



1
00:00:09,750 --> 00:00:08,070
nasa's jet propulsion laboratory

2
00:00:12,390 --> 00:00:09,760
presents

3
00:00:14,390 --> 00:00:12,400
the von carmen lecture a series of talks

4
00:00:17,670 --> 00:00:14,400
by scientists and engineers who are

5
00:00:32,709 --> 00:00:17,680
exploring our planet our solar system

6
00:00:37,030 --> 00:00:35,110
good evening ladies and gentlemen

7
00:00:39,830 --> 00:00:37,040
how is it

8
00:00:41,670 --> 00:00:39,840
oh thank you how is everyone tonight

9
00:00:43,750 --> 00:00:41,680
good well again thank you all so much

10
00:00:45,670 --> 00:00:43,760
for coming out to join us

11
00:00:48,389 --> 00:00:45,680
what will the first evidence of life

12
00:00:49,830 --> 00:00:48,399
outside our own solar system look like

13
00:00:52,150 --> 00:00:49,840

and what future technologies are

14

00:00:54,150 --> 00:00:52,160
required to discover that evidence

15

00:00:56,630 --> 00:00:54,160
the challenge is that exoplanet hunting

16

00:00:59,029 --> 00:00:56,640
space-borne telescopes must suppress the

17

00:01:01,349 --> 00:00:59,039
bright glare from stars up to 10 billion

18

00:01:03,430 --> 00:01:01,359
times in order to directly image the

19

00:01:05,910 --> 00:01:03,440
faint reflected light from a planet and

20

00:01:07,510 --> 00:01:05,920
look for telltale signatures of life

21

00:01:09,510 --> 00:01:07,520
to tackle this the jet propulsion

22

00:01:11,590 --> 00:01:09,520
laboratory is developing two novel

23

00:01:13,990 --> 00:01:11,600
starlight suppression approaches

24

00:01:15,429 --> 00:01:14,000
coronagraphs and star shades

25

00:01:17,030 --> 00:01:15,439
tonight we'll discuss what these

26

00:01:18,870 --> 00:01:17,040

technologies are

27

00:01:20,630 --> 00:01:18,880

where they are today and how they must

28

00:01:23,030 --> 00:01:20,640

evolve in order to support possible

29

00:01:24,390 --> 00:01:23,040

exoplanet missions in the next decade

30

00:01:26,469 --> 00:01:24,400

and beyond

31

00:01:28,230 --> 00:01:26,479

tonight's guest is an astrophysicist

32

00:01:30,149 --> 00:01:28,240

and the chief technologist for nasa's

33

00:01:31,749 --> 00:01:30,159

exoplanet exploration program located

34

00:01:33,910 --> 00:01:31,759

here at jpl

35

00:01:35,830 --> 00:01:33,920

with his team he helps identify and

36

00:01:37,749 --> 00:01:35,840

mature technologies needed for possible

37

00:01:39,510 --> 00:01:37,759

future nasa missions that will

38

00:01:42,149 --> 00:01:39,520

ultimately look for evidence of life on

39

00:01:44,550 --> 00:01:42,159

exoplanets he received his phd and

40

00:01:46,389 --> 00:01:44,560

masters from the university of arizona

41

00:01:48,230 --> 00:01:46,399

an mba from the rotterdam school of

42

00:01:49,830 --> 00:01:48,240

management in the netherlands and a

43

00:01:51,429 --> 00:01:49,840

bachelor's in chemical engineering from

44

00:01:53,350 --> 00:01:51,439

the stevens institute of technology in

45

00:01:55,030 --> 00:01:53,360

new jersey and has worked at the jet

46

00:01:56,469 --> 00:01:55,040

propulsion laboratory in a variety of

47

00:01:58,230 --> 00:01:56,479

systems engineering and project

48

00:01:59,190 --> 00:01:58,240

management roles for the last eight

49

00:02:01,030 --> 00:01:59,200

years

50

00:02:03,350 --> 00:02:01,040

he's also a fine example of how it's

51
00:02:05,109 --> 00:02:03,360
never too late to chase your dreams

52
00:02:06,469 --> 00:02:05,119
at the age of 33 he left an

53
00:02:08,309 --> 00:02:06,479
international career in chemical

54
00:02:10,229 --> 00:02:08,319
manufacturing while working for a

55
00:02:12,229 --> 00:02:10,239
subsidiary of a large consumer goods

56
00:02:14,229 --> 00:02:12,239
company and went back to school to

57
00:02:15,190 --> 00:02:14,239
become an astrophysicist his boyhood

58
00:02:16,790 --> 00:02:15,200
dream

59
00:02:18,150 --> 00:02:16,800
the journey took him nine and a half

60
00:02:20,150 --> 00:02:18,160
years from restarting as an

61
00:02:21,830 --> 00:02:20,160
undergraduate at harvard university

62
00:02:24,710 --> 00:02:21,840
concentrating in physics to finally

63
00:02:26,550 --> 00:02:24,720

completing his phd in 2007.

