Give us matter, and a little motion, and we will construct the universe.
Ralph Waldo Emerson

Circles on Circles

You're here, I'm here. In this module we'll look into why modern science -- not just astronomy,-- traces its roots to the Greeks and how the Greeks explain planetary motion.

So why does modern science generally trace its roots to the Greeks? Well, it wasn't like people all across the globe from all different cultures weren't scratching their heads, and looking up at the night sky, and trying to figure out what was going on. All cultures did that. But the Greeks were the first to develop logical and mathematical models that nature and emphasize the importance of having those models make predictions which agreed with observations. And this was unique. This had never happened before across cultures, across time, across the world. So that idea that you should have a mathematical, logical model that can be tested, that can be falsified is really the essence of the scientific process. And hence, this is generally why science traces its roots back to the Greeks. The Greeks used this idea of logical and mathematical models to make many discoveries, some of which are listed in that table below. Some we've already covered, like precession. We'll only going to cover one new one now.

Observation	Inference	Observer
Curved lunar terminator	Moon is a sphere	Pythagoreans
Round shadows during lunar eclipse	Earth is a sphere	Pythagoreans
Crescent phases of Moon	Moon between Earth and Sun	Aristotle
Different stars at zenith at different locations	Earth is a sphere	Aristotle
No stellar parallax	Distance Earth moves is small compared to the distance to stars	Aristotle
Relative sizes and angles of Moon's and Earth's shadow	Moon smaller than Earth; Sun bigger than Earth	Aristarcus
Angle from 1rst to 3rd quarter moons less than 180°	Sun 10 times farther from Earth than Moon	Aristarcus
Agular shift of zenith and linear distance on Earth	Circumference of Earth	Eratosthenes
North celestial pole shift with respect to constellations	Precession	Hipparchus

