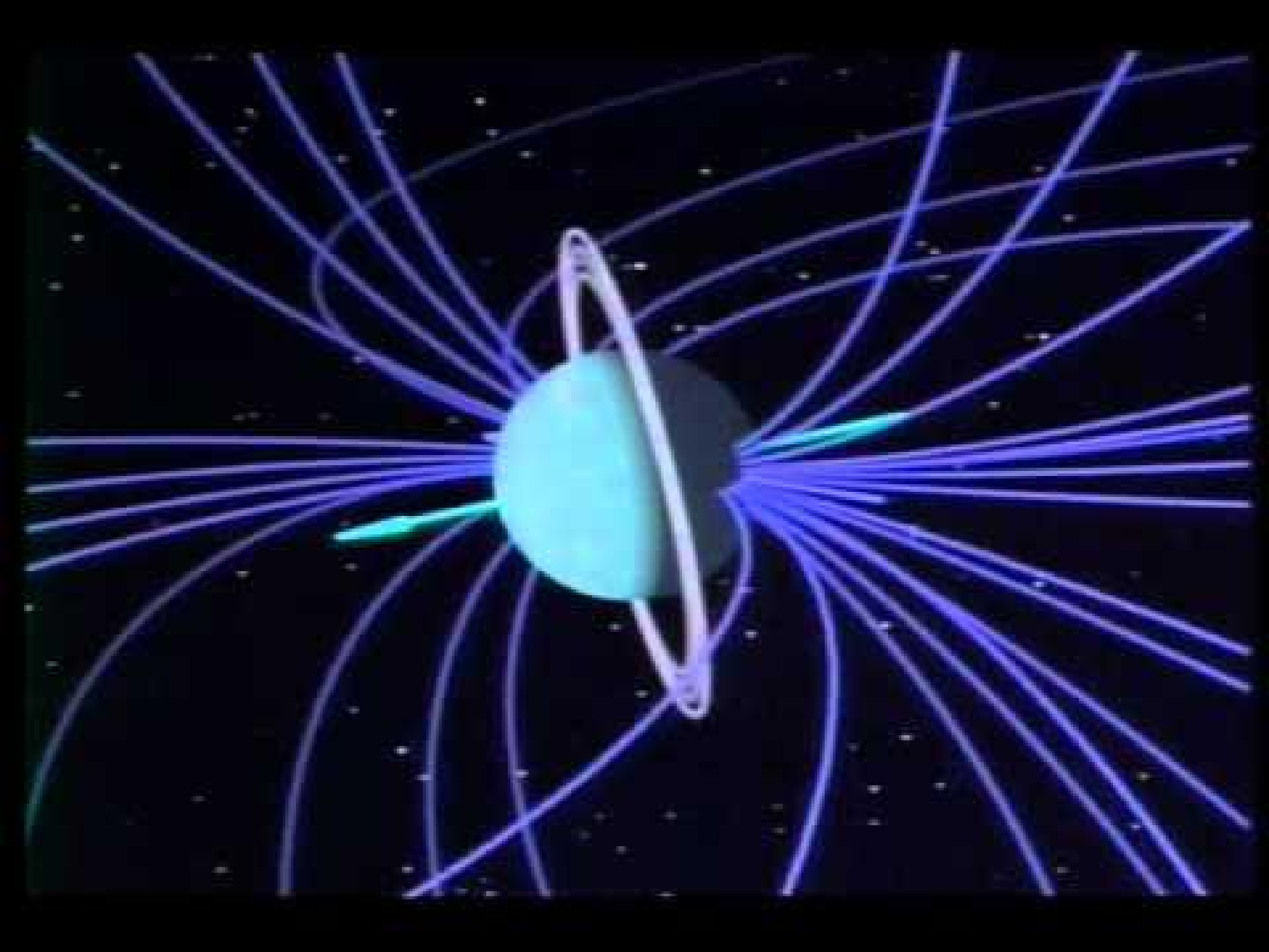

1
00:00:39,780 --> 00:00:37,950
many of us expected this would be a

2
00:00:41,580 --> 00:00:39,790
mission of major discovery but none of

3
00:00:43,680 --> 00:00:41,590
us really expected the degree of

4
00:00:46,049 --> 00:00:43,690
discovery the degree of diversity which

5
00:00:49,280 --> 00:00:46,059
we found in the outer solar system we

6
00:00:52,410 --> 00:00:49,290
were lucky we had the unique opportunity

7
00:00:55,890 --> 00:00:52,420
to explore planets that man had never

8
00:00:58,470 --> 00:00:55,900
been to before but Voyager didn't only

9
00:01:02,429 --> 00:00:58,480
carry sophisticated instrumentation it

10
00:01:06,210 --> 00:01:02,439
carried the hearts and the minds of its

11
00:01:10,109 --> 00:01:06,220
creators and all of us who were

12
00:01:13,289 --> 00:01:10,119
privileged enough to see what it saw and

13
00:01:15,690 --> 00:01:13,299

it will be unique for a long time

14
00:01:19,499 --> 00:01:15,700
because there isn't anything else out

15
00:01:23,820 --> 00:01:19,509
there to to explore for which you can

16
00:01:27,030 --> 00:01:23,830
get as much return from a single system

17
00:01:32,090 --> 00:01:27,040
I think Voyager will be remembered as

18
00:01:35,670 --> 00:01:32,100
part of the few decades where human race

19
00:01:38,030 --> 00:01:35,680
left its planet and Voyager will be a

20
00:01:40,560 --> 00:01:38,040
main chapter in that book

21
00:01:43,980 --> 00:01:40,570
Voyager kind of opened up the outer

22
00:01:46,320 --> 00:01:43,990
planets to everybody and I think they

23
00:01:48,719 --> 00:01:46,330
were vastly more interesting to me

24
00:01:51,630 --> 00:01:48,729
expected up to and including maybe even

25
00:01:53,580 --> 00:01:51,640
especially Neptune you only explore

26
00:01:59,300 --> 00:01:53,590
explore the solar system for the first

27
00:01:59,310 --> 00:02:11,520
and we did it

28
00:02:15,960 --> 00:02:14,400
the outer planets are giant planets

29
00:02:18,180 --> 00:02:15,970
they're distinctly different than the

30
00:02:20,460 --> 00:02:18,190
smaller rocky objects in the inner solar

31
00:02:23,670 --> 00:02:20,470
system such as Earth Mars Venus and

32
00:02:26,430 --> 00:02:23,680
Mercury and Voyager was designed to open

33
00:02:29,160 --> 00:02:26,440
up to exploration these giant outer

34
00:02:33,630 --> 00:02:29,170
planets which are spheres of rotating

35
00:02:36,300 --> 00:02:33,640
fluid gas surrounded by 57 moons totally

36
00:02:38,520 --> 00:02:36,310
each planet has a unique ring system and

37
00:02:40,440 --> 00:02:38,530
they have magnetic fields which were

38
00:02:43,410 --> 00:02:40,450

immense compared to the magnetic field

39
00:02:53,390 --> 00:02:43,420
of Earth voyagers job was to explore

40
00:02:58,290 --> 00:02:55,380
scientists at Cape Canaveral Florida

41
00:03:00,570 --> 00:02:58,300
sent another unmanned Voyager spacecraft

42
00:03:03,479 --> 00:03:00,580
on its way to Jupiter and Saturn today

43
00:03:05,400 --> 00:03:03,489
it lifted off flawlessly at 8:56 a.m.

