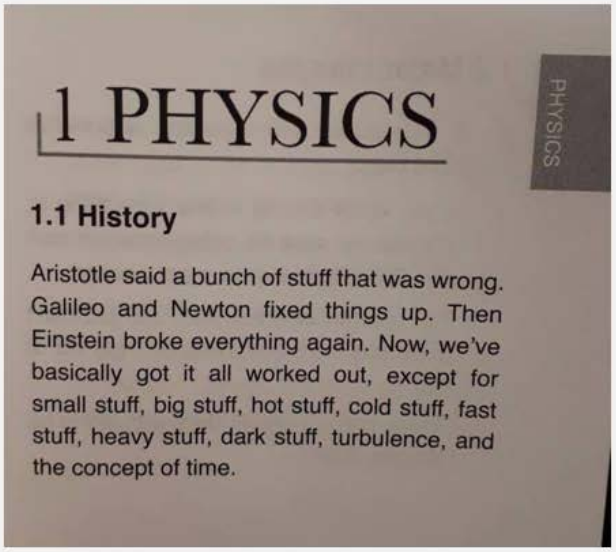
Logistical notes

- Survey-takers: additional info
- If you haven't gotten a clicker yet, visit Petty 321 to pick one up
- Download Stellarium, follow instructions in MasteringAstronomy lab assignment

(demo)

Spoiler: Thursday will involve clickers …

Today in science...



1 PHYSICS

PHYSICS

1.1 History

Aristotle said a bunch of stuff that was wrong. Galileo and Newton fixed things up. Then Einstein broke everything again. Now, we've basically got it all worked out, except for small stuff, big stuff, hot stuff, cold stuff, fast stuff, heavy stuff, dark stuff, turbulence, and the concept of time.

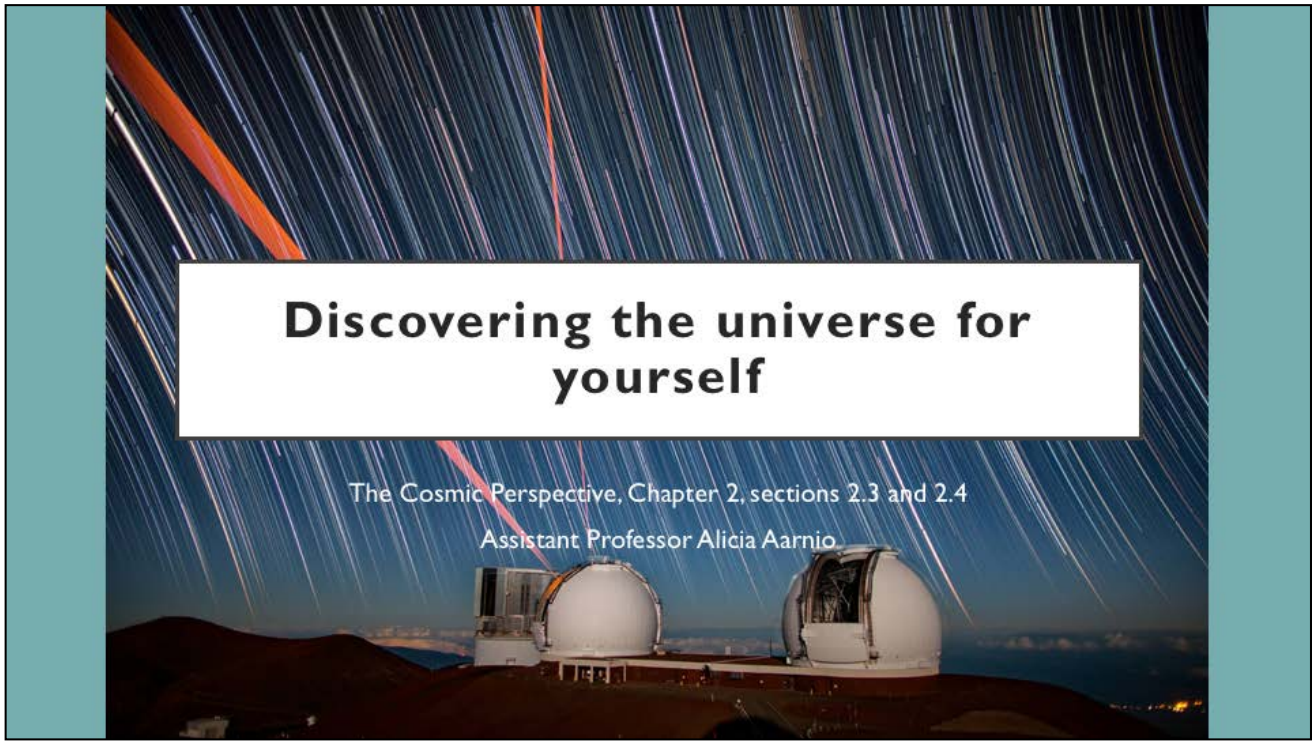
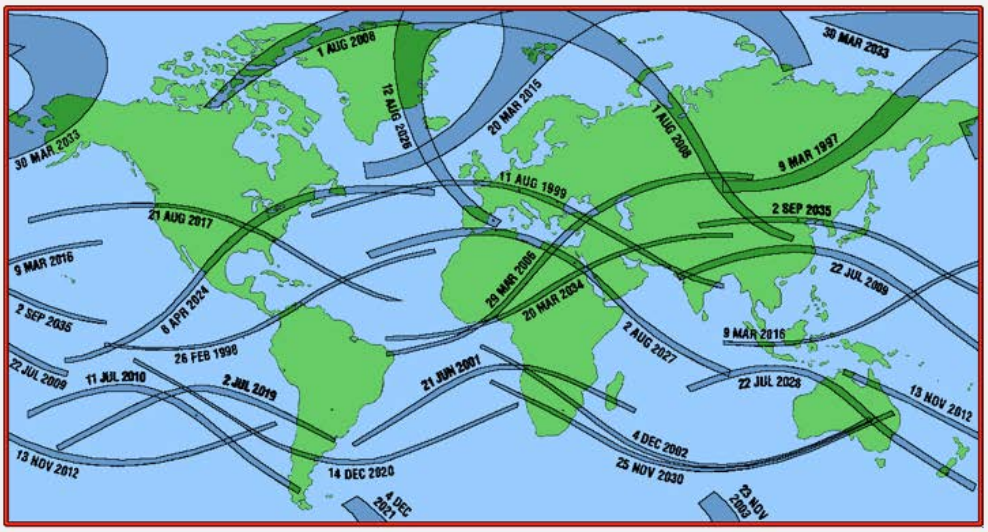


