1
00:00:00,000 --> 00:00:07,240
[Music]

2
00:00:13,940 --> 00:00:11,870
hi everybody welcome to NASA's Jet

3
00:00:16,310 --> 00:00:13,950
Propulsion Laboratory here in Pasadena

4
00:00:18,410 --> 00:00:16,320
California for our monthly public

5
00:00:21,050 --> 00:00:18,420
lecture and discussion of on Carmen

6
00:00:22,460 --> 00:00:21,060
series I'm Preston dykes so tonight

7
00:00:24,859 --> 00:00:22,470
we're going to talk about one of the

8
00:00:28,310 --> 00:00:24,869
most fundamental elements of space

9
00:00:29,870 --> 00:00:28,320
exploration how do we communicate with

10
00:00:32,170 --> 00:00:29,880
the robots that we send to far-off

11
00:00:34,930 --> 00:00:32,180
destinations across the solar system

12
00:00:37,250 --> 00:00:34,940
tonight our focus is deep space

13
00:00:39,380 --> 00:00:37,260

communications and the critical tool

14
00:00:42,049 --> 00:00:39,390
NASA uses for that task which we call

15
00:00:44,150 --> 00:00:42,059
the deep space network will hear from

16
00:00:45,560 --> 00:00:44,160
two speakers tonight and then we'll move

17
00:00:47,630 --> 00:00:45,570
on to discussion and then we'll take

18
00:00:50,000 --> 00:00:47,640
your questions and if you're watching

19
00:00:51,860 --> 00:00:50,010
live online you can submit questions on

20
00:00:53,240 --> 00:00:51,870
YouTube and Twitter and we'll be sure to

21
00:00:57,110 --> 00:00:53,250
work in a couple of those as well during

22
00:00:58,549 --> 00:00:57,120
the QA and so to start us off our first

23
00:01:01,010 --> 00:00:58,559
speaker will give us an overview of

24
00:01:02,540 --> 00:01:01,020
what's involved in communicating with

25
00:01:04,490 --> 00:01:02,550
spacecraft that are millions and

26
00:01:07,190 --> 00:01:04,500
sometimes billions of miles away from

27
00:01:08,840 --> 00:01:07,200
Earth please welcome the deputy director

28
00:01:12,790 --> 00:01:08,850
of the interplanetary Network

29
00:01:21,070 --> 00:01:12,800
Directorate here at JPL dr. les doigts

30
00:01:26,120 --> 00:01:24,230
Thank You Preston so those of you who

31
00:01:27,920 --> 00:01:26,130
think about the DDS enter the Deep Space

32
00:01:30,590 --> 00:01:27,930
Network when you think about us what you

33
00:01:45,860 --> 00:01:30,600
typically think about our large antennas

34
00:01:54,410 --> 00:01:45,870
like this one or or yeah let's try the

35
00:01:56,360 --> 00:01:54,420
keyboard or that one and we are somewhat

36
00:01:58,580 --> 00:01:56,370
about large antennas and about a lot of

37
00:02:01,280 --> 00:01:58,590
other things too here is one of our

38
00:02:03,170 --> 00:02:01,290

three complexes or sets of antennas that

39
00:02:05,390 --> 00:02:03,180
we have around the world this one

40
00:02:09,050 --> 00:02:05,400
happens to be in Canberra Australia and

41
00:02:10,880 --> 00:02:09,060
you can see in this our two sizes of

42
00:02:13,580 --> 00:02:10,890
antennas most of the antennas in this

43
00:02:15,980 --> 00:02:13,590
photo the ones that are toward the left

44
00:02:18,949 --> 00:02:15,990
are 34 meter antennas they're 34 meters

45
00:02:22,910 --> 00:02:18,959
in diameter the one that's over to the

46
00:02:24,350 --> 00:02:22,920
right is a 70-meter antenna and to give

47
00:02:26,960 --> 00:02:24,360
you an idea how big a 70-meter antenna

48
00:02:35,120 --> 00:02:26,970
is it's sort of like a football field on

49
00:02:36,710 --> 00:02:35,130
a big hinge it's that big being the deep

50
00:02:38,810 --> 00:02:36,720
space network means that we are

51
00:02:41,420 --> 00:02:38,820
automatically a global enterprise and

52
00:02:43,580 --> 00:02:41,430
and you can a little bit of thought you

53
00:02:45,920 --> 00:02:43,590
can prove this for yourself so this is a

54
00:02:49,729 --> 00:02:45,930
view looking down on the North Pole of

55
00:02:51,350 --> 00:02:49,739
the earth we have three let's see if

56
00:02:54,560 --> 00:02:51,360
this is the pointer work yes it does

57
00:02:56,780 --> 00:02:54,570
okay we have three of these locations

58
00:02:58,340 --> 00:02:56,790
that have antennas like that there the

59
00:03:01,090 --> 00:02:58,350
photo I showed you was in Canberra it's

60
00:03:04,460 --> 00:03:01,100
it's over here in Australia we have a

61
00:03:06,530 --> 00:03:04,470
complex near Madrid in Spain and one at

62
00:03:10,190 --> 00:03:06,540
Goldstone in the desert of California

63
00:03:13,370 --> 00:03:10,200

and the idea is as the Earth turns which

64
00:03:15,550 --> 00:03:13,380
is not a soap opera here if you are a if

65
00:03:18,830 --> 00:03:15,560
you are a spacecraft off in deep space

66
00:03:20,960 --> 00:03:18,840
as the Earth turns there's always one of

67
00:03:23,810 --> 00:03:20,970
these complexes that's in view of your

68
00:03:25,699 --> 00:03:23,820
spacecraft which means that we could

69
00:03:28,400 --> 00:03:25,709
provide continuous communication with

70
00:03:30,440 --> 00:03:28,410
you if you need it or we can provide

71
00:03:32,390 --> 00:03:30,450
communications with you when you need it

72
00:03:33,200 --> 00:03:32,400
at any particular time as long as

73
00:03:34,670 --> 00:03:33,210
there's not a planet

74
00:03:37,520 --> 00:03:34,680
blocking your view of us for instance

75
00:03:40,280 --> 00:03:37,530
and this is true for anything that's

76
00:03:43,400 --> 00:03:40,290
beyond 30,000 or so kilometers I also

77
00:03:45,290 --> 00:03:43,410
drew a geosynchronous orbit which is at

78
00:03:46,880 --> 00:03:45,300
40,000 kilometers that's the orbit at

79
00:03:48,350 --> 00:03:46,890
which if you have a spacecraft there it

80
00:03:53,930 --> 00:03:48,360
seems to stay over one point on the

81
00:03:56,810 --> 00:03:53,940
earth and I am a mathematician I'm

82
00:03:58,820 --> 00:03:56,820
neither a scientist nor an engineer so I

83
00:04:01,460 --> 00:03:58,830
think in terms of equations all the time

84
00:04:04,460 --> 00:04:01,470
there are a lot of factors that come in

85
00:04:06,380 --> 00:04:04,470
to describing the performance of a

86
00:04:08,000 --> 00:04:06,390
communications link with deep space and

87
00:04:09,500 --> 00:04:08,010
I've listed a bunch of them here and

88
00:04:11,420 --> 00:04:09,510

luckily I'm not going to talk about most

89
00:04:13,280 --> 00:04:11,430
of them so don't worry about that

90
00:04:15,050 --> 00:04:13,290
but I did want to point out that just

91
00:04:16,370 --> 00:04:15,060
the complexity of things there are a

92
00:04:18,500 --> 00:04:16,380
whole bunch of parameters that talk

93
00:04:20,060 --> 00:04:18,510
about how well the transmitting

94
00:04:21,470 --> 00:04:20,070
spacecraft works if is trying to send a

95
00:04:22,850 --> 00:04:21,480
message to the ground there are whole

96
00:04:25,610 --> 00:04:22,860
bunch of parameters to talk about how

97
00:04:27,830 --> 00:04:25,620
well the receiving antenna works but

98
00:04:29,200 --> 00:04:27,840
there's also all the stuff behind the

99
00:04:31,400 --> 00:04:29,210
spacecraft things that provide

100
00:04:33,020 --> 00:04:31,410
interference or noise in the environment

101
00:04:35,270 --> 00:04:33,030
that we have to work about but the most

102
00:04:37,820 --> 00:04:35,280
important parameter in deep space

103
00:04:39,320 --> 00:04:37,830
communications is the distance the

104
00:04:41,570 --> 00:04:39,330
distance between you and the spacecraft

105
00:04:43,430 --> 00:04:41,580
that's what makes communications in deep

106
00:04:45,290 --> 00:04:43,440
space different than communications

107
00:04:49,010 --> 00:04:45,300
anywhere else on the surface of the

108
00:04:50,600 --> 00:04:49,020
earth for instance and we can describe

109
00:04:52,400 --> 00:04:50,610
this pretty easily remember I'm in

110
00:04:54,020 --> 00:04:52,410
mathematician so here's here is an

111
00:04:55,970 --> 00:04:54,030
equation don't worry too much about it

112
00:04:57,770 --> 00:04:55,980
if you take all those parameters from

113
00:05:00,350 --> 00:04:57,780

the previous chart all the ones that are

114
00:05:01,940 --> 00:05:00,360
good they lump together in this term

115
00:05:03,740 --> 00:05:01,950
that's at the top of this fraction and

116
00:05:05,690 --> 00:05:03,750
all the ones that are bad the noise and

117
00:05:07,730 --> 00:05:05,700
interference on the bottom we call this

118
00:05:09,590 --> 00:05:07,740
thing a signal-to-noise ratio and we use

119
00:05:12,830 --> 00:05:09,600
this term a lot in the theory of

120
00:05:14,810 --> 00:05:12,840
communications and and it is a it is a

121
00:05:16,610 --> 00:05:14,820
figure of Merit the bigger this number

122
00:05:20,270 --> 00:05:16,620
the more bits per second we can get back

123
00:05:22,580 --> 00:05:20,280
from deep space as an example and that

124
00:05:26,300 --> 00:05:22,590
signal noise ratio is some complex

125
00:05:29,180 --> 00:05:26,310
constant over the distance between the

126
00:05:30,860 --> 00:05:29,190
spacecraft and you squared so that's

127
00:05:33,410 --> 00:05:30,870
what makes it hard it's that that

128
00:05:35,960 --> 00:05:33,420
distance becomes high and and the

129
00:05:38,600 --> 00:05:35,970
cartoon here shows this so I have a

130
00:05:40,490 --> 00:05:38,610
geosynchronous spacecraft orbiting the

131
00:05:42,080 --> 00:05:40,500
Earth in this picture that's the kind of

132
00:05:44,570 --> 00:05:42,090
spacecraft that provides your television

133
00:05:46,010 --> 00:05:44,580
signals for instance and most other

134
00:05:46,460 --> 00:05:46,020
communications on the surface of the

135
00:05:50,510 --> 00:05:46,470
earth use

136
00:05:53,660 --> 00:05:50,520
satellites and I also have a spacecraft

137
00:05:56,180 --> 00:05:53,670
of Jupiter and the differences of those

138
00:05:58,760 --> 00:05:56,190

d squared terms is large and the table

139
00:06:01,310 --> 00:05:58,770
shows this if we take that Geo satellite

140
00:06:05,630 --> 00:06:01,320
that TV satellite and say that has unit

141
00:06:07,040 --> 00:06:05,640
difficulty then even moving that even

142
00:06:08,510 --> 00:06:07,050
taking a spacecraft as far away as the

143
00:06:10,520 --> 00:06:08,520
moon makes it a hundred times more

144
00:06:13,130 --> 00:06:10,530
difficult to communicate that means if

145
00:06:15,350 --> 00:06:13,140
you can get back say a megabit per

146
00:06:16,880 --> 00:06:15,360
second from that geosynchronous thing

147
00:06:18,560 --> 00:06:16,890
you can only get back a hundredth of

148
00:06:21,350 --> 00:06:18,570
that just you know 10 kilobits per

149
00:06:24,950 --> 00:06:21,360
second at at at the moon with the same

150
00:06:27,500 --> 00:06:24,960
system Mars is even worse and in two

151
00:06:31,640 --> 00:06:27,510
Pater's where Jupiter for instance if if

152
00:06:33,560 --> 00:06:31,650
you can get 400 megabits per second back

153
00:06:35,990 --> 00:06:33,570
from that geo satellite if you move that

154
00:06:37,820 --> 00:06:36,000
same system to Jupiter you get one bit

155
00:06:42,440 --> 00:06:37,830
per second that's how much harder that

156
00:06:43,730 --> 00:06:42,450
problem is and that's why if you look at

157
00:06:45,650 --> 00:06:43,740
the history of the deep space network

158
00:06:47,659 --> 00:06:45,660
among other things that's the history of

159
00:06:50,000 --> 00:06:47,669
building bigger and bigger antennas when

160
00:06:55,909 --> 00:06:50,010
we started out we had 26 meter antennas

161
00:06:58,250 --> 00:06:55,919
which we would now consider small we

162
00:07:01,280 --> 00:06:58,260
went to 34 meter antennas we still use a

163
00:07:05,810 --> 00:07:01,290

lot of those we went to a 64 meter

164
00:07:10,070 --> 00:07:05,820
antennas at each site oh it worked that

165
00:07:12,350 --> 00:07:10,080
time and our largest antennas now are 70

166
00:07:14,719 --> 00:07:12,360
meters and if we need more than that we

167
00:07:16,490 --> 00:07:14,729
can array antennas together we can

168
00:07:18,530 --> 00:07:16,500
electronically combine the signals

169
00:07:20,930 --> 00:07:18,540
coming out of several of these antennas

170
00:07:23,120 --> 00:07:20,940
and the overall performance looks like

171
00:07:28,219 --> 00:07:23,130
an antenna that has the sum of the areas

172
00:07:30,530 --> 00:07:28,229
of the individual antennas so there's

173
00:07:32,450 --> 00:07:30,540
that same signal noise ratio it's also

174
00:07:34,430 --> 00:07:32,460
equal to a constant over what we call

175
00:07:36,350 --> 00:07:34,440
the noise temperature which is a

176
00:07:38,390 --> 00:07:36,360
description of all the random horrible

177
00:07:40,610 --> 00:07:38,400
events that can come between you and

178
00:07:42,680 --> 00:07:40,620
getting your signal and some of these

179
00:07:43,760 --> 00:07:42,690
can't be controlled and I when I showed

180
00:07:45,740 --> 00:07:43,770
that first chart with all those

181
00:07:47,750 --> 00:07:45,750
parameters on it if you have a planet

182
00:07:49,790 --> 00:07:47,760
behind your spacecraft that planet might

183
00:07:51,740 --> 00:07:49,800
be radiating radio signals just

184
00:07:53,870 --> 00:07:51,750
naturally in the band that you're trying

185
00:07:54,890 --> 00:07:53,880
to listen to that's noise as far as

186
00:07:57,650 --> 00:07:54,900
you're concerned don't want to hear that

187
00:07:59,690 --> 00:07:57,660
you want to your spacecraft there is

188
00:08:01,550 --> 00:07:59,700

cosmic microwave background just in the

189
00:08:03,200 --> 00:08:01,560
universe and it's always there in our

190
00:08:05,930 --> 00:08:03,210
system well we can't do anything about

191
00:08:07,460 --> 00:08:05,940
those but we focus on things we can do

192
00:08:10,340 --> 00:08:07,470
something about and try to make that tea

193
00:08:13,040 --> 00:08:10,350
as small as we can one of the things we

194
00:08:16,190 --> 00:08:13,050
do is we avoid you know human-made

195
00:08:19,640 --> 00:08:16,200
interference in our bands we locate our

196
00:08:22,130 --> 00:08:19,650
stations in in isolated locations and we

197
00:08:23,720 --> 00:08:22,140
control the existence of any other

198
00:08:25,790 --> 00:08:23,730
transmitters in the areas and nobody

199
00:08:28,280 --> 00:08:25,800
else is transmitting in our band and in

200
00:08:31,310 --> 00:08:28,290
fact for the frequencies we use for deep

201
00:08:32,870 --> 00:08:31,320
space communications we have guarantees

202
00:08:34,550 --> 00:08:32,880
from the International

203
00:08:36,260 --> 00:08:34,560
Telecommunications Union which is part

204
00:08:37,820 --> 00:08:36,270
of the United Nations it's something

205
00:08:40,880 --> 00:08:37,830
that all countries are signatories on

206
00:08:42,310 --> 00:08:40,890
that they will not transmit in our bands

207
00:08:45,380 --> 00:08:42,320
anything other than deep-space

208
00:08:48,620 --> 00:08:45,390
spacecraft communications and that's a

209
00:08:52,070 --> 00:08:48,630
that's a UN protected thing we also have

210
00:08:53,510 --> 00:08:52,080
the best low-noise amplifiers in the

211
00:08:55,940 --> 00:08:53,520
business these are the things that

212
00:08:58,190 --> 00:08:55,950
detect the radio waves as they come in

213
00:09:00,620 --> 00:08:58,200

to the antenna we actually cool them

214
00:09:02,240 --> 00:09:00,630
down to very close to absolute zero to

215
00:09:04,520 --> 00:09:02,250
get the best performance because there

216
00:09:07,430 --> 00:09:04,530
that's a direct contributor to that t

217
00:09:12,610 --> 00:09:07,440
term so our typical low noise amplifier

218
00:09:19,670 --> 00:09:15,920
but we do more and you're staring at the

219
00:09:22,550 --> 00:09:19,680
scene where this guy has typos all over

220
00:09:24,980 --> 00:09:22,560
the place but in fact you probably also

221
00:09:25,750 --> 00:09:24,990
read this correctly as error correcting

222
00:09:28,160 --> 00:09:25,760
codes

223
00:09:31,820 --> 00:09:28,170
that's because English is an error

224
00:09:34,010 --> 00:09:31,830
correcting code these are these are ways

225
00:09:37,190 --> 00:09:34,020
of encoding information that you want to

226
00:09:39,860 --> 00:09:37,200
transmit so so that you protect it from

227
00:09:41,840 --> 00:09:39,870
typos and in in deep space

228
00:09:43,670 --> 00:09:41,850
communications typos are when noise

229
00:09:45,350 --> 00:09:43,680
comes and clobbers a bit and flips it

230
00:09:47,000 --> 00:09:45,360
from a 1 to a zero or vice versa

231
00:09:49,790 --> 00:09:47,010
and I can show you a very quick example

232
00:09:51,590 --> 00:09:49,800
of how these work by looking at the 7

233
00:09:54,050 --> 00:09:51,600
for Hamming code don't worry about the

234
00:09:56,030 --> 00:09:54,060
name so we have a three circle Venn

235
00:09:58,400 --> 00:09:56,040
diagram and we want to send four bits

236
00:10:00,560 --> 00:09:58,410
from our spacecraft so we populate the

237
00:10:02,390 --> 00:10:00,570
intersections of the circles with the

238
00:10:05,690 --> 00:10:02,400

four bits of the message in this case

239
00:10:10,010 --> 00:10:05,700
one zero one zero then we do the

240
00:10:12,980 --> 00:10:10,020
encoding we complete the Venn diagram by

241
00:10:19,640 --> 00:10:16,970
they're adding bits so that each circle

242
00:10:20,920 --> 00:10:19,650
now has an even number of ones this is

243
00:10:23,690 --> 00:10:20,930
something that's uniquely doable

244
00:10:28,370 --> 00:10:23,700
depending on whatever your original four

245
00:10:32,380 --> 00:10:28,380
bits were now we transmit and on the

246
00:10:34,820 --> 00:10:32,390
ground we've got a typo so in this case

247
00:10:36,500 --> 00:10:34,830
when we transmitted from from the

248
00:10:38,180 --> 00:10:36,510
spacecraft to the round 0 flip to of 1

249
00:10:41,480 --> 00:10:38,190
because we had some noise in the system

250
00:10:43,520 --> 00:10:41,490
and it was bad but don't worry we can

251
00:10:47,270 --> 00:10:43,530
identify that as an error because now we

252
00:10:49,250 --> 00:10:47,280
look at which circles have have an odd

253
00:10:50,810 --> 00:10:49,260
number of ones and there's only one that

254
00:10:54,050 --> 00:10:50,820
has an odd number of ones and it's this

255
00:10:56,030 --> 00:10:54,060
one and therefore we know that all the

256
00:10:58,760 --> 00:10:56,040
bits that are bad are only in this

257
00:11:00,050 --> 00:10:58,770
circle so it's it it can't be an

258
00:11:01,280 --> 00:11:00,060
intersection with another circle it's

259
00:11:04,220 --> 00:11:01,290
only this one so that's got to be the

260
