Cosmos Transcript - Deeper, Deeper, Deeper Still

We live on one level of existence, but there are others. These hidden dimensions of reality are everywhere. Far away, across the light years.

Beneath our feet.

And even inside you and me. We are made of atoms.

There are more atoms in your eye, than there are stars and all the galaxies of the known universe.

The same is true of any solid object larger than the tip of your little finger.

I'm a collection of three billion, billion, billion intricately arranged atoms called Neil Degrasse Tyson.

You are a similar collection with a different name.

We don't usually think of ourselves this way because that level of reality lies beyond the realm of our senses.

But we're not gonna let that stop us.

We can go deeper into the wonder.

Atoms let matter do funny things.

To understand water, you need to know what its atoms are doing.

Every molecule of water is composed of two tiny hydrogen atoms attached to a larger oxygen atom.

That's why we call it H_20.

If it's not too hot or too cold, the molecules can slide and tumble past each other.

There's still some stickiness between the molecules, but not enough to lock them into a rigid solid.

That's what makes something a liquid. The sun warms the water.

And with more energy, the molecules move faster. That's all that temperature is.

Those molecules are moving fast enough to break the weak bonds that hold them to their neighbors.

That's evaporation.

The air we breathe is made of nitrogen and oxygen molecules with a scattering of water vapor and carbon dioxide.

Incoming! That's condensation.

A dewdrop is the momentary triumph of condensation over evaporation.

And while it lasts, it's a little cosmos with its own worlds creatures, drama.

To explore the far-flung realms of this dewdrop, we're gonna need a ship.

One with twin engines science and imagination.

That's a single-celled paramecium, one of a multitude of skilled hunter-warriors that roam the dewdrop.

But they, too, are hunted.

The Dileptus.

The paramecium's mortal enemy.

The paramecium might get lucky and score a direct hit.

Even if it doesn't, the recoil from the barrage will put some distance between the paramecium and its attacker.

What can I say? That's life in the dewdrop.

That little guy is tardigrade, an animal smaller than the head of a pin. Don't underestimate them.

Tardigrades have been living on this planet a lot longer than we have. About 500 million years.

For every one of us, there's at least a billion of them.

They can make a living anywhere on earth.

In the frigid peaks of the tallest mountains, in the cauldrons of erupting volcanoes, and in the deep ocean vents at the bottom of the sea.

Tardigrades are so tough, they can survive naked in the vacuum of space. They've survived all five of the most recent mass extinctions on this planet.

A visitor from another world could be forgiven for thinking of earth as the planet of the tardigrades.

If we're ever gonna get to the bottom of this dewdrop, better get a move on.

Every leaf and tiny clump of moss has hundreds of thousands of microscopic mouths called Stomata.

Plants breathe through them, taking in carbon dioxide and exhaling the oxygen that we need to live.

The plants can survive without us.

But we and all the other animals we'd be toast without them. The plants make food out of sunlight.

We animals can't do that.

To see how they do it, we have to go deeper, make ourselves about a thousand times smaller to get into their treasure house, the place where they keep the good stuff the chlorophyll.

That's the molecule that converts sunlight into energy.

Every one of those rectangles is a plant cell.

And those tiny green vehicles are its energy factories.

If we could steal their trade secrets, it would trigger a new industrial revolution. But to spy on them, we're gonna need to go deeper still.

What alien world has the ship of the imagination carried us to this time? It's the cosmos Contained within a dewdrop.

We're on an industrial espionage mission.

If we can penetrate the trade secrets of the manufacturing process in that chloroplast, let's just say our whole future hangs in the balance.

This chloroplast is using sunlight to break water molecules into atoms of hydrogen and oxygen.

It combines the hydrogen with carbon dioxide to make sugar, and releases the oxygen as a waste product.

To see how it happens, we have to go even deeper, get even smaller. We're talking atomic scale.

Bingo.

This assembly line is the heart of the molecular industrial complex. At the molecular level, things happen too fast for us to see.

So we'll have to slow them down about a billion times.

