Cathedrals as Solar Observatories

The Role of the Church in Restraining and Advancing the Science of Astronomy

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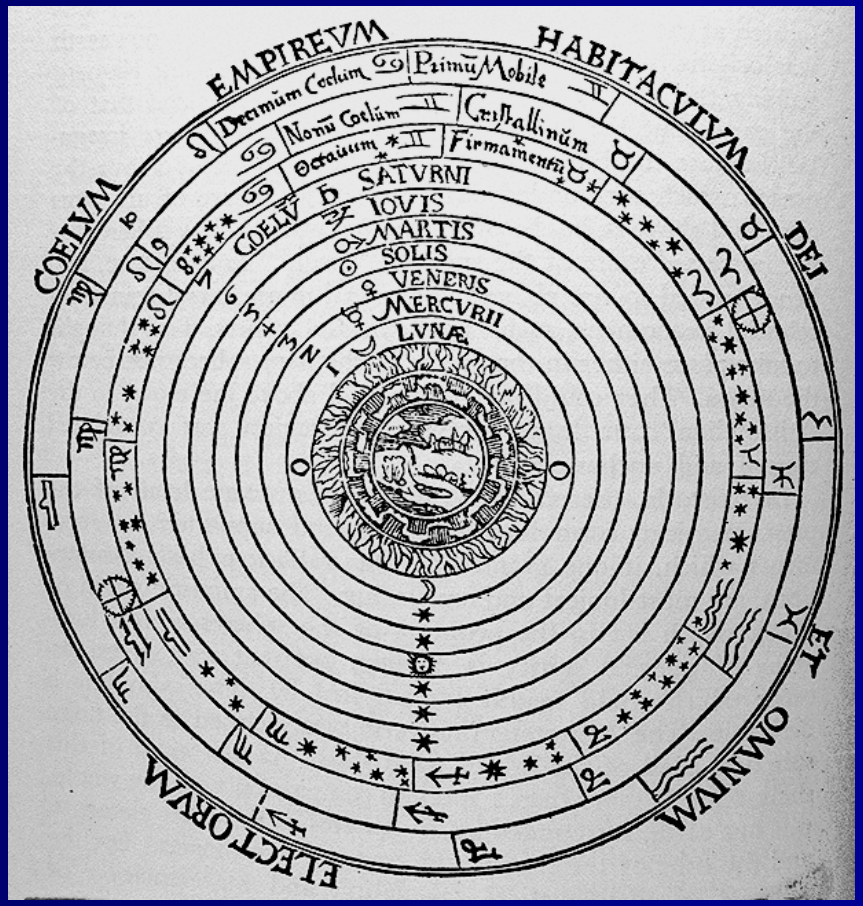
Wittenberg University
Grand Canyon Astronomer in Residence 2022 & 2023

March 31st, 2024

The Universe of the ancients

Geocentric Model



facultysites.vassar.edu/brvannor/Asia350/ptolemy.html

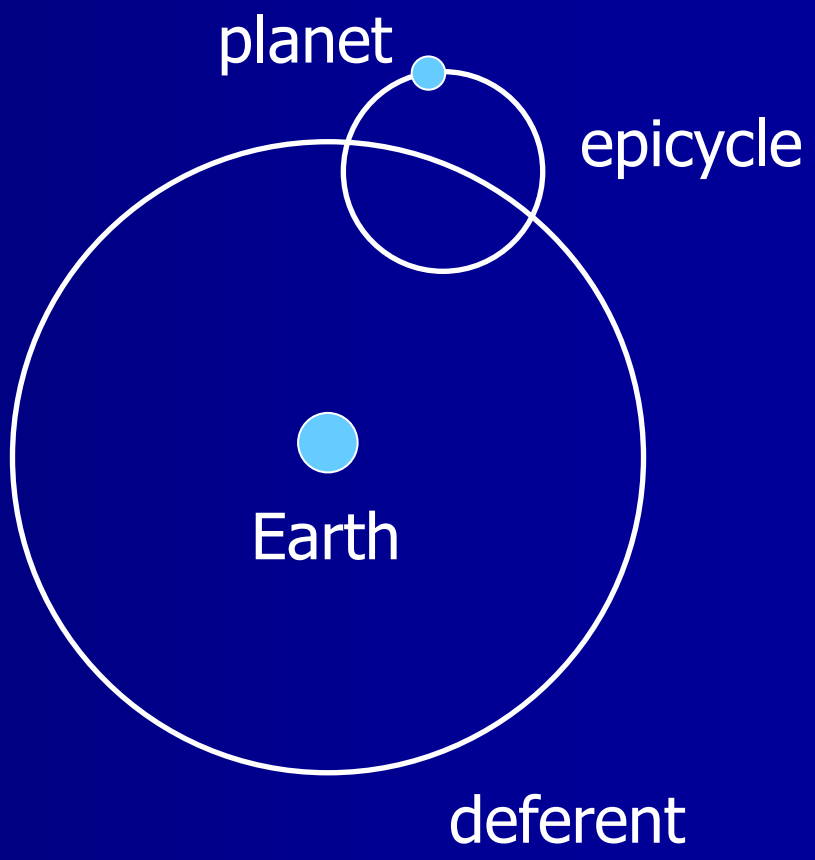
The problem of retrograde motion

http://www.star.ucl.ac.uk/~apod/apod/image/0604/Mars2005_6_tezel_c51.jpg

Ptolemy's solution

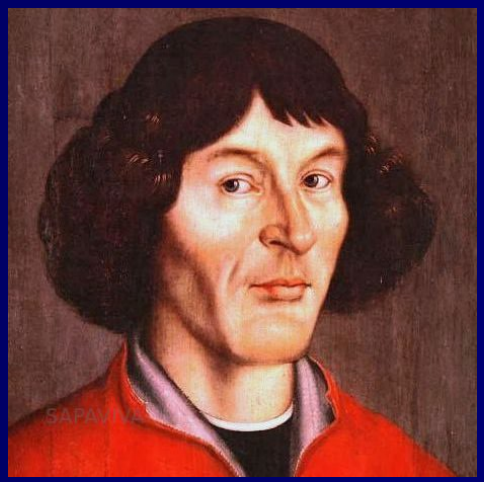
Claudius Ptolemaeus
c. 90 – c. 168 AD

https://www2.hao.ucar.edu/sites/default/files/styles/extra_large/public/2022-01/ptolemy.jpg?itok=x96nRkuQ

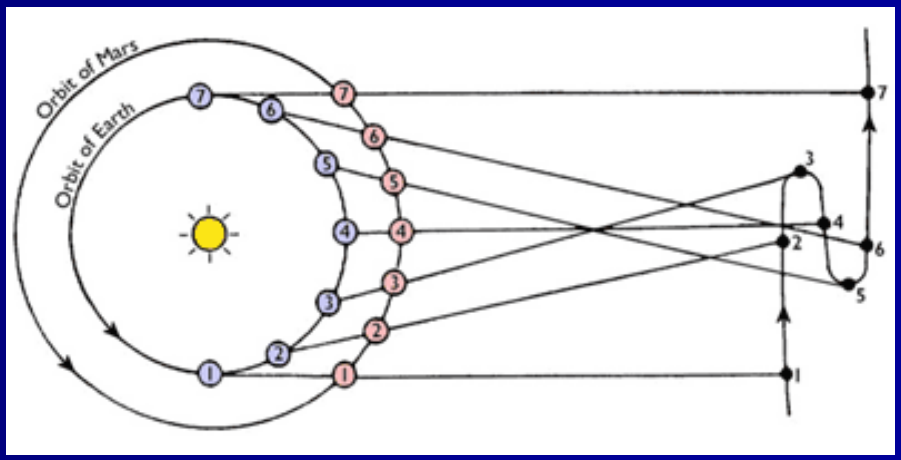


1500 Years Later: Copernicus' Solution

Nicolaus Copernicus
1473 - 1543 AD



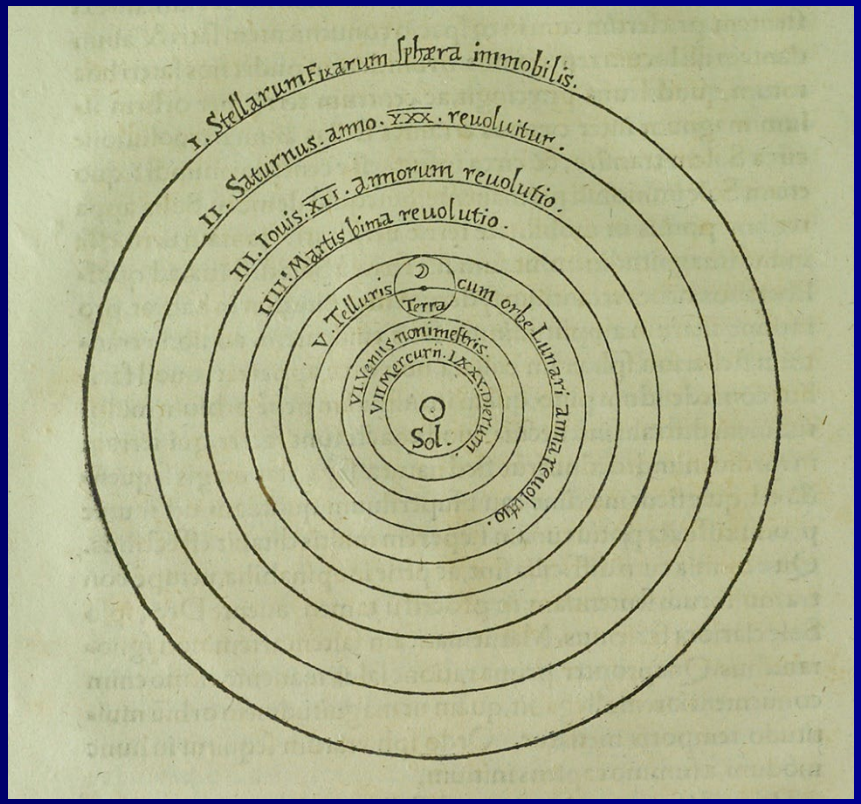
https://www.sapaviva.com/wp-content/uploads/2017/06/23S.-Nicolaus-Copernicus-1473-1543-463x463.jpg



https://demos.smu.ca/images/stories/Pics/retrograde/retrograde.gif

The Universe of Copernicus

Heliocentric Model



https://maa.org/sites/default/files/images/upload_library/46/Swetz_2012_Math_Treasures/Lehigh_University/Lehigh_Copernicus/Lehigh_4_065_left.jpg

Why the big change?

The traditional explanation:

- Increasing errors in predicted positions
- Increasing complexity of Ptolemaic model
- Wonderful simplicity of Copernican model
- Improved accuracy of Copernican model

Just four problems

- No increasing errors in Ptolemy
- No increasing complexity in Ptolemy
- Copernican model not so simple
- Copernican model not so accurate

Ptolemy: A closer look

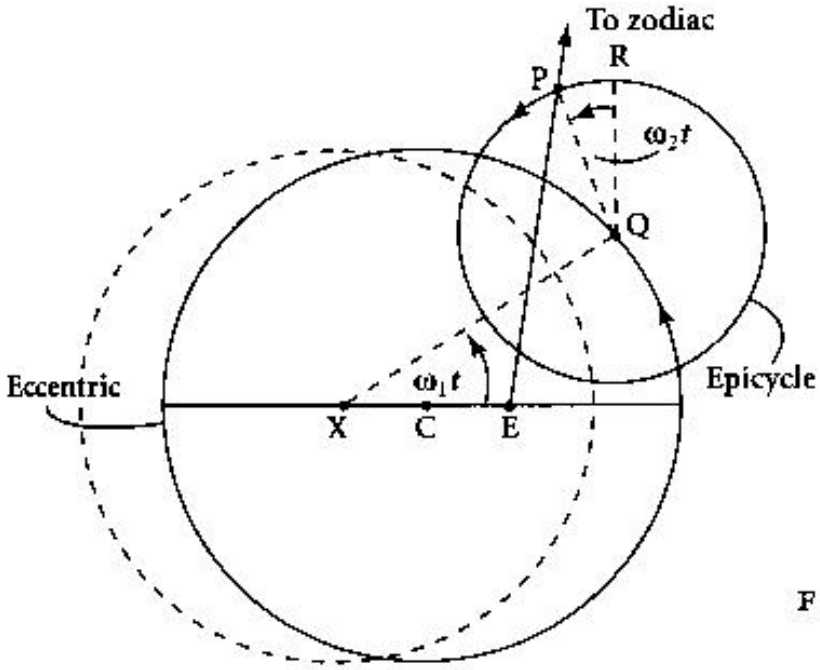
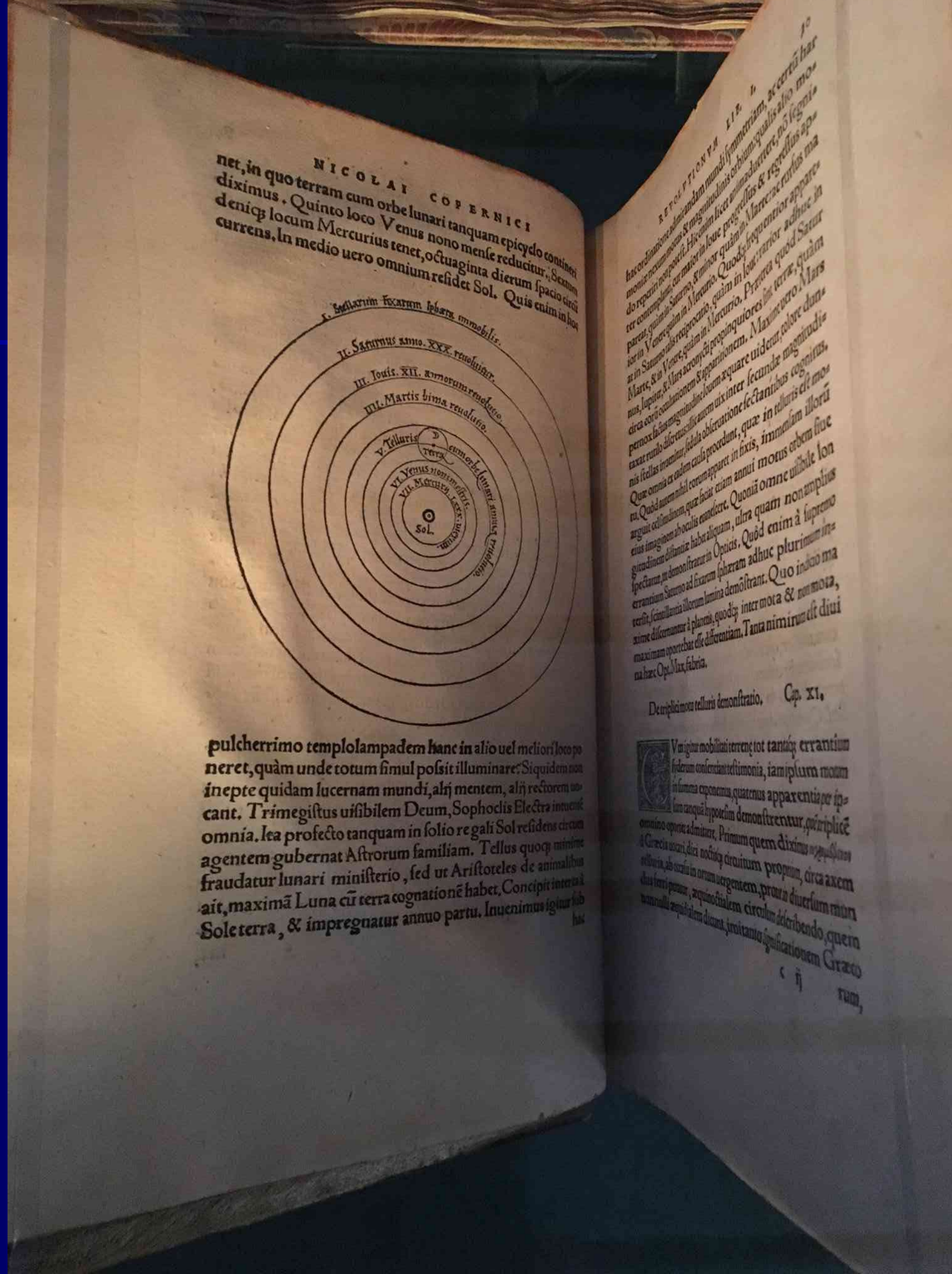


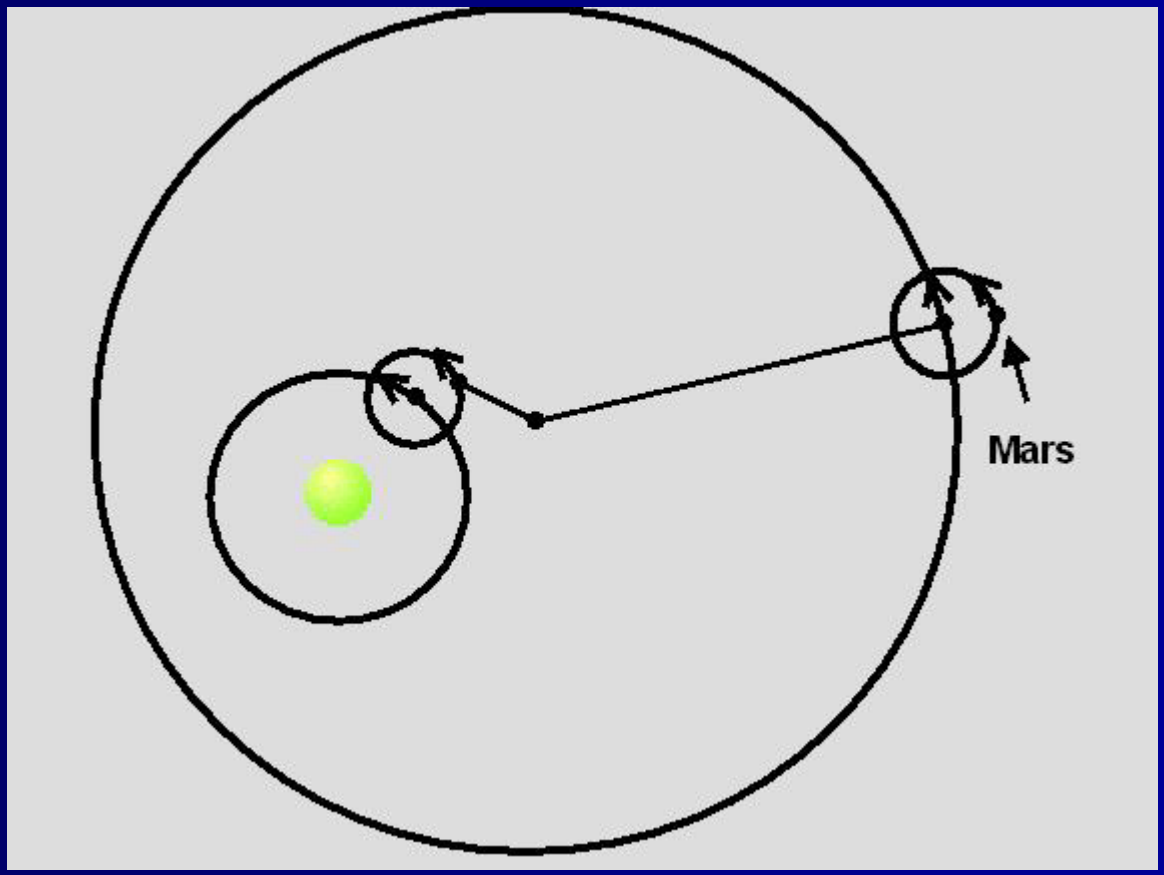
FIG. 3.15. Ptolemaic device of eccentric and epicycle.

The Sun in the Church, J.L. Heilbron


NICOLAI COPERNICI
net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono mense reducitur. Sextum deniq; locum Mercurius tenet, octuaginta dierum spacio circũ currens. In medio uero omnium residet Sol. Quis enim in hoc
I. Stellarum fixarum sphæra immobilis.
II. Saturnus anno. XXX. reuoluitur.
III. Iouis. XII. annorum reuolutio.
IIII. Martis bima reuolutio.
V. Telluris cum orbe lunari annua reuolutio.
Terra
VI. Venus nono mense.
VII. Mercurij. LXXX. dierum.
Sol.
pulcherrimo templo lampadem hanc in alio uel meliori loco poneret, quàm unde totum simul possit illuminare? Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem uocant. Trimegistus uisibilem Deum, Sophoclis Electra intuentẽ omnia. Ita profecto tanquam in solio regali Sol residens circum agentem gubernat Astrorum familiam. Tellus quoq; minime fraudatur lunari ministerio, sed ut Aristoteles de animalibus ait, maximã Luna cũ terra cognationẽ habet. Concipit interea à Sole terra, & impregnatur annuo partu. Inuenimus igitur sub hac
De triplici motu telluris demonstratio. Cap. XI.

Fleisch

Copernicus: A closer look



http://homework.uoregon.edu/pub/class/phys361/copermars.jpg

No simple explanation

The actual causes of the shift from geocentric to heliocentric are far more subtle.

To understand those causes, it's necessary to know their context.

Context: The Renaissance

Middle Ages

500 to 1400 AD

Renaissance

1400 – 1700 AD

Modern Era

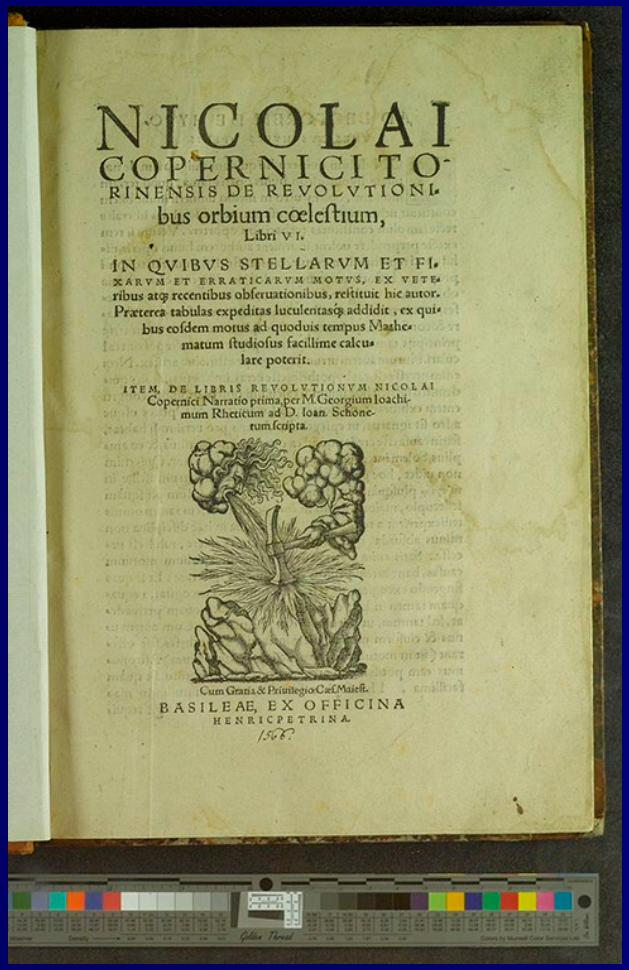
1700 AD – Present Day

"Renaissance" translates as "Rebirth"

Europe during the Renaissance

- Exploration
  - Columbus
  - Vasco da Gama
  - Magellan
- Reformation
  - Luther
  - Knox
- Art and Science
  - da Vinci
  - Michelangelo
  - Copernicus
  - Kepler
  - Galileo
- Inquisition
  - Spanish
  - Roman

De Revolutionibus


NICOLAI
COPERNICI TO-
RINENSIS DE REVOLVTIONI-
bus orbium cœleſtium,
Libri VI.
IN QVIBVS STELLARVM ET FI-
XARVM ET ERRATICARVM MOTVS, EX VETE-
ribus atq; recentibus obſeruationibus, reſtituit hic autor.
Præterea tabulas expeditas luculentasq; addidit, ex qui-
bus eoſdem motus ad quoduis tempus Mathe-
matum ſtudioſus facillime calcu-
lare poterit.
ITEM, DE LIBRIS REVOLVTIONVM NICOLAI
Copernici Narratio prima, per M. Georgium Ioachi-
mum Rheticum ad D. Ioan. Schone-
rum ſcripta.
Cum Gratia & Priuilegio Cæſ. Maieſt.
BASILEAE, EX OFFICINA
HENRICPETRINA.
1566

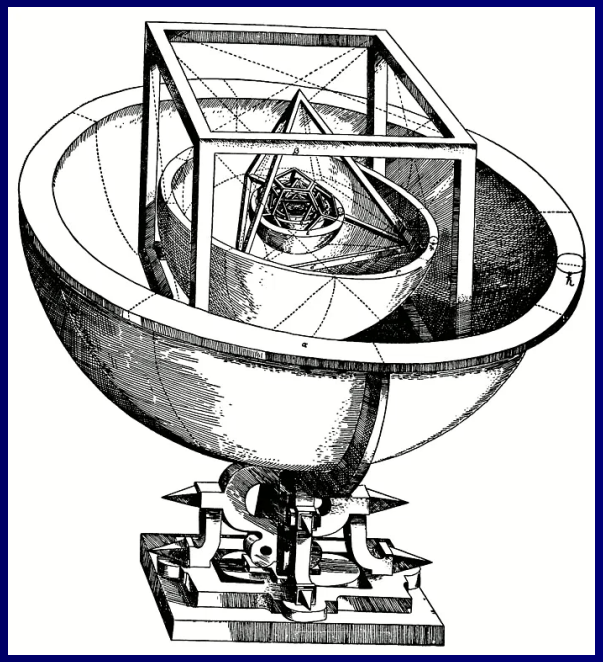
Copernicus' primary motivation:

He felt Ptolemy's equant was an inelegant solution.

