

PUBLIC LECTURE SERIES

Dangerous Worlds

Featuring Guest Speaker :
Elizabeth Tasker

1
00:00:06,829 --> 00:00:04,100
and we have a really special talk for

2
00:00:09,230 --> 00:00:06,839
you tonight somebody who just popped up

3
00:00:18,980 --> 00:00:09,240
on my email saying oh I'd love to give a

4
00:00:24,620 --> 00:00:22,609
our website for more information if you

5
00:00:27,349 --> 00:00:24,630
go to your favorite browser and putting

6
00:00:30,200 --> 00:00:27,359
public talks Republican couple public

7
00:00:35,299 --> 00:00:30,210
lecture series you can't say speech you

8
00:00:37,250 --> 00:00:35,309
could say Space Telescope probably - all

9
00:00:40,850 --> 00:00:37,260
this with the list of the upcoming

10
00:00:43,910 --> 00:00:40,860
lectures the watch live online you can

11
00:00:50,240 --> 00:00:43,920
watch the past lectures all the way back

12
00:00:54,770 --> 00:00:50,250
to 2005 so that's 12 years of and you

13
00:00:56,479 --> 00:00:54,780

can also sign up for our email that one

14

00:01:03,740 --> 00:00:56,489

one or two emails a month is too much

15

00:01:08,030 --> 00:01:03,750

you can also unsubscribe - or if you are

16

00:01:11,000 --> 00:01:08,040

fashioned just make sure you get added

17

00:01:15,260 --> 00:01:11,010

to the list if you have comments or

18

00:01:18,649 --> 00:01:15,270

questions I'm sending to public STS yeah

19

00:01:20,030 --> 00:01:18,659

that edu it'll come into my mailbox and

20

00:01:23,380 --> 00:01:20,040

we'll make sure you get your question

21

00:01:26,210 --> 00:01:23,390

answered okay let's see social media

22

00:01:28,969 --> 00:01:26,220

Facebook Twitter YouTube Instagram

23

00:01:30,620 --> 00:01:28,979

there's a lot of those if you would like

24

00:01:33,080 --> 00:01:30,630

to follow Space Telescope we are

25

00:01:38,300 --> 00:01:33,090

available social media

26

00:01:40,390 --> 00:01:38,310

I myself have Twitter but I'm as I say

27

00:01:44,120 --> 00:01:40,400

every month I'm only so often on there

28

00:01:46,789 --> 00:01:44,130

lots of other things to do and I do

29

00:01:50,240 --> 00:01:46,799

sometimes a blog on Hubble site if you

30

00:01:53,270 --> 00:01:50,250

want to follow me unfortunately the

31

00:01:55,310 --> 00:01:53,280

weather is not permitting tonight -

32

00:01:58,090 --> 00:01:55,320

those of you who brought the umbrellas

33

00:02:00,920 --> 00:01:58,100

in no definitely not pretty and

34

00:02:03,740 --> 00:02:00,930

unfortunately the observatory is not

35

00:02:05,450 --> 00:02:03,750

permitting the observatory is closed for

36

00:02:07,880 --> 00:02:05,460

repairs until further notice they had

37

00:02:09,680 --> 00:02:07,890

some problems with their dome and they

38

00:02:12,050 --> 00:02:09,690

emailed me today that they don't know

39

00:02:13,530 --> 00:02:12,060

when they'll be able to reopen

40

00:02:15,990 --> 00:02:13,540

so you

41

00:02:18,229 --> 00:02:16,000

go to md dot space grant org you will

42

00:02:21,390 --> 00:02:18,239

find this webpage over here on the right

43

00:02:23,819 --> 00:02:21,400

and the observatory status will not say

44

00:02:27,360 --> 00:02:23,829

check back on Friday it will say that

45

00:02:29,220 --> 00:02:27,370

check back next month or in a few weeks

46

00:02:30,780 --> 00:02:29,230

and will be able to tell you when the

47

00:02:32,699 --> 00:02:30,790

repairs will be done ok

48

00:02:35,009 --> 00:02:32,709

so unfortunately for the next couple of

49

00:02:37,979 --> 00:02:35,019

months possibly we will not have the

50

00:02:41,190 --> 00:02:37,989

Maryland space grant observatory ok all

51
00:02:46,460 --> 00:02:41,200
right now our news from the universe for

52
00:02:51,300 --> 00:02:46,470
November 2017 the first story tonight a

53
00:02:53,520 --> 00:02:51,310
wrinkle in space-time as you know I like

54
00:02:55,399 --> 00:02:53,530
to make small puns here this is of

55
00:02:58,949 --> 00:02:55,409
course is playing off Madeleine L'Engle

56
00:03:02,670 --> 00:02:58,959
famous story a wrinkle in time and what

57
00:03:04,949 --> 00:03:02,680
I'm talking about of course is the LIGO

58
00:03:07,860 --> 00:03:04,959
project the laser interferometer

59
00:03:11,699 --> 00:03:07,870
gravitational-wave Observatory which I

60
00:03:13,520 --> 00:03:11,709
told you about early last year has these

61
00:03:17,069 --> 00:03:13,530
two detectors one in Hanford Washington

62
00:03:19,949 --> 00:03:17,079
one in Livingston Louisiana and you can

63
00:03:22,140 --> 00:03:19,959

see they are these big long arrays that

64

00:03:23,879 --> 00:03:22,150

they send laser beams down each one of

65

00:03:25,289 --> 00:03:23,889

them and they the Blazer beans bounce

66

00:03:28,439 --> 00:03:25,299

off a mirror and come back and they

67

00:03:31,589 --> 00:03:28,449

measure the distance very very very

68

00:03:35,189 --> 00:03:31,599

accurately so that when the distances

69

00:03:38,039 --> 00:03:35,199

change they could tell by an incredibly

70

00:03:42,500 --> 00:03:38,049

small amount and they did measure an

71

00:03:49,199 --> 00:03:42,510

incredibly small amount of change and

72

00:03:50,099 --> 00:03:49,209

see what was observation done I can't

73

00:03:51,689 --> 00:03:50,109

remember the exact date of this

74

00:03:54,839 --> 00:03:51,699

observation but this was the detection

75

00:03:56,759 --> 00:03:54,849

of a black hole black hole merger that

76

00:03:58,099 --> 00:03:56,769

was about 1.3 billion light years away

77

00:04:02,429 --> 00:03:58,109

the first detection of gravitational

78

00:04:04,890 --> 00:04:02,439

waves and it was seen here is the data

79

00:04:07,619 --> 00:04:04,900

versus the predicted for langston and

80

00:04:09,539 --> 00:04:07,629

same for Hanford in fact it was detected

81

00:04:11,520 --> 00:04:09,549

in both of them and with the proper time

82

00:04:13,710 --> 00:04:11,530

delay for the light them to travel

83

00:04:16,710 --> 00:04:13,720

between them first detection of

84

00:04:19,949 --> 00:04:16,720

gravitational waves and on October 3rd

85

00:04:23,159 --> 00:04:19,959

of this year it was awarded the 2017

86

00:04:24,659 --> 00:04:23,169

Nobel Prize in Physics to these three

87

00:04:26,870 --> 00:04:24,669

gentlemen of the LIGO Virgo

88

00:04:28,670 --> 00:04:26,880

collaboration for the decisive

89

00:04:30,910 --> 00:04:28,680

contributions to the LIGO detector and

90

00:04:33,710 --> 00:04:30,920

the observational gravitational waves

91

00:04:36,470 --> 00:04:33,720

now we all sort of knew this was going

92

00:04:38,300 --> 00:04:36,480

to come because I could detect

93

00:04:39,080 --> 00:04:38,310

gravitational waves for the very first

94

00:04:41,620 --> 00:04:39,090

time

95

00:04:43,820 --> 00:04:41,630

yeah that's worthy of a Nobel Prize I

96

00:04:47,990 --> 00:04:43,830

personally did not expect it to come so

97

00:04:49,400 --> 00:04:48,000

quickly all right but you know since the

98

00:04:50,990 --> 00:04:49,410

discovery of those first black hole

99

00:04:53,420 --> 00:04:51,000

mergers they've discovered three or four

100

00:04:56,590 --> 00:04:53,430

more black hole black hole mergers so

101
00:05:01,100 --> 00:04:56,600
they're getting more observations but

102
00:05:05,890 --> 00:05:01,110
last summer on August 17th they also saw

103
00:05:11,540 --> 00:05:05,900
a neutron star neutron star merger okay

104
00:05:15,020 --> 00:05:11,550
so black holes are even alright so

105
00:05:17,930 --> 00:05:15,030
neutron it's a star can end up in

106
00:05:20,360 --> 00:05:17,940
several different ways okay a medium

107
00:05:21,970 --> 00:05:20,370
mass star low mass star ends up is

108
00:05:25,880 --> 00:05:21,980
what's called a white dwarf and that's

109
00:05:29,060 --> 00:05:25,890
about the the the density of the the

110
00:05:30,080 --> 00:05:29,070
atop the at the atom okay and it's

111
00:05:32,000 --> 00:05:30,090
supported by electron degeneracy

112
00:05:34,850 --> 00:05:32,010
pressure yada yada yada but it's about

113
00:05:38,210 --> 00:05:34,860

the density of an atom about the size of

114

00:05:40,790 --> 00:05:38,220

Earth okay all right and then there is a

115

00:05:42,560 --> 00:05:40,800

if you are more massive you can collapse

116

00:05:44,840 --> 00:05:42,570

down to what we call a neutron star

117

00:05:47,810 --> 00:05:44,850

which is about the density of an atomic

118

00:05:50,330 --> 00:05:47,820

nucleus okay and that's about the mass

119

00:05:52,130 --> 00:05:50,340

of the Sun compacted to about ten

120

00:05:54,290 --> 00:05:52,140

kilometers across or about the size of

121

00:05:56,090 --> 00:05:54,300

the Baltimore Beltway okay so take all

122

00:05:58,310 --> 00:05:56,100

the Sun could pass to the Baltimore

123

00:06:00,740 --> 00:05:58,320

Beltway size a ten kilometer cross and

124

00:06:02,870 --> 00:06:00,750

that's you get a neutron star a black

125

00:06:04,820 --> 00:06:02,880

hole goes even further than that is even

126
00:06:09,020 --> 00:06:04,830
more massive even even higher density

127
00:06:10,940 --> 00:06:09,030
okay so these neutron stars when they

128
00:06:12,500 --> 00:06:10,950
collide they're incredibly dense when

129
00:06:15,020 --> 00:06:12,510
they merge together they will also

130
00:06:16,760 --> 00:06:15,030
produce gravitational waves but not

131
00:06:20,840 --> 00:06:16,770
really as strong as a black hole black

132
00:06:23,720 --> 00:06:20,850
hole but this neutron star collision was

133
00:06:26,720 --> 00:06:23,730
only 130 million light years away which

134
00:06:29,120 --> 00:06:26,730
I know sounds pretty far but compared to

135
00:06:30,890 --> 00:06:29,130
the 1.3 billion light-years away that

136
00:06:34,100 --> 00:06:30,900
black hole black hole merger was is

137
00:06:36,170 --> 00:06:34,110
actually only 10% of that distance so

138
00:06:39,140 --> 00:06:36,180

they're able to see this neutron star

139

00:06:40,170 --> 00:06:39,150

neutron star collision with LIGO and

140

00:06:43,800 --> 00:06:40,180

Virgo

141

00:06:46,770 --> 00:06:43,810

is the European version of Lego however

142

00:06:51,570 --> 00:06:46,780

what made it even more exciting is it

143

00:06:53,550 --> 00:06:51,580

also was observed in optical light using

144

00:06:55,980 --> 00:06:53,560

both the LIGO detectors here in the US

145

00:07:00,950 --> 00:06:55,990

and the Virgo detector in Italy they

146

00:07:03,420 --> 00:07:00,960

were able to relatively relatively

147

00:07:05,520 --> 00:07:03,430

accurately determine where it was on the

148

00:07:07,830 --> 00:07:05,530

sky and astronomers were able to search

149

00:07:10,830 --> 00:07:07,840

for that point on the sky and found that

150

00:07:15,360 --> 00:07:10,840

there was an excess of radiation coming

151
00:07:17,700 --> 00:07:15,370
from this dot within the galaxy NGC 4990

152
00:07:20,040 --> 00:07:17,710
3 so they actually are able to do

153
00:07:22,230 --> 00:07:20,050
follow-up observations and neutron star

154
00:07:24,180 --> 00:07:22,240
neutron star collisions will have a lot

155
00:07:26,490 --> 00:07:24,190
of material around them and it will

156
00:07:29,939 --> 00:07:26,500
generate a lot of optical light okay so

157
00:07:32,300 --> 00:07:29,949
this is Hubble's observation from August

158
00:07:35,370 --> 00:07:32,310
22nd through August 28th over six days

159
00:07:36,749 --> 00:07:35,380
watching did you try and start a neutron

160
00:07:40,529 --> 00:07:36,759
star clip the light from that collision

161
00:07:41,730 --> 00:07:40,539
fade away all right and it's not just

162
00:07:43,950 --> 00:07:41,740
that it was seen by Hubble

163
00:07:46,469 --> 00:07:43,960

matter-of-fact Hubble was not the first

164

00:07:51,180 --> 00:07:46,479

one to see it it was actually first seen

165

00:07:53,399 --> 00:07:51,190

by family in gamma rays so it was seen

166

00:07:55,710 --> 00:07:53,409

in gravitational ways by LIGO and Virgo

167

00:07:58,860 --> 00:07:55,720

it was seen in gamma rays by Fermi

168

00:08:01,620 --> 00:07:58,870

integral and Swift it was seen in x-rays

169

00:08:03,930 --> 00:08:01,630

by Chandra it was seen in visible light

170

00:08:06,060 --> 00:08:03,940

by Hubble it was seen in infrared light

171

00:08:08,219 --> 00:08:06,070

by spitzer and it was seen by visible

172

00:08:09,810 --> 00:08:08,229

and infrared light by things like

173

00:08:13,439 --> 00:08:09,820

pan-starrs and other ground-based

174

00:08:16,379 --> 00:08:13,449

observatories so this is when

175

00:08:18,839 --> 00:08:16,389

astronomers can really get to work when

176

00:08:20,820 --> 00:08:18,849

it can really characterize the event

177

00:08:23,129 --> 00:08:20,830

when we see it in this many different

178

00:08:25,260 --> 00:08:23,139

wavelengths we see what's happening at

179

00:08:28,140 --> 00:08:25,270

lots of different energies and we can

180

00:08:30,180 --> 00:08:28,150

understand the event a lot more the

181

00:08:31,680 --> 00:08:30,190

black hole black hole merger that was

182

00:08:34,019 --> 00:08:31,690

that you know that won the Nobel Prize

183

00:08:35,699 --> 00:08:34,029

there were no follow-up studies we

184

00:08:38,610 --> 00:08:35,709

didn't see it in any other wavelengths

185

00:08:40,170 --> 00:08:38,620

this neutron star neutron star merger we

186

00:08:41,370 --> 00:08:40,180

were able to see in other wavelengths

187

00:08:43,350 --> 00:08:41,380

were able to get different

188

00:08:45,180 --> 00:08:43,360

characteristics of it and we're able to

189

00:08:48,090 --> 00:08:45,190

understand the processes that are going

190

00:08:50,430 --> 00:08:48,100

on and the basic result so far has been

