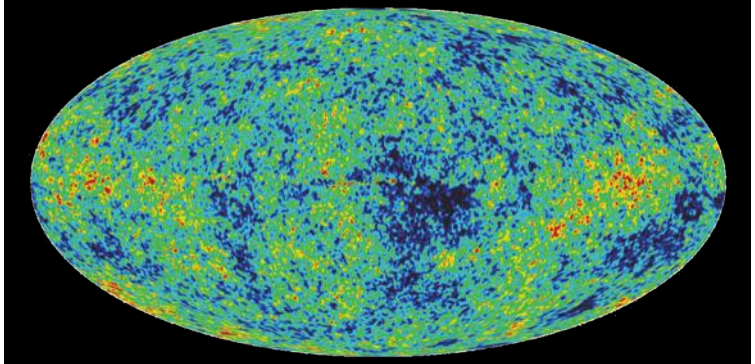
The Big Bang Theory



The Big Bang

- if ***universe*** is *expanding*, *must* have been *smaller*
- '*rewind*' ~ *14 billion years* & ***universe*** would be *a tiny, very hot & very dense* ***point***
- we call this moment ***The Big Bang***
- coined ***derisively*** by *Fred Hoyle* (1950)
- alternatives (like ***Static Universe Model***) are ***unable*** *to* ***explain*** *observations, predict like* ***BBT***

Expansion of the Universe

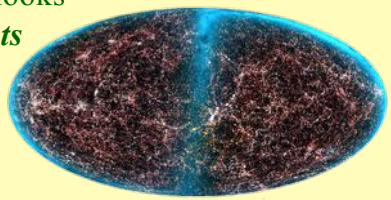
- universe ***not*** expanding into ***pre-existing space***
- universe ***itself*** *is growing*, ***creating spacetime***

(eg) *Where is north of the North Pole?*

- ***Cosmological Principle:***

(observable) universe looks the ***same*** from ***all points***

- ***no*** preferred *vantage*
- ***no center, no edge***

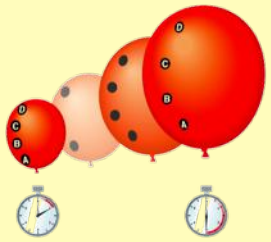


Q: *Evidence for this?*

- ***uniform*** distribution of galaxies on large scale

- *every* galaxy sees (all) others *moving away*

DEMO: *inflating a balloon*



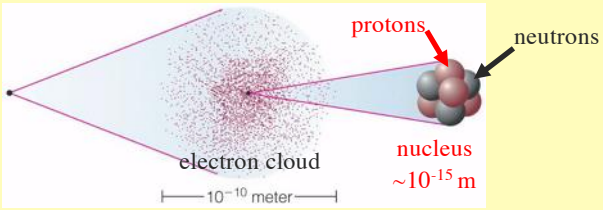
DEMO: *galaxy expansion with volunteers*

- ***expansion of space*** occurs ***away from*** regions with ***strong gravitation*** (*galaxy clusters, etc.*)

Particles & Matter

• matter is made of *tiny particles* called ***atoms***

(eg) *take a ruler and start with 1mm (10^{-3}m)…*



• ***protons & neutrons*** in the (dense) *nucleus*

• ***electrons*** in a "cloud" surrounding *nucleus*

• ***protons & neutrons*** made up of ***quarks***…

Matter & Energy

• ***photons*** are the ***particle*** form of ***light***

• contain *varying amounts* of ***energy***

(eg) ***shorter*** wavelength (***ie***. blue), ***greater*** energy

• $E = mc^2$

• *energy & matter* ***equivalent & interchangeable***

• ***antimatter*** *similar* to matter but with ***opposite*** properties ***eg***. *charge;* ***annihilates*** matter!

