Phantom of the Universe Script

[00:03] As we look out, into the night sky, we are both dazzled and comforted by the patches of light we find there: stars, planets, galaxies, and the moon. [00:25]

[00:34] But, as instruments became more advanced, astronomers began to suspect there was something more out there – something hiding… in the dark spaces. [00:45]

[00:47] We can't see it, feel it or touch it… but it's there. [00:53]

[00:59] It doesn't emit light or reflect it. It's a substance so mysterious, there's only one way to describe it: dark matter. [01:12]

[01:15] It's so massive, its gravitational pull influences the brightest and most colossal objects in space. [01:23]

[1:24] It's so powerful, it can change the course of light itself. [1:30]

[01:37] It's a humbling reminder that there's more to this universe than meets the eye. [01:43]

[01:45] In order to understand this mysterious substance, physicists on Earth are hunting down a very elusive particle they believe exists in the subatomic world. [01:56]

[2:05] This is CERN, the European Center for the Study of Particle Physics. [02:10]

[02:11] It's the home of the world's largest particle accelerator, the Large Hadron Collider. [02:17]

[02:19] Hidden deep underground, the Large Hadron Collider is the only place on Earth powerful enough to bring this mystery particle into existence. [02:28]

[02:30] At 27 kilometers in circumference – that's 17 miles – it straddles the border between France and Switzerland. [02:39]

[02:41] As we enter the accelerator tunnel, we'll experience – first hand – the fastest chase scene on Earth. [02:48]

[03:04] Here, inside the beam pipe, particles called protons are pushed to velocities approaching the speed of light. [03:11]

[03:17] Some of them will smash into *other* protons racing straight toward them. [3:20]

[3:25] It's all part of the hunt for a new kind of fundamental particle that forms *dark matter*. [03:30]

[03:39] Already the Large Hadron Collider has made an incredible discovery that lends weight to our story. Not that long ago there were fireworks at CERN on a recent Fourth of July as scientists announced the discovery of a particle called the Higgs boson. [3:57]

[3:58] Physicists had searched for this particle for 50 years, ever since theorists showed that the source of the mass of all fundamental particles requires its presence. Particles like electrons and quarks get their mass when they pass through the Higgs Field, and so might the particle that makes up dark matter. [04:20]

[04:23] Now, the search at the Large Hadron Collider turns to finding the dark matter particle itself. [4:28]

[4:33] Astrophysicists have demonstrated that over 80% of the mass in the cosmos consists of dark matter [04:41].

[4:43] TITLE SEQUENCE [5:03]

[04:47] This is the amazing story of how we discovered that most of the matter in the universe is of an extraordinary, invisible type. [04:57]

[05:05] Dark matter has been around since the beginning of time… the very beginning… [5:12]

[5:13] BIG BANG EXPLOSION

[5:14] Our universe was born in the form of a hot dense frenzy of energy expanding at an incredible rate. [05:21]

[5:25] A tiny fraction of a second later, energy transformed into the first particles of our universe. [05:32]

[5:34] Tiny particles called quarks formed protons and neutrons. These combined with electrons to create the first atoms. Atoms, in turn, make up regular matter, the substance of which, physical objects are made. [5:49]

[05:52] As conditions cooled and space expanded, *dark* matter's mass coalesced into strands. These strands formed an invisible skeleton in space. [6:06]

[6:08] Over hundreds of millions of years, the gravity from dark matter's mass was so powerful, it pulled regular mass to it, like meat to its ribs… and formed the sinewy structure of the universe. [06:23]

[06:33] The first galaxies grew at the intersections of these filaments. [06:37].

[06:41] Galaxies collided with other galaxies… and merged again to form super-clusters of galaxies. [06:47]

[06:48] Countless galaxies were drawn together by dark matter's pull. [6:55]

[6:57] and from there, they grew into the structure of the universe we see today. [7:01]

[7:02] Without dark matter, there would be no stars, no galaxies, no planets, no life. Without dark matter, we ourselves would not exist. [7:14]

[07:17] Dark matter lay hidden from human view for millennia until finally, traces of its influence became apparent to astronomers. [07:24]

Fritz Zwicky

[07:27] The first was Fritz Zwicky, a Swiss astronomer, who worked at Cal Tech in the 1930's. [7:33]

[7:35] Zwicky turned his telescope toward a group of galaxies not too far from our own Milky Way. This swarming network of over a *thousand* galaxies is known as the Coma Cluster and Zwicky's mission was to determine its mass. [7:50]

[7:51] He could do this by measuring its brightness... [7:54]

