Special Guest Dr. Robert Williams
"Probing the Universe With the Hubble Space Telescope"

Speaker 1: 00:00:00 Thank you for taking the time to join us for the 2020 Trudy Sundberg Lecture. This event is brought to you by the Sno-Isle Libraries Foundation to support its work of fostering a lifetime of learning, promoting civic engagement, and exploring issues of national and international significance. The Lecture Series honors Trudy Sundberg, a truly remarkable person. She was a creative thinker and advocate for the downtrodden, an author and a high school educator, founder of the Save Our Kids crusade and the Whidbey Island Democratic club. She was three-time President of the League of Women Voters of Whidbey Island, and recipient of the Lifetime Achievement Senator Warren Magnuson Award. These annual lectures reflect her passion for learning by providing an eminent speaker each year free to the community to explore an area of interest.

Speaker 1: 00:00:50 Since the Lecture Series was launched in 2016, numerous speakers have captivated audiences on subjects ranging from women in history to plastic pollution in the farthest corners of the globe, climate activism and journalism to economic inequality. Our upcoming speaker for today's event will be added to this list of distinguished voices and topics. Now, we invite you to sit back and breathe deeply in anticipation of today's presentation about the wonders of our galaxy revealed by the Hubble Telescope. You are part of a grand community of online attendees. Although we choose to care for one another by remaining socially distant, we are a community and we are linked by our love of ideas, new information, and learning. And now, on with the show.

Speaker 1: 00:01:51 The Trudy Sundberg Lecture Series is underwritten by donations and sponsorships to the Sno-Isle Libraries Foundation from community donors like you, who believe in the power of ideas and information. We'd like to thank the following corporate and community-based organizations for their generous support. Whidbey Island Bank, helping customers build their dreams and achieve their goals in their own communities through personal

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and business banking and wealth management services. The medical office of Dr. Ann C. Dannhauer, providing internal medicine services meeting the needs of adults in Coopersville, Washington and throughout Whidbey Island for more than two and a half decades. Rue & Primavera, friends working to meet the physical therapy, occupational therapy, and hand therapy needs of clients throughout Island County. Rue & Primavera, providing therapy tailored to help you feel better.

Speaker 1: 00:02:49 And friends of the Clinton Library, a non-profit organization of readers and library lovers dedicated to promoting, learning, encouraging, and enhancing the Clinton Library and community on Whidbey Island. Their financial support in yours honors the memory of Trudy Sundberg and her lifelong commitment to discover, explore, and cultivate the exchange of information, ideas, and opinions in respectful considerate environments. Please consider how you can join them to help make future events like this possible. To learn more, visit snow-islefoundation.org.

Paul Pitkin: 00:03:29 Hello and welcome to the Trudy Sundberg Lecture Series. My name is Paul Pitkin and I'm the executive director of the Sno-Isle Libraries Foundation. Like all Sno-Isle Libraries programming, our presentation today is digital, and we hope you enjoy it from the comfort of your living room. Ask questions and share comments anytime using chat. Our moderators will share them with me for the Q and A portion of our program. The Sno-Isle Libraries Foundation is the presenting sponsor of the Trudy Sundberg Lecture Series. Our mission is to mobilize people and resources to expand the reach of library services, promote civic engagement, and foster a lifetime of learning. If you'd like to learn more about the Sno-Isle Libraries Foundation or make a contribution to the many programs we support, including the Trudy Sundberg Lecture Series, please visit our website at www.sno-islefoundation.org.

Paul Pitkin: 00:04:23 Our speaker today is a man of science. Robert Williams is an astronomer who served as the Director of the Space Telescope Science Institute and the President of the International Astronomical Union. Prior to his work with the Science Institute, he was a professor of astronomy at the University of Arizona and was the Director of Cerro Tololo Inter American Observatory. As the Director of the Space Telescope Science Institute, Bob devoted a substantial portion of his time to the Hubble Space Telescope and the study of distant galaxies. This historic project resulted in the Hubble Deep Field, a landmark image showing in remarkable detail the structure of galaxies in the early universe. For his leadership of this project, Bob was awarded the Beatrice M. Tinsley Prize, the NASA Distinguished Public Service Medal, and the Karl Schwarzschild Medal. Ladies and gentlemen, please welcome Dr. Bob Williams.

Dr. Robert Williams: 00:05:21 Thanks, Paul, for that kind introduction. Thanks also to the Sundberg Lecture Committee for arranging these lectures and my invitation to talk to you. I wish I could be there. The COVID-19 pandemic, of course, has not allowed that. But I would much prefer to be able to be there and meet all of you and speak with you personally. I should say that my brother Al and his wife Barbara are longterm residents of Oak Harbor and they attend these lectures, and it would be nice if I could have a family visit there. But let me say, I am honored to participate in the Sundberg Lectures because of what they represent, and that is education of the citizenry. I think education is such an important part of the democratic process and education is what the Sno-Isle Libraries and the Sundberg Lectures are all about. And so I salute you for your commitment to education.

Dr. Robert Williams: 00:06:24 I was asked to speak about a topic that is of interest to me. I've been an astronomer all my life. I've been associated with Hubble Telescope for the past 30 years. So I thought that I would talk today about a subject that may seem like quite a stretch, and that is science on the grandest of scales, the entire cosmos. It turns out our understanding of the universe has advanced dramatically in the last few decades because of an advanced technology. We're able to build more sophisticated equipment, including high powered super computers that enable us to handle our data better and interpret it. And I can tell you that for the first time astronomers now feel that we have a rough idea of how large scale structures formed in the universe. That is, from the earliest moments of the Big Bang billions of years ago when the universe was hot, compact, and lacking any structure to the point nowadays where on a clear night, you go out, you look up and you see interesting planets, stars, and galaxies.

Dr. Robert Williams: 00:07:42 How all of this happened, it's really a fascinating story and so I want to devote this lecture to that particular topic. But let me begin by saying something about the Hubble Telescope itself and why it's up there above the atmosphere in space. The image that you see pretty much speaks for itself. It says it all. On the left, you see an image of a star forming region in a neighboring galaxy, satellite galaxy, in the Milky Way, the Magellanic Clouds, taken with one of the premier large ground-based telescopes that has a mirror eight meters, roughly 25 feet in diameter. Compare that with the same picture of the sky taken with Hubble Telescope. A much smaller telescope, but

