

PHYS 3989

Undergraduate Research-
Telescopes for Astronomical
Observations

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Introduction-

The study of optics is paramount to both the understanding and design of every telescope. This knowledge, of how light interacts with various materials and allows an observer to see has always been of great interest to mankind. In the 4th century B.C. Plato and his followers believed that sight worked through a “visual fire” that flowed out through the observer’s pupil, combined with other ambient light, and created a medium in which this knowledge was relayed to the soul [O'Regan]. Our current understanding, improved upon by generation after generation of scientists, offers a completely different framework for explaining sight. The current model explains that light, an electromagnetic radiation, is produced by some source and reflects off an object. After it is reflected off an object, it then enters the eye through a transparent outer covering called the cornea [American Optometric Association] as shown in diagram 1.

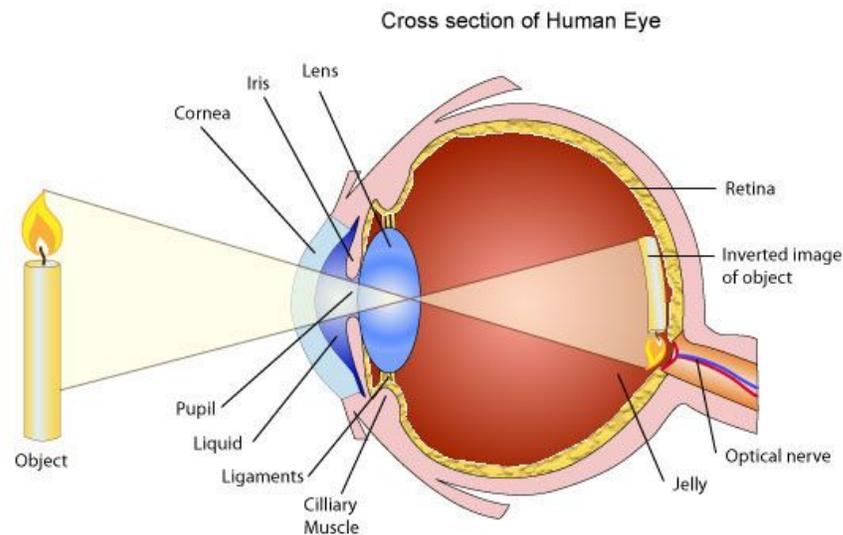


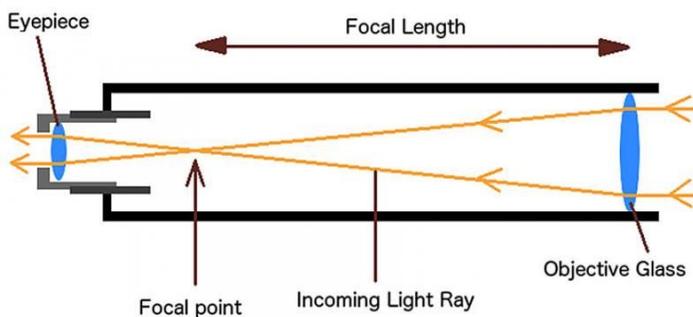
Diagram 1: Schematic view of the human eye

During this process the Iris, a muscle in the eye, opens and closes to adjust the amount of light which enters through a gap in the eye called the pupil. This adjustment of how much light is let through the pupil is called the aperture of the eye. It is important to recognize that because the eye's pupil is circular, doubling the pupil's radius is proportional to an increase of four times the light let in ($Area = \pi r^2$).

Once light makes its way through the pupil it passes through the eye's lens, and is refracted, or bent, so that the light is focused onto the retina. The retina is a light sensitive layer of tissue located at the back of the eye that contains 100 million light sensitive nerve cells. These nerve cells are divided into two distinct groups. The first group, the rods, are responsible for vision in low light. Cones, the second group, are activated in higher light situations. When light hits these rods it is converted into electrical impulses that the brain then uses to create an image. The optics of the eye produces an inverted image and the brain is able to flip it again and correctly orient the image.

