**Nova – Origins Part 4 – Back to the Beginning**

**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: how did all begin?

Right now, we're all eavesdropping on the birth pangs of the cosmos. The accidental discovery of the Big Bang leaves scientists with nagging questions about the universe.

**DAVID SPERGEL** (Princeton University)**:**...how big it is, how old it is, what's it made of, and what were the processes that made galaxies, that made us.

**NEIL deGRASSE TYSON:** So a furious race is on to solve the ultimate mystery.

**ANTHONY READHEAD** (California Institute of Technology)**:** The spirit of competition is one of the things, of course, that drives scientists.

Keep our fingers crossed. Let's hope and pray.

**NEIL deGRASSE TYSON:** And as our new vision of the universe emerges, strange ideas reveal themselves. It seems that we are stardust.

**STAN WOOSLEY** (University of California, Santa Cruz)**:** Stars are the ultimate alchemist.

**ROBERT KIRSHNER** (Harvard University)**:** You get carbon and nitrogen and oxygen made in stars.

**NEIL deGRASSE TYSON:** Those elements are the building blocks of life. That means...

**SANDRA FABER** (University of California, Santa Cruz)**:** ...our universe is hospitable to life. There are billions and billions of galaxies everywhere, making stars that are right for solar systems. The habitat for life is everywhere.

**NEIL deGRASSE TYSON:** A scientific detective story takes you back to the beginning on tonight's episode of *Origins*, on NOVA, right now.

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**NEIL deGRASSE TYSON:** The grand dance of our universe is a breathtaking vision. Stars parade across the sky in lockstep, night after night. The galaxies spin, vast cities of stars bound together to create stunningly elegant forms.

Until recently—our own lifetimes—we couldn't hope to answer the most basic questions about the cosmos. Has the universe always been here? Did it have a beginning?

I first encountered those grand mysteries as a nine year old kid. We came on a field trip here, to the Hayden Planetarium. Looked a lot different then, but that first trip changed my life. More or less on the spot, I decided to become an astrophysicist, even though I could barely pronounce the word.

And now, all grown up, I've returned to the Hayden as its director. And over that time, our understanding of the universe has been transformed again and again.

Astronomers believed that our cosmos had always existed, eternal and unchanging. In its last version, the idea even had a name, the steady state theory. But that was really just an assumption, and like so much received wisdom in science, it would only ultimately be proved wrong by accident.

The breakthrough came in the early days of the space race. In 1962, astronauts were heroes, and for a while, America went space crazy.

Space even made the charts when the song "Telstar," named for the first satellite to transmit transatlantic phone calls, rocketed up to number one.

The real Telstar satellite was built by AT&T, the phone company. Telstar was the first link in a truly global communications network. But there were a few bugs in the system, especially an annoying hiss in those early calls relayed by satellite. AT&T engineers wondered if the problem might lie in the way Telstar communicated with earth, using a form of energy called microwaves.

Telephones are actually very simple machines. They all work in pretty much the same way.

Hello. No, I'm kind of busy now. Can, can you call back later? Hang...hang...hang on a sec.

What they do is they convert sound waves into electrical impulses then take those same electrical impulses and convert them back into sound waves at the other end of the line.

I've got to go, I'm working here. Alright? Let's talk later, but thanks for calling. Bye.

Satellites take this one step further, they convert the electrical impulses into forms of light we call microwaves and radio waves.

To get a handle on that, let me introduce you to my cosmic tuner. It's sensitive to all forms of light there are. Most familiar is visible light with its rainbow of colors. What makes one color different from the next is simply its wavelength. And I can use this knob to tune one wavelength to the next.

Let's start with violet. It has the shortest of all wavelengths. Moving to longer and longer wavelengths, we pass from one color to the next, right on up to orange and then red. There ends visible light.

But light continues beyond that, just increase the wavelength. What do you get? Infrared. Can't see infrared, but we feel it, we sense it as heat. Beyond infrared, we find microwaves and then, the longest of them all, radio waves. Both radio waves and microwaves we use to communicate through earth's atmosphere and through space itself.

As it happens, almost everything in the night sky emits energy in the form of these same micro and radio waves. Here is the Milky Way photographed in visible light, and here is its image at radio wavelengths.

After World War II, this new way of looking at the sky launched the field of radio astronomy. And now it would lead to a phenomenal discovery.

Robert Wilson and Arno Penzias were both experts in the new fields of radio and microwave astronomy, and in 1964, AT&T's Bell Labs asked them to help figure out what might be causing the annoying hiss in satellite communications.

