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Introduction to Visual Satellite Observing

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comments/corrections appreciated

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What is "Visual Satellite Observing"

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----1.0 What Is "Visual Satellite Observing"?

Many readers probably have already, without knowing it, seen an artificial satellite moving across the sky. At first glance, there is nothing spectacular about watching "slowly moving stars", since that is what most artificial satellites look like. Yet, since the launch of Sputnik 1 in 1957, thousands of amateur astronomers have become fascinated by these artificial objects.

The reasons are manifold, but the sometimes unpredictable behavior of satellites and the scientific usefulness of observations certainly play an important role in this fascination. Most certainly, viewing objects such as the International Space Station and Soyuz capsules crossing the sky as points of light, makes one marvel that there are living beings aboard them.

Anyone who has ever spent some time star gazing shortly after sunset has probably noticed one or two of these "stars" gracefully sailing across the sky. These are orbiting satellites of various types and ages, visible due to the reflection of sunlight off their surfaces towards the observer. The tasks of satellites cover fields such as communications, astronomy, military applications, remote sensing, meteorology, geology, geography, climatology, and so on. Furthermore, the orbits they trace can indicate the condition of the upper atmosphere, the structure of the Earth, and the nature of the solar cycle.

The amateur observer can contribute to this field, despite the regular generation of satellite data on the Internet by Space-Track which is operated by the Air Force Space Command. Observations of various satellites can provide insight into the rarefied upper atmosphere and subtleties of the Earth's gravitational field. Amateurs can also help supplement measurements of tumbling satellites, leading to a better understanding of the near-Earth environment.

Visual satellite observing is an interest in locating, viewing, analyzing and identifying those points of light that move across the sky. Other skywatchers may see them occasionally during their observations of the dark sky, but more than likely, they do not have a good understanding of their origins, identities, and functions.

The tools used in this interest have changed dramatically over the past 10 years or more. The advent of the personal computer, the rapid growth of the Internet, and free or low cost tracking programs have made it relatively easy for the casual observer to obtain the information needed to both track and identify these moving points of light.

The tools available to the casual observer of 20 or 30 years ago were occasional newspaper articles, which described when a sighting might be made or when a satellite launch was scheduled and the planned inclination of its orbit.

The more ardent observers who were 'members' of the various professional observing programs such as Moonwatch and the English efforts under King-Hele and Pierre Neirinck, sent out predictions every week or so to fellow members via air mail.

It took a deeper understanding of orbital mathematics then to observe a satellite one night and subsequently estimate when it might be visible again. As late as 1990 orbital elements issued by the Orbital Information Group were very limited in size and were only mailed out to subscribed individuals via the postal services. Now, government agencies provide orbital information for non-classified satellites, and private individuals provide the orbital information for some of the unpublished satellites via the Internet. Observers can input the timely information into sophisticated tracking programs on their home computers to predict when and where satellites may be sighted.

The relative ease, with which satellites can be tracked now, does not diminish the excitement of observing them. Numerous satellites are launched every year, and many are visible to ground observers. Some are very bright, some have unusual or otherwise interesting visual characteristics, and finding some of them pose a challenge to even long-time observers, either because they are very dim or because their orbits are not well known. Government and private news sources on the Internet announce information about most upcoming launches and describe the various mission programs in detail, which enhances the excitement.

The presence of the bright International Space Station (ISS), visible to observers from about 85% of the Earth's surface and the frequent presence of the highly visible Space Shuttle, make satellite viewing possible for the most casual interested observer. The Russians placed the first element of the International Space Station called Zarya in an orbit similar to Mir's in November 1998. Then a month later, the Shuttle attached Unity to Zarya. The Russians then launched the Zvezda module with the living quarters. Additional modules will be attached over following years. The International Space Station is already another very bright satellite that is easily visible to casual observers.

Visual treats abound for the observer with periodic launches of especially interesting visual satellites that may have tethers, highly reflective surfaces, or unusual flashing behavior. There are also elusive dim satellites, sometimes in highly eccentric (non-circular) orbits, which challenge an observer's ability to locate and track.

Much of the original excitement of this hobby remains in the location and identification of unpublished satellites. Since they are classified, orbital elements for these satellites are not readily available to the public. However, private individual observers make positional measurements and create estimated orbital element sets. These preliminary elements, distributed on the Internet, allow other hobbyists to search the sky to enable sightings. This usually leads to additional sightings and allows for the generation of even more accurate orbital elements. In other instances, however, a classified satellite may be observed over a short period of time then subsequently disappear from further observations because of maneuvers to a different and more elusive orbit.

An interest in observing may be casual or it may be driven by a desire to make highly accurate observations so that others can benefit in subsequent viewing. Whatever specific interest an individual has, visual satellite observing can be interesting and enjoyable with as little investment as a computer connected to the Internet, a good viewing location, and maybe a relatively inexpensive pair of binoculars.

You probably already have access to a computer that's connected to the Internet, so what are you waiting for? Getting involved in tracking Earth satellites is easy. Tracking programs can be ordered through the mail from a provider on the Internet for a relatively modest cost. They can also be downloaded from Internet sites, either for free or for trial use. There are tracking programs for all types of computer platforms written by individuals who want to provide a "better, more versatile" program for satellite observers.

To keep the observer up-to-date on the orbital status of Earth satellites, there are satellite interest groups on the Internet, such as the SeeSat-L mailing list and the Usenet newsgroup, sci.astro.satellites.visual-observe. In addition, there is a multitude of satellite-related World Wide Web sites on the Internet that provide information regarding satellites. Most of these sites have links to other related sites.

There are even satellite prediction services on the Internet so novice observers don't even need a tracking program. However, having one's own tracking program may be preferable as it allows the information to be displayed in a format that the individual finds more suitable. Also, with a tracking program, the observer can pick and choose which satellites are to be tracked, rather than being restricted to those provided by prediction services. Personal tracking programs are easily updated periodically by downloading up-to-date orbital elements from an Internet site for the many satellites that orbit the Earth.

Note: Measurements used in the following sections are metric. For the metric impaired (those in the US :-), use the following approximate conversions to obtain the English equivalent measurements:

Meter to feet: m x 3.3 = feet

Centimeter to inches: cm x 0.4 = inches

Kilometer to miles: km x 0.6 = statute miles

Kilogram to pounds: kg x 2.2 = pounds

It's hope that this introduction will make it easier for any reader to locate and use information provided on the Internet to track and view Earth satellites, as well as serve as a resource for acquiring knowledge and sharpening the skills needed by those who are interested in the more demanding aspects of visual satellite observation.

---- 1.1 How Many Satellites Are In Orbit?

At the end of 2001, there have been over 4100 successful satellite launches since 1957. There were 58 successful launches in 2001 and there is expected to be 60-80 launches a year for the next few years. Each launch not only delivers one or more payloads into Earth orbit, but also leaves other objects in space besides the payload. These secondary objects include third or fourth stages of the rocket, shrouds, kick motors, payload platforms, and so on. In addition, some satellites and rocket bodies have exploded, littering the near-earth space environment with small orbiting fragments of debris.

By December 2004, over 28,000 orbital objects had been cataloged since 1957. There were over 3,100 cataloged satellite payloads in earth orbit. Over 16,000 objects have burned up in the Earth's atmosphere, landed on Earth or on another celestial body, or continued into the solar system and beyond. There is still an unknown number of very small debris fragments in orbit, which are too small to be discovered by radar and optical means and so remain un-cataloged.

