

# Symmetry and Parallel Universes

Kohtaro Yamakawa

Berkeley

October 30, 2021

# Physics: the study of the Universe and its behavior through space and time

Symmetry and Universes

Yamakawa

Symmetry

Symmetry Breaking

Parallel Universes

The image is a dense collage of mathematical concepts and diagrams. At the top left, it shows the derivative of a logarithm,  $(\ln(x))' = x^{-1}$ , and the sine rule,  $\frac{a}{\sin A} = \frac{b}{\sin B}$ . Below these are the binomial expansion  $(a+b)^n = \sum_{k=0}^n \binom{n}{k} a^k b^{n-k}$  and the identity  $e^{i\pi} + 1 = 0$ . In the center, there's a diagram of a cube with a smaller cube inside, and a 3D coordinate system. To the right, a Gaussian distribution curve is shown with its mean  $\mu$  and standard deviation  $\sigma$ . Further right, a sphere is depicted with a great circle. At the bottom, there's a diagram of a tree with height  $h$  and base  $b$ , and a right-angled triangle with hypotenuse  $h$  and angle  $\alpha$ . A sine wave is plotted on a coordinate system, and a complex plane diagram shows a point  $x$  on the real axis. The background is a dark blue space filled with stars and a silhouette of a human head in profile, looking towards the right.

Mathematical formulas and diagrams include:

- $(\ln(x))' = x^{-1}$
- $\frac{a}{\sin A} = \frac{b}{\sin B}$
- $(a+b)^n = \sum_{k=0}^n \binom{n}{k} a^k b^{n-k}$
- $e^{i\pi} + 1 = 0$
- $\int \frac{dx}{x^2 \pm a^2} = \ln|x + \sqrt{x^2 \pm a^2}| + C$
- $(a+b)^2 = a^2 + 2ab + b^2$
- $\tan \alpha = \frac{\sin \alpha}{\cos \alpha}$
- $\vec{A} \cdot (\vec{B} + \vec{C}) = \vec{A} \cdot \vec{B} + \vec{A} \cdot \vec{C}$
- $y = kx + m$
- $x \in [3; +\infty)$
- $(x^n)' = nx^{n-1}$
- $(\sqrt{x})' = \frac{1}{2\sqrt{x}}$
- $\sin^2 \alpha + \cos^2 \alpha = 1$
- $\sinh x = -i \sin(ix)$
- $\lim_{x \rightarrow 0} \frac{\sin x}{x} = 1$
- $f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$
- $U = \int_a^b f(x) dx$
- $\forall \epsilon > 0 \exists N \in \mathbb{N} \forall n > N |x_n - a| < \epsilon$
- $\sinh(x) = \frac{e^x - e^{-x}}{2}$
- $i = \sqrt{-1}$
- $e^{ix} = \cos x + i \sin x$
- $\int x^n dx = \frac{x^{n+1}}{n+1} + C$
- $A_n^k = \frac{n!}{(n-k)!}$
- $\cos A = \cos B \cos C + \sin B \sin C \cos \alpha$
- $a \perp m, a^{q(m)} = 1 \pmod{m}$
- $\log(ab) = \log a + \log b$
- $S = \frac{1}{2} ab \sin \alpha$
- $S = \frac{1}{2} abs \sin \alpha$
- $y = x^2$
- $\cos 2\alpha = 2 \cos^2 \alpha - 1$
- $(e^x)' = e^x$
- $\int_a^b f(x) dx$
- $\pi = 3,14$
- $y = |x-2|$
- $\ln(a-b)$
- $e^x \cos x = \operatorname{Re}\{e^{ix}\}$
- $x! = 1$
- $\sum_{k=0}^{\infty} \dots$

**Objective:** Understand better how symmetry helps us study the Universe around us

# What is Symmetry?





Symmetry and  
Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

Diagram with symmetry	Number of lines		
	3		4
	6		Infinite

Symmetry tells us how symmetric things are!