00:11:07,370 --> 00:11:04,230
bad bit and in fact just to show another

261
00:11:10,190 --> 00:11:07,380
example if instead this bit had flipped

262
00:11:11,240 --> 00:11:10,200
we would do the same decoding algorithm

263
00:11:13,340 --> 00:11:11,250

we discovered that there were two

264
00:11:15,530 --> 00:11:13,350
circles that had an odd number of bits

265
00:11:17,420 --> 00:11:15,540
and so the bit that's a uniquely at the

266
00:11:19,160 --> 00:11:17,430
intersection of those two circles has to

267
00:11:21,500 --> 00:11:19,170
be the one that's the it has the error

268
00:11:23,510 --> 00:11:21,510
so this is very very powerful to give me

269
00:11:25,550 --> 00:11:23,520
idea how powerful this is the kinds of

270
00:11:29,030 --> 00:11:25,560
codes that we use which are not this

271
00:11:32,210 --> 00:11:29,040
simple in the deep space network are so

272
00:11:33,890 --> 00:11:32,220
powerful that it's as if we had 10 times

273
00:11:36,680 --> 00:11:33,900
the communications performance by using

274
00:11:39,320 --> 00:11:36,690
these codes we can we can get the same

275
00:11:41,660 --> 00:11:39,330
bits per second down for 1/10 the power

276
00:11:44,090 --> 00:11:41,670
or a smaller antenna or something and

277
00:11:46,280 --> 00:11:44,100
that's huge because if we didn't have

278
00:11:48,020 --> 00:11:46,290
this we'd have to have for example 10

279
00:11:53,360 --> 00:11:48,030
times the number of DSN antennas to get

280
00:11:55,190 --> 00:11:53,370
the same overall performance we also do

281
00:11:56,990 --> 00:11:55,200
a lot of data compression we don't want

282
00:11:58,490 --> 00:11:57,000
to send anything from our spacecraft in

283
00:12:01,100 --> 00:11:58,500
deep space that we don't absolutely have

284
00:12:04,550 --> 00:12:01,110
to and I like to think of data

285
00:12:07,190 --> 00:12:04,560
compression as something like texting so

286
00:12:08,720 --> 00:12:07,200
here's a text message and you all can

287
00:12:12,920 --> 00:12:08,730
read this basically if you have children

288
00:12:15,020 --> 00:12:12,930

at home and what that says is for your

289
00:12:17,300 --> 00:12:15,030
information Joe will be right back to

290
00:12:18,860 --> 00:12:17,310
help later but look at the difference in

291
00:12:21,830 --> 00:12:18,870
the length of those care at the of those

292
00:12:24,170 --> 00:12:21,840
sentences if you do the calculation it's

293
00:12:26,660 --> 00:12:24,180
a compression ratio of 39 characters to

294
00:12:28,130 --> 00:12:26,670
24 we only sent 24 of you

295
00:12:30,380 --> 00:12:28,140
39 characters or it actually was a

296
00:12:33,290 --> 00:12:30,390
different set of 24 that's almost a

297
00:12:35,090 --> 00:12:33,300
factor of two to one we got by with

298
00:12:37,130 --> 00:12:35,100
sending only half the characters and we

299
00:12:39,530 --> 00:12:37,140
got the entire content of the message

300
00:12:42,320 --> 00:12:39,540
understood on the ground that's very

301
00:12:43,280 --> 00:12:42,330
powerful it turns out that the images

302
00:12:46,010 --> 00:12:43,290
that we take with our spacecraft

303
00:12:48,470 --> 00:12:46,020
ethically can be compressed ten to one

304
00:12:51,170 --> 00:12:48,480
so there's another factor of ten

305
00:12:54,680 --> 00:12:51,180
just like the coding it's just as

306
00:12:56,300 --> 00:12:54,690
powerful it turns out that if you have

307
00:12:58,550 --> 00:12:56,310
other kinds of data types that have even

308
00:13:00,680 --> 00:12:58,560
more redundancy in them more structure

309
00:13:02,660 --> 00:13:00,690
things like videos because videos are

310
00:13:04,130 --> 00:13:02,670
subsequent frames of images and so not

311
00:13:05,600 --> 00:13:04,140
only can the image be compressed but

312
00:13:08,060 --> 00:13:05,610
they don't change much between frames

313
00:13:10,820 --> 00:13:08,070

and that's important or hyperspectral

314
00:13:13,070 --> 00:13:10,830
images these are images or each pixel is

315
00:13:14,900 --> 00:13:13,080
actually a spectrogram that tells you

316
00:13:16,670 --> 00:13:14,910
for instance what kind of material we're

317
00:13:19,040 --> 00:13:16,680
looking at on the surface of a planet or

318
00:13:21,590 --> 00:13:19,050
a moon those things can be compressed

319
00:13:25,190 --> 00:13:21,600
more than ten to one and oops

320
00:13:26,870 --> 00:13:25,200
went a little too fast there are other

321
00:13:29,240 --> 00:13:26,880
things we can do that even do better

322
00:13:31,220 --> 00:13:29,250
compression ratios for instance as we

323
00:13:32,870 --> 00:13:31,230
navigate our spacecraft in deep space if

324
00:13:35,030 --> 00:13:32,880
we can do that without talking to the

325
00:13:38,020 --> 00:13:35,040
earth and just send the answer I'm going

326
00:13:40,580 --> 00:13:38,030
to be here tomorrow that's a huge

327
00:13:42,200 --> 00:13:40,590
compression of what needs to be sent we

328
00:13:43,820 --> 00:13:42,210
can also for instance take images but

329
00:13:45,740 --> 00:13:43,830
only send back the interesting parts of

330
00:13:48,800 --> 00:13:45,750
them we've done this with missions and

331
00:13:50,630 --> 00:13:48,810
we can in the in the limit we can answer

332
00:13:51,890 --> 00:13:50,640
some scientific questions on the

333
00:13:54,590 --> 00:13:51,900
spacecraft and only send the yes-or-no

334
00:13:57,020 --> 00:13:54,600
answer as opposed to tons and tons of

335
00:14:01,340 --> 00:13:57,030
information and we have research going

336
00:14:04,790 --> 00:14:01,350
on in all these areas at the moment so

337
00:14:06,620 --> 00:14:04,800
how well have we done since we started

338
00:14:10,310 --> 00:14:06,630

doing communication with deep space in

339
00:14:12,350 --> 00:14:10,320
the late 50s we have done phenomenally

340
00:14:14,630 --> 00:14:12,360
well and what this chart shows it's a

341
00:14:16,910 --> 00:14:14,640
little bit hard to understand because

342
00:14:18,080 --> 00:14:16,920
what I've done is normalized everything

343
00:14:20,120 --> 00:14:18,090
by the distance squared

344
00:14:21,650 --> 00:14:20,130
we've taken every point in this curve

345
00:14:23,720 --> 00:14:21,660
which is represented by a particular

346
00:14:26,450 --> 00:14:23,730
spacecraft communicating with the earth

347
00:14:29,510 --> 00:14:26,460
but we've in our minds we've moved that

348
00:14:32,150 --> 00:14:29,520
spacecraft to Jupiter so they all have

349
00:14:33,530 --> 00:14:32,160
the same distance squared so all that's

350
00:14:36,080 --> 00:14:33,540
left is everything else in those

351
00:14:39,500 --> 00:14:36,090
equations how big are the antennas how

352
00:14:40,550 --> 00:14:39,510
powerful the transmitters how efficient

353
00:14:41,690 --> 00:14:40,560
of the lowest

354
00:14:44,860 --> 00:14:41,700
fires how good are the codes and

355
00:14:46,910 --> 00:14:44,870
compression and if you just look at this

356
00:14:49,480 --> 00:14:46,920
for things that are under our control

357
00:14:51,680 --> 00:14:49,490
and distance isn't we have improved

358
00:14:57,440 --> 00:14:51,690
communications by a factor of 10 to the

359
00:14:59,570 --> 00:14:57,450
13th now that's a huge number we had to

360
00:15:01,190 --> 00:14:59,580
report this to Congress a couple years

361
00:15:02,780 --> 00:15:01,200
ago so we had to come up with a way for

362
00:15:06,280 --> 00:15:02,790
Congress to understand how big a number

363
00:15:09,500 --> 00:15:06,290

this was well we ended up telling them

364
00:15:12,350 --> 00:15:09,510
was that if you took all the words in

365
00:15:13,730 --> 00:15:12,360
the Library of Congress and added them

366
00:15:17,269 --> 00:15:13,740
up from all the books that are there and

367
00:15:23,120 --> 00:15:17,279
all the magazines and so forth twice you

368
00:15:24,290 --> 00:15:23,130
came up with 10 to the 13th so we do

369
00:15:26,210 --> 00:15:24,300
more than communicate with our

370
00:15:27,680 --> 00:15:26,220
spacecraft we also have to steer them we

371
00:15:29,120 --> 00:15:27,690
and this is an example of the dawn

372
00:15:32,120 --> 00:15:29,130
spacecraft is coming to the end of its

373
00:15:34,700 --> 00:15:32,130
mission but it launched from Earth it

374
00:15:36,710 --> 00:15:34,710
had a Mars flyby zoomed around a few

375
00:15:39,440 --> 00:15:36,720
times and got to it's it's pair of

376
00:15:41,180 --> 00:15:39,450
asteroids we had to know where it was we

377
00:15:44,710 --> 00:15:41,190
had to understand the direction it was

378
00:15:49,280 --> 00:15:44,720
going and this is hard to do because

379
00:15:52,579 --> 00:15:49,290
there is no GPS in deep space we can't

380
00:15:54,500 --> 00:15:52,589
do it this way so what do we do we

381
00:15:55,670 --> 00:15:54,510
actually do most of the navigation

382
00:15:57,230 --> 00:15:55,680
trying to understand where the

383
00:15:59,390 --> 00:15:57,240
spacecraft is and what direction it's

384
00:16:01,520 --> 00:15:59,400
going by looking at the radio signal and

385
00:16:03,680 --> 00:16:01,530
there are three main things that we do

386
00:16:06,980 --> 00:16:03,690
some are easy to understand some not as

387
00:16:09,230 --> 00:16:06,990
easy ranging what we do is we send a

388
00:16:11,360 --> 00:16:09,240

signal to the spacecraft and it

389
00:16:13,550 --> 00:16:11,370
immediately sends it back we measure the

390
00:16:15,260 --> 00:16:13,560
time and that gives us it that gives us

391
00:16:17,500 --> 00:16:15,270
a measure how far away the spacecraft is

392
00:16:20,510 --> 00:16:17,510
that's an easy one

393
00:16:22,640 --> 00:16:20,520
Doppler Doppler is a change in frequency

394
00:16:23,660 --> 00:16:22,650
that's the result of relative motion

395
00:16:25,760 --> 00:16:23,670
between the transmitter and receiver

396
00:16:27,470 --> 00:16:25,770
it's the same effect you have in a fire

397
00:16:30,260 --> 00:16:27,480
engine goes by you on the freeway and

398
00:16:32,290 --> 00:16:30,270
you hear that drop of signal is the drop

399
00:16:35,780 --> 00:16:32,300
of the frequency as it goes by and we

400
00:16:36,890 --> 00:16:35,790
look at at the Doppler measure the

401
00:16:38,900 --> 00:16:36,900
Doppler and the signal that the

402
00:16:40,340 --> 00:16:38,910
difference between the frequency we know

403
00:16:41,720 --> 00:16:40,350
that was transmitted and what we

404
00:16:43,280 --> 00:16:41,730
actually received and that tells us

405
00:16:46,850 --> 00:16:43,290
something about the relative motion of

406
00:16:49,250 --> 00:16:46,860
the spacecraft and the DSN and the third

407
00:16:51,230 --> 00:16:49,260
thing we do is something that's called

408
00:16:53,690 --> 00:16:51,240
Delta difference one-way ranging or

409
00:16:54,439 --> 00:16:53,700
delta door don't worry about that what

410
00:16:57,169 --> 00:16:54,449
it basically

411
00:16:59,840 --> 00:16:57,179
it's using a pair of DSN antennas to

412
00:17:01,549 --> 00:16:59,850
triangulate so have them both look at

413
00:17:03,829 --> 00:17:01,559

the spacecraft and very precisely

414
00:17:07,009 --> 00:17:03,839
measure the angle in that triangle and

415
00:17:09,949 --> 00:17:07,019
that tells us something about again the

416
00:17:12,230 --> 00:17:09,959
distance but also the distance relative

417
00:17:14,779 --> 00:17:12,240
to that baseline that between the two

418
00:17:16,309 --> 00:17:14,789
antennas these are the three main types

419
00:17:18,889 --> 00:17:16,319
of information we use to navigate our

420
00:17:20,179 --> 00:17:18,899
spacecraft we also supplement this with

421
00:17:22,039 --> 00:17:20,189
sensors that are onboard the spacecraft

422
00:17:24,049 --> 00:17:22,049
for instance if the spacecraft has a

423
00:17:26,539 --> 00:17:24,059
good camera onboard and it can

424
00:17:28,220 --> 00:17:26,549
photograph say the asteroid to which

425
00:17:29,990 --> 00:17:28,230
it's going against the stellar

426
00:17:32,750 --> 00:17:30,000
background it's sort of the same thing

427
00:17:35,240 --> 00:17:32,760
as how we navigated sailing ships in the

428
00:17:39,230 --> 00:17:35,250
Age of Exploration on earth and we can

429
00:17:41,029 --> 00:17:39,240
do the same thing in space last thing I

430
00:17:44,060 --> 00:17:41,039
want to talk about is the way we use the

431
00:17:45,919 --> 00:17:44,070
DSN as a science instrument directly so

432
00:17:48,080 --> 00:17:45,929
if we have a spacecraft in this case I'm

433
00:17:50,240 --> 00:17:48,090
showing Cassini sitting above the ring

434
00:17:52,669 --> 00:17:50,250
plane and Saturn and transmitting its

435
00:17:57,680 --> 00:17:52,679
radio signal through the Rings to the

436
00:18:00,320 --> 00:17:57,690
DSN we measure various perturbations in

437
00:18:02,210 --> 00:18:00,330
that signal that changes relative to

438
00:18:03,950 --> 00:18:02,220

what it should have done if they want to

439
00:18:07,009 --> 00:18:03,960
learn to any objects or anything in the

440
00:18:08,840 --> 00:18:07,019
way we you look at the amplitude of the

441
00:18:11,659 --> 00:18:08,850
signal to see how it how it fluctuates

442
00:18:13,970 --> 00:18:11,669
as the signal traverses things we look

443
00:18:15,830 --> 00:18:13,980
at wobble in the spacecraft and we look

444
00:18:17,389 --> 00:18:15,840
at the frequency deviation and this

445
00:18:19,399 --> 00:18:17,399
tells us a whole bunch of things about

446
00:18:23,180 --> 00:18:19,409
what is between the spacecraft and the

447
00:18:25,279 --> 00:18:23,190
DSN this allows us to study rings and

448
00:18:26,990 --> 00:18:25,289
particles in the path most of what we

449
00:18:29,210 --> 00:18:27,000
know about Saturn's rings including this

450
00:18:32,960 --> 00:18:29,220
particular image of the direct results

451
00:18:35,720 --> 00:18:32,970
of DSN science not photography we study

452
00:18:37,460 --> 00:18:35,730
atmospheres of planets again as as the

453
00:18:41,750 --> 00:18:37,470
spacecraft for instance continues and

454
00:18:43,129 --> 00:18:41,760
goes behind Saturn the beam actually

455
00:18:46,250 --> 00:18:43,139
goes through the atmosphere of Saturn

456
00:18:47,870 --> 00:18:46,260
and as it as it glances we can actually

457
00:18:50,060 --> 00:18:47,880
look at the beam transfer Traverse

458
00:18:52,340 --> 00:18:50,070
different altitudes in the atmosphere so

459
00:18:54,620 --> 00:18:52,350
we can get a measure of the density

460
00:18:57,100 --> 00:18:54,630
versus versus altitude in the atmosphere

461
00:18:59,629 --> 00:18:57,110
we learned about the interiors of bodies

462
00:19:01,430 --> 00:18:59,639
and we do that by looking at how the

463
00:19:02,750 --> 00:19:01,440

gravity in some of these irregular

464
00:19:04,879 --> 00:19:02,760
bodies affects the motion of the

465
00:19:06,649 --> 00:19:04,889
spacecraft this is how we know for

466
00:19:07,970 --> 00:19:06,659
instance there's a liquid ocean under

467
00:19:09,409 --> 00:19:07,980
the surface of Europa

468
00:19:15,010 --> 00:19:09,419
not because we found it some other way

469
00:19:20,740 --> 00:19:18,409
we have our challenges and that is

470
00:19:23,299 --> 00:19:20,750
although d squared isn't going to change

471
00:19:24,620 --> 00:19:23,309
the things that we send into space are

472
00:19:25,789 --> 00:19:24,630
getting better and better the

473
00:19:28,039 --> 00:19:25,799
instruments are getting better and

474
00:19:30,650 --> 00:19:28,049
better and we want to get more and more

475
00:19:33,080 --> 00:19:30,660
data back from them and when we do sort

476
00:19:35,600 --> 00:19:33,090
of a market analysis of this every year

477
00:19:37,730 --> 00:19:35,610
we look at 30 years into the future and

478
00:19:39,620 --> 00:19:37,740
we've tried to forecast as best as we

479
00:19:41,539 --> 00:19:39,630
can what missions might fly in that

480
00:19:44,780 --> 00:19:41,549
timeframe based on a constrained NASA

481
00:19:46,070 --> 00:19:44,790
budget and what kinds of data rates

482
00:19:48,560 --> 00:19:46,080
they're gonna want to get back from deep

483
00:19:51,080 --> 00:19:48,570
space and what you see here is a family

484
00:19:52,760 --> 00:19:51,090
of curves each one represents a

485
00:19:54,919 --> 00:19:52,770
different scenario different set of

486
00:19:56,990 --> 00:19:54,929
missions that might fly but they all

487
00:19:59,390 --> 00:19:57,000
have this upward slope and the upward

488
00:20:01,549 --> 00:19:59,400

slope is about a factor of 10 in bits

489
00:20:03,400 --> 00:20:01,559
per second per decade that's how much

490
00:20:06,470 --> 00:20:03,410
better we have to get on that 10 to the

491
00:20:08,510 --> 00:20:06,480
10 to the 13th curve every 10 years we

492
00:20:10,909 --> 00:20:08,520
have to go 10 to the 14 10 to the 15th

493
00:20:14,270 --> 00:20:10,919
and so forth just to keep up with our

494
00:20:16,250 --> 00:20:14,280
mission designers want to go and one of

495
00:20:19,190 --> 00:20:16,260
the things we're gonna be doing to help

496
00:20:21,289 --> 00:20:19,200
that is adding optical communications to

497
00:20:24,830 --> 00:20:21,299
the dsm communicate with photons on

498
00:20:26,539 --> 00:20:24,840
laser beams we're actually gonna be

499
00:20:29,000 --> 00:20:26,549
demonstrating this in deep space for the

500
00:20:31,100 --> 00:20:29,010
first time on the psychie mission which

501
00:20:34,460 --> 00:20:31,110
goes to the metal asteroid psyche in the

502
00:20:37,549 --> 00:20:34,470
main belt launches in 2022 it will carry

503
00:20:41,150 --> 00:20:37,559
a deep-space optical communications

504
00:20:43,460 --> 00:20:41,160
terminal on it for this demonstration

505
00:20:45,350 --> 00:20:43,470
we're gonna use the Palomar 200 inch

506
00:20:48,440 --> 00:20:45,360
optical telescope the Astronomy

507
00:20:50,030 --> 00:20:48,450
telescope as a receiver but we won't be

508
00:20:52,520 --> 00:20:50,040
able to do that afterward well have

509
00:20:53,990 --> 00:20:52,530
demonstrated the technology but to do

510
00:20:55,880 --> 00:20:54,000
this operationally we can't keep

511
00:20:58,280 --> 00:20:55,890
borrowing somebody's optical telescope

512
00:21:00,080 --> 00:20:58,290
we have to do something else so what

513
00:21:03,430 --> 00:21:00,090

we're going to do as depicted in this

514
00:21:06,080 --> 00:21:03,440
image is we're gonna add spherical

515
00:21:10,640 --> 00:21:06,090
optical mirrors to the inner eight

516
00:21:13,430 --> 00:21:10,650
meters of a 34 meter antenna if actually

517
00:21:16,190 --> 00:21:13,440