Those larger molecules are carbon dioxide.

Each one of them is made of one carbon and two oxygen atoms.

When sunlight strikes a green molecule of chlorophyll, it sets in motion a series of chemical reactions, breaking apart water molecules and freeing energetic electrons.

And that's just the day shift, when sunlight supplies the incoming stream of energy. There's a second shift that works day and night using the solar energy kept in reserve.

The energy of the free electrons is put to work, combining carbon dioxide with hydrogen from the water.

The end product is sugar, which stores the solar energy.

The chloroplast is a three-billion-year-old solar energy collector.

This sub-microscopic solar battery is what drives all the forests and the fields and the plankton of the seas.

And the animals. Including us.

The solar-powered biosphere collects and processes six times more power than our entire civilization.

We understand on a chemical level how photosynthesis works.

We can recreate the process in a laboratory. But we're not as good at it as plants are.

And it's not surprising, considering nature has been at this for billions of years, and we've only just started.

But if we could figure out the trade secrets of photosynthesis, every of other source of energy we depend on today—coal, oil, natural gas—would become obsolete.

Photosynthesis is the ultimate green power.

It doesn't pollute the air and is, in fact, carbon neutral.

Artificial photosynthesis on a big enough scale could reduce the greenhouse effect that's driving climate change in a dangerous direction.

Uh-oh, the place is evaporating.

Time to get out of here.

How fleeting is the life of a dewdrop.

It condenses from thin air in the cool of the night, only to vanish with the heat of the day.

And what of its inhabitants, the tardigrades? They'll be fine.

They can go without water for years.

It's hard to imagine, but plants covered the surface of the earth for hundreds of millions of years before they put forth their first flower.

That was about a hundred million years ago, shortly before the dinosaurs were wiped out.

Our world must've been a relatively drab-looking place back then, dominated by shades of green and brown.

Yeah, there were giant trees and ferns and other plant life, but not the purple of an iris or the crimson of a red, red rose.

Orchids were among the first flowering species to appear on earth, and they're the most diverse.

Darwin was particularly fascinated by the comet orchid of Madagascar, a flower whose pollen is hidden at the bottom of a very long, thin spur.

There can be no stronger test of an idea than its predictive power.

On the basis of his theory of evolution through natural selection, Darwin speculated that somewhere on the island of Madagascar, there must live flying insects with extraordinarily lengthy tongues, ones long enough to reach the pollen.

No one had ever seen such a beast there, but Darwin insisted that an animal fitting this description must exist.

Few people at the time believed him.

It wasn't until more than 50 years later that Darwin was proven right.

In 1903, a huge hawk moth, called the Morgan's sphinx was discovered in Madagascar.

Attracted by the Comet Orchid's scent, the moth slurps its pollen with its foot-long tongue, exactly as Darwin expected it would.

It's even more amazing that the Morgan's sphinx was discovered when you consider that more than 90% of Madagascar's rain forest had been destroyed.

In the years since Darwin's famous prediction, this moth species could have easily become extinct with all the others every one of them a unique phrase of life's poetry, written in the atoms by eons of evolution.

Ah, the fragrance of lilacs.

It's one of those scents that triggers a whole constellation of associations, all those junes of long ago.

But how does that happen? How does a smell prompt a movie to start running in your head? It's not something we can see.

Could it be a wave of energy, like light? Or is it some kind of microscopic particle? It's actually a molecule.

Every odor we can sense, whether it comes from burnt toast, gasoline, or a field of lilacs, is a cloud of molecules.

These molecules have particular shapes.

When I inhale them, they stimulate a particular set of receptor cells in my nose. An electrical signal then travels to my brain, which identifies the scent as lilac. Other scents are carried by different molecules with different shapes.

But when I smell a flower or the smoke from a campfire or the grease from a motor gear, I'm often flooded with memories.

Why is it that a simple thing such as the scent of a flower can trigger powerful memories? It has to do with the way our brains have evolved.

Our sense of smell kicks in when the olfactory nerve in our brain is stimulated.

