

Big Bang: the Creation of the Universe



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Cosmology

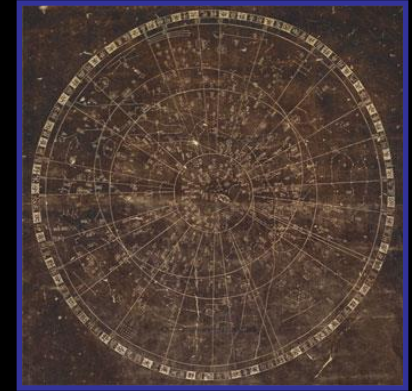


The Study of the Universe:

its structure, origin, evolution and destiny



Theories of the Origin of the Universe



- Theological Theories:

Greek Mythology

Chinese creation myth

Hinduism

Biblical account



Scientific Theories:

Big Bang Theory – the commonly accepted theory

Continuous creation – Steady State Theory



500 Years ago Universe appeared to be a small place

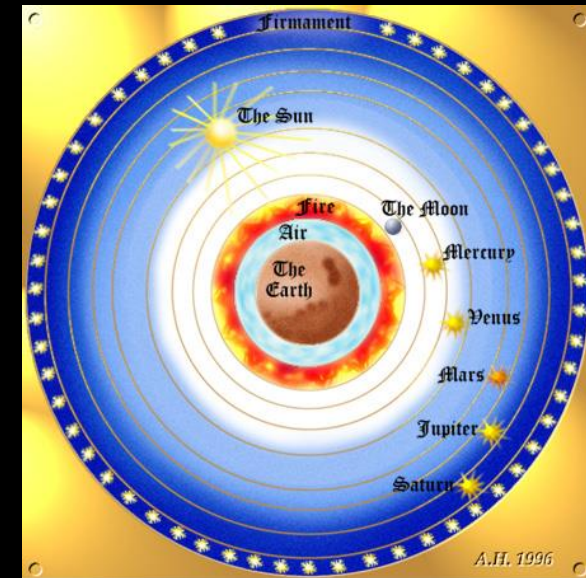
It was believed that our home - the **Earth** was the most important thing.

Earth was at the center of the Universe.

The **Sun** and the five planets (**Mercury, Venus, Mars, Jupiter & Saturn**) were thought to be small objects orbiting the Earth.

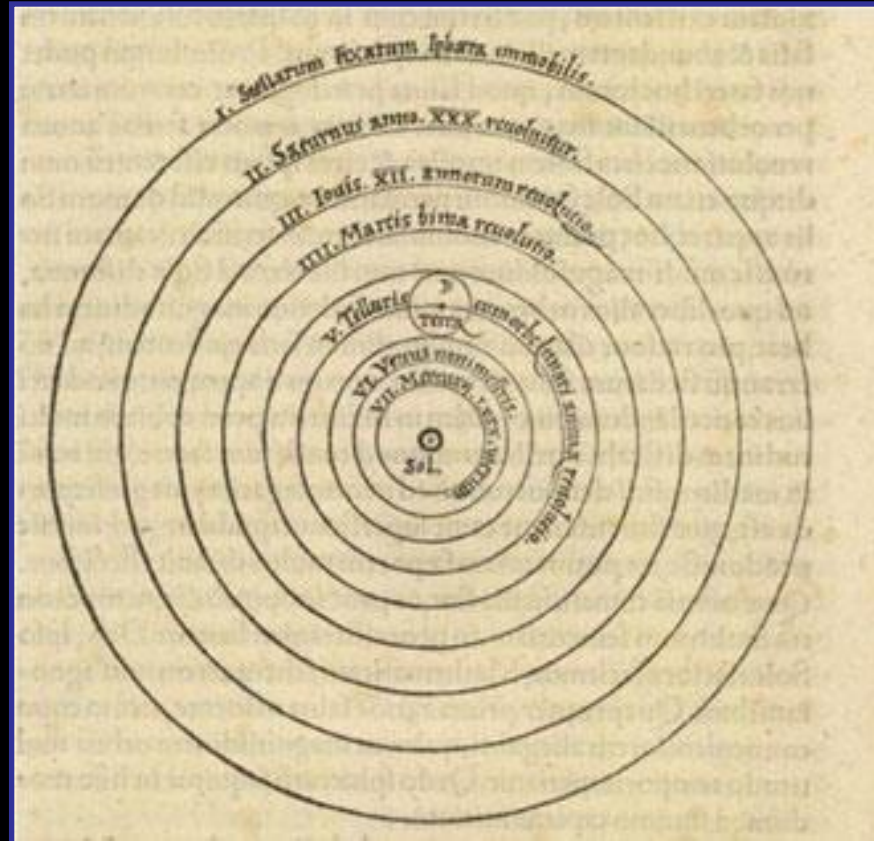
- **Stars** were believed to be points of light studded on a spherical shell centered on Earth.

Except for the changes in day and night and the seasons nothing much changed in the Universe.