64

00:02:28,710 --> 00:02:26,560

needless to say we're happy he's stuck

65

00:02:30,550 --> 00:02:28,720

with it ladies and gentlemen please help

66

00:02:42,550 --> 00:02:30,560

me welcome tonight's guest dr nick

67

00:02:46,150 --> 00:02:44,070

all right

68

00:02:49,670 --> 00:02:46,160

good evening everyone

69

00:02:52,229 --> 00:02:49,680

for countless generations over

70

00:02:55,110 --> 00:02:52,239

many millennia people have wondered

71

00:02:58,470 --> 00:02:55,120

are there other worlds like ours

72

00:03:00,550 --> 00:02:58,480

elsewhere not necessarily blue

73

00:03:02,790 --> 00:03:00,560

but alive

74

00:03:04,949 --> 00:03:02,800

we are very privileged to be amongst the

75

00:03:07,910 --> 00:03:04,959

first generations

76
00:03:09,750 --> 00:03:07,920
to actually be on the verge of answering

77
00:03:12,470 --> 00:03:09,760
that age-old question

78
00:03:14,790 --> 00:03:12,480
are we alone

79
00:03:17,110 --> 00:03:14,800
so tonight we're going to go on a short

80
00:03:18,470 --> 00:03:17,120
cosmic journey together

81
00:03:20,309 --> 00:03:18,480
we're going to bring you up to date on

82
00:03:22,470 --> 00:03:20,319
what we've learned about planets

83
00:03:24,949 --> 00:03:22,480
orbiting other stars we're going to tell

84
00:03:27,589 --> 00:03:24,959
you a little bit about the techniques of

85
00:03:30,229 --> 00:03:27,599
discovering life on those planets the

86
00:03:31,509 --> 00:03:30,239
technologies that enable that discovery

87
00:03:33,589 --> 00:03:31,519
and finally we'll tell you a little bit

88
00:03:35,750 --> 00:03:33,599

about the missions that nasa is

89

00:03:37,509 --> 00:03:35,760

considering so please bring your chairs

90

00:03:40,070 --> 00:03:37,519

to an upright position stow away your

91

00:03:44,470 --> 00:03:40,080

tables fasten your seat belts let's

92

00:03:48,869 --> 00:03:47,190

so this blue smudge that you could

93

00:03:51,190 --> 00:03:48,879

perhaps barely see in the middle of the

94

00:03:53,670 --> 00:03:51,200

screen is the largest

95

00:03:56,309 --> 00:03:53,680

stellar cluster in our galaxy it's

96

00:03:57,110 --> 00:03:56,319

called the omega centauri cluster it has

97

00:04:02,070 --> 00:03:57,120

10

98

00:04:05,030 --> 00:04:02,080

lot of stars

99

00:04:08,070 --> 00:04:05,040

but it doesn't feel like a large number

100

00:04:10,070 --> 00:04:08,080

until you see the heart of this cluster

101
00:04:11,589 --> 00:04:10,080
through the eyes of the hubble space

102
00:04:13,350 --> 00:04:11,599
telescope

103
00:04:15,350 --> 00:04:13,360
i have seen this picture

104
00:04:17,110 --> 00:04:15,360
hundreds of times since i was a young

105
00:04:20,229 --> 00:04:17,120
man and

106
00:04:22,710 --> 00:04:20,239
i continue to be stirred by it look at

107
00:04:24,870 --> 00:04:22,720
the concentration the density the

108
00:04:29,189 --> 00:04:24,880
different sizes and colors of all of

109
00:04:32,870 --> 00:04:29,199
these stars in such a small distance

110
00:04:35,430 --> 00:04:32,880
how could there not be at least one star

111
00:04:36,550 --> 00:04:35,440
harboring one planet

112
00:04:38,790 --> 00:04:36,560
harboring

113
00:04:41,270 --> 00:04:38,800

or rooting the beginnings of life on at

114

00:04:43,110 --> 00:04:41,280

least one of the planets at least one it

115

00:04:45,590 --> 00:04:43,120

almost seems

116

00:04:46,950 --> 00:04:45,600

statistically impossible that there is

117

00:04:49,270 --> 00:04:46,960

not life on at least one of these

118

00:04:50,950 --> 00:04:49,280

planets

119

00:04:53,830 --> 00:04:50,960

if we take this

120

00:04:54,710 --> 00:04:53,840

mass of stars and place it

121

00:04:58,710 --> 00:04:54,720

in

122

00:05:00,710 --> 00:04:58,720

or nearby the halo of our largest

123

00:05:02,469 --> 00:05:00,720

nearby galactic neighbor this is the

124

00:05:05,830 --> 00:05:02,479

andromeda galaxy

125

00:05:07,830 --> 00:05:05,840

it would only take up a small little dot

126
00:05:10,629 --> 00:05:07,840
in that entire galaxy

127
00:05:12,950 --> 00:05:10,639
in our own galaxy there are hundreds of

128
00:05:15,430 --> 00:05:12,960
billions of stars

129
00:05:17,990 --> 00:05:15,440
and there is evidence to back up the

130
00:05:20,390 --> 00:05:18,000
fact that there are as many

131
00:05:23,350 --> 00:05:20,400
galaxies in the universe

132
00:05:26,150 --> 00:05:23,360
as there are stars in our own galaxy

133
00:05:27,590 --> 00:05:26,160
so that's hundreds of billions of

134
00:05:31,830 --> 00:05:27,600
galaxies

135
00:05:34,550 --> 00:05:31,840
this is a picture from the hubble space

136
00:05:38,230 --> 00:05:34,560
telescope with its shutter open

137
00:05:40,390 --> 00:05:38,240
for 23 days

138
00:05:42,790 --> 00:05:40,400

every smudge on this image other than a

139

00:05:44,310 --> 00:05:42,800

few foreground stars

140

00:05:47,430 --> 00:05:44,320

are galaxies

141

00:05:48,390 --> 00:05:47,440

each containing tens of thousands tens

142

00:05:49,510 --> 00:05:48,400

of

143

00:05:52,550 --> 00:05:49,520

billions

144

00:05:54,870 --> 00:05:52,560

of stars

145

00:05:56,550 --> 00:05:54,880

if we are the only creatures to be alive

146

00:05:58,390 --> 00:05:56,560

in our galaxy

147

00:06:00,390 --> 00:05:58,400

you can't help but ask

148

00:06:02,629 --> 00:06:00,400

why all this space

149

00:06:04,830 --> 00:06:02,639

why all these galaxies why all these

150

00:06:08,550 --> 00:06:04,840

stars why all these

151

00:06:10,309 --> 00:06:08,560

planets alas here we are in meeting

152

00:06:13,110 --> 00:06:10,319

together in the first half of the 21st

153

00:06:14,629 --> 00:06:13,120

century and there is no evidence to the

154

00:06:17,670 --> 00:06:14,639

contrary

155

00:06:19,510 --> 00:06:17,680

we have no evidence for life outside of

156

00:06:22,070 --> 00:06:19,520

our own planet

157

00:06:24,309 --> 00:06:22,080

however it's still early days i kind of

158

00:06:27,430 --> 00:06:24,319

think of it akin to some of the earliest

159

00:06:30,150 --> 00:06:27,440

hominids who marching out to the edge of

160

00:06:32,550 --> 00:06:30,160

their own lands looking out over the sea

161

00:06:35,110 --> 00:06:32,560

wondering are there other lands

162

00:06:37,110 --> 00:06:35,120

near the horizon are there other

163

00:06:39,670 --> 00:06:37,120

sentient beings

164

00:06:42,390 --> 00:06:39,680

and we now know that indeed there are

165

00:06:44,870 --> 00:06:42,400

other worlds across the sea of space and

166

00:06:48,469 --> 00:06:44,880

we call them exoplanets

167

00:06:50,950 --> 00:06:48,479

exo means in greek outside outside of

168

00:06:52,469 --> 00:06:50,960

our own solar system

169

00:06:54,950 --> 00:06:52,479

so it just so happens

170

00:06:58,070 --> 00:06:54,960

that 20 years ago this year the first

171

00:07:01,110 --> 00:06:58,080

exoplanet was discovered

172

00:07:02,390 --> 00:07:01,120

around this star 51 pegasi

173

00:07:04,230 --> 00:07:02,400

the two

174

00:07:07,029 --> 00:07:04,240

swiss astronomers who discovered the

175

00:07:10,469 --> 00:07:07,039

planet never actually saw it

176
00:07:12,390 --> 00:07:10,479
because the star is just too bright so

177
00:07:13,270 --> 00:07:12,400
they use the technique

178
00:07:16,150 --> 00:07:13,280
called

179
00:07:18,550 --> 00:07:16,160
radial velocity

180
00:07:20,550 --> 00:07:18,560
and the way the technique works is if

181
00:07:22,309 --> 00:07:20,560
you can't see the planet

182
00:07:26,550 --> 00:07:22,319
you can look at the star

183
00:07:30,469 --> 00:07:28,710
adds a gravitational tug

184
00:07:32,230 --> 00:07:30,479
to the star so if you look at the star

185
00:07:33,189 --> 00:07:32,240
it's wobbling and that's due to the

186
00:07:34,870 --> 00:07:33,199
presence

187
00:07:36,870 --> 00:07:34,880
of the planet so even though you don't

188
00:07:39,110 --> 00:07:36,880

see the planet you know it's there in

189

00:07:41,990 --> 00:07:39,120

fact here's some of the early data that

190

00:07:43,350 --> 00:07:42,000

confirms the oscillatory nature of the

191

00:07:44,790 --> 00:07:43,360

wobbling

192

00:07:45,909 --> 00:07:44,800

what's absolutely amazing about this

193

00:07:48,390 --> 00:07:45,919

discovery

194

00:07:49,670 --> 00:07:48,400

is that the planet about the size of our

195

00:07:53,430 --> 00:07:49,680

own jupiter

196

00:07:57,110 --> 00:07:53,440

only required 4.2 days to make one trip

197

00:08:00,629 --> 00:07:57,120

around its star 4.2 days a far cry from

198

00:08:02,150 --> 00:08:00,639

our own jupiter which takes 11 years

199

00:08:05,029 --> 00:08:02,160

so this was a harbinger of things to

200

00:08:07,670 --> 00:08:05,039

come that exoplanets are very diverse

201
00:08:09,189 --> 00:08:07,680
and very surprising we had no idea this

202
00:08:10,710 --> 00:08:09,199
was going to happen in fact there's

203
00:08:13,029 --> 00:08:10,720
evidence to suggest that the planet

204
00:08:16,070 --> 00:08:13,039
orbiting the star is evaporating it's

205
00:08:18,390 --> 00:08:16,080
being vaporized by its own star

206
00:08:20,309 --> 00:08:18,400
so let's fast forward 20 years

207
00:08:22,430 --> 00:08:20,319
and here's where we are today i i

208
00:08:26,070 --> 00:08:22,440
checked our own database

209
00:08:27,270 --> 00:08:26,080
1838 confirmed exoplanets and believe me

210
00:08:28,950 --> 00:08:27,280
this is these are the ones we've

211
00:08:32,070 --> 00:08:28,960
confirmed we know that there are

212
00:08:34,310 --> 00:08:32,080
certainly many many more

213
00:08:36,310 --> 00:08:34,320

and as you can see i show the planet

214

00:08:38,870 --> 00:08:36,320

discoveries by year and it's clearly

215

00:08:40,870 --> 00:08:38,880

increasing i've color coded them so we

216

00:08:42,709 --> 00:08:40,880

see that the blues correspond to the

217

00:08:45,190 --> 00:08:42,719

technique in which they were discovered

218

00:08:47,070 --> 00:08:45,200

so blue is radial velocity and we just

219

00:08:49,190 --> 00:08:47,080

discussed that and you can see around

220

00:08:51,030 --> 00:08:49,200

2010 or so

221

00:08:52,870 --> 00:08:51,040

the blue starts to transition to green

222

00:08:54,790 --> 00:08:52,880

as being the more dominant technique

223

00:08:55,829 --> 00:08:54,800

what is the green it's a technique

224

00:08:58,310 --> 00:08:55,839

called

225

00:09:03,750 --> 00:08:58,320

transiting

226

00:09:07,590 --> 00:09:03,760

a nasa telescope called kepler

227

00:09:12,310 --> 00:09:07,600

and it is a very very simple technique

228

00:09:14,630 --> 00:09:12,320

kepler stars at about 150 000

229

00:09:17,269 --> 00:09:14,640

stars in our galaxy all at the same time

230

00:09:19,910 --> 00:09:17,279

hoping just hoping that there would be a

231

00:09:22,389 --> 00:09:19,920

planet that just serendipitously travels

232

00:09:25,190 --> 00:09:22,399

across the face such that the brightness

233

00:09:26,870 --> 00:09:25,200

of that star dips a little bit

234

00:09:28,790 --> 00:09:26,880

and then when the star uh when the

235

00:09:30,790 --> 00:09:28,800

planet reaches the other side the

236

00:09:32,230 --> 00:09:30,800

brightness of the the star will resume

237

00:09:35,030 --> 00:09:32,240

to where it was

238

00:09:36,630 --> 00:09:35,040

very simple and that infers the presence

239

00:09:38,790 --> 00:09:36,640

of a planet especially when the

240

00:09:39,829 --> 00:09:38,800

astronomers notice that it repeats

241

00:09:41,829 --> 00:09:39,839

itself

242

00:09:45,110 --> 00:09:41,839

which indicates that it's the planet is

243

00:09:47,590 --> 00:09:45,120

traveling around that star

244

00:09:48,949 --> 00:09:47,600

astronomers then take that information

245

00:09:51,910 --> 00:09:48,959

of the period

246

00:09:54,150 --> 00:09:51,920

they plug it into ironically johannes

247

00:09:56,470 --> 00:09:54,160

kepler's third law of orbital motion and

248

00:09:58,630 --> 00:09:56,480

they can extract the separations the

249

00:10:00,550 --> 00:09:58,640

distance between the planet and the star

250

00:10:02,470 --> 00:10:00,560

and that becomes very important because

251
00:10:05,509 --> 00:10:02,480
it tells us a little bit about

252
00:10:06,550 --> 00:10:05,519
habitability the distance

253
00:10:08,230 --> 00:10:06,560
so

254
00:10:10,949 --> 00:10:08,240
kepler and this is an artist

255
00:10:14,389 --> 00:10:10,959
illustration kepler has only looked at a

256
00:10:16,150 --> 00:10:14,399
sliver of the overall stars

257
00:10:18,389 --> 00:10:16,160
in our galaxy in fact the radial

258
00:10:20,550 --> 00:10:18,399
velocity technique and others only

259
00:10:22,630 --> 00:10:20,560
compromise a small area even smaller

260
00:10:25,430 --> 00:10:22,640
than what kepler has looked at

261
00:10:29,509 --> 00:10:25,440
however even from this small sample

262
00:10:32,550 --> 00:10:29,519
we have accumulated enough evidence

263
00:10:34,710 --> 00:10:32,560

to to conclude a couple things first is

264

00:10:36,949 --> 00:10:34,720

the diversity of planets

265

00:10:39,350 --> 00:10:36,959

and the commonness of planets let's take

266

00:10:41,590 --> 00:10:39,360

a look at the diversity of planets the

267

00:10:43,590 --> 00:10:41,600

next uh seven or eight slides are all

268

00:10:45,829 --> 00:10:43,600

going to be artists illustrations these

269

00:10:47,990 --> 00:10:45,839

are not photos we don't actually know

270

00:10:49,990 --> 00:10:48,000

what these planets look like

271

00:10:51,910 --> 00:10:50,000

but speaking of diversity there's

272

00:10:53,829 --> 00:10:51,920

evidence to suggest that there are

273

00:10:56,630 --> 00:10:53,839

planets this one in the foreground that

274

00:10:59,590 --> 00:10:56,640

are rocky and very close to the star

275

00:11:00,870 --> 00:10:59,600

very similar to what we saw about 51

276

00:11:03,030 --> 00:11:00,880

pegasi

277

00:11:05,350 --> 00:11:03,040

but because it's rocky there's evidence

278

00:11:08,150 --> 00:11:05,360

to suggest that this planet remains in a

279

00:11:10,310 --> 00:11:08,160

molten state permanently not very

280

00:11:12,389 --> 00:11:10,320

conducive to life

281

00:11:14,389 --> 00:11:12,399

there's evidence for ice planets

282

00:11:16,710 --> 00:11:14,399

we don't have ice planets in our own

283

00:11:18,630 --> 00:11:16,720

solar system we have icy moons but no

284

00:11:20,310 --> 00:11:18,640

icy planets these are rocky planets that

285

00:11:23,110 --> 00:11:20,320

are sufficiently far away from their

286

00:11:25,750 --> 00:11:23,120

stars where the evidence suggests that

287

00:11:29,350 --> 00:11:25,760

any carbon dioxide or water has

288

00:11:33,030 --> 00:11:29,360

crystallized the ice again not conducive

289

00:11:36,550 --> 00:11:34,310

now planets

290

00:11:39,190 --> 00:11:36,560

orbiting two stars that's something that

291

00:11:41,350 --> 00:11:39,200

we had hoped would be true why

292

00:11:43,430 --> 00:11:41,360

because most stars in the evening sky

293

00:11:45,910 --> 00:11:43,440

actually are in multiple systems so it

294

00:11:48,710 --> 00:11:45,920

was very important to us to know

295

00:11:50,630 --> 00:11:48,720

can planets survive having multiple

296

00:11:52,389 --> 00:11:50,640

stars and sure enough kepler has

297

00:11:54,550 --> 00:11:52,399

discovered

298

00:11:56,550 --> 00:11:54,560

evidence for this in fact this is an

299

00:12:00,150 --> 00:11:56,560

interesting case where

300

00:12:02,230 --> 00:12:00,160

reality imitates fiction some of you

301
00:12:05,110 --> 00:12:02,240
may be familiar with the star wars

302
00:12:09,590 --> 00:12:05,120
planet tattooing where they show two

303
00:12:15,190 --> 00:12:12,550
here's a planet that has been weighed in

304
00:12:19,190 --> 00:12:15,200
at 10 times the mass of our largest

305
00:12:21,829 --> 00:12:19,200
planet jupiter 10 times its mass what's

306
00:12:24,870 --> 00:12:21,839
equally as fascinating is this star is

307
00:12:27,430 --> 00:12:24,880
orbiting a star that happens to be in a

308
00:12:29,590 --> 00:12:27,440
quadruple system

309
00:12:32,069 --> 00:12:29,600
we never thought that was possible it

310
00:12:34,550 --> 00:12:32,079
speaks to the robustness of planets that

311
00:12:39,750 --> 00:12:34,560
they can survive the somewhat instable

312
00:12:46,710 --> 00:12:43,590
in some cases we've acquired the mass

313
00:12:48,310 --> 00:12:46,720

and the volume of the planet and for

314

00:12:50,629 --> 00:12:48,320

those of you that remember your your

315

00:12:52,710 --> 00:12:50,639

physics mass divided by volume gives you

316

00:12:55,670 --> 00:12:52,720

density the inference is that some of

317

00:12:58,790 --> 00:12:55,680

these planets are made up large amounts

318

00:13:00,870 --> 00:12:58,800

of water that's the density is is

319

00:13:03,350 --> 00:13:00,880

consistent with that

320

00:13:05,269 --> 00:13:03,360

may not be but we believe that there are

321

00:13:08,310 --> 00:13:05,279

planets out there that have 40 to 50

322

00:13:09,910 --> 00:13:08,320

percent maybe even more by mass water

323

00:13:12,470 --> 00:13:09,920

and our planet is even though it looks

324

00:13:16,150 --> 00:13:12,480

watery to you is less than one percent

325

00:13:22,069 --> 00:13:18,829

all planetary systems so we

326

00:13:24,150 --> 00:13:22,079

found stars that have multiple planets

327

00:13:26,790 --> 00:13:24,160

orbiting it which is what we would have

328

00:13:29,829 --> 00:13:26,800

expected similar to our own solar system

329

00:13:31,509 --> 00:13:29,839

where we have eight planets there is

330

00:13:33,269 --> 00:13:31,519

substantial evidence that a lot of the

331

00:13:34,949 --> 00:13:33,279

stars have multiple planets in fact at

332

00:13:37,590 --> 00:13:34,959

least 40

333

00:13:40,150 --> 00:13:37,600

of all the stars we've discovered so far

334

00:13:41,990 --> 00:13:40,160

are in multiple systems

335

00:13:44,389 --> 00:13:42,000

what's fascinating about this particular

336

00:13:47,990 --> 00:13:44,399

star is kepler-444

337

00:13:51,430 --> 00:13:48,000

is its age so scientists have concluded

338

00:13:53,750 --> 00:13:51,440

that the age of this star is around 11

339

00:13:54,949 --> 00:13:53,760
billion years old

340

00:13:57,509 --> 00:13:54,959
and that's important for a couple

341