That nerve is located very close to the amygdala, a structure that is integral to our experience of emotion.

It's also very close to the Hippocampus, which helps us form memories.

The network of neurons that carry the scent signal from my nose to my brain has been fine-tuned over hundreds of millions of years of evolution.

It's a survival mechanism that can alert us to danger or guide us to safety.

If you you can detect the predator before he's near enough to strike, or the fire before it traps you in the forest, you have a much better chance to survive and pass on your genes to the next generation.

That lovely scent from this field of flowers sets off a unique combination of nerve signals.

Only that exact combination can crack the safe where the memory of lilacs is stored inside my brain.

Wonder who they're for.

Maybe we'll find out later.

But first, there's another hidden cosmos waiting for us.

The plants are softly breathing, inhaling molecules of carbon dioxide and exhaling molecules of oxygen.

And I'm doing the opposite.

Unlike snowflakes and fingerprints, atoms or molecules of the same kind are utterly identical to one another.

With every breath we take, we inhale as many molecules as there are stars in all the galaxies in the visible universe.

And every breath we exhale is circulated through the air, and mixed gradually across the continents, it becomes available for others to breathe.

Breathe with me.

We all just inhaled about that once passed through the lungs of everyone who ever lived before us.

Think of it This kind of atomic reincarnation is another link to our distant ancestors, including those who first launched us on our explorations of the unseen universes.

These universes are as real as you or me, and they surround us.

There was a moment when we awakened to a new way of thinking and seeing.

It happened about 2,500 years ago on the Greek islands that lie between the empires of the east and west.

There, merchants, tourists and sailors freely mingled, exchanging tales of great kings and gods.

In Ionian cities and towns like Miletus, in what is now Turkey, the most fundamental elements of the way we live now first appeared.

Here, for the first time, reenactments of aspects of life created and executed by professionals with the expectation of touching something deep within the hearts of the audience, or just making them laugh The first plays, dramas and comedies, were performed.

Government by the people.

The first inklings, imperfect then as now, of a democracy, and the notion that the ordinary citizen might possess certain rights, come to us from this time and place.

But in my view, the most revolutionary innovation of all to come to us from this ancient world was the idea that natural events were neither punishment nor reward from capricious gods.

The workings of nature could be explained without invoking the supernatural. The first person to express this thought was a man named Thales.

When the thunder clapped or the earth quaked, it was not because something you did had somehow displeased the very demanding gods.

No, it was the result of natural processes that we were capable of understanding.

Though none of the books he is said to have written survive, Thales kindled a flame that still burns to this day: The very idea of cosmos out of chaos, a universe governed by the order of natural laws that we can actually figure out.

This is the epic adventure that began in the mind of Thales.

Only a century following Thales' death, another genius came along.

And he, more than any other, was the first to discover the existence of the hidden universes that surround us.

Democritus of Abdera was a true scientist, a man with a passionate desire to know the cosmos and to have fun.

This is the man who once said, "a life without parties would be like an endless road without an end." You mean, that's it? That's all there is? Just a bunch of atoms in a void? Yep.

Well, think about it.

The world has to be made of countless indivisible particles in a void.

Otherwise, nothing could move or grow, be divided or changed.

Without atoms and empty space for them to move in, so don't be sad, my friends.

Just think of the infinite possibilities that arise from different arrangements of those atoms.

Here's to the atoms in this cup and in this wine And to the laughter they make possible.

Dispersed through the Clay of the cup are microscopic mineral grains, different kinds of crystals, each with its own distinctive atomic architecture.

Mineral structures are exquisite, but they have a limited repertoire.

A grain of quartz is a lattice of the same three atoms repeated, without variation, over and over again.

Even a relatively complex mineral lattice like topaz, composed of ten or so atoms, can only repeat the identical atomic structure again and again.

Toenon, to free it from the lattice prison of endless repetition, you need an atom that can bond in all directions with other atoms like itself as well as with atoms of different kinds.

Behold the carbon atom the essential element for life on earth.

Why? Carbon is special because it can bond with up to four other atoms at a time.

