

1
00:00:00,030 --> 00:00:06,839
and we have a really special talk for

2
00:00:04,110 --> 00:00:09,240
you tonight somebody who just popped up

3
00:00:06,839 --> 00:00:13,160
on my email saying oh I'd love to give a

4
00:00:09,240 --> 00:00:13,160
talk and I was like oh this is great

5
00:00:18,989 --> 00:00:24,629
our website for more information if you

6
00:00:22,618 --> 00:00:27,359
go to your favorite browser and putting

7
00:00:24,629 --> 00:00:30,210
public talks Republican couple public

8
00:00:27,359 --> 00:00:35,309
lecture series you can't say speech you

9
00:00:30,210 --> 00:00:37,259
could say Space Telescope probably - all

10
00:00:35,308 --> 00:00:40,859
this with the list of the upcoming

11
00:00:37,259 --> 00:00:43,920
lectures the watch live online you can

12
00:00:40,859 --> 00:00:50,250
watch the past lectures all the way back

13
00:00:43,920 --> 00:00:54,780
to 2005 so that's 12 years of and you

14
00:00:50,250 --> 00:00:56,488
can also sign up for our email that one

15
00:00:54,780 --> 00:01:03,750
one or two emails a month is too much

16
00:00:56,488 --> 00:01:08,039
you can also unsubscribe - or if you are

17
00:01:03,750 --> 00:01:11,010
fashioned just make sure you get added

18
00:01:08,040 --> 00:01:15,270
to the list if you have comments or

19
00:01:11,010 --> 00:01:18,659
questions I'm sending to public STS yeah

20
00:01:15,269 --> 00:01:20,039
that edu it'll come into my mailbox and

21
00:01:18,659 --> 00:01:23,390
we'll make sure you get your question

22
00:01:20,040 --> 00:01:26,219
answered okay let's see social media

23
00:01:23,390 --> 00:01:28,978
Facebook Twitter YouTube Instagram

24
00:01:26,219 --> 00:01:30,629
there's a lot of those if you would like

25
00:01:28,978 --> 00:01:33,090
to follow Space Telescope we are

26
00:01:30,629 --> 00:01:38,310
available social media

27
00:01:33,090 --> 00:01:40,400
I myself have Twitter but I'm as I say

28
00:01:38,310 --> 00:01:44,129
every month I'm only so often on there

29

00:01:40,400 --> 00:01:46,799
lots of other things to do and I do

30
00:01:44,129 --> 00:01:50,250
sometimes a blog on Hubble site if you

31
00:01:46,799 --> 00:01:53,280
want to follow me unfortunately the

32
00:01:50,250 --> 00:01:55,319
weather is not permitting tonight -

33
00:01:53,280 --> 00:01:58,099
those of you who brought the umbrellas

34
00:01:55,319 --> 00:02:00,929
in no definitely not pretty and

35
00:01:58,099 --> 00:02:03,750
unfortunately the observatory is not

36
00:02:00,930 --> 00:02:05,460
permitting the observatory is closed for

37
00:02:03,750 --> 00:02:07,890
repairs until further notice they had

38
00:02:05,459 --> 00:02:09,689
some problems with their dome and they

39
00:02:07,890 --> 00:02:12,060
emailed me today that they don't know

40
00:02:09,689 --> 00:02:13,539
when they'll be able to reopen

41
00:02:12,060 --> 00:02:16,000
so you

42
00:02:13,539 --> 00:02:18,239
go to md dot space grant org you will

43
00:02:16,000 --> 00:02:21,400

find this webpage over here on the right

44

00:02:18,239 --> 00:02:23,829

and the observatory status will not say

45

00:02:21,400 --> 00:02:27,370

check back on Friday it will say that

46

00:02:23,829 --> 00:02:29,230

check back next month or in a few weeks

47

00:02:27,370 --> 00:02:30,789

and will be able to tell you when the

48

00:02:29,229 --> 00:02:32,709

repairs will be done ok

49

00:02:30,789 --> 00:02:35,019

so unfortunately for the next couple of

50

00:02:32,709 --> 00:02:37,989

months possibly we will not have the

51

00:02:35,019 --> 00:02:41,200

Maryland space grant observatory ok all

52

00:02:37,989 --> 00:02:46,469

right now our news from the universe for

53

00:02:41,199 --> 00:02:51,310

November 2017 the first story tonight a

54

00:02:46,469 --> 00:02:53,530

wrinkle in space-time as you know I like

55

00:02:51,310 --> 00:02:55,408

to make small puns here this is of

56

00:02:53,530 --> 00:02:58,959

course is playing off Madeleine L'Engle

57

00:02:55,408 --> 00:03:02,679

famous story a wrinkle in time and what

58
00:02:58,959 --> 00:03:04,959
I'm talking about of course is the LIGO

59
00:03:02,680 --> 00:03:07,870
project the laser interferometer

60
00:03:04,959 --> 00:03:11,709
gravitational-wave Observatory which I

61
00:03:07,870 --> 00:03:13,530
told you about early last year has these

62
00:03:11,709 --> 00:03:17,079
two detectors one in Hanford Washington

63
00:03:13,530 --> 00:03:19,959
one in Livingston Louisiana and you can

64
00:03:17,079 --> 00:03:22,150
see they are these big long arrays that

65
00:03:19,959 --> 00:03:23,889
they send laser beams down each one of

66
00:03:22,150 --> 00:03:25,299
them and they the Blazer beans bounce

67
00:03:23,889 --> 00:03:28,449
off a mirror and come back and they

68
00:03:25,299 --> 00:03:31,599
measure the distance very very very

69
00:03:28,449 --> 00:03:35,199
accurately so that when the distances

70
00:03:31,598 --> 00:03:38,048
change they could tell by an incredibly

71
00:03:35,199 --> 00:03:42,510
small amount and they did measure an

72
00:03:38,049 --> 00:03:49,209
incredibly small amount of change and

73
00:03:42,509 --> 00:03:50,108
see what was observation done I can't

74
00:03:49,209 --> 00:03:51,699
remember the exact date of this

75
00:03:50,109 --> 00:03:54,849
observation but this was the detection

76
00:03:51,699 --> 00:03:56,769
of a black hole black hole merger that

77
00:03:54,848 --> 00:03:58,108
was about 1.3 billion light years away

78
00:03:56,769 --> 00:04:02,438
the first detection of gravitational

79
00:03:58,109 --> 00:04:04,900
waves and it was seen here is the data

80
00:04:02,438 --> 00:04:07,628
versus the predicted for langston and

81
00:04:04,900 --> 00:04:09,549
same for Hanford in fact it was detected

82
00:04:07,628 --> 00:04:11,530
in both of them and with the proper time

83
00:04:09,549 --> 00:04:13,719
delay for the light them to travel

84
00:04:11,530 --> 00:04:16,720
between them first detection of

85
00:04:13,719 --> 00:04:19,959
gravitational waves and on October 3rd

86

00:04:16,720 --> 00:04:23,169
of this year it was awarded the 2017

87
00:04:19,959 --> 00:04:24,668
Nobel Prize in Physics to these three

88
00:04:23,168 --> 00:04:26,879
gentlemen of the LIGO Virgo

89
00:04:24,668 --> 00:04:28,680
collaboration for the decisive

90
00:04:26,879 --> 00:04:30,920
contributions to the LIGO detector and

91
00:04:28,680 --> 00:04:33,720
the observational gravitational waves

92
00:04:30,920 --> 00:04:36,480
now we all sort of knew this was going

93
00:04:33,720 --> 00:04:38,310
to come because I could detect

94
00:04:36,480 --> 00:04:39,090
gravitational waves for the very first

95
00:04:38,310 --> 00:04:41,629
time

96
00:04:39,089 --> 00:04:43,829
yeah that's worthy of a Nobel Prize I

97
00:04:41,629 --> 00:04:48,000
personally did not expect it to come so

98
00:04:43,829 --> 00:04:49,409
quickly all right but you know since the

99
00:04:48,000 --> 00:04:51,000
discovery of those first black hole

100
00:04:49,410 --> 00:04:53,430

mergers they've discovered three or four

101

00:04:51,000 --> 00:04:56,600

more black hole black hole mergers so

102

00:04:53,430 --> 00:05:01,110

they're getting more observations but

103

00:04:56,600 --> 00:05:05,900

last summer on August 17th they also saw

104

00:05:01,110 --> 00:05:11,550

a neutron star neutron star merger okay

105

00:05:05,899 --> 00:05:15,029

so black holes are even alright so

106

00:05:11,550 --> 00:05:17,939

neutron it's a star can end up in

107

00:05:15,029 --> 00:05:20,369

several different ways okay a medium

108

00:05:17,939 --> 00:05:21,980

mass star low mass star ends up is

109

00:05:20,370 --> 00:05:25,889

what's called a white dwarf and that's

110

00:05:21,980 --> 00:05:29,069

about the the the density of the the

111

00:05:25,889 --> 00:05:30,089

atop the at the atom okay and it's

112

00:05:29,069 --> 00:05:32,009

supported by electron degeneracy

113

00:05:30,089 --> 00:05:34,859

pressure yada yada yada but it's about

114

00:05:32,009 --> 00:05:38,219

the density of an atom about the size of

115
00:05:34,860 --> 00:05:40,800
Earth okay all right and then there is a

116
00:05:38,220 --> 00:05:42,570
if you are more massive you can collapse

117
00:05:40,800 --> 00:05:44,850
down to what we call a neutron star

118
00:05:42,569 --> 00:05:47,819
which is about the density of an atomic

119
00:05:44,850 --> 00:05:50,340
nucleus okay and that's about the mass

120
00:05:47,819 --> 00:05:52,139
of the Sun compacted to about ten

121
00:05:50,339 --> 00:05:54,299
kilometers across or about the size of

122
00:05:52,139 --> 00:05:56,099
the Baltimore Beltway okay so take all

123
00:05:54,300 --> 00:05:58,319
the Sun could pass to the Baltimore

124
00:05:56,100 --> 00:06:00,750
Beltway size a ten kilometer cross and

125
00:05:58,319 --> 00:06:02,879
that's you get a neutron star a black

126
00:06:00,750 --> 00:06:04,829
hole goes even further than that is even

127
00:06:02,879 --> 00:06:09,029
more massive even even higher density

128
00:06:04,829 --> 00:06:10,949
okay so these neutron stars when they

129
00:06:09,029 --> 00:06:12,509
collide they're incredibly dense when

130
00:06:10,949 --> 00:06:15,029
they merge together they will also

131
00:06:12,509 --> 00:06:16,769
produce gravitational waves but not

132
00:06:15,029 --> 00:06:20,849
really as strong as a black hole black

133
00:06:16,769 --> 00:06:23,729
hole but this neutron star collision was

134
00:06:20,850 --> 00:06:26,730
only 130 million light years away which

135
00:06:23,730 --> 00:06:29,129
I know sounds pretty far but compared to

136
00:06:26,730 --> 00:06:30,900
the 1.3 billion light-years away that

137
00:06:29,129 --> 00:06:34,110
black hole black hole merger was is

138
00:06:30,899 --> 00:06:36,179
actually only 10% of that distance so

139
00:06:34,110 --> 00:06:39,150
they're able to see this neutron star

140
00:06:36,180 --> 00:06:40,180
neutron star collision with LIGO and

141
00:06:39,149 --> 00:06:43,810
Virgo

142
00:06:40,180 --> 00:06:46,780
is the European version of Lego however

143

00:06:43,810 --> 00:06:51,579
what made it even more exciting is it

144
00:06:46,779 --> 00:06:53,559
also was observed in optical light using

145
00:06:51,579 --> 00:06:55,990
both the LIGO detectors here in the US

146
00:06:53,560 --> 00:07:00,959
and the Virgo detector in Italy they

147
00:06:55,990 --> 00:07:03,430
were able to relatively relatively

148
00:07:00,959 --> 00:07:05,529
accurately determine where it was on the

149
00:07:03,430 --> 00:07:07,840
sky and astronomers were able to search

150
00:07:05,529 --> 00:07:10,839
for that point on the sky and found that

151
00:07:07,839 --> 00:07:15,369
there was an excess of radiation coming

152
00:07:10,839 --> 00:07:17,709
from this dot within the galaxy NGC 4990

153
00:07:15,370 --> 00:07:20,050
3 so they actually are able to do

154
00:07:17,709 --> 00:07:22,239
follow-up observations and neutron star

155
00:07:20,050 --> 00:07:24,189
neutron star collisions will have a lot

156
00:07:22,240 --> 00:07:26,500
of material around them and it will

157
00:07:24,189 --> 00:07:29,949

generate a lot of optical light okay so

158

00:07:26,500 --> 00:07:32,310

this is Hubble's observation from August

159

00:07:29,949 --> 00:07:35,379

22nd through August 28th over six days

160

00:07:32,310 --> 00:07:36,759

watching did you try and start a neutron

161

00:07:35,379 --> 00:07:40,538

star clip the light from that collision

162

00:07:36,759 --> 00:07:41,740

fade away all right and it's not just

163

00:07:40,538 --> 00:07:43,959

that it was seen by Hubble

164

00:07:41,740 --> 00:07:46,478

matter-of-fact Hubble was not the first

165

00:07:43,959 --> 00:07:51,189

one to see it it was actually first seen

166

00:07:46,478 --> 00:07:53,408

by family in gamma rays so it was seen

167

00:07:51,189 --> 00:07:55,719

in gravitational ways by LIGO and Virgo

168

00:07:53,408 --> 00:07:58,870

it was seen in gamma rays by Fermi

169

00:07:55,720 --> 00:08:01,630

integral and Swift it was seen in x-rays

170

00:07:58,870 --> 00:08:03,939

by Chandra it was seen in visible light

171

00:08:01,629 --> 00:08:06,069

by Hubble it was seen in infrared light

172
00:08:03,939 --> 00:08:08,228
by spitzer and it was seen by visible

173
00:08:06,069 --> 00:08:09,819
and infrared light by things like

174
00:08:08,228 --> 00:08:13,449
pan-starrs and other ground-based

175
00:08:09,819 --> 00:08:16,389
observatories so this is when

176
00:08:13,449 --> 00:08:18,848
astronomers can really get to work when

177
00:08:16,389 --> 00:08:20,829
it can really characterize the event

178
00:08:18,848 --> 00:08:23,139
when we see it in this many different

179
00:08:20,829 --> 00:08:25,269
wavelengths we see what's happening at

180
00:08:23,139 --> 00:08:28,150
lots of different energies and we can

181
00:08:25,269 --> 00:08:30,189
understand the event a lot more the

182
00:08:28,149 --> 00:08:31,689
black hole black hole merger that was

183
00:08:30,189 --> 00:08:34,028
that you know that won the Nobel Prize

184
00:08:31,689 --> 00:08:35,708
there were no follow-up studies we

185
00:08:34,028 --> 00:08:38,620
didn't see it in any other wavelengths

186
00:08:35,708 --> 00:08:40,179
this neutron star neutron star merger we

187
00:08:38,620 --> 00:08:41,379
were able to see in other wavelengths

188
00:08:40,179 --> 00:08:43,359
were able to get different

189
00:08:41,379 --> 00:08:45,189
characteristics of it and we're able to

190
00:08:43,360 --> 00:08:48,100
understand the processes that are going

191
00:08:45,190 --> 00:08:50,440
on and the basic result so far has been

192
00:08:48,100 --> 00:08:53,860
