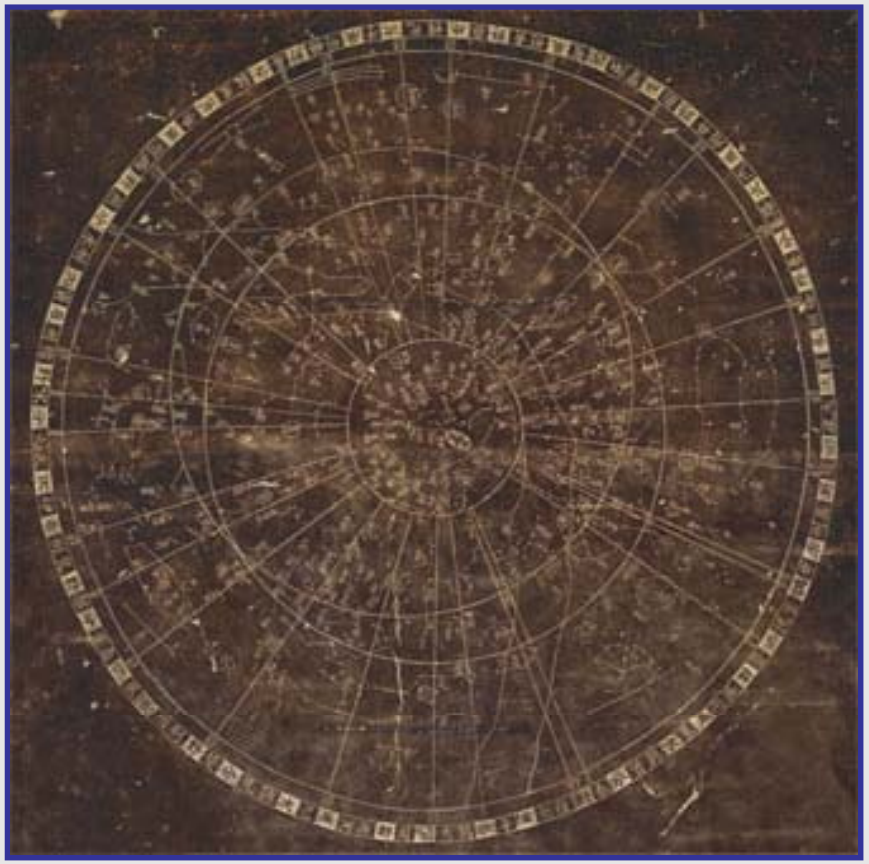
What is Cosmology?

