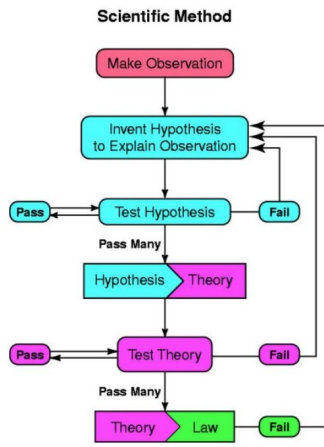


## Chapter 1 Scientific Theory and the Big Bang

### The Scientific Method:



**Hypothesis:** an educated guess based upon observation -> can be supported or rejection through experimentation or more observation -> cannot be proven to be true

**Theory:** summarizes hypothesis that explain a set of observations, supported by repeated testing -> valid as long as there is no firm evidence to dispute it -> still not guaranteed to be true but it's the best we can formulate based on current evidence

**Law:** governs body of observations -> describes certain scientific observation but do not explain why the observation happens governs body of observations

Ex. Newton's theory of Universal Gravitation provides the why that lies behind observations and the Law of gravity explains the observations we have of falling objects

### The Big Bang:

#### The Theory:

- Effort to explain exactly what happened at the very beginning of the universe
- At the birth of the universe time and space were created in a gigantic expansion that emanated from singularity
  - Singularity is an are in space time where gravitational force is so high that all known laws of physics break down and do not apply
- Gigantic expansion -> to have explosion there needs to be space -> but big bang created space and time -> so the band was more like an infinitesimally small balloon which in the tiniest fraction of time suddenly expands and keeps expanding

#### The Observations:

- Three Pillars of Proof:
  1. Recession of stars/galaxies (Hubble's Law)
  2. The Characteristics of Cosmic microwave background radiation
  3. Abundance of light elements

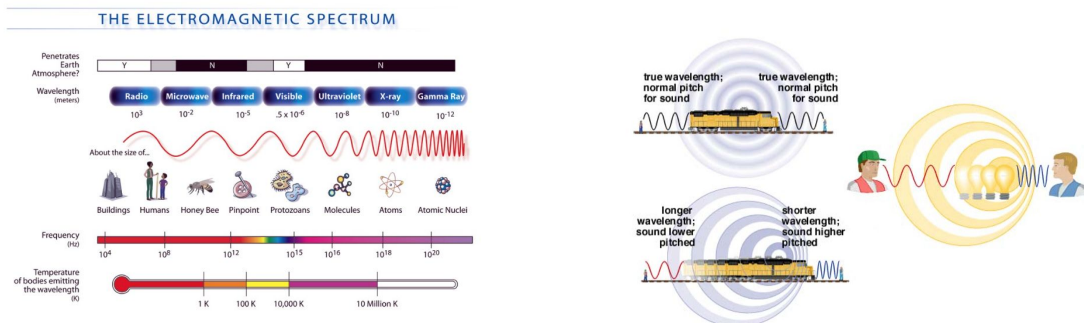
#### 1. Hubble's Law: $v = Hod$

## Geology U1

- $V$  = speed (km/s)
- $D$  = distance of star/galaxy away from earth in parsecs
- $H_0$  = speed of expansion of the universe -> Hubble assumed it was constant
  - Calculate how far from earth an object is by dividing its velocity by expansion rate factor
  - > your calculation assumes that  $H_0$  is constant so your calculations will be inaccurate if the rate has changed over time
- Edwin Hubble In his time (1889):
  - Demonstrated that there were many galaxies in the universe
  - Proved universe is expanding
  - Showed us how to measure distances in space

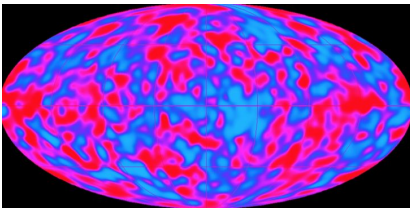
NASA installed huge optical telescope into Earth's Orbit and named it Hubble Space Telescope in honour of him

### Light's Redshift:



- Doppler Effect: when object coming toward you -> sound waves are compressed by motion of a noisy object -> it sounds differently to you than when the same waves are being carried off away from you
  - Light behaves similarly as proven by Keeler
    - If light source moving toward observer light wavelength appears to shorten (blue shifted) and if light moving away wavelengths lengthen (red shifted)
  - Speed of light is fixed and cannot change -> Hubble observed changes in speed of light it meant stars had to be moving away from earth
  - Applied to everything he could see -> whole universe was expanding
  - Amount of red shift can be used to measure star or galaxies distance from earth -> the more red the faster it's moving away