To do so, they began their detective work with this giant antenna that could receive signals from Telstar. To test the instrument they pointed it at an empty patch of sky. Aiming at nothing, they expected to find nothing. Instead, to their surprise, they picked up a faint microwave signal, apparently coming from empty space.

Sure that couldn't be right, they looked for any possible source of stray microwaves. They even climbed into the horn to clean up after a pair of unwelcome guests.

**ROBERT WILSON** (Harvard-Smithsonian Center for Astrophysics)**:** When was the last time we were up here?

**ARNO PENZIAS** (New Enterprise Associates)**:** Thirty-eight years ago.

**ROBERT WILSON:** '65 or'64. There had been a pair of pigeons living there and deposited pigeon droppings inside. And that was clearly a possible microwave-loss material. As a graduate student I did worse things. You probably did too.

**ARNO PENZIAS:** Oh, yeah. Yeah, you just do what you have to do. You do what you have to do every day.

**NEIL deGRASSE TYSON:** Nothing worked. The hiss was still there, and, mysteriously, it seemed to be coming from wherever they looked in the sky.

**ROBERT WILSON:** We could, by then, rule out that it came from the horn itself. We were unaware of anything in the sky that should do it, and we thought the horn should not be picking anything up from the ground. It was just was sort of surreal. It didn't fit our idea of physics.

**NEIL deGRASSE TYSON:** But the microwave hiss, so perplexing to Penzias and Wilson, did fit a radical idea being explored by a group of physicists just 40 miles down the road in Princeton, New Jersey.

The Princeton team was trying to prove that our entire universe had actually been born in a in a tremendous burst of energy, billions of years ago. Team leader Bob Dicke believed that some of that energy should still be detectable as a faint hiss of microwaves in space. To test that hunch, Dicke asked a young post-doc named David Wilkinson to set up this miniature antenna in his spare time.

**DAVID WILKINSON** (Princeton University (d. 2002)**:** We weren't in any particular hurry because Bob Dicke's idea was so original. We weren't too worried about somebody else getting there before we did. We went down to Arch Street in Philadelphia and dug around in the World War II surplus shops to find things that were cheap.

**NEIL deGRASSE TYSON:** But before their instrument was up and running, word reached Penzias and Wilson, who gave Dicke a call.

**DAVID WILKINSON:** He hung up the phone, and I'll never forget exactly what he said. These are his exact words. He said, "Well, boys, we've been scooped."

**NEIL deGRASSE TYSON:** Scooped indeed to the greatest discovery in cosmology, the Big Bang. In the Big Bang our entire universe, all the matter, all the energy that would ever exist, burst into being in a single instant. A flash of light filled the cosmos. And as the universe expanded, that light stretched with it to longer and longer wavelengths, through the visible range, to the infrared. Until, now, that flash of light remains as a faint glow of microwaves filling the entire sky, the glow that Robert Wilson and Arno Penzias detected with this antenna.

**DAVID SPERGEL:** Penzias and Wilson's discovery of the microwave background is what made cosmology a science.

**ANTHONY READHEAD:** It suddenly made you realize that history was being made. Here you were, and suddenly the universe, as understood by man, was different to what it had been like yesterday.

**DAVID SPERGEL:** All of a sudden you had data and you really tested a theory. You had a theory that said the universe started with this hot Big Bang, and what Penzias and Wilson saw was this leftover heat from the Big Bang.

**NEIL deGRASSE TYSON:** Their serendipitous discovery was so important it won Penzias and Wilson the Nobel Prize.

**ARNO PENZIAS:** The actual ceremony in Stockholm was kind of a blur. I never have quite gotten over the feeling of not being a grownup, that other people are smarter, older, and so forth, and that...I don't think that ever leaves.

**ROBERT WILSON:** When the Nobel Prize was announced I think probably one of the first things that I thought about was, "Do I really deserve this?" And "Should my name be on the same list with as Einstein?" Which just seemed completely wrong. Over the years I guess I've come to understand that the Nobel Prize is given for discovering something, not for being the smartest person around. So while there are much smarter people around, we did something significant and I feel comfortable with it now.

**NEIL deGRASSE TYSON:** Now that we know what to look for, it's not all that hard to detect the Big Bang.

Take an ordinary TV set, the old fashioned kind, before cable. All you need to do is change the channel until you come between two stations. Most of that static comes from stray local radio waves hitting these rabbit ear antennas, but amazingly, about one percent of the snow and noise comes from microwaves produced in the Big Bang itself.

Right now, we're all eavesdropping on the birth pangs of the cosmos.

