1
00:00:18,410 --> 00:00:01,150
that lies beyond

2
00:00:20,280 --> 00:00:18,420
[Music]

3
00:00:22,260 --> 00:00:20,290
good evening folks

4
00:00:24,540 --> 00:00:22,270
welcome to the Jet Propulsion Laboratory

5
00:00:25,740 --> 00:00:24,550
the von Karman series my name is Brian

6
00:00:27,839 --> 00:00:25,750
white from the JPL's office

7
00:00:31,109 --> 00:00:27,849
communication education and welcome to

8
00:00:37,020 --> 00:00:31,119
tonight's talk it broke a story of how

9
00:00:39,660 --> 00:00:37,030
we fixed it yeah percentage-wise NASA

10
00:00:41,550 --> 00:00:39,670
JPL has a pretty good track record our

11
00:00:43,920 --> 00:00:41,560
curiosity has given us insight on Mars

12
00:00:50,820 --> 00:00:43,930
and a few voyagers have set some golden

13
00:00:57,330 --> 00:00:50,830

records so you know where you're at

14
00:00:58,920 --> 00:00:57,340
right let your nerd flag fly so tonight

15
00:01:00,390 --> 00:00:58,930
we're gonna tell you a story maybe you

16
00:01:02,550 --> 00:01:00,400
haven't heard before and you would be

17
00:01:05,039 --> 00:01:02,560
forgiven for not remembering this

18
00:01:08,310 --> 00:01:05,049
spacecraft the tale of stress and

19
00:01:09,450 --> 00:01:08,320
ingenuity of deep space one a dedicated

20
00:01:11,760 --> 00:01:09,460
group of individuals that work

21
00:01:14,340 --> 00:01:11,770
tirelessly to save a spacecraft farther

22
00:01:17,789 --> 00:01:14,350
away than our Sun is a story of hope and

23
00:01:19,200 --> 00:01:17,799
what we have human beings are capable in

24
00:01:19,889 --> 00:01:19,210
the immortal words of commander Peter

25
00:01:24,899 --> 00:01:19,899
Taggart

26
00:01:26,099 --> 00:01:24,909
never give up never surrender our

27
00:01:27,779 --> 00:01:26,109
speaker tonight grew up in Toledo Ohio

28
00:01:29,010 --> 00:01:27,789
and earned a BA in physics from

29
00:01:31,469 --> 00:01:29,020
Princeton University

30
00:01:33,749 --> 00:01:31,479
he received an MS and physics from the

31
00:01:35,399 --> 00:01:33,759
University of Colorado in Boulder moving

32
00:01:37,679 --> 00:01:35,409
over to the joint Institute for

33
00:01:41,340 --> 00:01:37,689
laboratory astrophysics where he

34
00:01:42,749 --> 00:01:41,350
received his PhD he joined JPL in 1986

35
00:01:45,120 --> 00:01:42,759
has been the recipient of numerous

36
00:01:47,879 --> 00:01:45,130
honors and is the only person to have

37
00:01:50,010 --> 00:01:47,889
received both the exceptional technical

38
00:01:52,289 --> 00:01:50,020

excellence award and the exceptional

39
00:01:54,690 --> 00:01:52,299
leadership award two of JPL's most

40
00:01:56,370 --> 00:01:54,700
prestigious honors he holds a black belt

41
00:02:00,959 --> 00:01:56,380
in karate teaches dance with his wife

42
00:02:02,849 --> 00:02:00,969
who is also a brain scientist yeah he's

43
00:02:12,560 --> 00:02:02,859
one of those JPL underachievers please

44
00:02:18,960 --> 00:02:15,330
let's get right into it okay what was it

45
00:02:20,610 --> 00:02:18,970
that led you here the JPL well so I've

46
00:02:22,200 --> 00:02:20,620
been a space enthusiasts since I was

47
00:02:24,300 --> 00:02:22,210
four years old

48
00:02:25,790 --> 00:02:24,310
I've just loved it my whole life I

49
00:02:28,290 --> 00:02:25,800
decided when I was in the fourth grade

50
00:02:31,350 --> 00:02:28,300
that I want to get a PhD in physics and

51
00:02:33,090 --> 00:02:31,360
work for NASA a few more years till I

52
00:02:35,220 --> 00:02:33,100
did okay but but when I was in the

53
00:02:37,530 --> 00:02:35,230
fourth grade is when I wrote to JPL for

54
00:02:39,660 --> 00:02:37,540
the first time as well as other NASA

55
00:02:41,160 --> 00:02:39,670
centers and other scientific

56
00:02:44,250 --> 00:02:41,170
organizations around the country and

57
00:02:46,530 --> 00:02:44,260
even around the world so to me working

58
00:02:49,470 --> 00:02:46,540
here is it's truly a dream come true

59
00:02:54,210 --> 00:02:49,480
I mean I love it I just love it it is so

60
00:02:56,910 --> 00:02:54,220
cool and every day I just feel so so

61
00:02:58,770 --> 00:02:56,920
fortunate it's just it's tremendous it's

62
00:03:00,180 --> 00:02:58,780
fun I feel like I'm getting paid to do

63
00:03:03,330 --> 00:03:00,190

my hobby well don't tell anybody that

64
00:03:06,449 --> 00:03:03,340
you don't get paid that much so it's

65
00:03:08,190 --> 00:03:06,459
okay you've got a great career I feel

66
00:03:10,830 --> 00:03:08,200
like you've had your your dream job

67
00:03:12,360 --> 00:03:10,840
multiple times yeah yeah what were some

68
00:03:14,880 --> 00:03:12,370
of the missions that you saw I've I've

69
00:03:17,009 --> 00:03:14,890
worked on a number of fun things working

70
00:03:19,380 --> 00:03:17,019
on system to use lasers instead of

71
00:03:21,990 --> 00:03:19,390
radios for communicating with spacecraft

72
00:03:25,530 --> 00:03:22,000
far into the solar system who worked on

73
00:03:29,009 --> 00:03:25,540
a laser altimeter for Mars infrared

74
00:03:30,479 --> 00:03:29,019
Space Telescope missions to search for

75
00:03:38,340 --> 00:03:30,489
and characterize planets around other

76
00:03:42,569 --> 00:03:38,350
stars worked on mission to to measure

77
00:03:43,949 --> 00:03:42,579
the heights of waves on the ocean sample

78
00:03:46,440 --> 00:03:43,959
return a sample from Mars

79
00:03:49,199 --> 00:03:46,450
you got some bunch of yeah lots of fun

80
00:03:51,150 --> 00:03:49,209
things yeah but this was your what we're

81
00:03:54,210 --> 00:03:51,160
gonna talk about tonight this is your

82
00:03:56,759 --> 00:03:54,220
first end to end from vague concept

83
00:03:58,800 --> 00:03:56,769
cocktail napkin to the end of a

84
00:04:00,240 --> 00:03:58,810
successful spoiler alert the end of a

85
00:04:02,280 --> 00:04:00,250
successful mission right this is the

86
00:04:04,319 --> 00:04:02,290
first time I took one from the very

87
00:04:06,630 --> 00:04:04,329
beginning to the very end okay and how

88
00:04:08,039 --> 00:04:06,640

did that what did it's one behind me

89
00:04:10,289 --> 00:04:08,049
what is it step down so that's deep

90
00:04:11,880 --> 00:04:10,299
space one so what did you say what did

91
00:04:15,120 --> 00:04:11,890
it stem out of where did it okay so the

92
00:04:18,000 --> 00:04:15,130
in the 1990s there was a recognition

93
00:04:21,360 --> 00:04:18,010
that NASA was had sort of gotten into a

94
00:04:22,890 --> 00:04:21,370
vicious cycle where when when NASA

95
00:04:24,770 --> 00:04:22,900
started it was always using the most

96
00:04:27,630 --> 00:04:24,780
cutting-edge advanced technology

97
00:04:29,130 --> 00:04:27,640
but after a while that stopped and you

98
00:04:31,470 --> 00:04:29,140
can understand why if if you're

99
00:04:33,930 --> 00:04:31,480
responsible for a multi hundred million

100
00:04:36,450 --> 00:04:33,940
dollar mission you're not rewarded for

101
00:04:38,640 --> 00:04:36,460
taking a risk you're rewarded for

102
00:04:41,250 --> 00:04:38,650
getting the mission accomplished for

103
00:04:43,680 --> 00:04:41,260
being successful and the best way to be

104
00:04:46,860 --> 00:04:43,690
successful is not to take a risk with

105
00:04:48,360 --> 00:04:46,870
some fancy new technology rather it's to

106
00:04:51,090 --> 00:04:48,370
use something that the guy before you

107
00:04:53,370 --> 00:04:51,100
used because you know that it works in

108
00:04:55,770 --> 00:04:53,380
space it can survive the radiation the

109
00:04:58,020 --> 00:04:55,780
temperature of the rocket ride the all

110
00:05:00,630 --> 00:04:58,030
the forbidding aspects of a mission in

111
00:05:02,100 --> 00:05:00,640
space and so NASA got into the cycle of

112
00:05:06,210 --> 00:05:02,110
using older and older and older

113
00:05:08,490 --> 00:05:06,220

technology recognizing that if that

114
00:05:10,860 --> 00:05:08,500
there were promising new technologies

115
00:05:14,910 --> 00:05:10,870
but nobody would use them until somebody

116
00:05:16,380 --> 00:05:14,920
else did so in the mid-90s we started a

117
00:05:19,740 --> 00:05:16,390
program called the new millennium

118
00:05:22,740 --> 00:05:19,750
program that was designed to test these

119
00:05:24,090 --> 00:05:22,750
high-risk advanced technologies and if

120
00:05:25,710 --> 00:05:24,100
they worked then subsequent missions

121
00:05:26,100 --> 00:05:25,720
would use them without incurring the

122
00:05:28,950 --> 00:05:26,110
risk

123
00:05:30,840 --> 00:05:28,960
so basically Deep Space 1 and the other

124
00:05:33,810 --> 00:05:30,850
missions of the so-called new millennium

125
00:05:35,610 --> 00:05:33,820
program were designed to take the risks

126
00:05:40,140 --> 00:05:35,620
so future missions wouldn't have to

127
00:05:44,490 --> 00:05:40,150
sohere's Deep Space 1 and we had these

128
00:05:46,860 --> 00:05:44,500
12 astounding technologies and the point

129
00:05:49,740 --> 00:05:46,870
of the mission was to exercise these on

130
00:05:51,690 --> 00:05:49,750
an operational interplanetary mission

131
00:05:53,910 --> 00:05:51,700
and when we were talking about this you

132
00:05:56,070 --> 00:05:53,920
wanted me to make it very clear to me

133
00:05:58,800 --> 00:05:56,080
that Deep Space 1 actually did not have

134
00:06:00,900 --> 00:05:58,810
a science question it needed to answer

135
00:06:03,300 --> 00:06:00,910
right not in the conventional sense a

136
00:06:06,540 --> 00:06:03,310
question that we were asking was how

137
00:06:09,240 --> 00:06:06,550
well do these technologies work can we

138
00:06:10,590 --> 00:06:09,250

rely on them for future missions you

139
00:06:14,400 --> 00:06:10,600
know can they live up to their promise

140
00:06:17,070 --> 00:06:14,410
if they can't then we'll find out on ds1

141
00:06:21,270 --> 00:06:17,080
and not subject these subsequent

142
00:06:23,340 --> 00:06:21,280
missions to to these to these risks but

143
00:06:25,350 --> 00:06:23,350
we had some fancy technologies ion

144
00:06:27,310 --> 00:06:25,360
propulsion which I first heard of in a

145
00:06:31,750 --> 00:06:27,320
Star Trek episode

146
00:06:33,370 --> 00:06:31,760
and in fact that became a very important

147
00:06:35,680 --> 00:06:33,380
technology on another mission I worked

148
00:06:37,570 --> 00:06:35,690
on that just completed at the end of

149
00:06:39,730 --> 00:06:37,580
last year with a spacecraft orbiting a

150
00:06:42,730 --> 00:06:39,740
dwarf planet between Mars and Jupiter

151
00:06:44,280 --> 00:06:42,740
taking advantage of that we had this

152
00:06:47,020 --> 00:06:44,290
mind of its own means we have some

153
00:06:50,710 --> 00:06:47,030
artificial intelligence smart onboard

154
00:06:53,170 --> 00:06:50,720
systems that we didn't want to risk a

155
00:06:55,630 --> 00:06:53,180
mission with those until we till we

156
00:06:57,160 --> 00:06:55,640
tested them out and so that was the

157
00:06:58,480 --> 00:06:57,170
objective of the mission you get this

158
00:07:01,390 --> 00:06:58,490
this great mission

159
00:07:03,670 --> 00:07:01,400
your primary your primary mission was

160
00:07:07,330 --> 00:07:03,680
for how long it was 11 months 11 months

161
00:07:08,350 --> 00:07:07,340
from build to through that primary

162
00:07:11,700 --> 00:07:08,360
mission how about how long's that

163
00:07:15,040 --> 00:07:11,710

supposed to be well normally it takes

164
00:07:16,450 --> 00:07:15,050
more five years or so from the time you

165
00:07:20,530 --> 00:07:16,460
conceived of it until the time you

166
00:07:21,820 --> 00:07:20,540
launch ds1 shown here on the left when

167
00:07:23,980 --> 00:07:21,830
it was being built just a few hundred

168
00:07:27,480 --> 00:07:23,990
yards from here as we say up the hill in

169
00:07:30,100 --> 00:07:27,490
that direction we did in three years and

170
00:07:32,350 --> 00:07:30,110
it was at that time the lowest cost

171
00:07:37,480 --> 00:07:32,360
interplanetary mission NASA had ever

172
00:07:40,060 --> 00:07:37,490
done and part of the idea was to see if

173
00:07:43,720 --> 00:07:40,070
we can again break out of the cycle of

174
00:07:45,940 --> 00:07:43,730
big expensive missions using out-of-date

175
00:07:47,770 --> 00:07:45,950
technology okay so you've got this great

176
00:07:49,240 --> 00:07:47,780
photo of the spacecraft right nice you

177
00:07:51,160 --> 00:07:49,250
just say the solar rays are not mounted

178
00:07:53,860 --> 00:07:51,170
to it here so you're just seeing the the

179
00:07:55,600 --> 00:07:53,870
main spacecraft structure okay we've got

180
00:07:58,860 --> 00:07:55,610
that beautiful launch photo on October

181
00:08:02,440 --> 00:07:58,870
24th 1998 right it's a beautiful launch

182
00:08:05,710 --> 00:08:02,450
and exercise just include here also my

183
00:08:08,410 --> 00:08:05,720
favorite picture of ds1 sure so worked

184
00:08:11,500 --> 00:08:08,420
on it a lot spent a lot of time in the

185
00:08:14,200 --> 00:08:11,510
cleanroom but excuse me this is my

186
00:08:18,100 --> 00:08:14,210
favorite picture so this was taken by

187
00:08:22,660 --> 00:08:18,110
the famous 200-inch Hale telescope on

188
00:08:25,570 --> 00:08:22,670

Palomar and there's ds1 when it was nine

189
00:08:29,260 --> 00:08:25,580
times farther away than the moon

190
00:08:31,470 --> 00:08:29,270
and this is this is one of the greatest

191
00:08:33,400 --> 00:08:31,480
distances at which a human-made

192
00:08:36,130 --> 00:08:33,410
spacecraft has ever been photographed

193
00:08:37,390 --> 00:08:36,140
which a human-made object has ever been

194
00:08:40,120 --> 00:08:37,400
photographed when this picture was taken

195
00:08:42,760 --> 00:08:40,130
it was four million times fainter than

196
00:08:45,690 --> 00:08:42,770
you could see with your naked eye and I

197
00:08:48,550 --> 00:08:45,700
I love this picture you know when a

198
00:08:50,770 --> 00:08:48,560
telescope takes a picture of something

199
00:08:53,170 --> 00:08:50,780
of you know the Stars the telescope of

200
00:08:56,380 --> 00:08:53,180
course has to move to counteract Earth's

201
00:08:59,680 --> 00:08:56,390
rotation that's why the Stars are no

202
00:09:01,540 --> 00:08:59,690
circular focused sort of dots the shape

203
00:09:03,730 --> 00:09:01,550
of ds1 there doesn't tell you anything

204
00:09:05,760 --> 00:09:03,740
about the shape of the spacecraft but

205
00:09:07,810 --> 00:09:05,770
rather it had its own independent motion

206
00:09:10,330 --> 00:09:07,820
through the solar system while this

207
00:09:13,360 --> 00:09:10,340
picture was taken and so to me this just

208
00:09:16,060 --> 00:09:13,370
says we have a spacecraft out among the

209
00:09:18,460 --> 00:09:16,070
stars I mean what could be cooler than

210
00:09:22,080 --> 00:09:18,470
that so I I just really love this

211
00:09:25,390 --> 00:09:22,090
picture I love your excitement already

212
00:09:27,520 --> 00:09:25,400
so you get this great photo you're out

213
00:09:30,490 --> 00:09:27,530

there you've got a everything's going

214
00:09:31,960 --> 00:09:30,500
well the technologies are proven right

215
00:09:34,300 --> 00:09:31,970
we put them through their paces it was a

216
00:09:36,400 --> 00:09:34,310
very intensive very demanding mission

217
00:09:38,650 --> 00:09:36,410
you know most missions when you launch

218
00:09:41,770 --> 00:09:38,660
they travel a long time before they get

219
00:09:43,630 --> 00:09:41,780
to their destination but for ds1 we were

220
00:09:45,070 --> 00:09:43,640
immediately testing out these

221
00:09:47,850 --> 00:09:45,080
technologies putting them through their

222
00:09:50,260 --> 00:09:47,860
paces seeing how well they would work

223
00:09:52,030 --> 00:09:50,270
challenging them and you even got you

224
00:09:55,300 --> 00:09:52,040
got some a bonus thing out of this you

225
00:09:58,330 --> 00:09:55,310
got a we did a flyby right so the

226
00:10:01,120 --> 00:09:58,340
because we had the ion propulsion which

227
00:10:03,430 --> 00:10:01,130