191

00:08:53,850 --> 00:08:50,440

that hey it sort of fits what we think

192

00:08:55,889 --> 00:08:53,860

happens which is actually kind of crazy

193

00:08:57,509 --> 00:08:55,899

ideas you know and we say all right well

194

00:08:59,940 --> 00:08:57,519

this is our predictions we usually

195

00:09:01,519 --> 00:08:59,950

expect to be surprised oh nature be

196

00:09:03,720 --> 00:09:01,529

slightly differently than we predicted

197

00:09:05,280 --> 00:09:03,730

most of the predictions seem to be

198

00:09:07,530 --> 00:09:05,290

working out pretty well for this

199

00:09:09,180 --> 00:09:07,540

although there was one thing in terms of

200

00:09:12,389 --> 00:09:09,190

seeing it in ultraviolet that they

201
00:09:16,500 --> 00:09:12,399
didn't expect and the fact that it was a

202
00:09:18,600 --> 00:09:16,510
relatively faint gamma ray okay it's a

203
00:09:19,560 --> 00:09:18,610
short duration but it's a faint

204
00:09:21,960 --> 00:09:19,570
gamma-ray burst

205
00:09:23,460 --> 00:09:21,970
okay the short duration bursts for

206
00:09:25,370 --> 00:09:23,470
something so close it actually have been

207
00:09:27,660 --> 00:09:25,380
larger and they're not quite sure why

208
00:09:29,490 --> 00:09:27,670
but these are all the questions that

209
00:09:32,910 --> 00:09:29,500
come up when you have this many

210
00:09:34,740 --> 00:09:32,920
different ways of looking at it and are

211
00:09:36,530 --> 00:09:34,750
able to study it in so many ways so this

212
00:09:39,840 --> 00:09:36,540
not only have we moved into

213
00:09:41,579 --> 00:09:39,850

gravitational wave astrophysics but

214

00:09:43,410 --> 00:09:41,589

we've got follow-ups to be able to

215

00:09:48,120 --> 00:09:43,420

correlate it which makes it so much more

216

00:09:52,290 --> 00:09:48,130

valuable our second story tonight on the

217

00:09:54,540 --> 00:09:52,300

trail of asteroids now Hubble had this

218

00:09:56,759 --> 00:09:54,550

amazing project called the frontier

219

00:10:01,410 --> 00:09:56,769

fields okay and the frontier fields

220

00:10:03,360 --> 00:10:01,420

looked at six really massive clusters to

221

00:10:05,880 --> 00:10:03,370

look for gravitational lensing so this

222

00:10:08,340 --> 00:10:05,890

is the mass of galaxy cluster Abell 370

223

00:10:11,009 --> 00:10:08,350

and all these streaky things in here are

224

00:10:13,439 --> 00:10:11,019

gravitationally lens arcs okay and we've

225

00:10:16,769 --> 00:10:13,449

talked about that a lot and at the same

226

00:10:18,300 --> 00:10:16,779

time while they were doing the well

227

00:10:20,130 --> 00:10:18,310

they're looking at the galaxy cluster

228

00:10:22,680 --> 00:10:20,140

they also looked at what they called

229

00:10:23,730 --> 00:10:22,690

parallel fields so one detector of

230

00:10:25,740 --> 00:10:23,740

Hubble was looking at the cluster

231

00:10:27,689 --> 00:10:25,750

another detector was looking at the

232

00:10:29,460 --> 00:10:27,699

parallel field and then actually they

233

00:10:30,630 --> 00:10:29,470

rotated and then that one detector

234

00:10:32,610 --> 00:10:30,640

looked the parallel field and the other

235

00:10:35,569 --> 00:10:32,620

detector look at the cluster okay and

236

00:10:38,130 --> 00:10:35,579

they spent about a hundred hours of

237

00:10:41,370 --> 00:10:38,140

observation time on each of these

238

00:10:43,259 --> 00:10:41,380

clusters well these are the cleaned-up

239

00:10:45,480 --> 00:10:43,269

images that you see okay and of course

240

00:10:47,280 --> 00:10:45,490

the real observations have lots of you

241

00:10:49,139 --> 00:10:47,290

know cosmic rays and other things that

242

00:10:51,920 --> 00:10:49,149

happen you know detector artifacts that

243

00:10:54,150 --> 00:10:51,930

have to be cleaned up but there's also

244

00:10:56,340 --> 00:10:54,160

another thing that they had to clean up

245

00:11:03,750 --> 00:10:56,350

out of this these images that is

246

00:11:05,400 --> 00:11:03,760

illustrated by this movie so as this

247

00:11:06,430 --> 00:11:05,410

movie plays you'll start to see these

248

00:11:09,220 --> 00:11:06,440

little streak

249

00:11:14,070 --> 00:11:09,230

here and there numbered one through

250

00:11:18,100 --> 00:11:14,080

seven because these are seven unique

251
00:11:20,620 --> 00:11:18,110
asteroids that passed through the field

252
00:11:23,050 --> 00:11:20,630
over the hundred hours that Hubble was

253
00:11:25,570 --> 00:11:23,060
observing now Hubble doesn't observe it

254
00:11:27,010 --> 00:11:25,580
continuously it does a bit of

255
00:11:28,300 --> 00:11:27,020
observation and then it'll go off and do

256
00:11:30,250 --> 00:11:28,310
something else and I'll come back to the

257
00:11:33,160 --> 00:11:30,260
field and do some more observation etc

258
00:11:36,010 --> 00:11:33,170
which is why number seven here you can

259
00:11:38,290 --> 00:11:36,020
see is split into four separate little

260
00:11:39,460 --> 00:11:38,300
loops alright and why are they streaks

261
00:11:42,370 --> 00:11:39,470
and curved loops

262
00:11:45,190 --> 00:11:42,380
well Hubble and Earth are moving

263
00:11:47,500 --> 00:11:45,200

relative to the asteroid while we're

264

00:11:49,180 --> 00:11:47,510

taking observations so the asteroid

265

00:11:50,860 --> 00:11:49,190

actually ends up streaking and the

266

00:11:55,360 --> 00:11:50,870

parallax motion produces that little

267

00:11:57,220 --> 00:11:55,370

curve on there alright so for a Bell 370

268

00:12:00,040 --> 00:11:57,230

and it's parallel field here are the

269

00:12:02,470 --> 00:12:00,050

cleaned-up images and there are the

270

00:12:04,540 --> 00:12:02,480

images with the asteroid streaks now

271

00:12:06,790 --> 00:12:04,550

you'll notice we use the movie on the

272

00:12:09,880 --> 00:12:06,800

parallel field simply because there are

273

00:12:13,120 --> 00:12:09,890

ready these streaks in the in the

274

00:12:14,560 --> 00:12:13,130

gravitational lens those are actually

275

00:12:16,990 --> 00:12:14,570

galaxies that are beyond the

276

00:12:19,840 --> 00:12:17,000

gravitational lens but if I blink back

277

00:12:23,050 --> 00:12:19,850

and forth you can see the asteroids and

278

00:12:25,270 --> 00:12:23,060

where they appear in the field and this

279

00:12:28,510 --> 00:12:25,280

is kind of cool because what you've got

280

00:12:31,000 --> 00:12:28,520

here in one image is you've got some

281

00:12:32,620 --> 00:12:31,010

things within the solar system as well

282

00:12:35,980 --> 00:12:32,630

as you've got things that are billions

283

00:12:37,450 --> 00:12:35,990

of light-years away and it reinforces

284

00:12:39,280 --> 00:12:37,460

one of the things that we have to deal

285

00:12:41,560 --> 00:12:39,290

with an astronomy when you look out into

286

00:12:43,270 --> 00:12:41,570

the universe it's the sum of everything

287

00:12:46,090 --> 00:12:43,280

that you're looking through the solar

288

00:12:47,740 --> 00:12:46,100

system to the galaxies to the distant

289

00:12:49,540 --> 00:12:47,750

galaxies all the way to the edge of the

290

00:12:52,660 --> 00:12:49,550

universe that when you take an image

291

00:12:54,550 --> 00:12:52,670

you're combining all of that into one of

292

00:12:56,650 --> 00:12:54,560

those and here you can see some of the

293

00:12:58,690 --> 00:12:56,660

nearest things and some of the father's

294

00:13:00,540 --> 00:12:58,700

things in the universe all combined

295

00:13:04,090 --> 00:13:00,550

together that's kind of cool

296

00:13:06,970 --> 00:13:04,100

all right so now we'll go to our

297

00:13:10,600 --> 00:13:06,980

featured speaker and our featured

298

00:13:12,940 --> 00:13:10,610

speaker tonight let's see if her laptop

299

00:13:17,440 --> 00:13:12,950

takes over yes it does

300

00:13:19,650 --> 00:13:17,450

his doctor Elizabeth Tasker and she is

301
00:13:22,110 --> 00:13:19,660
from the originally from the UK

302
00:13:24,720 --> 00:13:22,120
she did her undergraduate work at Durham

303
00:13:27,900 --> 00:13:24,730
University and then did her graduate

304
00:13:29,520 --> 00:13:27,910
work at University of Oxford then she

305
00:13:31,620 --> 00:13:29,530
came across to the United States and

306
00:13:35,420 --> 00:13:31,630
Canada and did some post doctoral work

307
00:13:38,130 --> 00:13:35,430
here before going even further from home

308
00:13:42,060 --> 00:13:38,140
where she is an associate professor at

309
00:13:44,310 --> 00:13:42,070
the Japan aerospace exploration agency

310
00:13:46,110 --> 00:13:44,320
and I love JAXA because that's a great

311
00:13:48,470 --> 00:13:46,120
acronym to say it's almost it's it's

312
00:13:51,180 --> 00:13:48,480
like NASA but it has sort of an

313
00:13:53,910 --> 00:13:51,190

intriguing sound Jack's I just you know

314

00:13:58,500 --> 00:13:53,920

sounds as good as NASA in terms of a

315

00:14:01,410 --> 00:13:58,510

Space Agency she does her research work

316

00:14:04,350 --> 00:14:01,420

on the formation of stars and planets by

317

00:14:07,380 --> 00:14:04,360

doing computer simulations and today is

318

00:14:09,360 --> 00:14:07,390

a very special day for her because she

319

00:14:11,520 --> 00:14:09,370

has a book that is being published today

320

00:14:13,500 --> 00:14:11,530

and I'm sure she'll mention that in her

321

00:14:21,050 --> 00:14:13,510

talk ladies and gentlemen dr. Elizabeth

322

00:14:30,930 --> 00:14:23,070

well thank you very much

323

00:14:33,060 --> 00:14:30,940

is this something good okay so today I'm

324

00:14:36,090 --> 00:14:33,070

going to be talking about planets

325

00:14:38,250 --> 00:14:36,100

especially those beyond our solar system

326

00:14:41,670 --> 00:14:38,260

but I'm going to start with what I hope

327

00:14:42,930 --> 00:14:41,680

is a vaguely familiar image in a minute

328

00:14:46,050 --> 00:14:42,940

so I'll be starting with what I hope is

329

00:14:48,300 --> 00:14:46,060

a vaguely familiar image there we go so

330

00:14:50,730 --> 00:14:48,310

I hope these guys look somewhat familiar

331

00:14:54,329 --> 00:14:50,740

to everyone and I say this is a Sun and

332

00:14:57,630 --> 00:14:54,339

then just past the Sun we have our four

333

00:15:00,870 --> 00:14:57,640

smallest planets Mercury Venus Earth and

334

00:15:03,630 --> 00:15:00,880

Mars and just past Mars we have this

335

00:15:06,570 --> 00:15:03,640

band of rubble rubble rocky leftovers

336

00:15:09,210 --> 00:15:06,580

from the planet formation process that

337

00:15:12,420 --> 00:15:09,220

we call the asteroid belts which also

338

00:15:14,850 --> 00:15:12,430

contains the dwarf planet Ceres and then

339

00:15:17,640 --> 00:15:14,860

beyond the asteroid belt we have the

340

00:15:21,180 --> 00:15:17,650

giants Jupiter Saturn Uranus and Neptune

341

00:15:23,640 --> 00:15:21,190

and then we have this another pile of

342

00:15:26,280 --> 00:15:23,650

rocky leftovers from planet formation

343

00:15:28,140 --> 00:15:26,290

which is the Kuiper belts and of course

344

00:15:30,240 --> 00:15:28,150

it's most famous member is the dwarf

345

00:15:35,520 --> 00:15:30,250

planet Pluto that we never really talk

346

00:15:41,100 --> 00:15:35,530

about that anymore and you are here all

347

00:15:43,020 --> 00:15:41,110

right so if you were to base all our

348

00:15:46,110 --> 00:15:43,030

understanding of planet formation on our

349

00:15:48,900 --> 00:15:46,120

solar system we would note that you have

350

00:15:51,060 --> 00:15:48,910

two types of planets you have rocky

351
00:15:54,230 --> 00:15:51,070
planets so these guys Mercury through to

352
00:15:57,540 --> 00:15:54,240
Mars and here you have a solid surface

353
00:16:00,329 --> 00:15:57,550
with a relatively thin atmosphere and

354
00:16:03,360 --> 00:16:00,339
then beyond the asteroid belt you have

355
00:16:05,610 --> 00:16:03,370
gas giant planets where most of their

356
00:16:09,449 --> 00:16:05,620
volume is taken up with their atmosphere

357
00:16:13,170 --> 00:16:09,459
around a much smaller dense central core

358
00:16:16,199 --> 00:16:13,180
and this colossal atmosphere results in

359
00:16:19,170 --> 00:16:16,209
absolutely crushing pressures near their

360
00:16:21,300 --> 00:16:19,180
core so much so than in fact our

361
00:16:23,640 --> 00:16:21,310
hydrogen on Jupiter by the time you

362
00:16:26,190 --> 00:16:23,650
approach Jupiter's core it becomes so

363
00:16:29,449 --> 00:16:26,200

dense that it starts behaving as this

364

00:16:33,519 --> 00:16:29,459

kind of metallic compound

365

00:16:36,489 --> 00:16:33,529

so until 1990s these were all the plan

366

00:16:38,350 --> 00:16:36,499

we knew and we didn't think that our

367

00:16:41,019 --> 00:16:38,360

solar system was the only one out there

368

00:16:43,600 --> 00:16:41,029

but we haven't actually seen any others

369

00:16:49,780 --> 00:16:43,610

so nothing was definite but then

370

00:16:51,850 --> 00:16:49,790

everything changed so our Sun is one of

371

00:16:54,249 --> 00:16:51,860

about a hundred billion stars in the

372

00:16:57,249 --> 00:16:54,259

Milky Way galaxy and when we talk about

373

00:17:01,509 --> 00:16:57,259

extrasolar planets we mean extra as in

374

00:17:04,059 --> 00:17:01,519

outside and a solar as in of the Sun so

375

00:17:06,579 --> 00:17:04,069

an extrasolar planet or exoplanets

376

00:17:10,270 --> 00:17:06,589

is any planet that is not in our solar

377

00:17:13,720 --> 00:17:10,280

system and the story of extrasolar

378

00:17:20,059 --> 00:17:13,730

planets begins in 1990 when the Arecibo

379

00:17:44,700 --> 00:17:37,160

[Music]

