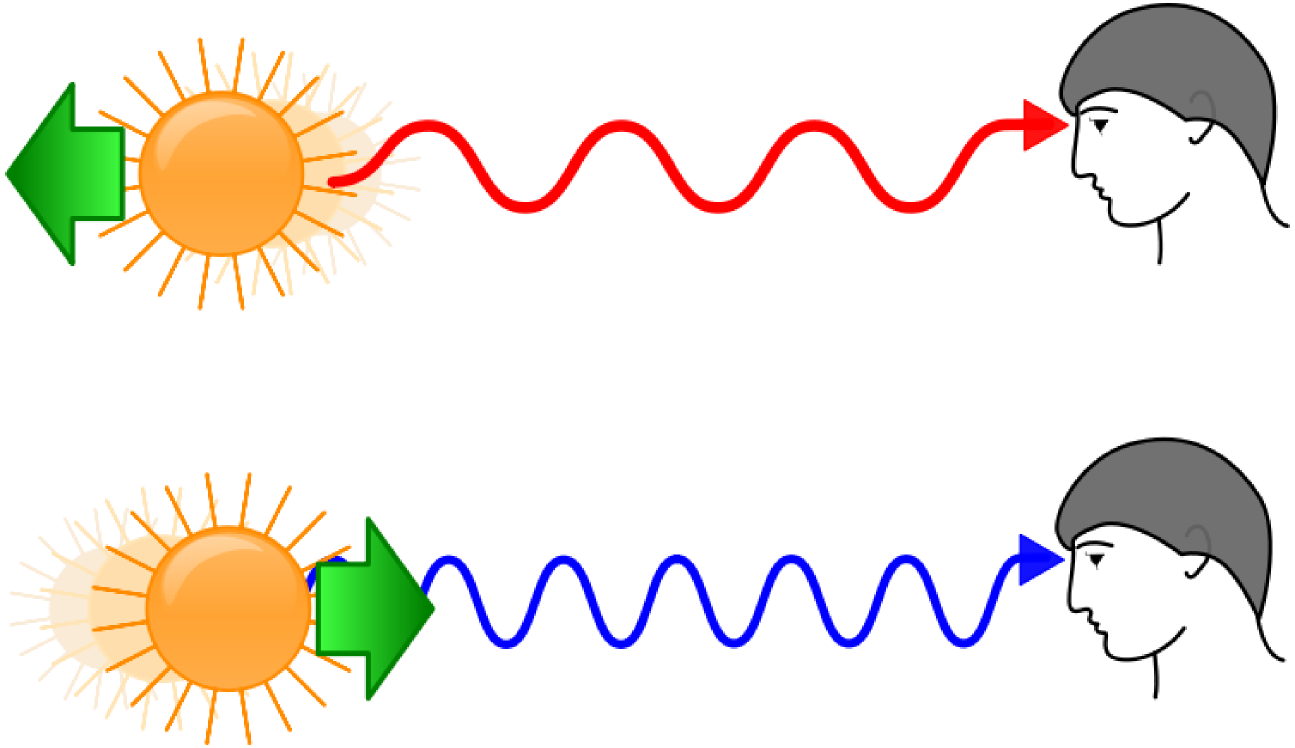
Topic 16: Cosmology

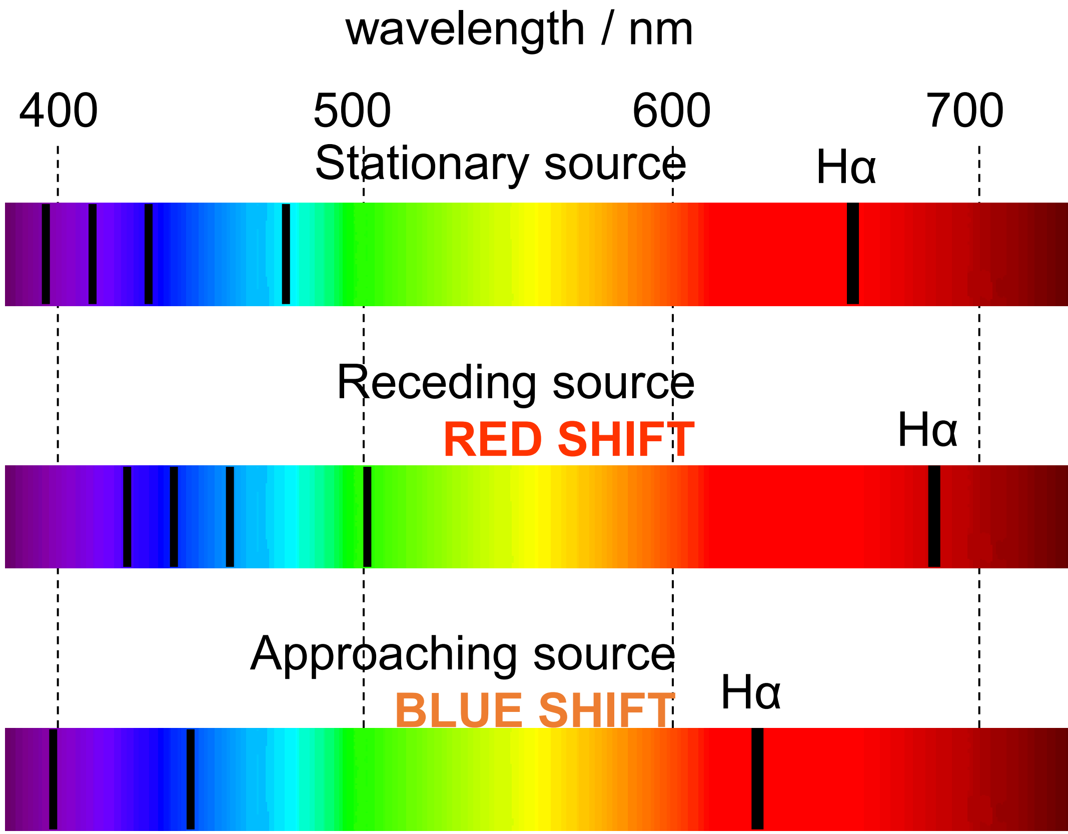
16.1 Redshift

- The Doppler effect - the observed frequency of a wave depends on the relative speed of the source and the observer.
- An object emitting waves moving towards the Earth would have its:
  - Wavelength decrease
  - Frequency increase



16.1 Redshift

- In the 1920s Hubble observed 50 distant galaxies.
- He discovered that the wavelengths of the light emitted were all longer (redshifted).
- Implying they are all moving away from us.



16.1 Redshift

- The change in wavelength is related to the radial velocity.

$$\frac{\lambda - \lambda_0}{\lambda_0} = \frac{v}{c}$$

$\lambda = Observed\ wavelength$

$\lambda_0 = Lab\ wavelength$

$c = speed\ of\ light = 300{,}000{,}000\ m/s$

$v = radial\ velocity\ of\ galaxy$

16.1 Redshift

Example 1

Hydrogen emits 21.106cm radio waves. These waves appear to have a wavelength of 21.133cm coming from a group of stars in a spiral arm in the Milky Way. Calculate how fast these stars are moving away from us.

Δλ = 21.133 - 21.106 = 0.027 cm

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

$$\frac{0.027}{21.106} = \frac{v}{3x10^8}$$

$$v = 3x10^8 x \frac{0.027}{21.206}$$

$$v = 3.8x10^5\ m/s$$

16.1 Redshift

Example 2

The Hydrogen Alpha line has a wavelength of 656nm. This line appears to be at 662nm in the light observed from a distant galaxy. Calculate the velocity of the galaxy. Is it going away or coming towards us?