Orbiting objects are regularly tracked by means of sensitive radar and optical equipment and then cataloged. Both the USA and Russia have this capability. In the USA, the United States Space Command (USSPACECOM) assigns a sequential Satellite Catalog Number and adds the International Designation (ID) to the payload, as assigned by the World Warning Agency for Satellites (WWAS). Subsequent non-payload objects (e.g., platform, booster) from the same launch will receive the same International Designation from USSPACECOM, using the next higher letter in the English alphabet. In the US, the US Air Force Space Command distributes the non-classified satellite information from USSPACECOM to the end user.

---- 1.1.1 Payloads

A payload provides the scientific or intelligence gathering information desired by the launching country or customer, either directly from radio communications or indirectly by observations made from Earth. By end of 2004, there were over 3100 payloads in orbit. About one quarter of these payloads are still active.

For identification purposes, payloads are normally assigned the first letter (and the next higher letter in case of multi-payloads) of the English alphabet in the International Designation (ID), e.g., 96-034 A. In this example, 96 refers to the launch year 1996, 034 is the sequential number assigned that year to an orbiting body, and the letter "A" indicates that the object is a payload. The year 2001 uses the designation 01-XXX.

---- 1.1.2 Rocket Bodies

Satellite rocket launchers have multistage boosters to place the platform/payload into orbit. The final stage booster(s) go into orbit with the payload. They are normally larger than the payload and usually are more easily visible to the observer than the payload. A rocket body's orbit normally decays faster and reenters the Earth's atmosphere before the platform or payload. In most cases, a booster rocket will have an elliptical orbit, bringing it very close to the upper atmosphere where significant drag will be encountered at its low point in orbit (perigee).

Another factor is the mass/area ratio of the object. If the ratio is low, then drag will have a greater influence on causing the orbit to decay faster.

Rocket bodies are assigned the next higher sequential English letter designation in the International Designation (ID), e.g., 96-034 B, unless a platform is utilized to launch a payload. In that case the platform usually gets the designation "B" and the rocket, designation "C". The US Air Force Space Command uses the acronym R/B for rocket body in their Two Line Element designations.

---- 1.1.3 Platforms

A platform may be used to support (for orientation, electrical and/ or propulsion requirements) a payload while it is being placed in orbit. Alan Pickup reviewed the Satellite Situation Reports between May 1987 and November 1997 and it shows 146 occasions when both a main rocket and a platform have been catalogued in Low Earth Orbit. For these launches the rocked decayed first only 11 times (8% of the total) while the platform decayed first 127 times (87% of the total). For the other 5% of the launches, both the rocket and platform decayed on the same day.

The platform (if used) is normally the first object identified after the payload designation with the next sequential English letter designation in the International Designation (ID), e.g., 96-034 B. OIG uses the acronym PLAT for platform in their Two Line Element designations.

---- 1.1.4 Debris

Debris presents hazards to present and future payloads due to the devastating amount of kinetic energy that can be released if debris collides with a payload. It is a scourge to present and future payloads because of the large numbers involved and the inability of the launcher countries to detect small debris. Debris in orbit occurs when parts (covers, fasteners, explosive bolts, thermal covers, etc.) are separated from the payload, when rocket body(s), or payloads disintegrate or explode (major contributor), or when objects are placed into free space from manned orbiting spacecraft during operations.

Above an altitude of 500 km (310 miles), knowledge of man made orbital debris 10-30 cm (4-12 inches) in diameter is incomplete. For debris smaller than 10 cm in diameter, knowledge of man made orbital debris is virtually nonexistent. Unfortunately, it is the altitude regime above 500 km that is the biggest long-term problem. Below this altitude, the debris population is purged fairly quickly by natural decay (atmospheric reentry). Above 500 km altitude, decay can take hundreds or thousands of years.

In an article on space debris in the August 1996 issue of Popular Mechanics, it was estimated that there could be 35 *million* pieces of debris in orbit around the Earth. The debris that is cataloged represents only a tiny fraction of the estimated total. Debris larger than 1 cm in diameter presents a catastrophic hazard to orbiting payloads. In addition, there is no known shielding material available for debris of this type for present operational satellites and for future satellites such as the International Space Station.

Only 7% of the cataloged orbit population are operational spacecraft, while 46% can be attributed to decommissioned satellites, spent upper stages, and mission related objects (launch adapters, lens covers, etc.). The remaining 47% has originated from over 130 on-orbit fragmentations which have been recorded since 1961. In these events, all but 1 or 2 of the explosions of spacecraft and upper stages, are assumed to have generated a population of 70,000 to 120,000 objects larger than 1 cm. Only near sizes of 0.1 mm from the sporadic flux from meteoroids prevails over man-made debris.

Smaller size debris can also be a problem, as documented by pits found in spacecraft windows, including the Shuttle's, and similar damage found on one of the Hubble Space Telescope's high gain antennae. In one instance, chemical analysis of a pit on the shuttle's window showed that it was caused by a chip of paint.

In late July of 1996 there was the first reported collision between two cataloged space objects. A French military micro- satellite called Cerise (International Designation 95-033B/ Satellite Catalog Number 23606) suddenly lost stability when it appeared that its stabilization boom was impacted. After analysis it was concluded that the possible culprit was a piece of space debris from an Ariane booster (86-019RF/18208). Controllers were able to reprogram the payload and regain attitude control.

The USA Shuttle has released radar calibration objects called ODERACS, as has many Russian Cosmos series satellites. In April 1996, the MSX (Midcourse Space Experiment) satellite 96-024A/23851 was launched into a 900 km orbit. One of its missions is to detect previously undetected orbital debris in known orbital debris fields, both in Low Earth Orbit (LEO - a period of rotation around the Earth of less than 225 minutes) and in Geosynchronous Earth Orbit (GEO - a period of rotation around the Earth of 1440 minutes or 24 hours), using optical instruments. In addition, MSX released 2 cm diameter reflective reference spheres that were tracked on a routine basis by the USA Haystack radar facility, to make precise measurements on atmospheric drag.

The Haystack radar facility is located near Boston, Massachusetts and can reportedly track 1 cm objects at an altitude of 1000 km. Measurements with this radar have provided the best and most comprehensive picture available of the small debris population.

Efforts are being made to improve upon the detection resolution of orbital debris. Serious efforts still need to be undertaken to minimize the hazard of orbital debris.

Debris objects have the highest sequential English letter assignments in the International Designation (ID), e.g., 96-034 D, 96-034 E, 96-034 F. Above 26 fragments, the scheme goes into double or triple characters, e.g., AA, AB, AC,...AAA, AAB, and so on. OIG uses the acronym DEB for debris in their Two Line Element designations. Debris objects represent 58% of the total cataloged objects.

Further information on orbital debris can be found at the URL:

http://sn-callisto.jsc.nasa.gov/

---- 1.2 How Many Satellites Can Be Seen?

---- 1.2.1 How Many Can Be Seen With The Naked Eye?

Depending upon the observer's location on Earth, there are normally hundreds of satellites above the local horizon at any one time. However, only several dozen satellites in total can be easily seen with the naked eye. Thus, at any one time, when the late evening or early morning conditions allow satellites to be seen from reflected sunlight under dark sky conditions, there may be one or two easily visible satellites above the observer's horizon during a 30 minute time period.

The US Space Shuttle in the past can become as bright as a steady magnitude -4 (about as bright as Venus, and brighter than Mir). The growing ISS can become as bright as mag -2.

