

400 Years of Astronomical Revolutions

Celebrating the International Year of Astronomy

In 1609, Galileo first used the newly invented telescope to peer into the heavens. His observations revolutionized astronomy. The astronomy world is celebrating the 400th anniversary of the telescope in 2009. It is a perfect time to look back over the last four centuries and examine the revolutions within the science and hobby of astronomy.

The First Revolution

Galileo was one of the first truly modern scientists, using experiments to uncover the secrets of the physical world. In 1609, he turned his attention to the heavens with a new invention—the telescope. Galileo's first telescope was quite poor by modern standards. It suffered from aberrations and was limited in size and power. The aperture was only about one inch. Compare this to the standard two inch diameter of a standard finderscope on a modern amateur telescope! With a magnification of 30x, the first telescope offered views never before seen by human eyes.

Making meticulous observations and records, Galileo was able to determine that Jupiter has moons orbiting it, Venus goes through phases, Earth's moon is covered in craters and mountains, and there are countless stars not visible to the unaided eye. These observations proved that Earth was not the center of the solar system, forever changing humankind's place in the universe.

Galileo's first telescope was the greatest revolution in astronomy and one of the great scientific revolutions of all time, but as the science advanced, more revolutions were to come.

Newton's Telescope

Galileo's telescope was a refractor, using lenses to collect and focus light. This was largely the reason for its aberrations and limitations. Later in the 17th Century, Isaac Newton dedicated a great deal of effort into understanding the nature of optics. His work set the stage for future development of the telescope. Perhaps his greatest contribution to astronomy was his invention of the reflecting telescope.

Newton analyzed the properties of glass and came to the conclusion that refracting telescopes would always suffer from noticeable

aberrations. The primary problem is chromatic aberration. This arises from a prism-like effect: as light passes through a lens and is bent (in order to bring it to focus), each wavelength of light is bent by a different amount. Red light is bent more than blue light and therefore focuses closer to the lens. Each color focuses to a different point. While this can be compensated for to some extent by using different types of glass, Newton concluded that chromatic aberration would always be present in a refractor. Modern glass types now allow for refractors to be virtually free of color aberrations, but Newton's solution to the problem in the 17th Century offered the next big revolution in astronomy.

Newton realizes that reflecting light, instead of refracting it, would solve the color aberration problem. When light is reflected off a concave surface, it is focused to a point. But unlike a refractor, all the wavelengths of light are bent by the same amount when reflected. This provided a way around the color problem. It also offered a way to build much larger telescopes, and the bigger a telescope is, the more it can see. Soon, large-aperture telescopes were making new discoveries, including the observation of many "nebulae", faint cloudy-looking objects, the nature of which was unknown at the time.

The Scale of the Universe

The mystery of the nebulae persisted into the 20th Century. Some were shown, by analyzing the spectrum of light from the objects, to be gaseous clouds. Others, called spiral nebulae from their distinct shapes, remained enigmatic. The prevailing theory was that the spiral nebulae were solar systems in formation. Some argued, though, that they were "island universes", objects outside our own Milky Way galaxy. Previously, the Milky Way was presumed to be the full extent of the universe.

Larger and larger reflecting telescopes had been constructed, but they seemed only to be showing more and more of the same thing: more stars and more nebulae. However, George Hale believed that if a large enough telescope were built, it would make a fundamental discovery about the universe. Thus the largest telescope in the world was constructed atop Mt. Wilson in California. At 100 inches in diameter, its mirror would collect light from incredibly faint objects in unprecedented detail.

