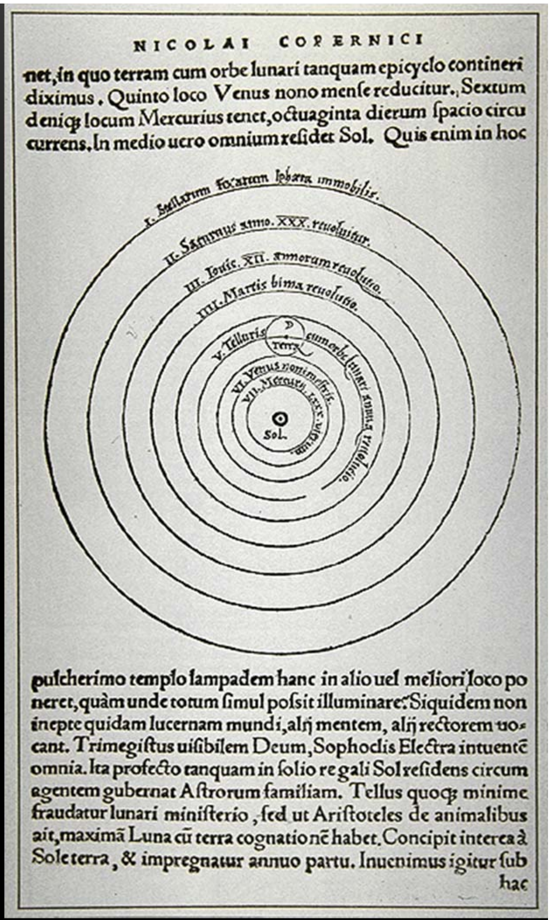
ADMINISTRIVIA

- Last of four Planetarium shows is Thursday at 5pm
  - Early part of the week there's maintenance going on, sorry
- Now that everyone's got their ebooks working, the bookstore will bill you the $85 today
- First test looks like it will be Friday Sept. 22
  - Chapters 1-5
  - Have posted a practice test on the assignments page
  - Also look at the review exercises for each chapter on the Mastering website

COPERNICUS:

- Sun-centered solar system with circular orbits
- The major motions are all there, even retrograde motion
- How about the precision?
  - Not much better than Ptolemy, actually
  - Circular orbits moved planets at constant rates, but in the sky they change speeds
  - Copernicus used small, slow epicycles to make it work better



NICOLAI COPERNICI

net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono mense reducitur. Sextum denique locum Mercurius tenet, octuaginta dierum spacio circu currens. In medio uero omnium residet Sol. Quis enim in hoc

pulcherimo 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 intuentē omnia. Ita profecto tanquam in solio regali Sol residens circum agentem gubernat Astrorum familiam. Tellus quoque minime fraudatur lunari ministerio, sed ut Aristoteles de animalibus ait, maximā Luna cū terra cognationē habet. Concipit interea à Sole terra, & impregnatur annuo partu. Inuenimus igitur sub

hac

COPERNICUS COMPARED TO PTOLEMY

- Accuracy of model:
  - About the same
- Predicts parallax
  - But this is still not observable (until 1838!)
  - Could be the stars are very far away
  - Predicts Mars brightness variations
- Simplicity:
  - Both use epicycles
  - Copernicus has fewer of them
- So, it's a draw

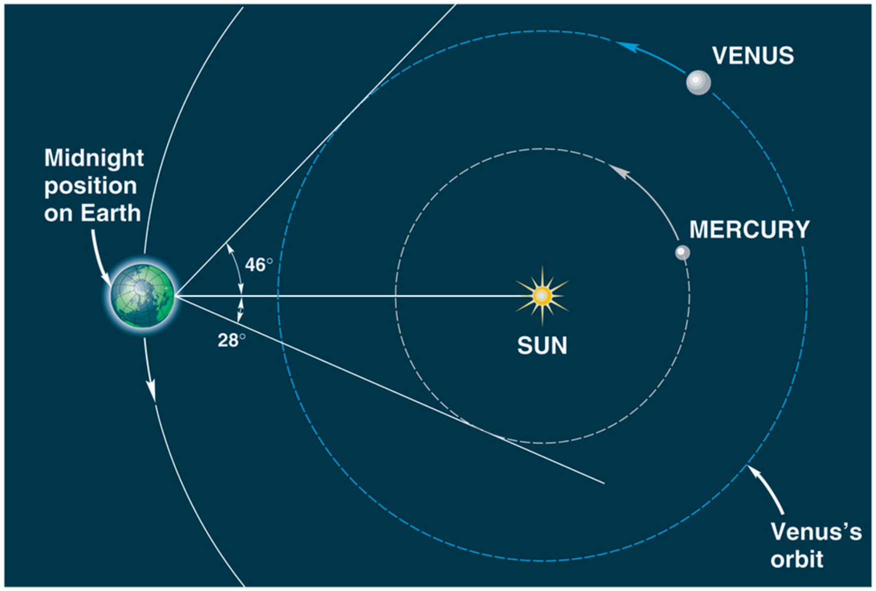
PREDICTIONS

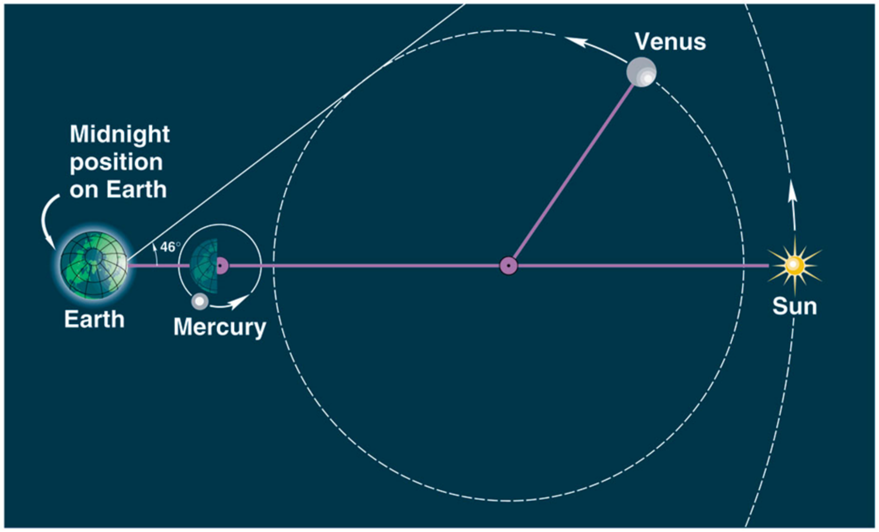
- Models must make testable predictions
  - Copernicus needed to figure out relative sizes of the planets' orbits for his model to do anything useful. His predictions are:

Planet	Copernicus	Today
Mercury	0.38 AU	0.387 AU
Venus	0.72	0.723
Earth	1.00	1.000
Mars	1.52	1.524
Jupiter	5.2	5.204
Saturn	9.2	9.582

Pretty Good!
But not testable
in the 1500's

AESTHETICS





- Simpler
  - Just compare how the inferior planets work
  - No difference between inferior and superior planets
- But a moving Earth makes much of Aristotle's physics not work right
- So, again a draw

