I. INTRODUCTION:

A. This is one of the most exciting times in the history of astronomy.
    1. Discoveries are being made at a rapid pace with powerful new instruments such as the Hubble Space Telescope and the Keck telescopes.
    2. Hardly a week goes by without an astronomical news story, and major headlines appear almost monthly. Some examples from the last decade of the millennium include the following:
        a. Planets have been detected orbiting other stars.
        b. Tentative evidence for primitive (microbial) life on Mars has been found.
        c. The process by which stars are created from clouds of gas and dust has been examined.
        d. The existence of black holes has been convincingly shown.
        e. The birth and evolution of galaxies has been studied.
        f. Tiny ripples in the distribution of material have been detected early in the history of the Universe, and it is from these fluctuations that clusters of galaxies formed.
        g. We have witnessed collisions between galaxies that induce giant burst of star formation.
        h. Colossal explosions have been seen billions of light years away.
        i. The age of the Universe has been measured fairly accurately.
        j. There is intriguing evidence that the Universe may be accelerating it's expansion rate.
    3. One of my main goals is to simply share with you the excitement and magnificence of the Universe.

B. A second major goal is to show you that astronomy is a quest for our origins, our place in the cosmos.
    1. How did we get here, and where are we going? For example,
        a. What is the Milky Way Galaxy?
        b. How did the Earth form?
        c. From where came the elements of which we are made?
        d. What is the fate of the Sun?
        e. Are there other intelligent creatures out there?
    2. Since this is a survey course, I won't be able to go into many details, but I'll give you the foundation you'll need for further explorations.
        a. Socrates said, "Education is the kindling of a flame, not the filling of a vessel."
        b. It is in this spirit that I teach the course.

C. Another of my goals is to give you some idea of how science is done, and also to convey the thrill of scientific discovery.
    1. Science is a dynamic process: new ideas are developed and tested, and modified when necessary. Scientists want to figure out how things work.
        a. In physics, we try to determine the fundamental laws, and use them to understand the many complex aspects of nature. Astronomy is the exploration of celestial phenomena, and the application of physics to such studies.
        b. Ideally, a scientific hypothesis should not only explain what is already known, but make a prediction of a previously unobserved phenomenon. If subsequent experiments confirm the prediction, belief in the hypothesis is strengthened.
    2. Some of our views at the cutting edge of astronomy are changing yearly. What is said here reflects the state of knowledge now, and part of it may be out of date shortly.
    3. But there are certain foundations that are unlikely to change, and upon which we can build.

        a. The concept of atoms, for example, has been proven beyond any reasonable doubt.
        b. Similarly, Newton's law of motion are extremely accurate within their realm of applicability.
    4. I will not use science to conclude why humans are here, or the reason for the existence of the laws of physics. These questions are more in the realm of theology, philosophy, and metaphysics.

D. This will be a visually rich course, with many photographs from the Hubble Space Telescope, planetary probes, and other modern instruments.
    1. The course is mostly descriptive, non-technical, and non-mathematical. I will focus on concepts and qualitative explanations.
        a. Nevertheless, astronomy is a physical science, and many people do want a quantitative component.
        b. Hence, where appropriate, I will introduce simple mathematical and physical *f*relationships.
        c. The quantitative aspects will serve as an introduction; I will generally not go into the details. A the course progresses, you will come to understand many of the physical principles that govern the Universe.
        d. Most of the quantitative parts will be easy to understand if you have a good knowledge of algebra and geometry, as well as some physical science.
    2. Here I provide a few definitions that will make it easier for you to understand the material in the first few lectures.
        a. <u>Light year:</u> The distance light travels in one year---about 10 trillion kilometers.
        b. <u>Star:</u> A self-luminous, gravitationally bound ball of gas that shines (or used to shine) because of nuclear reactions in it's core. The Sun is a typical star.
        c. <u>Planet:</u> A body of substantial size (larger than about 1000 kilometers in diameter), but
        d. <u>Planetary System:</u> A collection of planets and smaller bodies orbiting a star.
        e. <u>Quasar:</u> A star-like, extremely luminous (powerful) object billions of light year away.
        f. <u>Universe:</u> "All that there is ." Actually, there could be other, physically disjoint universes with which we have no direct interactions!)