And Copernicus had the expertise and free time to seek an alternative.

https://maa.org/sites/default/files/images/upload_library/46/Swetz_2012_Math_Treasures/Lehigh_University/Lehigh_Copernicus/Lehigh_4_064.jpg

Kepler partially agrees



https://www.worldhistory.org/img/r/p/1500x1500/17841.png.webp?v=1710877626

Wait – Who's Kepler?

November 11, 1572

A "new star" appears
in the constellation Cassiopeia

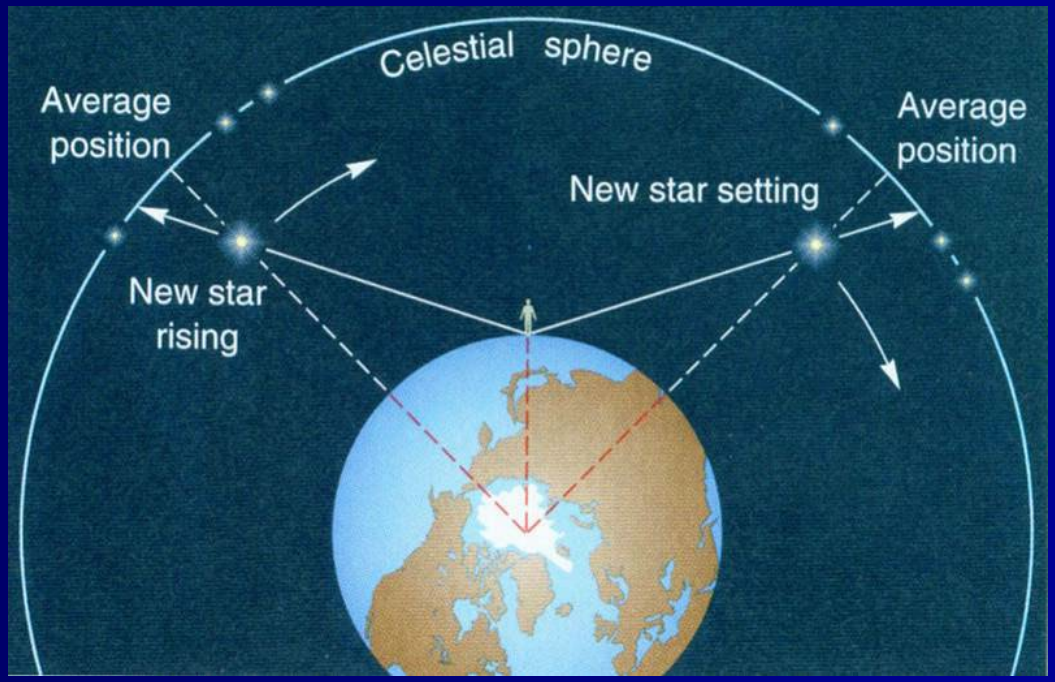
In Denmark, alchemist Tycho Brahe
takes note

Fleisch

http://galileo.rice.edu/images/people/brahe.gif

What Bugged Tycho

The "new star" didn't show any PARALLAX as it moved across the sky!



And only very distant objects don't show parallax.

Trouble for Aristotle

According to Aristotle:

- the celestial sphere is perfect

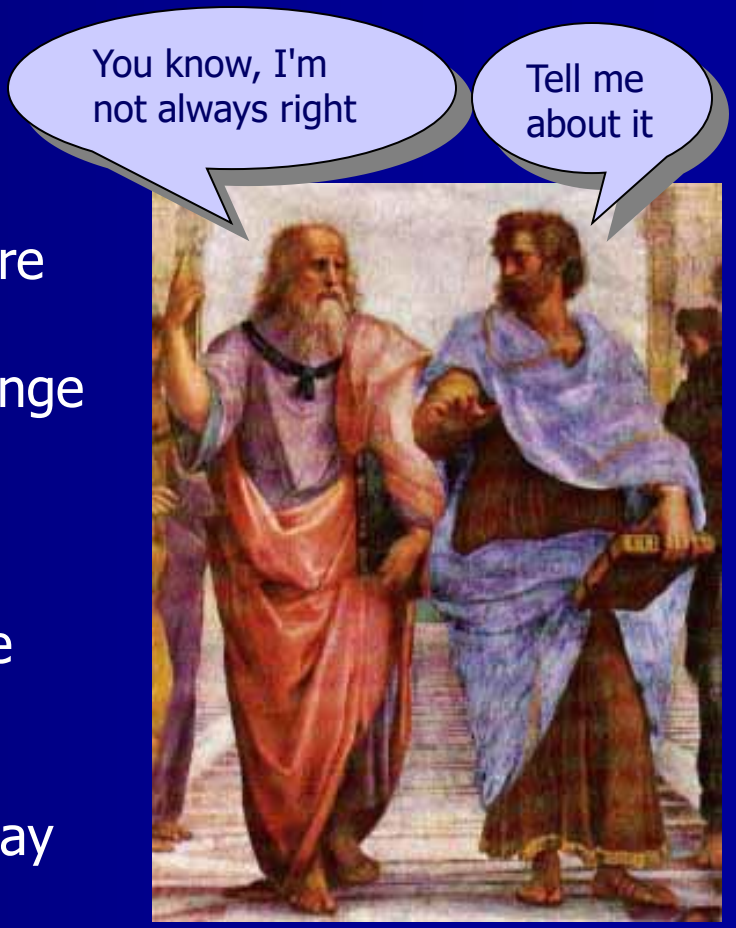
- nothing ever changes on the sphere

- objects "below the Moon" can change

But Tycho knew:

- the heavens DID change when the new star appeared

- the new star MUST be very far away



Right Guy, Right Place, Right Time

Columbus

Copernicus

Luther

By 1578, Tycho had become the most famous astronomer in the world

Tycho Brahe

Tycho was the first "modern" observational astronomer – he loved taking data

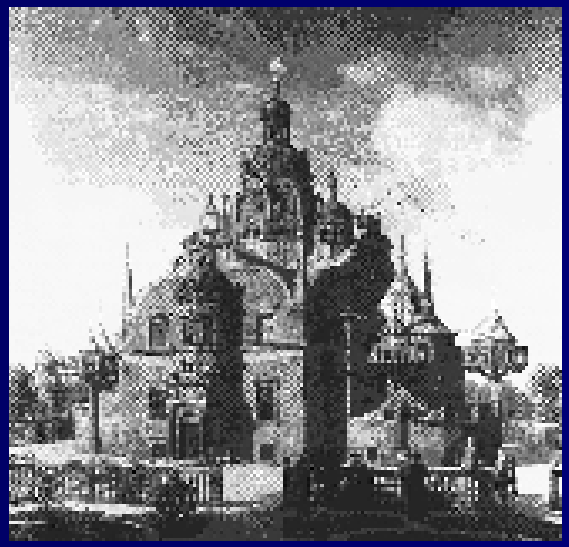
Kepler

Galileo

Newton

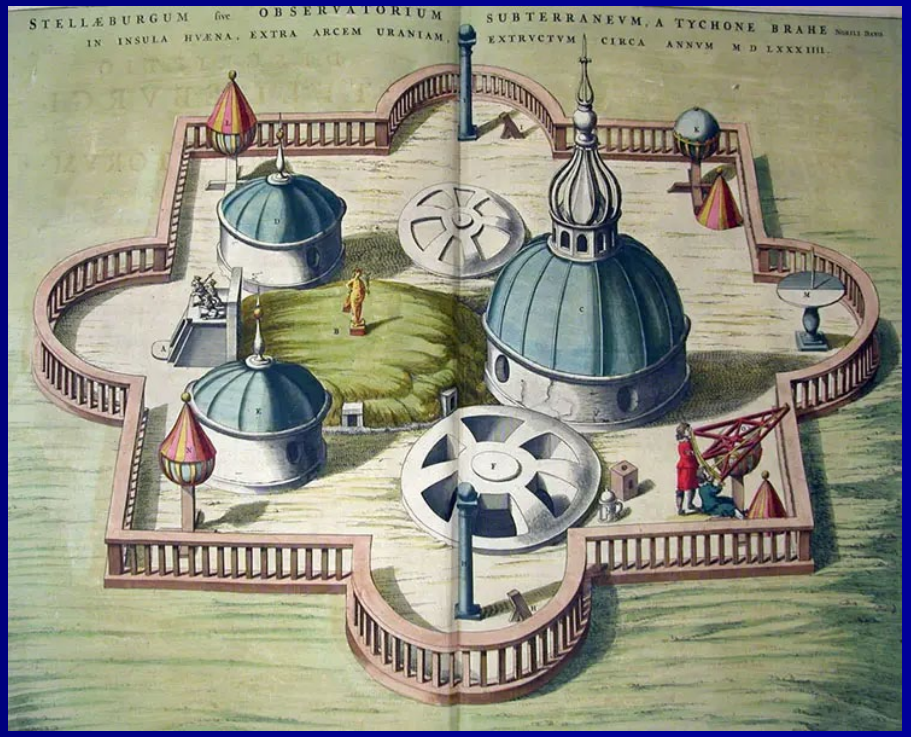
Tycho Brahe at Hven

King of Denmark: "How about a castle?"



https://faculty.wcas.northwestern.edu/infocom/Ideas/graphics/uraniborg1.jpg

Brahe: "What the hell, I'll take the whole island."



https://assets-us-01.kc-usercontent.com/9dd25524-761a-000d-d79f-86a5086d4774/742ebf9a-203d-4d67-851c-8d451a415a90/brahe2.jpg?w=741&h=600&auto=format&q=75&fit=crop

Uraniborg – "Celestial Castle"

Tycho Brahe outfitted Uraniborg with everything any astronomer would want:

1. Cylindrical observation towers with removable roofs
2. 38-ft brass and oak quadrant for measuring angles
3. 5-ft brass sphere on which star positions could be engraved
4. Scientific library
5. Multiple galleries and workshops
6. Portrait gallery showing eight greatest astronomers (including Tycho himself and his unborn descendant)
7. Jepp the dwarf

Brahe's "Data Product"

Without benefit of a telescope, Brahe consistently measured star and planet positions to within 1 arc minute (1/60°).

Over 20 years, Brahe catalogued the positions of over 770 stars and all five known planets.

http://galileo.rice.edu/images/things/mquadrant.gif

Enter Kepler

https://www.esa.int/var/esa/storage/images/esa_multimedia/images/2000/10/johannes_kepler_1571-1630/9233019-6-eng-GB/Johannes_Kepler_1571-1630_pillars.gif

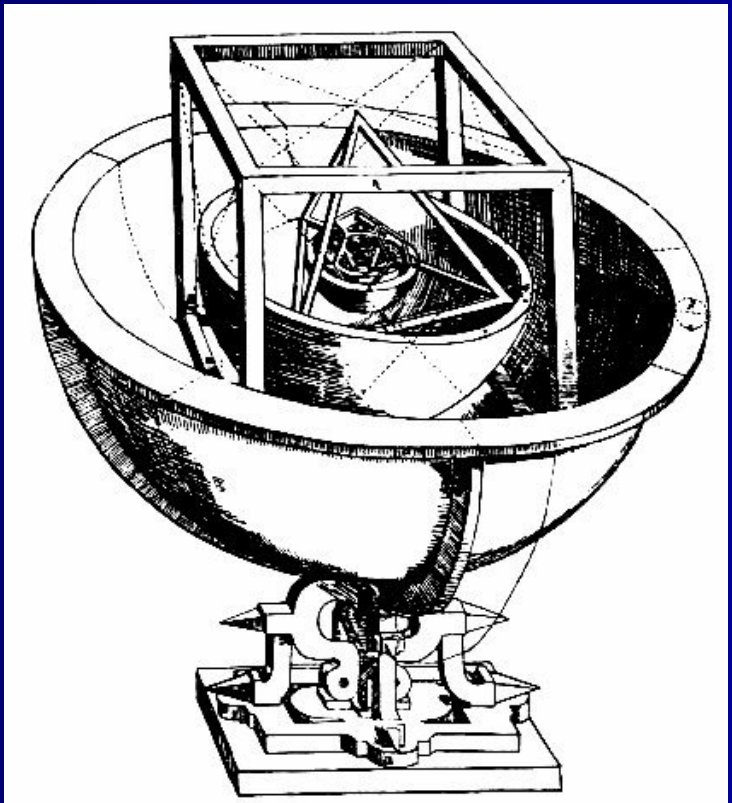
- German mathematician
- Born 1571, died 1630
- Dysfunctional family life
- Great supporter of Copernicus
- Became Brahe's assistant one year before Brahe's death

Whacky Ideas, Great Ideas

Wacky

5 planets,
5 "perfect" shapes

SHAPES DEFINE ORBITS!



https://www.worldhistory.org/img/r/p/1500x1500/17841.png.webp?v=1710877626

Great

Observations of planet's positions can help us understand the nature of their orbits

Kepler NEEDED all of Tycho's data

Kepler Gets Brahe's Data

https://i.ebayimg.com/images/g/9q0AAOSwDSJb8fiU/s-l1600.jpg

Brahe Brood

Kepler Clan

And the winner is … Johannes Kepler!

Kepler Prevails

Using Tycho Brahe's data, Kepler derived the "Laws of Planetary Orbits" that changed forever the way astronomers look at the heavens.

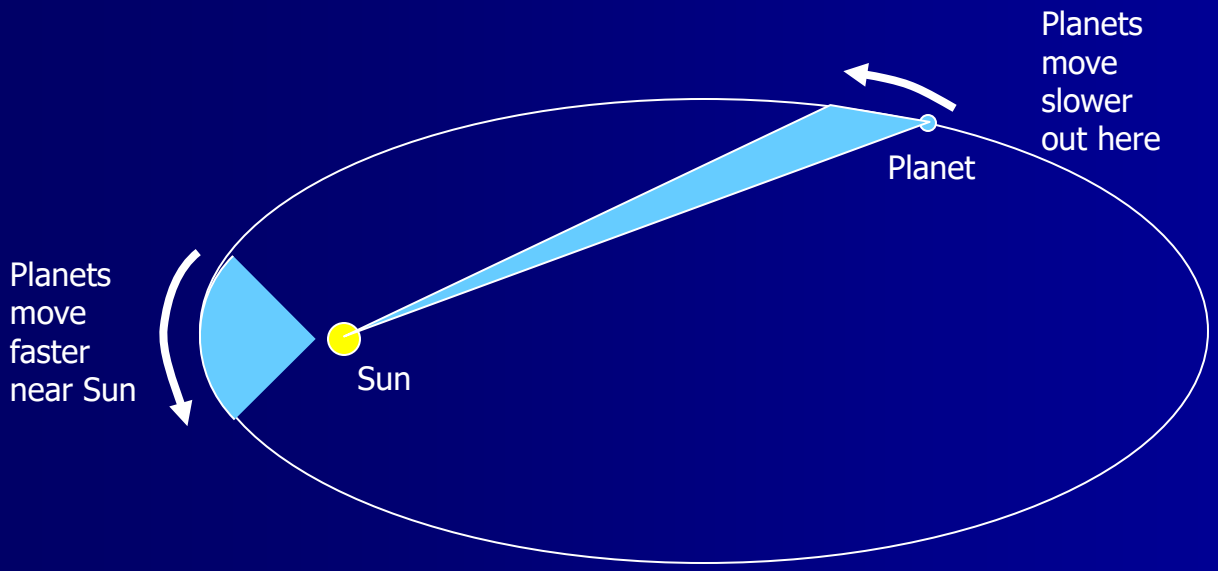
Gone were the unchanging "Celestial Sphere" and perfect circles of Aristotle.

Now we have the true figure of an orbit:

The ELLIPSE!

Kepler's 1st and 2nd Laws

1st Law: Planetary orbits are ellipses



2nd Law: Equal areas covered in equal times

Kepler's Third Law

$$P^2 = a^3$$

Period of Revolution (in years)

Distance from Sun (in Astronomical Units)

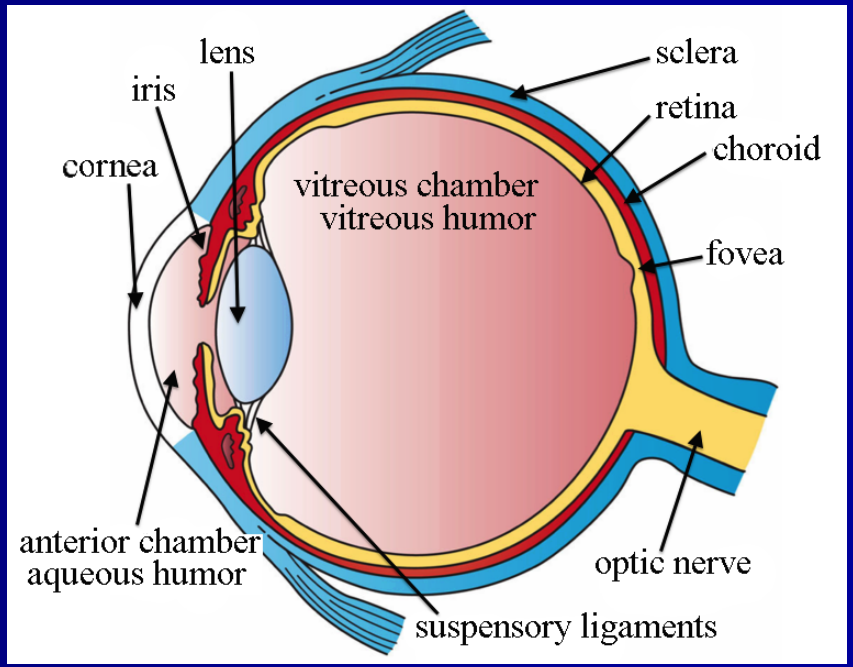
Technology Rears Its Head

https://catalogue.museogalileo.it/images/cat/oggetti_944/0554_3253_0429-018_944.jpg

Why This Technology Matters

Three ways in which Nature can hide from our sight:

- Tiny angular size
- Extreme faintness
- Wavelength beyond our detection range



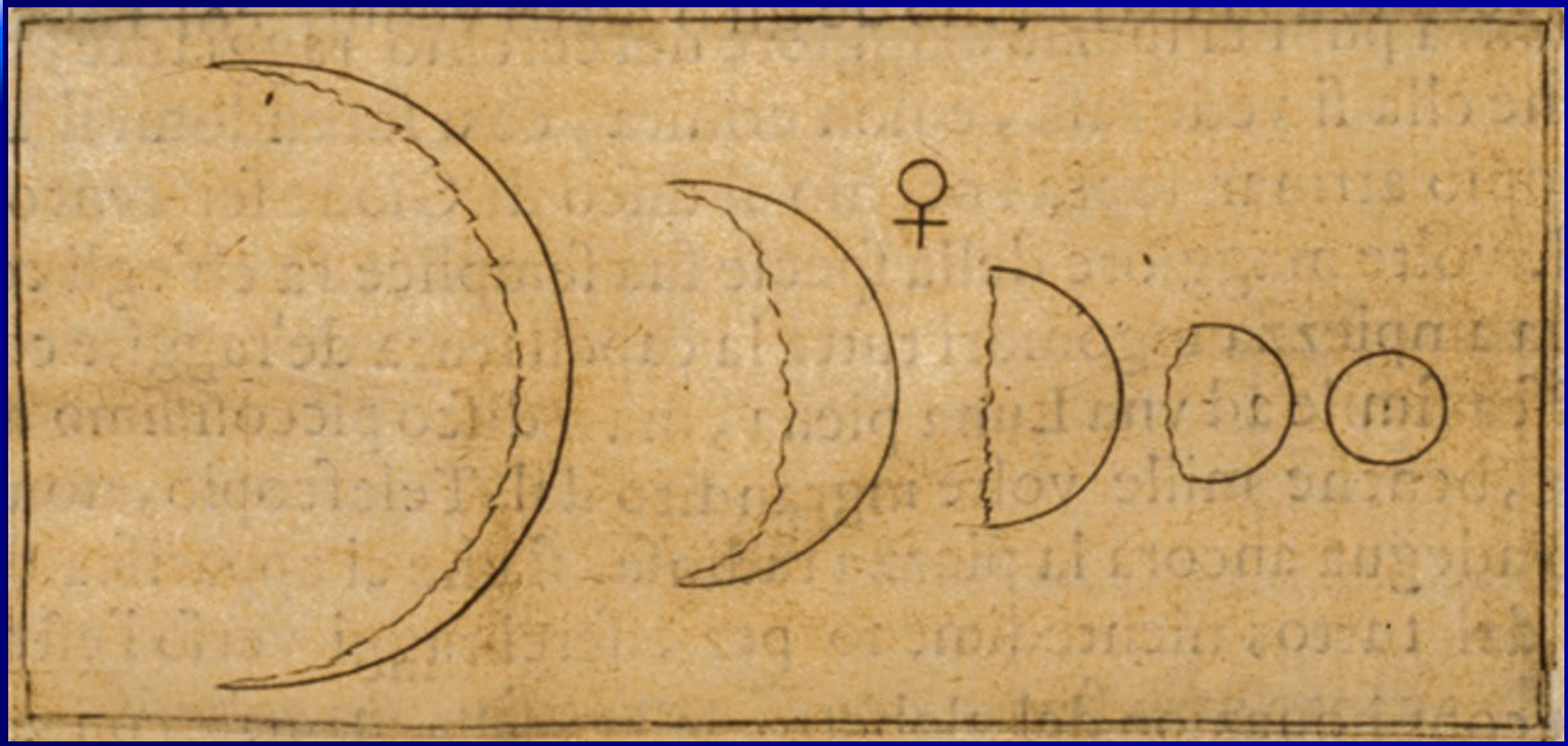
https://harvardeye.com/wp-content/uploads/2018/08/Diagram-of-the-Eye.png

Galileo Looks Up in 1609

Oh,
the things
you'll see

https://3.bp.blogspot.com/-yuda7JPsdeE/W4B5XQFWqDI/AAAAAAAAKbU/QGc0YjYFc-YfH1BVP_2hA0P2FgmFRcoKwCLcBGAs/s1600/Bertini_fresco_of_Galileo_Galilei_and_Doge_of_Venice.jpg

