Our Expanding Universe:

Humanity's changing vision of the cosmos

Structure and Evolution of the Universe

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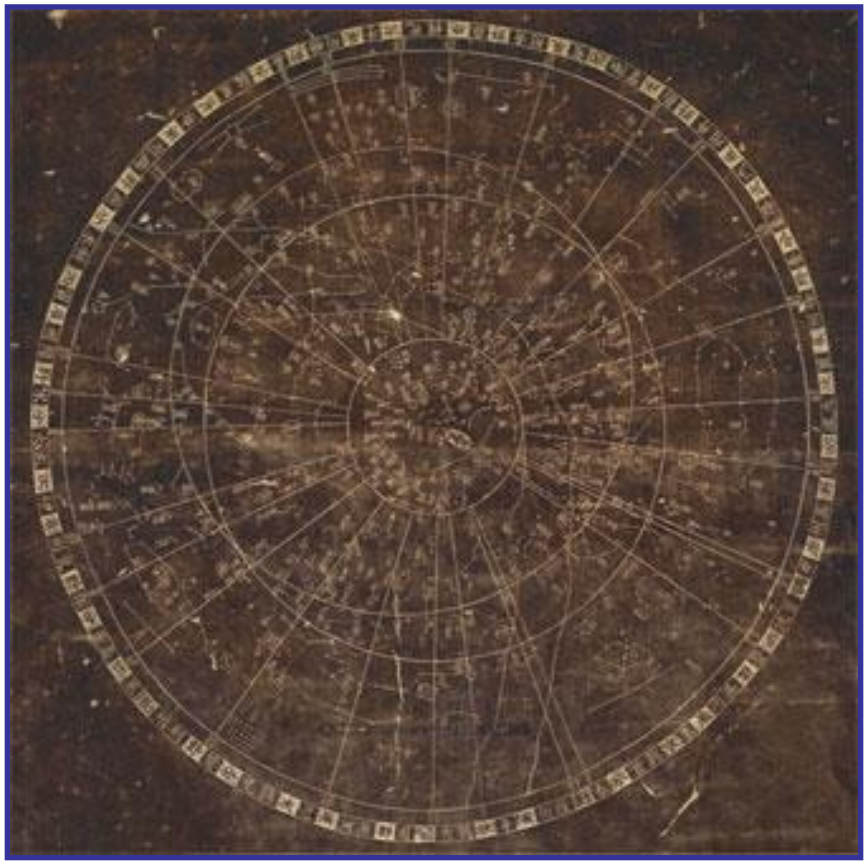
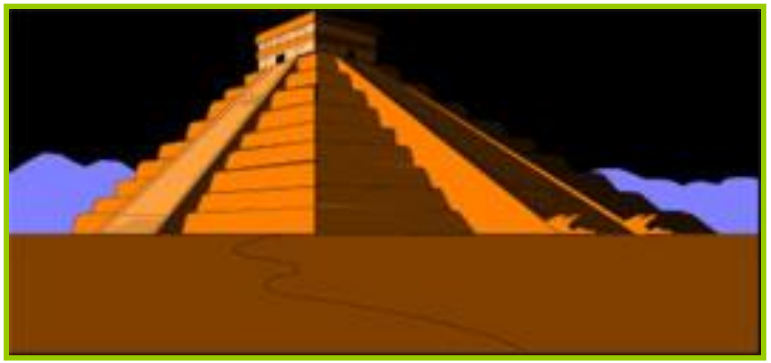
What is Cosmology?

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

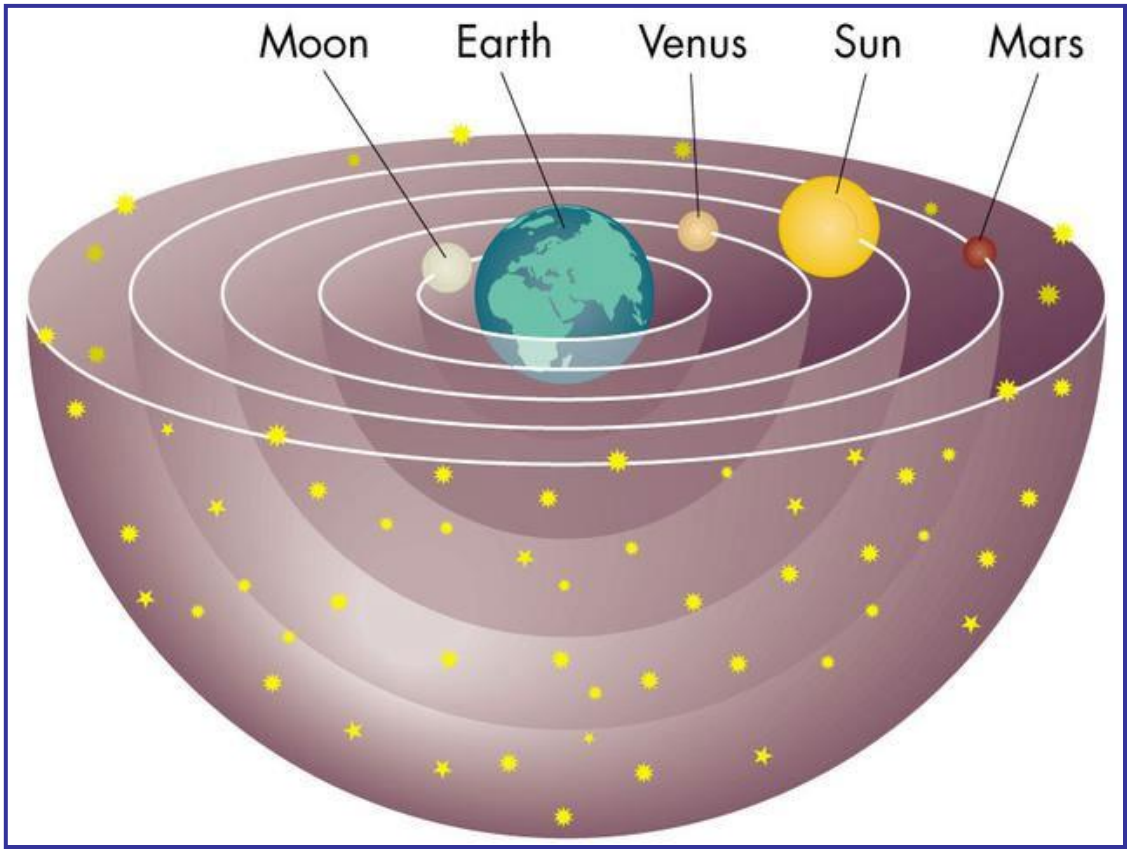
Big Idea: Universal physics; same laws everywhere

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

Model: Big Bang Cosmology

Big Idea: Universe is changing, evolving

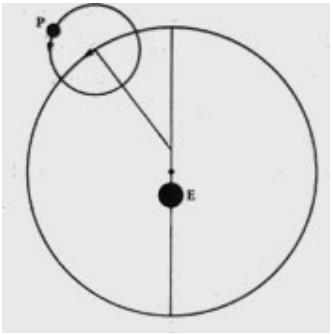
Earth-centered Cosmology: Claudius Ptolemy, 100-170 AD