that hey it sort of fits what we think

193
00:08:50,440 --> 00:08:55,899
happens which is actually kind of crazy

194
00:08:53,860 --> 00:08:57,519
ideas you know and we say all right well

195
00:08:55,899 --> 00:08:59,950
this is our predictions we usually

196
00:08:57,519 --> 00:09:01,528
expect to be surprised oh nature be

197
00:08:59,950 --> 00:09:03,730
slightly differently than we predicted

198
00:09:01,528 --> 00:09:05,289
most of the predictions seem to be

199
00:09:03,730 --> 00:09:07,539
working out pretty well for this

200

00:09:05,289 --> 00:09:09,189
although there was one thing in terms of

201
00:09:07,539 --> 00:09:12,399
seeing it in ultraviolet that they

202
00:09:09,190 --> 00:09:16,510
didn't expect and the fact that it was a

203
00:09:12,399 --> 00:09:18,610
relatively faint gamma ray okay it's a

204
00:09:16,509 --> 00:09:19,569
short duration but it's a faint

205
00:09:18,610 --> 00:09:21,970
gamma-ray burst

206
00:09:19,570 --> 00:09:23,470
okay the short duration bursts for

207
00:09:21,970 --> 00:09:25,379
something so close it actually have been

208
00:09:23,470 --> 00:09:27,670
larger and they're not quite sure why

209
00:09:25,379 --> 00:09:29,500
but these are all the questions that

210
00:09:27,669 --> 00:09:32,919
come up when you have this many

211
00:09:29,500 --> 00:09:34,750
different ways of looking at it and are

212
00:09:32,919 --> 00:09:36,539
able to study it in so many ways so this

213
00:09:34,750 --> 00:09:39,850
not only have we moved into

214
00:09:36,539 --> 00:09:41,588

gravitational wave astrophysics but

215

00:09:39,850 --> 00:09:43,420

we've got follow-ups to be able to

216

00:09:41,589 --> 00:09:48,130

correlate it which makes it so much more

217

00:09:43,419 --> 00:09:52,299

valuable our second story tonight on the

218

00:09:48,129 --> 00:09:54,549

trail of asteroids now Hubble had this

219

00:09:52,299 --> 00:09:56,769

amazing project called the frontier

220

00:09:54,549 --> 00:10:01,419

fields okay and the frontier fields

221

00:09:56,769 --> 00:10:03,370

looked at six really massive clusters to

222

00:10:01,419 --> 00:10:05,889

look for gravitational lensing so this

223

00:10:03,370 --> 00:10:08,350

is the mass of galaxy cluster Abell 370

224

00:10:05,889 --> 00:10:11,019

and all these streaky things in here are

225

00:10:08,350 --> 00:10:13,449

gravitationally lens arcs okay and we've

226

00:10:11,019 --> 00:10:16,778

talked about that a lot and at the same

227

00:10:13,448 --> 00:10:18,309

time while they were doing the well

228

00:10:16,778 --> 00:10:20,139

they're looking at the galaxy cluster

229
00:10:18,309 --> 00:10:22,689
they also looked at what they called

230
00:10:20,139 --> 00:10:23,740
parallel fields so one detector of

231
00:10:22,690 --> 00:10:25,750
Hubble was looking at the cluster

232
00:10:23,740 --> 00:10:27,698
another detector was looking at the

233
00:10:25,750 --> 00:10:29,470
parallel field and then actually they

234
00:10:27,698 --> 00:10:30,639
rotated and then that one detector

235
00:10:29,470 --> 00:10:32,620
looked the parallel field and the other

236
00:10:30,639 --> 00:10:35,578
detector look at the cluster okay and

237
00:10:32,620 --> 00:10:38,139
they spent about a hundred hours of

238
00:10:35,578 --> 00:10:41,379
observation time on each of these

239
00:10:38,139 --> 00:10:43,269
clusters well these are the cleaned-up

240
00:10:41,379 --> 00:10:45,490
images that you see okay and of course

241
00:10:43,269 --> 00:10:47,289
the real observations have lots of you

242
00:10:45,490 --> 00:10:49,149
know cosmic rays and other things that

243
00:10:47,289 --> 00:10:51,929
happen you know detector artifacts that

244
00:10:49,149 --> 00:10:54,159
have to be cleaned up but there's also

245
00:10:51,929 --> 00:10:56,349
another thing that they had to clean up

246
00:10:54,159 --> 00:11:03,759
out of this these images that is

247
00:10:56,350 --> 00:11:05,409
illustrated by this movie so as this

248
00:11:03,759 --> 00:11:06,439
movie plays you'll start to see these

249
00:11:05,409 --> 00:11:09,230
little streak

250
00:11:06,440 --> 00:11:14,080
here and there numbered one through

251
00:11:09,230 --> 00:11:18,110
seven because these are seven unique

252
00:11:14,080 --> 00:11:20,629
asteroids that passed through the field

253
00:11:18,110 --> 00:11:23,060
over the hundred hours that Hubble was

254
00:11:20,629 --> 00:11:25,580
observing now Hubble doesn't observe it

255
00:11:23,059 --> 00:11:27,019
continuously it does a bit of

256
00:11:25,580 --> 00:11:28,310
observation and then it'll go off and do

257

00:11:27,019 --> 00:11:30,259
something else and I'll come back to the

258
00:11:28,309 --> 00:11:33,169
field and do some more observation etc

259
00:11:30,259 --> 00:11:36,019
which is why number seven here you can

260
00:11:33,169 --> 00:11:38,299
see is split into four separate little

261
00:11:36,019 --> 00:11:39,470
loops alright and why are they streaks

262
00:11:38,299 --> 00:11:42,379
and curved loops

263
00:11:39,470 --> 00:11:45,200
well Hubble and Earth are moving

264
00:11:42,379 --> 00:11:47,509
relative to the asteroid while we're

265
00:11:45,200 --> 00:11:49,190
taking observations so the asteroid

266
00:11:47,509 --> 00:11:50,870
actually ends up streaking and the

267
00:11:49,190 --> 00:11:55,370
parallax motion produces that little

268
00:11:50,870 --> 00:11:57,230
curve on there alright so for a Bell 370

269
00:11:55,370 --> 00:12:00,049
and it's parallel field here are the

270
00:11:57,230 --> 00:12:02,480
cleaned-up images and there are the

271
00:12:00,049 --> 00:12:04,549

images with the asteroid streaks now

272

00:12:02,480 --> 00:12:06,800

you'll notice we use the movie on the

273

00:12:04,549 --> 00:12:09,889

parallel field simply because there are

274

00:12:06,799 --> 00:12:13,129

ready these streaks in the in the

275

00:12:09,889 --> 00:12:14,569

gravitational lens those are actually

276

00:12:13,129 --> 00:12:17,000

galaxies that are beyond the

277

00:12:14,570 --> 00:12:19,850

gravitational lens but if I blink back

278

00:12:17,000 --> 00:12:23,059

and forth you can see the asteroids and

279

00:12:19,850 --> 00:12:25,279

where they appear in the field and this

280

00:12:23,059 --> 00:12:28,519

is kind of cool because what you've got

281

00:12:25,279 --> 00:12:31,009

here in one image is you've got some

282

00:12:28,519 --> 00:12:32,629

things within the solar system as well

283

00:12:31,009 --> 00:12:35,990

as you've got things that are billions

284

00:12:32,629 --> 00:12:37,460

of light-years away and it reinforces

285

00:12:35,990 --> 00:12:39,289

one of the things that we have to deal

286
00:12:37,460 --> 00:12:41,570
with an astronomy when you look out into

287
00:12:39,289 --> 00:12:43,279
the universe it's the sum of everything

288
00:12:41,570 --> 00:12:46,100
that you're looking through the solar

289
00:12:43,279 --> 00:12:47,750
system to the galaxies to the distant

290
00:12:46,100 --> 00:12:49,550
galaxies all the way to the edge of the

291
00:12:47,750 --> 00:12:52,669
universe that when you take an image

292
00:12:49,549 --> 00:12:54,559
you're combining all of that into one of

293
00:12:52,669 --> 00:12:56,659
those and here you can see some of the

294
00:12:54,559 --> 00:12:58,699
nearest things and some of the father's

295
00:12:56,659 --> 00:13:00,549
things in the universe all combined

296
00:12:58,700 --> 00:13:04,100
together that's kind of cool

297
00:13:00,549 --> 00:13:06,979
all right so now we'll go to our

298
00:13:04,100 --> 00:13:10,610
featured speaker and our featured

299
00:13:06,980 --> 00:13:12,950
speaker tonight let's see if her laptop

300
00:13:10,610 --> 00:13:17,450
takes over yes it does

301
00:13:12,950 --> 00:13:19,660
his doctor Elizabeth Tasker and she is

302
00:13:17,450 --> 00:13:22,120
from the originally from the UK

303
00:13:19,659 --> 00:13:24,730
she did her undergraduate work at Durham

304
00:13:22,120 --> 00:13:27,909
University and then did her graduate

305
00:13:24,730 --> 00:13:29,529
work at University of Oxford then she

306
00:13:27,909 --> 00:13:31,629
came across to the United States and

307
00:13:29,529 --> 00:13:35,429
Canada and did some post doctoral work

308
00:13:31,629 --> 00:13:38,139
here before going even further from home

309
00:13:35,429 --> 00:13:42,069
where she is an associate professor at

310
00:13:38,139 --> 00:13:44,319
the Japan aerospace exploration agency

311
00:13:42,070 --> 00:13:46,120
and I love JAXA because that's a great

312
00:13:44,320 --> 00:13:48,480
acronym to say it's almost it's it's

313
00:13:46,120 --> 00:13:51,190
like NASA but it has sort of an

314

00:13:48,480 --> 00:13:53,920
intriguing sound Jack's I just you know

315
00:13:51,190 --> 00:13:58,510
sounds as good as NASA in terms of a

316
00:13:53,919 --> 00:14:01,419
Space Agency she does her research work

317
00:13:58,509 --> 00:14:04,360
on the formation of stars and planets by

318
00:14:01,419 --> 00:14:07,389
doing computer simulations and today is

319
00:14:04,360 --> 00:14:09,370
a very special day for her because she

320
00:14:07,389 --> 00:14:11,529
has a book that is being published today

321
00:14:09,370 --> 00:14:13,509
and I'm sure she'll mention that in her

322
00:14:11,529 --> 00:14:15,929
talk ladies and gentlemen dr. Elizabeth

323
00:14:13,509 --> 00:14:15,929
Tasker

324
00:14:21,059 --> 00:14:30,939
well thank you very much

325
00:14:23,080 --> 00:14:33,070
is this something good okay so today I'm

326
00:14:30,940 --> 00:14:36,100
going to be talking about planets

327
00:14:33,070 --> 00:14:38,260
especially those beyond our solar system

328
00:14:36,100 --> 00:14:41,680

but I'm going to start with what I hope

329

00:14:38,259 --> 00:14:42,939

is a vaguely familiar image in a minute

330

00:14:41,679 --> 00:14:46,059

so I'll be starting with what I hope is

331

00:14:42,940 --> 00:14:48,310

a vaguely familiar image there we go so

332

00:14:46,059 --> 00:14:50,739

I hope these guys look somewhat familiar

333

00:14:48,309 --> 00:14:54,338

to everyone and I say this is a Sun and

334

00:14:50,740 --> 00:14:57,639

then just past the Sun we have our four

335

00:14:54,339 --> 00:15:00,880

smallest planets Mercury Venus Earth and

336

00:14:57,639 --> 00:15:03,639

Mars and just past Mars we have this

337

00:15:00,879 --> 00:15:06,580

band of rubble rubble rocky leftovers

338

00:15:03,639 --> 00:15:09,220

from the planet formation process that

339

00:15:06,580 --> 00:15:12,430

we call the asteroid belts which also

340

00:15:09,220 --> 00:15:14,860

contains the dwarf planet Ceres and then

341

00:15:12,429 --> 00:15:17,649

beyond the asteroid belt we have the

342

00:15:14,860 --> 00:15:21,190

giants Jupiter Saturn Uranus and Neptune

343
00:15:17,649 --> 00:15:23,649
and then we have this another pile of

344
00:15:21,190 --> 00:15:26,290
rocky leftovers from planet formation

345
00:15:23,649 --> 00:15:28,149
which is the Kuiper belts and of course

346
00:15:26,289 --> 00:15:30,250
it's most famous member is the dwarf

347
00:15:28,149 --> 00:15:35,529
planet Pluto that we never really talk

348
00:15:30,250 --> 00:15:41,110
about that anymore and you are here all

349
00:15:35,529 --> 00:15:43,029
right so if you were to base all our

350
00:15:41,110 --> 00:15:46,120
understanding of planet formation on our

351
00:15:43,029 --> 00:15:48,909
solar system we would note that you have

352
00:15:46,120 --> 00:15:51,070
two types of planets you have rocky

353
00:15:48,909 --> 00:15:54,240
planets so these guys Mercury through to

354
00:15:51,070 --> 00:15:57,550
Mars and here you have a solid surface

355
00:15:54,240 --> 00:16:00,339
with a relatively thin atmosphere and

356
00:15:57,549 --> 00:16:03,370
then beyond the asteroid belt you have

357
00:16:00,339 --> 00:16:05,620
gas giant planets where most of their

358
00:16:03,370 --> 00:16:09,459
volume is taken up with their atmosphere

359
00:16:05,620 --> 00:16:13,179
around a much smaller dense central core

360
00:16:09,458 --> 00:16:16,208
and this colossal atmosphere results in

361
00:16:13,179 --> 00:16:19,179
absolutely crushing pressures near their

362
00:16:16,208 --> 00:16:21,309
core so much so than in fact our

363
00:16:19,179 --> 00:16:23,649
hydrogen on Jupiter by the time you

364
00:16:21,309 --> 00:16:26,199
approach Jupiter's core it becomes so

365
00:16:23,649 --> 00:16:29,458
dense that it starts behaving as this

366
00:16:26,200 --> 00:16:33,528
kind of metallic compound

367
00:16:29,458 --> 00:16:36,498
so until 1990s these were all the plan

368
00:16:33,528 --> 00:16:38,360
we knew and we didn't think that our

369
00:16:36,499 --> 00:16:41,028
solar system was the only one out there

370
00:16:38,360 --> 00:16:43,610
but we haven't actually seen any others

371

00:16:41,028 --> 00:16:49,789
so nothing was definite but then

372
00:16:43,610 --> 00:16:51,860
everything changed so our Sun is one of

373
00:16:49,789 --> 00:16:54,259
about a hundred billion stars in the

374
00:16:51,860 --> 00:16:57,259
Milky Way galaxy and when we talk about

375
00:16:54,259 --> 00:17:01,519
extrasolar planets we mean extra as in

376
00:16:57,259 --> 00:17:04,068
outside and a solar as in of the Sun so

377
00:17:01,519 --> 00:17:06,588
an extrasolar planet or exoplanets

378
00:17:04,068 --> 00:17:10,279
is any planet that is not in our solar

379
00:17:06,588 --> 00:17:13,730
system and the story of extrasolar

380
00:17:10,279 --> 00:17:17,379
planets begins in 1990 when the Arecibo

381
00:17:13,730 --> 00:17:17,380
radio telescope in Puerto Rico

382
00:17:20,068 --> 00:17:23,199
[Music]

383
00:17:37,170 --> 00:17:40,489
[Music]