A list/elset of "100 (or so) Brightest Satellites" can be found at the URL: http://celestrak.com/

The term "magnitude" refers to an object's brightness. It is a logarithmic (exponential) measurement of brightness. Extremely dim objects have large positive values, while extremely bright objects have large negative values. Objects can be observed with the naked eye in a dark sky down to magnitude +6. Thus, satellites visible to the naked eye can range in brightness magnitude values of from +6 to -2 and can sometimes become even brighter temporarily. The brightness of a satellite is a function of its size, surface reflectivity, how well and from what angle the Sun's light is illuminating the satellite, the satellite's height above the horizon, and the corresponding effects of atmospheric interference.

Another factor in observing a satellite is that it has to be above the observer's local horizon. The Shuttle's orbit is normally confined to between 30 degrees north/south latitude, but it can be visible as far as 60 degrees latitude when it's placed into a 57 degree inclination orbit with respect to the equator. Thus, an observer's location on Earth plays a large role in determining what satellites can be seen.

---- 1.2.2 How Many Can Be Seen With Binoculars?

Using binoculars, at least several hundred satellites have the potential to be seen. On average, a dozen or so satellites are visible at any given time to an observer using binoculars. These dimmer satellites are mainly smaller rocket stages, and active and dead payloads. Experienced observers have also reported seeing some of the debris near Mir using binoculars. Using 7X50mm (seven power magnification by fifty millimeter aperture) binoculars can allow one to see satellites under ideal viewing conditions as dim as about magnitude +8 or 9. Higher power and larger aperture instruments will allow one to spot even dimmer objects.

---- 1.2.3 How Many Can Be Seen With A Telescope?

By using a telescope and knowing exactly where to look through the use of prediction programs, thousands of additional satellites have the potential to be observed (if only briefly) in a telescope even with a relatively small field of view (FOV) of 2-3 degrees.

Because of the relatively small FOV, it will take some practice to track an object manually to keep it in view. Certainly helpful would be a corrective eye piece to re-invert the object found in reflective telescopes. Even with the corrective eye piece you still have the problem of the left-right viewing being reversed making tracking difficult by manual coordination but not impossible with practice. A refractor telescope, in which the image is not inverted or reversed, should make tracking easier.

An additional challenge arises when the satellite reaches its zenith and it becomes necessary to rotate the scope around its own axis. As the satellite gets to the local zenith the telescope is pointing nearly straight up, so the axis of the tube is aimed at the zenith. As the satellite moves to its 180-degree change in azimuth, the telescope needs to be rotated around its own axis. This situation may be dependent upon the type of mount used.

A special tracking program interface for a computer-driven telescope is helpful to actually follow satellites in Low Earth Orbit (LEO). These tracking systems, along with image intensifiers, are helpful to observe structural details of large and low orbiting satellites.

A telescope can also allow the observer to see some of the larger pieces of debris, as well as some of the more distant satellites, such as the geostationary platforms, which are located 36,000 km above the Earth's surface.

There are several amateurs who modify telescopes for tracking and who are imaging structural details of satellites such as the ISS and the Space Shuttle.

Alain Grycan and Eric Laffont in France have obtained some spectacular amateur-made images of Mir. In these images, the different Mir modules are clearly visible. Also clearly discernible is the Sofora mast structure and the Progress motor compartment.

Another image of Mir, taken in April 1991 with a 2.3 m (90 inch) telescope, was produced by Dave Harvey at the Steward Observatory in Arizona, using the Comsoft commercial satellite tracking package on several reflector telescopes.

Marek Kozubal and Ron Dantowitz at the Boston Museum of Science Observatory are experimenting with a 30 centimeter (12 inch) reflector using the ArchImage mount to obtain images of satellites. Recently they reported observing the docked Mir/Atlantis pair, noting details such as the solar panels, and the shuttle tail and nose.

Other images have been made by a ground based telescope at the USA Air Force Maui Optical Site (AMOS). The outline of the Shuttle is clearly visible, and there is a hint of detail. Images from frames in a video sequence were taken using a CCD (charge-coupled device) camera and a 1.2 m (48 inch) telescope at the USA Air Force Phillips Lab Malabar Test Facility over Florida during the STS-37 Shuttle mission.

Most of the images mentioned above can be found at the URL:

http://www.satobs.org/telescope.html

Possibly the most spectacular telescopic observations of any satellite were those rumored to have been made of the Space Shuttle Columbia during the STS-1 mission, by an orbiting Keyhole reconnaissance satellite. Supposedly to allay fears concerning detached thermal protection tiles on the underside of the Shuttle (crucial to determine whether the vehicle would survive the heat of reentry), the orbiting Keyhole satellite was used to examine the belly of Columbia after tiles were noticed to be missing from the Orbital Maneuvering System (OMS) pods at the rear of the craft. Subsequent analysis of the orbits of the shuttle and the known Keyhole (optical recon) satellites in orbit at the time of the mission indicate that only one possible photo opportunity arose. The two craft were several tens of kilometers apart at the time and traveling in different directions. Thus, any image would have more than likely suffered significantly from motion blur. It is debatable as to whether use of suitable image restoration techniques could reclaim sufficient resolution, in order to identify individual tiles or groups of tiles. In any event, one is unlikely to see such pictures, if they exist, for many years yet, if at all.

---- 1.3 When Are Satellites Visible?

Whether or not a satellite is visible to a given observer is dependent upon many factors such as observer location, time of day, satellite altitude, and sky condition. Knowing these details may aid an observer in determining the most favorable times for sightings and is most certainly necessary, in order to spot some of the more elusive targets that speed across the heavens.

---- 1.3.1 Factors Affecting Satellite Visibility

---- 1.3.1.1 Orbit Altitude And Inclination

The visibility of a satellite depends on its orbit, and the simplest orbit to consider is circular. A circular orbit can be characterized by stating the orbital altitude (height of the spacecraft above the Earth's surface) and the orbital inclination (the angle of the satellite's orbital plane to the Earth's equatorial plane). For simplicity, it is the values of these parameters that dictate whether an orbiting satellite can be seen by a particular observer.

Most orbits are elliptical, rather than perfectly circular. In an elliptical orbit, the satellite's height (above Earth) varies smoothly between the apogee (farthest point on the orbit from the Earth), and the perigee (closest point on the orbit to the Earth).

The orbital inclination dictates over which areas of the Earth the satellite will "fly". In an orbit of 25 degrees inclination, the ground track (the point on the Earth's surface directly below the satellite, which is traced out during its orbit) will never exceed 25 degrees North or 25 degrees South in latitude. This satellite would never be visible from Northern Europe, for example, unless its orbital altitude were some 1500 km or so (and thus would then appear considerably dimmer, than if it were in low Earth orbit or at a higher elevation in the local sky).

Orbital inclination is the measure of the angle between the Earth's equator and the orbit in question. It is measured counter-clockwise from East (0 degrees) to West (180 degrees). Based on inclination, we can place orbits in some general categories:

* Prograde/Retrograde Orbits

Orbits greater than 90 degrees are "retrograde" (they move in a westerly direction), while orbits less than 90 degrees are "prograde" or "direct" (they move in a easterly direction).

* Equatorial Orbits

Equatorial orbits are of low inclination (within a few degrees of the Earth's equator), where the majority of satellites will travel from west to east in the sky if launched in an easterly direction (prograde) or from east to west if launched in a westerly direction (retograde). Satellites launched in an easterly direction (prograde) can take advantage of the Earth's eastward rotation to assist the launch. This bonus can be used to either reduce the fuel requirement, or increase the payload capacity of the launch vehicle, or both.