…“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

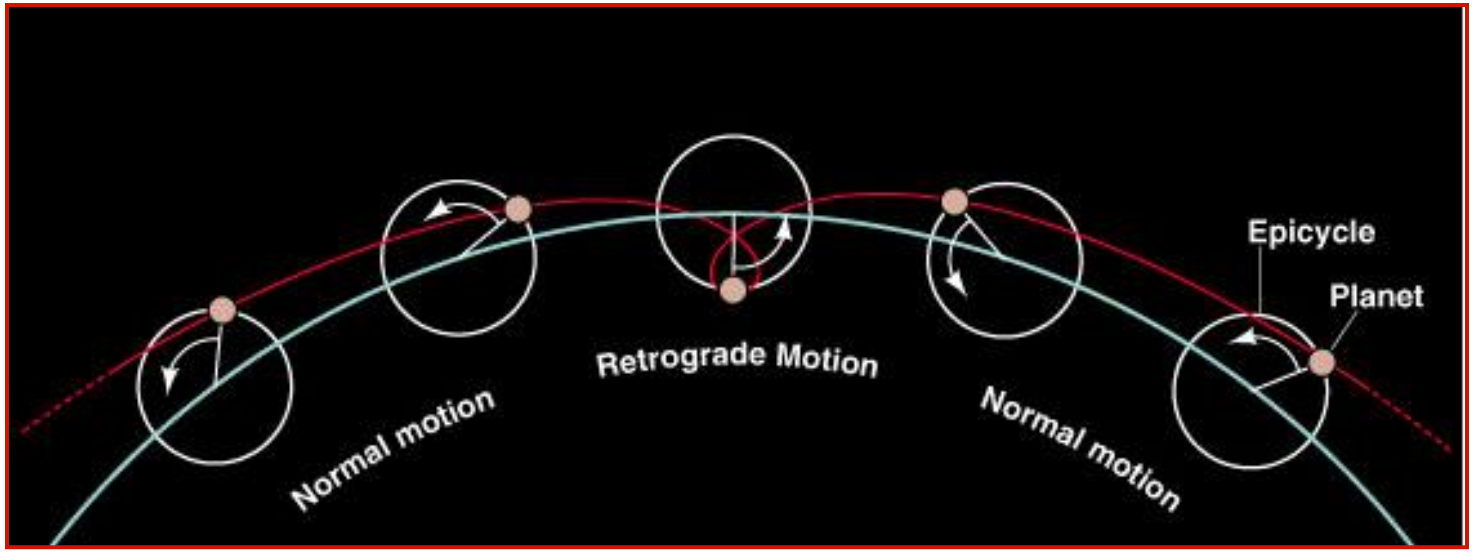
Testing the Earth-centered model



Prediction: Future planetary positions

Observation: retrograde motion of planets

Refine: epicycles



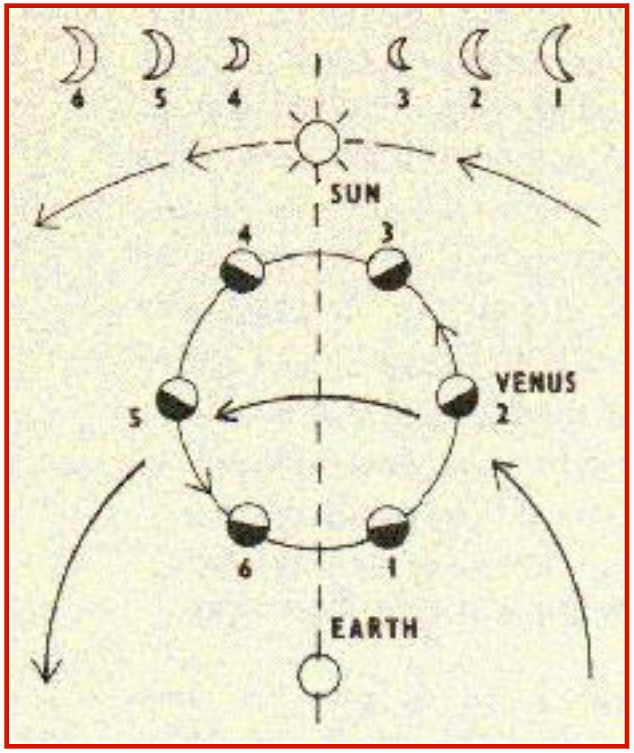
Success! For 1500 years

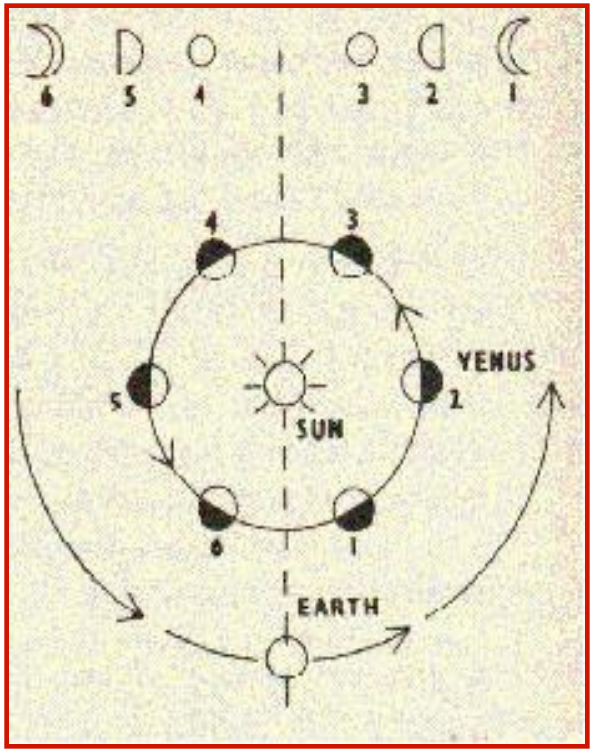
Testing the Earth-centered model

Prediction: Phases of Venus

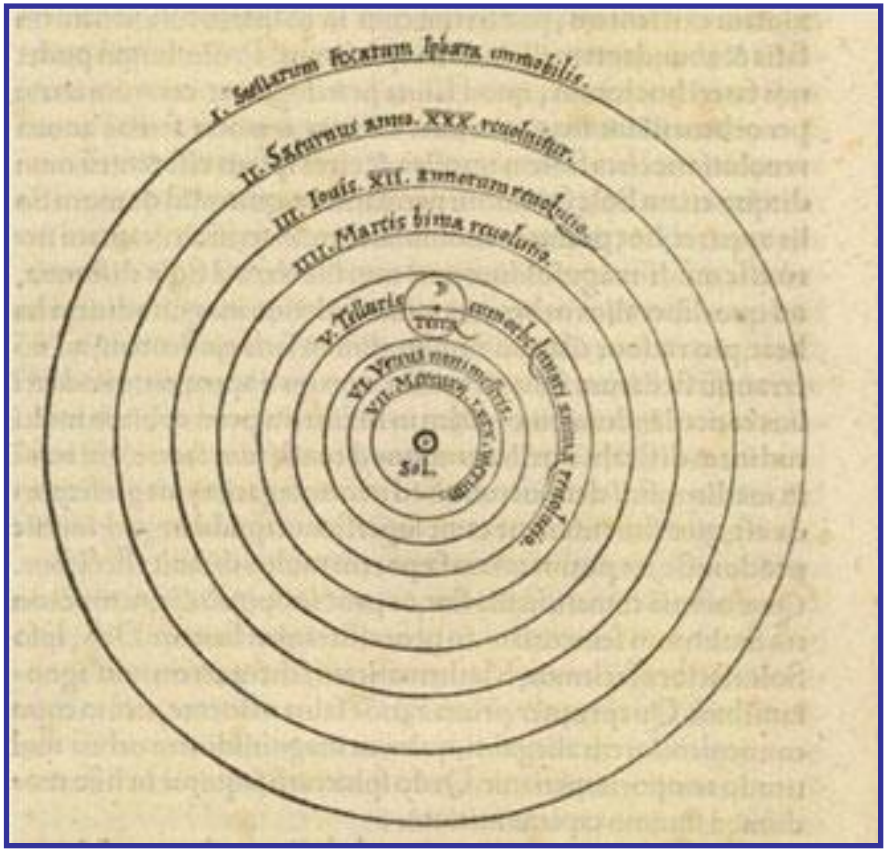
Observation: Full set of phases

Crisis!