00:13:59,590 --> 00:13:57,519
reasons one it speaks to the

342

00:14:00,790 --> 00:13:59,600
the the quickness in which planets

343

00:14:02,790 --> 00:14:00,800
formed

344

00:14:05,030 --> 00:14:02,800
we didn't know how long he would take

345

00:14:07,509 --> 00:14:05,040
second which might be interesting to us

346

00:14:09,910 --> 00:14:07,519
is it it tells you how much time

347

00:14:11,269 --> 00:14:09,920
alien life could have

348

00:14:13,670 --> 00:14:11,279
had

349

00:14:16,230 --> 00:14:13,680
11 billion years is a long time i wonder

350

00:14:19,509 --> 00:14:16,240
how sophisticated and advanced alien

351

00:14:23,430 --> 00:14:20,870

here's something we never would have

352

00:14:26,389 --> 00:14:23,440

guessed there are evidence for nomadic

353

00:14:30,790 --> 00:14:26,399

planets planets floating through the

354

00:14:32,389 --> 00:14:30,800

galaxy unbounded to any star we never

355

00:14:33,829 --> 00:14:32,399

predicted that

356

00:14:35,430 --> 00:14:33,839

and

357

00:14:37,590 --> 00:14:35,440

the evidence for this is through a

358

00:14:39,750 --> 00:14:37,600

technique called gravitational micro

359

00:14:41,750 --> 00:14:39,760

lensing it's another indirect

360

00:14:44,790 --> 00:14:41,760

technique

361

00:14:47,990 --> 00:14:44,800

and then lastly here's neptune roughly

362

00:14:50,389 --> 00:14:48,000

four times the size of our own earth

363

00:14:53,430 --> 00:14:50,399

and in our own solar system there are no

364

00:14:56,069 --> 00:14:53,440

other planets that bridge this

365

00:14:57,990 --> 00:14:56,079

distance the separation in size

366

00:15:00,230 --> 00:14:58,000

so there's no reason why we can't find

367

00:15:03,030 --> 00:15:00,240

planets of an intermediate size we just

368

00:15:05,350 --> 00:15:03,040

never have well sure enough kepler has

369

00:15:07,590 --> 00:15:05,360

found a whole range of of planets in

370

00:15:10,389 --> 00:15:07,600

between these two distances and we call

371

00:15:12,550 --> 00:15:10,399

them super earths we have no idea these

372

00:15:14,310 --> 00:15:12,560

super earths are just larger versions of

373

00:15:16,550 --> 00:15:14,320

our own earth they could be maybe

374

00:15:19,030 --> 00:15:16,560

smaller versions of the ice giant

375

00:15:20,389 --> 00:15:19,040

neptune or maybe they're these water

376

00:15:22,550 --> 00:15:20,399

worlds

377

00:15:24,629 --> 00:15:22,560

still very exciting to figure out what

378

00:15:27,030 --> 00:15:24,639

they are so i think you'll agree that

379

00:15:29,030 --> 00:15:27,040

there is enormous diversity in

380

00:15:31,269 --> 00:15:29,040

exoplanets that we did not actually

381

00:15:33,590 --> 00:15:31,279

predict and a lot of them are no where

382

00:15:36,470 --> 00:15:33,600

similar to what we have in our own solar

383

00:15:38,150 --> 00:15:36,480

system so let me show you

384

00:15:40,790 --> 00:15:38,160

what i believe are some of the three

385

00:15:41,910 --> 00:15:40,800

profound results from kepler and i have

386

00:15:42,949 --> 00:15:41,920

three of them

387

00:15:44,870 --> 00:15:42,959

first one

388

00:15:45,990 --> 00:15:44,880

planets orbiting other stars in the

389

00:15:49,269 --> 00:15:46,000

galaxy

390

00:15:50,870 --> 00:15:49,279

are indeed common so when you look up at

391

00:15:52,150 --> 00:15:50,880

the night sky

392

00:15:55,509 --> 00:15:52,160

on average

393

00:15:58,230 --> 00:15:55,519

every single one of those stars

394

00:16:00,389 --> 00:15:58,240

has at least one planet around it and

395

00:16:02,790 --> 00:16:00,399

maybe a whole planetary system that's

396

00:16:04,949 --> 00:16:02,800

something we did not know even a few

397

00:16:07,110 --> 00:16:04,959

years ago

398

00:16:09,189 --> 00:16:07,120

to add a little more data

399

00:16:11,910 --> 00:16:09,199

it's actually the stars that you don't

400

00:16:13,829 --> 00:16:11,920

see that are even that are equally as

401
00:16:15,590 --> 00:16:13,839
interesting there's a whole population

402
00:16:17,590 --> 00:16:15,600
of very dim stars some of you may have

403
00:16:19,110 --> 00:16:17,600
heard of them they're called m dwarfs

404
00:16:21,990 --> 00:16:19,120
or m stars

405
00:16:24,790 --> 00:16:22,000
these very faint stars about half the

406
00:16:25,910 --> 00:16:24,800
luminosity of our own sun if not less

407
00:16:28,389 --> 00:16:25,920
dominate

408
00:16:31,269 --> 00:16:28,399
the types of stars in our universe

409
00:16:33,910 --> 00:16:31,279
there are three quarters of these stars

410
00:16:35,670 --> 00:16:33,920
make up the stars in our own galaxy the

411
00:16:38,389 --> 00:16:35,680
reason that's important is there's

412
00:16:40,150 --> 00:16:38,399
preliminary evidence to suggest around

413
00:16:43,430 --> 00:16:40,160

all of these m dwarfs which you can't

414

00:16:45,430 --> 00:16:43,440

see in the night sky have at least two

415

00:16:46,710 --> 00:16:45,440

planets orbiting them

416

00:16:48,629 --> 00:16:46,720

so if you think about the fact that

417

00:16:51,110 --> 00:16:48,639

there's hundreds of billions of stars in

418

00:16:53,670 --> 00:16:51,120

our galaxy and each one of them has at

419

00:16:57,269 --> 00:16:53,680

least one planet and some of them have

420

00:16:59,829 --> 00:16:57,279

two it just speaks to the huge number of

421

00:17:01,509 --> 00:16:59,839

planets that we are certain are out

422

00:17:03,269 --> 00:17:01,519

there

423

00:17:06,549 --> 00:17:03,279

let's go to number two

424

00:17:07,990 --> 00:17:06,559

planets with sizes between half

425

00:17:11,750 --> 00:17:08,000

like mars

426
00:17:13,909 --> 00:17:11,760
and twice the size maybe a super earth

427
00:17:16,069 --> 00:17:13,919
are the most common types of planet

428
00:17:17,909 --> 00:17:16,079
that's important if you just knew number

429
00:17:19,429 --> 00:17:17,919
one you might say okay that's great

430
00:17:21,669 --> 00:17:19,439
there are a lot of stars but what

431
00:17:24,549 --> 00:17:21,679
happens if they're all gas planets or

432
00:17:27,189 --> 00:17:24,559
icy giants it doesn't bode very well for

433
00:17:29,510 --> 00:17:27,199
life does it but now we find out that

434
00:17:30,870 --> 00:17:29,520
the most common type of planets are

435
00:17:33,830 --> 00:17:30,880
those that are

436
00:17:36,870 --> 00:17:33,840
sort of like our own earth here's some

437
00:17:38,150 --> 00:17:36,880
early statistics from an unpublished uh

438
00:17:41,029 --> 00:17:38,160

candidate list

439

00:17:43,110 --> 00:17:41,039

down here we show the sizes of

440

00:17:45,350 --> 00:17:43,120

the planets and you can see planets that

441

00:17:47,350 --> 00:17:45,360

are about the size of jupiter or larger

442

00:17:49,909 --> 00:17:47,360

are a minority even though they're

443

00:17:52,150 --> 00:17:49,919

amongst the first they are a minority of

444

00:17:53,830 --> 00:17:52,160

the sizes of planets we're finding and

445

00:17:56,390 --> 00:17:53,840

if you take the earth size and the super

446

00:17:58,470 --> 00:17:56,400

earth size if you allow me to add them

447

00:18:00,150 --> 00:17:58,480

together and refer to them as earth size

448

00:18:03,350 --> 00:18:00,160

for now you'll see that these two

449

00:18:06,870 --> 00:18:03,360

together are the most common types of

450

00:18:08,390 --> 00:18:06,880

planets that bodes extremely well for

451
00:18:09,750 --> 00:18:08,400
life

452
00:18:11,430 --> 00:18:09,760
now

453
00:18:13,909 --> 00:18:11,440
that's all all well and good but what

454
00:18:15,909 --> 00:18:13,919
happens if these earth-sized planets are

455
00:18:17,669 --> 00:18:15,919
really close to the star

456
00:18:19,669 --> 00:18:17,679
it'd be really really hot wouldn't it or

457
00:18:22,230 --> 00:18:19,679
if it was very very far away it'd be

458
00:18:23,669 --> 00:18:22,240
very very cold so how many of them are

459
00:18:25,590 --> 00:18:23,679
actually in the temperate zone that's

460
00:18:27,750 --> 00:18:25,600
what we really want to know well

461
00:18:29,029 --> 00:18:27,760
kepler has come to the rescue

462
00:18:31,270 --> 00:18:29,039
again

463
00:18:33,430 --> 00:18:31,280

planets with sizes

464

00:18:35,430 --> 00:18:33,440

half to two times out of earth

465

00:18:37,430 --> 00:18:35,440

orbit in the habitable zone of their

466

00:18:38,470 --> 00:18:37,440

stars what's this habitable zone

467

00:18:40,789 --> 00:18:38,480

business

468

00:18:42,789 --> 00:18:40,799

the habitable zone is just simply a

469

00:18:44,710 --> 00:18:42,799

region around any star

470

00:18:48,310 --> 00:18:44,720

where a planet

471

00:18:50,710 --> 00:18:48,320

is just right to have liquid water on

472

00:18:52,950 --> 00:18:50,720

its surface if the planet was too close

473

00:18:54,470 --> 00:18:52,960

it'd be too hot the water would vaporize

474

00:18:56,470 --> 00:18:54,480

if the planet was too far away it'd be

475

00:18:59,350 --> 00:18:56,480

too cold it would turn the ice

476
00:19:01,430 --> 00:18:59,360
water we believe is really important in

477
00:19:06,310 --> 00:19:01,440
the search for life wherever we find

478
00:19:07,750 --> 00:19:06,320
water on this planet we find life

479
00:19:08,549 --> 00:19:07,760
so let me give you a little bit of data

480
00:19:10,789 --> 00:19:08,559
here

481
00:19:13,029 --> 00:19:10,799
and i'm going to be very conservative

482
00:19:14,950 --> 00:19:13,039
very conservative

483
00:19:17,270 --> 00:19:14,960
one out of every 10

484
00:19:19,350 --> 00:19:17,280
stars similar to our own

485
00:19:20,390 --> 00:19:19,360
appears to have one of these earth-sized

486
00:19:22,710 --> 00:19:20,400
planets

487
00:19:25,190 --> 00:19:22,720
in its habitable zone one out of every

488
00:19:27,350 --> 00:19:25,200

ten and that's a low

489

00:19:28,549 --> 00:19:27,360

estimate i have esteemed colleagues here

490

00:19:31,350 --> 00:19:28,559

in the audience who believe it's

491

00:19:33,029 --> 00:19:31,360

actually a few times higher than that

492

00:19:34,630 --> 00:19:33,039

and you remember those m stars we talked

493

00:19:35,990 --> 00:19:34,640

about

494

00:19:38,870 --> 00:19:36,000

they seem to be

495

00:19:42,070 --> 00:19:38,880

very common around those stars

496

00:19:44,150 --> 00:19:42,080

early evidence suggests that 50 percent

497

00:19:46,470 --> 00:19:44,160

of m stars

498

00:19:49,510 --> 00:19:46,480

have at one planet around the size of

499

00:19:52,070 --> 00:19:49,520

the earth in its habitable zone that's

500

00:19:54,870 --> 00:19:52,080

exactly what we were looking for i did a

501
00:19:57,110 --> 00:19:54,880
back of the envelope calculation

502
00:20:00,470 --> 00:19:57,120
i came up with a minimum

503
00:20:03,430 --> 00:20:00,480
of 80 billion planets

504
00:20:05,350 --> 00:20:03,440
of earth size in the habitable zone that

505
00:20:07,110 --> 00:20:05,360
is the num that is

506
00:20:09,909 --> 00:20:07,120
the type of communist the type of

507
00:20:11,029 --> 00:20:09,919
numbers we've been looking for

508
00:20:13,350 --> 00:20:11,039
so

509
00:20:15,270 --> 00:20:13,360
if there are 80 billion of these guys in

510
00:20:16,710 --> 00:20:15,280
a temperate zone

511
00:20:18,549 --> 00:20:16,720
and we're calling them candidate

512
00:20:20,230 --> 00:20:18,559
habitable planets because they're about

513
00:20:22,310 --> 00:20:20,240

the right size they're about at the

514

00:20:24,470 --> 00:20:22,320

right distance for liquid water

515

00:20:26,950 --> 00:20:24,480

so we call them candidate but to get to

516

00:20:28,390 --> 00:20:26,960

a confirmed habitable planet which is

517

00:20:29,990 --> 00:20:28,400

probably why we're here tonight to find

518

00:20:31,830 --> 00:20:30,000

out

519

00:20:33,270 --> 00:20:31,840

we need a little bit more information we

520

00:20:34,870 --> 00:20:33,280

need to know does the planet have an

521

00:20:38,070 --> 00:20:34,880

atmosphere

522

00:20:39,669 --> 00:20:38,080

and are there any signatures of biology

523

00:20:42,390 --> 00:20:39,679

that's what would make it a habitable

524

00:20:44,950 --> 00:20:42,400

planet so folks we're going to say thank

525

00:20:46,470 --> 00:20:44,960

you very much to the scientists and the

526

00:20:48,950 --> 00:20:46,480

engineers who worked on the kepler

527

00:20:51,510 --> 00:20:48,960

telescope they have done a tremendous

528

00:20:54,470 --> 00:20:51,520

job in advancing our knowledge and now

529

00:20:58,070 --> 00:20:54,480

we are ready for the next step

530

00:21:00,950 --> 00:20:59,110

there are

531

00:21:03,909 --> 00:21:00,960

are two techniques that we've already

532

00:21:05,190 --> 00:21:03,919

been searching for life for the last 50

533

00:21:07,190 --> 00:21:05,200

years or so

534

00:21:11,110 --> 00:21:07,200

the first one we know very well because

535

00:21:13,510 --> 00:21:11,120

jpl has been a leader within nasa for

536

00:21:15,510 --> 00:21:13,520

all of these decades

537

00:21:16,789 --> 00:21:15,520

the search for life in our own solar

538

00:21:18,390 --> 00:21:16,799

system

539

00:21:21,510 --> 00:21:18,400

i love this picture

540

00:21:23,669 --> 00:21:21,520

it's of the mars curiosity rover turning

541

00:21:29,990 --> 00:21:23,679

around and looking at the crater in

542

00:21:35,110 --> 00:21:31,270

i'll have you know

543

00:21:37,830 --> 00:21:35,120

that on july 14th write that down

544

00:21:40,549 --> 00:21:37,840

nasa's new horizons spacecraft is going

545

00:21:42,310 --> 00:21:40,559

to pass by pluto

546

00:21:44,549 --> 00:21:42,320

he'll take pictures it'll study it like

547

00:21:45,510 --> 00:21:44,559

no other mission ever has and at that

548

00:21:47,830 --> 00:21:45,520

point

549

00:21:50,549 --> 00:21:47,840

nasa will have visited

550

00:21:54,390 --> 00:21:50,559

every single large body

551
00:21:57,110 --> 00:21:54,400
in our solar system that's a phenomenal

552
00:21:59,190 --> 00:21:57,120
accomplishment in just 50 years i mean

553
00:22:01,029 --> 00:21:59,200
what are we going to do in the next 50

554
00:22:02,630 --> 00:22:01,039
years now

555
00:22:04,470 --> 00:22:02,640
unfortunately

556
00:22:07,029 --> 00:22:04,480
it looks like that the chances of

557
00:22:08,549 --> 00:22:07,039
intelligent life in our solar system are

558
00:22:11,270 --> 00:22:08,559
are quite small at this point and we've

559
00:22:13,430 --> 00:22:11,280
yet to find strong evidence of life

560
00:22:15,430 --> 00:22:13,440
we are not done with mars we will

561
00:22:17,350 --> 00:22:15,440
continue to look for fossils and other

562
00:22:19,750 --> 00:22:17,360
evidence of past life and we're not

563
00:22:21,669 --> 00:22:19,760

giving up on subterranean aquifers where

564

00:22:23,830 --> 00:22:21,679

life might exist

565

00:22:24,950 --> 00:22:23,840

and we are certainly remaining excited

566

00:22:26,470 --> 00:22:24,960

and hopeful

567

00:22:29,750 --> 00:22:26,480

for potential life

568

00:22:32,950 --> 00:22:29,760

in the subterranean oceans the deep

569

00:22:36,549 --> 00:22:32,960

salty oceans of some of the icy moons of

570

00:22:39,270 --> 00:22:36,559

jupiter and saturn here you see europa

571

00:22:43,270 --> 00:22:39,280

and jpl is playing a leading role in the

572

00:22:48,710 --> 00:22:43,280

investigation of this moon

573

00:22:53,830 --> 00:22:51,750

listening and watching for signs of

574

00:22:56,149 --> 00:22:53,840

intelligent life with some of our

575

00:22:58,870 --> 00:22:56,159

friends from the seti institute the

576
00:23:00,549 --> 00:22:58,880
search for extraterrestrial intelligence

577
00:23:02,310 --> 00:23:00,559
they're up in northern california who

578
00:23:04,149 --> 00:23:02,320
have used for the last 50 years these

579
00:23:06,710 --> 00:23:04,159
large

580
00:23:08,470 --> 00:23:06,720
radio single dish radio antennas

581
00:23:11,430 --> 00:23:08,480
and just recently they're starting to

582
00:23:12,789 --> 00:23:11,440
use these um allen telescope arrays in

583
00:23:13,830 --> 00:23:12,799
northern california there's a whole

584
00:23:15,990 --> 00:23:13,840
bunch of them

585
00:23:18,149 --> 00:23:16,000
just listening to hear if they can if

586
00:23:20,710 --> 00:23:18,159
they can hear any chatter from alien

587
00:23:23,350 --> 00:23:20,720
civilizations from perhaps one planet to

588
00:23:25,830 --> 00:23:23,360

another from a planet to their

589

00:23:28,149 --> 00:23:25,840

large spacecrafts or maybe the leakage

590

00:23:30,230 --> 00:23:28,159

of radio communications like we have on

591

00:23:31,990 --> 00:23:30,240

our own planet

592

00:23:33,590 --> 00:23:32,000

even though we're about to go radio

593

00:23:36,470 --> 00:23:33,600

quiet and we expect that alien

594

00:23:39,029 --> 00:23:36,480

civilizations might as well but

595

00:23:41,029 --> 00:23:39,039

the search is well worth taking we won't

596

00:23:43,909 --> 00:23:41,039

know unless we try

597

00:23:45,669 --> 00:23:43,919

seti has recently acquired another uh

598

00:23:48,630 --> 00:23:45,679

technique in their portfolio they're

599

00:23:50,630 --> 00:23:48,640

looking now for for high beams of light

600

00:23:52,870 --> 00:23:50,640

that that pulse at very very

601
00:23:54,710 --> 00:23:52,880
short

602
00:23:56,950 --> 00:23:54,720
frequencies

603
00:23:58,549 --> 00:23:56,960
and it's sort of like an optical morse

604
00:24:00,390 --> 00:23:58,559
code if you will they've been doing that

605
00:24:01,510 --> 00:24:00,400
for about a decade and they haven't seen

606
00:24:03,270 --> 00:24:01,520
anything

607
00:24:05,350 --> 00:24:03,280
irregular to date

608
00:24:07,430 --> 00:24:05,360
the search continues

609
00:24:08,950 --> 00:24:07,440
which takes us now to

610
00:24:11,350 --> 00:24:08,960
our next

611
00:24:13,269 --> 00:24:11,360
approach approach number three which is

612
00:24:15,430 --> 00:24:13,279
what i'll spend a little bit of time

613
00:24:18,870 --> 00:24:15,440

explaining probing the atmosphere of

614

00:24:21,830 --> 00:24:18,880

exoplanets for biological signatures so

615

00:24:23,830 --> 00:24:21,840

what's a biological signature basically

616

00:24:26,789 --> 00:24:23,840

as an example

617

00:24:29,669 --> 00:24:26,799

the gases that we release

618

00:24:32,390 --> 00:24:29,679

as a byproduct of life that remain in

619

