Planet Earth

Solar sea

1	06:01:31:23	NARRATOR: In a communications nerve center in Colorado, a nationwide alert warns that a massive explosion 93 million miles away will soon have a profound impact on planet Earth.
2	06:01:43:19	This is the Space Environment Services Center in Boulder, Colorado.
3	06:01:46:04	We have an alert. An X-ray event, *was observed today at 2150 universal time and we do expect proton..* .
4	06:01:52:25	NARRATOR: The power of the sun is beyond the grasp of human imagination.
5	06:01:57:16	A single solar flare can release the energy of 100 million hydrogen bombs -- enough to fuel the North American continent for 100,000 years.
6	06:02:09:12	Earth emerges from the dawn of time a planet solely dependent on the sun.
7	06:02:14:21	A giver of life, we have come to rely on the enduring strength of its heat and light.
8	06:02:21:14	But scientists around the world are now uncovering secrets that may well shatter age-old beliefs in the sun.
9	06:02:29:03	Their discoveries have reopened a century-long debate over its influence on planet Earth.
10	06:02:35:27	In a California library, a modern solar physicist seeks clues to the sun's behavior in forgotten books -- scientific observations set down over 300 years ago that are still vital today.
11	06:02:54:02	In Arizona, scientists have developed an unusual technique to reconstruct the history of climate.
12	06:03:01:12	Under a microscope, a telltale pattern may link the sun to the unknown fate of a lost civilization.
13	06:03:09:01	Halfway around the world in Australia's Outback, a geologist has made an extraordinary find: Ancient rocks may actually

		be a diary of the sun, a rare glimpse into its prehistoric past.
14	06:03:22:22	In Alaska, cameras of exceptional power aim skyward to capture an unprecedented look at the mysterious Northern Lights -- the Aurora Borealis.
15	06:03:33:21	20th century technology has now revealed the source of this astonishing phenomenon.
16	06:03:40:14	For 4,000 years, mankind has watched and worshipped the sun.
17	06:03:45:22	Now we are beginning to know the true dimensions of its influence on planet Earth.
18	06:03:56:14	Enter now the invisible domain of the sun.
19	06:03:59:24	Embark on a journey in time and space through the awesome world of the solar sea.
20	06:04:50:12	Corporate funding for *Planet Earth* is provided by IBM.
21	06:04:54:07	IBM is proud to support the innovative spirit of scientific inquiry that made this series possible.
22	06:05:05:29	NARRATOR: According to Hindu legend, the first primordial sunlight fell on the river Ganges.
23	06:05:11:26	And the universe was born.
24	06:05:15:26	Each morning at Benares, India's faithful still gather to mark the event.
25	06:05:25:07	To keep the sun from burning up, water is sacrificed and prayers offered.
26	06:05:35:11	Vishnu is the reigning sun god, but India's gods are many: Bhaskar is the creator of light; Dinakar the maker of day; Jivana the source of life.
27	06:05:52:16	Since the dawn of human history man has stood in awe of the sun's consummate power over the Earth.
28	06:06:13:10	Carefully aligned on a north-south axis, the pyramids of ancient Egypt still reflect the first light of the morning sun.
29	06:06:24:28	The Egyptians found order and meaning in the sun's daily cycle.

30	06:06:31:21	Personified by the god Ra, the pharaohs drew their powers from the sun, and together they ruled the ancient world in the timeless cycle of eternity.
31	06:06:42:25	Their monuments still stand today.
32	06:06:45:03	Each year at Abu Simbel, a remarkable event celebrates the anniversary of the reign of Ramses II.
33	06:06:53:20	At sunrise a stream of light penetrates the interior of the temple to bless a statue of the pharaoh.
34	06:07:18:18	For 3,000 years, the Egyptians worshipped the power of the sun and kept faith in its enduring cycles.
35	06:07:29:21	But on a distant continent, such reverence for the sun would take a prophetic turn.
36	06:07:35:11	The Maya of ancient Middle America, emerged from the shroud of time a civilization awed by the forces of nature.
37	06:07:43:14	Governed by superstition, they believed each movement of the sun was an omen of good or evil.
38	06:07:56:00	To foretell the future they built elaborate temples.
39	06:08:00:08	This one at Chichen Itza was probably used for astronomical observation.
40	06:08:09:18	Using fixed points, the sun's position in relation to the horizon could be calculated with amazing accuracy.
41	06:08:19:06	For millennia, the movement of the sun would control the ritual and ceremony of daily life, but the ancient world would remain unaware that the power of the sun over destiny could be far greater than ever imagined.
42	06:08:35:29	In the southwest corner of Colorado in a seemingly inaccessible maze of canyons, is Mesa Verde, setting for one of the most unusual dramas in American history: the disappearance of an entire civilization.
43	06:08:51:14	Carved in a cliff stands a citadel of stone -- a human beehive built by a mysterious people called the Anasazi -- "The Ancient Ones." Today Mesa Verde is a national park, a silent monument to the civilization that flourished here long before Columbus set foot in the New World.