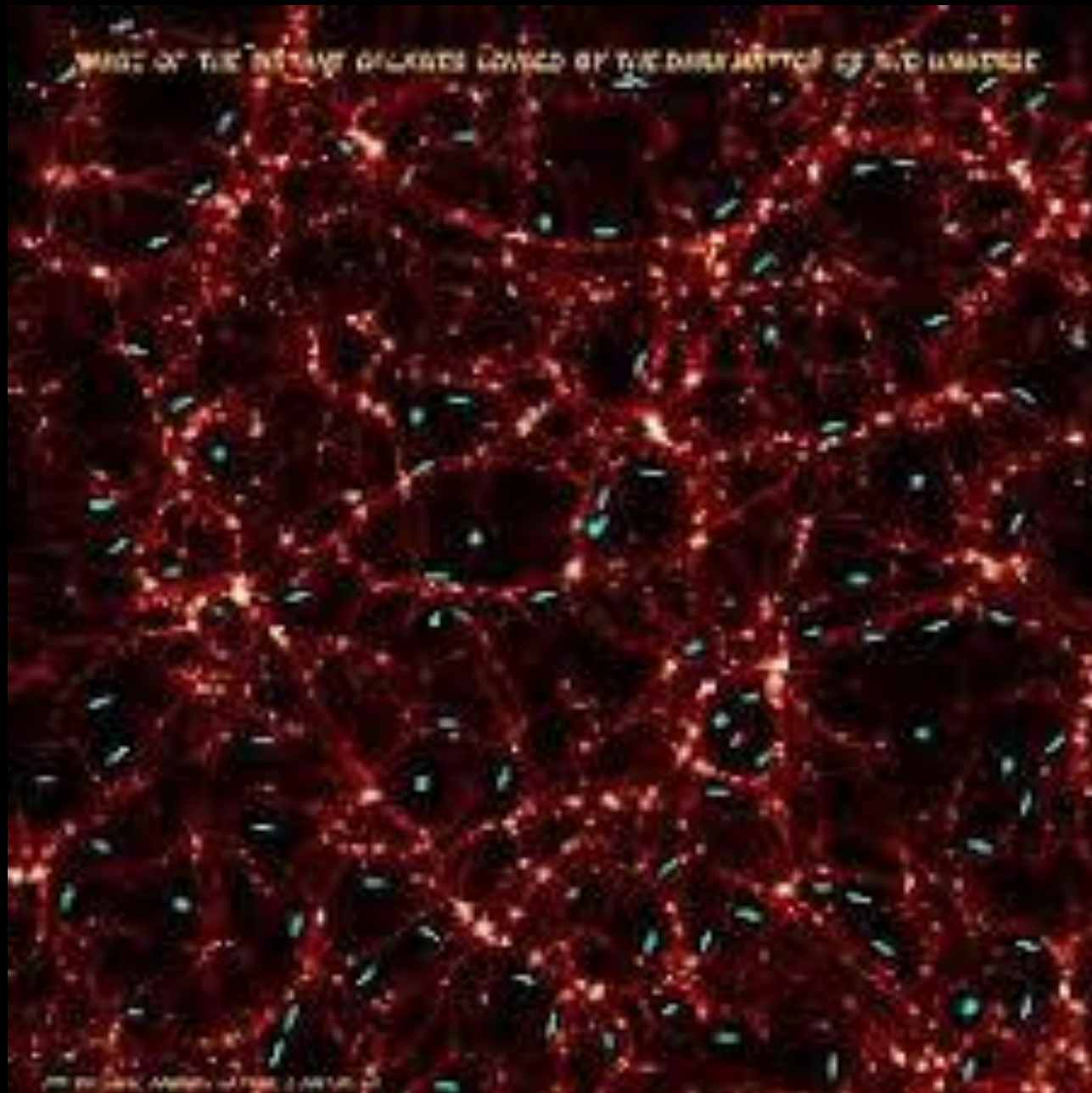
Universe was essentially unchanging – static, un-evolving!

Sun-centered Cosmology: Nicolaus Copernicus 1473-1543

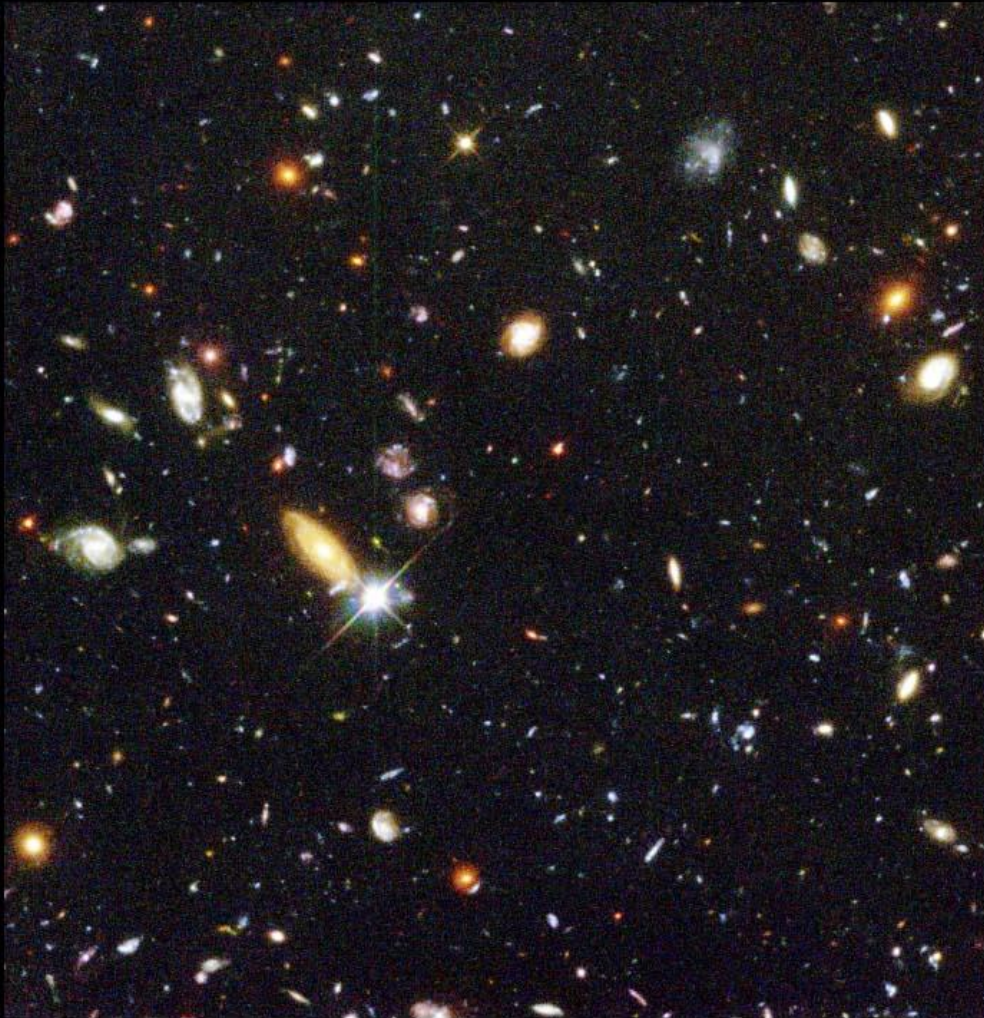


“At rest, however, in the middle of everything is the Sun.”
Nicholaus Copernicus, de Revolutionibus

Visible Universe 13.7 Billion Light years



A deep look at the Universe



This image is taken of galaxies that are billions of light-years away.