CONJUNCTION

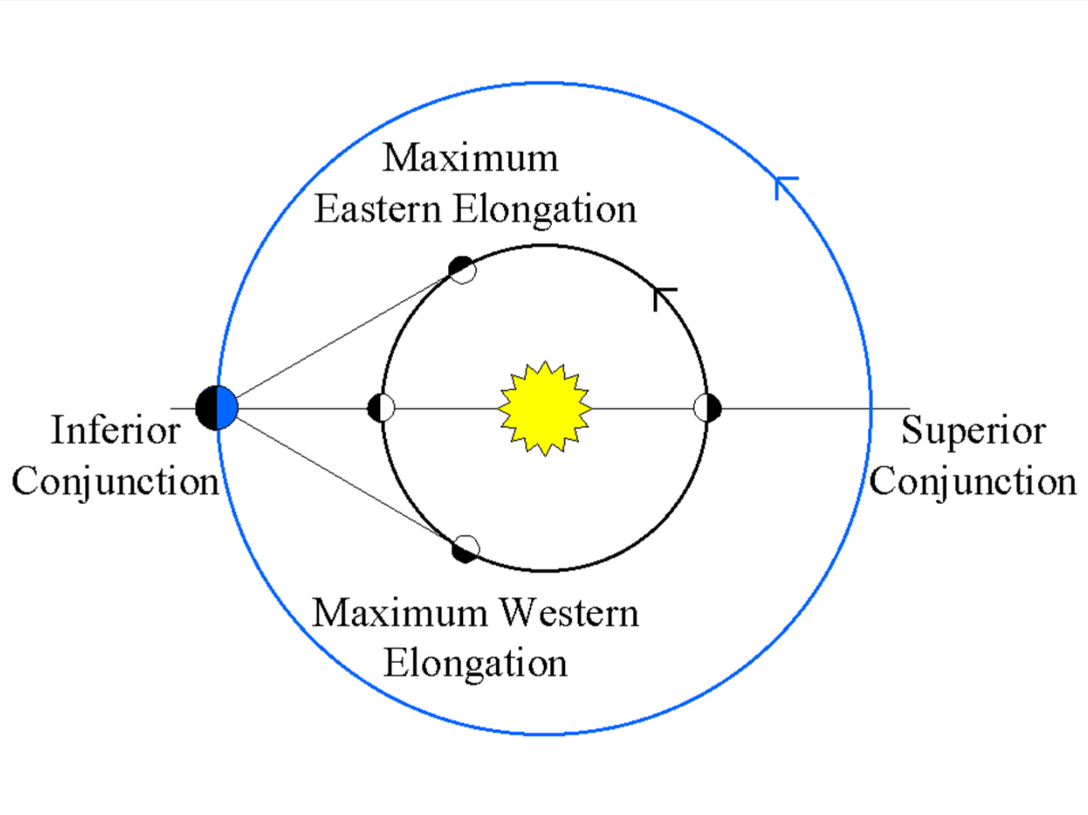
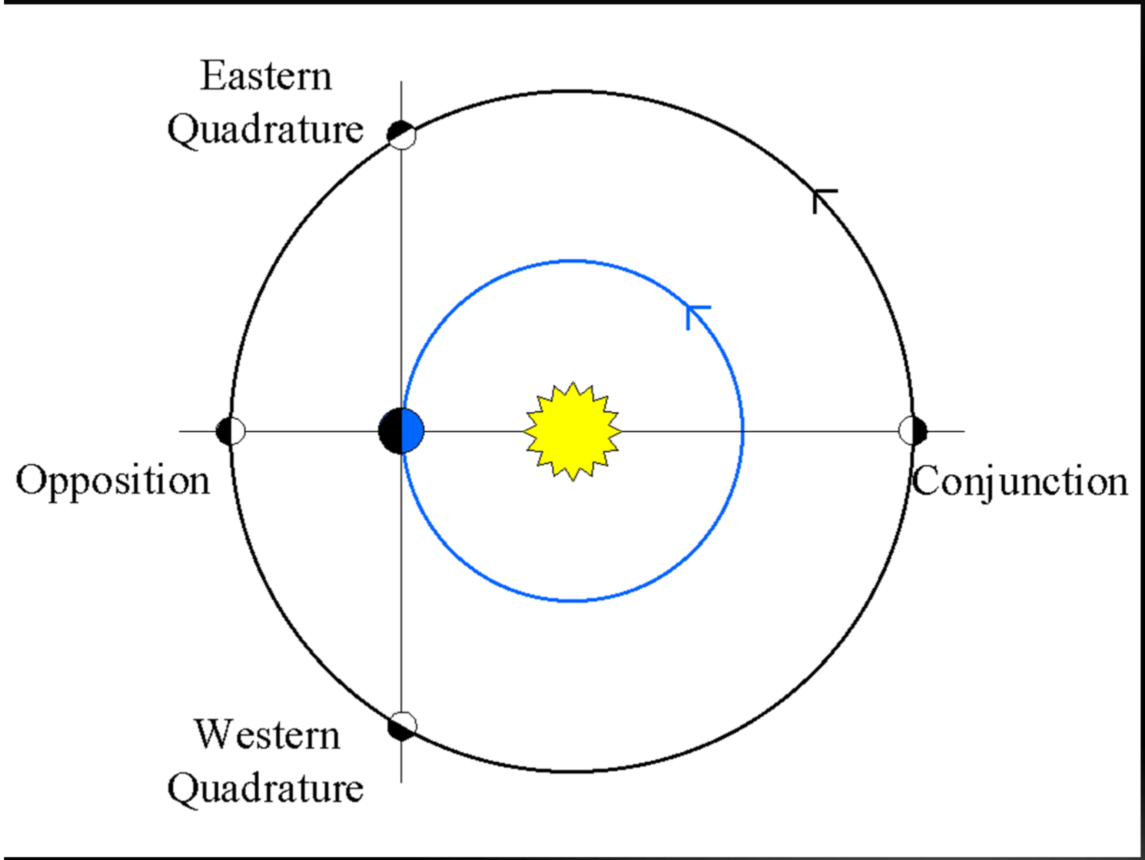


Figure by R.Pogge, OSU

- New terms:
- *Elongation* we talked about before
- *Conjunction* is when the planet is lined up with the sun
  - Superior on far side
  - Inferior on near side

OPPOSITION

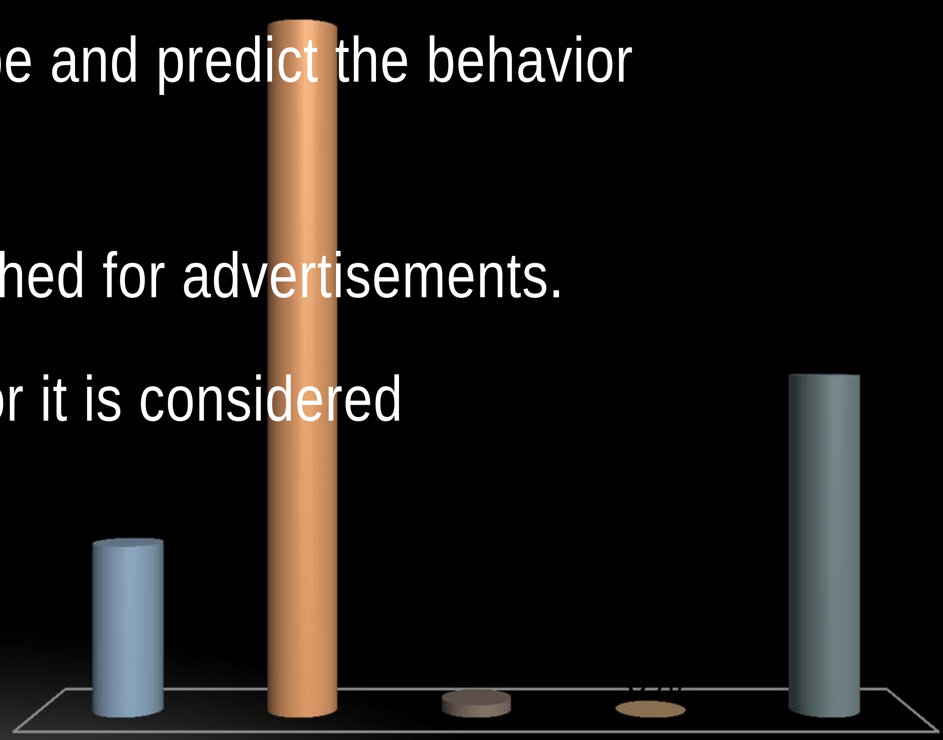


- *Opposition* :
  - The planet is directly opposite the sun
  - Would appear overhead at midnight
  - Rises when sun sets
  - Only happens for outer planets
- *Quadrature*
  - Planet is 90º from Sun

Figure by R.Pogge, OSU

A SCIENTIFIC MODEL…

1. is a small physical representation of a real-world system.
2. uses math and logic to describe and predict the behavior of a real-world system.
3. is a scientist who is photographed for advertisements.
4. must be completely accurate or it is considered pseudoscience.
5. 2 and 4



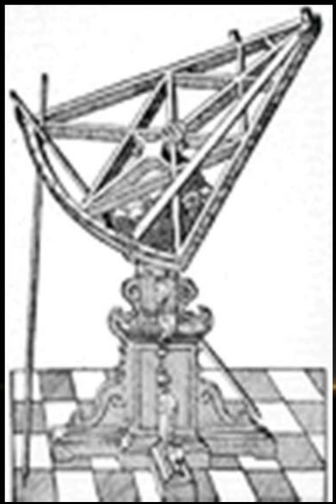
TYCHO BRAHE

- Danish astronomer 1546-1601
- Knew that the planetary positions Ptolemy and Copernicus had worked with weren’t especially accurate
- Also an alchemist and astrologer
- Made 20 years of accurate observations
  - Good to 0.1°!
  - First person to realize the importance of quoting tolerances

