**Nova – Origins Part 1 – Earth is Born**

**NEIL deGRASSE TYSON** (Astrophysicist)**:** A hellish, fiery wasteland, a molten planet hostile to life, yet somehow, amazingly, this is where we got our start. How? How did the universe, our planet, how did we ourselves come to be? How did the first sparks of life take hold here? Are we alone in the cosmos? Where did all the stars and galaxies come from? These questions are as ancient as human curiosity itself. And on *Origins*, a four-part NOVA mini-series, we'll hunt for the answers. This search takes unexpected twists and turns. Imagine meteors delivering Earth's oceans from outer space. Descend into a toxic underworld where bizarre creatures hold clues to how life got its start. And picture the view when the newborn moon, 200,000 miles closer to Earth than today, loomed large in the night sky. This cosmic quest takes us back in time to within moments of the Big Bang itself and retraces the events that created us, this place we call home and perhaps life elsewhere in the cosmos. Coming up tonight: the beginnings of planet Earth.

**MIKE ZOLENSKY** (NASA Johnson Space Center)**:**If you look under your bed, you'll find that little bits of dust are collecting together into large dust balls. And something like that must be what happened in the solar system, too.

**NEIL deGRASSE TYSON:** What started as a giant ball of debris floating in space turned into Earth, but four and a half billion years ago, it wasn't exactly home sweet home.

**MIKE ZOLENSKY:** The Earth, at some point, was totally molten, a big droplet of melt just floating in space.

**NEIL deGRASSE TYSON:** How did it change from a raging inferno like this to a place we all know and love? It seemed a series of massive disasters was the best thing to hit the infant planet.

**BILL HARTMANN** (The Planetary Science Institute)**:**We all hear about the impact 65 million years ago that wiped out the dinosaurs. And you're getting that kind of impact something like once a month on the early Earth.

**NEIL deGRASSE TYSON:** And more clues are embedded within these rocks, fragments left over from the first hours of Earth's life.

**STEPHEN MOJZSIS** (University of Colorado)**:** Very little is left behind from the Earth's earliest time period, but what is left behind has revealed to us a planet much more complicated than we ever thought.

**NEIL deGRASSE TYSON:** New discoveries rewrite the story of how our planet was born, on this episode of *Origins*, on NOVA, right now.

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Major funding for *Origins* is provided by the National Science Foundation, America's investment in the future.

Additional funding is provided by the NASA Office of Space Science, the Alfred P. Sloan Foundation to enhance public understanding of science and technology, and the George D. Smith Fund.

Major funding for NOVA is also provided by the Corporation for Public Broadcasting and by PBS viewers like you. Thank you.

**NEIL deGRASSE TYSON:** In its infancy, Earth was a primeval hell, a lifeless planet bombarded by massive asteroids and comets. The moon, much closer to Earth, loomed large in the sky. Instead of water, red hot lava streamed across the surface of our planet. Volcanoes spewed noxious gases into the primitive atmosphere. Scorched and battered, Earth was a planet under siege. Yet somehow, the world we call home emerged from these violent origins.

So how did Earth make such an astonishing transformation? How did it change from a raging inferno like this, to a place we all know and love, with firm ground under our feet, air we can breathe, and water covering nearly three quarters of its surface? A place where life could take hold and evolve into complex organisms like you and me?

Well, it turns out, Earth became a habitable planet only after a series of devastating disasters in its early years. And to see how this happened, let's imagine all of Earth's four-and-a-half-billion-year history condensed into a single day, just 24 hours on an ordinary clock or watch like this.

If we start right now, then the first humans walked the Earth only 30 seconds ago. Dinosaurs began roaming the planet just before 11 p.m. The first multi-celled animals evolved at 9:05. Before that, mostly single-celled organisms existed, and we think the first of those appeared around 4 o'clock on the morning.

Earth was born at midnight on this 24-hour clock, 4.5 billion years ago, but its violent history began well before that, when huge ancient stars that had reached the ends of their lives exploded. These supernovas cooked upall the chemicalelements we know today including iron, carbon, gold and even radioactive elements like uranium. Over time, gravity took hold, and this cloud of stardust collapsed into an enormous rotating disk: the solar nebula.

