DARK ENERGY, ROBOTS AND INTERGALACTIC CARTOGRAPHY

How Five Thousand Robots Are Mapping The Expanding Universe

BY IBRAHIM ABOUELFETTOUH

As night falls on the Western Hemisphere, half of the planet prepares to end its day. At the same time, somewhere in Arizona, on top of a mountain, five thousand little robots are only starting theirs. A job description only fitting for a science fiction novel, these five thousand robots are collecting data from the far reaches of deep space in an attempt to map out the universe through space and time. They are in search of answers to questions that have plagued the human species for as long as we have been able to look up. They are in search of dark energy.

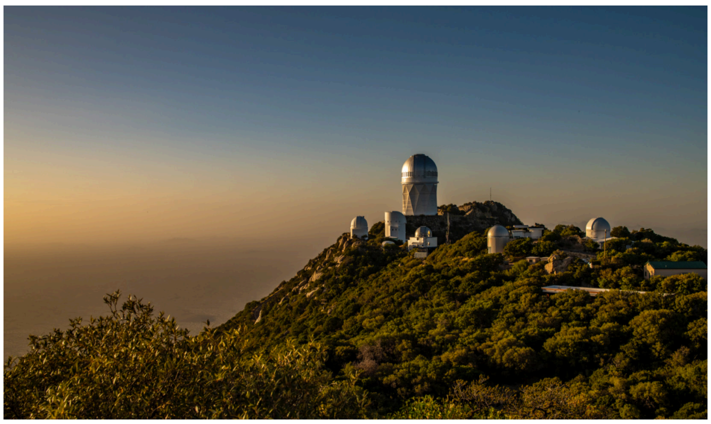

Figure 1: Nicholas U. Mayall Telescope, Kitt Peak National Observatory.[1] *Home to the Dark Energy Spectroscopic Instrument. **

THE MOTIVE

The universe is split into three components. First, there is baryonic matter, which is the measurable matter that we interact with everyday from the finest grain of sand to the air we breath to the fusion core of the sun. As abundant as it may seem, this constitutes only five percent of the observable universe. Second, dark matter, the so-called "missing mass" of the universe, makes up twenty-seven percent. Finally, there is dark energy, obscure and seldom detectable to humans, which fills a whopping sixty-eight percent. Where then, is all the dark energy, the missing majority of the universe?

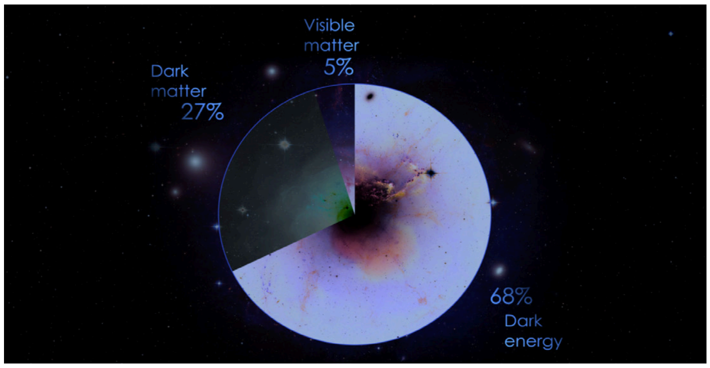

Figure 2: The composition of the universe.[2] *Credit: NASA*

The existence of dark energy was confirmed in 1998 by UC Berkeley's own Saul Perlmutter,who shared a Nobel Prize for the discovery that something, which we cannot detect, is accelerating the expansion of the universe. [3,4] Its properties are strange, and it is thought as the only medium to interact with gravity alone. Dark energy works against gravity, and thus, works against the natural clumping of matter that yields planets, stars and eventually, galaxies like our own Milky Way. For reasons unknown to us, there is enough dark energy in the universe to overpower gravity's attraction and cause the universe to expand apart from itself at an accelerated rate. Currently, dark energy is thought to occupy the universe uniformly and so despite its abundance, it is spread too thin to render itself detectable.

What do we mean when we say the universe is expanding? This is not to say that objects are moving apart from one another, but that the space between matter itself is expanding. Think of a balloon with points drawn on it. If we inflate the balloon, the points grow further apart, even though they are not in themselves moving across the surface. More importantly, physicists have discovered that this expansion has been accelerating over the last 9 billion years, meaning that this expansion *rate* has increased over time.[5]

In the case of the interstellar balloon, this would mean that the more it is inflated, the faster it will inflate. Because they do not entirely know why, scientists have defined "dark energy" as this undetermined cause of the expansion of the universe. This theory raises important questions. Why did dark energy only start accelerating the expanding universe 9 billion years ago? What is the nature of this interaction? What does dark energy tell us about the fate of the universe? Perhaps the most important question is: what can we find out? To this last question, we might have an answer.

