SCIENTIFIC AMERICAN FRONTIERS PROGRAM #1405
"The Dark Side of the Universe"
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IN THE BEGINNING
DARK MATTER
DARK ENERGY

In the Beginning

ALAN ALDA Once we thought our world was the center of the Universe. Today we know we're on a minor if privileged planet circling an average star in an inconspicuous spot in an unremarkable galaxy that's just one of billions of galaxies occupying a Universe that stretches farther than we can see -- even with our biggest telescopes. But in the last few years telescopes like these here in Chile have shown us that we are even less at the center of the Universe than we could ever have imagined. You and me and these rocks and the sun that shines on us and the stars that twinkle overhead aren't even built of the same stuff that most of the Universe is made of. And there's a mysterious force out there in space that literally comes out of nowhere. It's a force that seems to be pushing the Universe apart faster and faster - until one day everything out there beyond our own little solar system will simply disappear into blackness. Our Universe - and our place in it - just got a whole lot weirder.

ALAN ALDA (NARRATION) Staring at a patch of sky one-tenth the diameter of the moon, the Hubble Space Telescope recently peered farther out into our universe - and farther back in time - than any telescope before. For a million seconds it gazed, gathering light from 10,000 galaxies. The smallest and faintest are some 13 billion light years away, meaning their light has been traveling toward us since shortly after the Universe began. What gave birth to these first galaxies is one of the great mysteries of our Cosmos. But astronomers now suspect that matter we can see in the Universe -- including ourselves -- resulted from a titanic struggle between a form of matter we can't see - Dark Matter - and a force - Dark Energy - we've only recently detected. Together, Dark Matter and Dark Energy rule our Universe; and we're here to wonder about them only because in their battle for domination -which has gone of for most of eternity -- neither has triumphed. MISSION CONTROL Two, one, main engines start and lift-off of the Delta 2 rocket with the MAP spacecraft exploring the past and future of our Universe.

ALAN ALDA (NARRATION) This was the launch on June 30th, 2001 of a spacecraft able to look even farther back in time than the Hubble. Called WMAP, its mission was to capture the very first light of the Universe. That light has been traveling toward our own little corner of the Cosmos ever since it was released from what most astronomers now agree was the origin of everything we can see… planets…stars… galaxies like our own Milky Way… and the billions of other galaxies that have been expanding outward since the beginning. That beginning was the Big Bang, a ripping open of space and time inflating in an instant to become an unimaginably hot cauldron of energy and matter. It was light escaping from that cauldron that the WMAP satellite was sent to detect and measure - light now reduced by its journey through eternity to a faint afterglow called the cosmic microwave background radiation. What the satellite saw has been mapped onto something I can comfortably get my hands around - if not yet quite my head.

ALAN ALDA This device, this satellite, is picking up this cosmic background microwave radiation from way back in time, from the beginning of the Universe.

CHUCK BENNETT It's actually a direct picture of what the Universe used to be like, because it took that light all that time to get from there to the satellite.

ALAN ALDA OK, here's the thing… You have to help me visualize this. A lot of us when we first hear about the Big Bang think of it as an explosion happening in a point of space and moving out, and then somewhere we're in there or something. And a lot of us think when you look back in time, we want to look back to that point. But on the contrary, when you look back in time you're looking in every direction, you're looking all over some shell. And everywhere you look it's as far back as you can go. How could that be? Can you give me an image that helps me grasp that?

MAX TEGMARK You're trying to think of an explosion that happened in one place.

ALAN ALDA Yeah, I know, I know.

MAX TEGMARK And instead the Universe today doesn't have any particular center and it never did. Everywhere you were, you would have gone, it would have been expanding. I like to think of baking a loaf with little raisins in it, and when the bread rises all the raisins are moving away from all the other raisins, no raisin can really claim that it's in the center of this expansion any more than any other, right? And this is the same way we need to think of our space.

ALAN ALDA I know, but here's the problem. Every time one of those raisins wants to look at another raisin, it can look all the way across the loaf to a raisin on the other side. But if it looks in the other direction it sees the baking tin. That's a little bit different.

MAX TEGMARK That's because the bread is finite and we live in maybe an infinite space. If you live in an infinite loaf of bread there's nothing you can do to tell the difference.

CHUCK BENNETT The picture of an explosion as a ball of stuff is I agree that that's what many people think of, but that's just wrong. It's not what the Big Bang theory is all about. What the Big Bang theory is all about is space itself, think of it being stretchy and constantly stretching between every object everywhere, so that everything is getting farther away from everything else, and no matter where you are and you look out you see a glow left from the initial Big Bang.

ALAN ALDA So it needs to be called the big taffy pull instead of the Big Bang.

CHUCK BENNETT That would be a better name.

MAX TEGMARK It should be infinite then.

ALAN ALDA The infinite taffy pull. Well, I think we're getting closer. OK, show me what the implications of this mapping are.

MAX TEGMARK Well, what I love about, what I really love about Chuck's beach ball is that it represents this very basic fact that even though space itself may be infinite, we can only see a finite volume. It's a huge volume, this is about 13 billion light years in radius, but it's still only finite. So we're in the center of this and the most distant thing we can see is this hot glowing wall of hydrogen plasma, which is opaque. We just can't see what's on the other side.