Light travels a finite velocity.

Hence, this photograph is of the conditions that existed billions of years ago.

A deep look in space is like a peep into the past.

Hubble Deep Field

HST · WFPC2

PRC96-01a · ST ScI OPO · January 15, 1996 · R. Williams (ST ScI), NASA

Edwin Hubble

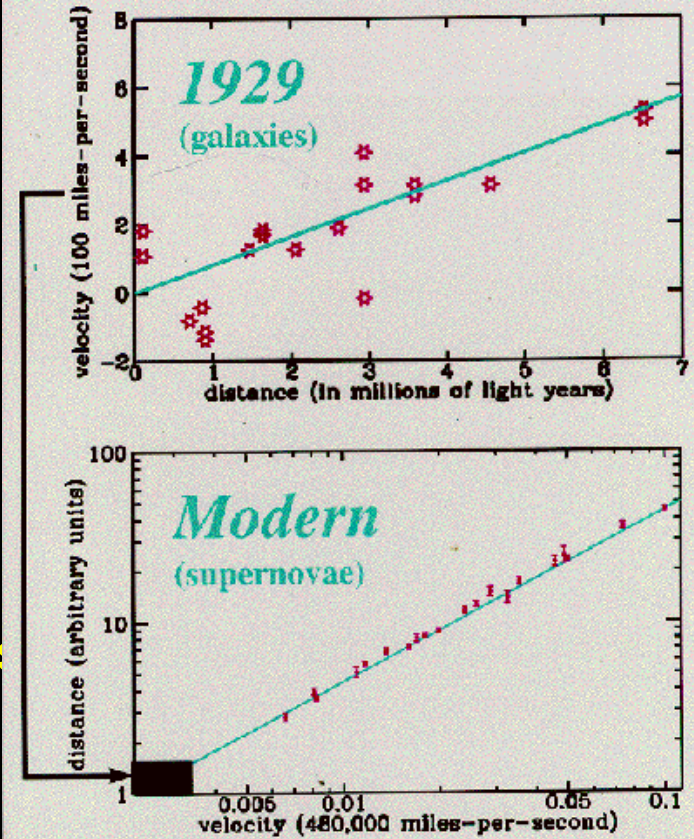


Two major break observations of Edwin Hubble
Discovery of external galaxies.

Using the Doppler effect, discovered that objects that were further away move away faster (and, hence, were redder) than nearer objects.

This discovery showed that the universe was expanding and still provides one of the best measurements of the age of the universe.

Hubble's Law



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Redshift

Hubble's Law

Lemaitre Hubble Law

$$v \propto d$$

$$v = Hd$$

$$H = 70 \text{ (km/s)/Mpc}$$

Big Bang Cosmology: Albert Einstein (1879-1955)

Albert Einstein's General Theory of Relativity predicts Expanding Universe – but ignored by him.

Lambda parameter



Origin of the Cosmos— 2 Options

- Option 1: Universe was created at a certain time. (**Big Bang Theory**)
- Option 2: The universe has always been here (**Steady State Theory**)

In favour of Option 1:

Creation of Universe

Humans, animals, plants, micro-organisms have a beginning (birth) & an end (death).

Atoms have a life time –they are created & destroyed.

Earth has an age – was created 4 billions years ago.

Moon has an age ~ about the same age of the Earth.

Sun has an age ~4.5 billion years.

All stars are created & destroyed.

Option 1: Creation of Universe

The universe came into existence through a cataclysmic explosion called the **Big Bang**.

Big Bang model

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

Prediction: The universe is expanding

Consequence

Evolving Universe

Beginning?

Finite Age?

End?



THE Big Bang/Nucleosynthesis

13.7 billion years ago

All the mass and energy was squeezed in a small region smaller than the head of a pin (singularity)

Unimaginable release of energy (an expansion not a traditional explosion) → trillions of degrees

