

Ways of knowing?

In science?

Empiricism!

Empiricism: evidence based on observations, our senses (sight, sound, taste, smell, touch)

How do you “know” the Earth moves?

What is your evidence, right now, without instruments?

Pre-Ptolemaic Astronomy

Calendars: When to plant

- Ancient Egyptian example (Dogs Days of Summer) (could be as old as 3000 BCE)
- Talked about many other calendars



Calendars: When to plant

- Ancient Egyptian example (Dogs Days of Summer) (could be as old as 3000 BCE)
- Talked about many other calendars to help know seasons

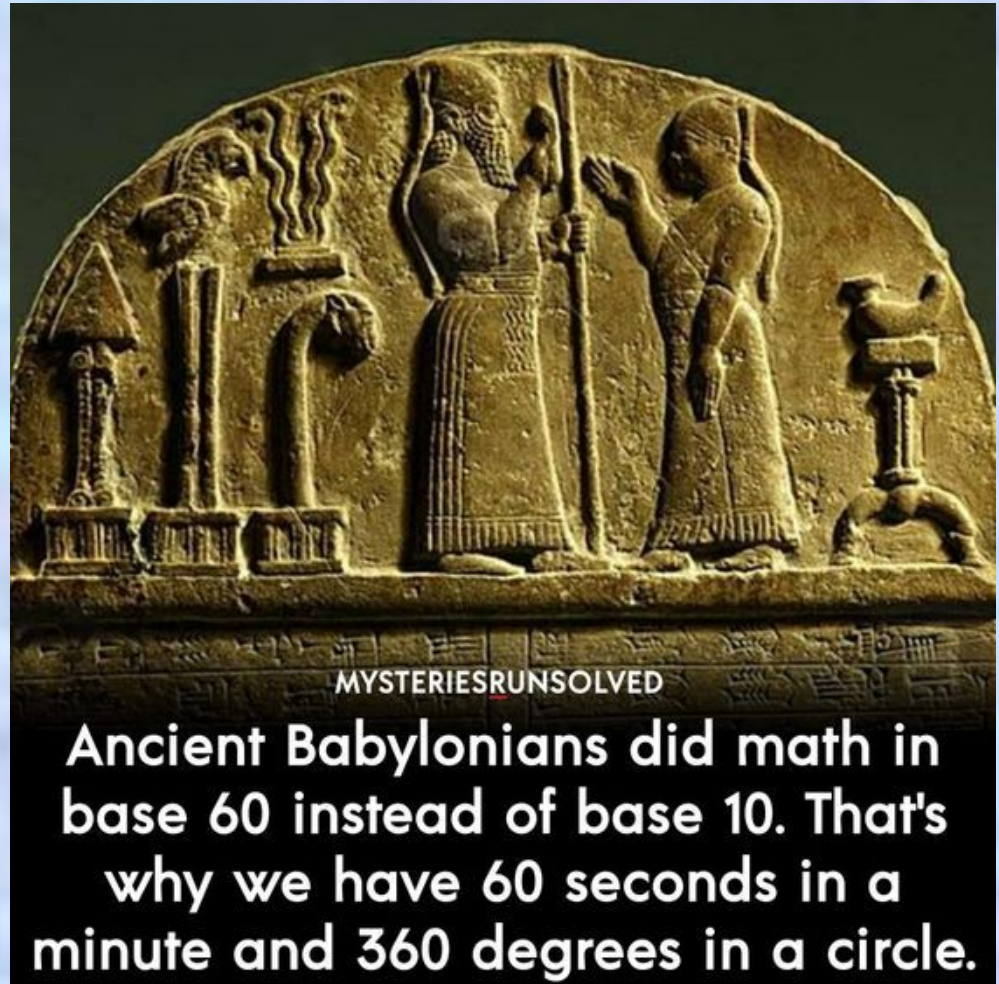
Thales (Greek, 624-546 BCE)

- Proposed non-mythological explanation of universe (Earth floats on water)
- Little Dipper (Polaris) as navigation tool
- Predicted eclipses? (Herodotus)

585 BCE The eclipse that stopped a war in modern day Turkey! (Herodotus again is the source, has to be 28 May 585 BCE) (Astronomy changes politics!!)

Ancient Calendars

- Every culture on Earth had some form of early calendar in its history
- Most of these calendars used a 360 day year, plus five extra days tacked on to the end
 - South and Central American cultures used 18 months of 20 days each, with the five extra days considered very unlucky and dangerous
 - Egyptians used a calendar with 12 months of 30 days, and the five extra days were used for celebration



Ancient Calendars

- Many of these calendars relied on direct observation of the Moon to signal a new month
 - Whenever an official observer would see a full moon, the start of the next month would be announced

Numbers and the Calendar

- Sexagesimal numbering system - Base 60
 - Used for time and angle measurements
- Babylonian Calendar
 - Lunisolar calendar
 - Day begins at sunset
 - 12 months - new month begins when crescent moon first visible after sunset
 - 12 lunar months = 354 days - extra month added every few years
 - Year began in spring - 3 seasons of 4 months
 - Early calendar - observational - around 500 BC, 19 year cycle = 235 months

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Where Did Our Calendar Originate?

The Julian Calendar

- Like many things in our culture, our calendar originates from the Roman Empire

- Julius Caesar introduced the 'Julian' calendar *in 45 BCE*, and its design was heavily influenced by Cleopatra

- Remember, the Egyptian calendar had 12 months of 30 days each

- The Julian calendar was very similar to our modern calendar, except for leap years

- The Julian calendar assumes the year is exactly 365.25 days and inserts a leap day every 4 years

- Remember, the mean year is actually more like 365.2422 days

- This is a very small difference, but will lead to an extra day of time every 128 years

JULIAN CALENDAR

DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	DAY
JAN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	JAN
FEB	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59				FEB
MAR	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	MAR
APR	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120		APR
MAY	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	MAY
JUN	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181		JUN
JUL	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	JUL
AUG	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	AUG
SEP	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273		SEP
OCT	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	OCT
NOV	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334		NOV
DEC	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	DEC

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Revisions to the Calendar

- It took quite some time for people to realize that the calendar was drifting
- In 1582, Pope Gregory finally took action, and adjusted the calendar accordingly
 - By this time, the calendar had drifted by about 10 whole days
 - In order to correct this, Pope Gregory eliminated October 5 - 14, 1582 from the calendar
 - He also revised the rules for leap years to ensure this wouldn't happen again
 - The new leap year rules (and still in used today) are:
 - Years divisible by 4 are leap years
 - Years that are divisible by 100 years are NOT leap years
 - Years that are divisible by 400 years are leaps
- The calendar was not accepted by the British and American colonies until 1752!
 - The Catholics and the Protestants didn't play well together
- This calendar, known as the Gregorian calendar, is the one we still use today
 - Note: Even with the confusing leap year rules, the Gregorian average year is 365.2425, different from the mean tropical year of 365.2422
 - Over a long period of time, our current calendar will drift also!

Months are Named After These:

- **January:** Named after the Roman god Janus.
- **February:** Named after the Roman festival of purification, Februa.
- **March:** Named after Mars, the Roman god of war.
- **April:** From the Latin word aperire, meaning "to open".
- **May:** Named after Maia, a Roman goddess associated with growth.
- **June:** Named after Juno, the Roman goddess of marriage & childbirth.
- **July:** Named after Julius Caesar.
- **August:** Named after Augustus Caesar.
- **September:** Comes from the Latin word septem, meaning "seven".
- **October:** Comes from the Latin word octo, meaning "eight".
- **November:** Comes from the Latin word novem, meaning "nine".
- **December:** Comes from the Latin word decem, meaning "ten".

