Overview of Relativity

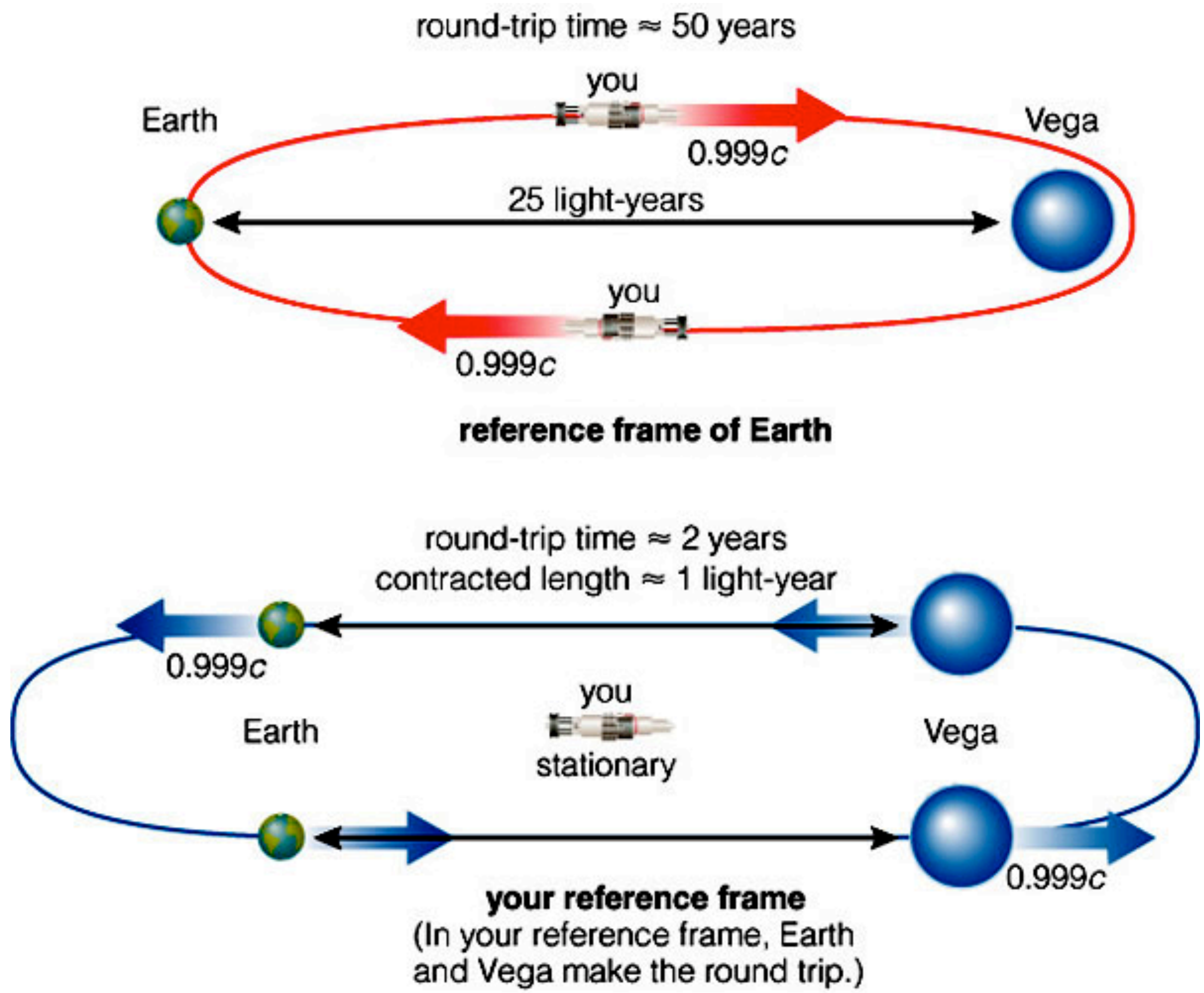
1. By the beginning of the 20th century, it became clear that Newton's Laws of Motion & Gravity were not completely general. In particular, Newton's Laws do not correctly describe motions of objects that are traveling ***near the speed of light or that are in a very strong gravitational field***.

2. Einstein developed several important postulates about motion:
   - There is no absolute rest frame in the Universe. The best that one can do is measure *relative* motions.
   - The speed of light, **c**, is **constant** with respect to all observers, independent of velocity. This makes light a very different phenomenon from objects with mass that have different apparent velocities depending on the motion of the observer. This result gives rise to different *relative* measures of time and length as determined by two observers in motion.