just started this project will place a

518
00:21:20,750 --> 00:21:16,200
photon counting optical detector at the

519
00:21:23,480 --> 00:21:20,760
apex which is this structure up here so

520
00:21:27,470 --> 00:21:23,490
the light will come in and bounce off go

521
00:21:30,440 --> 00:21:27,480
to the detector and we'll actually use a

522
00:21:32,300 --> 00:21:30,450
separate much smaller telescope to send

523
00:21:33,920 --> 00:21:32,310
information back to the spacecraft so

524
00:21:38,300 --> 00:21:33,930
we'll have a two-way length but using

525
00:21:49,480 --> 00:21:38,310
two different antennas and with that I

526
00:21:56,740 --> 00:21:53,080
all right thanks les okay well as you

527
00:21:57,970 --> 00:21:56,750
heard from les NASA anticipates that our

528
00:21:59,620 --> 00:21:57,980
spacecraft are going to be sending an

529
00:22:03,100 --> 00:21:59,630
ever increasing amount of data over the

530
00:22:06,310 --> 00:22:03,110
next several decades and so that means

531
00:22:07,750 --> 00:22:06,320
one thing we need more bandwidth so our

532
00:22:09,880 --> 00:22:07,760
next speaker is going to tell you about

533
00:22:12,040 --> 00:22:09,890
an important part of how we're going to

534
00:22:14,049 --> 00:22:12,050
address that challenge please welcome

535
00:22:24,440 --> 00:22:14,059
the manager of the deep-space networks

536
00:22:29,820 --> 00:22:27,720
thank you yeah

537
00:22:30,870 --> 00:22:29,830
so I'm gonna talk to you oops wrong way

538
00:22:32,580 --> 00:22:30,880

there we go

539
00:22:33,990 --> 00:22:32,590
so I'm gonna talk to you about the DSN

540
00:22:35,730 --> 00:22:34,000
aperture enhancement project which is

541
00:22:38,790 --> 00:22:35,740
one of the ways that we're going to deal

542
00:22:43,920 --> 00:22:38,800
with the ever increasing demands on the

543
00:22:47,160 --> 00:22:43,930
DSN so DSN aperture enhancement project

544
00:22:49,400 --> 00:22:47,170
or dep as you'll hear me refer to it is

545
00:22:52,620 --> 00:22:49,410
going to add capabilities to the DSN

546
00:22:54,210 --> 00:22:52,630
we're going to construct a new 34 meter

547
00:22:55,650 --> 00:22:54,220
beam wave got antennas at all of our

548
00:23:00,360 --> 00:22:55,660
complexes and at the end of the project

549
00:23:02,480 --> 00:23:00,370
we will end up with four new r4 34 meter

550
00:23:05,100 --> 00:23:02,490
beam waveguide antennas at each complex

551
00:23:06,930 --> 00:23:05,110
which not only gives us additional

552
00:23:08,910 --> 00:23:06,940
apertures additional antennas that can

553
00:23:10,650 --> 00:23:08,920
be scheduled but it also gives us the

554
00:23:13,710 --> 00:23:10,660
capability to array those four antennas

555
00:23:16,260 --> 00:23:13,720
which will provide capability similar to

556
00:23:21,210 --> 00:23:16,270
the 70-meter antenna as a backup to that

557
00:23:23,640 --> 00:23:21,220
limited resource so Diep started back in

558
00:23:26,160 --> 00:23:23,650
2009 with a construction of two new

559
00:23:28,260 --> 00:23:26,170
antennas at the Canberra complex those

560
00:23:30,120 --> 00:23:28,270
two antennas were delivered in 2014 and

561
00:23:32,090 --> 00:23:30,130
2016 and you can see some pretty

562
00:23:35,550 --> 00:23:32,100
pictures of our brand new antennas there

563
00:23:37,500 --> 00:23:35,560

in 2016 we broke ground on the next set

564
00:23:38,970 --> 00:23:37,510
of antennas at the madrid complex and

565
00:23:40,680 --> 00:23:38,980
those are currently under construction

566
00:23:42,840 --> 00:23:40,690
and I'm going to give you a little bit

567
00:23:45,810 --> 00:23:42,850
of a status update on those in a couple

568
00:23:48,390 --> 00:23:45,820
minutes and then we've just kicked off

569
00:23:49,950 --> 00:23:48,400
the next antenna which will be built at

570
00:23:53,460 --> 00:23:49,960
the Goldstone complex and delivered in

571
00:23:57,770 --> 00:23:53,470
2024 and then the final antenna will be

572
00:24:00,180 --> 00:23:57,780
built at Canberra and delivered in 2026

573
00:24:01,740 --> 00:24:00,190
so this is kind of a busy chart but this

574
00:24:04,560 --> 00:24:01,750
talks about the rollout plan for the

575
00:24:06,420 --> 00:24:04,570
entire project and so you can see each

576
00:24:09,120 --> 00:24:06,430
one of these boxes represents one of the

577
00:24:11,280 --> 00:24:09,130
complexes and up at the top you can see

578
00:24:12,600 --> 00:24:11,290
the beam waveguide and tennis and all

579
00:24:13,710 --> 00:24:12,610
the ones in the little boxes are the

580
00:24:16,970 --> 00:24:13,720
ones that we're developing and

581
00:24:19,560 --> 00:24:16,980
delivering now so in addition to adding

582
00:24:21,360 --> 00:24:19,570
these antennas you can see some more

583
00:24:22,950 --> 00:24:21,370
information up here shows that we're

584
00:24:25,260 --> 00:24:22,960
adding different frequencies so we'll be

585
00:24:26,730 --> 00:24:25,270
adding additional frequencies to some of

586
00:24:29,130 --> 00:24:26,740
these antennas and other ones will be

587
00:24:32,130 --> 00:24:29,140
delivered with higher power transmitters

588
00:24:34,050 --> 00:24:32,140

and all of these things together help

589
00:24:36,710 --> 00:24:34,060
increase the capabilities of the network

590
00:24:40,340 --> 00:24:38,720
so I keep talking about this 34 meter

591
00:24:42,950 --> 00:24:40,350
beam wave got antenna let me tell you a

592
00:24:44,720 --> 00:24:42,960
little bit about what I'm talking about

593
00:24:46,730 --> 00:24:44,730
so I like to start at the bottom so down

594
00:24:48,590 --> 00:24:46,740
here at the bottom we have the pedestal

595
00:24:51,440 --> 00:24:48,600
room it's a concrete foundation in a

596
00:24:54,620 --> 00:24:51,450
room where we can house the microwave

597
00:24:56,690 --> 00:24:54,630
transmitter and receiver electronics and

598
00:24:59,330 --> 00:24:56,700
then on top of that we have a steel

599
00:25:01,880 --> 00:24:59,340
support structure that not only supports

600
00:25:04,670 --> 00:25:01,890
the reflector but actually provides the

601
00:25:07,670 --> 00:25:04,680
motion in both the azimuth direction and

602
00:25:10,220 --> 00:25:07,680
in elevation and then of course at the

603
00:25:13,160 --> 00:25:10,230
top we have the 34 meter dish which is

604
00:25:15,290 --> 00:25:13,170
then why we call it 34 meters it's a

605
00:25:18,710 --> 00:25:15,300
large dish not quite as big as the 70

606
00:25:21,590 --> 00:25:18,720
meter but the way that this works is the

607
00:25:26,360 --> 00:25:21,600
large dish listens to space in it hits

608
00:25:28,310 --> 00:25:26,370
the radio signal and it focuses that

609
00:25:30,140 --> 00:25:28,320
energy up on the sub reflector which

610
00:25:32,570 --> 00:25:30,150
then in turn bounces it through a series

611
00:25:34,700 --> 00:25:32,580
of mirrors down into the pedestal where

612
00:25:36,080 --> 00:25:34,710
our electronics are and one of the key

613
00:25:37,520 --> 00:25:36,090

things that makes the beam waveguide

614
00:25:40,400 --> 00:25:37,530
antenna different from the some of the

615
00:25:42,830 --> 00:25:40,410
other designs is it takes all the

616
00:25:44,960 --> 00:25:42,840
electronics and the electronic feeds and

617
00:25:48,110 --> 00:25:44,970
puts them down here in a stationary room

618
00:25:50,420 --> 00:25:48,120
which is much easier to maintain you've

619
00:25:52,880 --> 00:25:50,430
got room to upgrade things and it takes

620
00:25:55,100 --> 00:25:52,890
them out of the tipping structure so you

621
00:25:59,480 --> 00:25:55,110
don't have to design them to move with

622
00:26:01,370 --> 00:25:59,490
the rest of the antenna so let's talk

623
00:26:02,840 --> 00:26:01,380
about Madrid I'll talk about a little

624
00:26:04,640 --> 00:26:02,850
bit of the process of how we build these

625
00:26:06,530 --> 00:26:04,650
antennas so the first thing we need to

626
00:26:08,000 --> 00:26:06,540
do is dig a big hole because this

627
00:26:11,600 --> 00:26:08,010
pedestal room actually resides

628
00:26:14,450 --> 00:26:11,610
underground so in Spain we actually used

629
00:26:17,480 --> 00:26:14,460
explosives to blast out this big hole

630
00:26:19,370 --> 00:26:17,490
and then we built a foundation so that

631
00:26:21,320 --> 00:26:19,380
foundation is about a meter thick of

632
00:26:23,360 --> 00:26:21,330
concrete you can see these are the

633
00:26:25,880 --> 00:26:23,370
people pouring the concrete this day it

634
00:26:28,220 --> 00:26:25,890
actually took 50 trucks of concrete to

635
00:26:31,580 --> 00:26:28,230
fill just the foundation level just the

636
00:26:33,440 --> 00:26:31,590
floor so after you let that cure you

637
00:26:35,960 --> 00:26:33,450
then build up the walls the walls are

638
00:26:39,530 --> 00:26:35,970

just under a meter thick but it takes

639
00:26:43,250 --> 00:26:39,540
two separate days pouring to to achieve

640
00:26:44,480 --> 00:26:43,260
the walls at the proper height and then

641
00:26:47,420 --> 00:26:44,490
once you do that you pour a concrete

642
00:26:49,220 --> 00:26:47,430
roof the roof is not quite as thick as

643
00:26:50,450 --> 00:26:49,230
the foundation but it still took 31

644
00:26:52,460 --> 00:26:50,460
trucks to pour the roof

645
00:26:55,970 --> 00:26:52,470
there's antennae and you can see a

646
00:26:57,380 --> 00:26:55,980
person here for a height reference

647
00:26:59,510 --> 00:26:57,390
once you're done pouring all that

648
00:27:00,800 --> 00:26:59,520
concrete we backfill the area and then

649
00:27:04,610 --> 00:27:00,810
you can start building the antenna on

650
00:27:06,320 --> 00:27:04,620
top of it so the first thing we do at

651
00:27:09,410 --> 00:27:06,330
that point is to put in the azimuth

652
00:27:12,350 --> 00:27:09,420
track so this is what the antenna

653
00:27:15,800 --> 00:27:12,360
actually sits on and rotates around and

654
00:27:17,600 --> 00:27:15,810
so this is a really precise installation

655
00:27:20,720 --> 00:27:17,610
we need to make sure it's well aligned

656
00:27:22,820 --> 00:27:20,730
and perfectly smooth to allow for the

657
00:27:24,830 --> 00:27:22,830
motion we need on the antenna and then

658
00:27:26,480 --> 00:27:24,840
we can start building up the actual

659
00:27:31,160 --> 00:27:26,490
structure including the beam waveguide

660
00:27:34,310 --> 00:27:31,170
itself so here we see the steel base

661
00:27:36,380 --> 00:27:34,320
frame structure and the the waveguide

662
00:27:39,050 --> 00:27:36,390
itself going up built up onto the

663
00:27:40,580 --> 00:27:39,060

pedestal and at the same time we start

664
00:27:42,500 --> 00:27:40,590
building the reflector structure but the

665
00:27:44,870 --> 00:27:42,510
reflector is built up of a lot of steel

666
00:27:46,310 --> 00:27:44,880
parts and so it doesn't make sense to

667
00:27:48,170 --> 00:27:46,320
build it on top they build it on the

668
00:27:50,360 --> 00:27:48,180
side where they can put all those pieces

669
00:27:53,720 --> 00:27:50,370
together they bolted together they weld

670
00:27:55,550 --> 00:27:53,730
it together and and then they bring in a

671
00:27:58,280 --> 00:27:55,560
very large crane and they lift it and

672
00:27:59,960 --> 00:27:58,290
install it on top and actually we are

673
00:28:01,250 --> 00:27:59,970
right now preparing for that first lift

674
00:28:04,520 --> 00:28:01,260
in Madrid which is scheduled to happen

675
00:28:05,930 --> 00:28:04,530
next week so we're busy measuring and

676
00:28:07,730 --> 00:28:05,940
doing the final preparations for that

677
00:28:09,800 --> 00:28:07,740
which is very exciting because once it

678
00:28:11,510 --> 00:28:09,810
gets up there on top that's when you can

679
00:28:12,920 --> 00:28:11,520
start installing the panels in the sub

680
00:28:14,780 --> 00:28:12,930
reflector you can start installing the

681
00:28:16,370 --> 00:28:14,790
electronics and all the facilities

682
00:28:19,010 --> 00:28:16,380
that's necessary to support these

683
00:28:23,090 --> 00:28:19,020
antennas and and test it and bring it

684
00:28:25,310 --> 00:28:23,100
into operations so there's lots of

685
00:28:28,010 --> 00:28:25,320
unique challenges in building new 34

686
00:28:30,290 --> 00:28:28,020
meter antennas it's kind of like

687
00:28:32,480 --> 00:28:30,300
building a multi-story building right

688
00:28:34,580 --> 00:28:32,490

it's a huge structure it's got a big

689
00:28:36,950 --> 00:28:34,590
foundation it's got to be analyzed to

690
00:28:40,160 --> 00:28:36,960
support the weight that's going on in

691
00:28:43,190 --> 00:28:40,170
but in the end it's not a building it's

692
00:28:46,220 --> 00:28:43,200
an instrument with very stringent and

693
00:28:48,800 --> 00:28:46,230
precise requirements so that adds a

694
00:28:50,210 --> 00:28:48,810
little bit of an interesting problem

695
00:28:51,950 --> 00:28:50,220
when you're talking about construction

696
00:28:53,900 --> 00:28:51,960
because it's hard to make these things

697
00:28:55,910 --> 00:28:53,910
very precise so there's all sorts of

698
00:28:57,620 --> 00:28:55,920
things that go into the design and then

699
00:28:59,780 --> 00:28:57,630
the assembly of these things on-site to

700
00:29:01,379 --> 00:28:59,790
make sure that we can meet the stringent

701
00:29:04,589 --> 00:29:01,389
Poynting requirements

702
00:29:06,810 --> 00:29:04,599
that once it points at a spacecraft in

703
00:29:09,289 --> 00:29:06,820
deep space that it can track it I can

704
00:29:12,509 --> 00:29:09,299
follow it smoothly and all of the motion

705
00:29:14,940 --> 00:29:12,519
continues to support the the link and

706
00:29:17,069 --> 00:29:14,950
you don't drop the link in addition

707
00:29:20,430 --> 00:29:17,079
they're specially designed electronics

708
00:29:22,739 --> 00:29:20,440
that last talked about some of our low

709
00:29:26,399 --> 00:29:22,749
nose amplifiers to receive these really

710
00:29:28,799 --> 00:29:26,409
weak signals in addition to the cryo

711
00:29:31,649 --> 00:29:28,809
cooled Ella neighs we are the low noise

712
00:29:34,919 --> 00:29:31,659
amplifier sorry what we also have ultra

713
00:29:37,709 --> 00:29:34,929

stable frequency references and then we

714
00:29:40,709 --> 00:29:37,719
have high power transmitters so for

715
00:29:42,690 --> 00:29:40,719
example the DSN could transmit your

716
00:29:45,719 --> 00:29:42,700
cable signal all the way to the surface

717
00:29:47,869 --> 00:29:45,729
of Jupiter right so this is a high power

718
00:29:51,029 --> 00:29:47,879
signal and it comes with some

719
00:29:52,979 --> 00:29:51,039
infrastructure challenges so we need to

720
00:29:55,079 --> 00:29:52,989
make sure to keep these high power

721
00:29:57,269 --> 00:29:55,089
transmitters cool so we have specially

722
00:29:59,069 --> 00:29:57,279
designed HVAC and cooling systems that

723
00:30:00,269 --> 00:29:59,079
all have to get integrated and then of

724
00:30:01,560 --> 00:30:00,279
course once you've launched your

725
00:30:03,209 --> 00:30:01,570
spacecraft do you want to make sure you

726
00:30:05,069 --> 00:30:03,219
get all of the data so everything has to

727
00:30:06,930 --> 00:30:05,079
be reliable going to make sure that the

728
00:30:10,769 --> 00:30:06,940
links all the way from through the

729
00:30:12,419 --> 00:30:10,779
antenna and all the way back to the

730
00:30:16,499 --> 00:30:12,429
through the data collection is very

731
00:30:18,619 --> 00:30:16,509
reliable okay so I'm gonna change gears

732
00:30:23,190 --> 00:30:18,629
really quick les mentioned the optical

733
00:30:24,899 --> 00:30:23,200
comm and the next antenna I said we were

734
00:30:26,699 --> 00:30:24,909
developing out at Goldstone will

735
00:30:28,259 --> 00:30:26,709
actually be the first one to receive an

736
00:30:30,509 --> 00:30:28,269
optical terminal that we're developing

737
00:30:32,489 --> 00:30:30,519
so right now we are in the prototype

738
00:30:34,649 --> 00:30:32,499

phase so in the next couple years we'll

739
00:30:37,109 --> 00:30:34,659
be developing a part of that system and

740
00:30:39,749 --> 00:30:37,119
we will be able to take it out to our

741
00:30:41,579 --> 00:30:39,759
test antenna at Goldstone and test it

742
00:30:43,109 --> 00:30:41,589
out and then take the things we learn

743
00:30:45,599 --> 00:30:43,119
from that prototype development and

744
00:30:49,229 --> 00:30:45,609
apply it to the implementation phase and

745
00:30:51,779 --> 00:30:49,239
we will have we plan to have an

746
00:30:55,589 --> 00:30:51,789
operational optical system at Goldstone

747
00:30:57,749 --> 00:30:55,599
in 2025 and it's kind of an exciting way

748
00:31:00,269 --> 00:30:57,759
to do this because you can take

749
00:31:02,430 --> 00:31:00,279
advantage of all of the infrastructure

750
00:31:04,709 --> 00:31:02,440
that's already there you've already got

751
00:31:07,049 --> 00:31:04,719
all of the foundation the steel

752
00:31:09,119 --> 00:31:07,059
structure all of the motion capabilities

753
00:31:11,489 --> 00:31:09,129
even all of the facilities that are

754
00:31:13,079 --> 00:31:11,499
necessary for a new antenna and so you

755
00:31:14,430 --> 00:31:13,089
can focus your efforts on really

756
00:31:16,380 --> 00:31:14,440
designing

757
00:31:18,930 --> 00:31:16,390
the technical capabilities of these

758
00:31:20,700 --> 00:31:18,940
mirrors and of the system because you

759
00:31:25,049 --> 00:31:20,710
get to install it on an already designed

760
00:31:27,990 --> 00:31:25,059
already existing antenna so that's where

761
00:31:28,799 --> 00:31:28,000
we're going in the future and very

762
00:31:31,049 --> 00:31:28,809
excited about it

763
00:31:33,270 --> 00:31:31,059

so I'm going to leave you now with a

764
00:31:35,130 --> 00:31:33,280
little video I talked a lot about the

765
00:31:36,990 --> 00:31:35,140
construction process of these antennas

766
00:31:38,580 --> 00:31:37,000
and we have a nice time lapse video of

767
00:31:41,520 --> 00:31:38,590
one of the antennas that was built in

768
00:31:43,169 --> 00:31:41,530
Canberra recently and les has put

769
00:31:45,120 --> 00:31:43,179
together a video which I'm gonna show

770
00:31:46,919 --> 00:31:45,130
you right now so you can see kind of how

771
00:31:48,630 --> 00:31:46,929
this really works and the complexities

772
00:31:50,810 --> 00:31:48,640
and the process of how this goes

773
00:32:53,720 --> 00:31:50,820
together

774
00:33:48,389 --> 00:33:04,900
[Music]