TYCHO'S OBSERVATIONS

- Appointed Danish Royal Astronomer
  - Given island of Hven, builds Uraniburg observatory
  - No telescopes – measured positions with naked eye and big surveying equipment
- Also sees Supernovae of 1572, comet in 1577
  - Measures that these weren't nearby (parallax!)
  - Proves heavens weren't unchanging

Quadrant

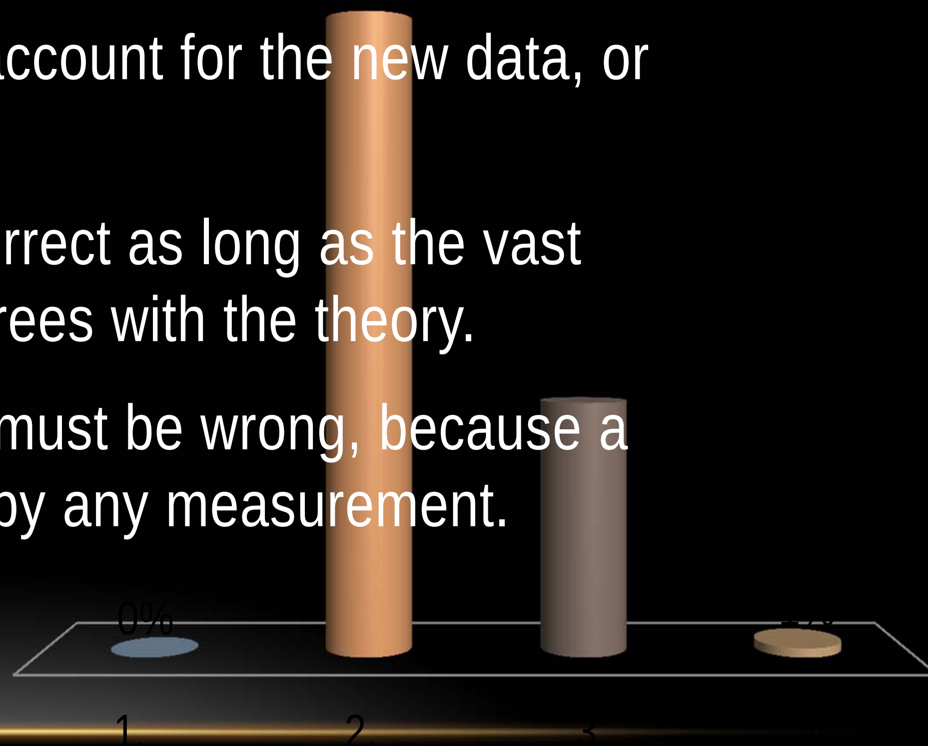


Sextant

Uraniburg

IF AN EXPERIMENT OR OBSERVATION CONTRADICTS A SCIENTIFIC THEORY, THEN

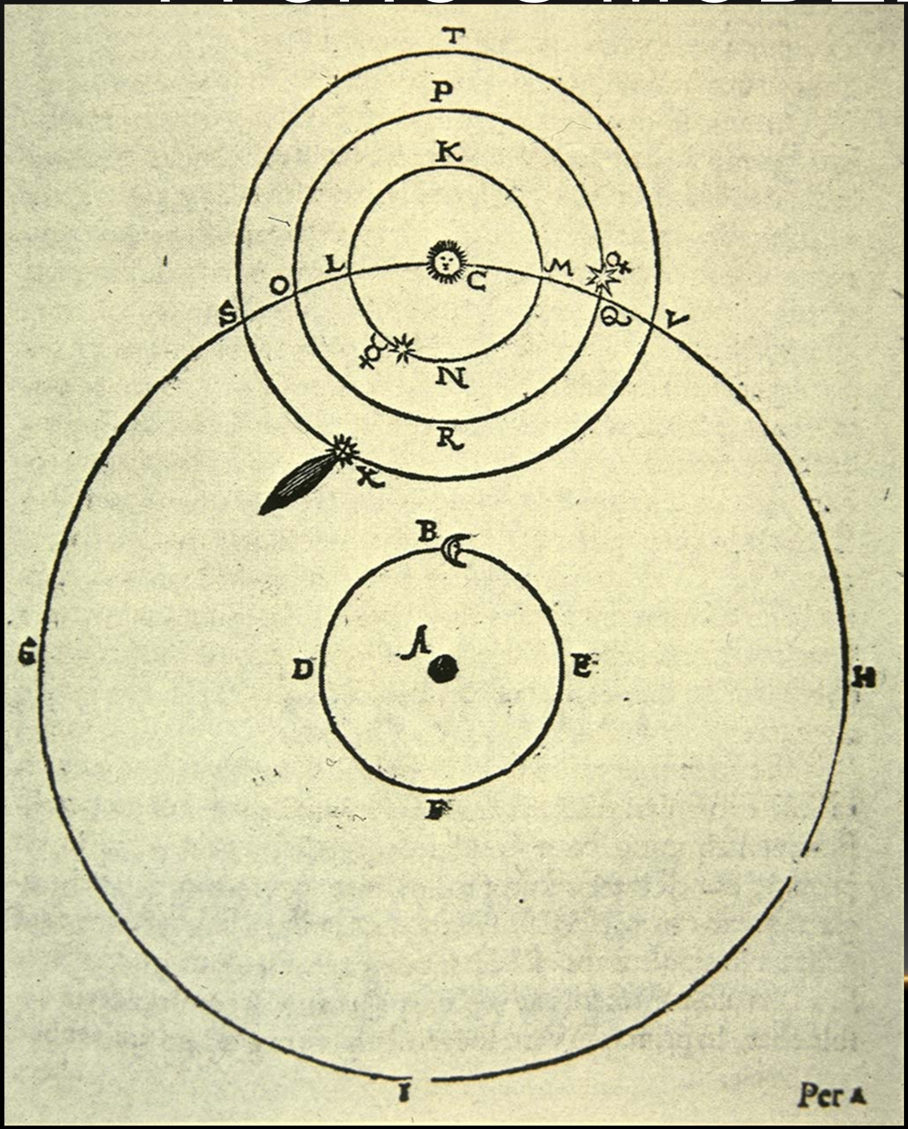
1. it must not have been a scientific theory, but pseudoscience.
2. ✓ the theory must be revised to account for the new data, or discarded.
3. the theory is still considered correct as long as the vast majority of experiments still agrees with the theory.
4. the experiment or observation must be wrong, because a theory cannot be contradicted by any measurement.



MODELS IMPROVE…

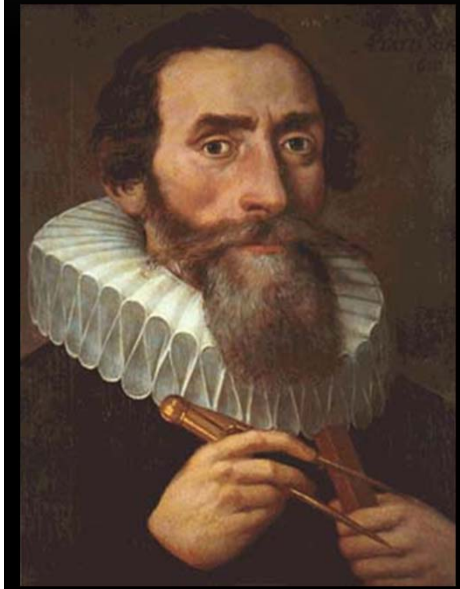
- Copernicus offers a heliocentric alternative to Ptolemy
  - Doesn't do a better predictive job
  - Solves some aesthetical problems, creates other philosophical ones
- Tycho makes very good observations
  - Now the "theorists" must also make their models more accurate, to match!
- Kepler modifies Copernican model to use ellipses
  - Very accurate theory, now a heliocentric model was the most accurate one around