* Geostationary/geosynchronous Orbits

These orbits are special cases of equatorial orbits. Here the orbital altitude is such (around 36,000 km) that it takes the satellite one day to orbit the Earth, and it thus "hovers" over the same point on Earth. Such orbits are suitable for communications or meteorological observation. Satellites in such orbits are, however, only observable with telescopes and binoculars, because they are so far away.

* Polar Orbit

A high inclination orbit (within 10 degrees of 90 degrees will take a satellite over the polar regions so that it covers the whole Earth's surface, as the Earth rotates below it.

* Low-inclination Orbit

This is an orbit defined as having an inclination of less than 45 degrees or greater than 135 degrees.

* High-inclination Orbit

Orbital inclinations between 45 and 135 degrees are considered high-inclination orbits.

Thus far, we can see that for a satellite to be easily visible to an observer it should be in low Earth orbit at an inclination that is almost equal to or greater than the observer's latitude.

---- 1.3.1.2 Earth's Shadow

The Earth's shadow must also be considered. When eclipsed, a satellite is naturally not visible. Such events are dependent upon the satellite's altitude, inclination, the time of year, and the observer's location. The Earth's shadow is, for example, "longer" or "higher" in the local sky for an observer at the equator than it is for, say, an observer in the northern polar region during June. The shadow at the same latitude in the southern hemisphere during the same time period is even higher. Thus the fraction of the night available for observing low Earth orbiting satellites is shorter in Ecuador than it is in Sweden (and even shorter in Australia) at that same time of year. In fact, Arctic observers may seldom see satellites disappear into Earth's shadow during their Summer as long as the sky is dark enough to observe.

---- 1.3.1.3 Ground Track

Precession Of course it is not simply a question of watching for a given satellite at the same time each night. Few satellites have an orbital period which is a simple fraction of one day, the geostationary satellites being the obvious exception. The orbital period is dictated by the satellite's altitude. The higher the altitude, the further it has to travel around the Earth and the longer it thus takes. Satellites in low Earth orbit (say 300 km) complete one orbit in around 90 minutes, whereas at geostationary altitudes (about 36,000 km) one orbit takes 24 hours. This is simple orbital mechanics.

Thus, the satellite arrives later (or earlier) on successive nights. With each delay/advance in arrival time, the Earth will have rotated a little farther (or less) with respect to the satellite's orbit. The consequence of this is that each night the satellite will appear in a different portion of the sky during each pass, and the number of visible passes will vary. This shifting is called ground track precession. This ground track precession is also due to the non-spherical shape of the Earth, which can cause the orbital plane to be shifted by a few degrees.

In the longer term (days to weeks) the passes will drift from evening to daylight hours, then into the morning before returning to the evening once more. Imagine trying to live a 22 hour day. As the days passed, one would gradually wake earlier and earlier until one was having breakfast when others were off to bed. With more time, one's waking hours would re-synchronize with everyone else's, before beginning this cycle once more. Thus, windows of satellite visibility are created.

Consider the International Space Station. It will be visible for a week or so in the evening sky, and the best passes (those of highest local elevation above the horizon) will occur earlier each day. Eventually it is lost in daylight for the next two weeks or so before emerging in the pre-dawn sky. After a series of early morning passes for a week or so, visible passes are again lost, due to the ISS being eclipsed by the Earth's shadow at around midnight, before reappearing in the evening sky. The ISS repeats this visibility cycle about every four weeks.

Many satellites in low Earth orbit go through a similar cycle of visibility. The cycle varies with orbital inclination, altitude, and observer location. In the case of the Shuttle, due to the short term nature of the missions (typically 7-10 days) an entire mission can occur entirely outside of one of these windows of visibility.

---- 1.3.1.4 Other Factors

The simple idea of circular/elliptical orbits presented here belies the complications, which arise from the fact that the satellite suffers greater air resistance the lower its orbit. This bleeds off the orbital energy, lowering the orbit yet further as the satellite begins to brush the upper atmosphere at perigee. The forces on the satellite due to the Earth (and Moon, Sun, etc.) vary throughout its orbit (the Earth is not a nice spherical shape!) giving rise to continual change in the orbit.

Fortunately, advanced orbital models using SGP4 and SDP4 codes take into account terrestrial, lunar and solar effects. These models are the basis for many software packages for satellite tracking and predicting. When used with recent and accurate orbital data, these programs yield very accurate predictions, which are a great aid to observers.

---- 1.3.2 Times Of Satellite Visibility

---- 1.3.2.1 Evening Viewing

Satellites viewed in the late evening and early night are more easily seen in the eastern half of the sky. As is the case with the Moon, one half of the satellite is always illuminated by the Sun, except when it's within the Earth's shadow. The relative position of the Sun, satellite, and observer determines whether the satellite will be more or less illuminated as seen by the observer. With the Sun in the west and a satellite located in the east, the angle between Sun-satellite-observer (phase angle) will be small. This means a greater portion of the illuminated satellite will be facing the observer. Although "normally" satellites may be located in the western part of the sky for a particular evening's observations, most likely, the observer will have difficulty in locating them as the major portion of the illuminated satellite will not be facing the observer.

Note, that phase angle can also be measured as the angle between the Sun-observer-satellite in which case the phase angle will increase as the satellite appears to be more illuminated by the Sun to the observer.

Many satellite prediction and tracking programs provide the phase angle and/or percent illumination of the satellite to the observer. Some programs can provide the empirical magnitude value (a value independent of the geometry of the pass) and/or the standard magnitude value (a value dependent upon the geometry of the pass).

---- 1.3.2.2 Morning Viewing

Similarly, satellites viewed in the early morning hours before dawn are more easily seen in the western half of the sky. Also, morning observations can have less light pollution as the general public is asleep and more building and area lights may be off.

---- 1.3.2.3 Other Times

Most Low Earth Orbit satellites (LEO, having an orbital period of less than 225 minutes) cannot be viewed for the entire overnight period, because they eventually fly into the Earth's shadow. Exceptions can occur at the beginning of Summer in an observer's hemisphere, when the Sun is at its highest inclination to the Earth. At that time, it is possible for some LEO satellites having high inclination orbits to avoid the Earth's shadow, so that they may be viewed several times during the "whole night". On the other hand, an extremely high latitude observer may not be able to view satellites during early summer, as the sky never gets dark enough for observations.

There are two other exceptions to these visibility constraints, though both are not exactly common methods of observation. The first is daytime viewing. This is not recommended, but only is mentioned, as a few individuals have reported viewing some of the brightest satellites, such as Mir, Shuttle and Iridiums during the daytime. It obviously helps to know exactly where to look (courtesy of one of the many prediction programs available) and to look under optimum lighting conditions, that is to say, when the Sun-satellite-observer angle (phase angle) is at a minimum, which occurs when either the satellite is quite low in the west just after sunrise, or low in the east shortly before sunset.

Binoculars are a great help with such observations, but be wary of the Sun, as -- SEVERE EYE DAMAGE -- will occur if the Sun is inadvertently viewed with or without binoculars! One technique, which may be of some use, is the use of a polarizing filter to increase the contrast between the sky and satellite. Sunlight scattered in the atmosphere becomes polarized. Thus, some contrast improvement may be gained by using an appropriately aligned filter. Note that ABSOLUTELY NO protection against eye damage caused by viewing the Sun is afforded with the use of such filters.