The discovery of the Big Bang was revolutionary, but from the start there was a nagging problem. According to the theory, the Big Bang made everything, all the energy and all the matter in the cosmos. In the modern universe, matter is concentrated into lumps, vast webs of galaxies with hardly anything in the voids between. But the microwave glow Penzias and Wilson had seen showed no structure at all. And that's the problem, a big one.

The microwave glow of the Big Bang seemed perfectly smooth, the same everywhere on the sky. But if that were true, then the universe that evolved from that Big Bang should be just as smooth, like this formless fog. So then how did our universe come to be filled with clumps of stuff, galaxies, suns, and planets?

Maybe the early universe was not as featureless as it seemed. Maybe it contained some tiny seeds, little dense spots that gravity could shape into the cosmic structures we see today. Cosmologists figured that those slightly denser regions in the early universe would show up as bright spots in the microwave glow of the Big Bang, so they set out to find them.

They would look, and look, and look, for thirty years, and they would find nothing.

**ANTHONY READHEAD:** The astonishing thing is that the harder we looked, the more mysterious the universe became, because all we saw was a blank sheet of paper, nothing was written on it at all. And we went down to a part in a thousand, it was a blank sheet. We went down to a part in ten thousand, it was a blank sheet. It was at this point that my colleagues at Cal Tech started telling me that I was proving we weren't here.

**NEIL deGRASSE TYSON:** No lumps, no galaxies, no us; that's what every observation of the Big Bang's microwave glow seemed to show. Either we just didn't understand the Big Bang, or secrets remained hidden within the microwave glow of the infant universe. Finally astronomers wanted to settle the question once and for all.

Flying above Earth's atmosphere, this satellite, called COBE, was designed to find the telltale bright spots within the apparently uniform microwave glow, if they were there.

**CHARLES L. BENNETT** (NASA Goddard Space Flight Center)**:** As a member of the COBE team, we wondered all the time, would we detect this non-uniformity or wouldn't we? We thought that, theoretically, it should be there. For 30 years people had thought that, too, and went out and made measurements and didn't find it. So we didn't know for a fact whether we'd see it or not. It was a, it was a crap shoot.

**NEIL deGRASSE TYSON:** NASA launched COBE in 1989. It would spend two years in near-Earth orbit, observing the microwave hiss, the energy of the Big Bang, at hundreds of thousands of points in the sky. When it accumulated enough data, COBE revealed this: a blotchy pattern that doesn't look very dramatic to most people. But to astronomers it was a revelation.

**CHARLES BENNETT:** Well, we didn't, as some people said, see the face of God in the COBE picture. What we did see was a spectacular face of the early universe, which was just what we wanted to see.

**NEIL deGRASSE TYSON:** This was what they had been waiting for. The blue colors reveal places where there's slightly more matter in the early universe. From these concentrations of matter gravity will carve out galaxies and stars, suns and planets, and eventually, our home. In one brilliant stroke, COBE confirmed that the universe, as we know it, evolved out of the cataclysm of the Big Bang.

But at the same time, it left much of the story untold. You see, COBE had a limitation, a kind of fuzzy vision. A COBE picture of me would look something like this.

You can tell that you're looking at a face but not whether I'm twenty years old or sixty, or anything in between. It was much the same with COBE. Its picture was too fuzzy to reveal much of what was really happening in the early universe.

**LYMAN PAGE** (Princeton University)**:** It was as though we had seen the Earth, and we knew there were oceans and we knew there were continents, but we didn't know how continents formed, we didn't know that there were mountain ranges, we didn't know there were grand canyons, that there were polar caps.

**DAVID SPERGEL:** The microwave background has encoded in it a tremendous amount of information about the properties of the universe: how old it is, what it's made of, how many atoms are in the universe, how fast it's expanding. And with the COBE data, we couldn't answer any of those questions.

**NEIL deGRASSE TYSON:** In other words, COBE was teasing us. Its fuzzy picture concealed clues to fundamental mysteries, everything from the age of the universe to the events that unfolded in the first moments of the Big Bang itself. To uncover these clues we needed a much sharper image of the Big Bang's microwave glow.

That's why NASA built this: COBE's successor, a satellite called WMAP. The "W" stands for the late David Wilkinson, one of the Princeton group that pioneered the search for the remnants of the Big Bang. Its twenty horns were designed to collect microwaves from the infant cosmos with unprecedented precision. And its state-of-the-art electronics could then assemble an ultra sharp image from the faint signal that the horns collected.

The WMAP team started work on its satellite in 1996, and from the beginning, as mission leader Chuck Bennett recalls...

