Edwin Hubble: The Surveyor of the Universe

Introduction:

One hundred years ago, on the night of October 5th, 1923, a discovery was made that changed our understanding of the cosmos. American astronomer Edwin Hubble, using the new 100" Hooker reflector telescope at Mt Wilson Observatory, identified within the Andromeda Nebula what was to become the first extragalactic variable star. This led to astronomers adopting the expanding universe theory! Some historians consider Hubble's discovery to be one of the greatest in astronomy since Galileo's time.

Through his work of studying variable stars in galaxies, Hubble broke new ground in our understanding the universe, and along the way sparked the basics of the Big Bang Theory. Today, we're going to look-back on his life and accomplishments, and talk a little bit about his discoveries.
We'll also review a number of my observations of Hubble's objects and how you can observe them too.

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<u>Galaxies – What are they:</u>

Galaxies are large systems of stars and interstellar matter, typically containing from several million to several trillion stars. They run in size from a few 10's of thousands to several 100,000 light years in size, and are separated from other galaxies by millions of light years.

<u>How do Galaxies form?</u>

They originate from large cosmic primordial clouds of gaseous matter (hydrogen and helium) in our Universe that slowly collapsed. Most galaxies have formed at about the same time, within the first billion years after the universe started to expand, from an initial hot state.
Thus, they are all almost as old as the universe itself, currently thought to be about 14 billion years.

<u>Where are Galaxies Located?</u>

Galaxies are scattered throughout the visible universe. We live inside a giant spiral galaxy, called the Milky-Way Galaxy. The Milky-Way is about 100,000 light years in diameter and contains a mass equal to about a trillion stars. Our galaxy has several small dwarf galaxies orbiting around it that are only a few 100,000 light years distant. The nearest giant galactic neighbor, the Andromeda Galaxy, also a spiral, is about 2-3 million light years distant. Some galaxies are isolated "island universes" which float lonely through an otherwise empty region of the universe. But the distribution of matter in the Universe is not uniform. That causes groups of galaxies, running to few dozens of galaxies, or even large clusters of up to several thousands of galaxies, to form. The galaxies of these groups are in mutual gravitational interaction, which may have significant influence on their appearance.

<u>Galaxy Morphology</u>

Galaxies come in several types, a wide variety of shapes and appearances, and have many common features. From their appearance, galaxies are classified as spiral, lenticular, elliptical, and irregular

<u>Elliptical</u>

Elliptical galaxies are shaped like giant luminous cosmic balls, and have no spiral or disk components. They have little or no rotation as a whole. Normally, elliptical galaxies contain very little or no interstellar matter, and consist of older population stars only:

<u>Lenticular</u>

Lenticular galaxies are shaped like spiral galaxies without a spiral structure.
They are smooth disk galaxies, where stellar formation has stopped long ago, because the interstellar matter was used up. They consist of mostly older population stars only. From their appearance and stellar contents, they can often be observationally confused with ellipticals.

<u>Spiral</u>

Spiral galaxies usually consist of three major components:
A flat, large disk which often contains interstellar matter visible as diffuse glowing emission nebulae or as dark dust clouds. Young open star clusters, associations, and random stars arranged in conspicuous and striking spiral patterns and / or bar structures. Finally, a central bulge or core, consisting of older stellar populations with little interstellar matter, and often surrounded by a halo of older globular star clusters.

Irregular
Irregular galaxies have many different shapes and sizes due to distortions caused by their intergalactic neighbors. These galaxies do not fit into the normal scheme and exhibit no particular shape.

We'll talk more about galaxy classification later in the presentation.

The "Local Group"
The "Local Group" is the group of galaxies that includes our home galaxy, the Milky Way, among others. It comprises more than 54 galaxies, counting low surface brightness dwarf galaxies, divided into three main sub-groups. The most massive member of the group is M31, the Andromeda Galaxy, followed next by the Milky Way, with the third being M33, the Triangulum Galaxy. Both the Milky Way and Andromeda galaxies each have a system of satellite dwarf galaxies. The gravitational center of the Local Group is located between the Milky Way and the Andromeda Galaxy. Overall, the Local Group has a rough diameter of around 10 million light-years, and contains three spirals, two elliptical, nine irregulars, and forty dwarf galaxies.

The Milky Way's satellite system consists of the Large Magellanic Cloud, Small Magellanic Cloud, and about a dozen dwarf galaxies. The much larger Milky Way is cannibalizing several of its smaller dwarf galaxies such as the Sagittarius and Canis Major dwarfs, which are in the process of being stretched into remnant stellar steams.

Andromeda's satellite system consists of the brighter members M32, M110, NGC 147, NGC 185, along with another 10 dwarf galaxies. The Andromeda galaxy is also in the process of gobbling-up several of its own smaller satellite galaxies.

The third sub-group is the Triangulum Galaxy, M33, which is the only unbarred spiral galaxy in the Local Group. M33 currently does not have any known satellite system of smaller galaxies.

Finally, there are a number of small dwarf galaxies in the Local Group that are not bound to any of the three main galaxies.

While there's currently 54 individual galaxies identified as members of the Local Group, with the Milky Way blocking a large band of the sky, new discoveries of galaxies with extremely low surface brightness, obscured by our galaxies dust are still being discovered, so the group membership will rise as we develop better instruments.

Island Universes - The Nebula Controversy:
In addition to the glowing cloud band of light known as the Milky Way, Ancient people also noticed other smaller patches of unmoving 'little clouds' up in the night sky, one in the constellation of Andromeda, and another in the stars of the triangle. Having only their naked-eyes, most people could only speculate as to what these night-time clouds were.
With modern science, we now understand what the Milky Way and the Andromeda and Triangulum galaxies are. We can trace the beginnings of scientific observations of the galaxies back through history over the last four centuries.

Galileo:
After the invention of the telescope, Italian astronomer Galileo Galilei was the first to use one to observe the Milky Way. Galileo reported in his book "The Starry Messenger" published in 1610, that he was able to resolve the nebulous glowing band into a multitude of individual stars so densely packed that without a telescope they appeared as clouds to the naked-eye.

During this period, German astronomer Simon Marius used his own telescope in 1612 to observe the Andromeda nebula which he described as a dull, pale light, "like a candle shining thru horn", but was not able to resolve it into stars.

Immanuel Kant:

In 1755, German Enlightenment philosopher Immanuel Kant in a paper titled "*Universal Natural History and Theory of the Heavens*" theorized that the stars of the Milky Way, like the sun and planets of the solar system, formed from a large spinning disk of gas and was held together by gravitational forces. This was known as his "Nebular Hypothesis". The reason that the Milky Way galaxy looked like a band was due to our being inside the disk. Kant also thought that other distant "nebulae", which he called 'Island Universes', might be other separate galaxies located outside the Milky Way.

Charles Messier:

While both the Andromeda and Triangulum nebula were well known in Charles Messier's time, in 1764 he still went ahead and listed both small clouds as the 31st and 33rd entry on his list of objects to avoid while comet hunting. Messier used various small telescopes from his observatory in Paris to view both nebulas describing M31 as "Beautiful nebula, shaped like a spindle, center appears clear without any stars appearing, and the light gradually diminishes until extinguished". And for M33 – "of a whitish light of almost even density and contains no stars".

William Herschel:

In 1785, As the 'Kings Personal Astronomer' to England's King George III, as part of his work to study everything about the night sky, William Herschel made the first attempt to define the actual shape of the Milky Way from observation and measurement by carefully counting the number of stars in different regions of the sky. From his observations, William created a diagram of the Milky Way, placing the solar system at its center, and devised his own theory that our galaxy was disk-shaped.

Herschel also used his "20 foot" reflector to observe both the M31 and M33 nebulas, resolving some features of each and giving them their own designations, such as NGC206 which is a bright section of spiral arm in M31, and NGC604 which is a bright HII region within M33. Additionally, Williams sister, Caroline, discovered the second satellite galaxy to M31, NGC205, also known in modern times as M110. Herschel described M31 as "brightest part approaches resolvable nebulosity, faint reddish hue to its core", and M33 as "Milky nebulosity, and has a mottled aspect". Herschel believed that both nebulae we know today as galaxies were clusters of unresolved stars which he called "Island Nebulae" to distinguish them from Kant.

