Chapter 5 Telescopes

Telescope Design

When we think of a telescope, we think of something that we can look through. These are light buckets, gathering photons and bringing them into focus for us to see. We will discuss *optical telescopes*, telescopes that bring us visible wavelengths. But be aware that there are many wavelengths that are invisible to our eyes and we have built detectors to "see" in those wavelengths.

Reflecting and Refracting Telescopes

There are 2 basic types of optical telescopes, the *reflector* and the *refractor*. A reflector uses a curved mirror to gather the light. It is called the *primary mirror*. The light will then bounce off another mirror, which directs it to your eye. This is called a *secondary mirror*. The distance between the primary mirror and the point where the light comes to focus is called the *focal length*. The focus of the primary mirror is called the prime focus. Quite often in major observatories, in stead of using a secondary mirror, they place the camera at the prime focus to take the pictures.

A refractor uses a lens instead of a mirror. The incoming light is refracted or bent as it passes through the lens. This is due to the fact that light slows down as it passes through the lens.

One of the jobs of telescopes is to produce images of objects. As telescopes have gotten bigger, a number of factors have come up to show why reflectors are better than refractors.

1) A single lens refractor will produce chromatic aberration or pretty colors. The lens acts like a prism and disperses the light. To correct this, a second lens made of a different material must be put into the telescope, increasing the cost immensely. This problem doesn't affect mirrors.
2) As light passes through the glass, some may be absorbed. This isn't very noticeable with visible light, but for infrared or UV they basically don't get through. Mirrors don't have this problem.
3) A large lens can be quite heavy. It is supported by the edge, which means that there are a lot of stresses on the lens. The biggest refractor is only 40" in size. Large mirrors are supported from behind, which means that the entire mirror is supported.
4) Refractors have lenses that must be optically pure and you must polish out 2 sides to perfection. Mirrors aren't as affected by some impurities in the glass and you only need to polish one side, thus making it less costly.

Types of Reflecting Telescopes

There are several types of reflecting telescopes. The simplest is the *Newtonian telescope*. Light strikes the primary mirror and then strikes a flat mirror that directs the light out at 90° to your eye. A *cassegrain telescope* has the light strike the primary mirror and then it strikes a convex secondary mirror that directs the light out the back of the telescope to your eye. Another type of telescope uses a set up similar to the cassegrain but it puts a third mirror in it to direct the light out the side. This is called a Nasmyth focus. From here it goes into a room to be analyzed. The room is called the coude' focus. Here you would have very heavy equipment or finely tuned equipment that can't be put on the telescope.

Images and Detectors

Depending on what wavelengths of light we want to study, we can place a variety of instruments on the telescope to be able to study different things.\

Image Acquisition

Film was the first method for recording information. The first astronomical image was taken of what? The problem with film is that it only records 1% of the photons that strike it. We now use electronic detectors called *charge coupled devices* or *CCD*s. Just like your digital camera, the CCD uses a chip that contains a number of *pixels*, each of which acts like a camera. Each one takes a small piece of the whole picture. The big advantage of this is that unlike film, the CCD records as much as 90% of the light that strikes it. This means that a CCD camera can show objects 10 – 20 times fainter with the same telescope and the same exposure time.

Image Processing

We can use computers to reduce the background noise that you find in CCD images. This noise has many causes: cosmic rays, heat, an electronic hiss from the detector itself, and others. We can also remove the known imperfections of the instrument. This means that we will see only the data from the object.

Wide Angle Views

Most large telescopes have a very narrow field of view. As the angle at which the light enters the telescope increases, it degrades the quality of the image. This effect is called *coma*. One design to overcome this effect is called the *Schmidt-Cassegrain telescope*. This telescope places a very special piece of glass in the front of the telescope. It provides for a wider field of view as compared to a telescope without the piece of glass.

Photometry

A CCD makes the telescope a high powered camera. Some astronomers don't want the picture, they want more specific data. This data could be the number of photons that strike the detector over a certain period of time. This is called *photometry*, which is a measure of brightness. Astronomers will use colored filters to determine how much of each color of light is coming from the object. These colored filters are also used to make color images with CCD cameras. A picture is taken through each of the filters and then it is combined in the computer to combine the images, providing you with a color image.

Telescope Size

The bigger the telescope the better is what most astronomers think. This is because the bigger the telescope, the more light you gather and the fainter the objects that you can see. The 2 main things that you will hear talked about is the *light gathering ability* and the *resolving power* of the telescope. Light gathering ability is pretty clear, but resolving power is very important. Resolving power says how clear you see the object. It doesn't do any good to record the light if the object can't be seen clearly.

Light Gathering Power

The collecting area is determined by the size of the main lens or mirror. This tells how much light the telescope can pull in. The area of a mirror or lens is calculated by the following formula: Area of Circle = πr^2 So as you double the size of the mirror, the area increases by 4 times. So the Keck Twins on Mauna Kea at 10 m have 4 times the light gathering ability that the 5m Palomar telescope in California. The Keck Twins are very special because they don't use a one piece mirror. They use 36 hexagonal segments that are computer controlled to act like one mirror that is 10 m across. The largest single mirrors are the 4 8.2 m mirrors in VLT in Chile, the 2 8.3 m mirrors being used in the Large Binocular Telescope and the 8.3 m mirror in the Subaru telescope.

Resolving Power

Another advantage of large telescopes is their *angular resolution*. Resolution refers to the ability to form a distinct, separate image. The finer the resolution, the finer the detail that we can see. One of the things that limit a telescope is the *diffraction limits*. This is the tendency of light to bend around corners. Diffraction introduces a certain fuzziness into the image.