Forces of Nature

• **today**, our universe has ***4 known, separate forces: Gravitational, Electromagnetic, Strong, Weak***

• ***Gravitation*** (***Newton***, 1687)

• ***electric force*** (***Coulomb***, 1785)

• ***electromagnetic force*** (***Oersted***, 1820)

• ***nuclear*** *forces* discovered "*recently*" (1930's)

• ***everything*** we see results from these 4 forces

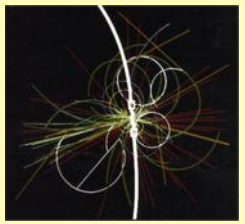
(eg) *Why can't you walk through walls?*

Unifying the Forces

• ***electromagnetic*** (***Maxwell***, 1864)

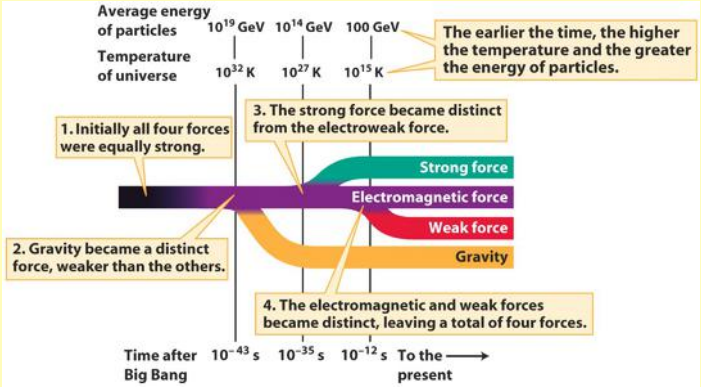
• ***electroweak*** (***CERN***, 1983)

• ***Grand Unified Theories*** (***GUTs***): ***strong+electroweak***



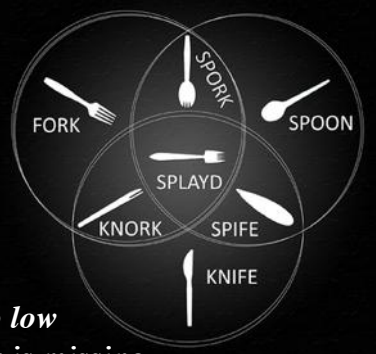
• ***Theories of Everything*** (***TOEs*** or ***Quantum Gravity***) unify ***all*** 4 forces (***GUT + gravity***)

• in early, very ***hot*** universe, ***all*** *forces were unified*



(eg) *ice, water, and water vapour appear* ***very*** *different but are all aspects of the* ***same*** *substance (water vapour) when cooled down enough!*

CLICKER*: The 4 fundamental forces are* ***NOT*** *currently* ***unified*** *because…?*



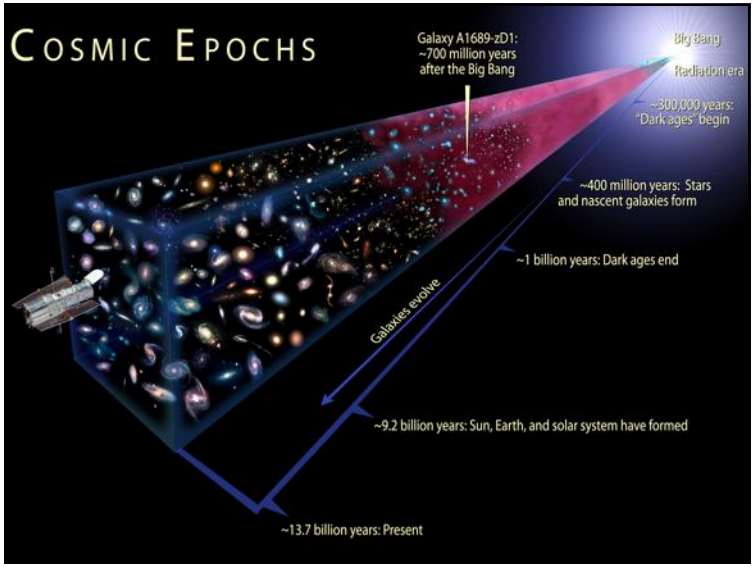
(a) temperatures are too low
(b) all of the anti-matter is missing
(c) gravity does not operate at the atomic level
(d) there are other forces yet to be discovered

