# 2009 THE INTERNATIONAL YEAR OF ASTRONOMY

## Significance and background

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THE UNIVERSE
YOURS TO DISCOVER
INTERNATIONAL YEAR OF
ASTRONOMY
2009

On December 20, 2007 the United Nations 62nd General Assembly proclaimed 2009 International Year of Astronomy.

The Resolution was submitted by Italy, Galileo Galilei's home country.

The International Year of Astronomy 2009 is an initiative of the International Astronomical Union and UNESCO.

"The International Year of Astronomy 2009 is a global effort initiated by the International Astronomical Union and UNESCO to help the citizens of the world rediscover their place in the Universe through the day- and night-time sky, and thereby engage a personal sense of wonder and discovery."

It celebrates the $400^{th}$ anniversity of the first use of an astronomical telescope by Galileo Galilei as well as that of the publication of Johannes Kepler's paradigm-setting work, *Astronomia Nova*; these events were the culmination of the Copernican revolution and mark the beginning of the modern era of empirical scientific research.

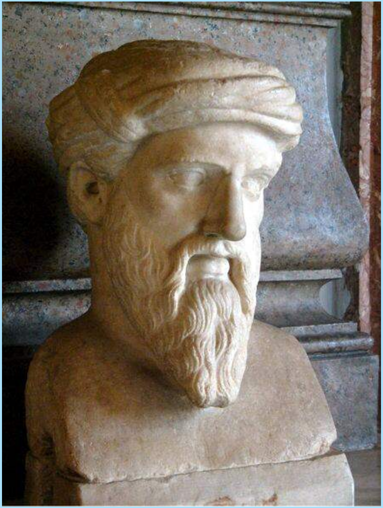
The aim of the IYA2009 is to stimulate worldwide interest, especially among young people, in astronomy and science under the central theme *"The Universe, Yours to Discover"*; it will be a global celebration of astronomy and its contributions to society and culture.

# The background

## Pythagoras and the dawn of science

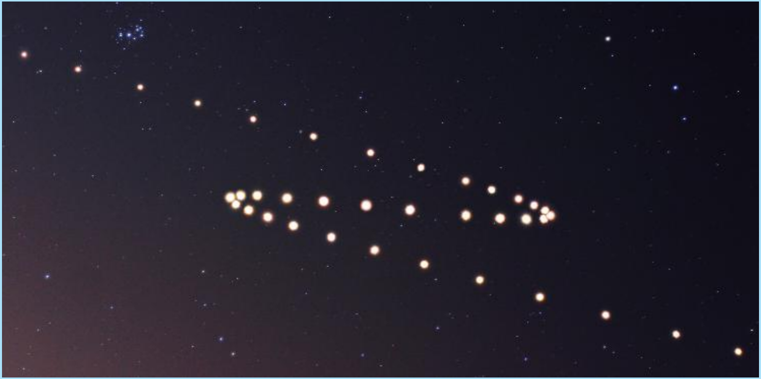
- Pythagoras (ca. 580 – 500 B.C.) and his brotherhood probably started experimentation, for example on the principles behind harmony in music.
- It was found that the harmonic musical intervals corresponded to simple ratios of small integer numbers.
- Pure numbers played also a role in Pythagorean theorem for a right-angled triangle, in particular for the case $3^2 + 4^2 = 5^2$.
- The Pythagoreans believed that the earth was spherical and moved around a central fire.

- They also are often believed to have had the view that the planets moved around the sun in manners guided by numbers and therefore musical notes.
- This produces harmony and was referred to as the *"Harmony of the Spheres"*.
- Their breakdown might have had to do with the discovery of irrational numbers ($1^2 + 1^2 = \sqrt{2}^2$).

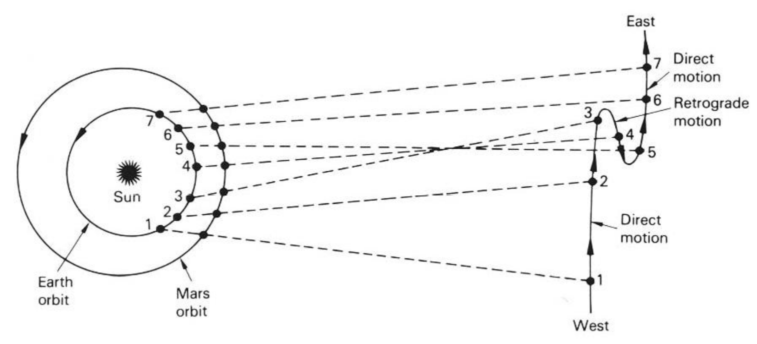


## The geocentric model

An important feature of the motions of the planets on the sky was that of retrograde motion.



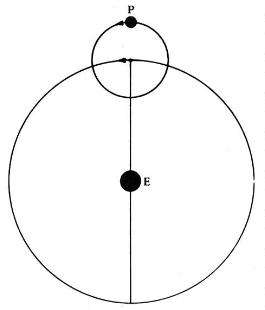
This results from the fact that we see the planets from the earth which also moves around the sun.[1]



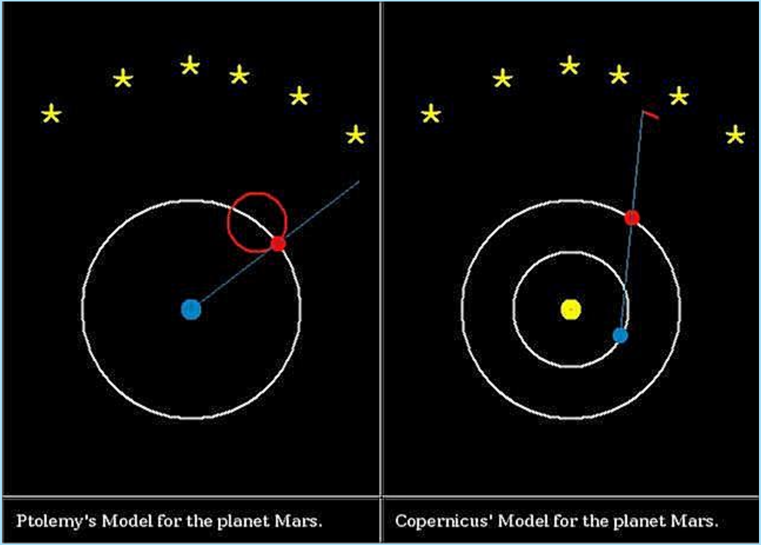

[1] See for an animation e.g. http://faculty.fullerton.edu/cmcconnell/Planetary_Motion.html

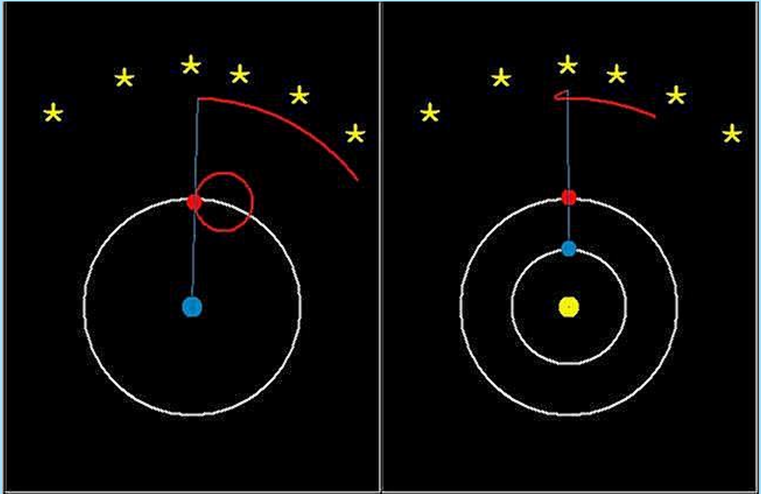
- In the geocentic model the planet moves on a epicycle whose center moves on a larger deferent.