380

00:17:51,970 --> 00:17:49,690

structural cracks so around the same

381

00:17:54,100 --> 00:17:51,980

time a similar radio telescope in Green

382

00:17:55,900 --> 00:17:54,110

Bank in the u.s. also has structural

383

00:17:58,390 --> 00:17:55,910

cracks which were ignored and the whole

384

00:17:59,860 --> 00:17:58,400

thing collapsed so in a fit of panic a

385

00:18:01,800 --> 00:17:59,870

receiver was like okay we've got the

386

00:18:05,290 --> 00:18:01,810

message we're gonna fix this

387

00:18:08,260 --> 00:18:05,300

but during repairs the telescope was not

388

00:18:11,320 --> 00:18:08,270

taken completely offline but it couldn't

389

00:18:13,120 --> 00:18:11,330

be moved so typically during a night to

390

00:18:16,360 --> 00:18:13,130

the telescope will move very slightly

391

00:18:18,250 --> 00:18:16,370

across the sky as it tracks objects but

392

00:18:20,350 --> 00:18:18,260

during these repairs nothing could be

393

00:18:23,620 --> 00:18:20,360

done it had to be absolutely stationary

394

00:18:26,650 --> 00:18:23,630

and this made it unfit for almost all

395

00:18:28,600 --> 00:18:26,660

projects however at the time was a

396

00:18:32,410 --> 00:18:28,610

postdoctoral researcher called Alex bull

397

00:18:34,990 --> 00:18:32,420

Shen and he asked to use a telescope for

398

00:18:37,090 --> 00:18:35,000

a month-long survey because this survey

399

00:18:40,000 --> 00:18:37,100

could be done while the telescope wasn't

400

00:18:42,400 --> 00:18:40,010

moving and normally such a proposal

401
00:18:42,970 --> 00:18:42,410
would never have gone through because he

402
00:18:45,100 --> 00:18:42,980
required

403
00:18:47,020 --> 00:18:45,110
half the telescope's time and this was

404
00:18:49,710 --> 00:18:47,030
the biggest telescope in the world for

405
00:18:52,090 --> 00:18:49,720
radio so people would be like you know

406
00:18:54,040 --> 00:18:52,100
but as it happened no one else could

407
00:18:57,700 --> 00:18:54,050
really use it he was based the telescope

408
00:19:00,750 --> 00:18:57,710
and they said fine and what Alex wanted

409
00:19:03,220 --> 00:19:00,760
to find were dead stars called pulsars

410
00:19:06,580 --> 00:19:03,230
so actually we've just had a very nice

411
00:19:09,220 --> 00:19:06,590
summary of these because a pulsar is

412
00:19:11,070 --> 00:19:09,230
what forms when a star that is much

413
00:19:13,840 --> 00:19:11,080

larger than our Sun more than 8 times

414

00:19:17,380 --> 00:19:13,850

eventually reaches the end of its life

415

00:19:19,720 --> 00:19:17,390

and it runs out of fuel to burn and when

416

00:19:22,660 --> 00:19:19,730

that happens the star dies in a

417

00:19:25,420 --> 00:19:22,670

supernova explosion and the bit that's

418

00:19:28,540 --> 00:19:25,430

left behind collapses to incredible

419

00:19:31,240 --> 00:19:28,550

densities so dense that its atoms

420

00:19:33,220 --> 00:19:31,250

actually starts to disintegrate and the

421

00:19:37,780 --> 00:19:33,230

protons and the electrons inside the

422

00:19:40,600 --> 00:19:37,790

atoms and so we therefore call these

423

00:19:41,920 --> 00:19:40,610

neutron stars which is exactly the same

424

00:19:45,580 --> 00:19:41,930

source of the gravitational waves

425

00:19:47,950 --> 00:19:45,590

mentioned earlier however as yeah and as

426

00:19:49,930 --> 00:19:47,960

mentioned these are tiny so only

427

00:19:53,440 --> 00:19:49,940

city-sized or indeed the

428

00:19:55,900 --> 00:19:53,450

the Baltimore Belt and yet they weigh

429

00:19:58,120 --> 00:19:55,910

between 1.4 and twice this master's son

430

00:19:59,980 --> 00:19:58,130

so they're incredibly dense objects and

431

00:20:03,160 --> 00:19:59,990

as they collapse their magnetic field

432

00:20:06,700 --> 00:20:03,170

also strengthens a lot and this magnetic

433

00:20:08,920 --> 00:20:06,710

field causes any remaining charges left

434

00:20:13,860 --> 00:20:08,930

on the neutron star to be ripped off and

435

00:20:18,160 --> 00:20:13,870

fired into the cosmos as powerful Jets

436

00:20:22,510 --> 00:20:18,170

now if these Jets happen to swing by the

437

00:20:26,020 --> 00:20:22,520

earth as the star rotates then we see a

438

00:20:29,950 --> 00:20:26,030

periodic light pulse and therefore we

439

00:20:33,700 --> 00:20:29,960

call these April's are now the accuracy

440

00:20:35,350 --> 00:20:33,710

for these pulses is incredibly high it's

441

00:20:37,240 --> 00:20:35,360

so high that when they were first

442

00:20:39,810 --> 00:20:37,250

discovered they were thought that they

443

00:20:42,250 --> 00:20:39,820

might even be extraterrestrial sources

444

00:20:43,900 --> 00:20:42,260

but in fact when more sources were

445

00:20:45,790 --> 00:20:43,910

discovered across the sky it was

446

00:20:48,700 --> 00:20:45,800

realized that actually a natural process

447

00:20:51,070 --> 00:20:48,710

must be causing these but their accuracy

448

00:20:56,200 --> 00:20:51,080

is such that it rivals that of atomic

449

00:21:00,280 --> 00:20:56,210

clocks except for this one pulsar that

450

00:21:04,000 --> 00:21:00,290

Alex Vause Shem saw so this pulsar was

451
00:21:07,300 --> 00:21:04,010
called PSR b12 57 plus 12 that very

452
00:21:10,390 --> 00:21:07,310
catchy name and for this particular

453
00:21:12,430 --> 00:21:10,400
pulsar so PSR is pulsating source of

454
00:21:14,670 --> 00:21:12,440
radio and then that's completely our

455
00:21:17,410 --> 00:21:14,680
memorable letters and numbers is the

456
00:21:20,110 --> 00:21:17,420
position in the sky but for this

457
00:21:23,830 --> 00:21:20,120
particular pulsar the time between the

458
00:21:26,080 --> 00:21:23,840
flashes changed very slightly and it was

459
00:21:28,990 --> 00:21:26,090
ultimately concluded that this was due

460
00:21:32,230 --> 00:21:29,000
to two planets orbiting the Pulsar and

461
00:21:34,840 --> 00:21:32,240
as the planets orbited the Pulsar the

462
00:21:37,420 --> 00:21:34,850
Pulsar wobbled very slightly due to the

463
00:21:39,850 --> 00:21:37,430

planet's gravity and as it wobbled his

464

00:21:42,610 --> 00:21:39,860

distance from the earth was changing a

465

00:21:44,290 --> 00:21:42,620

tiny amount and this was causing the

466

00:21:45,820 --> 00:21:44,300

flashes to have to travel slightly

467

00:21:48,310 --> 00:21:45,830

further and slightly less far and

468

00:21:53,350 --> 00:21:48,320

therefore their timing started to become

469

00:21:55,390 --> 00:21:53,360

off so the discovery was two planets

470

00:21:59,860 --> 00:21:55,400

which were again very imaginative named

471

00:22:01,430 --> 00:21:59,870

PSR b12 57 plus 12 B and C and they were

472

00:22:04,039 --> 00:22:01,440

roughly four

473

00:22:06,409 --> 00:22:04,049

times the mass of the earth and their

474

00:22:10,249 --> 00:22:06,419

years they're all bits around the Pulsar

475

00:22:13,009 --> 00:22:10,259

were 65 and 98 days so for comparison

476

00:22:15,830 --> 00:22:13,019

but Korea our innermost planet has an

477

00:22:17,749 --> 00:22:15,840

orbit of 88 days so if these two were

478

00:22:20,869 --> 00:22:17,759

around our own Sun they were sick either

479

00:22:23,149 --> 00:22:20,879

side of mercury and they are a rather

480

00:22:25,759 --> 00:22:23,159

staggering two thousand light years away

481

00:22:28,879 --> 00:22:25,769

which tells you exactly how sensitive

482

00:22:31,610 --> 00:22:28,889

this technique was now these were the

483

00:22:34,580 --> 00:22:31,620

first planets ever to be found outside

484

00:22:36,379 --> 00:22:34,590

our solar system and the discovery was a

485

00:22:38,600 --> 00:22:36,389

pretty enough published in the

486

00:22:42,919 --> 00:22:38,610

international journal Nature on the 9th

487

00:22:45,649 --> 00:22:42,929

of January in 1992 however he actually

488

00:22:48,350 --> 00:22:45,659

was linked earlier than that by the

489

00:22:51,669 --> 00:22:48,360

British British broadsheet newspaper the

490

00:22:54,980 --> 00:22:51,679

independence on the 29th of October 1991

491

00:22:58,039 --> 00:22:54,990

with the headline radio astronomer finds

492

00:22:59,269 --> 00:22:58,049

two planets in distant space now Alex

493

00:23:01,820 --> 00:22:59,279

Borstein was approached by the

494

00:23:03,710 --> 00:23:01,830

independent and asked by for a quote and

495

00:23:05,539 --> 00:23:03,720

this must have been fairly nerve-racking

496

00:23:07,129 --> 00:23:05,549

because obviously he wanted this

497

00:23:12,139 --> 00:23:07,139

discovery to be published in a journal

498

00:23:14,539 --> 00:23:12,149

such as nature but if news gets out

499

00:23:15,950 --> 00:23:14,549

early sometimes nature might be like

500

00:23:18,499 --> 00:23:15,960

well it's no longer news so we don't

501
00:23:20,659 --> 00:23:18,509
want it so as a result there's a very

502
00:23:22,789 --> 00:23:20,669
guarded comment by Alex Vause shown here

503
00:23:24,110 --> 00:23:22,799
saying professor volscian was not

504
00:23:26,149 --> 00:23:24,120
prepared to talk about his research

505
00:23:27,919 --> 00:23:26,159
because he feared it might prejudice the

506
00:23:32,269 --> 00:23:27,929
chances of being published in a

507
00:23:34,759 --> 00:23:32,279
scientific journal however despite this

508
00:23:37,730 --> 00:23:34,769
even after the nature publication there

509
00:23:39,019 --> 00:23:37,740
was very little public notice which when

510
00:23:41,149 --> 00:23:39,029
you think of the fuss that new

511
00:23:43,100 --> 00:23:41,159
discoveries have nowadays where you have

512
00:23:46,009 --> 00:23:43,110
multiple reports against the whole world

513
00:23:48,529 --> 00:23:46,019

media is very surprising that the first

514

00:23:50,840 --> 00:23:48,539

planets we ever found no one really

515

00:23:52,759 --> 00:23:50,850

talked about indeed at the time when my

516

00:23:54,259 --> 00:23:52,769

parents were taking the independent and

517

00:23:55,850 --> 00:23:54,269

this newspaper must have sat on our

518

00:23:59,690 --> 00:23:55,860

kitchen table and I don't remember it at

519

00:24:02,330 --> 00:23:59,700

all so what was the problem was it that

520

00:24:05,180 --> 00:24:02,340

just pulsar planets were just a bit too

521

00:24:07,070 --> 00:24:05,190

weird I mean you know pulsars dead stars

522

00:24:09,129 --> 00:24:07,080

can't really relate to those hopefully

523

00:24:11,389 --> 00:24:09,139

never will be able to relate to those

524

00:24:14,460 --> 00:24:11,399

maybe people just didn't really feel a

525

00:24:17,140 --> 00:24:14,470

connection connection

526

00:24:20,970 --> 00:24:17,150

so as a result these are sort of

527

00:24:23,350 --> 00:24:20,980

overlooked but pulsar timings

528

00:24:27,070 --> 00:24:23,360

unsurprisingly it can only be used to

529

00:24:29,350 --> 00:24:27,080

find planets around pulsars so what

530

00:24:32,200 --> 00:24:29,360

about finding planets around regular

531

00:24:34,690 --> 00:24:32,210

stars so we found the Pulsar planets

532

00:24:37,690 --> 00:24:34,700

because there is this slight change in

533

00:24:39,430 --> 00:24:37,700

the timing of the Pulsar flash due to

534

00:24:42,490 --> 00:24:39,440

this wobble in the Stars position

535

00:24:44,920 --> 00:24:42,500

because of the planets orbit so could we

536

00:24:47,470 --> 00:24:44,930

do this with normal star light as well

537

00:24:48,520 --> 00:24:47,480

and obviously the answer is yes or I

538

00:24:52,930 --> 00:24:48,530

would not have taken us in this

539

00:24:54,700 --> 00:24:52,940

direction so when you have a more

540

00:24:57,130 --> 00:24:54,710

regular star you have a system like this

541

00:24:59,470 --> 00:24:57,140

so here are we on the earth there's our

542

00:25:01,300 --> 00:24:59,480

star here and here is our planet and due

543

00:25:04,420 --> 00:25:01,310

to the planets orbit the star is going

544

00:25:07,000 --> 00:25:04,430

to make a small wobble now as the star

545

00:25:08,470 --> 00:25:07,010

moves away from the earth its light

546

00:25:11,200 --> 00:25:08,480

that's reaching us is going to get

547

00:25:14,110 --> 00:25:11,210

stretched out and this is going to cause

548

00:25:15,820 --> 00:25:14,120

it to become redder now as it swings

549

00:25:17,950 --> 00:25:15,830

around the other side of it's wobbling

550

00:25:20,260 --> 00:25:17,960

position the light waves are going to

551
00:25:22,660 --> 00:25:20,270
become compressed as the star starts

552
00:25:23,500 --> 00:25:22,670
approaching the earth and when they get

553
00:25:26,830 --> 00:25:23,510
compressed

554
00:25:29,230 --> 00:25:26,840
they liked gets bluer so what you see is

555
00:25:32,170 --> 00:25:29,240
this tiny shift from red to blue to red

556
00:25:34,780 --> 00:25:32,180
to blue as the star wobbles due to its

557
00:25:37,210 --> 00:25:34,790
orbit from the planet and we call this

558
00:25:40,140 --> 00:25:37,220
the radial velocity technique or

559
00:25:44,830 --> 00:25:40,150
sometimes a Doppler wobble technique

560
00:25:47,020 --> 00:25:44,840
however this is not a big shift the tiny

561
00:25:48,450 --> 00:25:47,030
tiny shift in light and it's incredibly

562
00:25:53,530 --> 00:25:48,460
hard to measure

563
00:25:56,410 --> 00:25:53,540

however in 1988 a new technique was

564

00:25:58,180 --> 00:25:56,420

established so in this technique you

565

00:26:00,400 --> 00:25:58,190

have your star emitting lights and

566

00:26:02,620 --> 00:26:00,410

you've got your telescope and in front

567

00:26:06,520 --> 00:26:02,630

of the telescope we're going to put a

568

00:26:08,500 --> 00:26:06,530

jar of gas and the point is here that

569

00:26:10,300 --> 00:26:08,510

here is your star and it's light is

570

00:26:14,590 --> 00:26:10,310

going to be slowly shifting from red to

571

00:26:16,930 --> 00:26:14,600

blue tiny tiny tiny shift but our jar of

572

00:26:18,970 --> 00:26:16,940

gas is also going to be a missing light

573

00:26:20,920 --> 00:26:18,980

that is not shifting because it's

574

00:26:23,650 --> 00:26:20,930

completely stationary in front of our

575

00:26:26,140 --> 00:26:23,660

telescope so what it is is it's a bit

576
00:26:27,970 --> 00:26:26,150
like slamming down a ruler and because

577
00:26:30,250 --> 00:26:27,980
you have a stationary point

578
00:26:32,470 --> 00:26:30,260
with which to compare that starlight it

579
00:26:35,980 --> 00:26:32,480
becomes much easier to measure tiny

580
00:26:37,990 --> 00:26:35,990
shifts so this allowed us to have much

581
00:26:42,370 --> 00:26:38,000
higher accuracy when trying to measure

582
00:26:45,880 --> 00:26:42,380
this radial velocity change and using

583
00:26:48,990 --> 00:26:45,890
this technique as early as 1988 a wobble

584
00:26:54,640 --> 00:26:49,000
was seen around a star called gammas Fe

585
00:26:55,830 --> 00:26:54,650
could this be from an exoplanet so there

586
00:26:58,930 --> 00:26:55,840
were some problems

587
00:27:01,630 --> 00:26:58,940
gammas Fe is part of a binary star

588
00:27:05,110 --> 00:27:01,640

system meaning it has a companion star

589

00:27:07,270 --> 00:27:05,120

and the two stars orbit one another so

590

00:27:09,460 --> 00:27:07,280

this was the first question mark would

591

00:27:12,430 --> 00:27:09,470

we even expect planets around a binary

592

00:27:13,690 --> 00:27:12,440

system if you had a sister star would

593

00:27:18,310 --> 00:27:13,700

that disrupt the planet formation

594

00:27:21,070 --> 00:27:18,320

process secondly the star that was

595

00:27:23,470 --> 00:27:21,080

wobbling was thought to be a giant star

596

00:27:26,380 --> 00:27:23,480

now this is the phase that stars reach

597

00:27:28,150 --> 00:27:26,390

near the end of their life and as they

598

00:27:31,180 --> 00:27:28,160

approach the end of their life they get

599

00:27:33,520 --> 00:27:31,190

quite crotchety so what you find is the

600

00:27:36,520 --> 00:27:33,530

outer layers of the star start to have a

601
00:27:39,039 --> 00:27:36,530
lot of vibrations and pulsations that

602
00:27:43,240 --> 00:27:39,049
look just like a small bubble from a

603
00:27:45,880 --> 00:27:43,250
planet so the astronomers were a bit

604
00:27:48,460 --> 00:27:45,890
suspicious and in the end they concluded

605
00:27:50,560 --> 00:27:48,470
oh it's a giant star it's a binary we

606
00:27:52,570 --> 00:27:50,570
don't really expect to see a planet here

607
00:27:55,240 --> 00:27:52,580
there are lots of other reasons for this

608
00:27:57,400 --> 00:27:55,250
possible wobble now we see a wobble but

609
00:27:59,620 --> 00:27:57,410
it's not a planet and when they

610
00:28:02,440 --> 00:27:59,630
announced that they missed discovering

611
00:28:04,780 --> 00:28:02,450
the first exoplanets because this wobble

612
00:28:06,850 --> 00:28:04,790
was due to a planet but its discovery

613
00:28:09,270 --> 00:28:06,860

was not finally announced I think until

614

00:28:12,850 --> 00:28:09,280

2013

615

00:28:15,730 --> 00:28:12,860

so the first discovery that actually

616

00:28:19,240 --> 00:28:15,740

everyone remembers is a planet called a

617

00:28:21,730 --> 00:28:19,250

51 pegasi B that was found in 1995 with

618

00:28:24,850 --> 00:28:21,740

this same radial velocity technique with

619

00:28:26,650 --> 00:28:24,860

a light shifting from red to blue and it

620

00:28:29,590 --> 00:28:26,660

was the first planet that was found

621

00:28:31,930 --> 00:28:29,600

around a star like our Sun rather than a

622

00:28:35,799 --> 00:28:31,940

giant star or a long-dead star like a

623

00:28:38,200 --> 00:28:35,809

pulsar and it opened the floodgates to

624

00:28:40,620 --> 00:28:38,210

finding thousands more because it proved

625

00:28:43,500 --> 00:28:40,630

this radial velocity wobble

626
00:28:45,660 --> 00:28:43,510
was detectable we could see it and from

627
00:28:46,730 --> 00:28:45,670
there we started discovering planets in

628
00:28:50,490 --> 00:28:46,740
droves

629
00:28:55,920 --> 00:28:50,500
however this planet was also rather

630