It can connect with many different kinds of atoms, as well as other carbon atoms.

It can curl into rings and string together into chains, building molecules far more complex

than any crystal.

No other atom has the same flexibility.

Even atoms that have similar chemical properties, like silicon, can't form the amazing variety of molecules built on carbon.

The carbon-based molecules we call proteins, the molecules of life, contain literally hundreds of thousands of atoms.

Carbon atoms are the backbone of the molecules that make every living thing on earth, including us.

That's the difference between rocks and living things.

Life can make enormous molecules of stunning size and complexity, freeing matter to improvise, evolve, and even love.

Take it easy, dad.

He never actually touched her.

In everyday life on our world, on the scale of atoms, material objects never really touch.

Each atom has a tiny nucleus at its center, surrounded by an electron cloud of lines of force.

As the atoms approach each other, the boy's electron clouds push away the girl's. More than 99.9% of the matter of any atom is concentrated in its nucleus.

The nucleus is surrounded by an electron cloud which produces an invisible field of force, and acts like a shock absorber.

The configuration of the electron cloud determines the nature of an element. In the ordinary course of things here on earth, the nuclei never touch.

We have a sensation of touching, but that's really just our invisible force fields overlapping and repelling each other.

The nucleus is very small compared to the rest of the atom.

If an atom were the size of this cathedral, its nucleus would be the size of that mote of dust.

An atom is mostly empty space.

To understand the nature of matter, we have to go deeper still, to a place 100,000 times smaller than the atom: Its nucleus.

The simplest and most plentiful atom in the cosmos is hydrogen.

Its nucleus is a single proton, which makes hydrogen element number one.

The clouds that surround it are the realms where the atom's lone electron is permitted to roam.

What happens when you have a nucleus with two protons? Protons repel each other. In order to hold them together in a nucleus, you need other particles called neutrons. Their job is to keep the protons from getting out of line.

They overwhelm the protons with their strong attractive nuclear force.

A nucleus with two protons is element number two, otherwise known as helium.

A nucleus with six protons is element number six, which is carbon, the fundamental building block of life.

The nucleus of a gold atom has 79 protons.

They attract 79 electrons in clouds around it.

The way light interacts with those electrons is what makes gold glitter.

Every additional proton in the nucleus requires enough neutrons to bind them together Up to a point.

There's an upper limit to the number of neutrons you can stuff into a nucleus before it becomes unstable.

I know a place where the nuclei of different atoms actually do touch each other.

The sun looks like a solid object, but it's not.

It's so hot that all its atoms are always in their gaseous state.

The bonds that join atoms to make solids and liquids on earth are not strong enough to withstand the heat of the broiling sun.

Those arcing streams of incandescent gas that dwarf the earth are guided by magnetic lines of force that emanate from below the surface of the sun.

Why is the sun so hot? Because its own stupendous gravity is squeezing its atoms

together.

The energy of gravity is being transformed into the energy of moving atoms.

That's what heat is.

The deeper we go into the sun, the greater the squeezing and the higher the temperature.

In the heart of the sun, the atoms are moving so fast that when they collide, they fuse.

Their nuclei touch.

The sun is a nuclear fusion reactor, held together by its own gravity.

It's balanced between the inward pull of gravity and the outward push of its hot gases.

That balance has lasted billions of years, providing stability that made possible the evolution of life on earth.

In the sun's core, the fusion of hydrogen into helium releases nuclear energy in the form of photons.

These particles of light slowly work their way to the surface, where they're seen as sunlight.

Helium is the ash of the sun's nuclear furnace. The sun is a medium-sized star.

Its core is only a lukewarm ten million degrees hot enough to fuse hydrogen, but too cold to fuse helium.

There are many stars in the galaxy that get much hotter, because they're more massive and have more gravity.

Such stars fuse helium into heavier elements, like carbon and oxygen. In their old age, they gently diffuse these elements into space.

Other stars, more massive yet, live fast and die young in cataclysmic supernova explosions.

In our galaxy, such stars go supernova about once a century.