Sun-centered Cosmology: Nicolaus Copernicus 1473-1543



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

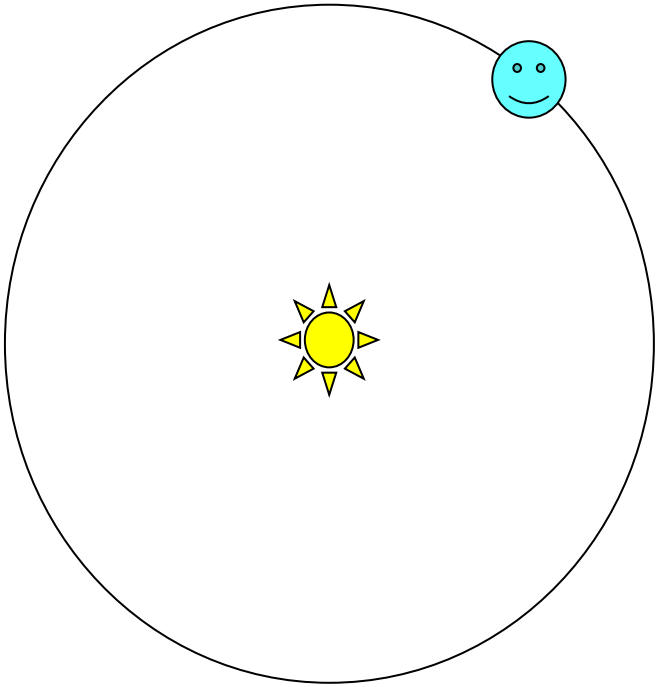
Nicholaus Copernicus, de Revolutionibus

Testing the Sun-centered model

Prediction: Future planetary positions

Observation: No better than Ptolemy

Refine: elliptical orbits (Johannes Kepler 1571-1630)

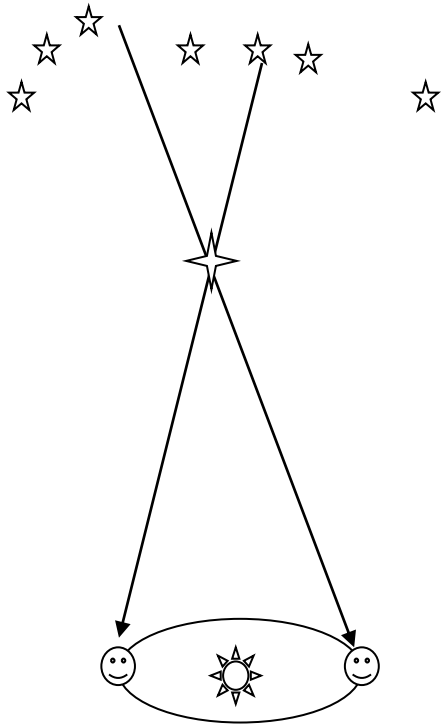


Testing the Sun-centered model

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)



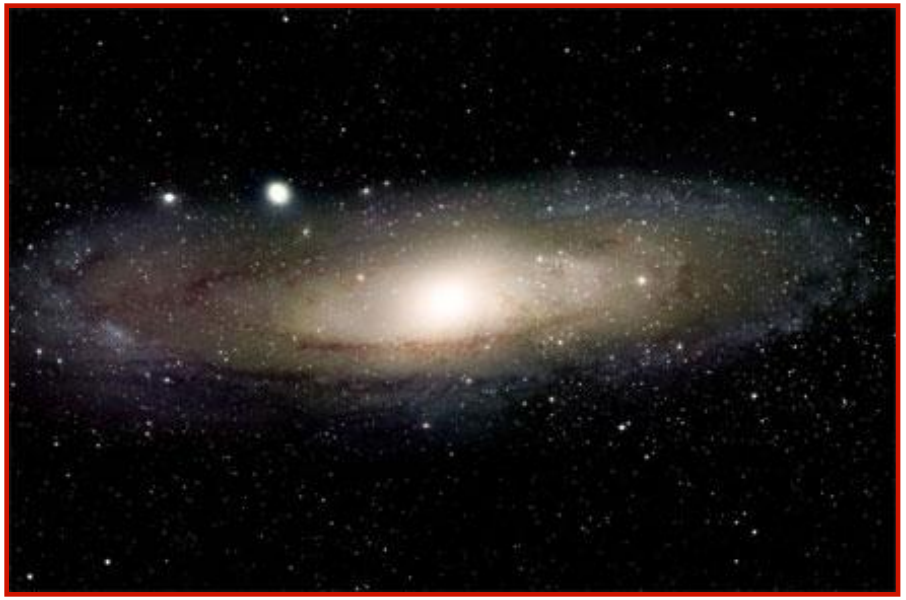
Testing the Sun-centered model

Prediction: Sun at center of Cosmos

Observation: Sun is not at center of universe (1918)

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

Crisis!



Big Bang Cosmology: Albert Einstein (1879-1955)

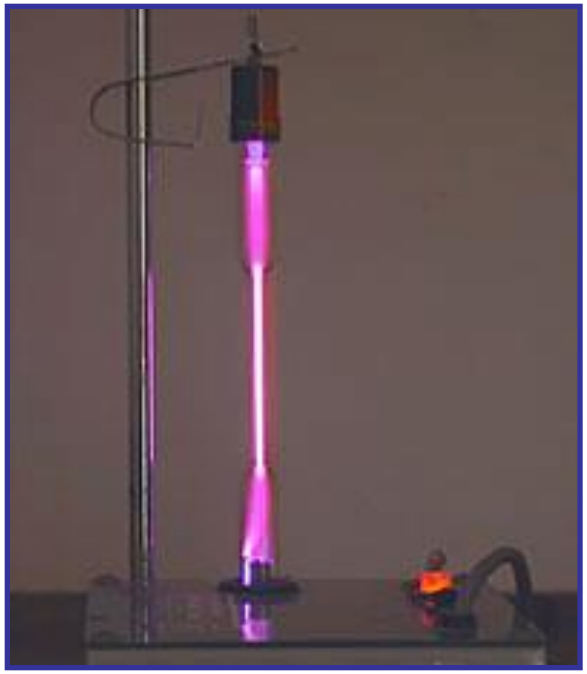
“A human being is part of a whole, called by us ‘universe’, a part limited in time and space.”

Testing the Big Bang model

Prediction: The universe is expanding

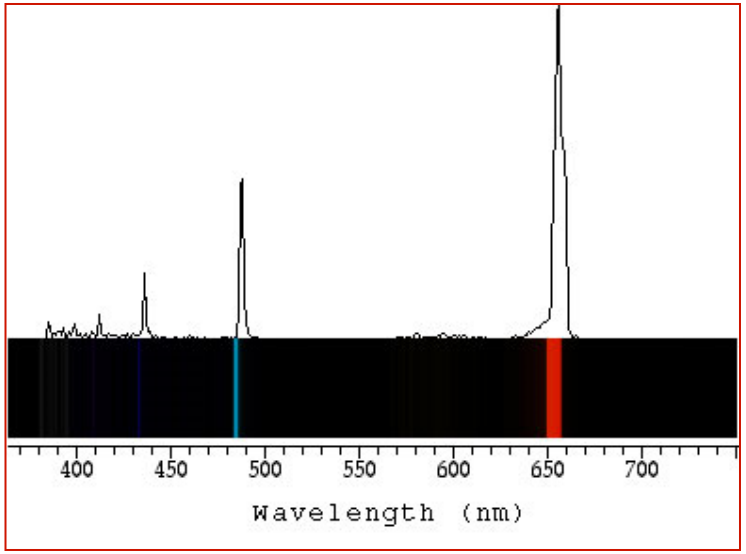
Observation: Galaxies are moving apart from each other (1929)