44
00:03:07,740 --> 00:03:05,410
and had none of the problems of the

45
00:03:09,630 --> 00:03:07,750
Voyager launched two weeks ago this

46
00:03:14,430 --> 00:03:09,640
voyager presumably will get to Jupiter

47
00:03:15,350 --> 00:03:14,440
in March of 1979 Lord you're too scared

48
00:03:19,259 --> 00:03:15,360
us

49
00:03:22,830 --> 00:03:19,269
Voyager 2 had problems in separating

50
00:03:26,580 --> 00:03:22,840
from the solid rocket kick stage the

51
00:03:28,830 --> 00:03:26,590
spacecraft today you know have a few

52
00:03:31,470 --> 00:03:28,840
problems but most of these problems were

53
00:03:34,320 --> 00:03:31,480
problems we experienced early on there

54
00:03:39,539 --> 00:03:34,330
was the the Voyager 2 spacecraft has a

55
00:03:41,850 --> 00:03:39,549
failed receiver and and a sick backup

56
00:03:45,760 --> 00:03:41,860
receiver that's the most serious problem

57
00:03:51,820 --> 00:03:48,430
the way we communicate with the with the

58
00:03:54,460 --> 00:03:51,830
Voyager spacecraft is that we send

59
00:03:56,560 --> 00:03:54,470
commands to the spacecraft series of

60
00:03:57,880 --> 00:03:56,570
digital bits and computer language that

61
00:03:59,500 --> 00:03:57,890
go to the spacecraft and it's the

62
00:04:03,100 --> 00:03:59,510
language that the spacecraft understand

63
00:04:06,370 --> 00:04:03,110

understands these bits are transmitted

64
00:04:07,840 --> 00:04:06,380
and from ground stations located around

65
00:04:10,480 --> 00:04:07,850
the earth what we call the Deep Space

66
00:04:12,940 --> 00:04:10,490
Network the three deep space network

67
00:04:16,560 --> 00:04:12,950
stations are located in Goldstone

68
00:04:19,540 --> 00:04:16,570
California outside of Madrid Spain and

69
00:04:22,240 --> 00:04:19,550
outside of Canberra Australia as the

70
00:04:24,070 --> 00:04:22,250
Earth turns we can maintain Kamiya

71
00:04:27,550 --> 00:04:24,080
continuous communication with the point

72
00:04:29,080 --> 00:04:27,560
in space the spacecraft in turn there's

73
00:04:30,610 --> 00:04:29,090
kind of the reverse link coming back

74
00:04:33,190 --> 00:04:30,620
down the information that the spacecraft

75
00:04:34,870 --> 00:04:33,200
gathers goes into a transmitter on the

76
00:04:36,130 --> 00:04:34,880
spacecraft it's transmitted into those

77
00:04:37,900 --> 00:04:36,140
big ears and the ground of the deep

78
00:04:40,120 --> 00:04:37,910
space network and transmitted back then

79
00:04:42,460 --> 00:04:40,130
on the ground to our control facility

80
00:04:45,490 --> 00:04:42,470
here in Pasadena the transmitter on

81
00:04:48,990 --> 00:04:45,500
Voyager is like tens of watts it's like

82
00:04:52,790 --> 00:04:49,000
20 watts less power than an average

83
00:04:55,830 --> 00:04:52,800
light bulb on your front porch

84
00:04:59,429 --> 00:04:55,840
on the other hand when that signal is

85
00:05:03,179 --> 00:04:59,439
received on the earth it is literally a

86
00:05:05,749 --> 00:05:03,189
tiny tiny fraction of a watt that has

87
00:05:09,450 --> 00:05:05,759
received the amount of power received by

88
00:05:12,300 --> 00:05:09,460

the ground antennas is something like a

89
00:05:20,690 --> 00:05:12,310
billion of the amount of power used by

90
00:05:24,870 --> 00:05:23,370
man is known about the planet Jupiter

91
00:05:26,730 --> 00:05:24,880
ever since he took a good look at the

92
00:05:28,470 --> 00:05:26,740
night sky it's not what you'd call a

93
00:05:30,840 --> 00:05:28,480
near neighbor though being more than

94
00:05:32,640 --> 00:05:30,850
four hundred million miles away but

95
00:05:37,140 --> 00:05:32,650
after all these centuries were getting a

96
00:05:39,210 --> 00:05:37,150
closer look than we've ever had when

97
00:05:42,060 --> 00:05:39,220
Voyager got up close and we looked at

98
00:05:44,580 --> 00:05:42,070
the time-lapse movies of the atmosphere

99
00:05:47,700 --> 00:05:44,590
in motion things were changing every day

100
00:05:50,180 --> 00:05:47,710
little storms would pop up out of

101
00:05:53,820 --> 00:05:50,190
nowhere and they'd get ripped apart

102
00:05:56,730 --> 00:05:53,830
dispersed all in a day or two and that

103
00:05:59,730 --> 00:05:56,740
made the mystery of the Great Red Spot

104
00:06:04,410 --> 00:05:59,740
and all those other large spots even

105
00:06:07,380 --> 00:06:04,420
deeper because how could they last for

106
00:06:10,430 --> 00:06:07,390
so long in the midst of all that chaotic

107
00:06:13,170 --> 00:06:10,440
motion it was a startling discovery as

108
00:06:15,870 --> 00:06:13,180
Voyager approached Jupiter the first

109
00:06:17,310 --> 00:06:15,880
thing that inter intercepted was what's

110
00:06:19,470 --> 00:06:17,320
called the bow shock that's a shock

111
00:06:22,200 --> 00:06:19,480
where the supersonic solar wind becomes

112
00:06:23,730 --> 00:06:22,210
subsonic and that shock the solar wind

113
00:06:26,430 --> 00:06:23,740

velocity which is a million miles per

114
00:06:28,320 --> 00:06:26,440
hour abruptly decreases to 250,000 miles

115
00:06:32,430 --> 00:06:28,330
per hour that abrupt change in velocity

116
00:06:34,890 --> 00:06:32,440
causes the ionized gas to vibrate and we

117
00:06:36,750 --> 00:06:34,900
can sense we can hear the shock and we

118
00:06:39,030 --> 00:06:36,760
can hear the vibrations associated with

119
00:06:40,740 --> 00:06:39,040
that shock as a spacecraft flew through

120
00:06:43,110 --> 00:06:40,750
the shock itself

121
00:06:46,470 --> 00:06:43,120
we had expected that the magnetic field

122
00:06:49,260 --> 00:06:46,480
might expend something like a million

123
00:06:50,940 --> 00:06:49,270
miles or so from the planet in fact it

124
00:06:52,650 --> 00:06:50,950
