to about $10^{-43}$ second of the Big Bang.
• Initially the universe was filled with protons.
• Within the first 4 seconds protons, neutrons, and electrons formed.
• D and He nuclei formed in the first 3 minutes.
• After about $1/2$ million years gravity began forming galaxies and stars.

The Big Bang – Broad Acceptance

• Experimental evidence supports the Big Bang in three major areas:
  • Cosmological redshift – galaxies today have a redshift in their spectrum lines
  • Cosmic microwave background – microwave radiation that fills all space and is thought to represent the redshifted glow from Big Bang
  • There is a H to He mass ratio of 3 to 1 in the stars and interstellar material, as predicted by the Big Bang model.

Inflationary Model of the Big Bang

• Much greater expansion took place between $10^{-35}$ second and $10^{-30}$ second than in the standard model.