1
00:00:11,480 --> 00:00:07,280
NASA's Jet Propulsion Laboratory

2
00:00:13,910 --> 00:00:11,490
presents the von Karman lecture a series

3
00:00:16,279 --> 00:00:13,920
of talks by scientists and engineers who

4
00:00:24,810 --> 00:00:16,289
are exploring our planet our solar

5
00:00:29,529 --> 00:00:27,279
hi everybody welcome to our monthly

6
00:00:30,759 --> 00:00:29,539
public lecture at the NASA's Jet

7
00:00:33,729 --> 00:00:30,769
Propulsion Laboratory the von Karman

8
00:00:36,910 --> 00:00:33,739
series here in Pasadena California my

9
00:00:39,970 --> 00:00:36,920
name is Preston dikes well 30 years ago

10
00:00:44,079 --> 00:00:39,980
there occurred a singular moment in

11
00:00:46,630 --> 00:00:44,089
human history 3.7 billion miles from

12
00:00:49,390 --> 00:00:46,640
Earth at the cold and distant outer

13
00:00:51,579 --> 00:00:49,400

fringes of our solar system a robotic

14
00:00:54,880 --> 00:00:51,589
emissary looked back one last time

15
00:00:57,880 --> 00:00:54,890
before heading out word to the stars it

16
00:01:00,039 --> 00:00:57,890
swept its gaze across the little family

17
00:01:02,829 --> 00:01:00,049
of worlds that orbit our Sun pausing

18
00:01:05,079 --> 00:01:02,839
briefly to collect a few feeble photons

19
00:01:07,750 --> 00:01:05,089
of light from each one to build up a

20
00:01:09,670 --> 00:01:07,760
sort of family portrait a last look

21
00:01:12,580 --> 00:01:09,680
around before closing its eyes forever

22
00:01:17,130 --> 00:01:12,590
and heading off into the great expanse

23
00:01:20,950 --> 00:01:17,140
of the galaxy this was the first time

24
00:01:24,100 --> 00:01:20,960
our species was capable of capturing for

25
00:01:28,750 --> 00:01:24,110
itself a view of its home solar system

26
00:01:33,700 --> 00:01:28,760
from the outside for every species it's

27
00:01:36,399 --> 00:01:33,710
a moment that comes only once now if

28
00:01:38,560 --> 00:01:36,409
that sounded like I might have been

29
00:01:40,810 --> 00:01:38,570
inspired by the words of a certain

30
00:01:43,140 --> 00:01:40,820
well-known planetary scientist whose

31
00:01:46,030 --> 00:01:43,150
voice continues to be very much missed

32
00:01:48,580 --> 00:01:46,040
that's no accident in tonight's show

33
00:01:51,610 --> 00:01:48,590
you'll hear about a very special image

34
00:01:53,830 --> 00:01:51,620
known as the pale blue dot the image of

35
00:01:56,620 --> 00:01:53,840
our home planet captured by that robotic

36
00:01:58,690 --> 00:01:56,630
emissary which was the vision of the

37
00:02:01,240 --> 00:01:58,700
great Carl Sagan and if you spend

38
00:02:04,450 --> 00:02:01,250

several others on NASA's Voyager mission

39
00:02:06,190 --> 00:02:04,460
and later will pivot to the future to

40
00:02:09,399 --> 00:02:06,200
hear about the quest to image another

41
00:02:12,940 --> 00:02:09,409
pale blue dot a distant earth-like world

42
00:02:14,920 --> 00:02:12,950
orbiting another star now we'll have two

43
00:02:16,630 --> 00:02:14,930
talks tonight on these profound topics

44
00:02:18,550 --> 00:02:16,640
and then we'll take your questions and

45
00:02:20,020 --> 00:02:18,560
if you're watching our live webcast on

46
00:02:23,080 --> 00:02:20,030
YouTube we'll work in a few of your

47
00:02:25,990 --> 00:02:23,090
questions as well so our first speaker

48
00:02:27,880 --> 00:02:26,000
is an astronomer at JPL he currently

49
00:02:30,070 --> 00:02:27,890
serves as the project manager for NASA's

50
00:02:32,320 --> 00:02:30,080
NuStar Space Telescope and has helped

51
00:02:35,020 --> 00:02:32,330
develop missions to many of the worlds

52
00:02:37,000 --> 00:02:35,030
in our solar system dr. Tyrell is the

53
00:02:38,979 --> 00:02:37,010
discoverer of four moons our

54
00:02:41,199 --> 00:02:38,989
around Saturn Uranus and Neptune and

55
00:02:43,089 --> 00:02:41,209
together with his Voyager mission

56
00:02:45,670 --> 00:02:43,099
colleague Brad Smith he took the first

57
00:02:49,750 --> 00:02:45,680
pictures of another solar system that is

58
00:02:53,740 --> 00:02:49,760
the debris disc that surrounds the

59
00:02:55,509 --> 00:02:53,750
nearby star beta Pictoris but 30 years

60
00:02:58,690 --> 00:02:55,519
ago he was a member of the Voyager

61
00:03:00,520 --> 00:02:58,700
imaging team and tonight he's here to

62
00:03:04,809 --> 00:03:00,530
share some perspective on the story of

63
00:03:15,759 --> 00:03:04,819

how this remarkable photo came to be

64
00:03:17,259 --> 00:03:15,769
please welcome rich Terrell I tell you

65
00:03:19,509 --> 00:03:17,269
it's a real pleasure to do this in this

66
00:03:21,849 --> 00:03:19,519
auditorium because we're in the midst of

67
00:03:24,009 --> 00:03:21,859
Voyager so what I'm going to do is I

68
00:03:25,720 --> 00:03:24,019
normally give a science talk and tell

69
00:03:27,280 --> 00:03:25,730
you how important our science is and how

70
00:03:28,990 --> 00:03:27,290
great it is and and and all the

71
00:03:30,490 --> 00:03:29,000
wonderful things we discovered this

72
00:03:32,229 --> 00:03:30,500
could be a little bit different we're

73
00:03:36,640 --> 00:03:32,239
gonna be talking about this incredible

74
00:03:39,970 --> 00:03:36,650
machine that was launched 47:43 years

75
00:03:42,039 --> 00:03:39,980
ago and and and designed you know early

76
00:03:44,890 --> 00:03:42,049
on and we're gonna talk about the

77
00:03:47,979 --> 00:03:44,900
personalities and the the difficulties

78
00:03:49,420 --> 00:03:47,989
and hurdles to create this image and we

79
00:03:50,710 --> 00:03:49,430
are gonna say dare I say it

80
00:03:53,949 --> 00:03:50,720
feelings we're gonna talk about the

81
00:03:56,349 --> 00:03:53,959
emotion and the and the meaning of this

82
00:04:01,420 --> 00:03:56,359
particular image so without further ado

83
00:04:03,220 --> 00:04:01,430
let's go back in time to 1968 this was

84
00:04:06,430 --> 00:04:03,230
the this was a terrible year by the way

85
00:04:08,890 --> 00:04:06,440
you may remember it this was the height

86
00:04:11,559 --> 00:04:08,900
of the Vietnam War was the meal I

87
00:04:14,319 --> 00:04:11,569
massacre it was the Tet Offensive it was

88
00:04:16,300 --> 00:04:14,329

the North Koreans stole the Pueblo or

89
00:04:19,750 --> 00:04:16,310
captured the Pueblo from us it was the

90
00:04:22,060 --> 00:04:19,760
murder of Martin Luther King and Bobby

91
00:04:24,279 --> 00:04:22,070
Kennedy was a Chicago riots just

92
00:04:26,710 --> 00:04:24,289
everything was going terribly that year

93
00:04:28,659 --> 00:04:26,720
until the very end the very end the

94
00:04:31,770 --> 00:04:28,669
christmas eve the apollo astronauts

95
00:04:35,080 --> 00:04:31,780
Borman Lovell and Anders gave us

96
00:04:39,820 --> 00:04:35,090
inspirational reading of scriptures of

97
00:04:42,070 --> 00:04:39,830
of Genesis from the moon and these were

98
00:04:44,170 --> 00:04:42,080
the first human beings to get far enough

99
00:04:46,930 --> 00:04:44,180
from the earth to actually see the earth

100
00:04:48,460 --> 00:04:46,940
as a planet and many many philosophers

101
00:04:50,920 --> 00:04:48,470
and scientists and and

102
00:04:53,830 --> 00:04:50,930
Engineers kind of thought that at that

103
00:04:56,830 --> 00:04:53,840
moment when the inhumanity finally sees

104
00:04:58,720 --> 00:04:56,840
the earth as alone in space a spaceship

105
00:05:00,280 --> 00:04:58,730
earth it would change everything there

106
00:05:03,610 --> 00:05:00,290
would be peace on earth goodwill to

107
00:05:08,170 --> 00:05:03,620
mankind we all know how that worked out

108
00:05:09,640 --> 00:05:08,180
a couple years later in 1972 Apollo 17

109
00:05:11,920 --> 00:05:09,650
captured this image this is a so-called

110
00:05:15,160 --> 00:05:11,930
Blue Marble image and this is an iconic

111
00:05:17,380 --> 00:05:15,170
image this was on the cover of the Whole

112
00:05:18,940 --> 00:05:17,390
Earth Catalog it was the default image

113
00:05:22,720 --> 00:05:18,950

on the first iPhones I had it on my

114
00:05:27,990 --> 00:05:22,730
iPhone for forever really almost my dogs

115
00:05:31,660 --> 00:05:28,000
on it now but anyway I show you that

116
00:05:33,460 --> 00:05:31,670
anyway it doesn't work her name is Daisy

117
00:05:36,250 --> 00:05:33,470
she's really cute anyway

118
00:05:38,500 --> 00:05:36,260
this so here we were now used to seeing

119
00:05:42,610 --> 00:05:38,510
the earth as this you know this iconic

120
00:05:45,159 --> 00:05:42,620
large image no borders we all live on

121
00:05:48,430 --> 00:05:45,169
this on this world and we were hoping

122
00:05:50,440 --> 00:05:48,440
that would make a change it you know but

123
00:05:52,510 --> 00:05:50,450
but what happens now when we shrink this

124
00:05:54,550 --> 00:05:52,520
dot this this image to a dot and that's

125
00:05:58,300 --> 00:05:54,560
really the story of the pale blue dot so

126
00:06:00,490 --> 00:05:58,310
in 1972 a remarkable thing happened we

127
00:06:03,100 --> 00:06:00,500
realized that there was an opportunity

128
00:06:05,409 --> 00:06:03,110
that year to launch a spacecraft in a

129
00:06:07,150 --> 00:06:05,419
few years that would be able to do the

130
00:06:08,860 --> 00:06:07,160
Grand Tour of the entire solar system

131
00:06:10,450 --> 00:06:08,870
it's an event that only happens once

132
00:06:13,330 --> 00:06:10,460
every hundred and seventy-eight years

133
00:06:15,310 --> 00:06:13,340
give or take a year and you know the

134
00:06:17,469 --> 00:06:15,320
last opportunity was Thomas Jefferson he

135
00:06:19,690 --> 00:06:17,479
missed out completely on doing it but

136
00:06:21,760 --> 00:06:19,700
Nixon did it okay he actually approved

137
00:06:25,150 --> 00:06:21,770
the mission and NASA launched it and

138
00:06:28,090 --> 00:06:25,160

designed in 1972 using 1972 technology

139
00:06:31,900 --> 00:06:28,100
this spacecraft Voyager this one right

140
00:06:34,120 --> 00:06:31,910
here in our room and the remarkable

141
00:06:35,530 --> 00:06:34,130
thing about this is and it was so

142
00:06:39,010 --> 00:06:35,540
remarkable is that it's hard to

143
00:06:42,340 --> 00:06:39,020
understand how barbarically simple the

144
00:06:44,080 --> 00:06:42,350
technologies were in 1972 okay here's

145
00:06:50,409 --> 00:06:44,090
the spacecraft you've seen it there

146
00:06:52,120 --> 00:06:50,419
there's a whoops let me go back oops how

147
00:06:54,550 --> 00:06:52,130
do I go back oh it's the wrong button

148
00:06:57,310 --> 00:06:54,560
there we go technology that's what we

149
00:06:58,779 --> 00:06:57,320
have so there's a button here that gives

150
00:07:00,130 --> 00:06:58,789
me a pointer so this is the stand

151
00:07:01,220 --> 00:07:00,140
platform and we'll be talking about

152
00:07:02,900 --> 00:07:01,230
these two cameras here the

153
00:07:06,890 --> 00:07:02,910
wide angle and narrow angle cameras on

154
00:07:09,140 --> 00:07:06,900
this platform here we go so here we're

155
00:07:13,630 --> 00:07:09,150
building the spacecraft putting it

156
00:07:16,730 --> 00:07:13,640
together again with 1972 technology 1972

157
00:07:20,060 --> 00:07:16,740
the complexity of Voyager was equivalent

158
00:07:21,770 --> 00:07:20,070
to 2000 color TV sets and I used the

159
00:07:22,940 --> 00:07:21,780
word color TV sets because that was a

160
00:07:24,740 --> 00:07:22,950
big thing in those days

161
00:07:27,500 --> 00:07:24,750
in fact 1972 was the first year that

162
00:07:30,380 --> 00:07:27,510
color TVs outsold black and white

163
00:07:32,360 --> 00:07:30,390

televisions and if you remember color

164
00:07:33,920 --> 00:07:32,370
TVs in those days you couldn't have

165
00:07:35,630 --> 00:07:33,930
mantra very long before you have to go

166
00:07:37,010 --> 00:07:35,640
up to him and smack him on the side and

167
00:07:39,430 --> 00:07:37,020
get him to work they were very unstable

168
00:07:42,290 --> 00:07:39,440
to think about having one of these

169
00:07:45,560 --> 00:07:42,300
having 2,000 of these television sets

170
00:07:48,320 --> 00:07:45,570
running for 40 years and not having any

171
00:07:49,910 --> 00:07:48,330
ability to touch them is remarkable and

172
00:07:53,450 --> 00:07:49,920
that's the kind of technology we flew

173
00:07:56,060 --> 00:07:53,460
the the spacecraft didn't have

174
00:07:58,270 --> 00:07:56,070
solid-state memory okay it had a any

175
00:08:00,290 --> 00:07:58,280
type 8-track tape recorder and

176
00:08:02,480 --> 00:08:00,300
remarkable tape recorder thousand feet

177
00:08:04,820 --> 00:08:02,490
of tape if you remember 8-track tapes in

178
00:08:06,740 --> 00:08:04,830
those days the thing you really remember

179
00:08:08,720 --> 00:08:06,750
about him are these things tangled tapes

180
00:08:10,820 --> 00:08:08,730
is trying to get them back into the set

181
00:08:12,590 --> 00:08:10,830
you know these and this to think that

182
00:08:14,510 --> 00:08:12,600
this thing is run for it for 40 years

183
00:08:17,170 --> 00:08:14,520
and in the tape recorder still works on

184
00:08:20,030 --> 00:08:17,180
voyagers it's just absolutely remarkable

185
00:08:22,610 --> 00:08:20,040
yeah this is the the vidicon this is the

186
00:08:25,280 --> 00:08:22,620
camera this is the the you know the the

187
00:08:27,140 --> 00:08:25,290
tiny sensor inside your smartphone this

188
00:08:29,450 --> 00:08:27,150

is the thing this is sits on my desk and

189
00:08:31,820 --> 00:08:29,460
it's you know it's it's large the sensor

190
00:08:33,530 --> 00:08:31,830
is right on this end and what happens is

191