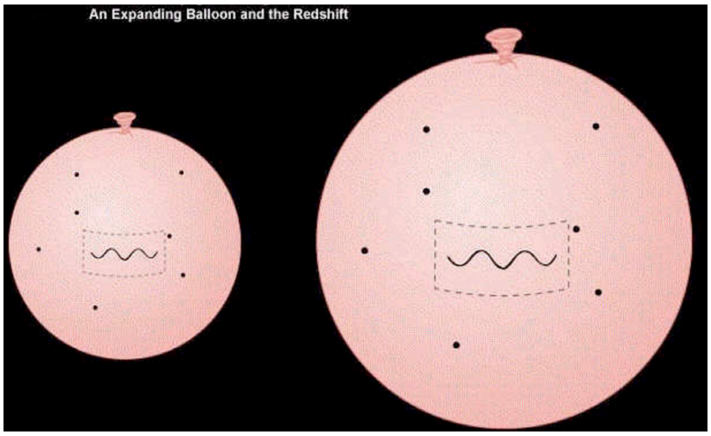

*Figure 3: Expanding universe on a balloon.[6] **

THE EXPERIMENT

Researchers at Lawrence Berkeley National Laboratories (LBNL) are building the largest 3D map of the universe to date.[7] The Dark Energy Spectroscopic Instrument (DESI) is an experiment attached to Arizona's Nicholas U.[8] Mayall Telescope and over the course of five years, it will measure the effect of dark energy on the acceleration of the universe's expansion.

Other than its relative amount and expansive properties, we know very little about the nature of dark energy. Because of this, as we look into the vast expanse of deep space, we do not know exactly what we are looking for. As such, scientists want to be as thorough, extensive and precise as possible, gathering as much data as our technologies allow. DESI is planning to use spectroscopy from over 30 million distant galaxies and clusters to shed some needed light on the direction and future of our universe, making this the most ambitious survey of the sky in history.

*Figure 4: The DESI (top) fitted on the Mayall Telescope (blue).[9] **

So how does it work? Having started in early 2020, DESI is collecting data to infer when the universe started accelerating in its expansion with extreme precision. They are able to do this by exploiting the finite and constant speed of light, known as the universal speed limit.

For a star that is one light-year away, it would take one year for its light to reach planet Earth. The sun is eight light-minutes away, meaning if the sun were to suddenly "turnoff," it would take eight minutes for us to stop seeing its light. Thus, contrary to the name, a light-year is a unit of distance, equivalent to 5.8 trillion miles. Generally, objects that are light-years away are effectively lagging behind in the past as their light takes time to reach us here on Earth.

This means that by looking farther and further into space, we are travelling back in time. Thus, many stars we see in the night sky are gone by now, yet we still see them. DESI uses this principle to take time-based data points of the universe's history. A galaxy that is 10 billion light years away is 10 billion years older at the time when we look at it. By surveying millions of galaxies, we get snapshots in time of what the physical properties of these galaxies were. By measuring the acceleration of the universe across these millions of galaxies, we can get an accurate overview of the evolution of dark energy and its effect on our universe without needing to ever observe it directly.

"...many stars we see in the night sky are gone by now, yet we still see them. DESI uses this principle to take time-based data points of the universe's history."

So how does DESI work? The answer is robots. DESI is equipped with five thousand robot positioners, each with their own