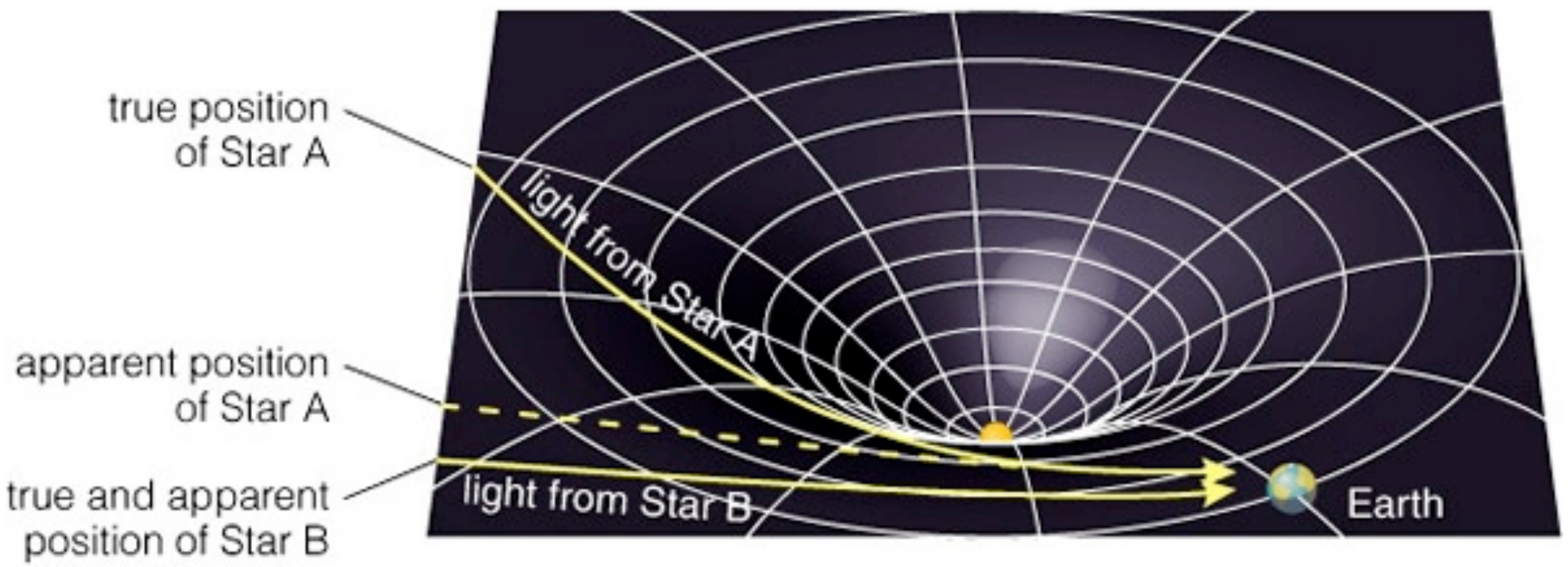
3. The above postulates gave rise to Einstein's famous law relating the equivalence of mass of energy.

4. Although Einstein's Theory of Relativity produced different results from Newton for velocities near light and for strong gravity, ***it completely agrees with Newton for lower velocities and gravity*** fields like that on Earth.

Time goes slower on fast moving objects



Space is curved by mass



Gravitational lenses

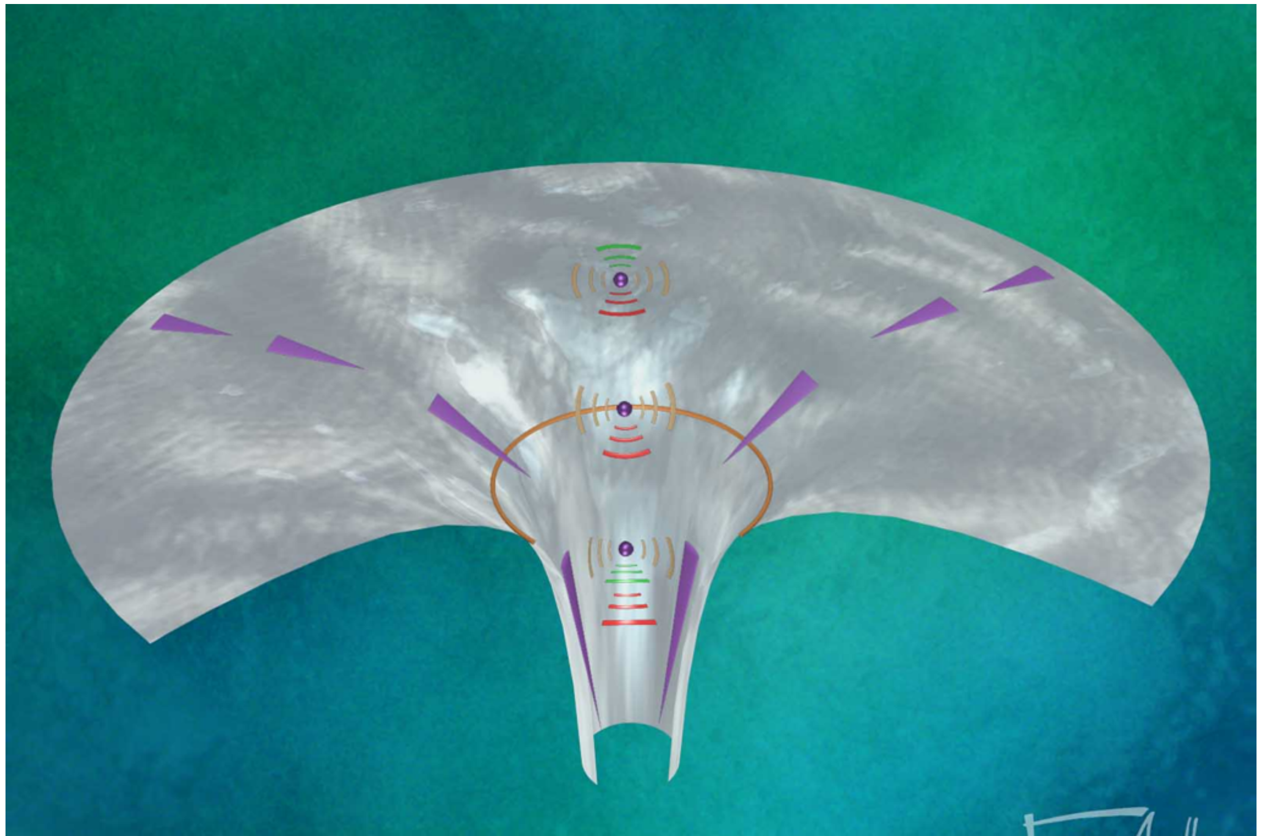
- Einstein's Relativity Theory predicts that the larger the mass, the greater the curvature (or indentation) of space-time. A black hole is the extreme example in which the indentation is infinitely deep.