is uniquely capable far far far more

228
00:10:05,560 --> 00:10:03,440
capable than conventional propulsion and

229
00:10:08,260 --> 00:10:05,570
we had this so called autonomous

230
00:10:10,510 --> 00:10:08,270
navigation system that is where the

231
00:10:12,430 --> 00:10:10,520
spacecraft could navigate itself we

232
00:10:14,500 --> 00:10:12,440
wanted to prove that we could do more

233
00:10:15,700 --> 00:10:14,510
than just send the spacecraft out into

234
00:10:17,920 --> 00:10:15,710
the solar system and sort of putter

235
00:10:20,680 --> 00:10:17,930
around but rather that we could actually

236
00:10:24,850 --> 00:10:20,690
travel to a specific solar system

237
00:10:28,660 --> 00:10:24,860
destination and so again we launched in

238
00:10:31,230 --> 00:10:28,670

October of 98 and July of 1999 we flew

239
00:10:34,690 --> 00:10:31,240
by an asteroid to prove that we could

240
00:10:37,570 --> 00:10:34,700
travel to navigate to a specific

241
00:10:38,860 --> 00:10:37,580
destination in space because that's what

242
00:10:40,840 --> 00:10:38,870
these technologies would have to do

243
00:10:42,640 --> 00:10:40,850
if they were used again very cool and

244
00:10:45,130 --> 00:10:42,650
you get so you get to the end of this 11

245
00:10:47,350 --> 00:10:45,140
months prime mission right and you got a

246
00:10:49,360 --> 00:10:47,360
you got a spacecraft up there we do we

247
00:10:52,240 --> 00:10:49,370
had a healthy spacecraft out there in

248
00:10:54,130 --> 00:10:52,250
the solar system and I don't know about

249
00:10:55,860 --> 00:10:54,140
you but the rest of us here who were

250
00:10:59,500 --> 00:10:55,870
taxpayers we'd all paid for this

251
00:11:02,260 --> 00:10:59,510
spacecraft and and we wanted to take the

252
00:11:03,730 --> 00:11:02,270
best advantage of it and so we actually

253
00:11:06,100 --> 00:11:03,740
proposed to NASA headquarters a

254
00:11:09,160 --> 00:11:06,110
so-called extended mission okay a new

255
00:11:11,290 --> 00:11:09,170
thing to do with the spacecraft and they

256
00:11:13,660 --> 00:11:11,300
concurred instead of testing more

257
00:11:16,030 --> 00:11:13,670
technologies the idea was to fly for

258
00:11:19,990 --> 00:11:16,040
another two years at the end of this 11

259
00:11:23,530 --> 00:11:20,000
month mission to fly to a comet and get

260
00:11:25,720 --> 00:11:23,540
a close-up picture of the comet and at

261
00:11:27,730 --> 00:11:25,730
that time we did not have good close-up

262
00:11:30,720 --> 00:11:27,740
picture of comet so this would be NASA's

263
00:11:32,740 --> 00:11:30,730

first attempt to send a spacecraft to

264
00:11:34,600 --> 00:11:32,750
comment now of course we've all seen

265
00:11:37,780 --> 00:11:34,610
cool pictures of comets you know there's

266
00:11:40,780 --> 00:11:37,790
a big or a roughly circular cloud of gas

267
00:11:42,910 --> 00:11:40,790
and dust called the coma and that can be

268
00:11:45,790 --> 00:11:42,920
many thousands and thousands of miles

269
00:11:47,980 --> 00:11:45,800
across bigger than Earth sometimes and a

270
00:11:50,829 --> 00:11:47,990
tail that can be even in some cases

271
00:11:54,400 --> 00:11:50,839
millions of miles long but deep inside

272
00:11:56,079 --> 00:11:54,410
that coma is a small solid object that

273
00:11:58,269 --> 00:11:56,089
can be a fraction of a mile or maybe a

274
00:12:02,740 --> 00:11:58,279
few miles across too small to be seen

275
00:12:04,360 --> 00:12:02,750
well from Earth and so our ambitious

276
00:12:08,070 --> 00:12:04,370
proposal that I mean how hard could this

277
00:12:10,750 --> 00:12:08,080
be was to fly for another two years and

278
00:12:14,110 --> 00:12:10,760
at that point roughly a billion miles or

279
00:12:15,940 --> 00:12:14,120
so and plunge into this coma and take a

280
00:12:17,800 --> 00:12:15,950
picture of the nucleus and that sounds

281
00:12:18,310 --> 00:12:17,810
like a great idea but this isn't it

282
00:12:20,860 --> 00:12:18,320
worked

283
00:12:24,100 --> 00:12:20,870
a story of nothing going wrong that's

284
00:12:28,000 --> 00:12:24,110
true I'm guessing something happened on

285
00:12:31,210 --> 00:12:28,010
the way that's right it did on November

286
00:12:36,090 --> 00:12:31,220
11th 1999 just a couple of months into

287
00:12:38,769 --> 00:12:36,100
this extended mission disaster struck so

288
00:12:41,769 --> 00:12:38,779

the there's a device on the spacecraft

289
00:12:45,910 --> 00:12:41,779
called a star tracker this is a clever

290
00:12:48,130 --> 00:12:45,920
name because it tracks stars and the

291
00:12:52,350 --> 00:12:48,140
idea of this thing is in the zero

292
00:12:54,819 --> 00:12:52,360
gravity of space far from anything

293
00:12:57,579 --> 00:12:54,829
spacecraft needs help to figure out its

294
00:13:00,220 --> 00:12:57,589
orientation you know we we figure out

295
00:13:02,440 --> 00:13:00,230
our orientation here on the ground by we

296
00:13:04,569 --> 00:13:02,450
sense gravity you know and we might

297
00:13:06,699 --> 00:13:04,579
recognize landmarks you might use a

298
00:13:09,520 --> 00:13:06,709
compass for example to tell you that

299
00:13:12,220 --> 00:13:09,530
that's north or you might you might

300
00:13:14,490 --> 00:13:12,230
recognize star patterns you know the

301
00:13:17,860 --> 00:13:14,500
North Star or the Big Dipper Orion

302
00:13:20,560 --> 00:13:17,870
Scorpius whatever you know star patterns

303
00:13:22,600 --> 00:13:20,570
are familiar you well the star tracker

304
00:13:25,329 --> 00:13:22,610
will actually work the same way it was a

305
00:13:26,920 --> 00:13:25,339
camera and a computer together in one

306
00:13:29,650 --> 00:13:26,930
unit this was not one of our advanced

307
00:13:32,260 --> 00:13:29,660
technologies but it would regularly take

308
00:13:34,360 --> 00:13:32,270
pictures of the stars it would recognize

309
00:13:37,810 --> 00:13:34,370
the star patterns and so then it would

310
00:13:39,280 --> 00:13:37,820
say to the computer I recognize that

311
00:13:41,620 --> 00:13:39,290
star pattern so I'm looking in that

312
00:13:44,740 --> 00:13:41,630
direction I'm oriented this way and

313
00:13:46,210 --> 00:13:44,750

that's how the spacecraft knew in the

314
00:13:50,380 --> 00:13:46,220
zero gravity of space how it was

315
00:13:52,090 --> 00:13:50,390
oriented until November 11 1999 I mean

316
00:13:56,050 --> 00:13:52,100
until January sorry you know November

317
00:13:58,960 --> 00:13:56,060
11th oh man you know 19 it failed and so

318
00:14:01,840 --> 00:13:58,970
the spacecraft then responded with what

319
00:14:05,650 --> 00:14:01,850
we call a safe mode this is protective

320
00:14:07,540 --> 00:14:05,660
software that's designed to respond when

321
00:14:10,360 --> 00:14:07,550
there's a problem and ds1 had sort of

322
00:14:13,110 --> 00:14:10,370
three levels of this and it responded

323
00:14:16,180 --> 00:14:13,120
with the one appropriately for the worst

324
00:14:18,069 --> 00:14:16,190
situations oh good and so we we need to

325
00:14:20,440 --> 00:14:18,079
spend a moment here discussing what it

326
00:14:23,319 --> 00:14:20,450
did so that you understand then the

327
00:14:25,510 --> 00:14:23,329
problem we were confronted with so it

328
00:14:27,280 --> 00:14:25,520
used a Sun sensor wherever you are in

329
00:14:28,600 --> 00:14:27,290
the solar system I'm sure you all know

330
00:14:31,030 --> 00:14:28,610
this wherever you've been in the solar

331
00:14:33,940 --> 00:14:31,040
system the one thing you can always spot

332
00:14:38,110 --> 00:14:33,950
is the Sun so I had a device to find the

333
00:14:40,569 --> 00:14:38,120
Sun would turn and point at that didn't

334
00:14:42,819 --> 00:14:40,579
know where Earth was or how to point at

335
00:14:46,510 --> 00:14:42,829
earth so it transmitted a very broad

336
00:14:48,579 --> 00:14:46,520
radio signal very broad figuring earth

337
00:14:51,250 --> 00:14:48,589
would be in them somewhere within that

338
00:14:53,560 --> 00:14:51,260

signal and then I would just rotate

339
00:14:55,420 --> 00:14:53,570
about once per hour so we saw some

340
00:14:56,770 --> 00:14:55,430
artists concepts earlier of the

341
00:14:59,140 --> 00:14:56,780
spacecraft but just want to take another

342
00:15:01,900 --> 00:14:59,150
look at it here to orient you so you can

343
00:15:04,500 --> 00:15:01,910
follow so here's the spacecraft again

344
00:15:10,980 --> 00:15:04,510
and the solar rays are just folded up

345
00:15:13,710 --> 00:15:10,990
here on the side here and here here's

346
00:15:16,710 --> 00:15:13,720
the Sun sensor so this thing was

347
00:15:20,699 --> 00:15:16,720
designed just to spot the Sun here's the

348
00:15:22,319 --> 00:15:20,709
main antenna but the main antenna was

349
00:15:25,350 --> 00:15:22,329
aligned with the Sun sensor so it was

350
00:15:28,319 --> 00:15:25,360
pointed at the Sun not at earth there's

351
00:15:30,240 --> 00:15:28,329
also an auxilary antenna here that could

352
00:15:34,530 --> 00:15:30,250
transmit this broad beam instead of a

353
00:15:37,800 --> 00:15:34,540
narrow radio beam and because it'll come

354
00:15:41,280 --> 00:15:37,810
up later I just want to show you in the

355
00:15:41,639 --> 00:15:41,290
back here as a camera we'll come back to

356
00:15:44,189 --> 00:15:41,649
that

357
00:15:46,410 --> 00:15:44,199
spoiler yeah and as long as we're

358
00:15:50,160 --> 00:15:46,420
looking at it also there's the star

359
00:15:52,710 --> 00:15:50,170
tracker but where that was our

360
00:15:55,290 --> 00:15:52,720
assessment of the star tracker so now

361
00:15:58,410 --> 00:15:55,300
with this with the main antenna pointed

362
00:16:01,139 --> 00:15:58,420
at the Sun and this broad beam we could

363
00:16:03,449 --> 00:16:01,149

just barely communicate with the

364
00:16:04,800 --> 00:16:03,459
spacecraft and remember this was after

365
00:16:07,139 --> 00:16:04,810
the prime mission so it was already

366
00:16:10,680 --> 00:16:07,149
farther away than we had ever planned

367
00:16:12,300 --> 00:16:10,690
for it to be and perhaps you know that

368
00:16:15,449 --> 00:16:12,310
when we communicate with interplanetary

369
00:16:18,090 --> 00:16:15,459
spacecraft we use the Deep Space Network

370
00:16:21,569 --> 00:16:18,100
these are these big antennas that we

371
00:16:24,030 --> 00:16:21,579
have what a complex of a few of them

372
00:16:26,730 --> 00:16:24,040
near near Goldstone here in California

373
00:16:28,949 --> 00:16:26,740
near Madrid Spain and near Canberra

374
00:16:31,590 --> 00:16:28,959
Australia so by being spaced around

375
00:16:35,220 --> 00:16:31,600
earth we have them pointed in all

376
00:16:37,980 --> 00:16:35,230
directions and these are big antennas

377
00:16:41,069 --> 00:16:37,990
only the ones that were 112 feet in

378
00:16:44,939 --> 00:16:41,079
diameter were had the equipment to

379
00:16:46,680 --> 00:16:44,949
transmit at D s ones radio frequency so

380
00:16:49,470 --> 00:16:46,690
those were the only kind we could use to

381
00:16:52,860 --> 00:16:49,480
send a signal to the spacecraft however

382
00:16:56,639 --> 00:16:52,870
it was so far away in using this weak

383
00:16:59,040 --> 00:16:56,649
antenna only the 230 foot diameter

384
00:17:01,290 --> 00:16:59,050
antennas could actually receive the

385
00:17:03,629 --> 00:17:01,300
signal from it so there are three of

386
00:17:05,010 --> 00:17:03,639
these antennas on our whole planet and

387
00:17:07,530 --> 00:17:05,020
of course they were busy doing other

388
00:17:10,650 --> 00:17:07,540

things and so now we had to schedule the

389
00:17:14,010 --> 00:17:10,660
use of simultaneously a 100 12-foot

390
00:17:16,140 --> 00:17:14,020
antenna and a 230-foot antenna just to

391
00:17:17,120 --> 00:17:16,150
communicate and the rate at which we

392
00:17:25,519 --> 00:17:17,130
communicate

393
00:17:31,139 --> 00:17:25,529
was about a quarter of how oh no fast

394
00:17:34,260 --> 00:17:31,149
were talking comparable to a good Morse

395
00:17:36,029 --> 00:17:34,270
code operator a good Morse code operator

396
00:17:38,330 --> 00:17:36,039
a good one okay not me trying it for the

397
00:17:40,769 --> 00:17:38,340
patient right but not good enough for

398
00:17:44,580 --> 00:17:40,779
serious interplanetary communications

399
00:17:48,450 --> 00:17:44,590
that sounds and it sounds impossible it

400
00:17:53,430 --> 00:17:48,460
sounds like well and in fact so I I

401
00:17:56,070 --> 00:17:53,440
don't I I wasn't happy about this and I

402
00:17:58,200 --> 00:17:56,080
mean the the in all seriousness the real

403
00:18:01,380 --> 00:17:58,210
assessment was this is fatal yeah

404
00:18:03,090 --> 00:18:01,390
there's a catastrophic failure we should

405
00:18:05,430 --> 00:18:03,100
retire the spacecraft that it had an

406
00:18:06,840 --> 00:18:05,440
incredibly successful mission retire the

407
00:18:10,200 --> 00:18:06,850
spacecraft and let it rest on its

408
00:18:13,500 --> 00:18:10,210
laurels this was catastrophic and that's

409
00:18:15,840 --> 00:18:13,510
what most people that was the

410
00:18:18,060 --> 00:18:15,850
perspective that most people had you but

411
00:18:19,769 --> 00:18:18,070
you've come up from four years old

412
00:18:22,560 --> 00:18:19,779
knowing how to do this going through the

413
00:18:24,299 --> 00:18:22,570

people walking on the moon I get the

414
00:18:25,560 --> 00:18:24,309
feeling that is not the type of person

415
00:18:27,659 --> 00:18:25,570
that you are mom that's right my

416
00:18:31,860 --> 00:18:27,669
philosophy was if it isn't impossible it

417
00:18:35,669 --> 00:18:31,870
isn't worth doing yeah and we wanted to

418
00:18:38,070 --> 00:18:35,679
fix this thing and the first challenge

419
00:18:40,529 --> 00:18:38,080
was just to point the antenna at earth

420
00:18:43,440 --> 00:18:40,539
okay could we do that so we could

421
00:18:44,909 --> 00:18:43,450
communicate with it for the possibility

422
00:18:45,330 --> 00:18:44,919
that there might be something we could

423
00:18:54,659 --> 00:18:45,340
do

424
00:18:56,549 --> 00:18:54,669
this well you you sort of think about I

425
00:18:59,460 --> 00:18:56,559
don't if you've ever seen the Apollo 13

426
00:19:01,470 --> 00:18:59,470
movie yes you there's a scene in there

427
00:19:03,450 --> 00:19:01,480
where the guy walks into a room and has

428
00:19:05,970 --> 00:19:03,460
a box and dumps it on the table

429
00:19:08,519 --> 00:19:05,980
you know when there's duct tape and few

430
00:19:11,010 --> 00:19:08,529
pens and pencils and notebook paper and

431
00:19:12,810 --> 00:19:11,020
you know a Moon Boot and things like

432
00:19:14,070 --> 00:19:12,820
that and says okay this is what we've

433
00:19:15,779 --> 00:19:14,080
got to work with and now we've got to

434
00:19:19,320 --> 00:19:15,789
make this circular device fit into the

435
00:19:22,799 --> 00:19:19,330
square device excuse me so we can get

436
00:19:25,169 --> 00:19:22,809
the air from the lunar module indicating

437
00:19:26,159 --> 00:19:25,179
with the air in the command module so

438
00:19:27,629 --> 00:19:26,169

you just sort of look around on the

439
00:19:29,580 --> 00:19:27,639
spacecraft you say what have we got to

440
00:19:30,540 --> 00:19:29,590
work with because you candle over to the

441
00:19:33,210 --> 00:19:30,550
Jiffy Lube

442
00:19:34,980 --> 00:19:33,220
right at this point the spacecraft was a

443
00:19:38,250 --> 00:19:34,990
hundred fifty million miles from Earth

444
00:19:40,230 --> 00:19:38,260
was six hundred or something like that

445
00:19:42,390 --> 00:19:40,240
six hundred times farther away more than

446
00:19:47,280 --> 00:19:42,400
six hundred times actually farther away

447
00:19:49,590 --> 00:19:47,290
than the moon at this point well well in

448
00:19:50,610 --> 00:19:49,600
excess of half a million times farther

449
00:19:55,050 --> 00:19:50,620
than astronauts on the International

450
00:19:56,880 --> 00:19:55,060
Space Station okay so it was up to I