		because it's in space and is not affected by the distortion and the earth's atmosphere, you see a much clearer picture where you see these stars here that are really fuzzy when imaged from the ground, and also dark areas where there are not many stars, not much gas, and you can actually see through them.
Dr. Robert Williams:	00:08:59	Notice how much darker it is in the image taken with the Hubble than it is from a ground-based telescope. So the fact is, even though space is a hostile environment, that's the best place for a telescope to be. Astronomers have always wanted to put a telescope up there ever since it became possible to think of doing so with the inception of the space shuttle. So the fact is when NASA announced the shuttle program, astronomers said, "Let's put a telescope up there." And NASA agreed, and so for 25 years it was developed, it was constructed, and it was launched in 1990. So let me say something about how that telescope works. The telescope weighs 11 tons, and so the highest point that the shuttle could orbit it was up 600 kilometers, or 400 miles, above the surface of the earth. That's good because at that height it's already above 99.9999% of the earth's atmosphere. So it's essentially in space. And at that height, it orbits the earth every hour and a half, every 98 minutes. Half that time, it's on the daylight side of the earth. Half that time, it's in the night side.
Dr. Robert Williams:	00:10:26	The telescope is powered by these solar arrays here that put out a kilowatt of energy. And they charge the batteries so that when the telescope is in the night's side of the earth, then the telescope can still operate. It operates 24/7. Astronomers propose for observations from around the world, and they are carried out at all times in the night and day. The data is stored on computers that are at the back end of the telescope, and six or seven times a day the data on those computers are uploaded to a geosynchronous satellite at 22,000 miles above the surface of the earth, who download it to White Sands proving Ground in New Mexico, and they fiber optically came lit over to Goddard Space Flight Center, our collaborators in the operation of the telescope. They send it to our institute. We look at the data and archive it and send it to the astronomers who have proposed the observations.
Dr. Robert Williams:	00:11:32	So this is been taking place for 30 years now. The cost of the telescope at the time of launch was $2 billion, making it the most expensive scientific project in history. It has since been superseded by the Large Hadron Collider atom smasher that the Europeans built in Switzerland. But the fact is the continued operation of the telescope now for 30 years has put the costs now at around $8 billion. 30 years of collecting data. The

telescope has worked very well for almost all of that time, but not the first three years, and that's worth commenting on. Here's an image, the first image that was taken by the telescope one month after the launch. It took a month to power everything up and bring all the systems online. So there was small group of astronomers and optical experts that were gathered at our institute and at Goddard looking at the first image.

Dr. Robert Williams: 00:12:41 The good news was the telescope worked. It had an image there. You see the stars like the telescope was actually functioning. But several astronomers noticed that if you looked at a magnified image of any of the stars, there was this halo around all of them that was different from the telescope simply being out of focus for some reason. It was clear after a week's analysis that the telescope suffered a serious aberration called a spherical aberration that is endemic actually to any lens or mirror system that attempts to focus light. So there was no easy fix to this because it was caused by a misshapen mirror, and you couldn't do anything to correct it without actually putting corrective optics in the light path, which is possible, because when you look at your single lens Nikon Reflex, all of the lenses there actually have about five or six pieces of glass, individual lenses, that are there to bring light to a focus and do so in a way that corrects for all of these natural aberrations.

Dr. Robert Williams: 00:14:03 Well, the fact is Hubble Telescope could be corrected one of two ways. By the way, here's what the first image was supposed to look like. Much clearer and sharper than this fuzzy image there. So you can either bring it down and rework the mirror, which we realized was no op, because the public and Congressional reaction to a $2 billion project that was not working right was really disastrous. Here's a political cartoon that's one of my favorite. Notice the orientation of the shuttle on the right. The fact is astronomy and NASA were in a very bad way. Congress demanded hearings. And so there was a committee that we established the decided that, in fact, because servicing missions had always been planned to refurbish the telescope, because after all, anything that works, has moving parts and electronics, will eventually decay and so it does need to be refurbished.

Dr. Robert Williams: 00:15:20 We conceived of a system of corrective optics that could be placed in the telescope to correct the spherical aberration. And so NASA was on board with this and the first servicing mission was launched in 1993. And I'm very fortunate in being able to show you some examples of what takes place in such a servicing mission through some videos that the astronauts have given me. So here is a typical activity of a servicing mission, particularly the first servicing mission that corrected the flawed optics. A crew of typically six or seven astronauts goes up and they do what they call ride the fire. For the first two and a half minutes, the shuttle is propelled by the solid rocket boosters, which then are ejected, and you'll see them flaming out right here. And the shuttle continues on its way up to the telescope. Within 24 hours, it catches up with a Hubble and latches onto it, and brings it into the bay. And for the next five or six days, teams of two astronauts spend eight hours on extra vehicular activity that refurbish the telescope.

Dr. Robert Williams: 00:16:43 One of the astronauts, as you can see here, has always got the feet anchored to the remote Canada Arm. And the other astronaut is the so-called free floater that hand walks around the telescope, assisting the astronaut who has all of these tools at the end of the Canada Arm. The free floater is always connected with a cable so they don't float away. Tethered basically, and the reason for that is because the astronauts all say that they have this fear of falling, and it's very difficult for them to do anything but release their hands from these yellow hand locks around the telescope. There's some very large doors at the back end of the telescope that give one access, and here you see it right there, to the instruments. And so they go in there and they change circuit boards and remove old instruments, old gyroscopes, and insert new ones. This has been done five times in the life of the telescope. The most recent one, the last one, was 10 years ago, and have really caused the telescope to operate so successfully.

Dr. Robert Williams: 00:18:05 Every once in a while, things don't go according to plan and corrective action has to be taken. Here was a famous situation where a bolt wouldn't come loose, and so the astronaut had to actually tear the hand grip off the instrument in order to get it out. All of the operations of the astronauts are carefully choreographed, because some of them have to be performed when light is good in the sunlight part of the orbit, others are done using their headlamps when they're in the night side of the earth. Here you can see an instrument being taken out and another one being placed. After four or five servicing missions, when all of the activity has been completed, the astronauts release the telescope, open the aperture door, and make their descent. And here you see a glass servicing mission as the shuttle is passing through the atmosphere, the ionic flame that is caused has it descends at high velocity through the atmosphere. In this particular servicing mission, bad weather in Florida requiring the shuttle to land at Edwards Air Force Base in California.