## Definition (Symmetry)

Symmetry is the principle that describes how many operations we can do without changing what something looks like.

# Symmetry in Physics

Symmetry and  
Universes

Yamakawa

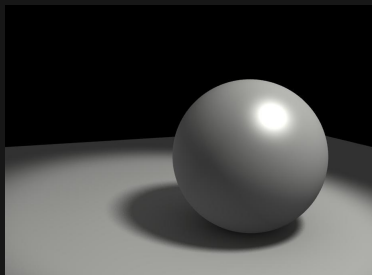
Symmetry

Symmetry  
Breaking

Parallel  
Universes

## Example (Uniform Compression)

Consider a perfect 3D sphere (ball). Compress it uniformly on all sides. What is its final shape?





# Symmetry in Physics

Symmetry and  
Universes

Yamakawa

Symmetry

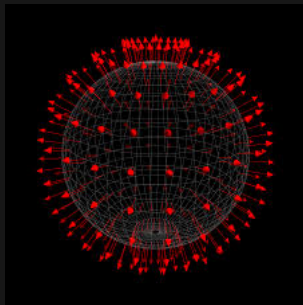
Symmetry  
Breaking

Parallel  
Universes

## Example (Uniform Compression)

Consider a perfect 3D sphere (ball). Compress it uniformly on all sides. What is its final shape?

A sphere! Spherical symmetry is conserved.



# Symmetry in Physics: Perfect Objects

Symmetry and  
Universes

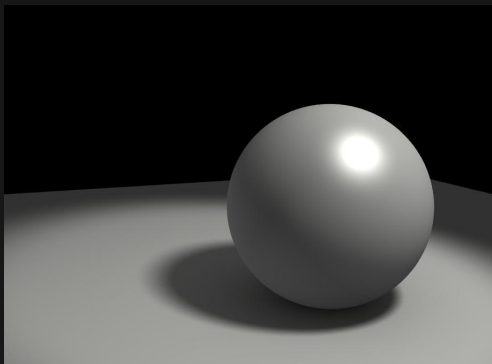
Yamakawa

## Perfect Objects

Symmetry

Symmetry  
Breaking

Parallel  
Universes



Only truly exists in our imagination. But a good approximation!

# Symmetry in Physics: Uniform Randomness

Symmetry and  
Universes

Yamakawa

**Isotropic symmetry.** Ex: Universe, paramagnets,

Symmetry

Symmetry  
Breaking

Parallel  
Universes



While not perfect any deviations that exist are random and on average are 0.

# Symmetry in Physics: Fundamental

Symmetry and  
Universes

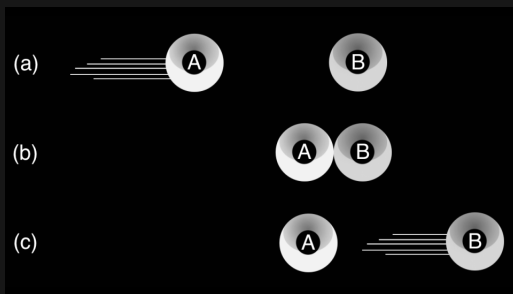
Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

**Time Reversal symmetry.** Ex: Newton's Laws, Momentum



Time can be reversed

# Symmetry as a Tool in Physics

Symmetry and  
Universes

Yamakawa

## Theorem (Symmetry Conservation Principle)

*If things start with symmetry, they respect that symmetry.*

Symmetry

Symmetry  
Breaking

Parallel  
Universes



# Any Questions?

Symmetry and  
Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

- ▶ Symmetry exists
- ▶ Symmetry is important
- ▶ Symmetry is conserved

# Broken Symmetry

Symmetry and  
Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

## Corollary (Symmetry Principle)

*If things break symmetry, there must be a source of that symmetry breaking.*

# Solve for the source of asymmetry!

Symmetry and  
Universes

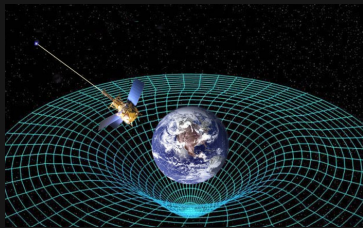
Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

For each point particle, mass  $m_1, m_2$ , Newton's Law of Gravitation Spherical symmetry. But, forces are between point particles.