The Study of the Universe: its structure, origin, evolution, and destiny

- Our universal "world view"
- Our cosmological model

Cosmology through the ages…



Universe models formed in many cultures

Our View of the Cosmos - the story of scientific models

Astronomy has seen 3 scientific revolutions in cosmology

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

Model: Earth-centered Cosmology

Big Idea: Different laws for Earth and the cosmos

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

Model: Sun-centered Cosmology

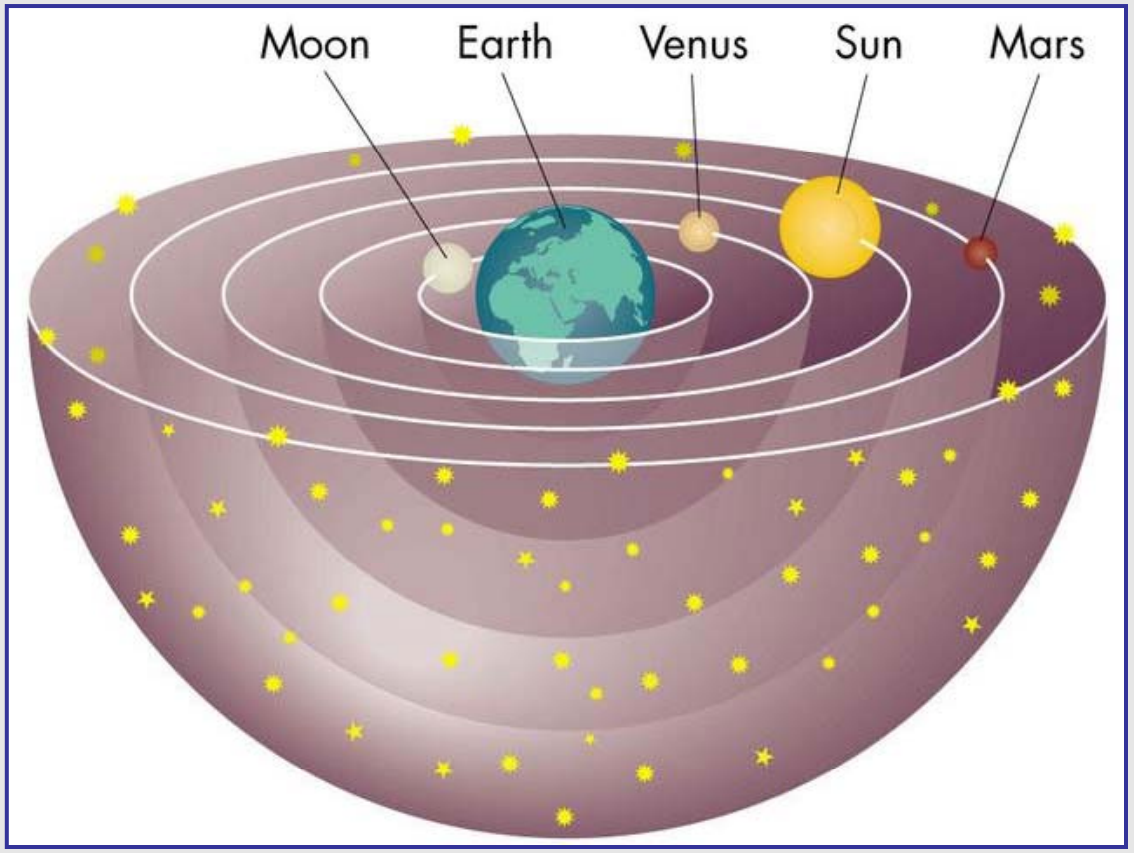
Big Idea: Universal physics; same laws everywhere

20th Century: Edwin Hubble **(Physics of Einstein)**

Model: Big Bang Cosmology

Big Idea: Universe is changing, evolving

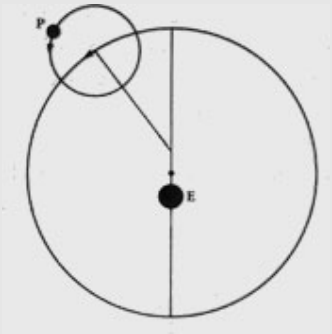
Earth-centered Cosmology: Claudius Ptolemy, 100-170 AD



…"the natural motion of the Earth ….is towards the center of the universe; that is the reason it is now lying at the center."