Days of the Week:

Seven Planets of the Week

Sunday



sun

Monday



moon

Tuesday



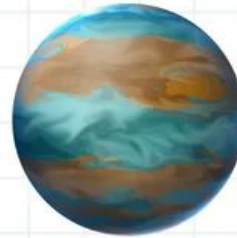
Mars

Wednesday



Mercury

Thursday



Jupiter

Friday

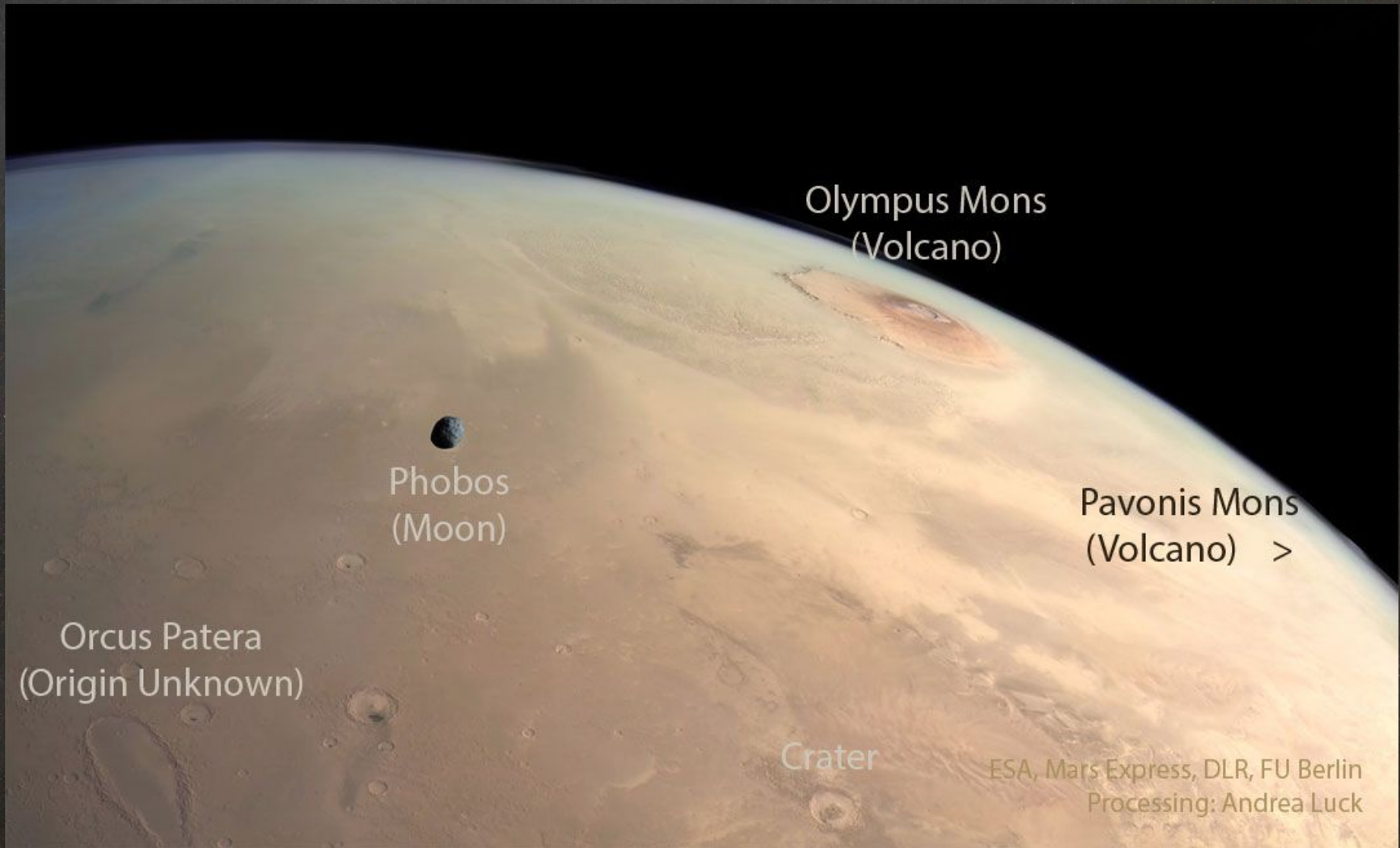


Venus

Saturday



Saturn



Orcus Patera
(Origin Unknown)

Phobos
(Moon)

Olympus Mons
(Volcano)

Pavonis Mons
(Volcano) >

Crater

ESA, Mars Express, DLR, FU Berlin
Processing: Andrea Luck

In-Class Small Group Assignment

1. Form groups of 3-4 students
2. Create a shared “Google Doc” and share it with your professors too (LAndres@BU.edu and Henebry@BU.edu)
3. Include the names of all students on your small team in the body of the document.
4. Create a Mars Calendar. **Be creative!!**
 - a. A day on Mars (called a “sol”) is 24 hours and 40 minutes
 - b. Mars goes around the sun in 668.6 days
 - c. The moons (Phobos and Deimos) take eight hours and 30 hours to travel around Mars. Our moon takes 27.3 days to Travel around the Earth.

Create Your Own Martian Calendar

- This is a situation we could run into if we ever colonize another world (Mars, for example)
- From the previous slides and your knowledge of our own calendar, you should realize there are multiple possible solutions to each situation, you choose which is best
- I will give the best grades to the most creative (see notes from Week 2 on Creativity and Design Principles)

Attempt to Satisfy These Criteria

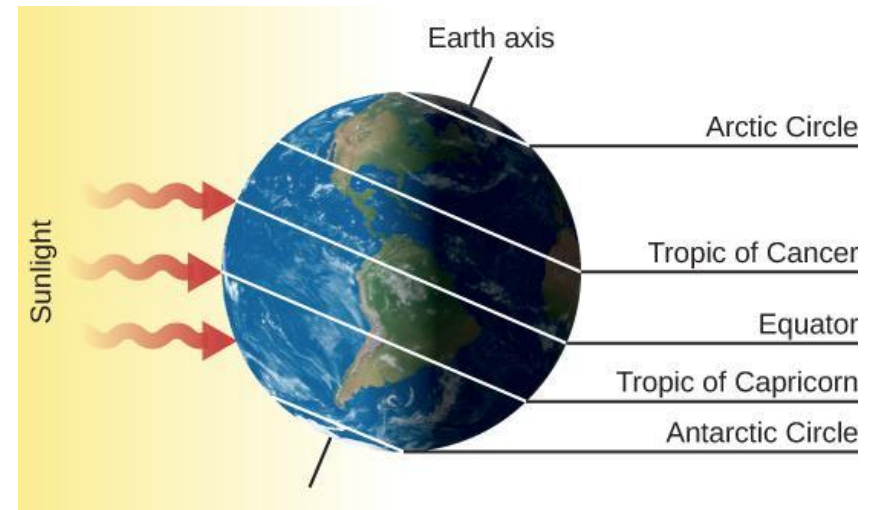
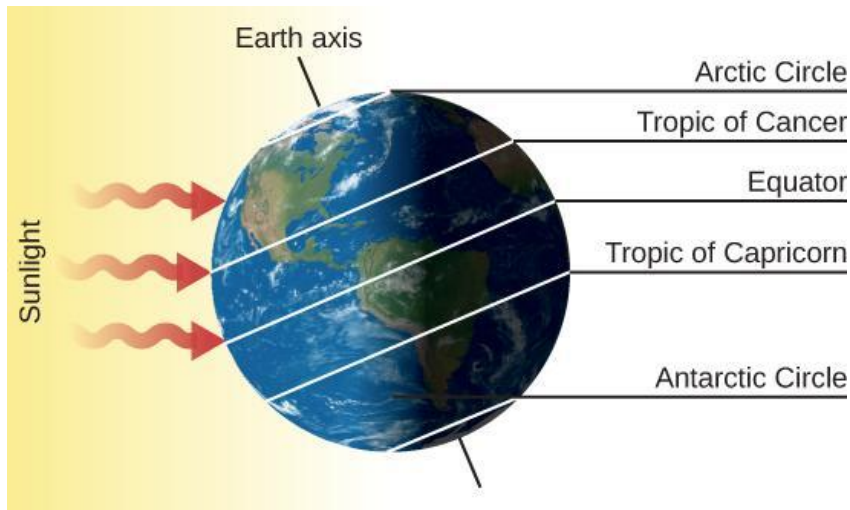
It would be convenient if the calendar met some criteria to match human comforts as well as possible. Your calendar will probably not satisfy all these conditions (neither does our own!).

- 1. Each day of the year has a place in your calendar. There are no extra or bonus days tacked onto the end of the year (like in the Egyptian example)**
- 2. The week has 7 days (like we are used to here on Earth)**
- 3. The months match your lunar cycle (this doesn't happen with our calendar)**
- 4. A whole number of weeks per month**
- 5. A whole number of weeks per year**
- 6. Number of months divides evenly into quarters (to mark the seasons)**

