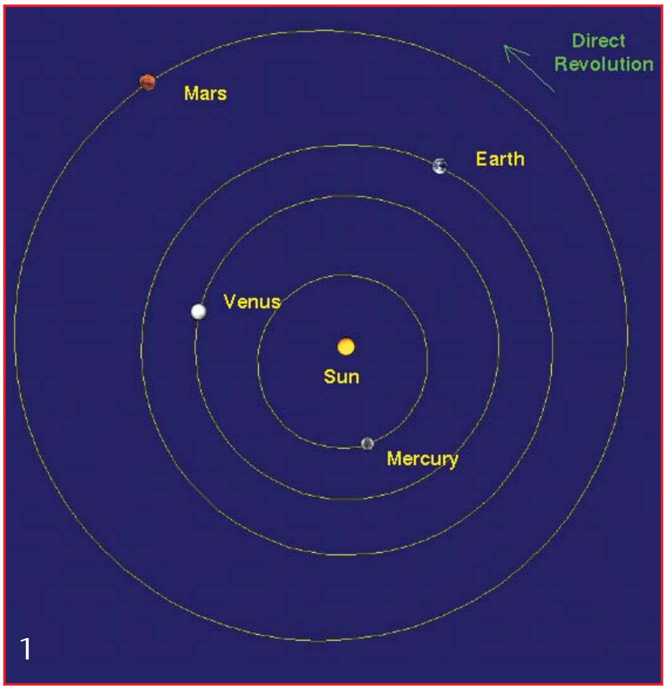
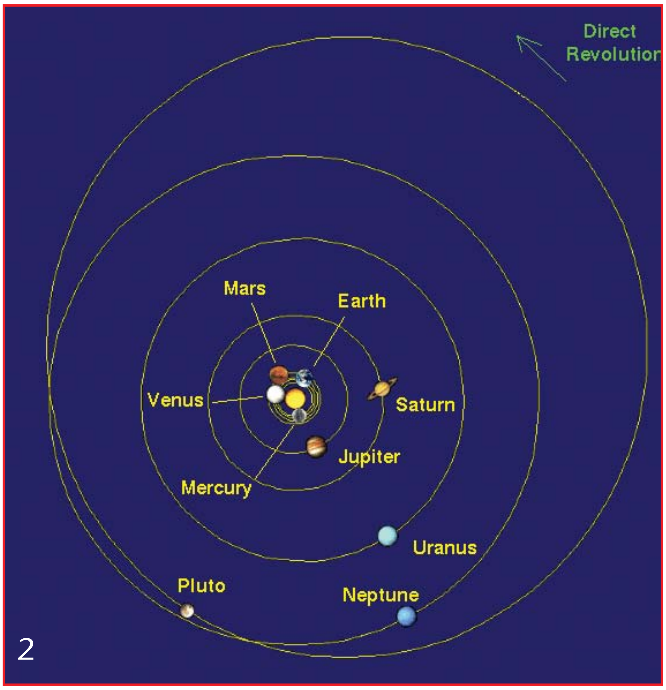
1. The Solar System

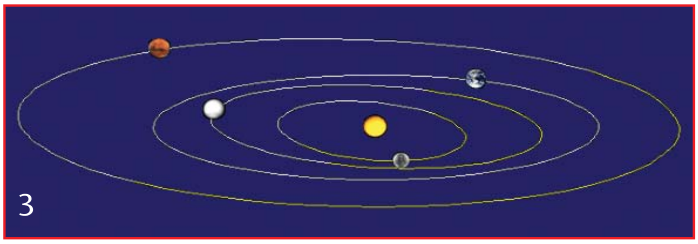
The solar system consists of the Sun; **the nine planets, over 100 satellites** of the planets, a large number of small bodies (the **comets** and **asteroids**), and the interplanetary medium (There are also many more planetary satellites that have been discovered but not yet officially named).

