# CosmoVerse Adventures

## Dark Energy

COST EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Funded by the European Union

# The classroom

## Introduction: The Dark Side of the Universe

**Teacher :**

*(Catching an apple tossed in the air)* Good morning, class! Can anyone tell me why this apple falls back down when I throw it up?

**Student 1 :**

That's gravity pulling it down, isn't it?

**Teacher :**

Precisely! Gravity pulls it back to Earth. But if I could throw this apple fast enough, at about 11 kilometres per second, it would reach escape velocity and not come back down. It would keep going where Earth's gravitational pull will be close to zero.

**Student 2 :**

So, it'd be like launching a rocket into space!

**Teacher :**

You got it. Now, let's connect this to our universe. Since the big bang, the universe has been expanding. We used to think it might start to decelerate because of gravity from all the galaxies and dark matter.

**Student 3 :**

Dark matter? That's the stuff we can't see, but it has gravitational effect, right?

**Teacher :**

Correct. But here's the surprise: Scientists discovered that the universe isn't shrinking or even expanding slowly; it's getting bigger faster and faster; it's accelerating!

**Student 1 :**

Wait, accelerating? How's that possible?

**Teacher :**

It's like throwing the apple up and instead of coming back down, it speeds away into space. Scientists think there's a special kind of energy causing this acceleration, called dark energy.

*Figure 1: Scientists were shocked to know that the universe is accelerating. It's like throwing an apple into the air and having it accelerate upward.*

## Student 2 :

So dark energy is different than dark matter?

## Teacher :

Exactly! Dark matter is the unseen mass that adds gravitational pull, acting more like a net that slows down the apple's flight.

## Student 2 :

How much dark energy is out there?

## Teacher :

Well, when scientists add up everything in the universe, they find that a staggering 95% is stuff we can't directly see. And two-thirds of that about 70% is dark energy—so powerful that it dominates the fate of our universe.

## Student 3 :

So, will the universe keep expanding forever?

## Teacher :

That's the big question. To find out, we look at the universe's geometry, and whether there's enough matter to stop the expansion. But with so much dark energy, the answer leans towards yes, the universe might expand forever.

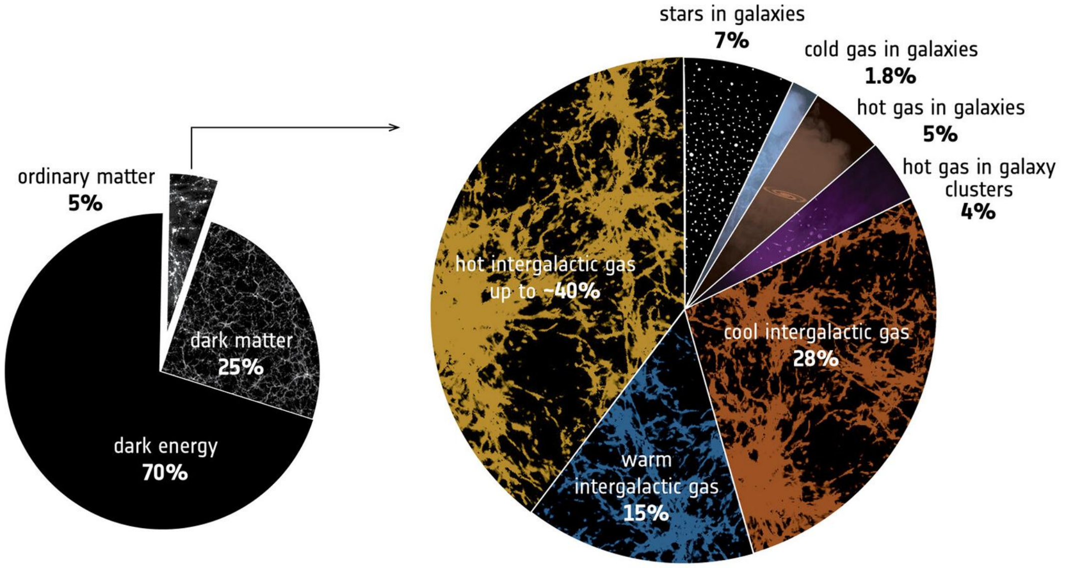



*Figure 2: Dark matter and dark energy make up 95 percent of our universe; the remaining 5 percent is made up of ordinary matter called baryons, most of which has remained hidden until recently. Scientists have now discovered much of the intergalactic material that they'd never previously seen. Credit: ESA.*

## Teacher :

Let's join Quark on his spaceship to explore this further and witness the fate of our universe and perhaps the end of time itself!

