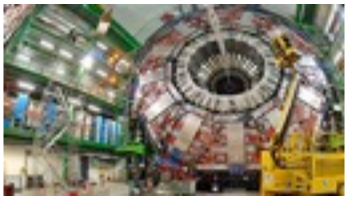
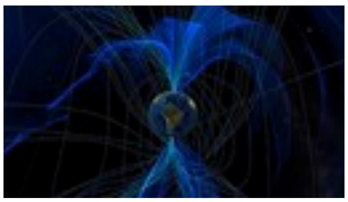
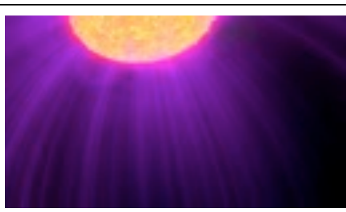
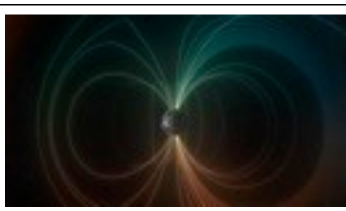
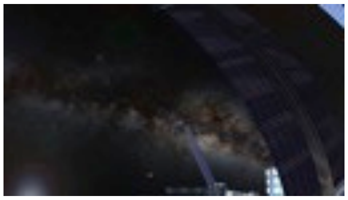
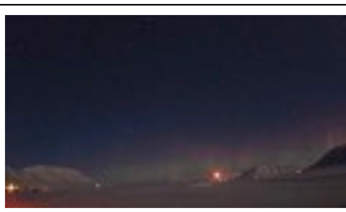
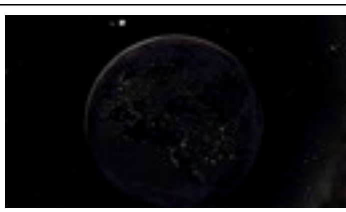
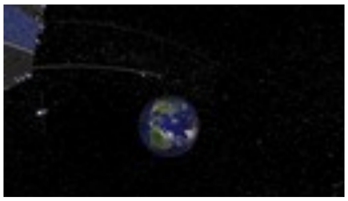
MAGNETISM

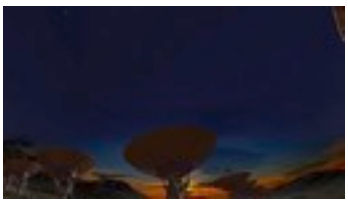
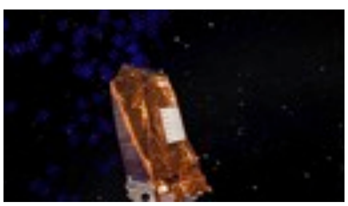
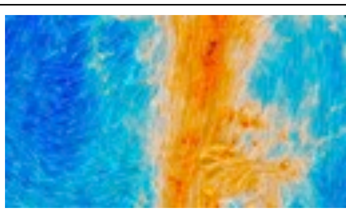
VERSION (SUBTITLES) REVISED: OCTOBER 11, 2017

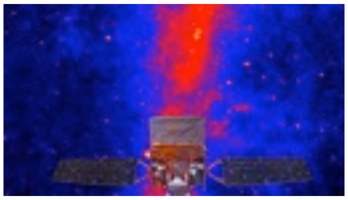
SCENE	TIME	SCRIPT
INTRO		
	00:18	The Large Hadron Collider lies in a tunnel below the border between France and Switzerland. A magnetic field, 100,000 times stronger than Earth's bends the paths of charged particles emerging from high-energy collisions...The curved tracks of these particles reveal their mass, charge, and energy.
	00:51	Meanwhile, high above our planet, Earth's magnetic field deflects charged particles coming from the sun and outer space. What is this invisible force that controls charged particles moving near the speed of light, directs the flow of matter in the cosmos, and creates a magnetic cocoon protecting life from the sun's deadly radiation?
TITLES		**OPENING TITLES**
	01:15	Magnetism: Defending the Planet: Defining the Cosmos
	01:24	Our star, the Sun, is the solar system's source of light and heat, driving Earth's climate and bringing our planet to life. Magnetism channels the paths of hot ionized gases climbing upward from the Sun's visible surface. These sunspots look harmless. But most of the sun's dramatic and potentially lethal eruptions begin in these active regions. Gases flow along these glowing arches. They rise up from the Sun, and then fall back; still trapped by the Sun's gravity and ruled by its magnetic field.
	02:27	The Sun's magnetic fields get tangled. Usually the Sun's gravity pulls these prominences back to the Sun. But if the magnetic field is twisted enough, the arches can break, releasing streams of hot plasma into space in a CME or coronal mass ejection. If this CME is headed toward Earth, a violent blast of charged particles will slam into our protective magnetosphere in a day or two.
	03:05	Earth's magnetosphere has cracks caused by magnetic reconnection. The solar wind pulls reconnected field lines into the Earth's magnetic tail. These stretched field lines ultimately connect again, blasting charged particles into Earth's upper atmosphere and resulting in shimmering auroras near Earth's poles. The Aurora Borealis or Northern Lights occurs most often along a circular zone across central Alaska, Canada, Greenland, northern Scandinavia and Russia. Because the magnetic tail is on the night