- The deferent of an outer planet corresponds with its orbit around the sun.
- Similarly the epicycle is a reflection of the motion of the earth around the sun.
- For an inner planet it is the other way around.




- In terms of positions on the sky the geo- and heliocentric models are equivalent.


Ptolemy's Model for the planet Mars.
Copernicus' Model for the planet Mars.



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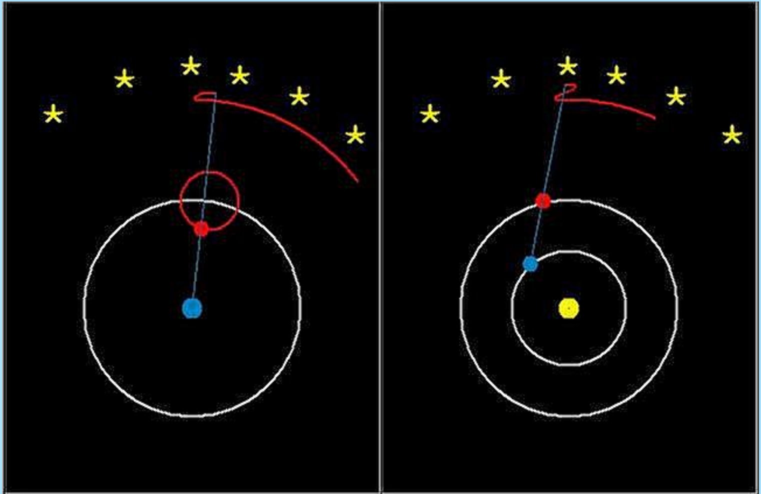

