
NASA Astrobiology Institute

University of Washington
Astrobiology Seminar Series

Tidal
Extinction…

or Gaia?

1
00:00:06,309 --> 00:00:02,869
here we are welcome everybody including

2
00:00:09,030 --> 00:00:06,319
our web audience to the first of the uh

3
00:00:11,830 --> 00:00:09,040
fall astrobiology series

4
00:00:14,629 --> 00:00:11,840
uh we're very pleased uh there'll be

5
00:00:16,470 --> 00:00:14,639
about four outside speakers and a number

6
00:00:18,950 --> 00:00:16,480
of internal speakers

7
00:00:20,550 --> 00:00:18,960
throughout the fall quarter

8
00:00:21,349 --> 00:00:20,560
our first speaker

9
00:00:23,029 --> 00:00:21,359
is

10
00:00:25,029 --> 00:00:23,039
rory barnes i'm very pleased to

11
00:00:27,830 --> 00:00:25,039
introduce him now because

12
00:00:29,429 --> 00:00:27,840
it was about what 1990 we won't say

13
00:00:31,830 --> 00:00:29,439

exactly when

14
00:00:33,190 --> 00:00:31,840
he came into my office as a young

15
00:00:36,470 --> 00:00:33,200
graduate student

16
00:00:38,229 --> 00:00:36,480
at that point upsilon andromeda was the

17
00:00:40,709 --> 00:00:38,239
first

18
00:00:43,110 --> 00:00:40,719
multiple planet system other than the

19
00:00:45,910 --> 00:00:43,120
solar system to be discovered

20
00:00:48,630 --> 00:00:45,920
and rory was very keen on looking at the

21
00:00:50,389 --> 00:00:48,640
stability of such systems and the

22
00:00:53,270 --> 00:00:50,399
stability of planetary systems in

23
00:00:56,389 --> 00:00:53,280
general and he's made quite a career of

24
00:00:57,830 --> 00:00:56,399
studying the now many i can't count them

25
00:01:00,229 --> 00:00:57,840
multiple

26
00:01:02,310 --> 00:01:00,239
systems and what that implies for the

27
00:01:04,630 --> 00:01:02,320
generic stability

28
00:01:05,509 --> 00:01:04,640
of planetary systems

29
00:01:07,830 --> 00:01:05,519
uh

30
00:01:10,469 --> 00:01:07,840
and very interesting results that most

31
00:01:13,109 --> 00:01:10,479
planetary systems are on the very edge

32
00:01:16,230 --> 00:01:13,119
of instability

33
00:01:18,789 --> 00:01:16,240
his thesis however i drug him into the

34
00:01:20,710 --> 00:01:18,799
topic of planet formation

35
00:01:22,149 --> 00:01:20,720
which he found out to be a very hard

36
00:01:23,990 --> 00:01:22,159
topic

37
00:01:25,109 --> 00:01:24,000
but he's been working away at that as

38
00:01:27,749 --> 00:01:25,119

well

39
00:01:31,030 --> 00:01:27,759
he got his thesis with me uh he then

40
00:01:32,870 --> 00:01:31,040
went on to be a postdoc at

41
00:01:34,469 --> 00:01:32,880
university of arizona where he continues

42
00:01:36,789 --> 00:01:34,479
work on

43
00:01:38,710 --> 00:01:36,799
stability of planetary systems and we're

44
00:01:40,870 --> 00:01:38,720
very happy to have him back as a post

45
00:01:43,350 --> 00:01:40,880
doc working with the vpl

46
00:01:44,870 --> 00:01:43,360
he'll join us in january but right now

47
00:01:47,550 --> 00:01:44,880
he's going to talk to us about the

48
00:01:50,230 --> 00:01:47,560
habitability of tidally locked

49
00:01:52,710 --> 00:01:50,240
extraterrestrial planets

50
00:01:54,310 --> 00:01:52,720
all right extra solar clouds

51
00:01:55,990 --> 00:01:54,320
thank you very much tom it's obviously a

52
00:01:57,190 --> 00:01:56,000
pleasure to be back here and even more

53
00:01:59,109 --> 00:01:57,200
of a pleasure to be coming back in

54
00:02:03,350 --> 00:01:59,119
january uh i don't know can everybody

55
00:02:06,550 --> 00:02:05,350
notes

56
00:02:08,550 --> 00:02:06,560
better

57
00:02:10,150 --> 00:02:08,560
all right very good

58
00:02:11,110 --> 00:02:10,160
so uh

59
00:02:12,630 --> 00:02:11,120
as a

60
00:02:13,830 --> 00:02:12,640
rick all right

61
00:02:14,630 --> 00:02:13,840
tom left out a part of the story and

62
00:02:16,630 --> 00:02:14,640
that i've

63
00:02:18,470 --> 00:02:16,640

recently started working on uh looking

64
00:02:20,309 --> 00:02:18,480
at how tides affect planets this was

65
00:02:21,670 --> 00:02:20,319
quite a new direction for me because i

66
00:02:23,510 --> 00:02:21,680
stopped thinking of planets as point

67
00:02:25,430 --> 00:02:23,520
masses and start to imagine them as

68
00:02:26,630 --> 00:02:25,440
actually being extended bodies and lo

69
00:02:27,830 --> 00:02:26,640
and behold there's interesting things to

70
00:02:29,589 --> 00:02:27,840
learn from that

71
00:02:31,030 --> 00:02:29,599
uh but today i want to focus

72
00:02:32,229 --> 00:02:31,040
specifically on some of these issues

73
00:02:33,430 --> 00:02:32,239
that i've learned looking at the

74
00:02:34,630 --> 00:02:33,440
habitability of some of these planets

75
00:02:35,910 --> 00:02:34,640
that are going to be around hopefully

76
00:02:36,949 --> 00:02:35,920
we're going to find around low mass

77
00:02:38,630 --> 00:02:36,959
stars

78
00:02:41,110 --> 00:02:38,640
before i get started i do need to uh

79
00:02:43,990 --> 00:02:41,120
acknowledge my uh colleagues here

80
00:02:45,030 --> 00:02:44,000
so uh rick greenberg is my boss down in

81
00:02:46,790 --> 00:02:45,040
tucson

82
00:02:48,150 --> 00:02:46,800
he's definitely an expert on on tides

83
00:02:50,390 --> 00:02:48,160
and planets he's probably most well

84
00:02:51,910 --> 00:02:50,400
known for his work on europa uh brian

85
00:02:53,350 --> 00:02:51,920
jackson is a graduate student who is

86
00:02:55,670 --> 00:02:53,360
working with rick and i

87
00:02:57,670 --> 00:02:55,680
uh his last two characters down here

88
00:02:59,270 --> 00:02:57,680

probably some are familiar some of you

89
00:03:01,750 --> 00:02:59,280
sean raymond is of course also a member

90
00:03:03,110 --> 00:03:01,760
of epl he's now colorado and andrew west

91
00:03:04,550 --> 00:03:03,120
is now at mit

92
00:03:06,149 --> 00:03:04,560
and they've been helping me out try and

93
00:03:08,229 --> 00:03:06,159
understand some of these issues with

94
00:03:08,949 --> 00:03:08,239
with planets

95
00:03:11,190 --> 00:03:08,959
so

96
00:03:12,869 --> 00:03:11,200
uh just as motivation for what this talk

97
00:03:15,589 --> 00:03:12,879
is going to be about or what really my

98
00:03:16,470 --> 00:03:15,599
motivation is for for this research is

99
00:03:21,509 --> 00:03:16,480
it

100
00:03:23,990 --> 00:03:21,519
meant to show is

101
00:03:25,750 --> 00:03:24,000
a transit is when a planet crosses in

102
00:03:27,589 --> 00:03:25,760
front of the disk of a star

103
00:03:29,270 --> 00:03:27,599
so what happens is that if an astronomer

104
00:03:31,110 --> 00:03:29,280
is at its telescope he's going to

105
00:03:33,589 --> 00:03:31,120
measure the brightness of this star over

106
00:03:35,430 --> 00:03:33,599
time and initially the brightness is

107
00:03:38,470 --> 00:03:35,440
very constant but then at some point it

108
00:03:39,910 --> 00:03:38,480
dips and when we see this sort of dip

109
00:03:41,670 --> 00:03:39,920
the inference is that something is

110
00:03:43,509 --> 00:03:41,680
blocking the light now it's more

111
00:03:45,270 --> 00:03:43,519
complicated than that in practice but

112
00:03:47,589 --> 00:03:45,280
this is one possibility

113
00:03:49,910 --> 00:03:47,599

and when a transit happens that's a very

114
00:03:51,830 --> 00:03:49,920
important event because you can learn a

115
00:03:54,550 --> 00:03:51,840
lot more about the planet than you could

116
00:03:56,470 --> 00:03:54,560
if you did not see this transit

117
00:03:58,390 --> 00:03:56,480
the the transits provide lots of

118
00:04:00,070 --> 00:03:58,400
information they provide not only just

119
00:04:01,509 --> 00:04:00,080
the mass but you can't get from just

120
00:04:03,110 --> 00:04:01,519
radial velocity data which is the

121
00:04:04,789 --> 00:04:03,120
standard way that planets are are found

122
00:04:06,869 --> 00:04:04,799
maybe i shouldn't say standard but the

123
00:04:08,630 --> 00:04:06,879
most common way planets are found but

124
00:04:10,390 --> 00:04:08,640
more than that it also gets you other

125
00:04:11,750 --> 00:04:10,400
actual physical properties of the planet

126
00:04:13,190 --> 00:04:11,760
like the radius

127
00:04:15,110 --> 00:04:13,200
the bulk density

128
00:04:16,949 --> 00:04:15,120
you can measure the surface temperature

129
00:04:19,749 --> 00:04:16,959
perhaps and you can also measure the

130
00:04:21,830 --> 00:04:19,759
atmospheric composition of the planet

131
00:04:23,110 --> 00:04:21,840
uh before i get started i just we're

132
00:04:25,350 --> 00:04:23,120
really get started here i want to just

133
00:04:27,430 --> 00:04:25,360
mention a few things about a few bits of

134
00:04:29,030 --> 00:04:27,440
jargon that maybe some of you heard i'm

135
00:04:30,310 --> 00:04:29,040
going to mainly be talking about super

136
00:04:31,189 --> 00:04:30,320
earths

137
00:04:32,790 --> 00:04:31,199
because i don't think there's a

138
00:04:34,790 --> 00:04:32,800

canonical definition of super earth yet

139
00:04:36,150 --> 00:04:34,800
but it's sort of anything that's sort of

140
00:04:38,070 --> 00:04:36,160
more massive than the earth but less

141
00:04:40,150 --> 00:04:38,080
than 10 earth masses and the reason why

142
00:04:42,629 --> 00:04:40,160
10 earth masses is sort of this limit is

143
00:04:44,230 --> 00:04:42,639
because most models of planet formation

144
00:04:46,230 --> 00:04:44,240
suggest that when a planet has more than

145
00:04:47,749 --> 00:04:46,240
10 earth masses of material in it it's

146
00:04:48,870 --> 00:04:47,759
going to start to create hydrogen and

147
00:04:51,749 --> 00:04:48,880
it's going to be more like a giant

148
00:04:54,550 --> 00:04:51,759
planet more like jupiter and so this is

149
00:04:56,950 --> 00:04:54,560
why this is sort of this magic range

150
00:04:58,310 --> 00:04:56,960
is because they anything less than that

151
00:05:00,629 --> 00:04:58,320
is going to have

152
00:05:02,790 --> 00:05:00,639
maybe a thin atmosphere is going to be

153
00:05:05,670 --> 00:05:02,800
more earth-like

154
00:05:07,590 --> 00:05:05,680
now a transit requires a few special

155
00:05:10,950 --> 00:05:07,600
things to happen it requires the correct

156
00:05:12,070 --> 00:05:10,960
viewing geometry uh basically the orbit

157
00:05:13,990 --> 00:05:12,080
could sort of the planet could be

158
00:05:15,350 --> 00:05:14,000
oriented anywhere in the galaxy anywhere

159
00:05:16,469 --> 00:05:15,360
in space point towards any point in the

160
00:05:17,990 --> 00:05:16,479
galaxy

161
00:05:19,909 --> 00:05:18,000
but it has to line up so that if the

162
00:05:20,950 --> 00:05:19,919
planet passes right between you and the

163
00:05:23,110 --> 00:05:20,960

star

164
00:05:24,390 --> 00:05:23,120
and so there's some small chance that

165
00:05:26,070 --> 00:05:24,400
that might happen and it does happen and

166
00:05:27,350 --> 00:05:26,080
we're seeing these planets

167
00:05:28,790 --> 00:05:27,360
and the other thing that you need is you

168
00:05:30,070 --> 00:05:28,800
have to block enough of the light from

169
00:05:31,430 --> 00:05:30,080
the star you have to actually be able to

170
00:05:34,950 --> 00:05:31,440
observe that dip that i showed in the

171
00:05:37,590 --> 00:05:36,469
but i think the most interesting thing

172
00:05:39,909 --> 00:05:37,600
about the transits from an

173
00:05:41,270 --> 00:05:39,919
astrobiological standpoint is that we're

174
00:05:43,590 --> 00:05:41,280
actually going you can actually measure

175
00:05:45,189 --> 00:05:43,600
the properties of the atmosphere and so

176
00:05:47,510 --> 00:05:45,199
this cartoon up here at the top is meant

177
00:05:49,909 --> 00:05:47,520
to show sort of schematically how this

178
00:05:51,270 --> 00:05:49,919
happens is that the star emits light

179
00:05:53,189 --> 00:05:51,280
some of that light is blocked by the

180
00:05:55,189 --> 00:05:53,199
solid part of the of the planet and then

181
00:05:57,510 --> 00:05:55,199
this atmosphere around here is able to

182
00:05:59,909 --> 00:05:57,520
plot parts of the light but not all of

183
00:06:01,510 --> 00:05:59,919
it what happens is that the light when

184
00:06:03,510 --> 00:06:01,520
it comes to earth we run it through some

185
00:06:05,270 --> 00:06:03,520
sort of apparatus a spectrograph and we

186
00:06:07,749 --> 00:06:05,280
get the spectrum of this of the the

187
00:06:09,590 --> 00:06:07,759
planet and we might notice some parts of

188
00:06:10,550 --> 00:06:09,600

the spectrum have been taken out these

189
00:06:12,070 --> 00:06:10,560
chunks that have been taken out

190
00:06:15,029 --> 00:06:12,080
correspond to different elements in the

191
00:06:17,189 --> 00:06:15,039
atmosphere and we can actually measure

192
00:06:18,469 --> 00:06:17,199
what the composition of these planets

193
00:06:20,629 --> 00:06:18,479
might be like

194
00:06:22,550 --> 00:06:20,639
now this has been done for some of the

195
00:06:24,150 --> 00:06:22,560
plants that we've discovered so far uh

196
00:06:26,150 --> 00:06:24,160
we've seen some of these molecules some

197
00:06:28,950 --> 00:06:26,160
of these elements so far water methane

198
00:06:30,469 --> 00:06:28,960
sodium and hydrogen and this is proof of

199
00:06:32,629 --> 00:06:30,479
a concept at least that we can we can

200
00:06:34,390 --> 00:06:32,639
really do this for smaller mass planets

201
00:06:36,469 --> 00:06:34,400
because right now all we've really been

202
00:06:38,469 --> 00:06:36,479
able to do is see these on these giant

203
00:06:40,710 --> 00:06:38,479
planets we have not been able

204
00:06:44,230 --> 00:06:40,720
we have not actually seen a transit of a

205
00:06:45,430 --> 00:06:44,240
low-mass terrestrial-like planet yet

206
00:06:46,870 --> 00:06:45,440
so

207
00:06:47,749 --> 00:06:46,880
we're going to see these planets but

208
00:06:48,870 --> 00:06:47,759
where are we going to see them well

209
00:06:51,350 --> 00:06:48,880
we're going to hopefully see them in the

210
00:06:52,790 --> 00:06:51,360
habitable zone and this is a pretty

211
00:06:54,309 --> 00:06:52,800
well-known plot play especially with

212
00:06:58,070 --> 00:06:54,319
people in this audience so i don't need

213
00:07:00,230 --> 00:06:58,080

to belabor it too much but uh basically

214
00:07:01,670 --> 00:07:00,240
uh my laser pointer there we go it's

215
00:07:02,870 --> 00:07:01,680
sort of working

216
00:07:05,990 --> 00:07:02,880
nothing there's two of them here let me

217
00:07:07,749 --> 00:07:06,000
try this one uh on the y-axis is the

218
00:07:09,430 --> 00:07:07,759
cellar mass

219
00:07:11,350 --> 00:07:09,440
ranging from what is said definitely

220
00:07:13,670 --> 00:07:11,360
below a stellar map or below anything

221
00:07:15,749 --> 00:07:13,680
that could be considered a star on up to

222
00:07:17,350 --> 00:07:15,759
a pretty large star and then these these

223
00:07:18,870 --> 00:07:17,360
uh letters here correspond to spectral

224
00:07:19,990 --> 00:07:18,880
classes don't worry about that too much

225
00:07:21,830 --> 00:07:20,000
the point is that i want you to pay