Seasons: Direct and Indirect Sunlight

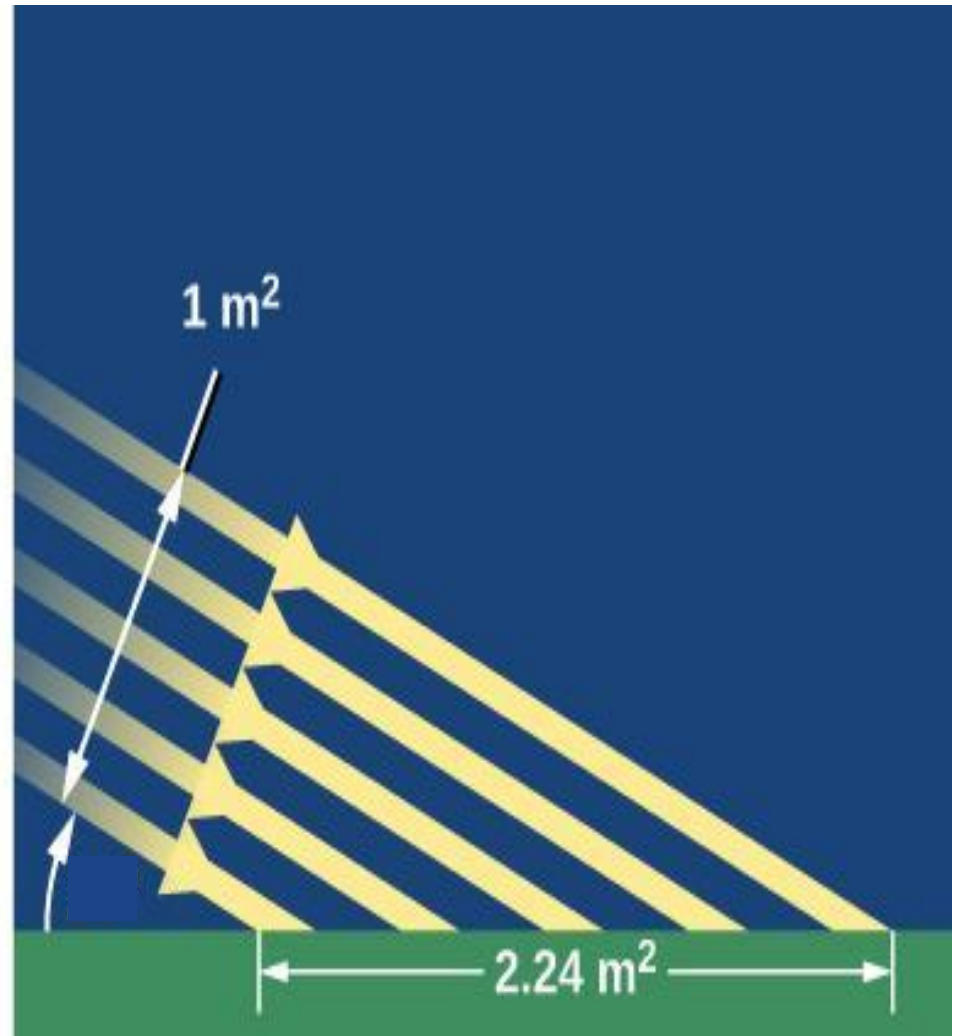
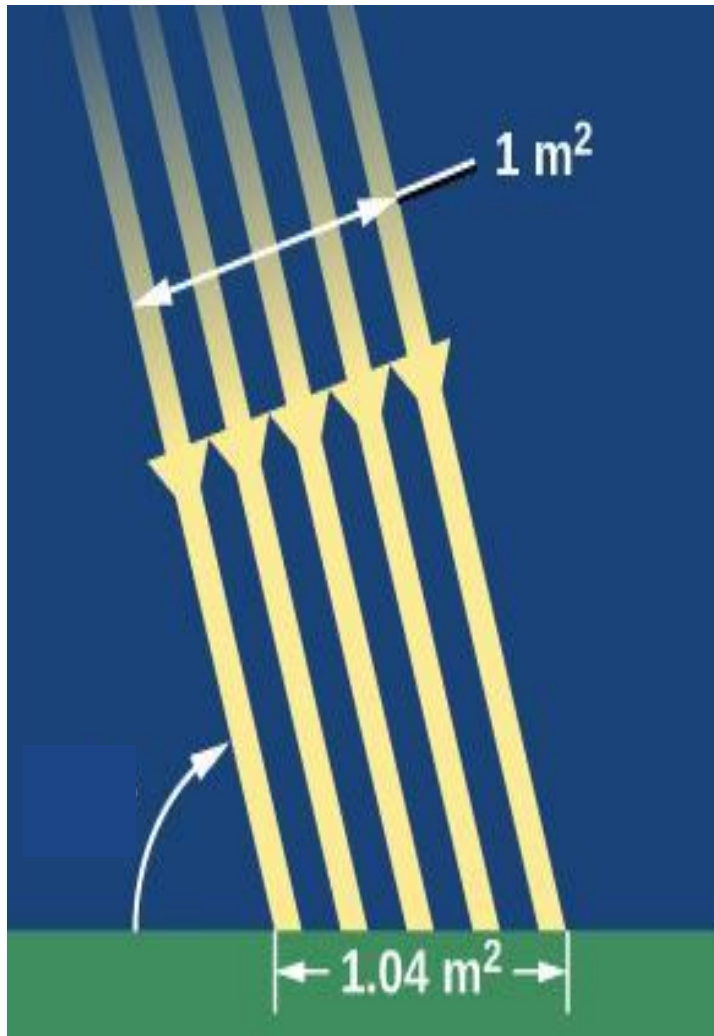
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The first main reason is based on how direct or indirect the sunlight is. One image shows the **summer solstice**, the other shows the **winter solstice**. See also next slide.



Seasons: Direct and Indirect Sunlight

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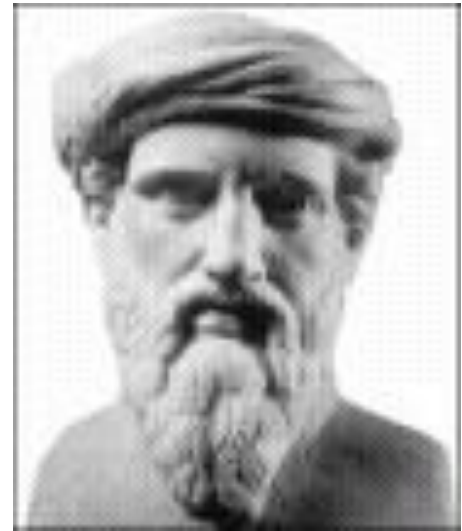
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Greek Astronomers

- **Pythagoras** (500 BC)
- Greek philosopher
- Believed that circles and spheres were “perfect” heavenly forms: thus the Earth must be a sphere (since the Earth was “obviously” at the center of the Universe).



Pre-Ptolemaic Astronomy

Anaximander (610-546 BCE)

- Student of Thales
- Propose Earth floats freely in space as opposed to floating on something, being supported
- A revolutionary idea that will be debated for 2000 years

Pythagoras (570-495 BCE)

- Earth is a sphere (preferred that shape, proposed the idea - See Aristotle)
- Everything moves in perfect circles
- Proposed mathematical perfection to the universe
- This “perfection” will constrain astronomers for 2000 years, until Kepler

Plato (428-348 BCE)

- His big idea/philosophy: The perfect forms underlie reality.
- Question: how can we explain the movements of the planets around to Earth using geometric principles (“Save the appearances with uniform circular motion”)



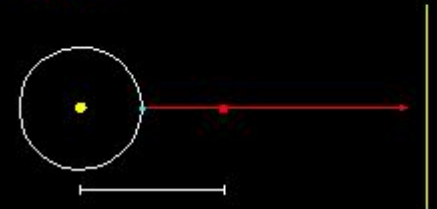
Pre-Ptolemaic Astronomy

Eudoxus (390-340 BCE)

- Student of Plato
- Solved the “Problem of the Planets” with 27 concentric spheres around the fixed Earth
- Did not account for the brightness changes of the planets



1998 Dec 31



Aristotle (384-322 BCE)

- Modifies Eudoxus to make 55 spheres
- Sublunar region: four elements (earth, water, air, fire), imperfect changeable
- Superlunar region: fifth element (aether, makes up entire realm); perfect, eternal, perfect shapes to “save the appearances”
- Earth is heaviest, so it falls to the center by nature
- Earth is a sphere (from curved shadow during lunar eclipse and ships hull disappears, while mast is still visible)

Aristarchus (310-230 BCE)

- Proposes heliocentrism, sun is much larger than earth, 1800 years before Copernicus, earth rotates daily on its axis and yearly around the sun
- Argument against (no stellar parallax observed, no wind or sense of motion)