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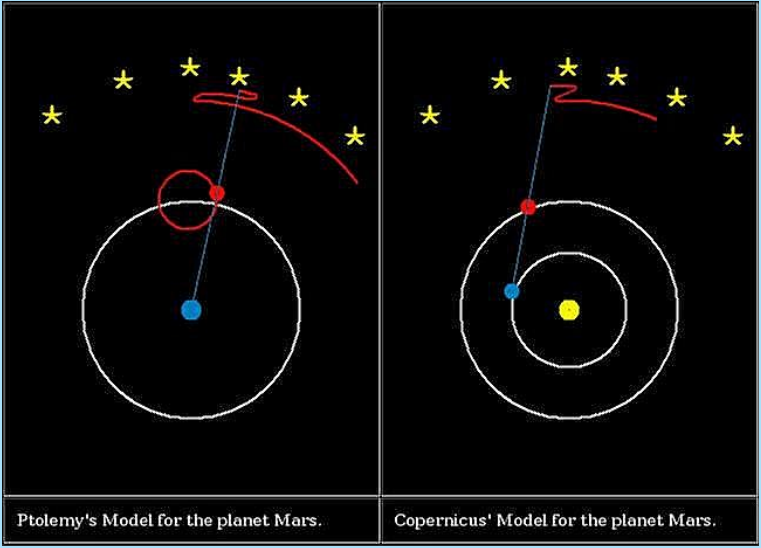
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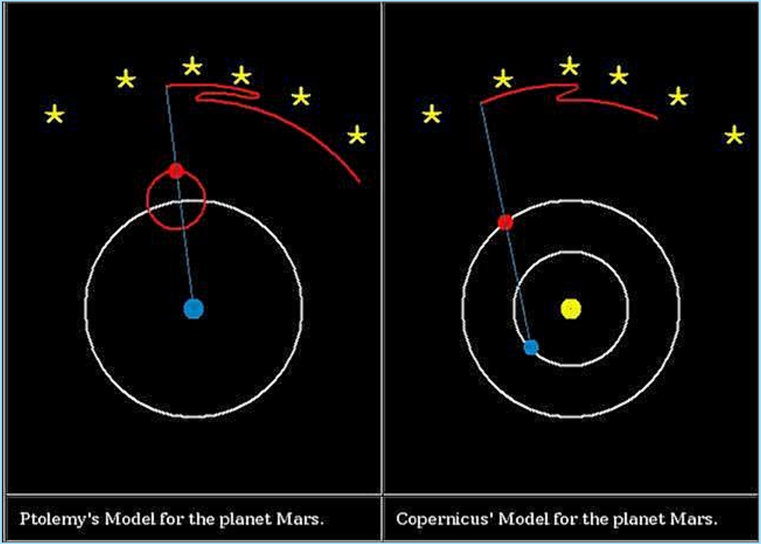
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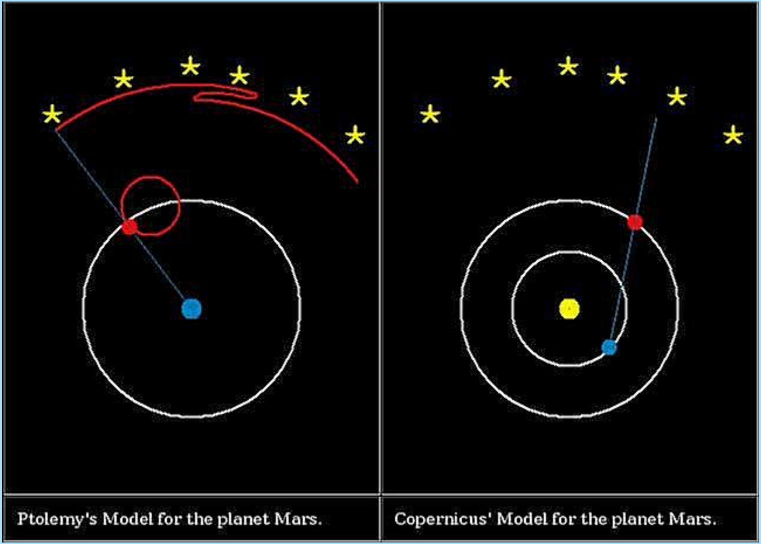
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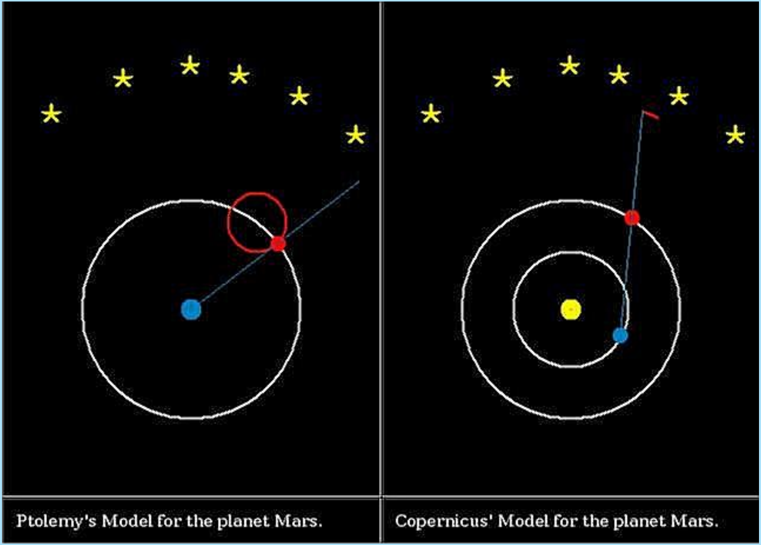
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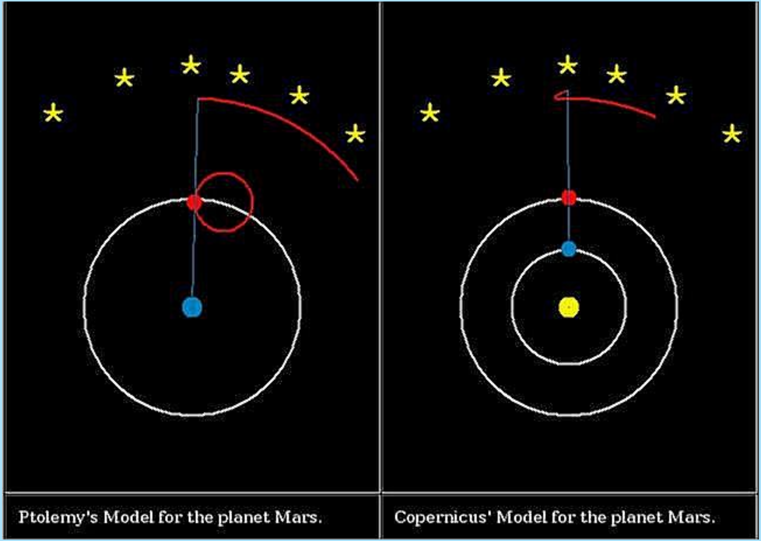
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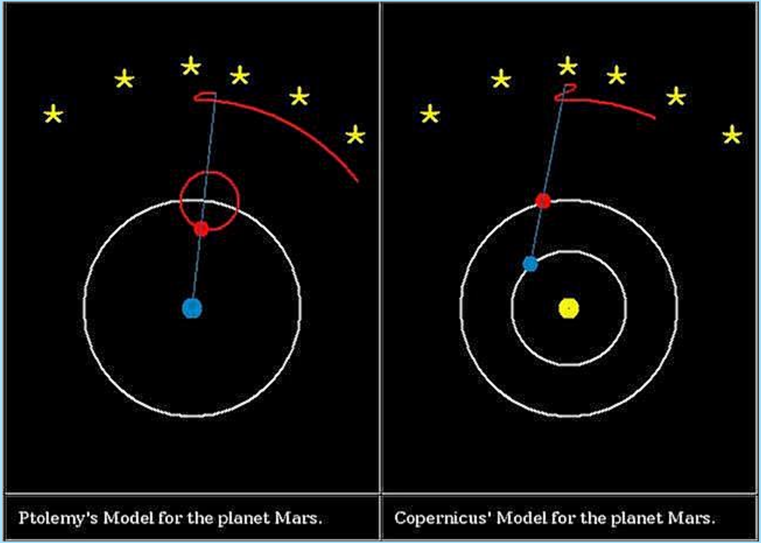
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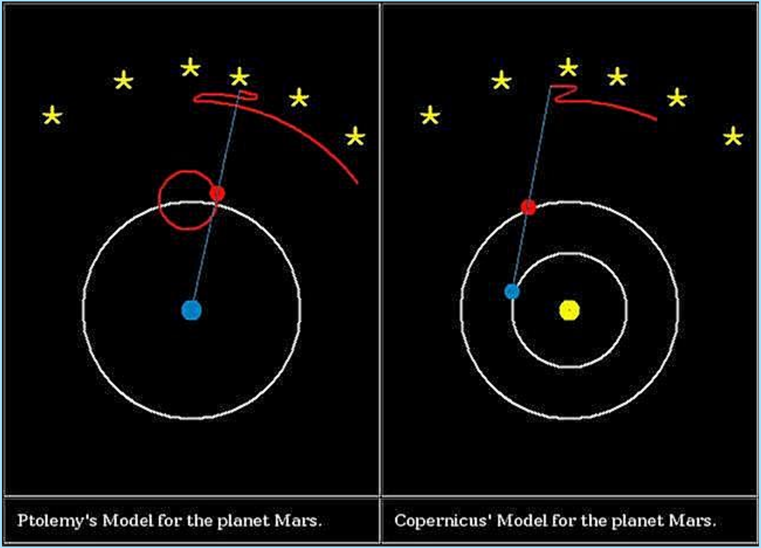
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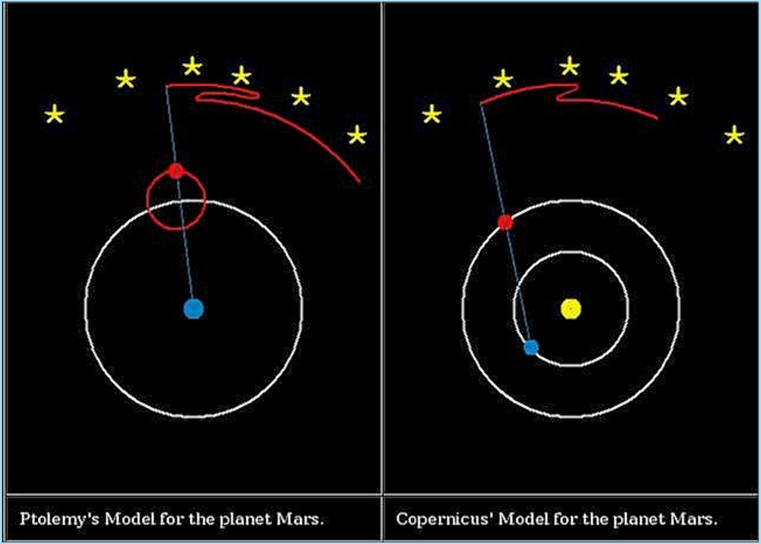
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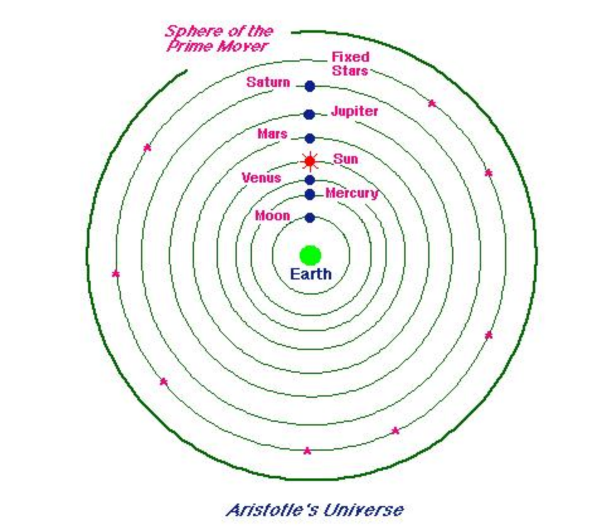
- The philosophies of Plato (417 – 348 BC) and Aristotle (384 – 322 BC) separated the world in the imperfect one here on Earth (the 'Sublunary') and from the Moon onward the perfect spheres of the Sun and planets and the starry sky.
- Consequently the motions of the Sun and planets had to be 'perfect', i.e. exactly on circles and with uniform angular velocity.
- The outer sphere is that of the Unmoved Mover that is the origin of all motion.