226
00:07:23,350 --> 00:07:21,840
attention to what this mass of the star

227
00:07:24,710 --> 00:07:23,360
is relative to m naught which is the

228
00:07:26,390 --> 00:07:24,720
mass of the sun

229
00:07:27,510 --> 00:07:26,400
these are low mass stars down here of

230
00:07:29,110 --> 00:07:27,520
course the sun is at one and that's

231
00:07:30,469 --> 00:07:29,120
where our solar system is

232
00:07:32,629 --> 00:07:30,479
uh then

233
00:07:35,990 --> 00:07:32,639
here on the y-axis the x-axis excuse me

234
00:07:36,950 --> 00:07:36,000
is the uh the distance from the star

235
00:07:39,110 --> 00:07:36,960
and uh

236
00:07:40,710 --> 00:07:39,120
this little river of yellow that runs

237
00:07:42,070 --> 00:07:40,720
through this plot is called the hazel

238
00:07:43,830 --> 00:07:42,080

zone at least traditionally that's what

239
00:07:45,589 --> 00:07:43,840
it's been called this is where basically

240
00:07:47,510 --> 00:07:45,599
an earth-like planet would receive about

241
00:07:50,070 --> 00:07:47,520
as much light from its host star as the

242
00:07:52,150 --> 00:07:50,080
earth does from the sun so maybe that's

243
00:07:54,390 --> 00:07:52,160
where planets might be habitable

244
00:07:56,869 --> 00:07:54,400
now you might also notice there's this

245
00:07:58,869 --> 00:07:56,879
line here now this line has been drawn i

246
00:08:00,150 --> 00:07:58,879
should maybe draw this line this title

247
00:08:01,670 --> 00:08:00,160
lock radius

248
00:08:03,430 --> 00:08:01,680
this has been drawn on every plot i've

249
00:08:05,589 --> 00:08:03,440
ever seen like this but it's not really

250
00:08:07,110 --> 00:08:05,599
been discussed in a whole lot of detail

251
00:08:08,230 --> 00:08:07,120
there has been there has been some i

252
00:08:09,510 --> 00:08:08,240
shouldn't say there's been none but

253
00:08:11,029 --> 00:08:09,520
there has been a little bit of

254
00:08:13,749 --> 00:08:11,039
examination on this but i really want to

255
00:08:16,550 --> 00:08:13,759
focus on what does it really mean to be

256
00:08:17,990 --> 00:08:16,560
to the left of this tidal lock radius

257
00:08:19,029 --> 00:08:18,000
uh and i'm not going to get into that

258
00:08:20,390 --> 00:08:19,039
just now we're going to talk about that

259
00:08:22,309 --> 00:08:20,400
in a minute but

260
00:08:23,909 --> 00:08:22,319
you know the point is is that in this

261
00:08:25,430 --> 00:08:23,919
region here

262
00:08:27,589 --> 00:08:25,440
the planet could be habitable but it's

263
00:08:30,070 --> 00:08:27,599

also affected by tides between the

264
00:08:30,950 --> 00:08:30,080
planet and the star

265
00:08:34,070 --> 00:08:30,960
so

266
00:08:35,750 --> 00:08:34,080
requirements for have or for being able

267
00:08:38,230 --> 00:08:35,760
to detect the transit we have to be able

268
00:08:40,389 --> 00:08:38,240
to see enough light blocked so for a 10

269
00:08:42,070 --> 00:08:40,399
earth mass planet that is earth light

270
00:08:43,990 --> 00:08:42,080
that is terrestrial light

271
00:08:45,990 --> 00:08:44,000
these black lines that i've drawn that

272
00:08:47,990 --> 00:08:46,000
are horizontal correspond to how much

273
00:08:49,269 --> 00:08:48,000
light would be blocked by the planet

274
00:08:50,710 --> 00:08:49,279
during transit

275
00:08:53,430 --> 00:08:50,720
it's called the transit depth quite

276
00:08:55,590 --> 00:08:53,440
often and so one percent half a percent

277
00:08:57,430 --> 00:08:55,600
and a tenth of a percent and from the

278
00:08:59,670 --> 00:08:57,440
ground we can sort of mainly see in this

279
00:09:01,509 --> 00:08:59,680
sort of range maybe half a percent or

280
00:09:03,030 --> 00:09:01,519
bigger now

281
00:09:05,190 --> 00:09:03,040
we are launching space telescopes that

282
00:09:10,150 --> 00:09:05,200
hopefully will be able to see smaller oh

283
00:09:10,160 --> 00:09:15,670
i know are the viruses attacking

284
00:09:15,680 --> 00:09:18,550
sorry

285
00:09:27,990 --> 00:09:19,910
if only there were refreshments we could

286
00:09:28,000 --> 00:09:41,030
long extra planets they'll be hurricanes

287
00:09:46,150 --> 00:09:42,070
all right

288
00:09:48,550 --> 00:09:47,190

okay

289
00:09:50,070 --> 00:09:48,560
all right so uh

290
00:09:51,670 --> 00:09:50,080
hopefully we'll be able to see some of

291
00:09:53,430 --> 00:09:51,680
these earth-like plants these are 10

292
00:09:55,590 --> 00:09:53,440
earth masses so this is sort of the most

293
00:09:57,110 --> 00:09:55,600
optimistic case you know we see a planet

294
00:09:58,310 --> 00:09:57,120
that's as big as it can be and be

295
00:09:59,670 --> 00:09:58,320
terrestrial-like

296
00:10:01,590 --> 00:09:59,680
we might be able to see it sort of in

297
00:10:04,630 --> 00:10:01,600
this range which is below about

298
00:10:06,389 --> 00:10:04,640
0.2 maybe if your optimistic 0.3 solar

299
00:10:09,590 --> 00:10:06,399
mass so a pretty small it's pretty small

300
00:10:11,750 --> 00:10:09,600
mass star but nonetheless sort of below

301
00:10:13,269 --> 00:10:11,760
this this line right here and down is

302
00:10:16,630 --> 00:10:13,279
where we might be able to see a

303
00:10:19,750 --> 00:10:16,640
transiting 10 earth mass planet

304
00:10:21,990 --> 00:10:19,760
on this plot

305
00:10:24,470 --> 00:10:22,000
as i said you also need to be able to

306
00:10:25,990 --> 00:10:24,480
see uh there has to be a chance that the

307
00:10:28,389 --> 00:10:26,000
the planet will actually block some of

308
00:10:30,310 --> 00:10:28,399
the light of the star so a bigger planet

309
00:10:31,829 --> 00:10:30,320
you might imagine has a better chance of

310
00:10:33,670 --> 00:10:31,839
blocking the light from the star because

311
00:10:35,829 --> 00:10:33,680
it doesn't have to be tilted directly

312
00:10:37,910 --> 00:10:35,839
edge on in order to be to block the

313
00:10:41,030 --> 00:10:37,920

light it can sort of be a grazing sort

314
00:10:43,829 --> 00:10:41,040
of uh eclipse or grazing transit

315
00:10:45,829 --> 00:10:43,839
and so these lines correspond to

316
00:10:48,470 --> 00:10:45,839
the geometric probability of a 10 earth

317
00:10:49,910 --> 00:10:48,480
mass planet blocking the light of the of

318
00:10:50,870 --> 00:10:49,920
the star

319
00:10:53,590 --> 00:10:50,880
and

320
00:10:55,829 --> 00:10:53,600
so what this tells us really is that

321
00:10:57,590 --> 00:10:55,839
this region surrounded by the red oval

322
00:11:00,389 --> 00:10:57,600
this is our best bet for finding

323
00:11:01,750 --> 00:11:00,399
terrestrial-like planets around stars

324
00:11:03,829 --> 00:11:01,760
around you know

325
00:11:05,350 --> 00:11:03,839
ten earth nest planet around any star

326
00:11:06,790 --> 00:11:05,360
your best bet is down here in this very

327
00:11:08,550 --> 00:11:06,800
low mass region

328
00:11:10,710 --> 00:11:08,560
so this is why we want to talk about

329
00:11:12,230 --> 00:11:10,720
these stars today and i want to talk

330
00:11:14,230 --> 00:11:12,240
about tidal waves flashlight i guess i

331
00:11:15,590 --> 00:11:14,240
need to say one other thing before i get

332
00:11:17,509 --> 00:11:15,600
to tides

333
00:11:18,949 --> 00:11:17,519
um the previous slide that this

334
00:11:20,710 --> 00:11:18,959
classical definition of the habitable

335
00:11:23,190 --> 00:11:20,720
zone is uh based on the idea that the

336
00:11:24,870 --> 00:11:23,200
planets are on circular orbit but we see

337
00:11:26,470 --> 00:11:24,880
a lot of extrasolar planets that are not

338
00:11:29,430 --> 00:11:26,480

on circular orbits they're on eccentric

339
00:11:31,509 --> 00:11:29,440
orbits and uh what does that do to the

340
00:11:33,110 --> 00:11:31,519
sort of amount of light that a star or

341
00:11:34,630 --> 00:11:33,120
excuse me that a planet receives over

342
00:11:36,470 --> 00:11:34,640
time well it turns out that it doesn't

343
00:11:37,910 --> 00:11:36,480
do a whole lot uh there's some work that

344
00:11:39,350 --> 00:11:37,920
was done i guess

345
00:11:42,230 --> 00:11:39,360
six years ago now by williams and

346
00:11:43,590 --> 00:11:42,240
pollard that suggested that for planets

347
00:11:45,509 --> 00:11:43,600
on eccentric orbits what really

348
00:11:47,590 --> 00:11:45,519
determines the sort of surface

349
00:11:49,590 --> 00:11:47,600
temperature on on average around one of

350
00:11:50,310 --> 00:11:49,600
these planet on one of these planets

351
00:11:52,069 --> 00:11:50,320
is

352
00:11:54,150 --> 00:11:52,079
the orbit average

353
00:11:55,430 --> 00:11:54,160
of the uh of the stellar light that it

354
00:11:56,949 --> 00:11:55,440
receives so

355
00:11:59,350 --> 00:11:56,959
yeah it receives a lot when it comes

356
00:12:01,110 --> 00:11:59,360
close to the star and it receives less

357
00:12:03,030 --> 00:12:01,120
when it's far away from the star but

358
00:12:05,190 --> 00:12:03,040
what really determines it is the the

359
00:12:07,030 --> 00:12:05,200
average and i should say i know that not

360
00:12:08,550 --> 00:12:07,040
all of you are astronomers like i am so

361
00:12:10,550 --> 00:12:08,560
what i mean by the eccentricity is sort

362
00:12:12,389 --> 00:12:10,560
of the elongation of the orbit so

363
00:12:13,990 --> 00:12:12,399

there's you have an eccentric orbit

364
00:12:15,350 --> 00:12:14,000
there's a point that passes close to the

365
00:12:17,350 --> 00:12:15,360
star and then it moves farther away and

366
00:12:18,870 --> 00:12:17,360
moves farther from the star

367
00:12:20,389 --> 00:12:18,880
and so as you imagine as you move

368
00:12:22,310 --> 00:12:20,399
farther and closer to the star the

369
00:12:23,590 --> 00:12:22,320
amount of light you receive changes and

370
00:12:26,069 --> 00:12:23,600
what this plot is just sort of showing

371
00:12:27,910 --> 00:12:26,079
is that despite some of these variations

372
00:12:29,430 --> 00:12:27,920
the and the amount of light that every

373
00:12:30,710 --> 00:12:29,440
that the planet receives is that the

374
00:12:33,030 --> 00:12:30,720
surface temperature doesn't really

375
00:12:34,870 --> 00:12:33,040
change by a whole lot now the the

376
00:12:36,550 --> 00:12:34,880
eccentricity of 0.4 is pretty large but

377
00:12:38,389 --> 00:12:36,560
we do see eccentricities that are

378
00:12:39,509 --> 00:12:38,399
considerably larger even in excess of

379
00:12:41,350 --> 00:12:39,519
0.9

380
00:12:42,790 --> 00:12:41,360
but this is at least a starting point to

381
00:12:44,710 --> 00:12:42,800
suggest that

382
00:12:46,310 --> 00:12:44,720
as we look at sort of eccentric planets

383
00:12:47,829 --> 00:12:46,320
then it's really going to be how much

384
00:12:49,350 --> 00:12:47,839
light they receive over the entire orbit

385
00:12:51,269 --> 00:12:49,360
that's really going to drive their

386
00:12:53,190 --> 00:12:51,279
habitability

387
00:12:55,190 --> 00:12:53,200
and so what my colleagues and i did is

388
00:12:56,230 --> 00:12:55,200

we just sort of took this these two

389
00:12:57,350 --> 00:12:56,240
results and sort of slapped them

390
00:12:59,269 --> 00:12:57,360
together

391
00:13:02,389 --> 00:12:59,279
of uh where the habitable zone is and

392
00:13:04,310 --> 00:13:02,399
this orbit average eccentricity idea

393
00:13:05,670 --> 00:13:04,320
and uh just determine what the handle

394
00:13:08,150 --> 00:13:05,680
zones might be and so that's what this

395
00:13:10,470 --> 00:13:08,160
plot shows and i know it's a little busy

396
00:13:11,990 --> 00:13:10,480
right here but let me just say that

397
00:13:13,509 --> 00:13:12,000
there's these shadings here correspond

398
00:13:15,670 --> 00:13:13,519
to handle zones that correspond to

399
00:13:18,069 --> 00:13:15,680
different amounts of cloud cover uh

400
00:13:20,389 --> 00:13:18,079
basically the original model casting had

401
00:13:22,230 --> 00:13:20,399
been has been updated a little bit and

402
00:13:23,990 --> 00:13:22,240
basically if you have water clouds they

403
00:13:25,990 --> 00:13:24,000
can reflect some of the light and that

404
00:13:27,350 --> 00:13:26,000
can improve your habitability if you're

405
00:13:29,509 --> 00:13:27,360
close to the star because it reflects

406
00:13:31,590 --> 00:13:29,519
some of that excessive radiation if

407
00:13:33,430 --> 00:13:31,600
you're far from the star there's you can

408
00:13:35,670 --> 00:13:33,440
get co2 clouds which actually work sort

409
00:13:37,670 --> 00:13:35,680
of as a greenhouse so these different

410
00:13:39,269 --> 00:13:37,680
shadings correspond to just different

411
00:13:40,470 --> 00:13:39,279
assumptions about the atmosphere of the

412
00:13:42,069 --> 00:13:40,480
planet

413
00:13:44,310 --> 00:13:42,079

uh what what i want you to take away

414
00:13:45,509 --> 00:13:44,320
though is that at larger eccentricity

415
00:13:48,710 --> 00:13:45,519
the uh

416
00:13:50,389 --> 00:13:48,720
semi-major axis of the

417
00:13:52,230 --> 00:13:50,399
of the orbits that are habit will

418
00:13:53,670 --> 00:13:52,240
increase it but the a over here is

419
00:13:55,110 --> 00:13:53,680
centimeter axis i'm sorry i didn't

420
00:13:57,110 --> 00:13:55,120
mention that right at the beginning so

421
00:13:58,790 --> 00:13:57,120
as i get to larger eccentricities the

422
00:14:01,990 --> 00:13:58,800
habitable zone actually moves farther

423
00:14:03,829 --> 00:14:02,000
from the star

424
00:14:06,949 --> 00:14:03,839
right so

425
00:14:09,590 --> 00:14:06,959
where do tides come in well it turns out

426
00:14:10,870 --> 00:14:09,600
that when a planet or in this case i've

427
00:14:12,710 --> 00:14:10,880
taken this sort of a well-known example

428
00:14:15,030 --> 00:14:12,720
from our solar system when a satellite

429
00:14:16,389 --> 00:14:15,040
is close to its central body its shape

430
00:14:18,550 --> 00:14:16,399
can get deformed

431
00:14:21,990 --> 00:14:18,560
due to the change in the gravitational

432
00:14:25,189 --> 00:14:22,000
field across the planet so in this model

433
00:14:27,990 --> 00:14:25,199
jupiter here is the central body

434
00:14:29,670 --> 00:14:28,000
and io goes around

435
00:14:30,949 --> 00:14:29,680
the in this sort of eccentric orbit you

436
00:14:32,790 --> 00:14:30,959
can see that it's not a circle and

437
00:14:34,790 --> 00:14:32,800
jupiter is not in the center so this is

438
00:14:35,829 --> 00:14:34,800

supposed to represent the eccentricity

439
00:14:38,790 --> 00:14:35,839
and

440
00:14:40,150 --> 00:14:38,800
the io is its shape is deformed more

441
00:14:41,829 --> 00:14:40,160
when it's close to jupiter than when

442
00:14:43,829 --> 00:14:41,839
it's far from jupiter

443
00:14:45,990 --> 00:14:43,839
and what this deformation does is it

444
00:14:48,069 --> 00:14:46,000
basically changes

445
00:14:50,949 --> 00:14:48,079
the the surface of the planet and it

446
00:14:52,949 --> 00:14:50,959
takes energy to do that and that energy

447
00:14:54,870 --> 00:14:52,959
it's transformed into friction as the

448
00:14:57,590 --> 00:14:54,880