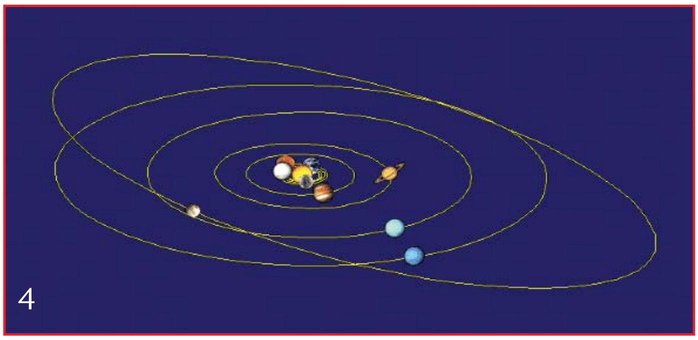
The **inner** solar system contains the **Sun, Mercury, Venus, Earth** and **Mars (1, 3)**

The planets of the **outer** solar system are **Jupiter, Saturn, Uranus, Neptune** and **Pluto (2, 4)**



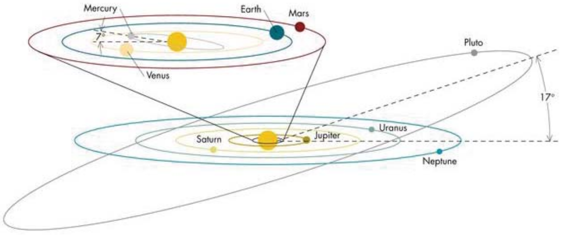






The orbits of the planets

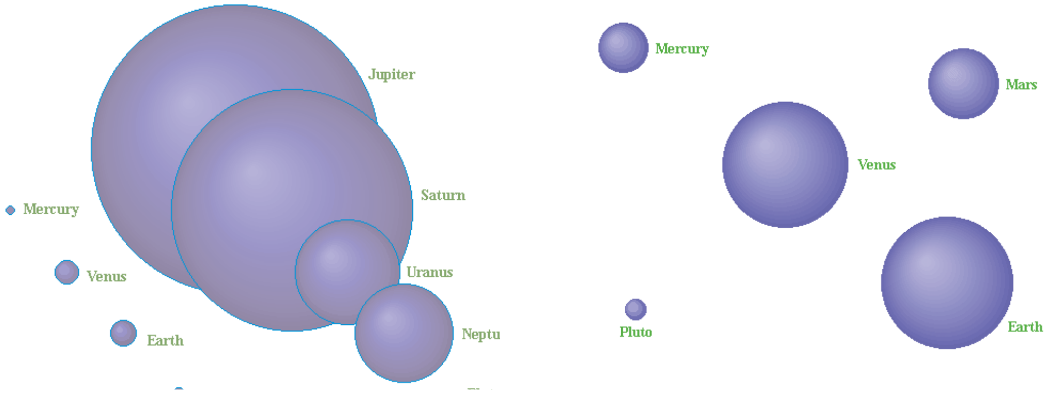
The **orbits** of the planets are **ellipses** with the Sun at one focus, though all except Mercury and Pluto are very nearly circular. The orbits of the planets are all more or less in the same plane (called the **ecliptic** and defined by the plane of the Earth's orbit). The ecliptic is inclined only 7 degrees from the plane of the Sun's equator. Pluto's orbit deviates the most from the plane of the ecliptic with an inclination of 17 degrees.



The above diagrams show the relative sizes of the orbits of the nine planets.

The relative sizes of the planets

One way to help visualize the relative sizes in the solar system is to imagine a model in which it is reduced in size by a factor of a billion (109). Then the Earth is about 1.3 cm in diameter (the size of a grape). The Moon orbits about a foot (´30.5 cm) away. The Sun is 1.5 meters in diameter (about the height of a man) and 150 meters (about a city block) from the Earth. Jupiter is 15 cm in diameter (the size of a large grapefruit) and 5 blocks away from the Sun. Saturn (the size of an orange) is 10 blocks away; Uranus and Neptune (lemons) are 20 and 30 blocks away. A human on this scale is the size of an atom; the nearest star would be over 40000 km away.