775
00:33:54,009 --> 00:33:52,090
all right thanks Amy if you didn't catch

776
00:33:55,750 --> 00:33:54,019
it at the start the the music in that

777
00:33:57,789 --> 00:33:55,760
video was actually performed by our

778
00:34:00,039 --> 00:33:57,799
first speaker les Deutsch he actually

779
00:34:06,700 --> 00:34:00,049
has a post as the official organist at

780
00:34:08,889 --> 00:34:06,710
Caltech so talented guy so while we're

781
00:34:10,210 --> 00:34:08,899
doing a little set change here I want to

782
00:34:11,619 --> 00:34:10,220
talk to you a little bit about what you

783
00:34:14,409 --> 00:34:11,629
see on the screen throughout our show

784
00:34:17,050 --> 00:34:14,419
this is what we like to call DSN now

785
00:34:20,169 --> 00:34:17,060
it's a real-time visualization of the

786
00:34:22,000 --> 00:34:20,179
activity on the Deep Space Network so on

787
00:34:24,010 --> 00:34:22,010
the Left over here you see the three

788
00:34:26,849 --> 00:34:24,020

antenna complexes each one has its own

789
00:34:29,290 --> 00:34:26,859
row in Spain and California and

790
00:34:30,940 --> 00:34:29,300
Australia and for whatever spacecraft

791
00:34:33,129 --> 00:34:30,950
we're talking to at any given time

792
00:34:35,530 --> 00:34:33,139
you'll see some squiggly lines that

793
00:34:38,770 --> 00:34:35,540
represent data coming up and going down

794
00:34:40,149 --> 00:34:38,780
and you can select any of the antennas

795
00:34:42,639 --> 00:34:40,159
you like and on the right it will

796
00:34:44,369 --> 00:34:42,649
display more detailed information about

797
00:34:46,960 --> 00:34:44,379
the mission that we're talking to

798
00:34:49,240 --> 00:34:46,970
including the strength of the signal the

799
00:34:51,040 --> 00:34:49,250
data rate even the wind speed at the

800
00:34:52,990 --> 00:34:51,050
antenna site so it's it's a lot of

801
00:34:56,139 --> 00:34:53,000
really cool info and it's run by the

802
00:34:58,120 --> 00:34:56,149
real data as it's happening so it's

803
00:35:00,640 --> 00:34:58,130
available on any browser including on

804
00:35:03,790 --> 00:35:00,650
mobile so just search for DSN now in

805
00:35:06,309 --> 00:35:03,800
your favorite search engine ok so let's

806
00:35:09,819 --> 00:35:06,319
talk a little bit more about deep space

807
00:35:12,490 --> 00:35:09,829
communications in addition to les and

808
00:35:17,260 --> 00:35:12,500
Amy we are joined by Mike Levesque he

809
00:35:22,130 --> 00:35:20,210
hey Mike you serve as the manager for

810
00:35:26,390 --> 00:35:22,140
service management and operations for

811
00:35:30,170 --> 00:35:26,400
the DSN right so let's talk a bit about

812
00:35:32,150 --> 00:35:30,180
just how many spacecraft the DSN is is

813
00:35:36,440 --> 00:35:32,160

tracking and communicating with it's not

814
00:35:39,230 --> 00:35:36,450
just five or six is it no in the course

815
00:35:43,070 --> 00:35:39,240
of a month we'll track up to 40

816
00:35:45,320 --> 00:35:43,080
spacecraft depends on a monthly basis

817
00:35:49,310 --> 00:35:45,330
but we have quite a few spacecraft in

818
00:35:52,850 --> 00:35:49,320
there really across NASA so of course

819
00:35:55,700 --> 00:35:52,860
JPL spacecraft our favorite but we all

820
00:35:57,560 --> 00:35:55,710
the agencies of NASA have spacecraft in

821
00:36:00,950 --> 00:35:57,570
deep space as well as international

822
00:36:05,780 --> 00:36:00,960
partners Jack's European Space Agency of

823
00:36:09,200 --> 00:36:05,790
course Indian Space Agency Korea's gonna

824
00:36:13,940 --> 00:36:09,210
send up deep-space probes so you know

825
00:36:17,450 --> 00:36:13,950
quite a group of spacecraft there now is

826
00:36:18,980 --> 00:36:17,460
the DSN unless the system that we use to

827
00:36:21,830 --> 00:36:18,990
communicate with the International Space

828
00:36:23,690 --> 00:36:21,840
Station and the satellites that are

829
00:36:25,609 --> 00:36:23,700
orbiting earth studying the planet no

830
00:36:27,560 --> 00:36:25,619
actually although the DSN is extremely

831
00:36:29,270 --> 00:36:27,570
well designed and optimized to track

832
00:36:30,680 --> 00:36:29,280
spacecraft that are very far away

833
00:36:33,109 --> 00:36:30,690
it has trouble of ones that are very

834
00:36:35,090 --> 00:36:33,119
very close and that's because like the

835
00:36:37,070 --> 00:36:35,100
International Space Station if you watch

836
00:36:39,470 --> 00:36:37,080
it come overhead it goes pretty fast and

837
00:36:41,210 --> 00:36:39,480
moving a 70-meter antenna at that speed

838
00:36:43,550 --> 00:36:41,220

is a very difficult thing to do and

839
00:36:46,490 --> 00:36:43,560
maintain the precision so in fact NASA

840
00:36:48,050 --> 00:36:46,500
has three communication networks they're

841
00:36:49,940 --> 00:36:48,060
all managed out of the space

842
00:36:52,760 --> 00:36:49,950
communications and navigation office

843
00:36:54,440 --> 00:36:52,770
scan at NASA headquarters the DSN the

844
00:36:56,870 --> 00:36:54,450
Deep Space Network is one of them there

845
00:36:59,359 --> 00:36:56,880
are two others there's something called

846
00:37:01,670 --> 00:36:59,369
the near Earth Network which is a set of

847
00:37:04,490 --> 00:37:01,680
very small antennas typically between

848
00:37:06,200 --> 00:37:04,500
five and twelve meters there's some 18

849
00:37:08,300 --> 00:37:06,210
meter antennas in the mix that

850
00:37:10,400 --> 00:37:08,310
communicate with a lot of satellites in

851
00:37:12,220 --> 00:37:10,410
low Earth orbit the international space

852
00:37:14,390 --> 00:37:12,230
station is one of the one of the

853
00:37:17,540 --> 00:37:14,400
spacecraft that actually communicate

854
00:37:19,430 --> 00:37:17,550
upward nASA has the third Network which

855
00:37:21,770 --> 00:37:19,440
is called the space network which is a

856
00:37:24,740 --> 00:37:21,780
set of relay spacecraft that's it a

857
00:37:26,240 --> 00:37:24,750
geosynchronous altitude so they stay in

858
00:37:29,190 --> 00:37:26,250
a fixed place over the surface of the

859
00:37:31,170 --> 00:37:29,200
earth as we mentioned before the ISS

860
00:37:33,630 --> 00:37:31,180
actually sends their radio waves upward

861
00:37:35,580 --> 00:37:33,640
and received by those spacecraft and

862
00:37:38,010 --> 00:37:35,590
then relayed back to earth and there's

863
00:37:39,930 --> 00:37:38,020

always one of those in view as the ISS

864
00:37:42,930 --> 00:37:39,940
orbit so they can get communication

865
00:37:44,250 --> 00:37:42,940
whenever they need it so how do you for

866
00:37:47,790 --> 00:37:44,260
the ones that you are talking to much

867
00:37:49,080 --> 00:37:47,800
farther out how do you meet the needs of

868
00:37:50,910 --> 00:37:49,090
all these missions in terms of

869
00:37:53,160 --> 00:37:50,920
scheduling I mean I can imagine that

870
00:37:55,770 --> 00:37:53,170
every mission would like to have a

871
00:37:57,240 --> 00:37:55,780
hotline to earth at any time that it

872
00:37:58,650 --> 00:37:57,250
wants it but that's it's just not

873
00:38:01,200 --> 00:37:58,660
possible right I mean how do you balance

874
00:38:04,140 --> 00:38:01,210
all of yeah that's right you can see we

875
00:38:05,790 --> 00:38:04,150
really only have 12 antennas and of

876
00:38:08,070 --> 00:38:05,800
course we're building new ones and

877
00:38:09,630 --> 00:38:08,080
decommissioning old ones and with those

878
00:38:13,080 --> 00:38:09,640
40 spacecraft is quite a bit of

879
00:38:15,690 --> 00:38:13,090
competition for time so you know back in

880
00:38:18,390 --> 00:38:15,700
the old days you know that was all done

881
00:38:20,700 --> 00:38:18,400
with paper cards on tables and

882
00:38:23,400 --> 00:38:20,710
negotiating every week about who's got

883
00:38:25,350 --> 00:38:23,410
what time slot you know and then you

884
00:38:27,030 --> 00:38:25,360
know thankfully somebody invented

885
00:38:30,390 --> 00:38:27,040
post-its so you know you got to use

886
00:38:34,560 --> 00:38:30,400
post-its which helps a lot but of course

887
00:38:38,810 --> 00:38:34,570
today we use software and we have some a

888
00:38:41,160 --> 00:38:38,820

I assisted software that we can put in

889
00:38:44,430 --> 00:38:41,170
requirements of each of the spacecraft

890
00:38:46,230 --> 00:38:44,440
and develop temporal networks of that

891
00:38:49,950 --> 00:38:46,240
and then construct the schedule from

892
00:38:52,680 --> 00:38:49,960
that and then when there when there are

893
00:38:55,410 --> 00:38:52,690
conflicts and ibly there are we have

894
00:38:57,210 --> 00:38:55,420
some collaboration software that the

895
00:38:59,640 --> 00:38:57,220
schedulers can t get together from the

896
00:39:01,470 --> 00:38:59,650
different missions and negotiate out you

897
00:39:04,410 --> 00:39:01,480
know who gets that time and make trades

898
00:39:06,060 --> 00:39:04,420
based on that so it's it's quite an

899
00:39:07,890 --> 00:39:06,070
endeavor interesting part of that

900
00:39:09,450 --> 00:39:07,900
problem if you look at fares look at DSN

901
00:39:12,720 --> 00:39:09,460
right now there's not a lot of activity

902
00:39:15,120 --> 00:39:12,730
at Madrid the activities in Goldstone

903
00:39:16,640 --> 00:39:15,130
and Canberra the reason for that is when

904
00:39:19,560 --> 00:39:16,650
people send spacecraft into deep space

905
00:39:21,600 --> 00:39:19,570
it's not just uniformly populated across

906
00:39:23,850 --> 00:39:21,610
deep space they tend to want to go to

907
00:39:25,290 --> 00:39:23,860
specific places Mars as a place of

908
00:39:27,570 --> 00:39:25,300
interest there's always a lot of

909
00:39:28,680 --> 00:39:27,580
spacecraft around Mars spacecraft tend

910
00:39:30,750 --> 00:39:28,690
to go to places where there are other

911
00:39:33,300 --> 00:39:30,760
objects to study for the most part not

912
00:39:35,550 --> 00:39:33,310
not unilaterally but that means that

913
00:39:37,740 --> 00:39:35,560

they tend to clump in parts of the sky

914
00:39:39,360 --> 00:39:37,750
and if you think of I'm just you know

915
00:39:40,740 --> 00:39:39,370
going outside with your telescope and

916
00:39:42,690 --> 00:39:40,750
looking at planets you know that

917
00:39:45,089 --> 00:39:42,700
sometimes there's only one planet

918
00:39:46,859 --> 00:39:45,099
you can see and sometimes therefore when

919
00:39:49,710 --> 00:39:46,869
therefore there's a lot more contention

920
00:39:52,920 --> 00:39:49,720
for the DSN and we're doing other things

921
00:39:54,720 --> 00:39:52,930
too in terms of scheduling so Mars is

922
00:39:56,880 --> 00:39:54,730
quite a few spacecraft around Mars today

923
00:40:00,089 --> 00:39:56,890
so we can actually point the antenna at

924
00:40:02,010 --> 00:40:00,099
Mars and communicate simultaneously with

925
00:40:03,780 --> 00:40:02,020
up to four spacecraft with one antenna

926
00:40:06,930 --> 00:40:03,790
because they're separated by frequencies

927
00:40:08,280 --> 00:40:06,940
so and generally we only have one uplink

928
00:40:10,050 --> 00:40:08,290
at a time but that can switch between

929
00:40:12,510 --> 00:40:10,060
those spacecrafts so and we call that

930
00:40:14,730 --> 00:40:12,520
multiple spacecraft per aperture and I

931
00:40:16,349 --> 00:40:14,740
helps a lot you can imagine talking to

932
00:40:18,839 --> 00:40:16,359
four spacecraft rather than one at a

933
00:40:20,760 --> 00:40:18,849
time and I mean some of the new

934
00:40:22,230 --> 00:40:20,770
capabilities you talked about will help

935
00:40:24,569 --> 00:40:22,240
to meet that increasing need as well

936
00:40:26,310 --> 00:40:24,579
right yes of course so we'll have new

937
00:40:30,030 --> 00:40:26,320
apertures which can be added to the

938
00:40:33,450 --> 00:40:30,040

schedule and so we'll have an easier job

939
00:40:34,950 --> 00:40:33,460
on some of the scheduling trouble but

940
00:40:37,829 --> 00:40:34,960
it's kind of interesting actually the

941
00:40:40,770 --> 00:40:37,839
order of construction of the dup

942
00:40:42,300 --> 00:40:40,780
antennas was designed specifically to

943
00:40:44,099 --> 00:40:42,310
meet the needs of spacecraft like les

944
00:40:45,540 --> 00:40:44,109
was saying they're clustered in certain

945
00:40:47,819 --> 00:40:45,550
places which means that at the beginning

946
00:40:49,740 --> 00:40:47,829
of da EP there was a need for additional

947
00:40:51,510 --> 00:40:49,750
apertures down at Canberra

948
00:40:54,270 --> 00:40:51,520
in the southern hemisphere and right now

949
00:40:55,950 --> 00:40:54,280
the Madrid antennas are being built to

950
00:40:58,609 --> 00:40:55,960
support the next set of missions that

951
00:41:02,040 --> 00:40:58,619
are going to Mars in the 2020 timeframe

952
00:41:05,460 --> 00:41:02,050
well so there are these three DSN sites

953
00:41:07,829 --> 00:41:05,470
around the globe and an array but but

954
00:41:10,020 --> 00:41:07,839
you guys all work for the American space

955
00:41:12,510 --> 00:41:10,030
program so how do you work this

956
00:41:13,680 --> 00:41:12,520
collaboration and coordination with the

957
00:41:16,800 --> 00:41:13,690
with all the other countries that are

958
00:41:18,210 --> 00:41:16,810
involved in this global enterprise so we

959
00:41:20,309 --> 00:41:18,220
mentioned before I think might mention

960
00:41:21,630 --> 00:41:20,319
that we track not just NASA spacecraft a

961
00:41:24,270 --> 00:41:21,640
spacecraft from a lot of other countries

962
00:41:27,390 --> 00:41:24,280
and in fact in fact some of those other

963
00:41:29,460 --> 00:41:27,400

countries also have Deep Space Network

964
00:41:33,150 --> 00:41:29,470
light capabilities the European Space

965
00:41:34,380 --> 00:41:33,160
Agency has a similar thing to the Deep

966
00:41:36,180 --> 00:41:34,390
Space Network now though there's only

967
00:41:39,059 --> 00:41:36,190
one antenna at each of three locations

968
00:41:40,589 --> 00:41:39,069
around the world basically what we've

969
00:41:43,890 --> 00:41:40,599
done is we've worked with all the space

970
00:41:47,339 --> 00:41:43,900
agencies of the world and created a set

971
00:41:50,280 --> 00:41:47,349
of standards for communications so that

972
00:41:52,890 --> 00:41:50,290
so that their spacecraft can talk to our

973
00:41:54,930 --> 00:41:52,900
antennas and and our spacecraft can talk

974
00:41:56,520 --> 00:41:54,940
to their antennas they all speak a

975
00:41:58,560 --> 00:41:56,530
similar data system

976
00:42:02,850 --> 00:41:58,570
language and that allows us to do this

977
00:42:05,280 --> 00:42:02,860
cooperative tracking and and and these

978
00:42:07,680 --> 00:42:05,290
these they're super capable and they're

979
00:42:10,290 --> 00:42:07,690
they're gigantic but they're also really

980
00:42:12,810 --> 00:42:10,300
precise you know hide high precision

981
00:42:14,910 --> 00:42:12,820
instruments right and Amy so can you

982
00:42:16,290 --> 00:42:14,920
talk a little bit about some of the ways

983
00:42:19,740 --> 00:42:16,300
that these things are very precisely

984
00:42:21,630 --> 00:42:19,750
engineered and and designed yeah so I

985
00:42:23,070 --> 00:42:21,640
talked a lot about the structure in the

986
00:42:25,190 --> 00:42:23,080
construction of antennas but I didn't

987
00:42:28,050 --> 00:42:25,200
talk too much about the reflector itself

988
00:42:30,450 --> 00:42:28,060

so the reflector is actually made up of

989
00:42:34,560 --> 00:42:30,460
a whole bunch of panels we have nine

990
00:42:37,350 --> 00:42:34,570
rows of panels that are very carefully

991
00:42:40,650 --> 00:42:37,360
designed and built so they are built

992
00:42:43,350 --> 00:42:40,660
with a surface two five thousandth of an

993
00:42:45,330 --> 00:42:43,360
inch that's the thickness of one or two

994
00:42:47,310 --> 00:42:45,340
sheets of paper and so they have to meet

995
00:42:48,840 --> 00:42:47,320
that surface tolerance they all have to

996
00:42:50,520 --> 00:42:48,850
be built to that surface tolerance and

997
00:42:52,020 --> 00:42:50,530
then we install them on the antenna and

998
00:42:54,060 --> 00:42:52,030
then actually once we install them on

999
00:42:55,650 --> 00:42:54,070
the antenna they're all adjustable so we

1000
00:42:58,740 --> 00:42:55,660
go in and do calibration and

1001
00:43:00,840 --> 00:42:58,750
measurements to set these panels exactly

1002
00:43:03,780 --> 00:43:00,850
the way we want them to make sure that

1003
00:43:06,090 --> 00:43:03,790
we have maximized they gain available to

1004
00:43:09,990 --> 00:43:06,100
us so we have a dual shaped system in

1005
00:43:13,560 --> 00:43:10,000
which we can we can really set this up

1006
00:43:22,490 --> 00:43:13,570
to maximize the gain for each of these

1007
00:43:25,710 --> 00:43:22,500
antennas the power in a direction right

1008
00:43:27,270 --> 00:43:25,720
so I wanted to just add to that it turns

1009
00:43:29,160 --> 00:43:27,280
out that the higher the frequencies that

1010
00:43:31,290 --> 00:43:29,170
they were communicating with the harder

1011
00:43:33,120 --> 00:43:31,300
it is to point the antennas and it's

1012
00:43:34,680 --> 00:43:33,130
it's it's saying a lot that these

1013
00:43:36,720 --> 00:43:34,690

antennas originally designed to operate

1014
00:43:38,460 --> 00:43:36,730
it maybe 2 gigahertz are operating

1015
00:43:41,160 --> 00:43:38,470
routinely at thirty two gigahertz today

1016
00:43:42,900 --> 00:43:41,170
but what really surprised me was when we

1017
00:43:44,700 --> 00:43:42,910
did the feasibility studies for adding

1018
00:43:47,670 --> 00:43:44,710
optical dishes to these 34 meter

1019
00:43:50,760 --> 00:43:47,680
antennas it turns out that the pointing

1020
00:43:53,040 --> 00:43:50,770
system is stable enough even for optimal

1021
00:43:56,310 --> 00:43:53,050
frequencies which is really saying a lot

1022
00:43:58,530 --> 00:43:56,320
about the precision and a design so

1023
00:44:02,310 --> 00:43:58,540
speaking of pointing then how do you

1024
00:44:06,000 --> 00:44:02,320
guys manage the the passing of the baton

1025
00:44:08,040 --> 00:44:06,010
so to speak from from antenna complex to

1026
00:44:09,900 --> 00:44:08,050
attend to complex because you know

1027
00:44:11,339 --> 00:44:09,910
you've got a spacecraft

1028
00:44:12,900 --> 00:44:11,349
up in the sky maybe it's a Jupiter and

1029
00:44:15,059 --> 00:44:12,910
so you're tracking Jupiter but Jupiter

1030
00:44:16,559 --> 00:44:15,069
is gonna eventually set and you can't

1031
00:44:19,470 --> 00:44:16,569
see it anymore so how do you how do you

1032
00:44:22,230 --> 00:44:19,480
hand it off to the next we call it

1033
00:44:24,839 --> 00:44:22,240
handoff in fact and so from complex to

1034
00:44:27,150 --> 00:44:24,849
complex you we do handoffs and that's

1035
00:44:29,160 --> 00:44:27,160
both uplink in the downlink and so you

1036
00:44:31,829 --> 00:44:29,170
can't uplink at the same time to that

1037
00:44:34,730 --> 00:44:31,839
spacecraft so we kind of precisely time

1038
00:44:37,020 --> 00:44:34,740

shutting off an uplink at one site and

1039
00:44:39,510 --> 00:44:37,030
activating the uplink at the next site

1040
00:44:41,609 --> 00:44:39,520
and of course you may have some little

1041
00:44:45,349 --> 00:44:41,619
glitches in that usually we're able to

1042
00:44:47,579 --> 00:44:45,359
overcome that and have a continuous

1043
00:44:49,109 --> 00:44:47,589
transmission both an uplink in that

1044
00:44:51,930 --> 00:44:49,119
downlink side even during these

1045
00:44:55,140 --> 00:44:51,940
handovers and we're actually handing

1046
00:44:56,970 --> 00:44:55,150
over for other agencies too so we're not

1047
00:45:02,510 --> 00:44:56,980
the only Deep Space Network there were

1048
00:45:05,609 --> 00:45:02,520
other sites around the globe for ISA has

1049
00:45:07,470 --> 00:45:05,619
three antennas in and JAXA has some

1050
00:45:08,819 --> 00:45:07,480
antennas and we do international

1051
00:45:11,579 --> 00:45:08,829
cooperation with them and are actually

1052
00:45:13,710 --> 00:45:11,589
able to do handoffs with them also and

1053
00:45:16,650 --> 00:45:13,720
also back each other up if we were in

1054
00:45:18,630 --> 00:45:16,660
the same location in the same view well

1055
00:45:19,920 --> 00:45:18,640
in addition to upgrading the technical

1056
00:45:23,460 --> 00:45:19,930
capabilities which we heard about from

1057
00:45:25,260 --> 00:45:23,470
Amy are you guys upgrading I I'm leading

1058
00:45:27,000 --> 00:45:25,270
you somewhere because I you're also

1059
00:45:28,829 --> 00:45:27,010
operating the the operational

1060
00:45:30,900 --> 00:45:28,839
capabilities though I mean can you talk

1061
00:45:32,760 --> 00:45:30,910
a little bit about some of those and you

1062
00:45:35,519 --> 00:45:32,770
it helped to develop this one really

1063
00:45:37,319 --> 00:45:35,529

interesting follow-the-sun idea as well

1064
00:45:38,849 --> 00:45:37,329
can you talk about yeah sure happy to

1065
00:45:40,710 --> 00:45:38,859
talk about follows Sun so what is this

1066
00:45:44,069 --> 00:45:40,720
thing well first of all it is operations

1067
00:45:46,799 --> 00:45:44,079
so you know operations is very important

1068
00:45:48,960 --> 00:45:46,809
to our organization you know all the

1069
00:45:50,910 --> 00:45:48,970
technology the less talked about and the

1070
00:45:52,710 --> 00:45:50,920
antennas that Amy talked about if we

1071
00:45:54,990 --> 00:45:52,720
can't operate them there's no joy right

1072
00:45:57,660 --> 00:45:55,000
there's no happiness the missions are

1073
00:45:59,220 --> 00:45:57,670
not getting their data so operations

1074
00:46:03,000 --> 00:45:59,230
first and foremost is an important part

1075
00:46:04,650 --> 00:46:03,010
of our organization and so to understand

1076
00:46:08,039 --> 00:46:04,660
this fall is something it's good to go

1077
00:46:10,170 --> 00:46:08,049
back say 50 years when in operations of

1078
00:46:12,329 --> 00:46:10,180
the DSN people were dialing in these

1079
00:46:13,950 --> 00:46:12,339
frequencies on receivers and

1080
00:46:17,760 --> 00:46:13,960
transmitters you know you remember

1081
00:46:19,680 --> 00:46:17,770
dialing in our radios right so 50 years

1082
00:46:22,230 --> 00:46:19,690
ago we were doing that in deep space

1083
00:46:25,170 --> 00:46:22,240
network dialing in these frequencies

1084
00:46:26,819 --> 00:46:25,180
if you fast-forward 25 years now

1085
00:46:28,079 --> 00:46:26,829
everything's computer-controlled and

1086
00:46:31,259 --> 00:46:28,089
digitally controlled and we have

1087
00:46:33,450 --> 00:46:31,269
networks and so we're able to take all

1088
00:46:36,599 --> 00:46:33,460

that operations which is at every

1089
00:46:39,089 --> 00:46:36,609
receiver and antenna and consolidating

1090
00:46:41,099 --> 00:46:39,099
into what we call the signal processing

1091
00:46:43,200 --> 00:46:41,109
center and that's when you see you know

1092
00:46:44,670 --> 00:46:43,210
the typical operations room you know

1093
00:46:48,450 --> 00:46:44,680
where everybody's around and it's kind

1094
00:46:49,859 --> 00:46:48,460
of a darkroom and so that's 25 years ago

1095
00:46:51,779 --> 00:46:49,869
and so today we just had our first

1096
00:46:56,519 --> 00:46:51,789
anniversary of follow-the-sun

1097
00:46:58,289 --> 00:46:56,529
operations and that was a Monday our

1098
00:47:00,480 --> 00:46:58,299
first anniversary and so we're pretty

1099
00:47:02,450 --> 00:47:00,490
excited about that and what father-son

1100
00:47:05,249 --> 00:47:02,460
is about is taking advantage of that

1101
00:47:06,599 --> 00:47:05,259
equidistant distribution of our sites

1102
00:47:08,989 --> 00:47:06,609
around the globe

1103
00:47:11,579 --> 00:47:08,999
where we can do day shift only

1104
00:47:14,789 --> 00:47:11,589
operations of the entire network so

1105
00:47:17,579 --> 00:47:14,799
we're now interconnected with very

1106
00:47:20,160 --> 00:47:17,589
reliable networks high-speed wide area

1107
00:47:22,410 --> 00:47:20,170
networks fully redundant and diverse and

1108
00:47:25,410 --> 00:47:22,420
so we're taking advantage of that by

1109
00:47:29,370 --> 00:47:25,420
controlling the entire network from one

1110
00:47:31,380 --> 00:47:29,380
location during the day shift and so for

1111
00:47:33,870 --> 00:47:31,390
instance right now it's daytime in

1112
00:47:37,170 --> 00:47:33,880
Canberra Canberra is controlling an

1113
00:47:38,970 --> 00:47:37,180

entire network later tonight about 11 or

1114
00:47:40,470 --> 00:47:38,980
12 o'clock tonight they'll hand over to

1115
00:47:43,049 --> 00:47:40,480
Madrid they'll control the entire

1116
00:47:44,700 --> 00:47:43,059
network tomorrow morning about 6:00 or

1117
00:47:46,470 --> 00:47:44,710
7:00 in the morning they'll hand over to

1118
00:47:47,849 --> 00:47:46,480
Goldstone and they'll control the entire

1119
00:47:50,729 --> 00:47:47,859
network and that'll happen every single

1120
00:47:53,309 --> 00:47:50,739
day and so there's a bunch of advantages

1121
00:47:55,319 --> 00:47:53,319
to that for us one we eliminate shift

1122
00:47:57,509 --> 00:47:55,329
work which is you know difficult and

1123
00:47:59,789 --> 00:47:57,519
hard on people and yet we kept the

1124
00:48:03,089 --> 00:47:59,799
resilience ease of our three sites

1125
00:48:05,970 --> 00:48:03,099
working and in fact we're actually can

1126
00:48:07,829 --> 00:48:05,980
control from the JPL's darkroom here if

1127
00:48:12,120 --> 00:48:07,839
you've ever seen it for the very first

1128
00:48:14,160 --> 00:48:12,130
time so yeah amplify this Mike and his

1129
00:48:15,599 --> 00:48:14,170
team have done such a good job at

1130
00:48:17,430 --> 00:48:15,609
increasing the efficiency in the

1131
00:48:19,799 --> 00:48:17,440
automation of the deep space network

1132
00:48:21,420 --> 00:48:19,809
that we've saved enough money but that's

1133
00:48:25,000 --> 00:48:21,430
actually what funds all the new antennas

1134
00:48:25,010 --> 00:48:30,930
[Applause]