384
00:17:44,710 --> 00:17:51,980
structural cracks so around the same

385
00:17:49,700 --> 00:17:54,110

time a similar radio telescope in Green

386

00:17:51,980 --> 00:17:55,910

Bank in the u.s. also has structural

387

00:17:54,109 --> 00:17:58,399

cracks which were ignored and the whole

388

00:17:55,910 --> 00:17:59,870

thing collapsed so in a fit of panic a

389

00:17:58,400 --> 00:18:01,810

receiver was like okay we've got the

390

00:17:59,869 --> 00:18:05,299

message we're gonna fix this

391

00:18:01,809 --> 00:18:08,269

but during repairs the telescope was not

392

00:18:05,299 --> 00:18:11,329

taken completely offline but it couldn't

393

00:18:08,269 --> 00:18:13,129

be moved so typically during a night to

394

00:18:11,329 --> 00:18:16,369

the telescope will move very slightly

395

00:18:13,130 --> 00:18:18,260

across the sky as it tracks objects but

396

00:18:16,369 --> 00:18:20,359

during these repairs nothing could be

397

00:18:18,259 --> 00:18:23,629

done it had to be absolutely stationary

398

00:18:20,359 --> 00:18:26,659

and this made it unfit for almost all

399

00:18:23,630 --> 00:18:28,610

projects however at the time was a

400
00:18:26,660 --> 00:18:32,420
postdoctoral researcher called Alex bull

401
00:18:28,609 --> 00:18:35,000
Shen and he asked to use a telescope for

402
00:18:32,420 --> 00:18:37,100
a month-long survey because this survey

403
00:18:35,000 --> 00:18:40,009
could be done while the telescope wasn't

404
00:18:37,099 --> 00:18:42,409
moving and normally such a proposal

405
00:18:40,009 --> 00:18:42,980
would never have gone through because he

406
00:18:42,410 --> 00:18:45,110
required

407
00:18:42,980 --> 00:18:47,029
half the telescope's time and this was

408
00:18:45,109 --> 00:18:49,719
the biggest telescope in the world for

409
00:18:47,029 --> 00:18:52,099
radio so people would be like you know

410
00:18:49,720 --> 00:18:54,049
but as it happened no one else could

411
00:18:52,099 --> 00:18:57,709
really use it he was based the telescope

412
00:18:54,049 --> 00:19:00,759
and they said fine and what Alex wanted

413
00:18:57,710 --> 00:19:03,230
to find were dead stars called pulsars

414
00:19:00,759 --> 00:19:06,589
so actually we've just had a very nice

415
00:19:03,230 --> 00:19:09,230
summary of these because a pulsar is

416
00:19:06,589 --> 00:19:11,079
what forms when a star that is much

417
00:19:09,230 --> 00:19:13,849
larger than our Sun more than 8 times

418
00:19:11,079 --> 00:19:17,389
eventually reaches the end of its life

419
00:19:13,849 --> 00:19:19,730
and it runs out of fuel to burn and when

420
00:19:17,390 --> 00:19:22,670
that happens the star dies in a

421
00:19:19,730 --> 00:19:25,430
supernova explosion and the bit that's

422
00:19:22,670 --> 00:19:28,550
left behind collapses to incredible

423
00:19:25,430 --> 00:19:31,250
densities so dense that its atoms

424
00:19:28,549 --> 00:19:33,230
actually starts to disintegrate and the

425
00:19:31,250 --> 00:19:37,789
protons and the electrons inside the

426
00:19:33,230 --> 00:19:40,610
atoms and so we therefore call these

427
00:19:37,789 --> 00:19:41,930
neutron stars which is exactly the same

428

00:19:40,609 --> 00:19:45,589
source of the gravitational waves

429
00:19:41,930 --> 00:19:47,960
mentioned earlier however as yeah and as

430
00:19:45,589 --> 00:19:49,939
mentioned these are tiny so only

431
00:19:47,960 --> 00:19:53,450
city-sized or indeed the

432
00:19:49,940 --> 00:19:55,910
the Baltimore Belt and yet they weigh

433
00:19:53,450 --> 00:19:58,130
between 1.4 and twice this master's son

434
00:19:55,910 --> 00:19:59,990
so they're incredibly dense objects and

435
00:19:58,130 --> 00:20:03,170
as they collapse their magnetic field

436
00:19:59,990 --> 00:20:06,710
also strengthens a lot and this magnetic

437
00:20:03,170 --> 00:20:08,930
field causes any remaining charges left

438
00:20:06,710 --> 00:20:13,870
on the neutron star to be ripped off and

439
00:20:08,930 --> 00:20:18,170
fired into the cosmos as powerful Jets

440
00:20:13,869 --> 00:20:22,519
now if these Jets happen to swing by the

441
00:20:18,170 --> 00:20:26,029
earth as the star rotates then we see a

442
00:20:22,519 --> 00:20:29,960

periodic light pulse and therefore we

443

00:20:26,029 --> 00:20:33,710

call these April's are now the accuracy

444

00:20:29,960 --> 00:20:35,360

for these pulses is incredibly high it's

445

00:20:33,710 --> 00:20:37,250

so high that when they were first

446

00:20:35,359 --> 00:20:39,819

discovered they were thought that they

447

00:20:37,250 --> 00:20:42,259

might even be extraterrestrial sources

448

00:20:39,819 --> 00:20:43,909

but in fact when more sources were

449

00:20:42,259 --> 00:20:45,799

discovered across the sky it was

450

00:20:43,910 --> 00:20:48,710

realized that actually a natural process

451

00:20:45,799 --> 00:20:51,079

must be causing these but their accuracy

452

00:20:48,710 --> 00:20:56,210

is such that it rivals that of atomic

453

00:20:51,079 --> 00:21:00,289

clocks except for this one pulsar that

454

00:20:56,210 --> 00:21:04,009

Alex Vause Shem saw so this pulsar was

455

00:21:00,289 --> 00:21:07,309

called PSR b12 57 plus 12 that very

456

00:21:04,009 --> 00:21:10,400

catchy name and for this particular

457
00:21:07,309 --> 00:21:12,440
pulsar so PSR is pulsating source of

458
00:21:10,400 --> 00:21:14,680
radio and then that's completely our

459
00:21:12,440 --> 00:21:17,420
memorable letters and numbers is the

460
00:21:14,680 --> 00:21:20,120
position in the sky but for this

461
00:21:17,420 --> 00:21:23,840
particular pulsar the time between the

462
00:21:20,119 --> 00:21:26,089
flashes changed very slightly and it was

463
00:21:23,839 --> 00:21:29,000
ultimately concluded that this was due

464
00:21:26,089 --> 00:21:32,240
to two planets orbiting the Pulsar and

465
00:21:29,000 --> 00:21:34,849
as the planets orbited the Pulsar the

466
00:21:32,240 --> 00:21:37,430
Pulsar wobbled very slightly due to the

467
00:21:34,849 --> 00:21:39,859
planet's gravity and as it wobbled his

468
00:21:37,430 --> 00:21:42,620
distance from the earth was changing a

469
00:21:39,859 --> 00:21:44,299
tiny amount and this was causing the

470
00:21:42,619 --> 00:21:45,829
flashes to have to travel slightly

471
00:21:44,299 --> 00:21:48,319
further and slightly less far and

472
00:21:45,829 --> 00:21:53,359
therefore their timing started to become

473
00:21:48,319 --> 00:21:55,399
off so the discovery was two planets

474
00:21:53,359 --> 00:21:59,869
which were again very imaginative named

475
00:21:55,400 --> 00:22:01,440
PSR b12 57 plus 12 B and C and they were

476
00:21:59,869 --> 00:22:04,048
roughly four

477
00:22:01,440 --> 00:22:06,419
times the mass of the earth and their

478
00:22:04,048 --> 00:22:10,259
years they're all bits around the Pulsar

479
00:22:06,419 --> 00:22:13,019
were 65 and 98 days so for comparison

480
00:22:10,259 --> 00:22:15,839
but Korea our innermost planet has an

481
00:22:13,019 --> 00:22:17,759
orbit of 88 days so if these two were

482
00:22:15,839 --> 00:22:20,878
around our own Sun they were sick either

483
00:22:17,759 --> 00:22:23,159
side of mercury and they are a rather

484
00:22:20,878 --> 00:22:25,769
staggering two thousand light years away

485

00:22:23,159 --> 00:22:28,889
which tells you exactly how sensitive

486
00:22:25,769 --> 00:22:31,620
this technique was now these were the

487
00:22:28,888 --> 00:22:34,589
first planets ever to be found outside

488
00:22:31,619 --> 00:22:36,388
our solar system and the discovery was a

489
00:22:34,589 --> 00:22:38,609
pretty enough published in the

490
00:22:36,388 --> 00:22:42,928
international journal Nature on the 9th

491
00:22:38,609 --> 00:22:45,658
of January in 1992 however he actually

492
00:22:42,929 --> 00:22:48,360
was linked earlier than that by the

493
00:22:45,659 --> 00:22:51,679
British British broadsheet newspaper the

494
00:22:48,359 --> 00:22:54,990
independence on the 29th of October 1991

495
00:22:51,679 --> 00:22:58,048
with the headline radio astronomer finds

496
00:22:54,990 --> 00:22:59,278
two planets in distant space now Alex

497
00:22:58,048 --> 00:23:01,829
Borstein was approached by the

498
00:22:59,278 --> 00:23:03,720
independent and asked by for a quote and

499
00:23:01,829 --> 00:23:05,548

this must have been fairly nerve-racking

500

00:23:03,720 --> 00:23:07,139

because obviously he wanted this

501

00:23:05,548 --> 00:23:12,148

discovery to be published in a journal

502

00:23:07,138 --> 00:23:14,548

such as nature but if news gets out

503

00:23:12,148 --> 00:23:15,959

early sometimes nature might be like

504

00:23:14,548 --> 00:23:18,509

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

505

00:23:15,960 --> 00:23:20,669

want it so as a result there's a very

506

00:23:18,509 --> 00:23:22,798

guarded comment by Alex Vause shown here

507

00:23:20,669 --> 00:23:24,120

saying professor volscian was not

508

00:23:22,798 --> 00:23:26,158

prepared to talk about his research

509

00:23:24,119 --> 00:23:27,928

because he feared it might prejudice the

510

00:23:26,159 --> 00:23:32,278

chances of being published in a

511

00:23:27,929 --> 00:23:34,769

scientific journal however despite this

512

00:23:32,278 --> 00:23:37,740

even after the nature publication there

513

00:23:34,769 --> 00:23:39,028

was very little public notice which when

514

00:23:37,740 --> 00:23:41,159

you think of the fuss that new

515

00:23:39,028 --> 00:23:43,109

discoveries have nowadays where you have

516

00:23:41,159 --> 00:23:46,019

multiple reports against the whole world

517

00:23:43,109 --> 00:23:48,538

media is very surprising that the first

518

00:23:46,019 --> 00:23:50,849

planets we ever found no one really

519

00:23:48,538 --> 00:23:52,769

talked about indeed at the time when my

520

00:23:50,849 --> 00:23:54,269

parents were taking the independent and

521

00:23:52,769 --> 00:23:55,859

this newspaper must have sat on our

522

00:23:54,269 --> 00:23:59,700

kitchen table and I don't remember it at

523

00:23:55,859 --> 00:24:02,339

all so what was the problem was it that

524

00:23:59,700 --> 00:24:05,190

just pulsar planets were just a bit too

525

00:24:02,339 --> 00:24:07,079

weird I mean you know pulsars dead stars

526

00:24:05,190 --> 00:24:09,139

can't really relate to those hopefully

527

00:24:07,079 --> 00:24:11,398

never will be able to relate to those

528
00:24:09,138 --> 00:24:14,469
maybe people just didn't really feel a

529
00:24:11,398 --> 00:24:17,149
connection connection

530
00:24:14,470 --> 00:24:20,980
so as a result these are sort of

531
00:24:17,150 --> 00:24:23,360
overlooked but pulsar timings

532
00:24:20,980 --> 00:24:27,079
unsurprisingly it can only be used to

533
00:24:23,359 --> 00:24:29,359
find planets around pulsars so what

534
00:24:27,079 --> 00:24:32,210
about finding planets around regular

535
00:24:29,359 --> 00:24:34,699
stars so we found the Pulsar planets

536
00:24:32,210 --> 00:24:37,700
because there is this slight change in

537
00:24:34,700 --> 00:24:39,440
the timing of the Pulsar flash due to

538
00:24:37,700 --> 00:24:42,500
this wobble in the Stars position

539
00:24:39,440 --> 00:24:44,930
because of the planets orbit so could we

540
00:24:42,500 --> 00:24:47,480
do this with normal star light as well

541
00:24:44,930 --> 00:24:48,529
and obviously the answer is yes or I

542

00:24:47,480 --> 00:24:52,940
would not have taken us in this

543
00:24:48,529 --> 00:24:54,710
direction so when you have a more

544
00:24:52,940 --> 00:24:57,140
regular star you have a system like this

545
00:24:54,710 --> 00:24:59,480
so here are we on the earth there's our

546
00:24:57,140 --> 00:25:01,310
star here and here is our planet and due

547
00:24:59,480 --> 00:25:04,430
to the planets orbit the star is going

548
00:25:01,309 --> 00:25:07,009
to make a small wobble now as the star

549
00:25:04,430 --> 00:25:08,480
moves away from the earth its light

550
00:25:07,009 --> 00:25:11,210
that's reaching us is going to get

551
00:25:08,480 --> 00:25:14,120
stretched out and this is going to cause

552
00:25:11,210 --> 00:25:15,829
it to become redder now as it swings

553
00:25:14,119 --> 00:25:17,959
around the other side of it's wobbling

554
00:25:15,829 --> 00:25:20,269
position the light waves are going to

555
00:25:17,960 --> 00:25:22,670
become compressed as the star starts

556
00:25:20,269 --> 00:25:23,509

approaching the earth and when they get

557

00:25:22,670 --> 00:25:26,840
compressed

558

00:25:23,509 --> 00:25:29,240
they liked gets bluer so what you see is

559

00:25:26,839 --> 00:25:32,179
this tiny shift from red to blue to red

560

00:25:29,240 --> 00:25:34,789
to blue as the star wobbles due to its

561

00:25:32,180 --> 00:25:37,220
orbit from the planet and we call this

562

00:25:34,789 --> 00:25:40,149
the radial velocity technique or

563

00:25:37,220 --> 00:25:44,839
sometimes a Doppler wobble technique

564

00:25:40,150 --> 00:25:47,030
however this is not a big shift the tiny

565

00:25:44,839 --> 00:25:48,459
tiny shift in light and it's incredibly

566

00:25:47,029 --> 00:25:53,539
hard to measure

567

00:25:48,460 --> 00:25:56,420
however in 1988 a new technique was

568

00:25:53,539 --> 00:25:58,190
established so in this technique you

569

00:25:56,420 --> 00:26:00,410
have your star emitting lights and

570

00:25:58,190 --> 00:26:02,630
you've got your telescope and in front

571
00:26:00,410 --> 00:26:06,529
of the telescope we're going to put a

572
00:26:02,630 --> 00:26:08,510
jar of gas and the point is here that

573
00:26:06,529 --> 00:26:10,309
here is your star and it's light is

574
00:26:08,509 --> 00:26:14,599
going to be slowly shifting from red to

575
00:26:10,309 --> 00:26:16,940
blue tiny tiny tiny shift but our jar of

576
00:26:14,599 --> 00:26:18,980
gas is also going to be a missing light

577
00:26:16,940 --> 00:26:20,930
that is not shifting because it's

578
00:26:18,980 --> 00:26:23,660
completely stationary in front of our

579
00:26:20,930 --> 00:26:26,150
telescope so what it is is it's a bit

580
00:26:23,660 --> 00:26:27,980
like slamming down a ruler and because

581
00:26:26,150 --> 00:26:30,259
you have a stationary point

582
00:26:27,980 --> 00:26:32,480
with which to compare that starlight it

583
00:26:30,259 --> 00:26:35,990
becomes much easier to measure tiny

584
00:26:32,480 --> 00:26:38,000
shifts so this allowed us to have much

585
00:26:35,990 --> 00:26:42,380
higher accuracy when trying to measure

586
00:26:38,000 --> 00:26:45,890
this radial velocity change and using

587
00:26:42,380 --> 00:26:49,000
this technique as early as 1988 a wobble

588
00:26:45,890 --> 00:26:54,650
was seen around a star called gammas Fe

589
00:26:49,000 --> 00:26:55,839
could this be from an exoplanet so there

590
00:26:54,650 --> 00:26:58,940
were some problems

591
00:26:55,839 --> 00:27:01,639
gammas Fe is part of a binary star

592
00:26:58,940 --> 00:27:05,120
system meaning it has a companion star

593
00:27:01,640 --> 00:27:07,280
and the two stars orbit one another so

594
00:27:05,119 --> 00:27:09,469
this was the first question mark would

595
00:27:07,279 --> 00:27:12,440
we even expect planets around a binary

596
00:27:09,470 --> 00:27:13,700
system if you had a sister star would

597
00:27:12,440 --> 00:27:18,320
that disrupt the planet formation

598
00:27:13,700 --> 00:27:21,080
process secondly the star that was

599

00:27:18,319 --> 00:27:23,480
wobbling was thought to be a giant star

600
00:27:21,079 --> 00:27:26,389
now this is the phase that stars reach

601
00:27:23,480 --> 00:27:28,160
near the end of their life and as they

602
00:27:26,390 --> 00:27:31,190
approach the end of their life they get

603
00:27:28,160 --> 00:27:33,529
quite crotchety so what you find is the

604
00:27:31,190 --> 00:27:36,529
outer layers of the star start to have a

605
00:27:33,529 --> 00:27:39,048
lot of vibrations and pulsations that

606
00:27:36,529 --> 00:27:43,250
look just like a small bubble from a

607
00:27:39,048 --> 00:27:45,889
planet so the astronomers were a bit

608
00:27:43,250 --> 00:27:48,470
suspicious and in the end they concluded

609
00:27:45,890 --> 00:27:50,570
oh it's a giant star it's a binary we

610
00:27:48,470 --> 00:27:52,579
don't really expect to see a planet here

611
00:27:50,569 --> 00:27:55,250
there are lots of other reasons for this

612
00:27:52,579 --> 00:27:57,409
possible wobble now we see a wobble but

613
00:27:55,250 --> 00:27:59,630

it's not a planet and when they

614

00:27:57,410 --> 00:28:02,450

announced that they missed discovering

615

00:27:59,630 --> 00:28:04,790

the first exoplanets because this wobble

616

00:28:02,450 --> 00:28:06,860

was due to a planet but its discovery

617

00:28:04,789 --> 00:28:09,279

was not finally announced I think until

618

00:28:06,859 --> 00:28:12,859

2013

619

00:28:09,279 --> 00:28:15,740

so the first discovery that actually

620

00:28:12,859 --> 00:28:19,250

everyone remembers is a planet called a

621

00:28:15,740 --> 00:28:21,740

51 pegasi B that was found in 1995 with

622

00:28:19,250 --> 00:28:24,859

this same radial velocity technique with

623

00:28:21,740 --> 00:28:26,660

a light shifting from red to blue and it

624

00:28:24,859 --> 00:28:29,599

was the first planet that was found

625

00:28:26,660 --> 00:28:31,940

around a star like our Sun rather than a

626

00:28:29,599 --> 00:28:35,808

giant star or a long-dead star like a

627

00:28:31,940 --> 00:28:38,210

pulsar and it opened the floodgates to

628
00:28:35,808 --> 00:28:40,629
finding thousands more because it proved

629
00:28:38,210 --> 00:28:43,509
this radial velocity wobble

630
00:28:40,630 --> 00:28:45,670
was detectable we could see it and from

631
00:28:43,509 --> 00:28:46,740
there we started discovering planets in

632
00:28:45,670 --> 00:28:50,500
droves

633
00:28:46,740 --> 00:28:55,930
however this planet was also rather

634
00:28:50,500 --> 00:28:58,450
strange so back to our own solar system