In the center of this disk, temperature and pressure rose, and a star, our sun, was born. Eventually, gases like hydrogen and helium would be swept to the far reaches of the disk, but closer to the sun were dust grains made of the heavier elements.

**MIKE ZOLENSKY:** They're circling around the early sun in little racetracks, and occasionally grains traveling nearby will collide. Something like this happens in your house. If you look under your bed, you find that little bits of dust are collecting together into large dust balls. And something like that must be what happened in the solar system, too. If they collide slowly, theycan add up to a larger object and gradually grow.

**NEIL deGRASSE TYSON:** With enough collisions, dust grew into pebbles and pebbles grew into rocks. And as the rocks grew larger, so did the collisions.

**MIKE ZOLENSKY:** If they collide head on or at higher velocities then they'll actually break apart, like shooting a gun at a wall.

**NEIL deGRASSE TYSON:** But other times, the rocks stuck together. And the larger they got, the stronger their gravity became.

**DAVE STEVENSON** (California Institute of Technology)**:** Because of the gravitational attraction between these bodies, you coalesce. Instead of just making a mess—and you do make a mess as well—you build bigger things, because gravity holds things together.

**NEIL deGRASSE TYSON:** In time, gravity shaped them into small, round planets, or planetesimals, just a few miles across.

**MIKE ZOLENSKY:** Gradually, they grow from golf ball size to rugby ball size and then house size and then township size. And then one or two of these objects would get large faster than anything else and become the big boys on the block.

**NEIL deGRASSE TYSON:** Eventually, some of these planetesimals grew as big as our moon. And then they combined to form the four small, rocky planets closest to the sun: Mercury, Venus, Mars and Earth.

But the early Earth bore little resemblance to the planet we're all familiar with. And today, working out exactly what Earth was like as a newborn planet is no easy task. It's sort of like looking at me as an adult, and trying to figure out exactly what I was like as a baby: When was I born? How much did I weigh?

Now, a snapshot will give you a pretty good idea of what I looked like when I was young, but the Earth was born 4.5 billion years ago, and hardly anything survives from that time to tell us about our planet's infancy.

That's because at midnight on the clock, the new-born planet was nothing but a fiery ball of rock covered with lava.

**DAVE STEVENSON:** As you go back to these very earliest times, the first few hundred million years, the Earth was so energetic and was recycling materials so vigorously and melting material, that rocks from that period have not survived.

**NEIL deGRASSE TYSON:** So to reconstruct the story of the Earth's infancy, we look for clues not from the ground but from outer space. More than a hundred million miles from Earth, between Mars and Jupiter, lies a region called the Asteroid Belt. Here, trillions of asteroids, enormous rocks left over from planet building, are held in orbit.

Every now and then, a fragment of one of these asteroids is knocked out of orbit and set on a collision course with Earth. Called meteors, they can have a big impact.

**PETER JENNINGS**(ABC News Anchor): This exclusive report is about an object from space buried in ice, described as a scientific mother lode. We take you first to the northwest corner of British Columbia, near the Alaska border.

**NEIL deGRASSE TYSON:** Here, a massive meteor plunged through the atmosphere leaving a streak across the sky. A local bush pilot discovered the debris scattered across this lake, which was frozen over at the time. Realizing the importance of the find, he mailed a few fragments to NASA meteorite expert, Michael Zolensky.

**MIKE ZOLENSKY:** He sent samples down frozen in a case, and so I had a real problem getting through U.S. Customs because they wanted to open and thaw these out. And they were concerned that they were containing deadly pathogens from Canada or something.

**NEIL deGRASSE TYSON:** Zolensky immediately recognized it as a carbonaceous chondrite, a carbon-rich meteorite formed from the very same stardust that built the Earth.

**MIKE ZOLENSKY:** The last time we had a major fall of a carbonaceous chondrite was 30 years ago, so that means it's about one time in a career you have this happening to you. And to have it happen to me in my career, while I was still young enough to take advantage of it, was a very exciting thing for me.

**NEIL deGRASSE TYSON:** A team of scientists scrambled to collect as much of the meteorite as possible. This was the opportunity of a lifetime. More than 400 fragments, strewn across the frozen lake, could each contain clues to the very beginning of Earth.

