Astronomy
1. Introduction and Observations
2. Sun and Solar System
3. Stars (Stellar Evolution)
4. Galaxies
5. Universe (Deep Space, Expanding Universe, Hubble Red Shift, Cosmology)

Also, there are two excellent periodicals related to astronomy – Astronomy and Sky and Telescope

Astronomy
1. Earth’s position in the solar system
2. Origin of the Universe
3. Natural interest in observing the night sky

Problems in understanding astronomy concepts:
1. Scale (distance and time)
2. Frame of reference (changing and 3-D)
3. Vast distance and time (large numbers and unfamiliar units/terminology)

1. Scale of the Universe
   - Earth orbit: 300 million km (diameter)
   - ~1 billion km (orbital path)
   - Solar System: 12 billion km across (~10^3 light years*)
   - Nearest Star: 4.27 light years
   - Milky Way Galaxy: 10^5 light years
   - Local Group of Galaxies: 2.5 million light years
   - Observable Universe: 13.7 billion light years

* One light year ~10^13 km, or ~10 trillion km
(It takes about 1/1000 of a year, or about 9 hours for light to travel across the solar system; 4.27 years for light from the nearest star to reach Earth; 434 years for light from Polaris to reach Earth; and ~10^5 years for light from the most distant stars in the Milky Way, our galaxy, to reach Earth)

Light Year – A unit of distance - “how far light travels in one year”
Calculate a light year (you could do this calculation!):
   ~300,000 km/s \( \rightarrow \) the “speed of light”
   \( \times 60 \) s/min
   ~18,000,000 km/min
   \( \times 60 \) min/hr
   ~1,080,000,000 km/hr
   \( \times 24 \) hr/day
   ~25,920,000,000 km/day
   \( \times 365 \) days/yr
   ~9,460,800,000,000 km
   \( \rightarrow \) speed of light (units = km/yr)
   ~9,460,800,000,000 km
   \( \rightarrow \) One light year (units = km)

So, one light year is approximately 10,000,000,000,000 km, or...
   10^{13} \text{ km}
   or...
   10 trillion km

http://hubblesite.org/newscenter/archive/releases/2004/07/ (~60 MB jpeg file)
Hubble Space Telescope (HST)  
Ultra Deep Field Image (2003-04)

- Can image 30th magnitude objects.
- Required 400 orbits, 11.3 days or recording.
- Image contains about 10,000 galaxies.
- Area covers 1/12.7 million of the entire sky.
- Like looking through an 2 ½ m (8 ft) long soda straw. With this view, astronomers would need about 50 Ultra Deep Fields to cover the entire Moon.
- Hubble’s keen vision (0.085 arc seconds) is equivalent to standing at the U.S. Capitol and seeing the date on a quarter 400 m (1/4 mile) away at the Washington monument.

Stars in Milky Way (spiral) galaxy (left) and in an elliptical galaxy (right) which contains large numbers of red dwarf stars.

USAToday, December 2, 2010
The Universe’s Most Ancient Object

The farthest and one of the very earliest galaxies ever seen in the universe appears as a faint red blob in this ultra-deep–field exposure taken with NASA’s Hubble Space Telescope. This is the deepest infrared image taken of the universe. Based on the object’s color, astronomers believe it is 13.2 billion light-years away.

The most distant objects in the universe appear extremely red because their light is stretched to longer, redder wavelengths by the expansion of the universe. This object is at an extremely faint magnitude of 29, which is 500 million times fainter than the faintest stars seen by the human eye.

The dim object is a compact galaxy of blue stars that existed 480 million years after the Big Bang, only four percent of the universe’s current age. It is tiny and considered a building block of today's giant galaxies. Over one hundred such mini-galaxies would be needed to make up our Milky Way galaxy.

The Hubble Ultra Deep Field infrared exposures were taken in 2009 and 2010, and required a total of 111 orbits or 8 days of observing. The new Wide Field Camera 3 has the sharpness and near-infrared light sensitivity that matches the Advanced Camera for Surveys’ optical images and allows for such a faint object to be selected from the thousands of other galaxies in the incredibly deep images of the Hubble Ultra Deep Field.