## 2. Cosmic Microwave Background (CMB) Radiation:



- Universe extremely hot in the first seconds of the universe and as it expanded it cooled down
- Hot light photons produced in early period have since lost energy and dropped from visible light energy range to microwave energy range

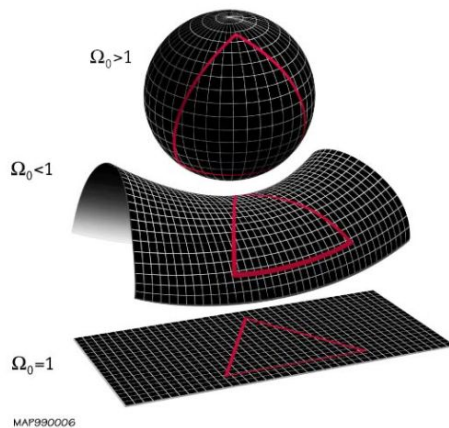
- CMB can be seen from anywhere in the Universe because it comes from all directions with nearly same intensity
- First discovered in 1965 as a noise in microwave radio receiver
- The only explanation that makes sense is that CMB represents very last remnants of light/heat energy of the Big Bang's initial expansion
  - Supported by the fact that while general temperature of space should be 0 Kelvins it's actually 2.7 K -> so its greatly exaggerated in the figure but no much in reality

### 3. Abundance of Light Elements:

- The ratio of the 3 lightest elements (H - 75%, He- 25%, and Li - trace) can only be explained if they originated from one single ratio of the first subatomic particles of matter that can be formed from super hot environment -> only way to get that is through unique event like big bang

### Shape of Universe:

- Important to know shape for many reasons one of the most is how the universe will end

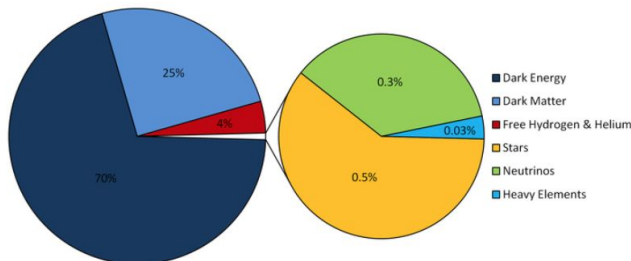


- All three models -> density parameter critical
  - Space negative curvature -> insufficient matter around to allow gravity to act and stop expansion ( $\Omega_0 < 1$ )
  - Space positive curvature -> more than enough matter around to allow gravity to pull everything back together ( $\Omega_0 > 1$ )
  - Space Flat -> exactly critical value of matter so prevents universe from pulling back or from expanding indefinitely to oblivion ( $\Omega_0 = 1$ )
- 1. Universe might have positive curvature (sphere)
  - Closed universe -> finite in size but without boundary
  - You could in principle fly a spaceship in one direction and it will eventually arrive back where you started from
  - Closed in time -> stop expanding then contract in a big crunch
  - There needs to be sufficient matter in Universe that gravity can eventually pull things back together
  - Production of universe cyclic -> bang - a universe, then a crunch collapse, bang - universe
- 2. Negative curvature (open)
  - Saddle shaped

## Geology U1

- Infinite and unbounded
  - Parallel lines eventually diverge
  - Open universe expand forever with the rate never approaching zero
3. Flat universe
- Infinite in spatial extent and have no boundaries
  - Parallel lines always parallel
  - Expand forever but expansion rate will approach zero (movement outward very slow)

### What Affects Gravity?



- Conventional matter (stars, plants, asteroid comets): less than 5% of the universe
  - If this is all there is pretty soon the distances between stars will be so great we will not be able to see any others than the sun
- Dark matter (27%): matter we have never seen because it gives off no electromagnetic energy -> we know it exists as we can detect gravitational attraction to conventional matter
  - If dark matter was all that was out there it would be enough matter to slow expansion and pull things back in big crunch -> but universe expansion is increasing
  - Dark energy: Mysterious force contributes to 70% of the universe and acts in opposition to gravity -> repelling matter
    - Seems to control expansion of space -> when it exactly counterbalances the kinetic energy of the big bang expansion -> flat universe -> right now universe is almost perfectly flat but has the slightest negative curvature