[8:01] ...and by measuring the <u>speed</u> of galaxies orbiting <u>inside</u> the cluster. [8:06]

[8:13] Zwicky discovered that the galaxies were moving much faster than he expected. [8:18]

[8:20] Especially considering the amount of mass in the cluster as indicated by brightness. [8:25]

[8:25] At these speeds, the visible mass wasn't great enough to hold the cluster together. [8:30]

[8:32] Zwicky theorized there must be some invisible substance lying in hiding holding the speeding galaxies into the cluster. [8:41]

[8:45] He called the substance “dark matter.” [08:48]

[8:50] But some ideas are ahead of their time. [8:53]

Vera Rubin

[8:54] Zwicky’s revolutionary findings went largely unnoticed until 40 years later when astronomer Vera Rubin started to study the orbital speeds of stars in galaxies. What she observed surprised and confounded her. [9:11]

[9:15] According to Newton’s Law of Gravitation, the sun’s powerful mass creates a gravitational pull that causes the inner planets to travel at faster speeds than planets that are farther out. [9:28]

[9:50] Since stars orbit around a galaxy’s center much the way planets orbit the sun, Rubin thought she’d see similar speed patterns when she observed the nearby Andromeda Galaxy. [10:01]

[10:04] But what she saw was radically different. [10:08]

[10:09] Stars that were in orbit far from the galaxy’s center were whizzing along at high speeds, identical to the stars much closer in. [10:18]

[10:22] This was not at all like the speeds of planets in our solar system, where the inner planets go much faster than the outer planets. [10:29]

[10:32] At these incredible speeds, without adequate gravitational pull from something massive, the stars should fly out of control and jettison out into space. [10:47]

[11:02] Rubin and her team concluded that there must be some strange, invisible mass that extended to the outer edges of the galaxy and beyond. [11:11]

[11:14] It was as if an invisible cloud held the stars together like a kind of glue. [11:18]

[11:19] We can see visual evidence of these dark matter halos in other parts of the universe as well. [11:25]

[11:31] We see the most dramatic evidence for dark matter in a celestial structure astronomers refer to as “the Bullet Cluster.” **When astronomers looked closely at galaxies in the cluster, they saw subtle distortions caused by something invisible.** [11:47]

[11:48] The suspect: dark matter. [11:50]

[11:52] Astronomers used an x-ray telescope in space to detect massive concentrations of hot interstellar gas whose bullet-like shapes give the cluster its name. [12:03]

[12:04] The Bullet Cluster was formed when two smaller clusters of galaxies collided. [12:09]

[12:10] If we could travel back in time to before the collision, we’d see two distinct clusters, each enclosed in its own cloud of dark matter. [12:20]

[12:21] When the two galaxy clusters collided, the dark matter clouds passed right through each other. [12:27]

[12:27] The dense clouds of gas and dust shown in pink, however, crashed into one another toward the center. [12:33]

[12:58] What is this dark matter, that can pass right though a galactic collision without interacting with anything? [13:03]

[13:05] Because of this unique quality, a dark matter particle like this one travelling through space, won’t let anything stand in its way. [13:13]

LUX

[13:32] Dark matter doesn’t exist only out in space; it’s everywhere… [13:39]

[13:48] Dark matter is all around us right now. [13:51]

[13:55] If you hold up your hand, millions of dark matter particles will pass through it within the next minute. [14:01]

[14:03] Particles you can't see or feel. As a matter of fact, there are billions of different subatomic particles flying through this room as we speak. [14:14]

[14:19] This is the entrance to the Homestake Mine in South Dakota. It’s the ultimate place to filter the dark matter particles out from the rest. [14:28]

[14:30] In order to isolate the dark matter particles, physicists conduct experiments

deep underground where most ordinary particles can't travel, but dark matter particles easily *can.* [14:43]

[14:46] Every morning, dozens of scientists travel down a giant elevator shaft 1500 meters underground -- that's almost a mile -- to work with the most sensitive dark matter detector in the world. [15:00]

[15:01] What they find in this sub-terrestrial labyrinth of abandoned mining tunnels could change the way we view the entire universe. [15:10]

[15:17] This was once a thriving gold mine but now instead of miners mining for gold, the physicists who work here are mining for an even more elusive substance: dark matter. [15:28]

[15:31] This is the Sanford Underground Research Facility [15:34]

[15:35] It's here that we'll find the Large Underground Xenon *Dark Matter* Experiment, or "LUX" for short. [15:40]

[15:42] This tank filled with liquid xenon will be the perfect theater for witnessing the first appearance of a dark matter particle. [15:50]

