Can habitable terrestrial planets form in systems where giant planets migrate?

Previous ideas and results:

- **4: NO BY ASSUMPTION** (Ward & Brownlee 2000; Lineweaver 2001; Gonzalez et al 2001; Lineweaver et al 2004)
- **1: NO - ASSUMING NOTHING SURVIVES MIGRATION** (Armitage 2003)
- **3: YES - MATERIAL DOES SURVIVE MIGRATION, BUT DISK IS DISTURBED** (Mandell & Sigurdsson 2003; Edgar & Artymowicz 2004; Fogg & Nelson 2005)
- **1: YES - ASSUMING ALL MATERIAL SURVIVES MIGRATION** (Raymond, Quinn & Lunine 2005)

Now, let's bring it all together!

1
00:00:06,019 --> 00:00:03,560
good morning or good afternoon everybody

2
00:00:09,740 --> 00:00:06,029
this is Carl pill to attend a I central

3
00:00:11,720 --> 00:00:09,750
and it is my pleasure to be welcoming

4
00:00:14,720 --> 00:00:11,730
you to and introducing the speakers for

5
00:00:18,099 --> 00:00:14,730
the second director seminar of this

6
00:00:21,470 --> 00:00:18,109
series one of the things that is really

7
00:00:25,880 --> 00:00:21,480
exciting about astrobiology to me is how

8
00:00:28,189 --> 00:00:25,890
it attracts many many young researchers

9
00:00:29,990 --> 00:00:28,199
beginning their careers and I think

10
00:00:32,229 --> 00:00:30,000
that's a testament to how exciting the

11
00:00:34,850 --> 00:00:32,239
field is and both of the first two

12
00:00:38,150 --> 00:00:34,860
director seminars of this series are

13
00:00:40,310 --> 00:00:38,160

being given by young researchers today's

14
00:00:43,549 --> 00:00:40,320
seminar is being given by Shawn Raymond

15
00:00:46,369 --> 00:00:43,559
in avi Mandell they have been

16
00:00:48,380 --> 00:00:46,379
researching the formation of habitable

17
00:00:51,500 --> 00:00:48,390
planets around other stars and have come

18
00:00:55,340 --> 00:00:51,510
up with a very interesting conclusion to

19
00:00:59,270 --> 00:00:55,350
a fundamental question namely can there

20
00:01:02,180 --> 00:00:59,280
be habitable planets around stars that

21
00:01:03,759 --> 00:01:02,190
also have giant planets close in and

22
00:01:10,250 --> 00:01:03,769
they're going to be telling us about

23
00:01:12,920 --> 00:01:10,260
their work Sean Raymond is a nai postdoc

24
00:01:15,320 --> 00:01:12,930
at the University of Colorado who got

25
00:01:17,359 --> 00:01:15,330
his PhD at the University of Washington

26
00:01:20,440 --> 00:01:17,369
in Seattle under Tom Quinn and is

27
00:01:23,480 --> 00:01:20,450
working now with John Valley at Colorado

28
00:01:26,120 --> 00:01:23,490
avi Mandell is in fact still a graduate

29
00:01:28,249 --> 00:01:26,130
student he got his undergraduate degree

30
00:01:31,910 --> 00:01:28,259
at Vassar College and he's a graduate

31
00:01:36,620 --> 00:01:31,920
student at Penn State working with Stein

32
00:01:39,050 --> 00:01:36,630
Sigurdsson and Jon Jay their research in

33
00:01:42,109 --> 00:01:39,060
both cases focuses on the formation and

34
00:01:43,730 --> 00:01:42,119
evolution of habitable planets and today

35
00:01:45,620 --> 00:01:43,740
they are going to be telling us about

36
00:01:47,780 --> 00:01:45,630
the formation of habitable planetary

37
00:01:49,490 --> 00:01:47,790
systems and they're going to provide an

38
00:01:57,350 --> 00:01:49,500

answer I guess to the question are we

39
00:02:02,040 --> 00:02:00,330
you come up first so hello everyone in

40
00:02:03,390 --> 00:02:02,050
this room who is kind of thinking this

41
00:02:06,540 --> 00:02:03,400
is weird since I'm sitting down whole

42
00:02:07,860 --> 00:02:06,550
time but that's because we want people

43
00:02:10,830 --> 00:02:07,870
who are not in this room to be able to

44
00:02:13,290 --> 00:02:10,840
see my face so I can't move further than

45
00:02:16,020 --> 00:02:13,300
about this bar on either side so hello

46
00:02:17,490 --> 00:02:16,030
everyone who's not here so I'm Sean and

47
00:02:19,230 --> 00:02:17,500
not me telling you guys a little bit of

48
00:02:20,280 --> 00:02:19,240
the background of this problem and then

49
00:02:21,890 --> 00:02:20,290
avi is going to tell you about the

50
00:02:24,390 --> 00:02:21,900
exciting new stuff we've been doing and

51
00:02:27,090 --> 00:02:24,400
so to start it off we've agreed it was

52
00:02:30,120 --> 00:02:27,100
kind of sexy picture right here which is

53
00:02:31,980 --> 00:02:30,130
showing four different planetary systems

54
00:02:33,930 --> 00:02:31,990
and so the one on the bottom right

55
00:02:35,480 --> 00:02:33,940
hopefully you'll recognize is a very

56
00:02:37,890 --> 00:02:35,490
rough schematic of the solar system

57
00:02:39,660 --> 00:02:37,900
nothing is even close to scale but you

58
00:02:41,670 --> 00:02:39,670
get the general idea you got Mercury

59
00:02:42,840 --> 00:02:41,680
Venus Earth and Mars in there earth is

60
00:02:44,280 --> 00:02:42,850
in this sweet spot and what we call a

61
00:02:46,740 --> 00:02:44,290
habitable zone I'll talk more about that

62
00:02:48,150 --> 00:02:46,750
in a minute an asteroid belt got Jupiter

63
00:02:49,860 --> 00:02:48,160

and there's more stuff further out and

64
00:02:52,740 --> 00:02:49,870
this is just showing the inner planetary

65
00:02:55,230 --> 00:02:52,750
system these other three planetary

66
00:02:58,530 --> 00:02:55,240
systems I'm showing our artificial ones

67
00:03:00,690 --> 00:02:58,540
that were created in a computer and we

68
00:03:02,880 --> 00:03:00,700
think they're reasonable representations

69
00:03:05,280 --> 00:03:02,890
of what might be out there and might be

70
00:03:08,070 --> 00:03:05,290
discovered in the next 5 10 20 years or

71
00:03:10,050 --> 00:03:08,080
so so on the top right is a system that

72
00:03:11,790 --> 00:03:10,060
includes a planet that looks a lot like

73
00:03:14,040 --> 00:03:11,800
the earth its orbit and composition and

74
00:03:15,270 --> 00:03:14,050
size are similar to the Earth's but the

75
00:03:17,550 --> 00:03:15,280
system as a whole looks a lot different

76
00:03:19,080 --> 00:03:17,560
the the only giant plant in the

77
00:03:21,210 --> 00:03:19,090
simulation is only about the size of

78
00:03:23,580 --> 00:03:21,220
Neptune rather than being a sentence of

79
00:03:25,320 --> 00:03:23,590
Jupiter and so in the end instead of

80
00:03:27,330 --> 00:03:25,330
forming it a relatively small number of

81
00:03:29,220 --> 00:03:27,340
terrestrial plants performed about six

82
00:03:30,900 --> 00:03:29,230
or seven terrestrial plants in there

83
00:03:33,870 --> 00:03:30,910
several of which are kind of Mars size

84
00:03:36,300 --> 00:03:33,880
in the top left is a system that

85
00:03:37,800 --> 00:03:36,310
includes a planet have rules owner as

86
00:03:40,830 --> 00:03:37,810
well that's just weird red one right

87
00:03:42,600 --> 00:03:40,840
there and the weird thing here is that a

88
00:03:44,670 --> 00:03:42,610

planet formed in the habitable zone

89
00:03:47,120 --> 00:03:44,680
which is at the right temperature for

90
00:03:51,150 --> 00:03:47,130
water to be liquid on a planet's surface

91
00:03:52,590 --> 00:03:51,160
but it turns out that planet was unlucky

92
00:03:54,690 --> 00:03:52,600
in some sense and actually doesn't have

93
00:03:56,000 --> 00:03:54,700
any water on it so it's this weird state

94
00:03:59,160 --> 00:03:56,010
of being in the right place to have

95
00:04:00,960 --> 00:03:59,170
water but water has a liquid but it's

96
00:04:03,570 --> 00:04:00,970
got no water honor so that's kind of

97
00:04:05,100 --> 00:04:03,580
unfortunate and the bottom left is it's

98
00:04:06,990 --> 00:04:05,110
a system that looks a lot different than

99
00:04:07,610 --> 00:04:07,000
our solar system remember nothing's even

100
00:04:08,930 --> 00:04:07,620
close to see

101
00:04:12,229 --> 00:04:08,940
here so this is a hot Jupiter right

102
00:04:13,910 --> 00:04:12,239
there even closer to the star is we call

103
00:04:16,069 --> 00:04:13,920
it a hotter if they're hot super if one

104
00:04:18,469 --> 00:04:16,079
plant a few times the mass of the earth

105
00:04:20,840 --> 00:04:18,479
that's you know within point 18 you of

106
00:04:22,580 --> 00:04:20,850
the star and out here is a planet on an

107
00:04:25,340 --> 00:04:22,590
orbit similar to the Earth's it's in the

108
00:04:27,469 --> 00:04:25,350
habitable zone it's got roughly similar

109
00:04:29,780 --> 00:04:27,479
properties to the earth the only

110
00:04:32,150 --> 00:04:29,790
difference is that this planet has maybe

111
00:04:34,760 --> 00:04:32,160
10 or 20 times as much water as the

112
00:04:39,219 --> 00:04:34,770
earth does and so it's probably covered

113
00:04:42,409 --> 00:04:39,229

in deep oceans alright so moving on

114
00:04:44,870 --> 00:04:42,419
here's a list of collaborators who have

115
00:04:46,879 --> 00:04:44,880
helped on on this project notably Tom

116
00:04:48,980 --> 00:04:46,889
Quinn and Stein and Jonathan you need

117
00:04:51,860 --> 00:04:48,990
those guys have helped a lot and we want

118
00:04:53,689 --> 00:04:51,870
to thank nasa astrobiology for funding

119
00:04:55,790 --> 00:04:53,699
personally i've been funded through them

120
00:04:57,860 --> 00:04:55,800
for the last four years or so at the

121
00:05:00,020 --> 00:04:57,870
university of washington then at the

122
00:05:01,520 --> 00:05:00,030
virtual planetary lab based on Caltech

123
00:05:05,120 --> 00:05:01,530
and then now at the university of

124
00:05:08,990 --> 00:05:05,130
colorado and avi is also supported at

125
00:05:10,100 --> 00:05:09,000
penn state and NASA Goddard so here's an

126
00:05:12,620 --> 00:05:10,110
outline what we're going to talk about

127
00:05:14,750 --> 00:05:12,630
I'll give a brief overview of the

128
00:05:17,540 --> 00:05:14,760
general picture we have of how the solar

129
00:05:18,740 --> 00:05:17,550
system planets formed I'll go into a

130
00:05:22,190 --> 00:05:18,750
little bit about what I'm talking about

131
00:05:23,900 --> 00:05:22,200
about a habitable planet then we'll look

132
00:05:26,210 --> 00:05:23,910
at planetary systems that are similar to

133
00:05:28,460 --> 00:05:26,220
our own and that they have if they have

134
00:05:31,580 --> 00:05:28,470
giant planets their exterior to the

135
00:05:33,260 --> 00:05:31,590
terrestrial planet region then planetary

136
00:05:35,810 --> 00:05:33,270
systems unlike our own which have a

137
00:05:38,330 --> 00:05:35,820
giant planet systems which are either

138
00:05:40,100 --> 00:05:38,340

interior or you have probably interior

139
00:05:42,860 --> 00:05:40,110
to the habitable zone it won't look at

140
00:05:45,050 --> 00:05:42,870
the known set of extrasolar planets and

141
00:05:48,830 --> 00:05:45,060
then conclusions are difficult in these

142
00:05:51,080 --> 00:05:48,840
kind of ducks so I'm going to do things

143
00:05:53,990 --> 00:05:51,090
a little bit backwards here at the very

144
00:05:55,730 --> 00:05:54,000
start is the punchline so this plot is

145
00:05:58,070 --> 00:05:55,740
highly confusing to everyone I ever show

146
00:06:06,350 --> 00:05:58,080
it to you so let me just just explain it

147
00:06:09,980 --> 00:06:06,360
very briefly and obvious as a function

148
00:06:14,750 --> 00:06:09,990
of stellar mass and this shaded region

149
00:06:16,910 --> 00:06:14,760
is the habitable zone and each of these

150
00:06:21,670 --> 00:06:16,920
dots on here represents one of the known

151
00:06:23,960 --> 00:06:21,680
at once the solid and dashed lines are

152
00:06:26,330 --> 00:06:23,970
limits which we've derived in a way that

153
00:06:29,420 --> 00:06:26,340
will tell you about later for where

154
00:06:30,950 --> 00:06:29,430
giant planets can be basically orbital

155
00:06:33,560 --> 00:06:30,960
limits for giant planets that allow

156
00:06:35,510 --> 00:06:33,570
terrestrial planets to form in the right

157
00:06:38,390 --> 00:06:35,520
place that we think may be liquid water

158
00:06:40,040 --> 00:06:38,400
can be on the service maybe life and so

159
00:06:41,630 --> 00:06:40,050
if you go out and find a new Jenna

160
00:06:43,580 --> 00:06:41,640
planet you can stick it on the spot

161
00:06:45,440 --> 00:06:43,590
assuming you've measured its orbit and

162
00:06:48,740 --> 00:06:45,450
the mass of the star that's around if

163
00:06:52,250 --> 00:06:48,750

that giant planet falls above the solid

164
00:06:54,860 --> 00:06:52,260
line or below the dashed line and also

165
00:06:56,510 --> 00:06:54,870
has certain other properties which are

166
00:06:58,940 --> 00:06:56,520
not showing explicitly in the plot like

167
00:07:04,250 --> 00:06:58,950
its orbital eccentricity is below a

168
00:07:07,070 --> 00:07:04,260
certain limit then the that system has a

169
00:07:08,560 --> 00:07:07,080
good chance that a terrestrial planet

170
00:07:10,700 --> 00:07:08,570
could have formed in the habitable zone

171
00:07:12,830 --> 00:07:10,710
so I know that's kind of long and

172
00:07:15,230 --> 00:07:12,840
convoluted sentence and obvi will

173
00:07:18,170 --> 00:07:15,240
clarify that much more later so that's

174
00:07:20,870 --> 00:07:18,180
nice okay so getting back to this idea

175
00:07:23,120 --> 00:07:20,880
of terrestrial planet formation we only

176
00:07:25,430 --> 00:07:23,130
know in detail of one planetary system

177
00:07:26,840 --> 00:07:25,440
the solar system here's the new solar

178
00:07:29,750 --> 00:07:26,850
system planets we only have eight of

179
00:07:33,080 --> 00:07:29,760
them now some people are sad about but I

180
00:07:34,970 --> 00:07:33,090
don't really mind and yeah so this the

181
00:07:36,680 --> 00:07:34,980
solar system gives us constraints we

182
00:07:39,080 --> 00:07:36,690
have models for how planets form and

183
00:07:40,280 --> 00:07:39,090
they have to match more or less the

184
00:07:42,140 --> 00:07:40,290
solar system because that's the one

185
00:07:44,120 --> 00:07:42,150
system we know in detail we have to

186
00:07:46,120 --> 00:07:44,130
match things like the massive planets we

187
00:07:49,520 --> 00:07:46,130
have to match the orbits of planets

188
00:07:52,490 --> 00:07:49,530

compositions their rough spacing I stop

189
00:07:54,290 --> 00:07:52,500
ratios populations of small bodies like

190
00:07:56,570 --> 00:07:54,300
asteroids and comets so that's kind of

191
00:07:57,980 --> 00:07:56,580
our baseline hopefully we have a theory

192
00:07:59,900 --> 00:07:57,990
that can more or less reproduce the

193
00:08:01,340 --> 00:07:59,910
solar system and what we're going to do

194
00:08:04,190 --> 00:08:01,350
is we're going to take that general

195
00:08:06,140 --> 00:08:04,200
picture that works for the solar system

196
00:08:08,150 --> 00:08:06,150
and apply it to other planetary systems

197
00:08:12,350 --> 00:08:08,160
and hopefully we'll learn something by

198
00:08:13,580 --> 00:08:12,360
doing that so now I'm going to be

199
00:08:16,430 --> 00:08:13,590
talking the rest of talk is going to

200
00:08:18,110 --> 00:08:16,440
deal a lot with with habitable planets

201
00:08:20,480 --> 00:08:18,120
and so what is a habitable planet

202
00:08:22,970 --> 00:08:20,490
obviously it's a planet that has the

203
00:08:24,830 --> 00:08:22,980
possibility of having life on it so what

204
00:08:27,180 --> 00:08:24,840
do you need what requirements are there

205
00:08:30,150 --> 00:08:27,190
for a plan to maybe

206
00:08:32,730 --> 00:08:30,160
be a habitable and so it's been proposed

207
00:08:34,710 --> 00:08:32,740
maybe you need a thick atmosphere if you

208
00:08:35,850 --> 00:08:34,720
need a thick atmosphere then your planet

209
00:08:38,490 --> 00:08:35,860
has to be big enough to have enough

210
00:08:40,350 --> 00:08:38,500
gravity to be able to retain an

211
00:08:42,300 --> 00:08:40,360
atmosphere of that size at the right

212
00:08:44,010 --> 00:08:42,310
orbital distance and that turns out to

213
00:08:45,540 --> 00:08:44,020

be a planet has to be at least about the

214
00:08:49,320 --> 00:08:45,550
size of Mars about a tenth of an earth

215
00:08:51,720 --> 00:08:49,330
masters some people argue have argued

216
00:08:55,410 --> 00:08:51,730
that faint tectonics is key for

217
00:08:57,710 --> 00:08:55,420
long-term climate stability on a planet

218
00:09:00,060 --> 00:08:57,720
so if that's a requirement for

219
00:09:02,310 --> 00:09:00,070
habitability then the planet needs to be

220
00:09:05,250 --> 00:09:02,320
bigger than maybe maybe two tenths of a

221
00:09:06,750 --> 00:09:05,260
nurse master sir and then if we kind of

222
00:09:09,270 --> 00:09:06,760
fiddle with the parameters there and say

223
00:09:11,340 --> 00:09:09,280
a planet has to have plate tectonics

224
00:09:13,560 --> 00:09:11,350
that lasts at least some amount of time

225
00:09:15,210 --> 00:09:13,570
maybe five billion years assume it has a

226
00:09:17,280 --> 00:09:15,220
density of something like four and a

227
00:09:20,160 --> 00:09:17,290
half grams per centimeter cube then you

228
00:09:23,280 --> 00:09:20,170
get a rough limit on what mass of a

229
00:09:25,320 --> 00:09:23,290
