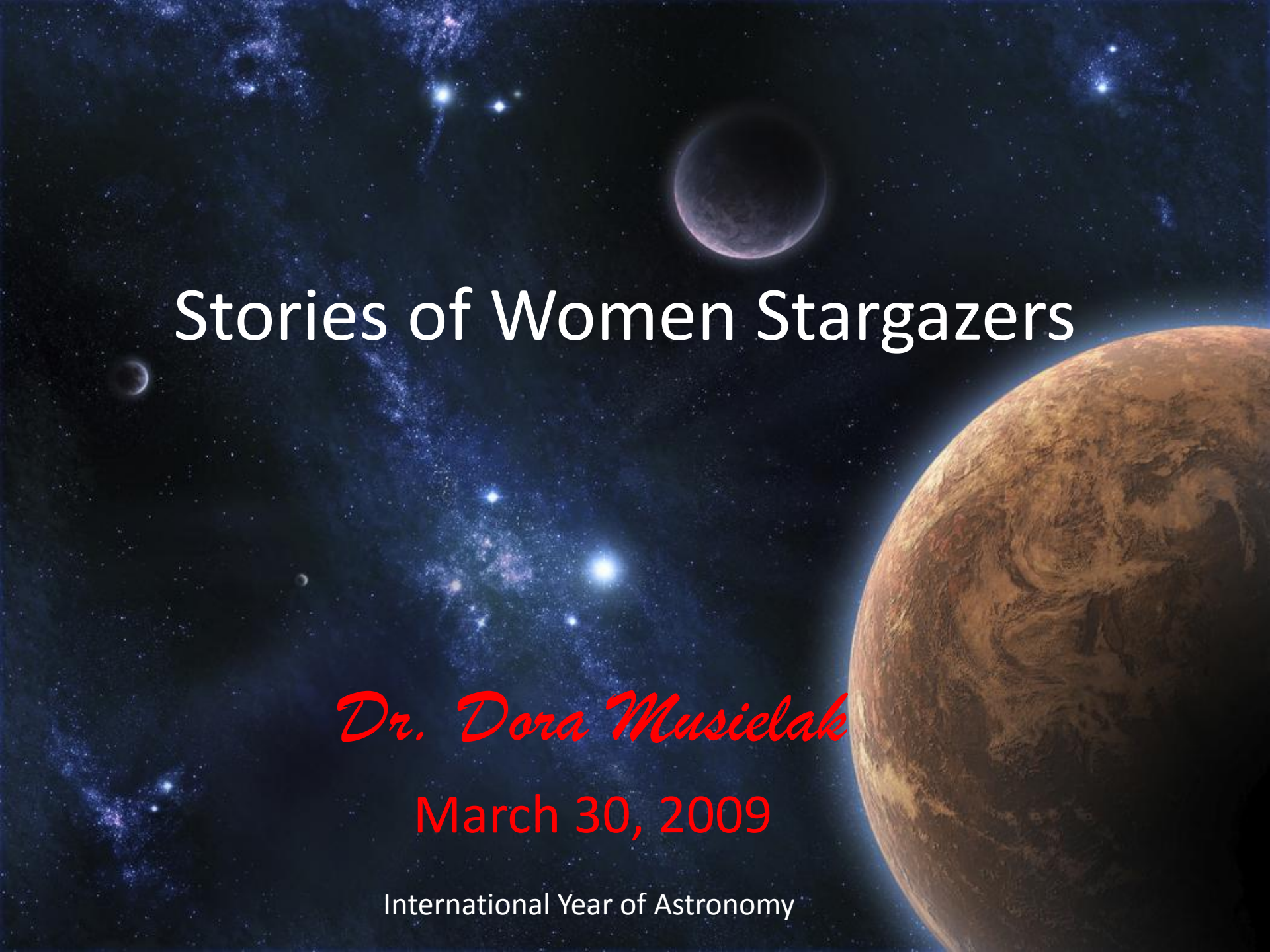


Stories of Women Stargazers

Dr. Dora Musielak

March 30, 2009

International Year of Astronomy

Space Age

17th Century

Copernicus

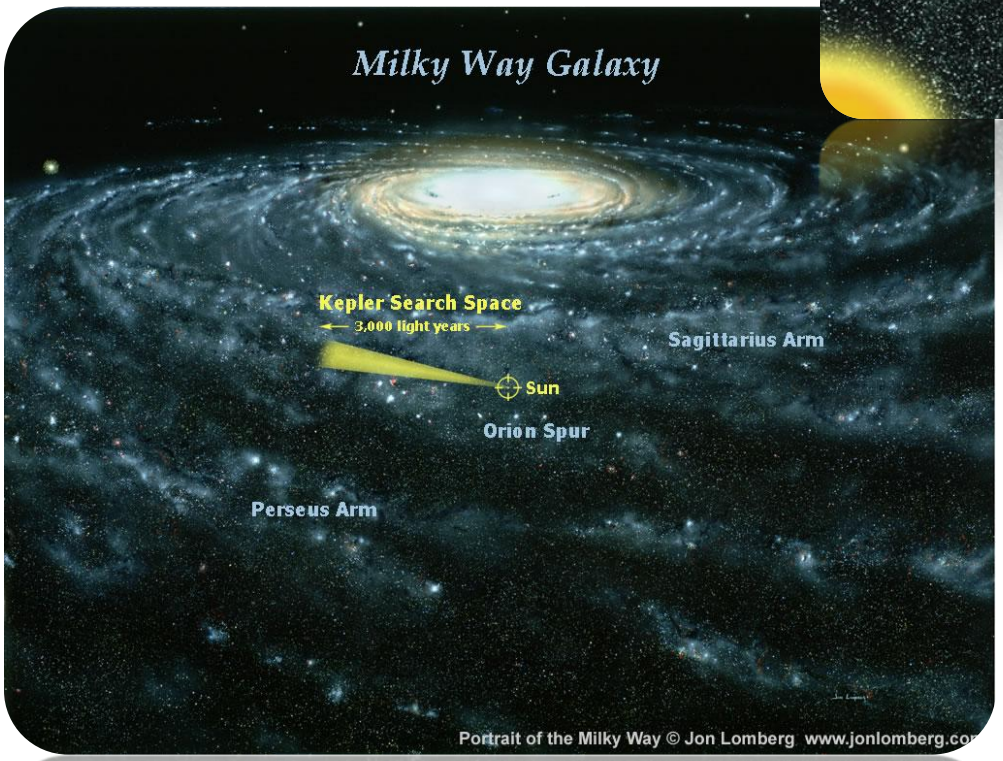
1543: Copernicus publishes heliocentric theory and with it he starts a scientific revolution.

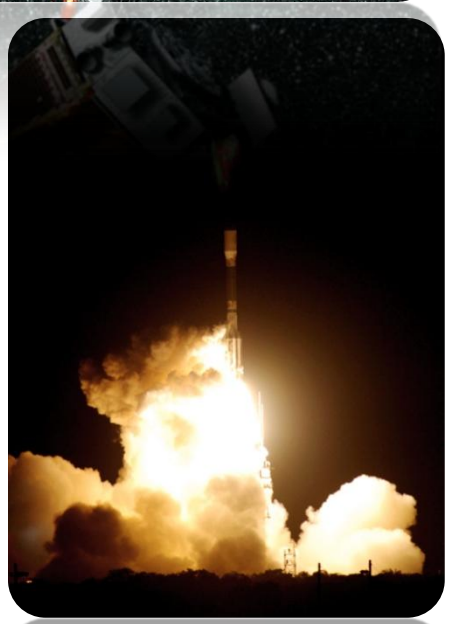
- 1605: Kepler investigates elliptical orbits of planets using observations of Tycho Brahe. Kepler finds that planets' positions follow three relatively simple mathematical laws.
- 1609: Galileo turns his telescope to heavens, starting modern astronomy.
- 1687: Newton publishes his revolutionary *Philosophiae Naturalis Principia Mathematica* establishing the theory of universal gravitation, a turning point in history of science.

- 1957: Sputnik 1 is lunched into space.
- 1961: First humans reach outer space
- 1969: First humans reach Moon
- 1990: Hubble launched.
- 1995: First verified exoplanet discovered.
- 1998: Dark energy and dark matter.
- 2001: Black hole detected in center of Milky Way
- 2009: Planet-hunter Kepler blasts off

NASA Planet Hunter Blasts into Space!

- Kepler, a planet-hunting telescope, rocketed into space March 6, 2009 on a historic voyage to track down other planets like ours in our Galaxy.





"*Urania*, the muse of astronomy, was a woman;

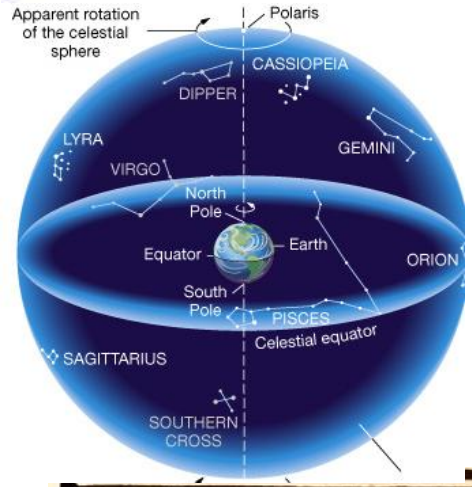
and, although most of her devotees have been men, the number of the gentler sex who have achieved success in the cultivation of the science of the stars has been much larger than is usually supposed."

H.J. Mozans (1913)

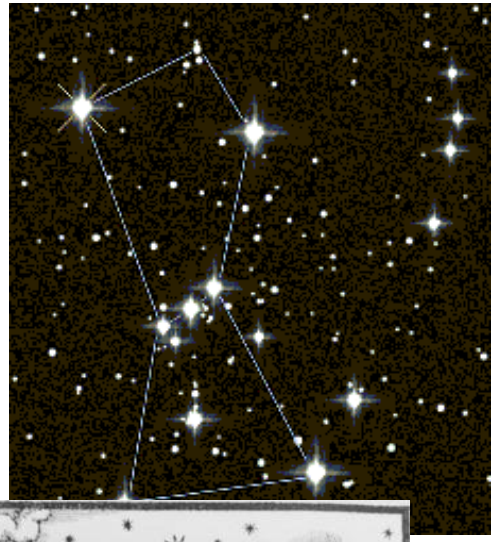
At the beginning….

To people, and to women in particular, astronomy must have been purely contemplative; for then, as today, the glory of the heavens spoke to the soul of woman, which has never changed.

