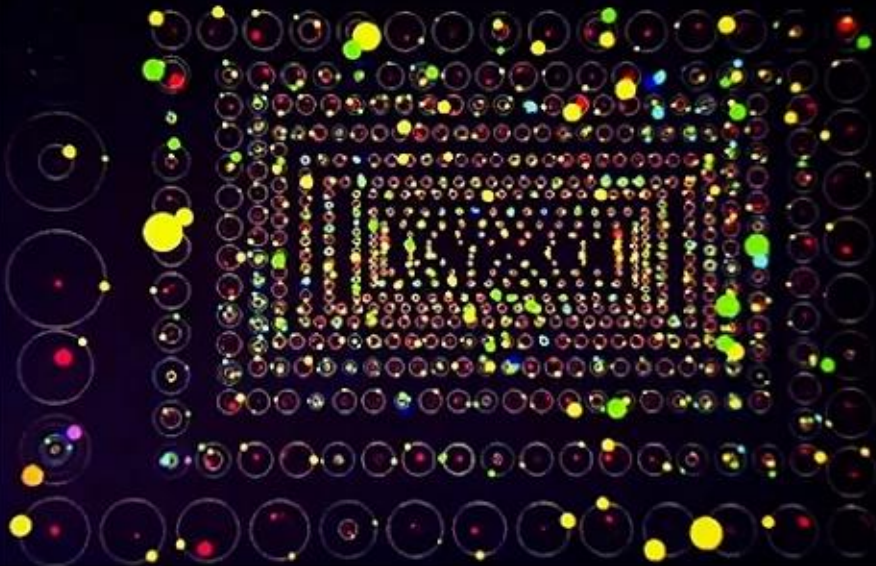


# The Kepler Orrery III

[BJD] = 2455268



1  
00:00:03,669 --> 00:00:02,070  
nasa's jet propulsion laboratory

2  
00:00:06,309 --> 00:00:03,679  
presents

3  
00:00:08,390 --> 00:00:06,319  
the von carmen lecture a series of talks

4  
00:00:11,669 --> 00:00:08,400  
by scientists and engineers who are

5  
00:00:25,910 --> 00:00:11,679  
exploring our planet our solar system

6  
00:00:31,349 --> 00:00:27,910  
good evening ladies and gentlemen how's

7  
00:00:35,190 --> 00:00:33,110  
well thank you very much for coming out

8  
00:00:37,030 --> 00:00:35,200  
uh it's nice and cool in here at least

9  
00:00:39,190 --> 00:00:37,040  
right

10  
00:00:41,110 --> 00:00:39,200  
so anyway shall we with thousands of

11  
00:00:42,869 --> 00:00:41,120  
planets now known around other stars

12  
00:00:44,630 --> 00:00:42,879  
it's natural to wonder why so many

13  
00:00:46,389 --> 00:00:44,640

planetary systems are quite different

14

00:00:48,310 --> 00:00:46,399

from our own

15

00:00:50,150 --> 00:00:48,320

some stars have several planets inside

16

00:00:52,229 --> 00:00:50,160

the location of mercury's orbit where

17

00:00:53,750 --> 00:00:52,239

our solar system is basically empty

18

00:00:55,990 --> 00:00:53,760

while other stars have planets more

19

00:00:58,790 --> 00:00:56,000

massive than our jupiter on looping

20

00:01:00,869 --> 00:00:58,800

eccentric orbits a few stars have hot

21

00:01:03,430 --> 00:01:00,879

jupiters circling every few days on

22

00:01:05,429 --> 00:01:03,440

orbits so tight the starlight heats the

23

00:01:07,510 --> 00:01:05,439

planet's atmospheres beyond the point

24

00:01:09,910 --> 00:01:07,520

where iron vaporizes

25

00:01:12,310 --> 00:01:09,920

and many stars have planets intermediate

26

00:01:14,390 --> 00:01:12,320

in size between our rocky earth and icy

27

00:01:15,990 --> 00:01:14,400

uranus sizes that are completely missing

28

00:01:18,789 --> 00:01:16,000

from our solar system

29

00:01:19,990 --> 00:01:18,799

and some planets orbit not one but two

30

00:01:21,510 --> 00:01:20,000

stars

31

00:01:23,749 --> 00:01:21,520

so where did all this diversity come

32

00:01:26,149 --> 00:01:23,759

from we know planets must form from the

33

00:01:27,910 --> 00:01:26,159

dust and gas orbiting young stars

34

00:01:29,670 --> 00:01:27,920

because we see the orbiting material

35

00:01:31,830 --> 00:01:29,680

with the hubble and spitzer telescopes

36

00:01:33,670 --> 00:01:31,840

and ground-based telescopes

37

00:01:35,590 --> 00:01:33,680

but the dust makes the material opaque

38

00:01:38,230 --> 00:01:35,600

at optical and infrared wavelengths so

39

00:01:40,390 --> 00:01:38,240

it's hard to know what's going on inside

40

00:01:42,310 --> 00:01:40,400

in recent years our view has become

41

00:01:44,149 --> 00:01:42,320

clear enough to make out some features

42

00:01:46,230 --> 00:01:44,159

that might be caused by young planets

43

00:01:47,910 --> 00:01:46,240

orbiting within the material tonight's

44

00:01:50,069 --> 00:01:47,920

guest will discuss several of the new

45

00:01:52,550 --> 00:01:50,079

images and a few of the 3d computer

46

00:01:54,469 --> 00:01:52,560

models astronomers are using to try to

47

00:01:55,670 --> 00:01:54,479

learn how planets are born into such

48

00:01:57,590 --> 00:01:55,680

diversity

49

00:01:59,429 --> 00:01:57,600

tonight's guest grew up in australia

50

00:02:00,950 --> 00:01:59,439

where as a teenager he built a small

51  
00:02:02,709 --> 00:02:00,960  
telescope that he used to study the

52  
00:02:04,230 --> 00:02:02,719  
milky way and comets

53  
00:02:06,310 --> 00:02:04,240  
he earned a bachelor's degree at the

54  
00:02:09,109 --> 00:02:06,320  
university of sydney then moved to the

55  
00:02:11,270 --> 00:02:09,119  
u.s for a phd in astrophysics at uc

56  
00:02:13,110 --> 00:02:11,280  
santa cruz and after his stints at the

57  
00:02:15,589 --> 00:02:13,120  
university of maryland and uc santa

58  
00:02:17,110 --> 00:02:15,599  
barbara he came to jpl where he now

59  
00:02:19,350 --> 00:02:17,120  
supervises the interstellar and

60  
00:02:21,270 --> 00:02:19,360  
heliospheric physics group

61  
00:02:23,270 --> 00:02:21,280  
for him a typical workday involves

62  
00:02:24,869 --> 00:02:23,280  
building computer programs to compare

63  
00:02:27,110 --> 00:02:24,879

models of what happens during planet

64

00:02:29,430 --> 00:02:27,120

formation with the observations sent

65

00:02:30,790 --> 00:02:29,440

back by space telescopes ladies and

66

00:02:42,150 --> 00:02:30,800

gentlemen please help me welcome

67

00:02:45,670 --> 00:02:43,670

hello and welcome

68

00:02:47,750 --> 00:02:45,680

i guess the mic is on

69

00:02:49,910 --> 00:02:47,760

uh so i would like to share with you the

70

00:02:53,990 --> 00:02:49,920

story of what we know so far about

71

00:02:57,509 --> 00:02:55,910

in the last 20 years thousands of

72

00:02:59,589 --> 00:02:57,519

planets have been discovered at an

73

00:03:01,750 --> 00:02:59,599

increasing rate

74

00:03:03,750 --> 00:03:01,760

only the few brightest

75

00:03:05,430 --> 00:03:03,760

are directly imaged like this one here

76  
00:03:07,350 --> 00:03:05,440  
so the star has been mostly removed in

77  
00:03:09,910 --> 00:03:07,360  
the center and then the three little

78  
00:03:12,710 --> 00:03:09,920  
dots b c and d are the three planets

79  
00:03:14,630 --> 00:03:12,720  
here but these are unusual they're uh

80  
00:03:17,110 --> 00:03:14,640  
particularly large and bright and

81  
00:03:19,270 --> 00:03:17,120  
particularly far from their star in most

82  
00:03:23,270 --> 00:03:19,280  
cases we cannot see these thousands of

83  
00:03:26,550 --> 00:03:25,190  
most were found by

84  
00:03:28,869 --> 00:03:26,560  
two methods

85  
00:03:30,869 --> 00:03:28,879  
either using the the motions of the

86  
00:03:33,430 --> 00:03:30,879  
stars in response to the planet so this

87  
00:03:35,350 --> 00:03:33,440  
movie shows a star here

88  
00:03:36,390 --> 00:03:35,360

and a planet going around it and you can

89

00:03:37,990 --> 00:03:36,400

see that

90

00:03:39,589 --> 00:03:38,000

although the planet is going around the

91

00:03:41,589 --> 00:03:39,599

star the star is also in a sense going

92

00:03:43,670 --> 00:03:41,599

around the planet it moves a little in

93

00:03:45,670 --> 00:03:43,680

response to the planet's gravity

94

00:03:47,830 --> 00:03:45,680

and that means that the bright star we

95

00:03:50,229 --> 00:03:47,840

can we can just look at it and see its

96

00:03:51,990 --> 00:03:50,239

motion towards us and away from us

97

00:03:53,670 --> 00:03:52,000

and in the same way that when a fire

98

00:03:54,949 --> 00:03:53,680

engine comes toward you its pitch gets

99

00:03:56,949 --> 00:03:54,959

higher and then as it goes away the

100

00:03:59,589 --> 00:03:56,959

pitch gets lower same thing happens with

101  
00:04:01,110 --> 00:03:59,599  
the star's light so we can see a bluing

102  
00:04:03,030 --> 00:04:01,120  
as it comes towards us and a reddening

103  
00:04:04,710 --> 00:04:03,040  
as it goes away so we can use this

104  
00:04:06,869 --> 00:04:04,720  
radial velocity method that's been used

105  
00:04:10,630 --> 00:04:06,879  
to discover many of the new planets

106  
00:04:12,789 --> 00:04:10,640  
the other main way is through transits

107  
00:04:14,550 --> 00:04:12,799  
and that basically is just a fancy way

108  
00:04:16,069 --> 00:04:14,560  
of saying that the planet goes in front

109  
00:04:17,349 --> 00:04:16,079  
of the star and blocks out a little bit

110  
00:04:19,430 --> 00:04:17,359  
of its light

111  
00:04:21,670 --> 00:04:19,440  
so uh the biggest planet in our own

112  
00:04:23,830 --> 00:04:21,680  
solar system jupiter is about one-tenth

113  
00:04:25,430 --> 00:04:23,840

as big across as the sun which means

114

00:04:27,990 --> 00:04:25,440

one-tenth in each direction means about

115

00:04:30,390 --> 00:04:28,000

1 100th total of the sun's light would

116

00:04:32,550 --> 00:04:30,400

be blocked if jupiter were to pass

117

00:04:34,390 --> 00:04:32,560

across its face as seen by

118

00:04:35,830 --> 00:04:34,400

somebody very far away

119

00:04:37,430 --> 00:04:35,840

and so

120

00:04:38,790 --> 00:04:37,440

many most of the planets that have been

121

00:04:40,710 --> 00:04:38,800

discovered have been found by this

122

00:04:42,790 --> 00:04:40,720

method using the kepler space telescope

123

00:04:44,629 --> 00:04:42,800

which studies a large number of stars

124

00:04:48,710 --> 00:04:44,639

looking for the slight dimming when a

125

00:04:53,670 --> 00:04:50,950

as better telescopes have been built and

126

00:04:55,030 --> 00:04:53,680

also as we've gotten better at analyzing

127

00:04:56,629 --> 00:04:55,040

the results from the telescopes are

128

00:04:58,070 --> 00:04:56,639

teasing out the little signals that we

129

00:04:59,830 --> 00:04:58,080

get from the planets

130

00:05:02,150 --> 00:04:59,840

the uh the masses of the planets that we

131

00:05:03,189 --> 00:05:02,160

can see have gone down so this shows

132

00:05:05,189 --> 00:05:03,199

years

133

00:05:08,150 --> 00:05:05,199

uh the the year in which each planet was

134

00:05:11,749 --> 00:05:08,160

discovered so the first one that

135

00:05:14,550 --> 00:05:11,759

everybody believed was about 1995 here

136

00:05:17,350 --> 00:05:14,560

and as a function of the of the the mass

137

00:05:18,710 --> 00:05:17,360

so jupiter is here neptune and the earth

138

00:05:20,710 --> 00:05:18,720

and you can see that as techniques have

139

00:05:23,029 --> 00:05:20,720

gotten better the the lowest mass that

140

00:05:25,510 --> 00:05:23,039

we can detect has gone down and down

141

00:05:27,830 --> 00:05:25,520

and now it's at about the mass of the

142

00:05:29,749 --> 00:05:27,840

earth so it's an exciting time

143

00:05:33,270 --> 00:05:29,759

to be part of this search for new

144

00:05:37,830 --> 00:05:35,350

by the way uh gray is the radial

145

00:05:39,830 --> 00:05:37,840

velocities and red is the transits and

146

00:05:41,990 --> 00:05:39,840

so you can see that when kepler the

147

00:05:45,430 --> 00:05:42,000

kepler telescope was launched into space

148

00:05:46,629 --> 00:05:45,440

in 2009 the red dots really take off so

149

00:05:49,510 --> 00:05:46,639

so many more planets have been

150

00:05:53,350 --> 00:05:51,430

it's also an exciting time because

151  
00:05:55,189 --> 00:05:53,360  
thousands more of the planets are going

152  
00:05:56,790 --> 00:05:55,199  
to be discovered in the next few years

153  
00:05:59,189 --> 00:05:56,800  
so a couple of years ago the european

154  
00:06:00,469 --> 00:05:59,199  
space agency launched gaia which

155  
00:06:02,469 --> 00:06:00,479  
measures the

156  
00:06:03,909 --> 00:06:02,479  
positions of the stars very accurately

157  
00:06:04,870 --> 00:06:03,919  
and so

158  
00:06:06,230 --> 00:06:04,880  
if the

159  
00:06:07,909 --> 00:06:06,240  
as the planet goes around once again you

160  
00:06:09,590 --> 00:06:07,919  
can see the stars motion but this time

161  
00:06:11,189 --> 00:06:09,600  
in the plane of the sky

162  
00:06:14,070 --> 00:06:11,199  
and so gaia should discover several

163  
00:06:17,830 --> 00:06:14,080

thousand more new planets

164

00:06:20,710 --> 00:06:17,840

and also tess which is a super kepler um

165

00:06:22,629 --> 00:06:20,720

with an even bigger fly's eye of of

166

00:06:24,230 --> 00:06:22,639

telescopes with more megapixels and it

167

00:06:26,870 --> 00:06:24,240

will because it has that bigger field of

168

00:06:29,270 --> 00:06:26,880

view it can study nearby stars kepler

169

00:06:32,309 --> 00:06:29,280

had to concentrate on a smaller field uh

170

00:06:34,070 --> 00:06:32,319

far away but uh tess the transiting

171

00:06:35,029 --> 00:06:34,080

exoplanet survey satellite will be able

172

00:06:37,029 --> 00:06:35,039

to see

173

00:06:39,189 --> 00:06:37,039

all of the nearby stars by scanning the

174

00:06:40,629 --> 00:06:39,199

sky so we'll find out about our

175

00:06:42,230 --> 00:06:40,639

neighbours the planets around our

176  
00:06:44,070 --> 00:06:42,240  
neighbor stars

177  
00:06:47,110 --> 00:06:44,080  
and that's due to launch in a couple of

178  
00:06:51,590 --> 00:06:49,670  
so tonight i'd like to discuss three

179  
00:06:53,909 --> 00:06:51,600  
questions first

180  
00:06:55,430 --> 00:06:53,919  
um what are other stars

181  
00:06:57,350 --> 00:06:55,440  
planets like

182  
00:06:59,189 --> 00:06:57,360  
uh and like the other questions this is

183  
00:07:01,510 --> 00:06:59,199  
one that people have been asking for a

184  
00:07:04,469 --> 00:07:01,520  
long time and it's it's great that now

185  
00:07:06,230 --> 00:07:04,479  
we have a chance at last to answer it

186  
00:07:07,110 --> 00:07:06,240  
and i'd like to share what we know so

187  
00:07:09,430 --> 00:07:07,120  
far

188  
00:07:11,990 --> 00:07:09,440

about the answer to this question

189

00:07:13,670 --> 00:07:12,000

and the second one is

190

00:07:15,110 --> 00:07:13,680

um how are they different from the

191

00:07:17,110 --> 00:07:15,120

planets around

192

00:07:18,710 --> 00:07:17,120

our own sun which we've known about for

193

00:07:20,550 --> 00:07:18,720

thousands of years and it turns out they

194

00:07:22,390 --> 00:07:20,560

are quite different many of them are

195

00:07:24,309 --> 00:07:22,400

totally unlike anything we've known up

196

00:07:26,070 --> 00:07:24,319

to now

197

00:07:27,990 --> 00:07:26,080

and then the third question is why are

198

00:07:29,670 --> 00:07:28,000

they different that is

199

00:07:31,510 --> 00:07:29,680

what's different about their history

200

00:07:33,029 --> 00:07:31,520

what's different about how they came to

201  
00:07:36,070 --> 00:07:33,039  