These explosions are far hotter than the core of the sun hot enough to transform elements like iron into all the heavier ones and spew them into space.

The large magellanic cloud is a neighboring galaxy of our milky way.

It's visible in the skies of the Southern hemisphere.

When a supernova explodes, its brightness rivals that of its entire galaxy.

But all that light is only about one percent of the energy liberated in the explosion.

The rest of the energy is carried off by the most common and the most mysterious particles in the cosmos.

There are trillions of them passing through you right now, and yet tracking down even one of them will take us to one of the strangest places on earth.

Stalking the wild neutrino is the rarest of sport.

The lengths one must go to track them down is nothing short of astonishing.

Welcome to Super Kamiokande, the subterranean Japanese neutrino detection chamber.

We're more than a half mile beneath earth's surface.

You might ask, "well, who in their right mind would bury an astronomical observatory so far underground?" Those who hunt the most elusive prey in the cosmos: The neutrino.

This enormous array of light detectors surrounding 50,000 tons of distilled water is a trap designed to catch neutrinos only.

Other particles, such as cosmic rays mostly protons and electrons that rain down from space cannot get through all that rock above us.

But matter poses no obstacle to a neutrino.

A neutrino could pass through without even slowing down.

Neutrinos hardly interact with matter at all.

That's why you need so much of it to catch even one of them.

On those rare occasions when a neutrino actually does collide with a particle of ordinary matter, it produces a ghostly, ring-shaped flash of light.

We're lying in wait for a particle that weighs next to nothing.

Even the miniscule electron has more than a million times its mass There! When the supernova in the large magellanic cloud blew its top in 1987, this is what it would have looked like in here.

Now remember, the large magellanic cloud is in our Southern hemisphere, so the neutrinos didn't come through that half-mile of rock above us, they had to pass through

the thousands of miles of rock and iron below us to reach this detector.

But the coolest thing was that those neutrinos hit earth three hours before the light from the supernova did.

If nothing can travel faster than light, how could that possibly be? This is a dead star walking.

It may look normal, but deep within it something cataclysmic is happening. This blue super giant star has already begun to explode inside.

Like rats deserting a sinking ship, the neutrinos produced in the heart of the exploding star race outward at near the speed of light, through overlying mass in only a few seconds.

But the shock wave of the exploding gas plods along from the center of the star at 1/10,000 the speed of light until it finally reaches the star's surface, turning it into supernova 1987a.

It took hours for the explosion to reach the surface of the star and blow it wide open, exposing the super hot core.

The neutrinos had an insurmountable head start.

That's why the flash of light arrived on earth so much later than the shower of neutrinos.

Before anyone had ever snared the wild neutrino, it existed in the mind of a theoretical physicist.

Just as Charles Darwin knew there must be an extremely long-nosed creature flying around somewhere in Madagascar, a 20th-century physicist named Wolfgang Pauli was desperately seeking a particle to rescue one of the pillars of modern physics, the law of the conservation of energy.

So why didn't I flinch? Because the laws of science differ fundamentally from those of other human endeavors.

In order for an idea to become a scientific law, it has to unbreakable.

That's why I was willing to bet this face on the laws of conservation of energy. Now, if you try this at home, take care not to give the cannonball a push. That's adding energy, and the ball will surely come back and do some damage. You just have to let it go, like this.

By lifting the ball, you give it gravitational energy, which is the potential to fall and accelerate.

The cannonball is going fastest when it's at the bottom of its arc, and at that moment, it's converted all of its gravitational energy to the energy of motion.

As it swings, the cannonball is constantly exchanging one of these two kinds of energy for the other, but the total amount of energy remains constant.

That's an example of the law of conservation of energy.

Once the cannonball is released, it can never gain more energy than it had to begin with.

It has no way to fly up and break my nose.

The energy accounting books are always strictly balanced.

There's no such thing as cheating.

So in the 20th century, when physicists first calculated the energy of atoms precisely, they were startled to discover an apparent violation of this law.

They found that in some radioactive atoms, the nucleus can spontaneously eject an electron.