planet that could have those properties

230
00:09:27,120 --> 00:09:25,330
is about a third of an earth master so

231
00:09:28,230 --> 00:09:27,130
point three earth masses and so that's

232
00:09:30,060 --> 00:09:28,240
the rough cut off we're going to use

233
00:09:32,640 --> 00:09:30,070
we're going to say the plants below that

234
00:09:34,440 --> 00:09:32,650
mess I both smaller chance of being

235
00:09:36,330 --> 00:09:34,450
habitable and maybe maybe in some

236
00:09:38,460 --> 00:09:36,340
instances they are habitable but we're

237
00:09:42,090 --> 00:09:38,470
going to use that as a rough divide a

238
00:09:44,250 --> 00:09:42,100

dividing line between smaller less abril

239
00:09:46,380 --> 00:09:44,260
plants and more massive habitable ones

240
00:09:48,840 --> 00:09:46,390
and so this this plot here shows a

241
00:09:50,880 --> 00:09:48,850
schematic of what the services of three

242
00:09:52,140 --> 00:09:50,890
different planets might look like all in

243
00:09:53,640 --> 00:09:52,150
the habitable zone it so the one on the

244
00:09:56,340 --> 00:09:53,650
left is showing maybe a mars-sized

245
00:09:59,430 --> 00:09:56,350
object and maybe this thing would end up

246
00:10:00,660 --> 00:09:59,440
being dry and desert like like Mars then

247
00:10:01,980 --> 00:10:00,670
we have the Goldilocks planet where

248
00:10:04,950 --> 00:10:01,990
everything is nice and happy which is

249
00:10:07,920 --> 00:10:04,960
where we live and maybe larger planets

250
00:10:09,750 --> 00:10:07,930
would end up having a lot a lot of water

251
00:10:11,130 --> 00:10:09,760
on them and and I'm not sure I agree

252
00:10:13,590 --> 00:10:11,140
with this theory but it's kind of a nice

253
00:10:17,430 --> 00:10:13,600
picture of what service of these planets

254
00:10:19,410 --> 00:10:17,440
might look like so you've heard all

255
00:10:20,730 --> 00:10:19,420
about the habitable zone and sure most

256
00:10:23,490 --> 00:10:20,740
you know what it is but let me just give

257
00:10:26,540 --> 00:10:23,500
you a very quick reminder so it's the

258
00:10:29,579 --> 00:10:26,550
region of orbital distances from a star

259
00:10:31,680 --> 00:10:29,589
where the temperature is right on the

260
00:10:33,329 --> 00:10:31,690
surface of a planet that water can be

261
00:10:35,280 --> 00:10:33,339
liquid and of course that depends on

262
00:10:37,260 --> 00:10:35,290
things like the planet's atmosphere and

263
00:10:39,449 --> 00:10:37,270

such and there could also be habitable

264
00:10:41,460 --> 00:10:39,459
niches where you have another so

265
00:10:42,840 --> 00:10:41,470
of heat for example you know Europa

266
00:10:44,340 --> 00:10:42,850
might be habitable given that it has a

267
00:10:46,919 --> 00:10:44,350
different source of heat rather than

268
00:10:48,660 --> 00:10:46,929
solar radiation but this is a very

269
00:10:50,400 --> 00:10:48,670
simple way to define it if your heats

270
00:10:52,379 --> 00:10:50,410
coming from the Sun then you have to be

271
00:10:54,569 --> 00:10:52,389
in this range of distances to have

272
00:10:57,329 --> 00:10:54,579
liquid water on your surface but the

273
00:10:58,799 --> 00:10:57,339
trick is not only do you have to be in

274
00:11:00,869 --> 00:10:58,809
the right spot we also have to actually

275
00:11:03,329 --> 00:11:00,879
and have liquid water on the surface of

276
00:11:04,919 --> 00:11:03,339
the planet and so this right here is the

277
00:11:07,710 --> 00:11:04,929
universal symbol of planetary

278
00:11:12,090 --> 00:11:07,720
habitability so that's what life life

279
00:11:13,919 --> 00:11:12,100
likes beer so the general stages and

280
00:11:16,139 --> 00:11:13,929
have dressed your plants form goes

281
00:11:18,419 --> 00:11:16,149
something like this and this picture

282
00:11:20,100 --> 00:11:18,429
kind of illustrates the rough so this

283
00:11:22,710 --> 00:11:20,110
image illustrates the rough model that

284
00:11:23,939 --> 00:11:22,720
we think we understand more or less so

285
00:11:26,790 --> 00:11:23,949
this stuff with several different stages

286
00:11:29,489 --> 00:11:26,800
first as planets are forming the disk of

287
00:11:32,790 --> 00:11:29,499
gas and dust around a star grains kind

288
00:11:36,239 --> 00:11:32,800

of settle to a mid plane a very thin mid

289
00:11:37,859 --> 00:11:36,249
plane of a you know in this disk around

290
00:11:41,129 --> 00:11:37,869
the star that takes something like

291
00:11:42,840 --> 00:11:41,139
10,000 years or so step 2 in this in

292
00:11:46,139 --> 00:11:42,850
this problem is very uncertain there's

293
00:11:48,720 --> 00:11:46,149
lots of hand waving in terms of how you

294
00:11:50,579 --> 00:11:48,730
get from small grains to kilometer-sized

295
00:11:52,530 --> 00:11:50,589
planetesimals we think that

296
00:11:54,419 --> 00:11:52,540
kilometer-sized planetesimals are really

297
00:11:56,579 --> 00:11:54,429
the building blocks of terrestrial

298
00:11:58,829 --> 00:11:56,589
planets and so we think that they have

299
00:12:00,470 --> 00:11:58,839
to form somehow and exactly how they

300
00:12:03,569 --> 00:12:00,480
form is not really well understood yet

301
00:12:05,699 --> 00:12:03,579
the third stage of terrestrial plant

302
00:12:08,850 --> 00:12:05,709
information deals with the agglomeration

303
00:12:12,449 --> 00:12:08,860
of kilometer-sized plant decimals into

304
00:12:14,999 --> 00:12:12,459
maybe moon-sized proto plants or they

305
00:12:17,039 --> 00:12:15,009
also called planetary embryos and the

306
00:12:18,840 --> 00:12:17,049
final accumulation of terrestrial

307
00:12:22,410 --> 00:12:18,850
planets is called late stage accretion

308
00:12:26,789 --> 00:12:22,420
and that occurs in maybe 10 50 100

309
00:12:29,220 --> 00:12:26,799
million years or so and a key thing to

310
00:12:31,769 --> 00:12:29,230
note here is the giant planets are

311
00:12:33,660 --> 00:12:31,779
required to form faster than a few

312
00:12:36,030 --> 00:12:33,670
million years so the final assembly of

313
00:12:38,579 --> 00:12:36,040

terrestrial planets takes place in the

314
00:12:39,929 --> 00:12:38,589
presence of any giant plants which may

315
00:12:42,749 --> 00:12:39,939
have formed and they don't have to form

316
00:12:44,160 --> 00:12:42,759
in every around every star but in the

317
00:12:46,079 --> 00:12:44,170
cases where you do have giant planets

318
00:12:48,150 --> 00:12:46,089
the final accumulation of terrestrial

319
00:12:49,519 --> 00:12:48,160
planets is influenced by those giant

320
00:12:54,329 --> 00:12:49,529
planets

321
00:12:55,860 --> 00:12:54,339
so what does this disk of gas and just

322
00:12:58,379 --> 00:12:55,870
look like from which the terrestrial

323
00:13:00,749 --> 00:12:58,389
planets form well one key thing is that

324
00:13:02,340 --> 00:13:00,759
close to the star is hotter when it's

325
00:13:05,040 --> 00:13:02,350
hotter then you can have you know you

326
00:13:06,629 --> 00:13:05,050
have different materials that are able

327
00:13:09,420 --> 00:13:06,639
to condense and so it's thought that

328
00:13:11,759 --> 00:13:09,430
close to the star you know what

329
00:13:13,949 --> 00:13:11,769
dominates the solid bodies are rocking

330
00:13:15,629 --> 00:13:13,959
iron further away it's more volatile

331
00:13:17,280 --> 00:13:15,639
materials that dominate like water and

332
00:13:20,579 --> 00:13:17,290
when you have very far away things like

333
00:13:23,879 --> 00:13:20,589
carbon dioxide methane and so on and one

334
00:13:26,059 --> 00:13:23,889
way that we think this is the case is by

335
00:13:28,710 --> 00:13:26,069
looking at classes of primitive

336
00:13:30,809 --> 00:13:28,720
asteroids right looking at meteorites

337
00:13:33,980 --> 00:13:30,819
which we think originated and families

338
00:13:36,900 --> 00:13:33,990

of asteroids which are supposedly

339
00:13:39,269 --> 00:13:36,910
representative of that of the conditions

340
00:13:40,410 --> 00:13:39,279
that where they formed and so if you

341
00:13:42,059 --> 00:13:40,420
look at those that's this plot on the

342
00:13:43,379 --> 00:13:42,069
left here showing the water content of

343
00:13:46,019 --> 00:13:43,389
those bodies is a function of orbital

344
00:13:48,180 --> 00:13:46,029
distance and kind of fitting this

345
00:13:49,740 --> 00:13:48,190
general picture more or less why is that

346
00:13:52,550 --> 00:13:49,750
a further away from the Sun have more

347
00:13:54,929 --> 00:13:52,560
water ones that are closer have less and

348
00:13:57,480 --> 00:13:54,939
so carbonaceous chondrite meteorites

349
00:14:00,420 --> 00:13:57,490
which originated and c-type asteroids

350
00:14:02,100 --> 00:14:00,430
and maybe 2.5 to 3 point to a you or so

351
00:14:08,069 --> 00:14:02,110
those have maybe five to ten percent

352
00:14:10,259 --> 00:14:08,079
water and so one interesting thing in

353
00:14:13,980 --> 00:14:10,269
terms of forming these habitable planets

354
00:14:16,319 --> 00:14:13,990
is I mentioned like on the earth for

355
00:14:17,850 --> 00:14:16,329
water to to be liquid on the surface of

356
00:14:21,360 --> 00:14:17,860
the earth it's got to be hotter than

357
00:14:24,389 --> 00:14:21,370
zero degrees Celsius okay the trick is

358
00:14:26,370 --> 00:14:24,399
how do you get water onto a planet the

359
00:14:27,449 --> 00:14:26,380
current thinking is that the only way

360
00:14:30,600 --> 00:14:27,459
you can really do this in large

361
00:14:33,360 --> 00:14:30,610
quantities is by accumulation of ice and

362
00:14:36,300 --> 00:14:33,370
so it's going to be in the form of icy

363
00:14:37,650 --> 00:14:36,310

material that ends up on the planet so

364
00:14:40,949 --> 00:14:37,660
that means that you have does some ice

365
00:14:42,720 --> 00:14:40,959
forming and in the low density

366
00:14:45,120 --> 00:14:42,730
environment of this protoplanetary disk

367
00:14:47,400 --> 00:14:45,130
it turns out that ice only condenses

368
00:14:50,759 --> 00:14:47,410
into a solid when it's colder than about

369
00:14:52,230 --> 00:14:50,769
negative 100 degrees Celsius so your

370
00:14:54,960 --> 00:14:52,240
habitable planet has to be hotter than

371
00:14:56,759 --> 00:14:54,970
zero degrees Celsius and colder than

372
00:14:57,400 --> 00:14:56,769
negative 100 degrees Celsius at the same

373
00:14:59,710 --> 00:14:57,410
time

374
00:15:02,050 --> 00:14:59,720
that doesn't sound right does it so

375
00:15:04,689 --> 00:15:02,060
that's kind of this we call a catch-22

376
00:15:11,259 --> 00:15:04,699
of habitable planet formation and the

377
00:15:13,180 --> 00:15:11,269
solution to this is oops oh I am I think

378
00:15:15,850 --> 00:15:13,190
we must remove that slide so the

379
00:15:18,309 --> 00:15:15,860
solution to this is a planet that forms

380
00:15:20,230 --> 00:15:18,319
at the right temperature to have water

381
00:15:22,090 --> 00:15:20,240
on its surface one where it's hotter

382
00:15:24,519 --> 00:15:22,100
than zero degrees Celsius must have

383
00:15:26,800 --> 00:15:24,529
incorporated some material which which

384
00:15:28,090 --> 00:15:26,810
originated further out in the disk so

385
00:15:31,509 --> 00:15:28,100
has to incorporate some material from

386
00:15:33,579 --> 00:15:31,519
mounted a few a you at least in order to

387
00:15:35,290 --> 00:15:33,589
even though it incorporate this material

388
00:15:38,379 --> 00:15:35,300

it still lies at the right temperature

389
00:15:40,569 --> 00:15:38,389
at 180 or so so that's the general

390
00:15:42,910 --> 00:15:40,579
solution this problem that even though

391
00:15:44,769 --> 00:15:42,920
planets the end up in the habitable zone

392
00:15:46,929 --> 00:15:44,779
or at the right temperature they can't

393
00:15:51,240 --> 00:15:46,939
form only from local material because

394
00:15:53,949 --> 00:15:51,250
that local materials probably drunk so

395
00:15:56,619 --> 00:15:53,959
putting all these pieces together has

396
00:15:58,410 --> 00:15:56,629
been done over the last 10 or 20 years

397
00:16:00,850 --> 00:15:58,420
or actually more like 50 years or so and

398
00:16:03,519 --> 00:16:00,860
the general picture looks pretty good

399
00:16:05,139 --> 00:16:03,529
this plot here is very hard to see it

400
00:16:08,559 --> 00:16:05,149
then transfer very well but what it's

401
00:16:10,720 --> 00:16:08,569
showing is from simulations by AG nor an

402
00:16:12,129 --> 00:16:10,730
Ag nor paper 99 is showing the mass of

403
00:16:14,230 --> 00:16:12,139
those planets that's formed in these

404
00:16:16,660 --> 00:16:14,240
simulations as a function of orbital

405
00:16:18,519 --> 00:16:16,670
distance and these squares you can kind

406
00:16:20,290 --> 00:16:18,529
of just roughly make out here are the

407
00:16:22,179 --> 00:16:20,300
terrestrial planets and these other

408
00:16:25,300 --> 00:16:22,189
symbols are plants they formed

409
00:16:27,610 --> 00:16:25,310
artificially in their computers and if

410
00:16:28,780 --> 00:16:27,620
you kind of squint it it looks like you

411
00:16:30,040 --> 00:16:28,790
can make yourself believe that the

412
00:16:32,319 --> 00:16:30,050
terrestrial plants fall on this

413
00:16:35,110 --> 00:16:32,329

distribution and that we're just kind of

414
00:16:36,939 --> 00:16:35,120
you know some somewhat you know in a

415
00:16:39,699 --> 00:16:36,949
normal distribution of planets we're

416
00:16:42,249 --> 00:16:39,709
just a high likelihood outcome the trick

417
00:16:43,929 --> 00:16:42,259
is these simulations are not as

418
00:16:46,449 --> 00:16:43,939
realistic as they would like to be

419
00:16:48,519 --> 00:16:46,459
because in any given simulation they

420
00:16:50,980 --> 00:16:48,529
didn't form for plants that look like

421
00:16:52,749 --> 00:16:50,990
mercury beasts Mercury Venus Earth and

422
00:16:54,610 --> 00:16:52,759
Mars they typically formed only to

423
00:16:55,990 --> 00:16:54,620
terrestrial planets but then if they

424
00:16:58,509 --> 00:16:56,000
plot them all on the same graph it looks

425
00:17:00,579 --> 00:16:58,519
kind of nice so this is not not the

426
00:17:01,780 --> 00:17:00,589
final answer on the bank but it's a step

427
00:17:04,419 --> 00:17:01,790
in the right direction and there's new

428
00:17:06,760 --> 00:17:04,429
new simulations which do produced the

429
00:17:08,679 --> 00:17:06,770
terrestrial planets much better and so

430
00:17:09,670 --> 00:17:08,689
in general these models can reproduce

431
00:17:15,490 --> 00:17:09,680
the

432
00:17:17,590 --> 00:17:15,500
Earth Mars pretty well starting from

433
00:17:21,160 --> 00:17:17,600
only these simulations here that in this

434
00:17:24,520 --> 00:17:21,170
plot only started from 30 or 32 50

435
00:17:27,130 --> 00:17:24,530
particles planetary embryo particles and

436
00:17:30,430 --> 00:17:27,140
so they do a rough a pretty good job of

437
00:17:32,520 --> 00:17:30,440
doing that we can explain the source of

438
00:17:36,040 --> 00:17:32,530

water on the earth that's coming from

439
00:17:38,580 --> 00:17:36,050
c-type asteroids like material stuff

440
00:17:41,230 --> 00:17:38,590
that originated may be 38 you or so

441
00:17:43,600 --> 00:17:41,240
there's a few big problems with this

442
00:17:45,940 --> 00:17:43,610
with the model so far the first one is

443
00:17:51,220 --> 00:17:45,950
the key there's no good explanation for

444
00:17:53,770 --> 00:17:51,230
Mars in every for every disc you know a

445
00:17:56,890 --> 00:17:53,780
model disc for every simulation that's

446
00:18:00,580 --> 00:17:56,900
out there no one's formed Mars that's

447
00:18:01,690 --> 00:18:00,590
small enough doing this properly and so

448
00:18:03,520 --> 00:18:01,700
that's a that's kind of a big issue

449
00:18:05,980 --> 00:18:03,530
that's still unexplained there's a

450
00:18:07,570 --> 00:18:05,990
couple of issues that they're still you

451
00:18:09,580 --> 00:18:07,580
know remain to be solved but the general

452
00:18:11,890 --> 00:18:09,590
picture looks pretty good so we have a

453
00:18:13,510 --> 00:18:11,900
decent model that can explain how our

454
00:18:15,400 --> 00:18:13,520
source is some terrestrial plants forms

455
00:18:17,260 --> 00:18:15,410
and so now we're going to do that part

456
00:18:20,230 --> 00:18:17,270
where we look at try to apply this to

457
00:18:22,240 --> 00:18:20,240
other planetary systems okay so the

458
00:18:24,460 --> 00:18:22,250
general we're going to do here is is

459
00:18:26,110 --> 00:18:24,470
looking computer simulations of how

460
00:18:28,810 --> 00:18:26,120
planets form we're going to look at

461
00:18:30,340 --> 00:18:28,820
mostly at that stage for from a few

462
00:18:32,530 --> 00:18:30,350
slides ago the final stage of

463
00:18:34,270 --> 00:18:32,540

terrestrial plant information and so

464
00:18:36,460 --> 00:18:34,280
what do our initial conditions look like

465
00:18:38,520 --> 00:18:36,470
in reality we think that there's

466
00:18:41,080 --> 00:18:38,530
probably a few hundred of these