The following composite shows the nine planets with approximately correct relative sizes.

Traditionally, the solar system has been divided into **planets** (the big bodies orbiting the Sun), their **satellites** (moons, variously sized objects orbiting the planets), **asteroids** (small dense objects orbiting the Sun) and **comets** (small icy objects with highly eccentric orbits). Unfortunately, the solar system has been found to be more complicated than this would suggest:

- there are several moons larger than Pluto and two larger than Mercury;
- there are several small moons that are probably captured asteroids;
- the Earth/Moon and Pluto/Charon systems are sometimes considered "double planets".

Name	Distance (au)	Radius (Earth's)	Mass (Earth's)	Rotation (Earth's)	# Moons	Obliquity	Density (g/cm3)
Sun	0	109	332.800	25-36	9	---	1.410
Mercury	0.39	0.38	0.05	58.8	0	0.1°	5.43
Venus	0.72	0.95	0.89	244	0	177.4°	5.25
Earth	1.0	1.00	1.00	1.00	1	23.45°	5.52
Mars	1.5	0.53	0.11	1.029	2	25.19°	3.95
Jupiter	5.2	11	3.18	0.411	16	3.12°	1.33
Saturn	9.5	9	95	0.428	18	26.73°	0.69
Uranus	19.2	4	17	0.748	15	97.86°	1.29
Neptune	30.1	4	17	0.802	8	29.56°	1.64
Pluto	39.5	0.18	0.002	0.267	1	119.6°	2.03

Name	Magnitude	Radius (km)	Mass (kg)
Sun	-26.8	697000	1.99 x 10^{30}
Moon	-12.7	1738	7.35 x 10^{22}
Venus	-4.4	6052	4.87 x 10^{24}
Jupiter	-2.7	71492	1.90 x 10^{27}
Mars	-2.0	3398	6.42 x 10^{23}
Mercury	-1.9	2439	3.30 x 10^{23}
Saturn	-0.7	60268	5.69 x 10^{26}
Uranus	5.5	25559	8.69 x 10^{25}