Lord Rosse:

Using his 72" reflector, in 1850, Anglo-Irish astronomer William Parsons, the 3rd Earl of Rosse reported that the disks of both M31 and M33, along with a number of other nebula, (particularly M51 which he nicknamed the "Whirlpool'), exhibited a spiral shape, and he began referring to these as 'spiral nebula' to distinguish them from the various other nebula. Parsons was also able to visually resolve some individual stars in the spiral nebula that he observed.

William Huggins:

English astronomer William Huggins, and later, along with his wife Margaret, pioneered the new field of astronomical spectroscopy during the latter half of the 19th century. In 1864, he was the first to successfully capture the spectrum of the planetary nebula NGC6543 in Draco. That planetary and other nebula that Huggins took displayed a pure emission spectra characteristic of a gas. But some 'nebula', such as M31, was different, and displayed the spectral characteristics of stars, rather than a gas.
From this discovery, astronomers determined that the Andromeda nebula and other similar spirals were stellar in nature.

Herber Curtis:

American astronomer Herber Curtis (1872 – 1942), born in Muskegon, Michigan and after attending the University of Michigan, earned his PHD in Astronomy in 1902 from the University of Virginia. Herber was known for his studies of solar eclipses, having participated in 11 eclipse expeditions. During his professional career, Curtis worked at Lick Observatory and served as president of the Astronomical Society of the Pacific. In 1918, he was the first astronomer to observe the jet coming out of the core of M87. He later was appointed in 1920 as director of the Allegheny Observatory in Pittsburgh. In 1930, Curtis accepted a position as director of the University of Michigan's astronomical observatories where he finished his career.

While at Lick Observatory in 1917, researching the spectrum of a prior nova, (1885A, S Andromedae), that appeared to be from within the Andromeda Nebula, Curtis uncovered 11 more examples of nova from within the nebula. Curtis determined all 12 of the 'Andromeda' nova had similar magnitudes that were at least 10 times fainter than similar nova from within the Milky Way. Taking into account the differences in nova magnitudes, Herber calculated that the Andromeda Nebula must be at least 490,000 light-years distance, well outside of the Milky Way galaxy. From this, Curtis became a leading proponent of Kant's 'Island Universe' hypothesis that spiral nebula were all external from the Milky Way.

Harlow Shapley:

American astronomer Harlow Shapley, (1885 - 1972), born in the small town of Nashville Missouri, studied astronomy at the University of Missouri starting in 1907, and later earned his PH.D from Princeton University. After graduating, Shapley was hired by George Hale to work at Mt Wilson Observatory with the 60" reflector, at the time, the largest telescope in the world.

Shapley served as director of the Harvard College Observatory from 1921–1952, and published a number of books on astronomy. One of the lesser known catalogs of open star clusters is the Harvard catalogue, of 21 open clusters and was compiled in 1930 by Shapely. His other major accomplishments include correctly estimating the size of the Milky-Way galaxy using RR Lyrae and Cepheid variable stars and their Period-Luminosity Relationship, and the sun's position within the Milky Way of being two-thirds toward the outer edge rather than in the center of the galaxy. Shapley was elected president of the American Association for the Advancement of Science in 1947. In 1953, he came up with the "Liquid Water Belt" habitable zone theory of planetary formation around stars.

During his early career, Shapley as an avid supporter of the Milky Way being the entire universe, with spiral nebula as just another type of nebulous gas object within the Milky Way. (his "Big Galaxy" model).

While initially criticizing and opposing astronomer Edwin Hubble's galaxy distance observations, after seeing and analyzing Hubble's data, Shapley realized that Hubble was fundamentally correct, and became a supporter of Hubble's theory. Shapley went on to make significant contributions in the research of galaxy distribution, mapping over 76,000 galaxies. He was one of the first astronomers to support the theory of galaxy superclusters.

The Great Debate - external galaxies vs. internal nebula:

At the turn of the 20th century, one of the major questions that professional astronomers were trying to answer was "how far away are the galaxies?" Does the Milky Way represent the extent of the entire known Universe, or was it just one of many galaxies in a much larger Universe?

In April of 1920, the question of what were spiral nebulae and the size of the universe came to a head. The National Academy of Sciences hosted a public lecture at the Smithsonian Museum between astronomers Curtis and Shapley who both presented opposing papers.

Shapley defended that spiral nebulae were all small objects located inside the Milky Way, and Curtis argued that the spiral nebulae are large 'island universes' that were located far outside the Milky Way.

Shapley's main line of argument was that as the overall luminosity of the Andromeda nova generally matched nova elsewhere in the Milky Way so that the nova observed in M31 must also be nearby. But his key supporting fact was based on observations from another astronomer (Adriaan Van Maanen) that rotation had been observed in M101, 'Pinwheel' Galaxy'. If the M101 spiral nebula was external to the Milky Way, this visible rotation would be a violation of the speed of light!

Curtis used his Andromeda nova magnitude research as his key evidence in arguing for galaxies being much further away external objects. He also used the measurable Doppler Redshift and the dark dust lanes visible in the spiral nebula arms that resembled the Milky Way's as additional proof that spiral nebulae were independent external galaxies.

The general consensus of the astronomical world after the debate was it was mostly a draw, with Shapley having the edge in being a stronger debater than Curtis. But, it soon turned-out that Curtis had the better observational facts, as Shapley's key supporting argument that rotation had been observed in M101 was based on Van Maanen's using an old optically defective blink-comparator machine and his observations were disproven. The answer to the question on spiral nebulae would have to wait until another astronomer could more accurately measure the distance to the galaxies.

<u>Edwin Hubble:</u>

<u>Childhood:</u>

American astronomer Edwin Hubble, (1889 – 1953), was born at his grandparents dairy farm home in Marshfield, Missouri on November 20th, 1889. The single story house was heated by only one fireplace, located in the living room, and lighted at night by kerosene lamps. Edwin's father, John, was a salesman in the insurance business, while his mother, Virginia, managed the Hubble household, which included raising seven other children in addition to Edwin. (Edwin was the third oldest).
Edwin's father enjoyed good success as a salesman, and was able to give Edwin and his siblings a normal childhood growing up in a middle-class family. In late 1899, the Hubble's moved first to Evanston, Illinois, before finally settling in nearby Wheaton.

As a young boy, Edwin learned to play the mandolin, and loved to read books, especially the stories of Jules Verne. For his eight birthday, Edwin's grandfather built a basic telescope for Edwin as a gift. Edwin stayed up all night looking thru the telescope. That is where Edwin developed a passion for astronomy, and loved to watch meteor showers from his yard. Two years later, in June of 1899, Edwin camped out all night with friends to view a total lunar eclipse. It was said by Edwin's friends that this eclipse may have been what sparked Edwin wanting to be an astronomer. By age twelve, Edwin was knowledgeable in astronomy, such that a letter that he wrote to his grandfather about the planet Mars was published in the local paper.

Edwin was a tall athletic boy, and eventually reached the height of 6' 3" in high school, where he excelled at the sport of track and field and broke the state record for the high jump. Hubble also excelled at his school studies in the sciences, algebra, and Latin, such that the school principle said of Hubble at his graduation – "*I have watched you for four years and never seen you study for ten minutes*". During the summer, Edwin would return to his grandparent's home in Marshfield where he worked on their dairy farm. Later, during Edwin's college years in Chicago, his father, John, moved the family to Shelbyville Kentucky, near Louisville, for a job promotion.

Education:

Upon graduating from high school at the age of 16 in 1906, Edwin received a scholarship to the University of Chicago where he studied mathematics, astronomy, and natural sciences, and spent a year working as a lab assistant for the university's famous physicist Robert Millikan.

Edwin also continued in sports, helping the men's basketball team win the Big Ten basketball championship in 1910.

Edwin graduated from the University of Chicago in 1910 with a degree in mathematics.

He then spent the next three years over in England as one of the first Rhodes Scholars at Queens College, in Oxford England where he studied law and graduated from in 1913 with a master's degree. During the winter and summer breaks from class, Edwin would take long trips across the channel to the European continent where he traveled throughout Spain and Germany.

While at Oxford, Edwin became immersed in the traditions of the English gentleman society in dress and manors, which he adopted and continued with those mannerisms once he was back in America.