**CHARLES BENNETT:** The enemy was Murphy. Murphy's Law happens. Murphy's Law says that if anything can go wrong it will go wrong. And believe me it's true.

**CO-WORKER**: "Hey, Chuck, did you hear about the problem we're having with the grounding?"

**NEIL deGRASSE TYSON:** This was Chuck Bennett's life, coping with the inevitable crises that almost daily threatened the WMAP mission. It would take at least seven years to get results, a schedule that would give NASA's rivals a window of opportunity.

Ambitious observers like Tony Readhead set out to see if they could beat NASA to major discoveries of their own.

**ANTHONY READHEAD:** I think it's, it's very important to recognize, of course, that the spirit of competition is one of the things, of course, that drives scientists just like everybody else. And then the idea that the, the huge agency of NASA was going to go out there, and they were really going to do the job properly—they were going to provide people with a three-course meal—made many of us feel that we would really like to go out there and perhaps get a few appetizers in, which might answer the most fundamental and interesting questions first.

**NEIL deGRASSE TYSON:** Beginning work in 1999, Tony knows he cannot compete with the space agency's formidable resources, so he sets his sights on one piece of the puzzle. He decides to make remarkably detailed observations of a few, tiny patches of the sky, hoping to capture the sharpest images yet of the Big Bang's microwave glow.

If he succeeds, he will be the first to go beyond COBE's fuzzy picture and identify the tiny seeds of matter that gave rise to the universe we live in. To make this discovery, Tony and his team build an instrument called the Cosmic Background Imager. What looks like an array of giant tin cans is 13 sensitive microwave antennas linked together. This kind of array is the perfect design to produce the exceptionally detailed images Tony seeks.

But there's a price to pay for such precision.

**ANTHONY READHEAD:** In order to do observations of the microwave background, you have to get above most of the water vapor in the atmosphere, so you either have to go to space, of course, but that's very expensive, or you have to go to the South Pole, or come to a place like this, which is up at a very high altitude in the Andes. In other words, you have to get halfway to space if you're going to want to compete with the guys who are out in space.

**NEIL deGRASSE TYSON:** But to work up this high, almost 17,000 feet, the team must use oxygen tanks, and they are always vulnerable to the bitter cold, the wind, and the weather.

Just ahead of what was supposed to be a routine observing run, a ferocious three-day blizzard knocks out a key telescope drive motor.

**ANTHONY READHEAD:** When you tried to drive it, it just didn't move.

**NEIL deGRASSE TYSON:** The instrument can't track the sky with the precision Tony needs. If the telescope can't move, Tony can't observe.

It's a setback, but a minor one, Tony devoutly hopes.

**ANTHONY READHEAD:** Of course this is extremely annoying, because we go to extraordinary lengths to try to ensure that we don't lose any observing time. We really cannot afford to be down for a few days, and if we are down for six weeks it is a very big problem indeed for us.

**NEIL deGRASSE TYSON:** Isolated on their mountaintop, Tony, Ricardo and Eduardo now struggle, without backup, to fix their broken motor. But in a way they're fortunate, the WMAP team will have no such luxury, to fix anything that breaks once their satellite reaches space.

**CHARLES BENNETT:** Once you launch the thing, you don't get to turn that screwdriver one last time, or make an adjustment, or replace the part that broke. It's got to be right. One of the key things to make sure that you've got it right is to test it and test it and test it again.

**NEIL deGRASSE TYSON:** WMAP's final hurdle comes in this giant vacuum chamber, built to replicate the cold and the airlessness of space itself. The satellite cycles through here again and again to ensure that no mission-threatening flaw remains.

**ANTHONY READHEAD:** Ricardo, can you check that there are no ladders around the telescope?

**NEIL deGRASSE TYSON:** Tony's struggle is paying off. After three days, the team believes they have resuscitated their broken motor.

**ANTHONY READHEAD:** Is it done? Okay, please switch on the drive key.

**MAN:**It's on.

**ANTHONY READHEAD:** I'm going to try a flare in Azimuth.

**MAN:** Keep our fingers crossed.

**ANTHONY READHEAD:** Keep our fingers crossed. Let's hope and pray. Okay.

**MAN:** That's fantastic.

**ANTHONY READHEAD:** This is really great. We've come back from a major crisis here over the last three days. These guys have done a great job.

**NEIL deGRASSE TYSON:** With his telescope operational again, Tony can finally get back to the painstaking task of collecting cosmic microwaves. It's slow work. It takes a minimum of fifty nights to create a usable image of a tiny patch of the sky.

