Dark energy is real : results from the WiggleZ Survey

Non-technical background information on WiggleZ survey press release

Observations by astronomers over the last fifteen years have produced one of the most startling discoveries in physical science: the expansion of the Universe, originally triggered by the Big Bang, has begun to speed up. According to the conventional laws of physics, the attractive force of gravity should slow down the cosmic expansion through the inward pull of gravity. In fact the reverse behaviour is observed. Astronomers have coined the term "dark energy" to describe the unknown physics driving this phenomenon. The action of dark energy in the Universe is as if you threw a ball in the air, but it did not return to Earth but rather kept speeding upwards faster and faster.

Dark energy appears to be the dominant component of our Universe and yet we still have no physical understanding of its existence or magnitude. This is considered one of the most important problems in astronomy because the nature of dark energy will unambiguously revolutionize our understanding of the laws of physics. In particular, dark energy is one of the only observable clues to the central dilemma of modern physics: quantum mechanics and Einstein's gravity, the two great accomplishments of twentieth-century physics, are mutually incompatible.

There are two important methods of tracking the effects of dark energy in the Universe. Firstly, we can measure the scale of the Universe: how far away are the distant galaxies? Dark energy will act as an anti-gravity and will fling these galaxies further away from us than we expected. Secondly, we can measure how strongly clumps of matter in the Universe are attracting each other, or equivalently how fast are clusters and superclusters growing by pulling in the surrounding matter? Dark energy will act as an anti-gravity and will slow down the rate of growth. Both measurements require observations of galaxies deep into the Universe's past. Both measurements need to work in tandem to unequivocally determine the nature of dark energy.

In order to measure the scale of the Universe, we need a measuring stick which can tell us the distance to faint galaxies. Historically, the best measuring stick is to use distant supernovae as standard candles. Assuming all supernovae have the same luminosity, their apparent brightness tells us how far away they are. This method has provided the most spectacular evidence for dark energy, because the supernovae were found to be dimmer than expected, being flung to greater distances through the action of dark energy. However, doubts remained. How do we know that the supernovae all have the same luminosity? What if the nature of supernovae changed with time, or if distant supernovae were dimmer because their host galaxies were dustier than expected?

In order to address these concerns, a second method of measuring the scale of the Universe was developed. This method uses as its measuring stick a standard ruler, not a standard candle (so is immune to the effects of dust). A standard ruler is an object of known size, whose apparent size tells us how far away it is. Specifically, we exploit a small preference for pairs of galaxies to be separated by a fixed distance – 490 million light years. This preferred separation actually represents the echos of sound waves in the plasma of the early, hot, dense Universe. In order to apply the ruler, we need to measure the separations of a very large number of pairs of galaxies, which we can achieve by constructing a large-scale, three-dimensional map of the galaxy distribution by carrying out a large galaxy survey.

Prior to our survey, such maps had only been constructed in the relatively nearby Universe, about 3-and-a-half billion light years away (compared to the total size of the observable Universe which is 13.7 billion light years). This was achieved by the Sloan Digital Sky Survey between 2000 and 2008. Our project, which required 276 nights of observations at the Anglo-Australian Telescope between 2006 and 2011, has built a map stretching over 7 billion light years, twice as far as had been previously achieved, and more than half-way back to the Big Bang. We have been able to track the effects of dark energy much further back into the history of the Universe, using the two methods of cosmic distances and cosmic growth.

There are two possible explanations of “dark energy”. Both require astonishing changes in our understanding of the Universe in order to generate an anti-gravity. Firstly, Einstein’s theory of gravity, General Relativity, could be modified on large cosmic scales to produce a repulsive gravitational force. Secondly, the Universe could be filled with a new, smooth material which unlike any known form of matter or energy, counters the attractive force of gravity via its uncontrollable desire to expand. In order to determine which explanation is correct, we combined our twin measurement of cosmic distances and cosmic growth.

We found that the second possibility explained our data : Einstein’s theory of gravity was correct, but we needed to introduce a new smooth anti-gravity material. The smoothness of this material leads to it being called a “cosmological constant”. Although we still do not understand the origin of this material or what causes it to fill space, we now know that it is smooth to within 1 part in 10 across the last 7 billion years of the history of the Universe. Our work should motivate new efforts by theorists to explain this material, and increase confidence that Einstein’s theory of gravity, General Relativity, is correct.

Furthermore, our results provide a powerful alternative probe of dark energy in addition to distant supernovae. Supernovae have been previously used as standard candles to provide the most spectacular evidence for dark energy. However, doubters could question whether supernovae were really standard candles? What if nearby and distant supernovae were different in nature, or the dustiness of the host galaxies varied with time, producing a confusing signal? Using entirely independent methods we have been able to confirm agreement with these supernovae measurements, increasing our confidence in the existence of “dark energy” as a real material.