Edwin also took up the English sport of rowing, though he never competed, and also participated on Oxfords track team until he twisted an ankle in the high jump. Hubble also helped form an American baseball team at Oxford who played against other local teams. And Edwin learned how to smoke a pipe while at Oxford, which later became his signature look at Mt Wilson.

The summer of 1913, while Edwin was still staying in England, his father John passed away, and Edwin returned home to Kentucky to care for his mother and younger siblings.

After spending a year teaching high-school physics and coaching the basketball team at a school across the river in New Albany, Indiana to its first undefeated season, Hubble re-enrolled back at the University of Chicago to study for a doctorate in astronomy. For Hubble, astronomy was his calling.

Hubble obtained a small scholarship, from Professor Edwin Frost the Director of the Yerkes Observatory at Williams Bay Wisconsin, allowing Hubble to use the observatory's 40" refractor, the largest in the world, in addition to a 24" reflector. While as a student at the observatory, Edwin had the opportunity to attend a conference of the American Astronomical Society where he was able to meet a number of the top astronomers from around the country, including V.M. Slipher from Lowell Observatory who was working on obtaining spectrographs and radial velocities of spiral nebula. This presentation inspired Edwin to devote himself to studying these spiral nebulas. After a rushed thesis, Hubble graduated with his PhD in astronomy in 1917. (We'll talk more about Hubble's work at Yerkes further below).

And, while still a student at Yerkes, Hubble met George Hale, the director of Mt Wilson Observatory who offered Hubble a job once he graduated. The day after Edwin passed his PhD exams, he wrote to Hale on the job offer: "*Regret cannot accept your invitation. I am off to the war*".

Service in WWI:

After graduating from the University of Chicago in 1917, the 28 year-old Hubble enlisted with the US Army to fight in WWI. The United States had entered the war on the side of England that spring, and Hubble with his ties to Oxford felt obligated to serve. Hubble quickly rose thru the ranks, promoted to a Captain and put in charge of training new recruits at an army camp in Rockford, Illinois. One of his duties was to train the recruits in how to navigate cross-country at night by using the stars. Hubble also became known as an expert sharpshooter on the riffle range, and it was said that crowds would gather to watch him target practice. Within a year, he was made a Major and placed in charge of the 2nd Battalion of the 343rd infantry of the American Expeditionary Forces. In September of 1918, Hubble and his troops shipped off overseas to England, and then on to France. While at the expeditionary camp in England, the Spanish Flu pandemic swept thru the ranks, taking several of Hubble's friends, including his favorite sergeant. Edwin appears to have avoided catching the illness.

But before Hubble could make it over to the battlefront near Bordeaux, the war ended. In a letter back to Edwin Frost at Yerkes, Hubble wrote sadly that "*I barely got under fire and altogether I am disappointed in the matter of war*". Hubble was then transferred back to Cambridge, England where he was assigned to work as a judge in court-martials and war reparations claims. During this assignment, Hubble attended meetings of the Royal Astronomical Society in London, and met there visiting astronomers from Mt Wilson Observatory that he would soon be working with.
The now 30 year-old Hubble was finally discharged from military service in the summer of 1919, and returned to the US to take up the position offered by George Hale at Mt Wilson.

Family Life:

During his high school and college years, Edwin had very few romantic attachments, except for during the summer vacation before his junior year of college at the University of Chicago, where he fell in love with a local Marshfield girl named Elizabeth. But she eventually broke off the relationship as she realized that she could 'never hope to rival Edwin's love of Mars and the stars'.
While at Oxford, and later during his years of graduate work at Yerkes, and then in the military, Edwin didn't have the time to spare. But, once he was settled in at Mt Wilson, the pace of Hubble's live slowed.

In late 1923, Edwin Hubble began dating Grace (Burke) Leib from Pasadena that he had met a few years before during a visitor's tour of the Mt Wilson Observatory. Edwin had also previously spent time with Grace during an expedition for a total solar eclipse that just grazed the southwestern corner of California in September of 1923. (She was part of a group from Lick Observatory with her uncle astronomer Fred Wright). Grace came from a wealthy, socially connected family, was a graduate from Stanford University, and found Hubble's work interesting.
Grace was very knowledgeable in art, music, and architecture. Like Edwin, she was also athletic and active in sports, and the pair enjoyed going on long hikes and other outdoor activities in the California Mountains. In February of 1924, the couple married.

The Hubble's purchased a two-story stone house in a quiet neighborhood of San Marino, about a three mile commute from the observatory office in Pasadena. The Spanish-style medium-size house wasn't considered to be very spacious, but the Hubble's found it fine for entertaining guests. It was said by their visitors that the Hubble's were a happy couple, devoted to each other.

When Edwin was not tied-up with an observing run on Mt Wilson, usually for about one week a month, he spent time either at the Pasadena office or working from his home study. This gave him enough free time that the couple was active in southern California social events, and became friends with a number of Hollywood stars, wealthy philanthropist, and California intellectuals including Frank Capra, Clark Gable, Charlie Chaplin, the Marx brothers, Howard Hughes, Randolph Hearst, and Walt Disney.
They also maintained friendships from Edwin's days over in Europe, with a number of famous British astronomers, novelist and playwrights, including Arthur Eddington, Fred Hoyle, H.G. Wells, and Aldous Huxley who visited the Hubble's in Pasadena. During Albert Einstein's visit to Mt Wilson, the famous physicist and his wife spent time at the Hubble's home, with Grace chauffeuring Einstein around Pasadena to various events. Einstein is quoted as saying to Grace – "*Your Husbands work is beautiful'*.

Edwin also found time to participle in local civic activities, including being on the board of trustees of the Huntington Library and Art Gallery of San Marino, and to be elected vice-president of the American Astronomical Society.

A few years after their marriage, Grace became pregnant. While Edwin was away on Mt Wilson for an observing run, Grace had a miscarriage and lost the baby. Afterwards, Grace and Edwin never had any additional children, being content with their lives together as a childless couple.

Service in WWII:
With the United States entering World War II after the bombing of Pearl Harbor, early in 1942, Edwin Hubble was asked to head-up the ballistics department at the Army's Aberdeen Proving Grounds in Maryland. (Edwin at first had tried to re-enlist in the army in December 1941, but was not accepted). After the war, Hubble mentioned in a talk that his name was at the top of the list of scientist the army was interested in recruiting for Aberdeen, as it was the army's view that Hubble being an officer in the last war would better appreciate the gunnery/ballistics problems as anyone else.

The Hubble's closed up their house in Pasadena and moved to Maryland, along the Chesapeake Bay where Grace ran the Hubble household until after the war ended and they were able to move back in 1946 to California. At first the Hubble's lived out of a local Aberdeen hotel, but eventually Edwin was able to arrange for them to live in a small cottage on a nearby island that was leased by the military for as additional testing grounds. That might have been a bad choice as the cottage's windows were constantly being cracked by test explosions from the other end of the island, and one morning, a particularly large detonation blew the house door off its hinges. From the Hubble's house in the later days of the war, Grace could watch troops practicing amphibious landing maneuvers at the local beach.

At the proving grounds, Hubble was put in charge and responsible for the ballistics testing of new artillery shells and bombs, and developing and calculating firing and bombing tables for each type of shell, bomb, and rocket. Part of the work on the firing range involved high-speed photography of projectiles in flight and then careful measuring of the photographic plates. Hubble accomplished this by utilizing astronomical photographic techniques that he was very experienced with.
Hubble's department eventually grew to 280 people, both civilian scientist and military personnel, and included two of the four existing early IBM mainframe computers.

Hubble also personally troubleshooted an issue with a new anti-tank weapon called the "Bazooka". The gun tended to malfunction and injure the solder operating it. Edwin used one repeatedly on the firing range, finally determining what was causing the issue which led to a design change to correct it. Hubble's unit was also responsible for the design and development of accurate bombsights used by American bombers in the war.

The war efforts by Edwin Hubble had not gone unnoticed by the enemies of the United States. According to Grace, a military source told her afterwards that a German U-boat had been intercepted and captured in Chesapeake Bay that contained written personal orders from Hitler to blow-up the Aberdeen Proving Grounds, along with "Dr Hubble".

