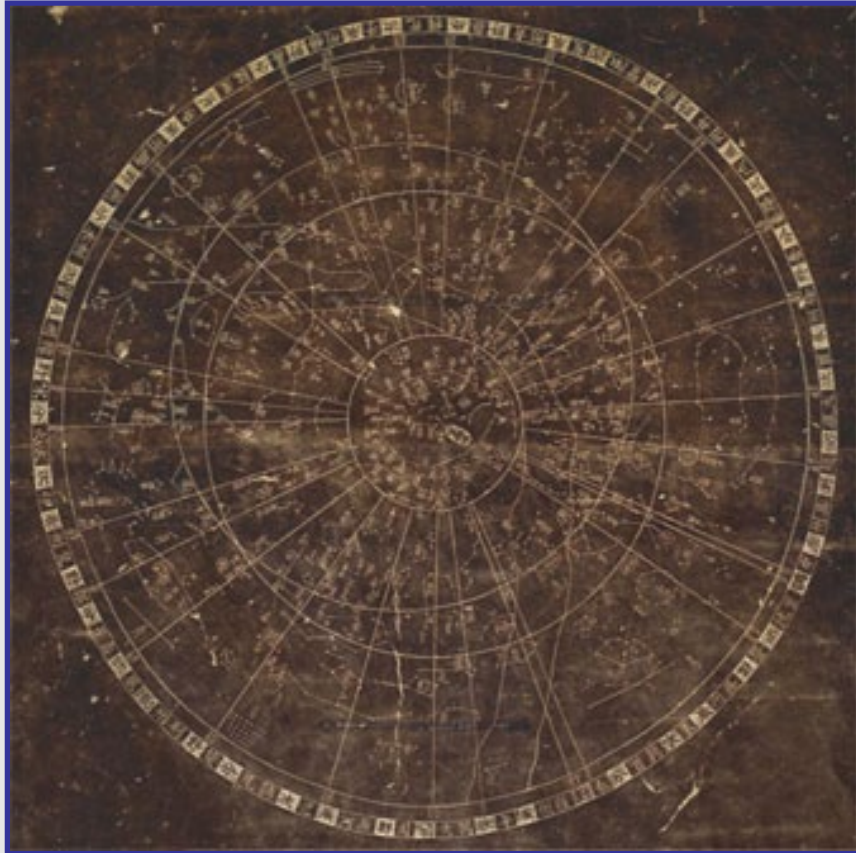


Cosmología y simbolismo

Las cosmologías ubicaban la sociedad y su entorno en el universo. Todas las cosas adquirirían un lugar y un sentido, y se entrelazaban en un profundo simbolismo. Los mitos contaban que al inicio de los tiempos, los creadores dieron a la gente lo necesario para la vida.

Cosmologies gave society and its surroundings a place in the universe. All things acquired a location and a meaning, and they were interwoven in a deep symbolism. According to myths, at the beginning of time the creators gave people all they needed for living.

Cosmology through the ages...



Universe models formed in many cultures

2nd Century: Claudius Ptolemy (**Physics of Aristotle**)

Model: Earth-centered Cosmology

Big Idea: Different laws for Earth and the cosmos

Existing since at least Eudoxus of Cnidus

16th Century: Nicolaus Copernicus (**Physics of Newton**)

Model: Sun-centered Cosmology

Big Idea: Universal physics; same laws everywhere

Predecessor: Aristarchus of Samos (310 – c. 230 BC)

20th Century: Hubble-Lemaître (**Physics of Einstein**)