shape of this actual planet tries to

449
00:14:58,470 --> 00:14:57,600
keep flexing back and forth between a

450
00:14:59,750 --> 00:14:58,480
lot of

451
00:15:02,470 --> 00:14:59,760
elongation and a little bit of

452
00:15:04,790 --> 00:15:02,480
elongation and for any real planet that

453
00:15:06,710 --> 00:15:04,800
drives heat inside the planet and not

454
00:15:08,710 --> 00:15:06,720
only that it's actually going to take

455
00:15:10,629 --> 00:15:08,720
energy from the orbit

456
00:15:12,629 --> 00:15:10,639
and transform it into the frictional

457
00:15:14,870 --> 00:15:12,639
heat inside the planet so it's taking

458
00:15:19,030 --> 00:15:14,880
orbital energy and transforming it into

459
00:15:22,230 --> 00:15:20,629
another way to think about this is in

460
00:15:23,910 --> 00:15:22,240
just terms of what does the planet

461
00:15:25,430 --> 00:15:23,920
actually see as as it's on one of these

462
00:15:26,629 --> 00:15:25,440
eccentric orbits and it's going around

463
00:15:28,870 --> 00:15:26,639

the star

464
00:15:30,470 --> 00:15:28,880
uh in this schematic here this circle

465
00:15:33,110 --> 00:15:30,480
sort of represents the

466
00:15:35,430 --> 00:15:33,120
equilibrium shape of this of this planet

467
00:15:37,030 --> 00:15:35,440
and these wings here represent the

468
00:15:39,829 --> 00:15:37,040
deformation of the

469
00:15:41,750 --> 00:15:39,839
the the planet and uh this little bulge

470
00:15:44,870 --> 00:15:41,760
here this stretching of the planet

471
00:15:47,110 --> 00:15:44,880
always wants to point towards the star

472
00:15:49,110 --> 00:15:47,120
and so when it's on an eccentric orbit

473
00:15:51,110 --> 00:15:49,120
the star seems to move around relative

474
00:15:53,910 --> 00:15:51,120
to if you were standing on the surface

475
00:15:56,069 --> 00:15:53,920
and so the bulge tries to follow that

476
00:15:57,910 --> 00:15:56,079
the the gravitational source of the the

477
00:15:59,749 --> 00:15:57,920
perturbation which is the star

478
00:16:01,189 --> 00:15:59,759
and uh so what this says is that the

479
00:16:02,870 --> 00:16:01,199
tide really is going to vary over the

480
00:16:04,710 --> 00:16:02,880
course of an orbit that's another way of

481
00:16:07,030 --> 00:16:04,720
saying what i just said that the shape

482
00:16:09,749 --> 00:16:07,040
is going to change over time

483
00:16:10,949 --> 00:16:09,759
but in reality for any sort of real body

484
00:16:12,790 --> 00:16:10,959
this is not going to be just

485
00:16:13,990 --> 00:16:12,800
instantaneously caught up to wherever

486
00:16:16,389 --> 00:16:14,000
the uh

487
00:16:17,509 --> 00:16:16,399
the star is it's going to lag it's not

488
00:16:18,790 --> 00:16:17,519

going to be able to keep up it's not

489
00:16:20,389 --> 00:16:18,800
going to be able to adjust

490
00:16:21,269 --> 00:16:20,399
instantaneously to the position of the

491
00:16:23,350 --> 00:16:21,279
star

492
00:16:24,389 --> 00:16:23,360
and so this is going to lead to a torque

493
00:16:26,629 --> 00:16:24,399
on the orbit that there's going to be

494
00:16:28,389 --> 00:16:26,639
this asymmetry in the system that it's

495
00:16:30,069 --> 00:16:28,399
not going to be perfectly lined up like

496
00:16:32,069 --> 00:16:30,079
it's i think it's shown here

497
00:16:34,069 --> 00:16:32,079
and it is this sort of asymmetry that's

498
00:16:36,949 --> 00:16:34,079
going to really result in the orbits

499
00:16:38,550 --> 00:16:36,959
shrinking and circularizing so over time

500
00:16:40,150 --> 00:16:38,560
these orbits are going to slowly

501
00:16:41,590 --> 00:16:40,160
collapse towards the star and they're

502
00:16:43,990 --> 00:16:41,600
going to go from being very elongated to

503
00:16:45,749 --> 00:16:44,000
being circular so that's really the

504
00:16:48,829 --> 00:16:45,759
process of tides at least in the context

505
00:16:50,949 --> 00:16:48,839
that we need to know about today

506
00:16:52,230 --> 00:16:50,959
so i've sort of said a lot of these

507
00:16:53,670 --> 00:16:52,240
words here and it might not be very

508
00:16:55,509 --> 00:16:53,680
clear so i want to show you this movie

509
00:16:57,829 --> 00:16:55,519
that i think maybe illustrates the point

510
00:17:00,389 --> 00:16:57,839
a little bit better

511
00:17:01,749 --> 00:17:00,399
so what i've done here is i've taken uh

512
00:17:04,309 --> 00:17:01,759
a planet that has an eccentricity

513
00:17:07,270 --> 00:17:04,319

initially of 0.84 this is or it's

514
00:17:08,870 --> 00:17:07,280
orbiting a 0.2 solar mass star

515
00:17:11,029 --> 00:17:08,880
which is represented by that red dot

516
00:17:11,909 --> 00:17:11,039
which is the hand is in the way remove

517
00:17:14,230 --> 00:17:11,919
that

518
00:17:15,429 --> 00:17:14,240
and so as the time is moving on here

519
00:17:16,870 --> 00:17:15,439
notice that it's moving along in

520
00:17:18,630 --> 00:17:16,880
billions of years

521
00:17:20,069 --> 00:17:18,640
this orbit you can see is slowly

522
00:17:22,870 --> 00:17:20,079
starting to shrink

523
00:17:25,110 --> 00:17:22,880
so the blue lines these correspond to

524
00:17:27,510 --> 00:17:25,120
the boundaries of the habitable zone

525
00:17:29,990 --> 00:17:27,520
at least for with a 50 of the surface

526
00:17:31,830 --> 00:17:30,000
being covered by clouds and you can see

527
00:17:34,710 --> 00:17:31,840
uh i guess i i need to finish a little

528
00:17:36,470 --> 00:17:34,720
bit here so this dashed circle here that

529
00:17:38,390 --> 00:17:36,480
corresponded to the semi-major axis of

530
00:17:40,950 --> 00:17:38,400
the uh the planet

531
00:17:42,789 --> 00:17:40,960
and the actual orbit was the solid black

532
00:17:44,950 --> 00:17:42,799
line and so you could see that the

533
00:17:47,669 --> 00:17:44,960
semi-major axis would decay and at the

534
00:17:49,430 --> 00:17:47,679
same time the orbit was circularizing so

535
00:17:50,549 --> 00:17:49,440
let me play it again because

536
00:17:51,909 --> 00:17:50,559
there were some

537
00:17:53,270 --> 00:17:51,919
things in there that i wanted to point

538
00:17:54,710 --> 00:17:53,280

out yep there it goes all right so

539
00:17:56,950 --> 00:17:54,720
remember so the blue lines are the

540
00:17:59,270 --> 00:17:56,960
habitable zone boundaries this

541
00:18:01,270 --> 00:17:59,280
dashed black line is the semi-major axis

542
00:18:03,190 --> 00:18:01,280
of the orbit so right now it's initially

543
00:18:05,590 --> 00:18:03,200
it's inside the habitable zone but it's

544
00:18:07,590 --> 00:18:05,600
pretty close to the inner edge

545
00:18:08,870 --> 00:18:07,600
and so then the black line is the orbit

546
00:18:10,710 --> 00:18:08,880
which is slowly decaying the

547
00:18:11,510 --> 00:18:10,720
eccentricity is dropping

548
00:18:13,029 --> 00:18:11,520
and

549
00:18:14,549 --> 00:18:13,039
so even though this planet started out

550
00:18:15,750 --> 00:18:14,559
with a very large eccentricity our

551
00:18:18,070 --> 00:18:15,760
assumption would be that it was

552
00:18:19,990 --> 00:18:18,080
initially habitable but then we can see

553
00:18:21,350 --> 00:18:20,000
that after four and a half giga years

554
00:18:23,029 --> 00:18:21,360
which of course is not a number i just

555
00:18:25,430 --> 00:18:23,039
pulled out of nowhere

556
00:18:27,350 --> 00:18:25,440
the the planet became uninhabitable it

557
00:18:29,909 --> 00:18:27,360
actually became became too close to the

558
00:18:32,390 --> 00:18:29,919
star and it's probably not going to be

559
00:18:34,070 --> 00:18:32,400
in a good position for hosting life

560
00:18:35,909 --> 00:18:34,080
so

561
00:18:38,549 --> 00:18:35,919
uh just to show it in a little bit more

562
00:18:40,150 --> 00:18:38,559
of a mathematical way oh those lines do

563
00:18:42,150 --> 00:18:40,160

not show up very well so hopefully you

564
00:18:45,510 --> 00:18:42,160
can see them let's look at the top panel

565
00:18:47,590 --> 00:18:45,520
first so on the y-axis here is the flux

566
00:18:49,110 --> 00:18:47,600
that the planet receives relative to

567
00:18:51,510 --> 00:18:49,120
that on the earth

568
00:18:53,590 --> 00:18:51,520
and the y-axis is gears this is for the

569
00:18:55,669 --> 00:18:53,600
the planet the model i just showed you

570
00:18:57,430 --> 00:18:55,679
this solid line here represents the

571
00:18:59,750 --> 00:18:57,440
orbit average flux that the planet

572
00:19:01,750 --> 00:18:59,760
received and then these two dotted lines

573
00:19:02,950 --> 00:19:01,760
which hopefully you can see correspond

574
00:19:04,789 --> 00:19:02,960
to the amount of light that the planet

575
00:19:06,150 --> 00:19:04,799
received at its closest approach to the

576
00:19:07,350 --> 00:19:06,160
star and at its farthest approach and

577
00:19:09,669 --> 00:19:07,360
you can see there's definitely quite a

578
00:19:11,750 --> 00:19:09,679
disparity by our twitters of magnitude

579
00:19:14,070 --> 00:19:11,760
but recall that i guess i didn't say

580
00:19:15,350 --> 00:19:14,080
this but the this the orbital period for

581
00:19:17,270 --> 00:19:15,360
this planet is only on the order of

582
00:19:18,870 --> 00:19:17,280
about five days so it's really whipping

583
00:19:20,950 --> 00:19:18,880
around the star quickly so even though

584
00:19:22,710 --> 00:19:20,960
it's it's got this huge disparity in the

585
00:19:24,549 --> 00:19:22,720
amount of light it receives close to the

586
00:19:25,909 --> 00:19:24,559
star and far from it there's enough

587
00:19:27,590 --> 00:19:25,919
thermal inertia in the atmosphere that

588
00:19:29,510 --> 00:19:27,600

probably this will still be habitable

589
00:19:32,310 --> 00:19:29,520
but you can see it's quite a range and

590
00:19:33,669 --> 00:19:32,320
as the eccentricity decreases

591
00:19:35,029 --> 00:19:33,679
these two all these three curves

592
00:19:36,950 --> 00:19:35,039
converge until finally when it's a

593
00:19:39,350 --> 00:19:36,960
circular orbit it's just they're all the

594
00:19:41,270 --> 00:19:39,360
same by definition

595
00:19:42,789 --> 00:19:41,280
uh another point

596
00:19:44,950 --> 00:19:42,799
to make is this on this bottom curve

597
00:19:46,470 --> 00:19:44,960
which is

598
00:19:48,710 --> 00:19:46,480
that the uh this is the number of

599
00:19:50,950 --> 00:19:48,720
rotations that the planet makes during

600
00:19:53,270 --> 00:19:50,960
one orbit so there's been a lot of

601
00:19:55,029 --> 00:19:53,280
discussion in the past that planets that

602
00:19:57,510 --> 00:19:55,039
are tidally locked that are close to

603
00:19:58,950 --> 00:19:57,520
their star are rotating synchronously

604
00:20:00,789 --> 00:19:58,960
there is an important difference between

605
00:20:03,750 --> 00:20:00,799
synchronous rotation and being tidally

606
00:20:05,990 --> 00:20:03,760
locked synchronous rotation means that

607
00:20:07,830 --> 00:20:06,000
one point remains below the star at all

608
00:20:09,990 --> 00:20:07,840
times

609
00:20:12,070 --> 00:20:10,000
tidally locked is has a more technical

610
00:20:14,230 --> 00:20:12,080
definition it face it means that there

611
00:20:16,470 --> 00:20:14,240
is no transfer of orbital or of any

612
00:20:18,310 --> 00:20:16,480
momentum between the rotational

613
00:20:20,870 --> 00:20:18,320

rotational angular momentum of the

614
00:20:22,710 --> 00:20:20,880
planet and its orbital angular momentum

615
00:20:25,029 --> 00:20:22,720
uh don't worry about the details on that

616
00:20:27,190 --> 00:20:25,039
the point is is that as the planet moves

617
00:20:29,669 --> 00:20:27,200
from being far away from the star to

618
00:20:31,510 --> 00:20:29,679
close to the star there is a torque on

619
00:20:34,390 --> 00:20:31,520
this tidal bulge and that drives a

620
00:20:37,029 --> 00:20:34,400
rotation rate so initially when the

621
00:20:39,110 --> 00:20:37,039
eccentricity is 0.84 this planet is

622
00:20:41,669 --> 00:20:39,120
actually rotating eight times for orbit

623
00:20:43,350 --> 00:20:41,679
so less than 24 hours is if this planet

624
00:20:44,630 --> 00:20:43,360
has initially eroded its rotational

625
00:20:46,950 --> 00:20:44,640
period it's day

626
00:20:50,310 --> 00:20:46,960
and then slowly over time it drops back

627
00:20:52,390 --> 00:20:50,320
down once the orbit is circular then the

628
00:20:55,270 --> 00:20:52,400
orbit is synchronous or i'm sorry the

629
00:20:56,950 --> 00:20:55,280
planet's rotation is synchronous

630
00:20:59,750 --> 00:20:56,960
so what happens to a planet that crosses

631
00:21:01,510 --> 00:20:59,760
through that habitable zone boundary

632
00:21:02,950 --> 00:21:01,520
well you know this planet maybe it was

633
00:21:04,470 --> 00:21:02,960
habitable maybe it had life for four and

634
00:21:07,990 --> 00:21:04,480
a half billion years

635
00:21:09,750 --> 00:21:08,000
does the life die or maybe if i were

636
00:21:11,430 --> 00:21:09,760
being an optimistic astrobiologist i

637
00:21:13,430 --> 00:21:11,440
would think maybe somehow the guy

638
00:21:14,950 --> 00:21:13,440

hypothesis is true and then maybe

639
00:21:17,190 --> 00:21:14,960
somehow despite this rather harsh

640
00:21:18,549 --> 00:21:17,200
environment there is a chance that life

641
00:21:20,070 --> 00:21:18,559
might survive

642
00:21:22,230 --> 00:21:20,080
so it's certainly important to think

643
00:21:24,070 --> 00:21:22,240
about this title evolution when we think

644
00:21:26,149 --> 00:21:24,080
about these planets they might

645
00:21:27,350 --> 00:21:26,159
actually be sort of a laboratory for

646
00:21:29,750 --> 00:21:27,360
understanding

647
00:21:31,590 --> 00:21:29,760
if this idea of gaia is actually true

648
00:21:32,789 --> 00:21:31,600
maybe these planets as they cross

649
00:21:34,950 --> 00:21:32,799
through that boundary find a way to

650
00:21:37,270 --> 00:21:34,960
survive and we might see planets that we

651
00:21:39,590 --> 00:21:37,280
think are not inhabitable but in fact

652
00:21:41,590 --> 00:21:39,600
they show signs of life because this

653
00:21:44,070 --> 00:21:41,600
gaia principle managed to maintain

654
00:21:45,750 --> 00:21:44,080
itself or maintain life on the planet

655
00:21:47,190 --> 00:21:45,760
but i don't know

656
00:21:48,950 --> 00:21:47,200
that's a that's

657
00:21:51,430 --> 00:21:48,960
uh certainly a lot of room for

658
00:21:53,029 --> 00:21:51,440
speculation there but uh i

659
00:21:55,110 --> 00:21:53,039
although i sort of throw this out as a

660
00:21:56,310 --> 00:21:55,120
as a hypothetical we're actually kind of

661
00:21:59,350 --> 00:21:56,320
getting close to actually being able to

662
00:22:01,350 --> 00:21:59,360
see planets that might be doing this um

663
00:22:02,870 --> 00:22:01,360

there is a system that's been that was

664
00:22:05,110 --> 00:22:02,880
discovered about a year ago called lisa

665
00:22:06,149 --> 00:22:05,120
581 it got a lot of press it actually

666
00:22:09,029 --> 00:22:06,159
was the

667
00:22:12,070 --> 00:22:09,039