Venus Has Phases



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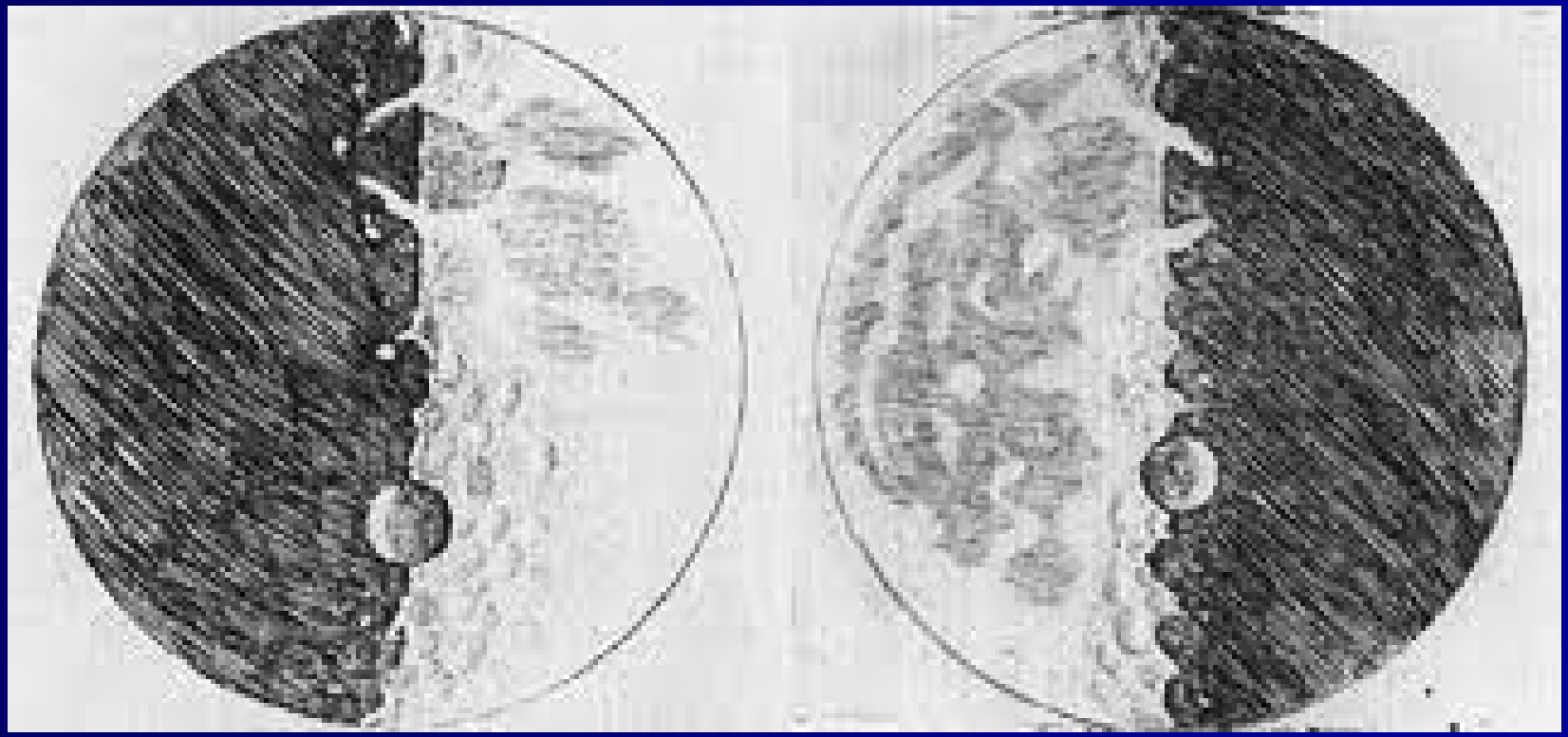
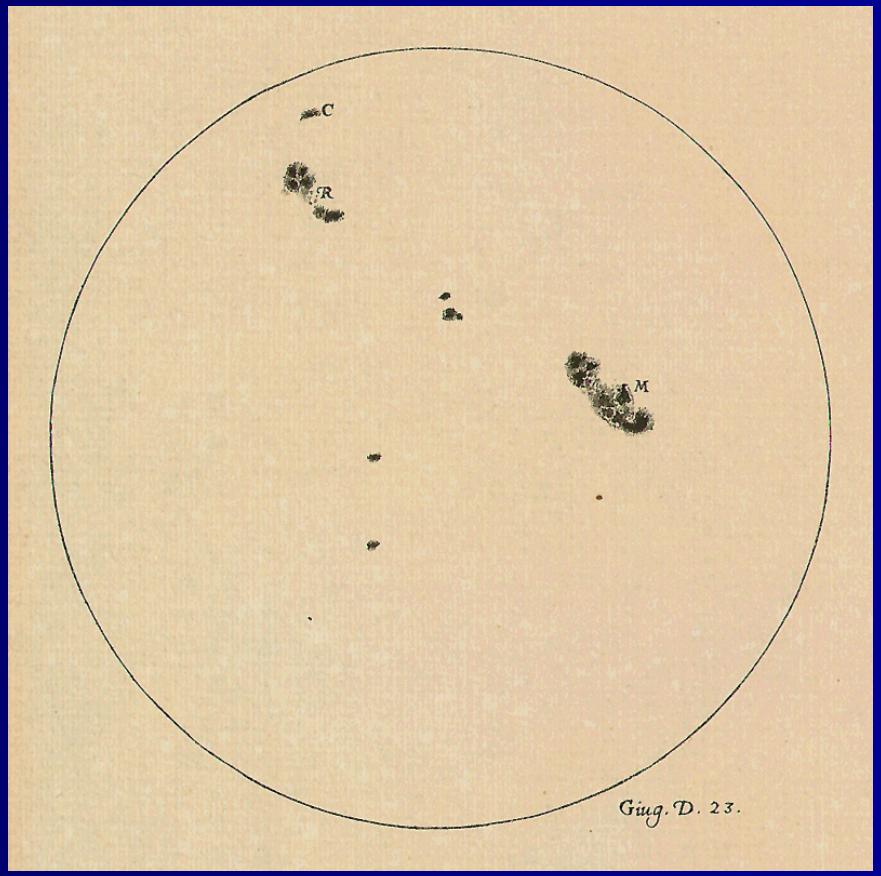
The Moon Has Craters



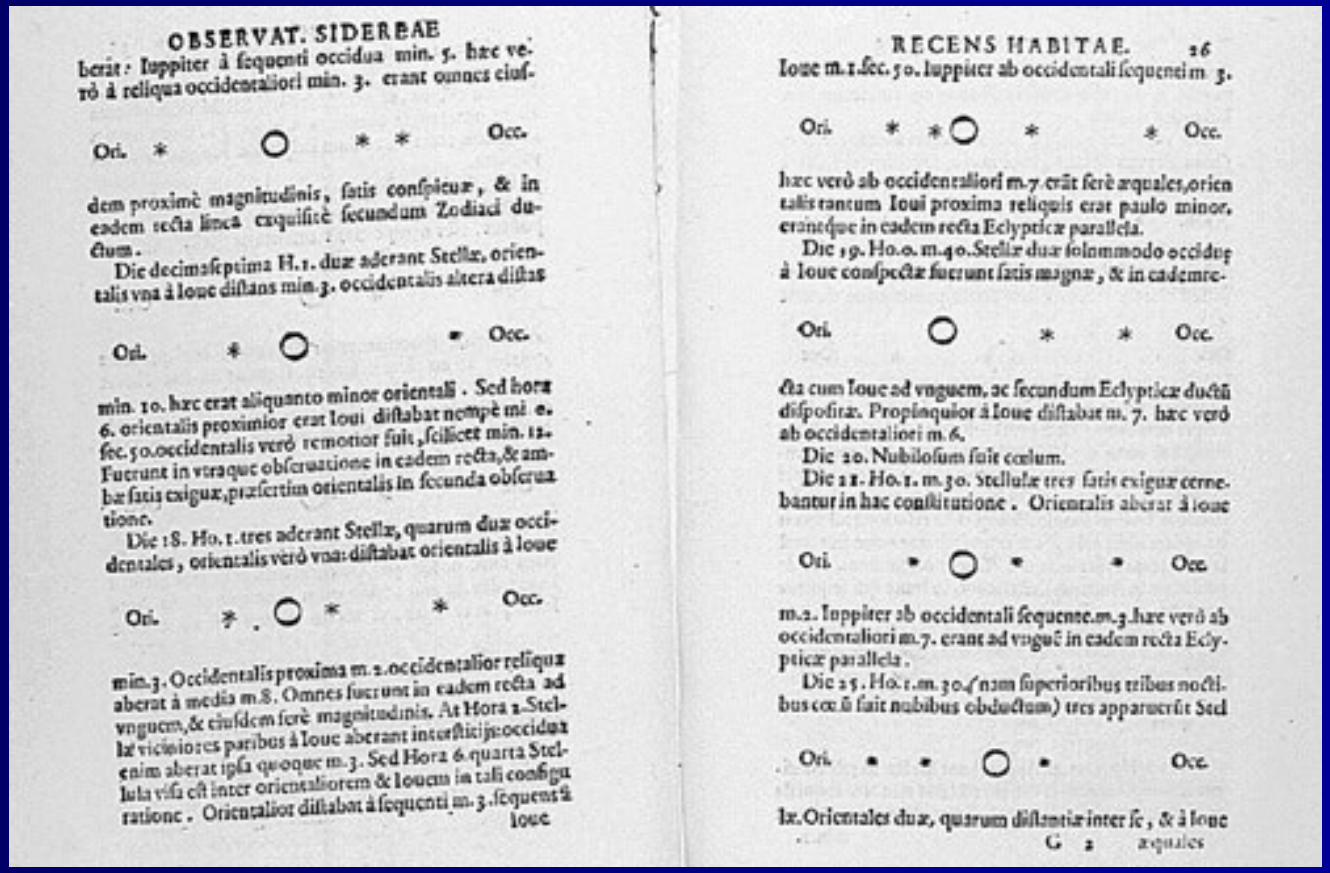
http://galileo.rice.edu/images/things/g_sidnun_moon-t.gif

The Sun Has Spots



http://galileo.rice.edu/images/things/sunspot_drawings/ss623-l.gif

Jupiter Has Moons



OBSERVAT. SIDERAE

berat: Iuppiter à sequenti occidua min. 5. hæc verò à reliqua occidentaliori min. 3. erant omnes ciusdem proximè magnitudinis, satis conspicuæ, & in eadem recta linea exquisitè secundum Zodiaci ductum.

Die decimaseptima H. 1. duæ aderant Stellæ, orientalis vna à Ioue distans min. 3. occidentalis altera distans min. 10. hæc erat aliquanto minor orientali. Sed hora 6. orientalis proximior erat Ioui distabat nempè min. 1. sec. 50. occidentalis verò remotior fuit, scilicet min. 12. Fuerunt in vtraque observatione in eadem recta, & ambæ satis exiguæ, præsertim orientalis in secunda observatione.

Die 18. Ho. 1. tres aderant Stellæ, quarum duæ occidentales, orientalis verò vna: distabat orientalis à Ioue min. 3. Occidentalis proxima m. 2. occidentalior reliqua aberat à media m. 8. Omnes fuerunt in eadem recta ad vnguem, & eiusdem ferè magnitudinis. At Hora 2. Stellæ viciniores paribus à Ioue aberant interstitijs: occidua enim aberat ipsa quoque m. 3. Sed Hora 6. quarta Stellula visa est inter orientaliorem & Iouem in tali consiguratione. Orientalior distabat à sequenti m. 3. sequens à Ioue

RECENS HABITAE. 26

Ioue m. 1. sec. 50. Iuppiter ab occidentali sequenti m. 3. hæc verò ab occidentaliori m. 7. erat ferè æquales, orientalis tantum Ioui proxima reliquis erat paulo minor, eranteque in eadem recta Ecypticæ parallela.

Die 19. Ho. 0. m. 40. Stellæ duæ solummodo occiduę à Ioue conspectæ fuerunt satis magnæ, & in eadem recta cum Ioue ad vnguem, ac secundum Ecypticæ ductū dispositæ. Propinquior à Ioue distabat m. 7. hæc verò ab occidentaliori m. 6.

Die 20. Nubilosum fuit cœlum.

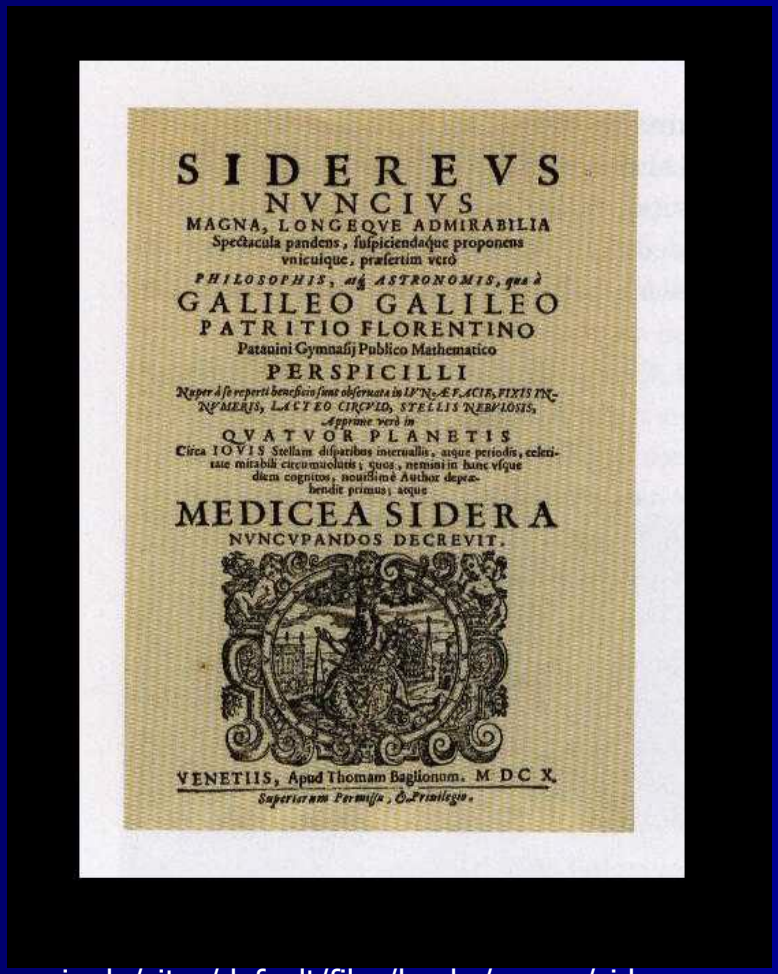
Die 21. Ho. 1. m. 30. Stellulæ tres satis exiguæ cernebantur in hac constitutione. Orientalis aberat à Ioue m. 2. Iuppiter ab occidentali sequente m. 3. hæc verò ab occidentaliori m. 7. erant ad vnguē in eadem recta Ecypticæ parallela.

Die 25. Ho. 1. m. 30. (nam superioribus tribus noctibus cœlū fuit nubibus obductum) tres apparuerūt Stellæ. Orientales duæ, quarum distantiæ inter se, & à Ioue

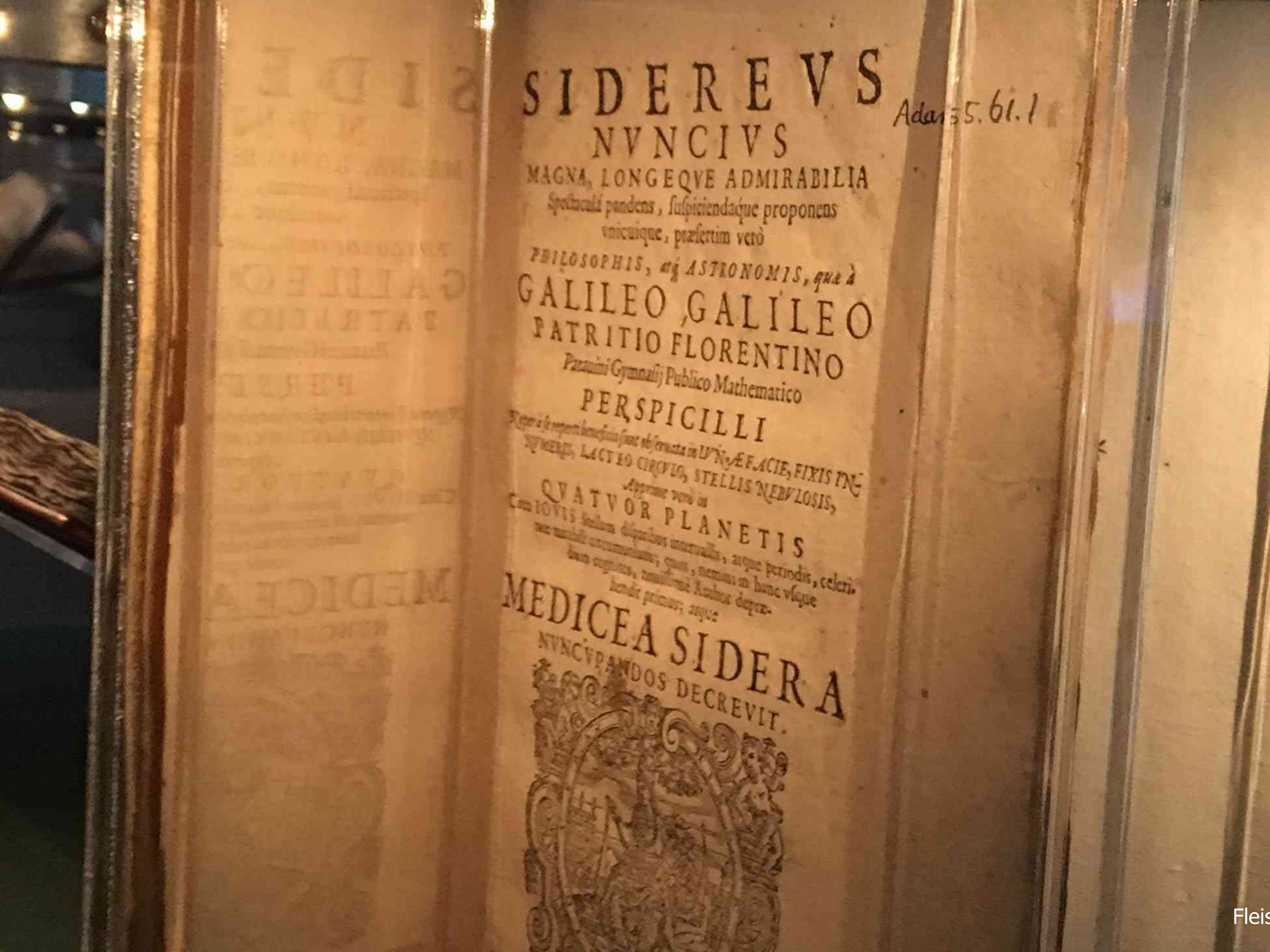
G 2 æquales

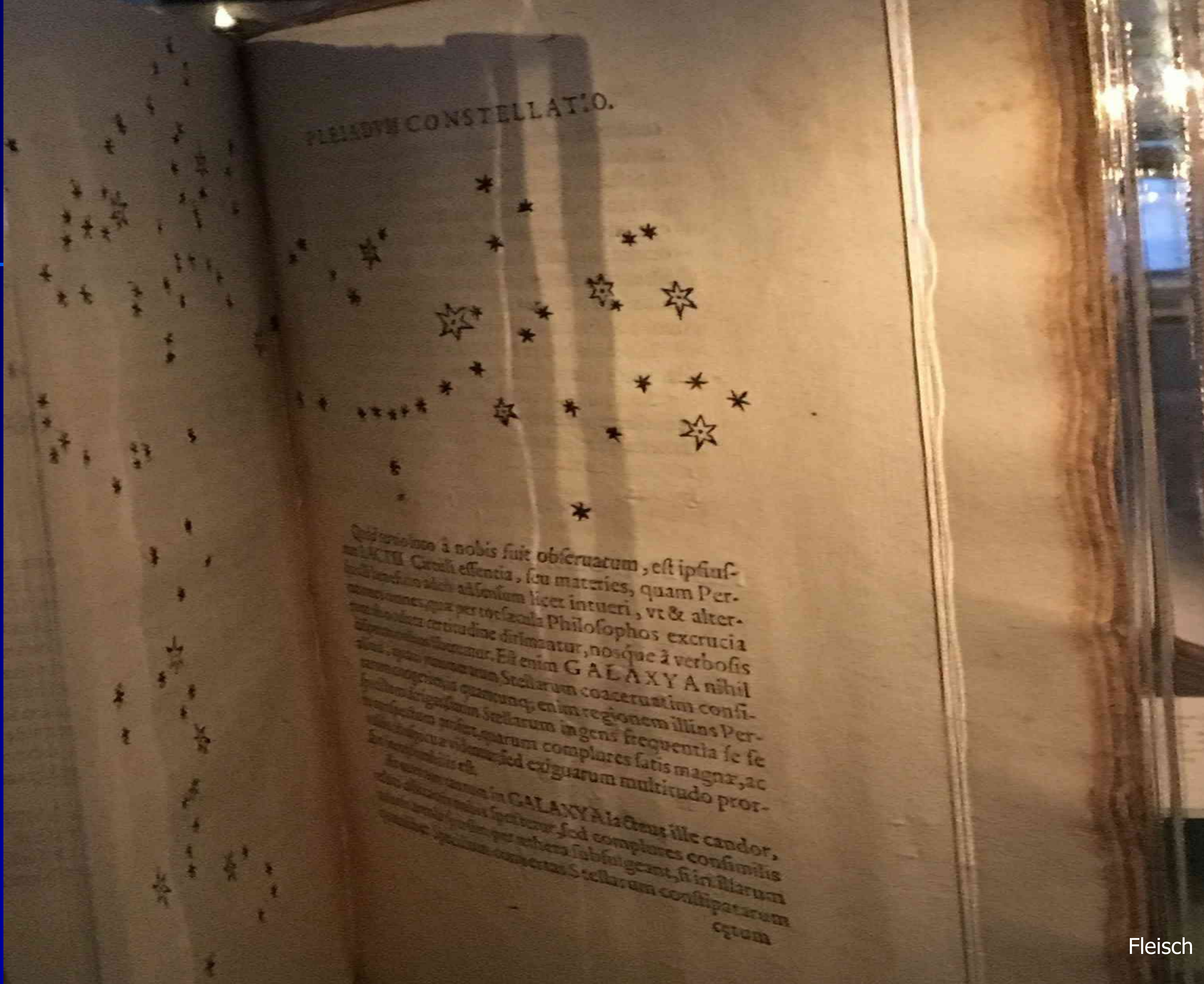
http://www.sites.hps.cam.ac.uk/starry/galileo2med.jpg

The Word Is Out



https://library.si.edu/sites/default/files/books/covers/sidereusnunciusm00gali_cover.jpg

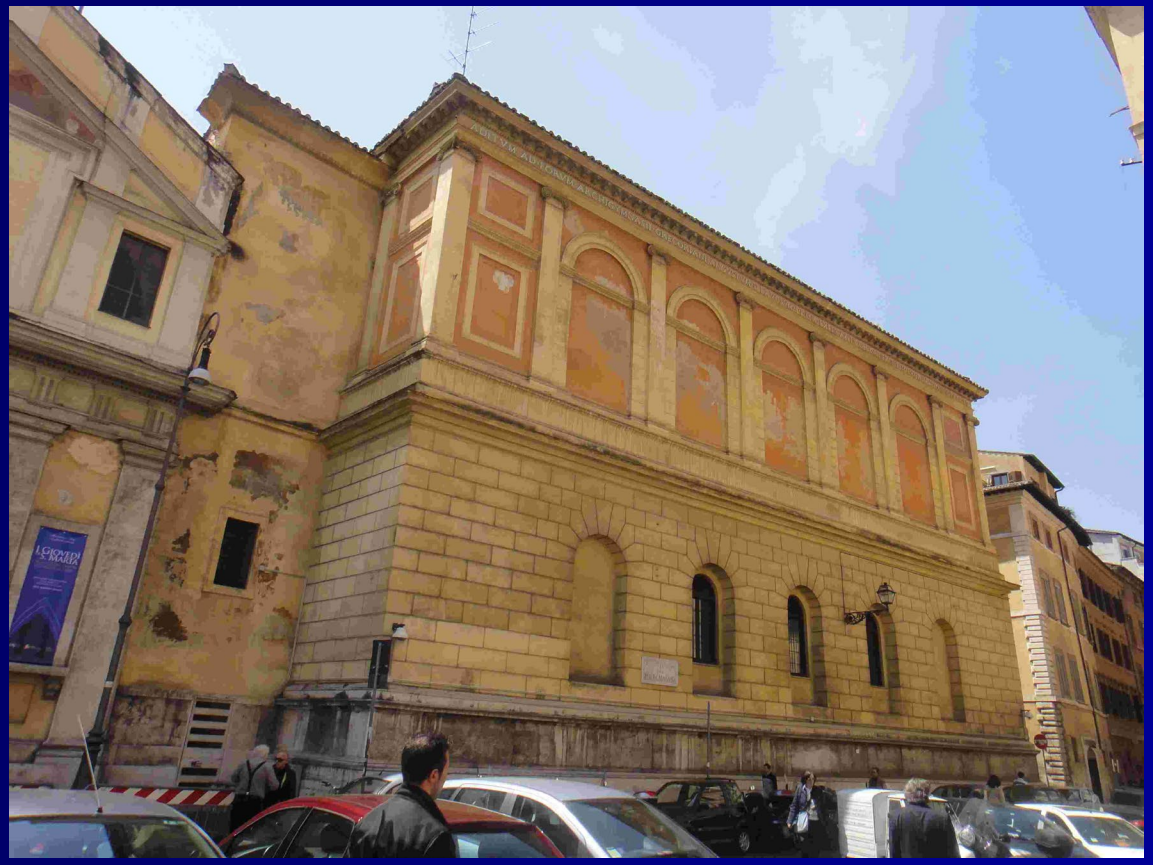

SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Publico Mathematico
PERSPICILLI
LACTEO CIRCVLO, STELLIS NEBVLOSIS,
QVATVOR PLANETIS
atque periodis, celeri-
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
Adam 5.61.1


PLEIADVM CONSTELLATIO.
à nobis fuit obseruatum, est ipsius-
Circuli essentia, seu materies, quam Per-
licet intueri, vt & alter-
Philosophos excrucia
dirimatur, nosque à verbosis
Est enim GALAXYA nihil
Stellarum coacervatim confi-
quamcunq; enim regionem illius Per-
Stellarum ingens frequentia se se
quarum complures satis magnæ, ac
sed exiguarum multitudo pror-
in GALAXYA lacteus ille candor,
sed complures consimilis
per æthera subfulgeant, si in illarum
Stellarum constipatarum
eorum

Fleisch

Did We Hear Something About the Heavens?