TYCHO'S MODEL



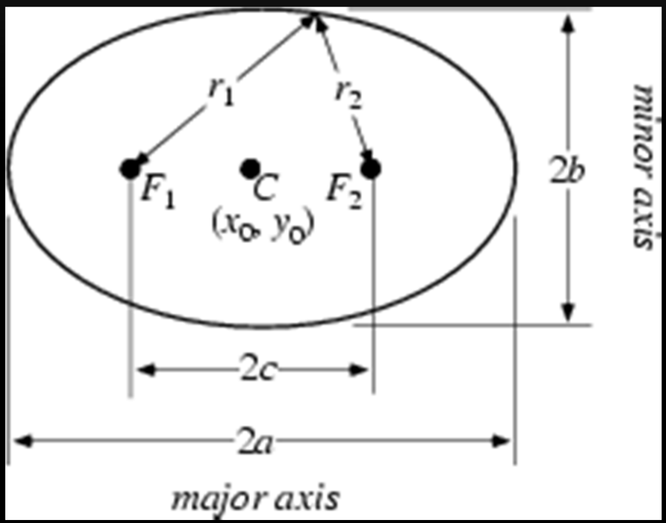
- Saw no parallax with even very careful measurements
  - Concludes Earth must be stationary
- Hybrid model
  - Sun, stars goes around earth
  - Planets go around sun
- Mutability of heavens undermines Aristotle's separation of things heavenly and things earthly

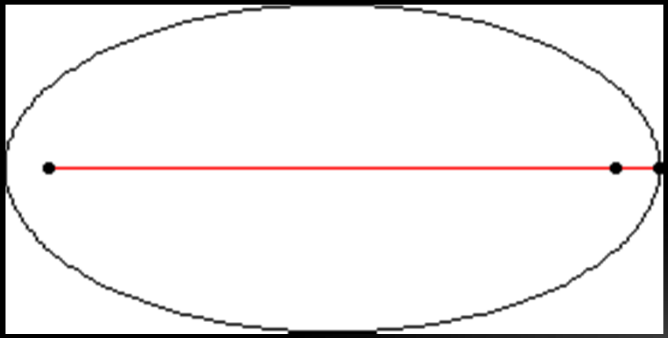
JOHANNES KEPLER



- Tycho's assistant in 1600 (then successor)
- Pioneering mathematician
- Tries to make epicycle model of Mars's motion match Tycho's observations
  - 4 years and 70 epicycles later, good to 0.13^o
    - "My war with Mars", thousands of pages of by-hand arithmetic
  - Still does not match well with 0.1^o observations!

ELLIPSES





- Circular things weren't working – how about ovals?
- Ellipse is a special oval
  - Has Major and Minor axes
  - Eccentricity
  - Sum of distance from two foci is constant
- Using elliptical orbits turns out to work well!

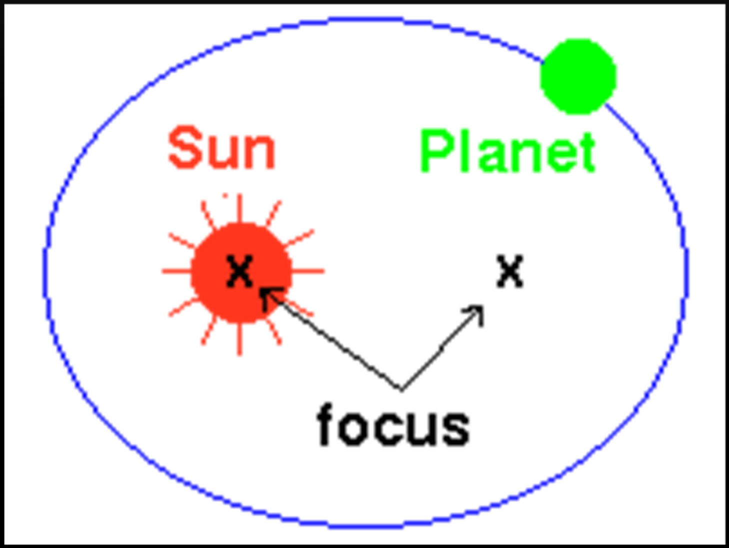
$$e = \sqrt{1-(b^2/a^2)}$$

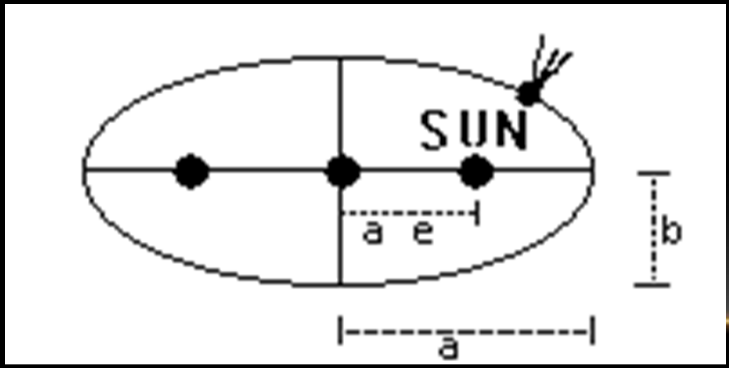
PLAY

KEPLER'S MODEL

- First published in 1609, Astronomia Nova
- Heliocentric
- Uses elliptical orbits
- Proves so accurate that now the parts of the model are known as: Kepler's Laws of Planetary Motion
- Is the basis of our current understanding of the solar system

KEPLER'S FIRST LAW

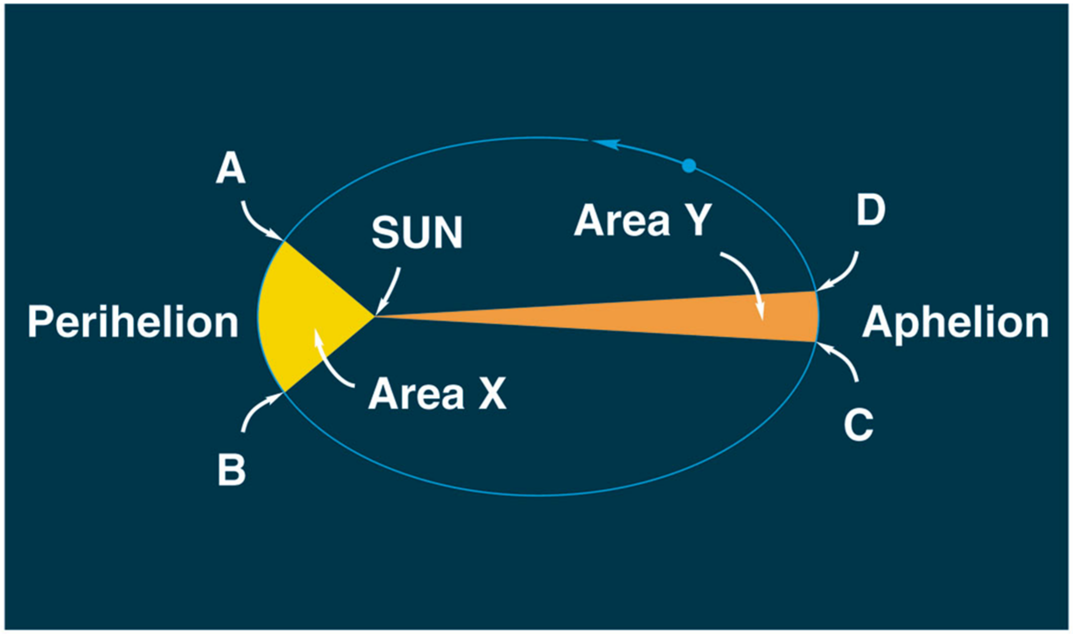




Animation by Bill Drennon

- Each planet's path around the Sun is an ellipse, with the Sun at one focus of the ellipse
- Note that this means the planet is at different distances at different times
- Real planet orbits not nearly this eccentric!