Photo credit: Dr. Joe Llama, Lowell Observatory

Photo is of star trails over Keck Observatory. Yes, those are laser beams coming out of the telescope dome!

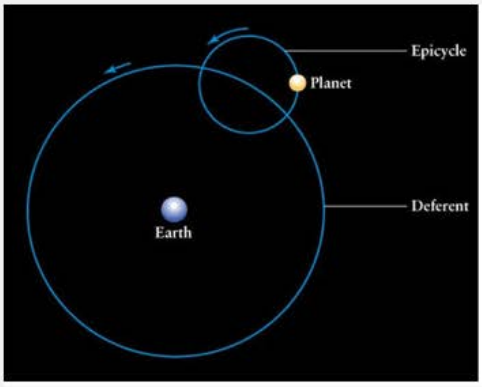
Eclipse forecasts!

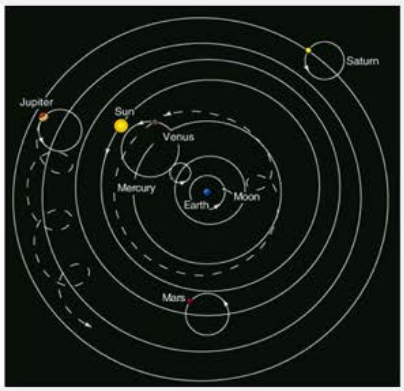


I forgot to mention this last time- but the next total eclipse in the US will be in 2024

Planetary motion in the sky

- We easily see 5 planets with the naked eye: Mercury, Venus, Mars, Jupiter, and Saturn
  - When do we see Venus and Mercury?
- Retrograde motion was incredibly difficult to explain in an Earth-centric model