635
00:28:55,930 --> 00:29:00,850
and one thing that we note is there are

636
00:28:58,450 --> 00:29:03,759
giant planets these huge gaseous ones

637
00:29:00,849 --> 00:29:06,279
sit a long way from the Sun we have the

638
00:29:03,759 --> 00:29:09,819
rocky ones close and we have the gaseous

639
00:29:06,279 --> 00:29:13,089
ones further away but this planet 51

640
00:29:09,819 --> 00:29:16,899
Pegasus B was a gas giant on the orbit

641
00:29:13,089 --> 00:29:21,220
of just four days so if remember mercury

642
00:29:16,900 --> 00:29:25,240
is 88 days that puts 51 Pegasus B really

643
00:29:21,220 --> 00:29:28,240
really close to its star so how do you

644
00:29:25,240 --> 00:29:30,160
form a planet there well let's just take

645
00:29:28,240 --> 00:29:34,059
a step back and ask why this is at all

646
00:29:30,160 --> 00:29:36,940
surprising so young stars are surrounded

647
00:29:34,059 --> 00:29:39,759
by disks of gas and dust known as

648
00:29:36,940 --> 00:29:42,220
protoplanetary discs now this image here

649
00:29:39,759 --> 00:29:46,470
is an artist's impression however this

650
00:29:42,220 --> 00:29:48,700
one is not this is a genuine image of a

651
00:29:46,470 --> 00:29:54,220
protoplanetary disc around a young star

652
00:29:48,700 --> 00:29:56,440
taken with Alma and in this disk of dust

653
00:29:54,220 --> 00:29:59,980
and gas dust starts off at micrometer

654
00:29:56,440 --> 00:30:02,590
sizes and it starts to collide and sli

655
00:29:59,980 --> 00:30:05,950
so we go from a chromatid to millimeter

656

00:30:02,589 --> 00:30:07,299
to centimeter up to meet her sizes and

657
00:30:05,950 --> 00:30:10,330
now we're starting to look a bit like

658
00:30:07,299 --> 00:30:13,180
the asteroids and eventually gravity

659
00:30:10,329 --> 00:30:16,299
finally gets seriously interested and it

660
00:30:13,180 --> 00:30:18,580
squishes our newly formed planet into a

661
00:30:16,299 --> 00:30:21,279
ball and we start to say yes okay I

662
00:30:18,579 --> 00:30:24,250
notice that's a planet now there is one

663
00:30:21,279 --> 00:30:28,119
subtlety to this process I'm sure will

664
00:30:24,250 --> 00:30:31,869
astound everyone if you are forming near

665
00:30:28,119 --> 00:30:33,459
the new star you're hot on the other

666
00:30:31,869 --> 00:30:37,569
hand if you're forming a long way away

667
00:30:33,460 --> 00:30:40,299
you're cold and this has one important

668
00:30:37,569 --> 00:30:43,000
effect there comes a point as you step

669
00:30:40,299 --> 00:30:45,669
away from the star that ice starts to

670
00:30:43,000 --> 00:30:48,250

form and we call this point the ice line

671

00:30:45,670 --> 00:30:50,350

the snow line or the frost line if you

672

00:30:48,250 --> 00:30:53,230

are inside the ice line and closer to

673

00:30:50,349 --> 00:30:54,339

the star water is a vapor on the other

674

00:30:53,230 --> 00:30:58,179

hand if you are the others

675

00:30:54,339 --> 00:31:00,759

side of it then it is a solid and that

676

00:30:58,179 --> 00:31:03,278

means you get a huge boost in

677

00:31:00,759 --> 00:31:05,679

planet-forming material the other side

678

00:31:03,278 --> 00:31:07,480

of the ice line because here you've got

679

00:31:05,679 --> 00:31:09,610

your silicates like what the earth is

680

00:31:07,480 --> 00:31:11,919

mainly formed off but out here you've

681

00:31:09,609 --> 00:31:14,829

got the silicates but also a huge a

682

00:31:11,919 --> 00:31:16,570

number of ices so you get a big step in

683

00:31:14,829 --> 00:31:20,980

density it's like being given a whole

684

00:31:16,569 --> 00:31:23,319

new letter set so as a result we expect

685
00:31:20,980 --> 00:31:25,659
small planets to form here where we have

686
00:31:23,319 --> 00:31:27,970
less building material and giant planets

687
00:31:25,659 --> 00:31:30,520
to form here where we have a lot more

688
00:31:27,970 --> 00:31:32,620
and this should be the same around every

689
00:31:30,519 --> 00:31:34,418
star because the only assumption I put

690
00:31:32,619 --> 00:31:36,129
in here is then you're hot if you're

691
00:31:34,419 --> 00:31:40,600
close to the star which you think would

692
00:31:36,130 --> 00:31:42,820
be universally true so how do we get a

693
00:31:40,599 --> 00:31:45,038
planet here there should be barely any

694
00:31:42,819 --> 00:31:47,079
building material there and yet 51

695
00:31:45,038 --> 00:31:51,460
pegasi B was roughly the same size as

696
00:31:47,079 --> 00:31:54,129
Jupiter so this is what we think happens

697
00:31:51,460 --> 00:31:55,750
as the planet grows it eventually

698
00:31:54,130 --> 00:31:57,820
reaches the size of Mars

699
00:31:55,750 --> 00:32:01,058
now Mars is not a big planet it is

700
00:31:57,819 --> 00:32:03,038
roughly a tenth of the mass of Earth but

701
00:32:01,058 --> 00:32:05,230
however at that point the planets

702
00:32:03,038 --> 00:32:07,750
gravity gets strong enough that it

703
00:32:05,230 --> 00:32:09,940
starts to pull on the surrounding gas

704
00:32:07,750 --> 00:32:13,329
and dust that still circle the young

705
00:32:09,940 --> 00:32:16,240
star and this gas and dust pulls back

706
00:32:13,329 --> 00:32:19,599
and the result is like being on a

707
00:32:16,240 --> 00:32:21,099
running track so here you are and you're

708
00:32:19,599 --> 00:32:24,538
going to be running this circular race

709
00:32:21,099 --> 00:32:27,908
with two buddies a buddy and a detective

710
00:32:24,538 --> 00:32:30,429
and a little later on oh no I'm sorry

711
00:32:27,909 --> 00:32:31,990
yes there's been a terrible addition

712
00:32:30,429 --> 00:32:35,320
where for some reason you've been tied

713

00:32:31,990 --> 00:32:37,899
to your friends with a piece of loop but

714
00:32:35,319 --> 00:32:39,939
a little later on war here now your

715
00:32:37,898 --> 00:32:41,349
bunny friend was on the inside running

716
00:32:39,940 --> 00:32:43,450
track and as I'm sure everyone remembers

717
00:32:41,349 --> 00:32:46,148
from school PE lessons that gives you a

718
00:32:43,450 --> 00:32:47,919
very unfair advantage so they're on a

719
00:32:46,148 --> 00:32:50,408
much shorter running track and he's

720
00:32:47,919 --> 00:32:52,270
pulled ahead of you on the other hand

721
00:32:50,409 --> 00:32:54,580
your detective friend or was on the

722
00:32:52,269 --> 00:32:56,829
outside running track and had further to

723
00:32:54,579 --> 00:32:59,139
go and therefore she is a little bit

724
00:32:56,829 --> 00:33:01,210
further behind but you're still tied

725
00:32:59,140 --> 00:33:03,429
together with this rope so you start to

726
00:33:01,210 --> 00:33:05,200
feel a force with the bunny pulling you

727
00:33:03,429 --> 00:33:07,840

forward and a detective pulling you back

728

00:33:05,200 --> 00:33:10,330
and the same thing happened

729

00:33:07,839 --> 00:33:12,849
due to gravity with our new planet in

730

00:33:10,329 --> 00:33:15,308
our disk where the gas closer to the

731

00:33:12,849 --> 00:33:16,869
star is pulling ahead and dragging on

732

00:33:15,308 --> 00:33:19,538
that planet to move it forward

733

00:33:16,869 --> 00:33:21,639
whereas the gas further out is pulling

734

00:33:19,538 --> 00:33:25,900
back and trying to slow that planet down

735

00:33:21,640 --> 00:33:29,049
and as a result you end up in this tug

736

00:33:25,900 --> 00:33:33,759
of war and the net result is usually

737

00:33:29,048 --> 00:33:36,879
that the planet feels a push inwards so

738

00:33:33,759 --> 00:33:39,579
what this means is oh yes and we call

739

00:33:36,880 --> 00:33:42,220
this migration so what this means is

740

00:33:39,579 --> 00:33:43,898
your planet can start far out it can

741

00:33:42,220 --> 00:33:46,120
form where there's lots of ice there's

742
00:33:43,898 --> 00:33:49,298
lots of building material and it can get

743
00:33:46,119 --> 00:33:52,689
big and jupiter-sized but it can then

744
00:33:49,298 --> 00:33:55,000
migrated inwards due to this pull from

745
00:33:52,690 --> 00:33:57,788
the gas disc and when the gas disc is

746
00:33:55,000 --> 00:34:00,730
finally evaporated by the star you end

747
00:33:57,788 --> 00:34:03,819
up with a large planet close to the star

748
00:34:00,730 --> 00:34:07,569
and we call these hot Jupiters because

749
00:34:03,819 --> 00:34:11,230
they're Jupiter size and hot so this

750
00:34:07,569 --> 00:34:13,119
explained 51 Pegasus B but what about

751
00:34:11,230 --> 00:34:16,809
the Pulsar planets what could explain

752
00:34:13,119 --> 00:34:19,030
them and were they even surprising well

753
00:34:16,809 --> 00:34:21,429
the problem with pulsar planets is as

754
00:34:19,030 --> 00:34:25,419
they briefly mentioned pulsars a start

755
00:34:21,429 --> 00:34:27,909
with an explosion a supernova so when

756
00:34:25,418 --> 00:34:30,819
they explode if they still have planets

757
00:34:27,909 --> 00:34:34,148
orbiting them too awful things can

758
00:34:30,820 --> 00:34:37,030
happen to those planets the first is one

759
00:34:34,148 --> 00:34:39,338
could be vaporized the second is the

760
00:34:37,030 --> 00:34:42,280
shockwave from that explosion can kick

761
00:34:39,338 --> 00:34:44,619
the planet out of the solar system so

762
00:34:42,280 --> 00:34:47,050
generally speaking we do not expect

763
00:34:44,619 --> 00:34:50,440
these planets to be able to survive this

764
00:34:47,050 --> 00:34:52,690
supernova explosion so how on earth do

765
00:34:50,440 --> 00:34:56,710
you end up with a pulsar orbited by

766
00:34:52,690 --> 00:34:59,230
planets well evidence to what might have

767
00:34:56,710 --> 00:35:01,599
happened was discovered in 2012 when a

768
00:34:59,230 --> 00:35:05,588
tiny star was found that seemed to be

769
00:35:01,599 --> 00:35:08,859
flashing red and then blue and it turned

770

00:35:05,588 --> 00:35:10,838
out to be orbiting a pulsar every and 93

771
00:35:08,858 --> 00:35:13,489
minutes which is actually the average

772
00:35:10,838 --> 00:35:16,519
commute time in the UK

773
00:35:13,489 --> 00:35:19,009
but as this planet orbited the Pulsar

774
00:35:16,519 --> 00:35:22,429
you actually started to see different

775
00:35:19,010 --> 00:35:24,560
sides of it so if the Pulsar is here and

776
00:35:22,429 --> 00:35:26,809
you are the earth first of all you're

777
00:35:24,559 --> 00:35:29,150
seeing the front side and the front side

778
00:35:26,809 --> 00:35:32,750
was being hit by the pulsars Jets and

779
00:35:29,150 --> 00:35:35,480
becoming very hot however as the star

780
00:35:32,750 --> 00:35:39,079
orbited you started to see the backside

781
00:35:35,480 --> 00:35:41,210
and this was much colder so what you

782
00:35:39,079 --> 00:35:42,889
were seeing was intermittently the hot

783
00:35:41,210 --> 00:35:45,079
side of the star then the cold side

784
00:35:42,889 --> 00:35:49,368

seeing this flash from red to blue and

785

00:35:45,079 --> 00:35:51,380

back again but because the Pulsar was

786

00:35:49,369 --> 00:35:54,530

being hit but purrs the star was being

787

00:35:51,380 --> 00:35:58,220

hit by the pulsars Jets the Pulsar was

788

00:35:54,530 --> 00:36:00,890

blowtorching it to pieces so you have a

789

00:35:58,219 --> 00:36:02,899

system a little bit like this one where

790

00:36:00,889 --> 00:36:06,049

the pulsars Jets were ripping over the

791

00:36:02,900 --> 00:36:08,720

star and shredding it and as the star

792

00:36:06,050 --> 00:36:11,810

ripped as a pulsar ripped this other

793

00:36:08,719 --> 00:36:15,529

star to pieces and disc formed from it's

794

00:36:11,809 --> 00:36:17,150

ruined body and in this disk planets

795

00:36:15,530 --> 00:36:19,970

could start to form again

796

00:36:17,150 --> 00:36:22,579

so pulsar planets have rather a morbid

797

00:36:19,969 --> 00:36:25,368

origin they require another star to be

798

00:36:22,579 --> 00:36:32,659

shredded to pieces and is broken body to

799
00:36:25,369 --> 00:36:35,650
form the birth ground of new planets so

800
00:36:32,659 --> 00:36:39,259
these first finds were strange worlds

801
00:36:35,650 --> 00:36:40,880
but later we found many planets that

802
00:36:39,260 --> 00:36:44,359
were much closer in size to the earth

803
00:36:40,880 --> 00:36:46,280
orbiting around normal stars around now

804
00:36:44,358 --> 00:36:48,969
we have found I think about three and a

805
00:36:46,280 --> 00:36:51,710
half thousand planets beyond our Sun and

806
00:36:48,969 --> 00:36:53,868
roughly a third of those have a radius

807
00:36:51,710 --> 00:36:56,840
that is less than twice of that of the

808
00:36:53,869 --> 00:37:03,789
earth so this brings us to the obvious

809
00:36:56,840 --> 00:37:06,559
question can we find earth 2.0 well

810
00:37:03,789 --> 00:37:08,449
let's look what we know with an example

811
00:37:06,559 --> 00:37:11,358
that hit the news at the beginning of

812
00:37:08,449 --> 00:37:12,858
this year and the telescope that made

813
00:37:11,358 --> 00:37:14,900
this news with a telescope called

814
00:37:12,858 --> 00:37:17,659
transiting planets and planetesimals a

815
00:37:14,900 --> 00:37:20,690
small telescope and it's a 60 centimeter

816
00:37:17,659 --> 00:37:23,449
telescope in Chile and if you take these

817
00:37:20,690 --> 00:37:26,720
letters very slightly randomly you can

818
00:37:23,449 --> 00:37:28,489
spell trust which I

819
00:37:26,719 --> 00:37:30,559
sure entirely ko is deadly because it's

820
00:37:28,489 --> 00:37:34,608
a Belgium telescope also happens to be

821
00:37:30,559 --> 00:37:37,190
the name of a Belgian beer but in

822
00:37:34,608 --> 00:37:38,019
February Trappist made an incredible

823
00:37:37,190 --> 00:37:42,260
discovery

824
00:37:38,019 --> 00:37:44,449
it found a star orbited by seven planets

825
00:37:42,260 --> 00:37:46,820
now as a telescope that made the

826
00:37:44,449 --> 00:37:49,429
discovery the star was named Trappist

827

00:37:46,820 --> 00:37:54,859
one and the planets became Trappist one

828
00:37:49,429 --> 00:37:58,969
b c d e f g and h so was this a solar

829
00:37:54,858 --> 00:38:00,069
system like our own well the press got

830
00:37:58,969 --> 00:38:02,959
pretty excited

831
00:38:00,070 --> 00:38:05,300
we had headlines like NASA's discovery

832
00:38:02,960 --> 00:38:07,670
of a solar system with seven earth-like

833
00:38:05,300 --> 00:38:10,609
planets will change how we hunt for

834
00:38:07,670 --> 00:38:13,010
alien life we had four new scientist

835
00:38:10,608 --> 00:38:13,909
exoplanet discoveries seven earth-sized

836
00:38:13,010 --> 00:38:16,940
exoplanet s--

837
00:38:13,909 --> 00:38:19,250
may have water or from the guardian

838
00:38:16,940 --> 00:38:22,420
exoplanet discovery seven earth sized

839
00:38:19,250 --> 00:38:24,739
planets found orbiting a nearby star

840
00:38:22,420 --> 00:38:26,150
clearly if you just read the press

841
00:38:24,739 --> 00:38:30,618

headlines you would think we'd found

842

00:38:26,150 --> 00:38:32,780

this clearly seven earth septuplets all

843

00:38:30,619 --> 00:38:37,910

identical probably already have

844

00:38:32,780 --> 00:38:42,349

Starbucks on them but what do we really

845

00:38:37,909 --> 00:38:43,969

know about them well these planets were

846

00:38:42,349 --> 00:38:46,250

discovered not with the radial velocity

847

00:38:43,969 --> 00:38:49,549

technique but with the transit technique

848

00:38:46,250 --> 00:38:52,338

and this is when the planets moves in

849

00:38:49,550 --> 00:38:54,830

front of the Stars surface and causes a

850

00:38:52,338 --> 00:38:56,750

tiny dip in the Starlight and it's how

851

00:38:54,829 --> 00:38:59,779

the Kepler space telescope finds its

852

00:38:56,750 --> 00:39:03,230

planets so in the case of the Trappist

853

00:38:59,780 --> 00:39:07,040

seven we see seven periodic dips as the

854

00:39:03,230 --> 00:39:10,070

planets passed by the star surface now

855

00:39:07,039 --> 00:39:12,230

transits usually give what they do they

856
00:39:10,070 --> 00:39:14,390
give you the planet radius the physical

857
00:39:12,230 --> 00:39:16,329
size of the planet so the bigger the

858
00:39:14,389 --> 00:39:19,279
planet the more light it blocks out and

859
00:39:16,329 --> 00:39:21,829
you can pick this up with the transit it

860
00:39:19,280 --> 00:39:26,900
doesn't normally tell you the planet

861
00:39:21,829 --> 00:39:30,588
mass normally but the Trappist planets

862
00:39:26,900 --> 00:39:33,858
were slightly different so Trappist one

863
00:39:30,588 --> 00:39:37,009
has many planets it has seven and as

864
00:39:33,858 --> 00:39:40,610
they orbit the star the planets pull on

865
00:39:37,010 --> 00:39:43,160
one another and as a result this slope

866
00:39:40,610 --> 00:39:44,750
change the time for each orbit so this

867
00:39:43,159 --> 00:39:46,759
is like if you're running around you're

868
00:39:44,750 --> 00:39:48,860
circular running track again but this

869
00:39:46,760 --> 00:39:52,430
time you've taken your dog along for the

870
00:39:48,860 --> 00:39:54,860
run and your dog is not always terribly

871
00:39:52,429 --> 00:39:57,079
cooperative sometimes your dog is

872
00:39:54,860 --> 00:39:59,480
pulling you forward and that means you

873
00:39:57,079 --> 00:40:01,730
make your lap time slightly quicker but

874
00:39:59,480 --> 00:40:04,219
sometimes your dog just wants to sniff

875
00:40:01,730 --> 00:40:06,289
stuff and it's pulling you back and so

876
00:40:04,219 --> 00:40:09,980
your lap time becomes slightly slower

877
00:40:06,289 --> 00:40:10,550
and these changes in lap time can be

878
00:40:09,980 --> 00:40:12,320
measured

879
00:40:10,550 --> 00:40:15,590
due to the planets pulling on each other

880
00:40:12,320 --> 00:40:21,320
and we call this transit timing

881
00:40:15,590 --> 00:40:24,220
variations or TT V so I have a movie

882
00:40:21,320 --> 00:40:24,220
that demonstrates this

883
00:40:26,949 --> 00:40:30,019
[Music]

884

00:40:38,150 --> 00:40:52,159
[Music]

885
00:40:54,559 --> 00:41:00,500
[Music]

886
00:41:02,579 --> 00:41:37,309
[Music]

