

# Physics 162: Intro To Cosmology

## Quintessence

### Abstract

The universal definition of quintessence, or ether, is defined as the fifth and highest element in ancient and medieval philosophy that permeates all nature and is the substance composing the celestial bodies. Many cosmologists believe that quintessence is a real form of energy, more precisely a canonical scalar field, distinct from any normal matter or radiation, or even “dark matter.” The existence of quintessence could be an explanation of the observation of an accelerating rate of expansion of the universe. With the fact that quintessence is a possible candidate which causes the universe to expand and speed up, many recent research suggest that it possesses the property to counter gravity with negative pressure. With the evidence we have collected so far, quintessence is still theoretical with many unknowns. But considering the strong evidence for the existence of dark matter, dark energy and many cosmological frames we have constructed, the mask of quintessence is very significant to be unveiled.

### 1 Introduction

This research paper aims to provide an overview of quintessence with some theoretical properties and possible effects on the universe. Exploring the effects and properties of quintessence is critical for human further understanding of how the universe behaves in the past, present and future. This paper will be categorized into three major sections with discussions on the relationship between quintessence and dark energy, the kinetic and potential aspects of quintessence, and possible means to find quintessence.

## 2 Quintessence, Dark Energy, and the Cosmological Constant

One of the most recent candidates for dark energy is the cosmological constant with  $w = -1$ . This implies that dark energy possesses the property of negative pressure that repulses the gravity within the universe, thus it potentially causes the universe to expand and accelerate. With some recent research suggesting that about two-thirds of the critical density in the universe might consist of an exotic form of dark energy, we could assume that there might be some correlations between quintessence and the cosmological constant. But, is there anything else we missed?

Based on general relativity, energy, momentum, and pressure are gravitated. Since cosmic acceleration can only occur if the pressure is sufficiently negative, quintessence must have a negative pressure. The strength of gravitational force is determined by  $\rho + 3P$ , where  $\rho$  is the energy density and  $P$  is the pressure. (Caldwell & Steinhardt 2000) Therefore, if the pressure is significantly negative, the gravitational force will be repulsive. The effect of negative pressure will repulse the surrounding and expand the geometry, as illustrated in the figure below:

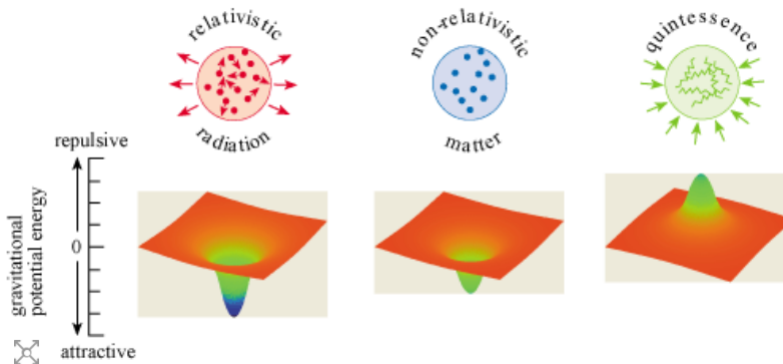


Figure 1: (From Caldwell & Linder 2005) Effects of different matters on the geometry of the universe

In 1917, Einstein introduced a possible theory of dark energy that dark energy is not made of particles but rather made of “vacuum energy”-the en-

ergy of empty space-with the assumption of a static universe. But, if we assume that dark energy has been decreasing since the Big Bang, similar to baryonic matter, then the “vacuum energy” theory might contain flaws because the density of dark matter has been changing. Therefore, the new concept of quintessence was introduced to solve this problem. The recent theory of quintessence describes it as a dynamic, time-evolving and spatially dependent form of energy with negative pressure sufficient to drive the accelerating expansion. Whereas the cosmological constant is in the form of vacuum energy.(Zlatev et al. 1999)

### 3 Kinetical Energy and Potential Energy of Quintessence

One recent model of quintessence proposed that it is a quantum field with a very long wavelength, with the size about the observable universe. The energy of the quantum field is composed of kinetic energy and potential energy. The kinetic energy depends on the rate of oscillations that positively contributes to the pressure, and the potential energy depends on the interaction of the field with itself and matter that negatively contributes to the pressure. The difference between the kinetic energy and potential energy determines the pressure of the quantum field. Since the wavelength is about the size of the observable universe, the period of oscillation can be assumed to be the age of the universe. Thus, kinetical effects of the field can be ignored, and the quantum field would only possess negative pressure. (Peebles & Ratra 2003)(Chiba et al. 2000)

### 4 Seeking The “Real” Quintessence

The ratio of pressure to the energy density, or  $w$ , determines the acceleration effect on the universe. Einstein’s model for cosmological constant has the equation of state  $w = -1$ . In contrast, quintessence has an equation of state  $w > -1$ . (Caldwell & Linder 2005) So, more precise measurements are needed to distinguish between the two. In addition, quintessence can affect the forces between particles when it interacts with them. So, if the quintessence field is varying spatially, it will potentially change the strength of the forces between particles as well. Therefore, examining the changes of the fundamental forces

between particles could be a possible method to find quintessence.

## 5 Thoughts And Conclusion

The study of quintessence is very significant in modern cosmology. Although the concept of quintessence is still waiting to be solidified, we have already found the tip of its iceberg. The finding of quintessence would be a breakthrough in the field of cosmology and even in other fields like quantum physics. If we could examine the behavior of quintessence, we might have the ability to better predict the future of our universe. Quintessence would surely not be the end of the story of cosmos. There are still many exciting things that are waiting for humans to explore.

## References

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