Evidence for an expanding universe



Hydrogen lamp

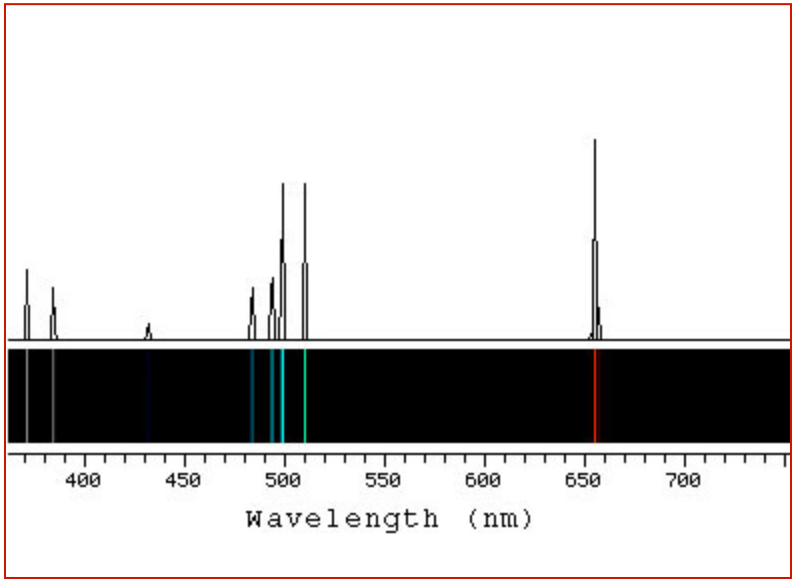
The spectrum of hydrogen gas is the unique fingerprint of that element



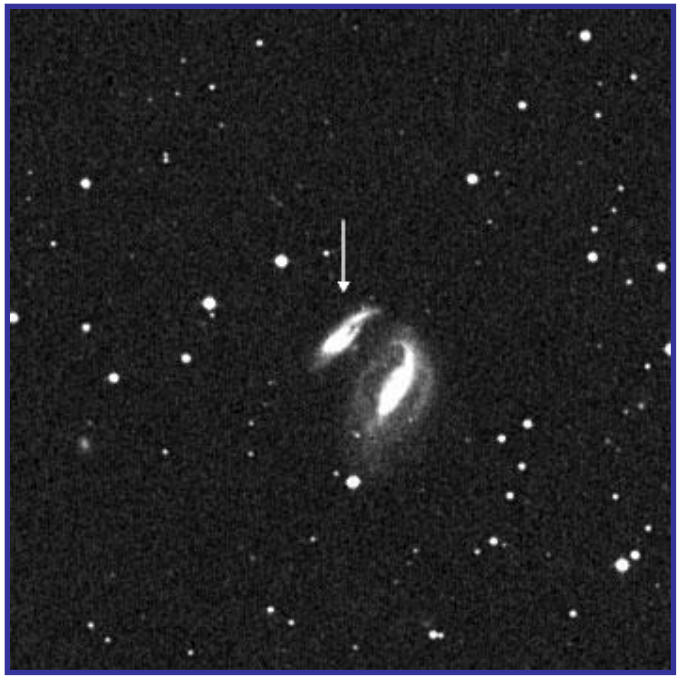
Evidence for an expanding universe

Orion Nebula

When we see a repeat of the pattern we saw in the lab, we know hydrogen is present

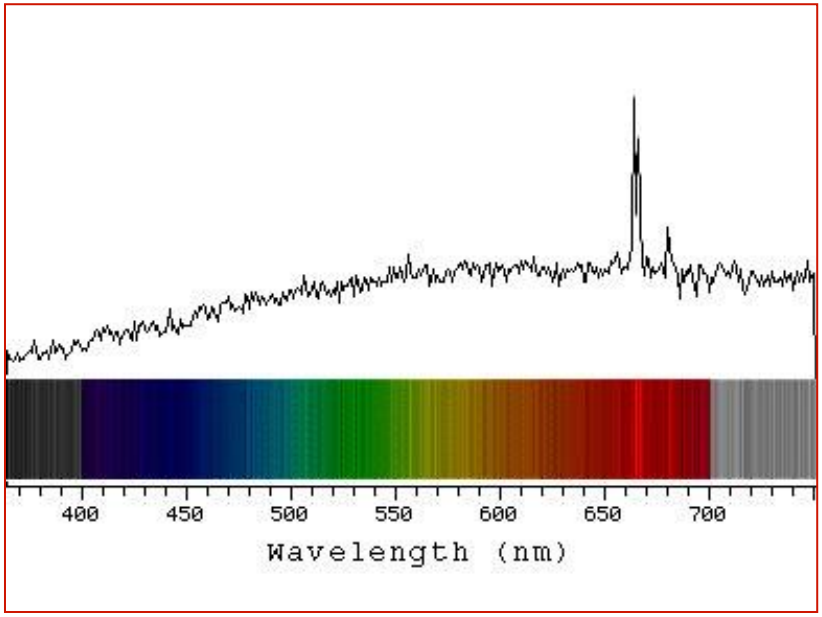


Evidence for an expanding universe



Galaxy UGC 12915

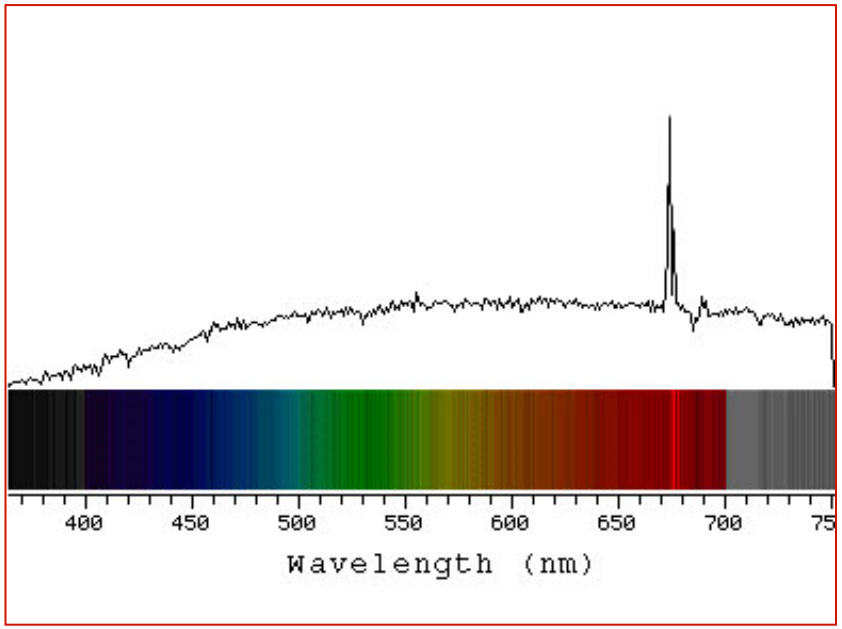
We see the same repeating pattern of lines in a galaxy, but displaced to the red