1135
00:48:35,380 --> 00:48:34,000
so then are there any other next steps

1136
00:48:39,460 --> 00:48:35,390
and operations that you guys want to

1137
00:48:42,009 --> 00:48:39,470
talk about or yeah I think yeah then the

1138
00:48:45,250 --> 00:48:42,019

next step for us is really completely

1139
00:48:47,410 --> 00:48:45,260
automating tracking passes and we're not

1140
00:48:51,370 --> 00:48:47,420
going to remove operations from the

1141
00:48:54,940 --> 00:48:51,380
equation but we think that reducing that

1142
00:48:57,490 --> 00:48:54,950
workload and and and stress of operating

1143
00:48:59,920 --> 00:48:57,500
through automation is very important and

1144
00:49:03,670 --> 00:48:59,930
what we're gonna do is adopt techniques

1145
00:49:07,180 --> 00:49:03,680
that were really first you know

1146
00:49:10,150 --> 00:49:07,190
discovered in and researched in

1147
00:49:14,349 --> 00:49:10,160
autopilot systems and it's called human

1148
00:49:16,960 --> 00:49:14,359
autonomy teaming and it's now gotten a

1149
00:49:18,460 --> 00:49:16,970
lot of more press with autonomous

1150
00:49:20,559 --> 00:49:18,470
driving and things like that so we're

1151
00:49:24,130 --> 00:49:20,569
gonna use these techniques of you know

1152
00:49:26,500 --> 00:49:24,140
pairing operations with automation and

1153
00:49:27,999 --> 00:49:26,510
getting the right teaming relationship

1154
00:49:30,759 --> 00:49:28,009
there and that involves things like

1155
00:49:32,529 --> 00:49:30,769
trust and and knowing what the

1156
00:49:35,109 --> 00:49:32,539
automation is doing as opposed to wait

1157
00:49:36,609 --> 00:49:35,119
you should be doing and and that's our

1158
00:49:39,670 --> 00:49:36,619
future in the next couple years we hope

1159
00:49:42,519 --> 00:49:39,680
to do that well so one more question for

1160
00:49:46,630 --> 00:49:42,529
me and and that is you let's talked

1161
00:49:48,640 --> 00:49:46,640
about using the DSN for science how do

1162
00:49:50,529 --> 00:49:48,650
you guys look at DSN s role as

1163
00:49:52,089 --> 00:49:50,539

essentially a giant scientific

1164
00:49:56,019 --> 00:49:52,099
instrument cuz I know there are a lot of

1165
00:49:58,900 --> 00:49:56,029
missions that think of your antennas as

1166
00:50:00,849 --> 00:49:58,910
sort of an extension of their spacecraft

1167
00:50:02,980 --> 00:50:00,859
that's just you know millions of miles

1168
00:50:06,700 --> 00:50:02,990
away in ways tens of thousands of you

1169
00:50:07,960 --> 00:50:06,710
know pounds how do you how do you guys

1170
00:50:09,339 --> 00:50:07,970
think and feel feel about that being

1171
00:50:12,430 --> 00:50:09,349
being kind of part of the mission oh

1172
00:50:13,359 --> 00:50:12,440
that's just part of a job and who

1173
00:50:15,670 --> 00:50:13,369
wouldn't want to be part of these

1174
00:50:17,380 --> 00:50:15,680
missions after all it turns out that

1175
00:50:20,079 --> 00:50:17,390
almost every spacecraft that goes into

1176
00:50:22,240 --> 00:50:20,089
deep space does DSN science just about

1177
00:50:23,230 --> 00:50:22,250
everyone at least radio science at least

1178
00:50:24,910 --> 00:50:23,240
the kinds of things we talked about

1179
00:50:27,059 --> 00:50:24,920
interrogating the rings and atmospheres

1180
00:50:30,249 --> 00:50:27,069
and so forth there's always something

1181
00:50:33,039 --> 00:50:30,259
even as New Horizons spacecraft passes

1182
00:50:34,960 --> 00:50:33,049
its first Kuiper belt object in January

1183
00:50:36,819 --> 00:50:34,970
it will be doing radio science to learn

1184
00:50:39,039 --> 00:50:36,829
something about that body that so

1185
00:50:41,319 --> 00:50:39,049
far away from Earth and it's exciting to

1186
00:50:43,059 --> 00:50:41,329
be part of this I'm not just part of the

1187
00:50:47,680 --> 00:50:43,069
engineering team but part of the science

1188
00:50:49,449 --> 00:50:47,690

team you know in any communications

1189
00:50:51,789 --> 00:50:49,459
there's at least two parts of it right

1190
00:50:53,890 --> 00:50:51,799
there's us the DSN but there's a

1191
00:50:56,170 --> 00:50:53,900
spacecraft part of that communication so

1192
00:50:58,959 --> 00:50:56,180
you know that's pretty critical and and

1193
00:51:00,579 --> 00:50:58,969
we try to optimize that communication as

1194
00:51:02,680 --> 00:51:00,589
much as possible push the envelope to

1195
00:51:05,859 --> 00:51:02,690
get as much data as possible so that

1196
00:51:08,229 --> 00:51:05,869
does make it more difficult when you

1197
00:51:10,559 --> 00:51:08,239
push that envelope and and if you go to

1198
00:51:13,390 --> 00:51:10,569
the museum and and here in the room

1199
00:51:15,729 --> 00:51:13,400
you'll notice none of these spacecraft

1200
00:51:19,120 --> 00:51:15,739
are the same they're going to different

1201
00:51:22,420 --> 00:51:19,130
places they're built uniquely for that

1202
00:51:25,630 --> 00:51:22,430
environment and they're pushing the

1203
00:51:27,219 --> 00:51:25,640
envelope of that environment and so each

1204
00:51:29,109 --> 00:51:27,229
one of the every time we talk to these

1205
00:51:31,719 --> 00:51:29,119
spacecraft it's it's a bit of a

1206
00:51:33,430 --> 00:51:31,729
challenge and especially when you're

1207
00:51:36,999 --> 00:51:33,440
doing things like initial acquisition

1208
00:51:40,779 --> 00:51:37,009
during launch or you're you're going

1209
00:51:42,609 --> 00:51:40,789
into orbit around a planet there's no

1210
00:51:45,130 --> 00:51:42,619
better thrill than getting that signal

1211
00:51:47,739 --> 00:51:45,140
down from the spacecraft it's really

1212
00:51:49,870 --> 00:51:47,749
there are times that we do science even

1213
00:51:51,219 --> 00:51:49,880

without the spacecraft yes and one of

1214
00:51:53,439 --> 00:51:51,229
the things that we do we haven't talked

1215
00:51:55,449 --> 00:51:53,449
much about so far as using the DSN as a

1216
00:51:56,650 --> 00:51:55,459
radar and we have very powerful

1217
00:51:59,019 --> 00:51:56,660
transmitters we have very sensitive

1218
00:52:01,630 --> 00:51:59,029
receivers and so we have over the years

1219
00:52:03,640 --> 00:52:01,640
done radar observations sometimes the

1220
00:52:05,949 --> 00:52:03,650
first glimpse of something comes from

1221
00:52:09,039 --> 00:52:05,959
the DSN the first glimpse of the surface

1222
00:52:11,670 --> 00:52:09,049
of Titan came from the DSN until we got

1223
00:52:16,109 --> 00:52:11,680
the Huygens spacecraft there and Cassini

1224
00:52:18,339 --> 00:52:16,119
we've done a lot of work lately on

1225
00:52:19,749 --> 00:52:18,349
asteroids prickly asteroids that come

1226
00:52:22,239 --> 00:52:19,759
close to the earth that might pose a

1227
00:52:23,680 --> 00:52:22,249
hazard to the earth someday it turns out

1228
00:52:25,900 --> 00:52:23,690
that although they're discovered with

1229
00:52:28,569 --> 00:52:25,910
optical telescopes if we can just do a

1230
00:52:31,390 --> 00:52:28,579
single DSN radar observation on them we

1231
00:52:35,499 --> 00:52:31,400
learn a lot about the structure and

1232
00:52:38,049 --> 00:52:35,509
shape and so forth of the object but we

1233
00:52:39,489 --> 00:52:38,059
also can predict its trajectory hundreds

1234
00:52:41,829 --> 00:52:39,499
of years into the future based on those

1235
00:52:43,209 --> 00:52:41,839
observations so we get a measure of

1236
00:52:46,410 --> 00:52:43,219
confidence and no we're not going to be

1237
00:52:48,790 --> 00:52:46,420
hit at least in a couple of centuries

1238
00:52:50,950 --> 00:52:48,800

well I think that's a good place for us

1239
00:52:52,630 --> 00:52:50,960
to stop talking to ourselves and and

1240
00:52:54,220 --> 00:52:52,640
hear from you guys so we'll take your

1241
00:52:56,590 --> 00:52:54,230
questions if you'll step to the

1242
00:52:57,790 --> 00:52:56,600
microphone that's in the middle of the

1243
00:52:59,800 --> 00:52:57,800
room in the middle of the aisle there

1244
00:53:03,100 --> 00:52:59,810
and also we'll work on in a few

1245
00:53:05,320 --> 00:53:03,110
questions from folks watching online so

1246
00:53:06,010 --> 00:53:05,330
step right up there and go ahead with

1247
00:53:09,840 --> 00:53:06,020
your question

1248
00:53:12,280 --> 00:53:09,850
hi well you guys were talking about with

1249
00:53:17,560 --> 00:53:12,290
having really you know powerful

1250
00:53:19,960 --> 00:53:17,570
transmitters both on the ground and on

1251
00:53:22,150 --> 00:53:19,970
the spacecraft like I I myself actually

1252
00:53:23,680 --> 00:53:22,160
work with radios a lot like like

1253
00:53:25,510 --> 00:53:23,690
portable ones that run off double A's

1254
00:53:27,160 --> 00:53:25,520
and nine volts and go like 100

1255
00:53:29,620 --> 00:53:27,170
milliwatts sometimes up to 250

1256
00:53:32,010 --> 00:53:29,630
milliwatts so I'm wondering to talk to

1257
00:53:35,140 --> 00:53:32,020
something like New Horizons or Voyager

1258
00:53:37,840 --> 00:53:35,150
like what the wattage cuz I'm sure it's

1259
00:53:40,630 --> 00:53:37,850
not milliwatts of what the wattage is

1260
00:53:42,340 --> 00:53:40,640
for the ground transmitters and what the

1261
00:53:44,440 --> 00:53:42,350
water well well why did you have to put

1262
00:53:46,270 --> 00:53:44,450
in the spacecraft at all it turns out

1263
00:53:48,160 --> 00:53:46,280

that yeah so it turns out that Voyager

1264
00:53:49,870 --> 00:53:48,170
uses a unique transmitter within the DSM

1265
00:53:52,390 --> 00:53:49,880
you only have one of them left it's

1266
00:53:55,060 --> 00:53:52,400
located in Australia it is a four

1267
00:53:58,030 --> 00:53:55,070
hundred kilowatt s-band continuous wave

1268
00:54:01,510 --> 00:53:58,040
transmitter so yes it's a lot bigger

1269
00:54:03,850 --> 00:54:01,520
than the ham equipment but the typical

1270
00:54:09,130 --> 00:54:03,860
transmitters we have are between 20

1271
00:54:15,490 --> 00:54:09,140
kilowatts and 80 kilowatts you're

1272
00:54:16,960 --> 00:54:15,500
talking about you know 10 20 watts it's

1273
00:54:19,630 --> 00:54:16,970
still amazing been in there it's still

1274
00:54:23,860 --> 00:54:19,640
amazing get it to go that far like 20

1275
00:54:26,670 --> 00:54:23,870
watts squared is really tough especially

1276
00:54:33,300 --> 00:54:26,680
when it's 20 40 watts from spacecraft

1277
00:54:39,880 --> 00:54:33,310
thanks regarding the issue of a

1278
00:54:43,120 --> 00:54:39,890
telescope array you mentioned the data

1279
00:54:46,110 --> 00:54:43,130
difference measurement what about the

1280
00:54:50,830 --> 00:54:46,120
idea of putting a distance between the

1281
00:54:54,460 --> 00:54:50,840
antennas put one here on earth and

1282
00:54:58,480 --> 00:54:54,470
another one on the moon where the moon

1283
00:54:59,450 --> 00:54:58,490
is actually face locked to earth so is

1284
00:55:03,230 --> 00:54:59,460
it physical

1285
00:55:06,520 --> 00:55:03,240
possible and what do you gain because of

1286
00:55:10,150 --> 00:55:06,530
this enormous distance between the two

1287
00:55:12,829 --> 00:55:10,160
antennas and another question if I pay

1288
00:55:19,549 --> 00:55:12,839

if you can make some comments about the

1289
00:55:22,250 --> 00:55:19,559
Internet Protocol for space okay so the

1290
00:55:23,990 --> 00:55:22,260
first one the same technique that we use

1291
00:55:26,809 --> 00:55:24,000
for delta door when it's used in

1292
00:55:28,880 --> 00:55:26,819
astronomy it's something they call this

1293
00:55:29,990 --> 00:55:28,890
very long baseline interferometry but

1294
00:55:32,599 --> 00:55:30,000
it's basically the same kind of

1295
00:55:34,520 --> 00:55:32,609
mathematics so although we don't need

1296
00:55:36,829 --> 00:55:34,530
any more accuracy for navigating the

1297
00:55:39,620 --> 00:55:36,839
spacecraft then and the antennas that

1298
00:55:41,450 --> 00:55:39,630
are a few miles apart to do certain

1299
00:55:43,160 --> 00:55:41,460
kinds of science observations using that

1300
00:55:46,490 --> 00:55:43,170
technique you want as large a baseline

1301
00:55:48,500 --> 00:55:46,500
as you can and we we do this in science

1302
00:55:51,049 --> 00:55:48,510
sense in Iran an intercontinental basis

1303
00:55:53,000 --> 00:55:51,059
today we can do more than that we have

1304
00:55:56,299 --> 00:55:53,010
flown there been a couple missions flown

1305
00:55:58,160 --> 00:55:56,309
a Japanese mission in particular that

1306
00:55:59,930 --> 00:55:58,170
carried one antenna with the other

1307
00:56:02,930 --> 00:55:59,940
antennas being on the earth and it was a

1308
00:56:05,150 --> 00:56:02,940
high Earth orbit er and so it provided

1309
00:56:08,059 --> 00:56:05,160
that large baseline not all the way to

1310
00:56:10,160 --> 00:56:08,069
the moon but getting close when we get

1311
00:56:11,900 --> 00:56:10,170
to the point of having infrastructure on

1312
00:56:14,210 --> 00:56:11,910
the moon you know we have already talked

1313
00:56:15,829 --> 00:56:14,220

about could we have DSN like stations on

1314
00:56:17,690 --> 00:56:15,839
the moon and what could you do with them

1315
00:56:20,390 --> 00:56:17,700
for things like this so absolutely we're

1316
00:56:22,579 --> 00:56:20,400
looking at that the other question was

1317
00:56:25,370 --> 00:56:22,589
about internet protocols okay it turns

1318
00:56:27,910 --> 00:56:25,380
out that we don't use internet protocols

1319
00:56:31,190 --> 00:56:27,920
in deep space because two things break

1320
00:56:33,020 --> 00:56:31,200
first of all these the Internet Protocol

1321
00:56:36,829 --> 00:56:33,030
suite that we use here on the surface of

1322
00:56:38,990 --> 00:56:36,839
the earth cannot work over those kinds

1323
00:56:42,829 --> 00:56:39,000
of delays in terms of how the speed of

1324
00:56:44,480 --> 00:56:42,839
light times the distance and and they're

1325
00:56:46,220 --> 00:56:44,490