$\Delta\lambda$ = 662-656 = 6nm

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

$$\frac{6}{656} = \frac{v}{3x10^8}$$

$$v = 3x10^8 x \frac{6}{656}$$

$$v = 2.74x10^6\ m/s$$

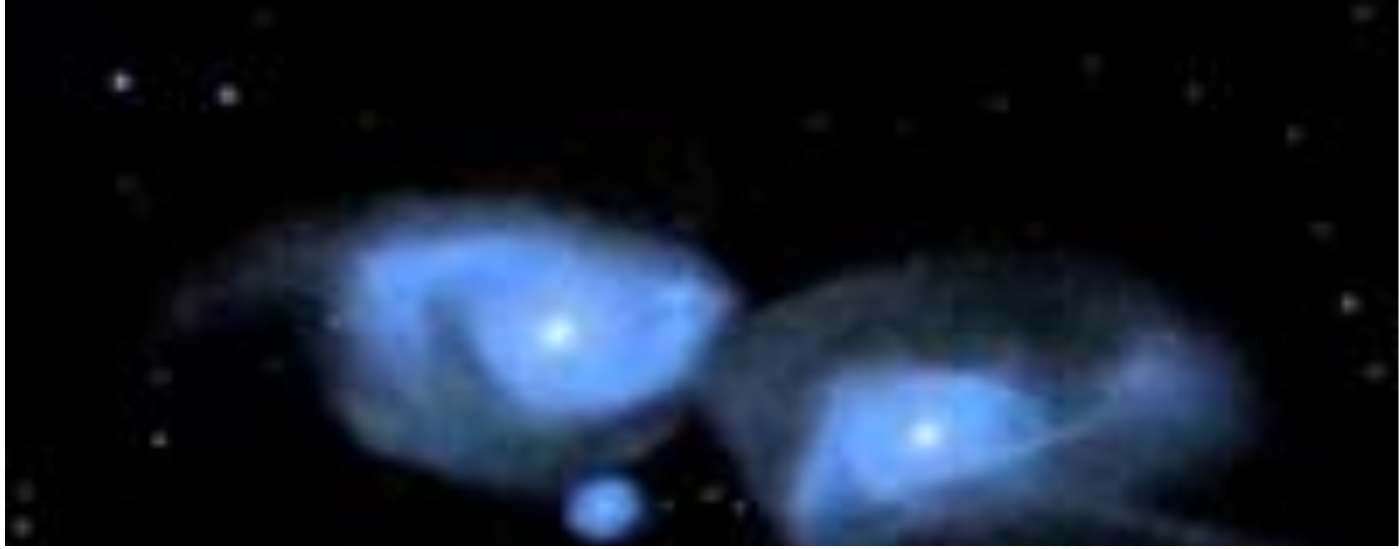
16.1 Redshift

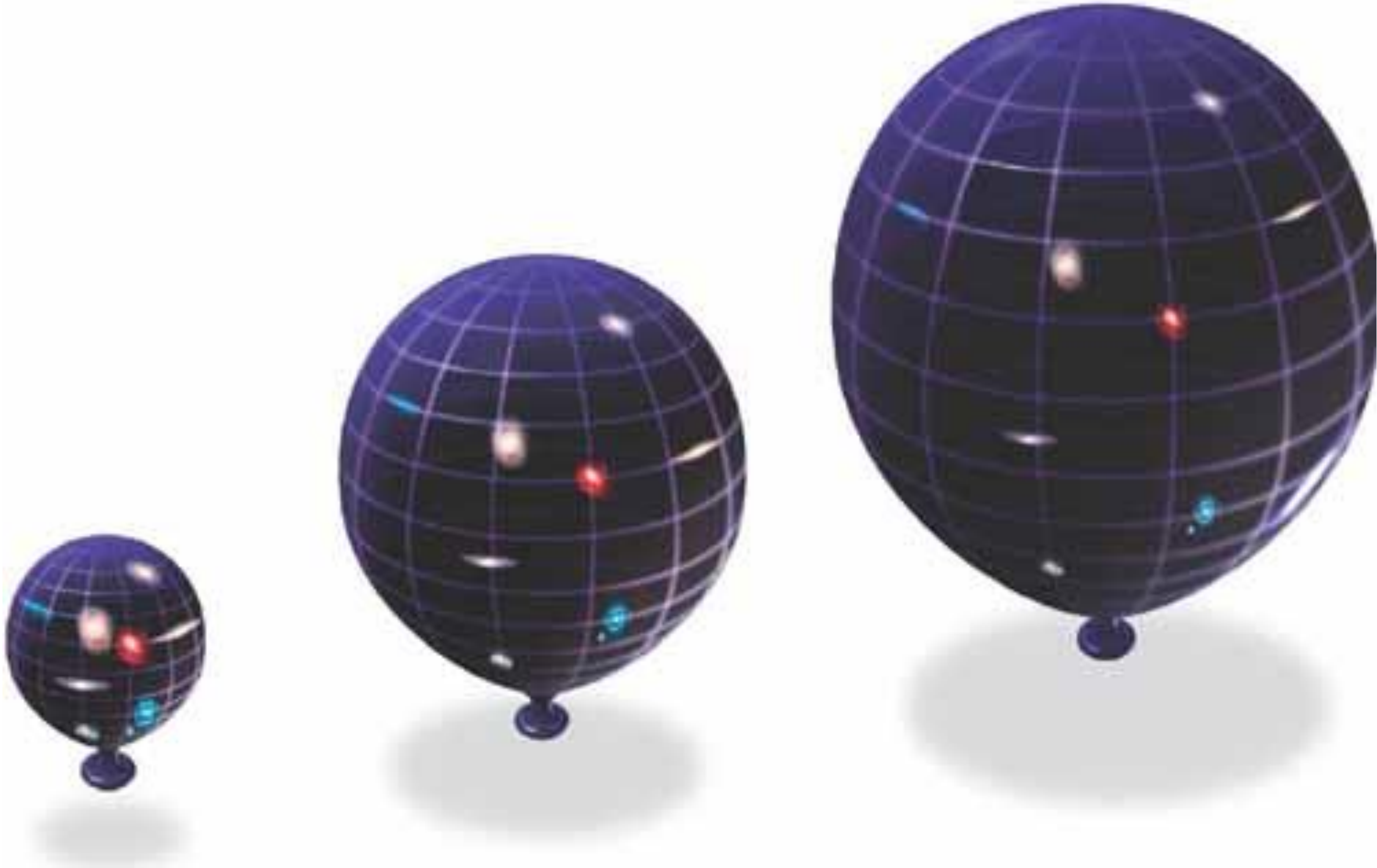
Question

The hydrogen-alpha spectra line of a distant galaxy occurs at a wavelength of 680 nm. In the lab this wavelength is 656 nm. Calculate the recessional velocity of the galaxy.