Dr. Robert Williams:	00:19:23	So these servicing missions have been very successful and leading to a very productive 30 year life of the telescope. And here's an example of a different image taken by Hubble. One of them after launch, when it was physically aberrated, here on the left before the servicing mission in 1993, and when the corrective optics had been installed, on the right, you see the corrected image. The telescope at this point was working to specs. Really, the corrective optics worked perfectly. And so in the past 27 years, after the first three years where the telescope was basically working though at a very limited way, the telescope has worked wonderfully, produced images that are iconic. Here's a series of them, actually. Up in the upper left, you see the planet Jupiter, which gravitationally attracted a comet. This was shortly after the first service mission in '94, summer of 94. Actually, it had disrupted, tidally disrupted this comet, which then crashed into Jupiter's atmosphere.
Dr. Robert Williams:	00:20:47	And there were 25 fragments, each one the size of a huge iceberg, maybe a quarter of a mile in size, that blasted into the atmosphere at high speed and actually heated up the atmosphere and formed these dark spots that caused the temperatures to be equivalent to the temperature of the surface of the sun. And these blotches has actually remained visible for a year after the crash. So sometimes violent things do happen up there. On the right side of the picture, there's some interesting images of stars that are in the later stages of their life and have basically exploded, gone into outburst, and sent off parts of themselves into the interstellar medium. Stars are fueled by the conversion of hydrogen to helium in fusion reactions, and as long as that hydrogen exists, the star can exist stably. But when the hydrogen is depleted, the star collapses, heats up, and that collapse ignites more complex fusion reactions that cause the star to explode.
Dr. Robert Williams:	00:22:10	And when it does so, it ejects the gases here that you see, and they enrich the material in between the stars, such that in this picture here, which is one of the really famous ones taken by the telescope, you see some very large complexes of dust and gas where stars are forming. Now, you don't see the stars themselves at this stage because they are hidden by the dust that obscures them, but there are little peninsulas here where stars are being formed. And there's a hot star that's not in this image, it's to the upper right, that is actually illuminating these clouds and causing dissipation of the dust and gas.
Dr. Robert Williams:	00:23:00	... gas, so in a hundred thousand years or so, the dust and gas will have dissipated, and those stars that are forming here will become visible, so our understanding of most of these stellar

explosions and how stars form has really been advanced by images and analysis of the data from Hubble telescope.

Dr. Robert Williams: 00:23:26 All of this activity takes place within what are the largest gravitationally confined structures in the universe, galaxies. Here's a Hubble picture of a galaxy that's a spiral, sort of a dish-shaped galaxy, much like our own Milky Way. These galaxies tend to contain gigantic black holes. Now, you don't see a black hole. That's a compact, massive object where light can't escape, but because of their high mass, they do attract material into the black hole, and before it enters a black hole, that material radiates, and so you see these bright spots around black holes that occupy the centers of galaxies. Our own galaxy has one. Most galaxies like the Milky Way tend to have them.

Dr. Robert Williams: 00:24:17 The point is, a galaxy consists of billions of stars. Again, our sun in the Milky Way is a representative star and there are untold millions of these objects in the universe and all of these processes, like the planets that form around stars, stars forming from dust clouds, stars that have used up all of their fuel and are losing mass and regenerating the gas in-between the stars, all of that occurs in galaxies, and so it's really interesting to understand how galaxies form, which really is a subject of cosmology, because these are fascinating objects, these galaxies, and so what I want to devote the rest of my talk to is essentially a description of how we believe galaxies form from the earliest inception of the universe.

Dr. Robert Williams: 00:25:34 Now, to do that, I need to introduce you to two concepts, but they're very simple, and it will help us understand exactly how the universe has evolved. Again, believe it or not. First concept is anytime you look out at an object, you are looking into the past. When we look at the sun, we are seeing as it was eight minutes ago when the light that enters our eyes left the sun. The sun is eight light minutes in distance away. When we look at the nearest galaxies, and suppose we are here in our Milky Way galaxy looking out at distant galaxies which typically are millions of light-years away, we are actually seeing those objects as they were when the light left them. Now, light has a finite speed, 186,000 miles a second, and therefore it takes a certain time. If you're at one million light-years distance, it takes one million years for the light to get here. If the galaxy is more distant, it takes three million years for the light to get there. You were seeing the galaxy as it was at that time.

Dr. Robert Williams: 00:26:52 This is the fascinating thing: Astronomy allows you to look directly into the past. The further out you look, the further back in time you are looking, and so we can reconstruct the history of anything that we see if we can see far enough into the past. But there's a catch, and that is the brightness of an object depends upon its distance, and so whether we're talking a car headlight, a flashlight, a filamentary light bulb, or a galaxy, the further away it is, the fainter it is, and so you can only look so far, even with the largest telescopes, before the object becomes too faint to see.

Dr. Robert Williams: 00:27:41 In the case of the largest ground-based telescopes, they can see a few billion light-years in the past, which means that anytime you image a galaxy that's very distant, even though it's faint, you're seeing as it was billions of years ago, and so this is a way in which we construct the history of the universe, but we can only see back so far. Now, the second concept, that's the first concept, you always look back into the past and we call that time difference between the object when it emits the light and we receive it "the look-back time." Galaxies have look-back times of millions or perhaps even billions of years.

Dr. Robert Williams: 00:28:34 Second concept is similar to that, and that is, it was discovered by Edwin Hubble and Belgian astronomer Georges Lemaître that the university is in uniform expansion, and this was actually a fairly simple conceptually result, and it came about when they took observations made by other astronomers and realized that all the galaxies appeared to be moving away from each other. Again, I can depict that in this video here, where suppose this is our Milky Way galaxy. The fact is space is expanding, the university is expanding, and when we look out at other galaxies, they are all moving away from us. The ones that are further away move away faster because of this uniform expansion. I say it's an easy observation to make and that's because of what is called the "Doppler effect." Many of you may be familiar with it. It's the same principle that a police officers use when they shoot a radar gun at you to determine the speed of your vehicle. The fact is anytime you have a wave that is emitted by an object, whether it's a light wave or an acoustic sound wave, if the object is moving away, the wavelengths are stretched, which means they become longer, and in the case of light, it becomes redder than if the object were at rest. Acoustically, same effect. That is, if you hear a siren, for example, an object that's moving toward you, the waves are compressed, they're at higher frequency, and therefore, they appear more like a treble, and as soon as the ambulance, say, passes you, then the object is moving away from you, the wavelengths become stretched and longer, and the tone becomes more bass-like, that is, a lower frequency.

