Physics 1040
Beginning Astronomy
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The Telescope

In class that day I had no clue what to do my research paper on. The deadline for the topic was eminent. When the challenge was issued for someone to do their research project on the telescope my first thought was, ah, I already know a lot about telescopes… I have even built one. I want to do my paper on something I don't know about so I will learn something new. The notion wore on me and by the end of class I realized that indeed there was much more for me to learn about telescopes. I now had a subject and a new perspective. My hope is that this report will give you some insight into all the new things I have learned about the mighty telescope!

History of the Telescope

For as long as man has been capable of wondering, the night sky has provided subject material to wonder about. Trying to see more clearly and to find greater detail of the objects in the sky had been a desire of all the ancient astronomers. The true beginning of telescopes is somewhat foggy in history but the roots of its development started somewhere in the 13^{th} century. An glassmaker noticed that if he looked through a glass disk just right, everything looked a little clearer and the object in view was slightly magnified. This discovery was probably by accident when small glass disks were made for leaded windows. This was the early beginning of eye spectacles. The glass disks were improved as time went on. They were commonly worn in Italy by the end of the 13^{th} century. It became well known that a lens would increase the magnification of an object.

Jumping now to the dawn of the 17^{th} century brings us into some minor controversy about who invented this amazing tool. There were three men who have laid claim to being the first to develop the telescope. James Metius of Alkmaar, Zacharias Jansen of Middelburg and the most recognized of the three is Hans Lippershey also of Middelburg. The Dutch spectacle maker, Hans Lippershey, noticed that if he put 2 of his eyeglass lenses together it greatly magnified the object he was looking at. He took them outside and carefully positioned them while pointing at a distant church. The view was wonderful. It was greatly enlarged and very sharp. The telescope was born. He mounted them together in a tube and called the device a "Looker". In 1608 he tried to market the Looker to the Dutch army as its inventor but was turned down because of the disputes over who actually had invented the device. Stories about the Looker spread rapidly and even a French Ambassador had obtained one. Soon news of the Looker made its way to northern Italy.

The stories of the Looker were buzzing in May of 1609 when a scientist and astronomer named Galileo Galilei came to Venice. He came to town and heard that a Belgian inventor had developed a perspective instrument that would bring nearer and enlarge the view of very distant objects. It worked by means of refraction of light through glass. When Galileo returned to his home in Padua, he claimed to have solved the problems of construction of a telescope by the next morning. He put a convex lens in one end of a lead tube with a concave lens at the other end. His first attempt gave an increase in magnification of about three diameters. After a few days he improved the performance significantly when he made a second telescope which boasted a magnification of about nine diameters (shown below)

He took this instrument back to Venice and communicated the details to the public. He presented the instrument to Doge Leonardo Donato while he was sitting in full council with the Senate. The Senate made a deal with him for lectureship at Padua for life and doubled his salary. Galileo claimed he invented the telescope independently but not until he had heard of others doing so.

Galileo's claim for independently inventing the telescope is insignificant compared to what he used it for. He was certainly the first to point the devise into the dark heavens above and begin recording the details of the hidden wonders of the universe. He was the first to document the moons of Jupiter and their movements, to outline the phases of Venus and to make detailed drawings of the face of the moon. As he continued to improve the magnification of the telescope to as much as 33 diameters the details of the once unknown began to unfold and be documented for the first time.

In 1611 Johannes Kepler was the first to explain theory and some of the practical advantages of a telescope that would be constructed of two convex lenses. He outlined this in his paper titled Catoptrics. It was not until 1630 when Jesuit Christopher Scheiner actually built a telescope with this design. A man named William Gascoigne was the first to practically appreciate the advantages of the design by Kepler versus a Galilean telescope. By the middle of the 17th century, Kepler's design came to be used the most. It was not because of the advantages pointed out by Gascoigne but rather the advantage of a much wider field of view that persuaded most astronomers to switch to this design.