headline on cnn.com for a few hours but

668
00:22:14,470 --> 00:22:12,080
that was in the middle of the night

669
00:22:16,070 --> 00:22:14,480
so uh anyway there are three planets in

670
00:22:18,390 --> 00:22:16,080
this system this inner one is quite

671
00:22:21,110 --> 00:22:18,400
large but then there's two that are at

672
00:22:22,870 --> 00:22:21,120
least their masses could be as small as

673
00:22:24,310 --> 00:22:22,880
five earth masses and eight earth masses

674
00:22:25,270 --> 00:22:24,320
so they're in that magic super earth

675
00:22:27,110 --> 00:22:25,280
range

676
00:22:29,750 --> 00:22:27,120
but what's really interesting is that

677
00:22:31,830 --> 00:22:29,760
this middle planet is just interior to

678
00:22:34,549 --> 00:22:31,840
the half of zone well or maybe it isn't

679
00:22:37,430 --> 00:22:34,559
even is in the habitable zone if i was

680
00:22:39,190 --> 00:22:37,440
really optimistic about its uh its cloud

681
00:22:42,070 --> 00:22:39,200
cover all right

682
00:22:43,990 --> 00:22:42,080
so this is the 100 cloud cover boundary

683
00:22:45,909 --> 00:22:44,000
this is 50 and this is

684
00:22:47,830 --> 00:22:45,919
uh zero by the way the earth's cloud

685
00:22:50,149 --> 00:22:47,840
cover is somewhere around 40 so that's

686
00:22:52,870 --> 00:22:50,159
why i sort of think of 50 as sort of the

687
00:22:54,870 --> 00:22:52,880
magic boundary here so the question that

688
00:22:57,430 --> 00:22:54,880

my colleagues and i asked ourselves well

689
00:22:59,270 --> 00:22:57,440
could it be that gliese 581c

690
00:23:00,789 --> 00:22:59,280
was in the habit zone in the past in

691
00:23:01,990 --> 00:23:00,799
other words is it one of these kinds of

692
00:23:04,789 --> 00:23:02,000
interesting planets that might be able

693
00:23:06,549 --> 00:23:04,799
to test the guy hypothesis

694
00:23:09,590 --> 00:23:06,559
and so what we did is we considered

695
00:23:11,830 --> 00:23:09,600
several different models

696
00:23:13,430 --> 00:23:11,840
of the planet now i don't want to go

697
00:23:14,470 --> 00:23:13,440
into this in too much detail but you can

698
00:23:15,990 --> 00:23:14,480
imagine that the planet might have

699
00:23:17,990 --> 00:23:16,000
different compositions and so it might

700
00:23:20,390 --> 00:23:18,000
have different properties and i sort of

701
00:23:22,149 --> 00:23:20,400
just summarize uh their properties in

702
00:23:23,350 --> 00:23:22,159
terms of radii the composition as you

703
00:23:26,070 --> 00:23:23,360
might imagine can determine what the

704
00:23:28,549 --> 00:23:26,080
radius of the planet is so for several

705
00:23:30,549 --> 00:23:28,559
different uh radii we plotted what would

706
00:23:32,070 --> 00:23:30,559
the semi-major axis do relative to the

707
00:23:33,830 --> 00:23:32,080
habitable zone boundaries back into the

708
00:23:36,149 --> 00:23:33,840
present time so basically we just take

709
00:23:37,909 --> 00:23:36,159
our title model and rewind it and just

710
00:23:39,270 --> 00:23:37,919
to try and determine could the planet

711
00:23:41,350 --> 00:23:39,280
have been happening or at least more

712
00:23:44,230 --> 00:23:41,360
habitable in the past

713
00:23:46,149 --> 00:23:44,240

and so you know these shadings represent

714
00:23:48,549 --> 00:23:46,159
those same sorts of planetary conditions

715
00:23:50,789 --> 00:23:48,559
that increase or or

716
00:23:52,070 --> 00:23:50,799
decrease the chance of habitability and

717
00:23:54,789 --> 00:23:52,080
so for these different models you can

718
00:23:57,430 --> 00:23:54,799
see well for the smallest mass planet

719
00:23:59,270 --> 00:23:57,440
maybe 10 giga years ago this planet was

720
00:24:01,750 --> 00:23:59,280
inside the 50 inside the half of the

721
00:24:05,029 --> 00:24:01,760
zone i'll just call this 50 percent

722
00:24:06,470 --> 00:24:05,039
region that happens on from now on uh if

723
00:24:08,630 --> 00:24:06,480
it was bigger it could have been in the

724
00:24:09,669 --> 00:24:08,640
habit zone more recently and if it was

725
00:24:10,950 --> 00:24:09,679
really big

726
00:24:12,470 --> 00:24:10,960
it could have been in the hell it could

727
00:24:14,230 --> 00:24:12,480
have almost reached the sort of very

728
00:24:15,510 --> 00:24:14,240
most conservative definition of

729
00:24:17,830 --> 00:24:15,520
habitability

730
00:24:18,950 --> 00:24:17,840
uh you know not requiring any cloud

731
00:24:20,310 --> 00:24:18,960
cover

732
00:24:21,909 --> 00:24:20,320
about well it wouldn't have but it would

733
00:24:24,070 --> 00:24:21,919
have gotten close about 10 giga years

734
00:24:25,350 --> 00:24:24,080
ago and uh we don't really know the age

735
00:24:26,710 --> 00:24:25,360
of the star very well there's actually

736
00:24:28,710 --> 00:24:26,720
quite a bit of controversy over that it

737
00:24:30,950 --> 00:24:28,720
could go anywhere from about 4 billion

738
00:24:32,710 --> 00:24:30,960

years to 10 billion years but

739
00:24:33,510 --> 00:24:32,720
nonetheless this is sort of suggesting

740
00:24:35,190 --> 00:24:33,520
that

741
00:24:37,269 --> 00:24:35,200
these kinds of planets could be out

742
00:24:40,149 --> 00:24:37,279
there uh the reason why i can't say

743
00:24:42,149 --> 00:24:40,159
definitively that this planet is in the

744
00:24:43,669 --> 00:24:42,159
habitable zone is because there are

745
00:24:46,310 --> 00:24:43,679
other planets in this system that

746
00:24:47,590 --> 00:24:46,320
provide important constraints uh as tom

747
00:24:48,710 --> 00:24:47,600
was mentioning you know i've done a lot

748
00:24:50,950 --> 00:24:48,720
of work looking at the dynamics of

749
00:24:52,630 --> 00:24:50,960
multiple planet systems and

750
00:24:55,029 --> 00:24:52,640
uh so i can assure you that these

751
00:24:56,630 --> 00:24:55,039
planets would be go unstable if i were

752
00:24:58,630 --> 00:24:56,640
to follow these tracks

753
00:25:00,070 --> 00:24:58,640
and of course uh what i mean by unstable

754
00:25:01,510 --> 00:25:00,080
is that the planetary system would

755
00:25:03,029 --> 00:25:01,520
actually break apart

756
00:25:05,510 --> 00:25:03,039
due to its gravitational interactions

757
00:25:07,990 --> 00:25:05,520
between the planets themselves so

758
00:25:09,269 --> 00:25:08,000
given that we see a planet today here

759
00:25:11,430 --> 00:25:09,279
that means that it couldn't have been

760
00:25:13,430 --> 00:25:11,440
destroyed earlier so it's a rather

761
00:25:15,510 --> 00:25:13,440
simple argument but

762
00:25:18,310 --> 00:25:15,520
the point is is that even though in this

763
00:25:19,750 --> 00:25:18,320

case we can't say that this planet maybe

764
00:25:22,149 --> 00:25:19,760
was some sort of fossil planet where

765
00:25:24,789 --> 00:25:22,159
there was life and it's now

766
00:25:26,230 --> 00:25:24,799
now there may or may not have life uh

767
00:25:27,590 --> 00:25:26,240
we're actually we're getting sensitive

768
00:25:29,669 --> 00:25:27,600
to these kinds of planets where we could

769
00:25:31,350 --> 00:25:29,679
actually make these kinds of assessments

770
00:25:32,870 --> 00:25:31,360
as to whether or not these planets were

771
00:25:34,149 --> 00:25:32,880
in the habitable zone and maybe we can

772
00:25:36,549 --> 00:25:34,159
start to understand

773
00:25:38,070 --> 00:25:36,559
uh you know how life how robust is life

774
00:25:40,230 --> 00:25:38,080
to these sorts of changing environmental

775
00:25:41,430 --> 00:25:40,240
conditions

776
00:25:42,950 --> 00:25:41,440
all right now i need to shift gears

777
00:25:44,310 --> 00:25:42,960
again i want to go back to tidal heating

778
00:25:45,510 --> 00:25:44,320
i mentioned that very briefly in the

779
00:25:46,630 --> 00:25:45,520
beginning

780
00:25:49,029 --> 00:25:46,640
uh

781
00:25:51,029 --> 00:25:49,039
so just to remind you recall that as the

782
00:25:52,789 --> 00:25:51,039
planet goes around in its orbit on an

783
00:25:54,710 --> 00:25:52,799
eccentric orbit the the shape is

784
00:25:57,110 --> 00:25:54,720
changing and it's getting heated

785
00:25:58,789 --> 00:25:57,120
due to uh due to this working of the of

786
00:25:59,990 --> 00:25:58,799
this planetary shape

787
00:26:02,390 --> 00:26:00,000
and uh

788
00:26:04,470 --> 00:26:02,400

this uh has of course has dramatic

789
00:26:06,149 --> 00:26:04,480
consequences in our solar system i hope

790
00:26:07,510 --> 00:26:06,159
all of you have seen this wonderful

791
00:26:08,789 --> 00:26:07,520
movie of a

792
00:26:11,909 --> 00:26:08,799
of a

793
00:26:13,669 --> 00:26:11,919
volcano called tavashtar on io that was

794
00:26:17,750 --> 00:26:13,679
taken by the new horizons spacecraft on

795
00:26:19,669 --> 00:26:17,760
its way to pluto about a year ago um but

796
00:26:21,830 --> 00:26:19,679
uh you know this this is this volcanic

797
00:26:22,630 --> 00:26:21,840
plume that was that was visible at the

798
00:26:24,870 --> 00:26:22,640
time

799
00:26:27,110 --> 00:26:24,880
of the flyby by jupiter

800
00:26:28,630 --> 00:26:27,120
and uh you know it's obviously a huge

801
00:26:31,190 --> 00:26:28,640
volcano relative to the size of the

802
00:26:33,269 --> 00:26:31,200
planet and the volcano and this wall

803
00:26:36,470 --> 00:26:33,279
this volcanism here is driven completely

804
00:26:38,230 --> 00:26:36,480
by tides so it is this there is no other

805
00:26:40,070 --> 00:26:38,240
source of energy that is driving this at

806
00:26:41,830 --> 00:26:40,080
least very little bit of any other

807
00:26:43,350 --> 00:26:41,840
energy on this on i o that could be

808
00:26:44,710 --> 00:26:43,360
driving this

809
00:26:45,430 --> 00:26:44,720
and uh

810
00:26:47,430 --> 00:26:45,440
so

811
00:26:50,310 --> 00:26:47,440
the orbit change is accompanied by this

812
00:26:53,430 --> 00:26:50,320
internal heating and so what we next

813
00:26:56,470 --> 00:26:53,440

asked ourselves was could tides

814
00:26:58,630 --> 00:26:56,480
you know drive uh volcanic volcanism on

815
00:26:59,990 --> 00:26:58,640
exoplanets

816
00:27:01,190 --> 00:27:00,000
and so we're going to use the same title

817
00:27:03,269 --> 00:27:01,200
model i've been talking about i didn't

818
00:27:05,990 --> 00:27:03,279
go into any detail but i want to make

819
00:27:07,590 --> 00:27:06,000
this point very emphatically that the

820
00:27:09,669 --> 00:27:07,600
model that we're using to sort of

821
00:27:11,909 --> 00:27:09,679
understand ties on these exoplanets was

822
00:27:14,149 --> 00:27:11,919
actually used to predict volcanoes just

823
00:27:16,310 --> 00:27:14,159
like this on io so

824
00:27:17,430 --> 00:27:16,320
you know but before voyager got to

825
00:27:19,590 --> 00:27:17,440
jupiter

826
00:27:21,750 --> 00:27:19,600
stan peel and collaborators said there's

827
00:27:24,070 --> 00:27:21,760
going to be volcanism on io due to tidal

828
00:27:24,950 --> 00:27:24,080
heating and it's going to be huge

829
00:27:26,390 --> 00:27:24,960
and

830
00:27:28,149 --> 00:27:26,400
literally like three days later after

831
00:27:29,510 --> 00:27:28,159
the article came out in nature they

832
00:27:31,269 --> 00:27:29,520
discovered this from the voyager

833
00:27:33,669 --> 00:27:31,279
spacecraft and this was independent of

834
00:27:36,310 --> 00:27:33,679
any knowledge of the composition of io

835
00:27:38,870 --> 00:27:36,320
it was just assuming that this had to be

836
00:27:41,350 --> 00:27:38,880
a body that was made of standard stuff

837
00:27:43,029 --> 00:27:41,360
it had to be kind of like rocky material

838
00:27:44,789 --> 00:27:43,039

and we were going to see volcanism and

839
00:27:46,070 --> 00:27:44,799
so as we think about these exoplanets

840
00:27:47,269 --> 00:27:46,080
whose compositions are completely

841
00:27:49,029 --> 00:27:47,279
unknown

842
00:27:50,549 --> 00:27:49,039
realize that this gravitational

843
00:27:52,310 --> 00:27:50,559
effective tides could probably will

844
00:27:53,830 --> 00:27:52,320
probably trump the compositional

845
00:27:56,230 --> 00:27:53,840
variations that might you might be

846
00:27:58,149 --> 00:27:56,240
worried about

847
00:28:00,870 --> 00:27:58,159
so what we did is we said we basically

848
00:28:02,710 --> 00:28:00,880
took planets in these habitable zones

849
00:28:04,070 --> 00:28:02,720
that i described where we do incorporate

850
00:28:06,070 --> 00:28:04,080
the eccentricity

851
00:28:07,830 --> 00:28:06,080
and we say well what is the tidal

852
00:28:08,950 --> 00:28:07,840
heating that these planets receive so

853
00:28:10,230 --> 00:28:08,960
these planets are going to be right

854
00:28:12,149 --> 00:28:10,240
smack dab in the middle of the habitable

855
00:28:14,149 --> 00:28:12,159
zone around low mass stars

856
00:28:15,669 --> 00:28:14,159
and so what i've plotted here is this

857
00:28:17,430 --> 00:28:15,679
heating flux this is sort of the

858
00:28:19,430 --> 00:28:17,440
standard way to measure the amount of

859
00:28:21,110 --> 00:28:19,440
internal energy coming out of the planet

860
00:28:22,950 --> 00:28:21,120
it's basically the energy coming out

861
00:28:24,230 --> 00:28:22,960
through unit surface area on the planet

862
00:28:25,430 --> 00:28:24,240
surface

863
00:28:27,830 --> 00:28:25,440

and

864
00:28:29,669 --> 00:28:27,840
what we looked at was just

865
00:28:31,590 --> 00:28:29,679
we just said okay suppose a planet is

866
00:28:33,110 --> 00:28:31,600
sitting right in one orbit right in this

867
00:28:35,830 --> 00:28:33,120
orbit it's not evolving or anything like

868
00:28:36,789 --> 00:28:35,840
that we're just going to observe it

869
00:28:39,430 --> 00:28:36,799
and uh

870
00:28:42,149 --> 00:28:39,440
this region right here would correspond

871
00:28:44,389 --> 00:28:42,159
to planets tender mass planets that have

872
00:28:46,230 --> 00:28:44,399
heating rates larger than io io's

873
00:28:47,909 --> 00:28:46,240
heating flux is 2 watts per square meter

874
00:28:50,230 --> 00:28:47,919
that's this contour line right here so

875
00:28:52,630 --> 00:28:50,240
this dark shaded region if i found

876
00:28:55,590 --> 00:28:52,640
a 10 earth mass planet orbiting a you

877
00:28:57,830 --> 00:28:55,600
know 0.15 solar mass star with a large

878
00:28:59,510 --> 00:28:57,840
eccentricity it's going to be an iowa

879
00:29:01,350 --> 00:28:59,520
like planet because i don't think

880
00:29:03,350 --> 00:29:01,360
there's really much way around it and

881
00:29:04,950 --> 00:29:03,360
you can see in fact that the heating

882
00:29:06,870 --> 00:29:04,960
rates can be orders of magnitude larger

883
00:29:08,549 --> 00:29:06,880
than i have you know 10

884
00:29:09,750 --> 00:29:08,559
or more so

885
00:29:11,909 --> 00:29:09,760
and this is just right in the middle of

886
00:29:14,230 --> 00:29:11,919
the habit zone it turns out that the the

887
00:29:15,510 --> 00:29:14,240
tidal heating is very sensitive to the

888
00:29:17,909 --> 00:29:15,520

distance that the planet is from the

889
00:29:19,750 --> 00:29:17,919