extends some three to four million miles

125
00:06:55,890 --> 00:06:52,660
from the planet now we understand

126
00:06:58,260 --> 00:06:55,900
because IO is injecting into the

127
00:07:00,870 --> 00:06:58,270
magnetic field some 1 to 2 tons of

128
00:07:03,630 --> 00:07:00,880
material every second that material as

129
00:07:05,520 --> 00:07:03,640
it spins with Jupiter is centrally

130
00:07:07,770 --> 00:07:05,530
expanding Jupiter's magnetic field

131
00:07:13,230 --> 00:07:07,780
inflating it to a much larger size than

132
00:07:16,530 --> 00:07:13,240
it would normally be we expected quite

133
00:07:18,680 --> 00:07:16,540
frankly the satellites of the outer

134
00:07:21,630 --> 00:07:18,690
solar system to be quite bland and

135
00:07:24,510 --> 00:07:21,640
geologically lifeless is we've flew

136
00:07:26,340 --> 00:07:24,520
closer I look less and less like

137
00:07:29,070 --> 00:07:26,350
anything we've ever seen the impact

138
00:07:33,030 --> 00:07:29,080

craters turned into a regular dark

139
00:07:35,430 --> 00:07:33,040
patterns and the colored patches red

140
00:07:38,310 --> 00:07:35,440
yellows painted on the surface as a

141
00:07:40,740 --> 00:07:38,320
matter of fact as we flew closer we saw

142
00:07:44,940 --> 00:07:40,750
nothing at all that resembled an impact

143
00:07:48,450 --> 00:07:44,950
crater if Voyager 1 discovered 11 active

144
00:07:50,190 --> 00:07:48,460
volcanoes and 9 of those were still

145
00:07:53,820 --> 00:07:50,200
active when Voyager 2 returned four

146
00:07:55,650 --> 00:07:53,830
months later I think the the event in

147
00:07:58,290 --> 00:07:55,660
the end the omission which really

148
00:07:59,190 --> 00:07:58,300
altered our view and our expectation for

149
00:08:02,040 --> 00:07:59,200
the rest of the mission was the

150
00:08:04,650 --> 00:08:02,050
discovery of the volcanoes an isle that

151
00:08:07,110 --> 00:08:04,660
was such a dramatic and unexpected thing

152
00:08:08,760 --> 00:08:07,120
to find that it really told us that we

153
00:08:11,310 --> 00:08:08,770
could no longer be complacent we could

154
00:08:13,080 --> 00:08:11,320
no longer expect to understand or

155
00:08:19,830 --> 00:08:13,090
anticipate what we were really going to

156
00:08:22,380 --> 00:08:19,840
see Voyager 1 flew in close to Isle for

157
00:08:26,850 --> 00:08:22,390
a close up flyby of IO to give good

158
00:08:29,510 --> 00:08:26,860
return from Isle and made its close

159
00:08:32,279 --> 00:08:29,520
encounters with the Galilean satellites

160
00:08:35,610 --> 00:08:32,289
after the closest approach of Jupiter

161
00:08:37,409 --> 00:08:35,620
if we look at Callisto it's one of the

162
00:08:40,680 --> 00:08:37,419
most heavily cratered objects in the

163
00:08:44,610 --> 00:08:40,690

solar saturated with impact craters when

164
00:08:46,770 --> 00:08:44,620
we looked at Ganymede we find two kinds

165
00:08:49,490 --> 00:08:46,780
of terrains one is a terrain looks very

166
00:08:51,740 --> 00:08:49,500
much like Callisto but in addition

167
00:08:56,030 --> 00:08:51,750
Ganymede has a

168
00:08:59,690 --> 00:08:56,040
very complex intercepting network of

169
00:09:01,970 --> 00:08:59,700
faults in a younger terrain which has

170
00:09:03,800 --> 00:09:01,980
evidently welled up from the interior

171
00:09:06,170 --> 00:09:03,810
and replaced these this old cratered

172
00:09:09,700 --> 00:09:06,180
terrain is so similar to crystal the

173
00:09:13,070 --> 00:09:09,710
case of Europa we see yet another style

174
00:09:16,880 --> 00:09:13,080
we see gargantuan fault patterns in

175
00:09:20,210 --> 00:09:16,890
which this ocean has frozen repeatedly

176
00:09:22,550 --> 00:09:20,220
broken open and fluids float up to the

177
00:09:24,620 --> 00:09:22,560
surface producing dark puddles of

178
00:09:27,340 --> 00:09:24,630
material within the faults these are

179
00:09:30,440 --> 00:09:27,350
then broken again so there's

180
00:09:32,840 --> 00:09:30,450
intersecting and cross-cutting networks

181
00:09:37,040 --> 00:09:32,850
there were two small satellites

182
00:09:39,950 --> 00:09:37,050
discovered at Jupiter one of them found

183
00:09:42,200 --> 00:09:39,960
orbiting just outside a very thin

184
00:09:45,080 --> 00:09:42,210
tenuous ring of material that was

185
00:09:49,790 --> 00:09:45,090
discovered the Jupiter the imaging team

186
00:09:51,830 --> 00:09:49,800
members planned one single photo an 11

187
00:09:54,290 --> 00:09:51,840
minute exposure that would be taken as

188
00:09:57,890 --> 00:09:54,300

the spacecraft plunged through the

189
00:09:59,380 --> 00:09:57,900
equator plane of Jupiter and it just so

190
00:10:02,170 --> 00:09:59,390
happened that there was a ring there

191
00:10:04,200 --> 00:10:02,180
it's dusty

192
00:10:09,070 --> 00:10:04,210
there it seems to be no indication of

193
00:10:17,650 --> 00:10:09,080
water or ice within the ring so it's

194
00:10:19,780 --> 00:10:17,660
probably a minute of rocky material an

195
00:10:21,910 --> 00:10:19,790
outerspace spectacular that was the

196
00:10:24,250 --> 00:10:21,920
stuff of dreams only a generation ago

197
00:10:26,769 --> 00:10:24,260
began snapping into the sharp focus of

198
00:10:28,570 --> 00:10:26,779
reality today after its billion mile

199
00:10:30,760 --> 00:10:28,580
journey from Earth to Voyager 1

200
00:10:32,590 --> 00:10:30,770
spacecraft sent back pictures of man's

201
00:10:33,550 --> 00:10:32,600
closest look yet at the ringed planet

202
00:10:35,949 --> 00:10:33,560
Saturn

203
00:10:37,780 --> 00:10:35,959
the closest encounter of spacecraft and

204
00:10:41,260 --> 00:10:37,790
planet occurs later tonight when Voyager

205
00:10:43,810 --> 00:10:41,270
sails just 77,000 miles from Saturn's