Source is: the setup of the problem!



# Solve for the source of asymmetry!

Symmetry and  
Universes

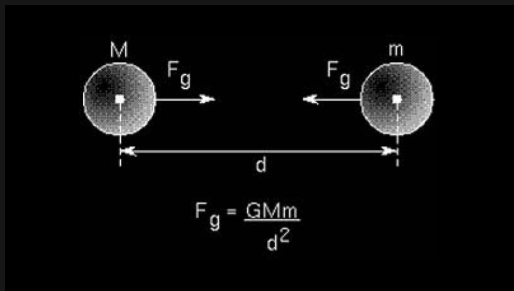
Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

For each point particle, mass  $m_1, m_2$ , Newton's Law of Gravitation Spherical symmetry. But, forces are between point particles.



Source is: the setup of the problem!

# Breaking Time Reversal Symmetry

Symmetry and  
Universes

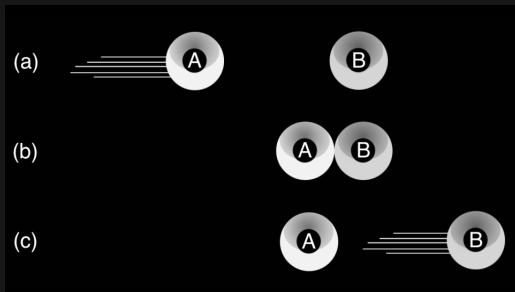
Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

For Newton's Laws, Time Reversal Symmetry. Consider boiling water.



**How do you unboil water?** (Entropy always increases)



# Break TRS via Causality

Symmetry and  
Universes

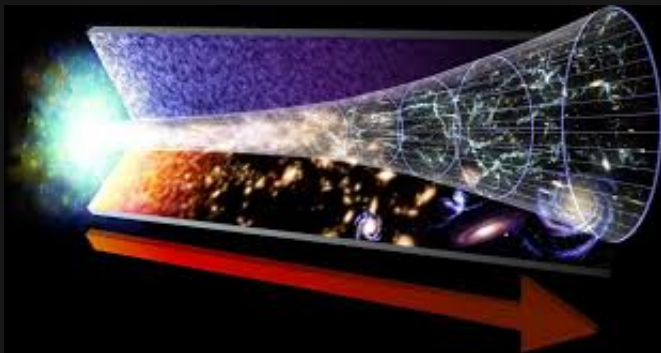
Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

The source is: **Causality!**



Fancy quote to take away:

*Causality is the source of Time Reversal Symmetry breaking of Newtonian mechanics and leads to an arrow of time inherent in the second law of thermodynamics*

Newton didn't embed causality into his theory. What a dumb dumb

# Solve for the source of asymmetry!

Symmetry and  
Universes

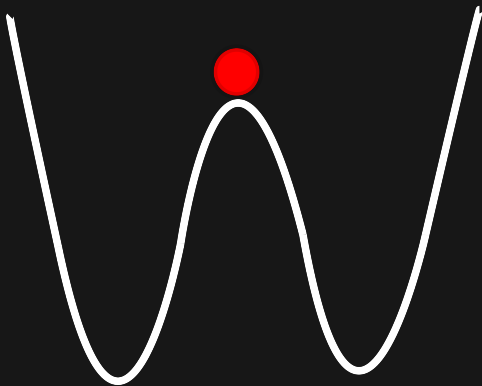
Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

Ball on hill, Mirror symmetry. Let it drop.