The scientists hoped that inside, the fragments would be uncontaminated in the same pristine condition as when they formed, four and a half billion years ago.

If it lives up to expectations, this meteorite could reveal the exact chemistry of the dust grains that built the newborn Earth.

**DAVE STEVENSON:** Meteorites are a window on the past, and they tell us something about the conditions in which the solid planets formed.

**MIKE ZOLENSKY:** This particular meteorite is really special. In the first place, it has the highest carbon content of any meteorite and the highest amount of these preserved interstellar stardust grains of any meteorite, and it has a very high water content as well.

**NEIL deGRASSE TYSON:** In addition, about 90 other elements have been identified. And already they are providing a chemical fingerprint of early Earth.

And within this meteorite are radioactive elements that decay at a precisely known rate, allowing scientists to calculate the meteorite's age. And since most meteorites formed at the same time as the planets, and from the same material, the age of the meteorite gives you the age of Earth and its neighbors.

**MIKE ZOLENSKY:** If you date meteorites, what you find is that almost all meteorites have the same age, about four and a half to five billion years old. They're all the same. It's pretty monotonous: within a couple of tens of millions of years to hundreds of millions of years, they are all exactly the same age. And so what we do is take the oldest of the ages and use that as the initial age of the solar system.

**NEIL deGRASSE TYSON:** That narrow range of ages indicates that all meteorites and planets coalesced extremely quickly in the early days of the solar system.

But Earth had barely taken shape before the first of several major disasters struck the young planet. Earth's gravity was pulling in huge quantities of debris from space, a continual bombardment that generated enormous amounts of heat on the surface. At the same time, radioactive elements trapped deep within the Earth were decaying, producing even more heat, roasting the planet from the inside. The combined effect was catastrophic.

By eight minutes after midnight on our 24-hour clock, the planet had become a raging furnace. And when the temperature reached thousands of degrees, dense metals such as iron and nickel in Earth's rocky surface melted.

**DAVE STEVENSON:** The outer part of the Earth would have been completely molten. We call that a magma ocean. It's a liquid rock ocean, hundreds of kilometers thick.

**MIKE ZOLENSKY:** We think the Earth, at some point, was a big droplet of melt just floating in space. When you have a totally molten object like this, the heaviest elements—and that includes things like iron—would sink to the center of this droplet, and the lightest elements—things rich in carbon and water for instance, or light elements—would float to the top and float there like algae on a lake.

**NEIL deGRASSE TYSON:** The global migration of the elements, known as the Iron Catastrophe, would have a profound effect on the future of our planet. The sinking iron accumulated at Earth's center where it created a molten core twice the size of the moon. The liquid iron is constantly swirling and flowing. And even today this motion generates electric currents which turn our planet into a giant magnet with north and south poles. The core is still in constant motion. And we can see evidence of Earth's liquid iron core on the cold, snowy wastes of arctic Canada.

**LARRY NEWITT** (Geological Survey of Canada)**:** The magnetic field is constantly fluctuating, on a minute to minute or even second to second basis. And one result of this is the fact that it causes the magnetic pole to actually move randomly over the course of a day.

**NEIL deGRASSE TYSON:** Every few years, geologist Larry Newitt sets out in search of the precise location of the magnetic north pole or north on a compass. Newitt spends days at a time on the ice in temperatures as low as minus 50 degrees Fahrenheit.

The geographic North Pole is in a fixed position, but the magnetic pole is always on the move. Over the last century, its position has changed dramatically.

To identify the pole's current position, Newitt measures the strength and direction of the magnetic field at about eight different sites then closes in on it.

**LARRY NEWITT:** Since we don't know where the pole is, we can't just go there and take a reading. So we surround it, and then I determine its location by a process of, well, what amounts to triangulation.

**NEIL deGRASSE TYSON:** At the time of the most recent survey, the pole had moved 125 miles off the Canadian coast. And Newitt and his colleagues have discovered something curious: its movement is picking up speed.

**LARRY NEWITT:** Over much of the past hundred years it's been around ten kilometers per year. But since about 1970, it started to accelerate, and now it's moving along at about 40 kilometers per year. If this keeps up, it'll reach Siberia in about another 40 or 50 years, but of course that's a rather dangerous extrapolation, we don't really know where it's going to go.