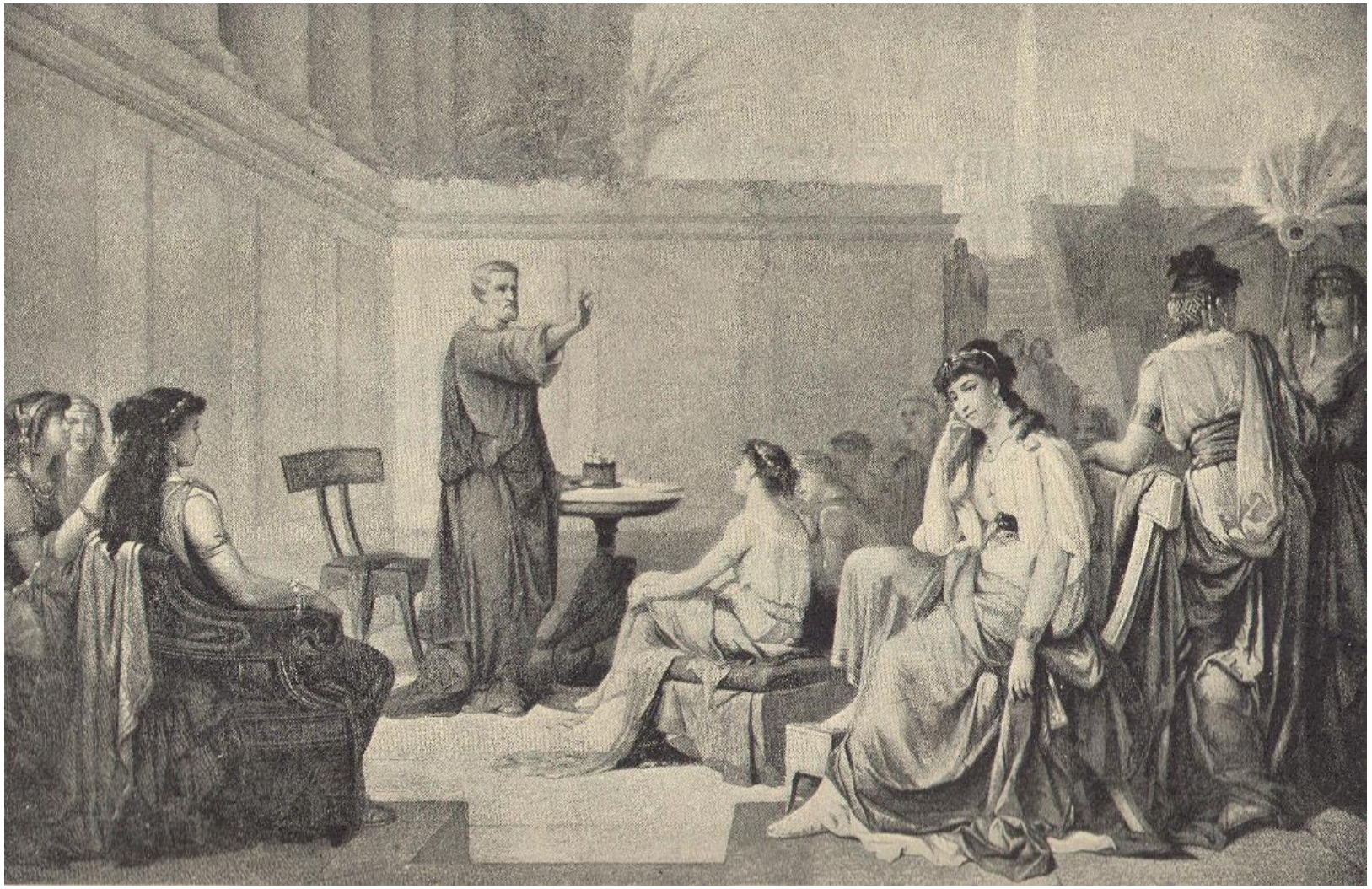
Later…



Contemplation soon gave place to observational and educational astronomy; woman's interest intensified, and her desire to understand the rhythms of the sky shaped her intellect…

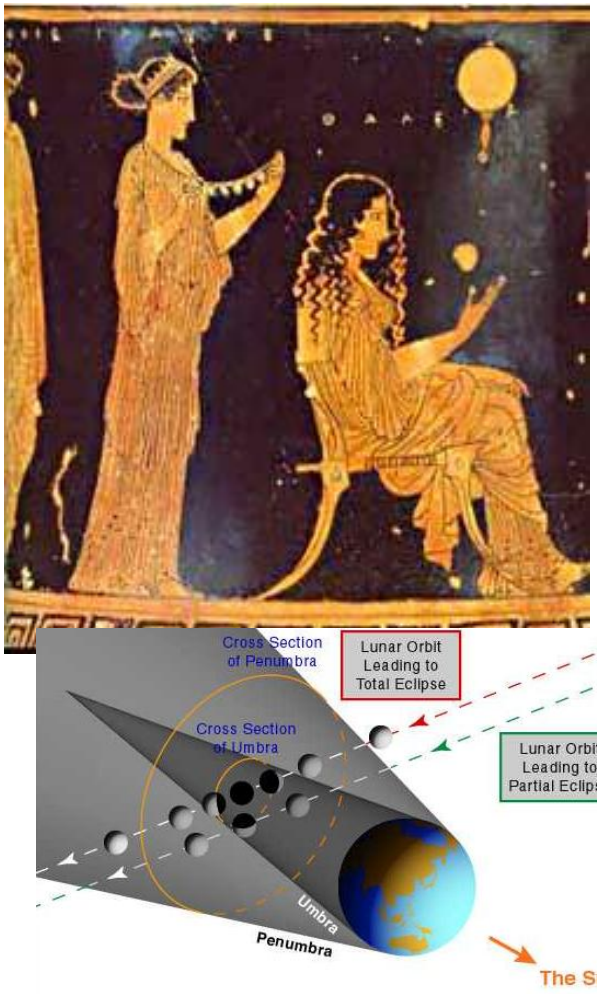


Theano of Samos and Pythagoras c. 550 B.C.

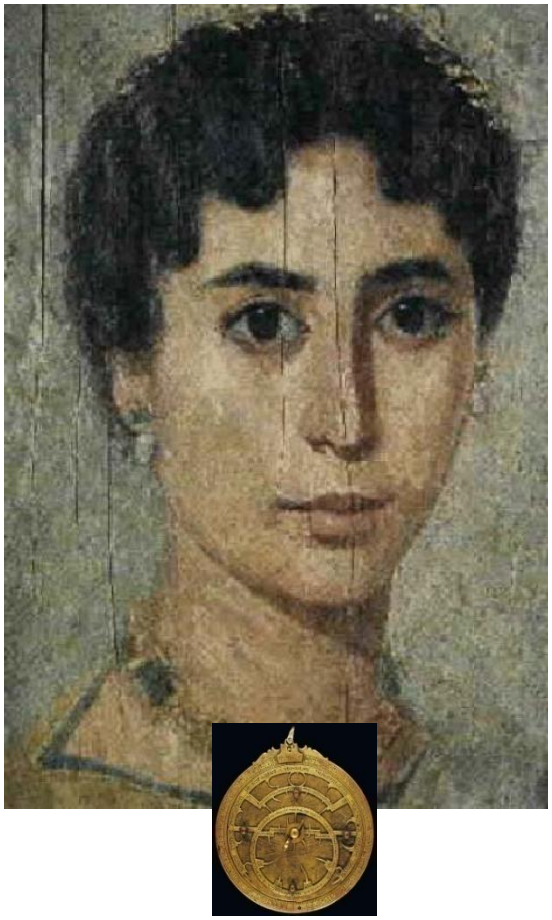


Aglaonice or Aganice (c. 200 B.C.)

- Woman astronomer considered by some as Greek (daughter of king Hegetoris of Thessaly), others say she was Egyptian, daughter of Pharaoh Sesostris.
- Regarded as a sorceress for her ability “to make moon disappear from the sky,” which we interpret to mean she could predict lunar eclipses.
- She knew lunar cycle *Saros*, a period of 18+ years, during which eclipses of Moon recur in nearly same order as during preceding period.
- Contemporary of Eratosthenes of Cyrene



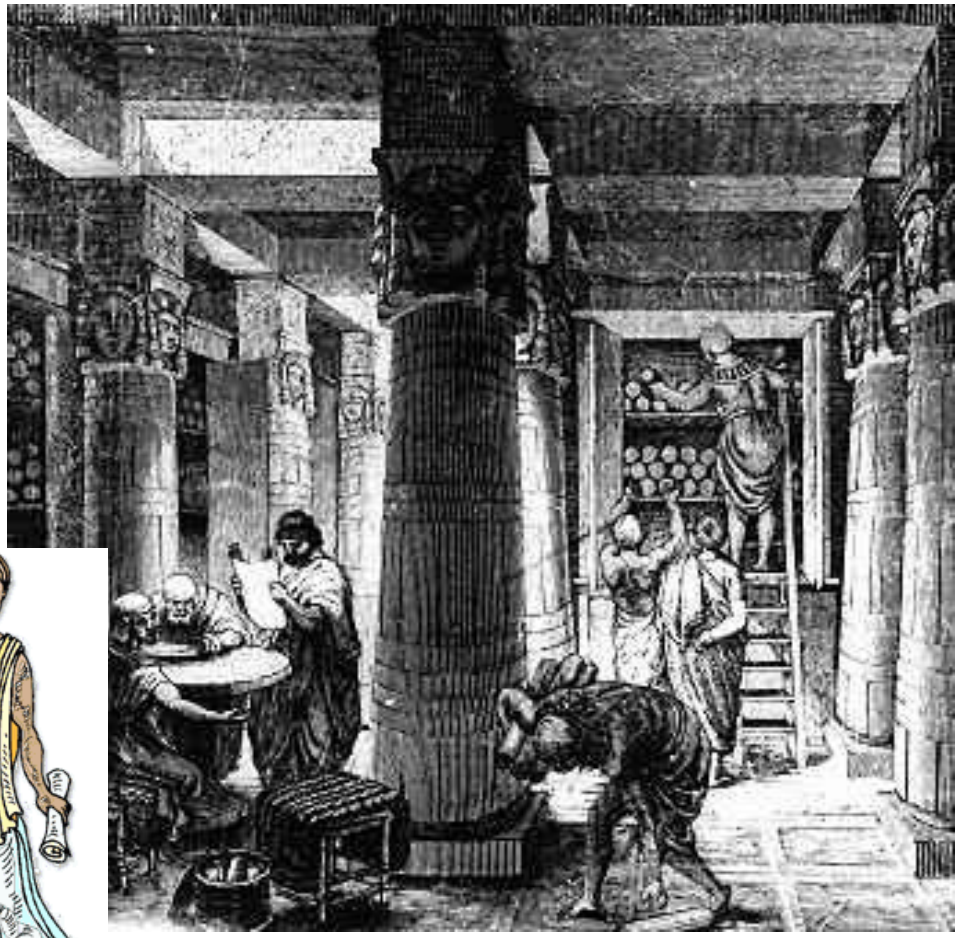
Hypatia of Alexandria (c. 370 – 415 A.D.)



Astrolabe measured how high north star is above horizon to determine latitude. Also used to measure height of a structure as a proportion of distance from measuring point.