KEPLER'S SECOND LAW

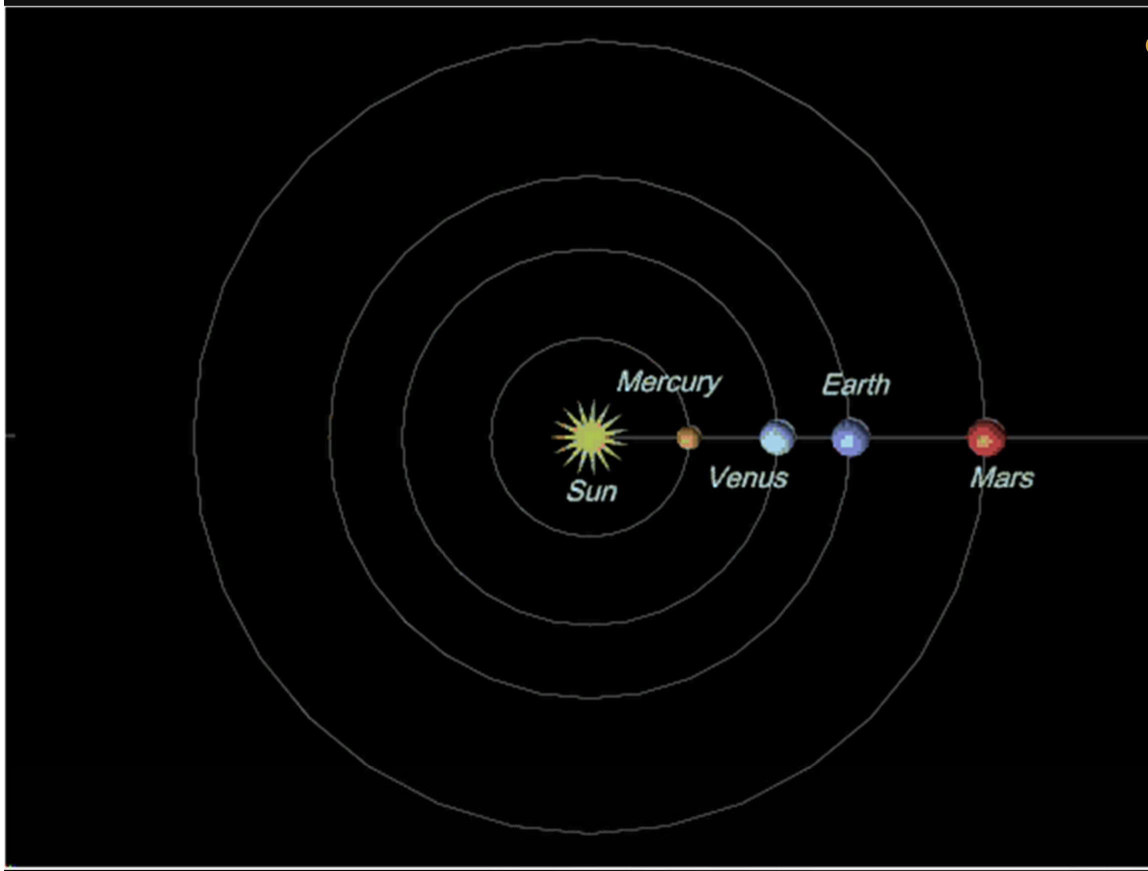


A planet moves along its elliptical path with a speed that changes in such a way that the line from the planet to the Sun sweeps out equal areas in equal times

- Fast at *Perihelion*
- Slow at *Aphelion*

PLAY

KEPLER'S THIRD LAW



- The ratio of the cube of the semi-major axis of a planet's orbit to the square of its orbital period around the sun is the same for each planet

$$\frac{a^3}{p^2} = 1(AU^3 / yr^2)$$

  - Closer planets orbit more quickly!

PLAY

PERIODS

- Kepler used the *sidereal* period
  - Like sidereal day – the true period of the orbit, as measured against the background stars
- There is a *synodic* period too
  - Like the solar day, it's the time it takes the planet to appear to be in the same place, as seen from the Earth
- Same terms as we saw for the moon's orbit

TESTING KEPLER'S LAWS

Planet	Distance	Period	a^3	p^2
Mercury	0.387 AU	0.241 yr	0.0580 AU^3	0.0581 yr^2
Venus	0.723	0.615	0.378	0.378
Earth	1.000	1.000	1.000	1.000
Mars	1.524	1.881	3.540	3.538
Jupiter	5.204	11.862	140.9	140.7
Saturn	9.582	29.457	879.8	867.7
Uranus	19.201	84.011	7079.0	7057.8
Neptune	30.047	164.79	27127	27156
Pluto	39.236	247.68	60402	61345

Differences now accounted for by planets interacting with each other gravitationally

UPDATING THE MODEL

- Kepler's laws provided extremely accurate predictions
  - Later the why and how explained by Newton with gravity
  - Deviations from these laws actually showed people where to look for new planets
- Aesthetics:
  - Simple, symmetric, "neat and clean"
  - But no underlying why and how: "*ad hoc*"

MORE KEPLER

- Proved how Logarithms work
- Optics
  - Figured out how the human eye works
  - Improved Galileo’s telescope design
    - Now the standard configuration
- Coined the term “satellite” to describe the Moon
  - Makes the connection between our moon and Galileo's discovery of Jupiter’s moons
- Observed the Supernova of 1604
- Laid the foundations for calculus

WHERE DO THINGS STAND?

- After Kepler, there was a model which was demonstrably more accurate
- Had some predictions which could not be tested at the time
- However, needed more to overcome the big downside of tossing out Aristotlean philosophy (*i.e.*, the equivalent to the laws of physics at the time)

THE HOW AND WHY

Some *reasons* why Kepler's model does what it does

QUICK REVIEW

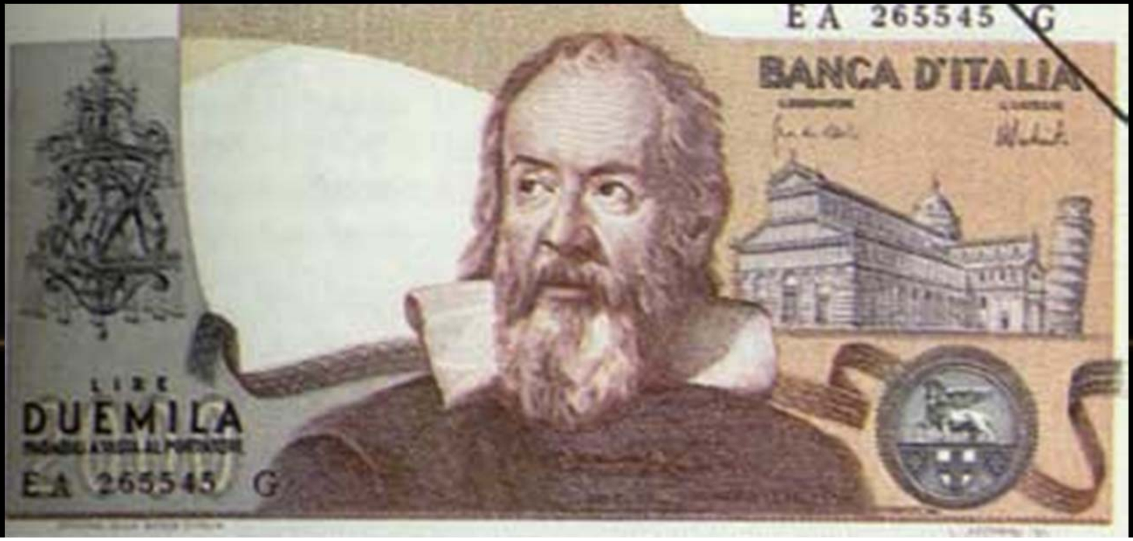
- Kepler’s model was very accurate
- But was still “*ad hoc*”, that is:
  - Ellipses appear to be the paths planets move on,
  - But doesn’t address <u>why</u> they do so
- Plus, a moving Earth messes up Aristotle’s models for how things happen on Earth

MISSING PIECES

- More observations
  - Try to detect things that would be different between geo- and helio-centric models
  - Galileo and his telescope
- A more complete theory
  - Put some reasons behind the model
  - Newton and his laws of gravity

GALILEO GALILEI

- In Pisa, Italy
- Worked in the early 1600's
  - Height of Renaissance
  - Knowledge busting out all over in Tuscany at the time
- Laid the foundations of freshman mechanics
  - Figured out a model of the pendulum
  - Studied falling objects



