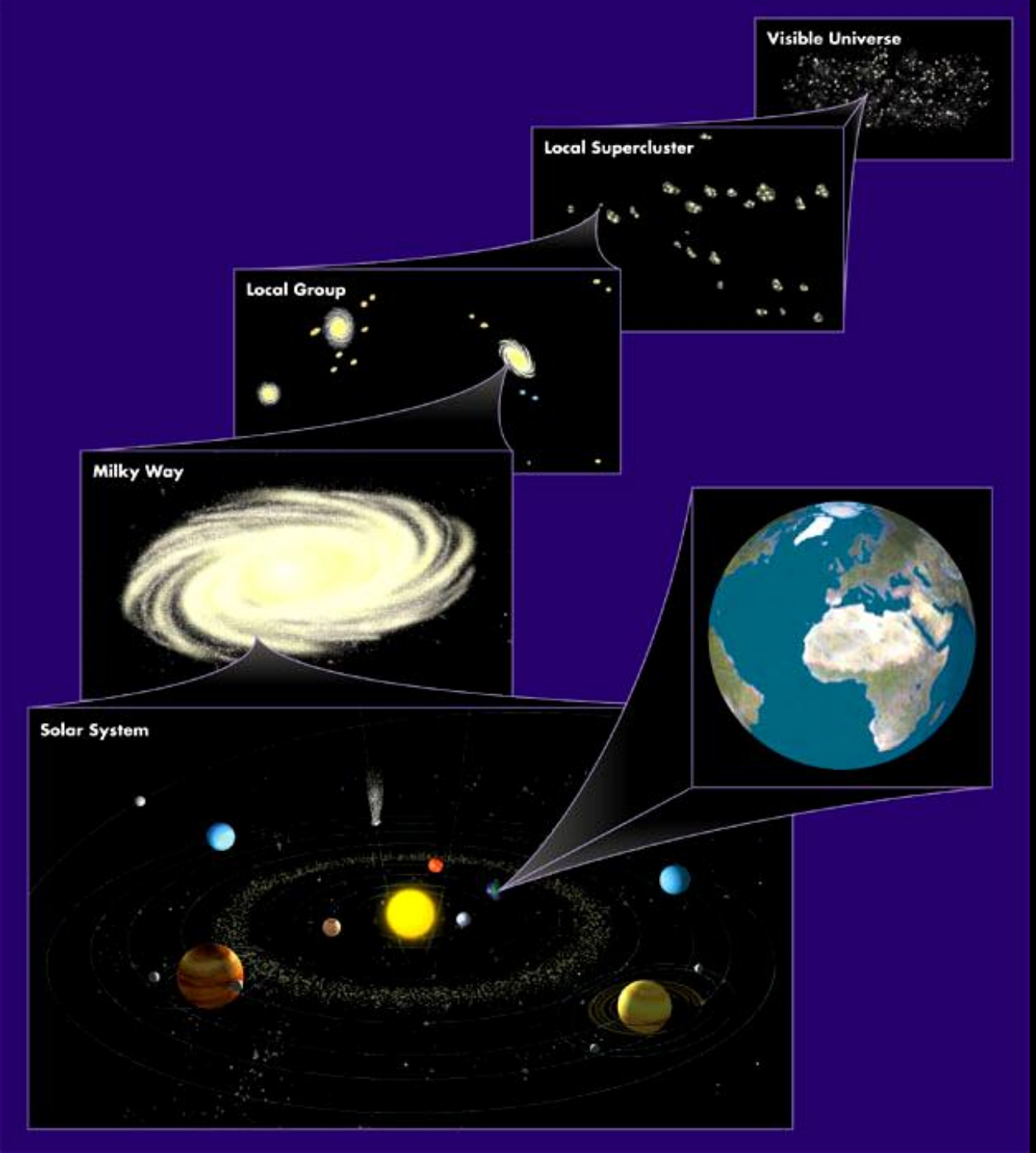
Where did our universe come from?

Mike Whybray
Orwell Astronomical Society (Ipswich)
7th April 2010



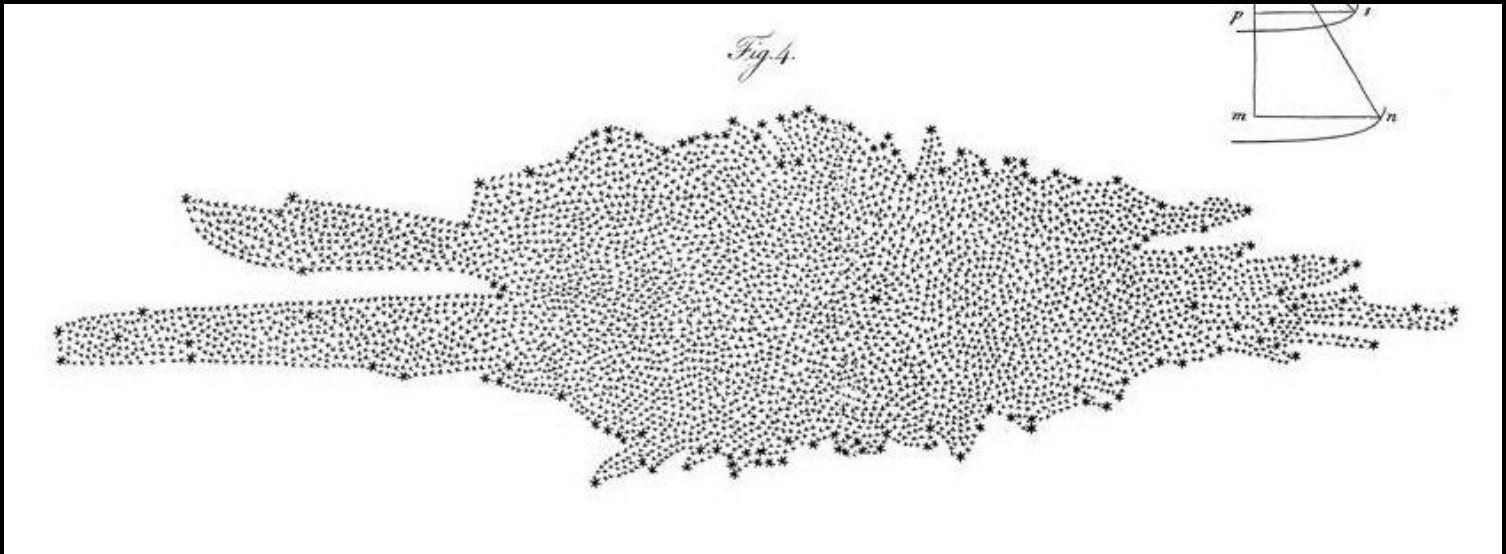
Our Universe:

~200 billion stars in our galaxy

~100 billion galaxies in the visible universe

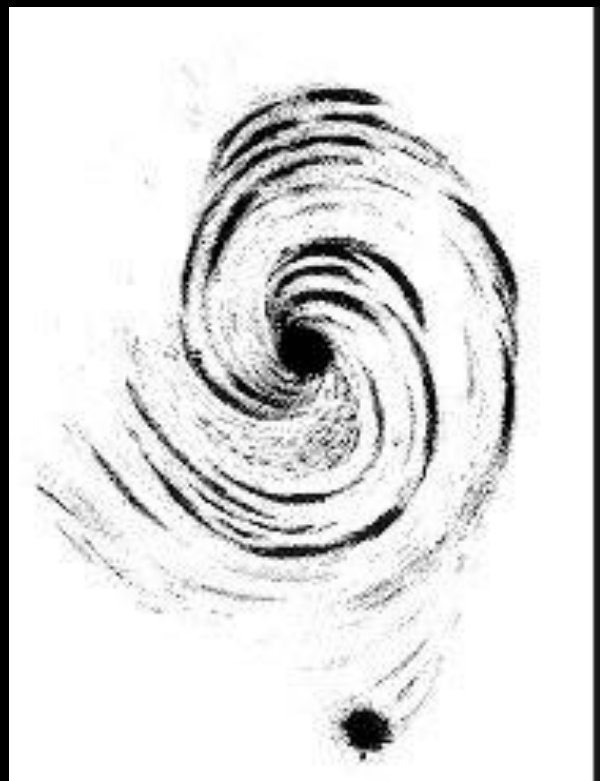
How big is our Universe?

- 1785 Sir William Herschel
  - Counted stars along 683 lines of sight using his 48-inch telescope.
  - Assumed stars were 'equally distributed' so number of stars in a direction was a measure of size in that direction.
  - Assumed that they could see all the way to the edges of the system
  - Subsequently realised he was wrong on both counts!



Our Island Universe

- 1845 Lord Rosse uses his 'Great Leviathan' telescope to view M51 (the Whirlpool galaxy)



The Expanding Universe

- 1912 Vesto Slipher obtains spectrum of M31 (Andromeda Galaxy)
  - Found spectrum of stars shifted towards the blue - deduced Andromeda is approaching at ~300 km/s
- 1917 Slipher obtained spectra of 25 spiral nebulae
  - Found most had a red shifted spectrum - moving away from us at up to 1000km/s
- 1912 Henrietta Leavitt discovers the relationship between luminosity and period of Cepheid variable stars
  - A 'standard candle' to measure the distance to a star (or the galaxy it is in)