just not designed to work that's an easy

1326
00:56:48,650 --> 00:56:46,230
run to fix but the other problem is on

1327
00:56:52,160 --> 00:56:48,660
the surface of the earth when you are

1328
00:56:54,890 --> 00:56:52,170
for instance accessing this live stream

1329
00:56:56,559 --> 00:56:54,900
from your home there may be 20 servers

1330
00:56:59,270 --> 00:56:56,569
in between here and there

1331
00:57:01,670 --> 00:56:59,280
every one of those links has to be

1332
00:57:06,140 --> 00:57:01,680
active at the same time for you to get

1333
00:57:08,390 --> 00:57:06,150
your video in your home we can't do that

1334
00:57:10,700 --> 00:57:08,400
in deep space because for instance as

1335
00:57:12,829 --> 00:57:10,710
the Earth turns one DSN site goes out of

1336
00:57:13,700 --> 00:57:12,839
view and the next one comes up so if

1337
00:57:15,140 --> 00:57:13,710
you're orbiting the plan

1338
00:57:16,700 --> 00:57:15,150

you have the same problem the planets

1339
00:57:19,880 --> 00:57:16,710
going to get in a way you need a set of

1340
00:57:23,170 --> 00:57:19,890
protocols that can handle both the long

1341
00:57:25,430 --> 00:57:23,180
delays and disruptions in in the

1342
00:57:28,220 --> 00:57:25,440
communications channel there is such a

1343
00:57:30,410 --> 00:57:28,230
sweet it's called DT N or disruption or

1344
00:57:32,560 --> 00:57:30,420
delay tolerant networking we're doing

1345
00:57:35,030 --> 00:57:32,570
research on it now it exists

1346
00:57:36,980 --> 00:57:35,040
operationally on the ISS on the space

1347
00:57:40,339 --> 00:57:36,990
station today and we have plans to

1348
00:57:46,730 --> 00:57:40,349
introduce this into the DSN in the next

1349
00:57:49,490 --> 00:57:46,740
few years hi two questions if I may with

1350
00:57:54,050 --> 00:57:49,500
regards to the optical communications

1351
00:57:57,200 --> 00:57:54,060
upgrade the first question is when

1352
00:58:00,859 --> 00:57:57,210
dealing with optical propagation that

1353
00:58:04,579 --> 00:58:00,869
there will be problems with atmospheric

1354
00:58:08,510 --> 00:58:04,589
interference such as clouds and rain and

1355
00:58:10,790 --> 00:58:08,520
so forth how do you plan on addressing

1356
00:58:14,000 --> 00:58:10,800
that are you going to use redundancy of

1357
00:58:17,210 --> 00:58:14,010
other stations the second question is

1358
00:58:18,200 --> 00:58:17,220
with regards to utilization of the beam

1359
00:58:21,920 --> 00:58:18,210
waveguides

1360
00:58:25,220 --> 00:58:21,930
well you have to down convert to

1361
00:58:27,260 --> 00:58:25,230
microwave to implement the mirrors as

1362
00:58:30,740 --> 00:58:27,270
design are you will you propagate

1363
00:58:33,470 --> 00:58:30,750

directly using the optical frequencies

1364
00:58:35,510 --> 00:58:33,480
thank you so to answer your first

1365
00:58:38,240 --> 00:58:35,520
question it definitely is dependent on

1366
00:58:39,710 --> 00:58:38,250
weather so that's why I will be

1367
00:58:41,720 --> 00:58:39,720
developing and delivering the first

1368
00:58:44,870 --> 00:58:41,730
system at Goldstone which is out in the

1369
00:58:47,660 --> 00:58:44,880
desert it's very dry we don't have to

1370
00:58:49,609 --> 00:58:47,670
worry too much about clouds or weather

1371
00:58:52,010 --> 00:58:49,619
and at the moment we're actually

1372
00:58:54,109 --> 00:58:52,020
studying the other sites and looking at

1373
00:58:55,970 --> 00:58:54,119
a whole host of years and years of

1374
00:58:59,480 --> 00:58:55,980
weather data and analyzing it to figure

1375
00:59:03,470 --> 00:58:59,490
out where the next site would be optimal

1376
00:59:05,570 --> 00:59:03,480
to deploy an optical system that we're

1377
00:59:07,579 --> 00:59:05,580
actually looking at the average increase

1378
00:59:10,099 --> 00:59:07,589
that optical communications give you and

1379
00:59:11,960 --> 00:59:10,109
that includes the outages from bad

1380
00:59:14,420 --> 00:59:11,970
weather and depending on where your site

1381
00:59:15,980 --> 00:59:14,430
is even even if you have those outages

1382
00:59:17,750 --> 00:59:15,990
if on average you come out better

1383
00:59:19,730 --> 00:59:17,760
because when the when the sky is clear

1384
00:59:21,530 --> 00:59:19,740
you get so many more bits per second

1385
00:59:22,940 --> 00:59:21,540
you're still better off doing this as

1386
00:59:25,609 --> 00:59:22,950
long as you have an automated way of

1387
00:59:27,270 --> 00:59:25,619
handling that link and that same set of

1388
00:59:29,099 --> 00:59:27,280

protocols I talked about

1389
00:59:31,589 --> 00:59:29,109
serves that purpose as well to

1390
00:59:33,000 --> 00:59:31,599
automatically pick up whenever the

1391
00:59:36,890 --> 00:59:33,010
weather is good again and get the link

1392
00:59:41,510 --> 00:59:36,900
going we hadn't had a second question

1393
00:59:43,829 --> 00:59:41,520
the we've got implementation yeah so

1394
00:59:45,960 --> 00:59:43,839
even though we're going to be putting

1395
00:59:47,550 --> 00:59:45,970
these these optical systems on beam wave

1396
00:59:49,740 --> 00:59:47,560
and antennas we're not actually using

1397
00:59:51,990 --> 00:59:49,750
the beam waveguide in the optical system

1398
00:59:53,790 --> 00:59:52,000
we're that's why we're putting the

1399
00:59:56,309 --> 00:59:53,800
optical receiver at the apex of the

1400
00:59:57,870 --> 00:59:56,319
antenna the idea is it doesn't then come

1401
01:00:00,510 --> 00:59:57,880
down through the waveguide it goes

1402
01:00:02,040 --> 01:00:00,520
electronically off of the apex and we

1403
01:00:03,359 --> 01:00:02,050
looked at both designs we did a trade

1404
01:00:05,849 --> 01:00:03,369
off and decided this was the better

1405
01:00:07,980 --> 01:00:05,859
design let's take a real quick question

1406
01:00:10,380 --> 01:00:07,990
from YouTube Jeff on YouTube wanted to

1407
01:00:15,900 --> 01:00:10,390
know how does solar flares affect RF

1408
01:00:18,210 --> 01:00:15,910
signals from spacecraft so I talked

1409
01:00:21,329 --> 01:00:18,220
about about the tees that you can't

1410
01:00:22,740 --> 01:00:21,339
control so that's a noise that we have

1411
01:00:24,359 --> 01:00:22,750
no control over it turns out to be

1412
01:00:27,089 --> 01:00:24,369
temporal it's not there all the time

1413
01:00:29,099 --> 01:00:27,099

it comes and goes it does affect the

1414
01:00:30,750 --> 01:00:29,109
communication system it can affect the

1415
01:00:32,609 --> 01:00:30,760
communications directly by affecting the

1416
01:00:33,180 --> 01:00:32,619
electronics in the DSM or on the

1417
01:00:35,430 --> 01:00:33,190
spacecraft

1418
01:00:38,460 --> 01:00:35,440
it can affect in stuff that happens in

1419
01:00:40,349 --> 01:00:38,470
between currently if we know about

1420
01:00:41,880 --> 01:00:40,359
flares in advance we turn spacecraft off

1421
01:00:45,780 --> 01:00:41,890
just to protect them so we don't

1422
01:00:47,490 --> 01:00:45,790
communicate but otherwise it's just it's

1423
01:00:49,200 --> 01:00:47,500
just another one of those tees and and

1424
01:00:51,440 --> 01:00:49,210
we have to have enough other

1425
01:00:54,329 --> 01:00:51,450
communication sessions to make up for it

1426
01:00:56,849 --> 01:00:54,339
about signal disruption and it is about

1427
01:00:58,589 --> 01:00:56,859
the electronics being disrupted because

1428
01:01:01,710 --> 01:00:58,599
it's different frequencies typically

1429
01:01:07,410 --> 01:01:01,720
although it is present in the in the T

1430
01:01:09,720 --> 01:01:07,420
factor let's point out so I'm really

1431
01:01:11,490 --> 01:01:09,730
inspired by this gorgeous model of

1432
01:01:13,470 --> 01:01:11,500
voyager over here and i've been really

1433
01:01:15,390 --> 01:01:13,480
curious how much longer do you think

1434
01:01:18,480 --> 01:01:15,400
we'll be able to communicate with the

1435
01:01:21,089 --> 01:01:18,490
Voyager spacecraft and what data are we

1436
01:01:22,470 --> 01:01:21,099
actually getting back right now so we're

1437
01:01:24,780 --> 01:01:22,480
actually getting back very important

1438
01:01:27,450 --> 01:01:24,790

data from Voyager from both voyagers but

1439
01:01:30,059 --> 01:01:27,460
from Voyager 2 right now because it is

1440
01:01:32,520 --> 01:01:30,069
about to cross the heliopause so Voyager

1441
01:01:35,790 --> 01:01:32,530
1 left left the solar system a long time

1442
01:01:37,290 --> 01:01:35,800
ago now but they purposely sent them in

1443
01:01:39,359 --> 01:01:37,300
different directions so that we can see

1444
01:01:40,980 --> 01:01:39,369
somewhat of the shape of that boundary

1445
01:01:42,540 --> 01:01:40,990
and Voyager 2 is about

1446
01:01:44,010 --> 01:01:42,550
go through that so that that's an

1447
01:01:45,390 --> 01:01:44,020
extremely important science resolve

1448
01:01:48,859 --> 01:01:45,400
that's coming from a forty-year-old

1449
01:01:51,060 --> 01:01:48,869
spacecraft right now we still get

1450
01:01:52,500 --> 01:01:51,070
measurements of magnetic fields and

1451
01:01:56,460 --> 01:01:52,510
particles and so forth from both the

1452
01:01:58,260 --> 01:01:56,470
voyagers and that's our only probe into

1453
01:02:00,359 --> 01:01:58,270
interstellar space at the moment that's

1454
01:02:03,570 --> 01:02:00,369
how we all we know about it is coming

1455
01:02:05,370 --> 01:02:03,580
from Voyager pretty much so and in terms

1456
01:02:10,130 --> 01:02:05,380
of how much longer we're trying to keep

1457
01:02:12,270 --> 01:02:10,140
them going as long as we can and around

1458
01:02:14,040 --> 01:02:12,280
2027 yeah that's correct

1459
01:02:15,480 --> 01:02:14,050
yeah at some point there's not enough

1460
01:02:18,240 --> 01:02:15,490
power to operate both the transmitter

1461
01:02:21,060 --> 01:02:18,250
and instruments and the heaters that

1462
01:02:22,350 --> 01:02:21,070
keep these things alive we're talking

1463
01:02:25,380 --> 01:02:22,360

about Voyager we actually got two

1464
01:02:27,330 --> 01:02:25,390
questions are from from the web from the

1465
01:02:28,560 --> 01:02:27,340
webcast viewers that relate to it so

1466
01:02:32,750 --> 01:02:28,570
I'll go ahead and slip them in here now

1467
01:02:36,060 --> 01:02:32,760
are you seeing any gravity science

1468
01:02:38,040 --> 01:02:36,070
signal from from from the Voyager as its

1469
01:02:39,330 --> 01:02:38,050
as its leaving the solar system and

1470
01:02:42,600 --> 01:02:39,340
going away from the Sun's gravity this

1471
01:02:44,310 --> 01:02:42,610
is from virtue or virtue on YouTube any

1472
01:02:47,370 --> 01:02:44,320
note of noticeable effects of gravity on

1473
01:02:50,040 --> 01:02:47,380
signals unfortunately we don't have

1474
01:02:52,349 --> 01:02:50,050
Voyager scientists here with us I don't

1475
01:02:54,570 --> 01:02:52,359
think we do I think we're mainly looking

1476
01:02:56,670 --> 01:02:54,580
at is is fields and particles data and

1477
01:02:59,010 --> 01:02:56,680
looking at the difference as as voyager

1478
01:03:01,470 --> 01:02:59,020
transfers traverses different regions at

1479
01:03:04,080 --> 01:03:01,480
the outer outskirts of the solar system

1480
01:03:05,700 --> 01:03:04,090
okay and then shove on youtube wanted to

1481
01:03:07,920 --> 01:03:05,710
know how many you have an estimate of

1482
01:03:08,400 --> 01:03:07,930
how many bits per second we get from

1483
01:03:11,400 --> 01:03:08,410
Voyager

1484
01:03:14,460 --> 01:03:11,410
of data

1485
01:03:17,250 --> 01:03:14,470
I think we're getting up to 1200 bits

1486
01:03:21,630 --> 01:03:17,260
per second and how does that compare to

1487
01:03:25,890 --> 01:03:21,640
something like Juno Mars Reconnaissance

1488
01:03:30,930 --> 01:03:25,900

Orbiter orbiting Mars is 6 megabits per

1489
01:03:34,670 --> 01:03:30,940
second we have earth trailing missions

1490
01:03:37,530 --> 01:03:34,680
tests 4 inches 125 megabits per second

1491
01:03:39,930 --> 01:03:37,540
so there's quite a variety of data rates

1492
01:03:42,750 --> 01:03:39,940
for the different missions but 1200 bits

1493
01:03:44,609 --> 01:03:42,760
per second isn't zero yes it's it was

1494
01:03:47,550 --> 01:03:44,619
what we did on modems you know 30 years

1495
01:03:49,770 --> 01:03:47,560
ago for our own computers and it's

1496
01:03:52,109 --> 01:03:49,780
enough for instance to transmit encoded

1497
01:03:54,870 --> 01:03:52,119
voice you can have a human on Voyager

1498
01:03:57,809 --> 01:03:54,880
and listen to them where's this

1499
01:03:58,499 --> 01:03:57,819
data rates now we are okay hi there how

1500
01:04:01,200 --> 01:03:58,509
you doing

1501
01:04:06,930 --> 01:04:01,210
I remember from the old days when dr.

1502
01:04:12,210 --> 01:04:06,940
Pickering and dr. brockton and dr.

1503
01:04:15,329 --> 01:04:12,220
Andrew Viterbi were working on the Deep

1504
01:04:17,460 --> 01:04:15,339
Space Network and I was a student at

1505
01:04:19,859 --> 01:04:17,470
that time and we're trying to figure out

1506
01:04:24,180 --> 01:04:19,869
what is going on we're learning this

1507
01:04:27,930 --> 01:04:24,190
thing for over this years you guys have

1508
01:04:31,980 --> 01:04:27,940
done magnificent job can you briefly

1509
01:04:35,220 --> 01:04:31,990
tell me from point A to what is

1510
01:04:44,970 --> 01:04:35,230
happening now what what has happened

1511
01:04:47,460 --> 01:04:44,980
over this period of time briefly so it

1512
01:04:48,930 --> 01:04:47,470
was 10 to the 13th per visit if you look

1513
01:04:51,180 --> 01:04:48,940

at all the Jags on that tenant of the

1514
01:04:53,099 --> 01:04:51,190
chamber each one represents a new

1515
01:04:55,440 --> 01:04:53,109
technology or new capability that came

1516
01:04:57,150 --> 01:04:55,450
in and e4 Trevor you mentioned at some

1517
01:04:59,490 --> 01:04:57,160
point we went to convolutional coding

1518
01:05:01,049 --> 01:04:59,500
using maximum likelihood decoder z'