206
00:10:46,150 --> 00:10:43,820
yellow clouds but already one scientist

207
00:10:48,900 --> 00:10:46,160
said in the strange world of Saturn's

208
00:10:52,000 --> 00:10:48,910
rings the bizarre has become commonplace

209
00:10:54,449 --> 00:10:52,010
the closer that Voyager got to Saturn

210
00:10:56,710 --> 00:10:54,459
the more and more detail and structure

211
00:10:58,900 --> 00:10:56,720
Saturn's rings turned out to have and

212
00:11:01,210 --> 00:10:58,910
this just was an enormous surprise to

213
00:11:03,750 --> 00:11:01,220

everybody the Rings were simultaneously

214
00:11:05,800 --> 00:11:03,760
breathtaking but completely baffling and

215
00:11:08,380 --> 00:11:05,810
there was just far more structure than

216
00:11:10,510 --> 00:11:08,390
people had anticipated not only did we

217
00:11:12,880 --> 00:11:10,520
find many many concentric features

218
00:11:16,210 --> 00:11:12,890
within the Rings but we found eccentric

219
00:11:18,850 --> 00:11:16,220
rings we found that the F frame which

220
00:11:21,370 --> 00:11:18,860
had been discovered by pioneer had

221
00:11:22,750 --> 00:11:21,380
braids in it and kinks and clumps all

222
00:11:24,760 --> 00:11:22,760
these things no one had ever even

223
00:11:27,340 --> 00:11:24,770
dreamed about before Voyager got to

224
00:11:31,840 --> 00:11:29,230
and then of course they were the spokes

225
00:11:34,330 --> 00:11:31,850
that Voyager discovered about a month or

226
00:11:37,060 --> 00:11:34,340
month and a half before encounter and

227
00:11:39,280 --> 00:11:37,070
these are these radial features in the B

228
00:11:44,860 --> 00:11:39,290
ring that come and go they are seen

229
00:11:47,830 --> 00:11:44,870
orbiting around the Rings and no one had

230
00:11:49,390 --> 00:11:47,840
a clue or at least not a yeah not a

231
00:11:51,040 --> 00:11:49,400
reasonable clue in the beginning as to

232
00:11:54,010 --> 00:11:51,050
what caused these features or even what

233
00:11:55,990 --> 00:11:54,020
they were that if you look at the rings

234
00:11:58,540 --> 00:11:56,000
of Saturn it for a period of time and

235
00:12:00,670 --> 00:11:58,550
watch the spokes go around and round and

236
00:12:03,190 --> 00:12:00,680
you examined the appearance of the

237
00:12:05,620 --> 00:12:03,200
spokes on the Rings that appearance

238
00:12:10,000 --> 00:12:05,630

changes and it changes with a period

239
00:12:13,480 --> 00:12:10,010
that is equal to the period of the spin

240
00:12:15,010 --> 00:12:13,490
of Saturn's magnetic field voyager found

241
00:12:17,620 --> 00:12:15,020
that Saturn's the magnetic field as

242
00:12:19,120 --> 00:12:17,630
pioneer 11 had already told us is is

243
00:12:20,800 --> 00:12:19,130
weaker that is it's only about

244
00:12:23,020 --> 00:12:20,810
one-twentieth the strength of Jupiter's

245
00:12:24,520 --> 00:12:23,030
magnetic field that means it's magnetic

246
00:12:26,050 --> 00:12:24,530
field doesn't extend as far from the

247
00:12:26,620 --> 00:12:26,060
planet about a million miles from the

248
00:12:29,290 --> 00:12:26,630
planet

249
00:12:31,270 --> 00:12:29,300
what Voyager discovered was how rapidly

250
00:12:32,920 --> 00:12:31,280
that magnetic field was rotating the

251
00:12:35,860 --> 00:12:32,930
magnetic field of Jupiter rotates with a

252
00:12:37,660 --> 00:12:35,870
period just under ten hours at Saturn it

253
00:12:39,460 --> 00:12:37,670
turns out the magnetic field rotates

254
00:12:41,050 --> 00:12:39,470
with a period of about 10 hours and 40

255
00:12:45,220 --> 00:12:41,060
minutes so this was the first measure of

256
00:12:48,630 --> 00:12:45,230
the length of the day on Saturn turns

257
00:12:51,700 --> 00:12:48,640
out when we finally measured the

258
00:12:53,860 --> 00:12:51,710
magnetic field and the radio emissions

259
00:12:57,820 --> 00:12:53,870
that are tied to the magnetic field that

260
00:13:01,390 --> 00:12:57,830
the inside of Saturn is moving quite

261
00:13:04,710 --> 00:13:01,400
slowly it's moving more slowly than most

262
00:13:07,270 --> 00:13:04,720
of the storms in the atmosphere and that

263
00:13:10,990 --> 00:13:07,280

the difference in those speeds

264
00:13:13,270 --> 00:13:11,000
translates to 500 meters per second for

265
00:13:14,590 --> 00:13:13,280
the winds which is over a thousand miles

266
00:13:17,950 --> 00:13:14,600
an hour

267
00:13:21,160 --> 00:13:17,960
and that made Saturn a lot windier

268
00:13:23,680 --> 00:13:21,170
planet than Jupiter that was the big

269
00:13:26,010 --> 00:13:23,690
surprise for me and we went Voyager got

270
00:13:34,300 --> 00:13:30,790
Voyager 1 approached Saturn in such a

271
00:13:36,460 --> 00:13:34,310
way that it flew past Titan before its

272
00:13:39,220 --> 00:13:36,470
closest approach to Saturn that

273
00:13:42,790 --> 00:13:39,230
trajectory then because of the tilt of

274
00:13:46,510 --> 00:13:42,800
the satellite system around Saturn

275
00:13:49,660 --> 00:13:46,520
caused the spacecraft to fly low

276
00:13:52,450 --> 00:13:49,670
initially and then get deflected as it

277
00:13:54,790 --> 00:13:52,460
made its closest approach to Saturn

278
00:13:56,080 --> 00:13:54,800
going through the ring plane up out of

279
00:14:01,450 --> 00:13:56,090
the plane of the ecliptic

280
00:14:07,570 --> 00:14:01,460
we knew that Titan had an atmosphere we

281
00:14:10,900 --> 00:14:07,580
had no idea how deep it was or what it

282
00:14:14,310 --> 00:14:10,910
was made out of and what Voyager found

283
00:14:18,760 --> 00:14:14,320
was a nitrogen atmosphere with traces of

284
00:14:20,980 --> 00:14:18,770
methane and other hydrocarbons and it

285
00:14:23,230 --> 00:14:20,990
was turned out to be quite a batma

286
00:14:25,750 --> 00:14:23,240