00:08:34,700 --> 00:08:33,540
the light falls in this end it's it's

192
00:08:36,469 --> 00:08:34,710
photoluminescence

193
00:08:38,210 --> 00:08:36,479
and it's right out with a with an

194
00:08:40,339 --> 00:08:38,220
electron beam that goes across here

195
00:08:42,560 --> 00:08:40,349
because it's an electron beam it's

196
00:08:45,020 --> 00:08:42,570
susceptible to magnetic fields it can

197
00:08:48,050 --> 00:08:45,030
bend those beams so what we have to do

198
00:08:49,310 --> 00:08:48,060
is we have to paint a series of dots on

199
00:08:51,110 --> 00:08:49,320
the front of this thing you'll see how

200
00:08:54,050 --> 00:08:51,120
that comes into our picture later on in

201
00:08:57,140 --> 00:08:54,060
the story so so that's the that's the

202
00:08:59,300 --> 00:08:57,150
camera the camera itself is right here

203
00:09:02,750 --> 00:08:59,310
the camera weighs it's got two two

204
00:09:07,640 --> 00:09:02,760
lenses a wide-angle and an aerial camera

205
00:09:09,710 --> 00:09:07,650
it weighs 84 pounds it takes 42 watts of

206
00:09:11,750 --> 00:09:09,720
electricity to run the thing I mean just

207
00:09:13,670 --> 00:09:11,760
and it's about a thousand times less

208
00:09:16,040 --> 00:09:13,680
sensitive to light in the the

209
00:09:18,110 --> 00:09:16,050
in your pockets right now just

210
00:09:19,250 --> 00:09:18,120
absolutely remarkable to think that we

211
00:09:21,070 --> 00:09:19,260
use the camera like this to take

212
00:09:25,579 --> 00:09:21,080
pictures of of the rings of Neptune

213
00:09:28,519 --> 00:09:25,589

which were half the reflectivity of suit

214
00:09:30,230 --> 00:09:28,529
against a jet black background with one

215
00:09:31,940 --> 00:09:30,240
thousandth the light that we have here

216
00:09:33,829 --> 00:09:31,950
on earth is just absolutely remarks

217
00:09:35,060 --> 00:09:33,839
mind-blowing that we had the audacity to

218
00:09:36,829 --> 00:09:35,070
actually think we can build a machine

219
00:09:38,690 --> 00:09:36,839
like this and we did build a machine

220
00:09:40,430 --> 00:09:38,700
like this the computers the biggest

221
00:09:42,440 --> 00:09:40,440
computers in the world in those days in

222
00:09:44,510 --> 00:09:42,450
1972 where things you have in your

223
00:09:46,389 --> 00:09:44,520
pocket and I'm not talking about your

224
00:09:48,800 --> 00:09:46,399
phones I'm talking about your key fobs

225
00:09:50,810 --> 00:09:48,810
ok I tried to think of something in my

226
00:09:53,780 --> 00:09:50,820
house that has got the equivalent

227
00:09:56,269 --> 00:09:53,790
computation that Voyager has and you

228
00:09:58,340 --> 00:09:56,279
know my shaver is smarter my electric

229
00:10:00,639 --> 00:09:58,350
toothbrush is smarter you know don't get

230
00:10:03,410 --> 00:10:00,649
me started about doorbells but you know

231
00:10:04,940 --> 00:10:03,420
there's really nothing in our in our

232
00:10:07,790 --> 00:10:04,950
consciousness that is that is like this

233
00:10:12,019 --> 00:10:07,800
but nevertheless we did this we launched

234
00:10:15,230 --> 00:10:12,029
it it's at 40 word memory in in its in

235
00:10:16,970 --> 00:10:15,240
its flight data system okay so here's

236
00:10:19,340 --> 00:10:16,980
the here's the wide angle and narrow

237
00:10:20,690 --> 00:10:19,350
angle camera the wide angle you think a

238
00:10:22,519 --> 00:10:20,700

wide angle I can take a picture of this

239
00:10:24,620 --> 00:10:22,529
room the wide angle camera has the field

240
00:10:28,070 --> 00:10:24,630
of view of looking through a soda straw

241
00:10:30,110 --> 00:10:28,080
that's a soda straw right there and then

242
00:10:33,800 --> 00:10:30,120
the narrow angle camera is you know

243
00:10:36,550 --> 00:10:33,810
pretty close up it's a about a 1/4 of a

244
00:10:39,980 --> 00:10:36,560
degree of sorry four tenths of a degree

245
00:10:42,470 --> 00:10:39,990
okay so here's the last time any human

246
00:10:44,390 --> 00:10:42,480
beings set their eyes on Voyager they

247
00:10:46,640 --> 00:10:44,400
were closing it up inside the spacecraft

248
00:10:50,420 --> 00:10:46,650
these people were the last people to see

249
00:10:52,790 --> 00:10:50,430
it and touch it that was in 1977 it was

250
00:10:54,440 --> 00:10:52,800
launched in 1977 and shortly after

251
00:10:56,269 --> 00:10:54,450
launch and by the way you think these

252
00:10:59,150 --> 00:10:56,279
2000 TV sets and before you even get to

253
00:11:00,860 --> 00:10:59,160
use them you shake the heck out of them

254
00:11:03,650 --> 00:11:00,870
in a spacecraft launch

255
00:11:06,650 --> 00:11:03,660
so anyway right after we launched a

256
00:11:08,449 --> 00:11:06,660
couple days out at about three and a

257
00:11:10,370 --> 00:11:08,459
half a million miles away from the earth

258
00:11:11,690 --> 00:11:10,380
a 7.5 million miles away from here we

259
00:11:12,920 --> 00:11:11,700
took this remarkable picture of the

260
00:11:14,569 --> 00:11:12,930
Earth and the moon together it was the

261
00:11:16,760 --> 00:11:14,579
first time the earth and the moon were

262
00:11:19,490 --> 00:11:16,770
taken together as objects this is an

263
00:11:21,410 --> 00:11:19,500

absolutely iconic first image it's the

264
00:11:24,650 --> 00:11:21,420
very very first light that went through

265
00:11:26,260 --> 00:11:24,660
the cameras on Voyager ok so and that's

266
00:11:27,220 --> 00:11:26,270
that's one book and that will

267
00:11:29,080 --> 00:11:27,230
at the very very end of this

268
00:11:30,100 --> 00:11:29,090
presentation so let's talk about

269
00:11:32,650 --> 00:11:30,110
personalities

270
00:11:34,510 --> 00:11:32,660
this is headstone edy stone is the heart

271
00:11:36,250 --> 00:11:34,520
and soul of voyager he's the project

272
00:11:38,020 --> 00:11:36,260
scientist has been the project scientist

273
00:11:39,880 --> 00:11:38,030
from day one he is still the project

274
00:11:43,030 --> 00:11:39,890
scientist I just interviewed him in his

275
00:11:45,310 --> 00:11:43,040
office about a week ago and stones an

276
00:11:47,440 --> 00:11:45,320
absolutely remarkable personality he is

277
00:11:50,650 --> 00:11:47,450
the perfect person for this job this job

278
00:11:53,020 --> 00:11:50,660
entails dealing with other scientists

279
00:11:55,570 --> 00:11:53,030
other scientific teams all the other

280
00:11:58,480 --> 00:11:55,580
different instruments on onboard Voyager

281
00:12:00,280 --> 00:11:58,490
and and negotiating and making sure that

282
00:12:02,410 --> 00:12:00,290
this science program is balanced and

283
00:12:04,930 --> 00:12:02,420
everybody is happy or I should say

284
00:12:07,210 --> 00:12:04,940
everybody is equally unhappy because

285
00:12:09,010 --> 00:12:07,220
there's limited limited amount of time

286
00:12:11,140 --> 00:12:09,020
limit amount of resources everybody

287
00:12:12,820 --> 00:12:11,150
wants to do everything they can and you

288
00:12:15,400 --> 00:12:12,830

can't possibly do everything it was the

289
00:12:16,990 --> 00:12:15,410
negotiator of this this is the imaging

290
00:12:18,520 --> 00:12:17,000
science team I was a member of the

291
00:12:20,620 --> 00:12:18,530
imaging science team I'm not in this

292
00:12:22,300 --> 00:12:20,630
picture but I'll show you later this is

293
00:12:24,010 --> 00:12:22,310
the core team the core team that was

294
00:12:25,600 --> 00:12:24,020
chosen by NASA at the very very

295
00:12:28,480 --> 00:12:25,610
beginning before they added anybody this

296
00:12:31,450 --> 00:12:28,490
is the head of the team Brad Smith Brad

297
00:12:35,100 --> 00:12:31,460
Smith was could be perceived as is maybe

298
00:12:37,720 --> 00:12:35,110
a bully okay he had a team that really

299
00:12:39,940 --> 00:12:37,730
sucked up most of the resources it was

300
00:12:41,920 --> 00:12:39,950
the imaging team but it was the imaging

301
00:12:43,480 --> 00:12:41,930
team of the eyes a Voyager most of the

302
00:12:44,830 --> 00:12:43,490
discoveries we've made most of the

303
00:12:46,690 --> 00:12:44,840
things we've seen for the public are

304
00:12:48,610 --> 00:12:46,700
through the imaging team so they are the

305
00:12:50,080 --> 00:12:48,620
eyes of Voyager next to him is Carl

306
00:12:53,920 --> 00:12:50,090
Sagan Carl Sagan was a celebrity

307
00:12:57,280 --> 00:12:53,930
astronomer Carl Sagan had a gift to put

308
00:13:01,060 --> 00:12:57,290
incredible concepts into into almost

309
00:13:02,560 --> 00:13:01,070
poetic words you go up to Carl and you

310
00:13:04,960 --> 00:13:02,570
tell him about some discovery you made

311
00:13:07,330 --> 00:13:04,970
and Carl would repeat back what you just

312
00:13:08,710 --> 00:13:07,340
told you is you mean and he repeated

313
00:13:11,920 --> 00:13:08,720

back and it would sound better than you

314
00:13:14,050 --> 00:13:11,930
said it and then he go in other words

315
00:13:17,080 --> 00:13:14,060
and he'd say it again and this time it

316
00:13:18,640 --> 00:13:17,090
was beautiful and I think we all really

317
00:13:20,440 --> 00:13:18,650
learned from Carl that that was really

318
00:13:21,910 --> 00:13:20,450
we really had to reflect more on what we

319
00:13:23,410 --> 00:13:21,920
were doing in order to communicate like

320
00:13:25,270 --> 00:13:23,420
that and he core was really remarkable

321
00:13:26,740 --> 00:13:25,280
any result come into the picture later

322
00:13:31,990 --> 00:13:26,750
he'll have a party ten years from this

323
00:13:34,540 --> 00:13:32,000
picture Candi Hansen and this is Andy

324
00:13:37,150 --> 00:13:34,550
Collins are both instrumental in

325
00:13:40,420 --> 00:13:37,160
creating they were the experiment reps

326
00:13:43,720 --> 00:13:40,430
and they would take the desires of the

327
00:13:46,900 --> 00:13:43,730
and then put them in to make them into

328
00:13:49,180 --> 00:13:46,910
sequences this is the same day I just

329
00:13:50,650 --> 00:13:49,190
want to show you that there I am I was a

330
00:13:53,290 --> 00:13:50,660
member of the imaging team invited by

331
00:13:55,990 --> 00:13:53,300
Brad I just got out of school with a PhD

332
00:13:58,960 --> 00:13:56,000
from Caltech in astronomy planetary

333
00:14:00,519 --> 00:13:58,970
science this was the absolute most

334
00:14:02,079 --> 00:14:00,529
remarkable thing to ever happen to

335
00:14:03,670 --> 00:14:02,089
somebody to start a career doing

336
00:14:05,590 --> 00:14:03,680
something like this to be on the imaging

337
00:14:07,630 --> 00:14:05,600
team on Voyager it was just absolutely

338
00:14:09,639 --> 00:14:07,640

remarkable I owe a great debt of thanks

339
00:14:12,250 --> 00:14:09,649
to to Brad he's been a great friend of

340
00:14:14,590 --> 00:14:12,260
mine unfortunately he passed away

341
00:14:17,949 --> 00:14:14,600
a year and a half ago Carl passed away

342
00:14:19,870 --> 00:14:17,959
in 1976 these this is a little spectrum

343
00:14:21,670 --> 00:14:19,880
I want to show here this is Carl he's a

344
00:14:23,170 --> 00:14:21,680
scientist on the imaging team and he's

345
00:14:24,940 --> 00:14:23,180
the visionary he's got an idea and he

346
00:14:26,980 --> 00:14:24,950
wants to make that idea happen this is

347
00:14:29,050 --> 00:14:26,990
Brad Brad's the head of the imaging team

348
00:14:31,449 --> 00:14:29,060
and his he's got to balance all the

349
00:14:34,060 --> 00:14:31,459
desires the imaging team and and and

350
00:14:37,269 --> 00:14:34,070
justify doing these things and then he

351
00:14:39,610 --> 00:14:37,279
says take that to the the project

352
00:14:41,380 --> 00:14:39,620
scientist Ed stone and that stone has to

353
00:14:43,570 --> 00:14:41,390
balance what the imaging team wants to

354
00:14:46,329 --> 00:14:43,580
do with all the other teams and this

355
00:14:48,910 --> 00:14:46,339
this is this is doctor know this this is

356
00:14:53,650 --> 00:14:48,920
the project manager in this case this is

357
00:14:56,740 --> 00:14:53,660
esker davis the project manager for the

358
00:14:59,380 --> 00:14:56,750
actual pale blue dot was norm Haines but

359
00:15:01,060 --> 00:14:59,390
this is the guy who his job and I'm a

360
00:15:02,500 --> 00:15:01,070
project manager as well now but I'm a

361
00:15:05,050 --> 00:15:02,510
scientist so I have a little bit of

362
00:15:06,640 --> 00:15:05,060
different flair for this but but his his

363
00:15:08,290 --> 00:15:06,650

job is to really not to break anything

364
00:15:10,320 --> 00:15:08,300
and to make sure they live within

365
00:15:13,360 --> 00:15:10,330
resources and the resources are scarce

366
00:15:14,590 --> 00:15:13,370
so he you know you look on his face is

367
00:15:16,660 --> 00:15:14,600
you know this is the guy who never

368
00:15:17,620 --> 00:15:16,670
wanted to confront did confront him you

369
00:15:19,810 --> 00:15:17,630
really want to have a rock-solid

370
00:15:21,880 --> 00:15:19,820
argument and the whole idea of the pale

371
00:15:22,360 --> 00:15:21,890
blue dot there's no science and the pale

372
00:15:25,050 --> 00:15:22,370
blue dot

373
00:15:27,699 --> 00:15:25,060
it's just visionary thing that Carl

374
00:15:29,650 --> 00:15:27,709
wanted to do thinking that it would be

375
00:15:31,390 --> 00:15:29,660
it would be a very very big benefit for

376
00:15:32,710 --> 00:15:31,400
Humanity yeah but you got to get that

377
00:15:34,390 --> 00:15:32,720
through the science team you got to get

378
00:15:36,160 --> 00:15:34,400
the project team and you got to get it

379
00:15:40,600 --> 00:15:36,170
through that guy's face okay so that's

380