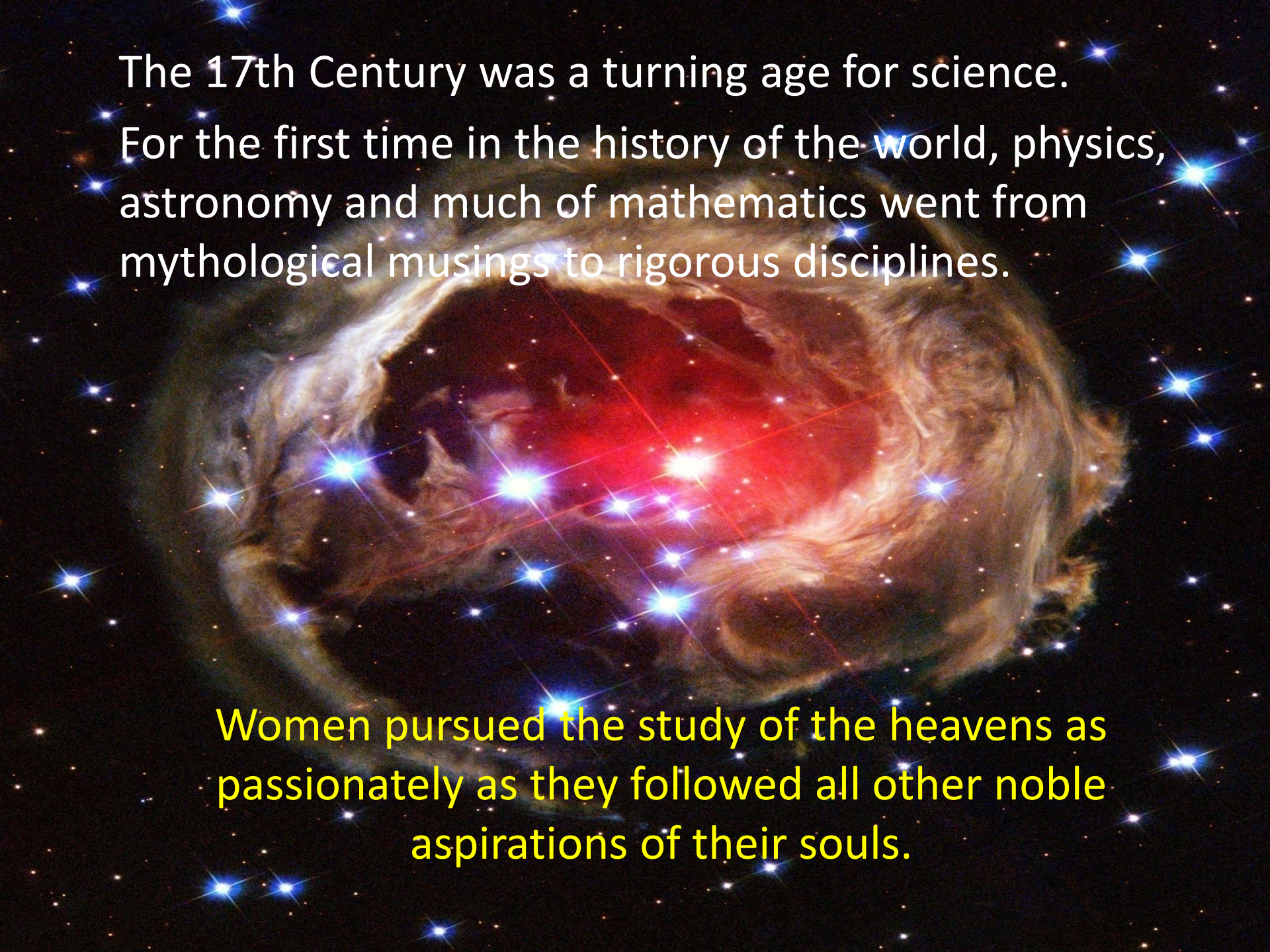
- First woman scholar to attain eminence as mathematician and astronomer.
- Taught by her father, mathematician Theon who was astronomer at Alexandria Museum (Egypt).
- Some think she invented an astrolabe, an astronomical instrument to locate and predict positions of Sun. Moon, planets, and stars.
- Documents from her student, Synesius of Cyrene, survive today.
- Ranked with masters of astronomical science Ptolmy, Erastosthenes, and Aristarchus.
- Died tragically, brutally murdered by a mob.

Alexandria Library



Hypatia as imagined by Raphael

The School of Athens, Fresco by Rapahel (1509-1510) in Vatican City

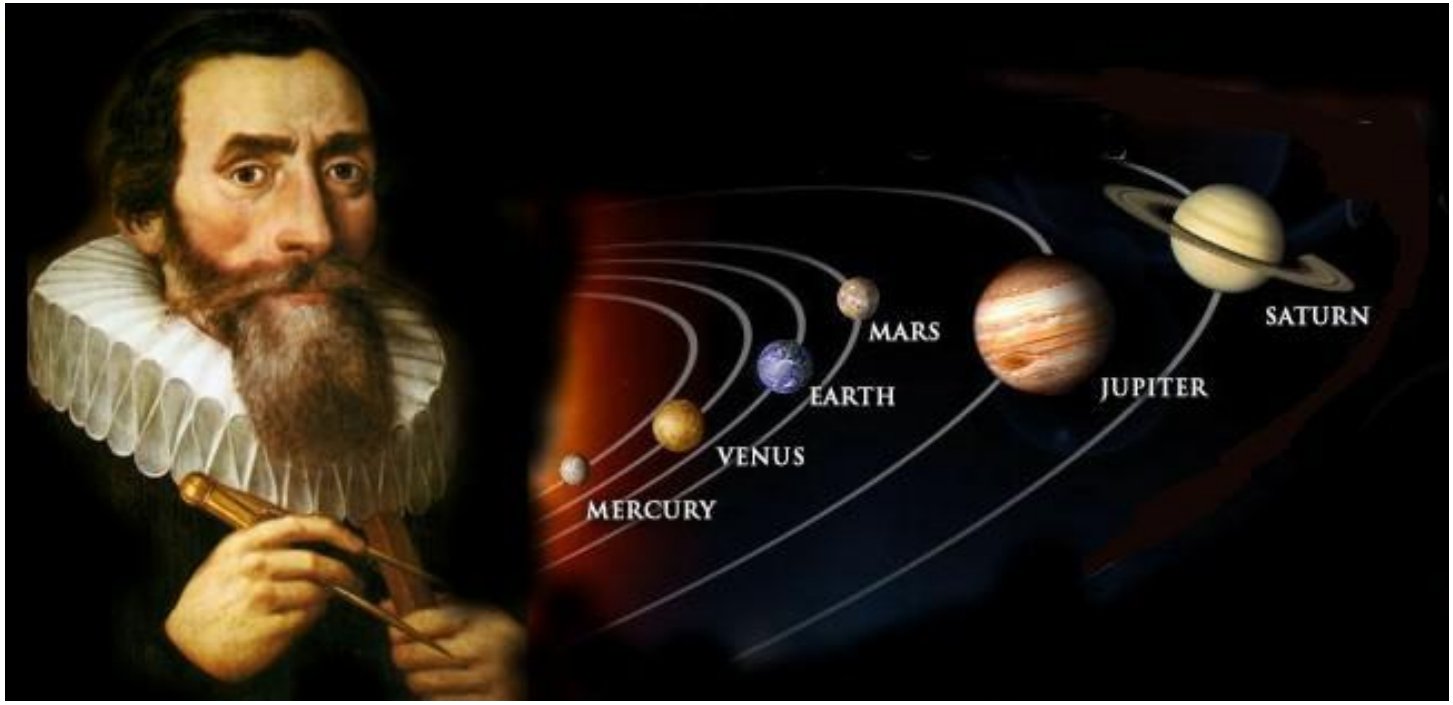


The 17th Century was a turning age for science.

For the first time in the history of the world, physics, astronomy and much of mathematics went from mythological musings to rigorous disciplines.

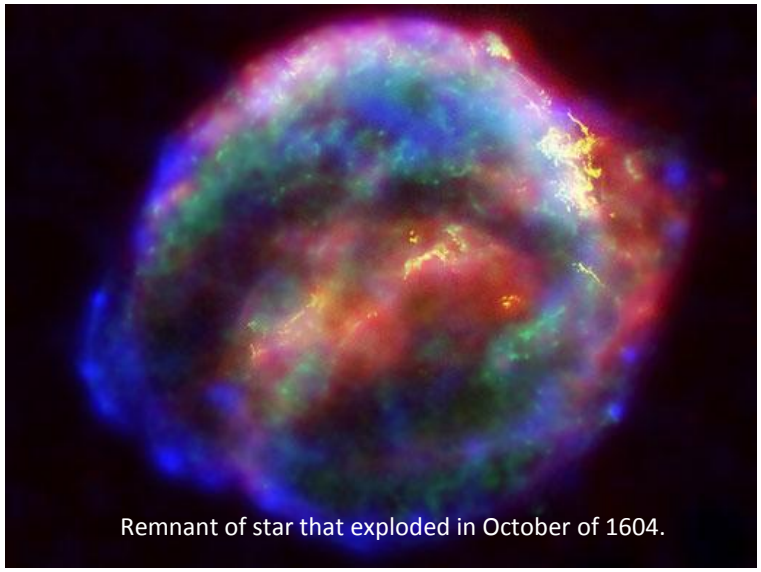
Women pursued the study of the heavens as passionately as they followed all other noble aspirations of their souls.

Dawn of 17th Century

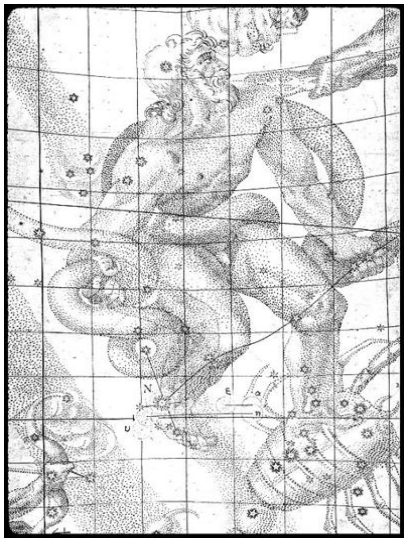


- Johannes Kepler (1571 - 1630) champions Copernicus Heliocentric Model of Solar System (Copernicus, 1543)
- 1605: Kepler starts investigating elliptical orbits of planets using observations of Tycho Brahe.
- 1609 - 1619: Kepler finds that Brahe's observations of planets' positions follow three simple mathematical laws.

Kepler's Supernova Remnant



Remnant of star that exploded in October of 1604.



