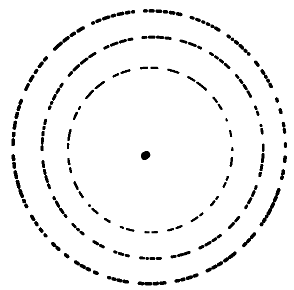
* There are approximately 10^{11} galaxies within the observable universe. Each galaxy has approximately 10^{11} stars on average.

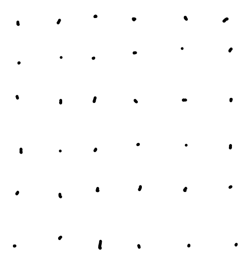
Cosmological Principle:

Universe is isotropic, which means you see the same thing regardless of the direction you look.

Two possibilities of an isotropic universe:



We are somehow at the center of the universe

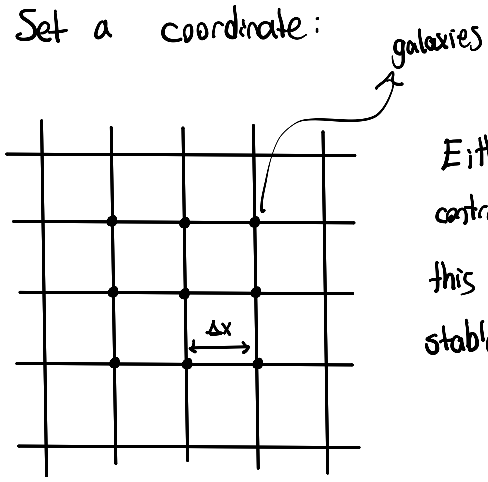


The universe is homogeneous

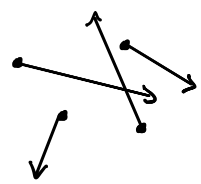
It was proved by observation that the universe is homogeneous. Therefore;

The universe is isotropic and homogeneous.

Set a coordinate:



Either if the universe is expanding or contracting, positions of the galaxies on this expanding/contracting grid should be stable.



if the movement was random, we couldn't be able to use a grid.

$D_{ab} = a \cdot \Delta x_{ab}$

- D_{ab} → real distance
- a → scale parameter
- Δx_{ab} → distance on the grid

general form ⟹ $D_{ab} = a(t)\sqrt{\Delta x_{ab}^2 + \Delta y_{ab}^2 + \Delta z_{ab}^2}$

for $D_{ab} = a \cdot \Delta x_{ab}$, $v_{ab} = \dot{D}_{ab} = \dot{a}(t)\,\Delta x_{ab} \Longrightarrow \frac{v_{ab}}{D_{ab}} = \frac{\dot{a}(t)}{a(t)} = H(t)$ → Hubble parameter (constant for a given time)

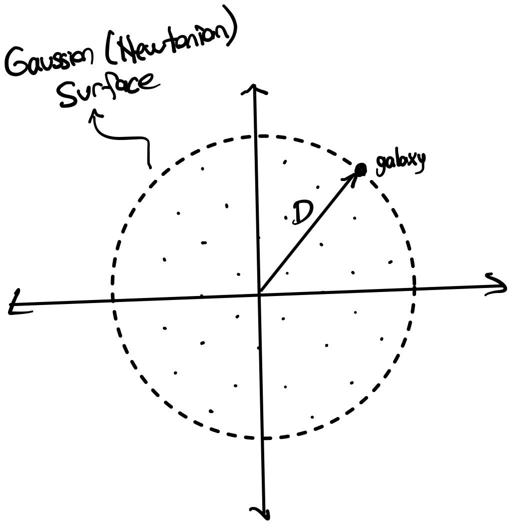
$m = \nu \Delta x \Delta y \Delta z$, $V = a^3 \Delta x \Delta y \Delta z$, $\rho = \frac{m}{V} = \frac{\nu}{a^3}$

m → independent of a; ν → amount of mass per unit volume

→ the fact that the density of the universe is time dependent is intuitive. If the universe expands, density decreases. If the universe contracts, density increases.

NEWTON'S MODEL OF UNIVERSE (STANDARD MODEL)

Let's take another coordinate which assumes that the Earth is at the center of the universe and is fixed in place.



$D = a(t)\sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2} = a(t)R \quad \left(R \equiv \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}\right)$

$V = \dot{D} = \dot{a}R$

$A = \dot{V} = \ddot{a}R$ (acceleration)

$F = -\frac{GMm}{D^2} \Longrightarrow A = -\frac{GM}{D^2} = -\frac{GM}{a^2R^2} = \ddot{a}R \Rightarrow -\frac{GM}{a^3R^3} = \frac{\ddot{a}}{a}$

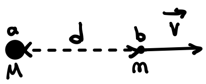
($F = -\frac{GMm}{D^2}$: Newton's law of gravity)

$V_{sphere} = \frac{4}{3}\pi D^3 = \frac{4}{3}\pi a^3 R^3 \Longrightarrow a^3R^3 = \frac{3}{4\pi}V \Longrightarrow \frac{\ddot{a}}{a} = -\frac{4}{3}\pi G\frac{M}{V} = -\frac{4}{3}\pi G\rho$ → independent of R

Since $\frac{\ddot{a}}{a} = -\frac{4}{3}\pi G\rho$, we can say that the universe is not static as long as it has a mass ($\rho \neq 0$)

$\frac{\ddot{a}}{a} = -\frac{4}{3}\pi G\rho = -\frac{4\pi G\nu}{3a^3} \Longrightarrow \ddot{a} = -\frac{4\pi G\nu}{3a^2}$ → according to this model, the universe is deccelerating

This model is not true because the universe is actually accelerating.



Total mechanical energy of particle b: $E = \frac{1}{2}mv^2 - \frac{GMm}{d}$

If $E > 0$, particle b cannot turn around because turning around requires $-\frac{GMm}{d} = E$ at turning point, which indicates negative mechanical energy.