Dr. Robert Williams:	00:30:44	Same thing's true of light. What Hubble noticed was that all of the galaxies appeared to be slightly redder than they would be if they were at rest, and therefore, he deduced from the fact that galaxies that were further away were moving faster than those that were closer implied a uniform velocity of expansion. What's profound about this is that this implies if you project backwards in time that everything was closer and more compact in the past, and that implies that there must have been a beginning.
Dr. Robert Williams:	00:31:31	Everything, like fireworks when they explode, the objects that you see illuminating in a single a ball of fireworks, the objects that are the furthest are there because they happen to be ejected at a higher velocity. If you project the fireworks back in time, you conclude that there was an origin for the particular outburst. This is the case in the universe, that its uniform expansion implies that there was a beginning, so the fundamental concept of cosmology that our universe had an origin in the past, that there was a beginning came from this very important deduction. That was done about a century ago. Hubble, a great contribution. That's why the telescope was named after him.
Dr. Robert Williams:	00:32:24	This instant of a creation of the universe has been called the "big bang," and so it implies a very interesting cosmology that we will represent here and come back to this various times that I want to present to you about what we can infer about the universe. Let's take a big chunk of the universe and project back in time in order to determine what the history of the universe has been. Let's start here at what I'll call the "present time," where time is evolving from the beginning left to right, okay? We look out now at the present time in our universe, we see galaxies. We know that the universe is expanding and therefore, if we project back in time, the universe was more compact.
Dr. Robert Williams:	00:33:28	Now, if we continue with this thought process, the known laws of physics and thermodynamics tell us that any time you compress something, it becomes hotter, and when things are hot, they radiate. This is how a filamentary light bulb works, right? You pass current through it, heats it up, and you get light. Astronomers deduce that at some point in the past, given our current universal expansion, the universe had been hot enough to glow, and if we could look back far enough, we should see this glow. Could we look back clear to the time and this instant of creation when the universe was so hot and compact? The answer was probably not, and that is because the hot universe here, this hot gas, was its own fog, and so we could only see to the start of that hot fog where it radiates, but not any further into it, so we devised a small telescope with NASA that was

		launched in the 1990s called "COBE," Cosmic Background Explorer, to see if we could detect this.
Dr. Robert Williams:	00:34:53	Now, since we're looking way back in time, therefore very great distances, the glow was expected to be very faint, if it even existed, if we could detect it, and in fact, this little satellite that you see up here, here's COBE. The project was actually repeated with a more modern instrument, more recently, about a decade ago, and they got the same result, but basically, after several years of observations looking past our galaxy, looking past the star to see if there was this uniform glow in all directions, and in fact, they found it. The glow was detected. Really, an amazing accomplishment that, in fact, confirmed our idea that the expansion of the universe did lead us to believe that back in time, the universe really was hot and there had been this moment of the inception, the big bang.
Dr. Robert Williams:	00:36:05	Here's a map of the entire sky where this glow is shown. Its detection was a real triumph and what's really interesting is that they found that it was very homogeneous, and that is what they're plotting here is the temperature and density of the early universe, and this is within about a half million years after the big bang, but they did detect inhomogeneities, and I don't know if you can see them on your screen, but in fact, there are slightly more dense or hotter and cooler regions here that implied a difference in density of material of one part in a hundred thousand.
Dr. Robert Williams:	00:36:54	In other words, the early universe was amazingly homogeneous, more homogeneous than the [inaudible 00:00:37:00], but there were these what are called "micro fluctuations," because the expansion at that point had caused what we call "quantum fluctuations." That is, very slight differences in the homogeneity, and so scientists immediately wondered, "Ah, so if the universe was really without structure, without form shortly after the big bang, could we explain the existence of structure beginning with these slightly over-dense regions?" and so even before more detailed observations could be made, scientists actually then tried to follow the hot, homogeneous universe from this point in time out to the point where now we have galaxy season form.
Dr. Robert Williams:	00:38:09	Because of our limitations in looking back in time, exactly observations of what occurred between that time, just a million years after the big bang and now billions of years, and I should say that the timescale between the present time and the big bang was 14 billion years, the big bang occurred 14 billion years ago, we did not really have observations in this area here that

indicated to us what the universe really looked like. Instead, theoreticians got the jump on we observers and took known for physical law and applied them to this hot, homogeneous universe to predict what the evolution of the university would look like, and they produced some amazing results that I'm going to show you here.

Dr. Robert Williams: 00:39:08 If we take a very hot, almost homogeneous universe, but having slight density fluctuations these micro fluctuations, one part in a hundred thousand, the question was: Of all known forces, could they lead to the formation of galaxies? Now, the answer is that of the known forces, electricity, magnetism, different kinds of nuclear forces and gravity, only gravity is expected to be able to influence objects in the universe over very large distance scales, and the reason for that is atoms are electrically neutral, and so we believe that on the whole, the universe is electrically neutral. Nuclear forces, they only operate on the scale of atoms, and so gravity is believed to be the only force that would operate here on this gas as it expands. Gravity is always attractive, it's not a repelling force.

Dr. Robert Williams: 00:40:27 The question is: If you took this situation and you allowed gravity to, among all of the gas here, to operate, what would happen if you then cause this gas to expand? Here, you have with a little time clock up here, and you'll see, we started around 50 million years after the big bang, and follow this gas as it expands under the influence of gravity and cools off, then here, basically in 17 seconds is the evolution of our universe on a grand scale predicted by what we know about the laws of nature at this time.

Dr. Robert Williams: 00:41:16 What happens, and I'll show this again, is you start with a homogeneous universe. I'm going to have to get back here and see if I can redo this. There we go. You start with this and you will notice that there's region in here, for example, is slightly brighter and therefore, a little more material there, whether it will be successful in gravitationally, attracting the material around it, and that turns out to be the case. You see time passing here very quickly and these regions of where the density is higher, you actually see the gravitational attraction of this mass here drawing everything toward it, such that at the end of 14 billion years, you are left with these voids where the micro fluctuations that are higher density were successful basically in attracting the rest of the gas to it, and so our projections are that the current universe should exist in what we call the "cosmic web" consisting of large concentrations of mass that are surrounding by these voids that were created by that mass, gravitationally attracting the material toward it.

Dr. Robert Williams:	00:42:46	This was a computer model. The question is: Does the sky, does the universe around us really look like that? The answer, amazingly, is yes. There been several surveys of the sky out to about a billion light-years where telescopes for some years now, this has gone on for 20 years, have mapped all of the galaxies that we can see with telescopes, just steadily take images and plot where the galaxies are, and this actually is an actual distribution of galaxies around the Milky Way galaxy, and you can see, in fact, the universe does have this cosmic web structure, exactly as we thought that it should, so really, a great accomplishment.
Dr. Robert Williams:	00:43:39	Now, the question is: With the basic confirmation of cosmology in place, that is, we had this hot fog back there that enables us to see within 400,000 years of the big bang, present time, we are here where the expansion has cooled off because an expanding gas always cools, the universe has cooled off, and then these micro fluctuations have led to this cosmic web. What do the observations tell us about this region here? Now, with ground-based telescopes before the Hubble, we could only see back into time only so far, just because the objects get too faint, but Hubble has enabled us to peer deeper into the cosmos in the past.
Dr. Robert Williams:	00:44:35	In order to investigate this and try to give observational confirmation of these theoretical predictions, a group of us at the Institute, as soon as this vertical aberration of Hubble telescope was corrected, made the decision to try to point the Hubble out in space, looking between the stars in our galaxy to actually see if we could image out there and try to capture what galaxies at great distances looked like, so I had gathered together, I was director of the Institute at that time and had access to the telescope because part of our contract with NASA is that the director of the Institute gets 10% of the telescope time to do as he or she chooses, and I thought with some young scientists at our Institute that it would really be worth taking the telescope for a long period of time and trying to see if we could detect very distant galaxies.
Dr. Robert Williams:	00:45:40	This was a risky project because there was no guarantee that we would have any success. In fact, there had been several studies undertaken by well-known astronomers that indicated that Hubble probably would not, even though it could do better than ground-based telescope, was not likely
Dr. Robert Williams:	00:46:00	... To be able to reveal very much about the evolution of the universe, more than four or five billion years back, although that still would have been progress. And there was several other

factors that were relevant and one of them was, with no guarantee of success, with astronomers around the world dying to get time on the telescope. What would the reaction be if we ended up with really no detection of distant galaxies, taking the telescope, it turns out for 10 days, which is what we decided to expose for, right after the servicing mission to correct this spherical aberration. It cost $1 billion. Director making a crazy decision like this. There was a lot of pressure basically within the community for us not to do this but a group of us felt then, given the fact that Hubble was a premier instrument, we had to try it.