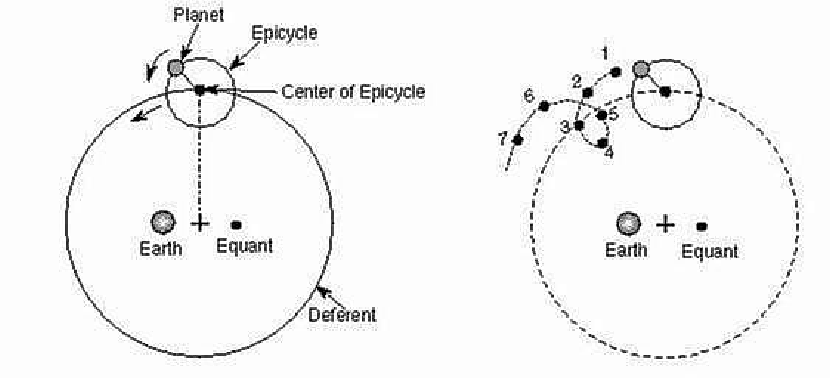
- The geocentric model was widely accepted in antiquity.
- One of the exceptions seems to have been Aristarchus (310 - ca. 230 BC).
- It did not take long to find that the circular motion failed to give accurate predictions of the positions of the planets.
- Claudius Ptolemy (±100 – 170 AD) completed the geocentric model that was used to describe the motions of the planets.

# Plato & Aristotle (left); Ptolemy (right)


Sphere of the Prime Mover
Fixed Stars
Saturn
Jupiter
Mars
Sun
Venus
Mercury
Moon
Earth
Aristotle's Universe

- The sun is not in the plane of every orbit, so an extra oscillation is required for the motions in latitude.
- In reality planets move with varying angular velocity in their orbits, so the model failed to predict position well.
- Ptolemy therefore assumed that the angular motion in the deferent was not uniform with respect to the center, but with respect to the equant.
- The equant is opposite and equidistant from the center with respect to the Earth.
- This looks contrived and it is surprising that this works.
- But there actually is an explanation for it.[2]

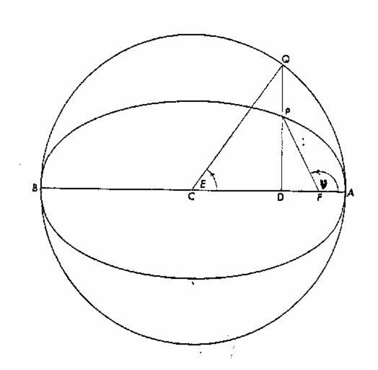
[2] See Deeming et al., Observatory 97, 84 (1977).


Planet
Epicycle
Center of Epicycle
Earth
Equant
Deferent
1
2
3
4
5
6
7
Earth
Equant

The orbit is described by the true anomaly $\nu$ and the excentric anomaly $E$.

$$\tan\left(\frac{\nu}{2}\right) = \sqrt{\frac{1+E}{1-E}}$$

$E$ does not increase linearly with time.




If we define a mean anomaly $M$ that is linear with time we get Kepler's equation:

$$M = \frac{2\pi}{T}(t - t_\circ) = E - e \sin E$$

- The angular velocity of the planet as seen from the Sun is

$$\frac{d\nu}{dt} \propto (1-e^2)^{1/2}(1-e\cos E)^{-2}$$

- This varies proportionally over a range from $(1-e)^{-2}$ at perihelion to $(1+e)^{-2}$ at aphelium.
- For the empty focus the appropriate formula is

$$\frac{d\nu'}{dt} \propto (1-e^2)^{1/2}(1-e^2\cos^2 E)^{-1}$$

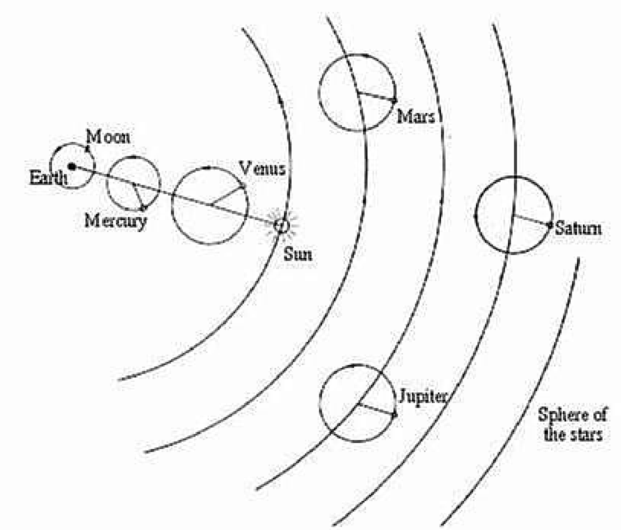
- This variation is over a relative range from $(1-e^2)^{-1}$ at perihelion and aphelion to 1 for $E=90^\circ$ or $E=270^\circ$.

- For an excentricity of the Earth's orbit ($e = 0.017$) the variation is from -3.4% to +3.4% around the mean from the Sun, but only between -0.014% to +0.014% from the empty focus.
- For Mars with an orbital excentricity $e = 0.093$, the difference is substantial and remarkable. The range is from -17.7% to +19.5 % from the Sun, but only between -0.4% and +0.4% from the empty focus!
- This is exactly why Ptolemy's model works reasonably (and surprisingly) well.