451
00:19:58,590 --> 00:19:56,890
mean all we could all we could work with

452
00:20:00,330 --> 00:19:58,600
was what was there and we could send

453
00:20:02,670 --> 00:20:00,340
ones and zeroes all right so what do we

454
00:20:04,260 --> 00:20:02,680
have how do we what's the first step on

455
00:20:06,350 --> 00:20:04,270
this well the first step maybe we could

456
00:20:09,180 --> 00:20:06,360
demonstrate it I would love to do that

457
00:20:14,970 --> 00:20:09,190
but is it just gonna be the two of us no

458
00:20:18,990 --> 00:20:14,980
I think we need some assistance okay so

459
00:20:22,590 --> 00:20:19,000
we've got Mason to help us here and I

460
00:20:26,070 --> 00:20:22,600
have a high fidelity model here of the

461
00:20:27,660 --> 00:20:26,080
spacecraft so I should tell you this is

462
00:20:29,700 --> 00:20:27,670
actually a high fidelity model of a

463
00:20:32,940 --> 00:20:29,710

different spacecraft one that I worked

464
00:20:34,740 --> 00:20:32,950
on called Dawn which is now circling a

465
00:20:37,800 --> 00:20:34,750
dwarf planet this was made by the

466
00:20:40,560 --> 00:20:37,810
four-year-old daughter of a colleague of

467
00:20:42,330 --> 00:20:40,570
mine the daughter was Laura Ratliff

468
00:20:45,270 --> 00:20:42,340
she's now an undergraduate at Georgetown

469
00:20:47,600 --> 00:20:45,280
but even when she was four I think she

470
00:20:51,120 --> 00:20:47,610
did better making this than I could now

471
00:20:52,890 --> 00:20:51,130
and the reason I'm using it excuse me is

472
00:20:56,160 --> 00:20:52,900
it's close enough to ds1 it has its

473
00:21:01,170 --> 00:20:56,170
solar arrays this is the main antenna

474
00:21:04,050 --> 00:21:01,180
and here's the camera and that's that's

475
00:21:07,560 --> 00:21:04,060
what you need to know and so we're gonna

476
00:21:09,900 --> 00:21:07,570
ask Mason here to be the earth Mason is

477
00:21:11,620 --> 00:21:09,910
going to be the earth this is not to

478
00:21:13,870 --> 00:21:11,630
scale

479
00:21:15,730 --> 00:21:13,880
right I think Mason's actually bigger to

480
00:21:16,900 --> 00:21:15,740
scale than yes that would indicate so

481
00:21:17,860 --> 00:21:16,910
hold that up so everybody can see

482
00:21:20,700 --> 00:21:17,870
there's earth okay

483
00:21:22,600 --> 00:21:20,710
what does do you need we need the Sun I

484
00:21:24,220 --> 00:21:22,610
sometimes think I'm the center of

485
00:21:26,200 --> 00:21:24,230
attention so I'll come over here okay

486
00:21:30,789 --> 00:21:26,210
right and your mom says you're bright so

487
00:21:34,690 --> 00:21:30,799
there you go she did once yes so so the

488
00:21:37,390 --> 00:21:34,700

situation was ds1 only all it could do

489
00:21:40,480 --> 00:21:37,400
was find the Sun it didn't know where

490
00:21:44,020 --> 00:21:40,490
earth was you see the Sun so it points

491
00:21:49,930 --> 00:21:44,030
its antenna there at the Sun and it's

492
00:21:51,430 --> 00:21:49,940
just doing this okay so the way we got

493
00:21:55,770 --> 00:21:51,440
the antenna to earth and this took us

494
00:21:59,169 --> 00:21:55,780
two months just to figure this out was

495
00:22:03,310 --> 00:21:59,179
instead of having it rotate around the

496
00:22:05,740 --> 00:22:03,320
antenna like that instead we said we

497
00:22:08,289 --> 00:22:05,750
know the spacecraft doesn't know but we

498
00:22:10,690 --> 00:22:08,299
know the angle from the Sun to the

499
00:22:14,320 --> 00:22:10,700
spacecraft to the earth let's say in

500
00:22:18,250 --> 00:22:14,330
this case the angle from Brian to ds1 to

501
00:22:21,520 --> 00:22:18,260
Mason is say 90 degrees so instead of

502
00:22:25,779 --> 00:22:21,530
having a rotate like that we say turn

503
00:22:30,700 --> 00:22:25,789
this way or actually turn this way and

504
00:22:32,380 --> 00:22:30,710
now rotate like that okay so it's

505
00:22:35,380 --> 00:22:32,390
rotating like that it's still sending

506
00:22:38,020 --> 00:22:35,390
this signal through the main antenna and

507
00:22:41,620 --> 00:22:38,030
it doesn't know where either earth or

508
00:22:45,070 --> 00:22:41,630
Mason are but it's doing that now I'm

509
00:22:48,820 --> 00:22:45,080
also going to bring in here just for

510
00:22:51,190 --> 00:22:48,830
illustration another high-tech device a

511
00:22:53,049 --> 00:22:51,200
flashlight people on TV won't be able to

512
00:22:56,289 --> 00:22:53,059
see this very well but trust me it's

513
00:22:59,710 --> 00:22:56,299

just projecting light and so as the

514
00:23:04,240 --> 00:22:59,720
spacecraft rotates sometimes this beam

515
00:23:08,289 --> 00:23:04,250
of light will go over earth I'm not

516
00:23:11,140 --> 00:23:08,299
using a laser for obvious reason but and

517
00:23:13,899 --> 00:23:11,150
then it continues on but the point is

518
00:23:17,529 --> 00:23:13,909
instead of so it's just this narrow beam

519
00:23:22,840 --> 00:23:17,539
that sweeps past and then goes around

520
00:23:24,240 --> 00:23:22,850
and then comes by again now because of

521
00:23:26,549 --> 00:23:24,250
the another concept

522
00:23:29,610 --> 00:23:26,559
of the failure of the star tracker was

523
00:23:33,539 --> 00:23:29,620
we couldn't even tell the spacecraft

524
00:23:35,190 --> 00:23:33,549
exactly how fast to turn so we didn't

525
00:23:37,799 --> 00:23:35,200
know how fast it was rotating and

526
00:23:41,070 --> 00:23:37,809
neither did it but every time this beam

527
00:23:43,980 --> 00:23:41,080
would sweep past Earth this radio beam

528
00:23:46,350 --> 00:23:43,990
we would detect the sort of blip at the

529
00:23:49,110 --> 00:23:46,360
deep space network and then we'd have

530
00:23:52,770 --> 00:23:49,120
we'd ask Mason to say there it is and

531
00:23:57,720 --> 00:23:52,780
then it would go around and roughly an

532
00:24:00,899 --> 00:23:57,730
hour later it would sweep past again did

533
00:24:03,570 --> 00:24:00,909
you hear him there it is ok and the real

534
00:24:06,600 --> 00:24:03,580
signal was a lot weaker than that

535
00:24:08,639 --> 00:24:06,610
and so we do this a few times and so

536
00:24:11,159 --> 00:24:08,649
then we could just measure the rate at

537
00:24:13,889 --> 00:24:11,169
which the spacecraft was turning that

538
00:24:15,840 --> 00:24:13,899

was the first step then we would just

539
00:24:18,450 --> 00:24:15,850
calculate this part of course it's

540
00:24:20,220 --> 00:24:18,460
pretty easy when's the next time the

541
00:24:22,799 --> 00:24:20,230
antennas going to be pointed at Earth

542
00:24:27,560 --> 00:24:22,809
now the spacecraft was so far away that

543
00:24:30,570 --> 00:24:27,570
radio signals took around 14 minutes to

544
00:24:33,289 --> 00:24:30,580
travel from Earth to the spacecraft it's

545
00:24:35,549 --> 00:24:33,299
a long way even for signals

546
00:24:39,810 --> 00:24:35,559
excuse me traveling at the speed of

547
00:24:41,609 --> 00:24:39,820
light so we would calculate when the

548
00:24:44,009 --> 00:24:41,619
next time the antenna was going to be

549
00:24:47,970 --> 00:24:44,019
pointed at Earth send a radio signal

550
00:24:49,340 --> 00:24:47,980
timed so that just when the antenna was

551
00:24:52,259 --> 00:24:49,350
pointed at earth for that brief moment

552
00:24:53,989 --> 00:24:52,269
the signal would get there and say stop

553
00:24:56,700 --> 00:24:53,999
rotating

554
00:24:59,989 --> 00:24:56,710
however we knew the spacecraft can't

555
00:25:02,759 --> 00:24:59,999
stop on a dime and so would actually

556
00:25:05,129 --> 00:25:02,769
overshoot a little bit but we had

557
00:25:10,139 --> 00:25:05,139
calculated that and so we were really

558
00:25:12,749 --> 00:25:10,149
told it to do is stop and back up and it

559
00:25:15,720 --> 00:25:12,759
worked perfectly and so for the first

560
00:25:20,159 --> 00:25:15,730
time in two months we finally had the

561
00:25:27,620 --> 00:25:20,169
main antenna pointed at Mason very cool

562
00:25:32,060 --> 00:25:30,680
Mason was very brave here today getting

563
00:25:33,680 --> 00:25:32,070

up on stage I know a lot of people don't

564
00:25:36,409 --> 00:25:33,690
like to do that that is my favorite

565
00:25:38,360 --> 00:25:36,419
stress ball it is yours now and so is

566
00:25:40,549 --> 00:25:38,370
and here's a little picture of deep

567
00:25:41,930 --> 00:25:40,559
space one and everybody who works in

568
00:25:43,880 --> 00:25:41,940
NASA knows one of the most important

569
00:25:45,289 --> 00:25:43,890
things is a cool lapel pin so there's a

570
00:25:55,190 --> 00:25:45,299
pin for deeps a swanny

571
00:25:57,289 --> 00:25:55,200
good job Mason and when you come to work

572
00:26:00,710 --> 00:25:57,299
at JPL we expect you to put that up on

573
00:26:03,289 --> 00:26:00,720
your wall and wear the pinyon very cool

574
00:26:05,480 --> 00:26:03,299
so we finally had the antenna pointed at

575
00:26:08,450 --> 00:26:05,490
Earth that actually allowed us to

576
00:26:10,220 --> 00:26:08,460
restore normal communications not like

577
00:26:12,710 --> 00:26:10,230
you would have with you know your home

578
00:26:14,090 --> 00:26:12,720
internet connection it's sort of dial up

579
00:26:16,789 --> 00:26:14,100
modem speed but that's how we

580
00:26:18,289 --> 00:26:16,799
communicate with interplanetary space

581
00:26:20,060 --> 00:26:18,299
great I want to take a half step back on

582
00:26:22,039 --> 00:26:20,070
this because I also want to know how

583
00:26:23,330 --> 00:26:22,049
much time did you because if you're

584
00:26:25,820 --> 00:26:23,340
gonna go meet something out there

585
00:26:28,130 --> 00:26:25,830
there's a time limit it's not that I

586
00:26:28,970 --> 00:26:28,140
have everyday all day for years to do

587
00:26:32,690 --> 00:26:28,980
this that's right

588
00:26:35,330 --> 00:26:32,700

so we we had this this exotic ion

589
00:26:37,970 --> 00:26:35,340
propulsion system if we were gonna meet

590
00:26:42,289 --> 00:26:37,980
our so where our date with the comet was

591
00:26:43,730 --> 00:26:42,299
set in September 2001 so the comet was

592
00:26:46,220 --> 00:26:43,740
gonna be at a particular place in the

593
00:26:49,250 --> 00:26:46,230
solar system that's where we had to meet

594
00:26:52,130 --> 00:26:49,260
it to get there we had to resume

595
00:26:56,899 --> 00:26:52,140
thrusting with the ion propulsion system

596
00:26:58,430 --> 00:26:56,909
no later than July 5th of 2000 so again

597
00:27:01,490 --> 00:26:58,440
the star tracker failed in November of

598
00:27:04,909 --> 00:27:01,500
99 it took us two months to get the

599
00:27:07,630 --> 00:27:04,919
antenna pointed at Earth then so that

600
00:27:10,789 --> 00:27:07,640
was January we had till July and I

601
00:27:13,039 --> 00:27:10,799
should also point out that I mean maybe

602
00:27:15,320 --> 00:27:13,049
most people don't know but the in fact

603
00:27:18,140 --> 00:27:15,330
100% of spacecraft

604
00:27:20,480 --> 00:27:18,150
prior to ds1 not just most of them but

605
00:27:23,390 --> 00:27:20,490
all of them including Voyager here and

606
00:27:25,640 --> 00:27:23,400
you know all all spacecraft Coast most

607
00:27:27,140 --> 00:27:25,650
of the time just like Earth coasts in

608
00:27:29,029 --> 00:27:27,150
orbit around the Sun and the moon coast

609
00:27:30,470 --> 00:27:29,039
in orbit around the earth and the

610
00:27:31,370 --> 00:27:30,480
International Space Station Coast in

611
00:27:33,049 --> 00:27:31,380
orbit around the Earth

612
00:27:35,539 --> 00:27:33,059
but with ion propulsion you have to

613
00:27:37,220 --> 00:27:35,549

thrust most of the time so we needed to

614
00:27:40,490 --> 00:27:37,230
get thrusting with that ion propulsion

615
00:27:41,000 --> 00:27:40,500
system by July to make our date with the

616
00:27:43,820 --> 00:27:41,010
comet

617
00:27:47,450 --> 00:27:43,830
essentially you've got one major league

618
00:27:49,880 --> 00:27:47,460
baseball season from disaster to giving

619
00:27:53,120 --> 00:27:49,890
this thing moving again and it's not

620
00:27:54,410 --> 00:27:53,130
like Oh cram the night before and so

621
00:27:55,550 --> 00:27:54,420
that's right good that's right I can't

622
00:27:59,390 --> 00:27:55,560
wait until I can't pull an all-nighter

623
00:28:01,940 --> 00:27:59,400
on July 4th yeah and and this system

624
00:28:05,690 --> 00:28:01,950
that we got working was great but it was

625
00:28:08,660 --> 00:28:05,700
very laborious because every time this

626
00:28:11,030 --> 00:28:08,670
when we had the antenna pointed at Earth

627
00:28:13,370 --> 00:28:11,040
the spacecraft would continue to drift

628
00:28:15,590 --> 00:28:13,380
around a little bit because the star

629
00:28:18,740 --> 00:28:15,600
tracker had failed and so when we would

630
00:28:21,140 --> 00:28:18,750
see that it was drifting by measuring

631
00:28:24,110 --> 00:28:21,150
the radio signal we would then have to

632
00:28:27,470 --> 00:28:24,120
send a command to say move a degree this

633
00:28:29,990 --> 00:28:27,480
way and moved two degrees that way so we

634
00:28:32,360 --> 00:28:30,000
had to have a team in Mission Control

635
00:28:35,990 --> 00:28:32,370
it's basically Joyce ticking the

636
00:28:39,170 --> 00:28:36,000
spacecraft from 150 million miles away

637
00:28:42,290 --> 00:28:39,180
and think of a joystick where you make a

638
00:28:45,020 --> 00:28:42,300

move and it's 28 minutes before you see

639
00:28:47,750 --> 00:28:45,030
the effect because of this round-trip

640
00:28:52,070 --> 00:28:47,760
radio signal thinking and should just

641
00:28:54,470 --> 00:28:52,080
point out one more thing or even even

642
00:28:56,930 --> 00:28:54,480
apart from that problem here's the

643
00:28:59,120 --> 00:28:56,940
antenna pointed at Earth well suppose we

644
00:29:01,880 --> 00:28:59,130
want to point the ion engine in that

645
00:29:04,760 --> 00:29:01,890
direction there say this is the ion

646
00:29:06,410 --> 00:29:04,770
engine here well you point it there you

647
00:29:09,080 --> 00:29:06,420
can't have the antenna pointed at earth

648
00:29:11,990 --> 00:29:09,090
any more so we couldn't even if the

649
00:29:13,280 --> 00:29:12,000
Joyce ticking were possible we couldn't

650
00:29:15,350 --> 00:29:13,290
do it because we needed to keep the

651
00:29:17,660 --> 00:29:15,360
antenna on earth so there was no way to

652
00:29:19,280 --> 00:29:17,670
point the ion engine in the direction

653
00:29:20,990 --> 00:29:19,290
needed to get to the comet and even if

654
00:29:23,960 --> 00:29:21,000
we had gotten there then we'd need to

655
00:29:25,880 --> 00:29:23,970
point the camera you know at it so this

656
00:29:30,080 --> 00:29:25,890
was great for getting started but

657
00:29:31,310 --> 00:29:30,090
entirely inadequate for for conducting

658
00:29:33,650 --> 00:29:31,320
this mission so how long were you

659
00:29:35,000 --> 00:29:33,660
playing this galactic pong essentially

660
00:29:36,740 --> 00:29:35,010
the the initial part of this the

661
00:29:38,990 --> 00:29:36,750
establishing the connection how long did

662
00:29:40,880 --> 00:29:39,000
that take that took us two months that's

663
00:29:45,020 --> 00:29:40,890

it we talents we got that in the second

664
00:29:47,600 --> 00:29:45,030
half of January of 2000 and then we had

665
00:29:50,750 --> 00:29:47,610
until the beginning of July to invent a

666
00:29:52,700 --> 00:29:50,760
way to fix a spacecraft that by all

667
00:29:54,289 --> 00:29:52,710
rights should be declared dead and if

668
00:29:56,049 --> 00:29:54,299
you're having to play this galactic pawn

669
00:29:58,850 --> 00:29:56,059
this was something we were talking about

670
00:30:02,180 --> 00:29:58,860
did I mean did you have an ace there 24

671
00:30:05,810 --> 00:30:02,190
hours a day well so an ace for people's

672
00:30:07,789 --> 00:30:05,820
now ace is the guy or the lady in

673
00:30:09,560 --> 00:30:07,799
Mission Control who actually is

674
00:30:13,310 --> 00:30:09,570
responsible for clicking the mouse to