# Spaceship of Imagination

## The Fate of the Universe

**Quark :**

Welcome back, cosmic explorers! Having journeyed through the universe's past, it's time to set our course for the future, to ponder how our universe might end.

**Student 1 :**

I've always wondered, what are the possible endings?

**Quark :**

Ah, the tales of the cosmic finales are as varied as they are thrilling. Let's travel forward in time, to the far future, aboard the spaceship of imagination.

*(The ship hums to life, stars streaking past as it accelerates into the future.)*

**Quark :**

Now, our story unfolds in three acts, each determined by the protagonist, Omega Ω—the ratio of all matter and energy to the critical density, the perfect balance for a flat universe.

**Student 2 :**

Omega Ω! It is named after the last letter in the Greek alphabet!

**Quark :**

Yes. In our first act, if Omega Ω is less than one, the universe is like a bowl too large for its contents. Space is curved like a cosmic saddle, forever open and expanding. This is the tale of the Big Freeze, where galaxies drift apart, leaving us in a cold, endless expanse, thanks to the enigmatic dark energy.

**Student 4 :**

That's... quite chilly.

**Quark :**

Indeed. In the second act, should Omega Ω exceed one, we find ourselves in a universe too small for its contents, curving like a sphere. Here, the universe's expansion slows, stops, and then reverses, collapsing back into a fiery singularity—a Big Crunch.

**Student 3 :**

Like the universe taking its last breath?

**Quark :**

A final sigh, young astrophysicist. But in our third act, where Omega Ω equals one, we have a perfectly balanced flat universe. Yet, even this balance tips in favour of a ceaseless expansion.

**Student 1 :**

So, dark energy is winning the cosmic tug -of-war?

**Quark :**

Exactly! Dark energy is like the hidden player in this cosmic drama. It's pushing the universe to expand faster, overpowering the gravitational pull of everything else. This makes the Big Freeze scenario a universe growing cold as it expands – the most likely ending.

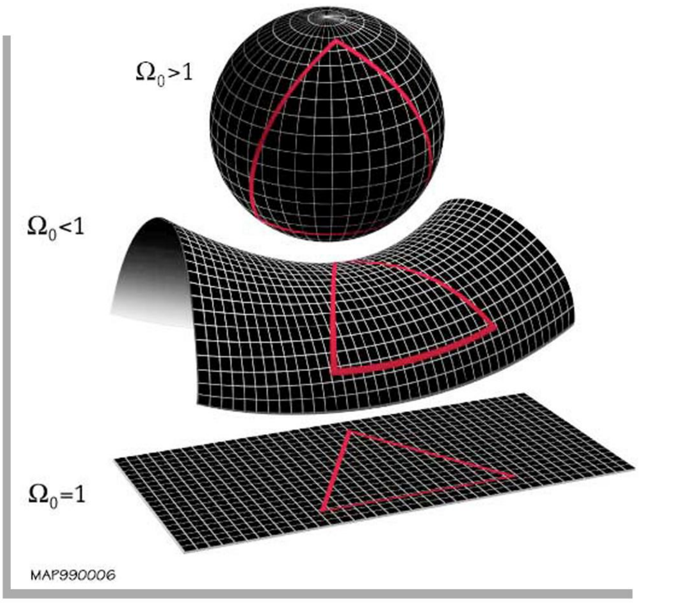



*Figure 3: The local geometry of the universe is determined by whether the relative density Ω is less than, equal to or greater than 1. From top to bottom: a spherical universe with greater than critical density (Ω>1, k>0); a hyperbolic, underdense universe (Ω<1, k<0); and a flat universe with exactly the critical density (Ω=1, k=0). The spacetime of the universe is, unlike the diagrams, four-dimensional. Image Credit: NASA.*

**Student 2 :**

Are we going to witness this Big Freeze?

**Quark :**

Not for many eons. But one day, galaxies at the edge of our vision will blink out, lost beyond an ever-growing cosmic horizon, leaving us in a dark, vast sea of emptiness. A paradoxical fate, where our universe grows yet reveals less of itself over time.

**Student 4 :**

What if dark energy gets stronger over time?