While Hubble was away, the Mt Wilson observatory was closed to the public, observational work at the observatory slowed from lack of employees, most of who had left for service in the war,
Once the war ended in May of 1945, Edwin wrapped up his tenure at Aberdeen, turning his department back over to a military lead, and he and Grace closed up their Maryland house. By December of 1945, Edwin was back to work at Mt Wilson Observatory. In 1946, Hubble was awarded the Medal of Merit by President Harry Truman for his service at Aberdeen.

Life as an Astronomer:

Yerkes Observatory:
While studying astronomy at the University of Chicago, at the Yerkes Observatory, Hubble worked under the direction of observatory director Edwin Frost and E.E. Barnard using the observatory's 24" reflector and 40" refractor to photograph nebula. Hubble based his PhD thesis "*Photographic Investigations of Faint Nebulae*" on this work. Hubble made his very first discovery from this project, using the 24" reflector, that the brightness of reflection nebula NGC2261 in Monoceros was variable.

This nebula has since become known as “Hubble’s Variable Nebula’. The comet shaped nebula is illuminated by the nearby bright variable star R Monocerotis. And it is thought that the nebula’s variability is caused by shadows cast by dense dust clouds that lay between the star and nebula.

As part of his thesis work, Hubble also studied nebula located far from the glowing band of the Milky Way, using the 24” reflector to photograph seven regions and discovered 512 new small nebulas. Hubble measured their individual positions, along with describing their shape, size, and brightness. In several of the regions Hubble studied, a number of small spiral nebulas grouped close together, prompting Hubble to speculate in his paper: “*Suppose them to be extra-sidereal and perhaps we see clusters of galaxies; suppose them within our system, their nature becomes a mystery*”. Hubble was beginning to conclude that spiral nebula were distant stellar systems at great distances.
Hubble’s work at Yerkes was interrupted by the United States entering WWI.

Mt Wilson Observatory:
Once back from his WWI military service, Hubble went to work for George Hale in Pasadena, CA. at the Mt Wilson Observatory in 1919 and was one of the first groups of astronomers to utilize the new 100” Hooker reflector in studying spiral nebula. Hubble was interested in resuming his research started at Yerkes in determining whether spiral nebula were just distant unresolvable gas and stars within our own galaxy, or if they were external systems to the Milky Way. Edwin would observe these nebula with the 100” every clear night that he could, and then use the smaller 60” reflector when the 100” was taken by other researchers. As part of this work, Hubble also began to develop a classification system for the nebula he was studying.

Hubble became friends with Mt Wilson night assistant and observer Milton Humason, and the two collaborated on a number of projects together. Humason once described Hubble’s approach to his research work: “*He was sure of himself – of what he wanted to do, and how to do it*”.
Hubble also became quickly known for his knowledge of the night sky and could describe the shape and location of hundreds of deep sky objects from memory.

While at Mt Wilson, Hubble developed a bit of a rivalry with astronomer Harlow Shapley, who also worked at that time at Mt Wilson studying Cepheid variables to determine whether they could be used as distance indicators within the Milky Way. Both men were interested in solving the mystery of spiral nebulae, with Shapley championing their being internal to the Milky Way, (his “Big Galaxy” as the universe model), while Hubble was in the camp of their being external objects. Hubble, being aware of the distance relationship of Cepheid’s hoped to be able to discover these stars within the Andromeda and Triangulum nebula and searched for them using the 100” Hooker Reflector.
We’ll talk more about how the rivalry ended in another section below.

Hubble also continued to make occasional observations of his variable nebula NGC2261 in Monoceros, and while these are listed in the observatory logbooks, Hubble but never formally published any additional research results on the nebula. Other than a four year period during WWII, when Edwin took a position with the army in Maryland to help with the WWII war effort, Hubble remained at Mount Wilson for the remainder of his career.

Palomar Observatory:
While still based out of Mt Wilson, Hubble became one of the first astronomers to use the completed 200” Hale reflector at Mt Palomar Observatory. As part of the grand opening on January 26th, 1949 of the new 200” Hale Reflector Telescope on Mt Palomar, Edwin Hubble was chosen to lead the first night of observing. Hubble selected the reflection nebula NGC 2261 “Hubble’s Variable Nebula” as the first object to be imaged as the 200” telescope's first light. After a 15 minute exposure, the first astronomical photograph taken with the 200” was done. The plate was labeled: “PH-1-H” (Palomar, Hale telescope, negative No.1, observer Hubble). Hubble then took four additional images, including M87.

Afterwards, Hubble submitted a paper to "Scientific American" on the first five historic photographs from Palomar.

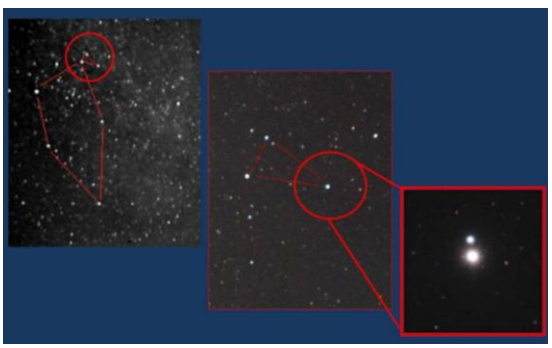
In addition to the 200" reflector, also in early 1949, the new 48" Schmidt telescope/camera was completed, and Hubble, along with his graduate associate observers Allan Sandage and Halton Arp, used the telescope's wide-field to image and study faint galaxy groups.

Hubble had only completed four observing runs with the new telescopes when health issues got in the way. After recovering from his illness in late 1950, Hubble only made it back to Palomar twice more.
In one of those sessions, Edwin successfully imaged a number of Cepheid's and several bright novas in both spiral galaxies M81 and M101. Hubble continued working with Milton Humason, and his new assistant Allan Sandage on further refining his redshift theory. On the evening of September 3rd, 1953, Edwin Hubble made his last observation using the Palomar 200" of the pair of interacting galaxies NGC520 (Arp157) in Pisces.

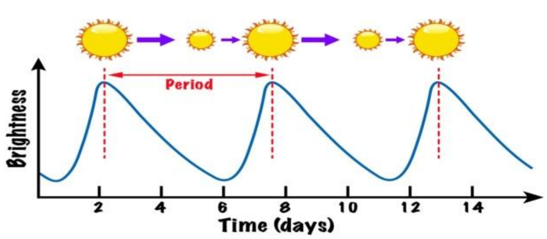
<u>Hubble's Discoveries:</u>

<u>What are Cepheid Variables:</u>

Cepheid variables are stars that vary their brightness by a specific range and timeframe.
(Generally 1 to 2 magnitudes with a typical period of 1 to 5 days).
The very first star of this type to be identified was +4 mag Delta Cephei in the constellation of Cepheus.
Delta Cephei has a period of 5.37 days and varies in magnification from a +3.5 to a +4.4 with a slow decline to minimum, then a rapid rise to maximum. At 890 light-years distant, Delta is the second nearest Cepheid variable to the Sun. (the closest Cepheid to us is the star Polaris at 433 light-years).



The reason Cepheid stars vary in brightness is due to instabilities in their nuclear fusion core.
As stars similar in size to our own Sun burn thru all of their hydrogen gas and contract in size and begin to burn ionized helium, the initial heat energy doubly ionizes the helium gas, which causes it to absorb light energy, making the star dim. But as the light energy is absorbed by helium, the star becomes hotter causing its outer layers to expand outwards, which then cools the star causing the helium to drop back down to only a single ionized state, making the star more light transparent, causing it to brighten.
As the star cools, it begins to once again contract, causing helium to once again doubly ionize and diming the star. These pulsations continue to repeat back and forth until eventually the star burns thru all its helium gas and contacts to become a white dwarf star.