675
00:30:15,590 --> 00:30:13,320
send the signal from Mission Control

676
00:30:17,149 --> 00:30:15,600
just a few hundred yards here out to the

677
00:30:20,149 --> 00:30:17,159
Deep Space Network and then out to the

678
00:30:23,299 --> 00:30:20,159
spacecraft no we didn't we had too small

679
00:30:25,100 --> 00:30:23,309
a team and in fact no mission is staffed

680
00:30:28,010 --> 00:30:25,110
24 hours a day there aren't enough

681
00:30:30,560 --> 00:30:28,020
antennas of the Deep Space Network to do

682
00:30:32,990 --> 00:30:30,570
that spacecraft have to be able to

683
00:30:34,820 --> 00:30:33,000
operate on their own so we would go

684
00:30:36,470 --> 00:30:34,830
through this laborious procedure of

685
00:30:38,690 --> 00:30:36,480
getting the antenna pointed to earth

686
00:30:40,430 --> 00:30:38,700
we'd have a communication session with

687
00:30:41,600 --> 00:30:40,440
and then when we were finished we

688
00:30:44,180 --> 00:30:41,610

actually had to have it go back to

689
00:30:45,830 --> 00:30:44,190
pointing at the Sun and then a few days

690
00:30:47,750 --> 00:30:45,840
later when we wanted to communicate with

691
00:30:49,820 --> 00:30:47,760
it again there would be a different

692
00:30:52,490 --> 00:30:49,830
angle between the Sun the spacecraft on

693
00:30:54,649 --> 00:30:52,500
earth so we'd have to change it by a

694
00:30:57,049 --> 00:30:54,659
different angle have it sweep around a

695
00:31:00,070 --> 00:30:57,059
few times it took hours and hours every

696
00:31:02,539 --> 00:31:00,080
time we did this just to communicate

697
00:31:03,560 --> 00:31:02,549
this this wasn't going to do it so we

698
00:31:05,090 --> 00:31:03,570
had to come up with a different method

699
00:31:08,180 --> 00:31:05,100
you got to find a new way to control the

700
00:31:09,740 --> 00:31:08,190
spacecraft without 24-hour or without

701
00:31:11,210 --> 00:31:09,750
Kinect without a connection to earth

702
00:31:12,649 --> 00:31:11,220
that's right without a connection dirt

703
00:31:16,940 --> 00:31:12,659
no micromanaging right

704
00:31:19,639 --> 00:31:16,950
yes and so we again looked at the

705
00:31:22,760 --> 00:31:19,649
spacecraft what do we have on board the

706
00:31:24,769 --> 00:31:22,770
spacecraft that can sense the external

707
00:31:28,220 --> 00:31:24,779
environment in a way other than the Sun

708
00:31:30,769 --> 00:31:28,230
sensor and other than the radio and the

709
00:31:34,610 --> 00:31:30,779
dust the best solutions seem to be with

710
00:31:36,380 --> 00:31:34,620
the camera yeah and so the camera seems

711
00:31:38,480 --> 00:31:36,390
like a pretty good way to do it it can

712
00:31:40,100 --> 00:31:38,490
take pictures and so I mean how hard

713
00:31:42,620 --> 00:31:40,110

could this be right we've got a

714
00:31:44,690 --> 00:31:42,630
spacecraft that maybe should be dead but

715
00:31:47,240 --> 00:31:44,700
you can fix it but to explain why this

716
00:31:48,980 --> 00:31:47,250
is hard I want to walk you through some

717
00:31:51,289 --> 00:31:48,990
of the differences between the camera

718
00:31:53,630 --> 00:31:51,299
the star tracker and the camera and the

719
00:31:57,919 --> 00:31:53,640
first is the field of view how much sky

720
00:32:00,230 --> 00:31:57,929
could the star tracker see it was 300

721
00:32:01,700 --> 00:32:00,240
times the area of the full moon so if

722
00:32:04,010 --> 00:32:01,710
you're out at night think of the full

723
00:32:05,840 --> 00:32:04,020
moon if you could see an area 300 times

724
00:32:08,480 --> 00:32:05,850
that that's a pretty sizable chunk

725
00:32:11,900 --> 00:32:08,490
of the sky the camera could only see an

726
00:32:14,779 --> 00:32:11,910
area twice the size of the moon okay so

727
00:32:16,460 --> 00:32:14,789
that's a that's better for the that

728
00:32:18,860 --> 00:32:16,470
means the star tracker is better in that

729
00:32:21,049 --> 00:32:18,870
returns up start right all right okay

730
00:32:23,810 --> 00:32:21,059
now the star tracker actually could see

731
00:32:25,520 --> 00:32:23,820
fainter stars and then we can see stars

732
00:32:27,230 --> 00:32:25,530
that are in this case they're four times

733
00:32:30,440 --> 00:32:27,240
fainter so there it had a lot of stars

734
00:32:32,600 --> 00:32:30,450
to choose from the camera again wasn't

735
00:32:34,279 --> 00:32:32,610
built to photograph stars so it could

736
00:32:36,529 --> 00:32:34,289
only see stars comparable in brightness

737
00:32:38,120 --> 00:32:36,539
to the ones we can see so once again

738
00:32:41,080 --> 00:32:38,130

that's a point in favor of the star

739
00:32:43,549 --> 00:32:41,090
tracker and so the problem was in

740
00:32:45,799 --> 00:32:43,559
general when you're orienting the

741
00:32:48,710 --> 00:32:45,809
spacecraft the star turn of the camera

742
00:32:52,789 --> 00:32:48,720
is not going to be able to be pointed at

743
00:32:55,789 --> 00:32:52,799
a recognizable star pattern okay so that

744
00:32:58,730 --> 00:32:55,799
didn't seem very good no but it turns

745
00:33:02,299 --> 00:32:58,740
out to be harder than that because the

746
00:33:04,430 --> 00:33:02,309
star tracker was designed to determine

747
00:33:07,789 --> 00:33:04,440
its orientation had a dedicated computer

748
00:33:09,770 --> 00:33:07,799
for that and so it's sent to the main

749
00:33:11,810 --> 00:33:09,780
spacecraft computer a mathematical

750
00:33:15,110 --> 00:33:11,820
description of the spacecraft's

751
00:33:17,210 --> 00:33:15,120
orientation would say you're pointed you

752
00:33:18,760 --> 00:33:17,220
know pointed there and oriented like

753
00:33:22,010 --> 00:33:18,770
this or whatever

754
00:33:23,690 --> 00:33:22,020
whereas all the camera could do was just

755
00:33:27,830 --> 00:33:23,700
take a picture of whatever it's looking

756
00:33:31,789 --> 00:33:27,840
at so that that didn't do anybody any

757
00:33:33,500 --> 00:33:31,799
good and so once again that was a thumb

758
00:33:36,770 --> 00:33:33,510
up in favor of the star tracker winds

759
00:33:39,049 --> 00:33:36,780
yeah and once again the star tracker was

760
00:33:41,330 --> 00:33:39,059
built specifically to do this it was

761
00:33:43,220 --> 00:33:41,340
dedicated to it so it had the capability

762
00:33:45,590 --> 00:33:43,230
to do this every quarter of a second

763
00:33:48,580 --> 00:33:45,600

four times a second it could calculate

764
00:33:51,710 --> 00:33:48,590
it could measure its orientation and

765
00:33:54,049 --> 00:33:51,720
tell it to the spacecraft computer this

766
00:33:56,270 --> 00:33:54,059
was before the days of modern digital

767
00:33:59,090 --> 00:33:56,280
cameras like everybody here has in their

768
00:34:01,450 --> 00:33:59,100
smart phones and the camera onboard the

769
00:34:04,520 --> 00:34:01,460
spacecraft could only take a picture

770
00:34:06,980 --> 00:34:04,530
process it and send it to the computer

771
00:34:11,480 --> 00:34:06,990
and have the computer open it once every

772
00:34:13,909 --> 00:34:11,490
thirty seconds once again star tracker I

773
00:34:15,710 --> 00:34:13,919
think I know something that the camera

774
00:34:17,510 --> 00:34:15,720
has that the star tracker doesn't it

775
00:34:19,909 --> 00:34:17,520
right the camera had one major thing

776
00:34:23,809 --> 00:34:19,919
going for it it was alive

777
00:34:27,259 --> 00:34:23,819
star tracker was dead so to me that

778
00:34:28,909 --> 00:34:27,269
thumb up outweighed yeah all the other I

779
00:34:32,419 --> 00:34:28,919
think that's deal yeah takes precedent

780
00:34:33,710 --> 00:34:32,429
right so so you have not training a

781
00:34:35,210 --> 00:34:33,720
camera you have to train it like the old

782
00:34:37,879 --> 00:34:35,220
disposed where you have to spin like

783
00:34:39,559 --> 00:34:37,889
that kind of time in between right we

784
00:34:43,849 --> 00:34:39,569
had to come up with a whole new method

785
00:34:46,849 --> 00:34:43,859
to make this work and with a spacecraft

786
00:34:51,559 --> 00:34:46,859
that's you know almost twice as far away

787
00:34:54,859 --> 00:34:51,569
as the Sun and we've got to do it in

788
00:34:56,509 --> 00:34:54,869

just a few months this was was it is

789
00:34:58,249 --> 00:34:56,519
gone now I need to be working here at

790
00:35:00,739 --> 00:34:58,259
JPL or if you particularly to be a part

791
00:35:05,779 --> 00:35:00,749
of ds1 you know come isn't one of the

792
00:35:07,069 --> 00:35:05,789
the words that comes to mind I could

793
00:35:08,420 --> 00:35:07,079
think of a whole lot of other ones but

794
00:35:13,910 --> 00:35:08,430
we're gonna be written well actually I

795
00:35:17,749 --> 00:35:13,920
can to the the you know we had people

796
00:35:21,259 --> 00:35:17,759
working seven days a week long hours

797
00:35:24,559 --> 00:35:21,269
yeah you just you could never stop you

798
00:35:26,479 --> 00:35:24,569
couldn't rest you couldn't you just

799
00:35:30,150 --> 00:35:26,489
couldn't wait I mean to me this is what

800
00:35:35,830 --> 00:35:34,060
this this is just incredibly stressful

801
00:35:41,109 --> 00:35:35,840
and that's that's my stress ohmmeter

802
00:35:43,600 --> 00:35:41,119
there you it's just incredible I mean

803
00:35:45,520 --> 00:35:43,610
you know all everybody that works at JPL

804
00:35:47,740 --> 00:35:45,530
solves hard problems yeah and everybody

805
00:35:49,510 --> 00:35:47,750
that's worked on these these spacecraft

806
00:35:51,460 --> 00:35:49,520
around here is software problems and I

807
00:35:53,109 --> 00:35:51,470
don't mean to diminish that well but

808
00:35:55,780 --> 00:35:53,119
most of the hardest problems they have

809
00:35:59,470 --> 00:35:55,790
to solve are while the spacecraft is on

810
00:36:02,440 --> 00:35:59,480
the ground figuring out how to design

811
00:36:06,010 --> 00:36:02,450
and build and plan out how you're gonna

812
00:36:10,450 --> 00:36:06,020
operate it but we had this spacecraft

813
00:36:14,710 --> 00:36:10,460

again over 150 million miles away with

814
00:36:17,230 --> 00:36:14,720
the clock ticking there constantly and

815
00:36:18,790 --> 00:36:17,240
we had to come up with a whole new way

816
00:36:21,850 --> 00:36:18,800
to do this you said to me that the

817
00:36:24,040 --> 00:36:21,860
people who are surprised the most of the

818
00:36:25,870 --> 00:36:24,050
spacecraft works are the people who work

819
00:36:27,580 --> 00:36:25,880
on that spacecraft that's right a friend

820
00:36:31,359 --> 00:36:27,590
of mine said this maybe he's even

821
00:36:33,790 --> 00:36:31,369
watching it hi George the you know all

822
00:36:36,460 --> 00:36:33,800
the ways things can go wrong and you

823
00:36:38,950 --> 00:36:36,470
know all the problems all the skeletons

824
00:36:41,200 --> 00:36:38,960
in the closet all the all the

825
00:36:43,950 --> 00:36:41,210
difficulties and as much as I've

826
00:36:47,290 --> 00:36:43,960
described it here I mean there were just

827
00:36:49,480 --> 00:36:47,300
uncountable number of problems and every

828
00:36:54,280 --> 00:36:49,490
time we'd solve one we'd discover five

829
00:36:56,200 --> 00:36:54,290
more and and we had again had to do this

830
00:36:58,780 --> 00:36:56,210
in a few months and then the spacecraft

831
00:37:02,740 --> 00:36:58,790
was gonna have to travel another 650

832
00:37:06,520 --> 00:37:02,750
million miles and 15 months you know

833
00:37:08,320 --> 00:37:06,530
reliably to get to the comet every

834
00:37:10,810 --> 00:37:08,330
solution you create causes another

835
00:37:13,510 --> 00:37:10,820
problem everything you're rushing you're

836
00:37:16,210 --> 00:37:13,520
turning a camera which is not built

837
00:37:18,160 --> 00:37:16,220
you're turning your spacecraft into a

838
00:37:18,370 --> 00:37:18,170

different spacecraft that's exactly

839
00:37:22,270 --> 00:37:18,380
right

840
00:37:23,890 --> 00:37:22,280
I mean it genuinely felt like by the by

841
00:37:25,390 --> 00:37:23,900
the time we had done this we were flying

842
00:37:27,550 --> 00:37:25,400
a different one from the one we had

843
00:37:29,800 --> 00:37:27,560
designed and built so we not only had to

844
00:37:31,480 --> 00:37:29,810
come up with new systems to work on the

845
00:37:34,030 --> 00:37:31,490
spacecraft but wholly different

846
00:37:36,790 --> 00:37:34,040
approaches to how to fly the spacecraft

847
00:37:39,450 --> 00:37:36,800
so you wake up you're stressed out

848
00:37:42,720 --> 00:37:39,460
you're thinking about no

849
00:37:49,260 --> 00:37:42,730
I wouldn't exactly say that because that

850
00:37:51,599 --> 00:37:49,270
sort of as soon as I slept it was just

851
00:37:53,880 --> 00:37:51,609
it was stressful it was just really

852
00:37:58,799 --> 00:37:53,890
stressful but it was yeah but you got

853
00:38:02,730 --> 00:37:58,809
there was neither time nor nor enough

854
00:38:04,410 --> 00:38:02,740
relaxation okay to sleep well I bet but

855
00:38:06,839 --> 00:38:04,420
you get the Star Trek you get the camera

856
00:38:08,609 --> 00:38:06,849
turned into a Star Trek er right so the

857
00:38:09,029 --> 00:38:08,619
the basic idea I don't want to go into

858
00:38:16,460 --> 00:38:09,039
it

859
00:38:20,630 --> 00:38:16,470
basic idea was we we had to pick

860
00:38:23,309 --> 00:38:20,640
individual isolated bright stars

861
00:38:26,279 --> 00:38:23,319
isolated because we couldn't afford to

862
00:38:28,650 --> 00:38:26,289
let the spacecraft mistakenly lock to a

863
00:38:31,230 --> 00:38:28,660

nearby star these distinct stars right

864
00:38:33,809 --> 00:38:31,240
distinct stars we would select them so

865
00:38:35,700 --> 00:38:33,819
let's say here again is the ion engine

866
00:38:39,089 --> 00:38:35,710
let's say we want to point the ion

867
00:38:41,190 --> 00:38:39,099
engine in this direction okay then we

868
00:38:44,339 --> 00:38:41,200
would have to find a star in that

869
00:38:46,440 --> 00:38:44,349
direction cuz the camera sorry from your

870
00:38:48,599 --> 00:38:46,450
point of view here's the camera and it

871
00:38:50,730 --> 00:38:48,609
looks this way the camera points there

872
00:38:53,789 --> 00:38:50,740
so we would tell the spacecraft turn to

873
00:38:56,519 --> 00:38:53,799
approximately that location okay start

874
00:38:59,339 --> 00:38:56,529
taking pictures find the star lock onto

875
00:39:02,549 --> 00:38:59,349
it and once it's locked on then we know

876
00:39:04,200 --> 00:39:02,559
the ion engine is pointed there so then

877
00:39:06,000 --> 00:39:04,210
thrust with the ion engine like that

878
00:39:08,220 --> 00:39:06,010
okay then when it's time to point the

879
00:39:10,650 --> 00:39:08,230
ion engine in I don't say this direction

880
00:39:13,500 --> 00:39:10,660
here yeah we'd pick a star over there

881
00:39:16,579 --> 00:39:13,510
and we would have to tell the spacecraft

882
00:39:19,799 --> 00:39:16,589
what the star is how bright it is

883
00:39:22,589 --> 00:39:19,809
approximately how to turn to it so would

884
00:39:24,420 --> 00:39:22,599
turn and then it would drift around but

885
00:39:27,599 --> 00:39:24,430
it would take pictures and find the star

886
00:39:29,460 --> 00:39:27,609
lock on to it and then it would know the

887
00:39:30,900 --> 00:39:29,470
ion engine was pointed there and then

888
00:39:32,940 --> 00:39:30,910

one was time to communicate with earth

889
00:39:34,769 --> 00:39:32,950
if we want the antenna now let's say

890
00:39:37,200 --> 00:39:34,779
earth is over there over there we'd say

891
00:39:39,750 --> 00:39:37,210
well there's a star up there turn and

892
00:39:42,589 --> 00:39:39,760
point to that so return of point to that

893
00:39:45,269 --> 00:39:42,599
star and then the antenna would be

894
00:39:47,490 --> 00:39:45,279
pointed at earth for our regular

895
00:39:49,620 --> 00:39:47,500
communication session so we could you

896
00:39:51,700 --> 00:39:49,630
know do our normal monitoring of the

897
00:39:53,650 --> 00:39:51,710