be where they are

202  
00:07:38,150 --> 00:07:36,080  
um that has made them so different from

203  
00:07:41,189 --> 00:07:38,160  
our own solar system and so diverse so

204  
00:07:44,309 --> 00:07:41,199  
different from one another

205  
00:07:45,589 --> 00:07:44,319  
so on to the first question

206  
00:07:48,230 --> 00:07:45,599  
so

207  
00:07:50,150 --> 00:07:48,240  
the first planets to be found were

208  
00:07:51,670 --> 00:07:50,160  
what are now called hot jupiters and

209  
00:07:54,390 --> 00:07:51,680  
they were first to be found because

210  
00:07:56,309 --> 00:07:54,400  
they're as big and as massive as jupiter

211  
00:07:58,390 --> 00:07:56,319  
you can see this one is

212  
00:08:00,629 --> 00:07:58,400  
a good fraction of the of the diameter

213  
00:08:02,869 --> 00:08:00,639

of its host star here

214

00:08:04,869 --> 00:08:02,879

so big and heavy means that they make

215

00:08:06,790 --> 00:08:04,879

the star move a lot so that that

216

00:08:07,990 --> 00:08:06,800

movement is easy to see and the other

217

00:08:09,589 --> 00:08:08,000

thing is that they are very close to

218

00:08:11,629 --> 00:08:09,599

their star many of them are in orbits of

219

00:08:14,390 --> 00:08:11,639

just a few days instead of

220

00:08:16,550 --> 00:08:14,400

365 days like our earth

221

00:08:18,150 --> 00:08:16,560

and so they're whizzing around the star

222

00:08:19,510 --> 00:08:18,160

so often that you just need to look for

223

00:08:21,430 --> 00:08:19,520

a few days with a telescope and you'll

224

00:08:23,110 --> 00:08:21,440

see that signal repeat you'll see the

225

00:08:24,710 --> 00:08:23,120

star move towards you and then away from

226

00:08:27,589 --> 00:08:24,720

you and then towards again

227

00:08:29,830 --> 00:08:27,599

and so because of that quick repetition

228

00:08:31,589 --> 00:08:29,840

they are easy to see

229

00:08:34,070 --> 00:08:31,599

but because they are so close to their

230

00:08:35,589 --> 00:08:34,080

stars they become very hot they become

231

00:08:37,750 --> 00:08:35,599

much hotter than even the innermost

232

00:08:39,589 --> 00:08:37,760

planet in our solar system mercury

233

00:08:43,029 --> 00:08:39,599

and on their surface the temperature is

234

00:08:44,070 --> 00:08:43,039

hot enough to meet to melt most metals

235

00:08:46,310 --> 00:08:44,080

and so

236

00:08:48,550 --> 00:08:46,320

they they have to be gas giants even if

237

00:08:51,110 --> 00:08:48,560

some of the gas is

238

00:08:52,310 --> 00:08:51,120

metal vapor

239

00:08:53,509 --> 00:08:52,320

and

240

00:08:54,550 --> 00:08:53,519

based on the number of these that have

241

00:08:57,750 --> 00:08:54,560

been found

242

00:09:00,710 --> 00:08:57,760

uh they must orbit around one percent of

243

00:09:02,470 --> 00:09:00,720

the nearby sun-like stars so there are a

244

00:09:05,509 --> 00:09:02,480

lot of them but they're still

245

00:09:11,910 --> 00:09:07,030

but they are completely

246

00:09:18,150 --> 00:09:15,030

the next easiest kind of of new planets

247

00:09:20,389 --> 00:09:18,160

to find are the eccentric giants so

248

00:09:22,550 --> 00:09:20,399

these may have a mass close to that of

249

00:09:25,509 --> 00:09:22,560

jupiter but instead on instead of going

250

00:09:27,430 --> 00:09:25,519

on a nice steady circular orbit they

251

00:09:29,750 --> 00:09:27,440

they go on big loops they start they

252

00:09:31,829 --> 00:09:29,760

start out far from their star they

253

00:09:34,150 --> 00:09:31,839

plunge in very close and they go far out

254

00:09:35,750 --> 00:09:34,160

again this example goes well outside the

255

00:09:37,350 --> 00:09:35,760

orbit of mars

256

00:09:39,750 --> 00:09:37,360

if if you were to place it in our solar

257

00:09:41,269 --> 00:09:39,760

system and in just inside the orbit of

258

00:09:42,550 --> 00:09:41,279

mercury

259

00:09:44,710 --> 00:09:42,560

and

260

00:09:45,990 --> 00:09:44,720

the fact that they're eccentric means

261

00:09:48,070 --> 00:09:46,000

that they must have had something

262

00:09:50,470 --> 00:09:48,080

violent happen to them in the past to

263

00:09:52,230 --> 00:09:50,480

knock them off the orbit where they were

264

00:09:54,150 --> 00:09:52,240

initially formed

265

00:09:55,990 --> 00:09:54,160

and the number of these that have been

266

00:09:58,790 --> 00:09:56,000

found suggested they orbit around five

267

00:10:03,990 --> 00:09:58,800

percent of the nearby sun-like stars

268

00:10:08,230 --> 00:10:05,910

but then the third kind the hardest to

269

00:10:10,230 --> 00:10:08,240

find but the most numerous

270

00:10:13,350 --> 00:10:10,240

are smaller

271

00:10:15,509 --> 00:10:13,360

and uh they're on they're on orbits less

272

00:10:18,470 --> 00:10:15,519

than about 100 days because that's what

273

00:10:22,230 --> 00:10:18,480

kepler has been able to detect this

274

00:10:27,509 --> 00:10:25,750

each so each little

275

00:10:28,630 --> 00:10:27,519

set of circles is one of the planetary

276  
00:10:30,630 --> 00:10:28,640  
systems

277  
00:10:32,470 --> 00:10:30,640  
the colors just show the

278  
00:10:34,470 --> 00:10:32,480  
the order so red is nearest to the star

279  
00:10:36,470 --> 00:10:34,480  
yellow is next and so on

280  
00:10:38,310 --> 00:10:36,480  
and you can see the relative sizes so

281  
00:10:40,550 --> 00:10:38,320  
here's a super jupiter and there are

282  
00:10:42,389 --> 00:10:40,560  
many smaller planets

283  
00:10:44,710 --> 00:10:42,399  
and for comparison up here is our solar

284  
00:10:45,670 --> 00:10:44,720  
system with mercury venus the earth and

285  
00:10:47,110 --> 00:10:45,680  
mars

286  
00:10:49,509 --> 00:10:47,120  
we're going to zoom in because a lot of

287  
00:10:51,509 --> 00:10:49,519  
these systems are really small very

288  
00:10:54,069 --> 00:10:51,519

compact you have in many cases several

289

00:10:56,310 --> 00:10:54,079

planets orbiting quite close to their

290

00:11:00,710 --> 00:10:56,320

star

291

00:11:04,710 --> 00:11:01,750

so

292

00:11:07,590 --> 00:11:04,720

but the bottom line from all of these

293

00:11:10,550 --> 00:11:07,600

uh three classes new classes of of

294

00:11:12,230 --> 00:11:10,560

planets is that if you look up at one of

295

00:11:14,870 --> 00:11:12,240

the bright stars in the sky bright means

296

00:11:17,030 --> 00:11:14,880

it's probably nearby there's about a 50

297

00:11:19,829 --> 00:11:17,040

percent chance that it has one or more

298

00:11:22,550 --> 00:11:19,839

planets earth mass or greater and these

299

00:11:24,389 --> 00:11:22,560

numbers are just because um

300

00:11:26,389 --> 00:11:24,399

this is what we are able to detect so

301  
00:11:31,910 --> 00:11:26,399  
far there could be more there could be

302  
00:11:35,590 --> 00:11:33,350  
so

303  
00:11:37,030 --> 00:11:35,600  
the the second question i'd like to talk

304  
00:11:40,150 --> 00:11:37,040  
about is

305  
00:11:43,110 --> 00:11:40,160  
uh how these planets are different

306  
00:11:44,949 --> 00:11:43,120  
from the planets in our own solar system

307  
00:11:46,949 --> 00:11:44,959  
and this is where it gets interesting

308  
00:11:48,949 --> 00:11:46,959  
because it starts to tie

309  
00:11:51,509 --> 00:11:48,959  
um the strangenesses of these new

310  
00:11:58,150 --> 00:11:51,519  
planets to how we perhaps came to be

311  
00:12:04,949 --> 00:11:59,269  
so

312  
00:12:06,870 --> 00:12:04,959  
is mercury and its orbit is 88 days long

313  
00:12:09,430 --> 00:12:06,880

it's about four tenths

314

00:12:11,910 --> 00:12:09,440

as big across as the orbit of the earth

315

00:12:13,190 --> 00:12:11,920

compare that with this one system of

316

00:12:14,550 --> 00:12:13,200

planets around another star the

317

00:12:17,190 --> 00:12:14,560

kepler-11

318

00:12:20,150 --> 00:12:17,200

system and it has one two three four

319

00:12:22,069 --> 00:12:20,160

five planets inside mercury's orbit and

320

00:12:25,509 --> 00:12:22,079

then another one in between mercury and

321

00:12:27,590 --> 00:12:25,519

venus if you put it in our system

322

00:12:30,150 --> 00:12:27,600

so in our solar system this region

323

00:12:32,629 --> 00:12:30,160

inside here is empty

324

00:12:34,230 --> 00:12:32,639

but in the other system there are

325

00:12:36,150 --> 00:12:34,240

quite a number of planets and this has

326

00:12:37,990 --> 00:12:36,160

been repeated again and again

327

00:12:39,910 --> 00:12:38,000

it's a common pattern among the systems

328

00:12:42,069 --> 00:12:39,920

that we've been able to see

329

00:12:43,670 --> 00:12:42,079

so this is a great mystery why is our

330

00:12:45,350 --> 00:12:43,680

solar system

331

00:12:46,470 --> 00:12:45,360

so different from these other systems

332

00:12:49,269 --> 00:12:46,480

why is our

333

00:12:50,710 --> 00:12:49,279

solar system special in some way

334

00:12:52,870 --> 00:12:50,720

or rare

335

00:12:54,790 --> 00:12:52,880

in most other respects in terms of our

336

00:12:56,710 --> 00:12:54,800

place in the galaxy or our galaxy's

337

00:12:58,310 --> 00:12:56,720

place in the universe

338

00:13:00,949 --> 00:12:58,320

uh we are not special we are just

339

00:13:08,230 --> 00:13:00,959

typical but our solar system does seem

340

00:13:13,590 --> 00:13:10,389

in our solar system

341

00:13:14,949 --> 00:13:13,600

so here's everything to scale the sun

342

00:13:17,350 --> 00:13:14,959

here on the left

343

00:13:20,710 --> 00:13:17,360

we have two big planets jupiter and

344

00:13:22,550 --> 00:13:20,720

saturn both about 10 times the radius of

345

00:13:25,190 --> 00:13:22,560

the earth shown here

346

00:13:27,269 --> 00:13:25,200

we also have two ice giants ice and gas

347

00:13:28,949 --> 00:13:27,279

giants uranus and neptune which are each

348

00:13:30,949 --> 00:13:28,959

about four times

349

00:13:32,790 --> 00:13:30,959

the diameter of the earth then we have

350

00:13:35,030 --> 00:13:32,800

earth and venus which are pretty similar

351

00:13:36,069 --> 00:13:35,040

except that venus is has serious

352

00:13:37,990 --> 00:13:36,079

greenhouse

353

00:13:43,910 --> 00:13:38,000

effect and then some smaller stuff

354

00:13:47,590 --> 00:13:46,389

in contrast around the stars that we've

355

00:13:51,829 --> 00:13:47,600

been able to see

356

00:13:53,829 --> 00:13:51,839

cold

357

00:13:56,230 --> 00:13:53,839

relatively distant giants like jupiter

358

00:13:57,509 --> 00:13:56,240

and saturn seem to be relatively rare

359

00:13:58,550 --> 00:13:57,519

there are the eccentric giants but

360

00:14:00,389 --> 00:13:58,560

they're quite different because they

361

00:14:01,350 --> 00:14:00,399

loop in close to their stars and become

362

00:14:03,670 --> 00:14:01,360

warm

363

00:14:06,230 --> 00:14:03,680

jupiter and saturn stay out

364

00:14:08,710 --> 00:14:06,240  
beyond where water can survive

365

00:14:10,150 --> 00:14:08,720  
and that as far as we can tell so far is

366

00:14:12,069 --> 00:14:10,160  
rare but that's just at the limit of our

367

00:14:20,470 --> 00:14:12,079  
knowledge now we're just being beginning

368

00:14:25,350 --> 00:14:23,430  
another interesting difference between

369

00:14:27,430 --> 00:14:25,360  
our solar system and

370

00:14:31,110 --> 00:14:27,440  
these other new ones

371

00:14:33,189 --> 00:14:31,120  
is that we have nothing in size

372

00:14:35,350 --> 00:14:33,199  
between the earth

373

00:14:38,550 --> 00:14:35,360  
and uranus and neptune which are about

374

00:14:39,829 --> 00:14:38,560  
four times the earth's diameter

375

00:14:41,990 --> 00:14:39,839  
they're very different in composition

376

00:14:42,870 --> 00:14:42,000

the earth is of course mostly rock and

377

00:14:45,030 --> 00:14:42,880

metal

378

00:14:47,030 --> 00:14:45,040

uranus and neptune have a core inside of

379

00:14:49,189 --> 00:14:47,040

rock and metal and then

380

00:14:53,189 --> 00:14:49,199

ice as well and then some gas some

381

00:14:56,230 --> 00:14:53,199

hydrogen and helium on the outside

382

00:14:57,750 --> 00:14:56,240

but when we look at the population of

383

00:14:59,670 --> 00:14:57,760

planets

384

00:15:02,870 --> 00:14:59,680

around the other stars we see something

385

00:15:05,030 --> 00:15:02,880

quite different so here this is a a bar

386

00:15:06,470 --> 00:15:05,040

chart so the average number of planets

387

00:15:08,870 --> 00:15:06,480

per star

388

00:15:12,629 --> 00:15:08,880

versus the radius of the planet so for

389

00:15:15,189 --> 00:15:12,639

example about 10 percent of these stars

390

00:15:20,550 --> 00:15:15,199

have planets between the earth's radius

391

00:15:25,269 --> 00:15:21,990

but then the interesting thing is that

392

00:15:27,829 --> 00:15:25,279

another 10 percent have have planets

393

00:15:29,189 --> 00:15:27,839

with radii between 1.4 and 2 times

394

00:15:30,310 --> 00:15:29,199

earth's radius and then yet another

395

00:15:31,110 --> 00:15:30,320

percent

396

00:15:33,189 --> 00:15:31,120

have

397

00:15:35,030 --> 00:15:33,199

planets in this next range up and it's

398

00:15:37,430 --> 00:15:35,040

only when we get up to here about four

399

00:15:39,030 --> 00:15:37,440

that our solar system has another one so

400

00:15:40,710 --> 00:15:39,040

the interesting thing is that we have a

401

00:15:42,389 --> 00:15:40,720

couple of planets here a couple of

402

00:15:44,870 --> 00:15:42,399

planets here and nothing in between and

403

00:15:46,629 --> 00:15:44,880

yet these are the most common among the

404

00:15:48,069 --> 00:15:46,639

ones we've been able to find around

405

00:15:50,150 --> 00:15:48,079

other stars

406

00:15:52,550 --> 00:15:50,160

so that's a mystery why why are we

407

00:15:54,230 --> 00:15:52,560

different again

408

00:15:56,470 --> 00:15:54,240

another thing that we can see here is

409

00:15:58,790 --> 00:15:56,480