Credit: NASA, ESA, G. Illingworth (University of California, Santa Cruz), R. Bouwens (University of California, Santa Cruz and Leiden University), and the HUDF09 Team

3. Vast Distances and Large Numbers...

Number of stars in the universe (just recently updated), in at least 3 trillion galaxies:

300 sextillion

(300 x 10²¹ or,... 3 trillion times 100 billion)

<table>
<thead>
<tr>
<th>Value (10^x)</th>
<th>Quantity</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^6</td>
<td>1,000,000</td>
<td>Million</td>
</tr>
<tr>
<td>10^9</td>
<td>1,000,000,000</td>
<td>Billion</td>
</tr>
<tr>
<td>10^12</td>
<td>1,000,000,000,000</td>
<td>Trillion</td>
</tr>
<tr>
<td>10^15</td>
<td>1,000,000,000,000,000</td>
<td>Quadrillion</td>
</tr>
<tr>
<td>10^18</td>
<td>1,000,000,000,000,000,000</td>
<td>Quintillion</td>
</tr>
<tr>
<td>10^21</td>
<td>1,000,000,000,000,000,000,000,000</td>
<td>Sextillion</td>
</tr>
</tbody>
</table>

3. Units of distance in astronomy:

km - not usually used except within the solar system.

A.U. - Astronomical Units, equals distance from the Earth to the Sun, about 150 million km.

Parsec angle - used when distances are determined by the parallax method; a parallax angle of 1 second of arc (1/3600 degrees angle) corresponds to a distance of 3.09 x 10¹³ km and is called one Parsec. Distant stars are measured in MegaParsecs (10⁶ Parsecs).

Light Year - distance that light travels in one year, ~9.5 trillion km, usually used for distance to galaxies and size of the known universe.
We view the stars in the sky as if they were all equal distance from Earth (as on a flat or spherical surface). However, the distance to stars varies greatly.

All of the objects that we see with the naked eye in the night sky are within the Milky Way galaxy (can see two other galaxies with excellent viewing or binoculars and many galaxies with a telescope).

Galileo’s observations of Jupiter’s moons demonstrated that moons revolved about a planet providing support for the Copernican theory that the Sun was the center of the solar system.

Jupiter has at least 63 moons. The largest (and mostly closest to the planet) were discovered by Galileo in 1610 and are called the Galilean moons.

Kepler’s 3rd law:
\[ P^2 \sim D^3 \]
Period squared is proportional to Distance cubed. The exact equation can be used to calculate the mass of a planet:
\[ M = \frac{4\pi^2D^3}{GP^2} \]


Close-up of Galilean Moons positions relative to Jupiter on the date and time shown (C = Callisto, E = Europa, I = Io, G = Ganymede). With the calculator (below) you can step through time (use 10 minute or 1 hour time steps) to see the orbits of the moons about Jupiter (viewed from Earth, approximately along the plane of the ecliptic).

Sky and Telescope javascript Jupiter’s moons orbit calculator:
http://www.skyandtelescope.com/wp-content/observing-tools/jupiter_moons/jupiter.html#.

Moon rotating (animation from multiple images from the NASA LRO (Lunar Reconnaissance Orbiter): http://www.youtube.com/watch?v=NUNB6CMmE8.
The moon does rotate about once every 27 days so that we always see the same “side” of the Moon. The rotation rate is caused by gravitational “locking” of the Moon to the Earth. It took 4 years of observations to gather the images for the animation.

The Moon as it appears from Earth (northern hemisphere): http://en.wikipedia.org/wiki/Moon

The Solar System (Sun and planets not to scale; Figure 15.17, text)

Solar system model (Orrery) – note that it is not at true scale in distances or diameters!
An excellent online Orrery (for viewing the planets in orbit) can be found at: http://www.gunn.co.nz/astrotour/?data=tours/retrograde.xml - main controls are speed, orbit brightness, planet size and zoom. (also: http://www.pbs.org/wgbh/nova/space/tour-solar-system.html)

A Brief Tour of the Solar System

The Sun and planets drawn to scale (orbital positions not to scale) Figure 15.18, text)

Another view of the Solar System

The Sun and planets drawn to scale (orbital position not to scale) (http://en.wikipedia.org/wiki/Planet).