Finally, five years into the project, the WMAP satellite passes its last test. There is nothing left to do: either the instrument will work in space or it won't. It's time to fly.

Chuck, of course, continues to fret.

**CHARLES BENNETT:** We finally reached the point in the project when it was time to package up the satellite and send it down to the Kennedy Space Center. Of course, the problems didn't stop there. We had to put some things back together again that we had to take apart, and we found little problems along the way.

**LAUNCH ACTUALITY:** Green board. Five, four, three, two, one, main engine start, and liftoff of the Delta 2 rocket with the MAP spacecraft.

**CHARLES BENNETT:** In the end we launched within the first seconds of the first day of our launch window. It was a picture perfect launch. Everything went very, very smoothly.

**LAUNCH ACTUALITY:** Initially a smooth flight being reported, solid motors are now at maximum thrust.

**LYMAN PAGE:** When it was being launched, your heart's in your mouth. You've poured your life into this thing. You know you eat it, you drink it, you breathe it. You wake up at night thinking about something that you might have not done right. And it launched, and it got off the ground. And that was incredible.

**NEIL deGRASSE TYSON:** After its launch, WMAP still has a three-month journey to reach its final destination, a million miles from earth: a special location, the sun and Earth's second Langrangian point, or L2. At L2, the combined gravitational pull of the sun and Earth will hold the satellite in a fixed orbit. In that position, WMAP's shielding can block out the contaminating microwave radiation from the sun and the earth.

But getting there takes one of the most complex trajectories ever planned for a space science mission.

**CHARLES BENNETT:** One of the headquarters officials was visiting me one day, and he asked me, "What part are you most worried about?" And I said, "Getting from here to there."

**NEIL deGRASSE TYSON:** WMAP's guidance systems perform flawlessly. But once it reaches L2, the satellite still needs a full year to produce its first results.

That year gives Tony just the time he needs. Before NASA's WMAP can report back, Tony manages to gather enough data to yield a major discovery.

**ANTHONY READHEAD:** One tends to forget, because of all the, the difficulties that one has to go through, just the true wonder of what we are seeing.

**NEIL deGRASSE TYSON:** What we are seeing are fine details, more than 100 times smaller than those COBE saw, the first direct observational link between the early universe and the one we live in.

**ANTHONY READHEAD:** These brighter spots, hotter in temperature, are showing where there is more stuff. And that's extremely exciting because it's actually showing where all the structure in the universe that we see around us today came from.

**NEIL deGRASSE TYSON:** Over billions of years, gravity will transform this slightly denser clump of stuff into this: a cluster of galaxies, home to trillions of stars like our own sun.

**ANTHONY READHEAD:** Had there not been seeds like this in the microwave background showing that there was more stuff, we wouldn't be here today talking about it.

This is a wonderful time in science. This is actually the best time of science, because we have the satisfaction of—through these observations and these discoveries—having confirmed certain predictions. We are actually on the brink of a revolution of unimaginable proportions.

**NEIL deGRASSE TYSON:** In February 2003, that revolution takes off. In just over a year, WMAP has sampled more than two million points in the sky. Finally, almost four decades after the faint glow of the Big Bang was first detected, the satellite delivers a beautifully detailed picture of the peaks and valleys that mark where the matter lies in our newborn universe.

So, David, this is it, huh?

**DAVID SPERGEL:** This is the map. This is what the universe looked like 380,000 years after the Big Bang.

**NEIL deGRASSE TYSON:** Were you the first one to see this when it came from the telescope?

**DAVID SPERGEL:** I think I was the first one to see this particular version of the map.

**NEIL deGRASSE TYSON:** What did it feel like?

**DAVID SPERGEL:** Oh, it was so cool. I mean, you know, to know that you are one of the few people that get to see this first was just awesome.

**NEIL deGRASSE TYSON:** In this version of the WMAP picture, the peaks are hot spots that show where the super clusters of galaxies will form; the valleys will become empty space. Most important, this pattern is so detailed that cosmologists can now piece together almost the entire story of what happened during the birth of the universe to create the structures we see today.

The Big Bang itself remains shrouded in mystery, although WMAP tells us that the universe's birthday took place 13.7 billion years ago. Using WMAP data, we can reach back almost to that beginning, at a time when the universe was tiny, much smaller than this pearl.

We're not sure what came next, but our best current idea is that an event we call inflation triggered a hyper-fast expansion, enlarging the universe a trillion, trillion, trillion fold. But just as suddenly as it began, inflation stops, leaving behind a dense, hot, violent universe. All of space is filled with a zoo of exotic particles, the precursors of ordinary matter. And all the light within the cosmos is trapped in an endless pinball game, bouncing off these particles.