44	06:09:14:00	You would have had a whole courtyard area, and it's out in these courtyards where these people did a lot of their work.
45	06:09:19:25	They would make their pottery out here.
46	06:09:21:19	The ladies would grind corn on grinding stones.
47	06:09:25:17	The men would work with their bone and stone tools.
48	06:09:28:06	You can imagine the children playing anywhere throughout the dwelling.
49	06:09:31:18	The Anasazi did have domesticated dogs as well as turkeys.
50	06:09:34:18	And from the evidence that we have, these animals were pretty much allowed to roam freely.
51	06:09:39:14	NARRATOR: The Anasazi left no written record, but these ruins testify to their genius for survival.
52	06:09:46:23	From their dwellings they climbed the canyon walls to the mesa.
53	06:09:52:05	Here they would till the soil and plant squash and corn.
54	06:09:56:21	Inventive farmers, they devised a complex system of reservoirs and dams to irrigate the semiarid plateau where rainfall is sparse.
55	06:10:05:26	For 700 years the Anasazi thrived here deeply rooted in the land.
56	06:10:09:24	Then, mysteriously, they abandoned their tribal home.
57	06:10:16:21	For those who listen, the walls still echo the past.
58	06:10:22:03	(*echoing sounds*) Why they left is unknown, but an unfinished temple to the sun hints at a reason.
59	06:10:36:10	The Anasazi worshipped the sun, but even their prayers may have failed to end a prolonged drought or an unusual time of cold.
60	06:10:45:08	It is ironic that seven centuries later, science is just beginning to investigate if changes in the sun could influence the Earth's weather.
61	06:10:53:26	It is no mystery that the sun powers the oceans and drives the circulation of Earth's atmosphere.

62 06:11:00:25 It creates our weather, and over time, the climate of planet Earth.

63 06:11:08:01 For eons the sun's output of energy has remained relatively constant, reducing the patterns of weather and climate.

64 06:11:15:18 (*thunder crashing*) But in the recent past, unseasonable changes in Earth's climate have raised provocative doubts about the influence of the sun.

65 06:11:33:11 Can dramatic changes in the Earth's climate be linked to subtle changes in the output of the sun?

66 06:11:42:15 In 1908, astronomer George Ellery Hale, working at the Mount Wilson Observatory, near Los Angeles, California, made an important discovery about one of the sun's most intriguing features: sunspots.

67 06:11:58:17 Long a source of curiosity, everything from baby booms to crop failures has been linked to their mysterious appearance.

68 06:12:06:29 Then, in the 19th century, it was learned that sunspots come and go in cycles -- every 11 years.

69 06:12:14:15 Hale would show that sunspots originate in the sun's magnetic field, which reverses its polarity every 22 years.

70 06:12:26:11 The discovery of the solar cycle seemed to confirm that the sun was a predictable star.

71 06:12:32:10 More than 60 years later, Jack Eddy of the High Altitude Observatory still had a nagging doubt.

72 06:12:39:27 The Hale Library in Pasadena, California contains an archive of solar observations dating back to the 17th century.

73 06:12:50:29 Nearly 100 years ago, another scientist, Walter Maunder, studied the same accounts of the sun and found that, from 1645 to 1715, sunspots had virtually disappeared.

74 06:13:03:13 His report, published in 1894, was scorned and forgotten until Eddy began his investigation.

75 06:13:17:17 To him, the accounts of early astronomers are as valuable today as they were 300 years ago.

76 06:13:25:23 Rare old books such as these, published more than three

		centuries ago, give us a direct record of what the sun was like in the past.
77	06:13:36:27	This one was written by Christopher Scheiner, a Jesuit priest, and published in the year 1630.
78	06:13:45:21	It is this book, more than any, that convinced me that we could trust the astronomers of the early and middle 17th century when their direct accounts, such as this one, showed us that the sun, at the time, was undergoing a major period of change.
79	06:14:02:25	NARRATOR: During the so-called Maunder Minimum, the appearance of sunspots was so rare they were often reported as new discoveries, and became the subject of elaborate drawings.
80	06:14:18:08	Digging further, Eddy found that the mysterious Northern Lights had also apparently vanished.
81	06:14:25:19	These ancient books revealed that, for 70 years, there had been a major change in the sun's behavior.
82	06:14:32:29	Though difficult for solar scientists to accept, proof would come from an unlikely source -- not from the sun, but from the Earth itself.
83	06:14:49:13	Trees are the oldest living things in the world.
84	06:14:54:29	Their rings keep a diary of the sun's behavior by recording the amount of an isotope -- carbon 14 -- in the Earth's atmosphere.
85	06:15:07:15	The annual production of carbon 14 is directly influenced by the sun.
86	06:15:12:22	Trees that were alive during the Maunder Minimum confirm the dramatic change in the solar cycle.
87	06:15:21:14	Now tree rings are also being analyzed to find out if the presence or absence of sunspots can influence weather.
88	06:15:31:08	For centuries, this ponderosa pine has struggled against the elements.
89	06:15:39:09	The account of its survival, in good years and bad, has attracted researchers from the University of Arizona's tree ring laboratory -- Barry Richards and Charles Stockton.

90	06:15:52:10	Barry, let's try this one over here to the left.
91	06:15:54:23	Looks pretty good.
92	06:15:56:07	It's got a scraggly top.
93	06:15:58:05	NARRATOR: In the past, tree rings have been analyzed to determine the severity of drought, but Stockton is more interested in the *pattern* of drought in the American West.
94	06:16:08:10	CHARLES STOCKTON: What we were doing was not really new.
95	06:16:11:02	This had been done before.
96	06:16:12:17	The thing that we were doing that was different was the fact that we were looking at many, many tree ring sites simultaneously, not just one.
97	06:16:21:29	NARRATOR: To reconstruct the pattern of drought, Stockton chose some 60 sites across the United States, all west of the Mississippi.
98	06:16:30:14	Here drought conditions are prevalent, and trees are more sensitive to subtle changes in the weather.
99	06:16:36:21	Tree rings vary in size each year of their growth.
100	06:16:40:25	They reflect variations in rainfall and temperature.
101	06:16:44:10	One tree can preserve hundreds of years of climate history.
102	06:16:50:16	A hollow coring device is drilled into the tree.
103	06:16:54:07	Stockton and Richards must work fast.
104	06:16:56:22	Within minutes, the tree will begin to heal.
105	06:16:59:18	It will close in around the corer and make it impossible to remove.
106	06:17:11:24	A steel rod removes the core.
107	06:17:14:10	Got the bark off it.
108	06:17:16:10	Hey, I got some variation here.
109	06:17:18:01	That's good.

