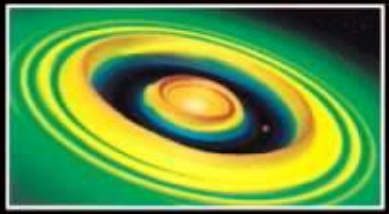
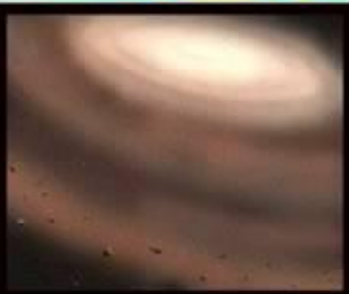
Important New Processes

- Giant Planet Migration ("type 2")
  - Massive planets (>Saturn-mass) open a gap in disk
    - Hill Radius > Disk Height
  - Torques with the gas disk can rapidly drive a giant planet to small orbital distances (Lin & Papaloizou 1986; Ward 1997)
- Aerodynamic Gas Drag
  - Planetesimals interact with the gaseous disk based on their size (assume 10 km)
  - Causes strong eccentricity damping, orbital infall





1
00:00:04,840 --> 00:00:03,080
yeah guys can hear you might like to

2
00:00:08,570 --> 00:00:04,850
welcome you all to this week's

3
00:00:11,270 --> 00:00:08,580
astrobiology seminar we're very pleased

4
00:00:16,760 --> 00:00:11,280
to have returning to the fold one of our

5
00:00:18,980 --> 00:00:16,770
own Sean Raymond who was in got his PhD

6
00:00:21,490 --> 00:00:18,990
in the Astronomy Department here and was

7
00:00:26,839 --> 00:00:21,500
also an affiliate of the astrobiology

8
00:00:30,800 --> 00:00:26,849
program affiliate through design not

9
00:00:33,160 --> 00:00:30,810
choice because I think you're sort of it

10
00:00:35,510 --> 00:00:33,170
too far on the new PhD program when

11
00:00:38,540 --> 00:00:35,520
astrobiology started but we count him as

12
00:00:40,280 --> 00:00:38,550
one of our most successful products even

13
00:00:43,250 --> 00:00:40,290

though he probably doesn't count us as

14
00:00:46,639 --> 00:00:43,260
one of these most successful mentors but

15
00:00:48,920 --> 00:00:46,649
we're very proud of so Sean's doing a

16
00:00:50,750 --> 00:00:48,930
NASA postdoctoral fellowship at the

17
00:00:54,400 --> 00:00:50,760
University of Colorado and he's going to

18
00:00:58,369 --> 00:00:54,410
talk to us today about exotic Earth's

19
00:01:03,080 --> 00:00:58,379
thanks Robi hey mind hitting the lights

20
00:01:06,830 --> 00:01:03,090
there alright so it's a it's a pleasure

21
00:01:08,510 --> 00:01:06,840
to be back in Seattle thanks for coming

22
00:01:11,330 --> 00:01:08,520
to my top I am you're talking about

23
00:01:13,010 --> 00:01:11,340
today is I'm going to talk about some

24
00:01:15,499 --> 00:01:13,020
things that are kind of related to the

25
00:01:17,840 --> 00:01:15,509
formation of habitable planets kind of

26
00:01:20,840 --> 00:01:17,850
like Earth but I'm going to talk about a

27
00:01:22,310 --> 00:01:20,850
few cases kind of a few systemic things

28
00:01:24,770 --> 00:01:22,320
that people don't usually talk about

29
00:01:27,410 --> 00:01:24,780
which actually play a really important

30
00:01:29,690 --> 00:01:27,420
role in terms of what earth-like planets

31
00:01:31,190 --> 00:01:29,700
might look like in terms of their water

32
00:01:32,990 --> 00:01:31,200
content in terms of their size in terms

33
00:01:35,090 --> 00:01:33,000
of where they could actually exist so

34
00:01:37,340 --> 00:01:35,100
for example here is another you know a

35
00:01:39,200 --> 00:01:37,350
planet that might be habitable planet

36
00:01:41,749 --> 00:01:39,210
that's actually in a hot Jupiter system

37
00:01:43,910 --> 00:01:41,759
so our ocean covered planet the Sun is

38
00:01:46,340 --> 00:01:43,920

just setting and we got a hot Jupiter

39
00:01:48,920 --> 00:01:46,350
right there and so this is a kind of

40
00:01:50,859 --> 00:01:48,930
planet that that we think might form you

41
00:01:53,210 --> 00:01:50,869
know quite often around other stars and

42
00:01:56,120 --> 00:01:53,220
I kind of talk about why that is and

43
00:01:57,469 --> 00:01:56,130
where they come from so before I get

44
00:01:58,789 --> 00:01:57,479
going I want to acknowledge my

45
00:02:00,800 --> 00:01:58,799
collaborators have lots of people who

46
00:02:01,870 --> 00:02:00,810
kind of help me with this with you know

47
00:02:03,770 --> 00:02:01,880
all the stuff I'm going to talk about

48
00:02:06,410 --> 00:02:03,780
lately I've been doing a lot of stuff

49
00:02:07,550 --> 00:02:06,420
with Rory Barnes and and Eric guide us

50
00:02:09,859 --> 00:02:07,560
in these guys but all these guys

51
00:02:11,180 --> 00:02:09,869
contributed to to what I'm going to talk

52
00:02:13,580 --> 00:02:11,190
about and I always

53
00:02:15,050 --> 00:02:13,590
nasa astrobiology institute for funding

54
00:02:17,720 --> 00:02:15,060
they've been funding me for the last

55
00:02:21,650 --> 00:02:17,730
five or six years or so so thanks to

56
00:02:23,240 --> 00:02:21,660
them so here's a little outline of the

57
00:02:24,550 --> 00:02:23,250
stuff I'm going to talk about first I'll

58
00:02:26,960 --> 00:02:24,560
give you kind of a standard picture

59
00:02:28,910 --> 00:02:26,970
which is you know kind of the normal

60
00:02:30,590 --> 00:02:28,920
picture what we think of how how will

61
00:02:33,350 --> 00:02:30,600
planets like Earth or thought to form

62
00:02:35,180 --> 00:02:33,360
and then I'll talk about these weirdos

63
00:02:36,860 --> 00:02:35,190

kind of three weirdos I'm talking about

64
00:02:38,840 --> 00:02:36,870
three weird stories probably 10 or 15

65
00:02:41,750 --> 00:02:38,850
minutes each I'll talk about aluminum 26

66
00:02:44,840 --> 00:02:41,760
which is a short-lived radioisotope

67
00:02:46,370 --> 00:02:44,850
which is present in the solar system we

68
00:02:48,440 --> 00:02:46,380
have evidence for meteorites that it was

69
00:02:50,780 --> 00:02:48,450
live in the solar system in the early

70
00:02:52,010 --> 00:02:50,790
stages of plant information and it might

71
00:02:54,560 --> 00:02:52,020
play an important role around other

72
00:02:57,050 --> 00:02:54,570
stars then I'll talk about hot Jupiters

73
00:02:58,400 --> 00:02:57,060
you know those those are gas giant

74
00:03:00,290 --> 00:02:58,410
planets very close to their stars we

75
00:03:02,300 --> 00:03:00,300
think they form further out and migrate

76
00:03:03,530 --> 00:03:02,310
it in and so i'll talk about whether how

77
00:03:05,870 --> 00:03:03,540
tall plants can form in those systems

78
00:03:08,090 --> 00:03:05,880
and then i'll talk about low mass stars

79
00:03:10,160 --> 00:03:08,100
about whether whether habitable planets

80
00:03:12,500 --> 00:03:10,170
can form in those systems and actually

81
00:03:13,610 --> 00:03:12,510
for many low-mass stars planets that are

82
00:03:15,860 --> 00:03:13,620
in the habitable zone would have a

83
00:03:19,340 --> 00:03:15,870
significant title evolution and I'll

84
00:03:20,840 --> 00:03:19,350
kind of mention that a bit so here we go

85
00:03:22,790 --> 00:03:20,850
here's the standard picture of how

86
00:03:24,110 --> 00:03:22,800
habitable planets form here's a little

87
00:03:26,600 --> 00:03:24,120
cartoon version that what we think is

88
00:03:28,910 --> 00:03:26,610

going on start with a molecular cloud

89
00:03:31,760 --> 00:03:28,920
little piece of it collapses get a disk

90
00:03:34,100 --> 00:03:31,770
and from that disk the solar system form

91
00:03:35,510 --> 00:03:34,110
so that's the very nice overview picture

92
00:03:38,360 --> 00:03:35,520
what's going on I'll give you a little

93
00:03:40,729 --> 00:03:38,370
more detail in a sec and here's kind of

94
00:03:42,290 --> 00:03:40,739
what we think the solar nebula you know

95
00:03:43,550 --> 00:03:42,300
the protoplanetary disk that formed the

96
00:03:46,009 --> 00:03:43,560
solar system when it might have looked

97
00:03:49,220 --> 00:03:46,019
like you know it's kind of hotter closer

98
00:03:51,500 --> 00:03:49,230
into the star and so kind of a species

99
00:03:53,240 --> 00:03:51,510
that are available to build solid

100
00:03:56,870 --> 00:03:53,250
planets depend on the local temperature

101
00:03:58,430 --> 00:03:56,880
which in turn depends on the location so

102
00:04:00,320 --> 00:03:58,440
very close to the star planets typically

103
00:04:01,820 --> 00:04:00,330
formed from you know refractory things

104
00:04:03,890 --> 00:04:01,830
like metal and rock further out they can

105
00:04:06,650 --> 00:04:03,900
form from things like ice and you know

106
00:04:08,240 --> 00:04:06,660
in more volatile species and this kind

107
00:04:10,460 --> 00:04:08,250
of evidence from this kind of process

108
00:04:12,830 --> 00:04:10,470
you know hotter closer in and cooler

109
00:04:14,449 --> 00:04:12,840
further out is seen in terms of the

110
00:04:16,759 --> 00:04:14,459
water content of primitive meteorites

111
00:04:20,150 --> 00:04:16,769
which we think are tied to classes of

112
00:04:22,159 --> 00:04:20,160
asteroids and so how do planets form in

113
00:04:24,140 --> 00:04:22,169

these kind of disks well there's a bunch

114
00:04:24,590 --> 00:04:24,150
of different stages I'm not going to go

115
00:04:32,180 --> 00:04:24,600
into

116
00:04:34,100 --> 00:04:32,190
thin plane in these disks from these

117
00:04:36,080 --> 00:04:34,110
small grains you form kilometer-sized

118
00:04:36,920 --> 00:04:36,090
things and this is step number two is

119
00:04:38,390 --> 00:04:36,930
kind of the one that's the most

120
00:04:40,370 --> 00:04:38,400
uncertain right now lots of people are

121
00:04:41,690 --> 00:04:40,380
thinking about how that really happens

122
00:04:44,120 --> 00:04:41,700
how you get these kind of

123
00:04:45,260 --> 00:04:44,130
kilometer-sized planetesimals to form

124
00:04:47,660 --> 00:04:45,270
because these things are really the

125
00:04:50,180 --> 00:04:47,670
building blocks of earth-like planets

126
00:04:53,480 --> 00:04:50,190
the next stage is the formation of

127
00:04:54,890 --> 00:04:53,490
larger things maybe Moon or Mars size

128
00:04:58,540 --> 00:04:54,900
things that we call planetary embryos

129
00:05:00,650 --> 00:04:58,550
and this this picture right here is a

130
00:05:02,930 --> 00:05:00,660
snapshots from a simulation of that

131
00:05:05,060 --> 00:05:02,940
third stage of what's called oligarchic

132
00:05:07,520 --> 00:05:05,070
growth and so you can see these little

133
00:05:09,920 --> 00:05:07,530
guys are forming or accreting to form

134
00:05:11,930 --> 00:05:09,930
larger bodies these moon-sized things

135
00:05:13,430 --> 00:05:11,940
which you have down here and they tend

136
00:05:15,500 --> 00:05:13,440
to form with kind of a characteristic

137
00:05:17,930 --> 00:05:15,510
spacing they tend to form with more or

138
00:05:22,460 --> 00:05:17,940

less a characteristic mass that tend to

139
00:05:24,320 --> 00:05:22,470
form closer end faster and this stage

140
00:05:26,960 --> 00:05:24,330
where you have this kind of a relatively

141
00:05:29,900 --> 00:05:26,970
small number of these large guys lasts

142
00:05:33,290 --> 00:05:29,910
until the amount of mass in the big guys

143
00:05:35,000 --> 00:05:33,300
and the small guys is about equal and

144
00:05:36,350 --> 00:05:35,010
when that happens kind of these feeding

145
00:05:39,050 --> 00:05:36,360
zones overlap and you end up having

146
00:05:40,730 --> 00:05:39,060
collisions between planetary embryos and

147
00:05:43,340 --> 00:05:40,740
kind of this final stage of growth of

148
00:05:45,380 --> 00:05:43,350
terrestrial planets and a key thing to

149
00:05:47,750 --> 00:05:45,390
make note of is that gas giant planets

150
00:05:49,640 --> 00:05:47,760
form pretty fast they form and maybe a

151
00:05:52,340 --> 00:05:49,650
few million years or so we know that

152
00:05:54,530 --> 00:05:52,350
because that's how long discs of gas are

153
00:05:56,030 --> 00:05:54,540
present around other stars so the

154
00:05:59,480 --> 00:05:56,040
gaseous planets have to form well those

155
00:06:00,980 --> 00:05:59,490
disks still around so those gas giant

156
00:06:03,080 --> 00:06:00,990
planets probably form faster than

157
00:06:05,210 --> 00:06:03,090
terrestrial planets so this final stage

158
00:06:06,860 --> 00:06:05,220
especially the stage for called late

159
00:06:08,660 --> 00:06:06,870
stage accretion which is his final sweep

160
00:06:10,850 --> 00:06:08,670
up of planetary embryos and

161
00:06:13,160 --> 00:06:10,860
planetesimals probably happens in the

162
00:06:16,010 --> 00:06:13,170
presence of any gas giant planets that

163
00:06:19,760 --> 00:06:16,020

formed in the system so here's a little

164
00:06:23,480 --> 00:06:19,770
movie of that happening so in this in

165
00:06:24,770 --> 00:06:23,490
this movie you know we're looking at

166
00:06:26,870 --> 00:06:24,780
distance from the star that starts here

167
00:06:29,750 --> 00:06:26,880
at zero orbital eccentricity on the

168
00:06:32,000 --> 00:06:29,760
y-axis and the temperature is kind of

169
00:06:32,770 --> 00:06:32,010
imposed a water structure here so close

170
00:06:34,120 --> 00:06:32,780
into the star

171
00:06:36,310 --> 00:06:34,130
our things are dry that's a red is

172
00:06:37,900 --> 00:06:36,320
further out they have more water out

173
00:06:41,650 --> 00:06:37,910
here they have you know five percent

174
00:06:43,750 --> 00:06:41,660
water by mass and just off the screen is

175
00:06:45,430 --> 00:06:43,760
a jupiter-sized giant planet that's not

176
00:06:47,290 --> 00:06:45,440
explicitly shown here but you'll see its

177
00:06:49,690 --> 00:06:47,300
effects in a sec so we're going to see

178
00:06:51,250 --> 00:06:49,700
straight away is a few vertical ones at

179
00:06:54,220 --> 00:06:51,260
certain distances and what those ours

180
00:06:57,310 --> 00:06:54,230
are mean motion resonances with the

181
00:06:59,200 --> 00:06:57,320
giant plan so here we go so boom there

182
00:07:01,659 --> 00:06:59,210
we go this was the three two one this

183
00:07:03,550 --> 00:07:01,669
was a 32 and 31 but they get smeared out

184
00:07:05,950 --> 00:07:03,560
pretty quickly you can see planets are

185
00:07:09,010 --> 00:07:05,960
forming faster closer in close to the

186
00:07:11,020 --> 00:07:09,020
star and you know slower further out you

187
00:07:12,280 --> 00:07:11,030
can see after you know 5 or 10 million

188
00:07:14,260 --> 00:07:12,290

years this guy here is about an

189
00:07:15,400 --> 00:07:14,270
earth-mass but he's still completely

190
00:07:18,100 --> 00:07:15,410
ready he still has doesn't have any

191
00:07:20,200 --> 00:07:18,110
water so it's still pretty dry but that

192
00:07:23,620 --> 00:07:20,210
as as time goes on more mixing happens

193
00:07:25,810 --> 00:07:23,630
between these different zones and you

194
00:07:28,150 --> 00:07:25,820
know by the end of the movie or even buy

195
00:07:29,860 --> 00:07:28,160
a few by about 20 or 30 million years

196
00:07:32,170 --> 00:07:29,870
this guy here which will be kind of the

197
00:07:34,659 --> 00:07:32,180
earth analog in this case has a good

198
00:07:37,000 --> 00:07:34,669
amount of water and you know these zones

199
00:07:39,730 --> 00:07:37,010
keep mixing and you end up with in this

200
00:07:41,680 --> 00:07:39,740
case three terrestrial planets form this

201
00:07:43,840 --> 00:07:41,690
guy right here it at 18 you is more or

202
00:07:45,070 --> 00:07:43,850
less like the earth and you can see that