Name	Magnitude	Maximum Elevation (degrees)	Observing Time (hours)
522 Helga	´14.4	´40 (mid-May)	5½
699 Hela	13.5´15.0	´30 (mid-May)	6
841 Arabella	´15.5	´30 (spring)	9
1250 Galanthus	´15.6	12 (1-15 June)	???
1368 Numidia	14.0´15.0	´35 (mid-April)	4
1727 Mette	15.0´16.0	´85 (end of March)	10
4979 Otawara	15.4´16.0	´29(1-10 June)	???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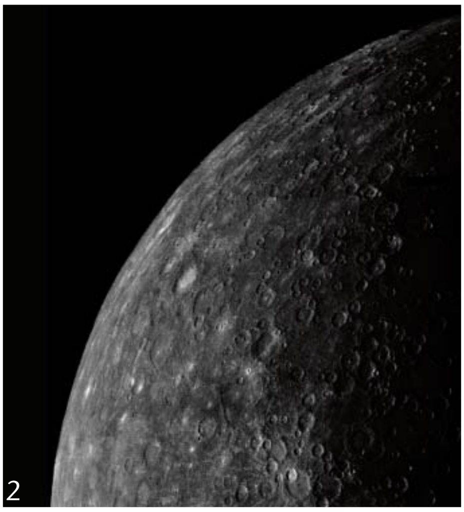
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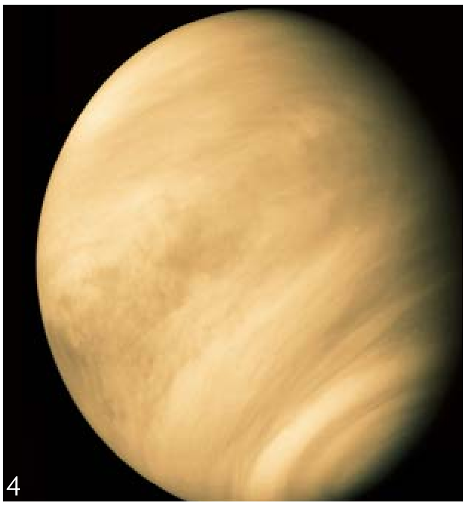
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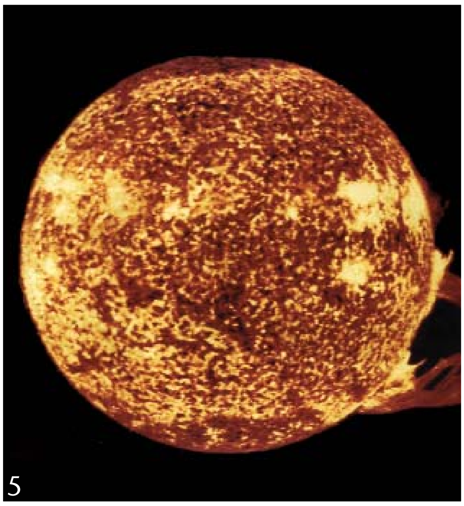
