Galileo: The First Optical Astronomer

Introduction:

A little over 410 years ago, in a time near what most historians consider to be the last days of the 'Renaissance', and just prior to start of the 'Age of Enlightenment', there was about a 150 year period, from the mid 15th to late 16th centuries, that saw a transformation of scientific ideas across the various philosophical sciences of biology, mathematics, and astronomy. This period in our history is called the 'Scientific Revolution', and came about from scholars questioning and turning away from the ancient Greek views that had dominated science for the past 1,500 years. This era was the foundation in establishing investigation and experimentation as the cornerstones of the modern sciences.

One of the major figures of that period of scientific questioning was the 16th century Italian astronomer and mathematician Galileo Galilei (1564 – 1642). Galileo straddled the old world of a natural philosopher, and mathematician, to that of the new world of modern science, and made fundamental contributions to science by his groundbreaking inventions and discoveries. He was one of the first to pioneer experimental scientific methods and in 1610 was the first astronomer to build and use a telescope and move the science of astronomy into a new age.

Through Galileo's work of studying the heavens with his new instrument, he broke new ground in our understanding of the universe, and along the way sparked a debate that challenged the ironclad rule of church doctrine over science. Today, we're going to look back on his life and accomplishments as the first optical astronomer. Along the way, we'll review Galileo's observations, along with a few of my own. *(LM)*

Discussion outline:

- **Naked-eye Astronomy before Galileo:**
- **Galileo: Childhood & Education, Professional Life, Family**
- **Invention of the Telescope:**
- **Galileo and the Telescope - 1609:**
- **Galileo's Observations and Discoveries - 1610:**
- **Revolutionary Ideas and Consequences:**
- **Galileo's Legacy & Conclusion**

Naked-eye Astronomy before Galileo:

For thousands of years, Man has studied the night sky, using just eyesight, and later a few simple measuring tools. There was the ancient Sumerians, Babylonians and Egyptians who discovered the seasonal cycles of the sky, along with determining the celestial movements of the Sun, Moon, and Planets. Then the Greek philosophers such as Aristarchus, (310-230 BC) who made the first attempt to measure the distances to the Sun and Moon, and proposed that the Earth revolved around the Sun (which even though his idea was discarded, turned out to be correct). Or Hipparchus, (~200 BC), who created the first star catalog of over 1,000 stars and developed the first model of the solar system with the Earth at the center. To Ptolemy, (~150 AD), who extended Hipparchus's star catalog and perfected the Earth centered 'geocentric' model of the universe (known as the Ptolemaic System) that lasted for over the next 1,400 years as accepted fact. (Until Copernicus published his Sun centered model in 1543).

Then more advanced visual observers such as Tycho Brahe, (1546 – 1601 AD), who built an observatory around large-scale, finely calibrated meridian transit circles to create the most accurate star positional catalog and measurements of planetary movement made by the naked-eye. This data was later used by Johannes Kepler in devising his three Laws of Planetary motion, along with proving that the Copernican (Sun-centric) System was correct.

Galileo Galilei:

Childhood & Education:

Galileo was born in Pisa, in the Duchy of Tuscany, in northwest Italy on February 15th, 1564. His father, Vincenzio, was a musician, composer, and scholar who studied ancient Greek music and stage drama, and was an early pioneer of Italian opera. Vincenzio also is known for his study of musical pitch and string tension and developed a mathematical theory of acoustics. He taught Galileo how to play the lute as a boy, and it is said that Galileo learned the importance of experimentation from his father. Galileo's mother, Giulia, was from an upper class family and she worked in the local silk trade. Galileo received his initial schooling from a private tutor, but at the age of 13 he was sent off for school to the Benedictine abbey of Vallombrosa near Florence. There he studied the usual subjects expected of a gentleman, including Greek, Latin, and the Arts, and developed a skill in drawing which was later useful in his astronomical work. After completing his school at the abbey in 1578, Galileo at first studied for the priesthood, but his father dissuaded him, so in 1580, he decided to go to the University of Pisa to study medicine. Within a few years, after becoming interested in the sweep motions of pendulums, he switched over to study mathematics and natural philosophy, graduating in 1586.

Professional Life:

Galileo's first job in 1588 was as an art instructor at the University of Florence. But he soon taught university level mathematics, first at Pisa in 1589, then taking a promotion in 1592 to the University of Padua, and then in 1610, after coming under the patronage of Cosimo II de' Medici the Grand Duke of Tuscany, as the court mathematician in Florence.

Family:

Seeing the financial and legal problems that his younger siblings encountered with not being able to pay their portion of marriage dowries, (and which Galileo being the eldest, became financially responsible for in 1591 when his father Vincenzo passed), Galileo never married. But he did fathered three children (two daughters, Virginia and Livia, and one son, Vincenzo Jr) out of wedlock with Marina Gamba who Galileo met in Venice and fell in-love with. But Marina was 14 years younger and of lower class than Galileo, and marrying her would negatively impact his career. So they lived separately from each other, he in his professor's house at the university, and she in a small house nearby.

After Marina died in 1612, both of his daughters were sent to the convent of San Matteo, where his eldest, Virginia took the name Maria Celeste. Galileo kept and raised his son, who he eventually had his birth legitimated in 1619 by the Grand Duke of Tuscany. Maria (Virginia) was a devoted daughter to Galileo, and the two of them exchanged many letters over the years, with Galileo occasionally visiting her at the convent.

Invention of the Telescope:

The telescope traces its history back to the late 13th century in northern Italy with the invention of simple glass magnifying lenses and spectacles to improve eyesight. Convex glasses for those whose close-up vision was blurry, (farsighted), and concave for those who couldn't clearly see far-away, (nearsighted). But it wasn't until around 1575 that both concave and convex lenses started to be used together. In 1608, Dutch inventor Jan Lippershey combined both types of lenses into an instrument (that was called the "Dutch perspective glass") consisting of a convex objective lens and a concave eyepiece that gave an erect image of 3x magnification allowing its user to see objects at a distance. There are a number of stories about how Lippershey came up with his idea of combining lenses, with one of the more popular being that he overheard two children who were playing with lenses talking about how they could make a far-away church spire looked closer while holding the two lenses.