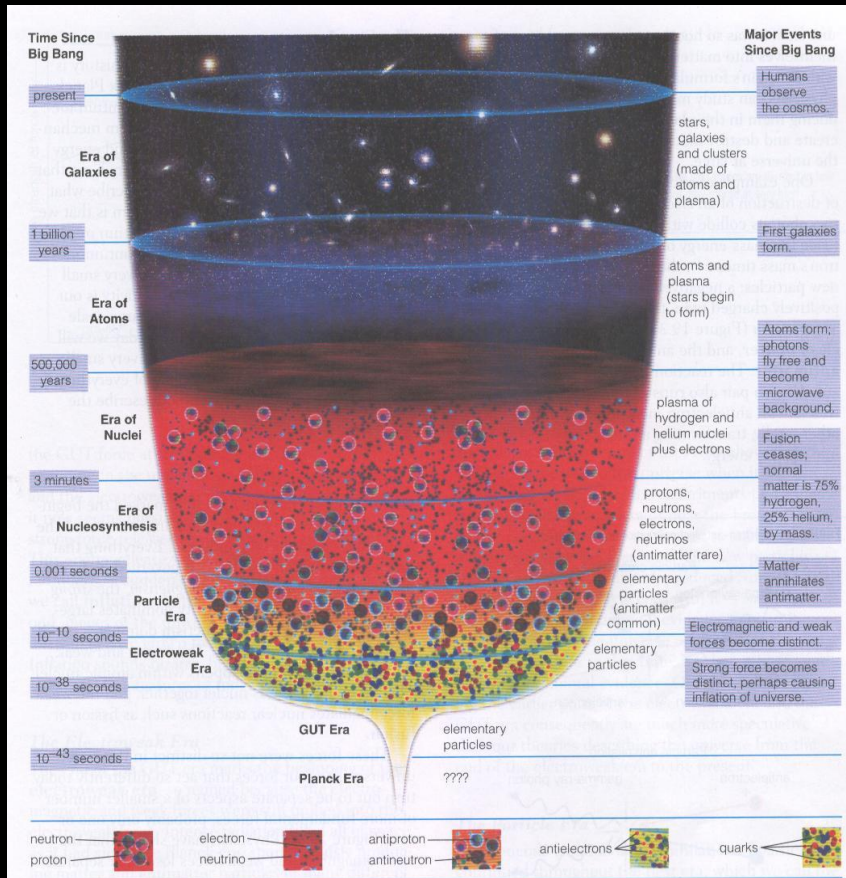
Nobody knows how/why it happened

Created space and time

Created the 4 main forces: gravity, strong, weak and electromagnetic forces.

Electrons, quarks and gluons created (building blocks for all atoms)

The Story of Creation



The Story is divided into eras, or time periods.

- Planck era: 10^{-43} s
- GUT era: 10^{-38} s
- Electroweak era: 10^{-10} s
- Particle era: 10^{-3} s
- Nucleosynthesis era: 3 min
- Nuclei era: 500,000 years
- Atoms era: 10^9 years
- Galaxies era: present

Planck era:

10^{-43} s after the big bang

As it began to cool, at around 10^{-43} seconds after creation, there existed an almost equal yet asymmetrical amount of matter and antimatter.

As these two materials are created together, they collide and annihilated one another creating energy.

Fortunately for us, there was an asymmetry in favour of matter. As a direct result of an excess of about one part per billion, the universe was able to mature in a way favourable for matter to persist.

As the universe first began to expand, this discrepancy grew larger. The particles which began to dominate were those of matter.

GUT era

Between 10^{-43} seconds and 10^{-36} seconds after the Big Bang

As the universe expanded and cooled, gravitation begins to separate from electromagnetism, the strong and weak nuclear forces.

Eventually, the grand unification is broken.

The only particle expected at this time is the Higgs boson.

Electroweak epoch

Between 10^{-36} seconds and 10^{-12} seconds after the Big Bang

The temperature of the universe is low enough (1028 K) to separate the strong force from the electroweak force.

This phase transition triggers a period of exponential expansion known as cosmic inflation.

Inflationary epoch

Between 10^{-36} seconds and 10^{-32} seconds after the Big Bang

During inflation, the universe is flattened (its spatial curvature is critical) and the universe enters a homogeneous and isotropic rapidly expanding phase which seeds of structure formation.

Nucleosynthesis

Between 3 minutes and 20 minutes after the Big Bang

The temperature of the universe falls to the point where atomic nuclei can begin to form.

Protons (hydrogen ions) and neutrons begin to combine into atomic nuclei in the process of nuclear fusion.

However, nucleosynthesis only lasts for a short time, after which time the temperature and density of the universe has fallen to the point where nuclear fusion cannot continue.

At this time, there is about three times more hydrogen than helium-4 (by mass) and only trace quantities of other nuclei.

Matter domination:

70,000 years after the big bang

At this time, the densities of non-relativistic matter (atomic nuclei) and relativistic radiation (photons) are equal.

The Jeans length, which determines the smallest structures that can form, begins to fall and perturbations begin to grow in amplitude.

Recombination:

377,000 years after the Big Bang

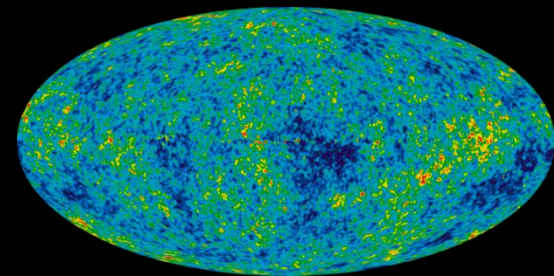
Hydrogen and helium *atoms* begin to form

Initially Hydrogen and helium are ionized,

As the universe cools down, the electrons get captured by the ions, making them neutral. This is known as recombination.

At the end of recombination, most of the atoms in the universe are neutral, therefore the photons can now travel freely: the universe has become transparent.

The photons in this epoch travel undisturbed and are those that we see in the cosmic microwave background (CMB) radiation.



Dark ages

- Before decoupling of matter from energy most of the photons in the universe interacted with electrons and protons in the photon-baryon fluid.
- As a result the universe is opaque or "foggy".

Structure formation

Reionization: 150 million to 1 billion years

The first quasars form from gravitational collapse. The intense radiation they emit reionizes the surrounding universe. From this point on, most of the universe is composed of plasma.

Formation of stars

The first stars, most likely Population III stars, form and start the process of turning the light elements that were formed in the Big Bang (hydrogen, helium and lithium) into heavier elements.

Structure formation in the big bang model proceeds hierarchically, with smaller structures forming before larger ones.

Formation of galaxies

Large volumes of matter collapse to form a galaxy. Population II stars are formed early on in this process, with Population I stars formed later.