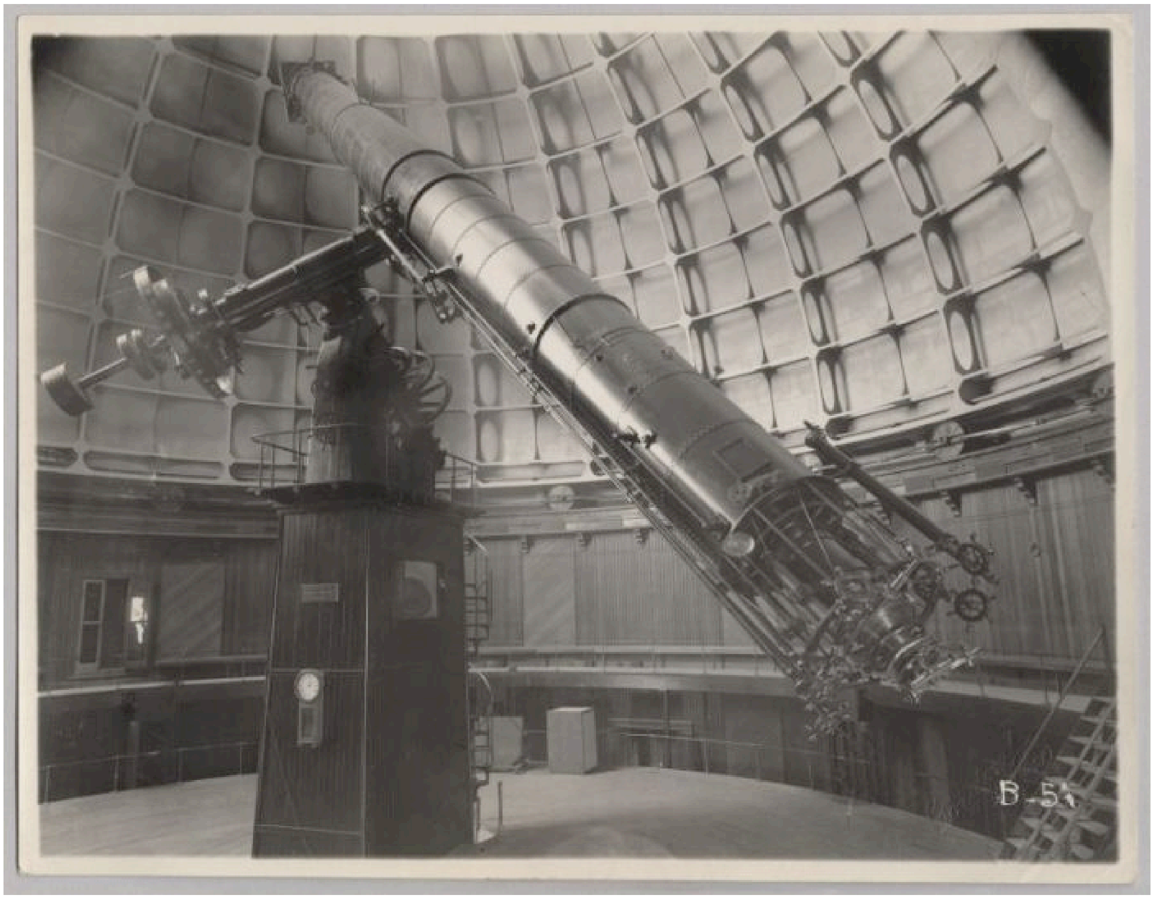
The first of the very powerful scopes with the Kepler design was built by Christaan Huygens with assistance from his brother. With a massive twelve foot focal length he discovered the brightest of Saturn's satellites (Titan). In 1655 Huygens published his Systema Saturnium in which he gave for the first time a true explanation of the rings of Saturn. His paper was based on observations he made with this enormous telescope. In 1672 Giovanni Cassini discovered Saturn's fifth satellite Rhea, by using a telescope with a 35 foot focal length. Later in 1684 using a 100 foot focal length telescope Cassini observed 2 more satellites of Saturn. Later Huygens and his brother made a 123 foot telescope and presented it to the Royal Society of London. Other scopes were claimed to have been made with focal lengths of up to 600 feet but no evidence exists that they were really ever able to be used in practical observations.

Until Sir Isaac Newton's discovery of the different refangibility of light of different colors, it was generally supposed that the object-glass of telescopes could not have any other errors than an imperfection from the spherical figure of the glass surface. Newton discovered that when light is reflected from a curved surface it produced a conic section and this corrected the spherical aberration created by the refracting lenses. By 1672 he fashioned a new telescope and the first Reflector was born (shown below).