00:15:42,790 --> 00:15:40,610
just that's tough all right so so let's

381
00:15:44,980 --> 00:15:42,800
go on here so now what I'm going to do

382
00:15:46,690 --> 00:15:44,990
is I'm going to race through the

383
00:15:48,760 --> 00:15:46,700
encounter I normally talk about the six

384
00:15:50,470 --> 00:15:48,770
incredible encounters we had in all the

385
00:15:52,510 --> 00:15:50,480
great science I'm going to just skip all

386
00:15:54,190 --> 00:15:52,520
that okay so I'm going to tell you very

387
00:15:56,290 --> 00:15:54,200
very briefly what it was

388
00:15:58,480 --> 00:15:56,300

to do that but I thought what better way

389
00:16:02,020 --> 00:15:58,490
to tell you is not to tell you from the

390
00:16:04,350 --> 00:16:02,030
rich Terrell from 19 from 2020 but to

391
00:16:05,890 --> 00:16:04,360
tell you from the rich Terrell from from

392
00:16:08,200 --> 00:16:05,900
1989

393
00:16:09,790 --> 00:16:08,210
this is anthe anger souls party after

394
00:16:12,760 --> 00:16:09,800
the Neptune encounter and there was a

395
00:16:13,990 --> 00:16:12,770
film crew they're from a KCET film

396
00:16:16,120 --> 00:16:14,000
called the astronomers and they were

397
00:16:20,140 --> 00:16:16,130
filming me and Brad for part of that

398
00:16:22,120 --> 00:16:20,150
series and I just had maybe a few too

399
00:16:24,550 --> 00:16:22,130
many champagne celebrating this thing

400
00:16:35,940 --> 00:16:24,560
but this is what this is what it was

401
00:16:38,260 --> 00:16:35,950
like emotionally it's one of the saddest

402
00:16:40,420 --> 00:16:38,270
here for the last ten years I've worked

403
00:16:43,030 --> 00:16:40,430
on this mission always anticipated one

404
00:16:44,860 --> 00:16:43,040
encounter after the next realizing

405
00:16:51,670 --> 00:16:44,870
they'd be fantastic realizing that

406
00:16:53,830 --> 00:16:51,680
there'd be things totally unexpected the

407
00:16:56,640 --> 00:16:53,840
first reconnaissance of the entire solar

408
00:17:03,610 --> 00:16:56,650
system you've rewritten the text books

409
00:17:06,550 --> 00:17:03,620
what do you do next what you do next is

410
00:17:10,329 --> 00:17:06,560
you have children it's another amazing

411
00:17:12,610 --> 00:17:10,339
experience okay so so here we are we've

412
00:17:16,000 --> 00:17:12,620
now left the solar system with with

413
00:17:18,180 --> 00:17:16,010

Voyager 1 Voyager 1 is now it's just

414
00:17:20,410 --> 00:17:18,190
that it's Saturn encounters now

415
00:17:23,010 --> 00:17:20,420
projecting up toward this end of the

416
00:17:26,770 --> 00:17:23,020
solar system Voyager 2 is now on its way

417
00:17:29,560 --> 00:17:26,780
to Uranus and then to Neptune so what

418
00:17:31,630 --> 00:17:29,570
happens now is mmm Carl has this great

419
00:17:33,070 --> 00:17:31,640
idea to take a picture of the earth and

420
00:17:34,300 --> 00:17:33,080
the first opportunity to take the

421
00:17:37,450 --> 00:17:34,310
picture of the earth is right after the

422
00:17:38,980 --> 00:17:37,460
Saturn encounter with Voyager 1 but

423
00:17:42,700 --> 00:17:38,990
nobody wants to do that because we're

424
00:17:44,500 --> 00:17:42,710
too busy scaling down the teams and

425
00:17:46,990 --> 00:17:44,510
getting everything ready so that's a no

426
00:17:49,360 --> 00:17:47,000
that's the first time second time is in

427
00:17:51,400 --> 00:17:49,370
1985 right before the Uranus encounter

428
00:17:53,650 --> 00:17:51,410
with Voyager to Voyager ones up here

429
00:17:55,180 --> 00:17:53,660
howling its comet is in the solar system

430
00:17:57,130 --> 00:17:55,190
we can take a picture of Halley's Comet

431
00:17:59,860 --> 00:17:57,140
and get kind of 3d view from the earth

432
00:18:01,450 --> 00:17:59,870
and from from Voyager the answer's no we

433
00:18:03,580 --> 00:18:01,460
got to prepare for the Uranus encounter

434
00:18:04,810 --> 00:18:03,590
right after the years encounter Halley's

435
00:18:07,660 --> 00:18:04,820
Comet is still there but it's now it's

436
00:18:09,010 --> 00:18:07,670
getting faint no we can't do that

437
00:18:10,510 --> 00:18:09,020
we have to stand down the team between

438
00:18:12,790 --> 00:18:10,520

Uranus and Neptune because there's a

439
00:18:13,930 --> 00:18:12,800
five year or four year gap here so the

440
00:18:17,320 --> 00:18:13,940
team's not gonna be able to do that

441
00:18:19,240 --> 00:18:17,330
that's another no tried again in 1989

442
00:18:23,050 --> 00:18:19,250
before the Neptune encounter that was a

443
00:18:26,170 --> 00:18:23,060
know finally on the sixth attempt six

444
00:18:28,480 --> 00:18:26,180
times the charm the answer was yes in

445
00:18:31,090 --> 00:18:28,490
other gentleman by the name of Bill

446
00:18:32,890 --> 00:18:31,100
Cosman was involved in in actually

447
00:18:34,840 --> 00:18:32,900
getting the idea that instead of just

448
00:18:36,400 --> 00:18:34,850
taking a picture of the earth we could

449
00:18:38,710 --> 00:18:36,410
take a picture of multiple objects and

450
00:18:39,790 --> 00:18:38,720
by this time his he developed an idea to

451
00:18:42,100 --> 00:18:39,800
take a picture of the entire solar

452
00:18:43,540 --> 00:18:42,110
system using the wide angle and narrow

453
00:18:45,760 --> 00:18:43,550
angle cameras now far enough from the

454
00:18:46,900 --> 00:18:45,770
Sun where we wouldn't destroy burn up

455
00:18:48,880 --> 00:18:46,910
the other instruments and that was a

456
00:18:50,380 --> 00:18:48,890
real concern we needed to use some of

457
00:18:52,210 --> 00:18:50,390
these other instruments for calibration

458
00:18:54,280 --> 00:18:52,220
for other things and nobody wanted to do

459
00:18:56,620 --> 00:18:54,290
that nobody got behind this ed stone was

460
00:18:58,930 --> 00:18:56,630
not supportive until the sixth attempt

461
00:19:01,360 --> 00:18:58,940
when it was our last chance it was the

462
00:19:03,010 --> 00:19:01,370
absolute last chance because the teams

463
00:19:04,890 --> 00:19:03,020

were going to go away after Neptune we

464
00:19:08,380 --> 00:19:04,900
would not have the capability to do that

465
00:19:09,880 --> 00:19:08,390
last chance all right let's do it so the

466
00:19:12,220 --> 00:19:09,890
only other stumbling block was it's

467
00:19:15,070 --> 00:19:12,230
going to cost 2.2 million dollars

468
00:19:17,260 --> 00:19:15,080
because of all the complexity of having

469
00:19:19,180 --> 00:19:17,270
to develop a sequence and and analysis

470
00:19:19,960 --> 00:19:19,190
getting the date on the ground where we

471
00:19:22,090 --> 00:19:19,970
gonna get that money

472
00:19:24,340 --> 00:19:22,100
this was the sequence that was designed

473
00:19:26,380 --> 00:19:24,350
it was a series of wide-angle camera

474
00:19:27,940 --> 00:19:26,390
views all the way from Neptune into the

475
00:19:29,770 --> 00:19:27,950
inner part of the solar system nobody

476
00:19:31,450 --> 00:19:29,780
ever pointed the camera within fifteen

477
00:19:33,390 --> 00:19:31,460
degrees of the Sun that was a constraint

478
00:19:35,590 --> 00:19:33,400
now we're gonna point it at the Sun

479
00:19:37,450 --> 00:19:35,600
fortunately it'll be the last pictures

480
00:19:40,180 --> 00:19:37,460
that Voyager ever takes so if we burn up

481
00:19:41,560 --> 00:19:40,190
the camera we don't really care but

482
00:19:43,030 --> 00:19:41,570
nevertheless it's it tough we didn't

483
00:19:45,100 --> 00:19:43,040
know what the camera was gonna respond

484
00:19:46,750 --> 00:19:45,110
to how much scattered light there was

485
00:19:50,740 --> 00:19:46,760
going to be over there so that was that

486
00:19:52,420 --> 00:19:50,750
was a concern 2.2 million dollars it

487
00:19:56,080 --> 00:19:52,430
turned out that norm Hayes the project

488
00:19:58,990 --> 00:19:56,090

manager Eddie stone and the assistant

489
00:20:02,140 --> 00:19:59,000
administrator of NASA Len Fisk were at

490
00:20:05,020 --> 00:20:02,150
the Athenaeum at Caltech and Carl and Ed

491
00:20:06,820 --> 00:20:05,030
stone came and talked to him and he they

492
00:20:08,470 --> 00:20:06,830
convinced him Carl convinced him very

493
00:20:09,730 --> 00:20:08,480
very eloquently that we really have to

494
00:20:13,030 --> 00:20:09,740
take this image it was the last chance

495
00:20:16,060 --> 00:20:13,040
he said you do it I'll find you the

496
00:20:18,550 --> 00:20:16,070
money and here's the view from from

497
00:20:20,560 --> 00:20:18,560
Voyager at the solar system and this is

498
00:20:21,379 --> 00:20:20,570
in fact the images that were taken laid

499
00:20:24,739 --> 00:20:21,389
up on top of that

500
00:20:28,489 --> 00:20:24,749
geometry these are the images of this of

501
00:20:31,069 --> 00:20:28,499
this Grand Tour sorry this this family

502
00:20:33,349 --> 00:20:31,079
portrait and here the individual images

503
00:20:35,089 --> 00:20:33,359
of the planets that were taken we

504
00:20:37,190 --> 00:20:35,099
actually had this mosaic here in this

505
00:20:39,049 --> 00:20:37,200
von Karman auditorium and the thing

506
00:20:41,989 --> 00:20:39,059
about it was that the image of the earth

507
00:20:43,969 --> 00:20:41,999
had to be replaced every couple weeks

508
00:20:45,469 --> 00:20:43,979
because people would touch it people

509
00:20:47,599 --> 00:20:45,479
wanted to touch the image of the earth

510
00:20:49,599 --> 00:20:47,609
it was really quite of amazing

511
00:20:52,039 --> 00:20:49,609
Candi Hansen which I showed you before

512
00:20:54,379 --> 00:20:52,049
this is not the earth this is a picture

513
00:20:57,649 --> 00:20:54,389

of Uranus but I wanted to show you a raw

514
00:21:00,289 --> 00:20:57,659
image avoid your RAW images were kind of

515
00:21:01,940 --> 00:21:00,299
nasty they have bright pixels all over

516
00:21:04,219 --> 00:21:01,950
the place these splotches these are the

517
00:21:05,869 --> 00:21:04,229
dark rizzo elements if you're taking a

518
00:21:07,789 --> 00:21:05,879
picture of a dot and the dot is behind

519
00:21:11,419 --> 00:21:07,799
one of those resolves you're not gonna

520
00:21:13,579 --> 00:21:11,429
see it and candy her job was to look at

521
00:21:15,709 --> 00:21:13,589
this image this image is greatly cleaned

522
00:21:17,209 --> 00:21:15,719
up from what it was she couldn't find

523
00:21:19,039 --> 00:21:17,219
the earth in this image

524
00:21:21,259 --> 00:21:19,049
it took her a half hour to finally

525
00:21:25,609 --> 00:21:21,269
realize that this little tiny splotch on

526
00:21:27,799 --> 00:21:25,619
top of this this this ray of scattered

527
00:21:30,919 --> 00:21:27,809
light is the earth and here's a better

528
00:21:33,259 --> 00:21:30,929
view of that a more enhanced version of

529
00:21:36,669 --> 00:21:33,269
that and we zoom in on that and you'll

530
00:21:39,649 --> 00:21:36,679
see it's it actually is a pale pink dot

531
00:21:42,199 --> 00:21:39,659
sort of blue this was taken in three

532
00:21:45,739 --> 00:21:42,209
filters not red green and blue as we

533
00:21:49,219 --> 00:21:45,749
normally do but blue but green blue and

534
00:21:52,399 --> 00:21:49,229
violet so it's it's not as blue as it

535
00:21:54,049 --> 00:21:52,409
would be if we had a red filter so there

536
00:21:56,509 --> 00:21:54,059
are no better ways to describe this

537
00:21:58,430 --> 00:21:56,519
thing then the way which Carl Sagan did

538
00:22:01,879 --> 00:21:58,440

and we got permission to use his words

539
00:22:06,409 --> 00:22:01,889
in his voice on this so I'd like to play

540
00:22:15,629 --> 00:22:12,559
that's here that's home that's us on it

541
00:22:19,169 --> 00:22:15,639
everyone you love everyone you know

542
00:22:23,029 --> 00:22:19,179
everyone you ever heard of every human

543
00:22:27,019 --> 00:22:23,039
being who ever was lived out their lives

544
00:22:28,949 --> 00:22:27,029
the aggregate or joy and suffering

545
00:22:31,699 --> 00:22:28,959
thousands of confident religions

546
00:22:35,609 --> 00:22:31,709
ideologies and economic doctrines every

547
00:22:38,009 --> 00:22:35,619
hunter and forager every hero and coward

548
00:22:40,709 --> 00:22:38,019
every creator and destroyer of

549
00:22:44,219 --> 00:22:40,719
civilization every King and peasant

550
00:22:47,909 --> 00:22:44,229
every young couple in love every mother

551
00:22:51,479 --> 00:22:47,919
and father hopeful child inventor and

552
00:22:55,529 --> 00:22:51,489
Explorer every teacher of morals every

553
00:22:59,279 --> 00:22:55,539
corrupt politician every superstar every

554
00:23:01,829 --> 00:22:59,289
Supreme Leader every saint and sinner in

555
00:23:07,430 --> 00:23:01,839
the history of our species lived there

556
00:23:12,809 --> 00:23:07,440
on a mote of dust suspended in a sunbeam

557
00:23:18,269 --> 00:23:12,819
the earth is a very small stage in a

558
00:23:21,689 --> 00:23:18,279
vast cosmic arena think of the rivers of

559
00:23:25,169 --> 00:23:21,699
blood spilled by all those generals and

560
00:23:26,999 --> 00:23:25,179
emperors so that in glory and triumph

561
00:23:31,950 --> 00:23:27,009
they could become the momentary masters

562
00:23:34,019 --> 00:23:31,960
of a fraction of a dot

563
00:23:37,320 --> 00:23:34,029

think of the endless cruelties visited

564
00:23:40,499 --> 00:23:37,330
by the inhabitants of one corner of this

565
00:23:43,799 --> 00:23:40,509
pixel on the scarcely distinguishable

566
00:23:45,950 --> 00:23:43,809
inhabitants of some other corner how

567
00:23:49,139 --> 00:23:45,960
frequent their misunderstandings how

568
00:23:52,460 --> 00:23:49,149