But as the universe continues to expand it cools until, at last, 380,000 years after the Big Bang, temperatures fall to the point at which familiar, stable atoms can form. In that instant, the primordial fog clears, and the light from the Big Bang flashes free, forming the image that WMAP has captured: a true baby picture of the cosmos.

**DAVID SPERGEL:** The really remarkable thing that MAP found was that the universe was incredibly simple. I think we're now close to the right story for how the universe evolved from a second or so after the Big Bang 'til today.

**NEIL deGRASSE TYSON:** But not so fast. There are no signs of life in this picture. The WMAP universe contains only the simplest atoms: mostly hydrogen, just a single proton with one electron, along with a little bit of helium. Living chemistry requires more complex building blocks: carbon, oxygen, iron and the rest. But if they didn't exist in the early universe, where did they come from?

Recent supercomputing simulations show the infant universe filled with vast, billowing clouds of hydrogen. Almost immediately, the clouds begin to condense, pulled together by their own gravity. As hydrogen piles on, the central region grows more and more dense, until something brand new lights up the universe: a star.

These first stars are hydrogen giants, 100 times or more larger than our own sun. Such large massive stars are short-lived—two or three million years at the most—and they go out with a bang in explosions so big they've been dubbed "hypernovae."

And it's with these cataclysms that the universe begins to accumulate the building blocks of life. All the atoms in the universe heavier than hydrogen and helium are forged by stars.

**ROBERT KIRSHNER:** Stars are really interesting. They, they don't just sit there. Because they last so much longer than we do, we think they're, they're permanent.

**STAN WOOSLEY:** Stars are the ultimate alchemists. They, they turn light elements into heavier ones. They get the energy they need to glow that way. The star begins its life made out of hydrogen and helium, mostly—about 70 percent hydrogen, 28 percent helium, in the case of the sun.

**NEIL deGRASSE TYSON:** In a star's core, the temperature and pressure are so high that hydrogen atoms fuse together to make helium. Hydrogen fusion releases prodigious amounts of energy, the heat and light of the star.

**ROBERT KIRSHNER:** That's the story for 90 percent of the life of a star, fusing hydrogen to make helium.

**NEIL deGRASSE TYSON:** Eventually, though, the star runs out of hydrogen and begins to fuse its stocks of helium, making yet heavier elements.

**STAN WOOSLEY:** And so the way it works, and it always works this way, is that it contracts and it gets hotter. And if it can find something new to burn, whether it's the kitchen sink or coal or whatever, it'll burn it.

**ROBERT KIRSHNER:** Helium is taken three at a time to make carbon.

**STAN WOOSLEY:** You can add one more helium to that carbon and make element number 8, oxygen.

**ROBERT KIRSHNER:** That's a tremendous step forward. You get carbon and nitrogen and oxygen made in stars.

**STAN WOOSLEY:** Now, this is great, because on the board, we already have the principal elements of life.

**ROBERT KIRSHNER:** Organic chemistry is the chemistry of carbon.

**NEIL deGRASSE TYSON:** Carbon fuses next, and still heavier elements begin to form.

**STAN WOOSLEY:** Sulfur, argon, chlorine.

**ROBERT KIRSHNER:** Potassium, calcium, scandium—the pace of this gets faster and faster.

**STAN WOOSLEY:** Back in the middle, silicon is starting to burn at three and a half billion degrees, a stupendous temperature.

**ROBERT KIRSHNER:** It makes titanium, vanadium, chromium...

**STAN WOOSLEY:** ...manganese, cobalt, nickel, and iron.

**ROBERT KIRSHNER:** Iron is really the end of the road. It's, it's sort of the nuclear turnip out of which you just cannot squeeze anymore.

**STAN WOOSLEY:** It's the end of the game. A star that has relied on fusion has come to the point where it has nothing more to spend.

**ROBERT KIRSHNER:** The star is suddenly caught in a disaster. There's radiation going out from the outside, but deep in the inside there's no more fuel.

**NEIL deGRASSE TYSON:** Iron can't fuel the stellar furnace. And so when a star builds up too much iron it dies.

**ROBERT KIRSHNER:** The core collapses, it bounces.

**STAN WOOSLEY:** And it begins to move out, first slowly, and then faster and faster.

**ROBERT KIRSHNER:** And that sends a very sharp wave back out through the star.

**STAN WOOSLEY:**And now, what was falling down is going out. The whole thing is blowing up, and you've made a supernova.