00:28:58,440 --> 00:28:55,930
strange so back to our own solar system

631
00:29:00,840 --> 00:28:58,450
and one thing that we note is there are

632
00:29:03,750 --> 00:29:00,850
giant planets these huge gaseous ones

633
00:29:06,270 --> 00:29:03,760
sit a long way from the Sun we have the

634
00:29:09,810 --> 00:29:06,280
rocky ones close and we have the gaseous

635
00:29:13,080 --> 00:29:09,820
ones further away but this planet 51

636
00:29:16,890 --> 00:29:13,090
Pegasus B was a gas giant on the orbit

637
00:29:21,210 --> 00:29:16,900
of just four days so if remember mercury

638
00:29:25,230 --> 00:29:21,220

is 88 days that puts 51 Pegasus B really

639

00:29:28,230 --> 00:29:25,240

really close to its star so how do you

640

00:29:30,150 --> 00:29:28,240

form a planet there well let's just take

641

00:29:34,050 --> 00:29:30,160

a step back and ask why this is at all

642

00:29:36,930 --> 00:29:34,060

surprising so young stars are surrounded

643

00:29:39,750 --> 00:29:36,940

by disks of gas and dust known as

644

00:29:42,210 --> 00:29:39,760

protoplanetary discs now this image here

645

00:29:46,460 --> 00:29:42,220

is an artist's impression however this

646

00:29:48,690 --> 00:29:46,470

one is not this is a genuine image of a

647

00:29:54,210 --> 00:29:48,700

protoplanetary disc around a young star

648

00:29:56,430 --> 00:29:54,220

taken with Alma and in this disk of dust

649

00:29:59,970 --> 00:29:56,440

and gas dust starts off at micrometer

650

00:30:02,580 --> 00:29:59,980

sizes and it starts to collide and slick

651
00:30:05,940 --> 00:30:02,590
so we go from a chromatid to millimeter

652
00:30:07,290 --> 00:30:05,950
to centimeter up to meet her sizes and

653
00:30:10,320 --> 00:30:07,300
now we're starting to look a bit like

654
00:30:13,170 --> 00:30:10,330
the asteroids and eventually gravity

655
00:30:16,290 --> 00:30:13,180
finally gets seriously interested and it

656
00:30:18,570 --> 00:30:16,300
squishes our newly formed planet into a

657
00:30:21,270 --> 00:30:18,580
ball and we start to say yes okay I

658
00:30:24,240 --> 00:30:21,280
notice that's a planet now there is one

659
00:30:28,110 --> 00:30:24,250
subtlety to this process I'm sure will

660
00:30:31,860 --> 00:30:28,120
astound everyone if you are forming near

661
00:30:33,450 --> 00:30:31,870
the new star you're hot on the other

662
00:30:37,560 --> 00:30:33,460
hand if you're forming a long way away

663
00:30:40,290 --> 00:30:37,570

you're cold and this has one important

664

00:30:42,990 --> 00:30:40,300

effect there comes a point as you step

665

00:30:45,660 --> 00:30:43,000

away from the star that ice starts to

666

00:30:48,240 --> 00:30:45,670

form and we call this point the ice line

667

00:30:50,340 --> 00:30:48,250

the snow line or the frost line if you

668

00:30:53,220 --> 00:30:50,350

are inside the ice line and closer to

669

00:30:54,330 --> 00:30:53,230

the star water is a vapor on the other

670

00:30:58,169 --> 00:30:54,340

hand if you are the others

671

00:31:00,750 --> 00:30:58,179

side of it then it is a solid and that

672

00:31:03,269 --> 00:31:00,760

means you get a huge boost in

673

00:31:05,669 --> 00:31:03,279

planet-forming material the other side

674

00:31:07,470 --> 00:31:05,679

of the ice line because here you've got

675

00:31:09,600 --> 00:31:07,480

your silicates like what the earth is

676

00:31:11,909 --> 00:31:09,610

mainly formed off but out here you've

677

00:31:14,820 --> 00:31:11,919

got the silicates but also a huge a

678

00:31:16,560 --> 00:31:14,830

number of ices so you get a big step in

679

00:31:20,970 --> 00:31:16,570

density it's like being given a whole

680

00:31:23,310 --> 00:31:20,980

new letter set so as a result we expect

681

00:31:25,649 --> 00:31:23,320

small planets to form here where we have

682

00:31:27,960 --> 00:31:25,659

less building material and giant planets

683

00:31:30,510 --> 00:31:27,970

to form here where we have a lot more

684

00:31:32,610 --> 00:31:30,520

and this should be the same around every

685

00:31:34,409 --> 00:31:32,620

star because the only assumption I put

686

00:31:36,120 --> 00:31:34,419

in here is then you're hot if you're

687

00:31:40,590 --> 00:31:36,130

close to the star which you think would

688

00:31:42,810 --> 00:31:40,600

be universally true so how do we get a

689

00:31:45,029 --> 00:31:42,820

planet here there should be barely any

690

00:31:47,070 --> 00:31:45,039

building material there and yet 51

691

00:31:51,450 --> 00:31:47,080

pegasi B was roughly the same size as

692

00:31:54,120 --> 00:31:51,460

Jupiter so this is what we think happens

693

00:31:55,740 --> 00:31:54,130

as the planet grows it eventually

694

00:31:57,810 --> 00:31:55,750

reaches the size of Mars

695

00:32:01,049 --> 00:31:57,820

now Mars is not a big planet it is

696

00:32:03,029 --> 00:32:01,059

roughly a tenth of the mass of Earth but

697

00:32:05,220 --> 00:32:03,039

however at that point the planets

698

00:32:07,740 --> 00:32:05,230

gravity gets strong enough that it

699

00:32:09,930 --> 00:32:07,750

starts to pull on the surrounding gas

700

00:32:13,320 --> 00:32:09,940

and dust that still circle the young

701

00:32:16,230 --> 00:32:13,330

star and this gas and dust pulls back

702

00:32:19,590 --> 00:32:16,240

and the result is like being on a

703

00:32:21,090 --> 00:32:19,600

running track so here you are and you're

704

00:32:24,529 --> 00:32:21,100

going to be running this circular race

705

00:32:27,899 --> 00:32:24,539

with two buddies a buddy and a detective

706

00:32:30,419 --> 00:32:27,909

and a little later on oh no I'm sorry

707

00:32:31,980 --> 00:32:30,429

yes there's been a terrible addition

708

00:32:35,310 --> 00:32:31,990

where for some reason you've been tied

709

00:32:37,889 --> 00:32:35,320

to your friends with a piece of loop but

710

00:32:39,930 --> 00:32:37,899

a little later on war here now your

711

00:32:41,340 --> 00:32:39,940

bunny friend was on the inside running

712

00:32:43,440 --> 00:32:41,350

track and as I'm sure everyone remembers

713

00:32:46,139 --> 00:32:43,450

from school PE lessons that gives you a

714

00:32:47,909 --> 00:32:46,149

very unfair advantage so they're on a

715

00:32:50,399 --> 00:32:47,919

much shorter running track and he's

716

00:32:52,260 --> 00:32:50,409

pulled ahead of you on the other hand

717

00:32:54,570 --> 00:32:52,270

your detective friend or was on the

718

00:32:56,820 --> 00:32:54,580

outside running track and had further to

719

00:32:59,130 --> 00:32:56,830

go and therefore she is a little bit

720

00:33:01,200 --> 00:32:59,140

further behind but you're still tied

721

00:33:03,419 --> 00:33:01,210

together with this rope so you start to

722

00:33:05,190 --> 00:33:03,429

feel a force with the bunny pulling you

723

00:33:07,830 --> 00:33:05,200

forward and a detective pulling you back

724

00:33:10,320 --> 00:33:07,840

and the same thing happened

725

00:33:12,840 --> 00:33:10,330

due to gravity with our new planet in

726

00:33:15,299 --> 00:33:12,850

our disk where the gas closer to the

727

00:33:16,860 --> 00:33:15,309

star is pulling ahead and dragging on

728

00:33:19,529 --> 00:33:16,870

that planet to move it forward

729

00:33:21,630 --> 00:33:19,539

whereas the gas further out is pulling

730

00:33:25,890 --> 00:33:21,640

back and trying to slow that planet down

731

00:33:29,039 --> 00:33:25,900

and as a result you end up in this tug

732

00:33:33,750 --> 00:33:29,049

of war and the net result is usually

733

00:33:36,870 --> 00:33:33,760

that the planet feels a push inwards so

734

00:33:39,570 --> 00:33:36,880

what this means is oh yes and we call

735

00:33:42,210 --> 00:33:39,580

this migration so what this means is

736

00:33:43,889 --> 00:33:42,220

your planet can start far out it can

737

00:33:46,110 --> 00:33:43,899

form where there's lots of ice there's

738

00:33:49,289 --> 00:33:46,120

lots of building material and it can get

739

00:33:52,680 --> 00:33:49,299

big and jupiter-sized but it can then

740

00:33:54,990 --> 00:33:52,690

migrated inwards due to this pull from

741

00:33:57,779 --> 00:33:55,000

the gas disc and when the gas disc is

742

00:34:00,720 --> 00:33:57,789

finally evaporated by the star you end

743

00:34:03,810 --> 00:34:00,730

up with a large planet close to the star

744

00:34:07,560 --> 00:34:03,820

and we call these hot Jupiters because

745

00:34:11,220 --> 00:34:07,570

they're Jupiter size and hot so this

746

00:34:13,109 --> 00:34:11,230

explained 51 Pegasus B but what about

747

00:34:16,800 --> 00:34:13,119

the Pulsar planets what could explain

748

00:34:19,020 --> 00:34:16,810

them and were they even surprising well

749

00:34:21,419 --> 00:34:19,030

the problem with pulsar planets is as

750

00:34:25,409 --> 00:34:21,429

they briefly mentioned pulsars a start

751
00:34:27,899 --> 00:34:25,419
with an explosion a supernova so when

752
00:34:30,810 --> 00:34:27,909
they explode if they still have planets

753
00:34:34,139 --> 00:34:30,820
orbiting them too awful things can

754
00:34:37,020 --> 00:34:34,149
happen to those planets the first is one

755
00:34:39,329 --> 00:34:37,030
could be vaporized the second is the

756
00:34:42,270 --> 00:34:39,339
shockwave from that explosion can kick

757
00:34:44,609 --> 00:34:42,280
the planet out of the solar system so

758
00:34:47,040 --> 00:34:44,619
generally speaking we do not expect

759
00:34:50,430 --> 00:34:47,050
these planets to be able to survive this

760
00:34:52,680 --> 00:34:50,440
supernova explosion so how on earth do

761
00:34:56,700 --> 00:34:52,690
you end up with a pulsar orbited by

762
00:34:59,220 --> 00:34:56,710
planets well evidence to what might have

763
00:35:01,589 --> 00:34:59,230

happened was discovered in 2012 when a

764

00:35:05,579 --> 00:35:01,599

tiny star was found that seemed to be

765

00:35:08,849 --> 00:35:05,589

flashing red and then blue and it turned

766

00:35:10,829 --> 00:35:08,859

out to be orbiting a pulsar every and 93

767

00:35:13,480 --> 00:35:10,839

minutes which is actually the average

768

00:35:16,510 --> 00:35:13,490

commute time in the UK

769

00:35:19,000 --> 00:35:16,520

but as this planet orbited the Pulsar

770

00:35:22,420 --> 00:35:19,010

you actually started to see different

771

00:35:24,550 --> 00:35:22,430

sides of it so if the Pulsar is here and

772

00:35:26,800 --> 00:35:24,560

you are the earth first of all you're

773

00:35:29,140 --> 00:35:26,810

seeing the front side and the front side

774

00:35:32,740 --> 00:35:29,150

was being hit by the pulsars Jets and

775

00:35:35,470 --> 00:35:32,750

becoming very hot however as the star

776
00:35:39,070 --> 00:35:35,480
orbited you started to see the backside

777
00:35:41,200 --> 00:35:39,080
and this was much colder so what you

778
00:35:42,880 --> 00:35:41,210
were seeing was intermittently the hot

779
00:35:45,070 --> 00:35:42,890
side of the star then the cold side

780
00:35:49,359 --> 00:35:45,080
seeing this flash from red to blue and

781
00:35:51,370 --> 00:35:49,369
back again but because the Pulsar was

782
00:35:54,520 --> 00:35:51,380
being hit but purrs the star was being

783
00:35:58,210 --> 00:35:54,530
hit by the pulsars Jets the Pulsar was

784
00:36:00,880 --> 00:35:58,220
blowtorching it to pieces so you have a

785
00:36:02,890 --> 00:36:00,890
system a little bit like this one where

786
00:36:06,040 --> 00:36:02,900
the pulsars Jets were ripping over the

787
00:36:08,710 --> 00:36:06,050
star and shredding it and as the star

788
00:36:11,800 --> 00:36:08,720

ripped as a pulsar ripped this other

789

00:36:15,520 --> 00:36:11,810

star to pieces and disc formed from it's

790

00:36:17,140 --> 00:36:15,530

ruined body and in this disk planets

791

00:36:19,960 --> 00:36:17,150

could start to form again

792

00:36:22,570 --> 00:36:19,970

so pulsar planets have rather a morbid

793

00:36:25,359 --> 00:36:22,580

origin they require another star to be

794

00:36:32,650 --> 00:36:25,369

shredded to pieces and is broken body to

795

00:36:35,640 --> 00:36:32,660

form the birth ground of new planets so

796

00:36:39,250 --> 00:36:35,650

these first finds were strange worlds

797

00:36:40,870 --> 00:36:39,260

but later we found many planets that

798

00:36:44,349 --> 00:36:40,880

were much closer in size to the earth

799

00:36:46,270 --> 00:36:44,359

orbiting around normal stars around now

800

00:36:48,960 --> 00:36:46,280

we have found I think about three and a

801
00:36:51,700 --> 00:36:48,970
half thousand planets beyond our Sun and

802
00:36:53,859 --> 00:36:51,710
roughly a third of those have a radius

803
00:36:56,830 --> 00:36:53,869
that is less than twice of that of the

804
00:37:03,780 --> 00:36:56,840
earth so this brings us to the obvious

805
00:37:06,550 --> 00:37:03,790
question can we find earth 2.0 well

806
00:37:08,440 --> 00:37:06,560
let's look what we know with an example

807
00:37:11,349 --> 00:37:08,450
that hit the news at the beginning of

808
00:37:12,849 --> 00:37:11,359
this year and the telescope that made

809
00:37:14,890 --> 00:37:12,859
this news with a telescope called

810
00:37:17,650 --> 00:37:14,900
transiting planets and planetesimals a

811
00:37:20,680 --> 00:37:17,660
small telescope and it's a 60 centimeter

812
00:37:23,440 --> 00:37:20,690
telescope in Chile and if you take these

813
00:37:26,710 --> 00:37:23,450

letters very slightly randomly you can

814

00:37:28,480 --> 00:37:26,720

spell trust which I

815

00:37:30,550 --> 00:37:28,490

sure entirely ko is deadly because it's

816

00:37:34,599 --> 00:37:30,560

a Belgium telescope also happens to be

817

00:37:37,180 --> 00:37:34,609

the name of a Belgian beer but in

818

00:37:38,010 --> 00:37:37,190

February Trappist made an incredible

819

00:37:42,250 --> 00:37:38,020

discovery

820

00:37:44,440 --> 00:37:42,260

it found a star orbited by seven planets

821

00:37:46,810 --> 00:37:44,450

now as a telescope that made the

822

00:37:49,420 --> 00:37:46,820

discovery the star was named Trappist

823

00:37:54,849 --> 00:37:49,430

one and the planets became Trappist one

824

00:37:58,960 --> 00:37:54,859

b c d e f g and h so was this a solar

825

00:38:00,060 --> 00:37:58,970

system like our own well the press got

826

00:38:02,950 --> 00:38:00,070

pretty excited

827

00:38:05,290 --> 00:38:02,960

we had headlines like NASA's discovery

828

00:38:07,660 --> 00:38:05,300

of a solar system with seven earth-like

829

00:38:10,599 --> 00:38:07,670

planets will change how we hunt for

830

00:38:13,000 --> 00:38:10,609

alien life we had four new scientist

831

00:38:13,900 --> 00:38:13,010

exoplanet discoveries seven earth-sized

832

00:38:16,930 --> 00:38:13,910

exoplanet s--

833

00:38:19,240 --> 00:38:16,940

may have water or from the guardian

834

00:38:22,410 --> 00:38:19,250

exoplanet discovery seven earth sized

835

00:38:24,730 --> 00:38:22,420

planets found orbiting a nearby star

836

00:38:26,140 --> 00:38:24,740

clearly if you just read the press

837

00:38:30,609 --> 00:38:26,150

headlines you would think we'd found

838

00:38:32,770 --> 00:38:30,619

this clearly seven earth septuplets all

839

00:38:37,900 --> 00:38:32,780

identical probably already have

840

00:38:42,339 --> 00:38:37,910

Starbucks on them but what do we really

841

00:38:43,960 --> 00:38:42,349

know about them well these planets were

842

00:38:46,240 --> 00:38:43,970

discovered not with the radial velocity

843

00:38:49,540 --> 00:38:46,250

technique but with the transit technique

844

00:38:52,329 --> 00:38:49,550

and this is when the planets moves in

845

00:38:54,820 --> 00:38:52,339

front of the Stars surface and causes a

846

00:38:56,740 --> 00:38:54,830

tiny dip in the Starlight and it's how

847

00:38:59,770 --> 00:38:56,750

the Kepler space telescope finds its

848

00:39:03,220 --> 00:38:59,780

planets so in the case of the Trappist

849

00:39:07,030 --> 00:39:03,230

seven we see seven periodic dips as the

850

00:39:10,060 --> 00:39:07,040

planets passed by the star surface now

851
00:39:12,220 --> 00:39:10,070
transits usually give what they do they

852
00:39:14,380 --> 00:39:12,230
give you the planet radius the physical

853
00:39:16,320 --> 00:39:14,390
size of the planet so the bigger the

854
00:39:19,270 --> 00:39:16,330
planet the more light it blocks out and

855
00:39:21,820 --> 00:39:19,280
you can pick this up with the transit it

856
00:39:26,890 --> 00:39:21,830
doesn't normally tell you the planet

857
00:39:30,579 --> 00:39:26,900
mass normally but the Trappist planets

858
00:39:33,849 --> 00:39:30,589
were slightly different so Trappist one

859
00:39:37,000 --> 00:39:33,859
has many planets it has seven and as

860
00:39:40,600 --> 00:39:37,010
they orbit the star the planets pull on

861
00:39:43,150 --> 00:39:40,610
one another and as a result this slope

862
00:39:44,740 --> 00:39:43,160
change the time for each orbit so this

863
00:39:46,750 --> 00:39:44,750

is like if you're running around you're

864

00:39:48,850 --> 00:39:46,760

circular running track again but this

865

00:39:52,420 --> 00:39:48,860

time you've taken your dog along for the

866

00:39:54,850 --> 00:39:52,430

run and your dog is not always terribly

867

00:39:57,070 --> 00:39:54,860

cooperative sometimes your dog is

868

00:39:59,470 --> 00:39:57,080

pulling you forward and that means you

869

00:40:01,720 --> 00:39:59,480

make your lap time slightly quicker but

870

00:40:04,210 --> 00:40:01,730

sometimes your dog just wants to sniff

871

00:40:06,280 --> 00:40:04,220

stuff and it's pulling you back and so

872

00:40:09,970 --> 00:40:06,290

your lap time becomes slightly slower

873

00:40:10,540 --> 00:40:09,980

and these changes in lap time can be

874

00:40:12,310 --> 00:40:10,550

measured

875

00:40:15,580 --> 00:40:12,320

due to the planets pulling on each other

876

00:40:21,310 --> 00:40:15,590

and we call this transit timing

877

00:40:26,940 --> 00:40:21,320

variations or TT V so I have a movie

878

00:41:37,300 --> 00:40:38,140

[Music]