A Warning Seems Warranted



The Holy Office of the Inquisition

Rough Road for Heliocentrism

Heliocentrism declared to be heretical in 1616.

Copernicus' book added to Index Librorum Prohibitorum

Galileo told to abstain from teaching or discussing his theories surrounding heliocentrism as fact.

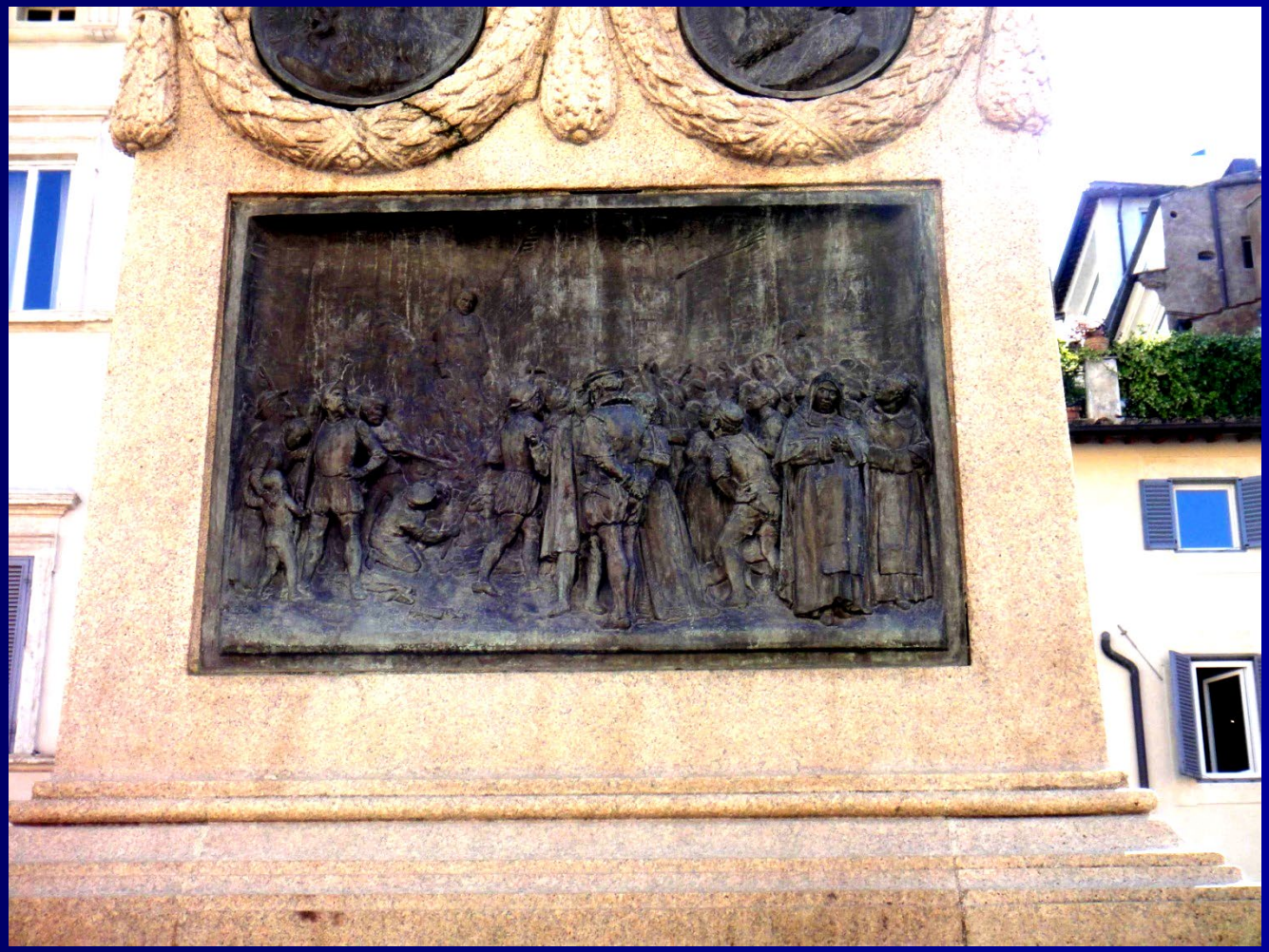
The Teeth in the Warning: Memory of Giordano Bruno

Giordano Bruno
(1548 – 1600)

Campo
dei Fiori

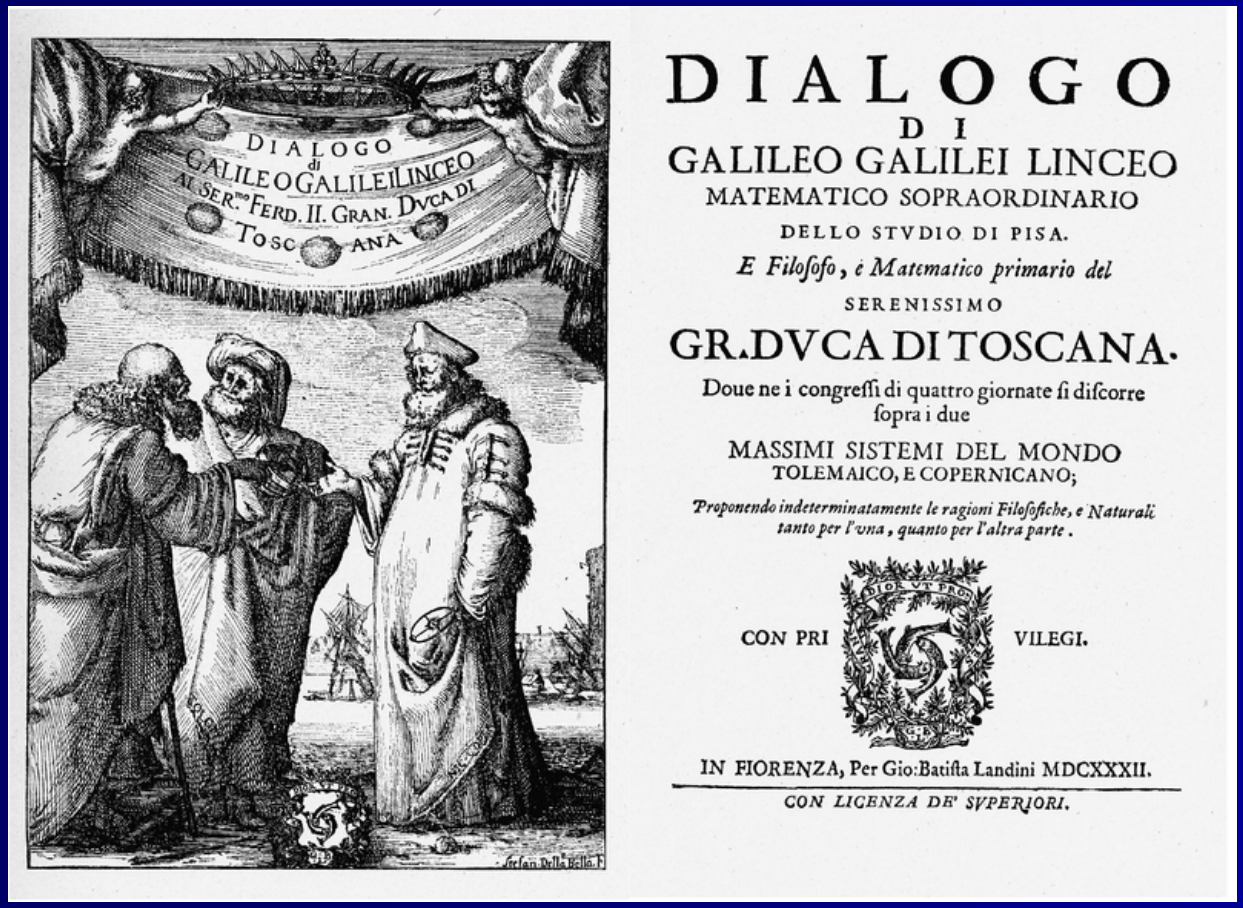
Fleisch

Bruno's Fate



Fleisch

The Warning Wears Off



Dialogue over the Two Chief Systems of the World

1632

https://64.media.tumblr.com/96b83d8fe81db06e9385e3431624dd36/tumblr_inline_oo9zq2pJai1uns891_1280.jpg

Two Pretty Smart Guys and One Not So Much

Salviati: Supports Copernicus
Sagredo: Neutral (initially)
Simplicio: Supports Ptolemy and Aristotle

“pure mathematical hypothesis”

1633: The Church Isn't Buying It

Verdict: "Vehemently Suspect of Heresy"

https://www.stthomas.edu/media/terrencejmurphyinstitute/galileo-inquisition-400x274.jpg

Galileo Forced to Abjure

"I have been judged vehemently suspect of heresy, that is, of having held and believed that the sun in the centre of the universe and immoveable, and that the earth is not at the center of same, and that it does move. Wishing however, to remove from the minds of your Eminences and all faithful Christians this vehement suspicion reasonably conceived against me, I abjure with a sincere heart and unfeigned faith, I curse and detest the said errors and heresies, and generally all and every error, heresy, and sect contrary to the Holy Catholic Church."

Abjure: to renounce, repudiate, or retract, especially with formal solemnity; to recant.

Galileo's Fate: House Arrest For the Rest of His Life

Fleisch

The Oft-told Story

By placing Galileo under house arrest, the Church seriously restricted the advancement of astronomy and science in general.

And this is certainly accurate.

But, as usual…

…there’s more to the story.

Right and Wrong

Ptolemy: Right about offset, wrong about epicyles

Copernicus: Right about heliocentrism, wrong about circular orbits

Kepler: Right about elliptical orbits, wrong about number of planets

Galileo: Right about Earth moving, wrong about tides

Trouble with Easter

Easter Sunday:

The first Sunday
after the first full Moon
after the vernal equinox.

So exactly which day is the holiest day of our liturgical calendar?

http://www.joyfulheart.com/easter/images/grunewald_resurrection150x250.jpg

An Inconvenient Number

Time from one vernal equinox to the next
= 1 solar year

1 solar year = 365.2433 solar days

Another Inconvenient Number

Time from one new moon to the next
= 1 synodic month

1 synodic month = 29.53059 solar days

Growing Discrepancy

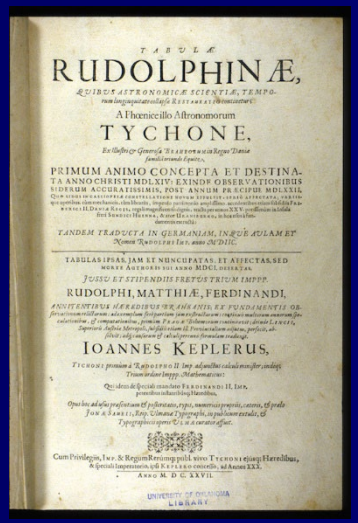
In 325 AD, the Council of Nicea set
1 year = 365.25 days

So every year, the time at which the Sun reached a certain position in the sky would shift by 11.2 minutes.

By 800 AD, the discrepancy was 3.7 days.

Vernal Equinox was falling on March 17th.

Full Employment for Mathematicians



TABVLÆ

RUDOLPHINÆ,

ÆQUIBUS ASTRONOMICÆ SCIENTIÆ, TEMPORUM longinquitate collapsæ RESTAURATIO continetur.

A Phœnicello Astronomorum

TYCHONE,

Ex illustri & Generosâ TRANSORANORUM Regni Daniæ familiâ oriundo Equite,

PRIMUM ANIMO CONCEPTÆ ET DESTINATÆ ANNO CHRISTI MDLXIV. EXINDE OBSERVATIONIBUS SIDERUM ACCURATISSIMIS, POST ANNUM PRÆCIPUE MDLXXII.

TANDEM TRADUCTÆ IN GERMANIAM, IN AULAM ET Nomen RUDOLPHI II. anno MDIIC.

TABULAS IPSAS, JAM ET NUNCUPATAS, ET AFFECTAS, SED MORTE AUCTORIS SUI ANNO MDCI. DESERTAS.

JUSSU ET STIPENDIIS FRETUS TRIUM IMPPP.

RUDOLPHI, MATTHIÆ, FERDINANDI,

ANNITENTIBUS HÆREDIBUS OPERARUM, EX FUNDAMENTIS ORSA

IOANNES KEPLERUS,

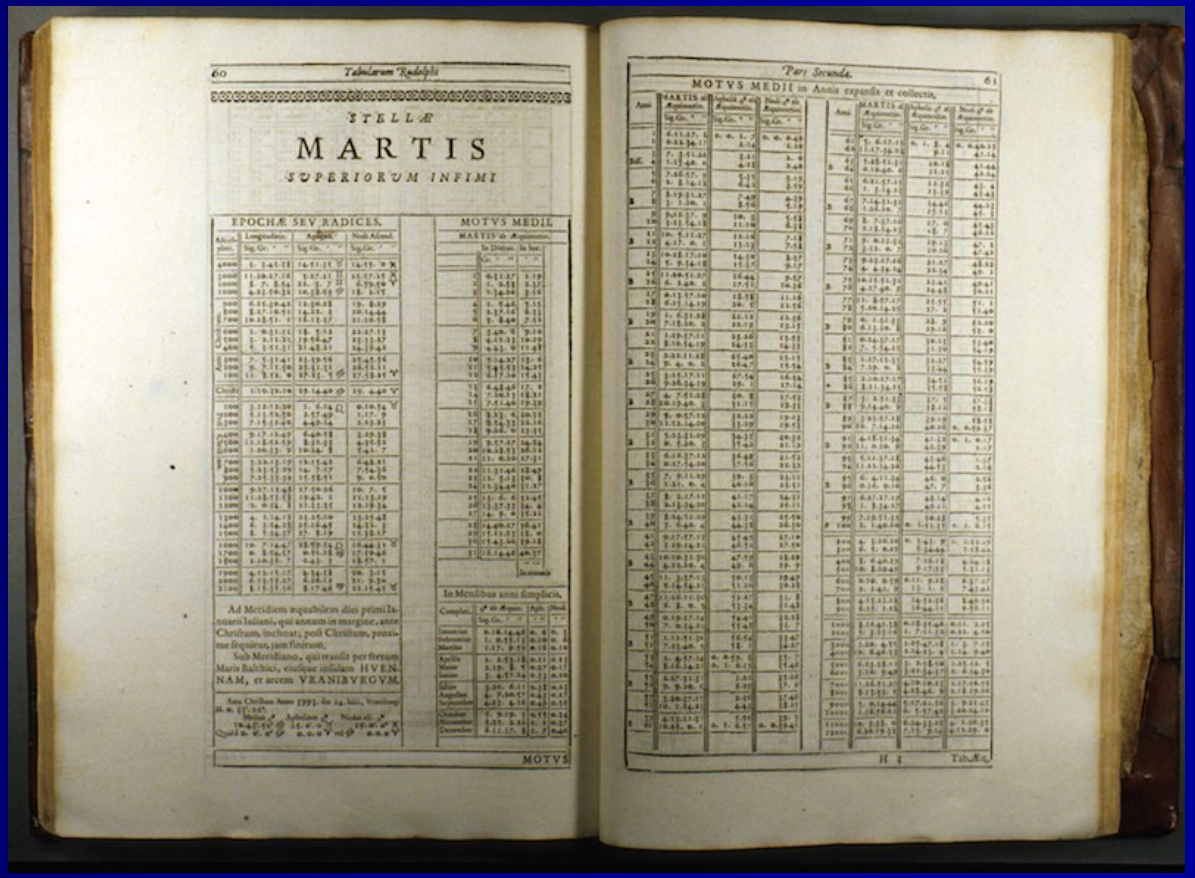
TYCHONIS primum à RUDOLPHO II. huc adscitus calculi munifer studiosus, Tumvidem longe, Mathematicus

Quidem deputati mandato FERDINANDI II. IMP. penedictus haereditarius Haredibus,

Opus hoc ad usus præsentium & posterorum, typis, numeris propriis, sumtu, & arte JOH. SAUBII, Reip. Ulmanæ Typographi, in palatium extrudi, & Typographicis operis Ulmensis curatis effari.

Cum Privilegio, Iuv. & Regiorum Reformq; priil. vivo TYCHONI ejusq; Hæredibus, & speciali Imperatoris, ipso KEPLERO concesso, ad Annos XXX.

ANNO M. D. C. XXVII.



60 Tabularum Rudolphi

STELLÆ

MARTIS

SUPERIORUM INFIMI

EPOCHÆ SEV RADICES.

MOTVS MEDII

Ad Meridiem æquabilem dies primi Ianuarii Iuliani, qui annum in margine, ante Christum, inchoat; post Christum, proxime sequitur, jam finitum.

Sub Meridiano, qui transit per Horam Maris Baltici, cuique insidiam HVENANAM, et arcem VRANIBVRGVM.

MOTVS

Pars Secunda. 61

MOTVS MEDII in Annis expansis et collectis.

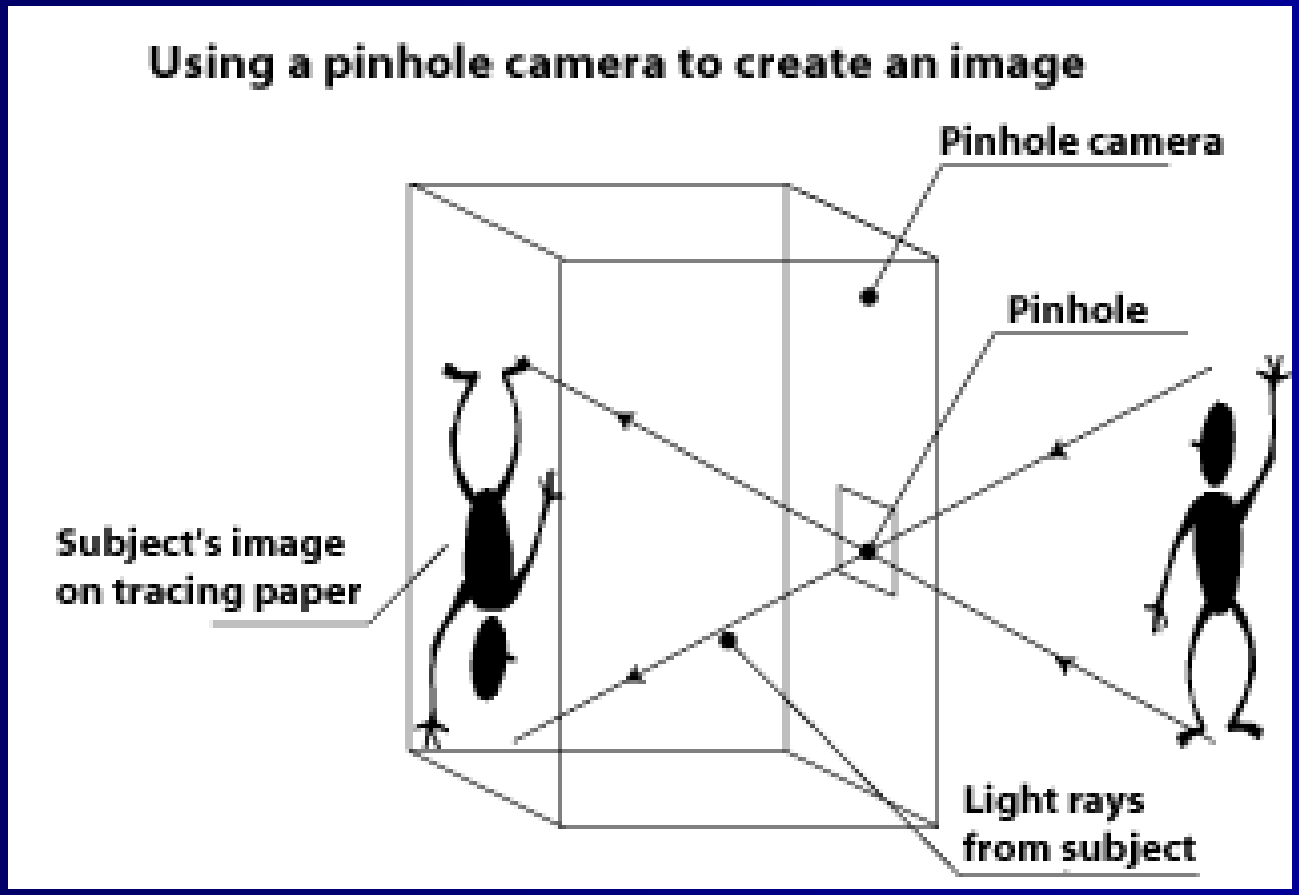
MARTIS

H 4 Tab. Æq.

How To Settle This?