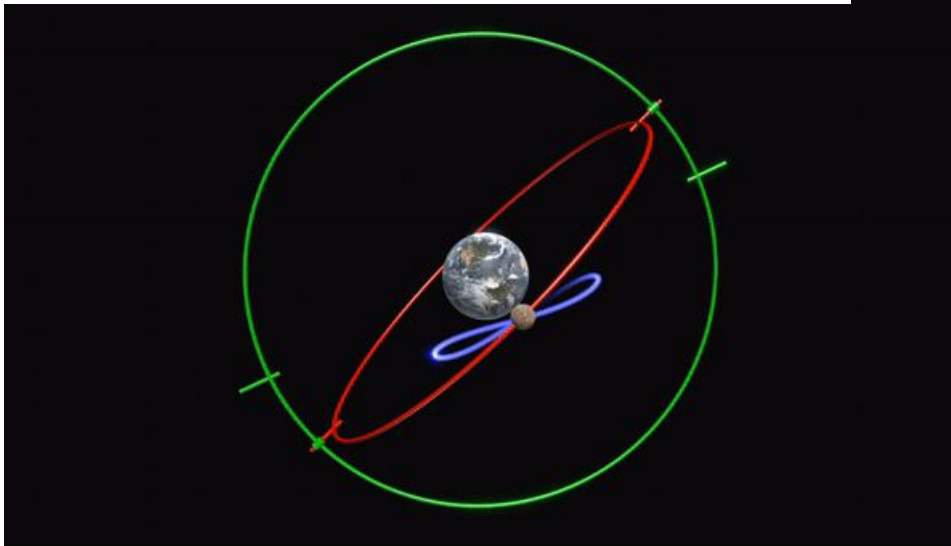
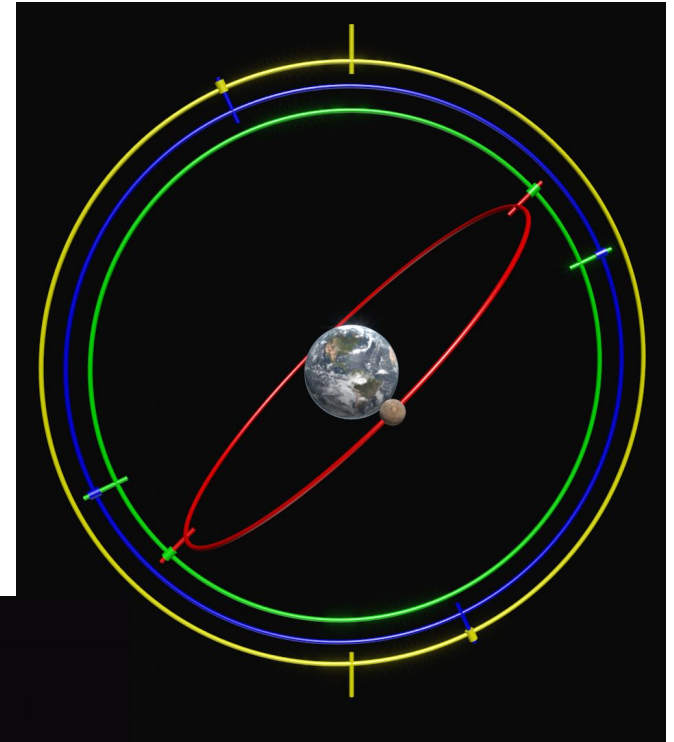
Greek Astronomers

Eudoxus (390-340 BC)

Student of Plato

The Moon and Sun have three spheres

Five planets have four spheres



Early Greek and Roman Cosmology

Things changed with the rudimentary invention of the principles of “science” in Miletus by Thales and his students, ~600 BCE. Our modern understanding of science requires having ***testable*** and ***verifiable*** ideas.

The Ancient Greek scholars (400s-100s BCE) knew more than we often give them credit for, and they did test their ideas against observations.

Aristotle



- Greek Philosopher (300 BC)
- Described evidence for spherical Earth (predicted by Pythagoras):
 - Lunar eclipse always showed curved shadow of Earth
 - Altitude of North Star changes as we travel north, suggesting Earth's surface is curved
 - As a ship sails over the horizon, we lose sight of the hull before the sail.



Early Greek and Roman Cosmology

24

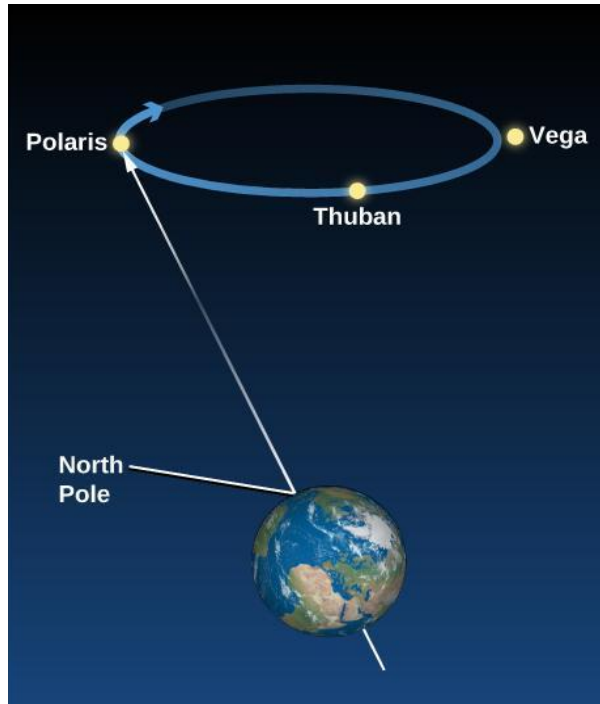
1) Ancient Greek scholars knew the Earth was round.

Aristotle notes two main reasons:

The **circular** shadow of the Earth during a lunar eclipse.



Early Greek and Roman Cosmology



Ancient Greek astronomers knew that the Earth's tilt “wobbled.”

Hipparchus (190-120 BC) cataloged stars and their brightnesses, and when he compared to earlier data he realized that Polaris has not always been the “North Star.”

The change was due to a 26,000 year cyclical motion called **precession**.

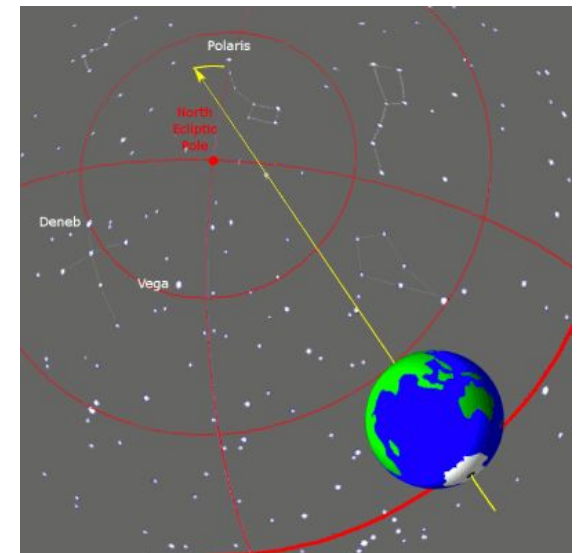
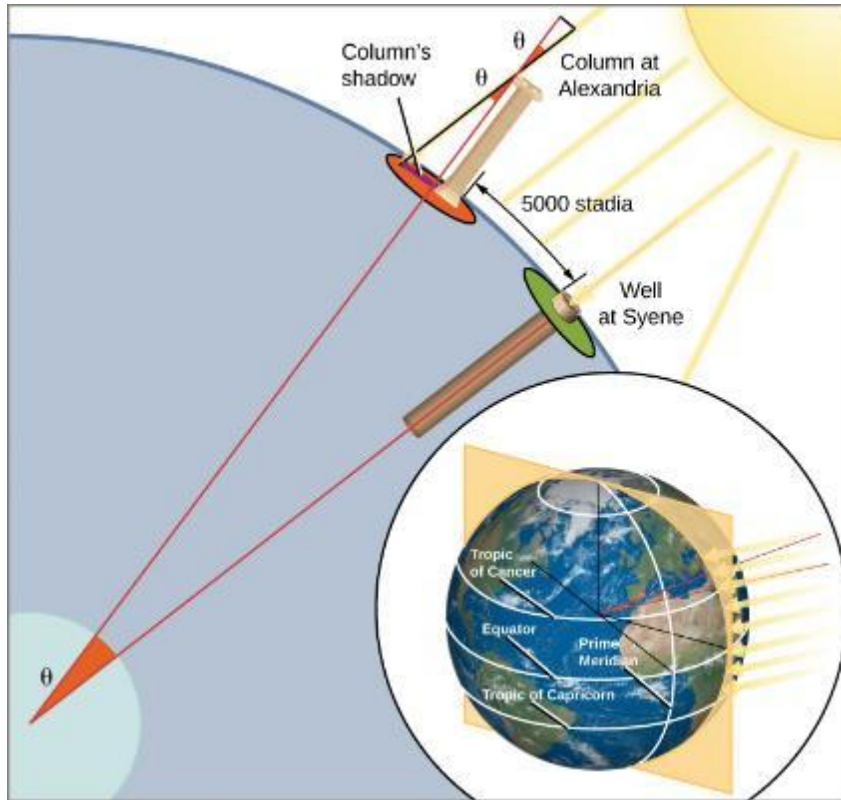