This transforms the atom into a different element. The physicists were mystified.

The energy of the escaped electron plus that of the new element adds up to less than the energy in the original nucleus.

But the law says, "thou shall not destroy or create energy." So where did the missing energy go? In 1930 Wolfgang Pauli predicted there must be an undiscovered particle, one that makes off with the missing energy.

At the time, Pauli lamented that such a phantom particle might be so minute, swift and evasive as to forever defy detection.

But that was a rare failure of his imagination because science is always searching for a way to go deeper still.

A generation later, Pauli's neutrinos were actually detected for the first time in radiation from a nuclear reactor.

And we've been finding them, with difficulty, ever since.

There are scientists today who are trying to find a way to ride those neutrinos all the way back to the beginning of time.

We'll go as far as they have gone to come up against the wall of forever.

The wall of forever is nothing new.

Our ancestors came up against it almost as soon as they first started imagining it.

A million dawns ago, in the 13th century BC, the Egyptian this temple at Abu Simbel to honor the Pharaoh Ramses II, depicted here in four colossal statues.

Reigning even above even this mighty king is the falcon-headed Ra-Harakhti, God of the sun.

The temple was designed so that the light from the rising sun could only enter the sanctuary on two days every year.

As the rays enter the temple, they burnish the statues of the gods with their golden light before penetrating the sanctuary.

Even then, one God remains in shadow.

Ptah, lord of creation, as if the origin of the universe must forever be concealed.

Feel the sun on your face.

The energy that warms you began its journey some ten million years ago in the heart of the sun.

Unlike neutrinos, the photons needed that long to work their way out from the core to the surface.

Why? Because they were colliding billions of times per second with the sun's atoms, every collision sending them off in a random direction.

But once they finally reached the surface, they were free to dash nonstop, at the speed of light, in a mere eight minutes and 20 seconds from the sun to you.

Ten-million-year-old light on your face.

What was happening when that light left the heart of the sun? The cosmic calendar compresses the entire 13.

8 billion year history of the universe into a single year. Every month represents about a billion years.

Every day, about 40 million years.

The universe is so old that, on the cosmic calendar, ten million years ago only takes us back as far as of the last day of the year.

And what about us? Humans had yet to evolve.

Ten million years ago, our ancestors were anthropoid apes, swinging through the trees of Africa.

To us, ten million years seems like a long time, but it's only the length of an afternoon on the timescale of the cosmos.

The sun began fusing hydrogen August 31 on the cosmic calendar. Our milky way galaxy is about 10,000 million years old.

The first galaxies formed about a few billion years earlier. Something keeps me from going any further back in time.

What is this? It's the nature of light and time.

Because light travels at a finite speed, to look across space is to look back in time.

So the farther we see, the older the light.

This is as far back in the history of the cosmos as we can see with light.

It's a baby picture of universe, when it was only 380,000 years old.

That's 15 minutes into January 1 on the cosmic calendar.

If we look as far as we can see in any direction using microwave telescopes, this is what we see, the glow left over from the Big Bang.

Imagine that all the matter and energy of the observable universe was concentrated into something no larger than this.

That's the size of the universe when it was a trillionth of a trillionth of a trillionth of a second old.

All the matter and energy of the hundred billion galaxies now splayed out across the billions of light-years were once pent up in something the size of a marble.

Can you imagine how tightly packed that marble must have been? Far too dense for any kind of light to move through it, but no obstacle for the likes of neutrinos.

The big bang must have produced stupendous numbers of neutrinos, which flew unhindered through that inconceivable crush of matter.

The very thing that makes them almost impossible to detect is what allows neutrinos to sail through the curtain that conceals the beginning of time.

Where are they now? They are here, they're there, everywhere throughout the universe. Neutrinos from creation are within you.

From a marble To the cosmos.

This is the road that Thales and Democritus put us on some 2,500 years ago a road of endless searching, a relentless, systematic hunt for new worlds and an ever-deepening understanding of nature.

Who among you will pick up that torch and take us down that next stretch of road?