00:24:34,390 --> 00:24:32,400

our atmosphere revealing the presence of

620

00:24:35,430 --> 00:24:34,400

life for example

621

00:24:37,110 --> 00:24:35,440

plants

622

00:24:39,669 --> 00:24:37,120

give off oxygen

623

00:24:42,870 --> 00:24:39,679

oxygen is consumed by humans

624

00:24:45,269 --> 00:24:42,880

we give off carbon dioxide there are

625

00:24:48,390 --> 00:24:45,279

bacteria that give off methane if we can

626
00:24:50,789 --> 00:24:48,400
capture any of these gases they could be

627
00:24:52,549 --> 00:24:50,799
related to life let's take a deeper look

628
00:24:54,549 --> 00:24:52,559
at that

629
00:24:56,470 --> 00:24:54,559
first of all i have to remind you that

630
00:24:57,830 --> 00:24:56,480
when you see planets in the night sky so

631
00:25:00,549 --> 00:24:57,840
here's venus

632
00:25:02,070 --> 00:25:00,559
here's jupiter that's our moon

633
00:25:04,549 --> 00:25:02,080
you see them not because they're

634
00:25:06,230 --> 00:25:04,559
self-luminous right these these planets

635
00:25:08,310 --> 00:25:06,240
don't glow in the dark

636
00:25:10,870 --> 00:25:08,320
you see them because they are reflecting

637
00:25:12,789 --> 00:25:10,880
the light from our sun

638
00:25:15,590 --> 00:25:12,799

into our eyeballs

639

00:25:18,310 --> 00:25:15,600

that's how we see the planets so the

640

00:25:20,870 --> 00:25:18,320

same technique for looking for life

641

00:25:23,669 --> 00:25:20,880

on exoplanets so here's a star

642

00:25:25,430 --> 00:25:23,679

it's emitting light and i've exaggerated

643

00:25:28,390 --> 00:25:25,440

the atmosphere of this

644

00:25:30,630 --> 00:25:28,400

potential exoplanet as the light passes

645

00:25:32,950 --> 00:25:30,640

through the atmosphere of this exoplanet

646

00:25:35,269 --> 00:25:32,960

it could reflect off a cloud it could

647

00:25:37,430 --> 00:25:35,279

reflect off the surface

648

00:25:39,190 --> 00:25:37,440

and then it makes its way to

649

00:25:40,870 --> 00:25:39,200

our telescope

650

00:25:42,549 --> 00:25:40,880

now on the way

651
00:25:46,070 --> 00:25:42,559
through the atmosphere and then back out

652
00:25:48,549 --> 00:25:46,080
again if it encounters certain gases

653
00:25:51,830 --> 00:25:48,559
like the ones we just described

654
00:25:53,430 --> 00:25:51,840
they absorb light at very specific

655
00:25:56,070 --> 00:25:53,440
frequencies

656
00:25:57,350 --> 00:25:56,080
so when we capture the light in our

657
00:25:59,830 --> 00:25:57,360
telescope

658
00:26:02,230 --> 00:25:59,840
and pass the light through a prism and

659
00:26:04,230 --> 00:26:02,240
break out the light from the planet into

660
00:26:06,470 --> 00:26:04,240
a rainbow of colors

661
00:26:08,870 --> 00:26:06,480
scientists will then look

662
00:26:12,470 --> 00:26:08,880
for the missing light

663
00:26:16,230 --> 00:26:12,480

right so in an interesting way the

664

00:26:19,830 --> 00:26:16,240

absence of light in our data

665

00:26:21,750 --> 00:26:19,840

reflects the presence of gases in the

666

00:26:23,830 --> 00:26:21,760

atmosphere of

667

00:26:27,590 --> 00:26:23,840

the

668

00:26:28,870 --> 00:26:27,600

could map

669

00:26:35,110 --> 00:26:28,880

the exact

670

00:26:36,870 --> 00:26:35,120

exact colors to very specific gases

671

00:26:39,190 --> 00:26:36,880

there is no doubt about the

672

00:26:42,630 --> 00:26:39,200

correspondence between the missing light

673

00:26:44,310 --> 00:26:42,640

their wavelengths and the gases

674

00:26:46,710 --> 00:26:44,320

so this is what the actual data looks

675

00:26:48,390 --> 00:26:46,720

like you're looking at real data let's

676
00:26:50,149 --> 00:26:48,400
show you how the astronomers interpret

677
00:26:51,750 --> 00:26:50,159
this because one day you're going to

678
00:26:54,630 --> 00:26:51,760
read the new york times and it will say

679
00:26:56,950 --> 00:26:54,640
nasa or an astronomer has discovered

680
00:26:57,909 --> 00:26:56,960
life this is what you're about to see

681
00:27:00,390 --> 00:26:57,919
this

682
00:27:02,549 --> 00:27:00,400
series of squiggly lines is what our

683
00:27:04,470 --> 00:27:02,559
evidence for life is going to look like

684
00:27:05,750 --> 00:27:04,480
i apologize no

685
00:27:08,230 --> 00:27:05,760
green aliens

686
00:27:10,549 --> 00:27:08,240
no flying saucers this is what it looks

687
00:27:12,470 --> 00:27:10,559
like on exoplanet so so here's a rainbow

688
00:27:14,230 --> 00:27:12,480

of colors i've mapped it perfectly to

689

00:27:15,830 --> 00:27:14,240

the wavelengths you see there's no color

690

00:27:18,630 --> 00:27:15,840

out here simply because we've entered

691

00:27:21,269 --> 00:27:18,640

the regime of the infrared the infrared

692

00:27:22,470 --> 00:27:21,279

has no color that's okay we can still

693

00:27:24,870 --> 00:27:22,480

measure it

694

00:27:26,710 --> 00:27:24,880

and on the vertical axis we have the

695

00:27:29,190 --> 00:27:26,720

relative brightness so for example up

696

00:27:31,669 --> 00:27:29,200

here we have a lot of purple light

697

00:27:34,070 --> 00:27:31,679

over here we have a less yellow light

698

00:27:36,390 --> 00:27:34,080

and out and out here we have even less

699

00:27:38,630 --> 00:27:36,400

infrared light if the planet had no

700

00:27:40,149 --> 00:27:38,640

atmosphere at all the curve would look

701

00:27:42,950 --> 00:27:40,159

something like this

702

00:27:46,470 --> 00:27:42,960

so every single one of these dips

703

00:27:48,630 --> 00:27:46,480

corresponds to a gas in the atmosphere

704

00:27:50,789 --> 00:27:48,640

of that planet let me share with you

705

00:27:53,029 --> 00:27:50,799

three of them

706

00:27:55,110 --> 00:27:53,039

this thin line is oxygen

707

00:27:58,470 --> 00:27:55,120

this broad line is water

708

00:27:59,750 --> 00:27:58,480

this trough here is methane so if we saw

709

00:28:03,590 --> 00:27:59,760

that

710

00:28:05,190 --> 00:28:03,600

remind you

711

00:28:07,510 --> 00:28:05,200

this spectrum here comes from our

712

00:28:09,990 --> 00:28:07,520

favorite planet comes from the earth

713

00:28:11,190 --> 00:28:10,000

so if you were aliens from far away and

714

00:28:13,190 --> 00:28:11,200

you got

715

00:28:14,710 --> 00:28:13,200

this data how would you interpret it

716

00:28:17,110 --> 00:28:14,720

would you be able to

717

00:28:18,149 --> 00:28:17,120

conclude there was life on this planet

718

00:28:21,669 --> 00:28:18,159

well

719

00:28:25,350 --> 00:28:23,110

methane comes

720

00:28:28,470 --> 00:28:25,360

besides leaks in natural gas it also

721

00:28:32,549 --> 00:28:28,480

comes from bacteria bacteria in the

722

00:28:37,830 --> 00:28:32,559

digestive tracts of ruminants like cows

723

00:28:38,630 --> 00:28:37,840

and sheep so burping farting cows

724

00:28:40,870 --> 00:28:38,640

but

725

00:28:42,549 --> 00:28:40,880

it may not be just that we have to be

726

00:28:44,950 --> 00:28:42,559

very careful in our interpretations they

727

00:28:47,909 --> 00:28:44,960

could also be water reacting with

728

00:28:49,590 --> 00:28:47,919

particular types of rocks like olivine

729

00:28:51,590 --> 00:28:49,600

in fact that's what we think is going on

730

00:28:54,310 --> 00:28:51,600

mars some of you may have heard that

731

00:28:55,870 --> 00:28:54,320

we've discovered methane on mars it very

732

00:28:59,190 --> 00:28:55,880

well could be a

733

00:29:01,590 --> 00:28:59,200

non-biological source

734

00:29:04,789 --> 00:29:01,600

water so this much water this is what we

735

00:29:07,750 --> 00:29:04,799

call a broad line this much water infers

736

00:29:09,510 --> 00:29:07,760

a lot of water vapor in the atmosphere

737

00:29:11,430 --> 00:29:09,520

and if you know your planet is in the

738

00:29:12,870 --> 00:29:11,440

habitable zone of its star

739

00:29:14,710 --> 00:29:12,880

now you're thinking wow

740

00:29:17,110 --> 00:29:14,720

that water vapor may very well be

741

00:29:19,029 --> 00:29:17,120

related to liquid water so now we're

742

00:29:20,389 --> 00:29:19,039

feeling pretty confident that we're onto

743

00:29:22,310 --> 00:29:20,399

something big

744

00:29:23,830 --> 00:29:22,320

and then oxygen

745

00:29:26,549 --> 00:29:23,840

oxygen on earth

746

00:29:29,510 --> 00:29:26,559

comes mainly from photosynthesis from

747

00:29:31,669 --> 00:29:29,520

plants and bacteria so if we find oxygen

748

00:29:33,350 --> 00:29:31,679

that would be a very exciting and

749

00:29:35,750 --> 00:29:33,360

momentous occasion

750

00:29:38,310 --> 00:29:35,760

especially because oxygen is so reactive

751
00:29:39,110 --> 00:29:38,320
it loves to rust things

752
00:29:42,230 --> 00:29:39,120
and

753
00:29:44,789 --> 00:29:42,240
it loves to solubilize in ocean so if we

754
00:29:47,430 --> 00:29:44,799
if we find this much oxygen we know

755
00:29:48,549 --> 00:29:47,440
something is continuously generating the

756
00:29:50,950 --> 00:29:48,559
oxygen

757
00:29:52,230 --> 00:29:50,960
so we that points to possible evidence

758
00:29:54,950 --> 00:29:52,240
of life

759
00:29:57,430 --> 00:29:54,960
and it loves to react with hydrocarbons

760
00:29:58,389 --> 00:29:57,440
so if we find

761
00:30:00,310 --> 00:29:58,399
methane

762
00:30:02,630 --> 00:30:00,320
in the presence of oxygen that is

763
00:30:04,870 --> 00:30:02,640

practically a slam dunk for the

764

00:30:06,389 --> 00:30:04,880

conclusion we have found life

765

00:30:09,110 --> 00:30:06,399

we may not know if it's intelligent life

766

00:30:09,909 --> 00:30:09,120

but we definitely have found life

767

00:30:12,149 --> 00:30:09,919

now

768

00:30:14,710 --> 00:30:12,159

let me take a step back

769

00:30:16,710 --> 00:30:14,720

we have no clue of what life might look

770

00:30:18,630 --> 00:30:16,720

like on another planet

771

00:30:21,110 --> 00:30:18,640

so we have no idea if it will follow

772

00:30:23,590 --> 00:30:21,120

this or take a different path so when we

773

00:30:24,630 --> 00:30:23,600

build our future instruments which we

774

00:30:28,549 --> 00:30:24,640

are

775

00:30:31,029 --> 00:30:28,559

sensitive enough and robust enough

776

00:30:32,870 --> 00:30:31,039

to measure a whole slew of gases and

777

00:30:35,990 --> 00:30:32,880

different types of phenomenon so we can

778

00:30:38,389 --> 00:30:36,000

piece that story together and conclude

779

00:30:40,310 --> 00:30:38,399

what is it that we have found oxygen by

780

00:30:43,350 --> 00:30:40,320

itself water by itself

781

00:30:45,190 --> 00:30:43,360

is compelling but it's the whole story

782

00:30:47,990 --> 00:30:45,200

together that allows us to conclude

783

00:30:49,590 --> 00:30:48,000

whether or not we have found life

784

00:30:50,389 --> 00:30:49,600

all right what's special about this

785

00:30:53,590 --> 00:30:50,399

technique

786

00:30:55,990 --> 00:30:53,600

is we have to capture the light from the

787

00:30:57,269 --> 00:30:56,000

star and the planet

788

00:30:59,269 --> 00:30:57,279

it's not like those other techniques

789

00:31:01,190 --> 00:30:59,279

that were indirect we have to capture

790

00:31:03,510 --> 00:31:01,200

the light from the planet

791

00:31:04,630 --> 00:31:03,520

so now let's move over to the technology

792

00:31:07,110 --> 00:31:04,640

portion

793

00:31:09,510 --> 00:31:07,120

of our journey it's called direct

794

00:31:12,149 --> 00:31:09,520

imaging of exoplanets very few

795

00:31:14,149 --> 00:31:12,159

exoplanets have ever been imaged out of

796

00:31:16,230 --> 00:31:14,159

those 1800

797

00:31:18,310 --> 00:31:16,240

planets that we discussed earlier only

798

00:31:20,389 --> 00:31:18,320

maybe three dozen or so have actually

799

00:31:23,029 --> 00:31:20,399

been imaged and they all are the same

800

00:31:25,830 --> 00:31:23,039

they're big gaseous

801
00:31:27,750 --> 00:31:25,840
young hot self-illuminous

802
00:31:31,269 --> 00:31:27,760
planets that make it easy to take a

803
00:31:32,789 --> 00:31:31,279
picture of no small older planets all

804
00:31:34,230 --> 00:31:32,799
right remember this chart here where we

805
00:31:36,230 --> 00:31:34,240
talked about how the light from the star

806
00:31:38,230 --> 00:31:36,240
reflects off the planet into our

807
00:31:40,549 --> 00:31:38,240
telescopes

808
00:31:42,950 --> 00:31:40,559
i didn't mention one important thing

809
00:31:45,110 --> 00:31:42,960
this telescope is certainly going to

810
00:31:47,750 --> 00:31:45,120
receive the light from the planet with

811
00:31:50,149 --> 00:31:47,760
potential evidence of life

812
00:31:52,470 --> 00:31:50,159
but it's also going to receive a lot of

813
00:31:54,549 --> 00:31:52,480

light from the star

814

00:31:55,430 --> 00:31:54,559

right so when a telescope stares at a

815

00:31:57,110 --> 00:31:55,440

star

816

00:31:58,470 --> 00:31:57,120

it doesn't see these beautiful planets

817

00:32:02,230 --> 00:31:58,480

like i show here

818

00:32:03,269 --> 00:32:02,240

it looks like this a big glaringly

819

00:32:07,590 --> 00:32:03,279

bright

820

00:32:09,350 --> 00:32:07,600

the light was scattering off some of the

821

00:32:11,190 --> 00:32:09,360

support optics

822

00:32:12,630 --> 00:32:11,200

the support structure within the optics

823

00:32:15,190 --> 00:32:12,640

and that's what all this

824

00:32:17,029 --> 00:32:15,200

scatter is so how are we going to find

825

00:32:19,350 --> 00:32:17,039

planets through all of that right what

826

00:32:20,389 --> 00:32:19,360

we want to do is dim the light of the

827

00:32:23,190 --> 00:32:20,399

star

828

00:32:25,190 --> 00:32:23,200

so that we can see any potential planets

829

00:32:28,789 --> 00:32:25,200

orbiting really close by

830

00:32:31,029 --> 00:32:28,799

that is really hard how hard

831

00:32:33,590 --> 00:32:31,039

an earth-sized planet in the habitable

832

00:32:34,870 --> 00:32:33,600

zone of a sun-like star

833

00:32:38,710 --> 00:32:34,880

is 10

834

00:32:41,669 --> 00:32:38,720

billion times fainter than the star so

835

00:32:43,750 --> 00:32:41,679

let me put that in context for you

836

00:32:47,110 --> 00:32:43,760

see this little planet over here

837

00:32:48,710 --> 00:32:47,120

it is 5 000 times fainter than the star

838

00:32:51,110 --> 00:32:48,720

that we masked out

839

00:32:53,590 --> 00:32:51,120

5 000 times so

840

00:32:55,590 --> 00:32:53,600

stare at this planet and now think of

841

00:32:58,389 --> 00:32:55,600

something that's 10

842

00:33:00,070 --> 00:32:58,399

million times fainter

843

00:33:02,310 --> 00:33:00,080

to get to 10 billion

844

00:33:03,350 --> 00:33:02,320

that's the challenge we have in front of

845

00:33:05,590 --> 00:33:03,360

us

846

00:33:08,389 --> 00:33:05,600

oh and oh by the way

847

00:33:10,710 --> 00:33:08,399

it's even more complicated

848

00:33:11,590 --> 00:33:10,720

imagine it's like trying to find a

849

00:33:14,950 --> 00:33:11,600

little

850

00:33:18,389 --> 00:33:14,960

teeny weeny firefly that's flying

851
00:33:22,149 --> 00:33:18,399
randomly in some direction around an

852
00:33:23,430 --> 00:33:22,159
enormously bright beacon of light

853
00:33:25,830 --> 00:33:23,440
and

854
00:33:27,750 --> 00:33:25,840
the lighthouse

855
00:33:29,750 --> 00:33:27,760
is off the coast of new york

856
00:33:31,750 --> 00:33:29,760
and we remain here

857
00:33:35,350 --> 00:33:31,760
in pasadena

858
00:33:37,509 --> 00:33:35,360
that's how hard this is

859
00:33:39,509 --> 00:33:37,519
okay so our challenge is to take a star

860
00:33:41,669 --> 00:33:39,519
like this

861
00:33:43,110 --> 00:33:41,679
remove as much of the starlight as

862
00:33:46,149 --> 00:33:43,120
possible

863
00:33:49,430 --> 00:33:46,159

and then probe the outer regions for

864

00:33:51,029 --> 00:33:49,440

evidence of planets let's take a look at

865

00:33:53,509 --> 00:33:51,039

the two techniques that are being

866

00:33:55,830 --> 00:33:53,519

championed here at jpl in fact i see a

867

00:33:58,789 --> 00:33:55,840

lot of the engineers that are working on

868

00:34:01,830 --> 00:33:58,799

these very challenging

869

00:34:04,710 --> 00:34:01,840

technologies first one the coronagraph

870

00:34:07,110 --> 00:34:04,720

it's a small optic that fits inside the

871

00:34:08,869 --> 00:34:07,120

telescope its job is to block

872

00:34:10,790 --> 00:34:08,879

the starlight

873

00:34:13,270 --> 00:34:10,800

the second technology

874

00:34:15,430 --> 00:34:13,280

is the star shade same thing instead of

875

00:34:17,349 --> 00:34:15,440

this little optic blocking starlight

876

00:34:19,109 --> 00:34:17,359

inside of your telescope this one is

877

00:34:21,669 --> 00:34:19,119

going to block the starlight

878

00:34:23,510 --> 00:34:21,679

outside of your telescope there are pros

879

00:34:25,750 --> 00:34:23,520

and cons for both

880

00:34:28,950 --> 00:34:25,760

why don't we go ahead and start with the

881

00:34:30,230 --> 00:34:28,960

star shade now who better to explain the

882

00:34:33,349 --> 00:34:30,240

star shades

883

00:34:37,589 --> 00:34:33,359

than our beloved carl sagan

884

00:34:38,790 --> 00:34:37,599

this clip was taken from circa 1979

885

00:34:40,550 --> 00:34:38,800

i don't know if any of you have ever

886

00:34:42,710 --> 00:34:40,560

seen this

887

00:34:50,069 --> 00:34:42,720

and on those other worlds

888

00:34:53,510 --> 00:34:51,270

here

889

00:34:55,430 --> 00:34:53,520

is a light bulb which is supposed to

890

00:34:57,510 --> 00:34:55,440

represent a nearby star

891

00:35:00,230 --> 00:34:57,520

and next to it and very hard to see

892

00:35:02,550 --> 00:35:00,240

because the bright light is a planet now

893

00:35:04,870 --> 00:35:02,560

we'll need a volunteer who would like to

894

00:35:07,030 --> 00:35:04,880

come up with these

895

00:35:08,550 --> 00:35:07,040

ordinarily you would have a hard time

896

00:35:12,630 --> 00:35:08,560

seeing the planet because it's so close

897

00:35:14,630 --> 00:35:12,640

that the star washes out the planet but

898

00:35:16,470 --> 00:35:14,640

if we were able to put something in

899

00:35:18,630 --> 00:35:16,480

front of the star

900

00:35:20,550 --> 00:35:18,640

to make an artificial eclipse then we

901
00:35:22,150 --> 00:35:20,560
might be able to see the planet so i'm

902
00:35:23,109 --> 00:35:22,160
going to stand over here imagine that