110	06:17:19:28	Tucked under the bleachers of the university's football stadium is Arizona's world-famous tree ring laboratory.
111	06:17:29:04	Thousands of years of climate history have been assembled here using trees from around the world.
112	06:17:36:02	Sanded, then mounted, to highlight the rings, the core is placed under a microscope for careful analysis.
113	06:17:42:24	Richards is looking for the lean years -- for the narrow rings.
114	06:17:47:19	Once the core is marked, the width of each ring is precisely measured and entered into a computer.
115	06:18:09:02	The computer analyzes both the wide and narrow rings for significant patterns.
116	06:18:14:22	It must then match the growth patterns from other trees to extend the drought profile back in time.
117	06:18:22:01	Now Stockton is able to construct a series of maps showing how much of the United States is affected by drought year after year.
118	06:18:31:22	The record goes back more than 300 years.
119	06:18:35:16	When Stockton converts his maps to a chart of abnormally wet and dry years, a dramatic pattern of recurring drought becomes clear.
120	06:18:46:02	These periods of drought have long been confirmed by history.
121	06:18:51:10	In the 1840s, diaries of the pioneers told of the great hardships in the trek west.
122	06:18:57:00	Among them was drought.
123	06:19:01:12	The 1930s saw America turn to dust, the worst drought in 300 years.
124	06:19:13:24	(*children shouting*) It is American folklore that rain follows the plow.
125	06:19:20:19	22 years after the infamous Dust Bowl, drought struck again.
126	06:19:26:20	The cycle of recurring drought is clear, but its similarity to events on the sun went totally unnoticed, until climatologist Murray Mitchell confronted Stockton.

127 06:19:39:27 Murray said, "Well, it looks to me like I can see "a definite periodic tendency in the data.

128 06:19:44:21 If you're not going to analyze it, will you let me analyze it?" And I said, "Sure. We'll send you the data." So we sent the data, a large box of cards, to his office in Washington, DC, and about two weeks later, we got a call from him, and he said, "Yes, there is "a significant 20-year periodicity in the data, "and I've already took liberties of comparing it *"to the solar cycle* .

129 06:20:11:25 *The two match up very, very well."* NARRATOR: When the pattern of sunspots is plotted against the pattern of drought, the match is intriguing evidence the two may be intimately linked.

130 06:20:21:25 For 300 years, the dramatic absence of rain has coincided with the appearance of sunspots.

131 06:20:28:17 One of the problems we have with the findings of our study is that many researchers, and rightfully so, think that perhaps what we're seeing is strictly coincidental.

132 06:20:38:22 We really don't have a physical mechanism in mind to explain this periodicity.

133 06:20:45:24 *We really need to develop some sort of way of explaining how the change in the solar cycle might really be affecting the Earth's atmosphere, which ultimately affects the occurrence of drought* .

134 06:20:55:03 NARRATOR: If Stockton is right, sometime in the 1990s, the American West can expect the next episode in the provocative history that links sunspots to drought.

135 06:21:05:08 To confirm the findings in tree rings, a longer record may be needed, a record millions of years old.

136 06:21:13:12 Only then can the connection between a changing sun and the Earth's climate be fully explored.

137 06:21:20:21 A prehistoric lake bed in South Australia may contain that record, a glimpse of the sun's behavior nearly a billion years ago.

138 06:21:38:21 For years, George Williams has been combing Australia's rugged wilderness.

139	06:21:45:06	An exploration geologist, he is looking for the natural resources of his native land.
140	06:21:51:26	Today, Pichi Richi Pass, north of Adelaide, is hot and dry, but 800 million years ago, it was covered by ice.
141	06:22:00:20	Here, Williams stumbled on an extraordinary find.
142	06:22:06:12	WILLIAMS: These are very interesting rocks.
143	06:22:08:22	They are siltstones and fine sandstones that were deposited in a glacier lake in pre-Cambrian time, about 700 to 800 million years ago.
144	06:22:17:29	The fascinating thing about these rocks is the regularity of the banding.
145	06:22:21:18	Both the half-inch banding and the millimeter banding repeat regularly in cyclic patterns, which are quite extraordinary.
146	06:22:27:24	It seemed to me when I saw these rocks that the regularity of the banding couldn't be explained by random processes.
147	06:22:34:27	It seemed that some astronomical control was necessary to provide this regular banding.
148	06:22:40:18	NARRATOR: Each summer as the sun melted the ice, a new layer of sedimentation was laid down.
149	06:22:47:23	If their thickness reflects temperature, it is an amazing record of the sun's behavior.
150	06:22:57:19	Cores from the field are brought back to the laboratory for careful analysis.
151	06:23:06:15	WILLIAMS: This piece of core represents about 900 years of sedimentation, but it's still just a small part of the full sequence we hold in cores, which represent about 18,000 years.
152	06:23:17:03	I'm holding in my hand a thin section that comes from a piece of core.
153	06:23:21:06	The section is cut by mounting the core on a glass sliver, and then the rock is ground down to a fraction of a millimeter in thickness until the rock is translucent.
154	06:23:29:10	In this particular thin section, the dark bands are very clearly

seen.