The source is: :(

# Solve for the source of asymmetry!

Symmetry and  
Universes

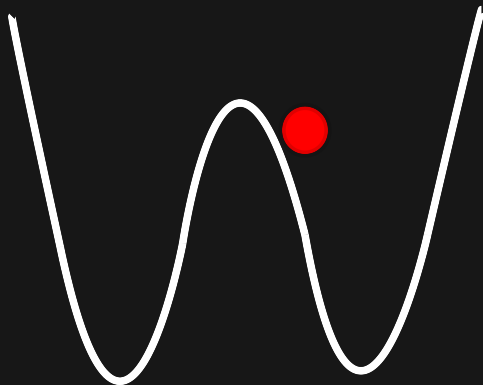
Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

Ball on hill, Mirror symmetry. Let it drop.



The source is: :(

# Solve for the source of asymmetry!

Symmetry and  
Universes

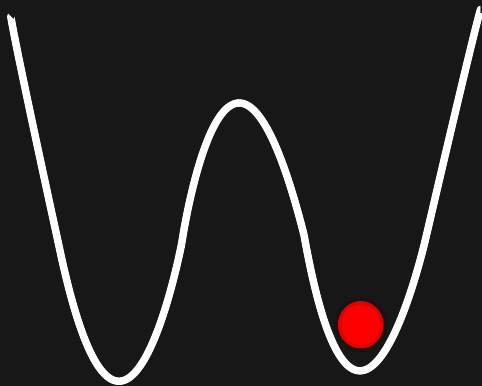
Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

Ball on hill, Mirror symmetry. Let it drop.



The source is: :(



# Symmetry not Conserved?

Symmetry and  
Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

Symmetry is not conserved and we can't find out why

## Definition (Spontaneous Symmetry Breaking)

The phenomenon when a system **seems** to break its own symmetry

Let's watch a SIMULATION.



# Hill (Symmetry breaking!)

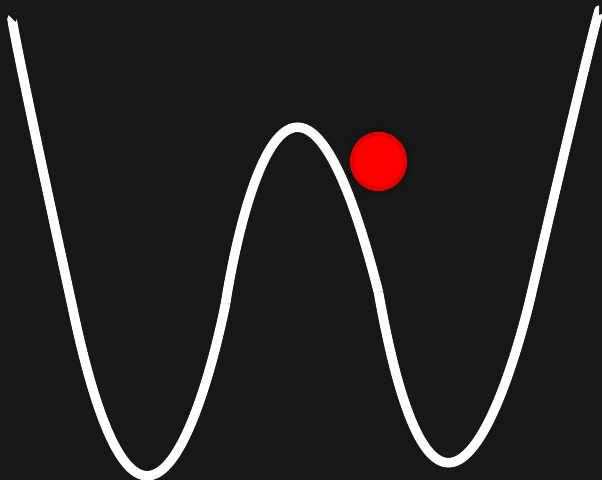
Symmetry and  
Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes



# Hill (Symmetry Broken)

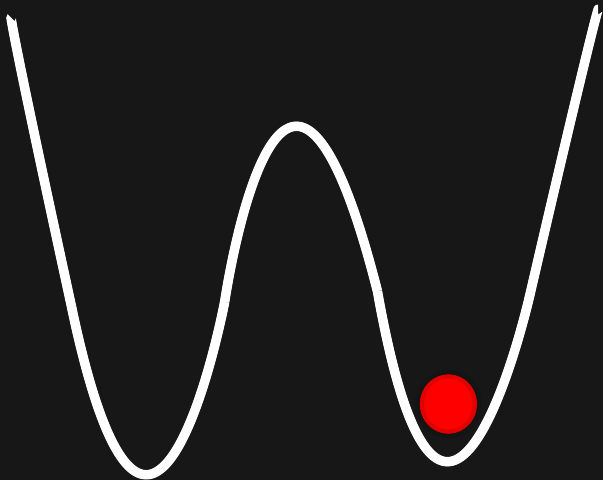
Symmetry and  
Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes



# Hill (Symmetry Broken)

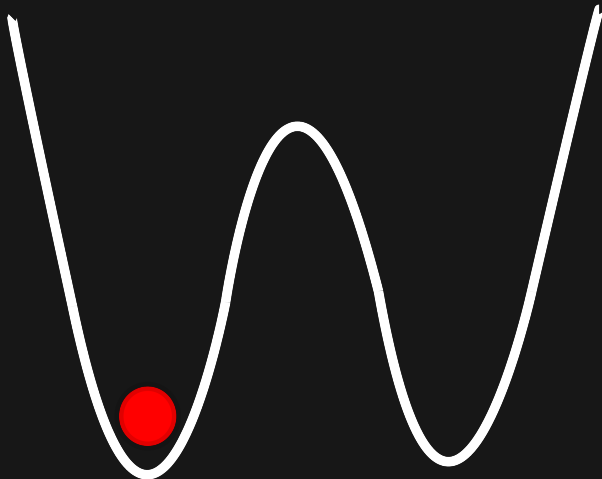
Symmetry and  
Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes



# Parallel Universes

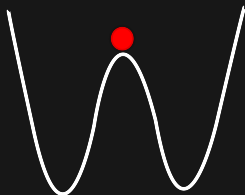
Symmetry and  
Universes

Yamakawa

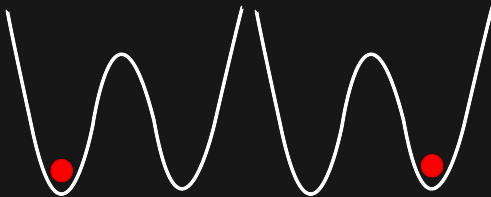
Symmetry

Symmetry  
Breaking

Parallel  
Universes



Mirror Symmetry persists in the possible outcomes.



**Symmetry has never been broken!**

It just looks like it when we do it.

# Symmetry is conserved

Symmetry and  
Universes

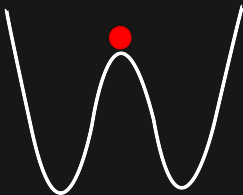
Yamakawa

Symmetry

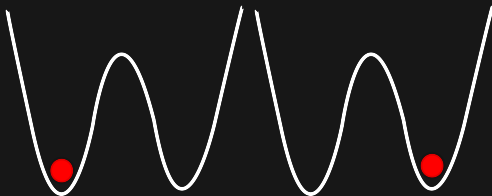
Symmetry  
Breaking

Parallel  
Universes

Symmetry is conserved at **all times**.



Existence of Parallel Universes (possible outcomes) conserves symmetry.



# Quick Recap

Symmetry and  
Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

- ▶ System seems to break symmetry by itself
- ▶ Parallel Universes restore symmetry
- ▶ Symmetry constrains our system at all points
- ▶ This phenomenon is Spontaneous Symmetry Breaking (SSB)



# Another SSB example!

Symmetry and  
Universes

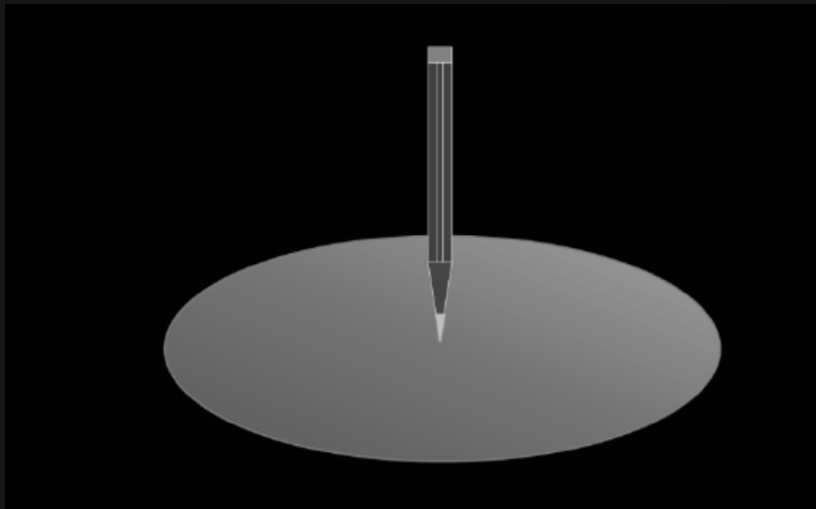
Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