that when we get down to so jupiter is

410

00:16:00,550 --> 00:15:58,800

about 11 times

411

00:16:02,629 --> 00:16:00,560

uh the earth's radius and saturn is

412

00:16:04,629 --> 00:16:02,639

about nine so they both fall in this

413

00:16:06,069 --> 00:16:04,639

bump here so you can see there's a steep

414

00:16:07,509 --> 00:16:06,079

fall off here and then a less steep

415

00:16:09,269 --> 00:16:07,519

falloff and

416

00:16:10,949 --> 00:16:09,279

there's this little bump here

417

00:16:13,189 --> 00:16:10,959

maybe that's telling us something about

418

00:16:15,670 --> 00:16:13,199

how these planets form maybe it's a bit

419

00:16:17,189 --> 00:16:15,680

more difficult as you grow as you try to

420

00:16:19,110 --> 00:16:17,199

form bigger and bigger planets either

421

00:16:21,110 --> 00:16:19,120

it's more difficult to form them or once

422

00:16:22,629 --> 00:16:21,120

they're formed they quickly grow until

423

00:16:24,550 --> 00:16:22,639

they come up to this size and then they

424

00:16:31,030 --> 00:16:24,560

stick there there's something special

425

00:16:34,949 --> 00:16:32,949

we have a little bit more information

426

00:16:37,829 --> 00:16:34,959

than just the radius

427

00:16:39,269 --> 00:16:37,839

for at least some of these new planets

428

00:16:40,949 --> 00:16:39,279

so we for some of them we can also

429

00:16:42,710 --> 00:16:40,959

measure the mass if we can see the

430

00:16:44,870 --> 00:16:42,720

radial velocity if we can see how the

431

00:16:47,110 --> 00:16:44,880

planet uh is driving its star then that

432

00:16:48,710 --> 00:16:47,120

tells us the mass in addition to seeing

433

00:16:51,590 --> 00:16:48,720

the size from how much of the star's

434

00:16:53,350 --> 00:16:51,600

light it blocks and if we put those two

435

00:16:54,870 --> 00:16:53,360

pieces of information together we can

436

00:16:57,110 --> 00:16:54,880

get the density

437

00:16:59,829 --> 00:16:57,120

so here the planet radius is plotted in

438

00:17:01,590 --> 00:16:59,839

earth radii radii the planet mass in

439

00:17:04,309 --> 00:17:01,600

earth masses so the earth is right here

440

00:17:05,029 --> 00:17:04,319

at one and one and venus is just below

441

00:17:09,350 --> 00:17:05,039

it

442

00:17:12,230 --> 00:17:09,360

our solar system is uranus up at the top

443

00:17:13,590 --> 00:17:12,240

right there about four earth radii and

444

00:17:15,189 --> 00:17:13,600

about 14

445

00:17:17,510 --> 00:17:15,199

earth masses

446

00:17:18,549 --> 00:17:17,520

and you can see that there is a lot in

447

00:17:21,029 --> 00:17:18,559

between

448

00:17:23,350 --> 00:17:21,039

um in this region that is completely

449

00:17:24,949 --> 00:17:23,360

unpopulated in our solar system

450

00:17:26,949 --> 00:17:24,959

so each of these colored points is one

451  
00:17:28,710 --> 00:17:26,959  
of the newly discovered planets we're a

452  
00:17:31,430 --> 00:17:28,720  
little bit uncertain on their masses and

453  
00:17:33,830 --> 00:17:31,440  
a bit less uncertain on their radii

454  
00:17:35,110 --> 00:17:33,840  
shown by the bars there

455  
00:17:36,950 --> 00:17:35,120  
and then

456  
00:17:38,630 --> 00:17:36,960  
when you put together a mass

457  
00:17:41,029 --> 00:17:38,640  
a mass and a radius then you get a

458  
00:17:43,750 --> 00:17:41,039  
density the interesting thing is that in

459  
00:17:45,830 --> 00:17:43,760  
the top left corner here these planets

460  
00:17:47,990 --> 00:17:45,840  
have densities less than one gram per

461  
00:17:49,669 --> 00:17:48,000  
cubic centimeter less than water

462  
00:17:52,150 --> 00:17:49,679  
so if they were small enough they would

463  
00:17:53,430 --> 00:17:52,160

float in a bathtub

464

00:17:55,190 --> 00:17:53,440

and that means that they have to be

465

00:17:57,750 --> 00:17:55,200

mostly gas in order to get the density

466

00:17:58,789 --> 00:17:57,760

that low if you made them out of

467

00:18:00,950 --> 00:17:58,799

out of

468

00:18:03,190 --> 00:18:00,960

earth rocks then they would have then

469

00:18:05,430 --> 00:18:03,200

their mass would increase in this way

470

00:18:07,350 --> 00:18:05,440

with radius if you made if you added

471

00:18:09,270 --> 00:18:07,360

some water it was half rock and half

472

00:18:11,830 --> 00:18:09,280

water it would follow this curve if it

473

00:18:13,510 --> 00:18:11,840

was all water it would be on this curve

474

00:18:15,110 --> 00:18:13,520

and many of these planets are up above

475

00:18:17,270 --> 00:18:15,120

even all water so that means they have

476  
00:18:19,430 --> 00:18:17,280  
to have some hydrogen and helium mixed

477  
00:18:21,430 --> 00:18:19,440  
in shown by the the dotted curves there

478  
00:18:23,830 --> 00:18:21,440  
how much of the hydrogen helium

479  
00:18:24,950 --> 00:18:23,840  
you need to mix in

480  
00:18:26,390 --> 00:18:24,960  
so

481  
00:18:29,590 --> 00:18:26,400  
um

482  
00:18:32,390 --> 00:18:29,600  
not only do we have planets in this

483  
00:18:35,510 --> 00:18:32,400  
region in between uh the earth and

484  
00:18:37,669 --> 00:18:35,520  
uranus and neptune in size but also

485  
00:18:40,470 --> 00:18:37,679  
they're quite different in composition

486  
00:18:43,029 --> 00:18:40,480  
they they're fluffy in a way that even

487  
00:18:45,430 --> 00:18:43,039  
uranus and neptune are not

488  
00:18:47,590 --> 00:18:45,440

so there again there are strange beasts

489

00:18:50,150 --> 00:18:47,600

unfamiliar beasts

490

00:18:52,070 --> 00:18:50,160

i didn't mention yet the colours of the

491

00:18:55,350 --> 00:18:52,080

points show how much light they receive

492

00:18:57,110 --> 00:18:55,360

from their star so this is the the flux

493

00:18:59,110 --> 00:18:57,120

in units of the flux that the earth

494

00:19:01,270 --> 00:18:59,120

receives from the sun you can see that

495

00:19:03,110 --> 00:19:01,280

many of the colors are yellow or red

496

00:19:05,510 --> 00:19:03,120

indicating that they receive a hundred a

497

00:19:07,830 --> 00:19:05,520

thousand or even ten thousand times

498

00:19:09,430 --> 00:19:07,840

as much light from their stars because

499

00:19:11,750 --> 00:19:09,440

remember these are close

500

00:19:12,789 --> 00:19:11,760

because we can most easily see the ones

501  
00:19:14,950 --> 00:19:12,799  
that are

502  
00:19:22,230 --> 00:19:14,960  
on orbits less than 100 days quite close

503  
00:19:28,070 --> 00:19:25,350  
but in another way many of these extra

504  
00:19:30,390 --> 00:19:28,080  
solar planets are quite like the solar

505  
00:19:33,510 --> 00:19:30,400  
system here's a little map of the solar

506  
00:19:35,590 --> 00:19:33,520  
system as seen from the side

507  
00:19:37,029 --> 00:19:35,600  
uh so the sun is here and the planets

508  
00:19:39,430 --> 00:19:37,039  
are lined up

509  
00:19:40,470 --> 00:19:39,440  
uh with the the planes of their orbits

510  
00:19:42,870 --> 00:19:40,480  
shown by

511  
00:19:45,590 --> 00:19:42,880  
uh the the lines here and the one that

512  
00:19:47,029 --> 00:19:45,600  
tilts the most out of the plane of of

513  
00:19:48,789 --> 00:19:47,039

all of the rest is mercury and it's

514

00:19:50,630 --> 00:19:48,799

about six degrees

515

00:19:52,310 --> 00:19:50,640

and the others are uh are all less than

516

00:19:54,549 --> 00:19:52,320

that so the numbers are listed down here

517

00:19:57,110 --> 00:19:54,559

many of them are less than one degree

518

00:19:59,270 --> 00:19:57,120

the earth is only 1.6

519

00:20:01,909 --> 00:19:59,280

so they're basically all lying in one

520

00:20:04,710 --> 00:20:01,919

plane and that's consistent at any rate

521

00:20:06,470 --> 00:20:04,720

with them all having formed together

522

00:20:08,710 --> 00:20:06,480

out of the same material

523

00:20:10,710 --> 00:20:08,720

so they they all share

524

00:20:12,549 --> 00:20:10,720

not quite share in orbit but they have

525

00:20:13,830 --> 00:20:12,559

orbits of different sizes in the same

526  
00:20:16,070 --> 00:20:13,840  
plane

527  
00:20:18,310 --> 00:20:16,080  
and we know that many of the uh the

528  
00:20:20,070 --> 00:20:18,320  
planets around other stars the systems

529  
00:20:22,710 --> 00:20:20,080  
that have multiple planets must be like

530  
00:20:24,470 --> 00:20:22,720  
that too because we see them go fro in

531  
00:20:26,470 --> 00:20:24,480  
front of the face of their star one by

532  
00:20:28,149 --> 00:20:26,480  
one one after the other and so that

533  
00:20:29,510 --> 00:20:28,159  
means again they have to lie very close

534  
00:20:31,510 --> 00:20:29,520  
to the same plane otherwise they would

535  
00:20:34,310 --> 00:20:31,520  
pass above the star or below it and we

536  
00:20:36,149 --> 00:20:34,320  
would not see those transits

537  
00:20:37,909 --> 00:20:36,159  
so in this way

538  
00:20:39,830 --> 00:20:37,919

the the other planets

539

00:20:41,270 --> 00:20:39,840

are similar to ours and perhaps that's

540

00:20:46,230 --> 00:20:41,280

saying that in some respects the way

541

00:20:50,230 --> 00:20:48,390

but some of the hot jupiters break this

542

00:20:52,310 --> 00:20:50,240

rule

543

00:20:55,110 --> 00:20:52,320

uh this is one that was found with the

544

00:20:57,029 --> 00:20:55,120

ground-based telescope so a wide-angle

545

00:20:58,149 --> 00:20:57,039

search for planets i think is is its

546

00:20:59,029 --> 00:20:58,159

moniker

547

00:21:03,190 --> 00:20:59,039

and

548

00:21:05,669 --> 00:21:03,200

here are showing the star is rotating

549

00:21:08,870 --> 00:21:05,679

like this around a vertical axis

550

00:21:10,870 --> 00:21:08,880

and yet the planet is uh plunging along

551  
00:21:13,430 --> 00:21:10,880  
this line here

552  
00:21:15,110 --> 00:21:13,440  
up and down around so it's almost the

553  
00:21:18,390 --> 00:21:15,120  
plane of its orbit is almost

554  
00:21:20,310 --> 00:21:18,400  
perpendicular to the equator of its star

555  
00:21:22,390 --> 00:21:20,320  
and this suggests that something violent

556  
00:21:32,310 --> 00:21:22,400  
has happened to uh to push it away from

557  
00:21:36,710 --> 00:21:34,630  
so finally i'd like to get on to the

558  
00:21:39,190 --> 00:21:36,720  
part that's speculation and this is what

559  
00:21:42,310 --> 00:21:39,200  
i do for my day job so i'm very happy to

560  
00:21:44,870 --> 00:21:43,190  
so

561  
00:21:46,870 --> 00:21:44,880  
we don't know the whole whole story of

562  
00:21:48,390 --> 00:21:46,880  
how they're born we're still trying to

563  
00:21:50,789 --> 00:21:48,400

piece it together

564

00:21:52,630 --> 00:21:50,799

i'll try to try to outline a few of the

565

00:21:54,070 --> 00:21:52,640

chapters a few of the things that we

566

00:22:00,710 --> 00:21:54,080

think may have happened even if we don't

567

00:22:05,990 --> 00:22:03,590

so first around many young stars we see

568

00:22:07,350 --> 00:22:06,000

orbiting clouds of dust and gas like

569

00:22:10,230 --> 00:22:07,360

this one

570

00:22:14,310 --> 00:22:10,240

so the star here is hidden so

571

00:22:16,149 --> 00:22:14,320

there's a disk of of uh opaque material

572

00:22:18,630 --> 00:22:16,159

around the star and it happens in this

573

00:22:20,390 --> 00:22:18,640

case to be seen edge on so we can't see

574

00:22:21,830 --> 00:22:20,400

the star directly

575

00:22:23,590 --> 00:22:21,840

instead

576  
00:22:26,549 --> 00:22:23,600  
what happens is that some of the dust

577  
00:22:29,029 --> 00:22:26,559  
and gas lies above and below the disc

578  
00:22:30,630 --> 00:22:29,039  
and that especially the dust there

579  
00:22:33,270 --> 00:22:30,640  
reflects the starlight scatters the

580  
00:22:35,990 --> 00:22:33,280  
starlight towards us so this light above

581  
00:22:38,789 --> 00:22:36,000  
and below the disc is the uh

582  
00:22:40,870 --> 00:22:38,799  
is the material the low density material

583  
00:22:42,789 --> 00:22:40,880  
in the outskirts of this cloud

584  
00:22:44,549 --> 00:22:42,799  
bouncing the starlight so that we can

585  
00:22:46,630 --> 00:22:44,559  
see it

586  
00:22:49,990 --> 00:22:46,640  
you can see the the line is a little bit

587  
00:22:51,830 --> 00:22:50,000  
red here because some some of the dust

588  
00:22:55,669 --> 00:22:51,840

the denser dust is absorbing some of the

589

00:22:59,590 --> 00:22:57,750

so the typical size for this cloud is

590

00:23:02,070 --> 00:22:59,600

about the size of the solar system or a

591

00:23:05,669 --> 00:23:02,080

little bit bigger so that's good because

592

00:23:08,549 --> 00:23:05,679

we need to form a planetary system

593

00:23:10,310 --> 00:23:08,559

the mass in it is about enough to form

594

00:23:12,789 --> 00:23:10,320

the planets

595

00:23:14,070 --> 00:23:12,799

plus some extra hydrogen and helium so

596

00:23:15,350 --> 00:23:14,080

that's one of the problems that we have

597

00:23:19,350 --> 00:23:15,360

to solve we have to get rid of that

598

00:23:20,230 --> 00:23:19,360

extra gas to leave the planets behind

599

00:23:22,870 --> 00:23:20,240

and

600

00:23:25,029 --> 00:23:22,880

we don't we can't uh watch one of these

601  
00:23:26,870 --> 00:23:25,039  
and see how long it lives

602  
00:23:28,549 --> 00:23:26,880  
because it lives for a few million years

603  
00:23:30,710 --> 00:23:28,559  
but we can look at

604  
00:23:33,110 --> 00:23:30,720  
star clusters of different ages we can

605  
00:23:35,029 --> 00:23:33,120  
work out the ages by studying the stars

606  
00:23:37,350 --> 00:23:35,039  
and we can see that around clusters that

607  
00:23:39,190 --> 00:23:37,360  
are more than a few million years old

608  
00:23:40,710 --> 00:23:39,200  
almost none of the stars still have

609  
00:23:42,149 --> 00:23:40,720  
these clouds

610  
00:23:43,669 --> 00:23:42,159  
so from that

611  
00:23:46,070 --> 00:23:43,679  
we guess

612  