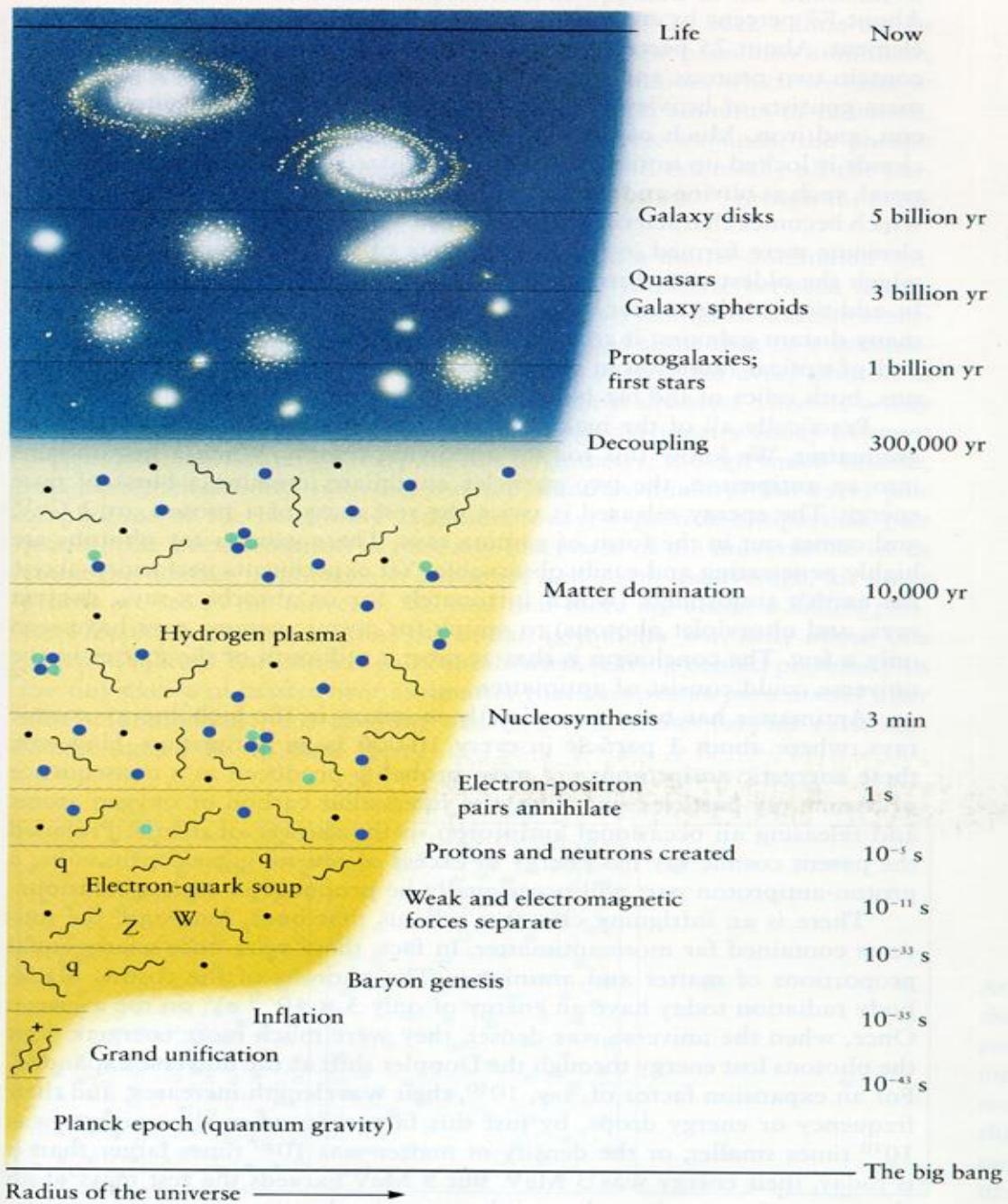
Formation of groups, clusters and superclusters

Gravitational attraction pulls galaxies towards each other to form groups, clusters and superclusters.

Today: 13.7 billion years

The best current data estimate the age of the universe today as 13.7 billion years since the big bang.

A CHRONOLOGY OF THE UNIVERSE



Ultimate fate of the universe

- Big freeze: 10^{14} years and beyond
- Big crunch: 100+ billion years
- Big rip: 20+ billion years from now
- Vacuum metastability event

Fate of the Universe

- Big freeze: 10^{14} years and beyond

 - The universe continues expanding as it has been.

 - Existing stars burn out

 - Stars cease to be created

 - The universe goes dark.

 - This scenario is generally considered to be the most likely

- Big crunch: 100+ billion years

 - If the energy density of dark energy were negative or the universe were closed, then it would be possible that the expansion of the universe would reverse and the universe would contract towards a hot, dense state.

 - This is often proposed as part of an oscillatory universe scenario, such as the cyclic model.

 - Current observations suggest that this model of the universe is unlikely to be correct, and the expansion will continue or even accelerate.

Fate continues.....

Big rip: 20+ billion years from now

This scenario is possible only if the energy density of dark energy increases without limit over time.

In this case, the expansion rate of the universe will increase without limit.

Everything will be ripped apart, clusters of galaxies, galaxies, planetary systems even atom.

Vacuum metastability event

If our universe is in a very long-lived vacuum, it is possible that the universe will go into a lower energy state. If this happens, all structures will be destroyed instantaneously, without any forewarning.

What decides the fate of the Universe

Mass of the Universe

Curvature of the Universe

Dark energy

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.

Thank You

Ancient Greek Cosmology

In the beginning there was an empty darkness.

The only thing in this void was Nyx (Chaos), a bird with black wings.