Pencil Standing, Azimuthal Symmetry. Falls Down



# Another SSB example!

Symmetry and  
Universes

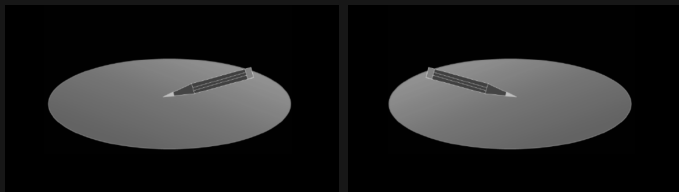
Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

Pencil Standing, Azimuthal Symmetry. Parallel Universes:



Parallel Universe for every angle  $\theta \in (0, 2\pi]$ .

# Another SSB example!

Symmetry and  
Universes

Yamakawa

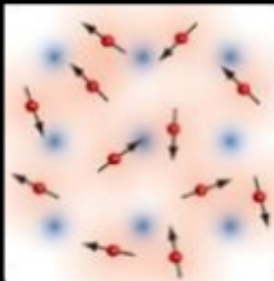
Symmetry

Symmetry  
Breaking

Parallel  
Universes

Paramagnet, 3D rotation symmetry

Paramagnet



# Another SSB example!

Symmetry and  
Universes

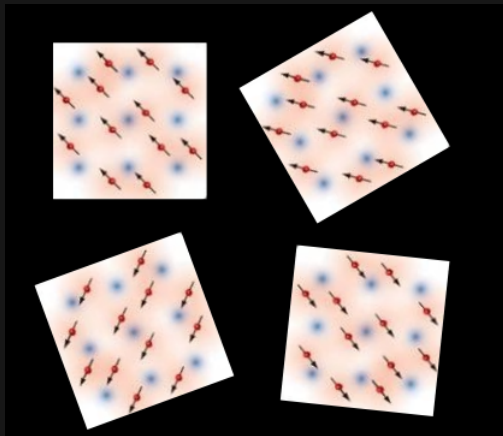
Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

Pencil Standing, Azimuthal Symmetry. Parallel Universes:



Parallel Universe for every  $\theta \in (0, 2\pi]$  and  $\phi \in (0, \pi]$ .

# Quick Recap

Symmetry and  
Universes

Yamakawa

Symmetry

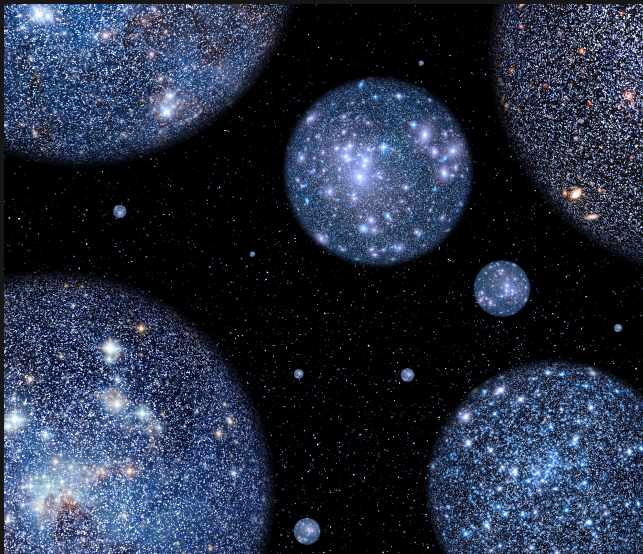
Symmetry  
Breaking

Parallel  
Universes

- ▶ Symmetry describes our Universe well
- ▶ Symmetry describes many systems well
- ▶ Symmetry seems to break in many places
- ▶ Parallel Universes are everywhere!