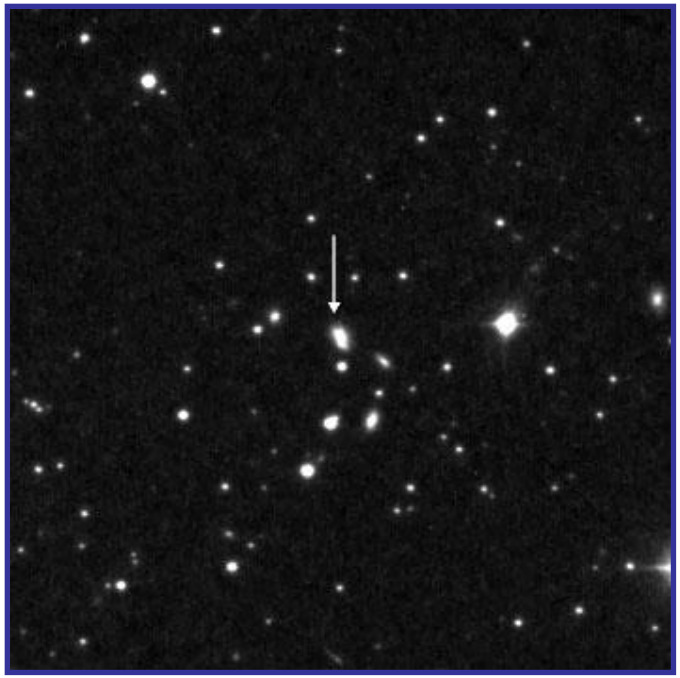
Evidence for an expanding universe

Galaxy UGC 12508

The further the galaxy,
the more the shift to the red

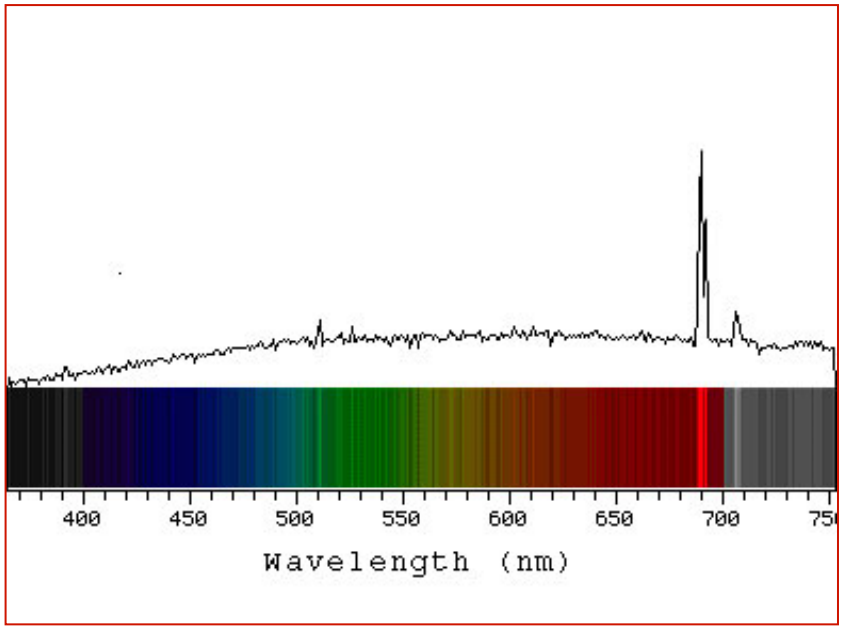


Evidence for an expanding universe

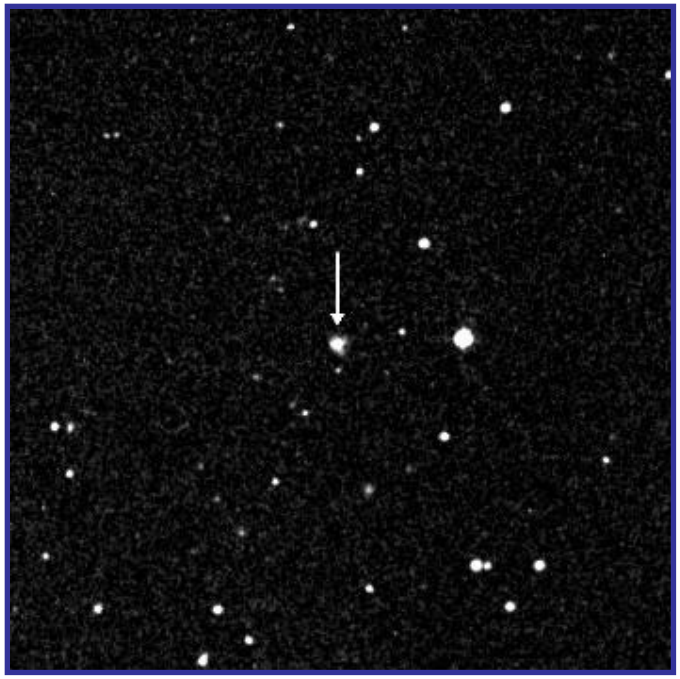


Galaxy KUG 1750

The greater the red shift,
the faster the galaxy is receding

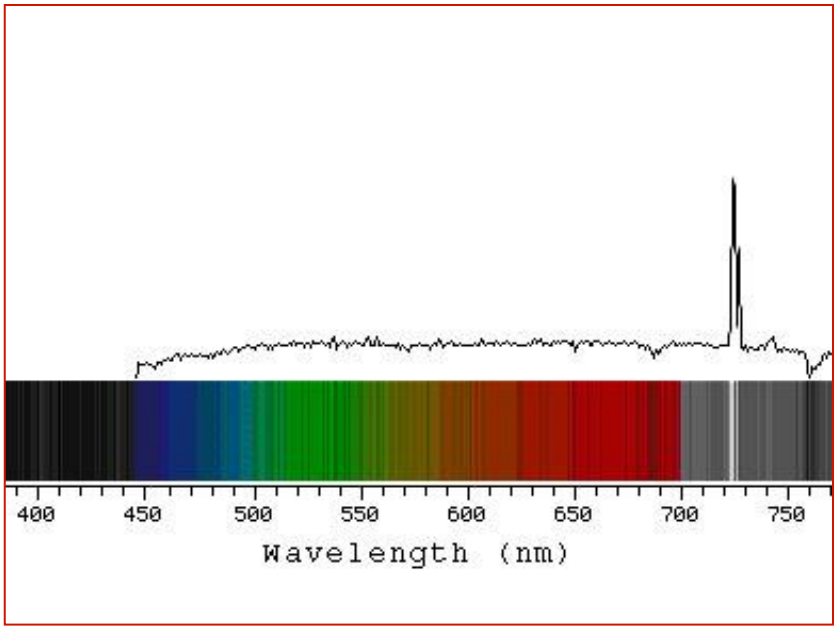


Evidence for an expanding universe

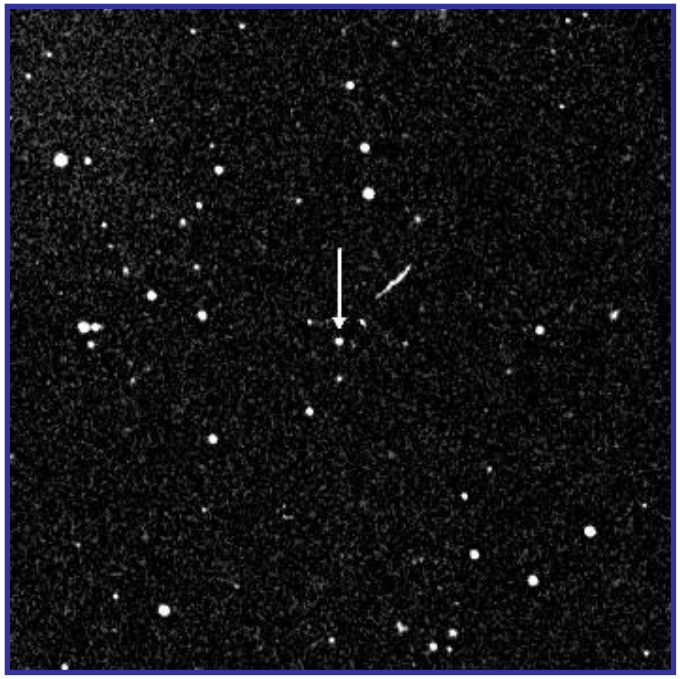


Galaxy KUG 1217

The red shift is caused
by the expansion of space.