**ROBERT KIRSHNER:** A supernova explosion can be as bright as four billion stars like the sun.

**STAN WOOSLEY:** A stupendous explosion.

**NEIL deGRASSE TYSON:** Such outrageous energies overcome the iron barrier, cooking iron atoms into all the rest of the elements on the periodic table.

**STAN WOOSLEY:** So starting right down here you can go, copper...

**ROBERT KIRSHNER:** ...zinc...

**STAN WOOSLEY:** ...gallium...

**ROBERT KIRSHNER:** ...germanium...

**STAN WOOSLEY:** ...arsenic...

**ROBERT KIRSHNER:** ...zirconium...

**STAN WOOSLEY:** ... Niobium, Molybdenum, Technetium...

**ROBERT KIRSHNER:** ...strontium...

**STAN WOOSLEY:** ...rhodium...

**ROBERT KIRSHNER:** Done! That's enough elements.

**NEIL deGRASSE TYSON:** We are all stardust: the carbon in our bodies, the iron in our blood, the calcium in our bones, every last atom was formed in a star. But it's not that simple.

No one star can produce more than just a dusting of heavy elements, so to create an environment friendly to life, the universe had to find a way to concentrate the good stuff, which it did in a process that is remarkably like the way chef Michael Romano cooks up a bowl of soup.

**MICHAEL ROMANO** (Union Square Cafe)**:** As you know, a cornerstone of great cooking is a rich soup. And all soup starts with water, so let's add some water in the pot.

**NEIL deGRASSE TYSON:** In this culinary cosmos, these ingredients stand in for the first stars, each flavoring the surrounding broth just a little bit.

**MICHAEL ROMANO:** And then we need heat, which we have.

**NEIL deGRASSE TYSON:** There's no shortage of heat in the cosmos, it turns out.

**MICHAEL ROMANO:** That's a good thing.

**NEIL deGRASSE TYSON:** In the broth left behind by the first stars, new stars form. That's this second round of ingredients. And as they simmer, the interstellar soup gets stronger and stronger.

**MICHAEL ROMANO:** Look at how rich that's become.

**NEIL deGRASSE TYSON:** I, I stillcan't wait.

**MICHAEL ROMANO:** Yeah. You remember that water we started with? And look what it's turned into. It's actually thickened, and a lot of flavor in there, so I think at this point it has enough flavor to support adding the star of the show, which is our shellfish and fish.

**NEIL deGRASSE TYSON:** Finally this cosmic soup is nearly ready, to the point where, after bubbling for billions of years, it can support the kind of life that would emerge on earth.

**MICHAEL ROMANO:** And there you go, Neil. That's for you.

**NEIL deGRASSE TYSON:** Thank you, Michael.

**MICHAEL ROMANO:** Enjoy it.

**NEIL deGRASSE TYSON:** Thank you.

What Michael just did is entirely analogous to what happens in the real universe, where each generation of stars enriches the broth out of which the next generation forms until, at last, the cosmic soup is rich enough for life.

We know this occurs, because we can see it happening next door, right in our own Milky Way galaxy, in perhaps the most famous astronomical image ever made: the Hubble Space Telescope portrait of the Eagle Nebula.

**JEFF HESTER** (Arizona State University)**:** It does feel like this image is everywhere, because this image is everywhere. It's not everybody who gets to see something that they've done show up on a postage stamp, or happen to see something that you've done on a tee shirt with somebody just walking across campus.

My wife will see this picture in some context and she'll poke me and say "Now, explain to me again why we don't get any royalties off that picture."

**NEIL deGRASSE TYSON:** That picture of the Eagle Nebula has been dubbed "The Pillars of Creation." It's become a modern icon. When the Hubble first transmitted it back to earth, scientists themselves were stunned at what they saw.

**JEFF HESTER:** We were not prepared for what we saw when we finally got the images of the Eagle Nebula put together. We weren't prepared for the beauty of what we had assembled. We weren't really prepared for the science of what emerged from it. Every now and then you get lucky.

**NEIL deGRASSE TYSON:** What the image revealed were places in our own Milky Way galaxy where new stars are actually forming.

**JEFF HESTER:** You see these little nodules sitting around here. Each one of those is large enough to swallow our solar system several times over. Embedded in at least some of those, we can see that there are young stars, stars that will become stars like our sun, around which are going to form solar systems, perhaps like our own.

Is it possible that four and a half billion years from now, some civilization on a planet orbiting that star will look up at the sky and wonder about where they came from? I'm not going to say it's likely, but it is certainly possible.

**NEIL deGRASSE TYSON:** Possible because conditions in the Eagle Nebula are close to what they are here, the one place in the universe we know that life exists, our own solar system.