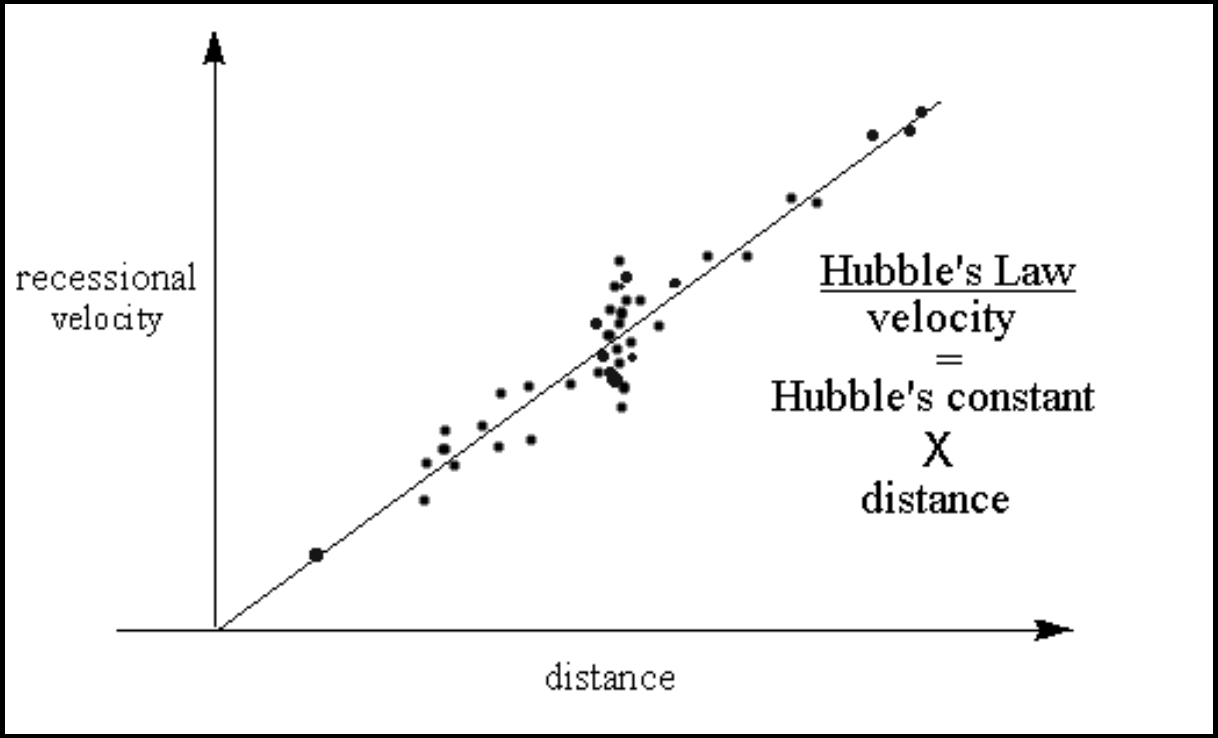
Hubble's Law

1929 Edwin Hubble's paper showing that redshift (Velocity) of a galaxy is proportional to its Distance

Velocity = H * Distance
where H is the Hubble constant

Holds only for galaxies at moderately low distances

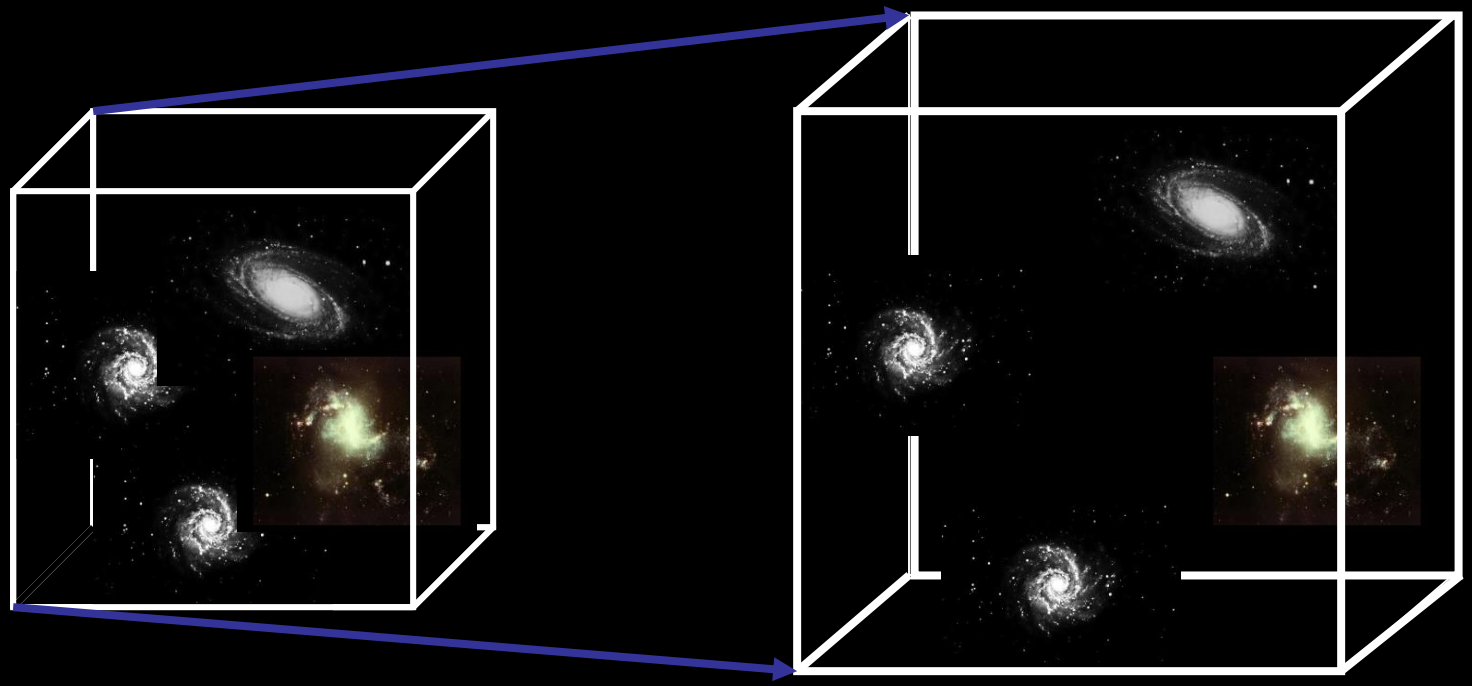
Applies only at the current time - a snapshot



The Expanding Universe

On large scales, galaxies are moving apart, with velocity proportional to distance (Hubble's Law)

It's not galaxies moving through space.
Space is expanding, carrying the galaxies along!



The galaxies themselves are not expanding

Big Bang or Steady State?

- Sir Fred Hoyle championed the Steady State theory: that the universe has always existed and has no beginning or end
  - Space continues to expand but is 'filled in' by spontaneous creation of hydrogen in empty space

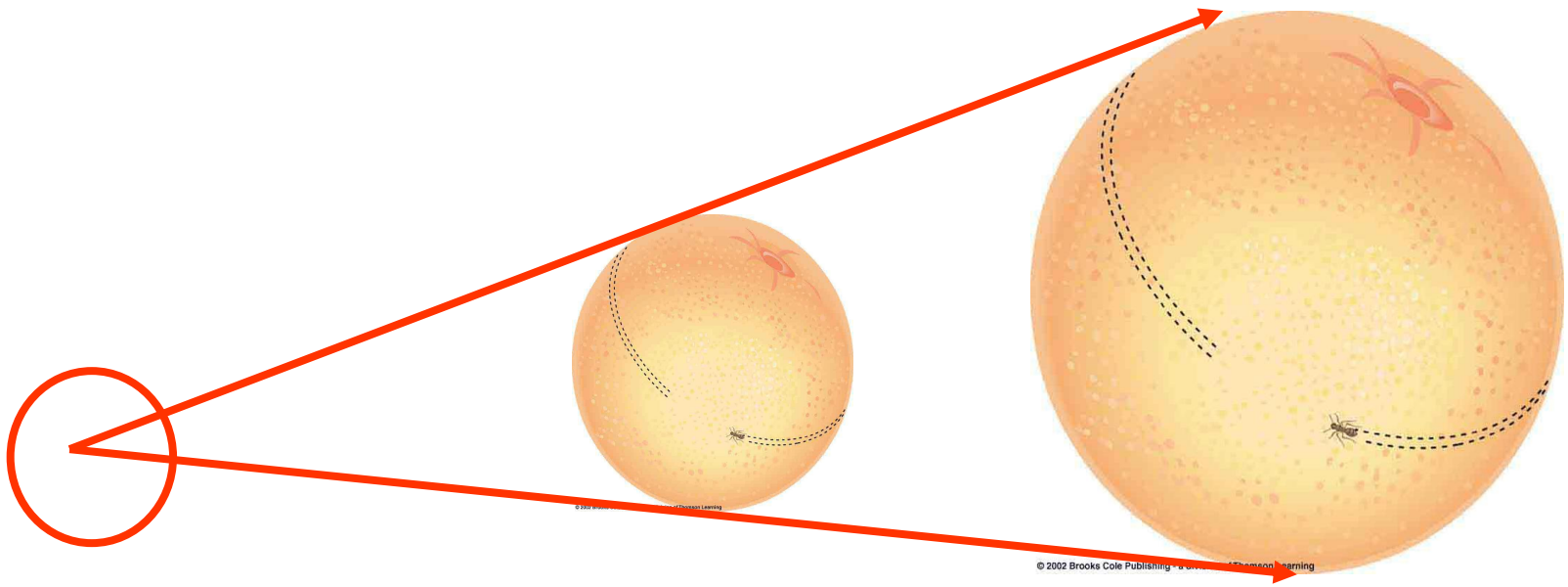
- He coined the disparaging term 'Big Bang' for the alternative theory: that the universe began at a fixed time in the past from a singularity. The name stuck.

- Sevaral lines of evidence point to the Big Bang theory being correct rather than the Steady State theory...

Evidence supporting the Big Bang theory (1)

If galaxies are moving away from each other with a speed proportional to distance, there must have been a beginning, when everything was concentrated in one single point:

The Big Bang!



The Age of the Universe

Knowing the current rate of expansion of the universe, we can estimate the time it took for galaxies to move as far apart as they are today:

Velocity = H * Distance

But Time = Distance / Velocity

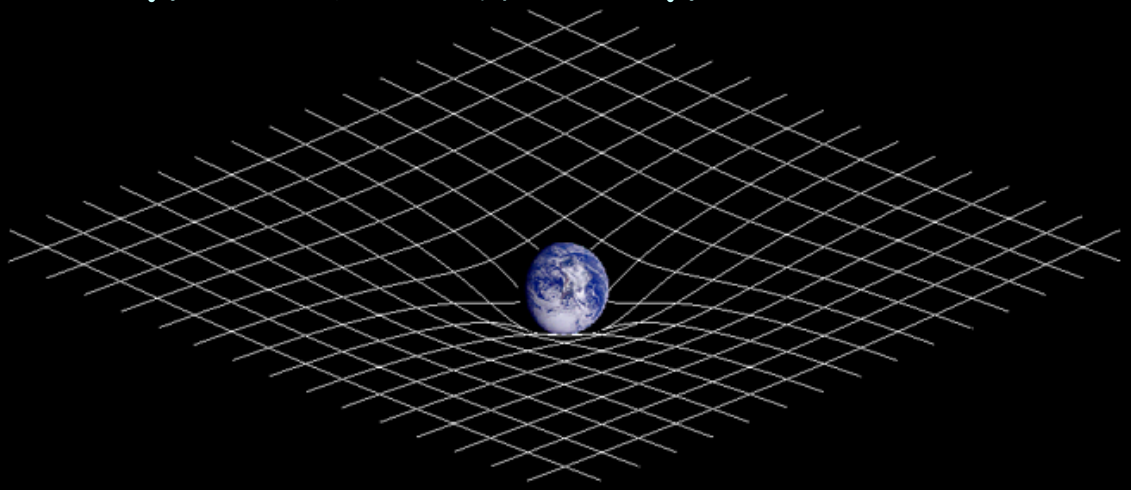
So Time = 1/H ~ 13.7 Billion Years

How can space expand?