00:23:47,830 --> 00:23:46,080  
it's an educated guess that

613  
00:23:48,950 --> 00:23:47,840

they live for a few million years that's

614

00:23:51,750 --> 00:23:48,960

the amount of time that we have

615

00:23:52,950 --> 00:23:51,760

available to collect together these

616

00:23:56,549 --> 00:23:52,960

interstellar

617

00:23:58,070 --> 00:23:56,559

tiny submicron sized grains of dust

618

00:24:02,230 --> 00:23:58,080

collect them together in their trillions

619

00:24:07,350 --> 00:24:04,710

another thing is that um

620

00:24:09,510 --> 00:24:07,360

if we if we work out how long it would

621

00:24:11,909 --> 00:24:09,520

take for this dust to settle down for

622

00:24:13,909 --> 00:24:11,919

all of this extra dust out here to

623

00:24:15,269 --> 00:24:13,919

collapse down and form a thin line in

624

00:24:16,070 --> 00:24:15,279

the middle

625

00:24:18,149 --> 00:24:16,080

it's

626  
00:24:20,870 --> 00:24:18,159  
maybe a few thousand years something in

627  
00:24:24,149 --> 00:24:20,880  
that ballpark so it's much less than the

628  
00:24:25,750 --> 00:24:24,159  
lifetimes of these clouds so that means

629  
00:24:27,909 --> 00:24:25,760  
that something has to be keeping the

630  
00:24:29,029 --> 00:24:27,919  
dust stirred up and preventing it from

631  
00:24:30,830 --> 00:24:29,039  
settling

632  
00:24:33,350 --> 00:24:30,840  
and that something is probably

633  
00:24:35,110 --> 00:24:33,360  
turbulence and that turbulence

634  
00:24:40,870 --> 00:24:35,120  
has a role to play in forming the

635  
00:24:46,549 --> 00:24:43,510  
from modeling in the computer we know

636  
00:24:49,029 --> 00:24:46,559  
that if you have a magnetic field

637  
00:24:51,430 --> 00:24:49,039  
and if the gas is ionized enough so that

638  
00:24:55,590 --> 00:24:51,440

it can feel the magnetic forces

639

00:24:57,430 --> 00:24:55,600

then the forces drive turbulence

640

00:24:58,870 --> 00:24:57,440

a magnetic field connects material close

641

00:25:01,190 --> 00:24:58,880

to the star with material a little bit

642

00:25:02,870 --> 00:25:01,200

further away and pushes the further away

643

00:25:04,630 --> 00:25:02,880

stuff onto a higher orbit while letting

644

00:25:05,830 --> 00:25:04,640

the closer stuff spiral into a lower

645

00:25:07,510 --> 00:25:05,840

orbit

646

00:25:09,590 --> 00:25:07,520

some of it eventually will spiral right

647

00:25:11,190 --> 00:25:09,600

in and and um

648

00:25:13,430 --> 00:25:11,200

collapse down onto the surface of the

649

00:25:15,190 --> 00:25:13,440

star so the star will grow a bit on the

650

00:25:17,350 --> 00:25:15,200

other hand the outer reaches of it are

651  
00:25:19,830 --> 00:25:17,360  
going to spread and the disc will get

652  
00:25:21,830 --> 00:25:19,840  
get bigger over time

653  
00:25:24,230 --> 00:25:21,840  
but all of that relies on

654  
00:25:26,070 --> 00:25:24,240  
on having enough ionization

655  
00:25:27,190 --> 00:25:26,080  
so it can couple to magnetic fields and

656  
00:25:33,350 --> 00:25:27,200  
we don't know

657  
00:25:37,350 --> 00:25:35,590  
we can even see planet formation

658  
00:25:40,070 --> 00:25:37,360  
beginning

659  
00:25:41,909 --> 00:25:40,080  
here is an image from a giant new radio

660  
00:25:46,230 --> 00:25:41,919  
telescope that's still being assembled

661  
00:25:48,230 --> 00:25:46,240  
in the atacama desert in south america

662  
00:25:50,549 --> 00:25:48,240  
it shows the disc around a young star

663  
00:25:53,190 --> 00:25:50,559

which is at the center here

664

00:25:55,350 --> 00:25:53,200

and at radio wavelengths the telescope

665

00:25:57,750 --> 00:25:55,360

is sensitive to

666

00:25:58,950 --> 00:25:57,760

pebble sized or sand grain sized

667

00:26:00,149 --> 00:25:58,960

particles

668

00:26:01,510 --> 00:26:00,159

which means they're far bigger than

669

00:26:02,630 --> 00:26:01,520

anything in the interstellar medium so

670

00:26:04,710 --> 00:26:02,640

that means at least the very early

671

00:26:06,870 --> 00:26:04,720

stages of planet formation

672

00:26:12,070 --> 00:26:06,880

have begun

673

00:26:16,070 --> 00:26:13,669

there are rings you can see that the

674

00:26:18,470 --> 00:26:16,080

dust seems to be gathered together so

675

00:26:19,750 --> 00:26:18,480

there are rings and gaps and more rings

676

00:26:21,430 --> 00:26:19,760

and more gaps

677

00:26:24,710 --> 00:26:21,440

and astronomers are still debating this

678

00:26:27,269 --> 00:26:24,720

is a new result in the last year

679

00:26:30,230 --> 00:26:27,279

maybe it's planets maybe it's the uh the

680

00:26:31,990 --> 00:26:30,240

tides of planets orbiting within it that

681

00:26:33,590 --> 00:26:32,000

uh so perhaps a planet has cleared this

682

00:26:34,789 --> 00:26:33,600

gap and another one has cleared this gap

683

00:26:37,269 --> 00:26:34,799

and so on

684

00:26:39,190 --> 00:26:37,279

but another possibility is that perhaps

685

00:26:40,630 --> 00:26:39,200

what's happening instead is that the

686

00:26:41,590 --> 00:26:40,640

dust particles are starting to stick

687

00:26:45,269 --> 00:26:41,600

together

688

00:26:47,750 --> 00:26:45,279

in regions where you're near the

689

00:26:50,310 --> 00:26:47,760

threshold for uh for vaporizing one of

690

00:26:52,789 --> 00:26:50,320

the materials that makes up the ices

691

00:26:55,510 --> 00:26:52,799

some of these these gaps seem to seem to

692

00:26:57,909 --> 00:26:55,520

correspond to those locations for uh for

693

00:27:00,470 --> 00:26:57,919

evaporating different ices

694

00:27:02,230 --> 00:27:00,480

and yet another possibility is that this

695

00:27:04,310 --> 00:27:02,240

material is dense enough to begin under

696

00:27:06,870 --> 00:27:04,320

its own gravity begin to accumulate

697

00:27:08,710 --> 00:27:06,880

together to build up these rings so you

698

00:27:10,789 --> 00:27:08,720

can see there are lots of possibilities

699

00:27:17,990 --> 00:27:10,799

and we have a lot of work to do to sort

700

00:27:23,110 --> 00:27:21,430

once we get beyond that pebble size we

701

00:27:25,190 --> 00:27:23,120

can't see what happens

702

00:27:26,710 --> 00:27:25,200

if you have a trillion dust grains

703

00:27:28,789 --> 00:27:26,720

floating around they have a lot of

704

00:27:31,750 --> 00:27:28,799

surface area but if you collect them

705

00:27:34,549 --> 00:27:31,760

together into a compact ball they have

706

00:27:35,990 --> 00:27:34,559

much less area and so they don't emit

707

00:27:37,909 --> 00:27:36,000

at all basically they have their

708

00:27:40,549 --> 00:27:37,919

emission is far too feeble

709

00:27:42,950 --> 00:27:40,559

for even the best of our telescopes to

710

00:27:46,070 --> 00:27:42,960

uh to see them

711

00:27:47,990 --> 00:27:46,080

but it seems likely that planets form

712

00:27:49,029 --> 00:27:48,000

easiest a little bit further out than

713

00:27:53,510 --> 00:27:49,039

the earth

714

00:27:55,590 --> 00:27:53,520

hot for water ice to survive

715

00:27:57,350 --> 00:27:55,600

as you can tell from seeing that comets

716

00:27:58,549 --> 00:27:57,360

when they pass the earth orbit begin to

717

00:28:00,549 --> 00:27:58,559

evaporate

718

00:28:02,549 --> 00:28:00,559

but if you go a bit further out you

719

00:28:03,669 --> 00:28:02,559

still have quite a lot of material

720

00:28:05,909 --> 00:28:03,679

and yet

721

00:28:07,990 --> 00:28:05,919

the water can survive

722

00:28:09,350 --> 00:28:08,000

this picture is taking it to the extreme

723

00:28:12,149 --> 00:28:09,360

this is an artist's impression of the

724

00:28:13,830 --> 00:28:12,159

surface of pluto and the sun is so far

725

00:28:16,389 --> 00:28:13,840

away that it's just a bright star and

726

00:28:18,470 --> 00:28:16,399

that's why pluto is so cold

727

00:28:20,230 --> 00:28:18,480

and for the same reason the

728

00:28:22,310 --> 00:28:20,240

outer reaches of the early solar system

729

00:28:24,389 --> 00:28:22,320

are a good place to build planets

730

00:28:26,870 --> 00:28:24,399

because you have a lot of ices and if

731

00:28:28,630 --> 00:28:26,880

you take the ice and add it to the rock

732

00:28:29,909 --> 00:28:28,640

then you triple or quadruple the amount

733

00:28:31,190 --> 00:28:29,919

of solid material that you have

734

00:28:32,149 --> 00:28:31,200

available

735

00:28:34,310 --> 00:28:32,159

so

736

00:28:39,029 --> 00:28:34,320

that's a good that helps in many ways to

737

00:28:43,350 --> 00:28:41,110

but if we form the planets in the outer

738

00:28:46,070 --> 00:28:43,360

solar system why are there so many of

739

00:28:47,029 --> 00:28:46,080

these planets around other stars close

740

00:28:51,990 --> 00:28:47,039

in

741

00:28:54,630 --> 00:28:52,000

the planet the young planet has to up

742

00:29:01,029 --> 00:28:54,640

and pack its bags and somehow

743

00:29:06,310 --> 00:29:03,990

one possibility is that they migrate

744

00:29:08,710 --> 00:29:06,320

inwards by interacting with the gas

745

00:29:10,950 --> 00:29:08,720

around them so here's a movie from

746

00:29:11,750 --> 00:29:10,960

another computer simulation

747

00:29:14,389 --> 00:29:11,760

and

748

00:29:16,230 --> 00:29:14,399

to look at things in detail uh even on

749

00:29:18,149 --> 00:29:16,240

the big computers that we have today we

750

00:29:21,190 --> 00:29:18,159

have to look at a small patch

751  
00:29:24,149 --> 00:29:21,200  
so our camera here is staying fixed on

752  
00:29:25,830 --> 00:29:24,159  
the planet as it orbits around the star

753  
00:29:27,510 --> 00:29:25,840  
you can see that material on the left

754  
00:29:29,750 --> 00:29:27,520  
side of the screen here is orbiting

755  
00:29:31,669 --> 00:29:29,760  
faster so it moves up relative to the

756  
00:29:32,950 --> 00:29:31,679  
planet material on the right side of the

757  
00:29:34,470 --> 00:29:32,960  
screen is orbiting slower because it's

758  
00:29:37,590 --> 00:29:34,480  
further from the star so it appears to

759  
00:29:39,269 --> 00:29:37,600  
move down relative to the planet

760  
00:29:41,350 --> 00:29:39,279  
and you can see that despite the

761  
00:29:43,190 --> 00:29:41,360  
turbulence that makes this calculation

762  
00:29:45,350 --> 00:29:43,200  
messy there's overall there's a spiral

763  
00:29:48,470 --> 00:29:45,360

arm pattern here so material that

764

00:29:51,029 --> 00:29:48,480

approaches the planet from below

765

00:29:52,789 --> 00:29:51,039

going faster it gets pulled a little bit

766

00:29:54,310 --> 00:29:52,799

towards the planet

767

00:29:57,510 --> 00:29:54,320

and that deflection means that there's

768

00:29:58,870 --> 00:29:57,520

extra material in this spiral arm

769

00:30:00,389 --> 00:29:58,880

downstream

770

00:30:01,750 --> 00:30:00,399

same thing happens on the other side for

771

00:30:03,830 --> 00:30:01,760

material that's lagging behind the

772

00:30:06,310 --> 00:30:03,840

planet once it's attracted to the planet

773

00:30:09,430 --> 00:30:06,320

it then collects into this spiral arm on

774

00:30:11,510 --> 00:30:09,440

the other side and each spiral arm

775

00:30:13,990 --> 00:30:11,520

exerts a force on the planet through its

776

00:30:16,710 --> 00:30:14,000

gravity but the forces aren't quite the

777

00:30:18,950 --> 00:30:16,720

same the typically

778

00:30:20,630 --> 00:30:18,960

the arm on the outside exerts a slightly

779

00:30:22,149 --> 00:30:20,640

bigger force

780

00:30:24,389 --> 00:30:22,159

and that means that the planet is

781

00:30:25,990 --> 00:30:24,399

gradually going to drift in

782

00:30:28,070 --> 00:30:26,000

towards the star

783

00:30:29,430 --> 00:30:28,080

over time it could approach the star

784

00:30:32,149 --> 00:30:29,440

very closely

785

00:30:36,630 --> 00:30:32,159

so this may be a good way to make those

786

00:30:38,950 --> 00:30:36,640

tightly packed systems of planets

787

00:30:40,549 --> 00:30:38,960

there is another way to get the planets

788

00:30:42,789 --> 00:30:40,559

in close which works at least for the

789

00:30:45,750 --> 00:30:42,799

hot jupiters

790

00:30:47,590 --> 00:30:45,760

and it involves tides just like the

791

00:30:49,669 --> 00:30:47,600

tides on the earth

792

00:30:51,669 --> 00:30:49,679

so if we have

793

00:30:54,549 --> 00:30:51,679

a distant jupiter

794

00:30:56,149 --> 00:30:54,559

it encounters another of its kind

795

00:30:57,909 --> 00:30:56,159

so it's scattered onto an eccentric

796

00:31:00,230 --> 00:30:57,919

orbit so it's looping in close to the

797

00:31:02,549 --> 00:31:00,240

sun and out again back to near where it

798

00:31:05,909 --> 00:31:02,559

started but when it's in close its

799

00:31:08,230 --> 00:31:05,919

gravity raises tides on its star

800

00:31:10,870 --> 00:31:08,240

and just as tides on the earth get

801  
00:31:13,190 --> 00:31:10,880  
dissipated by moving around the land

802  
00:31:14,710 --> 00:31:13,200  
masses tides in the star also get

803  
00:31:16,310 --> 00:31:14,720  
dissipated the star gets a little bit of

804  
00:31:18,470 --> 00:31:16,320  
extra heat from that

805  
00:31:20,710 --> 00:31:18,480  
and the planets orbit the outer end of

806  
00:31:21,830 --> 00:31:20,720  
its orbit grows shorter and shorter and

807  
00:31:24,549 --> 00:31:21,840  
it can

808  
00:31:28,549 --> 00:31:24,559  
eventually end up um

809  
00:31:30,630 --> 00:31:28,559  
in a a close orbit uh in tide around its

810  
00:31:32,789 --> 00:31:30,640  
star so here's what the tides do on

811  
00:31:34,549 --> 00:31:32,799  
earth

812  
00:31:36,310 --> 00:31:34,559  
you can see it's easy to get out to the

813  
00:31:37,590 --> 00:31:36,320

lighthouse at low tide and not at high

814

00:31:40,789 --> 00:31:37,600

tide

815

00:31:42,470 --> 00:31:40,799

so twice per rotation of the earth the

816

00:31:44,549 --> 00:31:42,480

gravity of the moon is pulling the ocean

817