ALAN ALDA (NARRATION) But on the side of the wall we can see - actually the inner surface of the beach ball - the incandescent plasma just beyond has cooled enough to go from being uniform and featureless to having eddies and ripples. It was these tiny imperfections that were imaged by the exquisitely sensitive eyes of the WMAP satellite.

MAX TEGMARK Chuck and his colleagues have stretched the contrast here by a factor of 100,000, to prevent it looking completely uniform. But there are nonetheless these tiny ripples where some places look hotter and some places look colder and that's just because there's a tiny bit more stuff in some directions than in other directions. And these little ripples are extremely important because it's because of them that we're here. You know if you had something that was extremely uniform it would stay uniform forever, it would never make clumps, planets, and we couldn't be here talking.

ALAN ALDA (NARRATION) To find out more about how those faint early ripples left over from the Big Bang became our Universe we've come here to the foothills of the Andes in Chile. This region has become home to some of the world's biggest and most powerful telescopes, lured here by clear skies and a smooth flow of air off the Pacific Ocean that reduces atmospheric turbulence, making for what astronomers call superb "seeing." This is the site of one such observatory, Las Campanas, run by the Carnegie Institution of Washington --- and the principle research site of an old friend of Frontiers, Alan Dressler.

ALAN DRESSLER Welcome to Las Campanas Observatory and the Magellan telescopes.

ALAN ALDA There seems to be two of them.

ALAN DRESSLER There are two, there are twin 6 1/2 meter telescopes which means they have mirrors that are about 22 feet across, which is a good size, and they collect light from distant stars and galaxies, and this is where we do most of our research.

ALAN ALDA (NARRATION) That research is focused on the formative years of the Universe.

ALAN DRESSLER At the beginning we know there was a very simple distribution of matter, it was very smooth, it was a very simple distribution of elements, hydrogen and helium, there were no stars, just gas. How did the Universe go from being deadly dull, with no variation, to tremendously complex so that there are creatures on it that look back and figure it all out? That's the fundamental question. And this zone, this sort of 3 billion years in to maybe 8 is where most of the complexity grew, and we can see that evolving, happening, by this strange ability to look back in time. I mean only in astronomy can you look back and see 5 billion years, 10 billion years into the past, you can see the past, because it took the light…

ALAN ALDA All those stories about time machines, we got one, we're looking at it. The light from the stars comes in through that mirror…

MIGUEL ROTH Exactly. Gets reflected on another mirror up there, which in turn reflects then the light through the hole in the black turret where there is another mirror, a diagonal mirror at 45 degrees that deflects the light into the instrument.

ALAN ALDA When the light hits that mirror, how long has it been traveling?

ALAN DRESSLER Well, for the things I'm looking at with Pat tonight, the light has been traveling for about 10 billion years. So pretty much the whole age of the Universe. And this is the first thing it hits in all that time. So it's got to be clean!

ALAN ALDA (NARRATION). Especially tonight - because it's the first time Alan will be using a brand new instrument.

ALAN DRESSLER Alan, this is Pat McCarthy, my science partner here. This is the slit mask.

ALAN ALDA (NARRATION) In what they call affectionately the wok, Pat has painstakingly cut tiny holes corresponding to the galaxies he and Alan plan to study.

ALAN DRESSLER In any area of the sky that we pick up, say a half a degree across, that's what this is looking at, that's the size of the moon, there would really be 100,000 galaxies, very faint, very distant galaxies, and we have selected in this case 700 of them we want to look at. So we must make sure the light from those 700 goes through the spectrograph, but nothing else.

ALAN ALDA (NARRATION) Alan's new instrument doesn't just take pictures of those distant galaxies: it can read their spectra. In fact, nearly everything we know about stars and galaxies comes from analyzing their light with the aid of a prism or - more commonly - a device called a diffraction grating.

ALAN DRESSLER When sunlight, or any light, strikes this, it's spread by color into its component colors. You can say how much red light, how much green light, how much blue light, tells you something about the temperature of the sun, and the sun is a star at 5000 degrees temperature, produces a lot of yellow light and so the middle of the spectrum, in the most intense part, is yellow green.

MIGUEL ROTH That we can see almost with our bare eyes. We can see red stars and bluer kind of stars, that has to so with the temperature of the star, basically.

ALAN ALDA (NARRATION) Here, for example, in one of the first images taken with Alan Dressler's new camera, both red stars and blue stars are visible in a galaxy nearby. But in the spectrographs astronomers use, the colors of a star can be analyzed in much finer detail than is visible in a rainbow. There are dark lines and bright lines at precise locations across the spectrum that reveal what a star is made of as well as its temperature and its size.

ALAN DRESSLER The reason that's important is different stars of different sizes last, they live, a different amount of time. The sun will last 10 billion years, it's halfway through its lifetime. A star much more massive than the sun might only live for one billion years. So if we can find those, we know that those are young stars, they cannot be any older than one billion years old, because they would already be gone.

ALAN ALDA Yeah, yeah.

ALAN DRESSLER So when I look across our galaxy I could do them one by one, I could tell you what each individual star is like. I could see a star like the sun all the way across our galaxy. And it I put together the light from billions of stars, I can see them all the way across the Universe and in that information is the rate at which new stars are being born in that galaxy, 3 billion years ago, 5 billion years ago, 7 billion years ago, so I begin to build up a picture of how rapidly were galaxies turning their gas into stars over their lifetime. A complete construction project.