- 1915 Einstein publishes his theory of General Relativity
- Views time as integrally tied up with the 3 physical dimensions: 4 dimensional spacetime
- Gravity is a warping of spacetime around massive objects

John Wheeler: "Matter tells space how to curve, space tells matter how to move"

So spacetime is stretchy!

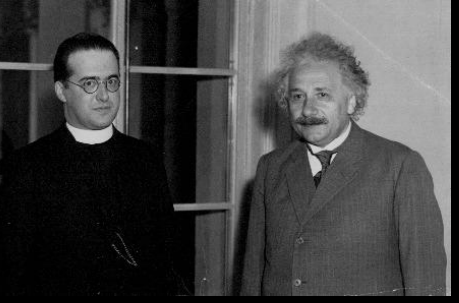


Expanding Universe

- Expanding space causes a 'Cosmological Redshift'
  - Space itself is expanding and stretching the light from distant galaxies

- Galaxies, Stars, Atoms etc. do NOT expand

- We are NOT at the centre of the expansion:



Einstein's Universe

- 1915 General Relativity can describe an expanding or contracting universe
- 1917 Einstein introduces a fudge factor - his Cosmological Constant (to make Universe static)
- 1927 Lemaitre publishes his paper suggesting the universe expanded from a 'primeval atom'
- 1929 Hubble publishes his findings of an expanding universe
- 1929 Einstein withdraws his Cosmological Constant

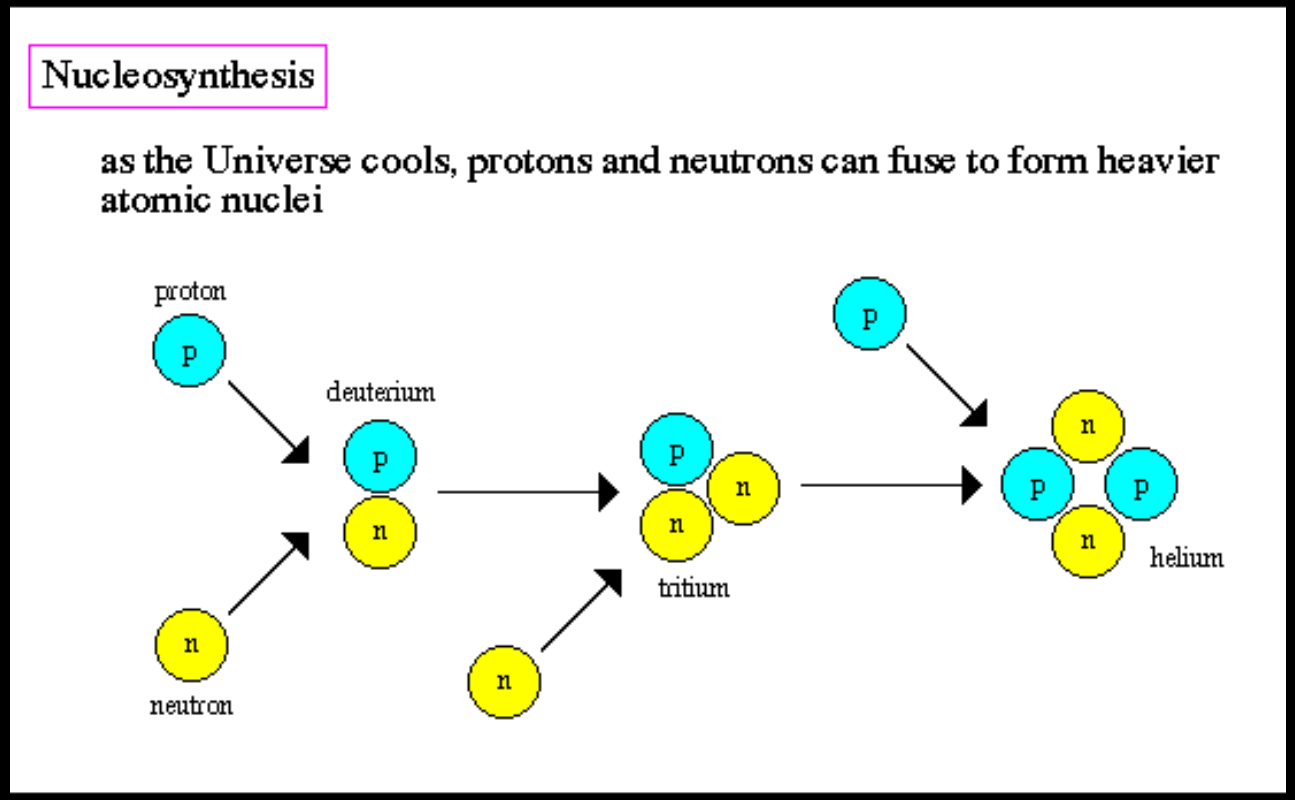
Some weird consequences

- Distant galaxies are receding at or faster than the speed of light:
  - Hubble Sphere:
    - Redshift of 1.46
    - Distance about 14 Billion Light Years
- Light from galaxies outside the Hubble Sphere can nevertheless reach us!:
    - Furthest galaxies observed with a redshift of 7.6
    - Distance about 45 Billion Light Years
- Because:
    - Hubble 'constant' is not actually constant
    - Space has expanded whilst photons travel through it

Other evidence supporting the Big Bang theory (2)

Proportions of the elements (including their isotopes):

Hydrogen
Helium
Lithium

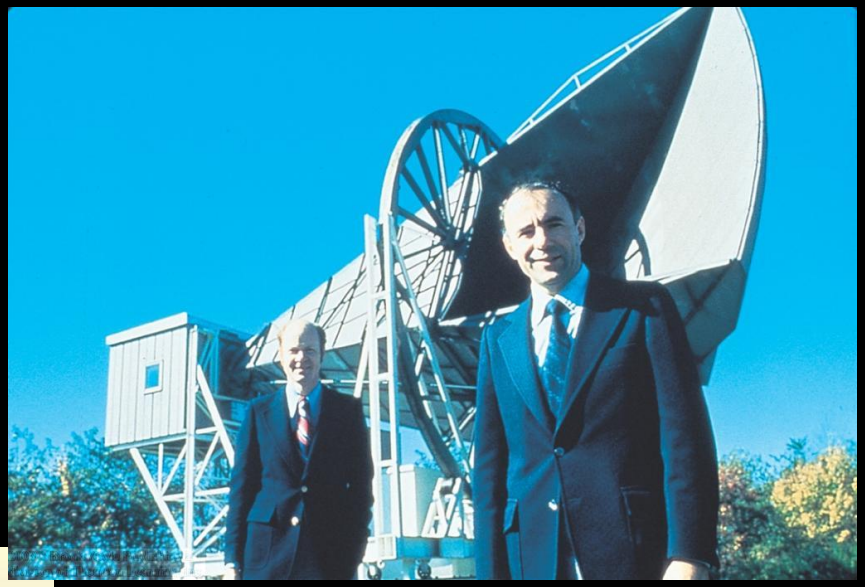


Other evidence supporting the Big Bang theory (3)

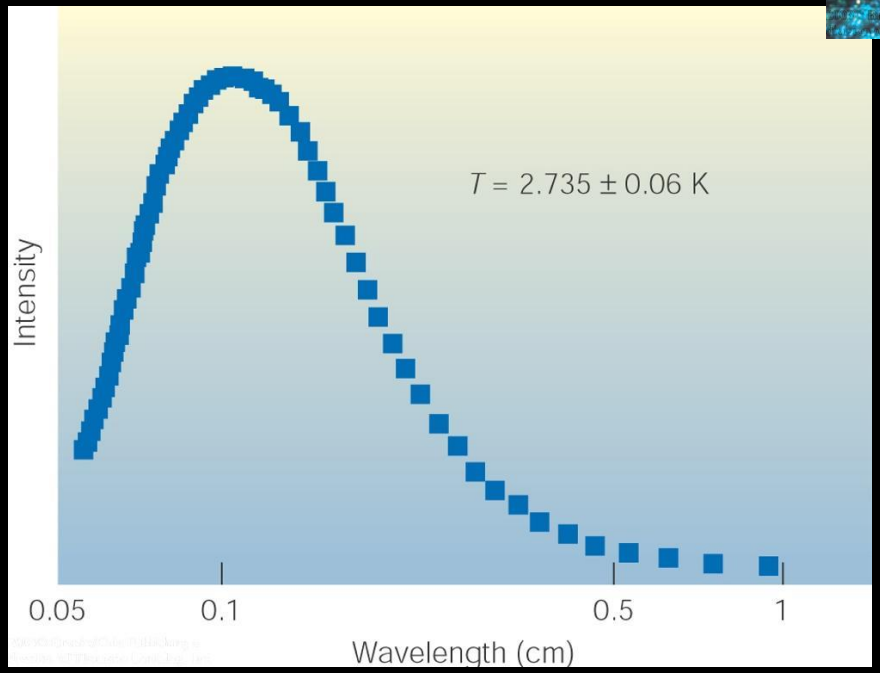
- Cosmic Microwave Background Radiation:
  - As the universe expands and cools, light from the Big Bang is trapped by ionised atoms
  - After about 380,000 years, atoms capture electrons and the light is free
  - Initial temperature about 3000 K
  - Redshifted about 1000 times so now 2.73 K

The Cosmic Background Radiation

The radiation from the very early phase of the universe is detectable today



R. Wilson & A. Penzias



Discovered in mid-1960s as the **Cosmic Microwave Background:**

Blackbody radiation with a temperature of T = 2.73 K

Other evidence supporting the Big Bang theory (4)

- Things further away look different (younger)
- 'Hubble' age of universe roughly matches that of the oldest known stars

The story so far...

- Cue video...