887
00:41:19,210 --> 00:41:39,320
and now what we see is a so the great

888
00:41:37,309 --> 00:41:44,389
bernard is going to have a ward effect

889
00:41:39,320 --> 00:41:46,910
on your lap time so ttv actually gives

890
00:41:44,389 --> 00:41:49,849
the mass of the planet in addition to

891
00:41:46,909 --> 00:41:52,730
the planet's physical size so what did

892
00:41:49,849 --> 00:41:54,799
we see with these seven worlds well

893
00:41:52,730 --> 00:41:56,990
let's look at radius as a function of

894
00:41:54,800 --> 00:41:58,820
Earth mass and we see we have three

895
00:41:56,989 --> 00:42:02,719
planets with almost exactly the same

896
00:41:58,820 --> 00:42:05,120
size as Earth and three planets with a

897
00:42:02,719 --> 00:42:07,609
slightly smaller size on earth and one

898
00:42:05,119 --> 00:42:10,489

slightly larger and if we look at the

899

00:42:07,610 --> 00:42:13,789

masses we have anything between 40 and

900

00:42:10,489 --> 00:42:18,529

140 times the matter percentage of the

901

00:42:13,789 --> 00:42:21,309

mass of the earth so we have roughly we

902

00:42:18,530 --> 00:42:26,650

have seven roughly earth sized planets

903

00:42:21,309 --> 00:42:32,029

so here is the question does earth size

904

00:42:26,650 --> 00:42:35,809

mean earth-like well what else do we

905

00:42:32,030 --> 00:42:38,300

know about this system now on earth a

906

00:42:35,809 --> 00:42:42,079

year so our lap around the Sun takes

907

00:42:38,300 --> 00:42:46,610

approximately 365 days if you were on

908

00:42:42,079 --> 00:42:50,269

Mars it would take 687 days if you're on

909

00:42:46,610 --> 00:42:55,099

Venus will be 225 and Mercury would be

910

00:42:50,269 --> 00:42:56,989

88 the Trappist planets the one furthest

911

00:42:55,099 --> 00:43:02,019

from the star that's going to take the

912

00:42:56,989 --> 00:43:06,649

longest orbital time will take 20 days

913
00:43:02,019 --> 00:43:10,940
twelve days nine days six days for 2.4

914
00:43:06,650 --> 00:43:13,250
and 1.5 days to make that orbit so if

915
00:43:10,940 --> 00:43:16,630
these were around our Sun all of these

916
00:43:13,250 --> 00:43:19,909
planets would sit inside Mercury's orbit

917
00:43:16,630 --> 00:43:22,519
so does this mean that the Trappist one

918
00:43:19,909 --> 00:43:25,359
worlds are in fact larva worlds with

919
00:43:22,519 --> 00:43:28,900
melted crusts of magma

920
00:43:25,360 --> 00:43:31,838
well something fortunately saves us

921
00:43:28,900 --> 00:43:34,809
and that is the Trappist one is very dim

922
00:43:31,838 --> 00:43:36,429
if we were to compare the size of the

923
00:43:34,809 --> 00:43:39,789
Sun with a basketball

924
00:43:36,429 --> 00:43:43,118
then Trappist one only has the size of a

925
00:43:39,789 --> 00:43:46,028
golf ball and it has only a thousands of

926
00:43:43,119 --> 00:43:48,460
the sun's brightness so that means you

927
00:43:46,028 --> 00:43:51,190
can afford it to be a lot closer but not

928
00:43:48,460 --> 00:43:53,829
that much hotter so if we compare

929
00:43:51,190 --> 00:43:55,929
instead the amount of radiation the

930
00:43:53,829 --> 00:43:58,480
planets receive then the amount of

931
00:43:55,929 --> 00:44:01,960
radiation that we get from the Sun over

932
00:43:58,480 --> 00:44:04,210
Venus Earth and Mercury is approximately

933
00:44:01,960 --> 00:44:08,889
equal to the amount of radiation

934
00:44:04,210 --> 00:44:12,159
received by planet C D E and F so very

935
00:44:08,889 --> 00:44:15,429
similar radiation for these planets so

936
00:44:12,159 --> 00:44:17,980
what about water well when we talk about

937
00:44:15,429 --> 00:44:19,929
water especially with exoplanets we

938
00:44:17,980 --> 00:44:23,679
typically talk about something called

939
00:44:19,929 --> 00:44:25,838
the habitable zone and this is the

940
00:44:23,679 --> 00:44:29,048
location where an earth-like planet

941

00:44:25,838 --> 00:44:31,058
could have water on its surface so you

942
00:44:29,048 --> 00:44:33,880
can imagine taking the earth and giving

943
00:44:31,059 --> 00:44:36,220
it a push towards the Sun and at the

944
00:44:33,880 --> 00:44:38,650
point where our water and our oceans

945
00:44:36,219 --> 00:44:40,588
become steam and evaporates that is the

946
00:44:38,650 --> 00:44:42,789
inner edge of the habitable zone

947
00:44:40,588 --> 00:44:44,920
conversely if we took the earth and

948
00:44:42,789 --> 00:44:47,769
pushed it outwards then there comes a

949
00:44:44,920 --> 00:44:50,579
point where the oceans freeze and that

950
00:44:47,768 --> 00:44:53,318
is our outer edge of our habitable zone

951
00:44:50,579 --> 00:44:55,809
so if we look at the planets around

952
00:44:53,318 --> 00:45:00,969
Trappist one the same habitable zone

953
00:44:55,809 --> 00:45:03,579
exists here over planets EF and G so

954
00:45:00,969 --> 00:45:07,389
does that mean we have three planets

955
00:45:03,579 --> 00:45:09,489

with water well not so fast

956

00:45:07,389 --> 00:45:12,998

we have to look at the small print of

957

00:45:09,489 --> 00:45:16,509

this habitable zone contract the

958

00:45:12,998 --> 00:45:18,159

habitable zone is defined as follows the

959

00:45:16,509 --> 00:45:21,759

habitable zone is where an earth-like

960

00:45:18,159 --> 00:45:25,018

planet can maintain liquid water on its

961

00:45:21,759 --> 00:45:28,630

surface and a small print here is

962

00:45:25,018 --> 00:45:31,899

earth-like so if you have a planet that

963

00:45:28,630 --> 00:45:34,059

is not an exact Earth clone it heavy has

964

00:45:31,900 --> 00:45:36,460

a larger mass a smaller mass a different

965

00:45:34,059 --> 00:45:38,319

atmosphere different rock type there is

966

00:45:36,460 --> 00:45:40,659

no guarantee at all

967

00:45:38,318 --> 00:45:42,699

that it will have water inside the

968

00:45:40,659 --> 00:45:45,099

habitable zone in

969

00:45:42,699 --> 00:45:47,379

of the exoplanets we've discovered we

970
00:45:45,099 --> 00:45:49,960
found roughly five times as many gas

971
00:45:47,380 --> 00:45:52,480
giants like Jupiter inside the habitable

972
00:45:49,960 --> 00:45:55,780
zone as we have planets that may have a

973
00:45:52,480 --> 00:45:58,840
rocky surface so then the question

974
00:45:55,780 --> 00:46:02,350
becomes these three planets there earth

975
00:45:58,840 --> 00:46:04,450
sized but are they earth-like earth-like

976
00:46:02,349 --> 00:46:06,569
enough for the habitable zone to be

977
00:46:04,449 --> 00:46:09,639
meaningful

978
00:46:06,570 --> 00:46:11,500
so with exoplanets we typically know two

979
00:46:09,639 --> 00:46:13,569
things and this doesn't just apply to

980
00:46:11,500 --> 00:46:16,869
the Trappist one it applies to all

981
00:46:13,570 --> 00:46:19,210
exoplanet discoveries we typically know

982
00:46:16,869 --> 00:46:20,889
either the planet radius if it's found

983
00:46:19,210 --> 00:46:23,380
through the transit technique looking at

984
00:46:20,889 --> 00:46:25,750
that light dip all we know the planet

985
00:46:23,380 --> 00:46:28,300
minimum mass if it's found from that red

986
00:46:25,750 --> 00:46:30,639
and blue Doppler wobble and occasionally

987
00:46:28,300 --> 00:46:32,170
like the Trappist system we know both so

988
00:46:30,639 --> 00:46:36,099
we know something about the planets

989
00:46:32,170 --> 00:46:38,950
physical extent we also know how much

990
00:46:36,099 --> 00:46:41,199
radiation it receives from the star now

991
00:46:38,949 --> 00:46:43,629
the small print here is this is not the

992
00:46:41,199 --> 00:46:45,399
same as surface temperature and the

993
00:46:43,630 --> 00:46:49,150
warning to that is in our own solar

994
00:46:45,400 --> 00:46:51,579
system so Venus receives roughly twice

995
00:46:49,150 --> 00:46:54,099
the amount of radiation that the earth

996
00:46:51,579 --> 00:46:56,139
does and if you were therefore to make a

997
00:46:54,099 --> 00:47:00,869
guess as a surface temperature of Venus

998

00:46:56,139 --> 00:47:04,480
you would guess 27 30 Celsius which is

999
00:47:00,869 --> 00:47:05,619
19 Fahrenheit maybe anyway it seems very

1000
00:47:04,480 --> 00:47:09,309
pleasant we should go there for a beach

1001
00:47:05,619 --> 00:47:11,319
holiday but in fact that is not true of

1002
00:47:09,309 --> 00:47:14,170
the surface of Venus the surface of

1003
00:47:11,320 --> 00:47:15,130
Venus is at 460 Celsius it doesn't even

1004
00:47:14,170 --> 00:47:16,690
really matter whether it is in

1005
00:47:15,130 --> 00:47:20,019
Fahrenheit it's just ridiculously hot

1006
00:47:16,690 --> 00:47:23,170
and the longest a spacecraft has ever

1007
00:47:20,019 --> 00:47:26,110
survived on the Venetian surface is less

1008
00:47:23,170 --> 00:47:29,079
than two hours and the difference is

1009
00:47:26,110 --> 00:47:31,599
Venus's huge atmosphere which we cannot

1010
00:47:29,079 --> 00:47:34,659
tell currently at a distance when we

1011
00:47:31,599 --> 00:47:36,909
look at exoplanets so we don't know

1012
00:47:34,659 --> 00:47:41,379

anything about the surface conditions of

1013

00:47:36,909 --> 00:47:43,719

these new worlds we found and what do we

1014

00:47:41,380 --> 00:47:46,720

need to know to say yes this is

1015

00:47:43,719 --> 00:47:48,909

earth-like well most certainly size is

1016

00:47:46,719 --> 00:47:51,609

important if you have a planet that's

1017

00:47:48,909 --> 00:47:53,019

Jupiter sized we can be pretty sure that

1018

00:47:51,610 --> 00:47:56,030

it's not going to have a solid surface

1019

00:47:53,019 --> 00:47:58,099

it's not going to be earth-like so you

1020

00:47:56,030 --> 00:48:01,220

definitely need to be in the ballpark of

1021

00:47:58,099 --> 00:48:03,469

the Earth's radius and mass but our

1022

00:48:01,219 --> 00:48:05,599

planet also has a protective magnetic

1023

00:48:03,469 --> 00:48:08,029

fields and this protects us from the

1024

00:48:05,599 --> 00:48:10,730

flares from the Sun that would strip our

1025

00:48:08,030 --> 00:48:12,410

atmosphere instead charged particles for

1026

00:48:10,730 --> 00:48:14,329

the Sun get caught safely in our

1027
00:48:12,409 --> 00:48:15,679
magnetic field and come down as the

1028
00:48:14,329 --> 00:48:17,840
northern and southern lights at our

1029
00:48:15,679 --> 00:48:20,000
poles occasionally we might have some

1030
00:48:17,840 --> 00:48:22,010
damage to our GPS systems but the

1031
00:48:20,000 --> 00:48:26,360
surface of our planet is mercifully not

1032
00:48:22,010 --> 00:48:28,040
sterilized volcanoes so you might think

1033
00:48:26,360 --> 00:48:30,289
a planet with no volcanoes sounds like a

1034
00:48:28,039 --> 00:48:31,789
rather good idea but it turns out

1035
00:48:30,289 --> 00:48:34,340
they're rather important for our

1036
00:48:31,789 --> 00:48:36,139
atmosphere during the early Earth we

1037
00:48:34,340 --> 00:48:37,640
needed volcanoes in order to get the

1038
00:48:36,139 --> 00:48:40,190
atmosphere that ultimately developed

1039
00:48:37,639 --> 00:48:42,109
life and indeed now it's one of the ways

1040
00:48:40,190 --> 00:48:45,639
that greenhouse gases are controlled

1041
00:48:42,110 --> 00:48:48,349
over geological timescales rock-type

1042
00:48:45,639 --> 00:48:50,929
again is how we control our greenhouse

1043
00:48:48,349 --> 00:48:53,269
gases over geological timescales and how

1044
00:48:50,929 --> 00:48:55,750
our planets manage to maintain very good

1045
00:48:53,269 --> 00:48:59,210
conditions for forming life for so long

1046
00:48:55,750 --> 00:49:01,550
the presence of water just because you

1047
00:48:59,210 --> 00:49:04,789
can support water there's no guarantee

1048
00:49:01,550 --> 00:49:06,860
you have water to support so as I

1049
00:49:04,789 --> 00:49:09,139
mentioned the earth formed inside the

1050
00:49:06,860 --> 00:49:11,960
ice line this may have meant it was

1051
00:49:09,139 --> 00:49:13,909
actually formed as a dry planet and as

1052
00:49:11,960 --> 00:49:16,820
how water could well have been delivered

1053
00:49:13,909 --> 00:49:18,500
later on by icy meteorites scattered

1054
00:49:16,820 --> 00:49:20,870
inwards by the giant planets like

1055

00:49:18,500 --> 00:49:23,119
Jupiter and Saturn so if you have a

1056
00:49:20,869 --> 00:49:25,940
different planetary system without those

1057
00:49:23,119 --> 00:49:27,799
big beefy planets outside you do you get

1058
00:49:25,940 --> 00:49:31,579
a scattering of icy meteorites to

1059
00:49:27,800 --> 00:49:34,070
deliver water we're not sure and plate

1060
00:49:31,579 --> 00:49:37,309
tectonics our crust our surface is

1061
00:49:34,070 --> 00:49:39,170
divided up into chunks and these chunks

1062
00:49:37,309 --> 00:49:42,949
allow our planet cool which helps

1063
00:49:39,170 --> 00:49:45,860
generate our magnetic fields and when we

1064
00:49:42,949 --> 00:49:47,750
observe a planet around another star we

1065
00:49:45,860 --> 00:49:49,849
only know about the first two we don't

1066
00:49:47,750 --> 00:49:52,820
know about any of these other effects at

1067
00:49:49,849 --> 00:49:55,730
the moment so it takes a lot to be like

1068
00:49:52,820 --> 00:50:00,440
Earth and we don't know very much about

1069
00:49:55,730 --> 00:50:03,559