The amount of diffraction is dependent on the wavelengths being observed. The longer the wavelength, the bigger the diffraction. On page 119 you can see how as the angular resolution gets better, the clearer the galaxy is.

High Resolution Astronomy

We may know the theoretical resolution of a telescope, but the atmosphere will deal it a blow. Turbulence will destroy the seeing of the telescope. There are other things that can affect the seeing.

Atmospheric Blurring

If you go out and look at some stars, you may see that they are twinkling. This is due to the atmosphere. You don't want this. One of the ways to help minimize this is to put the observatories on mountain tops. This gets you above most of the dust and crud in the air that will cause the stars to twinkle. Many of the telescopes are found in the southwest. Also on Mauna Kea in Hawaii, and in the Andes of Chile (Atacama Desert).

New Telescope Designs/Real time Control

One of the hot new ideas in astronomy is called *adaptive optics*. This is where you use a thin mirror that has a series of pistons behind the mirror. A laser dot is placed into the sky and the computer sees it. It will adjust the shape of the mirror until the dot is a circle and now you can use the telescope. This adjustment goes on while you are using the telescope. This got a big boost out of the Star Wars Project. The adaptive corrections are easier to apply to infrared than visible. It works well with longer wavelengths. We are now getting better resolution on some ground based telescopes than we are out of the Hubble Space Telescope.

Radio Astronomy

Besides visible light, the only other wavelength to get through the atmosphere is radio. There are a number of radio telescopes out there.

Early Observations

The original radio astronomer was Karl Jansky, even though he didn't realize it at first. He was building an antenna for Bell Labs in 1931 when he got this hiss. The hiss rose 4 minutes earlier each day. He knew that this was a sidereal day. The spot in the sky that was hearing happens to be the area that is known to be the center of the galaxy. Progress was slow, but finally by the 1940's this work was being recognized and accepted.

Essentials of Radio Telescopes

The largest steerable radio telescope is in West Virginia. It is 540 feet across. Page 124 They are built in the same basic way as the optical telescopes. You have a curved reflector and a receiver where the radio waves are collected. Radio telescopes are large because the sources are very faint. Resolution is poor, hence the large telescopes. The best angular resolution for a radio telescope is abut 10", which is 100 times worse than most optical telescopes. The largest radio telescope in the world is in Arecibo, Puerto Rico. It has a dish built into the ground that is 1000 feet across. The dish is built into the Earth and the detector is moved.

The Value of Radio Astronomy

One of the key advantages of a radio telescope is that you can use them 24 hours a day. Poor weather also is no problem. The biggest advantage is that it opens up a whole new window on the universe. There are 3 big reasons: 1) Many of the brightest radio emitters are very faint in visible light. 2) Light may be absorbed by interstellar dust while radio is not affected by the dust. 3) Many parts of the universe are invisible to use in the optical, but not to the radio.

Interferometry

Poor angular resolution can be overcome by doing *interferometry*. This is where different telescopes found in different areas all receive information from some object. The waves reaching the telescopes won't get there at exactly the same time. It is this difference that allows us to glean more information out of the object. It is called interferometry because when the information is combined by computer some of waves interfere with other waves and they will partly cancel each other out. As the Earth turns and we track the object, the interference pattern changes slightly and it helps us pull out the information. The Very Large Array in New Mexico has 27 82 foot radio telescopes that can be moved to form one radio dish that is 25 miles across. On page 129 there is a comparison of a radio image and an optical image of a galaxy called M 51. We are currently working on an interferometer that uses telescopes in California and Germany which means that the dish would be equivalent to one that is 8000 miles across.

Space Based Astronomy

Because our atmosphere absorbs so much of the electromagnetic radiation that is coming in, we must get out of the atmosphere to do it. This is why we put up satellites.

Infrared Astronomy

Moisture in the atmosphere will absorb infrared waves. We place *infrared telescopes* into space to avoid this. These telescopes are very similar to optical telescopes with the main difference being that the detectors are designed to pick up the longer wavelengths. Another word for infrared is heat, so we are looking for heat signatures of different objects. As you can see from the image of the Orion Nebula in infrared and optical light on page 132. The infrared image is in false color where the whiter the area the more intense in the infrared and therefore hotter. We have launched and are launching new satellites for the infrared.

Ultraviolet Astronomy

Again, the Earth's atmosphere blocks most of the ultraviolet that reaches the Earth. We must use Balloons, rockets and satellites to capture the light for our *ultraviolet telescopes*. These telescopes are very similar in design to the optical and infrared telescopes.

High Energy Astronomy

High energy astronomy is the area left for X-rays and gamma rays. The telescopes built to study these can't be like anything we have done so far because these rays would pass right through the mirror. The recent X-ray satellite called *Chandra* uses a series of mirrors that are angled so that the X-rays graze off them and are funneled to the detector. Page 134 Gamma ray detectors are simply pointed in a general direction and the photons are counted. In 1991 we put up the *Compton Gamma Ray Observatory*. At 17 tons, it was the largest satellite ever put up. It was a workhorse for 9 years until 2000 when it was brought back down and burned up.

Full Spectrum Coverage

We now observe most of the universe in all different wavelengths. As you can see on page 136 we have the Milky Way in radio, infrared, visible, X-ray, and gamma ray. You can see how they are different in different wavelengths. We are doing this all over the sky.