CLASSNOTES 2
Chapter 1
Read this chapter carefully. The sequence of Figures 1-1 to 1-12 are especially informative. Three natural systems may be identified:

— the Solar System: Sun plus nine planets plus miscellaneous pieces
— the Galaxy: billions of stars plus gas and dust and…
— the Universe: billions of galaxies plus…

Consider the *questions* on page 9. The *problems* on page 10 are on the whole too mathematical for us. But I suggest you think about no. 4, 5, 7, 10 and 11.

Scientific Notation
Seeds introduces this on page 3 and in more detail in Appendix A. Here, adapted from another text, is an introduction:
Powers-of-ten notation (also called scientific notation) is a shorthand method for expressing and working with very large or very small numbers. With this method, we express numbers as a few digits times ten to a power, or exponent. The power indicates the number of times that ten is multiplied by itself. For example, $100 = 10 \times 10 = 10^2$. Similarly, $1{,}000{,}000 = 10 \times 10 \times 10 \times 10 \times 10 \times 10 = 10^6$. Note that we do not need to always write out $10 \times$… Instead, we can simply count the zeros. Thus, 10,000 is 1 followed by 4 zeros so it is 10^4.

We can write 1 and 10 itself in power-of-ten notation as well: $1 = 10^0$ and $10 = 10^1$.

To write a number like 300, we break it into two parts 3×10^2. Similarly, we can write $352 = 3.52 \times 10^2$.

We can also write very small numbers (numbers less than 1) using powers of ten. For example, $0.01 = 1/100 = 1/10^2$. We can make this even more concise, however, by writing $1/10^2$ as 10^{-2}. Similarly, $0.0001 = 10^{-4}$. Note that for numbers less than 1, the power is 1 more than the number of zeros.

We can write a number like 0.00052 as $5.2 \times 0.0001 = 5.2 \times 10^{-4}$.

Suppose now we want to multiply numbers expressed in powers of ten. The rule is simple: we add the powers. Thus $10^3 \times 10^2 = 10^5$. Similarly, $2 \times 10^8 \times 3 \times 10^7 = 2 \times 3 \times 10^8 \times 10^7 = 6 \times 10^{15}$. In general, $10^a \times 10^b = 10^{a+b}$.

Division works similarly, except that we subtract the exponents. Thus $10^5/10^3 = 10^{5-3} = 10^2$. In general $10^a/10^b = 10^{a-b}$.

A further simplification is often used when very large or very small numbers are encountered.

— see Seeds Table A-1 on page A-3 for a partial list of prefixes.

Prefix	Symbol	Factor
giga	G	10^9
mega	M	10^6
kilo	k	10^3
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}

Example: the distance between the Sun and the center of the Galaxy is $8000 = 8 \times 10^3 = 8$kpc. (kpc = kiloparsecs)

Contents of the Universe

Nearest 50 AU
The *astronomical unit* (1 AU) is the semi-major axis of the Earth's orbit around the Sun (mean Earth-Sun distance = 150×10^6km). For us, semi-major axis is equivalent to the radius. All planets are within ~ 40 AU of the Sun. A few spacecraft have gone beyond 50 AU.

Nearest 5 parsecs
The parsec (1 pc) is the distance at which 1 AU subtends an angle of 1 arcsec:
1 pc $\cong 2 \times 10^5$ AU $\cong 3 \times 10^{13}$km $\cong$ 3 light years
Nearest star (at ~ 1.3 pc): Proxima Centauri, currently the nearest member of the triple system α Centauri.

Other stars:
— well spaced out; interstellar space is very empty. Mean distance between stars ~ 1 pc ~ 4×10^7 their radius (⇒ don't collide within lifetime of Galaxy, ~ 10^{10} years);
— majority are fainter, cooler, and of lower mass than the Sun;
— about half are double or multiple systems.

Space between stars: contains gas and dust. Gas may be cold or hot, dense or tenuous.

Nearest 20 kpc (1 kiloparsec = 10^3pc)

— includes most of Milky Way (our local Galaxy);
— mostly stars: single, double, multiple and clusters, containing from a few hundred stars (open or galactic clusters) to 10^5 – 10^6 stars (globular clusters). Total: ~ 10^{11} – 10^{12} stars;
— gas and dust (~10% by mass);
— high-energy particles (cosmic rays) and magnetic field.

The structure of the Milky Way is a flattened, smooth star distribution (disc) plus a low-density, roughly spherical halo. The Sun is in the mid-plane, about 8 kpc from the center, and dust hides the center in the optical (the center, in the constellation of Sagittarius, is visible in the infrared and radio). Bright stars and gas are concentrated in spiral arms. The gas is clumped in clouds, though there is also a diffuse background of gas.

Nearest megaparsec (10^6pc)

Most galaxies form part of a group or cluster of gravitationally bound galaxies. Our Local Group (radius ~ 3 Mpc) contains two dominant and similar galaxies, the Milky Way and Andromeda, each of mass ~ 10^{11} $M_{\odot}$. Each has several satellites:

- Milky Way – closest satellites are Large and Small Magellanic Clouds (LMC, SMC), at ~ 55 kpc; both are irregular in shape;
- Andromeda – main satellite is a spiral galaxy.