E. A brief overview of scientific notation, common prefixes, and units may be useful.
    1. It is cumbersome to write down and keep track of lots of zeros, so astronomers use scientific notation (also known as exponential notation).
        a. The basic idea is to express a quantity as a number between 1 and 10, multiplied by 10 raised to some integer (power).
        b. Numbers like 150,000,000 are written as 1.5×10^8, because you need to move *eight* spaces to the right of the decimal point in 1.5 to get 150,000,000.
        c. The number 0.0000158, on the other hand, are written as 1.58×10^{-5}, because you need to move *five* spaces to the *left* of the decimal point in 1.58 to get 0.0000158. In fact, 10^{-5} is just $1/10^5$, or 0.00001, and we have simply multiplied this by 1.58.
    2. Common prefixes are kilo (k; $1000 = 10^3$), centi (c; $1/100 = 0.01=10^{-2}$), and milli (m; $1/1000 = 0.001 = 10^{-3}$). Astronomers also use mega (M; 10^6), giga (G; 10^9), micro (μ; 10^{-6}), and nano (n; 10^{-9}).
    3. In this class we will generally use the metric system.
        a. The unit of length is the meter (m). One meter is 39.37 inches, a bit larger than a yard.
        b. The unit of mass is the gram (g). there are 453.6 grams in one pound.
        c. The unit of time is the second (s).

    d. Temperatures will be given on the absolute (Kelvin) scale, in which the lowest possible temperature is 0 K. Degrees Kelvin = degrees Celsius (C) + 273.
       Degrees Fahrenheit (F) = (9/5) C + 32.

F. The history of the Universe spans a vast amount of time and contains at least seven steps critical to the existence of humans.
  1. The Universe began roughly 14 billion years ago in an "explosion" known as the Big Bang.
    a. Clusters of galaxies are moving away from each other, and the speed of recession is proportional to distance. Extrapolation of the expansion backward in time suggests that the density was infinite 14 billion years ago.
    b. There is radiation left over from the initial hot phase of the Universe.
    c. Helium, synthesized from hydrogen during the first 3 minutes, is found in nearly uniform quantities throughout the Universe.
  2. Many galaxies, such as our own Milky Way Galaxy, formed about 13 billion years ago.
    a. The oldest globular star clusters in galaxies appear to be this old.
    b. The oldest elliptical galaxies appear to be this old.
  3. The Solar System formed about 4.6 billion years ago.
    a. Radioactive dating of meteorites gives such ages.
    b. Radioactive dating of moon rocks gives ages up to 4.4 billion year, a bit less than 4.6 billion years since it took some time for the initially molten material to solidify.
  4. Simple, unicellular life formed at least 3.5 billion years ago.
    a. Fossils indicating the presence of such cells have been found in ancient rocks.
    b. Since such primitive cells produce fossils that are difficult to find and recognize, life may have arisen even earlier than 3.5 billion years ago. Indeed, there is indirect evidence for life 3.8 billion years ago.
  5. A number of major jumps occurred in the evolution of life on Earth. One of the most important of these was the Cambrian explosion about 550 million years ago.
    a. There was an enormous diversification of life at this time.
    b. Fossils of large numbers of complex, hard-bodied animals (e.g. trilobites) have been found from this era.
  6. Dinosaurs suffered a sudden extinction 65 million years ago, after inhabiting the planet for about 180 million years.
    a. Fossils of dinosaurs are found in strata dating back to about 245 million years ago.
    b. The layers of rock containing dinosaur bones have a relatively sharp boundary dating back to 65 million years ago.
  7. The first humans appeared about 350,000 years ago.
    a. The oldest skeletons of homo sapiens date back to this time.
    b. Early hominids such as Australopithecus, direct ancestors of humans, appeared earlier – about 3.5 million years ago.