### **Age of Universe:**

#### Radioactivity:

- Certain elements are radioactive meaning they breakdown to form other components and give off energy in the process
- Figure out the age of the universe by:
  - Observing compositions of gases around old stars
  - Knowing exact radioactive processes required to produce these gas compositions from very first elements created in the Big Bang
  - Knowing all time factors involved in breaking down of one component to yield others
- Gives us age estimate of 11.5 and 17.5 billion years

#### Hubble's Expansion Constant

- Possible to use his equation to determine age of most distant light sources we can find
- 2002 -> Hubble Space Telescope found white dwarf stars -> remnants of stars that have consumed all their fuel and are cooling off -> very old -> good for dating
  - Gave dates between 12 - 13 billion years but it takes 1 billion for the cosmos to cool down so the universe has to fall between 13 and 14 billion years

CMB Radiation:

- Most accurate view of date conditions
- A sophisticated model of the universe has been produced based from the time represented by that CMB signal map back to time the Big Bang produced first photons
- Assuming right model has been developed the universe is 13.80 ± 0.04 billion years

What Banged?

- Neil Turok -> There were multiple Big Bangs and will be many more
    - Big Bang represents just one stage in an infinitely repeated cycle of expansion and contraction -> neither time or universe has a beginning or end
    - Universe consists of 2 infinite extensive sheets separated by a very thin layer of energy
      - Sandwich Model: once in a while the intermediate kayer become unstable and gravity starts pulling things together -> layers bounce together and form point of contact -> sufficient energy is generated to produce another big bang
      - From then till next period of instability universe continues expansion
- 

**Chapter 2**  
**Time and Space**

**Light Years:**

- Method to measure distances in space
- 1 Light year = distance that light travels in one year (300,000 km / second -> light travels 9.4608 × 10<sup>12</sup> km per year)
- When looking through a telescope it's like your looking in the past (at light that started its journey "n" amount of light years ago)

**Measuring Light Years:**

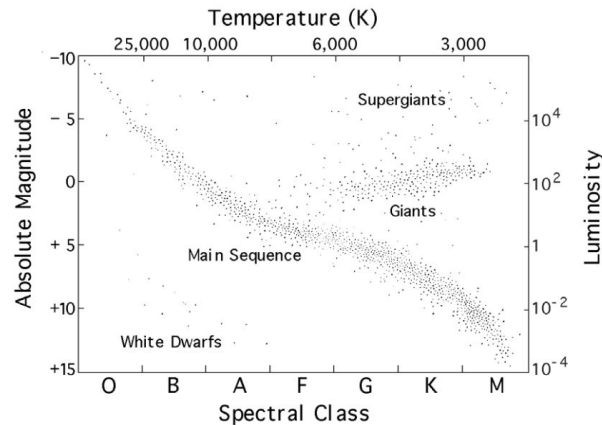
- Different measurement techniques are needed for different distance ranges and the middle range work (500 to 500 million light years) is the most complex

Up to 500 Light Years Distance:

- Trigonometric parallax: relies on an object appearing to be at a different place relative to the background depending on your viewpoints
- Earth rotates around the sun -> nearby star appears to wobble relative to distant stars
- Telescope will have to be moved by iny angle to see the same star a couple months later -> measure the angle and know the distance that earth has travelled in that time we can calculate the distance to the star

500 to 500 Million Light Year Distance:

1. **Main Sequence Fitting:** first technique deals with brightness of stars:



- Hertzsprung Russell Diagram is used which relates the luminosity of stars to their temperature
- Most of the stars are Main sequence
- Determine exact colour of star studies -> draw vertical line to intersect with main sequence -> measure on the brightness scale what the true brightness is
- Stars brightness dims with distance so the brightness you see from Earth (apparent brightness) is rather less than true
- Apparent brightness (which you see and measure) =  $\frac{\text{Intrinsic brightness (graph)}}{(4 \times \pi \times \text{distance}^2)}$
- Good up to distances about 150,000 light years away (beyond the Milky Way)
- 2. **Cepheid Technique:** Second use makes use of marker stars that have a special property
  - Pulsing brightness that peaks with absolute regularity which is completely related to the star's brightness -> Cepheids
  - Find a cepheid and measure time between one brightness peak and the next (intrinsic brightness value)
  - Then use same procedure as first technique
  - Since Cepheids are all over the place they tell us how far away galaxies are up to 500 million light years away