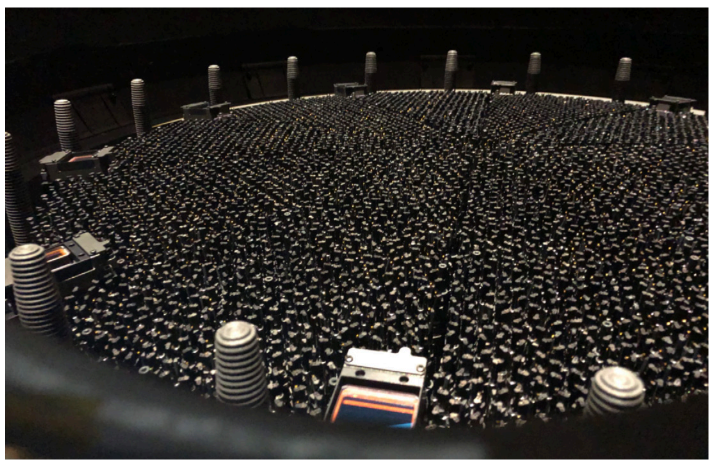

*Figure 5: Five thousand robots laid out on the DESI Focal Plane.[10] **

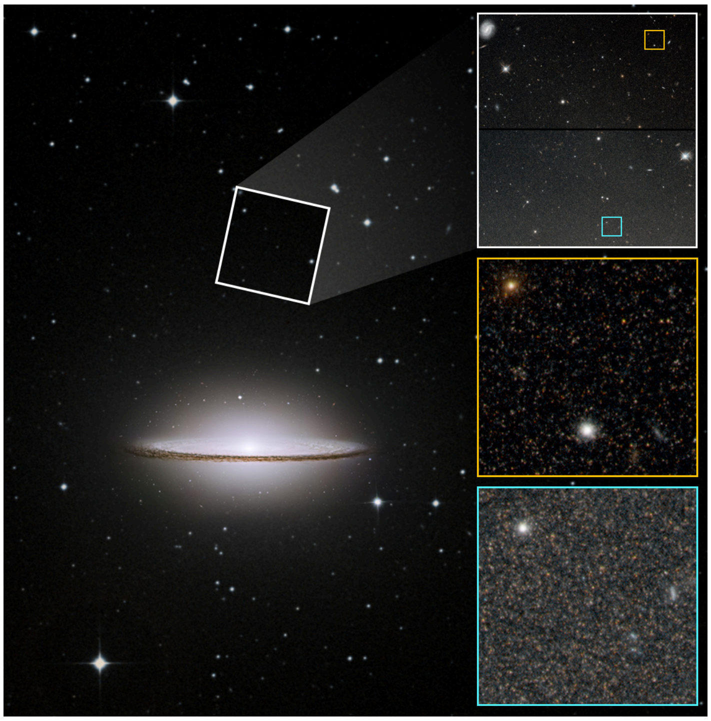

Figure 6: Hubble telescope zooming into deep seemingly empty space near the Sombrero Galaxy (left).[11] *The plethora of stars and galaxies detected in the square regions (right). Credit: NASA, STScI.*

capability to move around and look at a list of pre-determined galaxies in their field of view. The robots need to be choreographed to ensure they do not bump into one another, and as they dance, they use fiber optics to collect data from galaxy to galaxy.

As the Mayall Telescope shifts its perspective, the robots plan to survey one third of the night sky. To us, each slice of the sky the robots survey is a tiny, seemingly empty region of space. But, in reality, each invisible region of space contains within it hundreds of thousands of galaxies, as the image above illustrates.

Throughout its 5-year operation, DESI will collect an estimated 50TB of data using spectrograph detectors from the light hitting each robot's optic fiber "eye" from each galactic object.

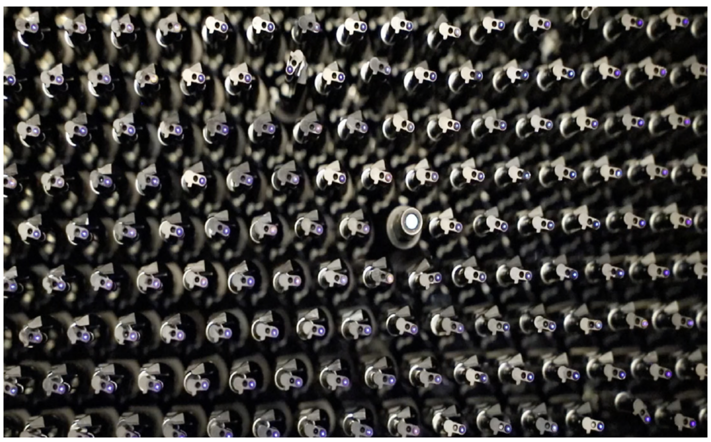

Figure 7: DESI robots close-up. *Each robot contains an optic fiber (dark blue dot) and can rotate independently.*[12] *

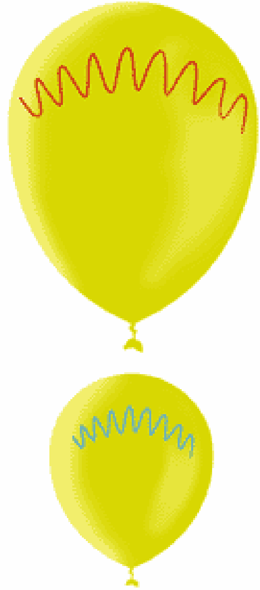

Figure 8: The effect of the universe's expansion on light waves, resulting in redshift.[13] *

Scientifically, how can DESI use these tiny points of light to map out the universe?