467
00:18:43,090 --> 00:18:41,090
moon-sized planetary embryos out there

468
00:18:45,340 --> 00:18:43,100
and they're embedded in a swarm of

469
00:18:48,250 --> 00:18:45,350
trillions of kilometer-sized

470
00:18:49,840 --> 00:18:48,260
planetesimals and that we're also

471
00:18:52,960 --> 00:18:49,850
assuming the giant planets are formed by

472
00:18:54,640 --> 00:18:52,970
this time of the final agglomeration of

473
00:18:56,440 --> 00:18:54,650
thruster planets any giant planets have

474
00:18:58,570 --> 00:18:56,450
already formed so that's kind of reality

475
00:19:00,670 --> 00:18:58,580
we think that's what things are really

476
00:19:03,250 --> 00:19:00,680
like the trick is you can't simulate

477
00:19:05,980 --> 00:19:03,260
trillions of particles at least not the

478
00:19:07,510 --> 00:19:05,990
moment because our computers are too

479
00:19:09,610 --> 00:19:07,520
slow or maybe what you've done i'm not

480
00:19:11,470 --> 00:19:09,620
sure but anyhow we can't do that so

481
00:19:13,360 --> 00:19:11,480
we're using these approximations where

482
00:19:16,060 --> 00:19:13,370
you use maybe up to a couple thousand

483
00:19:19,090 --> 00:19:16,070
initial particles maybe 10 to 20 earth

484
00:19:21,049 --> 00:19:19,100
masses and and we change the water

485
00:19:22,730 --> 00:19:21,059
content of bodies based on how close

486
00:19:25,190 --> 00:19:22,740
out of the Sun from that graph I showed

487
00:19:26,239 --> 00:19:25,200
you a few minutes ago and i think i'm

488
00:19:28,129 --> 00:19:26,249

actually going too slow so i'm going to

489
00:19:30,350 --> 00:19:28,139
speed up a bit reading out this plot

490
00:19:31,999 --> 00:19:30,360
here is showing kind of a typical set of

491
00:19:33,799 --> 00:19:32,009
initial conditions these bodies here

492
00:19:36,019 --> 00:19:33,809
what you really not too easy to see

493
00:19:37,489 --> 00:19:36,029
these are plants or embryos in the disk

494
00:19:40,159 --> 00:19:37,499
of planetesimals which are these guys

495
00:19:43,159 --> 00:19:40,169
and the water content goes from very

496
00:19:44,840 --> 00:19:43,169
small so much larger further out that's

497
00:19:48,470 --> 00:19:44,850
a typical set of initial conditions and

498
00:19:51,529 --> 00:19:48,480
here is a typical simulation this is a

499
00:19:52,879 --> 00:19:51,539
simulation with one giant planet which

500
00:19:55,279 --> 00:19:52,889
is meant to represent your

501
00:19:57,769 --> 00:19:55,289
representation of Jupiter at five and a

502
00:19:59,330 --> 00:19:57,779
half a you and so the starting each

503
00:20:03,200 --> 00:19:59,340
booga alright so each of these is

504
00:20:05,509 --> 00:20:03,210
showing snapshots in time of particles

505
00:20:07,009 --> 00:20:05,519
is showing the eccentricity of each park

506
00:20:09,619 --> 00:20:07,019
which is survived in the simulation as a

507
00:20:11,810 --> 00:20:09,629
function of its orbital distance the

508
00:20:14,509 --> 00:20:11,820
color of each body represents its water

509
00:20:17,239 --> 00:20:14,519
content red means that they're dry blue

510
00:20:20,720 --> 00:20:17,249
is five percent water in this case and

511
00:20:22,340 --> 00:20:20,730
so this is kind of snapshots in time of

512
00:20:25,190 --> 00:20:22,350
one of these simulations so what happens

513
00:20:27,440 --> 00:20:25,200

within you know a hundred thousand years

514
00:20:29,239 --> 00:20:27,450
or so bodies are getting some

515
00:20:30,859 --> 00:20:29,249
eccentricities and the inner disk

516
00:20:33,680 --> 00:20:30,869
eccentricities come from scattering

517
00:20:35,269 --> 00:20:33,690
among protoplanets and the outer just

518
00:20:37,220 --> 00:20:35,279
that I centricity comes from

519
00:20:38,840 --> 00:20:37,230
interactions with a giant plant which is

520
00:20:41,600 --> 00:20:38,850
just off the picture here so these are

521
00:20:43,940 --> 00:20:41,610
these vertical spikes are mean motion

522
00:20:45,560 --> 00:20:43,950
resonances with the giant plan when

523
00:20:47,960 --> 00:20:45,570
these bodies get eccentricities that

524
00:20:50,480 --> 00:20:47,970
means they're the range of orbital

525
00:20:51,739 --> 00:20:50,490
distance over over in orbit basically

526
00:20:53,749 --> 00:20:51,749
the range of distances from the start

527
00:20:55,340 --> 00:20:53,759
over in orbit changes so they can the

528
00:20:56,989 --> 00:20:55,350
orbits can cross you can have collisions

529
00:21:00,019 --> 00:20:56,999
and you can see bodies are starting to

530
00:21:01,489 --> 00:21:00,029
grow kind of from the inside out all the

531
00:21:02,779 --> 00:21:01,499
time scales are shorter and closer to

532
00:21:05,239 --> 00:21:02,789
the star so these things happen much

533
00:21:06,710 --> 00:21:05,249
faster close to the star they form from

534
00:21:08,570 --> 00:21:06,720
the inside out after ten million years

535
00:21:10,730 --> 00:21:08,580
this guy right here is almost the mass

536
00:21:12,739 --> 00:21:10,740
of the earth but you'll notice that it's

537
00:21:14,389 --> 00:21:12,749
still its orbit is pretty close to the

538
00:21:17,149 --> 00:21:14,399

Earth's orbit it's about one of you but

539
00:21:18,619 --> 00:21:17,159
it's completely dry but still you have

540
00:21:20,960 --> 00:21:18,629
all this material is blue material which

541
00:21:23,869 --> 00:21:20,970
is on all sorts of chaotic orbits at

542
00:21:25,009 --> 00:21:23,879
this time over the last you know a few

543
00:21:27,379 --> 00:21:25,019
hundred million years of the simulation

544
00:21:29,090 --> 00:21:27,389
all that material gets swept up some of

545
00:21:31,610 --> 00:21:29,100
the pits chucked out by Jupiter some of

546
00:21:34,640 --> 00:21:31,620
it ends up on terrestrial planets

547
00:21:36,170 --> 00:21:34,650
and in the end of this one this guy

548
00:21:38,120 --> 00:21:36,180
right here is about two times the mass

549
00:21:40,040 --> 00:21:38,130
the earth its orbit is quite similar to

550
00:21:43,610 --> 00:21:40,050
the Earth's its eccentricities a little

551
00:21:45,200 --> 00:21:43,620
bit bigger but it accumulated a good

552
00:21:47,090 --> 00:21:45,210
amount of water and it's you know a

553
00:21:48,500 --> 00:21:47,100
decent representation of the earth out

554
00:21:50,990 --> 00:21:48,510
here we have some asteroid particles

555
00:21:53,630 --> 00:21:51,000
which hung around two so this is kind of

556
00:21:55,040 --> 00:21:53,640
what a typical stimulation looks like in

557
00:21:57,290 --> 00:21:55,050
terms of what goes on during the

558
00:21:58,549 --> 00:21:57,300
simulation but well I'm going to skip

559
00:21:59,960 --> 00:21:58,559
this one because I think I don't have

560
00:22:01,490 --> 00:21:59,970
time this is just showing some of the

561
00:22:05,630 --> 00:22:01,500
details of what happened in that given

562
00:22:10,400 --> 00:22:05,640
simulation an interesting thing that

563
00:22:12,020 --> 00:22:10,410

that happens is giant I mentioned before

564
00:22:13,820 --> 00:22:12,030
the giant planets are really affecting

565
00:22:15,950 --> 00:22:13,830
what's happening in this final stage of

566
00:22:17,630 --> 00:22:15,960
terrestrial plant information and one

567
00:22:19,130 --> 00:22:17,640
thing that's been noticed among the

568
00:22:21,140 --> 00:22:19,140
known giant planets is lots of them have

569
00:22:23,150 --> 00:22:21,150
relatively large orbital eccentricities

570
00:22:25,120 --> 00:22:23,160
and so how does that affect the

571
00:22:27,530 --> 00:22:25,130
terrestrial planets well if you have a

572
00:22:29,210 --> 00:22:27,540
one giant planet on the same orbit of

573
00:22:31,580 --> 00:22:29,220
Jupiter and all you do is change its

574
00:22:33,620 --> 00:22:31,590
orbital eccentricity it really affects

575
00:22:35,450 --> 00:22:33,630
the terrestrial planets and so what each

576
00:22:38,240 --> 00:22:35,460
of these panels is showing is the final

577
00:22:41,390 --> 00:22:38,250
configuration of a given simulation the

578
00:22:44,150 --> 00:22:41,400
three on the left have a jupiter-sized

579
00:22:46,160 --> 00:22:44,160
giant plan on a circular orbit these

580
00:22:48,830 --> 00:22:46,170
guys all have giant planet on with next

581
00:22:50,750 --> 00:22:48,840
tricity point 1 and here point2 and so

582
00:22:52,669 --> 00:22:50,760
the punchline is all these terrestrial

583
00:22:55,730 --> 00:22:52,679
planets look nice and green or blue they

584
00:22:58,370 --> 00:22:55,740
got lots of water more read more read so

585
00:23:01,070 --> 00:22:58,380
what's happening is that eccentricity of

586
00:23:03,049 --> 00:23:01,080
the giant planet is basically exciting

587
00:23:05,120 --> 00:23:03,059
that water rich material in the outer

588
00:23:06,980 --> 00:23:05,130

kind of an asteroid region is chucking

589
00:23:09,049 --> 00:23:06,990
it out before it gets a chance to move

590
00:23:12,710 --> 00:23:09,059
in and end up on the terrestrial planets

591
00:23:14,030 --> 00:23:12,720
and in addition to these kind of

592
00:23:16,250 --> 00:23:14,040
systematic transit I'll talk more about

593
00:23:19,100 --> 00:23:16,260
in a sec there's a lot of diversity in

594
00:23:20,570 --> 00:23:19,110
terms of the plants that can form in

595
00:23:23,830 --> 00:23:20,580
these simulations so this is the final

596
00:23:26,570 --> 00:23:23,840
configuration of 11 simulations that

597
00:23:28,250 --> 00:23:26,580
form the planet on an orbit very similar

598
00:23:30,020 --> 00:23:28,260
to the Earth's so each of these

599
00:23:32,210 --> 00:23:30,030
simulations has a planet that form

600
00:23:32,530 --> 00:23:32,220
between point one we're not 0.9 and one

601
00:23:36,400 --> 00:23:32,540
point

602
00:23:37,780 --> 00:23:36,410
you and so you notice that the plants

603
00:23:39,910 --> 00:23:37,790
themselves these habitable planets

604
00:23:41,800 --> 00:23:39,920
themselves have a range in what they can

605
00:23:42,970 --> 00:23:41,810
look like the earth is shown the solar

606
00:23:44,710 --> 00:23:42,980
system is shown on the bottom right for

607
00:23:46,810 --> 00:23:44,720
scale so sometimes they're these

608
00:23:48,460 --> 00:23:46,820
humongous water plants which have this

609
00:23:50,500 --> 00:23:48,470
guy here is about fourth masses and it

610
00:23:53,050 --> 00:23:50,510
has a ton of water on it whereas this

611
00:23:54,640 --> 00:23:53,060
one here is when I showed earlier it's a

612
00:23:56,800 --> 00:23:54,650
little smaller than the earth and it has

613
00:23:59,410 --> 00:23:56,810

no water it got unlucky in some sense

614
00:24:02,680 --> 00:23:59,420
and notice also that the systems of

615
00:24:05,530 --> 00:24:02,690
plants themselves have a large diversity

616
00:24:07,270 --> 00:24:05,540
now this this top right one has just one

617
00:24:09,580 --> 00:24:07,280
dime plant or one so i went to rest real

618
00:24:12,550 --> 00:24:09,590
client that survived whereas this one

619
00:24:14,530 --> 00:24:12,560
down here has a whole load of smaller

620
00:24:16,030 --> 00:24:14,540
planets which hung around and the

621
00:24:18,520 --> 00:24:16,040
difference is that can probably be

622
00:24:20,740 --> 00:24:18,530
explained by the giant planets and this

623
00:24:23,410 --> 00:24:20,750
top right one that the giant planet was

624
00:24:24,820 --> 00:24:23,420
three times as massive as Jupiter so it

625
00:24:27,190 --> 00:24:24,830
cleared out that material much more

626
00:24:30,280 --> 00:24:27,200
effectively than Jupiter in this in this

627
00:24:31,780 --> 00:24:30,290
case down here the only giant planet was

628
00:24:33,310 --> 00:24:31,790
about the size of Neptune and so it

629
00:24:35,140 --> 00:24:33,320
didn't end up clearing out too much and

630
00:24:39,100 --> 00:24:35,150
so there's lots of crud floating around

631
00:24:41,490 --> 00:24:39,110
yet and so this is back to that initial

632
00:24:44,170 --> 00:24:41,500
plot this is the you know a rough

633
00:24:46,270 --> 00:24:44,180
completely not the scale representation

634
00:24:48,250 --> 00:24:46,280
of some of those simulations I just

635
00:24:49,750 --> 00:24:48,260
showed you here's the solar system for

636
00:24:51,880 --> 00:24:49,760
scale and then here's kind of a very

637
00:24:57,460 --> 00:24:51,890
rough picture of some of the possible

638
00:24:58,810 --> 00:24:57,470

outcomes and kind of this diversity in

639
00:25:01,090 --> 00:24:58,820
the systems of plants that can form

640
00:25:03,460 --> 00:25:01,100
comes from two sources one of them is

641
00:25:05,200 --> 00:25:03,470
very simple it's just that what is

642
00:25:06,970 --> 00:25:05,210
called the stochastic nature of the

643
00:25:08,920 --> 00:25:06,980
accretion process and why is it

644
00:25:11,050 --> 00:25:08,930
stochastic it's because as I mentioned

645
00:25:12,910 --> 00:25:11,060
there's only a few hundred or maybe even

646
00:25:14,620 --> 00:25:12,920
less of these protoplanets these

647
00:25:16,690 --> 00:25:14,630
planetary embryos which are the building

648
00:25:18,790 --> 00:25:16,700
blocks of terrestrial planets and so

649
00:25:21,910 --> 00:25:18,800
there's lots of noise in terms of what

650
00:25:24,580 --> 00:25:21,920
can happen you know if it was basically

651
00:25:25,540 --> 00:25:24,590
is because of a small number statistics

652
00:25:29,170 --> 00:25:25,550
that you can have a large range of

653
00:25:31,210 --> 00:25:29,180
outcomes but there's also systematic

654
00:25:32,830 --> 00:25:31,220
variations which depend on the giant

655
00:25:35,290 --> 00:25:32,840
planets for example as I mentioned

656
00:25:37,090 --> 00:25:35,300
before a higher eccentricity of dying

657
00:25:39,460 --> 00:25:37,100
plants can affect trust reply

658
00:25:41,980 --> 00:25:39,470
information as well as a mass and in

659
00:25:43,960 --> 00:25:41,990
addition the key one is the disc the

660
00:25:45,410 --> 00:25:43,970
disc of material from which these

661
00:25:47,870 --> 00:25:45,420
planets form

662
00:25:50,480 --> 00:25:47,880
both the total amount of mass in the

663
00:25:51,800 --> 00:25:50,490

disc as well as the density profile of

664
00:25:54,860 --> 00:25:51,810
the discs are very important so for

665
00:25:57,320 --> 00:25:54,870
example a more massive disc stirs up

666
00:25:59,150 --> 00:25:57,330
bodies more bodies have larger

667
00:26:01,940 --> 00:25:59,160
eccentricities what does that mean that

668
00:26:04,640 --> 00:26:01,950
means that over a given orbit a planet

669
00:26:06,680 --> 00:26:04,650
is going over a wider range of distances

670
00:26:08,270 --> 00:26:06,690
from the star what that does is it makes

671
00:26:10,730 --> 00:26:08,280
the feeding zone on that planet little

672
00:26:12,440 --> 00:26:10,740
wider it makes that planet more massive

673
00:26:15,530 --> 00:26:12,450
because it's sampling more material has

674
00:26:16,700 --> 00:26:15,540
more material from which to grow but it

675
00:26:18,800 --> 00:26:16,710
also means that you're gonna have fewer

676
00:26:20,630 --> 00:26:18,810
planets because you can't stack as many

677
00:26:24,860 --> 00:26:20,640
of these feeding zones in a given a

678
00:26:26,660 --> 00:26:24,870
given zone so I think that's where I'm

679
00:26:29,600 --> 00:26:26,670
transferring over so that's the end of

680
00:26:31,670 --> 00:26:29,610
my part and I'm gonna pass it to avi now

681
00:26:35,060 --> 00:26:31,680
who should be showing up on our TV

682
00:26:38,360 --> 00:26:35,070
screen any moments so market can you

683
00:26:44,990 --> 00:26:38,370
pass the thing to have a please yes it's

684
00:26:47,090 --> 00:26:45,000
passed all right can everyone hear me I

685
00:26:49,370 --> 00:26:47,100
hope so we're we're now going to be

686
00:26:52,190 --> 00:26:49,380
talking about the next phase of the the

687
00:26:54,620 --> 00:26:52,200
different types of systems arm that we

688
00:26:57,890 --> 00:26:54,630

can examine which are systems that don't

689
00:27:01,310 --> 00:26:57,900
look very similar to our own solar

690
00:27:04,040 --> 00:27:01,320
system and as Sean said with a small

691
00:27:06,470 --> 00:27:04,050
number statistics and very chaotic

692
00:27:08,330 --> 00:27:06,480
formation process there's lots of ways

693
00:27:10,190 --> 00:27:08,340
that a system can look different than

694
00:27:12,050 --> 00:27:10,200
our own solar system but we're going to

695
00:27:15,200 --> 00:27:12,060
discuss a line of research that we've

696
00:27:17,600 --> 00:27:15,210
taken recently that specifically

697
00:27:20,090 --> 00:27:17,610
explores systems similar to the

698
00:27:22,040 --> 00:27:20,100
extrasolar planetary systems that we've

699
00:27:25,670 --> 00:27:22,050
recently discovered in the last ten

700
00:27:28,010 --> 00:27:25,680
years or so now most people know by this

701
00:27:30,530 --> 00:27:28,020
point that most of the systems found

702
00:27:33,010 --> 00:27:30,540
outside our solar system our systems

703
00:27:38,120 --> 00:27:33,020