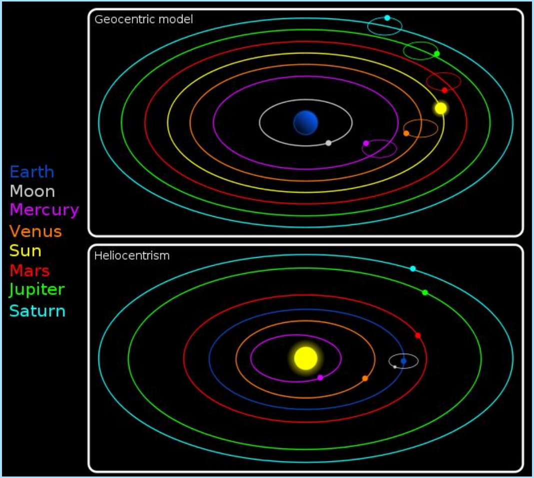
## Historic note on Kepler's second law

- Kepler's second law states that the orbital speed of a planet is such that its radius sweeps out equal areas in equal times.
- We now know this as conservation of angular momentum.
- Before defining this rule Kepler considered uniform motion as seen from the empty focus, reintroducing the equant.
- He noted this did not work accurately and replaced it with the inverse distance rule, which held that the orbital speed is inversely proportional to the radius.
- Only when this did not work did he arrive at the equal areas rule, where the tangential velocity is inversely proportional to the distance from the sun.

- There is a remarkable fact in the full picture of the solar system (which Ptolemy probably never drew).
- The directions in de the epicycles for the outer planets all *have to be the same*, while the epicycles of the inner planets both *have te be centered* on the line from the Earth to the Sun.
- We would consider this requiring further investigation to determine whether there requires an explanation or is pure coincidence.
- Also the changing brightness of Venus was ignored.


Moon
Earth
Mercury
Venus
Sun
Mars
Jupiter
Saturn
Sphere of the stars

Compare to this completely wrong representation from Wikipedia: http://en.wikipedia.org/wiki/Heliocentrism.



In this and the following slide I quote from Arthur Koestler's book, *"The Sleepwalkers: A History of Man's Changing Vision of the Universe"* (1959).

In his classic work *Science and the Modern World*, Alfred North Whitehead (1925) writes:
*"In the year 1500 Europe know less than Archimedes who died in the year 212 B.C."*

Koestler asks: *"What were the main obstacles which arrested the progress of science for such an immeasurable time?"*

and summarizes this as follows:

- The splitting of the world in two spheres.
- The geocentric dogma.
- The dogma of uniform motion on perfect circles.
- The divorcement of science from mathematics.
- The inability to realise that a body at rest remains at rest and a body in motion tends to remain in motion.

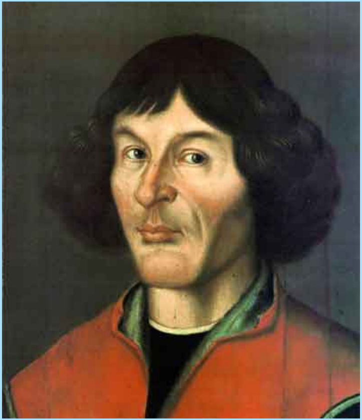
The removal of these obstacles was mainly done by three men: Copernicus, Kepler and Galilei, opening the road to the Newtonian synthesis.

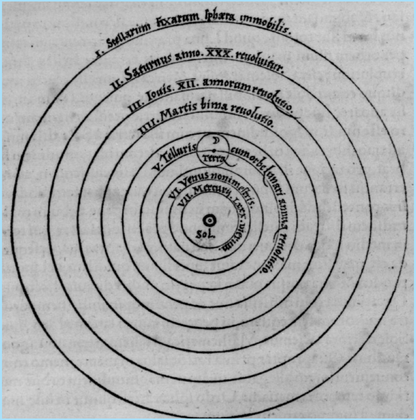
# The Copernican revolution

## Copernicus, Brahe & Kepler

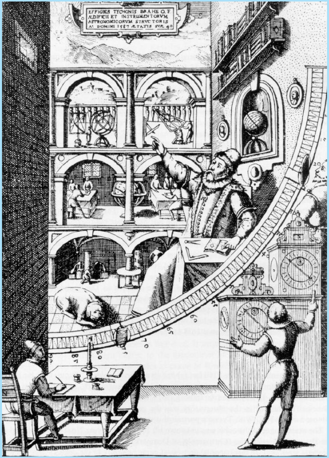
- Nicolaus Copernicus (1473 – 1543) made the model more complicated by approximating the orbits not by using the equant, but by superposing uniform circular motions, such that is corresponded more to what we now know te be Keplerian motion along ellipses.
- He then simplified the model by assuming that the Sun was in the center.
- Copernicus was more a man of the Middle Ages.

# Nicolaus Copernicus

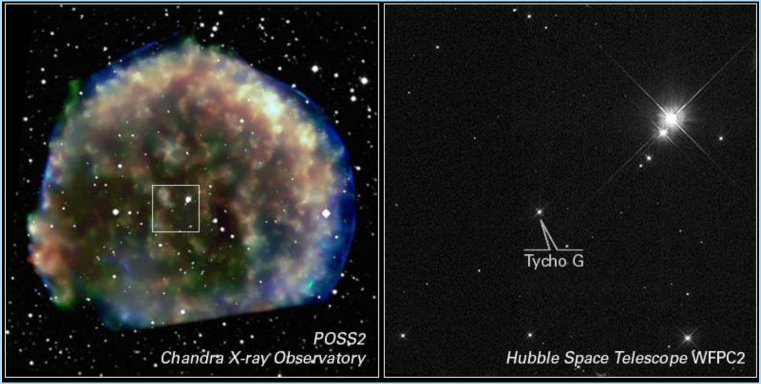




# Tycho Brahe

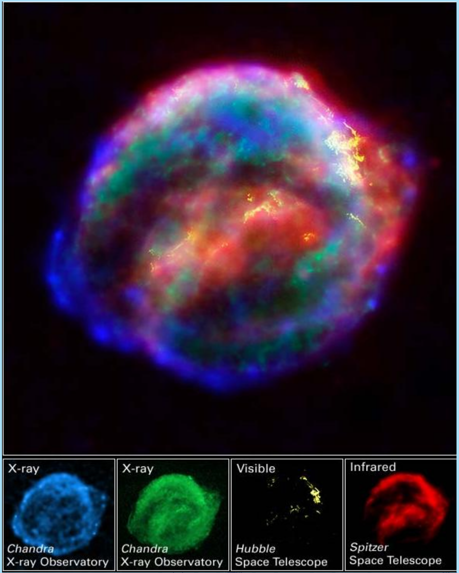

EFFIGIES TYCHONIS BRAHE O. F
ÆDIFICII ET INSTRUMENTORVM
ASTRONOMICORVM STRVCTORIS
A°. DOMINI 1587 ÆTATIS SVÆ 40

- The Danish astronomer Tycho Brahe (1546 – 1601) was the greatest observer of his time.
- He also described the great supernova (SN1572), known as Tycho's supernova, of November 11, 1572.
- This already shook the concept of the perfect world from the sphere of the Moon onwards.
- Recently the nature of the supernova was determined from a spectrum seen on reflection nebulosities!
- It is of type Ia, such that it originates from mass transfer onto a white dwarf in a binary system.
- The run-away companion has been seen also.