His selection of material to make the reflecting surface was an alloy of copper and tin. He polished and smoothed the mirror until he felt it overcame the aberrations caused by the refracting lenses. It actually took a while for his telescope to catch on but eventually as the technique was perfected the advantages of his design won over principally due to the much more manageable size and higher light gathering capability.

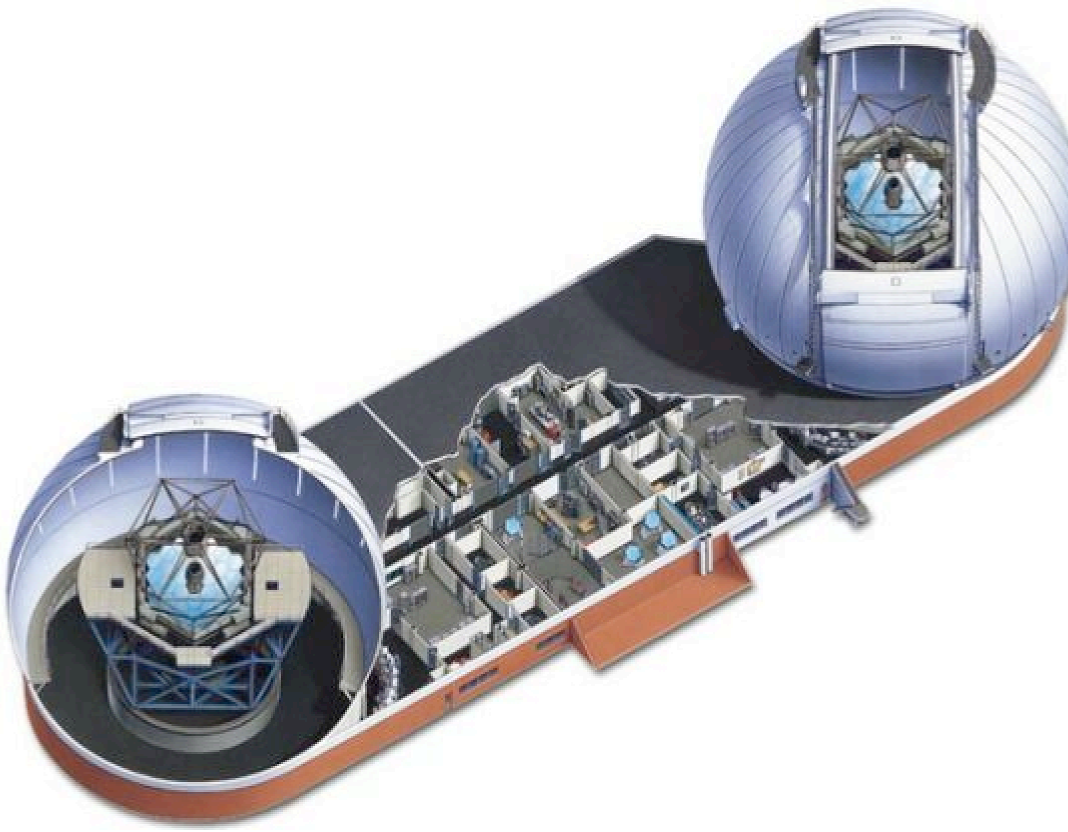
In 1781 having already discovered Uranus with a 6.25" Newtonian telescope, William Herschel went on to build a 12", then an 18.8" and finally a monstrous 48" x 40' super scope in which he discovered the sixth and seventh satellites of Saturn. In 1824 a Joseph Fraunhoefer greatly improved the figuring of lens and built a 9.5" x 14' refractor scope that was a masterpiece. It was the largest of its kind at the time and his design became the standard for future refractors. This design was what Percivelle Lowell patterned his 24" scope after in 1894. His observations and reports of the canals on Mars with this scope at the Lowell Observatory in Flagstaff Arizona gave much attention to and greatly increased interest in planetary study and observation.

In 1888 the Lick Observatory opened boasting a 36" refractor (shown below). This telescope became the center for study of radial velocities of stars and nebula. George Hale obtained the funds in 1897 to build a 40" refractor at the Yerkes Observatory. He used the argument to obtain the funds that he would "lick the Lick".