including a closing giant planet and

704
00:27:46,430 --> 00:27:38,130
this is a planet which is very close to

705
00:27:56,040 --> 00:27:54,090
hmm nope are there it is okay systems

706
00:27:58,650 --> 00:27:56,050
where a giant planet is very close to

707
00:28:00,570 --> 00:27:58,660
its parent star and that through theory

708
00:28:04,490 --> 00:28:00,580
and and also observation of different

709
00:28:06,470 --> 00:28:04,500
systems that are forming and theory

710
00:28:09,810 --> 00:28:06,480
simulations that we've done in different

711
00:28:11,700 --> 00:28:09,820
types of situations we now realize that

712
00:28:13,770 --> 00:28:11,710
those planets probably formed out where

713
00:28:16,350 --> 00:28:13,780

Jupiter has formed in our system and

714
00:28:18,840 --> 00:28:16,360
migrated inwards through the inner

715
00:28:20,940 --> 00:28:18,850
system and then park themselves very

716
00:28:23,610 --> 00:28:20,950
close to the star so that they pass

717
00:28:25,590 --> 00:28:23,620
through the habitable zone where a

718
00:28:28,470 --> 00:28:25,600
habitable planet might be forming at the

719
00:28:31,110 --> 00:28:28,480
time and then end up removed from the

720
00:28:34,200 --> 00:28:31,120
terrestrial planet zone and so one of

721
00:28:36,210 --> 00:28:34,210
the natural questions that you have in

722
00:28:38,100 --> 00:28:36,220
this situation is Ken habitable

723
00:28:40,770 --> 00:28:38,110
terrestrial planets form in systems

724
00:28:42,810 --> 00:28:40,780
where giant planets migrate and this is

725
00:28:44,940 --> 00:28:42,820
the most obvious question when when it

726
00:28:46,890 --> 00:28:44,950
comes to systems very different from our

727
00:28:48,750 --> 00:28:46,900
own because these systems have a giant

728
00:28:51,510 --> 00:28:48,760
planet and very interior part of the

729
00:28:53,130 --> 00:28:51,520
system and may or may not have a giant

730
00:28:57,720 --> 00:28:53,140
planet in the outer part of the system

731
00:29:01,920 --> 00:28:57,730
and so previous ideas well most people

732
00:29:05,630 --> 00:29:01,930
who previously discussed these questions

733
00:29:10,020 --> 00:29:05,640
really made pure assumptions based on

734
00:29:12,180 --> 00:29:10,030
ideas about planet formation and about

735
00:29:17,220 --> 00:29:12,190
the formation of these systems that were

736
00:29:19,010 --> 00:29:17,230
mostly based on speculation on several

737
00:29:20,880 --> 00:29:19,020
different groups suggested that the

738
00:29:23,760 --> 00:29:20,890

migration of a giant planet would

739
00:29:26,370 --> 00:29:23,770
completely vacuum up or or evacuate

740
00:29:28,590 --> 00:29:26,380
through scattering the interior region

741
00:29:30,810 --> 00:29:28,600
in the system and they would have no

742
00:29:32,760 --> 00:29:30,820
giant no terrestrial planets left over

743
00:29:34,830 --> 00:29:32,770
after a giant planet migrated through on

744
00:29:36,990 --> 00:29:34,840
some groups even speculated that this

745
00:29:39,650 --> 00:29:37,000
would cause the majority of extrasolar

746
00:29:42,330 --> 00:29:39,660
planetary systems to not contain any

747
00:29:46,110 --> 00:29:42,340
terrestrial planets armed and that this

748
00:29:47,970 --> 00:29:46,120
would make the possibility of life on

749
00:29:52,830 --> 00:29:47,980
others and other other planets and other

750
00:29:55,290 --> 00:29:52,840
systems a a rare event and if you if you

751
00:29:56,470 --> 00:29:55,300
sort of moved forward due time people

752
00:29:59,200 --> 00:29:56,480
began actually investing

753
00:30:02,380 --> 00:29:59,210
this question and the first group

754
00:30:05,890 --> 00:30:02,390
suggested that nothing would be able to

755
00:30:08,590 --> 00:30:05,900
form post migration in a system but but

756
00:30:09,789 --> 00:30:08,600
these the same simulations made the same

757
00:30:12,460 --> 00:30:09,799
assumption as earlier research

758
00:30:14,200 --> 00:30:12,470
researchers suggesting that nothing

759
00:30:16,539 --> 00:30:14,210
would survive the migration and

760
00:30:18,280 --> 00:30:16,549
therefore post migration nothing no

761
00:30:20,280 --> 00:30:18,290
material not enough material would be

762
00:30:26,310 --> 00:30:20,290
left over to continue forming planets

763
00:30:29,919 --> 00:30:26,320

however arm in 2003 and 2004 we began

764
00:30:32,560 --> 00:30:29,929
researchers began making models and

765
00:30:34,270 --> 00:30:32,570
simulations that actually began testing

766
00:30:36,010 --> 00:30:34,280
this hypothesis of whether material

767
00:30:38,440 --> 00:30:36,020
could survive migration in different

768
00:30:41,230 --> 00:30:38,450
types of systems and several groups

769
00:30:43,570 --> 00:30:41,240
showed that material much of the

770
00:30:45,190 --> 00:30:43,580
material survived migration of course

771
00:30:47,169 --> 00:30:45,200
that depended on various parameters such

772
00:30:50,169 --> 00:30:47,179
as the migration rate the size of the

773
00:30:53,200 --> 00:30:50,179
objects once as migration occurred the

774
00:30:55,060 --> 00:30:53,210
size of the giant planet just as similar

775
00:30:58,500 --> 00:30:55,070
simulations that shown in systems like

776
00:31:01,030 --> 00:30:58,510
our own the systems were fine-tuned

777
00:31:04,060 --> 00:31:01,040
depending on the parameters and the

778
00:31:07,390 --> 00:31:04,070
survival rates follow these these fine

779
00:31:10,270 --> 00:31:07,400
tuning parameters and then on another

780
00:31:13,900 --> 00:31:10,280
simulation in 2005 by Sean and others

781
00:31:16,120 --> 00:31:13,910
are looked actually at post migration

782
00:31:17,770 --> 00:31:16,130
formation and basically assume that all

783
00:31:20,950 --> 00:31:17,780
material does survive taking the

784
00:31:23,680 --> 00:31:20,960
opposite assumption of earlier research

785
00:31:26,650 --> 00:31:23,690
and actually looked at the formation

786
00:31:28,600 --> 00:31:26,660
process in the presence of a giant

787
00:31:31,380 --> 00:31:28,610
planet very close to the tsar and showed

788
00:31:34,330 --> 00:31:31,390

it in that scenario that you could have

789
00:31:36,370 --> 00:31:34,340
terrestrial planets form on the outside

790
00:31:38,169 --> 00:31:36,380
of giant planets in close orbits of

791
00:31:40,150 --> 00:31:38,179
course if you look at this whole list

792
00:31:42,580 --> 00:31:40,160
you have various assumptions that need

793
00:31:45,100 --> 00:31:42,590
to be tied together in a enough complete

794
00:31:49,480 --> 00:31:45,110
formation simulation and we decided to

795
00:31:51,700 --> 00:31:49,490
do that in our work last year so we had

796
00:31:55,350 --> 00:31:51,710
to include a couple new processes that

797
00:31:57,610 --> 00:31:55,360
had been found to be important and in

798
00:32:01,000 --> 00:31:57,620
systems that were forming very early and

799
00:32:02,830 --> 00:32:01,010
if you think about um giant planet

800
00:32:04,570 --> 00:32:02,840
migration giant planet migration has to

801
00:32:08,070 --> 00:32:04,580
occur in the presence of a gas disk

802
00:32:10,889 --> 00:32:08,080
because type 2 migration which is

803
00:32:13,409 --> 00:32:10,899
the site the name for giant planet

804
00:32:17,100 --> 00:32:13,419
migration in the literature relies on

805
00:32:19,440 --> 00:32:17,110
the torques from the gas disk and lock

806
00:32:21,840 --> 00:32:19,450
it the locking of the giant planet into

807
00:32:25,019 --> 00:32:21,850
this gas disk that then as the gas this

808
00:32:27,539 --> 00:32:25,029
falls onto the inward star this inner

809
00:32:30,180 --> 00:32:27,549
star the giant planet is forced inward

810
00:32:32,700 --> 00:32:30,190
to a small orbital distance and this is

811
00:32:35,130 --> 00:32:32,710
only effective simulations have shown

812
00:32:37,799 --> 00:32:35,140
for gap opening bodies which are bodies

813
00:32:40,139 --> 00:32:37,809

that have masses more than the mass of

814
00:32:42,389 --> 00:32:40,149
Jupiter ah of course that can be

815
00:32:44,580 --> 00:32:42,399
modified depending on the disk mask or

816
00:32:47,430 --> 00:32:44,590
other other parameters but the basic

817
00:32:49,680 --> 00:32:47,440
idea is that only fully formed giant

818
00:32:51,870 --> 00:32:49,690
planets that a certain size can open a

819
00:32:55,799 --> 00:32:51,880
gap and therefore undergo type to

820
00:32:58,980 --> 00:32:55,809
migration but the key is that um the key

821
00:33:00,750 --> 00:32:58,990
is that the first parts of planet for

822
00:33:02,519 --> 00:33:00,760
thrush co plant information and giant

823
00:33:04,919 --> 00:33:02,529
planet formation of migration therefore

824
00:33:08,100 --> 00:33:04,929
occur in the presence of the gas disk

825
00:33:10,440 --> 00:33:08,110
and so aerodynamic gas drag on small

826
00:33:13,440 --> 00:33:10,450
planetesimals and larger bodies is an

827
00:33:16,080 --> 00:33:13,450
important factor in these in this part

828
00:33:18,659 --> 00:33:16,090
of this stage of terrestrial and giant

829
00:33:22,139 --> 00:33:18,669
planet formation so we had to take these

830
00:33:23,669 --> 00:33:22,149
different processes into account when we

831
00:33:26,490 --> 00:33:23,679
are actually simulating the formation of

832
00:33:29,519 --> 00:33:26,500
planets in these circumstances and so we

833
00:33:31,649 --> 00:33:29,529
put these different processes into the

834
00:33:33,990 --> 00:33:31,659
code same similar codes that Sean and I

835
00:33:36,180 --> 00:33:34,000
had used in previous research to study

836
00:33:39,149 --> 00:33:36,190
formation of planets in the later stages

837
00:33:41,100 --> 00:33:39,159
and we looked at the formation of

838
00:33:44,070 --> 00:33:41,110

terrestrial planets in the presence of

839
00:33:47,460 --> 00:33:44,080
migration of a giant planet now this is

840
00:33:49,769 --> 00:33:47,470
a a plot it's a bit complicated but it's

841
00:33:53,909 --> 00:33:49,779
a basic plot showing from top to bottom

842
00:33:55,799 --> 00:33:53,919
the evolutionary stages steps through

843
00:33:59,220 --> 00:33:55,809
the migration and subsequent evolution

844
00:34:01,080 --> 00:33:59,230
of a planetary system where the giant

845
00:34:04,200 --> 00:34:01,090
planet you can see the giant planet is

846
00:34:07,080 --> 00:34:04,210
the large black object here and the as

847
00:34:09,899 --> 00:34:07,090
Sean mentioned in previous plots the

848
00:34:13,079 --> 00:34:09,909
color scheme responds refers to the

849
00:34:14,760 --> 00:34:13,089
bottom color bar which is the water mass

850
00:34:17,309 --> 00:34:14,770
fraction with the inner bodies that are

851
00:34:19,389 --> 00:34:17,319
red having less water content and the

852
00:34:22,369 --> 00:34:19,399
outer bodies which are dark blue

853
00:34:24,440 --> 00:34:22,379
much higher water contents and so the

854
00:34:27,200 --> 00:34:24,450
jupiter-mass planet here in the top

855
00:34:30,139 --> 00:34:27,210
starts out at five AU where Jupiter

856
00:34:32,540 --> 00:34:30,149
formed an island system or similar near

857
00:34:36,770 --> 00:34:32,550
to the location where Jupiter form and

858
00:34:38,840 --> 00:34:36,780
then over 100,000 years which is on

859
00:34:42,200 --> 00:34:38,850
basically falls in between this line

860
00:34:46,159 --> 00:34:42,210
here Jupiter migrates in to about point

861
00:34:49,099 --> 00:34:46,169
two five AU migrating through the

862
00:34:50,599 --> 00:34:49,109
interior region and then stops due to

863
00:34:52,790 --> 00:34:50,609

various processes which we could talk

864
00:34:54,950 --> 00:34:52,800
about in more detail stops in the inner

865
00:34:57,740 --> 00:34:54,960
system and and remains there for the

866
00:35:00,980 --> 00:34:57,750
remainder of the simulations now you see

867
00:35:02,030 --> 00:35:00,990
a lot of the same phenomena that Sean

868
00:35:04,609 --> 00:35:02,040
and mentioned in his previous

869
00:35:07,370 --> 00:35:04,619
simulations were these are residents

870
00:35:09,560 --> 00:35:07,380
reactions eccentricity which is on the

871
00:35:11,980 --> 00:35:09,570
left here this is eccentricities and on

872
00:35:14,090 --> 00:35:11,990
the bottom is distance semi-major axis

873
00:35:17,240 --> 00:35:14,100
eccentricities pumped up within

874
00:35:18,859 --> 00:35:17,250
resonances and bodies are scattered to

875
00:35:22,370 --> 00:35:18,869
the outer system you can see in this

876
00:35:28,790 --> 00:35:22,380
this third box that bodies end up with a

877
00:35:31,290 --> 00:35:28,800
characteristic arc yeah okay sure let me

878
00:35:36,030 --> 00:35:31,300
set up the laser pointer

879
00:35:40,470 --> 00:35:36,040
okay okay I hope you guys can see better

880
00:35:42,390 --> 00:35:40,480
now as I point to this this box on this

881
00:35:45,000 --> 00:35:42,400
third box here with the characteristic

882
00:35:48,150 --> 00:35:45,010
arc of bodies that eccentricity

883
00:35:50,850 --> 00:35:48,160
increases on with semi-major axis is

884
00:35:53,760 --> 00:35:50,860
that is characteristic of scattered

885
00:35:55,710 --> 00:35:53,770
bodies where a large body scatters the

886
00:35:58,020 --> 00:35:55,720
inner bodies out to further distances

887
00:36:00,180 --> 00:35:58,030
but what is noted here is that a large

888
00:36:03,960 --> 00:36:00,190

percentage of the mass actually remains

889
00:36:05,610 --> 00:36:03,970
in the system either through low energy

890
00:36:07,980 --> 00:36:05,620
scattering events which are these bodies

891
00:36:10,020 --> 00:36:07,990
here or higher energy scattering events

892
00:36:14,220 --> 00:36:10,030
that end up with highly eccentric yet

893
00:36:17,280 --> 00:36:14,230
armed gravitationally locked orbits

894
00:36:19,110 --> 00:36:17,290
within the system and what occurs over

895
00:36:21,570 --> 00:36:19,120
the next 200 million years is that the

896
00:36:23,610 --> 00:36:21,580
system continues to evolve after the

897
00:36:26,190 --> 00:36:23,620
giant planet has removed itself from the

898
00:36:27,960 --> 00:36:26,200
rest of the system from gravitational

899
00:36:31,470 --> 00:36:27,970
interactions with the rest of the system

900
00:36:34,650 --> 00:36:31,480
you can see what happens is a migration

901
00:36:37,350 --> 00:36:34,660
of water rich material occurs through

902
00:36:39,480 --> 00:36:37,360
the interaction of small bodies with the

903
00:36:42,060 --> 00:36:39,490
gaseous disk over the remainder of the

904
00:36:44,460 --> 00:36:42,070
10 million years this is the 10 million

905
00:36:46,230 --> 00:36:44,470
year box here down here and you can see

906
00:36:47,910 --> 00:36:46,240
that a lot of the water rich material

907
00:36:50,430 --> 00:36:47,920
the smaller bodies are migrating in

908
00:36:52,530 --> 00:36:50,440
words over time the other thing that

909
00:36:55,100 --> 00:36:52,540
occurs is a damping of the system

910
00:36:57,780 --> 00:36:55,110
through gas drag and you can see that

911
00:37:00,620 --> 00:36:57,790
bodies that were high eccentricities on

912
00:37:02,820 --> 00:37:00,630
an inclination which is not shown here

913
00:37:05,760 --> 00:37:02,830

inclination is shown with the error bars

914
00:37:07,680 --> 00:37:05,770
on H on H body here these these are not

915
00:37:09,510 --> 00:37:07,690
error bars in the actual information

916
00:37:11,790 --> 00:37:09,520
plotted but actually in the inclination

917
00:37:14,700 --> 00:37:11,800
of each body and so the inclination and

918
00:37:16,830 --> 00:37:14,710
eccentricity is going damped here now

919
00:37:19,470 --> 00:37:16,840
after 10 million years the gas disk has

920
00:37:20,760 --> 00:37:19,480
disappeared has dissipated arm from the

921
00:37:23,070 --> 00:37:20,770
system and the remainder of the

922
00:37:24,600 --> 00:37:23,080
evolution occurs without the presence of

923
00:37:26,550 --> 00:37:24,610
gas dragon what you see is that

924
00:37:29,280 --> 00:37:26,560
remaining bodies in the other system

925
00:37:31,350 --> 00:37:29,290
especially are pumped up in eccentricity

926
00:37:33,450 --> 00:37:31,360
and inclination and this occurs after

927
00:37:36,240 --> 00:37:33,460
the damping force from the gas has

928
00:37:40,450 --> 00:37:36,250
disappeared and this increases accretion

929
00:37:43,310 --> 00:37:40,460
in the end the later stages of

930
00:37:45,470 --> 00:37:43,320
formation and clears out the system so

931
00:37:47,840 --> 00:37:45,480
that after 200 million years you have in

932
00:37:50,420 --> 00:37:47,850
this case one planet left in the

933
00:37:52,400 --> 00:37:50,430
habitable zone and evolution of the

934
00:37:53,720 --> 00:37:52,410
system continues at a slower rate in the

935
00:37:55,670 --> 00:37:53,730
outer part of the system so you have

936
00:37:58,550 --> 00:37:55,680
bodies remaining on that are continuing

937
00:38:01,640 --> 00:37:58,560
to evolve dynamically compared to the

938
00:38:04,010 --> 00:38:01,650

inner system and this is a similar to

939
00:38:05,750 --> 00:38:04,020