00:31:46,389 --> 00:31:44,559

up and the same thing happens on the

818

00:31:50,950 --> 00:31:46,399

star

819

00:31:53,029 --> 00:31:50,960

gravity of its planet

820

00:31:55,269 --> 00:31:53,039

will uh pull the tides up and then the

821

00:31:56,789 --> 00:31:55,279

tides will dissipate into heat that

822

00:31:58,710 --> 00:31:56,799

removes energy

823

00:32:00,950 --> 00:31:58,720

from the orbit so this is a second way

824

00:32:02,710 --> 00:32:00,960

that we could make

825

00:32:06,950 --> 00:32:02,720

at least the hot jupiters be close to

826

00:32:09,669 --> 00:32:07,830

so i

827

00:32:11,590 --> 00:32:09,679

i see that i've come

828

00:32:14,230 --> 00:32:11,600

almost to the end already so i have

829

00:32:16,149 --> 00:32:14,240

plenty of time for questions

830

00:32:18,470 --> 00:32:16,159

these are the

831

00:32:21,190 --> 00:32:18,480

questions that we haven't answered but

832

00:32:26,070 --> 00:32:21,200

would like to these are the things that

833

00:32:30,950 --> 00:32:27,909

first how did the planetary systems come

834

00:32:33,029 --> 00:32:30,960

to be so different from one another

835

00:32:35,350 --> 00:32:33,039

um

836

00:32:37,430 --> 00:32:35,360

uh we've seen that some systems have hot

837

00:32:38,950 --> 00:32:37,440

jupiters and relatively few other

838

00:32:42,149 --> 00:32:38,960

planets the hot jupiters seem to be

839

00:32:43,830 --> 00:32:42,159

accompanied by uh fewer companions than

840

00:32:49,110 --> 00:32:43,840

other systems

841

00:32:49,990 --> 00:32:49,120

have the eccentric giants

842

00:32:52,470 --> 00:32:50,000

where

843

00:32:54,710 --> 00:32:52,480

there's a big body that plunges through

844

00:32:56,710 --> 00:32:54,720

the inner parts of the planetary system

845

00:32:59,430 --> 00:32:56,720

and out again so they must have had some

846

00:33:01,990 --> 00:32:59,440

kind of violent event in their past

847

00:33:04,710 --> 00:33:02,000

why do some systems have those those

848

00:33:07,750 --> 00:33:04,720

violent happenings and others do not

849

00:33:09,669 --> 00:33:07,760

and we've seen that yet other systems uh

850

00:33:12,389 --> 00:33:09,679

have several planets packed in close

851  
00:33:13,190 --> 00:33:12,399  
around their star where our solar system

852  
00:33:14,789 --> 00:33:13,200  
has

853  
00:33:16,950 --> 00:33:14,799  
basically nothing

854  
00:33:18,230 --> 00:33:16,960  
and so what's different about about the

855  
00:33:21,909 --> 00:33:18,240  
history

856  
00:33:24,549 --> 00:33:21,919  
of our solar system

857  
00:33:26,710 --> 00:33:24,559  
we have four coal giants also on orbits

858  
00:33:29,269 --> 00:33:26,720  
that are nearly circular and that uh

859  
00:33:31,430 --> 00:33:29,279  
seems to be unusual what's special about

860  
00:33:32,470 --> 00:33:31,440  
our solar system were we

861  
00:33:33,830 --> 00:33:32,480  
um

862  
00:33:36,070 --> 00:33:33,840  
lucky in a way that we didn't have a

863  
00:33:37,750 --> 00:33:36,080

violent event in the outer reaches and

864

00:33:40,950 --> 00:33:37,760

yet unlucky in that something special

865

00:33:42,789 --> 00:33:40,960

happened close into the sun

866

00:33:45,990 --> 00:33:42,799

we don't know it's still to be

867

00:33:48,230 --> 00:33:46,000

investigated and finally working towards

868

00:33:50,630 --> 00:33:48,240

uh

869

00:33:52,230 --> 00:33:50,640

finding other earths we'd like to know

870

00:33:53,750 --> 00:33:52,240

what the ones that we can see so far the

871

00:33:56,230 --> 00:33:53,760

ones that are just a little bit bigger

872

00:33:58,789 --> 00:33:56,240

than the earth what they are made of

873

00:34:00,950 --> 00:33:58,799

um and then how were they put together

874

00:34:02,710 --> 00:34:00,960

why do some of them have the that fluffy

875

00:34:05,509 --> 00:34:02,720

composition why they

876

00:34:06,870 --> 00:34:05,519

uh gas to a far bigger extent than the

877

00:34:11,030 --> 00:34:06,880

earth

878

00:34:12,470 --> 00:34:11,040

we find any that are rocky and yet they

879

00:34:15,190 --> 00:34:12,480

do have

880

00:34:19,190 --> 00:34:15,200

an atmosphere that we might recognize

881

00:34:24,790 --> 00:34:23,349

so uh i'll put back up my my starting

882

00:34:28,550 --> 00:34:24,800

slide

883

00:34:34,710 --> 00:34:31,909

and maybe i can say also

884

00:34:37,270 --> 00:34:34,720

i talked about migration for the for the

885

00:34:39,030 --> 00:34:37,280

giant planets but for the small

886

00:34:41,349 --> 00:34:39,040

rocky planets we'd like to know how they

887

00:34:43,270 --> 00:34:41,359

migrate too this artist's impression is

888

00:34:45,349 --> 00:34:43,280

showing uh uh

889

00:34:48,629 --> 00:34:45,359

what happens when you have some uh rocky

890

00:34:51,270 --> 00:34:48,639

material in close to the star

891

00:34:53,349 --> 00:34:51,280

i think the evidence from the fact that

892

00:34:55,669 --> 00:34:53,359

so many of those small planets are

893

00:34:57,670 --> 00:34:55,679

coplanar suggests that they must have

894

00:35:00,069 --> 00:34:57,680

undergone migration too i think that's

895

00:35:02,390 --> 00:35:00,079

probably the common thread because in

896

00:35:03,990 --> 00:35:02,400

our solar system

897

00:35:06,390 --> 00:35:04,000

all the planets share a plane in those

898

00:35:08,310 --> 00:35:06,400

other systems they do too and so it has

899

00:35:09,190 --> 00:35:08,320

to be that

900

00:35:14,790 --> 00:35:09,200

they

901  
00:35:16,230 --> 00:35:14,800  
so i i've come to the end so i'll be

902  
00:35:30,550 --> 00:35:16,240  
very grateful to take any of your

903  
00:35:35,510 --> 00:35:33,750  
i've been told to uh remind you to come

904  
00:35:38,790 --> 00:35:35,520  
up to the microphone please to ask

905  
00:35:50,150 --> 00:35:41,589  
that way our viewers online can

906  
00:35:55,670 --> 00:35:54,710  
my question is regarding the tides

907  
00:35:57,829 --> 00:35:55,680  
that

908  
00:35:59,109 --> 00:35:57,839  
between the sun and the planet

909  
00:36:02,310 --> 00:35:59,119  
that

910  
00:36:04,710 --> 00:36:02,320  
i believe you mentioned is possibly

911  
00:36:06,630 --> 00:36:04,720  
responsible for bringing the planets

912  
00:36:09,109 --> 00:36:06,640  
closer to the sun

913  
00:36:10,390 --> 00:36:09,119

and um

914

00:36:12,230 --> 00:36:10,400

i'm wondering

915

00:36:13,670 --> 00:36:12,240

about the difference between that

916

00:36:14,470 --> 00:36:13,680

scenario

917

00:36:18,710 --> 00:36:14,480

and

918

00:36:22,630 --> 00:36:18,720

where um

919

00:36:26,390 --> 00:36:22,640

the earth's rotation has been slowed due

920

00:36:28,310 --> 00:36:26,400

to the top the relationship between

921

00:36:31,190 --> 00:36:28,320

the earth and the moon and the moon

922

00:36:32,790 --> 00:36:31,200

actually is goes further out so i'm

923

00:36:35,270 --> 00:36:32,800

wondering about

924

00:36:37,670 --> 00:36:35,280

if there's a difference or what's going

925

00:36:41,109 --> 00:36:37,680

on there it's it's similar but just a

926  
00:36:42,150 --> 00:36:41,119  
little bit different so in that case

927  
00:36:44,069 --> 00:36:42,160  
because

928  
00:36:46,870 --> 00:36:44,079  
the earth rotates in one day whereas the

929  
00:36:48,790 --> 00:36:46,880  
moon orbits in 30 days or so

930  
00:36:50,550 --> 00:36:48,800  
and that means that

931  
00:36:51,829 --> 00:36:50,560  
the the bulge that the moon raises in

932  
00:36:53,510 --> 00:36:51,839  
the earth

933  
00:36:55,910 --> 00:36:53,520  
gets a little bit ahead

934  
00:36:57,990 --> 00:36:55,920  
of the moon's location in its orbit and

935  
00:36:59,750 --> 00:36:58,000  
it pulls on the moon and accelerates its

936  
00:37:00,630 --> 00:36:59,760  
forward and that's why the moon tends to

937  
00:37:01,990 --> 00:37:00,640  
move

938  
00:37:04,950 --> 00:37:02,000

further away

939

00:37:05,990 --> 00:37:04,960

but that's not guaranteed to happen in

940

00:37:07,829 --> 00:37:06,000

in

941

00:37:09,910 --> 00:37:07,839

exoplanet systems so for example you

942

00:37:12,950 --> 00:37:09,920

could have a situation as we actually

943

00:37:15,270 --> 00:37:12,960

have with mars and its two small moons

944

00:37:16,710 --> 00:37:15,280

where they're orbiting inside the point

945

00:37:18,790 --> 00:37:16,720

where they would be

946

00:37:20,230 --> 00:37:18,800

going around once per day

947

00:37:24,150 --> 00:37:20,240

so

948

00:37:25,270 --> 00:37:24,160

they're pulled back by the uh the bulge

949

00:37:27,270 --> 00:37:25,280

on the planet and so they will

950

00:37:31,270 --> 00:37:27,280

eventually crash into the surface i see

951  
00:37:38,150 --> 00:37:34,150  
i uh yes i was wondering how many uh

952  
00:37:41,190 --> 00:37:38,160  
main sequence objects you found

953  
00:37:43,990 --> 00:37:41,200  
in your new study of new planets

954  
00:37:46,870 --> 00:37:44,000  
and also is it possible

955  
00:37:48,829 --> 00:37:46,880  
that the stars could migrate through

956  
00:37:51,670 --> 00:37:48,839  
nuclear

957  
00:37:54,310 --> 00:37:51,680  
fusion um i guess i'd like to understand

958  
00:37:55,910 --> 00:37:54,320  
a little bit more about your question so

959  
00:37:58,710 --> 00:37:55,920  
um

960  
00:38:02,870 --> 00:37:58,720  
so it is certainly true that as stars

961  
00:38:05,349 --> 00:38:02,880  
use up the fuel in their insides they do

962  
00:38:07,430 --> 00:38:05,359  
they tend to expand generally as they

963  
00:38:09,270 --> 00:38:07,440

move through their main sequence

964

00:38:10,870 --> 00:38:09,280

life time

965

00:38:12,390 --> 00:38:10,880

and things could get interesting if you

966

00:38:14,950 --> 00:38:12,400

have a hot jupiter

967

00:38:16,790 --> 00:38:14,960

and one of those stars

968

00:38:20,310 --> 00:38:16,800

expands enough so that it approaches the

969

00:38:22,790 --> 00:38:20,320

jupiter's orbit and it could be that the

970

00:38:26,310 --> 00:38:22,800

the planet gets swallowed up

971

00:38:27,750 --> 00:38:26,320

we haven't seen anything like that yet

972

00:38:29,510 --> 00:38:27,760

as far as i know

973

00:38:31,510 --> 00:38:29,520

and that's probably because the

974

00:38:33,510 --> 00:38:31,520

swallowing up happens quickly

975

00:38:35,829 --> 00:38:33,520

once the planet is in the even the low

976

00:38:38,550 --> 00:38:35,839

density upper layers of the star it very

977

00:38:40,150 --> 00:38:38,560

quickly spirals down and is lost

978

00:38:42,150 --> 00:38:40,160

so if we would probably have to look at

979

00:38:43,430 --> 00:38:42,160

a lot of stars until we could get lucky

980

00:38:44,630 --> 00:38:43,440

enough to see

981

00:38:47,230 --> 00:38:44,640

that happen

982

00:38:51,030 --> 00:38:47,240

is it possible though that uh the

983

00:38:54,310 --> 00:38:51,040

geothermal process uh could uh add to

984

00:38:55,109 --> 00:38:54,320

the collapse of the star from the core

985

00:38:58,790 --> 00:38:55,119

well

986

00:38:59,829 --> 00:38:58,800

um even a jupiter has has only about one

987

00:39:02,870 --> 00:38:59,839

one

988

00:39:04,710 --> 00:39:02,880

of the mass of a sun-like star

989

00:39:07,589 --> 00:39:04,720

and so from that point of view it would

990

00:39:09,750 --> 00:39:07,599

only be a small perturbation

991

00:39:11,910 --> 00:39:09,760

it does add a little bit of extra heavy

992

00:39:13,829 --> 00:39:11,920

elements

993

00:39:16,310 --> 00:39:13,839

but they are probably deposited in the

994

00:39:18,310 --> 00:39:16,320

outer layers and so they they would have

995

00:39:21,109 --> 00:39:18,320

only a small effect

996

00:39:22,550 --> 00:39:21,119

on the star's own gravity and probably

997

00:39:24,470 --> 00:39:22,560

little effect on what's happening right

998

00:39:25,510 --> 00:39:24,480

at the core where the nuclear fusion is

999

00:39:27,510 --> 00:39:25,520

ongoing

1000

00:39:29,510 --> 00:39:27,520

but it might be detectable so there are

1001

00:39:33,270 --> 00:39:29,520

some people that

1002

00:39:36,550 --> 00:39:35,190

stars with planets may be a little bit

1003

00:39:38,310 --> 00:39:36,560

enriched in

1004

00:39:40,310 --> 00:39:38,320

heavy elements for example in their

1005

00:39:43,990 --> 00:39:40,320

surface layers

1006

00:39:48,470 --> 00:39:46,710

hi um this is a three-part question

1007

00:39:51,430 --> 00:39:48,480

um i was wondering if you can give us

1008

00:39:54,310 --> 00:39:51,440

examples of the type of violent events

1009

00:39:57,750 --> 00:39:54,320

that would have impacted the planets as

1010

00:40:00,150 --> 00:39:57,760

they formed the second question is um

1011

00:40:02,310 --> 00:40:00,160

would those events occur while the

1012

00:40:03,190 --> 00:40:02,320

planets are forming or after

1013

00:40:05,670 --> 00:40:03,200

and

1014

00:40:08,470 --> 00:40:05,680

have we been able to observe

1015

00:40:10,710 --> 00:40:08,480

any violent events

1016

00:40:11,670 --> 00:40:10,720

with planets that we're looking at now

1017

00:40:13,910 --> 00:40:11,680

um

1018

00:40:15,750 --> 00:40:13,920

yeah that's a third question

1019

00:40:17,510 --> 00:40:15,760

so um

1020

00:40:19,270 --> 00:40:17,520

similar to in the last question so

1021

00:40:20,630 --> 00:40:19,280

because they're violent they tend to be

1022

00:40:22,790 --> 00:40:20,640

over quickly

1023

00:40:24,310 --> 00:40:22,800

and so mostly we see the aftermath we

1024

00:40:27,030 --> 00:40:24,320

see the planets that are on unusual

1025

00:40:33,109 --> 00:40:28,069

so

1026

00:40:36,630 --> 00:40:33,119

years ago

1027

00:40:39,510 --> 00:40:36,640

comet that crashed into jupiter

1028

00:40:41,910 --> 00:40:39,520

and it um that was a violent event it

1029

00:40:43,990 --> 00:40:41,920

happened over just a few years that it

1030

00:40:45,829 --> 00:40:44,000

uh happened to have a close encounter

1031