The Eagle Nebula contains just about the same mix of heavy elements that our sun does: carbon, nitrogen and the rest. But the big question is whether life, or at least the conditions that could allow life to emerge, are widespread throughout the cosmos. Do we live in a universe that welcomes life? Or are the hundred billion galaxies out there mostly barren, empty desert?

That's the question that has brought Sandra Faber to the Keck Observatory in Hawaii. What are the odds for life in the cosmos as a whole?

**SANDRA FABER:** It's important to realize that, astronomically, the seeds of life on Earth were sown four and a half billion years ago when the sun and solar system formed. That's a long time back in the past, but we can ask ourselves now, "Can we see the seeds of life in other galaxies in great abundance back then? Or maybe even perhaps earlier than that?"

**NEIL deGRASSE TYSON:** Sandy uses the Keck Telescope as a kind of time machine that can look deep into the past. Its giant mirror, 36 feet across, can capture a snapshot of galaxies when they were much younger than our own.

But merely seeing such distant galaxies is not enough. Sandy wants to discover what they're made of. To find out, she uses an instrument called a spectrograph.

Sandy's spectrograph, called DEIMOS, is one of the most powerful in the world. It takes the light from up to a hundred and fifty galaxies at a time, each isolated in a single hole in a sheet of metal called a "slit mask." DEIMOS then breaks that light up into the visible spectrum, the rainbow of colors from violet to red.

Zooming in on a galactic spectrum reveals a forest of bright and dark lines, patterns that reveal the presence of particular elements.

**SANDRA FABER:** Using spectra as our tool, we can tell you what elements exist in that galaxy: oxygen, carbon, iron. And we can tell you whether the galaxy is rich in those elements. Has the broth cooked a lot? Or is it still too dilute to make planets?

**NEIL deGRASSE TYSON:** That's what Sandy will do tonight, measure the amounts of heavy elements, to determine each galaxy's readiness for life. Sandy and her team ultimately plan to examine 65,000 galaxies in all, in a massive census dubbed the "DEEP survey."

Here are the results, hot off the telescope.

**SANDRA FABER:** This is fantastic. That's oxygen and oxygen here**.**

**NEIL deGRASSE TYSON:** This bright spot marks the presence of oxygen in a galaxy five billion light years away.

**SANDRA FABER:** Just purely by coincidence, we're looking at galaxies, their light left just when our sun was forming in our own galaxy, right? And so this one here...

**NEIL deGRASSE TYSON:** Sandy uses the sun's level of oxygen and other heavy elements as her benchmark. If a galaxy has a similar mix of elements, then, potentially, it could support the same living chemistry we find here at home.

**SANDRA FABER:** So that would be, that galaxy would be a really good place to look for, for planets, because it's even more abundant in metals than our own galaxy is.

**NEIL deGRASSE TYSON:** Two years into a projected 10-year observing program, the deep survey team has already detected thousands of distant galaxies that are rich in the elements of life. And that leads to a startling conclusion.

**SANDRA FABER:** Our universe is hospitable to life, that there are billions and billions of galaxies everywhere, cooking elements, making stars that are ripe for solar systems. The habitat for life is everywhere.

**NEIL deGRASSE TYSON:** That's no proof that life itself exists anywhere else in the universe, but Sandy's work does confirm that the elements essential to life as we know it are widespread throughout the cosmos.

**SANDRA FABER:** The message of the DEEP survey, and all the other information that we're getting, is one beautiful story, a new version of Genesis, a new version of the cosmic myth, only this time it's scientifically based, from the Big Bang to now: Big Bang, formation of galaxies, formation of heavy elements in supernova, sun, Earth, life—one unbroken, great chain of being.

**JEFF HESTER:** Just in the last few years, we've reached the point that we can start with the origins of the universe, we can end with a conversation among intelligent beings about how things work, and have an awfully good understanding of every step that came in between the two.

**DAVID SPERGEL:** It was as if we were basically assembling this puzzle, and all of a sudden you look down at the puzzle and you realize you've got it. The pieces are there.

**NEIL deGRASSE TYSON:** For almost all of human history, the heavens have been beyond our reach. For our ancestors, it was a place where the gods lived, or else simply a vast, untouchable realm of lifeless beauty. But now, the study of cosmic origins tells a different story.

It tells us that the story of life, of us, extends far beyond earth. It tells us that the emergence of the conditions for our kind of life was no accident. Instead, it was a natural outcome of almost 14 billion years of cosmic evolution, a chain of connections that links the birth of the universe to us, right here, right now.