The History of the Universe

• *theoretical physics*, *observation* & *experiment* yield a ***timeline*** for the *evolution of universe*

• can ***directly*** test behaviour of matter & energy at temperatures ***~10^{15} K*** or ***~10^{-12} s*** after ***Big Bang***

• ***physics*** can make ***predictions*** back to ***~10^{-43} s*** after ***Big Bang*** (***"Planck Time"***) ***but no further***



***CLICKER**: Which of the following best sums up your **level of acceptance** of the **Big Bang Theory**?*

***(a) 100%** (sign me up for the BBT newsletter)*
***(b) mostly on board** (it DID inspire a hit TV show)*
***(c) on the fence but open to the idea** (info is good)*
***(d) critical** ("I want to believe", but…)*
***(e) no way** (it's more likely **Elvis** is still alive)*

Planck Era
(*before 10^{-43} s*)

- *least* well understood; ***beyond** our current physics*
- ***Why?** quantum fluctuations* (***energy***) would cause extreme *changes in time & space* (***mass***)
- *mass fluctuations* lead to *gravitational variations*
- but… *quantum* & *relativity* do ***not*** "get along"
- ***gravity*** **separates** from other forces ***by end of era***

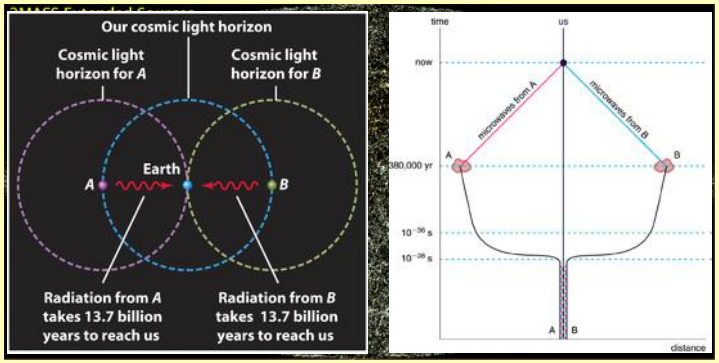
GUT & Inflation
(*~ 10^{-35} s*)

- 2 forces: ***gravity*** & ***GUT force***
- universe cools; ***Strong Force** separates from **GUT***
- released energy caused (?) a ***very*** rapid expansion

***Q:** What happens if you heat a gas quickly?*

- universe *expanded from **size of an atom** to **size of the solar system*** in *under 10^{-32} s*

- ***Alan Guth*** (1981) proposed *separation of strong force* from ***GUT*** caused ***inflation*** ***Q: Why needed?***



- explains ***why*** universe appears so *uniform*
- *widely separated* regions *today* **were** *very close*

ElectroWeak Era
(up to 10^{-12} s)

• *modern physics* & *particle accelerators* provide ***direct*** *evidence* of conditions at **end** of this era

• temperatures a *billion times hotter than Sun's core*

• *energy & matter* still *converting back & forth*

• by *end* of era, *all 4 forces were* ***separate***

Particle Era
(up to 10^{-3} s)

• *temperatures too low* for spontaneous "*creation*" *of matter/antimatter*

• so… **matter & antimatter** *annihilated*
• left with *slight* excess of *matter*

(eg) matter:antimatter excess ~ 1 part in a billion

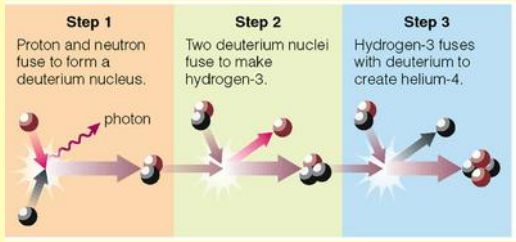
• ***quarks*** formed ***protons*** & ***neutrons***
• ***electrons***, ***neutrinos***, etc. also appear