G. To place astronomical time scales into perspective, one can suppose that the entire 14 billion year history of the Universe were compressed into one 24-hour day (86,400 seconds).
  1. In this model, the earth formed about 8 hours ago, because the ratio 4.6 billion to 14 billion is roughly the same as the ratio 8 hours to 24 hours.
  2. Similarly, humans appeared only about 2 seconds ago. A human lifetime of 100 years is only 0.0006 sec, or 6 ten-thousandths of a second!

H. Astronomical distance scales also span an enormous range.
  1. The averages distance between the Sun and the Earth is 150 million kilometers (1.5×10^8Km)

or 93 million miles (since 1 km = 0.6 miles).

   a. This is known as the “Astronomical Unit” (A.U.).
   b. Stars, and especially galaxies, are much farther away than an A.U.
2. A convenient way to give very large distances is in terms of the light travel time.
   a. The speed of light in a vacuum, $3 X 10^5$ km/s (or 186,000 miles per sec), is constant. It is the largest possible speed with which information can travel through space.
   b. If speed is constant, then distance equals speed multiplied by time (d=vt). Thus, solving for time, we have t =d/v, and for light this becomes t = d/c.
   c. Light traveling from the Moon, $3.84 X 10^5$ km)/$3 X 10^5$ km/s) = 1.3 seconds (sec) to reach us. We say that the Moon is “1.3 light seconds away.” This led to the noticeable delay in the responses of lunar astronauts to (radio transmitted) questions from people on Earth
   d. Since t = d/c = (1/c)d, we say that the light travel time is proportional to distance, and (1/c) is the constant of proportionality. This 6 trillion miles per year.
   e. The Sun is 390 times farther from Earth than the Moon is. Hence light from the Sun takes (1.3)(390) = 500 sec to reach us. This is 8.3 minutes, since 1 minute = 60 seconds.
   f. We say that the Sun is “8.3 light minutes away.” If the Sun abruptly stopped shining, we wouldn’t know it for 8.3 minutes because the emitted light is already on it’s way.
   g. A **light year** (ly) is the distance light travels on one year d= ($3 X 10^5$km/s)(1 year). Converting 1 year into seconds, we have:

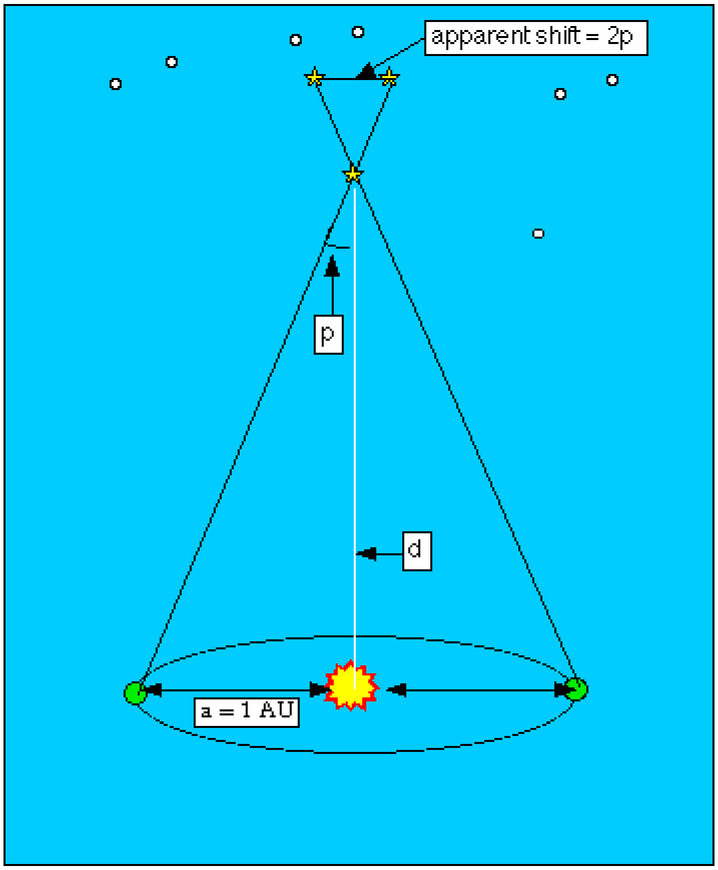
      (1year) (365.25 days/year)(24 hours/day)(60 minutes/hour)(60 seconds/minute) =