		side of Earth, the most intense, dynamic, and beautiful auroras occur near midnight.
	03:53	The low orbit of the International Space Station keeps it within Earth's protective magnetic field. In early 2016, astronauts gathered in the cupola, their favorite place to watch the Earth below. Anxiously they looked northward, hoping to see and photograph an aurora. As their path crossed over Europe they captured an aurora's green light along the northern horizon, dancing above Scandinavia. Gradually it faded from view as their path moved southward over the Black Sea. Meanwhile, for the first time, a crew in Tromso, Norway, photographed the same aurora from the Earth's surface.
	05:01	The aurora is a mysterious and unpredictable display of ghostly lights in the night sky, an eerie sign that our planet is electrically connected to the Sun. Auroras can appear as long, narrow arcs extending overhead, from horizon to horizon. From the side, they look like ribbons that kink, fold, and swirl. Their flickering rays align to the Earth's magnetic field and ruffle like curtains in an imaginary wind. They can also spread out like a heavenly crown, engulfing the sky in a misty veil.
	05:48	In an auroral substorm, sheets twist into waves and curls. Our ancestors saw great dragons or serpents in the sky. In Northern Europe, the aurora was the famous Bifrost, a glowing archway of the gods, to travel from heaven to Earth. In America, they were spirits carrying lanterns as they sought the souls of dead hunters.
	06:30	Auroral rays follow the lines of force in Earth's magnetic field. Oxygen atoms emit a green light when hit by high-energy electrons. Low energy electrons higher in the atmosphere cause oxygen atoms to glow red, giving the green aurora its red tip. These wispy auroras show us that our magnetic shield is still intact.
	06:54	When high-energy electrons strike Nitrogen atoms, the atoms produce blue auroras at high altitudes, and sometimes magenta auroras at low altitudes. The blending of aurora colors can produce purples, yellows, pinks, and whites. When you see auroras from the side, you can tell that the different colors come from different heights in the atmosphere. This diffuse blood red aurora spreads over the sky. During strong solar storms, these enormous red glows occur as far south as Florida and Texas. Auroras of all colors are signs that our planet is a life-bearing world with an atmosphere of Oxygen and Nitrogen, protected within Earth's magnetosphere.
	06:52	For centuries, sailors recognized that the star Polaris hovered very close to the North point in the sky. Patterns like the Big and Little Bears encircle this North Star. Explorers could sail the northern oceans by observing the position of Polaris in the night sky. But on cloudy nights, they needed another device to chart their course. The magnetic compass reached Western Europe in the early 13th century. With it, sailors could cross the planet's great oceans, discovering Earth's size and mapping its continents. Earth's