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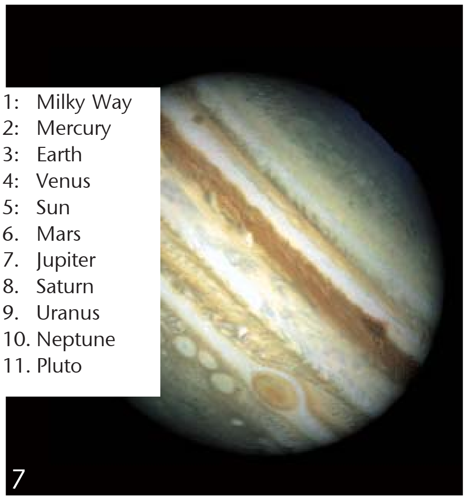
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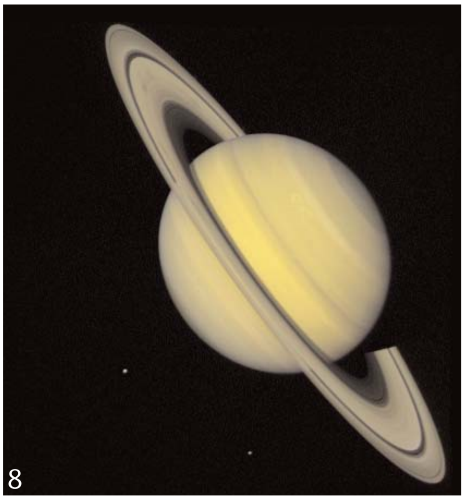
1: Milky Way
2: Mercury
3: Earth
4: Venus
5: Sun
6. Mars
7. Jupiter
8. Saturn
9. Uranus
10. Neptune
11. Pluto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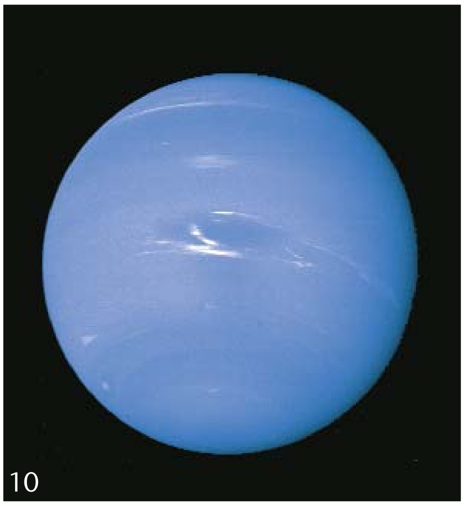
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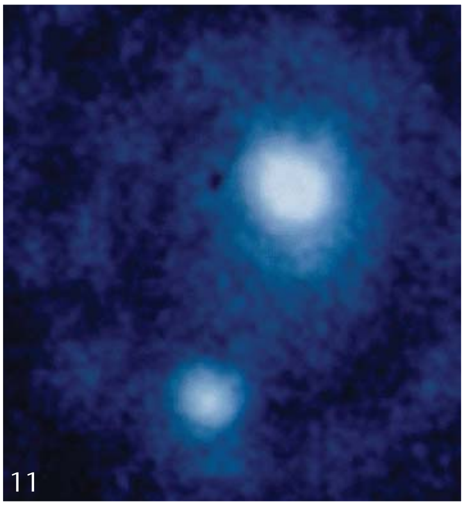
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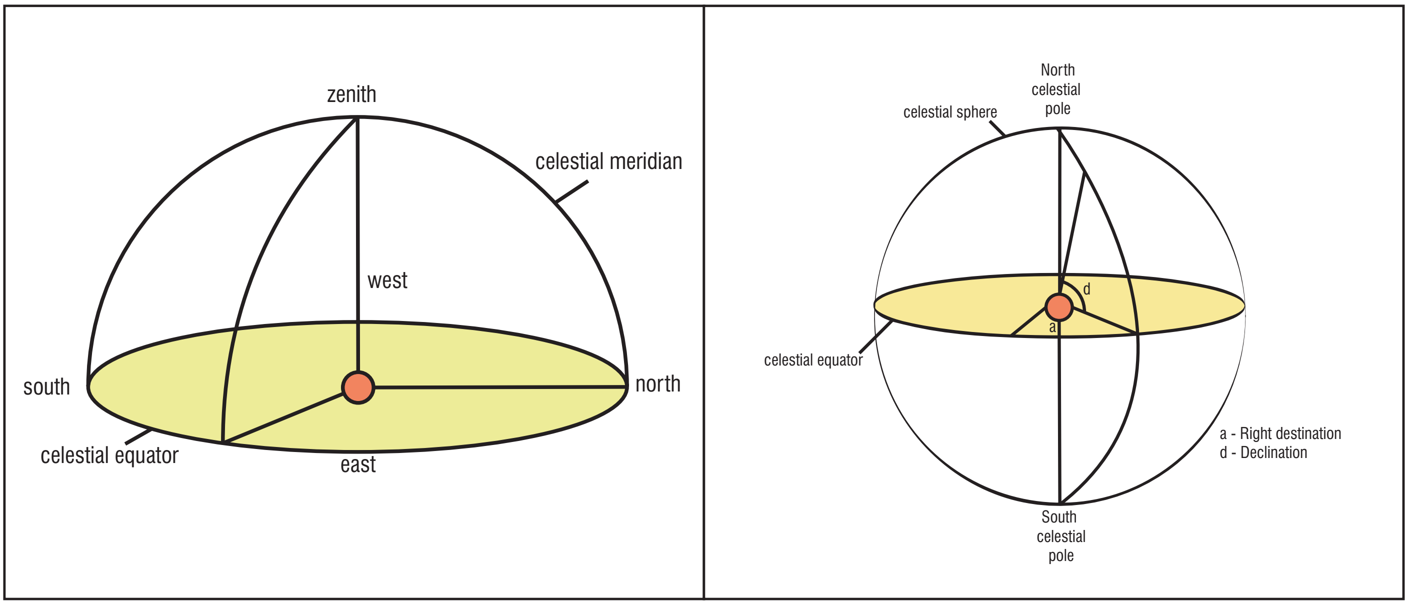
Classification of the planets