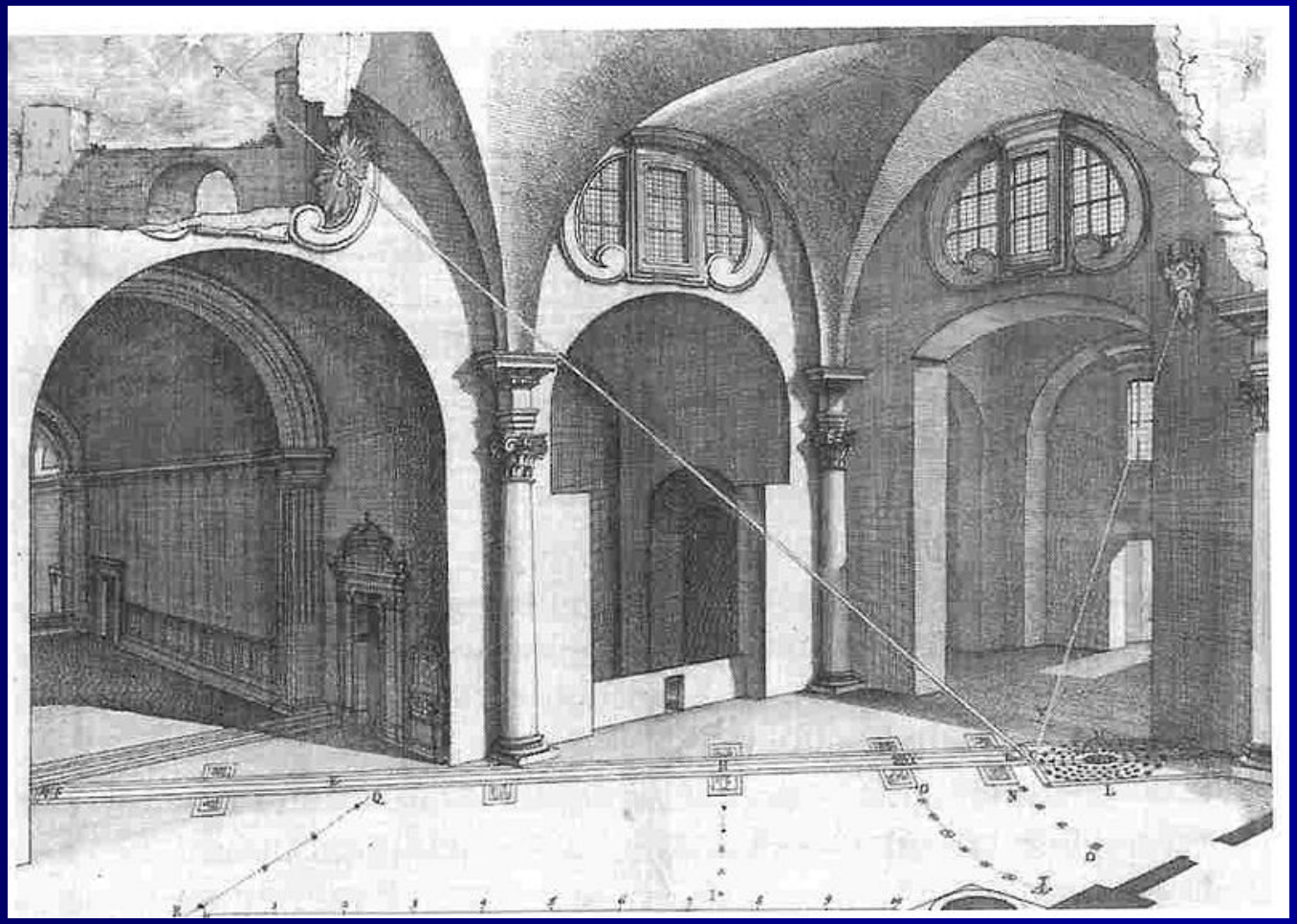
Fleisch

A Good Measuring Tool to Get Data on the Sun's Position



https://shenoutarphotography.files.wordpress.com/2014/05/pinhole.gif

Cathedral as Observatory



The Sun in the Church, J.L. Heilbron

A Line to Track the Sun

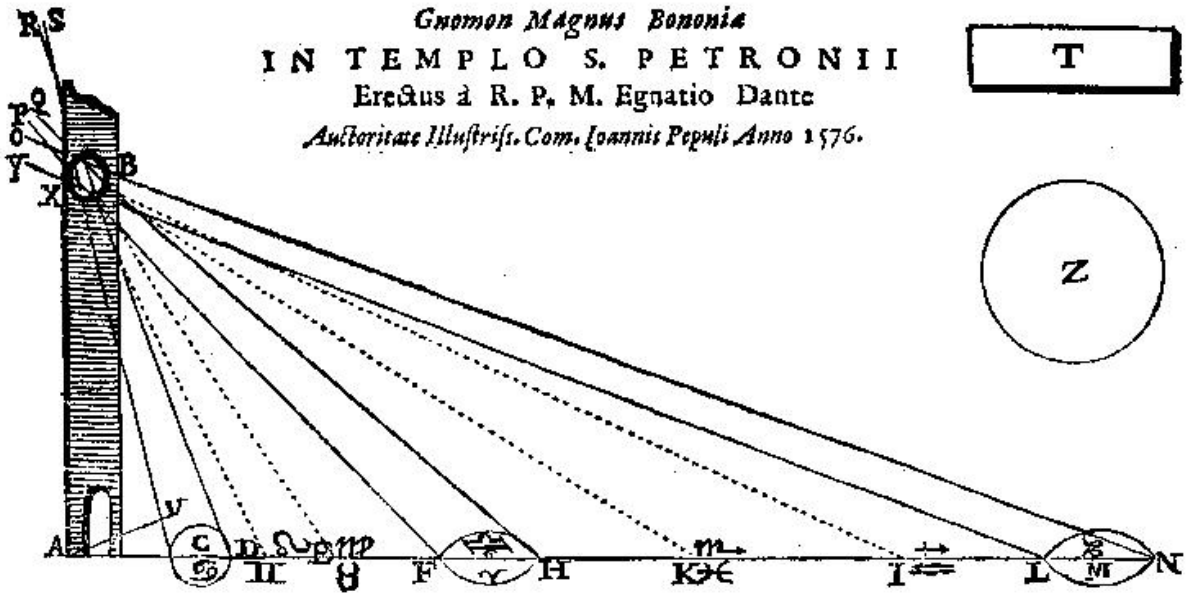


FIG. 2.31. Danti's *meridiana* in San Petronio. T is the cross-section, Z the size and shape of the hole. From Riccioli, *Almagestum novum*, 1:1 (1651), 132.

The Sun in the Church, J.L. Heilbron

Leveling the Line

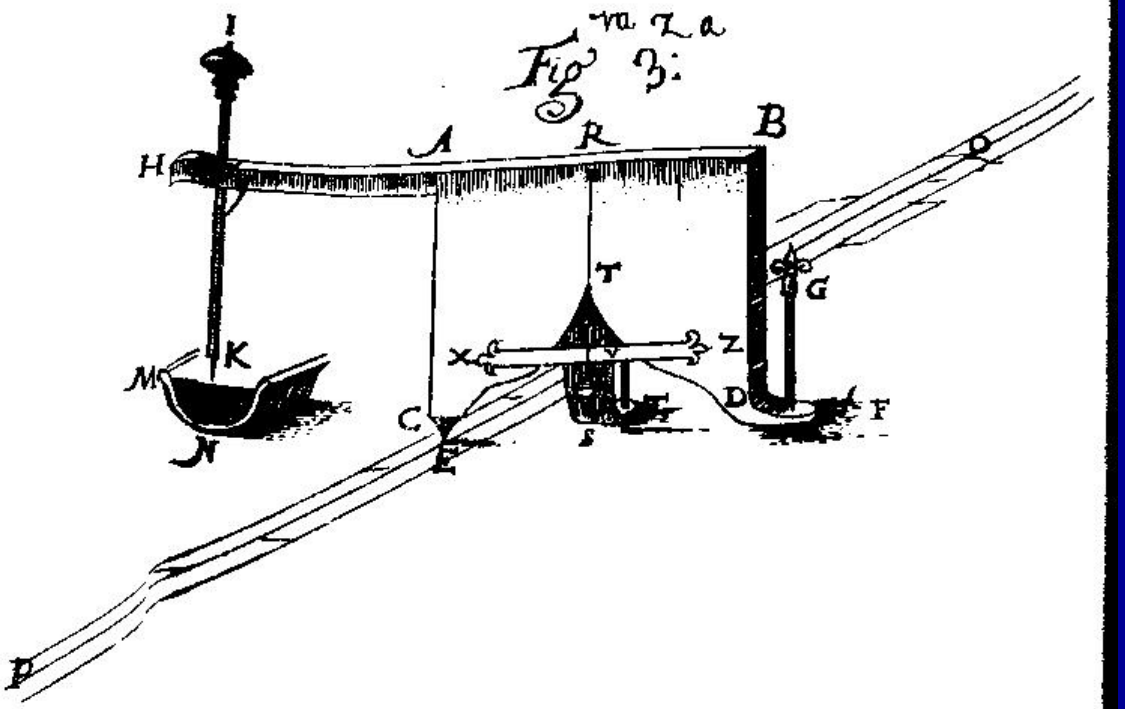


FIG. 3.2. Cassini's method of leveling. PQ is a section of the *meridiana*. From Cassini, *Meridiana* (1695).

The Sun in the Church, J.L. Heilbron

Santa Maria degli Angeli in Rome

Fleisch

Why this Church?

