1
PROLOGUE

For thousands of years, we have gazed in wonder at the Milky Way arching the night horizon believing that the entire universe unfolded from beyond its light.

However the real truth about the cosmos lies, not in what meets the eye, but in the darkness.

A mysterious, new reality is emerging from the shadows.

A strange, dark matter somehow binds stars and galaxies together.

And an even more enigmatic force called dark energy
is causing the expansion of the universe to speed up

Combined, dark matter and dark energy make up 95% of the universe.

But their actual nature remains a mystery.

This discovery challenges our understanding of the fundamental laws of nature.

This is the story of a brilliant group of scientist whose are the next big step in untangling the enigma

The tale of how the most powerful camera ever built was fitted to a giant telescope, to carry out the next greater map of the universe

This highly ambitious endeavor to discover why the expansion of the universe is speeding up bring us in the era of giant cosmic maps.

Series Title. **«THE ACCELERATING COSMOS»**
Part: I
Chapter Title
Chapter III: **«THE DARK ENERGY SURVEY COLLABORATION»**

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The simplest of observations, the darkness of the night, contains one of the universe's most complex mysteries.

The universe is expanding but, why is it accelerating?

We accompany the cosmologist Enrique Gaztañaga to New York on his visit to his fellow physicists to understand a little better how theorists face the mystery of dark energy...

Time Code 02:20

Título:

UNIVERSE'S LAWS

Theoretical Physicists

What is dark energy?

Time Code 02:31

The Pantheon, the great thinkers and classical architectural designs of the University of Columbia inspire us with '*The ability to strive for excellence, no matter what the challenge*'.

And today, the biggest challenge on physics is 'dark energy'

What could be?

Lam Hui

Well dark energy is the term we use to refer to whatever energy that dominates the universe currently that is responsible for making the universe accelerate. And we call it dark energy because we do not know what it is. It doesn't emit light and the only way we know its presence is by actually measuring very carefully how the universe expansion changes with time.

We have learnt a great deal about the cosmos, by speaking its own language, that of mathematics.

However a new mathematical model has emerged. Both astounding and beautiful, it is the most complex model we have ever seen.

From String/M theory, to the multiverse, theorists have proposed that parallel universes and extra-space dimensions exist.

Uni- means one, so all that exists is the universe. But is that the whole truth?

Lam Hui:

Today we have some reasons to believe that there could be many universes out there, so the currently observed universes may form a very small part of an immense Universe And these different parts of the universe may have very different physical laws.

However fascinating these theoretical ideas may be, this documentary

will shed light on the dark secrets of our directly observable universe.

It is through light that we will explore the dark forces of the cosmos and the fundamental laws that govern it

We will gaze out to the very edge of space and time where a mysterious force fuels the accelerating expansion of the universe.

Our hope is to learn something of how things have become what they are

THE LAWS OF PHYSICS

The expansion of the universe was predicted by Einstein's Theory of General Relativity, which explains the workings of the invisible on a large scale: how gravitational force dominates stars and galaxies, the whole universe, in fact.

The discovery of 'dark energy' could undermine Einstein's theory and indeed revolutionise the field of physics.

Do we need a new theory to replace that of General Relativity?

Lam Hui

There have been a lot of attempts to modify Einstein's theory to explain this phenomenon, namely maybe when you go to very large scales Einstein's theory breaks down, and that's why counter intuitively when the universe expands, it doesn't slow down, but in fact speeds up.

And I have also worked on these theories but I have to say, I think the experience of a lot of people who have tried to improve on one of Einstein's theory is that at best it's partially successful.

So, was Einstein wrong?

Lam Hui

Basically, Einstein's theory is just such a beautiful coherent framework.

If you try to add anything to it or try to improve it, either you run into inconsistencies, which is bad, or it just makes the theory very ugly, aesthetically not very pleasing, and complicated. And I think it's very likely, at least in lower energies Einstein's theory is correct.

The elegant theory of General Relativity provided us with a marvellous new means of regarding gravity, not as a force but the result of a curve in space-time.

Time Code 02:20

UNIVERSE'S STRUCTURE & EVOLUTION

Probing the Nature of Dark Energy

The search of cause from acceleration we facing a huge universe and a most ancient question: where did it come from? Why the universe is as it is?