POSS2
Chandra X-ray Observatory
Tycho G
Hubble Space Telescope WFPC2

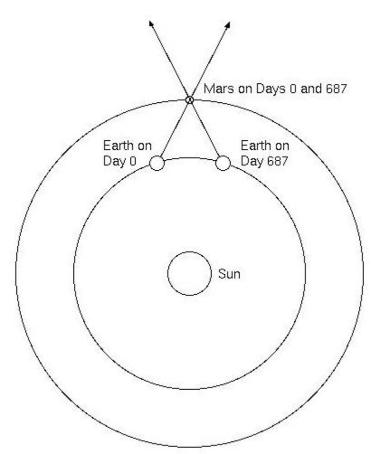
- Johannes Kepler (1571 – 1630) saw the supernova of 1604, (SN1604) which became known as Kepler's Sypernova, because he wrote a book about it ('De Stella Nova').
- Kepler noted the absence of parallax and concluded that it must be part of the sphere of fixed stars.
- This was inconsistent with the Aristotelian dogma.

Kepler's Supernova (SN1604) observed with the NASA Great Observatories



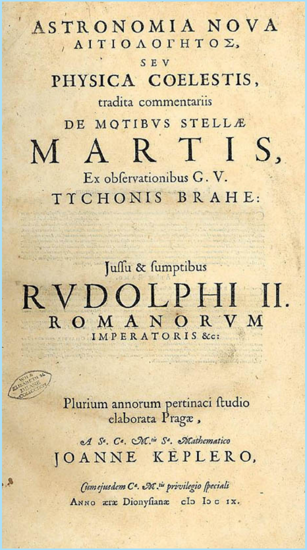
- Kepler actually *determined* the shape of the planetary orbits.
- He was the first to start from observations and questioned (for the first time in almost two millennia) the validity of the postulates of perfect motion by Plato and Aristotle.
- Kepler used observations from Tycho Brahe to do this first for the orbit of Mars.
- He used triangulation by selecting times when Mars was in the same position in its orbit, assumed the earth orbit to be circular.
- He then reversed the procedure to determine iteratively the orbit of the earth.
- In this way he derived his first two laws and abandoned the concept of the perfect circular, uniform motion.

# Johannes Kepler



In 1609 Kepler published his famous *Astronomia Nova*, in which he presented his first two laws:

- Planets move in ellipses, with the sun in one of the foci.
- Planets sweep out equal areas in equal times (conservation of angular momentum).
- The publication of this book 400 years ago is another reason for IYA 2009


ASTRONOMIA NOVA
ΑΙΤΙΟΛΟΓΗΤΟΣ,
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. C. M.tis S. Mathematico
JOANNE KEPLERO,
Cum ejusdem C. M.tis privilegio ſpeciali
ANNO æræ Dionyſianæ cIɔ Iɔ c ix.

Important features as a result of this were:

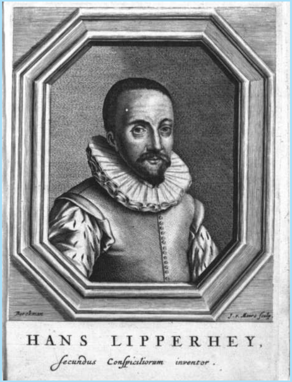
- Planets move neither along circles nor with uniform angular speed.
- The sun lies in the orbital plane of *every* planet.
- This removes the need for the vertical oscillations that were necessary to describe the motions in latitude.
- It also points at a physical relation between the motions of the planets and the sun in the form of a driving force.
- Kepler compared this to magnetism and described it as pushing the planets forward along their orbits.

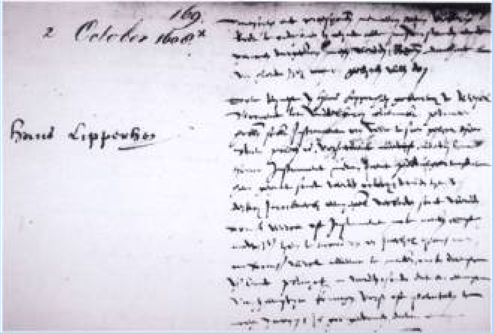
Kepler's 'harmonic law' ($T^2 \propto a^3$) came later and formed the basis of the inverse-square law for the gravitational force.

## Galilei and the telescope

- The immediate background for choosing 2009 to be the IYA is that Galileo Galilei first studied the night sky with a telescope in 1609.
- The year before this (1608) the telescope was 'invented', presumably in the Netherlands.
- It is not certain who invented the telescope. Probably many lensmakers and opticians thought of the idea.
- Lenses then were made for spectacles, so were good only in central part close to the eyeball.

- Hans Lipperhey (1570 – 1619) of Middelburg designed a working telescope ('spy glass') and *demonstrated* it in the Hague to Stadholder Maurits and many diplomats at an international peace conference in 1608.
- He *documented* it by submitting a request for a patent to the States General, which was refused (too easy to copy).
- Vital (and innovative) in Lipperhey's design was that he *stopped down* the aperture.
- These three things can certainly be put forward in favor of the position that Hans Lipperhey be regarded the inventor of the telescope.

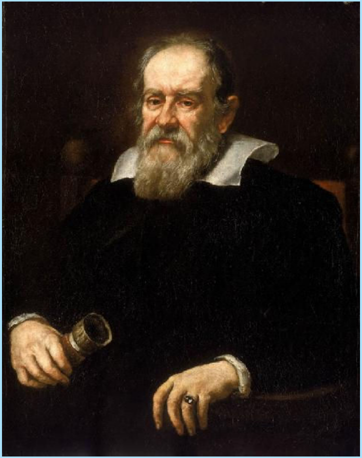


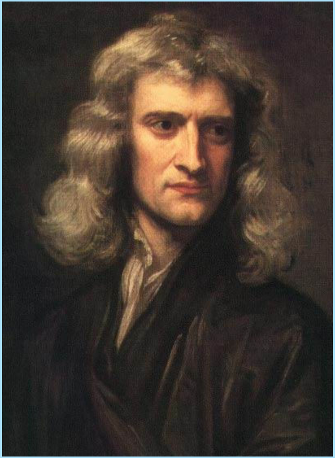



Hans Lipperhey and part of his request for a patent.

- Galilei Galileo (1564 – 1642) heard of the Dutch spy-glass, obtained one and quickly (with help?) improved it.
- The heliocentric model was confirmed by Galileo with his observations in 1609-1610 of
  - Craters on the Moon
  - Sunspots
  - Phases of Venus
  - Satellites of Jupiter
  - Stars in the Milky Way
- Eventually Isaac Newton (1642 – 1727) explained Kelper's laws (includig the harmonic law) as a prediction from his theory of gravity.