155 06:23:34:11 And within the cycles, between the dark bands, are further bands, which I'm interpreting as yearly banding.

156 06:23:40:23 The cyclic patterns displayed by the rocks match very closely the cyclic variations observed on the sun today.

157 06:23:48:02 So it would seem that this ancient glacier lake was acting as a solar observatory and faithfully recording the fluctuations of the sun in pre-Cambrian time, many hundreds of millions of years ago.

158 06:24:01:01 This is a very interesting observation, and it has important implications for our understanding of the modern sun.

159 06:24:07:04 It indicates that the behavior of the sun has remained pretty constant over hundreds of millions of years.

160 06:24:14:02 Our discoveries about the sun's ancient past are reassuring, despite evidence that the sun may have caused drought.

161 06:24:22:05 The fact is, the global climate of the Earth has remained stable for thousands of years.

162 06:24:29:09 But on the time scale of human history, civilizations rise and fall in a cosmic fraction of solar time.

163 06:24:36:26 Though we have renewed our confidence in the sun, our search to understand its ultimate impact on the climate of planet Earth is only just beginning.

164 06:24:48:08 The sun illuminates the darkness of space some 93 million miles from Earth.

165 06:24:56:28 In centuries past, the study of the sun has been a challenge to human ingenuity.

166 06:25:02:26 One of the most fascinating early instruments of exploration was built here in Jaipur, India, by the 18th Century maharajah, Jai Singh.

167 06:25:12:11 It was one of the astronomical wonders of his day, a personal observatory.

168 06:25:19:01 Looking more like a modern sculpture garden, this fabulous array of some 30 different instruments was designed for a single purpose: to calculate the motions of the sun and stars

from which the Hindus derive their intense belief in astrology.

169 06:25:37:05 Many of the instruments are sundials, virtually giant clocks.

170 06:25:42:22 The most impressive is the Samrat Yantra.

171 06:25:53:15 As the sun moves across the sky, a shadow falls on two marble plates, each finely etched to mark the time of day.

172 06:26:02:14 Incredibly, it measures time in seconds.

173 06:26:07:29 Keeping time by the sun became a science for Jai Singh, but it tells us little about the sun itself.

174 06:26:17:21 Seen with the naked eye, the sun is a vision of timeless perfection, but another instrument would extend our vision across interplanetary space and reveal a new and strangely unfamiliar sun.

175 06:26:33:03 The solar telescope at Kitt Peak, Arizona, is the largest of its kind in the world.

176 06:26:41:26 Inside, a series of mirrors captures the incoming sunlight and reflects it down a path 450 feet deep inside the mountain.

177 06:26:51:18 (*whirring*) What finally appears is a strikingly detailed image of the sun.

178 06:27:10:09 400 years ago, Galileo created a similar image with a primitive forerunner of the modern telescope.

179 06:27:17:21 It was his observation of sunspots that shattered an age-old belief in the sun's perfection.

180 06:27:24:23 Sunspots like those being traced by scientist Keith Pierce were our first clue that the sun is a changing and dynamic star.

181 06:27:34:04 Later, telescopes would reveal still more dramatic features.

182 06:27:38:14 They uncovered the existence of the sun's magnetic field, the source of its violent activity.

183 06:27:44:24 They showed us changes in the sun's brightness to challenge the long-held notion that its output of energy is constant.

184 06:27:54:16 And they allowed scientists to see the sun's outer atmosphere, the corona, an important link between the sun

		and Earth.
185	06:28:04:21	Telescopes brought us closer to the sun and gave us our first glimpse of its dynamic behavior, but a second ingenious invention would take us beyond to the surface of the sun itself.
186	06:28:21:06	Beyond human vision, a single beam of sunlight contains a wealth of information about the sun.
187	06:28:28:25	In the 17th century, the great physicist Sir Isaac Newton performed a simple yet elegant experiment to reveal a message in a beam of light.
188	06:28:39:13	When sunlight is passed through a prism, it creates a rainbow of colors called the spectrum.
189	06:28:46:11	What puzzled Newton was the nature of the spectrum.
190	06:28:50:02	Was the image produced by the glass, or was it contained in the light itself?
191	06:28:55:28	If the prism creates the color, a second prism should create still another spectrum.
192	06:29:01:19	Newton found that light through the second prism stayed red.
193	06:29:06:06	The individual colors of the spectrum could be separated no further.
194	06:29:11:13	Newton's experiment would prove that white light contains all the colors of the rainbow.
195	06:29:16:08	Light would become a tool for unlocking the secrets of the universe and form the basis of the modern spectrograph.
196	06:29:24:08	Like a prism, a spectrograph separates each color of the visible spectrum.
197	06:29:31:08	Seen in detail, hundred of black lines appear in distinctive patterns.
198	06:29:36:24	They are the chemical fingerprint of elements, like hydrogen and helium, elements present in the sun.
199	06:29:44:06	Called Fraunhofer lines, they would open a new frontier of solar exploration by revealing the composition, temperature

and density of the sun.