00:40:47,990 --> 00:40:45,839

and get captured by the planet and then

1032

00:40:50,069 --> 00:40:48,000

it went into jupiter uh crashed into the

1033

00:40:52,470 --> 00:40:50,079

atmosphere fairly quickly

1034

00:40:54,550 --> 00:40:52,480

um and for a similar reason we

1035

00:40:57,589 --> 00:40:54,560

um we would have to get quite lucky to

1036

00:40:58,390 --> 00:40:57,599

see one of these violent events

1037

00:41:00,630 --> 00:40:58,400

um

1038

00:41:02,710 --> 00:41:00,640

the violent events they would probably

1039

00:41:04,950 --> 00:41:02,720

involve a close passage so in the solar

1040

00:41:06,630 --> 00:41:04,960

system um the planets are mutually

1041

00:41:08,470 --> 00:41:06,640

stable they don't interfere with one

1042

00:41:09,430 --> 00:41:08,480

another terribly much

1043

00:41:10,790 --> 00:41:09,440

but

1044

00:41:12,710 --> 00:41:10,800

only just

1045

00:41:15,670 --> 00:41:12,720

so if you were to move jupiter or saturn

1046

00:41:17,589 --> 00:41:15,680

just a little bit towards each other

1047

00:41:19,750 --> 00:41:17,599

then you could

1048

00:41:21,990 --> 00:41:19,760

have them interact enough that they

1049

00:41:23,750 --> 00:41:22,000

would they would uh

1050

00:41:24,950 --> 00:41:23,760

uh get bigger and bigger disturbances

1051  
00:41:26,950 --> 00:41:24,960  
and eventually have some very close

1052  
00:41:28,470 --> 00:41:26,960  
passage and then go on to completely new

1053  
00:41:31,510 --> 00:41:28,480  
orbits

1054  
00:41:33,430 --> 00:41:31,520  
and um that's the kind of violent event

1055  
00:41:35,910 --> 00:41:33,440  
that that may have shaped some of these

1056  
00:41:37,670 --> 00:41:35,920  
extra solar planetary systems

1057  
00:41:39,430 --> 00:41:37,680  
but we just have to infer it from

1058  
00:41:41,190 --> 00:41:39,440  
computer models and from seeing the

1059  
00:41:42,950 --> 00:41:41,200  
debris basically that's left over

1060  
00:41:46,630 --> 00:41:42,960  
afterwards

1061  
00:41:50,870 --> 00:41:48,309  
so my question relates to the fact that

1062  
00:41:52,710 --> 00:41:50,880  
you made a number of claims based on um

1063  
00:41:55,670 --> 00:41:52,720

that our solar system is unique from

1064

00:41:57,990 --> 00:41:55,680

others i was curious about uniqueness uh

1065

00:41:59,910 --> 00:41:58,000

basically based on us only being able to

1066

00:42:03,270 --> 00:41:59,920

see certain types of other planets or

1067

00:42:05,349 --> 00:42:03,280

put another way um you think is our

1068

00:42:07,510 --> 00:42:05,359

research methods verifying we'll find a

1069

00:42:08,950 --> 00:42:07,520

larger percentage of solar systems like

1070

00:42:13,109 --> 00:42:08,960

our own

1071

00:42:15,109 --> 00:42:13,119

um my fear is that uh

1072

00:42:17,589 --> 00:42:15,119

we don't know enough yet

1073

00:42:19,430 --> 00:42:17,599

so we in particular

1074

00:42:21,510 --> 00:42:19,440

um so just in the last couple of years

1075

00:42:22,630 --> 00:42:21,520

we've been able to uh begin seeing

1076

00:42:24,069 --> 00:42:22,640

earth's

1077

00:42:25,750 --> 00:42:24,079

and

1078

00:42:28,309 --> 00:42:25,760

we're just now being being able to see

1079

00:42:30,230 --> 00:42:28,319

the cold giants

1080

00:42:31,990 --> 00:42:30,240

so in a few years time i hope that the

1081

00:42:34,309 --> 00:42:32,000

picture that i've given you today will

1082

00:42:36,870 --> 00:42:34,319

be still correct at least as far as the

1083

00:42:38,790 --> 00:42:36,880

close end planets but those outer ones

1084

00:42:40,790 --> 00:42:38,800

uh our knowledge is much less certain

1085

00:42:42,309 --> 00:42:40,800

and so the picture could change so for

1086

00:42:45,030 --> 00:42:42,319

example there's another method a new

1087

00:42:46,309 --> 00:42:45,040

method called microlensing when a star

1088

00:42:48,790 --> 00:42:46,319

and its planet

1089

00:42:51,109 --> 00:42:48,800

go in front of a background star the

1090

00:42:53,270 --> 00:42:51,119

background star gets lensed so the light

1091

00:42:55,430 --> 00:42:53,280

gets focused on us and it gets a little

1092

00:42:57,270 --> 00:42:55,440

bit brighter and we can see a extra

1093

00:42:58,950 --> 00:42:57,280

brightening for the planet and through

1094

00:43:01,030 --> 00:42:58,960

that method we can detect planets that

1095

00:43:02,550 --> 00:43:01,040

are further out from their star even if

1096

00:43:03,750 --> 00:43:02,560

we can only see them just that one time

1097

00:43:04,710 --> 00:43:03,760

they go in front of the background

1098

00:43:06,790 --> 00:43:04,720

object

1099

00:43:08,390 --> 00:43:06,800

and so through that method a few

1100

00:43:09,750 --> 00:43:08,400

planets have now been found that are

1101  
00:43:11,510 --> 00:43:09,760  
cold giants

1102  
00:43:13,349 --> 00:43:11,520  
so if a lot of those are found then that

1103  
00:43:14,309 --> 00:43:13,359  
part of the picture i've described could

1104  
00:43:17,990 --> 00:43:14,319  
change

1105  
00:43:21,910 --> 00:43:19,349  
i have a question about one of your

1106  
00:43:25,430 --> 00:43:21,920  
graphs you had an xy graph that showed

1107  
00:43:28,150 --> 00:43:25,440  
mass and size yes

1108  
00:43:30,150 --> 00:43:28,160  
and i just wondered you pointed out um

1109  
00:43:33,270 --> 00:43:30,160  
an open area in the upper left but what

1110  
00:43:34,230 --> 00:43:33,280  
happens at the bottom of that chart

1111  
00:43:36,870 --> 00:43:34,240  
um

1112  
00:43:39,430 --> 00:43:36,880  
there's is it because we can't visualize

1113  
00:43:41,670 --> 00:43:39,440

planets that are smaller at this time

1114

00:43:43,750 --> 00:43:41,680

that's right so to give a feeling for

1115

00:43:45,670 --> 00:43:43,760

that um if the earth went in front of

1116

00:43:48,710 --> 00:43:45,680

the sun the earth is about one percent

1117

00:43:50,470 --> 00:43:48,720

of the sun's diameter so it blocks out

1118

00:43:52,309 --> 00:43:50,480

about one part in ten thousand of the

1119

00:43:54,390 --> 00:43:52,319

sun's light so you need to measure the

1120

00:43:56,550 --> 00:43:54,400

brightness of all these stars to that

1121

00:43:59,670 --> 00:43:56,560

precision in order to pick up an earth

1122

00:44:03,670 --> 00:43:59,680

and that is now possible but just barely

1123

00:44:07,190 --> 00:44:05,109

all right so over the next couple of

1124

00:44:08,710 --> 00:44:07,200

years as more more powerful telescopes

1125

00:44:10,710 --> 00:44:08,720

come online i'm assuming we'll be able

1126

00:44:12,390 --> 00:44:10,720

to see smaller objects like earth size

1127

00:44:13,190 --> 00:44:12,400

and mercury size

1128

00:44:17,430 --> 00:44:13,200

what

1129

00:44:19,510 --> 00:44:17,440

different telescopes going to enable and

1130

00:44:21,670 --> 00:44:19,520

what would that actually tell us that we

1131

00:44:23,589 --> 00:44:21,680

can't already know the with the current

1132

00:44:25,510 --> 00:44:23,599

methods

1133

00:44:28,390 --> 00:44:25,520

um

1134

00:44:30,309 --> 00:44:28,400

well it's just a matter of the size and

1135

00:44:33,030 --> 00:44:30,319

and how accurately you can measure the

1136

00:44:36,230 --> 00:44:33,040

brightness and so

1137

00:44:40,790 --> 00:44:38,470

i mean it's it's a whole new unexplored

1138

00:44:42,069 --> 00:44:40,800

territory because we really don't know

1139

00:44:46,150 --> 00:44:42,079

what

1140

00:44:47,190 --> 00:44:46,160

in that size range smaller than the

1141

00:44:48,390 --> 00:44:47,200

earth

1142

00:44:49,910 --> 00:44:48,400

and those

1143

00:44:51,670 --> 00:44:49,920

those planets tend to be just the little

1144

00:44:53,750 --> 00:44:51,680

leftover bits they're the flecks of dust

1145

00:44:56,309 --> 00:44:53,760

that get flicked around when the big

1146

00:44:57,670 --> 00:44:56,319

ones undergo any kind of special event

1147

00:44:59,349 --> 00:44:57,680

and so it's certainly possible they

1148

00:45:00,710 --> 00:44:59,359

could be very different in other systems

1149

00:45:03,109 --> 00:45:00,720

from our own

1150

00:45:07,910 --> 00:45:03,119

but we just don't know yet so it's

1151

00:45:12,470 --> 00:45:10,470

hi um my question is

1152

00:45:14,309 --> 00:45:12,480

earlier you had a graph showing

1153

00:45:18,230 --> 00:45:14,319

our solar system and how all of the

1154

00:45:20,069 --> 00:45:18,240

planets are on a flat plane yes and how

1155

00:45:22,550 --> 00:45:20,079

some of the hot jupiters were knocked

1156

00:45:25,190 --> 00:45:22,560

off of that plane by a violent event

1157

00:45:27,750 --> 00:45:25,200

is is that does that mean that most

1158

00:45:29,430 --> 00:45:27,760

solar systems will have

1159

00:45:32,230 --> 00:45:29,440

most of the material or most of the

1160

00:45:34,870 --> 00:45:32,240

planets along that flat plain

1161

00:45:35,910 --> 00:45:34,880

most of the ones we've found so far are

1162

00:45:37,270 --> 00:45:35,920

like that

1163

00:45:38,790 --> 00:45:37,280

okay

1164

00:45:40,950 --> 00:45:38,800

but again

1165

00:45:42,390 --> 00:45:40,960

our knowledge is limited so we can see

1166

00:45:43,910 --> 00:45:42,400

the planets that go in front of their

1167

00:45:45,670 --> 00:45:43,920

star

1168

00:45:47,510 --> 00:45:45,680

we can go a little bit beyond that so in

1169

00:45:49,270 --> 00:45:47,520

some cases we see a planet go in front

1170

00:45:50,309 --> 00:45:49,280

of the star but the next time it doesn't

1171

00:45:52,630 --> 00:45:50,319

go

1172

00:45:53,829 --> 00:45:52,640

in front at quite the same uh

1173

00:45:55,510 --> 00:45:53,839

quite the time we expect like it's a

1174

00:45:57,109 --> 00:45:55,520

little bit irregular a bit ahead of

1175

00:45:58,710 --> 00:45:57,119

where we expected one orbit and a bit

1176  
00:46:00,790 --> 00:45:58,720  
behind the next and from that we can

1177  
00:46:02,069 --> 00:46:00,800  
work out there must be another planet

1178  
00:46:03,349 --> 00:46:02,079  
and we can work out roughly where it

1179  
00:46:04,870 --> 00:46:03,359  
should be it's a little bit off the

1180  
00:46:07,190 --> 00:46:04,880  
plane so it doesn't go across the face

1181  
00:46:09,510 --> 00:46:07,200  
of the star we can work out how

1182  
00:46:10,950 --> 00:46:09,520  
massive it must be to perturb the planet

1183  
00:46:12,870 --> 00:46:10,960  
that we can see

1184  
00:46:14,550 --> 00:46:12,880  
so from from that

1185  
00:46:15,910 --> 00:46:14,560  
you can get an idea about how many of

1186  
00:46:17,589 --> 00:46:15,920  
those

1187  
00:46:19,349 --> 00:46:17,599  
off off-plane

1188  
00:46:21,030 --> 00:46:19,359

planets there may be

1189

00:46:22,870 --> 00:46:21,040

and even when you include those it still

1190

00:46:25,829 --> 00:46:22,880

looks like the bulk of them are pretty

1191

00:46:26,950 --> 00:46:25,839

close to all lying in a plane do we do

1192

00:46:29,990 --> 00:46:26,960

we know why

1193

00:46:32,150 --> 00:46:30,000

most solar systems will form along that

1194

00:46:34,069 --> 00:46:32,160

one plane and not have a whole bunch of

1195

00:46:35,750 --> 00:46:34,079

planets that go a whole bunch of

1196

00:46:37,510 --> 00:46:35,760

different axes

1197

00:46:39,430 --> 00:46:37,520

well

1198

00:46:41,270 --> 00:46:39,440

the simplest answer is probably the best

1199

00:46:44,069 --> 00:46:41,280

there and that is that if you take that

1200

00:46:45,910 --> 00:46:44,079

cloud of dust and gas

1201

00:46:47,589 --> 00:46:45,920

it's supported by its rotation it's

1202

00:46:50,150 --> 00:46:47,599

basically in orbital motion around the

1203

00:46:52,470 --> 00:46:50,160

star so that supports it in in the

1204

00:46:54,950 --> 00:46:52,480

radial direction but in the vertical

1205

00:46:56,630 --> 00:46:54,960

direction um its rotation is not

1206

00:46:58,870 --> 00:46:56,640

supporting it it just has whatever

1207

00:47:00,630 --> 00:46:58,880

pressure it has inside the gas to stop

1208

00:47:02,470 --> 00:47:00,640

it from all collapsing to a thin sheet

1209

00:47:05,030 --> 00:47:02,480

at the middle that's why it's a disc

1210

00:47:07,190 --> 00:47:05,040

instead of a sphere it's uh it's thinner

1211

00:47:09,349 --> 00:47:07,200

in that direction along the rotation

1212

00:47:12,309 --> 00:47:09,359

axis so if the planets form from that

1213

00:47:15,030 --> 00:47:12,319

material they have to more or less share

1214

00:47:16,870 --> 00:47:15,040

the same rotation okay they can scatter

1215

00:47:18,870 --> 00:47:16,880

off each other a bit and push one up and

1216

00:47:21,910 --> 00:47:18,880

one down a bit but not very much okay

1217

00:47:26,630 --> 00:47:25,270

you had a remarkable image made by alma

1218

00:47:29,270 --> 00:47:26,640

of um

1219

00:47:30,630 --> 00:47:29,280

in the millimeter wavelengths of a

1220

00:47:32,630 --> 00:47:30,640

stellar disc

1221

00:47:35,190 --> 00:47:32,640

and i noticed a lot of uh radial

1222

00:47:38,550 --> 00:47:35,200

structure apparent is is that just an

1223

00:47:40,790 --> 00:47:38,560

artifact or is it something real do you

1224

00:47:43,829 --> 00:47:40,800

mean the uh the various rings or

1225

00:47:45,990 --> 00:47:43,839

something is the rays of radial

1226

00:47:50,150 --> 00:47:46,000

spokes coming out of it

1227

00:47:52,390 --> 00:47:50,160

well so my friends who are radio experts

1228

00:47:54,790 --> 00:47:52,400

tell me so the alma telescope

1229

00:47:58,390 --> 00:47:54,800

uh is not one big dish but instead it

1230

00:48:00,550 --> 00:47:58,400

has a few dozen smaller dishes that are

1231

00:48:01,910 --> 00:48:00,560

combined to make an image

1232

00:48:03,270 --> 00:48:01,920

and you can combine them in slightly

1233

00:48:04,870 --> 00:48:03,280

different ways like weighting

1234

00:48:07,349 --> 00:48:04,880

combinations of dishes close to the

1235

00:48:09,430 --> 00:48:07,359