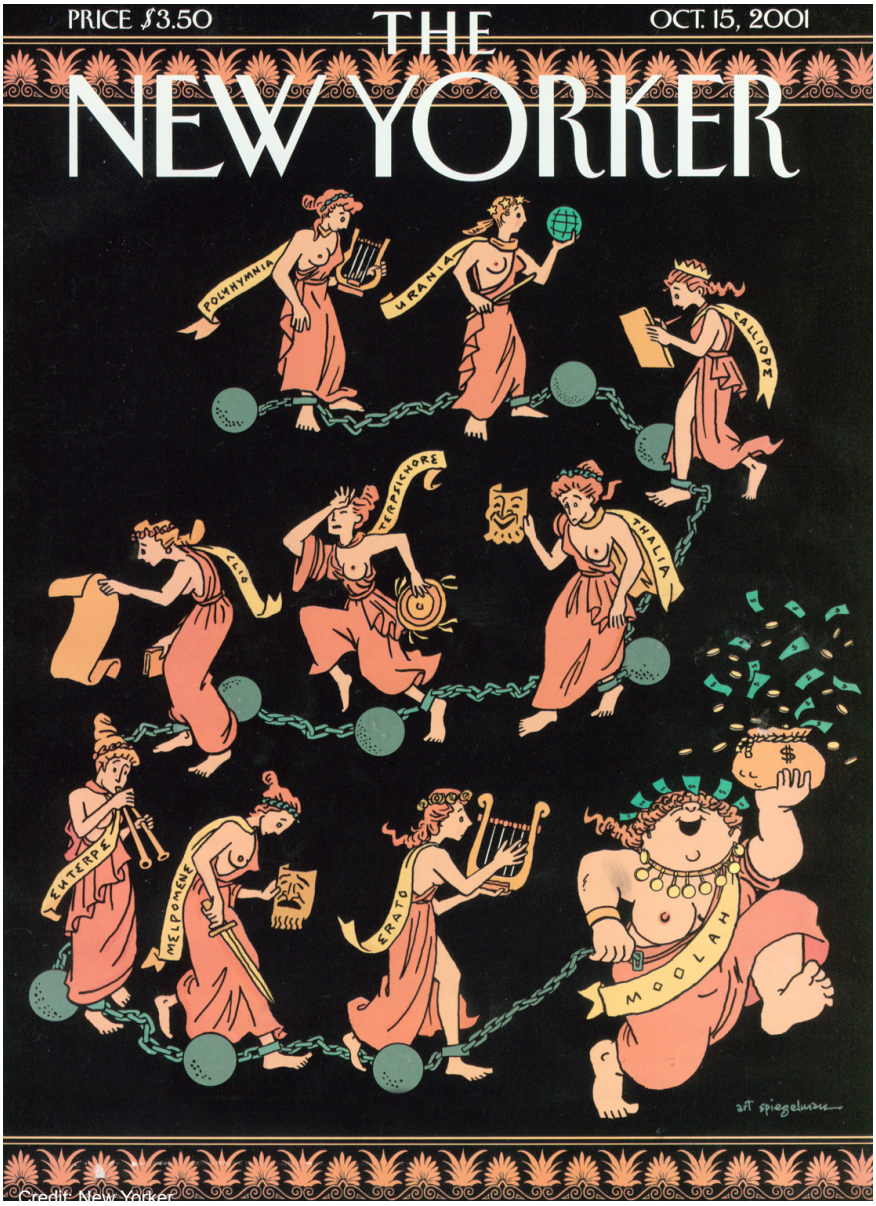
Credit:Wikipedia public domain

The Pythagoreans noticed that if you took a look at the Moon, and you looked at the terminator, that difference between white and the dark areas, it's not a straight line. It's curved. And so, the Pythagoreans reasoned that the only way it could be curved is if, well, either at the moon was a two-dimensional circle, which is silly, or a three-dimensional sphere. And so, the Greeks knew that the Moon was a round sphere.

Similarly for the Earth. During eclipses, because of the shape of the shadows cast, you could logically argue that the Earth was round. The Earth has been known to be a sphere since the Greeks. So the story about Columbus, and people worried about how the Earth was flat and he might fall off the flat edge of the Earth, that's all silly. I'm sure some people believed it, but in general, it had been known since the Greeks, certainly among learned people and absolutely known to the people putting money into Columbus's expedition knew that the Earth was round. There wasn't going to be any falling off.

It was in Alexandria, which was the center of Greek culture, that the idea of a state supported library -- it's not like a library that we think like today, that was sort of the genesis of the university, but they called it a library -- it was dedicated to the study of the muses. And those nine muses that they studied were poetry, both epic and lyrical, music, both secular and religious, drama, comedy and tragedy, dance, history, and astronomy.

Below is a whimsical image where you have the nine muses. And the muse of astronomy, by the way, is Urania, and she's up at the upper partof the figure. And all of the muses are chained following the great Moolah, which is probably true. Alexandria was a state supported institution, as it is today where public universities are generally state supported, but in some cases privately funded. But the idea of starting a place where people would study the muses was established in Alexandria.



Credit: New Yorker

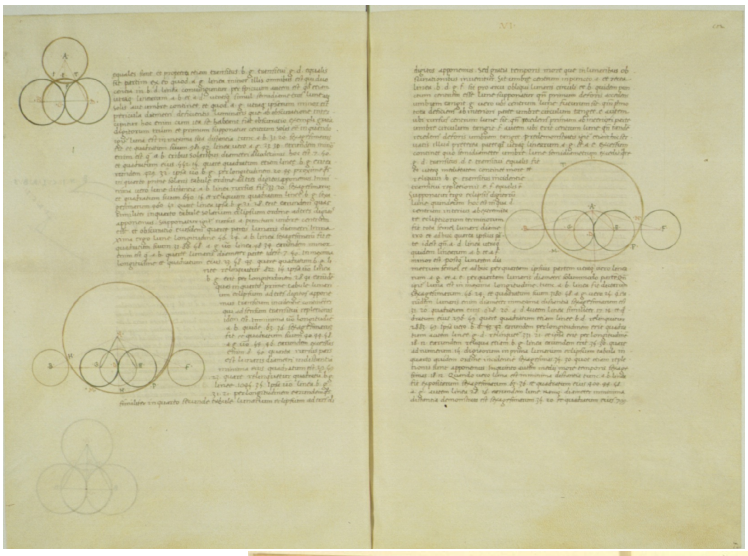
So in Alexandria around 200 BCE a character by the name Ptolemy synthesized all of known astronomy, in particular Greek astronomy, into 13 books that he called the Great Composition. The image there-- nobody knows what Ptolemy looked like, so all the renditions like the one image below that you see of him are going to be taking artistic liberty.

In the Great Composition, Ptolemy organized astronomy into a practical, do-it-yourself recipe book for astronomy. How do you tell directions, how to you tell time, how do you tell when eclipses are going to happen, how do you tell when retrograde motion is going to happen, how do you explain retrograde motion? All this in a very practical, do-it-yourself survival guide.

Credit: van Gent Joos, public domain

This model, the Greek model of putting the Earth at the center, was wildly successful because it worked. You could predict stuff, and it matched observations. The fundamental basis of science. This model lasted for about 1,700 until another character — Copernicus — came along. More on him later.