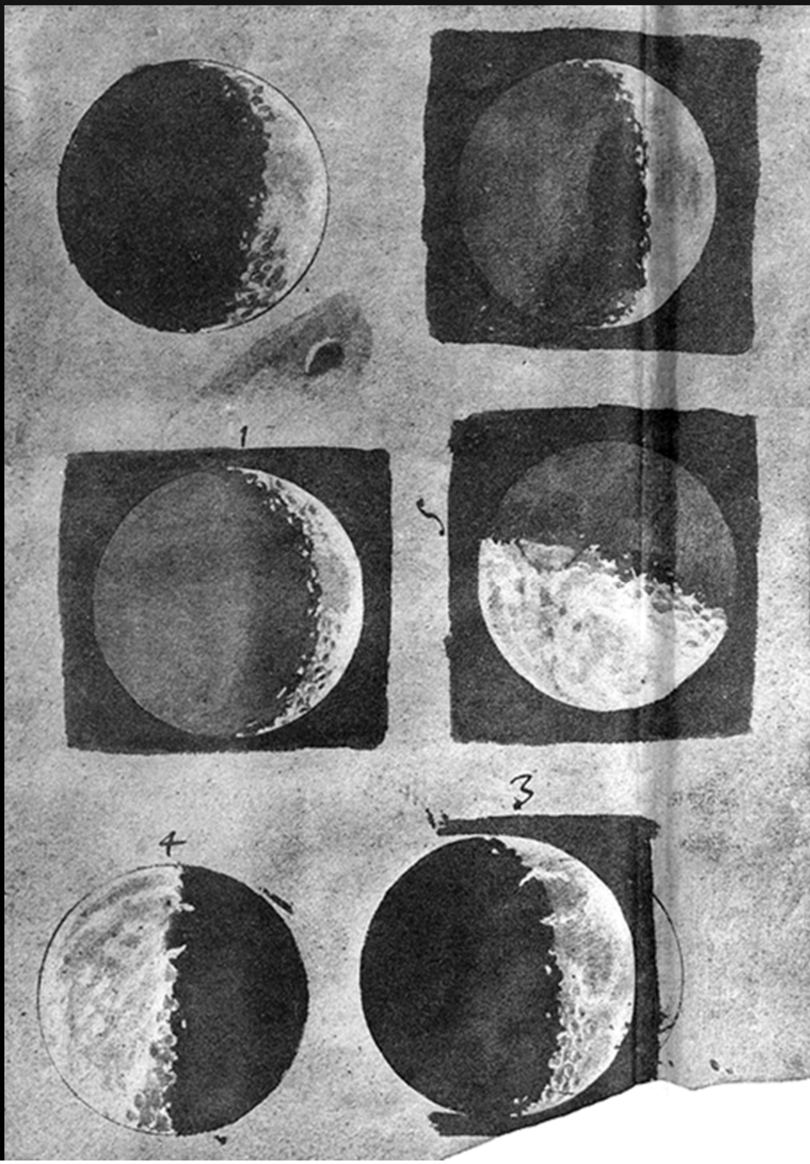
TELESCOPIC OBSERVATIONS

- Telescope invented in 1608
  - in the Netherlands
  - by Hans Lipperhey and Jacob Metius
- Galileo one of first to aim one at the sky
- Very cheesy scopes by today's standards – your binoculars have much better optics

WHAT DID HE SEE?

- Mountains and valleys on the Moon
- Sunspots
- Many more stars, including that the Milky Way is really a lot of faint stars
- The phases of Venus

DETAILS ON THE MOON



- Mountains, Valleys
- The moon looks really rough when seen close up
- Aristotle *et al* recognized that the moon was “imperfect”, but the telescope revealed more deformities than imagined

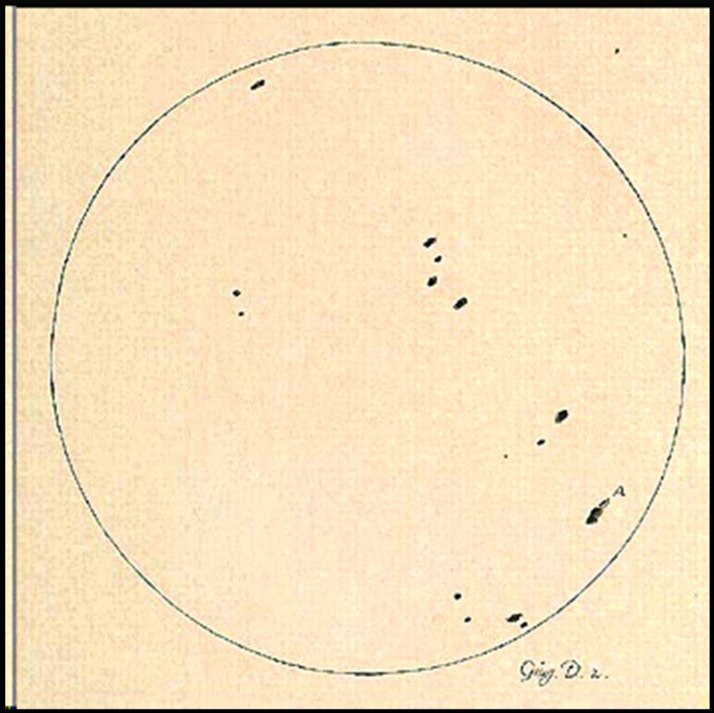
Wash drawings from Galileo’s notes.
He published others in <u>Sidereus Nuncius</u>, 1610.

A MODERN MOON VIEW

- Notice along the *terminator* (light/dark boundary)
  - Peaks lit
  - Valleys in shadow
- Craters galore!
- This photo from a standard back-yard telescope, by a couple of kids at Star Camp

Photo by Tolga Topalhan & Serkan Saygan

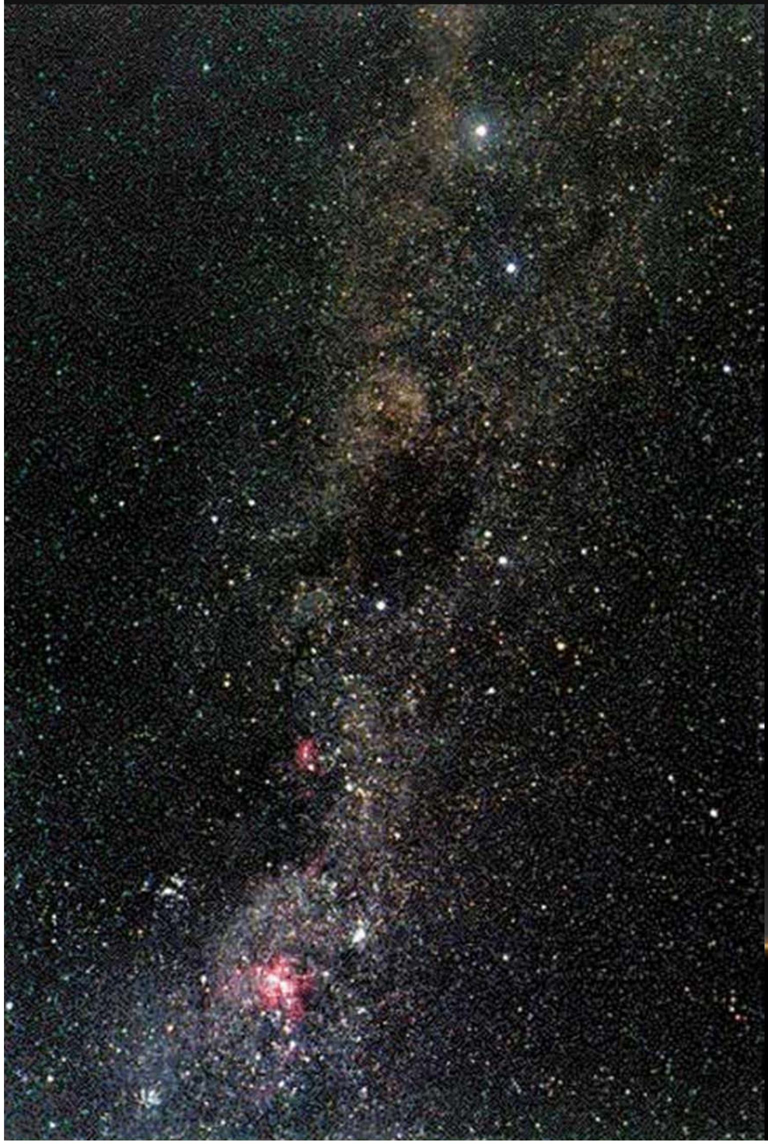
SUNSPOTS



Galileo's sketches from Istoria e Dimostrazioni Intorno Alle Macchie Solari e Loro Accidenti Rome, 1613

- Galileo also saw dark blotches on the Sun, as did others
- Galileo uses them to make his Copernican case
- The big debate – on Sun itself, or satellites of Sun?
- Detailed observations support the former
- Big Aristotlean problems – imperfections on the Sun!