**NEIL deGRASSE TYSON:** Without Earth's liquid iron core, life would be in trouble. This swirling ball of molten iron is what generates the magnetic field around our planet. And we need that magnetic field because every day a deadly stream of electrically charged particles bombards the Earth.

Ejected by the sun in monstrous solar flares, these particles hurtle through space at about a million miles an hour, forming what is known as the solar wind. Some think that if the solar wind ever reached our planet, it would strip away the atmosphere. But Earth's magnetic field creates a protective shield that deflects these deadly particles.

And you don't have to travel far to see the fate of a planet that lost its shield. Four billion years ago, Mars had a liquid iron core and a magnetic field just like Earth's. Mars built up a thick atmosphere and supported liquid water on its surface. The planet may even have been home to primitive forms of life. But Mars is just a fraction the size of the Earth, so it cooled more rapidly. And as it cooled, its molten iron core hardened. As a result, Mars stopped generating its magnetic shield. And, according to one theory, this left its atmosphere to be scoured away by the solar wind.

Today, the surface of Mars is a barren desert. Mars is a stark reminder of what our world could have become if its iron core had cooled, because without a magnetic shield a planet is left prey to the solar wind, and life, as we know it, could never flourish.

The time had reached 16 minutes after midnight; the Iron Catastrophe was over.

But even with the formation of Earth's core and magnetic shield, our planet remained a hostile and alien world. Volcanoes spewed clouds of noxious gases and Earth was enveloped in a suffocating atmosphere of carbon dioxide, nitrogen and steam. With no oxygen to breathe and no ozone layer to block the lethal ultraviolet radiation, this was not a hospitable place for life, at least life as we know it.

And in the midst of this hellish brew, the moon was born.

Beginning when I was about 11 years old, I used to climb the stairs to the roof of this apartment building, where my family lived, here in New York City, a building prophetically named the Skyview Apartments. And with simple binoculars, just like these, I gazed up above the streetlights, beyond the buildings and into the night sky. And nothing will ever capture the excitement I felt when I first turned my binoculars on the moon.

When I saw that the moon was packed with mountains and valleys and craters, I thought I discovered an entire new world. And then I began to wonder, where did the moon come from and how did it get there?

Well, little did I know that about the same time, the mystery of the moon's origin was also attracting the attention of a scientist named Bill Hartmann.

**BILL HARTMANN:** I'm always looking at the moon and thinking about its phases. And when I was a little kid I had a telescope. I used to be out there drawing craters on the moon and was very excited that I could even see these craters and mountains and so on. So it's always had a special interest for me.

**NEIL deGRASSE TYSON:** Hartmann has been studying the moon for the last 40 years. And when he began his career, in the late 1960s, he and many other planetary scientists hoped that NASA's Apollo missions would solve the mystery of how the moon formed.

**BILL HARTMANN:** One of the pitches to sell that program scientifically was that we were going to be able to go to the moon and find these old rocks from 4.5 billion years ago, and they were going to tell us everything about the origin of the moon.

**NEIL deGRASSE TYSON:** The Apollo astronauts collected hundreds of rocks from the moon's surface. Scientists calculated their age using radioactive dating. To their astonishment,they discovered that the moon was millions of years younger than Earth.

And those same rocks held another secret.

**BILL HARTMANN:** I think the biggest single surprise was that the materials on the moon have exactly the same chemistry as the Earth and different from any samples that we have anywhere else in the solar system. So that pretty well forced the idea that the moon has to have formed from the same basic material as the Earth.

**NEIL deGRASSE TYSON:** But even more mysterious was that the moon rocks contained very little iron, just like the rocks on Earth's surface.

In a flash of inspiration, Hartmann and a colleague came up with a controversial new theory for the formation of the moon.

**BILL HARTMANN:** We came up with this very simple idea that maybe as the Earth was forming at our distance from the sun, somewhere nearby, made out of the same material, was a second large body which got pretty big before it finally plowed into the Earth.

**NEIL deGRASSE TYSON:** They proposed that about 50 million years after Earth had formed, a huge planetesimal was still roaming the solar system. This massive rock, about the size of Mars, slammed into our planet. The energy of that impact was so great it melted both the planetesimal and Earth's outer layers; the two fused together forming a new, larger Earth.