Enrique Gaztañaga:

One of the biggest challenges of cosmology is to understand how stars, galaxies and planets are formed, or, in other words, how we got where we are now

If we think at the largest scales, the universe is soft, uniform and homogeneous.

However at smaller scale we discover compact structures like galaxies and that's an enigma: Where could proceed the existence of clumps at small scales?

WORLD MAP Title: Barcelona–La Serena, Cerro Tololo Inter-American Observatory, Chile

Marcelle Soares Santos:

Here with this instrument we are interested in looking at the largest scales in the universe, right? And the idea behind that is that in the very early universe, you have a universe that is very uniform with small fluctuations. And as the universe grows older and grows larger, these fluctuations grow as well. Matter starts to collapse into these potential wells. And you see a formation of structures.

Why is so significant related to the universe's expansion?

Marcelle Soares Santos:

So all the large scale structures we see today, galaxy clusters, filaments between galaxy clusters, they all originate from this primary module structure, and their distribution and their properties today, they are related to how the universe has expanded from that point to now. So that's why it is important for us to measure that. 4

In order to understand this formation, we need a context; we need to understand in which geometry objects are being formed. Thus the accelerating expansion of the universe becomes the framework within which we try to understand the formation of structures.

When telescopes were used to measure how the *expansion of the Universe has changed with time, it turned out, quite surprisingly, that during the first half of cosmic history, the expansion rate was actually slowing down.*

Then, a mysterious force, a sort of "anti-gravity" made the Universe 'hit the gas pedal' starting the acceleration we see today.

We live in a changing universe and yet few things are changing as quickly as the ideas we have about it.

It is work in progress. The handwriting is still being written. Where should we begin? We begin at the very beginning

According to the big bang theory, the universe was created 13,800 million years ago with a big explosion,

The beginning of space, time, the seeds of everything we see around us and the invisible too. Dark energy and dark matter were also formed in the fires of Genesis, at first second of time

Time Code 09:57

UNIVERSE'S CONTENT

Planck satellite Results

So, what is the universe made of?
Have you ever looked up into the night sky and wondered just how many stars there are in space?

There are probably more than 100 sextillion stars in total. This is a hundred times more stars in the universe than grains of sand on Earth.

The sky is studded with stars. The sheer enormity of this vast ocean of existence is inconceivable. However, all these stars are not even he 5% of energy-matter content of the universe. What about the other 95%?
In 2013, the measurements of the cosmic background radiation made by Planck satellite confirmed that the light-emitting universe represents a mere 5%, the rest is composed of 25% dark matter and 70% the mysterious dark energy that is accelerating its expansion.

Time Code 11:05

DARK UNIVERSE

Dark Matter & Dark Energy

"Let us receive the occult with an ovation"
R. BROWNING

Stars explode throughout the universe. They may be cosmic catastrophes, but they shine a torch into the darkness for scientists.

They help illuminate the epic struggle between two invisible forces.

Cosmologists are striving to comprehend these colossal forces at work and learn how to see beyond the darkness.

Time Code 11:50

Dark Matter & Ordinary Matter

Stars, The Sun, the Moon, the Earth, people...

Everything you see on Earth and in the Universe has one thing in common: it is composed of atoms.

The structure of the atom provides refreshing simplicity within the chaotic complexity of the universe.

But dark matter is exotic. We've never seen anything like it before.
So, what exactly is dark matter?

Josh Frieman

Dark matter makes up about a quarter of the universe and we don't actually know what it is, but we know what it does. (XXX) We know it cannot be made of ordinary matter, things that are made of atoms, things like all the world we see around us, it must be made of something more exotic.

Ofer Lahav

Dark matter is a component which is invisible but we have to put it there in order to actually explain the motions of stars within a galaxy or the motion of galaxies within clusters of galaxies.

Like that neither emits nor reflects light, for astronomers, the challenge of **mapping the Universe has been similar to mapping a continent from just the lights of the cities.** However they've been able to create a three—dimensional map of how this dark matter is distributed across the Universe, and that's a remarkable achievement.