Dr. Robert Williams: 00:47:15 The fact is we did commandeer the telescope for 10 days, taking exposure after exposure, electronically adding them all up and we imaged what we called the Hubble Deep Field. It was a blank area of sky, where we knew from earlier observations, Palomar Sky Survey, that we would see at least 50 to 100 galaxies. But the fact is what Hubble revealed, after 10 days of exposure, was 3000 galaxies, some of them relatively nearby and, therefore, brighter and larger. Here is a relatively nearby galaxy. By the way, its distance is one billion light years. There are others here. Here's a spiral galaxy. Down here as a spiral galaxy. And all rest of these objects, there are just a few stars here. There's one and there's one. But everything else that you see in this image are galaxies, some as close as a billion light years. The most distant, it turns out, at 12 billion light years. The fact is we were very fortunate in being successful and, essentially, in this image, this core image basically, where we're looking back in time, able to reveal the existence of galaxies and determine exactly what their morphology was like.

Dr. Robert Williams: 00:48:56 We could say, "Ah, this is how structuring the universe is achieved from a few billion years after the Big Bang to the present time. The size of this image, by the way, is essentially the size of a grain of sand held at arm's length. This is one teeny part of the cosmos. And the fact is, even though to most ground-based telescopes, it's essentially a blank piece of sky, this is what we can see with Hubble.

Dr. Robert Williams: 00:49:29 Let's take it a little more detailed look, actually, at some of the galaxies in that deep field image. Here is a plot of the brightest galaxies, which we advised the largest ground-based telescope at that time, which is the Keck 10 meter telescope in Hawaii, which was able to take spectra, that is of these galaxies, in order for us to determine their velocities so we would know what their distances are.

Dr. Robert Williams: 00:50:02 The fact is here is a plot of the intrinsic brightness and the morphology, the images of those galaxies as a function of the lookback time, that is their distance. What you see, and as excellent an instrument land breaking really as the Keck telescope was, they could only determine the distances by taking spectra of the brightest 125 of the galaxies, which are plotted here. The most distant galaxies are smaller and are down here and with a lookback time of 12 billion years. I realized Big Bang was 14 billion so we were looking back about 90% of the time from the present time to the Big Bang, seeing actually what galaxies looked like.

Dr. Robert Williams: 00:50:58 There is this swath of galaxies. Actually, you notice that there's a void here to the lower left and a void to the upper right. That is what we call a selection effect. Any galaxies here, of which many must exist, were too faint to be observed. And so, with Hubble even, you don't see them. And up here, galaxies that are intrinsically bright, and here we're plotting the intrinsic brightness of the galaxies, they are too rare for them to be captured in our very small field of view. This upward left to lower right swath of galaxies is a selection effect.

Dr. Robert Williams: 00:51:46 But that being the case, notice what these galaxies look like down here, which are the galaxies that existed shortly after the Big Bang, compared to the galaxies up here, which are the galaxies that appear now in the current epoch of the universe, modern time shall we say.

Dr. Robert Williams: 00:52:09 Here's a blowup of these galaxies here. Notice they are all dysmorphic, smaller and bluer than galaxies up here at the present time, which are larger and more symmetric. And this really is the observational confirmation of what galaxies looked like from the time they first started to form to the present time, when they're larger and have a more symmetric structure. Notice these here, all what one of my colleagues calls, "Train wrecks," as opposed to these galaxies here that are very much smoother. It turns out that the reason that these galaxies down here, the early galaxies, are blue is because of hot stars that have recently formed. Stars were forming two billion years after the Big Bang in galaxies. The galaxies at modern times are redder because these massive stars have been born and died. And all you see are cooler stars that have longer lifetimes up here in modern times. The fact is star formation started some billions of years after the Big Bang and is slowly dying out now, such that we really live in this expanding, dying universe. Now, interestingly, the question is, "How did these galaxies develop this nice symmetric shape and become larger?" I'm going to end this doc by showing you two videos that show how we believe galaxies formed. We go back to this video of the cosmic web and I was showing you, and we take one of these micro fluctuations and expand and study it in detail. 50 million years after the Big Bang, when you have these micro fluctuations and the university was expanding, starting to get cooler, so it wasn't so ionized, there is an image of the formation of galaxies that has been done on a super computer and took a month of computer time on the most advanced computer to do this. Here is a more detailed view of how we believe that galaxies form from this initial, almost homogeneous gas.

Dr. Robert Williams: 00:55:11 The universe expands and it gets less hot and, therefore, it radiates less and so, it enters what we call the dark ages. Now you see the micro fluctuation. This particular region here that was more dense is successfully gravitationally attracting material from around it as the void around it forms. Notice this random process of this object becoming more massive and creating material and notice what the shape looks like. It looks like a spiral galaxy. We believe that this is actually a representation of how this almost perfectly, but not quite homogeneous universe started forming these galaxies that now have a spiral structure. Now, not all galaxies have that structure. Some of them have this smooth, round elliptical appearance.

Dr. Robert Williams: 00:56:15 The last video that I want to show you is what happens if you have two of those spiral galaxies interacting with each other gravitationally. Here is an image that was done by John Dubinski that appeared, actually, in a National Geographic magazine about 10 years ago, and become an iconic video itself. If two galaxies come together under their own gravitational influence, the stars pass through each other. There's so much space between the individual stars that they actually don't collide themselves. You have these two galaxies merging under their own gravity and you'll notice the center of this galaxy, the center of this galaxy starting to merge.

Dr. Robert Williams: 00:57:06 And what will happen here in a few more seconds time is you get the spiral structure that you started with essentially destroyed through the title interaction of the merging of these galaxies. And whereas you started out with two nuclei, you end up basically with one that is more massive and we believe this is how supermassive black holes have formed. And so, you end up with a galaxy that looks like that and notice it has this more elliptical, not spiral structure. And so, we believe this merging process is what leads to these larger, smoother elliptical galaxies. There you have it. Two videos that demonstrate in more detail how we think that galaxies have formed.