203
00:07:47,140 --> 00:07:45,080
there's an asteroid belt that's kind of

204
00:07:49,420 --> 00:07:47,150
slowly getting cleared out there you

205
00:07:51,040 --> 00:07:49,430
stop this before finishes this guy looks

206
00:07:52,990 --> 00:07:51,050
a lot like the earth it's about the same

207
00:07:55,150 --> 00:07:53,000
mass of the earth it's about actually to

208
00:07:58,120 --> 00:07:55,160
earth masses or so but it's about the

209
00:07:59,440 --> 00:07:58,130
same orbit as the earth and you know

210
00:08:01,510 --> 00:07:59,450
this is kind of a standard picture this

211
00:08:03,640 --> 00:08:01,520
is how we think have role planets form

212
00:08:05,770 --> 00:08:03,650
this guy got some water bike reading

213
00:08:08,140 --> 00:08:05,780

material that originated further out and

214
00:08:09,760 --> 00:08:08,150
so it can be in the habitable zone and

215
00:08:11,590 --> 00:08:09,770
have the right temperature for water be

216
00:08:13,840 --> 00:08:11,600
liquid on its surface and also have

217
00:08:16,300 --> 00:08:13,850
gotten some water by mixing between

218
00:08:17,740 --> 00:08:16,310
these different zones so this is kind of

219
00:08:20,680 --> 00:08:17,750
what we think is going on what about

220
00:08:24,580 --> 00:08:20,690
assessing tricity popping back and forth

221
00:08:26,140 --> 00:08:24,590
was that continue hmm yeah that's kind

222
00:08:29,860 --> 00:08:26,150
of a typical thing that's I mean that

223
00:08:31,960 --> 00:08:29,870
happens the earth right now today the

224
00:08:35,920 --> 00:08:31,970
Earth's eccentricities between about

225
00:08:38,409 --> 00:08:35,930
zero and point 06 or so on a time scale

226
00:08:40,360 --> 00:08:38,419
of I think it's 20,000 years or so and

227
00:08:41,949 --> 00:08:40,370
so that's all the all the planets in the

228
00:08:43,870 --> 00:08:41,959
solar system are currently having

229
00:08:44,079 --> 00:08:43,880
eccentricity oscillations and you can

230
00:08:45,670 --> 00:08:44,089
see

231
00:08:46,869 --> 00:08:45,680
that explicitly in the movie where the

232
00:08:49,780 --> 00:08:46,879
plants were kind of bobbing up and down

233
00:08:51,280 --> 00:08:49,790
a little bit so that's kind of the same

234
00:08:52,960 --> 00:08:51,290
kind of thing is happening in the solar

235
00:08:56,259 --> 00:08:52,970
system right now it's just happening

236
00:08:57,369 --> 00:08:56,269
really slow so we can't see and so what

237
00:08:58,660 --> 00:08:57,379
happens if you do a bunch of these

238
00:09:01,840 --> 00:08:58,670

models as you can see there's a lot of

239
00:09:03,400 --> 00:09:01,850
diversity in terms of what terrestrial

240
00:09:06,670 --> 00:09:03,410
planet systems might be out there in

241
00:09:09,549 --> 00:09:06,680
this case there's 11 simulations that

242
00:09:11,530 --> 00:09:09,559
had a deformed a planet that was in the

243
00:09:13,480 --> 00:09:11,540
Avril zone at around one of you or so

244
00:09:15,429 --> 00:09:13,490
and then the solar system is here for

245
00:09:18,030 --> 00:09:15,439
scale and so you can see there's a lot

246
00:09:20,259 --> 00:09:18,040
lot of diversity between the actual

247
00:09:22,360 --> 00:09:20,269
systems of planets themselves for

248
00:09:24,699 --> 00:09:22,370
example you know this guy is just a one

249
00:09:26,049 --> 00:09:24,709
terrestrial planet system whereas this

250
00:09:28,420 --> 00:09:26,059
guy's on the opposite of the spectrum

251
00:09:31,900 --> 00:09:28,430
has seven or eight planets that are Mars

252
00:09:33,220 --> 00:09:31,910
size or larger and for example the

253
00:09:35,590 --> 00:09:33,230
actual planets that are in the habitable

254
00:09:37,480 --> 00:09:35,600
zone have a lot of variety as well now

255
00:09:39,100 --> 00:09:37,490
they range from these really big planets

256
00:09:41,019 --> 00:09:39,110
that have a lot of water to ones that

257
00:09:43,689 --> 00:09:41,029
looked a lot like the earth these guys

258
00:09:45,249 --> 00:09:43,699
the ones that are in the haverhill ism

259
00:09:47,559 --> 00:09:45,259
but actually have not accreted much

260
00:09:49,509 --> 00:09:47,569
water and so there's a lot of variety

261
00:09:51,129 --> 00:09:49,519
out there and these are you know the

262
00:09:53,410 --> 00:09:51,139
variety we see here these are all four

263
00:09:54,759 --> 00:09:53,420

systems that have very similar starting

264
00:09:56,590 --> 00:09:54,769
conditions the starting conditions were

265
00:09:58,059 --> 00:09:56,600
you know slightly different here and

266
00:10:00,040 --> 00:09:58,069
there but more or less the same starting

267
00:10:03,369 --> 00:10:00,050
conditions and so if there's this much

268
00:10:05,139 --> 00:10:03,379
variety in terms of outcomes you know

269
00:10:07,600 --> 00:10:05,149
for more or less the same starting

270
00:10:09,569 --> 00:10:07,610
conditions then for much different

271
00:10:12,999 --> 00:10:09,579
starting conditions there's probably

272
00:10:14,829 --> 00:10:13,009
exponentially more variety and what is

273
00:10:17,019 --> 00:10:14,839
it that really sets this variety there's

274
00:10:19,150 --> 00:10:17,029
kind of two factors that are that are

275
00:10:21,730 --> 00:10:19,160
you know important for the differences

276
00:10:23,710 --> 00:10:21,740
between planetary systems one is this

277
00:10:25,540 --> 00:10:23,720
stochastic noise which is kind of a

278
00:10:26,949 --> 00:10:25,550
random effect when you go from a large

279
00:10:29,499 --> 00:10:26,959
amount of baggage to a small number

280
00:10:31,030 --> 00:10:29,509
towards the end of that process you know

281
00:10:33,910 --> 00:10:31,040
individual scattering events become

282
00:10:35,559 --> 00:10:33,920
important for the outcome so if things

283
00:10:37,900 --> 00:10:35,569
are just a tiny little bit different you

284
00:10:39,819 --> 00:10:37,910
can have a quite a different outcome so

285
00:10:41,439 --> 00:10:39,829
that's kind of the random factor and in

286
00:10:43,600 --> 00:10:41,449
addition to that there's systematic

287
00:10:48,340 --> 00:10:43,610
variations and there are two kind of key

288
00:10:50,499 --> 00:10:48,350

parameters that determine them the first

289
00:10:52,179 --> 00:10:50,509
is simply the the disk of stuff that the

290
00:10:53,530 --> 00:10:52,189
planets are forming out of you know you

291
00:10:55,269 --> 00:10:53,540
change the disc the planets are forming

292
00:10:55,790 --> 00:10:55,279
on it and change the planets to form in

293
00:10:58,790 --> 00:10:55,800
the distance

294
00:11:01,250 --> 00:10:58,800
pretty simple for example a higher mass

295
00:11:03,530 --> 00:11:01,260
in the disk if a disc has more mass

296
00:11:05,960 --> 00:11:03,540
it'll tend to form a smaller number of

297
00:11:07,009 --> 00:11:05,970
planets that are more massive and why is

298
00:11:09,199 --> 00:11:07,019
that it's simply because the

299
00:11:10,850 --> 00:11:09,209
eccentricities get excited more when you

300
00:11:12,199 --> 00:11:10,860
have a distance more massive and so

301
00:11:14,480 --> 00:11:12,209
feeding zones tend to be a little bit

302
00:11:16,100 --> 00:11:14,490
wider and so you can sweep up more mass

303
00:11:18,590 --> 00:11:16,110
you know a given planet can sweep up

304
00:11:21,019 --> 00:11:18,600
more mass and it also depends on for

305
00:11:24,230 --> 00:11:21,029
example the surface density profile of

306
00:11:26,180 --> 00:11:24,240
the disk and you know giant planets also

307
00:11:28,370 --> 00:11:26,190
giant planets like i mentioned forming

308
00:11:29,930 --> 00:11:28,380
these disks also and influence the final

309
00:11:33,380 --> 00:11:29,940
phases of terrestrial plant information

310
00:11:38,540 --> 00:11:33,390
and so you know they affect you know the

311
00:11:40,790 --> 00:11:38,550
outcome as well so all right so that's

312
00:11:42,530 --> 00:11:40,800
it for the the standard story now we're

313
00:11:44,810 --> 00:11:42,540

going to move on to kind of other

314
00:11:46,880 --> 00:11:44,820
effects that deal with with this

315
00:11:48,710 --> 00:11:46,890
planetary habitability stuff so I'm

316
00:11:50,030 --> 00:11:48,720
going to talk about three effects and in

317
00:11:53,420 --> 00:11:50,040
a little cartoon and they kind of fall

318
00:11:56,180 --> 00:11:53,430
in different places so the 26 the

319
00:11:58,460 --> 00:11:56,190
alumina 26th or calls early on while the

320
00:12:00,650 --> 00:11:58,470
Sun was still in a her stars are still

321
00:12:02,420 --> 00:12:00,660
in embedded clusters during the first 10

322
00:12:05,060 --> 00:12:02,430
million years or so so i'll talk about

323
00:12:08,000 --> 00:12:05,070
that one first john planet migration

324
00:12:09,829 --> 00:12:08,010
happens in these discs around stars it

325
00:12:14,780 --> 00:12:09,839
relies on interactions between planets

326
00:12:16,910 --> 00:12:14,790
and disks and for mstars i'm going to

327
00:12:18,680 --> 00:12:16,920
talk in particular about title orbital

328
00:12:20,810 --> 00:12:18,690
effects which happen over billions of

329
00:12:23,720 --> 00:12:20,820
years so they happen after the system is

330
00:12:27,829 --> 00:12:23,730
completely formed just over long times

331
00:12:31,430 --> 00:12:27,839
gift so first off we'll talk about the

332
00:12:33,920 --> 00:12:31,440
kind of the aluminum 26 story and so

333
00:12:36,889 --> 00:12:33,930
this story is linking kind of some what

334
00:12:41,090 --> 00:12:36,899
we see in meteorites tells us something

335
00:12:44,060 --> 00:12:41,100
about the content of planetesimals in

336
00:12:45,439 --> 00:12:44,070
the early solar system that intern tells

337
00:12:49,250 --> 00:12:45,449
us something about the birth environment

338
00:12:52,699 --> 00:12:49,260

of the Sun and then by looking at you

339
00:12:55,610 --> 00:12:52,709
know by imagining clusters of stars that

340
00:12:56,750 --> 00:12:55,620
form you know stars like the Sun which

341
00:12:58,970 --> 00:12:56,760
eventually for planets like Earth

342
00:13:01,970 --> 00:12:58,980
looking at different stars on different

343
00:13:04,610 --> 00:13:01,980
orbits within the same clusters we can

344
00:13:07,850 --> 00:13:04,620
say something about what planets you

345
00:13:09,380 --> 00:13:07,860
know the composition of planets in stars

346
00:13:11,150 --> 00:13:09,390
like the Sun but who had

347
00:13:13,700 --> 00:13:11,160
slightly different orbital histories

348
00:13:15,950 --> 00:13:13,710
within that cluster so that's what we're

349
00:13:17,930 --> 00:13:15,960
going to get into so to start off

350
00:13:20,330 --> 00:13:17,940
there's evidence from primitive

351
00:13:25,760 --> 00:13:20,340
meteorites for live aluminum 26 in the

352
00:13:27,080 --> 00:13:25,770
early solar system and so in this plot

353
00:13:29,060 --> 00:13:27,090
we're looking at is we're basically

354
00:13:31,070 --> 00:13:29,070
looking at a different isotope of

355
00:13:33,740 --> 00:13:31,080
aluminum you know normalized by by

356
00:13:36,890 --> 00:13:33,750
isotope magnesium versus the daughter

357
00:13:39,590 --> 00:13:36,900
product of this of alumina 26 which is

358
00:13:41,470 --> 00:13:39,600
the heating element and make sure that

359
00:13:45,470 --> 00:13:41,480
this correlation is interpreted as

360
00:13:47,090 --> 00:13:45,480
evidence for live aluminum 26 at the

361
00:13:50,450 --> 00:13:47,100
time of formation of these minerals in

362
00:13:53,000 --> 00:13:50,460
this primitive meteor and so we think

363
00:13:55,070 --> 00:13:53,010

there was live radioactive stuff you

364
00:13:58,100 --> 00:13:55,080
know in these rocky bodies at the time

365
00:13:59,720 --> 00:13:58,110
of their formation and there's evidence

366
00:14:02,300 --> 00:13:59,730
for other ones besides just the lumen of

367
00:14:04,370 --> 00:14:02,310
26 that were in the in the solar nebula

368
00:14:06,230 --> 00:14:04,380
as you know rocky things are starting to

369
00:14:08,870 --> 00:14:06,240
form this evidence for example for

370
00:14:11,410 --> 00:14:08,880
beryllium 10 in the lumen 26 so on

371
00:14:13,610 --> 00:14:11,420
there's actually many more of these and

372
00:14:15,140 --> 00:14:13,620
you know it's been debated where these

373
00:14:17,000 --> 00:14:15,150
things come from there's a couple

374
00:14:19,550 --> 00:14:17,010
different ideas that kind of two

375
00:14:21,830 --> 00:14:19,560
competing ideas that the two main ideas

376
00:14:25,040 --> 00:14:21,840
are either kind of a local source versus

377
00:14:28,040 --> 00:14:25,050
an external source and the local source

378
00:14:29,560 --> 00:14:28,050
is just kind of its solar energetic

379
00:14:32,120 --> 00:14:29,570
particles coming from the Sun

380
00:14:34,820 --> 00:14:32,130
interacting with the disk can actually

381
00:14:38,690 --> 00:14:34,830
create some of these short-lived

382
00:14:41,210 --> 00:14:38,700
radionuclides you know locally in the

383
00:14:43,430 --> 00:14:41,220
disk the trick is that would kind of

384
00:14:45,350 --> 00:14:43,440
imply that they should be they shouldn't

385
00:14:47,330 --> 00:14:45,360
be homogeneous ly distributed within the

386
00:14:49,400 --> 00:14:47,340
disk this should be concentrated kind of

387
00:14:51,020 --> 00:14:49,410
towards the inner regions where they're

388
00:14:52,580 --> 00:14:51,030

actually being formed and it turns out

389
00:14:54,950 --> 00:14:52,590
there's some evidence to suggest that

390
00:14:56,270 --> 00:14:54,960
they that the radioactive stuff is

391
00:14:59,450 --> 00:14:56,280
actually pretty homogeneous ly

392
00:15:01,340 --> 00:14:59,460
distribute and so that's kind of some

393
00:15:02,840 --> 00:15:01,350
evidence against this idea it's not

394
00:15:04,760 --> 00:15:02,850
completely shooting that idea down but

395
00:15:06,740 --> 00:15:04,770
there's some evidence against it the

396
00:15:09,110 --> 00:15:06,750
idea that I'm going to go with is that

397
00:15:11,780 --> 00:15:09,120
the short-lived radionuclides came from

398
00:15:14,540 --> 00:15:11,790
massive stars both from from winds from

399
00:15:18,320 --> 00:15:14,550
massive stars and also from supernova

400
00:15:21,410 --> 00:15:18,330
ejecta and so iron 60 is actually kind

401
00:15:21,960 --> 00:15:21,420
of a smoking gun for a supernova having

402
00:15:24,269 --> 00:15:21,970
produced

403
00:15:26,069 --> 00:15:24,279
at that isotope that ended up in the

404
00:15:28,619 --> 00:15:26,079
solar nebula because you can't be

405
00:15:36,660 --> 00:15:28,629
produced locally like some less massive

406
00:15:39,900 --> 00:15:36,670
ones and so since you know so if the

407
00:15:42,269 --> 00:15:39,910
radionuclides in the solar nebula came

408
00:15:43,949 --> 00:15:42,279
from a massive star that actually

409
00:15:46,559 --> 00:15:43,959
requires the Sun to have formed in a

410
00:15:48,689 --> 00:15:46,569
pretty big cluster why is that because

411
00:15:51,509 --> 00:15:48,699