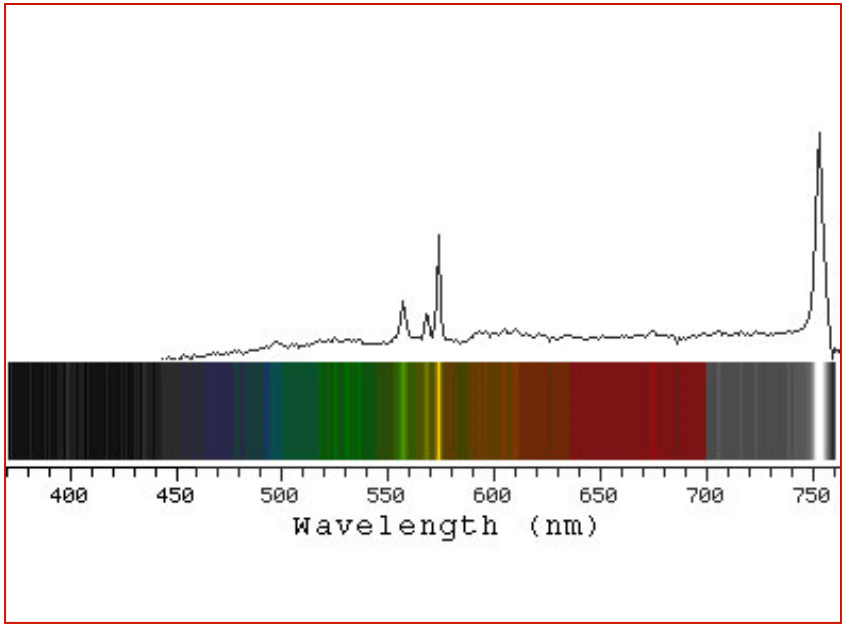


Evidence for an expanding universe



Galaxy IRAS F09159

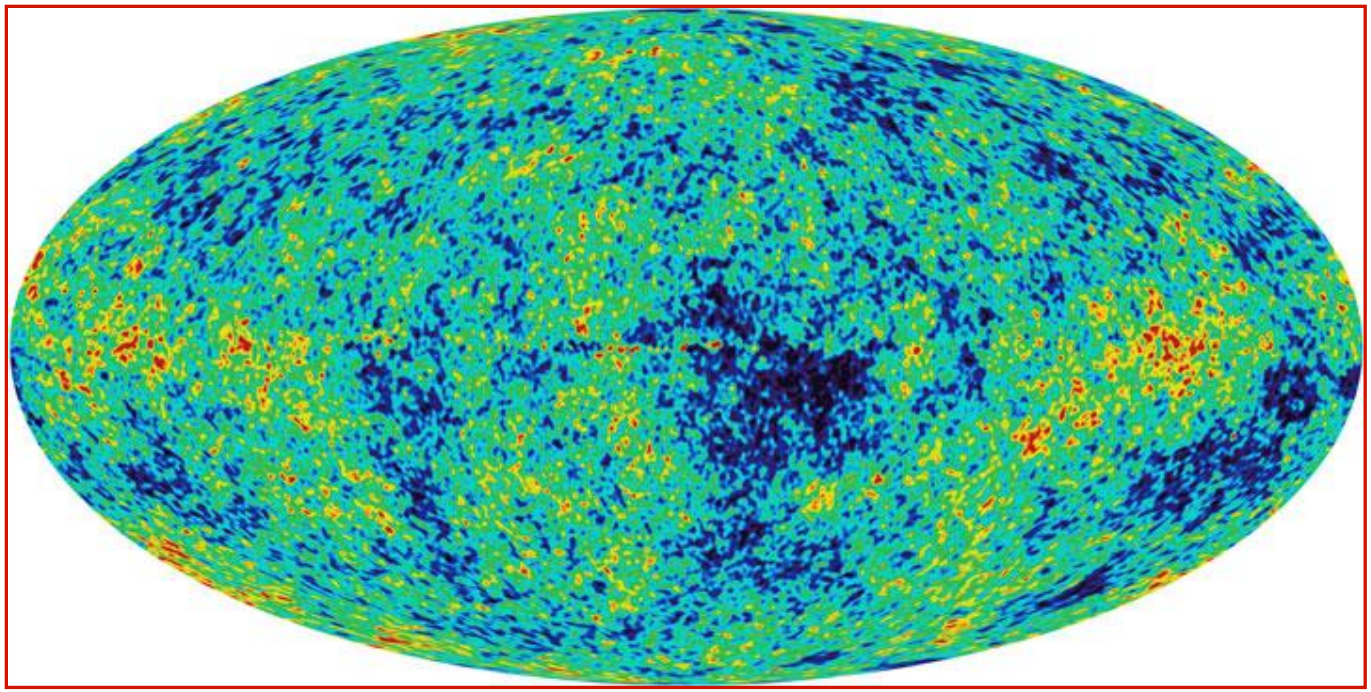
The red shift is evidence
for an expanding universe



Testing the Big Bang model

Prediction: If the universe was denser, hotter, in past, we should see evidence of left-over heat from early universe.

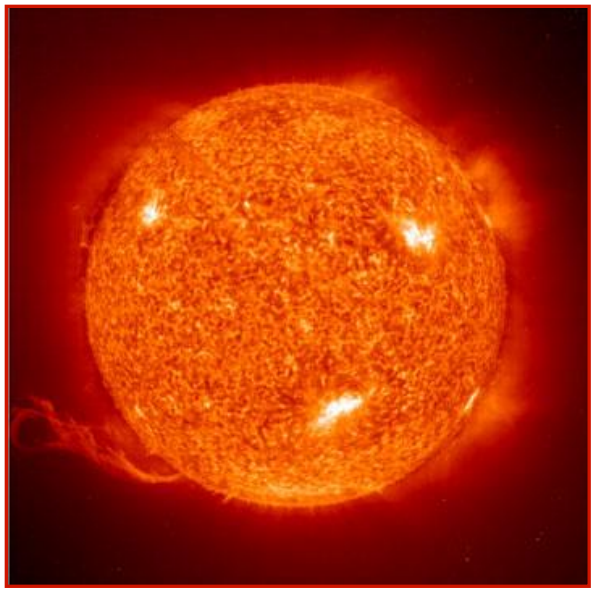
Observation: Left-over heat from the early universe. (Penzias and Wilson, 1965)



Testing the Big Bang model

Prediction: A hot, dense expanding universe, should be predominantly hydrogen, helium.

Observation: Universe is ~75% hydrogen, ~25% helium by mass



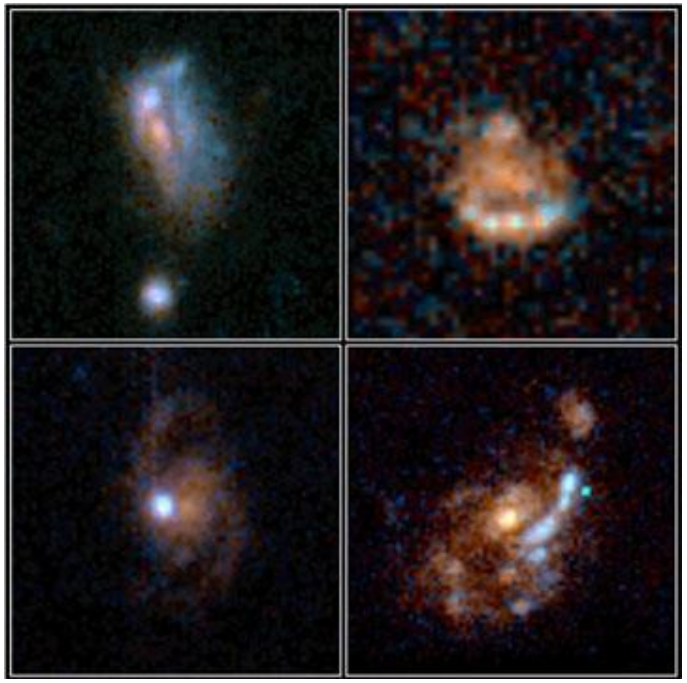
The Sun: 74.5% H, 24% He by mass

Cecilia Payne

Testing the Big Bang model

Prediction: An expanding universe is evolving over time. If we look at the early universe, it should appear different.

Observation: Distant galaxies less evolved, physically and chemically.



Testing the Big Bang model

Observation: 90% of matter is an unknown form: Dark Matter.

Refine: A new and unknown form of matter exists. But its gravity works the same way, and its presence is needed to explain how the universe looks.