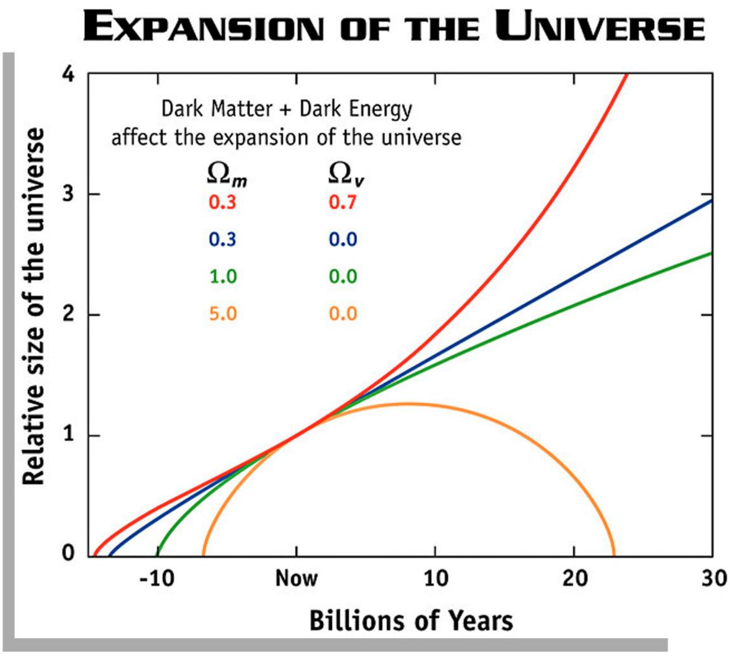
**Quark :**

If dark energy grows stronger, it could lead to a 'Big Rip.' Everything, even galaxies and atoms, might get torn apart as the universe's expansion accelerates uncontrollably.

**Student 1 :**

Can dark energy become weaker instead?

*Figure 4: Possible scenarios for the fate of the universe: the bottom orange curve represents a closed, high-density universe which expands for several billion years, then ultimately turns around and collapses under its own weight. The green curve represents a flat, critical density universe in which the expansion rate continually slows down (the curves becomes ever more horizontal). The blue curve shows an open, low-density universe whose expansion is also slowing down, but not as much as the previous two because the pull of gravity is not as strong. The top (red) curve shows a universe in which a large fraction of the matter is in a form dubbed "dark energy" which is causing the expansion of the universe to speed up (accelerate). There is growing evidence that our universe is following the red curve. Ωm (Omega_m) and Ωv (Omega_v) are parameters that cosmologists use to describe the content of the universe. Ωm refers to the density of matter in the universe, which includes both ordinary matter and dark matter. Ωv refers to the density of dark energy. Please note that their percentages are divided by 100. Image credit: NASA / WMAP science team.*




## Quark :

It's possible. If it weakens, we might still see a Big Freeze, but if it turns negative, it could lead to a Big Crunch, where the universe collapses back on itself. Although, if any change happens, it would take much longer than the universe's current age.

## Student 3 :

So, we're in a cosmic race against time?

## Quark :

Elegantly put. Our universe's story is still being written, and we have front-row seats. Let's keep our eyes wide with wonder. For now, let's make the most of our cosmic journey-for as long as the stars keep shining above us.

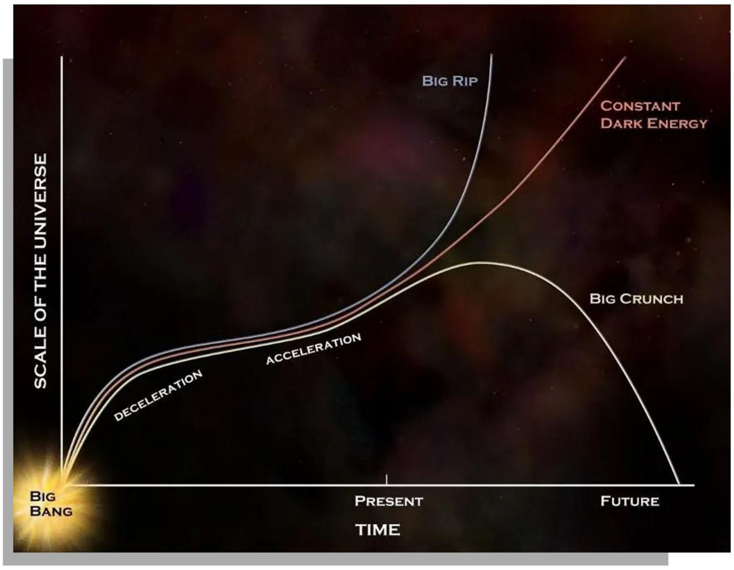



*Figure 5: The ultimate fate of the universe depends on dark energy's influence. If it continues to dominate at constant levels, the universe may increase in size without limit. If the strength of the dark energy increases too much, the cosmos could be pulled apart in a "big rip." If the dark energy weakens, and if the universe contains enough mass, the cosmos may eventually collapse in a "big crunch." Credit: NASA/CXC/M. Weiss*

## Student 4 :

I still wonder how did scientists actually discover Dark Energy?