center versus ones that are further out

1236

00:48:11,109 --> 00:48:09,440

and i think it's possible to make those

1237

00:48:13,030 --> 00:48:11,119

spokes go away

1238

00:48:16,150 --> 00:48:13,040

not the rings the rings stay no matter

1239

00:48:17,589 --> 00:48:16,160

what you do so we can't trust the spokes

1240

00:48:19,750 --> 00:48:17,599

yet in fact

1241

00:48:22,230 --> 00:48:19,760

people have done a thing where they they

1242

00:48:25,349 --> 00:48:22,240

try to wrap everything around

1243

00:48:28,230 --> 00:48:26,470

lay

1244

00:48:29,829 --> 00:48:28,240

the piece of the image that's at one

1245

00:48:30,790 --> 00:48:29,839

angle on the piece that's at another

1246

00:48:31,829 --> 00:48:30,800

angle

1247

00:48:33,589 --> 00:48:31,839

and

1248

00:48:35,670 --> 00:48:33,599

they cannot find any convincing evidence

1249

00:48:36,870 --> 00:48:35,680

for it not being perfectly symmetric

1250

00:48:38,150 --> 00:48:36,880

except for the fact that it's tilted

1251

00:48:39,589 --> 00:48:38,160

over a little bit

1252

00:48:42,470 --> 00:48:39,599

so as far as we can tell they're round

1253

00:48:46,549 --> 00:48:42,480

rings and nothing more good

1254

00:48:50,309 --> 00:48:48,470

hi thank you for the lecture um i have

1255

00:48:52,950 --> 00:48:50,319

two questions actually um the first

1256

00:48:57,109 --> 00:48:55,270

giving the

1257

00:49:00,150 --> 00:48:57,119

more to our solar system or

1258

00:49:01,750 --> 00:49:00,160

the missing planet theory in our solar

1259

00:49:04,549 --> 00:49:01,760

system can you shed some light on that

1260

00:49:06,950 --> 00:49:04,559

given the mass of the planet that was

1261

00:49:09,430 --> 00:49:06,960

supposedly in our solar system before it

1262

00:49:11,510 --> 00:49:09,440

escaped and the apparent position it had

1263

00:49:13,190 --> 00:49:11,520

in our solar system

1264

00:49:16,630 --> 00:49:13,200

well you could imagine a couple of

1265

00:49:17,829 --> 00:49:16,640

missing planets so one would be inside

1266

00:49:19,990 --> 00:49:17,839

mercury

1267

00:49:22,230 --> 00:49:20,000

why is there nothing there

1268

00:49:23,750 --> 00:49:22,240

and uh one answer that people have come

1269

00:49:26,630 --> 00:49:23,760

up with in that case is perhaps there

1270

00:49:28,870 --> 00:49:26,640

were some more planets inside mercury

1271

00:49:31,349 --> 00:49:28,880

and perhaps around mercury's orbit

1272

00:49:32,710 --> 00:49:31,359

but they went unstable

1273

00:49:35,349 --> 00:49:32,720

for some reason and some of them

1274

00:49:36,390 --> 00:49:35,359

collided so mercury is a bit unusual in

1275

00:49:38,470 --> 00:49:36,400

that

1276

00:49:40,790 --> 00:49:38,480

it has an enormous iron core

1277

00:49:41,990 --> 00:49:40,800

and relatively thin layer of rock on the

1278

00:49:43,349 --> 00:49:42,000

outside

1279

00:49:46,390 --> 00:49:43,359

and so perhaps what happened was some of

1280

00:49:48,630 --> 00:49:46,400

those collisions blasted off whatever uh

1281

00:49:50,069 --> 00:49:48,640

surface layers it had and it's just

1282

00:49:51,910 --> 00:49:50,079

um

1283

00:49:52,950 --> 00:49:51,920

it's just the fragment that's left at

1284

00:49:54,790 --> 00:49:52,960

the center

1285

00:49:57,030 --> 00:49:54,800

so that's that could be one explanation

1286

00:49:58,549 --> 00:49:57,040

for why there's a missing planet uh very

1287

00:50:00,870 --> 00:49:58,559

near the sun

1288

00:50:02,470 --> 00:50:00,880

as another possibility is that you could

1289

00:50:04,790 --> 00:50:02,480

say there's a missing planet in the

1290

00:50:06,630 --> 00:50:04,800

asteroid belt

1291

00:50:09,109 --> 00:50:06,640

why do we have some small fragments that

1292

00:50:11,190 --> 00:50:09,119

added up don't amount to anything even

1293

00:50:14,069 --> 00:50:11,200

close to mars

1294

00:50:15,990 --> 00:50:14,079

um and and not have another big planet

1295

00:50:17,430 --> 00:50:16,000

you could add add a planet there and not

1296

00:50:19,510 --> 00:50:17,440

much disturb the rest of the solar

1297

00:50:21,829 --> 00:50:19,520

system

1298

00:50:23,589 --> 00:50:21,839

and uh various ideas have been put

1299

00:50:25,670 --> 00:50:23,599

forward for that missing planet over the

1300

00:50:27,430 --> 00:50:25,680

years one is that

1301

00:50:30,630 --> 00:50:27,440

perhaps jupiter came inwards a little

1302

00:50:33,030 --> 00:50:30,640

bit early in the solar system's history

1303

00:50:34,549 --> 00:50:33,040

and then went back out again

1304

00:50:36,630 --> 00:50:34,559

perhaps under the influence of saturn as

1305

00:50:37,910 --> 00:50:36,640

saturn was forming if it did that it may

1306

00:50:39,430 --> 00:50:37,920

have cleared out

1307

00:50:41,349 --> 00:50:39,440

the asteroid belt region and may have

1308

00:50:43,190 --> 00:50:41,359

also contributed to mars being not that

1309

00:50:45,430 --> 00:50:43,200

big mars is only about one-tenth the

1310

00:50:47,670 --> 00:50:45,440

mass of the earth and so this is called

1311

00:50:49,670 --> 00:50:47,680

the grand tax scenario like a boat

1312

00:50:51,829 --> 00:50:49,680

tacking in and then out again so it

1313

00:50:54,549 --> 00:50:51,839

might be an explanation for another gap

1314

00:50:56,470 --> 00:50:54,559

in the solar system my second question

1315

00:50:58,549 --> 00:50:56,480

is um

1316

00:51:00,710 --> 00:50:58,559

are all jupiter-sized planets that

1317

00:51:03,670 --> 00:51:00,720

migrate in to their solar to their

1318

00:51:05,910 --> 00:51:03,680

parent star doomed or are they able to

1319

00:51:07,990 --> 00:51:05,920

theoretically stop in a position say

1320

00:51:10,470 --> 00:51:08,000

like in the goldilocks zone of earth

1321

00:51:15,510 --> 00:51:10,480

that is a good question and one that

1322

00:51:20,470 --> 00:51:17,430

because we do see some hot jupiters they

1323

00:51:23,589 --> 00:51:20,480

can't all plunge into their stars

1324

00:51:25,270 --> 00:51:23,599

and one way that they could stop is

1325

00:51:26,950 --> 00:51:25,280

perhaps in the later stages of planet

1326

00:51:29,829 --> 00:51:26,960

formation if as you come close to the

1327

00:51:32,069 --> 00:51:29,839

star there may be a gap so the gas comes

1328

00:51:32,790 --> 00:51:32,079

to an end perhaps it gets funneled onto

1329

00:51:51,829 --> 00:51:32,800

the

1330

00:51:54,150 --> 00:51:51,839

planet perhaps its migration could stop

1331

00:51:56,470 --> 00:51:54,160

at that point or near that point that's

1332

00:51:58,150 --> 00:51:56,480

one of the explanations people have

1333

00:52:01,670 --> 00:51:58,160

have put forward

1334

00:52:04,069 --> 00:52:01,680

if i could just squeak one more in um

1335

00:52:06,230 --> 00:52:04,079

have you discovered any planets around a

1336

00:52:07,750 --> 00:52:06,240

or o type stars

1337

00:52:09,270 --> 00:52:07,760

um

1338

00:52:11,109 --> 00:52:09,280

let me think so

1339

00:52:12,870 --> 00:52:11,119

i think somebody may have claimed an o

1340

00:52:15,270 --> 00:52:12,880

star but i'm not sure i believe it but

1341

00:52:16,390 --> 00:52:15,280

for a stars there are quite a few so

1342

00:52:19,589 --> 00:52:16,400

what people have done is look at

1343

00:52:20,710 --> 00:52:19,599

so-called retired a stars so a stars

1344

00:52:24,470 --> 00:52:20,720

that have gotten late enough in their

1345

00:52:26,309 --> 00:52:24,480

life so that their outer layers swell up

1346

00:52:28,309 --> 00:52:26,319

so i should fill in there so when a

1347

00:52:30,309 --> 00:52:28,319

stars are in the main part of their

1348

00:52:32,710 --> 00:52:30,319

lives just like the sun their outer

1349

00:52:35,190 --> 00:52:32,720

layers are hot enough so that most atoms

1350

00:52:36,710 --> 00:52:35,200

have lost um

1351

00:52:38,630 --> 00:52:36,720

enough electrons so that they don't

1352

00:52:40,230 --> 00:52:38,640

produce spectral lines and that means

1353

00:52:41,829 --> 00:52:40,240

that you you can't accurately measure

1354

00:52:44,230 --> 00:52:41,839

the velocity of the star towards you or

1355

00:52:45,990 --> 00:52:44,240

away from you so for the main sequence a

1356

00:52:48,230 --> 00:52:46,000

stars we don't really know whether they

1357

00:52:50,950 --> 00:52:48,240

have planets when they get older and

1358

00:52:53,109 --> 00:52:50,960

their outer layers swell up and cool off

1359

00:52:54,950 --> 00:52:53,119

they get the spectral lines back again

1360

00:52:56,549 --> 00:52:54,960

and so we can we can see the planets

1361

00:52:58,790 --> 00:52:56,559

then and so for those older stars there

1362

00:53:00,630 --> 00:52:58,800

are quite a few planets known

1363

00:53:01,990 --> 00:53:00,640

and i guess i haven't been reading up on

1364

00:53:04,150 --> 00:53:02,000

that lately but i think the last i

1365

00:53:06,870 --> 00:53:04,160

remember it looked like there were

1366

00:53:09,030 --> 00:53:06,880

um there was a deficit of planets in

1367

00:53:10,630 --> 00:53:09,040

close they started at about the earth's

1368

00:53:11,510 --> 00:53:10,640

distance from the sun

1369

00:53:12,950 --> 00:53:11,520

so

1370

00:53:14,710 --> 00:53:12,960

they seem to be a little bit different

1371

00:53:16,630 --> 00:53:14,720

than the sun-like stars in their

1372

00:53:22,549 --> 00:53:16,640

population of planets

1373

00:53:28,710 --> 00:53:25,270

hi thank you for a great talk

1374

00:53:31,349 --> 00:53:28,720

so we know that nebulae contain regions

1375

00:53:33,430 --> 00:53:31,359

of dense gas and dust

1376

00:53:35,589 --> 00:53:33,440

so one of the theories is that

1377

00:53:37,910 --> 00:53:35,599

a nearby supernova

1378

00:53:39,670 --> 00:53:37,920

releases some kind of a shock wave that

1379

00:53:42,150 --> 00:53:39,680

then bumps up against

1380

00:53:44,870 --> 00:53:42,160

that dense region of gas and dust and

1381

00:53:46,710 --> 00:53:44,880

triggering star formation

1382

00:53:48,470 --> 00:53:46,720

can you shed some light as to how that

1383

00:53:49,670 --> 00:53:48,480

happens i've thought about it a lot i'm

1384

00:53:53,270 --> 00:53:49,680

still having a little bit of a tough

1385

00:53:55,270 --> 00:53:53,280

time with the physics of how that occurs

1386

00:53:57,349 --> 00:53:55,280

well

1387

00:53:59,670 --> 00:53:57,359

seems like a couple of times a year

1388

00:54:01,190 --> 00:53:59,680

somebody claims to have observed that in

1389

00:54:03,750 --> 00:54:01,200

action

1390

00:54:05,589 --> 00:54:03,760

but it has been uh

1391

00:54:06,950 --> 00:54:05,599

it has been difficult to

1392

00:54:09,750 --> 00:54:06,960

to confirm

1393

00:54:15,190 --> 00:54:11,349

in one of these clouds it's going to

1394

00:54:19,349 --> 00:54:17,670

the outer layers can be quiescent when

1395

00:54:20,470 --> 00:54:19,359

the inner layers have already begun to

1396

00:54:22,309 --> 00:54:20,480

collapse

1397

00:54:24,470 --> 00:54:22,319

and so if we see

1398

00:54:26,309 --> 00:54:24,480

um

1399

00:54:28,470 --> 00:54:26,319

if we if we see

1400

00:54:30,549 --> 00:54:28,480

a system over which a shock wave has

1401

00:54:32,390 --> 00:54:30,559

just passed it's a little hard to know

1402

00:54:35,349 --> 00:54:32,400

if the collapse to form a star was

1403

00:54:37,030 --> 00:54:35,359

triggered by the shock wave or not

1404

00:54:38,630 --> 00:54:37,040

another another reason that that's a

1405

00:54:40,870 --> 00:54:38,640

hard problem is that we only get a

1406

00:54:43,349 --> 00:54:40,880

snapshot because the passage of the

1407

00:54:45,109 --> 00:54:43,359

shock wave can take many years many

1408

00:54:47,349 --> 00:54:45,119

astronomers lifetimes

1409

00:54:49,510 --> 00:54:47,359

and so we can't uh we can't get the

1410

00:54:50,630 --> 00:54:49,520

whole picture we just see an instant in

1411

00:54:54,069 --> 00:54:50,640

time

1412

00:54:56,630 --> 00:54:54,079

and for those reasons um

1413

00:54:59,589 --> 00:54:56,640

while it's it seems like a really

1414

00:55:01,670 --> 00:54:59,599

plausible idea and it may happen um i

1415

00:55:02,710 --> 00:55:01,680

don't think it's been very convincingly

1416

00:55:04,790 --> 00:55:02,720

shown

1417

00:55:07,430 --> 00:55:04,800

that it is happening in any one

1418

00:55:12,309 --> 00:55:07,440

particular case

1419

00:55:16,630 --> 00:55:14,870

i wanted to ask about the

1420

00:55:18,549 --> 00:55:16,640

the size of the star and what effect it

1421

00:55:20,710 --> 00:55:18,559

might have on the potential

1422

00:55:23,990 --> 00:55:20,720

planets that might form the types of

1423

00:55:29,349 --> 00:55:27,109

so the size of the star so people have

1424

00:55:30,870 --> 00:55:29,359

been searching for planets around stars

1425

00:55:32,549 --> 00:55:30,880

with a range of masses we talked just a

1426  
00:55:34,710 --> 00:55:32,559  
minute ago about the ones a bit more

1427  
00:55:36,309 --> 00:55:34,720  
massive than the sun

1428  
00:55:39,670 --> 00:55:36,319  
people have also looked at stars less

1429  
00:55:42,630 --> 00:55:40,549  
so

1430  
00:55:44,309 --> 00:55:42,640  
m dwarfs and even brown dwarfs and

1431  
00:55:46,390 --> 00:55:44,319  
there's certainly there have been

1432  
00:55:48,549 --> 00:55:46,400  
these disks found so disks of gas and

1433  
00:55:50,309 --> 00:55:48,559  
dust around the young examples many of

1434  
00:55:51,510 --> 00:55:50,319  
those are known

1435  
00:55:53,349 --> 00:55:51,520  
um

1436  
00:55:54,950 --> 00:55:53,359  
planets i think there are fewer but

1437  
00:55:56,710 --> 00:55:54,960  
there are some now

1438  
00:55:59,190 --> 00:55:56,720

um

1439

00:56:02,870 --> 00:55:59,200

i think there was a a uh

1440

00:56:05,349 --> 00:56:02,880

a prediction that there should be uh

1441

00:56:06,390 --> 00:56:05,359

fewer giant planets around the smallest

1442