It did and to this day it remains the largest refracting telescope in the world. Hale was unsatisfied with the results of his mega 40” refractor and so he used a mirror figured by George Ritchey to convince the Carnegie Institute of Washington to finance the construction of a giant reflector telescope at a new observatory atop Mount Wilson in 1908. Believe it or not, while undergoing its final testing before it was used, Hale convinced J D Hooker to finance the construction of another telescope named the “Hooker 100” which also was to reside atop Mount Wilson. It was completed by 1917. Now with 2 giant telescopes, Mount Wilson became a major astronomical research center. It was peering through the Hooker 100 that Edwin Hubble measured the distances to several spiral nebula and ended a long debate by showing they were actually galaxies, not nebula. Hale did not give up at 100” and putting together the Rockefeller Foundation and the California Institute of Technology he created a joint venture that ended up with a 200” telescope bearing his name which resides atop Mount Palomar. Though Hale died before its completion in 1948 this telescope was the largest and most productive for three decades.

Finally the Gigantic Keck telescopes atop Mauna Kea were constructed. They are the largest ever built. The Keck1 began operation in 1993 and Keck 2 in 1996. Each telescope weighs over 270 tons. The facility that houses them was erected at a cost of over a billion dollars. The primary mirrors of the telescopes were built in segments that are kept focused by a sophisticated computer system. New technology was developed to polish the mirrors. They are so smooth if they were expanded to the size of earth diameter they would not have an imperfection more than 3 feet high.



During observing, a computer-controlled system of sensors and actuators adjusts the position of each segment relative to its neighbors to an accuracy of four nanometers, about the size of a few molecules, or about 25,000 times thinner than a human hair. This twice-per-second adjustment effectively counters the tug of gravity on the heavy mirrors. Needless to say these telescopes are at the forefront of today's astronomical learning and discovery. We have come a long way since the three diameters of Galileo's first telescope.

I suppose any report on the history of the telescope would be incomplete without mentioning the most famous of all telescopes. The Hubble. It was named after Edwin Hubble who was the first to find evidence of an expanding universe. His findings are the foundation for the Big Bang Theory. Hubble was launched on April 24, 1990 from the space shuttle Discovery. It has a primary mirror of 94.5 inches and the whole device is about the size of a school bus. It is unique as the only optical telescope to be operating 300 miles in space where it has no atmospheric interference to deal with.

The object Hubble looks at most is Earth, but only because that is how it re-calibrates. Hubble is very energy efficient using only the equivalent of 28 household light bulbs for each orbit. At a cost of over $1.5 Billion Dollars Hubble was the most expensive telescope built at the time. It had a mission plan that spans 20 years and is due to be replaced in 2011 by a new space telescope that will see up to 100 times farther than Hubble. Hubble has made many discoveries in the mysterious cosmos. The great benefits from having a space based telescope available to scientists will hopefully keep one flying through the cosmos for a long time into the future.

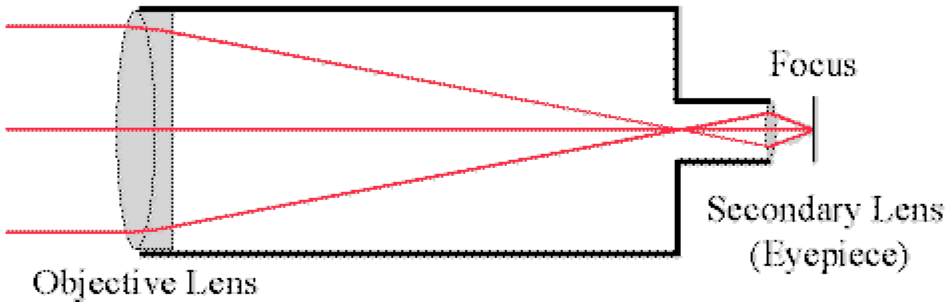
Types of Telescopes

There are several kinds of telescopes that operate in different wavelengths of the electromagnetic spectrum. The most familiar are telescopes that work with optical light or visible light. There are telescopes that operate in all wavelengths of light from gamma ray to radio waves. We sometimes don't think of them as telescopes because their configuration is built with antenna or capturing devises rather than with mirrors or optical glass. Outlined below is an explanation and description of each.