The physics of human sight is also very similar to how a telescope functions. In 1608, the first telescope was invented by a German-Dutch lens maker Hans Lippershey [Freudenrich]. In 1610, Galileo later refined Lippershey's design and improved it from an 8x magnification to a 20x magnification [CSIRO]. Galileo was the first person to use the telescope for astronomical observation and later used his telescope to discover the four largest moons of Jupiter, revolutionizing our understanding of science with direct evidence for a heliocentric model of the solar system [Freudenrich]. The telescope design Galileo used was the refractor telescope. In order to understand how this type of telescope works, one must understand refraction at a deeper level. Light travels through a vacuum at its fastest speed, 2.99×10^8 m/s. Light travels through

other materials at different and slower speeds, and these materials are classified by a certain index of refraction. The refractor telescope works by using an objective lens (labeled objective glass in diagram 2) at the front of the telescope to bend incoming light and focus it at a focal point. The eyepiece is then stationed slightly behind the focal point and is used to project the virtual image back into the observer's eye. The magnification of the refractor telescope is determined by the ratio of the focal length of the objective (the distance between the objective lens and the focal point) to the focal length of the eyepiece (see equation 2 and diagram 3) [Telescope Equations].



$$M = \frac{f_o}{f_e}$$

Diagram 2: Schematic diagram of a refractor telescope

Equation 2

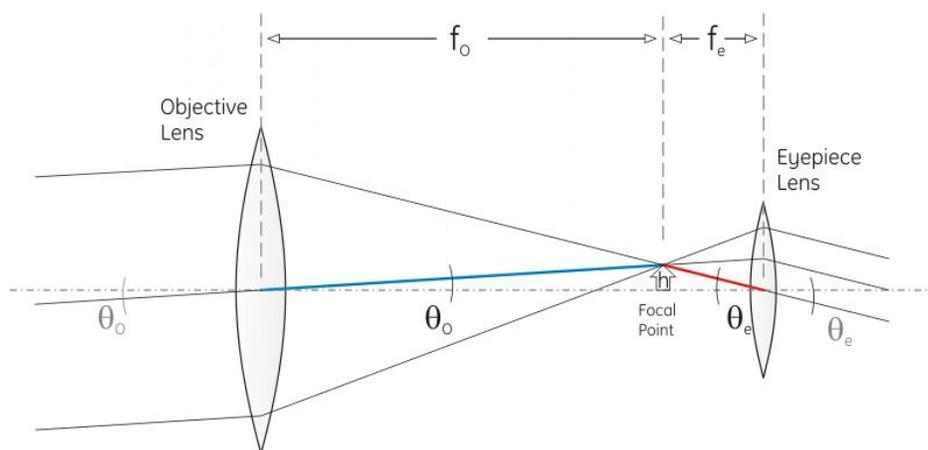


Diagram 3: Magnification of the refractor telescope

The simplicity of the refractor telescope is one of its advantages. But this design also comes with a few disadvantages. One of these is that because white light is composed of many different colors, the different wavelengths of light coming through are bent slightly different depending on the wavelength. Because of this, an effect known as chromatic aberration (see diagram 4) occurs and the colors are broken up exactly like light through prism. This effect significantly reduces the quality of an image from the refractor telescope. Additionally, because high quality lenses are expensive and outright difficult to make, refractor telescopes face the drawback of either being very expensive or being low quality. A larger lens is necessary in order to bring in more light and see more faint objects making a refractor telescope even less useful.