ALAN ALDA (NARRATION) With twilight, the Magellan telescope's dome is opened.

PAT MCCARTHY We need to rotate 0.335 degrees, plus, 0.335, tres, tres, cinquo.

ALAN ALDA So how many galaxies are going to have their spectra taken?

PAT MCCARTHY We're going to take the spectra of 700 galaxies tonight.

ALAN ALDA Seven hundred.

PAT MCCARTHY Yeah, that's probably as many as has ever been done. I've got to remember to put in the wok, because that's a big mistake if you don't do that, you've really blown it.

ALAN ALDA (NARRATION) This first exposure using the wok took a half an hour.

PAT MCCARTHY OK, so already we can see some objects, that's encouraging. There's a bright one.

ALAN ALDA (NARRATION) This is just the beginning of several months' work that will add up to some 50 hours of data. But even from these first few minutes of peering across the Universe, a trickle of light has left the signature of a galaxy in the full fury of creation.

ALAN DRESSLER So here is a very faint line that is a very faint galaxy, very far away, and here is this one color that represents probably 100 photons of light coming from a place where a million hot young stars have formed in that galaxy ten billion years ago.

ALAN ALDA So ten billon years ago and all that made it to us tonight were 100 photons?

ALAN DRESSLER A hundred photons, that's right.

ALAN ALDA So this is the first scientific run you've done, right?

ALAN DRESSLER Yes, new instrument.

ALAN ALDA How do you feel, is it a good start?

ALAN DRESSLER It's a good start. I wish we'd seen a lot more in the first exposures, but you've got to have a lot of patience if you're going to do something really hard. But it works. The instrument works. It's producing spectra.

ALAN ALDA You've been working on this instrument for how long now?

ALAN DRESSLER Six years.

ALAN ALDA Six years.

ALAN DRESSLER Took a long time to build, but now it's going to pay off for us.

ALAN ALDA (NARRATION) That pay-off will help illuminate one of the Universe's darkest secrets - how those early ripples left from the big bang became the seeds of the stars. A vital clue to that mystery was discovered because a little girl loved watching the movement of the stars in the night sky outside her bedroom window. That story next.

Dark Matter

ALAN ALDA (NARRATION) In the early 1970s, Vera Rubin was a rare young woman in the traditionally male dominated world of astronomy.

VERA RUBIN I got interested in astronomy by watching the stars as they moved outside my window. I had a window that faced north, I had a bed under the window and I could see during the night that the stars changed their positions. And that's really what got me interested in astronomy. So I guess I was always interested in how things moved.

ALAN ALDA (NARRATION) Vera decided to look at how stars moved as spiral galaxies - like our own Milky Way - revolve majestically in space. Most astronomers then studying galaxies were drawn to their centers, where the stars are densest. But as a then shy young graduate student, Vera looked instead to where galaxies trail off into empty space.

VERA RUBIN I had children and I didn't want to compete with what other people were doing. So I decided to study the outsides of galaxies.

ALAN ALDA (NARRATION) What she discovered there was revolutionary -- in both senses. In our solar system, the planets revolve more slowly the farther they are from the gravitational attraction of the sun. Galaxies were assumed to rotate similarly, with stars moving more slowly the farther they are from the center. Instead…

VERA RUBIN I found that the stars very far out were going just as fast as those near the center, sometimes even faster.

ALAN ALDA Sometimes faster?

VERA RUBIN Sometimes faster, and well beyond where there was no light. In fact, I brought - I went to my office this morning and got this. Here's the Andromeda, which is the largest galaxy, largest spiral, near us. At our position in our galaxy, which would be maybe a third of the way out here, we are moving at half a million miles an hour around the center of our galaxy.

ALAN ALDA You can hardly feel the wind.

VERA RUBIN That's right. And you don't notice it because everything around us, all the stars near us, everything, is going just at the same speed that we are. So here are the velocities of stars and gas all the way across. Newton's Laws, because this is where the luminosity is, would predict that the velocities rise and then fall rapidly, so that by the time you get to what looks like the edge of the galaxy, the stars would be moving almost negligibly, very, very slowly. So what you see instead is they're moving very, very fast, all the way out there.

ALAN ALDA So when you got that information then, did you think you were wrong?

VERA RUBIN No.

ALAN ALDA You knew you were right.

VERA RUBIN I never thought…

ALAN ALDA You never thought you were wrong?

VERA RUBIN No, I had some crazy ideas, and then shortly settled with what would have to be, that matter that isn't luminous, that you don't see, the galaxy has to extend that far out, there has to be something, there has to be matter that's gravitationally accelerating the little bit of gas that we could see.

ALAN ALDA (NARRATION) There had been hints of invisible matter in the Universe before, but Vera Rubin's startling discovery confirmed it. Her observations implied, in fact, that galaxies are embedded in immense halos of Dark Matter, invisible to our telescopes, and yet making up most of the actual mass of each galaxy, including our own.

VERA RUBIN The whole concept of Dark Matter is enormous. It means that when you're looking at the sky you're only looking at a few percent of the Universe, that most of the Universe is invisible.

ALAN ALDA (NARRATION) To look into one of the possible sources of this invisible Dark Matter, we've come to California and the first mountain top observatory ever built -- the Lick Observatory, dating back to 1888. MAN The founder's buried at the base of the telescope. James Lick was buried at the base of the pier here.