Vera Rubin

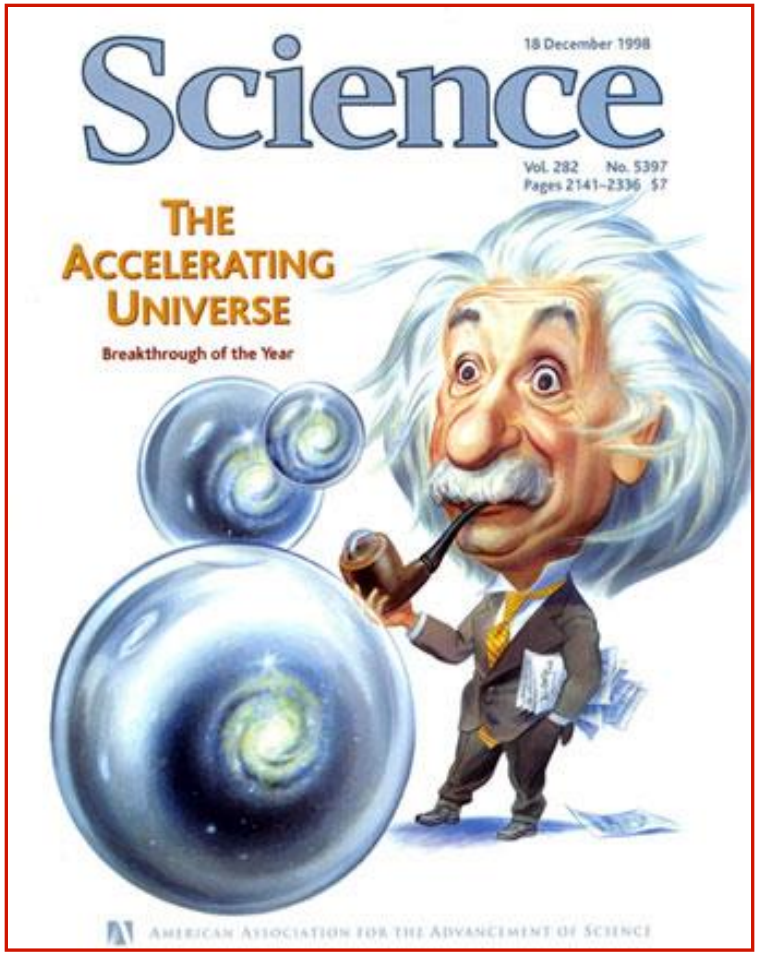
Testing the Big Bang model

Observation: Expansion is accelerating.

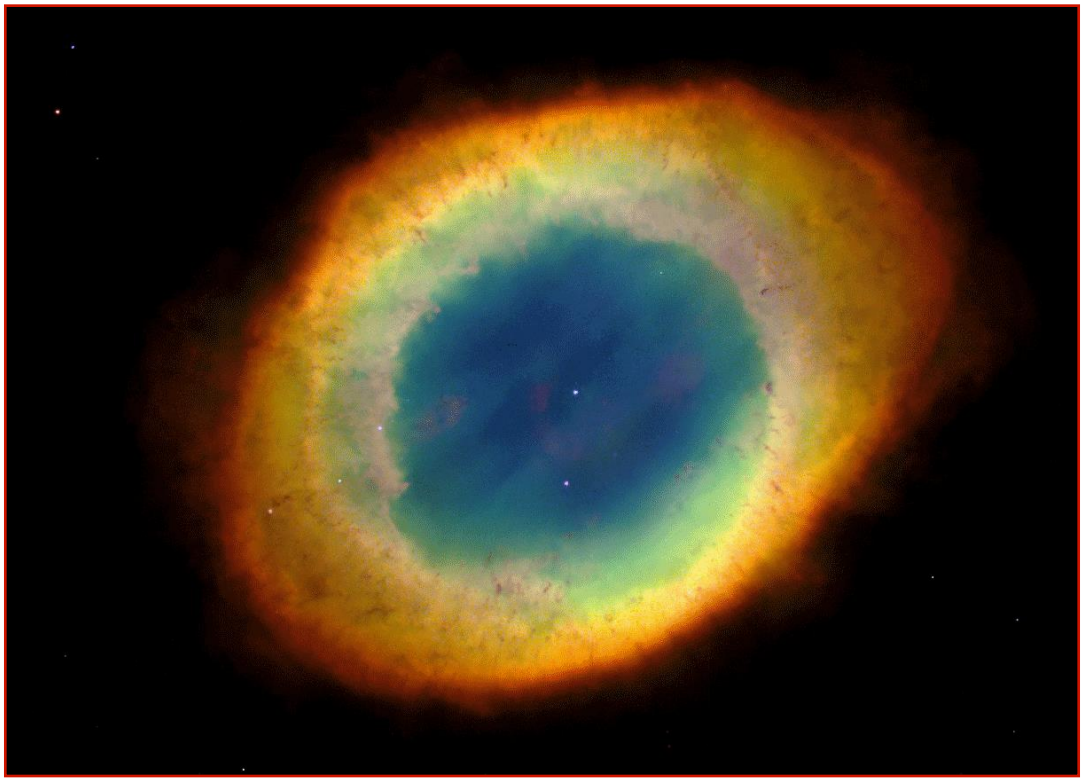
Refine: Extra energy content.

A recent discovery and of unknown origin,the concept of Dark Energy is actually an integral part of Einstein's theory of gravity.

theory of relativity lies nearest at hand; whether, from the standpoint of present astronomical knowledge, it is tenable, will not here be discussed. In order to arrive at this consistent view, we admittedly had to introduce an extension of the field equations of gravitation which is not justified by our actual knowledge of gravitation. It is to be emphasized, however, that a positive curvature of space is given by our results, even if the supplementary term is not introduced. That term is necessary only for the purpose of making possible a quasi-static distribution of matter, as required by the fact of the small velocities of the stars.