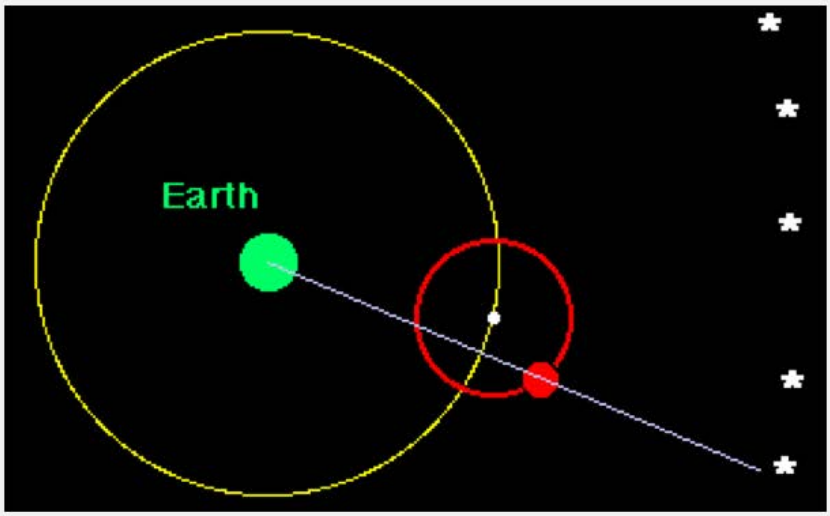


Finishing where we left off last class

Retrograde motion

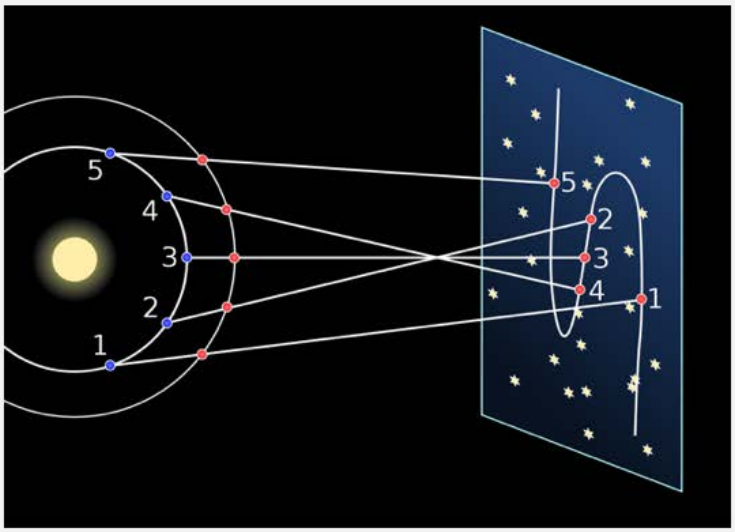
http://cseligman.com/text/sky/retrograde.htm

Retrograde motion



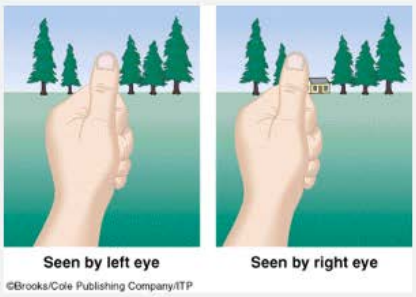
http://hildaandtrojanasteroids.net/epicycle-move.gif