The first "Dutch glasses" generally had lenses of about 1" in diameter and stopped-down using aperture masks, mounted in a stiffened paper tube of about 1 foot in length and with a fixed focus. Word of the new invention quickly spread across Europe, with opticians and mathematicians in major cities soon creating their own versions. These experimenters included German astronomer Simon Marius, who later competed with Galileo in astronomical discoveries. The lack of good quality optical glass, difficulty in obtaining lens grinding tools and supplies, figuring out how to optically test the quality of the lenses, along with the lack of good material to use for tubing, made building these instruments challenging. These basic 'spyglasses' were costly and only used by the military which found them useful, or as expensive toys of the nobility. They were not yet true 'telescopes'.

Galileo and the Telescope - 1609:

In May of 1609, while on a trip to Venice from his University home in Padua, Galileo heard the news about the new optical instrument for seeing distant objects. He immediately realized the importance of this new invention, and on the next day upon returning home, he began his own experimenting with convex and concave lenses.
Ready-made quality lenses were hard to come-by, so Galileo acquired the necessary tools to grind and polish lenses himself. Galileo quickly grasped the optical refractive relationship between the lenses and how the focal point distance impacted the instruments power. Some sources indicate that it may have actually been Galileo who came up with the idea of using an aperture mask in front of the objective lens to stop it down to help eliminate optical edge curvature defects within the lens, giving a clearer view.

Galileo's efforts improved on the convex lens, and he was able to create his own perspective glass, with an objective of 1 5/8" in a 20" tube giving a magnification of around 8x. He returned to Venice in August where he demonstrated his instrument to the city nobility and gifted the instrument to the Doge of Venice.
(A politically and socially smart move). Galileo's main interest in making these instruments was at the time not using them for astronomy, but as a product to sale to the military and merchant shipping from which he hoped to make a small fortune from. Galileo actually did make a profit from selling spyglass telescopes to local merchants.

Having received a large stipend from the Venetian nobles, Galileo returned to Padua where during that fall of 1609, he proceeded to build larger telescopes with increasing magnifications and clarity. He finally produced his two finest instruments that became the first astronomical telescopes, which are still preserved today. The larger instrument having a 1 3/4" inch convex objective (stopped down to 15mm) with a focal length of 980mm in a 49" paper tube using a concave 'eyepiece' of 22mm, giving a magnification of 20x. The second glass having a 1 5/8" objective in a 37" long tube and gave a 14x magnification. While Galileo's improvements on the eyepiece convex lens enabled it to reach focus with about 3" of eye-relief, they suffered from a narrow field-of-view (about 7.5' arcminutes or about ¼ the size of the Moon's disk) requiring the instrument to be mounted and not hand-held. Galileo called his new glass instruments a '*perspicillum*', which is Latin for "an instrument to look thru".

In April of 1611, at a dinner held in Rome to honor Galileo, a new name was given to Galileo's optical instrument by the Greek poet and mathematician Giovanni Demisiani. At the banquet, Galileo had brought one of his improved "Dutch glasses" to show the '*Medicean Stars* (moons)' of Jupiter. Demisiani felt that Galileo's invention needed a better name to differentiate it from the lesser glasses, so he came up with a new word - *teleskopos* – meaning 'far-seeing' based on the Greek words for 'far' (tele) and for 'to see' (skopein). Thus the modern word – "Telescope".

<u>Galileo's Observations and Discoveries - 1610:</u>

While it is not certain whether Galileo was actually the first person to use a telescope to observe the heavens, he was the first to document and publish the new discoveries of what he observed with it. As his skill in creating telescopes with better optics improved, he began to turn the new instruments towards the sky. By late November of 1609, Galileo had seen enough to convince him to begin a systematic research project of the heavens, starting with the Moon, using his best glass.

By January of 1610, the 45 year-old Galileo had made a number of spectacular discoveries in the night sky using his telescope. In addition to discerning surface features on the Moon, these discoveries included first three, then four new 'stars' that appeared to follow Jupiter and changed locations and alignments to one another each evening. He also resolved the glowing clouds of the Milky-Way into countless individual stars.

Galileo documented these discoveries and published them in a 24 page pamphlet in March 1610 titled the "*Starry Messenger*" or also called "*Sidereal Messenger*" (***Sidereus Nuncius***). This was the first scientific book based on astronomical observations made through a telescope! In some respects, the "*Starry Messenger*" really wasn't a book; it was more like an 'announcement' of newly discovered celestial phenomena that was revealed by his telescope. Galileo's style in writing it was not as dry formal textbook, but more as a conversational first-person perspective of the excitement of his discoveries.

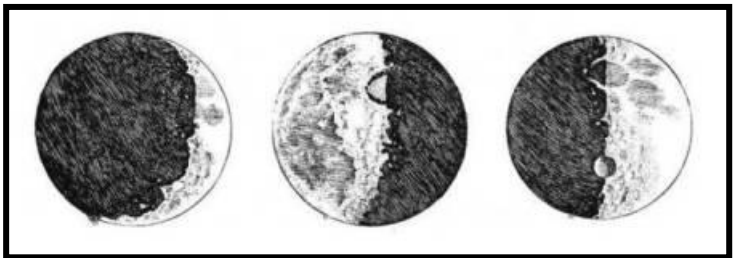

SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
GALILEO GALILEO
PATRITIO FLORENTINO
PERSPICILLI
QVATVOR PLANETIS
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
VENETIIS, Apud Thomam Baglionum. M. D. C. X.

Word of the book's contents had leaked out a few days before its release, creating a sensation, so when the book hit the streets in Venice on March 13th, the first 500 copies immediately sold out! Copies of the book were eventually sent all around Europe, but one copy was sent that very day of the 13th to the King of England by an English visitor who happened to be in Venice and hearing about the book realized its importance.