The nine bodies conventionally referred to as planets are often further classified in several ways:

By size:

- Small planets: Mercury, Venus, Earth, Mars and Pluto
  The small planets have diameters less than 13000 km
- Giant planets: Jupiter, Saturn, Uranus and Neptune
  The giant planets have diameters greater than 48000 km
- Mercury and Pluto are sometimes referred to as lesser planets
  (not to be confused with minor planets which is the official term for asteroids)
- The giant planets are sometimes also referred to as gas giants



By position relative to the Sun:

- Inner planets: Mercury, Venus, Earth and Mars
- Outer planets: Jupiter, Saturn, Uranus, Neptune and Pluto
- The asteroid belt between Mars and Jupiter forms the boundary between
  the inner solar system and the outer solar system

By position relative to Earth:

- Inferior planets: Mercury and Venus
  Closer to the Sun than Earth
  The inferior planets show phases like the Moon's when viewed from Earth
- Earth
- Superior planets: Mars thru Pluto
  Farther from the Sun than Earth
  The superior planets always appear full or nearly so

Statistical information for the Solar System

The Sun contains 99.85% of all the matter in the Solar System. The planets, which condensed out of the same disk of material that formed the Sun, contain only 0.135% of the mass of the solar system. Jupiter contains more than twice the matter of all the other planets combined. Satellites of the planets, comets, asteroids, meteoroids, and the interplanetary medium constitute the remaining 0.015%. The following table is a list of the mass distribution within our Solar System.

- Sun: 99.85%
- Planets: 0.135%
- Comets: 0.01%
- Satellites: 0.00005%
- Minor Planets: 0.0000002%
- Meteoroids: 0.0000001%
- Interplanetary Medium: 0.0000001% ?

2. Celestial Coordinates

Celestial Sphere: The celestial sphere is an imaginary shell of infinite radius, centered on the observer. This concept is useful for determining positions in the sky.

Zenith: This is the point in the sky directly above the observer.

Celestial Poles: As the Earth rotates, the sky appears to rotate around two points in the sky, one aligned with the geographic North Pole, and the other aligned with the geographic South Pole. These two points are the north celestial pole and the south celestial pole. The north celestial pole can be seen in the Northern Hemisphere, and currently is very close to the star Polaris.

Celestial Equator: This is a great circle on the celestial sphere that is in the same plane as the Earth's equator. It is 90 degrees from each celestial pole, so it is directly halfway in between them. To a person standing on the Earth's equator, the celestial equator would appear to pass through their zenith.

Celestial Meridian: This is a great circle passing through the celestial poles and the observer's zenith.

Ecliptic: The path of the sun in the sky.

Vernal Equinox: This is one of the two points on the celestial sphere where the celestial equator and the ecliptic intersect. The vernal equinox marks the first day of spring. The autumnal equinox is the other point, and it marks the first day of autumn.

Summer Solstice: This is the northernmost excursion of the Sun along the ecliptic. The summer solstice is the longest day of the year. The southernmost excursion is the winter solstice.

Hour Circle: A great circle on the celestial sphere running north and south through the celestial poles.

Hour Angle: This is measured westward along the celestial equator from the local celestial meridian to an object's hour circle. 15 degrees in arc units equals 1 hour in time units, because it takes an object one hour to apparently move 15 degrees across the sky.

Equator System: This is a coordinate system attached to the celestial sphere itself, using right ascension and declination to notate the positions of celestial objects.

Right Ascension: The arc distance measured eastward along the celestial equator from the vernal equinox to the hour circle of the star; comparable to longitude.

Declination: The arc distance from celestial equator either north or south to the star, along the hour circle given by right ascension; comparable to latitude.

Epoch: This is the time frame for which the object's coordinates are valid. The star's apparent coordinates change with time, because of precession and proper motion, so it is necessary to know the time for which the given coordinates are precise.