		uncharted lands became places on a map, its coastlines defined a world far larger than early sailors had imagined.
	08:46	The generator of Earth's magnetosphere lies deep in the planet's core. Here currents of liquid iron rise and turn with the Earth's rotation. The resulting electric current in the moving molten iron generates Earth's magnetic field. This field, in turn, reinforces the currents that created it. The result is a geodynamo, giving Earth its magnetic shield. This geodynamo turns Earth into a large bar magnet with north and south poles. We can see a bar magnet's magnetic field by dropping iron filings on a piece of paper above the magnet. The filings line up with the direction of the magnetic force. Earth's magnetic field has these same lines of force connecting its north and south poles. Creating this global magnetic shield required special conditions. Earth had to be large enough to have a molten core, and had to rotate fast enough to produce an electrical current that generates the planet's magnetosphere.
	10:01	Many different animals can sense Earth's magnetic field through structures in their eyes or brains. If fish swim along the direction of Earth's magnetic field lines, they sense nothing. But if they swim across the magnetic field, they can detect a tiny electrical force. This force guides them as they migrate north and south during the year. Hammerhead sharks have special gel-filled organs called the Ampullae of Lorenzini, which detect electric fields, both natural fields and those created from swimming across magnetic fields. Sensitivity to magnetic fields helps sharks and other fish swim in straight lines across the open ocean.
	11:02	The floor of the Atlantic Ocean tells us that Earth's magnetic field has not always been like it is today. A ridge runs from North to South in the Atlantic Basin. Here magma flows upward, spreads out, and turns into iron-rich rock. Like iron filings, the iron atoms in this rock are oriented to Earth's magnetic field at the time the rock hardened. From their changing orientation, we know that Earth's magnetic poles have flipped many times in geologic history. Currently Earth's magnetic field is decreasing in strength each decade. There could be a reversal of Earth's magnetic poles soon, perhaps in the next thousand years.
	11:52	Our advanced civilization depends on electromagnetic fields in communication, transportation, electricity production and power distribution. When the poles flip, the Earth will be temporarily without its magnetosphere. Astronauts and aircraft passengers could be grounded because there is no magnetic shield to protect them. The next magnetic pole reversal may be destructive and deadly.
	12:27	In March 2015, NASA launched a mission called the Magnetospheric Multiscale or MMS, aboard an Atlas 5 rocket. Its mission is to observe the conditions that allow charged particles to penetrate Earth's magnetic shield.

	13:14	On the night of March 12th, a rocket lifted off from Space Launch Complex 41 at Cape Canaveral Air Force Station, carrying the MMS spacecraft into Earth orbit. The Magnetospheric Multiscale mission requires four identical spacecraft working together to provide the first three-dimensional view of magnetic reconnection, a poorly understood process happening in Earth's magnetosphere and also on the Sun and throughout the universe. This suite of four spacecraft fly in a pyramid formation. MMS is the closest flying spacecraft formation ever launched, with the satellites just 7 kilometers apart. These satellites are also the highest altitude spacecraft to use GPS navigation.
	14:07	The MMS spacecraft travel directly through magnetic reconnection sites. Reconnection occurs when magnetic field lines annihilate each other, and release a gigantic burst of energy. This fundamental process taps energy stored in the magnetic field and converts it into fast moving charged particles. The MMS orbit was designed to fly precisely in the places where reconnection occurs. The discoveries from the mission will also tell us about reconnection in the Sun's atmosphere, in other stars, and in the vicinity of black holes and neutron stars.
	14:55	Astronauts in the International Space Station are within Earth's magnetosphere. But astronauts leaving Earth's cocoon on their way to the Moon or Mars have no magnetic shield and face a much greater danger. From 1969 to 1972, the United States sent 21 astronauts beyond Earth's protective magnetosphere. These Apollo missions were scheduled for a time of minimum sunspot activity when the solar wind is weakest. Yet on August 2nd, 1972, the sun produced three powerful flares in a span of 15 hours. The Apollo astronauts in their command module would not have survived if this flare had come 4 months earlier, during Apollo 16, or four months later, during Apollo 17. Apollo astronauts on the moon's surface were in sunlight and even less protected than those in the command module.
	16:11	Of the inner planets, only Mercury and Earth have magnetospheres. Mercury's magnetosphere is a hundred times weaker than Earth's. Perhaps future human settlements near Mercury's poles will benefit from this protective field. Venus is the size of Earth, but rotates so slowly that no dynamo could form in its core. The solar wind bombards its atmosphere directly. Although its rotation is fast enough, Mars lacks a liquid iron core to create a global magnetic field. Without a magnetic shield, the solar wind reaches the planet's thin atmosphere and has robbed Mars of most of its Hydrogen and Oxygen.
	16:59	Mars is now a dry desert, but it has features indicating that the red planet once had surface water and an atmosphere thick enough to support a water cycle, seas, and perhaps life. When Mars' core froze out, its magnetic shield disappeared. Now the surface water is gone, leaving only its polar ice caps and a hint of water vapor in the thin Martian atmosphere.