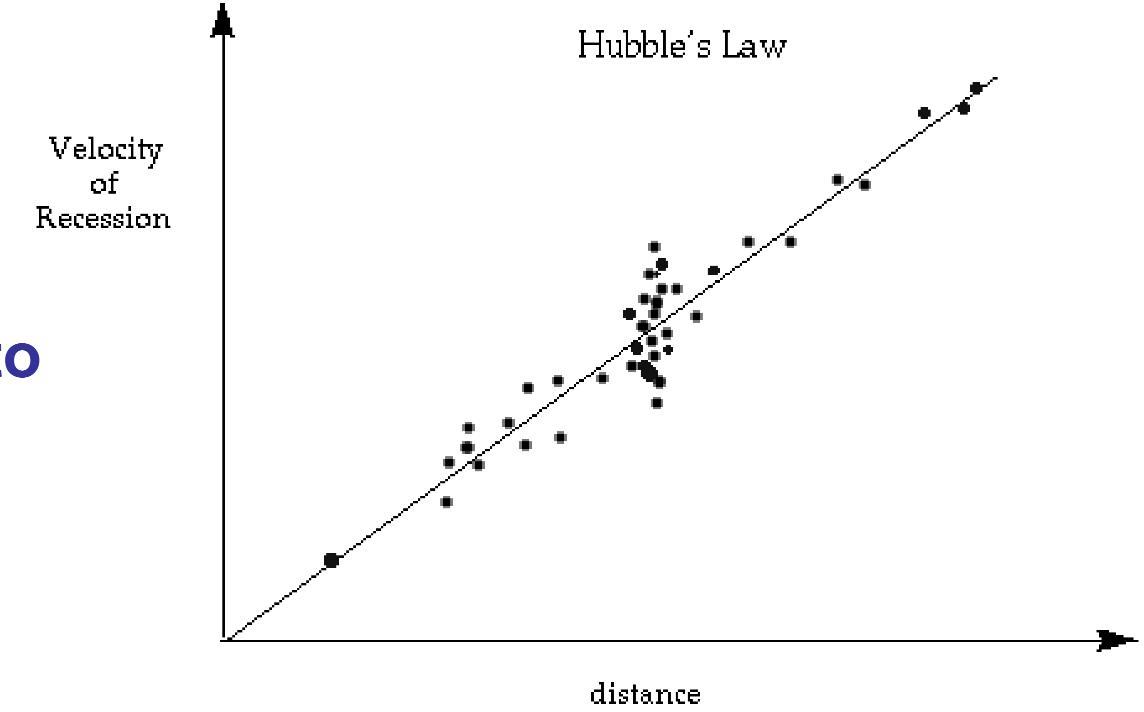
16.1 Redshift

- Some galaxies close to us are blue shifted, implying that they are coming towards us.
- However, astronomers have confirmed that all distant galaxies in the Universe are redshifted.
- This indicates that the universe is expanding and 'dragging' the galaxies with it.





16.2 Hubble's Law



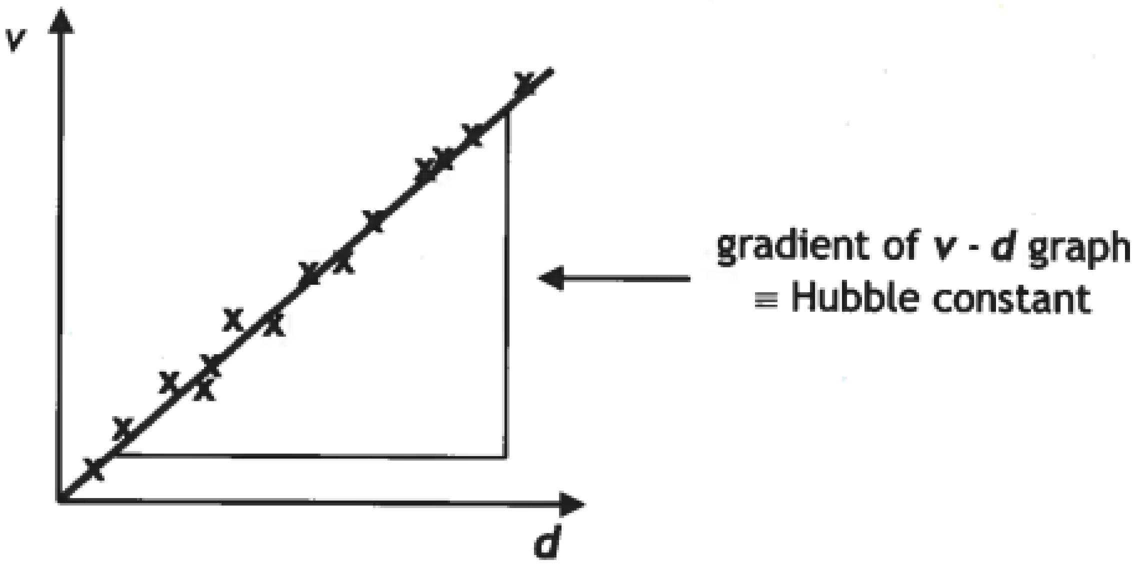
Hubble's law states that the speed of recession of a galaxy is proportional to the distance to the galaxy.

$$v \propto d$$

inserting a constant of proportionality:

$$v = H_o d$$

H_o = the **Hubble constant** = 68 km/s/Mpc



16.2 Hubble's Law

$$v = H_o d$$

H_o = the **Hubble constant** = 68 km/s/Mpc

A distant galaxy is 800 Mpc away from earth. Calculate the recession velocity of the galaxy in km/s

16.2 Hubble's Law

- The units for H_o (km/s/Mpc) contain 2 length units.
- If we convert km to Mpc then we can cancel these out to end up with units of /s (the inverse of time).
- If we invert this then we end up with a time, the Hubble time (T).
- This is the age of the Universe.

We know that:

H_0 = 68 km/s/Mpc

and

3.1×10^{19} km = 1 Mpc

Divide both sides of the second equation by 3.1×10^{19}:

1 km = 3.2×10^{-20} Mpc

Substitute for 1 km in H_0 value:

$H_0 = 2.2 \times 10^{-18}$ /s

Invert: $T = 4.6 \times 10^{17}$ s

16.2 Hubble's Law

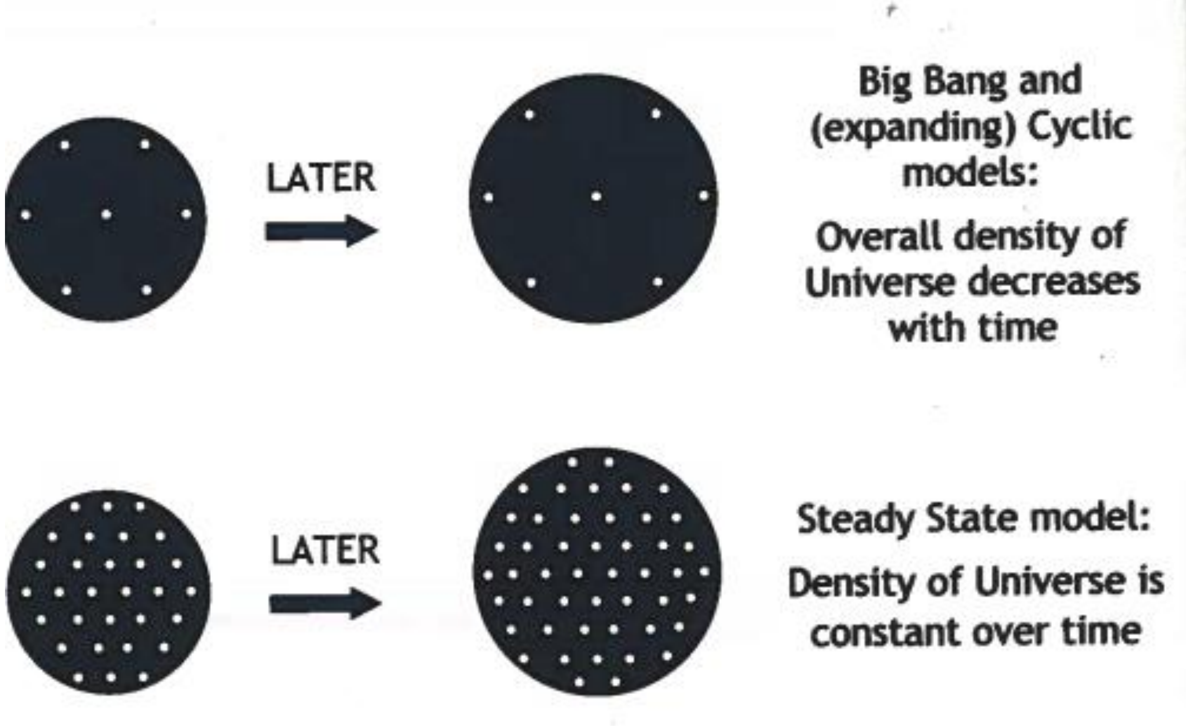
- The Hubble constant can be used to calculate the Hubble Length. i.e. the size of the Observable Universe.