Sidereal Day: This is the time required for the Earth to make a complete rotation with respect to the vernal equinox. This is slightly shorter than a solar day, which is the period of the Earth's rotation with respect to the Sun. The local day begins (00h 00m 00s) when the vernal equinox is on the celestial meridian. The sidereal day is 23 hours, 56 minutes, and 4.1 seconds long.

Sidereal Time: Official sidereal time is the day beginning at the hour angle of the vernal equinox. Star positions are given using this sidereal time. The position of a star with respect to the observer's meridian is then related to the sidereal time.

Ephemeris Time: A time system based on dynamics, and which, unlike the other time systems, has an invariable rate. The beginning of ephemeris time (0 days, 12 hours) was near the beginning of 1900 when the Sun's longitude was 279 degrees 41 minutes 48.04 seconds. The ephemeris second, ephemeris day, etc. are defined at having specific, unchanging lengths.

3. Exposure Times for imaging observations

A short tutorial on imaging observations: With a telescope, we collect light from various objects and entities in the Universe. This light has been coded with and thus conveys, most of the available information about the physical properties of its source. The light collected by the telescope is subsequently processed by auxiliary optical systems to reveal some of the information it contains, and eventually arrives to a sensor producing a Signal. In all experiments of the D-SPACE Basic Curriculum, the sensor used to detect the celestial light from the source of our interest, is a CCD. The CCD (Charge Coupled Device) is a two dimensional array (or 'mosaic') of small detectors (photosensitive pixels) on which the optical system re-directs the light collected by the telescope, in the following manner: Any distant celestial source (like stars which are located at infinity) produces a parallel beam of light which is made to converge on a localized area in the CCD containing a few pixels. The position of this area on the CCD mosaic can be deterministicaly related with the direction of the source in the sky. By reading and adding together the signal (charge) created in each of those pixels [because of the interaction of the incoming light with the pixel material (Si crystal)] we get a number (called "ADU") which in first approximation is proportional to the true brightness of the source.

Exposure is the amount of time we permit the light from the targeted astronomical object, to impinge on our detector, the CCD. CCDs, like photographic films, are integrating sensors. This means that as more light continue to fall on the sensor, new signal continues to be produced, which is added to whatever amount had been produced in the past.

Note that the process of detection of light is for simplicity a two-stage one (see the animation, http://knidos.snd.edu.gr/telescope/E-Exposur.html):

1st Stage: we let the pixels of the CCD to be exposed to the celestial light ("EXPOSE")
2nd Stage: we read the recorded signal in the exposed pixels (grey ones) ("READOUT")

With photographic film the signal that has been built on the sensor is permanent and there is no way to force the latter back to its original condition -i.e. when no light had fallen on it (this is why for every photograph we shoot we need to use a new piece of film). However with CCDs the recorded image is stored on the CCD chip electronically and can be erased very easily, so that the same CCD can be used over and over again.

As outlined above, the main property of an integrating sensor is that it will build more and more signal with time, as more and more light falls on it. This allows such sensors to detect faint light sources provided they are illuminated for a prolonged time (exposure). The concept is reminiscent of photography, when bright light illuminates the scene -e.g. on a sunny day, then one needs to expose the film for a very short time interval (usually one uses the fastest shutter speed on the camera maybe something like 1/1000s). However when the scene is not very well illuminated -e.g. on the afternoon, one would need to make much longer exposures (slow speeds like 1/15s), else the photograph will turn out to be dark and noisy, or even, there might be no image recorded at all! The same principle applies also to CCDs. Thus we need to expose long enough to record a good signal. The above consideration is translated to the following rule: short exposures are enough for bright objects and longer ones are necessary for fainter ones, and the fainter the object the longer the exposure that is needed.