One way is to use redshift distortion. Redshift is the concept that while light waves are moving towards us, the universe is expanding at the same time, and thus the waves get stretched. This is an example of the Doppler Effect. You experience this effect with sound waves when an ambulance is moving towards you, and the sound is higher in pitch as it gets closer, and then as it is moving away, the sound is lower in pitch. Redshift distortion is the Doppler Effect for objects moving away from us.

The farthest galaxies exhibit the highest redshift, which means that they seem to be moving away faster than nearer objects. The reason behind this is one of the original pieces of evidence for the expansion of the universe. If we are one dot on our interstellar balloon, then given a constant expansion rate, we would notice the near dots moving away from us slower. On the other side of the balloon, dots would appear to be moving faster as the surface area of the balloon increases and distorts our perspective.

The implications of this tie the expansion of the universe to redshift distortion, distance, and time, all which we can measure. In assuming a constant expansion rate, scientists expected this redshift-to-distance relationship to be linear: a straight line. Surprisingly, they measured a higher redshift-to-distance than expected: a line curved upwards. This startling discovery was of the first indications that the universe was not only expanding constantly but that it was accelerating too. The universe's own stretching causes the light we detect to be shifted and stretched. In essence, space is making more space and distorting our perception of light. We can use the redshifts of millions of galaxies to map the relative positions at different times, which tells us how the universe is expanding, and in what way it is accelerating. Why and how the acceleration occurred in the first place, we do not know. This is one of the major questions that DESI hopes to answer.

A natural question that follows would be: "How do we know what the furthest possible object is?" We have managed to detect a lingering noise across the universe called the Cosmic Microwave Background Radiation (CMBR). The light waves from the Big Bang stretched so much as the universe expanded over time, they became microwaves. Watching TV without tuning into anything, you get white noise. White noise is this very background radiation, and we are effectively tuning into the universe's history.

Because we know that farther away means longer ago, we can calculate, using the Doppler Effect, the age of the universe it-

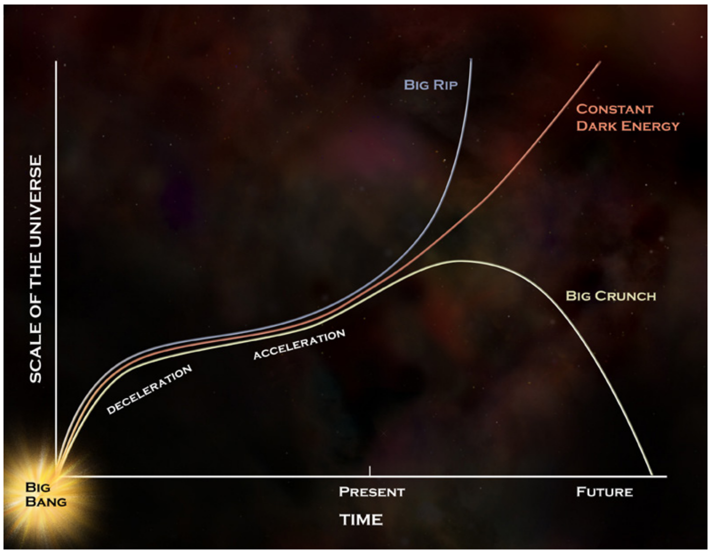

Figure 9: Predictions about the fate of the universe. *The acceleration of the universe's expansion is shown as curving the scale of the universe.* [14] *Credit: NASA/CXC/M. Weiss*

self. Scientists calculated it to be somewhere around 13.7 billion years old simply because it takes the light a maximum of 13.7 billion years to be stretched to the wavelength of this CMBR. DESI is hoping to peer 11 billion years into the past where galaxies and other interstellar objects are less common and harder to detect.

We use other relics in this space archeology to determine the acceleration of dark energy and its effects. The other principle method DESI will use is by measuring the Baryon Acoustic Oscillations of distant galaxies.[15] Though it is known that there is no sound in space due to its vacuum-state, this was not always the case. Back when the universe was young and hot, matter was unable to become neutral, which resulted in a charged plasma floating around. Whenever gravity compelled objects to attract to become patchier and denser, fluctuations were formed in the density of this plasma. These fluctuations are essentially just sound waves that come from a periodic compression and separation of matter flowing in this plasma. DESI measures these oscillations around