star it actually goes as the distance to

890
00:29:21,669 --> 00:29:19,760
the six and a half power

891
00:29:23,110 --> 00:29:21,679
so that just means if i move something

892
00:29:24,710 --> 00:29:23,120
by 10

893
00:29:27,029 --> 00:29:24,720
the heating rate is going to double so

894
00:29:29,350 --> 00:29:27,039
as i get closer into the star

895
00:29:31,669 --> 00:29:29,360
the heating rate goes up dramatically

896
00:29:33,190 --> 00:29:31,679
and so if i find a planet near the inner

897
00:29:34,789 --> 00:29:33,200
edge of the half of the zone it's almost

898
00:29:36,470 --> 00:29:34,799
assuredly going to have these monster

899
00:29:38,389 --> 00:29:36,480
heating flexes and though and as of

900
00:29:40,870 --> 00:29:38,399
course a planet that orbits closer to

901
00:29:43,590 --> 00:29:40,880
the star is even more detectable so what

902
00:29:45,430 --> 00:29:43,600
i think this is telling us is that

903
00:29:47,269 --> 00:29:45,440
maybe that the first planets that we

904
00:29:49,269 --> 00:29:47,279
really see that we really spot in the

905
00:29:50,950 --> 00:29:49,279
habitable zone or even maybe interior

906
00:29:52,710 --> 00:29:50,960
that are terrestrial like they're not

907
00:29:53,750 --> 00:29:52,720
going to be earth-like planets the way

908
00:29:59,029 --> 00:29:53,760
we like to think about them they're

909
00:30:01,669 --> 00:30:00,070
but

910
00:30:04,389 --> 00:30:01,679
heating isn't all bad

911
00:30:06,549 --> 00:30:04,399
on the earth heating can do lots of good

912
00:30:07,990 --> 00:30:06,559
for us it drives the plate tectonics

913
00:30:09,029 --> 00:30:08,000

which drives the carbonate silicate

914
00:30:10,950 --> 00:30:09,039
cycle

915
00:30:12,470 --> 00:30:10,960
this is not my area of expertise but let

916
00:30:14,549 --> 00:30:12,480
me try and explain it i'm sure a lot of

917
00:30:16,310 --> 00:30:14,559
you have seen this before and i stole

918
00:30:19,190 --> 00:30:16,320
this web this image from jim casting's

919
00:30:20,950 --> 00:30:19,200
website so uh you know this is pretty

920
00:30:22,870 --> 00:30:20,960
well documented but the basic idea is

921
00:30:24,549 --> 00:30:22,880
that when you have plate tectonics

922
00:30:27,110 --> 00:30:24,559
you're able to keep carbon dioxide out

923
00:30:28,870 --> 00:30:27,120
of the atmosphere and carbon dioxide is

924
00:30:31,190 --> 00:30:28,880
a greenhouse gas and so the plate

925
00:30:33,510 --> 00:30:31,200
tectonics prevents earth from becoming a

926
00:30:36,470 --> 00:30:33,520
venus-like planet which would be bad

927
00:30:38,149 --> 00:30:36,480
so what happens is that if uh like it's

928
00:30:40,389 --> 00:30:38,159
a cycle so i can kind of start anywhere

929
00:30:42,710 --> 00:30:40,399
if uh volcanoes

930
00:30:44,870 --> 00:30:42,720
emits carbon dioxide as they erupt

931
00:30:47,269 --> 00:30:44,880
carbon dioxide goes into the atmosphere

932
00:30:50,230 --> 00:30:47,279
then storms happen there's the carbon

933
00:30:51,990 --> 00:30:50,240
dioxide interacts with the continents

934
00:30:53,430 --> 00:30:52,000
during through weathering and the carbon

935
00:30:55,830 --> 00:30:53,440
dioxide is brought into the ocean where

936
00:30:57,269 --> 00:30:55,840
it reacts with the water in this uh in

937
00:30:59,510 --> 00:30:57,279
this environment and it becomes

938
00:31:02,070 --> 00:30:59,520

precipitates out and becomes part of the

939
00:31:03,269 --> 00:31:02,080
uh the oceanic crust and it's then

940
00:31:04,950 --> 00:31:03,279
subducted

941
00:31:05,750 --> 00:31:04,960
down into the mantle and then it erupts

942
00:31:07,350 --> 00:31:05,760
again

943
00:31:09,350 --> 00:31:07,360
so the way i like to think about it just

944
00:31:11,510 --> 00:31:09,360
as an astronomer is that this is just a

945
00:31:12,710 --> 00:31:11,520
little game for carbon dioxide to play

946
00:31:13,990 --> 00:31:12,720
rather than building up in our

947
00:31:16,470 --> 00:31:14,000
atmosphere and having a big party with

948
00:31:18,710 --> 00:31:16,480
all his carbon dioxide friends so the

949
00:31:20,950 --> 00:31:18,720
point is is just that when we can get

950
00:31:22,630 --> 00:31:20,960
something for carbon dioxide to do it's

951
00:31:24,950 --> 00:31:22,640
not going to

952
00:31:26,710 --> 00:31:24,960
cause a planet to become uninhabitable

953
00:31:28,870 --> 00:31:26,720
so we don't really understand plate

954
00:31:30,870 --> 00:31:28,880
tectonics even on the earth

955
00:31:32,470 --> 00:31:30,880
but one thing we do know a sufficient

956
00:31:34,389 --> 00:31:32,480
but not necessary condition is that

957
00:31:35,190 --> 00:31:34,399
there has to be an internal heat source

958
00:31:39,029 --> 00:31:35,200
for

959
00:31:40,789 --> 00:31:39,039
so

960
00:31:42,870 --> 00:31:40,799
it may be that tidal heating could do

961
00:31:44,710 --> 00:31:42,880
that may maybe the tidal heating can't

962
00:31:46,470 --> 00:31:44,720
do it but it may be that it could we

963
00:31:48,470 --> 00:31:46,480

don't know the answer yet

964
00:31:50,310 --> 00:31:48,480
but uh if i have tidal heating in the

965
00:31:52,070 --> 00:31:50,320
right kind of range maybe we can drive

966
00:31:53,509 --> 00:31:52,080
plate tectonics and improve a planet's

967
00:31:56,070 --> 00:31:53,519
chance of being

968
00:31:58,149 --> 00:31:56,080
inhabitable and so this is that same

969
00:32:01,190 --> 00:31:58,159
plot i showed you before but now this

970
00:32:03,029 --> 00:32:01,200
lighter shade this corresponds to a

971
00:32:03,909 --> 00:32:03,039
limit that maybe can drive plate next on

972
00:32:04,950 --> 00:32:03,919
it

973
00:32:07,029 --> 00:32:04,960
and so

974
00:32:08,710 --> 00:32:07,039
here before we had said this is going to

975
00:32:10,950 --> 00:32:08,720
be an io-like planet that's probably not

976
00:32:13,110 --> 00:32:10,960
good for habitability but

977
00:32:15,110 --> 00:32:13,120
if i have less heating than io but

978
00:32:17,190 --> 00:32:15,120
enough to drive plate tectonics the

979
00:32:18,630 --> 00:32:17,200
limit is thought to be about 0.04 watts

980
00:32:21,029 --> 00:32:18,640
per square meter

981
00:32:24,070 --> 00:32:21,039
then maybe this is a nice happy region

982
00:32:26,070 --> 00:32:24,080
for planets to support life

983
00:32:28,310 --> 00:32:26,080
this white region out here

984
00:32:30,870 --> 00:32:28,320
this is basically where the heating rate

985
00:32:32,310 --> 00:32:30,880
is too low for plate tectonics but there

986
00:32:34,149 --> 00:32:32,320
could be other sources there still there

987
00:32:35,990 --> 00:32:34,159
could still be radiogenic key that's

988
00:32:37,830 --> 00:32:36,000

what drives plate tectonics on the earth

989
00:32:39,669 --> 00:32:37,840
we certainly can't rule that out on

990
00:32:41,750 --> 00:32:39,679
these exoplanets in fact it may even be

991
00:32:43,430 --> 00:32:41,760
very likely that there's going to be

992
00:32:45,430 --> 00:32:43,440
this radiogenic source we just don't

993
00:32:46,789 --> 00:32:45,440
know it's not very easy to it won't be

994
00:32:49,110 --> 00:32:46,799
easy to measure that but

995
00:32:50,870 --> 00:32:49,120
the point is is in here we certainly

996
00:32:52,630 --> 00:32:50,880
will know just based on the mass and the

997
00:32:54,549 --> 00:32:52,640
orbits of these planets that there is

998
00:32:56,070 --> 00:32:54,559
some sort of engine inside this planet

999
00:32:58,630 --> 00:32:56,080
that could possibly stabilize the

1000
00:33:00,230 --> 00:32:58,640
climate over long terms so

1001
00:33:02,710 --> 00:33:00,240
this might suggest that there's sort of

1002
00:33:05,110 --> 00:33:02,720
a geophysical habitable zone that there

1003
00:33:07,509 --> 00:33:05,120
is sort of a sweet spot where the tidal

1004
00:33:09,029 --> 00:33:07,519
heating can make the planet habitable or

1005
00:33:10,310 --> 00:33:09,039
at least encourage it to be habitable

1006
00:33:12,149 --> 00:33:10,320
you certainly don't want anything to be

1007
00:33:15,269 --> 00:33:12,159
like iowa whether it's too much or too

1008
00:33:16,549 --> 00:33:15,279
little like mars which it went dead but

1009
00:33:18,070 --> 00:33:16,559
maybe that when you have sort of just

1010
00:33:20,389 --> 00:33:18,080
the right mixture

1011
00:33:21,909 --> 00:33:20,399
becomes just right

1012
00:33:23,430 --> 00:33:21,919
and so this suggests that there's

1013
00:33:25,590 --> 00:33:23,440

another way to think about planetary

1014
00:33:28,470 --> 00:33:25,600
habitability that it's not just the

1015
00:33:31,430 --> 00:33:28,480
classical habitable zone definition that

1016
00:33:34,149 --> 00:33:31,440
uh casting suggested that in fact there

1017
00:33:36,789 --> 00:33:34,159
is sort of a geophysical habitable zone

1018
00:33:38,310 --> 00:33:36,799
as well that overlaps with it and so

1019
00:33:40,310 --> 00:33:38,320
here this is basically just my own

1020
00:33:41,590 --> 00:33:40,320
version of the

1021
00:33:43,350 --> 00:33:41,600
casting cartoon that i showed you

1022
00:33:45,350 --> 00:33:43,360
earlier with the yellow strip of

1023
00:33:47,269 --> 00:33:45,360
habitability that's that's uh

1024
00:33:49,110 --> 00:33:47,279
represented by these black curves and

1025
00:33:50,789 --> 00:33:49,120
then these red curves here these

1026
00:33:52,789 --> 00:33:50,799
correspond to these these uh tidal

1027
00:33:55,110 --> 00:33:52,799
heating limits of 2 watts per square

1028
00:33:56,310 --> 00:33:55,120
meter and 0.04 watts per square meter

1029
00:33:58,230 --> 00:33:56,320
and so

1030
00:34:00,389 --> 00:33:58,240
it sort it says yes then that where

1031
00:34:01,830 --> 00:34:00,399
these two regions overlap

1032
00:34:03,830 --> 00:34:01,840
this is really what we mean by a

1033
00:34:04,710 --> 00:34:03,840
habitable zone around low mass stars

1034
00:34:06,470 --> 00:34:04,720
that

1035
00:34:08,710 --> 00:34:06,480
between these red curves and black

1036
00:34:10,869 --> 00:34:08,720
curves in this region right here this is

1037
00:34:13,349 --> 00:34:10,879
where we would want to look for a planet

1038
00:34:15,430 --> 00:34:13,359

of course with an eccentricity of 0.5

1039
00:34:16,310 --> 00:34:15,440
so i would argue that when you're if

1040
00:34:17,750 --> 00:34:16,320
we're going to try and look for these

1041
00:34:20,069 --> 00:34:17,760
planets around low mass stars this is

1042
00:34:21,750 --> 00:34:20,079
really the preferred region to hope to

1043
00:34:24,790 --> 00:34:21,760
find a planet is

1044
00:34:26,950 --> 00:34:24,800
somewhere in between these two curves

1045
00:34:28,869 --> 00:34:26,960
now and again i should mention that this

1046
00:34:30,869 --> 00:34:28,879
is these red curves are again for a 10

1047
00:34:33,270 --> 00:34:30,879
earth mass planet

1048
00:34:35,669 --> 00:34:33,280
now the the eccentricity matters as i

1049
00:34:37,030 --> 00:34:35,679
said before the uh when your planet is

1050
00:34:38,629 --> 00:34:37,040
more eccentric the heating rate is going

1051
00:34:40,069 --> 00:34:38,639
to be larger so i'm going to have

1052
00:34:41,030 --> 00:34:40,079
another movie here

1053
00:34:42,629 --> 00:34:41,040
and uh

1054
00:34:44,230 --> 00:34:42,639
i'm going to show you just how these

1055
00:34:45,990 --> 00:34:44,240
habitable zone boundaries change with

1056
00:34:47,349 --> 00:34:46,000
time oh it's not with time

1057
00:34:49,829 --> 00:34:47,359
that was exactly what i wanted you not

1058
00:34:51,669 --> 00:34:49,839
to think it's not time it's eccentricity

1059
00:34:53,510 --> 00:34:51,679
is changing and so i'll play this a few

1060
00:34:55,669 --> 00:34:53,520
times so as the eccentricity of the

1061
00:34:57,750 --> 00:34:55,679
planet is changed if i suppose i just

1062
00:34:59,750 --> 00:34:57,760
think about finding different planets

1063
00:35:01,510 --> 00:34:59,760

with different eccentricities this is

1064
00:35:04,710 --> 00:35:01,520
how the habitable zone boundaries will

1065
00:35:06,470 --> 00:35:04,720
change so you can see that initially as

1066
00:35:08,710 --> 00:35:06,480
eccentricity

1067
00:35:10,390 --> 00:35:08,720
goes up

1068
00:35:12,470 --> 00:35:10,400
here see

1069
00:35:14,950 --> 00:35:12,480
as eccentricity starts to increase

1070
00:35:17,109 --> 00:35:14,960
the uh sort of the geophysical hazards

1071
00:35:19,589 --> 00:35:17,119
capital zone changes quickly and it's

1072
00:35:21,750 --> 00:35:19,599
not until i get to large values

1073
00:35:25,109 --> 00:35:21,760
that uh it decides why did it stop at

1074
00:35:26,470 --> 00:35:25,119
0.86 i don't know well but once i get to

1075
00:35:28,550 --> 00:35:26,480
large x interesting then sort of the

1076
00:35:29,829 --> 00:35:28,560
classical song changes too what i think

1077
00:35:31,430 --> 00:35:29,839
is almost the most remarkable thing

1078
00:35:33,349 --> 00:35:31,440
about this plot is that the two

1079
00:35:34,950 --> 00:35:33,359
boundaries overlap for so much you know

1080
00:35:37,190 --> 00:35:34,960
like these are two totally different

1081
00:35:38,790 --> 00:35:37,200
processes and yet

1082
00:35:40,790 --> 00:35:38,800
for a large stretch or for a large

1083
00:35:41,829 --> 00:35:40,800
fraction of this parameter space you

1084
00:35:43,270 --> 00:35:41,839
know the

1085
00:35:45,670 --> 00:35:43,280
the haplozone

1086
00:35:47,109 --> 00:35:45,680
boundaries are the capital zone is they

1087
00:35:48,310 --> 00:35:47,119
overlapped the two the two regions

1088
00:35:49,829 --> 00:35:48,320

overlap

1089
00:35:54,470 --> 00:35:49,839
so

1090
00:35:55,270 --> 00:35:54,480
of course as a famous politician once

1091
00:35:56,950 --> 00:35:55,280
said

1092
00:35:59,190 --> 00:35:56,960
it's not all about just where you find

1093
00:36:01,030 --> 00:35:59,200
the planet today it's what happened in

1094
00:36:03,750 --> 00:36:01,040
the past the past matters for these

1095
00:36:06,470 --> 00:36:03,760
planets all right so i want to play

1096
00:36:07,510 --> 00:36:06,480
another movie for you now and this is uh

1097
00:36:11,109 --> 00:36:07,520
what

1098
00:36:13,670 --> 00:36:11,119
past suppose we discover a planet at

1099
00:36:14,710 --> 00:36:13,680
this blue dot right here this would be a

1100
00:36:17,670 --> 00:36:14,720
planet

1101
00:36:20,870 --> 00:36:17,680
around a 0.15 solar mass star it's 10

1102
00:36:23,349 --> 00:36:20,880
earth masses its semi-major axis is 0.05

1103
00:36:25,430 --> 00:36:23,359
and its eccentricity is 0.03 i think

1104
00:36:26,870 --> 00:36:25,440
most people who study extrasolar plants

1105
00:36:29,190 --> 00:36:26,880
think that this is a pretty good bet for

1106
00:36:30,470 --> 00:36:29,200
the at least a planet analogous to this

1107
00:36:32,390 --> 00:36:30,480
will be the first kind of planet that

1108
00:36:33,430 --> 00:36:32,400
we're going to uh to detect through

1109
00:36:35,510 --> 00:36:33,440
transits

1110
00:36:37,510 --> 00:36:35,520
around uh these uh these other stars

1111