# Galileo Galilei (left) and Isaac Newton (right)

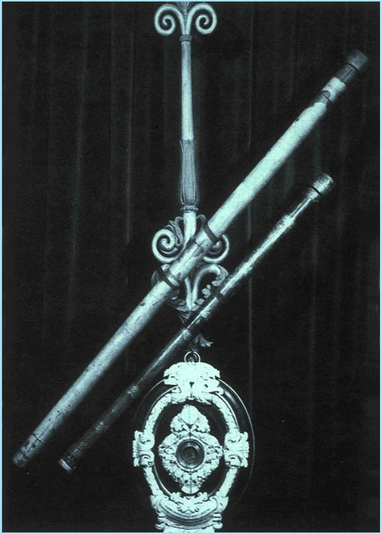




## Galilei's observations and Neptune

Galileo Galiei (probably with help of others) quickly improved telescope design and started observing the sky.

Here are some of his telescopes.



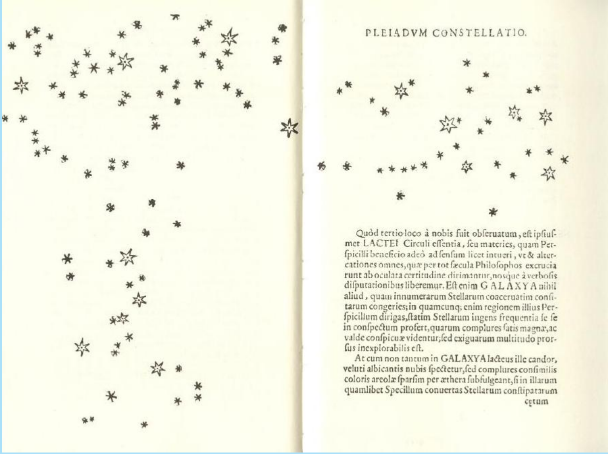
Galilei started observing the Moon on 30 November 1609.

He used initially a telescope with magnification about 3.

Here are some of Galilei's drawings.

In December 1609 he discovered that the Milky Way is full of stars.

On the left the lower part of Orion and on the right the Plejades.



PLEIADVM CONSTELLATIO.

Quòd tertio loco à nobis fuit obſeruatum, eſt ipſiuſmet LACTEI Circuli eſſentia, ſeu materies, quam Perſpicilli beneficio adeò ad ſenſum licet intueri, vt & altercationes omnes, quæ per tot ſæcula Philoſophos excruciarunt ab oculata certitudine dirimantur, noſque à verboſis diſputationibus liberemur. Eſt enim GALAXYA nihil aliud, quam innumerarum Stellarum coaceruatim conſitarum congeries; in quamcunq; enim regionem illius Perſpicillum dirigas, ſtatim Stellarum ingens frequentia ſe ſe in conſpectum profert, quarum complures ſatis magnæ, ac valde conſpicuæ videntur; ſed exiguarum multitudo prorſus inexplorabilis eſt.

At cum non tantum in GALAXYA lacteus ille candor, veluti albicantis nubis ſpectetur, ſed complures conſimilis coloris areolæ ſparſim per æthera ſubfulgeant, ſi in illarum quamlibet Specillum conuertas Stellarum conſtipatarum

cętum

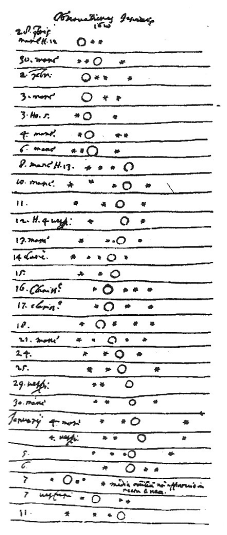
This is what Jupiter and the four brightests satellites look like through a small telescope.

On January 7, 1610 Galilei observed Jupiter with a telescope with magnification 30.

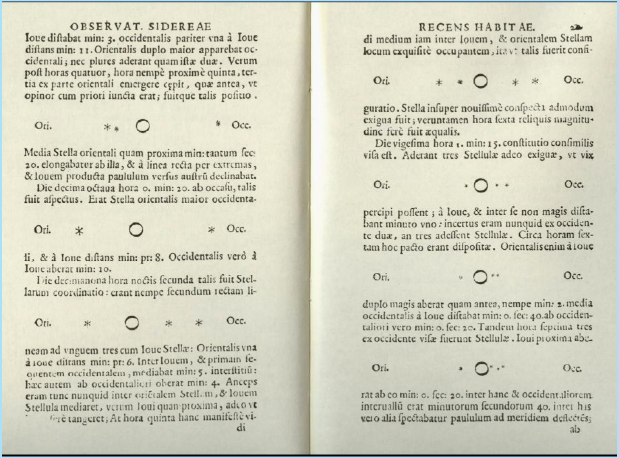
He discovered three 'stars' near Jupiter and on 10 January concluded that they circle around Jupiter.

On 13 January 1610 he discovered the fourth satellite (or 'moon').

Here is a page with Jupiter observations from Galilei's notebook for January 10.



Here two pages from Galilei's famous Sidereus Nuncius (the 'Starry Messenger'), published in 1610.



OBSERVAT. SIDEREAE

Ioue distabat min: 3. occidentalis pariter vna à Ioue distans min: 11. Orientalis duplo maior apparebat occidentali; nec plures aderant quam istæ duæ. Verum post horas quatuor, hora nempè proximè quinta, tertia ex parte orientali emergere cœpit, quæ antea, vt opinor cum priori iuncta erat; fuitque talis positio.

Ori. * * ○ * Occ.

Media Stella orientali quam proxima min: tantum sec: 20. elongabatur ab illa, & à linea recta per extremas, & Iouem producta paululum versus austrũ declinabat.
Die decima octaua hora o. min: 20. ab occasu, talis fuit aspectus. Erat Stella orientalis maior occidentali, & à Ioue distans min: pr: 8. Occidentalis verò à Ioue aberat min: 10.

Ori. * ○ * Occ.

Die decimanona hora noctis secunda talis fuit Stellarum coordinatio: erant nempe secundum rectam lineam ad vnguem tres cum Ioue Stellæ: Orientalis vna à Ioue distans min: pr: 6. Inter Iouem, & primam sequentem occidentalem, mediabat min: 5. interstitiũ: hæc autem ab occidentaliori aberat min: 4. Anceps eram tunc nunquid inter oriẽtalem Stellam, & Iouem Stellula mediaret, verum Ioui quam proxima, adeo vt ferè tangeret; At hora quinta hanc manifestè vidi

Ori. * ○ * * Occ.