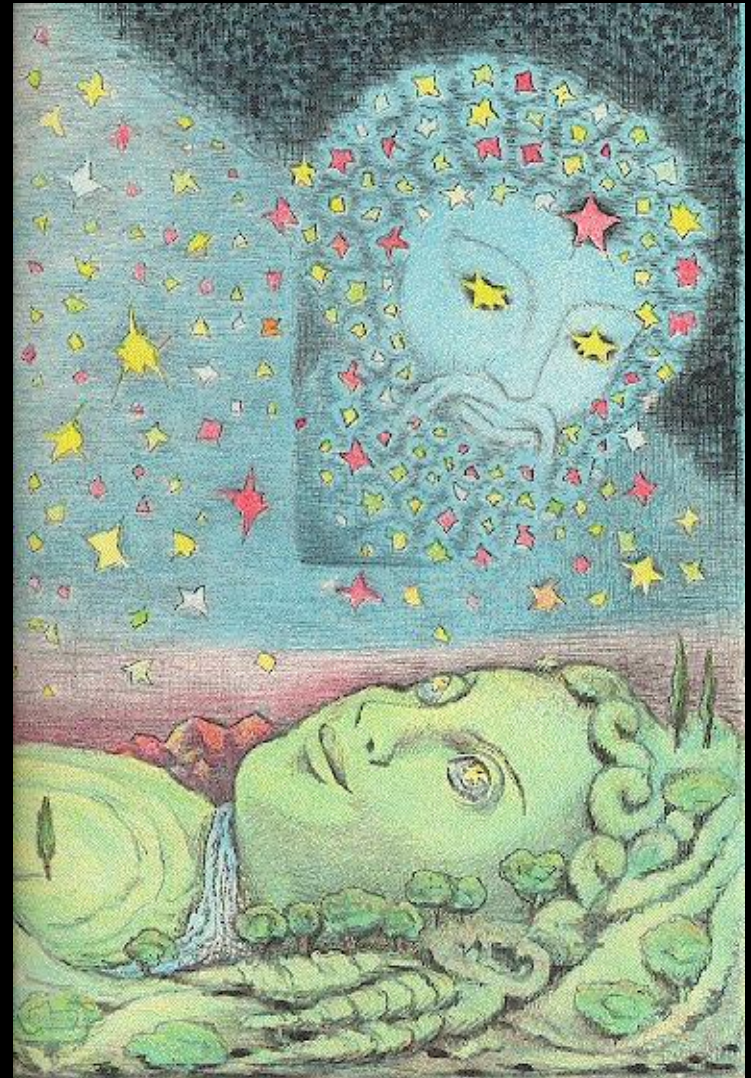
With the wind she laid a golden egg and for ages she sat upon this egg.

Finally life began to stir in the egg and out of it rose Eros, the god of love.

One half of the shell rose into the air and became the sky and the other became the Earth.

Eros named the sky Uranus and the Earth he named Gaia.

Then Eros made them fall in love.





Pangu and the Creation of the World

- **In the beginning there was darkness everywhere, and Chaos ruled.**
- **Within the darkness there formed an egg, and inside the egg the giant Pangu came into being.**
- **For aeons, safely inside the egg, Pangu slept and grew.**
- **When he had grown to gigantic size he stretched his huge limbs and in so doing broke the egg.**
- **The lighter parts of the egg floated upwards to form the heavens and the denser parts sank downwards, to become the earth.**
- **And so was formed earth and sky, Yin and Yang.**



Familiar Cosmology

In the beginning God created the heaven and the earth.

And the earth was without form, and void; and darkness was upon the face of the deep. And the Spirit of God moved upon the face of the waters.

3. And God said, Let there be light: and there was light.

4 And God, looking on the light, saw that it was good: and God made a division between the light and the dark,

5 Naming the light, Day, and the dark, Night. And there was evening and there was morning, the first day.....



Hinduism – creation of the universe

Hindu religion is the only one of the world's great faiths dedicated to the idea that the cosmos itself undergoes an immense, indeed an infinite number of deaths and rebirths. It is the only religion in which the time scales correspond, no doubt, by accident, to those of modern scientific cosmology.

Its cycles run from:

our ordinary day and night to

a day and night of Brahma 8.64 billion years long.

Longer than the age of the earth or the sun and about half of the time since the big bang. And there are much longer time scales still!

• The universe is but the dream of the god who after a 100 Brahma years... dissolves himself into a dreamless sleep... and the universe dissolves with him... until after another Brahma century... he starts... recomposes himself and begins again the dream... the great cosmic lotus dream.

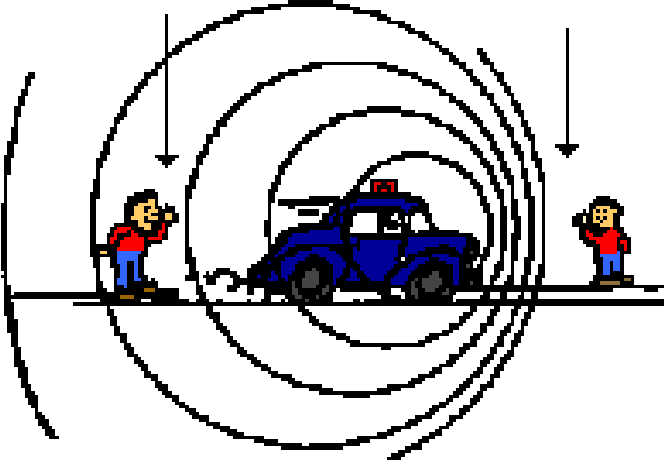
Meanwhile... elsewhere... there are an infinite number of other universes... each with its own god... dreaming the cosmic dream...