200 06:29:57:12 Ultimately, we would learn that the solar spectrum also includes powerful waves of invisible energy: radio, infrared, ultraviolet, x-rays, gamma rays, and cosmic rays.

201 06:30:12:23 Most are blocked by the filtering effects of the Earth's atmosphere.

202 06:30:18:13 In 1973, American scientists launched the most powerful array of solar telescopes ever carried into space.

203 06:30:30:29 Above Earth's atmosphere, *Skylab* would virtually peel away the sun's invisible layers to photograph its remarkable features.

204 06:30:46:08 Enhanced by computer, subtle details become vivid images of high temperatures and magnetic turbulence associated with violent activity.

205 06:30:59:23 An artificial eclipse reveals the intricate architecture of the sun's corona.

206 06:31:14:14 Ultraviolet and x-ray telescopes record the eruption of a solar prominence and dissect it layer by layer.

207 06:31:22:00 *Skylab* would capture details of the sun never seen before, images that would propel a search for the source of the sun's violent activity.

208 06:31:41:20 (*wind whistling*) It is one of the most hostile environments on Earth.

209 06:32:00:07 (*engine revving*) A perpetual desert of snow, where temperatures dip 100 degrees below zero.

210 06:32:09:04 But for those who study the sun, Antarctica is a virtual paradise.

211 06:32:15:00 At South Pole Station, summer begins in September.

212 06:32:18:06 For six months, the sun never sets.

213 06:32:21:21 Solar astronomers have long dreamed of observing the sun 24 hours a day.

214 06:32:28:16 In 1979, the first solar observatory was established at the South Pole.

215 06:32:34:27 In this crude-looking housing is all the precision required to track the sun continuously and obtain measurements of subtle changes on the solar surface.

216 06:32:44:23 (*high-pitched whirring*) (*wind whistling*) The need for continuous observation was brought home dramatically when Robin Stebbins and a team of scientists from the United States made an astounding find.

217 06:33:01:06 While trying to measure the sun's diameter, they accidentally discovered the sun was quaking, virtually ringing like a bell.

218 06:33:10:01 Just as earthquakes have long been a valuable tool for probing beneath Earth's surface, now solar oscillations may reveal the secrets of the sun's interior.

219 06:33:19:25 Back at Sacramento Peak Observatory in the mountains of New Mexico, Stebbins employs a computer to diagram complex patterns of solar oscillations.

220 06:33:29:15 Here, red represents parts of the solar surface moving away from us.

221 06:33:35:11 Blue, moving closer.

222 06:33:39:17 §

223 06:33:43:22 In a musical instrument, sound is made by a vibrating part, like the keys of a vibraphone or the strings of a bass.

224 06:33:51:25 (*bass playing*) Our ears can distinguish the mellow resonance of wood or the cool ring of steel.

225 06:34:03:21 §

226 06:34:06:27 Just as the sound an instrument creates tells us something about its composition and structure, the various patterns of solar oscillation will help scientists like Robin Stebbins fine-tune their theories about the interior of the sun.

227 06:34:22:03 STEBBINS: *There are over ten million such patterns* that are present on the sun.

228 06:34:25:25 They were all present at one time added together.

229 06:34:28:17 From this great wealth of information, we can learn a great deal about how the inside of the star is put together and what it's made of.

230 06:34:36:09 NARRATOR: Until now, the existence of sunspots and the strange behavior of the solar cycle have gone unexplained, their origins hidden deep in the sun's interior.

231 06:34:46:26 Now, knowledge of solar oscillations may begin a new era of discovery.

232 06:34:55:20 Of all the mysteries of the sun, one would remain beyond the reach of human knowledge until the dawn of the nuclear age.

233 06:35:07:23 The sun is a dense ball of gas.

234 06:35:10:10 Deep in its core, a thermonuclear furnace continually fuses hydrogen into helium to yield a seemingly inexhaustible supply of energy.

235 06:35:23:14 Moving outward from the core, densely packed atoms collide and release energy that is radiated toward the surface.

236 06:35:31:20 Near the surface, gasses from the interior are reheated and transported by convection to the photosphere, the visible face of the sun.

237 06:35:41:07 Here, it displays its most spectacular phenomenon.

238 06:35:47:18 (*rumbling*) Above lies the chromosphere and the corona.

239 06:36:02:13 Larger than the sun itself, the corona stretches thousands of miles above the surface.

240 06:36:07:28 Here, the sun boils away its outer layer and spews it into space.

241 06:36:16:07 Far from empty, the region between the sun and Earth is filled with star stuff; fragments of the sun itself; charged particles called "plasma." It is the lifeblood of the universe, the most common form of matter.

242 06:36:31:21 Plasma flows through interplanetary space at a million miles an hour to become the solar wind.

243 06:36:41:25 The discovery of the solar wind would prove a vital link between the sun and planet Earth.

244 06:36:49:22 Perched high on a mountaintop on the Papago Indian Reservation in Arizona, Kitt Peak Observatory is host to scientists from around the world.