spacecraft and give it the new

898
00:39:55,180 --> 00:39:53,660
information to continue the mission and

899
00:39:57,670 --> 00:39:55,190
you get this all tested out you get this

900
00:39:59,890 --> 00:39:57,680
all finally to a point where you're

901
00:40:02,230 --> 00:39:59,900
going this is it

902
00:40:03,880 --> 00:40:02,240
we've there's no there's no more time

903
00:40:06,430 --> 00:40:03,890
it's now or never

904
00:40:08,650 --> 00:40:06,440
when does that happen in our in our so

905
00:40:10,810 --> 00:40:08,660
again cutoff date the the failure

906
00:40:13,240 --> 00:40:10,820
occurred in November mm-hmm we first got

907
00:40:16,330 --> 00:40:13,250
the antenna even pointed to earth in

908
00:40:19,660 --> 00:40:16,340
late January you know and in early June

909
00:40:22,480 --> 00:40:19,670
we transmitted the software to the

910
00:40:24,960 --> 00:40:22,490
spacecraft using the same method we were

911
00:40:28,780 --> 00:40:24,970
then at that point have been using for

912
00:40:32,020 --> 00:40:28,790
for half a year during which time the

913
00:40:35,320 --> 00:40:32,030

spacecraft had coasted 350 million miles

914
00:40:38,410 --> 00:40:35,330
but not where we needed it to be to get

915
00:40:42,010 --> 00:40:38,420
to the comet so we had the software

916
00:40:45,190 --> 00:40:42,020
onboard the spacecraft in the second

917
00:40:47,080 --> 00:40:45,200
week of June turned it on activated it

918
00:40:49,660 --> 00:40:47,090
to everybody's amazement it actually

919
00:40:53,050 --> 00:40:49,670
worked great so for the first time in

920
00:40:55,240 --> 00:40:53,060
seven months we had the spacecraft

921
00:40:57,130 --> 00:40:55,250
they're operating in kind of a normal

922
00:41:00,040 --> 00:40:57,140
way I mean we had we had actually

923
00:41:01,720 --> 00:41:00,050
rescued this spacecraft taking seven

924
00:41:04,900 --> 00:41:01,730
months and if you've heard of this safe

925
00:41:08,230 --> 00:41:04,910
mode I don't think any I'm sure no JPL

926
00:41:10,150 --> 00:41:08,240
spacecraft has no us no NASA spacecraft

927
00:41:13,570 --> 00:41:10,160
has ever spent so long

928
00:41:16,470 --> 00:41:13,580
essentially in safe mode and then been

929
00:41:18,550 --> 00:41:16,480
rescued so now then all we had to do was

930
00:41:20,980 --> 00:41:18,560
15 months six hundred fifty million

931
00:41:23,320 --> 00:41:20,990
miles fly to the comet and figure out

932
00:41:25,950 --> 00:41:23,330
how to take pictures there with this

933
00:41:28,960 --> 00:41:25,960
Asian wounded crippled spacecraft I mean

934
00:41:30,430 --> 00:41:28,970
I'm almost left to do at that point okay

935
00:41:33,670 --> 00:41:30,440
you got it work in here I got going on

936
00:41:35,860 --> 00:41:33,680
vacation see you guys yeah probably not

937
00:41:38,200 --> 00:41:35,870
exactly yeah all right so you got to fly

938
00:41:39,730 --> 00:41:38,210

to the spacecraft and this 15 month

939
00:41:41,890 --> 00:41:39,740
fight of the iPod you're flying the

940
00:41:45,490 --> 00:41:41,900
spacecraft to the comment but this was a

941
00:41:48,670 --> 00:41:45,500
that's another 15 months added on plus

942
00:41:51,760 --> 00:41:48,680
you've got this the spacecraft was

943
00:41:53,530 --> 00:41:51,770
designed for an 11 month primary mission

944
00:41:55,870 --> 00:41:53,540
that's right and at this point it had

945
00:42:01,050 --> 00:41:55,880
been in flight now for almost two years

946
00:42:02,800 --> 00:42:01,060
you know and one of the consequences of

947
00:42:04,539 --> 00:42:02,810
flying for so much longer than

948
00:42:06,609 --> 00:42:04,549
originally anticipated

949
00:42:08,529 --> 00:42:06,619
is that we were running low on a

950
00:42:12,249 --> 00:42:08,539
resource that we had on the spacecraft

951
00:42:14,319 --> 00:42:12,259
so spacecraft carries a small supply of

952
00:42:17,859 --> 00:42:14,329
a conventional rocket propellant called

953
00:42:19,839 --> 00:42:17,869
hydrazine and I told you about the star

954
00:42:22,029 --> 00:42:19,849
tracker and now the camera that's how

955
00:42:25,479 --> 00:42:22,039
the spacecraft figures out where it's

956
00:42:28,390 --> 00:42:25,489
pointed and but it needs to control its

957
00:42:30,579 --> 00:42:28,400
orientation it's not good enough just to

958
00:42:33,549 --> 00:42:30,589
know it you need to control it so it has

959
00:42:35,559 --> 00:42:33,559
these little thrusters like here's a

960
00:42:37,359 --> 00:42:35,569
thruster in here as a thruster and if

961
00:42:39,160 --> 00:42:37,369
you squirt some hydrazine out of this

962
00:42:42,339 --> 00:42:39,170
thruster here then the spacecraft

963
00:42:45,089 --> 00:42:42,349

rotates like that and if you squirt some

964
00:42:48,999 --> 00:42:45,099
out of this one it rotates like that

965
00:42:52,150 --> 00:42:49,009
whoops standard space yeah yeah didn't

966
00:42:53,949 --> 00:42:52,160
know you were out I know and so if you

967
00:42:55,509 --> 00:42:53,959
just keep doing it out of here and doing

968
00:42:58,239 --> 00:42:55,519
it out of here you know you can control

969
00:43:01,390 --> 00:42:58,249
the orientation like this and that

970
00:43:03,339 --> 00:43:01,400
that's how spacecraft like Voyager here

971
00:43:04,299 --> 00:43:03,349
and deep space one and many others

972
00:43:07,419 --> 00:43:04,309
that's how they control their

973
00:43:10,239 --> 00:43:07,429
orientation but we didn't have enough

974
00:43:13,779 --> 00:43:10,249
hydrazine for this three-year mission

975
00:43:15,999 --> 00:43:13,789
especially since for myriad technical

976
00:43:19,630 --> 00:43:16,009
reasons that I'm not boring you with I

977
00:43:21,160 --> 00:43:19,640
hope I haven't bored you we we used a

978
00:43:23,469 --> 00:43:21,170
lot of extra hydrazine during this

979
00:43:26,289 --> 00:43:23,479
rescue okay and so the spacecraft

980
00:43:27,669 --> 00:43:26,299
actually didn't have enough hydrazine to

981
00:43:29,979 --> 00:43:27,679
control its orientation

982
00:43:32,589 --> 00:43:29,989
remember the ion propulsion system

983
00:43:34,809 --> 00:43:32,599
propels at some place the hydrazine

984
00:43:36,729 --> 00:43:34,819
holds its orientation we didn't have

985
00:43:40,779 --> 00:43:36,739
enough hydrazine to actually complete

986
00:43:43,029 --> 00:43:40,789
the mission to the comet okay so ready

987
00:43:44,469 --> 00:43:43,039
to come up with a nother fix you are

988
00:43:47,650 --> 00:43:44,479

getting very good at this MacGyver yeah

989
00:43:49,029 --> 00:43:47,660
and I'll tell you this is I think maybe

990
00:43:50,799 --> 00:43:49,039
one of the last problems we're going to

991
00:43:55,390 --> 00:43:50,809
talk about okay there were a bunch of

992
00:43:57,549 --> 00:43:55,400
other problems just talking like three

993
00:43:59,169 --> 00:43:57,559
or four in this conversation but there

994
00:44:00,819 --> 00:43:59,179
was what happened when radiation from

995
00:44:04,089 --> 00:44:00,829
the Sun flooded the camera and it got

996
00:44:05,529 --> 00:44:04,099
confused what happens when it lost track

997
00:44:07,150 --> 00:44:05,539
of the star what happens when I couldn't

998
00:44:08,499 --> 00:44:07,160
find the star at the end of a turn I

999
00:44:13,059 --> 00:44:08,509
mean there were a lot of other things

1000
00:44:14,650 --> 00:44:13,069
going on but but for this problem for

1001
00:44:17,309 --> 00:44:14,660
not being able to control its

1002
00:44:20,400 --> 00:44:17,319
orientation it turns out when we throw

1003
00:44:23,039 --> 00:44:20,410
with the ion propulsion system it

1004
00:44:25,259 --> 00:44:23,049
actually it's responsible for sending

1005
00:44:27,809 --> 00:44:25,269
the spacecraft someplace but it had the

1006
00:44:31,019 --> 00:44:27,819
capability in addition to control the

1007
00:44:34,079 --> 00:44:31,029
orientation so I told you a few minutes

1008
00:44:36,239 --> 00:44:34,089
ago that we thrust most of the time but

1009
00:44:39,150 --> 00:44:36,249
we don't thrust all the time we had to

1010
00:44:42,120 --> 00:44:39,160
get onto a trajectory where the

1011
00:44:44,880 --> 00:44:42,130
spacecraft and the comet were basically

1012
00:44:49,259 --> 00:44:44,890
heading to the same point so we

1013
00:44:50,819 --> 00:44:49,269

accomplished that in May of 2001 we

1014
00:44:51,719 --> 00:44:50,829
weren't going to get to that point until

1015
00:44:53,880 --> 00:44:51,729
September

1016
00:44:55,079 --> 00:44:53,890
so in principle the spacecraft and comet

1017
00:44:57,109 --> 00:44:55,089
could have just coasted to the same

1018
00:45:00,059 --> 00:44:57,119
point but we couldn't afford to Coast

1019
00:45:01,859 --> 00:45:00,069
because we didn't we couldn't afford the

1020
00:45:04,439 --> 00:45:01,869
hydrazine yeah so we had to keep

1021
00:45:06,660 --> 00:45:04,449
thrusting but the problem was when you

1022
00:45:08,189 --> 00:45:06,670
thrust you change your course we didn't

1023
00:45:10,069 --> 00:45:08,199
want to change course we were on course

1024
00:45:14,130 --> 00:45:10,079
for the comet

1025
00:45:17,969 --> 00:45:14,140
so we thrust at a low level which I

1026
00:45:19,589 --> 00:45:17,979
called impulse power and people who who

1027
00:45:21,989 --> 00:45:19,599
don't get that you need to do your

1028
00:45:24,329 --> 00:45:21,999
homework which is go home and watch Star

1029
00:45:25,019 --> 00:45:24,339
Trek the original series but for the

1030
00:45:27,959 --> 00:45:25,029
rest of you

1031
00:45:31,799 --> 00:45:27,969
that's thrusting at a low throttle level

1032
00:45:34,910 --> 00:45:31,809
thanks so yeah well the impulse power

1033
00:45:38,279 --> 00:45:34,920
it's low so we dressed at impulse power

1034
00:45:39,599 --> 00:45:38,289
like this low throttle level so we

1035
00:45:41,430 --> 00:45:39,609
didn't do too much damage to the

1036
00:45:44,039 --> 00:45:41,440
trajectory thrust like this for a week

1037
00:45:46,559 --> 00:45:44,049
then we thrust in the opposite direction

1038
00:45:48,930 --> 00:45:46,569

for a week then we thrust in this

1039
00:45:50,999 --> 00:45:48,940
direction for a week then the opposite

1040
00:45:53,039 --> 00:45:51,009
direction so basically I can't turn the

1041
00:45:55,170 --> 00:45:53,049
spacecraft fast enough here but

1042
00:45:59,189 --> 00:45:55,180
basically we instead of flying to the

1043
00:46:03,530 --> 00:45:59,199
comment like this we Zig zagged like

1044
00:46:06,740 --> 00:46:03,540
that tacking for five months

1045
00:46:09,650 --> 00:46:06,750
never being exactly on target for the

1046
00:46:12,020 --> 00:46:09,660
comet but constantly cancelling out

1047
00:46:14,030 --> 00:46:12,030
never getting too far off course so that

1048
00:46:17,420 --> 00:46:14,040
we could take constant advantage of the

1049
00:46:19,400 --> 00:46:17,430
ion propulsion system to get us to the

1050
00:46:21,560 --> 00:46:19,410
vicinity of the comet well yeah like

1051
00:46:25,040 --> 00:46:21,570
when you're when I'm driving to New York

1052
00:46:26,510 --> 00:46:25,050
from here in LA I'm not going yeah

1053
00:46:27,980 --> 00:46:26,520
there's a lot of zigzagging and you end

1054
00:46:29,990 --> 00:46:27,990
up but right you probably don't zig and

1055
00:46:31,070 --> 00:46:30,000
zag as much as the s1 jets lean on but

1056
00:46:34,130 --> 00:46:31,080
that but it actually raises another

1057
00:46:37,040 --> 00:46:34,140
point which is all missions not just ds1

1058
00:46:39,110 --> 00:46:37,050
when we target a destination far in the

1059
00:46:41,440 --> 00:46:39,120
solar system you know initially you aim

1060
00:46:44,300 --> 00:46:41,450
sort of in the general direction and

1061
00:46:47,270 --> 00:46:44,310
then as you get closer and closer you

1062
00:46:49,430 --> 00:46:47,280
you kind of have to tweak or adjust the

1063
00:46:51,680 --> 00:46:49,440

trajectory yeah we call it a trajectory

1064
00:46:53,660 --> 00:46:51,690
correction maneuver closer you get to

1065
00:46:55,850 --> 00:46:53,670
refine it just like when you're doing

1066
00:46:58,910 --> 00:46:55,860
your drive from Los Angeles to New York

1067
00:47:02,030 --> 00:46:58,920
you don't aim for your parking place you

1068
00:47:03,980 --> 00:47:02,040
aim for the west coast sorry Los Angeles

1069
00:47:07,420 --> 00:47:03,990
to New York I was thinking home game for

1070
00:47:11,660 --> 00:47:07,430
the East Coast I'm not a navigator I'm

1071
00:47:13,280 --> 00:47:11,670
doing for the East Coast and then only

1072
00:47:15,080 --> 00:47:13,290
when you get close to your parking place

1073
00:47:17,710 --> 00:47:15,090
do you do the final yeah you know

1074
00:47:20,200 --> 00:47:17,720
refinements so that's what we were doing

1075
00:47:22,580 --> 00:47:20,210
you know in the in the final weeks

1076
00:47:26,870 --> 00:47:22,590
before the encounters you're approaching

1077
00:47:31,210 --> 00:47:26,880
in Wednesday the scheduled encounter

1078
00:47:33,950 --> 00:47:31,220
date so we we had to get to the comet

1079
00:47:36,920 --> 00:47:33,960
from this 14 know from this 14 month

1080
00:47:38,390 --> 00:47:36,930
journey in 15 months for 15 months out

1081
00:47:40,220 --> 00:47:38,400
so we had to go all six hundred fifty

1082
00:47:42,710 --> 00:47:40,230
three million miles let's not leave any

1083
00:47:45,070 --> 00:47:42,720
miles out here I won't never again we

1084
00:47:48,680 --> 00:47:45,080
had to get there on September 22nd and

1085
00:47:51,310 --> 00:47:48,690
our one of our maneuvers was not too

1086
00:47:55,340 --> 00:47:51,320
long before that it was on a Tuesday

1087
00:47:58,610 --> 00:47:55,350
seemed like a day like any other and so

1088
00:48:00,350 --> 00:47:58,620

I was at home that morning getting ready

1089
00:48:02,390 --> 00:48:00,360
to come into work and a friend of mine

1090
00:48:04,610 --> 00:48:02,400
who I think I saw back here but maybe

1091
00:48:09,400 --> 00:48:04,620
not you know a friend of mine who's on

1092
00:48:12,260 --> 00:48:09,410
my team called me that morning and said

1093
00:48:16,310 --> 00:48:12,270
aircraft just hit the Twin Towers in New

1094
00:48:17,150 --> 00:48:16,320
York you know the United States is under

1095
00:48:20,660 --> 00:48:17,160
attack

1096
00:48:23,210 --> 00:48:20,670
and I sort of like everybody else I

1097
00:48:25,999 --> 00:48:23,220
couldn't really process that couldn't

1098
00:48:28,640 --> 00:48:26,009
really understand that but we had a job

1099
00:48:31,220 --> 00:48:28,650
to do we had to do a maneuver that day

1100
00:48:38,299 --> 00:48:31,230
in order to keep the spacecraft on

1101
00:48:39,499 --> 00:48:38,309
course for the for the comet so I you

1102
00:48:40,940 --> 00:48:39,509
know at first I didn't believe him but

1103
00:48:43,549 --> 00:48:40,950
it didn't make any difference yeah

1104
00:48:45,950 --> 00:48:43,559
told him you know let's just go to work

1105
00:48:48,769 --> 00:48:45,960
and we're gonna focus on this trajectory

1106
00:48:50,599 --> 00:48:48,779
correction maneuver so I raced over here

1107
00:48:52,579 --> 00:48:50,609
to JPL and everybody not the people on

1108
00:48:54,019 --> 00:48:52,589
TV but everybody who's here today knows

1109
00:48:56,240 --> 00:48:54,029
that when you approached JPL you drive

1110
00:48:58,370 --> 00:48:56,250
along Oak Grove Boulevard here Oak Grove

1111
00:49:00,380 --> 00:48:58,380
Drive I mean it's just one long narrow

1112
00:49:03,549 --> 00:49:00,390
street it was of course jammed with cars

1113
00:49:05,990 --> 00:49:03,559

because the lab was locked down our

1114
00:49:08,660 --> 00:49:06,000
security friends who all of you who saw

1115
00:49:12,499 --> 00:49:08,670
today were not letting anybody in it

1116
00:49:16,249 --> 00:49:12,509
didn't matter what your Excuse was the

1117
00:49:19,579 --> 00:49:16,259
country was under attack and go home go

1118
00:49:20,480 --> 00:49:19,589
home yeah and there was no excuse I mean

1119
00:49:22,490 --> 00:49:20,490
the guards were not going to be

1120