ALAN ALDA Does anyone ever think about that?

DEBRA FISCHER I used to think about that when I was observing at the 40-inch down at the end of the hall and in the middle of the night the wind would come whirring through the hall and you'd hear the clanking of the old heaters, and yeah, I was pretty sure he was coming down to visit me.

ALAN ALDA (NARRATION) The original telescope here is still used to look at the planets in our own solar system. But Debra Fischer is hunting for planets well beyond its range - in fact for planets around other stars.

DEBRA FISCHER So this is the little collecting mirror that we're going to use tonight. The starlight will come down and hits the mirror and is reflected up through that trough, rslides up there and goes through that hole in the side of the dome. Looks like fun, right, we want our photons to have fun. So the light that we saw, the light-path outside…

ALAN ALDA I love these little mechanical things…

DEBRA FISCHER That's right.

ALAN ALDA Like something from Jules Verne.

DEBRA FISCHER Exactly. The magic part of our whole project really is this iodide cell. And now as the starlight passes through the cell, the iodine is absorbing the starlight at particular wavelengths and so finally in the spectrum of the star, etched into the spectrum, we have a forest of iodine lines, thousands of them, and so it's essentially like a grid on our spectrum.

ALAN ALDA (NARRATION) Debra is looking for tiny telltale shifts of a star's signature spectrum against that fixed grid of iodine lines - a shift that betrays a star's moving toward and away from us due to a planet's tugging at it. The wobble also reveals the planet's size and orbit.

ALAN ALDA The bigger the wobble of the star, the more it's doing that, the bigger the planet is going around it, and the faster it wobbles, the closer it is.

DEBRA FISCHER That's exactly right, yeah.

ALAN ALDA OK, so in that way you can really tell us what's there.

DEBRA FISCHER That's right.

ALAN ALDA (NARRATION) Debra and her colleagues have found some 70 of the over 100 planets so far discovered orbiting other suns. Most of these planets are huge and orbiting fast, making their detection easier. Debra's team's most dramatic discovery attracted the attention of a fourth grade class in Moscow, Idaho.

DEBRA FISCHER And when we found this system, this first star with three planets, they sent me a letter, you know, "Dear Dr. Fischer, we've been reading about this discovery in the newspaper and we're doing scale models of the solar system with paper plates, but we wondered if you've named the planets yet, because if you haven't, we have a suggestion." And so they said the planet that's four times the mass of Jupiter should be called Fourpiter, and the one that's two times the mass of Jupiter should be called Twopiter -- of course -- and then the little one that just orbits every four days should be Dinky.

ALAN ALDA (NARRATION) The star that Debra's observing tonight she's already looked at some 200 times - and while it used to be thought an unlikely candidate to have a planet, she's now picking up the faint trace of a wobble. Planets are thought to form from discs of dust and gas that surround a sun. And it could be that many of the billions of stars out there have planets, so far undetected.

ALAN ALDA The fact that you're looking for planets that so far haven't been seen mostly, is that some of the missing matter, or what?

DEBRA FISCHER That's a good question, and one of the early hypotheses was that maybe the Dark Matter is just planets. After all, we now believe that planets when they form, some of those planets fall inward but some are ejected from the solar system. And the best way to get a handle, sort of a back of the envelope calculation, is to look at stars that are forming, being born out of molecular clouds, and to imagine that all of the material in these typical discs around the star is ejected. Let's just take that as an approximation. And then, would that be enough to make up all of the missing matter. And the answer is no, the calculation has been done, and that it probably isn't the, it's an order of magnitude, orders of magnitude, too low, to account for the missing matter.

ALAN ALDA (NARRATION) In fact, not only is most of the missing matter in the Universe probably not the stuff that stars and planets are made of - its probably not the stuff that anything is made of. Here on the Yorkshire coast of northern England the search for Dark Matter has gone underground. This is the Boulby Mine, whose mile deep shafts provide cover from something tantalizing similar to the prime suspect for missing matter.

NIGEL SMITH If you're standing on the surface of Earth, and you put your hand out, you get hit, one cosmic ray a second goes through your hand, and that would spoil the detector signal that we're looking for. So you go deep underground, and then the large amount of rock between us and the surface shields us from the cosmic rays. So when we're down in our labs, rather than one a second going through your hand, it's one a week.

ALAN ALDA (NARRATION) But while cosmic rays are exotic, at least they're made from subatomic particles that science is familiar with. By contrast, the things Nigel Smith is trying to detect are bizarre even to physicists. Here, a mile down in a vein of rock salt mined to spread on the winter roads of northern England, he is in a race with some half dozen groups set up in similar underground labs around the world to be the first to detect what are called - with tongue in cheek -- WIMPs, for Weakly Interacting Massive Particles. WIMPs have the apparently paradoxical property of being massive -- in the sense that they exert a gravitational tug - while being almost completely unable to connect with ordinary matter in any other way. In fact, to call them "weakly interacting" is to be generous.

NIGEL SMITH Most of them pass straight through the Earth and don't even notice. Most of them pass straight through the sun and don't even notice. But every so often there's just one or two a month of a year that will actually hit a nucleus head on, and that nucleus recoils and it's that nuclear recoil that we're looking for. But the majority of the billions of WIMPs that are passing through as we stand here every second, they just stream straight through and you never see them.