879

00:41:39,310 --> 00:41:37,310

and now what we see is a so the great

880

00:41:44,380 --> 00:41:39,320

bernard is going to have a ward effect

881

00:41:46,900 --> 00:41:44,390

on your lap time so ttv actually gives

882

00:41:49,840 --> 00:41:46,910

the mass of the planet in addition to

883

00:41:52,720 --> 00:41:49,850

the planet's physical size so what did

884

00:41:54,790 --> 00:41:52,730

we see with these seven worlds well

885

00:41:56,980 --> 00:41:54,800

let's look at radius as a function of

886

00:41:58,810 --> 00:41:56,990

Earth mass and we see we have three

887

00:42:02,710 --> 00:41:58,820

planets with almost exactly the same

888

00:42:05,110 --> 00:42:02,720

size as Earth and three planets with a

889

00:42:07,600 --> 00:42:05,120

slightly smaller size on earth and one

890

00:42:10,480 --> 00:42:07,610

slightly larger and if we look at the

891

00:42:13,780 --> 00:42:10,490

masses we have anything between 40 and

892

00:42:18,520 --> 00:42:13,790

140 times the matter percentage of the

893

00:42:21,300 --> 00:42:18,530

mass of the earth so we have roughly we

894

00:42:26,640 --> 00:42:21,310

have seven roughly earth sized planets

895

00:42:32,020 --> 00:42:26,650

so here is the question does earth size

896

00:42:35,800 --> 00:42:32,030

mean earth-like well what else do we

897

00:42:38,290 --> 00:42:35,810

know about this system now on earth a

898

00:42:42,070 --> 00:42:38,300

year so our lap around the Sun takes

899

00:42:46,600 --> 00:42:42,080

approximately 365 days if you were on

900

00:42:50,260 --> 00:42:46,610

Mars it would take 687 days if you're on

901
00:42:55,090 --> 00:42:50,270
Venus will be 225 and Mercury would be

902
00:42:56,980 --> 00:42:55,100
88 the Trappist planets the one furthest

903
00:43:02,010 --> 00:42:56,990
from the star that's going to take the

904
00:43:06,640 --> 00:43:02,020
longest orbital time will take 20 days

905
00:43:10,930 --> 00:43:06,650
twelve days nine days six days for 2.4

906
00:43:13,240 --> 00:43:10,940
and 1.5 days to make that orbit so if

907
00:43:16,620 --> 00:43:13,250
these were around our Sun all of these

908
00:43:19,900 --> 00:43:16,630
planets would sit inside Mercury's orbit

909
00:43:22,510 --> 00:43:19,910
so does this mean that the Trappist one

910
00:43:25,350 --> 00:43:22,520
worlds are in fact larva worlds with

911
00:43:28,890 --> 00:43:25,360
melted crusts of magma

912
00:43:31,829 --> 00:43:28,900
well something fortunately saves us

913
00:43:34,799 --> 00:43:31,839

and that is the Trappist one is very dim

914

00:43:36,420 --> 00:43:34,809

if we were to compare the size of the

915

00:43:39,779 --> 00:43:36,430

Sun with a basketball

916

00:43:43,109 --> 00:43:39,789

then Trappist one only has the size of a

917

00:43:46,019 --> 00:43:43,119

golf ball and it has only a thousands of

918

00:43:48,450 --> 00:43:46,029

the sun's brightness so that means you

919

00:43:51,180 --> 00:43:48,460

can afford it to be a lot closer but not

920

00:43:53,819 --> 00:43:51,190

that much hotter so if we compare

921

00:43:55,920 --> 00:43:53,829

instead the amount of radiation the

922

00:43:58,470 --> 00:43:55,930

planets receive then the amount of

923

00:44:01,950 --> 00:43:58,480

radiation that we get from the Sun over

924

00:44:04,200 --> 00:44:01,960

Venus Earth and Mercury is approximately

925

00:44:08,880 --> 00:44:04,210

equal to the amount of radiation

926
00:44:12,150 --> 00:44:08,890
received by planet C D E and F so very

927
00:44:15,420 --> 00:44:12,160
similar radiation for these planets so

928
00:44:17,970 --> 00:44:15,430
what about water well when we talk about

929
00:44:19,920 --> 00:44:17,980
water especially with exoplanets we

930
00:44:23,670 --> 00:44:19,930
typically talk about something called

931
00:44:25,829 --> 00:44:23,680
the habitable zone and this is the

932
00:44:29,039 --> 00:44:25,839
location where an earth-like planet

933
00:44:31,049 --> 00:44:29,049
could have water on its surface so you

934
00:44:33,870 --> 00:44:31,059
can imagine taking the earth and giving

935
00:44:36,210 --> 00:44:33,880
it a push towards the Sun and at the

936
00:44:38,640 --> 00:44:36,220
point where our water and our oceans

937
00:44:40,579 --> 00:44:38,650
become steam and evaporates that is the

938
00:44:42,779 --> 00:44:40,589

inner edge of the habitable zone

939

00:44:44,910 --> 00:44:42,789

conversely if we took the earth and

940

00:44:47,759 --> 00:44:44,920

pushed it outwards then there comes a

941

00:44:50,569 --> 00:44:47,769

point where the oceans freeze and that

942

00:44:53,309 --> 00:44:50,579

is our outer edge of our habitable zone

943

00:44:55,799 --> 00:44:53,319

so if we look at the planets around

944

00:45:00,960 --> 00:44:55,809

Trappist one the same habitable zone

945

00:45:03,569 --> 00:45:00,970

exists here over planets EF and G so

946

00:45:07,380 --> 00:45:03,579

does that mean we have three planets

947

00:45:09,479 --> 00:45:07,390

with water well not so fast

948

00:45:12,989 --> 00:45:09,489

we have to look at the small print of

949

00:45:16,499 --> 00:45:12,999

this habitable zone contract the

950

00:45:18,150 --> 00:45:16,509

habitable zone is defined as follows the

951
00:45:21,749 --> 00:45:18,160
habitable zone is where an earth-like

952
00:45:25,009 --> 00:45:21,759
planet can maintain liquid water on its

953
00:45:28,620 --> 00:45:25,019
surface and a small print here is

954
00:45:31,890 --> 00:45:28,630
earth-like so if you have a planet that

955
00:45:34,049 --> 00:45:31,900
is not an exact Earth clone it heavy has

956
00:45:36,450 --> 00:45:34,059
a larger mass a smaller mass a different

957
00:45:38,309 --> 00:45:36,460
atmosphere different rock type there is

958
00:45:40,650 --> 00:45:38,319
no guarantee at all

959
00:45:42,690 --> 00:45:40,660
that it will have water inside the

960
00:45:45,090 --> 00:45:42,700
habitable zone in

961
00:45:47,370 --> 00:45:45,100
of the exoplanets we've discovered we

962
00:45:49,950 --> 00:45:47,380
found roughly five times as many gas

963
00:45:52,470 --> 00:45:49,960

giants like Jupiter inside the habitable

964

00:45:55,770 --> 00:45:52,480

zone as we have planets that may have a

965

00:45:58,830 --> 00:45:55,780

rocky surface so then the question

966

00:46:02,340 --> 00:45:58,840

becomes these three planets there earth

967

00:46:04,440 --> 00:46:02,350

sized but are they earth-like earth-like

968

00:46:06,560 --> 00:46:04,450

enough for the habitable zone to be

969

00:46:09,630 --> 00:46:06,570

meaningful

970

00:46:11,490 --> 00:46:09,640

so with exoplanets we typically know two

971

00:46:13,560 --> 00:46:11,500

things and this doesn't just apply to

972

00:46:16,860 --> 00:46:13,570

the Trappist one it applies to all

973

00:46:19,200 --> 00:46:16,870

exoplanet discoveries we typically know

974

00:46:20,880 --> 00:46:19,210

either the planet radius if it's found

975

00:46:23,370 --> 00:46:20,890

through the transit technique looking at

976

00:46:25,740 --> 00:46:23,380

that light dip all we know the planet

977

00:46:28,290 --> 00:46:25,750

minimum mass if it's found from that red

978

00:46:30,630 --> 00:46:28,300

and blue Doppler wobble and occasionally

979

00:46:32,160 --> 00:46:30,640

like the Trappist system we know both so

980

00:46:36,090 --> 00:46:32,170

we know something about the planets

981

00:46:38,940 --> 00:46:36,100

physical extent we also know how much

982

00:46:41,190 --> 00:46:38,950

radiation it receives from the star now

983

00:46:43,620 --> 00:46:41,200

the small print here is this is not the

984

00:46:45,390 --> 00:46:43,630

same as surface temperature and the

985

00:46:49,140 --> 00:46:45,400

warning to that is in our own solar

986

00:46:51,570 --> 00:46:49,150

system so Venus receives roughly twice

987

00:46:54,090 --> 00:46:51,580

the amount of radiation that the earth

988

00:46:56,130 --> 00:46:54,100

does and if you were therefore to make a

989

00:47:00,860 --> 00:46:56,140

guess as a surface temperature of Venus

990

00:47:04,470 --> 00:47:00,870

you would guess 27 30 Celsius which is

991

00:47:05,610 --> 00:47:04,480

19 Fahrenheit maybe anyway it seems very

992

00:47:09,300 --> 00:47:05,620

pleasant we should go there for a beach

993

00:47:11,310 --> 00:47:09,310

holiday but in fact that is not true of

994

00:47:14,160 --> 00:47:11,320

the surface of Venus the surface of

995

00:47:15,120 --> 00:47:14,170

Venus is at 460 Celsius it doesn't even

996

00:47:16,680 --> 00:47:15,130

really matter whether it is in

997

00:47:20,010 --> 00:47:16,690

Fahrenheit it's just ridiculously hot

998

00:47:23,160 --> 00:47:20,020

and the longest a spacecraft has ever

999

00:47:26,100 --> 00:47:23,170

survived on the Venetian surface is less

1000

00:47:29,070 --> 00:47:26,110

than two hours and the difference is

1001

00:47:31,590 --> 00:47:29,080

Venus's huge atmosphere which we cannot

1002

00:47:34,650 --> 00:47:31,600

tell currently at a distance when we

1003

00:47:36,900 --> 00:47:34,660

look at exoplanets so we don't know

1004

00:47:41,370 --> 00:47:36,910

anything about the surface conditions of

1005

00:47:43,710 --> 00:47:41,380

these new worlds we found and what do we

1006

00:47:46,710 --> 00:47:43,720

need to know to say yes this is

1007

00:47:48,900 --> 00:47:46,720

earth-like well most certainly size is

1008

00:47:51,600 --> 00:47:48,910

important if you have a planet that's

1009

00:47:53,010 --> 00:47:51,610

Jupiter sized we can be pretty sure that

1010

00:47:56,020 --> 00:47:53,020

it's not going to have a solid surface

1011

00:47:58,090 --> 00:47:56,030

it's not going to be earth-like so you

1012

00:48:01,210 --> 00:47:58,100

definitely need to be in the ballpark of

1013

00:48:03,460 --> 00:48:01,220

the Earth's radius and mass but our

1014

00:48:05,590 --> 00:48:03,470

planet also has a protective magnetic

1015

00:48:08,020 --> 00:48:05,600

fields and this protects us from the

1016

00:48:10,720 --> 00:48:08,030

flares from the Sun that would strip our

1017

00:48:12,400 --> 00:48:10,730

atmosphere instead charged particles for

1018

00:48:14,320 --> 00:48:12,410

the Sun get caught safely in our

1019

00:48:15,670 --> 00:48:14,330

magnetic field and come down as the

1020

00:48:17,830 --> 00:48:15,680

northern and southern lights at our

1021

00:48:19,990 --> 00:48:17,840

poles occasionally we might have some

1022

00:48:22,000 --> 00:48:20,000

damage to our GPS systems but the

1023

00:48:26,350 --> 00:48:22,010

surface of our planet is mercifully not

1024

00:48:28,030 --> 00:48:26,360

sterilized volcanoes so you might think

1025

00:48:30,280 --> 00:48:28,040

a planet with no volcanoes sounds like a

1026

00:48:31,780 --> 00:48:30,290

rather good idea but it turns out

1027

00:48:34,330 --> 00:48:31,790

they're rather important for our

1028

00:48:36,130 --> 00:48:34,340

atmosphere during the early Earth we

1029

00:48:37,630 --> 00:48:36,140

needed volcanoes in order to get the

1030

00:48:40,180 --> 00:48:37,640

atmosphere that ultimately developed

1031

00:48:42,100 --> 00:48:40,190

life and indeed now it's one of the ways

1032

00:48:45,630 --> 00:48:42,110

that greenhouse gases are controlled

1033

00:48:48,340 --> 00:48:45,640

over geological timescales rock-type

1034

00:48:50,920 --> 00:48:48,350

again is how we control our greenhouse

1035

00:48:53,260 --> 00:48:50,930

gases over geological timescales and how

1036

00:48:55,740 --> 00:48:53,270

our planets manage to maintain very good

1037

00:48:59,200 --> 00:48:55,750

conditions for forming life for so long

1038

00:49:01,540 --> 00:48:59,210

the presence of water just because you

1039

00:49:04,780 --> 00:49:01,550

can support water there's no guarantee

1040

00:49:06,850 --> 00:49:04,790

you have water to support so as I

1041

00:49:09,130 --> 00:49:06,860

mentioned the earth formed inside the

1042

00:49:11,950 --> 00:49:09,140

ice line this may have meant it was

1043

00:49:13,900 --> 00:49:11,960

actually formed as a dry planet and as

1044

00:49:16,810 --> 00:49:13,910

how water could well have been delivered

1045

00:49:18,490 --> 00:49:16,820

later on by icy meteorites scattered

1046

00:49:20,860 --> 00:49:18,500

inwards by the giant planets like

1047

00:49:23,110 --> 00:49:20,870

Jupiter and Saturn so if you have a

1048

00:49:25,930 --> 00:49:23,120

different planetary system without those

1049

00:49:27,790 --> 00:49:25,940

big beefy planets outside you do you get

1050

00:49:31,570 --> 00:49:27,800

a scattering of icy meteorites to

1051

00:49:34,060 --> 00:49:31,580

deliver water we're not sure and plate

1052

00:49:37,300 --> 00:49:34,070

tectonics our crust our surface is

1053

00:49:39,160 --> 00:49:37,310

divided up into chunks and these chunks

1054

00:49:42,940 --> 00:49:39,170

allow our planet cool which helps

1055

00:49:45,850 --> 00:49:42,950

generate our magnetic fields and when we

1056

00:49:47,740 --> 00:49:45,860

observe a planet around another star we

1057

00:49:49,840 --> 00:49:47,750

only know about the first two we don't

1058

00:49:52,810 --> 00:49:49,850

know about any of these other effects at

1059

00:49:55,720 --> 00:49:52,820

the moment so it takes a lot to be like

1060

00:50:00,430 --> 00:49:55,730