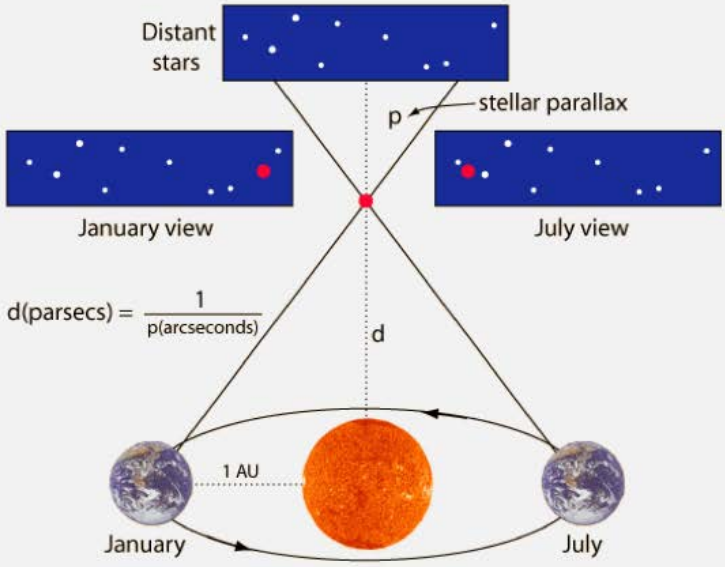
Retrograde motion



https://en.wikipedia.org/wiki/Apparent_retrograde_motion

Parallax



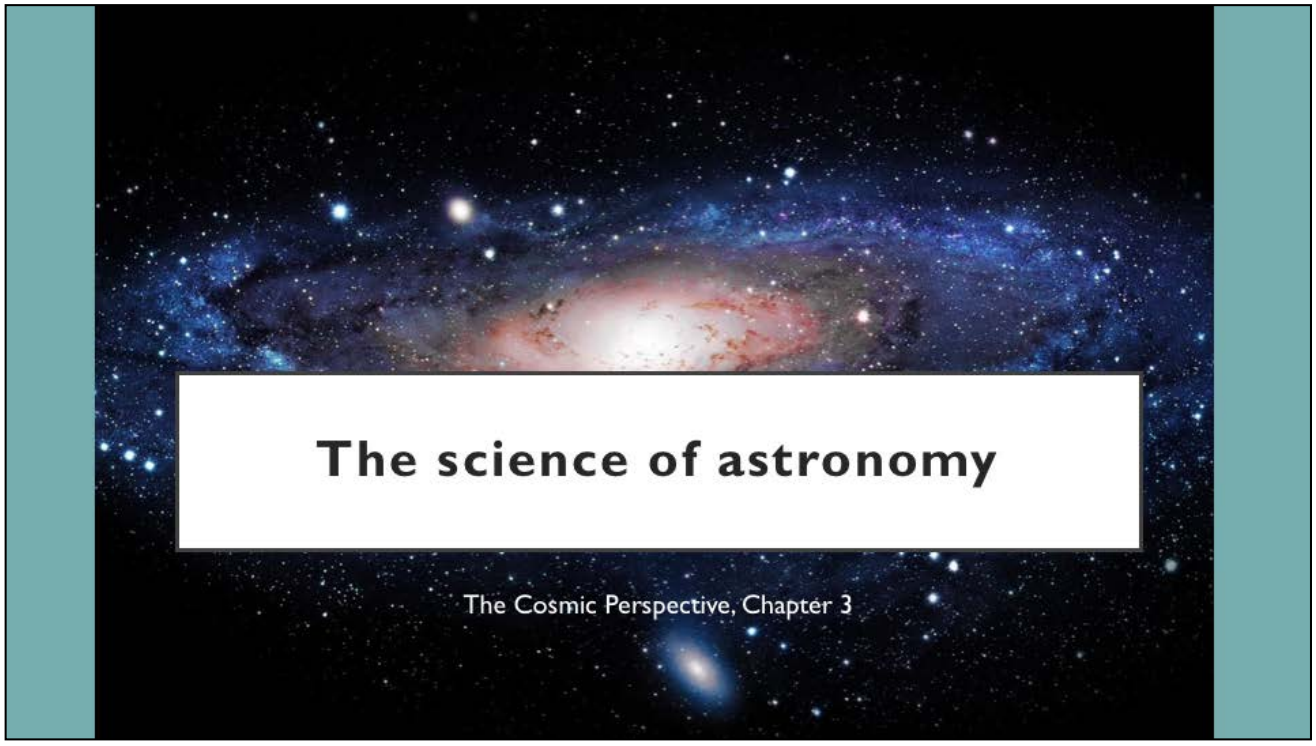


From thumb to stars—parallax is used to determine distances to stars

Fig on right from http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/para.html

Recap

- Last week/today, we talked about…
  - Recap: went over motion of the Sun in the sky, the analemma
  - Angular size of objects in the sky, and how to measure them with our own hands
  - The Moon:
    - Its orbit
    - Phases
  - Eclipses
    - Lunar (when Earth blocks the Sun's light to the Moon)
    - Solar (when the Moon blocks the Sun from Earth's view)
  - The motion of planets in the sky
  - Parallax, a way of measuring distances if you can do it well enough and why the ancient Greeks refused to believe the Earth was not the center of the Universe

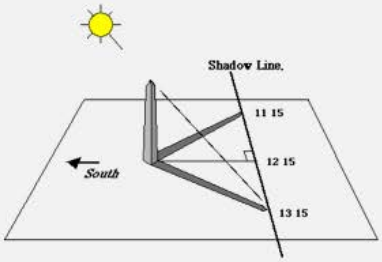

The science of astronomy
The Cosmic Perspective, Chapter 3

Ancient Observations

- How did the motions and behavior of celestial objects relate to weather and agriculture?
  - Observations of the Sun and Moon
  - Observations of stars and planets
- Chinese observatory in Beijing built 5,000 years ago!
  - Astronomical observations as well as solar
  - Used reflections in well water for solar observations
    - From 164 B.C.: "The black vapor in the middle of the Sun is a bad omen.. Yin is forcing Yang, and the people are alarmed."

Examples of Ancient Observations

- Determination of the time of day:
  - using gnomons to measure the Sun's shadow (sundials)
  - or the Moon's position and phase at night
- Determination of the time of year:
  - using sunrises at certain dates
- Lunar Cycles:
  - ~29-day orbit (recall: *moon*th word origin)
  - Metonic cycle: 19 yrs ~ 235 lunar months (a period between 2 subsequent locations of the Moon at the same place in the sky AND in the same phase)
    - This 19-year cycle helps to align solar and lunar calendars



General Example : at Local Noon, - here 1215 - the Sun gives the shortest possible shadow.

Ancient observations shape our time today

- Days → as long as the Sun is in the sky
- Weeks → 7 days long, each day named for 'wandering stars.' Germanic languages:
  - Sun/Sunna -- *Sunnandæg* -- Sunday
  - Moon/Máni -- *Mōnandæg* -- Monday
  - Mars/Tiws -- *Tīwesdæg* -- Tuesday
  - Mercury/Woden -- *Wōdnesdæg* -- Wednesday
  - Jupiter/Thor – *Þūnresdæg* -- Thursday
  - Venus/Frige -- *Frīgedæg* -- Friday
  - Saturn -- *Sæturnesdæg* -- Saturday
- Months → lunar orbital period
- Years → based on cycle of seasons

Our day names are Germanic in origin, corresponding to the Norse gods' equivalent to the Roman

There's no equivalent in Norse mythology to Saturn, their word literally meant 'washing-day.' the German equivalents meant "Sunday eve"

Ancient observations shape our time today

- If you studied French or Spanish…
  - Sunday – dimanche/domingo (diēs Sōlis, changed to dies Dominicus, Lord's day)
  - Monday – lundi/lunes (diēs Lūnae, moon's day)
  - Tuesday -- mardi/martes (diēs Mārtis, Mars' day)
  - Wednesday – mercredi/miércoles (diēs Mercuriī)
  - Thursday – juedi/jueves (diēs Ioves – Iove → Jove →Jovian)
  - Friday – vendredi/viernes (diēs Veneris, Venus' day)
  - Saturday – samedi/sábado (diēs Saturnī, Saturn's day, renamed for the Sabbath)