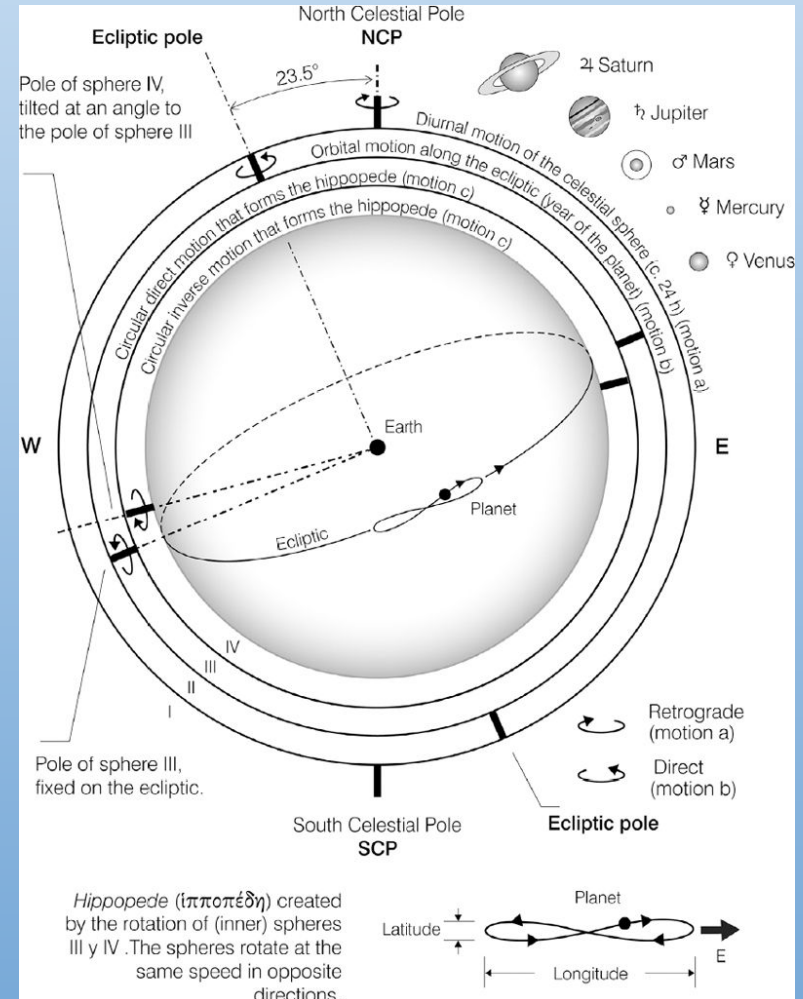
FIGURE 2.11



How Eratosthenes Measured the Size of Earth. Eratosthenes measured the size of Earth by observing the angle at which the Sun's rays hit our planet's surface. The Sun's rays come in parallel, but because Earth's surface curves, a ray at Syene comes straight down whereas a ray at Alexandria makes an angle of 7° with the vertical. That means, in effect, that at Alexandria, Earth's surface has curved away from Syene by 7° of 360° , or $1/50$ of a full circle. Thus, the distance between the two cities must be $1/50$ the circumference of Earth. (credit: modification of work by NOAA Ocean Service Education)

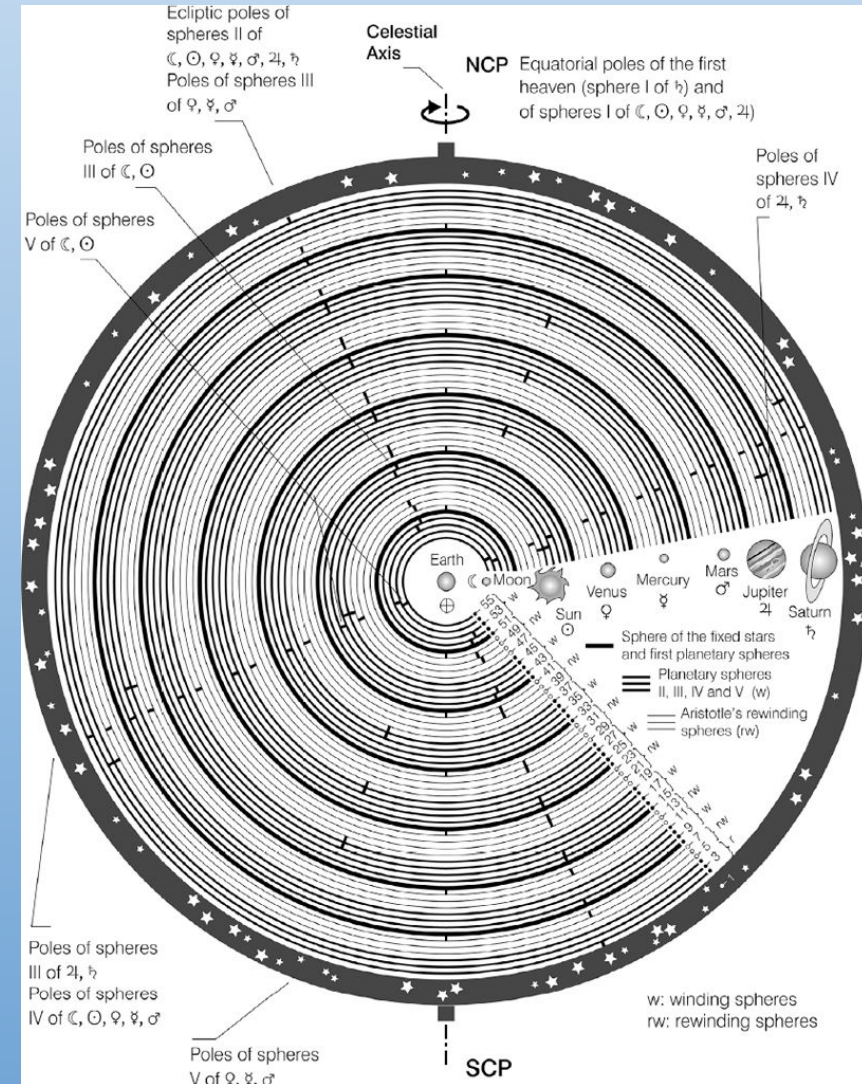
The Eudoxus-Aristotle system for the Planets

- In the system of Eudoxus, extended by Aristotle, the planets were the visible dots embedded on nested rotating spherical shells, centered on the Earth.



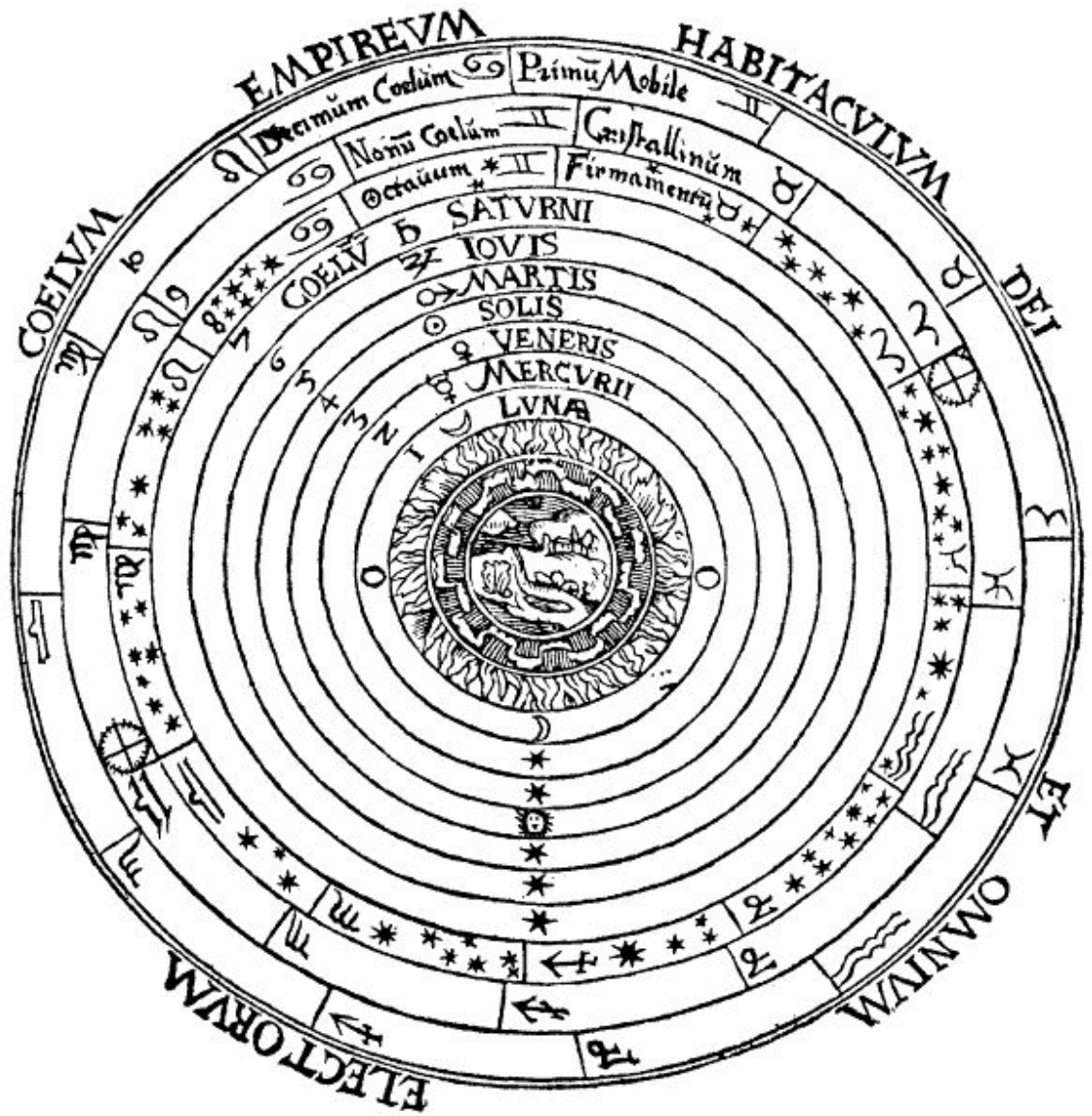
The Eudoxus-Aristotle system for the Planets