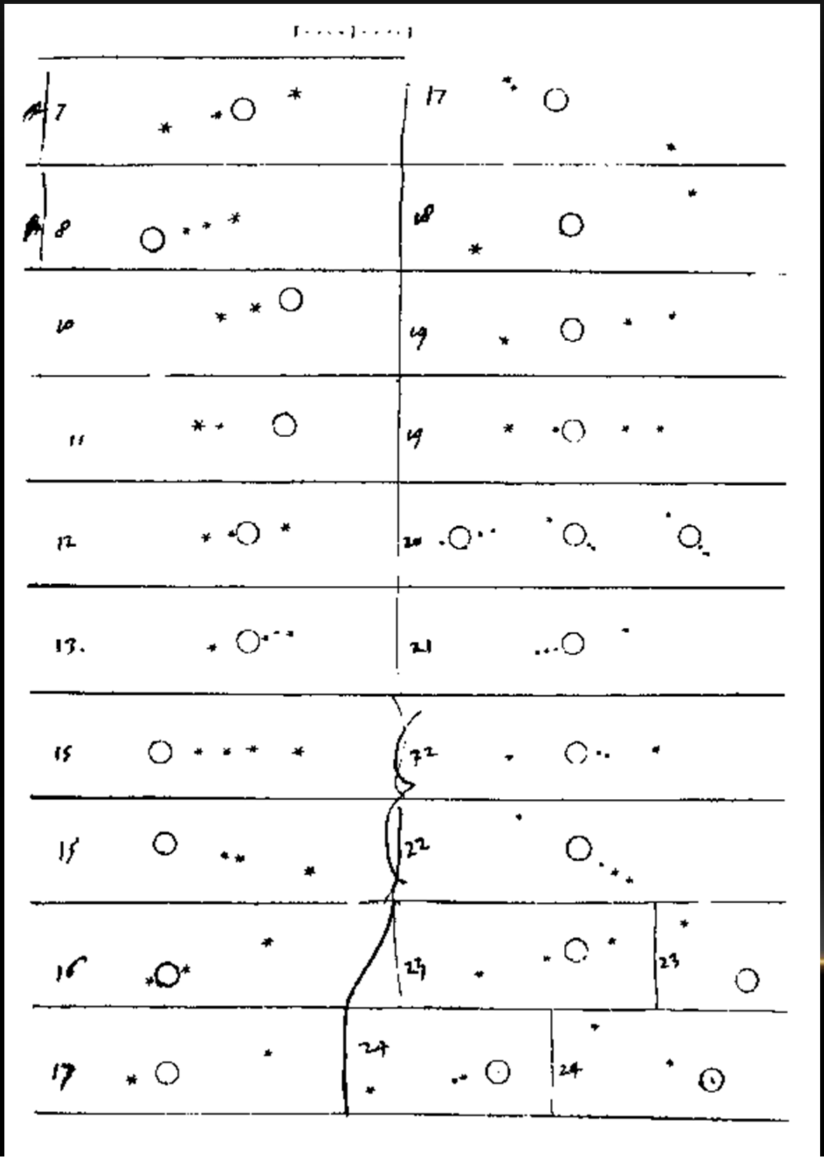
MANY FAINT STARS



- Telescopes revealed many stars where the eye saw none
- If stars were put into the sky "to shed light on the Earth", what purpose do invisible stars serve?

Photo of Southern Cross area
by Greg Bock, Southern Astronomical Society

MOONS AROUND JUPITER



- Galileo saw things orbiting Jupiter
- Changing from night to night
- Four satellites are found, and orbit Jupiter in very predictable fashion
- We see a mostly side-on view, so they appear in a line
- Sometimes nearest is hidden by Jupiter and farthest is out of the field of view

Galileo's Jovian moon observations, Sidereus Nuncius, 1610

THE IMPLICATIONS OF THIS…

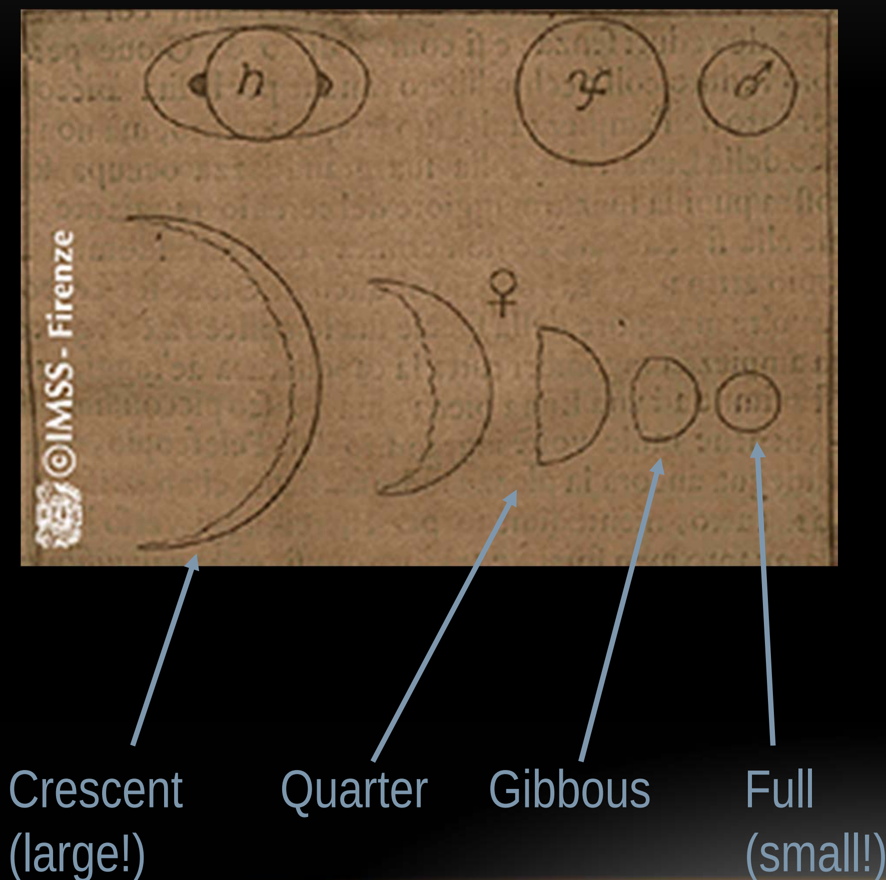
Photo by Philipp Salzgeber

- A “mini solar system” – things orbiting something that’s not Earth

  Conflicts with Ptolemaic model

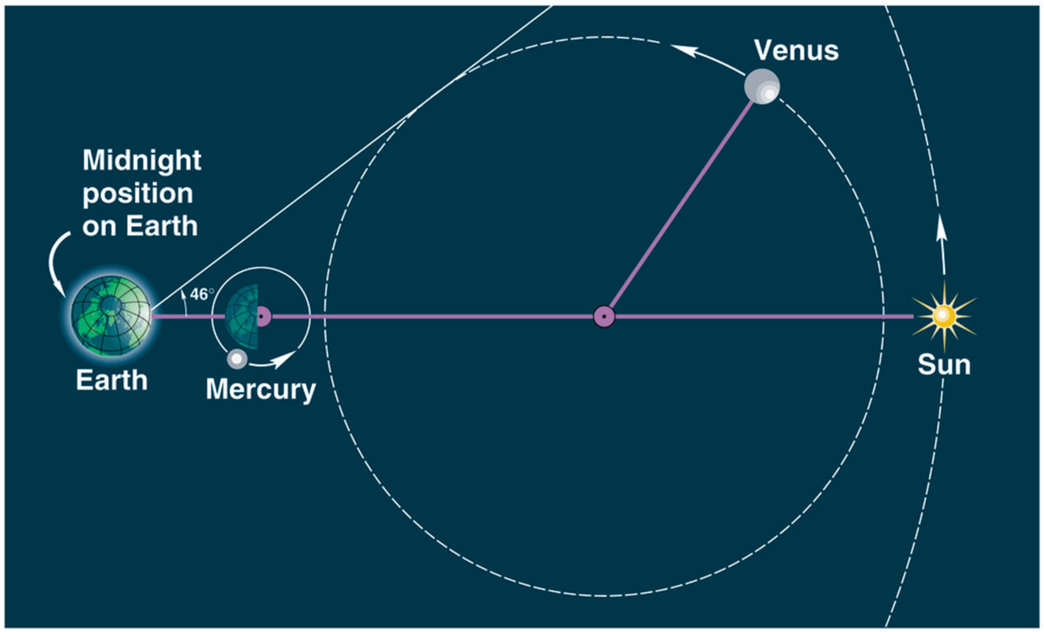
  If Jupiter can have moons and not leave them behind as it moves, then a moving Earth wouldn’t leave behind the Moon, either
- Go look yourself with binocs – see website for diagram