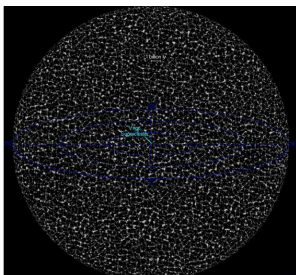
**Edwin Hubble:**

- Used cepheid technique to prove Milky Way Galaxy was not alone
- 1923 - photographed Andromeda (spiral shaped clump of stars)
  - Many thought it was part of the milky way but he found a cepheid star and managed to determine the distance between earth and the star
  - The clump of stars resided far beyond the confines of the Milky Way
  - Andromeda Galaxy closest neighbouring -> resembles a frisbee shape

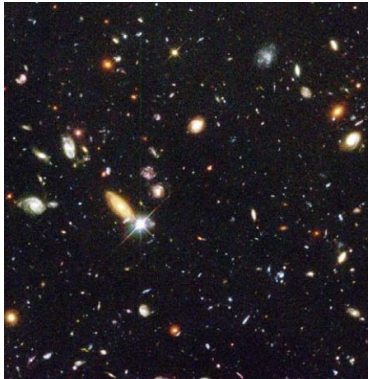
Beyond 500 Million Light Years:

- Hubble's Law is used for really distant objects

**Scale of Space:**



- Spots are galaxies (galaxy = collection of stars, gas, and dust held together by gravitational attraction)
- 100 billion of them



#### Deep Space Observed by Hubble Telescope:

- Every spot of light is a galaxy
- In our immediate environment is a group about 40-50 galaxies called the Local Group:
  - Consists of 3 really big galaxies:
    1. Andromeda
    2. Milky Way
    3. Triangulum
  - Andromeda is appearing to be hurtling toward the Milky Way at 500,000 km/hour -> expected to either crash or merge in 3 billion years
- The Death Valley night panorama demonstrates the disc shape of the Milky Way Galaxy
- Our solar system is located on the orion arm 2/3 from the core

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### Chapter 3 Matter and Nebular Hypothesis

#### Introduction

- Nebular hypothesis or Solar Nebular Disk Model – the latter process where the big bang created matter, that the most basic forms of this matter combined to form elements, and that eventually pockets of matter/elements combined to form star-planet systems

#### The Chemical Elements

- One second after the big bang, the universe was 10 billion K and filled with neutrons, protons etc.
- as the universe cooled, basic particles combined to make elements
- **Element**: a substance that cannot be broken down into anything simpler by any chemical means
- **Atom**: a particle of matter that has the unique properties of elements (pieces of elements)
  - **Nucleus** – the center of the atom
  - **Protons** – positively charged particles
  - **Neutrons** – neutral or particles with no charge
  - **Electrons** – negatively charged particles
    - This offsets or balances the positive charge of the nucleus, making most atoms neutral
  - **Ion** – an atoms with a negative charge (too many electrons) or positive charge (not enough electrons)
    - Positive ions usually combine with negative ions to form neutral compounds
    - An ion has an equal number of protons and electrons.
  - **Isotope** – all atoms of a certain type of elements have the same number of protons, however isotopes -> contain different number of neutrons within their nuclei
    - **Mass** – the sum of the protons and neutrons in the nuclei (is used to identify each isotope)
    - **Example**: The element lithium (symbol: Li) has two isotopes that are stable in nature (it is possible to temporarily produce unstable isotopes of lithium in the

lab by shooting a stream of particles at the otherwise stable atoms, but none of them occur in nature). Every nucleus of every lithium atom contains 3 protons, however some of the atoms contain 3 neutrons and some contain 4 neutrons. We thus have 2 isotopes: lithium-6 (3 protons + 3 neutrons = mass number of 6) and lithium-7 (3 protons + 4 neutrons). Normally, we use shorthand and call them  ${}^6\text{Li}$  and  ${}^7\text{Li}$ .

- **Half-life** : The rate of breakdown is constant, so no matter what amount (mass) you start with, 1/2 will be gone every 12.32 years
- **Radioactivity**: the spontaneous breakdown of unstable atoms (i.e., unstable isotopes) of an element, with the production of energy and other particles
  - **Fission** - a breakdown of the nucleus of a relatively heavy atom (i.e., isotope) into at least two other lighter particles plus energy (radioactivity)
  - **Fusion** - combination of two lighter atoms/isotopes to make one heavier atom/isotope plus energy (not radioactive)
- **Supernova**: the explosive death of a massive star (explosion is instantaneous, the bright effect can be seen for weeks in both the day and at night)

### Periodic Table of the Elements

- an arrangement of all the known chemical elements in a table according to a defined order
- **Atomic number** - the number of protons in the nucleus of the atom as we progress through the table from low atomic weight to high atomic weight