what Jean skipped over quickly which is

940
00:38:08,510 --> 00:38:05,760
just accretion trends over time and you

941
00:38:11,210 --> 00:38:08,520
can see that on for a body called a hot

942
00:38:13,430 --> 00:38:11,220
earth which um I'm going to go back one

943
00:38:15,500 --> 00:38:13,440
step to the previous you can see that

944
00:38:18,680 --> 00:38:15,510
hot Earth's are these bodies that form

945
00:38:20,540 --> 00:38:18,690
in the inside of the migrating giant

946
00:38:22,880 --> 00:38:20,550
planet now what happens is that material

947
00:38:25,220 --> 00:38:22,890
gets caught in a resonance with the

948
00:38:28,400 --> 00:38:25,230
giant planet as it moves in and this is

949
00:38:30,610 --> 00:38:28,410
aided by the forces of gas drag which

950
00:38:33,290 --> 00:38:30,620
stamps down the eccentricity and

951
00:38:35,570 --> 00:38:33,300
minimizes scattering of the of the

952
00:38:38,270 --> 00:38:35,580
material inside of the giant planet and

953
00:38:42,080 --> 00:38:38,280
what ends up as you get up get you risen

954
00:38:44,810 --> 00:38:42,090
result in a super-earth mass object

955
00:38:47,660 --> 00:38:44,820
interior to the giant planet our midst

956
00:38:50,840 --> 00:38:47,670
it's often has a one usually has a water

957
00:38:53,210 --> 00:38:50,850
content that is a mean or so of the

958
00:38:56,420 --> 00:38:53,220
material within the big giant planet and

959
00:38:59,150 --> 00:38:56,430
it's stable on on relatively long

960
00:39:00,560 --> 00:38:59,160
timescales depending on the damping

961
00:39:04,490 --> 00:39:00,570
forces in the system and that can be

962
00:39:06,040 --> 00:39:04,500
explored more at later times um but what

963
00:39:09,440 --> 00:39:06,050

you can see is that the hot earth

964
00:39:11,570 --> 00:39:09,450
receives most of its material right near

965
00:39:14,060 --> 00:39:11,580
the end of migration migration it ends

966
00:39:16,160 --> 00:39:14,070
here at ten to the fifth years while the

967
00:39:18,350 --> 00:39:16,170
bodies outside of the hot earth which

968
00:39:20,840 --> 00:39:18,360
are these outer terrestrials at 1a you

969
00:39:22,550 --> 00:39:20,850
and around 3a you received most of their

970
00:39:24,950 --> 00:39:22,560
material at later times as the gas

971
00:39:27,320 --> 00:39:24,960
dissipates the gas this disappears

972
00:39:28,850 --> 00:39:27,330
completely at ten to the seven years and

973
00:39:32,020 --> 00:39:28,860
the material begins to create at a

974
00:39:34,700 --> 00:39:32,030
faster rate once bodies are dynamically

975
00:39:37,060 --> 00:39:34,710
enhanced that their their eccentricities

976
00:39:39,560 --> 00:39:37,070
inclinations are dynamically enhanced

977
00:39:41,720 --> 00:39:39,570
however this is the water content here

978
00:39:43,310 --> 00:39:41,730
you can see the water mass fraction most

979
00:39:46,640 --> 00:39:43,320
of the bodies receive most of their

980
00:39:48,170 --> 00:39:46,650
water at the end of migration this is

981
00:39:50,240 --> 00:39:48,180
what most of the scattering occurs and

982
00:39:52,970 --> 00:39:50,250
most of the radial mixing in the in the

983
00:39:53,750 --> 00:39:52,980
system occurs here now what happens here

984
00:39:56,690 --> 00:39:53,760
at the end

985
00:39:58,670 --> 00:39:56,700
of the gas disk is that material has

986
00:40:00,770 --> 00:39:58,680
migrated inwards and as their

987
00:40:03,230 --> 00:40:00,780
eccentricities and inclinations increase

988
00:40:04,970 --> 00:40:03,240

the accretion of water rich material

989
00:40:07,010 --> 00:40:04,980
occurs more rapidly for the outer

990
00:40:09,320 --> 00:40:07,020
terrestrial planets so this just

991
00:40:11,300 --> 00:40:09,330
demonstrates a couple of the interesting

992
00:40:12,950 --> 00:40:11,310
facets of this different formation

993
00:40:16,130 --> 00:40:12,960
scenario for different types of systems

994
00:40:17,450 --> 00:40:16,140
I'm going to quickly go over the

995
00:40:21,320 --> 00:40:17,460
remainder of the slides here this is

996
00:40:26,060 --> 00:40:21,330
just a layer a layout of the giant

997
00:40:28,580 --> 00:40:26,070
interior giant supers hot Earth's inside

998
00:40:30,170 --> 00:40:28,590
the orbit of the giant plank arm these

999
00:40:33,440 --> 00:40:30,180
are from eight different simulations

1000
00:40:34,610 --> 00:40:33,450
which included gas drag in them I'll

1001
00:40:36,020 --> 00:40:34,620
explain the different types of

1002
00:40:37,790 --> 00:40:36,030
simulations later but you can see that

1003
00:40:40,220 --> 00:40:37,800
here at the top are listed the

1004
00:40:42,230 --> 00:40:40,230
resonances with the giant planet or

1005
00:40:43,340 --> 00:40:42,240
average residence is considering that

1006
00:40:45,800 --> 00:40:43,350
the planet is in a slightly different

1007
00:40:48,530 --> 00:40:45,810
orbital position as you can see that

1008
00:40:52,100 --> 00:40:48,540
what happens is that the super earth

1009
00:40:54,560 --> 00:40:52,110
bought tight bodies line up similar to

1010
00:40:56,870 --> 00:40:54,570
the resonances close to the residences

1011
00:40:59,270 --> 00:40:56,880
with the giant planet Armin and multiple

1012
00:41:01,310 --> 00:40:59,280
bodies can exist at the end of migration

1013
00:41:03,620 --> 00:41:01,320

in different residences slightly

1014
00:41:05,510 --> 00:41:03,630
interior due to their own migration due

1015
00:41:08,570 --> 00:41:05,520
to gas drag but close to the residence

1016
00:41:11,030 --> 00:41:08,580
position with the giant planet the

1017
00:41:13,280 --> 00:41:11,040
problem is that once gas disappears and

1018
00:41:15,770 --> 00:41:13,290
the dissipating effect of small bodies

1019
00:41:18,010 --> 00:41:15,780
as you can see here diminishes these

1020
00:41:21,530 --> 00:41:18,020
bodies can become unstable due to their

1021
00:41:23,960 --> 00:41:21,540
clothes on proximity to the central star

1022
00:41:25,490 --> 00:41:23,970
and to the giant planet I mean this is

1023
00:41:27,230 --> 00:41:25,500
something to be explored further in

1024
00:41:30,080 --> 00:41:27,240
other simulations the stability of these

1025
00:41:32,570 --> 00:41:30,090
bodies but this demonstrates that hot

1026
00:41:34,160 --> 00:41:32,580
Earth's can form through migration of

1027
00:41:35,630 --> 00:41:34,170
the giant planet and these bodies have

1028
00:41:38,900 --> 00:41:35,640
actually been discovered around several

1029
00:41:43,010 --> 00:41:38,910
stars recently in extrasolar planetary

1030
00:41:45,920 --> 00:41:43,020
systems now this slide that shows the

1031
00:41:47,870 --> 00:41:45,930
outcome of all 12 simulations on with a

1032
00:41:50,690 --> 00:41:47,880
giant with giant planet migration and

1033
00:41:52,100 --> 00:41:50,700
they include different parameters for

1034
00:41:54,980 --> 00:41:52,110
the initial conditions of the

1035
00:41:57,440 --> 00:41:54,990
simulations the top for simulations have

1036
00:42:00,020 --> 00:41:57,450
no gas drag while the bottom two

1037
00:42:00,440 --> 00:42:00,030
simulations do include gas drag from the

1038
00:42:02,839 --> 00:42:00,450

outer

1039
00:42:07,040 --> 00:42:02,849
is these top simulations were performed

1040
00:42:09,190 --> 00:42:07,050
mostly on as an end point on limitation

1041
00:42:12,920 --> 00:42:09,200
on the effects of gas drag to explore

1042
00:42:15,079 --> 00:42:12,930
how a system with no gas in it might

1043
00:42:16,940 --> 00:42:15,089
evolve over over the full lifetime of

1044
00:42:19,490 --> 00:42:16,950
the system and to be able to compare

1045
00:42:21,920 --> 00:42:19,500
with the other two simulations the other

1046
00:42:23,839 --> 00:42:21,930
two simulations this the one in the

1047
00:42:25,880 --> 00:42:23,849
middle the second one here includes both

1048
00:42:28,550 --> 00:42:25,890
Jupiter and Saturn you can see a

1049
00:42:31,280 --> 00:42:28,560
jupiter-mass body has migrated inwards

1050
00:42:34,579 --> 00:42:31,290
while a Saturn mass body remains in the

1051
00:42:36,109 --> 00:42:34,589
outer system and this includes no Saturn

1052
00:42:38,750 --> 00:42:36,119
mass body in the outer part of the

1053
00:42:40,670 --> 00:42:38,760
system and only one giant planet a

1054
00:42:44,150 --> 00:42:40,680
jupiter-mass body that is migrated in

1055
00:42:47,240 --> 00:42:44,160
and you can see in all simulations even

1056
00:42:49,300 --> 00:42:47,250
the simulations without any gas drag no

1057
00:42:52,640 --> 00:42:49,310
presence of a gas this you can see that

1058
00:42:56,680 --> 00:42:52,650
or close to Earth mass objects or in

1059
00:42:59,270 --> 00:42:56,690
many cases multi earth-mass objects arm

1060
00:43:01,130 --> 00:42:59,280
exist in the habitable zone of these

1061
00:43:03,890 --> 00:43:01,140
different systems on the bottom here you

1062
00:43:06,319 --> 00:43:03,900
see a schematic of the solar system with

1063
00:43:09,160 --> 00:43:06,329

earth Venus and Mars and the habitable

1064
00:43:12,680 --> 00:43:09,170
zone between point 8 + 1.5 a year system

1065
00:43:15,800 --> 00:43:12,690
and the system several of them have have

1066
00:43:19,069 --> 00:43:15,810
not finished evolving you can see this

1067
00:43:21,020 --> 00:43:19,079
JD 5 has most most likely cleared out

1068
00:43:23,140 --> 00:43:21,030
most bodies in the inner system while

1069
00:43:26,930 --> 00:43:23,150
other systems continue to evolve over

1070
00:43:28,040 --> 00:43:26,940
the next multi several billion years it

1071
00:43:30,589 --> 00:43:28,050
would take much longer than these

1072
00:43:33,530 --> 00:43:30,599
simulations have been integrated for it

1073
00:43:35,599 --> 00:43:33,540
to fully explore the evolution of the

1074
00:43:39,230 --> 00:43:35,609
outer system but you can see that very

1075
00:43:41,270 --> 00:43:39,240
water rich bodies form this is due to

1076
00:43:43,309 --> 00:43:41,280
the migration of water rich material and

1077
00:43:45,770 --> 00:43:43,319
the radial mixing from the migration

1078
00:43:47,359 --> 00:43:45,780
that occurs common and bodies are much

1079
00:43:50,359 --> 00:43:47,369
less water rich when you don't include

1080
00:43:52,880 --> 00:43:50,369
gas drag that's naturally due to the

1081
00:43:54,290 --> 00:43:52,890
lack of migrating smaller bodies from

1082
00:43:56,720 --> 00:43:54,300
the outer system which are water rich

1083
00:44:01,490 --> 00:43:56,730
and contribute to the water fraction

1084
00:44:04,430 --> 00:44:01,500
learning system so um this is a artist

1085
00:44:06,200 --> 00:44:04,440
rendition of one of these water rich

1086
00:44:07,520 --> 00:44:06,210
planets you can see that the planet

1087
00:44:10,490 --> 00:44:07,530
would most likely be covered completely

1088
00:44:12,079 --> 00:44:10,500

by global oceans that's D do the fact

1089
00:44:13,019 --> 00:44:12,089
that the water mass fraction is almost a

1090
00:44:15,359 --> 00:44:13,029
tenth

1091
00:44:16,799 --> 00:44:15,369
of the the solid material the rest of

1092
00:44:19,049 --> 00:44:16,809
the solid material on the planet and

1093
00:44:20,489 --> 00:44:19,059
therefore since the density is lower for

1094
00:44:22,169 --> 00:44:20,499
water most of it would be on the outer

1095
00:44:25,049 --> 00:44:22,179
parts of the planet and you would have

1096
00:44:29,249 --> 00:44:25,059
vast oceans and you can have a little

1097
00:44:32,069 --> 00:44:29,259
fun and talk about biological evolution

1098
00:44:34,409 --> 00:44:32,079
and possible large biological organisms

1099
00:44:37,199 --> 00:44:34,419
that might grow new systems but um we'll

1100
00:44:39,029 --> 00:44:37,209
leave that to later ah but the more

1101
00:44:41,189 --> 00:44:39,039
important factors what might we be able

1102
00:44:43,019 --> 00:44:41,199
to tell about known extrasolar planets

1103
00:44:45,089 --> 00:44:43,029
in other systems and this is just a

1104
00:44:47,729 --> 00:44:45,099
schematic various different ways of

1105
00:44:49,589 --> 00:44:47,739
representing extrasolar planetary

1106
00:44:52,019 --> 00:44:49,599
systems that have been discovered in the

1107
00:44:55,439 --> 00:44:52,029
last ten years on this pot on the lower

1108
00:44:59,999 --> 00:44:55,449
left shows semi-major axis the distance

1109
00:45:01,559 --> 00:45:00,009
with eccentricity of 168 planets known

1110
00:45:03,899 --> 00:45:01,569
around other stars and you can see that

1111
00:45:05,789 --> 00:45:03,909
a large fraction of the systems have

1112
00:45:08,699 --> 00:45:05,799
planets very close to their parent star

1113
00:45:12,029 --> 00:45:08,709

within point 1 au of their parent star

1114
00:45:15,149 --> 00:45:12,039
and systems farther out may have very

1115
00:45:17,219 --> 00:45:15,159
large eccentricities on or very low

1116
00:45:19,289 --> 00:45:17,229
eccentricities it's it's unclear what

1117
00:45:21,809 --> 00:45:19,299
drives the full range of eccentricities

1118
00:45:24,479 --> 00:45:21,819
and these systems we have not yet begun

1119
00:45:26,370 --> 00:45:24,489
to explore the region out past five AU

1120
00:45:28,259 --> 00:45:26,380
where Jupiter currently exists and

1121
00:45:30,989 --> 00:45:28,269
that's our that's hopefully going to

1122
00:45:33,890 --> 00:45:30,999
bring a whole new phase of planetary

1123
00:45:35,969 --> 00:45:33,900
exploration in the next ten years or so

1124
00:45:37,229 --> 00:45:35,979
you can see that systems are very

1125
00:45:39,329 --> 00:45:37,239
different from our inner solar system

1126
00:45:41,549 --> 00:45:39,339
you can see the upsilon Andromeda system

1127
00:45:43,620 --> 00:45:41,559
has three massive planets within the

1128
00:45:45,689 --> 00:45:43,630
range that our own in our solar system

1129
00:45:47,159 --> 00:45:45,699
and so these planets can be these

1130
00:45:49,859 --> 00:45:47,169
systems can be very different in the

1131
00:45:52,849 --> 00:45:49,869
size and orientation of these planets of

1132
00:45:56,159 --> 00:45:52,859
these systems so I'm going to move on

1133
00:45:57,839 --> 00:45:56,169
the as Sean mentioned you can you can

1134
00:46:00,809 --> 00:45:57,849
take these simulations that we produced

1135
00:46:03,449 --> 00:46:00,819
of planets that have migrated to their

1136
00:46:09,479 --> 00:46:03,459
inner part of their system and you can

1137
00:46:12,509 --> 00:46:09,489
try to come up with the a limit for how

1138
00:46:14,789 --> 00:46:12,519

terrestrial planets might form in

1139
00:46:17,699 --> 00:46:14,799
systems of different giant planet

1140
00:46:19,890 --> 00:46:17,709
orientation now if you look at this I'm

1141
00:46:23,039 --> 00:46:19,900
going to skip through to be able to get

1142
00:46:25,169 --> 00:46:23,049
some of the some of the lines that are

1143
00:46:26,330 --> 00:46:25,179
drawn on here if you look at the inner

1144
00:46:29,330 --> 00:46:26,340
giant planets you

1145
00:46:32,930 --> 00:46:29,340
can see that within a bit a proximity to

1146
00:46:36,230 --> 00:46:32,940
their to their they have a close

1147
00:46:37,760 --> 00:46:36,240
proximity a close proximity to

1148
00:46:40,280 --> 00:46:37,770
terrestrial planets that are formed

1149
00:46:43,790 --> 00:46:40,290
outside of these giant planets however

1150
00:46:45,980 --> 00:46:43,800
at minimum a factor of nine in orbital

1151
00:46:48,200 --> 00:46:45,990
period from the closest terrestrial

1152
00:46:51,860 --> 00:46:48,210
planet formed through the giant planet

1153
00:46:53,780 --> 00:46:51,870
arm in each in each system formed here

1154
00:46:55,820 --> 00:46:53,790
out of all of these eight systems the

1155
00:46:57,470 --> 00:46:55,830
closest proximity of a terrestrial

1156
00:47:00,020 --> 00:46:57,480
planet to a giant planet is about a

1157
00:47:03,770 --> 00:47:00,030
factor of nine in orbital period and if

1158
00:47:05,900 --> 00:47:03,780
you expand this out words basically to

1159
00:47:09,080 --> 00:47:05,910
look at the closest proximity that a

1160
00:47:11,110 --> 00:47:09,090
giant planet could be to a terrestrial

1161
00:47:14,600 --> 00:47:11,120
planet that forms in the habitable zone

1162
00:47:17,270 --> 00:47:14,610
you end up with a closest approach of

1163
00:47:18,920 --> 00:47:17,280

about point five AU if you moved one of

1164
00:47:21,200 --> 00:47:18,930
these giant planets throughout about

1165
00:47:23,030 --> 00:47:21,210
point five AU then you would have a

1166
00:47:25,640 --> 00:47:23,040
terrestrial planet forming at the outer

1167
00:47:27,890 --> 00:47:25,650
edge of the habitable zone now if you do

1168
00:47:31,070 --> 00:47:27,900
it get a similar result on from Raymond

1169
00:47:34,640 --> 00:47:31,080
at all 2005 in 2006 this gives an outer

1170
00:47:37,100 --> 00:47:34,650
limit of about 2.5 au for outer giant

1171
00:47:39,560 --> 00:47:37,110
planets and then you end up with a plot

1172
00:47:41,270 --> 00:47:39,570
that looks the plot that Sean showed at

1173
00:47:44,150 --> 00:47:41,280
the beginning of the talk which gives

1174
00:47:47,930 --> 00:47:44,160