- The motions of the visible planet were the result of combinations of circular motions of the spherical shells.
 - For Eudoxus, these may have just been geometric, i.e. abstract, paths.
 - For Aristotle the spherical shells were real physical objects, made of the fifth element.



celum emireum
habitaculum
dei et omnium
electorum

The Empyrean (place of
the highest heaven, filled
with fire or ether) of God
and the Elect
(Christian Synthesis)

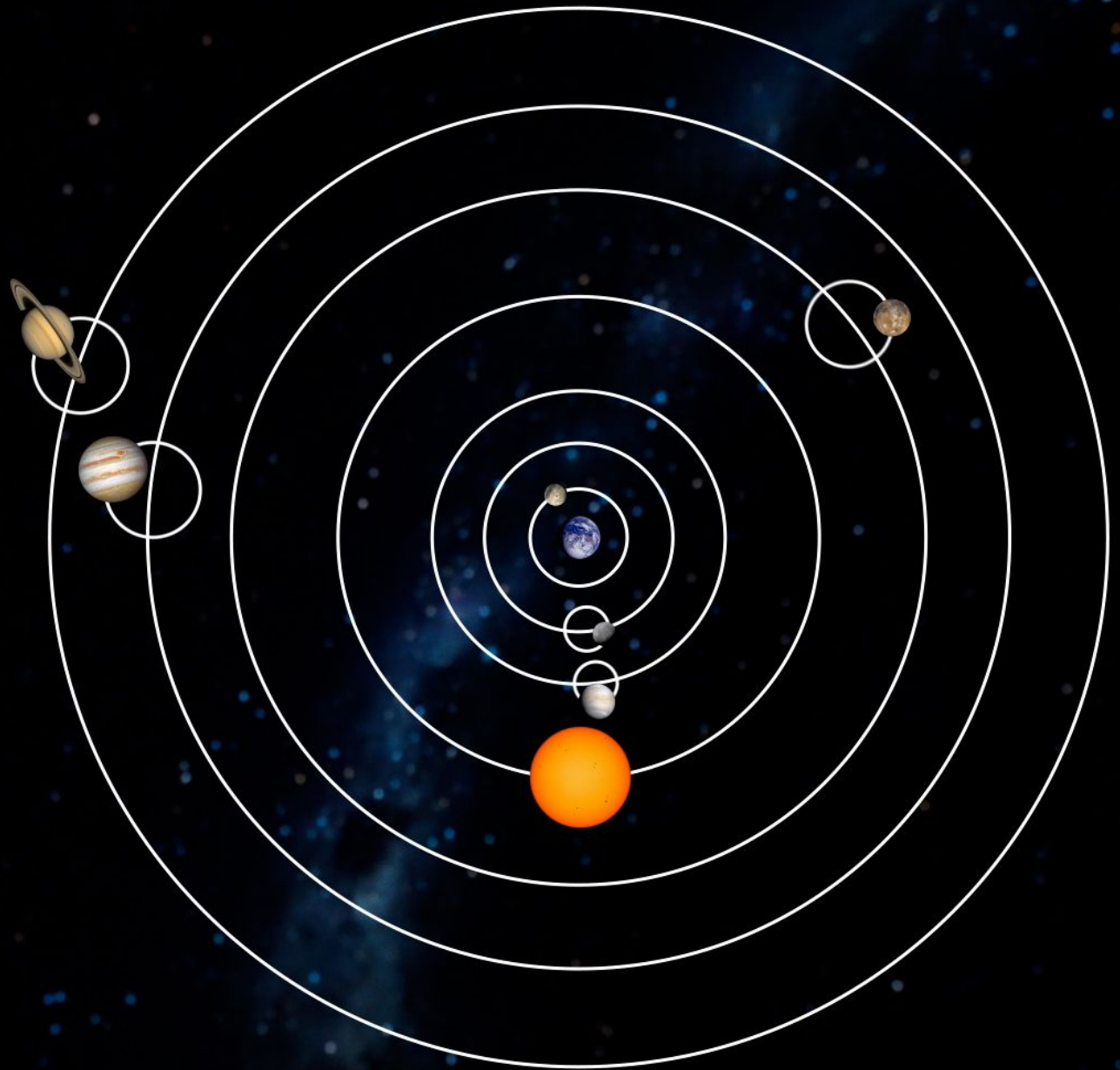


Aristotelian Cosmos

Ptolemy of Alexandria

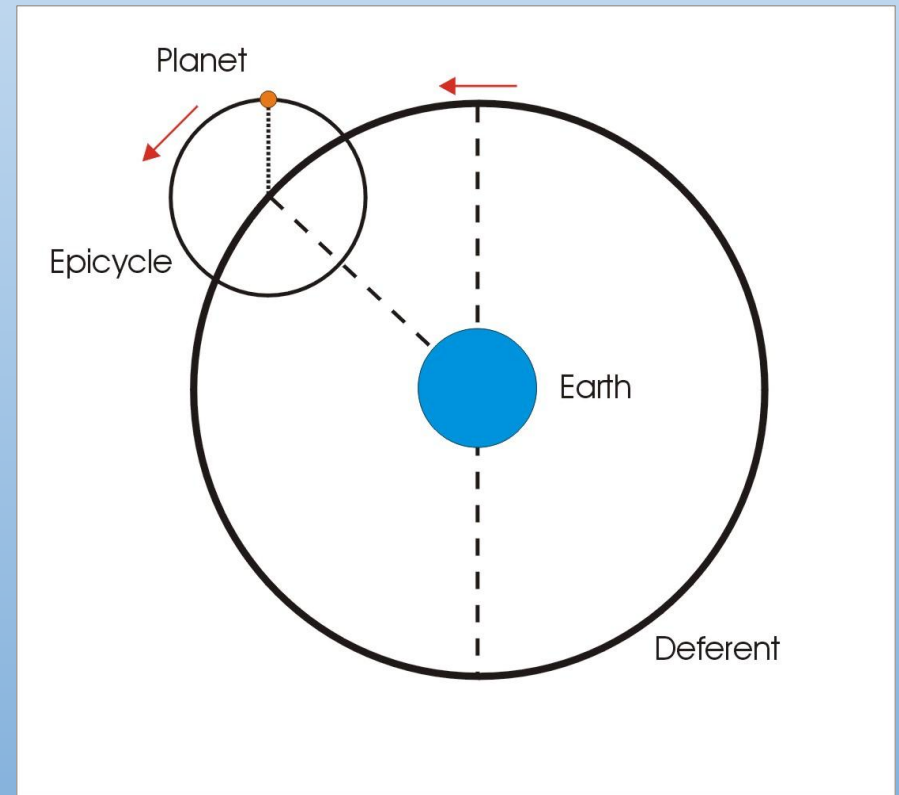


150 CE

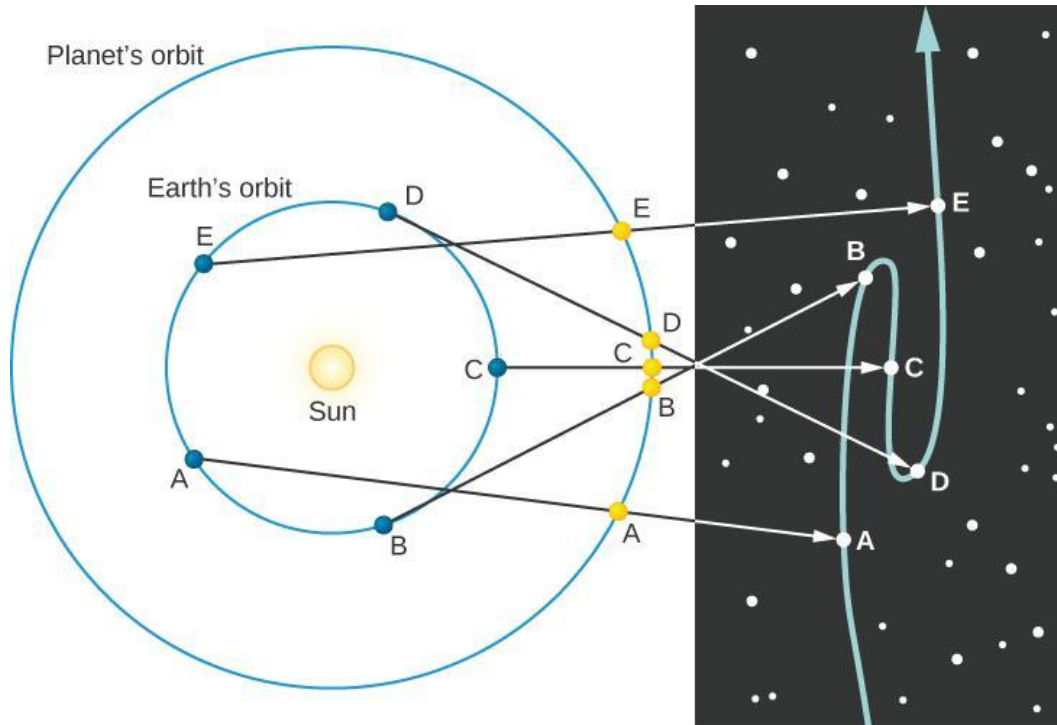


Epicycles and Deferents

- Ptolemy's system for each planet involves a large (imaginary) circle around the Earth, called the **deferent**, on which revolves a smaller circle, the **epicycle**.
- The visible planet sits on the edge of the epicycle.
- Both deferent and epicycle revolve in the same direction.