PHASES OF VENUS



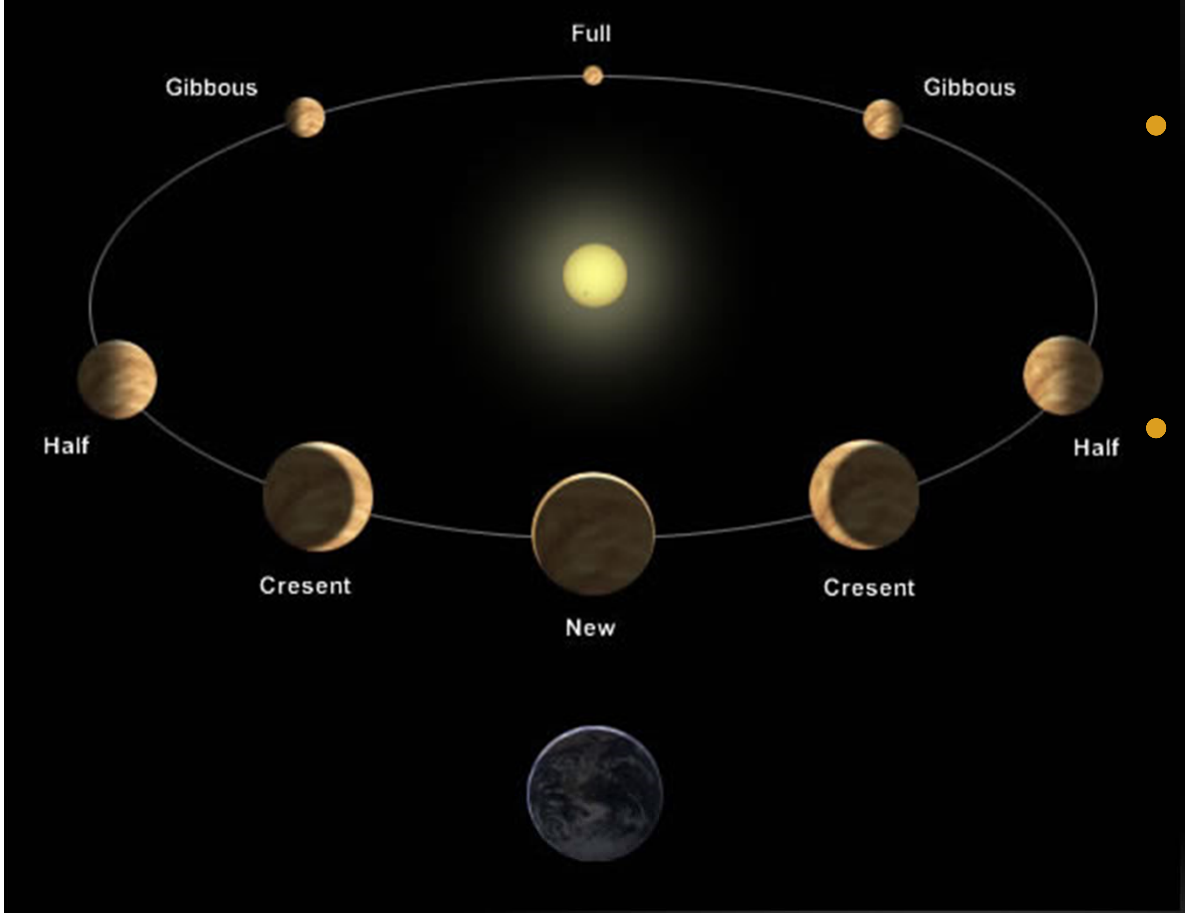
- Galileo observed Venus going through phases
  - Like moon
  - Apparent size changes too
- You need a telescope to see this
  - (or binoculars)

PTOLEMAIC VENUS



- Venus on epicycle tacked to line between Earth and Sun
- We never see much more than a crescent
- A more-full Venus is closer and appears bigger

HELIOCENTRIC VENUS



- If Venus goes around Sun, all phases are observed
- Venus is far away and appears smaller when full

PLAY

GALILEO'S CONTRIBUTIONS

- Galileo used the newfangled telescope to observe the skies
- Saw a number of things which contradict:
  - Aristotle
    - "Blemishes" on Moon and Sun, many faint stars
  - Ptolemy
    - Moons of Jupiter, phases of Venus

EVIDENCE ADDS UP

- None of these things alone was a show stopper
  - Maybe heavens aren't so perfect after all
  - We have many epicycles, why not more for Jupiter's moons
  - Venus phases fits Tycho's geocentric model too
    - Maybe Venus goes around Sun which goes around Earth
- But taken together, they start to make a Geocentric model less attractive
- Need a good how to finish the story (Newton!)

RELIGION AND POLITICS

- Galileo wasn't the only guy making these observations
  - Just the most outspoken
  - Really pushed the Copernican view
- Active in politics
  - In the era that brought us the term "Machiavellian"
  - Religion and Politics very wrapped together
- A recipe for trouble
  - Eventually a cardinal who gets mocked in one of Galileo's books becomes pope, puts him under house arrest, and forces him to recant

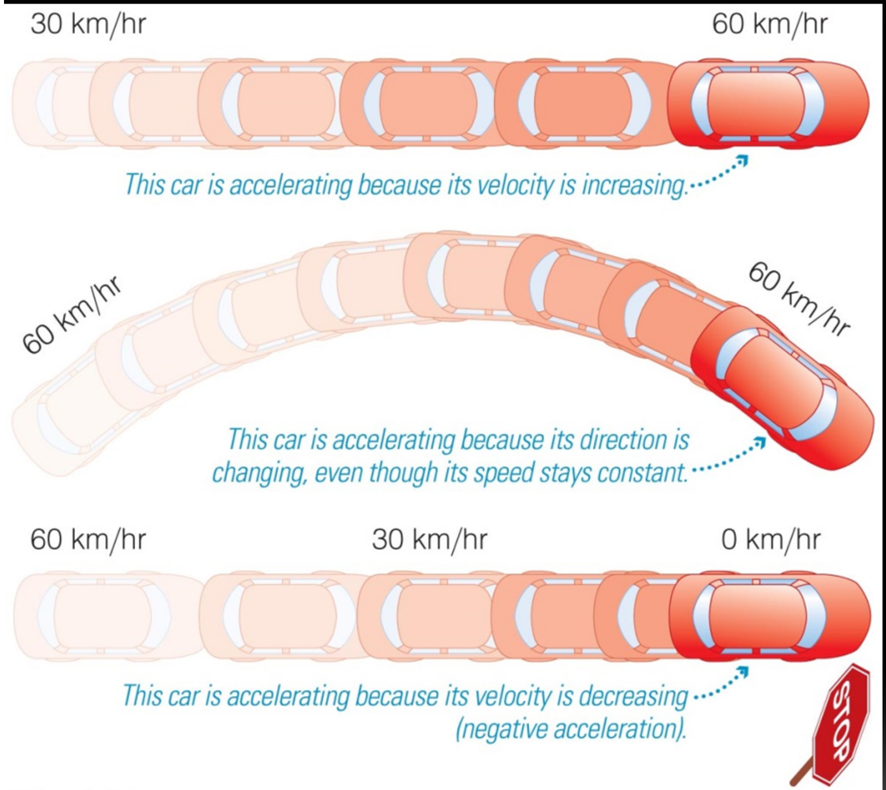
LESSONS OF THIS

- Classically held as an example of:
  - Religious persecution
  - Brave new scientific ideas being suppressed by The Establishment
- While there certainly was a bit of both going on, keep in mind:
  - Religion = politics at the time
  - Ideas weren't so brave and new – but the change between models <u>was</u> a huge one, and required a lot of evidence (which Galileo provided)

ISAAC NEWTON

- British, born just as Galileo died
- Wants to figure out what makes Kepler's Laws work
- To solve this, he invents
  - Theory of Gravity
  - Newton's Laws of Motion
  - Calculus
- Not only provides a better alternative to Ptolemy, but to Aristotle as well

MOTION



- Speed: rate at which something moves:
  - speed = distance/time (m/s, miles/hour, km/hr)
- Velocity: Speed with a direction
  - 70 mph south on I-35 is very different than 70mph north
- Acceleration: a change in velocity
  - Speed up, slow down, OR change direction
  - Units of (m/s)/s thus m/s^2

Fig.4.1