limits on known extrasolar planetary

1175
00:47:51,410 --> 00:47:47,940
systems based on the proximity of a

1176
00:47:54,050 --> 00:47:51,420
plant of a terrestrial planet forming in

1177
00:47:55,760 --> 00:47:54,060
relation to the giant planet and so it

1178
00:47:57,680 --> 00:47:55,770
can be shown that about a third of known

1179
00:48:01,970 --> 00:47:57,690
exoplanet systems could have formed a

1180
00:48:05,270 --> 00:48:01,980
habitable planet arm in the in known

1181
00:48:07,550 --> 00:48:05,280
episode systems in the Tabata Buhl's own

1182
00:48:11,180 --> 00:48:07,560
compared to the giant planets now this

1183
00:48:12,950 --> 00:48:11,190
is sean said assumes certain parameters

1184
00:48:15,620 --> 00:48:12,960
the giant planet has to have a low

1185
00:48:17,450 --> 00:48:15,630
eccentricity and it it's unclear what

1186
00:48:19,910 --> 00:48:17,460
the scaling with disk mask would be if

1187
00:48:21,860 --> 00:48:19,920
you have large stellar masses with the

1188
00:48:24,410 --> 00:48:21,870

disk mass be larger and with this that

1189
00:48:26,360 --> 00:48:24,420
change the formation and the proximity

1190
00:48:29,090 --> 00:48:26,370
of formation to the giant planets but

1191
00:48:31,010 --> 00:48:29,100
this is a first attempt at creating what

1192
00:48:35,019 --> 00:48:31,020
could be known as a habitable formation

1193
00:48:37,759 --> 00:48:35,029
zone in known exoplanet systems

1194
00:48:39,950 --> 00:48:37,769
so if you look again at the diversity of

1195
00:48:41,809 --> 00:48:39,960
habitable planetary systems you can look

1196
00:48:44,150 --> 00:48:41,819
at the solar system you can look at a

1197
00:48:48,259 --> 00:48:44,160
giant planet which is only 10 or if

1198
00:48:50,390 --> 00:48:48,269
masses and you form planetary habitable

1199
00:48:52,190 --> 00:48:50,400
planets in different formations more

1200
00:48:55,579 --> 00:48:52,200
possibly more habitable planets and more

1201
00:48:58,279 --> 00:48:55,589
water rich planets if you have you could

1202
00:49:01,940 --> 00:48:58,289
have a suit a saturn mass planet which

1203
00:49:04,190 --> 00:49:01,950
forms possibly super Earths which have

1204
00:49:06,170 --> 00:49:04,200
our very water rich and then you can

1205
00:49:09,589 --> 00:49:06,180
form systems with a jupiter-mass planet

1206
00:49:12,319 --> 00:49:09,599
interior system at small distances and

1207
00:49:14,870 --> 00:49:12,329
they have possible possibly very water

1208
00:49:18,380 --> 00:49:14,880
rich planets as well as hot Earth's in

1209
00:49:19,519 --> 00:49:18,390
this hot Jupiter system so we moving

1210
00:49:20,749 --> 00:49:19,529
through this slide when are we going to

1211
00:49:23,180 --> 00:49:20,759
find terrestrial planets around other

1212
00:49:24,589 --> 00:49:23,190
stars there's a number of missions that

1213
00:49:27,410 --> 00:49:24,599

are going up within the next ten years

1214
00:49:29,599 --> 00:49:27,420
kuro actually goes up hopefully by the

1215
00:49:31,729 --> 00:49:29,609
end of this year in 2006 and we'll be

1216
00:49:34,489 --> 00:49:31,739
able to detect two to three earth-mass

1217
00:49:37,099 --> 00:49:34,499
planets in the habitable zone of systems

1218
00:49:41,059 --> 00:49:37,109
like this Kepler will hopefully go up in

1219
00:49:42,920 --> 00:49:41,069
2009 and will will detect many more

1220
00:49:45,819 --> 00:49:42,930
earth-like planets possibly fifty

1221
00:49:48,880 --> 00:49:45,829
terrestrial planets and then these other

1222
00:49:51,410 --> 00:49:48,890
other missions are further delayed but

1223
00:49:53,329 --> 00:49:51,420
will have much greater chance to find

1224
00:49:55,969 --> 00:49:53,339
earth-like planets in the habitable zone

1225
00:49:58,309 --> 00:49:55,979
and possibly detect the spectra of

1226
00:50:00,709 --> 00:49:58,319
terrestrial planets to figure out what

1227
00:50:03,259 --> 00:50:00,719
the water content is and possibly what

1228
00:50:08,450 --> 00:50:03,269
the possibility of life is on those

1229
00:50:10,069 --> 00:50:08,460
planets conclusions very similar to the

1230
00:50:12,799 --> 00:50:10,079
ones we've mentioned multiple times

1231
00:50:16,729 --> 00:50:12,809
habitable planets like our own can form

1232
00:50:18,529 --> 00:50:16,739
a diverse range of planetary systems

1233
00:50:21,259 --> 00:50:18,539
with giant planets and different masses

1234
00:50:24,200 --> 00:50:21,269
orbits and they may have very different

1235
00:50:26,089 --> 00:50:24,210
compositions of these plants earth-like

1236
00:50:27,380 --> 00:50:26,099
planets can be very similar or very

1237
00:50:30,049 --> 00:50:27,390
different from our own earth-like

1238
00:50:31,999 --> 00:50:30,059

planets can conform with low water

1239
00:50:33,979 --> 00:50:32,009
contents or with very high water

1240
00:50:35,749 --> 00:50:33,989
contents possibly being water worlds or

1241
00:50:38,200 --> 00:50:35,759
desert worlds as Sean mentioned at the

1242
00:50:39,829 --> 00:50:38,210
beginning and giant planet dynamics

1243
00:50:41,989 --> 00:50:39,839
drastically affect the growth of

1244
00:50:44,989 --> 00:50:41,999
terrestrial planets and they're almost

1245
00:50:47,390 --> 00:50:44,999
always negative effects if you have very

1246
00:50:48,339 --> 00:50:47,400
few or very small giant planets in the

1247
00:50:49,779 --> 00:50:48,349
system

1248
00:50:52,120 --> 00:50:49,789
you will have very large and very water

1249
00:50:54,849 --> 00:50:52,130
rich terrestrial planets forming in that

1250
00:50:56,769 --> 00:50:54,859
system while if giant planets reside in

1251
00:50:58,509 --> 00:50:56,779
or near the habitable zone for long

1252
00:51:00,039 --> 00:50:58,519
periods of time you will have a very low

1253
00:51:04,539 --> 00:51:00,049
probability of having a habitable planet

1254
00:51:06,130 --> 00:51:04,549
and now using these using these factors

1255
00:51:08,289 --> 00:51:06,140
we can hope to begin to predict the

1256
00:51:11,650 --> 00:51:08,299
nature and have ability of extra solar

1257
00:51:14,799 --> 00:51:11,660
terrestrial planets hopefully useful for

1258
00:51:18,099 --> 00:51:14,809
future missions however we have to

1259
00:51:20,499 --> 00:51:18,109
really improve these models to to truly

1260
00:51:23,440 --> 00:51:20,509
understand the diversity of habitable

1261
00:51:24,759 --> 00:51:23,450
planets and different systems and these

1262
00:51:26,440 --> 00:51:24,769
are all the different ways that models

1263
00:51:29,259 --> 00:51:26,450

hopefully will be improved in the coming

1264
00:51:31,390 --> 00:51:29,269
years and we're reaching for this final

1265
00:51:33,670 --> 00:51:31,400
final point number four a holistic

1266
00:51:35,589 --> 00:51:33,680
planet formation model which is core

1267
00:51:39,069 --> 00:51:35,599
accretion of both terrestrial giant

1268
00:51:42,849 --> 00:51:39,079
planets with accurate water transport

1269
00:51:45,190 --> 00:51:42,859
and and destruction and formation of

1270
00:51:47,200 --> 00:51:45,200
water-rich bodies in the system and

1271
00:51:49,450 --> 00:51:47,210
hopefully we can predict the frequency

1272
00:51:52,029 --> 00:51:49,460
and diversity of planetary systems in

1273
00:51:54,729 --> 00:51:52,039
different environments so if you have

1274
00:51:58,180 --> 00:51:54,739
more questions you can contact sean or

1275
00:51:59,709 --> 00:51:58,190
me at our different emails the other

1276
00:52:02,049 --> 00:51:59,719
collaborator on the recent research

1277
00:52:05,829 --> 00:52:02,059
which signed sigurdsson my advisor at

1278
00:52:07,420 --> 00:52:05,839
penn state and you can also check out

1279
00:52:08,920 --> 00:52:07,430
shawn's website and read the different

1280
00:52:11,140 --> 00:52:08,930
papers that we've noted in this

1281
00:52:13,599 --> 00:52:11,150
presentation so leave it open to

1282
00:52:15,190 --> 00:52:13,609
questions that we have time for now at

1283
00:52:20,740 --> 00:52:15,200
the end and I guess we'll give the ball

1284
00:52:34,359 --> 00:52:32,030
there's anyone any question how we doing

1285
00:52:38,230 --> 00:52:34,369
questions we do them locally first of it

1286
00:52:42,170 --> 00:52:38,240
yeah go ahead do the local questions oh

1287
00:52:44,030 --> 00:52:42,180
okay go for Nick it seems like you're

1288
00:52:46,670 --> 00:52:44,040

the death sentence that you give to

1289
00:52:49,250 --> 00:52:46,680
desert world's comes from the assumption

1290
00:52:51,589 --> 00:52:49,260
that all water comes from asteroids so I

1291
00:52:54,589 --> 00:52:51,599
was hoping to see cometary water is one

1292
00:52:57,200 --> 00:52:54,599
of your future additions to the model

1293
00:52:59,359 --> 00:52:57,210
yes but you have reasons for thinking

1294
00:53:01,579 --> 00:52:59,369
it's not the most importantly how do

1295
00:53:03,349 --> 00:53:01,589
best become the most important role as

1296
00:53:05,150 --> 00:53:03,359
an asteroid water is not available I

1297
00:53:07,549 --> 00:53:05,160
agree we're actually looking at this the

1298
00:53:09,470 --> 00:53:07,559
moment with a naked at the University of

1299
00:53:10,670 --> 00:53:09,480
Washington we're in the process of

1300
00:53:11,780 --> 00:53:10,680
looking at that as well I guess we

1301
00:53:14,660 --> 00:53:11,790
didn't specifically mention it but

1302
00:53:16,220 --> 00:53:14,670
that's key to the puzzle as well in some

1303
00:53:19,400 --> 00:53:16,230
cases commentary water might be the

1304
00:53:22,190 --> 00:53:19,410
dominant source but they're done now

1305
00:53:24,289 --> 00:53:22,200
question for Augie what was the gas to

1306
00:53:26,299 --> 00:53:24,299
dust ratio in the simulations that you

1307
00:53:31,490 --> 00:53:26,309
showed and how is the outcome depend

1308
00:53:33,799 --> 00:53:31,500
upon the ratio well in the last

1309
00:53:35,660 --> 00:53:33,809
simulations we assume we start with a

1310
00:53:38,630 --> 00:53:35,670
certain amount of solid material

1311
00:53:40,609 --> 00:53:38,640
basically about between 15 and 20 earth

1312
00:53:44,599 --> 00:53:40,619
masses of material total in the system

1313
00:53:46,849 --> 00:53:44,609

and this is this is using this could be

1314
00:53:51,020 --> 00:53:46,859
said to be using a general gas the dust

1315
00:53:54,380 --> 00:53:51,030
ratio of about point 1 or 0 point 0 1

1316
00:53:56,900 --> 00:53:54,390
with the start point 0 1 for about 100

1317
00:53:59,270 --> 00:53:56,910
for the gas the desk ratio which is if

1318
00:54:01,190 --> 00:53:59,280
you assume point O one one-hundredth of

1319
00:54:03,470 --> 00:54:01,200
the mass of the star for the total mass

1320
00:54:06,230 --> 00:54:03,480
of the disk and 100 for the gas that's

1321
00:54:08,720 --> 00:54:06,240
ratio you get about 15 to 20 earth

1322
00:54:10,430 --> 00:54:08,730
masses of material in the system now the

1323
00:54:12,039 --> 00:54:10,440
way that the gas the dust ratio could

1324
00:54:17,390 --> 00:54:12,049
affect the final results would basically

1325
00:54:19,069 --> 00:54:17,400
be in the how quickly how much mass you

1326
00:54:21,620 --> 00:54:19,079
begin with at the beginning and how

1327
00:54:24,349 --> 00:54:21,630
quickly bodies would form in the system

1328
00:54:26,200 --> 00:54:24,359
as I mentioned at the beginning there's

1329
00:54:28,400 --> 00:54:26,210
a lot of uncertainty in how

1330
00:54:29,760 --> 00:54:28,410
kilometer-sized bodies how planetesimals

1331
00:54:33,090 --> 00:54:29,770
form and how

1332
00:54:36,140 --> 00:54:33,100
how that process is contingent on the

1333
00:54:38,250 --> 00:54:36,150
gas dust ratio is pretty uncertain um

1334
00:54:39,960 --> 00:54:38,260
we're hopefully going to be exploring a

1335
00:54:42,060 --> 00:54:39,970
little more of these factors as we as we

1336
00:54:44,010 --> 00:54:42,070
bring the simulations a little earlier

1337
00:54:46,290 --> 00:54:44,020
in the formation process to smaller

1338
00:54:49,350 --> 00:54:46,300

bodies many more smaller bodies in the

1339
00:54:53,160 --> 00:54:49,360
guest in the guest is but you're right

1340
00:54:58,050 --> 00:54:53,170
that the gas this ratio will affect both

1341
00:55:03,360 --> 00:54:58,060
the rapidity and size of the formation

1342
00:55:07,410 --> 00:55:03,370
of bodies and also the the effectiveness

1343
00:55:10,290 --> 00:55:07,420
of gas drag on those bodies could follow

1344
00:55:13,890 --> 00:55:10,300
up you remove the gas instantaneously at

1345
00:55:17,340 --> 00:55:13,900
a certain time or as a declining gas the

1346
00:55:18,990 --> 00:55:17,350
bust ratio of the models there's a

1347
00:55:23,100 --> 00:55:19,000
there's a decline well there's a

1348
00:55:25,560 --> 00:55:23,110
declining gas to solid ratio so there's

1349
00:55:27,890 --> 00:55:25,570
the declining gas the dust ratio what we

1350
00:55:31,500 --> 00:55:27,900
do is we start with a certain amount of

1351
00:55:34,410 --> 00:55:31,510
solid material we do not add particles

1352
00:55:37,470 --> 00:55:34,420
over time so we we assume that the

1353
00:55:39,540 --> 00:55:37,480
majority of large bodies were formed by

1354
00:55:41,640 --> 00:55:39,550
the start of our simulations so

1355
00:55:44,250 --> 00:55:41,650
additional planetesimals are not being

1356
00:55:47,340 --> 00:55:44,260
added to the simulation while the gas

1357
00:55:48,810 --> 00:55:47,350
mass is decreasing from the beginning of

1358
00:55:51,300 --> 00:55:48,820
the simulation until it disappears

1359
00:55:54,090 --> 00:55:51,310
completely at 10 million years so in

1360
00:55:58,800 --> 00:55:54,100
that sense the gas to dust ratio or the

1361
00:56:02,000 --> 00:55:58,810
gas to solid ratio he clowns 20 x 10

1362
00:56:09,350 --> 00:56:05,660
friend your conclusions were that you're

1363
00:56:12,740 --> 00:56:09,360

better off without gas giants and you

1364
00:56:15,770 --> 00:56:12,750
seem to like one or maybe two but we

1365
00:56:21,830 --> 00:56:15,780
have four so um how do you prevent

1366
00:56:24,590 --> 00:56:21,840
making gas giants well I mean alright

1367
00:56:26,720 --> 00:56:24,600
that's a big question so did everyone

1368
00:56:31,190 --> 00:56:26,730
hear the question okay I assume everyone

1369
00:56:32,840 --> 00:56:31,200
heard the question so basically what

1370
00:56:34,850 --> 00:56:32,850
we're saying was that gas giants are

1371
00:56:37,040 --> 00:56:34,860
usually a bad influence on terrestrial

1372
00:56:39,890 --> 00:56:37,050
plant information they sweep up material

1373
00:56:42,380 --> 00:56:39,900
they kept a lot of material out they

1374
00:56:43,790 --> 00:56:42,390
don't end up actually delivering much

1375
00:56:45,800 --> 00:56:43,800
water they don't really help the water

1376
00:56:47,420 --> 00:56:45,810
delivery process at all they just screw

1377
00:56:49,460 --> 00:56:47,430
everything up and our plot that we

1378
00:56:51,740 --> 00:56:49,470
showed on which giant planet orbits a

1379
00:56:53,780 --> 00:56:51,750
lot of terrestrial planets to form is

1380
00:56:55,310 --> 00:56:53,790
not which Jenna planet ornament you know

1381
00:56:57,260 --> 00:56:55,320
which giant planets can smile and say

1382
00:56:59,090 --> 00:56:57,270
hey trust your plants everything's happy

1383
00:57:02,060 --> 00:56:59,100
it's which ones don't screw everything

1384
00:57:03,980 --> 00:57:02,070
up so that restaurants can be there so

1385
00:57:06,620 --> 00:57:03,990
the trick is how many systems actually

1386
00:57:08,270 --> 00:57:06,630
have giant planets to start with there's

1387
00:57:11,000 --> 00:57:08,280
an interesting new observation

1388
00:57:13,580 --> 00:57:11,010

suggesting that the population of known

1389
00:57:16,850 --> 00:57:13,590
debris disks or you have rocky material

1390
00:57:19,790 --> 00:57:16,860
accreting in some sense is actually an T

1391
00:57:22,580 --> 00:57:19,800
correlated with the known giant plant

1392
00:57:25,240 --> 00:57:22,590
systems so there are lots of systems out

1393
00:57:28,070 --> 00:57:25,250
there where rocky things are colliding

1394
00:57:29,930 --> 00:57:28,080
but there's no giant planets and it's

1395
00:57:32,000 --> 00:57:29,940
hard to put a number on it right now but

1396
00:57:34,550 --> 00:57:32,010
it might turn out that a large fraction

1397
00:57:37,280 --> 00:57:34,560
maybe the majority of plant systems have

1398
00:57:40,310 --> 00:57:37,290
no jupiter-sized giant planets or at

1399
00:57:42,290 --> 00:57:40,320
least no inner detectable currently

1400
00:57:45,230 --> 00:57:42,300
detectable you know jupiter-sized

1401
00:57:49,150 --> 00:57:45,240
planets so so how do you do that you

1402
00:57:51,890 --> 00:57:49,160
don't have ice or you don't have gas

1403
00:57:54,710 --> 00:57:51,900
twining yeah there's lots of

1404
00:57:56,030 --> 00:57:54,720
possibilities I mean depending who you

1405
00:57:58,600 --> 00:57:56,040
talk to you John planets are either very

1406
00:58:01,010 --> 00:57:58,610
easy to form or very hard to form and so