Ancient observations shape our time today

- Clock originated in Egypt, 4000 years ago
  - Egyptians divided day and night into 12 equal parts each
  - Romans called this ante meridiem (a.m.) and post meridiem (p.m.)
- Ancient civilizations built cities and structures aligned with Solstices and Equinoxes
  - Stonehenge built ~3100 BC as religious and social gathering place
  - Pueblo people built the Sun Dagger, which intersects a spiral only at noon on summer solstice
  - Templo Mayor, built by Aztecs, had notches where Sun visible rising/setting on equinoxes
  - Incan people carefully monitored Sun's behavior: rulers believed to be descendants of the Sun

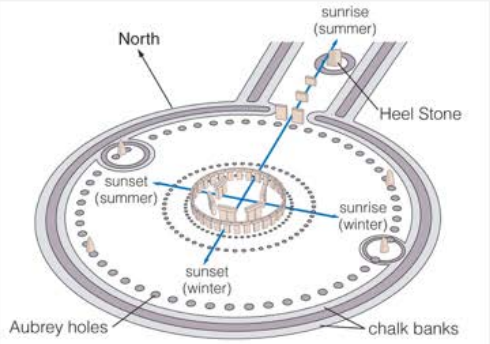
Macchu Picchu 1450 AD

Templo mayor, 1427 AD

Sun dagger- 1000 AD

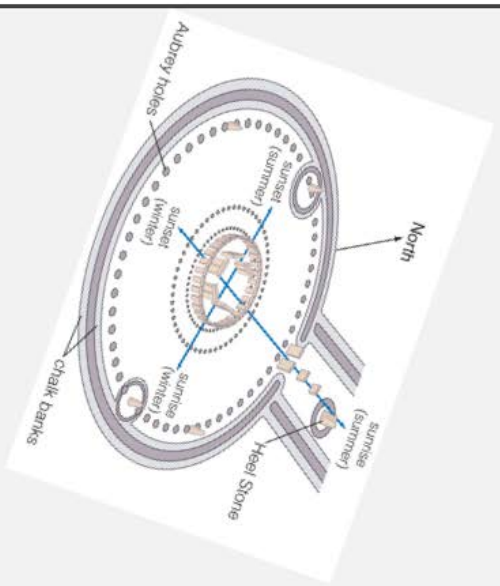
Stonehenge

- People gather at Stonehenge on the summer solstice at sunrise



b This sketch shows how archaeologists believe Stonehenge looked upon its completion in about 1550 B.C. Several astronomical alignments are shown as they appear from the center. For example, the Sun rises directly over the Heel Stone on the summer solstice.

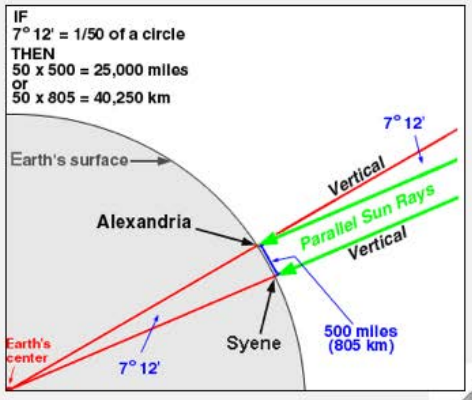
Stonehenge



Rotating it so the aerial view is at the same angle as the cartoon view…

Eratosthenes (275 – 195 B.C.)

- Invented geography
- Estimated Earth's diameter with remarkable accuracy
  - measured Sun's position in the sky at same time from two different places on a N-S line
  - Found that the Earth's circumference was 39500 km (modern value=40000 km)
- Measured tilt of Earth's axis
- Estimated distance from Earth to Sun, inventing the leap day



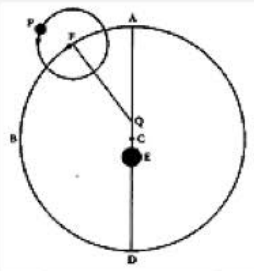
What was so cool about the Greeks? They applied math to explain the diligent observations of cultures up to that point

http://www.geo.hunter.cuny.edu/~jochen/gtech201/lectures/lec6concepts/Datums/Determining%20the%20earths%20size.htm

Ptolemaic model of the Universe

- Developed by Claudius Ptolemy (A.D. 100–170)
  - Geocentric universe
  - Sun is at the third orbit from Earth, after Mercury and Venus
  - Epicycles added to circular orbits of planets explain retrograde motion
- The Ptolemaic model and a catalog of positions of 1028 stars were published in his book, Almagest
- Geocentric model remained in use for ~1500 years (!!)