At the same time, this enormous collision ejected into orbit vast amounts of molten rock. This debris eventually coalesced to form the moon.

When Hartmann first went public with this idea, in 1974, it was considered scientific heresy.

**BILL HARTMANN:** So here we come in saying the moon formed out of this gigantic catastrophe that blew off part of the Earth's mantle. No one wanted to hear that. No on wanted to, uh, start thinking about that kind of model. All of us were taught, as junior geology students, that all processes in geology are slow, one sand grain at a time, erosion, and so on. And people would actually come to us and say we really shouldn't consider that model until we've exhausted all other models.

**NEIL deGRASSE TYSON:** Ten years passed before anyone would take the idea seriously. And that was only after hundreds of computer simulations showed that the moon could have formed from a giant impact. Today, Hartmann's big idea is almost universally accepted.

**BILL HARTMANN:** So it's been a long, slow process. And it's been really fun to see a little idea that you had a long time ago suddenly blossom forth as a leading theory.

**NEIL deGRASSE TYSON:** It was 16 minutes past midnight, 50 million years after our planet was born, and the moon had arrived.

But the repercussions of this disaster were just beginning to be felt. The moon started out about 200,000 miles closer to Earth than it is today, and appeared many times larger in the sky. Earth was spinning much faster than today making each day less than six hours long. And with the moon so close, its gravitational pull on Earth was enormous. Earth's surface rose and fell up to 200 feet during the cycle of the moon's phases. Over time, Earth's rotation slowed down as the moon drifted away, a process that continues even today.

**BILL HARTMANN:** The idea of being able to measure the movement of the moon away from the Earth has always been a challenge. And so, when the astronauts went to the moon, one of the things they did is they carried out this big device which was a reflector, a retroreflector that would beam a laser beam back in the direction that it came.

**NEIL deGRASSE TYSON:** On Earth, astronomers installed a laser so strong it could target the reflectors. In 1969, they made their first measurement of the time it took for the laser beam to reach the moon, hit the reflector, and bounce back to Earth, a round trip of about two and a half seconds.

**BILL HARTMANN:** Doing this year after year after year we've actually been able to confirm that the moon is moving slowly away. We not only get very exact information on the orbit of the moon, but we can actually see the orbit change.

**NEIL deGRASSE TYSON:** Now about 240,000 miles from Earth, the moon is moving away at a rate of one and a half inches every year.

The collision that created the moon was also a major stroke of luck for Earth. That impact was so immense that it forced Earth's axis to tilt in relation to the sun, causing the familiar seasons. And without the stabilizing influence of the moon, Earth would wobble dramatically about its axis. Today, the planet would experience wild climate swings.

But when did a planet that looks like the Earth we know begin to take shape?

Earth's hot molten surface took at least a billion years after the moon was created to cool and form a thick skin, its crust, or so scientists believed. But no one knewfor certain because Earth is such a geologically restless place that none of the original crust survives today.

Yet startling new evidence is causing a major rethinking of when Earth's crust first formed. The clues to this mystery are embedded within these rocks in Western Australia. Here, geologists have extracted tiny crystals called zircons. About the size of sand grains, zircons are nearly as tough as diamonds. These relics of the early Earth formed when molten rock cooled into solid crust, so the age of the zircon gives you the age of the crust itself.

And it was here that geologist Simon Wilde hit pay dirt when he found one crystal so old he's convinced it was formed in the Earth's original crust.

**SIMON WILDE** (Curtin University of Technology)**:** When we look at the chemistry in detail, from the zircons in this rock, we find that it's consistent with having grown in a piece of continental crust.

**NEIL deGRASSE TYSON:** Radioactive dating shows that the oldest of the zircons Simon Wilde found in these hills is 4.4 billion years old, suggesting that Earth might have cooled and formed a crust soon after the moon was formed.

**SIMON WILDE:** We don't know, of course, whether the continental areas were extensive or whether they were just small little islands of material. But certainly what we do know is that there was continental crust at 4.4 billion years ago.

**NEIL deGRASSE TYSON:** This was just 150 million years after Earth was born, not a billion years as previously thought. But that led to another mystery: once Earth was cool enough to form solid ground, water could collect on its surface, so when did that happen?