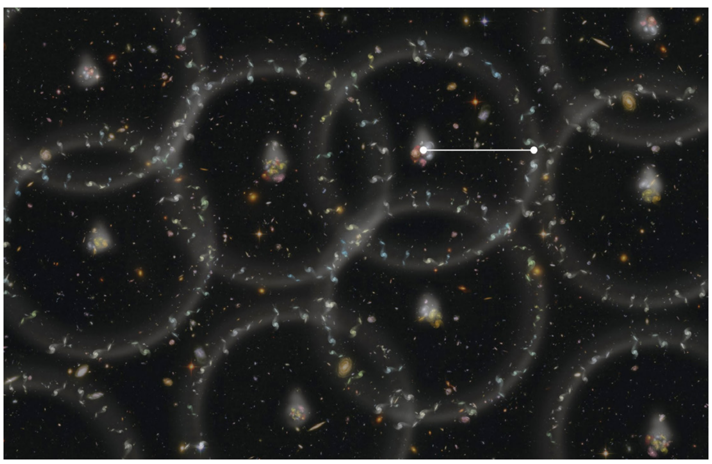

Figure 10: Baryon Acoustic Oscillations (artist's depiction) surrounding the early universe's galaxies.[16] *

> "DESI is hoping to peer 11 billion years into the past, where galaxies and other interstellar objects are less common and harder to detect."

old galaxies and they can tell us how the universe was expanding at that time.Our knowledge of dark energy, as the name suggests, is crude so far. DESI will gather data to build a true 3D map of tens of millions of galaxies. This data helps us understand more about how dark energy is accelerating the universe's expansion, refining our results and paving the way for new theories and groundbreaking physics.

DESI and its next-generation grandchildren have the potential to answer age-old questions in physics that tell us about our place in the universe. Where are we? When are we? Where are we going? These are questions that kept our ancestors awake looking up at the night sky and wondering in awe at its mystery.

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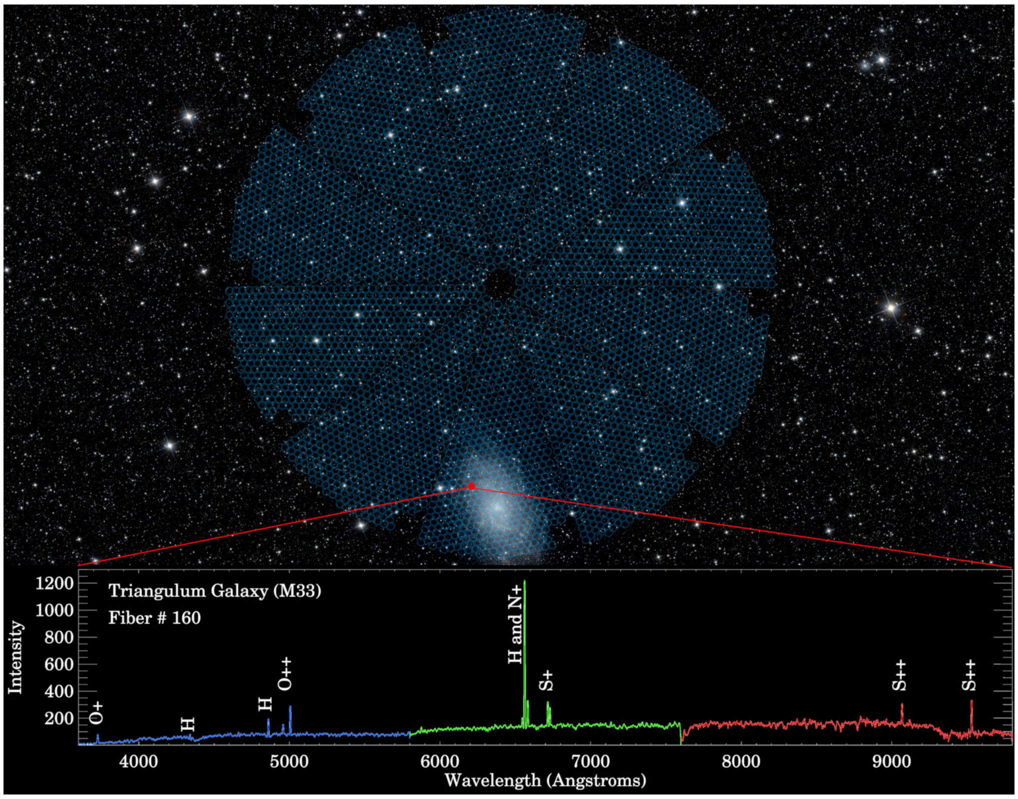

Figure 11: DESI's robots pointing at the night sky, taking spectroscopic light data (top). *Example of data point from the Triangulum Galaxy (bottom).*[17] *

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