Doppler Effect

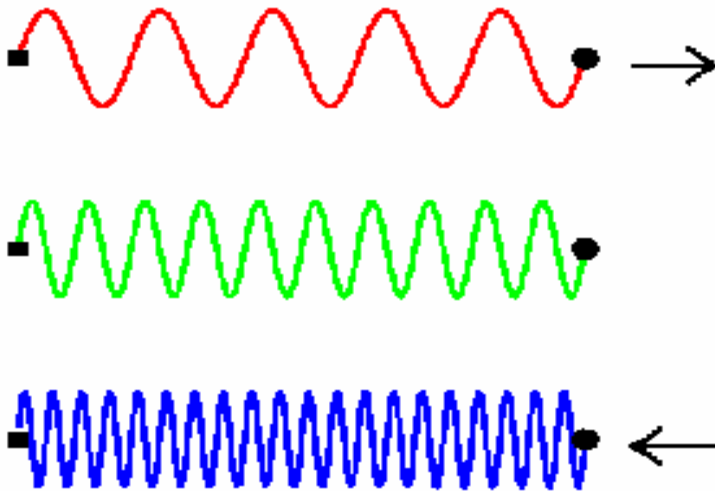
Long Wavelength
Low Frequency

Small Wavelength
High Frequency



The Doppler Effect for a moving sound source

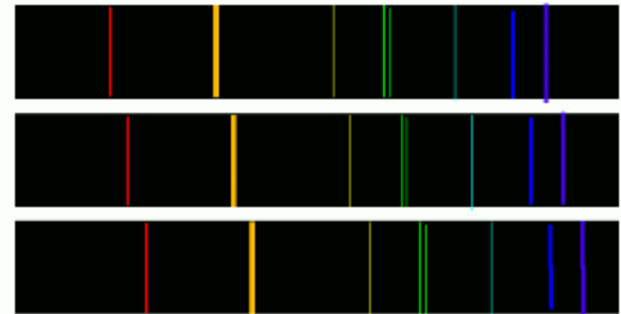
The Doppler effect says that things moving away from you look redder than they would if they weren't moving. Things moving towards you look more blue.