Aristotle, On the Heavens

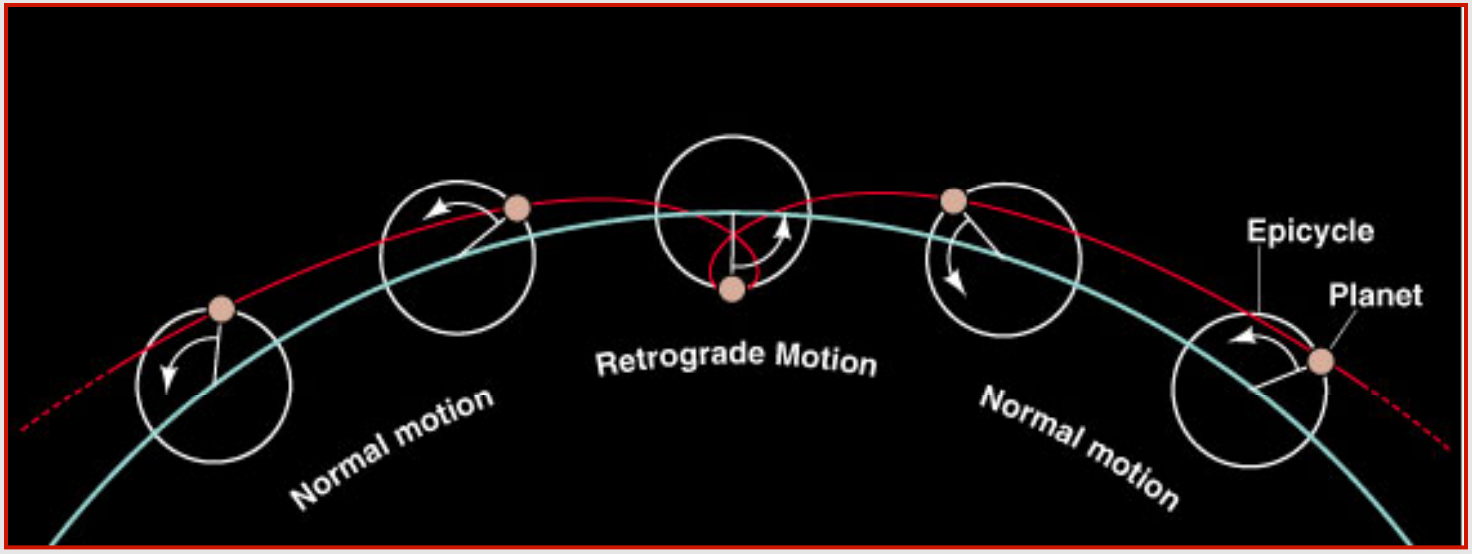
Testing the Earth-centered model



Prediction: Future planetary positions

Observation: retrograde motion of planets

Refine: epicycles

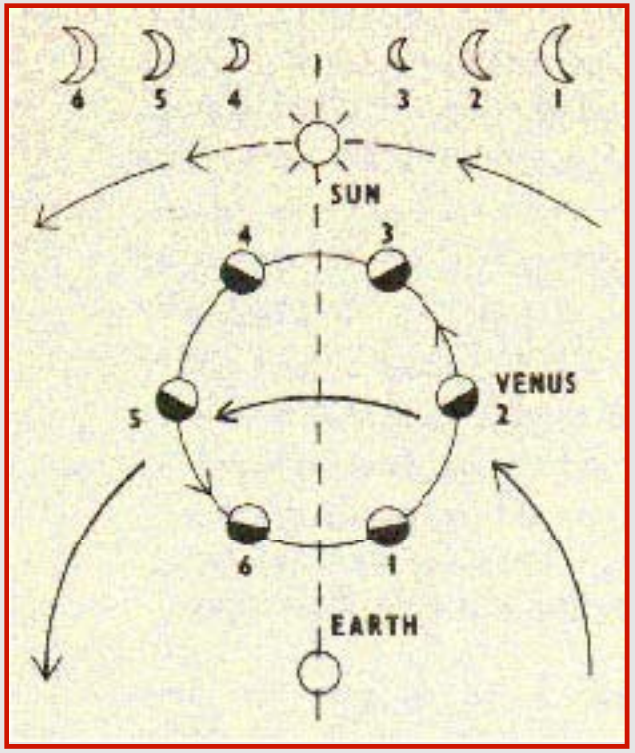