any of these exoplanets however in the

1070

00:50:00,440 --> 00:50:06,679

case of Trappist one unusually we do

1071

00:50:03,559 --> 00:50:09,559

know one other thing the planet orbits

1072

00:50:06,679 --> 00:50:12,649

of Trappist warned are in resonance

1073

00:50:09,559 --> 00:50:14,690

and that means that if you look at the

1074

00:50:12,650 --> 00:50:18,079

time for each planet to orbit the star

1075

00:50:14,690 --> 00:50:20,480

you see something rather interesting in

1076

00:50:18,079 --> 00:50:23,210

the time it takes for planet B to orbit

1077

00:50:20,480 --> 00:50:27,829

the star 24 times it takes planet

1078

00:50:23,210 --> 00:50:30,559

planets see orbits 15 times 15 not 15

1079

00:50:27,829 --> 00:50:32,690

point 5 not fifteen point three not

1080

00:50:30,559 --> 00:50:35,389

fifteen point one two seven eight three

1081

00:50:32,690 --> 00:50:38,929

it's an exact integer or very close to

1082

00:50:35,389 --> 00:50:41,839

it and the pattern continues 24 15 nine

1083

00:50:38,929 --> 00:50:44,239

six four three two one very close to

1084
00:50:41,840 --> 00:50:47,420
being exact integer ratios of one

1085
00:50:44,239 --> 00:50:50,809
another so how does this happen it seems

1086
00:50:47,420 --> 00:50:53,329
like a bit of a coincidence so what we

1087
00:50:50,809 --> 00:50:56,179
believe happens is that if the planets

1088
00:50:53,329 --> 00:50:58,730
are born far from the star and they go

1089
00:50:56,179 --> 00:51:01,909
through this migration process to come

1090
00:50:58,730 --> 00:51:04,579
further in if you have multiple planets

1091
00:51:01,909 --> 00:51:07,159
doing this and their gravity pulls on

1092
00:51:04,579 --> 00:51:09,769
one another they can end up locked in

1093
00:51:07,159 --> 00:51:12,019
these resonance positions so as they

1094
00:51:09,769 --> 00:51:14,420
both migrate in their orbits at some

1095
00:51:12,019 --> 00:51:17,659
point will sync up to exact ratios and

1096
00:51:14,420 --> 00:51:19,940
this turns out to be very stable so once

1097
00:51:17,659 --> 00:51:22,190
you hit this sweet spot you tend to stay

1098
00:51:19,940 --> 00:51:24,530
there and then the planets continue to

1099
00:51:22,190 --> 00:51:26,960
migrate in with these exact ratios as

1100
00:51:24,530 --> 00:51:31,040
their orbit and you might be like

1101
00:51:26,960 --> 00:51:33,110
walking but so what the point is that if

1102
00:51:31,039 --> 00:51:35,480
that happened to these planets that

1103
00:51:33,110 --> 00:51:38,000
means the planet started here further

1104
00:51:35,480 --> 00:51:42,079
away from the star behind the ice line

1105
00:51:38,000 --> 00:51:45,460
and then ended up here this would mean

1106
00:51:42,079 --> 00:51:48,230
that they formed with a lot of ice and

1107
00:51:45,460 --> 00:51:50,840
so maybe as they moved closer to the

1108
00:51:48,230 --> 00:51:55,519
star this may have melted to become a

1109
00:51:50,840 --> 00:51:57,680
global ocean so our other option instead

1110
00:51:55,519 --> 00:51:59,840
of a lava world it could be that the

1111
00:51:57,679 --> 00:52:01,969
Trappist one planets have a huge amount

1112

00:51:59,840 --> 00:52:06,950
of water and they're actually water

1113
00:52:01,969 --> 00:52:09,649
worlds with no exposed land at all so

1114
00:52:06,949 --> 00:52:11,899
this is a beautiful graphic by NASA and

1115
00:52:09,650 --> 00:52:17,630
if we go below the atmosphere this is

1116
00:52:11,900 --> 00:52:20,059
how we might picture a water world so

1117
00:52:17,630 --> 00:52:22,599
this then brings us to the obvious

1118
00:52:20,059 --> 00:52:25,838
question on water world's habitable

1119
00:52:22,599 --> 00:52:28,028
I mean water and life are intricately

1120
00:52:25,838 --> 00:52:30,489
asserted are associated on earth so is

1121
00:52:28,028 --> 00:52:33,099
more water and better for life

1122
00:52:30,489 --> 00:52:35,108
well the shorter answer is we don't know

1123
00:52:33,099 --> 00:52:37,119
we've got no analog in our solar system

1124
00:52:35,108 --> 00:52:40,808
to go and explore which has a surface

1125
00:52:37,119 --> 00:52:43,838
global ocean however we have some reason

1126
00:52:40,809 --> 00:52:47,559

to be slightly skeptical and it comes

1127

00:52:43,838 --> 00:52:49,358

down to the carbon dioxide in our air so

1128

00:52:47,559 --> 00:52:50,950

if we didn't have an atmosphere the

1129

00:52:49,358 --> 00:52:53,679

global temperature of the earth would be

1130

00:52:50,949 --> 00:52:56,018

-5 Celsius below the freezing point of

1131

00:52:53,679 --> 00:52:57,460

water however because we have an

1132

00:52:56,018 --> 00:52:59,978

atmosphere and it contains these

1133

00:52:57,460 --> 00:53:02,019

greenhouse gases we're able to trap heat

1134

00:52:59,978 --> 00:53:05,528

effectively and brings our global

1135

00:53:02,018 --> 00:53:08,199

temperature to about 15 Celsius and

1136

00:53:05,528 --> 00:53:11,018

exactly how warm our planet gets can be

1137

00:53:08,199 --> 00:53:12,848

controlled by geology through what we

1138

00:53:11,018 --> 00:53:15,639

call the carbon cycle or sometimes the

1139

00:53:12,849 --> 00:53:18,099

carbon silicate cycle so here carbon

1140

00:53:15,639 --> 00:53:20,139

dioxide in the air dissolves in

1141
00:53:18,099 --> 00:53:22,660
rainwater comes down as slightly acidic

1142
00:53:20,139 --> 00:53:25,028
rain it reacts with the rocks and forms

1143
00:53:22,659 --> 00:53:26,798
of solids this gets swept into the ocean

1144
00:53:25,028 --> 00:53:29,318
and it eventually gets returned to the

1145
00:53:26,798 --> 00:53:31,389
atmosphere through volcanoes now the

1146
00:53:29,318 --> 00:53:34,058
process is very slow so it doesn't

1147
00:53:31,389 --> 00:53:37,568
really protect us against man-made

1148
00:53:34,059 --> 00:53:40,269
increase in greenhouse gases but it does

1149
00:53:37,568 --> 00:53:43,568
protect us over at slower moving changes

1150
00:53:40,268 --> 00:53:45,939
for example in its early years the Sun

1151
00:53:43,568 --> 00:53:48,248
would have been much cooler and during

1152
00:53:45,940 --> 00:53:50,349
this time the our earth should have been

1153
00:53:48,248 --> 00:53:52,328
too cold for life but we have evidence

1154
00:53:50,349 --> 00:53:54,910
that it wasn't and one of the

1155
00:53:52,329 --> 00:53:57,278
possibilities is that this process was

1156
00:53:54,909 --> 00:53:59,978
able to change the amount of greenhouse

1157
00:53:57,278 --> 00:54:02,199
gases in our atmosphere so if the planet

1158
00:53:59,978 --> 00:54:04,058
was colder this reaction with the rocks

1159
00:54:02,199 --> 00:54:06,699
would have slowed down because chemical

1160
00:54:04,059 --> 00:54:08,019
reactions slowed when it's colder but we

1161
00:54:06,699 --> 00:54:09,879
still would have been spitting out

1162
00:54:08,018 --> 00:54:11,889
carbon dioxide into the atmosphere so

1163
00:54:09,880 --> 00:54:13,869
the amount of greenhouse gas in the

1164
00:54:11,889 --> 00:54:16,478
atmosphere would have risen and given us

1165
00:54:13,869 --> 00:54:18,849
a thicker thermal blanket and this

1166
00:54:16,478 --> 00:54:22,778
allows us to have a lot more time in

1167
00:54:18,849 --> 00:54:26,609
which life can develop on earth but in

1168
00:54:22,778 --> 00:54:29,920
Eveland so if you have a global ocean

1169

00:54:26,608 --> 00:54:33,670
can you have any kind of carbon silicate

1170
00:54:29,920 --> 00:54:35,349
cycle so could a Waterworld actually

1171
00:54:33,670 --> 00:54:37,300
regulate its temperature

1172
00:54:35,349 --> 00:54:40,000
if it couldn't it has two main effects

1173
00:54:37,300 --> 00:54:42,789
the first is your habitable zone which I

1174
00:54:40,000 --> 00:54:45,760
presented as a broadband shrinks to a

1175
00:54:42,789 --> 00:54:48,099
narrow point because the reason ours is

1176
00:54:45,760 --> 00:54:50,530
a broadband is that our carbon cycle can

1177
00:54:48,099 --> 00:54:52,449
adjust slightly our atmosphere to allow

1178
00:54:50,530 --> 00:54:55,120
us to manage in slightly warmer areas

1179
00:54:52,449 --> 00:54:57,219
and slightly colder areas if there's no

1180
00:54:55,119 --> 00:54:59,500
way of adjusting the thermostat of the

1181
00:54:57,219 --> 00:55:03,099
planet the radiation you receive from

1182
00:54:59,500 --> 00:55:04,750
your star needs to be bang-on perfect so

1183
00:55:03,099 --> 00:55:08,440

you get a very narrow band for that

1184

00:55:04,750 --> 00:55:11,320

habitable zone secondly because you

1185

00:55:08,440 --> 00:55:13,360

can't buffer against the star increasing

1186

00:55:11,320 --> 00:55:16,870

in luminosity you have a much shorter

1187

00:55:13,360 --> 00:55:19,630

time for life to be able to develop so

1188

00:55:16,869 --> 00:55:22,809

does that mean it's curtains for any

1189

00:55:19,630 --> 00:55:25,750

water wells well not necessarily it may

1190

00:55:22,809 --> 00:55:28,150

depend on ocean depth for example if the

1191

00:55:25,750 --> 00:55:30,400

ocean is shallow enough you can still

1192

00:55:28,150 --> 00:55:32,980

have a carbon silicon cycle with the

1193

00:55:30,400 --> 00:55:35,349

ocean bottom it's not as good because

1194

00:55:32,980 --> 00:55:38,380

the ocean changes temperature much more

1195

00:55:35,349 --> 00:55:41,049

slowly than the atmosphere birds maybe

1196

00:55:38,380 --> 00:55:43,150

not impossible if the ocean gets very

1197

00:55:41,050 --> 00:55:45,130

deep then the chances are the pressure

1198
00:55:43,150 --> 00:55:48,010
of that ocean floor will rise so much

1199
00:55:45,130 --> 00:55:50,470
your form Isis and these Isis will

1200
00:55:48,010 --> 00:55:52,720
completely seal off your rocky core from

1201
00:55:50,469 --> 00:55:57,609
your ocean and so it won't be able to

1202
00:55:52,719 --> 00:55:59,289
produce any kind of thermostat at all so

1203
00:55:57,610 --> 00:56:02,289
this always leads to the question of can

1204
00:55:59,289 --> 00:56:04,449
we go and check these planets out well

1205
00:56:02,289 --> 00:56:07,059
our closest exoplanet is the one

1206
00:56:04,449 --> 00:56:10,559
orbiting Proxima Centauri this is our

1207
00:56:07,059 --> 00:56:13,869
nearest star so is our nearest possible

1208
00:56:10,559 --> 00:56:16,779
exoplanets and it's four light-years

1209
00:56:13,869 --> 00:56:18,460
away now our fastest spacecraft is

1210
00:56:16,780 --> 00:56:19,840
Voyager one which is currently at the

1211
00:56:18,460 --> 00:56:21,970
edge of our solar system

1212
00:56:19,840 --> 00:56:24,490
if forager one was pointing in the right

1213
00:56:21,969 --> 00:56:26,559
direction which isn't it would still

1214
00:56:24,489 --> 00:56:29,709
take it 75 thousand years

1215
00:56:26,559 --> 00:56:32,139
is to reach Proxima Centauri B now there

1216
00:56:29,710 --> 00:56:33,940
are some other ideas in the pipeline for

1217
00:56:32,139 --> 00:56:36,489
instance this project star shots which

1218
00:56:33,940 --> 00:56:38,860
is an idea where we could use lasers to

1219
00:56:36,489 --> 00:56:42,009
send very very very light spacecraft

1220
00:56:38,860 --> 00:56:43,809
great distances reasonably quickly but

1221
00:56:42,010 --> 00:56:45,660
as futuristic technology and we don't

1222
00:56:43,809 --> 00:56:49,719
know yet whether it's at all feasible

1223
00:56:45,659 --> 00:56:51,279
however all is not lost there are a

1224
00:56:49,719 --> 00:56:53,139
couple of really or more a couple

1225
00:56:51,280 --> 00:56:55,300
several really exciting missions coming

1226

00:56:53,139 --> 00:56:58,150
up that are going to tell us a lot more

1227
00:56:55,300 --> 00:57:00,970
about these exoplanets so as the planet

1228
00:56:58,150 --> 00:57:02,980
transits across the star surface some of

1229
00:57:00,969 --> 00:57:05,919
our starlight is going to pass through

1230
00:57:02,980 --> 00:57:10,119
the planet's atmosphere if we can spot

1231
00:57:05,920 --> 00:57:12,460
that then we will see a fingerprint that

1232
00:57:10,119 --> 00:57:14,039
marks out the gases at the atmosphere so

1233
00:57:12,460 --> 00:57:16,300
the light passes through the atmosphere

1234
00:57:14,039 --> 00:57:18,369
particular molecules in the atmosphere

1235
00:57:16,300 --> 00:57:20,680
will absorb certain parts of the light

1236
00:57:18,369 --> 00:57:23,049
spectrum and so they'll be missing when

1237
00:57:20,679 --> 00:57:25,809
we observe them on earth and based on

1238
00:57:23,050 --> 00:57:27,510
those missing light waves we can tell

1239
00:57:25,809 --> 00:57:29,949
what gases might be in the atmosphere

1240
00:57:27,510 --> 00:57:33,070

and this gives us our first hint that

1241
00:57:29,949 --> 00:57:37,449
geological processes and maybe even a

1242
00:57:33,070 --> 00:57:38,920
whiff of life so obviously in a space

1243
00:57:37,449 --> 00:57:40,419
telescope I have to mention that one of

1244
00:57:38,920 --> 00:57:42,250
the major instruments that we'll be

1245
00:57:40,420 --> 00:57:45,880
looking for this is a course at James

1246
00:57:42,250 --> 00:57:47,949
Webb which is due to launch in 2019 but

1247
00:57:45,880 --> 00:57:49,840
there's also ESA is the European Space

1248
00:57:47,949 --> 00:57:52,799
Agency's aerial mission which is

1249
00:57:49,840 --> 00:57:56,039
hopefully to go up in 2026