To help convince people of what he had observed, Galileo built additional telescopes as powerful as his 1 ¾" 20x instrument and sent them along with copies of his book to a number of prominent leaders who were patrons of science throughout Europe, where he knew they would be shared with various court experts that would know how to verify his results. Galileo later went on over the next several years to be the first to observe and publish additional observations on the phases of Venus, Saturn, and Sunspots which he published in 1613 in a pamphlet titled "*Letters on Sunspots*".

The Moon:

That late fall of 1609, when Galileo would complete one of his glass instruments, if the Moon was in a favorable evening position, he would point the telescope at it to try out his latest increase of magnification to see what additional details it might make visible. He was beginning to see with better clarity landscape features that encouraged him to continue building better instruments. Finally, on the night of November 30th, having completed his 1 3/4" inch objective telescope with a 22mm eyepiece giving 20x magnification, Galileo began to sketch and write down descriptions of what he observed on the Moon's surface.



(Galileo)

The first thing he noted was that the Moon did not have a smooth, celestially perfect disk as he had been taught in school. (Those with good eyesight had noticed gray patches on the Moon before, but the assumption was that these were reflections from the Earth). But now, using his improved optics, Galileo instead observed that there were mountains, valleys, and large flat plains, pockmarked with depressions (that we know today are craters). At first Galileo wasn't sure if the 'craters' were small hills or holes. But by noting along the Moon's jagged, uneven terminator how the shadows and illumination of the crater walls and their interiors changed from where the Sun was positioned, just like watching shadows in an earthly landscape, he determined that these objects were actually holes and pits in the surface. Galileo was also able to use the same play of shadow and light to measure the angle of the mountains using simple geometry and calculate their height, finding peaks taller than any known on the Earth at that time. (His calculated results were two high, but in the ballpark). For the next month, Galileo observed the Moon for hours every clear evening, following it thru its phases and sketching what he had seen.

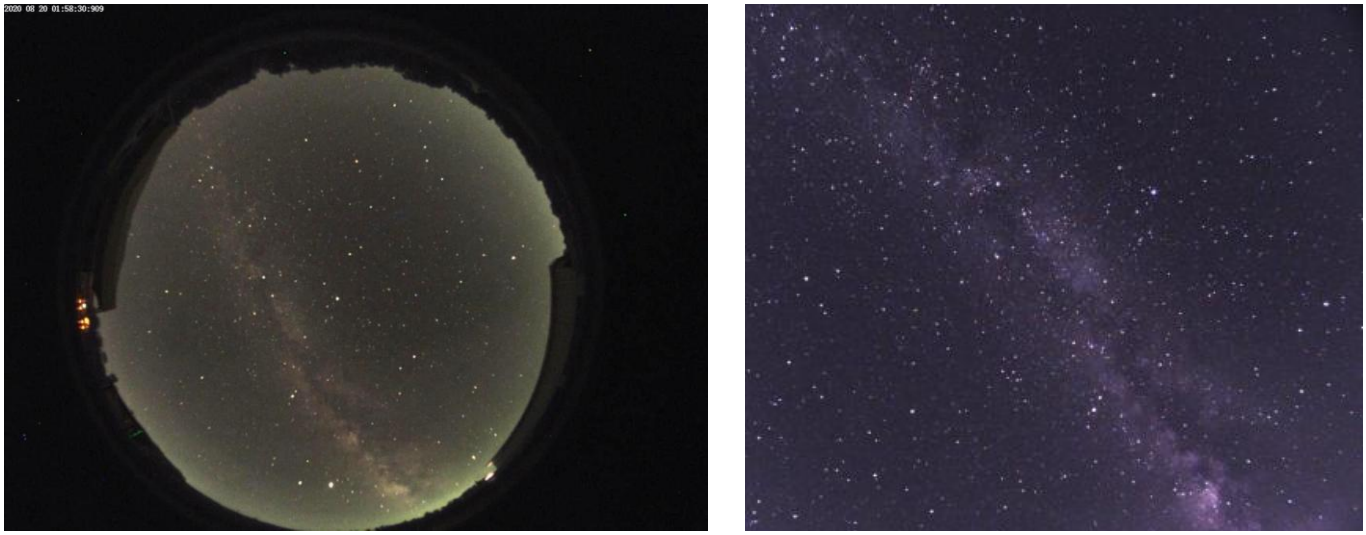
Taking this information, he then created rough topographical charts of the Moon. He included a number of these sketches and wash-style drawings in his book. Unfortunately, Galileo wasn't careful in accurately plotting the features as his main goal was to show that the Moon had Earth-like features. This makes his charts difficult to match with modern day photos.

(LM sketches & image – 80mm f3 Refractor)

Finally, Galileo also concurred with Kepler's belief on what was the cause of 'Earthshine' on the Moon.
The dimly illuminated areas visible on the Moon's surface right before and after its new phase are from reflected sunlight off of the Earth's oceans and clouds.

The Milky-Way:

In addition to the Moon, Galileo pointed his telescope to the Milky-Way star clouds.
Throughout antiquity, people thought the Milky-Way was nebulous clouds of smoke or some other matter.
But when Galileo observed the Milky-Way, his telescope resolved the 'smoke' into a multitude of countless faint stars, so densely packed together that their combined starlight resembled glowing clouds to the naked-eye.
He found the greatest concentration of stars among the clouds in the constellations of Scorpius and Sagittarius.
In the telescope, the stars all appeared as tiny blazes of light compared to the planets which showed disks.