(eg) BB to end of ***Particle Era*** quicker than *blink of an eye*

Era of Nucleosynthesis
(up to ~5 min)

• left over ***protons*** & ***neutrons*** merged into *heavier nuclei* ***(fusion)***

• universe expands; ***temperature & density*** drop: ***fusion*** *stops*



• left with *75% protons* (***H***) & *25% helium* (***He***) (by mass) & a little *deuterium* & *lithium*

Recombination
(~380,000 years)

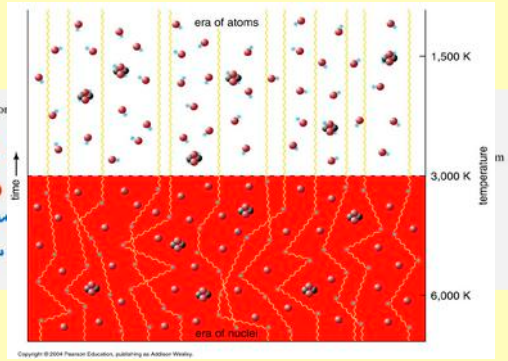
• by *end of* ***nucleosynthesis***, universe consists mostly of ***H*** & ***He*** *nuclei*, free ***electrons*** & ***photons***

• ***photons*** collided with ***electrons***

• *neutral atoms* ***ionized*** by "hot" ***photons until*** temp falls below ~3000 C: ***recombination***

• ***energy*** & ***matter*** decoupled; ***photons*** move ***freely***

• source of ***Cosmic Microwave Background***



• ***visible light photons*** emitted back then have been *stretched to microwaves* by expansion of universe

*(**eg**)* tune a TV "between" stations; about **1% of the "snow" you see** is result of ***CMB*** photons!

Dark Ages & First Stars

(~400 million years)

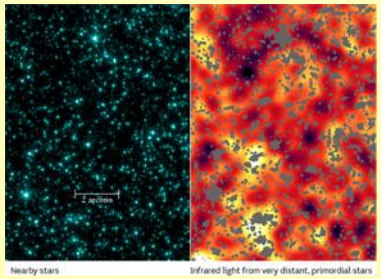
• after ***recombination***, left with *cooling atoms*

• *no other major source of photons* - "dark"

• gravity concentrated mass into massive "***Population III***" stars

• 100's x Sun's mass???

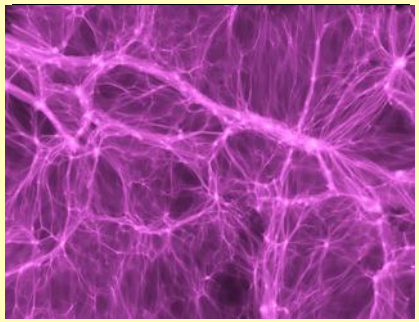
• made **only** of ***H***, ***He***



Formation of Galaxies

(~1 billion years)

• *material/stars aggregated* into clumps, forming first ***galaxies***



• ***galaxy*** *distribution* suggests there is "*more than meets the eye*"

***CLICKER:** Which era saw the creation of the simplest elements on the Periodic Table?*

(a) Dark Ages

(b) Era of Nucleosynthesis

(c) Planck Era

(d) Particle Era

Evidence for Big Bang

• why is ***Big Bang Theory*** a ***theory***?