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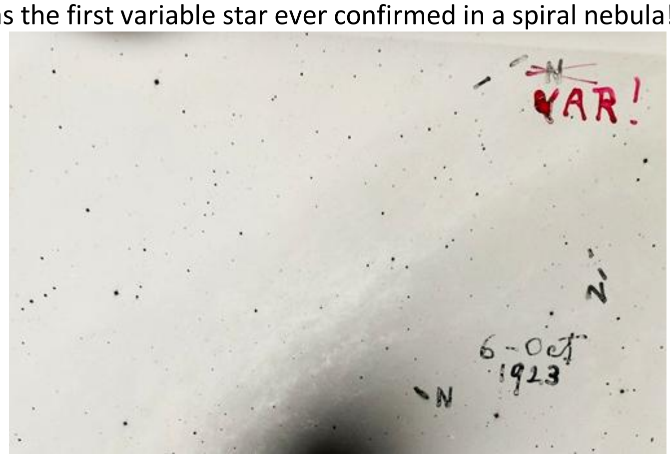
This relationship between the star's luminosity and period of change allows astronomers to determine what the stars true brightness is, and in turn, lets them determine the star's distance.
This characteristic was discovered in 1908 by Henrietta Leavitt, working at the Harvard Observatory. This fundamental characteristic of cosmology is known today as "Leavitt's Law".
Using this relationship, astronomers were able to accurately calculate distances to Cepheid's in our Milky-Way galaxy using the inverse square law of light (a luminous body appears to dim by its distance squared. An analogy of the inverse square law would be like turning down a volume knob on a stereo system, the loudness intensity is turned down, but without affecting the pitch of the music).

<u>Distance to M31 using Cepheid variables:</u>
In the early 1920's, American astronomer Edwin Hubble, was one of the first astronomers to utilize the new 100" Hooker reflector telescope at Mt Wilson Observatory in California.

On the night of October 5th, 1923, Hubble was making a photographic observation of the Andromeda Nebula, also known as M31, using the 100" telescope. Hubble was studying the spiral nebula looking for changes, doing this by taking photographs of the nebula and comparing that evening's image with a previous nights photo plates. On one 45 minute exposure plate of a region near the core of the Andromeda Nebula, Hubble discovered a faint star that was brighter than its image on the prior plate. Hubble at first thought the star was a new nova, as he had already found several that night within the nebula. But, after continuing observations over several nights, and reviewing additional past plates going back to 1909, Hubble realized that this particular star which had started to dim, had now begun to re-brighten, which was not the known behavior of a nova. The star was pulsating in brightness, which meant it was a variable star! Hubble relabeled the star as "V1" on the discovery photographic plate. This was the first variable star ever confirmed in a spiral nebula!



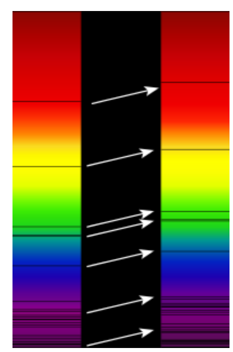
Once Hubble was able to plot the stars light-curve and identify the variable star as a Cepheid, he was able to calculate the star's distance of 1 million light-years, finding that the star was many times further away than what was considered to be the boundaries of the Milky Way, making both the star and the Andromeda Nebula extragalactic. The universe has suddenly expanded.

Hubble went on to discover several dozen other Cepheid variables within the Andromeda spiral nebula, along with 35 variables in the Triangulum spiral - M33 and another 11 in "Barnard's Galaxy" - NGC6822. Using Harlow Shapley's own Cepheid based calibrated Milky Way distance calculations; Hubble was able to determine that all of these other spiral nebula variable star distances, like that of V1, to be much greater than Shapley's own accepted "Big Galaxy" size of the Milky Way of 300,000 light-years. (Current, modern calculations have now revised the size of the Milky Way to about 100,000 light-years in size, and the distance to the Andromeda galaxy to about 2.5 million light-years).
Prior to his announcement being published in 1925, Hubble sent a letter describing the discovery to his old rival Harlow Shapley, who had since become the director of the Harvard Observatory.
Upon reading the letter, Shapley said to Harvard astronomer Cecilia Payne, "Here is the letter that destroyed my universe".

Hubble's observations of additional Cepheid's in the Andromeda and Triangulum nebulas proved conclusively that they were too distant to be located inside of the Milky Way and that spiral nebula were in fact external to the Milky Way. The first accurate distances to galaxies had finally been determined by Edwin Hubble using Cepheid variables.
Hubble had finally answered the old question of external galaxies vs. internal nebula and settled the Great Debate in favor of Immanuel Kant's 1755 'island universes'!

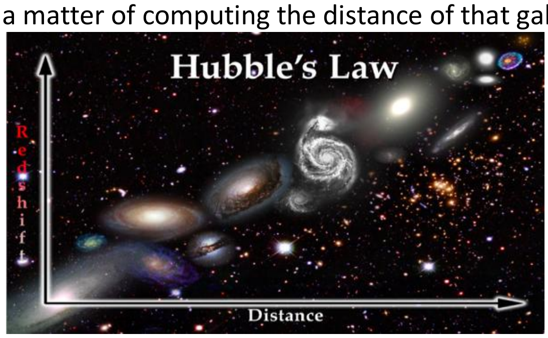
<u>Red shift and the expanding universe – Hubble's Law:</u>
With Hubble's discovery of Cepheid's in the nearby galaxies, such as M31 the Andromeda Galaxy, this allowed astronomers to extend accurate distances throughout the Local Group of galaxies.
But in galaxies further away, Cepheid's were not identifiable, so astronomers turned to another celestial yardstick, supernovas. Extra-galactic supernovas are similar to Cepheid's in that their intrinsic brightness could be compared against these stellar explosions that have occurred within our own galaxy. This allowed us to measure distances out into our nearby supercluster of galaxies, such as the Virgo and Coma Clusters.

To go even further out into the universe, Hubble realized that there was a relationship between a galaxy's determined distance, its faintness, and its spectroscopic radical velocity.
Working with astronomers Vesto Slipher from Lowell Observatory and Milton Humason, also at Mt Wilson, Hubble discovered in 1929 that every galaxy has a measurable redshift that could be utilized for calculating its distance. Every star gives off a spectrum of bright and dark emission and absorption lines, when viewed thru a spectrograph prism, made up of the various atomic elements within the star. Hydrogen and helium being the primary elements, along with oxygen, carbon, neon and nitrogen.
Depending on the direction that the star is moving, either toward us or away from us, the star's spectrum exhibits a light wave Doppler shift, similar to the sound wave Doppler effect, such as from a passing train.



If the object is approaching us, it is blueshifted, if it is receding from us, the spectrum is redshifted. The greater the spectral lines of an object are shifted towards the red end of the spectrum, the greater its distance is from us.
The symbol for redshift, expressed as a fractional displacement of wavelength is 'z'.
An object with z=0.0 or smaller has a low redshift and is nearby.
A redshift greater than z=0.0 is a high redshift and represents an object very far away. The bigger the number, the father away it is.

A central part of today's 'Big Bang' cosmology this key tenet is named Hubble's Law.
Basically stated, Hubble's Law is that the larger an objects redshift, the farther away it is and the faster it is receding from us. All astronomers had to do was measure the redshift of a galaxy and then it was just a matter of computing the distance of that galaxy. It is a critical piece of the expanding universe theory.



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Using Slipher's pioneering spectrographic work, Humason was able to take a multi night 45 hour long spectrum of elliptical galaxy NGC7619 in Pegasus resulting in a redshift of z=0.01234 and a receding radical velocity of 2400 miles per second. Based on the distance-velocity relationship law that Hubble has devised, he predicted that it would be around 24 million light-years distant, which Hubble then confirmed as correct after calculating its distance using Cepheid variables that he observed.

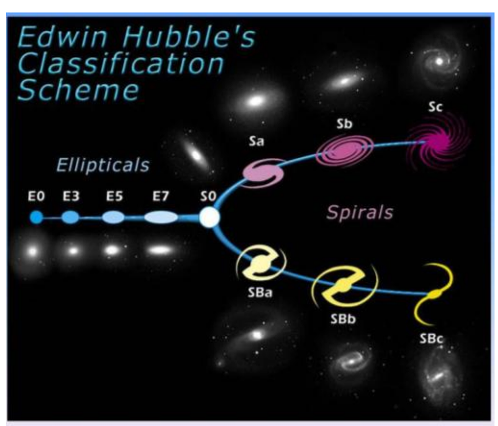
The Big Bang- the Hubble Constant:
Hubble's discovery of the velocity-distance law, is considered to be the first observational evidence for the expansion of the universe, and most often cited in support of the Big Bang model. Hubble's findings established that galaxies were not fixed in their positions, but most were moving outwards, away from the Milky Way at a rapid rate.