RECENS HABITAE. 23

di medium iam inter Iouem, & orientalem Stellam locum exquisitè occupantem, ita vt talis fuerit configuratio. Stella insuper nouissimè conspecta admodum exigua fuit; veruntamen hora sexta reliquis magnitudine ferè fuit æqualis.

Ori. * * ○ * * Occ.

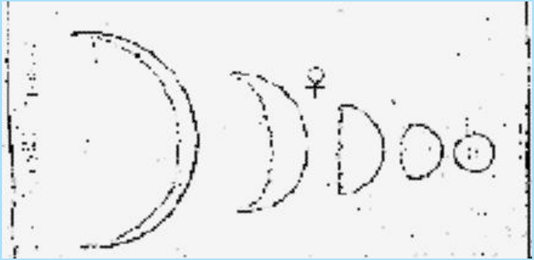
Die vigesima hora 1. min: 15. constitutio consimilis visa est. Aderant tres Stellulæ adeo exiguæ, vt vix percipi possent; à Ioue, & inter se non magis distabant minuto vno: incertus eram nunquid ex occidente duæ, an tres adessent Stellulæ. Circa horam sextam hoc pacto erant dispositæ. Orientalis enim à Ioue duplo magis aberat quam antea, nempe min: 2. media occidentalis à Ioue distabat min: o. sec: 40. ab occidentaliori vero min: o. sec: 20. Tandem hora septima tres ex occidente visæ fuerunt Stellulæ. Ioui proxima aberat ab eo min: o. sec: 20. inter hanc & occidentaliorem interuallũ erat minutorum secundorum 40. inter has vero alia spectabatur paululum ad meridiem deflectẽs; ab

Ori. * ○ * * Occ.

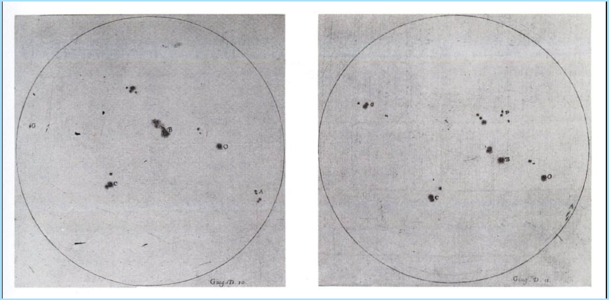
Ori. * ○ * * Occ.

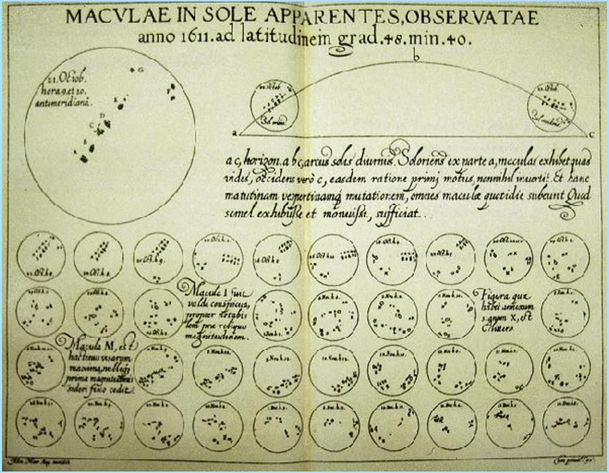
Ori. * ○ * * * Occ.

Galilei's observations of the phases of Venus, starting in September 1610.



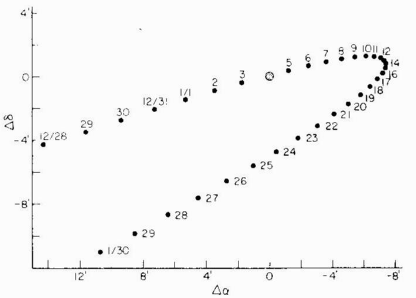
He later also observed sunspots, that were in disagreement with the perfectness of the sun in the Aristotelian philosophy.




MACVLAE IN SOLE APPARENTES, OBSERVATAE
anno 1611. ad latitudinem grad. 48. min. 40.

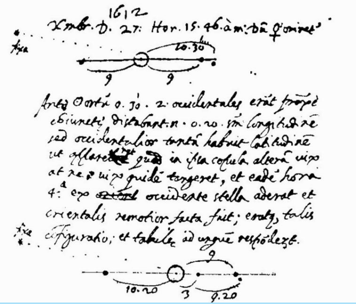
## Galilei's observations of Neptune

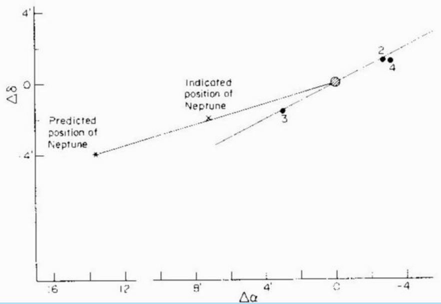
- Mutual occultations of planets are extremely rare.
- Between the superior planets there are only **9** between 1100 and 2500! (Next is Mars-Jupiter on December 2, 2223).
- On January 4, 1613 there was an occultation of Neptune by Jupiter.
- Galilei observed Jupiter at that time.



Here is Galilei's notebook for December 28, 1612.

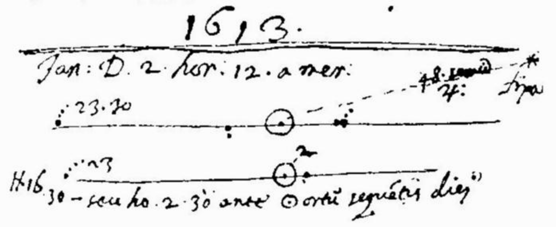
The 'star' indicated is not a known star and is in the correct direction to be Neptune, but at the edge of the page.



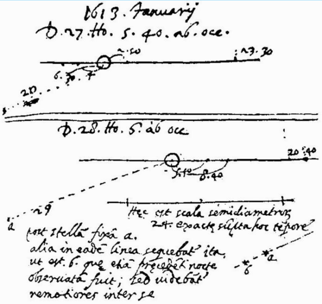


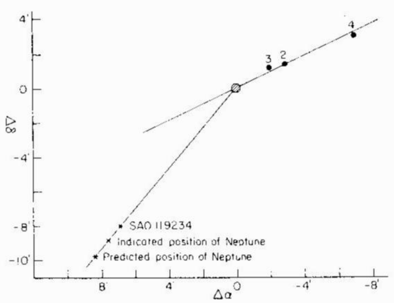
This is January 2, 1613 with a star (SAO119234), sketched at the edge of the page.

It says it is 48 jovian radii from Jupiter, while it actually is 52.



Again Neptune is present on the records of 27/28 January, 1613.






Galilei observed Neptune **234** years before it was discovered![3]

[3]Kowal & Drake, Nature **287**, 311 (1980)

This presentation is available as a pdf-file through

**www.astro.rug.nl/∼vdkruit/jea3/homepage/2009IYA.pdf**