- Consequences include:

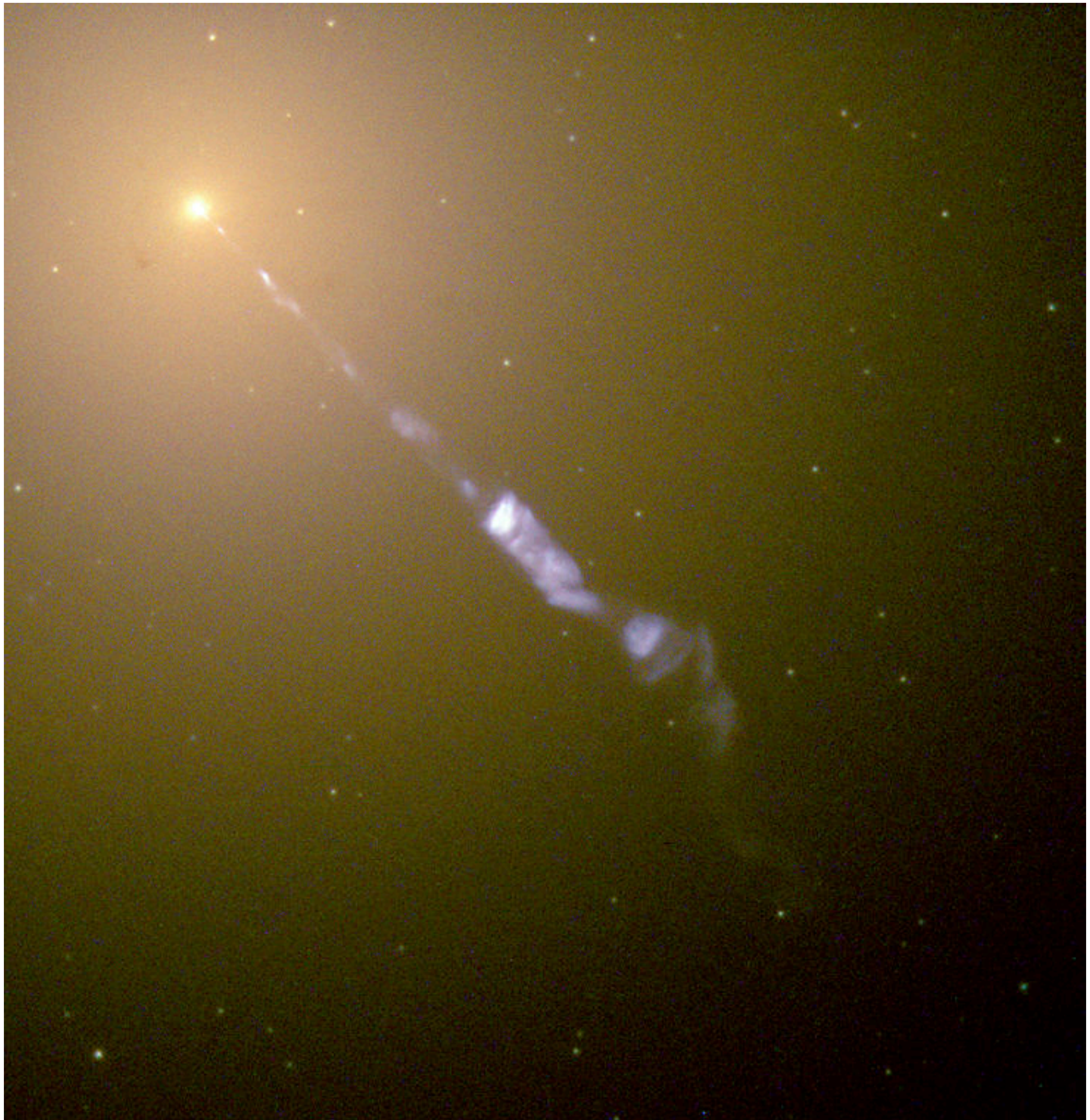
    - At the ``**event horizon**'' or *Schwarzschild* ***radius of a black hole, the escape velocity is equal to the speed of light.*** For an object with the mass of the Sun, this radius is only 1.5 km; for an object with 10Msun, this radius is 15 km.

    - Once an ***object falls inside the event horizon, it can never come back out***. It is lost forever to us. This includes light which is the reason we call this object a ``black hole''.

    - Although time would appear to run normally for an astronaut approaching a black hole, an outside observer would judge that the astronaut's clock is running slowly. In fact, that outside observer would see that it would appear to take an ***infinitely long time for the astronaut to fall into the black hole*** at the event horizon. This is due to the extreme curvature of space-time near the black hole.



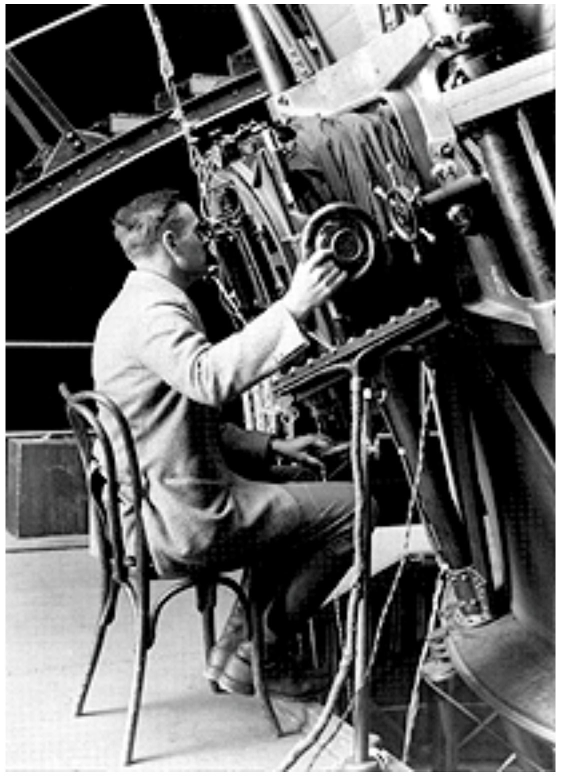
M87 giant elliptical galaxy has a powerful jet, which is coming from the a disk around 10^9Msun black hole



Universe: Expansion law, Age, Geometry

Universe: Expansion law, Age, Geometry

Edwin Powell Hubble (November 20, 1889 – September 28, 1953) was an American astronomer who played a crucial role in establishing the field of extragalactic astronomy and is generally regarded as one of the most important observational cosmologists of the 20th century. Wikipedia