Model: Big Bang Cosmology

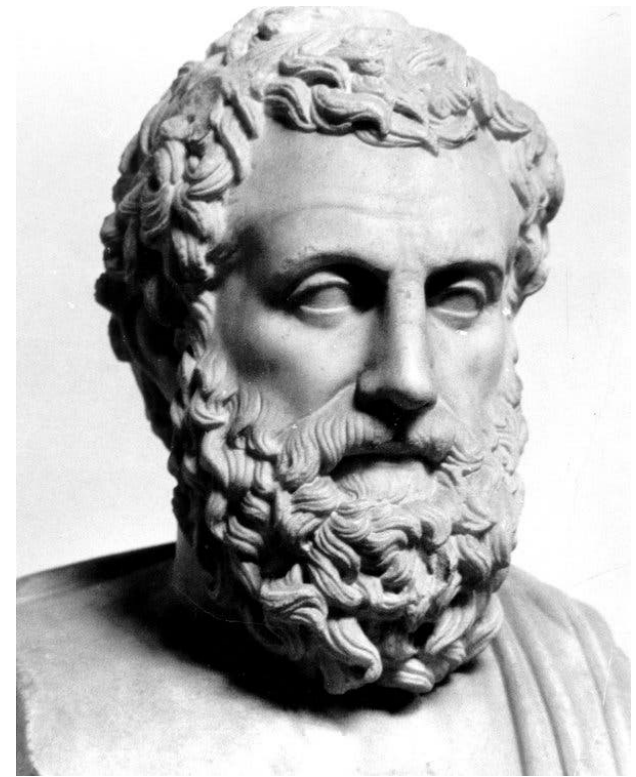
Big Idea: Universe is changing, evolving

La astronomía en el mundo greco-romano

(s. IV a.C.— s. XVI)

Basada en la **física de Aristóteles** (384-322 a.C.):
las leyes del Cosmos y de la Tierra son diferentes:

- Lugares naturales: cada elemento querría estar en una posición distinta relativa al centro de la **Tierra, centro del Universo.**
- Gravedad/levedad: para lograr esta posición, los objetos sienten una fuerza hacia arriba o hacia abajo.
- Movimiento rectilíneo a velocidad constante como respuesta a esta fuerza
- La velocidad es inversamente proporcional a la densidad del medio.
- El vacío es imposible de imaginar: el movimiento en un vacío es infinitamente rápido.
- El éter: todos los puntos del espacio están llenos con materia.
- Teoría del continuo: si existieran los átomos esféricos habría un vacío entre ellos, por lo que la materia no puede ser atómica.
- **Quintaesencia: los objetos por encima de la Tierra no están formados de materia terrenal.**
- **Cosmos incorruptible y eterno:** el Sol y los planetas son esferas perfectas, y no cambian.
- **Movimiento circular: los planetas** se mueven en un movimiento circular perfecto.