-Southern exposure

-Settled walls

-Symbolic value

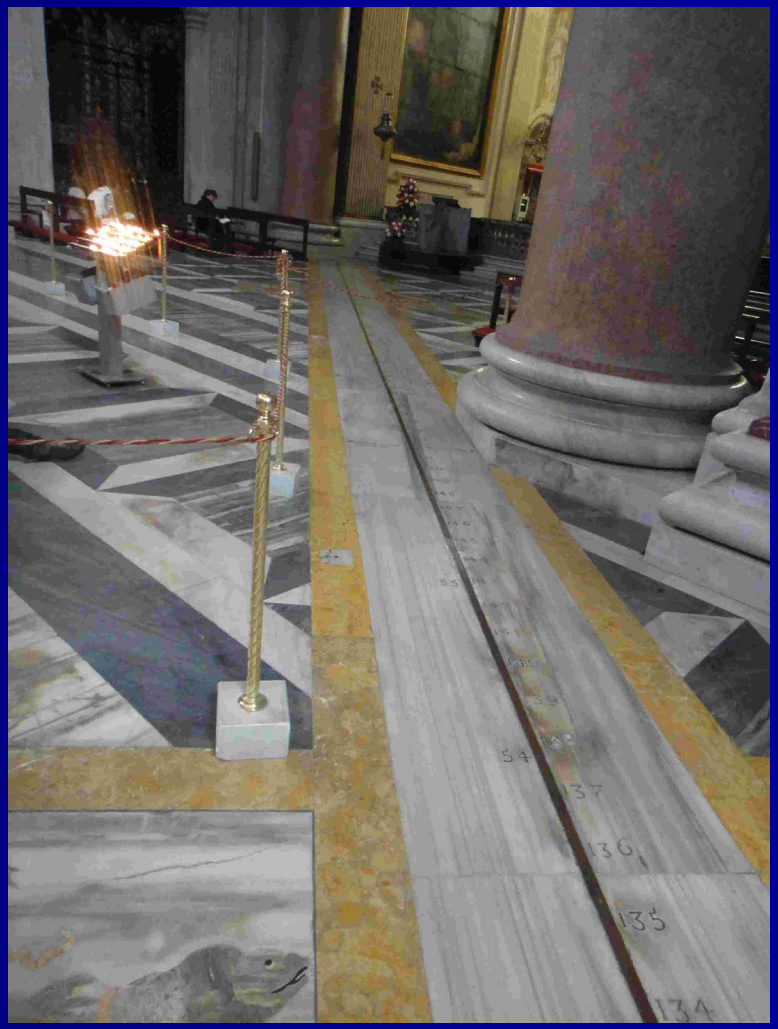
Interior of Santa Maria degli Angeli

Fleisch

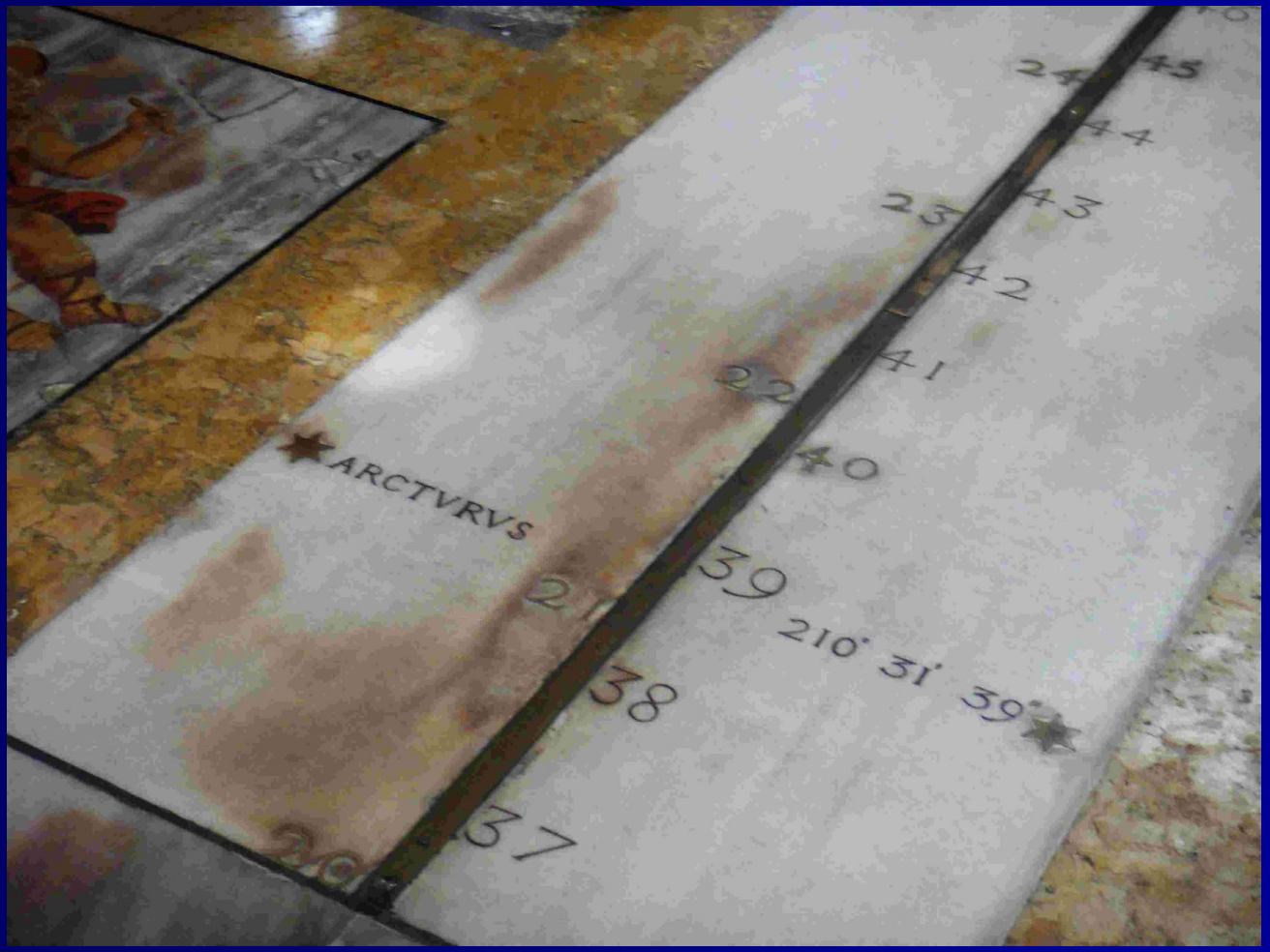
The Meridian Line

Fleisch

Completed in 1703



The Sun in the Church



Fleisch

Saint-Sulpice in Paris

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Interior of Saint-Sulpice

Fleisch

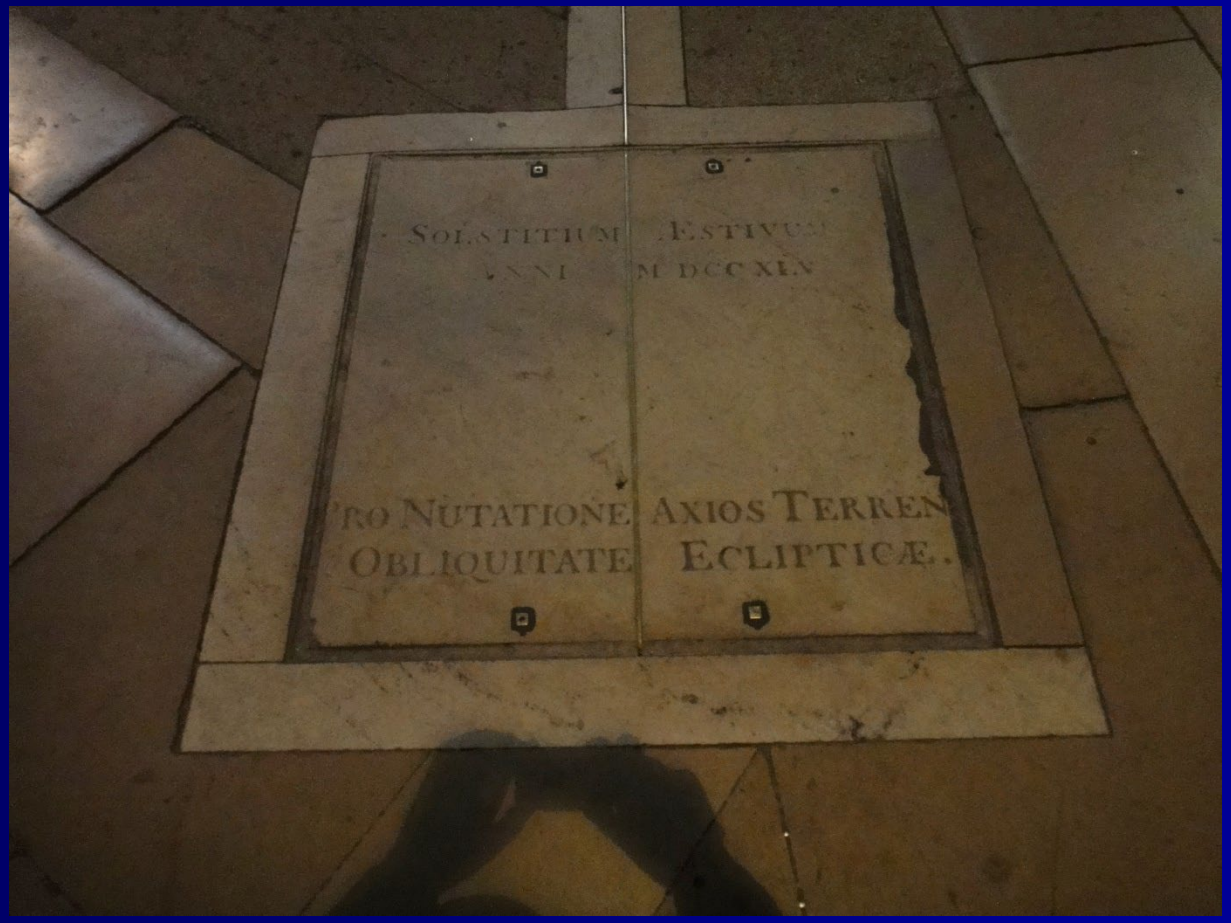
Meridian Line in Saint-Sulpice

Fleisch

Saint-Sulpice Pinhole

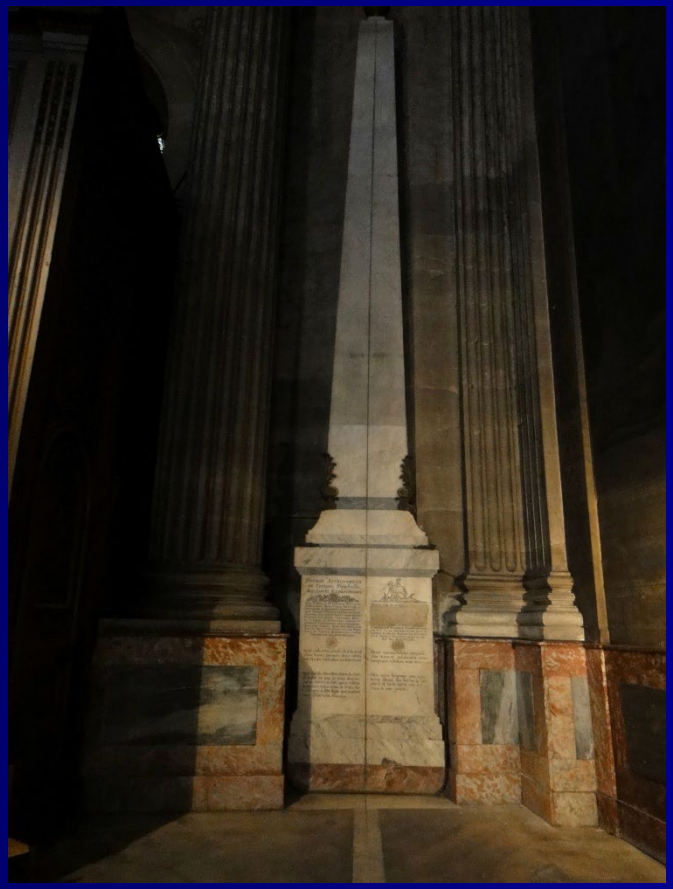
Fleisch

Beginning of Meridian Line

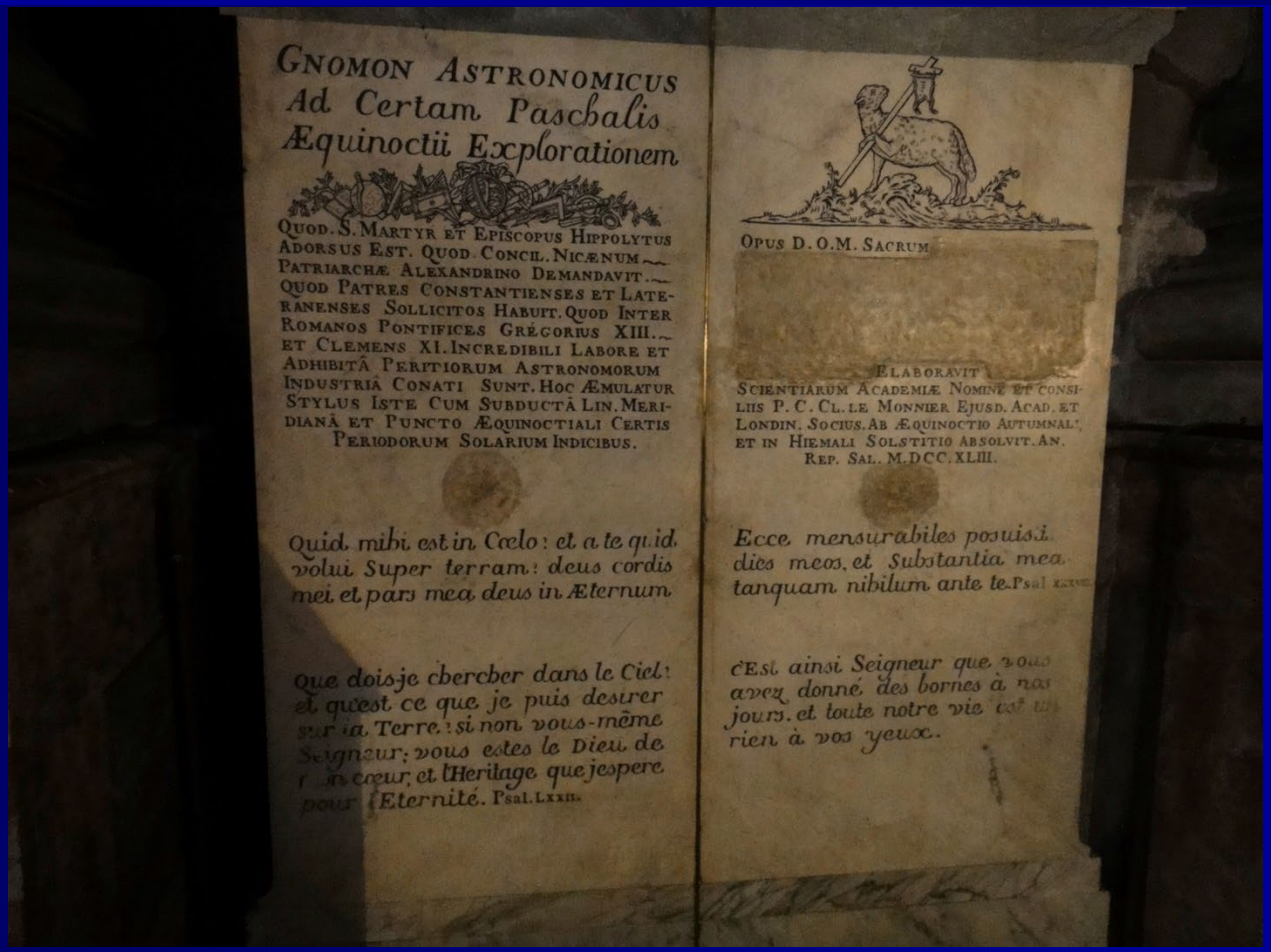


Fleisch

End of Meridian Line

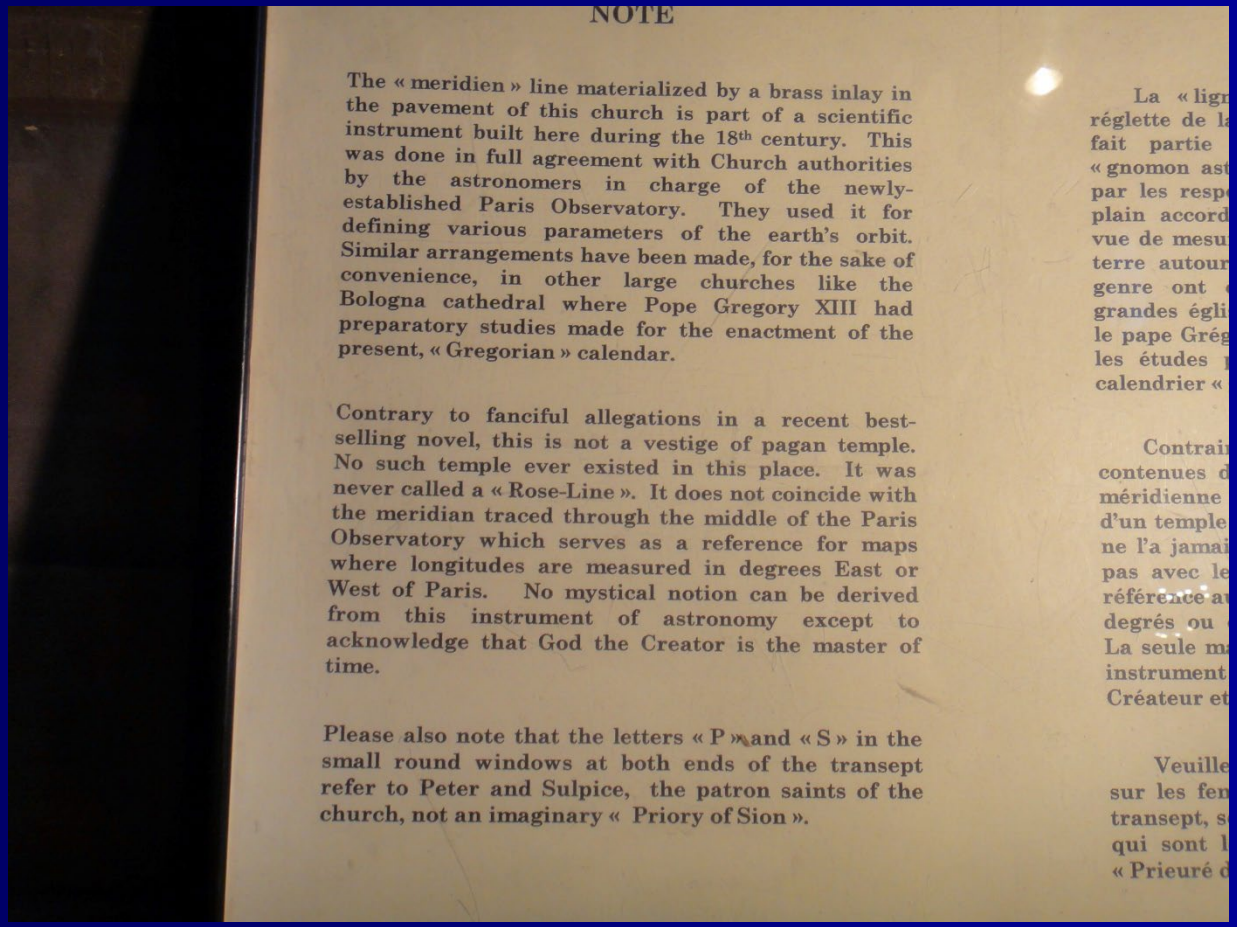


Meridian Line Inscription



Fleisch

Fixing Misconceptions



NOTE

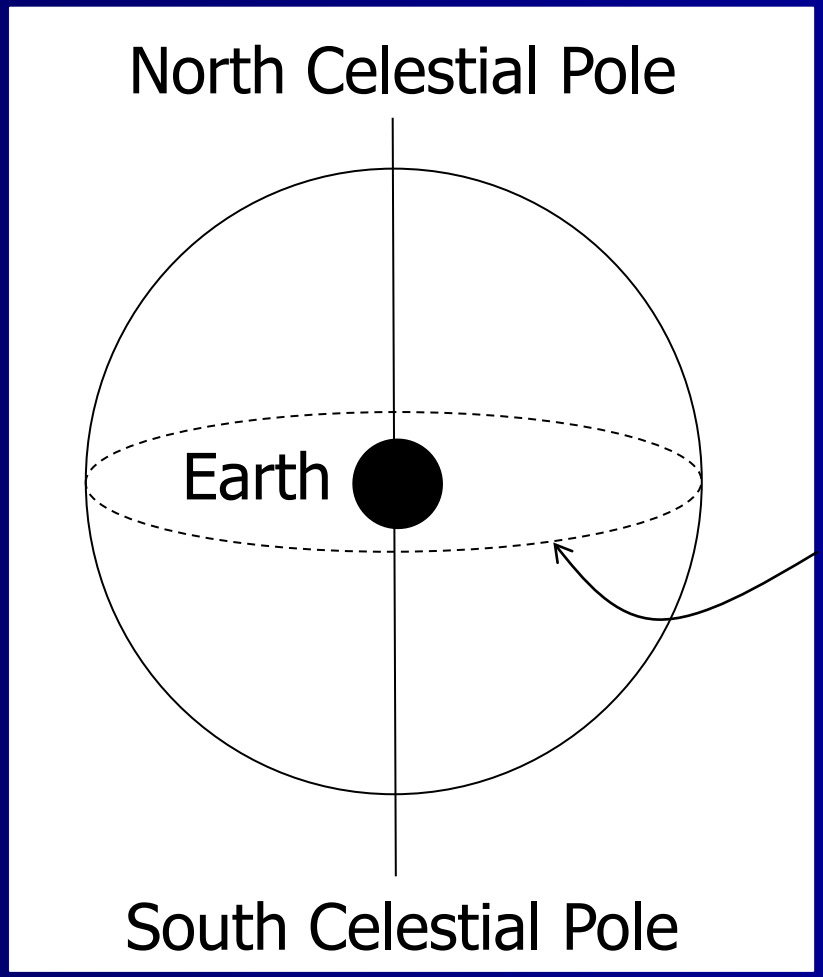
The « meridien » line materialized by a brass inlay in the pavement of this church is part of a scientific instrument built here during the 18th century. This was done in full agreement with Church authorities by the astronomers in charge of the newly-established Paris Observatory. They used it for defining various parameters of the earth's orbit. Similar arrangements have been made, for the sake of convenience, in other large churches like the Bologna cathedral where Pope Gregory XIII had preparatory studies made for the enactment of the present, « Gregorian » calendar.

Contrary to fanciful allegations in a recent best-selling novel, this is not a vestige of pagan temple. No such temple ever existed in this place. It was never called a « Rose-Line ». It does not coincide with the meridian traced through the middle of the Paris Observatory which serves as a reference for maps where longitudes are measured in degrees East or West of Paris. No mystical notion can be derived from this instrument of astronomy except to acknowledge that God the Creator is the master of time.

Please also note that the letters « P » and « S » in the small round windows at both ends of the transept refer to Peter and Sulpice, the patron saints of the church, not an imaginary « Priory of Sion ».