Universe: Expansion law

$$V = H \times R$$

Velocity, with which a galaxy moves away from our Milky Way is proportional to the distance to that galaxy

V is the velocity, with which the galaxy moves away from our Galaxy

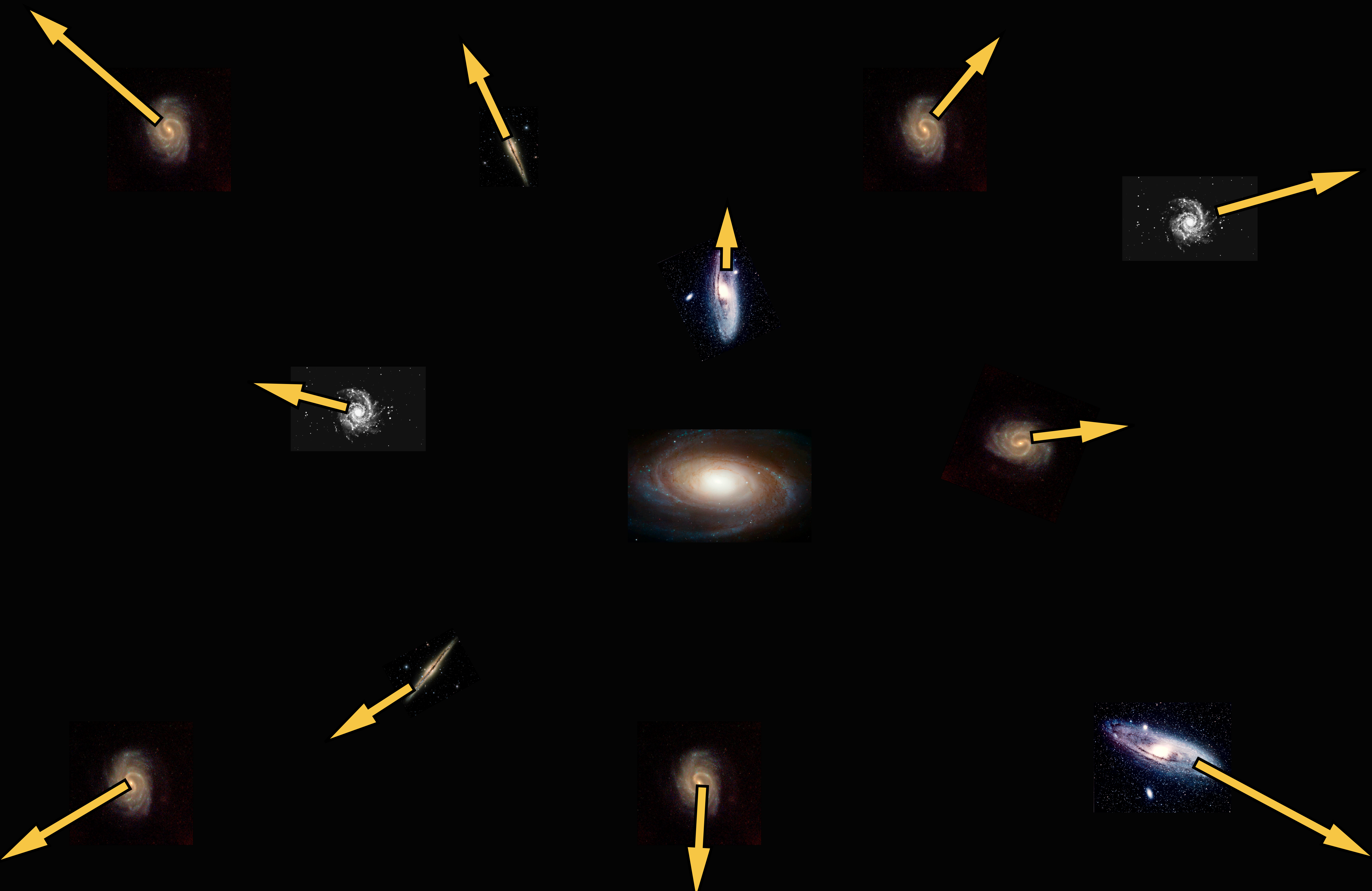
R is the distance between the galaxy and our Galaxy

H is a constant called the Hubble constant. It defines the rate of expansion of the Universe.

According to recent measurements,
H =70 km/s/Mpc

Expansion of the Universe

Expansion of the Universe



Questions:

- Center: If the Universe expands, is there a center of expansion?
- How can an infinite Universe expand?
- Expansion started about 13.6 billion years ago. What was before?
- How was it created?