Problems with the Big Bang theory as described

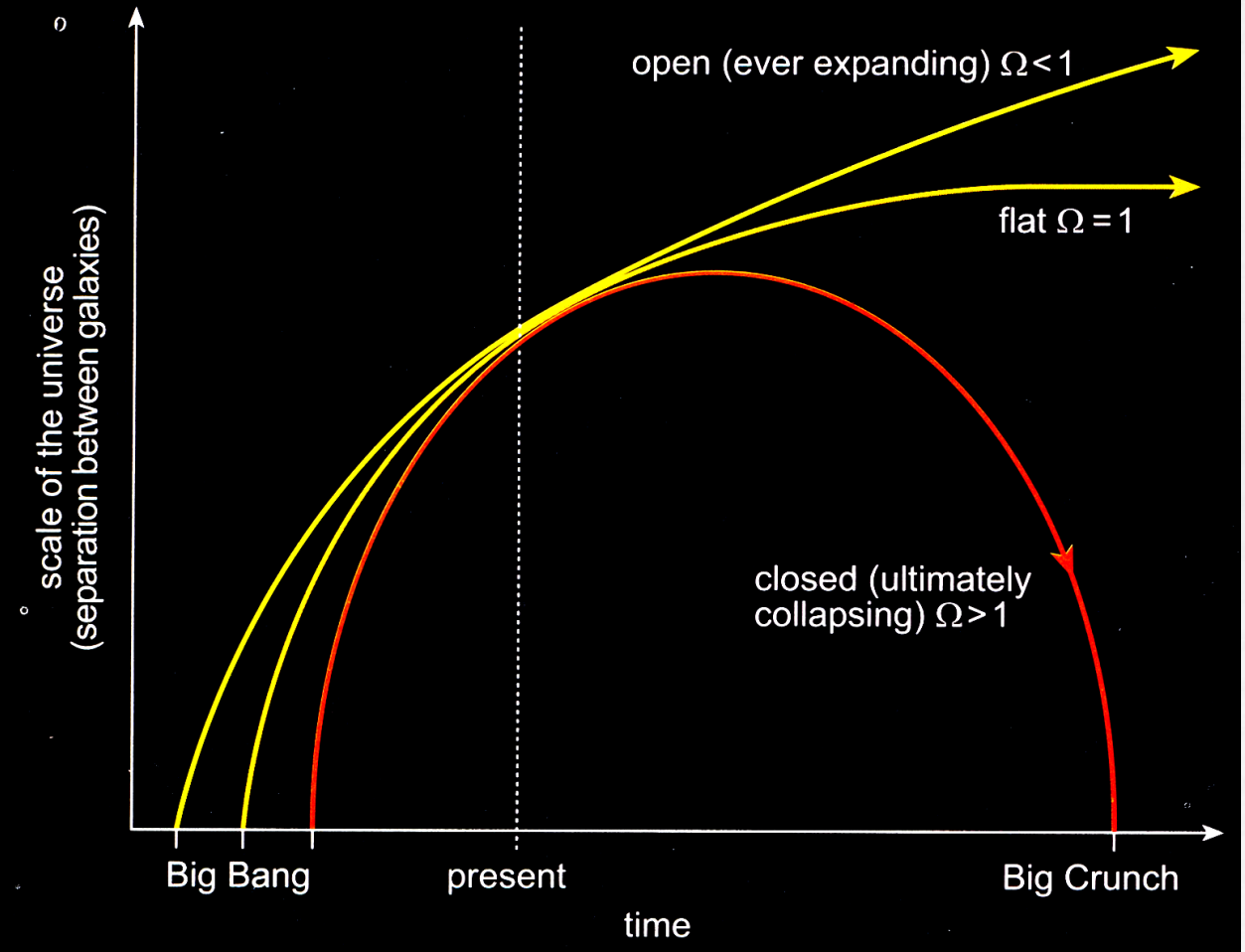
- The universe is:
  - too smooth (but not absolutely smooth)
  - too flat
  - has no magnetic monopoles

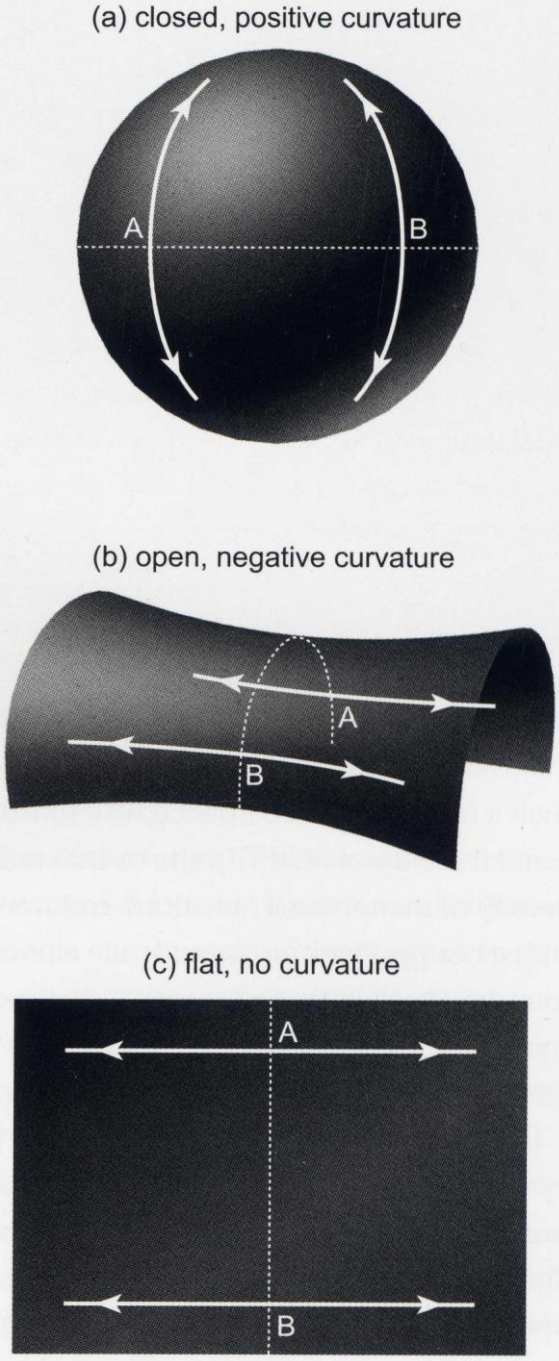
- If it was really created by a 'big bang' it would be: wildly different in different regions, topologically curved, and we'd have found a monopole by now

Smoothness Problem

The Cosmic Microwave Background (CMB) has only very small variations in temperature in different directions: only about 1 part in 10,000 away from the 2.73K average

Flatness problem





Magnetic Monopole Problem

- A standard Big Bang should have produced a large number of Magnetic Monopoles
- They have huge mass (almost a grain of sand!)
- None have been found despite many experiments

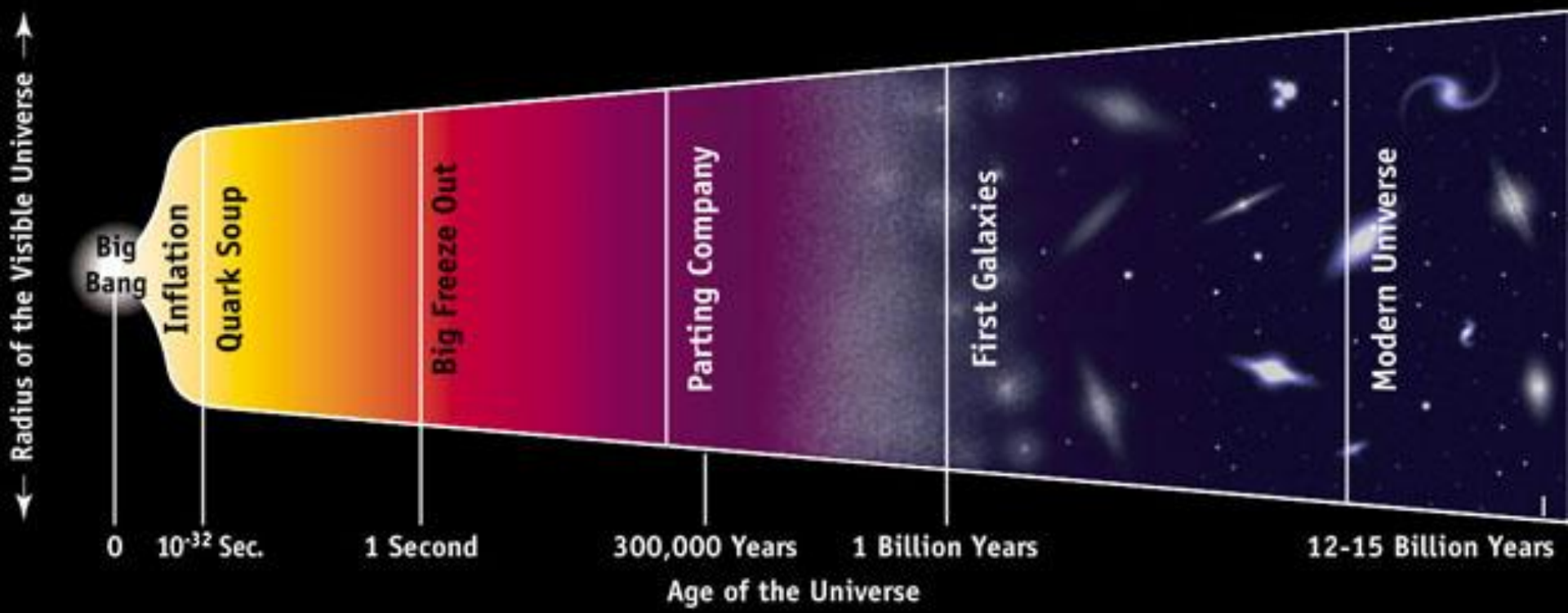
Scientific Notation - Powers of 10

- $1000 = 10 \times 10 \times 10 = 10^3$ (Ten to the 3)
- $1{,}000{,}000 = 10 \times 10 \times 10 \times 10 \times 10 \times 10 = 10^6$ (Ten to the 6)
- $1000000000000000000000000000000 = 10^{30}$ (Ten to the 30)
- $1/1000 = 1/(10 \times 10 \times 10) = 10^{-3}$ (Ten to the minus 3)
- $1/1000000000000000000000000000000 = 10^{-32}$ (Ten to the minus 32)
- $1/1000000000000000000000000000000000000000000 = 10^{-45}$ (Ten to the minus 45)

Inflationary Solution

- A very small area which
  - HAS achieved thermal equilibrium after 10^{-35} seconds
  - is stretched out in 10^{-32} seconds
  - by a factor of maybe 10^{30} times
  - to become our 'smooth' observable universe
- Quantum fluctuations are stretched out to provide the small unevenness which seeded galaxies and clusters
- The stretching also flattens our observable universe (Ω close to 1)
- Magnetic Monopole density is diluted