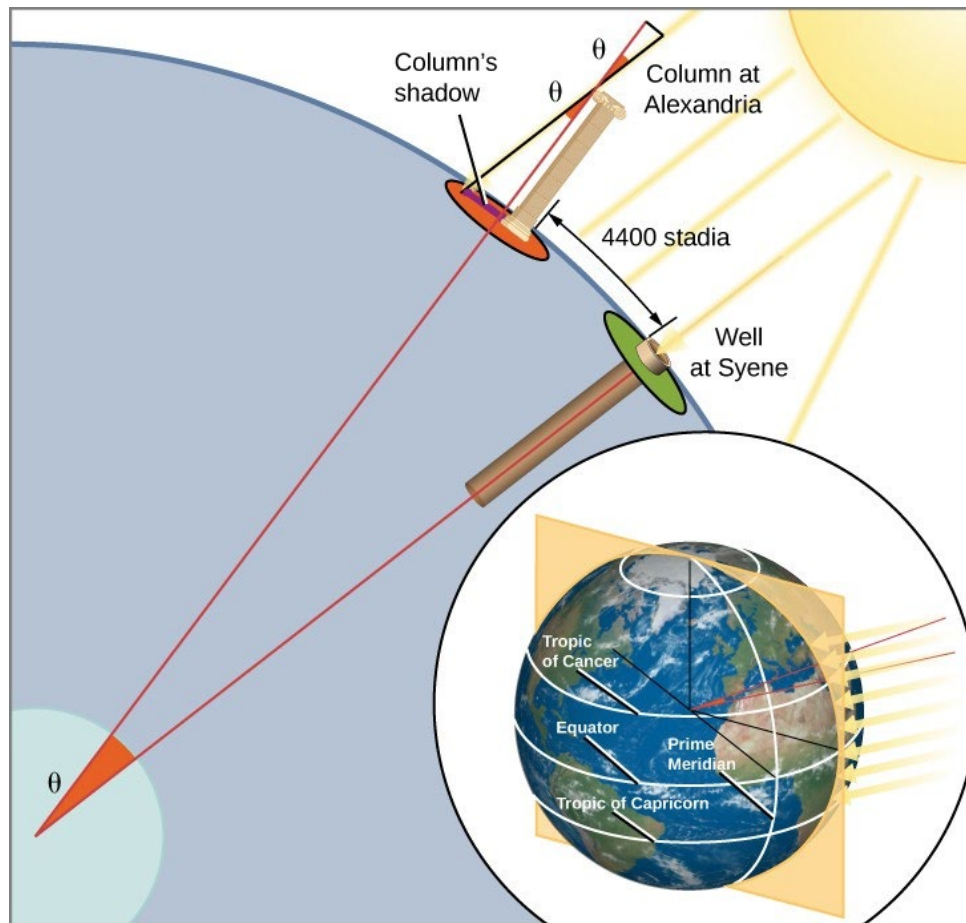


Eratóstenes de Cirene (276 – 195/194 a.C.) matemático, geógrafo, astrónomo y teórico de la música.

Basado en trigonometría básica, observando la sombra del Sol al mediodía del primer día del verano:

$\theta \sim 7^\circ \rightarrow$ Circunferencia de la Tierra $\sim 250,000$ estadios $\sim 40,000$ km

$\rightarrow$ Radio ~ 6.286 km (error de 1-20%).



(Lumen)



Eudoxus of Cnidus (c. 410 BC–c. 347 BC), to develop a system of Greek astronomy. Eudoxus rose to the challenge by Plato assigning to each planet a set of concentric spheres. By tilting the axes of the spheres, and by assigning each a different period of revolution, he was able to approximate the celestial "appearances." Thus, he was the first to attempt a mathematical description of the motions of the planets. (Wikipedia)

LIBRO I, La República (Cicerón s.I a.C.)

Filo: “De ese planetario había oído yo hablar gracias a la fama de Arquímedes (...) Porque decía Galo que era muy antigua la invención de aquella otra esfera sólida y entera que había torneado Tales de Mileto primeramente, y que luego Eudoxo de Cnido, discípulo, según el decía, de Platón, le había puesto astros y estrellas fijas en la órbita celestial (...). Pero este otro tipo de planetario, en el que se movían el sol y la luna, y también aquellas cinco estrellas que se llaman ‘errantes’ , y en cierto modo vagabundas, no podían acomodarse a aquel tipo de esfera sólida, y por eso es admirable el invento de Arquímedes, pues se las ingenió para reducir a una sola rotación varios cursos que eran desiguales por sus propias trayectorias. (p.51, l.10, pa.21)