Success! For 1500 years

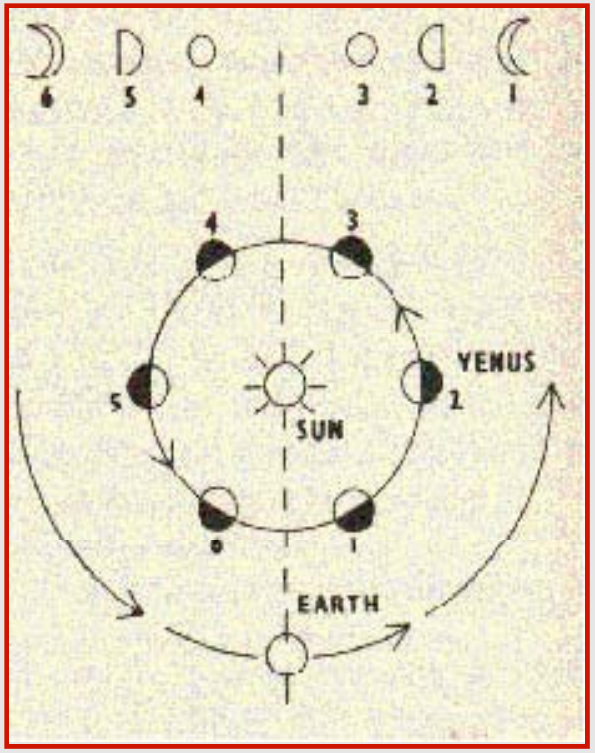
Testing the Earth-centered model

Prediction: Phases of Venus

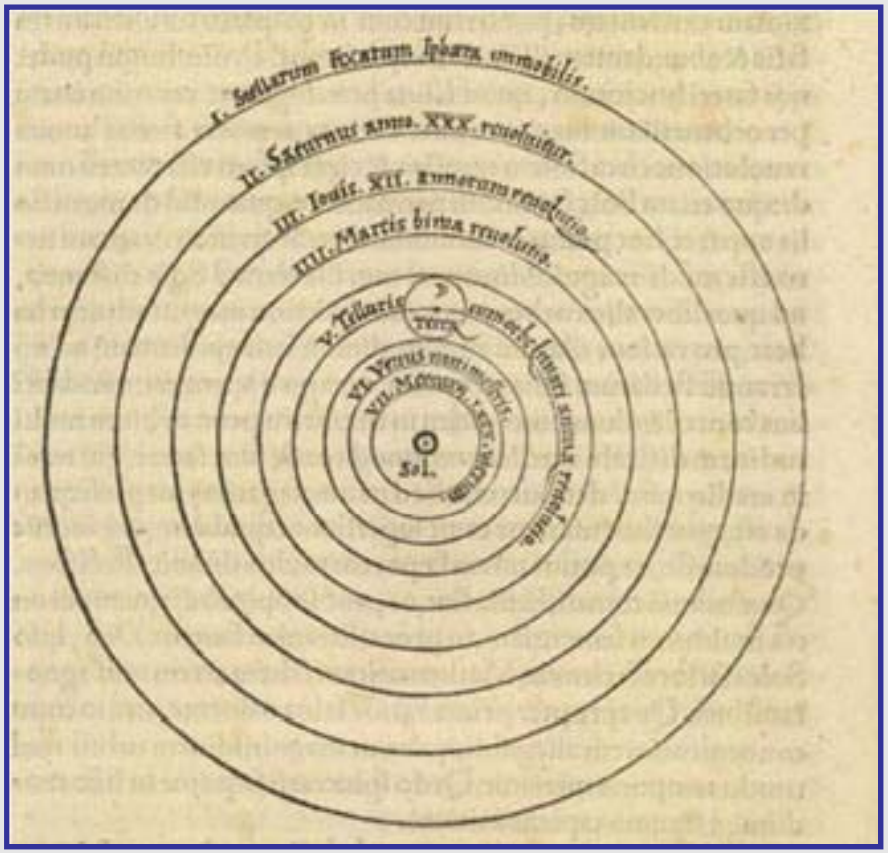
Observation: Full set of phases



Crisis!