Geologists, including Stephen Mojzsis, think the answer may lie in these same tiny zircon crystals. Zircons are extremely rare, so to find just a few crystals, Mojzsis had to pulverize and sift through hundreds of pounds of ancient rocks.

An analysis of the chemical composition of the crystals revealed that the oldest zircons contained a high concentration of a curious ingredient. It was a type of oxygen called Oxygen-18, an isotope that could only be present in large quantities if the zircon crystals had grown in water.

The news that water might have been present so early in Earth's history was a bombshell.

**STEPHEN MOJZSIS** (University of Colorado)**:** Not only was there crust present, which came as a surprise to most of us, it looks like, from some of the zircons, that that crust interacted with large volumes of liquid water.

**NEIL deGRASSE TYSON:** The idea that water settled on Earth's surface so soon is controversial, but if true, it suggests a planet much more like today's than anyone had ever imagined.

**STEPHEN MOJZSIS:** By 200 million years after the formation of the Earth you can imagine a landscape of islands and small continents, bathed by a primitive ocean.

**NEIL deGRASSE TYSON:** The time was only 10 minutes to one in the morning; the moon existed and so did a planet with not just land but water.

Liquid water is the key to life; every living thing requires it to survive. And eventually, water would cover nearly three quarters of the Earth's surface. In fact, all the world's oceans contain nearly one hundred million trillion gallons of it. It's an almost incomprehensible amount.

So, where did it all come from? How would Earth have ended up with such vast quantities of this stuff?

Well, strange as it sounds, these great oceans may have been there from the very beginning, just hidden away.

One key to the riddle was volcanoes, which, throughout Earth's infancy, pumped huge amounts of steam into the atmosphere. Then, as Earth cooled, that steam condensed into rain. Drop by drop, water collected in low-lying areas.

**DAVE STEVENSON:** There is nothing mysterious or surprising about this. The Earth does it right now. The main gas that comes out of Hawaiian volcanoes is water, steam. So, this is happening all the time.

**NEIL deGRASSE TYSON:** But some scientists argue it would take far too long to create such vast oceans by volcanic outgassing. Instead, Earth may have had some help.

The water in our oceans might have come from outer space, delivered to the surface by massive ice-bearing comets. The evidence for these ancient impacts is impossible to find today, since the original surface of our planet has long since been eroded or destroyed. But there's one place that preserves a record of impacts from that early era: our moon.

**BILL HARTMANN:** Every one of those craters was a meteorite explosion at some time.

**NEIL deGRASSE TYSON:** The moon's surface is littered with craters, some of them hundreds of miles across. In fact, the moon was ravaged by more than a million major impacts in its early years. Since Earth is much more massive, its gravitational pull would have attracted even more debris, resulting in possibly tens of millions of impacts.

**BILL HARTMANN:** We all hear about the impact 65 million years ago that wiped out the dinosaurs. And you're getting that kind of impact something like once a month on the early Earth. But this rain of debris left over from the formation of the solar system continues for several hundred million years.

**NEIL deGRASSE TYSON:** And in this cosmic debris field, comets containing huge amounts of dust and ice would have been plentiful, like dirty snowballs the size of mountains. Roughly half their mass was water.

One NASA scientist, Michael Mumma, wonders if these comets were the source of the water in Earth's oceans.

**MICHAEL MUMMA** (NASA Goddard Space Flight Center)**:** One possibility is that Earth's water was delivered by the impact of bodies from beyond the Earth. These would naturally be the comets, which are rich in water. The proof in that would be to measure the composition of the cometary water and to compare that with the composition of water in our oceans.

**NEIL deGRASSE TYSON:** But studying comets is a tricky business. In the last 20 years, just a handful have passed close enough to study in detail, including one in 1997 called Comet Hale-Bopp.

**MICHAEL MUMMA:** A comet like Hale-Bopp would deliver about 10 percent of the water needed to fill one of the Great Lakes. This is a lot of water. Of course the oceans are much larger, and so we need many more comets to fill the oceans. But we're fortunate; we had many such comets in the early solar system, so we have every reason to believe it was cometary delivery that brought water to the early Earth.