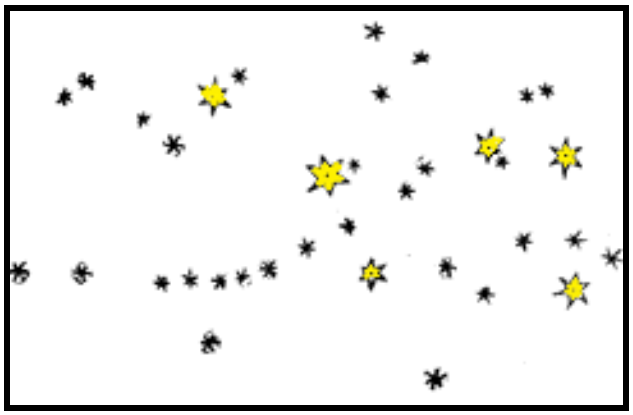


(LM image – fisheye lens)

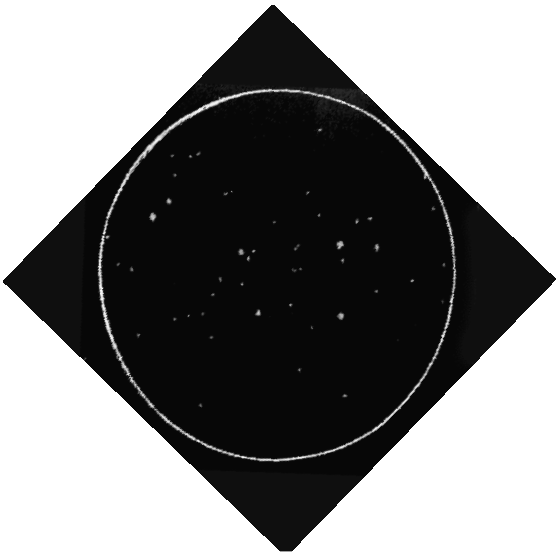
Turning to the 'Pleiades', in Taurus, Galileo found 40 more additional stars were visible other than the 6 or 7 that people had counted for centuries. Also, the Belt and Sword of Orion that normally showed only 9 stars visible to the naked-eye now showed upwards to 80 stars not visible without the telescope. (Galileo was not able to resolve the Orion Nebula, and thought he needed a bigger telescope, so he decided not to mention it)

And he viewed several of the 'nebulous clouds' mentioned in Ptolemy's catalog and was able to resolve them into swarms of tiny stars, such as the 'Praesepe Nebula', (M44), near gamma & delta Cancri in the constellation of Cancer, in which he counted 38 individual stars. He included sketches of all three of these objects in his book. Finally, Galileo also noted that several of the known named stars that had appeared to be a single star to the naked-eye, (such as Mizar in the Great Bear) were actually revealed by his telescope to be two individual stars.

M45 – Pleiades:

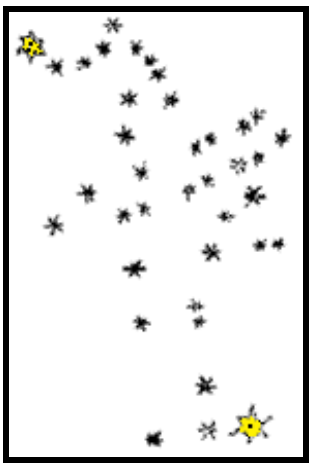


(Galileo)



(LM sketch– 80mm f3 Refractor)

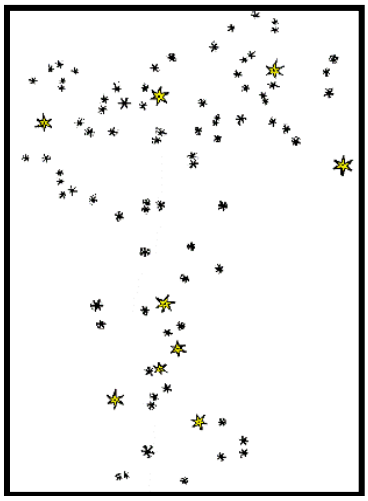
M44 – Praesepe:



(Galileo)

(LM image – Canon 50mm lens)

Orion's Belt and Sword:



(Galileo)

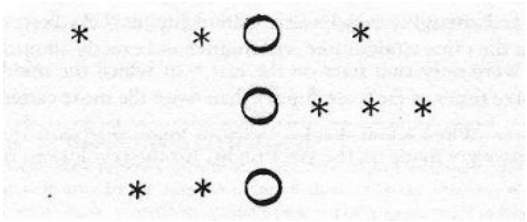
(LM image – Canon 25mm lens)

In later books, Galileo describes how he was able to measure stars by hanging a very thin string in the telescope eyepiece's line-of-sight, and using the known width of the string and the distance in which the string completely blocked the star, calculate the angle subtended by the star to give its size in arc-seconds. While Galileo's apparent sizes were greatly distorted by atmospheric diffraction, (which he was unaware of), his measurements were precise enough to add further data against the Ptolemaic System.

Jupiter & its Moons: (the Medicean Stars, later called the Galilean moons)

Having finished his observations of the Moon and the 'fixed stars', on the evening of January 7th, 1610, Galileo turned his telescope to one of the 'wondering stars', the planet Jupiter, then a brilliant object slowly gliding thru the horns of Taurus.

Immediately, Galileo noticed three small 'fixed stars', (as he called them), aligned nearly parallel with the planet, two on one side and the third on the opposite side. While these 'stars' were not visible to the naked-eye, they were very bright thru his telescope, brighter than any of the other nearby stars visible in the field. Galileo was intrigued by the view and made a descriptive note and sketch in his logbook of this observation.
The following evening, January 8th, he pointed his telescope back to Jupiter and was surprised to find that the three 'fixed stars' from the night before were all still there near Jupiter, but now in a different formation, and had moved in the same direction of Jupiter's path thru the ecliptic, and had not fallen behind like he expected them too.
When he went to view Jupiter on January 10th, (after a cloudy night on the 9th), only two of the new stars were visible, the third had disappeared. Galileo deduced that the third star must be blocked from view by Jupiter.