Optical Light Telescopes

There are the two main types of optical telescopes that operate in visible light. They are outlined below with a brief description of each.

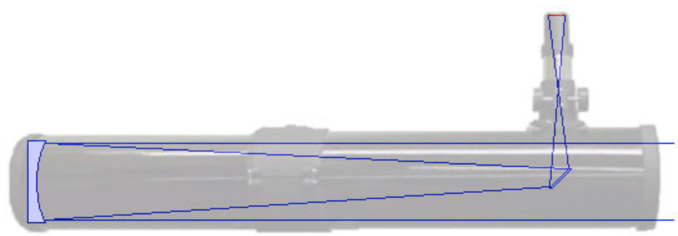
Refractors or Dioptrics – This is the type of telescope that Galileo invented. These provide a view by looking through a lens or series of lenses that focus at an eyepiece. There are three types of refractors**.**



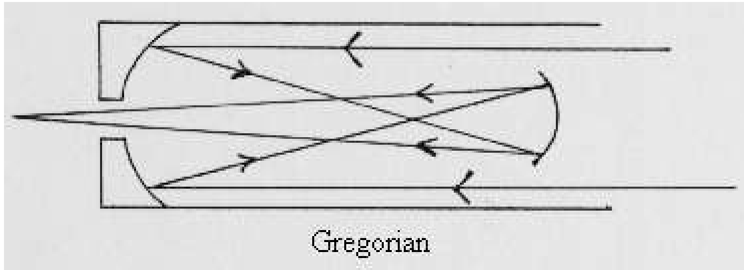
Achromatic – These were the first type of telescopes. They had chromatic aberration of the lens which shows itself as fringes of color around the image. This occurs because all colors cannot be focused at a single common position on the optical axis.
Non-Achromatic – These use lenses that minimize the effects of chromatic aberration
Apochromatic – These use non-achromatic lenses that are corrected to bring two of three primary colors into critical focus in the same plane with the third. This type of lens gives a very sharp image in all colors and makes them exceptional for photography as well as crisp viewing.

Reflectors or Catoptrics – This is the design invented by Sir Isaac Newton. These provide a view by reflecting the image off of a primary mirror that is parabolic and focuses the light into the eyepiece.

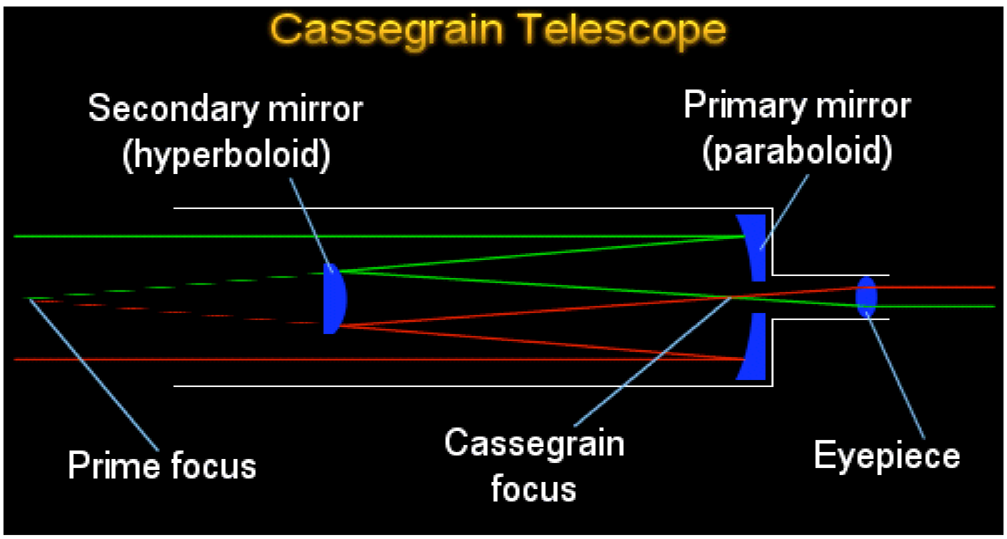
Newtonian - Named after Sir Isaac Newton. This telescope reflects light from a parabolic primary mirror to a flat secondary mirror and then to the eyepiece for viewing. This is the most popular type of telescope because it gathers a lot of light, viewing is powerful, it is easy to transport and is inexpensive to purchase.