In 1922 and 1923, Edwin Hubble used the 100-inch telescope to photograph the Great Andromeda Nebula, the largest (and presumably nearest) of the spiral nebulae. Taking the deepest exposure yet of Andromeda, Hubble was able to resolve individual stars within the nebula. Comparing multiple images of the nebula taken weeks apart, Hubble noticed one star that was previously much fainter. He noted the star as a

nova (or exploding star) on the photograph. A later picture then showed the star again as a fainter object. Further examination showed that rather than discovering a nova, Hubble had made a more important discovery: a variable star. Hubble knew that certain variable stars could be used to determine the distance to an object. In his excitement, he scratched out the word "Nova" on the photograph and wrote "Var!", recording one of the true "eureka" moments in the history of science.

By analyzing the variable star, Hubble determined the distance to the Andromeda Nebula as 1 million light years. This was well outside the established size of our Milky Way, proving that the spiral nebulae were galaxies in their own right, some containing billions of stars, some millions of light-years away. More refined modern measurements show that the Andromeda Galaxy is 2.8 million light-years distant.

Digital Imaging

The latest revolution in astronomy, particularly for amateurs, has been the advent of digital imaging. Astronomers, both professional and amateur, have been photographing the sky with film for decades. Photography itself was a major revolution in astronomy, allowing for objective observations of objects and the capture of much fainter detail than the human eye could detect. However, the process of capturing film astrophotos was arduous and required a major commitment of the part of the photographer. Exposures lasted many hours, and the results remained unseen until the film was later developed. This resulted in an extremely steep learning curve for the amateur photographer and prevented most amateurs from trying their hand at photography.

In 1969, at Bell Labs, the first CCD, or charge-coupled device, was invented. A CCD uses a silicon detector to capture photons of light, which are then converted into an electronic signal and sent to a computer. Two major advantages of the CCD camera over film stand out: the result can be seen immediately, and the sensitivity of the camera is much greater. In fact modern CCDs are as much as 50 times more sensitive to light than film, which is of huge importance when trying to capture photons from faint deep-sky sources such as nebulae and galaxies.

For amateurs, these two advantages make CCD imaging considerably easier than film photography. The ability to see and frame an object in near real time means a proper result is much more likely. Seeing the final image immediately allows the astronomer to quickly verify that all went well with the image, and to analyze and correct any problems right away. The greater sensitivity of the CCD translates into much shorter exposure times—minutes rather than hours. Overall, the

learning curve is much easier and the experience far more enjoyable. CCD imaging has opened up astrophotography to a huge number of amateurs, far more than ever would have engaged in film photography.

Future Revolutions

Predicting the future is always risky, since the predictions are almost inevitably wrong. But near-term predictions are not too difficult to make. As light pollution grows worse, digital devices will extend our visual observing. Many amateurs are already giving up their eyepieces in exchange for CCD cameras.

An aspect of amateur astronomy that is becoming popular is video imaging. This allows deep-sky objects to be seen in much greater detail than an observer would see at the eyepiece, but unlike CCD imaging, the images are seen in real time (or with only a couple seconds delay). However, the sensitivity of video systems is lower than a proper CCD camera. While great detail can be seen, a CCD camera can still beat a video system. Also, current high-sensitivity video systems are black-and-white, while CCD cameras can image in color. One prediction for the future is the advent of high-sensitivity color video cameras, which will allow real-time observing of deep-sky objects in all their glory. When this level of detail can be seen in real time, as the cost of such systems drops, and as light pollution increases, we will likely see a steep decline in visual observing.

As for professional astronomy, a new revolution may take place with the construction of giant new telescopes. George Hale's vision of the 100-inch telescope in the 20th Century as an instrument that would forever change our view of the universe may be replicated in the massive telescopes of the 21st Century. Hale believed—in opposition to the view of many—that a big enough telescope would make a fundamental discovery about the universe, and he was right. The current large telescopes have mirrors in the 8-10 meter range. Future telescopes are planned that will be 30-100 meters in aperture. Their light-gathering power will be as much as 100 times greater than today's telescopes, and their resolution up to 10 times better. They will see back to the earliest stages of the formation of our universe and will give us a more fundamental understanding of how stars and galaxies formed, and will perhaps once again change our place in the universe.