## Quark :

That's a great question! To uncover the story of Dark Energy's discovery, let's meet a brilliant mind who delved deep into these cosmic mysteries. It's time for us to join the renowned cosmologist Stephen Hawking, who can shed light on this dark enigma.

## Meet a scientist

### The Discovery of Dark Energy

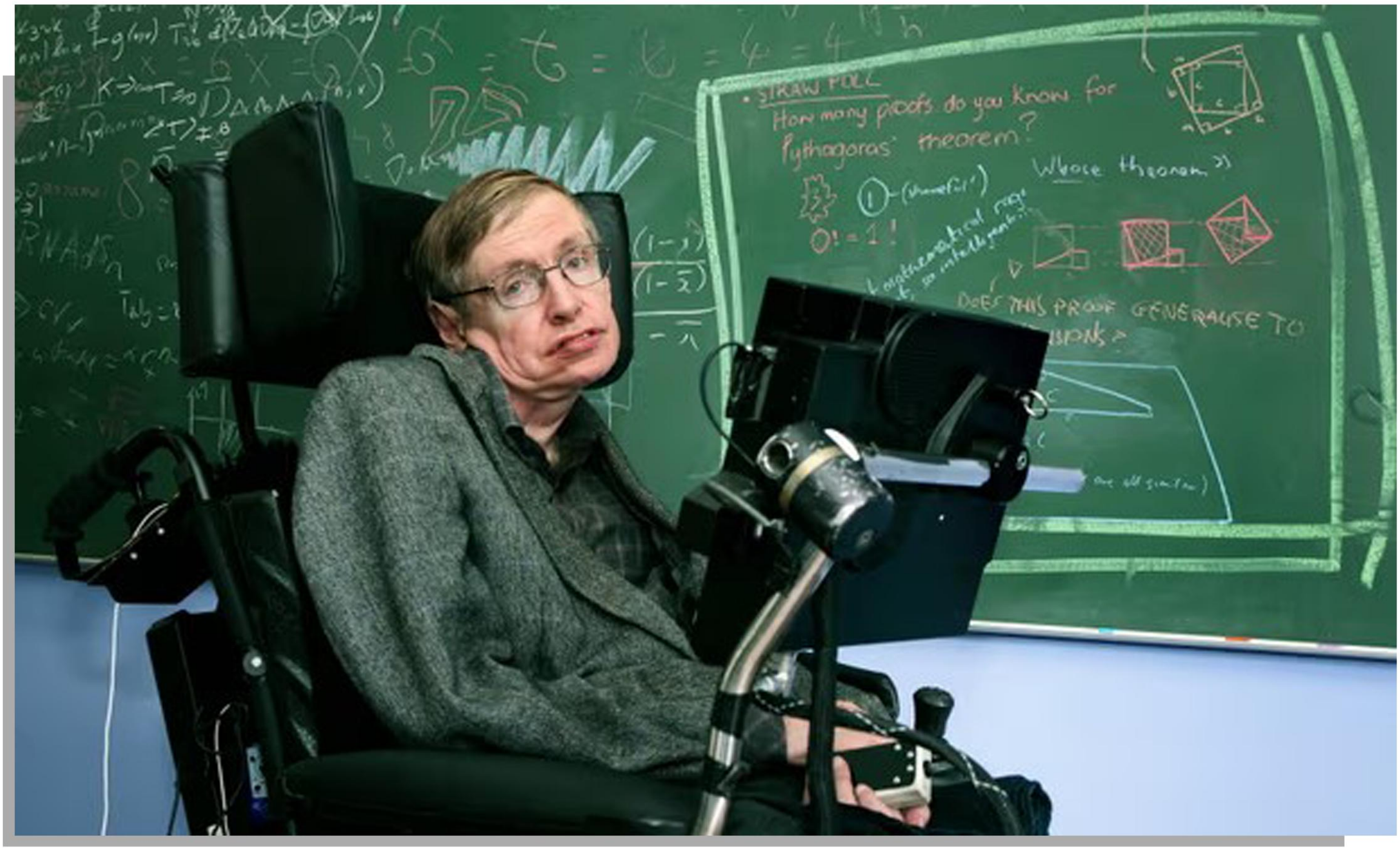



*Figure 6: Stephen Hawking at his office at the department of applied mathematics and theoretical physics at Cambridge University in 2005. Photograph: Murdo Macleod/The Guardian.*

**Quark :**

Welcome, young explorers! Today we have the honour to meet Professor Stephen Hawking, one of the greatest minds in cosmology!

**Student 3 :**

It's a pleasure meeting you professor! I wonder how the universe's expansion was measured, leading to the discovery of dark energy?

**Hawking :**

It's good to be here. The key to understanding the universe's expansion lies in every photon of light that reaches us. As space expands, it stretches the light, increasing its wavelength, creating what we call cosmological redshift.