sphere we suspect there might be an

287
00:14:28,750 --> 00:14:25,760
ocean of material called ethane

288
00:14:31,810 --> 00:14:28,760

there could be all kinds of complicated

289
00:14:34,420 --> 00:14:31,820
hydrocarbons of different colors and

290
00:14:37,990 --> 00:14:34,430
different states some ices some fluids

291
00:14:41,530 --> 00:14:38,000
there's all manner of hallucination

292
00:14:43,080 --> 00:14:41,540
about hydrocarbon goop that rains out of

293
00:14:45,820 --> 00:14:43,090
the atmosphere and falls on the surface

294
00:14:47,640 --> 00:14:45,830
as matter of fact Titan remains one of

295
00:14:52,170 --> 00:14:47,650
the really exciting challenges for

296
00:14:55,330 --> 00:14:52,180
future future exploration in the case of

297
00:14:59,160 --> 00:14:55,340
limas we see a crater on - that's about

298
00:15:02,260 --> 00:14:59,170
40% of its diameter a little larger and

299
00:15:06,010 --> 00:15:02,270
that would have been enough to shatter

300
00:15:07,180 --> 00:15:06,020
the object and of course we wouldn't see

301
00:15:10,200 --> 00:15:07,190
the crater then because it would really

302
00:15:12,490 --> 00:15:10,210
like a kind of a giant ball of sand and

303
00:15:14,680 --> 00:15:12,500
in the case of Tethys there's another

304
00:15:15,320 --> 00:15:14,690
very large crater even larger than the

305
00:15:19,430 --> 00:15:15,330
one on

306
00:15:22,460 --> 00:15:19,440
- but in that case notice the floor has

307
00:15:26,240 --> 00:15:22,470
is now rounded out so that it is curved

308
00:15:28,250 --> 00:15:26,250
as the rest of the object slain is the

309
00:15:31,670 --> 00:15:28,260
case of Diana you'll notice that most of

310
00:15:33,380 --> 00:15:31,680
the surface is pretty bland and only in

311
00:15:37,730 --> 00:15:33,390
this one region near the trailing

312
00:15:39,470 --> 00:15:37,740
hemisphere do we see a lot of detail on

313
00:15:42,079 --> 00:15:39,480

the surface here we see a lot of Criss

314
00:15:44,920 --> 00:15:42,089
crossing faults with wispy bright

315
00:15:47,720 --> 00:15:44,930
markings around them finally we look at

316
00:15:50,750 --> 00:15:47,730
Enceladus we're talking about very cold

317
00:15:54,079 --> 00:15:50,760
regions and here we are with this little

318
00:15:56,600 --> 00:15:54,089
tiny object showing geologic activity of

319
00:15:59,269 --> 00:15:56,610
the scale that Enceladus does in which

320
00:16:02,180 --> 00:15:59,279
the ancient cratered terrain has been

321
00:16:04,880 --> 00:16:02,190
broken and has collapsed into the

322
00:16:08,650 --> 00:16:04,890
interior fluids have flowed out into

323
00:16:17,090 --> 00:16:08,660
those open gashes in the crust

324
00:16:20,569 --> 00:16:17,100
repeatedly well after we got Voyager 1

325
00:16:23,690 --> 00:16:20,579
to Saturn we went back to NASA and said

326
00:16:26,030 --> 00:16:23,700
we have now satisfied all of the

327
00:16:29,139 --> 00:16:26,040
objectives for the MJS for the Voyager

328
00:16:32,480 --> 00:16:29,149
mission how about giving us money and

329
00:16:35,030 --> 00:16:32,490
giving us permission to target Voyager

330
00:16:37,400 --> 00:16:35,040
to tweak its trajectory just a little

331
00:16:41,000 --> 00:16:37,410
bit so that we can go on to Uranus it

332
00:16:42,270 --> 00:16:41,010
was a penalty for this the data that we

333
00:16:44,670 --> 00:16:42,280
got

334
00:16:47,580 --> 00:16:44,680
the quality of the mission at Saturn was

335
00:16:49,680 --> 00:16:47,590
a little bit less if we targeted for

336
00:16:52,620 --> 00:16:49,690
Uranus and it would be if we optimized

337
00:16:56,370 --> 00:16:52,630
percent and we bared all those facts to

338
00:16:58,140 --> 00:16:56,380

NASA we told them that it was maybe a 60

339
00:16:59,640 --> 00:16:58,150
70 percent chance but we thought it was

340
00:17:01,760 --> 00:16:59,650
worth it and I guess we were pretty

341
00:17:04,500 --> 00:17:01,770
persuasive because they bought the idea

342
00:17:07,620 --> 00:17:04,510
soon after Voyager twos closest approach

343
00:17:11,790 --> 00:17:07,630
to Saturn in fact while it was behind

344
00:17:14,970 --> 00:17:11,800
the planet its scan platform got stuck

345
00:17:18,600 --> 00:17:14,980
at a mechanical failure and we weren't

346
00:17:20,120 --> 00:17:18,610
able to aim the cameras and the other

347
00:17:24,540 --> 00:17:20,130
pointable instruments on the spacecraft

348
00:17:27,929 --> 00:17:24,550
at the targets after several years we

349
00:17:31,110 --> 00:17:27,939
concluded that in fact during the Saturn

350
00:17:36,240 --> 00:17:31,120
encounter we had moved this platform too

351
00:17:40,440 --> 00:17:36,250
much too fast and that if we used the

352
00:17:43,920 --> 00:17:40,450
platform in a consistently slow at a

353
00:17:46,920 --> 00:17:43,930
slower rate and if we constrained the

354
00:17:49,530 --> 00:17:46,930
total amount of angular motion that we

355
00:17:57,080 --> 00:17:49,540
applied to the platform then in fact we

356
00:18:02,220 --> 00:18:00,570
Voyageur to the amazing robot spacecraft

357
00:18:05,070 --> 00:18:02,230
that was launched eight and a half years

358
00:18:07,050 --> 00:18:05,080
ago and just kept on going past yet

359
00:18:09,420 --> 00:18:07,060
another milestone today as it became the

360
00:18:13,320 --> 00:18:09,430
first spacecraft to fly past the planet

361
00:18:16,320 --> 00:18:13,330
Uranus Uranus is not a very photogenic

362
00:18:20,550 --> 00:18:16,330
place it looks more or less like a big

363
00:18:22,470 --> 00:18:20,560

blue ping-pong ball but we did see

364
00:18:23,910 --> 00:18:22,480
clouds in the atmosphere of Uranus and

365
00:18:29,310 --> 00:18:23,920
they did tell us something

366