	17:26	Jupiter has metallic hydrogen flowing in its core, creating the dynamo to power a magnetosphere 20,000 times stronger than Earth's. Saturn has a smaller layer of metallic hydrogen than Jupiter's and therefore, a weaker magnetic field. Uranus contains both gases and ices of water, ammonia, and methane. Although this planet rotates on its side, its tilted magnetic shield protects like the other giant planets. Neptune's magnetic field is also strongly tilted, resulting in a lopsided magnetic shield with its poles occasionally exposed to the solar blast.
	18:15	This is just the beginning of our quest to find magnetic fields beyond our solar system. We can detect the effects of magnetic forces in wavelengths beyond our vision. Arrays of radio telescopes working together pick up radio waves from charged particles accelerated by magnetic fields far beyond our solar system.
	18:40	These telescopes have detected emissions from a nearby brown dwarf, about 20 light-years from Earth. These emissions indicate the presence of a magnetic field. Brown dwarfs are stillborn stars, too small to make their own light. As electrons spiral down into a brown dwarf's atmosphere, they produce radio emissions and excite hydrogen atoms. Unlike the green auroras from Oxygen, the hydrogen atoms in a brown dwarf emit a glowing pink light. These auroras are about a million times brighter and more powerful than auroras on Earth. The discovery of auroras beyond our solar system will help us detect auroras around other objects, especially distant planets.
	19:30	Observatories on orbit and on Earth have found evidence of planets orbiting other stars. We need to be able to detect magnetic fields at interstellar distances to identify which planets could have conditions suitable for life. The nearby giant planet HD189733b, eclipses its star once every 2 Earth days. When this happens, we see a dip in the star's light caused by the bow shock of its magnetic field and another dip caused by the planet. This is our first discovery of a magnetosphere around an extrasolar planet.
	20:33	We live in the disk of a barred spiral galaxy of over 200 billion stars. Its spiral arms stretch around us, creating the hazy Milky Way band. Our galaxy's appearance changes dramatically when we observe only the polarized radio noise, scattered by dust grains and oriented by the galaxy's magnetic field. Loops and arches show the direction of the magnetic field lines that outline our galaxy's spiral arms. The dark band marks the center of the Galactic Plane.
	21:17	Our Galaxy also looks very different in gamma rays, the most energetic part of the spectrum. Orbiting gamma ray observatories like Fermi can pinpoint the most energetic light sources in the universe. These are often collapsed stars with tightly wound magnetic fields focusing the light they emit.

	21:39	The Crab Nebula is the remnant of a supernova explosion that humans saw almost a thousand years ago. Deep inside the nebula lies the star's rapidly spinning imploded core. Here an intense magnetic field focuses radiation at the star's magnetic poles, producing a beam of radiation sweeping across space like a lighthouse beacon. Here the star's magnetic field contains and directs the flow of charged matter.
	22:17	Auroras crown our home world. They promise that our magnetic field still shields us from deadly solar storms as well as cosmic rays from far away supernovas. Within our protective cocoon, life has flourished, evolving into more complex forms and finally giving rise to sentient beings aware of the magnetosphere, which surrounds and protects the life bearing Earth below.
CREDITS		**ENDING CREDITS**
	22:51	Funded in part by NASA under Contract NNX15AG52G and by the National Science Foundation under grant DMR-1350237
Executive Producer		Patricia Reiff, Rice University
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Editing & Post-Production		Bryce Buchanan
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Narration		Jim Bratton
		EVANS & SUTHERLAND
Executive Producer		Kirk Johnson
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Additional Animation		Don Davis
Digistar 6 Modeling		Karen Klamczynski
Auroral Photography		Terence Murtagh Marty Sisam
		RICE UNIVERSITY
Magnetic Field Visualizations		Tom Casey, Home Run Pictures
Magnetic Field Line Tracing		Prof. Paul Cassak, West Virginia University
Content Review		Dr. Antoun Daou Dr. Jerry Goldstein Dr. Thomas E. Moore Prog. Andriy Nevidomskyy
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Spacecraft models courtesy of		Goddard Space Flight Center

Sound from Space courtesy of		The Radio and Plasma Wave Group, University of Iowa
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Science Visualizations		Adam Barnes Tony Butterfield
Content Review		Dr. Matthew Baring James Wooten Zackary Butterfield
Digistar 6 Animation		Geoffrey Baring Henry Baring Dante Barbieri Adithya Chunangad
ISS auroral footage courtesy of		Johnson Space Flight Center
With Special Thanks to		Mario Runco Susan Runco
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