00:56:07,430 --> 00:56:06,400

stars

1443

00:56:09,030 --> 00:56:07,440

perhaps because you just don't have

1444

00:56:10,870 --> 00:56:09,040

enough material

1445

00:56:12,230 --> 00:56:10,880

um and i'm not sure whether that has

1446

00:56:14,150 --> 00:56:12,240

been borne out

1447

00:56:16,309 --> 00:56:14,160

in the planets that people have looked

1448

00:56:17,829 --> 00:56:16,319

for of course most people are looking

1449

00:56:19,349 --> 00:56:17,839

for earths because that feels like the

1450

00:56:21,270 --> 00:56:19,359

most exciting thing

1451  
00:56:23,109 --> 00:56:21,280  
and so there are fewer people looking at

1452  
00:56:24,069 --> 00:56:23,119  
these smaller stars and so we don't know

1453  
00:56:26,150 --> 00:56:24,079  
as much

1454  
00:56:29,030 --> 00:56:26,160  
is there a

1455  
00:56:31,270 --> 00:56:29,040  
tapering off maybe of the maybe larger

1456  
00:56:32,630 --> 00:56:31,280  
larger and larger stars compared to the

1457  
00:56:34,870 --> 00:56:32,640  
sun

1458  
00:56:35,829 --> 00:56:34,880  
um

1459  
00:56:36,710 --> 00:56:35,839  
so

1460  
00:56:42,950 --> 00:56:36,720  
for

1461  
00:56:44,950 --> 00:56:42,960  
and there i don't think that there are

1462  
00:56:46,789 --> 00:56:44,960  
significantly fewer planets but just

1463  
00:56:47,910 --> 00:56:46,799

that they happen to be a little bit

1464

00:56:50,870 --> 00:56:47,920

further out

1465

00:56:54,390 --> 00:56:50,880

than for the sun-like stars

1466

00:57:01,349 --> 00:56:57,589

um how do the stars and planets from

1467

00:57:02,390 --> 00:57:01,359

other galaxies affect us

1468

00:57:03,190 --> 00:57:02,400

um

1469

00:57:07,990 --> 00:57:03,200

we

1470

00:57:09,190 --> 00:57:08,000

about the uh about the planets in other

1471

00:57:11,190 --> 00:57:09,200

galaxies

1472

00:57:12,630 --> 00:57:11,200

so

1473

00:57:14,710 --> 00:57:12,640

um

1474

00:57:17,270 --> 00:57:14,720

almost all of the planets that we know

1475

00:57:19,910 --> 00:57:17,280

of around other stars are within

1476

00:57:22,630 --> 00:57:19,920

um a couple of thousand light years of

1477

00:57:24,470 --> 00:57:22,640

us so within our region of the galaxy

1478

00:57:27,510 --> 00:57:24,480

microlensing which i mentioned earlier

1479

00:57:28,710 --> 00:57:27,520

in the question time there we can see

1480

00:57:30,230 --> 00:57:28,720

planets

1481

00:57:32,789 --> 00:57:30,240

just for a moment as they pass across a

1482

00:57:37,109 --> 00:57:32,799

distant star we can see planets that are

1483

00:57:38,789 --> 00:57:37,119

halfway to the center of our galaxy

1484

00:57:40,789 --> 00:57:38,799

but planets that are further away we

1485

00:57:42,309 --> 00:57:40,799

don't don't have a good way to detect

1486

00:57:44,630 --> 00:57:42,319

yet

1487

00:57:47,510 --> 00:57:44,640

um and i have another question

1488

00:57:50,069 --> 00:57:47,520

um how are the planets um

1489

00:57:52,549 --> 00:57:50,079

formed like are their sizes and shapes

1490

00:57:56,309 --> 00:57:52,559

formed based on the size of the star and

1491

00:57:57,430 --> 00:57:56,319

what and how what type of star it is

1492

00:57:59,349 --> 00:57:57,440

um

1493

00:58:01,190 --> 00:57:59,359

let me see if i can add anything so we

1494

00:58:02,390 --> 00:58:01,200

talked a little bit about the uh the a

1495

00:58:06,150 --> 00:58:02,400

stars

1496

00:58:07,510 --> 00:58:06,160

then the low-mass

1497

00:58:10,150 --> 00:58:07,520

ones

1498

00:58:13,430 --> 00:58:11,190

so

1499

00:58:15,109 --> 00:58:13,440

uh

1500

00:58:17,670 --> 00:58:15,119

it does seem like there there's a

1501

00:58:19,270 --> 00:58:17,680

gradient in in um

1502

00:58:20,630 --> 00:58:19,280

in

1503

00:58:23,109 --> 00:58:20,640

the size of the planets that you can

1504

00:58:24,789 --> 00:58:23,119

form and perhaps in how far out they are

1505

00:58:26,230 --> 00:58:24,799

from the star

1506

00:58:29,030 --> 00:58:26,240

i think i can add a little bit to that

1507

00:58:31,030 --> 00:58:29,040

so if we look at

1508

00:58:32,549 --> 00:58:31,040

the debris that's left over after the

1509

00:58:34,069 --> 00:58:32,559

gas has cleared

1510

00:58:38,230 --> 00:58:34,079

so

1511

00:58:40,309 --> 00:58:38,240

and comets are releasing dust all the

1512

00:58:42,150 --> 00:58:40,319

time into the solar system and so we

1513

00:58:43,030 --> 00:58:42,160

have the zodiacal light which you can

1514

00:58:45,510 --> 00:58:43,040

see

1515

00:58:48,230 --> 00:58:45,520

if you go out at a very dark sight and

1516

00:58:50,470 --> 00:58:48,240

look near the horizon just around sunset

1517

00:58:51,829 --> 00:58:50,480

or sunrise there's a little bit of dust

1518

00:58:53,670 --> 00:58:51,839

floating around

1519

00:58:56,309 --> 00:58:53,680

near the plain of the planets

1520

00:58:58,470 --> 00:58:56,319

and in some other planetary systems we

1521

00:59:00,630 --> 00:58:58,480

see that dust also

1522

00:59:03,190 --> 00:59:00,640

debris from the planets grinding and

1523

00:59:05,829 --> 00:59:03,200

asteroids grinding each other down

1524

00:59:08,150 --> 00:59:05,839

and it does seem that

1525

00:59:10,230 --> 00:59:08,160

around the lowest mass stars we don't

1526

00:59:12,390 --> 00:59:10,240

see that dust except in

1527

00:59:13,589 --> 00:59:12,400

one or two exceptional cases

1528

00:59:15,670 --> 00:59:13,599

so there may be something different

1529

00:59:16,950 --> 00:59:15,680

about the environment there so one idea

1530

00:59:19,109 --> 00:59:16,960

that has been suggested is that the

1531

00:59:20,630 --> 00:59:19,119

stellar wind the winds from those

1532

00:59:23,829 --> 00:59:20,640

low-mass stars

1533

00:59:25,430 --> 00:59:23,839

uh are able to uh to blow out the uh the

1534

00:59:26,630 --> 00:59:25,440

dust and so perhaps the dust is being

1535

00:59:28,549 --> 00:59:26,640

produced there perhaps there are still

1536

00:59:30,309 --> 00:59:28,559

planets but we don't see the dust

1537

00:59:32,549 --> 00:59:30,319

because it's been removed

1538

00:59:34,870 --> 00:59:32,559

so that's another difference between

1539

00:59:36,470 --> 00:59:34,880

in the planets around stars of different

1540

00:59:42,309 --> 00:59:36,480

sizes

1541

00:59:46,150 --> 00:59:43,910

from the internet

1542

00:59:48,549 --> 00:59:46,160

there you go sir thank you so i've been

1543

00:59:51,270 --> 00:59:48,559

given uh some questions

1544

00:59:52,150 --> 00:59:51,280

uh from social media

1545

00:59:53,109 --> 00:59:52,160

so

1546

00:59:56,309 --> 00:59:53,119

uh

1547

01:00:00,470 --> 00:59:56,319

daniel young t3 asks

1548

01:00:02,470 --> 01:00:00,480

um what types of signals or cycles can

1549

01:00:04,950 --> 01:00:02,480

we detect from exoplanets that we could

1550

01:00:07,030 --> 01:00:04,960

not detect before

1551

01:00:09,430 --> 01:00:07,040

i would like to take this in a slightly

1552

01:00:10,950 --> 01:00:09,440

different direction so

1553

01:00:13,270 --> 01:00:10,960

a signal that people have been looking

1554

01:00:15,910 --> 01:00:13,280

for is the radio signals perhaps

1555

01:00:16,789 --> 01:00:15,920

produced directly by planets

1556

01:00:19,589 --> 01:00:16,799

so

1557

01:00:21,270 --> 01:00:19,599

uh jupiter as it interacts with as its

1558

01:00:22,710 --> 01:00:21,280

magnetic field in particular interacts

1559

01:00:25,270 --> 01:00:22,720

with the solar wind

1560

01:00:26,069 --> 01:00:25,280

uh produces long wavelength

1561

01:00:27,109 --> 01:00:26,079

uh

1562

01:00:29,990 --> 01:00:27,119

radio

1563

01:00:32,150 --> 01:00:30,000

emission uh decameter wavelengths i

1564

01:00:33,190 --> 01:00:32,160

think so many yards

1565

01:00:34,789 --> 01:00:33,200

and

1566

01:00:38,390 --> 01:00:34,799

people have suggested that if you scale

1567

01:00:40,470 --> 01:00:38,400

up jupiter to uh a hot jupiter which is

1568

01:00:43,109 --> 01:00:40,480

much closer to its star so it's embedded

1569

01:00:44,549 --> 01:00:43,119

in a much stronger stellar wind and if

1570

01:00:47,030 --> 01:00:44,559

it's young may also have a stronger

1571

01:00:49,030 --> 01:00:47,040

magnetic field so it could produce a

1572

01:00:51,270 --> 01:00:49,040

really strong long wavelength radio

1573

01:00:53,670 --> 01:00:51,280

emission so there are some people here

1574

01:00:54,950 --> 01:00:53,680

at jpl working with colleagues in india

1575

01:00:56,470 --> 01:00:54,960

that have a big radio telescope that

1576

01:00:58,470 --> 01:00:56,480

have been searching for that i think

1577

01:01:00,789 --> 01:00:58,480

some people at caltech have also

1578

01:01:02,549 --> 01:01:00,799

started a search but nothing has been

1579

01:01:05,589 --> 01:01:02,559

found yet

1580

01:01:06,950 --> 01:01:05,599

so but that's an example of a signal

1581

01:01:09,589 --> 01:01:06,960

that we've been looking for and hope to

1582

01:01:13,270 --> 01:01:09,599

detect soon

1583

01:01:15,510 --> 01:01:13,280

uh also on social media ian mallett

1584

01:01:18,870 --> 01:01:15,520

asks uh could the reason that we're

1585

01:01:20,549 --> 01:01:18,880

seeing more planets near stars be

1586

01:01:22,390 --> 01:01:20,559

observational bias

1587

01:01:24,789 --> 01:01:22,400

absolutely it's

1588

01:01:26,710 --> 01:01:24,799

almost all observational bias not

1589

01:01:28,309 --> 01:01:26,720

entirely because we've seen kinds of

1590

01:01:31,270 --> 01:01:28,319

planetary systems that

1591

01:01:32,630 --> 01:01:31,280

we just don't have uh in our own case so

1592

01:01:34,150 --> 01:01:32,640

that that is certainly telling us

1593

01:01:36,549 --> 01:01:34,160

something completely new

1594

01:01:38,950 --> 01:01:36,559

but one of the of the problems that we

1595

01:01:40,870 --> 01:01:38,960

face is not fooling ourselves not

1596

01:01:42,710 --> 01:01:40,880

thinking that all that we've seen so far

1597

01:01:43,990 --> 01:01:42,720

is all that there is because there's a

1598

01:01:45,990 --> 01:01:44,000

lot more out there there's a lot more

1599

01:01:47,990 --> 01:01:46,000

further from the stars that we

1600

01:01:49,670 --> 01:01:48,000

haven't seen and won't be able to see

1601  
01:01:51,109 --> 01:01:49,680  
perhaps until they've done at least one

1602  
01:01:53,270 --> 01:01:51,119  
orbit i mean saturn's orbital period is

1603  
01:01:55,349 --> 01:01:53,280  
30 years so we might have to wait that

1604  
01:01:57,670 --> 01:01:55,359  
long to see a saturn using the radial

1605  
01:01:59,430 --> 01:01:57,680  
velocity method so people who haven't

1606  
01:02:00,230 --> 01:01:59,440  
been haven't even been looking for that

1607  
01:02:02,549 --> 01:02:00,240  
long

1608  
01:02:04,710 --> 01:02:02,559  
so there is a lot more to be discovered

1609  
01:02:07,510 --> 01:02:04,720  
and that i hope will be discovered

1610  
01:02:08,950 --> 01:02:07,520  
in the coming years

1611  
01:02:10,950 --> 01:02:08,960  
and then a third

1612  
01:02:12,549 --> 01:02:10,960  
question from social media prometheus

1613  
01:02:15,030 --> 01:02:12,559

256

1614

01:02:16,390 --> 01:02:15,040

asks how would we detect planets around

1615

01:02:19,589 --> 01:02:16,400

a far-flung

1616

01:02:21,829 --> 01:02:19,599

identical copy of our solar system

1617

01:02:24,309 --> 01:02:21,839

would our planets need to be detected

1618

01:02:28,150 --> 01:02:24,319

using the transit method

1619

01:02:31,430 --> 01:02:29,510

on the whole

1620

01:02:33,270 --> 01:02:31,440

yes and

1621

01:02:34,630 --> 01:02:33,280

so jupiter you could probably detect by

1622

01:02:35,990 --> 01:02:34,640

the radial velocity method if you're

1623

01:02:38,470 --> 01:02:36,000

willing to wait

1624

01:02:42,950 --> 01:02:38,480

one orbit or maybe two to be sure so 12

1625

01:02:45,750 --> 01:02:44,950

the other planets would be really tough

1626

01:02:48,309 --> 01:02:45,760

but

1627

01:02:50,069 --> 01:02:48,319

if they transited then you could detect

1628

01:02:51,349 --> 01:02:50,079

them if you had technology similar to

1629

01:02:53,670 --> 01:02:51,359

ours

1630

01:02:58,630 --> 01:02:56,710

you'd have to be lucky again because

1631

01:03:00,710 --> 01:02:58,640

our solar system is not compact like

1632

01:03:02,950 --> 01:03:00,720

those others it's quite spread out

1633

01:03:04,470 --> 01:03:02,960

so if you have a planet very close to

1634

01:03:05,670 --> 01:03:04,480

its star you have a decent chance if it

1635

01:03:07,750 --> 01:03:05,680

has a random orientation you have a

1636

01:03:09,829 --> 01:03:07,760

decent chance that it'll be along your

1637

01:03:11,670 --> 01:03:09,839

line of sight but if it's very far away

1638

01:03:13,190 --> 01:03:11,680

there's many more possibilities for its

1639

01:03:15,270 --> 01:03:13,200

orientation and you have to be much

1640

01:03:17,430 --> 01:03:15,280

there's a much smaller probability if

1641

01:03:19,829 --> 01:03:17,440

things are random that you will get it

1642

01:03:21,510 --> 01:03:19,839

along your line of sight exactly so for

1643

01:03:24,390 --> 01:03:21,520

somebody to see

1644

01:03:25,990 --> 01:03:24,400

our jupiter from a nearby star is much

1645

01:03:27,190 --> 01:03:26,000

less likely than for us to see a hot

1646

01:03:28,789 --> 01:03:27,200

jupiter

1647

01:03:30,390 --> 01:03:28,799

so

1648

01:03:32,069 --> 01:03:30,400

there's only a small number of aliens

1649

01:03:38,390 --> 01:03:32,079

looking at our solar system and seeing

1650

01:03:43,910 --> 01:03:40,870

so um i think

1651

01:03:45,349 --> 01:03:43,920

that's all i have from social media so

1652

01:03:46,789 --> 01:03:45,359

but i'm i'm

1653

01:03:48,630 --> 01:03:46,799

still got energy and rearing to go so

1654

01:03:50,230 --> 01:03:48,640

i'm happy to take more questions

1655

01:03:51,430 --> 01:03:50,240

if people have them

1656

01:03:52,710 --> 01:03:51,440

so