Earth and we don't know very much about

1061

00:50:03,550 --> 00:50:00,440

any of these exoplanets however in the

1062

00:50:06,670 --> 00:50:03,560

case of Trappist one unusually we do

1063

00:50:09,550 --> 00:50:06,680

know one other thing the planet orbits

1064

00:50:12,640 --> 00:50:09,560

of Trappist warned are in resonance

1065

00:50:14,680 --> 00:50:12,650

and that means that if you look at the

1066

00:50:18,070 --> 00:50:14,690

time for each planet to orbit the star

1067

00:50:20,470 --> 00:50:18,080

you see something rather interesting in

1068

00:50:23,200 --> 00:50:20,480

the time it takes for planet B to orbit

1069

00:50:27,820 --> 00:50:23,210

the star 24 times it takes planet

1070

00:50:30,550 --> 00:50:27,830

planets see orbits 15 times 15 not 15

1071

00:50:32,680 --> 00:50:30,560

point 5 not fifteen point three not

1072

00:50:35,380 --> 00:50:32,690

fifteen point one two seven eight three

1073

00:50:38,920 --> 00:50:35,390

it's an exact integer or very close to

1074

00:50:41,830 --> 00:50:38,930

it and the pattern continues 24 15 nine

1075

00:50:44,230 --> 00:50:41,840

six four three two one very close to

1076

00:50:47,410 --> 00:50:44,240

being exact integer ratios of one

1077

00:50:50,800 --> 00:50:47,420

another so how does this happen it seems

1078

00:50:53,320 --> 00:50:50,810

like a bit of a coincidence so what we

1079

00:50:56,170 --> 00:50:53,330

believe happens is that if the planets

1080

00:50:58,720 --> 00:50:56,180

are born far from the star and they go

1081

00:51:01,900 --> 00:50:58,730

through this migration process to come

1082

00:51:04,570 --> 00:51:01,910

further in if you have multiple planets

1083

00:51:07,150 --> 00:51:04,580

doing this and their gravity pulls on

1084

00:51:09,760 --> 00:51:07,160

one another they can end up locked in

1085

00:51:12,010 --> 00:51:09,770

these resonance positions so as they

1086

00:51:14,410 --> 00:51:12,020

both migrate in their orbits at some

1087

00:51:17,650 --> 00:51:14,420

point will sync up to exact ratios and

1088

00:51:19,930 --> 00:51:17,660

this turns out to be very stable so once

1089

00:51:22,180 --> 00:51:19,940

you hit this sweet spot you tend to stay

1090

00:51:24,520 --> 00:51:22,190

there and then the planets continue to

1091

00:51:26,950 --> 00:51:24,530

migrate in with these exact ratios as

1092

00:51:31,030 --> 00:51:26,960

their orbit and you might be like

1093

00:51:33,100 --> 00:51:31,040

walking but so what the point is that if

1094

00:51:35,470 --> 00:51:33,110

that happened to these planets that

1095

00:51:37,990 --> 00:51:35,480

means the planet started here further

1096

00:51:42,070 --> 00:51:38,000

away from the star behind the ice line

1097

00:51:45,450 --> 00:51:42,080

and then ended up here this would mean

1098

00:51:48,220 --> 00:51:45,460

that they formed with a lot of ice and

1099

00:51:50,830 --> 00:51:48,230

so maybe as they moved closer to the

1100

00:51:55,510 --> 00:51:50,840

star this may have melted to become a

1101
00:51:57,670 --> 00:51:55,520
global ocean so our other option instead

1102
00:51:59,830 --> 00:51:57,680
of a lava world it could be that the

1103
00:52:01,960 --> 00:51:59,840
Trappist one planets have a huge amount

1104
00:52:06,940 --> 00:52:01,970
of water and they're actually water

1105
00:52:09,640 --> 00:52:06,950
worlds with no exposed land at all so

1106
00:52:11,890 --> 00:52:09,650
this is a beautiful graphic by NASA and

1107
00:52:17,620 --> 00:52:11,900
if we go below the atmosphere this is

1108
00:52:20,050 --> 00:52:17,630
how we might picture a water world so

1109
00:52:22,589 --> 00:52:20,060
this then brings us to the obvious

1110
00:52:25,829 --> 00:52:22,599
question on water world's habitable

1111
00:52:28,019 --> 00:52:25,839
I mean water and life are intricately

1112
00:52:30,479 --> 00:52:28,029
asserted are associated on earth so is

1113
00:52:33,089 --> 00:52:30,489

more water and better for life

1114

00:52:35,099 --> 00:52:33,099

well the shorter answer is we don't know

1115

00:52:37,109 --> 00:52:35,109

we've got no analog in our solar system

1116

00:52:40,799 --> 00:52:37,119

to go and explore which has a surface

1117

00:52:43,829 --> 00:52:40,809

global ocean however we have some reason

1118

00:52:47,549 --> 00:52:43,839

to be slightly skeptical and it comes

1119

00:52:49,349 --> 00:52:47,559

down to the carbon dioxide in our air so

1120

00:52:50,940 --> 00:52:49,359

if we didn't have an atmosphere the

1121

00:52:53,670 --> 00:52:50,950

global temperature of the earth would be

1122

00:52:56,009 --> 00:52:53,680

-5 Celsius below the freezing point of

1123

00:52:57,450 --> 00:52:56,019

water however because we have an

1124

00:52:59,969 --> 00:52:57,460

atmosphere and it contains these

1125

00:53:02,009 --> 00:52:59,979

greenhouse gases we're able to trap heat

1126
00:53:05,519 --> 00:53:02,019
effectively and brings our global

1127
00:53:08,190 --> 00:53:05,529
temperature to about 15 Celsius and

1128
00:53:11,009 --> 00:53:08,200
exactly how warm our planet gets can be

1129
00:53:12,839 --> 00:53:11,019
controlled by geology through what we

1130
00:53:15,630 --> 00:53:12,849
call the carbon cycle or sometimes the

1131
00:53:18,089 --> 00:53:15,640
carbon silicate cycle so here carbon

1132
00:53:20,130 --> 00:53:18,099
dioxide in the air dissolves in

1133
00:53:22,650 --> 00:53:20,140
rainwater comes down as slightly acidic

1134
00:53:25,019 --> 00:53:22,660
rain it reacts with the rocks and forms

1135
00:53:26,789 --> 00:53:25,029
of solids this gets swept into the ocean

1136
00:53:29,309 --> 00:53:26,799
and it eventually gets returned to the

1137
00:53:31,380 --> 00:53:29,319
atmosphere through volcanoes now the

1138
00:53:34,049 --> 00:53:31,390

process is very slow so it doesn't

1139

00:53:37,559 --> 00:53:34,059

really protect us against man-made

1140

00:53:40,259 --> 00:53:37,569

increase in greenhouse gases but it does

1141

00:53:43,559 --> 00:53:40,269

protect us over at slower moving changes

1142

00:53:45,930 --> 00:53:43,569

for example in its early years the Sun

1143

00:53:48,239 --> 00:53:45,940

would have been much cooler and during

1144

00:53:50,339 --> 00:53:48,249

this time the our earth should have been

1145

00:53:52,319 --> 00:53:50,349

too cold for life but we have evidence

1146

00:53:54,900 --> 00:53:52,329

that it wasn't and one of the

1147

00:53:57,269 --> 00:53:54,910

possibilities is that this process was

1148

00:53:59,969 --> 00:53:57,279

able to change the amount of greenhouse

1149

00:54:02,190 --> 00:53:59,979

gases in our atmosphere so if the planet

1150

00:54:04,049 --> 00:54:02,200

was colder this reaction with the rocks

1151
00:54:06,690 --> 00:54:04,059
would have slowed down because chemical

1152
00:54:08,009 --> 00:54:06,700
reactions slowed when it's colder but we

1153
00:54:09,870 --> 00:54:08,019
still would have been spitting out

1154
00:54:11,880 --> 00:54:09,880
carbon dioxide into the atmosphere so

1155
00:54:13,859 --> 00:54:11,890
the amount of greenhouse gas in the

1156
00:54:16,469 --> 00:54:13,869
atmosphere would have risen and given us

1157
00:54:18,839 --> 00:54:16,479
a thicker thermal blanket and this

1158
00:54:22,769 --> 00:54:18,849
allows us to have a lot more time in

1159
00:54:26,599 --> 00:54:22,779
which life can develop on earth but in

1160
00:54:29,910 --> 00:54:26,609
Eveland so if you have a global ocean

1161
00:54:33,660 --> 00:54:29,920
can you have any kind of carbon silicate

1162
00:54:35,340 --> 00:54:33,670
cycle so could a Waterworld actually

1163
00:54:37,290 --> 00:54:35,350

regulate its temperature

1164

00:54:39,990 --> 00:54:37,300

if it couldn't it has two main effects

1165

00:54:42,780 --> 00:54:40,000

the first is your habitable zone which I

1166

00:54:45,750 --> 00:54:42,790

presented as a broadband shrinks to a

1167

00:54:48,090 --> 00:54:45,760

narrow point because the reason ours is

1168

00:54:50,520 --> 00:54:48,100

a broadband is that our carbon cycle can

1169

00:54:52,440 --> 00:54:50,530

adjust slightly our atmosphere to allow

1170

00:54:55,110 --> 00:54:52,450

us to manage in slightly warmer areas

1171

00:54:57,210 --> 00:54:55,120

and slightly colder areas if there's no

1172

00:54:59,490 --> 00:54:57,220

way of adjusting the thermostat of the

1173

00:55:03,090 --> 00:54:59,500

planet the radiation you receive from

1174

00:55:04,740 --> 00:55:03,100

your star needs to be bang-on perfect so

1175

00:55:08,430 --> 00:55:04,750

you get a very narrow band for that

1176
00:55:11,310 --> 00:55:08,440
habitable zone secondly because you

1177
00:55:13,350 --> 00:55:11,320
can't buffer against the star increasing

1178
00:55:16,860 --> 00:55:13,360
in luminosity you have a much shorter

1179
00:55:19,620 --> 00:55:16,870
time for life to be able to develop so

1180
00:55:22,800 --> 00:55:19,630
does that mean it's curtains for any

1181
00:55:25,740 --> 00:55:22,810
water wells well not necessarily it may

1182
00:55:28,140 --> 00:55:25,750
depend on ocean depth for example if the

1183
00:55:30,390 --> 00:55:28,150
ocean is shallow enough you can still

1184
00:55:32,970 --> 00:55:30,400
have a carbon silicon cycle with the

1185
00:55:35,340 --> 00:55:32,980
ocean bottom it's not as good because

1186
00:55:38,370 --> 00:55:35,350
the ocean changes temperature much more

1187
00:55:41,040 --> 00:55:38,380
slowly than the atmosphere birds maybe

1188
00:55:43,140 --> 00:55:41,050

not impossible if the ocean gets very

1189

00:55:45,120 --> 00:55:43,150

deep then the chances are the pressure

1190

00:55:48,000 --> 00:55:45,130

of that ocean floor will rise so much

1191

00:55:50,460 --> 00:55:48,010

your form Isis and these Isis will

1192

00:55:52,710 --> 00:55:50,470

completely seal off your rocky core from

1193

00:55:57,600 --> 00:55:52,720

your ocean and so it won't be able to

1194

00:55:59,280 --> 00:55:57,610

produce any kind of thermostat at all so

1195

00:56:02,280 --> 00:55:59,290

this always leads to the question of can

1196

00:56:04,440 --> 00:56:02,290

we go and check these planets out well

1197

00:56:07,050 --> 00:56:04,450

our closest exoplanet is the one

1198

00:56:10,550 --> 00:56:07,060

orbiting Proxima Centauri this is our

1199

00:56:13,860 --> 00:56:10,560

nearest star so is our nearest possible

1200

00:56:16,770 --> 00:56:13,870

exoplanets and it's four light-years

1201

00:56:18,450 --> 00:56:16,780

away now our fastest spacecraft is

1202

00:56:19,830 --> 00:56:18,460

Voyager one which is currently at the

1203

00:56:21,960 --> 00:56:19,840

edge of our solar system

1204

00:56:24,480 --> 00:56:21,970

if forager one was pointing in the right

1205

00:56:26,550 --> 00:56:24,490

direction which isn't it would still

1206

00:56:29,700 --> 00:56:26,560

take it 75 thousand years

1207

00:56:32,130 --> 00:56:29,710

is to reach Proxima Centauri B now there

1208

00:56:33,930 --> 00:56:32,140

are some other ideas in the pipeline for

1209

00:56:36,480 --> 00:56:33,940

instance this project star shots which

1210

00:56:38,850 --> 00:56:36,490

is an idea where we could use lasers to

1211

00:56:42,000 --> 00:56:38,860

send very very very light spacecraft

1212

00:56:43,800 --> 00:56:42,010

great distances reasonably quickly but

1213

00:56:45,650 --> 00:56:43,810

as futuristic technology and we don't

1214

00:56:49,710 --> 00:56:45,660

know yet whether it's at all feasible

1215

00:56:51,270 --> 00:56:49,720

however all is not lost there are a

1216

00:56:53,130 --> 00:56:51,280

couple of really or more a couple

1217

00:56:55,290 --> 00:56:53,140

several really exciting missions coming

1218

00:56:58,140 --> 00:56:55,300

up that are going to tell us a lot more

1219

00:57:00,960 --> 00:56:58,150

about these exoplanets so as the planet

1220

00:57:02,970 --> 00:57:00,970

transits across the star surface some of

1221

00:57:05,910 --> 00:57:02,980

our starlight is going to pass through

1222

00:57:10,110 --> 00:57:05,920

the planet's atmosphere if we can spot

1223

00:57:12,450 --> 00:57:10,120

that then we will see a fingerprint that

1224

00:57:14,030 --> 00:57:12,460

marks out the gases at the atmosphere so

1225

00:57:16,290 --> 00:57:14,040

the light passes through the atmosphere

1226
00:57:18,360 --> 00:57:16,300
particular molecules in the atmosphere

1227
00:57:20,670 --> 00:57:18,370
will absorb certain parts of the light

1228
00:57:23,040 --> 00:57:20,680
spectrum and so they'll be missing when

1229
00:57:25,800 --> 00:57:23,050
we observe them on earth and based on

1230
00:57:27,500 --> 00:57:25,810
those missing light waves we can tell

1231
00:57:29,940 --> 00:57:27,510
what gases might be in the atmosphere

1232
00:57:33,060 --> 00:57:29,950
and this gives us our first hint that

1233
00:57:37,440 --> 00:57:33,070
geological processes and maybe even a

1234
00:57:38,910 --> 00:57:37,450
whiff of life so obviously in a space

1235
00:57:40,410 --> 00:57:38,920
telescope I have to mention that one of

1236
00:57:42,240 --> 00:57:40,420
the major instruments that we'll be

1237
00:57:45,870 --> 00:57:42,250
looking for this is a course at James

1238
00:57:47,940 --> 00:57:45,880

Webb which is due to launch in 2019 but

1239

00:57:49,830 --> 00:57:47,950

there's also ESA is the European Space