Diagram 4: Illustrating chromatic aberration

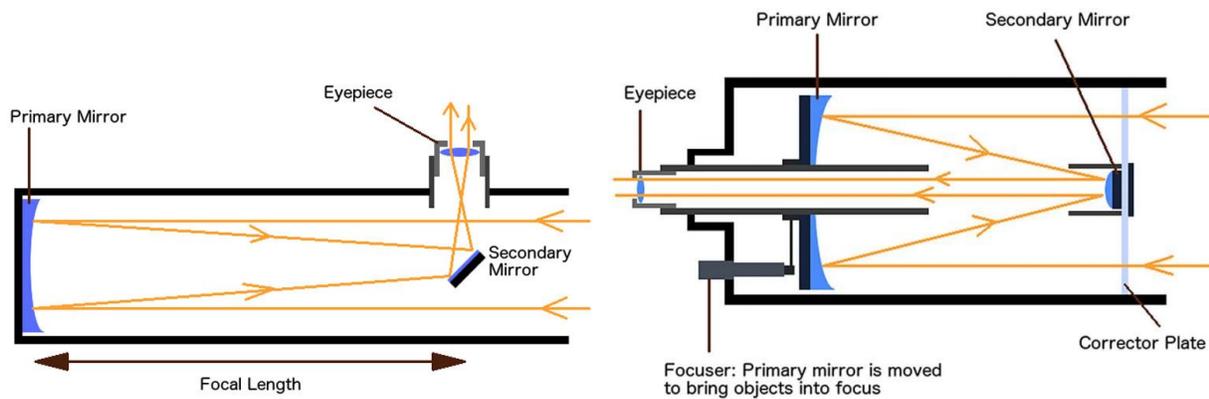


Diagram 4: Newtonian Reflector on left and Schmidt Cassegrain on right

In order to eliminate some of the problems apparent with refractor telescopes Sir Isaac Newton invented the Newtonian Reflector telescope. Unlike a refractor, the objective for a Newtonian telescope is actually a concave mirror and is placed in the back of the scope. As seen on the left side of Diagram 4, the light enters the telescope, reflects off the back and is reflected off a smaller secondary mirror into the observer's eye. Importantly, because this type of mirror is reflecting light and not refracting it, no chromatic aberration occurs. The angle of reflection depends solely on the angle of incidence. Additionally, large mirrors are significantly easier to produce than large glass lens. For example, the largest refracting telescope ever built sits inside the Yerkes Observatory with a diameter of 1 meter [Tate]. Meanwhile, the largest reflector telescope the Gran Telescopio Canarias measures 10.4 meters in diameter. Additionally, the Hawaii Supreme Court has just approved the construction of a 30 meter telescope atop Mauna Kea [Howell]. One drawback to this type of telescope is that the primary and secondary mirrors must always be properly aligned or else the image will not focus correctly. This adjustment of reflector telescopes is called collimation.

Another more modern invention in astronomy has been the use of Catadioptric telescopes. These telescopes combine both a lens to refract light as well as a mirrors for reflection in order to incorporate the advantages of both the refractor and reflector designs [Abel]. One famous design using catadioptrics is the Schmidt Cassegrain telescope (seen on the right side of diagram 5). The Schmidt Cassegrain telescopes are becoming very popular because the spherical mirror is easy to manufacture. Additionally, the telescope can be much shorter because the design reflects light inside itself twice creating a much longer focal length than can otherwise be reached using the same size refractor telescope. This more compact design is favorable when needing to travel and when setting up the telescope.

There have been many other advancements in telescope technology. Among these advancements is adaptive optics. Normally, turbulence in the Earth's atmosphere causes stars and other celestial objects to twinkle and blur [Adaptive Optics]. This is very troublesome for astronomers who wish to take clear pictures of the night sky and one way around this has been to launch telescopes into outer space. Adaptive optics solves this problem of turbulence in the atmosphere by using orange sodium lasers to measure the atmospheric conditions of the sky. This information is then received in real time and used to magnetically deform mirrors in the exact opposite conditions of the atmosphere so as to “re-distort” the image back to it’s normal conditions. Amazingly, because of the accuracy of this technology coupled with the benefit that much larger telescopes can be used on the earth's surface, the image quality of these telescopes are competitive with telescopes that are completely out of atmospheric conditions.