- Ptolemy was a Greco-Roman mathematician, astronomer, geographer, astrologer, and poet of a single epigram in the Greek Anthology



All that innovation on Earth, and we still believed it was the center of things…

P is silent; pronounced toll-eh-mee

Hypatia

- Born in Alexandria in 350-370 AD
- Lived to be ~44-65
- Philosopher, astronomer, and mathematician
- She is the first female mathematician whose life is reasonably well recorded
- Taught Philosophy and Astronomy at the Neoplatonic school in Alexandria
- No surviving solely-authored texts
- May have edited the surviving text of Ptolemy's *Almagest*
- Definitely wrote a commentary on Diophantus's thirteen-volume *Arithmetica*
- Pagan, but tolerant of Christianity
- Martyr: murdered by a mob of Christian monks

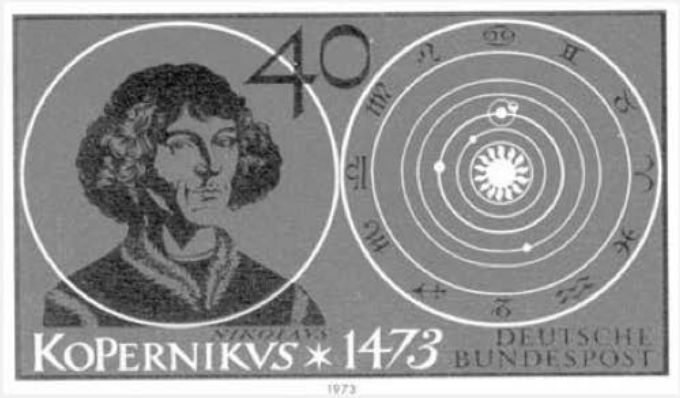
Hidden figure alert– most people don't know Hypatia ever existed

https://en.wikipedia.org/wiki/Hypatia

She was killed because she advised the government leader in Alexandria, Orestes, who was in a feud with Cyril, the Bishop of Alexandria. The monks thought she was telling Orestes to not make peace with Cyril, soooo they killed her.

Nicolaus Copernicus (1473-1543)

- Copernicus is said to be the founder of modern astronomy
- His central ideas:
  - Heliocentric solar system
  - The Earth is the third planet from the Sun (after Mercury and Venus)
  - Planets revolve around the Sun on circular orbits
- These ideas formed the Copernican Revolution



German stamp featuring Copernicus (who was Polish)

He's said to be the founder, but he wasn't the first to take a heliocentric view; ancient greeks had considered it already. Copernicus helped to publish, to codify, and get the idea out there. Didn't suffer much negative reaction from the church because he was ordained himself, and got along with the leadership well. It wasn't controversial in his time.

Nicolaus Copernicus

- Worked with data compiled by Spanish King Alphonso X, who once said,
  - "If I had been present at the creation, I would have recommended a simpler design for the universe."
- Copernicus used a heliocentric view to better explain much of the data, but …
  - Still assumed circular orbits, so his predictions weren't exact matches to the data
  - Still used epicycles
- His book, *De Revolutionius Orbium Coelestium*, On the Revolutions of Heavenly Spheres, he saw published on the day he died in 1543

Like a lot of scientists, it seems like Copernicus was worried the issues and inconsistencies in his work threatened his credibility

Tycho Brahe

- Tycho Brahe (1546-1601)
  - Danish nobleman born in Sweden
  - Expected to be politician or lawyer, family supported his interest in science instead
  - Tycho lost part of his nose in a duel, wore a brass prosthesis for the rest of his life

The duel was with his 3rd cousin, at a wedding, and they fought in the dark. Weddings are dangerous.

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Points for the pun, for the Brahe reference- a great, easy Halloween costume for you this year!

Image source unknown...

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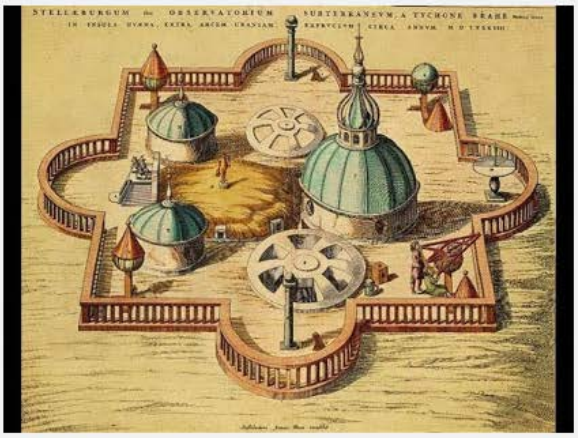
  - Tycho lost part of his nose in a duel, wore a brass prosthesis for the rest of his life
- Observed an exceedingly bright star in 1572, wrote about it in *De Nova Stella*
  - It was a supernova! A star exploding at the end of its life
    - No daily parallax, so definitely farther away than the Moon
    - No *monthly* parallax, either! Farther than the farthest planets known then
    - We now know 7,500 ly away
    - Discovery made his name as an astronomer