Dr. Robert Williams:	00:58:09	Now to summarize, basically, if we look back in time, and here's a graphic here that represents looking back from the present time out 14 billion years ago to the time of the Big Bang, the Hubble Deep Field took us back within about a million... Sorry, a billion and a half years from the Big Bang. Better instruments on the telescope that repeated the deep field and were able to look further and closer to the Big Bang actually got us within one billion years. That was called the Hubble Ultra Deep Field. And the follow-up telescope to the Hubble, the James Webb Space Telescope that is now being completed and ready for launch next year, should get us back to within 600 million years of the Big Bang.
Dr. Robert Williams:	00:59:09	This basically is a synopsis of our attempt to actually extend our observations ever closer to the epoch near the Big Bang when the first galaxies formed. That is what we now understand about the evolution of large scale structure.
Dr. Robert Williams:	00:59:38	Let me close by saying that I realize that many people would consider this topic a bit too removed from dealing with the current problems here on earth. Does it really justify the expense of supporting the astronomical community? And I would disagree with that. I would say it's short sighted. While it's true that the earth is a cradle of civilization, you can't remain in a cradle forever. And the fact is this environment here of galaxies and planets, it is the environment out of which life developed. And so, these galaxies, in a way, are part of humanities roots. The fact is our DNA is stamped with a chemistry that has gone on in those merging gas clouds and our own evolution as a species is a result of the same physical processes that govern what's going on there. And I believe that our deeper understanding of all of this serves really to unite humanity, not just with our global environment, but with each other and that certainly is of value.
Dr. Robert Williams:	01:01:08	Thank you so much. You've been a great virtual audience. Paul, back to you.
Speaker 1:	01:01:15	The Trudy Sundberg lecture series is underwritten by donations and sponsorships to the Sno-Isle Libraries Foundation from community donors like you, who believe in the power of ideas and information. We'd like to thank the following corporate and community based organizations for their generous support. The League of Women Voters of Whidbey Island, a nonpartisan organization for women and men that seeks to influence public policy through education and advocacy. The League of Women Voters of Whidbey Island encourages all citizens to be informed and active participants in government.

Speaker 1:	01:01:52	Stonebridge Environmental Incorporated, taking care of the environment by providing consulted engineering services, which apply the best available technology to protect the local groundwater and stormwater from the watersheds throughout Island County.
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Speaker 1:	01:02:25	And the Whidbey Island Democratic Club, a community organization gathering like-minded people in support of political causes and issues, which matter to the people of Whidbey Island.
Speaker 1:	01:02:37	Their financial support and yours honors the memory of Trudy Sundberg and her lifelong commitment to discover, explore, and cultivate the exchange of information, ideas, and opinions in respectful considerate environments. Please consider how you can join them to help make future events like this possible. To learn more, visit sno-islefoundation.org.
Paul Pitkin:	01:03:06	Bob, welcome back.
Dr. Robert Williams:	01:03:08	Thank you.
Paul Pitkin:	01:03:11	That was incredible. I'm still kind of reeling. I'm glad we had some announcements so I could sort of gather myself. I feel quite small to tell you the truth after looking at your lecture. We have so many questions. We almost have as many questions as the galaxies you observed. I want to get into them. We had just an incredible number of people who have had some extra questions for you. I will get this rolling so we can get to as many of them as we possibly can. But thank you so much, Bob, for that amazing lecture. just blows my mind. Thank you very much.
Dr. Robert Williams:	01:03:45	My pleasure.
Paul Pitkin:	01:03:46	Yeah. I want to start with Patrick from Whidbey Island. He says, "If the speed of light acts as a barrier we can't see beyond, what do you personally think lies beyond the current sphere of the observable universe? How do you think future observations will see beyond it?"
Dr. Robert Williams:	01:04:04	Don't know. Science addresses those questions about which we have facts. And so, anything that goes beyond that, that's not

supported by observations, is speculation. I can speculate but I honestly don't know. One could ask also and let me say, since we talked about the Big Bang, what happened before the Big Bang? Same answer, "Don't know." At the current time, we have very little information about the nature of the universe, observationally, from the time of this hot fog that existed for half a million years, back to the point when the initial expansion took place. We can build models using our current knowledge of physical processes to make predictions. But right now, it's very difficult to get any confirmation of those.

Dr. Robert Williams: 01:05:02 In fact, I'm not a betting person but, given the advance of physics in the past century, I would guess that in the next century, we probably will have some observational facts that we can apply to what exists between the 400,000 years from the Big Bang, back to the Big Bang. As far as what happened before that, have no idea. In fact, does time even have any conceptual meaning? I don't know.

Dr. Robert Williams: 01:05:37 But that wasn't quite what the question was. The question was similar to that and that is what do I guess occurred if we could see past the point where the limit that we can now see. And I would answer that, I think, with a little bit of confidence in terms of guessing what the situation was in the first 400,000 years. Also something worth saying is, because I frequently wondered, "How is it that you could take all of this mass in the universe and compress it down to something that is so compact?" Well, again, if you applied the laws of physics right now, where energy and mass are related to each other, remember Einstein's equation equals MC squared, that you can create mass from energy. You can create energy from mass.

Dr. Robert Williams: 01:06:27 What we believe is that there was no mass at the time of inception, that is at the time of the Big Bang. It was all energy. Now, it's easier for me to conceive of some incredible amount of energy than there is for mass. We believe that, in fact, very shortly, billions of a second after the Big Bang took place, that that energy converted into the mass and that's where all this mass came from, that turned out from the expansion, which is very rapid at the time of the Big Bang, because of the tremendous energy, is what produced this tremendous homogeneity, the sameness with these micro fluctuations, out of which everything that now exists began to form.

Paul Pitkin: 01:07:16 Yeah, that's amazing. And I know that's always a question that comes up whenever somebody looks at the Big Bang and the universe because it looks like, in your imaging, that, "Oh, there's a sphere that is the universe. What's on the other side?" So I'm not surprised we got that question.