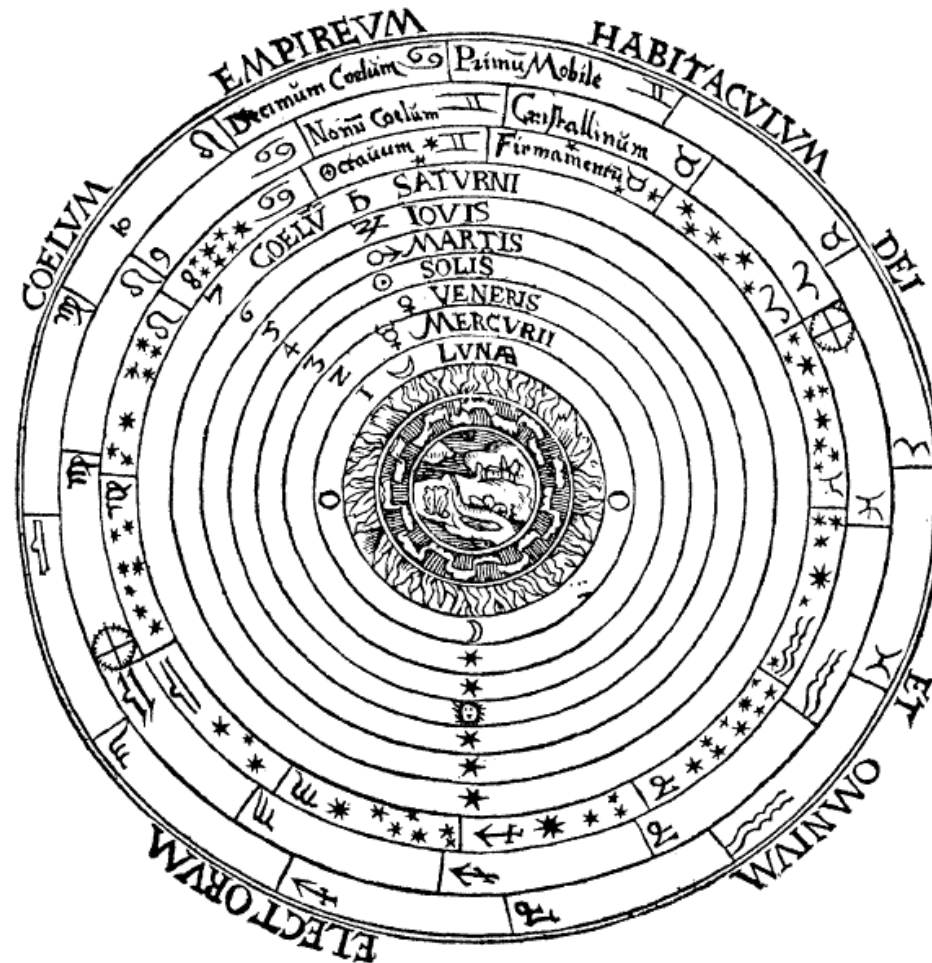
Antikythera (Grecia). Encontrado en 1901.
Nature (2008) video of reconstruction.



LIBRO VI, La República (Cicerón s.I a.C.)

Africano: “**Todo el Universo que puedes ver está encerrado en 9 órbitas...**”