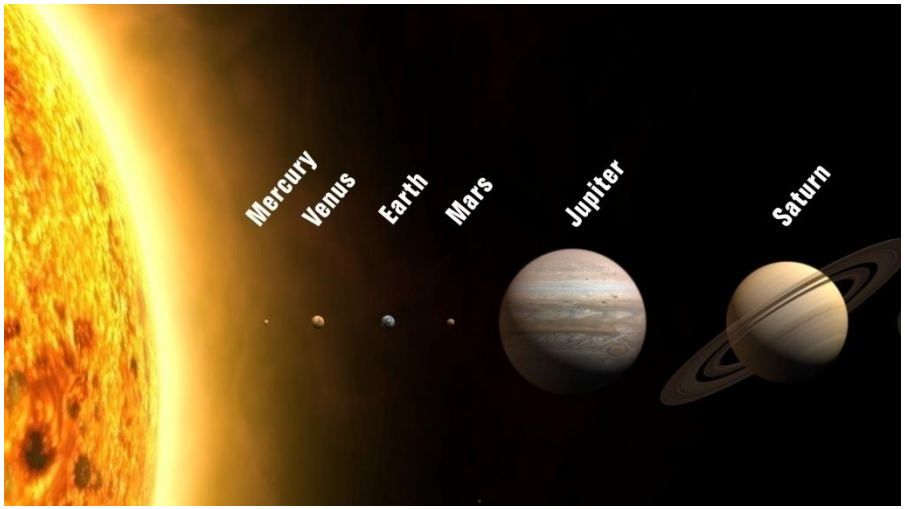
In 1604, Kepler discovered a "new star" that was" brighter than anything else in night sky except Venus." It was actually the end of a star, but he did not know, and because it was a new in the sky Kepler called it *stella nova*.

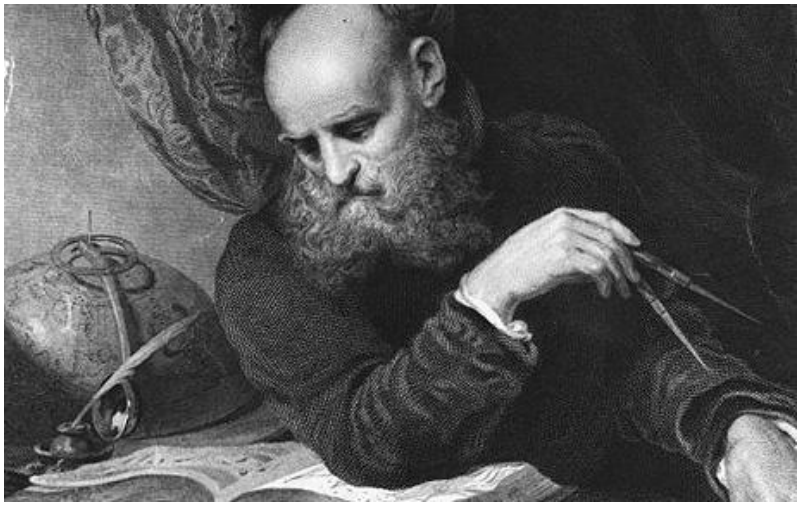
Kepler documented the new point of light near foot of Ophiuchus and kept very detailed records until star faded from view. He published a book on his observations, *De Stella Nova*, drawing image to show position of new star (an "N" in foot of Ophiuchus).

Supernova is a stellar explosion that cause a burst of radiation. Remnant of Kepler's supernova was discovered by astronomer in 1943 who reported discovering "a small patch of emission nebulosity, which is undoubtedly a part of the masses ejected during the outburst."

Galileo Galilei (1564-1642)

- At dawn of 17th century, before telescope, astronomers saw one Sun, one Moon, five planets, and a fixed array of stars.
- 1608: telescope invented in Netherlands, not as astronomical device.
- 1609: Galileo constructs his own telescope and turns it towards the sky.

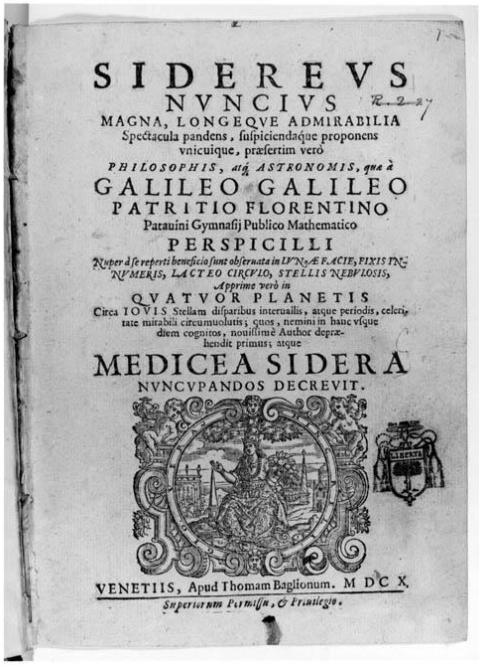


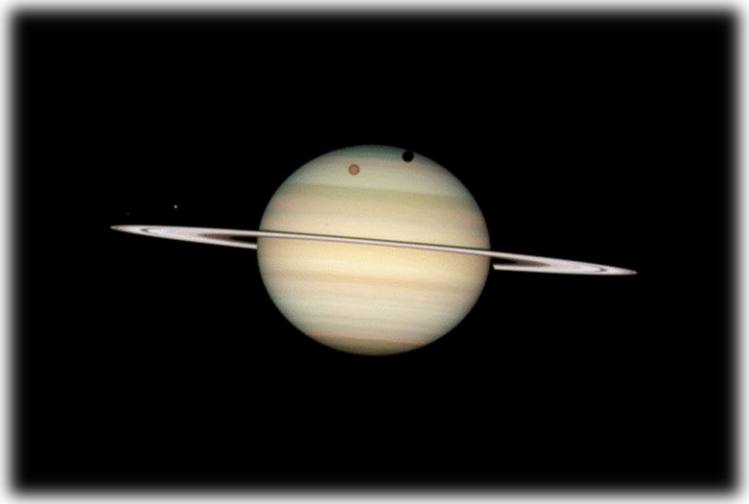


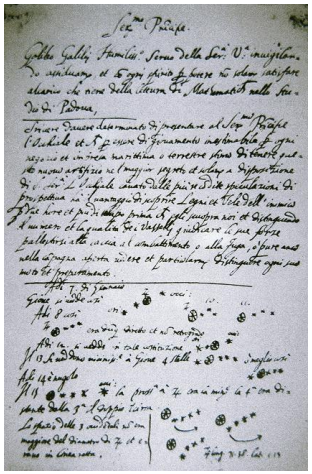
With his observations of the cosmos, Galileo triggered a chain of events that shook the foundation of human thought and launched an intellectual voyage that would lets us see deeper into the heavens.

Starry Messenger

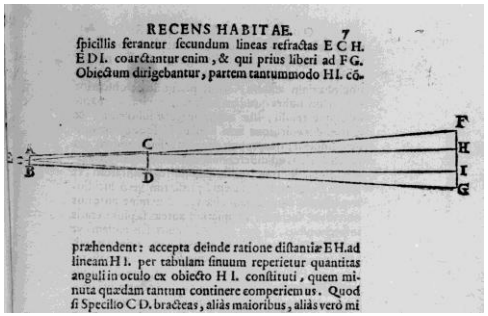
- In 1610, Galileo published a brief account of his amazing discoveries:
  - Moon craters
  - Individual stars in Milky Way
  - Four large moons of Jupiter


SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuper à se reperti beneficio sunt obseruata in LVNÆ FACIE, FIXIS IN-NVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam disparibus interuallis, atque periodis, celeritate mirabili circumuolutis; quos, nemini in hanc vsque diem cognitos, nouissimè Author deprehendit primus; atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
VENETIIS, Apud Thomam Baglionum. M DC X.
Superiorum Permissu, & Priuilegio.



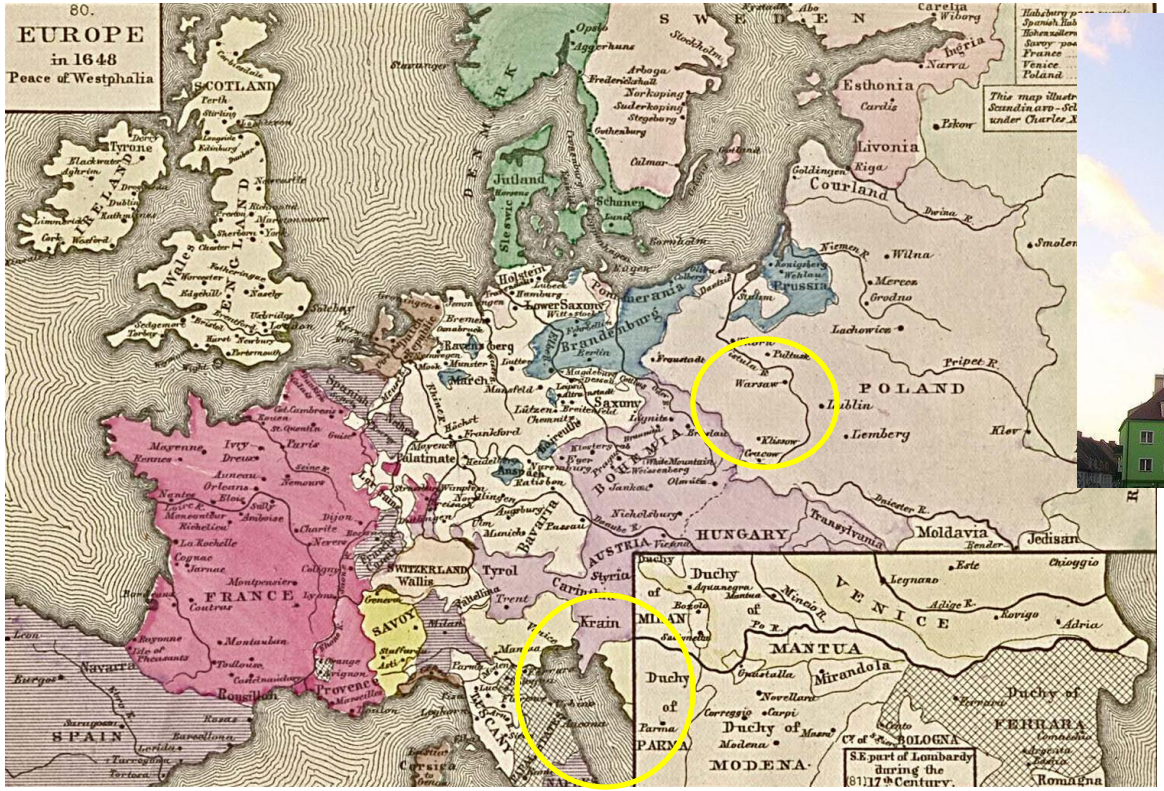


Galileo's Telescope


RECENS HABITAE. 7
spicillis ferantur secundum lineas refractas E C H.
EDI. coarctantur enim, & qui prius liberi ad FG.
Obiectum dirigebantur, partem tantummodo HI. cō-
prahendent: accepta deinde ratione distantiæ EH ad
lineam HI. per tabulam sinuum reperietur quantitas
anguli in oculo ex obiecto HI. constituti, quem mi-
nuta quædam tantum continere comperiemus. Quod
si Specillo CD. bracteas, aliàs maioribus, aliàs verò mi

c.1610 in Poland

- As Galileo explored the sky with his telescope, a little girl was born in Wołów, Poland, eldest daughter of a well-known doctor. Her name was Maria Kunicka (Cunitz)
- She was a gifted girl that grew up to become an astronomer and simplified Kepler's planetary tables.



In 1630, Maria married mathematician-astronomer Eliasza Kreszmara in Byczyna, a small Polish town.