of the mass distribution of stars as

412
00:15:53,730 --> 00:15:51,519
they form you know you know most stars

413
00:15:57,059 --> 00:15:53,740

are very small puny things and to form

414
00:15:58,259 --> 00:15:57,069
big things like oh the OB stars with

415
00:15:59,699 --> 00:15:58,269
their called these very massive stars

416
00:16:01,710 --> 00:15:59,709
that end up going supernova and

417
00:16:03,780 --> 00:16:01,720
polluting the rest of the cluster with

418
00:16:05,309 --> 00:16:03,790
these radionuclides you need kind of

419
00:16:07,019 --> 00:16:05,319
statistically a certain number of stars

420
00:16:10,050 --> 00:16:07,029
before you form one of these big ones

421
00:16:14,160 --> 00:16:10,060
and so actually it turns out that the

422
00:16:15,720 --> 00:16:14,170
most likely mass for the cluster or the

423
00:16:17,970 --> 00:16:15,730
likely most likely number for the amount

424
00:16:20,280 --> 00:16:17,980
of stars in the birth cluster of the Sun

425
00:16:22,379 --> 00:16:20,290
is something like 10,000 so since we

426
00:16:25,590 --> 00:16:22,389
have evidence for this stuff that was

427
00:16:27,360 --> 00:16:25,600
injected we think by a supernova the

428
00:16:29,850 --> 00:16:27,370
most likely cluster size is actually the

429
00:16:31,439 --> 00:16:29,860
size of about 10,000 stars or so and so

430
00:16:33,990 --> 00:16:31,449
that's kind of some indirect evidence

431
00:16:35,400 --> 00:16:34,000
for the son's birth environment and so

432
00:16:37,829 --> 00:16:35,410
the son was born in some kind of place

433
00:16:40,019 --> 00:16:37,839
like this is the Orion Nebula the Sun

434
00:16:42,420 --> 00:16:40,029
was actually born in a place much bigger

435
00:16:43,710 --> 00:16:42,430
and let's wimpy than the Orion Nebula

436
00:16:47,879 --> 00:16:43,720
with a lot more star something like

437
00:16:51,480 --> 00:16:47,889
10,000 so that's kind of neat how short

438
00:16:53,759 --> 00:16:51,490

loop or lease ah ok I didn't I have a

439
00:16:55,559 --> 00:16:53,769
big table that could I could show you

440
00:16:57,420 --> 00:16:55,569
with all the details of all this they

441
00:16:59,249 --> 00:16:57,430
tend to be about it the half-life tends

442
00:17:00,360 --> 00:16:59,259
to be about a million years or so the

443
00:17:02,600 --> 00:17:00,370
one that I'm going to talk about the

444
00:17:05,819 --> 00:17:02,610
most aluminum six has a half-life of

445
00:17:07,319 --> 00:17:05,829
700,000 years so they're short lived in

446
00:17:09,329 --> 00:17:07,329
terms of like the crossing time of the

447
00:17:11,329 --> 00:17:09,339
of the cluster for example so they have

448
00:17:17,460 --> 00:17:11,339
to have a relatively local source within

449
00:17:18,750 --> 00:17:17,470
the cluster all right so how do you get

450
00:17:21,630 --> 00:17:18,760
these these short-lived radionuclides

451
00:17:22,620 --> 00:17:21,640
from high mass stars well most stars are

452
00:17:26,490 --> 00:17:22,630
thought to actually form a pretty

453
00:17:28,110 --> 00:17:26,500
massive clusters you know with thousands

454
00:17:30,779 --> 00:17:28,120
of other stars and these massive

455
00:17:32,520 --> 00:17:30,789
clusters contain you know massive stars

456
00:17:34,140 --> 00:17:32,530
just statistically you know most stars

457
00:17:35,730 --> 00:17:34,150
are wimpy like I was saying but a few of

458
00:17:37,590 --> 00:17:35,740
a really big when you have a very

459
00:17:39,720 --> 00:17:37,600
massive cluster then you tend to have a

460
00:17:41,730 --> 00:17:39,730
few of these really massive stars that

461
00:17:44,400 --> 00:17:41,740
tend to actually be more or less at the

462
00:17:45,800 --> 00:17:44,410
center of the cluster and these are the

463
00:17:48,900 --> 00:17:45,810

massive stars that create the

464
00:17:50,850 --> 00:17:48,910
short-lived radionuclides and can

465
00:17:52,020 --> 00:17:50,860
pollute nearby stars with this material

466
00:17:54,300 --> 00:17:52,030
and so here's kind of the general

467
00:17:57,240 --> 00:17:54,310
picture we have of what's going on is

468
00:17:59,880 --> 00:17:57,250
that you know one of these large massive

469
00:18:01,680 --> 00:17:59,890
stars has various phases or goes through

470
00:18:03,990 --> 00:18:01,690
like this wolf or a win for example then

471
00:18:06,780 --> 00:18:04,000
supernova ejecta and nearby stars can be

472
00:18:08,340 --> 00:18:06,790
polluted with that material how does

473
00:18:10,980 --> 00:18:08,350
that actually happen well here's a model

474
00:18:12,840 --> 00:18:10,990
of what's going on in the inside of star

475
00:18:14,430 --> 00:18:12,850
so you can see the age of the started

476
00:18:18,870 --> 00:18:14,440
millions of years there versus its mass

477
00:18:21,030 --> 00:18:18,880
in solar units so 64 mass star and I

478
00:18:24,300 --> 00:18:21,040
lose mess there then during this is the

479
00:18:25,920 --> 00:18:24,310
space what's called the WN phase has

480
00:18:28,050 --> 00:18:25,930
very strong winds it's during that phase

481
00:18:30,240 --> 00:18:28,060
that most of the alumina 26 is created

482
00:18:32,190 --> 00:18:30,250
it's not to the very end that you get

483
00:18:36,360 --> 00:18:32,200
the spike of iron 60 in the actual

484
00:18:39,060 --> 00:18:36,370
supernova and how does that end up in a

485
00:18:41,520 --> 00:18:39,070
disc like the solar nebula what we think

486
00:18:43,470 --> 00:18:41,530
happens is if this shock front when you

487
00:18:46,140 --> 00:18:43,480
have this wind from from the massive

488
00:18:48,060 --> 00:18:46,150

star comment from the right a shock

489
00:18:50,870 --> 00:18:48,070
front is built the gas kind of flows

490
00:18:53,810 --> 00:18:50,880
along these lines but actual grains

491
00:18:56,880 --> 00:18:53,820
which contain much of this you know very

492
00:18:58,590 --> 00:18:56,890
refractory stuff these radioisotopes can

493
00:19:00,720 --> 00:18:58,600
actually get injected directly into the

494
00:19:03,030 --> 00:19:00,730
disc the grains can pass through the

495
00:19:04,440 --> 00:19:03,040
shock wears the gas can so this is kind

496
00:19:07,860 --> 00:19:04,450
of the general model for what we think

497
00:19:09,840 --> 00:19:07,870
is going on in terms of how you know

498
00:19:12,180 --> 00:19:09,850
this radioactive stuff gets gets into

499
00:19:13,560 --> 00:19:12,190
another disk and so the picture there is

500
00:19:16,590 --> 00:19:13,570
similar to for example this is a little

501
00:19:17,970 --> 00:19:16,600
proclip in Orion this is an observation

502
00:19:20,820 --> 00:19:17,980
you can see the disk right there and

503
00:19:23,490 --> 00:19:20,830
this kind of shock is the kind of thing

504
00:19:24,780 --> 00:19:23,500
that we think you know this this kind of

505
00:19:26,460 --> 00:19:24,790
picture we think is more or less what's

506
00:19:28,020 --> 00:19:26,470
going on here although in this case it's

507
00:19:32,220 --> 00:19:28,030
not super nova ejecta this happening but

508
00:19:33,270 --> 00:19:32,230
this kind of you know object is really

509
00:19:38,490 --> 00:19:33,280
out there and we think this is what's

510
00:19:39,870 --> 00:19:38,500
going on so so like we mentioned there's

511
00:19:42,810 --> 00:19:39,880
a there's kind of a delay of a few

512
00:19:44,700 --> 00:19:42,820
million years we could within a cluster

513
00:19:46,040 --> 00:19:44,710

before you can pollute it with the

514
00:19:47,970 --> 00:19:46,050
short-lived radionuclides

515
00:19:49,680 --> 00:19:47,980
and the reason for that is simply

516
00:19:51,390 --> 00:19:49,690
because once massive stars form they

517
00:19:53,010 --> 00:19:51,400
don't go off as supernova immediately

518
00:19:55,350 --> 00:19:53,020
they take a few million years like we

519
00:19:57,750 --> 00:19:55,360
saw before and so if you if you kind of

520
00:20:01,140 --> 00:19:57,760
simulate a star cluster with about

521
00:20:03,390 --> 00:20:01,150
10,000 members or so and then track the

522
00:20:06,900 --> 00:20:03,400
orbits of all the stars that are like

523
00:20:08,310 --> 00:20:06,910
the Sun and see kind of you know in this

524
00:20:10,920 --> 00:20:08,320
cluster there they're actually in this

525
00:20:13,170 --> 00:20:10,930
case three massive stars that go

526
00:20:17,120 --> 00:20:13,180
supernova and kind of keep track of how

527
00:20:21,720 --> 00:20:17,130
much in this case a limit of 26 ends up

528
00:20:23,700 --> 00:20:21,730
you know being embedded in that disk

529
00:20:25,650 --> 00:20:23,710
kind of in a relative sense because we

530
00:20:27,330 --> 00:20:25,660
it's difficult to calibrate an absolute

531
00:20:29,760 --> 00:20:27,340
sense but in a relative sense then you

532
00:20:33,690 --> 00:20:29,770
get kind of this curve and so the

533
00:20:35,730 --> 00:20:33,700
relative abundance of aluminum 26 in a

534
00:20:39,240 --> 00:20:35,740
cluster of about 10,000 members which is

535
00:20:41,670 --> 00:20:39,250
a typical cluster into our traction

536
00:20:44,190 --> 00:20:41,680
stars are formed the distribution of

537
00:20:46,470 --> 00:20:44,200
these short-lived stuff more or less

538
00:20:47,910 --> 00:20:46,480

good like this so it's kind of in this

539
00:20:49,170 --> 00:20:47,920
case it peaked around you know some

540
00:20:51,930 --> 00:20:49,180
nominal value which is actually pretty

541
00:20:54,870 --> 00:20:51,940
close to what we think is the value for

542
00:20:56,690 --> 00:20:54,880
the solar system and then you know

543
00:20:58,980 --> 00:20:56,700
there's a tale of stars which got more

544
00:21:00,390 --> 00:20:58,990
radioactive material which is probably

545
00:21:03,050 --> 00:21:00,400
something like five or ten percent of

546
00:21:05,340 --> 00:21:03,060
Stars got more aluminum 26 than the Sun

547
00:21:06,990 --> 00:21:05,350
then here you know some fraction got

548
00:21:08,370 --> 00:21:07,000
less and actually a large fraction

549
00:21:10,710 --> 00:21:08,380
something like fifty to eighty percent

550
00:21:13,380 --> 00:21:10,720
aren't even on this plot because by the

551
00:21:14,490 --> 00:21:13,390
time the super novae went off they

552
00:21:16,680 --> 00:21:14,500
weren't actually part of the cluster

553
00:21:18,660 --> 00:21:16,690
anymore so a lot of the stars aren't

554
00:21:20,760 --> 00:21:18,670
even shown shown on here at all because

555
00:21:22,740 --> 00:21:20,770
they were already gone and so actually

556
00:21:25,500 --> 00:21:22,750
what actually happens there is that the

557
00:21:27,150 --> 00:21:25,510
the gas is holding the little embedded

558
00:21:28,560 --> 00:21:27,160
clusters together when the gas

559
00:21:31,260 --> 00:21:28,570
dissipates the whole cluster kind of

560
00:21:33,720 --> 00:21:31,270
falls apart and the cluster is slowly

561
00:21:35,700 --> 00:21:33,730
falling apart during that process and so

562
00:21:37,740 --> 00:21:35,710
you know a good chunk of the star has

563
00:21:41,070 --> 00:21:37,750

never got any of this balloon with 26

564
00:21:43,080 --> 00:21:41,080
and all and so why do we really care

565
00:21:46,200 --> 00:21:43,090
about those delimited 26 stuff anyway

566
00:21:48,270 --> 00:21:46,210
well the reason is that aluminum 26

567
00:21:50,570 --> 00:21:48,280
heating is thought to have been really

568
00:21:53,820 --> 00:21:50,580
important in kind of small bodies maybe

569
00:21:56,220 --> 00:21:53,830
kilometer-sized bodies in the in the

570
00:21:58,710 --> 00:21:56,230
solar system for example the

571
00:21:58,920 --> 00:21:58,720
distribution of s vs. c-class asteroids

572
00:22:02,040 --> 00:21:58,930
can

573
00:22:03,840 --> 00:22:02,050
explained by by heating but actually I'm

574
00:22:05,360 --> 00:22:03,850
getting ahead of myself this plot here

575
00:22:08,940 --> 00:22:05,370
for example what we're looking at is

576
00:22:10,530 --> 00:22:08,950
decreasing time scale of bodies so you

577
00:22:13,110 --> 00:22:10,540
know up to up to 20 million years there

578
00:22:15,000 --> 00:22:13,120
and these curves are showing how much

579
00:22:16,560 --> 00:22:15,010
mass did not get heated up that much so

580
00:22:18,390 --> 00:22:16,570
it's a little bit backwards how much

581
00:22:20,940 --> 00:22:18,400
stuff didn't really get heated up that

582
00:22:23,220 --> 00:22:20,950
much as a function of the the time it

583
00:22:25,520 --> 00:22:23,230
takes them to form and so in green is

584
00:22:30,180 --> 00:22:25,530
the solar system's worth of aluminum 26

585
00:22:33,240 --> 00:22:30,190
and blue is is 10 times less and orange

586
00:22:34,470 --> 00:22:33,250
is kind of ten times more balloon 26 so

587
00:22:37,620 --> 00:22:34,480
what does this mean basically you get

588
00:22:40,110 --> 00:22:37,630

for a given kind of formation time if

589
00:22:42,180 --> 00:22:40,120
you have more of this looming 26 you

590
00:22:45,780 --> 00:22:42,190
heat up a whole lot more material to

591
00:22:47,820 --> 00:22:45,790
high temperatures which sends to get rid

592
00:22:51,030 --> 00:22:47,830
of all the volatile especially but we're

593
00:22:53,490 --> 00:22:51,040
concerned about here is water so it's a

594
00:22:56,070 --> 00:22:53,500
balance between the half-life of alumina

595
00:23:00,300 --> 00:22:56,080
26 which is 700,000 years and the

596
00:23:02,640 --> 00:23:00,310
formation time of bodies so like I was

597
00:23:06,720 --> 00:23:02,650
mentioning before these s vs. c-class

598
00:23:08,670 --> 00:23:06,730
meteorites sorry asteroids esta

599
00:23:10,050 --> 00:23:08,680
asteroids are tied to ordinary

600
00:23:13,140 --> 00:23:10,060
chondrites which don't have that much

601
00:23:14,580 --> 00:23:13,150
water c-class are tied to carbonaceous

602
00:23:16,380 --> 00:23:14,590
chondrites which have maybe ten percent

603
00:23:17,970 --> 00:23:16,390
water and the break between the two

604
00:23:22,350 --> 00:23:17,980
happens at about two and a half a year's

605
00:23:24,150 --> 00:23:22,360
though and that's explained by the

606
00:23:25,740 --> 00:23:24,160
formation time like I mentioned before

607
00:23:27,840 --> 00:23:25,750
it takes longer to form things further

608
00:23:30,180 --> 00:23:27,850
away from the star you're kind of racing

609
00:23:33,780 --> 00:23:30,190
to form things versus the decaying

610
00:23:36,270 --> 00:23:33,790
aluminum 26 and that's why you have dr

611
00:23:41,970 --> 00:23:36,280
things here and wetter things for the

612
00:23:43,530 --> 00:23:41,980
rent and so this division which was at

613
00:23:46,770 --> 00:23:43,540

about two and a half a you in the solar

614
00:23:48,930 --> 00:23:46,780
system is obviously a function of how

615
00:23:50,520 --> 00:23:48,940
much the lumix you have so for example

616
00:23:53,490 --> 00:23:50,530
here's the position of that division

617
00:23:56,730 --> 00:23:53,500
between wet stuff and dry stuff versus

618
00:23:58,320 --> 00:23:56,740
the relative abundance of alumina 26 and

