A Brief History of Dark Energy

I spent some time thinking about what I might write for my first article, hoping to generate some excitement and interest amongst the readers of FreieHonnefer. As a physicist, I spend a lot of time thinking about some of the tantalizing ideas emerging in cosmology and particle physics and so I finally decided that it might be a good idea to introduce the current state of theoretical physics from a historical perspective which would aid the interested reader in understanding how we arrived at some of the conclusions we now take for granted. Over the next few articles I plan to introduce some of the exciting ideas in cosmology, gravity and particle physics and show you how the two are gradually merging into the unified research field of string theory.

Einstein is commonly referred to as the grandfather or modern physics and his General theory of Relativity (GR) is a good place to start. Einstein had gained a huge amount of credibility in the physics community after his research regarding the photo-electric effect (for which he won the noble prize) and his special theory of relativity. This credibility gave him the freedom to pursue what would become his most significant theory, the General theory of relativity, which was completed in 1915. GR is commonly believed to be a theory of gravity, but I think that it is more useful to think of GR as a theory of space-time, from which the phenomenon we call gravity ultimately emerges. Although this magazine is written for the interested reader and assumes no mathematical knowledge I would like to include one single equation to demonstrate to you the beautiful simplicity of Einstein's theory. Einstein's field equation is

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \tag{0.1}$$

As remarkably simple as this might look, hidden within this powerful equation are in fact ten equations. Each equation can take many pages of calculations to solve. The left hand side of this equation describes the geometry of space-time, and the right hand side describes the matter and energy content of space-time. To solve this formula one inserts into the right side of the equation how much mass and energy we believe to be in the universe (stars, planets electromagnetic radiation etc) and by solving Einstein's equation we are told what the geometry of the universe *does* as a consequence of that matter energy content. Space-time can do one of three possible things, and each possibility is dependent on your initial guess as to the total mass-energy content of the universe. It can contract, remain static or it can expand. Einstein's initial discovered after solving the field equations implied that the universe is expanding. He disliked this result immensely as it was his profound belief that the universe was static, unchanging and eternal. To reconcile his disbelief in the predictions of his equation he added what physicists call a 'fudge' factor. He simply added an extra term to his equation 'by hand' that *forced* the universe to be static and unchanging. He called this term the 'Cosmological Constant'.

Much to Einstein's dismay, in 1929 the American astronomer Edwin Hubble made a profound discovery. He found that wherever he looked in the night sky, in general the galaxies seemed to be receding from Earth. Not only that, more distant galaxies appeared to be moving away much faster than the closer galaxies. This observation provided evidence to support the recently discovered 'big-bang' theory. Hubble's discovery was based on something called the cosmological red-shift, which is similar to the well known Doppler-effect on Earth. As a speeding ambulance drives past you, one notices a change in the pitch of the sound of the siren due to a kind of stretching of the sound waves. A similar effect happens to light and it is this phenomenon that reveals to us the motion of the galaxies.

What is particularly strange about this discovery is that on first glance it implies something very strange. If all the galaxies are moving away from us then that makes us somewhat *special*? It implies that Earth is located in some location that is of great cosmic significance.

Of course, Earth is not cosmically significant and the way to understand what is actually going on is to picture the following. Imagine drawing small dots on the surface of a deflated balloon. Each of the dots represents a galaxy in our universe. Now, as you blow up that balloon it stretches and all of the dots move further and further away from each other. From the perspective of a little creature situated on any of the dots it appears as though all the others dots (galaxies) are rushing away from you. And so, we can imagine space-time as being a *fabric* upon which all matter and energy is woven upon, and this fabric is currently *expanding*.

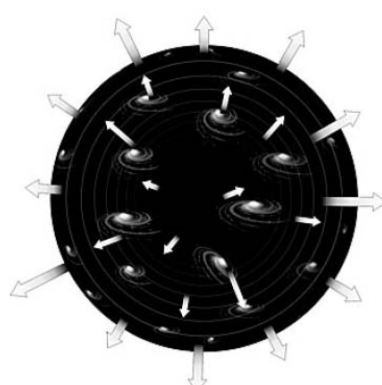

Figure 1: *In an expanding universe all galaxies appear to be moving away from each other.*

The idea that the universe is expanding has been cosmological dogma for nearly a century but in 1999 astronomers discovered something perhaps more profound than and expanding universe. By observing the cosmological red-shift of distant supernova it was discovered that the universe is actually accelerating! That is was not only expanding, but that the rate of expansion is getting larger.

What is particularly profound about this discovery is that some kind of exotic anti-gravitational field is necessary to account for this acceleration because common gravitational energy, which is ubiquitous throughout the universe, would cause the universe to *decelerate*. A contemporary term for this exotic field is ‘dark energy’. Research into dark energy is very popular today and numerous theoretical explanations exist as to its fundamental nature, but as of yet no commonly accepted theory exist.

My own research involves trying to uncover the nature of dark energy, and I plan to discuss both my ideas, and other popular theories regarding the nature of dark energy in later articles but I hope this short article has given you a glimpse into the exciting field of cosmology.