The terrestrial planets

The Sun and planets drawn to scale (orbital position not to scale) (http://en.wikipedia.org/wiki/Planet).

The gas giant planets (Jovian planets)

The Sun and planets drawn to scale (orbital position not to scale) (http://en.wikipedia.org/wiki/Planet).

Sunspot and image of Earth for scale). “Today [May 19, 2016], sunspot AR2546 is directly facing Earth. J.P. Brahic photographed the behemoth active region from his backyard observatory on Uzès, France.”
On July 19, 2013, in an event celebrated the world over, NASA’s Cassini spacecraft slipped into Saturn’s shadow and turned to image the planet, seven of its moons, its inner rings -- and, in the background, our home planet, Earth. (http://www.nasa.gov/mission_pages/cassini/mission/cassini20131112.html#.UoTHPD8wLpf)
Moon

Earth and moon

Zoom in to see Earth and Moon

Neptune (and great dark spot)  (Figure 15.40, text)

Asteroid Eros  (Figure 15.42, text)

Comet (dust and ion tail) orbiting the Sun  (Figure 15.43, text)

Planets and Solar System Websites

http://www.nasa.gov/worldbook/planet_worldbook_update.html
http://en.wikipedia.org/wiki/Planet
http://pds.jpl.nasa.gov/planets/
http://www.space.com/planets/
http://science.nationalgeographic.com/science/space/solar-system

Viewing the Night Sky

Observing Stars – Apparent Magnitude (brightness; what we see without adjusting for distance to the star) and Absolute Magnitude (brightness adjusted for distance).

The Sun has a brightness (apparent magnitude of -27; note that smaller magnitudes are brightest).

Faintest stars:  Apparent Magnitude
Naked Eye viewing  6
Binoculars  10
Amateur Telescopes  15
Modern Large Telescopes  25
1. The Stellar Parallax method

Stellar Parallax – distance determined from parallax angle, the smaller the parallax angle the greater the distance to the star. A parallax angle of 1 second of arc (1/3600 degrees angle) corresponds to a distance of 3.09 x 10^13 km and is called one Parsec. Distant stars are measured in MegaParsecs.

Another method is to take two pictures of the Moon at exactly the same time from two locations on Earth and compare the positions of the Moon relative to the stars. Using the orientation of the Earth, those two position measurements, and the distance between the two locations on the Earth, the distance to the Moon can be triangulated:

This is the method referred to by Jules Verne in From the Earth to the Moon.


Measuring Distance to Stars: 2. Brightness method

Light spreads out with distance such that the brightness varies by 1/r^2, where r is the distance. For example in the diagram above, the brightness at 4 m distance would be only 1/16th of the brightness at 1 m.
Variable Stars – Certain stars that have used up their main supply of hydrogen fuel are unstable and pulsate. RR Lyrae variables have periods of about a day. Their brightness doubles from dinnest to brightest. Cepheid variables have longer periods, from one day up to about 50 days. Their brightness also doubles from dinnest to brightest.

http://zebu.uoregon.edu/~soper/MilkyWay/cepheid.html

Empirical relationship (determined by observations of stars having a known distance) between period of pulsation for variable stars and luminosity. Absolute magnitude for a star whose distance is unknown can be calculated from the determined luminosity and then the distance to the star calculated from the brightness method using the absolute and apparent magnitude and $1/r^2$ relationship.

The sun is one of over 300 billion stars in the Milky Way Galaxy. It is about 25,000 light-years from the center of the galaxy, and it revolves around the galactic center once about every 250 million years.

The sun is a star with a diameter of approximately 1,390,000 km, about 109 times the diameter of Earth. The largest stars have a diameter about 1,000 times that of the sun.