ALAN ALDA (NARRATION) This is just one of three different kinds of detectors here at the United Kingdom's Dark Matter hunt, and the research project has just constructed an large new underground facility to house them. There are other detectors in tunnels beneath the Apennine mountains in Italy, where a joint Italian-Chinese team has been claiming evidence for WIMPs - a claim met with skepticism from their competitors… while in the United States a new facility is being constructed in a mine in northern Minnesota. All this effort to detect a hefty ghost particle that may not even exist. For those involved in the hunt, there's no doubt that it's worth it.

NIGEL SMITH It's a fantastic question. If you're an astronomer and someone says you don't know what two-thirds of the Universe is made from, that irritates you, so you want to go out there and find out what it is.

ALAN ALDA (NARRATION) And astronomers aren't the only ones in the hunt. Which is why I find myself driving a golf cart through the longest building in the world, the Stanford linear accelerator in California. I'm following the track of a subatomic particle as its accelerated during its two-mile trip to a speed approaching the speed of light. Eventually the beam of particles will be divided and spun around a couple of loops before crashing head on into particles coming in the opposite direction and smashing into smithereens. We're visiting the collision point, appropriately, with both a particle physicist and an astronomer.

ALAN ALDA So the beam of particles will come down here and go through that pipe?

PERSIS DRELL And then you hope that an electron and a positron will meet, annihilate, and new particles will be born.

ALAN ALDA (NARRATION) It's from collisions like this that scientists have built up their picture of the fundamental particles of matter in what they like to call the Standard Model. But for the Standard Model to work, physicists have been forced to invent a strange mirror world, in which the known particles have ghostly cousins called supersymmetric particles.

PERSIS DRELL This extra set of particles we haven't discovered yet, but they're our best candidate, we think it's the smoking gun, for the Dark Matter out there. So you and I aren't made of these supersymmetric particles, but the Dark Matter that's controlling a lot of what's happening in our Universe is made of these supersymmetric particles.

ALAN ALDA That's the best theory.

PERSIS DRELL That's our best guess at this point.

ALAN ALDA Now this is interesting. You are pretty sure or are you dead certain that these supersymmetric particles exist or have existed?

PERSIS DRELL Let Roger…

ROGER BLANDFORD Less than pretty sure but if this were a horse race this is the one I'd be putting my money on.

ALAN ALDA Is it thought that supersymmetric particles are all over the Universe?

PERSIS DRELL They're out there…

ALAN ALDA And how did they get started? Where did they come from?

PERSIS DRELL From the Big Bang itself.

ALAN ALDA From the Big Bang. So are you trying to create a situation something like the Big Bang where you get both the particles and the supersymmetric particles, the mirror versions of them? I thought you needed something a lot… I thought you needed a lot more energy than you could possible get on Earth to create a Big Bang.

PERSIS DRELL We're not recreating the Big Bang.

ALAN ALDA Right, thank God, because I'd stand a lot further away from it and I'd wear that hat.

PERSIS DRELL But we are able, if we have enough energy in our particle accelerators to create the constituents that were created in the Big Bang.

ALAN ALDA (NARRATION) And so at the same time as astronomers are going underground in their hunt for the missing Dark Matter, particle physicists too are burrowing to build the biggest atom smasher ever in the hope of creating Dark Matter. This is the construction of what's called the Large Hadron Collider at CERN in Switzerland. Due to come on line in 2007, the LHC will have gigantic detectors designed to peer into the wreckage of particle collisions of truly stupendous energies - if not quite the Big Bang, then certainly the closest we've ever been to it. The closest we've actually been to it, of course, was with the

WMAP spacecraft, which mapped the ripples left as the Big Bang cooled. In the pattern of these ripples, the WMAP scientists see direct evidence for Dark Matter.

MAX TEGMARK You only get this if you have about six times more Dark Matter than all atoms combined.

CHUCK BENNETT What we did was we generated literally tens of millions of possible Universes on the computer and we compared them with our measurement of the real Universe that we have. And I think of it like matching fingerprints. So this is the actual fingerprint of the real suspect and we have a mug-book of fingerprints and we match 'em up and we pick out the right suspect that way. And as Max described, the right suspect has this substantial amount of Dark Matter in it.

ALAN ALDA (NARRATION) Today, then, the evidence is mounting that most of the stuff in the Universe is not only invisible to us but isn't even what the visible stuff is made of. But to astronomers like Alan Dressler, looking back in time to see how the Universe began, Dark Matter is more than just astonishing; it allowed us to be.

ALAN ALDA So you're taking this picture of way back in time and you're seeing the formation of the stars. What role does Dark Matter play in that?

ALAN DRESSLER It's very important to see how galaxies form but they couldn't have formed we now believe without the Dark Matter. Because there wasn't enough gravity in all this kind of material that we're made of to coalesce and make stars. And that's where the Dark Matter played the pivotal role. It actually held this, what we call baryonic, normal matter together and allowed it to begin to concentrate and to cool and then make stars. So already there were those sort of wells, these places where gravity was strong… And all these atoms suddenly said, oh, there's gravity here from this Dark Matter, and they headed in that direction. So they fell into those little wells of gravity that had been growing since the Big Bang.

ALAN ALDA (NARRATION) But if Dark Matter's gravitational hug was indispensable to our Universe's birth, we now know that from the start it's been opposed by an anti-gravity force that might - if things had turned out just a little bit differently - have overwhelmed it, and instead blown the infant Universe apart. That story next.