00:36:39,349 --> 00:36:37,520
these small mass stars and notice that

1112
00:36:40,630 --> 00:36:39,359
i've even made it even more tightly of a

1113
00:36:43,190 --> 00:36:40,640

constraint here and then i've now stuck

1114
00:36:44,470 --> 00:36:43,200
it in this in the middle of this g astro

1115
00:36:46,310 --> 00:36:44,480
geophysical habitable zone that i've

1116
00:36:48,550 --> 00:36:46,320
just defined so this is really what

1117
00:36:50,550 --> 00:36:48,560
seemed to be like an ideal case for what

1118
00:36:51,910 --> 00:36:50,560
we might consider to be a habitable

1119
00:36:54,470 --> 00:36:51,920
super earth

1120
00:36:56,069 --> 00:36:54,480
but if i rewind the tides now if i just

1121
00:36:57,109 --> 00:36:56,079
say okay what happened in the past to

1122
00:36:58,870 --> 00:36:57,119
this planet

1123
00:36:59,829 --> 00:36:58,880
so as i'm going backwards in time so

1124
00:37:01,990 --> 00:36:59,839
this is

1125
00:37:03,990 --> 00:37:02,000
this clock is counting backwards in time

1126
00:37:06,470 --> 00:37:04,000
and watch i'm counting the heating flux

1127
00:37:08,710 --> 00:37:06,480
here the eccentricity is growing and

1128
00:37:10,710 --> 00:37:08,720
then just about three giga years ago it

1129
00:37:12,630 --> 00:37:10,720
was actually at this io limit

1130
00:37:13,750 --> 00:37:12,640
and it's not gonna stop it's just gonna

1131
00:37:15,190 --> 00:37:13,760
keep going

1132
00:37:16,710 --> 00:37:15,200
and so

1133
00:37:19,270 --> 00:37:16,720
of course it depends on how old this

1134
00:37:20,950 --> 00:37:19,280
planet is but in the past

1135
00:37:22,069 --> 00:37:20,960
the heating rates could have been quite

1136
00:37:24,069 --> 00:37:22,079
a bit larger this is going to get all

1137
00:37:26,870 --> 00:37:24,079
the way up to about 15. so about a

1138
00:37:30,550 --> 00:37:26,880

factor of 10 more volcanism more

1139
00:37:31,910 --> 00:37:30,560
outgassing more heating than on io

1140
00:37:33,430 --> 00:37:31,920
there's a critical difference between a

1141
00:37:35,349 --> 00:37:33,440
tenor of mass planet in io though and

1142
00:37:37,670 --> 00:37:35,359
that is that a 10 earth mass planet can

1143
00:37:39,510 --> 00:37:37,680
hold on to its atmosphere io is one

1144
00:37:42,069 --> 00:37:39,520
percent the mass of the earth it just

1145
00:37:45,190 --> 00:37:42,079
loses its atmosphere almost immediately

1146
00:37:47,270 --> 00:37:45,200
so if a super earth like this had

1147
00:37:49,750 --> 00:37:47,280
heating more than io for seven giga

1148
00:37:52,550 --> 00:37:49,760
years it very well could be that this

1149
00:37:53,589 --> 00:37:52,560
planet atmosphere is dominated by what

1150
00:37:56,069 --> 00:37:53,599
could be

1151
00:37:59,030 --> 00:37:56,079
uh see if i can get it to go again

1152
00:38:00,870 --> 00:37:59,040
uh what could be a lot of bad stuff a

1153
00:38:03,030 --> 00:38:00,880
lot of you know it could be dominated by

1154
00:38:05,510 --> 00:38:03,040
a carbon dioxide it could have a lot of

1155
00:38:07,030 --> 00:38:05,520
sulfur dioxide it could have

1156
00:38:09,510 --> 00:38:07,040
it could have become uninhabitable and

1157
00:38:11,510 --> 00:38:09,520
remain uninhabitable even as it enters

1158
00:38:13,190 --> 00:38:11,520
into the habitable zone down here so

1159
00:38:14,870 --> 00:38:13,200
even though we see it in the habit zone

1160
00:38:16,710 --> 00:38:14,880
even in this more tight definition of a

1161
00:38:18,870 --> 00:38:16,720
habit zone that i've just described

1162
00:38:20,950 --> 00:38:18,880
it still certainly does not mean that

1163
00:38:23,270 --> 00:38:20,960

that planet could be habitable

1164
00:38:24,870 --> 00:38:23,280
so sorry it's past that critical point

1165
00:38:25,990 --> 00:38:24,880
so i'm going to move on here

1166
00:38:28,069 --> 00:38:26,000
so

1167
00:38:29,750 --> 00:38:28,079
see if i go maybe i'll move on

1168
00:38:30,630 --> 00:38:29,760
how about there all right

1169
00:38:31,829 --> 00:38:30,640
so

1170
00:38:33,349 --> 00:38:31,839
i would argue that that planet could

1171
00:38:35,589 --> 00:38:33,359
very well be more

1172
00:38:38,390 --> 00:38:35,599
more correctly considered super venus

1173
00:38:40,390 --> 00:38:38,400
uh where the early atmos the early uh

1174
00:38:42,470 --> 00:38:40,400
planet or early in its history the uh

1175
00:38:44,390 --> 00:38:42,480
the planet had a quite a large amount of

1176
00:38:46,230 --> 00:38:44,400
eruptions it turns out that uh the

1177
00:38:47,670 --> 00:38:46,240
sulfur dioxide that is typical on

1178
00:38:50,069 --> 00:38:47,680
eruptions in our solar system is not

1179
00:38:51,990 --> 00:38:50,079
very stable in atmospheres it can either

1180
00:38:53,430 --> 00:38:52,000
be fertilized or it could precipitate

1181
00:38:54,630 --> 00:38:53,440
out with water

1182
00:38:56,470 --> 00:38:54,640
if there's any water left in the

1183
00:38:59,109 --> 00:38:56,480
atmosphere and so you could just end up

1184
00:39:01,430 --> 00:38:59,119
with so with sort of a 10 earth mass

1185
00:39:03,670 --> 00:39:01,440
super venus just a planet that has an

1186
00:39:06,390 --> 00:39:03,680
absolutely massive envelope of carbon

1187
00:39:07,670 --> 00:39:06,400
dioxide or perhaps other outgas material

1188
00:39:09,109 --> 00:39:07,680

and that might be

1189
00:39:11,670 --> 00:39:09,119
a typical kind of planet we might see

1190
00:39:13,190 --> 00:39:11,680
around these these low mass stars

1191
00:39:15,109 --> 00:39:13,200
of course as i said super ios i

1192
00:39:17,589 --> 00:39:15,119
mentioned those before

1193
00:39:18,550 --> 00:39:17,599
you know so it might be that if i don't

1194
00:39:20,230 --> 00:39:18,560
see

1195
00:39:23,109 --> 00:39:20,240
just all this carbon dioxide you might

1196
00:39:24,950 --> 00:39:23,119
still be able to see a lot of uh the

1197
00:39:27,190 --> 00:39:24,960
current if

1198
00:39:28,470 --> 00:39:27,200
excuse me if you saw sulfur dioxide in

1199
00:39:30,310 --> 00:39:28,480
the atmosphere that would be maybe an

1200
00:39:31,829 --> 00:39:30,320
indicative of there's still been a lot

1201
00:39:33,750 --> 00:39:31,839
of volcanism on

1202
00:39:34,870 --> 00:39:33,760
the the planet and so of course as i

1203
00:39:36,870 --> 00:39:34,880
said the uh

1204
00:39:38,630 --> 00:39:36,880
the planet would have this atmosphere so

1205
00:39:39,750 --> 00:39:38,640
this might be more like what you'd see

1206
00:39:41,910 --> 00:39:39,760
it

1207
00:39:44,230 --> 00:39:41,920
i know the graphics are amazing but the

1208
00:39:45,910 --> 00:39:44,240
point is nonetheless that you know there

1209
00:39:47,829 --> 00:39:45,920
could be these sort of if you could see

1210
00:39:49,430 --> 00:39:47,839
planets that had a lot of sulfur dioxide

1211
00:39:50,870 --> 00:39:49,440
and carbon dioxide in the atmosphere

1212
00:39:52,950 --> 00:39:50,880
they might actually suggest that they

1213
00:39:54,950 --> 00:39:52,960

are super ios going on under there that

1214
00:39:56,630 --> 00:39:54,960
uh they are in fact have a lot of

1215
00:39:57,829 --> 00:39:56,640
vulcanism going on

1216
00:39:59,190 --> 00:39:57,839
there's another possibility that's

1217
00:40:01,190 --> 00:39:59,200
pretty interesting

1218
00:40:03,430 --> 00:40:01,200
and that is maybe these are going to be

1219
00:40:04,230 --> 00:40:03,440
kind of super europa-like planets

1220
00:40:05,349 --> 00:40:04,240
uh

1221
00:40:07,349 --> 00:40:05,359
it's well known and i haven't talked

1222
00:40:09,990 --> 00:40:07,359
about this at all yet but uh m stars are

1223
00:40:11,750 --> 00:40:10,000
very active they uh they tend to have

1224
00:40:13,270 --> 00:40:11,760
they tend to blast off a lot of material

1225
00:40:16,790 --> 00:40:13,280
from their surfaces

1226
00:40:19,430 --> 00:40:16,800
uh and these uh ejections can basically

1227
00:40:20,950 --> 00:40:19,440
strip off an atmosphere right away uh

1228
00:40:23,109 --> 00:40:20,960
just you know just one one of these

1229
00:40:24,470 --> 00:40:23,119
injections could possibly do that and a

1230
00:40:26,310 --> 00:40:24,480
lot of times people have thought this is

1231
00:40:28,870 --> 00:40:26,320
going to be bad for habitability that a

1232
00:40:30,230 --> 00:40:28,880
planet needs to have an atmosphere well

1233
00:40:32,790 --> 00:40:30,240
instead if you think about it in this

1234
00:40:34,150 --> 00:40:32,800
new context well then perhaps they don't

1235
00:40:35,910 --> 00:40:34,160
need an atmosphere maybe this is

1236
00:40:37,670 --> 00:40:35,920
actually the most favorable kind of

1237
00:40:39,510 --> 00:40:37,680
condition for life where i have an

1238
00:40:42,950 --> 00:40:39,520

internal heat source that's going to

1239
00:40:44,950 --> 00:40:42,960
melt a water surface all right let me

1240
00:40:48,630 --> 00:40:44,960
then let me back up here i i didn't have

1241
00:40:50,550 --> 00:40:48,640
myself so imagine a planet that has a

1242
00:40:51,990 --> 00:40:50,560
large amount of water on its surface

1243
00:40:53,829 --> 00:40:52,000
initially if that planet has an

1244
00:40:55,349 --> 00:40:53,839
atmosphere that water is going to be in

1245
00:40:57,990 --> 00:40:55,359
a liquid form

1246
00:40:59,270 --> 00:40:58,000
but once the atmosphere is stripped away

1247
00:41:01,349 --> 00:40:59,280
then the surface temperature is going to

1248
00:41:02,550 --> 00:41:01,359
drop quickly and the planet might become

1249
00:41:04,470 --> 00:41:02,560
iced over

1250
00:41:06,069 --> 00:41:04,480
and that is going to be sort of that's

1251
00:41:08,150 --> 00:41:06,079
basically like europa the moon of

1252
00:41:09,109 --> 00:41:08,160
jupiter and uh

1253
00:41:11,750 --> 00:41:09,119
you know

1254
00:41:13,510 --> 00:41:11,760
as i mentioned my boss rick is uh

1255
00:41:15,430 --> 00:41:13,520
big on europa he's done a lot of work on

1256
00:41:17,030 --> 00:41:15,440
that and i know that some of the work is

1257
00:41:17,990 --> 00:41:17,040
controversial but the point here is is

1258
00:41:19,829 --> 00:41:18,000
that

1259
00:41:21,750 --> 00:41:19,839
there could be sort of this boundary

1260
00:41:24,470 --> 00:41:21,760
layer of ice on a planet

1261
00:41:26,470 --> 00:41:24,480
where as the planet gets moves around

1262
00:41:28,230 --> 00:41:26,480
its orbit it gets deformed and the ice

1263
00:41:30,150 --> 00:41:28,240

is brittle just like it is on earth and

1264
00:41:32,470 --> 00:41:30,160
it's going to crack and you might end up

1265
00:41:34,390 --> 00:41:32,480
with little seams in the the ice the icy

1266
00:41:35,910 --> 00:41:34,400
surface of this planet where organisms

1267
00:41:38,069 --> 00:41:35,920
can move around

1268
00:41:40,470 --> 00:41:38,079
and uh because of this tidal heating

1269
00:41:42,630 --> 00:41:40,480
underneath in the core then you're going

1270
00:41:44,390 --> 00:41:42,640
to be able to melt the ice that's below

1271
00:41:46,710 --> 00:41:44,400
the the the surface you're going to have

1272
00:41:48,069 --> 00:41:46,720
sort of a water mantle you have that

1273
00:41:49,910 --> 00:41:48,079
energy maybe you're going to have black

1274
00:41:54,069 --> 00:41:49,920
smokers and things like that

1275
00:41:55,670 --> 00:41:54,079
and a little moreover is that the this m

1276
00:41:57,589 --> 00:41:55,680
star that's very active is going to drop

1277
00:41:59,510 --> 00:41:57,599
a lot of high energy particles on the

1278
00:42:02,550 --> 00:41:59,520
surface and they can interact through

1279
00:42:03,510 --> 00:42:02,560
surface chemistry and create uh more

1280
00:42:04,950 --> 00:42:03,520
uh

1281
00:42:06,710 --> 00:42:04,960
they can create molecules that could be

1282
00:42:08,950 --> 00:42:06,720
beneficial for life so

1283
00:42:10,710 --> 00:42:08,960
in fact so the whole problem with the

1284
00:42:12,069 --> 00:42:10,720
atmospheres of these these planets was

1285
00:42:14,950 --> 00:42:12,079
you might lose them but you could sort

1286
00:42:16,710 --> 00:42:14,960
of think of this sort of ice region

1287
00:42:17,510 --> 00:42:16,720
as sort of a very thick atmosphere

1288
00:42:19,829 --> 00:42:17,520

that's going to be really good to

1289
00:42:21,270 --> 00:42:19,839
protect you from a lot of the radiation

1290
00:42:24,230 --> 00:42:21,280
from the star in fact the radiation

1291
00:42:25,589 --> 00:42:24,240
might even help you so a super europa or

1292
00:42:27,109 --> 00:42:25,599
maybe it doesn't even need to be a super

1293
00:42:29,990 --> 00:42:27,119
europe it could be a small europa that

1294
00:42:31,349 --> 00:42:30,000
might might help a lot too

1295
00:42:33,670 --> 00:42:31,359
another possibility is that you could

1296
00:42:35,190 --> 00:42:33,680
imagine a planet that had a lot of

1297
00:42:37,190 --> 00:42:35,200
volcanism and you might think that that

1298
00:42:38,710 --> 00:42:37,200
would build up in the atmosphere but

1299
00:42:40,630 --> 00:42:38,720
instead what happens is that the

1300
00:42:42,470 --> 00:42:40,640
activity from the star keeps blasting

1301
00:42:45,430 --> 00:42:42,480
off some of the atmosphere so you might

1302
00:42:46,710 --> 00:42:45,440
imagine that as the all this vulcanism

1303
00:42:49,030 --> 00:42:46,720
is coming out

1304
00:42:53,510 --> 00:42:51,109
the the it goes into the atmosphere and

1305
00:42:55,829 --> 00:42:53,520
then all this radiation or activity from

1306
00:42:57,270 --> 00:42:55,839
the star is going to blast off parts of

1307
00:42:59,430 --> 00:42:57,280
the atmosphere this is obviously a

1308
00:43:01,030 --> 00:42:59,440
delicate balance but it could be

1309
00:43:02,790 --> 00:43:01,040
something else we could imagine is that

1310
00:43:04,150 --> 00:43:02,800
it might be that these planets keep

1311
00:43:06,230 --> 00:43:04,160
replenishing their atmosphere even

1312
00:43:09,030 --> 00:43:06,240
though they keep the star keeps trying

1313
00:43:12,390 --> 00:43:10,710

so i've just sort of talked a lot about

1314
00:43:14,790 --> 00:43:12,400
all these gravitational effects but i've

1315
00:43:17,190 --> 00:43:14,800
left out composition and although i said

1316
00:43:19,430 --> 00:43:17,200
not too long ago that the uh you know we

1317
00:43:21,829 --> 00:43:19,440
can expect the ties to dominate the

1318
00:43:23,510 --> 00:43:21,839
composition to be more important than

1319
00:43:25,190 --> 00:43:23,520
the composition when it comes to

1320
00:43:26,790 --> 00:43:25,200
imagining the volcanism and the heating

1321
00:43:28,230 --> 00:43:26,800
rates we do know that for sure the

1322
00:43:30,150 --> 00:43:28,240
composition matters we need to have

1323
00:43:31,750 --> 00:43:30,160
water on these planets they need to be

1324
00:43:33,109 --> 00:43:31,760
able to have the right resources for

1325
00:43:35,270 --> 00:43:33,119
life to develop

1326
00:43:37,270 --> 00:43:35,280
well it turns out that there's been some

1327
00:43:39,270 --> 00:43:37,280
work that was done by vicky and others

1328
00:43:41,109 --> 00:43:39,280