Part of the equation that describes Hubble's law is the Hubble Constant, which can be interpreted as the relative rate of the expansion of the universe. The current value is about 70 (69.8) (km/s)/Mpc. (a mega parsec (Mpc) is equal to one million parsecs, or about 3,260,000 light years).
A small value, fewer than 100, means that the universe is expanding at a slow rate and is older.
A higher Hubble Constant value, over 400 – 500, means that the universe is expanding rapidly and was much younger. The current value of 70 gives us a universe that is about 14 billion years old.

The discovery of the Hubble Constant and along with it the expansion of the universe, led Albert Einstein to abandon his attempts to integrate a cosmological constant into his field equations of general relativity that would have made the universe static and not expanding. Einstein later referred to his cosmological constant as his biggest mistake. In 1931, Einstein made a special trip to Mount Wilson Observatory just to thank Edwin Hubble for his observational discovery that became the basis for modern cosmology and the Big Bang.

In Hubble's book "Realm of the Nebula", published in 1936, while commenting on his velocity law and the vast distances to the galaxies and age of the universe, Hubble states "*the history of astronomy is a history of receding horizons. ,,,, we know our immediate neighborhood rather intimately. Eventually, we reach the dim boundary – the utmost limits of our telescopes. There, we measure shadows, and we search among ghostly errors of measurement for landmarks that are scarcely more substantial*".

Hubble Sequence - Galaxy Classification – Tuning Fork:
As mentioned earlier, galaxies come in several types, and a wide variety of shapes and appearances.
In 1926, astronomer Edwin Hubble devised a galaxy classification diagram based on their visual appearance – elliptical, lenticular, spiral, or irregular. He organized these shapes into a sequence of morphological classifications that he invented to help astronomers determine the type of galaxy that they were studying. This classification sequence system is commonly called the: Hubble Tuning Fork diagram. Hubble divided the galaxies into three simple, broad classes: spirals, elliptical, and lenticulars, along with a fourth class of irregulars.



https://en.wikipedia.org/wiki/Hubble_sequence

All the main types have sub-category classifications, and we still use a modified version of this today. Elliptical 'E' galaxies are smooth, nearly featureless objects running from near-circular to an ellipsoidal shape. Lenticular "S0" galaxies have a bright central core surrounded by an extended, flattened disk with no visible spiral arm structure. Spiral "S" galaxies have a flattened disk with a central bulge, and multiple spiral arm structures. Roughly half of all spirals also have a bar-like structure, extending from the central bulge. These barred spirals are identified with the symbol "SB". The last type is Irregular "Irr" galaxies that do not have a distinct shape that fits into the first three categories. A lowercase 'd' appended in front of 'Irr' indicates a dwarf galaxy.

Miscellaneous:
The first astronomer to identify our local grouping of galaxies as the "Local Group" was Edwin Hubble. Hubble gave these galaxies this name in his 1936 book, *The Realm of Nebulae*, where he referred to the initial 12 galactic members as "a typical small group of nebulae".

Also, in early 1942, right before leaving to serve at the Aberdeen Proving grounds during WWII, Hubble solved the question of which direction did a galaxies spiral arms rotate. Did the arms trail the rotation of a galaxies' core? Did the arms lead the rotation? Or was it both? From a series of spiral galaxy images taken that February, Hubble determined that the arms trailed behind the core's rotation.

Amateur Observations of Hubble's Galaxies:
How to observe galaxies:
So, where can you find the galaxies that Hubble studied and how do you observe them? Galaxies in general can be found opposite the glowing band of light that we call the "Milky-Way", our home galaxy. Usually, when we want to observe bright or dark nebula and star clusters, the Milky-Way is exactly where we want to look, but for galaxies, this is the "Zone of Avoidance', as all the gas and dust nebula and stars of the spiral arms of our galaxy tend to obscure all the faint extra-galactic 'nebula' that we want to observe. Generally, galaxies come in all shapes, sizes, and brightness, and many are very interesting and worth the effort to find, regardless of the equipment that you use. With the exception of M31 & M33 and a few other brighter galaxies, most are small faint, and will require large aperture telescopes or imaging setups, along with a dark-sky location such as Cherry Springs.

There are a number of good 'galaxy' related observing guides available to the amateur astronomer. One of my favorites is "*The Night Sky Observers Guide – Volumes 1 & 2.* These handbooks were written by George Kepple and Glen Sanner, each chapter covering a specific constellation, along with finder charts, sketches, images, and visual descriptions of various deep sky objects, including various galaxies.

Amateur astronomer Alvin Huey has a great observing book on his website www.faintfuzzies.com
Called "Observing Local Group Members" devoted specifically to the Local Group of galaxies.
It contains finder charts, and DSS images for Local Group members.

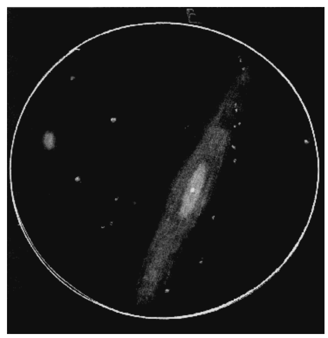
Ingredients to successfully observe Galaxies:
While most galaxies can be challenging, this is what makes them interesting to find and attempt to visually see or capture an image of. Observing them visually requires maintaining dark-adaptation, good starcharts, and slow sweeping with a wide-field low-power eyepiece and a fast low focal-length telescope. An 80mm F6 or shorter refractor piggybacked on a 10" or greater telescope would work very well. The 80mm acts as a low-power RFT giving you a wide-field in which to find the galaxy and the larger telescope it is attached to allows use of higher magnifications, depending on the object. You'll need all your visual observing skills to find and bring out these subtle objects.

Many galaxies are very faint, and depending on what size telescope you are using, may not be visible. But like any deep-sky object, half the fun is just successfully finding it and knowing what it is that you are observing.

For the Imagers, galaxies can also be challenging due to their faintest, in that even with an accurate GOTO mount, it may not position the telescope squarely on the object to where it's framed the way you want it. Having a photographic atlas or picture of the galaxy will help you in both locating and identifying the object and in framing your image. I've found that using short-exposure video-astronomy cameras works great in positioning and identifying galaxies.

<u>Andromeda and V1:</u>

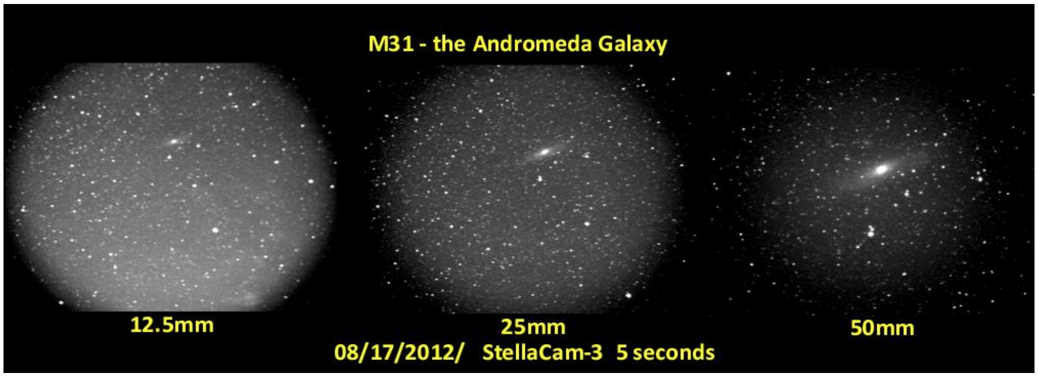
The Andromeda Galaxy, is the largest member of the Local Group, is also a barred-spiral galaxy with the bar oriented along the length of the galaxy, and including at least two tightly-wound spiral arms has a diameter of around 220,000 light-years with about one trillion stars. Andromeda's galactic core contains a radio source called 2C 56, with a supermassive black hole of 3 to 5 million solar masses, and a possible double nucleus. The Andromeda galaxy is the nearest major galaxy to the Milky Way at about 2.5 million light-years distant, and is moving at around 110 km per second in the direction of the Milky Way, which it will collide with in about 4.5 billion years.



The compact 8.7 magnitude elliptical satellite galaxy **M32** (with a diameter of about 6500 light-years) is thought to have once been a small spiral galaxy that had a close interaction with M31 around a billion years ago, which stripped away most of M32's arms and disk, leaving only the core which then underwent renewed star formation from infalling gas and dust, and partly regenerated the small galaxy. M32 contains a massive central black hole of between 1.5 to 5 million solar masses and is a faint radio and x-ray source.