eager they are to kill one another how

569
00:23:57,200 --> 00:23:52,470
fervent their hatreds

570
00:23:59,700 --> 00:23:57,210
our posturings our imagined

571
00:24:01,799 --> 00:23:59,710
self-importance the delusion that we

572
00:24:05,399 --> 00:24:01,809
have some privileged position in the

573
00:24:10,980 --> 00:24:05,409
universe are challenged by this point of

574
00:24:16,109 --> 00:24:10,990
pale light our planet is a lonely speck

575
00:24:20,720 --> 00:24:16,119
in the great enveloping cosmic dark in

576
00:24:23,999 --> 00:24:20,730
our obscurity in all this vastness there

577
00:24:28,440 --> 00:24:24,009
is no hint that help will come from

578
00:24:30,690 --> 00:24:28,450
elsewhere to save us from ourselves the

579
00:24:34,109 --> 00:24:30,700
earth is the only world known so far to

580
00:24:36,869 --> 00:24:34,119
harbor life there is nowhere else at

581
00:24:38,539 --> 00:24:36,879
least in the near future to which our

582
00:24:43,520 --> 00:24:38,549
species could migrate

583
00:24:46,730 --> 00:24:43,530
visit yes settle

584
00:24:51,470 --> 00:24:46,740
not yet like it or not for the moment

585
00:24:53,270 --> 00:24:51,480
the earth is where we make our stand it

586
00:24:55,300 --> 00:24:53,280
has been said that astronomy is a

587
00:24:59,420 --> 00:24:55,310
humbling and character-building

588
00:25:01,850 --> 00:24:59,430

experience there is perhaps no better

589
00:25:07,750 --> 00:25:01,860
demonstration of the folly of human

590
00:25:10,670 --> 00:25:07,760
conceits than this distant image to me

591
00:25:13,940 --> 00:25:10,680
it underscores our responsibility to

592
00:25:17,180 --> 00:25:13,950
deal more kindly with one another and to

593
00:25:27,560 --> 00:25:17,190
preserve and cherish the pale blue dot

594
00:25:30,380 --> 00:25:27,570
the only home we've ever known Thank You

595
00:25:33,410 --> 00:25:30,390
Carl Sagan mm-hmm I really miss him and

596
00:25:37,970 --> 00:25:33,420
thanks very much to endure in for

597
00:25:40,880 --> 00:25:37,980
allowing us to use those okay so here's

598
00:25:42,740 --> 00:25:40,890
the bookends this was the first image

599
00:25:44,510 --> 00:25:42,750
that that Voyager took and this is the

600
00:25:46,730 --> 00:25:44,520
last light that had ever recorded and

601
00:25:50,150 --> 00:25:46,740
that is the the picture of the earth the

602
00:25:53,300 --> 00:25:50,160
narrow angle view of the earth again in

603
00:25:57,950 --> 00:25:53,310
this in this in a scattered light from

604
00:26:00,800 --> 00:25:57,960
3.7 billion miles away I want to show

605
00:26:02,830 --> 00:26:00,810
you the the family portrait these are

606
00:26:05,420 --> 00:26:02,840
the close-ups of the planets that we

607
00:26:07,460 --> 00:26:05,430
found in our in our solar system we

608
00:26:09,590 --> 00:26:07,470
image Mars unfortunately couldn't be

609
00:26:11,480 --> 00:26:09,600
imaged it was a crescent the very very

610
00:26:13,880 --> 00:26:11,490
thin Crescent was only one DeeAnn above

611
00:26:17,420 --> 00:26:13,890
the background and it was too close to

612
00:26:19,190 --> 00:26:17,430
the Sun to really appear Uranus and

613
00:26:21,530 --> 00:26:19,200

Neptune appear as streaks because these

614
00:26:23,960 --> 00:26:21,540
are 15 second exposures and there was

615
00:26:26,750 --> 00:26:23,970
some spacecraft motion at the time earth

616
00:26:29,440 --> 00:26:26,760
is less than a eighth of a pixel wide

617
00:26:32,480 --> 00:26:29,450
and Jupiter and Saturn are barely

618
00:26:33,530 --> 00:26:32,490
resolved but what I want to do is I want

619
00:26:34,940 --> 00:26:33,540
to look at this front of this picture

620
00:26:38,540 --> 00:26:34,950
from another point of view I want to

621
00:26:40,820 --> 00:26:38,550
remove the labels and there are a

622
00:26:43,010 --> 00:26:40,830
trillion stars in our galaxy and

623
00:26:47,330 --> 00:26:43,020
probably more than a trillion planets

624
00:26:49,880 --> 00:26:47,340
out there so with our enormous enormous

625
00:26:52,520 --> 00:26:49,890
ly capable telescopes and coupled with

626
00:26:55,100 --> 00:26:52,530
silicon eyes we're now going to start to

627
00:26:56,780 --> 00:26:55,110
image the light from these faint points

628
00:26:59,210 --> 00:26:56,790
these planets

629
00:27:00,860 --> 00:26:59,220
these worlds around nearby stars and

630
00:27:02,930 --> 00:27:00,870
we'll have a collection of images like

631
00:27:06,560 --> 00:27:02,940
this the pale blue dots and yellow dots

632
00:27:09,410 --> 00:27:06,570
and red dots and imagine if these are

633
00:27:11,990 --> 00:27:09,420
pictures of extrasolar planets how would

634
00:27:13,670 --> 00:27:12,000
we know the inverse of what we've done

635
00:27:15,470 --> 00:27:13,680
now is instead of zooming out we're

636
00:27:19,190 --> 00:27:15,480
zooming and how do we know which ones of

637
00:27:22,430 --> 00:27:19,200
these five five of these have systems of

638
00:27:24,950 --> 00:27:22,440

moons only one doesn't how would we know

639
00:27:27,860 --> 00:27:24,960
that three of these have moons with

640
00:27:29,440 --> 00:27:27,870
oceans buried beneath the ice how would

641
00:27:32,810 --> 00:27:29,450
we know that

642
00:27:36,770 --> 00:27:32,820
two of these are terrestrial worlds one

643
00:27:39,440 --> 00:27:36,780
of them oblique hot desolate world but

644
00:27:42,050 --> 00:27:39,450
one of them with an ocean four billion

645
00:27:47,480 --> 00:27:42,060
years old with more than four billion

646
00:27:50,410 --> 00:27:47,490
years of life with 600 million years of

647
00:27:53,110 --> 00:27:50,420
complex life and now recently

648
00:27:57,170 --> 00:27:53,120
intelligent life a civilization a

649
00:27:59,750 --> 00:27:57,180
civilization with the wisdom to build

650
00:28:02,120 --> 00:27:59,760
spacefaring machines that can go out and

651
00:28:05,960 --> 00:28:02,130
explore and then look back at themselves

652
00:28:09,490 --> 00:28:05,970
and make them realize that they are just

653
00:28:12,230 --> 00:28:09,500
motes of dust suspended in a sunbeam

654
00:28:22,970 --> 00:28:12,240
that's the story and significance of the

655
00:28:28,729 --> 00:28:25,039
I'll be back I'll be back with questions

656
00:28:34,269 --> 00:28:28,739
later thank you so much rich that is

657
00:28:41,539 --> 00:28:38,450
well let's pivot now from looking back

658
00:28:43,970 --> 00:28:41,549
to looking outward our next speaker is

659
00:28:45,979 --> 00:28:43,980
an astronomer who specializes in the

660
00:28:48,950 --> 00:28:45,989
study of planets outside our solar

661
00:28:50,690 --> 00:28:48,960
system for the past 10 years he's been

662
00:28:52,759 --> 00:28:50,700
busy commissioning a new science

663
00:28:54,649 --> 00:28:52,769

instrument n years I say 10 years one

664
00:28:56,359 --> 00:28:54,659
year in the past year he's been busy

665
00:28:58,789 --> 00:28:56,369
commissioning a new science instrument

666
00:28:59,239 --> 00:28:58,799
at Palomar Observatory north of San

667
00:29:01,669 --> 00:28:59,249
Diego

668
00:29:03,799 --> 00:29:01,679
it's called Nessie and it will study

669
00:29:06,649 --> 00:29:03,809
dozens of these alien worlds to help

670
00:29:08,090 --> 00:29:06,659
identify future targets for high

671
00:29:10,489 --> 00:29:08,100
precision observations of the

672
00:29:12,979 --> 00:29:10,499
atmospheres of exoplanets by the next

673
00:29:15,109 --> 00:29:12,989
generation of space telescopes in his

674
00:29:17,659 --> 00:29:15,119
career so far he studied at the Vatican

675
00:29:20,330 --> 00:29:17,669
Observatory and observed from such

676
00:29:23,299 --> 00:29:20,340
storied locations as Mauna Kea Kitt Peak

677
00:29:25,909 --> 00:29:23,309
and the Hubble Space Telescope tonight

678
00:29:28,609 --> 00:29:25,919
he's here to share with us just what it

679
00:29:31,340 --> 00:29:28,619
will take to capture the image of

680
00:29:34,129 --> 00:29:31,350
another pale blue dot a world perhaps

681
00:29:36,109 --> 00:29:34,139
not too different from earth in orbit

682
00:29:46,350 --> 00:29:36,119
around a distant star

683
00:29:51,909 --> 00:29:48,869
hi everyone how's everyone doing tonight

684
00:29:54,940 --> 00:29:51,919
great so my name is Rob I'm here to talk

685
00:29:57,669 --> 00:29:54,950
about imaging extrasolar pale blue dots

686
00:30:00,519 --> 00:29:57,679
so when I look at this image here of

687
00:30:03,100 --> 00:30:00,529
taking my voyager all of us are here

688
00:30:04,690 --> 00:30:03,110

right now everyone in this room everyone

689
00:30:06,850 --> 00:30:04,700
online that's watching this lecture

690
00:30:10,450 --> 00:30:06,860
right now we're all in that little speck

691
00:30:13,810 --> 00:30:10,460
all the experiences I've ever had are in

692
00:30:15,820 --> 00:30:13,820
significantly tiny and tiny in that one

693
00:30:19,330 --> 00:30:15,830
photo and what really blows me away

694
00:30:21,460 --> 00:30:19,340
about this photo is how empty the space

695
00:30:23,049 --> 00:30:21,470
is completely around the earth right you

696
00:30:27,700 --> 00:30:23,059
only see the earth and just maybe some

697
00:30:28,720 --> 00:30:27,710
some sunbeams otherwise space is big

698
00:30:31,509 --> 00:30:28,730
right

699
00:30:33,549 --> 00:30:31,519
the Sun is eight light minutes away from

700
00:30:35,619 --> 00:30:33,559
us so if we could travel at the speed of

701
00:30:38,649 --> 00:30:35,629
light it would take us eight minutes to

702
00:30:40,029 --> 00:30:38,659
reach our owns closest star our Sun so

703
00:30:42,849 --> 00:30:40,039
if the Sun were to magically turn off

704
00:30:45,849 --> 00:30:42,859
one day we wouldn't know for eight full

705
00:30:48,549 --> 00:30:45,859
minutes the next nearest star to us is

706
00:30:49,930 --> 00:30:48,559
about three light years away so if we

707
00:30:52,210 --> 00:30:49,940
could travel at the speed of light it

708
00:30:54,999 --> 00:30:52,220
would take us over three years to reach

709
00:30:58,330 --> 00:30:55,009
our nearest stellar neighbor space is

710
00:30:59,919 --> 00:30:58,340
absolutely giants and one of the people

711
00:31:02,109 --> 00:30:59,929
that says the best is when my favorite

712
00:31:04,659 --> 00:31:02,119
authors in Douglas Adams and he says

713
00:31:08,859 --> 00:31:04,669

that space is big you won't just believe

714
00:31:11,200 --> 00:31:08,869
how vastly hugely mind-bogglingly big it

715
00:31:13,180 --> 00:31:11,210
is I mean you may think it's a long way

716
00:31:17,919 --> 00:31:13,190
down the road to the chemists but that's

717
00:31:21,249 --> 00:31:17,929
just peanuts to space space is giants so

718
00:31:23,349 --> 00:31:21,259
we're all here right we had this great

719
00:31:26,649 --> 00:31:23,359
photo taken by Voyager that's looking

720
00:31:29,649 --> 00:31:26,659
here back at our home planet but the

721
00:31:32,259 --> 00:31:29,659
question is is someone taking a photo

722
00:31:34,989 --> 00:31:32,269
like this today for externalist why our

723
00:31:37,389 --> 00:31:34,999
solar system is there a life form out

724
00:31:40,720 --> 00:31:37,399
there that is taking a direct image of

725
00:31:45,779 --> 00:31:40,730
our home earth so does anyone know that

726
00:31:48,999 --> 00:31:45,789
we're here if so where is everyone else

727
00:31:50,470 --> 00:31:49,009
is there anyone else despite what the

728
00:31:53,950 --> 00:31:50,480
History Channel tells you we have not

729
00:31:56,970 --> 00:31:53,960
found aliens yet but most depressingly

730
00:31:58,870 --> 00:31:56,980
potentially maybe we're all along

731
00:32:01,120 --> 00:31:58,880
so as questions

732
00:32:03,880 --> 00:32:01,130
like these that just boggles my mind and

733
00:32:05,620 --> 00:32:03,890
always made me love the theory of

734
00:32:07,600 --> 00:32:05,630
astronomy and the field of astronomy and

735
00:32:10,900 --> 00:32:07,610
that's what inspired me to become an

736
00:32:13,960 --> 00:32:10,910
astronaut so no no that's that's not me

737
00:32:15,670 --> 00:32:13,970
that's me so when I show this photo a

738
00:32:17,500 --> 00:32:15,680

lot of people ask me Rob did you ever

739
00:32:19,750 --> 00:32:17,510
want to be an astronaut as a kid and the

740
00:32:22,990 --> 00:32:19,760
answer is a definitely hard no because

741
00:32:25,930 --> 00:32:23,000
I'm terrified of heights so that would

742
00:32:29,050 --> 00:32:25,940
not do so I became the next best thing

743
00:32:31,950 --> 00:32:29,060
and now I'm an exoplanet astronomer here

744
00:32:35,410 --> 00:32:31,960
at JPL so let's unpack what this means

745
00:32:37,930 --> 00:32:35,420
exoplanet well that's just short for

746
00:32:40,300 --> 00:32:37,940
extrasolar planet Shriners are kind of

747
00:32:42,580 --> 00:32:40,310
lazy sometimes as same words so if you

748
00:32:45,870 --> 00:32:42,590
shorten things it's a lot better so

749
00:32:49,270 --> 00:32:45,880
extrasolar planet becomes exoplanet

750
00:32:52,840 --> 00:32:49,280
extrasolar literally means beyond the

751
00:32:55,600 --> 00:32:52,850
solar system so an exoplanet or planet

752
00:32:58,840 --> 00:32:55,610
is planet so an exoplanet is any planet

753
00:33:00,910 --> 00:32:58,850
outside of our own solar system an

754
00:33:03,100 --> 00:33:00,920
astronomer I'm sure most of you know

755
00:33:05,170 --> 00:33:03,110
what that is that is someone who stares

756
00:33:08,680 --> 00:33:05,180
the sky more likely their computer for

757
00:33:10,660 --> 00:33:08,690
way too long so I'm an excellent

758
00:33:12,430 --> 00:33:10,670
astronomer here at JPL and when I

759