$$distance = speed\ x\ time$$

$$Hubble\ Length = Speed\ of\ Light\ x\ Hubble\ Time$$

16.3 The Big Bang

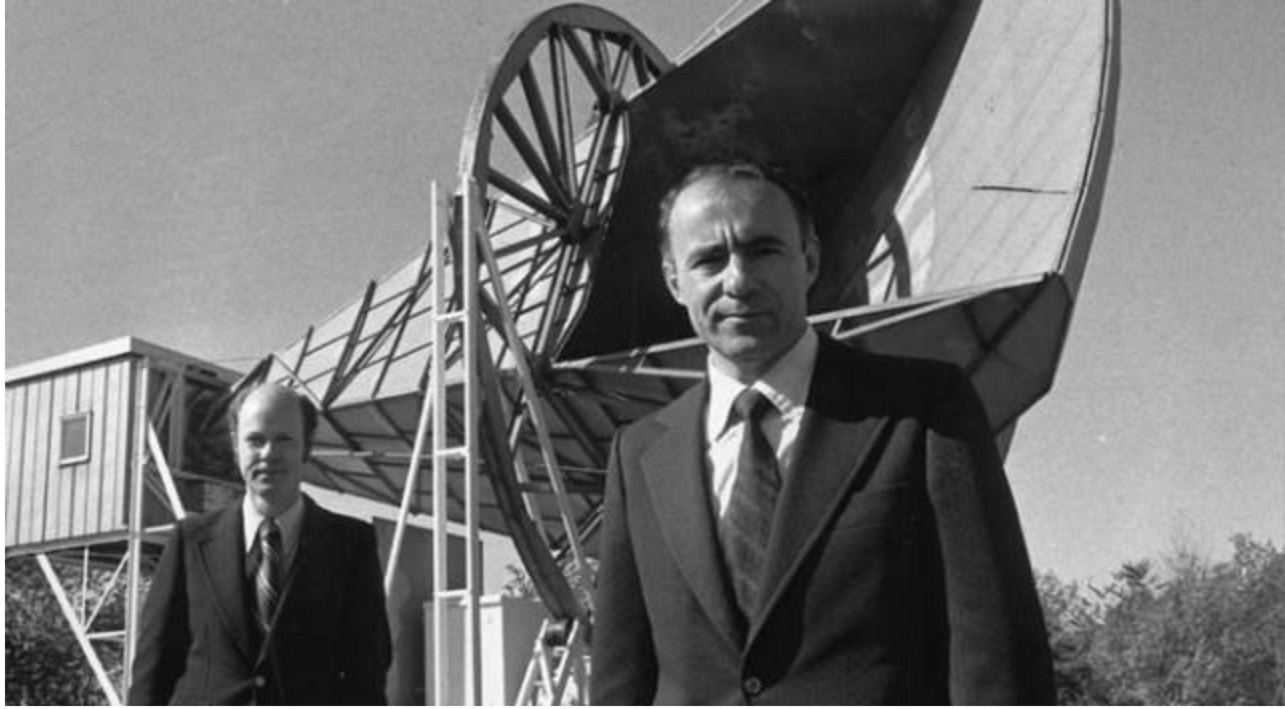
- The Universe began as an extremely small, hot, dense event called the Big Bang. This was a rapid expansion in which space and time came into existence.
- Another model is the Steady State where the Universe has always existed and expands with new matter continuously being created to keep the density uniform.
- The Cyclic Universe is where there have been a series of Big Bangs and Big Crunches.

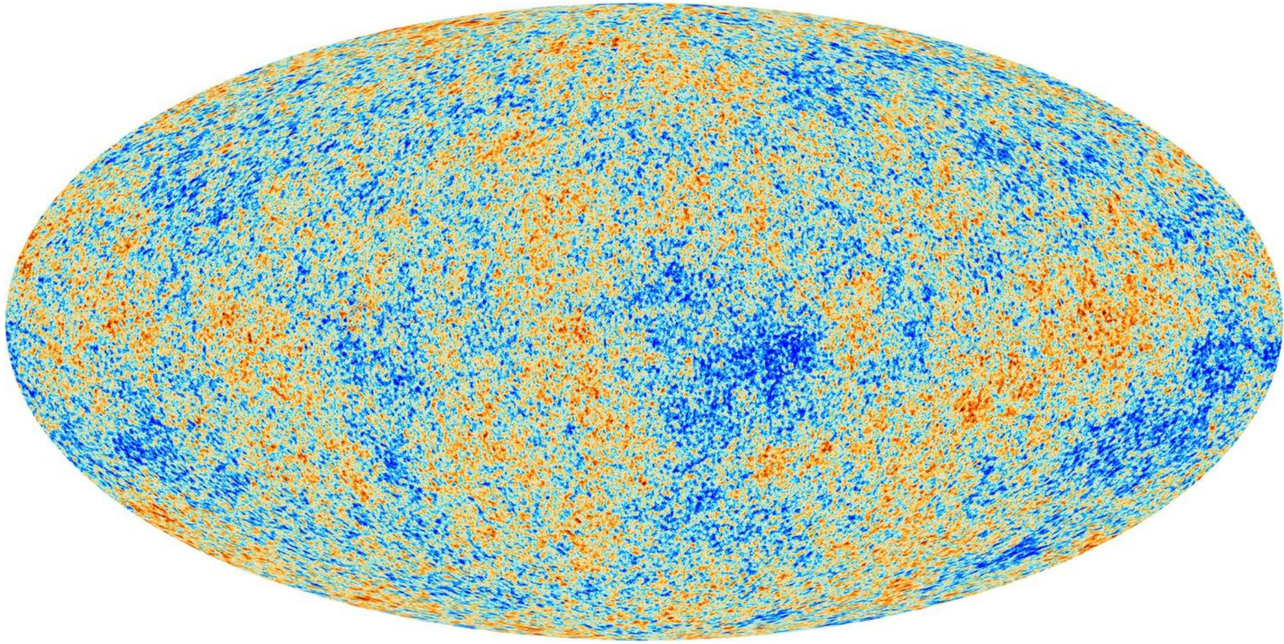


16.3 The Big Bang

Out of these models the Big Bang model has the most evidence:

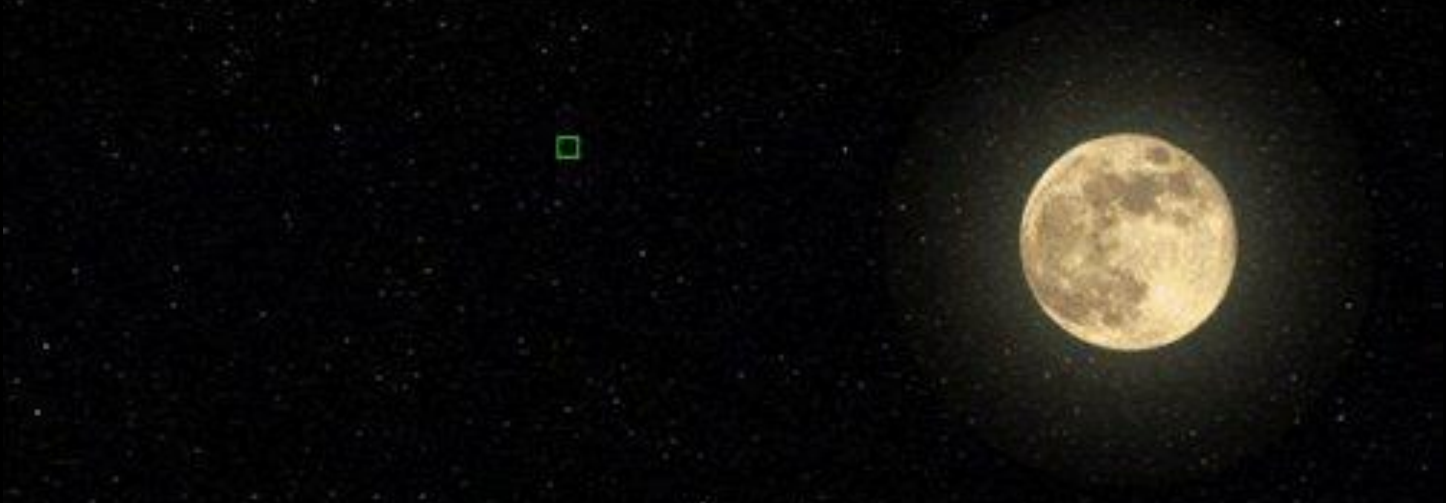
1. Quasars – these have high redshifts implying they are far away and were created a long time ago and more common in the early Universe.
2. Cosmic Microwave Background (CMB) – The Universe should cool as it expands. From calculations it was predicted to be a few degrees above absolute zero. The CMB was accidently discovered and it was 2.7 K.
3. Hubble Deep Field (HDF) – a long exposure image of 'empty space' revealed many thousands of distant closely packed galaxies.





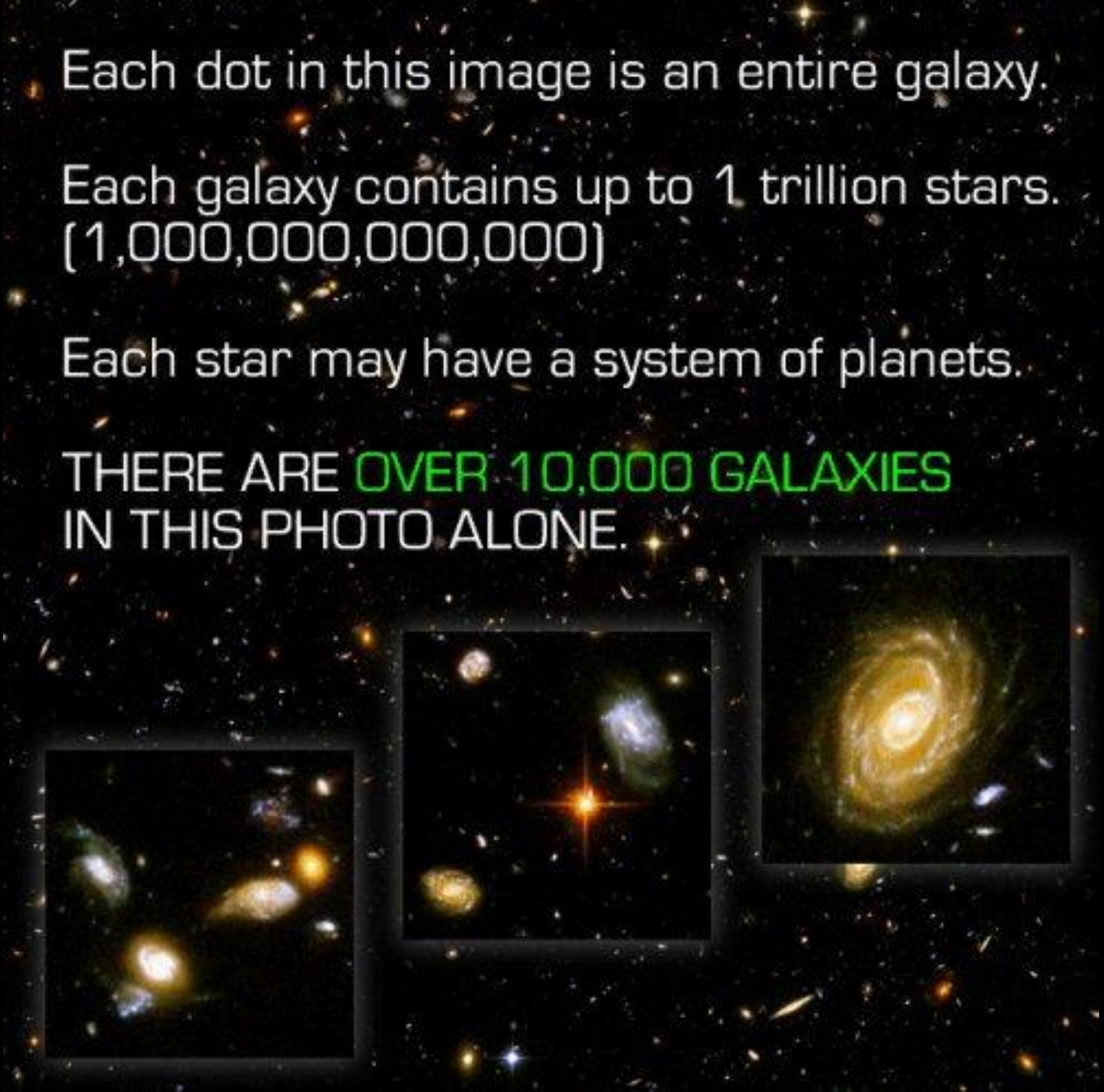
On September 3rd, 2003 ...

The area, about a tenth the size of the full moon, appeared to be complete blackness with no stars visible to the naked eye.