**NEIL deGRASSE TYSON:** Mumma thinks that the heat of an impact would have evaporated the ice within a comet, creating storm clouds over vast areas of the planet. These clouds produced a deluge of hot, possibly acidic rain that continued for millions of years. At first the rain would have formed lakes and rivers, and eventually water would cover almost the entire globe.

But there's a problem with this theory. Earth's oceans contain a mixture of normal water, H2O, and a much smaller amount of a more exotic kind, known as HDO, or heavy water which contains an extra neutron.

In the comets analyzed so far, the proportions of these two kinds of water don't match the composition of water in our oceans.

**MICHAEL MUMMA:** They have twice the amount of heavy water that we see in Earth's oceans so if they were the comets that delivered the Earth's oceans they wouldn't fit the bill. Basically, they don't have the right properties.

**NEIL deGRASSE TYSON:** But Mumma hasn't given up. The comets already studied come from the outer reaches of the solar system, and he thinks comets originatingcloser to the sun might be different. Formed at higher temperatures, these comets could have a lower proportion of heavy water more closely matching our oceans. And tonight, Mumma hopes to test this idea by getting a first hand look at one of these elusive comets.

**MICHAEL MUMMA:** If its chemistry is different, and if the heavy water to light water is like that on Earth, it would be the first proof positive, or the "smoking gun" evidence, that comets did in fact deliver water to the early Earth.

**NEIL deGRASSE TYSON:** But first, the team has to hunt down the comet.

**MICHAEL MUMMA:** As soon as he has acquired it, we should see an image of it on the screen. There it is alright, yes sir, right there. You can see the elongated material flowing outward from the nucleus.

Joe, that looks excellent.

**NEIL deGRASSE TYSON:** With the comet in the crosshairs of their telescope they can home in on the kind of water it's carrying.

**MICHAEL MUMMA:** People often ask, "How can you measure water in an object that is a hundred million miles away?" We do this by a method called spectroscopy. It's a little bit like taking fingerprints; the little ridges on your fingers look different for every person. And in the same way, the light that is emitted by a given molecular compound is different; it emits at different wavelengths.

**NEIL deGRASSE TYSON:** But it turns out this comet is a very dirty snowball indeed. There's so much dust on the surface that it can't reflect enough light for the team find out what kind of water is on board.

**MICHAEL MUMMA:** It did not brighten as expected. This was a bit of a disappointment. Comets are quite fickle, they're unpredictable. In some ways they are like cats, they both have tails and they both do what they want to.

**NEIL deGRASSE TYSON:** But with astronomers finding two or three comets a year from the inner part of the solar system, Mumma could soon have another chance to test his controversial ideas about the origin of Earth's oceans.

**MICHAEL MUMMA:** One of the key things that every scientist keeps in mind, is you should never fall in love with your theory. So it's an idea, it's a hypothesis, it fits all the known facts. But it has not yet been proven, and we must be willing to give it up and modify it if it is not proven. But we will learn something in doing so.

**DAVE STEVENSON:** It's still possible that comets played a role. In fact, it's hard to imagine that they played no role. But it seems more likely and more physically sensible to look closer to home for the source of the water.

**NEIL deGRASSE TYSON:** Besieged by volcanoes and battered by impacts, Earth endured its most extreme punishment in its early years. It was beaten, bombarded, mangled, and melted all in just the first hour of our 24-hour history of the planet.

The young Earth was still very different from the planet we know today. It was a hostile and forbidding place, with an atmosphere full of poisonous gases. Yet, somehow, these harsh conditions set the scene for a crucial phase of Earth's development: the origin of life.

**STEPHEN MOJZSIS:** Very little is left behind from the Earth's earliest time period, but what is left behind has revealed to us a planet much more complicated than we ever thought, with different rock types, liquid water present and the kind of planet that we might expect life to emerge on.

Do we know if life was around 4.3 billion years ago? Well, who can say? We can say, however, that the template, the ground underfoot was there.

Could life have been present? Why not?

**NEIL deGRASSE TYSON:** But first, the once hellish Earth would have to undergo another change as radical as any that had come before. Catastrophe and cataclysm transformed the Earth, now our planet would be ready for the greatest drama of all time: the rise of life.