The Great Composition was penned way back when, and certainly there had been several wars and upheavals throughout history. The Greeks were overthrown by the Arabs when they invaded, but they recognized the value of these 13 books, that it was a summary of all known astronomy from the Babylonians on up to the Greeks. They translated them into Arabic where it became known as Al Magisti. Later, when the Romans took over, they also recognized the value of the books, and it got translated again into Latin where it became known as the Almagest.

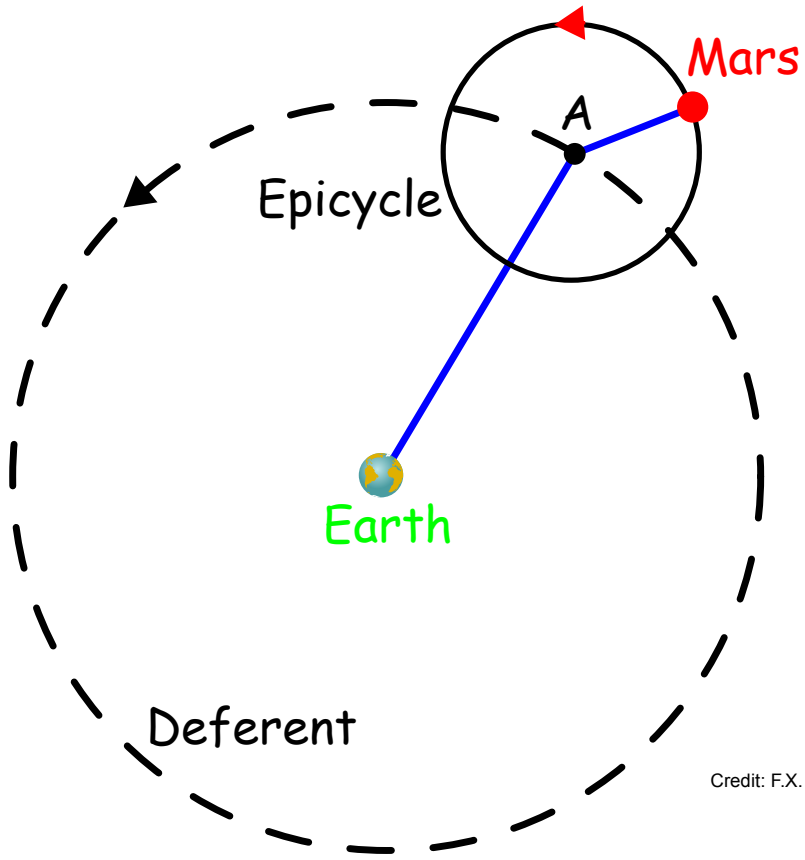


Greek

Arabic

Latin

So this is how we know about Babylonian astronomy, about Greek astronomy, through these various translations into different languages across time. It must have had immediate value for such effort to go into preservation.