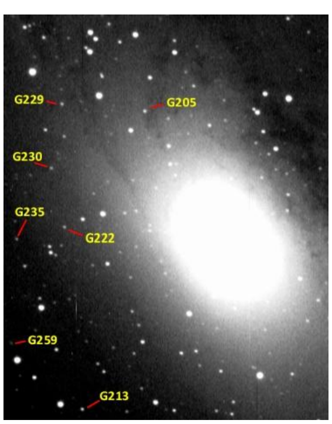
Andromeda's second satellite galaxy, NGC205 (or **M110**) at 8.5 magnitude, is a dwarf elliptical, (about 12,000 light-years across), and also shows signs of recently interacting with M31 from a stream of stars and gas stretching between the two. It is classified as being a 'peculiar' galaxy in that unlike most ellipticals, M110 has dust clouds and younger stars near its core. Astronomers have not observed any signs of M110 having a black hole in its galactic center.

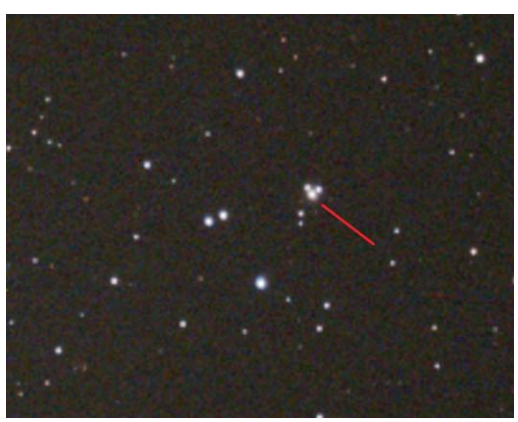
At a magnitude of 3.4, the Andromeda Galaxy is visible to the unaided-eye as a bright patch even from suburban areas on moonless nights. On fall nights, it is well-placed almost directly overhead for observing with binoculars or small to medium size telescopes which under good seeing conditions can reveal the galaxy's extended disk and dust lanes, along with its brightest globular clusters.



Also visible is the large starcloud **NGC206**, along with two small satellite galaxies M32 and NGC205 (M110) and several of their globular clusters. Larger size telescopes of 18" or greater will allow the observer to see additional internal structures within the spiral arms including clusters of OB associations and HII star forming regions. Andromeda's galactic plane is highly inclined to our point-of-view, around 77%, giving it a near edge-on look, making it difficult to observe its spiral arms.

<u>Observing Andromeda Globular Clusters:</u>
The Andromeda galaxy has over 450 globular clusters, a number of which are observable by amateur astronomers. These include the most massive cluster of the entire Local Group, named **Mayall-II**, which may actually be the remnant core of a small galaxy that was cannibalized by Andromeda.

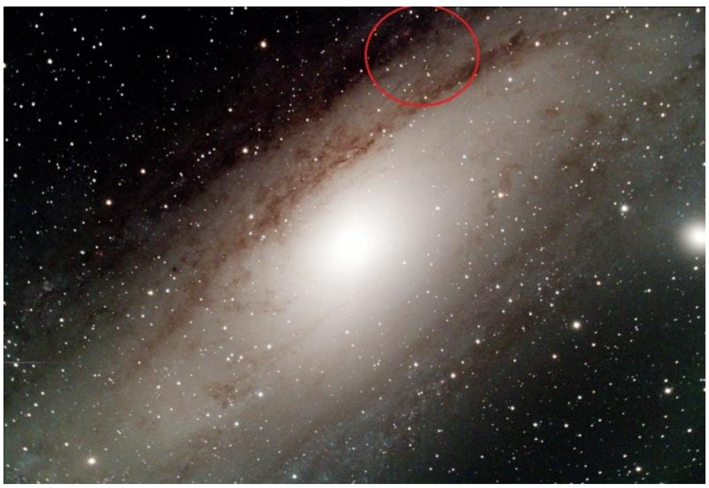


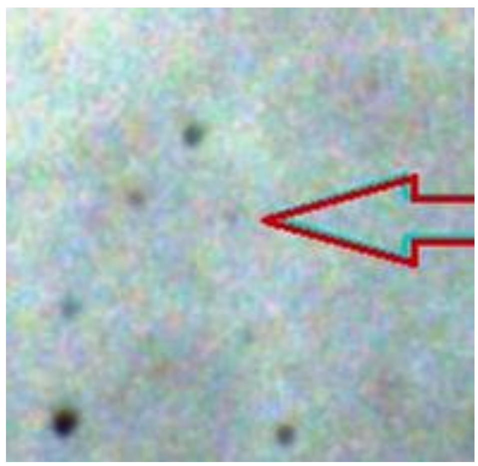


Observing V1:
Located near the busy core of the galaxy is the dim Cepheid variable whose discovery by Hubble in 1923 led to the confirmation that the Andromeda Nebula was actually an external galaxy to the Milky Way, leading to the expanding universe of the Big Bang.

Can this star be observed visually or imaged by amateur astronomers? **Yes!**
In fact, back in 2010, over a six month period, a number of amateurs from the AAVSO, as part of a project coordinating with NASA and the Hubble Space Telescope, actually observed the star for enough observations (214) to plot a light-curve of 31.39 days for the variable.
Other amateur astronomers have reported successfully visually observing and imaging VI in various magazines and the CloudyNights forum.

With the variable star, (V1), having a magnitude range of +18.5 to +19.8, to observe it visually, you will need a very large reflector – in the 30" mirror size category and use a high magnification eyepiece, along with attempting the observation from a very dark sky location. You will also need a detailed finder chart, such as one from the AAVSO, or a photo of the star's location. These can be found online. The best time to attempt the observations is during late fall, when M31 is high overhead near the zenith, and on nights of excellent transparency. Start by centering on Andromeda's core, then moving to its northeast side, opposite M32. Look for a small faint arrow-head asterism of stars that point away from the core.
There is a much smaller equilateral triangle just off the tip of the arrow with V1 being one of those stars.



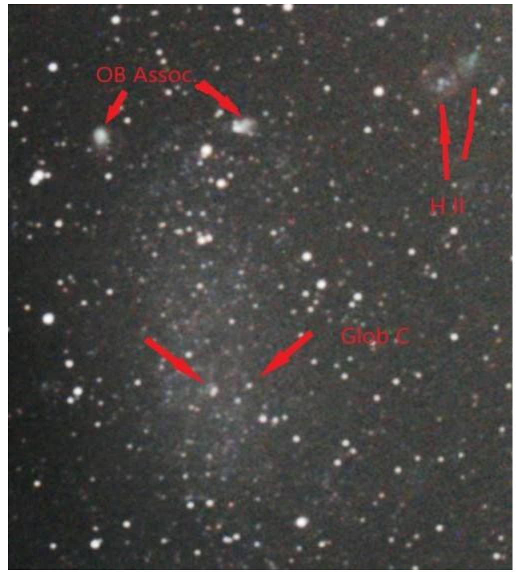


M33:
The Triangulum Galaxy, while it is the third largest member of the Local Group, is only about one-tenth the size of the Milky Way, but it is the only classic shaped spiral galaxy of the Local Group. It has two bright, loosely wound spiral arms, along with multiple connecting spurs, giving the galaxy an overall diameter of around 60,000 light-years with about 40 billion stars. Triangulum's galactic core does not contain either a radio source or a black hole, just a large HII nucleus. The galaxy has over 54 globular clusters identified, along with a number of OB associations. Triangulum does not have any satellite companions, though the Pisces Dwarf galaxy could possibly be in a very distant orbit around M33. The Triangulum Galaxy is about 2.7 million light-years distant, and is moving at around 190 km per second in the direction of the Andromeda galaxy. M33 may be gravitationally bound to the larger Andromeda galaxy. Depending on modeling, the Milky Way may actually collide with M33 just prior to colliding with M31. A three galaxy interstellar pileup!!!