00:33:14,470 --> 00:33:12,440
specialized in as Preston said in my

760
00:33:17,190 --> 00:33:14,480
intro is I use both ground and

761
00:33:19,360 --> 00:33:17,200
space-based telescopes to characterize

762
00:33:21,730 --> 00:33:19,370
exoplanets planets outside of our solar

763
00:33:24,430 --> 00:33:21,740

system specifically I'm trying to

764
00:33:26,350 --> 00:33:24,440
understand and characterize their makeup

765
00:33:28,420 --> 00:33:26,360
what molecules are in their atmosphere

766
00:33:30,600 --> 00:33:28,430
do they have weather do they have clouds

767
00:33:33,310 --> 00:33:30,610
what's their temperature profile like

768
00:33:36,940 --> 00:33:33,320
ultimately then whittling our way down

769
00:33:38,410 --> 00:33:36,950
to saying and answering them at the the

770
00:33:42,160 --> 00:33:38,420
biggest question probably in our field

771
00:33:44,050 --> 00:33:42,170
is are we alone so before we look at

772
00:33:46,030 --> 00:33:44,060
where we are currently and where we're

773
00:33:47,650 --> 00:33:46,040
going to in the next few decades it's

774
00:33:48,160 --> 00:33:47,660
always helpful to look back into the

775
00:33:51,220 --> 00:33:48,170
past

776
00:33:53,080 --> 00:33:51,230
so exoplanets is arguably one of the

777
00:33:55,690 --> 00:33:53,090
youngest fields in all of astronomy it's

778
00:33:58,630 --> 00:33:55,700
been around 20 to 30 years and despite

779
00:34:01,570 --> 00:33:58,640
this being a relatively new field the

780
00:34:03,520 --> 00:34:01,580
idea of exoplanets and also life outside

781
00:34:06,730 --> 00:34:03,530
of our solar system is absolutely

782
00:34:08,800 --> 00:34:06,740
nothing new so Giordano Bruno was a 16th

783
00:34:10,419 --> 00:34:08,810
century philosopher there he is on the

784
00:34:11,579 --> 00:34:10,429
top right of this slide looked like ever

785
00:34:14,579 --> 00:34:11,589
Palpatine

786
00:34:17,039 --> 00:34:14,589
and he postulated a few hundreds of

787
00:34:20,309 --> 00:34:17,049
years ago that there was planets outside

788
00:34:23,309 --> 00:34:20,319

of our solar system Isaac Newton he was

789
00:34:25,169 --> 00:34:23,319
the founder of Fig Newtons right and his

790
00:34:26,639 --> 00:34:25,179
book where he describes the theory of

791
00:34:29,699 --> 00:34:26,649
gravity Principia

792
00:34:32,639 --> 00:34:29,709
he also says and if the fixed stars are

793
00:34:35,039 --> 00:34:32,649
the Centers of similar systems they will

794
00:34:38,149 --> 00:34:35,049
all be constructed to a similar design

795
00:34:41,009 --> 00:34:38,159
in other words we have eight eight

796
00:34:43,859 --> 00:34:41,019
planets not nine guys eight planets in

797
00:34:46,199 --> 00:34:43,869
our solar system so it stands to reason

798
00:34:48,359 --> 00:34:46,209
when we go out into the night sky we

799
00:34:51,359 --> 00:34:48,369
look at all those stars in the sky that

800
00:34:53,009 --> 00:34:51,369
they have planets as well and we know

801
00:34:53,609 --> 00:34:53,019
that these two dead guys are absolutely

802
00:34:56,999 --> 00:34:53,619
correct

803
00:34:58,079 --> 00:34:57,009
we've now discovered over 4,000

804
00:35:00,749 --> 00:34:58,089
exoplanets

805
00:35:02,459 --> 00:35:00,759
thanks to ground-based surveys thanks to

806
00:35:05,219 --> 00:35:02,469
missions such as NASA's Kepler mission

807
00:35:07,019 --> 00:35:05,229
we've been discovering 4,000 exoplanets

808
00:35:09,479 --> 00:35:07,029
is our technology gets better as our

809
00:35:11,910 --> 00:35:09,489
telescopes bit bigger as our precision

810
00:35:14,130 --> 00:35:11,920
gets better we're able to discover more

811
00:35:17,370 --> 00:35:14,140
and more exoplanets with increasing

812
00:35:20,039 --> 00:35:17,380
amount of time but the question is how

813
00:35:21,870 --> 00:35:20,049

do we find exoplanets there's actually

814
00:35:24,059 --> 00:35:21,880
many different ways that we can find

815
00:35:25,829 --> 00:35:24,069
exoplanets but the method I'll be

816
00:35:28,109 --> 00:35:25,839
focusing on tonight is the direct

817
00:35:31,469 --> 00:35:28,119
imaging method for all intents and

818
00:35:34,849 --> 00:35:31,479
purposes this is taking photographs of

819
00:35:38,279 --> 00:35:34,859
exoplanets but we run into a big problem

820
00:35:41,189 --> 00:35:38,289
how do we see an exoplanet through the

821
00:35:43,079 --> 00:35:41,199
glare of its host star so let's take a

822
00:35:45,269 --> 00:35:43,089
big planet like a jupiter-sized planet

823
00:35:47,939 --> 00:35:45,279
let's also make it really hot so it's

824
00:35:50,759 --> 00:35:47,949
really bright if we stuck that hot

825
00:35:53,099 --> 00:35:50,769
Jupiter planet around a sun-like star

826
00:35:56,849 --> 00:35:53,109
that Jupiter planet would still be a

827
00:35:58,890 --> 00:35:56,859
million times fainter than its star it's

828
00:36:01,289 --> 00:35:58,900
like looking for a firefly around a

829
00:36:03,449 --> 00:36:01,299
lighthouse now let's replace that

830
00:36:06,329 --> 00:36:03,459
jupiter-sized planet with an earth-sized

831
00:36:09,209 --> 00:36:06,339
planet that earth-sized planet would be

832
00:36:12,239 --> 00:36:09,219
10 billion times fainter than its star

833
00:36:15,150 --> 00:36:12,249
that's like looking for one alga around

834
00:36:18,150 --> 00:36:15,160
that same lighthouse so how do you block

835
00:36:20,489 --> 00:36:18,160
out the star and resolve the very very

836
00:36:24,120 --> 00:36:20,499
miniscule amount of light emitted or

837
00:36:25,170 --> 00:36:24,130
reflected by these planets how many of

838
00:36:27,750 --> 00:36:25,180

you saw

839
00:36:29,400 --> 00:36:27,760
solar eclipse a few years ago I'm

840
00:36:32,309 --> 00:36:29,410
assuming also getting a thousand virtual

841
00:36:34,349 --> 00:36:32,319
hands up on the Internet - so remember

842
00:36:36,599 --> 00:36:34,359
how when the moon passed in front of the

843
00:36:38,430 --> 00:36:36,609
Sun you could see the stars around the

844
00:36:40,380 --> 00:36:38,440
Sun or when the moon passing from the

845
00:36:43,019 --> 00:36:40,390
Sun you could see the solar corona we

846
00:36:45,809 --> 00:36:43,029
can do the same thing with exoplanets so

847
00:36:48,809 --> 00:36:45,819
here's a picture of a star this star has

848
00:36:50,849 --> 00:36:48,819
an exoplanet orbiting around it we can't

849
00:36:52,349 --> 00:36:50,859
see through the glare of the star so

850
00:36:55,410 --> 00:36:52,359
what we can do is you can actually block

851
00:36:58,500 --> 00:36:55,420
out the light of the star and resolved

852
00:37:00,750 --> 00:36:58,510
the light of the exoplanet just like the

853
00:37:02,309 --> 00:37:00,760
moon gotten away the Sun and blocked out

854
00:37:04,920 --> 00:37:02,319
the sun's light allowing us to see

855
00:37:08,519 --> 00:37:04,930
directly around the Sun we can make a

856
00:37:10,890 --> 00:37:08,529
pupil that blocks off the the light from

857
00:37:13,140 --> 00:37:10,900
the star and resolve the light of the

858
00:37:15,779 --> 00:37:13,150
exoplanet and this is basically how

859
00:37:18,900 --> 00:37:15,789
direct imaging methods technology works

860
00:37:20,160 --> 00:37:18,910
but because I love showing videos I'm

861
00:37:25,920 --> 00:37:20,170
going to show you one that does a little

862
00:37:28,019 --> 00:37:25,930
bit in more detail a coronagraph is a

863
00:37:30,690 --> 00:37:28,029

way to see distant planets hidden by the

864
00:37:32,460 --> 00:37:30,700
glare of the star they orbit the

865
00:37:34,529 --> 00:37:32,470
coronagraph reduces the light coming

866
00:37:38,130 --> 00:37:34,539
directly from the star to separate it

867
00:37:39,900 --> 00:37:38,140
from the light reflected by the planet w

868
00:37:41,940 --> 00:37:39,910
first doesn't block the star's light

869
00:37:44,819 --> 00:37:41,950
with an opaque disc as a simple

870
00:37:46,769 --> 00:37:44,829
coronagraph light instead it uses a

871
00:37:49,589 --> 00:37:46,779
combination of discs with complex

872
00:37:51,480 --> 00:37:49,599
patterns and light blocking stops to

873
00:37:53,670 --> 00:37:51,490
create destructive interference with the

874
00:37:56,130 --> 00:37:53,680
star's light effectively making it

875
00:37:59,250 --> 00:37:56,140
disappear while allowing the light from

876
00:38:01,109 --> 00:37:59,260
planets to pass through a complicating

877
00:38:02,700 --> 00:38:01,119
factor is that the light picks up small

878
00:38:05,099 --> 00:38:02,710
distortions as it reflects off the

879
00:38:06,870 --> 00:38:05,109
telescopes series of mirrors and these

880
00:38:09,049 --> 00:38:06,880
distortions can reduce the effectiveness

881
00:38:11,490 --> 00:38:09,059
of the destructive interference

882
00:38:13,380 --> 00:38:11,500
collecting more light increases the

883
00:38:15,599 --> 00:38:13,390
image signal but the planets are still

884
00:38:18,750 --> 00:38:15,609
hidden under blobs of leftover distorted

885
00:38:20,609 --> 00:38:18,760
starlight to remove these blobs the

886
00:38:22,890 --> 00:38:20,619
coronagraph has special deformable

887
00:38:25,559 --> 00:38:22,900
mirrors that can change shape by using

888
00:38:27,900 --> 00:38:25,569

hundreds of tiny Pistons this corrects

889
00:38:30,390 --> 00:38:27,910
the distortions in the light beam as the

890
00:38:32,519 --> 00:38:30,400
mirrors deform the blobs of light slowly

891
00:38:35,190 --> 00:38:32,529
begin to disappear revealing brighter

892
00:38:37,049 --> 00:38:35,200
planets further adjustment brings

893
00:38:39,870 --> 00:38:37,059
fainter planets into

894
00:38:42,299 --> 00:38:39,880
advanced software processes this data

895
00:38:44,939 --> 00:38:42,309
further improving the contrast and

896
00:38:46,829 --> 00:38:44,949
clarity of the image this processing

897
00:38:49,109 --> 00:38:46,839
makes objects more than a billion times

898
00:38:52,229 --> 00:38:49,119
fainter than the star visible as a

899
00:38:54,539 --> 00:38:52,239
result W first will provide the first

900
00:38:58,609 --> 00:38:54,549
look at individual planets in star

901
00:39:01,169 --> 00:38:58,619
systems that might be similar to our own

902
00:39:02,759 --> 00:39:01,179
so I'll be claiming back in describing w

903
00:39:04,709 --> 00:39:02,769
first in more detail a little bit later

904
00:39:07,229 --> 00:39:04,719
but that's basically how you can take

905
00:39:09,149 --> 00:39:07,239
direct images of exoplanets or what I

906
00:39:10,979 --> 00:39:09,159
like to call magic right

907
00:39:13,019 --> 00:39:10,989
it's pretty intense that we can block

908
00:39:14,999 --> 00:39:13,029
out the star's light then add basically

909
00:39:17,609 --> 00:39:15,009
a washer to get rid of that a residual

910
00:39:20,339 --> 00:39:17,619
amount of light and then to form a very

911
00:39:23,729 --> 00:39:20,349
thin mirror to get rid of the residual

912
00:39:25,709 --> 00:39:23,739
aberrations to further resolve the very

913
00:39:28,559 --> 00:39:25,719

minuscule light from those exoplanets

914
00:39:30,719 --> 00:39:28,569
and this method of using a chronograph

915
00:39:33,599 --> 00:39:30,729
has been used a lot especially from the

916
00:39:36,299 --> 00:39:33,609
ground so here is roughly seven to ten

917
00:39:39,390 --> 00:39:36,309
years worth of data of a directly imaged

918
00:39:41,899 --> 00:39:39,400
solar system so this is an extrasolar

919
00:39:44,279 --> 00:39:41,909
solar system these are four planets

920
00:39:46,829 --> 00:39:44,289
orbiting around their host star over a

921
00:39:49,049 --> 00:39:46,839
period of years this system is called HR

922
00:39:51,749 --> 00:39:49,059
8799 this is taken by a ground-based

923
00:39:54,120 --> 00:39:51,759
telescope and you can see there's the

924
00:39:57,299 --> 00:39:54,130
exact there's the actual pictures of the

925
00:40:01,859 --> 00:39:57,309
exoplanets slowly orbiting around their

926
00:40:06,329 --> 00:40:01,869
host star it's pretty incredible okay so

927
00:40:09,630 --> 00:40:06,339
now what so we've observed 49 exoplanets

928
00:40:11,909 --> 00:40:09,640
with the direct imaging method but how

929
00:40:14,819 --> 00:40:11,919
do we take the next steps from Planet

930
00:40:16,439 --> 00:40:14,829
detection now to characterization how do

931
00:40:18,839 --> 00:40:16,449
we answer the questions doesn't

932
00:40:21,329 --> 00:40:18,849
exoplanet have an atmosphere what

933
00:40:24,899 --> 00:40:21,339
molecules are present in that planet's

934
00:40:27,509 --> 00:40:24,909
atmosphere is that atmosphere conducive

935
00:40:31,829 --> 00:40:27,519
to life could it support life and if so

936
00:40:34,099 --> 00:40:31,839
does life exist on that exoplanet so a

937
00:40:36,779 --> 00:40:34,109
physical law that we use to characterize

938
00:40:39,359 --> 00:40:36,789

exoplanets is something called beer's

939
00:40:41,640 --> 00:40:39,369
law so right here I'm gonna give a short

940
00:40:43,349 --> 00:40:41,650
description of what beers law is that is

941
00:40:45,539 --> 00:40:43,359
studying for a test or doing homework

942
00:40:47,519 --> 00:40:45,549
while beer is involved making difficult

943
00:40:48,059 --> 00:40:47,529
classes such as physical chemistry more

944
00:40:50,519 --> 00:40:48,069
bearable

945
00:40:50,970 --> 00:40:50,529
I like that beers law I followed it a

946
00:40:52,890 --> 00:40:50,980
lot

947
00:40:55,109 --> 00:40:52,900
grad school but the beer is law I'm

948
00:40:56,760 --> 00:40:55,119
actually talking about is this so

949
00:40:59,609 --> 00:40:56,770
basically what beers law does is

950