00:18:34,200 --> 00:18:29,320
in fact Uranus is a tipped-over version

367
00:18:36,210 --> 00:18:34,210
of Jupiter and Saturn the cloud patterns

368
00:18:38,820 --> 00:18:36,220
are more muted but they have the same

369
00:18:41,460 --> 00:18:38,830
kind of banded structure that Jupiter

370
00:18:43,800 --> 00:18:41,470
and Saturn have now what that says is

371
00:18:48,750 --> 00:18:43,810
that the spin of a planet is the

372
00:18:51,840 --> 00:18:48,760
all-important process or thing that

373
00:18:53,250 --> 00:18:51,850
organizes whether Uranus is a very

374
00:18:56,370 --> 00:18:53,260
peculiar plant in the sense it's tipped

375
00:18:58,910 --> 00:18:56,380
on its side right now with the south

376
00:19:01,500 --> 00:18:58,920
polar region headed pointed at the Sun

377
00:19:03,900 --> 00:19:01,510
we had expected that the magnetic field

378
00:19:05,400 --> 00:19:03,910
pole would also be up near the

379
00:19:06,780 --> 00:19:05,410
rotational axis so the magnetic field

380
00:19:09,540 --> 00:19:06,790
would be tipped on its side what we

381
00:19:11,070 --> 00:19:09,550
found was to everyone's surprise that

382
00:19:13,560 --> 00:19:11,080
the magnetic field rather than being

383
00:19:16,020 --> 00:19:13,570
pointed at the Sun was tilted some 60

384
00:19:17,460 --> 00:19:16,030
degrees from the rotation axis not only

385
00:19:19,140 --> 00:19:17,470
that but the center of the magnetic

386
00:19:21,510 --> 00:19:19,150
field was displaced from the center of

387
00:19:23,910 --> 00:19:21,520
the planet by almost a third of the

388
00:19:27,570 --> 00:19:23,920

radius of the planet Uranus is magnetic

389
00:19:31,620 --> 00:19:27,580
field is a bit stronger than that on on

390
00:19:34,860 --> 00:19:31,630
Saturn and it extends some 300,000 miles

391
00:19:36,210 --> 00:19:34,870
from the planet the rotation period that

392
00:19:37,800 --> 00:19:36,220
is the length of the day on you and this

393
00:19:40,770 --> 00:19:37,810
is measured by how rapidly the magnetic

394
00:19:43,890 --> 00:19:40,780
field rotating is about 17 and a quarter

395
00:19:45,660 --> 00:19:43,900
hours the big problem going on to Uranus

396
00:19:48,420 --> 00:19:45,670
is that it's twice as far away from the

397
00:19:50,730 --> 00:19:48,430
earth as Saturn is in order to

398
00:19:56,190 --> 00:19:50,740
compensate for the the darker

399
00:19:59,370 --> 00:19:56,200
environment we had to make sure that the

400
00:20:01,500 --> 00:19:59,380
spacecraft would be steadier and to make

401
00:20:03,660 --> 00:20:01,510
the spacecraft steadier we had to deal

402
00:20:05,010 --> 00:20:03,670
with the things that made the spacecraft

403
00:20:07,200 --> 00:20:05,020
move well

404
00:20:09,690 --> 00:20:07,210
flying through space the Iranian rings

405
00:20:15,780 --> 00:20:09,700
are inherently dark in fact they are no

406
00:20:17,790 --> 00:20:15,790
brighter than coal dust so imagine

407
00:20:19,650 --> 00:20:17,800
trying to take an image of coal dust at

408
00:20:26,070 --> 00:20:19,660
Twilight but it's even worse than that

409
00:20:30,510 --> 00:20:26,080
so we had to worry about the necessity

410
00:20:33,750 --> 00:20:30,520
of using long exposures and the fact

411
00:20:35,760 --> 00:20:33,760
that the spacecraft scan platform is not

412
00:20:38,520 --> 00:20:35,770
a stable platform and always move

413
00:20:41,370 --> 00:20:38,530

someone best image that we got in fact

414
00:20:43,830 --> 00:20:41,380
of the Iranian ring system we had to use

415
00:20:49,370 --> 00:20:43,840
image motion compensation what we saw in

416
00:20:51,390 --> 00:20:49,380
that image is a sheet of dust that

417
00:20:54,630 --> 00:20:51,400
extends throughout the iranian ring

418
00:20:57,450 --> 00:20:54,640
system and this sheet of dust is

419
00:21:00,270 --> 00:20:57,460
punctuated by by features many of them

420
00:21:03,570 --> 00:21:00,280
there are more features in that picture

421
00:21:05,730 --> 00:21:03,580
than there are rings seen from inbound

422
00:21:08,130 --> 00:21:05,740
so we have nine narrow rings seen in the

423
00:21:11,910 --> 00:21:08,140
inbound images and one newly discovered

424
00:21:13,590 --> 00:21:11,920
one the lambda ring as a matter of fact

425
00:21:16,320 --> 00:21:13,600
if we had our choice we never would have

426
00:21:20,280 --> 00:21:16,330
gone close to Miranda in order to get to

427
00:21:24,060 --> 00:21:20,290
Neptune we were obliged to go a

428
00:21:25,590 --> 00:21:24,070
particular distance from Uranus in order

429
00:21:27,450 --> 00:21:25,600
to get the right gravitational

430
00:21:29,970 --> 00:21:27,460
deflection on the spacecraft well turned

431
00:21:31,940 --> 00:21:29,980
out that that distance was exactly the

432
00:21:34,830 --> 00:21:31,950
distance that Miranda's orbit is from

433
00:21:37,650 --> 00:21:34,840
Uranus it is a very exotic and

434
00:21:41,100 --> 00:21:37,660
complicated place most of the regions

435
00:21:45,600 --> 00:21:41,110
that we viewed are heavily cratered cold

436
00:21:49,880 --> 00:21:45,610
rolling in chatterings but embedded in

437
00:21:53,190 --> 00:21:49,890
these are very unusual circular patches

438
00:21:54,900 --> 00:21:53,200

almost like racetracks of groove

439
00:21:58,260 --> 00:21:54,910
terrains that run around in circular

440
00:22:03,200 --> 00:21:58,270
bands surrounding very complicated Criss

441
00:22:09,659 --> 00:22:06,360
we address the the question what can we

442
00:22:11,519 --> 00:22:09,669
do to hear the data better we did come

443
00:22:15,440 --> 00:22:11,529
up with a technique called a rang where

444
00:22:17,880 --> 00:22:15,450
we took existing antennas and

445
00:22:20,100 --> 00:22:17,890
electronically wired them together so