Tycho's observatory, Uraniborg

- Danish observatory and alchemy lab, built in 1576
- Named for Urania, the muse of Astronomy
- A fortress, but Tycho viewed it as a temple
- Only worked there for 4 years until he and Danish King fell out (read: he lost funding support from the King) and he left Denmark
- Destroyed in 1601



https://en.wikipedia.org/wiki/Uraniborg

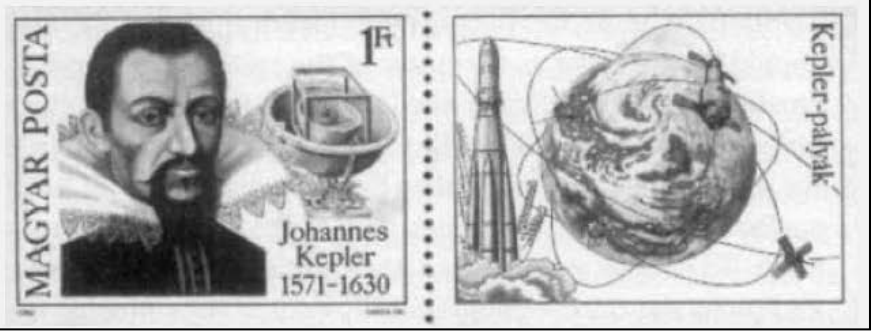
Tycho's Quadrant

- Assisted by his younger sister and student, Sophie Brahe
- Precision of the angular observations ~15 seconds of arc
  - Less than 1 arcminute (less than thickness of a fingernail at arm's length!)
  - About 5x as accurate as contemporaries' measurements
  - Despite this, never detected stellar parallax
- Remained convinced planets orbit the Sun, but all orbits the Earth

Today, a modern catalog is named for Tych- 2.5 million of the brightest observable stars

Johannes Kepler (1571 – 1630)

- German mathematician, astronomer, and astrologer
- Analyzed Tycho Brahe's observations of Mars
- Discovered three laws of planetary motion
- Matched Tycho's data well, supported Copernicus' heliocentric view

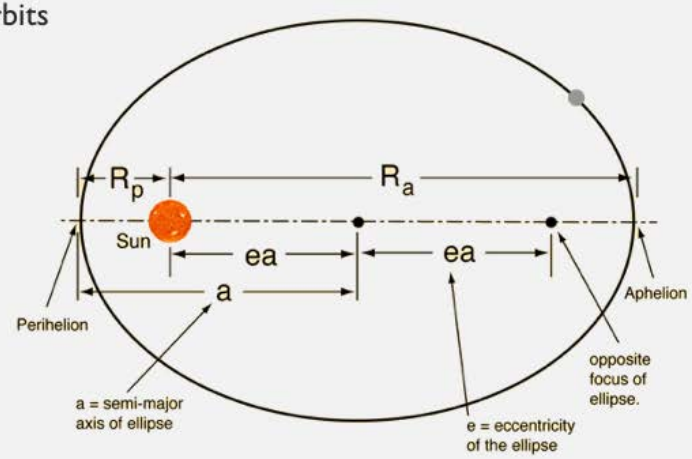


Hungarian stamp featuring Kepler, who was German

Brahe at first didn't want to share his data (bad scientific practice..) but Kepler impressed him

Kepler's Laws

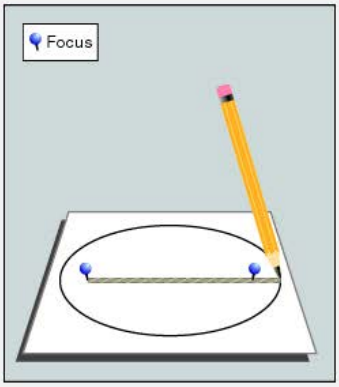
1. Planets move on elliptical orbits



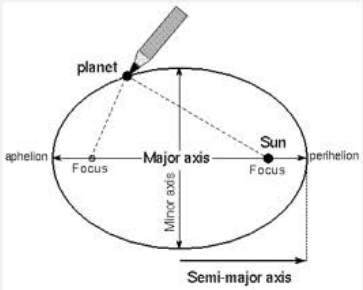
$R_a = a(1+e)$ $R_p = a(1- e)$

http://hyperphysics.phy-astr.gsu.edu/hbase/kepler.html

Ellipses



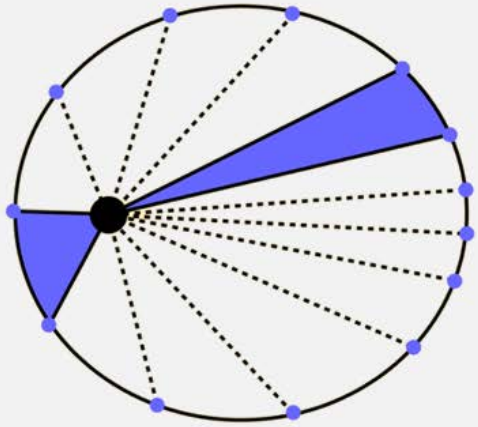
- A circle is a special kind of ellipse
  - The major and minor axes are equal
  - Eccentricity is 0



Drawing an **ellipse**: loop string around thumb tacks at each **focus** and stretch string tight with a pencil while moving the pencil around the tacks. The Sun is at one focus.