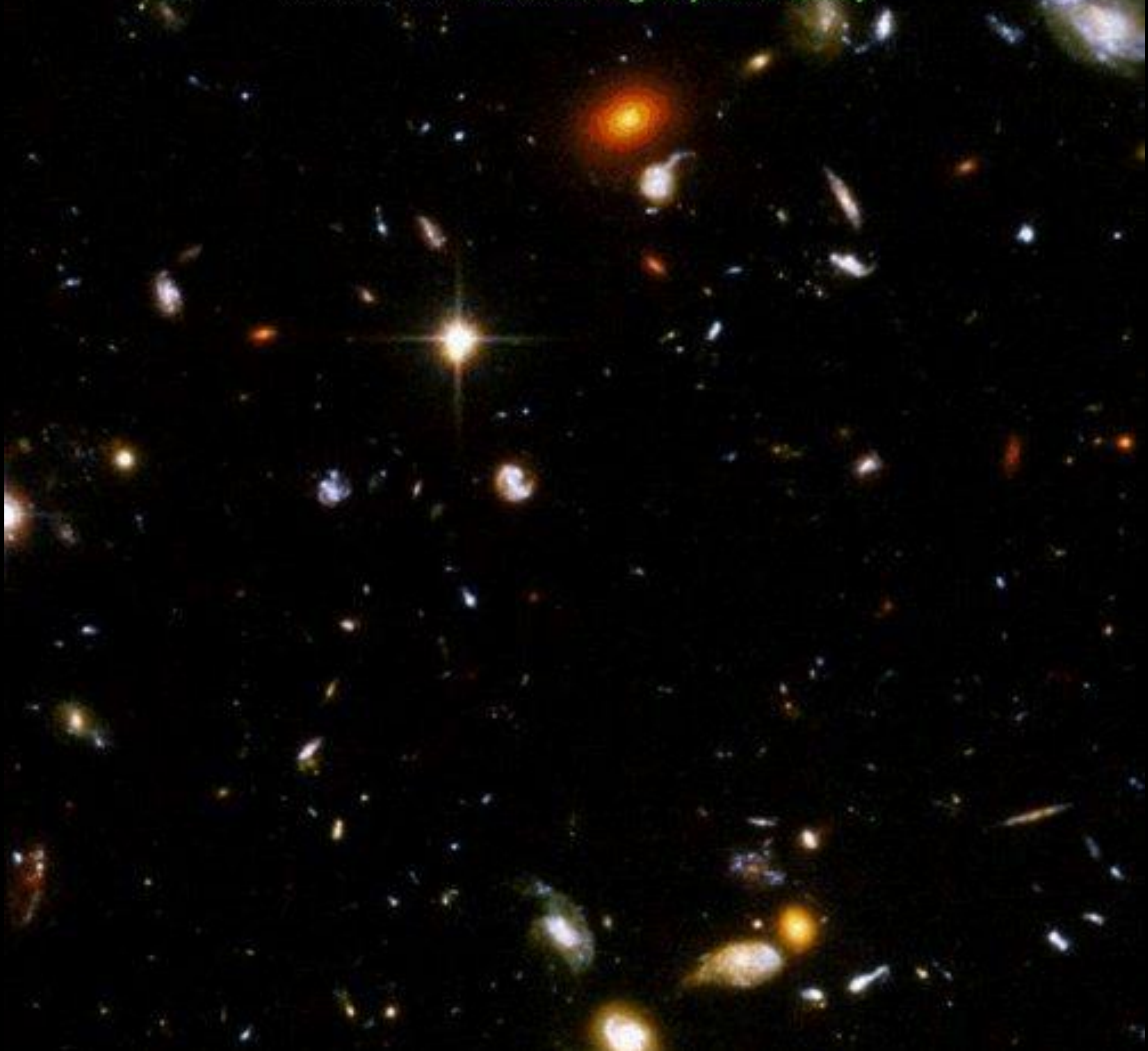


Hubble kept its camera pointed there for over 4 months, taking in all the light it could.

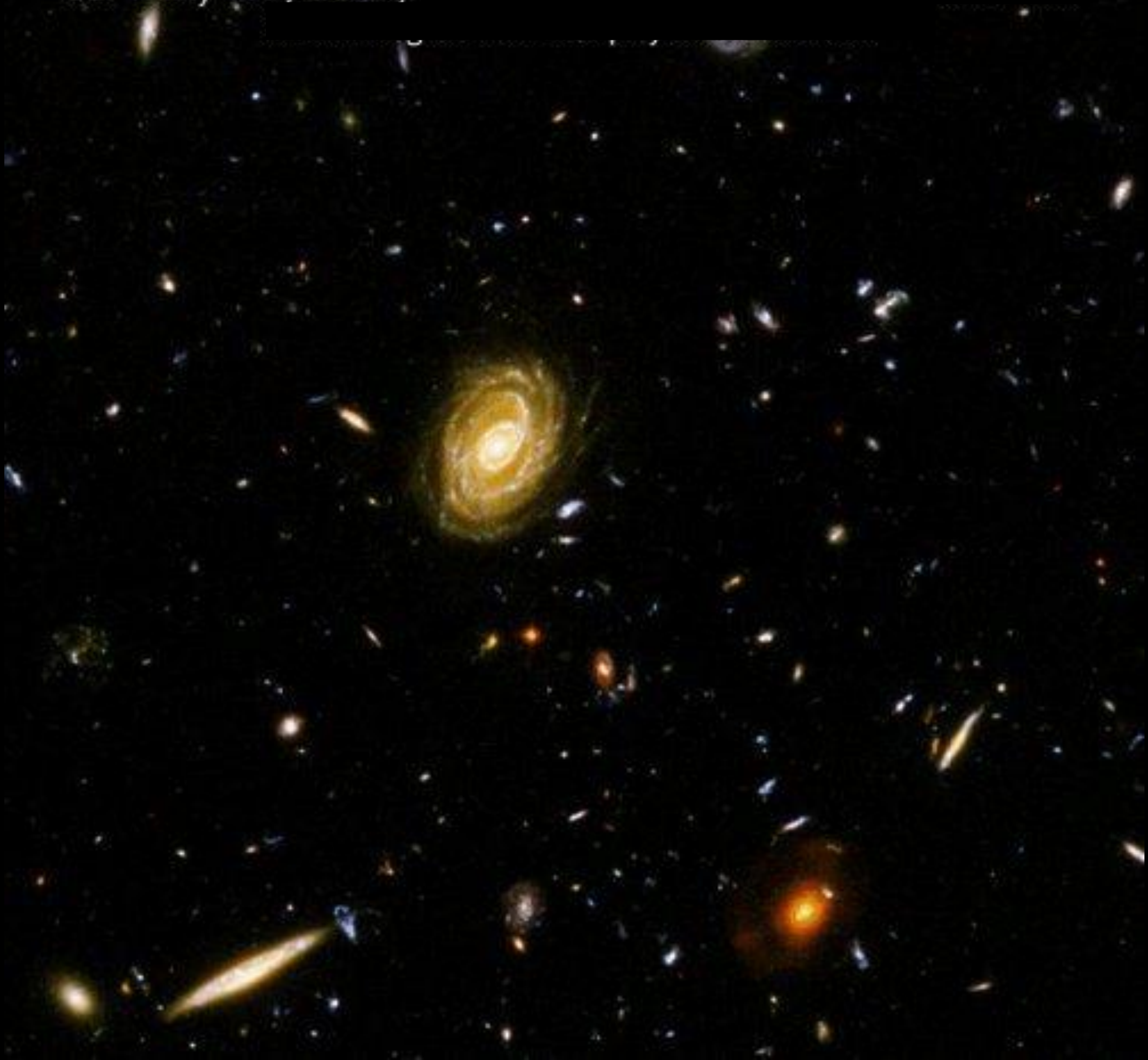
This is what Hubble saw...


Each dot in this image is an entire galaxy.
Each galaxy contains up to 1 trillion stars.
(1,000,000,000,000)
Each star may have a system of planets.
THERE ARE OVER 10,000 GALAXIES
IN THIS PHOTO ALONE.

These are the most distant objects ever photographed.
More than 13 billion light years away.