Time Code 13:32

Dark matter is not just an unseen component of the universe;
it's actually crucial to our existence.

In this simulation, we can see the complex patterns that are formed by dark matter.

This tangle of filaments and mass is what we call the « cosmic web ».

It is within these agglomerations of dark matter that galaxies *such as the Milky Way would have formed.*

These gases combine and condense to form stars.

Dark matter is the skeleton of the universe.
Its structure allows galaxies to form.

This has profound implications:
Dark matter helped create everything we see around us!
Without Dark matter there'd be no galaxies or stars.
Without stars, there'd be no planets.
And without planets, there'd be no life.

Josh Frieman

It feels gravity, it exerts a gravitational force, and it makes things clump together, and we think that dark matter is really the engine by which galaxies formed and structures in the universe formed.

We can visualize this by returning to New York to see the famous Christmas tree at Rockefeller Center. Think lights and colorful beads as in galaxies shining in the darkness. However, the branches of the tree are those who hold the lights. The branches would be the dark matter that holds galaxies lights or.

Dark matter behaves like ordinary matter: in that pulls things together by gravity and it dilutes with the expansion of the Universe.

Dark energy we really don’t know much about it other than that it has this gravitationally repulsive feature. So, what is dark energy?

Time Code 15:31

What is Dark Energy?

Ofer Lahav

Dark energy is another mysterious component and we still don't know what it is.

Lam Hui

Let's say for example if you throw a rock up into the sky, as the rock goes up you expect a rock to slow down and that's because basically gravity is attractive. So if you have anything that tries to expand, gravity will just hold it back and try to slow down the expansion. So the surprise about ten years ago was that the universe expansion was actually not slowing down at all, is that in fact accelerating. And that energy is the term we use to describe whatever substance might be responsible for this surprising fact

Time Code 15:51

Title: 1998 The discovery of acceleration is made public

Ofer Lahav

As you know, those two teams led by the astronomers had been recognized by awarding a Nobel prize in Physics 2011 for the discovery of the acceleration of the universe but we still don't know what is the acceleration due to, we still don't know if the dark energy is some correction to the curvature of the universe, or is it an actual substance that my cup of tea also has some dark energy in it and everywhere else in the universe has got that.

Unlike Dark Matter, Dark Energy does not dilute with the expansion and this results in a gravitational repulsion that accelerates the expansion.

Time Code 16:41

THE COSMIC SURVEYS

Mapping the World, Mapping the Universe

From ancient maps of Greece and Asia, through to the Age of Exploration, and on into the 21st century, people have created maps as essential tools to help them define, explain, and navigate their way around the world

The world is the assemblage of parts that compose the universe. Hanging an antique map of the world on your wall says something about you. It says you understand your place on this great globe, and you understand your place within the folds of time.

An antique world map suggests you are centered, self-aware, and confident. We make cosmic maps for that same reason. The more we realize we are not the centre of the universe, the more we need to know our place and how our fleeting existence weaves into the great tapestry of time.

Astrophysicist Luiz Da Costa is a pioneer in cosmic mapmaking.

And these pioneer maps of the galaxies started revealing something that they called 'the great wall' and, step by step, what is now known as the 'cosmic web, enormous filaments of galaxies that surround huge bubble-like voids.

Luiz Da Costa

Nobody had any idea about what galaxy distribution was supposed to look like. So in fact the old idea was that the universe was kind of uniform, and there were islands, you know, people already knew that there were clusters of galaxies and things like that. It was a great surprise even from the very first survey, even before the great wall in the early 80s that we had very empty visions.

Over the last 6 billion years, the universe has begun to accelerate outward… As gravity loses its grip on the universe to an unseen force called: dark energy. You can see evidence of this now, out in the huge voids of space between filaments of galaxies.

Luiz Da Costa

And the great wall is just a consequence. Basically we have these sheets of galaxies that form walls that exist not only in the north but also in the south so it's a part of the cosmic web. So you have these big regions surrounded by these structures surrounding them. So that was remarkable. So together with CFA we were the first to have this panoramic view of the universe. So it was exciting to find these walls, not just the great wall. Great walls exist everywhere.

Time Code 19:25

MAPS OF THE UNIVERSE

The Time Machine

But how can cosmic maps measure the universe's rate of expansion?