At magnitude of 5.7, the Triangulum Galaxy (also called the Pinwheel), may be visible to the naked-eye from a dark-sky country location on moonless nights. M33's galactic plane has an inclination of about 54° to us, allowing its spiral arms to be viewed without significant obstruction by gas and dust. There is no central bulge visible at the nucleus. On fall nights, like M31,it is well-placed overhead for observing with small to medium size telescopes which under good seeing conditions can reveal the galaxy's extended spiral arms, dust lanes, bright globular clusters, and HII star forming regions such as NGC588, 592, 595, IC132, IC133, with the largest and brightest being **NGC604**. With a diameter of around 1500 light-years, NGC604 is one of the largest and brightest known HII emission nebula in all of the galaxies of the Local Group. It, along with three other HII regions is located in the northern spiral arm, to the northeast of the central core. The southern arm of M33 has been a major source of extra-galactic supernova, with at least 100 supernova remnants having been identified.

NGC6822:

NGC6822, known as "Barnard's Galaxy" is a +8.5 magnitude Irregular barred-dwarf galaxy about 1.5 million light-years distant from the Milky Way, and is located in the constellation of Sagittarius and heavily obscured by the Milky Way. It has a diameter of about 7,000 light-years, and shows active star formation. After the Magellanic Clouds and the Sagittarius Dwarf galaxies, NGC6822 is the fourth closet galaxy to the Milky Way. Visibly, NGC6822 is highly inclined to our view point, with several HII star forming regions and large OB associations being observable in medium to large size telescopes.

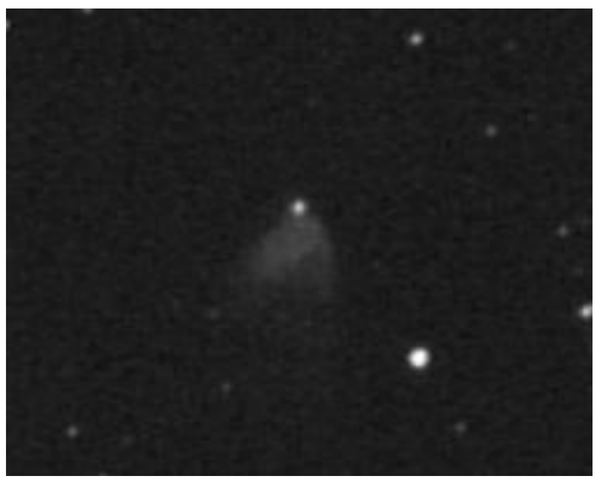


NGC7619:

NGC7619 is a +12.7 mag elliptical galaxy in the constellation of Pegasus. The bright oval-shaped galaxy is embedded near the middle of the Pegasus-I galaxy cluster. The galaxy displays a bright core surrounded by a diffuse halo.

NGC520 (Arp157):
NGC520 is a +12.2 mag pair of edge-on interacting spiral galaxies in the constellation of Pisces. The close bright pair is a peanut-shaped oval, with a dark lane separating the two objects. A very faint plume extends off of either end of the pair.

NGC2261 – Hubble's Variable Nebula:
NGC2261 is a +9 mag reflection nebula in the constellation of Monoceros, located next to the variable star R Monocerotis. The nebula has a comet-shaped appearance, with the bright star appearing as the head of the comet.



Hubble's Legacy & Conclusion:
Over the years, Edwin Hubble received various awards and metals for his work.
These include the Newcomb Cleveland Prize in 1924, the Barnard Metal in 1935, the Bruce Metal in 1938, the Franklin Medal in 1939, and the Gold Metal of the Royal Astronomical Society in 1940.
In 1927, Hubble was elected to the National Academy of Science of the USA; in 1928 he was elected to the Royal Astronomical Society of Great Britain, Elected to the Vienna Academy of Science in 1947, and elected to the French Academy of Science in 1949. Oxford University in 1934 also awarded Hubble an honorary degree of Doctor of Science.

Hubble was the first astronomer, in 1948, to have his portrait appear on the cover of Time magazine. Hubble also gave numerous public lectures at universities and scientific institutions around the country and over in Europe, and gave a series of talks over the radio, discussing the new 200" Palomar reflector, always stressing that the study of the universe must be pushed to even greater cosmological distances.

Throughout their marriage, both Edwin and Grace continued with athletic outdoor activities such as tennis, swimming, horseback riding, hiking and fishing. They enjoyed traveling to remote areas of the country for the scenic wilderness vacations. During the summer of 1949, after a successful observing run at Palomar, while vacationing on a fishing trip near Grand Junction Colorado, the 59 year-old Edwin suffered a sudden heart attack. It took several hours to get Hubble down off the remote mountain and make the 100 mile drive to a local hospital. While recovering there he suffered a second more serious heart attack and lost part of his heart function. The local doctors at the time didn't think he would survive, but Hubble pulled thru and after a month was able to return to Pasadena where he spent the next several years regaining his strength. Edwin was able to return to work part-time at the Pasadena office, but could no longer work long multiple nights in a row in the cold, high-altitude at either Mt Wilson or Mt Palomar. The few trips that Edwin was able to make to the observatories, Grace would accompany him and stay overnight, along with Edwin's observing assistant Allan Sandage.

Then, on September 28th, 1953, while being driven home from the office by Grace to have lunch at home, just as they were pulling into the driveway, the 64 year-old Edwin suffered a stroke and died there in the car from a cerebral thrombosis.

Years earlier, Edwin had told Grace that when he died, that he wanted to "*disappear quietly*".
Honoring his wishes, Grace had Edwin cremated, and there was no funeral or memorial service, and Hubble's ashes was buried in an unmarked location known only to Grace and four other people.
It is said that when Grace finally passed, in 1980 at the age of 90, that her cremated ashes were placed with Edwin's. As of this date, the four remaining people have all themselves passed on, leaving no information as to where the Hubble's final resting place is located. There is no cemetery monument honoring the greatest observer since William Herschel, but his discoveries still live on today.

Within a year of his death, Edwin Hubble was nominated for the Nobel Prize, but the selection committee had to reject his nomination, as per the Nobel award rules, the prize could not be awarded posthumously. But, in addition to the metals and awards that Hubble received while he was alive, he has since been further honored by the Hubble Space Telescope being named after him, the 25 mile diameter main-belt asteroid (2069), discovered in 1955 named 'Hubble', the crater 'Hubble' on the Moon, and a series of USPS Hubble stamps issued in 2000 and 2008 that honors both Edwin Hubble and the space telescope.

In conclusion,
Edwin Hubble is considered by some to be one of the great American observational astronomers of the 20th century, whose discovery of extragalactic variable stars led to a deeper understanding of our expanding universe. In just a ten-year period, from 1923 to 1933, Hubble confirmed that spiral nebulae were actually external galaxies, he developed a general classification of galaxies, and he discovered the expansion of the universe and confirmed the redshift theory leading to today's Big Bang cosmology! Few other astronomers, besides Copernicus or Galileo, have had such a revolutionary affect on our knowledge of the universe.

So I encourage everyone to get out tonight and try your hand at finding and observing the Island Universes of the Andromeda and Triangulum galaxies. And while doing so, think about the man whose observation that October night, just one hundred years ago, led to the Big Bang Theory.
Edwin Hubble, the Surveyor of the Universe!

Thank you.
Larry McHenry

Credits:

Books:

"*The Realm* of the *Nebulae*", by Edwin Hubble , 1936.
"*Galaxies*", by Harlow Shapley, 1943
"*The Red Limit*", Timothy Ferris, 1977
"*Webb Society Deep-Sky Observers Handbook – Vol4 Galaxies*", Kenneth Glyn Jones, 1981
"*Observing Variable Stars*", by David Levy, 1989
"*Edwin Hubble the discover of the Big Bang universe*", by Alexander Sharov and Igor Novikov, 1993
"*Edwin Hubble Mariner of the Nebula*", by Gale Christianson, 1996
"*The Night Sky Observer's Guide*", by George Kepple & Glen Sanner, 1998
"*The Local Group*", by Alvin Huey, 2008 www.faintfuzzies.com
"*Starlight Detectives*", by Alan Hirshfeld, 2014
"*A Short Biography of Astronomer Edwin Hubble*", by Doug West, 2015
"*Annals of the Deep Sky*", by Jeff Kanipe & Dennis Webb, 2015.

Magazines:

"*All About M31*", Deep Sky , Fall 1984
"*Observing the Local Group*", Deep Sky , Autumn 1991
"*A Visual Tour of M31*", Sky & Telescope, November 1993
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