**Student 1 :**

So, the more space expands, the more redshift we see?

**Hawking :**

Precisely. And by measuring the redshift and the distance light traveled, we can understand the universe's expansion history.

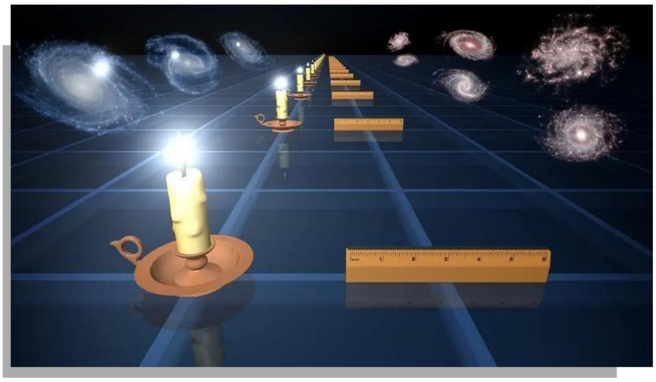


Figure 7: Artistic illustration to the concept, "Standard candles," which are astronomical objects with known luminosity, which means their true brightness is well-understood. By comparing their known luminosity with how bright they appear from Earth, astronomers can calculate their distance from us.

**Student 2 :**

But how do we measure how far light has traveled?

**Hawking :**

We use something known as the redshift-distance relationship. Redshift tells us how much space expanded, and distance is the amount of physical space the light covered.

**Quark :**

To track this expansion history, we needed to measure different redshifts and distances. But distance is hard to measure, especially for faraway objects.

**Hawking :**

That's where standard candles come in, objects whose true, intrinsic brightness is known. Their apparent faintness tells us their distance.

**Student 3 :**

Far away things are fainter than nearby things.

Figure 8: Type 1a supernova 1994D exploded near the outskirt of galaxy NGC4526. The supernova is the bright object in the lower left corner. Image credit: NASA/ESA, The Hubble Key Project Team and The High-Z Supernova Search Team.

**Hawking :**

Exactly. In the 1990s, two teams of scientists were using the world's biggest telescopes to peer as deeply as they could into the Universe looking for a special type of supernovae called Type Ia supernovae. These are white dwarfs that explode at a specific mass, making their luminosity nearly uniform.

**Student 4 :**

So, by knowing how bright they should be, we can tell how far away they are?

**Hawking :**

Exactly. By comparing their expected brightness with how bright they appear, we can calculate their distance. And by measuring their redshift, we know how much the universe expanded since their light was emitted.

**Quark :**

But something unexpected happened, right, Professor Hawking?

**Hawking :**

Indeed. The supernovae appeared fainter than expected, suggesting they were farther away. This meant the universe was expanding faster now than in the past.

**Student 1 :**

So, the universe's expansion is accelerating?

**Hawking :**

Correct. We expected it to be slowing down due to gravity. But the discovery that it's speeding up led to the conclusion that an unknown force, which we call dark energy, is driving this acceleration in the last 5 billion years.

**Student 2 :**

And that's how we found out about dark energy?

**Hawking :**

Yes, this groundbreaking discovery reshaped our understanding of the cosmos and earned a Nobel Prize. It's a clear example of how our universe continually surprises us, revealing deeper mysteries as we explore further.