1240

00:57:52,790 --> 00:57:49,840

Agency's aerial mission which is

1241

00:57:56,030 --> 00:57:52,800

hopefully to go up in 2026

1242

00:57:58,260 --> 00:57:56,040

so this is going to be very exciting and

1243

00:58:02,460 --> 00:57:58,270

just to end on an utterly shameless

1244

00:58:04,950 --> 00:58:02,470

pitch as Frank mentioned my book comes

1245

00:58:06,930 --> 00:58:04,960

out today officially in the US it is

1246

00:58:09,060 --> 00:58:06,940

full of truly awful planets I mean there

1247

00:58:10,980 --> 00:58:09,070

are the hot Jupiters there are Tatooine

1248

00:58:13,080 --> 00:58:10,990

worlds around two stars there are rogue

1249

00:58:15,960 --> 00:58:13,090

worlds that have no star at all there

1250

00:58:17,970 --> 00:58:15,970

are planets with seas of lava and tar so

1251
00:58:19,920 --> 00:58:17,980
really whatever your favorite way to die

1252
00:58:23,460 --> 00:58:19,930
horribly is you'll probably find it in

1253
00:58:25,560 --> 00:58:23,470
the pages of my book so if you're at all

1254
00:58:28,740 --> 00:58:25,570
interested I've put some little cards

1255
00:58:32,850 --> 00:58:28,750
here just to remind you please grab one

1256
00:58:47,630 --> 00:58:32,860
and thank you very much

1257
00:59:00,150 --> 00:58:58,109
questions alright so I'm sure we have a

1258
00:59:04,890 --> 00:59:00,160
few questions I see in the green back

1259
00:59:08,099 --> 00:59:04,900
there now that was you all these

1260
00:59:10,799 --> 00:59:08,109
terrible planets Oh what about ours

1261
00:59:14,069 --> 00:59:10,809
which is you know sort of so coddling

1262
00:59:16,190 --> 00:59:14,079
almost what is your knee-jerk reaction

1263
00:59:19,770 --> 00:59:16,200

when people talk about like a Gaia

1264

00:59:21,930 --> 00:59:19,780

hypothesis where it's like a system

1265

00:59:22,680 --> 00:59:21,940

working together to maintain this

1266

00:59:25,799 --> 00:59:22,690

balance

1267

00:59:29,010 --> 00:59:25,809

nothing wearing it yeah one giant

1268

00:59:31,079 --> 00:59:29,020

tortoise okay so I'm gonna repeat the

1269

00:59:33,030 --> 00:59:31,089

question for the online audience so the

1270

00:59:36,390 --> 00:59:33,040

question is what is your opinion on the

1271

00:59:38,280 --> 00:59:36,400

Gaia hypothesis considers a planet as

1272

01:00:06,870 --> 00:59:38,290

sort of being an entire organism and

1273

01:00:10,260 --> 01:00:06,880

such and the question is where is the

1274

01:00:12,390 --> 01:00:10,270

bottleneck is it that life is very hard

1275

01:00:14,280 --> 01:00:12,400

to start maybe you never get a planet

1276

01:00:18,720 --> 01:00:14,290

with the right organics to start life

1277

01:00:22,530 --> 01:00:18,730

maybe life develops but in fact it dies

1278

01:00:23,970 --> 01:00:22,540

really quickly or maybe that you can

1279

01:00:25,650 --> 01:00:23,980

develop life quite easily and actually

1280

01:00:26,970 --> 01:00:25,660

it thrives but it just never becomes

1281

01:00:29,039 --> 01:00:26,980

intelligent life because it's not

1282

01:00:33,299 --> 01:00:29,049

selected for those sort of options and

1283

01:00:35,280 --> 01:00:33,309

one hypothesis put forward by Charlie

1284

01:00:38,520 --> 01:00:35,290

lineweaver was actually what he calls

1285

01:00:40,829 --> 01:00:38,530

the Gaya bottleneck where he says that

1286

01:00:42,210 --> 01:00:40,839

you have to not only form life you have

1287

01:00:44,160 --> 01:00:42,220

to form it fast enough

1288

01:00:46,410 --> 01:00:44,170

that it can actually change your

1289

01:00:49,680 --> 01:00:46,420

planet's environment to self sustain

1290

01:00:52,109 --> 01:00:49,690

itself and so that's the idea that in

1291

01:00:54,450 --> 01:00:52,119

the early stages of our earth the carbon

1292

01:00:57,030 --> 01:00:54,460

cycle that I mentioned before was not

1293

01:00:58,740 --> 01:00:57,040

sufficient to actually protect our

1294

01:01:00,900 --> 01:00:58,750

it's atmosphere and keep it temperate

1295

01:01:44,650 --> 01:01:00,910

enough but because we were able to form

1296

01:01:48,950 --> 01:01:47,059

obviously the aliens are trying to drown

1297

01:01:53,120 --> 01:01:48,960

out her talk and she's revealing too

1298

01:01:54,890 --> 01:01:53,130

many secrets folks those of you who've

1299

01:02:00,230 --> 01:01:54,900

been here know this has absolutely never

1300

01:02:03,289 --> 01:02:00,240

happened before in my 17 years we've

1301

01:02:08,420 --> 01:02:03,299

never had that kind of noise let's see

1302

01:02:11,029 --> 01:02:08,430

so yes I will also note that we just had

1303

01:02:13,339 --> 01:02:11,039

some major work done on the auditorium

1304

01:02:15,559 --> 01:02:13,349

honor if you noticed the projectors are

1305

01:02:18,829 --> 01:02:15,569

4k and other things and the audio system

1306

01:02:22,250 --> 01:02:18,839

was updated a little bit so I apologize

1307

01:02:25,609 --> 01:02:22,260

we are this is the first live event to

1308

01:02:28,430 --> 01:02:25,619

test out the system in detail so you can

1309

01:02:30,740 --> 01:02:28,440

see that it is being tested out okay so

1310

01:02:32,960 --> 01:02:30,750

back to what you were saying so even

1311

01:02:35,950 --> 01:02:32,970

though I obviously external forces tried

1312

01:02:39,109 --> 01:02:35,960

to stop me answering this question I

1313

01:02:41,299 --> 01:02:39,119

would say that I would consider life as

1314

01:02:43,220 --> 01:02:41,309

to be definitely part of the planets I

1315

01:02:44,420 --> 01:02:43,230

think when we talk about origins of life

1316

01:02:45,620 --> 01:02:44,430

we also have to talk about plant

1317

01:02:59,240 --> 01:02:45,630

information and they are intricately

1318

01:03:01,339 --> 01:02:59,250

connected yes okay yes so the question

1319

01:03:03,499 --> 01:03:01,349

was on there's the cellular type of

1320

01:03:05,240 --> 01:03:03,509

Trappist one is that what the root

1321

01:03:08,870 --> 01:03:05,250

you're asking about yes this is a red

1322

01:03:29,930 --> 01:03:08,880

dwarf yeah it is a red dwarf red dwarfs

1323

01:03:34,940 --> 01:03:29,940

are interesting they're good why is it

1324

01:03:41,270 --> 01:03:39,230

so yeah a Trappist one red dwarfs have

1325

01:03:43,760 --> 01:03:41,280

pros and cons one of the pros is that

1326

01:03:46,070 --> 01:03:43,770

being very small and dim stars is much

1327

01:03:49,160 --> 01:03:46,080

easier to find planets circling them and

1328

01:03:51,320 --> 01:03:49,170

indeed Kepler's successor test is going

1329

01:03:54,620 --> 01:03:51,330

to be focusing on red dwarfs for exactly

1330

01:03:56,780 --> 01:03:54,630

this reason however they're also

1331

01:03:59,240 --> 01:03:56,790

extremely rambunctious when they're

1332

01:04:02,300 --> 01:03:59,250

young and they are prone to a lot of

1333

01:04:04,550 --> 01:04:02,310

stellar flares and it is possible that a

1334

01:04:06,770 --> 01:04:04,560

planets around red dwarfs may become

1335

01:04:08,840 --> 01:04:06,780

sterilized because during this early

1336

01:04:10,250 --> 01:04:08,850

phase and the star's evolution it just

1337

01:04:12,260 --> 01:04:10,260

might have nuked everything that might

1338

01:04:13,940 --> 01:04:12,270

be developing on the planets at the

1339

01:04:15,830 --> 01:04:13,950

moment we just don't know the

1340

01:04:18,290 --> 01:04:15,840

interesting thing about Trappist one is

1341

01:04:20,450 --> 01:04:18,300

if they genuinely did this migration it

1342

01:04:22,160 --> 01:04:20,460

might just have saved them because they

1343

01:04:24,560 --> 01:04:22,170

would have started further away from the

1344

01:04:27,790 --> 01:04:24,570

star when the star was younger and maybe

1345

01:04:30,380 --> 01:04:27,800

that it would have got over its and

1346

01:04:34,910 --> 01:04:30,390

awkward adolescent stage by the time the

1347

01:04:45,080 --> 01:04:34,920

planet started approaching it all the

1348

01:04:46,970 --> 01:04:45,090

way in the very back row there okay so

1349

01:04:49,160 --> 01:04:46,980

do you anticipate any technology that

1350

01:04:52,700 --> 01:04:49,170

will allow us to see not just exoplanets

1351

01:04:54,020 --> 01:04:52,710

but also exomoons I guess start his

1352

01:04:57,380 --> 01:04:54,030

answer and see if everything cuts off

1353

01:04:59,540 --> 01:04:57,390

again yes absolutely so renie heller who

1354

01:05:02,270 --> 01:04:59,550

is an expert on EXO moon formation in

1355

01:05:04,820 --> 01:05:02,280

germany told me that he feels that

1356

01:05:07,580 --> 01:05:04,830

exomoons is where exoplanets was at the

1357

01:05:09,980 --> 01:05:07,590

start of the 1990s we are on the brink

1358

01:05:11,750 --> 01:05:09,990

and indeed their active search is

1359

01:05:15,109 --> 01:05:11,760

currently going on for EXO meals

1360

01:05:17,240 --> 01:05:15,119

one of them is called HEC which I forgot

1361

01:05:20,900 --> 01:05:17,250

what it stands for but it's using Kepler

1362

01:05:22,790 --> 01:05:20,910

to look for moons and the PI on that is

1363

01:05:25,340 --> 01:05:22,800

David Kipping at Columbia University and

1364

01:05:28,400 --> 01:05:25,350

currently Kepler is sensitive enough to

1365

01:05:30,320 --> 01:05:28,410

find a very very large moon in fact

1366

01:05:33,290 --> 01:05:30,330

slightly larger than we believe would

1367

01:05:35,960 --> 01:05:33,300

form around a gas giants but could

1368

01:05:38,560 --> 01:05:35,970

potentially be captured now of course if

1369

01:05:40,810 --> 01:05:38,570

we find that earth sized moons exist

1370

01:05:43,400 --> 01:05:40,820

then we have a lot more real estate

1371

01:05:45,620 --> 01:05:43,410

because our gas giants are mobbed with

1372

01:05:46,340 --> 01:05:45,630

moons so if you imagine a gas giant in

1373

01:05:49,370 --> 01:05:46,350

the habit

1374

01:05:51,560 --> 01:05:49,380

then it's not habitable but it might

1375

01:05:53,570 --> 01:05:51,570

have a whole bunch of moons that are now

1376

01:05:55,040 --> 01:05:53,580

it's a slightly interesting game when

1377

01:05:57,380 --> 01:05:55,050

you start looking at exomoons and

1378

01:05:59,930 --> 01:05:57,390

habitability in particular they get

1379

01:06:02,540 --> 01:05:59,940

multiple sources of heat because they

1380

01:06:04,790 --> 01:06:02,550

get the star but they also get heat

1381

01:06:07,400 --> 01:06:04,800

coming from the planet so that may mean

1382

01:06:09,980 --> 01:06:07,410

that if the planet is in the ideal spot

1383

01:06:12,950 --> 01:06:09,990

to support liquid water its moons may

1384

01:06:16,820 --> 01:06:12,960

potentially be too hot so it might be

1385

01:06:18,890 --> 01:06:16,830

your ideal Endor or a walk filled moon

1386

01:06:20,900 --> 01:06:18,900

would actually left live slightly

1387

01:06:22,520 --> 01:06:20,910

outside the habitable zone with the

1388

01:06:38,150 --> 01:06:22,530

planet providing that additional source

1389

01:06:43,400 --> 01:06:41,120

so what can we learn if we are able to

1390

01:06:45,259 --> 01:06:43,410

travel to Mars and explore it what shall

1391

01:06:48,650 --> 01:06:45,269

we learn that will enhance our knowledge

1392

01:06:50,539 --> 01:06:48,660

on this subject so I think probably what

1393

01:06:56,359 --> 01:06:50,549

most people would love to find is life

1394

01:06:58,460 --> 01:06:56,369

of any kind or even idea where is

1395

01:07:00,799 --> 01:06:58,470

everyone but one of the questions might

1396

01:07:04,069 --> 01:07:00,809

be does life just never start anywhere I

1397

01:07:07,009 --> 01:07:04,079

mean that's possible right if we were to

1398

01:07:09,079 --> 01:07:07,019

find a second genesis of life that would

1399

01:07:11,839 --> 01:07:09,089

probably imply that actually life is

1400

01:07:13,630 --> 01:07:11,849

pretty easy to kick-start now Mars isn't

1401
01:07:16,039 --> 01:07:13,640
necessarily the best place for that

1402
01:07:18,440 --> 01:07:16,049
because it's sufficiently close to the

1403
01:07:20,630 --> 01:07:18,450
earth that we can share material indeed

1404
01:07:22,160 --> 01:07:20,640
there isn't some theories that it's just

1405
01:07:25,220 --> 01:07:22,170
about possible life originated on Mars

1406
01:07:26,870 --> 01:07:25,230
and then came across to earth we never

1407
01:07:29,509 --> 01:07:26,880
found any evidence for life on Mars so

1408
01:07:32,870 --> 01:07:29,519
far and we're maybe more interesting

1409
01:07:34,819 --> 01:07:32,880
area might be Europe so as a moon of

1410
01:07:37,910 --> 01:07:34,829
Jupiter it has these deep subsurface

1411
01:07:39,680 --> 01:07:37,920
oceans if we were able to find evidence

1412
01:07:41,240 --> 01:07:39,690
of life on those I think we could be

1413
01:07:43,279 --> 01:07:41,250

more certain to say this was an

1414

01:07:45,740 --> 01:07:43,289

independent genesis of life and

1415

01:07:59,529 --> 01:07:45,750

therefore life is at least easy to start

1416

01:08:01,700 --> 01:07:59,539

if not continue the hot Jupiters

1417

01:08:06,260 --> 01:08:01,710

eventually lose our atmosphere by being

1418

01:08:10,509 --> 01:08:06,270

so close and why isn't our Jupiter hot

1419

01:08:10,509 --> 01:08:10,519

[Music]