245	06:36:59:18	Today, researchers from West Germany, Great Britain and the United States will attempt to create and photograph the world's first artificial comet to learn more about the solar wind.
246	06:37:11:02	Gerhard Haerendel, of West Germany's Max Planck Institute, heads the effort.
247	06:37:16:14	In a few hours, he will order the release of two canisters of barium from a satellite orbiting 70,000 miles above the Earth.
248	06:37:24:15	His objective is to simulate what happens when plasma from a hot star, like the sun, hits a cold object, like the Earth.
249	06:37:35:03	The experiment, which we hopefully will see if the sky will be clear on the morning of Christmas Day, is the very first in its kind.
250	06:37:44:17	We have started to develop this technique of throwing a dye into a cosmic plasma already 20 years ago, but we have never had the opportunity to get out of the Earth's magnetic field way into the solar wind, and, also, to fly it this experiment on a spacecraft which is equipped with a lot of detectors.
251	06:38:06:27	NARRATOR: A second satellite, operated by a team of British researchers, trails behind.
252	06:38:12:29	Equipped with sophisticated sensors, it will actually fly through the tail of the comet.
253	06:38:19:17	So, in this configuration, this is completely new -- we have not done it before; nobody has done it before -- and so it's very exciting.
254	06:38:26:11	NARRATOR: 30 years ago, space was considered a vacua, except for a curious clue: the tail of a comet.
255	06:38:34:00	Regardless of the direction it traveled, its tail always pointed away from the sun -- a mystery unexplained until the discovery of the solar wind.
256	06:38:44:17	By late afternoon, clouds obscure Kitt Peak.
257	06:38:48:11	For the experiment to succeed, Haerendel must have three observation points to locate the comet in space.
258	06:38:54:27	He has already lost one.

259 06:38:56:28 In addition to Kitt Peak, cameras have been set up in New Mexico, Hawaii, and aboard aircraft in Tahiti and California.

260 06:39:04:12 So, any change?

261 06:39:06:04 (*speaking German*) Listen, Paul, it's extremely important, we have to have a rather reliable prediction from you.

262 06:39:15:11 Because now we would only have you and the Southern Pacific aircraft, there's no other station clear.

263 06:39:23:16 *The Convair 990 did not get off the ground* .

264 06:39:26:00 *Did I tell you that? I think so* .

265 06:39:28:21 Without the NASA aircraft, I would be very hesitant.

266 06:39:32:12 *If anything goes wrong somewhere,* then we lose our triangulation possibility.

267 06:39:37:25 Okay, Mike?

268 06:39:40:02 Yeah, we got distracted...

269 06:39:43:05 *White sensors not really quite clear* .

270 06:39:44:09 Yeah, right.

271 06:39:46:01 Okay.

272 06:39:48:03 Well, same to you, Mike.

273 06:39:49:19 I'm sorry?

274 06:39:51:10 Good. One day, we'll get a winner.

275 06:39:53:17 Okay. Yes. Bye-bye.

276 06:39:55:11 NARRATOR: Two days later, all the observation points are cleared.

277 06:39:59:29 A specially equipped aircraft from NASA's Ames Research Center in California makes a second attempt to record the comet.

278 06:40:07:05 ***WARNING FORMAT ERROR

279 06:40:09:25 (*machine bleeping*) *Ten seconds* .

280 06:40:16:12 *Five, four, three, two, one* .

281 06:40:22:17 (*explosion*) ***WARNING FORMAT ERROR *and that's the object right there* .

282 06:40:29:06 *I saw it blow up... big, bright object on the screen, the brightest thing you can see, I think, isn't it* ?

283 06:40:33:23 ***WARNING FORMAT ERROR

284 06:40:35:13 *Yeah* .

285 06:40:36:25 *About halfway between center and the left edge* .

286 06:40:38:24 *Roger* .

287 06:40:39:25 *Seems to be holding... or shrinking* ?

288 06:40:43:24 MAN 3: Seven-one-two, over.

289 06:40:46:04 Kitt Peak, we have a comet.

290 06:40:48:02 We have the comet. It is on tape. Over.

291 06:40:51:16 ***WARNING FORMAT ERROR

292 06:40:52:26 Out the window, it looks more like about four or five.

293 06:40:56:04 *Okay* .

294 06:40:58:06 I can still... I'm not very (*inaudible*).

295 06:41:00:08 (*faint radio chatter continues*) So, okay. What do you make of the tail orientation?

296 06:41:05:24 Well, we have a tail at the end...

297 06:41:09:06 The tail is coming up here towards the top.

298 06:41:12:27 It's very faint here in this image, Yeah.

299 06:41:14:11 ...but it's there.

300 06:41:17:02 NARRATOR: This vivid image was captured over the South Pacific.

301 06:41:21:01 It was hoped that the comet would be visible for an hour, but after only six minutes, it vanished, blown away by the unpredictable speed of the solar wind.

302	06:41:36:09	The behavior of the comet is important to understanding the impact of this powerful force on an invisible envelope around the Earth: the magnetosphere.
303	06:41:47:07	Like the sun, the Earth has a magnetic field, believed to be the result of electrical currents generated deep in its core.
304	06:41:54:17	When Earth's magnetic field interacts with the solar wind, it forms a shield.
305	06:42:02:08	It also forms the shape of a comet; the magnetic field facing the sun deflects the solar wind around the Earth.
306	06:42:09:25	It bends the Earth's magnetic field into a tail that stretches a million miles into space.
307	06:42:16:10	The only visible manifestation of the solar wind ripples across the polar sky like an eerie veil: the Aurora Borealis.
308	06:42:25:18	For more than a thousand years, songs have been written to it, children named after it, poetry inspired by it.
309	06:42:32:18	Some say the Northern Lights are the glare of arctic ice and snow, and some say it's electricity -- and nobody seems to know.
310	06:42:41:20	In his famous ballad of the Northern Lights, Robert Service, the poet of the Yukon, describes the mystery that has baffled mankind for centuries.
311	06:42:53:00	Rarely seen in Europe, the appearance of an aurora in 1570 is vividly chronicled in a medieval manuscript.
312	06:43:01:02	The town was illuminated as if it were ablaze.
313	06:43:04:02	When the people saw it, they were horrified and said that no such gruesome spectacle had ever been seen or heard of within living memory.
314	06:43:14:20	In Alaska, where the aurora is commonplace, few fear it.
315	06:43:19:13	But William Tyson is an Eskimo, and he does.
316	06:43:23:01	Some Eskimos carry knives to protect themselves.
317	06:43:26:24	We're scared of them and we respect them.
318	06:43:30:22	Because they can come down and take the people away from the Earth.