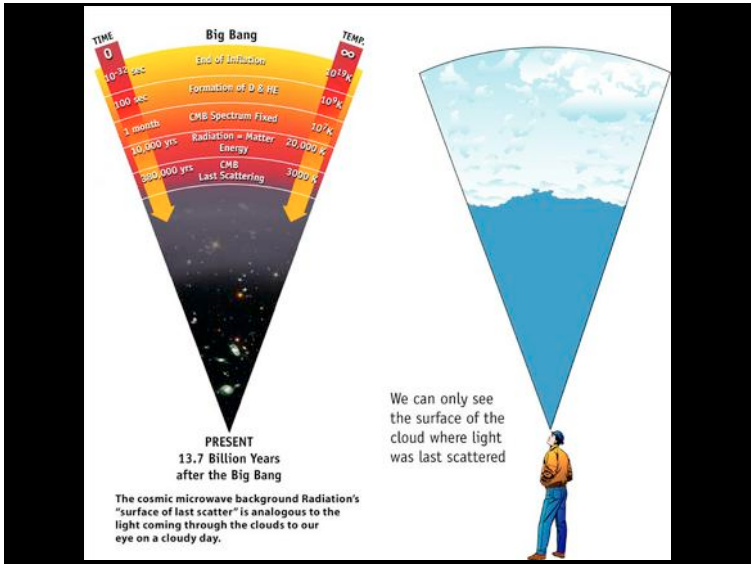
1) ***Cosmic Microwave Background*** radiation

2) ***nucleosynthesis***, ***(eg) helium abundance***

3) explains observed ***expansion*** (***red-shift***)

4) explains ***darkness of the night sky***

5) explains ***varying appearance of old galaxies***



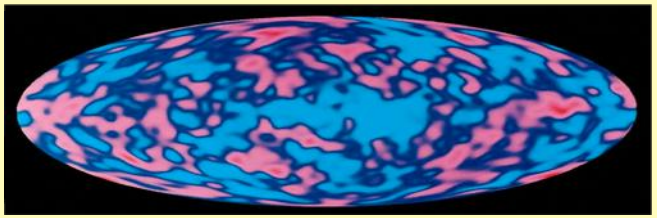
Cosmic Microwave Background

Q: What *is* the Cosmic Microwave Background?

• ***radiation*** from universe when *~400,000 years old*
• temperature then ***~ 3000 K***

• expansion *red-shifted* the *radiation* to ***microwaves***
• current temperature predicted to be ***~ 3 K***

• MW "noise" discovered (Penzias & Wilson 1965)

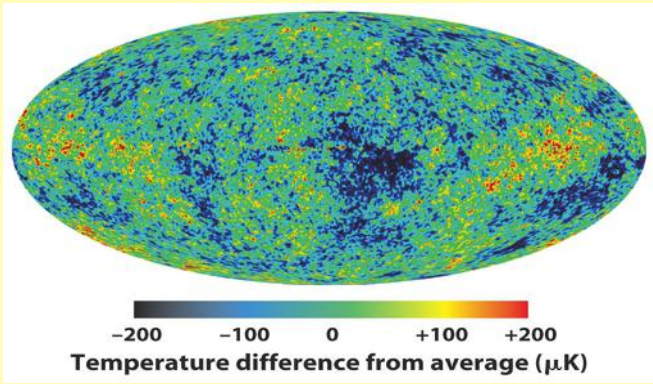


• characteristics *precisely* match predictions of ***BB***

• ***COBE (COsmic Background Explorer):*** 1990's

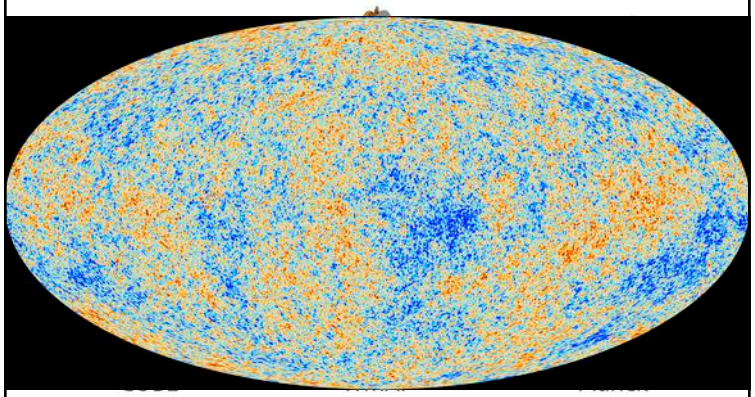
• ***COBE*** saw ***very*** *uniform temperature field*