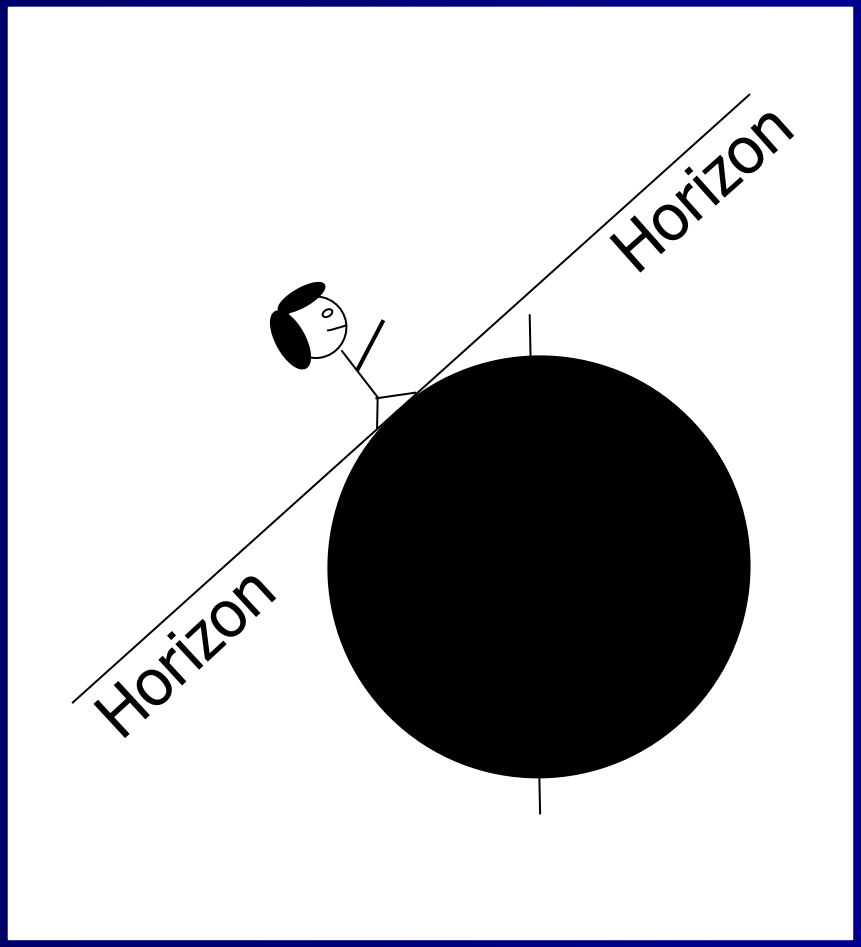
Fleisch

To Understand Meridian Lines, Start with the Celestial Sphere



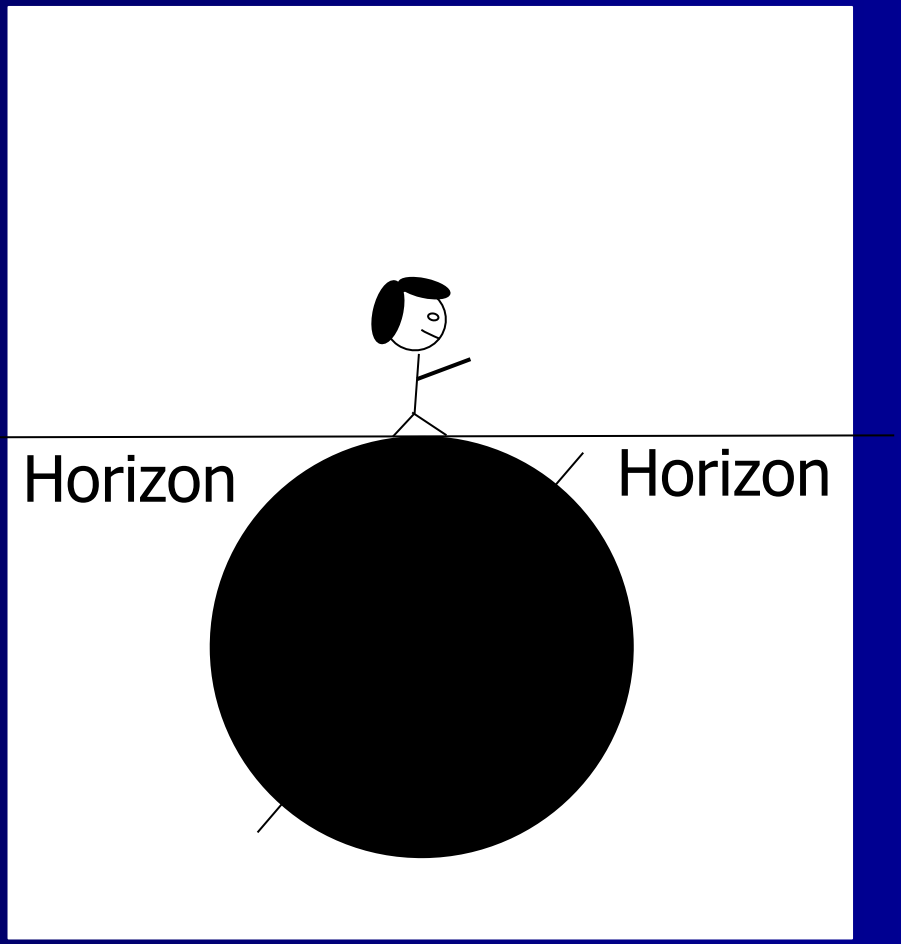
Fleisch

To Understand the Celestial Sphere, Start with a Giant Girl on Earth



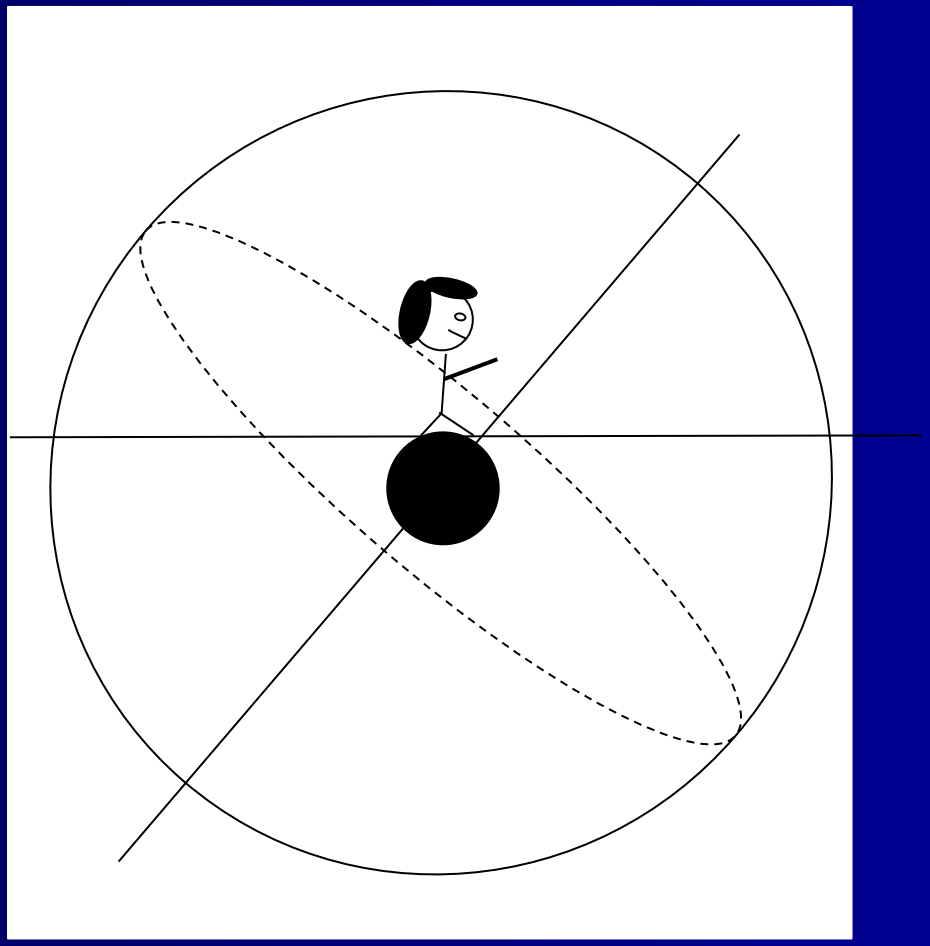
Fleisch

The Giant Girl Believes She's on Top of the World



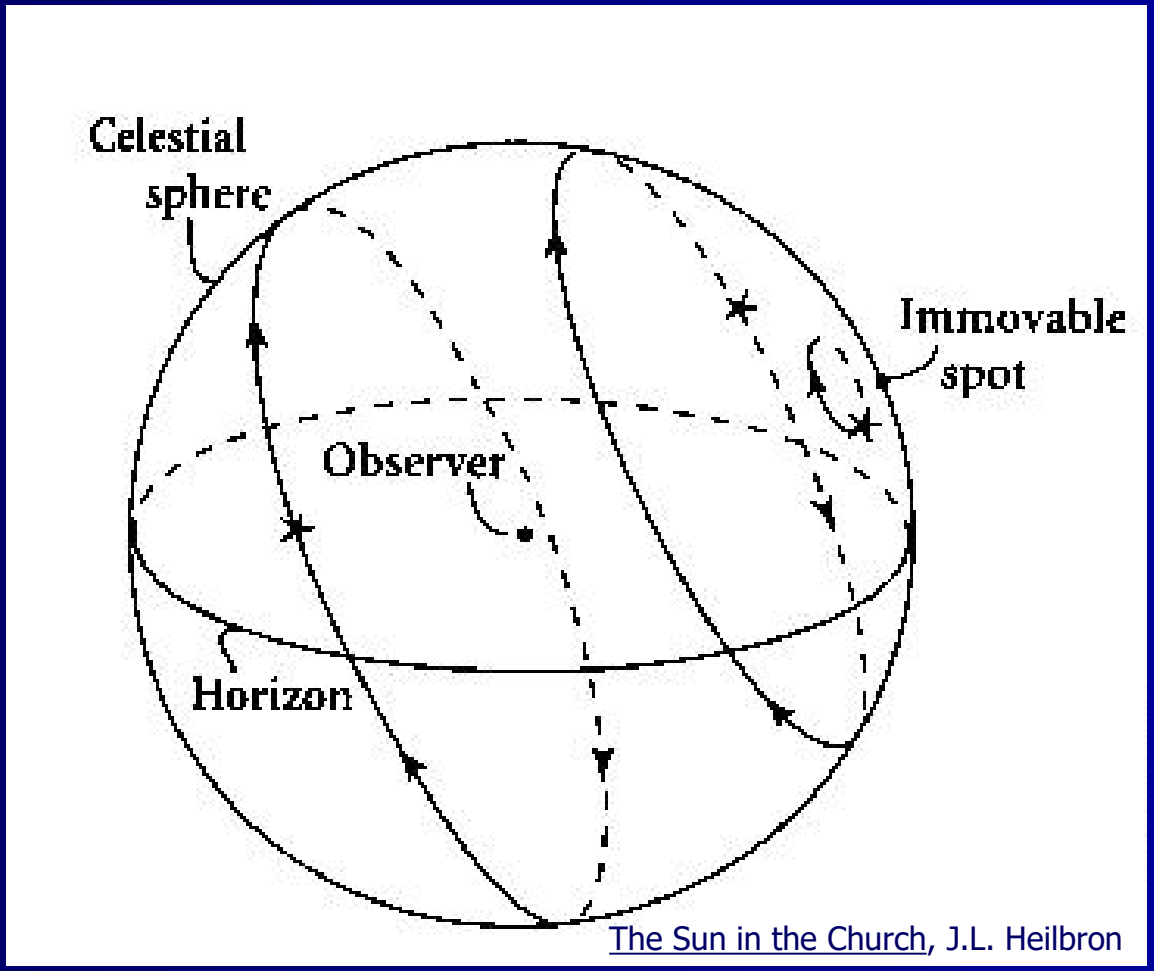
Fleisch

The Giant Girl's Celestial Sphere



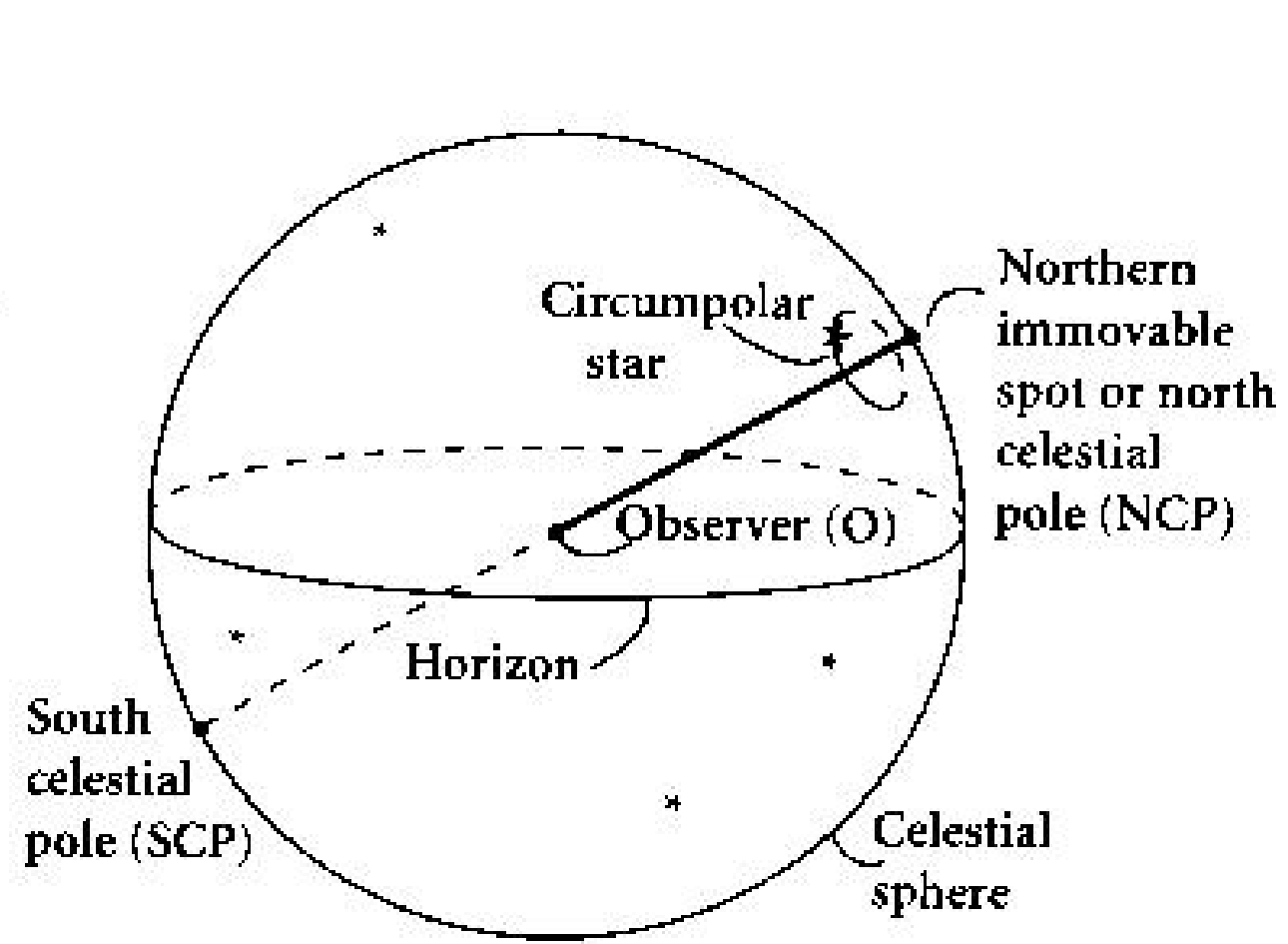
Fleisch

The Celestial Sphere as Usually Drawn



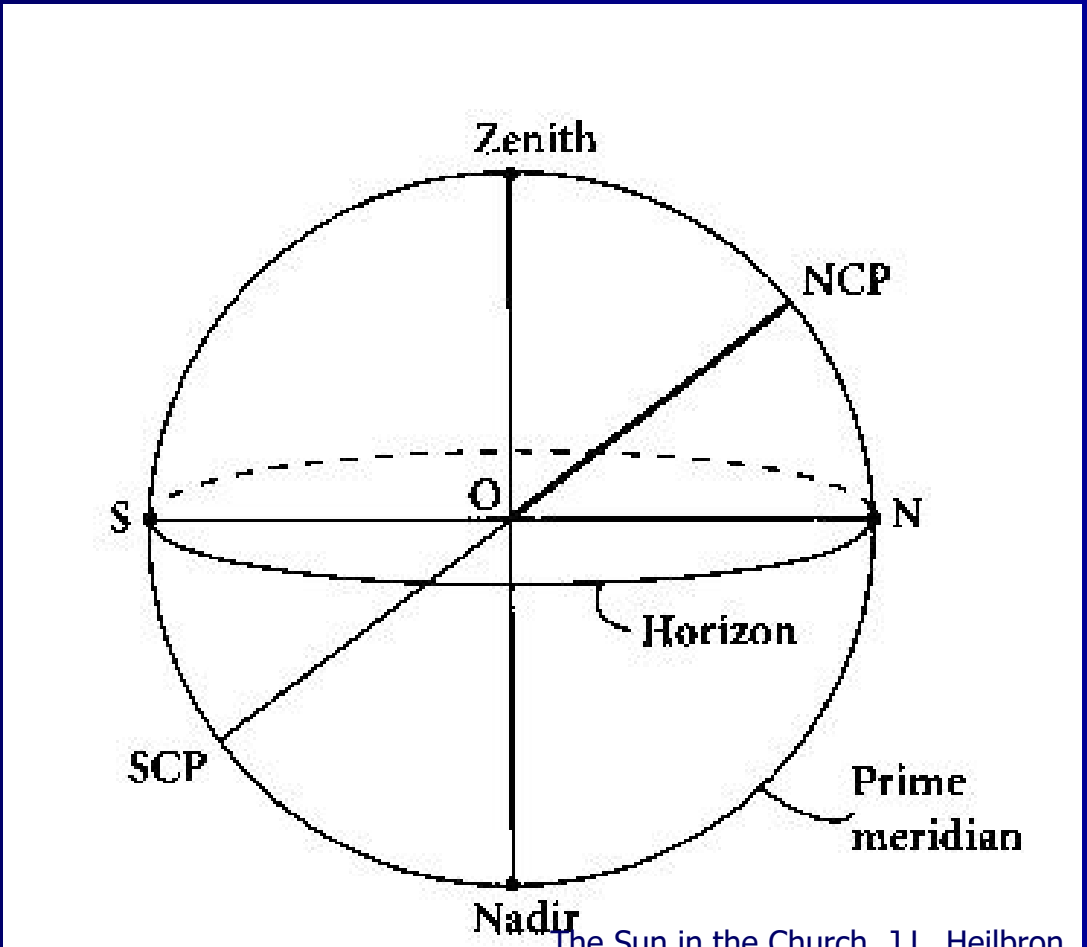
The Sun in the Church, J.L. Heilbron

Circumpolar Stars



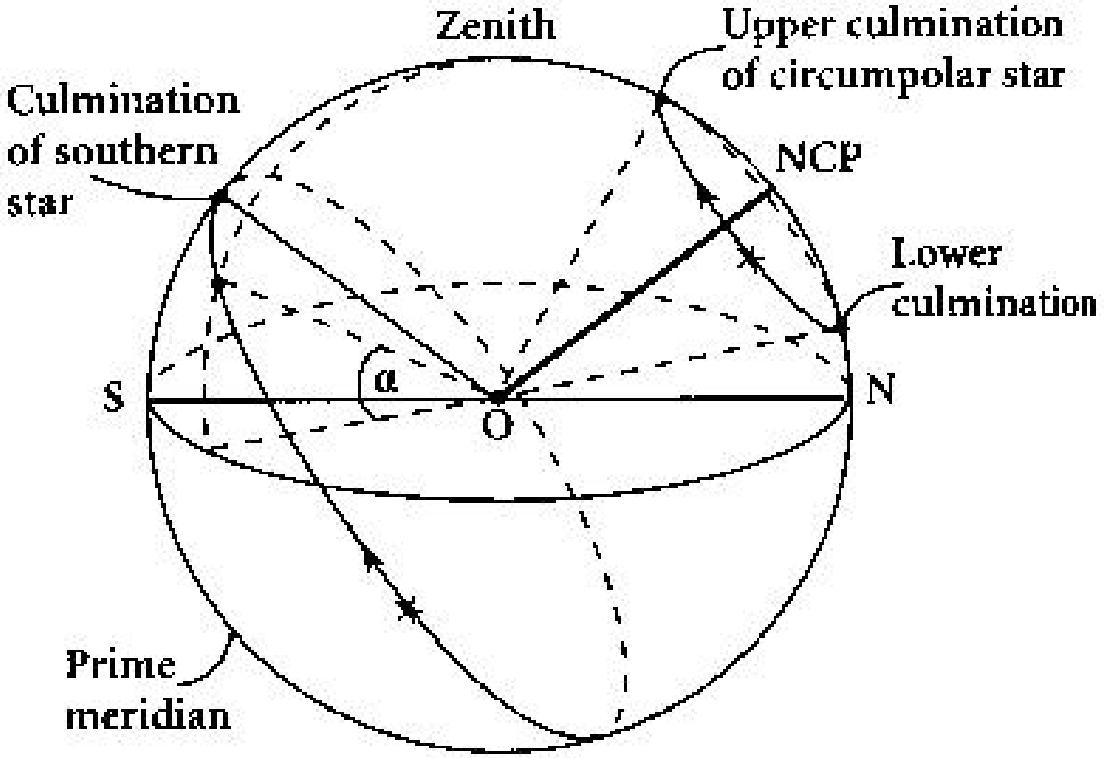
The Sun in the Church, J.L. Heilbron

Celestial Sphere Terminology



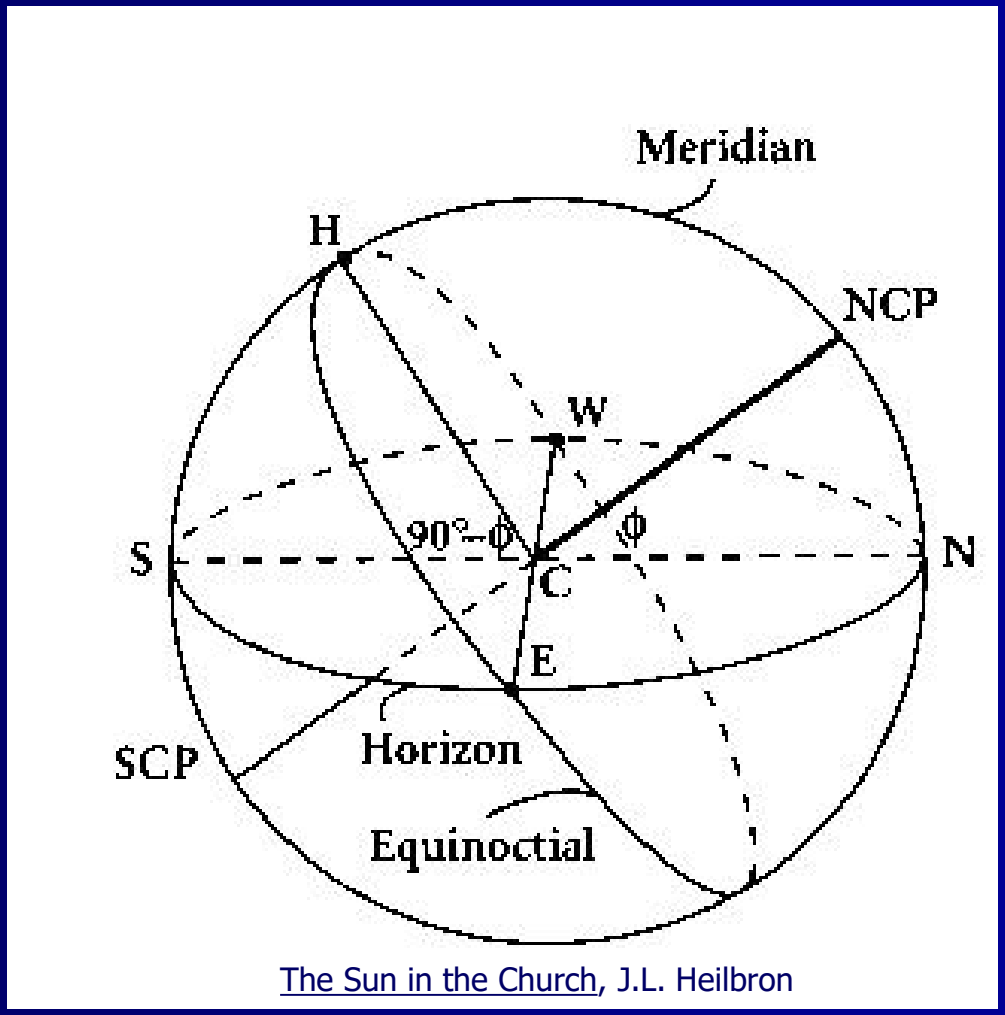
The Sun in the Church, J.L. Heilbron

Culmination



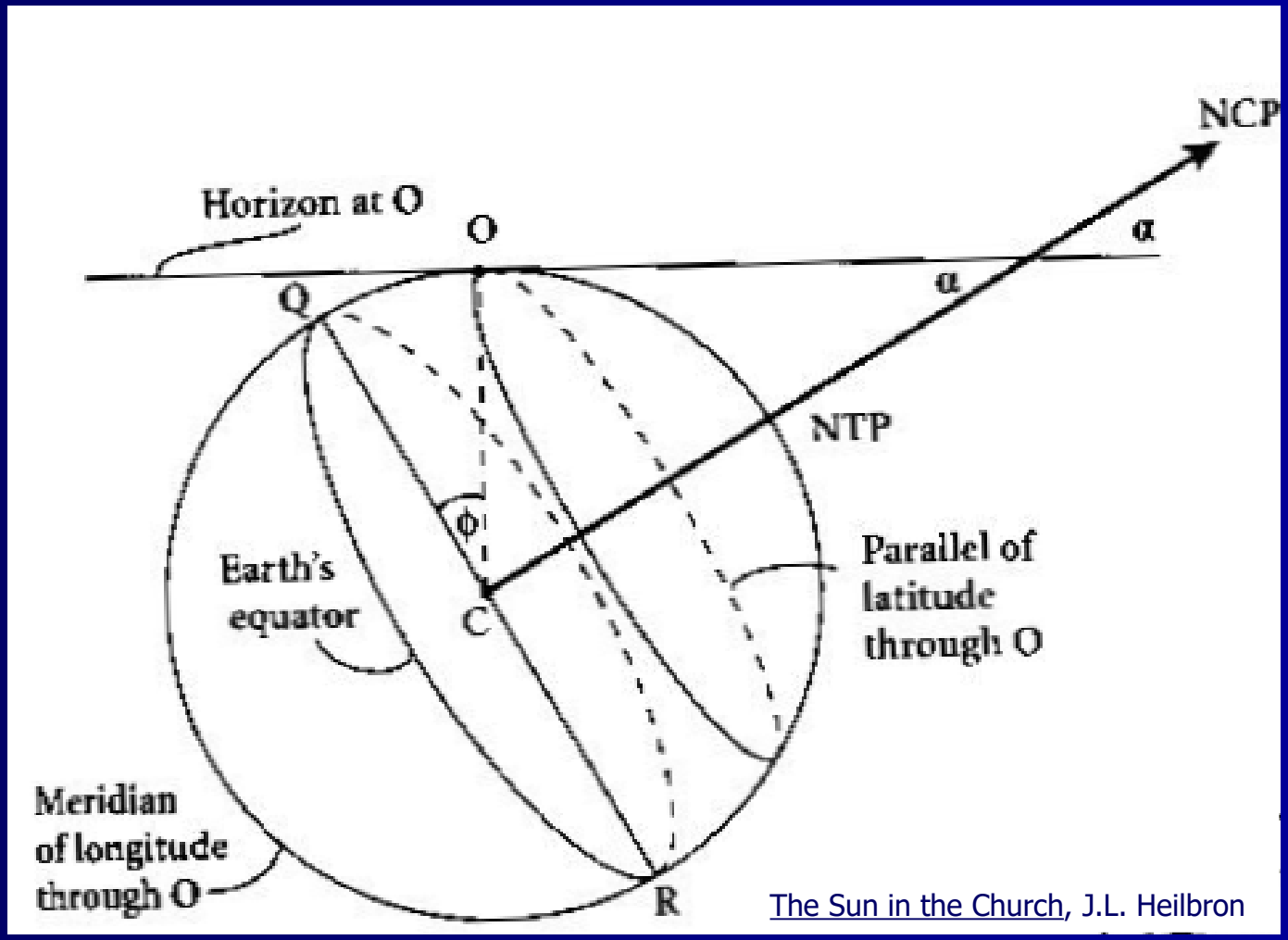
The Sun in the Church, J.L. Heilbron

Halfway Between the Poles: the Equinoctial



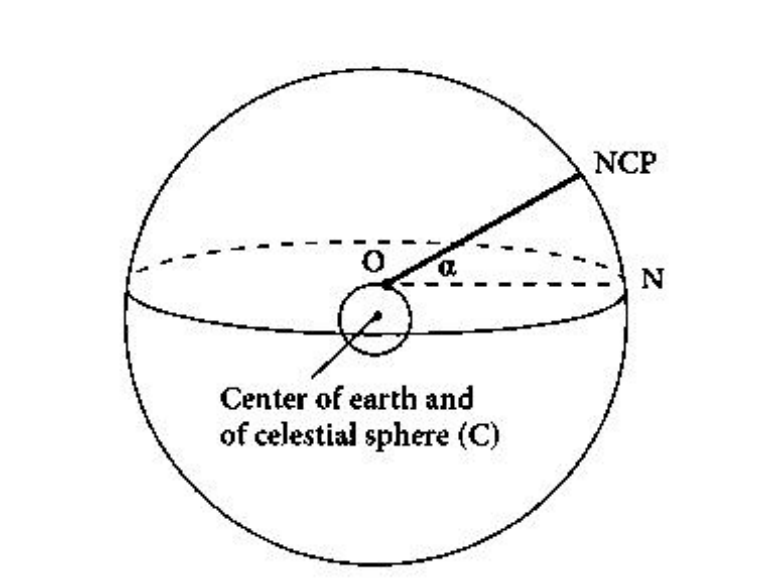
The Sun in the Church, J.L. Heilbron

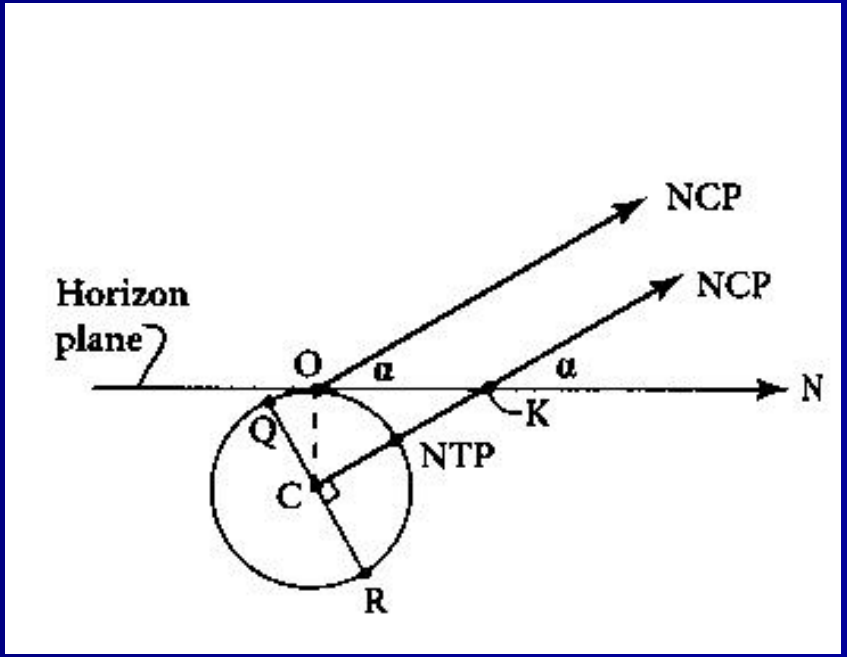
Finding Latitude is Easy



The Sun in the Church, J.L. Heilbron

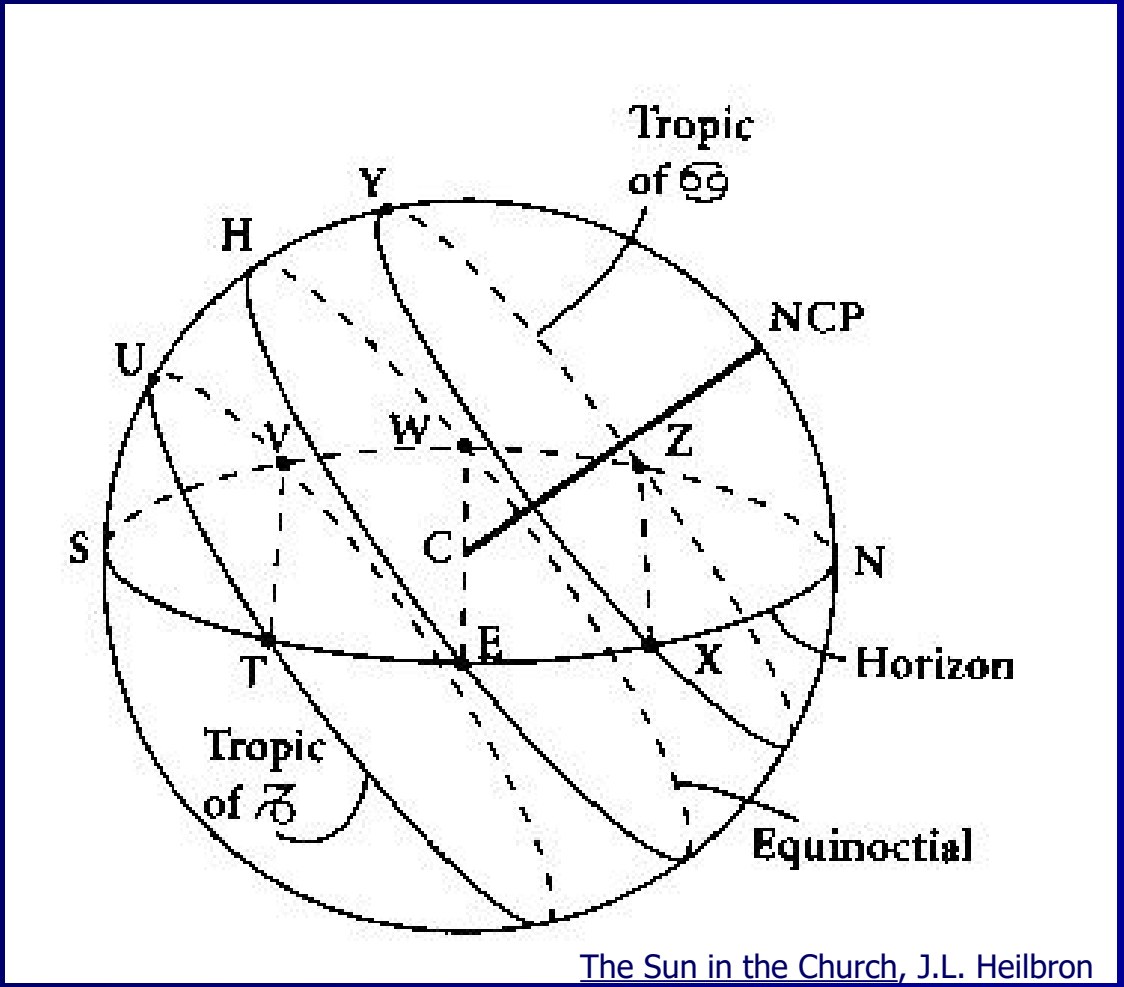
For Stars, Parallax is Negligible over Earth's Surface





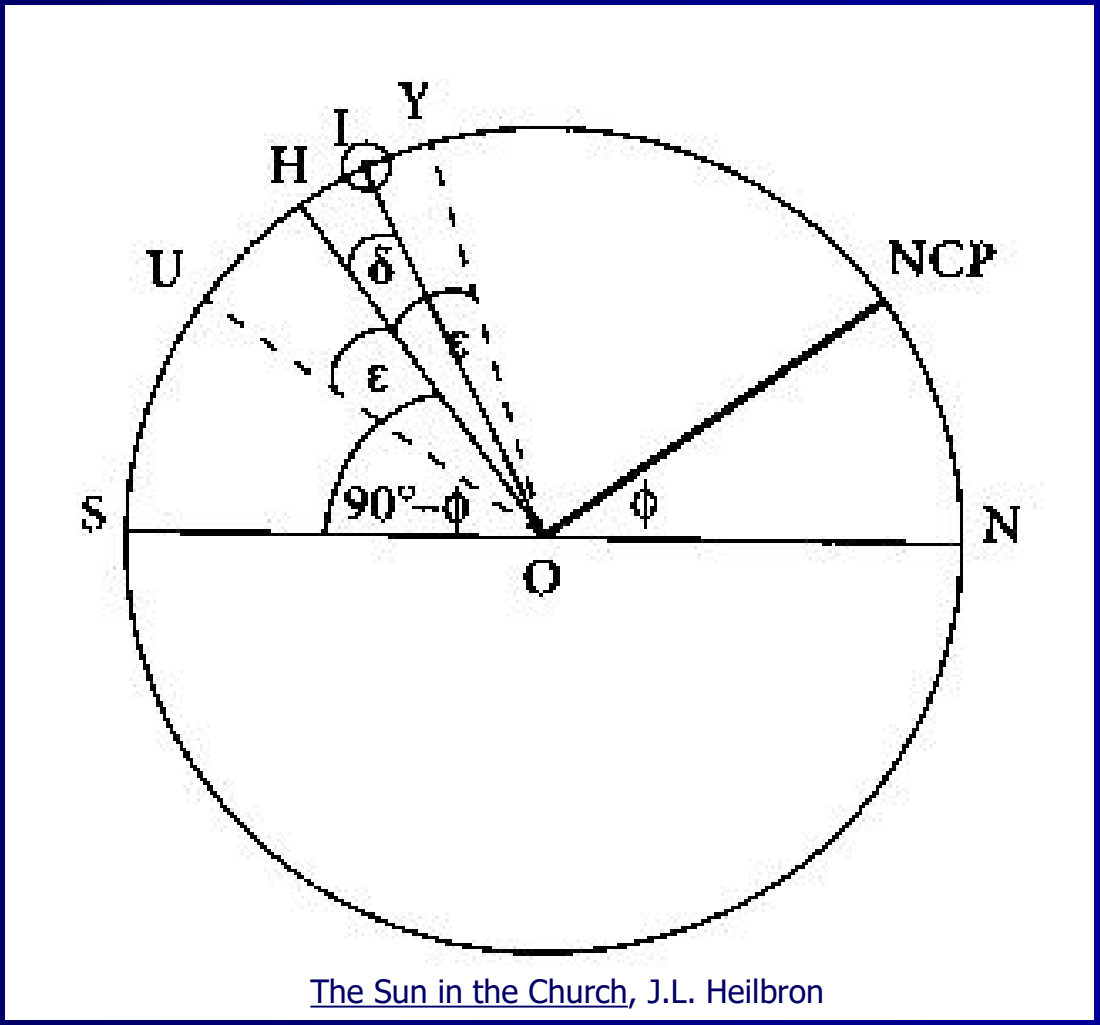
The Sun in the Church, J.L. Heilbron

The Sun's Position on the Celestial Sphere



The Sun in the Church, J.L. Heilbron

Highest in the South, Highest in the Summer



The Sun in the Church, J.L. Heilbron

Correction: Refraction

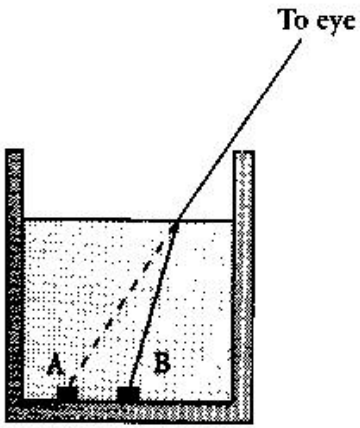


FIG. 3.6. A familiar example of refraction in water; the coin appears to the left of its true position.