A second exception lies in the fiery death of an orbiting body reentering Earth's atmosphere. A few observers make public predictions on the decay of satellites. However, a prediction for decay is not an exact science. Many variables will cause a decay to occur earlier or later than predicted. However, lucky observers may find themselves in the right place at the right time to witness a reentry, as the satellite experiences frictional heating in the upper atmosphere, leaving a fiery trail across the night (or even daytime) skies.

---- 1.4 What Do Satellites Look Like?

---- 1.4.1 "Normal" Satellites

The majority of satellites (normally payloads) have a steady (non-pulsating) illumination associated with them. A gradual brightening and dimming may be observed, but it is associated with the changing phase angle of illumination. As the satellite traverses from one horizon to the other, the area illuminated by the Sun changes its orientation with respect to the observer and the amount of area illuminated (depending upon the geometry of the satellite) changes causing a change in brightness.

These satellites have a stable orientation in orbit. They may not be rotating at all, because they have an attitude control system of some type or they have become gravity gradient stabilized or because their rotational energy has been dissipated by eddy current torques. They may be spin stabilized and have evenly reflective surfaces, so that their observed brightness is relatively stable.

Most satellites appear white, others may be off-white. A few appear yellow, or even a somewhat reddish hue. These color differences can normally be attributed to the satellite's surface color and finish and can be very subtle. The reconnaissance satellites called Lacrosse have a reddish hue associated with them because of the red-colored kapton insulation used on the surface of these large LEO satellite. In addition, a brief color change can occur as the satellite enters or leaves the Earth's shadow.

---- 1.4.2 "Flashing" Satellites

Flashing (pulsating) satellites provide additional interest to observers. The flashing is caused by the satellite body rotating and different parts of the satellite reflecting different intensities of brightness back to the observer. A satellite may rotate around more than one of its three axes, producing spectacular and irregular flashing. There can be several different observable types of light intensity pulsations associated with one satellite.

The flashing characteristics can change over time as the satellite's rotation about one or more rotation axes changes. The changes can be the result of venting gasses, interaction with the upper atmosphere, and interaction with the Earth's magnetic field.

---- 1.4.3 "Flaring" Satellites

A series of communication satellites were added to the skies in 1997, 1998 and 2002 called the Iridium satellite. A relatively small satellite, it can provide a brilliant reflective light for anywheres between 5-10 seconds to an observer. The brilliant reflective light or "flare" is observed in a relatively small local area (20-30 km in diameter) as the satellite passes overhead at an altitude of 780 km. Some flares have been observed during the day if the observer knows where to look. Not all Iridiums will provide this flare on every pass. The geometry has to be just right between the observer, satellite and Sun for the brilliant reflection to seen. The standard brightness for these satellites is around mag +6, or just barely visible naked eye. Flares have been observed much brighter than Venus (mag -4.7).

Additional information on these satellites can be found at:

http://www.satobs.org/iridium.html

An on-line predictions service for the Iridium satellites called Heavens-Above.Com is located below in section 1.5.1.3.3 .

---- 1.4.4 What does the Space Shuttle and ISS Look Like?

The USA Space Shuttle and the ISS are normally the brightest satellites visible to the naked eye with the exception of the brief Iridium satellite flares. They are very easy to spot by virtually anyone, regardless of equipment or experience. The ISS has been reported as bright as magnitude -2.

---- 1.4.4.1 Space Shuttle

The USA Space Shuttle is also easily visible to the naked eye. The 37 meter long by 24 meter wide vehicle is sometimes observed to be brighter than the Mir complex. This can be attributed to the bright white upper surface wing area and the extension of the highly reflective Shuttle cooling radiators inside the opened cargo bay doors. Additionally, the Shuttle normally flies at a lower altitude of approximately 300 km, compared to Mir's altitude of 390 km.

The Shuttle maintains various attitudes during its missions for experimental purposes and for cooling considerations. The attitude of the Shuttle, as well as its location over the Earth during a mission, can be found in real time on the NASA web page for the Shuttle and International Space Station at the URL: http://spaceflight.nasa.gov/

Unique to the Shuttle is the periodic observance of water dumps. The water turns to ice crystals and until it subliminates to a vapor, can be visible as a hazy cloud around the immediate area of the Shuttle vehicle. Sub-satellites are sometimes launched from a Shuttle during a mission. These sub-satellites either trail or lead the Shuttle by 100 km or so while deployed, so as to not be influenced by contamination originating from the Shuttle. Most sub-satellites are recovered by the Shuttle before the end of the mission. Normally these objects, while deployed, can be viewed with the use of binoculars (or even naked eye) and can be seen keeping formation with the Shuttle.

---- 1.4.4.2 International Space Station (ISS)

The ISS is also easily visible to the naked eye. Its color is whitish-blue. It presently consists of four modules, Zarya, Unity with the large P6 solar array, Zavezda and Destiny . It is in an inclined orbit of 52 degrees at an average altitude of 350 km.

---- 1.5 What Equipment And Knowledge Are Needed To See Satellites?

---- 1.5.1 Equipment

The only equipment that is absolutely necessary are eyes and a set of predictions indicating when and where to look to see naked-eye satellites.

---- 1.5.1.1 Binoculars

Naturally, use of binoculars or a telescope improves the viewing over the unaided eye. Much fainter objects can be seen, but at the expense of a smaller field of view. Binocular larger than 8x become heavy and could require a mounting system in order to provide a stable view. As the aperture of the instrument increases, fainter satellites can be seen. As a rough guide, a decent 50 mm pair of binoculars (e.g., 7x50, which magnifies sevenfold and which has an objective diameter of 50 millimeters) will extend visibility from the naked eye limit of about magnitude +6 to about magnitude +8 or +9, in dark skies with stable atmospheric conditions. The purchase and use of a relatively inexpensive pair of astronomical binoculars greatly increases the observability of satellites. For new purchases, an objective diameter of at least 50 mm with fully coated optics is highly recommended.

---- 1.5.1.2 Telescope

With a 20 centimeter (6-8 inch) reflector telescope, satellites as faint as magnitude +14 can be viewed. With experience, a small telescope can be manually slewed to track a satellite during the pass. Tracking a satellite with a large telescope is easier with a computer motor driven mount and use of accurate satellite coordinates during the pass. Even when using valid, up-to-date USSPACECOM elements, the tracking error can amount to up to one degree. This is even without considering the maneuvering the shuttle will perform regularly.

---- 1.5.1.3 Tracking Programs And Internet Resources

---- 1.5.1.3.1 Home Computer Tracking Programs

Tracking software is widely available for amateur satellite observers on the Internet, either commercially or as Shareware or Freeware. Most of these programs use Earth-centered orbital Keplerian Two Line Elements (TLEs). The TLE is a standard mathematical model to describe a satellite's orbit. TLEs are just one type of format for orbital elements. Another type is known as the AMSAT format and is mainly used for software that predicts amateur radio satellites.

Two Line Elements (TLEs) are processed by a computer tracking software program, yielding predictions for viewing time and position. The program determines the location of selected satellites above the horizon from a chosen observing location.

The satellite's celestial Right Ascension (RA) and Declination (Dec) coordinates and/or local coordinates of the satellite in terms of elevation (angle above the local horizon) and azimuth (true compass heading) during the pass are provided by the program at a frequency determined by the observer. Most of the tracking programs display these predicted coordinates and related information both graphically and in text format.