Standard solution: Inflation



Inflationary Consequences

- The 'actual' universe could well be enormously larger again e.g. 10^{30} times larger or more than our visible universe

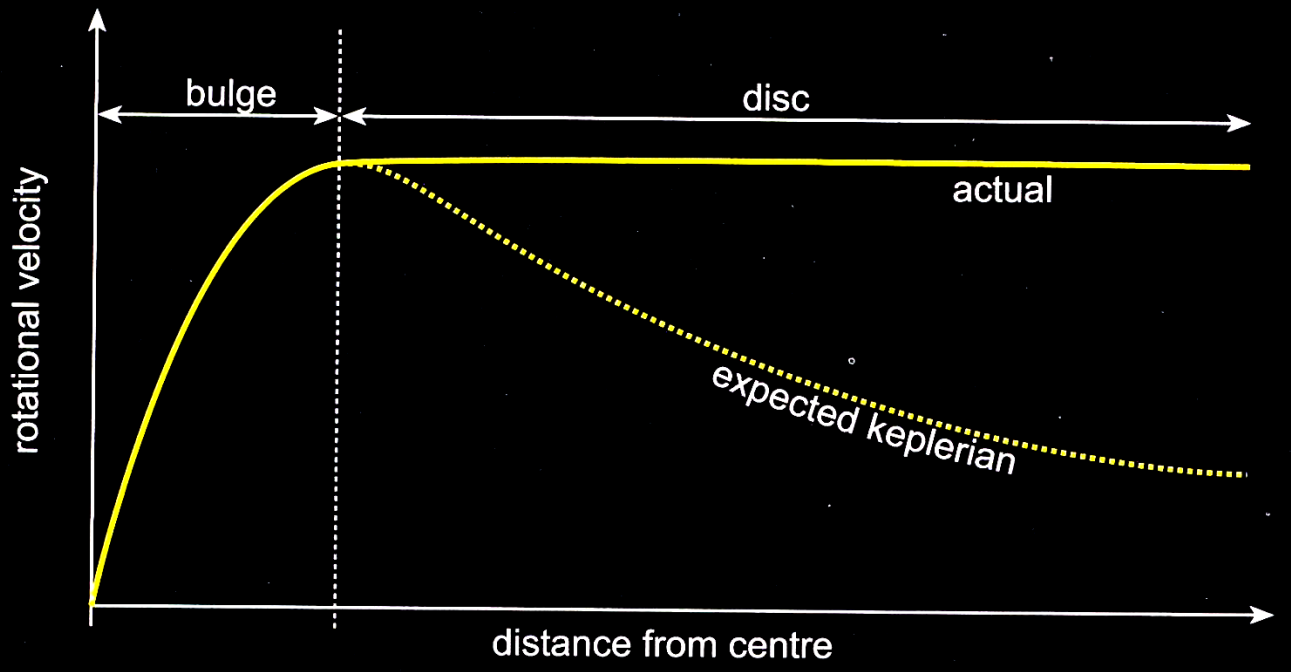
- Chaotic, eternal inflation also thought likely - creating an infinity of different, completely isolated or 'pocket' universes

End of the story?

- Universe begins with a singularity 13.7 million years ago
- Inflation expands universe by 10^{30} or more within 10^{-32} seconds
- Smoothed universe then expands more slowly
- Energy turns to Matter (H, He, Li)
- Matter clumps into stars and galaxies

No - something is wrong

- Stars near the edge of a galaxy 'should' rotate about its centre much slower than those near the core:



Something is missing

Combined mass of all "visible" matter (i.e. emitting/ absorbing radiation) in the universe adds up to much less (~4%) than the 'critical density' (Ω=1)

Gravitational lensing shows that some clusters contain 10 times as much mass as is directly visible.

What is Dark Matter?

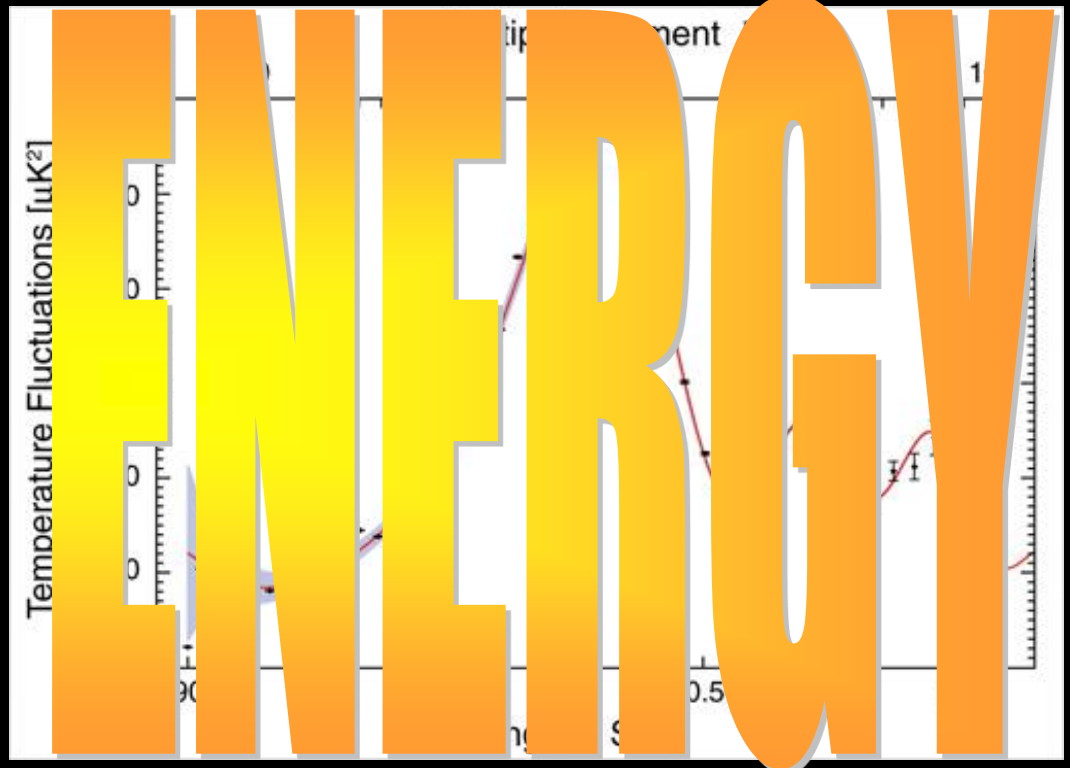
- MOND?
- MACHOs?
- Not baryons (protons, neutrons etc.)?
- Neutrinos?
- WIMPs?
  - Neutralinos?
  - Kalusa-Klein particles?
  - Wimpzillas?
- Axions?
- Neuterinos?
- Matter in another universe, affecting ours by gravity?

Something is STILL missing!

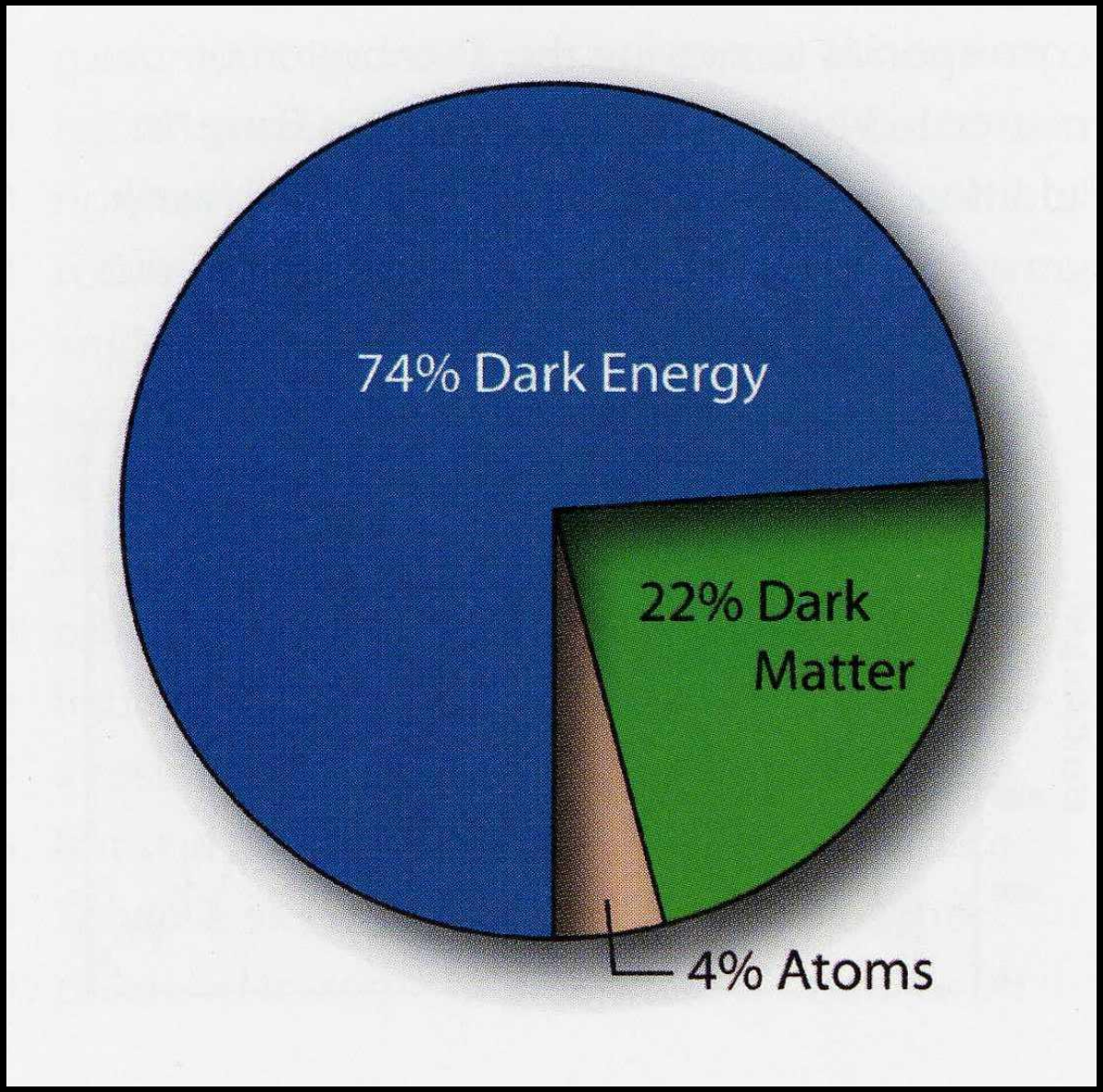
Combined mass of all Visible Matter and Dark Matter in the universe STILL adds up to much less (~26%) than the 'critical density' (Ω=1).