Galileo

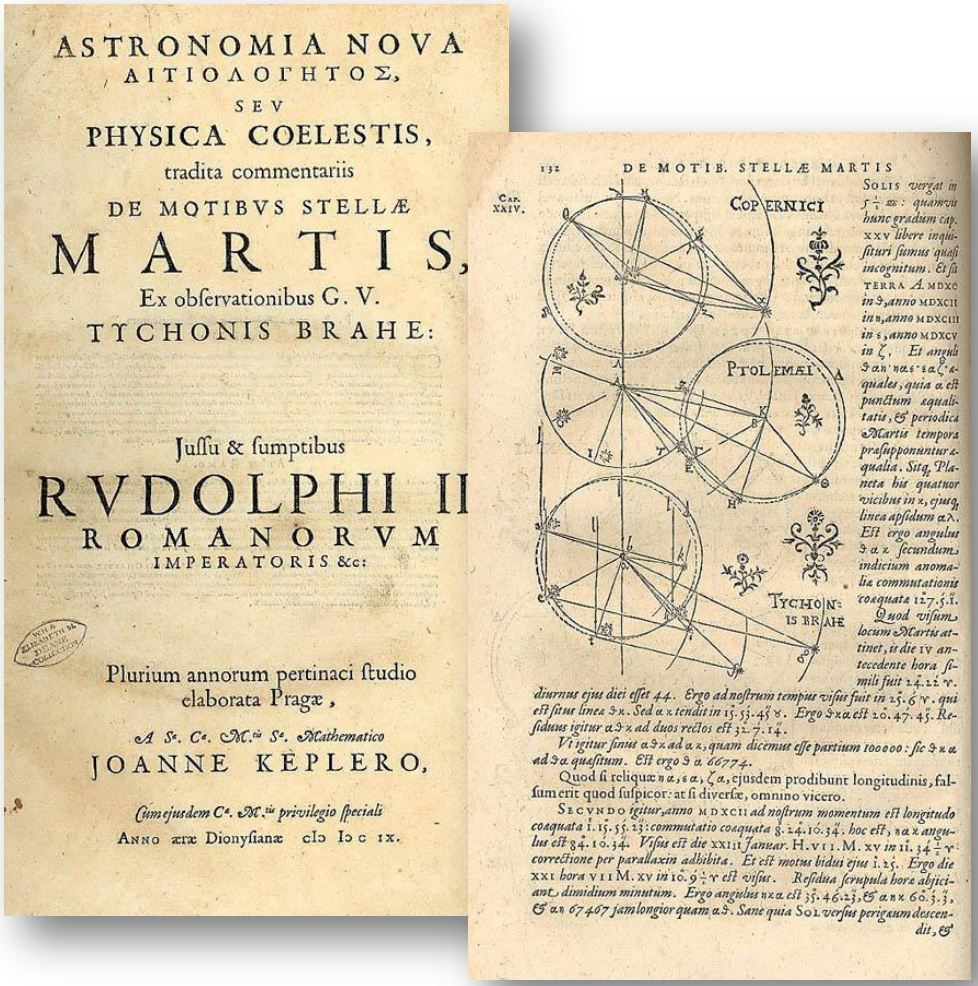
Europe between 1630 -1640

- Kepler died in 1630.
- Astronomers were fascinated by what they saw through telescopes, were digesting Kepler's laws of planetary motion, and were learning to use Kepler's Rudolphine Tables.
- Maria Kunicka had grown, equally enthralled by her own study of mathematics and astronomy.

Astronomers were then guided by Kepler's *Astronomia nova (1609), Epitome astronomiae Copernicanae* (1621), and his Rudolphine Tables (1627).

Kepler's *Astronomia Nova* (1609)

- Kepler's most important work in astronomy.
- Focus on Mars orbit, Kepler abandoned circle, which had dominated accounts of planetary motions from Aristotle and Ptolemy.
- Using Tycho Brahe's planetary tables, Kepler found that orbit of Mars fitted ellipse shape.
- He formulated two laws of planetary motions, stating that all planets move in elliptical orbits.
- *Astronomia nova* is prefaced with a short autobiography.



ASTRONOMIA NOVA
AITIOΛOΓHTOΣ,
SEV
PHYSICA COELESTIS,
tradita commentariis
DE MOTIBVS STELLÆ
MARTIS,
Ex observationibus G. V.
TYCHONIS BRAHE:

Jussu & sumptibus
RVDOLPHI II
ROMANORVM
IMPERATORIS &c:

Plurium annorum pertinaci studio
elaborata Pragæ,

A S^e. C^a. M^ti. S^a. Mathematico
JOANNE KEPLERO,

Cum ejusdem C^a. M^ti. privilegio speciali
ANNO æræ Dionysianæ CIↃ IↃ C IX.

132 DE MOTIB. STELLÆ MARTIS

Cap. XXIV.

COPERNICI

PTOLEMÆI

TYCHONIS BRAHE

Solis vergat in ♑ : quamvis hunc gradum cap. XXV libere inquisituri sumus quasi incognitum. Et si TERRA A. MDXC in ♑, anno MDXCII in ♓, anno MDXCIII in ♉, anno MDXCV in ♊. Et anguli ♑a ♓a ♉a æquales, quia a est punctum æqualitatis, & periodica Martis tempora præsupponuntur æqualia. Sitq; Planeta his quatuor vicibus in x, ejusq; linea apsidum aλ. Est ergo angulus ♑a x secundum indicium anomaliæ commutationis coæquata 127.5.1.

Quod visum locum Martis attinet, is die IV antecedente horæ simili fuit 24.22 ♈. diurnus ejus diei esset 44. Ergo ad nostrum tempus visus fuit in 25.6 ♈. qui est situs linea ♑x. Sed a x tendit in 15.53.48 ♉. Ergo ♑xa est 20.47.45. Residuus igitur a ♑ x ad duos rectos est 32.7.14.

Vi igitur sinus a ♑x ad a x, quam dicemus esse partium 100000: sic ♑x a ad ♑a quæsitum. Est ergo ♑a 66774.

Quod si reliquæ na, ea, ζa, ejusdem prodibunt longitudinis, falsum erit quod suspicor: at si diversæ, omnino vicero.

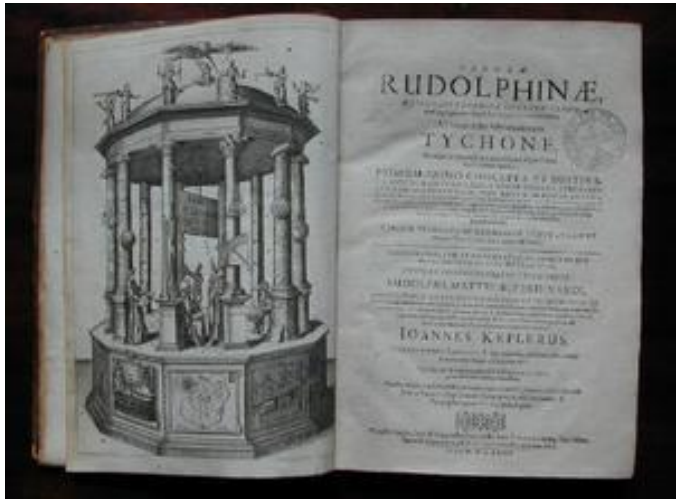
SECVNDO igitur, anno MDXCII ad nostrum momentum est longitudo coæquata 1.15.55.23: commutatio coæquata 8.24.10.34. hoc est, ♑x anguli est 84.10.34. Visus est die XXIII Januar. H. VII. M. XV in II. 34 ♈ correctione per parallaxin adhibita. Et est motus bidui ejus 1.25. Ergo die XXI hora VII M. XV in 10.9 ♈ est visus. Residua scrupula horæ abjiciant, dimidium minutum. Ergo anguli ♑xa est 35.46.23, & ♑x 60.3.3, & ♑a 67407 jam longior quam a ♑. Sane quia SOL versus perigæum descendit, &

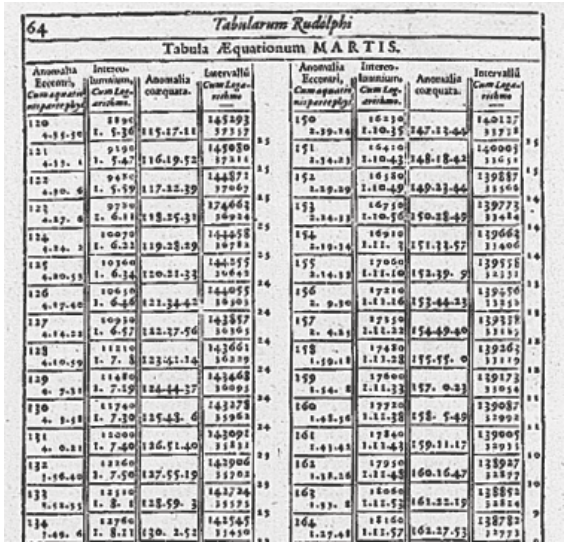
Astronomia nova - seu, Physica coelestis, tradita commentariis De motibus stellae martis, ex observationibus G.V. Tychonis Brahe. Pragae : 1609.

Kepler's Rudolphine Tables (1627)

- *Tabulae Rudolphinae* is a star catalog and planetary tables .
- Named after Emperor Rudolf II, tables contain positions for 1,006 stars measured by Tycho Brahe, and 400 more stars from Ptolemy and Johann Bayer with directions for locating planets.
- Rudolphine Tables included many function tables of logarithms and antilogarithms, and instructive examples for computing planetary positions.
- To find longitude of a planet at a given time required solving what's now called Kepler's equation (transcendental equation):

  $x = 1 - e \sin[x]$





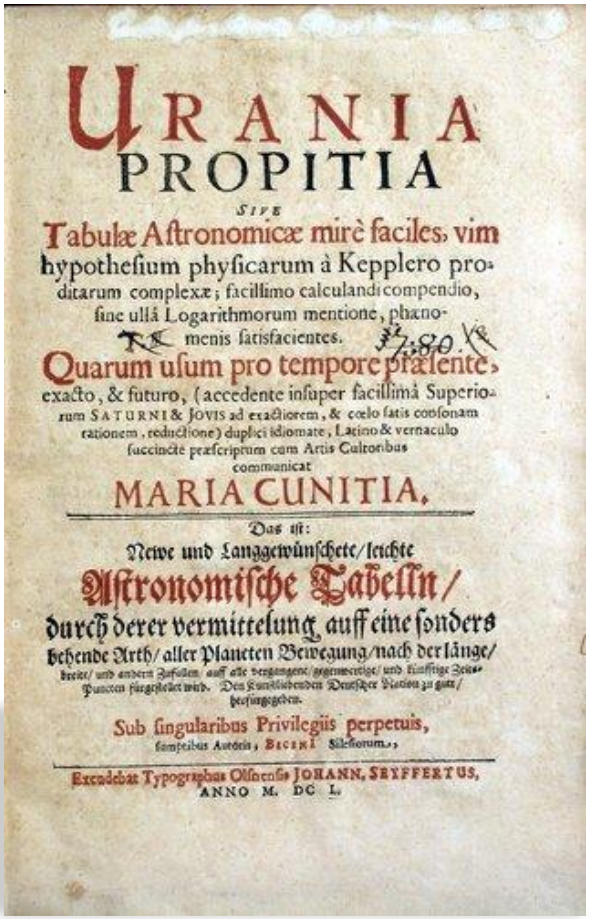
Maria Cunitz (sometime after 1640)

- Maria lived for a while in Łubnice, Poland, an estate of Cistercian convent of Ołobok.
- There she wrote her most important work: an astronomy book that explained Kepler's laws and attempted to improve his astronomical tables.
- She wrote in both Latin and German, to increase accessibility of her work.
- King of Poland, Wladyslaw IV (1632-1648) was trying to insulate Poland from the conflict of 30 year war.