1250
00:57:52,800 --> 00:57:58,269
so this is going to be very exciting and

1251
00:57:56,039 --> 00:58:02,469
just to end on an utterly shameless

1252
00:57:58,269 --> 00:58:04,960
pitch as Frank mentioned my book comes

1253
00:58:02,469 --> 00:58:06,939
out today officially in the US it is

1254
00:58:04,960 --> 00:58:09,070
full of truly awful planets I mean there

1255
00:58:06,940 --> 00:58:10,990
are the hot Jupiters there are Tatooine

1256
00:58:09,070 --> 00:58:13,090
worlds around two stars there are rogue

1257
00:58:10,989 --> 00:58:15,969
worlds that have no star at all there

1258
00:58:13,090 --> 00:58:17,980
are planets with seas of lava and tar so

1259
00:58:15,969 --> 00:58:19,929
really whatever your favorite way to die

1260
00:58:17,980 --> 00:58:23,469
horribly is you'll probably find it in

1261
00:58:19,929 --> 00:58:25,569
the pages of my book so if you're at all

1262
00:58:23,469 --> 00:58:28,750
interested I've put some little cards

1263
00:58:25,570 --> 00:58:32,860
here just to remind you please grab one

1264
00:58:28,750 --> 00:58:47,159
and thank you very much

1265
00:58:32,860 --> 00:58:47,159
[Applause]

1266
00:58:47,639 --> 00:59:00,159
questions alright so I'm sure we have a

1267
00:58:58,119 --> 00:59:04,900
few questions I see in the green back

1268
00:59:00,159 --> 00:59:08,108
there now that was you all these

1269
00:59:04,900 --> 00:59:10,809
terrible planets Oh what about ours

1270
00:59:08,108 --> 00:59:14,078
which is you know sort of so coddling

1271
00:59:10,809 --> 00:59:16,200
almost what is your knee-jerk reaction

1272
00:59:14,079 --> 00:59:19,780
when people talk about like a Gaia

1273
00:59:16,199 --> 00:59:21,939
hypothesis where it's like a system

1274
00:59:19,780 --> 00:59:22,690
working together to maintain this

1275
00:59:21,940 --> 00:59:25,809
balance

1276
00:59:22,690 --> 00:59:29,019
nothing wearing it yeah one giant

1277
00:59:25,809 --> 00:59:31,089
tortoise okay so I'm gonna repeat the

1278
00:59:29,019 --> 00:59:33,039
question for the online audience so the

1279
00:59:31,088 --> 00:59:36,400
question is what is your opinion on the

1280
00:59:33,039 --> 00:59:38,289
Gaia hypothesis considers a planet as

1281
00:59:36,400 --> 01:00:06,880
sort of being an entire organism and

1282
00:59:38,289 --> 01:00:10,269
such and the question is where is the

1283

01:00:06,880 --> 01:00:12,400
bottleneck is it that life is very hard

1284
01:00:10,269 --> 01:00:14,289
to start maybe you never get a planet

1285
01:00:12,400 --> 01:00:18,730
with the right organics to start life

1286
01:00:14,289 --> 01:00:22,539
maybe life develops but in fact it dies

1287
01:00:18,730 --> 01:00:23,980
really quickly or maybe that you can

1288
01:00:22,539 --> 01:00:25,659
develop life quite easily and actually

1289
01:00:23,980 --> 01:00:26,980
it thrives but it just never becomes

1290
01:00:25,659 --> 01:00:29,048
intelligent life because it's not

1291
01:00:26,980 --> 01:00:33,309
selected for those sort of options and

1292
01:00:29,048 --> 01:00:35,289
one hypothesis put forward by Charlie

1293
01:00:33,309 --> 01:00:38,530
lineweaver was actually what he calls

1294
01:00:35,289 --> 01:00:40,838
the Gaya bottleneck where he says that

1295
01:00:38,530 --> 01:00:42,220
you have to not only form life you have

1296
01:00:40,838 --> 01:00:44,170
to form it fast enough

1297
01:00:42,219 --> 01:00:46,419

that it can actually change your

1298

01:00:44,170 --> 01:00:49,690

planet's environment to self sustain

1299

01:00:46,420 --> 01:00:52,119

itself and so that's the idea that in

1300

01:00:49,690 --> 01:00:54,460

the early stages of our earth the carbon

1301

01:00:52,119 --> 01:00:57,039

cycle that I mentioned before was not

1302

01:00:54,460 --> 01:00:58,750

sufficient to actually protect our

1303

01:00:57,039 --> 01:01:00,909

it's atmosphere and keep it temperate

1304

01:00:58,750 --> 01:01:05,820

enough but because we were able to form

1305

01:01:00,909 --> 01:01:05,819

life it was able to replace the carbon

1306

01:01:44,659 --> 01:01:48,960

obviously the aliens are trying to drown

1307

01:01:47,068 --> 01:01:53,130

out her talk and she's revealing too

1308

01:01:48,960 --> 01:01:54,900

many secrets folks those of you who've

1309

01:01:53,130 --> 01:02:00,240

been here know this has absolutely never

1310

01:01:54,900 --> 01:02:03,298

happened before in my 17 years we've

1311

01:02:00,239 --> 01:02:08,429

never had that kind of noise let's see

1312
01:02:03,298 --> 01:02:11,038
so yes I will also note that we just had

1313
01:02:08,429 --> 01:02:13,348
some major work done on the auditorium

1314
01:02:11,039 --> 01:02:15,569
honor if you noticed the projectors are

1315
01:02:13,349 --> 01:02:18,838
4k and other things and the audio system

1316
01:02:15,568 --> 01:02:22,259
was updated a little bit so I apologize

1317
01:02:18,838 --> 01:02:25,619
we are this is the first live event to

1318
01:02:22,260 --> 01:02:28,440
test out the system in detail so you can

1319
01:02:25,619 --> 01:02:30,750
see that it is being tested out okay so

1320
01:02:28,440 --> 01:02:32,970
back to what you were saying so even

1321
01:02:30,750 --> 01:02:35,960
though I obviously external forces tried

1322
01:02:32,969 --> 01:02:39,118
to stop me answering this question I

1323
01:02:35,960 --> 01:02:41,309
would say that I would consider life as

1324
01:02:39,119 --> 01:02:43,230
to be definitely part of the planets I

1325
01:02:41,309 --> 01:02:44,430
think when we talk about origins of life

1326
01:02:43,230 --> 01:02:45,630
we also have to talk about plant

1327
01:02:44,429 --> 01:02:59,250
information and they are intricately

1328
01:02:45,630 --> 01:03:01,349
connected yes okay yes so the question

1329
01:02:59,250 --> 01:03:03,509
was on there's the cellar type of

1330
01:03:01,349 --> 01:03:05,250
Trappist one is that what the root

1331
01:03:03,509 --> 01:03:08,880
you're asking about yes this is a red

1332
01:03:05,250 --> 01:03:29,940
dwarf yeah it is a red dwarf red dwarfs

1333
01:03:08,880 --> 01:03:33,170
are interesting they're good why is it

1334
01:03:29,940 --> 01:03:33,170
always on my answers as well

1335
01:03:34,949 --> 01:03:41,279
so yeah a Trappist one red dwarfs have

1336
01:03:39,239 --> 01:03:43,769
pros and cons one of the pros is that

1337
01:03:41,280 --> 01:03:46,080
being very small and dim stars is much

1338
01:03:43,769 --> 01:03:49,170
easier to find planets circling them and

1339
01:03:46,079 --> 01:03:51,329
indeed Kepler's successor test is going

1340

01:03:49,170 --> 01:03:54,630
to be focusing on red dwarfs for exactly

1341
01:03:51,329 --> 01:03:56,789
this reason however they're also

1342
01:03:54,630 --> 01:03:59,250
extremely rambunctious when they're

1343
01:03:56,789 --> 01:04:02,309
young and they are prone to a lot of

1344
01:03:59,250 --> 01:04:04,559
stellar flares and it is possible that a

1345
01:04:02,309 --> 01:04:06,779
planets around red dwarfs may become

1346
01:04:04,559 --> 01:04:08,849
sterilized because during this early

1347
01:04:06,780 --> 01:04:10,260
phase and the star's evolution it just

1348
01:04:08,849 --> 01:04:12,269
might have nuked everything that might

1349
01:04:10,260 --> 01:04:13,950
be developing on the planets at the

1350
01:04:12,269 --> 01:04:15,840
moment we just don't know the

1351
01:04:13,949 --> 01:04:18,299
interesting thing about Trappist one is

1352
01:04:15,840 --> 01:04:20,460
if they genuinely did this migration it

1353
01:04:18,300 --> 01:04:22,170
might just have saved them because they

1354
01:04:20,460 --> 01:04:24,570

would have started further away from the

1355

01:04:22,170 --> 01:04:27,800

star when the star was younger and maybe

1356

01:04:24,570 --> 01:04:30,390

that it would have got over its and

1357

01:04:27,800 --> 01:04:34,920

awkward adolescent stage by the time the

1358

01:04:30,389 --> 01:04:45,089

planet started approaching it all the

1359

01:04:34,920 --> 01:04:46,980

way in the very back row there okay so

1360

01:04:45,090 --> 01:04:49,170

do you anticipate any technology that

1361

01:04:46,980 --> 01:04:52,710

will allow us to see not just exoplanets

1362

01:04:49,170 --> 01:04:54,030

but also exomoons I guess start his

1363

01:04:52,710 --> 01:04:57,389

answer and see if everything cuts off

1364

01:04:54,030 --> 01:04:59,550

again yes absolutely so renie heller who

1365

01:04:57,389 --> 01:05:02,279

is an expert on EXO moon formation in

1366

01:04:59,550 --> 01:05:04,830

germany told me that he feels that

1367

01:05:02,280 --> 01:05:07,590

exomoons is where exoplanets was at the

1368

01:05:04,829 --> 01:05:09,989

start of the 1990s we are on the brink

1369
01:05:07,590 --> 01:05:11,760
and indeed their active search is

1370
01:05:09,989 --> 01:05:15,118
currently going on for EXO meals

1371
01:05:11,760 --> 01:05:17,250
one of them is called HEC which I forgot

1372
01:05:15,119 --> 01:05:20,910
what it stands for but it's using Kepler

1373
01:05:17,250 --> 01:05:22,800
to look for moons and the PI on that is

1374
01:05:20,909 --> 01:05:25,349
David Kipping at Columbia University and

1375
01:05:22,800 --> 01:05:28,410
currently Kepler is sensitive enough to

1376
01:05:25,349 --> 01:05:30,329
find a very very large moon in fact

1377
01:05:28,409 --> 01:05:33,299
slightly larger than we believe would

1378
01:05:30,329 --> 01:05:35,969
form around a gas giants but could

1379
01:05:33,300 --> 01:05:38,570
potentially be captured now of course if

1380
01:05:35,969 --> 01:05:40,819
we find that earth sized moons exist

1381
01:05:38,570 --> 01:05:43,410
then we have a lot more real estate

1382
01:05:40,820 --> 01:05:45,630
because our gas giants are mobbed with

1383
01:05:43,409 --> 01:05:46,349
meals so if you imagine a gas giant in

1384
01:05:45,630 --> 01:05:49,380
the habit

1385
01:05:46,349 --> 01:05:51,569
then it's not habitable but it might

1386
01:05:49,380 --> 01:05:53,579
have a whole bunch of moons that are now

1387
01:05:51,570 --> 01:05:55,050
it's a slightly interesting game when

1388
01:05:53,579 --> 01:05:57,389
you start looking at exomoons and

1389
01:05:55,050 --> 01:05:59,940
habitability in particular they get

1390
01:05:57,389 --> 01:06:02,549
multiple sources of heat because they

1391
01:05:59,940 --> 01:06:04,800
get the star but they also get heat

1392
01:06:02,550 --> 01:06:07,410
coming from the planet so that may mean

1393
01:06:04,800 --> 01:06:09,990
that if the planet is in the ideal spot

1394
01:06:07,409 --> 01:06:12,960
to support liquid water its moons may

1395
01:06:09,989 --> 01:06:16,829
potentially be too hot so it might be

1396
01:06:12,960 --> 01:06:18,900
your ideal Endor or a walk filled moon

1397

01:06:16,829 --> 01:06:20,909
would actually left live slightly

1398
01:06:18,900 --> 01:06:22,530
outside the habitable zone with the

1399
01:06:20,909 --> 01:06:29,000
planet providing that additional source

1400
01:06:22,530 --> 01:06:29,000
of heat okay other questions over here

1401
01:06:38,159 --> 01:06:43,409
so what can we learn if we are able to

1402
01:06:41,130 --> 01:06:45,269
travel to Mars and explore it what shall

1403
01:06:43,409 --> 01:06:48,659
we learn that will enhance our knowledge

1404
01:06:45,268 --> 01:06:50,548
on this subject so I think probably what

1405
01:06:48,659 --> 01:06:56,368
most people would love to find is life

1406
01:06:50,548 --> 01:06:58,469
of any kind or even idea where is

1407
01:06:56,369 --> 01:07:00,809
everyone but one of the questions might

1408
01:06:58,469 --> 01:07:04,078
be does life just never start anywhere I

1409
01:07:00,809 --> 01:07:07,019
mean that's possible right if we were to

1410
01:07:04,079 --> 01:07:09,089
find a second genesis of life that would

1411
01:07:07,018 --> 01:07:11,848

probably imply that actually life is

1412
01:07:09,088 --> 01:07:13,639
pretty easy to kick-start now Mars isn't

1413
01:07:11,849 --> 01:07:16,048
necessarily the best place for that

1414
01:07:13,639 --> 01:07:18,449
because it's sufficiently close to the

1415
01:07:16,048 --> 01:07:20,639
earth that we can share material indeed

1416
01:07:18,449 --> 01:07:22,169
there isn't some theories that it's just

1417
01:07:20,639 --> 01:07:25,230
about possible life originated on Mars

1418
01:07:22,170 --> 01:07:26,880
and then came across to earth we never

1419
01:07:25,230 --> 01:07:29,519
found any evidence for life on Mars so

1420
01:07:26,880 --> 01:07:32,880
far and we're maybe more interesting

1421
01:07:29,518 --> 01:07:34,828
area might be Europe so as a moon of

1422
01:07:32,880 --> 01:07:37,920
Jupiter it has these deep subsurface

1423
01:07:34,829 --> 01:07:39,690
oceans if we were able to find evidence

1424
01:07:37,920 --> 01:07:41,250
of life on those I think we could be

1425
01:07:39,690 --> 01:07:43,289
more certain to say this was an

1426
01:07:41,250 --> 01:07:45,750
independent genesis of life and

1427
01:07:43,289 --> 01:07:59,539
therefore life is at least easy to start

1428
01:07:45,750 --> 01:08:01,710
if not continue the hot Jupiters

1429
01:07:59,539 --> 01:08:06,270
eventually lose our atmosphere by being

1430
01:08:01,710 --> 01:08:10,510
so close and why isn't our Jupiter hot

1431
01:08:06,269 --> 01:08:10,509
[Music]