On the other hand both film and CCD will reach saturation at some point. This means that no more signal can be effectively stored on the sensor, and therefore any additional signal produced is lost forever! Thus, the sensor has reached its brightest "white" level possible and any additional signal (from light) is simply clipped to "white" on the final image. For example, this is what happens when some part of a scene is overexposed on a photograph, and everything there turns out to be a featureless white. The same phenomenon can happen with a CCD, but with CCDs there is also the phenomenon of "blooming", i.e. when too much charge is stored on a pixel, it can start bleeding up and down contaminating the neighboring pixels! This obviously destroys the information stored in other pixels and must be avoided.

Furthermore, as it becomes clear from the above discussion, the observer must carefully determine the proper exposure time to get the best results. With astronomical objects, since most are inherently faint, it's true that the longer the exposure the better, provided -of course- we are away from saturation. However, it is always desirable to use as short exposures as possible, for many reasons: Among other things (like better time-sampling of any brightness variations of the source), we can optimally exploit the telescope time available (reduce the time engagement of the telescope to achieve a certain photometric measurement), and also avoid problems with the telescope tracking (possible enlogation of point source images spreading light in such a way which is difficult to be handled in the subsequent analysis of the CCD frame by software), or even random events like wind bursts which could shake the telescope and ruin the image!

This raises the question: what is the shortest exposure I can use on an object to get a good result? The answer to this probably varies depending on the type of observation we want to do. The most usual is the making of some photometric measurement on stars of interest within the image. This implies an experimental prerequisite: we need these stars to have a good signal-to-noise ratio (S/N) -i.e. we need to have a Signal(=response of the detector to the light from the source/object) that is well above the Noise background (=responses of the detector system, not due to the light from the observed source/object), in order to make precise measurements. A rule of thumb is to have S/N=100, or something like that, which would eventually lead to a precision in the measurement of brightness of the order of 0.01mag (surpassing the requirements of most observational exercises of the Educational Curriculum of D-SPACE). According to the discussion above, to get a S/N ratio of that order, we need to expose the CCD for an appropriate period of time. Recall that our Signal is increased with exposure time, as more and more signal (charge) is built (accumulated) on the sensor. However, the superposed result of the presence of several noise sources (producing unwanted "signals"),) is increased as well and the increase of S/N is usually not linear with exposure time. Using a first approximation we can (in most cases -time intervals) assume a square root relation: and the Pogson law (relating brightness measurements (S) to the traditional 'magnitude' system (m)) of:

$$S/N \propto \sqrt{T} \xrightarrow{S \propto T} S/N \propto \sqrt{S}$$

$$m_1 - m_0 = -2.5log(s_1/S_0)$$

From the above relations we can deduce a conclusion: to increase the signal-to-noise ratio by a factor of 10 we would need to increase the exposure time (i.e. increase the signal) by a factor of 100! Or, equivalently, we could state that with a certain exposure time two stars (=point sources) would have to have a 5mag difference in brightness for their S/N ratio to differ by a factor of 10.

Example Exercise

Given that on a CCD image taken with 4sec exposure time, a 14.5mag star exhibits S/N=200, what is the minimum exposure that we need to use in order to make photometry on a 17.0mag star?

Solution:

Since we want to make precise photometry it would be desirable to have a S/N=100 at least. Therefore we need to find out how much we have to increase the exposure time in order to obtain this S/N ratio.

Since the 14.5mag star has S/N=200 at 4sec exposure, a 17.0mag is 10 times less bright (17mag- 14.5mag=2.5mag or S1/So=1/10), and therefore would have a signal-to-noise of:

but we need S/N=100, i.e a factor of 100/63.2=1.58 improvement on S/N. Therefore we should increase the exposure time by the square of that factor, ie:

Here is a useful table to help you make reasonable decisions on the determination of Exposure Times. Use it to eliminate the possibility of submitting inappropriate Observing Request which will return scientifically useless images and sacrifice valuable telescope time resources:

TABLE: Recommended Exposure Times for D-Space' Telescope "Andreas Michalitsianos"

Object Brightness (mag)	Exposure Time (seconds)
12	2
14	5
16	15
18	60
19	120