Sun-centered Cosmology: Nicolaus Copernicus 1473-1543



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

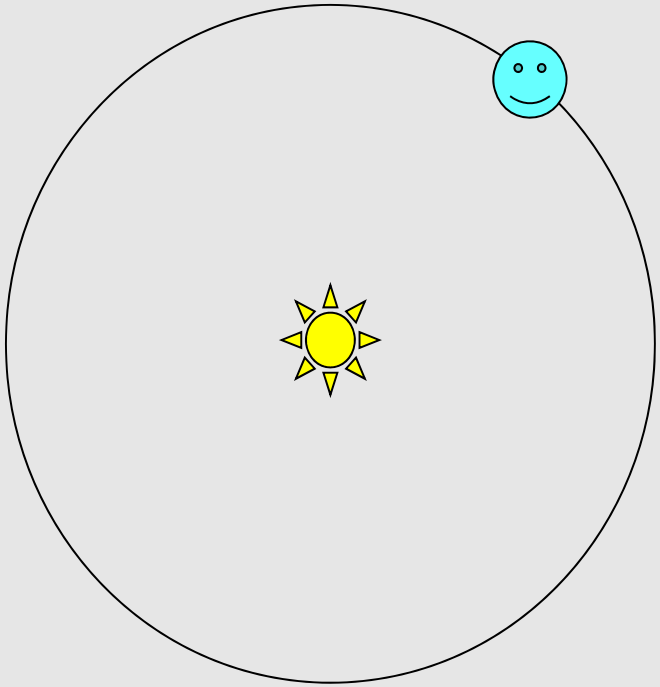
Nicholaus Copernicus, de Revolutionibus

Testing the Sun-centered model

Prediction: Future planetary positions

Observation: No better than Ptolemy

Refine: elliptical orbits (Johannes Kepler 1571-1630)

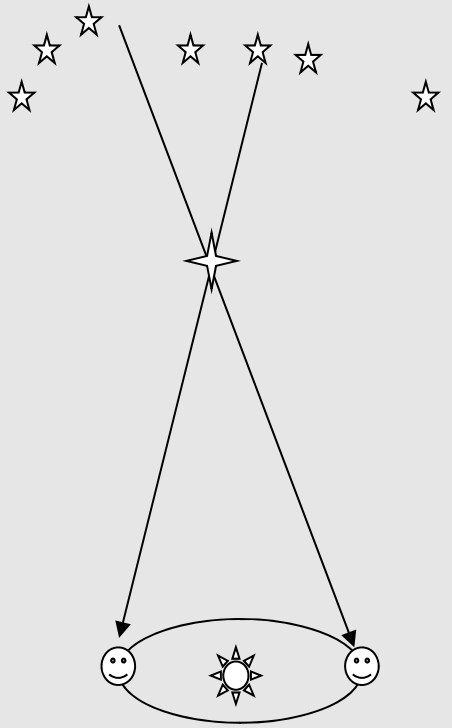


Testing the Sun-centered model

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)