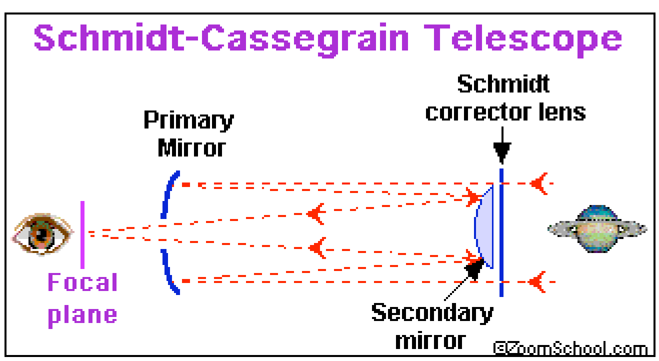
Gregorian – In 1663 a Scottish mathematician named James Gregory designed a telescope that had a small secondary mirror that reflected light through a hole drilled in the main mirror. The design also called for two concave mirrors, with the secondary mirror placed outside the focal point of the main mirror. Unfortunately, the technology of the mid-1600's could not produce mirrors accurate enough for his design to work properly.



Cassegrain - In 1672 a Frenchman named Cassegrain, wrote to the Paris Academy of Sciences on the topic of the megaphone in which he also described a reflecting telescope designed. The main difference between Cassegrain's design and that of Gregory was that Cassegrain used a convex secondary mirror and moved it inside the focal point of the main mirror.

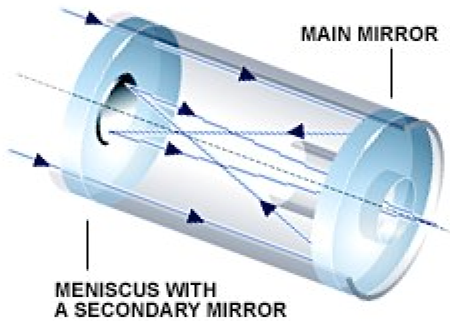


Schmidt-Cassegrain - Nearly 260 years passed before the next major development took place. This was in 1930 when an Estonian astronomer, lens and mirror maker, Bernard Schmidt, developed a lens called a 'corrector plate' that would compensate for the Cassegrain's optical distortion – it was developed to correct spherical aberration. This design was the first lens used for astronomical photography. In the Schmidt Camera, a curved photographic plate holder was placed exactly at the focal plane of the primary mirror for super sharp images. Later the Schmidt Corrector Plate was applied to the Cassegrain design and the Schmidt-Cassegrain Telescope was born.



Maksutov-Cassegrain - A. Bouwers of Amsterdam, Holland, in February of 1941 and Dmitry Maksutov of Moscow, Russia, in October of 1941 independently conceived the idea of replacing Schmidt's complexly shaped corrector plate with a curved lens, called the Meniscus Corrector Shell.

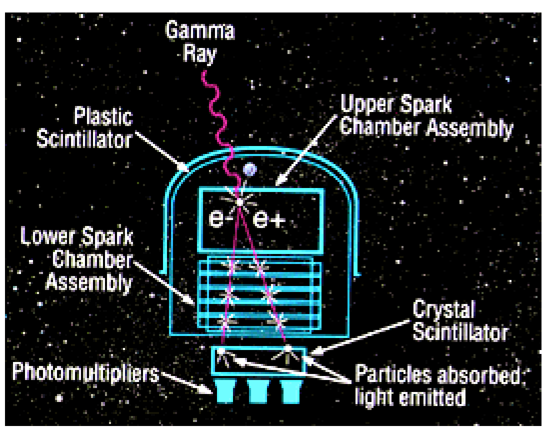
This fixed the problems of spherical aberration and was easier to manufacture. This telescope developed into what we now know as the Maksutov-Cassegrain. This design actually combines reflector and refractor technology in order to operate.



Gamma-Ray Telescopes

Gamma-Ray Telescopes are not telescopes in a traditional sense. They work by detecting high energy photons. Since gamma-rays pass through most materials and thus cannot be reflected by a mirror as light does in an optical or even and X-ray telescope, the tools of high-energy physics must be used to detect the gamma-ray photons. With these detectors scientists can observe the cosmos in energies with up to 1 T-eV (1,000,000,000,000 eV,) or beyond!