Ptolemy's Model (authority for over 1000 years)

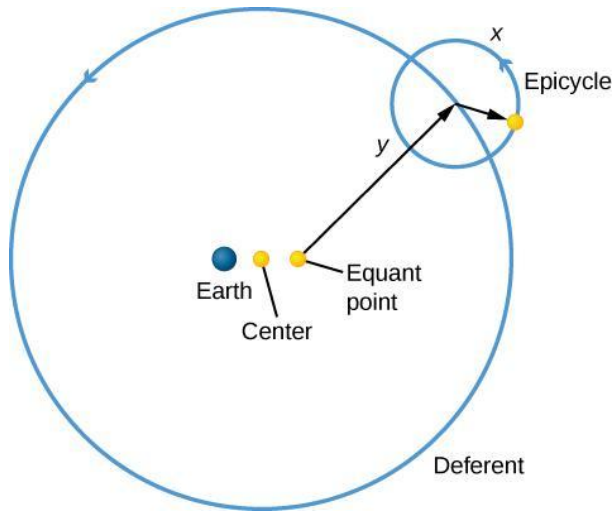


Some of the known planets seem to move **backwards** through the sky. This is called **retrograde motion**, and it occurs when we “catch up and pass” a slower planet.

[Planetary Motion Simulator](#)

Ptolemy's Model (authority for 1400 years)

The way to deal with this motion in a geocentric idea was to create additional circles. **Ptolemy** added these circles, called **epicycles**.



Ptolemy's epicycles were “circles on circles.” This model lasted for 1000 years and was eventually accepted as authoritative (unquestionable truth) in Christian Europe.

[Ptolemaic Simulation](#)

FIGURE 2.16

Nicolaus Copernicus (1473–1543).

Copernicus was a cleric and scientist who played a leading role in the emergence of modern science. Although he could not prove that Earth revolves about the Sun, he presented such compelling arguments for this idea that he turned the tide of cosmological thought and laid the foundations upon which Galileo and Kepler so effectively built in the following century.

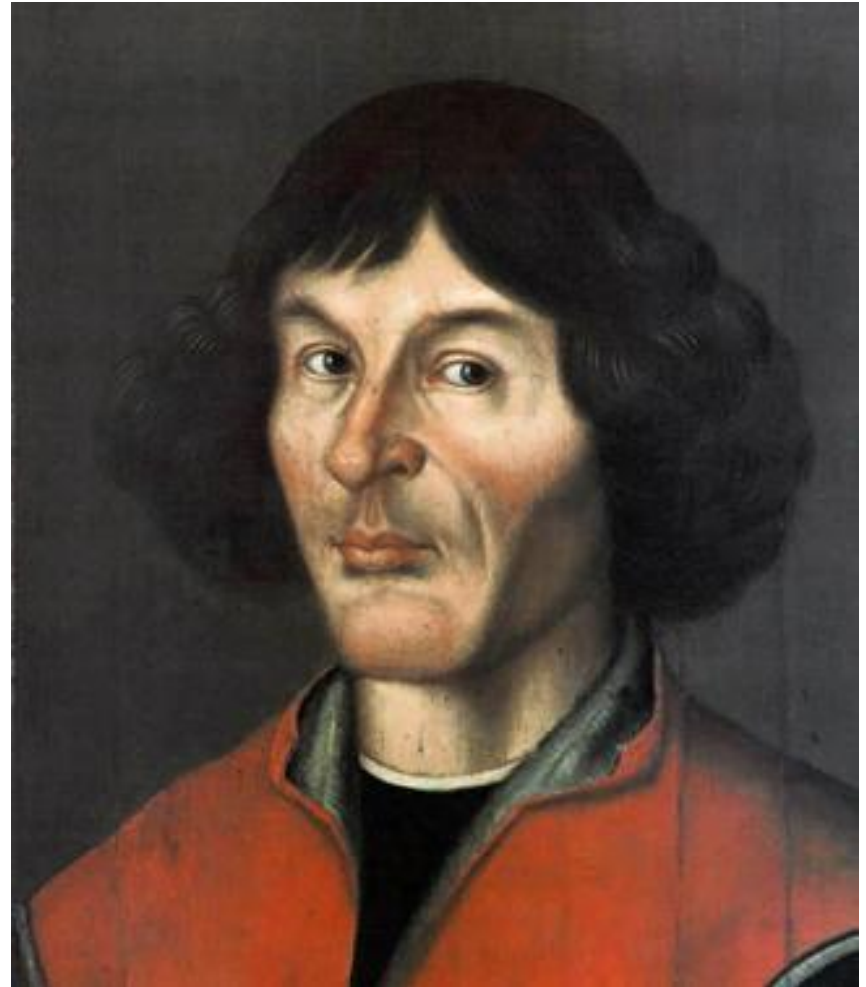
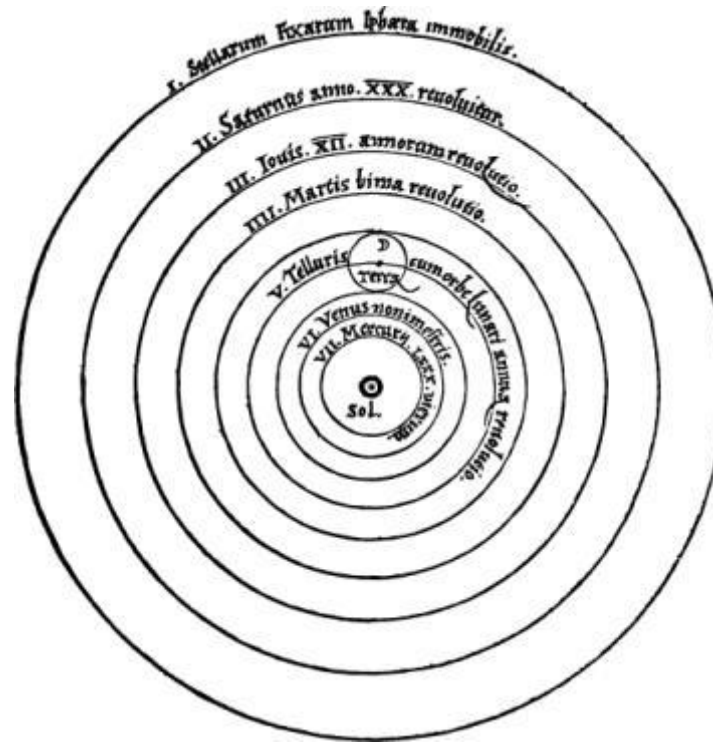


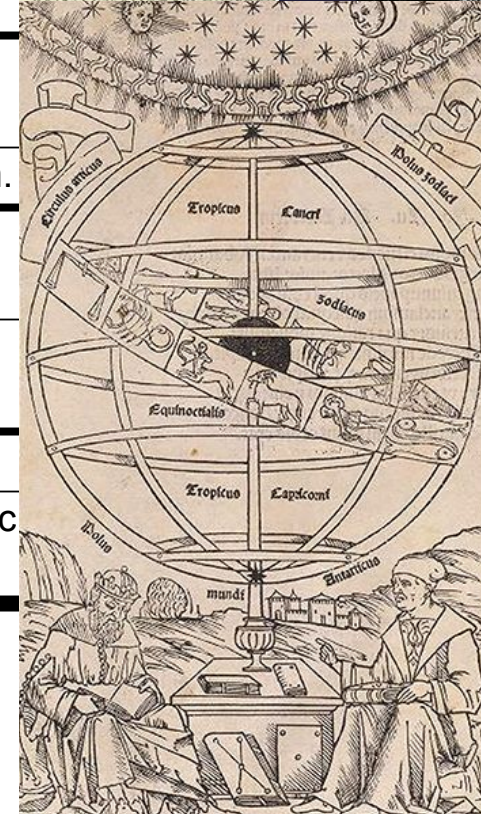
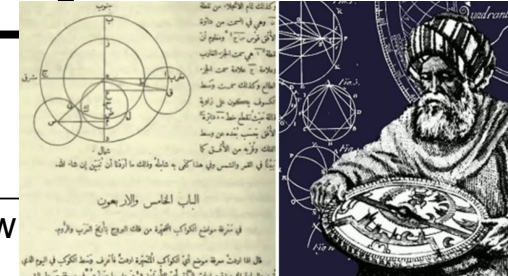
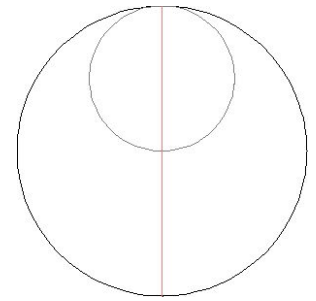
FIGURE 2.17