00:49:23,870 --> 00:49:22,500
interested in my story I have a

1121
00:49:26,749 --> 00:49:23,880
spacecraft yeah right

1122
00:49:29,089 --> 00:49:26,759
and so like everybody else I tried to

1123
00:49:30,620 --> 00:49:29,099
turn around on that narrow road and you

1124
00:49:34,970 --> 00:49:30,630
know get home as quickly as I could

1125
00:49:37,269 --> 00:49:34,980
this was before the time of texting and

1126
00:49:40,370 --> 00:49:37,279
easy telecom tella you know

1127
00:49:43,420 --> 00:49:40,380
telecommunications sessions via phone so

1128
00:49:45,799 --> 00:49:43,430
we set up among all the team members

1129
00:49:47,720 --> 00:49:45,809
most of us were at home two of the

1130
00:49:51,170 --> 00:49:47,730
people had come in early that day before

1131
00:49:52,670 --> 00:49:51,180
the lockdown one guy just worked

1132
00:49:54,920 --> 00:49:52,680
different hours from the rest of us he

1133
00:49:56,779 --> 00:49:54,930
normally got here about 5:00 and worked

1134
00:49:58,009 --> 00:49:56,789
till the early afternoon somebody else

1135
00:50:00,589 --> 00:49:58,019
had come in for some other reason that

1136
00:50:02,839 --> 00:50:00,599
frankly I don't even remember but he had

1137
00:50:04,519 --> 00:50:02,849
come in before the lockdown they were in

1138
00:50:06,349 --> 00:50:04,529

Mission Control they weren't comfortable

1139
00:50:09,289 --> 00:50:06,359
doing this they didn't know how to do it

1140
00:50:13,730 --> 00:50:09,299
by themselves so we had everybody set up

1141
00:50:16,640 --> 00:50:13,740
a telephone tag system basically and I

1142
00:50:18,829 --> 00:50:16,650
had one phone you know to the next guy

1143
00:50:20,450 --> 00:50:18,839
in line and one phone to the guys the

1144
00:50:22,370 --> 00:50:20,460
two guys in Mission Control happened to

1145
00:50:25,789 --> 00:50:22,380
be two men but there were it was a

1146
00:50:29,210 --> 00:50:25,799
normal team of men and women and we

1147
00:50:30,560 --> 00:50:29,220
basically talked these two nervous

1148
00:50:34,070 --> 00:50:30,570
people

1149
00:50:36,970 --> 00:50:34,080
through how to send the commands and the

1150
00:50:39,140 --> 00:50:36,980
deep space network wasn't locked down

1151
00:50:40,430 --> 00:50:39,150
and in fact I don't think yeah why I

1152
00:50:41,900 --> 00:50:40,440
think we weren't even using the one in

1153
00:50:44,900 --> 00:50:41,910
California at the time we're using one

1154
00:50:46,850 --> 00:50:44,910
of the ones in Madrid okay

1155
00:50:49,550 --> 00:50:46,860
to send the commands to the spacecraft

1156
00:50:52,340 --> 00:50:49,560
and you know this whole time you're

1157
00:50:53,540 --> 00:50:52,350
thinking about I mean again my country's

1158
00:50:56,750 --> 00:50:53,550
under attack I don't know what's going

1159
00:51:00,230 --> 00:50:56,760
on but but we had to stay focused I mean

1160
00:51:02,330 --> 00:51:00,240
there was a unambiguous need to get

1161
00:51:06,680 --> 00:51:02,340
these instructions to the spacecraft so

1162
00:51:08,630 --> 00:51:06,690
it could execute this maneuver to to

1163
00:51:11,030 --> 00:51:08,640

catch up with the comet just 11 days

1164
00:51:12,530 --> 00:51:11,040
late to get there by September 22nd yeah

1165
00:51:14,120 --> 00:51:12,540
in fact actually I just realized the

1166
00:51:15,710 --> 00:51:14,130
anniversary that's coming up just a few

1167
00:51:20,050 --> 00:51:15,720
days early is coming back yes very very

1168
00:51:23,270 --> 00:51:20,060
soon happy anniversary Thanks you too

1169
00:51:24,320 --> 00:51:23,280
you get there you so you you have this

1170
00:51:28,070 --> 00:51:24,330
successful maneuver and you're

1171
00:51:32,570 --> 00:51:28,080
approaching and there's a comet there's

1172
00:51:34,550 --> 00:51:32,580
you worked so hard yeah but get to this

1173
00:51:37,040 --> 00:51:34,560
point but it's not over it's not over

1174
00:51:40,220 --> 00:51:37,050
yet yeah so there were still a lot of

1175
00:51:42,320 --> 00:51:40,230
challenges ahead excuse me and again I

1176
00:51:46,040 --> 00:51:42,330
can't go into all of them but just a

1177
00:51:48,290 --> 00:51:46,050
couple here to illustrate let me remind

1178
00:51:51,380 --> 00:51:48,300
you what we could see from Earth is this

1179
00:51:54,590 --> 00:51:51,390
big calm a thousands many many thousands

1180
00:51:57,470 --> 00:51:54,600
of miles across bigger than Earth and

1181
00:52:00,130 --> 00:51:57,480
the spacecraft had to plunge into that

1182
00:52:03,440 --> 00:52:00,140
and find the nucleus on its own and we

1183
00:52:06,440 --> 00:52:03,450
didn't even know is the nucleus gonna be

1184
00:52:09,590 --> 00:52:06,450
dark against the light background of the

1185
00:52:11,210 --> 00:52:09,600
coma or is it going to be bright against

1186
00:52:12,380 --> 00:52:11,220
the darker background of space is it

1187
00:52:14,570 --> 00:52:12,390
gonna look this about the same

1188
00:52:16,640 --> 00:52:14,580

brightness as the coma so the spacecraft

1189
00:52:19,580 --> 00:52:16,650
actually had to fly into the coma and

1190
00:52:21,290 --> 00:52:19,590
find the nucleus on its own but let me

1191
00:52:23,360 --> 00:52:21,300
remind you of course what would do that

1192
00:52:25,430 --> 00:52:23,370
with the camera but it also had to keep

1193
00:52:29,750 --> 00:52:25,440
turning occasionally to point the cat

1194
00:52:32,150 --> 00:52:29,760
point the camera at a star to to sort of

1195
00:52:35,600 --> 00:52:32,160
fix its attitude then it would turn back

1196
00:52:37,250 --> 00:52:35,610
to the nucleus to you know look around

1197
00:52:39,320 --> 00:52:37,260
for the nucleus then it would turn to a

1198
00:52:40,970 --> 00:52:39,330
reference star and would look at the

1199
00:52:44,510 --> 00:52:40,980
nucleus and it would turn to a different

1200
00:52:46,700 --> 00:52:44,520
aphorism back then back and forth and

1201
00:52:50,390 --> 00:52:46,710
and it was gonna be on its own in there

1202
00:52:53,300 --> 00:52:50,400
I mean this was way way way too far for

1203
00:52:54,710 --> 00:52:53,310
us to be able to joystick it and of

1204
00:52:56,480 --> 00:52:54,720
course it couldn't be couldn't waste at

1205
00:53:00,530 --> 00:52:56,490
the time pointing its antenna mm-hmm

1206
00:53:03,290 --> 00:53:00,540
had earth excuse me but there were

1207
00:53:05,840 --> 00:53:03,300
challenges beyond even that okay because

1208
00:53:08,840 --> 00:53:05,850
it was flying through the coma 37,000

1209
00:53:11,630 --> 00:53:08,850
miles per hour I hope that's faster than

1210
00:53:15,109 --> 00:53:11,640
you drove on Oak Grove Drive today

1211
00:53:19,099 --> 00:53:15,119
and so it's plunging into this coma

1212
00:53:22,580 --> 00:53:19,109
which is has not only a lot of gas but

1213
00:53:26,660 --> 00:53:22,590

dust in it as well and so it's flying

1214
00:53:30,890 --> 00:53:26,670
through this cloud potentially filled

1215
00:53:37,490 --> 00:53:30,900
with dust and it's not as dense as you

1216
00:53:39,859 --> 00:53:37,500
know you're the Beach say but but that

1217
00:53:44,300 --> 00:53:39,869
has many of these little particles in it

1218
00:53:46,870 --> 00:53:44,310
and at this velocity one particle 1

1219
00:53:49,820 --> 00:53:46,880
particle smaller than the head of a pin

1220
00:53:51,109 --> 00:53:49,830
80 microns in diameter for those of you

1221
00:53:53,630 --> 00:53:51,119
who know that but smaller than the head

1222
00:53:55,640 --> 00:53:53,640
of a pin hitting the spacecraft would

1223
00:53:58,520 --> 00:53:55,650
impart as much energy to the spacecraft

1224
00:54:01,160 --> 00:53:58,530
as a bowling ball does when it hits the

1225
00:54:05,270 --> 00:54:01,170
pins that's not good for the spacecraft

1226
00:54:07,160 --> 00:54:05,280
health you saved it from a Star Trek or

1227
00:54:09,980 --> 00:54:07,170
you've saved it from zigging and zagging

1228
00:54:11,480 --> 00:54:09,990
and finding the Sun and all of these

1229
00:54:15,140 --> 00:54:11,490
things and now you're getting ready to

1230
00:54:19,520 --> 00:54:15,150
go in through the coma and a speck of

1231
00:54:19,940 --> 00:54:19,530
dust could end it all right how did it

1232
00:54:23,359 --> 00:54:19,950
go

1233
00:54:25,280 --> 00:54:23,369
well I mean the reality is we didn't

1234
00:54:27,230 --> 00:54:25,290
expect it to be successful I mean it

1235
00:54:30,859 --> 00:54:27,240
shouldn't be should not be should not be

1236
00:54:33,440 --> 00:54:30,869
successful and and in fact even it

1237
00:54:36,430 --> 00:54:33,450
didn't go as expected it didn't go as

1238
00:54:45,039 --> 00:54:36,440

expected it was incredibly successful

1239
00:54:51,309 --> 00:54:48,609
and it's nicely applauded because I'll

1240
00:54:53,709 --> 00:54:51,319
tell you after it worked to me the

1241
00:54:55,179 --> 00:54:53,719
biggest risk there were there were tons

1242
00:54:57,939 --> 00:54:55,189
of risks the biggest risk was the

1243
00:55:00,130 --> 00:54:57,949
seismic risk to Southern California from

1244
00:55:02,409 --> 00:55:00,140
the applause that erupted in Mission

1245
00:55:07,059 --> 00:55:02,419
Control right across the street there

1246
00:55:10,809 --> 00:55:07,069
yeah you know it was it was pretty

1247
00:55:13,089 --> 00:55:10,819
pretty scary and here's this incredible

1248
00:55:16,749 --> 00:55:13,099
image that we got when we got this this

1249
00:55:19,569 --> 00:55:16,759
showed more detail in a comet than we

1250
00:55:22,269 --> 00:55:19,579
had ever seen and so you can see here

1251
00:55:25,630 --> 00:55:22,279
this is the nucleus it's a few miles

1252
00:55:27,849 --> 00:55:25,640
across and there's this jet of gas now

1253
00:55:31,269 --> 00:55:27,859
this is not like the long tail do you

1254
00:55:34,659 --> 00:55:31,279
see from Earth this this jet of gas and

1255
00:55:38,189 --> 00:55:34,669
dust here is maybe 30 or 50 miles long

1256
00:55:39,809 --> 00:55:38,199
and so I hope you're impressed with the

1257
00:55:42,639 --> 00:55:39,819
market

1258
00:55:45,159 --> 00:55:42,649
okay so if you could do better than that

1259
00:55:48,399 --> 00:55:45,169
but when we got this this was still

1260
00:55:50,019 --> 00:55:48,409
pretty neat but then we actually even

1261
00:55:51,870 --> 00:55:50,029
got a picture we're now you could really

1262
00:55:54,459 --> 00:55:51,880
see the shape maybe it looks like a

1263
00:55:56,049 --> 00:55:54,469

drumstick or a bowling pin actually now

1264
00:55:58,689 --> 00:55:56,059
that I think of a bowling it's a good

1265
00:56:00,489 --> 00:55:58,699
one yeah I thought of that yeah so when

1266
00:56:02,379 --> 00:56:00,499
we got this this we were pretty happy

1267
00:56:05,559 --> 00:56:02,389
about this but then we also got this

1268
00:56:08,969 --> 00:56:05,569
this and this turned out to be three and

1269
00:56:12,179 --> 00:56:08,979
a half times better than our best case

1270
00:56:15,009 --> 00:56:12,189
objective for what we could hope to get

1271
00:56:16,389 --> 00:56:15,019
just hope to get its mass we got and

1272
00:56:17,949 --> 00:56:16,399
we're not going to take the time here

1273
00:56:19,269 --> 00:56:17,959
actually see it's it's getting late but

1274
00:56:21,279 --> 00:56:19,279
there's there's a lot of you this was

1275
00:56:24,729 --> 00:56:21,289
the first time we saw the nucleus of a

1276
00:56:27,159 --> 00:56:24,739
comet in enough detail to actually do

1277
00:56:29,469 --> 00:56:27,169
geology on it this is again NASA's first

1278
00:56:32,589 --> 00:56:29,479
close-up picture of the nucleus of a

1279
00:56:34,899 --> 00:56:32,599
comet and you can see this sort of lobe

1280
00:56:37,120 --> 00:56:34,909
down here maybe you can even make out

1281
00:56:40,539 --> 00:56:37,130
some canyons here you can see them in

1282
00:56:42,909 --> 00:56:40,549
the full image bright areas and dark

1283
00:56:44,469 --> 00:56:42,919
areas and in fact when you look at it

1284
00:56:46,929 --> 00:56:44,479
like this you can see these two pieces

1285
00:56:50,589 --> 00:56:46,939
they're not stuck together like this

1286
00:56:54,009 --> 00:56:50,599
it's more like this I'm exaggerating it

1287
00:56:56,979 --> 00:56:54,019
just so you can see and so the this

1288
00:56:58,440 --> 00:56:56,989

really revealed a lot in this this was

1289
00:57:00,000 --> 00:56:58,450
the path I mean this

1290
00:57:04,670 --> 00:57:00,010
when this picture came in to Mission

1291
00:57:06,599 --> 00:57:04,680
Control this that that event was that

1292
00:57:09,480 --> 00:57:06,609
was pretty special

1293
00:57:12,089 --> 00:57:09,490
I I mean what we've been living under a

1294
00:57:15,480 --> 00:57:12,099
dark cloud for a long time I mean in the

1295
00:57:19,140 --> 00:57:15,490
in just in the time in part of the

1296
00:57:21,059 --> 00:57:19,150
encounter roughly a half hour around it

1297
00:57:23,370 --> 00:57:21,069
the spacecraft was just mentioning this

1298
00:57:28,620 --> 00:57:23,380
to you just just a few minutes ago yeah

1299
00:57:31,589 --> 00:57:28,630
spacecraft had 4700 instructions and

1300
00:57:34,200 --> 00:57:31,599
parameters that all had to be right in

1301
00:57:36,870 --> 00:57:34,210
that half hour and if even one of them

1302
00:57:39,150 --> 00:57:36,880
was wrong wouldn't have worked that

1303
00:57:41,039 --> 00:57:39,160
doesn't not talking about the rescue I'm

1304
00:57:44,000 --> 00:57:41,049
not talking about the 15 months of

1305
00:57:47,059 --> 00:57:44,010
getting there just in the half hour and

1306
00:57:49,970 --> 00:57:47,069
there were so many times that I thought

1307
00:57:52,700 --> 00:57:49,980
you know if just one of them is wrong

1308
00:57:56,940 --> 00:57:52,710
I'm gonna spend the rest of my life

1309
00:58:01,260 --> 00:57:56,950
thinking you know if only if only we

1310
00:58:03,839 --> 00:58:01,270
gotten that one right it was she'd been

1311
00:58:05,819 --> 00:58:03,849
living in this in this until that

1312
00:58:08,410 --> 00:58:05,829
picture showed up yeah and then when the

1313
00:58:12,519 --> 00:58:08,420

picture showed up to me

1314
00:58:15,370 --> 00:58:12,529
it was it was this and everybody this is

1315
00:58:17,980 --> 00:58:15,380
my representation everybody in Mission

1316
00:58:25,329 --> 00:58:17,990
Control we just went to a happy place

1317
00:58:31,359 --> 00:58:25,339
and and this is this to me is what it

1318
00:58:37,900 --> 00:58:31,369
felt like and my stress ohmmeter went

1319
00:58:39,880 --> 00:58:37,910
went way down and tell you so I like to

1320
00:58:42,220 --> 00:58:39,890
think of myself as being of at least

1321
00:58:45,190 --> 00:58:42,230
average eloquence and you didn't pretty

1322
00:58:47,470 --> 00:58:45,200
much effort for three hours after this

1323
00:58:49,930 --> 00:58:47,480
happened the only thing I could say

1324
00:58:53,620 --> 00:58:49,940
every 30 seconds was I can't believe how

1325
00:58:55,599 --> 00:58:53,630
incredibly cool this is and one of my

1326
00:58:58,269 --> 00:58:55,609
friends in fact the same guy who called

1327
00:59:00,279 --> 00:58:58,279
me on September 11th told me mmm

1328
00:59:03,190 --> 00:59:00,289
we stood outside Mission Control and we

1329
00:59:06,789 --> 00:59:03,200
cried together in fact actually just

1330
00:59:14,970 --> 00:59:06,799
thinking about it just is making me feel

1331
00:59:20,370 --> 00:59:16,890
and another one of my friends on the

1332
00:59:21,900 --> 00:59:20,380
team we were standing together talking

1333
00:59:23,880 --> 00:59:21,910
about it and at practically the same

1334
00:59:25,980 --> 00:59:23,890
time this was hours later practically at

1335
00:59:28,260 --> 00:59:25,990
the same time we said to each other I

1336
00:59:32,760 --> 00:59:28,270
just want to hug you and we just hugged

1337
00:59:34,500 --> 00:59:32,770
and I mean this this was this was a

1338
00:59:37,170 --> 00:59:34,510

pretty special well this was a high

1339
00:59:39,569 --> 00:59:37,180
point me seriously this this happened

1340
00:59:42,210 --> 00:59:39,579