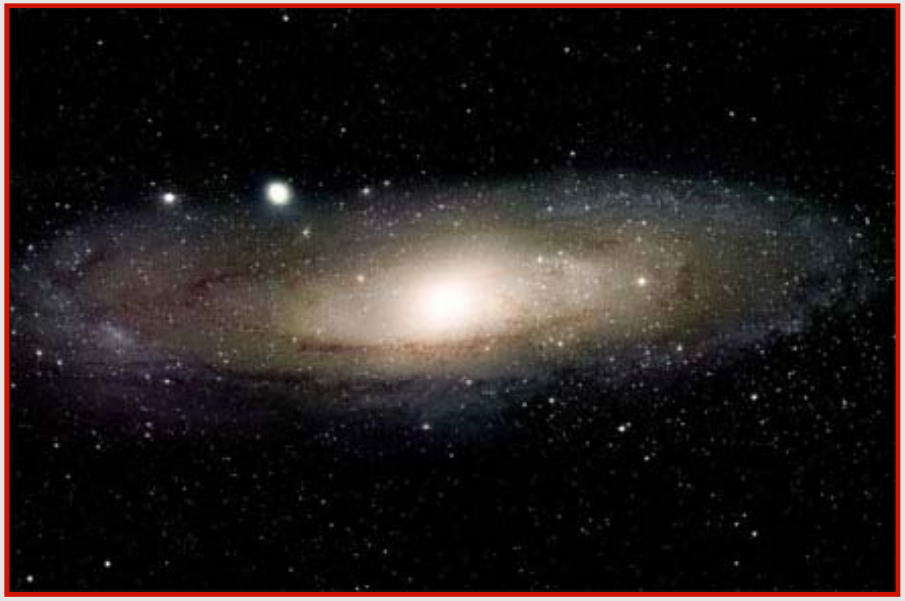
Testing the Sun-centered model

Prediction: Sun at center of Cosmos

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

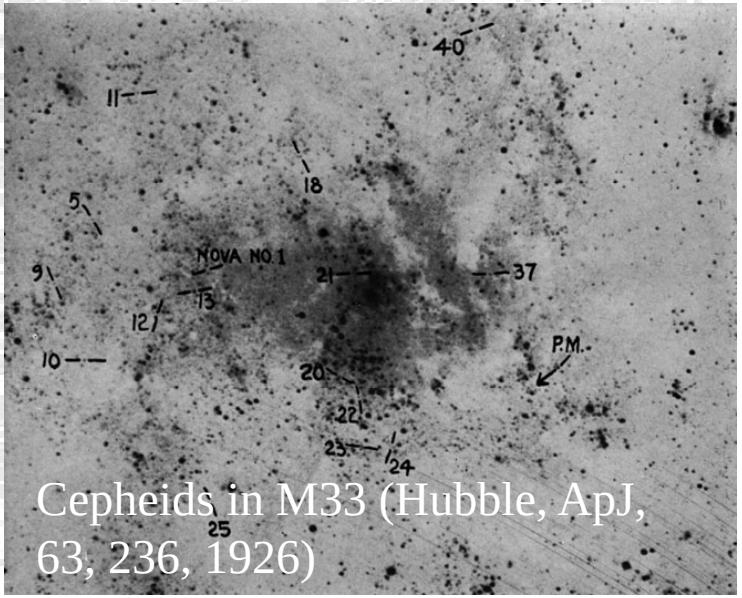
Observation: The galaxy is not the entire universe (1923), Hubble, …

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 nebule)
- 1885 William Parson: spiral structures in M33, M51, M101
- 1908 Henrietta Swan Leavitt´s L-P cepheid correlation in *Annals of the Astronomical Observatory of Harvard College*
- 1917: Herber Curtis nobas in M31 hence M31 at great distance
- 1920: Sharpley-Curtis Great Debate -> start of Extragactic Astronomy
- 1925-29: Edwin Hubble identifies cepheids in M31, M33 and IC1613 -> precision distances



Cepheids in M33 (Hubble, ApJ, 63, 236, 1926)

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 Schwarzchild, Arthur Eddington… and
- 1922 Alexander Friedman´s expanding universe solution
- 1927 George Lemaitre´s “Primival 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 19^{th} 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
75 years ago	---	The “Modern” Universe (2 Gly in *radius*)
Today	---	An Infinite Universe (the visible part has a radius of ~45 Gly)

1905 - 2005

INSIDE EINSTEIN'S UNIVERSE

Credits

Colliding galaxies: NASA & the Hubble Heritage Team (STScI)

Phases of Venus: Albert Van Helden

Star field: NASA/GSFC

Andromeda: Palomar Observatory, P. Challis, CfA

HGC 87: Gemini Observatory/GMOS-S

Galaxy cluster: Jean-Charles Cuillandre (CFHT), Hawaiian Starlight, CFHT

Edge-on galaxy: Bruce Hugo and Leslie Gaul, Adam Block (KPNO Visitor Program), NOAO, AURA, NSF

Please contact einstein2005@cfa.harvard.edu for more information about non-credited historical images.

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