619
00:23:59,550 --> 00:23:58,330
there's you know there's some

620
00:24:01,980 --> 00:23:59,560
uncertainty here because we don't know

621
00:24:04,500 --> 00:24:01,990
exactly how long it took to form things

622
00:24:05,400 --> 00:24:04,510
at at a given distance and so these

623
00:24:07,920 --> 00:24:05,410
three curves are four different

624
00:24:12,810 --> 00:24:07,930
formation time scales at two and a half

625
00:24:16,769 --> 00:24:12,820
a you but in general if you have more

626
00:24:19,080 --> 00:24:16,779
illumine 26 then the division between

627
00:24:20,610 --> 00:24:19,090
dry stuff and wet stuff is further out

628
00:24:22,740 --> 00:24:20,620
you know it's not exactly know where it

629
00:24:24,180 --> 00:24:22,750
is but it's further out and for that

630
00:24:26,399 --> 00:24:24,190
large chunk of systems that didn't get

631
00:24:29,279 --> 00:24:26,409
any aluminum 26 you know it's close to

632
00:24:31,560 --> 00:24:29,289
run and what does that mean well before

633
00:24:33,210 --> 00:24:31,570
we were looking at you know plants like

634
00:24:35,970 --> 00:24:33,220
Earth forming and needing this mixing

635
00:24:38,730 --> 00:24:35,980
between zones to get water onto a punt

636
00:24:41,610 --> 00:24:38,740
and so if the the region you need to mix

637
00:24:44,430 --> 00:24:41,620
from is further and further out and it's

638
00:24:46,590 --> 00:24:44,440

harder to get water on there so for

639
00:24:48,450 --> 00:24:46,600
example here you know here's the average

640
00:24:50,850 --> 00:24:48,460
results of about thirty simulations that

641
00:24:54,740 --> 00:24:50,860
are designed to rip to replicate the

642
00:24:56,970 --> 00:24:54,750
solar system to reproduce earth and so

643
00:24:58,710 --> 00:24:56,980
you know we're looking at here is a

644
00:25:00,960 --> 00:24:58,720
water content versus the location of

645
00:25:03,180 --> 00:25:00,970
that division between dry stuff and wet

646
00:25:05,070 --> 00:25:03,190
stuff and like you'd expect when the you

647
00:25:06,629 --> 00:25:05,080
know that division is closer in it's

648
00:25:08,279 --> 00:25:06,639
much easier to get water on planets and

649
00:25:10,529 --> 00:25:08,289
so you could have planets with maybe you

650
00:25:12,659 --> 00:25:10,539
know ten times more water than earth if

651
00:25:14,490 --> 00:25:12,669
there was more aluminum 26 that

652
00:25:17,549 --> 00:25:14,500
divisions further out and you probably

653
00:25:19,379 --> 00:25:17,559
get less okay and so the general

654
00:25:22,169 --> 00:25:19,389
punchline of this piece of the story is

655
00:25:24,570 --> 00:25:22,179
simply you know depending on the the

656
00:25:26,999 --> 00:25:24,580
birth environment of the star he can be

657
00:25:30,990 --> 00:25:27,009
closer or further away from supernova

658
00:25:33,060 --> 00:25:31,000
you have more or less alumina 26 and so

659
00:25:34,980 --> 00:25:33,070
say you get less that means the division

660
00:25:37,320 --> 00:25:34,990
between dry stuff and wet stuff in the

661
00:25:39,240 --> 00:25:37,330
disk stuff that you're forming would be

662
00:25:43,200 --> 00:25:39,250
closer in and you end up with wetter

663
00:25:46,789 --> 00:25:43,210

dress your plants so that's part one all

664
00:25:48,930 --> 00:25:46,799
right part two hot Jupiters all right

665
00:25:55,350 --> 00:25:48,940
Ken habitable planets form with hot

666
00:25:56,669 --> 00:25:55,360
Jupiters okay so giant plants are all

667
00:25:58,590 --> 00:25:56,679
thought to form kind of further away

668
00:26:01,169 --> 00:25:58,600
from their stars there's different lines

669
00:26:03,299 --> 00:26:01,179
of reasoning for that so we think that

670
00:26:06,210 --> 00:26:03,309
planets form kind of out here where

671
00:26:09,149 --> 00:26:06,220
Jupiter is however lots of them are

672
00:26:10,590 --> 00:26:09,159
observed really close in so what's going

673
00:26:12,389 --> 00:26:10,600
on there well we think what's happening

674
00:26:14,970 --> 00:26:12,399
is they form for their out they move

675
00:26:16,919 --> 00:26:14,980
inward and become hot Jupiters and so

676
00:26:18,720 --> 00:26:16,929
during that process you know they're

677
00:26:20,690 --> 00:26:18,730
migrating right through the zone where

678
00:26:23,789 --> 00:26:20,700
plants like Earth are trying to form and

679
00:26:25,270 --> 00:26:23,799
so key thing is can you still have

680
00:26:26,590 --> 00:26:25,280
planets like earth

681
00:26:28,870 --> 00:26:26,600
given that this is happening in those

682
00:26:31,300 --> 00:26:28,880
kind of systems can you still form have

683
00:26:33,610 --> 00:26:31,310
real plans and so people have argued

684
00:26:37,150 --> 00:26:33,620
about this in the past obviously so

685
00:26:39,700 --> 00:26:37,160
previous results there's some know

686
00:26:41,020 --> 00:26:39,710
despite kind of by assumption you know

687
00:26:43,060 --> 00:26:41,030
if a giant planets migrating through

688
00:26:45,070 --> 00:26:43,070

this region you can't form little teeny

689
00:26:48,850 --> 00:26:45,080
rocky planets some people have thought

690
00:26:52,060 --> 00:26:48,860
that some people say no if you know

691
00:26:54,460 --> 00:26:52,070
waving your hands this way you know then

692
00:26:58,000 --> 00:26:54,470
you can say yes if this is happening or

693
00:27:00,190 --> 00:26:58,010
yes if that you know basically it's time

694
00:27:04,720 --> 00:27:00,200
to look at this in more detail so that's

695
00:27:06,940 --> 00:27:04,730
what we did so all right key things in

696
00:27:08,980 --> 00:27:06,950
addition to just gravity which was

697
00:27:10,180 --> 00:27:08,990
included in those previous calculation

698
00:27:13,450 --> 00:27:10,190
like that previous movie I showed you

699
00:27:15,130 --> 00:27:13,460
here we had some new stuff for example

700
00:27:17,140 --> 00:27:15,140
we included the effects of type 2

701
00:27:19,330 --> 00:27:17,150
migration this is migration of a giant

702
00:27:21,130 --> 00:27:19,340
planet which is embedded in the disk its

703
00:27:24,760 --> 00:27:21,140
massive enough to actually carve a gap

704
00:27:26,410 --> 00:27:24,770
an annular gap in the disk that happens

705
00:27:29,140 --> 00:27:26,420
when the giant planets kind of region of

706
00:27:31,570 --> 00:27:29,150
influence is larger than the scale

707
00:27:33,550 --> 00:27:31,580
height of the dip and then the giant

708
00:27:35,170 --> 00:27:33,560
plan ends of migrating inward on a

709
00:27:37,120 --> 00:27:35,180
timescale of maybe maybe a hundred

710
00:27:39,130 --> 00:27:37,130
thousand years or so and we also

711
00:27:40,570 --> 00:27:39,140
included the effects of gas drag which

712
00:27:42,810 --> 00:27:40,580
are important especially for smaller

713
00:27:46,390 --> 00:27:42,820

bodies planetesimals have their orbits

714
00:27:49,150 --> 00:27:46,400
recirculating by gas Dre and so that's

715
00:27:51,640 --> 00:27:49,160
important to include as well and so

716
00:27:54,220 --> 00:27:51,650
here's another movie what we have here

717
00:27:56,080 --> 00:27:54,230
is the same kind of thing as before like

718
00:27:58,300 --> 00:27:56,090
the different colors represent the same

719
00:28:00,100 --> 00:27:58,310
thing as before in red is dry blue is

720
00:28:01,570 --> 00:28:00,110
five percent water this guy right here

721
00:28:03,340 --> 00:28:01,580
is a giant planet that we're going to

722
00:28:05,410 --> 00:28:03,350
migrate through here and notice that

723
00:28:06,640 --> 00:28:05,420
we're on a log scale now just so you can

724
00:28:13,690 --> 00:28:06,650
kind of see what's going on very close

725
00:28:15,070 --> 00:28:13,700
to this time where's Marcus the Shan you

726
00:28:17,680 --> 00:28:15,080
haven't said what the patient causes of

727
00:28:19,810 --> 00:28:17,690
migration is it okay I didn't want to go

728
00:28:21,280 --> 00:28:19,820
into much detail with us but what causes

729
00:28:23,710 --> 00:28:21,290
of migration is basically the planet

730
00:28:26,230 --> 00:28:23,720
when it carves a gap becomes tied to be

731
00:28:28,390 --> 00:28:26,240
evolution the disk what the disk does is

732
00:28:30,670 --> 00:28:28,400
most of the disk viscously accretes onto

733
00:28:33,070 --> 00:28:30,680
the star so as I kind of is falling onto

734
00:28:34,600 --> 00:28:33,080
the star it drags the planet with it and

735
00:28:37,240 --> 00:28:34,610
that's the that's what this type to

736
00:28:38,380 --> 00:28:37,250
migration is it doesn't always have to

737
00:28:40,150 --> 00:28:38,390
go inward and so

738
00:28:41,140 --> 00:28:40,160

cases it could actually go outward but

739
00:28:44,830 --> 00:28:41,150
for hot Jupiters it's thought that

740
00:28:46,780 --> 00:28:44,840
that's what's going on moving anyway all

741
00:28:49,320 --> 00:28:46,790
right so here we go now to bitter is

742
00:28:52,210 --> 00:28:49,330
being moved inward so what's going on

743
00:28:54,040 --> 00:28:52,220
apply through all this rocky stuff these

744
00:28:56,230 --> 00:28:54,050
vertical lines are specific resonances

745
00:28:57,910 --> 00:28:56,240
mean motion resonances with the giant

746
00:29:00,700 --> 00:28:57,920
planet this is three to two and two to

747
00:29:02,350 --> 00:29:00,710
one you can see about half the material

748
00:29:04,420 --> 00:29:02,360
will end up being pushed inward by the

749
00:29:06,400 --> 00:29:04,430
giant planet and about half line of

750
00:29:10,870 --> 00:29:06,410
being scattered outward on these high

751
00:29:15,010 --> 00:29:10,880
eccentricity high inclination orbits so

752
00:29:16,150 --> 00:29:15,020
it's kind of neat you can see things as

753
00:29:18,130 --> 00:29:16,160
before things are performed pretty

754
00:29:19,510 --> 00:29:18,140
quickly in there and then some of them

755
00:29:20,890 --> 00:29:19,520
are just getting chucked out you know

756
00:29:22,810 --> 00:29:20,900
they're being shepherded here by the

757
00:29:24,190 --> 00:29:22,820
giant planet but if by chance you know

758
00:29:25,240 --> 00:29:24,200
their orbits aren't quite aligned right

759
00:29:27,850 --> 00:29:25,250
then they can have a close encounter

760
00:29:29,170 --> 00:29:27,860
nothing they get chucked out but in the

761
00:29:31,270 --> 00:29:29,180
end about half of that total disc

762
00:29:33,340 --> 00:29:31,280
material ends up being pushed inward

763
00:29:35,230 --> 00:29:33,350

about half chucked out and a

764
00:29:37,870 --> 00:29:35,240
surprisingly small amount actually hits

765
00:29:39,550 --> 00:29:37,880
the giant planet and so the real

766
00:29:41,500 --> 00:29:39,560
question here for for forming planets

767
00:29:44,620 --> 00:29:41,510
like Earth you know there are one of you

768
00:29:47,320 --> 00:29:44,630
so can this scattered stuff form another

769
00:29:49,600 --> 00:29:47,330
generation of terrestrial planets that's

770
00:29:51,840 --> 00:29:49,610
the real question and so to address that

771
00:29:54,100 --> 00:29:51,850
we have another movie and in this case

772
00:29:56,440 --> 00:29:54,110
same thing as before but instead of only

773
00:29:57,850 --> 00:29:56,450
going to a hundred thousand years this

774
00:29:59,650 --> 00:29:57,860
one's going to go for 200 million years

775
00:30:01,690 --> 00:29:59,660
and we're also including an extra

776
00:30:04,210 --> 00:30:01,700
component of kind of commentary type

777
00:30:06,190 --> 00:30:04,220
material which starts off exterior to

778
00:30:07,720 --> 00:30:06,200
the giant planet and like I mentioned

779
00:30:09,010 --> 00:30:07,730
because the interactions with the gas

780
00:30:10,660 --> 00:30:09,020
some of this stuff can actually spiral

781
00:30:14,050 --> 00:30:10,670
inward a little bit and that'll be

782
00:30:15,990 --> 00:30:14,060
that'll be important so who the

783
00:30:18,490 --> 00:30:16,000
migration happened really fast here

784
00:30:21,040 --> 00:30:18,500
100,000 years and then the stuff gets

785
00:30:23,080 --> 00:30:21,050
scattered out here you can see it's the

786
00:30:24,490 --> 00:30:23,090
mixing between zones is really big it's

787
00:30:25,900 --> 00:30:24,500
kind of like a rainbow out there after

788
00:30:28,300 --> 00:30:25,910

10 night here's everything's going to go

789
00:30:30,610 --> 00:30:28,310
nuts because that's when the gas discs

790
00:30:31,750 --> 00:30:30,620
dissipates the gas was damping the

791
00:30:33,640 --> 00:30:31,760
eccentricities of the planetesimals

792
00:30:36,900 --> 00:30:33,650
which were interned damping

793
00:30:38,920 --> 00:30:36,910
eccentricities of larger thing and so

794
00:30:41,770 --> 00:30:38,930
let me to stop this guy before it's

795
00:30:43,180 --> 00:30:41,780
completely over alright so this is more

796
00:30:45,670 --> 00:30:43,190
or less the end of the movie so what

797
00:30:47,290 --> 00:30:45,680
happened is interior to the time planet

798
00:30:50,080 --> 00:30:47,300
we got this we call it kind of a hot

799
00:30:51,680 --> 00:30:50,090
earth is rocky and it's very close then

800
00:30:55,220 --> 00:30:51,690
it got Shepherd

801
00:30:57,590 --> 00:30:55,230
then in front of the 221 residents in

802
00:30:58,850 --> 00:30:57,600
this case with the giant planet exterior

803
00:31:00,200 --> 00:30:58,860
to the giant plan all these things had

804
00:31:02,749 --> 00:31:00,210
really high eccentricities really high

805
00:31:04,549 --> 00:31:02,759
inclinations in time they got decreased

806
00:31:08,210 --> 00:31:04,559
to some degree by integrations with the

807
00:31:10,369 --> 00:31:08,220
gas and the key thing is mixing between

808
00:31:13,249 --> 00:31:10,379
zones that we need to get water on two

809
00:31:14,389 --> 00:31:13,259
planets is really really strong because

810
00:31:15,980 --> 00:31:14,399
you know all these things had really

811
00:31:19,039 --> 00:31:15,990
high eccentricity so mixing is very

812
00:31:21,980 --> 00:31:19,049
vigorous and so this planet right here

813
00:31:23,810 --> 00:31:21,990

they've formed at about point 9au ends

814
00:31:26,600 --> 00:31:23,820
up with with something like 20 times as

815
00:31:29,570 --> 00:31:26,610
much water as the earth and that's not

816
00:31:31,549 --> 00:31:29,580
20 times as much water that's basically

817
00:31:33,019 --> 00:31:31,559
20 times as much water compared with

818
00:31:34,970 --> 00:31:33,029
other simulations designed to reproduce

819
00:31:37,279 --> 00:31:34,980
the earth because we still don't know

820
00:31:39,379 --> 00:31:37,289
exactly how to account for water loss

821
00:31:42,529 --> 00:31:39,389
during large collisions that's kind of a

822
00:31:45,470 --> 00:31:42,539
tricky thing but you know this guy has

823
00:31:48,139 --> 00:31:45,480
about 20 times more water than cases

824
00:31:49,789 --> 00:31:48,149
where we can reproduce the earth so we

825
00:31:52,549 --> 00:31:49,799
think this guy really has a lot of water

826
00:31:55,549 --> 00:31:52,559