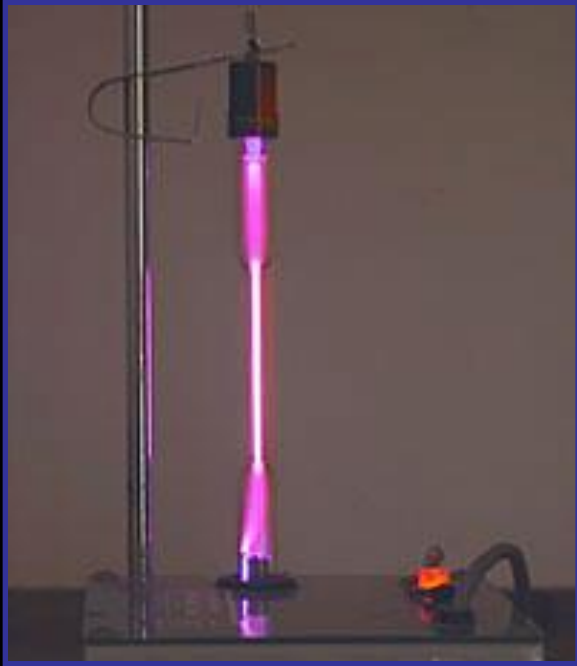
red shift

no motion

blue shift

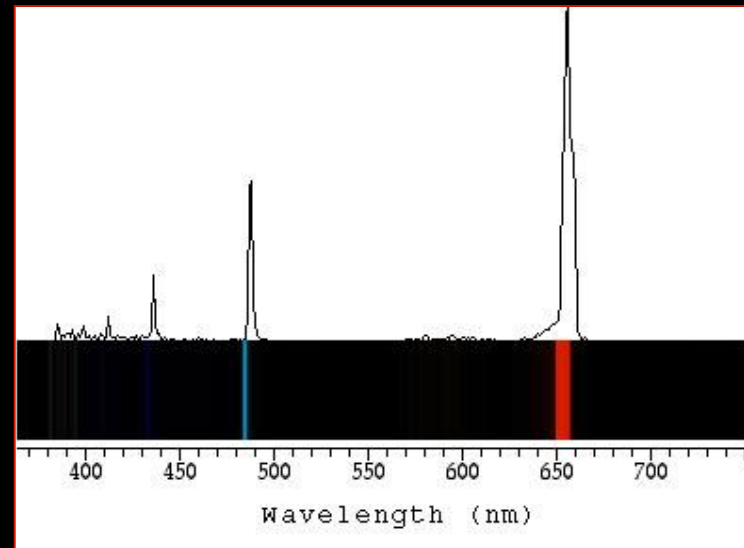


Evidence for an expanding universe



Hydrogen lamp

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

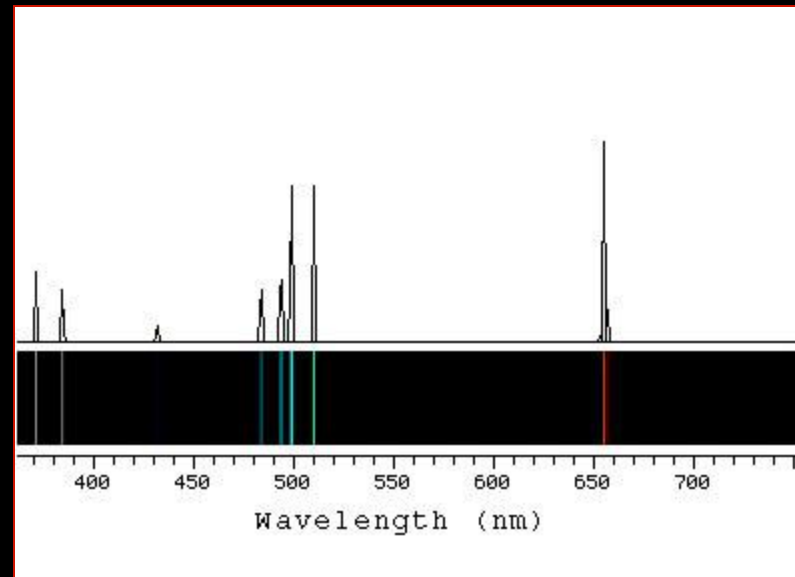


Evidence for an expanding universe

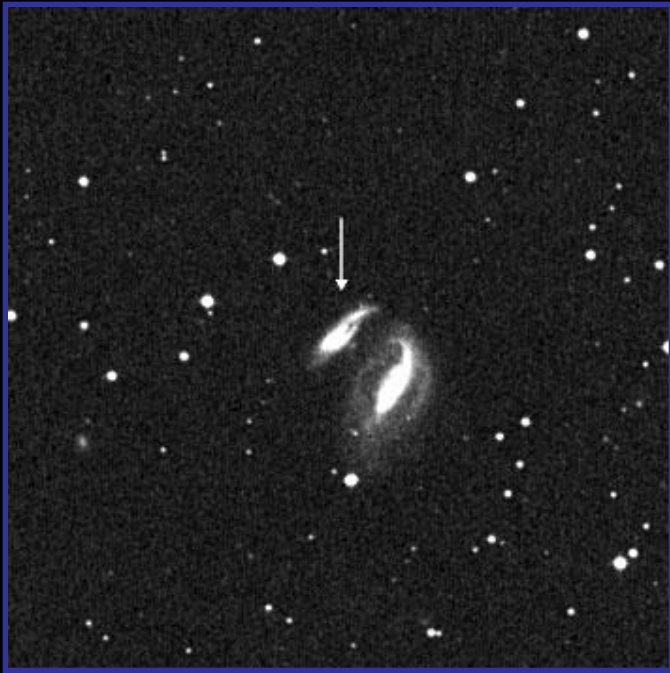


Orion Nebula

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

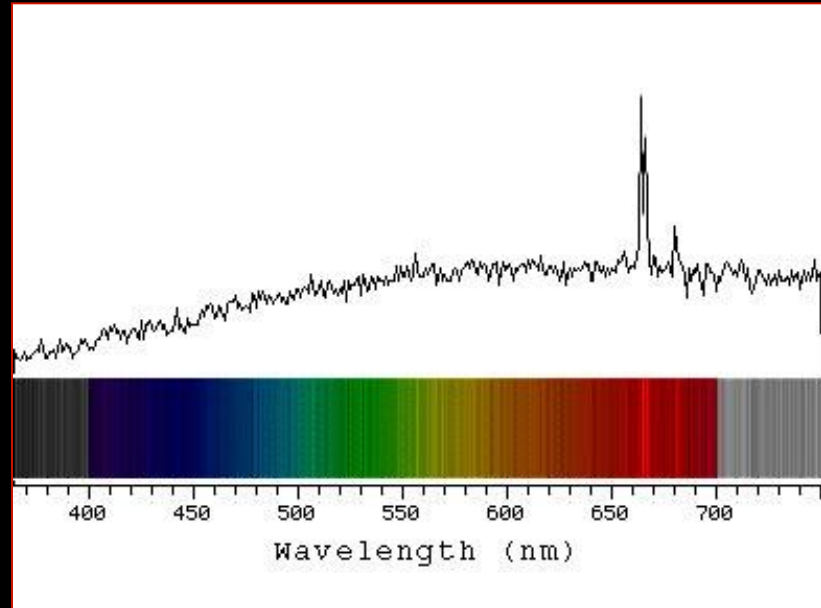


Evidence for an expanding universe



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

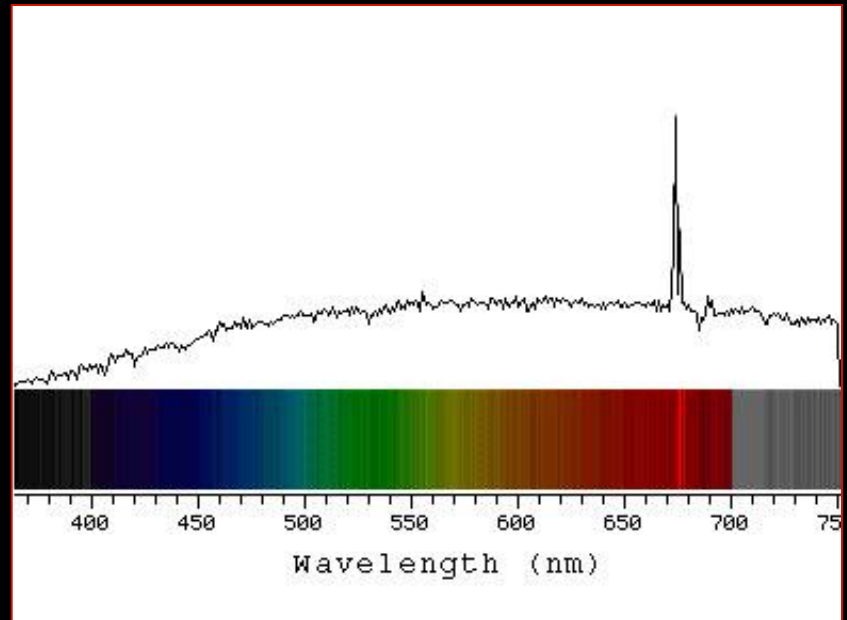
Galaxy UGC 12915



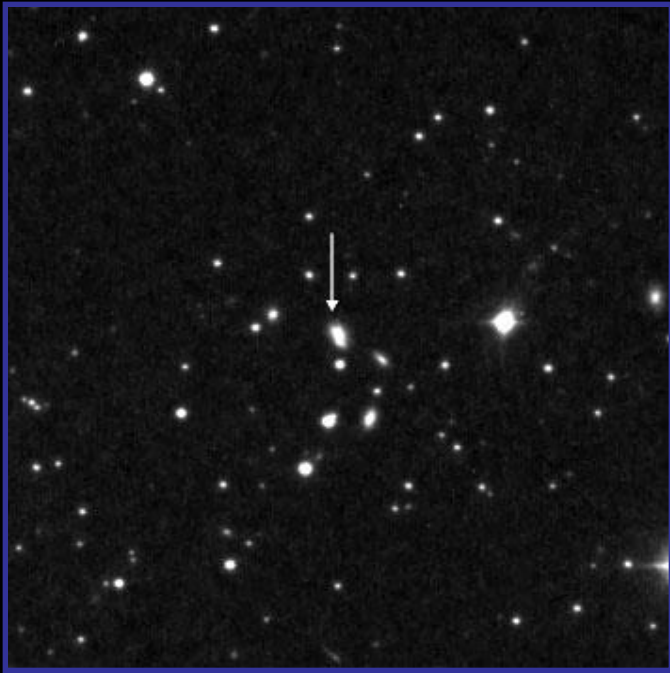
Evidence for an expanding universe



Galaxy UGC 12508



Evidence for an expanding universe



Galaxy KUG 1750

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