Expansion of the Universe: every galaxy is the center

E. Hubble, 1929

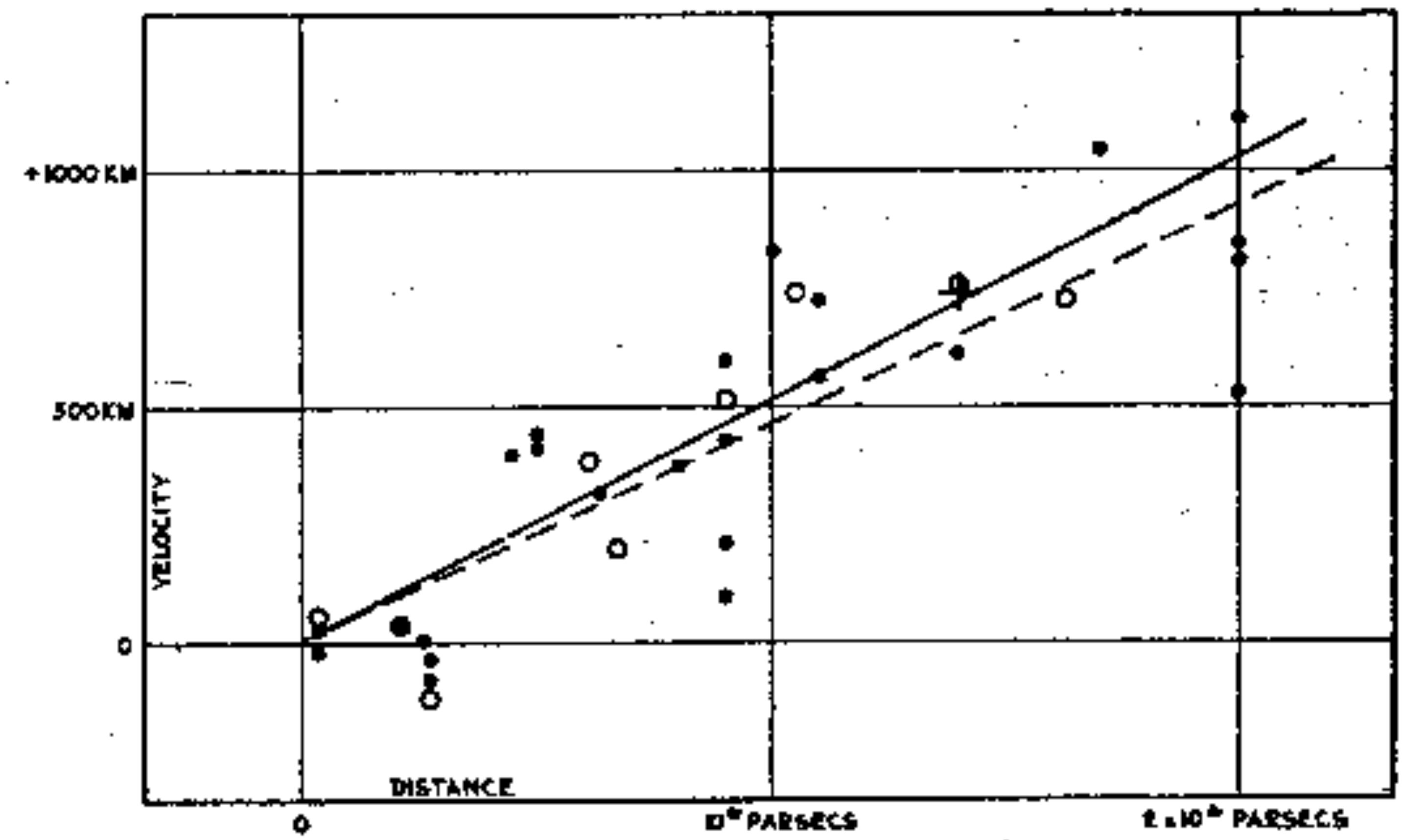
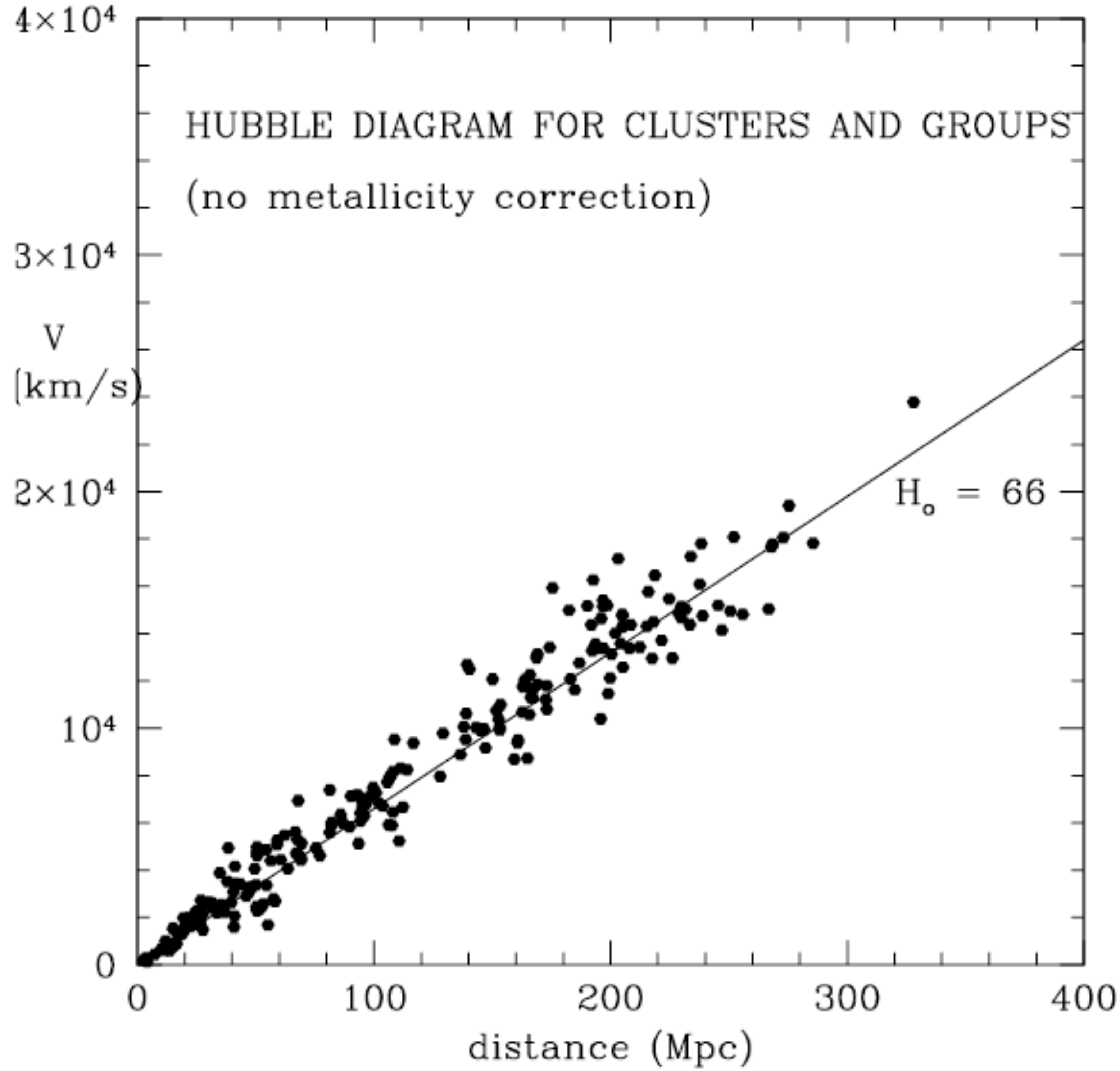