because of how it formed and what does

827
00:31:57,049 --> 00:31:55,559
this look like well this is you know how

828
00:32:01,009 --> 00:31:57,059
we started probably look something like

829
00:32:02,659 --> 00:32:01,019
this you know ocean covered surface you

830
00:32:06,259 --> 00:32:02,669
know it's just at sunset which is really

831
00:32:07,970 --> 00:32:06,269
nice time for these kind of pictures get

832
00:32:09,529 --> 00:32:07,980
the hot Jupiter there even plus or in

833
00:32:14,389 --> 00:32:09,539
there's a little flip that's the hot

834
00:32:16,100 --> 00:32:14,399
earth planet on earth storms tend to get

835
00:32:18,080 --> 00:32:16,110
really big over water and kind of peter

836
00:32:21,110 --> 00:32:18,090
out over land so if you got no land

837
00:32:22,909 --> 00:32:21,120
maybe you have really big storms but the

838
00:32:25,159 --> 00:32:22,919

storm can't block the view you know so

839
00:32:28,009 --> 00:32:25,169
it's just the storefront is just coming

840
00:32:29,419 --> 00:32:28,019
in just now this is perfect and could

841
00:32:32,149 --> 00:32:29,429
you have any life on this planet well

842
00:32:34,070 --> 00:32:32,159
who knows of course but we want to went

843
00:32:36,919 --> 00:32:34,080
ahead and drew some you know some kind

844
00:32:38,710 --> 00:32:36,929
of crazy beast in there and I had to

845
00:32:41,869 --> 00:32:38,720
throw in one more joke from my my thesis

846
00:32:44,450 --> 00:32:41,879
this is another possible scene from one

847
00:32:46,759 --> 00:32:44,460
of these planets there's a famous movie

848
00:32:49,480 --> 00:32:46,769
called water world about this and you

849
00:32:51,280 --> 00:32:49,490
got to go hunting and such so

850
00:32:57,760 --> 00:32:51,290
that's what that's what you eat on this

851
00:33:00,790 --> 00:32:57,770
planet these crazy beasts John you had

852
00:33:02,860 --> 00:33:00,800
the gas dissipating in the last one was

853
00:33:04,180 --> 00:33:02,870
that just something you imposed or is

854
00:33:07,419 --> 00:33:04,190
that something actually comes out of

855
00:33:09,040 --> 00:33:07,429
your models we impose that yeah so you

856
00:33:11,169 --> 00:33:09,050
know observation act that we see that in

857
00:33:12,370 --> 00:33:11,179
other stocks colleges yeah observations

858
00:33:14,740 --> 00:33:12,380
suggest it takes like a few million

859
00:33:16,990 --> 00:33:14,750
years to disperse the gas in this case

860
00:33:18,700 --> 00:33:17,000
we went for 10 million years which is it

861
00:33:20,890 --> 00:33:18,710
kind of on the long end but yeah we

862
00:33:22,840 --> 00:33:20,900
dispersed it and exactly how the gas

863
00:33:24,430 --> 00:33:22,850

disperses is not really well known but

864
00:33:26,590 --> 00:33:24,440
as exponential in real life it's

865
00:33:28,750 --> 00:33:26,600
probably some kind of exponential but

866
00:33:32,130 --> 00:33:28,760
with a step you know a step type shape

867
00:33:34,270 --> 00:33:32,140
due to kind of nearby stars you know

868
00:33:36,010 --> 00:33:34,280
periodically of yeah yeah what time

869
00:33:37,900 --> 00:33:36,020
sorry periodically photo operating lot

870
00:33:40,450 --> 00:33:37,910
of the disc and so we can add a linear

871
00:33:41,440 --> 00:33:40,460
decay but it doesn't matter too much it

872
00:33:46,660 --> 00:33:41,450
doesn't really affect what happening

873
00:33:49,270 --> 00:33:46,670
exactly other desk kisses OH assumptions

874
00:33:51,580 --> 00:33:49,280
about water pretension do you Oh in that

875
00:33:53,410 --> 00:33:51,590
case everything was retained and so

876
00:33:55,419 --> 00:33:53,420
that's obviously not realistic and

877
00:33:56,830 --> 00:33:55,429
that's why we compare the outcome with

878
00:34:02,350 --> 00:33:56,840
other simulations rather than with the

879
00:34:03,910 --> 00:34:02,360
earth directly okay so I mentioned that

880
00:34:05,020 --> 00:34:03,920
in we know with the migration you can

881
00:34:06,100 --> 00:34:05,030
form lots of these clothes in

882
00:34:08,379 --> 00:34:06,110
terrestrial planets so for example

883
00:34:10,780 --> 00:34:08,389
here's nine cases where this is the

884
00:34:12,639 --> 00:34:10,790
giant planet that got migrated into here

885
00:34:15,280 --> 00:34:12,649
and here's the the heart planets that

886
00:34:17,020 --> 00:34:15,290
form and they tend to form you know I've

887
00:34:19,300 --> 00:34:17,030
been shepherd by maybe the two to one

888
00:34:20,800 --> 00:34:19,310

residence is the most common you know

889
00:34:23,379 --> 00:34:20,810
kind of shovel that pushes these things

890
00:34:25,419 --> 00:34:23,389
inward and beat the masses in these

891
00:34:27,220 --> 00:34:25,429
cases tend to be something like a few

892
00:34:29,440 --> 00:34:27,230
earth masses total but that will depend

893
00:34:31,540 --> 00:34:29,450
on the disc mess because typically about

894
00:34:33,849 --> 00:34:31,550
half the solids and the disc end up

895
00:34:37,690 --> 00:34:33,859
being pushed inward and actually in this

896
00:34:39,490 --> 00:34:37,700
case very interestingly if the giant

897
00:34:42,580 --> 00:34:39,500
planet here if each of these were

898
00:34:43,690 --> 00:34:42,590
orbiting a star a distant star and if

899
00:34:46,330 --> 00:34:43,700
each of these giant planets were

900
00:34:48,700 --> 00:34:46,340
transiting its star and you were to look

901
00:34:51,129 --> 00:34:48,710
in kind of deviations in the timing of

902
00:34:52,629 --> 00:34:51,139
transit from a perfect chronometer stuff

903
00:34:57,370 --> 00:34:52,639
like Eric Hagel and Jason Stefan are

904
00:35:00,099 --> 00:34:57,380
doing then these planets would actually

905
00:35:01,760 --> 00:35:00,109
be detectable they would have a big

906
00:35:03,950 --> 00:35:01,770
enough signal in terms of the DBA

907
00:35:07,880 --> 00:35:03,960
shin of the timing of the giant planet

908
00:35:10,430 --> 00:35:07,890
transits that you could detect or infer

909
00:35:12,620 --> 00:35:10,440
the presence of these extra you know

910
00:35:14,750 --> 00:35:12,630
rocky plans it's that's kind of neat

911
00:35:18,790 --> 00:35:14,760
that's one other way besides you know

912
00:35:22,190 --> 00:35:18,800
more direct method to actually find and

913
00:35:24,140 --> 00:35:22,200

one other thing you can do here is kind

914
00:35:26,120 --> 00:35:24,150
of extrapolate these results to try to

915
00:35:28,370 --> 00:35:26,130
figure out based on these formation

916
00:35:30,920 --> 00:35:28,380
models which of the known giant plant

917
00:35:32,780 --> 00:35:30,930
systems could have planets like Earth

918
00:35:33,620 --> 00:35:32,790
and I know how much time talk about this

919
00:35:34,880 --> 00:35:33,630
so I'm going to kind of skip over

920
00:35:36,620 --> 00:35:34,890
quickly but the only thing I want to

921
00:35:39,230 --> 00:35:36,630
point out is it kind of a neat thing is

922
00:35:41,690 --> 00:35:39,240
that on this list we made before this

923
00:35:44,660 --> 00:35:41,700
thing was discovered was we kind of said

924
00:35:46,270 --> 00:35:44,670
you know this is the star gliese 581 is

925
00:35:48,500 --> 00:35:46,280
one of these candidates that could maybe

926
00:35:50,180 --> 00:35:48,510
also have a planet in the habitable zone

927
00:35:53,240 --> 00:35:50,190
and we're going to be talking more about

928
00:35:55,700 --> 00:35:53,250
that star in a minute so that's the end

929
00:35:57,140 --> 00:35:55,710
of story number two now on the story

930
00:35:59,900 --> 00:35:57,150
number three talking about low mass

931
00:36:02,630 --> 00:35:59,910
stars a prospect for habitable planets

932
00:36:03,950 --> 00:36:02,640
around low mass stars so first of all

933
00:36:05,900 --> 00:36:03,960
what's different about low mass stars

934
00:36:08,060 --> 00:36:05,910
that's you know not the same as I

935
00:36:11,270 --> 00:36:08,070
mastering or you know normal sun-like

936
00:36:13,580 --> 00:36:11,280
stars well obviously they're faint the

937
00:36:16,160 --> 00:36:13,590
luminosity of low-mass stars goes down

938
00:36:19,250 --> 00:36:16,170

with the the stellar-mass to the about

939
00:36:20,630 --> 00:36:19,260
the three or four power which means a

940
00:36:23,270 --> 00:36:20,640
few things it means that the have roll

941
00:36:24,290 --> 00:36:23,280
zone is very close in a region where

942
00:36:26,270 --> 00:36:24,300
you're getting the same amount of flux

943
00:36:28,610 --> 00:36:26,280
from the star it's closer to the star

944
00:36:31,250 --> 00:36:28,620
and what that in turn can mean is that

945
00:36:34,300 --> 00:36:31,260
tides are very important so for example

946
00:36:36,740 --> 00:36:34,310
here this plot is showing stellar mass

947
00:36:38,180 --> 00:36:36,750
versus you know sorry that the location

948
00:36:40,310 --> 00:36:38,190
that have rolled zone four different

949
00:36:41,930 --> 00:36:40,320
stellar masses and two log scale six

950
00:36:45,560 --> 00:36:41,940
point one point two point three point

951
00:36:47,810 --> 00:36:45,570
for up to one solar mass this shaded

952
00:36:49,340 --> 00:36:47,820
region is the habitable zone and this

953
00:36:51,680 --> 00:36:49,350
dashed line represents the limit of

954
00:36:53,480 --> 00:36:51,690
where tides are important so in here

955
00:36:56,240 --> 00:36:53,490
tides are important now here they're not

956
00:36:58,430 --> 00:36:56,250
so important and these little different

957
00:36:59,630 --> 00:36:58,440
shadings here are estimates of the

958
00:37:01,280 --> 00:36:59,640
haverhill zone for different amount of

959
00:37:03,110 --> 00:37:01,290
cloud cover that are doing slightly

960
00:37:04,460 --> 00:37:03,120
different things now clouds out here

961
00:37:07,030 --> 00:37:04,470
that could be warming or clouds here

962
00:37:10,640 --> 00:37:07,040
that could be cooling to some degree and

963
00:37:14,720 --> 00:37:10,650

i'll talk more about that one of the

964
00:37:15,330 --> 00:37:14,730
things that's important is is that the

965
00:37:17,870 --> 00:37:15,340
map

966
00:37:22,620 --> 00:37:17,880
in protoplanetary discs seems to scale

967
00:37:24,240 --> 00:37:22,630
about linearly with the stellar-mass but

968
00:37:27,270 --> 00:37:24,250
you know on top of that there's a very

969
00:37:29,550 --> 00:37:27,280
large scatter and so typically lower

970
00:37:31,650 --> 00:37:29,560
mass stars will have less massive discs

971
00:37:32,930 --> 00:37:31,660
although in every case that you know

972
00:37:35,010 --> 00:37:32,940
that doesn't have to be true in an

973
00:37:40,350 --> 00:37:35,020
individual basis but in general that's

974
00:37:42,690 --> 00:37:40,360
the case so you know given that there's

975
00:37:44,550 --> 00:37:42,700
less stuff statistically for low-mass

976
00:37:46,800 --> 00:37:44,560
stars to build have real planets and how

977
00:37:49,020 --> 00:37:46,810
will zone is so much closer in we're

978
00:37:51,570 --> 00:37:49,030
actually the own in which there is

979
00:37:54,600 --> 00:37:51,580
material is smaller means that the kind

980
00:37:56,880 --> 00:37:54,610
of typical mass you would expect for

981
00:37:58,980 --> 00:37:56,890
planets in the aboral zone if they're

982
00:38:01,410 --> 00:37:58,990
forming kind of right institute is

983
00:38:02,970 --> 00:38:01,420
smaller for low-mass stars and so this

984
00:38:04,680 --> 00:38:02,980
applause don't got a stellar mass you

985
00:38:07,680 --> 00:38:04,690
know the typical mass in the habitable

986
00:38:08,850 --> 00:38:07,690
zone it drops pretty quickly from you

987
00:38:11,280 --> 00:38:08,860
know one or if mass is where we

988
00:38:13,580 --> 00:38:11,290

calibrated for one solar mass you know

989
00:38:16,190 --> 00:38:13,590
down it gets very small pretty quick and

990
00:38:18,480 --> 00:38:16,200
you know there are various hand-wavy

991
00:38:20,040 --> 00:38:18,490
limits you can put on you know how

992
00:38:22,020 --> 00:38:20,050
massive a planet you need to have life

993
00:38:25,200 --> 00:38:22,030
and those tend to fall kind of in this

994
00:38:27,570 --> 00:38:25,210
in this shaded area so either way for

995
00:38:29,460 --> 00:38:27,580
you know whatever limit you choose for

996
00:38:31,470 --> 00:38:29,470
low-mass stars the prospects for having

997
00:38:34,800 --> 00:38:31,480
a planet that's you know massive enough

998
00:38:37,290 --> 00:38:34,810
to be habitable are less and so this

999
00:38:38,640 --> 00:38:37,300
this leads us to thank things that you

1000
00:38:41,040 --> 00:38:38,650
know have real planets around low mass

1001
00:38:42,270 --> 00:38:41,050
stars might be might be rare just

1002
00:38:44,400 --> 00:38:42,280
because you won't be massive enough to

1003
00:38:45,660 --> 00:38:44,410
have things like plate tectonics or a

1004
00:38:47,880 --> 00:38:45,670
thick atmosphere or that kind of thing

1005
00:38:50,970 --> 00:38:47,890
and of course right after we were doing

1006
00:38:52,620 --> 00:38:50,980
this kind of research that the first you

1007
00:38:55,910 --> 00:38:52,630
know maybe a virile planet was found

1008
00:38:58,470 --> 00:38:55,920
around an M star so felt very clever and

1009
00:39:02,010 --> 00:38:58,480
yeah so this is the star called Gliese

1010
00:39:05,670 --> 00:39:02,020
581 it was discovered in April this year

1011
00:39:08,790 --> 00:39:05,680
and there are three known planets in the

1012
00:39:11,490 --> 00:39:08,800
system with masses or minimum masses

1013
00:39:13,140 --> 00:39:11,500

between five and 15 earth masses and

1014
00:39:14,490 --> 00:39:13,150
Roger was just mentioning that there was

1015
00:39:15,630 --> 00:39:14,500
something on the BBC that they might

1016
00:39:19,410 --> 00:39:15,640
have found another planet in the system

1017
00:39:21,510 --> 00:39:19,420
which I don't know about but you know

1018
00:39:22,890 --> 00:39:21,520
that's pretty pretty cool I'm just going

1019
00:39:24,330 --> 00:39:22,900
to talk about what we can say about

1020
00:39:26,280 --> 00:39:24,340
these planets without knowing if there's

1021
00:39:29,280 --> 00:39:26,290
another one but who knows it could be

1022
00:39:35,230 --> 00:39:33,039
Yeah right that's a good time all right

1023
00:39:37,720 --> 00:39:35,240
so so the planets that are of the most

1024
00:39:40,270 --> 00:39:37,730
interest are kind of the second and

1025
00:39:42,250 --> 00:39:40,280
third planet out and so here is the Sun

1026
00:39:43,839 --> 00:39:42,260
basically the plants in solar system and

1027
00:39:46,569 --> 00:39:43,849
the planets in the solar system Gliese

1028
00:39:49,120 --> 00:39:46,579
581 kind of shown to the same more or

1029
00:39:51,099 --> 00:39:49,130
less the same scale temperature what ok

1030
00:39:53,349 --> 00:39:51,109
so this planet c was initially announced

1031
00:39:55,420 --> 00:39:53,359
to be in the habitable zone but it turns

1032
00:39:57,490 --> 00:39:55,430
out it's not it's kind of it's even

1033
00:39:59,349 --> 00:39:57,500