903
00:35:24,790 --> 00:35:23,119
i'm

904
00:35:27,670 --> 00:35:24,800
a telescope

905
00:35:30,390 --> 00:35:27,680
somewhere near the earth and tab if

906
00:35:32,630 --> 00:35:30,400
you'd slowly move the disc across

907
00:35:34,310 --> 00:35:32,640
good a little faster be nice

908
00:35:35,510 --> 00:35:34,320
but now you're just beginning to cover

909
00:35:37,510 --> 00:35:35,520
over the star

910
00:35:40,310 --> 00:35:37,520
i i really can't see the planet at all

911
00:35:43,430 --> 00:35:40,320
keep going good now right there

912
00:35:44,630 --> 00:35:43,440
i can't see the star at all and i see

913
00:35:47,030 --> 00:35:44,640

the planet

914

00:35:49,829 --> 00:35:47,040

lit by the light of the star

915

00:35:54,870 --> 00:35:49,839

now that is a method for looking

916

00:36:01,990 --> 00:35:57,670

i love her face

917

00:36:03,430 --> 00:36:02,000

the definition of deep infatuation

918

00:36:07,510 --> 00:36:03,440

okay so

919

00:36:10,069 --> 00:36:07,520

35 years later after that video came out

920

00:36:13,270 --> 00:36:10,079

that carl explained his concept

921

00:36:15,349 --> 00:36:13,280

jpl engineers in collaboration with our

922

00:36:18,390 --> 00:36:15,359

colleagues at universities and in

923

00:36:23,670 --> 00:36:18,400

industry have come up with the concept

924

00:36:27,030 --> 00:36:24,470

we

925

00:36:30,470 --> 00:36:27,040

fly two spacecrafts at the same time

926
00:36:36,230 --> 00:36:30,480
they separate in space here's oops let's

927
00:36:41,349 --> 00:36:37,349
they

928
00:36:43,750 --> 00:36:41,359
is your telescope

929
00:36:46,390 --> 00:36:43,760
here is your shade you can see the shade

930
00:36:48,470 --> 00:36:46,400
has unfurled its petals now it's it's

931
00:36:51,510 --> 00:36:48,480
extending its inner structure

932
00:36:53,670 --> 00:36:51,520
out to the size of a baseball diamond

933
00:36:55,430 --> 00:36:53,680
these are two individual spacecrafts

934
00:36:57,829 --> 00:36:55,440
they communicate with each other the

935
00:36:59,670 --> 00:36:57,839
shade is now heading towards its first

936
00:37:01,670 --> 00:36:59,680
star of interest

937
00:37:04,790 --> 00:37:01,680
the telescope is aligning itself to it

938
00:37:06,710 --> 00:37:04,800

waiting for the shade to pass in front

939

00:37:08,950 --> 00:37:06,720

of the star and then

940

00:37:10,790 --> 00:37:08,960

we see the reflected light

941

00:37:17,750 --> 00:37:10,800

from the planets

942

00:37:22,790 --> 00:37:19,829

let's take a closer look at

943

00:37:26,950 --> 00:37:22,800

this technology so the star shade itself

944

00:37:28,950 --> 00:37:26,960

is tens of meters in diameter

945

00:37:30,550 --> 00:37:28,960

us it blocks the starlight if there

946

00:37:33,190 --> 00:37:30,560

happens to be a planet

947

00:37:35,510 --> 00:37:33,200

its light will skirt the edges of the

948

00:37:37,109 --> 00:37:35,520

shade and enter the telescope once it

949

00:37:38,950 --> 00:37:37,119

enters the telescope it goes through the

950

00:37:42,150 --> 00:37:38,960

prism the prism breaks it out into a

951
00:37:44,470 --> 00:37:42,160
rainbow of colors we look for evidence

952
00:37:47,589 --> 00:37:44,480
of life the distance between these two

953
00:37:50,150 --> 00:37:47,599
spacecrafts are 30 to 50 thousand

954
00:37:51,510 --> 00:37:50,160
kilometers so to put that in a ballpark

955
00:37:52,470 --> 00:37:51,520
that maybe we can understand more

956
00:37:56,630 --> 00:37:52,480
readily

957
00:37:58,550 --> 00:37:56,640
three to four earth diameters

958
00:38:00,230 --> 00:37:58,560
and then as the two as these two

959
00:38:03,190 --> 00:38:00,240
spacecrafts are aligning they have to

960
00:38:06,630 --> 00:38:03,200
maintain an alignment to an offset of

961
00:38:09,670 --> 00:38:06,640
about one meter in either direction

962
00:38:11,750 --> 00:38:09,680
that's pretty tight

963
00:38:14,069 --> 00:38:11,760

once the observation of the star has

964

00:38:15,670 --> 00:38:14,079

concluded either the telescope or the

965

00:38:18,310 --> 00:38:15,680

star shade will now

966

00:38:21,589 --> 00:38:18,320

slew across the sky and look for its

967

00:38:24,870 --> 00:38:21,599

next target they realign and we start

968

00:38:27,910 --> 00:38:26,069

now

969

00:38:31,030 --> 00:38:27,920

some of you are probably asking what's

970

00:38:33,270 --> 00:38:31,040

with the pedals right carl did not show

971

00:38:34,870 --> 00:38:33,280

those petals well perhaps what carl

972

00:38:36,710 --> 00:38:34,880

didn't have time to explain to his

973

00:38:37,589 --> 00:38:36,720

elementary school class

974

00:38:39,990 --> 00:38:37,599

is

975

00:38:42,069 --> 00:38:40,000

diffraction

976

00:38:42,950 --> 00:38:42,079

we're going to get into physics here

977

00:38:44,630 --> 00:38:42,960

here's

978

00:38:46,390 --> 00:38:44,640

an aerial view of an island off the

979

00:38:48,710 --> 00:38:46,400

coast off the coast of norway

980

00:38:50,230 --> 00:38:48,720

you can see the ocean or the sea is

981

00:38:52,390 --> 00:38:50,240

moving from the bottom

982

00:38:55,030 --> 00:38:52,400

right to the top left you would think

983

00:38:57,829 --> 00:38:55,040

you would think that this island should

984

00:39:00,230 --> 00:38:57,839

act like an umbrella it should just stop

985

00:39:03,510 --> 00:39:00,240

the waves and behind it there should be

986

00:39:06,230 --> 00:39:03,520

just still water and that's absolutely

987

00:39:09,190 --> 00:39:06,240

what you don't see behind it you see the

988

00:39:12,310 --> 00:39:09,200

effects of diffraction the bending of

989

00:39:14,230 --> 00:39:12,320

light the bending of water

990

00:39:16,470 --> 00:39:14,240

you can see it's bending this way it's

991

00:39:19,430 --> 00:39:16,480

bending this way so back here there are

992

00:39:21,750 --> 00:39:19,440

plenty of waves same over here

993

00:39:24,550 --> 00:39:21,760

land masses don't seem to stop the

994

00:39:26,310 --> 00:39:24,560

effects of diffraction let's take a look

995

00:39:28,310 --> 00:39:26,320

at a simulation

996

00:39:29,430 --> 00:39:28,320

by some colleagues at st mary's

997

00:39:31,670 --> 00:39:29,440

university

998

00:39:35,030 --> 00:39:31,680

in canada

999

00:39:36,950 --> 00:39:35,040

imagine the star shade is placed edge on

1000

00:39:38,550 --> 00:39:36,960

and it's right here again you would

1001
00:39:40,790 --> 00:39:38,560
think that the star shade would just

1002
00:39:42,550 --> 00:39:40,800
block all the light so back here you

1003
00:39:44,150 --> 00:39:42,560
would see nothing well sure enough

1004
00:39:46,710 --> 00:39:44,160
because of the effects of diffraction

1005
00:39:48,150 --> 00:39:46,720
the light has bent around it so

1006
00:39:50,310 --> 00:39:48,160
if you're interested in putting a

1007
00:39:52,950 --> 00:39:50,320
telescope there or a camera you're going

1008
00:39:58,630 --> 00:39:52,960
to be still blinded by the light of the

1009
00:40:03,510 --> 00:40:02,390
so the petals are analytically designed

1010
00:40:05,589 --> 00:40:03,520
to not

1011
00:40:08,790 --> 00:40:05,599
stop the fraction you could never stop

1012
00:40:11,750 --> 00:40:08,800
diffraction but you can redirect it you

1013
00:40:14,390 --> 00:40:11,760

can redirect it away from your telescope

1014

00:40:16,390 --> 00:40:14,400

and your camera such that there's a dark

1015

00:40:18,790 --> 00:40:16,400

shadow behind it here's a computer

1016

00:40:20,550 --> 00:40:18,800

simulation that shows how the pedals

1017

00:40:23,990 --> 00:40:20,560

work they send all the light to the

1018

00:40:27,030 --> 00:40:24,000

outside leaving behind a very deep and

1019

00:40:28,230 --> 00:40:27,040

dark shadow where we can maybe find the

1020

00:40:31,510 --> 00:40:28,240

faint

1021

00:40:32,710 --> 00:40:31,520

evidence of these exoplanets so here's

1022

00:40:34,230 --> 00:40:32,720

your shadow

1023

00:40:36,550 --> 00:40:34,240

and that's where you place your

1024

00:40:40,710 --> 00:40:36,560

telescope the telescope just has to sit

1025

00:40:42,550 --> 00:40:40,720

in the shadow created by the star shade

1026

00:40:44,790 --> 00:40:42,560

you're probably also wondering about now

1027

00:40:48,230 --> 00:40:44,800

how do we get something the size of a

1028

00:40:49,910 --> 00:40:48,240

baseball diamond folded into a rocket

1029

00:40:52,950 --> 00:40:49,920

well let's work backwards here's your

1030

00:40:54,390 --> 00:40:52,960

fully deployed star shade it folds like

1031

00:40:55,589 --> 00:40:54,400

an accordion or it folds like an

1032

00:40:58,150 --> 00:40:55,599

umbrella

1033

00:40:59,750 --> 00:40:58,160

the inner the inner portions do and then

1034

00:41:02,950 --> 00:40:59,760

you're just left with the pedals and the

1035

00:41:04,630 --> 00:41:02,960

pedals will just furl around a hub

1036

00:41:07,109 --> 00:41:04,640

and then you can end up with a very

1037

00:41:09,829 --> 00:41:07,119

stowed tightly

1038

00:41:13,030 --> 00:41:09,839

stoned configuration that fits nicely

1039

00:41:16,309 --> 00:41:14,790

let's take a look at a demo that we just

1040

00:41:17,910 --> 00:41:16,319

did recently

1041

00:41:19,750 --> 00:41:17,920

at jpl so

1042

00:41:20,390 --> 00:41:19,760

let's pick up the story where the pedals

1043

00:41:24,230 --> 00:41:20,400

are

1044

00:41:26,870 --> 00:41:24,240

of our

1045

00:41:28,069 --> 00:41:26,880

ace engineers and a summer student in

1046

00:41:29,030 --> 00:41:28,079

the back

1047

00:41:30,950 --> 00:41:29,040

and

1048

00:41:32,710 --> 00:41:30,960

i'm gonna run this video for you we only

1049

00:41:35,190 --> 00:41:32,720

put four pedals on by the way because we

1050

00:41:37,990 --> 00:41:35,200

couldn't fit any more pedals in the room

1051

00:41:39,990 --> 00:41:38,000

this is a half scale demonstration so

1052

00:41:41,589 --> 00:41:40,000

it's it's certainly not complete but

1053

00:41:43,430 --> 00:41:41,599

it's a proof of concept

1054

00:41:45,510 --> 00:41:43,440

and i just want to point out there's a

1055

00:41:47,670 --> 00:41:45,520

bunch of what we call trusses and the

1056

00:41:49,349 --> 00:41:47,680

trusses are folded into each other and

1057

00:41:51,430 --> 00:41:49,359

you're about to see them

1058

00:41:52,710 --> 00:41:51,440

expand and keep your eye on the pedals

1059

00:41:54,950 --> 00:41:52,720

how do they go

1060

00:41:57,030 --> 00:41:54,960

from a vertical configuration to a

1061

00:41:58,390 --> 00:41:57,040

horizontal configuration

1062

00:42:00,309 --> 00:41:58,400

i'll give you a hint

1063

00:42:03,510 --> 00:42:00,319

there's a couple very small motors in

1064

00:42:05,910 --> 00:42:03,520

here that are pulling on a steel cable

1065

00:42:11,030 --> 00:42:05,920

and as they do that everything starts to

1066

00:42:15,270 --> 00:42:13,190

okay here we go

1067

00:42:16,710 --> 00:42:15,280

we we sped this up a little bit

1068

00:42:18,470 --> 00:42:16,720

now

1069

00:42:21,030 --> 00:42:18,480

oops sorry i did that again let's try it

1070

00:42:24,390 --> 00:42:23,430

okay here we go

1071

00:42:25,910 --> 00:42:24,400

so

1072

00:42:27,349 --> 00:42:25,920

we've sped this up this engineer here by

1073

00:42:29,030 --> 00:42:27,359

the way is keeping his eye on the motor

1074

00:42:30,950 --> 00:42:29,040

that's one of the two motors

1075

00:42:33,589 --> 00:42:30,960

and it's like reeling in a fishing line

1076

00:42:36,069 --> 00:42:33,599

as the as the cable gets reeled in it

1077

00:42:38,870 --> 00:42:36,079

spreads out these trusses until they

1078

00:42:40,230 --> 00:42:38,880

continue to elongate elongate elongate

1079

00:42:42,870 --> 00:42:40,240

and then at certain point in fact you

1080

00:42:45,349 --> 00:42:42,880

can see they're still not fully

1081

00:42:51,349 --> 00:42:45,359

deployed wait for it at some point

1082

00:42:55,829 --> 00:42:53,030

right there just before there's a little

1083

00:42:57,430 --> 00:42:55,839

hiccup there and it's fully deployed

1084

00:42:59,510 --> 00:42:57,440

the good news is that there's a lot of

1085

00:43:01,670 --> 00:42:59,520

heritage for this type of technology

1086

00:43:03,349 --> 00:43:01,680

we've borrowed from our friends in the

1087

00:43:05,670 --> 00:43:03,359

aerospace industry that have flown

1088

00:43:07,030 --> 00:43:05,680

things like this for

1089

00:43:09,670 --> 00:43:07,040

radio

1090

00:43:11,270 --> 00:43:09,680

communications and antennas in fact

1091

00:43:14,309 --> 00:43:11,280

there's one right behind you in the

1092

00:43:16,150 --> 00:43:14,319

corner that is that's the smap telescope

1093

00:43:19,349 --> 00:43:16,160

that was just deployed just a few months

1094

00:43:21,510 --> 00:43:19,359

ago using some very similar technology

1095

00:43:24,710 --> 00:43:21,520

so we're confident that it would work

1096

00:43:26,710 --> 00:43:24,720

the engineers at jpl have simplified

1097

00:43:27,910 --> 00:43:26,720

design making it simpler

1098

00:43:29,829 --> 00:43:27,920

lighter

1099

00:43:30,950 --> 00:43:29,839

and integrates with

1100

00:43:32,790 --> 00:43:30,960

the pedals

1101

00:43:35,190 --> 00:43:32,800

we encourage you perhaps during an open

1102

00:43:36,710 --> 00:43:35,200

house to come and visit us

1103

00:43:41,589 --> 00:43:36,720

we'll be perhaps a little bit more

1104

00:43:45,270 --> 00:43:42,950

all right how about how it works

1105

00:43:47,829 --> 00:43:45,280

optically so our colleagues at northrop

1106

00:43:50,150 --> 00:43:47,839

grumman here in southern california

1107

00:43:52,790 --> 00:43:50,160

received a grant from nasa

1108

00:43:53,750 --> 00:43:52,800

to demonstrate how this works optically

1109

00:43:55,589 --> 00:43:53,760

so

1110

00:43:57,990 --> 00:43:55,599

here's northrop grumman's

1111

00:44:01,670 --> 00:43:58,000

setup in a dry

1112

00:44:03,670 --> 00:44:01,680

lake bed in the deserts of nevada

1113

00:44:06,309 --> 00:44:03,680

here's your telescope

1114

00:44:09,750 --> 00:44:06,319

two kilometers away you see

1115

00:44:11,990 --> 00:44:09,760

a simulated star it's a very bright lamp

1116

00:44:14,069 --> 00:44:12,000

what you don't see are the simulated

1117

00:44:14,950 --> 00:44:14,079

planets that are next to the bright

1118

00:44:18,230 --> 00:44:14,960

lamp

1119

00:44:20,950 --> 00:44:18,240

and then in the middle

1120

00:44:23,589 --> 00:44:20,960

is a prototype of the star shade and the

1121

00:44:27,270 --> 00:44:23,599

shape is really really important in fact

1122

00:44:33,349 --> 00:44:29,270

and this is something we've tested or or

1123

00:44:39,349 --> 00:44:36,550

the actual star shade will be about 120

1124

00:44:40,710 --> 00:44:39,359

times bigger than this one

1125

00:44:43,109 --> 00:44:40,720

and what you don't see and maybe

1126

00:44:44,069 --> 00:44:43,119

afterwards you can come up these petals

1127

00:44:46,790 --> 00:44:44,079

have

1128

00:44:49,109 --> 00:44:46,800

lots of wiggles and those wiggles are

1129

00:44:52,230 --> 00:44:49,119

critical because they help with the

1130

00:44:53,670 --> 00:44:52,240

diffraction of the starlight

1131

00:44:58,470 --> 00:44:53,680

let's take a look

1132

00:45:02,790 --> 00:45:00,790

so they're going to move the star shade

1133

00:45:04,870 --> 00:45:02,800

in position in front of the lamp and

1134

00:45:11,510 --> 00:45:04,880

boom right there there's our first

1135

00:45:15,510 --> 00:45:13,430

i'll let that run again

1136

00:45:18,390 --> 00:45:15,520

so the objective is to get

1137

00:45:20,470 --> 00:45:18,400

to see planets as close as possible to

1138

00:45:22,630 --> 00:45:20,480

the starship

1139

00:45:24,230 --> 00:45:22,640

okay so let's take a look at some of

1140

00:45:26,309 --> 00:45:24,240

their data they were thrilled to get

1141

00:45:28,309 --> 00:45:26,319

this bright planet

1142

00:45:29,349 --> 00:45:28,319

but do you guys see this faint planet

1143

00:45:30,710 --> 00:45:29,359

that was the one they were really

1144

00:45:32,550 --> 00:45:30,720

excited about that's getting a little

1145

00:45:34,870 --> 00:45:32,560

bit closer to what we're looking for

1146

00:45:37,910 --> 00:45:34,880

that simulated planet is a hundred

1147

00:45:40,470 --> 00:45:37,920

million times fainter than the simulated

1148

00:45:42,150 --> 00:45:40,480

star so we're getting closer to our

1149

00:45:45,430 --> 00:45:42,160

overall objectives

1150

00:45:47,990 --> 00:45:45,440

we acknowledge that the sizes

1151
00:45:50,230 --> 00:45:48,000
are not exactly what we expect in space

1152
00:45:51,829 --> 00:45:50,240
as we mature our demonstrations they

1153
00:45:55,589 --> 00:45:51,839
will get a little bit closer to what we

1154
00:45:56,550 --> 00:45:55,599
will actually fly but it's a good start

1155
00:45:58,069 --> 00:45:56,560
all right

1156
00:46:00,710 --> 00:45:58,079
let's now go

1157
00:46:02,630 --> 00:46:00,720
to the coronagraph so imagine taking

1158
00:46:04,870 --> 00:46:02,640
that big star shade

1159
00:46:06,630 --> 00:46:04,880
and shrinking it down so it can fit in

1160
00:46:07,990 --> 00:46:06,640
between your fingers

1161
00:46:11,910 --> 00:46:08,000
and put that

1162
00:46:13,510 --> 00:46:11,920
into into your telescope

1163
00:46:15,750 --> 00:46:13,520

the the motivation for the for the

1164

00:46:18,390 --> 00:46:15,760

chronograph comes from studies of the

1165

00:46:21,510 --> 00:46:18,400

corona so the corona is these faint

1166

00:46:22,470 --> 00:46:21,520

wispy structures in the atmosphere of

1167

00:46:24,309 --> 00:46:22,480

our sun

1168

00:46:27,030 --> 00:46:24,319

and they can only be seen when we have a

1169

00:46:29,190 --> 00:46:27,040

perfect eclipse of the sun

1170

00:46:31,349 --> 00:46:29,200

by the moon well if you're a scientist

1171

00:46:33,349 --> 00:46:31,359

wanting to study this it's kind of a

1172

00:46:34,870 --> 00:46:33,359

long time to wait for an eclipse then

1173

00:46:37,750 --> 00:46:34,880

you have to travel to

1174

00:46:39,910 --> 00:46:37,760

the other other parts of the earth so a

1175

00:46:42,870 --> 00:46:39,920

french astronomer asked the question why

1176

00:46:44,790 --> 00:46:42,880

not have a synthetic

1177

00:46:47,190 --> 00:46:44,800

eclipse that he could put into his