Tracking program resources are at many URLs, including:

http://www.satobs.org/tletools.html

http://www.satobs.org/orbsoft.html

http://www.satobs.org/otherinfo.html

http://celestrak.com/

http://www.idb.com.au/

http://www.amsat.org/amsat/ftpsoft.html

ftp://seds.lpl.arizona.edu/pub/software/

---- 1.5.1.3.2 Orbital Element Sets

For Tracking Programs Naturally, tracking programs need accurate and recent data in order to generate accurate predictions. This data comes in the form of Keplerian or Two-Line Elements (TLEs). Groups of TLEs are also sometimes called "elsets".

---- 1.5.1.3.2.1 TLE & Satellite Data On The Internet

Space-Track is the primary public distributor of satellite orbital data on the Internet. It receives its information from the USSPACECOM (United States Space Command). Space-Track disseminates non-classified information to other agencies and to the public on the Internet. The Jet Propulsion Laboratory (JPL) disseminates the information to the public via their anonymous FTP site.

In addition, there are private individuals and organizations not affiliated with government agencies that generate data on the Internet regarding Earth orbiting satellites.

Positional measurements of satellites are made from observations by private individuals around the world. More accurate orbital data derived from subsequent observations is again generated by private individuals and is disseminated on the Internet. Four such resources having Two-Line Elements (TLEs) generated by private individuals are:

* SeeSat-L (Listserver) Subscribe via e-mail to Seesat-L-Request@lists.satobs.org (in the subject line type "subscribe" without quotes)

* SeeSat-L Archives at http://www.satobs.org/seesat/index.html

* Mike McCants priviately generated (classfd.zip) TLE files at http://www.io.com/~mmccants/tles/classfd.zip

US government issued Two Line Element sets (TLEs or elsets), can be found at several Internet locations. A few of the many Internet sites containing TLEs are:

* Space-Track - registration required for TLE access

http://www.space-track.org/

* KSC - http://www.ksc.nasa.gov/

* Other links -

http://celestrak.com/

http://www.io.com/~mmccants/

http://www.idb.com.au/

Visual Satellite Observer - http://www.satobs.org/tletools.html

---- 1.5.1.3.2.2 Brief Introduction To TLEs And Satellite IDs

Keplerian or Two-Line Element Sets (TLEs) are distributed in the form shown in the example below:

Elements

```
THOR ABLESTAR R/B
1 00047U 60007C 96198.95303667 -.00000008 +00000-0 +24803-4 005026
2 00047 066.6626 011.9766 0252122 190.4009 169.1818 14.34618735877842
```

For clarfication, Line 1 by its self, follows.

```
1 00047U 60007C 96198.95303667 -.00000008 +00000-0 +24803-4 005026
                ^^^^^^^^^^^^^^
```

The epoch date is the third element in line 1 of the TLE. The epoch is the sequential date in a given year when the satellite crossed the Earth's equator in an ascending (northerly) direction following observations by tracking stations.

Jim Varney, a subscriber to SeeSat-L responded to a question poised by another subscriber as to what the epoch date referred to in the TLE. His response (in part) was:

> "Tracking stations measure the early/late error and the off-track (plane) error compared to predictions made from their own ephemeris software, not elsets. If the errors are acceptable, the satellite is considered 'correlated'. If the errors are too large or the object is completely unknown, it is considered an uncorrelated target (UCT).
>
> Once a UCT is found, ground stations attempt to obtain tracking data for a minimum of 5.5 percent of one orbital period. This is their rule of thumb for the minimum data needed to generate a good set of elements.
>
> Correlated objects are always observed from multiple ground stations to sample different parts of the orbit. The observed track is far less than is done for UCT's. The multiple observations from multiple stations are used to correct the previous element set using differential corrections. These working 'elements' are state vectors plus perturbation terms. Two-line mean elsets are made after the state vector elements are produced.
>
> The only exception to the use of multiple ground stations is for objects near decay. Then they use what observations they can get. For most objects in the catalog (provided by OIG) there is no correlation between the 2-line elset epoch and any given ground observation. In a sense you could say that most elsets are 'predicted' because the elset position at epoch is never the raw observed position. The near decay objects appear to be highly correlated to ground observations only because one or two stations are contributing to the analysis."

```
THOR ABLESTAR R/B
1 00047U 60007C 96198.95303667 -.00000008 +00000-0 +24803-4 005026
                ^^^^^^^^^^^^^^
```

In the above example for Line 1, observations calculated the satellite made an ascending (northerly) equatorial crossing on day 198.95303667 in the year 1996. Universal Time (UT), formally known as Greenwich Mean Time (GMT), is the time standard that is used. Specifically, the equatorial crossing for the series of observations was made on day 198 of the year 1996 at 22:52 UT [24 (hours) x 0.95303667 = 22.87288 hours, and 60 (minutes) x 0.87288 = 52.3728 minutes].

Most tracking programs will inform the user how old the element is by using the epoch date element. This tells the user if an old and possibly unreliable TLE is being used.

```
THOR ABLESTAR R/B
1 00047U 60007C 96198.95303667 -.00000008 +00000-0 +24803-4 005026
  ^^^^^
2 00047 066.6626 011.9766 0252122 190.4009 169.1818 14.34618735877842
  ^^^^^
```

The first element in line 1 (00047U) and in line 2 (00047) is the Satellite Catalog Number assigned by USSPACECOM. The official title for this identifier is "Satellite Catalog Number". However, many acronyms are used because of their brevity and past history of use. These include NORAD (North American Air Defense), NSSC (NORAD Space Surveillance Center), Cat # (Catalog Number), Object Number, USSPACECOM (US Space Command) number, and so on. Thus the satellite in the example TLE was 47th satellite ever cataloged by the USSPACECOM.

"Satellite Catalog Number" comes from the early days of satellite identification done at Hanscom Field, Massachusetts, USA in the late 1950's, where they kept track of the satellites they identified, by giving them the next ascending number in a log that began with the number 00001 for Sputnik. When NORAD took over the responsibility for tracking, they continued using the sequence. Now USSPACECOM continues the assignment.

```
THOR ABLESTAR R/B
1 00047U 60007C 96198.95303667 -.00000008 +00000-0 +24803-4 005026
         ^^^^^^
```

The second element in line 1 (60007C) indicates the International Designation (ID). This indicates a launch in 1960 and it was the 7th successful orbital launch for that year. "C" designates the third object catalogued for that launch. The International Designation is also described by terms such as International ID, COSPAR (COmmittee for SPAce Research) number, and COSPAR/WWAS (COSPAR World Warning Agency for Satellites) number.

The World Warning Agency (WWAS) is the body authorized by the United Nations to issue the International ID. WWAS issues the International Designation for the payload but not for any of the other objects placed in orbit as a result of the launch. Subsequent International Designations for non-payload objects are normally assigned by USSPACECOM using the same designation as the payload, but using the next higher English letter in the alphabet.

```
THOR ABLESTAR R/B
^^^^^^^^^^^^^^^^^^
1 00047U 60007C 96198.95303667 -.00000008 +00000-0 +24803-4 005026
2 00047 066.6626 011.9766 0252122 190.4009 169.1818 14.34618735877842
```

Line 0 (the line above line 1) provides the common name of the satellite object. Not all TLEs have common names associated with them, but they are an additional enhancement provided by some TLE distributors to allow the tracking program to provide a common name for the satellite in addition to the Satellite Catalog Number and/or International ID. Note, "R/B" is an OIG acronym for rocket.

---- 1.5.1.3.3 Satellite Prediction Services On The Internet

Heavens-Above.Com

http://www.heavens-above.com

Heavens-Above provides prediction services for satellites brighter than magnitude +4.5 for any location in the world, including the "Flaring" Iridium satellites. This site provides tools for the user to determine their geographical location. Normal observation of satellites only requires the user to know their location within 80-100 km to ensure the satellite will be above their local horizon.

