Graviton

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Abstract

Introduce the history of gravitons and the theory about graviton.

1 Introduce

Motivation

It has been a long time that I had heard about the scientists want to create a Grand Unified Theory. But It is very hard to unify the gravity. So I want to study about a part of GUT,i.e quantum gravity. But due to some scholarly limitations, I would only study about Graviton. I also want to know that what's wrong with graviton? I think that it make sense to describe the gravity just like the other fundamental force.

The History of Graviton

[1]Albert Einstein discussed quantized gravitational radiation in 1916, the year following his publication of general relativity. The term graviton was coined in 1934 by Soviet physicists Dmitry Blokhintsev and Fyodor Galperin. In 1959, Paul Dirac noted in his lectures that the energy of the gravitational field should be quantized as quanta, i.e, the energy is not continuous.

Why the Idea of Graviton is Proposed?

No matter in electromagnetic interaction or weak interaction or even strong interaction, they are now can be explained by some elementary particle like photon, W Z bosons, gluon. Apparently, there is only left a interaction: gravitational interaction. So, scientist tried to proposed an idea just like those bosons: graviton.

2 Properties of Gravitons

1. **Graviton has zero mass**

Due to the characteristic of infinity range interaction, the graviton have to be massless just like photon. Once the graviton has mass, it can no longer propagate at speed c to infinity. Instead, it will follow the relation similar to Z,W boson[2]

$$V_{Yukawa}(r) \propto -g^2 \frac{e^{-\alpha m r}}{r} \qquad (1)$$

where α is a constant, m is the mass of the particle. We can see that if the m is not zero, the potential describe by Yukawa will decade very fast(exponential) which results in the property of small interaction distance. But, there are still theory that state the graviton is massive. I will discuss later.

[1]*Graviton-Wikipedia* `https://en.wikipedia.org/wiki/Graviton`

[2]*Yukawa-potential* `https://en.wikipedia.org/wiki/Yukawa_potential`

2. **Graviton is a spin 2 boson**

Since the source of gravitation is the stress-energy tensor, a second-order tensor. In the Quantum field theory, Pauli-Fierz field(gravity field) corresponds to spin-2 particle.[3]

3. **Massive graviton theory**

We just said that the graviton has zero mass. But that is just a statement in the general relativity. [4]In 1930, Wolfgang Pauli and Markus Fierz come up with a new theory about a massive field of spin-2(we can think field is actually constructed by particle, so we say massive and spin-2) propagating on a flat spacetime (In modern physics, if there is massive thing exist, the curvature of the spacetime should be changed, which means it's not "flat").

But in the 1970s, it was found that massive graviton suffered from some pathologies such as ghost(stability problem)
gauge symmetric

Before discussing about ghost, I want to talk about gauge symmetric first. In this video about massive graviton[5], they explained gauge symmetric as a consistent of choosing object to observe. To put it more simply, if you want to observe the period of the merry-go-round. You will choose a horse and see when it comes back to the same place. And gauge symmetric say that you will get the same result if you choose different horse to observe.
Now, if the graviton is massive, it wouldn't apply to gauge symmetric anymore. And it will have five polarizations. Further more, the theory needed to describe that polarization will result in a 6 degree of freedom which produce the Ghost particle. [6] [7] [8]
Ghost

Ghost particle has negative energy, which means that if a ghost particle with a velocity is moving, it will release energy, causing the other object to absorb those energy. This is very horrible since that there will be no bound for the energy of ghost. The ghost can just release the energy forever and having infinity low energy and the environment can absorb the energy.

This situation is very weird and contradict to the rule of stability. Stability means that something can always decade to the most stable state. [9]
How we deal with Ghost

[3]*Understanding Graviton Spin: Unveiling the Mystery of Spin 2* https://www.physicsforums.com/threads/understanding-graviton-spin-unveiling-the-mystery-of-spin-2.91769/

[4]*Massive gravity- Wikipedia* https://en.wikipedia.org/wiki/Massive_gravity

[5]YouTube: *Ep 3 - Testing general relativity: can the graviton be massive?*https://www.youtube.com/watch?v=pMwJEgc6cyQ&t=474s

[6]*Massive spin-2 fields on black hole spacetimes: Instability of the Schwarzschild and Kerr solutions and bounds on the graviton mass* https://arxiv.org/pdf/1304.6725

[7]YouTube:*Ep 3 - Testing general relativity: can the graviton be massive?* https://www.youtube.com/watch?v=pMwJEgc6cyQ&t=474s

[8]YouTube*The Woman Who Broke Gravity | Claudia de Rham* https://www.youtube.com/watch?v=Ve_Mpd6dGv8

[9]YouTube*The Woman Who Broke Gravity | Claudia de Rham* https://www.youtube.com/watch?v=Ve_Mpd6dGv8

The exist of ghost seems to be inevitable, but *Claudia de Rham* recently erase the ghost with a very special way[10], which is too hard for me to understand.

4. **The Difficulty of Observing Graviton**

   (a) **Scale problem**

   The gravity force is the weakest in the fundamental force. In general, we always discuss gravity in a macroscopic scale different from the other three fundamental force that is discussed in microscopic scale. In microscopic scale, the effect of the gravity is very tiny. So it is hard to be observed.

   And here is the my idea about how to prove the exist of massive graviton after reading the paper and video in the reference. Since the massive graviton broke the gauge symmetry, the observation of gravity wave should be a little different from the different observation station

   (b) **Skill Issue**

   For modern technique, the Large Hadron Collider can't produce enough energy to detect graviton

3 Something Else About Massive Graviton

After searching for the paper about massive graviton, There are something interesting

1. **Describe Very Small Curvature Region**
   [11]The massive gravity theory might be able to explain the gravity for very large distance,i.e very small curvature, which is not considered in the General relativity.

2. **A candidate for dark energy**

   Massive graviton is a candidate for dark energy, since it provide an explanation for the accelerated expansion of the universe without the exist of dark energy.[12] [13]

4 References

1. understanding graviton spin unveiling the mystery of spin
2. Massive Gravitons as Feebly Interacting Dark Matter Candidates
3. Ghost Mode
4. Massive gravity theory
5. Graviton
6. Yukawa potential
7. *de Rham, C., Gabadadze, G., Tolley, A. J. (2024, November 26). Resummation of Massive Gravity. Department*

[10]*Claudia de Rham et al.Resummation of Massive Gravity. November 26, 2024* https://arxiv.org/pdf/1011.1232

[11]YouTube: *The Woman Who Broke Gravity | Claudia de Rham* https://www.youtube.com/watch?v=Ve_Mpd6dGv8

[12]*Massive gravity- Wikipedia* https://en.wikipedia.org/wiki/Massive_gravity

[13]*Massive Gravitons as Feebly Interacting Dark Matter Candidates* https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.128.081806

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8. Ep 3 - Testing general relativity: can the graviton be massive?