446
00:22:23,909 --> 00:22:20,110
that in fact it had the appearance of

447
00:22:26,250 --> 00:22:23,919
being one larger antenna and we did that

448
00:22:30,690 --> 00:22:26,260
in Australia the primary receiving site

449
00:22:33,600 --> 00:22:30,700
at Uranus and combined the DSN stations

450
00:22:34,950 --> 00:22:33,610
with a borrowed antenna from the

451
00:22:42,950 --> 00:22:34,960
Australian radio at Radio Astronomy

452
00:22:46,860 --> 00:22:45,389
while we were moving from uranus and

453
00:22:48,240 --> 00:22:46,870
neptune on the ground we had two major

454
00:22:50,070 --> 00:22:48,250
things to do first of all we

455
00:22:52,860 --> 00:22:50,080
reprogrammed the software and board the

456
00:22:54,810 --> 00:22:52,870
spacecraft to do two things to stabilise

457
00:22:56,639 --> 00:22:54,820
the spacecraft so the pictures would not

458
00:22:58,200 --> 00:22:56,649
be smeared and to add some new

459
00:23:00,990 --> 00:22:58,210
techniques to the spacecraft it will

460
00:23:02,279 --> 00:23:01,000
allow it to pan and track the planet

461
00:23:04,470 --> 00:23:02,289
when we were taking pictures near the

462
00:23:07,200 --> 00:23:04,480
planet second thing we had to do is

463
00:23:09,029 --> 00:23:07,210

improve the communications capability we

464
00:23:10,889 --> 00:23:09,039
did that since the since neptune is

465
00:23:13,289 --> 00:23:10,899
twice as far away from the communication

466
00:23:15,120 --> 00:23:13,299
standpoint as uranus we did that by

467
00:23:17,430 --> 00:23:15,130
enlarging the size the antennas on the

468
00:23:19,710 --> 00:23:17,440
earth and by adding several new sets of

469
00:23:27,160 --> 00:23:19,720
antennas into our deep space network to

470
00:23:31,840 --> 00:23:29,830
it is mission accomplished for Voyager -

471
00:23:34,090 --> 00:23:31,850
the space probe is headed out of the

472
00:23:35,890 --> 00:23:34,100
solar system tonight after photographing

473
00:23:40,120 --> 00:23:35,900
parts of the universe no one had ever

474
00:23:42,970 --> 00:23:40,130
seen before now we had some hints from

475
00:23:46,780 --> 00:23:42,980
earth-based observations that Neptune

476
00:23:49,990 --> 00:23:46,790
had a few clouds and it was that was

477
00:23:52,900 --> 00:23:50,000
better than Uranus but we really weren't

478
00:23:56,520 --> 00:23:52,910
prepared for the spectacular weather

479
00:23:58,750 --> 00:23:56,530
activity that was found in fact

480
00:24:00,610 --> 00:23:58,760
Neptune's the windiest planet in the

481
00:24:07,000 --> 00:24:00,620
solar system and I was totally

482
00:24:09,940 --> 00:24:07,010
unprepared for that the winds are 325

483
00:24:13,450 --> 00:24:09,950
meters per second that's the speed that

484
00:24:16,930 --> 00:24:13,460
the great dark spot is moving relative

485
00:24:18,520 --> 00:24:16,940
to the inside of Neptune everything's

486
00:24:21,000 --> 00:24:18,530
going to the east but the great dark

487
00:24:24,820 --> 00:24:21,010
spot is going more slowly to the east

488
00:24:27,580 --> 00:24:24,830

than the inside of mention we had

489
00:24:29,440 --> 00:24:27,590
expected because Neptune does is not

490
00:24:31,570 --> 00:24:29,450
tipped on its side as a planet but is an

491
00:24:33,760 --> 00:24:31,580
upright planet that the magnetic field

492
00:24:36,130 --> 00:24:33,770
acts with axis would be aligned with the

493
00:24:37,930 --> 00:24:36,140
rotation axis that is the poles would be

494
00:24:40,180 --> 00:24:37,940
near the rotational pole we were

495
00:24:42,640 --> 00:24:40,190
surprised again the magnetic field is

496
00:24:44,560 --> 00:24:42,650
tilted by 47 degrees in the case of

497
00:24:46,750 --> 00:24:44,570
Neptune and it's center of the magnetic

498
00:24:49,630 --> 00:24:46,760
field is offset by almost two-thirds of

499
00:24:51,460 --> 00:24:49,640
the radius of the planet its magnetic

500
00:24:53,650 --> 00:24:51,470
field is somewhat weaker only about half

501
00:24:56,230 --> 00:24:53,660
of that of Saturn's for instance at the

502
00:24:58,360 --> 00:24:56,240
surface and its magnetic field extends

503
00:25:00,910 --> 00:24:58,370
only about 400,000 miles from its

504
00:25:04,270 --> 00:25:00,920
surface we did discover that the

505
00:25:07,810 --> 00:25:04,280
rotation period of the magnetic field is

506
00:25:10,360 --> 00:25:07,820
about 16 and hours and 7 minutes faster

507
00:25:17,610 --> 00:25:10,370
than Uranus but slower than both Cupit

508
00:25:24,880 --> 00:25:23,710
yes I'd like to report the scam as we

509
00:25:26,170 --> 00:25:24,890
approach Neptune we were approaching

510
00:25:28,000 --> 00:25:26,180
with the Sun and the earth almost

511
00:25:30,430 --> 00:25:28,010
directly behind us so you can see we're

512
00:25:32,710 --> 00:25:30,440
virtually a full disk of Neptune and we

513
00:25:35,530 --> 00:25:32,720

aimed to go right over the North Pole

514
00:25:37,600 --> 00:25:35,540
right up over the top of Neptune very

515
00:25:40,600 --> 00:25:37,610
very close to Neptune the trajectory is

516
00:25:43,270 --> 00:25:40,610
then bent by gravity moved south and we

517
00:25:47,590 --> 00:25:43,280
intercepted Triton while it was behind

518
00:25:50,590 --> 00:25:47,600
the up tun and underneath it well as we

519
00:25:54,400 --> 00:25:50,600
got closer and closer to Triton it got

520
00:25:55,720 --> 00:25:54,410
smaller and smaller and smaller and at

521
00:25:57,400 --> 00:25:55,730
the same time brighter and brighter

522
00:25:59,770 --> 00:25:57,410
turned out to be the brightest thing

523
00:26:02,140 --> 00:25:59,780
we've seen in the solar system north of

524
00:26:04,240 --> 00:26:02,150
the polar cap in the North just above

525
00:26:09,250 --> 00:26:04,250