Maria Cunitz: Second Hypatia

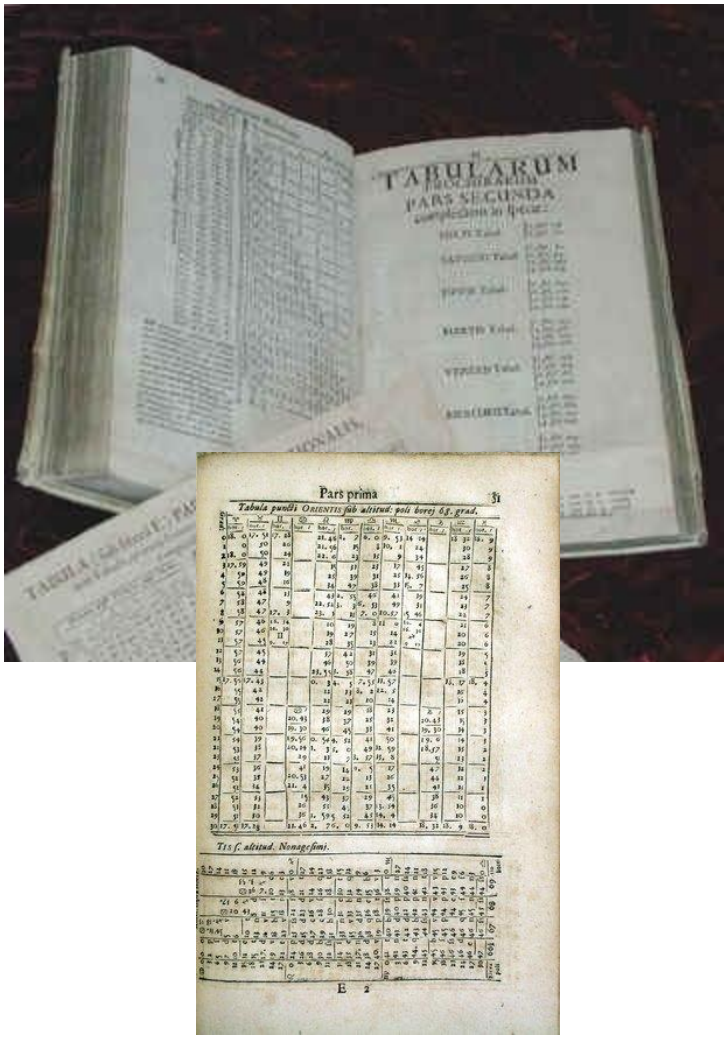
- In 1650, Cunitz published *Urania propitia*, a book in which she provided new tables, new ephemera, and a more elegant solution to Kepler's Problem.
- Kepler's problem is a special case of two-body problem.
- Cunitz was also called the "Silesian Pallas" (In Greek mythology, a goddess of wisdom)
- In his 1727 book *Educated Silesian Women and Female Poets*, Johan Kaspar Elberti wrote that

(Maria) Cunicia or Cunitzin was a well-educated woman, like a queen among the Silesian womanhood. She was able to converse in 7 languages, German, Italian, French, Polish, Latin, Greek and Hebrew, was an experienced musician and an accomplished painter. She was a dedicated astrologist and especially enjoyed astronomical problems.


URANIA
PROPITIA
SIVE
Tabulæ Astronomicæ mirè faciles, vim
hypotheſium phyſicarum à Kepplero pro-
ditarum complexæ; facillimo calculandi compendio,
ſine ullâ Logarithmorum mentione, phæno-
menis ſatisfacientes.
Quarum uſum pro tempore præſente,
exacto, & futuro, (accedente inſuper facillimâ Superio-
rum SATURNI & JOVIS ad exactiorem, & cœlo ſatis conſonam
rationem, reductione) duplici idiomate, Latino & vernaculo
ſuccinctè præſcriptum cum Artis Cultoribus
communicat
MARIA CUNITIA.
Das iſt:
Newe und Langgewünſchete/leichte
Aſtronomiſche Tabellen/
durch derer vermittelung auff eine ſonders
behende Arth/ aller Planeten Bewegung/nach der länge/
breite/ und andern Zufällen auff alle vergangene/gegenwertige/ und künfftige Zeit-
Puncten fürgeſtellet wird. Den kunſtliebenden Deutſcher Nation zu gute/
herfürgegeben.
Sub ſingularibus Privilegiis perpetuis,
ſumptibus Autoris, BICINI Silesiorum.,
Excudebat Typographus Olſnenſis JOHANN. SEYFFERTUS,
ANNO M. DC L.

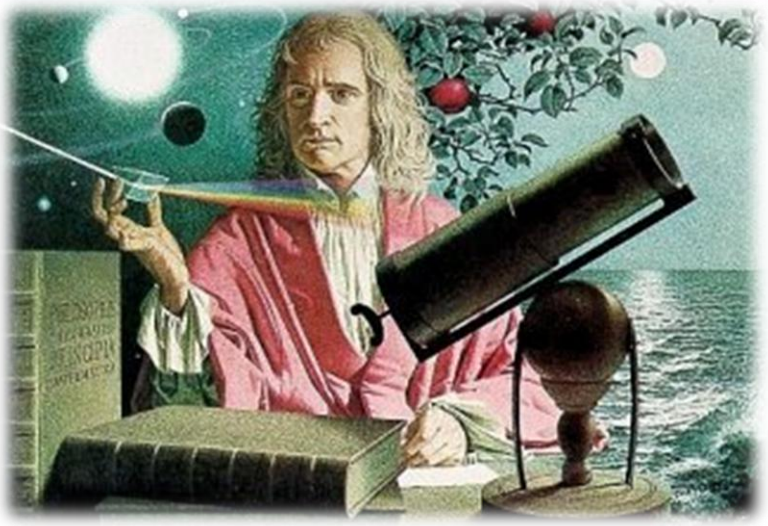
Urania Propitia (1650)

- Maria Cunitz's book examines theory and art of astronomy, presents her calculations, and gives a guide to astronomy for nonscientists.
- Cunitz wrote that there are four components to astronomy:
  - carefully recorded observations,
  - construction of astronomical instruments,
  - theory,
  - calculations or tables of predictions.



Newton (1642-1727)

- Kepler had proposed three laws of planetary motion that applied to the known planets.
- What about the motion of other bodies in the Universe? Kepler's laws were empirical and there was no doubt the laws worked, but….
- Neither Maria Cunitz, nor her contemporaries knew that one day an Englishman would demonstrate that the motion of objects on the Earth and the universe could be described by three laws of motion.

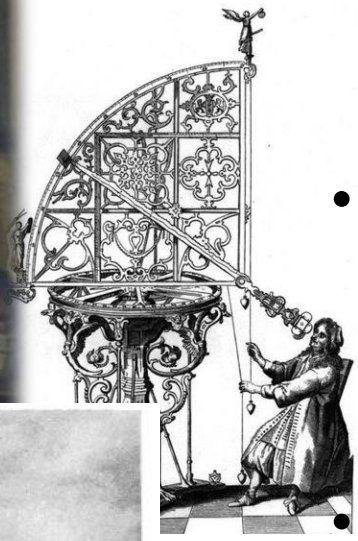


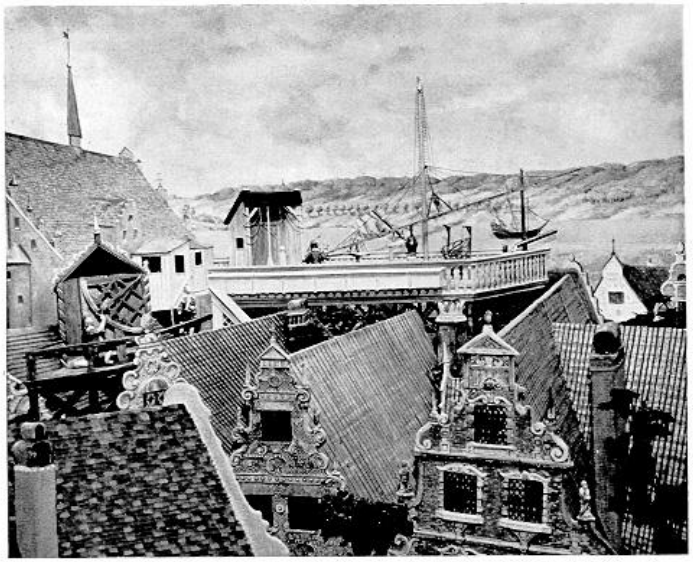
- Isaac Newton went on to show that Kepler's laws were in fact special cases of his laws if a force of a particular kind (gravitational force) were postulated to exist between all objects in the Universe.
- ***Newton's revolutionary discovery would not happen until 1687.***

In this house in the 17th century was born Astronomer Maria Kunic

* Cunitz was born in Wołów (Poland)
* Married, lived, and died in Byczyna
* Wrote her book in Łubnice (Poland)

1647 Gdansk (Poland

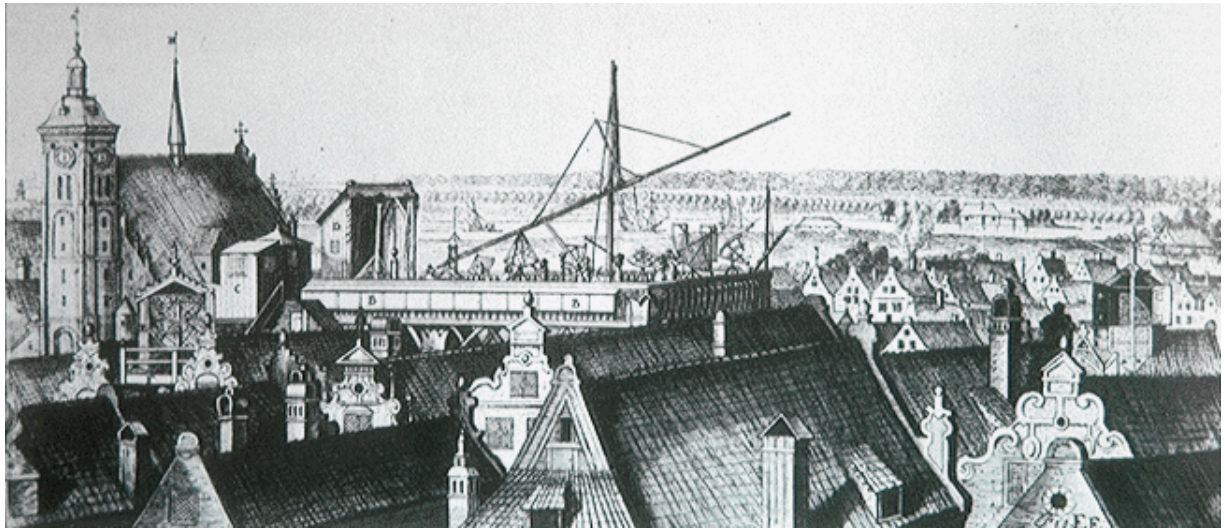




- When Maria Cunitz worked on her manuscript, a little Polish girl was born miles away, in Gdansk, the largest city of Poland by the Baltic Sea.
- There, a daring astronomer was dazzling the world with his grand observatory, possibly the largest ever built at that time, and his pioneering lunar cartography.
- The little Polish girl was destined to become the astronomer's wife, his assistant, and the first woman astronomer observer and recorder of stars.