Gamma-ray detectors are bombarded with contamination from cosmic rays. Cosmic Rays are elementary particles which are come from all parts of the cosmos and often affect the detectors in a similar manner to the way the Gamma Rays that are being looked at affect them. This" background noise" must be suppressed in order to obtain a pure signal from the source. This is even more important when you consider that sources of cosmic gamma-rays are extremely weak and require long observations, sometimes several weeks, to get a significant detection or accurate measurement of a source.



There are two types of Gamma-Ray detectors. The first are what would typically be called spectrometers or photometers in optical astronomy. These are instruments which are "light buckets" and focus on a region of the sky containing the object of interest collecting as many photons as possible... The second class is detectors that image gamma-ray emitions. Detectors of this type either rely on the nature of the gamma-ray interaction with other elements to calculate the arrival direction of the incoming photon, or use a device such as a coded-mask to allow an image to be reconstructed.

Gamma-ray detectors have only been around for about 30 years. They have improved significantly in that time frame. Gamma-ray detectors are meant to measure the same things detectors at other wavelengths measure, but the challenge of working in this very high and dangerous energy range is far more challenging to instrument developers than most other fields. Future detectors are beginning to use more advanced solid-state technology to overcome some of these problems and provide large, sensitive detectors which will make gamma-ray astronomy a source for great discovery in the future.

X-Ray Telescopes

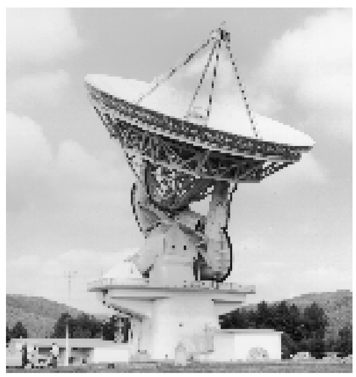
X-Ray telescopes are unique in the way they function. Since X-Rays are absorbed by the Earth's atmosphere, space-based observatories are necessary to study X-ray emitions. By studying them, scientists can learn more about everything from black holes to quasars. They provide a unique laboratory to study the physics of the universe that can not be replicated within the earth's atmosphere.

NASA's Chandra X-Ray Observatory (artist's depiction shown) is the world's most powerful X-Ray telescope. With a combination of sensitive instruments and highly X-Ray reflective mirrors, the observatory allows scientists to study the origin, structure and evolution of our universe in greater detail than ever before. It has already found many amazing things like a brilliant ring around the heart of the Crab Nebula (M1).

Chandra is the third in NASA's family of "Great Observatories." Complementing the Hubble Space Telescope and the Compton Gamma Ray Observatory, which are in Earth's orbit as well, the Chandra X-Ray Observatory studies only X-Rays. By capturing images created by these invisible light waves, the observatory allows scientists to analyze some of the greatest mysteries of the universe. By mapping the location of X-Ray energy throughout the universe, they are finding clues to among other things, the identity of the missing mass called "Dark Matter" that must exist but cannot be seen.

Radio Telescopes

The first non-visual spectral region that was used for astronomical observations was the radio frequency band. Telescopes observing at these wavelengths are commonly called radio telescopes. Like the Gamma-Ray or X-Ray telescopes, they also do not look like optical telescopes. Radio telescopes are built to collect waves from the radio frequencies, just as visual reflecting telescopes collect light in a visual range. Radio telescopes can be combined and used together even if they are in different locations. When scientists link multiple radio telescopes they operate them as if they were a single telescope. Linked together they produce images that have extremely high resolution.

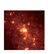


This radio telescope has an antenna of 140 feet in diameter and is located in Green Bank, West Virginia. The Arecibo radio telescope is the largest single radio telescope in the world. The huge "dish" is 305 m (1000 feet) in diameter, 167 feet deep, and covers an area of about twenty acres. The surface is made of almost 40,000 perforated aluminum panels, each measuring about 3 feet by 6 feet, supported by a network of steel cables strung across the underlying Karst sinkhole. It is a spherical, not parabolic, reflector. Suspended 450 feet above the reflector is the 900 ton platform that houses electronic and scientific equipment which helps operate the monstrous scope.