319 06:43:34:23 And if the aurora come down and take the people, that person will never appear again.

320 06:43:40:01 Before the Second World War, for one year, all winter long, we saw the...

321 06:43:45:14 anytime we see the aurora, it start getting red from the west end up almost halfway, and then change color again.

322 06:43:56:00 That happened all winter long, and then, in the fall, the war broke out.

323 06:44:02:15 Then my grandmother told me that anytime the aurora get red, there's going to be a lot of bloodshed.

324 06:44:07:22 NARRATOR: Just 30 years ago, the upper atmosphere was inaccessible.

325 06:44:12:24 Now, an arsenal of scientific weapons stands ready to explore the mysterious aurora.

326 06:44:20:05 (*siren buzzing*) 30 miles north of Fairbanks, is a unique research facility -- the University of Alaska's Poker Flat Research Range.

327 06:44:39:11 When intense auroral activity is expected, preparations begin early.

328 06:44:44:12 A three-stage rocket is carefully moved to its launch pad for assembly.

329 06:44:49:14 The procedure is time-consuming and can be dangerous.

330 06:44:53:08 The payload is a nine-inch explosive charge.

331 06:44:58:05 It will eject a tracer of barium into the aurora.

332 06:45:04:12 The accuracy of the rocket is dependent on the wind and the weather.

333 06:45:08:11 A balloon is released every hour to track minute changes in wind speed and direction.

334 06:45:22:07 By nightfall, preparations are complete.

335 06:45:28:00 Eugene Wescott of the University of Alaska will monitor the rocket launch and the barium release.

336 06:45:34:04 If all goes well, one more chapter will be written in the search

to understand the dynamics of this remarkable event.

337 06:45:41:24 By putting up a barium release -- which is like a tracer, like putting dye into a stream -- we hope to understand more fully the electrodynamics of what's going on.

338 06:45:53:16 If we're lucky, we'll see something that we've never seen before that'll give us a deeper understanding of, really, what's going on.

339 06:46:01:28 FAA, this is Poker Flat. We're at T-minus five minutes, and we'd like to pick up the count.

340 06:46:06:18 Could I have clearance?

341 06:46:07:25 20 minutes clearance in Zone One West, please?

342 06:46:10:13 Thank you.

343 06:46:12:23 NARRATOR: Wescott has been carefully monitoring the aurora.

344 06:46:16:13 Now, he will decide whether to proceed with the launch.

345 06:46:20:27 Okay, Pat, we'll go.

346 06:46:23:01 On my mark, we'll be at T minus 20 seconds and counting.

347 06:46:27:02 Roadblock one and two, we're at 20 seconds and counting.

348 06:46:30:09 20 seconds.

349 06:46:32:26 Ten, nine, eight, seven, six, five, four, three, two, one, launch.

350 06:46:52:22 NARRATOR: As the rocket intercepts the aurora, charged particles hit the barrier to illuminate the night sky.

351 06:46:59:11 30 years of experiments like this have finally revealed the origin of the aurora.

352 06:47:06:02 The solar wind acts like a generator.

353 06:47:08:29 As it strikes the magnetosphere, it discharges billions of watts of electrical power.

354 06:47:14:28 The energy flows down Earth's magnetic field lines toward the poles.

355 06:47:20:10 As it hits the upper atmosphere, it begins to glow like a halo of fire to form the aurora -- a permanent feature of the Earth's atmosphere at both the North and South Poles.

356 06:47:31:22 Recently, a unique instrument designed by the University of Iowa, was flown aboard a polar-orbiting satellite, a Dynamics Explorer.

357 06:47:41:03 The result? This breathtaking time-lapsed image of the Aurora Borealis seen from space for the first time.

358 06:48:08:15 In another laboratory at Poker Flat, an even more dramatic experiment is underway.

359 06:48:14:02 A system of extraordinary television cameras, sensitive enough to see the glow of a cigarette five miles away, will attempt to record tonight's aurora.

360 06:48:23:19 Violent and elusive, it is difficult to capture, but Syun Akasofu and his associate, Dan Osborne, have perfected the technique.

361 06:48:33:14 Television cameras are the latest tool for detecting the subtle features of an aurora.

362 06:48:39:13 They also enable us to witness, in real time, the most dazzling light show the world has ever seen.

363 06:48:47:09 (*resonating*) (*resonating continues*) Much has been learned about the aurora, but a key question remains: exactly what happens when billions of watts of electrical power are pumped into Earth's atmosphere?

364 06:50:12:29 In Boulder, Colorado, the Space Environment Service Center monitors the sun 24 hours a day, 365 days a year.

365 06:50:24:01 A global network of telescopes and orbiting satellites watches the sun for changes in its behavior.

366 06:50:30:14 When solar activity begins on the sun, time is critical.