Dark Energy

ALAN ALDA (NARRATION) In the early 1990s, two groups of astronomers came up with a new idea for discovering the ultimate fate of the Universe. Both groups -

which were soon to become rivals - used several telescopes in their quest, including this one at Cerro Tololo in Chile.

CHRIS SMITH They have their nights on the telescope, sometimes actually immediately after our nights, or in between our nights.

ALAN ALDA So do you go around looking for scraps of paper the other one's left, or what?

CHRIS SMITH No, sometimes we look at, you know we try to figure out what they've observed, but usually it's a friendly rivalry.

ALAN ALDA (NARRATION) Both teams used the telescope to look for the same thing - the death of a star. But not just any stellar death - a particular kind caused when a companion star dumps material onto a so-called white dwarf, until the white dwarf reaches a critical mass and explodes. This is called a Type 1a Supernova - and the astronomers like it because all Type 1a Supernovae are almost exactly alike -- identical flashbulbs popping off randomly all over the sky.

NICK SUNTZEFF With just a two-minute exposure on this telescope, we can see half way across the Universe. That's how powerful the telescopes are and how bright supernovae are. So we can take very short exposures and cover large parts of the sky to discover supernovae.

ALAN ALDA (NARRATION) But discovering them is only the beginning. Once a supernova is spotted, other even bigger telescopes are standing by to pounce on its light and read its spectrum.

NICK SUNTZEFF If we don't find supernovae in this telescope, then all the other telescopes who are waiting have nothing to do. They get real mad at us.

ALAN ALDA Is this the first night you're observing in this test?

NICK SUNTZEFF Yeah, this is the beginning of our season, so we're going to go three months now, thirty half nights searching for supernovae. And tonight is the first night.

ALAN ALDA So your exposure is covering all of this and that's even more than a full moon would be in the sky. So what's the probability that you'll find a supernova?

NICK SUNTZEFF In this one field?

ALAN ALDA Yes.

NICK SUNTZEFF It's about one.

CHRIS SMITH It's one for the month.

ALAN ALDA So sometime during this month you're going to, if you keep pointing there, you're going to catch at least one.

NICK SUNTZEFF Oh, yes, definitely.

CHRIS SMITH Now the telescope is slewing so stars are whipping by.

NICK SUNTZEFF Here's a cool image. This is the first image that came off tonight. And so you can see lots of galaxies. Very faint galaxies, stars. There's a very nice spiral galaxy here with distorted arms. So you're going to observe, right?

ALAN ALDA You mean, more than I am now?

NICK SUNTZEFF Yes, right here.

ALAN ALDA You want me to actually…

NICK SUNTZEFF Sit here, yes.

ALAN ALDA The end of science as we know it. All right. OK. Well now, let's see, I'll just hit a few keys.

NICK SUNTZEFF No!

ALAN ALDA I just like to poke around, that's how I learn, you know. What should I do first?

CHRIS SMITH When he says OK, you hit enter.

ALAN ALDA And that's it?

CHRIS SMITH That's it, yes. OPERATOR OK.

ALAN ALDA OK

CHRIS SMITH And that sound was the shutter opening.

ALAN ALDA Oh yeah, I heard that.

NICK SUNTZEFF Your first image in search of supernovae.

ALAN ALDA I hope I find one.

ALAN ALDA (NARRATION) That first night of the season, Nick and Chris and their team took 16 different snapshots of the sky. By the next night, now no longer observing from the telescope but from a control room in the nearby town, they had processed several of those images. And one of them - though sadly not mine - came up trumps. GAIUS So here we've got a big diffuse source of light. And in both the images there's apparently a new light source just outside that galaxy. That looks like a supernova to me.

NICK SUNTZEFF Yeah, great. This would be a really good candidate if we get a follow-up image to do spectroscopy. As a matter of fact, we don't need a follow-up image. This definitely is a supernova.

ALAN ALDA (NARRATION) Supernovae are very rare events. The last one in our galaxy was 300 years ago. So it's only by staring at tens of thousands of galaxies at a time that the supernova hunters can hope for success. Once they've found one, then there are a few days while its explosion continues for a large telescope like the Keck in Hawaii to get its spectrum. This not only confirms it's a Type 1a, but also gives its age: the older the light, the more it's been stretched as space itself has expanded, and so the longer its wavelength -- the more it is shifted toward the red. And because every Type 1a supernova explodes like a standard flashbulb, its brightness reveals how far away it is. And this is why both rival teams of astronomers were hunting so eagerly for Type 1a Supernovae: by finding them of different ages and measuring their distance, both groups hoped to find the answer to one of astronomy's great questions: what is the ultimate fate of the Universe? We met members of one team at Cerro Tololo. The other is based here in at the Lawrence Berkeley Laboratory in California, and is led by Saul Perlmutter. Both teams expected to measure how much the expansion of the Universe has been slowing due to gravity - especially the gravity of all that recently discovered Dark Matter.

SAUL PERLMUTTER We thought it was going to be a great project. We were going to find out whether the Universe was going to last forever or not, or whether some day all this stuff in the Universe, all the matter in the Universe, would slow the expansion down to the point where it would come to a halt and then collapse. And what we ended up with, when we started looking at the data, it looked like it was very little matter in the Universe, in fact it wasn't slowing very much at all. And then as you really looked at the data you started noticing, oh, it's not only not slowing down much at all, it's not even slowing, it's actually speeding up. And that was a real shock, because it was not part of the original, you know, description of our project when we were applying to use the telescopes. It was way better than that.