An additional piece of essential technology in astronomy is the tracking telescope mount. Because the earth makes one full rotation every day, when observing astronomical objects it

appears that they are moving out of the telescopes field of view. This makes it difficult to track one object for extended periods of time, and impossible to take clear long exposure pictures of the night sky. In order to avoid this problem two different types of telescope mounts have been invented. First is the equatorial mount, which is the most common and cost effective design for smaller size telescopes [Telescope Mounts]. The equatorial mount works by aligning one axis in parallel with the celestial pole of the Earth. After doing this the Equatorial mount uses one motor to rotate the telescope in the opposite direction to Earth's rotation, effectively canceling out the apparent motion due to Earth's rotation. This design allows an object to be viewed constantly until it completely disappears along the horizon. The other leading design for the telescope mount is the Altitude Azimuth Mount. This design is generally preferred over the equatorial mount for larger telescopes because it is easier and more economic to build on a large scale. The Azimuth mount works much like the Equatorial mount, but instead it uses two motors independently set at variable speeds and on different axis to correctly track the motion of the stars. Because this motion is often complicated, a computer guiding system generally controls the motors and allows the set up to be very accurate. The Azimuth mount does offer one large negative. Because this type of mount only rotates on a horizontal and vertical axis, it does not fix stars relative position to each other as the earth rotates. This effect known as field rotation can cause problems for astrophotographers and must be edited afterwards with specialized software. The equatorial mount will be a large part of the independent study selection of this paper.

Astronomical observation and its technology has come a long way since Lippershey's first refractor telescope. Modern engineering has allowed for incredibly advanced designs such as the Schmidt Cassegrain telescope, Adaptive Optics, and advanced motion tracking for

telescopes. The goal of this independent study is to implement some of these advancements into the telescopes used by the Avery Point Astronomy Club in order to upgrade their working capacity.

Independent Study Projects-

Project 1- Installation and utilization of charge-coupled device camera

The first portion of this project was installing a CCD camera onto the 90mm Unitron refractor telescope. A Canon Powershot G2 camera was used with an existing 23mm Meiji microscope to camera adapter. This setup was picked because the camera was already owned by the UConn Laboratory for Astrophysics department for previous research. The Unitron lens to eyepiece adapter was slightly larger than the 23mm Meiji adapter so aluminum foil was used to slightly decrease the diameter allowing for a tight seal to secure the camera to the telescope shown in diagram 5. The finished Unitron to CCD camera is shown in diagram 6. After adjusting the camera to the correct long exposure settings, the CCD camera was used to take a picture of the moon as shown in diagram 7.



Diagram 5: Aluminium foil around unitron lens to eyepiece adapter



Diagram 6: Finished unitron telescope with mounted CCD camera.



Diagram 7: Picture of Moon taken with Unitron CCD camera setup

Project 2- Installing the Uniron on an equatorial mount

The second project for this independent study was to install an equatorial mount onto the 90mm Unitron refractor telescope. An iOptron SmartEQ Pro+ equatorial mount and dovetail plate were purchased. First, the Unitron was disassembled from the wooden tripod and was then mounted onto the dovetail plate as seen in diagram 8. The iOptron SmartEQ Pro+ equatorial mount was then taken out of its packaging and assembled alongside the Unitron telescope.

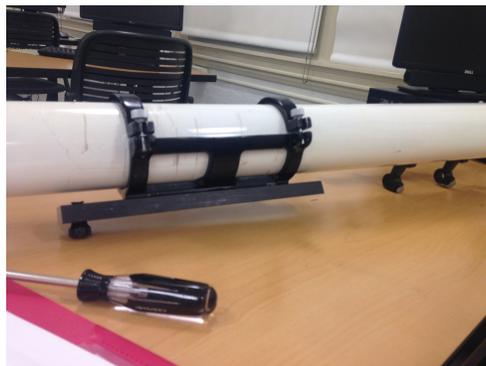


Diagram 8: Unitron being mounted to dovetail plate

After the equatorial mount plate was assembled properly, the dovetail plate was installed directly onto it. This concluded the installation of the equatorial mount as seen in diagram 9.