367 06:50:34:21 Warnings are immediately issued to the Department of Defense, NASA, and to airlines that fly the polar routes.

368 06:50:43:05 At this time, I would like to issue an alert for an x-ray event.

369 06:50:46:25 NARRATOR: Eight minutes after the eruption of a solar flare, a blast of x-rays and high-energy radiation tears into Earth's

upper atmosphere.

370 06:50:54:05 We would expect protons to accompany this event within the next 48 hours.

371 06:50:59:08 NARRATOR: Protons are accelerated by the solar wind.

372 06:51:02:24 In hours they will bombard the upper atmosphere to create a storm in the Earth's magnetic field.

373 06:51:09:14 During a proton event, short-wave radio signals can be blacked out for days, telephone circuits can experience overloads, and power stations a surge in electrical currents.

374 06:51:22:15 (*electricity surging*) Ironically, Skylab, which had given science so much information about the sun, tumbled prematurely from space in 1979 *because* of the sun.

375 06:51:35:20 It was solar activity that heated and expanded the upper atmosphere to increase the drag on the spacecraft.

376 06:51:42:28 Its orbit decayed, and the friction of Skylab's rapid descent turned it into a blazing hail of fire.

377 06:51:53:18 The early demise of Skylab was a valuable lesson.

378 06:51:56:09 The sun has now become a critical factor in the design of spacecraft.

379 06:52:03:00 In the near future, six astronauts will live and work aboard a permanent station in space, vastly safer than a decade ago.

380 06:52:15:14 Under the blanket of Earth's atmosphere, most of us are unaware of the potential dangers of solar activity.

381 06:52:23:21 Like the people of the ancient world, we, too, worship the sun, each in our own personal way.

382 06:52:30:18 NEWSCASTER: *Cities in the valleys are peaking around 102* .

383 06:52:33:25 *And now for the moment you've all been waiting for: let's turn so you don't burn* .

384 06:52:38:26 NARRATOR: Unfortunately, we have recently discovered that the sun can be hazardous to our health.

385 06:52:44:26 Excessive exposure to invisible ultraviolet radiation is the primary cause of skin cancer.

386 06:52:51:22 Fifteen miles above Earth, the sun interacts with the atmosphere to create a protective shield called the ozone layer.

387 06:53:00:27 Ozone protects us from most ultraviolet radiation.

388 06:53:04:08 Although the sun steadily creates ozone, scientists have recently discovered that violent outbursts of solar activity can also destroy it.

389 06:53:12:23 A scientist from the National Oceanographic and Atmospheric Administration witnessed just such an event: George Reid.

390 06:53:20:28 In August of 1972, we observed the most intense solar flare we've seen in the 30 years or so since we've been studying these events.

391 06:53:28:05 *For the first time, we can observe directly how these events can weaken our protective ozone layer by introducing nitric oxide, which is a powerful chemical destroyer of ozone* .

392 06:53:39:19 NARRATOR: At the University of Colorado, concern over this dramatic discovery has prompted a unique experiment.

393 06:53:46:07 Students are manning a satellite, the *Solar Mesosphere Explorer,* launched by NASA in 1981.

394 06:53:53:03 We are now transmitting sensitive commands to the spacecraft.

395 06:53:56:01 NARRATOR: A virtual laboratory in space, the satellite is monitoring changes in ultraviolet radiation and ozone.

396 06:54:05:01 Early results from the satellite have confirmed a direct link between the destruction of ozone and the increases in nitric oxide produced by ultraviolet radiation.

397 06:54:18:25 We now know that the ozone layer is far more delicate than we ever envisioned.

398 06:54:24:05 The balance between its creation and destruction took billions of years to evolve.

399 06:54:30:16 The question now is: can man destroy that delicate balance?

400 06:54:35:18 By changing the atmosphere through his industrial, agricultural and chemical emissions, can we severely

damage our protective blanket?

401 06:54:44:16 How far can we go before the ozone layer is seriously depleted?

402 06:54:48:09 How can we be sure of these things?

403 06:54:50:03 These are questions to which scientists are only just beginning to find the answers.

404 06:54:54:13 NARRATOR: A profound revelation of the 20th century is man's impact upon his global environment, one that may now touch upon his relationship to the sun itself.

405 06:55:07:08 Still, the affairs of man are but an epilogue to the history of Earth.

406 06:55:11:29 Billions of years ago, the sun cast its control over planet Earth, setting the stage for evolution.

407 06:55:18:25 Only now are we beginning to grasp the full dimensions of its incredible power.

408 06:55:23:29 For the first time we have seen it from space awed by its violence and imperfection.

409 06:55:31:22 We probed its surface and beneath found infinite rhythms and subtleties that shake our confidence in its reliability.

410 06:55:46:20 We've explored the invisible realm of interplanetary space and expanded our earthbound vision of the solar sea.

411 06:55:59:13 Yet, we have found visible proof that although the sun is ever-changing, it has never endangered life's delicate foothold on planet Earth.

412 06:56:10:13 Our connection to the sun goes far beyond what we ever envisioned.

413 06:56:16:14 1,500 light-years from Earth, in the Orion Nebula, stars much like our own are being born, and with them the ingredients of living matter.

414 06:56:27:18 The chemical elements of life have their origin in the living and dying of stars.

415 06:56:33:23 Born to planet Earth, we are truly children of the sun.

416 06:56:38:13 Our link to the stars was forged from the beginning of time.

417 06:58:23:29 *For information about this and other Annenberg Media programs, call: and visit us at:*