• *space* has temperature of *2.7 °K*
• varies less than *1/10,000 K in all directions*

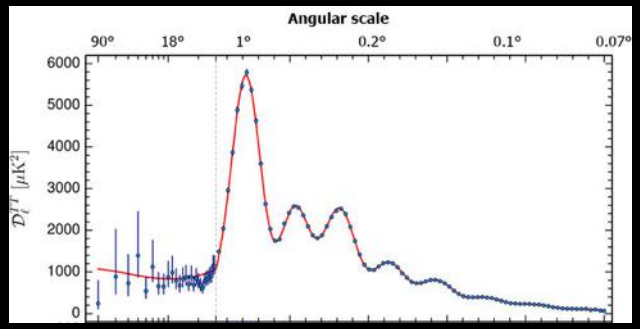


• ***WMAP (Wilkinson Microwave Anisotropy Probe):*** 2003 confirmed these fluctuations, indicating density perturbations that would *eventually* form galaxies

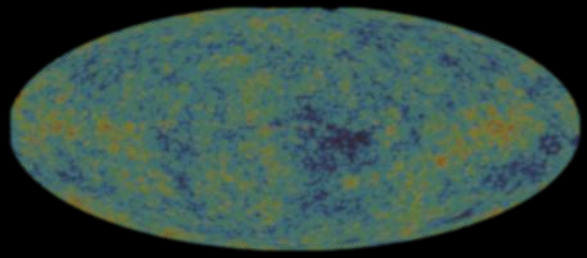
Planck results



Planck results



CLICKER: The slight temperature variations seen in the CMB are...?



(a) precursors of galaxies & galaxy clusters

(b) measurement uncertainties

(c) variations due to dust in the Milky Way

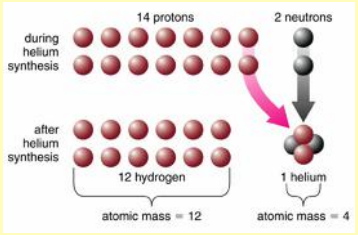
(d) the signature of matter-antimatter reactions

Nucleosynthesis

• ***Big Bang Theory*** predicts temperature & density of early universe ⇒ amount & type(s) of ***fusion***

• see ***He*** "everywhere" in ***observable universe***

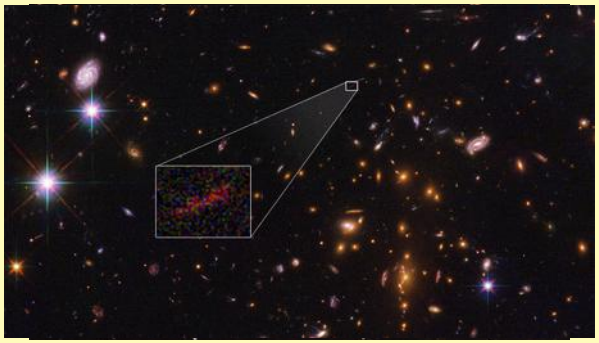
• BUT… *stars can only account for ~10% of He*



• ***BB prediction***: ***H*** *to* ***He*** *ratio of 3-to-1* by mass
• ***observation***: galaxies are 25%* ***He*** by mass

Early Galaxies

• early galaxies are *smaller*, *distorted* in appearance



• ***HST*** images looking back ***13+ Gy***

CLICKER: *Which of the following is the Big Bang Theory* ***unable*** *to explain?*
(a) *the ratio of H to He in the universe*
(b) the source of the cosmic microwave background
(c) the cause of the Big Bang
(d) the distorted appearance of early galaxies
(e) the uniformity in appearance of the universe

Review: Big Bang

• *expansion of spacetime* ***between*** galaxies carries them away from each other; began with ***Big Bang***

• "***cosmological redshift***" - light is stretched, too

• understanding *history of universe* involves understanding *forces*, *particles*, & *energy*

• ***significant experimental evidence*** supports ***BBT***