ALAN ALDA (NARRATION) Instead of slowing down due to gravity, the expansion of the Universe appeared to be speeding up as if under the influence of some sort of anti-gravity. The rival team was coming to the same mind-boggling conclusion.

ALAN ALDA Was it an exciting moment of was it just puzzling?

CHRIS SMITH Puzzling and concerning, because it wasn't the expected result. We were expecting deceleration. So really the knot twists up in your stomach saying, OK, let's go back and do this again and make sure this is right. And you go back through the numbers once again, and you go back through the numbers yet again and now you're starting to believe, well, we're on to something here. Wow! And the whole group - we're distributed and so the emails start coming in, saying, jeez, can this be right?

SAUL PERLMUTTER You don't want to come out with anything that's wrong, of course, in a scientific, you know, a major scientific announcement, and so you're being so careful trying to check, well maybe it's this, maybe it's that, you're looking at every possible thing. Finally we came to the conclusion, well, we have to come out and say it.

ALAN ALDA Were you all getting it at around the same time?

NICK SUNZTEFF Yeah, we announced at the same time in 1998 at a conference in Santa Barbara, and both groups came out and we sort of knew that the other team was going to announce the same thing, and I'm never sure how we knew that.

ALAN ALDA Were you pointing your telescope in their window and looking at their paper?

NICK SUNZTEFF No, we wouldn't do that!

SAUL PERLMUTTER The fact that both teams got the same result I think gave people a lot of confidence that it wasn't just some mistake somebody had made in their calculations, because they knew that the two teams would have loved to, you know, been able to get the right answer and show the other one might be wrong.

ALAN ALDA (NARRATION) Not everyone was taken aback by the idea of a runaway Universe. Michael Turner had actually predicted the possibility several years earlier, reviving an old idea of none other than Albert Einstein. Turner came up with a name for a force that could push the Universe apart - Dark Energy -- but its roots lay in one of Einstein's famous equations.

ALAN ALDA The notion of Dark Energy was, as I understand it, something that he came up with and didn't really understand he'd come up with it. How far off am I with that?

MICHAEL TURNER That catches a lot of it. I mean, in science, people are often confused and so Einstein was confused about the expansion of the Universe. His equations wanted a Universe that expanded and so he put in this fudge factor that canceled the attractive gravity of matter.

ALAN ALDA (NARRATION) When just a few years later the Universe was discovered actually to be expanding, the Cosmological Constant - Einstein's anti-gravity fudge factor - was no longer needed. He gratefully discarded it, calling it his greatest blunder.

MICHAEL TURNER But one of the wonderful things about science is that when we're in this struggle to try to understand, we invent things. And once you take something out of Pandora's Box, you can't put it back. And so this idea was laying around in our idea box and it's sort of like anti-gravity, it's a repulsive gravity, and so it resurfaced again in trying to understand why the Universe, not is expanding, but the expansion is speeding up.

ALAN ALDA How did you come up with the name Dark Energy?

MICHAEL TURNER It's kind of a nice yin and yang with the Dark Matter. You know, so we have Dark Matter and we have Dark Energy and they're fundamentally different - you know, matter is different than energy - and then today we have the battle between the Dark Matter and the Dark Energy.

ALAN ALDA (NARRATION) There is one uniquely privileged spectator to the battle between Dark Matter and Dark Energy - the Hubble Space Telescope. Perched high above the atmosphere of Earth, it has a clear view of the supernova beacons used to track the Universe's history. We went to visit the control room for the Hubble Space Telescope in Baltimore.

ADAM RIESS Welcome to the Space Telescope Science Institute.

ALAN ALDA (NARRATION) My guide is supernova hunter Adam Riess.

ALAN ALDA Can you tell me what all these folks in here are doing? I mean, there's constant activity and chatter. What is it all about?

ADAM RIESS Right. They're primarily monitoring health and safety. They're looking at telemetry. They're looking at temperatures and voltages of thousands of different components pf the telescope to make sure they're all within tolerances. They're looking at heating on one side of the telescope when it's in the sun side. About once a week we upload a whole week's worth of observations, what's supposed to be done that week with the telescope. So if we find a supernova, for example, we usually have to find it by Tuesday, because Tuesday is a special day when they build the calendar for the next week. It's sort of funny. The light's been traveling for 11 billion years and it finally arrives and it's got to arrive on Tuesday.

ALAN ALDA (NARRATION) In March 2002, the space shuttle Columbia - on what was to turn out to be its last completed mission - installed a new camera on the Hubble, the Advanced Camera for Surveys.

ADAM RIESS This camera is much more sensitive to light, and it has more area, so I have a better chance of finding a supernova every time I pick an image in the sky.

ALAN ALDA (NARRATION) Adam's plan was to look back with the new camera to supernovae exploding when the Universe was young. He found some half dozen, ranging in age back to 11 billion years ago. His hope was to find out if the Universe has always been pushed apart by Dark Energy, or if once it had been reined in by the gravitational pull of Dark Matter. Adam Riess works closely with Mario Livio. Adam observes the Universe, Mario comes up with theories about it.