Kepler's Laws

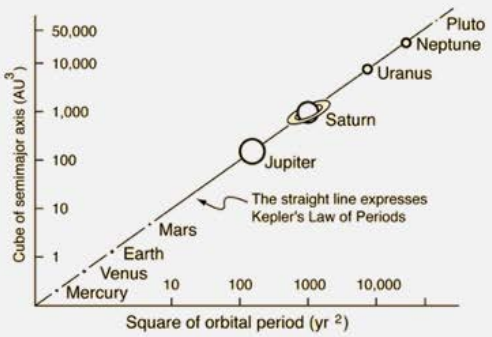
1. Planets move on elliptical orbits
2. The planet's radius-vector sweeps out the same areas in equal times



http://hyperphysics.phy-astr.gsu.edu/hbase/kepler.html

Kepler's Laws

1. Planets move on elliptical orbits
2. The planet's radius-vector sweeps out the same areas in equal times
3. The squares of the periods of the planets are proportional to the cubes of their semi-major axes



http://hyperphysics.phy-astr.gsu.edu/hbase/kepler.html

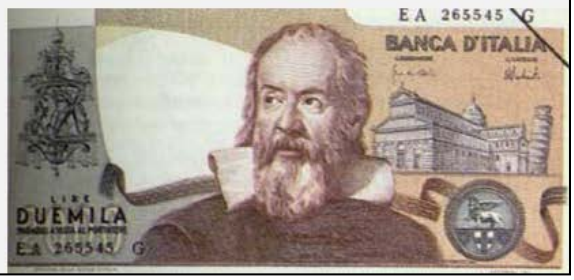
Why was geocentric view still so popular?

- But Aristotle said…
  - If Earth is moving, things falling on the Earth would be left behind as the Earth moves
  - The heavens are perfect- ellipses aren't perfect, so orbits and motions **must** be circular
- And, no one had detected stellar parallax yet: if Earth orbits the Sun, this must be happening.

Galileo, and others, tested all 3 of these ideas.

Galileo Galilei (1564-1642)

- Objects falling being left behind by the Earth?
  - Galileo found, before Newton, that objects in motion will stay in motion unless acted against
  - So, if objects are moving **with** the Earth, they should continue to do so unless something acts against their motion



Italian money (lire) with Galileo on it

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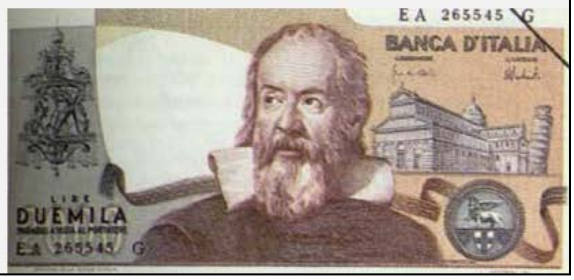
- Perfect, spherical, circular orbiting and unchanging heavens?
  - Tycho's supernova observation challenged this
  - Galileo's telescope did too--observed sunspots!



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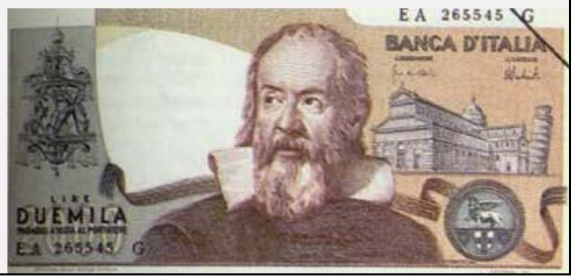
- …stellar parallax?



Italian money (lire) with Galileo on it

Galileo's Discoveries

- Galileo was the first to use the telescope as a scientific instrument in 1609
- His discoveries include:
  - Sunspots
  - Mountains and valleys on the Moon
  - Four satellites of Jupiter which orbited the planet, not Earth
  - Phases of Venus, proving that Venus orbits the Sun, not Earth

- However … even with the telescope, Galileo was not able to discover motion of stars due to motion of the Earth around the Sun (parallax)
- But, he was able to see more stars with the telescope than anyone imagined, suggesting they were more numerous and farther away than anyone had estimated

Galileo

- Wins for science, but maybe not Galileo… bad timing
- Heliocentrism was fairly uncontroversial after Copernicus; Pope Gregory XIII used Copernicus' work to reform the calendar in 1582
- Tycho Brahe's boisterous nature brought ruin: Copernicus had said stars are too far, Tycho was arrogant and overconfident in his measurements that they **must** be good enough to see parallax if it is there
- Religious objections to Earth's motion arose
  - "the world is firmly established, it cannot be moved."
  - "the Lord set the earth on its foundations; it can never be moved."
  - "And the sun rises and sets and returns to its place."
- In 1633, brought before inquisition for opposing Church doctrine at the time
- Ordered to recant his claims; he did. Under house arrest for remaining 7 years of his life
- Church ceased opposing heliocentric view in 1757, but didn't formally pardon/vindicate Galileo until 1992

At first, Galileo was a friend of the church and of the Pope. As he wrote more about heliocentrism and religious opposition rose, the pope asked him to include counter-arguments refuting heliocentrism, as well as the Pope's own views on a geocentric universe. Galileo included the Pope's views, but not counter-arguments, and that made the Pope angry. The Pope ceased defending Galileo from pursuit by the inquisition

Astronomy history, recap

- The basic parts of scientific thinking are observations, trail-and-error, testing hypotheses, modeling with math fundamentals
- New knowledge rests upon old discoveries
- The Copernican revolution was a long process, involving careful observations and theoretical work by many people