(p.164, l.13, pa.17) Sabían que si no, tendrían que ver las paralajes de las estrellas

Schema huius præmissæ diuisionis Sphærarum .

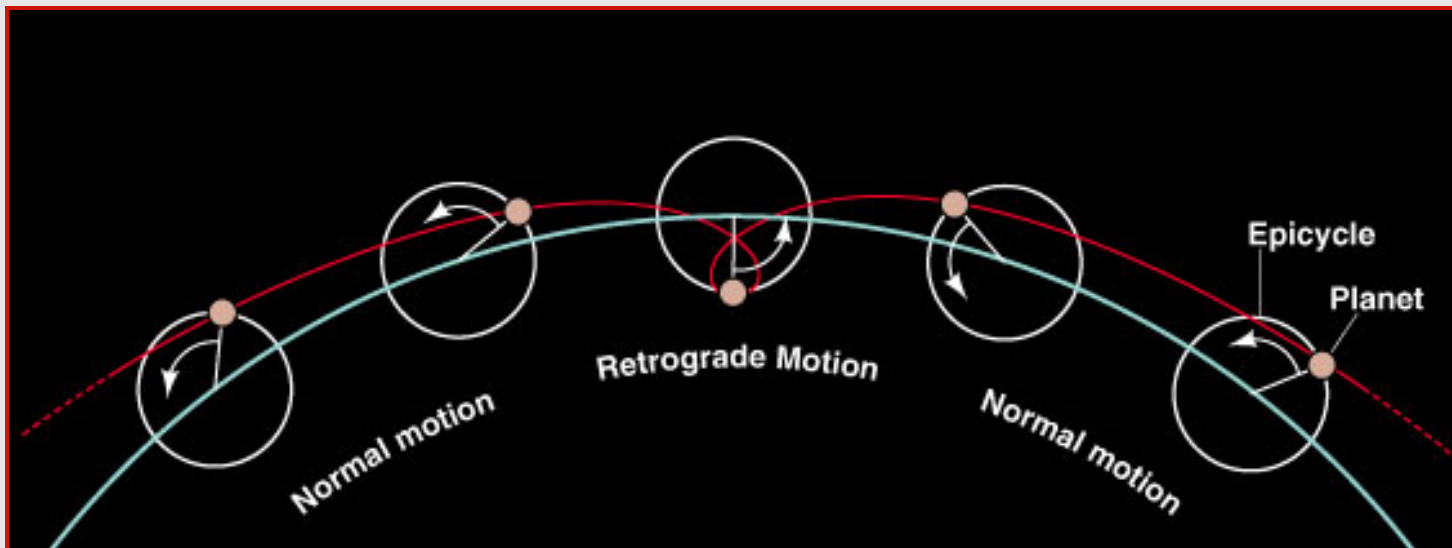
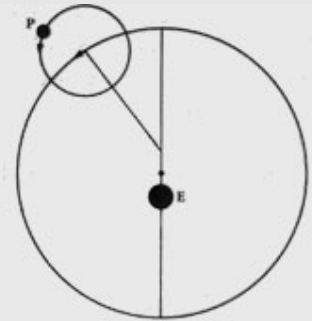