00:41:02,190 --> 00:40:59,619
describes how light is scattered in and

951
00:41:04,530 --> 00:41:02,200
out of a beam so if I put a light bulb

952
00:41:07,020 --> 00:41:04,540
right here and I fill this chamber with

953
00:41:08,940 --> 00:41:07,030
gas that light will come out the other

954
00:41:11,670 --> 00:41:08,950
end a little bit dimmer in a different

955
00:41:14,160 --> 00:41:11,680
color another way to think about it is

956
00:41:15,810 --> 00:41:14,170
if we're observing a yellow star what

957
00:41:19,560 --> 00:41:15,820
color would expect that yellow star to

958
00:41:21,300 --> 00:41:19,570
be yellow exactly now what happens if I

959
00:41:23,340 --> 00:41:21,310
put a cloud of gas and fern day yellow

960
00:41:24,420 --> 00:41:23,350
star would it be at the same color or

961
00:41:28,740 --> 00:41:24,430
different it would be the same

962
00:41:30,480 --> 00:41:28,750
brightness or different different so the

963
00:41:32,910 --> 00:41:30,490

color the intensity would change a

964
00:41:35,670 --> 00:41:32,920
little bit so if we can observe what an

965
00:41:38,040 --> 00:41:35,680
object does look like and compare it to

966
00:41:40,170 --> 00:41:38,050
what it should look like we can actually

967
00:41:42,630 --> 00:41:40,180
use beers law to back out the

968
00:41:44,640 --> 00:41:42,640
composition of the absorbing medium so

969
00:41:46,890 --> 00:41:44,650
we could then say oh this cloud has

970
00:41:49,830 --> 00:41:46,900
molecules in it for example just by

971
00:41:52,080 --> 00:41:49,840
looking at how light is affected by the

972
00:41:54,510 --> 00:41:52,090
absorbing a medium it's pretty

973
00:41:56,910 --> 00:41:54,520
incredible so now if we change gears a

974
00:42:00,270 --> 00:41:56,920
little bit let's replace our star with a

975
00:42:02,820 --> 00:42:00,280
young bright hot planet so when planets

976
00:42:05,580 --> 00:42:02,830
form all they're dusting gas collapses

977
00:42:08,520 --> 00:42:05,590
on in on their core and that generates a

978
00:42:10,530 --> 00:42:08,530
lot of residual heat so this planet is

979
00:42:13,770 --> 00:42:10,540
very warm it's very young it has a very

980
00:42:16,410 --> 00:42:13,780
young a very warm core and that core is

981
00:42:17,970 --> 00:42:16,420
emitting light and heat but as that heat

982
00:42:20,490 --> 00:42:17,980
and light escapes out through the

983
00:42:22,410 --> 00:42:20,500
exoplanet it passes through the planet's

984
00:42:26,010 --> 00:42:22,420
atmosphere which is comparatively cooler

985
00:42:28,380 --> 00:42:26,020
and as a result that light changes color

986
00:42:30,180 --> 00:42:28,390
and changes the wavelength a little bit

987
00:42:33,000 --> 00:42:30,190
so then astronomers at the other end

988
00:42:35,130 --> 00:42:33,010

such as Young rub can determine that

989
00:42:37,800 --> 00:42:35,140
that planet has methane in its

990
00:42:40,020 --> 00:42:37,810
atmosphere let's think of another

991
00:42:41,730 --> 00:42:40,030
scenario if we have an exoplanet

992
00:42:44,460 --> 00:42:41,740
orbiting around the stars like Jupiter

993
00:42:47,670 --> 00:42:44,470
orbiting around our own Sun the star

994
00:42:49,349 --> 00:42:47,680
will emit its light and then that planet

995
00:42:52,200 --> 00:42:49,359
if it has clouds on its surface or

996
00:42:55,890 --> 00:42:52,210
reflective media it will then reflect

997
00:42:58,590 --> 00:42:55,900
the light from the star but since that

998
00:43:00,570 --> 00:42:58,600
planet more efficiently reflects light

999
00:43:02,040 --> 00:43:00,580
at different wavelengths the perceived

1000
00:43:03,990 --> 00:43:02,050
wavelength to us will look a little bit

1001
00:43:05,000 --> 00:43:04,000
different so the star is emitting yellow

1002
00:43:06,680 --> 00:43:05,010
light and we see

1003
00:43:08,720 --> 00:43:06,690
as red light and that allows astronomers

1004
00:43:10,880 --> 00:43:08,730
at the other end then to say that this

1005
00:43:14,120 --> 00:43:10,890
planet for example has clouds on its

1006
00:43:17,030 --> 00:43:14,130
surface so that's what beers law enables

1007
00:43:19,880 --> 00:43:17,040
us to do it allows us to characterize an

1008
00:43:23,680 --> 00:43:19,890
exoplanets composition by observing how

1009
00:43:26,930 --> 00:43:23,690
it emits absorbs and reflects light so

1010
00:43:29,599 --> 00:43:26,940
right here are actually some real-life

1011
00:43:32,810 --> 00:43:29,609
data of a few exoplanets that been

1012
00:43:35,200 --> 00:43:32,820
directly imaged right here on this axis

1013
00:43:38,240 --> 00:43:35,210

this is their flux their brightness and

1014
00:43:40,310 --> 00:43:38,250
effectively how warm they are on this

1015
00:43:42,740 --> 00:43:40,320
axis these are various wavelengths this

1016
00:43:46,130 --> 00:43:42,750
is across the infrared so what we've

1017
00:43:48,620 --> 00:43:46,140
done is we've measured the visa these

1018
00:43:52,880 --> 00:43:48,630
exoplanets light as a function of their

1019
00:43:55,940 --> 00:43:52,890
wavelength and you can see also that at

1020
00:43:58,010 --> 00:43:55,950
these wavelengths here these wavelengths

1021
00:44:00,560 --> 00:43:58,020
corresponding water so if I see an

1022
00:44:03,109 --> 00:44:00,570
absorption feature at those wavelengths

1023
00:44:05,480 --> 00:44:03,119
I can infer that water is the absorbing

1024
00:44:07,790 --> 00:44:05,490
species at these wavelengths these

1025
00:44:09,109 --> 00:44:07,800
correspond to methane so if I see a bump

1026
00:44:11,090 --> 00:44:09,119
or wiggle at these wavelengths they're

1027
00:44:15,920 --> 00:44:11,100
likely due to methane at this wavelength

1028
00:44:17,720 --> 00:44:15,930
over here is carbon monoxide so that's

1029
00:44:19,490 --> 00:44:17,730
how if we take the light of an exoplanet

1030
00:44:21,380 --> 00:44:19,500
and observe it in many different

1031
00:44:23,870 --> 00:44:21,390
wavelengths we can characterize the

1032
00:44:25,280 --> 00:44:23,880
composition of that exoplanet just by

1033
00:44:27,470 --> 00:44:25,290
lung Kia had some bumps and Wiggles on

1034
00:44:28,790 --> 00:44:27,480
the screen pretty nuts all right some of

1035
00:44:30,140 --> 00:44:28,800
the eagle-eyed people in the audience

1036
00:44:32,420 --> 00:44:30,150
might have noticed something peculiar

1037
00:44:34,010 --> 00:44:32,430
about this plot such as these gaps in

1038
00:44:37,880 --> 00:44:34,020

the data I don't have any guesses of

1039
00:44:41,230 --> 00:44:37,890
what those gaps could be here rhymes

1040
00:44:44,810 --> 00:44:41,240
with the Earth's atmosphere any one

1041
00:44:46,849 --> 00:44:44,820
Earth's atmosphere good job guys all

1042
00:44:49,640 --> 00:44:46,859
right get back awake get some coffee out

1043
00:44:53,330 --> 00:44:49,650
here so the Earth's atmosphere gets in

1044
00:44:55,580 --> 00:44:53,340
the way right so the earth has molecules

1045
00:44:58,030 --> 00:44:55,590
in the atmosphere good for us bad for

1046
00:45:01,609 --> 00:44:58,040
astronomy sometimes so water for example

1047
00:45:03,920 --> 00:45:01,619
absorbs a lot of infrared lights so that

1048
00:45:06,290 --> 00:45:03,930
causes these wavelengths to be

1049
00:45:07,280 --> 00:45:06,300
inaccessible from the ground so what's

1050
00:45:08,480 --> 00:45:07,290
the solution if you can't observe

1051
00:45:08,900 --> 00:45:08,490
something from the ground what do you do

1052
00:45:11,960 --> 00:45:08,910
next

1053
00:45:14,540 --> 00:45:11,970
exactly you go up into space so I'm

1054
00:45:17,930 --> 00:45:14,550
lucky enough to work on W first the wide

1055
00:45:19,819 --> 00:45:17,940
field Infrared Survey telescope

1056
00:45:21,800 --> 00:45:19,829
and this is a Hubble size space

1057
00:45:23,780 --> 00:45:21,810
telescope that'll have a hundred times

1058
00:45:26,000 --> 00:45:23,790
the field of view of Hubble and this

1059
00:45:27,950 --> 00:45:26,010
will study astrophysics dark energy and

1060
00:45:31,730 --> 00:45:27,960
exoplanets and this will be launching

1061
00:45:34,490 --> 00:45:31,740
tentatively in 2025 and I specifically

1062
00:45:37,069 --> 00:45:34,500
what I work on is w first chronograph

1063
00:45:39,530 --> 00:45:37,079

CGI the corona graphic instrument and

1064
00:45:41,329 --> 00:45:39,540
I'm on the product science team or I'm

1065
00:45:44,839 --> 00:45:41,339
developing how we're trying to figure

1066
00:45:46,700 --> 00:45:44,849
out how we actually process our images

1067
00:45:49,550 --> 00:45:46,710
and get rid of lots of noise from our

1068
00:45:52,400 --> 00:45:49,560
signals but CGI specifically is a

1069
00:45:54,980 --> 00:45:52,410
technology demonstration of space-based

1070
00:45:57,109 --> 00:45:54,990
imaging so W first will be the first

1071
00:45:58,910 --> 00:45:57,119
time w first CGI will be the first time

1072
00:46:01,730 --> 00:45:58,920
we're ever using deformable mirrors in

1073
00:46:04,220 --> 00:46:01,740
space combined with the coronagraph and

1074
00:46:06,470 --> 00:46:04,230
as a result it'll be a hundred times to

1075
00:46:08,599 --> 00:46:06,480
a thousand times better than any current

1076
00:46:11,180 --> 00:46:08,609
telescope we have today and this

1077
00:46:13,760 --> 00:46:11,190
technology is very necessary to help

1078
00:46:14,870 --> 00:46:13,770
pave the way for future missions future

1079
00:46:16,880 --> 00:46:14,880
missions I'll be launching in the next

1080
00:46:18,920 --> 00:46:16,890
few decades or so that I'll be able to

1081
00:46:20,780 --> 00:46:18,930
image an earth-like planet and

1082
00:46:23,540 --> 00:46:20,790
potentially discover life on that

1083
00:46:26,920 --> 00:46:23,550
planets so currently where we are right

1084
00:46:30,770 --> 00:46:26,930
now is we're limited typically to bright

1085
00:46:32,960 --> 00:46:30,780
hot planets large planets as well so

1086
00:46:34,700 --> 00:46:32,970
we're limited to hot super Jupiter

1087
00:46:37,010 --> 00:46:34,710
planets far away from their star

1088
00:46:38,660 --> 00:46:37,020

comparatively the distance from the star

1089
00:46:40,280 --> 00:46:38,670
matters because if you have something

1090
00:46:42,050 --> 00:46:40,290
that blocks all the star's light the

1091
00:46:44,150 --> 00:46:42,060
farther away from the star the less

1092
00:46:46,579 --> 00:46:44,160
likely it is also obscured by your

1093
00:46:48,319 --> 00:46:46,589
chronograph and if something's large and

1094
00:46:51,140 --> 00:46:48,329
bright gives off more flux so it's

1095
00:46:54,140 --> 00:46:51,150
easier to see what CGI will do is it'll

1096
00:46:57,050 --> 00:46:54,150
push that planetary detection ability

1097
00:46:58,160 --> 00:46:57,060
closer to their host star and also be

1098
00:47:00,470 --> 00:46:58,170
looking at planets that are

1099
00:47:03,650 --> 00:47:00,480
comparatively cooler so we'll actually

1100
00:47:07,130 --> 00:47:03,660
be able to look at true jupiter analogs

1101
00:47:10,150 --> 00:47:07,140
of w for a cgi and this step from hot

1102
00:47:12,680 --> 00:47:10,160
Jupiters down to jupiter-like planets is

1103
00:47:15,440 --> 00:47:12,690
absolutely necessary if we want to study

1104
00:47:16,760 --> 00:47:15,450
earth sized planets remember from the

1105
00:47:20,000 --> 00:47:16,770
slide I showed you before how much

1106
00:47:22,550 --> 00:47:20,010
dimmer earth sized objects are W first

1107
00:47:24,319 --> 00:47:22,560
will demonstrate the technology that we

1108
00:47:26,809 --> 00:47:24,329
will need on the next generation of

1109
00:47:28,940 --> 00:47:26,819
missions to actually observe an

1110
00:47:31,050 --> 00:47:28,950
earth-like planet around a solar type

1111
00:47:33,300 --> 00:47:31,060
star in an earth-like orbit

1112
00:47:37,440 --> 00:47:33,310
potentially discover life on those

1113
00:47:39,240 --> 00:47:37,450

exoplanets so currently here's all the

1114
00:47:41,040 --> 00:47:39,250
exoplanet missions and ground-based

1115
00:47:45,150 --> 00:47:41,050
telescopes that are sponsored by NASA

1116
00:47:47,820 --> 00:47:45,160
so we've direct imaging has been able to

1117
00:47:50,010 --> 00:47:47,830
benefit a lot from the lovely foundation

1118
00:47:51,000 --> 00:47:50,020
that's been established by ground-based

1119
00:47:54,420 --> 00:47:51,010
telescopes

1120
00:47:56,910 --> 00:47:54,430
Hubble Spitzer Kepler tests James Webb

1121
00:47:59,760 --> 00:47:56,920
and the next step the next telescope

1122
00:48:02,070 --> 00:47:59,770
will be W first establishing that this

1123
00:48:05,700 --> 00:48:02,080
method can work in space and we can get

1124
00:48:07,890 --> 00:48:05,710
to very dim objects then w first we'll

1125
00:48:09,150 --> 00:48:07,900
be demonstrating the technology for the

1126
00:48:11,430 --> 00:48:09,160
missions out here these are the

1127
00:48:14,370 --> 00:48:11,440
next-generation missions they'll be

1128
00:48:15,210 --> 00:48:14,380
launching in the 2030s and beyond the

1129
00:48:18,210 --> 00:48:15,220
two over here

1130
00:48:20,640 --> 00:48:18,220
Lavar and have X these are explicitly

1131
00:48:24,090 --> 00:48:20,650
designed to take direct images of

1132
00:48:25,650 --> 00:48:24,100
earth-like planets so potentially if one

1133
00:48:28,140 --> 00:48:25,660
of these two missions are selected and

1134
00:48:30,360 --> 00:48:28,150
they're launched they could potentially

1135
00:48:32,280 --> 00:48:30,370
detect an earth-like planet and then

1136
00:48:34,050 --> 00:48:32,290
finally answer that question if we're

1137
00:48:36,120 --> 00:48:34,060
alone in the universe by taking a