hotter than venus really it gets more

1034
00:40:01,299 --> 00:39:59,359
about fifty percent more flux from the

1035
00:40:02,770 --> 00:40:01,309
star than venus does and so it's

1036
00:40:06,309 --> 00:40:02,780
probably it's probably too hot to be

1037
00:40:08,200 --> 00:40:06,319
Avril now Planet B is close very close

1038
00:40:09,970 --> 00:40:08,210

sentence so that one's probably not

1039
00:40:12,309 --> 00:40:09,980
habitable this other planet planet d

1040
00:40:14,890 --> 00:40:12,319
it's kind of the outer edge of the

1041
00:40:16,510 --> 00:40:14,900
habitable zone or so and so maybe that

1042
00:40:19,599 --> 00:40:16,520
one's good for habitability we're not

1043
00:40:22,150 --> 00:40:19,609
really sure so a key thing is is that

1044
00:40:24,910 --> 00:40:22,160
tides are actually important for these

1045
00:40:32,799 --> 00:40:24,920
two planets and so going to look at the

1046
00:40:34,569 --> 00:40:32,809
effects of tides on those planets so so

1047
00:40:37,390 --> 00:40:34,579
tides that can actually change the orbit

1048
00:40:40,450 --> 00:40:37,400
of a planet so how does that happen what

1049
00:40:43,240 --> 00:40:40,460
happens is a planet on actually has to

1050
00:40:46,089 --> 00:40:43,250
be an eccentric orbit will raise have a

1051
00:40:48,309 --> 00:40:46,099
title so any plant that's orbiting a

1052
00:40:50,380 --> 00:40:48,319
star can have a tidal bulge raised on it

1053
00:40:51,579 --> 00:40:50,390
by the star and actually the star X you

1054
00:40:53,799 --> 00:40:51,589
can have a bulge raids on it by the

1055
00:40:56,079 --> 00:40:53,809
planet but that's a much less important

1056
00:40:58,450 --> 00:40:56,089
thing and rarely actually affects the

1057
00:41:01,299 --> 00:40:58,460
orbit of the planet these tides end up

1058
00:41:04,059 --> 00:41:01,309
dissipating energy and can actually

1059
00:41:07,180 --> 00:41:04,069
cause orbits to move inward and tend to

1060
00:41:08,859 --> 00:41:07,190
become more circular and to have this

1061
00:41:11,230 --> 00:41:08,869
happen to a large degree where they

1062
00:41:12,970 --> 00:41:11,240
requires some kind of eccentric orbit so

1063
00:41:15,039 --> 00:41:12,980

so this picture is kind of showing the

1064
00:41:17,559 --> 00:41:15,049
general idea you know the difference in

1065
00:41:20,079 --> 00:41:17,569
gravity across this planet due to this

1066
00:41:21,730 --> 00:41:20,089
star is such that there's a stretching

1067
00:41:23,530 --> 00:41:21,740
force a point right here is drawing

1068
00:41:25,180 --> 00:41:23,540
inward at this point sorry I join

1069
00:41:26,890 --> 00:41:25,190
towards the center of the planet this

1070
00:41:28,660 --> 00:41:26,900
point is drawn towards the star and

1071
00:41:31,270 --> 00:41:28,670
relative to the center the plan at this

1072
00:41:33,640 --> 00:41:31,280
point here is drawn away from the planet

1073
00:41:34,839 --> 00:41:33,650
or away from the stars all right so the

1074
00:41:37,569 --> 00:41:34,849
planet itself is getting kind of

1075
00:41:40,599 --> 00:41:37,579
squished apart and so what happens on

1076
00:41:42,400 --> 00:41:40,609
long time scales is that if you have an

1077
00:41:44,589 --> 00:41:42,410
eccentric orbit like this

1078
00:41:46,690 --> 00:41:44,599
the degree to which the planet is

1079
00:41:50,440 --> 00:41:46,700
deformed you know it varies over the

1080
00:41:53,799 --> 00:41:50,450
orbit and on long time scales the orbits

1081
00:41:58,210 --> 00:41:53,809
tend to tend to move inward on average

1082
00:42:00,520 --> 00:41:58,220
and become more circular okay that's the

1083
00:42:02,349 --> 00:42:00,530
general process that happens and the

1084
00:42:03,910 --> 00:42:02,359
degree to which that happens depends on

1085
00:42:07,059 --> 00:42:03,920
things like the size of the planet

1086
00:42:08,980 --> 00:42:07,069
because that will determine the amount

1087
00:42:11,910 --> 00:42:08,990
of deformation that can happen and

1088
00:42:14,289 --> 00:42:11,920

things like titled what's called title

1089
00:42:15,609 --> 00:42:14,299
dissipation parameters which are deal

1090
00:42:17,230 --> 00:42:15,619
with the internal structure of the

1091
00:42:23,770 --> 00:42:17,240
planet and how well it can actually

1092
00:42:26,200 --> 00:42:23,780
retain a tidal bulge over time okay and

1093
00:42:28,900 --> 00:42:26,210
since let me just kind of jump on a

1094
00:42:32,500 --> 00:42:28,910
different boat for a second since this

1095
00:42:34,150 --> 00:42:32,510
requires eccentric orbits then what is

1096
00:42:37,990 --> 00:42:34,160
the haverhill zone mean if your orbit is

1097
00:42:39,849 --> 00:42:38,000
very eccentric well one way to look at

1098
00:42:41,349 --> 00:42:39,859
this is that climate models for the

1099
00:42:44,200 --> 00:42:41,359
earth suggested the kind of the key

1100
00:42:46,900 --> 00:42:44,210
thing to maintain a nice environment on

1101
00:42:49,599 --> 00:42:46,910
the earth is not necessarily the exact

1102
00:42:51,940 --> 00:42:49,609
orbit but rather kind of the orbit

1103
00:42:54,150 --> 00:42:51,950
averaged flux so the amount of flux that

1104
00:42:57,789 --> 00:42:54,160
the earth gets over a whole torment and

1105
00:43:00,190 --> 00:42:57,799
so that means basically the orbit

1106
00:43:02,170 --> 00:43:00,200
average flux change is a bit with

1107
00:43:03,460 --> 00:43:02,180
eccentricities but not that much you can

1108
00:43:06,220 --> 00:43:03,470
get you can calculate it changes a

1109
00:43:07,750 --> 00:43:06,230
little bit such that that at large

1110
00:43:10,329 --> 00:43:07,760
eccentricities you get a little bit more

1111
00:43:12,700 --> 00:43:10,339
flux if you're at the same semi-major

1112
00:43:14,769 --> 00:43:12,710
axis and so what does that mean what it

1113
00:43:17,140 --> 00:43:14,779

really means is that have very for very

1114
00:43:18,880 --> 00:43:17,150
eccentric orbits the habitable zone is

1115
00:43:20,440 --> 00:43:18,890
actually little further out and so this

1116
00:43:21,970 --> 00:43:20,450
box showing kind of location of the

1117
00:43:25,329 --> 00:43:21,980
haverhill zone as a function of

1118
00:43:27,730 --> 00:43:25,339
eccentricity for a fixed solar mass I

1119
00:43:30,130 --> 00:43:27,740
still a massive in this case point 18

1120
00:43:31,390 --> 00:43:30,140
solar masses and you can see for it's

1121
00:43:33,849 --> 00:43:31,400
more or less constant out to

1122
00:43:35,289 --> 00:43:33,859
eccentricities or so but then it gets a

1123
00:43:41,170 --> 00:43:35,299
bit further away for higher

1124
00:43:43,480 --> 00:43:41,180
eccentricities so now tying this to that

1125
00:43:45,160 --> 00:43:43,490
planet Gliese 581c okay so we're doing

1126
00:43:47,380 --> 00:43:45,170
here is looking at that planet Gliese

1127
00:43:49,089 --> 00:43:47,390
581c the one that's just past the inner

1128
00:43:51,430 --> 00:43:49,099
edge of the habitable zone so when it's

1129
00:43:52,870 --> 00:43:51,440
a little bit hotter than Venus and what

1130
00:43:54,370 --> 00:43:52,880
we're going to do is we we think we know

1131
00:43:57,130 --> 00:43:54,380
more or less how title

1132
00:43:59,430 --> 00:43:57,140
orbital evolution works and so we're

1133
00:44:02,050 --> 00:43:59,440
going to rewind the orbit of that planet

1134
00:44:03,190 --> 00:44:02,060
given you know we don't know a lot about

1135
00:44:04,390 --> 00:44:03,200
it and so we have to kind of make

1136
00:44:05,980 --> 00:44:04,400
different assumptions about what's going

1137
00:44:08,470 --> 00:44:05,990
on on that planet but we're going to

1138
00:44:10,720 --> 00:44:08,480

rewind the orbit of that planet and see

1139
00:44:13,000 --> 00:44:10,730
if in the past its orbit might have been

1140
00:44:15,460 --> 00:44:13,010
happening so it's not habitable now it's

1141
00:44:17,170 --> 00:44:15,470
you know how do them Venus but maybe in

1142
00:44:19,120 --> 00:44:17,180
the past since its orbit has

1143
00:44:20,650 --> 00:44:19,130
progressively been moving inward maybe

1144
00:44:23,230 --> 00:44:20,660
in the past its orbit was further out

1145
00:44:24,640 --> 00:44:23,240
and maybe it was habitable on and so

1146
00:44:27,430 --> 00:44:24,650
we're looking at here is kind of looking

1147
00:44:28,780 --> 00:44:27,440
back in time and at the orbit of that

1148
00:44:31,180 --> 00:44:28,790
planet the orbital distance of that

1149
00:44:35,200 --> 00:44:31,190
planet for three different assumptions

1150
00:44:37,180 --> 00:44:35,210
about the size of the plant okay so in

1151
00:44:39,940 --> 00:44:37,190
this case the plan would be very large

1152
00:44:42,070 --> 00:44:39,950
could be water rich probably in this

1153
00:44:43,570 --> 00:44:42,080
case the plan to be very condensed it's

1154
00:44:45,490 --> 00:44:43,580
very small in the tidal effects trash a

1155
00:44:47,230 --> 00:44:45,500
little smaller and so you can see these

1156
00:44:50,200 --> 00:44:47,240
are kind of the the black line shows the

1157
00:44:51,850 --> 00:44:50,210
orbit rewound of the planet and the

1158
00:44:53,650 --> 00:44:51,860
reason these gray lines which are

1159
00:44:55,510 --> 00:44:53,660
estimate to the habitable zone for

1160
00:44:57,850 --> 00:44:55,520
different cloud covers are moving is

1161
00:45:00,340 --> 00:44:57,860
because of what I was talking about that

1162
00:45:02,470 --> 00:45:00,350
the eccentric have rolls own as these

1163
00:45:04,690 --> 00:45:02,480

planets are winding in time their

1164
00:45:06,190 --> 00:45:04,700
average distance is moving out but their

1165
00:45:08,320 --> 00:45:06,200
eccentricity is also getting bigger and

1166
00:45:12,160 --> 00:45:08,330
so the haverhill zone is actually moving

1167
00:45:13,690 --> 00:45:12,170
out and so you know they're trying to in

1168
00:45:14,890 --> 00:45:13,700
some sense their approach and handles on

1169
00:45:16,780 --> 00:45:14,900
but the have will zone at the same time

1170
00:45:18,970 --> 00:45:16,790
is movement for their app and so you can

1171
00:45:20,080 --> 00:45:18,980
see is right now you know if if this

1172
00:45:22,030 --> 00:45:20,090
planet had one hundred percent cloud

1173
00:45:23,890 --> 00:45:22,040
cover of clouds that were doing just the

1174
00:45:25,630 --> 00:45:23,900
right thing and there's a chance that it

1175
00:45:28,720 --> 00:45:25,640
could be habitable but it would need

1176
00:45:30,640 --> 00:45:28,730
complete cloud cover in the past you

1177
00:45:32,800 --> 00:45:30,650
know if it if it's relatively large one

1178
00:45:34,390 --> 00:45:32,810
in the past it could have been pretty

1179
00:45:36,580 --> 00:45:34,400
close to be inhabitable it would have

1180
00:45:38,380 --> 00:45:36,590
required much less clouds to to maintain

1181
00:45:40,630 --> 00:45:38,390
the right temperature in none of these

1182
00:45:42,070 --> 00:45:40,640
models do do you know does the orbit

1183
00:45:43,570 --> 00:45:42,080
actually go into this dark period region

1184
00:45:46,260 --> 00:45:43,580
where it's you know pretty pretty

1185
00:45:48,310 --> 00:45:46,270
certain that time but it's pretty close

1186
00:45:50,560 --> 00:45:48,320
you know there's a decent chance to this

1187
00:45:54,160 --> 00:45:50,570
planet could have had more habitable

1188
00:45:55,780 --> 00:45:54,170

conditions in the past the trick is you

1189
00:45:57,940 --> 00:45:55,790
can't just look at that one planet oops

1190
00:45:59,740 --> 00:45:57,950
I forgot about that point here we go so

1191
00:46:01,900 --> 00:45:59,750
so the trick is you know first of all

1192
00:46:03,820 --> 00:46:01,910
how far back in time do we need to go

1193
00:46:06,130 --> 00:46:03,830
well that depends on the age of the star

1194
00:46:08,059 --> 00:46:06,140
right so we want to go back until the

1195
00:46:09,109 --> 00:46:08,069
system was formed we

1196
00:46:11,239 --> 00:46:09,119
for that we need to know the age of the

1197
00:46:13,789 --> 00:46:11,249
star it turns out it's really tricky to

1198
00:46:16,009 --> 00:46:13,799
nail down pages of stars in this case

1199
00:46:18,380 --> 00:46:16,019
the star is older than 2 to 3 billion

1200
00:46:20,959 --> 00:46:18,390
years and some people think that it

1201
00:46:23,829 --> 00:46:20,969
might be as old as 8 to 10 billion years

1202
00:46:26,599 --> 00:46:23,839
based on its very low x-ray flux but

1203
00:46:28,609 --> 00:46:26,609
statistically that this relation that

1204
00:46:30,439 --> 00:46:28,619
x-ray flux decreases in time is true

1205
00:46:31,849 --> 00:46:30,449
statistically but it's not always true

1206
00:46:33,079 --> 00:46:31,859
for each individual one because there's

1207
00:46:35,269 --> 00:46:33,089
some scatter in terms of how much

1208
00:46:37,249 --> 00:46:35,279
there's so we think the star might be

1209
00:46:39,999 --> 00:46:37,259
quite old so we might have to rewind the

1210
00:46:42,920 --> 00:46:40,009
orbit for up to 10 billion years Russa

1211
00:46:44,479 --> 00:46:42,930
but it turns out that planets not in

1212
00:46:45,799 --> 00:46:44,489
isolation it's in the system appliance

1213
00:46:48,019 --> 00:46:45,809

and so we have to look at interactions

1214
00:46:49,160 --> 00:46:48,029
between planets as well so here we're

1215
00:46:52,370 --> 00:46:49,170
looking at that planet we were talking

1216
00:46:54,499 --> 00:46:52,380
about Plan C rewound in time and then

1217
00:46:55,759 --> 00:46:54,509
also Planet B and the third planet is

1218
00:47:00,170 --> 00:46:55,769
way out up there and about a quarter

1219
00:47:02,930 --> 00:47:00,180
Renee you and so in the most kind of

1220
00:47:04,219 --> 00:47:02,940
optimistic model this planet was going

1221
00:47:06,079 --> 00:47:04,229
back and being very close to the

1222
00:47:09,829 --> 00:47:06,089
habitable zone about 10 billion years

1223
00:47:11,539 --> 00:47:09,839
ago but it turns out if that happens it

1224
00:47:15,729 --> 00:47:11,549
would have to cross the three two one

1225
00:47:18,499 --> 00:47:15,739
resonance with the clothes implement and

1226
00:47:21,439 --> 00:47:18,509
that kind of residence crossing usually

1227
00:47:23,539 --> 00:47:21,449
leads to capture such that the planets

1228
00:47:25,430 --> 00:47:23,549
should be in residence now but they're

1229
00:47:26,900 --> 00:47:25,440
not in residence now so they probably

1230
00:47:29,630 --> 00:47:26,910
never did across the three two one

1231
00:47:31,130 --> 00:47:29,640
resident and so we played around with

1232
00:47:33,469 --> 00:47:31,140
this and there was actually one of their

1233
00:47:36,049 --> 00:47:33,479
solution where planet be moved out of it

1234
00:47:38,479 --> 00:47:36,059
and plants see also moved out but in

1235
00:47:39,499 --> 00:47:38,489
that case their initial orbits you know

1236
00:47:42,410 --> 00:47:39,509
which had much higher eccentricities

1237
00:47:43,789 --> 00:47:42,420
would have been unstable and that

1238