Testing the Earth-centered model

Prediction: Future planetary positions

Observation: retrograde motion of planets

Refine: epicycles

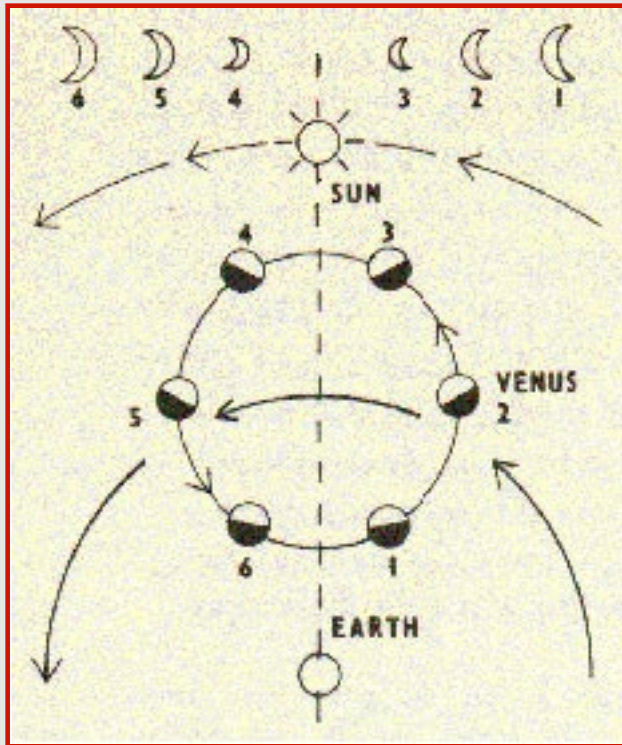


Success! For 1500 years

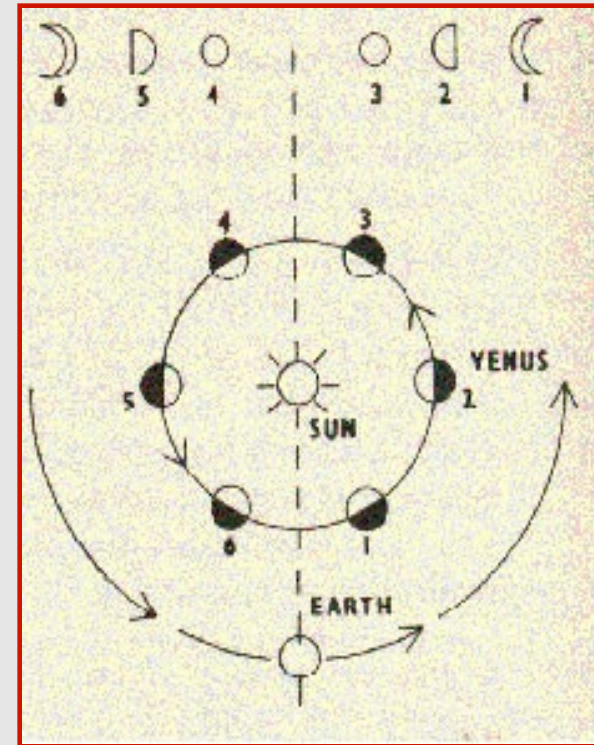
Testing the Earth-centered model

Prediction: Phases of Venus

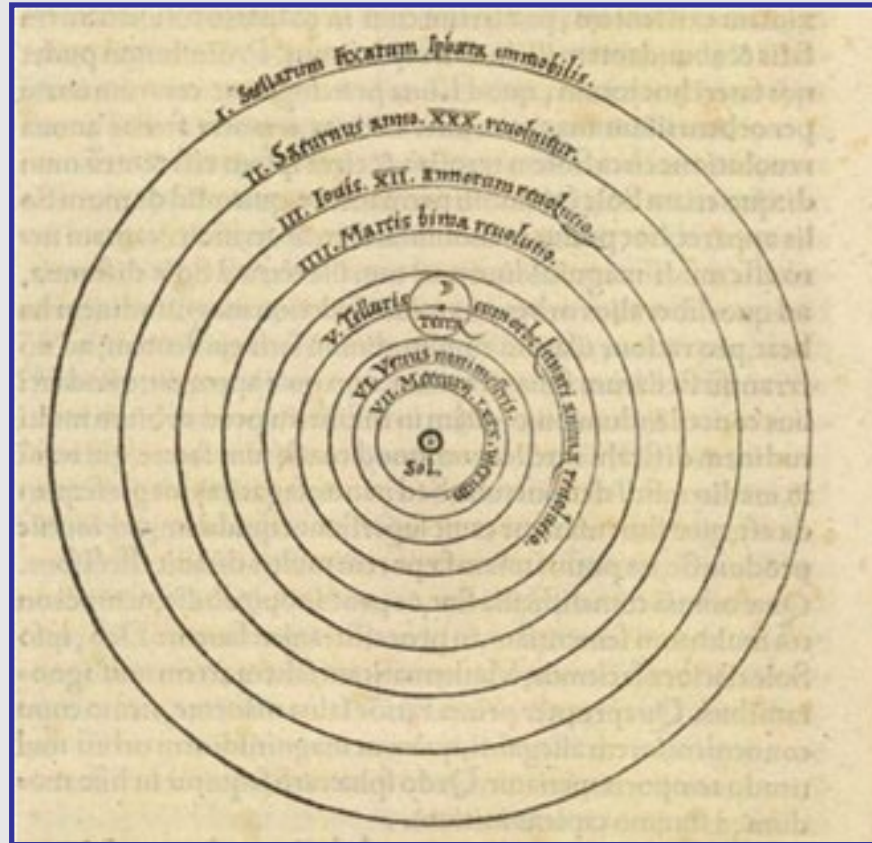
Observation: Full set of phases



Crisis!



Sun-centered Cosmology: Nicolaus Copernicus 1473-1543



“At rest, however, in the middle of everything is the Sun.”