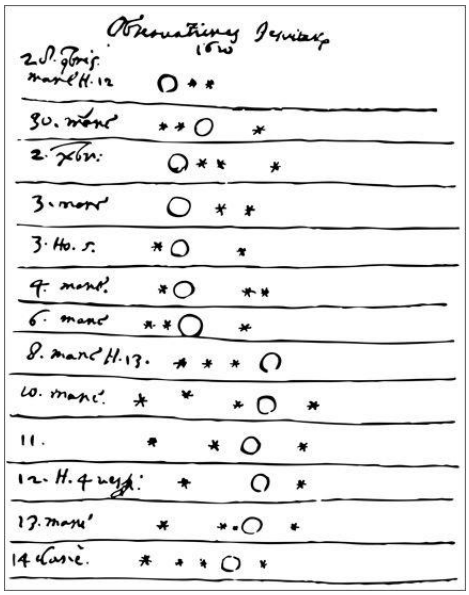


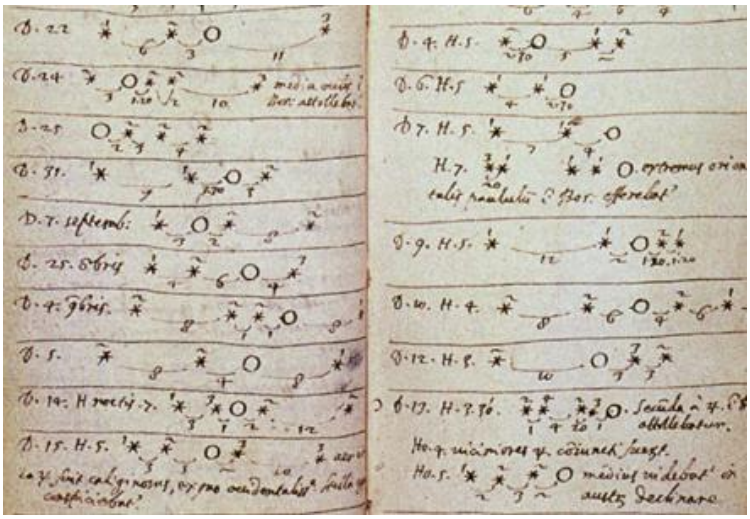
A few days later, on January 13th, he was surprised to not only find the three 'stars' that he had become accustomed to seeing, but now a fourth 'star' was visible!

Throughout this period Galileo kept wondering what these objects were. Every night the new stars changed locations around Jupiter, sometimes leading in front of the planet, and sometimes lagging behind the planet, but always staying with the planet. As he observed these new objects over time, he realized that their slowly changing

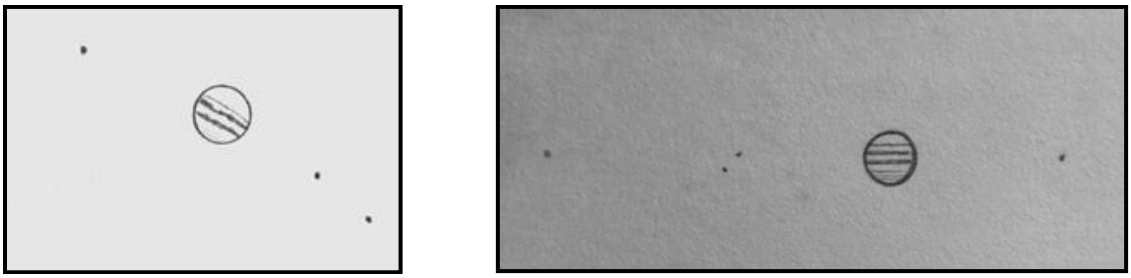
positions around Jupiter that would not be possible if they were true 'fixed stars'. Galileo finally came to the only possible conclusion, that they were new satellite 'Moons' revolving around another planet! The Earth was no longer the center of the universe. Other bodies could also be their own center with their own system of worlds in revolution around them!

Galileo also realized the implications of his observations, and that he needed to get his book describing these new Moons into print. But, he knew that only a few days' worth of observations wouldn't be enough proof of what he was going to announce to the world. Galileo had already nearly finished writing the book's section on the Moon, and had started writing about his observations of the 'Milky Way'. But now, fearing that his discoveries might be scooped by someone else who had heard him talking about his observations, Galileo rushed thru writing the Jupiter section into the manuscript, and keeping it updated by adding in each previous night's information during the next day. He also took time to add in further details and sketches to the 'fixed stars' section.





(Galileo)



(LM sketch– 8" SCT f10)

So, for the next two months, leading right up to the last few days before publishing his observations in March, Galileo studied these four new 'Moons', and began keeping more detailed notes on their positions relative to Jupiter and one another, their movements, and brightness to each other, and including the time of night.
He even began taking multiple observations during the night, recording and sketching what he saw, and included all in his book. Today, many historians consider his observations of Jupiter's Moons to be Galileo's most important of all his discoveries and the crown jewel of the book.

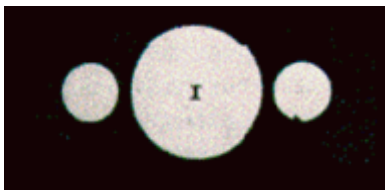
Recalling how his fortunes had increased by gifting a telescope to the Doge of Venice, Galileo shrewdly named his discovery the "Medicean Stars" in honor of Cosimo II de' Medici, the Grand Duke of Tuscany, and his brothers. (William Herschel followed Galileo's footsteps 172 years later by trying to name his new planet after King George)

But astronomers of the day soon took to calling them the “Galilean moons” for their discoverer.
Still, Galileo’s play to the Grand Duke worked, and after his observations were confirmed by other astronomers, he received a hero’s welcome in Rome, and secured an appointment as the Duke’s court astronomer in Florence with a hefty increase in salary.

Eventually, there was some dispute as to who actually was the first to discover the moons of Jupiter.
German astronomer Simon Marius (above) published a book (*Mundus Lovialis*) in 1614 where he claimed to have independently seen the moons a day earlier than Galileo, but because Galileo was the first to publish nearly 4 years earlier and because of Galileo’s more extensive descriptions; Galileo is given the principle credit for their discovery. But Marius names for the four moons, Io, Europa, Callisto, Ganymede, was eventually adopted as the official names, so he does get some credit.