Dr. Robert Williams:	01:07:33	Yeah but, well, we believe its infinite. Now, there another concept that we use. It's a mathematical concept, very useful in us making predictions but I cannot conceive of... I can say the word. I cannot conceive of anything that is truly infinite. But the point is you deal with these infinities and to what extent does the actual physical reality deviate from the mathematical representation. And the answer that there probably is a deviation but it's hard for us to know exactly where that is and how to represent it.
Paul Pitkin:	01:08:13	We've had several viewers ask this question, "Please speak a bit more about dark matter. What is it? What have we learned about dark energy?" And somebody added, "The concept blows my mind and I would appreciate any light Bob can shine on it. Pun intended."
Dr. Robert Williams:	01:08:30	Well, let's go to the next question then. Dark energy, we don't know what it is. I mean, there's been several... Well, the Nobel Prize that was announced a week ago was also in astrophysics for something that a Hubble had something to do with, but there were other telescopes, really with Keck telescope in Hawaii and telescopes in Chile, they made tremendous advances that told us something about supermassive black holes. Again, I'm
Dr. Robert Williams:	01:09:00	I'm getting away from your question. So, the universe is not only expanding. We thought 30 years ago that gravity must be slowing it down. We wanted to know exactly what that rate of slow down was, because it would tell us something about the mean density of the universe, and that's an interesting quantity that would help us understand it. That turned out not to be the case. The universe is not slowing down. It's speeding up. What is causing that? We know of no force that would act to produce this. So, there is this tremendous source of energy, dark energy. I don't like the nomenclature. Dark simply means that we're in the dark about that as we don't really understand it. So can't tell you. There's various theories about that, and it's always hard to explain something to anyone else so they understand it if you don't understand that yourself, and I have to admit that I don't really understand the detailed physics that goes into this. In any event, so, I'm afraid I cannot illuminate you much about dark energy.
Dr. Robert Williams:	01:10:09	Dark matter's different. We still don't really know what it is, but I think we've got a better picture about it and a better chance of

		understanding of what it consists of, because we do know of dark particles, neutrinos. Maybe you've heard of them, okay. Neutrinos are particles. They have a speed that's roughly the speed of light, and they do not interact with radiation. And so, they are dark. And in fact, dark matter could be neutrinos, of which we know they exist. Very unlikely though, because if you posit neutrinos, which we understand something about, as dark matter, from the expansion of the universe, the time around the big bang, you don't get the formation of structure as we observe it. And so, there is dark matter, but we don't know exactly what those particles are. They're particles whose existence we have not confirmed.
Dr. Robert Williams:	01:11:16	What we can say is we can map it, because all matter, whether it interacts with radiation light or not, is affected by gravity. And so, the Hubble has taken very nice images of arcs that are produced when you look at a very distant source, and then you see it looking through a cluster of galaxies, which have lot of mass, and actually bend the light. We've been able to map dark matter that way, and although we do not know what the particles are that make up dark matter, we have been able to map its distribution. So, we can say, yes, it exists, and it tends to actually be associated with normal matter the atoms makeup.
Dr. Robert Williams:	01:12:09	So, I haven't been able to tell you what dark energy is. Dark matter, I can't really tell you what those particles are, but we are able to map it, and we believe that there are certain reactions that we expect that may enable us to detect it. Such experiments are underway. So far, no positive results. But it may well be in another decade or so that we will be able to characterize exactly what dark matter is. But more than that, I'm afraid, I can't tell you more.
Paul Pitkin:	01:12:51	Well, I'm sure you, you knew this question was coming from [Janet 01:12:55] on Camano Island. Is it assumed that there is, was, life on distant galaxies?
Dr. Robert Williams:	01:13:02	There is no evidence for life anywhere other than on Earth. We've looked for it on Mars. Now, first of all, it's hard to detect, I suppose, even with the greatest telescopes. Looking at Mars, for example, close planet, wouldn't be able to detect it if it were there. We are fortunate to have been able to send probes there, and they actually dig into the soil, and do chemical analysis, and mass spectrometry in the light, and it is actually difficult to detect life directly. What you need to do is look for the signatures of life, of which one is ozone, and then there are other. And there's still no direct evidence anywhere for life.

Dr. Robert Williams: 01:13:54 So, let's back up and ask the question, if you ask scientists, do we believe that life exists in the universe? Most scientists would say, "Yes." For the simple reason that the universe is so huge, and we know that there is Earth and life on Earth. It stands to reason out of the jillions of stars, at least half of which have planets, multiple planets, there's got to be other earths out there. Well, we know that life did evolve in a certain way on our planet, stands to reason that life is somewhere else out there. And so, although there's no evidence for it, most scientists, most astronomers would say, "Yeah, life probably exists."

Dr. Robert Williams: 01:14:41 But you've asked me. I would say, yes, I think life, no doubt exists, but if you asked me if it exists in any complex form, I would have doubts about that. So, let me say several things about life. There's no consensus as to exactly what defines it. If we take this most simple definition, that is life consists of an organism that does two things: metabolizes, that is it intakes something and it creates energy, and it reproduces. So those two attributes, reproduction and metabolism, quite simply, I would say it's stands to reason that they exist somewhere.

Dr. Robert Williams: 01:15:34 I actually used to not think that, because to me, this double helical structure of DNA always seemed so unusual to me. I thought this is just floopy. That turns out not to be the case. In the past 20 years, biochemical engineers, researchers have demonstrated that if you take complex molecules in amino acids, amino acids are the components of proteins, that generally, they exist in a fluid, some sort of fluid say, that they have a very chaotic structure. That is the atoms are hooked together in just a crazy quilt way. No structure. What they've found is that depending upon the characteristics of the medium they are in, a low energy state of these complex molecules, amino acids, can form that turns out to be helical. That is the helical structure of amino acids is a what's called a low energy state, and if you do something as simple as change, for example, the level of acidity, the pH, of a medium, you can take a chaotic amino acid and find that bloop. It becomes helical. Amazing. And so that to me helped me understand that, well, this strange, I thought, helical structure of DNA is not something that is that bizarre. So I find it easy to believe that a single cell structure like a paramecium, or amoeba, or something like that could exist elsewhere.

Dr. Robert Williams: 01:17:18 But if you asked me personally now about life that, like humans are self-aware, I have my doubts really that even in humongously large universe with zillions of planets, that all of the things, components of evolution that led to mankind, something like this occurred on another planets, I'm not convinced of that.

Paul Pitkin: 01:17:53 All right. From David, his question is it true that the James Webb telescope to be launched in 2021, he says, question mark, will be 10 times more powerful than Hubble. What sorts of questions will the Webb telescope help us answer?

Dr. Robert Williams: 01:18:11 10 times? Yes, in many attributes, I would say James Webb will be, its mirror, the area will not quite be 10 times the size of the Hubble, but close enough. But what is unique about the Webb is that whereas Hubble looks in the visible and optical wavelengths, James Webb is infrared. There are two things that Webb will be able to do much better than Hubble can do. It turns out that long wavelength, infrared light, or even radio waves, penetrates solid particles, dust, much better than visible light, and a lot of interesting things occur in the universe in dusty environments, because when you have gas converted into solid particles, you usually start off with very small particles. We call it dust. And the fact is that dust obscures wavelengths that Hubble looks at with. James Webb is going to be able to peer through those and see the formation of objects, like planets and stars, much better than Hubble can do. So, we're going to learn a lot more about planetary formation and star formation.