1432
01:08:10,518 --> 01:08:15,328
that the Stars gravitational field

1433
01:08:13,469 --> 01:08:17,519
starts to penetrate that atmosphere and

1434
01:08:15,329 --> 01:08:19,770
literally starts siphoning it off we

1435
01:08:17,520 --> 01:08:21,960
call that a rich loop in flow and we've

1436
01:08:19,770 --> 01:08:24,480
also seen evidence of some hot Jupiters

1437
01:08:21,960 --> 01:08:29,609
rapidly using their answers so certainly

1438
01:08:24,479 --> 01:08:32,009
for some of them if they're close yes is

1439
01:08:29,609 --> 01:08:35,639
a big mystery so the idea of migration

1440
01:08:32,009 --> 01:08:37,920
was not actually invented when we found

1441
01:08:35,639 --> 01:08:40,679
hot Jupiters indeed the idea of been

1442
01:08:37,920 --> 01:08:42,690
around since the 1980s and we knew that

1443
01:08:40,679 --> 01:08:44,819
it was possible that this migration

1444
01:08:42,689 --> 01:08:46,500
process could occur but we look to our

1445
01:08:44,819 --> 01:08:48,810
own solar system didn't see any evidence

1446
01:08:46,500 --> 01:08:49,770
of strong migration and therefore is

1447
01:08:48,810 --> 01:08:51,990
assumed

1448
01:08:49,770 --> 01:08:54,330
either didn't happen or it just wasn't a

1449
01:08:51,989 --> 01:08:56,429
major player now we've discovered all

1450
01:08:54,329 --> 01:08:59,579
these exoplanets we realize it's a major

1451
01:08:56,430 --> 01:09:02,520
sculptor of exoplanet systems so then

1452
01:08:59,579 --> 01:09:04,140
the question comes I'll be weird so what

1453
01:09:02,520 --> 01:09:06,180
people think happened with our gas

1454

01:09:04,140 --> 01:09:08,609
giants is that jupiter was formed and

1455
01:09:06,180 --> 01:09:10,319
indeed it did start migrating and it

1456
01:09:08,609 --> 01:09:12,210
started to munch its way towards the

1457
01:09:10,319 --> 01:09:14,609
inner solar system which would have not

1458
01:09:12,210 --> 01:09:16,980
look good for earth but as it was doing

1459
01:09:14,609 --> 01:09:19,890
so saturn formed and caught up with it

1460
01:09:16,979 --> 01:09:21,959
as it started its own migration and at

1461
01:09:19,890 --> 01:09:24,480
that point the gravitational pull of the

1462
01:09:21,960 --> 01:09:28,020
two planets together caused a u-turn

1463
01:09:24,479 --> 01:09:29,519
that we call the grand tack model after

1464
01:09:28,020 --> 01:09:31,380
the sailing turn we turn the boat around

1465
01:09:29,520 --> 01:09:34,080
so the two planets moved in together

1466
01:09:31,380 --> 01:09:36,930
they actually do the u-turn around about

1467
01:09:34,079 --> 01:09:39,088
the position of Mars and moved out and

1468
01:09:36,930 --> 01:09:41,880

it's one of the explanations we have for

1469

01:09:39,088 --> 01:09:43,199

why Mars is so small because naively we

1470

01:09:41,880 --> 01:09:45,270

would have thought further away from the

1471

01:09:43,199 --> 01:09:47,189

star where the star's gravity is a

1472

01:09:45,270 --> 01:09:49,260

little bit weaker you should actually be

1473

01:09:47,189 --> 01:09:51,659

able to build a blob of planets but

1474

01:09:49,260 --> 01:09:53,130

instead we have a real squiffy one it's

1475

01:09:51,659 --> 01:09:54,180

possible that it was Jupiter just

1476

01:09:53,130 --> 01:09:55,500

marched right in there

1477

01:09:54,180 --> 01:09:59,700

eat up all the building material and

1478

01:09:55,500 --> 01:10:01,229

then left now whether this is common we

1479

01:09:59,699 --> 01:10:03,389

don't know yet because it's harder to

1480

01:10:01,229 --> 01:10:05,639

see planets at Jupiter's distance around

1481

01:10:03,390 --> 01:10:07,440

other stars as we start to see more

1482

01:10:05,640 --> 01:10:08,970

planets that are further out and get a

1483
01:10:07,439 --> 01:10:10,949
more complete picture of planetary

1484
01:10:08,970 --> 01:10:14,369
systems I think we'll get a better idea

1485
01:10:10,949 --> 01:10:16,289
about whether this grand tak system is

1486
01:10:14,369 --> 01:10:20,069
common or whether actually we have a

1487
01:10:16,289 --> 01:10:22,649
very unique system question in the

1488
01:10:20,069 --> 01:10:25,920
center there and there's kind of a

1489
01:10:22,649 --> 01:10:27,750
follow up is the word migration it

1490
01:10:25,920 --> 01:10:29,480
indicates that it's still moving could

1491
01:10:27,750 --> 01:10:34,529
these could these hot Jupiters

1492
01:10:29,479 --> 01:10:37,289
eventually go in actually hit the star

1493
01:10:34,529 --> 01:10:38,880
that they're that they're of form so

1494
01:10:37,289 --> 01:10:41,130
this is my creative process

1495
01:10:38,880 --> 01:10:45,319
can this migrating process end with the

1496
01:10:41,130 --> 01:10:45,319
planet being absorbed by the star

1497
01:10:49,920 --> 01:10:55,359
[Music]

1498
01:10:51,149 --> 01:10:58,539
gasps disk circling about 10 million

1499
01:10:55,359 --> 01:11:02,170
years the star vaporizes its planet

1500
01:10:58,539 --> 01:11:04,719
migration due to the gaseous stops there

1501
01:11:02,170 --> 01:11:07,270
is also normally a gap at the disk edge

1502
01:11:04,719 --> 01:11:09,698
so the planet could go up to that gap

1503
01:11:07,270 --> 01:11:12,969
just before it reaches a star also stop

1504
01:11:09,698 --> 01:11:14,710
because there's no gas that site so in

1505
01:11:12,969 --> 01:11:17,469
terms of gas drip and migration you

1506
01:11:14,710 --> 01:11:18,849
shouldn't throw the whole planet into

1507
01:11:17,469 --> 01:11:21,520
the star there should be some kind of

1508
01:11:18,849 --> 01:11:23,909
stopping mechanism now exactly what

1509
01:11:21,520 --> 01:11:26,920
stops the planets we're not certain

1510
01:11:23,908 --> 01:11:29,170
because we don't see planets all exactly

1511

01:11:26,920 --> 01:11:30,190
the same distance which would suggest it

1512
01:11:29,170 --> 01:11:32,800
was just stopping at the disk edge

1513
01:11:30,189 --> 01:11:34,839
instead we see hot and warm Jupiter's

1514
01:11:32,800 --> 01:11:36,579
that obviously seemed to have migrated

1515
01:11:34,840 --> 01:11:38,889
but stopped at different distances and

1516
01:11:36,578 --> 01:11:40,929
we're still not entirely sure why that

1517
01:11:38,889 --> 01:11:43,359
happens there's different ideas for

1518
01:11:40,929 --> 01:11:45,190
these planet traps that can cause for

1519
01:11:43,359 --> 01:11:47,649
instance sharp density gradients at the

1520
01:11:45,189 --> 01:11:50,678
ice line that can slow a planet down and

1521
01:11:47,649 --> 01:11:51,969
hold it for a bit and also see the gas

1522
01:11:50,679 --> 01:11:54,489
disc can evaporate at slightly different

1523
01:11:51,969 --> 01:11:57,730
times and in job effectively beaching

1524
01:11:54,488 --> 01:11:59,289
the planets but for the hot Jupiters we

1525
01:11:57,729 --> 01:12:06,729

found now because the gas disc is no

1526

01:11:59,289 --> 01:12:10,090

longer when you make comments or

1527

01:12:06,729 --> 01:12:12,879

observations about orbits on distant

1528

01:12:10,090 --> 01:12:14,860

worlds it seems to me we're making the

1529

01:12:12,880 --> 01:12:17,800

assumption that we'll use an earth time

1530

01:12:14,859 --> 01:12:20,738

but a time is relative is it possible

1531

01:12:17,800 --> 01:12:22,630

that time is very different on these

1532

01:12:20,738 --> 01:12:25,448

different worlds and has it completely

1533

01:12:22,630 --> 01:12:27,960

different I don't know if a second is

1534

01:12:25,448 --> 01:12:47,578

ten times longer than is here whatever

1535

01:12:27,960 --> 01:12:47,578

the impact would be different

1536

01:12:56,439 --> 01:13:02,229

so we see everything in a time yeah it's

1537

01:13:00,640 --> 01:13:12,360

we're all measuring it from our point of

1538

01:13:02,229 --> 01:13:16,329

view measurements in other solar systems

1539

01:13:12,359 --> 01:13:19,299

is there a minimum distance from the

1540
01:13:16,329 --> 01:13:28,420
star and a maximum distance is that is

1541
01:13:19,300 --> 01:13:31,829
that kind of area from on the planet

1542
01:13:28,420 --> 01:13:36,909
from the star and a maximum distance is

1543
01:13:31,829 --> 01:13:38,890
that area where planets forms of systems

1544
01:13:36,909 --> 01:13:40,238
is there a minimum distance from the

1545
01:13:38,890 --> 01:13:43,960
star or a maximum distance from a star

1546
01:13:40,238 --> 01:13:46,269
for planets so the prototype disk is

1547
01:13:43,960 --> 01:13:48,640
perfectly between one three percent of

1548
01:13:46,270 --> 01:13:56,050
the mass of the star and for that build

1549
01:13:48,640 --> 01:13:57,640
up process from it does not control

1550
01:13:56,050 --> 01:13:59,469
where the plants ultimately end up

1551
01:13:57,640 --> 01:14:01,300
because the addition to this gas

1552
01:13:59,469 --> 01:14:02,260
migration which would incur system

1553
01:14:01,300 --> 01:14:05,670
within that disk

1554
01:14:02,260 --> 01:14:07,960
there's also specially so if you have

1555
01:14:05,670 --> 01:14:10,210
multiple clients in their system they

1556
01:14:07,960 --> 01:14:12,579
can gravitationally pinboard each other

1557
01:14:10,210 --> 01:14:13,930
out the system so in our own solar

1558
01:14:12,579 --> 01:14:16,390
system we see evidence for that

1559
01:14:13,930 --> 01:14:19,239
happening in small objects so for

1560
01:14:16,390 --> 01:14:21,340
example our long-range comets come from

1561
01:14:19,238 --> 01:14:23,769
an area we call the Oort cloud which is

1562
01:14:21,340 --> 01:14:25,480
a huge distance away from us and it's

1563
01:14:23,770 --> 01:14:27,670
thought that objects there couldn't

1564
01:14:25,479 --> 01:14:29,379
possibly afford that they must have

1565
01:14:27,670 --> 01:14:31,270
formed much closer where our normal

1566
01:14:29,380 --> 01:14:33,369
planets are and then being scattered

1567
01:14:31,270 --> 01:14:35,710
gravitationally by planets like Jupiter

1568

01:14:33,369 --> 01:14:37,988
Saturn in this kind of gravitational

1569
01:14:35,710 --> 01:14:40,060
pinball game and when we look at

1570
01:14:37,988 --> 01:14:42,939
extrasolar planets we do sometimes see

1571
01:14:40,060 --> 01:14:44,860
planets that are far more distance then

1572
01:14:42,939 --> 01:14:48,069
there should have been a decent amount

1573
01:14:44,859 --> 01:14:51,069
of gas and dust in existence and we

1574
01:14:48,069 --> 01:14:52,389
genuinely believe that that is beyond

1575
01:14:51,069 --> 01:14:53,979
the edge where we expect planet

1576
01:14:52,390 --> 01:14:56,110
formation and they probably didn't form

1577
01:14:53,979 --> 01:14:58,959
there but it's a scattering event job

1578
01:14:56,109 --> 01:15:01,630
them further out so as a result we don't

1579
01:14:58,960 --> 01:15:03,939
have a hard edge to where we expect to

1580
01:15:01,630 --> 01:15:06,670
see a planet not because we believe it

1581
01:15:03,939 --> 01:15:09,988
could have formed infinitely far but

1582
01:15:06,670 --> 01:15:09,989

just because the scattering Pro

1583

01:15:22,310 --> 01:15:26,970

protection of the earth and what we are

1584

01:15:24,569 --> 01:15:30,359

doing to it I mean I think it's so

1585

01:15:26,970 --> 01:15:32,880

crucial to do all right so the question

1586

01:15:30,359 --> 01:15:34,920

was since you're studying all these

1587

01:15:32,880 --> 01:15:37,619

thoughts how do you feel about the

1588

01:15:34,920 --> 01:15:41,310

protection of our own planet how we

1589

01:15:37,619 --> 01:15:46,500

might be treating it I believe it's a

1590

01:15:41,310 --> 01:15:51,060

controversial statement and the reason

1591

01:15:46,500 --> 01:15:54,869

is it got hold of one of the things I

1592

01:15:51,060 --> 01:15:57,630

hate so much with this idea in

1593

01:15:54,869 --> 01:15:59,849

understand that you saw a planet so

1594

01:15:57,630 --> 01:16:02,520

we're not remotely earth-like once more

1595

01:15:59,850 --> 01:16:04,710

they were incredible distances away so

1596

01:16:02,520 --> 01:16:06,810

much so that the only way possible and

1597
01:16:04,710 --> 01:16:09,350
ending that movie was it go so

1598
01:16:06,810 --> 01:16:14,310
completely crazy

1599
01:16:09,350 --> 01:16:16,530
I think that tells you that even if life

1600
01:16:14,310 --> 01:16:18,690
is common in the universe even if there

1601
01:16:16,529 --> 01:16:20,369
are no bottlenecks even if the Fermi

1602
01:16:18,689 --> 01:16:23,009
paradox is not a thing and you can

1603
01:16:20,369 --> 01:16:25,800
develop life for all these worlds we may

1604
01:16:23,010 --> 01:16:27,869
never ever reach it and that means as

1605
01:16:25,800 --> 01:16:33,690
far as we're concerned we've only got

1606
01:16:27,869 --> 01:16:37,250
one earth all right we will see you

1607
01:16:33,689 --> 01:16:37,250
again next month

1608
01:16:41,119 --> 01:16:49,800
[Applause]