FIGURE 1

From the Proceedings of the National Academy of Sciences
Volume 15 : March 15, 1929 : Number 3
A RELATION BETWEEN DISTANCE AND RADIAL VELOCITY AMONG EXTRA-GALACTIC NEBULAE
By Edwin Hubble
Mount Wilson Observatory, Carnegie Institution of Washington
Communicated January 17, 1929

Universe: Expansion law, Age, Geometry



M. Rowan-Roberson 2000

Universe: Age

The universe is 13.6 billion years old.

$$\mathbf{V = H \times R}$$

The Hubble law can be used to estimate the age:
If we know the recession velocity and the distance, then the time to move to the distance with this velocity is just:

$$\text{Time} = \text{Distance}/\text{Velocity}$$

This gives: $\mathbf{Age = 1/H}$

The Hubble constant is H = 70 km/s/(10^6parsec). The age of the Universe is slightly different than this estimate because H changes with time. However, the simple estimate is quite accurate.

Universe: Age

The universe is 13.6 billion years old. ← *From the rate of expansion*

Age of oldest stars in our Galaxy 10-12 billion years. ← *From HR diagram and evolution of stars*

Age of the Earth is 4.6 billion years. ← *Decay of isotops*

Long House can host many people

Infinitely Long House can host infinite number of people.
It can infinitely expand without running on a boundary

This is a simple model of a Universe, which does not have boundaries and which expands.

Universe: Size

Distance to Andromeda Nebula is 0.7 Mpc

Distance to nearest large cluster of galaxies in Virgo is 10 Mpc

Size of a Giant Void in the distribution of galaxies 100 Mpc

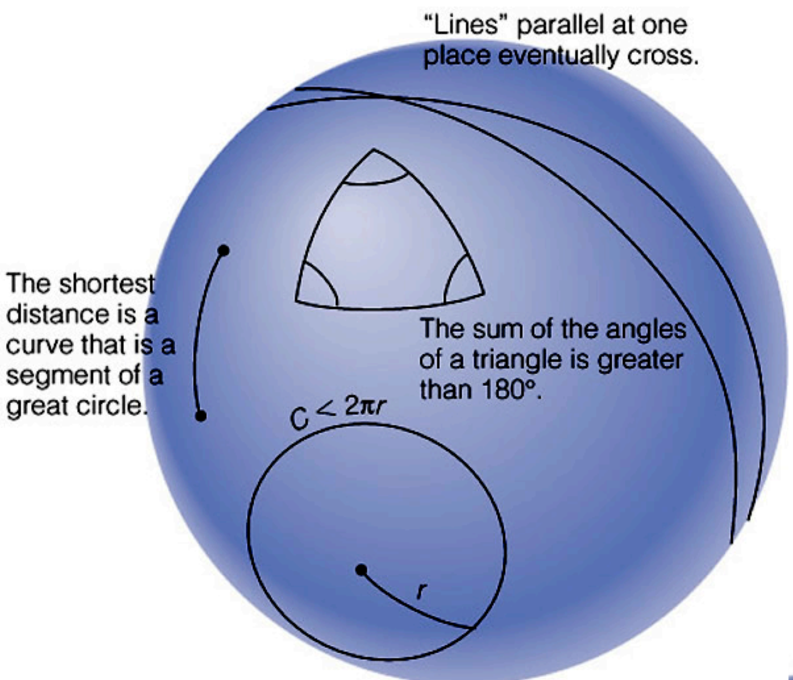
The most remote observed objects (galaxies) are 10,000 Mpc away

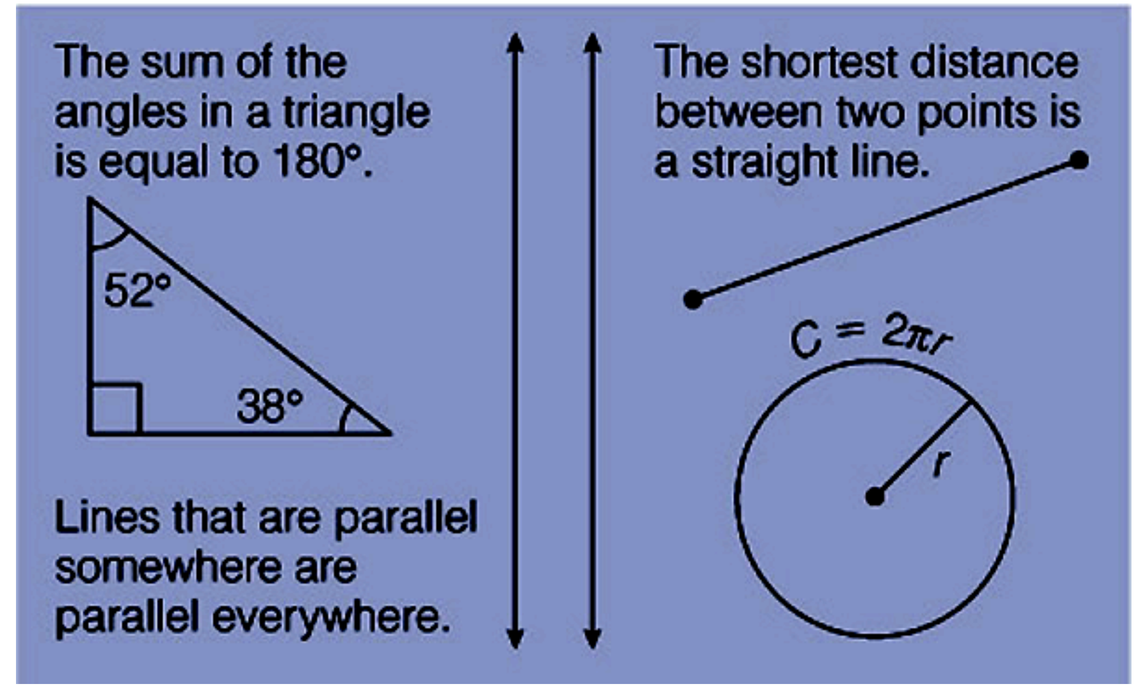
With the average distance between galaxies of 1Mpc, the number of galaxies in the Universe is 1 trillion