that suggest that it may be that these

1329
00:43:44,069 --> 00:43:41,119
planets around these m stars are going

1330
00:43:46,550 --> 00:43:44,079
to be pretty volatile poor

1331
00:43:49,430 --> 00:43:46,560
uh in this simulation uh

1332
00:43:50,710 --> 00:43:49,440
basically they started with planets

1333
00:43:52,950 --> 00:43:50,720
i'm sorry with planetesimals and

1334
00:43:55,430 --> 00:43:52,960
protoplanets that had a composition that

1335
00:43:59,109 --> 00:43:55,440
was determined by their local origin so

1336
00:44:04,069 --> 00:44:01,990
uh the the left hand the left panel here

1337
00:44:05,589 --> 00:44:04,079
the y axis excuse me is the eccentricity

1338
00:44:08,630 --> 00:44:05,599

that's not so important in this in this

1339
00:44:09,829 --> 00:44:08,640
context but this x-axis here corresponds

1340
00:44:12,150 --> 00:44:09,839
to the distance that each of these

1341
00:44:13,829 --> 00:44:12,160
little bodies is from the star initially

1342
00:44:15,349 --> 00:44:13,839
when you're close to the star which is

1343
00:44:18,309 --> 00:44:15,359
on the left here

1344
00:44:20,390 --> 00:44:18,319
the uh the composition tends to be a

1345
00:44:22,630 --> 00:44:20,400
volatile port that's because it's close

1346
00:44:24,150 --> 00:44:22,640
to the star and there's there's not

1347
00:44:26,550 --> 00:44:24,160
there's too much energy from the star to

1348
00:44:28,550 --> 00:44:26,560
let the volatiles form but farther away

1349
00:44:30,390 --> 00:44:28,560
they can be water rich and so these

1350
00:44:32,630 --> 00:44:30,400
colors correspond to the amount of water

1351
00:44:35,829 --> 00:44:32,640
basically on the uh each of these bodies

1352
00:44:37,430 --> 00:44:35,839
so red is dry blue is very water rich

1353
00:44:40,470 --> 00:44:37,440
and the earth is somewhere in sort of

1354
00:44:42,150 --> 00:44:40,480
this yellowish green area and so around

1355
00:44:44,790 --> 00:44:42,160
not a very low mass star about half a

1356
00:44:46,069 --> 00:44:44,800
solar mass the uh the the simulation

1357
00:44:47,349 --> 00:44:46,079
goes on

1358
00:44:49,349 --> 00:44:47,359
all these bodies kind of interact with

1359
00:44:51,910 --> 00:44:49,359
each other they hit each other and

1360
00:44:54,390 --> 00:44:51,920
basically over time this this what was

1361
00:44:57,109 --> 00:44:54,400
initially a very discretized sort of

1362
00:44:57,910 --> 00:44:57,119
composition of this disc gets all mixed

1363
00:44:59,430 --> 00:44:57,920

up

1364
00:45:01,750 --> 00:44:59,440
because these bodies these blue and red

1365
00:45:03,349 --> 00:45:01,760
bodies are intermingling but they don't

1366
00:45:04,950 --> 00:45:03,359
intermingle enough

1367
00:45:06,550 --> 00:45:04,960
that essentially at the end of the

1368
00:45:08,630 --> 00:45:06,560
simulation when you just have a few

1369
00:45:10,870 --> 00:45:08,640
bodies that would be a solar system

1370
00:45:14,069 --> 00:45:10,880
a regular planetary system they would be

1371
00:45:15,910 --> 00:45:14,079
pretty dry yeah

1372
00:45:17,270 --> 00:45:15,920
yeah that's the next point is that it

1373
00:45:19,670 --> 00:45:17,280
gets worse

1374
00:45:21,990 --> 00:45:19,680
as the planets as the star gets smaller

1375
00:45:23,589 --> 00:45:22,000
this problem only gets worse so this

1376
00:45:25,190 --> 00:45:23,599
suggests that well it's all great that i

1377
00:45:26,950 --> 00:45:25,200
spent all this time talking about

1378
00:45:28,069 --> 00:45:26,960
habitable planets but we're not going to

1379
00:45:30,550 --> 00:45:28,079
have them

1380
00:45:32,790 --> 00:45:30,560
but i i knew that that was not going to

1381
00:45:34,710 --> 00:45:32,800
be true because sean has also done some

1382
00:45:35,670 --> 00:45:34,720
other interesting work where it showed

1383
00:45:39,109 --> 00:45:35,680
that

1384
00:45:40,630 --> 00:45:39,119
planets in a different way

1385
00:45:41,829 --> 00:45:40,640
the the previous way i think is the way

1386
00:45:43,109 --> 00:45:41,839
most of us sort of imagine

1387
00:45:44,390 --> 00:45:43,119
planetswarming they just sort of form

1388
00:45:46,230 --> 00:45:44,400

from their local

1389
00:45:47,829 --> 00:45:46,240
stuff but it's possible that you could

1390
00:45:50,309 --> 00:45:47,839
have planets

1391
00:45:52,550 --> 00:45:50,319
moving around inside this disc of

1392
00:45:53,750 --> 00:45:52,560
this disc of forming planets and these

1393
00:45:56,309 --> 00:45:53,760
planets gonna

1394
00:45:58,309 --> 00:45:56,319
push material around in in ways that you

1395
00:46:00,950 --> 00:45:58,319
maybe didn't expect so this is a very

1396
00:46:02,710 --> 00:46:00,960
similar kind of idea where i've just now

1397
00:46:05,030 --> 00:46:02,720
i'm taking a one solar mass star and

1398
00:46:07,670 --> 00:46:05,040
i've slapped down a disc of of rocky

1399
00:46:09,430 --> 00:46:07,680
bodies again dry in here

1400
00:46:12,470 --> 00:46:09,440
some water lots of water and now i've

1401
00:46:13,750 --> 00:46:12,480
stuck jupiter out at the end now what's

1402
00:46:15,190 --> 00:46:13,760
going to happen in this movie is that

1403
00:46:17,349 --> 00:46:15,200
what you don't see is that there's a lot

1404
00:46:19,750 --> 00:46:17,359
of gas in this disc still and the gas

1405
00:46:21,670 --> 00:46:19,760
can actually push jupiter around

1406
00:46:23,910 --> 00:46:21,680
and so in this movie what happens is

1407
00:46:25,190 --> 00:46:23,920
that jupiter is migrating in this is

1408
00:46:27,510 --> 00:46:25,200
actually becoming a pretty well known

1409
00:46:28,710 --> 00:46:27,520
phenomenon in in astrophysics is that

1410
00:46:31,030 --> 00:46:28,720
these planets are going to migrate

1411
00:46:33,270 --> 00:46:31,040
around and in this case what happened is

1412
00:46:36,069 --> 00:46:33,280
that jupiter actually moved in

1413
00:46:37,670 --> 00:46:36,079

and uh pushed a lot of this water-rich

1414
00:46:39,430 --> 00:46:37,680
material

1415
00:46:40,550 --> 00:46:39,440
into this inner region

1416
00:46:42,710 --> 00:46:40,560
and

1417
00:46:44,069 --> 00:46:42,720
basically you get left with planets that

1418
00:46:45,990 --> 00:46:44,079
have a lot more blue in them which is

1419
00:46:48,710 --> 00:46:46,000
good so this might be a way in which we

1420
00:46:50,230 --> 00:46:48,720
can form these planets to be volatile

1421
00:46:53,829 --> 00:46:50,240
rich

1422
00:46:55,190 --> 00:46:53,839
but there's a problem in that

1423
00:46:57,589 --> 00:46:55,200
let's try that way

1424
00:46:59,670 --> 00:46:57,599
uh when you have multiple planet systems

1425
00:47:02,150 --> 00:46:59,680
uh things get a lot more complicated the

1426
00:47:05,190 --> 00:47:02,160
uh the x and the basically these orbits

1427
00:47:06,710 --> 00:47:05,200
can change over time because the

1428
00:47:08,069 --> 00:47:06,720
gravitational interactions between the

1429
00:47:09,430 --> 00:47:08,079
planets can drive eccentricity

1430
00:47:11,270 --> 00:47:09,440
oscillations

1431
00:47:13,030 --> 00:47:11,280
so these orbits go from being circular

1432
00:47:13,829 --> 00:47:13,040
to stretch to circular stretched over

1433
00:47:16,069 --> 00:47:13,839
time

1434
00:47:17,990 --> 00:47:16,079
and this can lead to things like

1435
00:47:20,550 --> 00:47:18,000
variable internal heating rates variable

1436
00:47:21,750 --> 00:47:20,560
stellar flux and variable rotation rates

1437
00:47:24,630 --> 00:47:21,760
over time

1438
00:47:26,390 --> 00:47:24,640

so as an example i want to mention uh

1439
00:47:27,670 --> 00:47:26,400
suppose i go back to the system glisa

1440
00:47:29,510 --> 00:47:27,680
581

1441
00:47:32,309 --> 00:47:29,520
and now i want to stick a jupiter mass

1442
00:47:33,589 --> 00:47:32,319
planet at on the outside of these other

1443
00:47:36,230 --> 00:47:33,599
three planets

1444
00:47:38,630 --> 00:47:36,240
at 0.75 a u with an eccentricity of 0.3

1445
00:47:40,470 --> 00:47:38,640
this eccentricity is about the mean of

1446
00:47:42,150 --> 00:47:40,480
of the known solar planet

1447
00:47:43,589 --> 00:47:42,160
and so just remember that planet c is

1448
00:47:46,069 --> 00:47:43,599
interior to the halvazone and d is

1449
00:47:48,309 --> 00:47:46,079
exterior to the haplozone and i'm going

1450
00:47:51,190 --> 00:47:48,319
to show you this movie

1451
00:47:53,030 --> 00:47:51,200
hope that's already going uh where uh

1452
00:47:54,950 --> 00:47:53,040
the uh this shows sort of how all these

1453
00:47:56,630 --> 00:47:54,960
different interactions occur

1454
00:47:57,750 --> 00:47:56,640
so in uh

1455
00:48:00,390 --> 00:47:57,760
in the top panel here these are the

1456
00:48:03,109 --> 00:48:00,400
orbits so blue is the outer planet d and

1457
00:48:04,950 --> 00:48:03,119
c is the uh the middle planet red it's

1458
00:48:06,870 --> 00:48:04,960
red i don't show the other two planets

1459
00:48:08,309 --> 00:48:06,880
that are in the system uh and you can

1460
00:48:10,630 --> 00:48:08,319
see that they oscillate around the star

1461
00:48:12,150 --> 00:48:10,640
which is this fixed black point here

1462
00:48:13,990 --> 00:48:12,160
and as they oscillate around and the

1463
00:48:16,309 --> 00:48:14,000

orbits become elongated and less

1464
00:48:18,550 --> 00:48:16,319
elongated the uh the heating fluxes and

1465
00:48:21,109 --> 00:48:18,560
the and this and the stellar light that

1466
00:48:22,790 --> 00:48:21,119
they receive change over time so down

1467
00:48:25,270 --> 00:48:22,800
here this is the logarithm of the

1468
00:48:27,670 --> 00:48:25,280
heating flux and these blue dots are

1469
00:48:29,910 --> 00:48:27,680
just the values that they have at any

1470
00:48:32,549 --> 00:48:29,920
moment the this is the earth and this is

1471
00:48:34,950 --> 00:48:32,559
io's values and you can see that they

1472
00:48:35,910 --> 00:48:34,960
move back and forth over time this is

1473
00:48:37,510 --> 00:48:35,920
the uh

1474
00:48:39,990 --> 00:48:37,520
stellar flux down here on this bottom

1475
00:48:41,750 --> 00:48:40,000
bar the uh this this dot here at the

1476
00:48:44,710 --> 00:48:41,760
center corresponds to the orbit average

1477
00:48:46,630 --> 00:48:44,720
flux and then so as the bars grow and

1478
00:48:49,030 --> 00:48:46,640
shrink that corresponds to the

1479
00:48:50,630 --> 00:48:49,040
periastron or sorry the close approach

1480
00:48:51,510 --> 00:48:50,640
amount of flux it receives and the far

1481
00:48:53,990 --> 00:48:51,520
approach

1482
00:48:57,190 --> 00:48:54,000
uh the farthest distance amount of flux

1483
00:48:59,750 --> 00:48:57,200
so over over one orbit so it will be

1484
00:49:01,990 --> 00:48:59,760
here for the moment the this is how much

1485
00:49:03,990 --> 00:49:02,000
starlight the fleet the planet received

1486
00:49:06,470 --> 00:49:04,000
on average but then it also receives

1487
00:49:08,230 --> 00:49:06,480
this amount at any particular moment so

1488
00:49:10,390 --> 00:49:08,240

let me just let's play that again so you

1489
00:49:12,069 --> 00:49:10,400
can sort of watch if you kind of pay

1490
00:49:13,990 --> 00:49:12,079
attention when uh

1491
00:49:15,030 --> 00:49:14,000
the the red dot gets up to i o look up

1492
00:49:16,549 --> 00:49:15,040
here real quick and you'll see that it

1493
00:49:18,390 --> 00:49:16,559
looks a little more elongated and then

1494
00:49:19,190 --> 00:49:18,400
as it comes back down here look up and

1495
00:49:21,670 --> 00:49:19,200
you'll see it looks a little more

1496
00:49:23,829 --> 00:49:21,680
circular and so there's this complex

1497
00:49:25,430 --> 00:49:23,839
interplay then where if i expect the

1498
00:49:27,190 --> 00:49:25,440
planet to have the right ingredients for

1499
00:49:28,870 --> 00:49:27,200
life it's also going to be going through

1500
00:49:30,790 --> 00:49:28,880
all these oscillations and note that

1501
00:49:32,309 --> 00:49:30,800
these time scales are not very long

1502
00:49:33,589 --> 00:49:32,319
these could these are just you know

1503
00:49:35,030 --> 00:49:33,599
especially in terms of the atmosphere

1504
00:49:37,030 --> 00:49:35,040
these are these are going to be forcings

1505
00:49:38,710 --> 00:49:37,040
that are going to really change the

1506
00:49:40,390 --> 00:49:38,720
properties of these planets quite

1507
00:49:42,069 --> 00:49:40,400
quickly so

1508
00:49:43,510 --> 00:49:42,079
let's see if i can move on here i think

1509
00:49:44,790 --> 00:49:43,520
i'm running a little late on time here

1510
00:49:46,309 --> 00:49:44,800
so uh

1511
00:49:48,710 --> 00:49:46,319
one way to think about this is that

1512
00:49:50,630 --> 00:49:48,720
these panels or bars just correspond to

1513
00:49:52,069 --> 00:49:50,640

different kinds of physics there's the

1514
00:49:53,910 --> 00:49:52,079
astrophysics of just how the orbits are

1515
00:49:56,309 --> 00:49:53,920
going to change there's the geophysics

1516
00:49:58,230 --> 00:49:56,319
of how the the interiors of these

1517
00:50:00,069 --> 00:49:58,240
planets change and then there's also the

1518
00:50:02,390 --> 00:50:00,079
atmospheric response to how the flux

1519
00:50:03,750 --> 00:50:02,400
changes over time

1520
00:50:04,870 --> 00:50:03,760
and so you can imagine that as we think

1521
00:50:06,870 --> 00:50:04,880
about where these planets are going to

1522
00:50:08,870 --> 00:50:06,880
be we can sort of imagine a parameter

1523
00:50:10,710 --> 00:50:08,880
space where we might expect to see

1524
00:50:13,589 --> 00:50:10,720
different types of planets appear and

1525
00:50:15,190 --> 00:50:13,599
just for for fun really i just labeled

1526
00:50:17,030 --> 00:50:15,200
these different parameters for

1527
00:50:18,470 --> 00:50:17,040
visualization as astrophysics geophysics

1528
00:50:20,069 --> 00:50:18,480
and atmospheric science

1529
00:50:22,390 --> 00:50:20,079
and what we might expect is that we

1530
00:50:24,230 --> 00:50:22,400
really need to understand where these

1531
00:50:25,349 --> 00:50:24,240
planets what what types of planets are

1532
00:50:26,710 --> 00:50:25,359
going to live in which parts of this

1533
00:50:28,710 --> 00:50:26,720
parameter space

1534
00:50:30,630 --> 00:50:28,720
now i i hope that the plural of venus is

1535
00:50:31,910 --> 00:50:30,640
venom but i don't know if it is or not

1536
00:50:34,470 --> 00:50:31,920
if it hasn't been decided yet that's

1537
00:50:36,150 --> 00:50:34,480
what i argue for it should be v9 um but

1538
00:50:37,510 --> 00:50:36,160

you know the point here is is that

1539
00:50:39,670 --> 00:50:37,520
there's going to be a lot of different

1540
00:50:41,910 --> 00:50:39,680
complex phenomena going on here and but

1541
00:50:45,510 --> 00:50:41,920
yet somehow we could expect that super

1542
00:50:47,190 --> 00:50:45,520
ios all share a certain kind of common

1543
00:50:48,549 --> 00:50:47,200
you know common properties

1544
00:50:50,230 --> 00:50:48,559
and all and it's the same with all of

1545
00:50:52,230 --> 00:50:50,240