(Additional observations from 1610 in Galileo’s next book “*Letters on Sunspots*”, published in 1613.)

Saturn & Rings:
In July of 1610, Galileo began to observe the planet Saturn, then rising toward the meridian late evenings in the constellation of Aquarius. Turning his telescope to the bright yellow-hued star, Galileo was the first to see the planets disk. But he also noticed something strange; the planet appeared to be composed of three objects almost touching one another lined-up in parallel. Two smaller ones were on either side of the larger disk. (kind of like Mickey Mouse ears!) He thought that perhaps in this three-bodied system, the smaller two objects were moons, but unlike the Medicean Stars of Jupiter, these around Saturn did not change position over the many weeks of observations.



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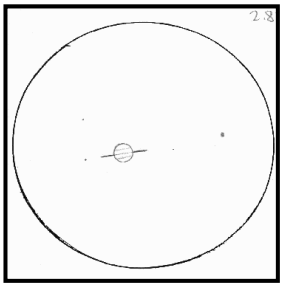
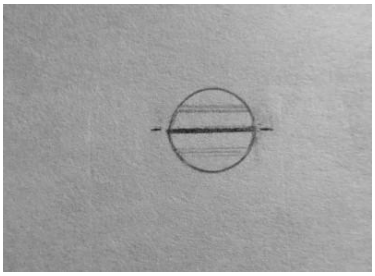


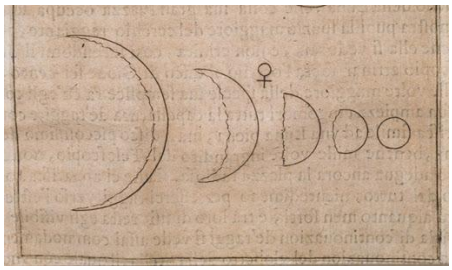


(LM sketch– 8” SCT f10)

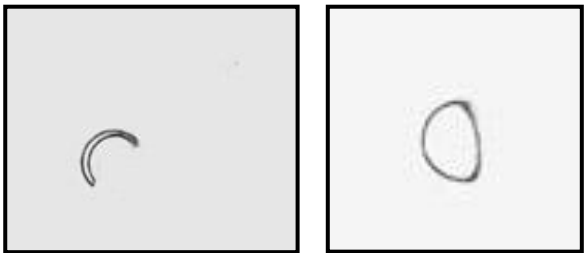
Even using a newer telescope that gave 32x magnification, Galileo’s telescopes did not have the clarity to show him that these two smaller ‘objects’ were actually a ring system around the central planet, with the ring nearly edge-on to the Earth, giving a narrow angle. Continuing to observe the planet over the next two years, the viewing angle got worse as Saturn’s rings reached edge-on and disappeared from Galileo’s limited telescopic view. Galileo speculated that perhaps the larger disk had consumed the smaller two objects. Then a few years later, in 1616, the two small bodies reappeared on either side of the Saturn’s disk. He was greatly confounded by his observations and never realized that he was looking at a ring that had turned edge-on and was now beginning to open back up. Not until 1659, did Dutch astronomer Christiaan Huygens, using a better quality telescope with a magnification of 50x solve the mystery!

The Phases of Venus:

In September of 1610, Galileo turned his telescope toward the planet Venus and immediately discovered that it was not a fully illuminated disk. He watched Venus over a period of many months, with the planet slowly going thru its crescent, gibbous and full phases and change in disk diameter. In either of Galileo's small telescopes, there were no details to be seen on Venus's brilliant white disk.



(Galileo)



(LM sketch– 8" SCT f10)

Once he reported his observations of Venus going thru phases, something that was never supposed to happen according to the Ptolemaic World view, the traditional geocentric or Earth-centered model became even more unacceptable to Galileo's contemporary astronomers.

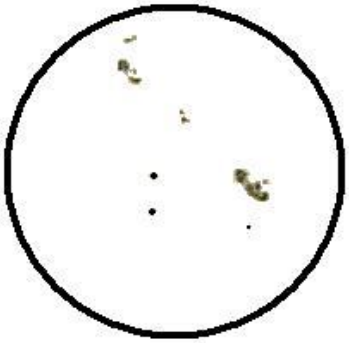
The Sun-centered Copernican World View's acceptance was now growing among the scientist and philosophers of the time. Galileo's telescopic discovery of the phases of Venus contributed greatly to this transition.

Sunspots:

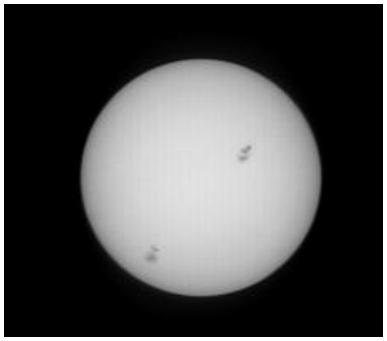
Going back for nearly 2,000 years, astronomers and other skywatchers have noticed occasional naked-eye dark blemishes on the face of the Sun, particularly at sunrise or sunset when hazy skies helped cut down on the Sun's glare. Galileo himself, pre-telescope had made these kind of observations, but again, as he had been taught in school, the Sun was a celestially perfect heavenly disk and like the Moon, these dark spots were just reflections from the Earth.

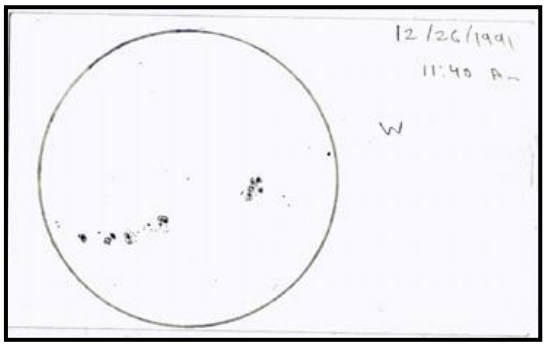
With his discovery observations of lunar terrain still fresh in his memory, and while recognizing the optical dangers of the Sun's rays, in November of 1610, Galileo devised a way to observe the Sun safely with his telescope.
He would only observe the Sun by projecting the image it thru the telescope onto a flat shaded surface.
He would never actually look thru his telescope at the Sun.