(WMAP Cosmic Microwave Background results)

DARK ENERGY

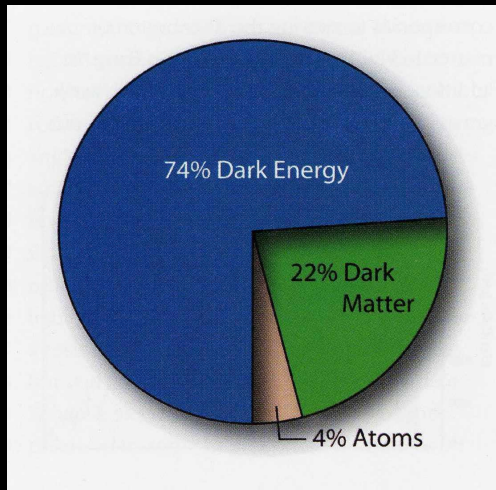


% of Stuff in our Universe

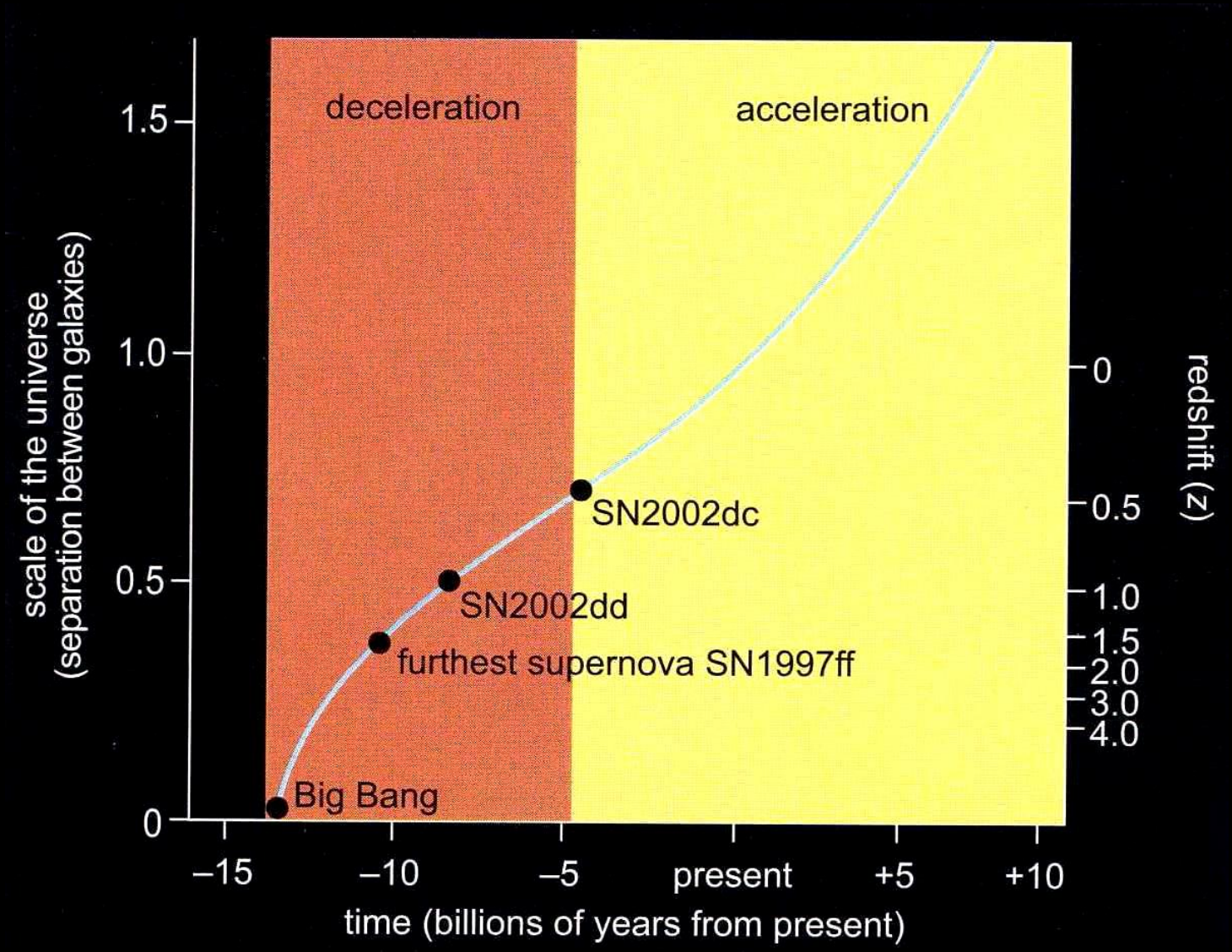


Effect of Dark Energy

- A weakly repulsive force
- Density is constant or slowly falling as space expands
- Now driving the expansion of the universe
  - from about 5 billion years ago, that expansion began accelerating!



Accelerating Expansion



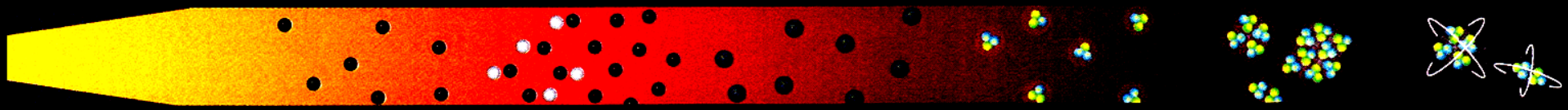
What is Dark Energy?

- Cosmological Constant?
- Vacuum Energy?
- Quintessence?
- Phantom Energy?

History of the Universe to date

The cosmic timeline continues with fairly well-established events leading to the present day.

Earliest Moments of the Big Bang → Formation of Atoms



10^{-35} second
Cosmic inflation creates a large, smooth patch of space filled with lumpy quark soup

10^{-30} s
One potential type of dark matter (axions) is synthesized

10^{-11} s
Matter gains the upper hand over antimatter

10^{-10} s
A second potential type of dark matter (neutralinos) is synthesized

10^{-5} s
Protons and neutrons form from quarks

0.01–300 s
Helium, lithium, and heavy hydrogen nuclei form from protons and neutrons

380,000 years
Atoms form from nuclei and electrons, releasing the cosmic microwave background radiation

Dark Ages → Modern Era

380,000–300 million yr
Gravity continues to amplify density differences in the gas that fills space

300 million yr
First stars and galaxies form

1 billion yr
Limit of current observations (highest-redshift objects)

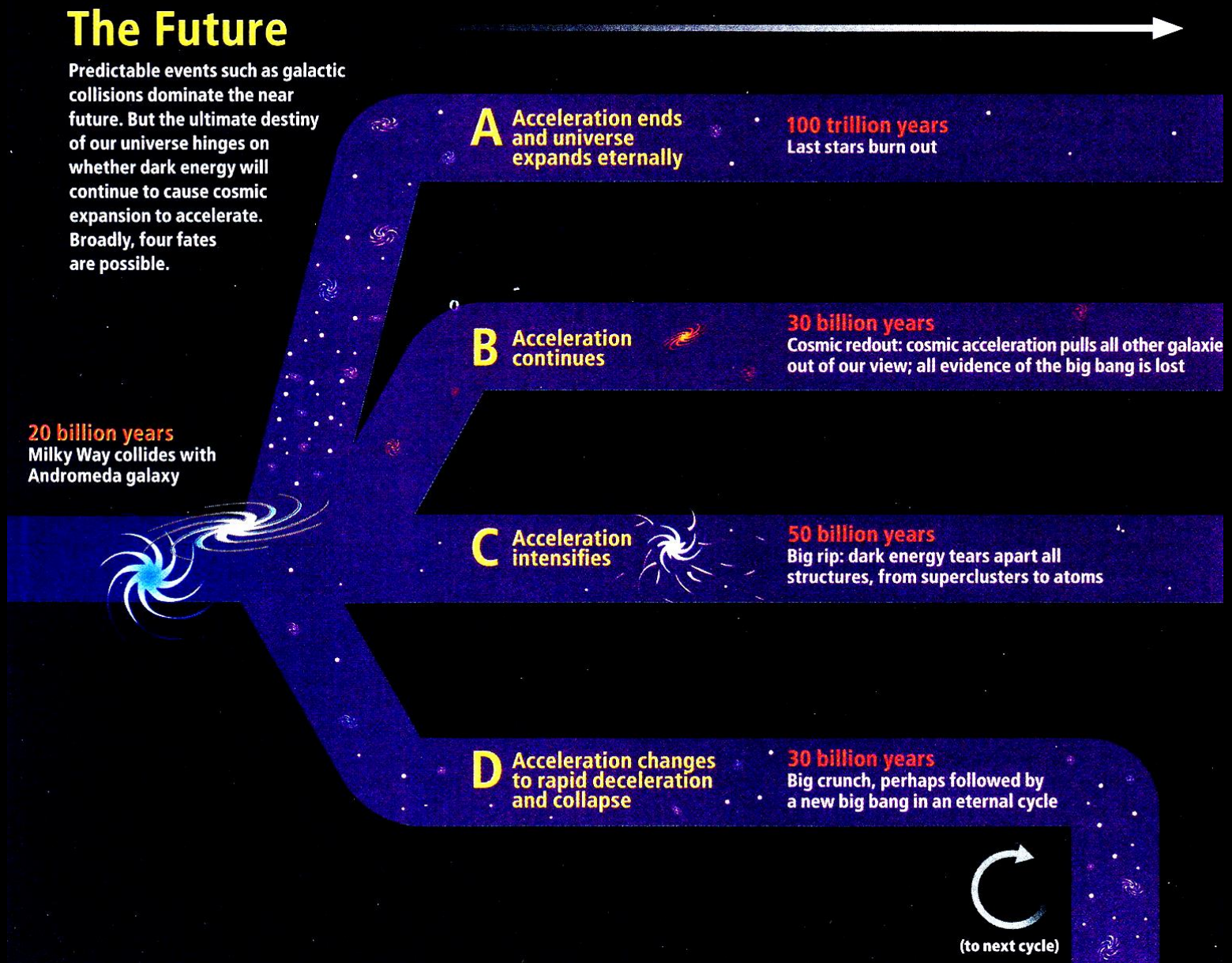
3 billion yr
Clusters of galaxies form; star formation peaks