Enrique Gaztañaga

If you can measure the velocity of an object at two different times you can calculate the acceleration. This is, as it were, a simplification.

in order to make this reference you need to know the times, and in cosmology knowing the time is the same as knowing the distance.

Time inevitably figures in stargazing as well as in mapping the cosmos, since everything we see in the night sky belongs to the past.

Enrique Gaztañaga

Time is distance… because whatever you observe will always correspond to something which is at exactly the distance which the light has had to travel to reach you,

Through a telescope, you can see galaxies and quasars that are billion light-years away. Their light it's older than planet Earth.

The idea of collecting light from such vast expanses in space-time make us feel insignificant in comparison. However, doing so has extraordinary consequences...

Enrique Gaztañaga

"Cosmic maps are time machines". We have the wonderful opportunity to see today things that happened long ago. Let's imagine that we position ourselves at a certain point in space…. We put the Earth here, or the Sun, and as we look back we can see the light from the cosmos as it reaches us. And what happens is that the objects closest to us belong to more recent times, simply because the light that we observe from them has taken less time to reach us than that of the more distant objects.

We see the Moon as it was 1.3 seconds ago, the Sun as it was 8 minutes ago, bright stars as they were decades or even centuries ago, and galaxies as they were millions of years ago.

Enrique Gaztañaga

Therefore the more distant objects are older, and so you've got a time machine

Enrique Gaztañaga

Every layer in our cosmic map must be from a more distant past.
In such a way that, there is a limit to this which is the last visible layer, and this is cosmic background radiation. The universe at that moment was about 300,000 years old and corresponds to the approximately thirteen thousand million years that the light has taken to reach us from that last layer.

This is the oldest possible cosmic map...

But, what is the relationship between these two maps that look so different?

Enrique Gaztañaga

What we are seeing when we compare the cosmic background radiation maps with the galaxy maps, these are simply maps of the universe at different cosmic times.

Enrique Gaztañaga

Surveys such as the Sloan Digital Sky Survey reveal the universe as it was a few thousand million years ago. However, in the near future we will be able to make much bigger maps, such as the DES or PAU… These maps will take us ***further in space and time*** *and therefore we will be able to measure how structure growsfrom the Universe's first light (CBR) to the present time.*

Title Movie:

A JOURNEY THROUGH THE UNIVERSE

FROM THE UNIVERSE'S FIRST LIGHT
(COSMIC BACKGROUND RADIATION)

THROUGHOUT THE LARGE SCALE STRUCTURES

TO THE PRESENT TIME

Time Code 23:06

WORLD MAP(S) Title: 1. Illinois–Chicago-Fermilab—La Serena, Chile

2. Barcelona—La Serena, Cerro Tololo, Chile

3. Cerro Tololo Inter-American Observatory, Chile

Dark Energy Survey Collaboration

DES

Now we've reached this point, let's go back once again to the crucial question.
Why is the expansion of the universe speeding up?
Fifteen years have passed and still nobody knows. However, it seems we won't have to wait too much longer.
After all, the next big step in untangling this dark mystery has been happening for the last nine years.
How is it going to be achieved? This is another chapter in the story: the tale of how the most powerful digital camera ever built was fitted to a 4 meter long telescope under one of the clearest skies in the world. The camera was built as part of a project to make a cosmic map, the likes of which has never been seen before. « Great discoveries need great demonstrations »

WORLD MAP Title: 1. Barcelona——FERMILAB, Illinois, USA

2. FERMILAB, Chicago, Illinois, USA

Fermi National Accelerator Laboratory

FERMILAB

Set on the plains of Illinois, Fermi National Accelerator Laboratory, Fermilab is one of the world's greatest particle accelerators and leads the way not only in particle physics, but also in researching the cosmic abyss: from particles to galaxies.

But why would a group of people who study collisions of particles in an accelerator want to map the universe with a camera and telescope"?