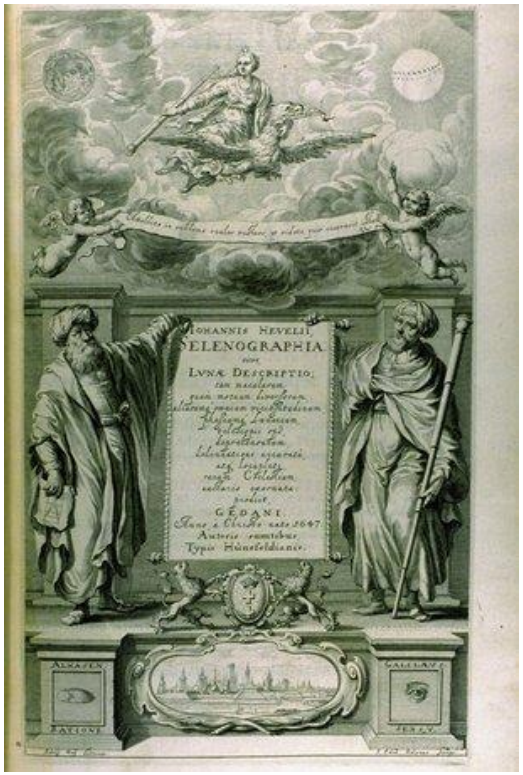
Johannes Hevelius

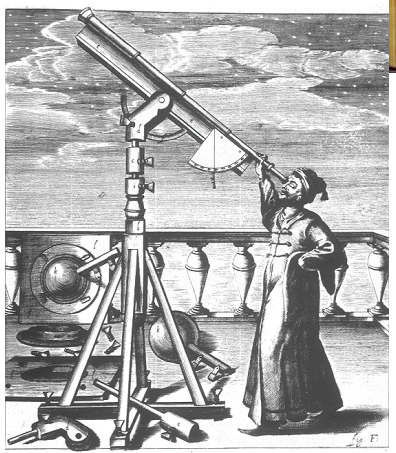
- Polish astronomer born on 28 January 1611 in Gdansk, Poland.
- He studied Law at Leiden, Netherlands, traveled through Europe, and returned to Gdansk where he took his family's brewing business.
- In 1639, he started to fully devote himself to astronomy, tapping into his family wealth to construct a private observatory.
- Through his travels, Hevelius came in contact and corresponded with many astronomers and, due to his excellent work, in 1664 Hevelius was inducted into London Royal Society.
- He was sponsored by Polish King Jan III Sobieski through a generous pension.



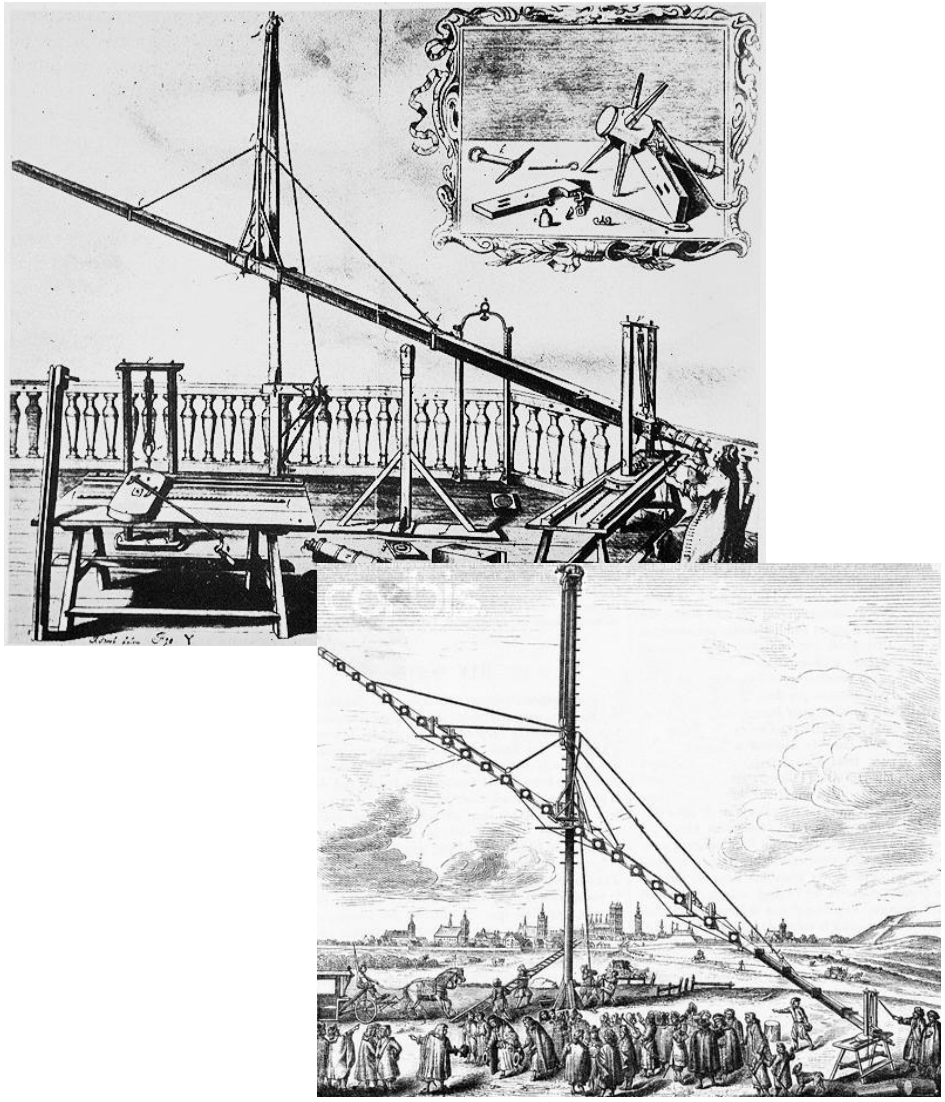
Race for the Moon

- Galileo's book set off the 17th century race for the Moon ➔ astronomer's race to map its surface, which was accomplished by Hevelius.
- In 1647, Hevelius published *Selenographia*, first lunar atlas.





Telescope advances in 17th Century

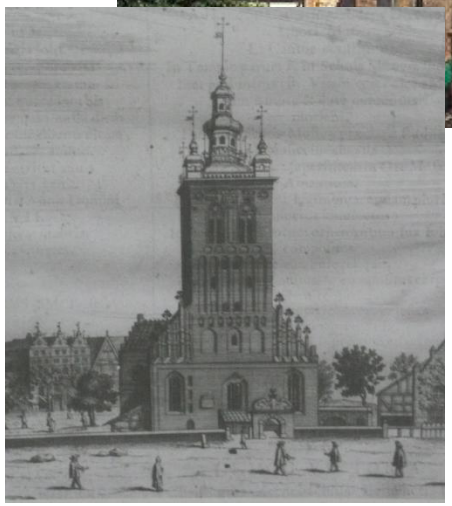


- Refracting telescopes became extraordinarily long.
- Hevelius led the race to build a super telescope
- Hevelius telescope (50x mag) had 150 ft (46 m) focal length. Tube was suspended by ropes and pulleys.
- The telescope tube was not light-tight – could only be used in total darkness.

Elisabetha (Elzbieta) Koopman

- Elisabetha was born 17 Jan 1647 in Gdansk, Poland.
- She was fascinated by the night sky, and when still a child, she approached Hevelius. He promised the little girl that he would show her "the wonders of the heavens" when she was older.
- Hevelius's first wife died in March 1662; some time later, Elisabetha again approached Hevelius and reminded him that he promised to show her the heavens from his observatory when she was older−and now she was fifteen.
- Elisabetha had become even more enthusiastic about astronomy .

Elisabetha and Hevelius



- Hevelius, age 52, took the pretty sixteen-year old Catherina Elisabetha Koopman, daughter of another prosperous Gdansk merchant, as his second wife and astronomer assistant.
- They were married in St. Catherine Church, Gdansk, on February 3, 1663.

The astronomer found in the young, much admired lady, a skilful and untiring, and understanding and loyal helpmate in his observations and labours.

Elisabetha and her passion

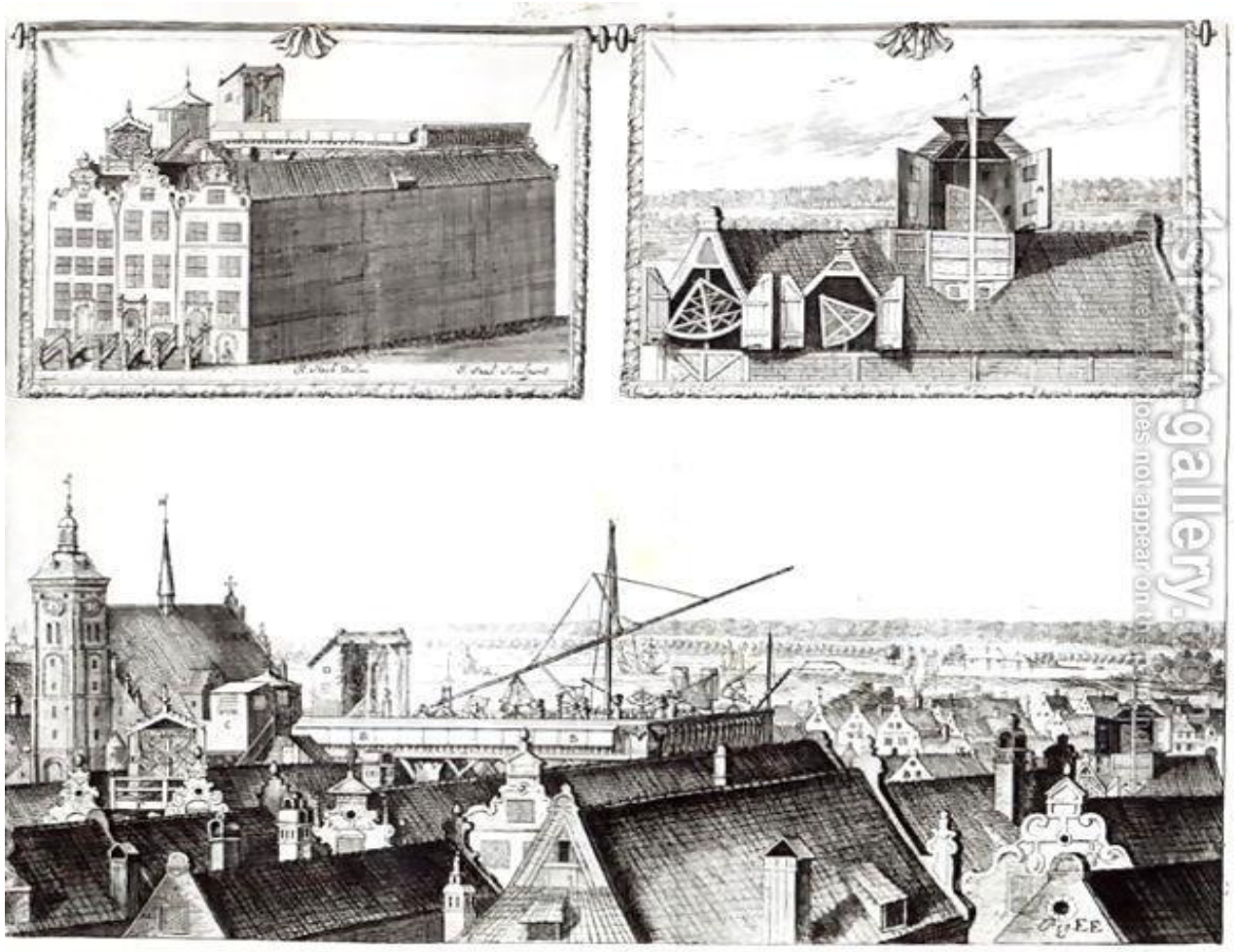
"And when in the star-lit night she followed with enraptured gaze and beating heart, through his giant telescope, the shinning full moon on her silent path, she exclaimed with enthusiasm:

'*To remain and gaze here always, to be allowed to explore and proclaim with you the wonder of the heavens, that would make me perfectly happy*!'

And the worthy man felt that it might make him happy too."

E.F. MacPike, *Hevelius, Flamsteed and Halley*. London, 1937, pp. 3-4

Elisabetha and Hevelius Heaven



- Sternenburg observatory, illustration from *Machina Coelestis* by Johann Hevelius, engraved by Izaak Saal, 1674, a painting by Andrzej Stech.

Hevelius and Halley

- Hevelius had exceptionally keen eyesight, to the point of being able to see stars of the seventh magnitude.
- Following the lead of Tycho Brahe, Hevelius constructed very large measuring instruments, and managed to improve the accuracy of measured naked-eye stellar positions down to 1 minute of arc on a routine basis, in doing so exceeding even Tycho in accuracy.
- In 1670s, Hevelius became involved in a heated controversy with John Flamsteed (1646-1719) and later Robert Hooke (1635-1703), who advocated the use of telescope and micrometers for accurate determinations of stellar positions.
- The debate ended in 1679, when Edmund Halley (1656-1742), commissioned by the Royal Society, visited Hevelius in Gdansk.
- Halley confirmed to the Royal Society that Hevelius' position determination were as accurate as anything he could achieve with the state-of-the-art micrometric telescope he had taken along from England.

Fire Destroys Home and Telescopes

- Elisabetha and Hevelius home and observatory were destroyed by fire on 26 September 1679.
- Hevelius wrote to his patron King Louis XIV of France, explaining what happened that night. The beginning is useful in describing Elisabetha's contributions:-

  "On the unhappy evening before the fire I felt deeply troubled by unaccustomed fears. To lift my spirits, I persuaded my young wife, the faithful assistant for my nightly observations, to spend the night in our country retreat outside the walls of the city ..."

Elisabetha's correspondence

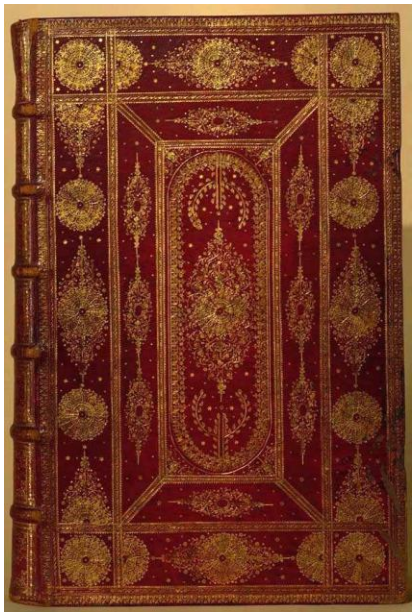
- A rumour reached England that Hevelius was dead.
- Elisabetha had asked Halley to buy a dress for her in England.
- In October 1679, Halley sent the dress to the secretary of Gdansk writing:-
- *"I quite realise that [Hevelius's] heartbroken spouse must be wearing sad-coloured apparel, yet for several reasons I have thought well to send the gown procured for her ... because I am not yet certain her husband is dead, in which case I judge nothing would be more unwelcome than delay ... since it is of silk and of the newest fashion, I am confident it will highly please Mme Hevelius, if only it should be granted to her to wear it ..."*
- After giving precise details of the cost of the silk and the making of the dress, Halley requests Elisabetha to send him three copies of Hevelius's books to cover the cost.
- Elisabetha wrote a letter in Latin to Halley, dated March 1680, asking for name of a doctor who he had recommended, when living in their home, as knowing of a diet that would cure arthritis. One assumes that it is Hevelius who suffers from arthritis and his wife is seeking a cure for him.

Elisabetha's Accomplishments

- **Elisabetha wrote Latin**; copies of her letters to other scientists exist. Hevelius wrote Latin, but historians say that Elisabetha wrote with more style than her husband.
- **Elisabetha undertook mathematical work**; Hevelius wrote that she did very useful mathematical calculations to support their astronomical observations. Unclear whether she was taught the necessary mathematical skills by Hevelius, or she had lessons in mathematics as a child.
- **Elisabetha carried out astronomical observations**; as Hevelius made it clear in his correspondence and in his published books, observations after 1664 are the work of three people: himself, one other assistant, and his dearest wife (*conjugam meam charissimam*).

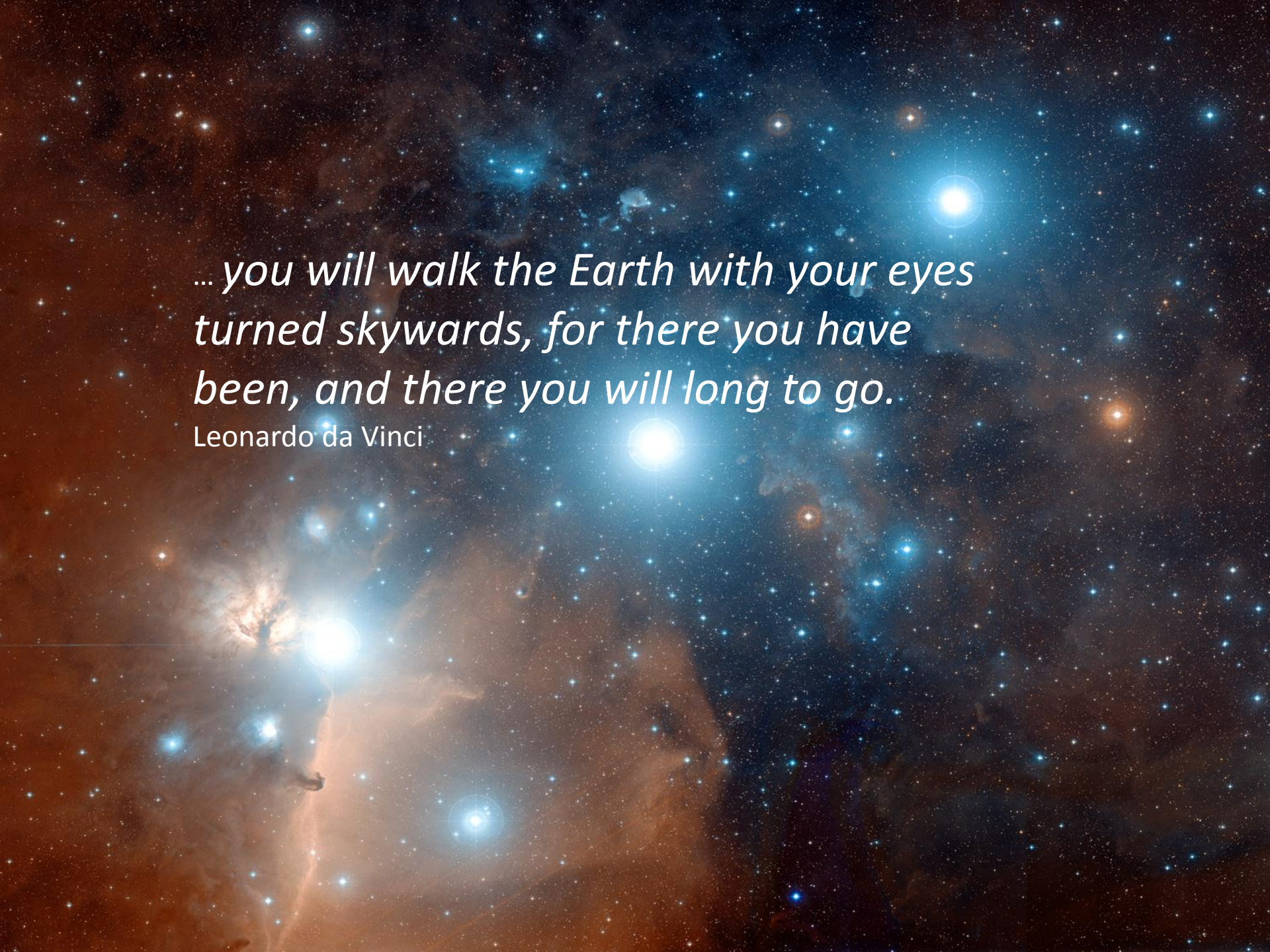
Elisabetha and Hevelius Books

- Hevelius died in Gdansk on January 28, 1687, on his 76th birthday.
- Elisabetha prepared three of her husband's unfinished books for publication.
- The first of the three works, *Stellarum Fixarum* was published by Elisabetha in 1687.
- She also published *Firmamentum Sobiescianum sive Uranographia etc*. (1690) which contained 56 star charts, and *Prodromus Astronomiae* (1690) containing a catalogue of 1564 stars.
- As well as editing these works, much of their contents were due to Elisabetha in the years she worked with Hevelius.
- Elisabetha Hevelius died in December 1693 and was buried in the same tomb as her husband. She was 46 years old.



Stars in 17th Century Sky

- Johannes Kepler (1571-1630)
- Galileo (1564-1642)
- Maria Kunitz (1610-1664)
- Johannes Hevelius (1611-1687)
- Isaac Newton (1642-1727)
- Elisabetha Koopman (1647-1693)
- Edmond Halley (1656-1742)
- Maria Winkelmann (1670-1720)
- Maria Einmart (1676-1707)


… you will walk the Earth with your eyes turned skywards, for there you have been, and there you will long to go.
Leonardo da Vinci