      $3.15X 10^7$ seconds, so d = $9.6 X 10^{12}$ km, about 10 trillion km (i.e. 6 trillion miles)

   h. The nearest star, Proxima Centauri (a companion of Alpha Centauri) is 4.3 ly away. Other stars visible in the night sky are tens, hundreds, or even thousands of light years away. Thus different stars are seen at different times in the past.
   i. The nearest large collection of stars, the Andromeda galaxy, is over 2 million ly away (and about 100 thousand ly is diameter). Galaxies are typically millions of ly apart.
   j. The faint light just now reaching us from distant galaxies many billions of ly away allows us to see them as they were billions of years ago.
   k. A ly is about 63,240 A.U., or the distance sufficient to line up 800 Solar Systems side by side.
   l. If you were to hop into your car and travel at the speed limit of 55 miles per hour (88 km/hr), it would take your 12.2 million years to travel 1 light year. The Sun would be long dead before you had gone this far.
3. Quasars are not seen nearby; they are always billions of ly away. They appear to be an early stage in the early stage in the formation of some galaxies.
4. Hence, the finite speed of light gives us a “fossil record” of the Universe’s history. If we assume that distant parts of the Universe are fundamentally similar to nearby parts, we can gain insights into how our own cosmic environment may have evolved.
5. The *Parsec.* Astronomers use this unit to measure distance beyond our solar system. It is sometimes used instead of light-years.
   a. One parsec = 3.26 ly
   b. Parsec is an abbreviation for parallax-second, or the distance at which an object would seem to change it’s position by 1 second of arc when viewed from opposite sides of the earth’s orbit, 6 months apart.

c. A second of arc, by the way, is only one 1,800 th the Moon’s diameter, or one 3,600th the width of your little finger held at arm’s length.

6. Observing something against a background from two positions is called observing it’s parallax.



$$p \;=\; \text{parallax angle} \;\cong\; \tan(p) \;=\; \frac{\text{radius of Earth's orbit (a)}}{\text{distance to star (d)}}$$

a. The basic idea is that the position of a nearby object shifts relative to distant objects when viewed from different lines of sight.

b. This technique is applied to stars as follows:

i) Photograph a nearby star.

ii) Photograph it again, about 6 months later.

iii) Measure the angular shift relative to galaxies or very distant stars, whose positions are stationary or nearly so.

iv) The “parallax” (p) of a star is defined to be half of the angular shift produced over a 6 month baseline (2 A.U., the diameter of Earth’s orbit.

v) Thus, as viewed from the star, the parallax is simply the angle subtended (i.e. covered by 1 A.U.

vi) The distance of a star whose parallax is 1” (1 second of arc) is called 1 parsec, abbreviated 1 pc. [A full circle is 360^0, 1^0 = 60 minutes of arc (60’), 1’ = 60 seconds of arc (60”)].