Diagram 9: Before-with wooden tripod mount After-with iOptron SmartEQ Pro+ mount

Project 3-Setting up Stellarium Software to Celestron

The last project for this independent study was to hook up the Stellarium Software to the Celestron 9.25" telescope. Here a Sabrent USB 2.0 to Serial 9-Pin DB-9 RS-232 Converter Cable was connected to the lab's laptop. Then a Nexstar RS-232 cable was connected directly from this cable to a port on the telescope. This setup allowed a direct connection between the telescope and the software so that the telescope could be controlled directly from the computer. The interface, shown in diagram 10, allows the user to select from a large selection of celestial objects and then slew the telescope to their true location. From here, information is presented on the object allowing for a very interactive experience.

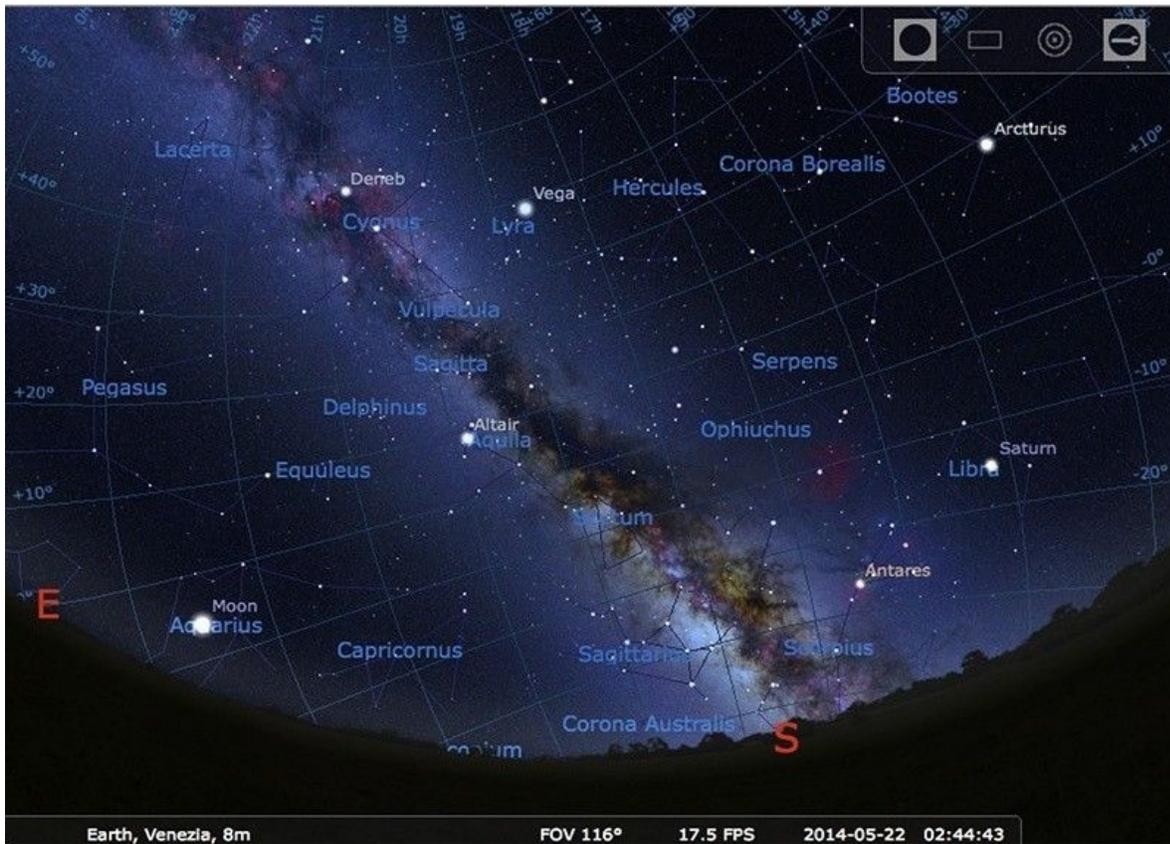


Diagram 10-Stellarium Software

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