Observation of Iridium flares requires the observer to know his location with a few kilometers to obtain a sucessful flare prediction.

The ephemeris service at Manfred Bester's web-site:

http://www.bester.com/satpasses.html

provides ephemerides for six preselected satellites. The geographic location is limited to one of 72 major cities in North America. If the user lives further than 100 km from a selected city, the output viewing information will probably not be accurate enough to readily spot the satellite.

Other on-line satellite prediction services will provide graphical displays for your location such as:

If your web-browser has Java capabilities, you can view satellites in 2D by going to J Track 2.5

or in 3D by going to 3D JTrack

---- 1.5.1.4 Watch And Computer Time Settings

An accurate watch (with low drift and set to a time standard) is necessary for making accurate positional and flash period measurements. A one-second error in timing will result in a location error of 8 km (5 miles) for a LEO satellite traveling at nearly 30,000 km/hr (18,000 mi/hr).

Time standard signals are available by short wave radio, telephone, and the Internet. WWV in Boulder, Colorado transmits time signals on 2.5, 5.0, 10, 15, and 20 Mhz. WWVH in Hawaii transmits on 2.5, 5.0, 10 and 15 Mhz. Their radio service is for the Continental USA and Pacific area with a delay time of 1-10 milliseconds. Reception outside these regions will result in additional delay.

WWV can also be accessed by telephone at 1-303-499-711 and WWVH can be accessed at 1-808-335-4363. However, be aware that some long distant telephone services use satellite connections with the associated transmission delays.

In Europe the following radio time services can be used for an accurate timing reference.

```
_Freq (KHz)_          _Station_       _Location_
 75                    HBG         Neuchatel Observatory, Czech.
 77.5                  DCF77       Bundesantalt, FRG
 2,500                 MSF         Rugby, UK
 5,000                 MSF         Rugby, UK
 10,000                MSF         Rugby, UK
```

The USA Naval Observatory (USNO) provides various time services on the Internet at several URLs, e.g.:

* telnet://tick.usno.navy.mil:13

* telnet://tock.usno.navy.mil:13

* http://tycho.usno.navy.mil/what.html

Most telephone companies provide a time service, but the accuracy varies considerably, and caution must be exercised. In the USA, ATT provides (for a fee) a supposedly accurate time service over land lines (no satellite transmission delays) from the US Naval Observatory at 1-900-410-TIME.

Note that some telephone and Internet time services do not correct for network transmission delays. When using a tracking program in real time to locate a satellite, the computer's internal clock must be accurately set to a time standard before using the program, to provide useful real-time tracking information. Some tracking software allows the user to set the computer's internal clock from the tracking program.

Most computers, unless they have specific hardware and software installed, will not keep accurate time over a relatively short period (several hours). The USNO provides links to various time services, including links to software that will allow a computer's internal clock to be more accurate with and without modem time synchronization.

Further information can be found at the URL: http://tycho.usno.navy.mil/ctime.html

---- 1.5.1.5 Stopwatch

A stopwatch can be used to time flash periods or to accurately mark a satellite's position. A stopwatch accurate to within 0.1 seconds is necessary for accurate positional and flash period measurements. A quartz watch with 0.1 seconds readout and the ability to store and retrieve at least 50 "lap" times is better. Having this capability is more convenient for a session of flash measurements, because the observer doesn't have to write down the elapsed time after each satellite pass. A "lap" stopwatch is also needed for positional measurements if the observer wants to take more than one measurement during a pass. Note that it is very important to synchronize the stopwatch to an accurate time standard, as discussed in the previous section.

One method used in accurately determining the position of an observed satellite is to commence timing with a stopwatch when a satellite passes between two known stars, whose position can be determined from either a star catalog or astronomy program. Timing should stop on the announced full minute, utilizing a radio time signal. Subtracting the recorded duration from the announced reference time gives the time, at which the satellite passed between the two stars. The observer should always use Universal Time (UT) (formally called Greenwich Mean Time - GMT) and date when an observation is reported. Also, the location of the satellite between the two known star positions must be interpolated.

Determination of UT with respect to the observer's location can be found at URL:

http://tycho.usno.navy.mil/tzones.html

One method used to time flash periods associated with rotating satellites is to count several dozen flashes and the duration between flash 0 and flash n, then dividing the duration by n. Note that the flash count must begin at 0, because the flash *period* is the time duration *between* flashes. This method is much easier than timing every single flash. The error of the calculated flash period is also much smaller than that resulting from timing only *one* flash period.

---- 1.5.1.6 Tape Recorder

A portable battery powered tape recorder with fresh batteries is most useful for recording observer commentary and for later flash period data reduction. Running a WWV broadcast in the background can provide an accurate time standard reference for later study.

---- 1.5.1.7 Chair

It's important to be comfortable during long viewing sessions. Since one is usually looking up, it's best to be in a reclined position. A lightweight reclining lawn chair is portable and quite suitable for remote observing locations. At home, an old beat-up swivel recliner works great. The next best thing would be any type of back supported chair.

---- 1.5.2 Knowledge

It's not necessary to have much knowledge of astronomy to enjoy satellite viewing, but some basic knowledge does help in knowing where to look and how to make observation reports.

Further detailed information on basic concepts described below can be found in "Basics of Space Flight Learners' Workbook", located on the Jet Propulsion Laboratory web site at the URL:

http://www.jpl.nasa.gov/basics/

---- 1.5.2.1 Celestial Coordinates

If the satellite is not very bright, it is difficult to use only local azimuth and elevation as coordinates. In most cases, it is more practical to use the Right Ascension (RA) and Declination (Dec) to locate the track of the satellite in a star field. Celestial object positions specified in this coordinate system are convenient, because an object's RA/Dec coordinates remain the same regardless of the viewing location on Earth.

---- 1.5.2.1.1 Right Ascension (RA)

Right ascension is the angular distance measured eastward along the celestial equator in hours, minutes, and seconds (sometimes measured in degrees) from a reference point called the vernal equinox. The vernal equinox is that point on the celestial sphere, where the Sun's path crosses the celestial equator, going from south to north, each year on or near March 21st. The celestial location for 0 hrs Ra is located approximately in the constellation Pisces.

A full rotation on the celestial sphere from beginning to end at the equator is, of course, 360 degrees. This full rotation is also normally measured as an angular distance of 24 hours. Therefore, one hour in RA corresponds to 15 degrees eastward rotation (360 degrees/24 hours)

For example, a RA of 02:30:30 (2 hours, 30 minutes, 30 seconds) corresponds to an angle of rotation of 30 degrees (for 2 hours), plus 7.5 degrees (for 30 minutes), plus 0.125 degrees (for 30 seconds), giving a total angle of 37.625 degrees eastward from the vernal equinox along the celestial equator.

---- 1.5.2.1.2 Declination (Dec)

Declination, which is measured in degrees positive or negative, corresponds to the global coordinate of latitude on the Earth. It is a measure of how far north or south the object is located from the celestial equator. Thus a declination of -10 degrees would mean that the object is located 10 degrees south of the celestial equator. Similarly, a declination of +10 degrees would mean that the object is located 10 degrees north of the celestial equator.

Most satellite tracking and prediction programs provide the celestial coordinates of a satellite in RA and Dec. This is very handy, as celestial coordinates are the same, regardless of where on the Earth's surface the observer is located.