00:47:44,959 --> 00:47:43,799

doesn't work either because if they were

1239
00:47:48,259 --> 00:47:44,969
unstable then they wouldn't be around

1240
00:47:50,779 --> 00:47:48,269
now so this was kind of our best fit of

1241
00:47:52,549 --> 00:47:50,789
what happened in the past of the orbits

1242
00:47:55,130 --> 00:47:52,559
these two points so plants he probably

1243
00:47:58,120 --> 00:47:55,140
moved in maybe only know one point lets

1244
00:48:00,529 --> 00:47:58,130
you a you or so it didn't it didn't ever

1245
00:48:02,390 --> 00:48:00,539
we think ever ever starting to have

1246
00:48:05,269 --> 00:48:02,400
rolls on but it started a bit closer

1247
00:48:07,069 --> 00:48:05,279
being habitable and a kind of a neat

1248
00:48:08,829 --> 00:48:07,079
thing about this is that using these

1249
00:48:11,349 --> 00:48:08,839
constraints of crossing residences and

1250
00:48:13,849 --> 00:48:11,359
stability you can constrain actually the

1251
00:48:16,009 --> 00:48:13,859
you know the interior structure of these

1252
00:48:18,109 --> 00:48:16,019
planets to some degree in terms of how

1253
00:48:21,299 --> 00:48:18,119
much energy is dissipated by tides

1254
00:48:24,370 --> 00:48:21,309
during this process and so that's

1255
00:48:28,210 --> 00:48:24,380
the luminosity of small chunks darkness

1256
00:48:30,039 --> 00:48:28,220
changes matches oh you mean on the main

1257
00:48:32,890 --> 00:48:30,049
sequence that on the main sequence

1258
00:48:34,240 --> 00:48:32,900
luminosity changes more slowly so you

1259
00:48:36,309 --> 00:48:34,250
know the sun's what thirty or fifty

1260
00:48:38,319 --> 00:48:36,319
percent brighter now than it was four

1261
00:48:40,660 --> 00:48:38,329
and a half billion years ago that effect

1262
00:48:42,039 --> 00:48:40,670
is smaller for low-mass stars but it

1263
00:48:43,569 --> 00:48:42,049

turns out that low mass stars actually

1264
00:48:45,670 --> 00:48:43,579
take longer to reach the main sequence

1265
00:48:51,240 --> 00:48:45,680
so early on their evolution their

1266
00:48:53,289 --> 00:48:51,250
luminosity decreases much more slowly so

1267
00:48:55,240 --> 00:48:53,299
I'm kind of running out of time so I'll

1268
00:48:56,799 --> 00:48:55,250
skip this but what we did is you can you

1269
00:49:00,430 --> 00:48:56,809
can kind of generalize this idea for

1270
00:49:03,039 --> 00:49:00,440
more try to apply to general systems of

1271
00:49:05,829 --> 00:49:03,049
plants around low mass stars but I won't

1272
00:49:07,150 --> 00:49:05,839
go in that now so let's let me jump to

1273
00:49:09,609 --> 00:49:07,160
the conclusions I got three conclusions

1274
00:49:11,950 --> 00:49:09,619
for you first of all the the alumina

1275
00:49:13,150 --> 00:49:11,960
six-story depending on the orbit of

1276
00:49:15,549 --> 00:49:13,160
planets within their kind of birth

1277
00:49:18,039 --> 00:49:15,559
cluster and get more or less limited 26

1278
00:49:20,980 --> 00:49:18,049
which affects in the end the water

1279
00:49:23,140 --> 00:49:20,990
content of planets like Earth and hot

1280
00:49:25,240 --> 00:49:23,150
Jupiter systems you probably also have

1281
00:49:27,190 --> 00:49:25,250
these hot Earth's these clothes in

1282
00:49:28,660 --> 00:49:27,200
earth-like planets which might be

1283
00:49:30,819 --> 00:49:28,670
detectable with transits of transit

1284
00:49:33,660 --> 00:49:30,829
timing and you might form you know very

1285
00:49:37,089 --> 00:49:33,670
water rich ocean planets behind them and

1286
00:49:40,180 --> 00:49:37,099
lastly for low-mass stars models suggest

1287
00:49:42,970 --> 00:49:40,190
that you can't form very massive planets

1288
00:49:44,950 --> 00:49:42,980

in scituate admiral zone but we see them

1289
00:49:47,769 --> 00:49:44,960
so how did they get there that's a whole

1290
00:49:50,019 --> 00:49:47,779
nother question and then tides also have

1291
00:49:51,789 --> 00:49:50,029
an important effect on the you know the

1292
00:49:55,960 --> 00:49:51,799
lifetime of planets in the habitable

1293
00:50:08,220 --> 00:49:55,970
zone so that's all I got for you thanks

1294
00:50:12,339 --> 00:50:11,200
six when you shows a little 13 before

1295
00:50:14,319 --> 00:50:12,349
you were talking about it being injected

1296
00:50:16,930 --> 00:50:14,329
it looks as though you're claiming that

1297
00:50:18,940 --> 00:50:16,940
the disc would have already formed say I

1298
00:50:20,680 --> 00:50:18,950
know pretty serious that was

1299
00:50:22,750 --> 00:50:20,690
injected during a supernova that would

1300
00:50:25,059 --> 00:50:22,760
have caused the disc form so you're

1301
00:50:27,609 --> 00:50:25,069
saying that the supernova occurred after

1302
00:50:29,970 --> 00:50:27,619
the distance mark yeah there's there's

1303
00:50:32,440 --> 00:50:29,980
evidence for the injection happening

1304
00:50:34,180 --> 00:50:32,450
late so it probably happened after

1305
00:50:35,410 --> 00:50:34,190
things actually started to form so

1306
00:50:37,059 --> 00:50:35,420
probably happened when there was already

1307
00:50:43,210 --> 00:50:37,069
a disc present rather than causing the

1308
00:50:44,799 --> 00:50:43,220
disc to form but the Husker is worthy

1309
00:50:48,250 --> 00:50:44,809
Jesus the development of a water-rich

1310
00:50:49,890 --> 00:50:48,260
noon those candidates 40 of the giant

1311
00:50:52,299 --> 00:50:49,900
planet as it moves in yes that one ah

1312
00:50:54,670 --> 00:50:52,309
okay there's a few different effects

1313
00:50:56,950 --> 00:50:54,680

that go on as a giant planet migrates

1314
00:50:58,990 --> 00:50:56,960
inward if it has a moon orbiting

1315
00:51:00,790 --> 00:50:59,000
pro-grade that moon actually moves

1316
00:51:04,569 --> 00:51:00,800
inward a little bit that's one effect

1317
00:51:06,010 --> 00:51:04,579
the kind of the another thing that as

1318
00:51:08,109 --> 00:51:06,020
its migrating is migrating through all

1319
00:51:10,329 --> 00:51:08,119
this rocky stuff which is getting hurled

1320
00:51:12,160 --> 00:51:10,339
past the giant planet in some cases you

1321
00:51:13,960 --> 00:51:12,170
could have a relatively large body you

1322
00:51:15,339 --> 00:51:13,970
know larger than the moon's it's you

1323
00:51:17,079 --> 00:51:15,349
know the moves themselves actually

1324
00:51:19,599 --> 00:51:17,089
getting close and maybe disrupting them

1325
00:51:21,730 --> 00:51:19,609
and then also when it's very close in

1326
00:51:24,760 --> 00:51:21,740
it's hard for for a large moon to

1327
00:51:26,230 --> 00:51:24,770
survive actually for tidal effects which

1328
00:51:27,760 --> 00:51:26,240
go in the opposite sense in certain

1329
00:51:30,190 --> 00:51:27,770
cases depending on the rotation rates

1330
00:51:32,559 --> 00:51:30,200
and so very close in digha plants

1331
00:51:34,569 --> 00:51:32,569
probably don't have large moons they can

1332
00:51:36,280 --> 00:51:34,579
have them outside maybe half an au or so

1333
00:51:40,390 --> 00:51:36,290
you can have a large moon but inside

1334
00:51:42,190 --> 00:51:40,400
that it's unlikely Laurel are there hot

1335
00:51:43,720 --> 00:51:42,200
Jupiter migration scenarios to take

1336
00:51:45,370 --> 00:51:43,730
place later time

1337
00:51:46,990 --> 00:51:45,380
I after terrestrial planets we've

1338
00:51:48,760 --> 00:51:47,000

actually formed or do they actually

1339
00:51:53,320 --> 00:51:48,770
require the presence of gas in this

1340
00:51:55,060 --> 00:51:53,330
converter to migrate they in general

1341
00:51:56,680 --> 00:51:55,070
they it's thought to happen because of

1342
00:51:59,020 --> 00:51:56,690
interactions between the gas and the

1343
00:52:01,540 --> 00:51:59,030
giant planets some people have proposed

1344
00:52:02,950 --> 00:52:01,550
the idea that you could have you know a

1345
00:52:05,590 --> 00:52:02,960
large amount of migration by scattering

1346
00:52:07,810 --> 00:52:05,600
small bodies like in in the soul like in

1347
00:52:10,090 --> 00:52:07,820
the outer solar system but to have that

1348
00:52:12,340 --> 00:52:10,100
happen to move a planet really far in

1349
00:52:14,140 --> 00:52:12,350
word is tricky because the accretion

1350
00:52:15,580 --> 00:52:14,150
time is such that you're not gonna have

1351
00:52:17,260 --> 00:52:15,590
a whole population of small bodies to

1352
00:52:19,359 --> 00:52:17,270
schedule you have a few large ones and

1353
00:52:20,620 --> 00:52:19,369
getting that to happen in a nice smooth

1354
00:52:23,710 --> 00:52:20,630
way where you end up always going the

1355
00:52:24,790 --> 00:52:23,720
same direction is not so not so clear so

1356
00:52:26,530 --> 00:52:24,800
in general it's thought to happen

1357
00:52:29,859 --> 00:52:26,540
migration start to happen where you sell

1358
00:52:32,859 --> 00:52:29,869
the gasser will come to some questions

1359
00:52:36,550 --> 00:52:32,869
from the first and then come back so

1360
00:52:41,140 --> 00:52:36,560
paint chen you have a question yes Sean

1361
00:52:45,010 --> 00:52:41,150
greyhawk hey I question is on the ocean

1362
00:52:50,140 --> 00:52:45,020
planet in the migrated janpanese

1363
00:52:52,870 --> 00:52:50,150

scenario after the gen planimetric to

1364
00:52:55,170 --> 00:52:52,880
west coast where stars seem to have

1365
00:52:58,210 --> 00:52:55,180
ocean pallets from the recent Lodge

1366
00:53:03,250 --> 00:52:58,220
eccentricities if I'm reading of cloth

1367
00:53:05,560 --> 00:53:03,260
correctly and and the disco probably has

1368
00:53:09,400 --> 00:53:05,570
so ready dissipated by that time by the

1369
00:53:12,780 --> 00:53:09,410
energy vibration hugs and those social

1370
00:53:16,960 --> 00:53:12,790
planets reduce Eric traffic centricity

1371
00:53:19,380 --> 00:53:16,970
if that's possible thank you ok so what

1372
00:53:23,230 --> 00:53:19,390
we think is going on the story is the

1373
00:53:25,780 --> 00:53:23,240
the giant planet forms in the in the gas

1374
00:53:27,580 --> 00:53:25,790
disk then migrates inward because of the

1375
00:53:30,160 --> 00:53:27,590
gash is just kind of pushing it in some

1376
00:53:32,740 --> 00:53:30,170
sense and then one thing that's not

1377
00:53:35,740 --> 00:53:32,750
really understood as how migration stops

1378
00:53:37,480 --> 00:53:35,750
and that's kind of a key a key part to

1379
00:53:40,300 --> 00:53:37,490
your question because one idea is that

1380
00:53:42,220 --> 00:53:40,310
migration stops at because migration is

1381
00:53:44,470 --> 00:53:42,230
happening as the disk is dissipating and

1382
00:53:45,700 --> 00:53:44,480
so once the amount of mass in the disk

1383
00:53:48,010 --> 00:53:45,710
is less than the amount of mass in the

1384
00:53:52,030 --> 00:53:48,020
planet then the disk can't really push

1385
00:53:54,220 --> 00:53:52,040
the planet around anymore so that's one

1386
00:53:56,880 --> 00:53:54,230
idea in that case there's not that much

1387
00:53:58,980 --> 00:53:56,890
gas left when migration ends

1388
00:54:02,100 --> 00:53:58,990

and so there's less of this orbital

1389
00:54:03,930 --> 00:54:02,110
damping from the gas you know on these

1390
00:54:07,260 --> 00:54:03,940
on these plant protoplanets that we

1391
00:54:09,210 --> 00:54:07,270
reject scattered outward I mean so we

1392
00:54:11,130 --> 00:54:09,220
rent some cases in that case where you

1393
00:54:14,310 --> 00:54:11,140
have very little gas left and it turns

1394
00:54:16,410 --> 00:54:14,320
out you can still form planets exterior

1395
00:54:17,940 --> 00:54:16,420
to the hot Jupiters the time scale from

1396
00:54:21,390 --> 00:54:17,950
information is actually quite a bit

1397
00:54:23,490 --> 00:54:21,400
longer because the gas has a nice effect

1398
00:54:25,140 --> 00:54:23,500
of reducing the inclinations as well and

1399
00:54:27,630 --> 00:54:25,150
so you increase the cross section for

1400
00:54:29,940 --> 00:54:27,640
collisions and so it's easier to perform

1401
00:54:31,830 --> 00:54:29,950
this next generation of planets if you

1402
00:54:34,530 --> 00:54:31,840
have a good amount of gas left after

1403
00:54:40,500 --> 00:54:34,540
migration but it's not required for that

1404
00:54:43,920 --> 00:54:40,510
time I just ate had some questions yes I

1405
00:54:45,870 --> 00:54:43,930
had a question about the aluminum 26

1406
00:54:49,220 --> 00:54:45,880
effect on the water line I might have

1407
00:54:51,630 --> 00:54:49,230
missed this but was this because of the

1408
00:54:54,840 --> 00:54:51,640
radioactive decay that's forcing the

1409
00:54:58,860 --> 00:54:54,850
water line to change yeah it's kind of a

1410
00:55:02,040 --> 00:54:58,870
race between the decay aluminum 26 and

1411
00:55:05,940 --> 00:55:02,050
the formation of larger bodies basically

1412
00:55:08,250 --> 00:55:05,950
if if you form large bodies very quickly

1413
00:55:10,740 --> 00:55:08,260

you incorporate the aluminum 26 and I

1414
00:55:12,870 --> 00:55:10,750
kind of heats up the whole thing if the

1415
00:55:14,460 --> 00:55:12,880
larger body its form very slowly then

1416
00:55:16,530 --> 00:55:14,470
the illuminant y 6 can actually get rid

1417
00:55:19,610 --> 00:55:16,540
of most of its heat without heating up

1418
00:55:22,740 --> 00:55:19,620
that much material and so it's kind of a

1419
00:55:23,820 --> 00:55:22,750
combination of accretion time scale of

1420
00:55:27,060 --> 00:55:23,830
things that are at least about a

1421
00:55:29,190 --> 00:55:27,070
kilometre in size versus the decay of

1422
00:55:31,020 --> 00:55:29,200
the aluminum 26 and if it happens if

1423
00:55:32,640 --> 00:55:31,030
things form within maybe 10 or 20

1424
00:55:34,800 --> 00:55:32,650
million years then they feel the

1425
00:55:38,190 --> 00:55:34,810
aluminum 26 or if they form very slowly

1426
00:55:39,660 --> 00:55:38,200
they don't and so basically when they

1427
00:55:43,680 --> 00:55:39,670
feel it that means that they're driving

1428
00:55:45,480 --> 00:55:43,690
off the water Sean I i also have a

1429
00:55:48,390 --> 00:55:45,490
question here this is the other Sean at

1430
00:55:51,240 --> 00:55:48,400
Penn State great talk by the way the one

1431
00:55:53,310 --> 00:55:51,250
question I had was how much chemistry

1432
00:55:55,050 --> 00:55:53,320
information can you get out of your

1433
00:55:57,180 --> 00:55:55,060
models is it is it you just have sort of

1434
00:55:59,790 --> 00:55:57,190
a density number and a water versus rock

1435
00:56:01,980 --> 00:55:59,800
content or can you get into more detail

1436
00:56:03,720 --> 00:56:01,990
than that for those of us that may want

1437
00:56:06,660 --> 00:56:03,730
to you know find out what some of these

1438
00:56:08,310 --> 00:56:06,670

planets end up looking like after they

1439
00:56:10,510 --> 00:56:08,320
formed

1440
00:56:12,100 --> 00:56:10,520
yeah that's I mean right now what we do

1441
00:56:14,140 --> 00:56:12,110
is very simple all we do is we keep

1442
00:56:16,570 --> 00:56:14,150
track of we have a rough initial