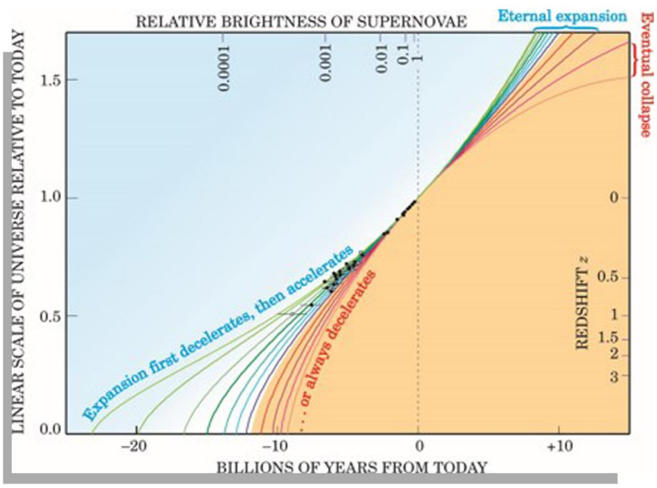



*Figure 9. This graph represents the expansion of the universe over time, as determined by observing Type Ia supernovae. The horizontal axis shows time, with the past to the left and the future to the right, and the vertical axis indicates the relative size of the universe. The point where both axes meet represents the present size of the universe. The coloured bands show different models of the universe's expansion. The blue region models suggest that the universe's expansion is speeding up over time due to a mysterious force called dark energy or vacuum energy. The curves in this region show different amounts of this energy, from a lot at the top to less at the bottom. The yellow region, on the other hand, shows models where the universe always slows down as it expands because there is a lot of mass. In the most extreme cases on the right of this band, the universe's expansion even stops and reverses, leading to a collapse. The black dots represent actual measurements from supernovae. By comparing the expected brightness of these supernovae with how bright they actually appear, we can see how fast the universe was expanding at different points in time. These measurements suggest that the universe's expansion first slowed down and then started to speed up, which is consistent with the blue region's models that include dark energy. Image credit: Perlmutter S., Physics Today.*

# Action Lab

## Demo: Expanding Universe

### Objective :

To understand the concept of dark energy and its impact on the expanding universe.

### Preparation Time : 5 minutes

### Activity Time : 5 minutes

### Materials Needed :

- Balloons
- Small round stickers
- Markers
- Ruler or tape measure
- Graph paper

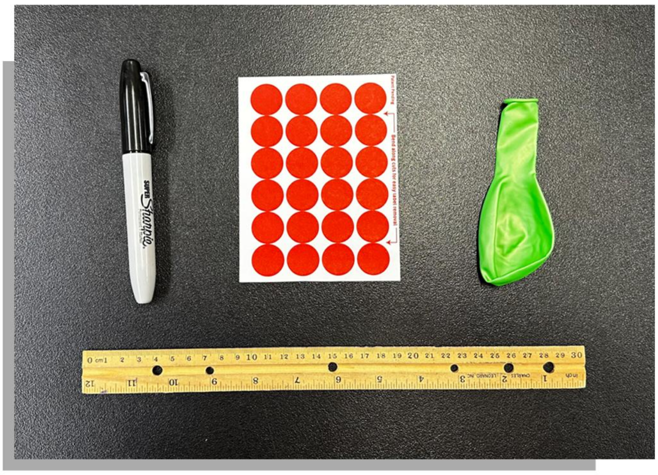


*Figure 10: Image credit: NASA/JPL-Caltech*

### Observations :

- Divide students into groups of two or three.
- Have student groups inflate their balloons just enough to take shape, but don't tie them off. The balloon represents the - universe.
- Give each group five to ten stickers to place on the balloon. If stickers aren't available, students can mark spots with a marker.
- Instruct students to draw a lightwave on the balloon to represent light traveling between galaxies.

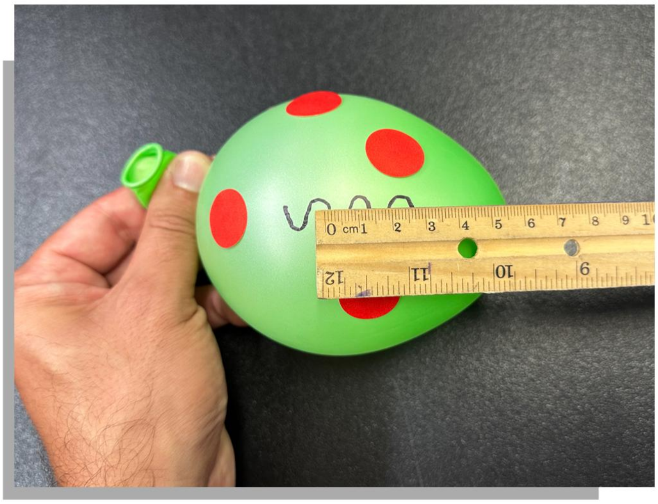


*Figure 11: Image credit: NASA/JPL-Caltech*

- Students should measure and record the distance between two stickers and two crests of the waves they drew. This initial measurement represents the starting point of their universe.
- Have students partially inflate the balloon a bit more, still without tying it off. They should observe and measure the distances again between the same two stickers

and wave crests

- Students should continue this process, inflating the balloon a little more each time and recording their observations. They should note how the distances between the stickers (galaxies) and wave crests (lightwaves) increase as the balloon (universe) expands.