1519
01:05:05,789 --> 01:05:01,059
which other people call Viterbi decoder

1520
01:05:06,120 --> 01:05:05,799
z' and that went in in in the late 70s I

1521
01:05:07,980 --> 01:05:06,130
think

1522
01:05:12,240 --> 01:05:07,990
reed-solomon Irving Reid you may be

1523
01:05:14,130 --> 01:05:12,250
ravine Reed Solomon those codes came in

1524
01:05:16,109 --> 01:05:14,140
in the mid 80s

1525
01:05:18,660 --> 01:05:16,119
so we all these people you're talking a

1526
01:05:22,140 --> 01:05:18,670
Breton is the architect of the DSN he's

1527
01:05:24,660 --> 01:05:22,150
responsible for well how it looks in the

1528
01:05:26,400 --> 01:05:24,670
overall concept so all these people that

1529
01:05:30,289 --> 01:05:26,410
contribute is aboard they were sitting

1530
01:05:32,940 --> 01:05:30,299
here in the same place and talking about

1531
01:05:41,309 --> 01:05:32,950
I'm sure to talk to some of them about

1532
01:05:42,839 --> 01:05:41,319
this over the years thank you you had a

1533
01:05:45,299 --> 01:05:42,849
question a while back about the effect

1534
01:05:48,269 --> 01:05:45,309
of weather on the optical navigation I

1535
01:05:51,029 --> 01:05:48,279
assume you're using infrared as a far

1536
01:05:55,039 --> 01:05:51,039
infrared or near-infrared the standard

1537
01:05:59,569 --> 01:05:55,049
that we've developed is 1515 an alerts

1538
01:06:06,510 --> 01:06:01,680

there's too much too much microwave in

1539
01:06:11,410 --> 01:06:09,310
several years ago I heard a rumor that

1540
01:06:13,540 --> 01:06:11,420
there was a consideration of actually

1541
01:06:14,920 --> 01:06:13,550
using Internet protocols among the

1542
01:06:16,960 --> 01:06:14,930
spacecraft they're currently orbiting

1543
01:06:18,550 --> 01:06:16,970
Mars are you using the delay tolerant

1544
01:06:20,170 --> 01:06:18,560
networks they're are using internet

1545
01:06:22,030 --> 01:06:20,180
protocols that we're not using either of

1546
01:06:24,370 --> 01:06:22,040
those protocols at the moment we do have

1547
01:06:26,710 --> 01:06:24,380
a proprietary sort of international

1548
01:06:29,500 --> 01:06:26,720
space protocol that we use for relays at

1549
01:06:31,780 --> 01:06:29,510
Mars it's neither of those but in the

1550
01:06:32,740 --> 01:06:31,790
future we expect DTN to be implemented

1551
01:06:35,470 --> 01:06:32,750
there yeah

1552
01:06:37,540 --> 01:06:35,480
the final thing is just a little remark

1553
01:06:38,980 --> 01:06:37,550
did a quick calculation as I was

1554
01:06:42,580 --> 01:06:38,990
standing here the data rate from Voyager

1555
01:06:48,900 --> 01:06:42,590
is 15 times the data rate from Mariner 4

1556
01:06:53,520 --> 01:06:51,730
someone mentioned earlier you get the

1557
01:06:56,800 --> 01:06:53,530
ability to communicate with four

1558
01:06:58,720 --> 01:06:56,810
spacecraft simultaneously in one place

1559
01:06:59,500 --> 01:06:58,730
when they're conveniently located like

1560
01:07:02,770 --> 01:06:59,510
that

1561
01:07:04,840 --> 01:07:02,780
adding sort of the optical wavelengths

1562
01:07:07,750 --> 01:07:04,850
I'm imagine that's not just going up by

1563
01:07:09,700 --> 01:07:07,760

one using different frequencies you just

1564
01:07:11,230 --> 01:07:09,710
mentioned 1550 but are you using

1565
01:07:13,150 --> 01:07:11,240
different frequencies or different ways

1566
01:07:16,540 --> 01:07:13,160
to encode that so you can get more than

1567
01:07:19,300 --> 01:07:16,550
four simultaneous communication so I

1568
01:07:21,310 --> 01:07:19,310
think Mike mentioned that at radio

1569
01:07:23,740 --> 01:07:21,320
frequencies we actually although they

1570
01:07:25,390 --> 01:07:23,750
may all be at expand which is like 8.4

1571
01:07:27,220 --> 01:07:25,400
gigahertz down like there are a slightly

1572
01:07:30,220 --> 01:07:27,230
different X bands so there's separated

1573
01:07:31,840 --> 01:07:30,230
in frequency space at the moment we

1574
01:07:33,550 --> 01:07:31,850
haven't thought too much about multiple

1575
01:07:35,050 --> 01:07:33,560
optic optical spacecraft in the same

1576
01:07:37,330 --> 01:07:35,060
beam because we don't even have one yet

1577
01:07:39,370 --> 01:07:37,340
but we will be thinking about that and

1578
01:07:41,620 --> 01:07:39,380
there are people working on either

1579
01:07:43,990 --> 01:07:41,630
either wavelength diversity or code

1580
01:07:46,030 --> 01:07:44,000
diversity the the various techniques you

1581
01:07:51,370 --> 01:07:46,040
can use and we haven't decided on the

1582
01:07:53,530 --> 01:07:51,380
right one yet cool thank you yeah hi um

1583
01:07:55,480 --> 01:07:53,540
forgive me if my question is a bit of a

1584
01:07:58,180 --> 01:07:55,490
stretch from what we're generally

1585
01:08:00,580 --> 01:07:58,190
looking at right now but in my physics

1586
01:08:02,860 --> 01:08:00,590
class we're studying the fuel sources

1587
01:08:04,390 --> 01:08:02,870
that we can use as a society by any

1588
01:08:11,220 --> 01:08:04,400

chance do you know if the main fuel

1589
01:08:13,540 --> 01:08:11,230
source that are that's powering the the

1590
01:08:15,530 --> 01:08:13,550
sorry I forget the word I'm a little

1591
01:08:19,410 --> 01:08:15,540
nervous right now but

1592
01:08:22,890 --> 01:08:19,420
but the main systems that were using

1593
01:08:25,650 --> 01:08:22,900
right now to get the signals from the

1594
01:08:27,930 --> 01:08:25,660
outer space missions that were sending

1595
01:08:30,990 --> 01:08:27,940
okay so most of the spacecraft most

1596
01:08:32,370 --> 01:08:31,000
spacecraft have have solar power and the

1597
01:08:34,230 --> 01:08:32,380
exceptions are ones that are too far

1598
01:08:37,280 --> 01:08:34,240
from the Sun so there's not on a solar

1599
01:08:40,020 --> 01:08:37,290
flux to generate and those are carrying

1600
01:08:41,970 --> 01:08:40,030
small pieces of radioactive material

1601
01:08:44,160 --> 01:08:41,980
that generate heat that's converted into

1602
01:08:46,620 --> 01:08:44,170
electricity so that that's what that's

1603
01:08:49,590 --> 01:08:46,630
what's in space on ground we mostly use

1604
01:08:52,200 --> 01:08:49,600
commercial power and so it's not our

1605
01:08:53,910 --> 01:08:52,210
choice as to how it the power is being

1606
01:08:55,320 --> 01:08:53,920
generated it's locally what's available

1607
01:08:57,810 --> 01:08:55,330
in the three countries in the three

1608
01:08:59,940 --> 01:08:57,820
places we have over the years looked at

1609
01:09:02,370 --> 01:08:59,950
installing alternate alternative energy

1610
01:09:03,349 --> 01:09:02,380
sources at the complexes and still under

1611
01:09:07,380 --> 01:09:03,359
discussion

1612
01:09:11,190 --> 01:09:07,390
thank you another question from from

1613
01:09:13,680 --> 01:09:11,200

David on YouTube he wanted to know do

1614
01:09:15,990 --> 01:09:13,690
the antennas communicate in duplex mode

1615
01:09:18,240 --> 01:09:16,000
or do they switch back and forth from

1616
01:09:20,900 --> 01:09:18,250
transmit to receive can they only do one

1617
01:09:24,630 --> 01:09:20,910
thing at a time or can they do them both

1618
01:09:28,950 --> 01:09:24,640
or one at a time so we have different

1619
01:09:31,740 --> 01:09:28,960
modes of operating so there's one-way

1620
01:09:34,530 --> 01:09:31,750
mode which is we typically call downlink

1621
01:09:37,740 --> 01:09:34,540
only as we see it from the space the

1622
01:09:41,160 --> 01:09:37,750
ground side we have two-way mode where

1623
01:09:43,349 --> 01:09:41,170
we're uplinking and coherently turning

1624
01:09:46,880 --> 01:09:43,359
that signal around on the downlink so

1625
01:09:50,610 --> 01:09:46,890
that's Donley mode and then we also do

1626
01:09:52,380 --> 01:09:50,620
two-way non-coherent which the

1627
01:09:53,880 --> 01:09:52,390
turnaround ratio is not used on the

1628
01:09:55,950 --> 01:09:53,890
spacecraft so we have an uplink and a

1629
01:09:57,900 --> 01:09:55,960
downlink so you may ask why we have so

1630
01:10:00,000 --> 01:09:57,910
many modes and and one of the reasons is

1631
01:10:01,620 --> 01:10:00,010
when you when you operate in a full

1632
01:10:03,990 --> 01:10:01,630
duplex mode the performance goes down

1633
01:10:05,880 --> 01:10:04,000
slightly and so if you're trying to get

1634
01:10:07,260 --> 01:10:05,890
the last possible bits per second out of

1635
01:10:08,580 --> 01:10:07,270
the spacecraft like you have an

1636
01:10:10,620 --> 01:10:08,590
encounter with the planet you're trying

1637
01:10:12,780 --> 01:10:10,630
to get as much data down that day as you

1638
01:10:15,350 --> 01:10:12,790

can you'll go to one-way mode because

1639
01:10:19,860 --> 01:10:15,360
you pick up a little bit of performance

1640
01:10:22,080 --> 01:10:19,870
all right hi you had mentioned earlier

1641
01:10:24,900 --> 01:10:22,090
that you might use these satellites to

1642
01:10:27,990 --> 01:10:24,910
help get the shapes and and and

1643
01:10:31,890 --> 01:10:28,000
distances of asteroids in the field I'm

1644
01:10:34,560 --> 01:10:31,900
so what sensitivities do we have for the

1645
01:10:38,010 --> 01:10:34,570
resolution like how how close so we can

1646
01:10:40,170 --> 01:10:38,020
we get to the size and whatever yes so

1647
01:10:42,270 --> 01:10:40,180
that's really a question about the DSN

1648
01:10:44,100 --> 01:10:42,280
being used as a radar and it turns out

1649
01:10:46,230 --> 01:10:44,110
that the distance isn't isn't what too

1650
01:10:48,990 --> 01:10:46,240
affects the resolution it's the it's the

1651
01:10:50,280 --> 01:10:49,000
bandwidth of the signals how how much

1652
01:10:52,620 --> 01:10:50,290
frequency bandwidth there is in the

1653
01:10:54,120 --> 01:10:52,630
signal and we recently recently maybe

1654
01:10:57,620 --> 01:10:54,130
four or five years ago upgraded our

1655
01:11:00,180 --> 01:10:57,630
radar system we get about four meters of

1656
01:11:07,140 --> 01:11:00,190
resolution on these objects so a pixel

1657
01:11:08,970 --> 01:11:07,150
is about four meters I think we were

1658
01:11:11,240 --> 01:11:08,980
mostly all aware of the fact that we

1659
01:11:14,460 --> 01:11:11,250
can't change the distance of the

1660
01:11:16,320 --> 01:11:14,470
spacecraft to the DSN and that we can't

1661
01:11:19,320 --> 01:11:16,330
really necessarily increase the fastest

1662
01:11:21,180 --> 01:11:19,330
speed of the data coming through so I

1663
01:11:22,770 --> 01:11:21,190

was wondering what steps are being taken

1664
01:11:25,740 --> 01:11:22,780
to increase the effectiveness of

1665
01:11:28,500 --> 01:11:25,750
communication for the crewed missions

1666
01:11:33,330 --> 01:11:28,510
going in the to Mars in the 2030s and

1667
01:11:34,920 --> 01:11:33,340
2822 and also I I heard a brief mention

1668
01:11:37,380 --> 01:11:34,930
of artificial intelligence within the

1669
01:11:39,720 --> 01:11:37,390
DSN oh I was thinking maybe you can

1670
01:11:41,880 --> 01:11:39,730
elaborate on that so let's take the

1671
01:11:45,260 --> 01:11:41,890
human the astronaut question first

1672
01:11:48,060 --> 01:11:45,270
so the DSN was involved in Apollo and

1673
01:11:49,410 --> 01:11:48,070
and we were also involved in the shuttle

1674
01:11:51,750 --> 01:11:49,420
program particularly when it used to

1675
01:11:53,220 --> 01:11:51,760
land on the west coast and we were we

1676
01:11:56,670 --> 01:11:53,230
were part of the landing sequence for

1677
01:11:59,970 --> 01:11:56,680
for the shuttle but since then the DSN

1678
01:12:01,740 --> 01:11:59,980
has not been involved directly in in in

1679
01:12:04,470 --> 01:12:01,750
supporting astronauts in space so we're

1680
01:12:07,200 --> 01:12:04,480
very excited with the return of American

1681
01:12:10,170 --> 01:12:07,210
astronauts to deep space which will

1682
01:12:12,240 --> 01:12:10,180
happen in in a few years and so we've

1683
01:12:14,910 --> 01:12:12,250
been working toward that for a while

1684
01:12:16,800 --> 01:12:14,920
we've we've installed in the DSN the

1685
01:12:18,990 --> 01:12:16,810
different kinds of communication

1686
01:12:22,620 --> 01:12:19,000
standards that that those missions want

1687
01:12:25,830 --> 01:12:22,630
to use and so we are we are completely

1688
01:12:27,570 --> 01:12:25,840

ready to support the first foray which

1689
01:12:28,560 --> 01:12:27,580
are the exploration mission sequences

1690
01:12:30,990 --> 01:12:28,570
starting with em1

1691
01:12:34,170 --> 01:12:31,000
which is not piloted and then em2 which

1692
01:12:37,380 --> 01:12:34,180
is yeah so those will happen over the

1693
01:12:39,540 --> 01:12:37,390
next few years then of course the next

1694
01:12:41,640 --> 01:12:39,550
thing is there's the lunar orbiting

1695
01:12:44,160 --> 01:12:41,650
gateway which NASA is now

1696
01:12:45,660 --> 01:12:44,170
designing and we've been involved in

1697
01:12:48,240 --> 01:12:45,670
helping define the communications

1698
01:12:51,360 --> 01:12:48,250
architecture for it because the DSN will

1699
01:12:53,460 --> 01:12:51,370
again be the main link to that as far as

1700
01:12:54,930 --> 01:12:53,470
Mars we've been working on Mars for

1701
01:12:57,780 --> 01:12:54,940
quite a while in fact one of the reasons

1702
01:12:59,490 --> 01:12:57,790
that we're very excited about the

1703
01:13:01,530 --> 01:12:59,500
optical communications and the beam

1704
01:13:03,210 --> 01:13:01,540
waveguides is that will likely be the

1705
01:13:08,700 --> 01:13:03,220
way we communicate it communicate with

1706
01:13:11,640 --> 01:13:08,710
astronauts on Mars in terms of AI we had

1707
01:13:13,470 --> 01:13:11,650
some area algorithms in our scheduling

1708
01:13:15,570 --> 01:13:13,480
software which I talked a little bit

1709
01:13:17,280 --> 01:13:15,580
about which is based really on temporal

1710
01:13:19,610 --> 01:13:17,290
of dependency networks and kind of

1711
01:13:22,350 --> 01:13:19,620
construction algorithms to construct the

1712
01:13:23,850 --> 01:13:22,360