He immediately telescopically observed various sunspot groups and determined that they were physical features on the Sun. Galileo tracked the sunspot groups on a regular basis for many weeks, watching them grow and decay. Eventually, he realized that based on his observations, the Sun had a rotation period of about one month.
Galileo published his solar observations in a new book called "*Letters on Sunspots*". With this book, Galileo also firmly declared his being in favor of the Copernican System. Once again, Galileo's telescopic observations and writings were in conflict with church doctrine that the Sun as a heavenly body was supposed to be unchanging in its perfection, and was also another blow against the geo-centric Ptolemaic System.



(Galileo)





(LM image and sketch– 80mm f3 Refractor)

As with Galileo's Jupiter observations, a dispute arose over who was the first to use a telescope to 'discover' sunspots. Jesuit priest Christoph Scheiner also claimed to have observed sunspots in late 1610, and his claim led to a long and bitter feud between him and Galileo. Once again, with Galileo's detailed descriptions published before Scheiner's, Galileo was given the credit for being first. But being a Jesuit, Scheiner was in more favor with the church, and that worked against Galileo later on.

Neptune: a missed opportunity?

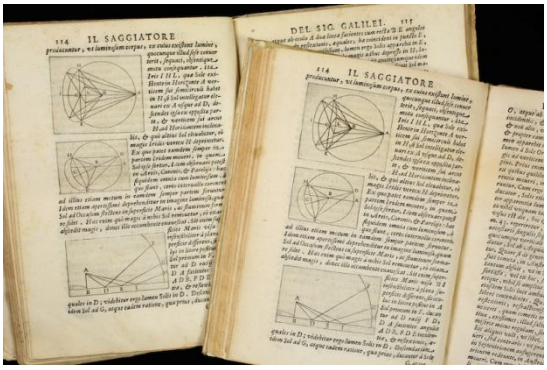
Apparently in 1612, Galileo also observed the planet Neptune without realizing what it was. He has it recorded in his notebooks as a dim star that looked to be slowly moving in relation to the other background stars.
But after only a few observations, he lost track of it. Calculating Neptune's current orbital location in reverse puts it in the location of Galileo's 1612 observation. If Galileo had stuck with following the dim moving star, he might have made another world shaking discovery! Neptune now had to wait another 234 years before German astronomer Johann Galle located it on September 23rd, 1846.

Revolutionary Ideas and Consequences:

The observations made by Galileo in 1610 quickly convinced him that the Copernican system was correct and he became an outspoken advocate for it. This, along with his observations that the Sun, Moon, and Venus were not perfect, unchanging celestial spheres of divine substance, an example of the perfection of the Heavens, but,, Were just like the rough, changeable, corruptible terrestrial things on Earth! Publishing this in the "*Starry Messenger"* put him in conflict with the religious teachings of the church. This unintended challenge to religious dogma caused such an uproar that some church officials even after hearing from others describe what they have seen visible in Galileo's telescope still refused to look themselves through it in fear that the instrument was bewitched. Galileo's response to these officials was that he hoped they would soon have a good view of the new moons while on their way up to Heaven. (Implying that he wished them dead, Galileo's outspoken quick wit probably didn't help his case).

His next published book in 1613, "*Letters on Sunspots*", where Galileo presented his observations on Sunspots, Saturn, and the phases of Venus, and again praised the Copernican System as being correct, further inflamed his critics and led to an investigation by the Inquisition. In 1616, the Papal church officially ordered him to stop teaching or writing about the Copernican system.

In 1623, Galileo published the book, '*The Assayer* ', which is considered to be one of the early pioneering works of advocating using mathematical tools and physical observations as part of the scientific method. In the book, which concerned the nature of comets, Galileo highly criticized a prominent Jesuit astronomer and permanently alienated the Roman Jesuit College who had previously been supportive of Galileo.



Galileo then published "*Dialogue Concerning the Two Chief World Systems"* in 1632 where he satirically compared the old Ptolemaic geo-centered model with the new Copernican system, arguing thru logic that the sun-centric model was correct. (This book is considered to be one of the most important scientific papers ever written). Galileo thought he had received permission to write and publish the book, from Pope Urban, as long as he didn't personally support the Copernican system. So Galileo wrote the book in which three fictional characters debated

amongst themselves the merits of the two systems. But Galileo made a huge miscalculation of unintentionally insulting the Pope by using the Pope's own arguments in support of the Ptolemaic System for a dimwitted character in the book. Galileo was literally 'playing with fire', as in living memory, philosopher and mathematician Giordano Bruno was burned at the stake (in 1600) for teaching the heretical view of the Copernican System.

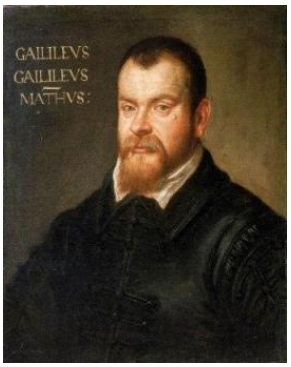
This book was the last straw for Pope Urban, who summoned Galileo to Rome in 1633 to face the Inquisition. After spending two months under house arrest at the Villa Medici, Galileo was finally put on trial, where he was found to be 'vehemently suspect of heresy'. But it wasn't a unanimous decision as a number of judges voted to acquit and refused to sign the verdict. Galileo was forced to knell before the court and publicly recant his belief in the Copernican system and swear that the unmoving Earth was the center of the universe. According to some accounts, as Galileo was standing up and turning away from the judges, he whispered: "*But it does move*"!
Galileo was confined to his villa in Arcetri near Florence under house arrest for the remainder of his life.
The 69 year-old astronomer was forbidden to publish anything new, and all his older books placed on the list of church banned books which was not rescinded until 1835.