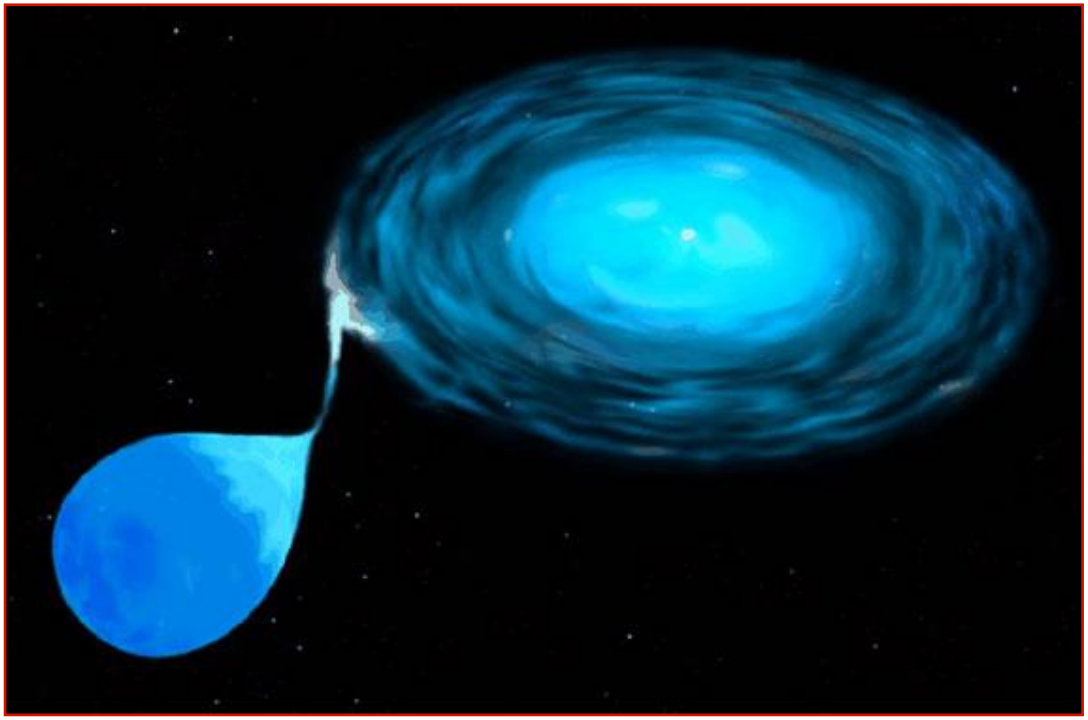


Evidence for Dark Energy - supernovae as distance indicators - step 1



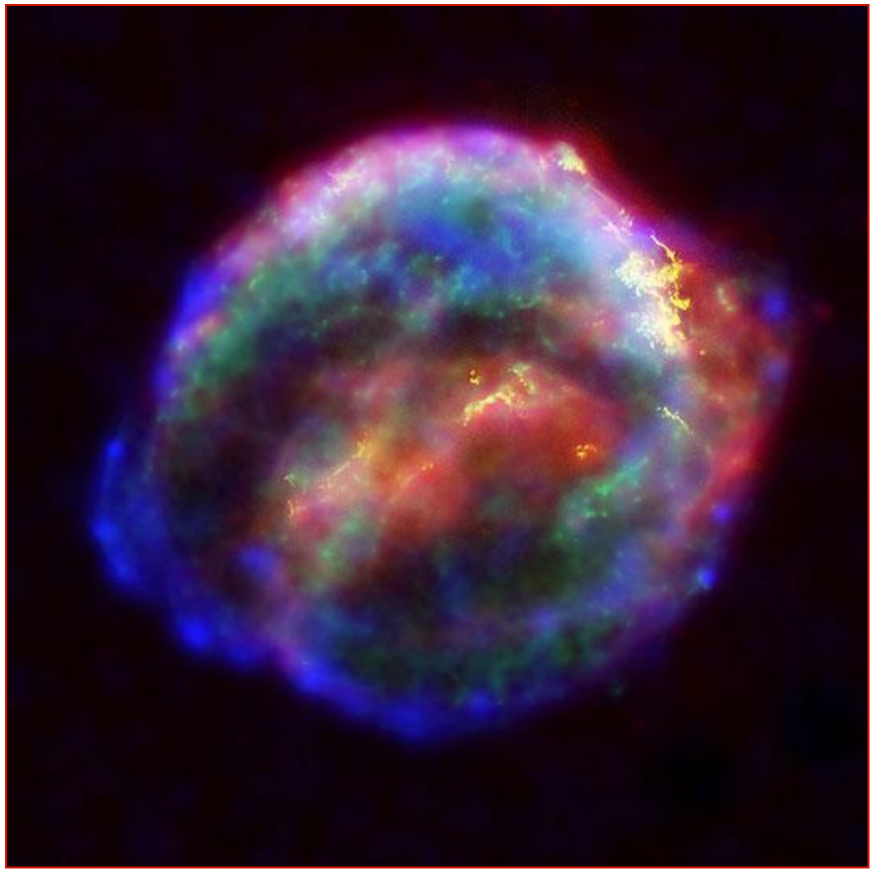
A dying star becomes a white dwarf.

Evidence for Dark Energy - supernovae as distance indicators - step 2



The white dwarf strips gas from its stellar companion….

Evidence for Dark Energy - supernovae as distance indicators - step 3



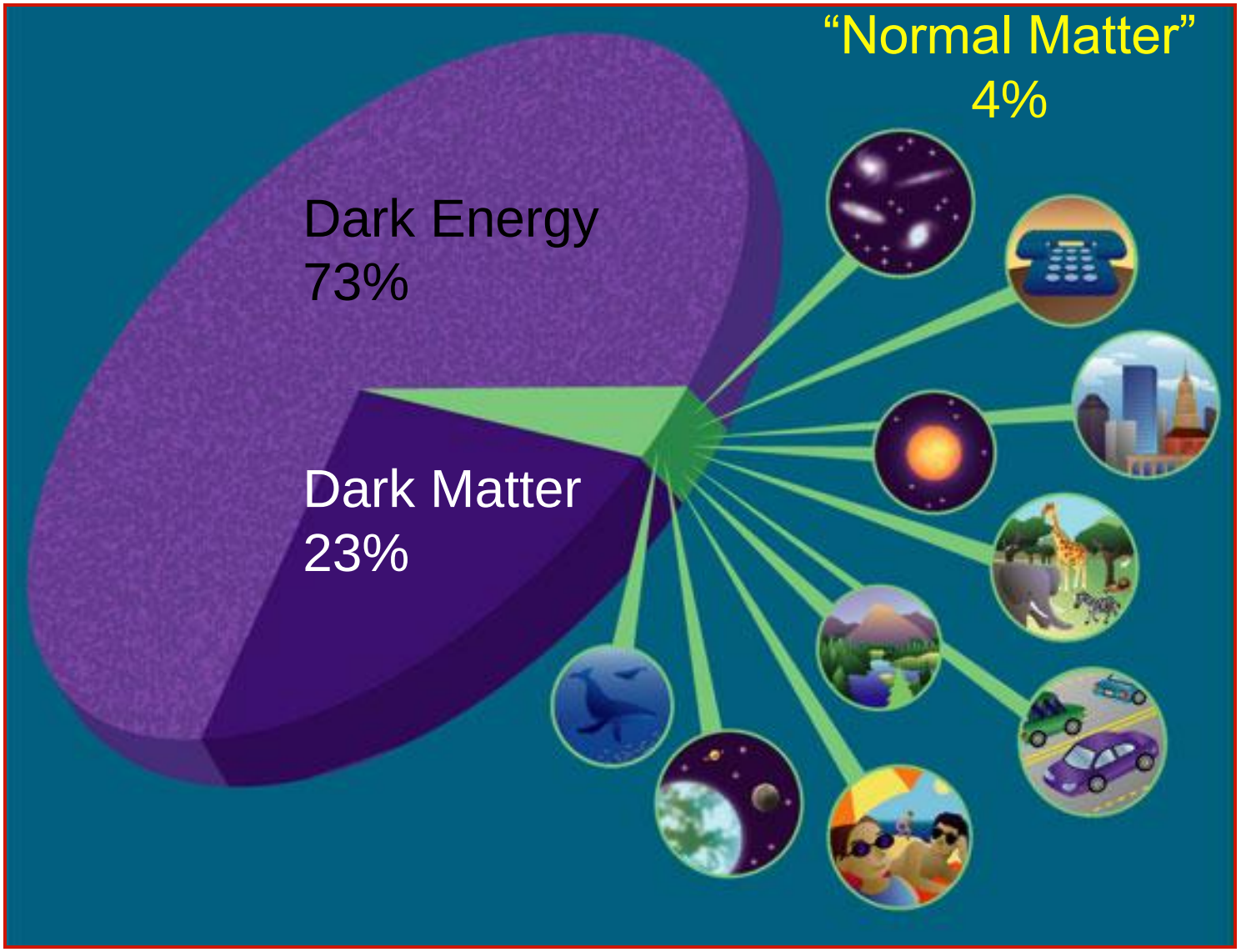
….and uses it to become a hydrogen bomb. Bang!

Evidence for Dark Energy - supernovae as distance indicators - step 4

The explosion is as bright as an entire galaxy of stars….

Evidence for Dark Energy - supernovae as distance indicators - step 5

…..and can be seen in galaxies across the universe.


“Normal Matter”
4%
Dark Energy
73%
Dark Matter
23%

Conclusions

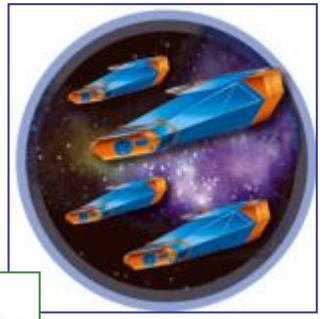
- Big Bang model describes our current understanding of the universe.

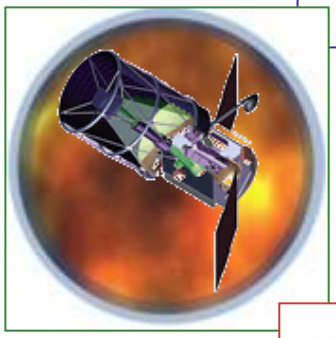
- New discoveries, such as dark matter and accelerating expansion (Dark Energy), lead us to refine our model, but there is no crisis in our understanding (yet).

- Science is an ongoing process - forcing us to test our model through prediction and observation. The more tests it passes, the greater is our confidence in it.

The Future of Cosmology: Beyond Einstein

- What powered the Big Bang?
- What is Dark Energy?
- How did the Universe begin?





THANK YOU