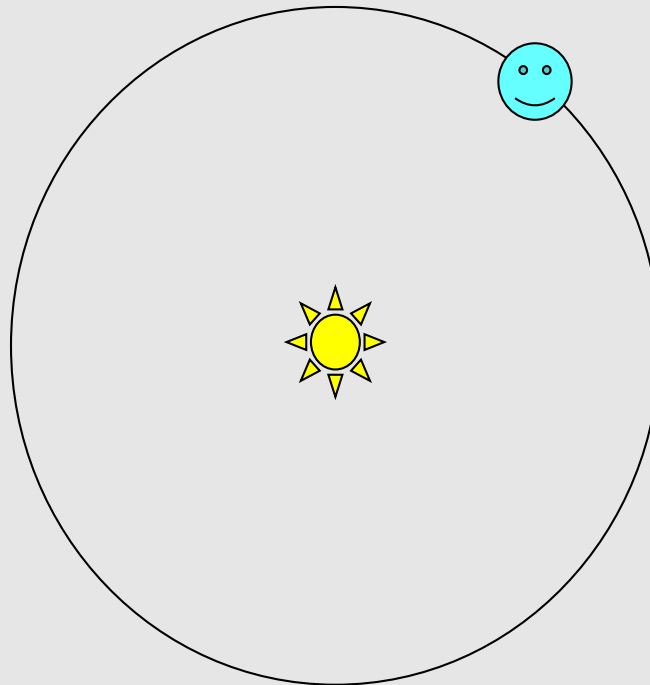
Nicholaus Copernicus, de Revolutionibus

Testing the Sun-centered model

Prediction: Future planetary positions

Observation: No better than Ptolemy

Refine: elliptical orbits (Johannes Kepler 1571-1630)

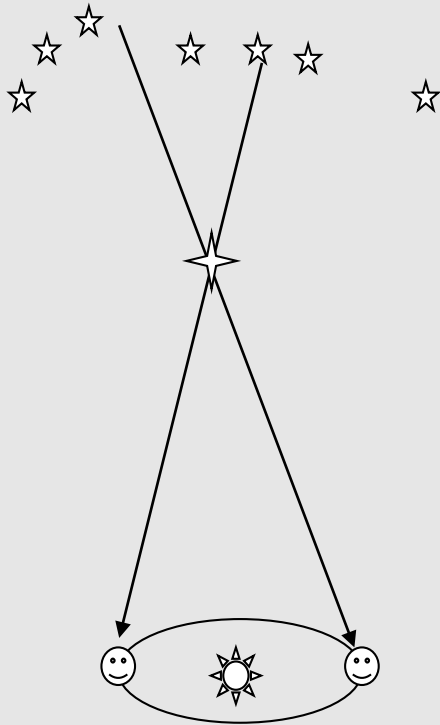


Testing the Sun-centered model

Prediction: Observed shift in position of stars (parallax) as the earth moves around the Sun.

Observation: No shift.

Crisis? No, but we had to wait until 1838 (Friedrich Bessel)



Testing the Sun-centered model

Prediction: Sun at center of Cosmos

Observation: Sun is not at center of universe (1918), Shapley, Leavitt ...

Observation: The galaxy is not the entire universe (1923), Hubble, ...

Crisis!