1178

00:46:49,510 --> 00:46:47,200

telescope and observe the corona any

1179

00:46:51,510 --> 00:46:49,520

time he wants that that's exactly what

1180

00:46:53,670 --> 00:46:51,520

he did and he was very successful in

1181

00:46:55,190 --> 00:46:53,680

observing the corona however as we've

1182

00:46:57,190 --> 00:46:55,200

just learned

1183

00:47:00,230 --> 00:46:57,200

these circular discs are not that

1184

00:47:03,349 --> 00:47:00,240

effective because of diffraction to look

1185

00:47:05,750 --> 00:47:03,359

for faint planets so astronomers

1186

00:47:07,990 --> 00:47:05,760

here at jpl as well as elsewhere have

1187

00:47:11,109 --> 00:47:08,000

worked over the last 20 years in

1188

00:47:13,990 --> 00:47:11,119

modifying these masks to take care of

1189

00:47:15,430 --> 00:47:14,000

the diffraction to redirect it same

1190

00:47:18,790 --> 00:47:15,440

thing

1191

00:47:20,790 --> 00:47:18,800

let's let's take a look at

1192

00:47:22,829 --> 00:47:20,800

how the chronograph works

1193

00:47:25,349 --> 00:47:22,839

this is probably a good time to dim the

1194

00:47:26,470 --> 00:47:25,359

lights and you might recognize the

1195

00:47:27,270 --> 00:47:26,480

narrator

1196

00:47:48,390 --> 00:47:27,280

but

1197

00:47:52,710 --> 00:47:50,630

this exoplanet in the distant solar

1198

00:47:54,870 --> 00:47:52,720

system appears to have features very

1199

00:47:58,630 --> 00:47:54,880

similar to our own earth

1200

00:48:00,630 --> 00:47:58,640

it has continents oceans and clouds

1201

00:48:02,870 --> 00:48:00,640

this star has another planet

1202

00:48:06,550 --> 00:48:02,880

this one appears to be a gas giant not

1203

00:48:08,790 --> 00:48:06,560

unlike jupiter in our own solar system

1204

00:48:11,589 --> 00:48:08,800

as we move further away the two planets

1205

00:48:13,430 --> 00:48:11,599

disappear into the glare of their sun

1206

00:48:15,430 --> 00:48:13,440

the star now looks like all the other

1207

00:48:17,430 --> 00:48:15,440

stars in the night sky

1208

00:48:19,190 --> 00:48:17,440

how will we ever see these planets we

1209

00:48:21,510 --> 00:48:19,200

cannot yet travel there for the

1210

00:48:23,270 --> 00:48:21,520

distances to even the closest stars are

1211

00:48:25,910 --> 00:48:23,280

well beyond humanity's current

1212

00:48:28,150 --> 00:48:25,920

capability to traverse in our lifetimes

1213

00:48:29,750 --> 00:48:28,160

we will have to rely on a space

1214

00:48:32,870 --> 00:48:29,760

telescope

1215

00:48:35,349 --> 00:48:32,880

science instrument called the

1216

00:48:38,390 --> 00:48:35,359

coronagraph that is designed to separate

1217

00:48:39,990 --> 00:48:38,400

starlight from reflected planet light

1218

00:48:42,150 --> 00:48:40,000

as the light makes its way to the

1219

00:48:44,069 --> 00:48:42,160

chronograph we also notice signs of

1220

00:48:46,069 --> 00:48:44,079

small distortions picked up when the

1221

00:48:48,069 --> 00:48:46,079

light reflected off the tiniest of

1222

00:48:49,030 --> 00:48:48,079

imperfections in the telescope's larger

1223

00:48:51,349 --> 00:48:49,040

mirrors

1224

00:48:53,510 --> 00:48:51,359

with the chronograph not yet activated

1225

00:48:55,910 --> 00:48:53,520

we see on the monitor what the star

1226
00:48:58,390 --> 00:48:55,920
looks like through a telescope no matter

1227
00:49:00,710 --> 00:48:58,400
how large and perfect the telescope is

1228
00:49:03,349 --> 00:49:00,720
it turns what was once a point of light

1229
00:49:05,750 --> 00:49:03,359
in space into a round disc surrounded by

1230
00:49:08,069 --> 00:49:05,760
concentric rings the effect of what is

1231
00:49:10,150 --> 00:49:08,079
known as diffraction

1232
00:49:11,910 --> 00:49:10,160
somewhere behind the rings of light are

1233
00:49:14,069 --> 00:49:11,920
the two feign planets

1234
00:49:16,309 --> 00:49:14,079
as you're about to see a coronagraph

1235
00:49:17,750 --> 00:49:16,319
helps directly image faint planets by

1236
00:49:19,829 --> 00:49:17,760
doing three things

1237
00:49:22,069 --> 00:49:19,839
first a coronagraph blocks most of the

1238
00:49:24,309 --> 00:49:22,079

incoming starlight using a mask with a

1239

00:49:26,390 --> 00:49:24,319

dark central region the mask is

1240

00:49:28,790 --> 00:49:26,400

carefully designed to redirect the

1241

00:49:30,790 --> 00:49:28,800

starlight that it does not block off to

1242

00:49:33,109 --> 00:49:30,800

the edges of the beam

1243

00:49:35,510 --> 00:49:33,119

as we see on the monitor the inserted

1244

00:49:37,349 --> 00:49:35,520

mask has already decreased much of the

1245

00:49:39,670 --> 00:49:37,359

central starlight

1246

00:49:41,589 --> 00:49:39,680

secondly a coronagraph removes the

1247

00:49:43,430 --> 00:49:41,599

effects of diffraction

1248

00:49:45,829 --> 00:49:43,440

when something that looks like a washer

1249

00:49:48,069 --> 00:49:45,839

is placed into the light path it blocks

1250

00:49:50,309 --> 00:49:48,079

the light in the edges of the beam and

1251
00:49:52,710 --> 00:49:50,319
the rings disappear

1252
00:49:54,870 --> 00:49:52,720
we have now managed to remove almost all

1253
00:49:57,030 --> 00:49:54,880
of the starlight and are now able to

1254
00:49:59,190 --> 00:49:57,040
view objects more than a million times

1255
00:50:00,870 --> 00:49:59,200
fainter than the star

1256
00:50:01,990 --> 00:50:00,880
but what happens to the light from a

1257
00:50:03,910 --> 00:50:02,000
planet

1258
00:50:05,670 --> 00:50:03,920
why doesn't it also get blocked by the

1259
00:50:07,270 --> 00:50:05,680
mass

1260
00:50:09,750 --> 00:50:07,280
because the telescope is pointing

1261
00:50:12,870 --> 00:50:09,760
directly at the star a planet's light

1262
00:50:16,150 --> 00:50:12,880
comes in at an angle misses the mask and

1263
00:50:17,990 --> 00:50:16,160

passes through the center of the washer

1264

00:50:19,670 --> 00:50:18,000

but we are still unable to see the

1265

00:50:21,990 --> 00:50:19,680

planets

1266

00:50:23,589 --> 00:50:22,000

if we look closely at the monitor when

1267

00:50:25,829 --> 00:50:23,599

we turn up the image signal by

1268

00:50:27,990 --> 00:50:25,839

collecting more light what appears to

1269

00:50:30,950 --> 00:50:28,000

have been a blank field actually

1270

00:50:33,030 --> 00:50:30,960

consists of blobs of leftover starlight

1271

00:50:35,270 --> 00:50:33,040

this scattered light due to minute

1272

00:50:37,670 --> 00:50:35,280

imperfections in the telescope's optics

1273

00:50:39,430 --> 00:50:37,680

is still hiding the faint planets so

1274

00:50:41,510 --> 00:50:39,440

this takes us to the third and last

1275

00:50:43,829 --> 00:50:41,520

element of the chronograph the removal

1276
00:50:45,750 --> 00:50:43,839
of these scattered blobs a special

1277
00:50:47,910 --> 00:50:45,760
mirror is used with hundreds of tiny

1278
00:50:50,150 --> 00:50:47,920
pistons behind it that can change its

1279
00:50:52,069 --> 00:50:50,160
shape so as to correct the distortions

1280
00:50:54,630 --> 00:50:52,079
in the light beam

1281
00:50:57,190 --> 00:50:54,640
as the mirror deforms the blobs of light

1282
00:50:59,510 --> 00:50:57,200
as seen on the monitor slowly begin

1283
00:51:02,230 --> 00:50:59,520
disappearing finally revealing the

1284
00:51:04,630 --> 00:51:02,240
brighter of the two planets

1285
00:51:07,349 --> 00:51:04,640
afterwards the fainter planet also comes

1286
00:51:11,750 --> 00:51:09,430
we can now start to see objects more

1287
00:51:13,109 --> 00:51:11,760
than a billion times fainter than the

1288
00:51:19,030 --> 00:51:13,119

star

1289

00:51:20,950 --> 00:51:19,040

have discovered our two planets

1290

00:51:22,549 --> 00:51:20,960

and if the light from these is passed

1291

00:51:24,870 --> 00:51:22,559

through a prism

1292

00:51:26,630 --> 00:51:24,880

we will see the lights spread out into

1293

00:51:28,870 --> 00:51:26,640

rainbows of color

1294

00:51:29,990 --> 00:51:28,880

but when looking closely some colors are

1295

00:51:32,230 --> 00:51:30,000

missing

1296

00:51:34,150 --> 00:51:32,240

they were absorbed by gases in each

1297

00:51:36,790 --> 00:51:34,160

planet's atmosphere giving us important

1298

00:51:39,109 --> 00:51:36,800

clues about their composition

1299

00:51:49,190 --> 00:51:39,119

the search for life in the universe has

1300

00:51:55,190 --> 00:51:51,430

so a little more complicated than it

1301
00:51:59,510 --> 00:51:56,870
so i just wanted to bring you up to date

1302
00:52:01,990 --> 00:51:59,520
on where we are with this technology so

1303
00:52:03,670 --> 00:52:02,000
here at jpl i i have the privilege of

1304
00:52:06,630 --> 00:52:03,680
working with some of the finest optical

1305
00:52:08,710 --> 00:52:06,640
engineers on the planet and here you see

1306
00:52:11,670 --> 00:52:08,720
two vacuum chambers that are meant to

1307
00:52:13,829 --> 00:52:11,680
resemble the vacuum of space and inside

1308
00:52:16,230 --> 00:52:13,839
of these chambers are these fairly large

1309
00:52:18,950 --> 00:52:16,240
optical tables and on them you will see

1310
00:52:21,589 --> 00:52:18,960
a setup that resembles the chronograph

1311
00:52:24,870 --> 00:52:21,599
so we get to test the masks and the

1312
00:52:26,069 --> 00:52:24,880
electronics and these deformable mirrors

1313
00:52:27,510 --> 00:52:26,079

so i just wanted to show you some

1314

00:52:30,230 --> 00:52:27,520

pictures

1315

00:52:33,910 --> 00:52:30,240

of the masks here's the one that was in

1316

00:52:35,589 --> 00:52:33,920

the animation here is another uh concept

1317

00:52:38,390 --> 00:52:35,599

from our friends at princeton university

1318

00:52:41,270 --> 00:52:38,400

that appears to work equally as well and

1319

00:52:42,549 --> 00:52:41,280

here's a a more advanced design that

1320

00:52:44,470 --> 00:52:42,559

we're looking at from the university of

1321

00:52:46,549 --> 00:52:44,480

arizona that has some other special

1322

00:52:48,710 --> 00:52:46,559

features here's what the deformable

1323

00:52:50,950 --> 00:52:48,720

mirror looks like from a company called

1324

00:52:52,870 --> 00:52:50,960

zynetics in massachusetts and here's

1325

00:52:55,109 --> 00:52:52,880

some really early data this data is

1326
00:52:57,670 --> 00:52:55,119
probably a couple of months old it shows

1327
00:52:58,950 --> 00:52:57,680
you that this the the laser light which

1328
00:53:02,790 --> 00:52:58,960
simulates our

1329
00:53:04,630 --> 00:53:02,800
star is blocked out and around it we

1330
00:53:06,150 --> 00:53:04,640
have probed down to regions that are

1331
00:53:12,630 --> 00:53:06,160
less than

1332
00:53:14,790 --> 00:53:12,640
million times fainter than the laser

1333
00:53:17,030 --> 00:53:14,800
light so we're heading towards 10

1334
00:53:21,270 --> 00:53:17,040
billion and this is a pretty good

1335
00:53:26,390 --> 00:53:24,150
okay we are in the last section of our

1336
00:53:27,349 --> 00:53:26,400
journey let's talk about

1337
00:53:30,390 --> 00:53:27,359
what

1338
00:53:32,309 --> 00:53:30,400

concepts does nasa have

1339

00:53:36,710 --> 00:53:32,319

what are they thinking about what are

1340

00:53:41,270 --> 00:53:38,150

here's some of the telescopes that we've

1341

00:53:43,910 --> 00:53:41,280

already had enormous success with

1342

00:53:45,030 --> 00:53:43,920

you're all familiar with the hubble

1343

00:53:46,309 --> 00:53:45,040

you're probably familiar with the

1344

00:53:48,630 --> 00:53:46,319

spitzer telescope that has

1345

00:53:51,030 --> 00:53:48,640

revolutionized our understanding of the

1346

00:53:52,710 --> 00:53:51,040

infrared world what's interesting is

1347

00:53:54,950 --> 00:53:52,720

neither one of both of these two

1348

00:53:57,270 --> 00:53:54,960

telescopes were not designed

1349

00:53:59,270 --> 00:53:57,280

specifically to look for exoplanets

1350

00:54:01,349 --> 00:53:59,280

however we've learned just enormous

1351
00:54:03,910 --> 00:54:01,359
amount of information even though we

1352
00:54:06,470 --> 00:54:03,920
didn't design it that way

1353
00:54:08,549 --> 00:54:06,480
of course the kepler was designed to

1354
00:54:11,510 --> 00:54:08,559
look for planets and it has

1355
00:54:13,430 --> 00:54:11,520
clearly revolutionized our understanding

1356
00:54:14,630 --> 00:54:13,440
what's in the pipeline well just in a

1357
00:54:16,069 --> 00:54:14,640
couple years

1358
00:54:19,670 --> 00:54:16,079
the tess

1359
00:54:22,470 --> 00:54:19,680
mission the transiting exoplanet survey

1360
00:54:24,950 --> 00:54:22,480
satellite is going to pick up where

1361
00:54:27,829 --> 00:54:24,960
kepler left off

1362
00:54:29,430 --> 00:54:27,839
tess will use the transit technique but

1363
00:54:31,589 --> 00:54:29,440

instead of where kepler was looking

1364

00:54:33,109 --> 00:54:31,599

which was thousands of light-year

1365

00:54:35,670 --> 00:54:33,119

faraway stars

1366

00:54:37,670 --> 00:54:35,680

kepler will look at the closest stars

1367

00:54:40,069 --> 00:54:37,680

looking for the closest planets giving

1368

00:54:43,910 --> 00:54:40,079

us a better chance to

1369

00:54:47,510 --> 00:54:43,920

probe the atmospheres of planets

1370

00:54:50,829 --> 00:54:47,520

followed by in 2018 the long-awaited

1371

00:54:53,430 --> 00:54:50,839

james webb space telescope

1372

00:54:56,390 --> 00:54:53,440

unquestionably the largest and most

1373

00:54:58,150 --> 00:54:56,400

complicated telescope that nasa has ever

1374

00:54:59,829 --> 00:54:58,160

flown it's i wanted to show you a

1375

00:55:01,750 --> 00:54:59,839

prototype of it

1376

00:55:04,390 --> 00:55:01,760

in the yard

1377

00:55:07,430 --> 00:55:04,400

at nasa goddard space flight center in

1378

00:55:10,390 --> 00:55:07,440

greenbelt maryland it is unquestionably

1379

00:55:12,470 --> 00:55:10,400

uh a bemid it is almost three times the

1380

00:55:14,710 --> 00:55:12,480

size of our own hubble space telescope

1381

00:55:15,589 --> 00:55:14,720

the mirror is so large that it could not

1382

00:55:19,109 --> 00:55:15,599

fit

1383

00:55:22,230 --> 00:55:19,119

onto a rocket so they broke up the

1384

00:55:23,750 --> 00:55:22,240

the mirror into one meter class segments

1385

00:55:27,109 --> 00:55:23,760

and some of these segments will actually

1386

00:55:29,990 --> 00:55:27,119

fold so we can fit it onto a rocket

1387

00:55:32,710 --> 00:55:30,000

this telescope will certainly find new

1388

00:55:34,390 --> 00:55:32,720

planets like jupiter's and saturn's it

1389

00:55:36,950 --> 00:55:34,400

wasn't designed to find some of the

1390

00:55:39,589 --> 00:55:36,960

smallest planets but it does have an

1391

00:55:42,630 --> 00:55:39,599

interesting opportunity to discover life

1392

00:55:45,589 --> 00:55:42,640

or signs of life in a small

1393

00:55:47,829 --> 00:55:45,599

set of scenarios here i show you

1394

00:55:49,270 --> 00:55:47,839

a planet that has a relatively thick

1395

00:55:51,829 --> 00:55:49,280

atmosphere and if

1396

00:55:54,069 --> 00:55:51,839

if james webb is lucky enough

1397

00:55:58,470 --> 00:55:54,079

to find a planet that is transiting

1398

00:56:00,390 --> 00:55:58,480

across the face of a nearby star

1399

00:56:02,309 --> 00:56:00,400

and this planet has a reasonably sized

1400

00:56:04,470 --> 00:56:02,319

atmosphere then the light that's

1401

00:56:06,390 --> 00:56:04,480

traveling from the star

1402

00:56:08,789 --> 00:56:06,400

passes through the atmosphere

1403

00:56:11,510 --> 00:56:08,799

absorbed by some of the gases and then

1404

00:56:13,589 --> 00:56:11,520

when the detector on the telescope

1405

00:56:16,630 --> 00:56:13,599

detects it it'll see some of the missing

1406

00:56:18,870 --> 00:56:16,640

light so it in a finite range of

1407

00:56:20,710 --> 00:56:18,880

scenarios can actually find the

1408

00:56:23,990 --> 00:56:20,720

signatures of life that work that we've

1409

00:56:28,069 --> 00:56:25,910

one of the telescopes that i am very

1410

00:56:30,630 --> 00:56:28,079

excited about happens in the middle of

1411

00:56:32,950 --> 00:56:30,640

the next decade it's not official just

1412

00:56:34,789 --> 00:56:32,960

yet it's currently a study but it's

1413

00:56:37,270 --> 00:56:34,799

building up a lot of momentum i would

1414

00:56:39,829 --> 00:56:37,280

argue that this telescope wfirst which

1415

00:56:42,870 --> 00:56:39,839

stands for wide field infrared survey

1416

00:56:45,109 --> 00:56:42,880

telescope is amongst the most compelling

1417

00:56:48,150 --> 00:56:45,119

science missions that nasa has ever

1418

00:56:49,910 --> 00:56:48,160

flown it carries two instruments

1419

00:56:51,670 --> 00:56:49,920

and one of them

1420

00:56:53,349 --> 00:56:51,680

attempts to answer some of the most

1421

00:56:55,589 --> 00:56:53,359

profound questions

1422

00:56:56,789 --> 00:56:55,599

in all of astrophysics what is dark

1423

00:56:58,710 --> 00:56:56,799

matter

1424

00:57:00,150 --> 00:56:58,720

what is dark energy

1425

00:57:01,750 --> 00:57:00,160

and on top of that

1426

00:57:03,270 --> 00:57:01,760

it uses another

1427

00:57:05,829 --> 00:57:03,280

technique that we mentioned briefly

1428

00:57:07,670 --> 00:57:05,839

called gravitational microlensing to

1429

00:57:09,990 --> 00:57:07,680

indirectly detect

1430

00:57:11,910 --> 00:57:10,000

planets that are further away from the

1431

00:57:13,430 --> 00:57:11,920

star compared to some of the other

1432

00:57:16,309 --> 00:57:13,440

techniques it will complete our

1433

00:57:17,829 --> 00:57:16,319

knowledge our census of exoplanets

1434

00:57:19,190 --> 00:57:17,839

around stars

1435

00:57:21,190 --> 00:57:19,200

and then the instrument that i'm

1436

00:57:22,710 --> 00:57:21,200

personally very excited about

1437

00:57:25,670 --> 00:57:22,720

is the first

1438

00:57:27,990 --> 00:57:25,680

high contrast coronagraph instrument

1439

00:57:30,549 --> 00:57:28,000

exactly as we showed earlier

1440

00:57:33,670 --> 00:57:30,559

we've never flown a coronagraph that is

1441

00:57:36,069 --> 00:57:33,680

capable of detecting small planets it's

1442

00:57:38,069 --> 00:57:36,079

kind of a technology demonstrator

1443

00:57:40,470 --> 00:57:38,079

and we're very excited to see if this

1444

00:57:42,309 --> 00:57:40,480

technology actually works