Ramon Miquel,

Now there are also new windows opening in the field of astronomy, cosmology-using galaxy surveys. This is particularly true since 1998, 1999 when two teams of astronomers discovered that the expansion of the universe is accelerating. This has been interpreted as having a substance called dark energy, which makes up 70% of the energy and matter content of the universe, 70%. So certainly a lot of particle physics have decided that we need to understand what this 70% is. As far as we know now the only way to really attacking this problem is through a galaxy surveys.

Fermilab was key in getting Dark Energy Survey started and is where the dark energy camera had been assembled.

Brenna Flaugher:

DES (the Dark Energy Survey) began in 2003 which was about the time when dark energy was really being accepted and this whole idea of the accelerated expansion of the universe was being understood, and at the Blanco telescope they put out an announcement of opportunity to build a new instrument and then in exchange for the instrument to get time on the telescope to use the telescope and the camera to measure whatever you wanted

Josh Frieman:

The reason we began it was that a few years earlier astronomers had found, had discovered, that the universe was accelerating, the expansion was speeding up, and this was a real surprise. We wanted to understand this in greater detail. We wanted to address the question of why is the universe speeding up.

In order to
answer this question accurately, scientists of the Dark Energy Survey realized they would need to carry out a new kind of survey, far greater than

any that had been made before and that they would need to build a new camera and put it on a giant telescope in order to probe the nature of dark energy.

The initial idea grew from discussions between Josh Frieman and others colleagues and then they making the connection with CTIO, and after with the other countries in the collaboration.

(VOICEOVER)
The project's first director, John peoples worked very hard initially building a collaboration of labs and universities and got the whole thing going, so he was really a sort of guiding light in the early days.

John Peoples

So when you undertake a project that's going to take 20 years, 10 years just to start. It's massive in size. You need many brilliant people at different stages, you sure do need collaboration. One person cannot do it alone.

So, in 2003, at Fermilab, Josh Frieman, Brenna Flaugher and others seriously discussing the idea of building a camera to carry out this huge survey.

John Peoples

So here we are, nine years later, we have a magnificent camera and a magnificent telescope and a great opportunity to do some superb science.

The telescope, having been built about 30 years ago, is very robust. It is big enough and sturdy enough to hold a very heavy camera, the one that we have here.

But it was not easy. In Fermilab scientists had to build a scale replica of the telescope in order to assemble the Decam. It took seven months to achieve.

It was this combination of factors that helped make it happen here in Chile.

SOLVING THE

UNIVERSE'S BIGGEST MYSTERY

THE END OF THE BEGINING

(In) The next chapter takes us on a quest that will unite people from all around the world on a journey to this unique place: the Cerro Tololo Inter-American Observatory.

Meanwhile, we have more questions than answers.

Will it be possible to work out what dark energy really is?

Marcelle Soares Santos

It's too early to tell. We have high hopes to help build and understanding of what is causing the accelerating expansion of the universe but you have to ask me again in five years

Dark energy is still a term coined for calling something we don't understand.

Is it a substance that is a constant?
Or is it the energy within a vacuum?

Is it just the consequence of having misunderstood gravity?
Or is it something completely new?

Brenna Flaugher

There are many, many ideas for what this cosmic acceleration is caused by... It's a huge effect: 96% of the universe is in dark energy and dark matter and we have no clue what they are, so I think we're missing something big and I really hope that the Dark Energy Survey data will help narrow it down and point us on the right path.

In the meantime, the expansion of the universe keeps accelerating. And the evolution of the cosmos continues. Not only around us but also within us. We live in the accelerating universe.

The fundamental laws and dark forces created at the first second in time are still operating across the majestic ballet of the galaxies and in every beat of our hearts.

Their history is also our history.
The story of a whole dark universe out there waiting to be understood

Hence our exposure history about the universe and dark forces dominates it

But **this is not the end of the story, not even the beginning of the end, but the end of the beginning**

The end of building and installing the most powerful combination of camera and telescope ever seen.

The beginning of carry out the next big survey in the universe

The end of the beginning to solve the riddle of dark energy

But the work is on going

The script is still being written

And the ink is not yet dry...

Come with us to know how the story goes?

If you got here, you are part of the journey.

And don't forget to look up into the sky...

There's much to see,

And much more hidden in the darkness...

CREDITS

Alex Muntada,
Barcelona, early 2019

——————END OF THE SCRIPT——————