Copernicus' System. Copernicus developed a heliocentric plan of the solar system. This system was published in the first edition of *De Revolutionibus Orbium Coelestium*. Notice the word *Sol* for "Sun" in the middle. (credit: Nicolai Copernici)

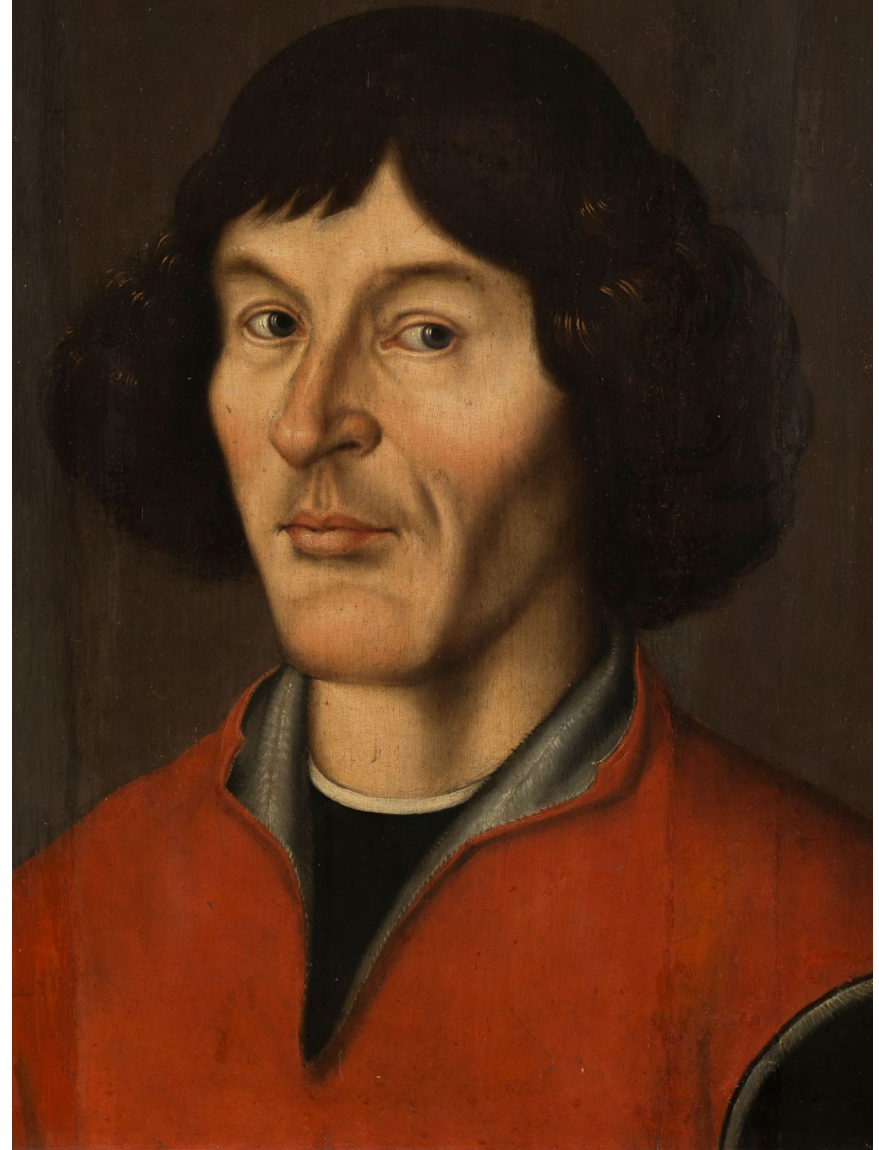
Period	Key Development	People and Contribution
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c. 150 CE	Synthesis	Ptolemy
		Geocentric model codified in the <i>*Almagest*</i> .
9th-13th C.	Islamic Golden Era: Preservation & Critique	Al-Battani, Ibn al-Haytham, Al-Tusi, Ibn al-Shatir
		Refined data, criticized physical models, created new devices (Tusi-couple).
12th-13th C.	Translation	European Translators
		Ptolemy's refined work returned to Europe via Latin.
15th Century	Renewed Scrutiny	Peuerbach & Regiomontanus
		Produced mathematical and widely read textbook critique of the <i>Almagest</i> .
1543	Revolution	Nicolaus Copernicus
		Published <i>De revolutionibus</i> , proposing a heliocentric universe and igniting the Scientific Revolution.



Copernicus (1473-1543)

- Polish doctor, lawyer, mathematician, and amateur astronomer
- Sought simpler model
- Solution: Heliocentric – or sun-centered – model, but the model lacked evidence
- Published outline of ideas first in 1514 (“Little Commentary”)



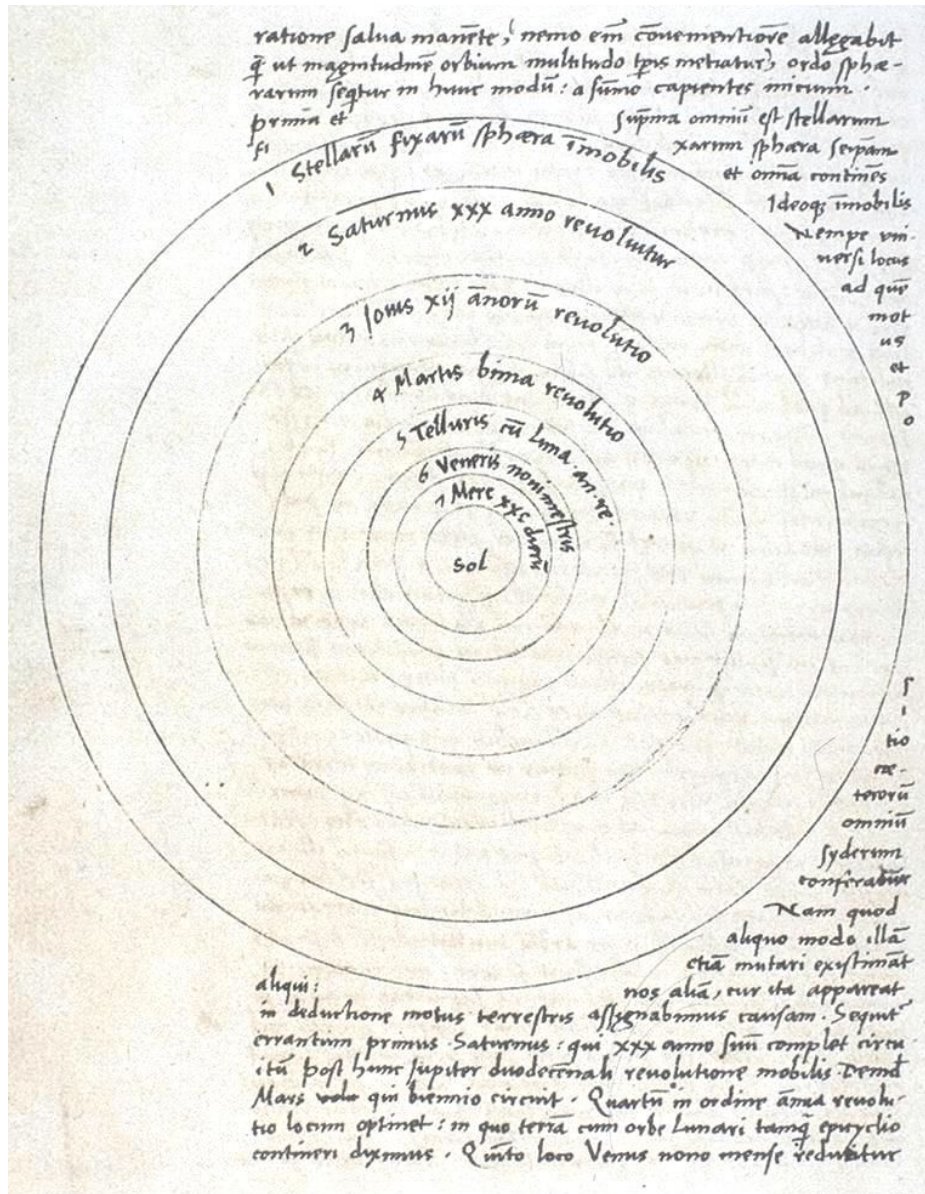
The Path to Revolution: Copernicus

- Published heliocentric model in *De revolutionibus orbium coelestium* (On the Revolutions of the Heavenly Spheres)



Astronomer Copernicus, or Conversations with God by Jan Matejko (1873)

The Path to Revolution: Copernicus



Astronomer Copernicus, or Conversations with God by Jan Matejko (1873)