1138
00:48:43,530 --> 00:48:36,130

picture of an extrasolar pale blue dot

1139
00:48:49,320 --> 00:48:47,060
all right thank you so much Rob

1140
00:48:50,990 --> 00:48:49,330
absolutely fascinating stuff give us

1141
00:48:53,400 --> 00:48:51,000
just a moment here as we switch over

1142
00:48:55,560 --> 00:48:53,410
because it's time for questions from you

1143
00:48:57,450 --> 00:48:55,570
guys so if you have a question go ahead

1144
00:48:59,520 --> 00:48:57,460
and make your way to the to the

1145
00:49:01,350 --> 00:48:59,530
microphone in the in the audience there

1146
00:49:03,210 --> 00:49:01,360
and the the center aisle and we'll get

1147
00:49:05,670 --> 00:49:03,220
to a couple questions from those of you

1148
00:49:08,040 --> 00:49:05,680
who are watching our webcast on YouTube

1149
00:49:10,800 --> 00:49:08,050
as well so if I get my speakers back

1150
00:49:14,820 --> 00:49:10,810
here let's see and thanks so much to

1151
00:49:17,630 --> 00:49:14,830
Nikki I'm gonna hand for Nikki slepping

1152
00:49:23,940 --> 00:49:21,930
thanks so much my friend all right well

1153
00:49:27,540 --> 00:49:23,950
let's see while we're waiting let's I

1154
00:49:29,010 --> 00:49:27,550
guess I'll go ahead and and pull up a

1155
00:49:34,800 --> 00:49:29,020
question that we have from our YouTube

1156
00:49:37,170 --> 00:49:34,810
audience rich what I mean this is a big

1157
00:49:39,660 --> 00:49:37,180
one but what surprised you the most in

1158
00:49:42,090 --> 00:49:39,670
in in the Voyager mission it was a

1159
00:49:44,040 --> 00:49:42,100
mission full of absolutely chock-full of

1160
00:49:45,630 --> 00:49:44,050
surprises but what really stands out for

1161
00:49:47,610 --> 00:49:45,640
you the thing that surprised me the most

1162
00:49:50,220 --> 00:49:47,620
and this is maybe a cop-out question is

1163
00:49:52,470 --> 00:49:50,230

that the thing that we grew to expect

1164
00:49:55,410 --> 00:49:52,480
was we expected to be totally blown away

1165
00:49:57,810 --> 00:49:55,420
and surprised and I think the thing that

1166
00:50:00,420 --> 00:49:57,820
was most surprising was the first

1167
00:50:02,850 --> 00:50:00,430
encounter with with Jupiter everything

1168
00:50:05,280 --> 00:50:02,860
up until that point in in planetary

1169
00:50:06,990 --> 00:50:05,290
imaging was she kind of looks like the

1170
00:50:09,420 --> 00:50:07,000
moon kind of looks like the moon it's

1171
00:50:11,940 --> 00:50:09,430
like craters and we got the Jupiter we

1172
00:50:14,250 --> 00:50:11,950
saw moons that looked like looked like a

1173
00:50:15,900 --> 00:50:14,260
pizza we couldn't figure out what it was

1174
00:50:17,430 --> 00:50:15,910
and then when we did figure out what it

1175
00:50:20,850 --> 00:50:17,440
was it was one of those head exploding

1176
00:50:22,770 --> 00:50:20,860
moments it's a planet that has geology

1177
00:50:26,730 --> 00:50:22,780
that changes like weather does here a

1178
00:50:28,830 --> 00:50:26,740
planet the moon Io had erupted volcanoes

1179
00:50:31,650 --> 00:50:28,840
where we went back there four months

1180
00:50:33,150 --> 00:50:31,660
later with Voyager 2 and the surface was

1181
00:50:34,560 --> 00:50:33,160
different there was significant changes

1182
00:50:35,970 --> 00:50:34,570
on the surface it was just absolutely

1183
00:50:37,740 --> 00:50:35,980
mind-blowing is right out of science

1184
00:50:40,470 --> 00:50:37,750
fiction it's right here in our backyard

1185
00:50:43,350 --> 00:50:40,480
it's a real place all right I want to

1186
00:50:45,750 --> 00:50:43,360
give credit to at Cynergy 3k for that

1187
00:50:48,770 --> 00:50:45,760
question on yeah and here's our first

1188
00:50:52,700 --> 00:50:48,780

question from the audience go ahead I

1189
00:50:56,740 --> 00:50:52,710
think your last slide you you had a

1190
00:51:00,630 --> 00:50:56,750
missionary you didn't mention the Stars

1191
00:51:03,070 --> 00:51:00,640
and I understand I think there was a

1192
00:51:06,460 --> 00:51:03,080
presentation here of von Karman lecture

1193
00:51:08,410 --> 00:51:06,470
on that some years ago and I understand

1194
00:51:10,060 --> 00:51:08,420
the difficulties of starshade because

1195
00:51:14,460 --> 00:51:10,070
you have to get it lined up just right

1196
00:51:19,480 --> 00:51:14,470
and is there but could you combine

1197
00:51:21,630 --> 00:51:19,490
starshade along with all the the optics

1198
00:51:23,950 --> 00:51:21,640
you're doing to do even better

1199
00:51:27,430 --> 00:51:23,960
yeah great questions so for everyone

1200
00:51:29,260 --> 00:51:27,440
else starshade basically it's a way to

1201
00:51:30,520 --> 00:51:29,270
block out the star's light so it's

1202
00:51:33,160 --> 00:51:30,530
almost like an artificial moon it

1203
00:51:35,980 --> 00:51:33,170
literally looks like a giant star or

1204
00:51:37,810 --> 00:51:35,990
even a giant flower and actually unfurls

1205
00:51:40,120 --> 00:51:37,820
like origami and when it does is it

1206
00:51:42,340 --> 00:51:40,130
blocks out the light from the star so

1207
00:51:45,490 --> 00:51:42,350
you can better reduce the light with CGI

1208
00:51:48,730 --> 00:51:45,500
for example and W first CGI was actually

1209
00:51:50,770 --> 00:51:48,740
ordered to be star shade ready and there

1210
00:51:52,810 --> 00:51:50,780
is a potentially an opportunity that if

1211
00:51:54,820 --> 00:51:52,820
star shade were to be launched in the

1212
00:51:56,590 --> 00:51:54,830
next few years that CGI could actually

1213
00:51:58,300 --> 00:51:56,600

work in concert with star shade and

1214
00:52:04,360 --> 00:51:58,310
actually achieve even better performance

1215
00:52:06,190 --> 00:52:04,370
so absolutely thank you so working to

1216
00:52:08,140 --> 00:52:06,200
search for exoplanets you're going

1217
00:52:10,090 --> 00:52:08,150
through a lot of data from ground-based

1218
00:52:12,250 --> 00:52:10,100
observatories one of the things that's

1219
00:52:14,230 --> 00:52:12,260
come up recently is that as we're

1220
00:52:16,840 --> 00:52:14,240
launching more sort of swarms of

1221
00:52:18,820 --> 00:52:16,850
satellites into low-earth orbit we're

1222
00:52:19,810 --> 00:52:18,830
getting flaring and and people are

1223
00:52:21,700 --> 00:52:19,820
saying it's gonna interfere with

1224
00:52:25,090 --> 00:52:21,710
astronomy from the ground is that a

1225
00:52:27,430 --> 00:52:25,100
concern for the exoplanet search luckily

1226
00:52:29,260 --> 00:52:27,440
enough for me so the typically for for

1227
00:52:30,910 --> 00:52:29,270
ground-based detection is what I'm doing

1228
00:52:33,460 --> 00:52:30,920
at Palomar is using a different plant

1229
00:52:35,230 --> 00:52:33,470
detection method called transits and our

1230
00:52:36,640 --> 00:52:35,240
images are actually comparatively short

1231
00:52:38,350 --> 00:52:36,650
on the order of seconds to about a

1232
00:52:40,480 --> 00:52:38,360
minute but if you have to take a long

1233
00:52:42,730 --> 00:52:40,490
exposure if your target is very dim and

1234
00:52:44,800 --> 00:52:42,740
you cannot stack up all your images then

1235
00:52:47,050 --> 00:52:44,810
yes it's absolutely concern anything in

1236
00:52:51,390 --> 00:52:47,060
space that has a reflective coating can

1237
00:52:56,560 --> 00:52:54,250
hello thank you for the presentation by

1238
00:52:58,540 --> 00:52:56,570

the way I have a Voyager question you

1239
00:53:00,670 --> 00:52:58,550
had mentioned it took like six times to

1240
00:53:03,940 --> 00:53:00,680
convince the powers-that-be to take that

1241
00:53:06,880 --> 00:53:03,950
final picture and once you got the go so

1242
00:53:09,760 --> 00:53:06,890
how did you tell Voyager to tell to take

1243
00:53:14,920 --> 00:53:13,120
the you don't just tell Voyager you have

1244
00:53:17,980 --> 00:53:14,930
to actually design a sequence that fits

1245
00:53:23,230 --> 00:53:17,990
into that 50 words it actually took 49

1246
00:53:26,770 --> 00:53:23,240
words to make that that experiment and

1247
00:53:29,770 --> 00:53:26,780
you had to you know every time you

1248
00:53:32,950 --> 00:53:29,780
specify a change in in exposure time or

1249
00:53:35,800 --> 00:53:32,960
position it causes you uses words so it

1250
00:53:38,320 --> 00:53:35,810
was a it was a very very difficult thing

1251
00:53:40,210 --> 00:53:38,330
to do you you there a series of

1252
00:53:42,250 --> 00:53:40,220
programmers that were working and they

1253
00:53:43,690 --> 00:53:42,260
work just in zeros and ones because you

1254
00:53:45,040 --> 00:53:43,700
have to you know you you don't use these

1255
00:53:47,560 --> 00:53:45,050
high level languages you have to use

1256
00:53:49,359 --> 00:53:47,570
every single shred so with that sequence

1257
00:53:51,370 --> 00:53:49,369
is developed on the ground tested on the

1258
00:53:56,370 --> 00:53:51,380
ground and then it's brought to these

1259
00:53:59,410 --> 00:53:56,380
very very large radio telescopes its

1260
00:54:01,090 --> 00:53:59,420
signal sent up or transmitted up to the

1261
00:54:04,300 --> 00:54:01,100
spacecraft spacecraft with its large

1262
00:54:06,520 --> 00:54:04,310
antenna collects that signal programs

1263
00:54:08,200 --> 00:54:06,530

its computer and then the rest of the

1264
00:54:10,000 --> 00:54:08,210
history that's how we do it but it's

1265
00:54:11,710 --> 00:54:10,010
it's a long process it's not just oh I

1266
00:54:13,150 --> 00:54:11,720
have an idea let's do this I've got to

1267
00:54:15,609 --> 00:54:13,160
translate that idea into something that

1268
00:54:17,980 --> 00:54:15,619
actually fits into the spacecraft hey

1269
00:54:20,200 --> 00:54:17,990
Rob cue on YouTube wants to know do you

1270
00:54:21,910 --> 00:54:20,210
have a method for detecting life on an

1271
00:54:24,310 --> 00:54:21,920
exoplanet if you find something that

1272
00:54:26,560 --> 00:54:24,320
seems earth-like is there a way to

1273
00:54:29,859 --> 00:54:26,570
detect life yeah so you can use beers

1274
00:54:30,910 --> 00:54:29,869
law to look for signatures of life so

1275
00:54:33,220 --> 00:54:30,920
there's actually a lot of research going

1276
00:54:35,109 --> 00:54:33,230
into right now and trying to establish

1277
00:54:36,609 --> 00:54:35,119
what a bio signatures so it's

1278
00:54:39,370 --> 00:54:36,619
effectively where the bumps and Wiggles

1279
00:54:41,530 --> 00:54:39,380
of a spectrum of an axial planet that

1280
00:54:43,599 --> 00:54:41,540
would definitively say that life exists

1281
00:54:46,390 --> 00:54:43,609
on these planets and with current

1282
00:54:47,770 --> 00:54:46,400
technology right now we're possibly on

1283
00:54:49,540 --> 00:54:47,780
the cusp of being able to detect these

1284
00:54:52,270 --> 00:54:49,550
bio signatures but hopefully in the next

1285
00:54:53,830 --> 00:54:52,280
few years as new instrumentation new

1286
00:54:56,230 --> 00:54:53,840
technology new missions are launched

1287
00:54:57,580 --> 00:54:56,240
will have the sensitivity to look for

1288
00:54:59,950 --> 00:54:57,590

and definitively detect those bio

1289
00:55:06,099 --> 00:54:59,960
signatures and establish that a planet

1290
00:55:09,099 --> 00:55:06,109
has definitive life on its surface so I

1291
00:55:11,770 --> 00:55:09,109
have a question on coronagraph II what

1292
00:55:15,470 --> 00:55:11,780
happened is the image or the data you

1293
00:55:19,870 --> 00:55:15,480
get differ based on the planets position

1294
00:55:28,700 --> 00:55:22,940
so I'm sorry yeah a little bit

1295
00:55:30,380 --> 00:55:28,710
sorry so it has to be the right distance

1296
00:55:31,970 --> 00:55:30,390
from the star it can't be too close to

1297
00:55:33,740 --> 00:55:31,980
the star or else the chronograph will

1298
00:55:35,510 --> 00:55:33,750
block or the star's light it also can't

1299
00:55:37,370 --> 00:55:35,520
be too way far away from the star or

1300
00:55:40,730 --> 00:55:37,380
your your your deformable mirrors that

1301
00:55:43,130 --> 00:55:40,740
you've done you've basically steered

1302
00:55:48,790 --> 00:55:43,140
them to take out the the imperfections

1303
00:55:52,910 --> 00:55:51,380
those those can get worse the farther

1304
00:55:56,060 --> 00:55:52,920
away you go from the dark hole or the

1305
00:55:57,290 --> 00:55:56,070
center of your chronograph so yes you

1306
00:55:59,720 --> 00:55:57,300
have to take into account where the

1307
00:56:01,430 --> 00:55:59,730
planet is around the star and it's it's

1308
00:56:03,260 --> 00:56:01,440
it's sort of dependent upon your

1309
00:56:05,090 --> 00:56:03,270
instrument itself there are actually

1310
00:56:07,970 --> 00:56:05,100
types of exoplanet observations where

1311
00:56:09,620 --> 00:56:07,980
the plant you the planets movement

1312
00:56:11,840 --> 00:56:09,630
around its star actually changes its

1313
00:56:13,370 --> 00:56:11,850

spectrum and tells you things about the

1314
00:56:16,040 --> 00:56:13,380
planet right you want to say anything

1315
00:56:17,690 --> 00:56:16,050
about that we've done the spitzer

1316
00:56:19,430 --> 00:56:17,700
they're just just in Addis mission last

1317
00:56:20,960 --> 00:56:19,440
week yes so for example spitzer which

1318
00:56:22,700 --> 00:56:20,970
just recently was retired within the

1319
00:56:26,150 --> 00:56:22,710
last few days it actually was able to

1320
00:56:28,070 --> 00:56:26,160
take phase resolved spectra or actually

1321
00:56:30,400 --> 00:56:28,080
photometry of exoplanets so it's

1322
00:56:33,620 --> 00:56:30,410
actually able to look at how a planet's

1323