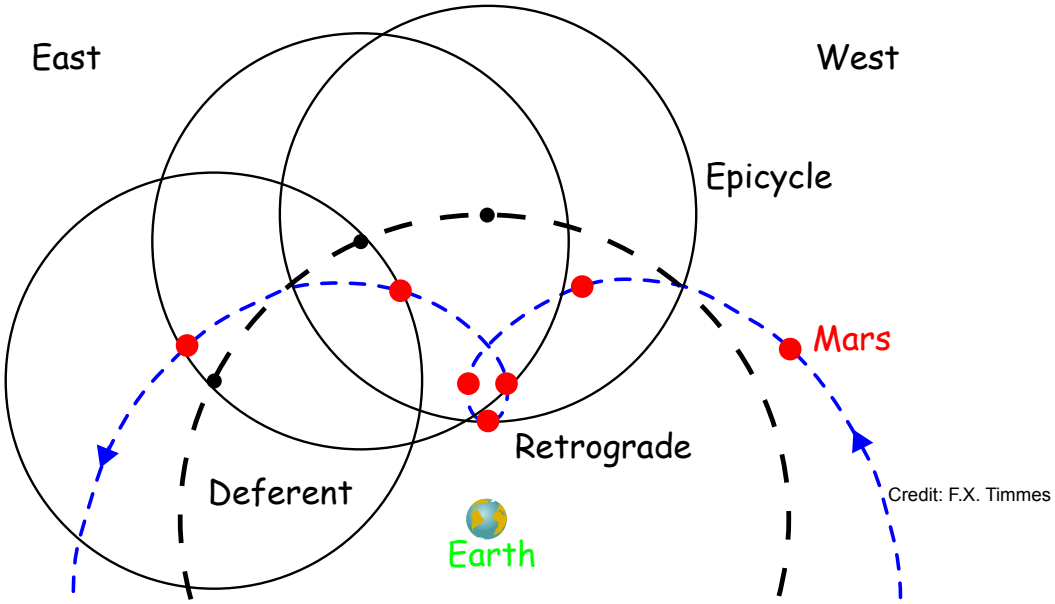
Credit: F.X. Timmes

In order to explain the biggest mystery, why the planets go backwards and when they're brighter when they go backwards, Ptolemy introduced the idea of what is called the deferent epicycles. That's kind of jargon, so you can just say it's circles on circles

You have the Earth at the center, and then you have a big circle, which is referred to as the deferent. And then you have a little circle, which is called the epicycle, so it's circles on circles.

Both circles can rotate uniformly, but you can change the rotation rate, and you can change the rotation direction. And of course, you can change the different sizes of the circles depending on what you need.

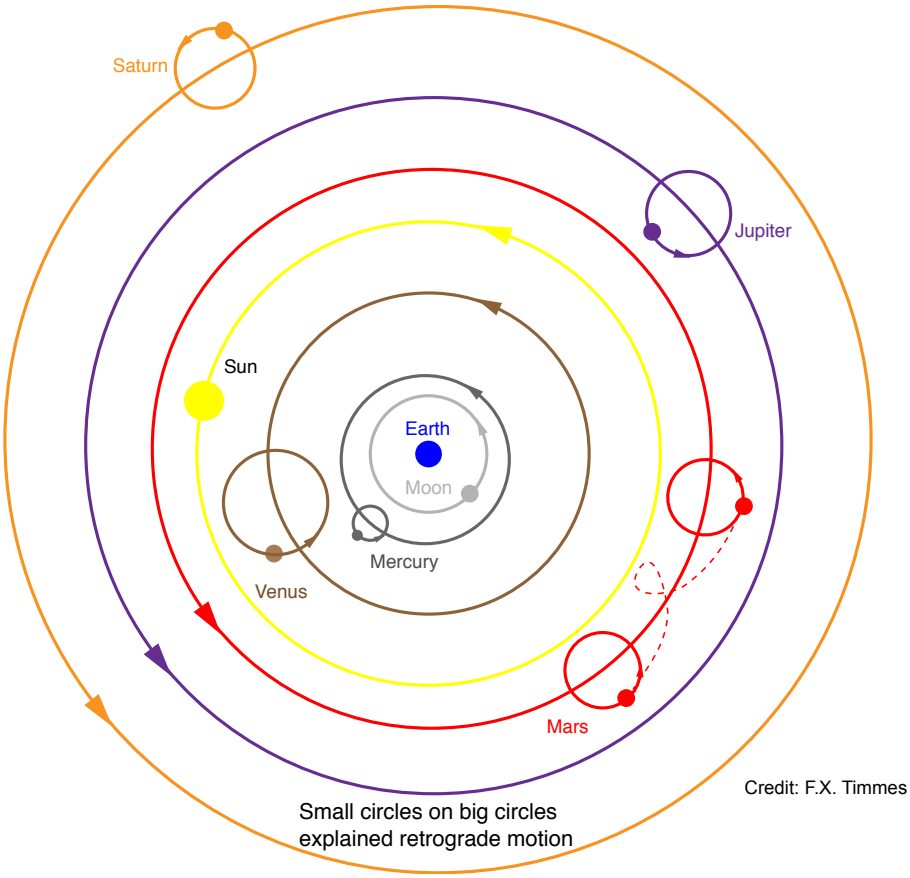
It's a very powerful technique. By adding circles on circles on circles, you can create orbits of any shape, even square if that's what you observed. So it's a very powerful technique on how to carve out orbits.



By arranging the rotation rate and the size of the circles, Ptolemy could make a planet undergo retrograde motion. The image tabove is showing Earth at the center, and it shows the large circle. And then as Mars goes around the large circle, but also goes around its small circle, you arrange it such that to Earth, as the dotted line shows there, Mars goes backwards.