### Elements: From First to Last

- big bang resulted in the production of three elements: Hydrogen, Helium, and Lithium
  - these are the first three elements on the periodic table, therefore the lightest
- **deuterium** - the isotope  ${}^2\text{H}$  and is the most important/abundant, played an important role in the early moments of the universe
  - Much of the early-formed deuterium went through a reaction to form helium (He) and a little bit of lithium (Li) - and that is how those two elements were formed!
- **Supernovae** - an explosion of a big star releases so much heat/pressure that all the heavy elements can be produced (this is what we/the earth are made of)

### The Nebular Hypothesis

- Suggests that the Solar System formed over a relatively brief span of time and all as a unit (the sun, planets and so on) from a nebula (a cloud of interstellar gas)
- The cloud was very low density, and contracted under its self-gravity

### Collapse

- Not all gas clouds collapse and turn into solar systems
- a pocket of the cloud begins to contract (from whatever triggered it (we don't know yet) ex: the shock wave produced by a nearby supernova)
- The collapsed region will increase in density
- The collapse of the cloud will then accelerate
- the temperature will increase, causing the cloud to become smaller and denser
- particles become so densely packed that the heat can no longer escape as they are blocked by surrounding layers of dense matter
- particles near the center are moving at very high speeds, so that can provide enough sustaining pressure to stop any further collapse

## Geology U1

- Fusion reactions can now take place, and a star is born
- the conversion of hydrogen to helium by the sun releases enormous amounts of heat and light energy → *when sun runs out of hydrogen atoms it becomes red giant*

### Cloud Flattening

- **Momentum** – a measure of an object's tendency to move at a constant speed along a straight path
- **Angular Momentum** – a measure of the amount of spin (or orbital motion) of object
- **Conservation of angular momentum** – if no outside force acts on a spinning (or orbiting) object, the object's angular momentum will not change with time, no matter how the object interacts with other objects
- The slight direction of the movement of particles within the cloud defines the sense of rotation/angular momentum
- The increasing rapid spin of orbiting material leads to its flattening out (just like a figure skater!)
- This is why the solar system is flat and everything moves in the same direction as the sun

### Condensation of the Planetary Disk

- Newly formed nebula has a temperature gradient, hot in the middle, and gradually gets colder towards the outside
- Before the collapse, everything was made out of the same things, and the collapse itself did not lead to any compositional differences from region to region
- the reason why all the planets are not composed of the same is not because of the temperature gradient
- **Dew point temperature** – the temperature to which one must be cooled to reach water saturation/water molecule formation
- in the cooler outer parts the temperature was low enough that everything condensed
- closer to the sun where it was much hotter, not everything could condense in the swirling nebula

### Volatile vs Refractory:

- **volatile elements** – elements which boil at low temperatures
- **refractory elements** – elements that do not readily respond to heat
- near the hot sun small grains of refractory materials (alloys of nickel, and iron) condensed and grew to the size of pebbles
- out where Jupiter was formed everything was condensed, whereas closer in where Mercury was formed, only the heavier (refractory) elements condensed
- Note: the difference in composition is not caused by the fact that heavy elements were more abundant near the Sun. It is simply that the light gases do not condense at the high temperatures that prevail in the inner parts of the Solar System. Since they never became locked up into grains, they never accumulated into planets.

### **From Pebbles to Planets (Accretion)**

- Pebbles are all moving in the same direction because of the original motion of the nebula
- Accretion – when two pebbles met in relatively gentle fashion at moderate speeds, and stuck together
- As various lumps grew, so did their gravitational forces
- Large lumps turned into stones, then boulder, and eventually planetesimals (small planets)

The Magic Broom

- Leftover gases were swept out of the solar system towards the end of the formation of the planetary system

**Some Predictions**

- There must have been very large numbers of planetesimals orbiting around and colliding with the growing protoplanets. Since the planetesimals got 'used up' by forming the planets, their numbers would have decreased
- Bombardments rate (the number of collisions) should have been very high early on
- Late in the formation process, there must have been some pretty large lumps moving around in the Solar System. Not all of these would have been orbiting in completely parallel paths, thus there may occasionally have been really vigorous collisions between enormous fast-moving lumps of rock
  - Explains why Uranus is tipped on its side
  - Why the rotation of Venus is retrograde (the opposite of most other planets)
  - How the moon came to be
  - Why Mercury's orbital inclination varies chaotically

*class of stars called T Tauri stars are believed how the sun would have looked during its formation*