1443
00:56:17,980 --> 00:56:16,580
distribution of iron versus rock and a

1444
00:56:19,990 --> 00:56:17,990
rough initial distribution of you know

1445
00:56:20,740 --> 00:56:20,000
where the water is and then the end we

1446
00:56:22,210 --> 00:56:20,750
kind of combine the different

1447
00:56:24,670 --> 00:56:22,220
ingredients and say you know what do you

1448
00:56:26,920 --> 00:56:24,680
end up with and it's really hard to take

1449
00:56:28,030 --> 00:56:26,930
into account depletion nick cave and i

1450
00:56:29,920 --> 00:56:28,040
are looking right now I'm trying to take

1451
00:56:31,690 --> 00:56:29,930
an account depletion of water during

1452
00:56:33,940 --> 00:56:31,700
these impacts in the somewhat consistent

1453
00:56:36,580 --> 00:56:33,950
way but it's it's a tricky thing to do

1454
00:56:39,430 --> 00:56:36,590
and we're kind of lacking in data on

1455
00:56:41,530 --> 00:56:39,440
both ends in terms of you know where

1456
00:56:42,520 --> 00:56:41,540
where are the condensation lines for

1457
00:56:45,160 --> 00:56:42,530
four different elements that are

1458
00:56:46,720 --> 00:56:45,170
important and also exactly what's the

1459
00:56:48,370 --> 00:56:46,730
composition of the earth anyway that

1460
00:56:49,960 --> 00:56:48,380
we're trying to match in terms of how

1461
00:56:52,210 --> 00:56:49,970
the earth formed and we're actually

1462
00:56:54,280 --> 00:56:52,220
lacking in data on both ends to really

1463
00:56:55,990 --> 00:56:54,290

reproduce that and so if anyone wants to

1464
00:56:57,580 --> 00:56:56,000
think about this in more detail let me

1465
00:57:01,180 --> 00:56:57,590
know because it's very interesting but

1466
00:57:03,250 --> 00:57:01,190
it's not an easy thing thanks great talk

1467
00:57:07,720 --> 00:57:03,260
those are all the questions we have all

1468
00:57:09,670 --> 00:57:07,730
right reach what assumptions do you make

1469
00:57:12,580 --> 00:57:09,680
about the clouds or the albedo relative

1470
00:57:13,720 --> 00:57:12,590
to the wavelength of this door all of

1471
00:57:15,850 --> 00:57:13,730
the clouds for that for the habitable

1472
00:57:18,130 --> 00:57:15,860
zone thing we grab that right out of a

1473
00:57:20,890 --> 00:57:18,140
paper like a it's basically the gym

1474
00:57:22,240 --> 00:57:20,900
casting adult type model and you know

1475
00:57:23,860 --> 00:57:22,250
clouds can have certain effects

1476
00:57:25,060 --> 00:57:23,870
basically heating effects or cooling

1477
00:57:26,740 --> 00:57:25,070
effects depending on the properties of

1478
00:57:28,720 --> 00:57:26,750
the clouds and such that's what we were

1479
00:57:30,280 --> 00:57:28,730
looking at that was kind of the reason

1480
00:57:32,710 --> 00:57:30,290
we threw that in there is the part that

1481
00:57:33,970 --> 00:57:32,720
I didn't really talk about was showing

1482
00:57:36,400 --> 00:57:33,980
that in some cases you could have a

1483
00:57:38,710 --> 00:57:36,410
planet form in the region where you

1484
00:57:40,810 --> 00:57:38,720
don't need clouds you know where it's

1485
00:57:43,510 --> 00:57:40,820
pretty pretty confident that if a planet

1486
00:57:45,010 --> 00:57:43,520
isn't that at that zone it's got a good

1487
00:57:46,240 --> 00:57:45,020
chance be inhabitable and we were

1488
00:57:48,850 --> 00:57:46,250

looking at the time it would take for

1489
00:57:51,190 --> 00:57:48,860
for tides to affect the orbit of that

1490
00:57:53,650 --> 00:57:51,200
planet such they would move inside like

1491
00:57:55,180 --> 00:57:53,660
the fifty percent clouds which is around

1492
00:57:57,490 --> 00:57:55,190
corresponds more or less the orbit of

1493
00:57:59,080 --> 00:57:57,500
Venus or so and so we were looking at

1494
00:58:00,880 --> 00:57:59,090
that in terms of going from somewhere

1495
00:58:02,770 --> 00:58:00,890
that was pretty certain to be habitable

1496
00:58:04,630 --> 00:58:02,780
to somewhere that was kind of doubtful

1497
00:58:07,150 --> 00:58:04,640
to be habitable I didn't I didn't end up

1498
00:58:09,250 --> 00:58:07,160
talking that about that much but the

1499
00:58:13,210 --> 00:58:09,260
details of that are really right out of

1500
00:58:17,900 --> 00:58:16,220
when you're modeling the accumulation of

1501
00:58:20,239 --> 00:58:17,910
aluminum 26 in the cluster environment

1502
00:58:22,670 --> 00:58:20,249
are you assuming then that the clusters

1503
00:58:24,049 --> 00:58:22,680
unbound and that the soon as the gas

1504
00:58:26,749 --> 00:58:24,059
dissipates nothing's holding the stars

1505
00:58:29,359 --> 00:58:26,759
together yeah so we did it let's see

1506
00:58:31,039 --> 00:58:29,369
when Eric did these first he actually

1507
00:58:33,470 --> 00:58:31,049
screwed him up but anyway we did them

1508
00:58:36,319 --> 00:58:33,480
again they were ready and so what we do

1509
00:58:38,150 --> 00:58:36,329
is is it's it's consistent in that you

1510
00:58:41,210 --> 00:58:38,160
have a cluster of these nine thousand

1511
00:58:43,759 --> 00:58:41,220
stars that you know with a dissipating

1512
00:58:46,039 --> 00:58:43,769
gas potential retaining them and at the

1513
00:58:48,170 --> 00:58:46,049

end you know we there's three stars that

1514
00:58:51,380 --> 00:58:48,180
are massive that are injecting the the

1515
00:58:53,420 --> 00:58:51,390
radioactive stuff into discs and by the

1516
00:58:55,460 --> 00:58:53,430
end of the integration which is ten

1517
00:58:59,089 --> 00:58:55,470
million years the cluster is dispersed

1518
00:59:00,650 --> 00:58:59,099
completely okay so yeah I mean it's like

1519
00:59:02,299 --> 00:59:00,660
the embedded cluster idea rather than

1520
00:59:04,789 --> 00:59:02,309
leaving behind an open color right yes

1521
00:59:06,710 --> 00:59:04,799
if my question was going to be yet has

1522
00:59:08,870 --> 00:59:06,720
anybody looked if the cost is a pound

1523
00:59:11,029 --> 00:59:08,880
cluster like in the minority situation

1524
00:59:12,170 --> 00:59:11,039
now we we haven't like the day yet we

1525
00:59:14,269 --> 00:59:12,180
started off just looking at kind of the

1526
00:59:15,950 --> 00:59:14,279
most like the outcome and actually the

1527
00:59:18,200 --> 00:59:15,960
case where Eric screwed it up was

1528
00:59:19,009 --> 00:59:18,210
leaving behind a bound cluster oh and so

1529
00:59:21,319 --> 00:59:19,019
it was kind of interesting the

1530
00:59:22,549 --> 00:59:21,329
distribution of illuminance I 26 for

1531
00:59:24,079 --> 00:59:22,559
those runs which were not what we

1532
00:59:25,039 --> 00:59:24,089
thought they were at first I was

1533
00:59:26,839 --> 00:59:25,049
actually kind of interesting was a

1534
00:59:28,400 --> 00:59:26,849
little different it was it was bimodal

1535
00:59:32,450 --> 00:59:28,410
actually instead of having that one big

1536
00:59:33,859 --> 00:59:32,460
peak based on you know which clusters

1537
00:59:35,630 --> 00:59:33,869
actually stayed around in the cluster in

1538
00:59:44,930 --> 00:59:35,640

which ones so I wish stars stayed around

1539
00:59:46,400 --> 00:59:44,940
the cluster which ones then but hey and

1540
00:59:49,160 --> 00:59:46,410
embrace all the grains or could you

1541
00:59:56,089 --> 00:59:49,170
actually use it to get relative ages of

1542
00:59:57,829 --> 00:59:56,099
the race so whether sorry you're asking

1543
01:00:02,360 --> 00:59:57,839
whether aluminum 26 can actually use to

1544
01:00:11,300 --> 01:00:05,420
I wanted to see which is the first rain

1545
01:00:14,090 --> 01:00:11,310
of context and so for example like the

1546
01:00:15,650 --> 01:00:14,100
reason I know it's done to some degree

1547
01:00:17,390 --> 01:00:15,660
to look at you know you look at the ages

1548
01:00:19,400 --> 01:00:17,400
of lots of these different individual

1549
01:00:20,930 --> 01:00:19,410
inclusions inside of meteorites and you

1550
01:00:23,060 --> 01:00:20,940
can see difference in ages for example

1551
01:00:26,090 --> 01:00:23,070
between the oldest ones which are called

1552
01:00:29,030 --> 01:00:26,100
calcium calcium aluminum inclusions the

1553
01:00:32,480 --> 01:00:29,040
CAS and ones that have aluminum 26 for

1554
01:00:34,400 --> 01:00:32,490
example and that kind of method is is

1555
01:00:37,070 --> 01:00:34,410
how it's been figured out that there was

1556
01:00:39,260 --> 01:00:37,080
a later injection of luminal 26 that

1557
01:00:41,120 --> 01:00:39,270
happen after the formation of the CAS in

1558
01:00:43,220 --> 01:00:41,130
terms of looking at the details of

1559
01:00:45,290 --> 01:00:43,230
individual grains I think these guys in

1560
01:00:47,990 --> 01:00:45,300
general don't trust necessarily each

1561
01:00:49,430 --> 01:00:48,000
grain but try to get a statistical

1562
01:00:51,020 --> 01:00:49,440
sample to try to see what's really going

1563
01:00:57,530 --> 01:00:51,030

on I don't know too much about the

1564
01:00:59,750 --> 01:00:57,540
details of ality don't know what

1565
01:01:04,700 --> 01:00:59,760
actually measured is excess been using

1566
01:01:09,670 --> 01:01:04,710
26 points to decay 06 typical guy is

1567
01:01:19,400 --> 01:01:13,730
7 but there are variations or systematic

1568
01:01:22,339 --> 01:01:19,410
deviations also some things that don't

1569
01:01:24,980 --> 01:01:22,349
show excesses that was the implication

1570
01:01:29,030 --> 01:01:24,990
they were given aid or this stuff but

1571
01:01:38,299 --> 01:01:29,040
salty salty but that's how the quality

1572
01:01:40,460 --> 01:01:38,309
is awesome number 26 and axes okay well

1573
01:01:43,010 --> 01:01:40,470
shown is going to be around all week I

1574
01:01:48,940 --> 01:01:43,020
believe what here's another question oh

1575
01:01:54,380 --> 01:01:48,950
okay in 10 you have another question oh

1576
01:01:57,140 --> 01:01:54,390
yes so this is related to the grants

1577
01:02:00,280 --> 01:01:57,150
scenario of how to bring water to

1578
01:02:03,620 --> 01:02:00,290
Twitter like planet did you see that it

1579
01:02:06,859 --> 01:02:03,630
took about 20 to 30 million years for

1580
01:02:11,420 --> 01:02:06,869
water to reach this planet is that a

1581
01:02:15,460 --> 01:02:11,430
typical time scale and a Anna do any

1582
01:02:18,530 --> 01:02:15,470
question is the water presumably are

1583
01:02:22,510 --> 01:02:18,540
brought in by the plant has moles and

1584
01:02:27,880 --> 01:02:22,520
did anybody looked like looked at how

1585
01:02:31,670 --> 01:02:27,890
the water on those these targets

1586
01:02:36,319 --> 01:02:31,680
evolving time if it's a really fun be 30

1587
01:02:39,410 --> 01:02:36,329
million years time scale thank you okay

1588
01:02:41,000 --> 01:02:39,420

so so in terms of how long it takes for

1589
01:02:43,490 --> 01:02:41,010
this kind of mixing between zones that

1590
01:02:45,920 --> 01:02:43,500
happen and for you know water rich stuff

1591
01:02:47,450 --> 01:02:45,930
to end up at one of you that can vary a

1592
01:02:49,670 --> 01:02:47,460
bit from simulation simulation it's

1593
01:02:51,530 --> 01:02:49,680
typically not immediate it take there's

1594
01:02:53,270 --> 01:02:51,540
some delay you know just to have

1595
01:02:55,400 --> 01:02:53,280
eccentricities stirred up enough to

1596
01:02:57,200 --> 01:02:55,410
really mix different zones so it's

1597
01:02:59,270 --> 01:02:57,210
typically of delay of maybe 10 to 20

1598
01:03:02,210 --> 01:02:59,280
million years so that part we think is

1599
01:03:04,250 --> 01:03:02,220
really happening you know that delay but

1600
01:03:06,980 --> 01:03:04,260
the process continues you know since you

1601
01:03:09,170 --> 01:03:06,990
know from when it happens until you know

1602
01:03:10,730 --> 01:03:09,180
till the ending to you till you find

1603
01:03:12,289 --> 01:03:10,740
kind of clear out the ass / bill and you

1604
01:03:14,870 --> 01:03:12,299
clear out all the rest of this stuff and

1605
01:03:17,000 --> 01:03:14,880
so it can extend to maybe 50 or 100

1606
01:03:19,130 --> 01:03:17,010
million years or so in terms of small

1607
01:03:20,599 --> 01:03:19,140
bodies still impact in the earth there's

1608
01:03:21,850 --> 01:03:20,609
a constraint that the last you know

1609
01:03:24,040 --> 01:03:21,860
large impact on the earth

1610
01:03:26,080 --> 01:03:24,050
didn't happen later than maybe 30 or 50

1611
01:03:29,590 --> 01:03:26,090
million years or so in terms of water

1612
01:03:32,350 --> 01:03:29,600
attention on the earth you know the key

1613
01:03:34,990 --> 01:03:32,360

factors are you know how fast the impact

1614
01:03:36,700 --> 01:03:35,000
is happening and also what's going on I

1615
01:03:38,620 --> 01:03:36,710
guess you know better what's going on on

1616
01:03:40,840 --> 01:03:38,630
the planet and so maybe if impacts

1617
01:03:42,520 --> 01:03:40,850
happen later the planets cooled off a

1618
01:03:45,340 --> 01:03:42,530
bit maybe it's a bit easier to retain

1619
01:03:48,250 --> 01:03:45,350
water I think that might've been what

1620
01:03:50,380 --> 01:03:48,260
you're getting at is that rent yeah

1621
01:03:52,930 --> 01:03:50,390
that's certainly one important aspect of

1622
01:03:57,430 --> 01:03:52,940
the retention problem the other part is

1623
01:04:01,320 --> 01:03:57,440
how is water how can water remain all

1624
01:04:03,160 --> 01:04:01,330
those smaller objects at the first plate

1625
01:04:06,130 --> 01:04:03,170
yeah that's I mean that's a good

1626
01:04:07,780 --> 01:04:06,140
question of of you know whether if

1627
01:04:10,390 --> 01:04:07,790
bodies of eccentric orbits that take

1628
01:04:11,830 --> 01:04:10,400
them very close to to the Sun you know

1629
01:04:13,960 --> 01:04:11,840
for a long time before they end up

1630
01:04:16,840 --> 01:04:13,970
impacting the earth and will they retain

1631
01:04:19,930 --> 01:04:16,850
much of their fall dose you no comments

1632
01:04:22,900 --> 01:04:19,940
take what 10 or 100 passes close to the

1633
01:04:24,280 --> 01:04:22,910
Sun to break apart so maybe they have 10

1634
01:04:26,440 --> 01:04:24,290
or 100 orbits before they need to

1635
01:04:28,180 --> 01:04:26,450
collide with something before they lose

1636
01:04:29,290 --> 01:04:28,190
most of their water we're not sure that

1637
01:04:31,690 --> 01:04:29,300
hasn't really been looked at in much

1638
01:04:32,740 --> 01:04:31,700

detail that's a that's just one

1639
01:04:34,270 --> 01:04:32,750
uncertainty and there's already plenty

1640
01:04:36,520 --> 01:04:34,280
of uncertainty in terms of how much is

1641
01:04:38,200 --> 01:04:36,530
retained in large and small collisions

1642
01:04:41,920 --> 01:04:38,210
and so I don't think anyone's anyway

1643
01:04:44,470 --> 01:04:41,930
thank you what kind of show will be

1644
01:04:46,690 --> 01:04:44,480
around all week if you want to speak to

1645
01:04:49,480 --> 01:04:46,700
him further yep leaving friday i believe

1646
01:04:51,430 --> 01:04:49,490
a friday morning friday morning so take