these and so what we need to do is

1546
00:50:53,510 --> 00:50:52,240
understand how to actually pick apart

1547
00:50:55,270 --> 00:50:53,520
all the different physics here and

1548
00:50:57,109 --> 00:50:55,280
understand which planets are likely to

1549
00:50:58,230 --> 00:50:57,119
be super earth first which ones are

1550
00:50:59,990 --> 00:50:58,240
likely to be

1551
00:51:01,670 --> 00:51:00,000
super veni

1552
00:51:03,109 --> 00:51:01,680
so what we really need to do is somehow

1553
00:51:06,230 --> 00:51:03,119
go from this kind of image of where we

1554
00:51:08,390 --> 00:51:06,240
see a black dot in front of a star

1555
00:51:10,950 --> 00:51:08,400
which we know as a transit and then

1556
00:51:13,430 --> 00:51:10,960
understand well is that black dot really

1557
00:51:15,670 --> 00:51:13,440
a super earth a super europa a super

1558
00:51:17,589 --> 00:51:15,680
venus or a super eye or any other kind

1559
00:51:19,190 --> 00:51:17,599
of planet you might want to imagine and

1560
00:51:21,430 --> 00:51:19,200
that's really what the task is because

1561
00:51:23,349 --> 00:51:21,440
these planets are going to be found

1562
00:51:25,030 --> 00:51:23,359
and moreover we actually have a tool

1563
00:51:26,230 --> 00:51:25,040

that's coming online here very soon that

1564
00:51:27,990 --> 00:51:26,240
hopefully we'll be able to measure some

1565
00:51:30,069 --> 00:51:28,000
of these properties and that's the james

1566
00:51:31,190 --> 00:51:30,079
webb space telescope which will actually

1567
00:51:33,109 --> 00:51:31,200
hopefully be able to measure some of

1568
00:51:34,950 --> 00:51:33,119
these molecules in the atmospheres of

1569
00:51:36,390 --> 00:51:34,960
course venus i mean sorry

1570
00:51:39,430 --> 00:51:36,400
the super europa doesn't really have an

1571
00:51:40,549 --> 00:51:39,440
atmosphere but maybe we point james webb

1572
00:51:42,549 --> 00:51:40,559
at one of these planets and we see

1573
00:51:44,309 --> 00:51:42,559
nothing in in its spectrum maybe that

1574
00:51:46,069 --> 00:51:44,319
actually means it's a good bet for being

1575
00:51:47,190 --> 00:51:46,079
habitable maybe it's one of these ice

1576
00:51:49,270 --> 00:51:47,200
worlds

1577
00:51:50,870 --> 00:51:49,280
so hopefully

1578
00:51:52,230 --> 00:51:50,880
you know in the five years from now once

1579
00:51:54,230 --> 00:51:52,240
we can actually do these sorts of

1580
00:51:56,549 --> 00:51:54,240
detections we'll have been able to build

1581
00:51:58,790 --> 00:51:56,559
up this theory well enough to understand

1582
00:52:00,470 --> 00:51:58,800
when we look at which how we want to

1583
00:52:02,309 --> 00:52:00,480
first of all divvy up the time on the

1584
00:52:05,030 --> 00:52:02,319
james webb space telescope to actually

1585
00:52:06,549 --> 00:52:05,040
spot super support for grand prize but

1586
00:52:09,510 --> 00:52:06,559
maybe we'll also be able to distinguish

1587
00:52:12,150 --> 00:52:09,520
between these other possibilities

1588
00:52:14,470 --> 00:52:12,160

so let me show you my summary slide here

1589
00:52:16,470 --> 00:52:14,480
so i hope that i've convinced you

1590
00:52:18,790 --> 00:52:16,480
that the gravity is important for these

1591
00:52:21,109 --> 00:52:18,800
kinds of planets around low-mass stars

1592
00:52:23,030 --> 00:52:21,119
that is really going to drive a lot of

1593
00:52:24,950 --> 00:52:23,040
the properties of these planets

1594
00:52:26,630 --> 00:52:24,960
that they uh you know i made this point

1595
00:52:28,950 --> 00:52:26,640
early on that the tides can actually

1596
00:52:31,430 --> 00:52:28,960
pull a planet out over into a household

1597
00:52:32,870 --> 00:52:31,440
i didn't really talk about into but uh

1598
00:52:34,150 --> 00:52:32,880
it actually that's going to be much less

1599
00:52:36,790 --> 00:52:34,160
of an effect as

1600
00:52:38,230 --> 00:52:36,800
i as i said the the power of tides falls

1601
00:52:39,670 --> 00:52:38,240
off very quickly with distance so it's

1602
00:52:40,790 --> 00:52:39,680
unlikely to pull a planet into the half

1603
00:52:41,829 --> 00:52:40,800
of the zone

1604
00:52:43,829 --> 00:52:41,839
um

1605
00:52:45,750 --> 00:52:43,839
the tides can dominate over planetary

1606
00:52:47,190 --> 00:52:45,760
heating uh i guess i forgot to mention

1607
00:52:49,430 --> 00:52:47,200
that the heating rate on the earth is

1608
00:52:52,069 --> 00:52:49,440
about 0.1 watts per square meter so when

1609
00:52:53,510 --> 00:52:52,079
we're talking about ios and super ios

1610
00:52:54,630 --> 00:52:53,520
those are orders of magnitude more

1611
00:52:56,790 --> 00:52:54,640
heating

1612
00:52:58,630 --> 00:52:56,800
the tides can set the planetary rotation

1613
00:53:00,710 --> 00:52:58,640

rate not just synchronous they can

1614
00:53:03,589 --> 00:53:00,720
actually drive rotation rates that are

1615
00:53:05,910 --> 00:53:03,599
faster than the orbital period

1616
00:53:07,670 --> 00:53:05,920
uh as i said before also the orbit

1617
00:53:09,750 --> 00:53:07,680
average flux apparently determines the

1618
00:53:11,349 --> 00:53:09,760
surface temperature so we as we see

1619
00:53:13,510 --> 00:53:11,359
eccentric planets we need to bear in

1620
00:53:15,910 --> 00:53:13,520
mind that the electricity can matter as

1621
00:53:17,589 --> 00:53:15,920
far as just how much plus the plant

1622
00:53:20,470 --> 00:53:17,599
receives over time

1623
00:53:22,309 --> 00:53:20,480
there's a whole wide menagerie of

1624
00:53:23,510 --> 00:53:22,319
possibilities for what these plants can

1625
00:53:25,910 --> 00:53:23,520
be obviously when you start thinking

1626
00:53:28,309 --> 00:53:25,920
about tidal heating surface fluxes

1627
00:53:30,230 --> 00:53:28,319
rotation rates and then they can change

1628
00:53:32,069 --> 00:53:30,240
over time i think the sky is the limit

1629
00:53:34,069 --> 00:53:32,079
as to how what kinds of planets you can

1630
00:53:35,829 --> 00:53:34,079
imagine and so it'll be interesting to

1631
00:53:37,190 --> 00:53:35,839
try and figure out how

1632
00:53:38,790 --> 00:53:37,200
to distinguish all these different

1633
00:53:41,270 --> 00:53:38,800
possibilities and really understand

1634
00:53:42,470 --> 00:53:41,280
which kind of planet is happening

1635
00:53:44,630 --> 00:53:42,480
but i think

1636
00:53:47,430 --> 00:53:44,640
moreover this i'll say

1637
00:53:50,069 --> 00:53:47,440
i sort of suggested a refinement of the

1638
00:53:52,309 --> 00:53:50,079

habitable zone where we also consider

1639
00:53:54,390 --> 00:53:52,319
the stellar the internal heating in

1640
00:53:58,069 --> 00:53:54,400
addition to the stellar flux

1641
00:53:59,750 --> 00:53:58,079
uh i think that i would argue that uh

1642
00:54:02,069 --> 00:53:59,760
habitable plans are most likely to be in

1643
00:54:03,270 --> 00:54:02,079
multiple planet systems which just is

1644
00:54:05,510 --> 00:54:03,280
again

1645
00:54:07,910 --> 00:54:05,520
drives all this complexity and leads to

1646
00:54:10,790 --> 00:54:07,920
things like variable rotation and grades

1647
00:54:12,630 --> 00:54:10,800
and heating fluxes and just stellar flux

1648
00:54:14,710 --> 00:54:12,640
and so somehow what i'm hoping to do

1649
00:54:16,309 --> 00:54:14,720
when i come here in january is work with

1650
00:54:18,309 --> 00:54:16,319
vicky and

1651
00:54:19,990 --> 00:54:18,319
try and put all this together a lot you

1652
00:54:21,270 --> 00:54:20,000
know obviously with a lot of help and

1653
00:54:22,950 --> 00:54:21,280
hopefully we'll make some progress

1654
00:54:24,390 --> 00:54:22,960
towards being able to determine whether

1655
00:54:33,750 --> 00:54:24,400
these planets are going to be habitable

1656
00:54:33,760 --> 00:54:49,750
thank you rory do people have questions

1657
00:54:52,549 --> 00:54:51,270
yeah so actually um

1658
00:54:54,870 --> 00:54:52,559
there is no chance of that actually

1659
00:54:56,230 --> 00:54:54,880
being the case uh what happens is when

1660
00:54:57,990 --> 00:54:56,240
you have these sort of title effects

1661
00:55:00,069 --> 00:54:58,000
going on the moon would actually be

1662
00:55:01,829 --> 00:55:00,079
ripped off of this off the planet by the

1663
00:55:03,589 --> 00:55:01,839

same tidal forces or it would slam into

1664
00:55:05,510 --> 00:55:03,599
the planet there's actually uh some

1665
00:55:07,510 --> 00:55:05,520
papers that were done about seven years

1666
00:55:09,270 --> 00:55:07,520
ago or so that really showed that these

1667
00:55:10,150 --> 00:55:09,280
planets will just their orbits the moons

1668
00:55:12,069 --> 00:55:10,160
of these planets would just get

1669
00:55:14,069 --> 00:55:12,079
stretched out and they'd be either

1670
00:55:14,790 --> 00:55:14,079
stripped off or they've applied it

1671
00:55:16,150 --> 00:55:14,800
though

1672
00:55:19,109 --> 00:55:16,160
fortunately that can't mitigate any of

1673
00:55:23,190 --> 00:55:20,870
and yeah so in your plots of tidal

1674
00:55:24,710 --> 00:55:23,200
heating versus eccentricity right above

1675
00:55:26,630 --> 00:55:24,720
an eccentricity of point five or so

1676
00:55:28,470 --> 00:55:26,640
heating actually goes down ah yes that

1677
00:55:31,430 --> 00:55:28,480
is because the habitable zone moves out

1678
00:55:33,190 --> 00:55:31,440
so if you recall uh i showed that the uh

1679
00:55:34,710 --> 00:55:33,200
for a large eccentricity the the

1680
00:55:36,230 --> 00:55:34,720
semi-major axes that correspond to

1681
00:55:38,870 --> 00:55:36,240
habitable zones are farther away from

1682
00:55:40,150 --> 00:55:38,880
the star and so for those i have pop i

1683
00:55:42,630 --> 00:55:40,160
put the planets right in the middle of

1684
00:55:44,390 --> 00:55:42,640
the habit zone so above 0.5 the habit

1685
00:55:46,390 --> 00:55:44,400
zone is moving out and so that's what's

1686
00:55:48,150 --> 00:55:46,400
making the heating rate less so yeah

1687
00:55:49,750 --> 00:55:48,160
that is a that is a subtlety of those

1688
00:55:52,390 --> 00:55:49,760

plots that yeah i should have mentioned

1689
00:55:54,950 --> 00:55:53,589
nick

1690
00:55:56,630 --> 00:55:54,960
um

1691
00:55:58,069 --> 00:55:56,640
so the importance of the title heating

1692
00:56:00,230 --> 00:55:58,079
is going to depend on how many of these

1693
00:56:03,030 --> 00:56:00,240
terrestrial planets are at least start

1694
00:56:05,109 --> 00:56:03,040
off on eccentric orbits

1695
00:56:07,030 --> 00:56:05,119
do you have a feeling about that given

1696
00:56:09,589 --> 00:56:07,040
the sort of formation and migration

1697
00:56:11,750 --> 00:56:09,599
scenarios like plant plant scattering

1698
00:56:13,990 --> 00:56:11,760
versus gradual migration

1699
00:56:15,829 --> 00:56:14,000
yeah so uh migration rates tend to not

1700
00:56:18,230 --> 00:56:15,839
drive eccentricity up really large sort

1701
00:56:19,829 --> 00:56:18,240
of you know maybe .1.2

1702
00:56:21,750 --> 00:56:19,839
at most point three is the largest

1703
00:56:24,710 --> 00:56:21,760
eccentricity that migration can tend to

1704
00:56:26,789 --> 00:56:24,720
produce scattering can eject planets so

1705
00:56:28,150 --> 00:56:26,799
eccentricity is larger than one and uh

1706
00:56:29,750 --> 00:56:28,160
it seems that a lot of people have done

1707
00:56:31,829 --> 00:56:29,760
simulations and it sort of suggests that

1708
00:56:34,710 --> 00:56:31,839
they can fill in that whole range from

1709
00:56:36,549 --> 00:56:34,720
circular to basically just barely on the

1710
00:56:38,069 --> 00:56:36,559
edge of not being ejected so i think

1711
00:56:39,829 --> 00:56:38,079
there's basically a sort of a peak at

1712
00:56:41,430 --> 00:56:39,839
around point three but i think that

1713
00:56:42,870 --> 00:56:41,440

that's pretty broad sort of anywhere

1714
00:56:45,270 --> 00:56:42,880
from point one to point five it's going

1715
00:56:46,789 --> 00:56:45,280
to be typical so and and from the known

1716
00:56:48,789 --> 00:56:46,799
exoplanets that we see the the peak of

1717
00:56:50,390 --> 00:56:48,799
eccentricity is about 0.3

1718
00:56:52,549 --> 00:56:50,400
so there is yeah it's not going to i

1719
00:56:53,910 --> 00:56:52,559
don't if assuming that exoplanets form

1720
00:56:55,109 --> 00:56:53,920
in similar ways as

1721
00:56:56,950 --> 00:56:55,119
terrestrial

1722
00:56:58,470 --> 00:56:56,960
exoplanets form in a similar way as the

1723
00:57:00,470 --> 00:56:58,480
gas giants or the giant kinds of

1724
00:57:02,230 --> 00:57:00,480
terrestrial planet or exoplanets they're

1725
00:57:06,710 --> 00:57:02,240
going to be sort of a similar orbits i

1726
00:57:21,910 --> 00:57:08,950
any other questions

1727
00:57:25,829 --> 00:57:23,510
uh yeah well i didn't really look in our

1728
00:57:27,430 --> 00:57:25,839
solar system very much yeah the the for

1729
00:57:29,109 --> 00:57:27,440
our solar system the tides fall off very

1730
00:57:30,710 --> 00:57:29,119
quickly as well i mean uh you might have

1731
00:57:33,109 --> 00:57:30,720
noticed in some of those slides i showed

1732
00:57:35,589 --> 00:57:33,119
that mercury has been affected by tides

1733
00:57:37,589 --> 00:57:35,599
it's in this uh its rotation rate is set

1734
00:57:39,750 --> 00:57:37,599
by tides but the tides don't come out as

1735
00:57:40,950 --> 00:57:39,760
far as the as the earth so this really

1736
00:57:42,390 --> 00:57:40,960
doesn't affect

1737
00:57:48,789 --> 00:57:42,400
the picture of formation in our solar

1738
00:57:52,150 --> 00:57:50,150

well i suppose it just depends what you

1739
00:57:54,630 --> 00:57:52,160
mean by circular eccentric i mean the

1740
00:57:56,870 --> 00:57:54,640
earth's orbit is not circular right now

1741
00:57:58,309 --> 00:57:56,880
uh certainly as it was forming it was

1742
00:57:59,750 --> 00:57:58,319
getting jostled around i mean it

1743
00:58:01,589 --> 00:57:59,760
certainly had to go through phases where

1744
00:58:02,870 --> 00:58:01,599
the eccentricity was larger than it is

1745
00:58:04,870 --> 00:58:02,880
now but i i mean

1746
00:58:06,390 --> 00:58:04,880
you know i i would say maybe point one

1747
00:58:08,150 --> 00:58:06,400
is sort of probably the eccentricity

1748
00:58:10,549 --> 00:58:08,160
that the earth got and most and it's

1749
00:58:12,789 --> 00:58:10,559
forming but again i i think you could

1750
00:58:15,589 --> 00:58:12,799
you it's such a stochastic process all

1751
00:58:17,589 --> 00:58:15,599
this you know being hit by moon or lunar

1752
00:58:19,270 --> 00:58:17,599
sized objects or moon mars size objects

1753
00:58:21,109 --> 00:58:19,280
that you know form the moon and things

1754
00:58:23,030 --> 00:58:21,119
like that that you know i can't really

1755
00:58:24,710 --> 00:58:23,040
speak to how large the exponential ever

1756
00:58:26,950 --> 00:58:24,720
got but i think most simulations sort of

1757
00:58:28,630 --> 00:58:26,960
suggest that terrestrial planets tend to

1758
00:58:33,030 --> 00:58:28,640
not get eccentricities over about 0.1 or