Pictures from each Type of Telescope

The best way to summarize each of the different types of telescopes is to show you how each of them view an object.

Below are photographs taken of one of my favorite objects, the Andromeda Galaxy (M31). Each photograph is taken with a telescope that looks at the sky in a different wavelength of light in the electromagnetic spectrum. As you can see, each one sees Andromeda in a little different way. This is a visual demonstration that each type of telescope has a purpose and each adds a little more information to gain an overall clear picture of what is going on with objects that we study.


X-Ray:


Ultraviolet:


Visible BW


Visible Color


Mid-Infrared:


Mid-Infrared:


Far-Infrared:


Radio:

By combining all the data from these different telescopes, we understand much more than ever before about the objects we study. With newer and better telescopes being developed all the time we continue to deepen our understanding of the cosmos and our place in it.

World’s Biggest Telescopes

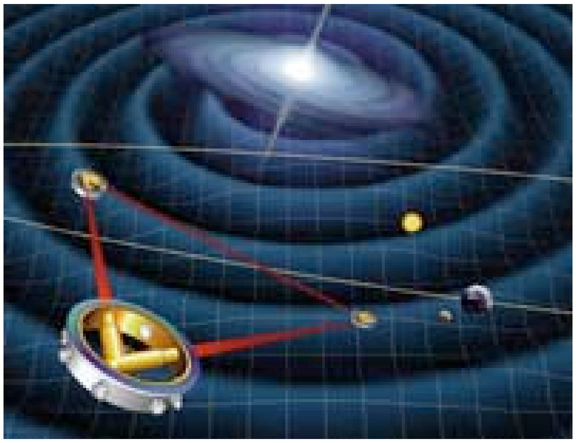
Since I know you are curious to know what the biggest telescopes are, I have listed below the largest optical telescopes. They are sorted by the size of the primary mirror diameter. This list was compiled from “Astronomy Online”.

Mirror (meters)	Name	Location
10.0	Keck	Mauna Kea, Hawaii
	Keck II	
~10	SALT	South African Astronomical Observatory
9.2	Hobby-Eberly	Mt. Fowlkes, Texas
8.3	Subaru	Mauna Kea, Hawaii
8.2	Antu	Cerro Paranal, Chile
	Kueyen	
	Melipal	
	Yepun	
8.1	Gillett	Mauna Kea, Hawaii
	Gemini South	Cerro Pachon, Chile
6.5	MMT	Mt. Hopkins, Arizona
	Walter Baade	La Serena, Chile
	Landon Clay	
6.0	Bolshoi Teleskop Azimutalnyi	Nizhny Arkhyz, Russia
	LZT	British Columbia, Canada
5.0	Hale	Palomar Mountain, California
4.2	William Herschel	La Palma, Canary Islands, Spain
	SOAR	Cerro Pachon, Chile
4.0	Victor Blanco	Cerro Tololo, Chile
3.9	Anglo-Australian	Coonabarabran, NSW, Australia
3.8	Mayall	Kitt Peak, Arizona
	UKIRT	Mauna Kea, Hawaii

Conclusions

After learning about the history and types of telescopes man has engineered and built over the centuries, I have come to believe that this instrument in its various forms has single handedly provided more information about the universe we live in, than any other invention or information source known to mankind. Our knowledge of the cosmos has increased at an amazing rate since young Galileo peered through his first telescope and changed the view of the entire world.

What is to come? Well NASA is working on a new space-based telescope that will be in a triangular design and connected by laser optics. This Laser Inferferometer Space Antenna or LISA will be dedicated to studying gravitational waves (artist's depiction below from NASA website). Each corner will be a whopping 3.1 million miles apart. This project is planned to be launched by the year 2015. I wonder what we will discover with this one!



Sources

There are really too many to name, so I have provided a list of the sources that I gleaned the majority of information and photos from.

Internet sites.

www.absoluteastronomy.com www.planaterium.net www.physics.ku.edu
www.answers.com www.hubblesite.org
http://astro.nineplanets.org www.munishingwebsites.com www.shuttlepresskit.com
www.naic.edu/public/the_telescope.htm www.omni-optical.com
www.r-clarke.org.uk/astrolinks_radio.htm www.nasa.gov

Astronomy magazine – August. September and October 2005 editions