MARIO LIVIO Basically, you have the Universe behaving something like this. At first, it is expanding against gravity. So think of it as being held back by some sort of spring…

ALAN ALDA But it's getting bigger and bigger and bigger over millions, billions of years…

ADAM RIESS That's right.

ALAN ALDA And then at some point it's…

ADAM RIESS About five billion years ago, we think…

ALAN ALDA It stops slowing down, and instead of collapsing - that's what we would expect, it would get that big and then come back, right?

MARIO LIVIO Well, maybe not come back, but it would go slower and slower and slower. Instead, it suddenly starts going faster and faster and faster.

ALAN ALDA And you found out when it started going faster and faster and faster?

ADAM RIESS That's right. We actually witnessed the transition from the more recent accelerating expansion to the earlier slowing expansion.

ALAN ALDA (NARRATION) This literal turning point in the history of the Universe came at about five billion years ago, when Dark Matter began losing its gravitational pull against Dark Energy's inexorable push.

MARIO LIVIO You know, gravity increases in proportion to distance. You know if you double the distance, gravity becomes four times weaker. This force that you get from Dark Energy, when you double the distance the force becomes twice larger.

ALAN ALDA Oi, oi, oi!

ADAM RIESS We think it's a property, actually of the vacuum. So when there's more vacuum between you and a distant galaxy, there's more of this Dark Energy.

ALAN ALDA So there is a factor of an increase in the amount of Dark Energy that has a factor on speed?

ADAM RIESS Yes, that's right. It's a little bit like a built-in spring in the vacuum, and as something gets further away, there are more and more of these springs connected and it's harder to compress. In fact, they're pushing more and more. And so the bigger the Universe gets, Dark Matter is losing its pull on the Universe, Dark Energy is gaining its push.

ALAN ALDA It's always been there, right?

ALAN ALDA (NARRATION) The question that's now obsessing astronomers - including Michael Turner - is what Dark Energy might be.

MICHAEL TURNER We just don't know what it is. If it is like Einstein's' Cosmological Constant, then it's just the energy of nothing. And according to quantum mechanics, nothing is not nothing, it's full of particles that are living on borrowed time and borrowed energy.

ALAN ALDA That pop into existence…

MICHAEL TURNER Pop into existence and then when the accountants come along, they disappear. And so, if it's the energy of nothing, it's always been here, and then we're in for a very tough bit of history in the future because the Universe will keep speeding up and speeding up and speeding up and things will get farther and farther away and instead of the beautiful sky we have today with billions of galaxies, we'll only see a couple. It could be that it's just a phase we're going through, that something's out of whack and that the Dark Energy will dissipate. I think what you're starting to see is that we don't know much about it at all.

ALAN ALDA All this stuff didn't fill us in that much.

MICHAEL TURNER We need some help, we need some help.

ALAN ALDA (NARRATION) Help may be on the way from a proposed new spacecraft expressly designed for supernova hunting. With a camera able to image thousands of supernovae at a time, the SNAP satellite would hugely increase the number of beacons out there measuring the Universe's expansion. This might not only help find out what Dark Energy is, but also help answer what is perhaps the deepest question of all. Is there a reason why the Universe turns out to be in almost perfect balance between the pull of Dark Matter and the push of Dark Energy? Or is the fact that Dark Energy didn't blow it apart in its infancy just a lucky accident? Maybe the Big Bang that turned out so well for us was just one big bang among many.

MICHAEL TURNER If this burst of expansion happened here, there's no reason it wouldn't have happened here and there, and in that past and in the future.

ALAN ALDA In the same Universe?

MICHAEL TURNER In the same Universe.

ALAN ALDA In what was, what should amount…

MICHAEL TURNER So now we need new language, right? So the Universe is a whole ball of wax, but there are different disconnected parts in it.

ALAN ALDA It's like bubbles in a glass of champagne.

MICHAEL TURNER Exactly.

ALAN ALDA The champagne is the Universe at any given time, or the multiverse, and each bubble is a new Universe.

MICHAEL TURNER Is a new Universe.

ALAN ALDA If this is our Universe, where would the other Universes be in this multiverse?

MAX TEGMARK Thanks for passing me the Universe. We're actually kind of sloppy in astronomy when we talk about the Universe. What we usually mean is just the interior of this beach ball.

CHUCK BENNETT The part of the Universe that we can observe, we call the Universe.

MAX TEGMARK And that's of course, strictly speaking, not true at all, because I don't have a single colleague who would entertain that space ends here, you know, there's a sign here saying "space ends here, mind the gap." We all believe that space goes on outside, right?

ALAN ALDA Yes.

MAX TEGMARK And most of us believe that space actually goes on forever, it's infinite. Which means there's another sphere like this and in the middle of that maybe there's another planet where people discuss their Universe and can't see ours, and there's probably infinitely many of these.

MARIO LIVIO If you have this ensemble of universes, there may be some basic things which are true for all of them, but there may be some quantities which are accidental in these different universes Some of those universes will allow life to evolve and us to be here and speak about it, and some won't.

ALAN ALDA (NARRATION) We said at the outset that our Universe just got a whole lot weirder, dominated by matter we can't see and a force we can't feel. But maybe it's even weirder than that. Not only are we not at the center of our Universe; we are not even in the only universe, just one in which Dark Matter and Dark Energy fought each other - at least when it mattered, back when the stuff we're made of was created - to a standstill.