[16:06] The bait for detecting that dark matter particle will be the nucleus of a xenon atom. [16:11]

[16:11] When a dark matter particle hits, the nucleus will give off a flash of light…or release electrons. [16:19]

[16:23] These interactions will then be recorded by sensors on the bottom and top of the detector. [16:28]

[16:44] Dark matter interactions of *any* kind are rare, but physicists hope they'll see one very soon. [16:50]

CERN

[17:04] On the other side of the world, another group of physicists is working on *creating* their *own* dark matter particle. [17:12]

[17:15] They're doing it here, at CERN, the world's largest research center for the study of particle physics, located outside Geneva, Switzerland. [17:24]

[17:35] Here, thousands of scientists from many nations have joined together to track down answers to humankind's most complex, and age-old questions, concerning the nature of matter. [17:46]

[17:57] Hidden beneath CERN's sprawling 450 acre / 2 square kilometer campus and the surrounding forests and farms of the European countryside, lies the biggest and most complex machine in the world: the Large Hadron Collider, otherwise known as the "LHC." [18:17]

[18:18] Inside it, two beams of protons travel in opposite directions around the ring at incredible speeds. [18:25]

[18:28] The protons then collide inside four gigantic detectors located on the LHC track. [18:35]

[18:48] The LHC is a giant particle racetrack. Instead of fuel, these subatomic racers are accelerated around the track by electric fields, and steered by high-powered magnets. [19:04]

[19:06] The particles are then guided toward collision, in the core of each detector. [19:11]

[19:13] The largest detector is appropriately called ATLAS. It weighs 7000 tons and took 15 long years to build. [19:24]

[19:25 – 20:05] ATLAS / Transformers Scene

[20:06] At almost 8-stories tall, ATLAS is the size of a cathedral. [20:11]

[20:13] More than three thousand scientists from 175 institutions in 38 countries work in collaboration on its experiments. [20:23]

[20:26] In essence, ATLAS is an enormous microscope aimed down into the subatomic realm. [20:32]

[20:34] With billions of protons traveling around the track in opposite directions, the scene can seem more like a demolition derby than a racetrack. [20:44]

[20:46] When two protons collide, hundreds of new particles are formed. [20:50]

[20:52] The incredible energy of the collision can produce particles with far greater mass than that of the two protons that created them. [21:00]

[21:01] This is exactly what physicists predict will happen if they create a dark matter particle with great mass. [21:09]

[21:10] Every line in this collision display reflects the presence of a newly created particle. [21:16]

[21:17] The curvature of the line tells us the particle's momentum. [21:20]

[21:24] ATLAS records the collisions with several devices that are arranged in concentric layers. [21:29]

[21:32] Each device is like an extraordinary camera, specially designed to detect and record different kinds of particles. [21:39]

[21:43] According to Sir Isaac Newton, momentum traveling in opposite directions must balance out, as it does in this display. The yellow squares show an even distribution of particles and momentum. [21:57]

[21:59] In the case of a dark matter particle, however, there will be a *gap* where the particle flew through ATLAS without interacting with *any* of its sub-detectors. [22:09]

[22:10] How can a dark matter particle fly through the world's most sensitive particle detector without leaving a trace? [22:16]

SUSY

[22:18] A theory called Super-Symmetry predicts the existence of a particle that would act in exactly this manner. [22:25]

[22:27] According to this theory, for every known particle, like an electron or quark, there's a corresponding super particle with a much greater mass. [22:37]

[22:44] As you can see, the correspondence creates a nice symmetry. [22:48]

[22:49] Physicists believe that one of these predicted super particles may be the dark matter particle. [22:55]

[22:56] Now to find it… [22:57]

[23:02] ATLAS takes pictures of the most important collision events 40 million times per second. [23:07]

[23:19] Collision data is stored in a massive network of computers at CERN and around the world called "The Grid." [23:26]

[23:27] Computer programs scan data in the Grid looking for patterns that might fit the profile of a dark matter particle. [23:34]

[23:35] Very few collisions are expected to create dark matter particles, but if one did, looking through all the collision data would be a daunting task. [23:43]

[23:47] Fortunately, modern science is a collaborative endeavor. Physicists all over the planet are working around the clock to analyze the data. [23:56]

[23:58] A CERN engineer invented a thing called the "World Wide Web" in order to share this kind of information. [24:04]

[24:06] With all this brainpower looking for dark matter and exploring the fundamental nature of our universe, who knows what they may find? [24:14]

[24:16] Ultimately, it's the big questions that bring humankind closer together as we strive to understand the workings of this vast universe and our place in it. [24:27]

[24:33] END OF FADE TO BLACK