you know September of 2001 this is the

1341
00:59:45,109 --> 00:59:42,220
high point of my professional career and

1342
00:59:48,660 --> 00:59:45,119
you know as a lifelong space enthusiasts

1343
00:59:50,040 --> 00:59:48,670
seeing this and you've all seen some

1344
00:59:51,960 --> 00:59:50,050
many of my friends and colleagues and

1345
00:59:53,970 --> 00:59:51,970
others you know in Mission Control and

1346
00:59:56,010 --> 00:59:53,980
televised events of course this because

1347
00:59:57,900 --> 00:59:56,020
of 9/11 you know you didn't hear about

1348
00:59:59,640 --> 00:59:57,910
it the world's news was focused on that

1349
01:00:02,040 --> 00:59:59,650
you've seen people in Mission Control

1350
01:00:04,319 --> 01:00:02,050
jumping and hugging and things like that

1351
01:00:07,980 --> 01:00:04,329
I can tell you there's nobody there who

1352
01:00:10,050 --> 01:00:07,990
felt any more excited gratified we did

1353
01:00:11,190 --> 01:00:10,060
after this rescue ok we need to see some

1354
01:00:12,780 --> 01:00:11,200
of those people let's skip ahead and

1355
01:00:16,079 --> 01:00:12,790
take yeah let's get bad there's some

1356
01:00:17,010 --> 01:00:16,089
common stuff here that will I don't

1357
01:00:19,440 --> 01:00:17,020
think we have time for

1358
01:00:20,609 --> 01:00:19,450
let me just quickly show you if you want

1359
01:00:23,309 --> 01:00:20,619
to talk about it afterwards the

1360
01:00:24,780 --> 01:00:23,319
trajectory we took but I do want to show

1361
01:00:26,940 --> 01:00:24,790
you some of the people on the team

1362
01:00:28,710 --> 01:00:26,950
because I'm up here getting to share

1363
01:00:30,720 --> 01:00:28,720

this with you but I'm not the only one

1364
01:00:33,000 --> 01:00:30,730
who did it

1365
01:00:37,260 --> 01:00:33,010
here is in effect this picture here this

1366
01:00:41,900 --> 01:00:37,270
was taken before that same day before

1367
01:00:44,700 --> 01:00:41,910
the comet encounter this was taken after

1368
01:00:48,780 --> 01:00:44,710
and some of these on other days this was

1369
01:00:52,770 --> 01:00:48,790
this was also after so this was this was

1370
01:00:55,950 --> 01:00:52,780
a great team and and it was you know on

1371
01:00:59,069 --> 01:00:55,960
behalf of all of you we were doing this

1372
01:01:01,589 --> 01:00:59,079
I think everybody who ever looks up with

1373
01:01:03,329 --> 01:01:01,599
the night sky and just wonders what's

1374
01:01:05,040 --> 01:01:03,339
out there you know everybody

1375
01:01:07,920 --> 01:01:05,050
participates in this and that's why we

1376
01:01:10,200 --> 01:01:07,930
did it do you see this team I do I mean

1377
01:01:11,970 --> 01:01:10,210
I still work with some of them and the

1378
01:01:14,069 --> 01:01:11,980
ones I don't work with every day you

1379
01:01:16,109 --> 01:01:14,079
know I often pass outside here on the

1380
01:01:18,780 --> 01:01:16,119
mall and in fact every five years we

1381
01:01:22,260 --> 01:01:18,790
have a party on the anniversary of

1382
01:01:26,280 --> 01:01:22,270
launch we just had one not too long ago

1383
01:01:27,839 --> 01:01:26,290
and we still get together and I would

1384
01:01:28,160 --> 01:01:27,849
say and I know there's some here today

1385
01:01:31,579 --> 01:01:28,170
it was

1386
01:01:36,319 --> 01:01:31,589
fun to see rich and John and a few other

1387
01:01:38,270 --> 01:01:36,329
people and I think we share we share

1388
01:01:40,370 --> 01:01:38,280

something pretty special and at the end

1389
01:01:43,700 --> 01:01:40,380
of the mission you just want to show you

1390
01:01:45,710 --> 01:01:43,710
one more picture oh actually this is

1391
01:01:47,960 --> 01:01:45,720
this is just another picture of of our

1392
01:01:50,650 --> 01:01:47,970
rescue team just standing on the steps

1393
01:01:54,170 --> 01:01:50,660
across the across the mall there and

1394
01:01:58,839 --> 01:01:54,180
then at the end of the mission we just

1395
01:02:03,859 --> 01:01:58,849
gave sort of one last farewell salute

1396
01:02:06,559 --> 01:02:03,869
looking up at the sky to say goodbye to

1397
01:02:09,770 --> 01:02:06,569
the team and that was our that was our

1398
01:02:11,990 --> 01:02:09,780
last picture of the team on the last day

1399
01:02:15,650 --> 01:02:12,000
we communicated with the spacecraft at

1400
01:02:25,180 --> 01:02:15,660
the end of the mission so that's our

1401
01:02:28,790 --> 01:02:27,260
we're gonna open it up for some

1402
01:02:30,110 --> 01:02:28,800
questions for mark if you have a

1403
01:02:31,430 --> 01:02:30,120
question please step up to the

1404
01:02:33,560 --> 01:02:31,440
microphone if you're watching online

1405
01:02:35,870 --> 01:02:33,570
your questions are coming up to me right

1406
01:02:37,340 --> 01:02:35,880
now but I'm gonna open this up real

1407
01:02:42,080 --> 01:02:37,350
quick with do you still have nightmares

1408
01:02:46,760 --> 01:02:42,090
about this actually I do

1409
01:02:48,920 --> 01:02:46,770
so it's funny i yeah I actually still

1410
01:02:50,680 --> 01:02:48,930
have student anxiety dreams I've been on

1411
01:02:54,260 --> 01:02:50,690
a school for a long time in fact I

1412
01:02:55,610 --> 01:02:54,270
actually this is true I had a dream not

1413
01:02:58,430 --> 01:02:55,620

too long ago that I was in the third

1414
01:02:59,870 --> 01:02:58,440
grade and you know I'd missed classes I

1415
01:03:01,820 --> 01:02:59,880
didn't know where I was supposed to be

1416
01:03:04,160 --> 01:03:01,830
hadn't done the homework and even in the

1417
01:03:07,970 --> 01:03:04,170
dream I thought gosh I have a PhD but I

1418
01:03:10,910 --> 01:03:07,980
just got but but I still still regularly

1419
01:03:15,100 --> 01:03:10,920
have dreams about ds1 either we can't

1420
01:03:17,780 --> 01:03:15,110
save it or more commonly we rescued it

1421
01:03:20,600 --> 01:03:17,790
we're heading for the comet but we're

1422
01:03:22,220 --> 01:03:20,610
not prepared for the encounter or wait a

1423
01:03:24,410 --> 01:03:22,230
second I think the encounter was an hour

1424
01:03:26,180 --> 01:03:24,420
ago and we never even finished preparing

1425
01:03:28,730 --> 01:03:26,190
and aren't I supposed to be at JPL and

1426
01:03:31,280 --> 01:03:28,740
Mission Control I'm at home and yeah I

1427
01:03:33,620 --> 01:03:31,290
still have I still have those anxiety

1428
01:03:34,550 --> 01:03:33,630
dreams but I always wake up and go back

1429
01:03:38,450 --> 01:03:34,560
to that happy place

1430
01:03:39,830 --> 01:03:38,460
very yeah so if we don't get a chance to

1431
01:03:41,810 --> 01:03:39,840
get to everybody today mark is gonna

1432
01:03:44,270 --> 01:03:41,820
stick around for for a few minutes you

1433
01:03:46,430 --> 01:03:44,280
yeah be happy to be happy to talk for a

1434
01:03:48,770 --> 01:03:46,440
little bit more but first question thank

1435
01:03:50,210 --> 01:03:48,780
you for this two questions first do you

1436
01:03:54,080 --> 01:03:50,220
have a working theory as to why this

1437
01:03:56,330 --> 01:03:54,090
star tracker failed and second the image

1438
01:04:00,170 --> 01:03:56,340

that you showed of the comet it reminds

1439
01:04:01,370 --> 01:04:00,180
me of the 2014 mu 69 Ultima Thule so is

1440
01:04:02,900 --> 01:04:01,380
this do you think this is a contact

1441
01:04:05,540 --> 01:04:02,910
binary or something to form simile

1442
01:04:07,880 --> 01:04:05,550
similarly to that okay so the first

1443
01:04:09,530 --> 01:04:07,890
question everybody heard it

1444
01:04:10,490 --> 01:04:09,540
participatory mind it was do we have an

1445
01:04:14,360 --> 01:04:10,500
idea of what happened to the star

1446
01:04:16,840 --> 01:04:14,370
tracker and in short no the star tracker

1447
01:04:19,460 --> 01:04:16,850
again wasn't one of our new technologies

1448
01:04:22,280 --> 01:04:19,470
we of course once we determined that it

1449
01:04:24,170 --> 01:04:22,290
wasn't working we were focused on saving

1450
01:04:26,360 --> 01:04:24,180
the spacecraft and you know rescuing the

1451
01:04:28,310 --> 01:04:26,370
spacecraft and moving on but we did have

1452
01:04:30,230 --> 01:04:28,320
a separate group of people to look at

1453
01:04:31,610 --> 01:04:30,240
all the telemetry we got from the

1454
01:04:35,570 --> 01:04:31,620
spacecraft once we had the main antenna

1455
01:04:36,870 --> 01:04:35,580
pointed at Earth and we even sent some

1456
01:04:39,059 --> 01:04:36,880
instructions of space

1457
01:04:41,730 --> 01:04:39,069
to run some diagnostic tests and things

1458
01:04:45,720 --> 01:04:41,740
like that and JPL NASA go through a

1459
01:04:48,960 --> 01:04:45,730
formal process to investigate things

1460
01:04:50,579 --> 01:04:48,970
like this and it's okay to say that yeah

1461
01:04:54,150 --> 01:04:50,589
I think it is okay so please do their

1462
01:04:56,450 --> 01:04:54,160
conclusion was their conclusion was it

1463
01:05:00,180 --> 01:04:56,460

just crapped out

1464
01:05:02,130 --> 01:05:00,190
so no official report right the other

1465
01:05:05,400 --> 01:05:02,140
question I'm gonna rephrase it but this

1466
01:05:07,980 --> 01:05:05,410
gentleman recognizes that earlier this

1467
01:05:12,089 --> 01:05:07,990
year the new Horizons spacecraft flew by

1468
01:05:13,349 --> 01:05:12,099
an object in the Kuiper belt the largest

1469
01:05:15,299 --> 01:05:13,359
object in the Kuiper belt you've all

1470
01:05:17,910 --> 01:05:15,309
heard of is Pluto maybe you've heard of

1471
01:05:22,140 --> 01:05:17,920
others and in some ways it looks like

1472
01:05:23,509 --> 01:05:22,150
comet Borelli that is two objects of

1473
01:05:26,549 --> 01:05:23,519
different size sort of stuck together

1474
01:05:28,620 --> 01:05:26,559
comet churyumov-gerasimenko looks

1475
01:05:31,829 --> 01:05:28,630
similar to that as well and others do

1476
01:05:35,249 --> 01:05:31,839
too so there this seems to be a theme in

1477
01:05:37,259 --> 01:05:35,259
the solar system Borelli was the an

1478
01:05:39,509 --> 01:05:37,269
early subject object early one to be

1479
01:05:41,490 --> 01:05:39,519
discovered but now we're seeing more and

1480
01:05:43,680 --> 01:05:41,500
more of these that apparently were

1481
01:05:47,220 --> 01:05:43,690
formed when using exactly the words you

1482
01:05:48,930 --> 01:05:47,230
did it's a contact binary two objects

1483
01:05:52,109 --> 01:05:48,940
that at some point in the solar system

1484
01:05:56,190 --> 01:05:52,119
history came together not fast enough to

1485
01:06:00,079 --> 01:05:56,200
smash apart slowly enough perhaps to

1486
01:06:04,220 --> 01:06:00,089
join and stay joined like that and so

1487
01:06:08,759 --> 01:06:04,230
this provides valuable information about

1488
01:06:11,009 --> 01:06:08,769

processes for how these so-called small

1489
01:06:12,599 --> 01:06:11,019
bodies that that picture I showed you

1490
01:06:15,930 --> 01:06:12,609
that object is only five miles of

1491
01:06:18,630 --> 01:06:15,940
ferment to end so how these small bodies

1492
01:06:20,039 --> 01:06:18,640
form and we're learning more about the

1493
01:06:21,900 --> 01:06:20,049
evolution of the solar system from that

1494
01:06:25,529 --> 01:06:21,910
we're gonna go online okay you will be

1495
01:06:27,630 --> 01:06:25,539
next Niels asks as NASA become more

1496
01:06:32,730 --> 01:06:27,640
willing to fund cheap fast and slightly

1497
01:06:35,430 --> 01:06:32,740
more risky missions after ds1 it has so

1498
01:06:37,980 --> 01:06:35,440
NASA has to find the right balance we're

1499
01:06:40,769 --> 01:06:37,990
investing your personal tax dollars and

1500
01:06:42,870 --> 01:06:40,779
my tax dollars as well so you have to

1501
01:06:45,240 --> 01:06:42,880
manage the risk right you can't take

1502
01:06:48,359 --> 01:06:45,250
your responsible risks but by the same

1503
01:06:49,720 --> 01:06:48,369
token we recognize that not we can't

1504
01:06:52,000 --> 01:06:49,730
afford to spend

1505
01:06:54,100 --> 01:06:52,010
a billion or several billion dollars on

1506
01:06:56,520 --> 01:06:54,110
every mission when you spend a billion

1507
01:06:57,730 --> 01:06:56,530
dollars you get a fabulous return

1508
01:07:01,030 --> 01:06:57,740
fabulous

1509
01:07:03,610 --> 01:07:01,040
but we we can't do a lot of missions

1510
01:07:06,250 --> 01:07:03,620
like that and so nASA has a balanced

1511
01:07:10,290 --> 01:07:06,260
program from the big expensive missions

1512
01:07:14,740 --> 01:07:10,300
now to the smaller riskier missions

1513
01:07:16,720 --> 01:07:14,750

where you take more responsible risk and

1514
01:07:21,460 --> 01:07:16,730
and I think that's paying off very well

1515
01:07:25,560 --> 01:07:21,470
for NASA great does the spacecraft have

1516
01:07:29,050 --> 01:07:25,570
reaction wheel for orientation and also

1517
01:07:32,590 --> 01:07:29,060
could you explain a little more I'll use

1518
01:07:34,870 --> 01:07:32,600
the thruster to control orientation okay

1519
01:07:36,340 --> 01:07:34,880
so for everybody else this gentleman

1520
01:07:39,040 --> 01:07:36,350
referred to a devices called reaction

1521
01:07:41,590 --> 01:07:39,050
wheels which are sort of like gyroscopes

1522
01:07:44,650 --> 01:07:41,600
they're discs which you spin

1523
01:07:47,980 --> 01:07:44,660
electrically and by changing the speed

1524
01:07:49,960 --> 01:07:47,990
at which you spin these disks you can

1525
01:07:52,630 --> 01:07:49,970
control the orientation of the

1526
01:07:55,300 --> 01:07:52,640
spacecraft some spacecraft carry them

1527
01:07:57,550 --> 01:07:55,310
but deep space one did not and so we

1528
01:07:59,410 --> 01:07:57,560
couldn't use that as a brief aside a

1529
01:08:00,940 --> 01:07:59,420
mission that I just finished working on

1530
01:08:03,250 --> 01:08:00,950
this one that's orbiting this dwarf

1531
01:08:05,470 --> 01:08:03,260
planet which was NASA's second mission

1532
01:08:08,170 --> 01:08:05,480
to use ion propulsion he used it because

1533
01:08:09,880 --> 01:08:08,180
we tested it on deep space one did have

1534
01:08:10,420 --> 01:08:09,890
these reaction wheels and they all

1535
01:08:12,910 --> 01:08:10,430
failed

1536
01:08:15,370 --> 01:08:12,920
so in fact actually we got it seriously

1537
01:08:18,010 --> 01:08:15,380
we got to have another thing of it broke

1538
01:08:20,250 --> 01:08:18,020

too and we fixed it but anyway so

1539
01:08:23,980 --> 01:08:20,260
reaction wheels have their own problems

1540
01:08:25,300 --> 01:08:23,990
and just briefly yeah the other question

1541
01:08:27,070 --> 01:08:25,310
I think you're asking is how did we use

1542
01:08:30,670 --> 01:08:27,080
the ion engine to control the

1543
01:08:33,670 --> 01:08:30,680
orientation so the ion engine unlike

1544
01:08:37,000 --> 01:08:33,680
Laura Ratliff's sophisticated model here

1545
01:08:40,330 --> 01:08:37,010
it wasn't fixed it was actually mounted

1546
01:08:41,080 --> 01:08:40,340
on a gimbal and so we could pivot it

1547
01:08:44,890 --> 01:08:41,090
like this

1548
01:08:47,080 --> 01:08:44,900
and so we could tip and tilt it to

1549
01:08:49,360 --> 01:08:47,090
control the orientation it's a little

1550
01:08:50,140 --> 01:08:49,370
more complicated than that but but

1551
01:08:51,760 --> 01:08:50,150
that's the short answer

1552
01:08:53,830 --> 01:08:51,770
we're gonna go to it another online one

1553
01:08:57,820 --> 01:08:53,840
real quick and I think this is one that

1554
01:09:01,030 --> 01:08:57,830
you can summarize real quick yeah that's

1555
01:09:02,560 --> 01:09:01,040
why we love you Marlo what was the main

1556
01:09:03,970 --> 01:09:02,570
takeaway what were the main takeaways

1557
01:09:06,660 --> 01:09:03,980
and benefits and this is from Joe

1558
01:09:09,130 --> 01:09:06,670
benefits to humanity from this mission

1559
01:09:10,810 --> 01:09:09,140
the benefits to humankind from the

1560
01:09:14,380 --> 01:09:10,820
mission I think there are several mm-hmm

1561
01:09:16,450 --> 01:09:14,390
I think one of the benefits from ok you