---- 1.5.2.2 Local Coordinates

Most tracking programs will also provide the local coordinates of a satellite for a particular viewing location in terms of azimuth and altitude angles. Of course, the observer's local latitude and longitude coordinates must be known fairly accurately, in order for the program to generate accurate local coordinates. An observer can refer to a detailed geographical map to obtain a close approximation. A detailed geodetic map should provide adequate latitude and longitude information.

In the USA, such maps are produced by the United States Geological Survey (USGS) and are generally available for purchase from specialty map stores.

Also in the USA, one can use online services to determine latitude and longitude. Two such services, which both use place name keywords to perform a search, are at the URLs:

http://tiger.census.gov/

Outside the US one can use a coordinate locator service by Heavens-Above at URL:

http://heavens-above.com/

Another resource is to use a Global Position System (GPS) at the observer's site to obtain the geographical coordinates. These systems have come down in price dramatically over the last few years and are particularly helpful when using a remote site.

---- 1.5.2.2.1 Azimuth (Az)

Azimuth is measured in degrees, corresponding to the points on a compass heading on the local horizon. To accurately locate an object, the observer must become familiar with the location directions on the horizon in terms of compass heading, where both 0 and 360 degrees correspond to true North; 90 degrees corresponds to true East; 180 degrees corresponds to true South; and 270 degrees corresponds to true West.

Azimuth angles are "true" (i.e., geographic) headings, not magnetic headings. For observers in the northern hemisphere, the star Polaris is currently less than 1 degree misaligned from true North and is therefore a useful guide for locating the four cardinal points of the compass heading on the local horizon.

One method to locate the magnitude +2 star Polaris is to locate the Big Dipper and use the two stars that make up the end of the Dipper's cup. These two stars point toward Polaris about 5 times the distance between the two pointing stars. Polaris will be at an altitude equivalent your latitude. Knowing where Polaris, the North Star is located, you can then estimate the four geographical cardinal points; North, East, South and West in determining the azimuth angle given in your satellite prediction program.

If you have Java capabilities on your computer, you can go to:
http://www.astro.wisc.edu/~dolan/constellations/constellationjavalist.html

and click on the link for the constellation Ursa Major where the Big Dipper resides. This will allow you to view the relationship between the Big Dipper and the Little Dipper (where Polaris is located).

By using a magnetic compass and compensating for local magnetic deviation (the difference between True North and Magnetic North) you can also locate the true heading. The magnetic deviation for a given location can be found at URL:

http://gsc.nrcan.gc.ca/geomag/field/cgrf_e.php

---- 1.5.2.2.2 Altitude

Altitude is a measure in degrees above the local horizon. An altitude of 30 degrees would mean that the object is located 30 degrees above the local horizon. (Note, 10 degrees can be approximated by the width of one's fist held at arm's length, so an object at 30 degrees altitude would appear to be approximately three fist widths above the horizon.) An object having an altitude of 0 degrees would be directly on the observer's local horizon. An object having an altitude of 90 degrees would be on the observer's zenith (directly overhead).

It takes continual practice to accurately estimate or locate an object's local coordinates.

---- 1.5.2.3 Brightness Of Stars

In astronomy, the brightness of any star is measured using the magnitude scale. This method was devised originally by the ancient Greeks, who classified the stars that were visible to the unaided eye as being first magnitude (brightest) to sixth magnitude (dimmest). This rough method was altered in the 19th century, so that magnitude +1 stars were defined as being exactly 100 times brighter than magnitude +6 stars. The brightness factor between successive magnitude values is approximately 2.5. Thus, the magnitude could be expressed as varying logarithmically (exponentially) with the star's brightness. With the advent of accurate modern photometry, the scale was extended in both directions.

At one extreme, the bright Sun is magnitude -27. At the other extreme, some of the faintest observed stars are about magnitude +24. The full moon is magnitude -12.5. Sirius, the brightest star in the nighttime sky, is magnitude -1.5, while the faintest stars visible to the naked eye under good conditions are about magnitude +6.

It is very useful to know some stellar magnitudes in order to estimate the brightness of a satellite during a pass. The advantage of this method is, of course, that the stars are readily available for comparison with a satellite. Knowledge of stellar magnitudes also helps in judging the current viewing conditions. It is useless to look for a magnitude +5 satellite, if atmospheric conditions limit the seeing down to only magnitude +3. Some tracking programs provide the magnitude value of stars on their display star field as an aid to the observer.

A quick guide to atmospheric conditions and satellite brightness can be gleamed from examining a suitable constellation. In the Northern hemisphere, Ursa Minor ("Little Bear") is ideal. (Note, the "Little Dipper" asterism is only a part of the constellation Ursa Minor or Little Bear. An asterism is a group of easily recognized stars that are a part of one or more constellations.) Circumpolar, and thus usually visible to a Northern hemisphere observer, Ursa Minor contains stars ranging in magnitude from +2 down to +6. Brighter satellites can be gauged by comparing against some of the more brilliant stars, such as Sirius (-1.5), Vega (0.0), Altair (+0.8), and Deneb (+1.3).

The closest equivalent to Ursa Minor in Southern hemisphere skies is the constellation Crux (Southern Cross). Similarly circumpolar, it contains stars ranging in magnitude from +0.8 down to +6.5.

---- 1.5.2.4 Tracking Considerations

If the satellite is not very bright, it is difficult to use only azimuth and elevation as coordinates. In most cases, it is more practical to use Right Ascension and Declination coordinates to draw or locate the track of the satellite in a star field, as shown in an atlas or astronomy program. Some graphical tracking programs show the satellite's location in a star field. To locate and track the satellite, choose an easy reference point along the orbit, such as passage near a bright star, passage between two bright stars, and so on.

The predicted track can deviate from the true one, if the input orbital elements are not very recent. The track can also change considerably due to the influence of the Earth's atmosphere, which in turn depends on varying solar activity. Any orbital maneuvering of an active satellite can also cause deviations from predicted track.

Fortunately, for most satellites, such deviations are a matter of at most one minute in time and one degree in position. For satellites in an orbit lower than 300 km, however, or for active maneuvering) satellites, the track deviations can reach half an hour in time and several degrees in position. Most rocket stages can be predicted fairly accurately for longer than a month. But for the Space Shuttle, which maneuvers frequently, predictions can lose accuracy very rapidly.

To locate and track a satellite, start watching the selected area of the star field a few minutes before the satellite is predicted to pass through that field. To anticipate deviations from the predicted track, "sweep" or "scan" with binoculars in a direction that is perpendicular to the predicted track. At about the predicted time, the satellite should appear in the field of view. The satellite can be tracked from that point, and rotational or positional measurements made.

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This introduction was written by a subscriber of the SeeSat-L mailing list, which is devoted to visual satellite observation. Members of this group also maintain a World Wide Web site and a listserver called SeeSat-L. The home page and information on subscribing to SeeSat-L can be found at the URL:

http://www.satobs.org/satintro.html

The information on the VSOHP site is much more dynamic than that found in this introduction. For example, the VSOHP site contains current satellite visibility and decay predictions, as well as information about current and upcoming Space Shuttle missions and ISS dockings. The VSOHP site also contains many images, equations, and data/program files that could not be included in this introduction while maintaining its plain text form.

This introduction was originally located at

> http://home.att.net/~janjeff (Now is a broken link)

and was last updated on January, 2005. However, since I changed my ISP, as of November 29, 2006, this introduction is maintained by Aris Tanone's at his satellite resource site in the US:

> http://www.mysattrack.com/tutorial.htm/

Aris Tanone mainly checking that all the links are still functional.