the equator we find one thing we call

526
00:26:15,040 --> 00:26:09,260
the cantaloupe terrain it has a system

527
00:26:17,590 --> 00:26:15,050
of criss-crossing ridges which produce a

528
00:26:20,620 --> 00:26:17,600
set of almost squarish to ovoid dimples

529
00:26:23,140 --> 00:26:20,630
throughout the surface now we're talking

530
00:26:25,390 --> 00:26:23,150
about a surface which is 37 degrees

531
00:26:28,110 --> 00:26:25,400
above absolute zero this is a coldest

532
00:26:30,880 --> 00:26:28,120
thing in the solar system by far even

533
00:26:35,800 --> 00:26:30,890
the cold atmospheres of things like

534
00:26:40,690 --> 00:26:35,810
Neptune are warmer it was unthinkable to

535
00:26:43,150 --> 00:26:40,700
find activity going on a planet whose

536
00:26:44,410 --> 00:26:43,160
surface temperature is that low I mean

537
00:26:47,230 --> 00:26:44,420
this is getting down a point with

538
00:26:50,680 --> 00:26:47,240

molecules stop it was about a month

539
00:26:56,020 --> 00:26:50,690
after the Reuter encounter that we were

540
00:26:59,830 --> 00:26:56,030
looking at stereo images way down in the

541
00:27:04,600 --> 00:26:59,840
southern most part of tritons polar cap

542
00:27:06,130 --> 00:27:04,610
and we saw most of the features lined up

543
00:27:09,910 --> 00:27:06,140
as if they were on a perfect sphere in

544
00:27:13,270 --> 00:27:09,920
fact the two best examples turn out to

545
00:27:15,970 --> 00:27:13,280
be active RUP shion's in which material

546
00:27:19,630 --> 00:27:15,980
is being blown from the surface in a

547
00:27:21,600 --> 00:27:19,640
vertical column to an altitude of 8

548
00:27:24,330 --> 00:27:21,610
kilometers roughly 5 miles

549
00:27:25,910 --> 00:27:24,340
Roger discovered six new moons at

550
00:27:28,880 --> 00:27:25,920
Neptune

551
00:27:33,740 --> 00:27:28,890
two of them were found in the ring our

552
00:27:37,180 --> 00:27:33,750
core ring system orbiting along two of

553
00:27:40,040 --> 00:27:37,190
the ring arcs so apparently shepherding

554
00:27:42,730 --> 00:27:40,050
the edges of those ring arcs in some way

555
00:27:46,960 --> 00:27:42,740
when we look at Neptune's ring system as

556
00:27:51,160 --> 00:27:46,970
we can see here in this mosaic we see

557
00:27:52,970 --> 00:27:51,170
three continuous rings quite easily

558
00:27:56,170 --> 00:27:52,980
there is an outer ring

559
00:27:59,180 --> 00:27:56,180
it's the ring in which in fact the three

560
00:28:01,910 --> 00:27:59,190
arcs are embedded there's an inner ring

561
00:28:05,300 --> 00:28:01,920
which at in high phase geometry appears

562
00:28:07,400 --> 00:28:05,310
brighter than the outer ring that tells

563
00:28:09,350 --> 00:28:07,410

us right away it's dusty dustier than

564
00:28:13,100 --> 00:28:09,360
the outer ring and then we see an inner

565
00:28:15,020 --> 00:28:13,110
more diffuse ring at something like 42

566
00:28:18,650 --> 00:28:15,030
thousand kilometers from the centre of

567
00:28:20,000 --> 00:28:18,660
this of the planet we believe now that

568
00:28:22,400 --> 00:28:20,010
we'll be able to communicate with

569
00:28:24,980 --> 00:28:22,410
Voyager essentially as long as it stays

570
00:28:25,430 --> 00:28:24,990
alive two things will probably stop its

571
00:28:27,170 --> 00:28:25,440
life

572
00:28:28,940 --> 00:28:27,180
first of all it has a power source on

573
00:28:33,220 --> 00:28:28,950
board which is a small nuclear power

574
00:28:37,760 --> 00:28:36,170
radioactive decay of plutonium which

575
00:28:40,280 --> 00:28:37,770
generates heat which in turn is

576
00:28:42,620 --> 00:28:40,290
converted into electricity in about 20

577
00:28:44,690 --> 00:28:42,630
to 25 years we expect to be low enough

578
00:28:46,460 --> 00:28:44,700
so that there's not enough power to keep

579
00:28:49,550 --> 00:28:46,470
the critical subsystems of the

580
00:28:51,650 --> 00:28:49,560
spacecraft operating or at about the

581
00:28:53,960 --> 00:28:51,660
same time we could possibly run out of

582
00:28:55,460 --> 00:28:53,970
attitude control fuel that's the fuel

583
00:28:57,140 --> 00:28:55,470
which goes to the little thrusters which

584
00:28:59,480 --> 00:28:57,150
keeps the spacecraft stabilized and

585
00:29:01,910 --> 00:28:59,490
pointed at the earth now between the

586
00:29:04,070 --> 00:29:01,920
stars is a dilute gas ionized gas

587
00:29:05,690 --> 00:29:04,080
filling interplay interstellar space

588
00:29:08,060 --> 00:29:05,700

it's called the interstellar medium

589
00:29:11,150 --> 00:29:08,070
each star blows a bubble in that

590
00:29:13,130 --> 00:29:11,160
interstellar gas our own Sun does that

591
00:29:15,200 --> 00:29:13,140
that bubble in the case of our Sun is

592
00:29:17,660 --> 00:29:15,210
called the heliosphere we don't know how

593
00:29:19,160 --> 00:29:17,670
large that bubble is it may be that the

594
00:29:21,560 --> 00:29:19,170
distance to the edge of the bubble

595
00:29:23,300 --> 00:29:21,570
called the heliopause is a hundred times

596
00:29:24,950 --> 00:29:23,310
the distance from the earth to the Sun

597
00:29:29,210 --> 00:29:24,960
that is three times further than it is

598
00:29:31,460 --> 00:29:29,220
out to Neptune in which case 25 years

599
00:29:33,080 --> 00:29:31,470
Voyager 1 which will at that point be a

600
00:29:35,210 --> 00:29:33,090
hundred and thirty times as far from the

601
00:29:36,140 --> 00:29:35,220
Sun as the earth could well be returning

602
00:29:39,250 --> 00:29:36,150
data from

603
00:29:41,960 --> 00:29:39,260
interstellar space for the first time

604
00:29:44,540 --> 00:29:41,970
there will be a part of earth which will

605
00:29:52,920 --> 00:29:44,550
roam essentially forever in the galaxy