1562
01:09:18,100 --> 01:09:16,460
said to be quick you asked the wrong guy

1563
01:09:20,260 --> 01:09:18,110

thanks working at it I knew what I was

1564
01:09:22,090 --> 01:09:20,270
getting into yeah I think one of them is

1565
01:09:25,090 --> 01:09:22,100
the kind of thing I showed in that first

1566
01:09:27,850 --> 01:09:25,100
picture I mean we have we have

1567
01:09:31,090 --> 01:09:27,860
spacecraft out among the stars I think

1568
01:09:32,910 --> 01:09:31,100
you know even when when humankind

1569
01:09:37,330 --> 01:09:32,920
demonstrates some of its worst

1570
01:09:40,180 --> 01:09:37,340
attributes like it did on 9/11 we also

1571
01:09:43,000 --> 01:09:40,190
can demonstrate some of our best we can

1572
01:09:44,890 --> 01:09:43,010
rise above things and once again I think

1573
01:09:49,720 --> 01:09:44,900
everybody shares in this sort of thing

1574
01:09:53,080 --> 01:09:49,730
seriously and I I'm proud to live in a

1575
01:09:56,950 --> 01:09:53,090
country and a culture that can that can

1576
01:09:59,410 --> 01:09:56,960
invest in learning about the mysteries

1577
01:10:02,170 --> 01:09:59,420
of the cosmos I mean we take the best of

1578
01:10:06,970 --> 01:10:02,180
humankind science and technology to

1579
01:10:10,450 --> 01:10:06,980
undertake noble missions that you know

1580
01:10:12,910 --> 01:10:10,460
nurture our souls and the teach us about

1581
01:10:17,470 --> 01:10:12,920
the cosmos and I think everybody who's

1582
01:10:21,430 --> 01:10:17,480
ever felt that that longing to know the

1583
01:10:24,580 --> 01:10:21,440
universe to carry out a bold adventure

1584
01:10:27,040 --> 01:10:24,590
far from home anybody who's ever looked

1585
01:10:28,870 --> 01:10:27,050
at the night sky and Wonder seriously I

1586
01:10:30,970 --> 01:10:28,880
mean this is this is what I think

1587
01:10:32,770 --> 01:10:30,980
everybody participates in a mission like

1588
01:10:34,510 --> 01:10:32,780

this and I think there's real value I

1589
01:10:36,910 --> 01:10:34,520
mean this is a real science we're not

1590
01:10:39,460 --> 01:10:36,920
just saying maybe this works this way

1591
01:10:42,430 --> 01:10:39,470
maybe this works that way we don't make

1592
01:10:47,140 --> 01:10:42,440
this stuff up I mean the the real test

1593
01:10:48,640 --> 01:10:47,150
is can you fly more than a billion miles

1594
01:10:51,130 --> 01:10:48,650
to a comet

1595
01:10:55,330 --> 01:10:51,140
get these data and then learn something

1596
01:10:58,540 --> 01:10:55,340
about the solar system from it and can

1597
01:11:00,250 --> 01:10:58,550
we commit to undertaking these

1598
01:11:03,550 --> 01:11:00,260
adventures and in the face of adversity

1599
01:11:06,640 --> 01:11:03,560
like in galaxy quest never give up never

1600
01:11:09,160 --> 01:11:06,650
surrender which I mean I think is their

1601
01:11:12,970 --> 01:11:09,170
words to live by

1602
01:11:13,960 --> 01:11:12,980
we do that so I think I think that's

1603
01:11:15,700 --> 01:11:13,970
that's the kind of thing of course there

1604
01:11:17,410 --> 01:11:15,710
a lot of specific lessons one of them is

1605
01:11:18,970 --> 01:11:17,420
don't let your star tracker fail yeah

1606
01:11:20,530 --> 01:11:18,980
you know there are a lot of specific

1607
01:11:23,440 --> 01:11:20,540
things but to me these are some of the

1608
01:11:25,030 --> 01:11:23,450
big kinds of things that are a value to

1609
01:11:27,730 --> 01:11:25,040
humankind

1610
01:11:35,870 --> 01:11:27,740
that that I think enrich all of us

1611
01:11:38,780 --> 01:11:38,060
a systems architecture question with two

1612
01:11:41,990 --> 01:11:38,790
parts

1613
01:11:44,690 --> 01:11:42,000

what sort of mission does ion propulsion

1614
01:11:47,540 --> 01:11:44,700
make the most sense the other question

1615
01:11:50,150 --> 01:11:47,550
is if ion propulsion is used which tends

1616
01:11:51,980 --> 01:11:50,160
to be unidirectional long duration does

1617
01:11:52,730 --> 01:11:51,990
that drive you towards durable high gain

1618
01:11:54,950 --> 01:11:52,740
antenna

1619
01:11:57,920 --> 01:11:54,960
it's terrible cameras okay so the first

1620
01:12:00,650 --> 01:11:57,930
question is what kind of missions is ion

1621
01:12:03,940 --> 01:12:00,660
propulsion suitable for is that a any

1622
01:12:07,490 --> 01:12:03,950
mission where you need to do a lot more

1623
01:12:11,660 --> 01:12:07,500
maneuvering a lot of thrusting very very

1624
01:12:12,980 --> 01:12:11,670
high velocity and so the the mission

1625
01:12:14,960 --> 01:12:12,990
this other mission that I've referred to

1626
01:12:17,450 --> 01:12:14,970
a couple of times dawn which I've just

1627
01:12:20,300 --> 01:12:17,460
recently worked on is the only

1628
01:12:22,220 --> 01:12:20,310
spacecraft ever in more than sixty years

1629
01:12:24,380 --> 01:12:22,230
of exploring the solar system this is

1630
01:12:27,080 --> 01:12:24,390
the only spacecraft that we sent to a

1631
01:12:29,540 --> 01:12:27,090
distant solar system destination Vesta

1632
01:12:31,970 --> 01:12:29,550
the second largest object between Mars

1633
01:12:33,500 --> 01:12:31,980
and Jupiter when in - excuse me went

1634
01:12:36,800 --> 01:12:33,510
into orbit around it maneuver it in

1635
01:12:39,500 --> 01:12:36,810
orbit broke out of orbit and then went

1636
01:12:42,620 --> 01:12:39,510
to dwarf planet Ceres and orbited it

1637
01:12:44,990 --> 01:12:42,630
it's the only spacecraft ever to orbit

1638
01:12:46,520 --> 01:12:45,000

two extra-terrestrial destinations and

1639
01:12:50,450 --> 01:12:46,530
that mission would be not just difficult

1640
01:12:53,750 --> 01:12:50,460
but impossible impossible with

1641
01:12:55,670 --> 01:12:53,760
conventional chemical propulsion and now

1642
01:12:59,060 --> 01:12:55,680
JPL right now is working on another

1643
01:13:02,180 --> 01:12:59,070
mission called psyche psy C 80 which is

1644
01:13:04,190 --> 01:13:02,190
gonna launch in August of 2020 to fly to

1645
01:13:06,470 --> 01:13:04,200
the main asteroid belt again Dawn's the

1646
01:13:08,060 --> 01:13:06,480
only spacecraft that's ever orbited an

1647
01:13:09,830 --> 01:13:08,070
object than the main asteroid belt and

1648
01:13:14,390 --> 01:13:09,840
the first one to get to a dwarf planet

1649
01:13:16,370 --> 01:13:14,400
Ceres it's gonna orbit an object called

1650
01:13:19,250 --> 01:13:16,380
psyche which we believe to be the metal

1651
01:13:21,770 --> 01:13:19,260
core of a proto planet early in the

1652
01:13:24,260 --> 01:13:21,780
solar system history that broke up it

1653
01:13:26,570 --> 01:13:24,270
would be impossible with conventional

1654
01:13:29,120 --> 01:13:26,580
propulsion so missions like that it's

1655
01:13:31,910 --> 01:13:29,130
also being considered for future

1656
01:13:33,920 --> 01:13:31,920
missions to Mars where you want to bring

1657
01:13:36,200 --> 01:13:33,930
a sample back from Mars we can't do that

1658
01:13:40,460 --> 01:13:36,210
with conventional propulsion and briefly

1659
01:13:42,880 --> 01:13:40,470
you said unidirectional it's not

1660
01:13:44,990 --> 01:13:42,890
unidirectional at all you can point the

1661
01:13:46,970 --> 01:13:45,000
spacecraft any direction you want to

1662
01:13:49,020 --> 01:13:46,980
point the ion engine the articulated

1663
01:13:50,790 --> 01:13:49,030

high gain antenna it's a little

1664
01:13:53,910 --> 01:13:50,800
technical for discussing here it's

1665
01:13:55,560 --> 01:13:53,920
convenient but by no means required ds1

1666
01:13:57,959 --> 01:13:55,570
didn't have one Don didn't have one

1667
01:13:58,979 --> 01:13:57,969
psyche doesn't have one and all these

1668
01:14:00,930 --> 01:13:58,989
missions do fine

1669
01:14:03,060 --> 01:14:00,940
it might be more convenient but

1670
01:14:04,350 --> 01:14:03,070
articulated high gain antennas have

1671
01:14:06,120 --> 01:14:04,360
their own problems for other people that

1672
01:14:09,240 --> 01:14:06,130
just means an antenna that you can

1673
01:14:11,370 --> 01:14:09,250
independently move on the spacecraft

1674
01:14:13,890 --> 01:14:11,380
thank you very much all right so we've

1675
01:14:15,689 --> 01:14:13,900
got time for one last question so if

1676
01:14:17,370 --> 01:14:15,699
you're in my last question in this in

1677
01:14:19,770 --> 01:14:17,380
this format and then you have and then

1678
01:14:22,020 --> 01:14:19,780
I'll do one quick wrap-up so this is our

1679
01:14:26,370 --> 01:14:22,030
last question thanks for a great talk

1680
01:14:29,879 --> 01:14:26,380
told really well sure so when the star

1681
01:14:32,189 --> 01:14:29,889
tracker failed you mentioned that a lot

1682
01:14:32,520 --> 01:14:32,199
of people thought this was the end of

1683
01:14:36,270 --> 01:14:32,530
the mission

1684
01:14:37,919 --> 01:14:36,280
yeah how did you convince people working

1685
01:14:40,260 --> 01:14:37,929
for you and people you worked for and

1686
01:14:42,390 --> 01:14:40,270
people you worked with that it was worth

1687
01:14:43,620 --> 01:14:42,400
pursuing into the extended mission

1688
01:14:45,330 --> 01:14:43,630

because this wasn't prime mission this

1689
01:14:47,459 --> 01:14:45,340
was extended so you could could easily

1690
01:14:49,020 --> 01:14:47,469
cut your losses and just kind not

1691
01:14:51,930 --> 01:14:49,030
continue and then how did your posture

1692
01:14:53,790 --> 01:14:51,940
toward risk change once you decided to

1693
01:14:54,990 --> 01:14:53,800
go on with the extended mission and

1694
01:14:58,049 --> 01:14:55,000
you're exactly right I mean we could

1695
01:15:00,600 --> 01:14:58,059
well everybody could well have said this

1696
01:15:02,189 --> 01:15:00,610
fate and just end it and as I said

1697
01:15:07,109 --> 01:15:02,199
earlier probably let it rest on its

1698
01:15:09,510 --> 01:15:07,119
laurels it was we projected to some

1699
01:15:13,859 --> 01:15:09,520
people perhaps an unrealistically

1700
01:15:16,410 --> 01:15:13,869
optimistic assessment you know like yeah

1701
01:15:18,810 --> 01:15:16,420
this seems fatal but I mean we know what

1702
01:15:22,169 --> 01:15:18,820
we're doing here you know we're gonna go

1703
01:15:25,229 --> 01:15:22,179
I mean to the to my team it was in all

1704
01:15:27,600 --> 01:15:25,239
seriousness let's review Galaxy Quest

1705
01:15:29,580 --> 01:15:27,610
never give up never surrender

1706
01:15:31,140 --> 01:15:29,590
you know wouldn't this be fun if we

1707
01:15:34,950 --> 01:15:31,150
rescued this and we could have shirts

1708
01:15:37,020 --> 01:15:34,960
made that say deep-space one rescue team

1709
01:15:39,359 --> 01:15:37,030
and some of you who know me know that I

1710
01:15:40,529 --> 01:15:39,369
still wear shirts like that sometimes in

1711
01:15:42,330 --> 01:15:40,539
fact the briefcase that I brought

1712
01:15:44,939 --> 01:15:42,340
tonight that I bring to JPL every day

1713
01:15:46,740 --> 01:15:44,949

says on a deep-space 1 rescue team would

1714
01:15:49,470 --> 01:15:46,750
it be cool if we had you know a rescue

1715
01:15:54,000 --> 01:15:49,480
team things we can do this you know

1716
01:15:56,520 --> 01:15:54,010
let's not give up now and because we

1717
01:15:58,830 --> 01:15:56,530
already had some funding for doing this

1718
01:16:00,870 --> 01:15:58,840
two-year extended mission obviously a

1719
01:16:03,780 --> 01:16:00,880
responsible thing to do

1720
01:16:05,640 --> 01:16:03,790
is for NASA acorss not to commit to

1721
01:16:08,550 --> 01:16:05,650
giving us all of that but because there

1722
01:16:10,560 --> 01:16:08,560
was some already available we asked just

1723
01:16:13,020 --> 01:16:10,570
for enough to see if we could get the

1724
01:16:14,790 --> 01:16:13,030
main antenna pointed to earth because

1725
01:16:18,419 --> 01:16:14,800
that would allow us to diagnose the star

1726
01:16:20,280 --> 01:16:18,429
tracker problem completely to give us a

1727
01:16:22,110 --> 01:16:20,290
shot at continuing and another thing I

1728
01:16:24,270 --> 01:16:22,120
didn't have talk time to talk about here

1729
01:16:27,209 --> 01:16:24,280
but I'll just briefly mention it two

1730
01:16:29,000 --> 01:16:27,219
days before the failure we had taken

1731
01:16:33,240 --> 01:16:29,010
advantage of our advanced technology

1732
01:16:35,189 --> 01:16:33,250
camera to take high-quality infrared

1733
01:16:36,570 --> 01:16:35,199
spectra maybe you don't know what that

1734
01:16:39,169 --> 01:16:36,580
means but I'll tell you later

1735
01:16:42,060 --> 01:16:39,179
high quality infrared spectra of Mars

1736
01:16:44,340 --> 01:16:42,070
they were on board the spacecraft and

1737
01:16:45,840 --> 01:16:44,350
stranded there because we could only

1738
01:16:47,399 --> 01:16:45,850

send them down through the main antenna

1739
01:16:51,629 --> 01:16:47,409
I hadn't told only had to talk about

1740
01:16:54,419 --> 01:16:51,639
then so let us just just see if we can

1741
01:16:56,970 --> 01:16:54,429
do this then we'll get those data down

1742
01:16:58,320 --> 01:16:56,980
we'll definitively diagnose the star

1743
01:17:00,899 --> 01:16:58,330
tracker where we know what the

1744
01:17:04,590 --> 01:17:00,909
definitive diagnosis was now crapped out

1745
01:17:06,360 --> 01:17:04,600
and and by then maybe we'll think of

1746
01:17:10,649 --> 01:17:06,370
something else we can do and so it was

1747
01:17:12,600 --> 01:17:10,659
this sort of incremental process and it

1748
01:17:16,590 --> 01:17:12,610
didn't cost a lot we had a very small

1749
01:17:18,899 --> 01:17:16,600
team very small perhaps uniquely small

1750
01:17:21,209 --> 01:17:18,909
I'm not sure but certainly very small so

1751
01:17:24,060 --> 01:17:21,219
there was not a lot of money in ds1 by

1752
01:17:26,430 --> 01:17:24,070
its nature its goal was to take the

1753
01:17:28,410 --> 01:17:26,440
risks so that subsequent missions didn't

1754
01:17:31,860 --> 01:17:28,420
have to there was a risk we had never

1755
01:17:34,470 --> 01:17:31,870
thought about but but NASA and JPL were

1756
01:17:36,990 --> 01:17:34,480
very supportive of our of our attempt to

1757
01:17:38,610 --> 01:17:37,000
do this and it paid off so thank you

1758
01:17:40,320 --> 01:17:38,620
thank you very much so that's all the

1759
01:17:42,810 --> 01:17:40,330
time that we have for questions

1760
01:17:44,490 --> 01:17:42,820
one last youtube comment from Fidelio

1761
01:17:49,439 --> 01:17:44,500
says it's sweet that you held on to that

1762
01:17:51,300 --> 01:17:49,449
phone model for over 12 years let's

1763
01:17:54,479 --> 01:17:51,310

thank Laura again for making that a top

1764
01:17:56,939 --> 01:17:54,489
model that is all the time we have for

1765
01:17:58,290 --> 01:17:56,949
tonight I please join us in October

1766
01:18:00,180 --> 01:17:58,300
we're gonna be doing it's darkness

1767
01:18:01,890 --> 01:18:00,190
surrounds us the other 95% of the

1768
01:18:05,220 --> 01:18:01,900
universe we're gonna take a deep dive

1769
01:18:08,189 --> 01:18:05,230
into dark energy and dark matter but as

1770
01:18:10,830 --> 01:18:08,199
Mark pointed out there are so many

1771
01:18:12,450 --> 01:18:10,840
missions that we urge you to go and take

1772
01:18:14,670 --> 01:18:12,460
a look at of these things that have

1773
01:18:17,120 --> 01:18:14,680
happened Mark expressed with his team

1774
01:18:19,440 --> 01:18:17,130
there are so many brilliant people

1775
01:18:23,160 --> 01:18:19,450
working on all of these different things

1776
01:18:25,860 --> 01:18:23,170
that go this was one amazing beautiful

1777
01:18:28,470 --> 01:18:25,870
incredible example of something that

1778
01:18:30,060 --> 01:18:28,480
we've fixed so go do your research go

1779
01:18:32,710 --> 01:18:30,070
learn about all these other things and

1780
01:18:39,080 --> 01:18:32,720
let's thank dr. Raymond one last time

1781
01:18:48,460 --> 01:18:39,090
[Applause]

1782
01:18:48,470 --> 01:18:55,180
I was telling him

1783
01:18:55,190 --> 01:19:18,470
[Music]