1445

00:57:43,829 --> 00:57:42,319

in space so that's why you saw those

1446

00:57:46,470 --> 00:57:43,839

vacuum chambers

1447

00:57:49,030 --> 00:57:46,480

churning away to advance this technology

1448

00:57:50,630 --> 00:57:49,040

as quickly as possible

1449

00:57:53,270 --> 00:57:50,640

i would be remiss if i just didn't say

1450

00:57:54,549 --> 00:57:53,280

one comment about new ground-based

1451

00:57:55,670 --> 00:57:54,559

telescopes

1452

00:57:58,390 --> 00:57:55,680

there

1453

00:58:00,470 --> 00:57:58,400

ground-based telescopes in the next

1454

00:58:02,789 --> 00:58:00,480

decade there are at least three that i

1455

00:58:04,789 --> 00:58:02,799

know of that are underway the 30 meter

1456

00:58:06,950 --> 00:58:04,799

telescope in hawaii the giant magellan

1457

00:58:08,789 --> 00:58:06,960

telescope in chile and the european

1458

00:58:13,109 --> 00:58:08,799

extremely large telescope in chile these

1459

00:58:14,549 --> 00:58:13,119

are the largest telescopes ever built

1460

00:58:17,589 --> 00:58:14,559

it's not clear

1461

00:58:19,190 --> 00:58:17,599

how capable these huge telescopes are in

1462

00:58:21,750 --> 00:58:19,200

detecting planets

1463

00:58:23,829 --> 00:58:21,760

the problem with the earth is we have

1464

00:58:25,750 --> 00:58:23,839

this atmosphere that distorts light

1465

00:58:28,069 --> 00:58:25,760

despite the fact that they come equipped

1466

00:58:30,710 --> 00:58:28,079

with the most sophisticated adaptive

1467

00:58:32,950 --> 00:58:30,720

optics we're not certain that they will

1468

00:58:34,950 --> 00:58:32,960

be able to correct the distortions

1469

00:58:37,829 --> 00:58:34,960

enough to detect

1470

00:58:41,750 --> 00:58:37,839

exoplanets i would never bet against a

1471

00:58:45,109 --> 00:58:43,349

all right after that

1472

00:58:48,470 --> 00:58:45,119

so here's the mission that

1473

00:58:49,910 --> 00:58:48,480

we believe could be the life finder

1474

00:58:51,589 --> 00:58:49,920

right it will incorporate everything

1475

00:58:53,430 --> 00:58:51,599

we've discussed tonight

1476

00:58:55,270 --> 00:58:53,440

and it will just point its stars and

1477

00:58:57,910 --> 00:58:55,280

hopefully block out the light and look

1478

00:58:59,990 --> 00:58:57,920

for all those biological signatures

1479

00:59:02,829 --> 00:59:00,000

we don't have a name for it yet so it's

1480

00:59:06,549 --> 00:59:02,839

got a placeholder called the new worlds

1481

00:59:07,510 --> 00:59:06,559

telescope nasa is launching a couple

1482

00:59:09,750 --> 00:59:07,520

teams

1483

00:59:12,470 --> 00:59:09,760

next year to study the science

1484

00:59:14,789 --> 00:59:12,480

capabilities the the architecture and

1485

00:59:16,950 --> 00:59:14,799

we're very excited to see what comes out

1486

00:59:18,549 --> 00:59:16,960

a couple scenarios that have been thrown

1487

00:59:20,390 --> 00:59:18,559

out one is something called the

1488

00:59:21,750 --> 00:59:20,400

habitable exoplanet imaging mission

1489

00:59:24,710 --> 00:59:21,760

imagine taking the hubble space

1490

00:59:27,030 --> 00:59:24,720

telescope and making it even bigger

1491

00:59:29,670 --> 00:59:27,040

and more powerful and imagine flying it

1492

00:59:31,589 --> 00:59:29,680

with either a coronagraph

1493

00:59:34,069 --> 00:59:31,599

or a star shade and this telescope would

1494

00:59:36,789 --> 00:59:34,079

be optimized to look for

1495

00:59:38,870 --> 00:59:36,799

exoplanets and for those of us in our

1496

00:59:41,430 --> 00:59:38,880

community who are feeling frisky and

1497

00:59:44,069 --> 00:59:41,440

perhaps even more ambitious there are

1498

00:59:46,789 --> 00:59:44,079

even more ambitious designs on the table

1499

00:59:48,950 --> 00:59:46,799

imagine a telescope even larger than the

1500

00:59:52,630 --> 00:59:48,960

james webb space telescope somewhere

1501
00:59:53,829 --> 00:59:52,640
between 8 to 12 meters this would be an

1502
00:59:56,150 --> 00:59:53,839
amazing

1503
00:59:57,670 --> 00:59:56,160
feat of engineering

1504
00:59:59,990 --> 00:59:57,680
so

1505
01:00:01,589 --> 01:00:00,000
you'll be all made aware of our progress

1506
01:00:03,670 --> 01:00:01,599
over the next few years to see which of

1507
01:00:07,030 --> 01:00:03,680
these telescopes if any

1508
01:00:08,710 --> 01:00:07,040
are selected by a decadal survey

1509
01:00:11,109 --> 01:00:08,720
committee at the national academies who

1510
01:00:12,390 --> 01:00:11,119
will make their decision sometime

1511
01:00:15,270 --> 01:00:12,400
around the

1512
01:00:17,270 --> 01:00:15,280
end of the decade

1513
01:00:18,710 --> 01:00:17,280

all right we're getting to

1514

01:00:20,549 --> 01:00:18,720

really far out i'm not sure where i'm

1515

01:00:22,789 --> 01:00:20,559

going to be in 2050 but i just thought i

1516

01:00:25,190 --> 01:00:22,799

would share this with you once we find

1517

01:00:26,870 --> 01:00:25,200

life on exoplanets we're going to be

1518

01:00:29,109 --> 01:00:26,880

dying to find out a little bit more

1519

01:00:32,150 --> 01:00:29,119

right what does the surface look like

1520

01:00:35,510 --> 01:00:32,160

are there oceans is there night life is

1521

01:00:38,789 --> 01:00:35,520

there any evidence of photosynthesis

1522

01:00:45,349 --> 01:00:41,589

so so so here's the concept that came

1523

01:00:47,190 --> 01:00:45,359

out in the 1990s by a french astronomer

1524

01:00:51,190 --> 01:00:47,200

antoine laberdy

1525

01:00:53,349 --> 01:00:51,200

and this was way out there in the 1990s

1526

01:00:55,109 --> 01:00:53,359

it is still way out there

1527

01:00:57,030 --> 01:00:55,119

today

1528

01:00:57,990 --> 01:00:57,040

so his concept

1529

01:01:01,270 --> 01:00:58,000

involved

1530

01:01:03,829 --> 01:01:01,280

flying an armada a flotilla of

1531

01:01:07,670 --> 01:01:03,839

telescopes anywhere between one and six

1532

01:01:10,789 --> 01:01:07,680

meters flying out in space imitating

1533

01:01:13,109 --> 01:01:10,799

a humongous telescope maybe hundreds of

1534

01:01:15,270 --> 01:01:13,119

kilometers in size

1535

01:01:18,230 --> 01:01:15,280

and these telescopes would capture the

1536

01:01:20,470 --> 01:01:18,240

light from that planet and they would

1537

01:01:21,589 --> 01:01:20,480

reflect that light into what i call the

1538

01:01:24,230 --> 01:01:21,599

mother ship

1539

01:01:26,470 --> 01:01:24,240

or perhaps the beam combiner and it

1540

01:01:29,510 --> 01:01:26,480

would piece together all of that light

1541

01:01:30,950 --> 01:01:29,520

and be able to maybe make out

1542

01:01:33,750 --> 01:01:30,960

oceans

1543

01:01:35,589 --> 01:01:33,760

continents maybe a little maybe a little

1544

01:01:37,430 --> 01:01:35,599

bit of vegetation

1545

01:01:39,910 --> 01:01:37,440

apart from this i could imagine us

1546

01:01:42,069 --> 01:01:39,920

pointing all our radio telescopes

1547

01:01:44,069 --> 01:01:42,079

listening for activities but this would

1548

01:01:47,109 --> 01:01:44,079

be probably something along the lines of

1549

01:01:53,829 --> 01:01:47,119

what we would need to look for features

1550

01:01:58,309 --> 01:01:55,430

folks we have come

1551
01:02:01,030 --> 01:01:58,319
to the end we have come back to where we

1552
01:02:03,430 --> 01:02:01,040
started the the only planet

1553
01:02:06,150 --> 01:02:03,440
in the galaxy that we know of that has

1554
01:02:08,309 --> 01:02:06,160
life i'll leave you with one remaining

1555
01:02:09,109 --> 01:02:08,319
image

1556
01:02:10,549 --> 01:02:09,119
in

1557
01:02:12,309 --> 01:02:10,559
1990

1558
01:02:14,630 --> 01:02:12,319
nasa commanded

1559
01:02:16,150 --> 01:02:14,640
the voyager 1

1560
01:02:17,990 --> 01:02:16,160
spacecraft

1561
01:02:20,069 --> 01:02:18,000
that one right there

1562
01:02:22,630 --> 01:02:20,079
to turn around from its trajectory

1563
01:02:23,990 --> 01:02:22,640

leaving the solar system and take one

1564

01:02:25,670 --> 01:02:24,000

last picture

1565

01:02:28,309 --> 01:02:25,680

of the earth

1566

01:02:33,670 --> 01:02:30,390

it's right there

1567

01:02:34,789 --> 01:02:33,680

so folks everyone you've ever known

1568

01:02:36,549 --> 01:02:34,799

loved

1569

01:02:38,309 --> 01:02:36,559

admired

1570

01:02:39,829 --> 01:02:38,319

envied

1571

01:02:41,109 --> 01:02:39,839

has lived on

1572

01:02:43,430 --> 01:02:41,119

that planet

1573

01:02:44,630 --> 01:02:43,440

let's take a

1574

01:02:45,829 --> 01:02:44,640

greater

1575

01:02:48,150 --> 01:02:45,839

shot at it

1576

01:02:50,870 --> 01:02:48,160

this is what carl sagan referred to as

1577

01:02:51,670 --> 01:02:50,880

the pale blue dot

1578

01:02:53,750 --> 01:02:51,680

so

1579

01:02:55,430 --> 01:02:53,760

imagine if we can acquire a picture like

1580

01:02:57,829 --> 01:02:55,440

that knowing from everything we've

1581

01:02:59,430 --> 01:02:57,839

discussed tonight that there are signs

1582

01:03:01,670 --> 01:02:59,440

of life on it

1583

01:03:04,470 --> 01:03:01,680

would that be transformational

1584

01:03:06,950 --> 01:03:04,480

what would that mean for us well at

1585

01:03:09,829 --> 01:03:06,960

minimum i think it would inspire

1586

01:03:12,230 --> 01:03:09,839

generations of young people to go on to

1587

01:03:14,549 --> 01:03:12,240

science and engineering

1588

01:03:16,789 --> 01:03:14,559

it would perhaps revolutionize our

1589

01:03:19,109 --> 01:03:16,799

understanding of biology and how life

1590

01:03:22,549 --> 01:03:19,119

formed on our own planet maybe stir up

1591

01:03:25,349 --> 01:03:22,559

some more interest in science and

1592

01:03:27,750 --> 01:03:25,359

astronomy maybe some investments

1593

01:03:29,990 --> 01:03:27,760

in our technology i'll point out that we

1594

01:03:32,630 --> 01:03:30,000

are not limited by brain power at nasa

1595

01:03:35,430 --> 01:03:32,640

we are limited by money

1596

01:03:36,950 --> 01:03:35,440

and perhaps it would establish the next

1597

01:03:38,069 --> 01:03:36,960

frontier

1598

01:03:41,270 --> 01:03:38,079

of

1599

01:03:44,950 --> 01:03:41,280

our ability to know where life is

1600

01:03:48,230 --> 01:03:44,960

and herald in a new era of interstellar

1601

01:04:09,910 --> 01:03:48,240

communication and maybe even one day

1602

01:04:12,950 --> 01:04:11,190

so i think

1603

01:04:15,430 --> 01:04:12,960

i think we have some time for some

1604

01:04:17,670 --> 01:04:15,440

questions if you have any we've set up a

1605

01:04:19,990 --> 01:04:17,680

microphone so please um

1606

01:04:22,390 --> 01:04:20,000

go up there we have a live stream that's

1607

01:04:24,069 --> 01:04:22,400

being sent out throughout the planet so

1608

01:04:25,829 --> 01:04:24,079

those folks want to hear you

1609

01:04:27,270 --> 01:04:25,839

as well i'll be sticking around

1610

01:04:37,990 --> 01:04:27,280

afterwards so if you have any specific

1611

01:04:43,430 --> 01:04:41,190

i have a question about the star shade

1612

01:04:45,510 --> 01:04:43,440

if it's going if it's

1613

01:04:47,190 --> 01:04:45,520

several earth diameters separated from

1614

01:04:50,870 --> 01:04:47,200

the telescope

1615

01:04:53,670 --> 01:04:50,880

it's going to be really in its own orbit

1616

01:04:55,829 --> 01:04:53,680

and you can't really have it in a close

1617

01:04:57,910 --> 01:04:55,839

orbit around the earth because

1618

01:05:01,029 --> 01:04:57,920

that's only one diameter

1619

01:05:02,710 --> 01:05:01,039

so i i did a little looking on online

1620

01:05:06,069 --> 01:05:02,720

and i found

1621

01:05:08,789 --> 01:05:06,079

a brief mention of a halo orbit around

1622

01:05:11,190 --> 01:05:08,799

maybe the l2 point

1623

01:05:13,029 --> 01:05:11,200

and so my question is

1624

01:05:15,910 --> 01:05:13,039

is there a limit on how long the

1625

01:05:18,230 --> 01:05:15,920

exposures can be if you're in some orbit

1626

01:05:19,029 --> 01:05:18,240

like that is when the

1627

01:05:23,990 --> 01:05:19,039

if

1628

01:05:25,990 --> 01:05:24,000

keep moving relative to each other

1629

01:05:30,950 --> 01:05:26,000

because they're in these separated

1630

01:05:34,710 --> 01:05:32,710

you're absolutely right that if you're

1631

01:05:36,950 --> 01:05:34,720

going to have such huge separations you

1632

01:05:39,270 --> 01:05:36,960

can't fly the starshade

1633

01:05:41,430 --> 01:05:39,280

around the earth the earth is too bright

1634

01:05:44,069 --> 01:05:41,440

and we couldn't and it would it

1635

01:05:45,589 --> 01:05:44,079

it incurs a certain gravitational pull

1636

01:05:48,309 --> 01:05:45,599

on the star shade so he's absolutely

1637

01:05:51,589 --> 01:05:48,319

right we need to find someplace else

1638

01:05:52,630 --> 01:05:51,599

really far away from the earth and there

1639

01:05:55,270 --> 01:05:52,640

are

1640

01:05:57,670 --> 01:05:55,280

points of stability in space that orbit

1641

01:05:59,190 --> 01:05:57,680

the sun that are very very stable and

1642

01:06:01,829 --> 01:05:59,200

one of them is called

1643

01:06:03,510 --> 01:06:01,839

the lagrangian two point and that's

1644

01:06:05,270 --> 01:06:03,520

exactly what we're thinking that would

1645

01:06:07,829 --> 01:06:05,280

be an ideal place it's not the only

1646

01:06:10,390 --> 01:06:07,839

place but it is certainly an ideal

1647

01:06:12,870 --> 01:06:10,400

place and then once that alignment is

1648

01:06:15,510 --> 01:06:12,880

made then the telescope will

1649

01:06:18,150 --> 01:06:15,520

keep its shutters open for as long as

1650

01:06:20,150 --> 01:06:18,160

possible we are eventually limited by

1651

01:06:22,230 --> 01:06:20,160

some some background noises

1652

01:06:25,430 --> 01:06:22,240

if there is if there's dust around the

1653

01:06:28,069 --> 01:06:25,440

star will be eventually limited by that

1654

01:06:31,190 --> 01:06:28,079

another thing i found was that

1655

01:06:34,309 --> 01:06:31,200

the shade has to be kind of

1656

01:06:36,950 --> 01:06:34,319

edge on to the sun otherwise there's too

1657

01:06:39,190 --> 01:06:36,960

much light that gets scattered

1658

01:06:41,029 --> 01:06:39,200

clearly that would constrain what what

1659

01:06:43,109 --> 01:06:41,039

what targets you can look at so what we

1660

01:06:45,430 --> 01:06:43,119

didn't talk about is in the starship the

1661

01:06:48,710 --> 01:06:45,440

star shade always has to know where the

1662

01:06:50,630 --> 01:06:48,720

heck is the star right the sun right we

1663

01:06:52,710 --> 01:06:50,640

have to know where the sun is because if

1664

01:06:54,789 --> 01:06:52,720

it's if it's positioned in such a way

1665

01:06:55,829 --> 01:06:54,799

that it could blind the the telescope

1666

01:06:57,910 --> 01:06:55,839

that wouldn't be good so you're

1667

01:06:59,589 --> 01:06:57,920

absolutely right there are a series

1668

01:07:01,349 --> 01:06:59,599

there's a range of angles where the star

1669

01:07:04,230 --> 01:07:01,359

shade will function and we always have

1670

01:07:06,470 --> 01:07:04,240

to be aware of it we're very concerned

1671

01:07:09,029 --> 01:07:06,480

about the amount of glint that reflects

1672

01:07:11,109 --> 01:07:09,039

off off the starshade that could blind

1673

01:07:13,190 --> 01:07:11,119

our telescope said that's part of our

1674

01:07:15,910 --> 01:07:13,200

technology effort excellent set of

1675

01:07:22,069 --> 01:07:17,430

hi hi

1676

01:07:25,109 --> 01:07:22,079

uh regarding uh glossier 581g

1677

01:07:27,029 --> 01:07:25,119

i want to know if the system was

1678

01:07:29,109 --> 01:07:27,039

discovered by

1679

01:07:33,109 --> 01:07:29,119

the doppler's uh

1680

01:07:35,349 --> 01:07:33,119

spectroscope or by radial velocity

1681

01:07:37,270 --> 01:07:35,359

so what is it that you know about this

1682

01:07:39,270 --> 01:07:37,280

star that makes it so interesting to you

1683

01:07:41,910 --> 01:07:39,280

or this planet what i know about the

1684

01:07:45,510 --> 01:07:41,920

star that makes it so interesting is

1685

01:07:46,630 --> 01:07:45,520

that uh it has the conditions uh for uh

1686

01:07:48,870 --> 01:07:46,640

being a

1687

01:07:51,589 --> 01:07:48,880

habitable habitable

1688

01:07:54,069 --> 01:07:51,599

uh star it's not too cold and not too

1689

01:07:56,549 --> 01:07:54,079

hot there are other stars

1690

01:08:00,390 --> 01:07:56,559

i mean there are other planets that are

1691

01:08:04,230 --> 01:08:00,400

orbiting the star like c and d which uh

1692

01:08:06,950 --> 01:08:04,240

uh reflect the greenhouse reflect uh and

1693

01:08:08,710 --> 01:08:06,960

so it's too hot and or

1694

01:08:11,589 --> 01:08:08,720

it's uh murky

1695

01:08:14,789 --> 01:08:11,599

and it's uh too distant from the red

1696

01:08:16,550 --> 01:08:14,799

star that it's orbiting so so just if i

1697

01:08:18,630 --> 01:08:16,560

can cheat just a little bit just by the

1698

01:08:20,070 --> 01:08:18,640

name of the star it tells me that it was

1699

01:08:21,990 --> 01:08:20,080

not discovered necessarily by the

1700

01:08:24,709 --> 01:08:22,000

transit technique but most likely

1701

01:08:26,709 --> 01:08:24,719

through the radial velocity technique i

1702

01:08:29,510 --> 01:08:26,719

would think it would be radial velocity

1703

01:08:31,990 --> 01:08:29,520

but i wanted to verify that yeah in fact

1704

01:08:33,030 --> 01:08:32,000

if you just go on google to wikipedia it

1705

01:08:34,149 --> 01:08:33,040

actually gives you pretty good

1706

01:08:34,950 --> 01:08:34,159

information

1707

01:08:41,110 --> 01:08:34,960

yeah

1708

01:08:44,390 --> 01:08:42,070

all right

1709

01:08:46,470 --> 01:08:44,400

oh i i believe we have some questions

1710

01:08:48,229 --> 01:08:46,480

from the cybersphere

1711

01:08:51,510 --> 01:08:48,239

there might be aliens who have emailed

1712

01:08:55,910 --> 01:08:52,870

oh thank you

1713

01:08:58,950 --> 01:08:55,920

so tony who's tony

1714

01:09:01,910 --> 01:08:58,960

tony asks how does star size affect

1715

01:09:03,990 --> 01:09:01,920

planetary systems in terms of the number

1716

01:09:05,590 --> 01:09:04,000

of possible planets

1717

01:09:08,229 --> 01:09:05,600

wow that's a great question how does

1718

01:09:11,349 --> 01:09:08,239