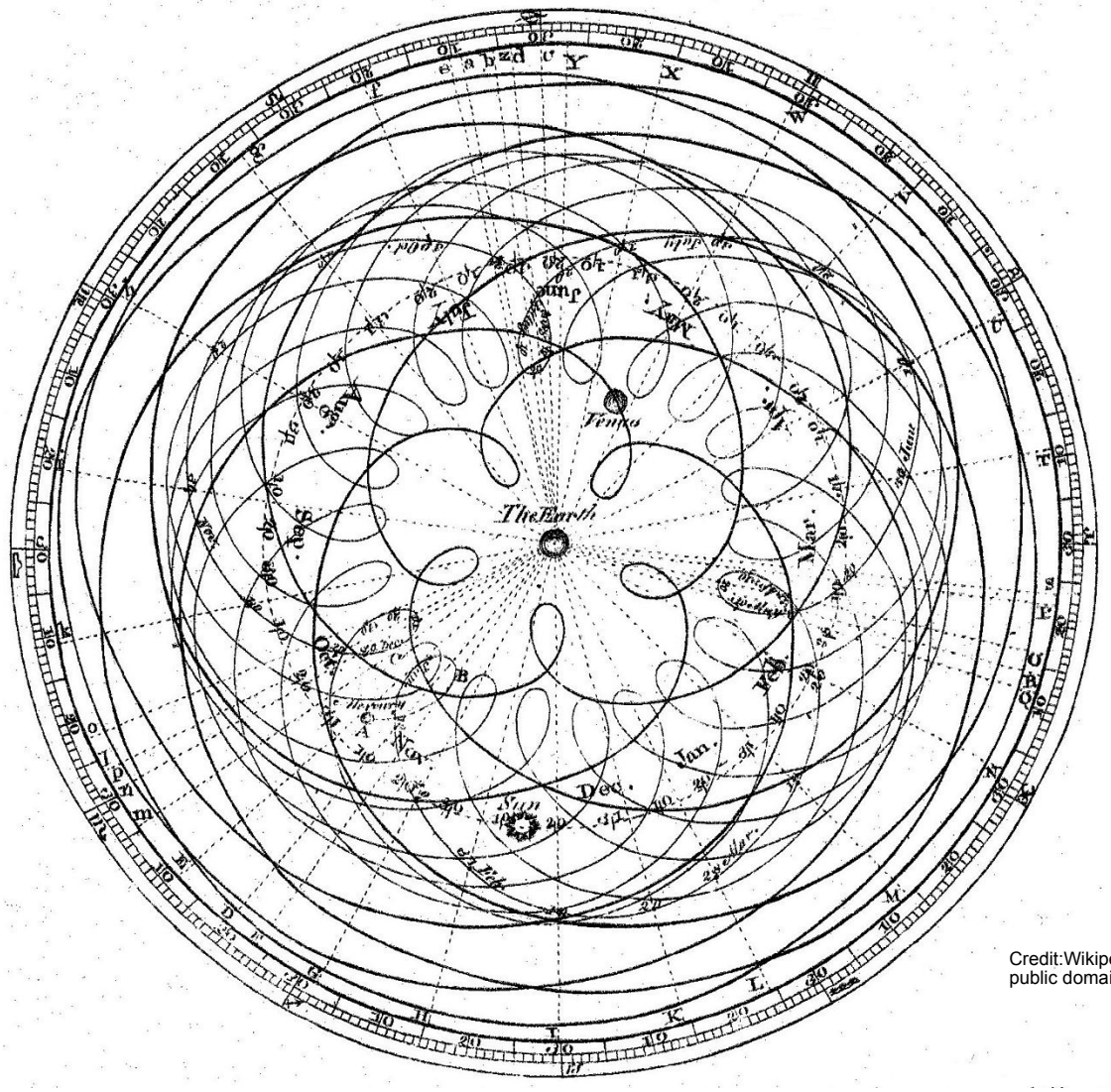
And not only that, MegaBonus, why is it brighter when it goes backwards? It's brighter because it's closer Earth. If something is a certain brightness, and the closer it gets to you, it gets brighter. The farther away, the dimmer it is. So this was an amazing construction in that you could get retrograde motion and it would be brighter at the same time.

And in the geocentric model of the solar system, Ptolemy's model, this motion is real. It is physical. So the Greeks thought that this retrograde motion was an actual, physical motion that the planets underwent.



This cosmology, the geocentric cosmology of the Greeks shown above, was wildly successful. It lasted 1,700 years because it worked. You have Earth at the center, followed by the Sun, followed by Mercury. And note the small circle, so you've got the big circle and the little circle. Epicycle deferent. Then you've got Venus, then you've got the Sun, then you've got Mars, Jupiter, and Saturn as it goes on out. The other planets-- Uranus, Neptune-- those were much too distant to be measured by the Greeks.

This model gave some interesting total motions, for example Venus and Mars:



Credit:Wikipedia
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Thanks. Bye Bye!