There are about 20 other galaxies, mostly small (10^6-10^9 $M_{\odot}$) and either *irregular* or *elliptical* in shape.

Irregulars – lots of gas, dust and young stars;
Ellipticals – almost no gas or dust, old stars, smooth shape.

Note that galaxies are generally much closer together, compared to their size, than stars: Milky Way to Andromeda ~ 600 kpc ~ 50 R_{Gal}. Collisions between galaxies occur.

Nearest 20 Mpc

Beyond the Local Group, other small groups, and larger clusters, are clustered together into the *Local Supercluster*, centered on the *Virgo cluster* within about 15 Mpc.

Nearest 100 Mpc

Many groups and clusters appear, some in other superclusters. We begin to detect:

— large-scale structure of the Universe: galaxies found in filaments and sheets, at the boundaries of voids, which are empty of galaxies, or nearly so;
— a general expansion of the Universe, following Hubble's law:

$$v_{\text{expansion}} = H_0 d$$

$V_{\text{expansion}}$ is a galaxy's velocity of recession, d is its distance and H_0 is Hubble's constant, whose value is about 70 km s^{-1} Mpc^{-1}.

Nearest 10^4 Mpc (radius of observable Universe)

Galaxies (faint!) are seen to distances of about 3000 Mpc. Quasars – probably energetic nuclei of galaxies – are seen to greater distances.

Our horizon is set by the fact that light, our source of information about remote objects, travels at a finite speed. The Universe is approximately 14 billion years old. This means that light now reaching us can have travelled at most 14 billion light years, or about 45 billion parsecs or 45 Gpc.

Distances in Astronomy

Three measures of distance are commonly used in astronomy:

— the astronomical unit
— the parsec
— the light year

Roughly,
1 pc = 3 ly = 200,000 AU
Of course, we also use kilometer, etc.

Since some distances are enormous, we use abbreviations such as kpc, Mpc and Gpc where
1 kpc = 1000 pc
1 Mpc = 10^6 = 1,000,000 pc.

We'll discuss these three measures in subsequent classes. But remember a light year is a measure of DISTANCE not time.

Time and the Universe

Our discussion of the Universe not only spans great distances but also long time intervals. The Universe is about 14 billion years old. An alternative representation (see the Universe Bow on the inside cover of Seeds. Figure 1-15 from **The Cosmic Perspective** by Bennett et al.) shows a cosmic calendar scaled to 1 year ≡ 12 billion years. Human civilization spans the last minute of the last day.

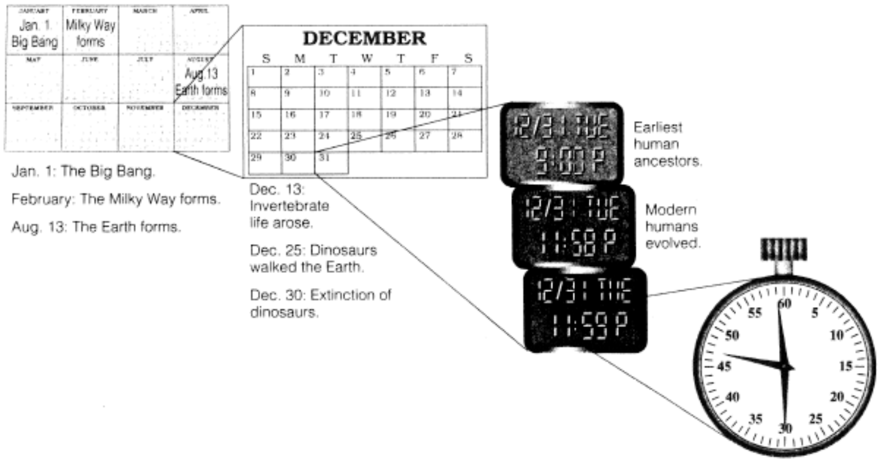

FIGURE 1.15 The cosmic calendar compresses the history of the universe into 1 year; this version assumes that the universe is 12 billion years old. The stopwatch shows the last minute of the last hour of the last day (December 31); it is only here that human civilization has taken shape.

> “Mandalay is rather a disagreeable town -- it is dusty and intolerably hot, and it is said to have five main products all beginning with P, namely pagodas, pariahs, pigs, priests and prostitutes." If anything attracted his interest in the city, it was the seamy side, not the relatively genteel world of Beadon and the regulars at the Upper Burma Club. He made a point of getting to know the most disreputable Englishman in Mandalay, a former army captain who had been dismissed from the military police and was leading the life of an opium addict. The man, whose name was Captain H.R. Robinson, would tell anyone who would listen that he had discovered the secret of the universe. It was all contained in a single sentence but he could never remember it after his opium trances were over. During a long crazy night of dreaming about this secret, he managed to write down the pearl of wisdom, but when he looked at in the morning, all it said was, ‘The banana is great, but the skin is greater.’”

George Orwell, *Burmese Days*

Over the semester, we shall discuss ‘the secret of the universe’ unravelled by astronomical observations. We shall also discuss secrets not yet unravelled; for example, 90% or more of the energy and mass in the universe has yet to be seen by telescopes. ‘Dark energy’ and ‘dark matter’ are the leading problems in contemporary astronomy.