star size affect planetary systems in

1719

01:09:12,950 --> 01:09:11,359

terms of the number of possible planets

1720

01:09:15,349 --> 01:09:12,960

well

1721

01:09:18,470 --> 01:09:15,359

i i think the actual answer is we're not

1722

01:09:20,390 --> 01:09:18,480

yet sure of of how it does

1723

01:09:21,829 --> 01:09:20,400

there is some evidence

1724

01:09:25,349 --> 01:09:21,839

to suggest that

1725

01:09:28,229 --> 01:09:25,359

small stars tend to have actually more

1726

01:09:30,789 --> 01:09:28,239

planets but that might just be a bias of

1727

01:09:32,470 --> 01:09:30,799

of our data that perhaps

1728

01:09:34,550 --> 01:09:32,480

those planets tend to be a little bit

1729

01:09:37,110 --> 01:09:34,560

closer to their star so we've seen them

1730

01:09:38,870 --> 01:09:37,120

we haven't been as sensitive to the

1731

01:09:39,669 --> 01:09:38,880

planets further

1732

01:09:42,070 --> 01:09:39,679

away

1733

01:09:43,749 --> 01:09:42,080

would you have anything to add to that

1734

01:09:45,430 --> 01:09:43,759

most stars have about the same number of

1735

01:09:48,309 --> 01:09:45,440

planets so

1736

01:09:49,990 --> 01:09:48,319

um what we think is most planets most

1737

01:09:52,950 --> 01:09:50,000

stars have roughly the same number of

1738

01:09:56,229 --> 01:09:52,960

planets we haven't seen any evidence yet

1739

01:09:58,470 --> 01:09:56,239

that the star size the star mass

1740

01:10:00,070 --> 01:09:58,480

impacts the number of planets but we

1741

01:10:03,030 --> 01:10:00,080

will get more data

1742

01:10:05,910 --> 01:10:03,040

shortly i'll take your question

1743

01:10:08,070 --> 01:10:05,920

thank you um i wanted to ask about the

1744

01:10:09,110 --> 01:10:08,080

approach three when you were discussing

1745

01:10:14,550 --> 01:10:09,120

the

1746

01:10:17,270 --> 01:10:14,560

you said that we were looking for

1747

01:10:20,550 --> 01:10:17,280

the biological elements that we know

1748

01:10:22,709 --> 01:10:20,560

would produce life like water oxygen and

1749

01:10:26,470 --> 01:10:22,719

methane right how do you take into

1750

01:10:28,870 --> 01:10:26,480

account that on another planet maybe

1751

01:10:30,950 --> 01:10:28,880

the intelligent life or even any kind of

1752

01:10:32,709 --> 01:10:30,960

life doesn't survive on those types of

1753

01:10:33,990 --> 01:10:32,719

elements maybe they use something else

1754

01:10:37,350 --> 01:10:34,000

how do you take that into account

1755

01:10:39,189 --> 01:10:37,360

absolutely absolutely absolutely in fact

1756

01:10:41,430 --> 01:10:39,199

statistically speaking it's very

1757

01:10:43,270 --> 01:10:41,440

unlikely that alien life would have

1758

01:10:45,430 --> 01:10:43,280

followed the same evolutionary track

1759

01:10:46,390 --> 01:10:45,440

that ours is i think that's a fact well

1760

01:10:49,110 --> 01:10:46,400

it's not it's we don't know if it's a

1761

01:10:50,709 --> 01:10:49,120

fact but it's certainly a hypothesis so

1762

01:10:52,790 --> 01:10:50,719

to answer your question

1763

01:10:55,110 --> 01:10:52,800

it's important for us and we will be

1764

01:10:57,110 --> 01:10:55,120

arguing this amongst ourselves now for

1765

01:10:58,550 --> 01:10:57,120

the next several years how important it

1766

01:11:00,870 --> 01:10:58,560

is to

1767

01:11:02,630 --> 01:11:00,880

build our instruments

1768

01:11:03,669 --> 01:11:02,640

so such that they are sufficiently

1769

01:11:04,790 --> 01:11:03,679

sensitive

1770

01:11:08,229 --> 01:11:04,800

enough

1771

01:11:10,630 --> 01:11:08,239

to detect a wide range of gases right

1772

01:11:12,870 --> 01:11:10,640

and it'll just be fascinating to see

1773

01:11:14,709 --> 01:11:12,880

that if we can piece together a whole

1774

01:11:16,709 --> 01:11:14,719

new set of gases what could that

1775

01:11:19,350 --> 01:11:16,719

possibly mean and that search will it

1776

01:11:20,390 --> 01:11:19,360

will will obviously detect gases but

1777

01:11:23,110 --> 01:11:20,400

then we have to run that through our

1778

01:11:25,270 --> 01:11:23,120

computer models and see well we know

1779

01:11:27,669 --> 01:11:25,280

these gases can exist on earth or maybe

1780

01:11:31,510 --> 01:11:27,679

not and how do they play with the others

1781

01:11:34,070 --> 01:11:31,520

and it'll be a fascinating

1782

01:11:37,430 --> 01:11:34,080

cottage industry if you will so i hope

1783

01:11:40,470 --> 01:11:37,440

i've answered your question thank you

1784

01:11:42,229 --> 01:11:40,480

all right explorer iss asks

1785

01:11:43,750 --> 01:11:42,239

do different stars have different

1786

01:11:45,750 --> 01:11:43,760

habitable zones

1787

01:11:47,590 --> 01:11:45,760

okay that's a great fundamental question

1788

01:11:50,310 --> 01:11:47,600

so the habitable zone is not you know

1789

01:11:54,550 --> 01:11:50,320

that special it's an imaginary region of

1790

01:11:56,709 --> 01:11:54,560

space but it's all about how bright is

1791

01:11:57,830 --> 01:11:56,719

the star the best analogy that i can

1792

01:12:01,510 --> 01:11:57,840

give

1793

01:12:02,790 --> 01:12:01,520

explorer iss is imagine you've built a

1794

01:12:04,630 --> 01:12:02,800

campfire

1795

01:12:06,310 --> 01:12:04,640

right so if you want to stay warm at

1796

01:12:08,630 --> 01:12:06,320

your campfire if it's a really big

1797

01:12:10,550 --> 01:12:08,640

campfire you probably don't want to stay

1798

01:12:12,709 --> 01:12:10,560

too close right so

1799

01:12:15,830 --> 01:12:12,719

the analogy is that a big campfire like

1800

01:12:19,270 --> 01:12:15,840

a big star its habitable zone is much

1801
01:12:21,750 --> 01:12:19,280
further away a smaller lighter star like

1802
01:12:23,350 --> 01:12:21,760
a small campfire allows you to come a

1803
01:12:24,950 --> 01:12:23,360
little bit closer it's more of a

1804
01:12:27,430 --> 01:12:24,960
temperate region as you're as you're

1805
01:12:29,990 --> 01:12:27,440
closer and that's your new habitable

1806
01:12:32,310 --> 01:12:30,000
zone so clearly the star

1807
01:12:35,030 --> 01:12:32,320
brightness the star size defines where

1808
01:12:36,310 --> 01:12:35,040
the habitable zone is

1809
01:12:38,310 --> 01:12:36,320
i'll take your question uh quick

1810
01:12:40,390 --> 01:12:38,320
question um basically as technology

1811
01:12:42,149 --> 01:12:40,400
changes uh looking long-term like the

1812
01:12:43,510 --> 01:12:42,159
next hundred two hundred years with uh

1813
01:12:45,590 --> 01:12:43,520

things like nano technology where we can

1814

01:12:47,430 --> 01:12:45,600

build better lenses and things if we can

1815

01:12:49,189 --> 01:12:47,440

take out all the diffusion of light

1816

01:12:50,390 --> 01:12:49,199

basically all the scatter

1817

01:12:52,550 --> 01:12:50,400

if we were able to do that with

1818

01:12:54,550 --> 01:12:52,560

technology would we be able to directly

1819

01:12:56,310 --> 01:12:54,560

look at almost like a google map if you

1820

01:12:58,310 --> 01:12:56,320

will uh image satellite image of the

1821

01:13:00,229 --> 01:12:58,320

planet or would there be too much debris

1822

01:13:02,390 --> 01:13:00,239

in space and dust and you know various

1823

01:13:04,310 --> 01:13:02,400

dust clouds and things cluttering that i

1824

01:13:07,030 --> 01:13:04,320

was just curious okay so is is your

1825

01:13:08,790 --> 01:13:07,040

question about our ability to

1826

01:13:10,390 --> 01:13:08,800

to probe the surface of

1827

01:13:12,149 --> 01:13:10,400

basically how much light is really

1828

01:13:13,590 --> 01:13:12,159

coming off in this planet is there

1829

01:13:14,709 --> 01:13:13,600

enough that we could actually just image

1830

01:13:16,310 --> 01:13:14,719

it if we could take out all the

1831

01:13:17,510 --> 01:13:16,320

diffusion of light okay that's a great

1832

01:13:18,709 --> 01:13:17,520

question so

1833

01:13:20,470 --> 01:13:18,719

um

1834

01:13:22,229 --> 01:13:20,480

so for the typical telescopes that we

1835

01:13:24,550 --> 01:13:22,239

discussed tonight except for that crazy

1836

01:13:26,630 --> 01:13:24,560

last um

1837

01:13:28,870 --> 01:13:26,640

animation we showed typically our

1838

01:13:31,189 --> 01:13:28,880

telescopes will

1839

01:13:34,470 --> 01:13:31,199

stare at a star for a very very long

1840

01:13:35,669 --> 01:13:34,480

time so during that time the planet is

1841

01:13:38,870 --> 01:13:35,679

is

1842

01:13:41,750 --> 01:13:38,880

revolving around its own uh um center of

1843

01:13:43,510 --> 01:13:41,760

axis and it's also moving so what we get

1844

01:13:46,390 --> 01:13:43,520

is kind of

1845

01:13:49,110 --> 01:13:46,400

a mess right of light all combined

1846

01:13:51,110 --> 01:13:49,120

together so it it it prevents us from

1847

01:13:53,830 --> 01:13:51,120

being able to pick out

1848

01:13:56,070 --> 01:13:53,840

simple and direct details okay right

1849

01:13:57,830 --> 01:13:56,080

that's why we need to go to that really

1850

01:14:00,790 --> 01:13:57,840

amazing last simulation where we can

1851

01:14:03,510 --> 01:14:00,800

build a telescope big enough

1852

01:14:06,709 --> 01:14:03,520

light quick enough exactly to acquire

1853

01:14:07,830 --> 01:14:06,719

the light quick enough so we can

1854

01:14:09,750 --> 01:14:07,840

collect it

1855

01:14:13,110 --> 01:14:09,760

while it hasn't rotated

1856

01:14:14,630 --> 01:14:13,120

very much so we can pick up um

1857

01:14:17,990 --> 01:14:14,640

photo um

1858

01:14:20,390 --> 01:14:18,000

evidence of of of chlorophyll vegetation

1859

01:14:22,390 --> 01:14:20,400

right oceans so it has to happen very

1860

01:14:25,030 --> 01:14:22,400

quickly for it to happen very quickly

1861

01:14:27,430 --> 01:14:25,040

you need a big big telescope that's why

1862

01:14:28,950 --> 01:14:27,440

we're really hoping and astronomers

1863

01:14:30,870 --> 01:14:28,960

should never hope but we're really

1864

01:14:33,830 --> 01:14:30,880

hoping because we're so interested in

1865

01:14:35,669 --> 01:14:33,840

life that we can find a nearby star with

1866

01:14:37,990 --> 01:14:35,679

a nearby planet so the telescope

1867

01:14:40,870 --> 01:14:38,000

wouldn't have to be that large gotcha

1868

01:14:42,550 --> 01:14:40,880

okay well thank you

1869

01:14:51,430 --> 01:14:42,560

hi

1870

01:14:55,669 --> 01:14:54,390

when you look through the prism um after

1871

01:14:58,390 --> 01:14:55,679

you take the light from the star if

1872

01:15:00,709 --> 01:14:58,400

whatever i understood um how do you rep

1873

01:15:02,470 --> 01:15:00,719

how do you understand which gases

1874

01:15:04,149 --> 01:15:02,480

represent which

1875

01:15:07,030 --> 01:15:04,159

gases represent the

1876

01:15:08,390 --> 01:15:07,040

gaps in the rainbow sheen right right

1877

01:15:10,709 --> 01:15:08,400

okay great

1878

01:15:13,030 --> 01:15:10,719

so again the question is we have all of

1879

01:15:15,030 --> 01:15:13,040

these gaps of light

1880

01:15:17,750 --> 01:15:15,040

uh in the rainbow so how do we know

1881

01:15:19,430 --> 01:15:17,760

which one is which so um one day when

1882

01:15:21,030 --> 01:15:19,440

you're a little bit older and smarter

1883

01:15:22,470 --> 01:15:21,040

than your father

1884

01:15:25,270 --> 01:15:22,480

you're going to learn about quantum

1885

01:15:27,430 --> 01:15:25,280

mechanics so quantum mechanics is is is

1886

01:15:30,310 --> 01:15:27,440

the physics of the very small and the

1887

01:15:33,189 --> 01:15:30,320

physics of the very small predicts

1888

01:15:37,189 --> 01:15:33,199

predicts very precisely at what

1889

01:15:38,470 --> 01:15:37,199

particular colors light will absorb

1890

01:15:41,669 --> 01:15:38,480

like be absorbed

1891

01:15:43,510 --> 01:15:41,679

right so when we see these black gaps in

1892

01:15:45,270 --> 01:15:43,520

our rainbow

1893

01:15:47,669 --> 01:15:45,280

it we just have to look at a handbook

1894

01:15:50,070 --> 01:15:47,679

that tells us well at this wavelength

1895

01:15:53,189 --> 01:15:50,080

these are the type of gases that

1896

01:15:55,910 --> 01:15:53,199

possibly were absorbed and because these

1897

01:15:58,149 --> 01:15:55,920

these these black bars these black gaps

1898

01:15:59,910 --> 01:15:58,159

are so narrow in wavelength it makes it

1899

01:16:01,030 --> 01:15:59,920

very easy to do that

1900

01:16:02,630 --> 01:16:01,040

i don't know if that makes sense to you

1901

01:16:08,870 --> 01:16:02,640

that makes sense great

1902

01:16:08,880 --> 01:16:12,390

oh boy

1903

01:16:12,400 --> 01:16:15,030

go ahead

1904

01:16:19,990 --> 01:16:18,229

if the star shield mission is launched

1905

01:16:21,510 --> 01:16:20,000

that's an awful lot of maneuvering

1906

01:16:24,310 --> 01:16:21,520

that's going to have to take place to

1907

01:16:26,470 --> 01:16:24,320

redirect to look at different um targets

1908

01:16:28,229 --> 01:16:26,480

what kind of propulsion system is going

1909

01:16:29,990 --> 01:16:28,239

to be used on that and what type of

1910

01:16:32,790 --> 01:16:30,000

operational life can that mission expect

1911

01:16:34,229 --> 01:16:32,800

to have that's a great question in fact

1912

01:16:35,990 --> 01:16:34,239

i'm going gonna pass the question i'm

1913

01:16:37,830 --> 01:16:36,000

gonna i'm gonna ask

1914

01:16:40,070 --> 01:16:37,840

the gentleman standing behind you who is

1915

01:16:42,310 --> 01:16:40,080

a world expert in this field

1916

01:16:44,790 --> 01:16:42,320

to come to the microphone and answer

1917

01:16:53,990 --> 01:16:44,800

that question

1918

01:16:56,870 --> 01:16:55,350

so there's um

1919

01:16:59,350 --> 01:16:56,880

uh

1920

01:17:01,430 --> 01:16:59,360

different technologies we can use

1921

01:17:04,070 --> 01:17:01,440

and uh conventional propulsion is

1922

01:17:05,430 --> 01:17:04,080

chemical like i used on these spacecraft

1923

01:17:07,189 --> 01:17:05,440

and

1924

01:17:09,669 --> 01:17:07,199

that is limited capability because of

1925

01:17:11,510 --> 01:17:09,679

the energy capacity of the of the fuel

1926

01:17:13,350 --> 01:17:11,520

that you can fit into a spacecraft so

1927

01:17:14,310 --> 01:17:13,360

what we really want to do for

1928

01:17:16,390 --> 01:17:14,320

the

1929

01:17:18,630 --> 01:17:16,400

better missions that last longer is to

1930

01:17:19,590 --> 01:17:18,640

use solar electric propulsion

1931

01:17:21,030 --> 01:17:19,600

so

1932

01:17:24,390 --> 01:17:21,040

that's

1933

01:17:26,870 --> 01:17:24,400

using a lot of power to generate ions

1934

01:17:28,630 --> 01:17:26,880

and accelerate it out an engine at very

1935

01:17:30,470 --> 01:17:28,640

low thrust and so

1936

01:17:32,390 --> 01:17:30,480

that's a relatively new technology but

1937

01:17:33,910 --> 01:17:32,400

like the don mission recently that was

1938

01:17:36,310 --> 01:17:33,920

an early technology demonstration of

1939

01:17:38,550 --> 01:17:36,320

that technique so it's very low thrust

1940

01:17:40,709 --> 01:17:38,560

thrust but it's very efficient so for a

1941

01:17:43,189 --> 01:17:40,719

given amount of propellant you can

1942

01:17:45,590 --> 01:17:43,199

get a lot of uh motion out of it thank

1943

01:17:48,790 --> 01:17:45,600

you doug so so we have fuel

1944

01:17:49,990 --> 01:17:48,800

to um to rotate the star shade we have

1945

01:17:52,229 --> 01:17:50,000

fuel

1946

01:17:53,910 --> 01:17:52,239

and and propulsion to keep it aligned

1947

01:17:56,950 --> 01:17:53,920

but when it comes to traversing across

1948

01:17:58,550 --> 01:17:56,960

the cosmos to the next star then doug is

1949

01:18:00,790 --> 01:17:58,560

right that's we're considering the fact

1950

01:18:02,470 --> 01:18:00,800

that we can't carry that much fuel so

1951

01:18:03,350 --> 01:18:02,480

solar electric propulsion might be an

1952

01:18:06,630 --> 01:18:03,360

ideal

1953

01:18:09,750 --> 01:18:08,310

all right what else do i have oh okay

1954

01:18:11,430 --> 01:18:09,760

all right

1955

01:18:13,669 --> 01:18:11,440

i'll play along

1956

01:18:15,510 --> 01:18:13,679

what inspired you to get into this field

1957

01:18:17,830 --> 01:18:15,520

of study

1958

01:18:20,390 --> 01:18:17,840

all right so

1959

01:18:22,149 --> 01:18:20,400

carl sagan

1960

01:18:25,430 --> 01:18:22,159

cosmos

1961

01:18:31,189 --> 01:18:29,030

um and the apollo missions right and

1962

01:18:34,470 --> 01:18:31,199

and um

1963

01:18:37,750 --> 01:18:34,480

i can't help to think how inspirational

1964

01:18:39,030 --> 01:18:37,760

nasa can and should continue to be i

1965

01:18:40,709 --> 01:18:39,040

think

1966

01:18:43,110 --> 01:18:40,719

speaking from my generation and perhaps

1967

01:18:45,350 --> 01:18:43,120

the generations before me

1968

01:18:48,149 --> 01:18:45,360

we were all inspired by what nasa has

1969

01:18:49,510 --> 01:18:48,159

achieved and that's why having i think a

1970

01:18:50,229 --> 01:18:49,520

a well-funded

1971

01:18:52,310 --> 01:18:50,239

and

1972

01:18:53,430 --> 01:18:52,320

an enriched nasa will continue to

1973

01:18:55,350 --> 01:18:53,440

inspire

1974

01:18:57,750 --> 01:18:55,360

future generations of scientists and

1975

01:18:59,669 --> 01:18:57,760

engineers like myself to continue to

1976

01:19:02,950 --> 01:18:59,679

reach for the stars and this is the best

1977

01:19:04,870 --> 01:19:02,960

job a person could ever

1978

01:19:07,189 --> 01:19:04,880

desire but you don't have to be a

1979

01:19:09,510 --> 01:19:07,199

scientist we need lots of engineers

1980

01:19:12,550 --> 01:19:09,520

electrical mechanical so there's so much

1981

01:19:15,110 --> 01:19:12,560

opportunity and

1982

01:19:16,950 --> 01:19:15,120

i i often joke with my boss that that we

1983

01:19:19,270 --> 01:19:16,960

work here at nasa for our second

1984

01:19:21,669 --> 01:19:19,280

paycheck our first paycheck comes with

1985

01:19:23,430 --> 01:19:21,679

dollars but the second paycheck is that

1986

01:19:25,669 --> 01:19:23,440

intrinsic value of we're doing things

1987

01:19:28,950 --> 01:19:25,679

like this that are just so inspiring

1988

01:19:30,310 --> 01:19:28,960

that we can't wait to come to work

1989

01:19:31,590 --> 01:19:30,320

folks i think we've come to the end of