9 billion yr
Solar system forms

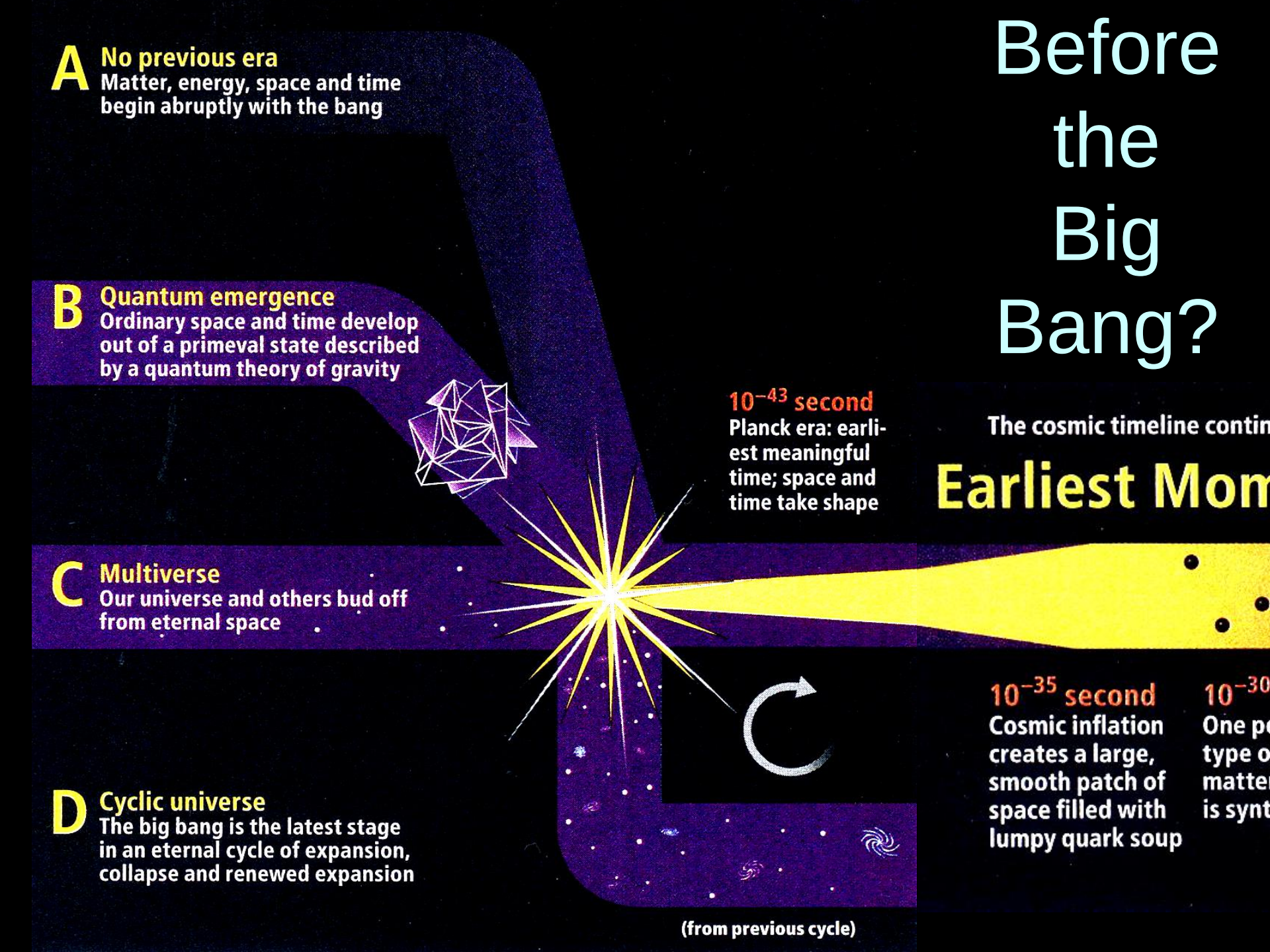
10 billion yr
Dark energy takes hold and expansion begins to accelerate

13.7 billion yr
Today

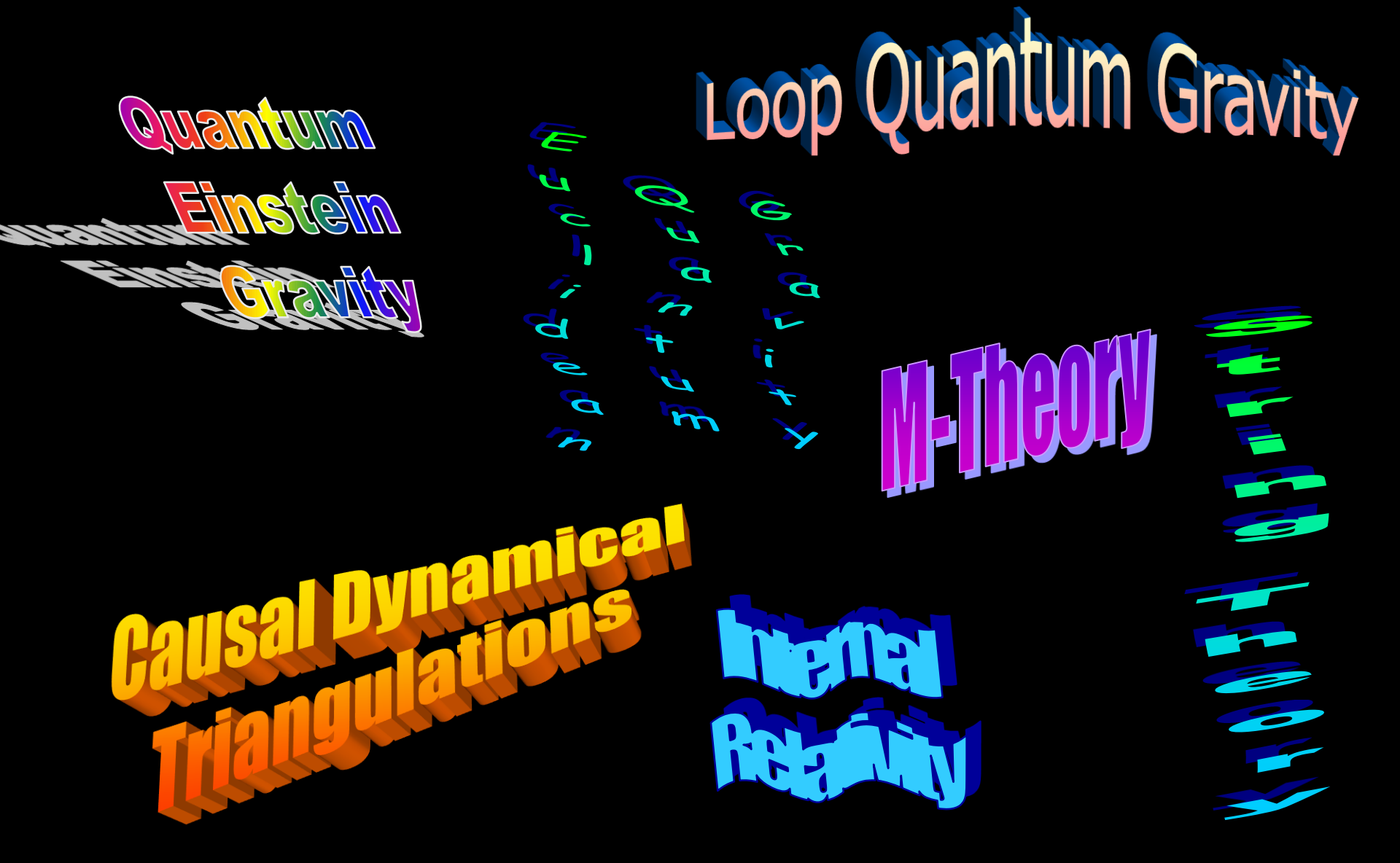
Future History of the Universe



Before the Big Bang?



Competing Theories



Causal Dynamical Triangulation

- Building block is the 4-simplex
  - a triangle in 4 dimensions (3 space, 1 time)
- Simplexes can only join together so that time flows in one direction (Causal)
- Simulations show that the Causality constraint spontaneously produces 3+1 D universes

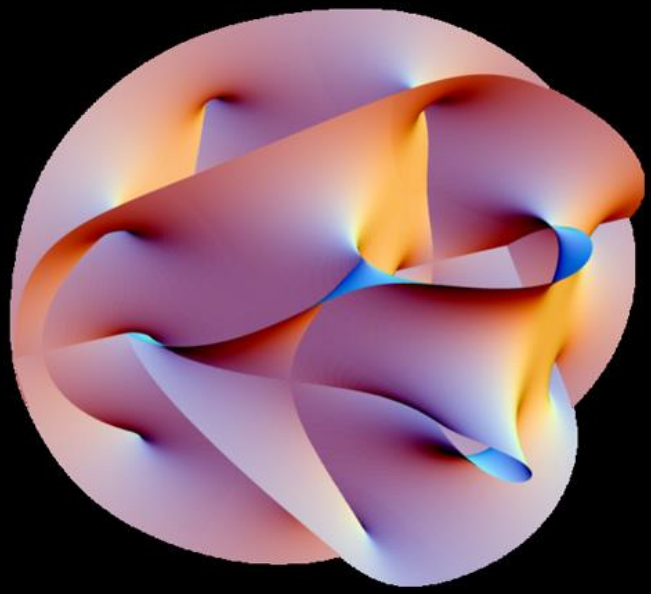
Quantum Gravity

- **Singularity** - mathematical term for a point where quantities become infinite or undefined
  - Einstein's theory of gravity (General Relativity) breaks down at this point

- Quantum Gravity: theories merging quantum theory with relativity
  - Smallest meaningful length is the Planck Length - about 10^{-35} metres
  - Shortest meaningful time is the Planck Time - about 10^{-43} seconds