# Parallel Universes

What does it look like?



Symmetry and  
Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

# Stability of Parallel Universes

Symmetry and  
Universes

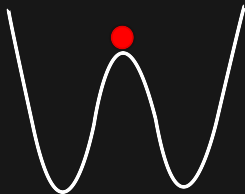
Picture a small human in the ball.

Yamakawa

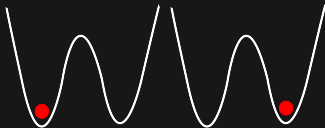
Symmetry

Symmetry  
Breaking

Parallel  
Universes



When symmetry breaks, we become rigid, stable.



Deep in one of the potential valley, the other is **virtually** unreachable.

# Applications

## Symmetry and Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

- ▶ How Paramagnets become Ferromagnets
- ▶ How Liquids become Gas
- ▶ How the Universe settled
- ▶ How electroweak force splits into Electric Force and Weak Force
- ▶ Essential in Higgs Mechanism
- ▶ Almost all modern systems in research

Each Parallel Universe looks different.



# Moving between the Universes

Symmetry and  
Universes

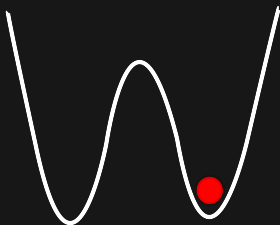
Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

How do we move?



- ▶ Change our perspective
- ▶ Make an explosion

# A lonely Universe

Symmetry and  
Universes

Yamakawa

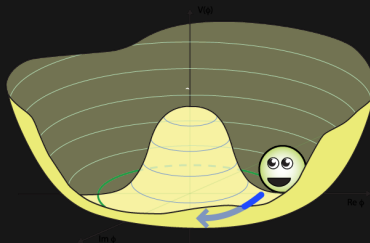
Symmetry

Symmetry  
Breaking

Parallel  
Universes

*To go from one [Parallel Universe] to another would require changing the directions of an infinite number of dipoles, an impossible task for the finite little man*

But don't go bombing things to see the universe!!!  
We can't... Probably? At least likely not intentionally.



# But why tho

Good for fun and midnight conversations and philosophical musing.



Symmetry and  
Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

# The Paradigm of symmetry

Symmetry and  
Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

Since Landau's work in the 40's, symmetry is at the center of describing the world in physics.

- ▶ Universality Classes
- ▶ Criticality at symmetry breaking transitions
- ▶ Topological transitions (non-symmetry breaking)

Classification can help us systematically study systems and their *excitations*.

How to learn more:

# The Paradigm of symmetry

Symmetry and  
Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

Since Landau's work in the 40's, symmetry is at the center of describing the world in physics.

- ▶ Universality Classes
- ▶ Criticality at symmetry breaking transitions
- ▶ Topological transitions (non-symmetry breaking)

Classification can help us systematically study systems and their *excitations*.

How to learn more: Get Good

# Thank you!

Symmetry and  
Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

## Search Friendly words

- ▶ Lev Landau
- ▶ Emmy Noether (Noether's Theorem)
- ▶ Spontaneous Symmetry Breaking
- ▶ Criticality
- ▶ Topological transitions

## Examples:

- ▶ Ferromagnet (Ising, XY,  $O(N)$ , Potts, Heisenberg model)
- ▶ Liquid -Gas Transition
- ▶ Higgs Mechanism
- ▶ Chiral Symmetry breaking
- ▶ Electroweak Symmetry breaking

# Excitations

Symmetry and  
Universes

Yamakawa

Symmetry

Symmetry  
Breaking

Parallel  
Universes