1407
00:58:02,570 --> 00:58:01,020
the reason this would happen maybe the

1408
00:58:05,120 --> 00:58:02,580
discs dissipates too quickly maybe the

1409
00:58:07,400 --> 00:58:05,130
gas has gone too fast for runaway gas

1410
00:58:10,430 --> 00:58:07,410
accretion to happen maybe the amount of

1411
00:58:12,260 --> 00:58:10,440
solid material is lower maybe the time

1412
00:58:14,480 --> 00:58:12,270
scale is simply too long for these

1413
00:58:16,490 --> 00:58:14,490

things too it's a girl to a given boat

1414
00:58:17,540 --> 00:58:16,500
or maybe it's too hot right so there's

1415
00:58:19,730 --> 00:58:17,550
lots of ways that you can do that or

1416
00:58:23,870 --> 00:58:19,740
maybe they foreman are destroyed that's

1417
00:58:26,990 --> 00:58:23,880
also possible oh I yeah if I could add

1418
00:58:30,560 --> 00:58:27,000
to that the the formation scenarios for

1419
00:58:33,230 --> 00:58:30,570
giant planets suggests that you need to

1420
00:58:35,720 --> 00:58:33,240
get to a certain critical point a

1421
00:58:39,170 --> 00:58:35,730
critical mass or a or a critical cooling

1422
00:58:40,820 --> 00:58:39,180
rate on actually since we don't run

1423
00:58:42,740 --> 00:58:40,830
simulations on giant plant information

1424
00:58:44,750 --> 00:58:42,750
we can't comment in detail on this but

1425
00:58:47,090 --> 00:58:44,760
the idea is that you need to have a

1426
00:58:48,770 --> 00:58:47,100
critical point where a gas giant will

1427
00:58:52,160 --> 00:58:48,780
either have a critical run away gasps

1428
00:58:55,310 --> 00:58:52,170
accretion or a gravitational collapse

1429
00:58:58,070 --> 00:58:55,320
now you could have if you have either a

1430
00:59:00,170 --> 00:58:58,080
small amount of gas or a rapid

1431
00:59:03,260 --> 00:59:00,180
evacuation of the gas in the system in

1432
00:59:05,170 --> 00:59:03,270
high mass systems you could have solid

1433
00:59:07,760 --> 00:59:05,180
bodies for me without the actual

1434
00:59:08,840 --> 00:59:07,770
processes needed to form gas giants and

1435
00:59:11,480 --> 00:59:08,850
so you could have a whole bunch

1436
00:59:13,550 --> 00:59:11,490
basically a whole bunch of small bodies

1437
00:59:15,350 --> 00:59:13,560
that happen none of them have reached

1438
00:59:18,500 --> 00:59:15,360

the critical parameters needed to form

1439
00:59:20,120 --> 00:59:18,510
gas giants and so it's as Sean said

1440
00:59:22,640 --> 00:59:20,130
depending on who you talk to you get

1441
00:59:24,590 --> 00:59:22,650
different different understanding of how

1442
00:59:26,270 --> 00:59:24,600
important each parameter is but there

1443
00:59:28,010 --> 00:59:26,280
are various scenarios where you could

1444
00:59:31,610 --> 00:59:28,020
end up with lots of small bodies in the

1445
00:59:35,390 --> 00:59:31,620
system and either none or very small gas

1446
00:59:38,099 --> 00:59:35,400
giants so we have a question from NASA

1447
00:59:42,779 --> 00:59:40,559
hi yeah this is dave d marais here I

1448
00:59:45,509 --> 00:59:42,789
have a question about a process or a

1449
00:59:47,489 --> 00:59:45,519
roll giant planets it seems like it's

1450
00:59:49,829 --> 00:59:47,499
related to your discussion and that is

1451
00:59:51,630 --> 00:59:49,839
this role of a shepherd the idea that

1452
00:59:54,660 --> 00:59:51,640
having a giant planet somewhere in the

1453
00:59:57,269 --> 00:59:54,670
system will capture a lot of asteroids

1454
00:59:59,910 --> 00:59:57,279
and so forth and avoid impacts on earth

1455
01:00:01,950 --> 00:59:59,920
earth-like planet in the case of where

1456
01:00:04,349 --> 01:00:01,960
the giant planet is inside the orbit of

1457
01:00:06,269 --> 01:00:04,359
a habitable planet I would seem to me

1458
01:00:09,089 --> 01:00:06,279
that that role would not be as effective

1459
01:00:10,950 --> 01:00:09,099
but is it still something that would be

1460
01:00:12,660 --> 01:00:10,960
important in other words what a giant

1461
01:00:14,819 --> 01:00:12,670
planet just inboard of a terrestrial

1462
01:00:18,299 --> 01:00:14,829
habitable planet have any kind of a

1463
01:00:21,779 --> 01:00:18,309

protection role with respect to asteroid

1464
01:00:25,829 --> 01:00:21,789
impacts and stuff I let me answer this

1465
01:00:27,930 --> 01:00:25,839
one or I'll start off so the idea that

1466
01:00:31,470 --> 01:00:27,940
Jupiter is a great protector for the

1467
01:00:34,019 --> 01:00:31,480
earth is not as well established as some

1468
01:00:36,329 --> 01:00:34,029
might think because the Comets that

1469
01:00:38,549 --> 01:00:36,339
Jupiter protects us from would not be on

1470
01:00:40,470 --> 01:00:38,559
those orbits if Jupiter hadn't put them

1471
01:00:42,450 --> 01:00:40,480
on those orbits so it's somewhat

1472
01:00:43,680 --> 01:00:42,460
circular and it's not the Jupiter isn't

1473
01:00:44,999 --> 01:00:43,690
protecting us in some sense but I

1474
01:00:48,779 --> 01:00:45,009
haven't seen any papers which really

1475
01:00:50,609 --> 01:00:48,789
address this properly if you had a

1476
01:00:53,819 --> 01:00:50,619
system we got a plan in the habitable

1477
01:00:55,440 --> 01:00:53,829
zone and then an inner giant planet that

1478
01:00:58,559 --> 01:00:55,450
giant planet would probably not do too

1479
01:01:00,989 --> 01:00:58,569
much protecting of the plant and avril

1480
01:01:03,690 --> 01:01:00,999
zone in a few instances you might have

1481
01:01:06,630 --> 01:01:03,700
very high eccentricity comets you know

1482
01:01:08,009 --> 01:01:06,640
just miss the earth-like planet and then

1483
01:01:09,239 --> 01:01:08,019
have a close encounter with the giant

1484
01:01:11,249 --> 01:01:09,249
planet and then end up getting scattered

1485
01:01:12,720 --> 01:01:11,259
out that could happen in a few cases but

1486
01:01:17,470 --> 01:01:12,730
I think in general it wouldn't be a big

1487
01:01:17,480 --> 01:01:23,609
okay I'm is the question that got it

1488
01:01:31,050 --> 01:01:28,240

yeah this is Mike mumma it question

1489
01:01:34,390 --> 01:01:31,060
really devolves around this issue of

1490
01:01:38,290 --> 01:01:34,400
what do we mean by a comet and its role

1491
01:01:42,640 --> 01:01:38,300
in delivering water to these earth-like

1492
01:01:45,130 --> 01:01:42,650
planets first of all we should probably

1493
01:01:48,490 --> 01:01:45,140
call the bodies of interest I see

1494
01:01:50,050 --> 01:01:48,500
planetesimals which begs the question of

1495
01:01:51,640 --> 01:01:50,060
whether they're the asteroids in the

1496
01:01:55,150 --> 01:01:51,650
four to five AU region that you've been

1497
01:01:58,420 --> 01:01:55,160
talking about or the icy bodies further

1498
01:02:00,849 --> 01:01:58,430
out which presumably constituted the

1499
01:02:02,260 --> 01:02:00,859
feedstock that let the cores of Jupiter

1500
01:02:05,170 --> 01:02:02,270
and Saturn growth massage where they

1501
01:02:08,830 --> 01:02:05,180
could capture a nebular gas and grow to

1502
01:02:12,210 --> 01:02:08,840
their present sizes and the interesting

1503
01:02:16,960 --> 01:02:12,220
issue then the testable hypothesis is

1504
01:02:19,270 --> 01:02:16,970
whether there is a d2h ratio gradient in

1505
01:02:22,450 --> 01:02:19,280
the water ice in those icy planetesimals

1506
01:02:25,720 --> 01:02:22,460
as one goes from for a you to say 10 a

1507
01:02:32,170 --> 01:02:25,730
you because this should then show up as

1508
01:02:33,849 --> 01:02:32,180
a testable aspect of your your model as

1509
01:02:36,730 --> 01:02:33,859
to whether in fact the material

1510
01:02:39,609 --> 01:02:36,740
scattered from the Jovian Saturn region

1511
01:02:41,830 --> 01:02:39,619
can in fact impact terrestrial planets

1512
01:02:44,530 --> 01:02:41,840
enlarged abundance of our liver

1513
01:02:46,630 --> 01:02:44,540

significant mass as the as opposed to

1514
01:02:51,520 --> 01:02:46,640
merely going out and populating your

1515
01:02:54,910 --> 01:02:51,530
cloud during its formation phase so I

1516
01:02:58,330 --> 01:02:54,920
think there are in fact many us hidden

1517
01:03:00,180 --> 01:02:58,340
assumptions in the present models that

1518
01:03:03,940 --> 01:03:00,190
have been published about the role of

1519
01:03:06,250 --> 01:03:03,950
icy bodies from the five to say ten au

1520
01:03:07,610 --> 01:03:06,260
region and their contributions which

1521
01:03:11,840 --> 01:03:07,620
I've encouraged you to

1522
01:03:13,250 --> 01:03:11,850
to explore in some detail yeah right

1523
01:03:16,850 --> 01:03:13,260
there's there's lots uncertainty in

1524
01:03:18,380 --> 01:03:16,860
terms of the the ddh ratio of comets as

1525
01:03:19,910 --> 01:03:18,390
far as i know it's only known for three

1526
01:03:22,640 --> 01:03:19,920
comments all of which are work cloud

1527
01:03:24,410 --> 01:03:22,650
comets and the formation location of

1528
01:03:27,050 --> 01:03:24,420
those comets is quite uncertain in

1529
01:03:30,080 --> 01:03:27,060
addition there's lots of uncertainty in

1530
01:03:32,120 --> 01:03:30,090
terms of the dth ratio evolution on the

1531
01:03:34,700 --> 01:03:32,130
earth it might not have stayed constant

1532
01:03:36,260 --> 01:03:34,710
over time and these are things that need

1533
01:03:39,790 --> 01:03:36,270
to be looked at in more detail the

1534
01:03:41,990 --> 01:03:39,800
general model the general picture as

1535
01:03:44,720 --> 01:03:42,000
envisioned by this morbid le paper in

1536
01:03:46,850 --> 01:03:44,730
2000 suggests that the dth ratio of

1537
01:03:49,040 --> 01:03:46,860
water on the earth is a nice nice match

1538
01:03:51,080 --> 01:03:49,050

to the dth ratio and carbonaceous

1539
01:03:52,640 --> 01:03:51,090
chondrite meteorites which have a source

1540
01:03:54,680 --> 01:03:52,650
region of something like 38 you or so

1541
01:03:56,720 --> 01:03:54,690
and so that's the general argument why

1542
01:03:59,330 --> 01:03:56,730
asteroidal water well it's one of the

1543
01:04:01,820 --> 01:03:59,340
arguments why asteroidal water might be

1544
01:04:05,120 --> 01:04:01,830
favored but there's other things which

1545
01:04:06,920 --> 01:04:05,130
are obviously uncertain well I would

1546
01:04:08,900 --> 01:04:06,930
respond to your comment first about

1547
01:04:11,570 --> 01:04:08,910
Peter weight ratio and with three comics

1548
01:04:13,340 --> 01:04:11,580
which has been measured really only one

1549
01:04:15,830 --> 01:04:13,350
of those three measurements is highly

1550
01:04:19,790 --> 01:04:15,840
reliable and that one is for common

1551
01:04:23,290 --> 01:04:19,800
halle the other two comets are based on

1552
01:04:26,060 --> 01:04:23,300
a single rotational line of HDO and

1553
01:04:28,490 --> 01:04:26,070
water measured by a different instrument

1554
01:04:31,160 --> 01:04:28,500
at a different time this means that the

1555
01:04:35,810 --> 01:04:31,170
line formation region in the coma is

1556
01:04:37,910 --> 01:04:35,820
different for HDO and h2o and therefore

1557
01:04:40,070 --> 01:04:37,920
there's a tremendous extrapolation

1558
01:04:42,560 --> 01:04:40,080
getting to a do H ratio for that

1559
01:04:45,200 --> 01:04:42,570
individual common case of hell Bob and

1560
01:04:47,390 --> 01:04:45,210
also Hyakutake so it may well be that

1561
01:04:51,620 --> 01:04:47,400
the agreement amongst the three comets

1562
01:04:54,770 --> 01:04:51,630
is is coincidental the second comment I

1563
01:04:57,620 --> 01:04:54,780

would make is that millimeter infrared

1564
01:05:01,370 --> 01:04:57,630
observations of parent volatile

1565
01:05:04,190 --> 01:05:01,380
specifically organics in recent comets

1566
01:05:07,630 --> 01:05:04,200
that a dozen or so have shown that there

1567
01:05:11,750 --> 01:05:07,640
are at least two separate populations

1568
01:05:13,310 --> 01:05:11,760
based on the organic chemistry and the

1569
01:05:14,650 --> 01:05:13,320
suggestion has been made that one

1570
01:05:16,910 --> 01:05:14,660
population

1571
01:05:20,720 --> 01:05:16,920
dominant New York cloud was actually

1572
01:05:23,300 --> 01:05:20,730
formed in the outer giant planets region

1573
01:05:26,210 --> 01:05:23,310
whereas the organic depleted fraction

1574
01:05:29,210 --> 01:05:26,220
the other population was likely formed

1575
01:05:31,370 --> 01:05:29,220
in the inner or giant planet region so

1576
01:05:35,240 --> 01:05:31,380
in that case if that's correct it holds

1577
01:05:37,310 --> 01:05:35,250
water it would mean that again you

1578
01:05:41,390 --> 01:05:37,320
really couldn't use the measurements in

1579
01:05:43,300 --> 01:05:41,400
those three comets of d2h to interpret

1580
01:05:46,010 --> 01:05:43,310
what would have been delivered to earth

1581
01:05:48,200 --> 01:05:46,020
because they would have been more

1582
01:05:50,570 --> 01:05:48,210
characteristic of population in the

1583
01:05:57,380 --> 01:05:50,580
outer giant planets region not the inner

1584
01:05:59,510 --> 01:05:57,390
oh as what we need nope so we need is

1585
01:06:01,970 --> 01:05:59,520
someone to go and tell us the dth ratio

1586
01:06:05,480 --> 01:06:01,980
of all these comments than it that's

1587
01:06:09,920 --> 01:06:05,490
exactly right current well I look

1588
01:06:13,790 --> 01:06:09,930

forward to hearing the answer also on i

1589
01:06:18,290 --> 01:06:13,800
I uh I wanted to say something about

1590
01:06:21,860 --> 01:06:18,300
water pure kids water in in young

1591
01:06:23,360 --> 01:06:21,870
planetary systems the location and

1592
01:06:25,970 --> 01:06:23,370
transport of water and young planetary

1593
01:06:28,250 --> 01:06:25,980
systems is something that I think is one

1594
01:06:31,190 --> 01:06:28,260
of the biggest controversies in planet

1595
01:06:33,770 --> 01:06:31,200
formation period right now I mean our

1596
01:06:36,110 --> 01:06:33,780
understanding of where water forms where

1597
01:06:38,990 --> 01:06:36,120
solid body water forms in the system and

1598
01:06:42,920 --> 01:06:39,000
how that evolves is itself still

1599
01:06:44,540 --> 01:06:42,930
evolving right now because as we probe

1600
01:06:46,250 --> 01:06:44,550
the temperature temperature structure of

1601
01:06:49,250 --> 01:06:46,260
disks and as we understand more about

1602
01:06:51,920 --> 01:06:49,260
how passive and active circumstellar

1603
01:06:53,750 --> 01:06:51,930
disks evolved over their lifetime which

1604
01:06:56,270 --> 01:06:53,760
is the critical point where

1605
01:07:00,200 --> 01:06:56,280
planetesimals are being formed in the in

1606
01:07:01,940 --> 01:07:00,210
the disk it involves the as we say frost

1607
01:07:04,250 --> 01:07:01,950
line involves from the interior to the

1608
01:07:07,820 --> 01:07:04,260
exterior the X theory to the interior

1609
01:07:10,070 --> 01:07:07,830
and back again in the disc and so

1610
01:07:11,390 --> 01:07:10,080
understanding that evolution of the of

1611
01:07:13,100 --> 01:07:11,400
the temperature structure and how that

1612
01:07:16,460 --> 01:07:13,110
affects the formation of bodies in the

1613
01:07:18,770 --> 01:07:16,470

disc and then as we said understanding

1614
01:07:21,800 --> 01:07:18,780
how that might affect the dth ratio arm

1615
01:07:23,830 --> 01:07:21,810
as as solid water is formed in different

1616
01:07:26,540 --> 01:07:23,840
parts of the disc on different bodies I

1617
01:07:28,490 --> 01:07:26,550
think we have a long way to go I

1618
01:07:30,380 --> 01:07:28,500
it's understanding of where the water

1619
01:07:36,140 --> 01:07:30,390
came from on earth and in other systems

1620
01:07:37,580 --> 01:07:36,150
so just let's just put it up on the

1621
01:07:44,000 --> 01:07:37,590
University of Washington you have a

1622
01:07:46,370 --> 01:07:44,010
question yeah so the presumably your end

1623
01:07:49,700 --> 01:07:46,380
result depends a lot on how quickly the

1624
01:07:52,970 --> 01:07:49,710
giant planet migrates which in turn is a

1625
01:07:54,260 --> 01:07:52,980
function of the disc properties so it's

1626
01:07:55,970 --> 01:07:54,270
just wondering if you could talk a

1627
01:07:57,440 --> 01:07:55,980
little more detail about what the

1628
01:08:00,350 --> 01:07:57,450
properties of your discs were

1629
01:08:02,990 --> 01:08:00,360
particularly sort of relationship to our

1630
01:08:11,630 --> 01:08:03,000
for a canonical minimum mass solar

1631
01:08:15,020 --> 01:08:11,640
nebula I'll start with that one um the

1632
01:08:17,780 --> 01:08:15,030
the disc as you said the disc properties

1633
01:08:20,510 --> 01:08:17,790
were mostly related to the migration of

1634
01:08:22,640 --> 01:08:20,520
the giant planet and then the effect of

1635
01:08:25,490 --> 01:08:22,650
gas drag on the smaller bodies in the

1636
01:08:29,329 --> 01:08:25,500
system the migration of the giant planet

1637
01:08:32,090 --> 01:08:29,339
that was was based on simulations of

1638
01:08:35,450 --> 01:08:32,100

giant planet migration in hydro dynamic

1639
01:08:39,470 --> 01:08:35,460