Dr. Robert Williams: 01:19:25 The other thing that Hubble, sorry, Webb is going to be able to do is the fact that when you look further out in space, because of the higher velocities of the distant galaxies, their light shifted into the red, into the infrared. And so in order to detect the most distant galaxies, it is advantageous to go to longer wavelengths. Hubble can only look to two microns. Sorry, I'm being a little technical here, but enough of you probably understand that. James Webb will be able to look out to 30 microns, much further into the red, and so the other great contribution of James Webb will be doing a deep fields that will extend much closer to this initial cosmic fog than the Hubble.

Paul Pitkin: 01:20:15 So we've had some folks ask some pretty technical questions. I think this might be one of them. Jay from Port Ludlow, are there theories for what the distant universe might look like right now? Since we are seeing eight to 12 billion years ago, what might it look like right this minute at those far distances? Do you offer any courses on learning platforms like Coursera, edX, or FutureLearn? I would love to take online courses from you. You are a very interesting and understandable speaker.

Dr. Robert Williams: 01:20:51 I consider writing perhaps one of my gifts, speaking, not so. In any event, yeah, the theories that have already go back to the time of the inception of the universe, really within billions of seconds of it, that explain the creation all of the bizarre particles, the subatomic particles that exist, have done a pretty good job of explaining the creation of forces that we are familiar with, electricity, magnetism, nuclear forces and the like. So the answer is yes, right now, physical theory does a pretty good job of describing things from as close to the big bang as we can get, because of course at the moment of this inception, the temperatures, and densities, and energy densities are so great that probably our understanding breaks down. And so again, a typical situation in science where you make some assumptions, make some predictions, and try to have them verified with things that happen. And I would say we've done a remarkably good job of coming up with a consistent theory that explains what has happened within seconds after the big bang to the present time.

Dr. Robert Williams: 01:22:29 It's not to say that there are surprises won't occur. A century from now we'll find that some of these things that we think are true are not, but look at gravity. Gravity has been successfully explained and confirmed for centuries. I think the broad brush picture of our current understanding that I presented is likely, for the most part, to hold water in the future.

Paul Pitkin: 01:23:00 Well, and I think part of the gist of the question was since you're looking backwards at these galaxies, aged 12 billion years, if even though it's impossible, if there was some way to look at it, what it looks like right now, those galaxies that you look at and you see them 12 billion years ago, what might they look like right now? Would they be, are they-

Dr. Robert Williams: 01:23:20 Ah! They probably look like the galaxies around us now.

Paul Pitkin: 01:23:24 Yeah, just the way you described. They formed and-

Dr. Robert Williams: 01:23:25 We can't, no guarantee, but one of the interesting things is when we look out in all directions, it does look like, and on large scales, the universe is homogeneous. So, you look this way, it looks pretty much the same as if you look the opposite. So we don't think that there is any special section of our universe in which things evolve, in which physical laws are different, such that right now those things would be completely different from the epoch we're in.

Paul Pitkin: 01:24:02 Yeah. They would just develop like all the other galaxies have developed. [inaudible 01:24:06].

Dr. Robert Williams:	01:24:06	Correct. Correct. In fact, the current universe, now, that we can't outlaw the fact that there may be other universes, so the current universe that we are in, that we are observing is defined in terms of the physical laws that are appropriate to it, and so this is how we define our universe. It is this regional space that obeys the same laws that we find here, that when we make these measurements on Earth. And so the answer to the question is if those galaxies that we have seen billions of years ago, we wonder what are they like now, by definition, if they are in this current universe, they obeyed the same physical laws, they're going to look like things that are near us now.
Paul Pitkin:	01:24:57	Yeah. So I want to, boy we could go on like this forever. I wanted to ask you one more question, because ... Where is that one? Yeah. Because Sno-Isle Libraries and the Sno-Isle Libraries Foundation, we're all about learning, and you have a very particular job, and you've had very particular experience. So, William in Seattle asks, what would you say to a young person who was also fascinated by space and wonders what it takes to pursue a career like yours? Is excellence in higher math absolutely necessary?
Dr. Robert Williams:	01:25:31	No. Follow your passion. I have mentored many students and met, talked with many of them. There are precious few who find the universe and the study of it fascinating who don't have the smarts to succeed. It is more a situation of maintaining your discipline and getting into a situation where you can be educated. Really, you don't have to be a genius in math. There is-
Paul Pitkin:	01:26:11	So basically just maintain your discipline, and hopefully you can get the scholarships and whatever you need to get through the educational program, right?
Dr. Robert Williams:	01:26:21	If you really love doing something and you want to keep doing it, there are enough opportunities that exist out there for you generally to be able to fulfill that interest. Really.
Paul Pitkin:	01:26:36	Fantastic.
Dr. Robert Williams:	01:26:36	So don't worry about your own attributes, which by the way, are going to develop with time and change. If you want to be a lawyer, whatever, rocket scientist, go for it.
Paul Pitkin:	01:26:53	Well, I think that's great, because I think there are a lot of kids and a lot of people who think if you're not at the calculus level,

by fifth grade, then you should just kiss a career like yours goodbye.

Dr. Robert Williams: 01:27:06 Correct. Correct.

Paul Pitkin: 01:27:06 So I think that's a great message.

Dr. Robert Williams: 01:27:09 And one of our jobs for those of us who are in this is to mentor such students and help them develop to fulfill their passion.

Paul Pitkin: 01:27:14 Yep. Well, that's great. Bob, I have learned more in this webinar then I think I've learned in the last year. This has just been fascinating, and I want to echo what some of the questions said, which is that you are a very relatable lecturer, which is, when talking about issues that are this huge, that really makes a difference. And I've found myself just really able to follow along and understand what you were saying, even though I know it goes into a lot more depth than that. So, I want to thank you so much for joining us, and we'll talk offline. Maybe there's a way that we can get some more of these questions out and answered. There were so many of them.

Paul Pitkin: 01:27:56 But for now, I want to thank you so much, and on behalf of the Trudy Sundberg Lecture Series, on behalf of the Sno-Isle Libraries Foundation, and on behalf of Sno-Isle Libraries, thank you. And I also want to thank our audience. I hope you enjoyed this as much as I did. I hope you were fascinated as I was. This is big picture stuff, and I can't think of a better thing to do on a Friday evening, then talk about the origin of universe. So like I said, I hope you enjoyed it as much as we did. It's been an absolute pleasure. Thank you for registering, thank you for your great questions, and thank you for participating in the Trudy Sundberg Lecture Series.

Speaker 1: 01:28:35 The Trudy Sundberg Lecture Series is underwritten by donations and sponsorships to the Sno-Isle Libraries Foundation from community donors like you, who believe in the power of ideas and information.

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