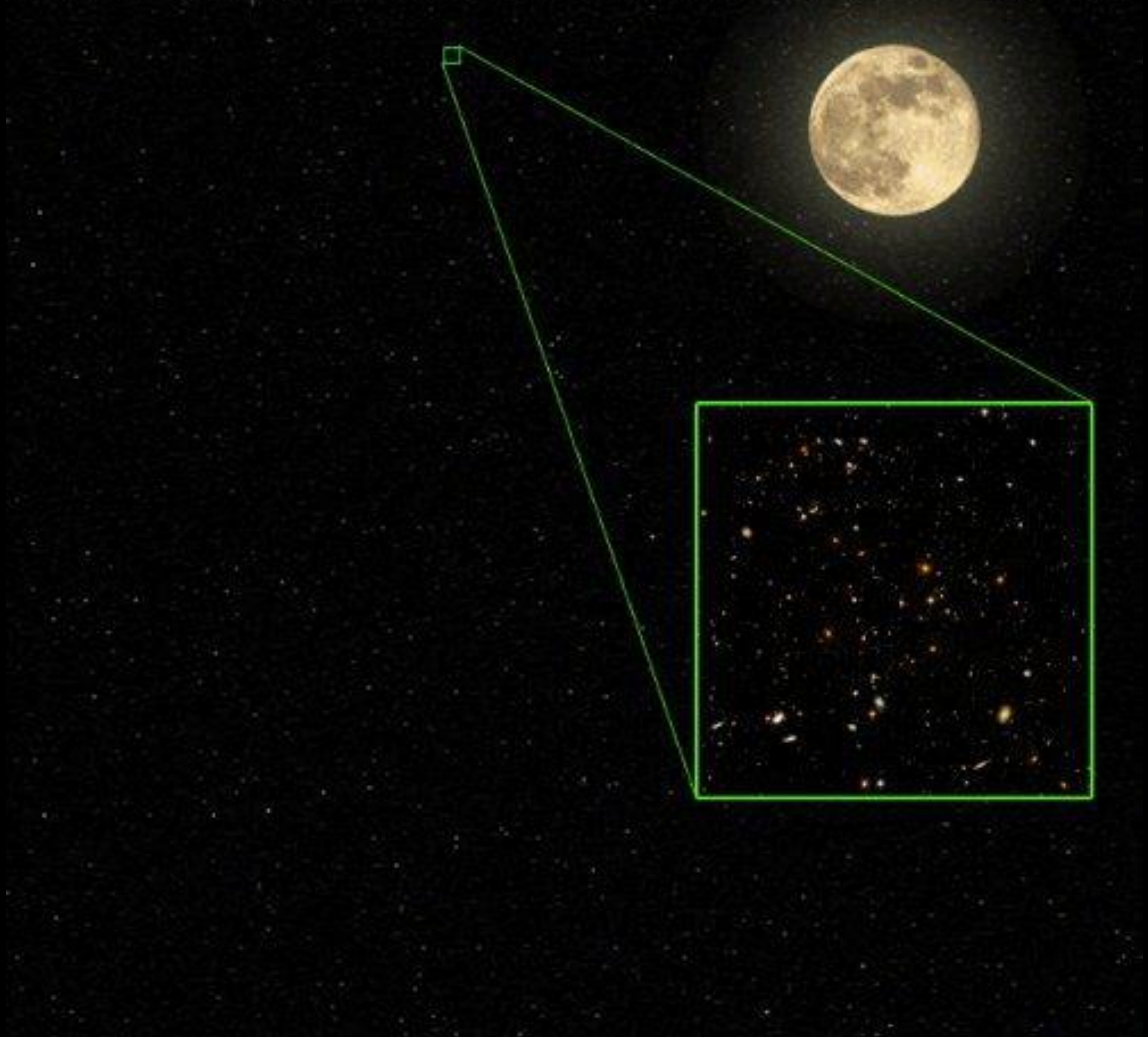


The large galaxy pictured here contains 8 times as many stars as our Milky Way Galaxy.



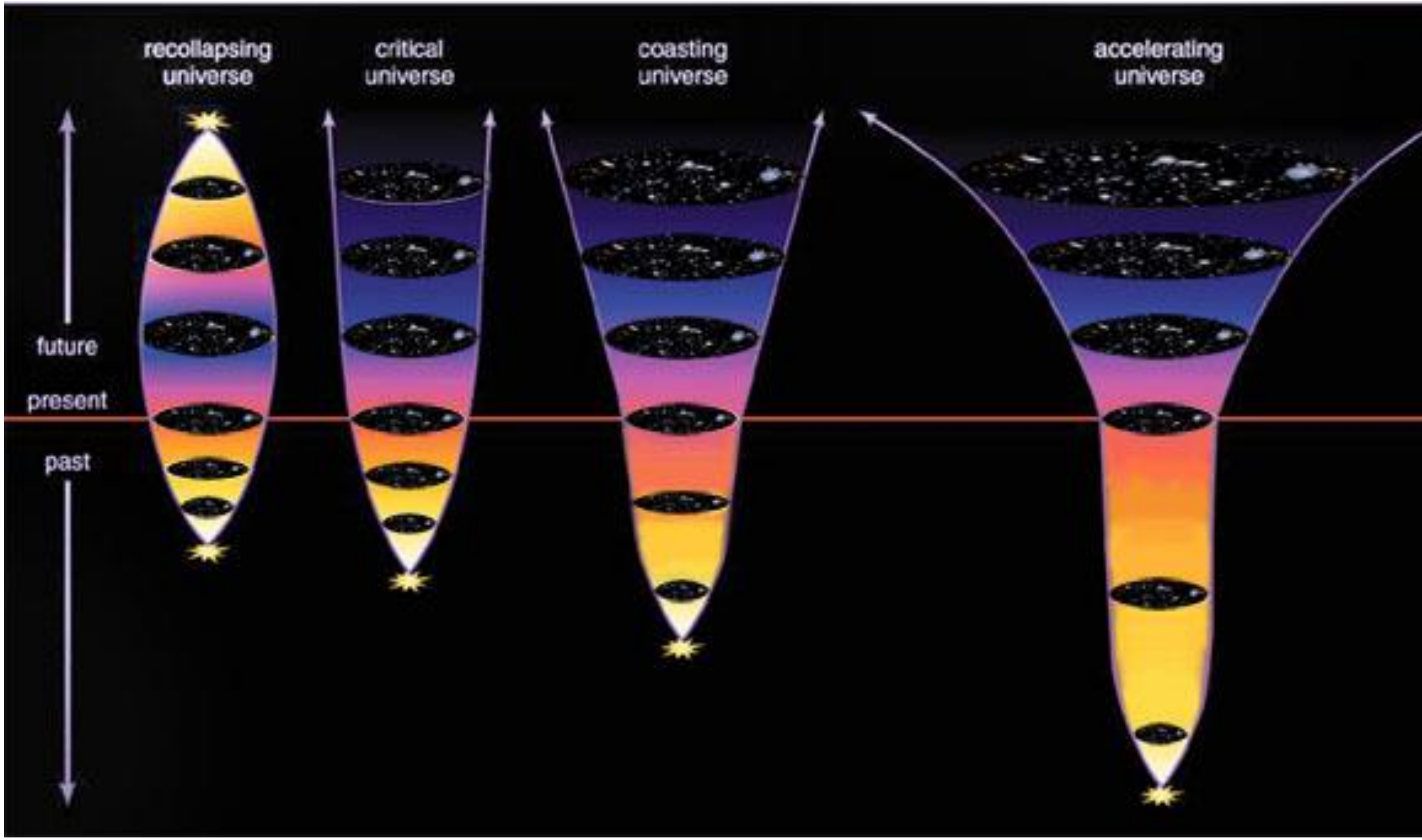
The entire Star Trek series takes place in ONE galaxy.
The USS Enterprise (NCC-1701-D) at maximum warp (9.6) would take almost 10 million years to reach this Galaxy.

All from what looked like NOTHING!