Fewer than 5 percent of the stars in the Milky Way are brighter or more massive than the sun. But some stars are more than 100,000 times as bright as the sun, and some have as much as 100 times the sun’s mass. At the other extreme, some stars are less than $1/10,000$ as bright as the sun, and a star can have as little as 7% of the sun’s mass. There are hotter stars, which are much bluer than the sun; and cooler stars, which are much redder.

http://www.nasa.gov/worldbook/sun_worldbook.html

The Sun – A Typical Star

Main composition of the Sun

- Hydrogen: 73.46%
- Helium: 24.85%
- Oxygen: 0.77%
- Carbon: 0.29%
- Iron: 0.16%

http://nineplanets.org/sol.html

Spectacular loops and prominences are often visible on the Sun’s limb.
Comprising about 99.8632% of the total mass of the Solar System – most of the remainder is Jupiter.

http://en.wikipedia.org/wiki/Sun

Sun and planets – diameters shown to same scale (http://nineplanets.org/sol.html)

Adapted from: http://missionscience.nasa.gov/sun/MysteriesOfTheSun_Book.pdf

The Corona
Radiative Zone
Photosphere
Core
-5600 K
Core ~15 million K
Core ~2 million K
Energy moves slowly outward – taking more than 170,000 years to radiate through the layer of the Sun known as the radiative zone.

Nuclear Fusion in the Sun
Nuclear Fusion in the Sun (and other stars) – the proton-proton chain reaction:

The decrease in mass (from 4 protons to 2 protons and 2 neutrons) is only 0.7% but the energy release is large because of the equation e=mc².

Also note that at the end of the reaction, there are still two protons remaining, so the reaction continues as a chain reaction always releasing energy.

http://en.wikipedia.org/wiki/Nuclear_fusion

Nuclear Fusion in the Sun (and other stars) – the proton-proton chain reaction:
The proton–proton chain reaction occurs around 9.2×10^17 times each second in the core of the Sun. The Sun releases energy at the mass-energy conversion rate of 4.26 million metric tons per second, (3.546×10^26 W) or 9.192 × 10^10 megatons of TNT per second.

http://en.wikipedia.org/wiki/Sun
Nuclear Fusion in the Sun (and other stars) – the proton-proton chain reaction:
Reaction continues until the Hydrogen (source of the protons) is nearly all converted to Helium.
Energy from nuclear fusion in stars larger than the Sun (hotter and higher pressure core) is generated by the Carbon-Nitrogen-Oxygen (CNO), or other, chain reactions.

http://en.wikipedia.org/wiki/Nuclear_fusion

Life Cycle of the Sun

In about another 5 billion years, the hydrogen will be nearly depleted and the Sun’s core will collapse and heat up resulting in helium fusion and the Sun will become a Red Giant with a size that will probably extend out to the present orbit of Mars.

http://en.wikipedia.org/wiki/Sun

Sunspots

Sunspots are temporary phenomena on the photosphere of the Sun that appear visibly as dark spots compared to surrounding regions. They are caused by intense magnetic activity, which inhibits convection, forming areas of reduced surface temperature.

http://en.wikipedia.org/wiki/Sunspot

Note 11 year cycle of sunspots

http://en.wikipedia.org/wiki/Sun
Galaxies—Typically consist of 1 billion to over 100 billion stars. Most are relatively flat. Stars in the galaxy revolve around a central area, and thus don’t collapse (at least not quickly) from gravity (similar to the solar system). Most galaxies (including the Milky Way) probably have black holes in the center of the galaxy accounting for a substantial part of its mass.

Types of Galaxies: Elliptical, Spiral, Irregular, Dwarf

A tour of some galaxies…


Spiral Galaxy Andromeda

Very bright stars have more shorter-wavelength radiation and higher temperatures. These measurements are from spectrometers.


Spiral Galaxy M81 (NASA)

Above: The Milky Way (panorama from Earth).

Right: Spiral galaxy NGC 2997 (similar to Milky Way).

Figure 16.17, text

Figure 16.19, text

Spiral Galaxy Andromeda

Figure 16.2, text
The Barred spiral galaxy

(Figure 16.16, text)