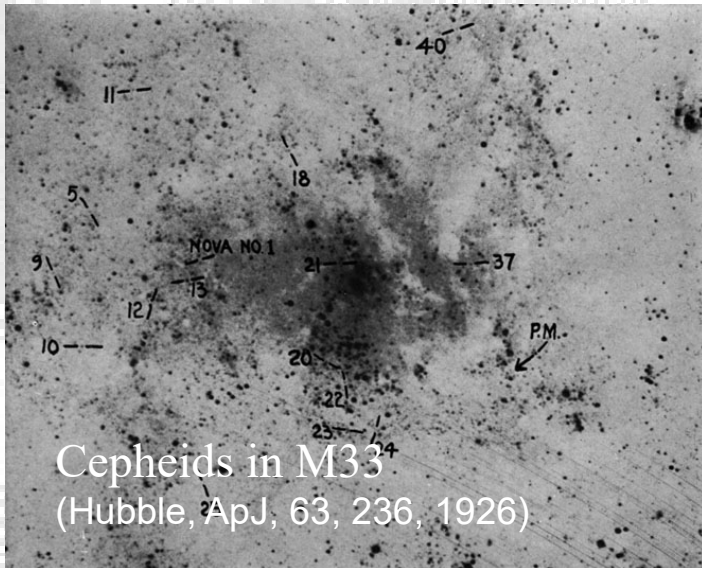


The discovery of galaxies

- 1755 Immanuel Kant: nebulae are independent systems made of stars
- 1771 Messier's Catalogue «*Catalogue des Nébuleuses et des amas d'Étoiles, que l'on découvre parmi les Étoiles fixes sur l'horizon de Paris*» M82, M31 (Andromeda), M33,...
- 1786 William Herschel's "Catalogue of Nebulae and Clusters of Stars" to be later expanded into the "General Catalogue of Nebulae and Clusters of Stars" (GC) by John Herschel. The CN and GC are the precursors to John Louis Emil Dreyer's "New General Catalogue" (NGC): NGC4151, NGC5548, ...
- 1868 William Huggings' M31 **spectrum: flat** unlike others (planetary nebulae)
- 1885 William Parson, 3rd Earl of Rosse, with his 72-inch speculum-metal reflector: **spiral structures** in M33, M51, M101
- 1890 Keeler & Curtis, 36" at Lick Observatory and photography: spirals common
- 1908 Henrietta Swan Leavitt's **L-P Cepheid correlation** in *Annals of the Astronomical Observatory of Harvard College*
- 1912 V. Slipher's spectra at Lowell Obs., **M31 large radial velocity**
- 1917: Herber Curtis **nobas in M31** hence M31 at great distance

The discovery of galaxies

- 1920: **Sharpley-Curtis Great Debate** -> start of **Extragalactic Astronomy**, galaxies are “island universes” outside the Milky Way
(https://apod.nasa.gov/debate/1920/cs_nrc.html)
 - The “white nebulae” occur far from the galactic plane, in fact avoiding it, unlike other nebular constituents
 - Some galaxies, seen edge-on, look much like the visual Milky Way
- 1925-29: **Edwin Hubble identifies Cepheid stars in M31, M33 and IC1613** - > **precision distances using Leavitt’s law, or L-P method**



The Birth of Cosmological Physics

- 1917 Albert Einstein: General Relativity

$$R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

- Developments by Willem de Sitter, Karl Schwarzschild, Arthur Eddington... and
- 1922 Alexander Friedman's expanding universe solution
- 1927 George Lemaitre's "Primeval Atom", independent of Friedman's calculations
- 1930 Fred Hoyle in a BBC program coined the "Big Bang" term

Olbers' Paradox

- Named for Wilhelm Olbers (1758-1840), but known to Kepler and Halley
 - ▶ Consider spherical shell of radius r and thickness dr
 - ▶ Number of stars in this shell is $4\pi r^2 n dr$, where n is number density of stars
 - ▶ Light from each star is $L/4\pi r^2$, therefore light from shell is $nL dr$, independent of r
 - ▶ therefore, in infinite universe, night sky should be infinitely bright (or at least as bright as typical stellar surface – stars themselves block light from behind them)
- Why is the sky dark at night?

Olbers' Paradox: solution(s)

- Light is absorbed by intervening dust
 - ▶ suggested by Olbers
 - ▶ doesn't work: dust will heat up over time until it reaches the same temperature as the stars that illuminate it
- Universe has finite size
 - ▶ suggested by Kepler
 - ▶ this works (integral is truncated at finite r)
 - ▶ but now Newtonian universe will definitely collapse
- Universe has finite age
 - ▶ equivalent to finite size if speed of light finite
 - ▶ light from stars more than ct distant has not had time to reach us
 - ▶ (currently accepted explanation)
- Universe is expanding
 - ▶ effective temperature of distant starlight is redshifted down
 - ▶ this effect not known until 19th century
 - ▶ (does work, but does not dominate (for stars) in current models)

Olbers + Newton could have led to prediction of expanding universe

Changing Worldviews

Age		Universe
100 years AD	---	The Earth + Celestial Sphere
400 years ago	---	The Solar System
100 years ago	---	The Milky Way
80 years ago	---	The “Modern” Universe (2 Gly in *radius*)
Today	---	An Infinite Universe (the visible part has a radius of ~45 Gly)