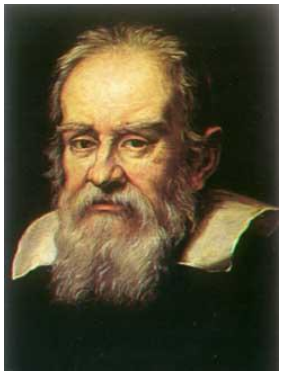
Galileo was already in poor health prior to his trial, and the pressure of the trial and house arrest left him depressed and sicker. Galileo requested several times to be allowed to travel to Florence to see a doctor, but his requests were denied by the church. His daughter Sister Maria Celeste died the following year, 1634, which left him even lonelier. During this time, Galileo's eyesight, which had given him problems for a number of years, began to fail. Over the centuries people have speculated that it was possible that Galileo had damaged his eyesight from his studying of sunspots 25 years earlier. But, it really had nothing to do with his telescopic observations of the Sun as he never directly looked at the Sun 'thru' the telescope. Eye damage from looking at the Sun damages the central fovea region of the eye, and does not cause total blindness. Galileo suffered from both glaucoma and cataracts in both eyes, which caused him to slowly lose his vision and eventually go completely bind by 1638. Galileo's friends eventually were able to get the church to ease-up on his punishment, allowing him to see a doctor, have occasional visitors and to have a personal secretary and caretaker. In late November of 1641, Galileo became very ill with a fever, and at the age of 77, on January 8th, 1642, passed away.

Galileo's supporters wanted him buried in the main chapel in the church of Santa Croce in Florence, but the Pope refused to allow it, so he was buried in a small side room of the church. Eventually, the church relented in 1737, allowing Galileo's body to be moved to a grand tomb in the main chapel at Santa Croce. It is said that his daughter, Sister Maria Celeste was reburied with him.
It was not until 1992 that the church finally rescinded Galileo's guilty verdict of heresy, clearing his name.

Galileo's Legacy:

Galileo and his telescopic observations made many significant contributions to astronomy. He has been referred to as the "Father of Modern Astronomy". But Galileo also made discoveries in other areas of science, among which:
Galileo studied speed and velocity, gravity and free fall via his famous 'Leaning Tower of Pisa' experiments where he dropped objects (cannonballs) of different weights from the tower.
He experimented and described the properties of pendulums and "hydrostatic balances".
Galileo formulated the concept of *inertia*: an object in a state of motion remains in that state of motion unless an external force acts on it. He invented a measuring instrument called a 'Sector' or 'Military Compass', which was a calculating instrument used to solve navigation, surveying, and cannon gunnery problems in trigonometry.
He discovered the pneumatic principle in which a liquid rises and falls as the temperature changes and invented an instrument called a 'Thermoscope' that shows the change in temperature, and was a precursor to the modern thermometer. In 1619, he studied the Northern Lights and speculated that the phenomenon was caused by sunlight reflecting off of the Earth's atmosphere. (which was incorrect). But he did come up with the name that we use today, the 'Aurora Borealis'.
And, while under house arrest in 1636, he wrote his last book, "*Discourses and Mathematical Demonstrations Relating to Two New Sciences*", which summarized much of his experimental work over his last 30 years and laid the foundations of modern physics. Due to the church ban on all of his books, including anything new, Galileo had the book smuggled out of Italy a few pages at a time, and published in Holland, which was not under the Inquisition's control.





In conclusion:
The 'Scientific Revolution' is said to have begun with the Copernicus sun-centered model in 1543 and concluded with Isaac Newton publishing his 'Principia *Mathematica '* in 1687. Galileo lived and made his groundbreaking scientific contributions during this time. A late day 'Renaissance Man', who helped lead the science of astronomy into the 'Age of Enlightenment'.

Galileo's celestial observations changed the way people thought about the universe, and our own world.
His invention of the first true "telescope" and turning it to the night sky overthrew the geocentric world-view and transformed our cosmic perspective:

- Our Moon was another feature-filled world just like the Earth, and not a celestially perfect globe.
- The Milky-Way was countless far-away stars.
- Other Moons rotated around Jupiter.
- Venus showed phases, just like our Moon.
- The Sun was pocked-marked with changing spots.

And **ALL** of it rotated around the Sun. Copernicus was correct; the Earth was not the center of all cosmic motion and itself rotates around a blemished Sun that was not a changeless orb. The Ptolemaic System was up-ended.
All these discoveries by Galileo led to a NEW 'Renaissance' in Astronomy, and a new understanding of our place in the Universe that continues to this day.

So I encourage everyone to get out tonight and try your hand at finding and observing these Galilean objects, and think about the man who was the first to observe them with a telescope. Galileo, the First Optical Astronomer!

Thank you! *Larry McHenry*

Credits:

Books:

"*The Telescope*", by Louis Bell, 1981.
"*The Atlas of the Solar System*", by Patrick Moore & Garry Hunt, 1983.
"*Seeing and Believing*", by Richard Pane, 1998.
"*Astronomical Scrapbook*", by Joseph Ashbrook , 1984.
"*The Clockwork Universe*", by Edward Dolnick, 2011.
"*Boltzmann's Tomb*", by Bill Green , 2011.
"Galileo's Daughter", by Dava Sobel, 1999.
"*The Starry Messenger*", by Galileo, 1610.

Magazines:

"*Galileo's New Universe*", Sky & Telescope, February 2009
"*Celebrate Galileo's 455th Birthday*", Astronomy, May 2009
"*Who Invented the Telescope*", Sky & Telescope, July 2009
"*Galileo – The Genus Who Charted the Universe*", National Geographic, 2005

Internet:

Wikipedia & Wikimedia
seds.org
"Earth Centered Universe" by David Lane http://www.nova-astro.com/
Astronomical League – Galileo Club: https://www.astroleague.org/al/obsclub/galileo_club/galileo_club.html