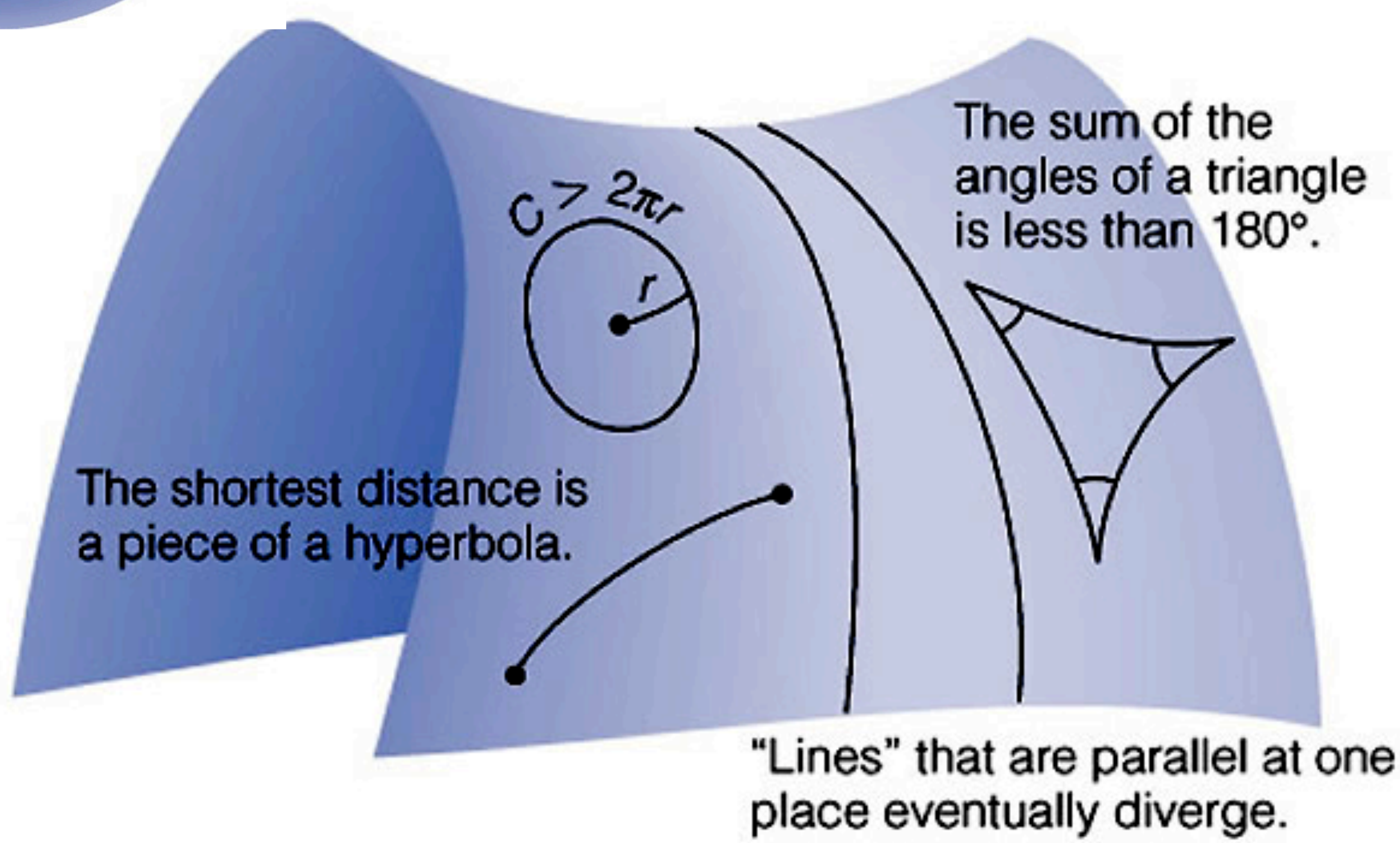
Observing the young Universe

When we look at galaxies at very large distances , we see them when they emitted light long ago. The galaxies were very young then.