        c. It turns out that with this definition of a parsec, the relationship between distance and parallax is very simple. A star's distance d (in parsecs) is simply the inverse of it's parallax p (in seconds of arc): d = 1/p.
            i) For example, a star whose measured parallax is 0.5 " has a distance of 1/0.5 = 2pc.
            ii) The nearest star, Proxima Centauri, has a parallax of 0.77", and hence a distance of 1.3 pc (i.e. 4.2 ly).
    7. Clearly, parallax decreases with increasing distance, so this technique works best for nearby stars.
        a. The distances of a few hundred stars within about 20 parsecs (i.e., whose parallaxes are larger than 0.05") can be accurately measured from the ground.
        b. The uncertainties increase with distance, and are unacceptably large beyond about 100 pc (parallax < 0.01"); fewer than 10,000 stars can be measured.
        c. The Hipparcos satellite was used in the early 1990s to measure parallaxes down to 0.001" (i.e. stars out to about 1000 pc). The parallaxes of over half a million stars were measured.
    8. Distances across our Milky Way Galaxy are often given in kiloparsecs. (3,260 ly)
    9. Our Sun is about 8.5 kiloparsecs from the Milky Way Center.
    10. Distances to other galaxies are usually measured in megaparsecs.
    11. Astronomers must also consider objects on tiny scales, such as atoms and subatomic particles.
        a. The physical properties of subatomic particles help determine the overall structure of the Universe on large scales.
        b. Atoms emit and absorb light, thereby allowing us to study distant objects.
        c. A hydrogen atom is roughly 5 X 10^{-11}meter (m) in radius, as defined by the probable location of the electron.
        d. The nucleus (proton) of a hydrogen atom is 10^{-15}m in radius, 5- thousand times smaller than the electron distance. Thus, although it appears opaque, a solid object consists almost entirely of empty space.

I. Scale models can help put all of these distances into perspective.
    1. Suppose the *Sun,* 1.4 X 10^{6} Km in diameter (about 110 times the diameter of the Earth), were only the size of the period at the end of this sentence (about 0.5 mm).
        a. A star 5 ly away would be at a distance of 16 km in this model.
        b. The Milky Way Galaxy, about 10^{5} ly in diameter, would be 320,000 km is size –not quite the distance to the Moon.
    2. Now suppose a hydrogen atom were the diameter of an apple, about 8 cm.
        a. On this scale, a human (20 billion times larger) would be 1.6 million km high ---over four times the distance to the Moon!
        b. Nevertheless, the nucleus (proton) of the atom would be only 1.6 millionths of a meter (i.e. 1.6µm) in diameter.
J. Questions:
    1. Describe briefly some of the exciting topics being investigated by astronomers.

2. State the primary goals of this course.

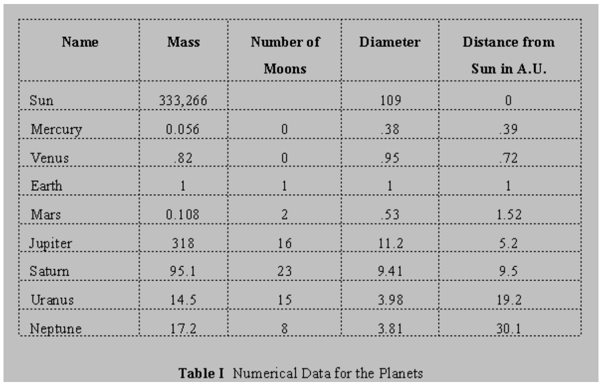
3. List and define some of the main constituents of the Universe.

4. Explain, generally, what scientists are trying to accomplish with their studies.

5. Explain how the finite speed of light allows us to look back in time, thereby getting a direct view of the Universe early in it’s evolution.

6. Describe several key events (and their times) in the history of the Universe.

7. Use the data table below to construct a scale model of our Solar System by choosing a specific object to represent the Sun or the Earth.



Name	Mass	Number of Moons	Diameter	Distance from Sun in A.U.
Sun	333,266		109	0
Mercury	0.056	0	.38	.39
Venus	.82	0	.95	.72
Earth	1	1	1	1
Mars	0.108	2	.53	1.52
Jupiter	318	16	11.2	5.2
Saturn	95.1	23	9.41	9.5
Uranus	14.5	15	3.98	19.2
Neptune	17.2	8	3.81	30.1

Table I Numerical Data for the Planets

8. Which is larger: the ratio of the radius of a hydrogen atom to the radius of a proton, or the ratio of Earth’s distance from the Sun to the Sun’s radius? Show work

9. What is the quantity for the speed of light? Metric
10. How many kilometers does light travel in one year?
11. How many ly are in a parsec?
12. How long does it take light to get here from the Andromeda Galaxy?
13. Change 6.67×10^{-11} to numerical form:
14. Change 550, 000,000,000 to scientific notation.
15. Explain how a parallax is calculated in your own words.