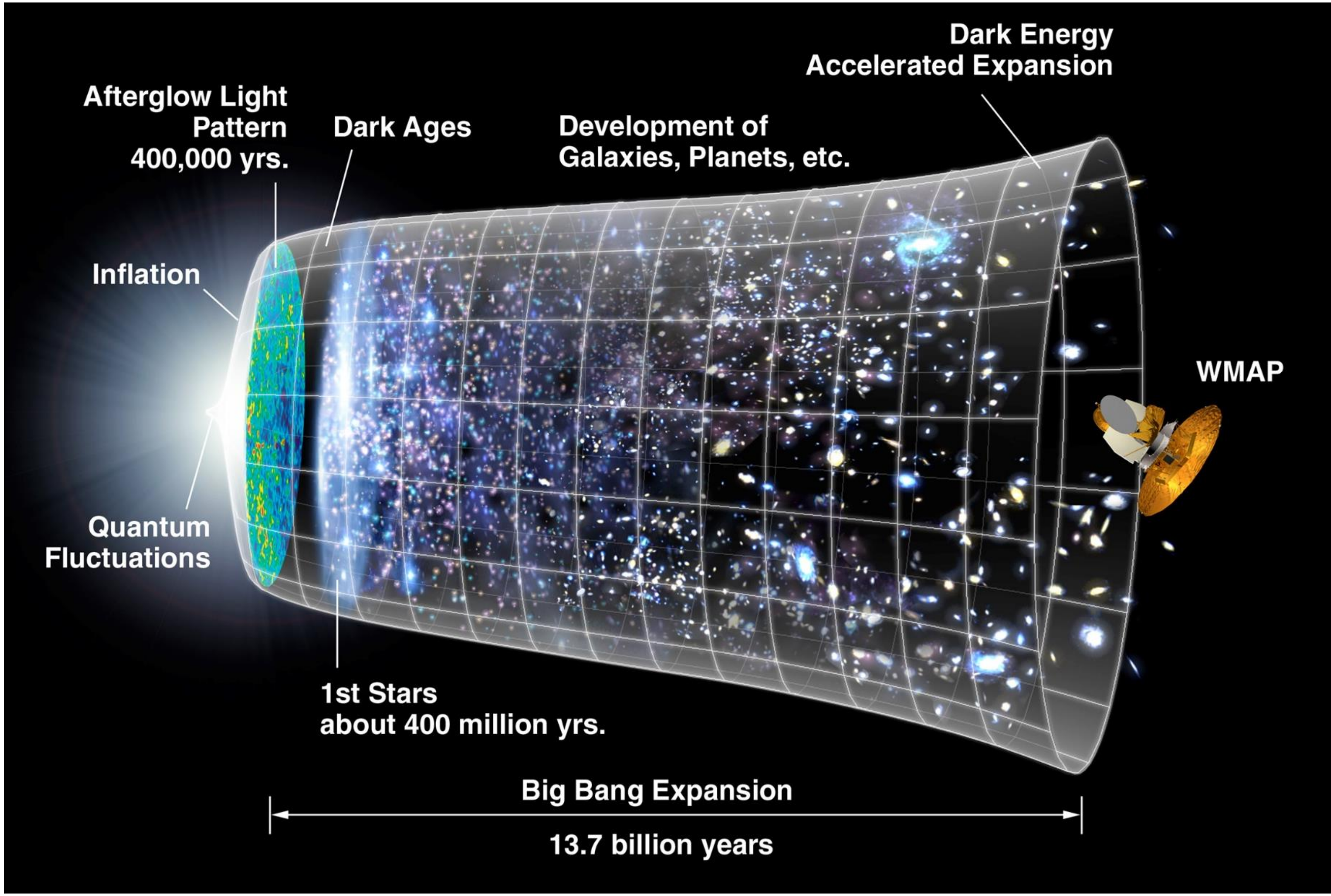
16.3 The Big Bang

- The fate of the Universe is uncertain.
- If the expansion is decelerating it will either expand indefinitely or collapse.
- A coasting Universe will expand at a constant rate.
- If the rate of expansion increases (due to dark energy) it will be an accelerating Universe.



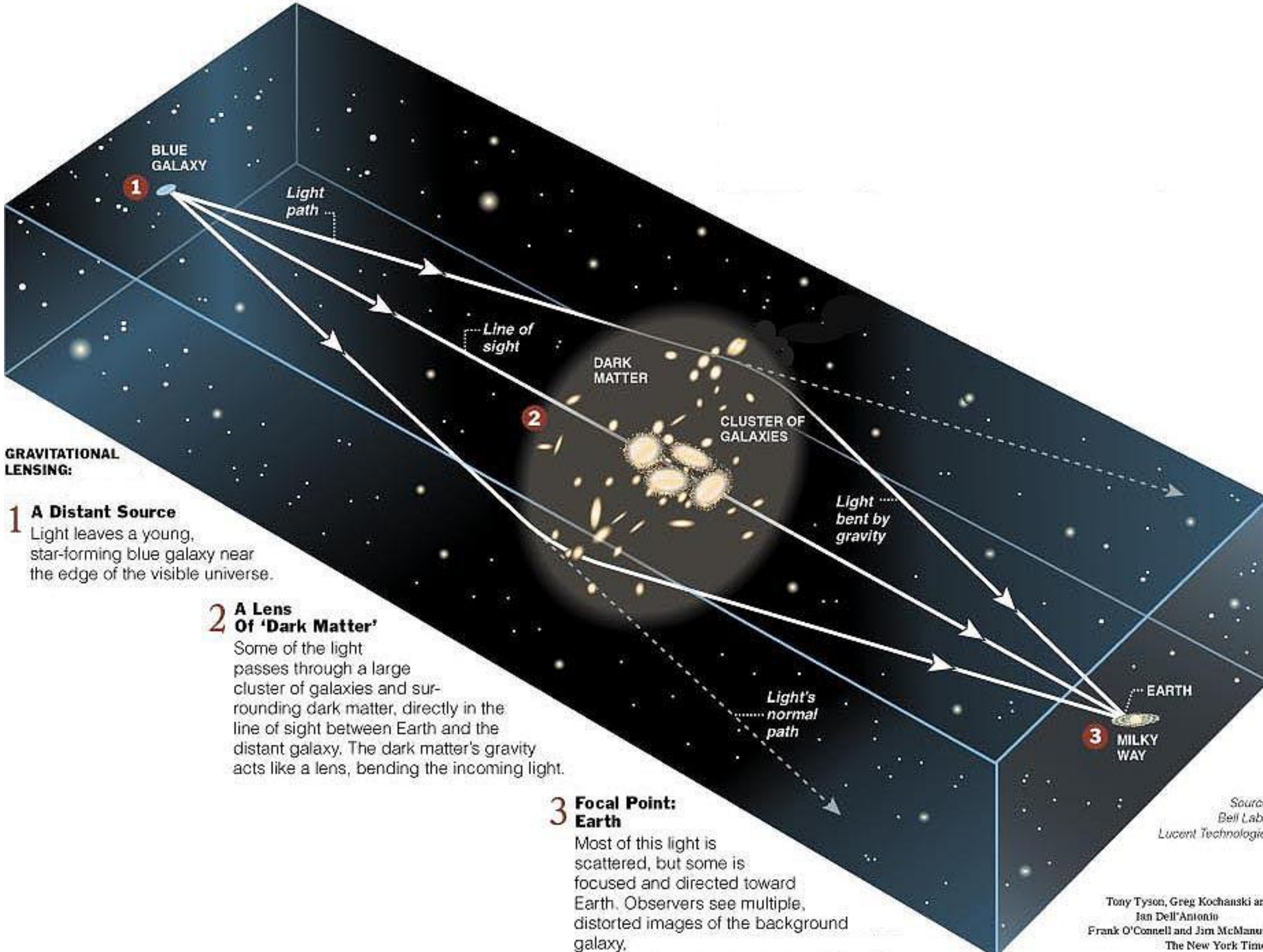
16.3 The Big Bang

- Recent space missions reveal that:
  - The Universe is slightly older than previously thought
  - ~25% of the Universe is invisible dark matter
  - Cosmic inflation happened – the rapid uniform expansion shortly after the Big Bang.



16.3 The Big Bang

- There is still a lot to learn about the Universe.
- Even though we can see the effects of dark matter and dark energy, the 95% of the Universe they make up is currently undetectable .
- Dark matter causes gravitational lensing and it is thought that they take the form of WIMPS (Weakly Interacting Massive Particles).




93,000,000,000 light-years