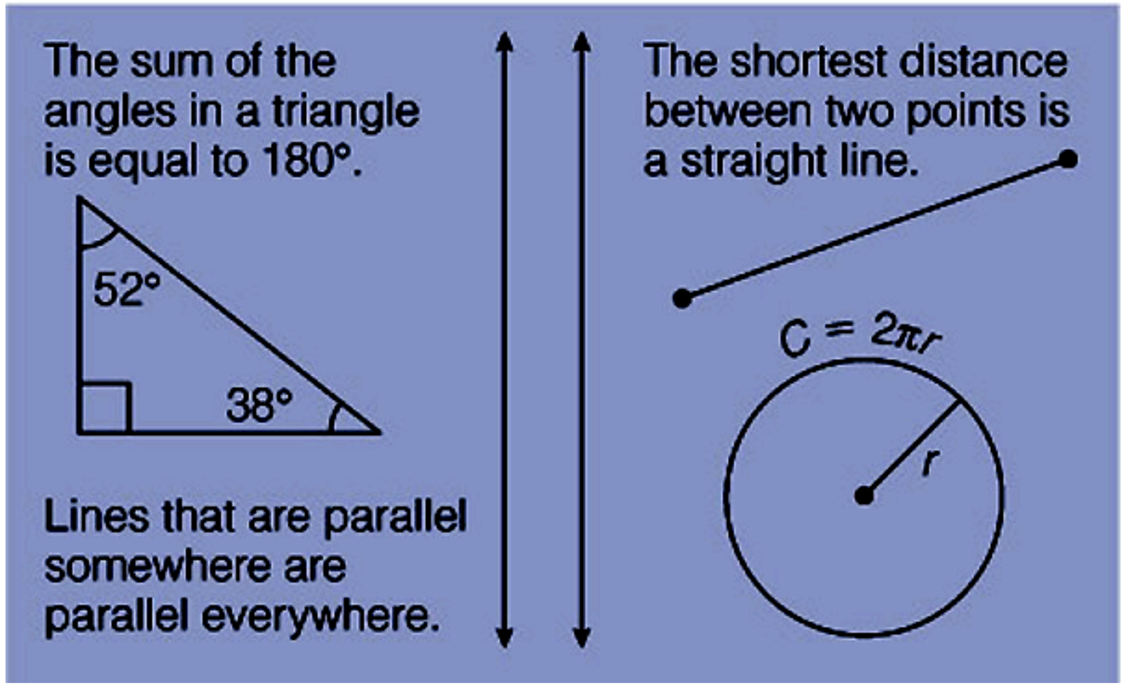
Universe: Geometry: three choices







Universe: Geometry is flat



The Steady State Model

- Throughout the 1950's and early 1960's, the most popular model of the Universe was the *Steady State* model.
- The Steady State model assumes the Universe is the same at all times and in all locations. Thus, the Universe had no beginning and will have no end.
- For this to be true in light of the Hubble expansion, there must be continuous creation of matter to keep the average density of the Universe constant.

At the end this model was rejected

The Big Bang Model

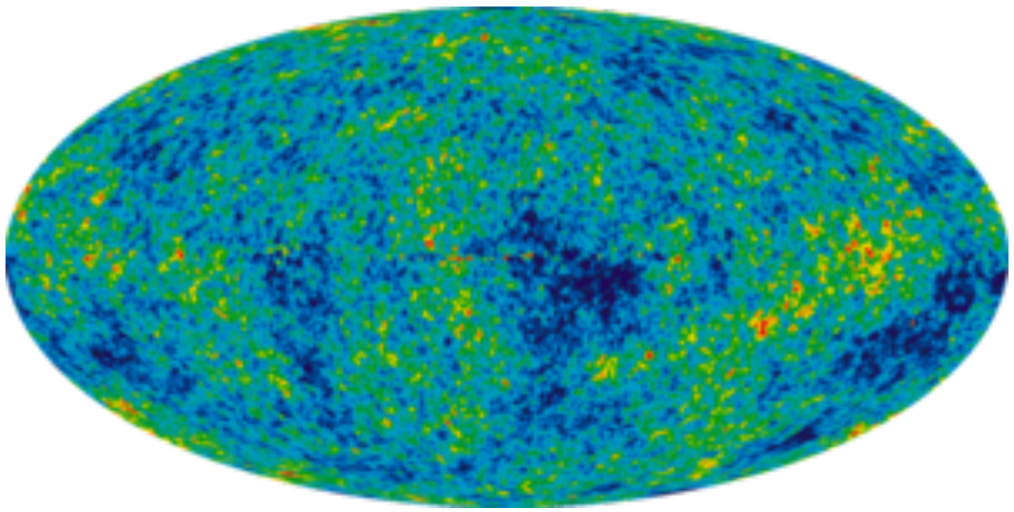
- First proposed in the late 1940's is today called the *Big Bang*. It requires the Universe to have a definite beginning about 15 billion yrs ago.
- The Universe started with very fast expansion. In this model, there is no center or edge of the Universe. The Universe began everywhere at the same time.
- In the earliest epochs, the Universe was very hot. It resembled an extremely hot blackbody. The model predicts that as the Universe expands, the temperature of this *cosmic or primordial background radiation* will decrease.
- In 1964, A. Penzias and R. Wilson from Bell Laboratories accidentally discovered this radiation while making very sensitive observations of the sky with a new radio receiver and telescope. More recent measurements by NASA's COBE (Cosmic Background Explorer) satellite has confirmed that the broad spectral shape of this background radiation perfectly matches a blackbody and has a temperature of 2.74 K.
- The background radiation matches well the predictions of the Big Bang. However, it conflicts with the Steady State model because this radiation shows that the Universe has cooled and evolved with time; therefore, it violates the perfect cosmological principle.
- The energy of the Universe was dominated by radiation for the first 100,000 yrs. After this time, the Universe cooled enough to become transparent to radiation. Matter formed into protons and atoms. These eventually combined to produce the larger scale structures previously discussed.

Discovery of microwave background radiation

Working at Bell Labs in Holmdel, New Jersey, in 1964, Arno Penzias and Robert Wilson were experimenting with a supersensitive, 6 meter (20 ft) horn antenna originally built to detect radio waves

When Penzias and Wilson reduced their data they found a low, steady, mysterious noise that persisted in their receiver. This residual noise was 100 times more intense than they had expected, was evenly spread over the sky, and was present day and night. They were certain that the radiation they detected on a wavelength of 7.35 centimeters did not come from the Earth, the Sun, or our galaxy.

Universe: How it started



Map of small deviations in temperature of the cosmic microwave background radiation.

We are looking at the Universe when it was 100,000 years old. No galaxies. No stars or planets. Small waves traveling in quickly expanding hot Universe.

Photons emitted by this hot 3000 K plasma eventually reached us. It took them 13 billions years. Because the photons were traveling in the expanding Universe, their wavelengths became much longer (redshifted). Temperature of the microwave background radiation is now 3 K.

There are 100 photons in every cubic centimeter of the Universe - billions of time more than the number of photons emitted by stars.