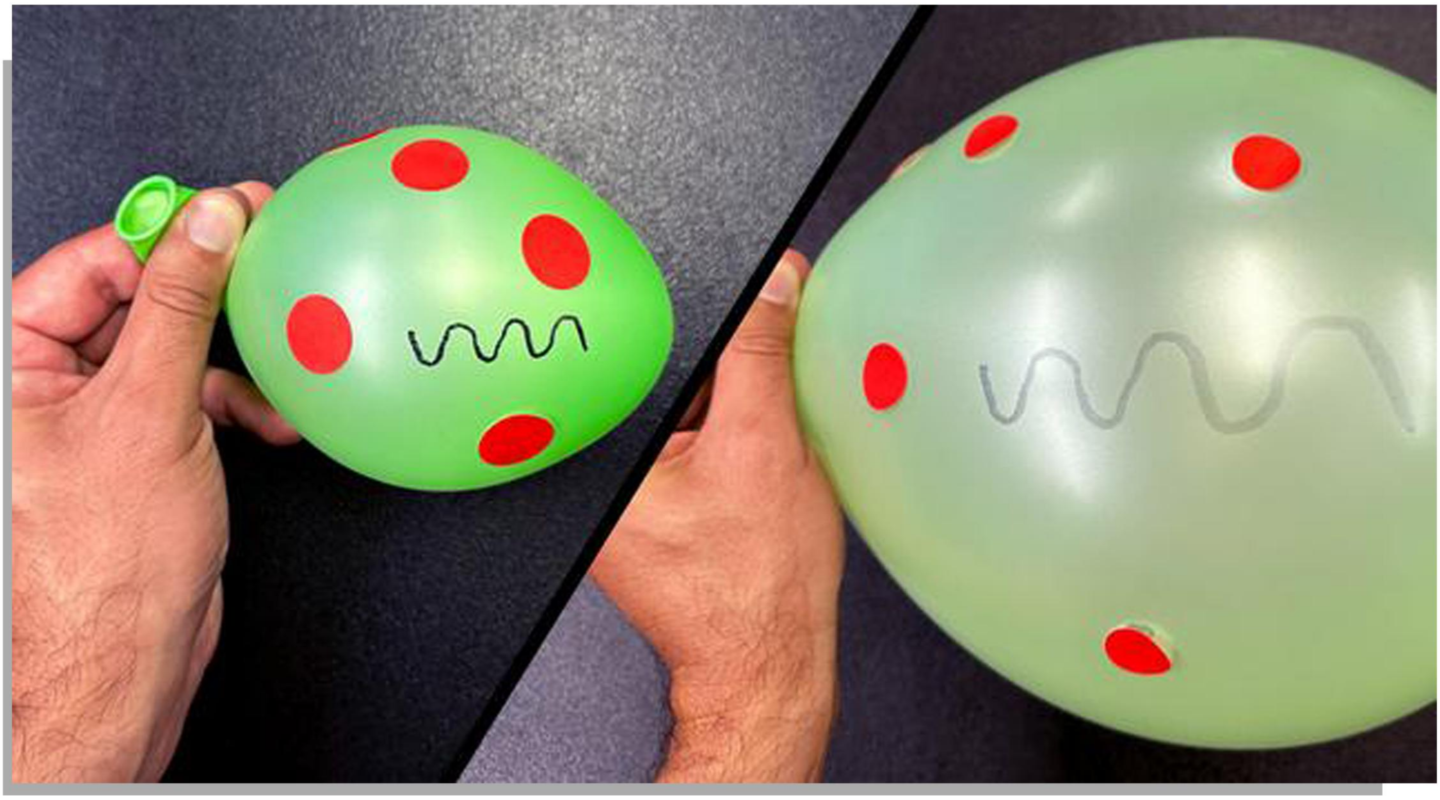


*Figure 12: Students use a balloon to model the expanding universe. Image credit: NASA/JPL-Caltech.*

## Demonstration and Discussion :

### Teacher :

Today, we'll demonstrate one of the leading theories about dark energy: that it's a property of space itself.

### Student 1 :

How are we going to do that?

### Teacher :

We'll use these balloons as our 'universes.' As you inflate the balloon, notice how the stickers move apart. This simulates galaxies moving away from each other in our expanding universe. The lightwaves you drew also stretch, representing the - redshift phenomenon. Keep in mind to be gentle and avoid popping your universe!

### Student 3 :

So, as we inflate more, the distances keep increasing. Is this like the universe getting bigger over time?

### Teacher :

Exactly! And the increasing space between your stickers is a simple way to visualize how dark energy might be causing the universe to expand faster.

### Student 4 :

So, dark energy is like the air filling the balloon?

### Teacher :

Exactly. Dark energy is thought to be a property of space, and as space expands, more of it appears, pushing the universe to expand faster. This is similar to an idea Einstein had in 1917, called the cosmological constant.

### Student 2 :

What was that about?

### Teacher :

Einstein proposed that this mysterious energy in space counterbalances gravity, preventing the universe from collapsing. At that time, he believed the universe was static and unchanging, and the cosmological constant seemed to explain that.

**Student 3 :**

But the universe isn't static, right?