simulations arm which is as you as you

1640
01:08:42,289 --> 01:08:39,480
know is related mostly to the viscosity

1641
01:08:45,770 --> 01:08:42,299
of the of the disk and Hydra the hydro

1642
01:08:48,260 --> 01:08:45,780
simulations and however if you assume an

1643
01:08:50,930 --> 01:08:48,270
in fall rate on to the star on that can

1644
01:08:53,300 --> 01:08:50,940
that can give you a transport rate of

1645
01:08:56,539 --> 01:08:53,310
the gas in the disk and that can give

1646
01:08:59,090 --> 01:08:56,549
you an inspiring rate for the material

1647
01:09:01,670 --> 01:08:59,100
and the way the type to migration works

1648
01:09:04,550 --> 01:09:01,680
is that the giant planet is locked into

1649
01:09:06,800 --> 01:09:04,560
the disk and then spirals inwards with

1650
01:09:08,360 --> 01:09:06,810
the gas spiraling and so hundred

1651
01:09:10,849 --> 01:09:08,370
dynamics simulations of giant planet

1652
01:09:15,110 --> 01:09:10,859
migration have shown that type 2

1653
01:09:17,930 --> 01:09:15,120
migration is generally very robust on

1654
01:09:21,140 --> 01:09:17,940
between one hundred thousand to a

1655
01:09:24,890 --> 01:09:21,150
million years for the migration rate for

1656
01:09:28,340 --> 01:09:24,900
a giant planet that can if you have a

1657
01:09:29,809 --> 01:09:28,350
very low mass disk that can affect it or

1658
01:09:32,630 --> 01:09:29,819
if you have possibly a very high mass

1659
01:09:34,579 --> 01:09:32,640
disk where the planet is is subject to

1660
01:09:36,740 --> 01:09:34,589
other forces greater than type to

1661
01:09:39,410 --> 01:09:36,750
migration but we're assuming a general

1662
01:09:41,900 --> 01:09:39,420
gap opening rate of about

1663
01:09:45,320 --> 01:09:41,910

two thousand years for type 2 migration

1664
01:09:47,780 --> 01:09:45,330
of the giant planet um I other other

1665
01:09:49,249 --> 01:09:47,790
simulations have shown that you can have

1666
01:09:50,959 --> 01:09:49,259
a variation in the scattering rate

1667
01:09:52,610 --> 01:09:50,969
depending on the migration rate of the

1668
01:09:55,000 --> 01:09:52,620
giant planet we published the paper

1669
01:09:58,970 --> 01:09:55,010
about three years ago showing that arm

1670
01:10:00,680 --> 01:09:58,980
but we're right here on a much more

1671
01:10:02,450 --> 01:10:00,690
detailed how to dynamic simulations to

1672
01:10:05,150 --> 01:10:02,460
give us the rate of migration prototype

1673
01:10:07,610 --> 01:10:05,160
to migration now for gas drag on the

1674
01:10:11,390 --> 01:10:07,620
smaller bodies on that's much more

1675
01:10:14,120 --> 01:10:11,400
uncertain we assume as you said a basic

1676
01:10:16,280 --> 01:10:14,130
guest dust ratio of about a hundred and

1677
01:10:20,150 --> 01:10:16,290
that gives us a certain density for the

1678
01:10:21,520 --> 01:10:20,160
initial density for the gas in different

1679
01:10:24,860 --> 01:10:21,530
parts of the disk we assume a certain

1680
01:10:28,370 --> 01:10:24,870
surface density profile to to go along

1681
01:10:30,919 --> 01:10:28,380
with that and so those are as you could

1682
01:10:34,400 --> 01:10:30,929
say arbitrary choices that we make in

1683
01:10:36,740 --> 01:10:34,410
our gas density our gas parameters for

1684
01:10:38,840 --> 01:10:36,750
the disc and I think a lot more work

1685
01:10:41,360 --> 01:10:38,850
needs to be done to understand the role

1686
01:10:43,360 --> 01:10:41,370
of a less dense or more dense or

1687
01:10:48,110 --> 01:10:43,370
different surface density profiles on

1688
01:10:50,720 --> 01:10:48,120

the delivery of water to habitable

1689
01:10:52,550 --> 01:10:50,730
planets however since we don't know that

1690
01:10:53,959 --> 01:10:52,560
much about the evolute we're not

1691
01:10:59,530 --> 01:10:53,969
including that much about the evolution

1692
01:11:01,459 --> 01:10:59,540
of water ice creation in the disk I

1693
01:11:03,290 --> 01:11:01,469
think we I think we have other

1694
01:11:05,209 --> 01:11:03,300
parameters that that need to be refined

1695
01:11:07,400 --> 01:11:05,219
as well as those for us to better

1696
01:11:09,620 --> 01:11:07,410
understand the water transport so in

1697
01:11:12,439 --> 01:11:09,630
these similar simulations we have we

1698
01:11:16,760 --> 01:11:12,449
have assumed intermediate values for the

1699
01:11:19,280 --> 01:11:16,770
gas disk and the water content in the in

1700
01:11:21,380 --> 01:11:19,290
the disk but that can that can be

1701
01:11:28,890 --> 01:11:21,390
modified to explore more parameter space

1702
01:11:35,290 --> 01:11:32,650
hi Sean and avi is Jim casting actually

1703
01:11:39,580 --> 01:11:35,300
i'll be your last response can you hear

1704
01:11:41,590 --> 01:11:39,590
me yes your last last response sort of

1705
01:11:43,840 --> 01:11:41,600
sets up my question if I understood you

1706
01:11:45,970 --> 01:11:43,850
correctly you assume a hundred percent

1707
01:11:48,520 --> 01:11:45,980
retention of water on these growing

1708
01:11:51,220 --> 01:11:48,530
planetesimals what do you think the

1709
01:11:53,770 --> 01:11:51,230
actual percentage of water retention

1710
01:11:57,460 --> 01:11:53,780
should be for Earth or for planet in

1711
01:11:59,800 --> 01:11:57,470
general there's lots of stuff that goes

1712
01:12:02,170 --> 01:11:59,810
into that oh are you going there should

1713
01:12:03,700 --> 01:12:02,180

i go other there you go shark so there's

1714
01:12:05,290 --> 01:12:03,710
fine there's lots of details that go

1715
01:12:07,450 --> 01:12:05,300
into their as you know there's you know

1716
01:12:11,050 --> 01:12:07,460
during big collisions there's probably a

1717
01:12:13,060 --> 01:12:11,060
decent amount of water loss and there's

1718
01:12:15,820 --> 01:12:13,070
some new simulations by Robin can up and

1719
01:12:17,740 --> 01:12:15,830
Betty Piazza saying you know with with a

1720
01:12:19,360 --> 01:12:17,750
few different impact parameters and

1721
01:12:21,640 --> 01:12:19,370
impact speeds showing that maybe half

1722
01:12:24,670 --> 01:12:21,650
half or so the water should be retained

1723
01:12:26,560 --> 01:12:24,680
in giant impacts so over the course of

1724
01:12:28,900 --> 01:12:26,570
the formation of a planet like the earth

1725
01:12:31,660 --> 01:12:28,910
I mean a hand wavy number is something

1726
01:12:33,040 --> 01:12:31,670
like you know a quarter or maybe as low

1727
01:12:34,810 --> 01:12:33,050
as ten percent of the total water

1728
01:12:36,640 --> 01:12:34,820
probably ends up on the surface of the

1729
01:12:40,240 --> 01:12:36,650
planet there's lots of unknowns in there

1730
01:12:42,630 --> 01:12:40,250
the reason that like our key thing that

1731
01:12:44,590 --> 01:12:42,640
we're saying that in hot Jupiter systems

1732
01:12:45,970 --> 01:12:44,600
terrestrial planets that form probably

1733
01:12:47,680 --> 01:12:45,980
have lots of water the reason we think

1734
01:12:49,630 --> 01:12:47,690
that is because we're not comparing

1735
01:12:52,210 --> 01:12:49,640
those to the earth we're comparing those

1736
01:12:53,500 --> 01:12:52,220
two other simulations with the similar

1737
01:12:56,710 --> 01:12:53,510
assumptions that were designed to

1738
01:12:58,750 --> 01:12:56,720

reproduce the earth and so we think that

1739
01:13:00,010 --> 01:12:58,760
that conclusion is pretty robust those

1740
01:13:02,320 --> 01:13:00,020
simulations that were designed to

1741
01:13:04,030 --> 01:13:02,330
reproduce the earth tend to have too

1742
01:13:06,220 --> 01:13:04,040
much water by may be a factor of five or

1743
01:13:08,260 --> 01:13:06,230
ten and so that's kind of a very hand

1744
01:13:11,710 --> 01:13:08,270
wavy number to give in terms of how much

1745
01:13:15,810 --> 01:13:11,720
water but make depletion occurs maybe

1746
01:13:25,140 --> 01:13:18,270
okay we have a question from goddard

1747
01:13:27,270 --> 01:13:25,150
space flight center well okay the

1748
01:13:30,979 --> 01:13:27,280
question is you were saying the planets

1749
01:13:33,240 --> 01:13:30,989
formats I mean investments at 0.1 I you

1750
01:13:35,640 --> 01:13:33,250
there some of them are reaching water

1751
01:13:37,229 --> 01:13:35,650
how is stable is water than normally the

1752
01:13:38,450 --> 01:13:37,239
delivery you were saying is kind of fast

1753
01:13:40,770 --> 01:13:38,460
it's at the beginning of the simulation

1754
01:13:47,760 --> 01:13:40,780
so how is table is this water you

1755
01:13:51,209 --> 01:13:47,770
deliver there and I might as well take

1756
01:13:54,030 --> 01:13:51,219
it that the I mean that at the beginning

1757
01:13:55,470 --> 01:13:54,040
of simulation of planetesimals at 0.1

1758
01:13:58,020 --> 01:13:55,480
are in the anterior part of the disk

1759
01:14:00,930 --> 01:13:58,030
have very or no water basically and then

1760
01:14:02,760 --> 01:14:00,940
their water is delivering through radial

1761
01:14:04,500 --> 01:14:02,770
migration and you end up with bodies

1762
01:14:07,169 --> 01:14:04,510
that have some amount of water you're

1763
01:14:09,689 --> 01:14:07,179

correct that we don't include any loss

1764
01:14:11,189 --> 01:14:09,699
of water in bodies that are formed our

1765
01:14:13,080 --> 01:14:11,199
mini simulations so we don't include

1766
01:14:15,839 --> 01:14:13,090
evaporation will include destruction

1767
01:14:18,089 --> 01:14:15,849
through collisions on so in the interior

1768
01:14:19,260 --> 01:14:18,099
part of the system if the water is on

1769
01:14:21,510 --> 01:14:19,270
the surface it will be quickly

1770
01:14:23,970 --> 01:14:21,520
evaporated away if there's not a thick

1771
01:14:25,560 --> 01:14:23,980
steam atmosphere which may be more of

1772
01:14:27,689 --> 01:14:25,570
the atmospheric scientists could tell us

1773
01:14:30,479 --> 01:14:27,699
a little more about the the retention of

1774
01:14:32,430 --> 01:14:30,489
water under a dense atmosphere but um we

1775
01:14:33,780 --> 01:14:32,440
don't include any loss of water in these

1776
01:14:37,200 --> 01:14:33,790
simulations so you would have to have a

1777
01:14:41,160 --> 01:14:37,210
more detailed evolution of the say super

1778
01:14:44,879 --> 01:14:41,170
earth at close distances but arm you

1779
01:14:47,100 --> 01:14:44,889
could have a much smaller mass of the

1780
01:14:48,930 --> 01:14:47,110
actual planet than you would then we

1781
01:14:51,240 --> 01:14:48,940
would find in our simulations at small

1782
01:14:53,760 --> 01:14:51,250
distances because of if a large fraction

1783
01:14:55,310 --> 01:14:53,770
of the the materials these volatiles and

1784
01:14:57,450 --> 01:14:55,320
that is lost through evaporation

1785
01:14:59,189 --> 01:14:57,460
possibly planets that you discovered now

1786
01:15:01,319 --> 01:14:59,199
would be much smaller than them might

1787
01:15:02,910 --> 01:15:01,329
have originally occurred during the

1788
01:15:08,959 --> 01:15:02,920

formation process so you're right that's

1789
01:15:18,479 --> 01:15:14,189
we have a question from mark Claire mark

1790
01:15:22,290 --> 01:15:18,489
are you there hi Sheldon avi this is

1791
01:15:25,770 --> 01:15:22,300
mark from u-dub I the trailer we talked

1792
01:15:28,200 --> 01:15:25,780
was are we normal so I would guess I was

1793
01:15:30,570 --> 01:15:28,210
wondering about our solar system and

1794
01:15:32,520 --> 01:15:30,580
what your simulations might show as to

1795
01:15:34,709 --> 01:15:32,530
that fact we had a lot of gas we form

1796
01:15:38,700 --> 01:15:34,719
these large gas giants but they did not

1797
01:15:41,610 --> 01:15:38,710
migrate into the inner solar system what

1798
01:15:43,290 --> 01:15:41,620
constraints to that place on on how

1799
01:15:45,300 --> 01:15:43,300
planets formed in our own solar system

1800
01:15:52,729 --> 01:15:45,310
and whether or not that might be a

1801
01:15:52,739 --> 01:16:00,580
Sean meet what do you want to do

1802
01:16:11,490 --> 01:16:03,939
um what rishon that's not really I'm

1803
01:16:15,220 --> 01:16:11,500
just my moment oh okay you are the

1804
01:16:18,040 --> 01:16:15,230
question of how how common our system

1805
01:16:21,060 --> 01:16:18,050
would be versus other systems which have

1806
01:16:24,669 --> 01:16:21,070
a close-in giant planet i think is

1807
01:16:27,010 --> 01:16:24,679
reserved for more detailed simulations

1808
01:16:31,990 --> 01:16:27,020
of a variety of disk parameters with

1809
01:16:34,240 --> 01:16:32,000
giant planet migration included in it

1810
01:16:36,459 --> 01:16:34,250
what we tried to do in our simulations

1811
01:16:38,919 --> 01:16:36,469
will show under a variety of these

1812
01:16:43,780 --> 01:16:38,929
conditions if you had giant planets in a

1813
01:16:45,700 --> 01:16:43,790

variety of of orientations whether you

1814
01:16:49,030 --> 01:16:45,710
could form planets that were like Earth

1815
01:16:51,939 --> 01:16:49,040
or not like earth and how how similar

1816
01:16:58,930 --> 01:16:51,949
the final characteristics might be to

1817
01:17:01,330 --> 01:16:58,940
our own earth it's a good question the

1818
01:17:04,030 --> 01:17:01,340
trick is no one knows how migration

1819
01:17:06,339 --> 01:17:04,040
stops and so it's most people think that

1820
01:17:09,250 --> 01:17:06,349
plants do migrate and how do they stop

1821
01:17:11,800 --> 01:17:09,260
some people think that maybe the disc is

1822
01:17:18,810 --> 01:17:11,810
dissipating and so once the mass in the

1823
01:17:25,800 --> 01:17:22,050
ah I might as well finish what genres

1824
01:17:29,209 --> 01:17:25,810
say um Sean as soon as the mass is

1825
01:17:31,740 --> 01:17:29,219
dissipated in the disk you end up with

1826
01:17:34,229 --> 01:17:31,750
the planet not having enough material

1827
01:17:36,030 --> 01:17:34,239
exterior to the to the planet during

1828
01:17:37,350 --> 01:17:36,040
migration to continue to force it in

1829
01:17:40,919 --> 01:17:37,360
words and so the planets can stop

1830
01:17:42,689 --> 01:17:40,929
migrating through that process other

1831
01:17:45,330 --> 01:17:42,699
people believe that our system would be

1832
01:17:47,490 --> 01:17:45,340
even more unusual than other systems

1833
01:17:50,729 --> 01:17:47,500
because Jupiter and Saturn formed close

1834
01:17:53,729 --> 01:17:50,739
together relatively within for a year of

1835
01:17:55,609 --> 01:17:53,739
each other and if planets some

1836
01:17:58,200 --> 01:17:55,619
simulations show that planets within

1837
01:18:00,089 --> 01:17:58,210
that form close to each other evacuate

1838
01:18:05,300 --> 01:18:00,099

the gas mass between them and this may

1839
01:18:08,069 --> 01:18:05,310
halt migration for the interior planet

1840
01:18:10,200 --> 01:18:08,079
hopefully Sean Kentucky when he gets

1841
01:18:17,189 --> 01:18:10,210
back on bye bye week okay as he said I

1842
01:18:21,180 --> 01:18:17,199
can act out later okay all right all

1843
01:18:24,180 --> 01:18:21,190
right we just got back again can you get

1844
01:18:26,160 --> 01:18:24,190
it all right yeah yeah I kind of

1845
01:18:27,839 --> 01:18:26,170
completed your your statement about the

1846
01:18:33,689 --> 01:18:27,849
different ways that migration could halt

1847
01:18:36,560 --> 01:18:33,699
but um that works hi hi this is Carla I

1848
01:18:41,250 --> 01:18:36,570
thought I'd break in before the

1849
01:18:44,040 --> 01:18:41,260
technical glitches end us abruptly and

1850
01:18:45,419 --> 01:18:44,050
just thank our speakers again and I'd

1851
01:18:47,550 --> 01:18:45,429
also like to thank all the participants

1852
01:18:50,430 --> 01:18:47,560
and particularly all the folks who asked

1853
01:18:52,649 --> 01:18:50,440
questions I'm kind of new to this format

1854
01:18:55,229 --> 01:18:52,659
and I'm thrilled frankly with the amount

1855
01:18:57,800 --> 01:18:55,239
of interaction that we've had both the

1856
01:19:01,740 --> 01:18:57,810
talk and then the last half hour of QA

1857
01:19:06,240 --> 01:19:01,750
so thanks once again to both avi and

1858
01:19:08,819 --> 01:19:06,250
Sean thanks to Goddard for hosting avi

1859
01:19:11,700 --> 01:19:08,829
there and i don't think i mentioned that

1860
01:19:13,979 --> 01:19:11,710
in my introduction and thanks to

1861
01:19:17,580 --> 01:19:13,989
everybody who participated we will not

1862
01:19:19,859 --> 01:19:17,590
have a director seminar in december

1863
01:19:22,740 --> 01:19:19,869

because of the holidays so the next

1864
01:19:24,890 --> 01:19:22,750
director seminar will be in January will

1865
01:19:27,629 --> 01:19:24,900
be sending out a note about that and the

1866
01:19:30,479 --> 01:19:27,639
speaker is there I believe are going to

1867
01:19:31,680 --> 01:19:30,489
be Lisa pratt & T

1868
01:19:34,379 --> 01:19:31,690
he onstott and they're going to be

1869
01:19:36,390 --> 01:19:34,389
talking about the deep biosphere work

1870
01:19:39,450 --> 01:19:36,400
that has been done by the Indiana

1871
01:19:41,580 --> 01:19:39,460
Princeton and Tennessee team so thanks