Loop Quantum Gravity

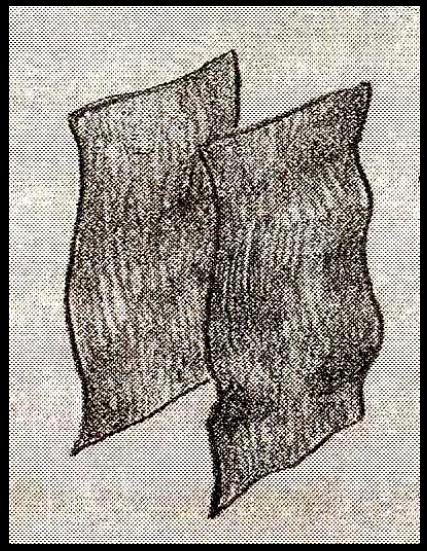
- Based on String Theory
  - every particle is modelled as a minute 1-dimensional string (or closed loop) vibrating in 10 or 11 dimensional space
  - all but 3 spatial dimensions are compact



- Gravity becomes repulsive at the Planck scale
- Avoidance of a singularity allows a 'bouncing' universe

M-Theory

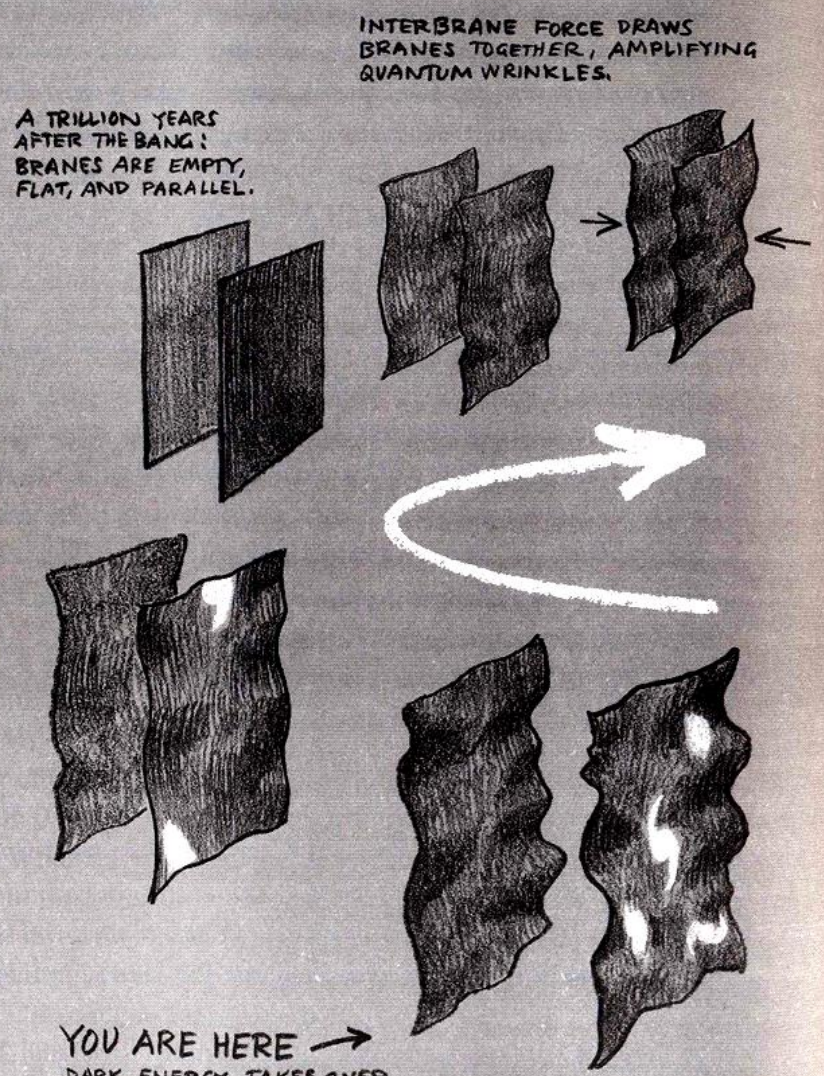
- Unifies various String Theories into one
- Membrane (or Brane) Theory
  - Our universe is a 9 dimensional 'brane'
    - 3 spatial dimensions that we can perceive
    - 6 dimensions are 'compact'
  - Our brane lies close to a second brane, and between them is a 10th dimension
  - Time is an extra dimension (11 total)



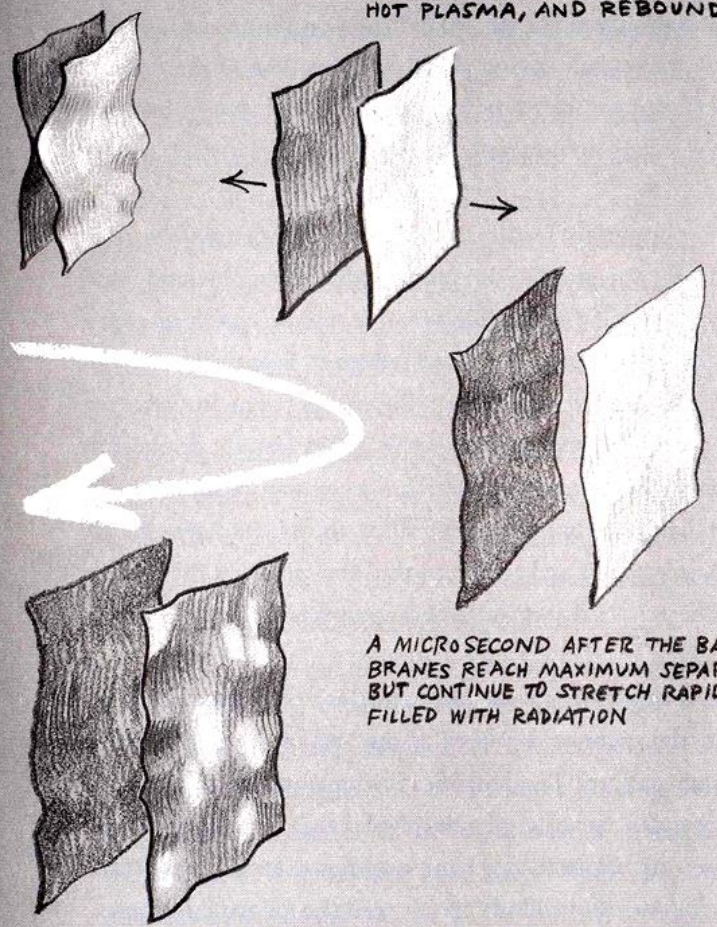
Bouncing Branes

- Collision of the two branes is the Big Bang - they bounce apart, both filled with energy
- Universe evolves as per standard model
- Dark Energy drives expansion of the branes which flatten and empty
- The branes are eventually drawn together again to collide once more

THE CYCLIC UNIVERSE



TWO BRANES ENGAGE IN AN ENDLESS CYCLE OF COLLISION, REBOUND, STRETCHING, AND COLLISION ONCE AGAIN



Inflationary or Cyclic Universe?

- **Inflationary**
- Requires inflation field + Dark Energy
- Infinity of multiverses with different physical laws
- Time and space have a beginning (Singularity)

- **Cyclic (branes)**
- Requires only Dark Energy
- Universe has repeating physical laws and structure
- Time and space are eternal (No Singularity)

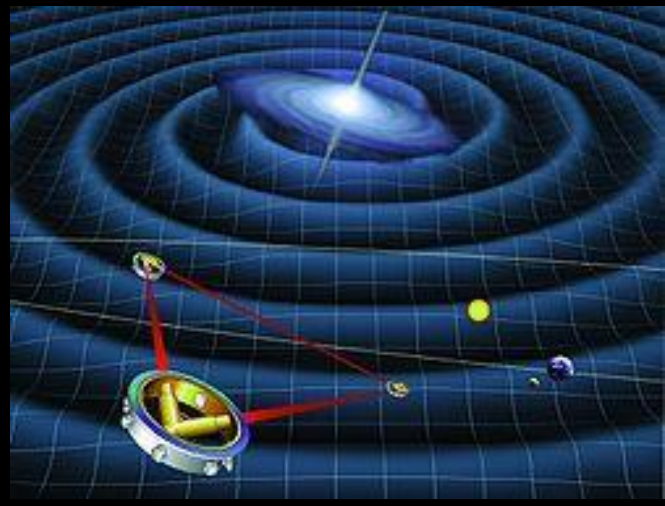
Inflationary or Cyclic Universe?

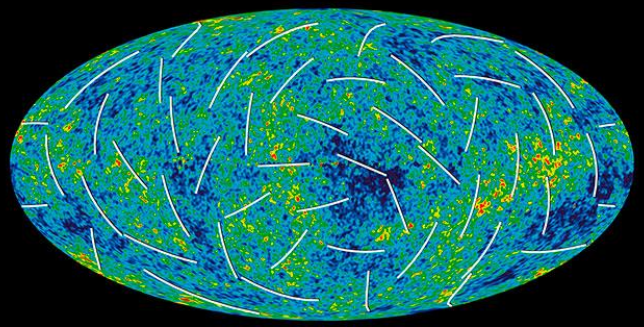
- **Inflationary**
- Requires Inflation field + Dark Energy
- Infinity of multiverses with different physical laws
- Time and space have a 'beginning' (Singularity)
- Gravitational waves should be strong and have scale invariant frequency spectrum

- **Cyclic (branes)**
- Requires only Dark Energy
- Universe has repeating physical laws and structure
- Time and space are eternal (No Singularity)
- Gravitational waves should be weak but increase strongly at higher frequencies

Detecting Gravitational Waves

- Direct detection:
  - LIGO - advanced 2014
  - LISA - launch 2020
- Polarization of the Cosmic Microwave Background:
  - WMAP 2006
  - Planck
    - Launched 2009
    - Data analysis expected 2012





Where our universe came from..

- Very strong multiple evidence for a Big Bang 13.7 Billion years ago
- Strong evidence for Dark Matter and Dark Energy
- Timeline from ~10^{-32} seconds to now pretty much agreed
- Inflationary theory (pre 10^{-32} seconds) challenged by Cyclic theories
- Evidence from Gravitational Waves should distinguish between the two

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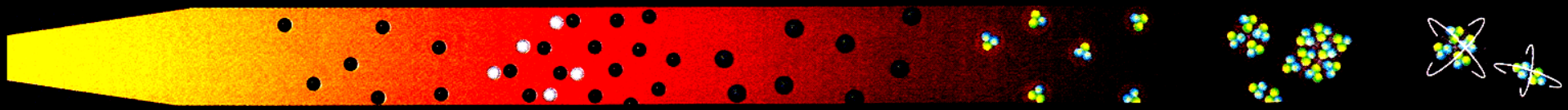

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References

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O *The dark side of the universe.* Iain Nicolson. Published Canopus Publishing Ltd. Bristol. 2007.

Also - several web urls as given in the notes.

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