**Teacher :**

Exactly! In 1929, Hubble discovered that the universe is expanding, which contradicted Einstein's idea of a static universe. This made Einstein reconsider his cosmological constant, even calling it his greatest blunder.

**Student 3 :**

But in a way, Einstein's 'blunder' has found new life in our understanding of dark energy.

**Teacher :**

Indeed! Now, let's talk about other ideas. Some scientists think dark energy could be from temporary virtual particles appearing and disappearing in space. Another idea is that dark energy could be something we call ''Quintessence" an unknown kind of dynamic energy fluid or field which permeates the entire universe, but somehow has the opposite effect on the universe than normal energy and matter.

**Student 1 :**

Are there any limitation with these theories?

**Teacher :**

Calculations for these theories don't match our observations well. They either give us too much energy or suggest dark energy changes over time, which doesn't fit what we see in the universe now.

**Student 2 :**

So, we're still trying to figure it out?

**Teacher :**

Yes, and that's what makes science exciting. There's always more to discover and understand about our universe. As Albert Einstein once said, '' The most beautiful thing we can experience is the mysterious. It is the source of all true art and science. He to whom the emotion is a stranger, who can no longer pause to wonder and stand wrapped in awe, is as good as dead; his eyes are closed.''

# Cosmic Library

## Videos :

The Dark Side Of The Universe – Brian Green
What Is Dark Energy?
What is Dark Matter and Dark Energy?
Unraveling the Mysteries of Dark Energy with NASA's WFIRST
What is Dark Energy made of? Quintessence? cosmological constant?
Dark Energy, Cosmology part 2: Crash Course Astronomy
Will the Universe Expand Forever?
Why the Universe Needs Dark Energy
What Does Dark Energy Really Do?
Neil deGrasse Tyson: What is Dark Matter? What is Dark Energy?
Mapping the universe: dark energy, black holes, and gravity

## Interactive & Infographics :

Dark Energy simulation
Dark Matter and Dark Energy Explained (infographic)

## Websites & Articles :

The Five Ways The Universe Might End
Different articles and news about Dark Energy
Four Ways That Our Universe Might End
Dark Energy, Dark Matter - NASA
Accelerating the Expansion of the Universe
Dark Matter and Dark Energy – National Geographic
Dark Energy: The Biggest Mystery in the Universe

## Books :

physics-for-21st-century-dark-energy-online-textbook

## Documentaries :

Dark Energy: The Biggest Mystery In The Universe

Most of the Universe is Missing

## Quiz :

Dark Energy Quiz

The Mystery of Dark Energy

# Glossary

**Big Bang:** The theory that describes the origin of the universe, starting from a singular point and expanding over time.

**Big Crunch:** A hypothetical scenario in which the universe's expansion eventually reverses, leading to a collapse back into a singularity.

**Big Freeze:** A potential fate of the universe where it continues expanding until it reaches a state of absolute cold and galaxies drift apart.

**Big Rip:** A theoretical end of the universe where dark energy grows stronger over time, eventually causing all matter, even galaxies and atoms, to be torn apart.

**Baryons:** Particles such as protons and neutrons that, along with electrons, form atoms and make up ordinary matter in the universe.

**Cosmological Constant:** A concept introduced by Einstein, representing a constant energy density filling space homogeneously.

**Cosmological Redshift:** The redshifting (lengthening of wavelength) of light from distant galaxies, indicating that the universe is expanding.

**Dark Energy:** A mysterious form of energy that is causing the acceleration of the universe's expansion.

**Dark Matter:** An unseen form of matter that does not emit or absorb light but exerts gravitational effects on visible matter.

**Escape Velocity:** The minimum speed needed for an object to break free from the gravitational attraction of a massive body.

**Galaxies:** Large systems of stars, dust, and gas bound together by gravity, such as the Milky Way.

**Gravity:** The force by which a planet or other body draws objects toward its center.

**Omega Ω:** A cosmological parameter representing the ratio of the actual density of the universe to the critical density.

**Quintessence:** A hypothetical form of dark energy, described as a dynamic energy fluid or field.

**Standard Candles:** Astronomical objects, like Type Ia supernovae, whose luminosities are known and can be used to measure distances in the universe.

**Supernovae:** Explosive events at the end of a star's life cycle, particularly Type Ia supernovae used in measuring cosmic distances.

**Type Ia Supernovae:** A subclass of supernovae resulting from the explosion of a white dwarf in a binary system.

This article/publication is based upon work from COST Action CA21136 – "Addressing observational tensions in cosmology with systematics and fundamental physics (CosmoVerse)", supported by COST (European Cooperation in Science and Technology)

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