schedule and repair algorithms when

1713
01:13:26,880 --> 01:13:23,860

there's some breakage in the schedule

1714
01:13:30,510 --> 01:13:26,890
and and then we're also looking at

1715
01:13:32,730 --> 01:13:30,520
machine learning for doing things like

1716
01:13:35,190 --> 01:13:32,740
situational awareness so like as we move

1717
01:13:36,510 --> 01:13:35,200
into more automation we're also going to

1718
01:13:38,700 --> 01:13:36,520
automate some of the monitoring

1719
01:13:41,340 --> 01:13:38,710
functions so we're using machine

1720
01:13:43,440 --> 01:13:41,350
learning to to ingest a lot of data to

1721
01:13:47,010 --> 01:13:43,450
understand relationships between that

1722
01:13:49,830 --> 01:13:47,020
data and detect errors or faults as

1723
01:13:52,710 --> 01:13:49,840
they're occurring or or before they

1724
01:13:54,900 --> 01:13:52,720
occur and kind of warn operations that

1725
01:13:59,120 --> 01:13:54,910
you ought to pay attention to this or

1726
01:14:01,710 --> 01:13:59,130
that when we're in a more automated mode

1727
01:14:04,860 --> 01:14:01,720
are you going to build any more of the

1728
01:14:06,540 --> 01:14:04,870
really big antennas the 70-meter the

1729
01:14:08,670 --> 01:14:06,550
football field sized ones to help

1730
01:14:10,800 --> 01:14:08,680
communicate with astronauts or are you

1731
01:14:13,020 --> 01:14:10,810
guys gonna just keep building the the 34

1732
01:14:14,910 --> 01:14:13,030
meters that Amy talked about so at the

1733
01:14:16,860 --> 01:14:14,920
moment we're building a 34 in a reason

1734
01:14:19,710 --> 01:14:16,870
fetish we actually did a study a while

1735
01:14:22,290 --> 01:14:19,720
back and said suppose we need to have

1736
01:14:23,970 --> 01:14:22,300
that much more area and our antennas

1737
01:14:25,710 --> 01:14:23,980
what's the most efficient way to do it

1738
01:14:27,240 --> 01:14:25,720

if you go back far enough in time the

1739
01:14:28,950 --> 01:14:27,250
only way to drill was with one big one

1740
01:14:31,140 --> 01:14:28,960
but now we know how to array these

1741
01:14:33,270 --> 01:14:31,150
together that's not the question is is

1742
01:14:35,640 --> 01:14:33,280
it better operationally and economically

1743
01:14:37,710 --> 01:14:35,650
to build one big one or set of small

1744
01:14:39,510 --> 01:14:37,720
ones and if it's a set of small ones

1745
01:14:42,210 --> 01:14:39,520
what should the diameter be should they

1746
01:14:45,270 --> 01:14:42,220
be a bunch of 34s or a lot more twelves

1747
01:14:47,400 --> 01:14:45,280
or a whole bunch of sixes and we did the

1748
01:14:48,990 --> 01:14:47,410
trade-off study and it turns out that at

1749
01:14:51,510 --> 01:14:49,000
the time we did it which was you know a

1750
01:14:53,310 --> 01:14:51,520
few years back and for the kind of extra

1751
01:14:55,110 --> 01:14:53,320
aperture we wanted which for the

1752
01:14:56,820 --> 01:14:55,120
equivalent of six of these antennas

1753
01:14:59,100 --> 01:14:56,830
thirty-four meter was the right answer I

1754
01:15:01,860 --> 01:14:59,110
expect as technology advances that

1755
01:15:03,330 --> 01:15:01,870
number will go down and and so if you

1756
01:15:05,640 --> 01:15:03,340
come back and ask this question who of

1757
01:15:08,010 --> 01:15:05,650
this panel 20 years from now we may be

1758
01:15:14,010 --> 01:15:08,020
building 10 meter antennas for our

1759
01:15:16,650 --> 01:15:14,020
arrays thank you yeah I was just curious

1760
01:15:18,660 --> 01:15:16,660
as to where all of the antenna hardware

1761
01:15:22,530 --> 01:15:18,670
is built and how do you get it shipped

1762
01:15:24,440 --> 01:15:22,540
out to the three sites yeah so it very

1763
01:15:27,180 --> 01:15:24,450

much depends on on what it is so

1764
01:15:29,460 --> 01:15:27,190
generally the electronics are developed

1765
01:15:32,670 --> 01:15:29,470
and built here JPL and we have some

1766
01:15:35,040 --> 01:15:32,680
pieces that are bought from industry and

1767
01:15:37,740 --> 01:15:35,050
then assembled here and tested at the

1768
01:15:40,380 --> 01:15:37,750
system level for our electronics but

1769
01:15:44,130 --> 01:15:40,390
things like the steel structure is

1770
01:15:46,440 --> 01:15:44,140
bought locally and the panels are also

1771
01:15:47,790 --> 01:15:46,450
the panels and sub reflectors for the

1772
01:15:51,360 --> 01:15:47,800
antennas I'm building right now come

1773
01:15:52,770 --> 01:15:51,370
from Italy and so it's a combination but

1774
01:15:55,140 --> 01:15:52,780
most of the electronics are developed

1775
01:15:58,230 --> 01:15:55,150
here at JPL is there a problem with the

1776
01:16:00,960 --> 01:15:58,240
shipping I mean it yeah yeah so what we

1777
01:16:04,020 --> 01:16:00,970
end up doing is we pack all of our

1778
01:16:06,810 --> 01:16:04,030
electronics into C van so big 20-foot or

1779
01:16:09,750 --> 01:16:06,820
40-foot C containers and then we load

1780
01:16:12,360 --> 01:16:09,760
them on a ship and they ship across the

1781
01:16:14,490 --> 01:16:12,370
ocean and then they get unpacked over

1782
01:16:17,300 --> 01:16:14,500
there so for example for one of these

1783
01:16:19,890 --> 01:16:17,310
antennas there will be four to six

1784
01:16:23,310 --> 01:16:19,900
20-foot sea vans full of equipment that

1785
01:16:25,350 --> 01:16:23,320
will be shipped over there so it is it's

1786
01:16:27,630 --> 01:16:25,360
like a game of Tetris right to get

1787
01:16:29,820 --> 01:16:27,640
everything packed in there safely so

1788
01:16:31,620 --> 01:16:29,830

that any sort of movement all of the

1789
01:16:33,450 --> 01:16:31,630
movement in that C container doesn't

1790
01:16:35,280 --> 01:16:33,460
damage anything but we get kind of an

1791
01:16:37,080 --> 01:16:35,290
efficient use of space we have a whole

1792
01:16:40,020 --> 01:16:37,090
logistics operation that's done by our

1793
01:16:42,540 --> 01:16:40,030
our American contractor perotin and and

1794
01:16:44,460 --> 01:16:42,550
they take care of the logistics for this

1795
01:16:46,680 --> 01:16:44,470
they have they have Depot's for for

1796
01:16:48,180 --> 01:16:46,690
managing inventory and all the stuff

1797
01:16:50,640 --> 01:16:48,190
that goes along with with a modern

1798
01:16:52,440 --> 01:16:50,650
operation like this okay thank you

1799
01:16:54,570 --> 01:16:52,450
so here's a question from Ethan on

1800
01:16:56,700 --> 01:16:54,580
youtube he wanted to know Ethan wanted

1801
01:16:58,880 --> 01:16:56,710
to know if we're planning anything with

1802
01:17:00,000 --> 01:16:58,890
to do with quantum communication

1803
01:17:01,890 --> 01:17:00,010
satellites

1804
01:17:05,060 --> 01:17:01,900
I don't maybe that is related to

1805
01:17:08,100 --> 01:17:05,070
encryption or ours or encoding the data

1806
01:17:10,290 --> 01:17:08,110
so when people use the word quantum

1807
01:17:12,360 --> 01:17:10,300
in communications in the same breath it

1808
01:17:14,280 --> 01:17:12,370
could be many things but but but we are

1809
01:17:16,740 --> 01:17:14,290
doing research in quantum communications

1810
01:17:20,100 --> 01:17:16,750
it's one of the things that we might go

1811
01:17:21,660 --> 01:17:20,110
to for the next step of performance

1812
01:17:23,880 --> 01:17:21,670
improvement after optical for instance

1813
01:17:25,410 --> 01:17:23,890

and when I think of quantum

1814
01:17:29,010 --> 01:17:25,420
communications what I'm thinking of

1815
01:17:32,420 --> 01:17:29,020
specifically is two things two things

1816
01:17:35,130 --> 01:17:32,430
I'm thinking specifically one is is

1817
01:17:37,890 --> 01:17:35,140
taking the photons that we would

1818
01:17:39,990 --> 01:17:37,900
transmit over an optical channel and not

1819
01:17:41,460 --> 01:17:40,000
just measuring whether they exist or not

1820
01:17:43,140 --> 01:17:41,470
which is what we're gonna be doing in

1821
01:17:45,270 --> 01:17:43,150
the first generation but looking at

1822
01:17:46,710 --> 01:17:45,280
their States and carrying information in

1823
01:17:48,540 --> 01:17:46,720
the states of the photon not just the

1824
01:17:50,610 --> 01:17:48,550
presence or absence of the photon that's

1825
01:17:52,200 --> 01:17:50,620
classical quantum communications then

1826
01:17:55,050 --> 01:17:52,210
there's stuff like quantum entanglement

1827
01:17:57,930 --> 01:17:55,060
the idea is you if you pair photons at

1828
01:18:00,300 --> 01:17:57,940
the source and force them to to

1829
01:18:02,400 --> 01:18:00,310
synchronize their States and then move

1830
01:18:03,930 --> 01:18:02,410
one to the destination then you can

1831
01:18:06,210 --> 01:18:03,940
change the state of one and see the

1832
01:18:08,400 --> 01:18:06,220
change occur at some point on the other

1833
01:18:10,200 --> 01:18:08,410
one as well and we are doing research in

1834
01:18:12,060 --> 01:18:10,210
that there have been demonstrations on

1835
01:18:14,970 --> 01:18:12,070
the surface of the earth the Chinese

1836
01:18:17,160 --> 01:18:14,980
have put this in orbit I haven't even

1837
01:18:18,390 --> 01:18:17,170
seen the results yet that it's very

1838
01:18:20,520 --> 01:18:18,400

prominent at some point somebody's going

1839
01:18:22,320 --> 01:18:20,530
to make this work and we are definitely

1840
01:18:24,150 --> 01:18:22,330
following this and invest in a small

1841
01:18:26,520 --> 01:18:24,160
amount of our technology money to

1842
01:18:29,310 --> 01:18:26,530
understand it so that we're ready to to

1843
01:18:32,190 --> 01:18:29,320
take advantage of what comes there the

1844
01:18:36,420 --> 01:18:32,200
problem of the D that no no

1845
01:18:38,100 --> 01:18:36,430
unfortunately none of this none of this

1846
01:18:44,010 --> 01:18:38,110
is in conflict news in conflict with

1847
01:18:45,600 --> 01:18:44,020
Einstein's theory yet yeah is it

1848
01:18:47,250 --> 01:18:45,610
possible that long-term cost in

1849
01:18:49,260 --> 01:18:47,260
communications with these deep-space

1850
01:18:51,840 --> 01:18:49,270
spacecraft could potentially alter their

1851
01:18:56,010 --> 01:18:51,850
trajectories like similar to a solar

1852
01:18:57,930 --> 01:18:56,020
sail so yes it is at the levels that we

1853
01:18:59,400 --> 01:18:57,940
transmit to the spacecraft you'd be

1854
01:19:01,590 --> 01:18:59,410
hard-pressed to measure that difference

1855
01:19:03,030 --> 01:19:01,600
but if you have a large enough

1856
01:19:05,070 --> 01:19:03,040
collecting area on the spacecraft you

1857
01:19:06,540 --> 01:19:05,080
see a solar sail and you transmit with a

1858
01:19:08,580 --> 01:19:06,550
large transmitter from the earth you

1859
01:19:11,430 --> 01:19:08,590
will be able to move it and and in fact

1860
01:19:13,140 --> 01:19:11,440
there are designs for for demonstrations

1861
01:19:15,060 --> 01:19:13,150
of that technology we haven't done it

1862
01:19:17,340 --> 01:19:15,070
yet but that's something we could do

1863
01:19:20,460 --> 01:19:17,350

with the DSN is demonstrate if we can

1864
01:19:21,689 --> 01:19:20,470
put a solar sail out that we can

1865
01:19:23,760 --> 01:19:21,699
actually change the

1866
01:19:25,439 --> 01:19:23,770
the trajectory of the spacecraft with a

1867
01:19:27,330 --> 01:19:25,449
transmitter from the earth that's

1868
01:19:34,169 --> 01:19:27,340
absolutely that does not violate

1869
01:19:35,640 --> 01:19:34,179
Einstein either hi so is there a

1870
01:19:37,470 --> 01:19:35,650
specific reason why those three

1871
01:19:40,290 --> 01:19:37,480
locations like Madrid and Goldstone were

1872
01:19:41,750 --> 01:19:40,300
chosen to like build the antennas or is

1873
01:19:45,180 --> 01:19:41,760
it kind of just because of convenience

1874
01:19:47,250 --> 01:19:45,190
yes and no so from my first diagram that

1875
01:19:48,419 --> 01:19:47,260
showed the view Phaneuf and the North

1876
01:19:50,430 --> 01:19:48,429
Pole of the earth you want to have

1877
01:19:52,500 --> 01:19:50,440
things that are about equidistant around

1878
01:19:55,350 --> 01:19:52,510
the earth and that's just operationally

1879
01:19:56,820 --> 01:19:55,360
so there's something always in view but

1880
01:19:57,810 --> 01:19:56,830
you also know how much of other things

1881
01:20:00,600 --> 01:19:57,820
you want to be in a place that has

1882
01:20:02,760 --> 01:20:00,610
reasonable weather that has a good work

1883
01:20:05,760 --> 01:20:02,770
force intelligent people who can operate

1884
01:20:08,090 --> 01:20:05,770
the antennas for you that is politically

1885
01:20:10,050 --> 01:20:08,100
aligned with the US the policy wise

1886
01:20:12,689 --> 01:20:10,060
understand like for instance when the

1887
01:20:14,430 --> 01:20:12,699
DSN was was knew we had an antenna in

1888
01:20:17,760 --> 01:20:14,440

South Africa but when apartheid went to

1889
01:20:20,550 --> 01:20:17,770
affect we moved that complex away so

1890
01:20:22,800 --> 01:20:20,560
politics does come into play so all

1891
01:20:24,060 --> 01:20:22,810
these things there when one of my

1892
01:20:25,439 --> 01:20:24,070
friends at headquarters says there's

1893
01:20:30,510 --> 01:20:25,449
science and there's political science

1894
01:20:32,689 --> 01:20:30,520
that both valid okay thank you yeah well

1895
01:20:36,479 --> 01:20:32,699
I think unless there any other questions

1896
01:20:38,100 --> 01:20:36,489
then I think that's all though I'll talk

1897
01:20:40,229 --> 01:20:38,110
about tonight here I'm with regard to

1898
01:20:42,419 --> 01:20:40,239
the DSN so thanks to all of our speakers

1899
01:20:43,950 --> 01:20:42,429
and to all of you for being here

1900
01:20:47,880 --> 01:20:43,960
thanks to everyone who's watching online

1901
01:20:49,650 --> 01:20:47,890
as well our next show is on January 11th

1902
01:20:51,630 --> 01:20:49,660
so join us right here for our

1903
01:20:54,190 --> 01:20:51,640
celebration of 50 years of exploring

1904
01:21:07,640 --> 01:20:54,200
Mars we'll see you then good night