00:56:35,300 --> 00:56:33,630
brightness changed as it rotated in and

1324
00:56:37,550 --> 00:56:35,310
out of view so as the planet orbited

1325
00:56:40,490 --> 00:56:37,560
around its star we can actually look and

1326
00:56:42,890 --> 00:56:40,500
make longitudinal slices of that star of

1327
00:56:44,930 --> 00:56:42,900
that of that planet so we could then say

1328
00:56:46,910 --> 00:56:44,940
that this site is hot this site is cold

1329
00:56:49,280 --> 00:56:46,920
this site has a lot of methane this site

1330
00:56:51,620 --> 00:56:49,290
is methane devoid this side might have a

1331
00:56:53,780 --> 00:56:51,630
lot of clouds so by looking at how it

1332
00:56:55,760 --> 00:56:53,790
orbits around its star you can actually

1333
00:56:57,140 --> 00:56:55,770
gain additional information so for

1334
00:57:00,560 --> 00:56:57,150
example if we were to observe as I

1335
00:57:03,170 --> 00:57:00,570
showed that HR 8799 graphic if you door

1336
00:57:05,450 --> 00:57:03,180
that across many different wavelengths

1337
00:57:08,320 --> 00:57:05,460
you can then back out and actually start

1338
00:57:11,030 --> 00:57:08,330

to resolve how that planet's surface

1339
00:57:12,740 --> 00:57:11,040
changes so for example this side is

1340
00:57:14,240 --> 00:57:12,750
really hot this side is cold or this

1341
00:57:16,430 --> 00:57:14,250
side has more molecules or different

1342
00:57:18,109 --> 00:57:16,440
molecules than the other so it's a lot

1343
00:57:21,710 --> 00:57:18,119
you can learn from squiggly lines that's

1344
00:57:24,050 --> 00:57:21,720
the moral of the story hi so let's look

1345
00:57:25,970 --> 00:57:24,060
in the future a little bit you guys find

1346
00:57:27,849 --> 00:57:25,980
a planet and you find intelligent life

1347
00:57:31,329 --> 00:57:27,859
on it perhaps even more intelligent

1348
00:57:34,450 --> 00:57:31,339
than us or advanced what's NASA's policy

1349
00:57:35,829 --> 00:57:34,460
on letting us all know about him I mean

1350
00:57:37,870 --> 00:57:35,839
that would be an earth I mean literally

1351
00:57:39,729 --> 00:57:37,880
to make a joke but that would be an

1352
00:57:41,859 --> 00:57:39,739
earth-shattering thing for humanity to

1353
00:57:43,239 --> 00:57:41,869
find this out it would be more important

1354
00:57:44,829 --> 00:57:43,249
than all the news that we're hearing all

1355
00:57:46,479 --> 00:57:44,839
the time so my brother-in-law is

1356
00:57:50,289 --> 00:57:46,489
actually probably watching this from

1357
00:57:52,239 --> 00:57:50,299
Tennessee right now humanly thinks that

1358
00:57:53,559 --> 00:57:52,249
I know about aliens and my security

1359
00:57:55,509 --> 00:57:53,569
clearance is too high and I can't tell

1360
00:57:57,249 --> 00:57:55,519
him about extraterrestrial life and

1361
00:58:01,870 --> 00:57:57,259
despite what I'm telling you every

1362
00:58:03,460 --> 00:58:01,880
single time Ryan Reid we don't

1363
00:58:06,279 --> 00:58:03,470

definitively know about life outside of

1364
00:58:07,539 --> 00:58:06,289
our solar system or even you know on on

1365
00:58:08,979 --> 00:58:07,549
the source system other than you know

1366
00:58:12,309 --> 00:58:08,989
the life that we have here on earth

1367
00:58:14,400 --> 00:58:12,319
so I'm friends also with a bunch of

1368
00:58:16,720 --> 00:58:14,410
people that work on like Mars missions

1369
00:58:18,789 --> 00:58:16,730
so you know you've had the whole hoopla

1370
00:58:20,529 --> 00:58:18,799
about them the face on Mars being a face

1371
00:58:22,210 --> 00:58:20,539
and then we come back to it it's longer

1372
00:58:23,620 --> 00:58:22,220
looking like a face we're all on

1373
00:58:25,390 --> 00:58:23,630
Facebook all the time we're all on

1374
00:58:28,210 --> 00:58:25,400
Twitter all the time it'd be kind of

1375
00:58:30,069 --> 00:58:28,220
hard to keep that secret and as far as I

1376
00:58:32,979 --> 00:58:30,079
know there's no official sort of

1377
00:58:34,539 --> 00:58:32,989
requirement on on you know how to dispel

1378
00:58:36,880 --> 00:58:34,549
that information probably people would

1379
00:58:41,710 --> 00:58:36,890
do a giant press release I can't say

1380
00:58:44,289 --> 00:58:41,720
anything about it I just your security

1381
00:58:46,359 --> 00:58:44,299
clearance is higher the mindset he's

1382
00:58:47,799 --> 00:58:46,369
right but you guys all watch science

1383
00:58:49,539 --> 00:58:47,809
fiction movies probably like a lot of

1384
00:58:51,910 --> 00:58:49,549
people in this room I mean it's part of

1385
00:58:54,729 --> 00:58:51,920
the culture and aren't you at least a

1386
00:58:58,299 --> 00:58:54,739
little concerned about humanity how they

1387
00:59:00,450 --> 00:58:58,309
will respond to this news I I'm

1388
00:59:04,630 --> 00:59:00,460

concerned about it I'm concerned that

1389
00:59:06,160 --> 00:59:04,640
we're so innard by by being bombarded by

1390
00:59:09,309 --> 00:59:06,170
science fiction everything else that if

1391
00:59:10,930 --> 00:59:09,319
we did discover a life or intelligent

1392
00:59:11,739 --> 00:59:10,940
life on another planet with you you know

1393
00:59:14,289 --> 00:59:11,749
you're not gonna be able to communicate

1394
00:59:15,849 --> 00:59:14,299
with it it's not like it's here you just

1395
00:59:17,890 --> 00:59:15,859
know that there was another civilization

1396
00:59:19,089 --> 00:59:17,900
out there I had this terrible feeling

1397
00:59:21,789 --> 00:59:19,099
that we're gonna have you know a

1398
00:59:24,729 --> 00:59:21,799
commemorative stamp a Franklin Mint coin

1399
00:59:26,140 --> 00:59:24,739
a lot of jokes on at late-night

1400
00:59:28,749 --> 00:59:26,150
television and then it's just back to

1401
00:59:32,979 --> 00:59:28,759
normal I just fear that that's gonna

1402
00:59:34,420 --> 00:59:32,989
happen anything that Independence Day of

1403
00:59:37,059 --> 00:59:34,430
the movie taught me is we need to freeze

1404
00:59:39,880 --> 00:59:37,069
Will Smith to be there as a safeguard in

1405
00:59:44,170 --> 00:59:39,890
case the Atlanta aren't so nice

1406
00:59:47,300 --> 00:59:44,180
hi there so my question is about w first

1407
00:59:48,440 --> 00:59:47,310
why do you need deformable mirrors and W

1408
00:59:51,470 --> 00:59:48,450
first because it's all saddled

1409
00:59:52,850 --> 00:59:51,480
atmosphere and yeah because there's

1410
00:59:54,620 --> 00:59:52,860
internal reflections inside the

1411
00:59:56,720 --> 00:59:54,630
telescope and also imperfections on the

1412
00:59:57,710 --> 00:59:56,730
mirrors themselves so by having the

1413
00:59:59,300 --> 00:59:57,720

different moveable mirrors you can

1414
01:00:02,440 --> 00:59:59,310
actually correct for some of those those

1415
01:00:05,470 --> 01:00:02,450
aberrations as well great question

1416
01:00:08,150 --> 01:00:05,480
rich we get this question a lot and

1417
01:00:10,070 --> 01:00:08,160
fairly often is is why can't the

1418
01:00:12,170 --> 01:00:10,080
voyagers turn their cameras back on

1419
01:00:13,820 --> 01:00:12,180
I mean even if the even if the if this

1420
01:00:16,340 --> 01:00:13,830
that picture of the Sun didn't burn

1421
01:00:18,080 --> 01:00:16,350
Voyager one's camera why don't you take

1422
01:00:19,880 --> 01:00:18,090
another portrait from from further away

1423
01:00:22,520 --> 01:00:19,890
thirty years on it's a terrific question

1424
01:00:25,760 --> 01:00:22,530
and I've asked the question myself there

1425
01:00:28,250 --> 01:00:25,770
a number of reasons the primary reason

1426
01:00:29,330 --> 01:00:28,260
is that the voyagers run on radio

1427
01:00:30,920 --> 01:00:29,340
thermal generators and they have

1428
01:00:32,960 --> 01:00:30,930
plutonium in the air it's got a finite

1429
01:00:34,460 --> 01:00:32,970
half-life and they've now degraded to

1430
01:00:36,890 --> 01:00:34,470
the point where there's not enough power

1431
01:00:39,800 --> 01:00:36,900
to turn the the cameras back on

1432
01:00:42,770 --> 01:00:39,810
but even if you could turn the cameras

1433
01:00:45,590 --> 01:00:42,780
back on Voyager is now thirteen and a

1434
01:00:47,810 --> 01:00:45,600
half billion miles away from the Sun

1435
01:00:49,460 --> 01:00:47,820
it's it's three and a half times further

1436
01:00:51,920 --> 01:00:49,470
away than when we took that family

1437
01:00:53,660 --> 01:00:51,930
portrait so that does two terrible

1438
01:00:57,140 --> 01:00:53,670

things one of them it makes the earth a

1439
01:00:59,960 --> 01:00:57,150
lot dimmer it's only about eight percent

1440
01:01:02,150 --> 01:00:59,970
the brightness of it was it was when we

1441
01:01:03,800 --> 01:01:02,160
took that picture so if it were ten

1442
01:01:07,670 --> 01:01:03,810
DeeAnn above background it's less than

1443
01:01:09,880 --> 01:01:07,680
one right now it's the amount of

1444
01:01:13,280 --> 01:01:09,890
brightness it's not a brightness yeah so

1445
01:01:16,490 --> 01:01:13,290
yes so it's it's it's eight percent

1446
01:01:18,890 --> 01:01:16,500
brightness and it's also almost four

1447
01:01:21,560 --> 01:01:18,900
times closer to the Sun so that puts it

1448
01:01:24,470 --> 01:01:21,570
into a much more scattered bright

1449
01:01:26,060 --> 01:01:24,480
background so even if we could run the

1450
01:01:27,260 --> 01:01:26,070
cameras it would be impossible to see

1451
01:01:30,800 --> 01:01:27,270
the earth right now with those kinds of

1452
01:01:32,030 --> 01:01:30,810
cameras get to one more question from

1453
01:01:32,990 --> 01:01:32,040
YouTube and we'll give the last one to

1454
01:01:35,090 --> 01:01:33,000
you sir

1455
01:01:37,490 --> 01:01:35,100
just for either one of you or both of

1456
01:01:40,760 --> 01:01:37,500
you what's let's from let's see this is

1457
01:01:42,380 --> 01:01:40,770
from Q what's the question or mystery

1458
01:01:45,140 --> 01:01:42,390
your most anticipating to answer within

1459
01:01:47,900 --> 01:01:45,150
the next five to ten years and please

1460
01:01:53,130 --> 01:01:47,910
form your Frazer answer in the form of a

1461
01:02:02,230 --> 01:01:58,510
nice he said yeah I mean that really is

1462
01:02:04,720 --> 01:02:02,240
one of the biggest focuses of NASA's

1463
01:02:07,090 --> 01:02:04,730

exploration right now for for both

1464
01:02:08,800 --> 01:02:07,100
astrophysics and planetary sciences is

1465
01:02:10,600 --> 01:02:08,810
understanding the conditions for life

1466
01:02:10,990 --> 01:02:10,610
and and and what makes it possible right

1467
01:02:15,190 --> 01:02:11,000
right

1468
01:02:18,400 --> 01:02:15,200
sir go ahead yes I was just curious

1469
01:02:21,190 --> 01:02:18,410
and thank you for the great is wonderful

1470
01:02:24,970 --> 01:02:21,200
but in there is a slide that projected

1471
01:02:28,980 --> 01:02:24,980
some future missions and so forth is

1472
01:02:31,990 --> 01:02:28,990
there anything in like relatively

1473
01:02:36,540 --> 01:02:32,000
current technology that can tell if a

1474
01:02:40,000 --> 01:02:36,550
planet is in tidal lock around a star

1475
01:02:41,980 --> 01:02:40,010
spectroscopy R something like that yeah

1476
01:02:43,840 --> 01:02:41,990
so a lot of these plants that we're

1477
01:02:46,360 --> 01:02:43,850
observing right now are most of them are

1478
01:02:49,090 --> 01:02:46,370
very close to their host star so one

1479
01:02:51,040 --> 01:02:49,100
side of the the planet always faces the

1480
01:02:52,540 --> 01:02:51,050
star just like the moon is tightly

1481
01:02:53,770 --> 01:02:52,550
locked to the earth we only see one side

1482
01:02:56,380 --> 01:02:53,780
of the Moon at all times

1483
01:02:59,170 --> 01:02:56,390
these planets always perpetually face

1484
01:03:00,760 --> 01:02:59,180
one side of their star so missions that

1485
01:03:01,720 --> 01:03:00,770
and ground-based telescopes have been

1486
01:03:03,880 --> 01:03:01,730
able to confirm this

1487
01:03:05,830 --> 01:03:03,890
so Spitzer for example has been able to

1488
01:03:08,290 --> 01:03:05,840

watch as a planet orbits around its star

1489
01:03:10,420 --> 01:03:08,300
you're able to sample the entire surface

1490
01:03:12,550 --> 01:03:10,430
of the exoplanet and you can confirm

1491
01:03:14,890 --> 01:03:12,560
because one side is very very hot and

1492
01:03:16,660 --> 01:03:14,900
one side is comparatively cold you can

1493
01:03:17,950 --> 01:03:16,670
confirm that planets are indeed Tyler

1494
01:03:20,290 --> 01:03:17,960
locked to their star at least the ones

1495
01:03:22,630 --> 01:03:20,300
that are close in farther planets out

1496
01:03:24,490 --> 01:03:22,640
like such as in our solar system they're

1497
01:03:27,070 --> 01:03:24,500
not all tightly locked right they all

1498
01:03:31,090 --> 01:03:27,080
rotate on their axes so the like HR 8799

1499
01:03:33,400 --> 01:03:31,100
that's likely not tightly locked alright

1500
01:03:35,320 --> 01:03:33,410
alright thanks so much that's all the

1501
01:03:37,210 --> 01:03:35,330
time we have for this month thanks to

1502
01:03:40,120 --> 01:03:37,220
everyone here at an online for joining

1503
01:03:42,310 --> 01:03:40,130
us and thank you to our speakers join us

1504
01:03:43,870 --> 01:03:42,320
again next month for our show as we

1505
01:03:46,570 --> 01:03:43,880
continue talking about the search for

1506
01:03:48,790 --> 01:03:46,580
life this time on how we explore the

1507
01:03:51,250 --> 01:03:48,800
ocean worlds and that's plural ocean

1508
01:03:51,930 --> 01:03:51,260
worlds of our solar system so we'll see

1509
01:03:58,330 --> 01:03:51,940
you then good night