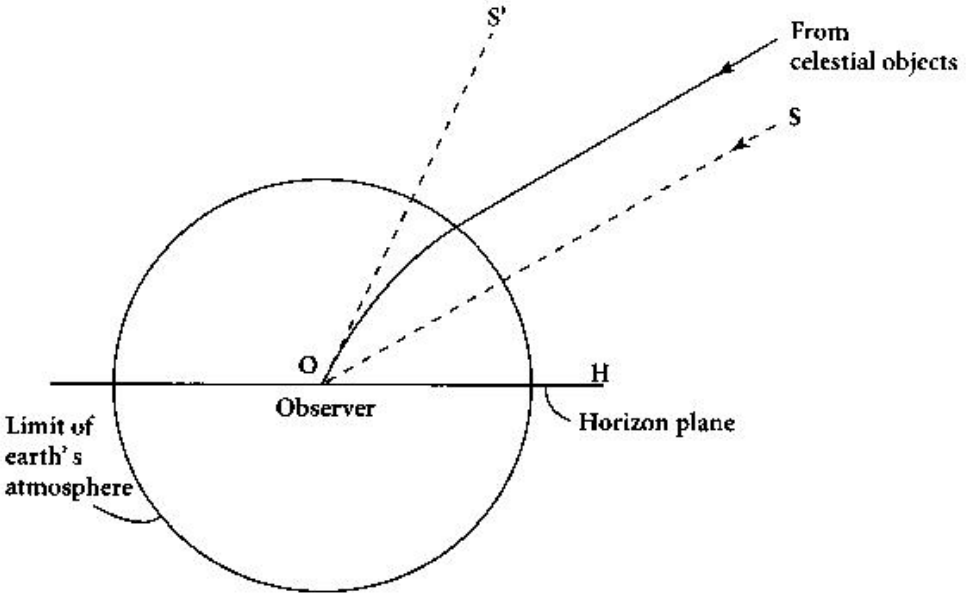


FIG. 3.7. The effect, much exaggerated, of refraction on astronomical observation; the star appears at S' rather than at S to the observer O.

The Sun in the Church, J.L. Heilbron

Correction: Solar Parallax

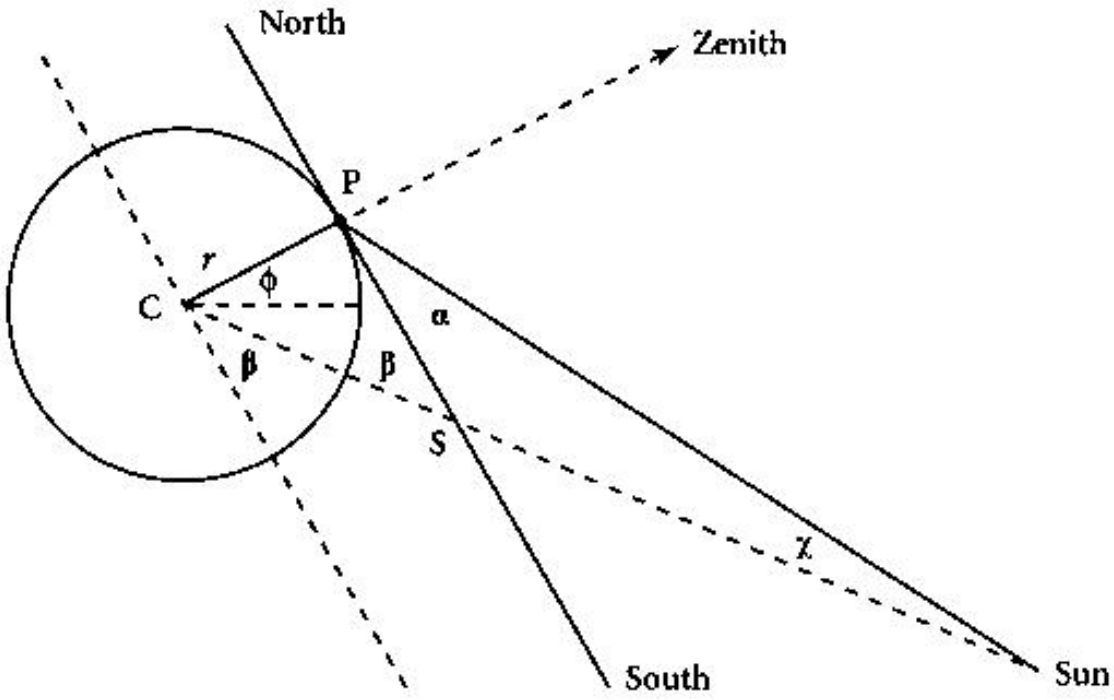


FIG. 3.8. Definition of solar parallax χ.

The Sun in the Church, J.L. Heilbron

Bisecting the Eccentricity

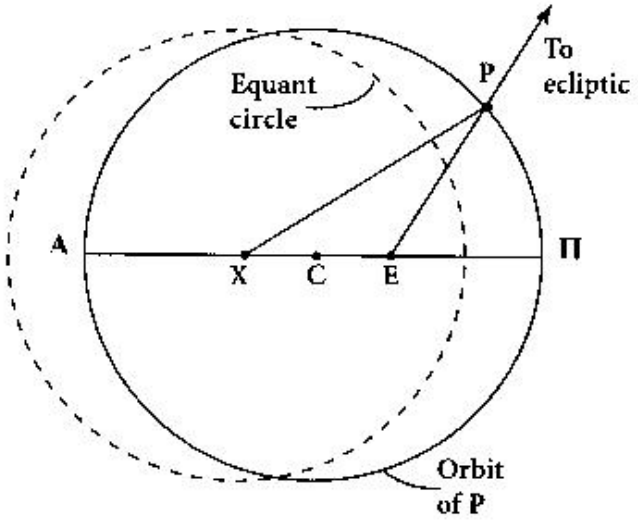


FIG. 3.13. Eccentric and equant X; the eccentricity is bisected, XC = CE = $ae/2$.

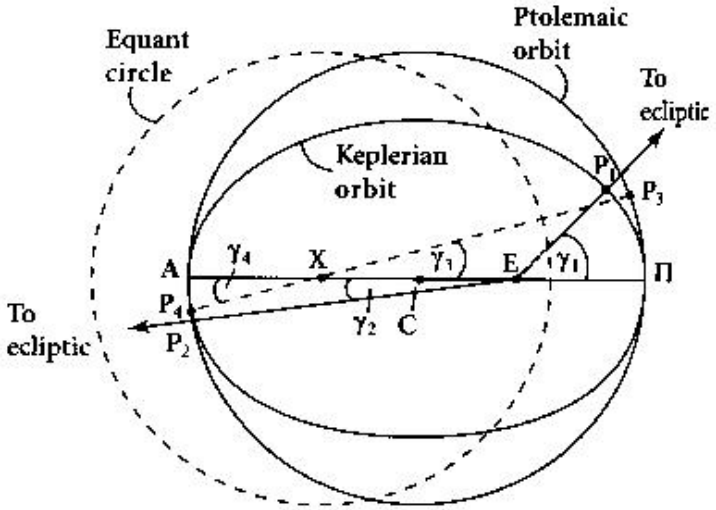


FIG. 3.14. A Ptolemaic circular orbit with eccentric and equant compared with a Keplerian ellipse.

The Sun in the Church, J.L. Heilbron

A Factor of Two in Change of Image Size

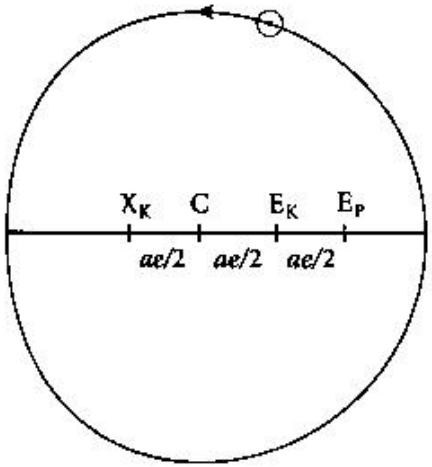


FIG. 3.16. Comparison of apsidal distances in Ptolemy's and Kepler's representations of the sun's orbit.

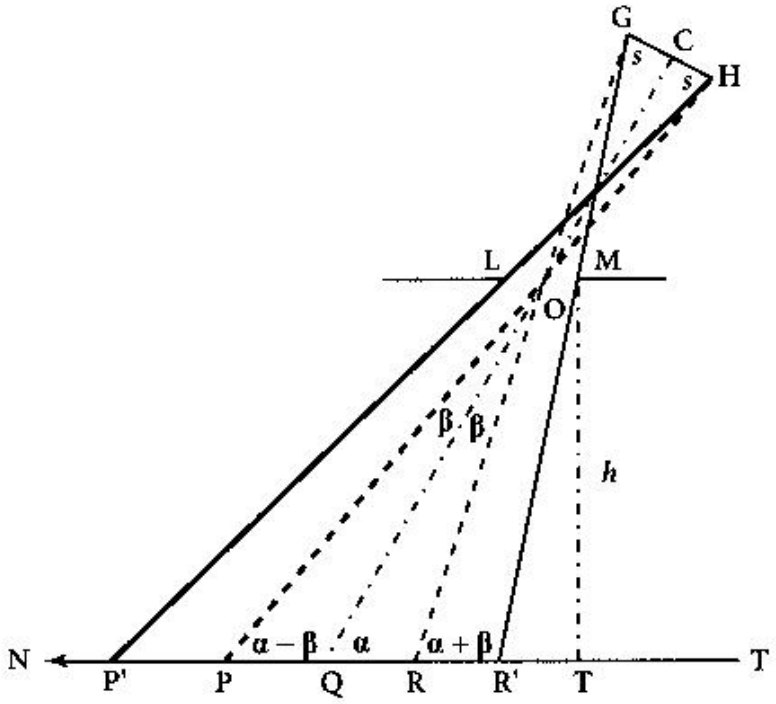
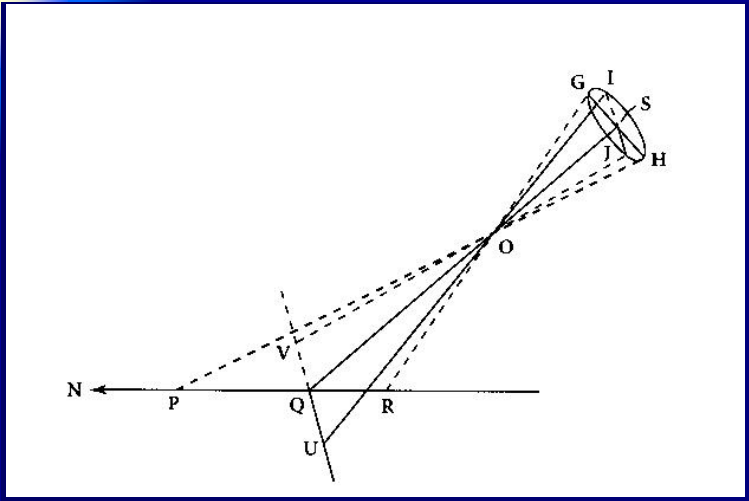


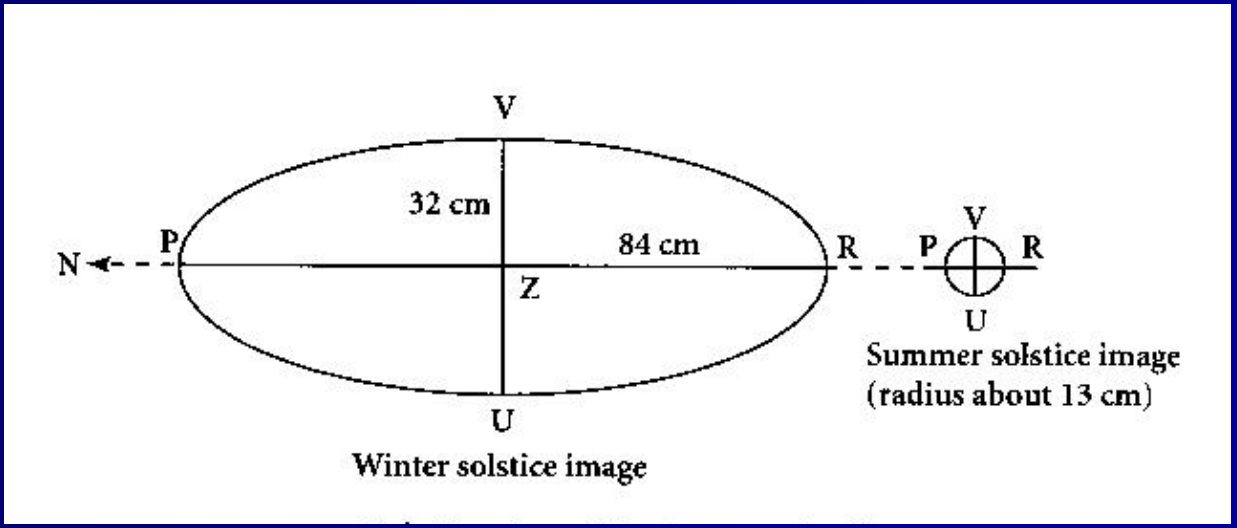
FIG. 3.17. Longitudinal diameter (P'R') of the sun's image in San Petronio.

The Sun in the Church, J.L. Heilbron

The Size of the Spot



The Sun in the Church, J.L. Heilbron



The Result

-Ptolemaic Model predicts image size change of 2’ between solstices

-Keplerian Model predicts image size change of 1’ between solstices

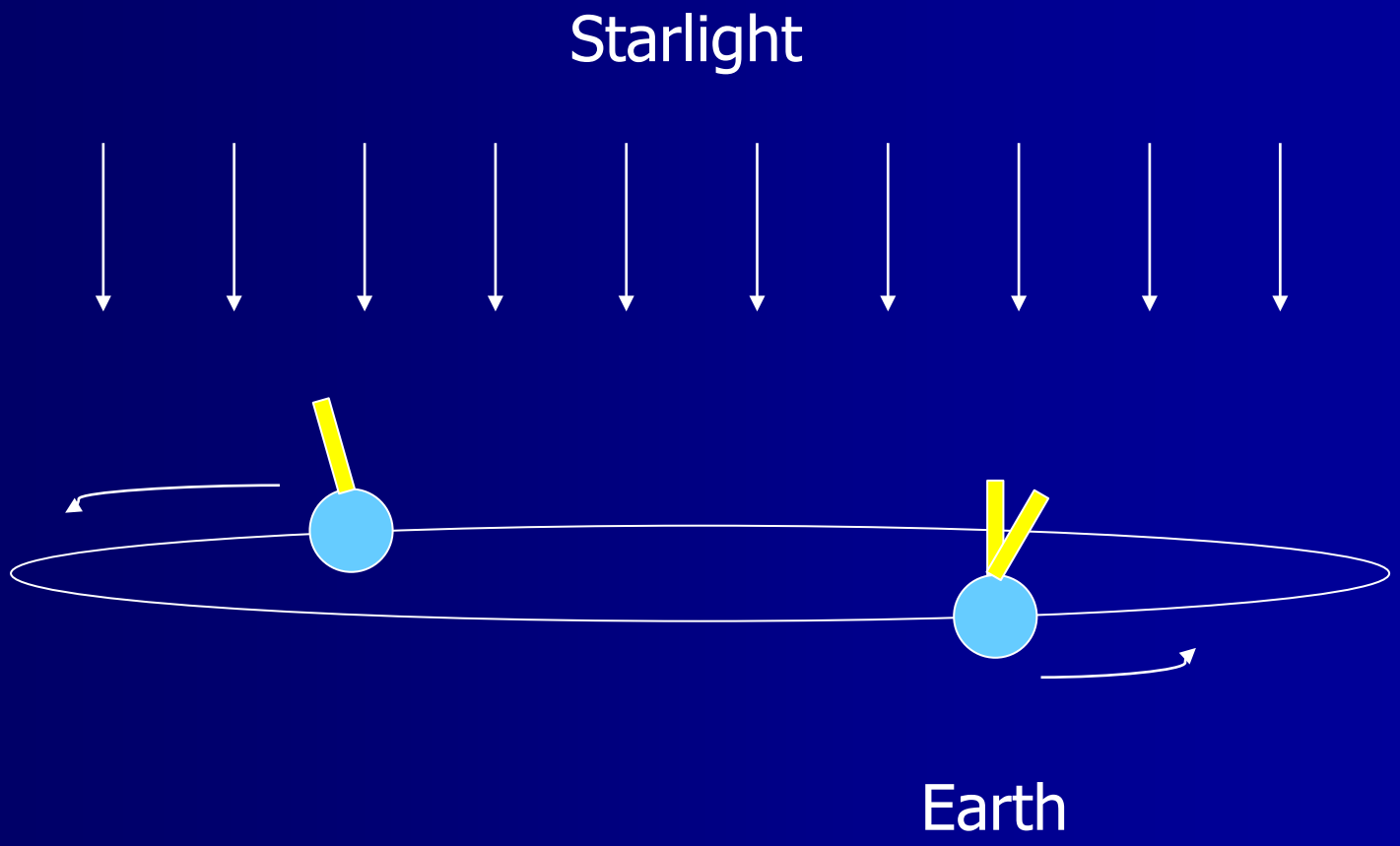
-The meridian line measurement: Image size changes by 1’

Overwhelming Evidence in Favor of Kepler and Moving Earth

-Meridian lines provide accurate timing to about 1 second per year, and elliptical (rather than circular) models fit the data

-Telescopic observations reveal the aberration of starlight

Aberration of Starlight



So…

The evidence gathered by priest-astronomers using Church-funded meridian lines and other instruments eventually rendered the concept of purely circular motion, perfect heavenly orbs, and the Earth-centered Universe untenable.

Progress

1822: Church removes ban on Galileo's books

1992: Pope John Paul II acknowledges that Galileo's imprisonment had been a mistake caused by "tragic mutual mis-comprehension."

And While They Were At It …

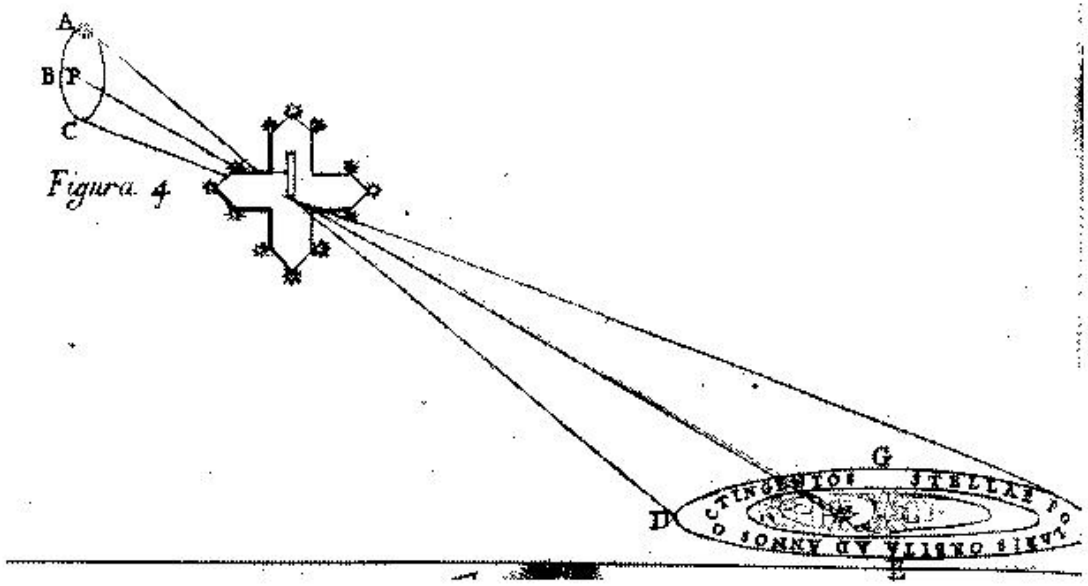


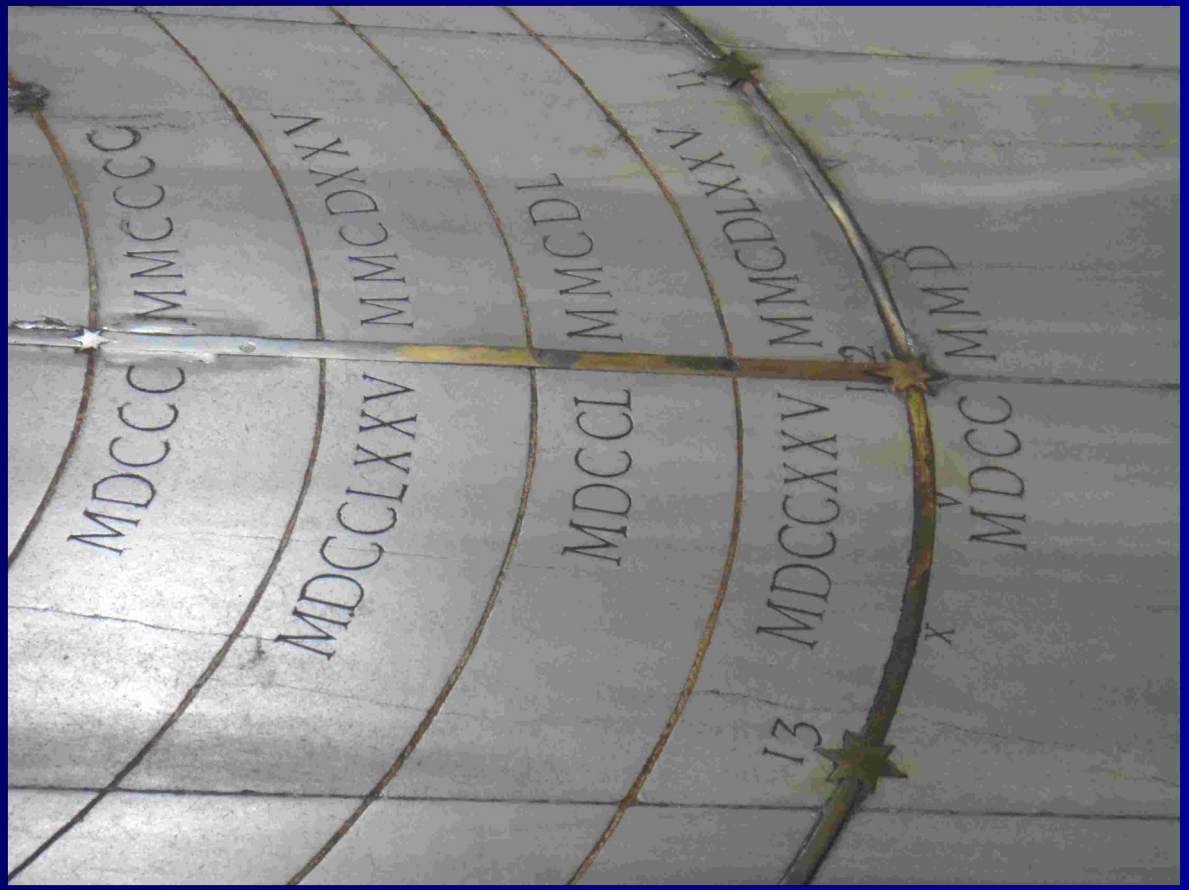
FIG. 5.7. The northern gnomon at S. M. degli Angeli, Rome. ABC indicates Polaris' diurnal orbit, GDE its image on the pavement. The Latin says "the polestar's orbits for 800 years." From Bianchini, *De nummo* (1703).

The Sun in the Church, J.L. Heilbron

Polaris and the Celestial Pole

Fleisch

The Long View



Fleisch

Read More About It

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Siderius Nuncius, G. Galilei, A. Van Helden (trans)
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Galileo, S. Drake, Sterling Publishing (1980)

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Giordano Bruno and Renaissance Science, H. Gatti,
Cornell University Press (2002)