1420

01:08:15,319 --> 01:08:13,460

that the Stars gravitational field

1421

01:08:17,510 --> 01:08:15,329

starts to penetrate that atmosphere and

1422

01:08:19,760 --> 01:08:17,520

literally starts siphoning it off we

1423

01:08:21,950 --> 01:08:19,770

call that a rich loop in flow and we've

1424

01:08:24,470 --> 01:08:21,960

also seen evidence of some hot Jupiters

1425

01:08:29,599 --> 01:08:24,480

rapidly using their answers so certainly

1426

01:08:31,999 --> 01:08:29,609

for some of them if they're close yes is

1427

01:08:35,629 --> 01:08:32,009

a big mystery so the idea of migration

1428

01:08:37,910 --> 01:08:35,639

was not actually invented when we found

1429

01:08:40,669 --> 01:08:37,920

hot Jupiters indeed the idea of been

1430

01:08:42,680 --> 01:08:40,679

around since the 1980s and we knew that

1431

01:08:44,809 --> 01:08:42,690

it was possible that this migration

1432

01:08:46,490 --> 01:08:44,819

process could occur but we look to our

1433

01:08:48,800 --> 01:08:46,500

own solar system didn't see any evidence

1434

01:08:49,760 --> 01:08:48,810

of strong migration and therefore is

1435

01:08:51,980 --> 01:08:49,770

assumed

1436

01:08:54,320 --> 01:08:51,990

either didn't happen or it just wasn't a

1437

01:08:56,420 --> 01:08:54,330

major player now we've discovered all

1438

01:08:59,570 --> 01:08:56,430

these exoplanets we realize it's a major

1439

01:09:02,510 --> 01:08:59,580

sculptor of exoplanet systems so then

1440

01:09:04,130 --> 01:09:02,520

the question comes I'll be weird so what

1441

01:09:06,170 --> 01:09:04,140

people think happened with our gas

1442

01:09:08,599 --> 01:09:06,180

giants is that jupiter was formed and

1443

01:09:10,309 --> 01:09:08,609

indeed it did start migrating and it

1444

01:09:12,200 --> 01:09:10,319

started to munch its way towards the

1445

01:09:14,599 --> 01:09:12,210

inner solar system which would have not

1446

01:09:16,970 --> 01:09:14,609

look good for earth but as it was doing

1447

01:09:19,880 --> 01:09:16,980

so saturn formed and caught up with it

1448

01:09:21,950 --> 01:09:19,890

as it started its own migration and at

1449

01:09:24,470 --> 01:09:21,960

that point the gravitational pull of the

1450

01:09:28,010 --> 01:09:24,480

two planets together caused a u-turn

1451

01:09:29,510 --> 01:09:28,020

that we call the grand tack model after

1452

01:09:31,370 --> 01:09:29,520

the sailing turn we turn the boat around

1453

01:09:34,070 --> 01:09:31,380

so the two planets moved in together

1454

01:09:36,920 --> 01:09:34,080

they actually do the u-turn around about

1455

01:09:39,079 --> 01:09:36,930

the position of Mars and moved out and

1456

01:09:41,870 --> 01:09:39,089

it's one of the explanations we have for

1457

01:09:43,190 --> 01:09:41,880

why Mars is so small because naively we

1458

01:09:45,260 --> 01:09:43,200

would have thought further away from the

1459

01:09:47,180 --> 01:09:45,270

star where the star's gravity is a

1460

01:09:49,250 --> 01:09:47,190

little bit weaker you should actually be

1461

01:09:51,650 --> 01:09:49,260

able to build a blog of planets but

1462

01:09:53,120 --> 01:09:51,660

instead we have a real squiffy one it's

1463

01:09:54,170 --> 01:09:53,130

possible that it was Jupiter just

1464

01:09:55,490 --> 01:09:54,180
marched right in there

1465

01:09:59,690 --> 01:09:55,500
eat up all the building material and

1466

01:10:01,220 --> 01:09:59,700
then left now whether this is common we

1467

01:10:03,380 --> 01:10:01,230
don't know yet because it's harder to

1468

01:10:05,630 --> 01:10:03,390
see planets at Jupiter's distance around

1469

01:10:07,430 --> 01:10:05,640
other stars as we start to see more

1470

01:10:08,960 --> 01:10:07,440
planets that are further out and get a

1471

01:10:10,940 --> 01:10:08,970
more complete picture of planetary

1472

01:10:14,360 --> 01:10:10,950
systems I think we'll get a better idea

1473

01:10:16,280 --> 01:10:14,370
about whether this grand tak system is

1474

01:10:20,060 --> 01:10:16,290
common or whether actually we have a

1475

01:10:22,640 --> 01:10:20,070
very unique system question in the

1476

01:10:25,910 --> 01:10:22,650

center there and there's kind of a

1477

01:10:27,740 --> 01:10:25,920

follow up is the word migration it

1478

01:10:29,470 --> 01:10:27,750

indicates that it's still moving could

1479

01:10:34,520 --> 01:10:29,480

these could these hot Jupiters

1480

01:10:37,280 --> 01:10:34,530

eventually go in actually hit the star

1481

01:10:38,870 --> 01:10:37,290

that they're that they're of form so

1482

01:10:41,120 --> 01:10:38,880

this is my creative process

1483

01:10:49,910 --> 01:10:41,130

can this migrating process end with the

1484

01:10:55,350 --> 01:10:51,140

[Music]

1485

01:10:58,530 --> 01:10:55,360

gasps disk circling about 10 million

1486

01:11:02,160 --> 01:10:58,540

years the star vaporizes its planet

1487

01:11:04,709 --> 01:11:02,170

migration due to the gaseous stops there

1488

01:11:07,260 --> 01:11:04,719

is also normally a gap at the disk edge

1489

01:11:09,689 --> 01:11:07,270

so the planet could go up to that gap

1490

01:11:12,959 --> 01:11:09,699

just before it reaches a star also stop

1491

01:11:14,700 --> 01:11:12,969

because there's no gas that site so in

1492

01:11:17,459 --> 01:11:14,710

terms of gas drip and migration you

1493

01:11:18,839 --> 01:11:17,469

shouldn't throw the whole planet into

1494

01:11:21,510 --> 01:11:18,849

the star there should be some kind of

1495

01:11:23,899 --> 01:11:21,520

stopping mechanism now exactly what

1496

01:11:26,910 --> 01:11:23,909

stops the planets we're not certain

1497

01:11:29,160 --> 01:11:26,920

because we don't see planets all exactly

1498

01:11:30,180 --> 01:11:29,170

the same distance which would suggest it

1499

01:11:32,790 --> 01:11:30,190

was just stopping at the disk edge

1500

01:11:34,830 --> 01:11:32,800

instead we see hot and warm Jupiter's

1501
01:11:36,569 --> 01:11:34,840
that obviously seemed to have migrated

1502
01:11:38,879 --> 01:11:36,579
but stopped at different distances and

1503
01:11:40,919 --> 01:11:38,889
we're still not entirely sure why that

1504
01:11:43,350 --> 01:11:40,929
happens there's different ideas for

1505
01:11:45,180 --> 01:11:43,360
these planet traps that can cause for

1506
01:11:47,640 --> 01:11:45,190
instance sharp density gradients at the

1507
01:11:50,669 --> 01:11:47,650
ice line that can slow a planet down and

1508
01:11:51,959 --> 01:11:50,679
hold it for a bit and also see the gas

1509
01:11:54,479 --> 01:11:51,969
disc can evaporate at slightly different

1510
01:11:57,720 --> 01:11:54,489
times and in job effectively beaching

1511
01:11:59,280 --> 01:11:57,730
the planets but for the hot Jupiters we

1512
01:12:06,720 --> 01:11:59,290
found now because the gas disc is no

1513
01:12:10,080 --> 01:12:06,730

longer when you make comments or

1514

01:12:12,870 --> 01:12:10,090

observations about orbits on distant

1515

01:12:14,850 --> 01:12:12,880

worlds it seems to me we're making the

1516

01:12:17,790 --> 01:12:14,860

assumption that we'll use an earth time

1517

01:12:20,729 --> 01:12:17,800

but a time is relative is it possible

1518

01:12:22,620 --> 01:12:20,739

that time is very different on these

1519

01:12:25,439 --> 01:12:22,630

different worlds and has it completely

1520

01:12:27,950 --> 01:12:25,449

different I don't know if a second is

1521

01:12:56,430 --> 01:12:27,960

ten times longer than is here whatever

1522

01:13:02,220 --> 01:13:00,630

so we see everything in a time yeah it's

1523

01:13:12,350 --> 01:13:02,230

we're all measuring it from our point of

1524

01:13:16,320 --> 01:13:12,360

view measurements in other solar systems

1525

01:13:19,290 --> 01:13:16,330

is there a minimum distance from the

1526

01:13:28,410 --> 01:13:19,300

star and a maximum distance is that is

1527

01:13:31,820 --> 01:13:28,420

that kind of area from on the planet

1528

01:13:36,900 --> 01:13:31,830

from the star and a maximum distance is

1529

01:13:38,880 --> 01:13:36,910

that area where planets forms of systems

1530

01:13:40,229 --> 01:13:38,890

is there a minimum distance from the

1531

01:13:43,950 --> 01:13:40,239

star or a maximum distance from a star

1532

01:13:46,260 --> 01:13:43,960

for planets so the prototype disk is

1533

01:13:48,630 --> 01:13:46,270

perfectly between one three percent of

1534

01:13:56,040 --> 01:13:48,640

the mass of the star and for that build

1535

01:13:57,630 --> 01:13:56,050

up process from it does not control

1536

01:13:59,459 --> 01:13:57,640

where the plants ultimately end up

1537

01:14:01,290 --> 01:13:59,469

because the addition to this gas

1538

01:14:02,250 --> 01:14:01,300

migration which would incur system

1539

01:14:05,660 --> 01:14:02,260

within that disk

1540

01:14:07,950 --> 01:14:05,670

there's also specially so if you have

1541

01:14:10,200 --> 01:14:07,960

multiple clients in their system they

1542

01:14:12,570 --> 01:14:10,210

can gravitationally pinboard each other

1543

01:14:13,920 --> 01:14:12,580

out the system so in our own solar

1544

01:14:16,380 --> 01:14:13,930

system we see evidence for that

1545

01:14:19,229 --> 01:14:16,390

happening in small objects so for

1546

01:14:21,330 --> 01:14:19,239

example our long-range comets come from

1547

01:14:23,760 --> 01:14:21,340

an area we call the Oort cloud which is

1548

01:14:25,470 --> 01:14:23,770

a huge distance away from us and it's

1549

01:14:27,660 --> 01:14:25,480

thought that objects there couldn't

1550

01:14:29,370 --> 01:14:27,670

possibly afford that they must have

1551
01:14:31,260 --> 01:14:29,380
formed much closer where our normal

1552
01:14:33,360 --> 01:14:31,270
planets are and then being scattered

1553
01:14:35,700 --> 01:14:33,370
gravitationally by planets like Jupiter

1554
01:14:37,979 --> 01:14:35,710
Saturn in this kind of gravitational

1555
01:14:40,050 --> 01:14:37,989
pinball game and when we look at

1556
01:14:42,930 --> 01:14:40,060
extrasolar planets we do sometimes see

1557
01:14:44,850 --> 01:14:42,940
planets that are far more distance then

1558
01:14:48,060 --> 01:14:44,860
there should have been a decent amount

1559
01:14:51,060 --> 01:14:48,070
of gas and dust in existence and we

1560
01:14:52,380 --> 01:14:51,070
genuinely believe that that is beyond

1561
01:14:53,970 --> 01:14:52,390
the edge where we expect planet

1562
01:14:56,100 --> 01:14:53,980
formation and they probably didn't form

1563
01:14:58,950 --> 01:14:56,110

there but it's a scattering event lob

1564

01:15:01,620 --> 01:14:58,960

them further out so as a result we don't

1565

01:15:03,930 --> 01:15:01,630

have a hard edge to where we expect to

1566

01:15:06,660 --> 01:15:03,940

see a planet not because we believe it

1567

01:15:22,300 --> 01:15:06,670

could have formed infinitely far but

1568

01:15:26,960 --> 01:15:24,560

protection of the earth and what we are

1569

01:15:30,350 --> 01:15:26,970

doing to it I mean I think it's so

1570

01:15:32,870 --> 01:15:30,360

crucial to do all right so the question

1571

01:15:34,910 --> 01:15:32,880

was since you're studying all these

1572

01:15:37,610 --> 01:15:34,920

thoughts how do you feel about the

1573

01:15:41,300 --> 01:15:37,620

protection of our own planet how we

1574

01:15:46,490 --> 01:15:41,310

might be treating it I believe it's a

1575

01:15:51,050 --> 01:15:46,500

controversial statement and the reason

1576

01:15:54,860 --> 01:15:51,060

is it got hold of one of the things I

1577

01:15:57,620 --> 01:15:54,870

hate so much with this idea in

1578

01:15:59,840 --> 01:15:57,630

understand that you saw a planet so

1579

01:16:02,510 --> 01:15:59,850

we're not remotely earth-like once more

1580

01:16:04,700 --> 01:16:02,520

they were incredible distances away so

1581

01:16:06,800 --> 01:16:04,710

much so that the only way possible and

1582

01:16:09,340 --> 01:16:06,810

ending that movie was it go so

1583

01:16:14,300 --> 01:16:09,350

completely crazy

1584

01:16:16,520 --> 01:16:14,310

I think that tells you that even if life

1585

01:16:18,680 --> 01:16:16,530

is common in the universe even if there

1586

01:16:20,360 --> 01:16:18,690

are no bottlenecks even if the Fermi

1587

01:16:23,000 --> 01:16:20,370

paradox is not a thing and you can

1588

01:16:25,790 --> 01:16:23,010

develop life for all these worlds we may

1589

01:16:27,860 --> 01:16:25,800

never ever reach it and that means as

1590

01:16:33,680 --> 01:16:27,870

far as we're concerned we've only got